THE SILURIAN CORAL REEFS OF NORTHERN INDIANA AND THEIR ASSOCIATED STRATA.

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The Silurian (Niagaran) rocks of northern Indiana are characterized at numerous localities by unusual dips, indicating cone, dome or quaquaversal structures. The origin of these peculiar structures with their highly inclined beds has long been a matter of controversy. Associated with these structures is a definite stratigraphic sequence, consisting of a number of distinct lithologic units.

It is the purpose of the present paper to present evidence that these structures are ancient coral reefs; and to propose names for the various units of the associated stratigraphic sequence.

Summary of the Literature.

The earliest mention of these structures was by Richard Owen (1862, 98), but no theory was advanced to explain their origin. Collett (1872, 307) accounted for the high dips at Delphi by "profound cross-bedding"; but said of the quarry near Kentland (1883, 59), where dips as high as 90 degrees are present: "This quarry is a mystery". Gorby (1886, 228-241) suggested a narrow anticline extending across the State, to which he gave the name "Wabash Arch". In this proposal he was heartily seconded by Maurice Thompson (1889, 41-53; 1892, 177-186), who emphatically stated that Gorby's conclusions were absolutely correct.

Phinney (1891, 653) was the first geologist to study the structures in detail. He presented evidence against Gorby's hypothetical "Wabash Arch", and suggested for the first time the coral reef theory of their origin. Later Elrod and Benedict (1892, 200-238; 1894, 22) spoke of the dome-like structures in Wabash County, calling the rock composing them "Picket Rock", and accounting for the high dips as a variety of cleavage, simulating stratification planes. Ashley and Siebenthal (1899, 190) mentioned high dips in the vicinity of Kentland and attributed them to "volcanic or other agencies" which "had produced an upheaval of a kind seldom found in nature".

These high dips at Kentland, sometimes as much as 90 degrees, are due to faulting and associated crumpling, as outcrops now visible clearly show, and are not related in origin to the dome-like structures found elsewhere in the northern part of the state.

Elrod (1902, 207) in discussing the unconformities in the Niagaran rocks of Indiana, mentioned a number of high dips in several northern counties; but said nothing of their origin. Blatchley (1904, 229, 235, 237) mentioned high dips as due to true upheaval, and quoted L. C. Ward, who had stated that the dips at Huntington pointed to "a greatly complicated set of folds or faults, or both". Kindle (1902, 221-224; 1903,

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459-468; 1904, 411) suggested that the structures may be analogous in origin to the mud-lumps of the Mississippi Delta. Ward (1906, 216) realized the complexity of the high dips near Kentland, stating: "It is a synclinal fold, much broken in the folding". That there has been faulting at Kentland is now perfectly clear. Cumings (1922, 449) considered these high dips, especially at Kentland, where the Ordovician is brought to view, as genuinely vulcanic or disastrophic in origin, and suggested the possibility that cryptovolcanic action might be responsible for the dome-like structures.

THE ASSOCIATED STRATIGRAPHIC SEQUENCE.

Associated with the dome-like structures of northern Indiana, and in part contemporaneous with them, is a series of strata consisting of five lithologic units or formations.

Mississinewa shale. The basal formation of this mass is a drab to bluish-gray, calcareous shale. It outcrops in the west part of Huntington, just west of the tourist camp; at a number of points along the Wabash River from Huntington to Lagro; in the vicinity of Lagro at the base of the Hanging Rock; at the south end of the bridge over the Salamonie River just west of Hanging Rock; at the Narrows upstream a short distance from the outcrop just mentioned; northeast along the Wabash Railroad; southwest along the Wabash River, and along Lagro Creek; one and one-half miles northwest of Warren along the Salamonie River; at a number of places between Lagro and Wabash; along the small stream in the tourist camp and city park in the west part of Wabash; on the flanks of the "Wabash Dome"; in the deep road cut on the south side of the river and along the river bluff in South Wabash; along the Mississinewa River at Marion, Jalapa, Mt. Vernon, Somerset, Maple Grove, Morgan's Cliff and Red Bridge; along Liston Creek in Wabash County; at low water level in the Wabash River opposite the mouth of Little Pipe Creek, one mile west of Peru; at the base of the Kokomo limestone in the Markland Avenue quarry in Kokomo; in quarries one mile east of Yorktown along White River; at Alexandria and vicinity; and in a quarry in the bank of White River one-half mile west of Anderson.

To this formation from the base of the yellow limestone above, downward as far as typical development continues, is given the name *Mississinewa Shale,* from the Mississinewa River, along which it is well exposed and typically developed at or near river level at the localities mentioned above.

Owing to its slight dip, no one exposure shows both the top and the bottom of the formation. In fact the true base of the formation has never been seen by the writers. The greatest observed thickness is at Wabash, where 75 feet are exposed. Here it outcrops on the south side of the river in the bed of the stream, some 300 feet downstream from the bridge on Wabash Street, and is found in the bluff, 75 feet above the river. Outcrops elsewhere show from one to 50 feet. Elrod and Benedict, on the basis of well logs, reported 114 feet at Lagro; and stated that the formation is probably as much as 250 feet thick.

The Mississinewa shale includes the "thick-bedded argillaceous limestone" and "hydraulic limestone" of Collett (1872, 326) and the equivalent formations: the "laminated shale," "cement rock," and probably the "hydraulic limestone" of Elrod and Benedict (1892, 197, 201-203), who gave an excellent description of the way the formation weathers, and also described its lithologic characteristics. It is unlikely, however, that they ever realized the true relations of the formation to the dome-like structures.

Below are given four chemical analyses of samples of this formation from widely separated localities.

	Yorktown	Somerset	Wabash	Lagro
Loss on ignition	26.38	29.81	25.44	26.70
Silica	30.28	30.60	30.89	31.06
Alumina	14.07	16.72	13.21	12.16
Ferric oxide	5.80	2.48	5.69	3.02
Titanium oxide	0.73	....	0.68	0.64
Lime (CaO)	15.90	14.34	15.70	17.16
Magnesia	5.72	6.05	6.82	8.85
	98.88	100.00	98.43	99.59

The striking homogeneity of the formation is shown by comparing the above analyses. They show little more than four and one-half per cent difference in any one constituent. This fact is significant when one notes that Yorktown and Lagro are more than 50 miles apart. It is very probable that this marked homogeneity is characteristic of the shale over its entire outcrop area.

A second fact to be noted is the high percentage of argillaceous material, alumina (Al_2O_3), ferric oxide (Fe_2O_3), and silica (SiO_2). Since the argillaceous material constitutes 50 per cent or more of the samples, it is seen that the formation is a calcareous shale or argillaceous limestone (calcilutyte). In view of the fact that the formation, when weathered, splits into laminae like a typical shale, and has no sharp bedding planes and joints, it is deemed best to speak of it as a calcareous shale rather than as an argillaceous limestone.

In fresh outcrops the formation appears very massive; but on weathering it changes from bluish-gray to drab or buff in color, and breaks up into large irregular blocks with conchoidal fracture, and finally into thin slabs and flakes characteristic of weathered shale.

In the quarries near Yorktown a Graptolite (*Dictyonema*) fauna is found associated with Brachiopods, Gastropods, Trilobites and Cephalopods. Strap-like markings, probably plant remains, are also quite abundant. Specimens of Graptolites have also been found at Wabash in the shale on the flanks of the Wabash Dome and in the deep road cut south of the river; along the Mississinewa River near Double Cliffs; in the shale at the base of the Kokomo limestone in the Markland Avenue quarry in Kokomo, where they are associated with abundant specimens of

Atrypa reticularis and other common Niagaran fossils; and at Markle, where they occur in great abundance in a formation that greatly resembles the Mississinewa shale, but has not yet been identified with certainty.

Red Bridge Limestone. Lying above the Mississinewa shale is a bed of reddish-yellow colored, impure, argillaceous limestone, varying from six inches to six feet in thickness. It outcrops one mile west of Huntington, along Little River; in a ravine one-half mile east of Lagro; along the bluff in South Wabash; along the Mississinewa River at Mt. Vernon, Somerset, Maple Grove, and Red Bridge; and along Liston Creek in southwestern Wabash County, where it is responsible for the Liston creek falls.

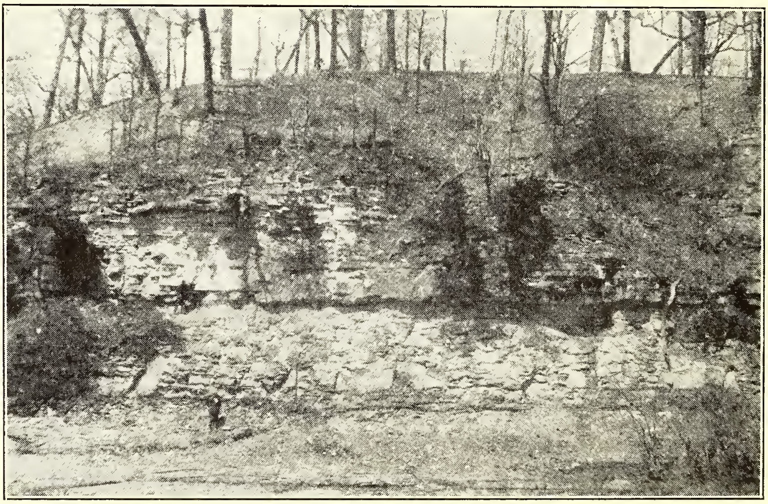

Fig. 1. View of the Red Bridge section. The lower shaly formation is the Mississinewa shale. The massive five-foot bed is the Red Bridge limestone, which is in turn overlain by the Liston Creek limestone.

To this bed is given the name *Red Bridge Limestone,* from the village of Red Bridge on the Mississinewa River in southwestern Wabash County, where it is well exposed in a high bluff on the north bank of the river west of the bridge. In this excellent outcrop both the underlying and overlying formations are beautifully exposed, as shown in figure 1. The Red Bridge limestone at the type section is from three to five feet thick. Its normal thickness is about two feet.

The formation is lithologically different from both the underlying and overlying formations. Its color also is distinctive. Weathering changes the color from reddish-yellow to yellow, and reduces the bed to a fine sand or silt. It is very persistent in its lithologic characteristics and thickness throughout its outcrop area, and is always found between the underlying Mississinewa shale and the overlying cherty limestone. For this reason it forms an excellent key horizon and is very useful in structural determinations.

As yet no fossils have been found in this formation, although careful search has been made at several localities. It is very doubtful if either Collett or Elrod and Benedict recognized this horizon, since no mention is made of it in their reports.

Liston Creek Limestone. Lying above the Red Bridge limestone is a series of thin slabby limestone beds, with considerable associated chert. This formation is seen outcropping in a ravine one-half mile northeast of Lagro; along Charley Creek in the west part of Wabash; along the bluff in South Wabash; one-half mile west of Rich Valley in an abandoned quarry; along the Mississinewa River at Mt. Vernon, Somerset, Maple Grove, Morgan's Cliff, Red Bridge, and Seven Pillars or "The Cliffs"; and along Liston Creek.

Fig. 2. View of Liston Creek Falls. The water is flowing over the Red Bridge limestone. The shaly formation under the falls is the Mississinewa shale. The Liston Creek limestone overlies the Red Bridge limestone and is 26 feet thick.

To this cherty formation, 26 feet thick in the type section, is given the name *Liston Creek Limestone*, from Liston Creek in southwestern Wabash County, along which are well developed outcrops. Only a portion of the formation can be seen in any of the sections. Its top is unknown. Its relation to underlying strata is shown in figure 2.

The lower portion of the formation is slabby and contains less chert than the upper part. In the upper part there are often thin layers or beds of chert, which seldom exceed four inches in thickness. Chert nodules are also present in the thin limestone layers.

Fossils are found sparingly throughout the entire formation; and there is a thin zone near the middle which contains large numbers of Bryozoa.

This formation has been used throughout Wabash and Miami counties in the region of its outcrop, for road material. Good exposures are often found in abandoned quarries; for example, in South Wabash; one-half mile west of Rich Valley; and along the Mississinewa River. Quarrying is never carried deeper than the Red Bridge limestone, for the latter is useless for road material. Therefore in all abandoned quarries, from which the Liston Creek limestone has been taken, the Red Bridge limestone will be found to form the floor of the quarry.

The Liston Creek limestone is the equivalent of the "paving stone" of Collett (1872, 326) and the upper part of the "quarry stone" or the "Wabash Flagging" of Elrod and Benedict (1892, 197).

In a few outcrops a druzy brown or yellow very fossiliferous dolomite is associated with the Liston Creek. The exact position of this formation is not certain. It may represent an overlying formation distinct from the Liston Creek, or it may be only a local development of it, found only adjacent to the coral reefs. This brown formation is found in South Wabash, one-eighth of a mile east of the deep road cut, in an abandoned quarry; in an abandoned quarry north of Mt. Vernon on the north bank of the Mississinewa River; and about a mile upstream from Peoria along the south bluff of the Mississinewa River. Each of these exposures is near the flank of a coral reef, and it is likely that the prolific fauna found in the formations represents the inhabitants of the waters near the reef. Further work will be necessary before the exact status of the formation can be determined.

The Kokomo Limestone. Unconformably overlapping the Niagaran sequence above described is the Kokomo limestone of Foerste (1904, 33), which is probably of Cayugan Age. This formation consists of 60 feet of finely laminated impure limestone, more argillaceous in the lower portion and more calcareous in the upper portion. Alternate beds of earthy material and purer limestone are characteristic.

This formation is exposed in several quarries in Kokomo, one on Defenbaugh Street, and one on West Markland Avenue, the last being the best exposure in Kokomo at the present time; in two abandoned quarries a mile southwest of Kokomo; one mile west of Peru opposite the mouth of Little Pipe Creek, where it unconformably overlies the Mississinewa shale; one and one-half miles west of Peru along the newly excavated drainage canal; along several small streams west of Peru, on the south side of the Wabash; in the lime quarry three miles east of Logansport; at Kenneth on the Pennsylvania Railroad, six miles west of Logansport, where it is beautifully exposed in an active quarry; at Big Blue Hole Quarry, now abandoned, three miles west of Logansport; and in the south bank of the Wabash opposite Kenneth. Its characteristics have been noted elsewhere and need not be repeated here.

The Kenneth Limestone. Resting upon the Kokomo limestone is a very cherty limestone formation from one to 20 feet thick in the outcrops. The base of this formation is exposed in the Defenbaugh and Markland Avenue quarries in Kokomo. Greater thicknesses are seen in the Big Blue Hole and Kenneth quarries, and in the vicinity of the latter place.

This formation is appropriately called the *Kenneth Limestone*, from the fine exposures in the great quarries at Kenneth Station, and in other outcrops in the immediate vicinity. The top of the formation is not known. Kenneth Station is selected as the type locality because the quarries and other outcrops are in the upland well above drainage, and can never be totally obscured by water, as is now the case with the type section of the Noblesville.

Certain peculiar structural relations of this cherty limestone and the underlying Kokomo, seen in the Markland Avenue quarry at Kokomo, indicate the possibility of an unconformity between the two. Further work will be required, however, to determine this point.

It will be noted that in the preceding discussion no definite thickness has been assigned several of the formations. The reason is obvious. The formations occur in a deeply drift-covered region of little relief, where outcrops are few, and usually along the beds or low banks of streams, or in shallow quarries. There is also very little dip to the main sequence above described. Occasionally the coral reefs, because of their greater resistance to erosion, give rise to structural hills, on the flanks of which may occur small outcrops of the stratified beds. Few outcrops show both the bottom and the top of a formation. In fact only the Red Bridge and the Kokomo formations have been seen in their entirety in any one outcrop. Of the other formations only the top or the bottom has been seen. It is obvious, therefore, that in naming these formations it was necessary to select a place where as much as possible of the typically developed formation was present, and also where there was a minimum likelihood that the outcrop would ever be obscured.

Finally attention should be called to the fact that no mention has been made of Kindle's Noblesville and Huntington formations (1904, 407-408). The type section of the Noblesville is now almost completely hidden by the water of the new city reservoir on the river above Noblesville; and it is very difficult to get hold of enough material to indicate what the significant lithologic characteristics and fauna of this formation are. The Huntington formations are in a similar situation since the old quarries at the type locality are nearly full of water and the rock can be seen only around the edge. The fate of these two type sections should be a warning to geologists to select type sections with a view to the future. Work now in progress will ultimately indicate the validity and stratigraphic position of these two formations. For the present it seems best to regard them as phases of the reef rock next to be described.

THE CORAL REEFS.

As promised in the introduction, evidence will now be presented indicating that the dome-like structures found in northern Indiana are fossil coral reefs. These structures will therefore, in the balance of this paper be spoken of as *reefs*.

General characteristics. These reefs are in general dome-shaped masses of calcareous material having a massive unstratified core composed partly of the remains of Stromatoporoids, corals, Bryozoa and other reef-building organisms, and thickly set with small irregular pockets of calcite. A distinctive fauna characterizes the reefs. This central core will hereafter be spoken of as the *reef proper* or *core*.

Adjacent to this central unstratified mass or core, are found well stratified thick beds of dolomite leaning against the core at high angles, but changing to lower dips as they extend away from the core toward the periphery of the reef-dome, and finally assuming a horizontal position and interfingering with or intergrading into the surrounding sediments of the normal stratigraphic sequence. The latter represents the deposits of the level sea-bottom of the inter-reef areas. Its chief representative is the Mississinewa shale, already described.

The reef proper or core. The reef proper is the central unstratified mass against which the inclined strata were deposited, and represents the direct constructive work of the reef building organisms. In the reefs open to observation in northern Indiana the exposed part of the reef proper is never over 45 feet in height, and seldom exceeds 300 feet in diameter. Since, however, neither the true top nor base of any reef has been seen, the total height of the reefs is not known. It is certain that the true height is much greater than the figure stated above.

The rock composing the reef proper is a hard, gray to pink, ragged, porous dolomite, containing many pockets of calcite, and in some cases numerous poorly preserved Stromatoporoids, corals and other fossils. It is very resistant to erosion, so that the reefs often form structural hills, such as may be seen at many points along the Wabash River. It breaks into jagged splintery pieces. This rock has been called "Picket Rock" by the people of the region. (See Elrod and Benedict, 1892, 197.)

Calcite occurs in abundance both in cavities or pockets, along the slickensided surfaces (joints and fault planes), and in fault breccias. Where it occurs in pockets it probably represents original vacuities in the reef or occupies cavities produced by the destructive solution of fossils, especially corals. The fossils of the core are nearly always very poorly preserved and often quite unidentifiable.

Slickensides constantly characterize the reef proper. The slickensided surfaces are often inclined at very high angles, 45 to 65 degrees, and may cause the center of the core to present the appearance of great cones set one over the other. It is probable that many of these slickensided surfaces represent joints and faults rather than bedding planes. Stylolites are abundantly developed along the slickensided surfaces and bedding planes, and as mentioned by Stockdale (1921, 54), extend vertically, and not normal to the surface on which they are found. These stylolites are, therefore, due to intraformational solution under the static pressure of the overlying rock, and were obviously formed after the solidification of the rock. Stylolites are especially well developed in the west end of the quarry one-eighth of a mile east of the deep road cut in South Wabash.

Typical exposures of the reef proper may be seen at the locality just mentioned; in the "Wabash Dome" at Wabash; at Georgetown; west of Logansport; and in the south bank of the Wabash River at Lockport.

The inclined beds surrounding the reef proper. Dipping sharply away from the core are highly inclined stratified beds of yellowish-gray to pinkish limestone and dolomite, which as they extend outward, thin rapidly, forming wedge-shaped masses that interfinger with the members of the normal stratigraphic sequence already described. These dips, being in all directions from the more or less cylindrical core, give rise to a quaquaversal structure, presenting the false appearance of upheaval.

The angle of dip of these beds varies from four or five degrees at the outer margin or periphery of the structure to as much as 65 degrees where they join the core. It is such extraordinarily high dips that have proved a stumbling block to nearly all investigators who have tried to explain the structures.

For example, Elrod and Benedict (1892, 222) say: "Compound bedding, conformation to irregular surfaces, and unequal shrinkage, either alone or in combination, are sufficient to explain the variations of the dip in true stratification, but fail to account for the phenomena where it exceeds twenty-five degrees. Some theory must be applied to the rocks in which a high angle dip is the most obvious feature." Kindle (1904, 404-405) states: "A serious objection to the coral reef theory is the frequent absence or scarcity of corals where the dips are the heaviest. Corals are not at all abundant in the Niagaran of this region. They have not been observed anywhere in sufficient abundance to form reefs. While inequalities in the sea bottom may be responsible for some of the smaller undulations in the strata, neither they nor 'offshoots of the Cincinnati Arch' appear to offer a satisfactory explanation of dips from 45 degrees to 75 degrees in the Niagara beds which the accompanying photographs show." One of these photographs referred to shows nearly vertical strata near Kentland. As already explained it is not germane to the present discussion.

Twenhofel (1926, 433, 526-528) says that the highest initial dip material may have, due to the angle of repose, is 41 degrees; but further states that the initial dip may be subsequently steepened by settling or slumping. One dip of 54 degrees, in the Shoonmaker quarry, near Wauwatosa, Wisconsin, is mentioned. (See also Grabau, 1903, 342). Grabau (1901, 176) describes and figures a coral reef near Alpena, Michigan, and says: "The strata dip away from the reef in all directions. At first the angle is 28 degrees, then it falls to 14 degrees, and then to 4 degrees, and finally to 2 degrees, the normal dip of the strata in the quarry." This structure could be closely duplicated in northern Indiana. Grabau (1903, 338-342) further mentions dips of from 30 to 40 degrees in the Alpena limestone of Michigan, and quotes Chamberlin, who mentioned: "The increase in thickness of the sedimentary layers toward the reef with which they finally merge". Grabau says: "Of forty-one slopes determined on the Bahama Islands, the lowest is 0 degrees, the highest 26 degrees 18 minutes. Seventy-five per cent of the slopes are below 10 degrees, while one-third of the entire number of determined slopes fall below 5 degrees."

"On the Keeling Islands on the other hand, only a few slopes below

10 degrees are recorded by Dietrich. Nearly half of the number lie between 30 and 43 degrees, one being as high as 63 degrees 21 minutes."

It is clear from the preceding quotations that slopes of 30 to 45 degrees are not uncommon on coral reefs, and that slopes as high as 63 degrees have actually been observed. High dips are, therefore, to be expected, rather than the contrary.

The paucity or absence of corals in these structures is not to be taken too seriously, since the greater part of many modern reefs often consists of the contributions of organisms other than corals, especially lime-secreting algae. In the Indiana reefs Stromatoporoids appear to have made the chief contribution, and their dolomitized remains are often extremely abundant in the reef core. In a few cases, as at Georgetown, Bluffton, and South Wabash, corals are common; but not abundant. Some of the abundant calcite has probably replaced some of the corals and other organisms. In the slightly inclined strata near the periphery of the reef, corals are often extremely abundant and very well preserved, as is the case at Bluffton and Huntington.

Slickensides are usually well developed in these inclined beds near the core, and occur along bedding planes, and probably along joints also. They are probably due to the downward slipping of the beds upon one another because of the great weight of superincumbent strata that once undoubtedly covered the entire region, but have long since been eroded away.

Faults are frequently found in the inclined beds. One of the best examples is in the abandoned quarry at Wallick's Mill, one and one-half miles southwest of Peru, along Little Pipe Creek, just below the railroad bridge. Here a well developed fault breccia can be traced for a distance of 75 feet. Minor faults are given off at right angles to the main fracture. The movement seems to have been chiefly vertical.

In the large quarry south of the railroad switches in the northeastern part of Huntington, the evidence points to a slight vertical displacement in the east end of the quarry, in beds dipping about 25 degrees.

Within 250 feet of the reef core the inclined beds usually flatten out and interfinger or merge with the members of the normal stratigraphic sequence. This interfingering is a very characteristic feature of reefs, and is mentioned by Grabau, Twenhofel, and other students of such structures. The formation most commonly seen in this relationship is the Mississinewa shale, which flanks most of the reefs. At South Wabash the Red Bridge and Liston Creek limestones are also represented. At Georgetown the horizontal beds of the Kokomo-Kenneth sequence approach the reef in an apparently unconformable relationship, although there is a possibility that here the reef continued into Cayugan time.

How far down into the Mississinewa formation the reef structure extends is not known, since nowhere is the base of a reef exposed. The relations of the reefs to this formation are best shown at Wabash; but may also be studied at Huntington; near Mt. Vernon and Double Cliffs on the Mississinewa; at Hanging Rock near Lagro; and one-half mile east of Yorktown on White River.

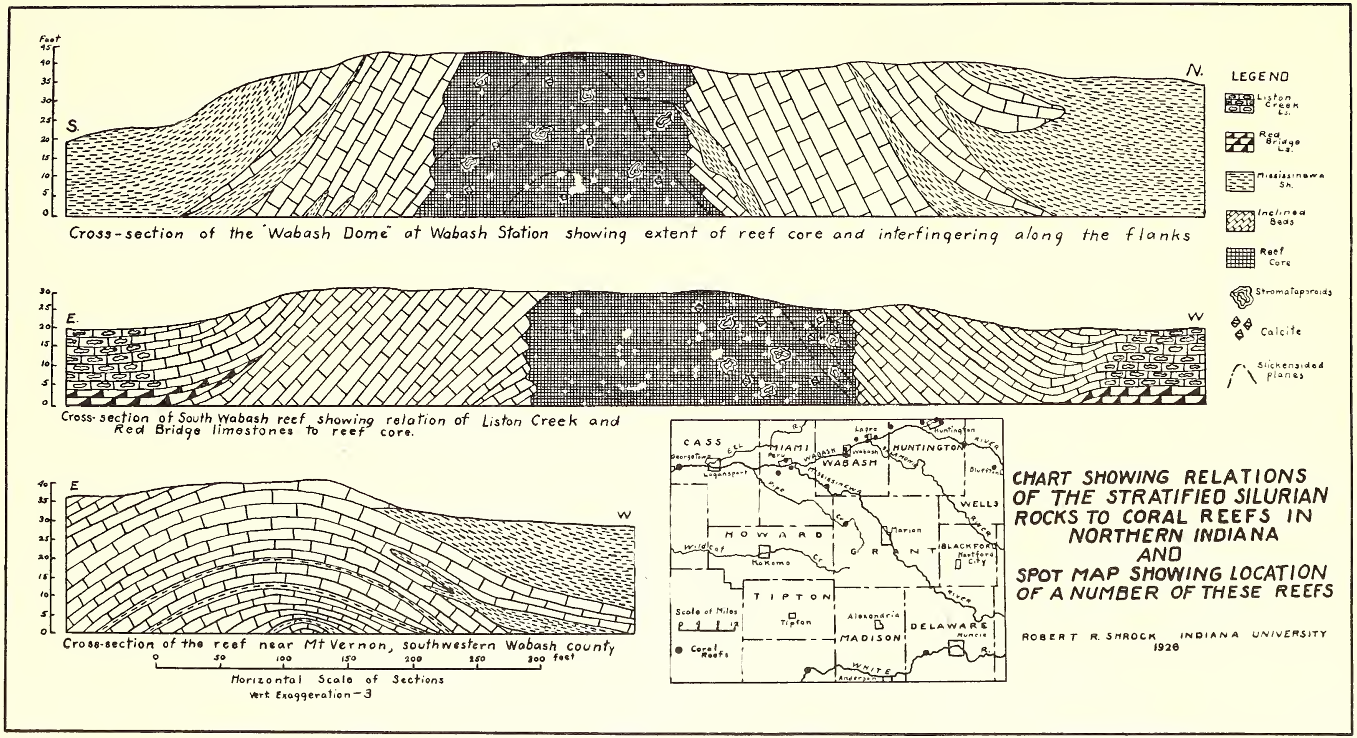

Fig. 3. Chart showing relations of the stratified Silurian rocks to coral reefs in northern Indiana, and spot map showing location of a number of these reefs.

DESCRIPTION OF CHARACTERISTIC REEFS.

The Wabash Reef. It now remains to describe in some detail several of the more typical reefs. (Fig. 3.)

In the railroad cut at Wabash station is a classic section cutting exactly through the center of one of these reefs, along a north-south axis. The isolated spur of rock east of the tracks aids in constructing a corresponding east-west section; and reveals an abundance of the Stromatoporoids that built the reef.

As revealed in the section (fig. 3), the exposed part of the reef core is some 250 feet long, and not over 40 feet high. Considerable calcite is present, and slickensides are common. There is no indication of definite bedding planes in the core; but the slickensided surfaces show dips as high as 65 degrees. These slickensided surfaces dip to

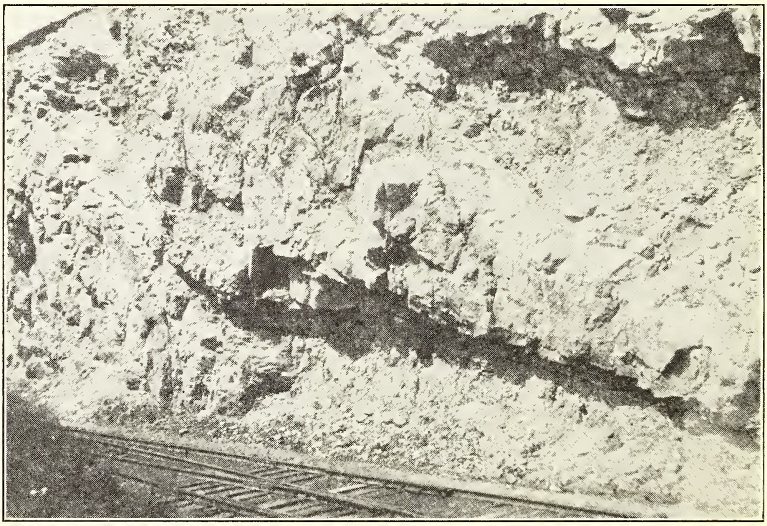

Fig. 4. View of the north flank of the "Wabash Dome" showing the interfingering of the Mississinewa shale and the inclined beds. Note the thickening of the limestone lens toward the core of the reef, to the left.

the west, north and south on the west wall of the cut, and east, north and south on the east wall, thus giving rise to a cone-like structure.

The inclined beds, near the core, vary from three to six feet or more in thickness, and dip at angles of from 12 to 65 degrees. The rock is a pink-tinted gray dolomite, containing a few fossils and small pockets of calcite. The beds dip from 30 to 50 degrees, ordinarily, near the core, but quickly flatten out to angles of from 12 to 18 degrees and finally become practically horizontal. Dips of 55 degrees were measured on the east wall of the cut, and one as high as 65 degrees was measured on a small lens of shale on the back of the spur that forms the east side of the cut. This is the highest dip observed anywhere in northern Indiana, outside of Kentland; and therefore represents the maximum for the true reef structures.

Small shale lenses are present in the south flank of the reef, and are even present in the core. The north flank shows the interfingering of the shale and the reef rock, particularly well, and is one of the most instructive exhibits in the state. The dip at this point is 30 degrees. The accompanying photograph (fig. 4) shows this interfingering very clearly. Just beyond the zone of interfingering, the shale is horizontal, and continues thus for half a mile north along the railroad, in its normal stratigraphic position. It is perfectly evident that the Mississinewa shale is contemporaneous with the reef, and that the latter was being built while the calcareous mud of the shale was being deposited in the adjoining waters.

The South Wabash Reef. This reef is located in South Wabash, across the river from the structure just described, and one-eighth mile east of a deep road cut in the Mississinewa shale. Although it is not as well exposed as the Wabash reef, nevertheless its structure can be fairly well determined from outcrops in a number of small quarries along the brow of the hill.

The reef proper is about 275 feet in diameter, but is exposed to a depth of less than 30 feet. While the Wabash reef is associated with the upper part of the Mississinewa shale, this reef, or at least its exposed portion, is associated with the Red Bridge and Liston Creek limestones.

In the west part of an active quarry that exposes the core of the reef many Stromatoporoids and some corals, very poorly preserved, are found, associated with much calcite. The latter occurs both in pockets and in connection with slickensides. The slickensided surfaces are inclined 45 to 50 degrees. The rock in the reef core resembles in all respects the rock of the reef previously described. On the west flank of the reef, however, where the inclined beds begin, the rock changes to a pinkish crinoidal limestone of rather crystalline texture. It has the characteristics of a coral breccia.

The inclined beds dip away from the reef core at angles varying from 50 degrees to zero, where they join the normal sequence. The Red Bridge and Liston Creek limestones appear to grade laterally into the inclined beds, with a transition in lithologic characters. At this point, on the west flank of the reef, a structural irregularity is present. The Red Bridge and Liston Creek beds lie horizontal, but the adjacent inclined beds dip at first downward *toward* the core at an angle of about 10 degrees, through a horizontal distance of 50 feet, and then gradually change to a dip of 15 degrees *away* from the core. Interwedging of the strata is conspicuous where this change of dip takes place.

Here also a yellow, very fossiliferous bed is present at the top of the exposure. Trilobites, Branchiopods and Bryozoa are very abundant. This rock probably represents a local development of the Liston Creek limestone, adjacent to the flank of the reef.

The Mississinewa shale outcrops near the reef on both the east and west sides; and it is likely that, were exposures available, the same relations of the shale to the reef would be seen as are found in the Wabash reef.

The Mt. Vernon Reef. At the old dam site on the Mississinewa River a mile north of Mt. Vernon and one-eighth mile above the bridge, the north flank of the well-defined reef is exposed. The outcrop is on the south side of the river where a small stream enters. As shown in figure 3, the section is tangential to the reef, and to one side of the core. The reef proper, therefore, is not exposed in the river bluff. Along the small stream the northward dip steepens, and it is probable that the core of the reef lies 300 feet south of the bluff. The Mississinewa shale is exposed along the west end of the bluff, interfingering in the usual fashion with the inclined beds, which here have rather low dips. Near the center of the outcrop the shale beds are observed to arch over the reef with the inclined beds.

This section shows just what would be expected if a section were taken along a chord near the outer limit of one of the reefs already described.

SUMMARY AND CONCLUSIONS.

It has been shown in the foregoing discussion that there is a definite stratigraphic sequence, consisting of distinct lithologic units, associated with the dome-like structures of the Silurian rocks of northern Indiana. The members of this sequence are named and described.

Strong evidence is presented indicating that the dome-like structures are coral reefs formed in the Silurian Sea. The massive, unstratified reef core, with its Stromatoporoids and corals, calcite pockets and slickensides and stylolites; the inclined strata, steeply dipping near the core, but rapidly changing to horizontality at the periphery of the structure, and interfingering with the members of the normal stratigraphic sequence; and finally the normal sequence itself, everywhere nearly horizontal and containing a fauna distinct from that of the core, all point to this conclusion.

Many puzzling structures, such as Hanging Rock, Morgan's Cliff, the outcrops at Wallick's Mill, Double Cliffs, and many others, inexplicable on any other basis, are easily and simply explained by the coral reef hypothesis. Such extensive structures as those of Huntington and Noblesville, and possibly Delphi, seemingly so complicated, may easily be explained as large composite reefs.

These reefs were contemporaneous with probably the entire Mississinewa shale, the Red Bridge and Liston Creek limestones, and possibly even with the Kokomo-Kenneth sequence. That they existed throughout Niagaran time is practically certain, and it is possible that some of them extended into Cayugan time.

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