A Geologic and Topographic Section

ACROSS SOUTHERN INDIANA

FROM THE OHIO RIVER, AT HANOVER, TO THE WABASH RIVER, AT VINCENNES, WITH A DISCUSSION OF THE GENERAL DISTRIBUTION AND CHARACTER OF THE KNOBSTONE GROUP IN THE STATE OF INDIANA.

BY JOHN FLESHER NEWSOM,
Stanford University, California, 1901.

LETTER OF TRANSMITTAL.

Prof. W. S. Blatchley, State Geologist:

Dear Sir—I hand you herewith my report on a geologic and topographic section across southern Indiana from Hanover to Vincennes, with a discussion of the general distribution of the Knobstone group in the State of Indiana,

And remain very respectfully yours,

J. F. NEWSOM.

CONTENTS.

INTRODUCTION.

The following paper relates to the geological formations represented in southern Indiana, especially where these are crossed by the row of townships numbered 3 north. The field work, on which the paper is based, was done in 1896-1897-1898.*

During this time a topographic map was constructed covering a strip of country six miles wide, and extending from the Ohio River in the neighborhood of Madison on the east to the Wabash River at Vincennes on the west. This section passes over the various formations exposed in this part of the State, beginning in the Ordovician rocks at the east and ending with the Merom sandstone of Carboniferous (or Post-Carboniferous age) at the west.

Some glacial deposits are also crossed by this section, but no attempt has been made to outline the glacial deposits in detail. The distribution of the other rocks in the area covered by the topographic section is shown on the geologic map accompanying it. On this sheet Plate II is a profile of cross-sections showing the general structure and sequence of the strata. These sections are taken along the middle line of Township 3 north.

The area covered by the formation generally known as the "Knobstone Group" (Lower Carboniferous) is shown on the accompanying maps, Plates III and IV. This group of strata, and the area covered by it, is taken up in more detail than the others.

On Plate I (a small skeleton map of Indiana) are shown the mapped areas on which this paper is based.

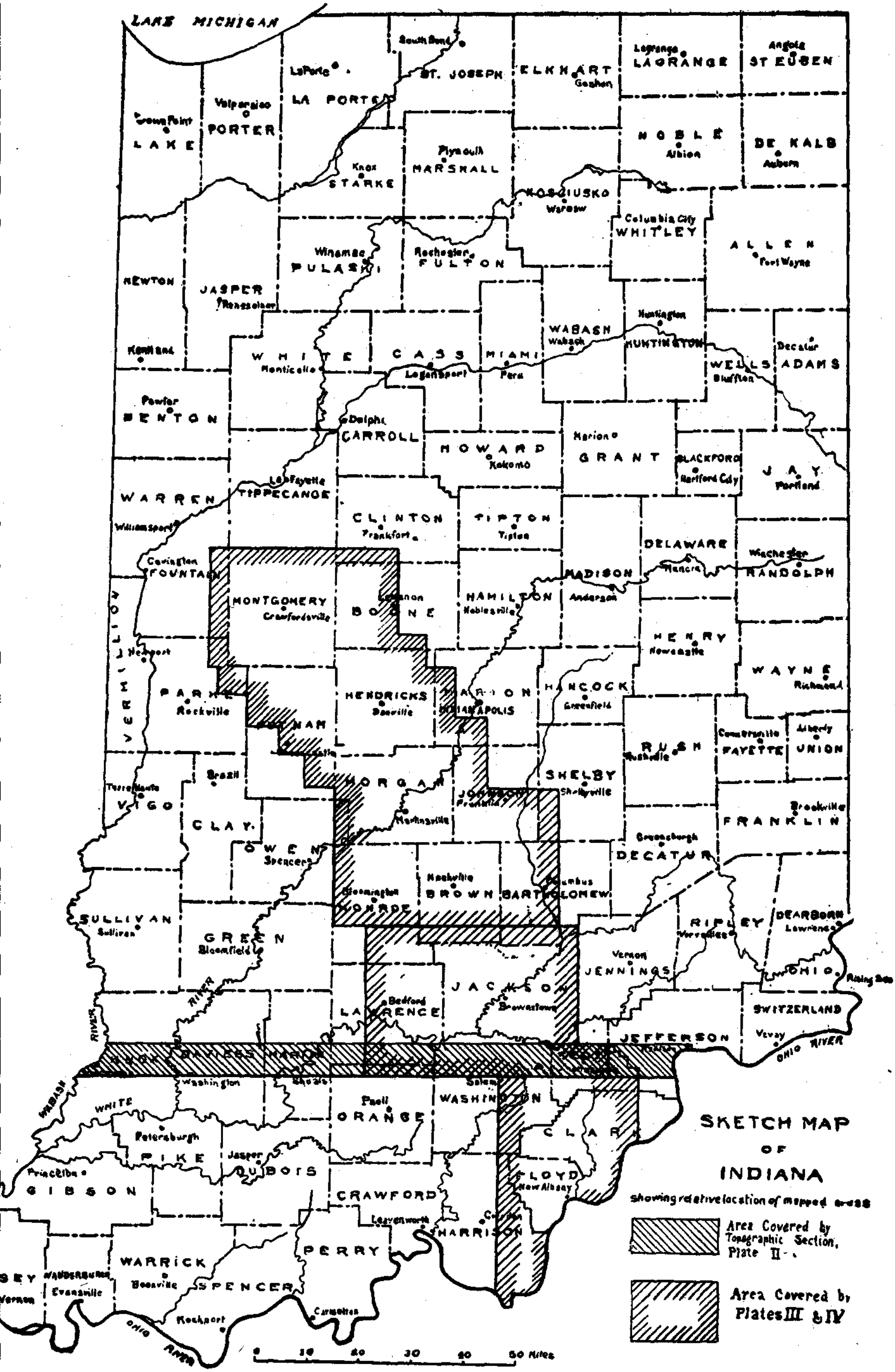
The topographic work was done by means of aneroid barometers; the aneroid readings were checked by a line of elevations run through the territory by means of the vertical arc. The elevations thus obtained are as accurate as the necessities of ordinary topography and

*Full acknowledgment is made in this place to Messrs. J. A. Price, L. F. Bennett, A. C. Veatch, B. V. Goshorn, C. G. Daily, L. F. Hunt and L. H. Jones for their work in connection with the mapping of the areas treated in the following pages.

Their field work as assistants on the Indiana University Geological Survey, under the writer's direction, covered most of the ground of the accompanying maps.

Acknowledgment is also made to Dr. T. C. Hopkins for work on the contact between the Knobstone and overlying limestones, between townships 11 and 14 north, and for data in regard to the details of that contact between townships 15 and 17 north.

Plate I.


LAKE MICHIGAN
LAKE
PORTER
LA PORTE
ST. JOSEPH
ELKHART
LAGRANGE
ST EUBEN
NOBLE
DE KALB
STARKE
MARSHALL
KOSCIUSKO
WHITLEY
ALLEN
NEWTON
JASPER
PULASKI
FULTON
WABASH
HUNTINGTON
WHITE
CASS
MIAMI
WELLS
ADAMS
BENTON
CARROLL
HOWARD
GRANT
BLACKFORD
JAY
WARREN
TIPPECANOE
CLINTON
TIPTON
DELAWARE
RANDOLPH
FOUNTAIN
MONTGOMERY
BOONE
HAMILTON
MADISON
HENRY
WAYNE
VERMILLION
PARKE
HENDRICKS
MARION
HANCOCK
PUTNAM
RUSH
FAYETTE
UNION
VIGO
CLAY
MORGAN
JOHNSON
SHELBY
FRANKLIN
OWEN
DECATUR
SULLIVAN
GREENE
MONROE
BROWN
BARTHOLOMEW
RIPLEY
DEARBORN
JENNINGS
OHIO
LAWRENCE
JACKSON
SWITZERLAND
JEFFERSON
OHIO RIVER
ORANGE
WASHINGTON
CLARK
PIKE
DUBOIS
GIBSON
CRAWFORD
FLOYD
HARRISON
WARRICK
PERRY
SPENCER
VANDERBURGH
OHIO RIVER
WABASH
WHITE RIVER
0 10 20 30 40 50 Miles
SKETCH MAP OF INDIANA
Showing relative location of mapped areas
Area Covered by Topographic Section, Plate II.
Area Covered by Plates III & IV

geologic cross-sections demand. The levels obtained by the vertical arc were checked on the Jeffersonville, Madison and Indianapolis, and Baltimore and Ohio Southwestern railroads where these roads were crossed.

The section selected was chosen for mapping because the geologic horizons and the topography crossed by it are typical of the entire southern portion of the State.

In the following pages the different formations will be discussed in their order, beginning with the lowest. References to the literature relating to the various formations are given under the discussions of those formations. No attempt is made to make these lists complete on any subject, but the more important papers are cited in each case; neither is an attempt made to give lists of the species that have been identified from all the formations crossed by Township 3 north, as such lists would include over 2,000 species. Under the discussion of the various formations references are given to the more important papers where lists of species can be found.

GENERAL OBSERVATIONS.

STRATIGRAPHY.

ORDOVICIAN.—The oldest rocks exposed in Indiana are the calcareous shales and limestones of the Hudson River, or Cincinnati group. These beds are exposed in the southeastern part of the State, where, in the neighborhood of Madison, on the Ohio River, they have an exposed thickness of 250 to 300 feet.

SILURIAN.—Overlying the Hudson River shales and limestone is the Clinton limestone, a very persistent thin bed of limestone, having usually a reddish-brown or salmon color. Next overlying the Clinton are the limestones and shales of the Niagara group. In Township 3 north, 9 east, Section 13, near Hanover, the Niagara beds have a thickness of 68 feet.

DEVONIAN.—The Niagara limestones and shales are overlain by the Corniferous limestone, above which is the Hamilton limestone and a black shale. These three beds have an aggregate thickness of about 190 feet.

LOWER CARBONIFEROUS.—The top of the Devonian black shale (known as the New Albany black shale) is marked by the Rockford goniatite limestone (Lower Carboniferous), a bed of greenish mottled limestone, having a thickness of from eight inches to three feet. This limestone is the lowest bed of the Lower Carboniferous strata of Indiana. For so thin a bed it is an exceptionally persistent one, occurring along almost the entire line of contact between the Lower Carboniferous and Devonian rocks where this contact is exposed.

The Lower Carboniferous beds are made up of three distinct groups of strata. Beginning with the lowest these are:

First. A series of shales with overlying heavily bedded sandstones. The series has a thickness of 550 feet where crossed by the section. This series of rocks has long been known as the Knobstone group, that name having been given it by Owen.

Second. A series of limestones with interbedded cherts, with a thickness of about 375 feet. These limestones are made up of three different groups of strata as recognized by Hopkins and Siebenthal.*

*Department of Geology and Natural Resources of Indiana, 21st Annual Report. "The Bedford Oölitic Limestone." By T. C. Hopkins and C. E. Siebenthal, pp 196–199. Indianapolis, 1897.

Third. A series of sandstones and interbedded limestones with a thickness of 125 feet, and recognized by Mr. E. M. Kindle as belonging to the Kaskaskia group.

COAL MEASURES.—Overlying the Kaskaskia beds is the massive Mansfield sandstone of Hopkins, often having an underlying bed of coal. This sandstone is the base of the Coal Measures and corresponds to the sandstone so widely known as the "Millstone Grit." It has a thickness of from 100 to 150 feet where crossed by the section.

Above the Mansfield sandstone are the shales and sandstones of the Productive or Bearing Coal Measures. These beds have a total thickness of about 800 feet where crossed by Township 3 north.

PERMO-CARBONIFEROUS.—Lying unconformably upon the Productive Coal Measures is a sandstone of Upper Carboniferous or Permo-carboniferous age. At Vincennes it has a thickness of about 45 feet.

PLEISTOCENE GLACIAL.—Overlying the Silurian and Devonian and the eastern part of the Knobstone strata at the east, and overlying the Productive Coal Measures at the west end of the section under discussion, are deposits of glacial debris. This glacial material occurs, for the most part, only on the hilltops through Townships 4, 5, 6, 7 and 8 east, having been entirely removed by erosion in the valleys. In 9 east, however, the surface is made up almost entirely of glacial material. The townships west of 3 north, 5 west, are almost entirely covered by glacial debris.

The accompanying columnar section (with sections of the New York and Arkansas strata for comparison) (Fig. 1) shows the thicknesses and relations of these various formations as they occur in Township 3 north. Where crossed by the topographic section they have an aggregate thickness of about 2,500 feet.

The sections bring out the fact that, as compared with New York, Indiana was a region of slight sedimentation from Ordovician to the end of Lower Carboniferous time. This is because the Indiana region was far removed during that time from large land masses where much erosion was taking place. Something of the importance of the erosion that took place after the deposition of the Lower Carboniferous strata is also brought out by the thickness of the sediments deposited in the Arkansas region during that time.

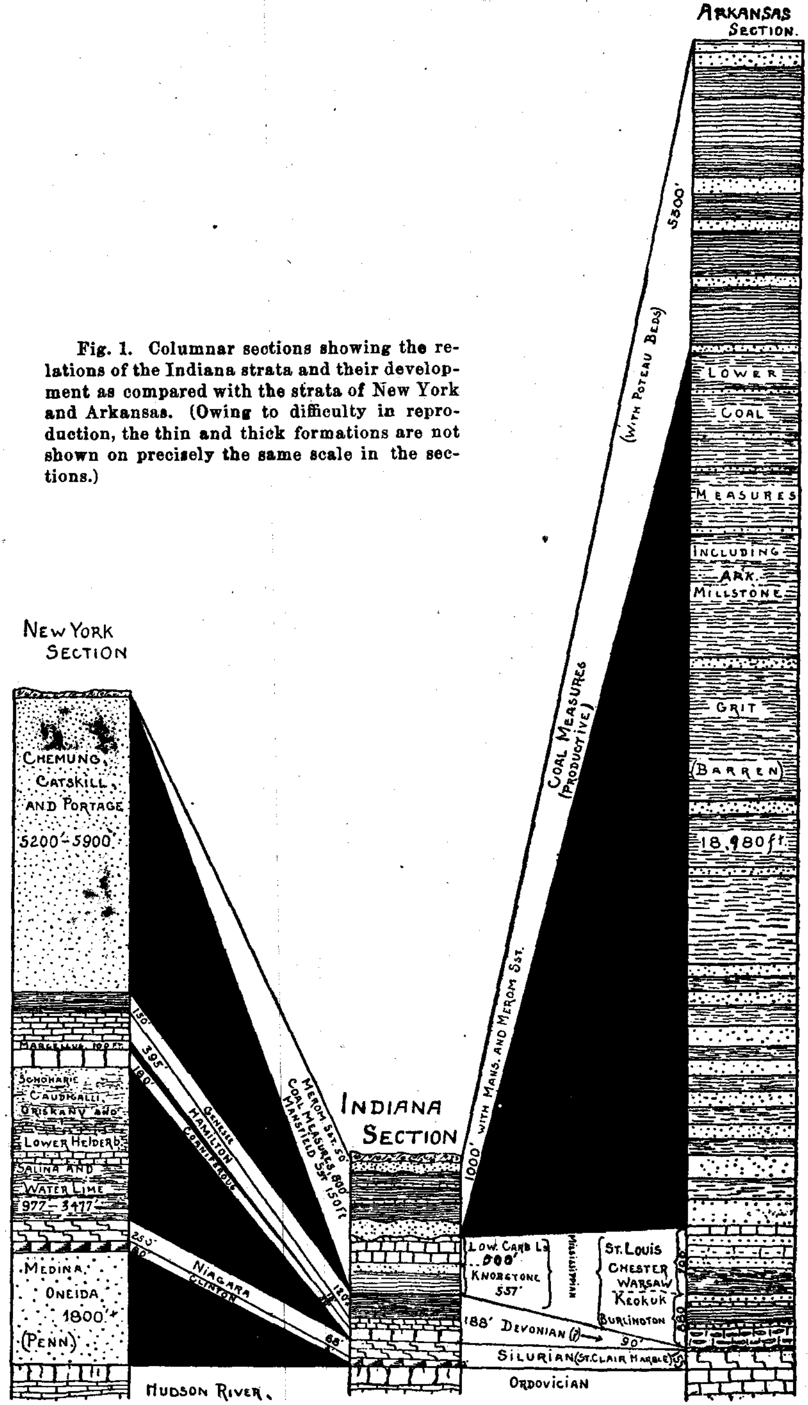


Fig. 1. Columnar sections showing the relations of the Indiana strata and their development as compared with the strata of New York and Arkansas. (Owing to difficulty in reproduction, the thin and thick formations are not shown on precisely the same scale in the sections.)

STRUCTURE.

The geologic structure of southern Indiana is very simple. Situated as the rocks are, at the west side of the low dome of the Cincinnati Arch, the beds all have a gentle westward and southwestward dip. There are local variations in the dip, but for the most part where seen outcropping in ledges the strata appear to be flat. Where measured in Township 3 north, the westward dip varies from 20 to 46 feet per mile. These dips are sufficient, however, to exercise a marked control over the drainage of the region.

In the coal regions many small local faults occur.*

The writer has observed only one fault of considerable extent in the State. This break has been traced more or less continuously from 3 north, 2 east, Section 1, in a northwesterly direction to 9 north, 1 east, Section 10, a distance of 36 miles. This fault is discussed under the subject of the Knobstone.

The only place in the region crossed by the topographic section at which anything approaching a distinct fold occurs is in 3 north, 8 east, along the line of westernmost exposure of the Hamilton limestone. Here the limestone and shales have a perceptible westward dip.

TOPOGRAPHY.

The topography crossed in going from east to west across the State is somewhat varied, owing to the succession of thick series of hard and soft beds. It is made up, as would be expected, from the succession of the rocks and their gentle westward dips, of three eastward-facing escarpments, and as many gentle westward sloping plateaus in various stages of dissection. The general character of the topography is illustrated by the accompanying generalized section, Fig. 2.

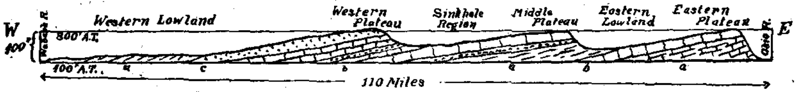


Fig. 2. Ideal east-west section in southern Indiana showing the general topographic effect of the succession of hard and soft strata.

The shales a, a, a, weather more rapidly than the limestones b, b. The limestones b weather faster than the massive sandstone c.

Owing to the exaggerated vertical scale the westward inclination of the strata appears too great.

The controlling strata are: *First*, the thick Niagara and Corniferous limestones; *second*, the thick sandstones with their capping

*Indiana Department of Geology and Natural Resources. 23rd Annual Report, pp. 53–61. Indianapolis, 1899.

cherty limestones at the top of the Knobstone group and the base of the Harrodsburg limestone; and *third,* the heavy beds of the Mansfield sandstone. The broad north-south troughs or valleys of the southern portion of the State are due to the shale beds and softer or more easily eroded limestones that lie between these controlling beds. The best marked of these broad troughs is that lying between the Knobstone at the west and the limestones at the east. It is clearly marked from New Albany to Edinburg, north of which place the topography owes its character to glacial deposits. The Jeffersonville, Madison and Indianapolis Railroad follows the bottom of this trough or lowland from Louisville to Edinburg.

The topographic maps, with their accompaning profile sections, show the relations between these different topographic features.*

THE FORMATIONS IN DETAIL.

In the following discussion the oldest strata will be taken up first:

ORDOVICIAN.

HUDSON RIVER (OR CINCINNATI) GROUP.

The oldest rocks exposed in Indiana are those of the Hudson River group.

CHARACTER OF ROCKS.—This group is here made up of a series of bluish thin-bedded limestones intercalated with bluish-green calcareous shales, which are quite soft, while at the top of the series are massive sandy limestone beds of a brownish color. These massive beds contain but few fossils, while the calcareous shales below are very fossiliferous, and the bluish limestones are in places largely made up of fossils.

The shales are often scarcely more than slightly indurated clays, and the fossils in them are well preserved. It happens, therefore, that large quantities of well preserved fossils weather out and collect in the beds of all the small streams flowing eastward and southward into the Ohio River in the neighborhood of Madison and Hanover. This is generally true of the streams that cut down as much as 150 or 200 feet into the rocks of the Hudson River group throughout southeastern Indiana.

*The topography in its relations to the structure of southern Indiana is discussed by Leverett, in Part IV, 18 An. Rep., U. S. Geological Survey, pp. 429-431. See also Journal of Geology, Vol. VI, pp. 250-256, "A Geological Section Across Southern Indiana from Hanover to Vincennes." By J. F. Newsom, Chicago, 1898.

AREAL DISTRIBUTION.—In the section under discussion the Hudson River beds outcrop only in the bluffs along the gorge on the Ohio River, where they form a strip of country from one-quarter of a mile to one and one-quarter miles wide.

DETAILED SECTIONS.—In the neighborhood of Hanover the following section is exposed, beginning with the Clinton bed at the top:

		Feet.
1.	Clinton	2
2.	Thin bedded limestones at the top with underlying massive impure limestones (Madison beds of Foerste) about	50
3.	Calcareous shales with intercalated limestones (very fossiliferous)	72

Below three the rocks are concealed at the point where this section was taken, but they are made up of a succession of calcareous shales and intercalated limestones, similar in character to the 72 feet of beds shown at the base of the section.

In 3 north, 9 east, Section 12, a total thickness of 208 feet of Hudson River rocks is exposed along the Hanover Landing Road, from the Clinton bed near the top, to the junction of the Hanover Landing Road with the river road, near the foot of the hill. This latter point is some 40 feet higher than low water in the Ohio, so these beds have an exposed thickness of 250 feet in 3 north, 9 east.

The Ordovician rocks of southern Indiana have been recently studied by Cummings, who gives* a number of detailed sections of the beds in Dearborn, Ohio, Switzerland and Jefferson counties.

The following section taken along the railroad cut north of Madison† shows well the character of the Hudson River group:

		Ft.	In.
65.	Massive white arenaceous limestone (Niagara)	2	6
64.	From a few inches to nearly a foot of pinkish or yellowish to salmon colored crystalline limestone (Clinton)	1	0
63.	Massive white arenaceous limestone	4	2
62.	Thick bedded argillaceous, arenaceous limestone	9	8
61.	Same as 62, but banded on weathered surface with pink, gray and buff	12	10
60.	One massive conspicuous arenaceous layer	3	6
59.	Thin-bedded, argillaceous, arenaceous, weathering brownish, with some calcareous layers containing Bryozoa	7	0
58.	Nothing to four inches of coarse limestone with Ordovician fossils	0	4

*Proceedings of the Indiana Academy of Science, 1900. Notes on the Ordovician rocks of southern Indiana, by Edgar R. Cummings, pp. 200-215. Indianapolis, 1901.

†Ibid., p. 212-213.

		Ft.	In.
57.	Sandstone with lenticles of limestone containing Bryozoa	3	0
56.	Argillaceous layer. *Favistella stellata*	2	0
55.	Shale	6	0
54.	*Favistella stellata*	1	2
53.	Thin layers of limestone alternating with argillaceous and sandy layers. Bryozoa (very abundant). *Rafinesquina, Hebertella*	5	3
52.	Massive soft sandstone	7	8
51.	Blue fossiliferous limestone shale and arenaceous layers	6	0
50.	Fine shale with layers of limestone, *Rhynchotrema, Hebertella, Monticulipora, Calymene, Rafinesquina*.	10	0
49.	Same as 50. *Strophomena, Streptelasma, Plectambonites, Dalmanella, Platystrophia laticosta, Ambonychia*	8	0
48.	Probably shale and thin layers of limestone, covered by talus	22	0
47.	Heavy layers of limestone seen in the *west* side of the south cut, at the top	0	0
46.	Heavy layers of limestone seen in the east side of the south cut, at the top. The lowest layers in the big cut (north cut) are 24 feet above the top of No. 45 if the foot of the big cut be taken as 210 feet above the river. Part of the layers of No. 46 would therefore be repeated in 45. Allowance is made for this fact. Nos. 46 and 47 together	24	0
45.	Shale. The top of No. 45 is at the culvert, just north of the south cut	10	0
44.	Several layers of limestone with *Cyclonema, Rafinesquina, Calymene*, etc	1	2
43.	Shaly limestone. *Cyclonema*	2	8
42.	Limestone, *Ambonychia, Cyclonema, Rafinesquina, Monticulipora*, Crinoids	2	0
41.	Limestone and shale. *Ambonychia*	5	0
40.	Compact close-grained limestone, *Rafinesquina*	0	3
39.	Limestone and shale. *Zygospira, Ambonychia*	2	4
38.	Limestone. *Rafinesquina* edgewise (very abundant)	0	4
37.	Argillaceous compact limestone. *Rafinesquina*	6	9
36.	Limestone. Bryozoa	0	6
35.	Shaly limestone	5	8
34.	Limestone	0	8
33.	Shaly limestone	2	8
32.	Limestone. *Rafinesquina, Calymene, Hebertella* (?), Gastropoda, Bryozoa	0	8
31.	Shale, with occasional 2-inch to 3-inch layers of limestone	10	8
30.	Limestone. *Rafinesquina* edgewise (very abundant)	0	3

		Ft.	In.
29.	Shaly limestone. *Rafinesquina* (very abundant), *Modiolopsis* (very abundant), *Zygospira* (very abundant)	6	9
28.	Similar to 26	0	4
27.	Shaly limestone	1	4
26.	Blue fine-grained limestone. *Zygospira* (exceedingly abundant)	0	3
25.	Shaly limestone. *Rafinesquina*, etc	13	0
24.	Very compact fine-grained limestone; no fossils	0	6
23.	Shale and limestone, with excellently preserved specimens of *Rafinesquina* (very abundant)	4	2
22.	Limestone with top of layer, composed of immense numbers of *Zygospira modesta*	0	3
21.	Rather coarse shale	2	0
20.	Lumpy, shaly limestone. *Asaphus*, *Rafinesquina*	3	0
19.	Coarse to fine-grained barren limestone	0	8
18.	Lumpy, shaly limestone. *Rafinesquina* (very abundant), Trilobites (abundant), *Zygospira*, *Streptelasma*, Bryozoa	12	0
17.	Limestone, with *Rafinesquina*, *Zygospira* (very abundant), Bryozoa, *Orthoceras*	5	10
16.	Shale, with thin layers of limestone	1	0
15.	Very compact, fine-grained, blue, barren limestone	0	6
14.	Shale	0	8
13.	Compact limestone. *Calymene*, *Zygospira*, etc	0	5
12.	Limestone. *Calymene* (very abundant), Bryozoa, *Rafinesquina*, *Orthoceras*	1	3
11.	Shale with thin layers of limestone	3	8
10.	Thin argillaceous limestone with *Calymene* and Bryozoa (abundant)	1	0
9.	Massive blue limestone. *Rafinesquina*, Trilobites, Bryozoa	0	7
8.	Limestone. *Rafinesquina*, *Zygospira*, Bryozoa	2	9
7.	Thin argillaceous yellow-spotted limestone. *Platystrophia*, *Hebertella*, *Rafinesquina*, Bryozoa	1	0
6.	Limestone. *Hebertella* (very abundant), *Rafinesquina nasuta*, *Platystrophia lynx*	1	2
5.	Bryozoal limestone	0	4
4.	Covered, probably shale	1	0
3.	Limestone with Trilobites, *Zygospira*, etc	0	2
2.	Coarse crystalline limestone. *Hebertella*	0	6
1.	Covered to river level	62	0
	Total	315	9

Only that portion of Cummings' section from the Niagara beds down is quoted.

In his study of the fauna of the various sections of the Ordovician rocks of southeastern Indiana, Cummings recognizes the following faunal zones in ascending order:*

1. *Dalmanella multisecta* (200-240 feet).
2. *Rafinesquina alternata* (50-70 feet).
3. *Platystrophia* (60-80 feet).
4. *Rafinesquina alternata* var. *fracta* (100 feet +).
5. *Dalmanella Meeki* (20 feet +).
6. *Streptelasma.*
7. *Strophomena* (10 feet +).
8. *Rhynchotrema capax* (10 feet +).

The waterfalls at the heads of the ravines along the gorge of the Ohio near Hanover are formed principally by the Hudson River beds. The profile of one of these falls is shown in Fig. 3, which also indicates the character of the strata forming it.

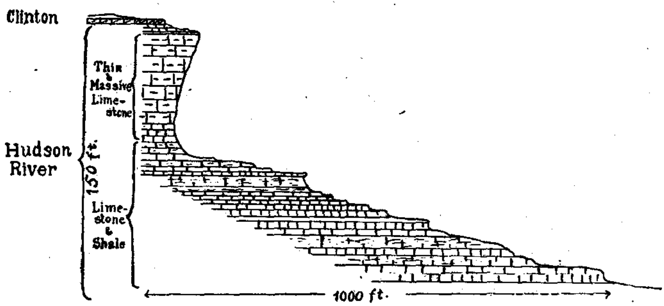


Fig. 3. Profile of falls immediately southeast of Hanover, Indiana.

The upper part of the Hudson River group has been studied in detail by Foerste.† He recognizes the following subdivisions, beginning at the top.‡

"Madison beds and their northern equivalents. Overlying the typical Madison beds are the *Murchisonia hamelli* beds and the terminal white limestone layer.

"The richly fossiliferous shales and limestones below the Madison beds. The equivalents of the Madison beds northward present the same characteristics as these lower beds.

"Gasteropod or Marble Hill bed.

"Section below not studied."

*Loc. cit., p. 215.

†Indiana Department of Geology and Natural Resources. 21st Annual Report (1896), p 213 et seq.; 24th Annual Report (1899), p. 41 et seq. (The later report contains a synonomy and many references.)

‡Indiana Department of Geology and Natural Resources. 21st Annual Report (1896). p. 218.

PALEONTOLOGY.—The Hudson River group is rich in fossils. The species described from this formation have been brought together by Kindle,* to whose list the student is referred.

SILURIAN.

CLINTON.

CHARACTER AND AREAL DISTRIBUTION.—Lying immediately above the rocks of the Hudson River group is the Clinton limestone. In Township 3 north, 9 east, it is a rather close grained rock with a salmon color. Its thickness near Hanover is about two feet. This bed comes to the surface along the gorge of the Ohio in a sinuous line, passing out around the high points and back around the heads of the deep ravines that are here cut down into the underlying Hudson River beds. The Clinton limestone usually outcrops in the stream beds a short distance above the crests of the waterfalls at the heads of the ravines just mentioned.

TOPOGRAPHY AND GENERAL REMARKS.—The Clinton varies in thickness in Indiana from a few inches to about seven feet. In Ohio it ranges from 30 to 40 feet thick, thus showing a general thinning out toward the west.

Owing to its thinness it exercises practically no control on the topography of the region in which it outcrops, neither is it of commercial importance. It is a very persistent bed, occurring at most places where its horizon is exposed. At some places, however, it is absent, and near Osgood and southwest of Versailles pebbles have been found in it. These facts have led Foerste to advance the opinion that during Clinton time there was a land mass not far west of the present line of Clinton outcrop.†

While this thin formation contains many fossils, these are usually imbedded firmly in the rock and are difficult to obtain. For lists of Clinton fossils the reader is referred to the papers by Kindle‡ and by Foerste.§

In 1883, the Clinton was recognized at Parker's Mill by Elrod,¶ but the true limits of the formation were not recognized by him else-

*Indiana Department of Geology and Natural Resources. 22d Annual Report (1897), A Catalogue of the Fossils of Indiana, by E. M. Kindle Pages 407-514. Indianapolis, 1898.

†Journal of the Cincinnati Society of Natural History. Vol. XVIII, p. 200.

‡Indiana Department of Geology and Natural Resources. 22d Annual Report (1897). pp. 408-514. A Catalogue of the Fossils of Indiana, by E. M. Kindle. Indianapolis, 1898.

§Report of the Geological Survey of Ohio. Vol. VII. Fossils of the Clinton group in Ohio and Indiana, by August F. Foerste, pp. 516-601.

¶Indiana Department of Geology and Natural History. 12th Annual Report, p. 130.

where. Foerste first called attention to the true limits of the Indiana Clinton in 1896* and has later published papers in which many Clinton localities are mentioned, and lists of collected fossils are given.†

NIAGARA.

CHARACTER.—The Niagara group in southeastern Indiana is made up of limestones and shales. In Township 3 north, 9 east, these rocks have at Hanover, in the southwest quarter of Section 12, a thickness of about 68 feet.

The section of the Niagara beds shown in Fig. 4, is exposed on the Hanover Landing Road, beginning at the top of the hill at Hanover.

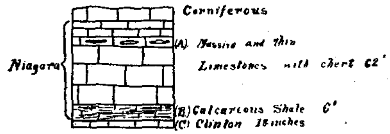


Fig. 4. Section showing the relations of the Niagara beds near Hanover.

The Niagara strata are known locally as the "cliff rock," owing to the fact that the more massive and indurated beds resist the action of the weather, and form cliffs along the ravines where they outcrop.

AREAL DISTRIBUTION.—On the accompanying map (Plate II) the narrow sinuous strip of outcropping Niagara beds is shown at the east side of 3 north, 9 east, and the west side of 3 north, 10 east. These beds form the bluffs on the high points and along the crests of the hills, on the west side of the Ohio gorge. They are always to be found also, at the sides of, and crossing, the ravines immediately above the numerous waterfalls of this locality. These hard beds frequently form low falls in the streams above the main falls of the region.

In the Niagara group of this and the neighboring localities in Indiana, where it outcrops, the following divisions have been recognized by Foerste.‡

Niagara Group—	Feet.
Louisville limestone and Utica lime rock	40- 55
Waldron shale	5- 10
Laurel limestone or cliff rock	35- 45
Osgood beds	15- 25
Totals	95-135

*Journal of the Cincinnati Society of Natural History, pp. 188-200.

†See the papers by August F. Foerste in the following annual reports of the Indiana Department of Geology and Natural Resources. 21st Annual Report (1896) pp. 214-288; 22d Annual Report (1897), pp. 195-255; 24th Annual Report (1899), pp. 41-80.

‡Indiana Department of Geology and Natural Resources. 21st Annual Report (1896), p. 217. Indianapolis, 1897.

TOPOGRAPHY.—Composed as it is, of shales and limestones, with the limestones generally predominating, and resisting the action of the weather, the Niagara strata often form steep slopes, bluffs and waterfalls along their line of outcrop.

ECONOMIC GEOLOGY.—In the region of 3 north, these beds are of little economic importance commercially, though some small quarries have been opened and some stone has been obtained for local building purposes. Northward, however, the Niagara rocks are in some localities hard and compact, of even texture and color, and occur in thin, easily separated layers, usually from three to ten or twelve inches thick. Under these circumstances they have proven valuable and have been of considerable commercial importance as building, curbing and paving stones. The largest quarries are in Ripley, Decatur and Franklin counties, where practically all the rock quarried is taken from the Laurel beds.*

PALEONTOLOGY.—The Niagara group is very prolific of fossils and for lists of the species the reader is referred to Kindle's Catalogue of Indiana Fossils, cited above, which contains, besides a list of the fossils, a bibliography of the writers on Indiana paleontology. The first important papers containing figures and descriptions of the Niagara group species of Indiana are those of Hall.†

DEVONIAN.

The Devonian rocks of southern Indiana have an aggregate thickness, at Scottsburg, of 190 feet, as shown in the deep well at that place. They consist of more or less pure limestones and black bituminous and arenaceous shales. So far as the author has observed these are conformable one with another, and the lowest bed lies conformably upon the Niagara limestone,‡ while the topmost bed (the black shale) is overlain by the Rockford goniatite limestone, which is

*Indiana Department of Geology and Natural Resources. 22nd Annual Report (1897), p. 195 et seq. Indianapolis, 1898.

†28th Annual Report of the New York State Museum of Natural History. The Fauna of the Niagara group in Indiana, by James Hall, pp. 99-210. Plates I to XXXIV. Albany, 1879.

Indiana Department of Geology and Natural History. 11th Annual Report, pp. 217-345, Plates I to XXXVI. Indianapolis, 1882.

Also, 12th Annual Report, pp. 272-275 and accompanying plates. Indianapolis, 1883.

‡A slight unconformity exists between the Niagara and overlying Devonian limestone in southern Shelby county. See 25th Annual Report Department Geology and Natural Resources, p. 557 and Plate XVI.

also conformable with it. The accompanying section, Fig. 5, indicates the relations of these Devonian strata.

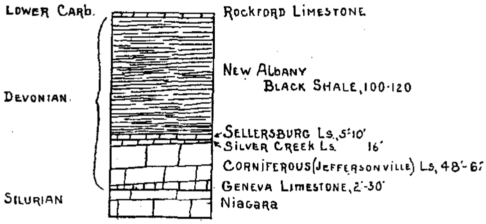


Fig. 5. Section showing the character and relations of the Devonian strata of southern Indiana.*

THE LIMESTONES.

Of the Devonian limestones there are two distinct series of beds. These two series were originally grouped together as Upper Helderberg by Hall.†

Afterwards they were recognized as having distinct characteristics and the lower beds were recognized as the *Corniferous* limestone, while the upper division was correlated with the Hamilton of New York. These two divisions of the Devonian limestones of Indiana are recognized by Dana.‡

In 1899 Kindle§ suggested for the lower of the two divisions the name of Jeffersonville limestone, owing to its development in the neighborhood of that city; while for the upper beds he has suggested the name of "Sellersburg beds," owing to the development and exposure of these rocks at the town of that name in Clark County.

In 1900 Siebenthal subdivided the Sellersburg limestone, retaining the name Sellersburg for the white and gray crystalline limestone lying between the cement rock and the New Albany black shale, and naming the underlying cement rock the Silver Creek Hydraulic limestone.||

*The Pendleton sandstone, which, further north, lies between the Niagara and Corniferous, has not been recognized as far south as township 3 north, and it is therefore omitted from the section.

†American Journal of Science. 1843. Vol. 45, p. 158.

‡Manual of Geology. By James D. Dana. Fourth edition, pp. 580, 592. 1895.

§Bulletin of American Paleontology, No. 12. The Devonian and Lower Carboniferous Faunas of southern Indiana and central Kentucky. By E. M. Kindle, p. 8. Ithaca, New York, 1899.

||Indiana Department of Geology and Natural Resources. 25th Annual Report (1900), pp. 332-393. See pp. 339 and 345. Indianapolis, 1901.

Corniferous or Jeffersonville Limestone.

Character and Thickness.—The Corniferous limestone varies in color from gray to bluish and buff. Where very pure and crystalline it usually has a bluish gray color. In thickness it varies from 20 feet to about 60 feet. At the Falls of the Ohio its thickness, according to Kindle,* is at least 20 feet. At Scottsburg, in Township 3 north, 7 east, where the Corniferous and Hamilton limestones are penetrated in a deep well at a depth of 172 feet, the combined thickness of the two formations is reported to be 68 feet. The total thickness of the Corniferous was not observed at any one place in 3 north, but the variations from 20 to 50 feet may be taken as about correct for it.

Areal Distribution and Topography.—The Corniferous rocks outcrop along a belt of country ranging in width from two to six miles in Township 3 north. The eastern margin of these rocks is along the bluffs at the west side of the gorge of the Ohio River; the western margin is on a comparatively level tableland. Lying between the Jeffersonville and Niagara limestones in the extreme southern part of the State is a thin bed of buff or brownish colored magnesian limestone to which the name "Geneva limestone" was given by Collett in 1881.† Thin and unimportant in the region of the Ohio River, this limestone becomes thicker to the northward, reaching in Bartholomew and Shelby counties a thickness of from 20 to 30 feet, and apparently replacing the Jeffersonville and Sellersburg beds as recognized farther south.

The Corniferous (with the Geneva limestone) strata lie immediately above the Niagara limestones in the region of township 3 north and protect those beds from erosion. The escarpment along the Ohio River in the region of Madison is due to the combined influence of both the Corniferous and Niagara beds. The topography of the Corniferous area is shown on Plate II. On that map the Corniferous and Hamilton areas are shown together.

The Hamilton Limestones (Sellersburg and Silver Creek Limestones).

Character.—The Hamilton rocks of southern Indiana vary in thickness from 6 to 20 feet.‡ They are made up for the most part of

*Bulletin of Amer. Pal., Loc. cit., p. 23. Ithaca, New York, 1899.

†Indiana Department of Geology and Natural History. 11th Annual Report (1881), p. 63, Indianapolis, 1882.

‡Bulletin of American Paleontology, No. 12. The Devonian and Lower Carboniferous Faunas of Southern Indiana and Central Kentucky. By E. M. Kindle, p. 8. Ithaca, New York, 1893.

a fine grained siliceous limestone, with a buff color, and conchoidal fracture. Overlying this impure limestone is sometimes a thin bed of purer limestone, which is in turn overlain by the New Albany black shale.

AREAL DISTRIBUTION.—In township 3 north the Hamilton beds outcrop along a narrow strip just east of the eastern margin of the New Albany black shale. They are here usually concealed by glacial drift, and the actual line of contact between them and the Corniferous beds was not traced.

The head waters of Hog Creek and Woods Fork have cut down through the black shale in township 3 north, 9 east, in sections 18, 30 and 31, respectively, Plate II, exposing the underlying Hamilton and often the Corniferous limestones. The limestones thus exposed extend down stream for five or six miles, being exposed all along Woods Fork, Hog Creek and their tributaries, and along Stucker's Fork in the neighborhood of Lexington and for two miles below that town. They finally disappear below the surface in 3 north, 8 east, sections 19 and 29, along a general northwest-southeast line; the rocks along this line have a perceptible southwestward dip.

Silver Creek Hydraulic Limestone.—The Silver Creek Hydraulic limestone is a fine-grained stone which has hydraulic properties. It is usually massive, and ranges in thickness from a few inches in Township 3 north, to over 15 feet in the Silver Creek region in Clark County. It breaks with a sub-conchoidal fracture, and in color varies from buff on weathered surfaces to bluish drab on freshly exposed surfaces.

The following analyses* show the composition of this limestone:

	Ohio Valley.	Speed's.	Belknap's.	Black Diamond.	Hausdals.
Insoluble in hydrochloric acid	25.90	18.68	12.75	13.03	21.26
Lime (CaO) soluble in acids	30.41	34.55	29.40	29.08	33.99
Magnesia (MgO) soluble in acids	8.48	7.97	16.71	15.70	7.57
Ferric oxide (Fe_2O_3) soluble in acids	.47	.43	.85	1.15	.39
Alumina (Al_2O_3) soluble in acids	.27	.30	.25	.80	.32
Loss on ignition	33.46	36.65	40.47	39.29	35.16
Total	98.99	98.58	100.43	99.05	98.69

The insoluble portions consist principally of silica (SiO_2) and alumina (Al_2O_3). The ratio of the alumina to silica varies in the

*Loc. cit., p. 366.

different samples from 1 to 3.89 in the Ohio Valley stone, to 1 to 5.56 in the Belknap stone.

Just north of the center of the southeast quarter of Section 21, Township 3 north, 8 east, 14 inches of hydraulic limestone is exposed at a spring house; it is here overlain by three feet of shaly limestone, and underlain by blue compact limestone. To the south it becomes thicker, reaching a thickness of five feet one mile east of Lexington, and continuing to thicken further south, till it reaches its maximum in the region of Silver Creek. To the north it becomes thinner, and finally disappears altogether in Section 16, Township 3 north, 8 east, north of which place it has not been observed.*

For detailed information regarding the Silver Creek and Sellersburg limestones throughout the southern Indiana region the reader is referred to Mr. Siebenthal's paper on that subject, cited above.

Sellersburg Limestone.—The Sellersburg Limestone lies between the cement rock and the black shale, and where the cement rock is absent in southern Indiana includes the beds from top of the Corniferous to the overlying New Albany black shale.

It is not always present between the cement rock and black shale, but is usually to be found where its interval is exposed. In Township 3 north it varies in thickness from 2½ to 5½ feet. At the Spring house in the southeast quarter of Section 21, Township 3 north, 8 east, it is three feet thick and is overlain by the New Albany black shale.

Further south in the Silver Creek region it reaches a thickness according to Siebenthal† of from five to ten feet, rarely reaching the latter thickness.

ECONOMIC GEOLOGY.—The Silver Creek hydraulic limestones, of the Hamilton, are valuable as cement producers, and are quarried for that purpose at Sellersburg. North of that place the northernmost exposure of the rock which is suitable for the manufacture of cement and thick enough to be worked is about one mile east of Lexington, where the bed is from five to six feet thick. A good cement is said to have been made from samples of this rock, but it has not been quarried here for that purpose.

TOPOGRAPHY AND STRUCTURE.—The Hamilton beds exercise no marked control over the topography of the country over which they outcrop. They have a dip from Big Spring, Township 3 north, 9 east, Section 16, to Section 20, in 3 north, 8 east, of 231 feet, or a little over 33 feet per mile. This dip is not constant, but varies from

*Ibid., p. 359.
†Ibid., p. 341.

20 to 46 feet per mile, and is in every respect sufficient to cause the westward flow of the streams.

PALEONTOLOGY OF THE DEVONIAN LIMESTONES.—The Devonian limestones are prolific in fossils and many lists of them have been published. The completest are those of Kindle.*

Most of the lists of Hamilton limestone fossils in Indiana have the species all grouped together, regardless of whether they come from the cement rock or overlying strata. Siebenthal, however, in his report upon the cement rock cited above, gives separate lists of the fossils he found in the Sellersburg, Silver Creek and Jeffersonville limestones. Many of the Corniferous corals were listed and figured by Hall in the 12th Annual Report of the Department of Geology and Natural History of Indiana.†

NEW ALBANY BLACK SHALE.‡ (Genesee.)

CHARACTER.—Lying upon the Hamilton limestones is a bed of black bituminous and arenaceous fissile shale known as the New Albany black shale, and often referred to simply as "the black shale." After exposure to the weather it usually loses its jet black color, and weathers to a drab. After weathering it also shows its finely laminated structure which is not always apparent in unweathered fragments. At some places it contains enough bituminous matter to cause it to burn when thrown into a fire. This fact, coupled with its jet black color in southern Indiana, has led to much misguided search for coal. In the northern part of the State it does not have the jet black color that it has in the Ohio River region. In Indiana it rests conformably upon the underlying limestones; in Kentucky there is an unconformity between the black shale and the underlying limestone.§

The thickness of the New Albany black shale is 120 feet at Scottsburg, where its top lies 52 feet below the surface; at Salem, where it occurs at a depth of 627 feet, it has a thickness of 103 feet; at New Albany its thickness is 104 feet; at Lafayette it is 120 feet thick,

*Bulletins of American Paleontology, Vol. 3, No. 12. The Devonian and Lower Carboniferous faunas of southern Indiana and Kentucky. (Ithaca, 1899.) Also, Indiana Department of Geology and Natural Resources. 22nd Annual Report, pp. 407–488. (Indianapolis, 1898.)

†Pages 275-318, Plates XV-XXIV. Indianapolis, 1883. See also the 35th Annual Report of the New York State Museum of Natural History, pp. 421–464, Plates XXIII-XXX. Albany, 1884.

‡The New Albany black shale is generally referred to in this paper simply as the *black shale.*

§Bulletin of American Paleontology, No. 12. The Devonian and Lower Carboniferous Faunas of southern Indiana. By E. M. Kindle, p. 8. Ihaca, New York, 1899.

while its thickness at Bloomington, where its top is 755 feet below the surface, is 155 feet. Eleven miles northwest of Columbus at the well of J. W. Johnson, in Section 11, 10 north, 3 east, it is 110 feet below the surface and has a thickness of 195 feet. These thicknesses at widely separated points in the State show a remarkably even distribution for this formation.

STRATIGRAPHIC POSITION.—The stratigraphic position of this shale has long been a matter of discussion among geologists who have worked in Indiana. In 1837 it was classed by Owen as a member of the Sub-Carboniferous group, which included those beds lying below the Carboniferous or coal-bearing formation.* Later, in 1843, 1844, it was regarded by Owen as the equivalent of the Marcellus shale of the New York section.† This view was held also by Dr. A. Clapp‡ in 1841. Hall and Rogers also concurred in this correlation. In 1848 Edward de Verneuil correlated the black shale of Indiana, Ohio and Kentucky with the Genesee shale of New York.§ This correlation was accepted by Meek and Worthen in 1861.‖ This conclusion was reached also by Whitfield from a study of the black shale fossils in 1874.¶ In 1879 Hall came to regard it as the equivalent of the "shales succeeding the Hamilton group of New York."** This view has been generally accepted since 1874.

The only local name that has been applied to this formation is that given in 1873 by E. T. Cox, State Geologist of Indiana, where, in speaking of the black shale of Ohio and Indiana, he says, "I have thought best to speak of it in this State as the New Albany black slate."†† In the same volume§§ W. W. Borden, in his report on Clark and Floyd counties uses this name, and says, "The black slate is largely exposed at New Albany, and on that account I propose to designate it in this report as the "New Albany black slate."

Since that time the name New Albany "black slate," or black shale, has been continuously applied to this formation, and in strati-

*Report of a Geological Reconnaissance of the State of Indiana made in the year 1837 in conformity to an order of the Legislature, by D. D. Owen, M.D., State Geologist. American Journal of Science, Vol. XXXIV, 1838, pp. 193, 194.

†American Journal of Science. Vol. XLV, 1843. p. 152.

‡Proceedings of the Philadelphia Academy of Science. Vol. I, 1841. pp. 18, 19.

§American Journal of Science. Vol. V. 2d series. 1848. p. 370.

‖Remarks on the age of the Goniatite limestone at Rockford, Indiana, and its relations to the "Black Slate" of the Western States, and to some of the succeeding rocks above the latter; by F. B. Meek and A. H. Worthen. American Journal of Science. Vol. XXXII. 2d series. pp. 167-177.

¶Sixth Annual Report of the Geological Survey of Indiana, made during the year 1874. p. 181. Indianapolis, 1875.

**Natural History of New York. Paleontology. Vol. V, Plate II, p. 152. Albany, 1879,

††Fifth Annual Report of the Geological Survey of Indiana, made during the year 1873. p. 102. Indianapolis, 1874.

§§Ibid., p. 158.

graphic position, it is regarded as the equivalent of the Genesee shale of the New York section.

The Devonian stratigraphy is discussed, many detailed sections are given and the fossils are described and figured by Kindle in an excellent paper in 1900,* to which the reader is referred for more detailed information regarding the various localities where the Devonian rocks outcrop in Indiana.

AREAL DISTRIBUTION.—The black shale comes to the surface in southern Indiana in the low north-south trough immediately east of the high eastward facing escarpment formed by the Knobstone group and the limestones overlying it. South of an east-west line drawn through Edinburg its western margin is near the bottom of this trough, while its eastern margin is from 10 to 25 miles further east, at a higher altitude and usually in a country that is somewhat rolling.

North of the east-west line above referred to the black shale area widens out, but is generally deeply buried under glacial debris. From Edinburg to New Albany the Jeffersonville, Madison and Indianapolis Railroad runs parallel to the upper contact of this shale and not far from it.

In township 3 north the black shale outcrops over a strip of country about fourteen miles wide. The easternmost point at which it occurs is in 3 north, 9 east near the center of the east half of Section 27. The contact between the black shale and the underlying limestone is not often seen in the south half of 3 north, 9 east because this township is for the most part covered by several feet of glacial clay. The line of contact can be seen, however, just south of Big Spring near the center of the north half of Section 16. From this place it can be traced to the point where it crosses the north line of the township, a half mile west of Kent Postoffice, near the northwest corner of Section 6. This lower contact crosses Township 3 north in a general northwest-southeast direction, almost at right angles to the dip of the strata.

Passing westward from its eastern edge the shale is carried successively lower by its westward dip. Notwithstanding the westward dip of the strata the creeks in 3 north, 8 east, viz.: Stucker's Fork, near Lexington, and Woods Fork and Hog Creek, farther north, have cut down through the shale, exposing the underlying limestones. The bottoms of the valleys of these creeks are therefore limestone, while the adjacent hillsides and hilltops are of black shale, of which a thickness of from 50 to 60 feet is often exposed.

*Indiana Department of Geology and Natural Resources. 25th Annual Report (1900), pp. 529-758. Plates I-XXXI. Indianapolis, 1901.

The westernmost exposures of these isolated limestone areas, which are surrounded by the black shale, are in Sections 29 and 18 along a line almost parallel with the eastern edge of the black shale.

The western edge of the black shale, i. e., its upper contact with the rocks of the overlying Knobstone group, crosses the south line of 7 east a little east of the center of the south line of Section 34. The line of contact from here northwestward is marked by the overlying goniatite limestone, and can be seen occasionally in gullies and on the hillsides, until a point is reached about one mile east of Scottsburg near the west line of Section 20 where the limestone and shale outcrop. Northwest of Scottsburg the contact passes through a low flat country and is usually overlain by from 40 to 50 feet of clay. By means of well sections the line of contact was approximately determined; it passes just east from Scottsburg, and thence in a northwesterly direction, to the west line of Section 7, crossing the north line of Township 6 east immediately west of the northwest corner of Section 1.

Topography.—Most of the country underlain by the black shale is quite rolling. The topography through Townships 3 north, 6, 7, 8, and 9 east may be taken as generally typical of this formation, with the exception that to the northward the eastern margin of the formation occurs in a country usually more broken than that shown on the map, because the streams that cut across it are larger in that region, and have cut out deeper valleys.

The western margin of the black shale where not covered by glacial debris, is in a region of low hills.

In 3 north, 9 east the extreme eastern edge of the black shale is quite thin. On Plate II it will be observed that a number of westward flowing streams have their sources from a mile to two miles west of this eastern contact. This is a region in which dissection has scarcely begun.

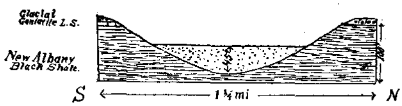


Fig. 6. North-south section from the center of southwest quarter of Section 21, to the center of the west half of Section 16, Township 3 north, 7 east, showing silted up valley. The soil of the silted up valleys is for the most part a light colored clay.

Further west in Township 8 east and the eastern part of Township 7 east, the streams have cut valleys from 60 to 100 feet deep. In 7 east, Stucker's Fork and its tributaries flow through flat silted up valleys. These valleys have been filled at least 45 feet in some cases.

At Scottsburg the valley has been filled to a depth of 48½ feet, which probably represents about the amount the valleys of this general region have been filled.

Owing to this silting up of the valleys, the hills at the west side of the black shale area, formerly full as high, or higher than those at the center of that area, are now much lower and have gentler slopes than do those further east.

ECONOMIC GEOLOGY.—The black shale is of small economic importance. It is used locally as a road metal, when nothing better can be had. It has been tried as a roofing material, being ground, mixed with tar and spread upon felt. It was found to crack upon long exposure and was thus worthless for this purpose and its use was discontinued.*

The character of the black shale and the results of experiments in distilling oil and gas from it are discussed by Mr. Hans Duden in the 21st Annual Report of the Department of Geology and Natural Resources.†

LOWER CARBONIFEROUS.

The Lower Carboniferous rocks of Indiana consist of shales, sandstones, limestones and some cherts, and aggregate 1,050 feet where crossed by Township 3 north.

At the base of this series of strata lies the Rockford goniatite limestone, resting conformably upon the Genesee shale. The Lower Carboniferous strata are overlain unconformably by the massive Mansfield sandstone, which lies at the base of the Productive Coal Measures.

The different strata making up the Lower Carboniferous group lie conformably one with another. The following section (Fig. 7) shows the relations between these strata.

THE ROCKFORD GONIATITE LIMESTONE.

CHARACTER AND DISTRIBUTION.—The Rockford goniatite limestone, which is the lowest of the Lower Carboniferous strata recognized in Indiana, is a thin but remarkably persistent bed. It is a close grained rock with a conchoidal fracture. Upon a freshly broken

*Fifth Annual Report of the Geological Survey of Indiana, made during the year 1873, p. 159. Indianapolis, 1874.

†Indiana Department of Geology and Natural Resources. 21st Annual Report (1896), pp. 108-119. Some notes on the black slate or Genesee shale, of New Albany, Indiana. By Hans Duden. Indianapolis, 1897.

surface it usually shows a mottled greenish color; upon weathering it turns brown.

Below it is the black shale, and immediately above is the light greenish argillaceous shale, forming the base of the Knobstone shales. While this limestone is usually less than two feet thick, it is rarely entirely wanting in southern Indiana where its horizon is exposed. At New Albany it outcrops along the creek at the north and west edges of the town, and has a thickness of two feet. In Lot 62 of the

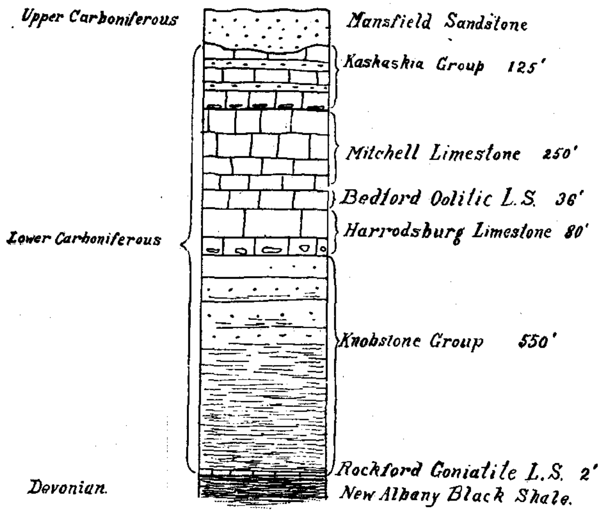


Fig. 7. Section showing the relations of the Lower Carboniferous strata, along the middle line of Township 3 north.

Illinois Grant, Clark County, about a quarter of a mile west of the center of the east line, the goniatite limestone is 18 inches thick, and in a space of 100 feet it thins down to a feather edge. At this place the contact between the upper and lower beds is well exposed and the

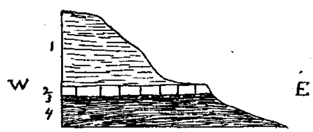


Fig. 8. Profile showing the occurrence of the Rockford goniatite limestone a quarter of a mile west of the center of the east line of Lot 62 of the Illinois Grant. (1) 20 feet of greenish argillaceous shale, typical of the base of the Knobstone group. (2) 18 inches goniatite limestone. (3) 6 inches of soft shale, resembling that overlying the limestone. (4) New Albany black shale.

occurrence is shown in the accompanying profile section (Fig. 8). The occurrence shown in Fig. 8 is typical of this limestone, so far as the writer's observations have gone, except that the underlying thin greenish shale is not always present. Near the west side of Township 3 north, 7 east, Section 21, near Mr. Munden's house, one mile east of Scottsburg, the limestone has a thickness of 18 inches.

The northernmost exposure of the Rockford limestone, known to the writer, is in the bed of White River at the village of Rockford. It is reported to have been exposed in a cut on the Jeffersonville, Madison and Indianapolis Railroad about one and one-half miles north of Rockford on the west side of White River.

North of this locality the Rockford limestone horizon is covered over by glacial drift. It occurs about 11 miles northwest of Columbus, where it is struck in the well of Mr. J. W. Johnson, 10 north, 4 east, in the southwest quarter Section 11. At this place it lies 106 feet below the surface and is reported to be four feet thick. The following section (beginning at the surface) is reported from this well; it shows that the stratigraphic relations of the beds in 10 north, 4 east are precisely the same as at exposed localities further south:

	Feet.
Yellow clay (glacial)	56
Clay shale (Knobstone)	50
Limestone (goniatite)	4
Black shale (Genesee)	195
Limestone (Hamilton and Corniferous)	50

Four miles southeast of this place, in 10 north, 5 east, the southwest quarter Section 20, Mr. W. S. Bevis has a well in which the goniatite limestone is 79 feet below the surface, and has a thickness of two feet. Its relations to the overlying and underlying beds at this place are identical with those given in the above section.

STRATIGRAPHIC POSITION. — The stratigraphic position of the goniatite limestone has long been a question of controversy among American geologists. Occurring as it does at the top of the Devonian it has been regarded as belonging to the Devonian by some writers, notably by Hall, while others place it with the Lower Carboniferous. The latter view is the one generally accepted at the present time.

In 1861 the Rockford limestone was correlated by Hall with the Marcellus beds of the New York section.*

In 1862 Hall regarded this limestone as "parallel with the Chemung group,"† which view he did not change. In 1861 Meek and

*Thirteenth Annual Report of the Regents of the University of the State of New York. p. 95. Albany, 1860.

†Fifteenth Annual Report of the Regents of the University of the State of New York. p. 81. Albany, 1861.

Worthen correlated the Rockford limestone with the Chouteau of Missouri.* In 1898, Kindle summed up the discussions relative to the age of this limestone and arrived at the conclusion that it is the equivalent of the Lithographic or Louisiana limestone of Missouri.† Kindle bases this correlation on stratigraphic evidence, and points out that the stratigraphic position of the Rockford limestone relative to the black shale, as well as its lithologic character, agrees almost exactly with that of the Lithographic limestone of Missouri, while the paleontologic evidence on which Meek and Worthen made their correlation with the Chouteau is not sufficient to justify that correlation.

In the writer's opinion Kindle's views are correct. There is certainly no member of the Lower Carboniferous group in Indiana that is lower than the Rockford limestone, while there is a very close correspondence between the Missouri section from the Hamilton up to the Burlington limestone, and the southern Indiana section from the Hamilton up to the Harrodsburg limestones of Hopkins and Siebenthal's section of the Lower Carboniferous limestones. Kindle, however, omits the Rockford limestone from his generalized section,‡ in which section that limestone falls between the "black shale" and the "argillaceous blue and green shales," thus holding a position identical with the Lithographic limestone of the Missouri section. This stratigraphic correlation is much strengthened by the fact that *Prodromites gorbyi* occurs both in the Rockford limestone, at Rockford, and in the Louisiana (Lithographic) limestone at Sedalia, Missouri. This species is found also in the Kinderhook at Burlington, Iowa.§

PALEONTOLOGY.—The following species have been identified from the Rockford limestone in Indiana:

PROTOZOA.

Palæacis enormis Meek and Worthen.

CŒLENTERATA.

Amplexus ? rockfordensis Miller and Gurley.

Zaphrentis ida Winchell.

ECHINODERMATA.

Synbathocrinus oweni Hall.

*American Journal of Science. 2d series. Vol. XXXII, p. 167.

†Bulletins of American Paleontology, No. 12. The Devonian and Lower Carboniferous Faunas of Southern Indiana and Kentucky. By Edward M. Kindle. pp. 91, 92, 93. Ithaca, New York, 1889.

‡Bulletins of American Paleontology, No. 12. The Devonian and Lower Carboniferous Faunas of Southern Indiana and Kentucky. By Edward M. Kindle. p. 92. Ithaca, New York, 1899.

§*Prodromites*, A New Ammonite Genus from the Lower Carboniferous, by J. P. Smith and Stuart Weller, Journal of Geology, Vol. IX, No. 3 (1901), p. 255.

BRACHIOPODA.

Ambocœlia gregaria Hall.
Chonetes geniculatus White?
Cryptonella ? inconstans Herrick.
Reticularia cooperensis Swallow.
Rhipidomella ocassus Hall.
Rhynchonella obsolescens Hall.
Spirifer maroonensis Shumard.
Spirifer rostellatus Hall?
Spiriferina solidirostris White.

LAMELLIBRANCHIA.

Aviculopecten tenuicostis Winchell
Anatina leda Hall.
Cardiopsis radiata Meek and Worthen.
Cypricardia ventricosa Hall.
Nucula hians Hall.

GASTEROPODA.

Bellerophon cyrtolites Hall.
Bellerophon lineolatus Hall.
Euomphalus lens Hall.
Murchisonia limitaris Hall.
Platyceras haliotoides Meek and Worthen.
Pleurotomaria mitigata Hall.
Pleurotomaria vadosa Hall.
Straparollus lens Hall.
Straparollus spirorbis Hall.

PTEROPODA.

Hyolithes aculeatus Hall.

CEPHALOPODA.

Brancoceras ixion Hall.
Cyrtoceras rockfordense Winchell.
Goniatites lyoni Meek and Worthen.
Gyroceras gracile Hall.
Gyroceras ? rockfordense Meek and Worthen.
Munsteroceras oweni Hall.
Munsteroceras parallelum Hall.
Nautilus rockfordensis Meek and Worthen.
Nautilus trisulcatus Meek and Worthen.
Orthoceras heterocinctum Winchell.
Orthoceras icarus Beecher.
Orthoceras indianense Hall.
Orthoceras marcellense Vanuxem.
Orthoceras whitei Winchell.
Prodromites gorbyi Miller.

Prodromites præmaturus Smith and Weller.
Soleniscus rockfordensis Miller.
Solenochilus rockfordensis Miller.
Trematodiscus trisulcatus Meek and Worthen.

ARTHROPODA.
Phillipsia rockfordensis Winchell.
Prœtus doris Hall.

PISCES.
Orodus multicarinatus Norwood and Worthen.

ECONOMIC GEOLOGY AND TOPOGRAPHY.—Owing to its thinness the Rockford goniatite limestone has no economic value, and neither does it exercise any control upon the topography of the region in which it outcrops. It outcrops for the most part in a gently rolling region, the relief of which is determined entirely by the overlying and underlying beds.

THE KNOBSTONE GROUP OF INDIANA.

INTRODUCTORY.

Overlying the goniatite limestone, and where that formation is absent, lying upon the black shale, is a series of clay shales, and friable, arenaceous shales and sandstones, containing in some places thin limstone beds.

This series of strata ranges in thickness from 440 to 650 feet.* In 1859 Owen gave it the name *Knobstone Group*, because "these siliceous strata weather into peculiar conical knobs or hills."† This grouping was based on lithological evidence, and the name was suggested by a topographic characteristic. This name has become so well established in the literature of Indiana geology, however, and the series of rocks to which it applies is so well known that, though other names have been suggested, their adoption would result only in multiplying names, and in confusing rather than simplifying the subject. The name "Knobstone" is therefore retained as applying to the same strata to which this name was applied by Owen. Owing to the importance of the Knobstone group in Indiana, and also to the fact that the strata composing it have never been treated as a whole this group of rocks will be taken up somewhat in detail and the area covered by it in the State will be discussed.

*It is 650 feet thick at Bloomington, as shown by the deep well drilled at that place.

†Report of a geological reconnaissance of the State of Indiana, made in the year 1837, p. 21, by D. D. Owen. Indianapolis, 1859.

CHARACTER AND THICKNESS OF THE ROCKS.

The Knobstone group in southern Indiana is made up of three terranes of somewhat distinct lithologic characteristics.

THE NEW PROVIDENCE SHALE. — Overlying the goniatite limestones is a series of soft clay shales, usually of a greenish or bluish color, with a thickness of from 50 to 120 feet. This shale has been designated by Borden* as the New Providence shale. It attains its greatest thickness in the neighborhood of New Albany, and thins out to 50 feet or less at the south side of Scott County. In Township 3 north, and northward from that township, this basal knob shale, or New Providence shale, can not be easily distinguished from the overlying shales, and, if it occurs at all, is of small importance.

THE UPPER KNOBSTONE SHALE.—Overlying the basal knob shale is a series of soft light-gray or greenish shales. This second series of shales varies in composition from soft clay shale toward the bottom to an impure fine grained sandstone at the top. This series of beds which may be called the upper knob shales grades upward into the more or less massive knob sandstone. Owing to this gradation, the line of demarkation between the shales and the overlying sandstones is not easily distinguished, and the line of contact is therefore a more or less arbitrary one. The upper knob shale has a thickness of 200 feet in 2 south, 6 east, Section 10. Its thickness in Township 3 north, is about 250 feet. To the northward in Jackson, Brown and Bartholomew counties the upper knob shale contains a larger proportion of sand than at the extreme southern portion of the State.

THE KNOBSTONE SANDSTONE.—The Knobstone group is capped by the Knobstone sandstone which is not a single sandstone bed, but is rather a series of more or less pure, and usually soft, sandstones intercalated with which are sandy shales. In the southern portion of the State these uppermost beds of sandstone and intercalated shales have a thickness of from 75 to 100 feet, which represents approximately their thickness in Township 3 north. Further north, in Jackson, Brown, Bartholomew and Monroe counties, the sandstones become of more importance and are from 350 to 450 feet thick. Owing to the slight dip, and the wide area covered by the sandstone beds in this latter region, it is not possible to accurately measure their total thickness.

To the northward from Brown County the whole Knobstone group is more or less covered by glacial material, and where exposed at all only the uppermost beds are to be seen.

*Fifth Annual Report of the Geological Survey of Indiana, made during the year 1873, p. 161. Indianapolis, 1874.

One of the northernmost exposures of this group of rocks is at Riverside, in Warren County, where it has been quarried for building purposes. Owing to its occurrence at this village, it has been called "Riverside Sandstone" by Hopkins.*

TRANSITION BEDS.—At the top of the Knobstone strata and below the overlying limestones, are transition beds varying in thickness from 5 to 30 feet. These beds are sandy, impure limestones, usually containing intercalated chert bands and geodes. These transition beds are grouped with the overlying limestones. They occur, therefore, immediately west of the western limits of the Knobstone strata as outlined on the accompanying maps (Plates III, IV).

The three divisions of the Knobstone group, as outlined above, can be best recognized in the extreme southern part of the State, where the shales predominate, and where the entire group has its least development.

Further north, however, in Jackson, Brown and Bartholomew counties, the entire group is made up of alternating impure sandstones and clay shales in which the sandstones predominate.

Where the Knobstone strata outcrop along Sugar Creek, near Crawfordsville, the bluish massive sandy shales predominate.

The type sections (Fig. 9) show the general character and relations of the beds composing the Knobstone group in different parts of the area covered by that formation.

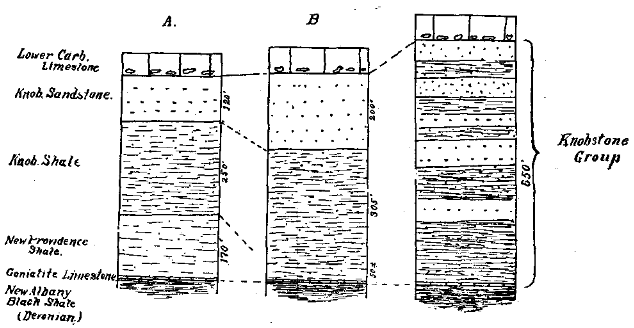


Fig. 9. Three type sections of the Knobstone group.

A. Section in Floyd County, just west of St. Joseph postoffice.
B. Section on the middle line of Township 3 north.
C. Section on the north line of Township 8 north, adapted from Bennett's cross section.

THICKNESS OF THE KNOBSTONE GROUP.—Section A., Fig. 9, shows the entire group to have a thickness, as determined by aneroid barom-

*Indiana Department of Geology and Natural Resources. 20th Annual Report, p. 317. Indianapolis, 1896.

eter, of 550 feet. At St. Joseph postoffice, where this section is taken, the Knobstone outcrops over a strip of country three and one-half miles wide.

At Section B., along the middle line of Township 3 north, the thickness is 550 feet, as determined by the vertical arc, allowing 26 feet per mile as the average dip. Along this line the strip covered by these strata, from the upper contact to the lower, is 12 miles wide.

At Section C., along the north line of Township 8 north, the thickness (as shown in the deep well at Bloomington) is 650 feet. The strip of country covered by these strata is here 28 miles wide.

At Rockville, Parke County, the Knobstone was shown by a deep well drilled there to have a thickness of 530 feet. Just west of New Albany its thickness is 471 feet. From the foregoing it is seen that the thickness of this series of strata varies from 471 feet near New Albany, to 650 feet at Bloomington, while at Rockville, in Parke County, it has a thickness of 530 feet. These variations in thickness are remarkably slight when the distances between the points at which the measurements are made are taken into consideration.

AREAL DISTRIBUTION.

The Knobstone strata outcrop over a strip of country extending in a general northwest-southeast direction, from south of New Albany, in Floyd County, to the neighborhood of Crawfordsville, in Montgomery County. They crop out also along the Wabash River in Warren County, and probably underly the western part of Tippecanoe County, but in this region they are deeply covered by glacial drift and little is known of their distribution. The areal distribution from the north side of Township 19 north, Montgomery County, southward to where the group is cut across by the Ohio River is shown on the accompanying maps (Plates III and IV). From these maps it will be seen that the area covered by these strata narrows down to a strip less than four miles wide in some places at the south, while to the northward it rapidly widens out until in Jackson, Monroe, Brown and Bartholomew counties, the strip covered ranges from 25 miles to over 38 miles in width.

This narrowing down of the Knobstone area to the south, and widening out to the north has been generally ascribed to a corresponding thinning and thickening of the strata themselves.

This, however, can not be the cause, for, with other conditions remaining the same, the difference of 100 feet in thickness would not account for a difference of about 25 miles in the width of the strip covered, as displayed in the profile section at St. Joseph, in Floyd

County, and along the north line of Township 8 north, from Columbus to Bloomington.

This increased width is considered to be due to two causes as follows:

1. In Jackson, Brown, western Bartholomew and eastern Monroe counties, almost the entire group is made up of alternating sandstones and shales, with the sandstones predominating. These alternating sandstones and shales have not succumbed to erosion as readily as have the strata further south, where the shales predominate, and where the sandstones occur only at the top of the group, thus allowing soft shales below to be worn away as rapidly as exposed by the removal of the overcapping sandstones.
2. Near the western margin of the Knobstone area, parallel to it, and extending at least from Unionville, in 9 north, 1 east, Section 10, in Monroe County, to 3 north, 2 east, Section 1, in Washington County, a distance of 36 miles, is a fault with the upthrust on the east side. The displacement of the rocks along this fault has not been measured throughout its extent but it is more than 100 feet in several places, and it is probable that, in so long a fracture the displacement may reach 200 to 300 feet or more.

   Whether this displacement be large or small, its effect is to reduce the westward dip of the beds lying east of it. This lessening of the dip of the Knobstone strata, combined with the alternating sandstone and shale beds which occur in the area of greatest width would be sufficient to account for this increased width.

The following sections, partially after Bennett* (Fig. 10) taken

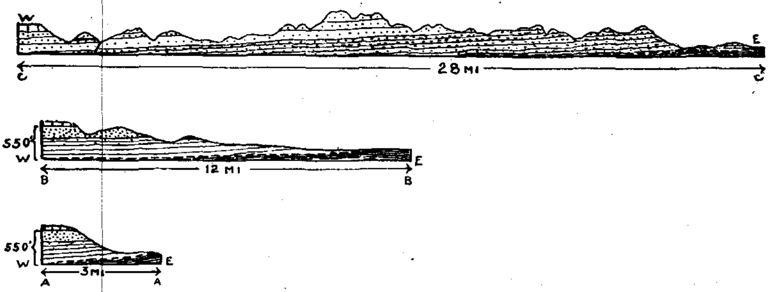


Fig. 10. AA. St. Joseph section. (Bennett after Newsom.)
BB. Section along the center line of 3 north. (Bennett after Newsom.)
CC†. Generalized section along the north line of 8 north. (Adapted from Bennett.)
The overlying limestone and underlying black shales are shown in each case.

*Proceedings Indiana Academy of Science, 1897, pp. 258-262.

†The fault shown in section C is not shown on Bennett's section.

near St. Joseph, along the middle line of Township 3 north, and along the north line of Township 8 north, illustrate the variations in distribution of these strata.

The accompanying map sheets show the location of the fracture here referred to, and also the location of the cross-sections shown in Fig. 11. On the maps these cross-sections are designated A-A, B-B and C-C, respectively.

It might be remarked that the fracture here mentioned is at the west side of the Cincinnati Arch, and that the line of fracture is at right angles to the prevailing dips of the rocks of this region.

It occurs, therefore, in the exact position that would relieve the tension produced in the strata in this locality by the gradual uplifting of the rocks to the east and it probably originated in this manner. This fault is further discussed under the subject of "Structure," p. 274.

Details of the areal distribution will be seen on the accompanying map sheets and need not be referred to in this connection.

In tracing out the upper contact of the Knobstone group, the transition beds, especially the chert layers, and residual chert masses, even when not occurring in the original unweathered beds, were classed with the overlying limestones. Thus, the line showing the eastern margin of the overlying limestone on the map will often be *east* of the real line of undecomposed limestones as they occur in the field.

Attention should be called to the fact, also, that north of Monroe, Brown and Bartholomew counties (Plate IV), the Knobstone strata are more or less covered by glacial debris, the thickness of this covering increasing generally to the northward.

From the northwest corner of Bartholomew County, southward to the Silver Hills at the south side of Scott County, the glacial debris laps up against the foothills of the "knobs" or Knobstone escarpment to the west, showing that the ice sheet encroached upon this area, and that it was crowded close up against the eastern slope of the Knobstone hills.

TOPOGRAPHY.

In the region north of Township 3 north, sandstones are the predominating strata as shown in Section C., Fig. 9. In the region south of Township 3 north, the shales predominate. In both of these districts, however, the shales are more abundant at the bottom of the group than they are at the top, and throughout the area, where unaffected by the glacial drift, the conditions (i. e., resisting strata overlying softer and more easily eroded beds) are therefore favorable for the formation of steep hillsides and narrow ravines.

The hills resulting from the erosion of the Knobstone strata present the most important topographic feature of southern Indiana. They usually stand from 250 to 500 feet above the lowlands lying east of them, and above the drainage level of the surrounding country.

Topographically the Knobstone area may well be divided into three parts:

First, the *southern district*, embracing the country lying between Township 3 north, and the Ohio River; second, the *central district*, extending from Township 3 north, to the northern edges of Monroe, Brown and western Bartholomew counties; third, the *northern district*, embracing that portion of the area lying north of Monroe, Brown and western Bartholomew counties, in which the topography is greatly modified, and for the most part controlled, by thick deposits of glacial debris.

THE SOUTHERN DISTRICT.—As is indicated on the map (Plate III), the outcropping Knobstone strata between the Ohio River and Township 3 north, present a bold, continuous eastward facing escarpment, with occasional more or less detached outlying points or "knobs" a short distance east of the main escarpment. From 5 south, to 3 north, this escarpment is cut through at only one place, viz.: In 1 south, and one north, 5 east, where it makes a sharp detour to the west and where the head waters of Muddy Fork of Silver Creek, and small tributary of Blue River have cut down through it, forming the narrow pass through which the Monon Railroad runs. South of Muddy Fork there are practically no foothills east of the main escarpment. North of this creek the foothills extend from one to four miles east of the main escarpment and finally merge into the lowlands of the black shale area to the eastward.

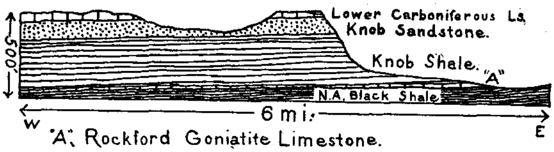


Fig. 11. Profile section from the northwest corner of Section 5, Township 2 south, 6 east eastward to the base of the Knobstone strata, showing the relations of the strata and the resulting topography. The knob shales of this region contain nodules of limonite and lenses of iron carbonate.

The profile (Fig. 11) in 2 south, 5 east, extending from the northwest corner of Section 5 eastward across the entire Knobstone area at that locality, shows the topographic and structural relations of this general region.

The Knobstone escarpment is trenched by numerous small eastward flowing streams, forming deep, narrow V-shaped valleys, varying in length from one-half mile to four or five miles. Seen from the low country to the east the high points between these valleys present the appearance of knobs, similar to the few outlying hills.

The divide between the short eastward flowing streams, and those flowing westward is usually at the very crest of the escarpment. The country westward from this crest is a comparatively level or gently rolling plateau, over which the streams flow with a grade which, except in their upper courses, is somewhat less than the dip of the strata. These features are well seen in the eastward and westward flowing streams south of Muddy Fork of Silver Creek.

Where the Lower Carboniferous limestones, which are really the protecting cap rocks of the Knobstone group, have been cut through, as by the headwaters of Indian Creek in 1 and 2 south, 5 and 6 east, the country is quite rolling, because, when once the limestones are worn through the underlying sandstones are readily attacked by the streams, with the result that considerable valleys are soon cut out. Streams of corresponding size flowing over the limestones only, have much shallower valleys.

The differences in the gradients of the eastward and the westward flowing streams of this extreme southern portion of the Knobstone area, where the overlying limestones more nearly approach the eastern face of the escarpment than anywhere else in the entire area, are shown in the accompanying profile (Fig. 12). This profile is taken along the course of a small tributary of Indian Creek, from Georgetown up to Edwardsville, at the south side of 2 south, 5 east. Thence

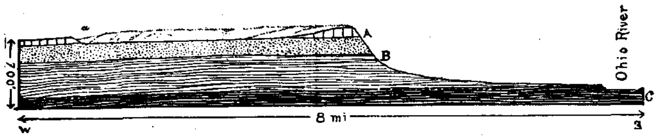


Fig. 12. Section from Georgetown to New Albany showing the plateau character of the country west of the Knobstone escarpment; and the differences in gradients of streams flowing eastward across the dip, and westward with the dip of the strata. The limestone which is barely cut through by the stream dips westward at the rate of 33 feet per mile. At *a* the stream, whose gradient is shown from *b* to *a*, turns aside; the section is prolonged slightly to show the general plateau character of the region. A=Lower Carboniferous limestone, B=Knobstone group, C=New Albany shale.

it extends eastward over the divide and down the eastward flowing stream that reaches the alluvial bottoms of the Ohio just west of

New Albany. It shows very well the differences in the topography produced by these eastward and westward flowing streams.

The above remarks apply more particularly to the region south of Muddy Fork of Silver Creek. They apply also to the region between Muddy Fork and Township 3 north, with the exception that in this latter region the overlying limestones have been entirely worn away several miles west of the escarpment face; because of this denudation the valleys west of the escarpment are somewhat deeper than are those further south which are similarly situated.

In Township 3 north, the Knobstone area is drained by streams leading northward into White River. The Knobstone plateau has been very perfectly dissected by these streams, which with their small tributaries from intricate dendritic systems of valleys, as is shown on the topographic sheet (PlateII) in 3 north, 2, 3, 4 and 5 east.

It will be noticed that these streams, after having cut through the overlying limestones, have in all cases quickly cut down to their present base levels of erosion, and that the main streams, especially Rush and Delaney creeks, flow through flat bottomed valleys. As their topography indicates, these are silted up valleys in which the alluvial filling is from 20 to 40 feet thick.

This silting up has been brought about by a depression of the land from a former higher elevation, when the valleys were eroded more deeply than at present. With the depression of the surface the streams gradually became checked and the valleys filled. All of the main tributaries of East White River in southern Indiana flow through valleys that have been filled in this manner from 20 to 60 or 75 feet. The accompanying section (Fig. 13) shows this feature.

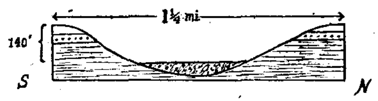


Fig. 13. North-south section across Rush Creek Valley in 3 north, 3 east, Sections 5 and 8.

THE CENTRAL DISTRICT (north of Township 3 north).—In the area north of 3 north, or more properly speaking, north of the Muscatatuck and East White rivers, the topography developed in the Knobstone area is quite different from that south of those streams.

As pointed out, south of Township 3 north, the region immediately west of the Knobstone escarpment, which is continuous and abrupt, is a gently westward sloping plateau which is but slightly dissected by the westward flowing streams. In 3 north, this plateau is completely dissected owing to the nearness of White River (the master stream of this section) combined with the fact that the streams flow partially across the dip of the beds.

North of East White River dissection has advanced much further than in the southern region. In Jackson, Brown and western Bartholomew counties the Knobstone plateau is perfectly dissected by the tributaries of East White River, Salt Creek and Bean Blossom Creek. In these counties the area of the Knobstone is made up of high ridges and steep sided V-shaped valleys. These valleys are unproductive, except where bottom lands have been formed in them by the silting up process. In this region the descent from the highest Knobstone hills to the lowlands to the east is gradual, and across rolling foothills which merge into low glacial hills, and finally into the low bottom lands of East White River.

The complete dissection of the Knobstone plateau north of East White River has been made possible by the early removal of the overlying limestones. Whether the early removal of these protecting limestones was due to their having been originally quite thin or to their having been more elevated and exposed in this locality than further south is not known; either of these causes, or the two combined would account for the present topographic conditions.

The preponderance of sandstone strata, in conjunction with the fault mentioned on p. 265, and the probable decreased westward dip caused thereby have kept the westward retreat of the eastward facing escarpment from keeping pace with the retreat of the overlying limestones.

The Northern District.—North of the northern edges of Monroe, Brown and western Bartholomew counties the Knobstone area is usually covered by glacial debris, and the strata are exposed only in the stream valleys. Where the strata are cut through by the larger streams, bluffs are often formed. Such bluffs are to be seen along West White River about Martinsville, and along Sugar Creek above and below Crawfordsville; at both of these localities are excellent exposures of the Knobstone strata. This northern portion of the area presents a glacial topography almost entirely and will not be discussed in this paper.

TOPOGRAPHIC FEATURES COMMON TO BOTH CENTRAL AND SOUTHERN DISTRICTS.

The effect of the gentle westward dip of the Knobstone and overlying limestone strata is not noticeable as affecting the topography, further than has been suggested in relation to the escarpment south of Township 3 north.

This westward dip has been sufficient to control the initial drainage of the country, however, and it is thus indirectly responsible for the topography of both the southern and central areas. It is also responsible for the arrangement of the main drainage lines that cross it, with the exception of the lower course of the Muscatatuck and the middle course of East White River.

The generally narrow V-shaped valleys cutting the country in all directions, apparently without systematic arrangement, form the most noticeable and important topographic characteristic of the Knobstone area. In the central area particularly, the valleys are well developed. Here they have the tangled dendritic arrangement common to flat plateau countries, where folds and faults are absent.

Differential Weathering of the Knobstone Strata.—It is a noticeable fact that throughout the whole Knobstone area where unaffected by glacial material, and where the valley systems are well developed, the south hillsides have gentler slopes than those facing northward, i. e., that erosion is further advanced on the south-sloping hills than on those sloping northward.

This feature is most noticeable along the east-west valleys. In north-south valleys the gentler slope, when one is gentler than the other, is usually on the east side of the valley, i. e., on the westward sloping hillside. The difference in the angle of slope between east and west hillsides is not so noticeable as that between north and south slopes.

Fig. 14 is a profile taken across a typical east-west valley showing this feature of differential weathering.

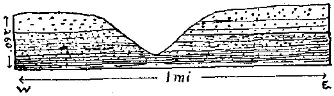


Fig. 14. North-south section across a typical east-west Knobstone valley, showing the difference between north and south slopes.

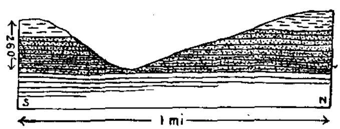


Fig. 15. East-west section across a typical north-south valley in the Knobstone area from west half-mile corner to center of east half of Section 23, Township 3 north, 3 east.

Fig. 15 is a profile across a typical north-south valley.

Fig. 16 shows the topography of a main east-west valley, with small tributaries. It will be noticed that the north side of the valley has a very gentle slope, while the south side is quite steep. There is no marked difference in the angle of slope of the sides of the small valleys entering the main valley from the south.

This differential weathering of the slopes is attributed to the effect of temperature changes, especially of freezing and thawing, upon the rocks. Changes in temperature probably have a more potent effect in breaking up these rocks than has any other agent.

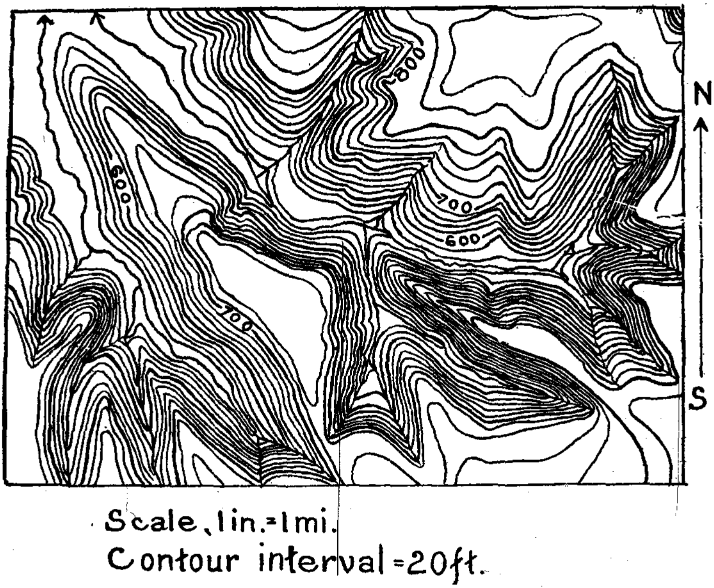


Fig. 16. Topography of the upper portion of Delaney's Creek valley, 3 north, 4 and 5 east showing the variation in north and south slopes.

The Knobstone strata, being soft, absorb water easily, although they do not permit the free passage of water through them. Owing to their property of absorbing much moisture, they are easily disintegrated by frost action.*

The south hillsides are exposed to many more changes of temperature in the course of a year, and especially in the winter time, than are the hillsides facing northward. During the winter months in this region the nights are cold, often for weeks at a time, freezing a crust over the ground, which next day is thawed out on the south-sloping hillsides. The north slopes, however, being sheltered from the sun's rays, are frozen, or covered with snow, and remain so almost the whole winter long. Thus while the rocks of the south slopes will be successively frozen and thawed out many times during the winter, the

*It is owing to this fact that the sandstones of the Knobstone group have been failures as building stones wherever they have been tried.

corresponding north slopes may be frozen and thawed only two or three times.

One has only to cross this country on a warm winter's day after a cold freezing night, and to see the muddy streams flowing down from the south hill slopes while the north slopes remain solidly frozen, to realize the importance of this process in the wearing away of these rocks. Both the climate and the structure of the rocks are peculiarly favorable for this class of erosion.

There is considerable difference also in the quantity of heat that reaches east and west slopes, the westward slopes receiving more heat than those facing eastward, owing to the fact that the afternoon is the warmest part of the day. Because of this the westward slopes are sometimes more gentle than those facing eastward. These slopes are not so noticeably different, however, as are the north and south hillsides.

These differences can not be due to the gentle south-westward dip of the beds, because if they were so controlled, the westward slopes would certainly be the most gentle of all, as the prevailing dip is westward.

The effect of temperature change upon the disintegration of the Knobstone strata may be seen at the falls at the Shades of Death, in Montgomery County. These falls are in the typical massive sandy shales of the Knobstone group. The influence of protection against changing temperature is here most strongly brought out because the protection is afforded by running water, ordinarily the most important of all the erosive agents. Instead of having the ordinary horseshoe-shaped brink, these falls belly out at the brink and the water passes over the protuberance. At either side of the protuberance the rocks are worn away more rapidly than over the protuberance itself. The accompanying illustrations (Plates V and VI and Fig. 17) show the character of one of these falls.*

Plate V is a view of the fall from below, looking up toward its brink.

Plate VI is a view of the fall from the side. Fig. 17 is a contour sketch showing the plan of the fall.

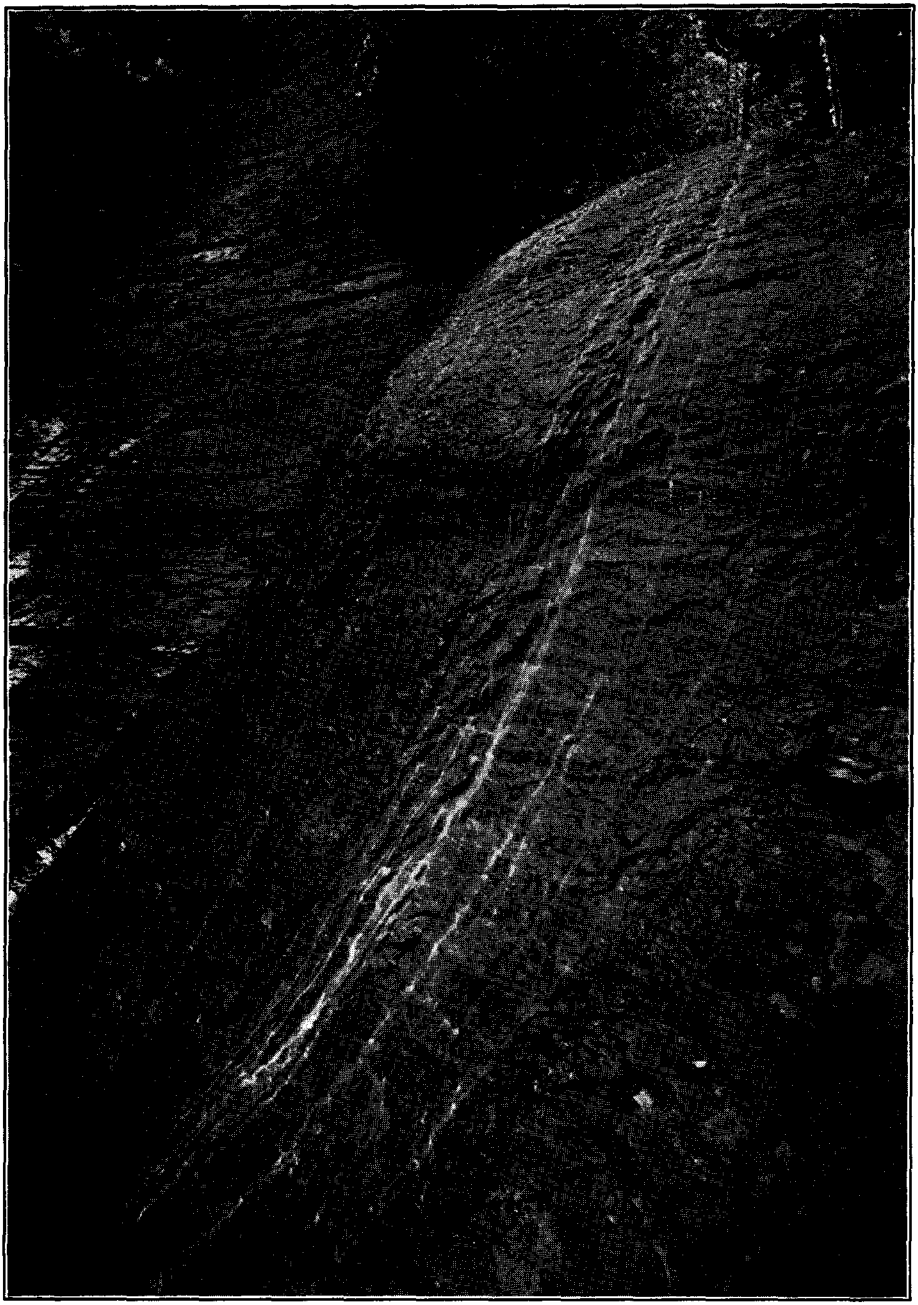
The explanation of this characteristic in these falls is as follows: The water pours over the falls in a thin stream. It is largely supplied by springs and does not carry much material in suspension, and has, therefore, but little erosive power. In the winter time the water protects the rocks from changes in temperature. The rocks at the

*These plates are from photographs which were obtained through the kindness of Prof. C. R. Dryer, of Terre Haute.

PLATE V.

View of the Fall at the Shades of Death, Montgomery County, looking up from near the bottom.

PLATE VI.



Side view of Fall shown in plate V.

sides are unprotected and are therefore subjected to many changes in temperature in the course of a winter, causing them to exfoliate more rapidly than the protected portion. This goes on until the stream at the brink of the fall is diverted to one side or the other, when the newly protected portion ceases to recede. In this way an equilibrium is maintained, the protuberance probably always having about the form shown in the illustrations.

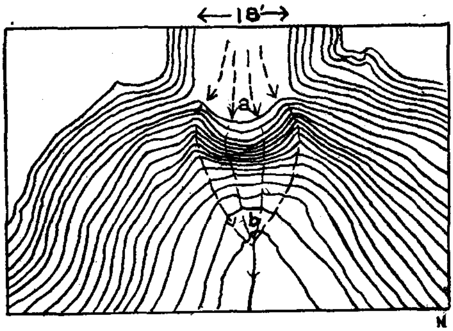


Fig. 17. Topographic sketch of the fall shown in Plates V, VI. The brink of the fall (a) is about 55 feet higher than the point (b).

This feature of the weathering at the falls of the Shades of Death is dealt with in some detail at this place because it emphasizes the fact that change of temperature and not running water is the agent of primary importance in the breaking up of the Knobstone strata.

Exfoliation.—Throughout the Knobstone area, where the massive clayey sandstones and sandy shales are exposed in bluffs, they weather largely by exfoliation, large slabs, often cutting across many bedding planes, becoming loosed by frost action. The tendency towards exfoliation is seen at the right and left sides of Fig. 17.

It should be remarked also that the occasional drying out of the Knobstone strata at their exposed surfaces may play no inconsiderable part in weathering them.

STRUCTURE.

Dips of the Strata.—The structural features of the Knobstone strata are very simple: The beds have a gentle southwestward dip, conforming in this respect to the overlying and underlying strata. Near Bloomington they have a dip, according to Kindle, of 64 feet per mile. In 3 north, 3, 4 and 5 east, the westward dip is 26 feet per mile. At the south side of 2 north, 5 east, the westward dip, as shown by the elevations of the Louisville, Evansville and St. Louis Consolidated Railroad is 33 feet per mile.

No folds of more than local extent occur. There are, however, occasional low undulations in the strata. One of these undulations is the cause in part at least, of the exposures of Knobstone along Indian Creek in 2 south, 4 and 5 east.

FAULT.—But one fault has been observed in the Knobstone area. It is called the "Unionville Fault," from the village of that name in Monroe County, which is located about one-half mile west of the line of fracture. The line of faulting has been traced more or less continuously from this point in 9 north, 1 east, Section 10, to 3 north, 1 east, Section 1, in the north edge of Washington County, a distance of about 36 miles. The fracture probably extends both north and south from these points, but its location beyond these limits is not known. On the map sheets (Plates III, IV) the location of this line of fracture is indicated.

The following figures (Figs. 18, 19) show the structural relations along this fault:

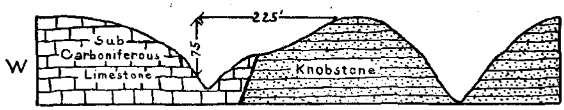


Fig. 18. Section in Township 9 north, 1 east, Section 10. (Price after Newsom.)

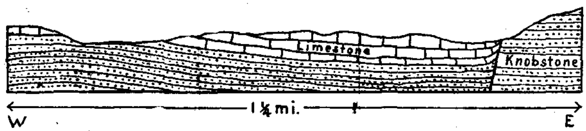


Fig. 19. Generalized east-west section across the Unionville fault, showing its effect upon the areal distribution of the limestone immediately west of the line of fracture.

It is observed that the downthrow is on the west side of the fracture. The displacement is over 50 feet in several places, and at one place, in Section 26, Township 4 north, 2 east, it is about 200 feet; it is probably greater than this at places, if not through most of its extent. The data by which the extent of displacement can be measured are usually lacking.

There is usually a strip of limestone from one-half to one and one-half miles wide immediately west of the fracture. West of this strip the Knobstone strata sometimes come to the surface in the highest ridges, though often the lower layers of limestones and cherts are continuous along the very tops of the ridges, connecting the more or less isolated limestone strip with the main limestone area to the west.

This limestone remnant (see Plates III, IV, Townships 5, 6 north, 1 east, and 4 and 5 north, 2 east) has been called the "Heltonville limestone strip"* by Siebenthal, who outlined its limits, and who suggested both faulting and unconformity as possible explanations for its occurrence east of the main mass of lower carboniferous limestone.

The line of fracture of the Unionville fault may be observed when it crosses the creek and cuts the Knobstone strata near the town of Leesville, in Township 5 north, 2 east, near the southeast corner of Section 22.

No fault has been observed at the west side of the Heltonville limestone strip, the structure and relations of which are indicated by Fig. 19, a generalized section across the area.

Some sections and notes on this area were published by Mr. J. A. Price in 1897.†

The possible effect of this faulting upon the areal distribution of the Knobstone to the east of it has been mentioned above, p. 264.

UNCONFORMITY.—No unconformity is known to exist between the Knobstone strata and the underlying Devonian. Neither is there an unconformity between the Knobstone strata and the overlying lower carboniferous beds. There is, however, an important denudation interval at the top of the lower carboniferous limestones which has entirely removed these beds and also part of the Knobstone sandstones and shales at the north end of the Knobstone area. In the west edge of Montgomery County the Mansfield sandstone (or basal Coal Measures sandstone) rests unconformably upon the Knobstone sandstones and shales; this unconformity may be observed along Sugar Creek and at many other places, as pointed out by Hopkins.‡

At the north, viz., in northern Putnam and Montgomery counties, and northward therefrom, this interval of erosion has been sufficient to remove the Lower Carboniferous limestones, which probably formerly extended over this region. It probably removed also much of the Knobstone strata of Tippecanoe County, though whether these strata ever extended far north and east of their present limits in that region can not be known. To the southward the same unconformity exists between the Coal Measures sandstones and the Lower Carboniferous beds, but here these latter have not

*Indiana Department of Geology and Natural Resources. 21st Annual Report, p. 390. Indianapolis, 1897.

†Proceedings of the Indiana Academy of Science of 1897, pp. 262-266. Indianapolis, 1898.

‡Indiana Department of Geology and Natural Resources. 20th Annual Report, Plates IX, X, and accompanying text. Indianapolis, 1896.

been entirely removed. They become successively thicker in passing southward from the north side of Putnam County.

The erosion interval occurred at the end of Lower Carboniferous time. From the amount of denudation that took place, it is evident that the interval was long and important.

The erosion interval in Indiana between the Lower and Upper Carboniferous strata corresponds with the erosion interval that is generally recognized through the northern Mississippi valley between those formations. It corresponds also with a period of deposition in the southwest during which, in the Arkansas region, at least, as much as 18,480 feet of sediment were deposited, as shown by a cross section run by the writer in the Arkansas River Valley.*

ECONOMIC GEOLOGY.—The strata of the Knobstone group have but little economic value. The shales will in many places undoubtedly make good vitrified bricks. They have been used for this purpose near New Albany, but no data are at hand regarding the character of the bricks produced.†

*In the American Journal of Science, Fourth Series, Vol. II, pp. 229-236, Dr. J. C. Branner discusses the thickness of the Paleozoic sediments of Arkansas, and calls attention to the section mentioned.

Later attention has been called to the Arkansas sediments and their probable correlation with the above mentioned erosion interval by Keyes. Bulletin of the Geological Society of America, Vol. XII, pp. 173-196.

†A large deposit of Knobstone shale, located at "Blue Lick," Jackson County, a switch on the B. & O. S. W. Railway in the northeast quarter section 6 (5 north, 5 east), is now being utilized as the clay ingredient in the manufacture of Portland cement by the Lehigh Portland Cement Company, of Mitchell. It has been found highly suitable for that purpose. Similar deposits occur near Freetown, close to the Southern Indiana Railway, and on the land of D. M. Hughes, near Medora. Chemical analyses of two of these Knobstone shales suitable for cement manufacture are herewith given:

ANALYSES OF KNOBSTONE SHALES FROM JACKSON COUNTY, INDIANA.

	"Blue Lick," Per Cent.		*Hughes, Per Cent.*	
Silica (SiO_2)	59.64		64.59	
Titanium oxide (TiO_2)	1.05		.30	
Alumina (Al_2O_3)	19.14		16.37	
Combined water (H_2O)	4.36		3.71	
Clay base and sand		84.19		84.97
Ferric oxide (Fe_2O_3)	3.39		5.37	
Ferrous oxide (FeO)	4.20		1.59	
Lime (CaO)	.26		.16	
Magnesia (MgO)	2.31		1.56	
Potash (K_2O)	3.53		4.24	
Soda (Na_2O)	.80		.97	
Fluxes		14.49		13.89
Carbon dioxide (CO_2)		.35		.43
Total		99.03		99.29

It is probable that the Knobstone shales in many places will be found suitable for Portland cement manufacture. Care must be taken, however, to secure the true shales, and not the shaley sandstones of the transition beds or upper strata of the Knobstone, as the latter are too high in silica to make a good cement.
W. S. B.

Many nodules of limonite of considerable size are found in the knob shales, and these are sometimes found thickly strewn over the surface. Their manufacture into iron has been advocated at one time and another, but they do not occur in sufficient quantity at any place to be valuable for that purpose. When these limonite concretions are broken up and worn into creek gravels, however, they make an excellent road metal, for which purpose they are used in the neighborhood of New Albany.

The sandstones at the top of the series have been used for building purposes. They can be worked easily, but unfortunately they absorb much moisture and invariably spall off when exposed to extreme atmospheric changes. Upon weathering they also become much stained by the oxidation of the iron contained in them. For these reasons they are unsuited for building purposes.

The soils derived from the decay of the Knobstone strata are unproductive sands and clays. For this reason the region lying wholly within the Knobstone area is one of the poorest in the entire State.

Although the Knobstone strata absorb water easily they are practically impervious as far as circulating waters are concerned, for which reason springs are rarely found in them. Drinking water is mostly obtained from wells, and this is ordinarily of a very poor quality. At the top of these impervious strata, however, and at the base of the overlying pervious limestones is a natural spring horizon, and along this line of contact springs are abundant.*

STRATIGRAPHIC POSITION.—The lower shales of the Knobstone group were correlated with the Chemung of New York by Hall in 1841,† while the sandstones above he regarded as Sub-Carboniferous.‡

De Verneuil grouped these beds with the Carboniferous.§

Owen classed them as Sub-Carboniferous in 1856.‖

The final correlation of the Rockford goniatite limestone at the base of the Lower Carboniferous limestone, where it undoubtedly belongs, established the Knobstone in the Carboniferous also. The lower layers of the group probably correspond to the Kinderhook, of Illinois, and the middle Waverly, of Ohio. The Kinderhook beds

*A number of springs issuing from the New Providence shale in Clark, Floyd and Brown counties produce mineral water which is quite extensively used for medicinal purposes. The waters of these springs are mentioned in detail in a preceding paper on "The Mineral Waters of Indiana," in the present volume. *W. S. B.*

†Reports of the first, second and third meetings of the Association of American Geologists and Naturalists, 1840-1842, p. 280. Boston, 1843.

‡Ibid., Vol. I, p. 28.

§American Journal of Science, second series, Vol. 7, p. 46.

‖Kentucky Geological Report, Vol. I, p. 89.

especially are lithologically similar to the lower beds of the Knobstone.

The tracing out of the contact of Knobstone and the overlying limestones has established beyond a reasonable doubt that the characteristic Keokuk crinoid beds of Crawfordsville are in the Knobstone strata. These crinoid beds are in shale containing lenses of limestones, that resemble, lithologically, the beds that are found further south, from 100 to 200 feet below the top of the Knobstone group. The crinoid beds are certainly in the Knobstone group, which, therefore, must be of Keokuk age in its upper portion.*

It should be remarked in this connection that the geodes usually so abundant in the Keokuk rocks occur to some extent in the upper Knobstone strata.

The following species have been identified from the shales at the base of the Knobstone group in Indiana:†

	Kinderhook.	Burlington.	Keokuk.	St. Louis.	Kaskaskia.	Coal Measures.
COELENTERATA.						
Zaphrentis dalei E. and H.	....	×	×	×	....	×
BRACHIOPODA.						
Athyris lamellosa L'Eveillé	×	....	×	....	....	....
†*Chonetes illinoisensis* Worthen	....	×	....	....	....	....
†*Chonetes logani* Norwood and Pratten	×	×	....	....	....	....
Derbya keokuk Hall	×	....	×	....	....	....
†*Orthothetes crenistria* Phillips	....	LC	....	....	....	....
Productus arcuatus Hall	×	....	....	....	....	....
†*Productus gracilis* Winchell	×	....	....	....	....	....
†*Productus semireticulatus* Martin	×	....	×	×	....	×
†*Porductella shumardana* Hall ?	×	....	....	....	....	....
Rhipidomella oweni Hall and Clarke	×	....	....	....	....	....
Spirifer lateralis Hall ?	....	....	....	×	....	....
†*Spirifer mortonanus* Miller	....	....	×	....	....	....
†*Spirifer suborbicularis* Hall	....	....	×	....	....	....
†*Syringothyris texta* Hall	×	....	×	....	....	....
LAMELLIBRANCHIATA.						
†*Palæoneilo bedfordensis* Meek	....	W3	....	....	....	....
CEPHALOPODA.						
‡*Remeleceras clarkense* Miller and Gurley	KS	....	....	....	....	....

*The upper portion of the Knobstone group was referred to the Keokuk by Worthen in 1866. Geological Survey of Illinois, Vol. I (1866), pp. 116-117.

†In the following lists names preceded by a † are of fossils that have been found both in the Knobstone shales and the sandstones: L. C. = Lower Carboniferous; W = Waverly; W 1 = Lower Waverly; W 3 = Upper Waverly.

‡Cited from Knobstone near Clark County, Indiana, by Miller and Gurley. Illinois State Museum of Natural History, Bulletin 12, p. 49, plate IV.

Following is a list of species from the Knobstone sandstones:

	Kinderhook.	Burlington.	Keokuk.	St. Louis.	Kaskaskia.	Coal Measures.
ECHINODERMATA.						
Catillocrinus bradleyi Meek and Worthen			×			
BRACHIOPODA.						
Athyris incrassata Hall ?		×				
Camarotœchia sappho Conrad	×					
†*Chonetes illinoisensis* Worthen		×				
†*Chonetes logani* Norwood and Pratten		×				
Chonetes planumbonus Meek and Worthen			×			
Cryptonella ? eudora Hall	×					
Eumetria marcyi Shumard				×	×	
Lingulodiscina newberryi Hall	×					
†*Orthothetes crenistria* Phillips	LC					
†*Orthothetes umbraculum* Hall and Clarke	LC					
Productus alternatus Norwood and Pratten			×			
Productus burlingtonensis Hall		×				
†*Productus gracilis* Winchell	×					
Productus newberryi Hall	×					
Productus punctatus Martin						×
†*Productus semireticulatus* Martin	×		×	×		×
Productella pyxidatus Hall	×					
†*Productella shumardana* Hall ?	×					
Reticularia pseudolineata Hall		×	×			
Reticularia tenuispinata Hall	×					
Spirifer keokuk Hall			×			
†*Spirifer mortonanus* Miller			×			
†*Spirifer suborbicularis* Hall			×			
Spiriferina depressa Herrick ?	×					
Spiriferina subelliptica McChesney (Kentucky)			×			
†*Syringothyris texta* Hall	×		×			
LAMELLIBRANCHIATA.						
Grammysia ventricosa Meek	×					
Myalina keokuk Worthen			×			
†*Palæoneilo bedfordensis* Meek		W3				
Schizodus chemungensis Herrick	×					
Streblopteria media Herrick	W1					
GASTROPODA.						
Bellerophon galericulatus Winchell	×					
Platyceras herzeri Winchell (Kentucky)	×					
Platyceras lodiense Meek (Kentucky)	×					
PTEROPODA.						
Conularia micronema Meek	×					
Conularia newberryi Winchell	W1					
CEPHALOPODA.						
Goniatites greenii Miller	KS					
Triboloceras degonum Meek and Worthen			×			
CRUSTACEANS.						
Proetus missouriensis Shumard	W					

To the lists given above should be added the names of those fossils* that have been found in the shales and sandstones, with intercalated limestones that crop out along Sugar Creek near Crawfordsville, as the beds from which the typical Keokuk fauna of this place come are undoubtedly the equivalents of the Knobstone further south.

*For lists of the Crawfordsville fossils, see The American Geologist, Vol. I, pp. 407-412. The Keokuk Group at Crawfordsville, Indiana, by Charles S. Beechler.

Also, Indiana Department of Geology and Natural History. 16th Annual Report, pp. 65-70; 340, et seq.

LOWER CARBONIFEROUS STRATA EXCLUSIVE OF THE KNOBSTONE GROUP AND THE ROCKFORD GONIATITE LIMESTONE.

Overlying the Knobstone group are the Lower Carboniferous limestones, with interstratified sandstones at the top of the series. The sequence of these beds is shown in the columnar section, Fig. 7. Their thicknesses were not measured in Township 3 north; the thicknesses given are those given by Siebenthal and Kindle.*

THE HARRODSBURG LIMESTONE.

CHARACTER AND THICKNESS.—With the Harrodsburg limestone are included those transitional beds of cherts and limestones that lie immediately above the Knobstone. Masses of chert fragments at the surface, resulting from the decay of these lowest beds are included (Plates III, IV) with the Harrodsburg limestone, and consequently the line of contact as shown on the maps between these beds and the lower strata is often some distance east of the real eastern edge of the undecomposed limestones.

The Harrodsburg limestone is made up of massive and thin beds, with occasional shales and cherts intercalated. According to Siebenthal, it is from 60 to 90 feet thick.†

As already remarked, these beds lie conformably upon the Knobstone strata.

AREAL DISTRIBUTION.—On the map sheet (Plate II) the Oölitic and Harrodsburg limestone areas are shown together. The area covered by them has a width of from half a mile to two or three miles, passing in a sinuous line around the heads of the northward flowing streams, and capping the high ridges in Townships 1, 2, 3, 4 and 5 east.

The Harrodsburg limestone is the cap rock that protects the softer Knobstone below, and to its protecting influence the bold, unbroken escarpment presented by the Knobstone strata south of East White River is largely due. In 3 north this limestone has a westward dip of 26 feet to the mile.

TOPOGRAPHY.—Much of the drainage from the Harrodsburg limestone is underground; for this reason small sink holes are numerous

*Indiana Department of Geology and Natural Resources. 20th and 21st Annual Reports. Indianapolis, 1896 and 1897.

†Indiana Department of Geology and Natural Resources. 21st Annual Report, pp. 296–298. Indianapolis, 1897.

in the area underlain by it. These sink holes are never as large or deep, however, as are those a few miles further west in the Mitchell limestone area, where there is a greater thickness of limestone.

The Harrodsburg limestone outcrops, for the most part, at the tops of steep-sided hills and ridges, whose lower portions are composed of Knobstone strata. The tops of these hills form a more or less even plateau, sloping gently to the west. (See Plate II, 3 north, 2, 3, 4 and 5 east.)

The Harrodsburg limestone is probably correlative with the upper or Keokuk portion of the Augusta limestone of Keyes.

The Bedford Limestone.

Character.—Lying conformably upon the Harrodsburg limestone is the formation known as the Bedford limestone. It has a bluish or buff color, and is an extremely homogeneous bed. In thickness it varies from 25 or 30 feet to about 100 feet. In Township 3 north its thickness is from 25 to 36 feet or more.

The stone is sometimes of fine texture; sometimes it is coarse, depending upon the size of the shells of which it is made, and also upon the degree to which these have been pulverized.

Areal Distribution.—The oölitic limestone outcrops in a sinuous band ranging usually from 100 yards to one-fourth mile wide, lying between the Harrodsburg and Mitchell limestones.

Topography.—Its thickness is not sufficient to develop a topography of its own. Where the bed is thickest, however, and the strip covered the broadest, the slopes on which it outcrops are gentle, and the country, so far as it is controlled by the Bedford limestone, is gently rolling.

Economic Geology.—Next to the coal beds of Indiana the oölitic limestone is the most important geological formation in the State from a commercial standpoint. Owing to the ease with which it may be worked in any direction, its freedom from bedding planes, and its general uniformity in color, coupled with its crushing strength, and its power of resisting the action of the weather, it makes an ideal building stone, and has long been recognized as the standard among the limestones of the country.

Its fauna shows that Bedford limestone belongs to the St. Louis group.

The Mitchell Limestone.

Character.—Lying conformably upon the Bedford limestone, and underlying the lowest beds of the Kaskaskia group, is the Mitchell limestone, a series of close-grained limestones, shales and cherts. It varies in thickness from 150 to 250 feet, and is regarded as belonging to the upper part of the St. Louis group. Owing to its low dip and the width of the area covered by it, its thickness could not be accurately measured in Township 3 north.

Areal Distribution.—In Township 3 north the Mitchell limestone outcrops over a strip of country about 20 miles wide. To the northward it is usually much narrower than this, while further south it becomes somewhat wider.

Topography.—This limestone forms for the most part a fairly level plateau, which is pitted with great numbers of sink holes. These sink holes lead to underground water channels, which form the true drainage lines of the country. The sinks vary in depth from a few feet up to 50 or 75 feet, and cover from a quarter of an acre and less to 200 or 300 acres.

Where the underground drainage is best developed there is scarcely any surface drainage. The notable absence of surface streams in 3 north, 1 and 2 west and 1 and 2 east (see Plate II) is due to highly developed underground drainage systems. This underground drainage is made possible, not by the Mitchell limestone alone, but by these beds in conjunction with the underlying Bedford and Harrodsburg limestones, making a thick series of beds which are more or less jointed, and easily attacked by underground waters.

This combination of strata, coupled with the fact that the drainage level of the country in which the beds occur is usually from 200 to 300 feet below the general level of the plateau made by the Mitchell limestone, affords favorable conditions for the formation of underground caverns.

The character of the topography of the Mitchell limestone area is shown on Plate II, Townships 1 and 2 east and 1 and 2 west. It is not possible on a map of the small scale of Plate II to show the great number of small sink holes that pit the surface of the country in Townships 1 and 2 east.

Economic Geology.—Except for the manufacture of lime, the Mitchell limestone is of small economic importance. It often resembles lithographic limestone, but at no place has this stone been found free from veinlets and of such quality as to be useful for lithographing.

The soil resulting from its decay is a stiff clay, which does not compare in fertility with the glacial and bottom lands of more favored portions of the State.*

The Kaskaskia Group.

Character.—Overlying the Mitchell limestone is a series of limestones and sandstones, regarded by Kindle as belonging to the Kaskaskia group.† This group is made up of three limestone beds and two beds of sandstone. The limestones are designated by Kindle as the Lower, Middle and Upper Kaskaskia limestone, and the sandstones as the Lower and Upper Kaskaskia sandstone. The aggregate thickness of the Kaskaskia group in 3 north is about 125 feet.

The Lower and Upper Kaskaskia sandstones vary in texture from very fine grained to coarse grained rocks. In color they are usually buff or gray. In some places they carry concretions of limonite and thin beds of coal.

In all three of the Kaskaskia limestones occur chert lenses, which are usually thin and of small lateral extent.

Areal Distribution.—In 3 north the Kaskaskia area extends from the east side of 1 west to the middle of 4 west. Owing to the gentle dip of the rocks, the different beds composing the group outcrop in successive bands, the lowest bed forming the most easterly band.

The lower contact of this group, as shown on the map, Plate II, can be regarded as only approximately correct. The Lower Kaskaskia limestone resembles the Mitchell limestone closely; outcrops in the region of the contact between these two formations are not plentiful; these conditions, coupled with the fact that this region is pitted by thousands of sink holes, extending through the Kaskaskia beds, and down into the Mitchell limestone, make it well-nigh impossible to correctly locate the line of contact between the two formations.

Topography.—The topography of the Kaskaskia beds is more rugged than that of the lower limestones to the east. This is due in part to the beds themselves, and also to the thick Carboniferous sandstones that overlie them. Passing westward from the east side of 3 north, 1 west (i. e., from the east side of the Kaskaskia area)

*The Mitchell limestone is a very pure carbonate of lime, and is now being utilized by the Lehigh Portland Cement Company, of Mitchell, as the carbonate of lime ingredient in the manufacture of Portland cement, 2,000 barrels or more being the daily output of the factory, which was completed in August, 1902. Two other large cement factories will soon be erected near Mitchell, and will use the limestone for the same purpose. *W. S. B.*

†Indiana Department of Geology and Natural Resources. 20th Annual Report. The Whetstone and Grindstone Rocks of Indiana, by E. M. Kindle, pp. 328-368.

the hills become gradually higher until the rugged hills in Townships 2, 3 and 4 west are reached.

Most of the drainage from the Kaskaskia area in 3 north is subterranean. The sink holes of this region are much larger than those further east, valleys sometimes three or four miles long and two or three hundred feet deep being drained through underground channels. This gives rise to confusing systems of hills and valleys, though the topographic map brings out certain well-defined drainage lines, or valleys, which are themselves usually made up of series of sink holes.

ECONOMIC GEOLOGY.—The Kaskaskia limestones afford a good lime and are often burned for that purpose. In some localities the Kaskaskia sandstones make excellent whetstones. They are quarried for this purpose in Orange County.

UPPER CARBONIFEROUS.

Lying unconformably above the Kaskaskia group are the rocks of the Upper Carboniferous, with beds of possible Permian age at their top. Taken as a whole, these strata may be broadly grouped as follows, beginning at the bottom:

(a) Mansfield sandstone. (Basal sandstones often accompanied by some shale and one or two thin beds of coal.)
(b) The Productive Coal Measures.
(c) The Merom sandstone; a sandstone of Carboniferous or Permo-Carboniferous age lying unconformably upon the topmost Coal Measures beds.

MANSFIELD SANDSTONE (THE BASAL SANDSTONE).

CHARACTER.—The Mansfield sandstone lies unconformably upon the Kaskaskia beds, and is overlain unconformably by the beds of the Productive Coal Measures. It was designated as the "Millstone grit" and "conglomerate sandstone," by writers on Indiana geology until 1896, when it was given the name Mansfield sandstone by Hopkins.

The Mansfield sandstone has a thickness in 3 north of about 150 feet, as exposed in the bluffs along White River above Shoals, in Martin County. It varies in texture here from a moderately fine grained sandstone to a coarse stone, in some places becoming conglomeritic. It is yellow to brown in color and often has distinct cross bedding planes. At the base of the Mansfield sandstone a shale bed, with one or two thin beds of coal, often occurs. In places this shale has a thickness of 20 feet.

Areal Distribution.—The Mansfield sandstone outcrops in 3 north over a strip of country about 22 miles wide. Its easternmost outcrop is near the middle of the east line of 2 west, where its base is near the tops of the hills. Westward from this it is the cap rock of the high hills through 2, 3 and 4 west, being carried gradually lower in the hills by its gentle westward dip.

Its base finally passes beneath the drainage near the center of Township 5 west (Plate II).

Topography.—The topography of the Mansfield sandstone area is quite rugged (see Plate II, Townships 3, 4 and 5 west). The valleys are arranged in the intricate dendritic systems. The hilltops are protected by the heavy sandstone capping them, while the streams have cut down through the underlying softer beds, making of the area a thoroughly dissected plateau. The hills at the west edge of the Mansfield sandstone area are less rugged than those at the east simply because in this region the beds have been brought near to their base level of erosion (the level of East White River) by their westward dip.

Economic Geology.—In some localities the Mansfield sandstone is an important building stone. Where it occurs with an even, sharp grit, as it does in some portions of Orange, Martin and Dubois counties, it makes excellent grindstones and whetstones, and is used for these purposes.

The coal beds found at its base are of small commercial importance. At its base there is often a bed of kaolin, which may prove of future commercial importance.*

*This kaolin is a very pure silicate of alumina, its chemical composition, determined by Noyes, being as follows:

ANALYSIS OF KAOLIN FROM NEAR HURON, LAWRENCE COUNTY, INDIANA.

	Per Cent.
Silica	44.75
Alumina	38.69
Water	15.17
Ferric oxide	.95
Lime	.37
Magnesia	.30
Potash	.12
Soda	.23
Total	100.58

This kaolin was used for years in the manufacture of alum sulphate for sizing paper. Lack of transportation facilities caused the abandonment of the enterprise. The principal beds are located four miles from Huron, a station on the B. & O. S. W. Railway. Thousands of tons are in sight in the four slope shafts which have been opened. It is not plastic, but very refractory, and is suitable, when mixed with a small quantity of plastic clay, for making high-grade refactory wares, ultramarine, etc. *W. S. B.*

THE PRODUCTIVE COAL MEASURES.

CHARACTER AND AREAL DISTRIBUTION.—The Productive Coal Measures consist for the most part of shales and sandstones, with beds of coal. Fire-clays and some beds of limestone also occur in them. All of the important coal beds of the State occur in this group of strata, between which and the Mansfield sandstone is a slight unconformity. This division of the Upper Carboniferous is subdivided by Ashley* into Divisions II to VIII, inclusive. These divisions are more or less arbitrary and are made for convenience in the discussion of the geology of individual localities in the coal region.

In thickness the Productive Coal Measures strata vary much in different parts of the State. In Township 3 north they have a thickness of 800 feet where penetrated by a bore hole at Vincennes. Except when covered by glacial debris, these strata, with the overlying Merom sandstone, outcrop over a broad strip of country, extending from 3 north, 4 west to the Illinois line at Vincennes.

TOPOGRAPHY.—The topography of the Productive Coal Measures of Indiana is almost always gently rolling or quite flat. The general character of the topography is best seen on the accompanying map (Plate II), from 3 north, 4 west, on westward.

The low relief of the Productive Coal Measures area is mainly due to the glacial covering over it, coupled with one of two causes, depending upon previous conditions, as follows:

1. The beds of the Productive Coal Measures may have been thicker originally than they are at the present time. If such conditions obtained, then these formerly thick strata were removed by erosion prior to glacial times until their present level was approximately reached, giving the low relief of the present time. The strata being made up of soft and easily eroded sandstones and shales would have made this possible.
2. The Productive Coal Measures may never have been elevated much above their base level of erosion, i. e., above their present level. In such event the present relief would, of course, be the inevitable result.

ECONOMIC GEOLOGY.—The Productive Coal Measures are the chief source of the State's coal, fire-clays and shale for the manufacture of vitrified bricks.

*Indiana Department of Geology and Natural Resources. 23rd Annual Report, p. 89, et seq. Indianapolis, 1899.

THE MEROM SANDSTONE.

Lying above the Productive Coal Measures and separated from them by an unconformity is a sandstone with a thickness at Vincennes of from 40 to 50 feet. This sandstone has been known as the Merom sandstone, owing to its good exposures at the town of Merom.

In general appearance it resembles the Mansfield sandstone, for which it has sometimes been mistaken. Whether it is of Carboniferous or later age has not been satisfactorily determined.

As indicated in Fig. 1, the Merom sandstone is overlain by glacial and alluvial deposits.

TERTIARY AND PLEISTOCENE.

Tertiary.—Gravels of possible Tertiary age occur in Township 3 north, 1 west on the ridge just north of the center of the southeast quarter of Section 10. These gravels may occur on other ridges west of this point, but they were not observed elsewhere by the writer.

Pleistocene.—In 3 north, glacial gravels, sands and clays, ranging from one to over one hundred feet in thickness, are encountered from Township 6 east eastward to the Ohio River, and from Township 5 west westward to the Wabash River. No attempt is made to outline the limits of these glacial deposits on the maps. In character these deposits are similar to the glacial deposits found generally in the Mississippi Valley near the southern limits of the glaciated area.

DRAINAGE OF SOUTHERN INDIANA.

INTRODUCTION.

Only those features of the drainage of southern Indiana which are dependent upon geological structure and are not controlled primarily by glacial drift are here discussed. This limits the discussion to that portion of the State that lies south of a line running from Indianapolis east to the Ohio State line, and from Indianapolis southwestward along the course of West White River to the mouth of that stream.

While the eastern tributaries of West White River from Indianapolis to the mouth of Bean Blossom Creek and the tributaries of East White River in northern Shelby and Johnson counties owe their positions largely or entirely to the drift,* the main streams of the area referred to are controlled by the underlying strata.

The driftless region of southern Indiana is an irregularly triangular area, with the base of the triangle along the Ohio River, reaching from Mt. Vernon to a point a few miles above Jeffersonville, a direct distance of 135 miles, and the apex of the triangle near the northeast corner of Monroe County, 135 miles northeast of Mt. Vernon and 85 miles slightly west of north from Jeffersonville.

Over most of the region both directly east and west from the unglaciated area the covering of drift is comparatively thin. In the region to the east especially the drift covering is rarely as much as 100 feet thick, and many of the streams have cut down through it and into the underlying rocks. In some cases these streams occupy preglacial channels; in others the valleys have been cut out entirely since glacial times, leaving the drift in remnants only upon the hilltops and uplands.

The thin mantle of drift that covers that portion of the State east of the driftless area lies on strata that dip gently to the southwest, and on an old surface whose general contour prior to the deposition of the drift was similar to that of the present time. Therefore, while the minor lines of drainage have been modified by the drift, the general south and southwest drainage of the country is such as would be logically developed in a country of such combinations of hard and soft southwestward dipping strata as southern Indiana possesses, and it is practically the same now as it was in preglacial times.

There are, in southern Indiana, three thick series of shale beds, between which are groups of harder and more resisting limestones and sandstones. In going from east to west across the State these groups are as follows: (1) the Hudson River shales, along the east side of the State; (2) the resisting Niagara limestone, and limestones at the base of the Devonian; (3) the New Albany and Knobstone shales, all soft and easily eroded beds; (4) the Knobstone sandstones and overlying Lower Carboniferous limestones, which are in turn overlain by the sandstones at the base of the Coal Measures;† (5) the soft Coal Measures shales and sandstones of the west side of the State.

*These small streams are not included in the following remarks regarding the drainage Neither are the streams between West White and the Wabash rivers discussed, although those streams are shown on the map, Plate VII.

†The Lower Carboniferous limestones are eroded more easily than the beds lying both east and west of them (see page 282), but their denudation has not been so great as to form a separate drainage basin in the area underlain by them.

The softer groups of strata, viz., 1, 3 and 5, form drainage areas discussed below as the eastern, central and western drainage areas, that are more or less separate from each other in each case, while the harder groups, 2 and 4, form the divides, or watersheds, between those areas.

The strata that form the different drainage areas and the watersheds between them in the southern part of the State, extend northward under the glacial mantle for some distance beyond the boundary of the accompanying map (Plate VII). Therefore, it might be expected that the preglacial relief of the country underlaid by those strata was similar to the present relief in the unglaciated area to the south. Well records show this to be the case as regards the central drainage area or trough and its eastern rim at least. In preglacial time this trough and its eastern rim certainly extended as far north as the north side of Clinton County, while the highlands west of it certainly extended as far north as northern Montgomery County.

This preglacial topography makes it seem quite probable that the preglacial drainage of this trough was from the eastern rim down the dip of the underlying limestones to the southwest, along lines generally parallel with those of the present streams further south, which are in accordance with, and are controlled by, the geologic structure.

The relations of the different drainage areas and the structure controlling them is shown by the cross sections on the drainage map, Plate VII.

It will be seen, therefore, that the drainage of southern Indiana may be treated in accordance with the groups of strata that are the controlling features.

An examination of the geology in its relation to the drainage shows that there are the three following general drainage areas:* (1) the eastern area covered by rocks of the Hudson River group, and including some short streams that rise on the Niagara strata and flow eastward into the Hudson River area; (2) the central area, covered by the strata from the base of the Niagara up to the Knobstone sandstone; (3) the western area, covered by the rocks from the Knobstone sandstone to the top of the Coal Measures. This last area includes the entire southwestern part of the State, and in the eastern part of it the streams have in many places cut down through the limestones and Knobstone sandstones and into the

*These areas can not be regarded as basins in the proper sense of the term, for each area is drained by many different streams.

Knobstone shales. These shales, however, have had no part in the formation of the western drainage area, which, while largely underlain by sandstones and limestones, has its eastern watershed along the Knobstone escarpment within a few miles of the lowest part of the central area.

From each of the watersheds, viz., between the eastern and central, and the central and western areas, the streams that flow east across the dip of the strata are short and have steep gradients (see Fig. 12), while those that flow west, with the dip of the strata are long and have low gradients.

The larger streams of southern Indiana flow through filled valleys similar to that shown in Fig. 6, p. 254. The depth to which the valleys have been filled varies from a few feet to over 100 feet.

The different drainage areas will be taken up in their order, and the features of their drainage so far as these seem to depend upon the structure of the underlying rocks will be pointed out. The boundaries between these areas do not follow exactly the outcrops of the strata which form the divides between them, for short streams which belong to the area underlaid by Hudson River beds, for example, may rise in the Niagara beds and flow westward across the dip of those beds for a short distance before entering the area of the Hudson River strata. The same is true of streams belonging to the central basin, which rise at the top of the Knobstone escarpment. On the other hand, the streams flowing westward sometimes cut down through the hard strata that formed the watershed, exposing the underlying softer strata. These facts must be kept in mind in treating the general drainage areas in accordance with the underlying strata.

The Eastern Drainage Area.

While the highest points in the eastern area are almost as high as the watershed at its western side, the streams of this area have cut out valleys from 100 to 400 feet deep in the soft Hudson River strata, and the average level of the country is, therefore, considerably lower than that of the country immediately west.

The Hudson River strata are almost horizontal and the streams flow, with few exceptions, more or less directly to the Ohio River.

Attention should be called, however, to the upper courses of the Whitewater River,* Laughery and Indian creeks.

The upper courses of these streams are almost in line. They flow nearly due south, parallel with the watershed formed by the Niagara

*Whitewater River flows through a preglacial valley below Connersville.

strata, and only a few miles east of that watershed.* Excepting those of Indian Creek, the tributaries of these streams from the east and north are comparatively long, while those from the west, which rise in the Niagara strata and flow eastward across the dip, are short.

The main drainage lines and their relations to the controlling beds to the west are shown on the drainage map (Plate VII).

Indian Creek, which drains portions of Ripley and Jefferson counties, flows southward parallel with the watershed at the west, but, owing to its shortness and its proximity to the Ohio, this is the course that would be expected of it, regardless of the dips of the rocks of the area.

It should be noted also that when the Ohio strikes the region of outcropping Niagara limestone at Madison it makes an abrupt turn to the south, and flows south for about 18 miles before turning to the southwest and cutting through the Niagara strata.

It is seen, then, from what has been said above, that the area of the Hudson River strata has its main drainage lines parallel with its western rim; that for the most part there are southward flowing streams in the area immediately east of and practically all along this rim; that the tributaries from the west are short, while those from the east are long, and that these features of the erosion are probably due to the gentle westward inclination of the strata at the west edge of the area.

As the streams approach the Ohio their relations to the watershed at the west are lost, as is seen by the abrupt eastward turn of the Whitewater in northeast Franklin County, and of the Laughery Creek in southeast Ripley County.

The Central Drainage Area.

The central drainage area has its eastern watershed formed by the Niagara and Devonian limestones, while its western watershed is formed by the Knobstone sandstones and overlying limestones that form the crests of the hills known as the Knobs.

The east-west profile of this area, and its geological relations are shown on that portion of the cross section and topography, Plate II (see also Plate VII), extending from the Niagara strata to the Knobstone sandstones. The east side of the basin has a gentle slope to the west, while the west side has a steep slope to the east.

The shape of the central drainage area is shown on Plate VII, where its streams are shown in blue. This area is about 55 miles

*It seems probable that these streams have been shifted to these positions by the westward inclination of the beds, although this inclination is very slight.

across in its widest part at the north, and narrows down until it is less than a mile wide along the Ohio River at the south.

On Plates II and VII this trough, the axis of which extends from near Edinburg (A, Plate VII) slightly east of south to the Ohio River near New Albany, is shown. From Edinburg to the Ohio the axis is followed approximately by the line of the Jeffersonville, Madison and Indianapolis Railroad. The central area, in which the control of the structure upon the drainage is more clearly marked than in either the eastern or western areas, is made up of two districts: A southern district, from which the streams flow directly into the Ohio River, and a northern district, drained by East White River and its tributaries into the Wabash.

The Southern District.—After cutting through the Niagara and Devonian limestones the Ohio River flows west and southwest across the southern district until it reaches the strata of the Knobstone group west of New Albany. Here it is deflected to the south and runs close under the bluffs formed by the Knobstone sandstone and overlying limestones for about 18 miles to Taylor Township, Harrison County, where it turns to the west and cuts through the Knobstone sandstones and overlying limestones (see Plate III). The southern deflection of the Ohio west of New Albany is very similar to its southern deflection by the Niagara and Devonian limestones just west of Madison.

The streams that enter the Ohio from the west below New Albany are short and have steep gradients. Most of these streams have noticeable southern deflections where they enter the Ohio bottom lands, their mouths having been shifted down stream by the deposition of sediments on their up-stream sides.

Above New Albany, Silver and Fourteen Mile creeks are the principal streams. Silver Creek rises in the Knobstone hills at the south side of Scott County and flows almost due south until it reaches the Ohio above New Albany. Muddy Fork, one of the tributaries of Silver Creek, rises well over in the Knobstone area near the west edge of Clark County and flows eastward for 15 miles, across the dip of the strata, before entering the main stream and turning south to the Ohio.

Fourteen Mile Creek rises in the southwestern part of Jefferson County, flows slightly west of south with the dip of the strata and enters the Ohio three miles southeast of Charleston. In its lower portion Fourteen Mile Creek cuts down into the Hudson River strata. Other shorter streams have their sources in the area covered by the Niagara limestones, or the Devonian strata and flow more or less directly into the Ohio across Hudson River strata. While the general courses of these streams are such as might be expected from the structure of the underlying strata (with the exception perhaps of Muddy Fork of Silver Creek), the influence of that structure on them is by no means so clearly marked as it is on the streams in the district next to be considered.

The Northern District.—It is in the northern district, drained by the East White and Muscatatuck rivers, that the effect of the structure upon the drainage is most clearly seen.

The streams that drain the northern district rise for the most part near the watershed which separates this from the eastern drainage area, within a few miles of the main drainage lines of the eastern area, and flow westward down the gentle slope that owes its inclination to the dip of the underlying beds. In their upper portions most of the streams have gradients greater than the dip of the underlying beds and have consequently cut down from newer into older strata. In their lower courses the gradients are less than the inclination of the strata, and the streams pass across successively newer beds.* The streams that rise on the western rim of the northern district and flow eastward are short and have steep gradients.

Except for the course of East White River below Seymour (with which is included the lower course of the Muscatatuck) the drainage lines of the central area are evidently controlled by the geological structure of the country. The effect of the structure upon these streams is well shown in the case of Ramsey Creek, a tributary of the Muscatatuck, which rises near the northeast corner of Township 3 north, 9 east, within one and one-half miles of the Ohio River, and 360 feet above that stream. The waters of Ramsey Creek flow into the Muscatatuck, then through East and West White rivers, and the lower Wabash, and finally empty into the Ohio at the extreme southwestern corner of the State, a direct distance of 170 miles from the source which was within one and one-half miles of the Ohio.

From Edinburg to Rockford, a distance of 27 miles, East White River flows southward, parallel to the Knobstone hills and but a few miles east of them. Its tributaries from the west are short and have steep gradients. Those from the east and northeast rise at the watershed formed by the Niagara strata and flow with the dip

*This feature is well shown by the tributaries of Stucker's Fork, in Townships 3 north, 8 and 9 east. These streams rise in the Devonian shale area, flow westward with the dip, but cut down through the shale, exposing the underlying limestones for a distance of about six miles, and then, the fall becoming less than the dip of the underlying beds, again pass out into the shale area. See Plate II.

down the southwestward slope of the country. The sources of some of the eastern tributaries of East White River are but a few miles west of the Whitewater River—the main drainage stream of the eastern area.

The asymmetry of the area drained by East White River is shown by the accompanying drainage map (Plate VII).

One of the most interesting features of the drainage of the central area is the course of East White River below Rockofrd (C, Plate VII). From Edinburg to Rockford this stream flows south along the bottom of the trough formed east of the Knobstone hills. But while this trough extends on southward to the Ohio River and is apparently the line along which White River could have most easily developed its course, that stream, instead of following the valley (A., C., B., Plate VII) to the Ohio, turns to the west at Rockford and flows through broad bottom lands until it is joined by the Muscatatuck, at the south side of Jackson County. Just below the mouth of the Muscatatuck it enters a comparatively narrow valley (Plate III), which has been cut down through the Knobstone strata, the overlying Lower Carboniferous limestones and the Mansfield sandstone. This valley varies in depth from less than 50 to over 250 feet; its length is about 75 miles. In width, the bottom of the valley (which is filled with alluvium from 50 to 75 feet or more), varies from one-half mile to over one mile.

Thus it is seen that instead of carving out a valley along the strike of easily eroded strata, southward from Rockford directly to the Ohio, a distance of 50 miles, it turns to the west, flows through a valley cut across hard strata, and finally reaches the Ohio through the Wabash at a point over 150 miles from Rockford.

Two hypotheses may be advanced in explanation of the course of East White River below Rockford.

The first is that the present is approximately the original course of the river; that as this region was first elevated the drainage from the land at the east was deflected to the south parallel with the Knobstone sandstones, and behind (i. e., east of them) or else that it shifted itself to this position during its early history; that in the vicinity of the present village of Rockford the drainage turned to the west, cutting across the edges of the strata, and that it deepened its valley in this position as the strata were elevated—gradually establishing itself in approximately the position now occupied across the Knobstone, the Lower Carboniferous limestone, and the Mansfield sandstone. Even though this entire region may have been partially base-leveled since the original drainage was established, elevation subsequent to the base leveling would have reëstablished the main drainage along its original lines.

The width of the valley throughout its length from the Muscatatuck to the Coal Measures suggests an age greater than has elapsed since the ice invasion and makes the above explanation seem probable. The present course of the stream through its gorge below the mouth of the Muscatatuck can not be explained by stream capture, if it be supposed that East White River originally entered the Ohio in the neighborhood of New Albany. If it originally entered the Ohio near New Albany its course below Rockford (C, Plate VII) would have been along the strike of easily eroded shales, and directly to the Ohio, a distance of 50 miles from Rockford. It is 150 miles southwest from Rockford to the mouth of the Wabash, through which East White River at present reaches the Ohio, and one-third of this distance is across the strike of resisting limestones and sandstones. It is obvious, therefore, that East White River could not have been captured at or below Rockford by a stream which flowed to the southwest across those hard strata. Moreover, there is no evidence to show that the former course of the stream was directly into the Ohio at New Albany.

Reversed drainage owing to elevation of the strata to the east and northeast is not regarded as a probable explanation of the lower course of White River, even if it be supposed that the original course of that stream was towards the east, north or northeast.*

The second hypothesis is as follows: It presupposes that prior to the ice invasion the upper portion of East White River (viz., east of the present mouth of the Muscatatuck) flowed either north or northeastward, or possibly emptied directly into the Ohio at New Albany,—in any event that it flowed generally parallel with the Knobstone hills, east of those hills, and did not cut through them; that short tributaries of this main stream entered from the west, occupying about the courses of the East White and Muscatatuck rivers for 15 miles above the junction of those streams, but flowing in the opposite direction; that these short eastward flowing streams formed the triangular *cul de sac* in the Knobstone hills, in the center of which stand the Brownstown Knobs (see Plates III and VII) with the Silver Hills of Scott County projecting east of the main line of hills; that west of the Knobstone escarpment the general drainage to the southwest was the same as at the present time† and that a

*The details of the preglacial drainage north and east from Rockford are obscured by the drift. The general preglacial contour of this part of the country, however, must have been about the same as that of the present time.

†In Monograph XXXVIII, U. S. Geological Survey, Plate IX, Mr. Frank Leverett shows the preglacial westward drainage of this region.

low pass was formed between the westward flowing streams and those flowing eastward which formed the corner of the *cul de sac* above referred to.*

During the glacial period the ice passed immediately east of the Knobstone hills in western Bartholomew County, through Jackson, and crowded up against the projecting knobs known as the Silver Hills in Scott County (see Plate VII). If the suggested conditions existed at that time the triangular *cul de sac* in the Knobstone hills would have had its eastern outlet completely shut off by the ice, and the basin thus formed would have filled with water from the melting ice until it poured over the pass into the westward flowing streams; the pass would have been cut down, and finally the stream would have become established in its new course, and into this it would have led the waters of its entire drain basin as the ice retreated.

The shape of the *cul de sac*, in which the Brownstown hills stand (E, Plate VII), with the eastward projecting Silver Hills (D, Plate VII), against which the ice was pushed to the south, makes this second hypothesis seem probable. The principal objection to it is found in the general width of the valley of East White River below the mouth of the Muscatatuck. There are no *narrows* in the cañon to correspond with the position of the original divide between the east and west flowing streams. The bottom, or present flood plain, of the valley varies in width from one-half mile to over one mile, and would certainly seem to antedate the ice invasion, and the writer believes that explanation of the present conditions is to be found in the first hypothesis, given above.

The Western Drainage Area.†

The main drainage lines of the western area are such as would be developed by the structure of the country, and they are practically the same at the present as they were in preglacial times. The Knobstone sandstones, with their capping of limestones, rise in an eastward facing escarpment, unbroken except where cut through by East White River, from the Ohio River at the south side of Harrison County to the northeast corner of Brown County. This escarpment

*A condition of affairs quite similar to that hypothecated here exists at the present time in Townships 1 south and 1 north, 5 and 6 east, where Muddy Fork of Silver Creek forms a triangular valley opening out to the east, while the divide between this stream and Blue River, which flows west, is quite low.

†The drainage of southern Indiana, in its relations to the glacial period, is discussed and mapped by Leverett in Monograph XXXVIII, U. S. Geological Survey, p. 97, et seq.

See, also, Mr. Leverett's discussion in Part IV, 18th Annual Report U. S. Geological Survey, pp. 446–458.

rises from 200 to 400 feet above the lowlands of the central drainage basin immediately east of it, while to the west the country is rolling and descends gradually. The streams rising near the escarpment at the east, flow down the gentle slope to the west and finally enter the Ohio, White or Wabash rivers.

The control of the structure upon the drainage lines of this area is best seen immediately west of the Knobstone escarpment between East White and the Ohio rivers (Plate II). North of East White River apparently only the general course of the drainage is controlled by the structure; in a general way the longest tributaries of the streams are those coming in from the east and northeast. This feature is by no means clearly marked, even in the area underlain by the comparatively hard Lower Carboniferous limestones and Mansfield sandstone. It is noteworthy that the streams of the western area, which flow across both the area underlain by the Lower Carboniferous limestones and that underlain by the (Mansfield) sandstone at the base of the Coal Measures, are not deflected as they pass from the limestone into the sandstone area.

The Mansfield sandstone is often massive, and forms a rugged topography in the region in which it outcrops, and it might be expected that the streams would be deflected to the north or south by it. However, no such change in their courses occurs; instead of being deflected they pass directly from the limestone area across the sandstones, through which they have cut deep valleys (see Plate II, Townships 3 north, 2, 3, 4 west) until they reach the comparatively flat region underlain by the soft Coal Measures shales and sandstones at the west side of the Mansfield sandstone. These conditions lead to the conclusion that the streams from the land at the east cut directly across the Mansfield sandstone as that sandstone was first being elevated above the water, and thus early established themselves in approximately their present courses. In the region underlain by the soft sandstones and shales of the Productive Coal Measures the only systematic arrangement noticeable in the streams is that of their general southwest directions.

Attention should be called in this connection to the sudden southward deflection of the east and west forks of White River, where these streams after passing through the Mansfield sandstone areas, strike the area of the Productive Coal Measures in Martin (D, Plate VII) and Greene (E, Plate VII) counties.

The deflected portions of these streams are in a line with the south course of Anderson River between Spencer and Perry counties (F, Plate VII) in the extreme southern part of the State.

The coinciding deflections of these streams are suggestive, as they occur in a line approximately parallel with the position that must have been occupied by the shore line during a portion, at least, of Productive Coal Measures time, and the suggestion is made that these streams had their courses turned parallel with the old shore line at that time, and that the streams have occupied approximately that position ever since. In this connection the south deflection of the Wabash near Covington and its due south course from Covington to Terre Haute parallel to the above mentioned portions of the two forks of White River and in a line with the southward deflection of West White River near northeast of Vincennes (D, Plate VII) is of interest, and suggests the same causes.

The general absence of surface drainage systems through the region underlain by the Lower Carboniferous limestones owing to the cavernous nature of those limestones, and the well developed underground drainage has already been remarked upon (page 282).

East White River flows from the central across the western area and forms one of the principal streams of the western area.

North of the north line of Monroe and Brown counties the tributaries of West White River flow through glacial debris and are left out of the discussion, as are also those streams that flow across the Productive Coal Measures west of West White River.

SUMMARY.

In summing up the discussion of the drainage systems of southern Indiana attention is called to the following points:

1. The drainage in the region but thinly covered with drift, as well as in the driftless region, is controlled by the geologic structure.

   The drainage (except in the eastern area) is towards the southwest, with the dip of the strata, and is such as would logically develop from a gradual elevation of a land surface beginning at the east part of the State, and a corresponding recession of the water towards the southwest. The evidence points to the conclusion that the present drainage has developed from such ancient initial drainage, and the writer believes this to have been the case.

2. The writer is unacquainted with any evidence in southern Indiana that the drainage has ever been towards the north and east.*

*See the Ohio State Academy of Science, special papers No. 3, p. 68, et seq. Preglacial drainage conditions in the vicinity of Cincinnati, by Gerard Fowke. Evidence is produced to show that the Ohio flowed northeastward in preglacial time from near Madison.

If the preglacial drainage of southern Ohio and southeastern Indiana (the eastern area of the present discussion) was formerly towards the north and east, as is believed by some to be the case, then the watershed between such northeastward drainage and the southwestward drainage of Indiana was the highland formed by the Niagara and Devonian limestones, i. e., the present watershed between the eastern and central drainage areas of southern Indiana.

How far north this watershed may have extended can not be conjectured, but it probably extended at least as far north as Clinton County (see Plate I).

3. It is believed that that portion of the State in which the preglacial topography and structure were similar to the present topography and structure of the driftless region, had also preglacial drainage systems parallel in a general way with the present drainage systems of the driftless region, and this includes most of that region which lies west of the southwestward dipping Niagara and Devonian limestones.* By "driftless region" is here meant that region in which the drainage systems are not controlled primarily by the drift.

CONCLUSIONS.

The study of the strata of southern Indiana brings out the following facts:

First. Between the Hudson River epoch and the end of Carboniferous times there were the following general periods of deposition:

1. From the Hudson River epoch to the end of the Hamilton was a period during which the sea was shallow or only moderately deep, and the conditions were favorable for the deposition of limestone and calcareous shales.
2. From the Genesee to the end of the Knobstone epoch was a period during which, with the exception of short intervals, the sea carried much sediments. During this period of muddy seas the New Albany shale and the Knobstone strata were deposited.
3. At the end of the Knobstone epoch there was a general reversion to clear seas and conditions favorable to marine life, and to the deposition of limestones. During this period the Lower Carboniferous limestones were deposited.

*The drainage through the north end of the central area—i. e., in the region of Clinton County and northwest of there—may have been towards the northwest so far as the structure is concerned, but the writer knows of no reason for supposing that it was in that direction.

4. In the area of western and southwestern Indiana Upper Carboniferous time was marked by alternating shallow sea and inland basin conditions. The waters, whether salt or fresh, were heavily charged with sediments during this time, and sandstones, shales, and coal beds were deposited.

Second. From Lower Silurian to the end of Lower Carboniferous time the sea that covered southern Indiana was shallow or only moderately deep, with the possible exception of a portion of Lower Carboniferous times. Shallow water conditions prevailed also during Upper Carboniferous time.

Third. Except for the pebbles found in the Clinton (cited on page 244) and the absence of that formation in certain localities, and the slight unconformity between the Niagara and Devonian limestones (cited on page 246), there is no evidence to show that the rocks were raised above the surface of the sea for an important interval at any time between Lower Silurian and the end of Lower Carboniferous time; the unconformity between the New Albany shale and underlying limestone of Kentucky has not been recognized in Indiana.

Fourth. At the end of Lower Carboniferous time the sea floor was raised above the surface and following this elevation was a long period of denudation. The elevation of the land was greater in the northern (i. e., in the region about Crawfordsville and Lafayette) than in the southern portion of the State during this period. This is the *first denudation interval* which is certainly known to have interrupted the deposition of strata in southern Indiana.

Fifth. Following the *first denudation interval* was a period of subsidence. The depression of strata was sufficient to completely submerge what is now the western and southwestern part of the State, i. e., that portion of the State that is covered over by the Mansfield sandstone. As the sea encroached upon the land during this period of subsidence the Mansfield (Basal Coal Measures) sandstone was deposited along the shore lines.

Sixth. After the deposition of the Mansfield sandstone the rocks were again elevated above the sea, and a period of denudation followed in which the Mansfield sandstone was in part removed. This is the *second important denudation interval* certainly known to occur in the southern Indiana section.

Seventh. After the second interval of denudation there was a subsidence, followed by many oscillations of the strata. During this period that portion of Indiana which is at present covered by the Productive Coal Measures was alternately below the sea, and near to or above the surface of inland fresh waters. The Productive Coal Measures were deposited during this time.

After a period of erosion at the end of the Productive Coal Measures time there was a submergence of the strata during which the Merom sandstone was deposited. Probably only the western part of the area covered by the Coal Measures was submerged at this time.

Eighth. After the deposition of the Merom sandstone there was an elevation of the entire region of southern Indiana. Evidence that indicates that the region has been submerged since Carboniferous times is cited in the next paragraph.

Ninth. The evidence that indicates that the area of southern Indiana has been submerged since Carboniferous times consists of gravels of supposed Tertiary age that occur on some of the high hills in the southern part of the unglaciated area of the State. In the region crossed by Township 3 north, this evidence is very meager indeed.

Tenth. While there have been a number of changes in elevation during the past geologic history of the region under discussion these changes have been of the nature of broad uplifts and depressions, as is shown by the fact that no sharp local folds were produced.

Eleventh. That the southern part of Indiana formerly stood at a higher elevation than at the present time, is indicated by the filled valleys that are the rule in that region.

Twelfth. The Crawfordsville Crinoid beds (regarded as of Keokuk age) are the equivalents of strata that belong to the Knobstone group further south. The latter must therefore be, in part at least, of Keokuk age, if the correlation of the Crawfordsville beds be correct.

In regard to the topographic features of Indiana, the following facts are brought out:

Thirteenth. In passing from east to west across southern Indiana three prominent topographic features are crossed. These features and the combinations of strata that have caused them are as follows, where crossed by Township 3 north:

(1) The high eastward facing escarpment along the Ohio River caused by a thick series of easily eroded calcareous shales overlain by thick and resisting limestones. (2) The high eastward-facing escarpment with its outliers to the east, known as the "Knobs." This escarpment is the result of a thick series of soft clay and sandy shales, protected by sandstone and resisting limestones. Along the line under discussion this escarpment is 28 miles west of the escarpment along

the Ohio. (3) The high hills of Martin County, which are the result of a series of limestones and sandstones capped by more resisting sandstones and which do not rise as an escarpment from the east, but become gradually higher, owing to the resisting nature of their lowest beds. The distance from the Knobstone escarpment to the highest hills capped with the Mansfield sandstone is about 30 miles. Between these prominent topographic features are broad, flat trough like valleys worn out in the soft beds which lie between the hard and resisting series of strata just mentioned.

Fourteenth. The structure of each of these topographic features where crossed by the section is essentially the same in different stages of development, i. e., that of dissected plateaus sloping gently to the west.

Fifteenth. The top of the eastern plateau where crossed by the section through the center of Township 3 north, is 800 feet above the sea, that of the middle is 820 feet, and that of the western 880 feet above tide, while but a short distance to the north or south the topographic sheets show the elevations of these plateaus to correspond even more closely.

Sixteenth. These closely corresponding elevations suggest that the present topography of southern Indiana may have been developed from an old base level. A former plain of deposition, or a combination of a plain of deposition and a base level of erosion might, however, have given rise to the present topographic features.

Seventeenth. The present drainage systems of southern Indiana owe their general arrangement to the geological structure of the region (with the possible exception of East White River below Rockford); they are very old, and the modifications in them caused by the ice invasion were of minor importance, with the possible exception of East White River.*

* Owing to absence in the field the author was not able to read the proof of this paper.