

## Thick High-Purity Limestone and Dolomite, In Carroll County, Indiana

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### Introduction

Large-size high-purity dolomite deposits of reefal origin are well known in northern Indiana, northeastern Illinois, Michigan, and northwestern Ohio, but high-purity limestone reefal deposits are rare. Without doubt the original reef composition was limestone, but in many of the deposits diagenesis has changed the limestone to dolomite. Exceptions seem to occur, however, almost as accidents of nature, and because of this we were pleasantly surprised to discover two thick sections of high-purity carbonate rock in reefs of Silurian age, one limestone and one dolomite, about 6 miles apart in Carroll County (Fig. 1). Discovery of the high-purity limestone was propitious because the demand for high-purity carbonate rock for use in flue gas desulfurization, fluidized bed

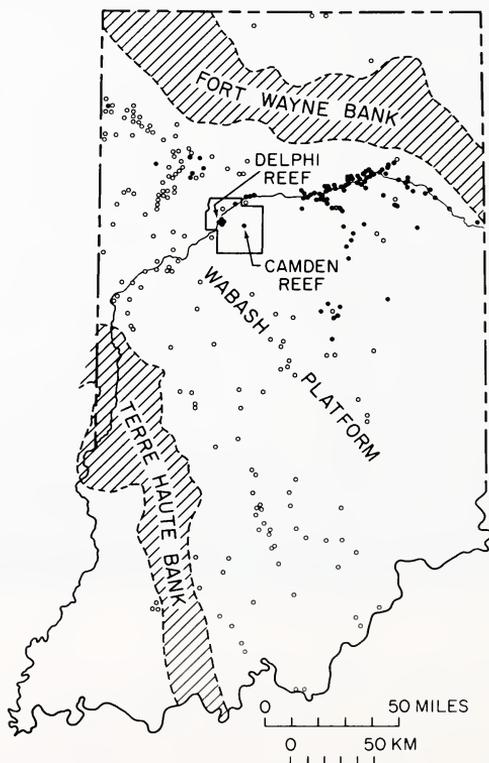


FIGURE 1. Map of Indiana showing areas of Fort Wayne and Terre Haute Bank and locations of some exposed (dots) and buried (circles) Silurian reefs. Reef interpretations by Curtis H. Ault, John B. Droste, and Robert H. Shaver.

combustion, lime, glass raw materials, and chemical products has been increasing. The dolomite is currently being exploited for aggregate, but the limestone awaits commercial development.

### Background

In 1973 the Indiana Geological Survey drilled a core hole (SDH 244) in the center of the Delphi reef as part of a study of reefs in northern Indiana by Curtis H. Ault and Robert H. Shaver. The reef was found to be 398 feet thick; this is the thickest continuous section of high-magnesium dolomite in Indiana ever analyzed by the Survey. Despite the impressive thickness and purity of the deposit, the full surface diameter and shape of the Delphi reef was not known until three more Survey cores were drilled in 1976 and 1977 as part of the Ault-Shaver study and for a detailed paleontologic and stratigraphic study by the Indiana University Paleontology Seminar of 1976-77 under the direction of Robert H. Shaver (4).

Location of a reef of Silurian age near Camden, in Carroll County, was recorded in 1927 by Cumings and Shrock (3). Only a small outcrop of the Camden reef is visible in and near Little Deer Creek in the NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 25, T. 25 N., R. 1 W. Cumings and Shrock described the outcrop as limestone, but samples of the limestone collected by the Survey in 1975 were dolomitic and considered unsuitable for many chemical uses.

SDH 262 was drilled near the outcrops of the Camden reef in 1976 as part of the Ault-Shaver study. This is also the thickest section of high-calcium limestone ever analyzed by the Survey. A second test, SDH 264, was drilled in the reef one-quarter mile to the north to determine the extent of the reef and the amount of its stone reserves.

Discovery of thick high-calcium limestone in the first test in the Camden reef was announced in a news release and Survey newsletter in December 1976. As a result, requests for additional information came from nearly 20 companies and individuals. Acreage on the reef has been leased commercially, and the deposit is now being evaluated by test drilling and chemical analysis of core samples for possible exploitation.

### Geologic Setting

The Delphi and Camden reefs are part of a regional archipelago of Silurian reefs that extends from New York to Iowa and bounds major parts of the Appalachian, Michigan, and Illinois Basins in Ohio, Ontario, Wisconsin, Michigan, Indiana, and Illinois. Two carbonate banks, the east-westward-trending Fort Wayne Bank in northern Indiana and the northwest-southeastward-trending Terre Haute Bank in southwestern Indiana (Fig. 1)(1), were the loci for profuse reef growth during Silurian time. The banks define the limits of the Wabash Platform of central Indiana, a broad shallow-water shelf between the Michigan and Illinois Basins during the Silurian Period, where hundreds and probably thousands of solitary reefs grew, among them the Delphi and Camden reefs.

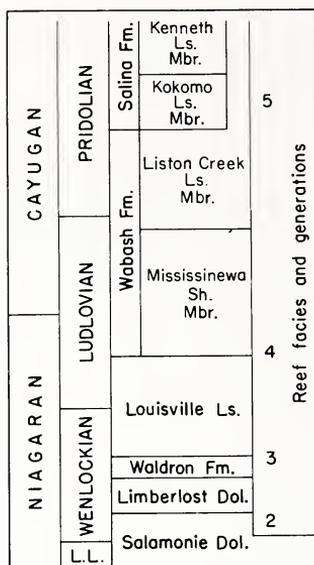


FIGURE 2. Stratigraphic chart showing Middle and Upper Silurian rocks in north-central Indiana.

Growth and accumulation of some reefs on the platform were continuous from Niagaran (Wenlockian) through Cayugan (Pridolian) time (Fig. 2). The thick Delphi reef is one of these large long-lived reefs. It belongs to the second of five generations of Silurian reefs described by Droste and Shaver (2) and Shaver (5) for part of the Great Lakes area. The Camden reef appears to have roots in the Louisville Limestone and to be a third-generation reef.

### Geology of the Delphi Reef

The Delphi reef is centered in the SW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 19, T. 25 N., R. 2 W. It is in the abandoned south pit of the Delphi Limestone, Inc., quarry immediately north of U.S. 421 near the west edge of Delphi and less than one-quarter mile east of the Wabash River. It is one of at least two large reefs and may be part of a larger reef complex north and northeast of town. Reefal dolomite is also exposed near Deer Creek in the south part of town.

The roots of the reef are in the Salamonie Dolomite; the overlying Limberlost Dolomite, Waldron Shale, Louisville Limestone, Wabash Formation, and Salina Formation (Fig. 2) have been recognized in cores in and near its edge (6).

SDH 244 was drilled in the south quarry pit in the structural center of the reef. This is indicated by flank beds dipping away from the center in all directions. A secondary center on the north side of the reef in the active quarry pit (Fig. 3) has been described by the Indiana University Paleontology Seminar (4).

Chemical analysis of this reef, except for an 8-foot section that was not cored at the top of SDH 244 and 20-foot interval of core lost at a depth of 220



FIGURE 3. Active Delphi Limestone, Inc., quarry in north flank of Delphi reef.

feet, indicated that it was high-magnesium dolomite with less than 2 percent noncarbonate impurities (Table 1).

The skeletal dolomite is light gray and sucrosic but has poorly defined fossil outlines and original textural features because of dolomitization. It is porous and friable in part. Its texture varies somewhat from the center to the edge of the reef because of fossils of different types and fragment sizes, but differences in lithology are not as distinctive as those in the Camden limestone reef.

TABLE 1. Chemical analyses (weighted average in percent) for the Delphi and Camden reefs.

Location	Thickness (ft.)	CaCO <sub>3</sub>	MgCO <sub>3</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	MnO
Delphi	370 <sup>1</sup>	54.8	44.3	0.32	0.087	0.20	nd <sup>3</sup>	tr <sup>4</sup>
Camden	257 <sup>2</sup>	97.3	0.93	0.74	0.38	0.10	0.021	0.011

<sup>1</sup>Includes core samples from SDH 244, SW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 19, T. 25 N., R. 2 W., and samples from quarry face near SDH 244; does not include 28 feet not cored.

<sup>2</sup>Includes core samples from SDH 262, SE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 25, T. 25 N., R. 1 W., from a depth of 57 to 323 feet; does not include three intervals of solution-cavity fill totaling 4.1 feet or two intervals of core loss totaling 4.8 feet.

<sup>3</sup>nd = not determined.

<sup>4</sup>tr = trace.

Our knowledge of the shape of the reef and the amount of its stone reserves is increasing rapidly because of new information. Three Survey test holes drilled in 1976 and 1977 indicate that the reef is about a mile in diameter at the surface (Fig. 4). It is laterally expansive upward with two main periods of growth, one during Salamonie deposition and a later one of extensive growth during deposition of the Mississinewa Shale Member (Wabash Formation).

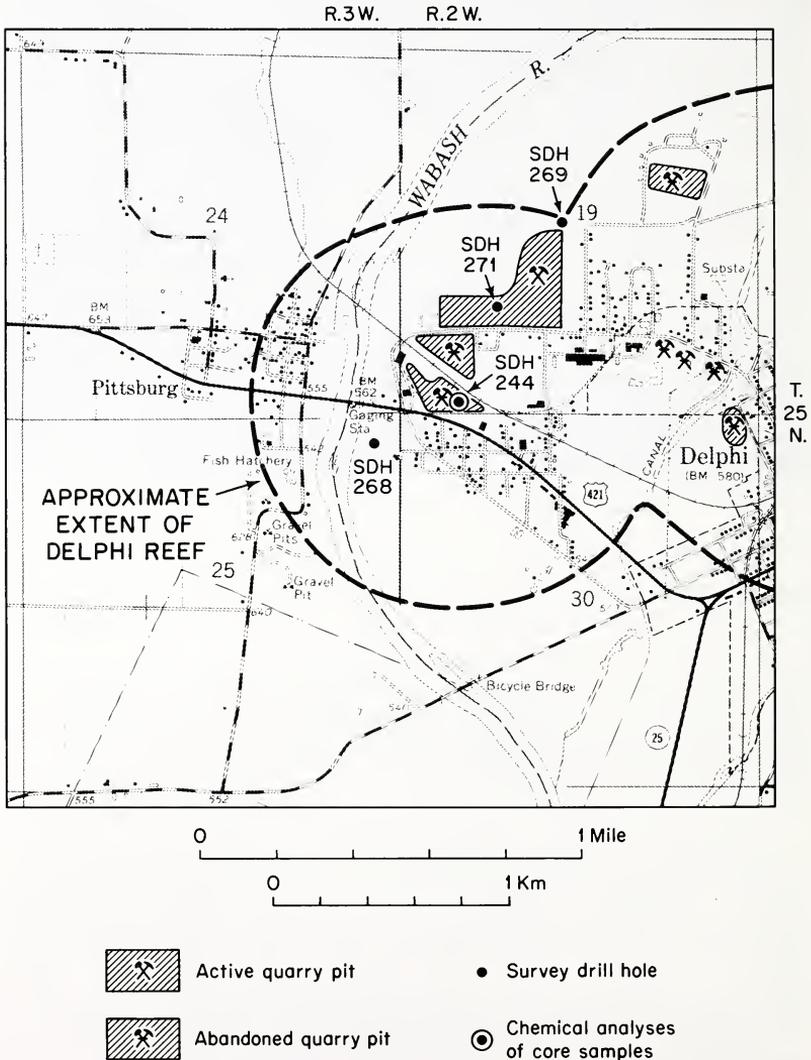


FIGURE 4. Approximate extent of Delphi reef and locations of quarry pits and Survey drill holes.

The great thickness of the reef indicates the large amount of stone reserves left, even though the reef is much smaller near its base than at the surface. The thick section of high-magnesium dolomite at the center also indicates large



the banks and in the streambed of Little Deer Creek, a few hundred feet south of the junction of County Roads 300 North and 300 East (Fig. 5).

The full extent and shape and detailed lithology, chemistry, and stratigraphy of the Camden reef are incompletely known, even though several industrial core holes and two Survey core holes have now been drilled into or through the reef. Although much of the industrial data is proprietary and cannot be published, much can be said about the reef in a general way.

Available core data indicate that the roots of the reef are in the Louisville Limestone, less than 20 feet above the top of the Waldron Formation, which is poorly developed at this location. The Louisville is blue gray, mottled, and easily differentiated from the overlying light-colored skeletal reefal limestone. Toward the southeast edge of the reef, some Mississinewa shale of the Wabash Formation has been recognized overlying the Louisville, but to date no nearby test holes have been drilled beyond the edge of the reef to reveal the stratigraphy of the uppermost Silurian interreef rocks. In a few holes, a thin brown silty dolomitic limestone or dolomite containing a few horn corals overlies the reef. These rocks have tentatively been identified as Devonian in age, possibly of the Traverse Formation.

The reef is more than three-fourths of a mile in diameter and probably more than a mile in diameter in its upper part. Its thickness of more than 300 feet in SDH 262 and nearly 250 feet in SDH 264 indicate that stone reserves are more than enough for commercial aggregate and probably for commercial chemical stone, which depends on the size of the body of high-calcium limestone. That such a body exists seems likely because only 18 feet of the 308 feet of reef rock cored in SDH 262 exceeded 5 percent  $MgCO_3$ . All limestone in the core contained less than 2 percent noncarbonate impurities, but a few solution cavities containing clay and silt, probably washed in by ground water, were found in most drill holes. In SDH 264, 90 feet of the 172 feet of high-calcium limestone cored in the reef was a continuous section.

The high-calcium limestone of the reef is light tan to pink bioclastic limestone that is thought to have been deposited on the reef flanks; it contains moderate to abundant sparry calcite cement. Inclined bedding was observed in all flank beds cored, but direction of the flank dips is poorly understood. Vague bedding dips in the outcrops in and near Little Deer Creek are to the east and southeast.

Determination of the center of the reef—important if much dolomitization is associated with the center and near-center rocks and if we are to know the full extent of the reef—can only be speculated on at this time. Much micritic blue-gray dolomitic limestone and dolomite containing little-disturbed light-colored shells and stromatoporoids were cored in the top 160 feet at SDH 264. Bedding in this lithology is irregular and has little discernible dip. The distinction between this zone and the steeply dipping bioclastic skeletal limestone of the pink to light-buff flank beds is pronounced. SDH 264 thus may be in a near-center position for the upper part of the reef, although dipping flank beds were indicated in the bottom part of the core and lesser amounts of near-center lithologies were found in other drill holes.

In general, increased dolomitization of the flank beds has been found south, southeast, and southwest of SDH 262. Nowhere does the amount of dolomitized limestone and dolomite with more than 5 percent  $MgCO_3$  exceed 30 percent of the total reef section drilled. Generally, less than 20 percent, and in several wells less than 10 percent, of the reef rock is more than 5 percent  $MgCO_3$ . Even where the amount of dolomitic limestone and dolomite is nearly 30 percent, thick continuous sections of high-calcium limestone have been core.

Our preliminary data show dolomitization in two parts of the reef: (1) dolomitized carbonate muds that were deposited in the near-center areas of the reef and that have well-preserved and little-disturbed light-colored calcitic shells, corals, and large stromatoporoids, and (2) some dolomitized flank beds, possibly associated in part with interfingering interreef beds near the edge of the reef. Again, more information is needed to determine if dolomitization is confined to individual flank beds following the steep 30-40° dips, or if the dolomitized zones are independent of bedding boundaries. Selective dolomitization in porous zones by dolomitizing fluids probably was involved, but we have seen no obvious evidence of such permeable zones in the cores.

Our study of the reef has been limited to microscopic examination of two cores and macroscopic examination of others. Detailed petrographic studies using thin section, staining, and SEM techniques would undoubtedly shed more light on the processes and effects of dolomitization.

#### **Geological and Commercial Implications Of The Delphi and Camden Reefs**

Discovery of thick chemical-quality carbonate stone in the Delphi and Camden reefs has prompted an examination of their relationship to the overall stratigraphy and reef distribution of northern Indiana. Obviously important is the relationship of the size and chemical composition of the Delphi and Camden reefs to reefs originating in similar stratigraphic positions in other areas. Both reefs have older beginnings than many reefs in Indiana, but their earlier Niagaran origins relate them to many Indiana reefs beginning at this same time. Thus we can make geologically and commercially important inferences concerning physical size, number, distribution, and composition of the reefs.

##### *The Delphi Generation*

The reef at Delphi arose out of Salamonie and Limberlost rocks, Droste and Shaver's (2) and Shaver's (5) second generation for part of the Great Lakes area (but the first generation of reefs in Indiana). Many small reefs of this generation in eastern Indiana and northwestern Ohio, where early Niagran rocks are well exposed in several quarries and some outcrops, have been described by geologists. Some of these early Silurian reefs were little more than mounds of biota that did not survive the environmental restrictions during deposition of the Limberlost Dolomite. Other reefs, though, gained a good foothold and survived to enlarge and expand later.

An excellent exposure of the latter, a reef that breaches the Limberlost Dolomite and the Waldron Formation, can be seen in the Muncie Stone Co. quarry at Montpelier, Wells County. The Delphi reef is another example of a second generation reef breaching these formations and expanding greatly in late

Louisville and later time. Reefs that were able to survive the apparently restricted environments during deposition of parts of the Limerlost Dolomite and the Louisville Limestone, and possibly the Waldron Formation, were quite likely to continue their growth and eventually to become large reefs containing commercial deposits. Significantly, none of the known reefs of this generation are calcareous; all are dolomite, and many are high-magnesium dolomite.

#### *The Camden Generation*

Several large known reefs in northern Indiana, including the Camden reef are of this generation, the third generation for part of the Great Lakes area. The large reefs at Lapel, Madison County, and at Huntington, Huntington County, are believed to be of this generation. Drilling data indicate that their roots are at or near the base of the Louisville Limestone. Because of their large size, they are among the most important reefs for commercial mining in Indiana.

Reefs of this generation apparently grew with little hindrance from incoming impurities deposited in the Louisville, but the seas were probably of above-average salinity during deposition of the middle part of the Louisville, a time of evaporite deposition in the Michigan Basin, which restricted the growth of some reefs and probably caused the termination of many.

The third generation of reefs presents a lithologic mystery for Indiana reefs. Most reefs of Indiana have been thoroughly dolomitized, but the thickest known section of high-calcium limestone in Indiana, that in SDH 262 in the Camden reef, was deposited in a reef of this generation. There is little evident difference in the stratigraphy at the Camden reef and other dolomitized reefs of this generation. But the eroded tops at the bedrock surface of the larger reefs of this generation are at different stratigraphic levels. Available chemical analyses show few compositional differences or at least no obvious pattern of variable composition in the substrate and interreef rocks near the limestone reefs as compared with those near the dolomite reefs.

Large reefs of the third generation offer excellent promise as commercial sources of both high-magnesium dolomite and high-calcium limestone.

#### *Other generations*

Two large reefs of the fourth generation, one at Bluffton, Wells County, and the other at the Pipe Creek Jr quarry in southwestern Grant County, have roots in upper Louisville limestone. The Pipe Creek Jr reef has a surface diameter of about a mile, and a 139-foot section of high-calcium limestone averaging less than 2 percent noncarbonate impurities has been core drilled on the south flank of the reef. The large dolomitic reef at Bluffton has been quarried for aggregate for many years. Cores at this reef show an earlier and apparently separate episode of third-generation reefing in basal Louisville limestone. Large fourth-generation reefs, such as Bluffton and Pipe Creek Jr, are prime exploration targets for commercial stone reserves.

Small reefs of this generation with slightly younger beginnings in silty and argillaceous dolomite of the Mississinewa Shale Member of the Wabash Formation are present in large numbers in the Wabash Valley east of Logansport. As many as five reefs per square mile are exposed east of Lagro, Wabash County. Obvious commercial disadvantages are their small size and,

for some, their mixed composition. Few known Wabash Valley reefs of this generation are more than one-third of a mile in diameter in their maximum dimension or are much more than a hundred feet thick. Their reserves for commercial exploitation are limited, usually less than those required for a modern permanent quarry.

A reef of the youngest Indiana generation, the fifth, has been identified by core drilling in Cass County about 10 miles northeast of the Camden reef and 3 miles west of Logansport on the south bank of the Wabash River. The reef, although small, contains high-calcium limestone.

From present knowledge, the fifth-generation reefs, originating in Salina rocks in Indiana, offer the least potential for large reserves of high-calcium limestone or high-magnesium dolomite. This is due to their small size and the limited geographic distribution of Salina rocks on the Wabash Platform.

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