Indiana University

Department of Geology

FIELD TRIP ON SILURIAN SEDIMENTARY GEOLOGY

WITH SPECIAL EMPHASIS ON THE REEFS,

GREAT LAKES AREA

Robert H. Shaver

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INTRODUCTION

This trip has been planned for Indiana University students enrolled in G420, Regional Geologic Field Trip, and consists of 15 principal stops during five days and about 1450 miles of travel from southern Indiana to central northern Ohio, to eastern Iowa, and to southern Indiana.

The Silurian rocks of this area and of the Great Lakes area in general have been the subject of intense studies from the time of now-classic study (1800's to 1920's) to the present. Especially the remarkable reefs, among the most numerous and both diverse and largest of reefs of any geologic system, have received much attention (fig. 1). They have served as models for the understanding of reefs of other systems, even for understanding the principles of modern reef development to some degree.

Several fads in geologic study, as they were, have come and gone and come again during this period with respect to application to the Silurian reefs. These fads posed serious questions as to the "true-reef" nature of the Silurian carbonate buildups, as to the depth of water attending the reefs, as to the tectonic circumstances that perhaps facilitated reef growth and reef abortion, as to the relationship of terrigenous clastics in the reef environment (at what level are they impediments to reef growth?), as to the stratigraphic relationship between the reefs and thick salt deposits in the Michigan and Appalachian Basins, and as to the cyclicity of Silurian sedimentation and fluctuations in sea level. (The latter phraseology may appear biased, as would "transgressions and regressions," and so "fluctuations in water depth," or "shallowing and deepening" are other ways to state the meaning here.)

Nowhere more than at Indiana University and in the Indiana Geological Survey has greater and prolonged attention been given to the Great Lakes area Silurian reefs and interreef rocks. This attention as been given particularly to the fundamental nature of reefs
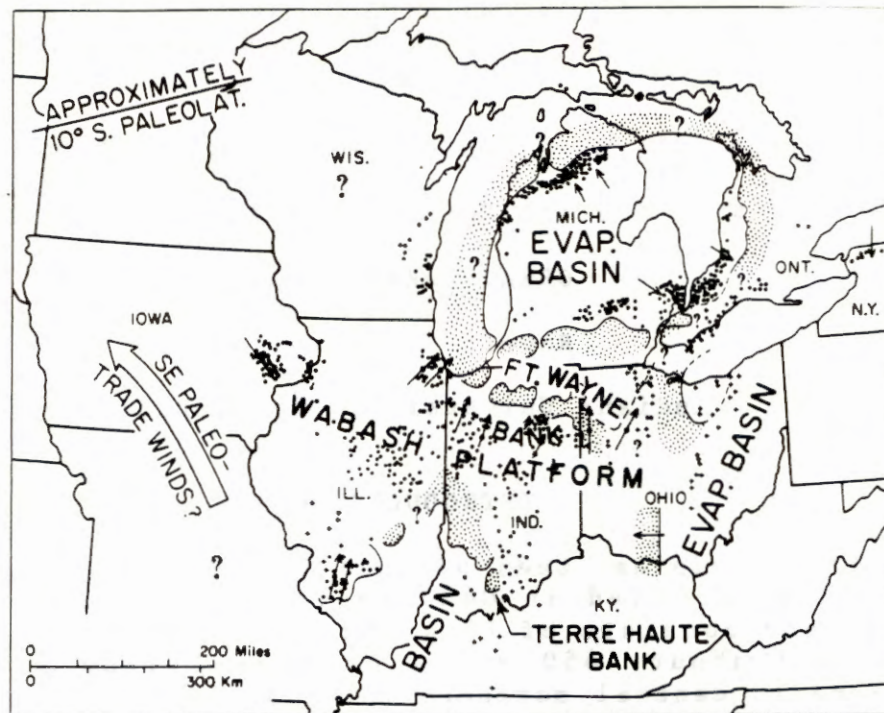
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Fig. 1. Map of the Great Lakes area showing a composite reconstruction of [?] Silurian reef archipelago. Dots show locations of known reefs or suspe[?] reefs; stippled areas represent barrierlike carbonate banks that d[?] along basin-platform edges and that probably contain many more or [?] crete reef structures therein (not shown by dots). Thousands of sma[?] [?] (principal dimensions of a few feet) are not shown as also many more lately discovered reefs are not shown. Arrows show forereef to backreef directions as reported in the literature. From Shaver and others (1978).
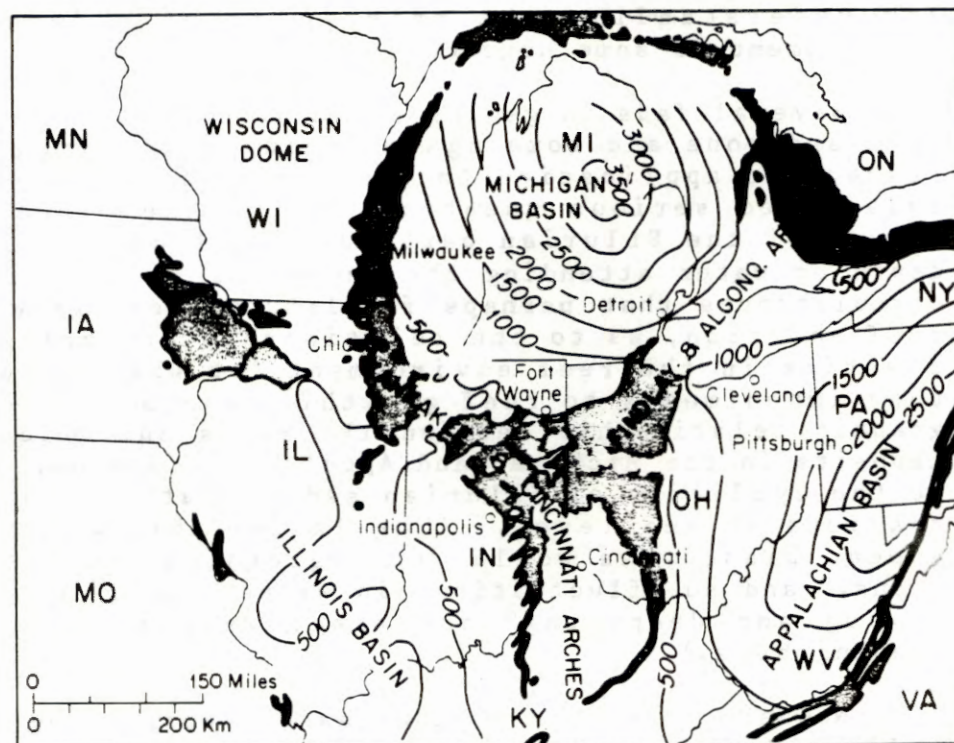

Fig. 2. Map of the Great Lakes area showing the Silurian outcrop area (pattern), present major structural features, and thickness of Silurian rocks. Thickness interval 500 feet. From Droste, Rexroad, and Shaver (1980).

(e.g., Cumings and Shrock, 1928) and to the geographic and stratigraphic distribution and biology and geometry of the reefs. Most importantly, the later attention by Indiana geologists has integrated the stratigraphic histories of three principal basins and the intervening platform area. In so doing, both constraints and greater latitudes have been placed on the many models and ideas on sedimentation that have arisen more or less independently for one basin or another, or for the outcrop area, or in one school or another focussing on: geochemical (e.g., evaporites) study, on search for hydrocarbons, and on biologic study (e.g., of reefs).

A more or less authoritative approach to regional geology is taken below and provides a background against which the field-trip group can integrate the geologic records observed at the 15 stops, which, because of geographic constraints, are not in stratigraphic order. Authorative approach or not, many questions remain to be answered as to the general to detailed geologic history of the midwestern Silurian sedimentational province.

Questions are posed at the stops, some designed to lead the observer to the general regional history that is presented in the account here, some designed to encourage disagreement with that account if the evidence permits, and some designed to produce possible answers to questions that so far have gone unanswered. The part of regional geologic history that is deliberately left unanswered, partly from ignorance, has to do with cyclicity in Silurian sedimentation and its relationship to global sea level changes and, therefore, probably to global tectonics.

Students may debate any statement here, of course, but at the end of the trip they also should have gained some perspective that allows them to address, if not settle, debates currently going on in the area of interpretation noted last above; also, in the area of water depths attending reef growth, and even in the area of mode of reef growth itself.

ITINERARY

First Day

Departure: The field-trip group leaves from the Geology Building parking lot at 7:45 a.m.

Route to stop 1: East and south to Third Street; east on Ind. 46 to Greensburg; southeast on U.S. 421 to Napoleon; and Ind. 229 east to Napoleon Quarry in Ripley County; 79 miles; 9:45 a.m.

Stop 1:   Time allocated to examination of exposures in the Napoleon Quarry of the Newpoint Stone Co. is 1.50 hours; 11:15 a.m.

Route to stop 2:   East and north on Ind. 229; west on U.S. 52; north on Ind. 121, north on Ind. 1; north-east, north, and east on Ind. 67, becoming Ohio 29; east on Ohio 29; south on county road; and east into quarry about 4 miles west of Celina, Ohio; 125 miles; 3:30 p.m.; time allows 0.75 hour for lunch and 1 hour for time change.

Stop 2:   Time allocated to examination of exposures in the John W. Karch Stone Co. quarry is 2.50 hours; 6:00 p.m.

Route to overnight stop: North on county road; east on Ohio 29; east and southeast on U.S. 33; and north into Indian Lake State Park camping area near Russells Point; 58 miles; 7:15 p.m.

Second Day

Departure: The group leaves Indian Lake State Park at 7:45 a.m.

Route to stop 3:   Southeast on U.S. 33; north on Ohio 117; north on Ohio 235; northeast on I75; south-east on Ohio 15; north into Vanlue; east on county road to Ohio 568; east on Ohio 568 to Carey; 67 miles; 9:15 a.m.

Composite stop 3:   Time allocated to viewing several glacially sculptured klintar and to examination of exposures along edges of quarries is 2.00 hours; 11:15 a.m.; quarries will not be entered here.

Route to stop 4:   North on U.S. 23; northwest on Ohio 199 nearly to West Millgrove; and east into quarry; 24 miles; 12:30 p.m.; time includes 45 minutes for lunch in Fostoria.

Stop 4:   Time allocated to examination of the exposures in the MacRitchie Materials Co. quarry is 2:25 hours; 2:45 p.m.

Route to stop 5:   North on Ohio 199; west on U.S. 6; north on I 75; west and north on I 475 and U.S. 23; northeast on U.S. 24; northwest on Salisbury Road in Maumee; and northeast into quarry; 34 miles; 3:30 p.m.

Stop 5:   Time allocated to examination of exposures in the Maumee Stone Co. quarry is 2.50 hours;

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6:00 p.m.

Route to overnight stop: Southeast on Salisbury
Road; southwest on U.S. 24; south on Ohio 281; east on
Ohio 281; and north into Independence Dam State Park
camping area near Defiance; 49 miles; 7:15 p.m.

Third Day

Departure: The group leaves Independence Dam
State Park at 7:45 a.m.

Route to stop 6: West on Ohio 281; West on Ohio
424; southwest on U.S. 24 to west edge of New Haven;
south on Hartzell Road; west on Tillman Road becoming
Lower Huntington Road; north on Ardmore Avenue; and
west into quarry; 58 miles; 8:30 a.m.; time allows 1
hour time change.

Stop 6: Time allocated to examining the exposures
in Ardmore Quarry of May Stone and Sand, Inc., is 2.00
hours; 10:30 a.m.

Route to stop 7: South on Ardmore Avenue; east on
Lower Huntington Road; south on Bluffton Road; south on
Ind. 1 to Ind. 18; west on Ind. 18 to Montpelier;
north, west, and north on city streets and county road;
and east into quarry; 34 miles; 11:15 a.m.

Stop 7: Time allocated to examination of
exposures in the Erie Stone Co., Inc., quarry is 2.00
hours; 1:15 p.m.

Route to stop 8: South on city streets to Ind.
18; west on Ind. 18; south on I 69; west on Ind. 26;
north on 600 West Road, west on 600 South Road; and
south into quarry; 29 miles; 2:45 p.m.; time allows 45
minutes for lunch.

Stop 8: Time allocated to examination of
exposures in the Pipe Creek Jr. Quarry is 2.00 hours;
4:45 p.m.

Route to stop 9: West on 600 South Road, north on
Ind. 13 to stop 9 south of the Wabash River at Wabash;
26 miles; 5:15 p.m.

Stop 9: Time allocated to examination of
exposures in road cut along Ind. 13 and 15, south of
Wabash River, is 0.50 hour; 5:45 p.m.

Route to stop 10: North on Ind. 13, crossing
Wabash River; east on East Hill Street, becoming county
road along north side of river; south at Lagro on Ind.

524 and then east on county road to stop 10 at Hanging rock; 7 miles; 6:00 p.m.

Stop 10: Time allocated to examining the exposures in the klint known as Hanging Rock is 0.50 hour; 6:30 p.m.

Route to overnight stop: West on county road to Ind. 524; east on Ind. 524 into Salamonie Forest State Recreation Area; 4 miles; 6:45 p.m.

Fourth Day

Departure: The group leaves the Salamonie Forest State Recreation Area at 7:45 a.m.

Route to stop 11: Northwest on Ind. 524; west on county road along north side of Wabash River, becoming East Hill Street; south two blocks on Allen Street; east two blocks on East Market Street to site of former Big Four Railroad Station; 8 miles; 8:00 a.m.

Stop 11: Time allocated to examination of exposures in the Wabash Reef is 1.00 hour; 9:00 a.m.

Route to stop 12: West on East Market Street; west on West Hill Street; west on Mill Street; west on U.S. 24; south on U.S. 31; east on Ind. 218 to Bunker Hill; north, west, and north on county road; and east into quarry; 23 miles; 9:30 a.m.

Stop 12: Time allocated to examination of exposures in the Mill Creek Stone and Gravel Co. quarry is 1.50 hours; 11:00 a.m.

Route to stop 13: South, east, and north on county road; west on Ind. 218; north on U.S. 31; west on U.S. 24, north on I 65; west on I 80 and 294 to Harvey, Illinois; south on Ill. 1 (South Halstead Street; east and north on Ridge Road; east on Margaret Street; south on William Street, and west into quarry area; 146 miles; 2:30 p.m.; time allows 30 minutes for lunch.

Stop 13: Time allocated to examination of exposures in quarry developed in the Thornton Reef is 2.50 hours; 5:00 p.m.

Route to overnight stop: Retrace route from quarry to Ill. 1; north on Ill. 1; west on I 80 to Ottawa; south on Ill. 23; west on Ill. 71, and north into Starved Rock State Park camping area; 79 miles; 6:30 p.m.

Fifth Day

Departure: The group leaves Starved Rock State
Park at 7:45 a.m.

Route to stop 14: West on Ill. 71; north on Ill.
351; west on U.S. 6; north on U.S. 51; west on I 80 and
after 67 miles north on I 80 and cross Mississippi
River; northeast on U.S. 67 to north of LeClaire, Iowa;
west on county road; and south into quarry of LeClaire
Quarries, Inc.; 90 miles; 9:30 a.m.

Stop 14: Time allocated to examination of
exposures in quarry at LeClaire is 2.00 hours; 11:30
a.m.

Route to stop 15: Southwest on U.S. 67; west on I
80; north and northwest on Iowa 38; north 2 miles on
county road; west 1 mile on county road; and south into
the Brady Quarry; north 47 miles; 1:00 p.m.; time
allows 0.50 hour for lunch.

Stop 15: Time allocated to examination of
exposures in the Brady Quarry is 1.50 hours; 2:30 p.m.

Route to Bloomington, Indiana: Retrace route to
Iowa 38; south on Iowa 38; east and then south on I 80;
south, southeast, and east on I 74 to Crawfordsville,
Indiana; south on U.S. 231 to Spencer; and southeast on
Ind. 46 to Bloomington; 378 miles; 7.0 hours driving
time; total trip mileage, 1375.

REGIONAL GEOLOGY AND GENERAL GEOLOGIC HISTORY

The field-trip area actually extends to parts of
three intracratonic basins that had begun to develop by
Silurian time (fig. 2), and it covers part of the broad
intervening platform that has been called the Wabash
Platform for middle Paleozoic time (fig. 1). Thickness
of Silurian rocks in the three basins varies greatly,
the principal reason being that the Michigan Basin
received particularly large amounts of evaporites and
the Appalachian Basin received large amounts of both
siliciclastic and evaporite sediments. The Illinois
Basin remained open to circulation during Silurian
time, receiving no evaporites and only modest amounts
of siliciclastic sediments. Therefore, regional
Silurian thickness there did not reach 1000 feet.

Thick and thin sections not withstanding, even
parts of the outcrop area contain rock records that
represent perhaps 75 to 90 percent of post-Alexandrian
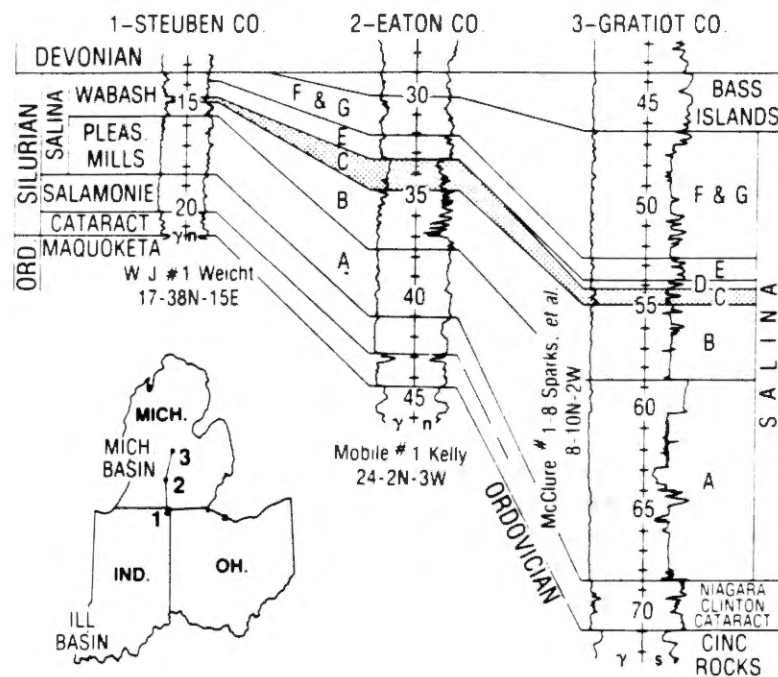Silurian time for those places that experienced the

Fig. 3. Chart showing representative sections of Silurian rocks in the Great Lakes area. Stippled pattern represents ages of the rocks; gray overlay pattern represents thicknesses. From Droste and Shaver (1985).

Fig. 4. Geophysically and lithologically correlated sections extending from the inner Illinois Basin to the peripheral Michigan Basin. From Droste and Shaver (1985).

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Fig. 5. Geophysically and lithologically correlated sections extending from the peripheral to inner Michigan Basin. From Droste and Shaver (1985).
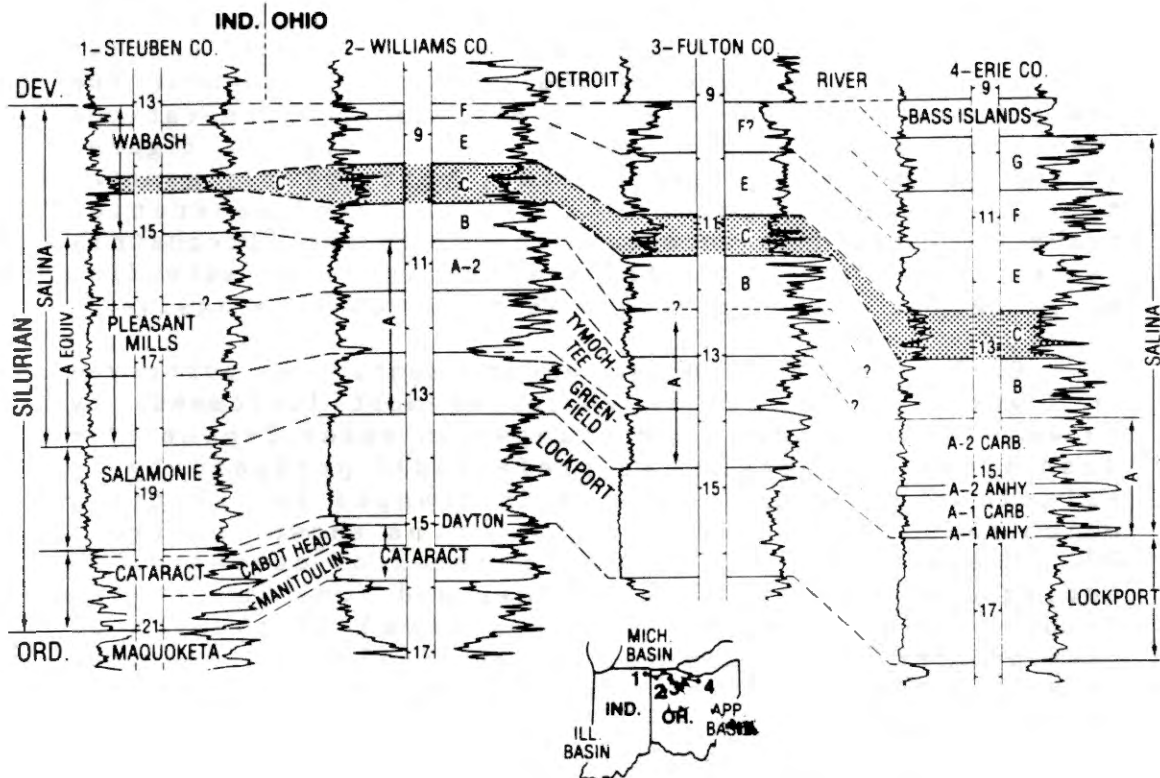

Fig. 6. Geophysically and lithologically correlated sections extending from the peripheral Michigan Basin into the Appalachian Basin. From Janssens (1977) and Droste and Shaver (1982).

least amount of post-Silurian erosion (fig. 3). The
disproportionality between the length of time repre-
sented by different Silurian sections and the thicknes-
ses of these sections (fig. 3) suggests that the basins
may have subsided four or five times the amount that
the platform subsided.

The rock columns listed in figure 3 have been
correlated in both conventional and unconventional
ways: (1) By geophysical correlations and by coordi-
nated sample and core examination (for example, as
shown in figs. 4-6);

(2) By biostratigraphic applications of such
repeatedly tested (against a modern vertically stacked
stratigraphy) standards as afforded by conodonts (fig.
7), pentameracean brachiopods (fig. 8), and miscellan-
eous groups (fig. 9); and

(3) By cyclicity of environmental and sedimenta-
tional events.

Considerable confidence attaches, therefore, to
the Great Lakes-wide correlations made by the Indiana
geologists and shown in figure 10, although refinements
will continue to be needed. The cyclicity of sedi-
mentational events noted above is particularly evident
in the pattern of reef generations and abortions that
seem to have some general coordination throughout the
Great Lakes area. Some of the six numbered generations
(keyed to stratigraphic levels of starting) of figures
10 and 11 are somewhat artificial, particularly genera-
tion 1; also, generation 4 is a collected generation
probably related in uncertain manner to the alternately
restricted and less restricted environments attending
early Salina salt deposition in the evaporite basins.

Cyclicity in Silurian environments, as portrayed
in figures 12-17, can be expressed most fundamentally
in sea-level changes (or changes in water depths if a
less biased expression is preferred); periodicity in
siliciclastic influxes, and in changes in salinity,
which factors are portrayed by curves shown in figure
10. These factors were interrelated of course, some
acting directly with one another and some in inverse
fashion. For example, high sea level is thought to
have brought about improved water circulation, restora-
tion of normal salinity, cessation of salt deposition
in the evaporite basins, renewed reef growth, and
influxes of clastics of terrigenous derivation; low sea
level, on the other hand, resulted in environmental
restriction, renewal of salt deposition in two basin,
loss of terrigenous clastic influxes, and reef abor-
tion. These factors acted both to produce the most
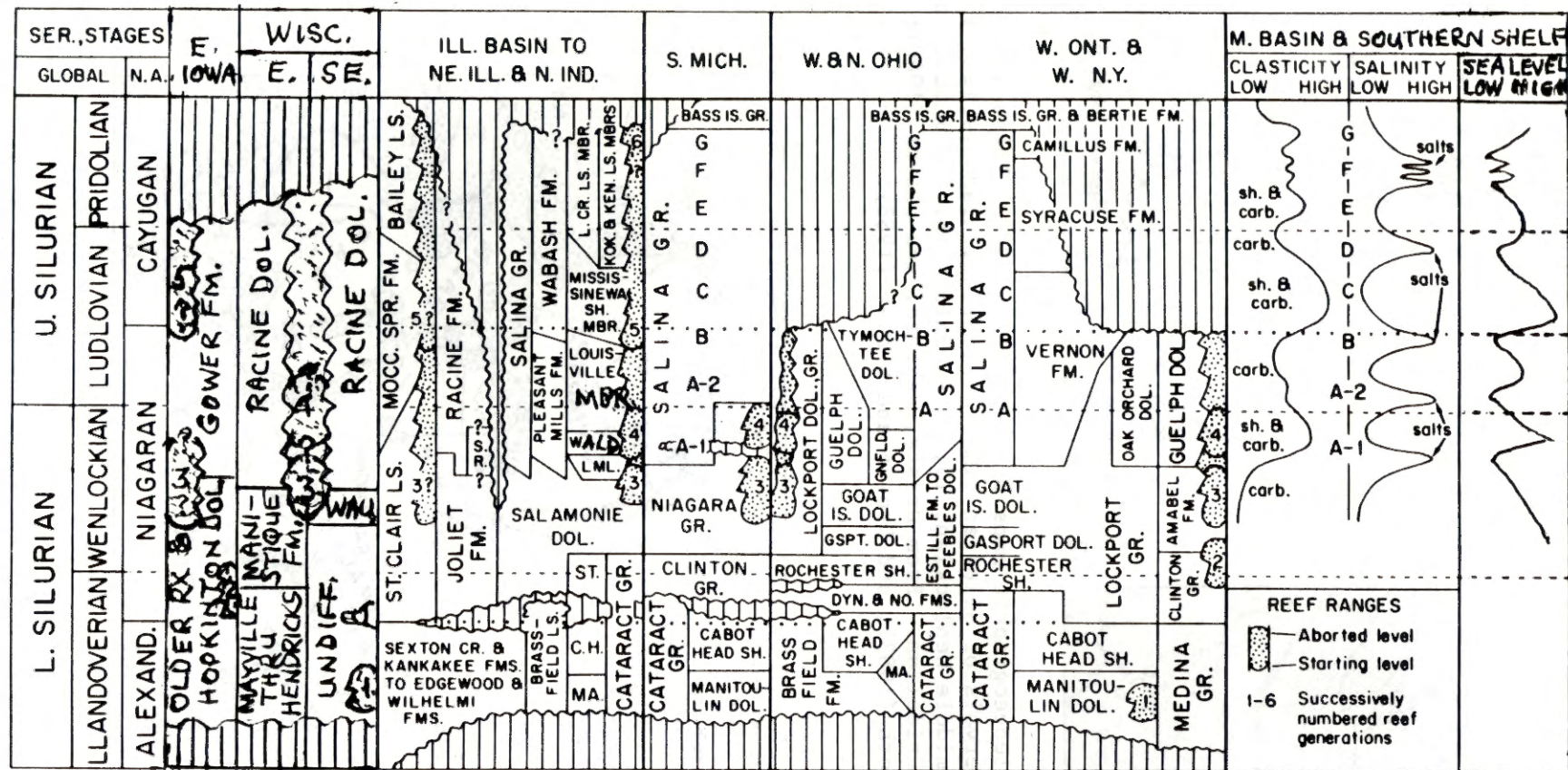extreme effects and to produce only modest effects

Fig. 7. Chart showing biostratigraphic zonation of Silurian rocks of the Great Lakes area by means of conodonts. From Droste and Shaver (1985); data especially from Carl B. Rexroad and associates.

Fig. 8. Chart showing biostratigraphic zonation of Silurian rocks of the Great Lakes area by means of pentameracean brachiopods. From Droste and Shaver (1985); fossil identifications for many places from A. J. Boucot.

Fig. 9. Chart showing biostratigraphic zonation of Silurian rocks of the Great
Lakes area by means of miscellaneous groups of fossils. From Droste and
Shaver (1985); data also from Cumings and Shrock (1928), Ross (1962), Schwalb
(1975), Tollefson (1979), and Wood (1975).

Fig. 11. Chart showing stratigraphic ranges of exemplary Silurian reefs in the
Great Lakes area and their proposed arrangement into six principal generations
keyed to starting levels. Generations 1 and 4 especially are collected genera-
tions of not wholly contemporaneous reefs. From Droste and Shaver (1985).

Fig. 10. Chart showing correlation of Silurian rocks, including six principal reef generations and cyclicity of selected environmental parameters in relation to general rock types, in the Great Lakes area. Modified from Shaver and others (1983) and Droste and Shaver (1985). Wau., Waukesha; S.R., Sugar Run; Lml., Limberlost.

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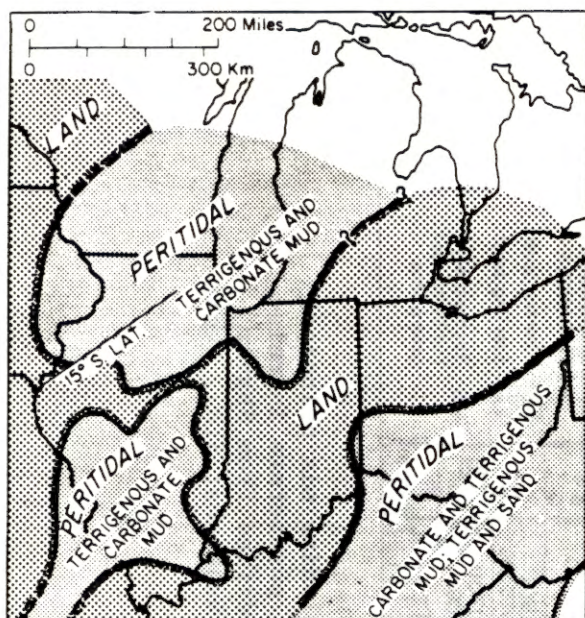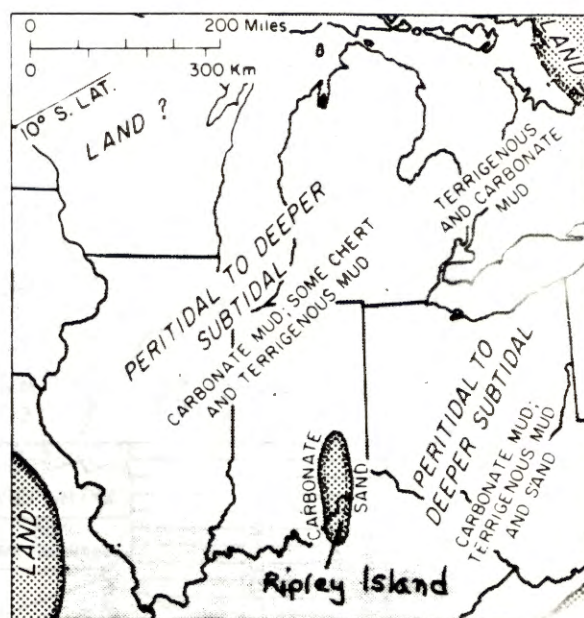
Figs. 12-17. Six paleogeographic maps of the southern Great Lakes area for selected short intervals of Silurian time. 12, Middle Llandoverian; 13, late Llandoverian; 14, middle Wenlockian; 15, late Wenlockian; 16, middle Ludlovian; and 17, middle(?) Pridolian. From Droste, Rexroad, and Shaver (1980); Shaver, Sunderman, and others (1983); and Droste and Shaver (1983).
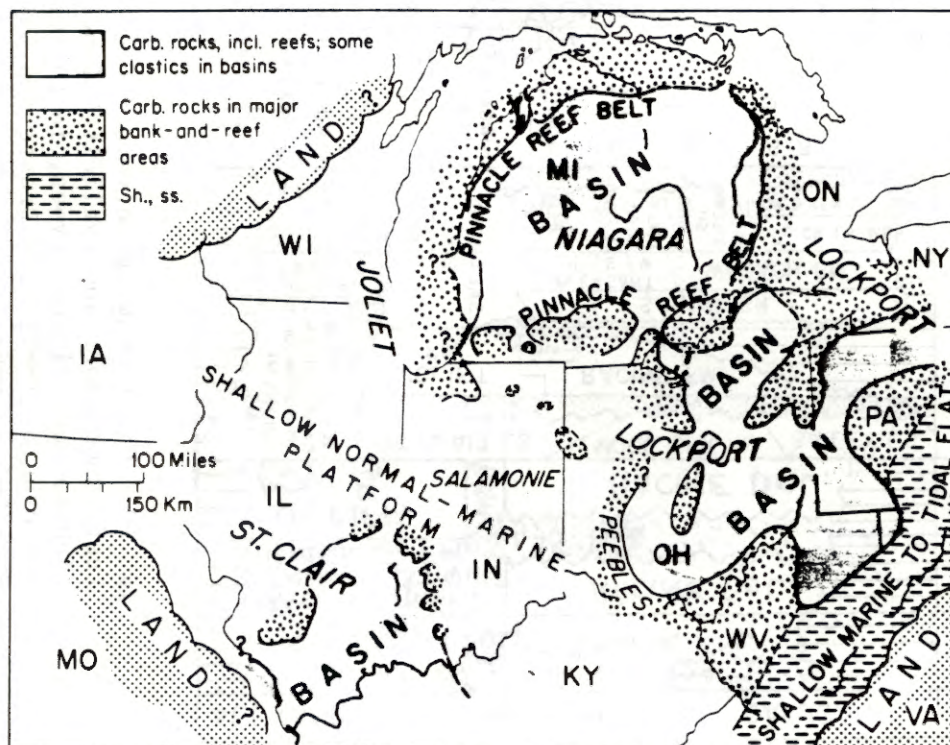
Fig. 14. See figure 12 (middle Wenlockian).
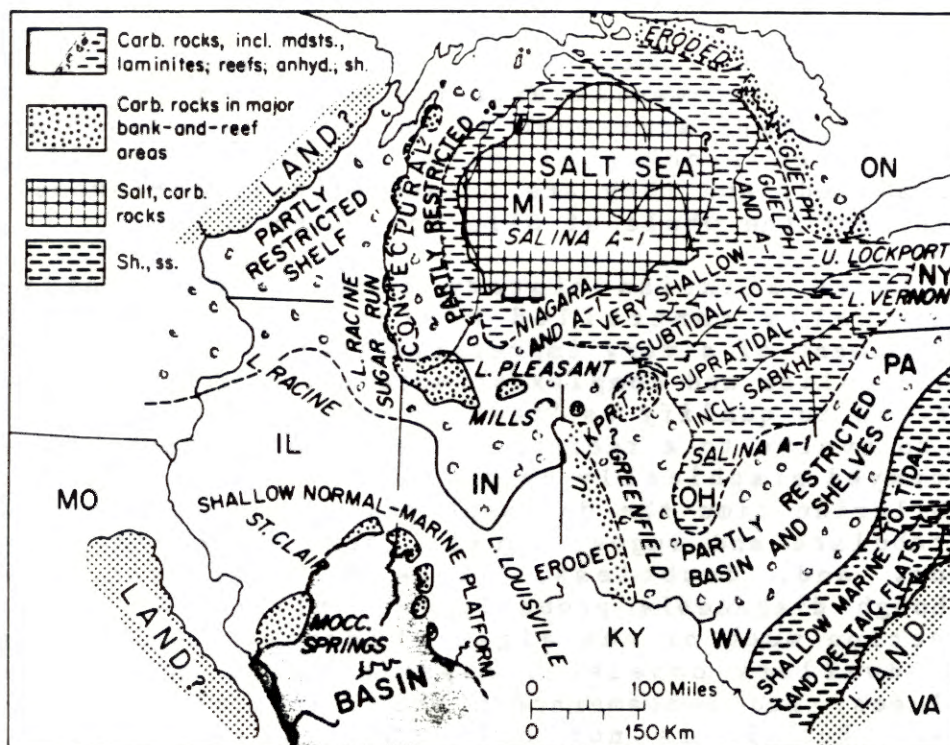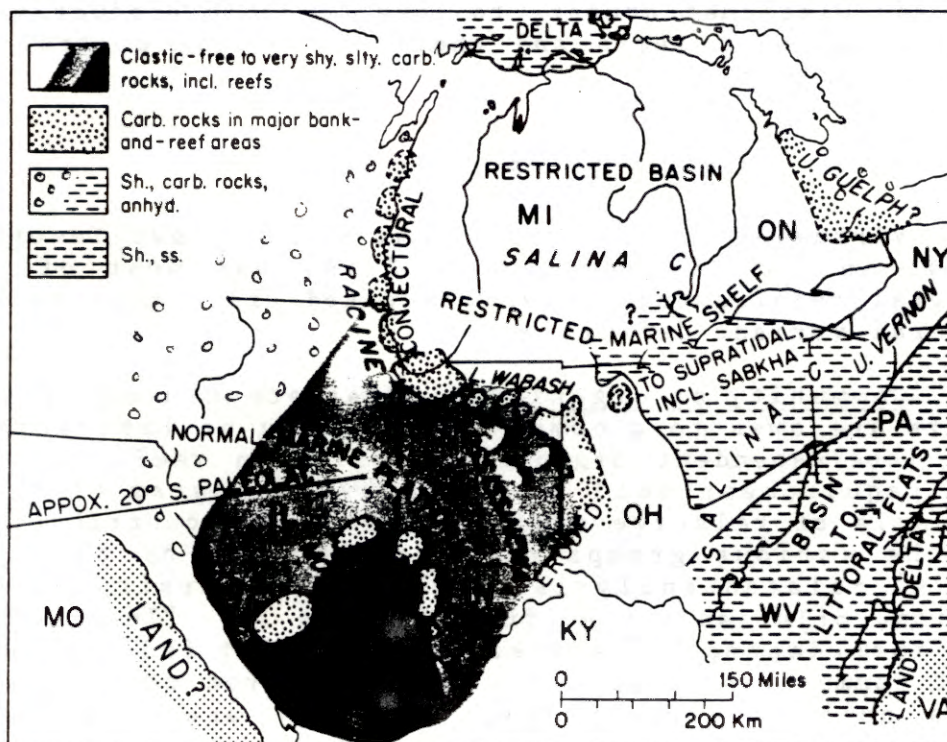
Fig. 15.   See figure 12 (late Wenlockian).

Fig. 16.   See figure 12 (middle Ludlovian).

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depending upon locale within the Great Lakes area. For
example, environmental extremes were much less in the
Illinois Basin area than in the Michigan Basin area.
The paleoenvironmental maps of figures 12-17 are
generalized, and they are presented only for exemplary
times, not the whole of Silurian history.

Later Silurian history became increasingly an
organically controlled history, considering the
development of a very impressive reef system. To build
such peculiar and complex structures, and large ones at
that, as to qualify as "reefs," the organic world first
had to evolve to a reef-potential state, which has been
portrayed graphically by Heckel (1974), among others.
By Silurian time the dominant frame builders consisted
of tabulate and rugose corals, stromatoporoids, bryo-
zoans, and, doubtless, algae of different kinds,
although diagenesis probably has obliterated from our
detection much of the algal evidence. The dominant
reef dwellers consisted especially of echinoderms,
molluscs, and pentameracean and inarticulate brachio-
pods. But it is not only through recognition of
increasing numbers and diversity of fossils in the
 xonomic sense that suggests an increasing organic
    tigraphy during later Silurian time. It is also
   large volume of skeletal carbonate sands, shed from
reefs and distributed generally to the interreef areas
far and wide that attests to great organic productivity
associated with reefs and their increasing control of
the environment.

THE NATURE OF SILURIAN REEFS

Virtually every reef pundit has his own favorite
twist in defining what a reef is, but most of the
several requirements generally cited are common to the
several variant definitions.

Community of organisms: Most structures called
reefs are owed to a complex community of interacting
and interdependent organisms. Silurian reefs satisfy
the requirement well as shown by Lowenstam's (1950)
analysis of relative amounts of skeletal contributions
by the various groups of organisms and by Shaver's
(1974) related analysis of species diversity of the
Indiana Silurian reefs (figs. 18A and B). "Interacting
and interdependent" are keys here, as it follows that
reef communities should be different from contemporan-
eous nonreef communities, and they are (e.g., see
Lowenstam, 1948; Shaver, 1974; and Griest and Shaver,
1983).

Stop 2 near Celina, Ohio, is one place for obser-
vation, but this requisite is to obviously demonstrable

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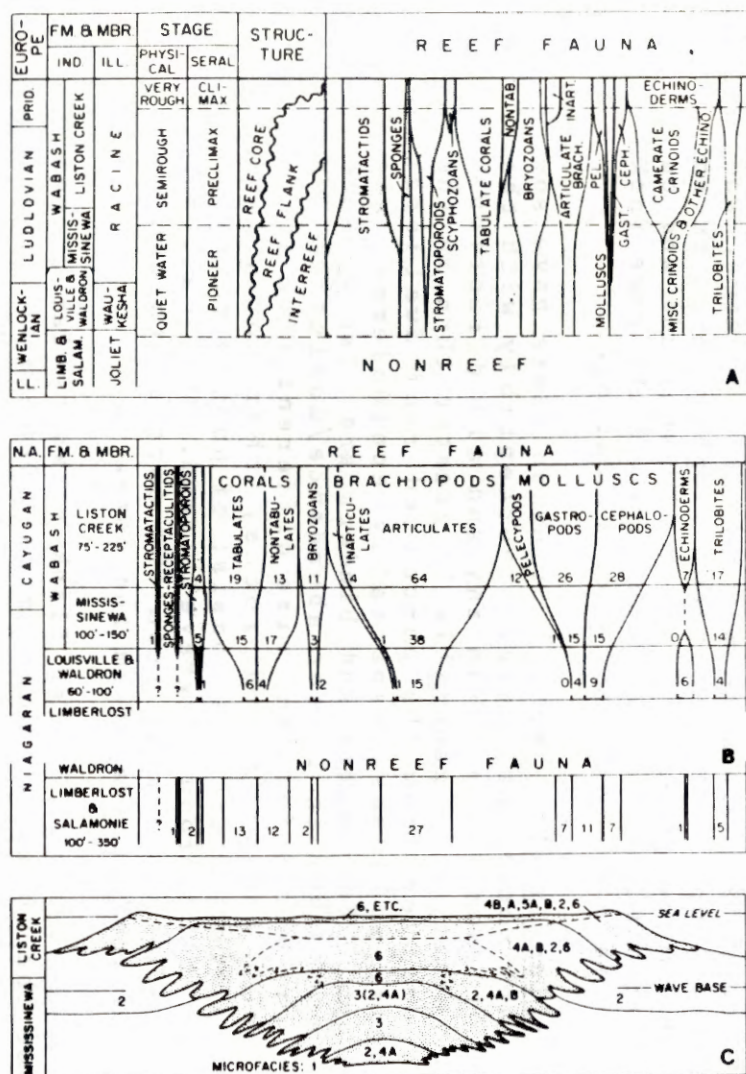
Fig. 17. See figure 12 (middle? Pridolian).

Fig. 18. Three-part analysis of Silurian carbonate buildups of the Great Lakes area as organic-framework reefs. A, Lowenstam's (1950) and Nicol's (1962) diagram showing relative volumes of skeletal contributions and physical and seral stages; stratigraphic fit by Shaver (1974). B, Shaver's (1974) diagram showing macrospecies diversities for Indiana reef faunas; numbers refer to numbers of taxa. C, Textoris' and Carozzi's (1964) diagram showing evolution of microfacies of Indiana reefs, mostly of generation 5 of figures 10 and 11. (See original sources.)

for Silurian reefs in general. Many of the northern
Indiana macrofossil taxa are known only from reefs,
some of the younger pentameracean brachiopods of figure
8 being an example. Further, the interacting and
interdependent idea is part and parcel of the idea of
organic evolution of the reef community, and certainly
the analyses of figure 18 constitue evidence extending
through perhaps as much as 10 million years of time.
(Original sources should be consulted, as the truth of
these statements is dependent upon a differing nonreef
community, which is not analyzed in figure 18.)

Organic framework core: Part of the reef commun-
ity consisted of so-called framebuilders, the sedentary
forms that included both encrusters and binders, the
latter partly in the sense of steel rods in reinforced
concrete. For example, rugose corals and some bryo-
zoans were characterized by vertical growth and so
acted as baffles to trap suspended sediment, sediment
in traction, and sediment derived in place. Stromato-
poroids were prime examples of encrusters and also of
binders of one kind.

One of the enigmas of Silurian reefs, however, is
that their cores commonly lack abundant ready evidence
of encrusters and binders; rather, one sees an abun-
dance of dense bluish-gray dolomitic mudstone lacking
structure. This has left room for geologists to devise
such safe terms as carbonate mud mounds, bioherms, and
carbonate buildups. It also permits speculation on an
algal role unrecognized in its actual magnitude and on
intense diagenesis and/or bioturbation of the core rock
so as to obviate ready fossil identification.

Reef-flank rock: Typical Silurian reefs have so-
called flank rocks that merge imperceptibly with the
core and dip away from it in any and all directions.
Fossil diversity here generally is greater than in the
core and derives from the so-called reef dwellers:
brachiopods, molluscs, especially echinoderms, and
other groups. Encrusters and binders are also present
in flank rocks but in lesser abundance/dominance and
commonly in colony form and size different from those
in the reef core. Flank rocks, therefore, are
dominantly bioclastic and consist of poorly to well-
sorted skeletal carbonate gravel, sand, silt, and mud
that generally fine away from the core as thickness
generally decreases away from the core.

In mature, large reefs, flank rocks by far exceed
in volume the volume of core rocks. Debate continues
today as to how much of the flank debris is autochonous
(and was cemented almost immediately in place) and how
much was allochthonous (travelled down reef slope).
This is an important question bearing on energy rela-

tionships, depth of water, and on the fundamental nature of reefs in themselves.

Flank rocks dip very little in the example of small, fledgling reefs but dip as much as 50 degrees in the upper parts of very large reefs. Such high dip gradually gives way downward within the older part of the reef and is known, wherever observable, to reverse direction so that the dip is inward toward the bottom of the reef. This point has escaped most of the geologists who have attempted to reconstruct the reef environment and the diagenetic history.

The geometric relationships between flank and core as described above are suggested by the lower part of the cross section shown in figure 19. The upper part is rather theoretical because if such reefs exist or existed, developed to the atoll stage, they are either in the subsurface, there not well understood, or they have been eroded below the atoll structure if they are outcropping reefs.

Figure 19 shows two other geometric aspects of most Silurian reefs: (1) They describe broad inverted cones in cross-sectional shape. This is to say that they are not flat bottomed as much of the literature suggests, and it is to say that as the reefs grew upward they also grew laterally, expanding over the penecontemporaneously accumulated interreef rocks. (2) In plan view, many Silurian reefs are circular to asymmetrically ovate in shape; in rarer examples, some are fairly elongate.

Much of this described geometry is borne out in actual examples of exposed reefs in northern Indiana (fig. 20).

Reef zonation: Given the geometry described above and the relationship between core and flank, Silurian reefs are necessarily zoned. Two kinds of interrelated zones are present, biozones and lithologic zones, and, obviously they are responses to both physical and organic factors in the environment. (See examples, one real and one theoretical, shown in figures 20A and 18C.)

Topographic relief: Silurian reefs, and reefs in general, must have had, by definition, topographic relief above the sea floor. This requisite is related to the idea that the organic community had the capacity to raise its level above the surroundings, in fact, to raise its own structure into the zone of wave action. (See the named reef stages, relating to depth and energy of the environment, in figure 18A.) The idea of reefs growing up out of deep water and into the surf
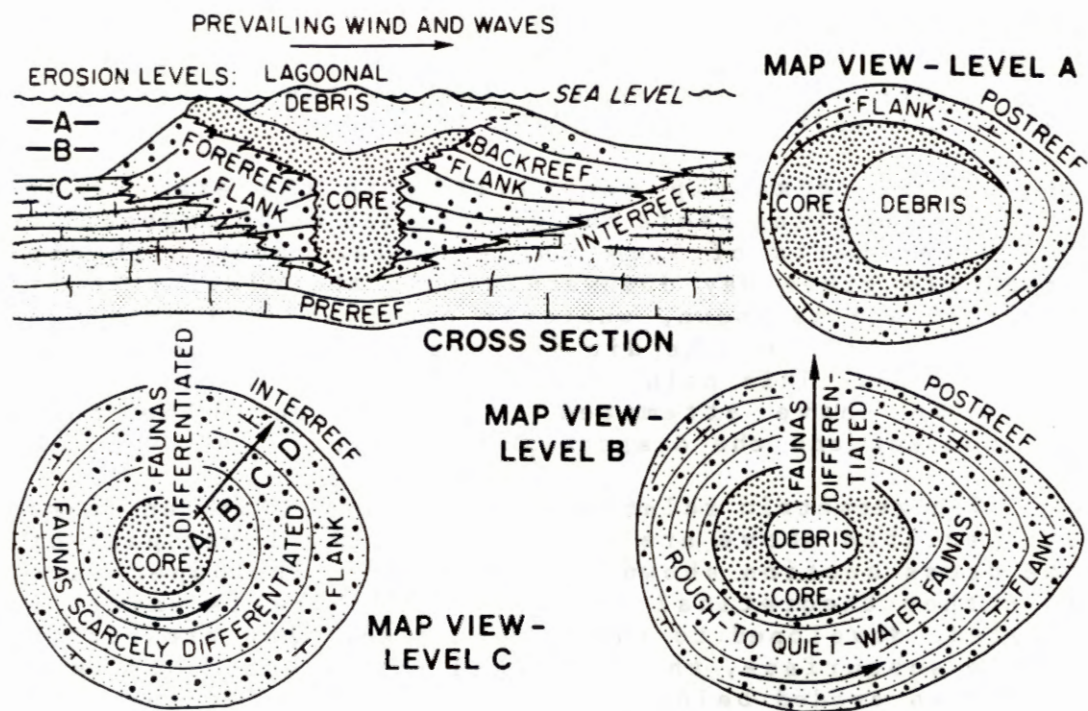
PREVAILING WIND AND WAVES

Fig. 19. Partly hypothetical cross-sectional and eroded map-view Silurian reef relationships. From Shaver (1977) as modified in part from Lowenstam (1950).
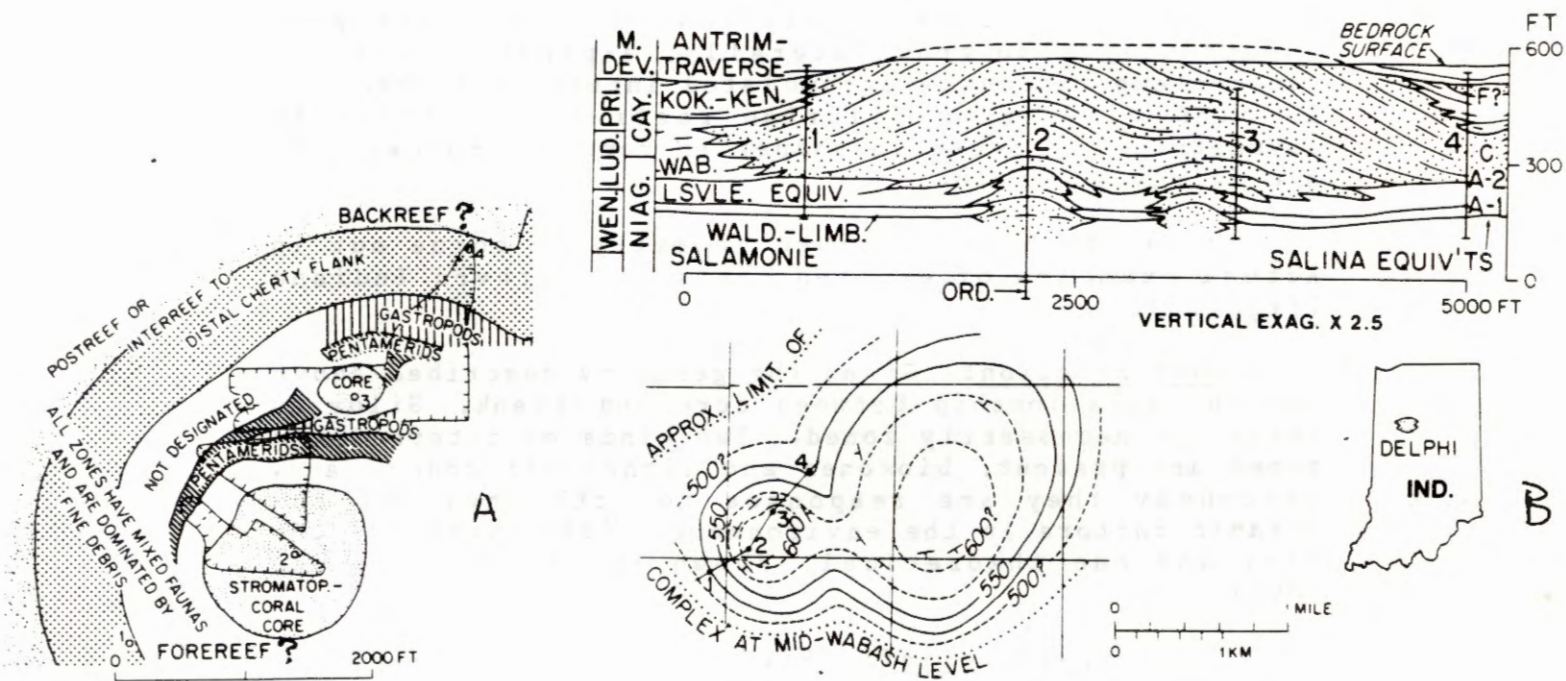

Fig. 20. Delphi Reef, Indiana. A, Biozonal map made from data collected from quarry surfaces and core holes; B, Cross-section showing fitful history of reef growth. Two parts are not to same scale. Note: the map view should be considered essentially as an erosion surface, not as a single growth plane. From Indiana University Paleontology Seminar (1980).

level (implicit in fig. 18A) is oversimplified for many reefs, because it is now known that many silurin reefs originated in shallow water, and if they reached great thickness, that thickness was accommodated by subsidence of the area (or by rise in sea level), not by an initial great depth of water.

Resistance to wave action: The ability to resist wave action has often been applied as the reef test for fossil carbonate buildups that pass all the other reef tests. Surely, this is mostly an ambiguous test. If the fossil structure is there, exhibiting relief and zoned relations between core and flank, it obviously was resistant to whatever wave action was present.

Intertonguing with interreef strata: Hardly any Silurian reef is known that does not intertongue with contemporaneous interreef sediments, but some Michigan Basin pinnacle reefs may lack a large contemporaneous nonreef equivalent. This intertonguing relationship must be understood if reef environments (e.g., depth of water) are to be properly reconstructed. Often, however, this factor has been ignored.

Settling and other deformation: Silurian reefs show much evidence, direct and indirect, of internal structural adjustment, part of it having resulted from diagenesis. Such adjustment affected the underlying, laterally equivalent, and overlying nonreef rocks. This phenomenon is not a requisite of the reef definition, but it is a very important factor, mostly ignored by geologists, to be reckoned with for environmental reconstruction and for understanding diagenetic history.

An example may be posed as a question: Are flank dips of 50 degrees primary, or are they secondarily attained, and how does the answer affect interpretation of the reef? Indeed, how does it affect exploration for hydrocarbons associated with reef structures?

Increasing control on sedimentation: Once-living reefs, properly identified as reefs, exerted some controls on their own environments and in fact increasingly modified their environment. Much evidence has been cited in this reagard of the Great Lakes-area Silurian reefs (e.g., Lowenstam, 1948; Shaver, 1974; and Droste and Shaver, in preparation).

It includes the idea that the upward-noted difference between Mississinewa and Liston Creek rocks, to be seen during this field trip, may have resulted from a multitude of reefs reaching such maturity as to shed huge amounts of carbonate sands that became distributed throughout the interreef areas and thus determined the

basic character of the regionally distributed Liston Creek Member (Wabash Formation). Another example is the idea that mature reef growth in peripheral basin areas helped isolate the basins sufficiently to permit salt deposition.

THE STOPS

Napoleon Quarry, Indiana, Stop 1

The Napoleon Quarry of the Newpoint Stone Co. is located 1 mile east of Napoleon, Ripley County, in the NE 1/4 sec. 29, T9N, R11E. In 1980 about 43 feet of section was exposed in the quarry walls and extended upward from Upper Ordovician rocks (Whitewater Formation) in the quarry floor through the Brassfield Limestone and the Osgood and Laurel Members of the Salamonie Dolomite (middle Llandoverian to middle Wenlockian). (See figures 10 and 21.)

The Brassfield lithology here is characteristic for Indiana, consisting of brassy-brown coarsely bioclastic limestone. In some places, however, the Brassfield contains shaly intercalations reworked from the Ordovician surface at the time when Early Silurian seas transgressed the Indiana area from three directions (figs. 12 and 13). Ordovician microfossils, including conodonts, are often found mixed with Silurian fossils, even as high as 30 feet above the Ordovician-Silurian unconformity (Pinsak and Shaver, 1964), but proper taxonomic identification of Silurian conodonts (Rexroad, 1980) places the Napoleon section well up in the Llandoverian Series, suggesting that the nearness of this section to the Silurian land mass called Ripley Island (see fig. 13) in northeastern Indiana resulted in late arrival of the earliest transgressive Silurian sea.

An unconformity representing appreciable time lapse is present above the Brassfield, which here is lacking its upper member, the Lee Creek Member, and in places in southeastern Indiana the Brassfield is entirely absent so that Osgood rocks lie next above the Whitewater Formation.

Question: What field-type evidence here, if any, suggests the presence of a regional unconformity?

Above the Brassfield, the Osgood and Laurel Members represent the beginning of a widespread invasion of the continental interior of very long duration. Throughout the field-trip area, no major unconformity of regional scope can be found within Silurian rocks, which are as young as middle Pridolian (very late
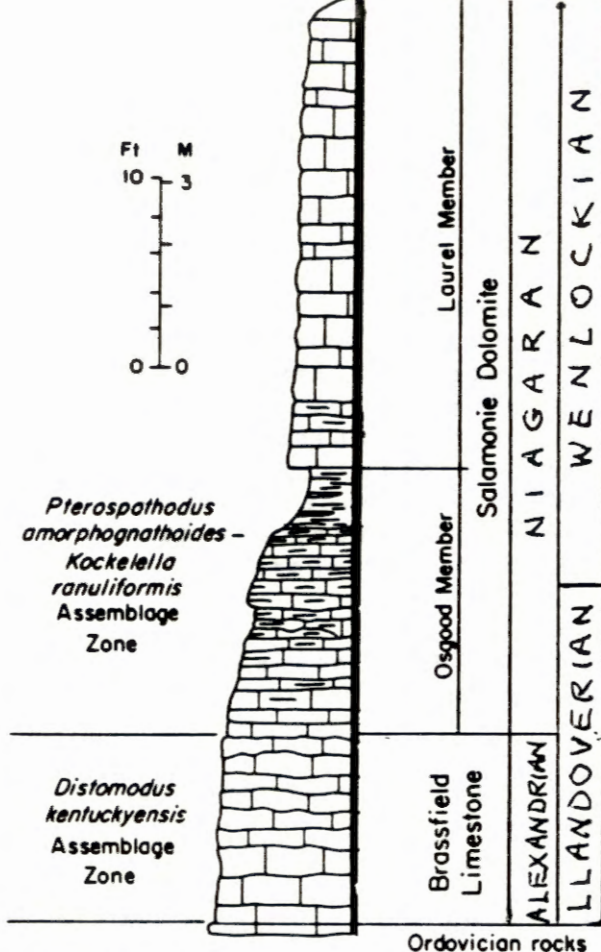
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Fig. 21. Columnar section showing lithologies and conodont zonation of rocks exposed in the Napoleon Quarry, Ripley County, Indiana. Modified from Rexroad (1980).
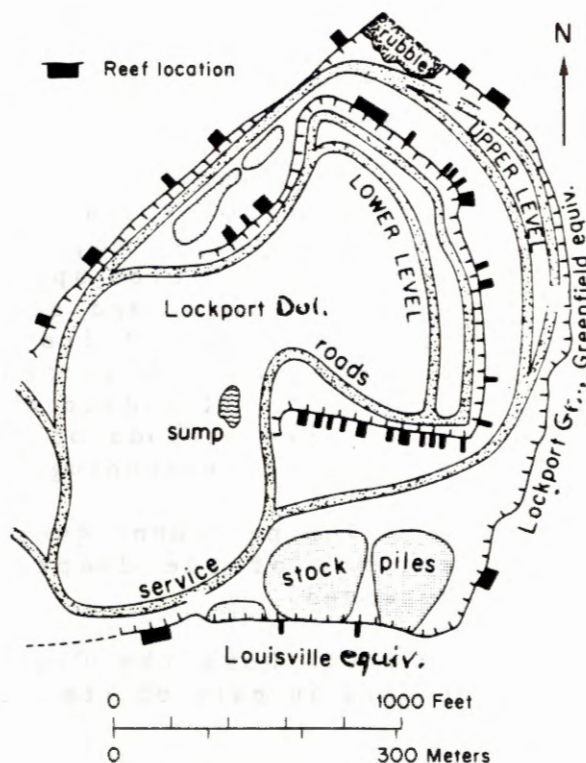

Fig. 22. Map of the John W. Karch Stone Co. quarry near Celina, Ohio. From Griest and Shaver (1982).
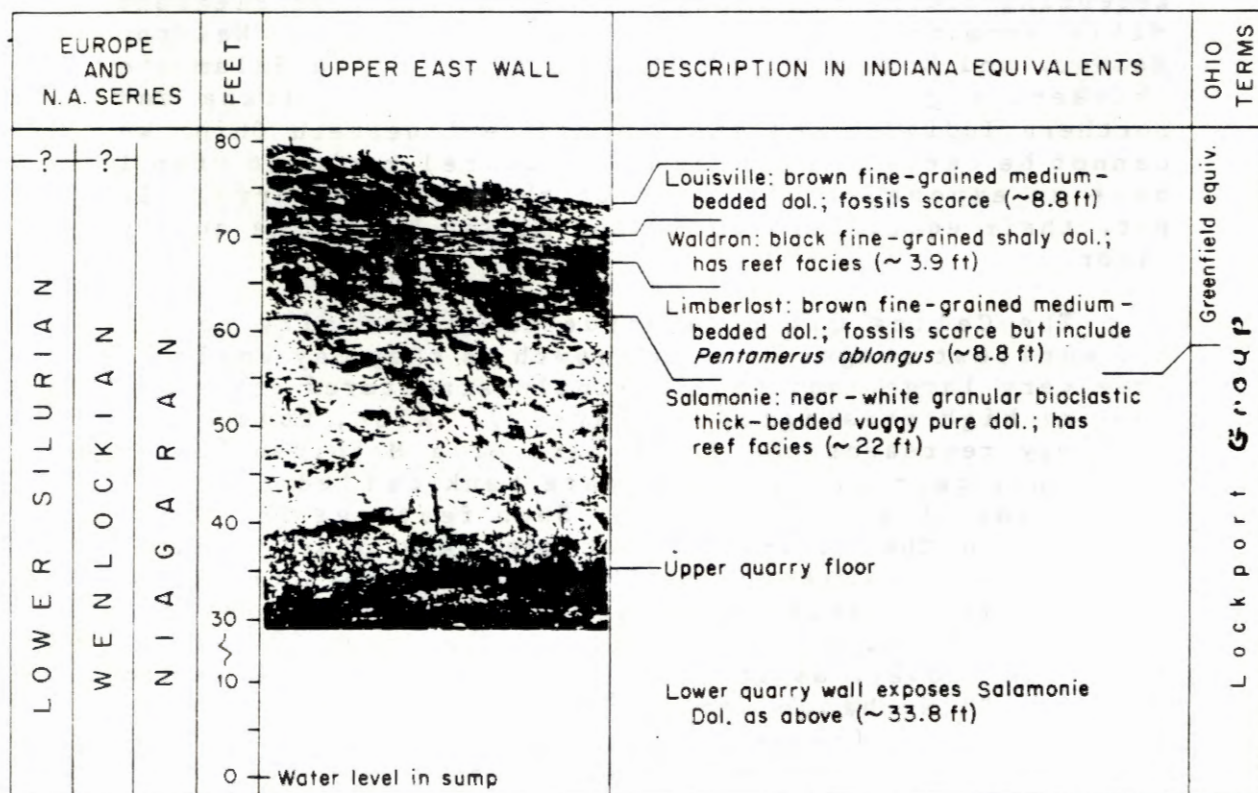

Fig. 23. Chart depicting the stratigraphic section along upper northeast quarry wall in John W. Karch Stone Co. quarry. Modified from Griest and Shaver (1983).

Silurian) where found below upper Lower Devonian rocks in part of the northern Indiana outcrop area.

The Osgood-Laurel section, consisting of shaly limestone below and purer, but cherty limestone above, is the principal objective for this stop. Overall, the Salamonie section appears to represent a shallowing-upward history, and one objective of the entire field-trip is to build from this stratigraphic level and observation. A succession of such sequences may be expected. If indeed this is found to be true, any two successive periods of shallowing had to be separated by a period of deepening.

Two pertinent questions are: (1) Will actual rock records of the deepening (transgressive) events be observed?

(2) Does the Osgood itself here suggest such a record in part of its vertical extent?

Celina Quarry, Ohio, Stop 2

The Celina Quarry (fig. 22) of the John W. Karch Stone Co. is located 4 miles west and 1/2 mile south of Celina, Mercer County, Ohio, in the NE 1/4 sec. 5, T6S, R2E. The quarry is excavated in about 80 feet of dolomite assigned, in indiana terminology and in ascending order, to the Salamonie Dolomite and Pleasant Mills Formation (Limberlost Dolomite Member, Waldron Member, and Louisville Member; fig. 23). The Salamonie thickens significantly between southern Indiana and northern Indiana, and here in adjacent western Ohio, we cannot be certain that the upper Laurel rocks at stop 1 have an exposed equivalent in the Celina Quarry. If not, their equivalent would not be far below the quarry floor.

The Celina Quarry affords an opportunity to see the earliest stages of reef growth as they may apply to some very large, apparently single-structured reefs (as seen at high stratigraphic levels). Also, this exposure may represent the lower part of a Michigan Basin-fringing, barrierlike carbonate bank called the Fort Wayne Bank (figs. 14 and 44). Such features are often depicted in the literature but are very poorly under-stood. (See discussion in Shaver and others (1978, p. 25).) Ohio stratigraphic terminology has not been applied definitively here, because the upper 20 feet of rocks are midway, as it were, through a regional facies change. This change occurs between two kinds of car-bonate rocks: (a) dense algal-laminated rocks that represent restricted environments and that are called the Greenfield Dolomite nearby and part of the A-

carbonate unit of the Salina Group in subsurface basin sectins (fig. 10) and (b) coarser grained bioclastic, even reefy rocks that are typical of the Guelph Dolomite of the western New York-Ontario area. Probably, Ohio geologists of a generation ago would have assigned the lower, whitish rocks to the Cedarville Dolomite and the brownish rocks to the Guelph Dolomite, both formations belonging to the Lockport Group in modern Ohio Geological Survey terms (fig. 10). In these terms, the lower whitish pure rocks would be called the Goat Island Dolomite (named from the Niagara Falls area). If terminology were chosen here to emphasize the lithologic character of the upper brownish rocks that represent a somewhat restricted environment, the term Tymochtee Dolomite could apply to the uppermost 10 feet of rocks (Louisville equivalent) present in the Celina Quarry (figs. 10 and 23). That is, an uppermost part of the section labelled as "Greenfield equivalent" of figure 23 could correlate with the lower Tymochtee.

Back to Indiana terminology: The upper Salamonie and equivalent rocks are hosts to many reefs of generation 3 in the scheme shown in figures 10 and 11 throughout much of the southern Great Lakes area. Dozens of such reefs are seen in the Celina Quarry (figs. 22 and 24), but insofar as can be ascertained, considering how the bedrock surface truncates the section, all the Celina reefs arising from the Salamonie were aborted just below or within the fine-grained brown rocks of the Limberlost Dolomite Member (Greenfield equivalent) that overlie the whitish Salamonie rocks.

The inexperienced observer may be surprised to see the label reef applied to the many massive bluish-gray carbonate structures that have digitate but diffuse boundaries with the enclosing whitish rocks. Tell-tale fossils are not all that abundant, but diagenesis has wrought great changes within these rocks, destroying much of the former nature of the skeletal contributions. Nevertheless, figure 25 reveals a marked contrast between two kinds of fossil communities, one from within the rocks called reefs in this account and the other from without.

Five pertinent questions are: (1) How well do these reefs, at their small size, fulfill the prophesies from Lowenstam's (1950, 1957) and Shaver's (1974) reef models? (See figure 18.) (This question pertains both to stage of community evolution and to reef structure, e.g., relative amounts of reef-core rock and reef-flank rock.)

(2) How deep was the water here in which the reefs began to grow, and does the answer fit well with the
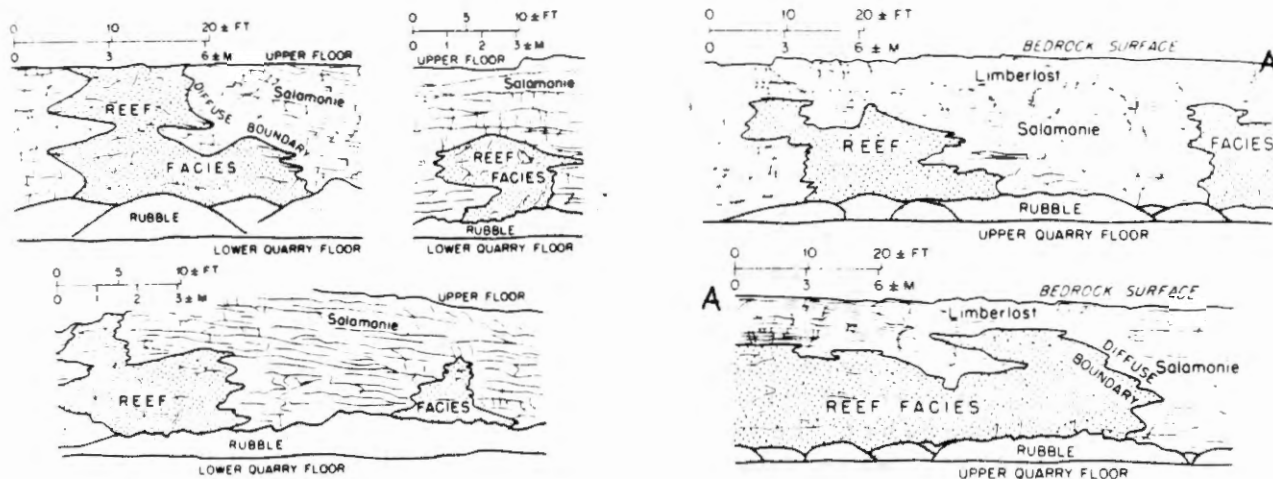
Fig. 24. Sketches of reefs exposed in walls of John W. Karch Stone Co. quarry
showing reef and interreef relations and abortion of reefs below or within the
Limberlost Dolomite Member (Pleasant Mills Formation). From Griest and Shaver
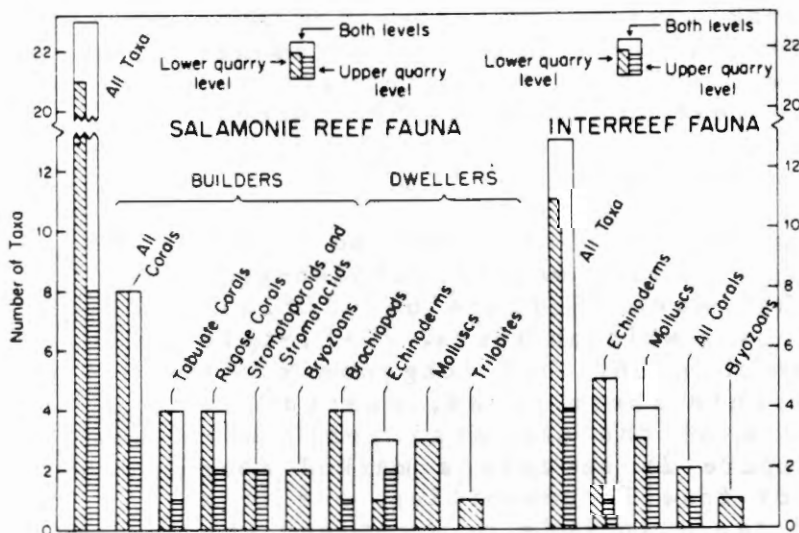(1983).

Fig. 25. Histograms showing comparison of the
Salamonie reef and interreef faunas in the
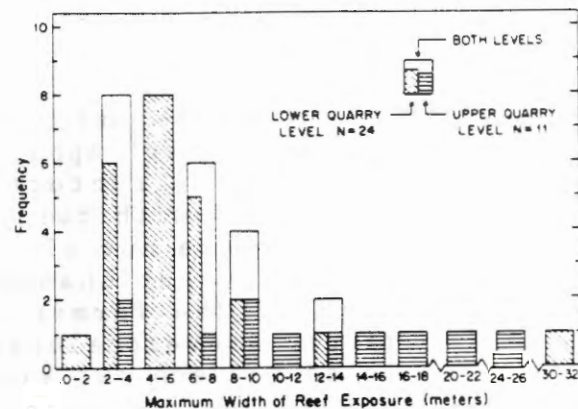John W. Karch Stone Co. quarry. From Griest
and Shaver (1983).

Fig. 26. Histogram showing size dis-
tribution of reefs exposed in vertical
walls of the John W. Karch Co. quarry.
From Griest and Shaver (1983).

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Lowenstam model and with what can be called the more modern University of Wisconsin Silurian reef model? (See such a model as discussed by Shaver and Sunderman, 1982, and further noted and referenced in Shaver, Sunderman, and others, 1983.)

(3) Are there differences between sizes of reefs exposed in the two quarry levels, and are there differences in numbers of reefs between the two quarry levels? If so, explain. (See figure 26.)

(4) Would you expect the Celina reefs to be randomly distributed or predictably distributed? Why?

(5) Would you expect the pattern of reef abortion to be predictable with respect to stratigraphic level and geographic position, and can you think of two possible reasons for reef abortion that would fit the field evidence?

The thin dark-colored strata, a few feet thick and seen high in the upper quarry wall, consist of argillaceous to shaly dolomite assigned to the Waldron Member (Pleasant Mills Formation) in Indiana terminology. These rocks host small and quickly aborted lenslike reefs (generation 4, fig. 10) of normal-marine aspect, insofar as limited access permits determination. These reefs may be visible in the southernmost quarry walls adjacent to stock piles of crushed stone. (See figures 22 and 27.) This phenomenon of two successive but quickly aborted reef generations is repeated throughout the eastern Indiana-western Ohio area within the same stratigraphic interval (e.g., as shown in fig. 28).

The Louisville rocks, next above the Waldron, nearly repeat the Limberlost lithology, but Waldron-like sediments are found within the lower Louisville rocks.

Overall, the Celina section appears to represent two periods of normal-marine environments and two of restricted environments. (See figures 14 and 15 for general regional portrayals of these two kinds of environments.)

Two pertinent questions are: (1) How should the Celina section be analyzed in terms of shallowings (regressions) and deepenings (transgressions)?

(2) Is the actual rock record one of shallowing-upward only, deepening-upward only, or both? And if the latter, weighted in what direction?
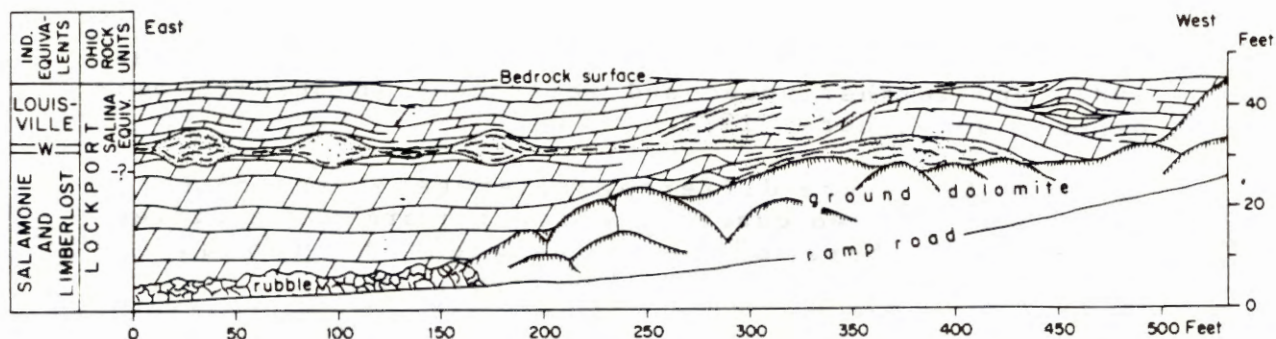
A final question: The thin bluish-gray dense

Fig. 27. Sketch of south wall, near ramp, of John W. Karch Stone Co. quarry showing a series of lenslike reefs developed in Waldron-equivalent rocks that represent a generation of reefs younger than the generation of aborted reefs in the Salamonie-equivalent. From Shaver (1974).
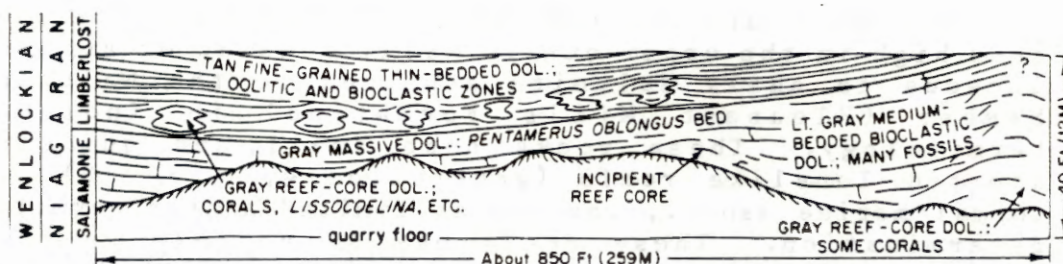

. 28. Sketch of north wall of John W. Karch Stone Co. quarry near New Corydon, Adams County, Indiana, showing two generations of small aborted reefs in stratigraphic relations similar to those seen in the Karch quarry near Celina, Ohio. From Shaver and others (1978).
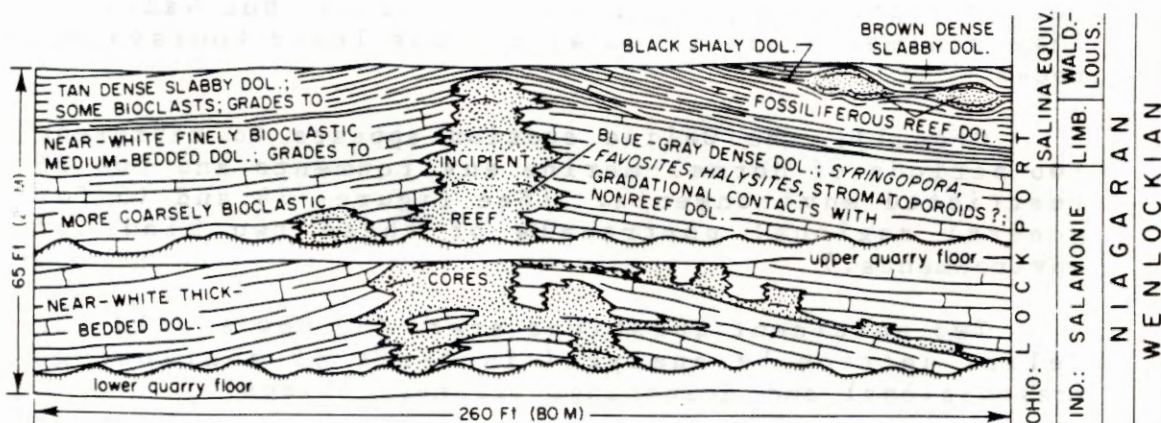

Fig. 29. Composite, idealized sketch of reefs of two generations and their stratigraphic relations as seen in the two levels of the John W. Karch Co. quarry at Celina, Ohio. From Shaver and others (1978).

carbonate-mudstone stringers seen in many places to extend outward for many feet from reef cores have been said (in a thesis by Ganley, 1984) to represent storm deposits. What do you think? (One such stringer is idealized in figure 29 herein.)


Klintar and Quarry Area, Carey, Ohio, Composite Stop 3

The town of Carey is located in northwestern Wyandot County, Ohio. Structurally, it is east of the axis of the Findlay Arch (fig. 2) and, therefore, is at the edge of the Appalachian Basin or what sometimes has been called, for Silurian time, the Ohio Basin. Here, exposed in quarries operated by the National Stone and Lime Co. and represented geomorphically, is one of the most remarkable complexes of Silurian carbonate build-ups to be seen anywhere. Yet, remarkably little has been written about this place since Cumings (1930) described these buildups as reefs and vaguely referred to them as part of a great barrier reef. Indeed, this place cries out for modern investigation and interpretation.

This complex carbonate buildup appears to be part of a regionally distributed barrierlike, certainly reeflike in part, massive structure that fringed a part of the appalachian Basin as it was developing during Silurian time in northern and northeastern Ohio (figs. 14 and 30). Here, then, is a second opportunity to appraise in firsthand view one of the features vaguely referred to in the literature as barrier reefs or massive carbonate banks.

This place also affords an opportunity to appraise the classic so-called "Niagaran-Cayugan unconformity," which even today is still proposed by some persons (following Cumings, 1930) to separate all reef-bearing rocks ("Niagaran"; the whitish rocks at Carey) from all the salt-bearing (in basins) rocks (Salina Group, that is, "Cayugan"; the brownish rocks at Carey).

Stop 3A: This stop or stops, east of Vanlue (fig. 31), west of Carey, and along the county road, is to view the geomorphic expression of the carbonate build-ups, that is, these physiographic features called klintar (singular, klint). These klintar are among the most striking to be seen in the Great Lakes area. They rise as much as 100 feet above their surroundings (Cumings, 1930; fig. 31 herein). Glacial sculpturing doubtless was the primary shaping process, but such a process should have been guided by the presence of reef-framework areas within the general carbonate bank. This probable relationship has not been made clear here, but some opportunity to observe may be afforded

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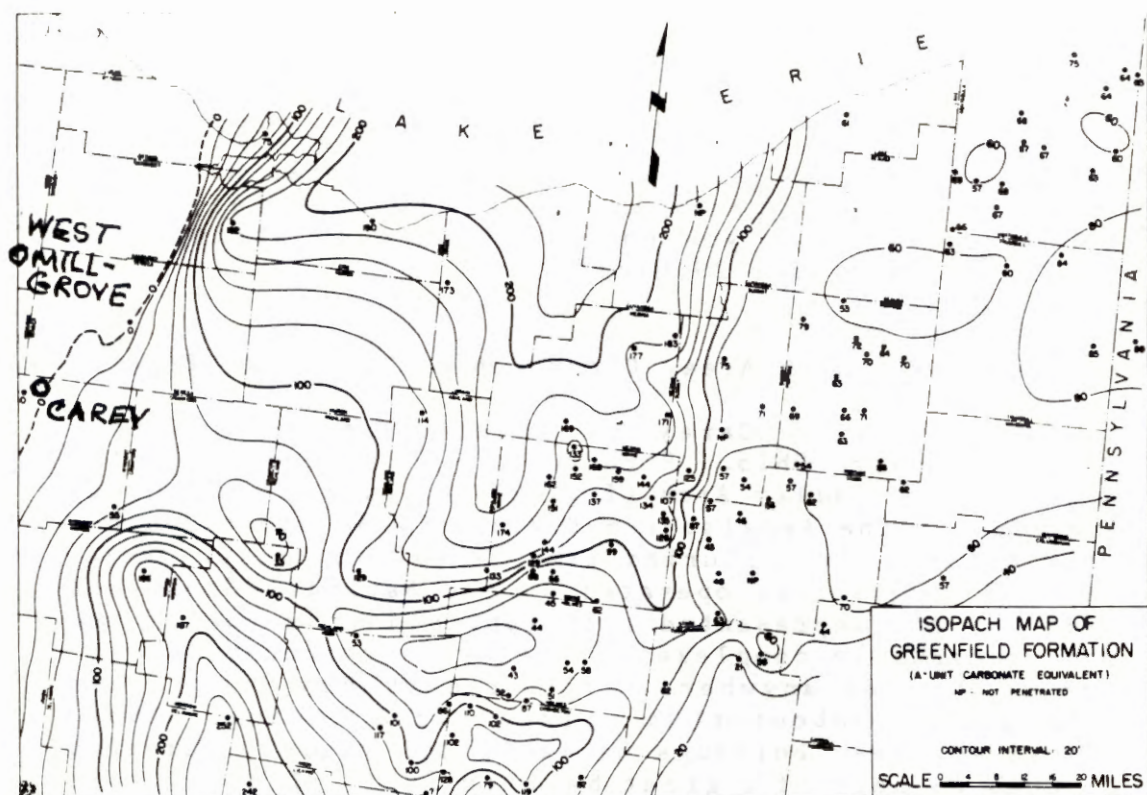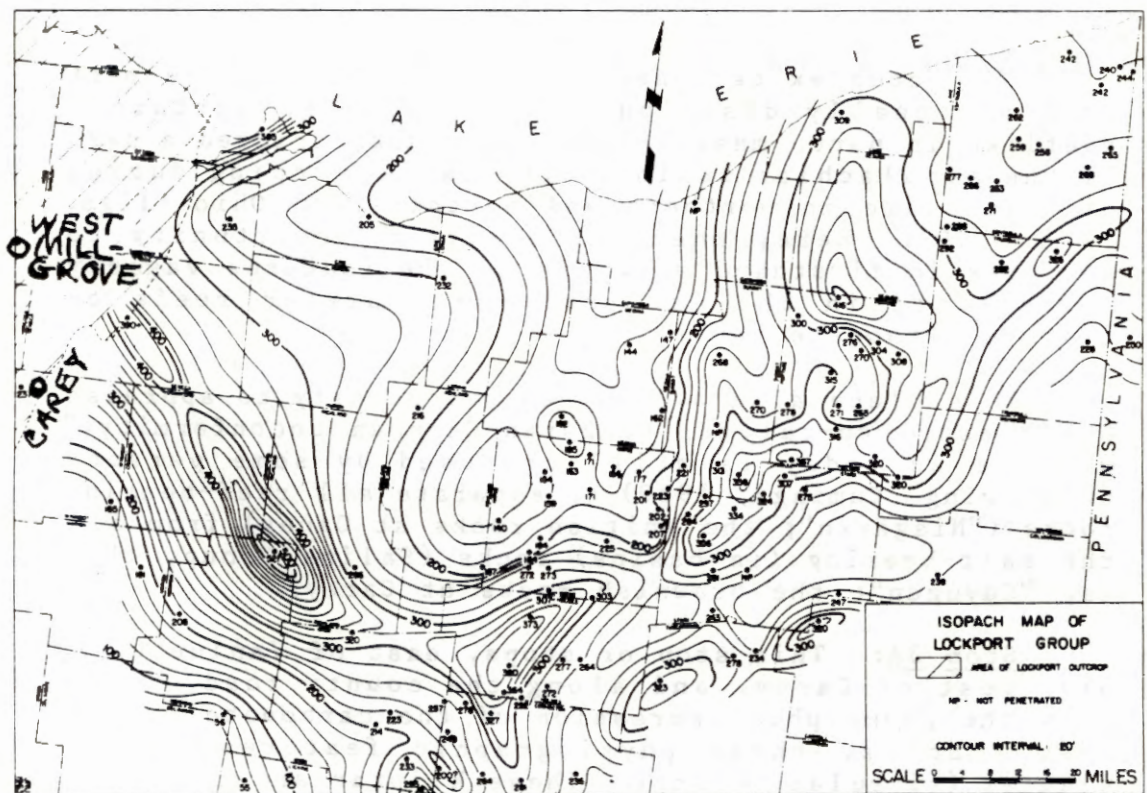
Fig. 30. Thickness maps of the A-unit carbonate rocks of the Salina Group (A) and of the Lockport Group (B) in northeastern Ohio. From Ulteig (1964). Note complementary thickness relationships between the two groups of rocks, proposed here to represent a facies relationship, about which, however, Ulteig was uncertain. Ulteig's Greenfield includes all of the A unit (Salina), which leaves no provision for the Tymochtee Dolomite, thought by Janssens (1977) to be represented by A-2 carbonate rocks.
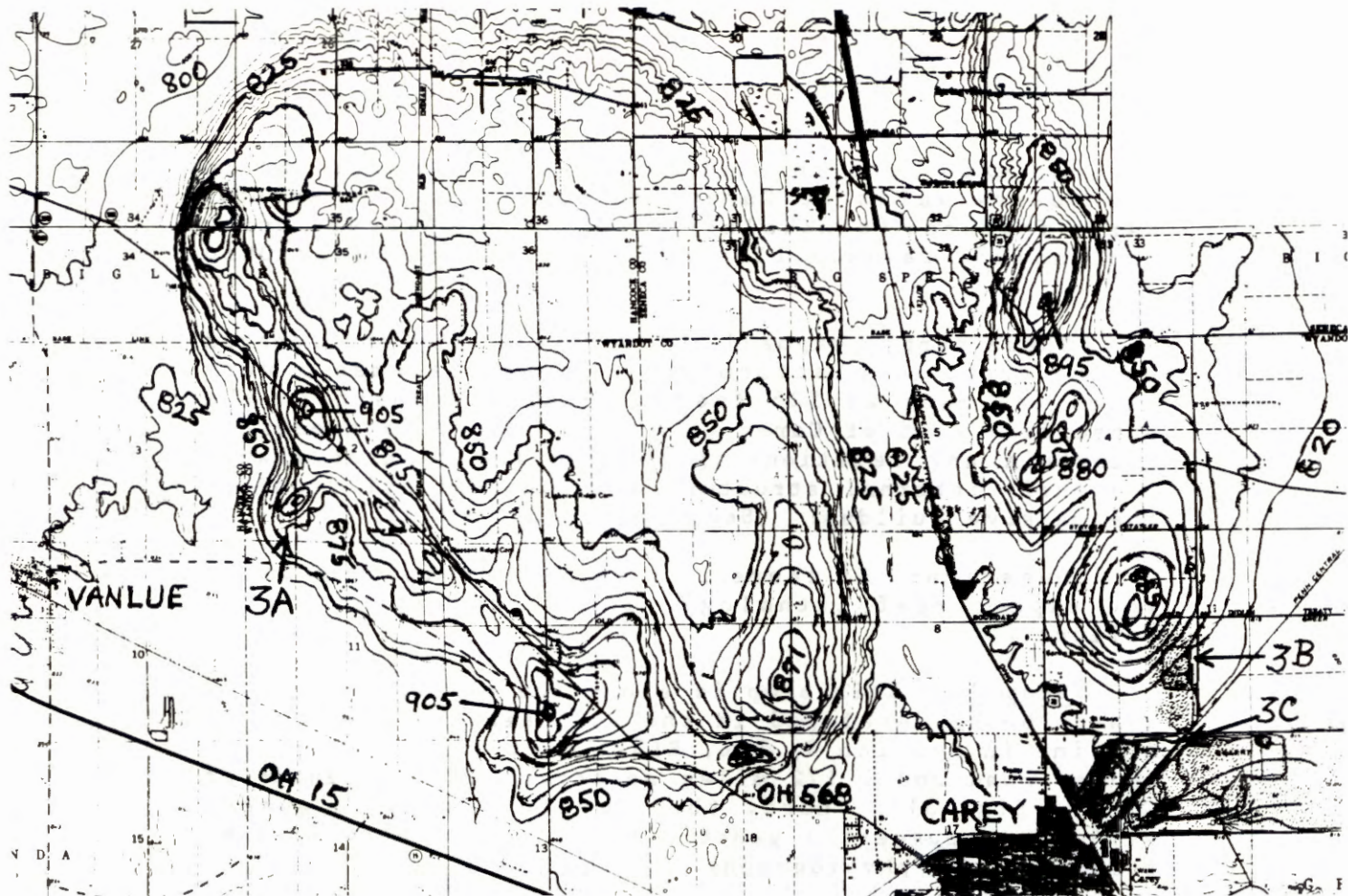
Fig. 31. Map showing several klintar, some having relief greater than 75 feet, in the Carey area of Ohio. Reduced from the U.S. Geological Survey Carey and McCutchenville Quadrangles. Contours are selectively reinked. 3A, B, and C refer to field-trip stops.
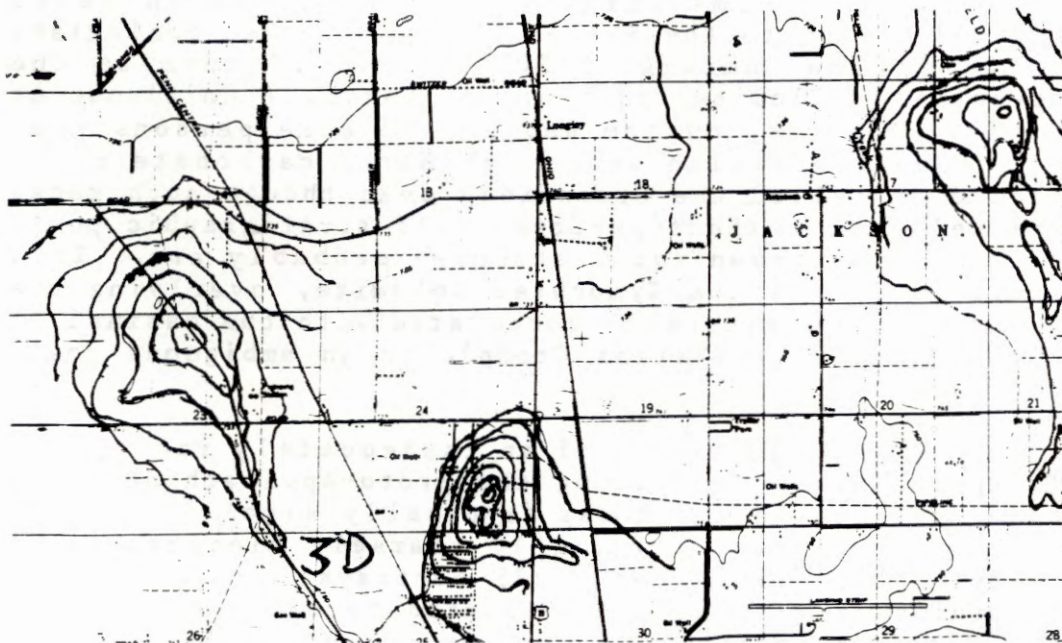

Fig. 32. Map showing three probable klintar having 25 or more feet of vertical relief above their surroundings in the area 3 to 4 miles north of Fostoria, Ohio. Reduced from U.S. Geological Survey Fostoria Quadrangle map. Reefs as large as 1 mile in diameter are suggested. Stop 3D is located approximately.

by poor exposures in road cuts east of Vanlue and in the quarry walls at Carey (no permission to enter). Karst features (sinkholes) also may be observed here, and include caverns (Indian Trail Cavern along Ohio 568).

These partly exposed buildups at Carey are located on the arch, or platform side of what becomes a very thick (as much as 525 feet) elongate deposit in the subsurface east of Carey (fig. 30). Study is needed to ascertain any relationship between the klintar shapes and their internal structure and the regional trend of the massive buildup. (See figures 30 and 31.)

Question: If there is a relationship, how would you expect reef lithology, zones, and structure to reflect it?

Stop 3B: This stop is along the eastern edge of a quarry being developed in the southeastern quadrant of a klint in section 9, T1S, R13E, west of a north-south county road and 1 1/2 miles northeast of the center of Carey (fig. 31). Here, the structure seen in quarry walls does suggest a genetic relationship between reef structure and physiography of the klint.

The whitish rocks (below) belong to the Lockport Group at a stratigraphic level that is probably higher than that of the Goat Island Dolomite; that is, they probably are Guelph (Oak Orchard) in age in New York and Ontario terms (fig. 10). The brownish rocks (above) belong to the Salina Group, and most geologists would follow Cumings (1930) and assign them to the Greenfield Dolomite (part of the Salina A unit) out of habit. This is, custom suggest to some persons that all lowest brownish dense laminated carbonate rocks should be called the Greenfield even though such rocks are well above the type-Greenfield stratigraphic position, as the brown rocks at Carey probably are. This practice leaves the Tymochtee Dolomite, overlying the Greenfield and generally correlated with the basinal A-2 carbonate unit (Salina Group), in an ambiguous position.

The problem is one of an inadequately recognized facies relationship, along the proto-Appalachian Basin edge, between Salina rocks (typically algal laminated) and Lockport rocks (typically coarsely bioclastic and reefy). (See Janssen's (1977) portrayal of such relationships in section BB' presented herein under stop 4 and Ulteig's isophachous mapping of such relationships should in figure 30 herein.)

In this guidebook, the brownish rocks are prefer-ably assigned to the Tymochtee Dolomite (surface term-

inology; subsurface equivalent, A-2 carbonate unit; both of the Salina Group). The Greenfield (defined by lithologic character, as well as by stratigraphic position) would be absent by reason of facies change (into Lockport rocks).

Stop 3C: This stop (fig. 31) is 1/4 mile southwest of stop 3B, along the southeast side of a northeast-southwest road and railroad (NE 1/4 sec. 16, T1S, R13E). Here, southeast of the tracks and at the quarry edge, can be observed close up the Lockport and Tymochtee? (A-2 carbonate) lithologies and the contact between them.

Question: What is your opinion of evidence here for the so-called "Niagaran-Cayugan" unconformity? Carey is one of the places where such an unconformity has been claimed on some earlier field trips (e.g., during the Summerson and others 1963 field trip). The basis often has been a weathered clayey zone atop localized reef structures and beneath the brownish commonly laminated Salina rocks.

Question: What is your opinion of the use of this kind of evidence as claim for a regional unconformity?

Stop 3D: If for no other result, this stop (fig. 32) is for viewing a set of possibly three klintar that can be seen north of Fostoria in Perry and Jackson Counties, Wood County, along the route to stop 4. These physiographic features rise as much as 30 feet above their surroundings and suggest reefs having areal dimensions as great a 1 mile (fig. 32). They are located on the same northwest-southeast trend of a massive barrierlike carbonate bank (Lockport), as was noted for the Carey area, that fringed a Silurian basin in what is now the western Appalachian Basin area (figs. 14 and 30).

West Millgrove Quarry, Ohio, Stop 4

The West Millgrove Quarry (fig. 33), operated by the MacRitchie Materials Co., is located east of Ohio 199 at the southeast edge of West Millgrove, Wood County (SE 1/4 sec. 4, T3N, R12E). Structurally and paleoenvironmentally, the geologic section is similar to that of the Carey locale. (stop 3), but here the field-trip group has a hands-on opportunity.

By the late 1970's the quarry had been developed at two levels. The younger, lower level exposed two normal-marine reef structures rising from fairly pure bioclastic and biostromal dolomite of the Lockport Group (fig. 34). These structures were called "patch
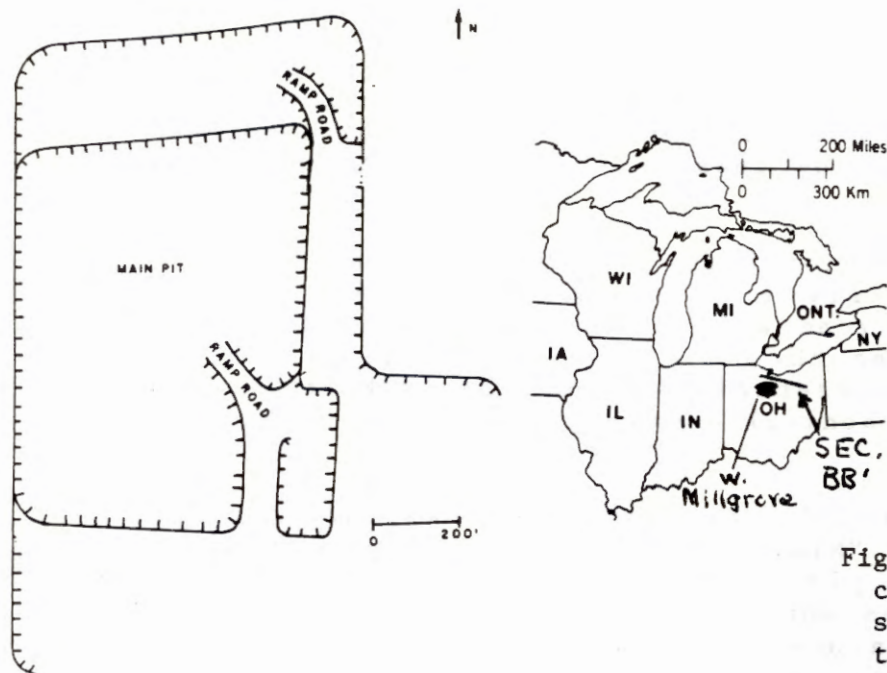
Fig. 33. Map of the MacRitchie Materials Co. quarry at West Millgrove, Wood County, Ohio. From Lehle (1980).
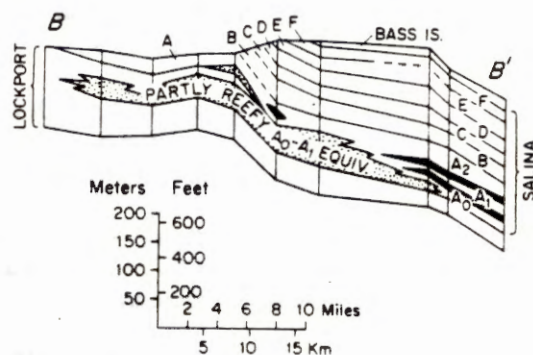
Fig. 37. One of a suite of similar cross sections prepared by Janssens' (1977) to show his interpretation of a transgressive Lockport-Salina facies relationship along the western Appalachian Basin (eastern Findlay Arch), including application to the West Millgrove area.

Fig. 34. Sketches of parts of walls in MacRitchie Materials Co. quarry as observable in the late 1970's. A, Composite section in southeastern part of quarry showing reefy algal rocks of the Salina Group and B, northwestern part of main pit showing reef structure in the Lockport Group. From Shaver and others (1978).

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reefs" by Lehle (1980) and were located along the northwest corner and the south wall of the main pit (see fig. 33). They consist of some reef-framework rocks (corals, stromatoporoids) 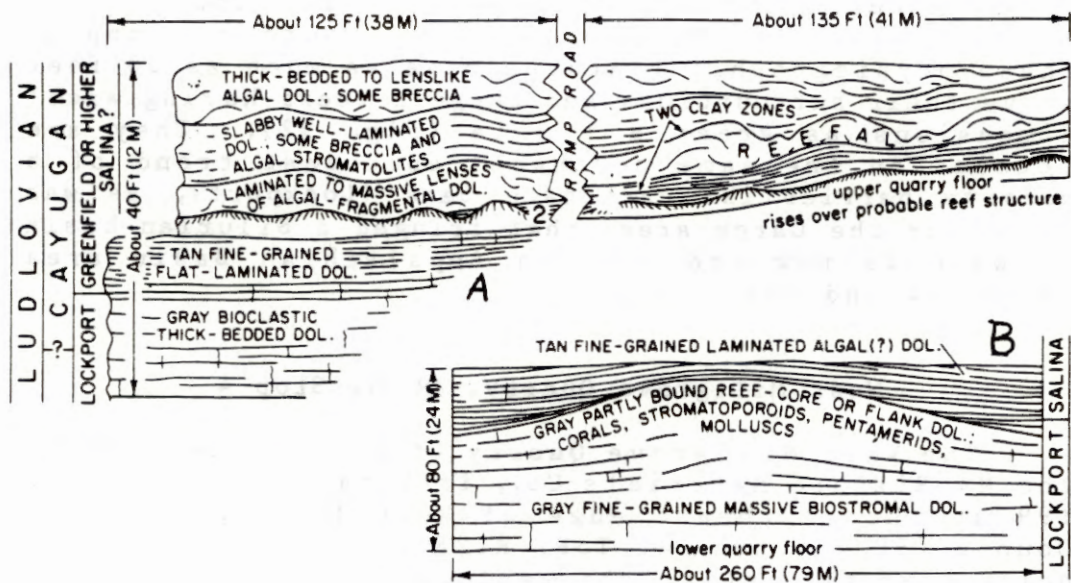and reef-flank rocks exhibiting several reef-dweller fossils (figs. 34 and 35A). These buildups in 1980 could be seen to have been aborted amidst the generally overlying brownish algal-rich rocks of the Salina Group.

The upper quarry level in 1980 exhibited an interesting suite of brownish fine-grained to micritic algal-rich dolomites of the Salina Group, including algal stromatolites, breccias, and reefy algal masses (fig. 35).

Shaver (1977) and Shaver and others (1978), in the course of three visits to the quarry, preferred to emphasize a degree of conformity between the Lockport and Salina Groups, especially as suggested by transition zones in off-reef locales and even along the lower reef flanks, which would be parallel with observations elsewhere of local unconformities atop reefs, in places with clayey seams and pockets, that die out down the reef flank.

Lehle (1980), however, chose to emphasize the evidence of unconformity atop the reefs here, including hard grounds and other evidences, and, in fact, he drew in the classic "Niagaran-Cayugan unconformity" between the bioclastic Lockport rocks and the laminated Salina rocks (fig. 36). He thereby totally ignored Janssens' (1977) subsurface work that advocates a transgressive Lockport-Salina facies relationship (fig. 37) along the west flank of the Appalachian Basin (Ohio Basin of some authors for Silurian time). (Compare the two parts of figure 36; also, see figures 10 and 37.) In disagreement with Lehle, therefore, another judgment is that the laminated Salina rocks here belong to a higher-than-Greenfield interval, that is, to the Tymochtee Dolomite (Salina Group) in surface terminology and to the A-2 Salina unit in subsurface terminology. This is to say that reefy Lockport rocks accreted here after the time of first salt deposition in the Michigan Basin.

The field-trip group should appraise the evidence here of two strikingly different environments, including by use of Lehle's depictions of evidence (fig. 35). Also, it should examine the Lockport-Salina contact relations if access can be had to the contact.

Questions: What is the general history for changing water depth for this place?

How deep was the water for each of the two major

Major Lithologic Units:
A: Guelph Buildup
  1: Stabilization
  2: Colonization
  3: Diversification
B: Post-buildup Lockport
C: MacRitchie Dolomite
D: Greenfield Formation

Guelph Fauna:

Crinoids	⊙	Brachiopods	▽
Bivalves	⬭	Horn Corals	⬭
Trilobites	⬭	Gastropods	▲
Sheet Bryozoa	⊞	Oval Shaped Bryozoa	⬭
Sheet Corals	⊞	Ramose Bryozoan	Y
Massive Corals	⊞	Nautiloids	⬭

Stromatoporoids:
Tabular
Laminar ⬭
Hemispherical ⬭

Lithologic Descriptions:

Hemispherical Stromatolites
Flat-Laminated Algal ? Mudstones
Bioturbated Mudstones
Breccias
Dolomitic Shale
Evaporite Molds and Birdseye
Unconformity

Vertical Scale 1"=10'

Major Lithologic Units:
7: MacRitchie Dolomite
8: Greenfield Formation

Lithologic Descriptions:

Hemispherical Stromatolite
Flat-Laminated Algal ? Mudstones
Bioturbation
Disrupted Laminations
Evaporite Molds and Birdseye
Dolomitic Shale
Finely Laminated Mudstones
Mudcracks
Flat Pebble Conglomerate
Breccia
Unconformity

Post-Buildup Lockport
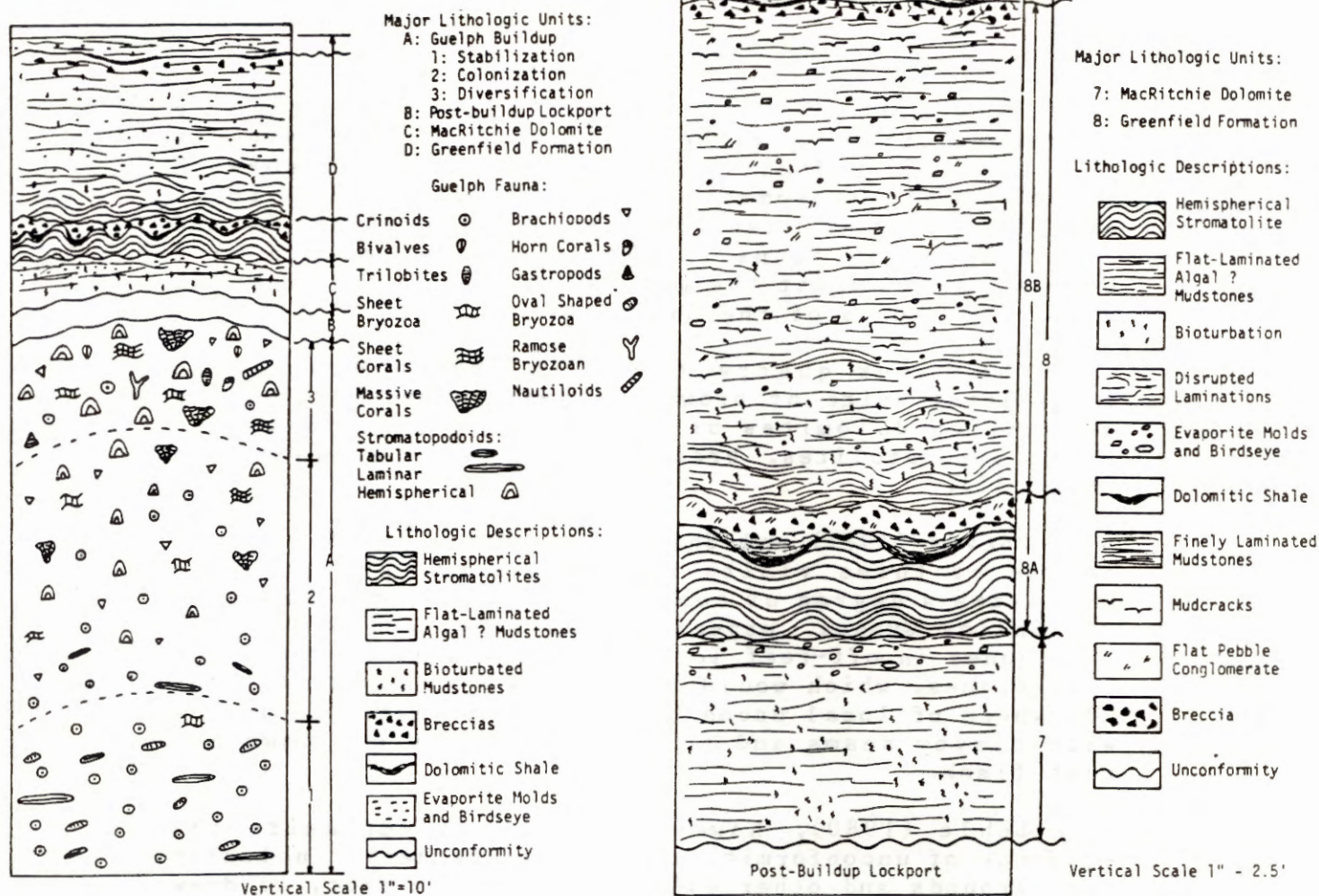
Vertical Scale 1" - 2.5'

Fig. 35. Two diagrammatic sections showing details of Lockport lithology (on the left) and of Salina lithology (on the right). From Lehle (1980).
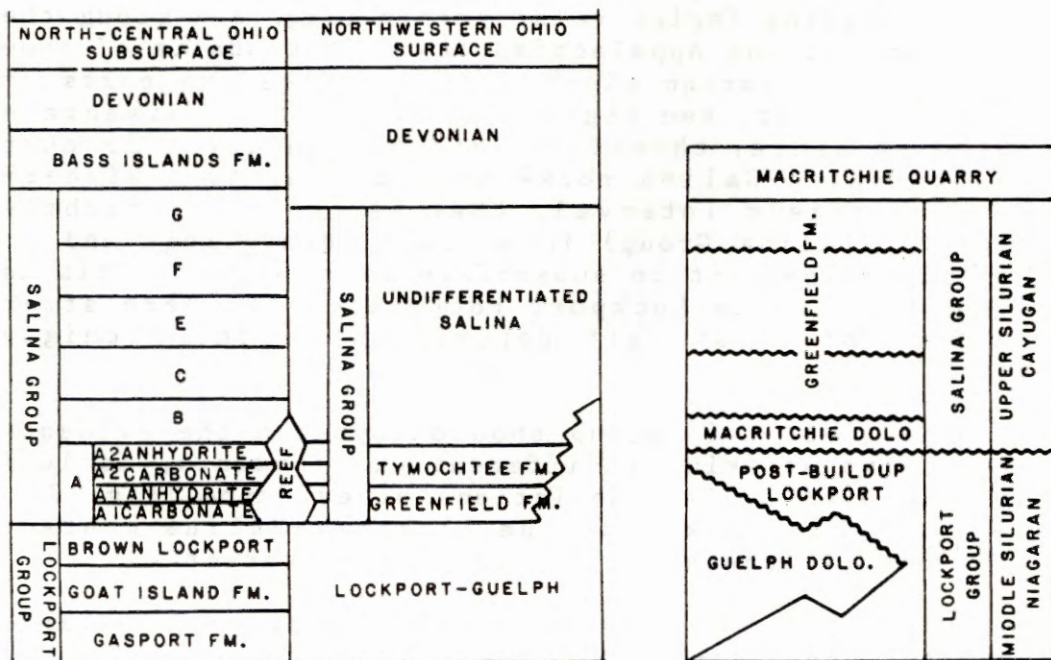

Fig. 36. Two charts showing contrasting terminology and age assignments for rocks exposed in the West Millgrove quarry: Janssens' (1977) interpretation on the left and Lehle's (1980) on the right.

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formations? (Use relative if not absolute terms.)

Now, recall that especially a University of Wisconsin School (see Shaver and Sunderman, 1982, and Shaver, Sunderman, and others, 1983) has been advocating deep-water environments for such reefs as Pipe Creek Jr. (stop 8) and Thornton (stop 13) in Indiana and Illinois.

Do the West Millgrove relatins suggest any constraints on how far the deep-water school can go with their ideas? How? Part of the answer may be deferred until other normal-marine reefs have been seen.

Maumee Stone Co. Quarry, Ohio, Stop 5

The now geologically famous quarry on the northwest side of Maumee (fig. 38), operated by the Maumee Stone Co., is located in section 35, T2, Twelvemile Square Reservation, Lucas County, Ohio. It has been the subject of a series of field trips, 1960's to the present, organized by the Michigan Basin Geological Society, the North-Central Section of the Geological Society of America, and other organizations (e.g., Summerson and others, 1963; and Kahle, 1974 and 1978).

Its popularity is owed to two principal circumstances. One, it is an exposed example of a reef whose structure and complicated diagenetic history are similar to that of deeply buried pinnacle reefs in the Michigan Basin that remain today as targets for intensive hydrocarbon search (fig. 39). Two, it became exposed during the period when it became fashionable to think of 400-foot drawdowns in the Michigan Basin to account for major salt deposition, even in sabkhalike conditions, and to account for the two-stage reef development there, the latter stage being algal stromatolitic (Mesolella and others, 1974); also, it was fashionable to think of fresh-water (vadose) environments as being responsible for certain diagenetic effects in carbonate rocks, including dolomitization, pisolitization, and karstlike development, all of which can be seen here at Maumee (figs. 38 and 40).

Here then at Maumee were the champions of very shallow water schools that went beyond the Maumee example in their applications, and these applications included resurrection of that old all-but-disproved Niagaran-Cayugan unconformity. This idea has been portrayed over and over again in correlation charts, for example as illustrated by Lehle on the right side of figure 36, herein. This school ran headon into the University of Wisconsin school that seems to want to apply the very deep water idea far and wide.
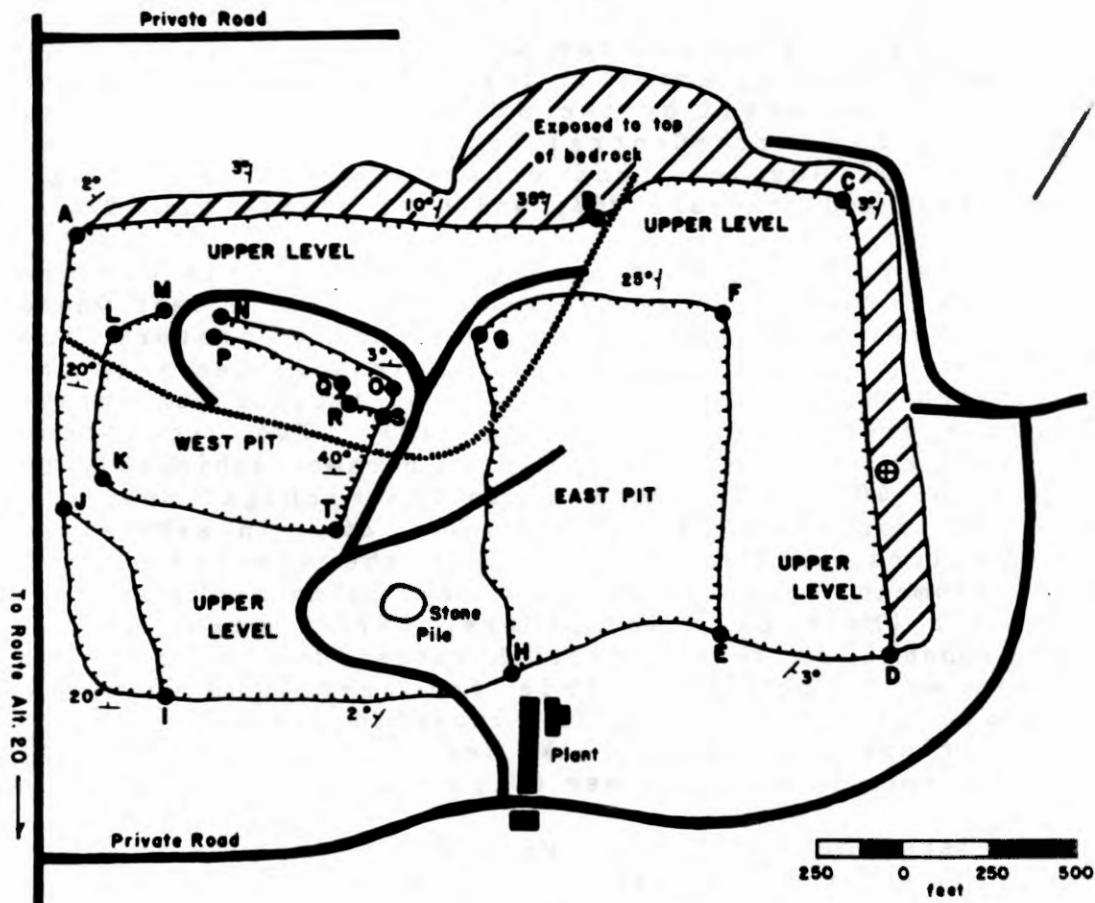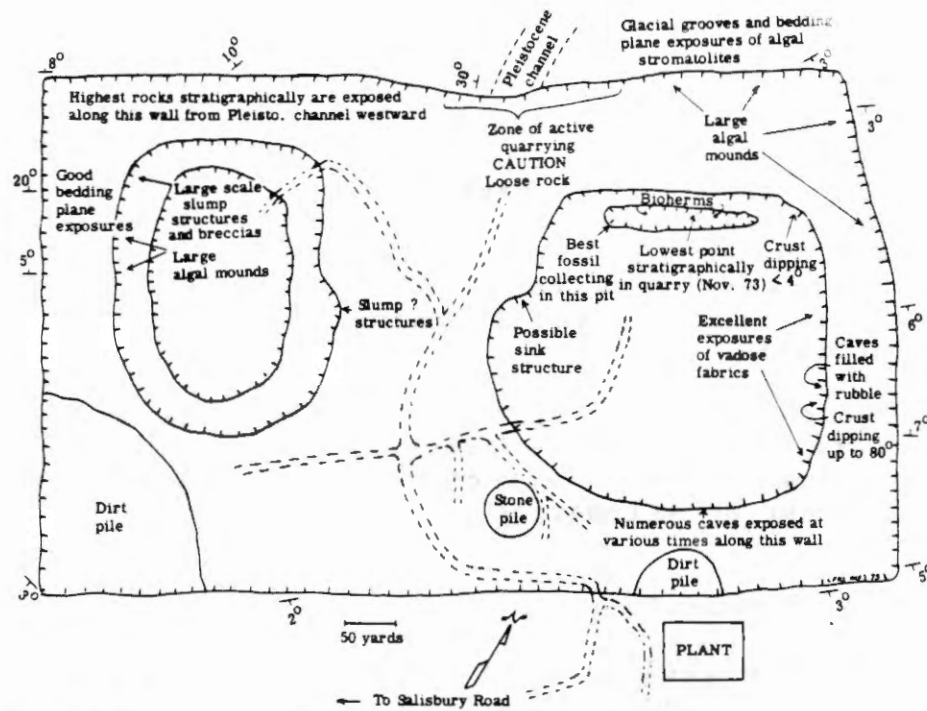
Fig. 38. Two maps, 1974 above and 1978 below, of the Maumee Stone Co. quarry at Maumee, Lucas County, Ohio. The older map records locations of interesting geological features, but not all of these are observable at this time. From Kahle (1974 and 1978).

Where, then, did this leave the Indiana school and its middle ground? Both enviably and unenviably, it left the indiana school appearing to speak out of both sides of its mouth to either of the other schools. This was the safer ground, however. Of course, there were very shallow-water environments as demonstratable from the Maumee evidence, and there were in other areas or at different times deeper (subtidal) environments that fit the field evidence.

One mistake has been to apply the extremes to areas where they were inapplicable. For example, the shallow-water adherents and a group of evaporite geologists (Michigan Basin) would like for the Silurian sea world and all reef growth to have ended forever, everywhere, except at the edge of and within the evaporite basins, at the time that the unconformity seen in the Maumee Quarry developed. Another mistake has been to ignore Janssens' (1977) subsurface work that represents the only respectable effort to place the Maumee Quarry in regional stratigraphic context (fig. 41). Apparently, no dating by means of standard fossil zones has yet been accomplished.

The rocks exposed in the lowest quarry levels consist of normal-marine rocks belonging to the Lockport Group and referred to as "bioherms" by Kahle (1974) (fig. 40 herein). They have been highly altered, however, not only by dolomitization but also by pisolitization that has pervasively invaded the tabulate-coral and other fossil structures, rendering them in part to pisolitic masses with no trace remaining of the original skeletal structures. This kind of texture/structure is associated with what appears to be karstification of the Lockport reef, including the development of caves and sinks, and with development of an unconformity across the top of this normal-marine reef. This unconformity is shown very low in Kahle's figure (fig. 40 herein).

Kahle has repeatedly made a rather convincing case, or so it would seem, for a subaerial, vadose history to account for the diagenetic effects, including pisolitization, and in 1978 he spoke of three stratigraphic levels supposedly recording drawdowns in the adjacent Michigan Basin, at which time vadose and/or other evidences of shallowings developed and at which time (or times) salt was deposited northward. Where all these levels are in figure 40 Shaver doesn't know. Kahle has also been opposed, however, by some carbonate petrologists who point out parallels (more or less, for the Maumee example) in which hypersaline environments, subtidal to phreatic, are invoked to account for the Maumee evidence, including pisolitiza-
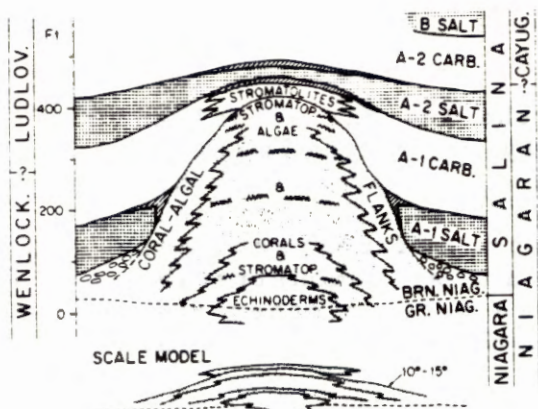
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Fig. 39. Idealized and vertically exaggerated cross section of a buried pinnacle reef in Michigan, whose history of development and diagenesis is to be compared with those of the reef exposed at Maumee, Ohio. From Mantek (1973).
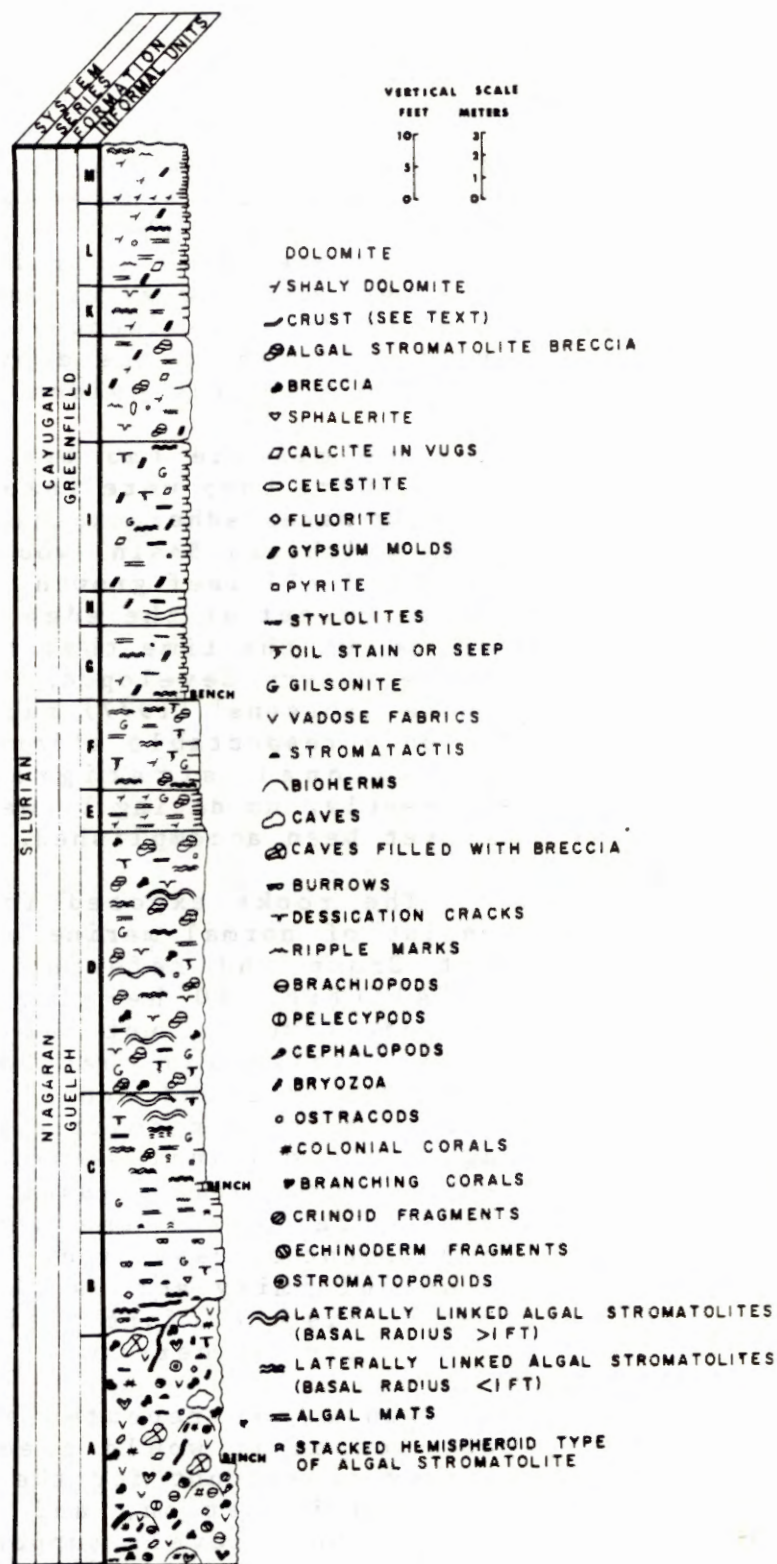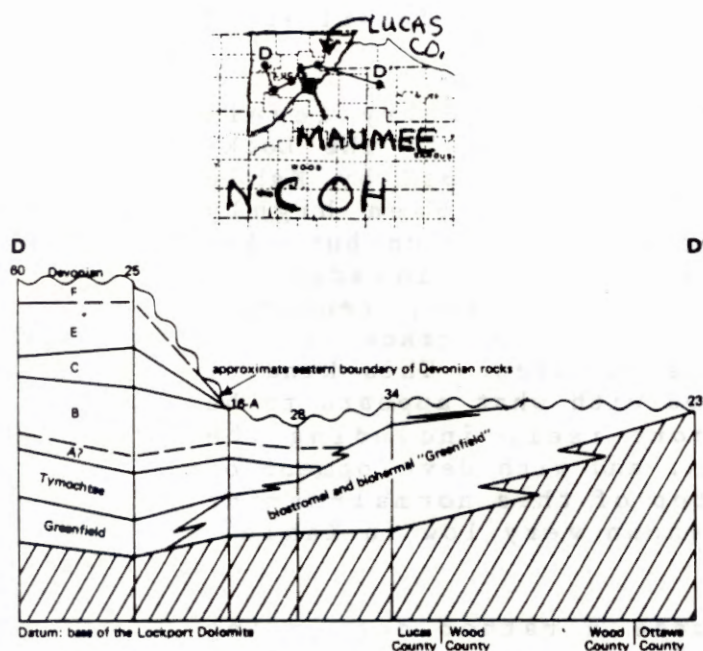

Fig. 41. One of a suite of similar cross sections prepared by Janssens (1977) to show his interpretation of a transgressive Lockport-Salina facies relationship along the southeastern Michigan Basin (northwestern Findlay Arch), including application to the Maumee area.

VERTICAL SCALE

DOLOMITE
SHALY DOLOMITE
CRUST (SEE TEXT)
ALGAL STROMATOLITE BRECCIA
BRECCIA
SPHALERITE
CALCITE IN VUGS
CELESTITE
FLUORITE
GYPSUM MOLDS
PYRITE
STYLOLITES
OIL STAIN OR SEEP
G GILSONITE
VADOSE FABRICS
STROMATACTIS
BIOHERMS
CAVES
CAVES FILLED WITH BRECCIA
BURROWS
DESSICATION CRACKS
RIPPLE MARKS
BRACHIOPODS
PELECYPODS
CEPHALOPODS
BRYOZOA
OSTRACODS
COLONIAL CORALS
BRANCHING CORALS
CRINOID FRAGMENTS
ECHINODERM FRAGMENTS
STROMATOPOROIDS
LATERALLY LINKED ALGAL STROMATOLITES (BASAL RADIUS >1 FT)
LATERALLY LINKED ALGAL STROMATOLITES (BASAL RADIUS <1 FT)
ALGAL MATS
STACKED HEMISPHEROID TYPE OF ALGAL STROMATOLITE

Fig. 40. Representative composite section of lithologies and stratigraphic assignments for the Maumee Quarry, Ohio. From Kahle (1974).

tion. In fact, other stops on this field trip exhibit
pisolites not thought by some persons to be vadose in
origin, but they are not exact parallels of the
pisolites here.

All the upper rocks, exposed in the Maumee Quarry
and overlying the pisolitized rocks discussed above,
ought to be assigned to the Salina Group on the basis
of objective lithologic criteria that are of the Salina
character. They consist of a complex of algal-reef,
algal-stromalolitic, straight algal-laminated, brec-
ciated, and other rocks exhibiting dessication and
other features suggesting intratidal to supratidal
environments. In 1974, however, Kahle assigned part of
these Salina rocks to the Guelph Dolomite (fig. 40
herein). Evidently his basis was that his Guelph part
of these rocks is the algal-reef part. This follows an
old practice, followed also by some persons for the
Michigan Basin, of calling everything that is a reef as
a part of the Lockport Group, specifically the Guelph
Dolomite part, and the Niagaran Series, no matter what
kind of reef it is and what the associated rocks are.
Not that an attempt at age assessment is made for
series-assignment purposes|

Associated with the algal-stromatolitic rocks are
straight laminated rocks that Kahle showed in his
figure above the algal reef and assigned to the Green-
field Dolomite.

Such an assignment, which Kahle modified in 1978,
disagrees with Janssens' (1977) subsurface work in this
area. The Maumee locale is on the northwest side of
the Findlay Arch (fig. 2) and, therefore, is along the
edge of the Michigan Basin. Just, as for the eastern
side of the arch, Janssens has shown reeflike buildups
along the Michigan Basin side that rise well above the
Lockport Dolomite (pre-Guelph) stratigraphic level and
that are proposed to be in facies relationship with
properly identified Salina rocks (fig. 41). Therefore,
the rocks called "Greenfield" here could be in a
Tymochtee to even higher position, of subsurface termi-
nology, that is, in A-2 to B positions in the Salina
Group.

The field-trip group should examine the three
basic kinds of rock here: (1) the reefy but pisolitized
and karstified(?) Lockport rocks, (2) the overlying
algal-reefy rocks, and (3) the more regularly laminated
rocks of typical Salina character and exhibiting dessi-
cation and related fabrics/structures/textures.

Questions: What is the general history of change
in water depth recorded in the rocks at Maumee? Were
there lesser fluctuations superimposed on the overall

directional change? Is there convincing evidence here that the pisolitic and karstlike features developed under either vadose (fresh-water) or hypersaline conditions, whether subtidal, intradital, or supratidal, for example, in the phreatic zone?

Ardmore Quarry, Fort Wayne, Stop 6

The Ardmore Quarry of may Stone and Sand, Inc. (fig. 42), is located along the southwest edge of Fort Wayne in the NE 1/4 sec. 29, T30N, R12E, Allen County, Indiana. This quarry, being one of the deepest in Indiana, is more than 270 feet deep and exposes more than 200 feet of becrock consisting of about 45 feet of ldle Devonian rocks (above) and about 160 feet of urian rocks below (fig. 43). This stop affords another opportunity to examine a barrierlike (as mapped regionally) feature that has been called a carbonate bank. One of the other opportunities at Carey, Ohio, however, was probably at a lower stratigraphic level where observed and is related to the Appalachian Basin. The Fort Wayne Bank relates to the Michigan Basin.

The lowest Silurian rocks exposed are assigned to the Louisville Member of the Pleasant Mills Formation alina Group). They consist of brownish-mottled fine-ained medium-bedded cherty dolomite that contains brachiopods, tabulate corals, and stromatoporoids. Brachiopods are most conspicuous as a few-foot near-coquinoid bed of Rhipidium that can be seen at the top of the lower quarry wall where the lower bench begins. This pentameracean brachiopod helps to fix the age of the Louisville as late Wenlockian to early Ludlovian (fig. 8) and is here at its highest known range in Indiana.

The Louisville is about 120 feet thick here, the larger part being below the quarry floor, which means that the Louisville has doubled its normal thickness in comparison with that of the area one county southward. This thickened condition is a reflection of the intercalation of large numbers of stromatoporoids (partly chertified) and of the Louisville role here as a precursor to a fully mature Fort Wayne Bank (fig. 44) at the overlying Mississinewa stratigraphic level and at a still higher now-eroded level.

Above the Louisville and very nearly coinciding with the interval represented between the lower and middle quarry benches (fig. 43) is a 109-foot nearly pure reef facies of the Mississinewa Shale Member of the Wabash Formation (Salina Group). As will be observed at later stops, the Mississinewa normally consists of very fine griuned massive-appearing (on
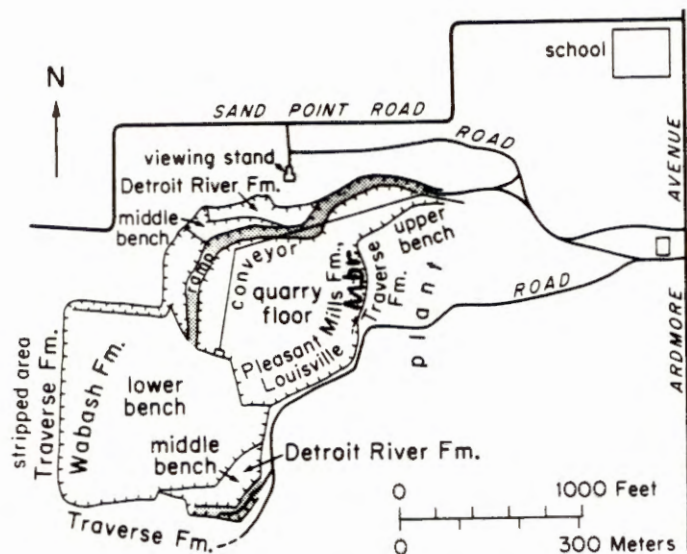
Fig. 42. Map of the Ardmore Avenue Quarry of May Stone and Sand, Inc., at Fort Wayne, Indiana. From Shaver, Sunderman, and others (1983).

Fig. 43. Stratigraphic section depicting thickness, lithology, and age relations of strata exposed in the Ardmore Avenue Quarry of May Stone and Sand, Inc. Trav., Traverse. Modified from Shaver, Sunderman, and others (1983).
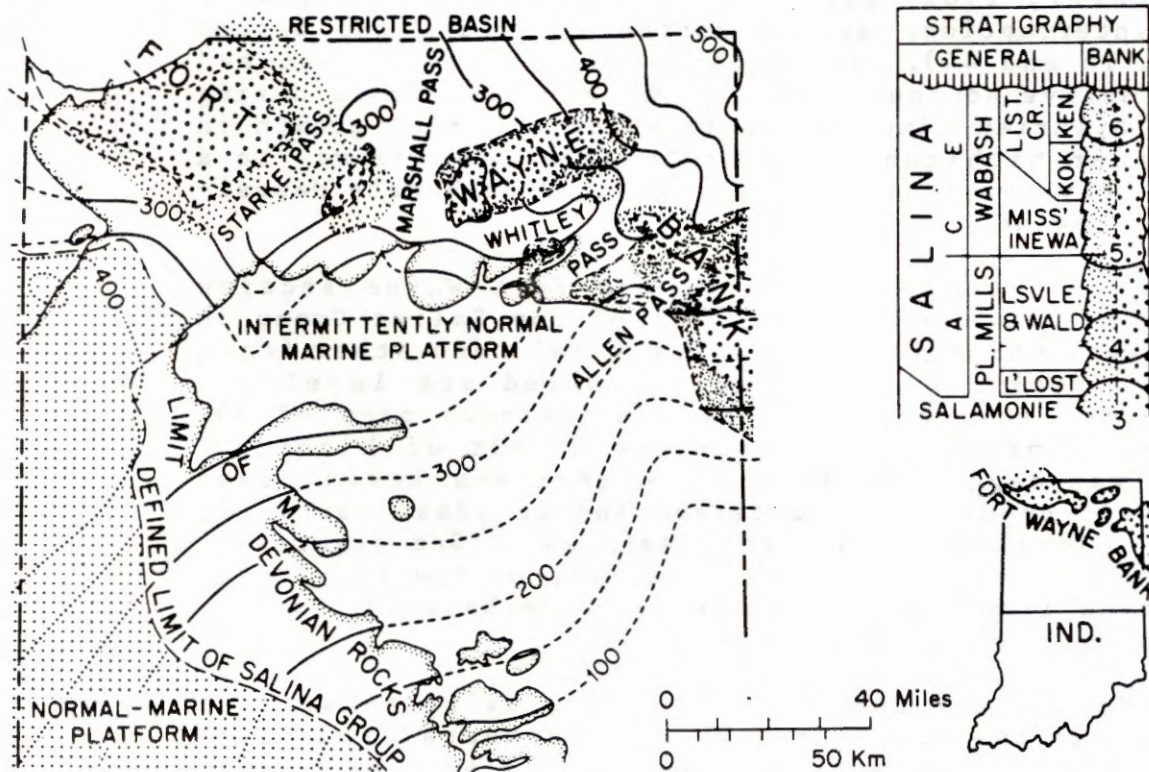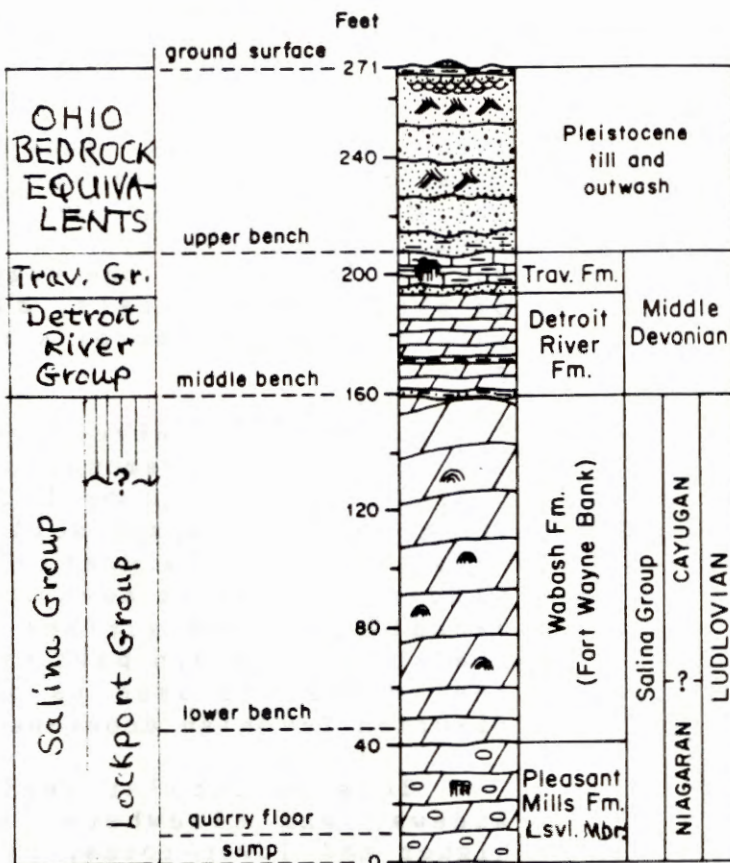

Fig. 44. Map of northern Indiana showing developmental phases of the Fort Wayne Bank and thickness and distribution of the Salina Group and equivalent rocks. Map first made by Droste, Rexroad, and Shaver (1980); later published by Shaver, Sunderman, and others (1983). The Fort Wayne stop is located in the area of the finest stipple, meaning that only the Mississinewa part of the Fort Wayne section was interpreted as reef (carbonate bank) rock. Numbers in the columnar section refer to reef generations shown in figure 10.

fresh exposure) argillaceous silty dolostone. Impurities, clay and quartz silt, make up 25 to 50 percent of the dolostone, but here in its mature reef facies impurities probably are less than 5 percent of the whole. Obviously, the vuggy reef rock consists largely of skeletal materials, although diagenesis has been intense. Stromatoporoids remain most readily identifiable.

An Indiana University Paleontology Seminar group has estimated the amount of reef-framework material at different places to be 15 to 50 percent of the volume. These figures compare well with those for modern reefs. These reefy rocks mostly appear massive, but growth planes that can be seen in the quarry walls suggest a broadly hummocky surface at time of accretion, and in the older, eastern part of the quarry steeply dipping reef rocks are seen to be sharply truncated by the Silurian-Devonian erosional unconformity.

This particular reef expression of the Mississinewa, and elsewhere the reef expression of both higher and lower rocks, has been mapped in the subsurface (Pinsak and Shaver, 1964; Okla, 1976; and Droste and Shaver, 1982) and has been shown to extend, with some interruption, across northern Indiana and beyond (figs. 16 and 44). It is thought to have represented an effective southern edge of the Michigan Basin during later Silurian time, prior to which all reef growth in the inner Michigan Basin had ceased, giving way to a dominantly evaporite and fine-grained carbonate depositional regime.

The Louisville part of the Fort Wayne section represents much of the A-2 unit of the Salina Group in Michigan, which includes a thick salt and other (carbonate) rocks representing a lowered sea level and restricted environment. The Mississinewa part of the section represents at least the C unit of Michigan, which was deposited during a higher sea level stand when salt deposition had ceased and at least partially normal circulation had been restored. (See figures 15 and 16.) These circumstances relate, of course, to the different lithologies seen here, or perhaps this statement should be turned around.

When Droste and Shaver (1982), using subsurface data, made their maps of the developmental stages of the Fort Wayne Bank (see composite in figure 44 herein) they labelled "reef" (or "carbonate bank") on any named stratigraphic interval if more than half of the interval consists of fairly pure reef rock; "nonreef" if less than half. At Fort Wayne, the Louisville was not tagged "reef," whereas the Mississinewa was.

Question: All things are relative, of course, but how would you have designated the Louisville at this place? Why?

Questions: If one accepts the interpretation given above for relative sea levels in relation to the Louisville and Mississinewa depositional episodes, it would seem that the Mississinewa rocks here represent the deeper water, that is, the aftermath of a regional deepening (transgressive?) event that followed B salt deposition in the Michigan and Appalachian Basins. Yet, one thinks of reefs as representative of generally shallow water.

What do you think, could the Louisville here represent even shallower water?

Is it possible that we must first think of the general regional condition, and then could more localized reef growth (e.g., as in the Fort Wayne Bank) reverse locally the regionally generality for relative water depth? Explain.

If such delicate balances should apply here, what can you conclude about the proposals by some persons for deep-water regimes for the northern Indiana and Illinois reef province? (These proposals have been for several hundreds of feet of water, even one or two thousand feet, for reefs yet to be seen on this trip.)

Erie Stone Co., Inc., Quarry, Montpelier, Stop 7

The Erie Stone Co., Inc., quarry (fig. 45) is located at the north edge of Montpelier, near the center of the W 1/2 of sec. 3, T24N, R11E, Blackford County, Ind. As shown by figure 46, the quarry walls reveal a reef, asymmetrically overgrown toward the west, that extends from below the quarry floor to the glacial pavement that is the bedrock surface.

This reef has been cored, the core running out of reef rock 5 to 10 feet below the quarry floor amidst oolitic dolomite of the Limberlost Dolomite (Pleasant Mills Formation, Salina Group). Because of the upward expanding shape of Silurian reefs, one core is inadequate to learn whether the reef began to grow within these Limberlost rocks or within the underlying Salamonie rocks. This reef belongs, therefore, either to generation 3 or 4 of figures 10 and 11, and at this locale the environmental restrictions that resulted in total abortion east of here (e.g., at Pleasant Mills Indiana, Shaver, Sunderman and others, 1983, and at Celina, Ohio, stop 2 herein) were not extreme enough to prevent normal-marine reef growth at the A-1 and A-2

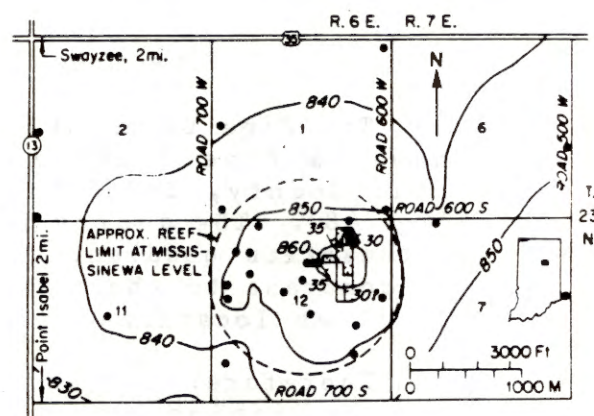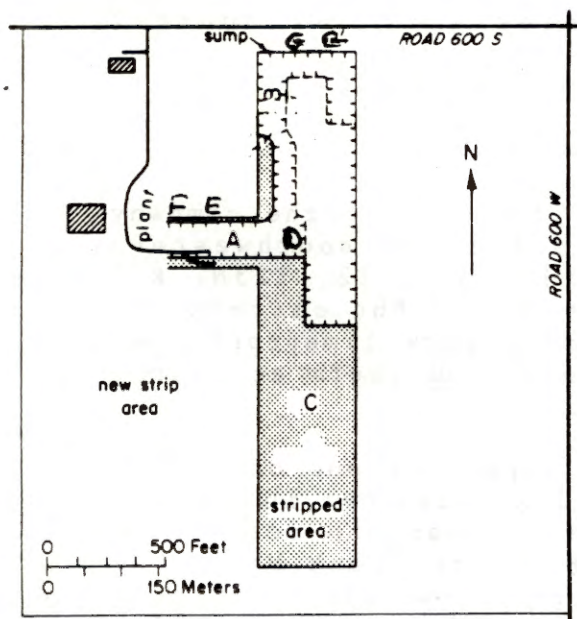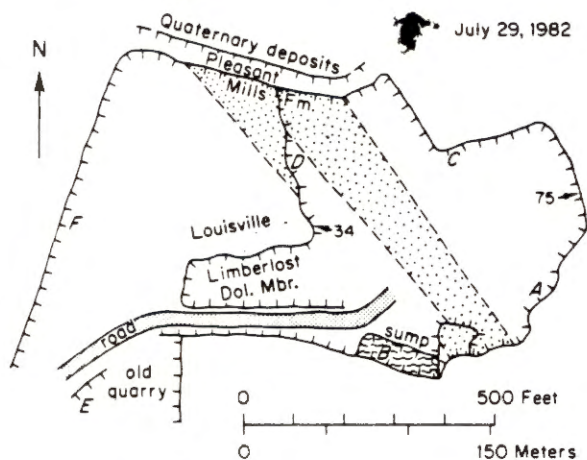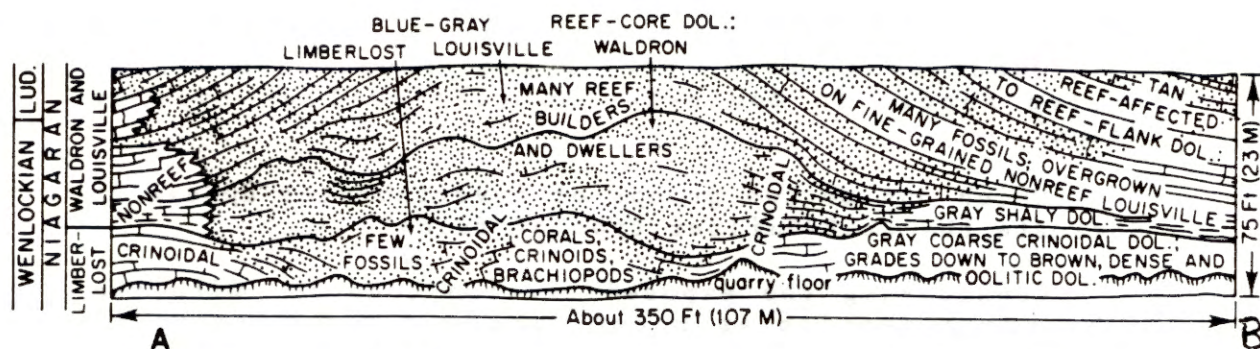carbonate intervals of the Salina Group. (Major salts were deposited within these intervals in Michigan.)

One of the oddities of the Montpelier structure is that it is a rare example of a very elongate reef located on what was the Wabash Platform during Silurian time. Why such a reef developed in an area character- ized by circular to ovate reefs (in plan view) is unknown, but Wahlman (1974) said that the forereef side (direction from which winds, water, or currents approached) was to the southwest, which is in keeping with one aspect of the NW-SE long axis of the reef (fig. 45).

The Montpelier Reef probably illustrates the phenomenon of subreef settling and deformation, as can be seen by the complex, bewildering structure traced on either quarry wall to which the elongate reef has been quarried out (fig. 45). Although such phenomena have been pointed out since Cumings' and Shrock's (1928) time, some geologists appear to deny their existence, at least one reason being their ideas of very early cementation of reef and substrate.

As figure 46 shows, the regional rock-unit con- tacts can be traced into and through the reef's cross- sectional aspect, even though the named rock units thicken and take on much different, reefy characters, including characters imparted by many kinds of fossils identifiable as reef-framework builders and reef dwel- lers (fig. 46). These fossils have been studied in their separate but interrelated reef roles, including roles assigned to pioneering and more mature communi- ties (Wahlman, 1974).

The oolites that dominate the Limberlost here are prevalent over much of this part of Indiana. The nonreef Louisville here could be seen at one time, if not now, in the old quarry shown in figure 45. It consists of darker colored (than reefy Louisville), mottled dense carbonate rocks that are devoid of recog- nizable fossils and that are generally characteristic of the restricted environments that are proposed herein to have included higher-than-normal salinities (fig. 10). The Waldron Member (Pleasant Mills Formation) presents a striking contrast between its nonreef shaly or argillaceous fine-grained character and its greatly swollen fossiliferous reefy character.

The Salamonie rocks, examined here by means of the coring noted above, are very much like the whitish rocks of the Lockport Dolomite exposed in the lower and lower upper quarry levels in the Celina, Ohio, quarry (stop 2).

Fig. 45. Map of Erie Stone Co., Inc.,
quarry at Montpelier, Indiana. From
Shaver, Sunderman, and others (1983).

Fig. 46. Cross-sectional exposure of
reef as seen along section AB (fig.
45) in Erie Stone Co., Inc., quarry.
From Shaver and others (1978).

Fig. 47. Map of Pipe Creek Jr. quarry,
southwestern Grant County, Ind. From
Shaver and Sunderman (1982).

Fig. 48. Map of part of southwestern
Grant County, Ind., showing bedrock
topography, approximate bounds of
the Pipe Creek Jr. Reef, quarry lo-
cation, and positions of core holes.
From Shaver and Sunderman (1982).

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Questions: Which one or two groups of invertebrates appear to dominate the reef-dweller type of fauna?

Which one or two groups of invertebrates appear to dominate the reef-builder type of fauna?

Considering the exposed section together with the subsurface section as noted, what is the history of deepening and/or shallowing (transgressions/regressions) represented here in general by the nonreef rocks?

Could the presence of the reef here modify locally (at the reef) the regional answer? Explain.

What comments or advice do you have for the advocates of deep-water reef environments? (Remember that the Montpelier locale is very near the next stop, Pipe Creek Jr. Reef, at which one of the deep-water pronouncements has been made.)

Do you have any modifications to offer for Lowenstam's (1950, 1957) ideas of the three stages of reef growth from quieter and deeper water to very shallow and rough water as portrayed in figure 18A? Explain.

If one ran insoluble residues on both nonreef and reefy Waldron rocks here, what contrasts would you expect to find? Would you expect to find the same amount of impurities in narrow vertical nonreef sections of the entire Waldron? Explain.

Pipe Creek Jr. Quarry, Stop 8

The Pipe Creek Jr. quarry (fig. 47) of the company known as Pipe Creek Jr. is located in southwestern Grant County, Ind., in the NE 1/4 sec. 12, T23N, R6E (fig. 48). The quarry is excavated in the eastern and northeastern quadrants of a nearly pure limestone reef (in contrast to thoroughly dolomitized reefs at nearly all other locations in Indiana).

Therefore, the structural aspect is one of mostly steeply dipping (35 to 40°) flank beds, but in the far northeastern corner of the quarry, near the reef periphery, one can see a leveling out of flank beds. At this place the flank beds also thin down dip and become interdigitate with the impure, argillaceous, and silty rocks of the Mississinewa Shale Member (Wabash Formation, Salina Group) (figs. 49 and 50).

Also, the northwest corner affords inspection of fresh Mississinewa rocks, here in a subreef position.
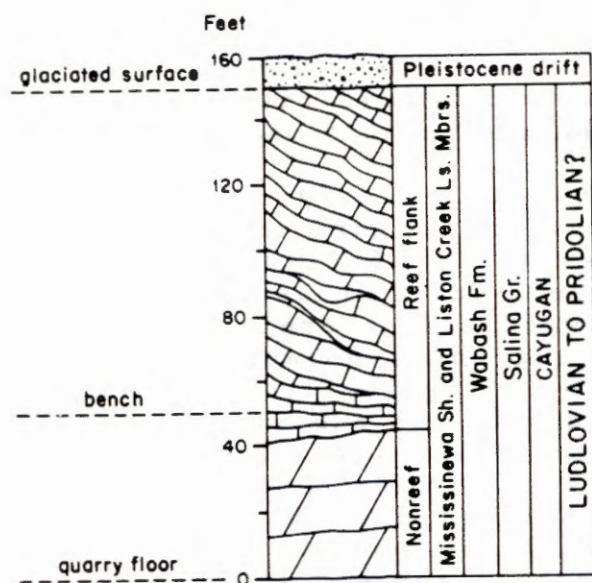
Fig. 49. Columnar section depicting thickness, lithologies, structure, and classification of reef and other strata exposed in the Pipe Creek Jr. quarry. From Shaver, Sunderman, and others (1983).
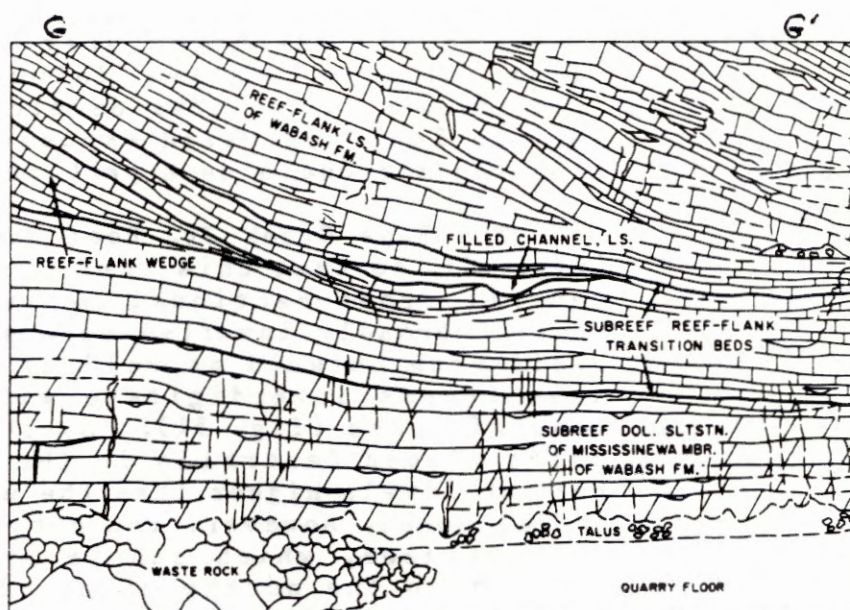

Fig. 50. Sketch by Jack Sunderman of north wall of Pipe Creek Jr. quarry in reef and subreef beds of the Mississinewa Shale Member. From Shaver and Sunderman (1982).
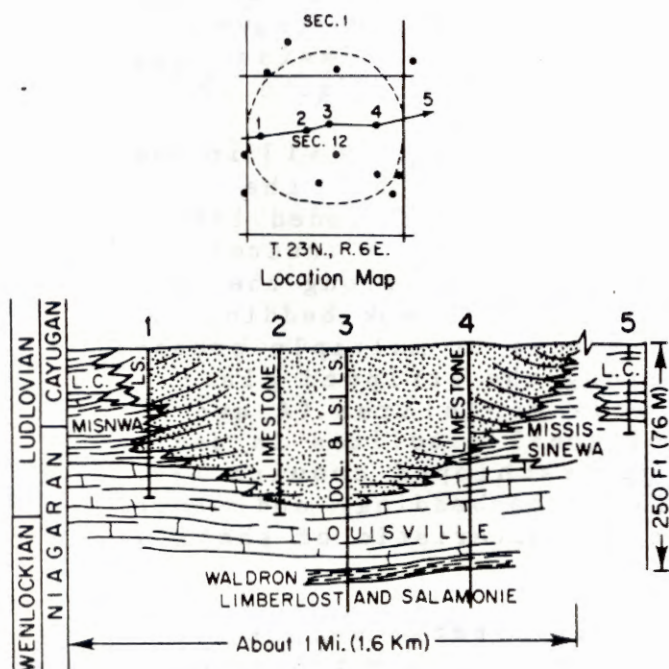

Fig. 51. Cross-sectional relationships of the Pipe Creek Jr. Reef. From Shaver and others (1978).
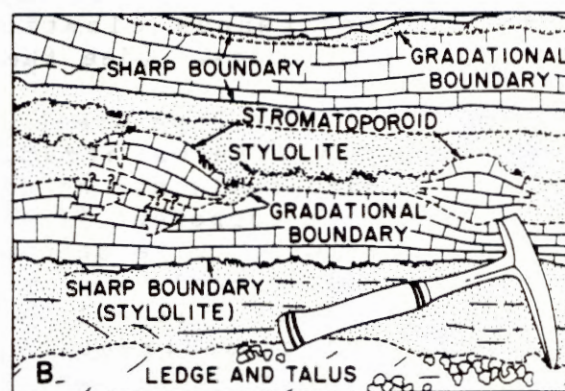

Fig. 52. Sketch (Jack Sunderman) of part of northwest wall of Pipe Creek Jr. quarry showing rhythmic and graded bedding in reef-flank rocks. Each couplet consists of a tan bio-grainstone layer bearing stromatoporoids and corals and a gray calcareous siltstone layer. From Shaver and Sunderman (1982).

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These rocks consist of gray dense argillaceous and silty (quartz) massive dolomite (25 to 50 percent impurities). Such rocks develop a scaly shaly appearance on long-weathered exposures, which gave rise to the misnomer Shale as a part of the rock-unit name.

The Pipe Creek Jr. Reef has bee extensively cored (fig. 48), so that this reef is known to conform to the general cross-sectional shape expected of Silurian reefs: broadly inverted cone shaped, which shows that reefs grew outward as well as upward and, therefore, also became interdigitate with the contemporaneous nonreef rocks (fig. 51). As shown by figure 51, core holes placed centrally in the reef did not run out of reef at levels higher than the upper Louisville. Peripheral cores, however, ran out of reef within the lower Mississinewa, which can be appreciated also by the visitor in the northwestern part of the quarry. The corss section (fig. 51) also suggests a subreef structural depression as has been noted for other reefs wherever control permitted observation.

The Pipe Creek Jr. Reef is a generation 5 reef (figs. 10 and 11) that began to grow, as did other reefs in the upper Wabash Valley, after the end of major salt (A-2) deposition in the Michigan Basin (com are figures 15 and 16) and at a time when water ha pened and normal circulation and salinity had been stored. This freshening and renewed reef growth was accompanied by an influx of fine-grained far-travelled terrigenous clastics that make up the Mississinewa impurities. (See the clasticity curve of figure 10.)

The Pipe Creek Jr. exposure is probably all in the Mississinewa stratigraphic interval, but the reef undoubtedly had an now mostly or entirely eroded liston Creek component (fig. 49). Some especially interesting features to be seen are filled fissures (along the ramp road denoted as A in fig. 49), graded flank bedding (B; fig. 52), glacial striae and traces of multiple cross-cutting sedimentary dikes along the stripped glacial pavement (C), many conspicuous stylolites (A and partly in quarry blocks), polygonal pisolites in sedimentary dikes (E), Kirkidium brachiopod coquina (F), and evidence of cut-and-fill, crossbedding, and other features suggesting energies characteristic of shallow water (GG'; fig. 50).

This reef has provoked considerable debate: (1) Concerning the nearly pure limestone composition--early cementation bringing about loss of porosity and of access by dolomitizing fluids?;

(2) Depth of water--on the order of 50 meters and in the euphotic zone (Shaver and Sunderman, 1982) or on

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the order of hundreds of feet and presumably in dark-
ness and low energies (Lehmann, 1978)?;

(3) Concerning original angle of repose of the
steeply dipping (35 to 40°) flank beds--within 1 to 3°
of present dip or perhaps as little as half the present
angle?;

(4) Concerning autochonous or allochthonous nature
of sediments in flank rock--mostly generated in place
(Univ. Wisconsin school) or much travelled material?;

(5) Origin of the pisolites in sedimentary dikes--
growth in place (Univ. Wisconsin school) or formed
elsewhere and rolled into fissures (Jack Sunderman)?;
and

(6) History or no history of internal and subreef
structural adjustment influencing significantly or not
influencing present angle of repose of flank beds?

Questions: Students may now answer to the debates
noted above, especially those noted as nos. 2, 3, 4,
and 6, which are particularly amenable to solution by
field evidence.

Road Cut South of Wabash, Stop 9

The road cut along Ind. 13 and 15 south of the
Wabash River (fig. 53) exposes about 45 feet of Missis-
sinewa dolomite and a few feet of the overlying Liston
Creek (both of the Wabash Formation, fig. 10). As
already noted, for the Pipe Creek Jr. Reef at stop 9,
the Mississinewa is host for the lower parts of great
numbers of reefs of generation 5. Many of these reefs
were unearthed during late glacial time as flooding
melt waters poured down the Wabash sluiceway and etched
out many of the reefs as klintar, Peru in Miami County
to Huntington in Huntington County (fig. 53). These
were the reefs of classic study in Indiana beginning
more than 100 years ago.

Question: Does the stratigraphic sequence at stop
9 represent deepening upward or shallowing upward?
Why?

Hanging Rock Reef, Stop 10

Hanging Rock is a craggy reef remnant rising about
80 feet above the south bank of the Wabash River, 1
mile east of Lagro, Wabash County, Ind. (fig. 53). It
is part of an exhumed reef of generation 5 (probably)
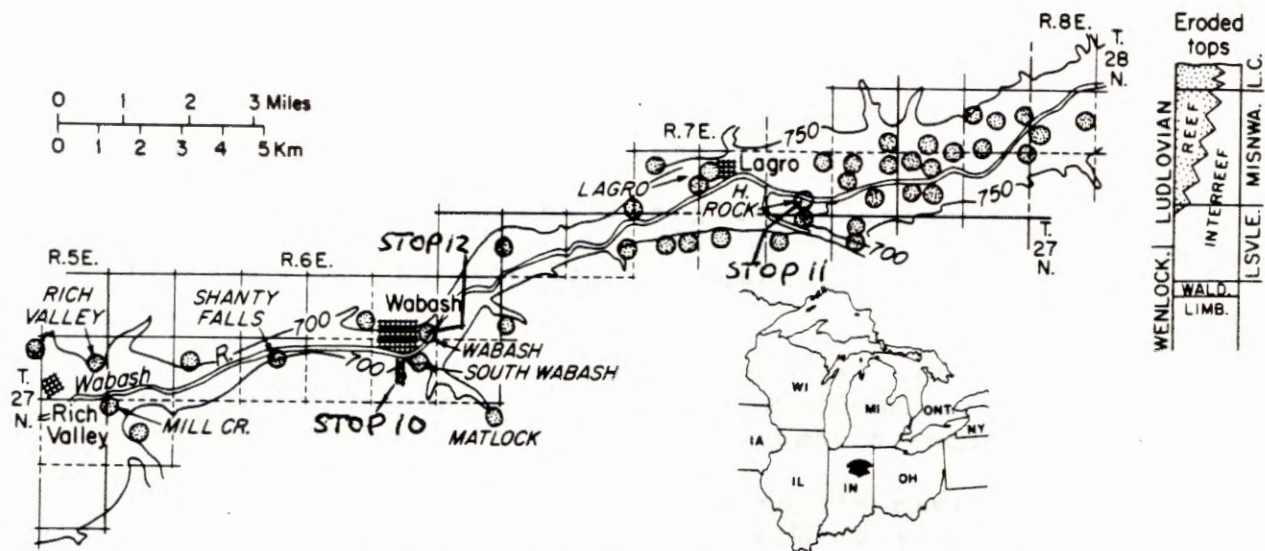that has been all but eroded away by the Wabash River.

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Fig. 53. Map of a segment of the upper Wabash Valley in Indiana showing geographic and stratigraphic distribution of Silurian reefs of generation 5 (figs. 10 and 11), most of them being exposed as klintar. Named reefs labelled in italics. Contour lines denote approximate locations of valley walls. From Shaver and others (1978).
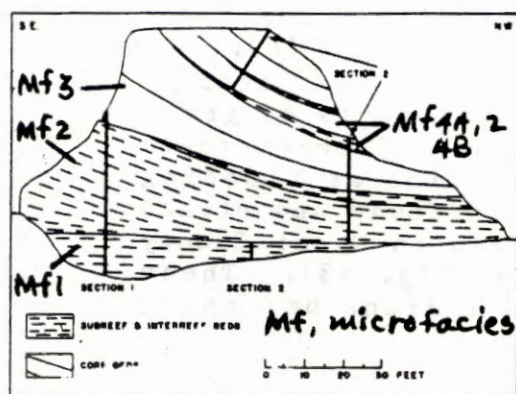
Fig. 54. Cross-sectional diagram of Hanging Rock Reef 1 mile east of Lagro. The noted sections have been described in terms of microfacies 2 through 4A and B of figure 18C. From Textoris and Carozzi (1964).

Fig. 55. Map of 3-square-mile area 2½ miles east of Lagro, upper Wabash Valley, showing locations of Silurian reefs (stipple) and their physiographic effects as klintar and as the upstream bulwarks of rock-defended terraces. Only the 700-, 710-, and 750-foot (valley wall) contours are shown. From Shaver (in editorial preparation).

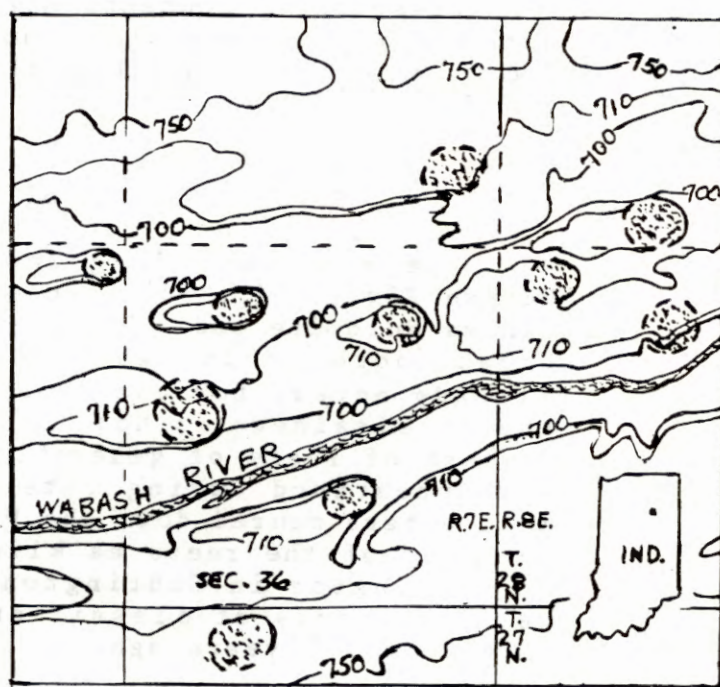A second craggy exposure, south of the road, is entirely separated from Hanging Rock itself.

This erosional remnant, a klint, consists above of a great wedge of reef-flank strata dipping southward away from the river, and below it consists of more gently dipping transitional beds of mixed Mississinewa character that rest on nonreef Mississinewa rocks like those seen at stop 9 near Wabash (fig. 54). This structure suggests that the center of the reef lay about at the center of the river (Textoris and Carozzi, 1964), and possibly some reef rock remains below the channel floor.

This exposure affords an opportunity to examine the gradational reef microfacies described by Textoris and Carozzi (1964; fig. 18C herein) from microfacies 1 (nonreef) and to microfacies 2 through 3 and 4A (but not as high as microfacies 6 of fig. 18C). Clasticity studies by Textoris and Carozzi suggested to them that energy levels increased upward into microfacies 3, which represents deposits related to a low-energy core formed below wave base. The reef-flank proper consists of limestone, rather than dolomite, so that these rocks presumably have been less altered than those of most Silurian reefs. Recognizable fossil content increases upward, and it includes fairly intact crinoid columnals, which is another indication of a modest energy level.

Cumings and Shrock (1928) and Shrock (1929) were responsible for establishing the American type examples of Silurian klintar (a German term first used for the physiographic expressions of Silurian reefs in northern Europe). Their American type examples are here in the Wabash Valley, Wabash and Lagro areas (fig. 53 and 55).

According to Cumings and Shrock, the upper Wabash Valley reefs had been partially exhumed by erosion prior to the onset of Pleistocene glaciation but were then buried in glacial drift. Exhumation again occurred during late glacial and Holocene time as melt waters and the modern Wabash River did their erosive work. Exhumation has been only partially completed, however, as the reefs now act as bulwarks for rock-defended terraces that tail both nonreef bedrock and glacial drift down valley. The contour patterns in figure 55 reflect these terraces (reef rock upstream, nonreef tails downstream).

A number of these klintar and their associated terraces can be seen along the route from stop 9 to stop 10 and to stop 11.

The Wabash Reef, exposed in a railroad cut, is located immediately northeast of the site of the former Big Four Railroad Station at the southeast edge of Wabash, Ind. (SE 1/4 sec. 11, T27N, R6E,; fig. 56 herein). Here is one of the more famous reefs in North America, although it is of modest size, because its stark long-enduring and cross-cutting exposure attracted attention before the ecologic-reef origin was ascribed to the Silurian buildups and because it was one of the few prime examples for the pioneering studies of Cumings and Shrock (1928) and Lowenstam (1950).

The exposure is complete from one periphery, through the core (center), and to the other periphery (fig. 57). Great wedges of granualr bioclastic flank rocks are exposed to best vantage on the northeast side, there dipping steeply, thinning distally, and interfingering with contemporaneous silty argillaceous dolomite of the Mississinewa Member. The core rock itself is massive, but slickensided surfaces and other evidences of growth planes can be seen.

Here is Lowenstam's (1950, 1957) type example of Stromatactis, a problematical fossil that supposedly was a major part of the binding for such core rock. As applied later by many geologists to many reefs, Stromatactis includes inorganic structures mistakenly thought to be highly altered organic remains. At Wabash, Stromatactis abounds as irregular sparry calcite masses within the dolomitic core rock. According to Textoris and Carozzi (1964), many of these calcite masses represent the partially replaced remains of bryozoans, but the tenuousness of Lowenstam's assertion of a binding agent (Stromatactis), if not also of Textoris' and Carozzi's, has permitted some geologists to discount the Wabash structure as an ecologic reef and to coin such terms instead as "carbonate mud mound."

How odd that a principal American type example of fossil reefs should be held in such tenuous light| The Wabash Reef, if truth be admitted, held too much attention to serve as a good type example. And because of the dearth of readily identified framework in this particular buildup, it has overinfluenced students of reefs and contributed to such philosophical positions (as opposed to determinative positions) as espoused by Braithwaite (1973) and Stanton (1967).

The Wabash Reef, of course, is an immature reef at the stratigraphic level of its preservaton below the erosive bedrock surface (fig. 57). It may never, at this level and before diagenesis, have exhibited the
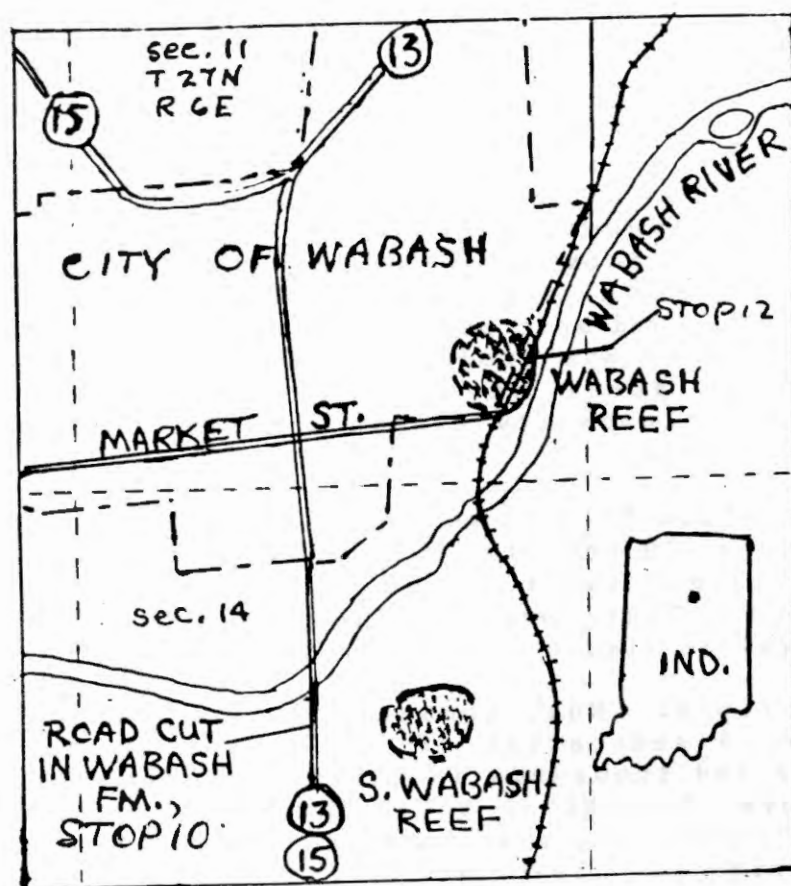
Fig. 56. Outline map of Wabash and vicinity, Indiana, showing locations of two reefs (stipple) and stops 10 and 12. From Shaver (in editorial preparation).

Fig. 57. Cross section of the Wabash Reef showing stratigraphy, geometry, and interrelationships of core rocks (cross hatch), flank rocks (brick), and interreef host rocks (laminar). Reef is about 750 feet across. From Cumings and Shrock (1928) for part above track level; Shaver (in editorial preparation) for part below track level (partly conjectural).

relative amounts of framework, the degree of species diversity and biozonation, and the evidence of high energy that some other, larger and more mature buildups do.

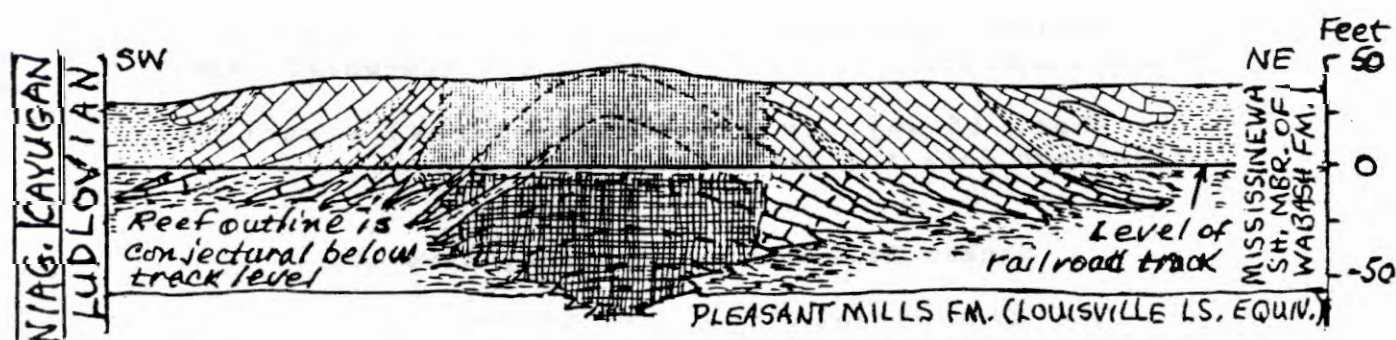In the Textoris and Carozzi (1964) scheme of microfacies and evolutionary development (fig. 18C), the present exposure does not rise above the highest part of the microfacies labelled "3(2,4A)" in figure 18C. Modest energies are indicated from their scheme, but the higher and most peripheral wedges of flank rock would relate to now-eroded microfacies (6) that were produced at about wave base. In this scheme, terrigenous clasticity within the reef decreased as energy increased.

The Wabash Reef is believed to belong to generation 5 (figs. 10 and 11), but unlike some other reefs known certainly to be of this generation, it has not been cored. Therefore, the part of the reef below track level in figure 57 is partly conjectural.

Questions: What comments do you have on this great no. 5 generation of reefs--surely there are thousands and thousands in northern Indiana to judge from figure 53--that is so intimately associated with interreef rocks having as much as 50 percent of impurities (terrigenous clastics)?

Isn't this association contrary to what you have generally heard about reefs and warm clear waters?

Do you know of modern reef associations with "dirty" environments? Where?

Putting aside Stromatactis in this reef for a moment, did you see other evidence of framework? What?

What, if any, evidence for internal structural adjustment does the Wabash Reef exhibit?

Bunker Hill Quarry, Indiana, Stop 12

The Mill Creek Stone and Gravel Co. quarry is located a fraction of mile northwest of Bunker Hill, Ind., in the center of the W 1/2 sec. 29, T26N, R4E (fig. 58). About 100 feet of section is exposed beginning with the Kokomo Limestone Member (Wabash Formation, Salina Group; fig. 10) in the sump and ending at the top with the Kenneth Limestone Member (Wabash Formation) along part of the bedrock surface and with the Traverse Formation (Middle Devonian) along another part of the surface. (See figure 59.)
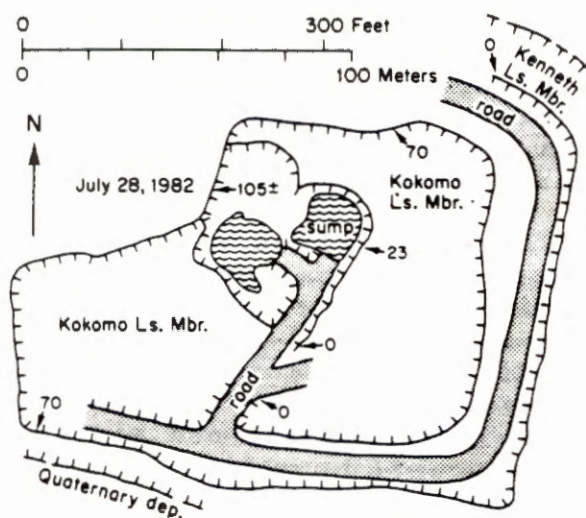
Fig. 58. Map of the Mill Creek Stone and Gravel Co. quarry at Bunker Hill, Indiana. Numbers refer to approximate heights of quarry walls in feet. From Shaver, Sunderman, and others (1983).
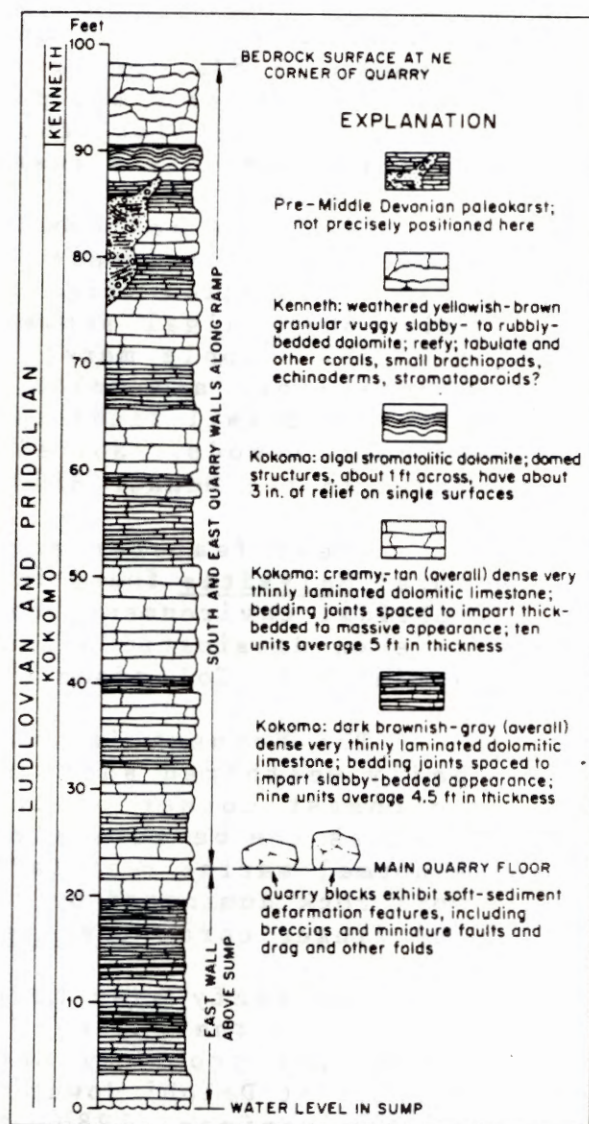

Fig. 59. Columnar section for Bunker Hill Quarry idealized to show cyclcal Kokomo deposits. From Shaver, Sunderman, and others (1983).

EXPLANATION

Pre–Middle Devonian paleokarst; not precisely positioned here

Kenneth: weathered yellowish-brown granular vuggy slabby- to rubbly-bedded dolomite; reefy; tabulate and other corals, small brachiopods, echinoderms, stromatoporoids?

Kokomo: algal stromatolitic dolomite; domed structures, about 1 ft across, have about 3 in. of relief on single surfaces

Kokomo: creamy-tan (overall) dense very thinly laminated dolomitic limestone; bedding joints spaced to impart thick-bedded to massive appearance; ten units average 5 ft in thickness

Kokomo: dark brownish-gray (overall) dense very thinly laminated dolomitic limestone; bedding joints spaced to impart slabby-bedded appearance; nine units average 4.5 ft in thickness

Quarry blocks exhibit soft-sediment deformation features, including breccias and miniature faults and drag and other folds

Fig. 60. Photographs showing brecciation (A) and soft-sediment deformation (B, X1.3) in Kokomo rocks. From Shaver, Sunderman, and others.

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As described at an early time (e.g., Cumings and Shrock, 1928), more recently described in detail by Tollefson (1979), and presumably to be detailed further by William Nellist (thesis in preparation), the Kokomo represents mostly a restricted environment.

Telltale sedimentary features include very fine lamination superimposed on coarser cyclical units (fig. 59), brecciation (fig. 60A), soft-sediment deformation (fig. 60B), algal stromatolites (at top of Kokomo; see fig. 59), ripple marks, leperditiid-ostracod coquinas, channelling, and molds of evaporite-mineral crystals. Discrete fossil finds include eurypterids and odd kinds of cephalopods. Not all these items, however, can be found in the Bunker Hill Quarry.

These features and others, such as the tabulate coral Halysites found in some places, suggest a shallow subtidal environment, to an intratidal environment, and to even dessicated and sabkha environments as proposed variably by Tollefson (1979) and others.

The Kenneth is almost inaccessible here, but a badly weathered short section may be examined at the northeast corner of the quarry where the ramp road reaches the bedrock surface (fig. 58). It consists of a normal-marine reef facies here as evidenced by framework rock dominated by the tabulate coral Halysites and the finger coral Coenites (Cladopora).

The reefy mass here is one of a few known in the Kenneth in the Wabash Valley between Peru and Logansport, and probably another Kenneth reef facies is present at Delphi downriver (Indiana University Paleontology Seminar, 1980; fig. 20B herein). These small Kenneth reefs are the basis for reef generation 6 in the Great Lakes scheme shown in figures 10 and 11, and they are the youngest known Silurian reefs of that area. All bottom out (outcrop or in cored sections) atop the laminated Kokomo. Their age very likely is well within the Pridolian range, as Carl Rexroad (written communication, Jan. 1, 1983) has identified the highest Silurian zonal conodont, Ozarkodina eosteinhornenis (fig. 7) in the Kenneth reefy mass at Bunker Hill. Elsewhere, the three highest zonal ostracods, shown in figure 9 and indicating highest Silurian biozones in Appalachia (Tollefson, 1979), have been found in the Kenneth. These age findings for the Kenneth are of very great import to study of Silurian reefs and associated sediments and phenomena in the Great Lakes area--consider that some persons still like to believe that nothing on outcrop postdates buried reefs in Michigan and the beginning of salt deposition there|

The Kokomo and Kenneth are facies of the Liston

Creek (fig. 10), a small part of which was seen at one of the Wabash stops (Tollefson, 1979; Droste and Shaver, 1982). At Bunker Hill, for example, a core shows that the Kokomo extends 20 feet below water level in the sump and rests directly on Mississinewa sediments (no Liston Creek). This regional circumstance for the Kokomo was interpreted by Tollefson (1979) as showing that the Kokomo was deposited on a very shallow water platform area in northern Indiana (amidst what generally was a shallow-water platform).

Questions: Consider your answer to the question at stop 9 (Wabash highway cut) on a deepening or shallowing upward sequence. Does the Mississinewa-Kokomo sequence as described here for Bunker Hill suggest the same answer or a different one?

Consider the exposed Kokomo-Kenneth sequence at Bunker Hill, especially the contact relations. Is one cycle or two cycles (in regressive and transgressive sense) represented? Explain.

If you said two, is there an actual rock record present to represent the transgressive event? Explain.

Thornton Quarry, Illinois, Stop 13

The Materials Service Corp. quarry is located in parts of sections 27, 28, 33, and 34, T36N, R14E, at the west edge of Thornton, northeastern Illinois (fig. 61). It is developed in a very large Silurian reef of broad oval shape (plan view) of well more than 1 mile in major dimension (fig. 62). The reef extends well beyond the present quarry area along parts of its periphery as could be noted where the field-trip route along I 80 and 295 between Hammond, Ind., and Harvey, Ill., passed through a shallow cut in what remains of this low-lying glacially sculptured klint.

The Thornton Reef probably has surpassed the Wabash Reef (stop 11) as the single most renown American Silurian reef. It has been intensely studied as a large-volume quarry operation has permitted step-by-step inspection of this large reef's interior as no other operation has in other Silurian reefs. It was one of the principal reefs from which Lowenstam (1950, 1957) derived his oft-cited reef principles; other persons before him at the University of Chicago also studied the Thornton Reef.

Many interesting reef features can be seen here from which the field-trip group will have to select. They include (and are indicated by substops labelled in figure 61): panoramic overview (substop 13A), reef-
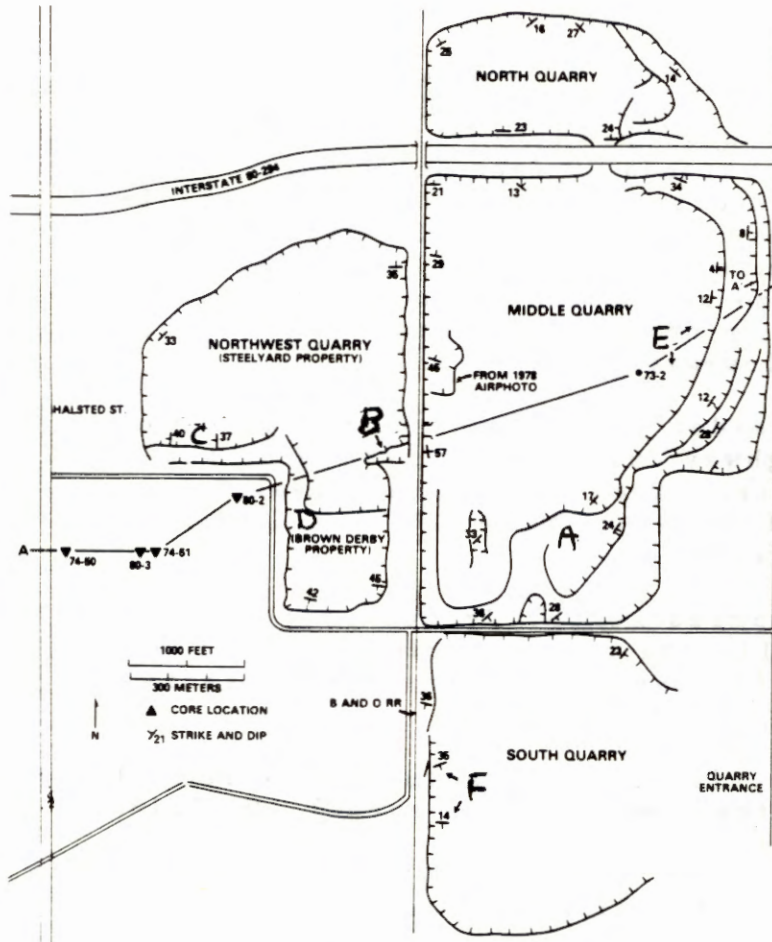
Fig. 61. Map of Materials Service Corp. quarry
at Thornton, Ill. From Mikulic and others
(1983).

Fig. 62. Idealized cross section through the Thornton Reef along line AA' in
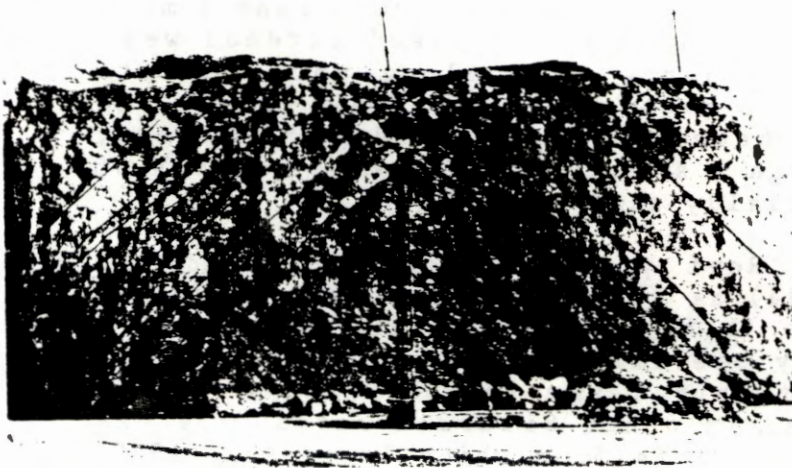figure 61. From Mikulic and others (1983).

Fig. 63. Photograph of short south quarry wall
near tunnelled entrance to northwest quarry
showing structure, sharply overturning, at very
center of the reef. Some bedding planes have
been enhanced by ink. Wall is 48 meters high.
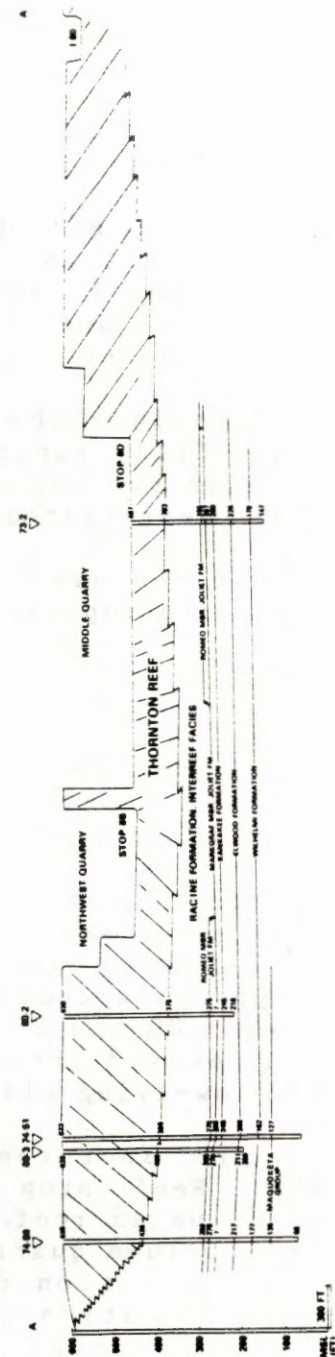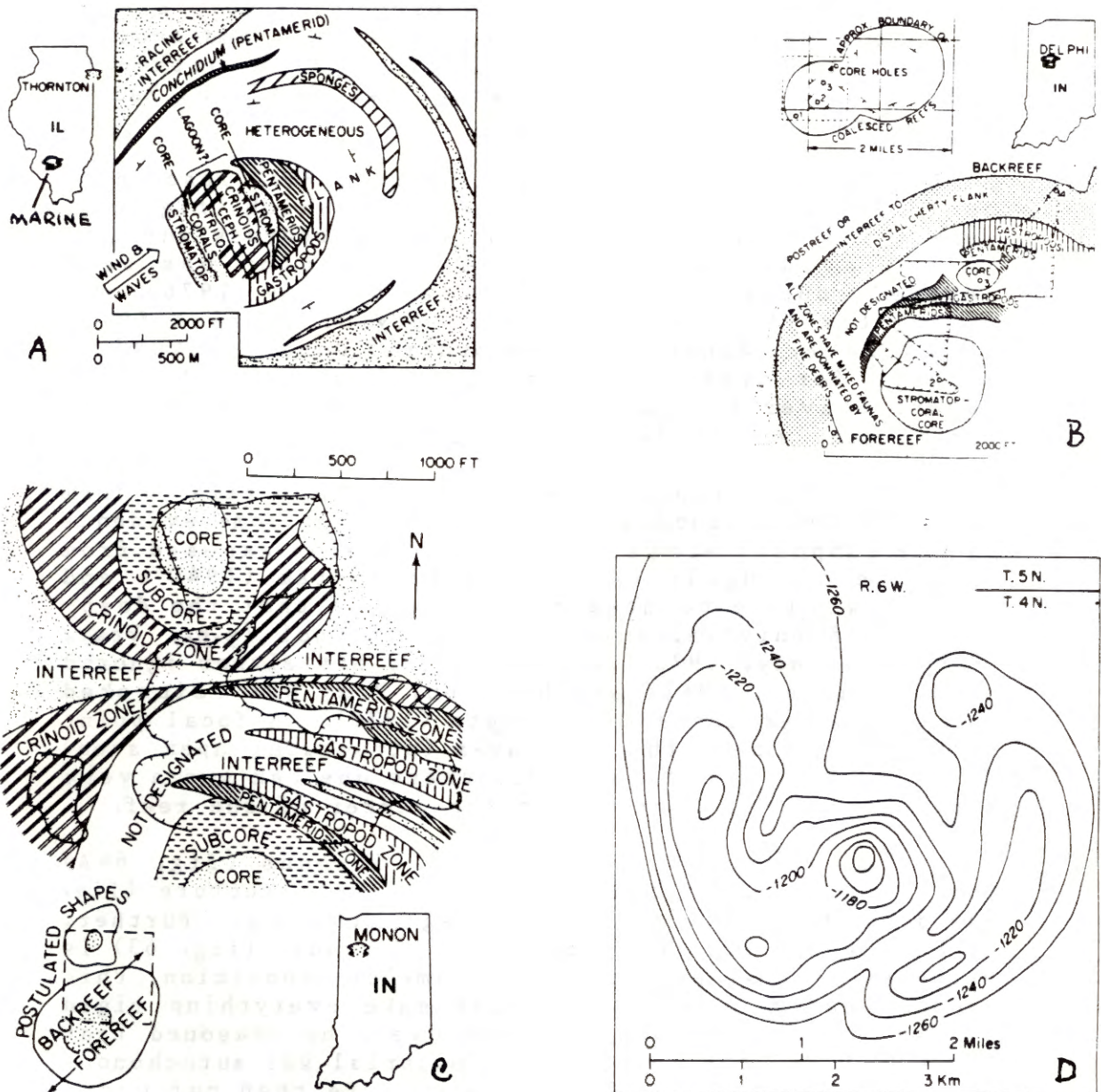From Mikulic and others (1983).

Fig. 64. Map views of four large Silurian reefs showing similarities in bio-
zonation, geometry, and orientation with respect to assumed wind and wave
directions. A, Thornton Reef, Illinois (stop 13), from Ingels (1963); B,
Delphi Reef, Indiana, from Indiana University Paleontology Seminar (1980);
C, Monon Reef, Indiana, courtesy J. J. Sepkoski and published by Shaver (1977);
and D, buried Marine Reef, southwestern Illinois, from Lowenstam (1948). A-C
are based on quarry surfaces and glacial pavements; D, on structure contours
on top of probably little-eroded reef (contour interval 20 feet). A and D
reached the atoll stage according to their authors; A and B represent genera-
tion-3 reefs of figures 10 and 11.

core facies at structural apex (B; also, fig. 63), proximal biozones of Ingels (1963) (C; also, fig. 64A), sedimentary dikes filled with pisolites (D), distal flank facies exhibiting megabreccias (E), and another distal flank facies exhibiting large allocthonous clasts and cherty impure interreef facies of the Racine Formation (F).

According to Ingels, the Thronton Reef reached an atoll stage, the zonal attributes of which (fig. 64A) were still preserved below the eroded bedrock surface, he believed. His atoll interpretation has been severely questioned, for example, by Pray (1976), and during the 1983 Geological Society of America field trip (Shaver, Sunderman, and others) Donald Mikulic's support for Ingels was faint at best; neither has Robert Shaver been able to find all of Ingel's zones during many visits dating back to 1963.

The field-trip group will hardly have time to form any well-based conclusion of its own, but some evidence of the supposed atoll stage that remains exposed from `e time of Ingels (1963) and Lowenstam (1940's and 0's) will be pointed out, evidence that the deep- ar-reef University of Wisconsin school (e.g., Pray, _376; McGovney, 1978; Lehmann, 1978) has either ignored or discounted. Here at Thornton, Pray has reinvoked the deep-water ideas of Lecompte (1938). A focal point of Pray's has been the core area (structural apex area) at stop 13B (figs. 61 and 63), where one can see a very sharp structural overturn at the center of the reef.

Pray reasoned that Ingels' biozones (fig. 64A) could not be right because the central structure (fig. 63) doesn't fit very well the lagoonal idea. Further, he believed that the steep angle of repose (fig. 63) is very nearly that prevailing at time of deposition, this because early cementation would make everything rigid almost from the beginning. Moreover, he reasoned that virtually all the layered rock material was autochonous (generated and cemented in place). He then put word in the mouths of other students of reefs by saying they couldn't be right about their ecologic-reef concept that provides essentially only for allochthonous material in layered reef beds. He reasoned that with such a sharp structural apex the materials in dipping reef beds couldn't have been generated on such an inferred small reef-top platform and then travelled down reef--there wouldn't be room for generation on top--as advocates of the ecologic-reef concept neces- sarily require, he thought. Pray and his associates further observed at Thornton that flank beds could be traced from top to bottom of a quarry wall 100 feet high, say, and not appear to change in thickness; therefore, again autochonous sedimentation was their

answer. _Ergo_, virtually all autochthonous sediments, plastered in place, layer after layer! And permissiveness for deep-water reefs? Formed in hundreds of feet of water, 1000 feet, why not 2000 feet?, he said.

Whatever degree of imagination Ingels (1963, fig. 64A herein) may have used, later independent studies, using both quantitative and qualitative methods, have resulted in portrayals of similar patterns of biozonation as mapped along horizontal quarry and erosion surfaces in large Silurian reefs comparable to Thornton: the Delphi and Monon Reefs in Indiana (fig. 64B and C). (Note how the core zone and the pentameracean and gastropod zones appear in the same ordered sequence; the repetition of pentameracean and gastropod zones in the Delphi Reef has been interpreted as related to multiple core structure; in the Monon Reef, to an interruption and resumption of reef growth, presumably requiring changes in water depth.)

The Marine Reef in southwestern Illinois (fig. 64D) has been reckoned as an atoll (Lowenstam, 1948), which may have given Ingels some encouragement for an atoll interpretation at Thornton.

Questions: Are Pray and his associates necessarily correct in assuming that the bedding planes seen at Thornton have changed hardly at all from their original angles? What evidence did you see at the Pipe Creek Jr. Reef (stop 8) that bears on this question? Do you see any similar evidence at Thornton? (For thorough appraisal of these questions, one should read the most detailed observations yet assembled on subreef settling and suprareef drape (Droste and Shaver, 1980; also, Shaver and Sunderman, 1982).)

Even given the structue seen at substop 13B (fig. 63), which doesn't seem to fit the central lagoonal idea very well, is it possible, in the light of your considerations given to the questions above, that Ingels (1963) basic concept is correct and that evidence still exists in the Thornton Quarry walls for atoll structure? Explain.

What do you conclude about the nature of rock at the core (structural apex) (fig. 63, stop 13B of fig. 61), is it best classified as framework type of rock or reef-flank rock?

Considering your answers so far, are pray's reasonings about autochthonous and allochthonous sediments in relation to the stop 13B area well founded? Explain.

What evidence do you cite to the autochthonous-

allochthonous question for Silurian reefs in general? If Thornton observations were insufficient, what does the Pipe Creek Jr. Reef have to say on this question as to whether flank beds should be at an autochthonous extreme or an allochthonous extreme?

Do you have any explanation for Pray relative to his observation of uniformly thick reef-flank beds extending from top to bottom of quarry walls at Thornton? Explain. Clue: what did you see in the northern part of the Pipe Creek Jr. quarry? So, why the difference in how these things appear in the two quarries?

What do you think about the practice of some geologists who compute minimum depths of water around a reef by measuring the vertical distance between opposite ends of a single flank bed (seen dipping on a quarry wall) and then saying that that distance is the minimum water depth? Explain.

Or what about the practice of reconstructing the original reef (before erosion) by projecting up (and down) the eroded (sub-quarry floor) ends of flank beds to whatever reef top (bottom) is conceptualized (was the top perhaps a reef platform at surf level?) and then saying that the projected vertical distance is the minimum depth of water attending the reef? Explain.

Does the relationship between reef and interreef rocks have any bearing on how one should figure water depths? Explain. Do you think this factor could have been ignored when some computations of water depth suggested in the literature were made?

Does your observation so far of reef cores and near-core flank rocks support or detract from deep-water (shallow-water) ideas? Explain.

Given early cementation of Silurian reefs (R. Shaver doesn't argue the point), does this phenomenon necessarily prove the idea that we see today very nearly the original angles of repose in reef-flank beds? Explain. If you answered yes, how do you explain the subreef and suprareef structures discussed by Droste and Shaver (1980)? If you didn't answer yes, what other processes (besides early cementation) do you think about, whether further diagenetic, or tectonic, or sedimentational, or whatever?

LeClaire Quarry, Iowa, Stop 14

The quarry of LeClaire Quarries, Inc., is located immediately north of LeClaire, Iowa, in the SW 1/4 sec. 26 and the NW 1/4 sec. 35, T79N, R5E, Scott County.

This Iowa stop and the next one westward in the Brady Quarry have been selected in the interests of an improved regional perspective. We have been dealing with a decidedly dominant carbonate sedimentational history, and a question has been: Were we looking at generally shallow water facies or generally deep water facies? If shallow, perhaps we would expect the nuances of carbonate facies to come and go on a rather local basis. But do they in this Silurian province we have been examining? The Iowa dimension surely makes the scope of our examination a regional scope.

At the time of John Droste's and Robert Shaver's examination of the LeClaire Quarry in about 1975 an impressive section, possibly near 150 feet thick, was exposed, all in the Gower Formation (figs. 10, 65, and 66). The major part of the exposed Gower consisted of the dense laminated carbonate-mudstone referred to as the Anamosa Facies of the Gower (figs. 65 and 66). More recently this facies was named the Anamosa Member (Bunker, Ludvigson, and Witzke, 1985).

In the bottom of the quarry in 1975 the Gower laminated rocks could be seen to be steeply "humped up" and to extend over what doubtless was a buried reef in the Scotch Grove Formation (Palisades-Kepler Mound Facies of fig. 65). The Brady Facies of the Gower (fig. 65) probably was exposed, but determinative examination was not made. The Brady Facies (now named the Brady Member, Bunker, Ludvigson, and Witzke, 1985) is a near-reef facies characterized especially by brachiopods, algal heads, ostracods, and other fossils, and it has been considered as a second and "last-gasp" stage of the upper Scotch Grove reefs (Philcox, 1972). Despite the apparently unfavorable environment (Gower) that had set in, the Brady near-reef facies no doubt owes its development to the favored higher sea-floor position atop the buried Scotch Grove reefs.

High up on the quarry walls and in the shallow, ancient part that remained in 1975 in the overall LeClaire Quarry could be seen small normal-marine reefs, perhaps 30 feet thick, there truncated across their tops by the modern bedrock surface. They were entirely separated from the Brody Facies by several tens of feet of the laminated Anamosa Facies. These high reefy Gower rocks are not represented in figure 65, nor in figure 66 unless Witzke's zone 22, with its tabulate corals, represents the bottom of these reefs.

These high reefy rocks were long called the LeClaire Facies and have recently (Bunker, Ludvigson, and Witzke, 1985) been named the LeClaire Member. In now-abandoned shallow quarries across the Mississippi River at Port Byron is exposed the Illinois reefy
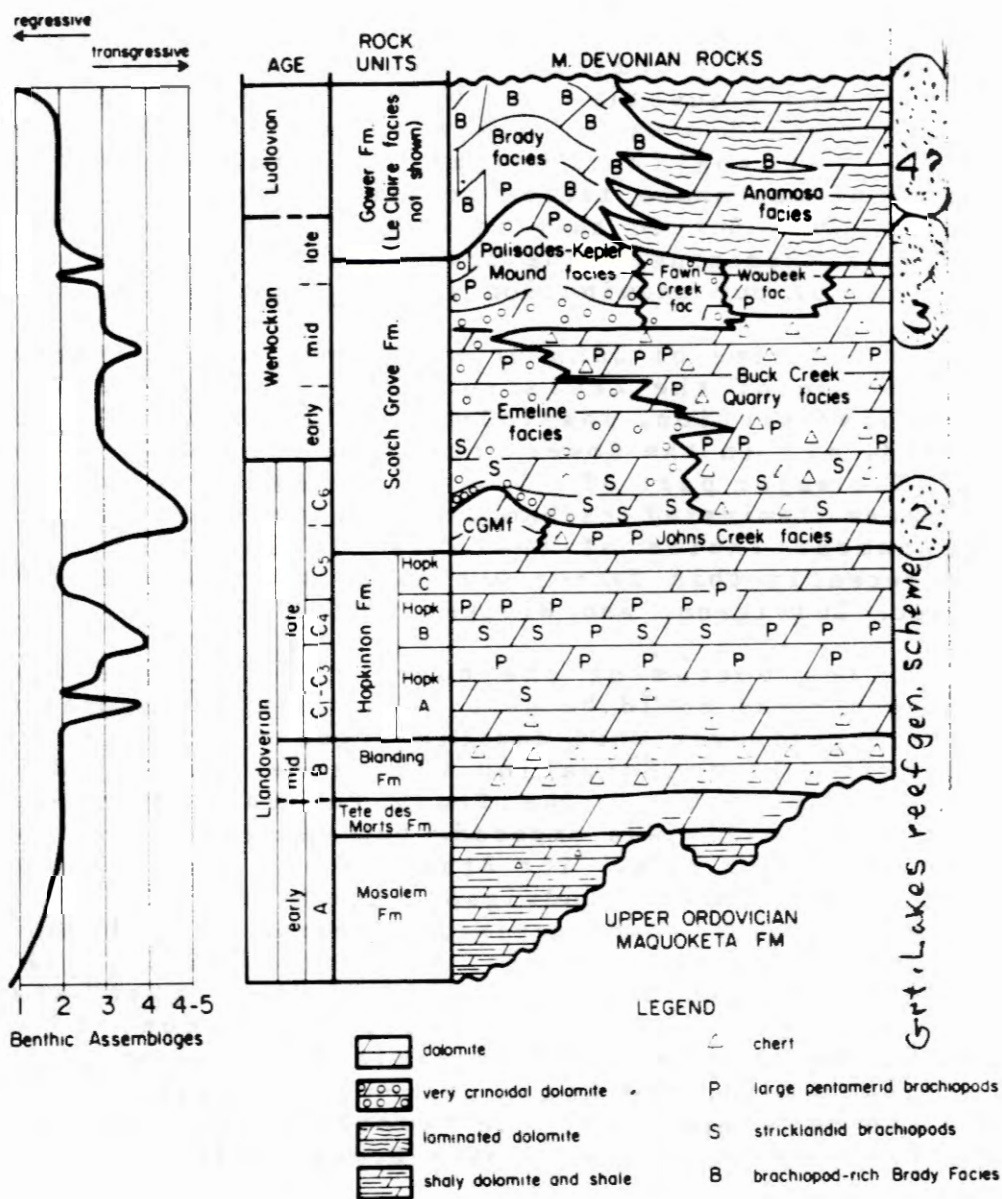
Fig. 65. Generalized Silurian stratigraphic section for eastern Iowa but lacking provision for the highest, reefy rocks in the LeClaire Quarry (stop 14). From Witzke (1983); reef generation scheme on right added here to show probable coordination of Iowa reefs with those of figures 10 and 11. The Scotch Grove Formation is relatively new, and it is approximately equivalent of the upper part of the Hopkinton Dolomite of figure 10, including some that is Llandoverian in age.
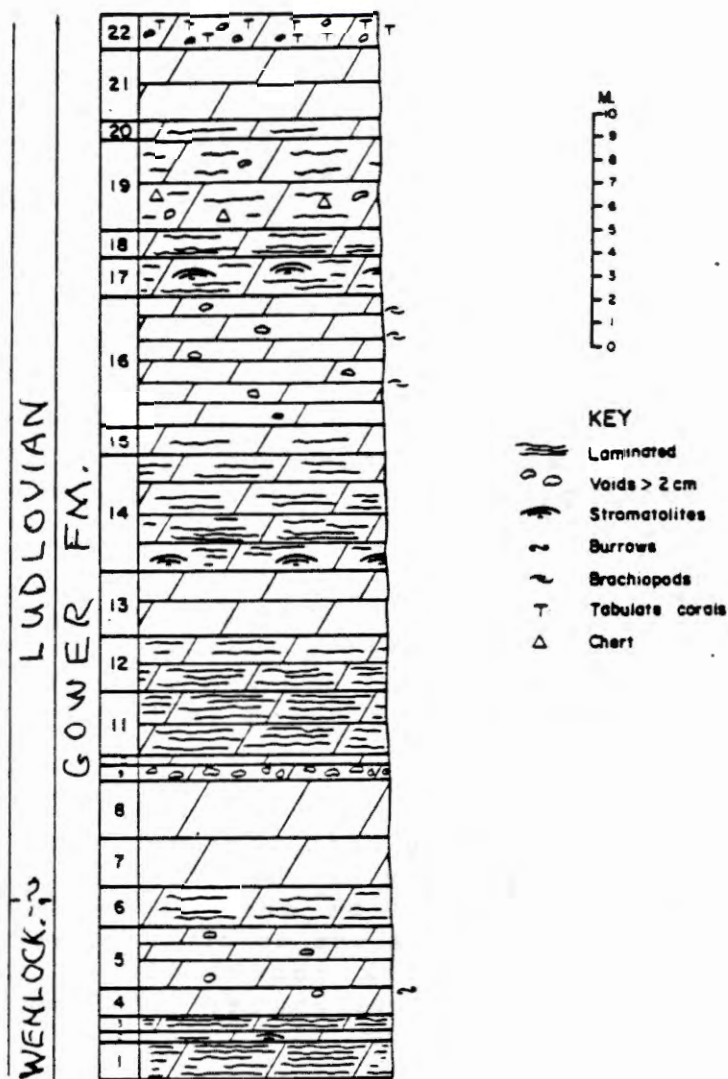
Fig. 66. Columnar section showing details of lithology of the Gower Formation exposed in the quarry at LeClaire, Iowa (stop 14). A once-exposed reefy facies at the very top of the bedrock section (reef generation 5?, fig. 10) is not shown. Modified from Witzke (1981).
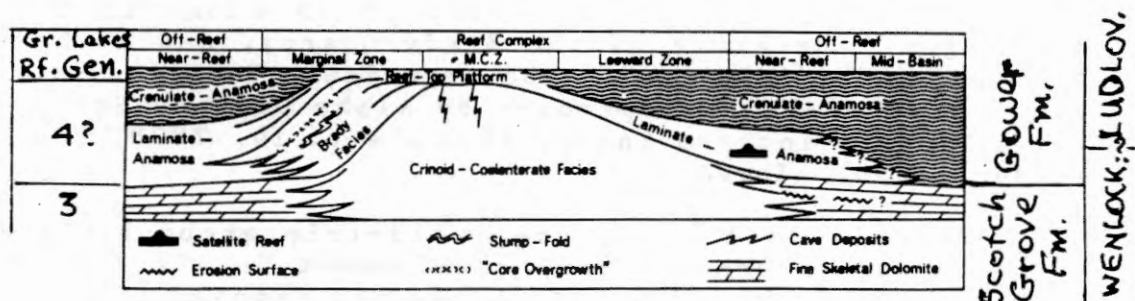
Fig. 67. Idealized cross section through a Gower reef in Iowa that probably is two staged (generations 3 and 4 of fig. 10?) and that illustrates the burial (abortion) of Gower reefs amidst dense laminated Gower rocks representing a restricted (high salinity?, very shallow water?) environment. Forereef thought to be to the left. Modified from Philcox (1972) by adding the formal rock-unit names from Bunker and others (1985) and by proposition here of fit with the Great Lakes reef-generation scheme of figures 10 and 11.

equivalent of the LeClaire, there being part of the 300-foot-thick Racine Formation of Willman (1973), who apparently had little idea that much of his Racine consists there of nse laminated rocks (i.e., Gower equivalent) and t a lower part is reefy (Scotch Grove equivalen ike the upper part. The Racine is not just the reef formation of Illinois, therefore, as Willman inferred; its history of development is complex like that of the Scotch Grove and Gower of Iowa combined.

The field-trip group should examine the Gower exposure at LeClaire and assess the responsible environmental parameters. (See the sedimentary structures shown in figure 66.)

Questions: What is your assessment of the environmental parameters and of their history of change that relate to the LeClaire section? Begin with the buried Scotch Grove reef and end with the high reefs that can be seen at Port Byron in Illinois if not at LeClaire.

Would you like to correlate the section here and the events represented with what you have seen elsewhere on this trip? Why or why not? Give details for your answer. It would be nice if we had some good index fossils here to assure us of any correlation, but if you don't like quick correlations, read Witzke 1983); also, Droste and Shaver (1977 and 1985) and aver and others (1978).

You may feel better qualified to answer these questions after seeing the section at stop 15.

Brady Quarry, Iowa, Stop 15

The quarry visited as stop 15 is known in the geologic literature as the Brady Quarry, and it has obvious relationship with the term Brady Facies. This quarry presently is operated by Alpha Crushed Stone, Inc., and is located in the SE 1/4 sec. 14, T80N, R3W, Cedar County, Iowa.

At this last stop, the field-trip group has an opportunity to observe reef development in the Scotch Grove itself (fig. 67), which was not exposed in 1975 in the LeClaire Quarry (stop 14). Depending upon just how quarrying has proceeded recently, the Palisades-Kepler Mound Facies (reef) should be seen, succeeded by the near-reef Brady Facies (fig. 67). According to Philcox (1972), the Brady Facies developed toward the forereef sides of reefs (fig. 67). Further, that such exposures as are (or were) in the Brady Quarry caught

in the act, so to speak, the burial (abortion) of
<Scotch Grove§ reefs in shallow-water carbonates
(laminated Anamosa Facies) of the Gower Formation.

The field-trip group should note, as may be possi-
ble, the interfingering of the laminated rocks with
what appear to be normal-marine (with expectable reef
fossils) reef-flank rocks; also, how some reef-flank
beds may exhibit the unusual phenomenon of thickening
offreef. This phenomenon previously has been noted as
characteristic of reefs undergoing abortion.

Questions: If you are bold enough to assign the
Iowa reefs you have seen to the Great Lakes generation
scheme of figure 10, how many of such generations did
you see at the two Iowa stops?

What are the numbers (reef generations) that apply
at each place and stratigraphic level?

To ask these questions in another way, what is
your assessment of the degree of regionality that
applies to the different environmental events you would
like to reconstruct for the field-trip area?

CONCLUDING THOUGHTS AND QUESTIONS

This trip has been designed to show the great
stratigraphic range of Silurian reefs and, concomi-
tantly, a range in sizes. The trip, however, omitted
the earliest Silurian reefs of the Great Lakes area
from its itinerary. To see the oldest reefs would have
required travel to northeastern Wisconsin; an Iowa
perspective was chosen instead in order to add geo-
graphic range rather than stratigraphic range.

The trip has been only five days long, yet the
field-trip participants have seen more Silurian reefs
and more reef stratigraphy than perhaps nine of ten
persons who have added to the midwestern Silurian reef
literature| Nineteen of twenty? So, participants
should not necessarily shrink from these far-reaching
questions that are still being debated or are just now
being advanced:

1. Do the Silurian carbonate buildups (not neces-
sarily every last one) deserve to be classified as
reefs in the modern ecologic concept of reefs? Explain
why or why not.

2. If you answered yes to question 1, how does
your idea relate to the current question of deep vs.
shallow water attending the Silurian reefs? Explain.
(Take "deep" vs. "shallow" in the context set forth in

this guide.)

3. Do you have explanations for the abortions of groups of these reefs that have not been advanced in this guidebook? If so, what are they?

4. How far would you like to go in using cyclicity in reef growth and abortion as a tool for correlaiton? (This question cannot be fully answered from the evidence alone that could be garnered during the field trip.)

5. How many cycles (let's say second-order cycles) of transgressions (deepening upward) and regressions (shallowing upward) did you observe during the trip? (Consider that one cycle begins with deepening and ends with regression.)

6. Did the evidence of deepening or shallowing dominate the actual rock record (as read from sedimentary features and thicknesses of strata)? How much did one dominate the other, or explain in some way what you interpreted.

7. If you observed any cyclicity at all and wish to think some intraregional correlation is possible, could strictly local controls be possible (e.g., such as local tectonics or what is called autocylcic sedimentation)?

8. Are you aware of the general sedimentologists' truism that supposedly answers question 6 above? If so, did your trip observations support, deny, or support and modify the general truism? Explain.

9. If you answered no to question 7 above what kind of controls would you like to advance and why?

10. Can you list several ways that such a field trip as this one enhances a geologists' ability to explore for economic hydrocarbon accumulations in the subsurface? If so, do so.

11. Can you specify how the information gained from such a field tirp would benefit a new quarry operator as he planned development of a quarry in reef rocks? If so, do so.

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Addendum

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