STATE OF INDIANA
RALPH F. GATES, GOVERNOR

DEPARTMENT OF CONSERVATION
JOHN H. NIGH, DIRECTOR
INDIANAPOLIS

DIVISION OF GEOLOGY
CHARLES F. DEISS, STATE GEOLOGIST
BLOOMINGTON

BULLETIN NO. 3

CORRELATION OF THE WALDRON AND MISSISSINEWA FORMATIONS

BY

R. E. ESAREY AND D. F. BIEBERMAN

PRINTED BY AUTHORITY OF THE STATE OF INDIANA

BLOOMINGTON, INDIANA
APRIL 1948

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CORRELATION OF THE WALDRON AND MISSISSINEWA FORMATIONS

BY R. E. ESAREY AND D. F. BIEBERMAN

INTRODUCTION

EXPLANATORY STATEMENT

Silurian and Devonian outcrops of Indiana are divided roughly into two areas, northern and southeastern Indiana. The bedrock of the northern area is largely covered by glacial drift, whereas the bedrock of the southeastern area is well exposed. These two areas are separated by an intervening zone which is blanketed completely by glacial drift. Although accurate and detailed work has been done on the Silurian and Devonian outcrops of the state, the formations of the two areas have never been correlated.

The Silurian and Devonian formations in Indiana dip off the Cincinnati and Kankakee Arches into the Michigan Basin and the Eastern Interior Basin. The formations are difficult to trace in subsurface studies, because they are composed of a series of gradational limestones, dolomites, and calcareous siltstones. The surface formations have not been recognized in the subsurface strata. Some of the subsurface beds cannot be correlated with the outcropping beds, because additional sediments deposited in the basin do not appear on the arches.

The Silurian-Devonian contact lacks identifying characteristics over much of the area, and, for this reason, many subsurface reports have considered both systems as one unit. The writers believe that accurate determinations of thickening, thinning, and pinching-out of the Silurian and Devonian formations on the flanks of the arches would be of great assistance in future prospecting for oil.

These two problems, the geology of the arches and the geology of the basins, go hand in hand. Additional subsurface correlation studies are needed to clarify the Silurian and Devonian stratigraphy of Indiana.

PURPOSE AND METHOD OF STUDY

Although the study of the Silurian and Devonian formations of Indiana is incomplete at this time, the Waldron shale can now be correlated with the Mississinewa shale. Of all the Silurian formations, these two shales are most easily traced from the outcrop sections into the subsurface where they merge. The writers believe that the Waldron-Mississinewa marker bed is the key to the solution of Silurian-Devonian stratigraphy.

Samples were collected from representative Silurian outcrops in the northern and southeastern areas and were crushed to the size of well samples for microscopic comparison. Samples were studied from 75 wells distributed throughout the state. Both the outcrop and the well samples were mounted on cardboard strips according to footages to facilitate the identification and tracing of zones and horizons. Conclusions are based largely upon lithologic comparisons supported by siliceous residue analyses.

ACKNOWLEDGMENTS

The writers wish to express special thanks to Dr. J. J. Galloway, Indiana University, for his careful criticism of ideas presented in this report. Dr. Galloway spent many hours with the junior writer identifying fossils and discussing Silurian and Devonian stratigraphic problems.

The cooperation of Dr. G. V. Cohee, United States Geological Survey, Ann Arbor, Michigan, is greatly appreciated. Dr. Cohee discussed freely his Silurian subsurface correlations and permitted the use of his collection of well samples.

PHYSIOGRAPHY

Southeastern Indiana has a fairly rugged topography, despite a mantle of drift left by the Illinoian ice sheets. Streams have dissected the territory since glacial times, producing the widespread exposures of bed rock now known as the southern outcrop region. Figure 1 shows the northern and southern outcrop areas of Silurian rocks in Indiana.

The northern two-thirds of Indiana is essentially a till plain slightly modified by postglacial stream erosion. The area north of Brown, Bartholomew, Decatur, and Franklin Counties is mantled by both Illinoian and Wisconsin drift. Only isolated exposures of the underlying formations can be found, and most of these occur along the main drainage channels. Silurian rocks crop out chiefly along the Wabash and White Rivers and their larger tributaries.

The zone separating the northern and southern outcrop belts is covered completely by glacial drift. This intervening zone includes Hancock, Henry, Shelby, Rush, and parts of adjoining counties (Fig. 1). The two outcrop areas, which would normally form a continuous north-south belt, are separated by approximately 32 miles. The quarries and reported outcrops at Spiceland (Henry County) have been filled with water or covered for more than 30 years. No additional outcrops of Silurian rocks have been found between the town of Milroy in southern Rush County and the town of Ingalls in southern Madison County.

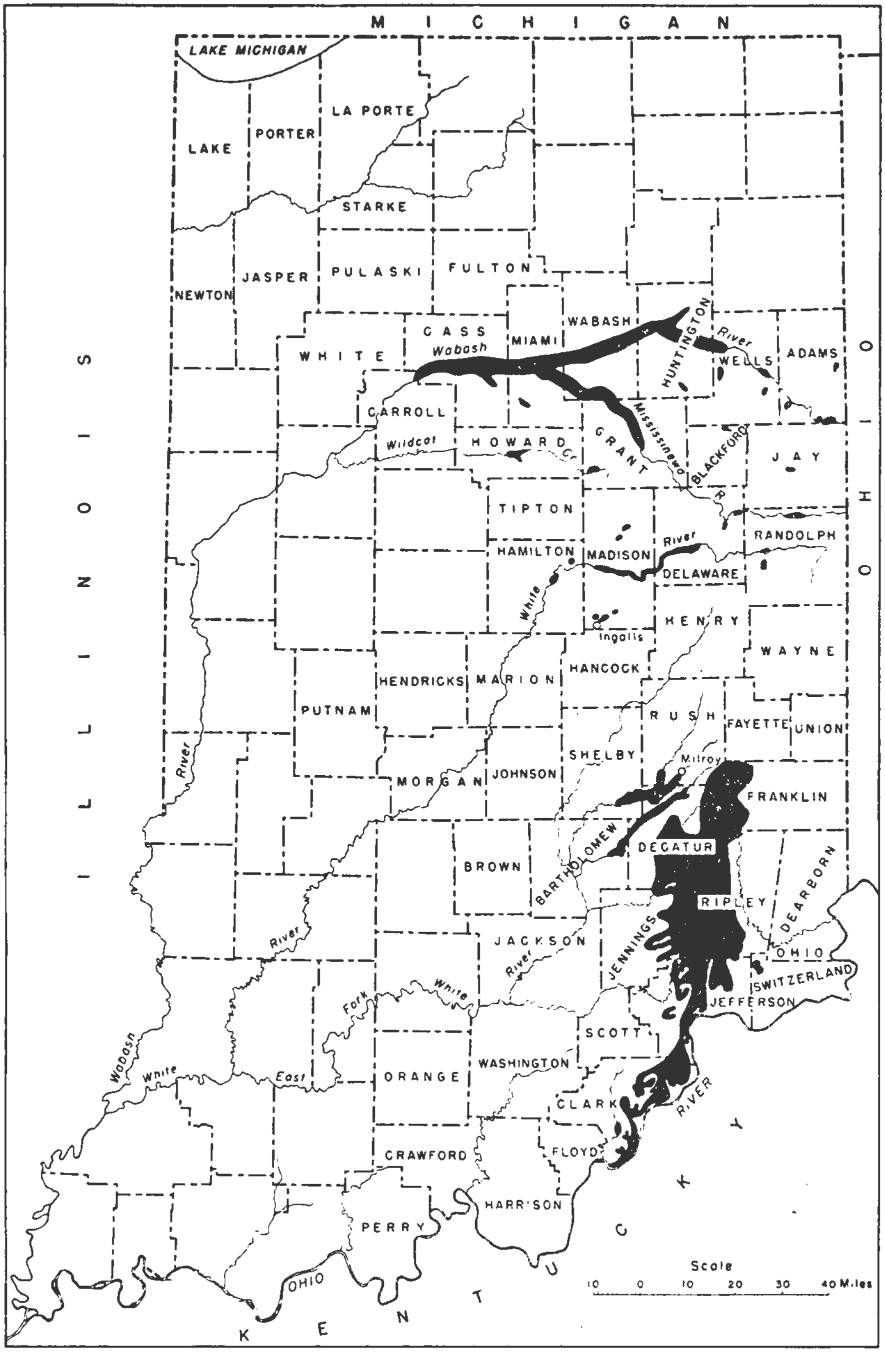


Figure 1. *Map of Indiana showing northern and southern Silurian outcrop areas*

REGIONAL STRUCTURE

Indiana is situated in the interior plains region of the United States where sedimentary rocks, chiefly Paleozoic in age, compose the surface formations. As a whole, Indiana has been an area of little disturbance, effected mostly by regional warping. About 4,000 feet of sedimentary rocks overlie the basement complex on the Cincinnati Arch in eastern Indiana. The sediments thicken into the Eastern Interior Basin, totaling 12,000 feet or more in southwestern Indiana.

The major geologic structures of the region are the Cincinnati Arch, the Kankakee Arch, the Eastern Interior Basin, and the Michigan Basin (Fig. 2). The Cincinnati Arch extends from the Nashville Dome in Tennessee northward through Kentucky into Ohio and Indiana. The arch is a broad, gentle structure off which the formations dip 10 to 30 feet per mile. This great anticline divides into two arms north of Cincinnati; the larger one continues northeastward in Ohio along the Indiana boundary and passes beneath Lake Erie near Toledo, and the other extends northwestward across Indiana and dies out near Logansport in Cass County. The name Findlay Arch is used for the northeast branch and the name Wabash Arch for the northwest branch. The Wabash Arch terminates in a depression known as the Logansport Sag which connects the Eastern Interior Basin with the Michigan Basin. The Kankakee Arch extends from the Wisconsin Highlands into Lake, Jasper, and Newton Counties, Indiana, and also disappears in the Logansport Sag.

The Eastern Interior Basin includes about one-third of Indiana in the western and southwestern portion, part of northwestern Kentucky, and most of Illinois. The basin is essentially a broad, shallow depression elongated northwest to southeast. The Michigan Basin includes approximately the three northern tiers of counties in Indiana. The formations dip 10 to 20 feet per mile northward and northeastward from the Wabash and Kankakee Arches into the basin. Bed rock in this part of Indiana is covered with thick deposits of glacial drift. The Logansport Sag in Cass and adjoining counties probably connected the Michigan Basin with the Eastern Interior Basin during much of geologic time.

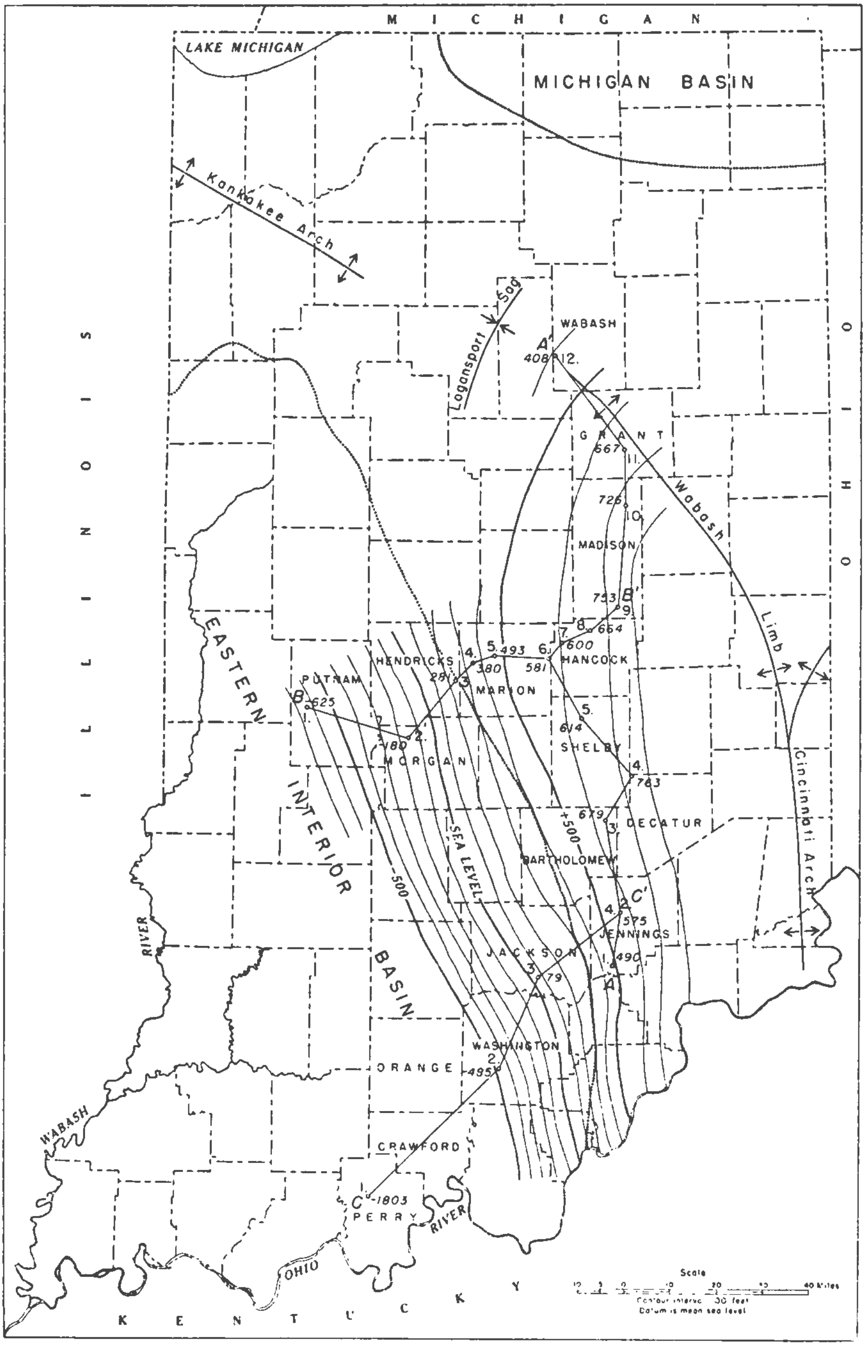


Figure 2. *Map of Indiana showing location of wells used in cross sections, regional structural features, and contours on base of Waldron*

STRATIGRAPHY

INTRODUCTORY STATEMENT

The Silurian system is divided into three time units: the Lower Silurian or Albion series, the Middle Silurian or Niagaran series, and the Upper Silurian or Cayugan series (Swartz, and others, 1942, Chart No. 3). The Brassfield limestone, Albion in age, is the oldest Silurian formation known in Indiana. It crops out on the Cincinnati Arch in the southeastern part of the state. The Niagaran series, which comprises the largest portion of the Silurian rocks in Indiana, includes the Osgood shale, Laurel limestone, Waldron shale, and Louisville limestone of southeastern Indiana, and the Mississinewa shale, Liston Creek limestone, and Huntington dolomite of northern Indiana. The Cayugan series is represented by the Kokomo limestone which occurs in the Logansport Sag of northern Indiana. The Kenneth limestone of Cumings and Shrock (1927, p. 6) overlies the Kokomo limestone, but its age has not been determined.

As the Waldron shale and Mississinewa shale are of Niagaran age, only this series is considered in detail in the present report. The Brassfield limestone is indicated in cross sections (Pls. 1, 2, and 3) and is discussed under the headings Silurian system, and Geologic history. As the Kokomo limestone does not occur in the area under consideration, no further discussion is devoted to it.

WALDRON SHALE

Name.—David Christy discovered fossil beds of Niagaran age at Waldron, Indiana, in 1860. He sent a collection of these fossils to James Hall, who described and illustrated them in three publications between the years 1862 and 1882. Hall (1882, p. 219-220) pointed out the similarity of the lithology and fauna of the shaly fossiliferous beds at Rochester, New York, and the fossil beds at Waldron, Indiana. Throughout his publication, Hall referred to the Waldron locality of the Niagaran group but in no way gave the shale enclosing the fossil horizon a formation name. The term "Waldron beds" and "Waldron fossil beds" were used in the literature until Elrod (1884, p. 95) applied the name "Waldron shale" to the blue shale of southeastern Indiana, which contains the famous Waldron fossils.

Elrod (1884, p. 95-96) observed the Waldron shale in Rush, Shelby, and Bartholomew Counties where it marks the junction of the Silurian and Devonian periods. He thought the beds formed the top of the Upper Silurian and were local in extent. Foerste (1897, p. 232) traced the Waldron shale southward to Charlestown Landing, Clark County, and mentioned similar shaly clay in the vicinity of Louisville, thus extending the length of the Waldron shale outcrop to 90 miles. He recognized that the Waldron occurred beneath the Louisville limestone in this southern area. Price (1900, p. 84), in his report on the Waldron shale in Decatur, Bartholomew, Shelby, and Rush Counties, called attention to the 10 to 12 feet of Niagaran limestone which occurs above the Waldron shale in some localities. This limestone, he stated, corresponds stratigraphically to Foerste's Louisville limestone farther south.

Lithologic characteristics.—At a typical outcrop, the Waldron shale appears to be a greenish to bluish-gray, clay shale which disintegrates rapidly into a yellowish clay. The calcareous nature of the Waldron can be observed only at isolated outcrops. Fossils occur irregularly in the shale. One exposure may contain a prolific faunal assemblage, but the same horizon only a few hundred feet away may be barren. The Waldron shale ranges from 0 to 20 feet in thickness within its outcrop area.

Microscopic study indicates that the Waldron is a calcareous siltstone, not a typical clay shale. After fragments are dissolved in hydrochloric acid, a characteristic insoluble residue of fine arenaceous material remains.

Outcrop area.—The outcrop area of the Waldron shale in southeastern Indiana extends 90 miles along the western flank of the Cincinnati Arch. Exposures occur in Clark, Jefferson, Jennings, Ripley, Bartholomew, Decatur, Shelby, and Rush Counties. The northern-most exposure observed by the writers is in an abandoned quarry half a mile south of Milroy on Little Flat Rock Creek, Rush County.

MISSISSINEWA SHALE

Name.—Cumings and Shrock (1927, p. 2) named the Mississinewa shale from typical exposures along the Mississinewa River. They stated, "To this formation from the base of the yellow limestone above, downward as far as typical development continues, is given the name *Mississinewa Shale* . . ." The base of the formation is not exposed, and this fact has led to confusion of the downward limitation of the term Mississinewa.

Cumings and Shrock (1928a, p. 57) stated: "The formation (Mississinewa) includes the strata lying between the base of the Niagaran and the base of the overlying cherty limestone." Further on in the paper (p. 61-62), Cumings and Shrock reported 75 feet of Mississinewa shale at the Wabash outcrop. They referred to Ward who recorded 117 feet of blue shale, "probably from a well," three miles west of Wabash, and to Elrod and Benedict who recorded 114 feet of shale in a well at Lagro and mentioned that perhaps hydraulic properties continue on down to 250 feet. From this evidence Cummings and Shrock concluded: "In the absence of well cuttings or outcrops, however, we cannot say that this is all shale, hence it may not all be included in the Mississinewa shale as defined. Should the basal portion of this mass turn out to be limy, then the term *formation* might replace the name *shale* and the Mississinewa formation thus defined be made to include all strata between the top of the Mississinewa shale and the base of the Niagaran."

Owing to these discrepancies in the application of the term Mississinewa, the writers are restricting the Mississinewa formation to the original definition. In this paper, the term Mississinewa shale includes only the lithologic shale unit.

Lithologic characteristics.—At a fresh exposure, the Mississinewa shale appears to be a massive, blue-gray calcareous shale or argillaceous limestone. True bedding planes and joints are rare. The formation breaks down into large, irregular blocks displaying a conchoidal fracture, weathers drab to buff, and splits into the small slabs of a typical shale. The Mississinewa shale is partly or totally replaced by reefs of the same age in many outcrops.

The Mississinewa does not look like a shale under the microscope, but rather a calcareous siltstone. The insoluble residue of the Mississinewa is fine arenaceous material and is identical with that in the Waldron.

Outcrop area.—The Mississinewa shale has a large outcrop area, but actual exposures are confined to stream courses and quarries. It is best exposed along the Wabash, Salamonie, and Mississinewa Rivers in Huntington, Wabash, and Miami Counties. Farther south it crops out along the White River and Pipe Creek in Madison and Delaware Counties. The southern-most exposure is in the Pendleton Reformatory quarry, one mile northeast of Ingalls, Madison County.

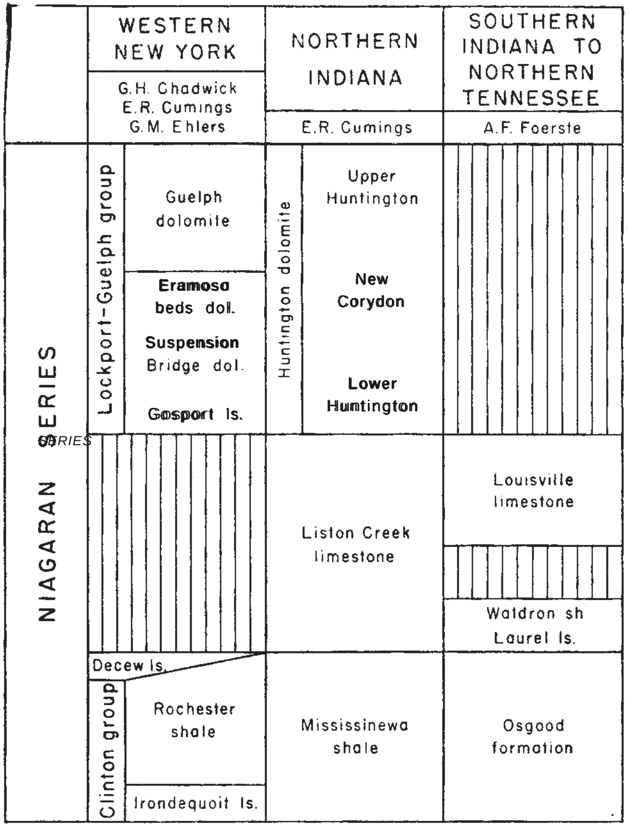


Figure 3. *Correlation of Niagaran series of western New York, northern Indiana, and southern Indiana to northern Tennessee*
AFTER SWARTZ

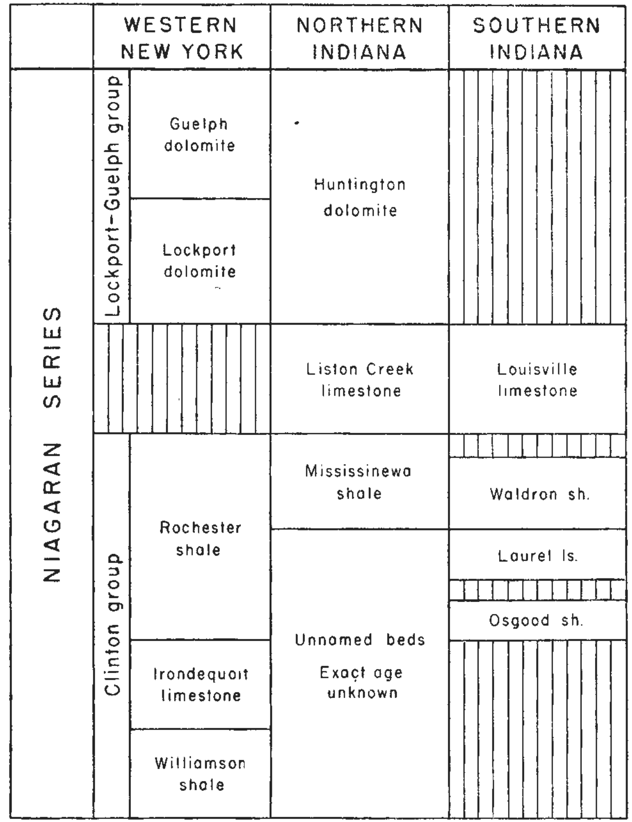


Figure 4. *Revised correlation of the Niagaran series of western New York and Indiana*

CORRELATION OF NIAGARAN FORMATIONS

Explanatory statement.—The Silurian subcommittee (Swartz and others, 1942) published "Chart No. 3—Correlation of Silurian formations of North America." Figure 3 presents the section of Chart 3 which pertains to the Niagaran series of western New York, northern Indiana, and southern Indiana to northern Tennessee. This chart was compiled by competent Silurian workers and, therefore, represents the accumulation of knowledge resulting from previous investigations. The chart reflects the latest trends in Niagaran correlation, and, for this reason, the writers have used it as a basis for subsequent correlation.

The correlation chart of the writers (Fig. 4) combines the facts known to date. Formations above and below the Waldron and Mississinewa shales have not been studied sufficiently to permit fixed correlations. Future investigations may alter the chart considerably.

The fact that few macrofossils escape pulverization in well cuttings does not exclude the use of fossils in subsurface correlation. Stratigraphic units can be traced to their outcrop equivalents, and the fossils collected from the outcrop section can be used for approximate age determinations. Fossil lists from the Niagaran of northern Indiana (Cumings and Shrock, 1928a, p. 59-60, 79-81) (Cumings, 1930b, p. 208-211) were compared with lists from the Niagaran of southern Indiana (Bassler, 1915, p. 1487-1495). Both were compared with the Rochester and Lockport lists compiled by Bassler (1915, p. 1487-1489, 1496-1498). The correlation of northern and southern Indiana formations and the grouping of them into Rochester and Lockport times were based upon this study.

Comparison of Niagaran faunal lists of southern Indiana and western New York.—Few will question the assignment of the Osgood shale to Rochester age. A total of 48 Rochester species are found in the Osgood, 11 of which also are found in the Irondequoit and 4 in the Lockport.

Fossils are scarce in the Laurel limestone, and many of them have not been reported elsewhere. Most of the comparable species are long ranged and, therefore, of little value. After eliminating such fossils, 1 Laurel-Rochester, 1 Laurel-Osgood, and 4 Laurel-Waldron species remain. The fossil list is disappointing and inconclusive. As the Laurel shows a closer faunal relationship to the Waldron than to the Osgood, one must look to the Waldron for further evidence of age.

Bassler (1915, pl. 3) placed the Waldron in the Lockport group. The "Geological map of Indiana" (Logan, 1932) followed this example. The faunal lists, however, show that 34 Rochester species occur in the Waldron, but only 4 long-range Lockport species are represented. Further checking shows that 9 of the Waldron-Rochester and 1 of the Waldron-Osgood species re-occur in the Guelph. After eliminating all long-range species, 16 Rochester species and 1 Guelph species remain. The writers, therefore, agree with Schuchert (1943, p. 582) in assigning the Waldron shale to late Rochester.

The Louisville limestone was placed in the Lockport group by the early workers in Indiana geology. In his later work, Cumings (1930a, p. 193, 198) considered the Louisville limestone as very early Lockport, older than the typical Lockport of New York. The Silurian subcommittee (Fig. 3) placed the Louisville, Waldron, and Laurel in the erosion interval between the Clinton group and the Lockport-Guelph group. Schuchert (1943, p. 582) stated that the Louisville is "older than Lockport." The faunal lists bear out his interpretation. The assemblage of 18 Rochester species and 22 Lockport-Guelph species found in the Louisville limestone indicates that the Louisville is transitional between Lockport and Rochester times.

Comparison of Niagaran faunal lists of northern Indiana and western New York.—Cumings and Shrock (1928a, p. 63) noted that the Mississinewa graptolites are closely related to the graptolites at Hamilton, Ontario, which in turn are allied with the graptolites of the Gasport member, early Lockport. Cumings and Shrock concluded that the Mississinewa shale is late Rochester or early Lockport in age. Cumings (1930b, p. 211) stated, "The general cast of this (Mississinewa) fauna is Rochester; and is in line with the indications of the extensive graptolite fauna described by Shrock . . ." The Silurian subcommittee has correlated the Mississinewa with the Rochester shale and the Irondequoit limestone of Clinton age.

Excluding the graptolites, 18 Rochester species and 18 Lockport-Guelph species are represented in the Mississinewa fossils listed by Cumings and Shrock (1928a, p. 59-60). In a later list published by Cumings (1930b, p. 210-211), 16 new Mississinewa species are given, all of which were collected from one reef flank. Of these additional species, 6 are confined to the Rochester, and 3 are both Rochester and Lockport. Fossils in the Mississinewa shale are irregularly distributed, and, as yet, the list is far from complete. Further collecting may prove definitely that the Mississinewa shale is late Rochester in age.

Cumings and Shrock (1928a, p. 84) stated that the Liston Creek fauna checks with the typical Lockport fauna of New York and Ontario, but Cumings (1930a, p. 193, 198) later decided that the Liston Creek is older than the Lockport of New York. The Silurian subcommittee represented the Liston Creek as post-Clinton and pre-Lockport in age. The writers prefer this interpretation. After the elimination of long range forms, 9 Rochester species and 9 Lockport-Guelph species are found in the normal Liston Creek fauna. Liston Creek reef fossils, however, favor the Lockport-Guelph, 9 to 2. Cumings and Shrock (1928a, p. 187) pointed out that new forms appear first in the reef facies, indicating that more favorable living conditions existed there.

The Huntington dolomite, according to Cumings and Shrock (1928a, p. 102), has a distinctive Racine-Guelph fauna. The Huntington dolomite does not appear in the cross sections and has no direct bearing on the correlation of the Waldron and Mississinewa formations. Therefore, it does not receive further consideration in this paper. The writers are following the Silurian subcommittee in correlating the Huntington dolomite with the Lockport-Guelph group.

Comparison of Niagaran faunal lists of northern and southern Indiana.—Cumings and Shrock (1928a, p. 84) referred to the close faunal relationships of the Louisville limestone and the Liston Creek limestone. Cumings (1930b, p. 208-210) listed fauna from a Liston Creek reef north of Lapel, Madison County. After a short discussion of new Liston Creek species found here, he concluded, "The correlation of the Liston Creek limestone with the Louisville can, therefore, no longer be regarded as doubtful." The Liston Creek limestone and Louisville limestone have 50 species in common.

Of 85 species described from the Mississinewa shale, 27 are graptolites. Since the Waldron faunal list contains but 2 graptolite species, the Mississinewa graptolites have little comparative value. Eliminating the graptolites, the Mississinewa shale has only 58 species, while the Waldron shale has 206. The Liston Creek limestone has 129 species and the Louisville limestone 201. The range in the number of species in the 4 formations is so great that a simple statement of the number of species in common would be misleading. Percentages have been computed to compensate for this. The results are as follows: 39 percent of the Liston Creek species are found in the Louisville limestone; 45 percent of the Mississinewa species are found in the Waldron shale.

Cumings and Shrock (1928a, p. 84) mentioned shale beds occurring in the Liston Creek limestone which contain fossils with Waldron affinities and speculated as to whether or not these beds represent the northward extension of the Waldron shale. Although 32 percent of the Liston Creek species do occur in the Waldron shale, 36 percent of the Mississinewa species occur in the Louisville limestone!

The faunal assemblages show a greater change between Waldron and Louisville than between Mississinewa and Liston Creek formations. Only 12½ percent of the Waldron species carry over into the Louisville limestone, whereas 67 percent of the Mississinewa species carry over into the Liston Creek limestone. The outcrop of the Waldron shale is high on the flank of the Cincinnati Arch. The shale was deposited near sea level and was subject to wave action and perhaps subaerial erosion. In places the Waldron is absent. The Mississinewa shale was deposited in a shallow sea which was, as yet, unaffected by movements of the arch. Continuous deposition occurred from Mississinewa time into Liston Creek time, and, consequently, more species survived.

STRATIGRAPHIC CROSS SECTIONS

EXPLANATORY STATEMENT

The stratigraphic cross section A-A′ of Plate 1 shows a series of wells extending from southern Indiana along the western flank of the Cincinnati Arch into northern Indiana. The purpose of this section is two fold: to show the continuous nature of the Waldron shale from the southern outcrop area into the northern outcrop area where it has been given the name Mississinewa; and to show the thickening of the Niagaran series and the thinning of the Cincinnatian series northward. A regional structure map drawn on the base of the Waldron shale (Fig. 2) shows that, although the section lies essentially parallel to the arch, it unavoidably crosses and recrosses the structure contour lines. As a section constructed on sea level elevations would produce false structures and distortion, the stratigraphic cross section A-A′ was constructed on the base of the Waldron shale.

The stratigraphic cross section B-B′ of Plate 2 shows a central east-west section from the Cincinnati Arch into the Eastern Interior Basin. Wells no. 6, 7, 8, and 9 of this section duplicate wells no. 6, 7, 8, and 9 of section A-A′ (Fig. 2). In tying the two sections together, these wells were repeated because they fall in the critical area between the northern and southern outcrop belts. As section B-B′cuts across the Waldron structure contours at approximately right angles, the wells were set up on sea level and thus form a fairly accurate structural picture.

The stratigraphic cross section C-C′ of Plate 3 shows a southern east-west section from the Cincinnati Arch into the Eastern Interior Basin. Well no. 4 of the section repeats well no. 2 of the north-south section, A-A′. The wells of this section also are set up on sea level datum, thus showing the formations dipping down the flank of the arch into the basin.

LOCATION OF WELLS

The location of the wells in the stratigraphic cross sections A-A′, B-B′, and C-C′ is shown graphically in Figure 2. The wells in the stratigraphic cross section A-A′ of Plate 1 are:

1. J. E. Johnson No. 1, drilled by Comisky Oil Associates in the NE¼ NE¼ sec. 23, T. 5 N., R. 7 E., Jennings County. Elevation 650.

2. E. L. Phillips No. 1, drilled by The Ohio Oil Company in the NE¼ NE¼ sec. 30, T. 7 N., R. 8 E., Jennings County. Elevation 725.

3. Frank Fishel No. 1, drilled by Haw Creek Oil and Gas Company in the NE¼ NE¼ sec. 15, T. 10 N., R. 7 E., Bartholomew County. Elevation 764.

4. Lafayette Peck No. 2, drilled by St. Paul Natural Gas Company in the SW¼ SW¼ sec. 34, T. 12 N., R. 8 E., Decatur County. Elevation 883.

5. Nora Bowman No. 1, drilled by Phillips and Kost in the SE¼ SE¼ sec. 26, T. 14 N., R. 6 E., Shelby County. Elevation 799.

6. William F. Kleiman No. 1, drilled by J. W. Adams in the SE¼ SE¼ sec. 22, T. 16 N., R. 5 E., Marion County. Elevation 867.

7. Ira Brock No. 1, drilled by Chafee in the NE¼ SW¼ sec. 6, T. 16 N., R. 6 E., Hancock County. Elevation 870.

8. Fannie L. Andis No. 1, drilled by Art Laws in the SW¼ SW¼ sec. 24, T. 17 N., R. 6 E., Hancock County. Elevation 874.

9. McCallister No. 1, drilled by Laws in the NE¼ SE¼ sec. 25, T. 18 N., R. 7 E., Madison County. Elevation 898.

10. W. D. Montgomery No. 1, drilled by Frontier Petroleum Corporation in the NW¼ SW¼ sec. 8, T. 21 N., R. 8 E., Madison County. Elevation 891.

11. C. Knight and others No. 1, drilled by Reynolds in the NE¼ SW¼ sec. 8, T. 23 N., R. 8 E., Grant County. Elevation 822.

12. Maude Barnette No. 1, drilled by Joseph Minneci in the SE¼ NE¼ sec. 23, T. 27 N., R. 5 E., Wabash County. Elevation 659.

The wells in the stratigraphic cross section B-B′ of Plate 2 are:

1. Ross P. Wells No. 1, drilled by Stanolind Oil and Gas Company in the NW¼ NW¼ sec. 15, T. 14 N., R. 5 W., Putnam County. Elevation 755.

2. G. R. Brown No. 1, drilled by C. E. Jefferson in the NW¼ NE¼ sec. 16, T. 13 N., R. 1 W., Morgan County. Elevation 660.

3. Hobbs Nursery Farm No. 1, drilled by Griffin Oil Company in the NE¼ SE¼ sec. 17, T. 15 N., R. 2 E., Hendricks County. Elevation 796.

4. Samuel Ashby No. 1, drilled by Eagle Creek Oil Company in the SE¼ SE¼ sec. 26, T. 16 N., R. 2 E., Marion County. Elevation 754.

5. Indianapolis Water Company No. 3, drilled by White River Oil and Gas Corporation in the NE¼ SE¼ sec. 15, T. 16 N., R. 3 E., Marion County. Elevation 698.

6. William F. Kleiman No. 1, drilled by J. W. Adams in the SE¼ SE¼ sec. 22, T. 16 N., R. 5 E., Marion County. Elevation 867.

7. Ira Brock No. 1, drilled by Chafee in the NE¼ SW¼ sec. 6, T. 16 N., R. 6 E., Hancock County. Elevation 870.

8. Fannie L. Andis No. 1, drilled by Art Laws in the SW¼ SW¼ sec. 24, T. 17 N., R. 6 E., Hancock County. Elevation 874.

9. McCallister No. 1, drilled by Laws in the NE¼ SE¼ sec. 25, T. 18 N., R. 7 E., Madison County. Elevation 898.

The wells in the stratigraphic cross section C-C′ of Plate 3 are:

1. De Laisse No. 1, drilled by Central Pipe Line Company in the SW¼ NE¼ sec. 25, T. 4 S., R. 3 W., Perry County. Elevation 637.

2. E. Cauble No. 1, drilled by Washington County Development in the NW¼ NE¼ sec. 10, T. 1 N., R. 3 E., Washington County. Elevation 670.

3. Terkhorn No. 1, drilled by Aetna in the SW¼ NW¼ sec. 6, T. 4 N., R. 5 E., Jackson County. Elevation 549.

4. E. L. Phillips No. 1, drilled by The Ohio Oil Company in the NE¼ NW¼ sec. 30, T. 7 N., R. 8 E., Jennings County. Elevation 725.

BASIS OF CORRELATION

The correlations presented in the stratigraphic cross sections are based principally upon lithologic characteristics. Established Silurian formations of the northern and southern outcrop sections were sampled. The rock fragments were crushed to the size of well cuttings, washed, and examined. A careful microscopic study of the outcrop samples revealed distinctive lithologic characteristics which could be traced into the subsurface.

Thicknesses of formations could not be used as a guide in determining correlations, because the thicknesses of the rocks were influenced, to a large extent, by the position of the Cincinnati Arch during Silurian times. The cross sections presented in this report (Pls. 1, 2, and 3) show the Silurian formations thickening westward down the flank of the arch and northwestward off the crest of the initial arch.

The few macro-fossils found in the well cuttings proved useful for systemic correlations. Four Niagaran forms, Dalmanella elegantula, Camarotoechia acinus, Reticularia bicostata petila, and Duncanella borealis, were identified by J. J. Galloway from the limestone sequence beneath the Mississinewa shale, proving that this series is, indeed, Silurian.

ORDOVICIAN SYSTEM

Only the upper part of the Trenton limestone (Middle Ordovician) is represented in the three stratigraphic cross sections. In southern Indiana, the Trenton is composed of white crystalline and brown dense fine-grained limestones. In northern Indiana, however, the upper part of the Trenton is tan crystalline dolomite. Pyrite often occurs in the first 5 to 10 feet below the Trenton-Cincinnatian contact.

No attempt is made in this report to divide the Cincinnatian series (Upper Ordovician) into the Eden, Maysville, and Richmond groups. Three lithologic units, however, can be recognized in the well cuttings. The lower unit is composed of black shale which grades upward into gray shale and interbedded limestone stringers. These shales range in thickness from 200 to 400 feet. The middle unit consists of interbedded limestones and shales which grade into the shaly, gray and white mottled, fossiliferous limestones of the upper unit. Calcareous green shale, 5 to 20 feet thick, occurs in the upper unit directly below the Ordovician-Silurian contact in Putnam, Hendricks, Morgan, Marion, and Shelby Counties. Sandy dolomite is present in the upper 100 feet of the Cincinnatian in two Marion County wells. The combined thickness of the middle and upper units ranges from 100 to 500 feet.

The Cincinnatian series in southeastern Indiana reaches its maximum thickness, 803 feet, in Jennings County (Pl. 1, well no. 1). From this point, the Cincinnatian series thins rapidly northward, and is only 345 feet in Wabash County (Pl. 1, well no. 12). The Cincinnatian series also thins westward from the Cincinnati Arch region to Putnam County (Pl. 2, well no. 1) where it is 360 feet thick, and southwestward into Perry County (Pl. 3, well no. 1) where it is 570 feet thick. The middle shale and limestone unit, and the upper shaly, fossiliferous limestone unit thin proportionately in the same directions. The lower shale unit, therefore, makes up a greater and greater portion of the Cincinnatian series northward, westward, and southwestward.

SILURIAN SYSTEM

Brassfield limestone.—Strangely enough, the Brassfield limestone (Lower Silurian) has not been identified in the wells nearest its outcrop exposures. The thickness of the Brassfield in measured outcrop sections ranges from 6 inches to 10 feet. In some localities, however, the Brassfield is absent. The formation typically is hard, coarsely crystalline, greenish-gray to salmon-pink, mottled limestone. This distinctive lithology should be traceable into subsurface. Despite this fact, such a lithology has not been found in well cuttings. The Brassfield may be missing because of erosion or nondeposition in wells no. 1, 2, 3, 4, and 10, 11, 12 of the cross section A-A′ of Plate 1 (including well no. 4 of cross section C-C′, pl. 3).

The zone designated Brassfield on the three stratigraphic cross sections is a distinctive brown, cherty dolomite that contains glauconite grains in the lower few feet. The dolomite ranges in thickness from 7 to 60 feet, generally thickening into the Eastern Interior Basin (Pl. 2, section B-B′). This Brassfield zone can be traced in subsurface westward into southern Illinois, where it is called Sexton Creek limestone, and northward into Michigan, where it merges with the Cataract formation of Cohee (1948).

Osgood and Laurel formations.—The typical Osgood formation, described from outcrops in Jefferson County, consists of a thin basal limestone, a lower shale bed, an upper limestone, and an upper shale bed. The formation becomes a rubbly limestone to the north in Ripley and Jennings Counties. This gradation from shales to limestone occurs in the subsurface section not only northward but also westward down the flank of the Cincinnati Arch. For this reason, the Osgood and Laurel formations are not readily divisible in subsurface work and, therefore, are considered as one unit in the present report.

The Osgood-Laurel subsurface section consists of white, gray, and tan, crystalline to sublithographic limestones and dolomites. The rocks can be divided roughly into two units, a lower unit of dolomites and an upper unit of limestones. The limestones are frequently silty and cherty and occasionally contain thin shale lenses. Glauconite is sometimes present. In approximately half of the wells pink crinoid stems and detrital pink limestone fragments occur as inclusions in beds of white crystalline limestone. Such pink inclusions occur occasionally in the lower dolomite (Pl. 1, wells no. 3 and 5).

The combined thickness of the Osgood and Laurel formations in the outcrop region averages 45 feet. The subsurface section (Pl. 1, well no. 1) is 40 feet thick in southwestern Jennings County and retains essentially the same thickness to northern Decatur County (Pl. 1, well no. 4). However, between this point and the next, located in northern Shelby County (Pl. 1, well no. 5), the section increases 51 feet making a total thickness of 85 feet. The section thickens northward to 260 feet in Wabash County (Pl. 1, well no. 12). Westward and southwestward, off the flank of the Cincinnati Arch, the Osgood-Laurel section also thickens, but to a lesser degree, totaling 120 feet in Putnam County (Pl. 2, well no. 1), and 90 feet in Perry County (Pl. 3, well no. 1).

Waldron shale.—The stratigraphic cross section A-A′ of Plate 1 shows a succession of wells extending from the Waldron outcrops in southern Indiana to the Mississinewa outcrops in northern Indiana. The Waldron shale can be traced throughout the length of this cross section, thus demonstrating that the Waldron and Mississinewa formations are one and the same. Stratigraphic sections (Pl. 2, B-B′; pl. 3, C-C′) show that the Waldron thickens down the western flank of the Cincinnati Arch and begins to thin farther out into the basin.

Although the Waldron is shaly in places, the formation, as a whole, is a calcareous siltstone. Cuttings from a well near the Waldron outcrop appear to be identical to the well cuttings collected from the Mississinewa outcrop area. These cuttings match samples from wells in the intermediate area (northern Shelby, Marion, and Hancock Counties) and also match samples from the area westward down the flank of the Cincinnati Arch (Washington, Jackson, and Morgan Counties). When all samples (outcrop and subsurface) of the Waldron and Mississinewa formations are dissolved in hydrochloric acid, a typical residue of fine arenaceous material remains. A little shale and sometimes small flakes of mica and disseminated grains of pyrite also occur in the insoluble residue.

As shown in the stratigraphic cross section A-A′ of Plate 1, the Waldron shale thickens northward from Jennings County where it is 5 to 10 feet thick (wells no. 1 and 2) into Wabash County where it reaches a thickness of 120 feet or more (well no. 12). The actual contact of the Mississinewa and Liston Creek cannot be established for this well because the upper formation has been removed by glaciation. This thickness, 120 feet, is probably a near maximum, judging from nearby water wells which have penetrated both the Liston Creek and the Mississinewa.

In the stratigraphic cross section B-B′ of Plate 2, the Waldron gradually thickens westward from the Cincinnati Arch to a maximum of 55 feet in western Marion County (well no. 4), and then thins to 45 feet in Putnam County (well no. 1). In the stratigraphic cross section C-C′ of Plate 3, the Waldron similarly thickens westward from the arch to a maximum of 85 feet in Washington County (well no. 2) and thins to 60 feet in Perry County (well no. 1).

The Waldron shale is absent in only two wells in the stratigraphic cross sections. The Louisville limestone rests directly upon the Osgood-Laurel section in well no. 3 of Plate 1. As well no. 3 is within the Waldron outcrop area where the Waldron is known to be locally absent in exposed sections, its absence in this well, although interesting from the paleogeographic viewpoint, does not affect the correlation of the Waldron and Mississinewa formations. The absence of the Waldron in well no. 5 of Plate 2 deserves more attention because it is in Marion County, a part of the critical area between the Waldron and Mississinewa outcrop areas. In well no. 5 the rock equivalent in age to the Waldron is reef rock. The photographed Silurian section of this well and of well no. 4 (Pl. 2) appears in Plate 4, and the reef problem is discussed in detail in the geologic history of the Waldron shale.

Louisville limestone.—Although the Liston Creek limestone is correlated tentatively with the Louisville limestone on evidence from fossils, no occasion arises in the cross sections to use such a correlation. The Liston Creek limestone is absent in wells no. 9, 10, 11, and 12 (Pl. 1), which are located in the Liston Creek outcrop area. The first samples collected from wells no. 9, 10, and 11 are Mississinewa shale, and, therefore, no records of upper formations could be obtained. In well no. 12, glacial drift lies above the shale.

The Louisville limestone in the subsurface is more often a dolomite than a limestone. The Louisville is present in only 3 of the wells in the north-south cross section A-A′ of Plate 1. In well no. 1, Jennings County, white to light gray, crystalline dolomite (which looks very much like reef rock) makes up the top 40 feet of the section. The lower 20 feet are composed of tan finely crystalline limestone that contains grains of glauconite. In well no.

3, Bartholomew County, the Louisville is 20 feet thick and rests on cherty Laurel limestone. Here, the Louisville is composed of tan crystalline dolomite. A few large, rounded sand grains appear in the samples. A 5-foot bed of tan dolomite rests upon the Waldron in well no. 4. From this point northward the Louisville disappears, and the Geneva dolomite (Devonian) rests directly upon the Waldron.

The Louisville can be traced down the western flank of the Cincinnati Arch into the Eastern Interior Basin (Pl. 2, section B-B′). The Louisville limestone first appears in well no. 5, Marion County, where it is represented by 5 feet of light-brown, crystalline dolomite. The section continues at the same thickness in wells no. 4 and 3, but thickens to 55 feet in Morgan County (well no. 2). The lower 50 feet is composed of gray, crystalline dolomite broken only by a 5 foot clay-shale bed. This rock is reef-like in lithology. The upper 5 feet of the section consists of light-tan dolomite. In well no. 1, Putnam County, the Louisville is represented by 90 feet of gray and white reef-like dolomite.

The Louisville limestone is present in only one well (no. 2) in the cross section C-C′ of Plate 3. This well is in Washington County and has a 20 foot section of Louisville. The upper 10 feet is composed of the white to gray crystalline dolomite suggestive of a reef, but the lower ten feet is composed of the typical tan Louisville dolomite.

DEVONIAN SYSTEM

Devonian formations are indicated on the stratigraphic cross sections because the base of the New Albany shale is a logical starting point for Devonian and Silurian investigations, and the Geneva dolomite is an excellent subsurface marker throughout the great area in which it is present. As the Devonian section thickens rapidly into the Eastern Interior Basin, new beds appear which are not present in the surface exposures, and surface marker beds disappear making the Silurian-Devonian boundary in some of the wells still open to question: for example, wells no. 1 and 2, pl. 3.

In the stratigraphic cross sections, the Devonian has been divided into four units; the lower undivided Devonian beds, the Geneva dolomite, the Devonian limestones, and the New Albany shale. Wells no. 1 and 2 of the cross section B-B′ of Plate 2 show a small section of undivided Devonian rocks below the Geneva and above the Louisville. These rocks do not appear in the Indiana outcrop section.

The Geneva dolomite, probably of Schoharie age, is chocolate brown, saccharoidal dolomite both in the surface and the subsurface sections. Chert occurs in a southern Rush County exposure and is present in the subsurface section in Hancock County (Pls. 1 and 2, well no. 8). Sand grains were found in the Geneva dolomite in wells no. 7 and 8, Hancock County. The Geneva dolomite is the basal Devonian formation in eastern Indiana and, therefore, is important in determining the Silurian-Devonian boundary in that area. The Geneva is not basal Devonian, however, farther out in the Eastern Interior Basin (Pl. 2). The feather edge of Devonian rocks beneath the Geneva is shown in the Putnam and Morgan County wells (wells no. 1 and 2). Unfortunately, the Geneva dolomite disappears southwestward into the Eastern Interior Basin (Pl. 3). Since the Geneva dolomite is not present in this area, the Devonian section in wells no. 1 and 2 has not been divided. The great increase of Devonian rocks in these wells probably is due to the addition of Devonian beds older than Geneva in age.

The Jeffersonville, Silver Creek, and Beechwood limestones are not differentiated in this report. However, during the progress of the work, a very interesting unit was found in the Jeffersonville limestone (Onondaga age) directly above the Geneva dolomite in the northern Jennings, Bartholomew, Shelby, Marion, Hendricks, and Morgan County wells, and 12 feet above the Geneva in the Putnam County well. This unit, 10 to 55 feet thick, is composed of scattered, large and small, rounded, frosted sand grains enclosed in a fine-grained matrix of dolomite. Dawson (1941, p. 17 and notes inside front cover) described this unit as lying below the *Spirifer accuminatus* zone and above the laminated zone in the Jeffersonville outcrops near the city of Vernon, Jennings County. The unit is only 4 feet thick at this point. Evidently, the unit thickens to the north and to the west at the expense of the lower Jeffersonville beds.

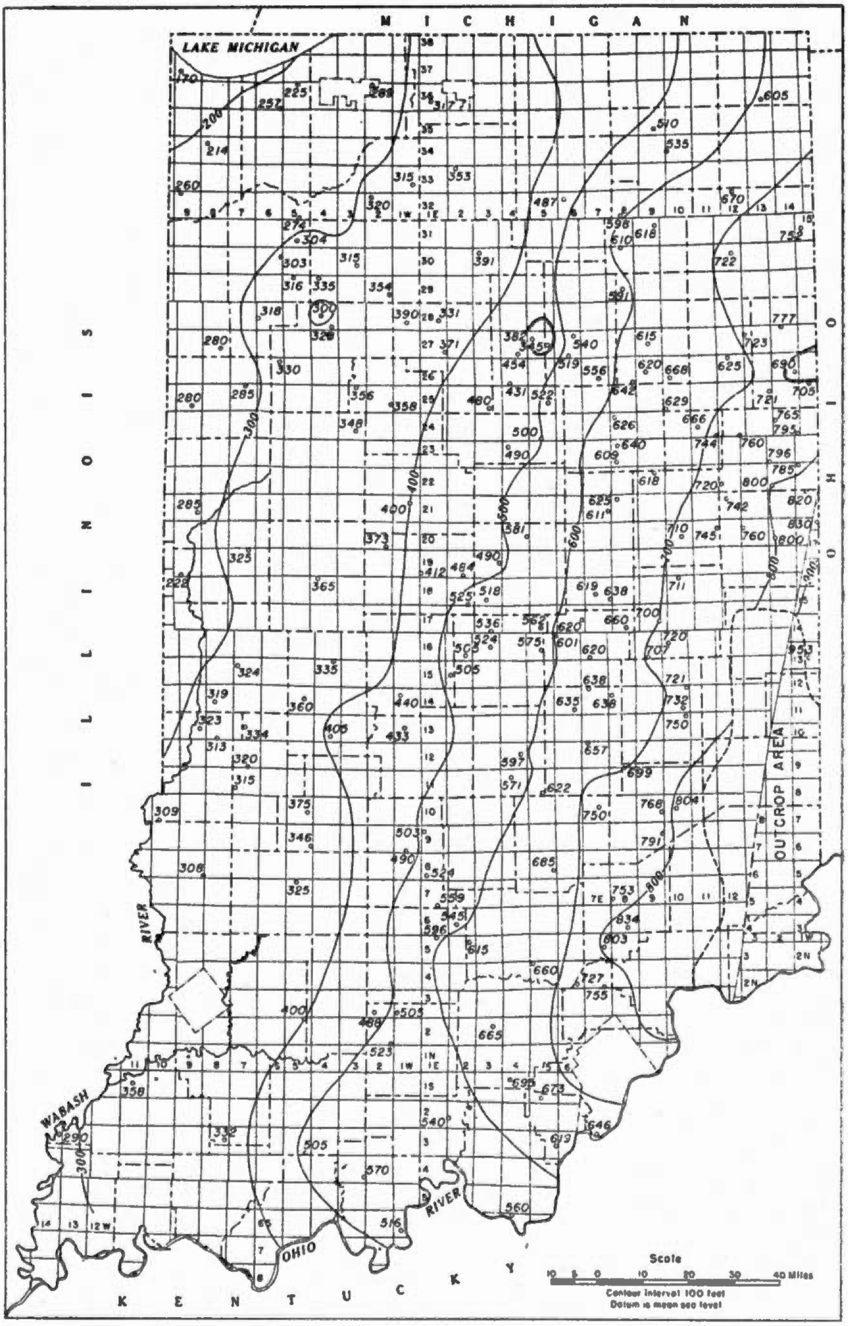


Figure 5. *Isopach map of Cincinnatian series in Indiana*

GEOLOGIC HISTORY

MIDDLE AND UPPER ORDOVICIAN SEAS

During Trenton times, Indiana was covered by a large inland sea that extended eastward into the Ohio Basin and deepened abruptly into the Appalachian geosyncline. Although the Trenton limestone ranges in thickness from 1,250 feet in southeastern Ohio to 325 feet in northwestern Indiana, it is remarkably uniform over large areas, indicating stable sea conditions with no evidence of interruption by the Cincinnati Arch. The sea receded from Illinois and western Indiana during Eden (early Cincinnatian) time but lingered in the Ohio Basin which, in this period, included southeastern Indiana. The maximum recession took place during Maysville time, and the seas began once more to advance in early Richmond time. The transgressive sea gradually proceeded westward covering all of Indiana and entering Illinois where, during Maquoketa time, it joined a sea from the northwest, which had invaded Iowa and northwestern Illinois (Savage, 1924, p. 425).

Figure 5, an isopach map of the Cincinnatian series in Indiana, is based on well samples and driller's logs and shows thicknesses greater than 800 feet around the Cincinnatian outcrop region in southeastern Indiana. The section thins west, southwest, and northwest across Indiana to a minimum of less than 300 feet along **the Illinois boundary.**

The Cincinnatian series (Pls. 1, 2, and 3) is composed of three lithologic units, the lower shales, the middle shales and limestones and the upper, shaly fossiliferous limestones. The lower shale unit remains fairly constant, ranging from 200 to 400 feet in thickness. The middle and upper units, however, range from 100 to 500 feet in thickness and definitely thin to the northwest, west, and southwest. The writers do not mean to suggest that these lithologic units be correlated temporally. The lower shale unit in southeastern Indiana may correspond roughly to the Eden shale, but this same lithologic unit may be late Maysville in western Indiana, and represent Richmond time in Illinois. Rather, these lithologic units record the progress of a transgressive sea and, therefore, transcend time boundaries.

During most of the Cincinnatian epoch, southeastern Indiana was part of the Ohio Basin. Only in late Richmond time did the Cincinnati Arch begin to take form. The first differential movement, subsidence of the Eastern Interior Basin and possible upward movement of the initial arch (Switzerland, Ohio, Dearborn, Ripley, and Franklin Counties), took place at the end of Saluda time. The Whitewater beds were deposited disconformably upon the slightly eroded surface of the Saluda formation. The initial arch was eroded again during or at the end of Whitewater time. Only a foot of Whitewater is present at Madison, Jefferson County, but in Wayne County, 60 miles to the north along the crest of the present arch, the Whitewater is 80 feet thick.

The Elkhorn beds comprise the youngest formation of the Richmond group in Indiana. These beds overlie the Whitewater beds in Wayne and Fayette Counties and there attain a thickness of 50 feet. The Elkhorn formation thins rapidly southward and disappears about halfway to the Ohio River. Either the Elkhorn beds were not deposited across the arch in late Richmond time or were eroded before Silurian deposition took place. The Saluda, Whitewater, and Elkhorn beds dip northward along the axis of the arch, indicating either pronounced deepening of the basin north of Wayne and Fayette Counties or uplift of the initial arch in the southern portion of the arch region which produced tilting on the northern flank. After the emergence of the initial arch in late Richmond time, a general withdrawal of the seas took place, probably leaving most of North America as a low-lying land mass.

LOWER SILURIAN SEAS

Early in the Silurian, the seas again invaded the North American continent, probably first from the south into the Mississippi embayment region. Apparently the region was unstable during the first stages and had fluctuating shore lines. The sea advanced and retreated several times before it spread over the surrounding land masses and attained its maximum extent during Brassfield time.

The Orchard Creek shale of southwestern Illinois and southeastern Missouri, the oldest Silurian formation in the Mississippi embayment region, rests unconformably upon the Thebes sandstone (Richmond age) and carries both late Richmond and early Silurian fauna. The Orchard Creek is a shale which contains intercalated beds of limestone in the upper portion. These beds locally grade upward into the Girardeau limestone. The Girardeau has a restricted outcrop area and disappears to the north where the Edgewood limestone rests unconformably upon the Orchard

Creek shale. The Edgewood limestone is unconformable with the formations above and below. During the time of its deposition, the sea had spread northward, covering northern Illinois, Iowa, and probably northwestern Indiana and Michigan. Continued expansion of the sea culminated in late Brassfield time, when the sea extended from Oklahoma to Michigan, covering northern Arkansas, southeastern Missouri, Tennessee, Kentucky, Illinois, Indiana, and western Ohio.

The lithologic facies of the Brassfield in the Little Saline Creek area, Missouri, can be divided into three units (Ball, 1939, p. 119): a basal chert; a middle limestone and chert carrying glauconite; and an upper, gray to pink, crystalline limestone. In subsurface, the cherty layers can be traced eastward across Illinois and Indiana to the western flank of the Cincinnati Arch, thence northward through Indiana into Michigan. The upper, gray to pink, crystalline limestone crops out high on the flank of the Cincinnati Arch in southeastern Indiana. Apparently the transgressive Brassfield sea first covered the low-lying land area surrounding the Cincinnatian Arch and finally covered the arch before withdrawing in late Albion time.

CLINTON SEAS

Osgood-Laurel sea.—A general withdrawal of the seas took place at the close of the Brassfield, leaving most of Indiana as a land mass during early and middle Clinton times. The sea may have lingered in northeastern Indiana throughout this period and transgressed southward, covering all of Indiana in early Rochester time. The Cincinnati Arch was near sea level throughout the Rochester and was probably elevated several times, causing periodic nondeposition and perhaps erosion on the crest. Continuous deposition took place in the surrounding seas.

The Osgood-Laurel section rapidly thickens down the northwest flank of the initial arch (Pl. 1). The Grant County well (no. 11) has a normal section of the Osgood-Laurel, 145 feet thick. Northward in Wabash County (well no. 12), the section has thickened to 260 feet, and a well drilled still farther north in Whitley County (sec. 3, T. 30 N., R. 8 E.) shows the greatest known thickness of 355 feet. The abnormal thicknesses of the Osgood-Laurel section in this northern region may have resulted from continuous deposition from Brassfield to Rochester time.

Outcrops of the Osgood formation in southeastern Indiana consist of alternating limestones and shales. This outcrop area which includes eastern Clark, Jefferson, and southern Ripley Counties, is located high on the western flank of the initial arch and records the unstable condition of the arch at that time. A break in sedimentation took place at the end of Osgood time, and the Laurel limestone was deposited disconformably on the Osgood. The Osgood-Laurel section thickens northward off the flank of the initial arch and westward into the Eastern Interior Basin. The rocks of this section are basically limestones and dolomites, and a sedimentary break has not been found within them.

Schuchert, in his *Paleogeography of North America* (1910, pls. 66 and 67), showed a land barrier across middle Indiana separating the northern and southern Silurian seas. In his *Stratigraphy of the Eastern Central United States* (1943, p. 581), Schuchert still clung to the idea of a barrier dividing the Silurian of northern Indiana into one succession of formations and the Silurian of southern Indiana into another. Cumings and Shrock also postulated a barrier to separate their northern Indiana formations from the well-established southern formations. Cumings and Shrock (1928a, p. 166) stated: "Did the Louisville sea transgress the Indiana barrier? . . . The authors believe that the southern and northern provinces were connected in Louisville time because of the striking similarity of the Louisville and Liston Creek corals."

Because of the intervening glacial drift, the Silurian formations of southern Indiana cannot be traced on the surface into northern Indiana. In subsurface, however, the formations can be traced into the northern region. The formations consistently thicken away from the arch, northwest, west, and southwest. The postulated barrier would have to be composed of older rocks, Cincinnatian or Clinton, with the northern and southern Silurian formations feathering out against it. If the barrier were formed of arched Cincinnatian rocks, contours on the top of the Trenton limestone would reflect an upwarping in central Indiana with an east-west axis. Such a structure does not exist on the Trenton limestone (Logan, 1931, fig. 14). If the Cincinnatian rocks were elevated to sea level or near sea level in the barrier region while deposition was taking place, the section would be thinned by nondeposition. If the Cincinnatian rocks were elevated above sea level during Silurian times to form the barrier, the section would be thinned by erosion. The Cincinnatian isopach (Fig. 5) shows no such thinning of the Cincinnatian rocks in the central region. If the arching occurred during Clinton time, a thinning of the Osgood-Laurel section would occur in the region. The Stratigraphic cross section A-A′ of Plate 1 shows no thinning of this section. On the contrary, a decided thickening takes place northward away from the initial arch. Furthermore, the upper formations do not feather out on the flanks of the assumed barrier. The writers were unable to find any evidence of the existence of an east-west barrier in central Indiana during Silurian times.

Waldron sea.—Further upwarping of the Cincinnati arch occurred at the close of Laurel time. As the initial arch was raised above sea level, silt and shale from the arch were deposited on the western and northwestern flanks and out into the deeper water. A lithologic break, siltstone upon limestone, resulted. The western flank was near sea level, and frequent shifting of the shore line occurred. Continuous deposition took place northwest, west, and southwest. In favorable localities away from the muddy banks, colonies of marine life flourished, building reefs higher and higher to keep pace with the gentle subsidence of the basin and deepening of the water. These conditions persisted until the close of Rochester time.

The Waldron shale is missing from the Silurian sequence in scattered outcrops on the western flank of the arch. The thickness of the Waldron ranges from a few inches to 20 feet in the outcrop belt, but increases in subsurface to 85 feet westward and more than 120 feet northward. Evidently the arch was a fluctuating, low-lying land mass where the sediments were eroded, dumped, shifted, and redeposited from time to time. Farther out in the sea thick sections of silt accumulated.

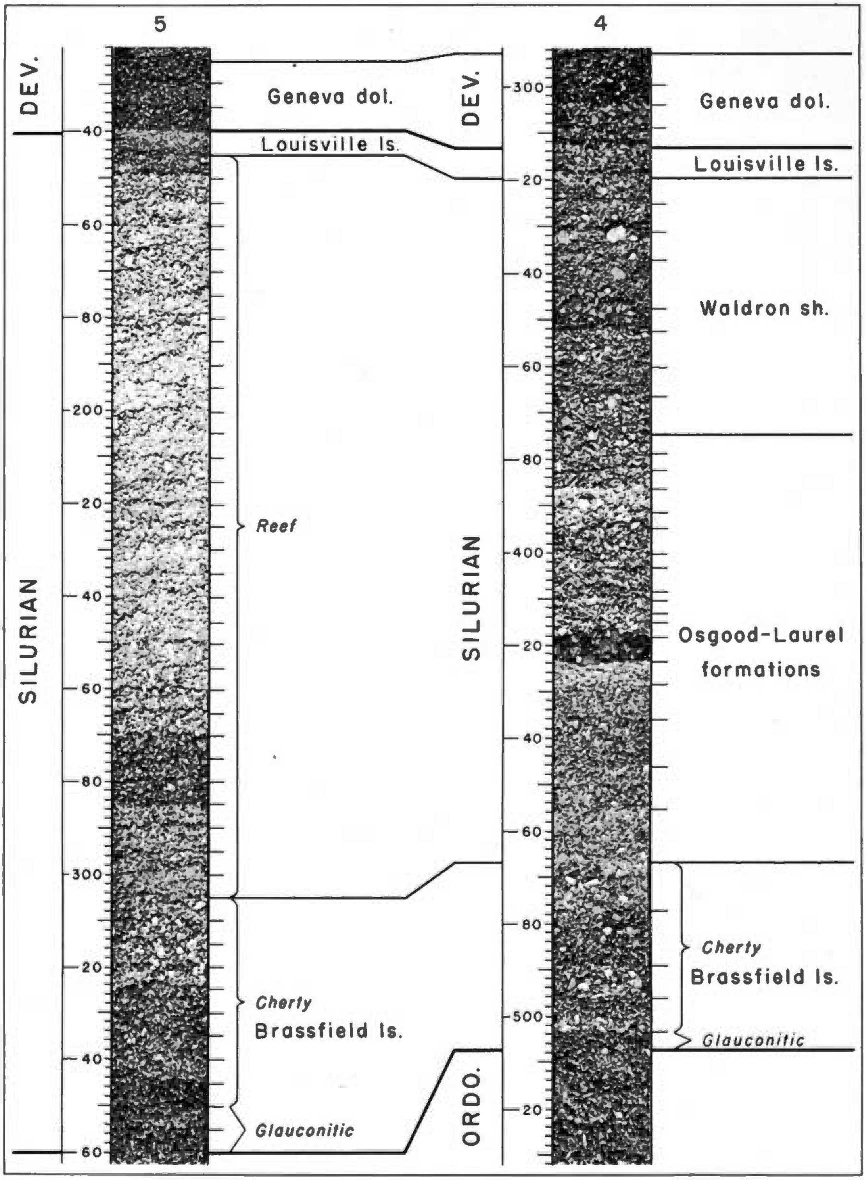
Cumings and Shrock (1928b, p. 611) located 70 Silurian reefs in northern Indiana, the majority of which are situated along drainage channels where streams have cut through the glacial drift and the weaker bed rock formations. These reefs crop out as far south as Noblesville, Hamilton County. Prolific reef building occurred in the Silurian seas of Indiana, and probably many more reefs would be uncovered if the area were stripped of glacial drift. Additional reefs have been penetrated by wells, not only in the reef outcrop area, but also farther south where the reef-bearing strata now lie beneath thick sections of younger rocks.

Plate 4 is a photograph of the Silurian sections of two wells in Marion County.[1] The distance between these wells is only 5 miles. The Geneva dolomite marker, a thin section of Louisville, and the Brassfield chert beds are readily traceable from one well to the next. In well no. 4, a normal succession of Waldron silts and Osgood-Laurel beds occurs, but in well no. 5, the cream, porous dolomite of a reef 160 feet thick makes up this part of the section. The dolomite is uniform from top to bottom, except for 15 feet of gray dolomite near the bottom of the section. The intercalation of inter-reef facies in the reef proper is a normal occurrence in vertical reef sections. Reefs are irregular in growth, and wedge-shaped layers of inter-reef material sometimes extend almost to the solid reef cores. This is an excellent example of a reef interrupting the normal sequence of deposition as found in subsurface geology.

Cumings and Shrock maintained that reefs began to grow in Mississinewa time and extended into Liston Creek and Huntington times, but they reject the possibility of earlier reef growth. They said (1928a, p. 62): "The known reefs . . . all have their roots in the upper 100 feet of this formation (Mississinewa). We are not certain that we have ever seen the true base of a reef, hence nothing can be stated with certainty about the horizon at which the reefs began to grow. It is not likely, however, that they extended below the upper 100 feet of the formation." Reefs found in wells sometimes interrupt the entire Mississinewa sequence. In well no. 5 (Pl. 4) the reef extends from the bottom of the Osgood to the top of the Waldron.

Conditions were favorable during Niagaran times for extensive reef development. Reefs grew in southern, central, and northern Indiana alike, beginning at any horizon where favorable conditions prevailed and continued to grow until the reef building organisms were destroyed by environmental changes. Higher on the western flank of the arch, pockets of fossils are found in Waldron outcrops. Perhaps colonies of organisms attempted to build reefs here but were destroyed in their initial stages by wave action and shifting shore line conditions. The surviving marine life apparently moved on to better localities while the weaker organisms, especially the younger ones, were buried in the sediments and preserved.

[1] Mounted well samples show the normal sequence of formations in one well (Pl. 2, well no. 4) and the interruption of sequence by reef structure in the other (Pl. 2, well no. 5). Scale on left shows depth from surface in feet. Marks on right show amount of footage covered in drilling sample.



PHOTOGRAPH OF SILURIAN SECTIONS OF TWO WELLS IN MARION COUNTY

SUMMARY

Subsurface studies reveal additional information about the Silurian formations of Indiana. The new interpretations and correlations are made after careful consideration of previous surface work and outcrop data. The following conclusions appear to be justified.

The Cincinnati Arch first appeared at the end of Richmond time and greatly influenced subsequent deposition.

The early Silurian seas entered Indiana from the southwest and covered the Cincinnati Arch in late Brassfield time. The cherty beds of early Brassfield age can be identified in subsurface throughout most of the state.

No barrier existed between northern and southern Indiana during Silurian times. Silurian formations can be traced in subsurface from southern Indiana across the intermediate area into northern Indiana.

The series of rocks labeled Osgood-Laurel in the stratigraphic cross sections thickens from the southern outcrop area into the northern outcrop area where it forms a thick sequence of limestones and dolomites older than Mississinewa in age.

The Waldron shale continues without interruption into the northern area where it was named the Mississinewa shale. This fact is substantiated by stratigraphic position, by comparison of outcrop macro-fossils, and by surface and subsurface lithology. The Waldron also extends westward down the flank of the arch into the Eastern Interior Basin and, therefore, is a good stratigraphic marker over a large area.

Coral reefs frequently interrupt the normal succession of Niagaran subsurface strata in Indiana.

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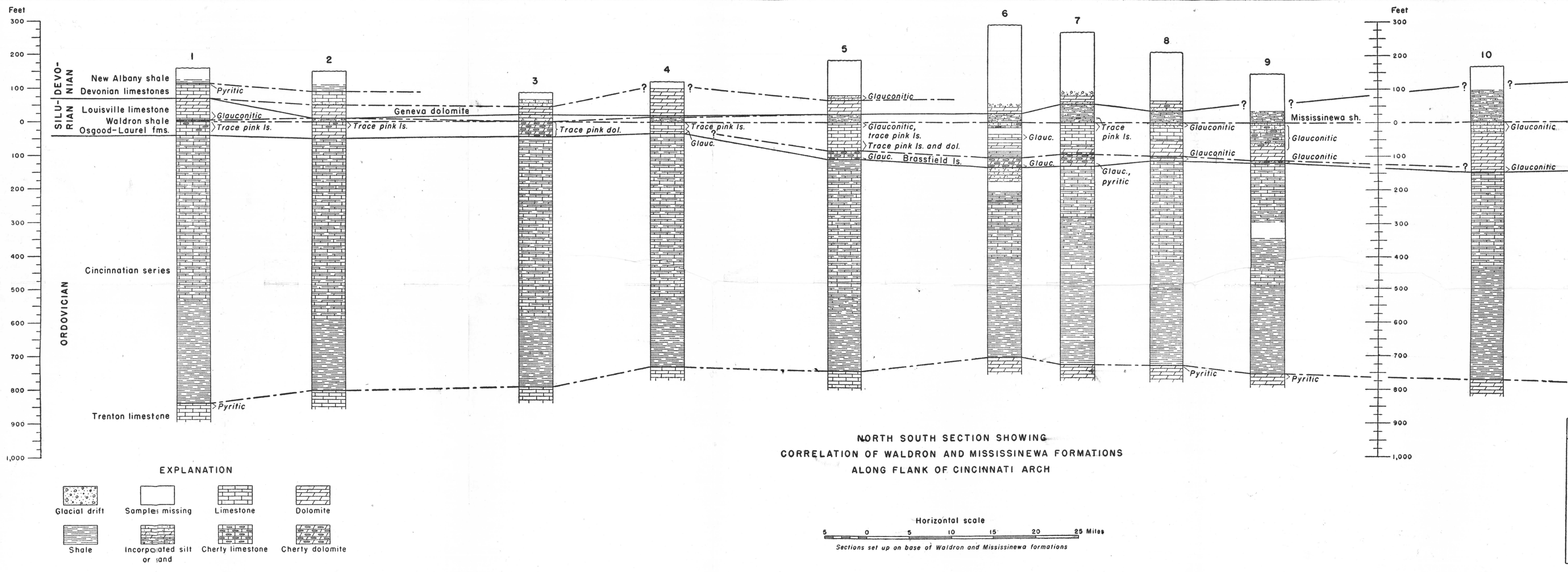
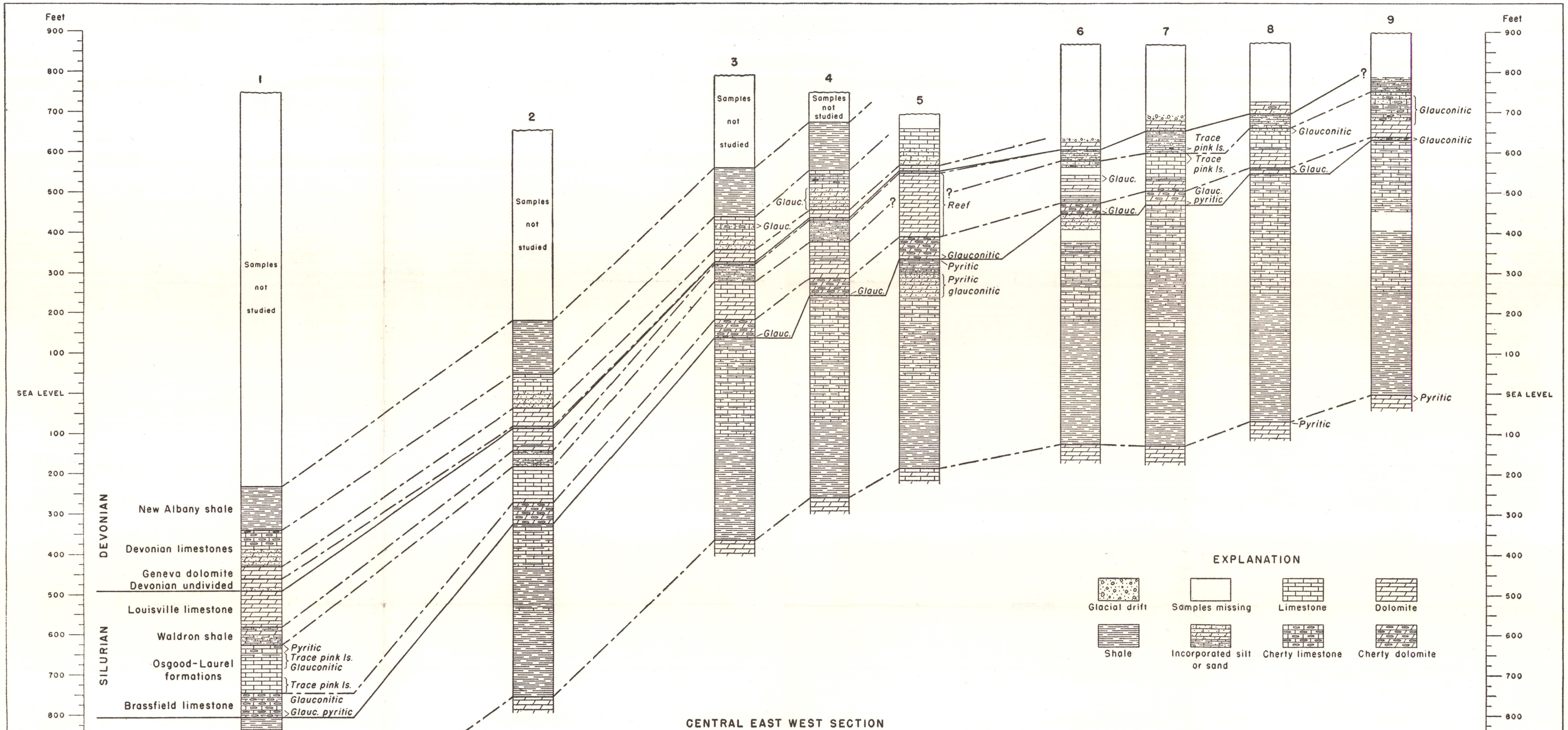


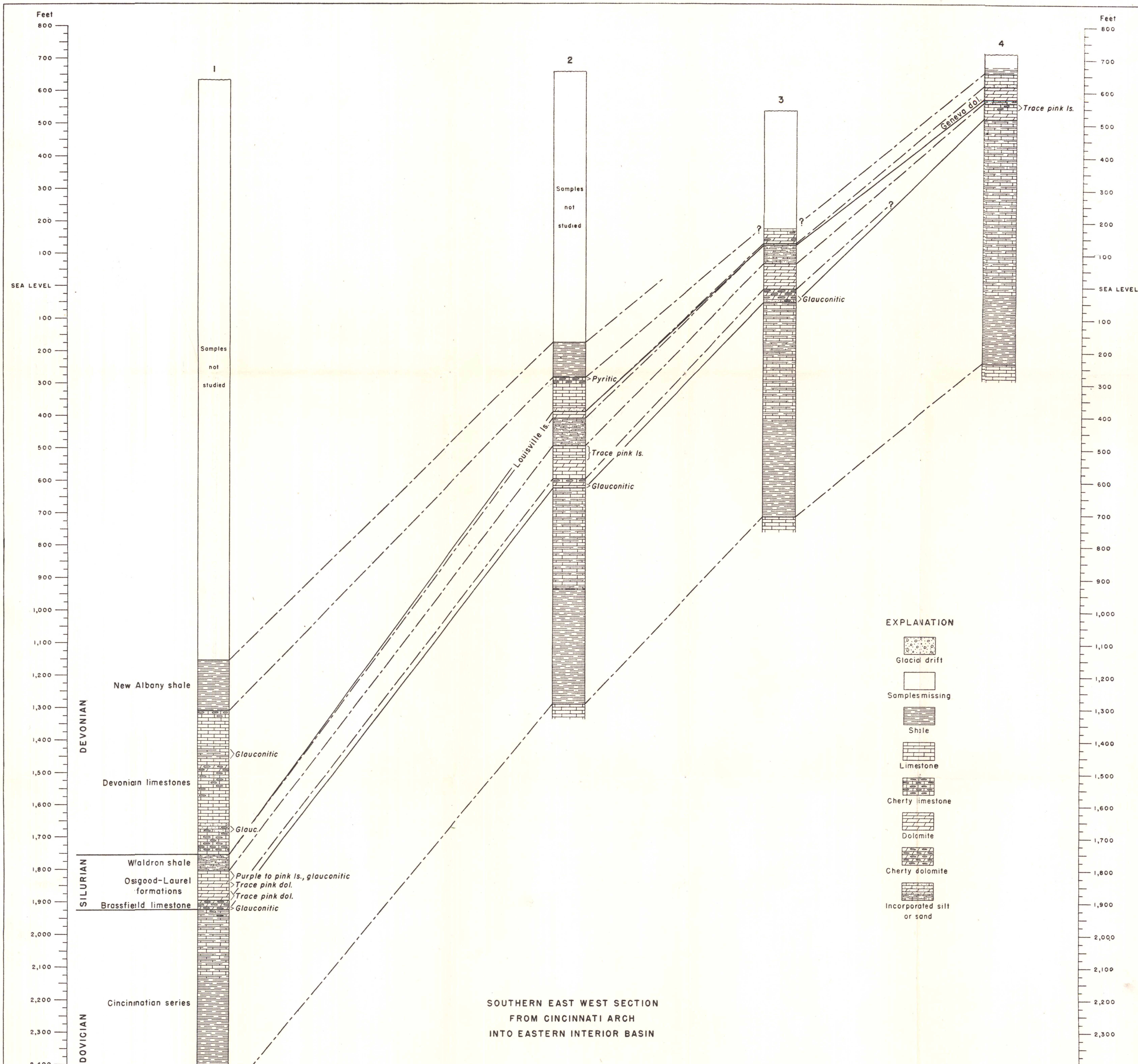
Well Section	Name	Section	Township	Range
1	J. E. Johnson No. 1 by Comisky Oil Associates	23	5N	7E
2	E. L. Phillips No. 1 by The Ohio Oil Company	30	7N	8E
3	Frank Fishel No. 1 by Haw Creek Oil and Gas Co.	15	10N	7E
4	Lafayette Peck No. 2 by St. Paul Natural Gas Co.	34	12N	8E
5	Nora Bowman No. 1 by Phillips and Kost	26	14N	6E
6	William F. Kleiman No. 1 by J. W. Adams	22	16N	5E
7	Ira Brock No. 1 by Chafee	6	16N	6E
8	Fannie L. Andis No. 1 by Art Laws	24	17N	6E
9	McCallister No. 1 by Laws	25	18N	7E
10	W. D. Montgomery No. 1 by Frontier Pet. Corp.	8	21N	8E
11	C. Knight and others No. 1 by Reynolds	8	23N	8E
12	Maude Barnette No. 1 by Joseph Minneci	23	27N	5E

STRATIGRAPHIC CROSS SECTION A-A′



Well Section	Name	Section	Township	Range
1	Ross P. Wells No. 1 by Stanoline Oil and Gas Company	15	14N	5W
2	G. R. Brown No. 1 by C. E. Jefferson	16	13N	1W
3	Hobbs Nursery Farm No. 1 by Griffin Oil Company	17	15N	2E
4	Samuel Ashby No. 1 by Eagle Creek Oil Company	26	16N	2E
5	Indianapolis Water Co. No. 3 by White River Oil and Gas Corp.	15	16N	3E
6	William F. Kleiman No. 1 by J. W. Adams	22	16N	5E
7	Ira Brock No. 1 by Chafee	6	16N	6E
8	Fannie L. Andis by Art Laws	24	17N	6E
9	McCallister No 1 by Laws	25	18N	7E

STRATIGRAPHIC CROSS SECTION B-B′



SOUTHERN EAST WEST SECTION
FROM CINCINNATI ARCH
INTO EASTERN INTERIOR BASIN

Well Section	Name	Section	Township	Range
1	De Laisse No. 1 by Central Pipe Line Company	25	4S	3W
2	E. Cauble No. 1 by Washington County Dev	10	1N	3E
3	Terkhorn No. 1 by Aetna	6	4N	5E
4	E. L. Phillips No. 1 by The Ohio Oil Company	30	7N	8E

STRATIGRAPHIC CROSS SECTION C-C′