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Several trilobite associations are identified from Silurian rocks. The homalonotid-acastomorph association has a low diversity and is found in nearshore, high-energy environments having high rates of sedimentation (Benthic Assemblage 1-2). Level-bottom communities occupying a mid-shelf Benthic Assemblage 3 position are characterized by the trilobites *Calymene*, *Dalmanites*, and *Encrinurus*. *Dicelosia* communities (Benthic Assemblage 4-5) occupy an outer-shelf position and contain a diverse association of trilobites, including calymenids, such as *Flexicalymene*, along with *Dalmanites*, phacopids, and *Otarion*. Outer-shelf and shelf-slope communities are characterized by odontopleurids and *Aulacopleura*.

Trilobites on a generic or higher taxonomic level are not confined to particular environments, but some groups are more abundant or diverse in certain environments. An examination of different groups of trilobites shows differing levels of correlation

between occurrence and environment. Dalmanites, Encrinurus, calymenids, and proetids occur throughout a wide range of shelf environments, but a more detailed examination of proetids and calymenids may reveal a more restricted distribution at the generic and specific levels. Encrinurus reaches a maximum abundance in Benthic Assemblage 3 mid-shelf communities. Homalonotids and acastomorphs are typical of nearshore clastic environments. Lichids are restricted to mid-shelf communities and illaenids and scutelluids are most common in similar, carbonate envrionments. Otarionids and phacopids are more typical of outer-shelf environments and odontopleurids and Raphiophorus are typical of outer-shelf and shelf-slope.

Examples are given showing that specific trilobite associations can occur with different brachiopod communities suggesting that each group may respond differently to environmental characteristics.

Rarity and low-diversity of proetids in most of North America compared with Europe during the Silurian is due to biogeographic differences and not environmental differences.

Trilobite associations of Silurian carbonate buildups (Benthic Assemblage 3) have a definite composition and mode of occurrence worldwide. The dominant trilobite association is the illaenid-scutelluid-lichid association, which is typical of the core are of carbonate buildups. These trilobites are found in accumulations of disarticulated skeletal elements stacked in a convex-side-down orientation; cephalopods are often associated with them. Experimental evidence and field observations suggest that these accumulations form by the concentration of molted trilobite exoskeletons and dead cephalopod shells in depressions in the substrate or behind large objects and other sediment traps. Trilobite-cephalopod accumulations are found in Ordovician-Carboniferous carbonate buildups, while cephalopod accumulations are also found in Permian-Jurassic buildups.

A second trilobite association in reef environments is characterized by *Sphaerexochus*, encrinurids, and calymenids; this association is typically found in outer flank pelmatozoan-rich beds, representing a lower-energy environment than the central reef core. The presence of these associations in most carbonate buildups indicates that environmental conditions are similar in these structures, regardless of the variety of current environmental interpretations.

Two different biogeographic groupings of the illaenid-scutelluid-lichid association are observed in the central United States. These groups cannot be attributed to difference in age or observable environmental differences.

The trilobite faunas of Ordovician-Permian reefs are conservative in their morphologic occurrence and abundance. Illaenids, scutelluids, lichids, and cheirurids are the dominant trilobites in

Ordovician-Devonian buildups, while proetids are dominant in Carboniferous and Permian buildups. Most trilobite groups and morphologic types found in later buildups are already present in the Ordovician. Only a few taxa from four families Illaenidae, Proetidae, Cheiruridae, and Lichidae dominate the carbonate buildups through the Ordovician-Permian.

The Silurian lithostratigraphy of southeastern Wisconsin is discussed in light of new exposures. A complete section through the Silurian is now known for the southern part of the study area and lithologic correlation with Silurian units in the Chicago area is possible.

The Paleoecology of Silurian Trilobites with a Section on the Silurian Stratigraphy of Southeastern Wisconsin

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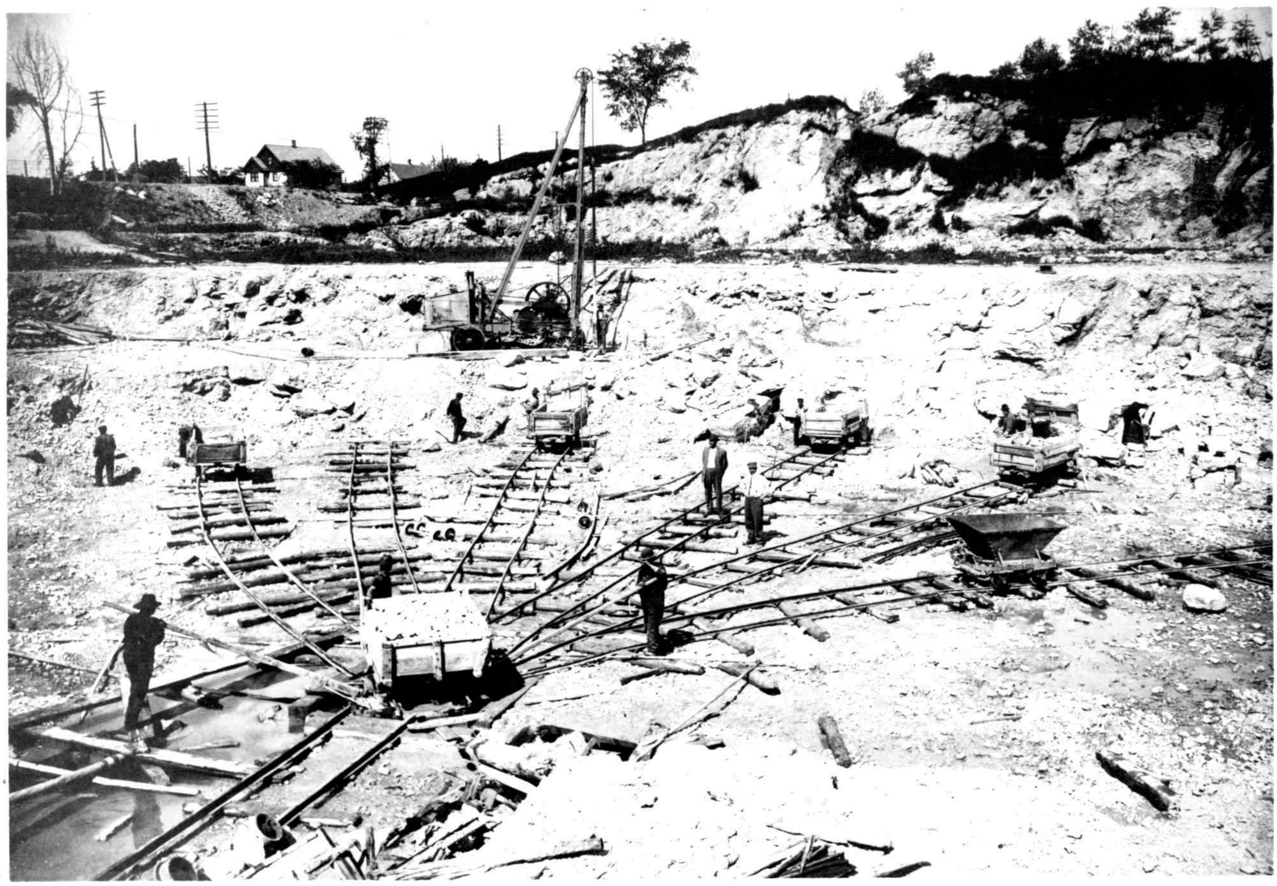


THE PALEOECOLOGY OF SILURIAN TRILOBITES, WITH A SECTION ON THE SILURIAN STRATIGRAPHY OF SOUTHEASTERN WISCONSIN

INTRODUCTION

This study will consider the association and distribution of Silurian trilobites in both level-bottom and reef environments. Although community studies of Silurian level-bottom environments are numerous, little work has been done on the trilobites since they make up only a small percentage of each of the communities. Since there are few geographic areas where most of the major types of known Silurian environments exist it was necessary to obtain information on a worldwide basis for this study.

This study has been divided into three parts. The first considers level-bottom Silurian trilobite associations and is generally based on data and information from previously studied environments. A number of brachiopod communities have been described in the Silurian whose distribution appears to be controlled by specific environmental factors. This study was undertaken, in part, to determine whether trilobite associations are controlled by the same environmental factors as those affecting brachiopod distribution.

In the second part of this study, particular emphasis has been placed on the trilobites in reefs and other carbonate buildups because of the high diversity of the trilobite faunas and the unusual mode of occurrence of some of the trilobites in these environments.

The third and final part of the study deals with the Silurian stratigraphy of southeastern Wisconsin. This part of the study was undertaken because a significant amount of information on trilobite distribution, particularly from reef environments, was derived from southeastern Wisconsin. The stratigraphy of this area was not well known, but new exposures and subsurface information have allowed new interpretations of the lithostratigraphy to be made.

SILURIAN LEVEL-BOTTOM TRILOBITE ASSOCIATIONS

Introduction

Numerous studies of Silurian benthic community composition and distribution have been published since Ziegler's (1965; Ziegler et al., 1968) initial work on the Llandoverian communities of Wales and the Welsh Borderland. Most of these studies have emphasized the brachiopod component of each community since brachiopods are usually the most numerous fossil group represented. Specific details concerning other fossil groups are generally lacking.

Ziegler's work established a pattern of communities which occurs along a shoreline-proximity, depth-correlated gradient from shallow-water, nearshore environments to offshore, deep-water, basinal environments (see Table 1). This pattern of community occurrence related to changes in water depth has served as a model for later work. Some modification, however, has been necessary since it has been found that water depth, although correlating with, and partially influencing, environmental conditions which control community distribution, is not in itself the primary controlling factor.

It has also been found that Ziegler's communities are much broader and all-inclusive than those used by modern marine ecologists (Boucot, 1975). Problems have arisen in trying to use

Table 1. Comparison of Ziegler's (1965) community scheme for the Upper Llandovery and Boucot's (1975) benthic assemblage (B.A.) scheme. B.A. 1 is high intertidal; B.A. 2 is low intertidal; B.A. 3 is subtidal, photic zone; B.A. 4-6 are in the subphotic zone. Reef communities occur in B.A. 3. Table is based on Boucot (1975, Table 1 and Figure 15).

	Ziegler	Boucot	
shallow water	*Lingula* Community	B.A. 1	nearshore
	Eocoelia Community	B.A. 2	
	Pentamerus Community	B.A. 3	
	Stricklandia Community	B.A. 4	
	Clorinda Community	B.A. 5	
deep water		B.A. 6	offshore

Ziegler's terminology in other time periods and geographic areas.

Boucot (1975) has proposed using a benthic assemblage scheme for developing a community framework in which to relate different communities in time and space. This approach avoids the need to identify a group of communities with the name of a particular taxon which may or may not be present in all communities (see Table 1). Benthic assemblages are arranged in a manner similar to the community occurrences described by Ziegler (1965); they are, however, based more on their proximity to shoreline than on depth. Depth may be reflected in the proximity to shoreline, but it is not implicit in the definition of benthic assemblages (Boucot, 1975).

Watkins (1979a) has made a detailed study of the benthic communities of the Ludlow Series present along a single transect in the Welsh Borderland. In his work he placed more emphasis on defining observable physical environmental characteristics, such as sedimentary structures, of the sedimentary rocks to determine relationships between communities.

An analysis of the trilobite distribution in association with described brachiopod-dominated communities has been undertaken in this study. Information from published studies, examination of collections used in those studies, and additional collections from some of the same localities were utilized in this analysis. Data from isolated communities lacking supplemental environmental information based on sedimentological evidence were not used. Published faunal lists were not used because many stratigraphic units may contain a wide range of environments and, consequently, several communities might unknowingly be combined.

In this study the number of trilobites was determined by taking the number of the most abundant skeletal element (cephala, cranidia, pygidia, or hypostomes , along with the number of complete specimens, if any, as the minimum number of individuals in each collection. Thoracic segments were excluded from these counts. The percentage of trilobites in all collections is somewhat exaggerated since there is no accurate method for determining how many specimens may represent molts of the same individual. Modern arthopods are quite variable in the number of molts they produce, which changes in frequency with age and other factors such as temperature.

The following sections describe the trilobite associations in recognized communities for which some corroborating evidence for environmental determination exists.

Waldron Shale

The Waldron Shale is one of the more notable Silurian formations in North America because of íts well preserved, diverse biota. Surprisingly, little detailed information has been published on the paleoecology or sedimentology of this unit. Fossils from the famous locality along Conn's Creek (type locality of the Waldron Shale; see Appendix I) near Waldron, Indiana, were first discovered in 1860 by D. Christy (Hall, 1882). James Hall assembled a large collection of fossils from this locality and described the fauna in a series of publications (Hall, 1864, 1877, 1879, 1882). Other than limited taxonomic studies there has been little published on the Waldron in recent years.

The Waldron Shale in northern Indiana is a poorly fossiliferous argillaceous or dolomitic limestone (Pinsak and Shaver, 1964). In southeastern Indiana, central Kentucky, and north-central Tennessee the Waldron is a light greenish-gray shale with limestone beds in its lower half. Some beds of theWaldron are highly fossiliferous in southeastern Indiana and north-central Tennessee, but surprisingly few fossils have been reported from exposures in Kentucky.

In southeastern Indiana the Waldron Shale ranges from zero to ten feet in thickness and is a thin-bedded, greenish- or bluish-gray calcareous shale with a few thin beds of argillaceous limestone in its lower layers. Many of the outcrops in Shelby, Bartholomew, and Ripley Counties, as well as other areas of Indiana, are poorly fossiliferous. It appears that the fossils are generally associated with the more calcareous beds. The type locality and primary collecting locality on Conn's Creek, near Waldron, have long been inaccessible, but in recent years good exposures have been available at the Blue Ridge quarry, a short distance to the southeast.

A general section through the Waldron Shale at the Blue Ridge quarry (see Appendix I for locality details) has been recently published by Frest (1977), who indicated that the lower two feet of the Waldron contain limestone beds and unbedded limestone masses (bryozoan mounds). He also stated that three-fourths of the crinoid taxa reported from the Waldron are not found above these limestone beds.

Halleck (1973) described the sedimentological and paleoecological characteristics of the lower beds of the Waldron Shale and its contact with the underlying Laurel Limestone as exposed at the Blue Ridge quarry. She noted that the contact between these two units was not everywhere gradational and that in some areas the upper surface of the Laurel was a hardground. She found that the fauna attached to this hardground had to modify its mode of attachment at the onset of Waldron deposition because of the resulting soft substrate. Many forms (crinoids, for example had to initially settle on a hard object, such as a shell, and later use branching root systems to penetrate the soft substrate as they grew too large to be supported.

In general, the Waldron Shale at this locality (Blue Ridge quarry) shows a significant vertical variation in the abundance and diversity of its biota. The lower limestone and shale beds contina a typical, abundant, well preserved, diverse Waldron fauna, the abundance and diversity of which appears to be directly related to the presence of the limestone beds.

A significant feature of these lower beds is the local occurrence of small bryozoan mounds or carbonate buildups. These structures appear to have been constructed by encrusting and branching bryozoans, and possibly algae, and are somewhat similar to the bryozoan mounds in the Irondequoit of western New York (see section on the Rochester Shale). These mounds are one to two feet high, several feet in diameter, and have a domal surface. The lower portions of these structures have not been observed, so the nature of the substrate on which they developed is not known. Frest (1977) diagrammatically illustrated these mounds resting on a limestone bed in the Waldron Shale and not in contact with the Laurel surface. The beds surrounding the bryozoan mounds do not seem to dip away from, or dome over, the mounds to any great degree. It is of particular interest that the diversity and abundance of fossils appears to increase in the vicinity of these mounds; it is not known whether this is a taphonomic effect or if the mounds maintained some control over the distribution of various organisms. It is probable that these mounds provided a large surface area for the attachment of many different organisms that was not generally available elsewhere in the Waldron Shale. Away from the mounds fossils are scattered.

Trilobites are uncommon in these lower beds (see Table 2) although probably all of the Waldron trilobite species are present, including the following, of which Calymene breviceps and Dalmanites verrucosus are most predominant: Calymene breviceps, Dalmanites verrucosus, Dalmanites halli, Otarion christyi, Lichas breviceps, Arctinurus boltoni, Trimerus delphinocephalus, Bumastus cf. armatus, Bumastus cf. ioxus, Cheirurus dilatatus, "Acidaspis" fimbriata, and Decoroproetus? sp. Away from the bryozoan mounds, Calymene and Dalmanites are still the most common trilobites, with occasional specimens of Arctinurus and Otarion. The preservation of trilobites in these beds is variable. Specimens of Calymene are occasionally found articulated or partially articulated; the same is true for Otarion. Dalmanites is very rarely found articulated although isolated skeletal elements are common and cephala are frequent; this is in contrast to the Rochester Shale of New York where complete specimens are not rate, but cephala are seldom found. The rest of the Waldron trilobites are usually represented by isolated, disarticulated skeletal elements. Trilobite abundance and diversity increase in the vicinity of the bryozoan mounds and nearly all of the Waldron trilobite species have been found there.

Boucot (1979, personal communication) stated that the fauna from these lower limestone and shale beds belongs to the Striispirifer Community and placed it within his Benthic Assemblage 3.

Proceeding upward in the section at the Blue Ridge quarry, limestone beds significantly decrease in occurrence and fossils

Table 2. Taxic percentages of the Striispirifer Community (Benthic Assemblage 3) based on collections of the Waldron Shale at Waldron, Indiana (U. S. N. M. 10C 17595), along Clifty Creek in Bartholomew and Shelby Counties, Indiana (Ausich, 1975, localities 21, 48, 88, and 89) and at Newsom, Tennessee (U. S. N. M. 10C 13628). Collection USNM 10C 17595 is from the Bryozoan beds near the base of the section. Bryozoans were not counted in any collections, but they are common. See Appendix I for locality details.

	17595	Locality 21 Unit 4	Locality 21 Unit 8	Locality 21 Float	Loc. 48	Loc. 88	Loc. 89	13628
Brachiopods	97.8%	69.3%	88.8%	66.8%	90.6%	82.0%	77.7%	90.1%
Gastropods	1.3	1.6	6.6	5.5	1.7	4.9	6.5	0.8
Crinoids	0.7	6.5	2.0	22.0	2.3	6.7	2.3	6.5
Sponges	-	-	-	0.1	0.1	0.3	1.1	0.4
Bivalves	-	-	0.2	0.2	0.3	0.1	-	0.4
Tabulate Corals	-	20.9	0.8	3.8	2.4	4.0	4.4	-
Annelids	-	-	-	-	0.1	-	-	-
Cornulitids	-	-	-	0.8	-	-	-	-
Blastoids	-	-	0.8	0.3	-	-	-	-
Trilobites	0.2	1.6	0.2	0.3	2.3	1.7	3.4	0.2
Total number of individuals	604	124	465	1341	1244	725	471	243

become rare and much less diverse. There is, however, a highly fossiliferous limestone bed near the top of the Waldron which contains a low diversity biota of typical Waldron fossils. Brachiopods again are the dominant taxa, but nearly all are rhynchonellids. Only a few specimens of other brachiopods are present; Boucot (1979, personal communication) has identified Atrypa "reticularis," Leptaena "rhomboidalis," Dalejina sp., Resserella sp., and strophomenaceans from this bed. The gastropod Cyclonema and small branching bryozoans are common. Eucalyptocrinites is the only crinoid taxon found. Trilobites are not rare, however, one species (Otarion christyi) accounts for the greatest percentage of this group. Lichas breviceps is next most abundant, followed by Calymene breviceps. Dalmanites and most of the rest of the trilobites found in the lower layers of the Waldron are absent in this bed (see Table 3). Larger-sized Waldron taxa are rare or absent in this horizon. Boucot (1979, personal communication) assigned this fauna to a Benthic Assemblage 3 position.

In general, the ecologic conditions controlling the changing distribution of the Waldron biota seem to be related to the conditions of sedimentation. Halleck (1973) has shown that an influx of sediment at the beginning of Walsron deposition resulted in a significant change in the relationship between various organisms and the substrate. The major factor controlling distribution appears to have

Table 3. Composition of the trilobite fauna of the Waldron Shale. Column 1: Bryozoan Beds of the Waldron Shale in southeastern Indiana, percentages based on the original data used in Table 2. Column 2: Single layer near the top of the Waldron Shale at Blue Ridge quarry at Waldron, Indiana. Column 3: Based on collections from a quarry at Newsom, Tennessee, near USNM 10C 13628 from Table 2 (see Appendix I). Even though only a few specimens are present in the collection in Column 3, an examination of other collections from museums indicates that this is a representative collection. Species indicated by C, U, and R have been identified from those locations in museum collections and in field work, but are not present in the collections in Table 3. C=common, U = uncommon, R = rare, representing approximate unquantified rates of occurrence based on field observation. Total number of trilobite individuals was determined by taking the number of the most common skeletal element (excluding thoracic segments), in the counted collections, as representing the minimum number of individuals in each collection. Percentages indicate the percent that each species represents of the total trilobite fauna.

Trilobite	1	2	3
Calymene breviceps	62.1%	8.0%	29.0%
Dalmanites verruscosus	34.8	-	47.0
Dalmanites halli	30.0	-	-
Otarion christyi	C	77.0	C?
Arctinurus boltoni	U	-	6.0
Cheirurus dilatatus	R	-	18.0
Lichas breviceps	U	15.0	-
Bumastus cf. *armatus*	U	-	U
Bumastus cf. *ioxus*	R	-	-
Illaenoides sp.	-	-	R
"*Acidaspsis*" *fimbriata*	R	0.4	-
Decoroproetus? sp.	R	-	-
Trimerus delphinocephalus	R	-	-
Total number of trilobite individuals	66	264	17

been location of a suitable substrate for larval attachment; this included the few tabulate corals, many of which grew on erect crinoids, a position probably shared by some other taxa. Examination of collections of Waldron fossils shows that many of the specimens have epizoans, including corals, bryozoans, annelids, brachiopods, crinoids, and snails. Some trilobite specimens and cephalopods are covered with bryozoans; this may, however, have been a post-mortem or, in the case of trilobites, post-molting phenomenon. This dependence on hard substrate may be the reason for the concentration of organisms around the bryozoan mounds. The decrease in the numbers of fossils in the upper beds may be related to an increase in the rate of sedimentation, as suggested by the near disappearance of limestone beds. The absence or rarity of the typical Waldron fauna in these upper beds may also be related to an increase in turbulence that may have resulted in an unstable substrate to which most of the organisms could not adapt. A major change in other environmental factors is not likely since the fauna in the upper beds, when it does appear, is composed of the same taxa that are present in the lower, more fossiliferous layers.

Overall, the Waldron Shale appears to represent a low-energy environment, suggested by the predominance of articulated brachiopods, occasionally articulated crinoids, and lack of high-energy sedimentary structures.

Ausich (1975) described a number of highly fossiliferous exposures of Waldron Shale in the Clifty Creek area, near Hartsville, Indiana, south of Waldron. He found the same general sedimentological and paleontological relationships as exhibited at the Blue Ridge quarry. The upper beds are poorly fossiliferous and most of the typical Waldron fauna is confined to the lower limestone and shale beds which locally contain bryozoan mounds. Ausich noted that some of the mounds were constructed exclusively by either encrusting or branching bryozoans. He also found that at one locality the contact between the Waldron and the underlying Laurel was very irregular. In shallow depressions in the irregular Laurel surface he found a number of articulated, right-side-up specimens of Calymene breviceps. This interesting occurrence may suggest some sort of behavioral characteristic as opposed to chance taphonomic happenings.

South of Indiana the Waldron Shale is a typical greenish-gray shale, but is seldom fossiliferous except in the vicinity of Newsom, Tennessee, where a typical Waldron fauna occurs similar to that found in the lower limestone and shale layers in Indiana (see Table 2). The Waldron Shale exposures around Newsom have not been well studied in recent years. The general lithology of the rock is similar to that at Waldron except for being darker in color, as are the fossils. McKemie (1976) briefly described the general sedimentologic and paleoecologic characteristics of the Waldron near Newsom, noting that there is an upward decrease in echinoderm abundance and diversity in the section there. Boucot (1979, personal communication) placed the fauna at Newsom in the *Striispirifer* Community and gave it a Benthic Assemblage 3 assignment in his proximity to shoreline classification. Boucot also stated that there is a change in Waldron community composition in central Tennessee resulting in a Benthic Assemblage 4 assignment based on abundant specimens of *Leangella tennesseensis* found at Newsom, Swallow Bluff, New Era, and Clifton, Tennessee, as reported by Foerste (1935).

While the overall faunal composition at Newsom is very similar to that of southeastern Indiana, a detailed examination shows consistent minor differences in occurrence of some of the taxa. Cephalopods are very rare and poorly preserved in Indiana Waldron localities, but at Newsom specimens of *Dawsonoceras* are not rare and are well preserved. Also, the cystoid *Caryocrinites* is found at Newsom, but is absent in Indiana. There are notable differences in the trilobite fauna as well; *Calymene* and *Dalmanites* are common in both places, but *Cheirurus dilatatus* is common at Newsom but very rare in Indiana. The opposite is true for *Otarion* which appears to be rare at Newsom, but common in Indiana. The only other trilobites found at Newsom are *Arctinurus boltoni*, *Bumastus* cf. *armatus*, and *Illaenoides* sp. (see Table 3). There are also some differences in the mode of preservation wherein articulated or partially articulated specimens of _Calymene_ are very rare at Newsom as opposed to being fairly common in southeastern Indiana. Bryozoan mounds have not been reported from Newsom, but otherwise the overall pattern of sedimentation appears to be similar to that in Indiana.

The Waldron Shale has not received the sedimentologic and paleoecologic study necessary for a good understanding of the environmental controls on the biota. However, enough is known to suggest that variation in faunal distribution and abundance is possibly due to changes in the rate of sedimentation and nature of the substrate. The differences between Indiana and Tennessee are not well understood.

Rochester Shale

The Rochester Shale is a richly fossiliferous unit exposed along the Niagaran Escarpment from Hamilton, Ontario, to central New York; it is also found in the central Appalachians to the south. This unit is Wenlockian in age (Berry and Boucot, 1970), and is characterized, in large part, by the _Striispirifer_ Community, which is assigned a Benthic Assemblage 3 position (Boucot, 1975, p. 22-24).

The Rochester Shale fauna has been well known since James Hall's work in the mid-nineteenth century (1843, 1852), but has not been thoroughly revised since that time. The trilobites from the Rochester Shale were among the first trilobites described from North America. They are often listed as though they belong to a single association, but this is misleading. Brett (1978) has made a thorough study of the Rochester echinoderm fauna, in which he included significant ecologic and community information.

The Rochester Shale in New York and Ontario displays both vertical and lateral environmental variation. The unit has long been known to exhibit a pronounced faunal difference between its lower and upper subunits (Ringueberg, 1882). Brett (1978) has examined these variations in detail and the following descriptions are based largely on his work.

The Irondequoit Limestone underlies the Rochester Shale throughout western New York and eastern Ontario. The petrology of this unit was described by Freedenberg (1976), who noted that the upper beds are a crinoidal biosparite which formed above wave-base in a shallow-water, high-energy environment. Sedimentological evidence for this type of depositional environment is primarily represented by winnowing and sorting of the sediment, as well as the rounding and abrasion of crinoid debris. Brett (1978) added that ctenostome bryozoan borings are found on all sides of shells and echinoderm plates, indicating a slow rate of deposition. He also observed that almost all echinoderms and brachiopods were disarticulated and frequently broken and abraded, supporting Freedenberg's observations. Brett listed *Atrypa*, *Whitfieldella*, and *Leptaena* as the main brachiopods in this unit. The top of the Irondequoit occasionally contains small bryozoan mounds, some of which project up into the overlying Rochester Shale. The only trilobites present in the upper Irondequoit are found in these mounds; they include abundant *Bumastus ioxus*, common *Kosovopeltis* sp., and rare *Cheirurus* sp. and *Calymene* sp. This is a typical carbonate buildup trilobite association and will later be discussed in detail.

The contact between the Irondequoit and the overlying Rochester Shale is gradational, with the lower three feet of the Rochester containing some argillaceous limestone beds having a bryozoan and brachiopod fauna similar to the Irondequoit (Brett, 1978).

Above this basal unit is the main lower subunit of the Rochester as described by Brett (1978). The subunit consists primarily of interbedded shales and limestones; these are known as the Bryozoan Beds because of the abundance and dominance of bryozoans. The Bryozoan Beds contain the *Striispirifer* Community of Boucot (1975). Most of the typical fossils associated with the Rochester Shale are limited to these beds with the exception of some of the trilobites. Brett (1978) described these Bryozoan Beds as displaying a significant lateral variation indicated by an eastward thinning from a maximum development at Grimsby, Ontario. He interpreted the depositional history of most of these beds to have involved long periods of low-energy, undisturbed, slow deposition (represented by limestone beds) which allowed a maximum diversity and abundance of the biota to develop. The deposition of these limestone beds was interrupted by short periods of rapid deposition, occasionally accompanied by scouring and wave activity, which killed off most of the biota. Tables 4 and 5 list faunal data on a number of collections made by Brett in this portion of the Rochester Shale.

All of the trilobites reported from the Rochester, with the possible exception of *Deiphon*, are found in these Bryozoan Beds. *Deiphon* has not been collected in either Brett's or my work, but it is present in some older collections; however, this genus is probably from the Bryozoan Beds also. *Bumastus* and *Calymene* are the most common trilobites found in the Bryozoan Beds, with other trilobites occasionally being common. *Dalmanites limulurus* and *Trimerus delphinocephalus* are seldom common in the Bryozoan Beds and occur locally in only a few specific horizons; they are, however, typical of the upper barren shale subunit. Preservation of the trilobites throughout the Rochester Shale ranges from

Table 4. Taxic percentages of the *Striispirifer* Community (Benthic Assemblage 3) from the Bryozoan Beds of the Lower Rochester Shale at Middleport, New York, and from the *Homocrinus* Band at Lockport Gulf, New York (see Appendix I for locality details). Bryozoans were abundant, but were excluded from this tabulation. Data from Brett (1978, Tables 17 and 18).

	Bryozoan Beds				
	Layer I	Layer III	Layer IVm	Layer VIm	Homocrinus Band
Corals	5.4%	1.5%	0.6%	0.9%	0.3%
Brachiopods	89.2	81.8	87.7	95.0	86.7
Molluscs	-	4.2	1.6	0.3	-
Echinoderms	-	9.2	5.8	1.9	5.8
Cornulites	-	-	3.1	-	0.1
Trilobites	5.4	3.3	1.2	1.9	7.1
Total number of individuals	130	336	486	319	675

Table 5. Composition of the trilobite fauna of the Lower Rochester Shale. Columns 1-4 are from the Bryozoan Beds of the Lower Rochester Shale at Middleport, New York, and Column 5 is from the *Homocrinus* Band at Lockport Gulf, New York. Data in Columns 1-5 are from Brett (1978, Tables 17 and 18)(see Appendix I for locality details). Column 6 represents an additional collection made by the author from the Bryozoan Beds of the Lower Rochester Shale at Middleport, New York. Rare *Illaenoides* sp., *Cheirurus* sp., and *Deiphon* sp. are present in the Lower Rochester Shale, but are not present in these collections.

	Bryozoan Beds					
	Layer I	Layer III	Layer IVm	Layer VIm	Homocrinus Band	Middleport
Arctinurus boltoni	42.9%	-	-	-	10.4%	39.1%
Bumastus cf. *ioxus*	14.2	9.1	-	33.3	10.4	21.7
Calymene cf. *niagarensis*	42.9	90.9	100.0	50.0	16.6	30.4
Dalmanites limulurus	-	-	-	16.7	54.1	-
Decoroproetus? sp.	-	-	-	-	4.1	4.3
Dicranopeltis sp.	-	-	-	-	-	4.3
Trimerus delphinocephalus	-	-	-	-	4.1	-
Total number of individuals	7	11	6	6	48	23

articulated individuals to more typical disarticulation and scattering of skeletal elements. Calymene is commonly the only trilobite found articulated.

Brett (1978) described the upper barren shale subunit as a calcareous, platy, rather homogenous shale with few fossil layers when compared with the underlying Bryozoan Beds. He found the contact with the Bryozoan Beds to be sharp and representing a complete faunal change. Striispirifer and Caryocrinites are absent, along with most of the bryozoans and echinoderms present below. The barren beds exhibit an upward increase in grain size and a gradational contact with the overlying DeCew Dolomite (Brett, 1978). Sedimentary structures indicate intermittent scouring and rapid redeposition of silty sediment in a shallow-water environment. He attributed the lack of fauna to high rates of sedimentation and agitation of the bottom sediments, resuspending fine silts. In general, the fauna of this upper subunit is very low in diversity when compared with the Bryozoan Beds. The brachiopods Strophonella, Coolinia, and Dalejina may cover some bedding planes, but are generally uncommon. This subunit contains a few limestone lenses made entirely of size-sorted tentaculitids, ostracods, and crinoidal debris. The crinoids found in these upper shale beds do not have cementing holdfasts. The trilobites are predominantly represented by Dalmanites limulurus and Trimerus delphinocephalus, which are present in approximately equal numbers. Scattered articulated or partially articulated specimens of these trilobites are found, as are lenses of disarticulated specimens.

The overlying DeCew Dolomite is a dolomitic siltstone deposited in a possible lagoonal restricted environment (Brett, 1978), which may represent a Benthic Assemblage 1-2 position. The trilobites Dalmanites limulurus and Trimerus delphinocephalus are present, but, in general, fossils are rare (Zenger, 1965).

The overall vertical trend in the Rochester seems to represent a shallow-water, high-energy environment, which was rapidly altered to a lower-energy environment accompanied by an influx of terrigenous clastic sediments. This phase is followed by a shallowing-upward, low-energy sequence, accompanied by a high rate of sedimentation, ceasing at the onset of the DeCew.

The Rochester Shale grades into the Herkimer Sandstone to the east. The Herkimer appears to represent a shallower-water, higher-energy, nearer-shore environment than the Rochester. As mentioned before, the Rochester Bryozoan Beds disappear towards the east, as do the limestone beds, while the shale beds become thicker. The Herkimer is subdivided into two members: the Joslin Hill Member on the west and the Jordanville Member on the east. The Joslin Hill Member consists of quartzose dolomite, dolomitic siltstone, and dolomitic sandstone on its eastern edge, grading laterally into more shaley beds to the west. This member contains ripple marks and cross-laminated beds (Zenger, 1971). The Joslin Hill was deposited above wavebase in a shallow-water, nearshore environment (Zenger, 1971). Trimerus delphinocephalus, Dalmanites limulurus, Calymene niagarensis, and Calymene sp. are the most common trilobites, with Trimerus being the most wide-ranging. In some beds the trace fossils Rusophycus and Cruziana are also common (Osgood and Drennen, 1975). To the east, the Jordanville Member of the Herkimer is unfossiliferous and represents a beach deposit (Zenger, 1971).

The Rochester Shale in Pennsylvania, Maryland, and West Virginia has a limited trilobite fauna compared with the Rochester to the north in New York and Ontario. The trilobite fauna is composed primarily of Dalmanites limulurus, Trimerus delphinocephalus, Calymene spp., and rare Encrinurus sp. (Swartz, 1923). Folk (1962) found lithologic evidence that the Rochester was a lagoonal deposit in a limited area of West Virginia, but in most other areas of West Virginia it is a normal marine deposit (Smosna, 1978, personal communication). In any event, it is probable that the deposition of the Rochester Shale in this area represents a shallow-water, low-energy environment. The Rochester is, in some areas of West Virginia, bounded on the east by the high-energy Keefer Sandstone, containing a similar trilobite fauna consisting of Dalmanites, *Trimerus*, and *Calymene*, and forming a high-energy barrier (Folk, 1962). The environmental characteristics of the Rochester Shale in Pennsylvania, Maryland, and West Virginia bear close resemblance to that of the upper barren shale subunit of the Rochester in New York and Ontario. The higher-energy conditions present in these southern localities appear to have prohibited the development of the Bryozoan Beds which required long periods of low-energy, undisturbed, slow deposition.

Hopkinton Dolomite

The Hopkinton Dolomite is a Late Llandoverian to Early Wenlockian platform carbonate found in eastern Iowa. Fossils in the Hopkinton are generally preserved as internal and external molds and the trilobites are almost always disarticulated. Several recent studies (Philcox, 1970; Johnson, 1975, 1977; Witzke, 1976) have examined various features of this unit.

Philcox (1970) described the general characteristics of several small bioherms in Jones and Clinton Counties, Iowa. He concluded that large coral growths in the core acted as sediment traps leading to mound buildup; the cores are surrounded by dipping flank beds with abundant crinoidal debris, and fenestrate bryozoans are prolific in the outer portions of the flanks.

Johnson (1975) described the overall community composition and succession of the Hopkinton, which he related to changes in water depth. Johnson (1977) later expanded on these ideas, presenting detailed faunal tabulations from a number of collections made throughout the Hopkinton.

Witzke (1976) described the lithology and paleoecology of the Hopkinton Dolomite in a study on pelmatozoans found in this unit. Witzke stressed the importance of examining the rock texture in thin-section for various communities since significant sedimentologic and biologic information may otherwise be overlooked. He also used Johnson's overall community model in this study.

Johnson (1975, 1977) recognized several communities in the Hopkinton Dolomite (see Figure 1), three of which contain trilobites. He stated that the change in the distribution of these communities through the reflected variations in water depth. In the shallowest environments he identified a Coral Community, which he believed reached effective wavebase. Johnson considered this community equivalent to Ziegler's (1965) Eocoelia Community, which would, then, occupy a Benthic Assemblage 2 position. Boucot (1979, personal communication) stated that this community occupies a Benthic Assemblage 3 position, however. Johnson's second community containing trilobites is the Pentamerid Community, dominated by pentamerid brachiopods, and equivalent to Ziegler's (1965) Pentamerus Community. Johnson considered this community to represent a

Figure 1. Figure 1 shows the relationships of Johnson's (1975) stratigraphic units to community occurrence and his suggested sea-level fluctuations in the Hopkinton Dolomite of eastern Iowa. Modified from Johnson (1977). C = Coral; S = Stricklandid; P = Pentamerid

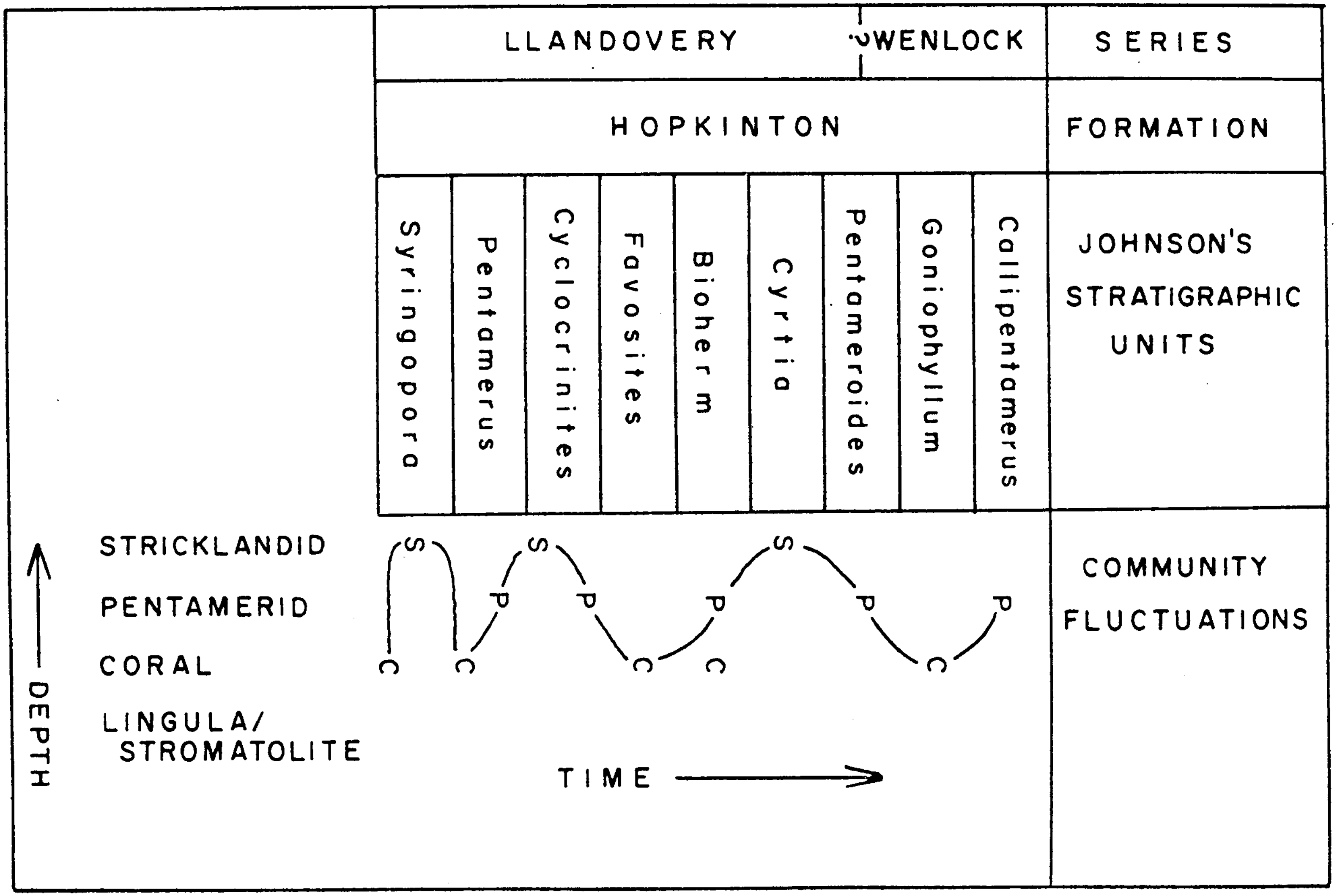

LLANDOVERY
? WENLOCK
SERIES
HOPKINTON
FORMATION
Syringopora
Pentamerus
Cyclocrinites
Favosites
Bioherm
Cyrtia
Pentameroides
Goniophyllum
Callipentamerus
JOHNSON'S STRATIGRAPHIC UNITS
STRICKLANDID
PENTAMERID
CORAL
LINGULA/ STROMATOLITE
DEPTH
TIME
COMMUNITY FLUCTUATIONS

Figure 1

below wavebase, deeper-water environment than the Coral Community. The last community of Johnson's which contains trilobites is the deep-water Stricklandid Community, which he stated was equivalent to Ziegler's (1965) *Costistricklandia* Community. Johnson stated that all three of these communities were located within the photic zone, having a maximum depth of about 100 meters, based on the presence of the calcareous green alga *Cyclocrinites dactioloides*. He also formulated a pattern of sea-level fluctuation based on the succession of these communities through a vertical sequence.

For this study collections were made from a number of localities, supplemented by data from Johnson's work and information from all three of the aforementioned studies. This information was used to determine if there are any trilobite associations related to the previously described communities and environments.

An examination of the shallow-water Coral and Pentamerid Communities indicates a low abundance and diversity of trilobites, which is supported by Johnson's counts for collections from these communities (see Table 6). The trilobite *Stenopareia* is generally the only trilobite found in these communities although *Calymene* and possibly *Encrinurus* may occur.

The deeper-water Stricklandid Community has a significantly higher diversity of trilobites, which are sometimes common in this community, occasionally reaching over 14 percent of the total fauna

Table 6. Trilobite composition of collections made in different stratigraphic subdivisions of the Hopkinton Dolomite of Iowa. Data derived from Johnson (1977).

Communities Present in Subdivision	Stratigraphic Subdivisions	Total Number of Collections	Number of Collections with Trilobites	Percent Collections with Trilobites	Percent Trilobites in each Collection	Number of Trilobite Taxa
Stricklandid/ Coral	*Syringopora* Beds	10	1	10.0%	0.1%	1
Pentamerid	*Pentamerus* Beds	9	1	12.0	0.5	1
Stricklandid/ Pentamerid	*Cyclocrinites* Beds	14	1	7.0	0.1	1
Coral/ Pentamerid	*Favosites* Beds	7	0	-	-	-
Pentamerid/ Coral	Bioherm Beds	3	1	33.3	0.3	1
Stricklandid/ Clorindid	*Cyrtia* Beds	7	7	100.0	4.8	10
Pentamerid	*Pentameroides* Beds	3	0	-	-	-

as indicated by Johnson's counts (see Tables 6 and 8). *Stenopareia*, lichids, and scutelluids are the most frequently found trilobites.

The biotic composition of these communities appears to be variable at different stratigraphic horizons. A prime example of this is the Pentamerid Community. In most stratigraphic horizons in the Hopkinton Dolomite the Pentamerid Community is usually low in diversity, however, in the upper half of Johnson's *Cyclocrinites* Beds (see Figure 1), the Pentamerid Community locally has a very high diversity of most taxa, including pelmatozoans, cephalopods, gastropods, trilobites, brachiopods, and corals. This association of fossils in the *Cyclocrinites* Beds is very reminiscent of typical reef communities found throughout the Silurian of the Midwestern United States, but there is no evidence for any carbonate buildup here. This association appears to represent a level-bottom complex of communities developed in environmental conditions similar to those found in reefs.

The *Cyclocrinites* Beds also demonstrate a basic problem in determining the true diversity of low abundance taxa within specific communities. In most community studies blocks of rock are broken down and all identifiable fossils are saved and tabulated. Collections of more than 100 specimens are usually adequate to accurately determine the abundance of more common taxa and major biologic groups. This method is sufficient for defining the overall characteristics of a particular community, but is inadequate for determining diversity and abundance of some taxonomic groups. Johnson's data for the Cyclocrinites Beds accurately indicate that trilobites represent a very low percentage of the total biota, but his data also suggest that trilobite diversity in the Cyclocrinites Beds is also very low (Johnson recorded only Stenopareia) as in other occurrences of the Pentamerid Community. Collections of the Pentamerid Community made in the upper layers of the Cyclocrinites Beds of some localities indicate that at least five trilobite genera are present, three of which are not particularly rare (see Table 7). Examination of other exposures of the Pentamerid Community substantiate the low diversity reported for this community by Johnson. As trilobites are usually rare in most Silurian communities this problem is probably inherent in most community studies.

A significant variation of the Stricklandid Community was observed by Johnson (1975) in the lower layers of his Cyrtia Beds (see Figure 1). Here, locally bryozoan-rich layers contain a high diversity of brachiopods, bryozoans, and trilobites (see Table 8), whereas the Stricklandid Community elsewhere does not display this high diversity. The Cyrtia Beds constitute the only stratigraphic horizon in the Hopkinton in which Johnson found trilobites in all of his collections (see Table 6). Johnson stated that these highly diverse lower layers in the Cyrtia Beds were deposited in low inter-reef areas

Table 7. Trilobite composition of the high diversity Pentamerid Community of the *Cyclocrinites* Beds at the Lang quarry (Johnson's locality 91, 1977), near Monticello, Iowa. See Appendix I for locality details.

Trilobite	Number of Individuals of Each	Percent of Trilobite Fauna
Stenopareia sp.	37	56.1%
Arctinurus sp.	11	16.7
scutelluid	13	19.7
Dicranopeltis sp.	2	3.0
Cheirurus sp.	3	4.5
Total number of individuals	66	

Table 8. Trilobite composition of the Stricklandid Community of the Cyrtia Beds of the Hopkinton Dolomite of Iowa. All data from Johnson (1977) except Columns 2 and 9. John Creek II is from Johnson's locality 73. 1; Lux Quarry is the same as Johnson's locality 21 and both collections are in my possession. All locality numbers at the heads of columns refer to Johnson's (1977) locality numbers. See Appendix I for locality details.

Trilobite	John Creek I 73. 1	John Creek II	43. 1	43. 2	21. 1	21. 2	73. 2	77. 1	Lux Quarry
Stenopareia sp.	16. 6%	22. 0%	25. 0%	25. 0%	100%	80. 0%	100%	100%	43. 8%
illaenid	16. 6	9. 5	50. 0	-	-	-	-	-	-
Dicranopeltis sp.	6. 6	15. 8	-	-	-	-	-	-	7. 3
Encrinurus sp. A	6. 6	6. 3	-	-	-	-	-	-	1. 6
Dicranopeltis? sp.	36. 6	19. 0	-	-	-	-	-	-	26. 0
cheirurid	-	4. 7	-	25. 0	-	-	-	-	4. 8
calymenid	6. 6	3. 1	12. 5	25. 0	-	-	-	-	7. 3
scutelluid	-	7. 9	-	25. 0	-	-	-	-	3. 2
Encrinurus sp. B	6. 6	7. 9	-	25. 0	-	-	-	-	0. 8
Arctinurus sp.	-	1. 5	-	-	-	-	-	-	-
lichid	-	-	-	-	-	-	-	-	4. 8
proetid	3. 3	1. 5	-	-	-	-	-	-	-
Youngia sp.	-	-	12. 5	-	-	20. 0	-	-	-
Trilobites as percent of total fauna	14. 5	-	7. 2	4. 0	3. 4	1. 5	7. 0	1. 3	-
Number of trilobite individuals	30	63	8	4	1	5	1	2	95

at the onset of a deepening phase of sea-level which terminated reef development of the Bioherm Beds (see Figure 1).

Johnson noted that the Bioherm Beds contain the Coral and Pentamerid Communities. The buildups in the Bioherm Beds themselves contain very few trilobites, but scattered large specimens of Arctinurus and scutelluids are present in the core areas. The flank beds are composed predominantly of disarticulated pelmatozoans; however, layers of abundant, large fenestrate and branching bryozoans are present also. These bryozoan layers contain a highly diverse trilobite association (see Table 9), the trilobites of which are generally small in size. The morphologic characteristics of these bryozoans and trilobites indicate a low-energy depositional environment. These bryozoan layers are in some ways similar to the bryozoan layers of the Cyrtia Beds, however, a comparison of Tables 8 and 9 present some differences in their composition.

At least two or three trilobite associations can be recognized in the Hopkinton Dolomite. A moderate diversity association of Stenopareia, Arctinurus, and scutelluids is typical of the Pentamerid Community in the Cyclocrinites Beds and possibly in the reef cores in the Bioherm Beds. A highly diverse trilobite association is found in low-energy, bryozoan-rich flank beds of reefs in the Bioherm Beds, which is dominated by small lichids, such as Dicranopeltis, common scutelluids, Stenopareia, odontopleurids, and cheirurids.

Table 9. Trilobite composition of bryozoan-rich flank beds of the Bioherm Beds of the Hopkinton Dolomite of Iowa. Monticello quarry (Jones Co., Iowa) is the same as Johnson's (1977) locality 103, and Elwood quarry (Clinton Co., Iowa) is the same as Johnson's (1977) locality 82 (see Appendix I for locality details). These collections are in the author's possession.

Trilobite	Monticello Quarry	Elwood Quarry
Stenopareia sp.	12.5%	4.8%
scutelluid	18.7	4.8
Arctinurus sp.	18.7	3.2
Dicranopeltis sp.	37.0	30.6
proetid	6.0	1.6
Ceratocephala sp.	6.0	9.6
Dudleyaspis sp.	-	4.8
Cheirurus sp.	-	17.7
Deiphon sp.	-	8.0
Acidaspis sp.	-	6.4
Otarion? sp.	-	3.2
Calymene sp.	-	1.6
Total number of individuals	16	62

A third trilobite association is recognized in the lower *Cyrtia* Beds, which is dominated by *Stenopareia* and other illaenids, small lichids, and encrinurids; this association is very similar to the flank beds of the Bioherm Beds, however, the presence of encrinurids in the *Cyrtia* Beds is notable. Johnson (1977) assigned this part of the *Cyrtia* Beds to the Stricklandid Community, indicating a Benthic Assemblage 4 position. Boucot (1979, personal communication), however, stated that the high-diversity community represented by Johnson's (1977) 73.1 collection occupies a Benthic Assemblage 3-4 position.

Stonehouse Formation, Arisaig, Nova Scotia

The general stratigraphic and lithologic characteristics of the Stonehouse Formation have been well described by Boucot *et al.* (1974) as part of a general study of the Silurian rocks of the Arisaig region of Nova Scotia, Canada. Watkins and Boucot (1975) have also described the composition and succession of brachiopod communities for the Silurian of the same area. This information and the collections assembled for the above studies provide a good foundation for examining the trilobites associated with specific environments in the Silurian of this region. Most of the trilobites collected are from the Stonehouse Formation although a comparable number of collections and specimens are available from some other units.

The Stonehouse Formation is a series of mudstones, shales, and siltstones, exhibiting common shallow-water sedimentary structures, ranging in age from Pridolian to Early Devonian (Boucot et al., 1974). The unit represents an upward-shallowing sequence, conformably grading into Early Devonian nonmarine beds (Boucot et al., 1974). The brachiopods of the Stonehouse belong to the Quadrifarius-Protochonetes Community, which is a nearshore, shallow-water, low-diversity community found in beds with common scour structures, cross-bedding, and coquinite beds (Watkins and Boucot, 1975). This community is placed in a Benthic Assemblage 2 position with communities such as the Eocoelia Community of Ziegler (1965).

The trilobites of the Stonehouse are not common, being found in only about one-third of the collections assembled, and make up approximately three percent of the total number of individuals of all taxa reported in each collection. The trilobite diversity is low when compared with many offshore communities in other areas, but, surprisingly, trilobites are much more common and slightly more diverse than offshore, older Silurian communities described by Watkins and Boucot (1975). Only two genera are commonly found in most collections, representing 96 percent of the trilobite specimens. The most common, Calymene, accounts for an average of 63 percent of all trilobites, followed by Scotiella, which accounts for 33 percent of the total number of trilobite individuals. Another trilobite, Homalonotus, was found in only two of the collections. In the larger of the two collections it accounts for 10 percent of the trilobite fauna, but represents only three percent of all the trilobites in all collections. The only other trilobite in these collections is a single specimen of a phacopid. McLearn (124) described the Stonehouse Formation trilobites and indicated no additional genera although he did record two species of Homalonotus. Table 10 shows several important features of the Stonehouse Formation collections. The trilobites in the Stonehouse collections are all disarticulated and the skeletal elements are scattered. Calymene is represented by nearly equal numbers of cranidia and pygidia and a few hypostomes. Scotiella is also represented by nearly equal numbers of cranidia and pygidia and a few cephala. Homalonotus is represented by pygidia only.

Watkins and Boucot (1975) have described community replacement and evolution of the brachiopods in the Silurian rocks of the Arisaig region. There is no evidence, however, for trilobite community evolution or replacement in the same collections. This is probably due to the rarity of trilobites in rock units older than the Stonehouse; only four of the sixteen collections from the underlying Ludlovian Moydart Formation contained trilobites. In these Moydart collections there are only ten trilobites, which represent only one to four percent of all taxa present. All specimens are of Calymene

Table 10. Composition of the trilobite fauna of the Quadrifarius-Protochonetes Community (Benthic Assemblage 2) of the Stonehouse Formation of the Arisaig region of Nova Scotia, Canada. Numbers above the columns refer to the U. S. National Museum (USNM) localities (see Appendix I for locality details).

	10206	10203	10835	10185	10189	10205	10184	10187	10910	10192	10191	10188	Average % trilobites in all collections
Calymene sp.	50.0%	100.0%	-	97.0%	42.0%	52.0%	100.0%	66.0%	57.0%	4.0%	93.0%	100.0%	63.0%
Scotiella sp.	50.0	-	75.0	3.0	57.0	48.0	-	33.0	30.0	96.0	7.0	-	33.1
homalonotid	-	-	25.0	-	-	-	-	-	10.0	-	-	-	3.2
phacopid	-	-	-	-	-	-	-	-	< 1.0	-	-	-	< 1.0
Percent trilobites of all taxa	4.0	< 1.0	2.0	2.0	4.0	14.0	< 1.0	< 1.0	2.0	4.0	8.0	< 1.0	3.7
Total number of trilobite individuals	22	1	4	4	7	42	3	3	39	26	29	1	

except for one possible Scotiella. In the Upper Wenlockian Doctors Brook Formation only one collection of fifteen contains any trilobites. Only three specimens of Calymene and one Scotiella are present, constituting much less than one percent of this one collection which contains over 4000 brachiopods. The Doctors Brook contains the Salopina submedia-"Camarotoechia" aff. planorugosa Community which is found in similar nearshore environmental conditions as the Quadrifarius-Protochonetes Community. The change represented by these different communities may be evolutionary (Watkins and Boucot, 1975) or partly environmental. Only one in 43 collections of the Lower Wenlockian French River Formation contains any trilobites. This unit contains the Isorthis mcadamensis, Meristina, and Plagiorhyncha cf. plastica Communities which represent offshore, possibly Benthic Assemblage 3-4, environmental conditions (Watkins and Boucot, 1975). The low number of trilobites in this unit is unusual since these communities generally have a higher diversity than nearshore communities.

McLearn's (1924) work indicates that Dalmanitina weaveria is the only other trilobite genus from the Arisaig region Silurian, but he does list different species for different units. He also indicated that Calymene ranges through the Silurian in this area and Homalonotus ranges from the Wenlockian French River Formation through the Pridolian part of the Stonehouse. Scotiella first appears in the

Ludlovian Moydart Formation, while Dalmanitina weaveri is found only in the upper member of the Upper Llandoverian Ross Brook Formation; this may suggest that Scotiella has functionally replaced Dalmanitina weaveri in the Late Ludlovian Moydart, however, more information is needed since large collections are not presently available from these units.

Silurian Level-Bottom Carbonate Trilobite Associations of Wisconsin and Illinois

Introduction

The Silurian rocks of the Great Lakes area in the Midwestern United States are predominantly composed of carbonates and represent a wide variety of environments. In general, the area was a broad, shallow epicontinental sea during the Silurian, having only minor variations in topography, with the exception of several deep-water basins. In Late Wenlockian and Ludlovian time reefs became locally common, particularly along the shelf-basin margins, forming more complex environments. The distribution and composition of these reefs will be discussed in the section on the Racine Dolomite.

Many of the level-bottom carbonates deposited in this area during the Silurian are either poorly fossiliferous or have a low diversity, so trilobies are lacking in many of these environments. The lack of a distinct nearshore-to-offshore gradient in many parts of this region makes environmental determination of identifiable communities difficult. There are, however, a few distinctive trilobite associations which can be recognized. Some of the most distinctive associations are those found in reef environments. An association dominated by illaenids, scutelluids, and lichids is prominent in the core area of many reefs and carbonate buildups. The highly crinoidal reef flank environments contain a somewhat different trilobite association of which Sphaerexochus, Calymene, and Dalmanites are characteristic. These trilobite associations from reef environments will be described in more detail in a later section.

No homalonotid-acastomorph type of association has been found in carbonates of Wisconsin and Illinois although the carbonate equivalent of the environment (Benthic Assemblage 1-2) in which this association commonly occurs appears to be present in this area.

High-energy, level-bottom, shallow-water penatmerid and coral communities (approximately Benthic Assemblage 3 of Boucot's, 1975, classification) found in the Manistique Formation (Llandoverian) in northern Wisconsin are characterized by a high abundance, but low diversity of organisms. Trilobites are rare, but a few specimens of the illaenid Stenopareia and scutelluids are occasionally found. The occurrence of Stenopaeria in these communities contrasts with the occurrence of Encrinurus in the same types of communities in the Manistique Formation of northern Michigan and the

Fossil Hill Formation of Ontario, both to the east. The rarity of trilobites in these communities and, therefore, the small sample size makes these observations tentative, however.

The *Flexicalymene celebra* Association

One of the most notable trilobite associations from the Silurian of this area is the *Flexicalymene celebra* association. This trilobite association occurs in *Dicoelosia* communities; Boucot (1975) assigned the *Dicoelosia* Community to a Benthic Assemblage 4-5 position. This community is commonly found in level-bottom beds which are laterally equivalent to well-developed reefs in Milwaukee County, Wisconsin (see Hartung quarry, Zimmerman quarry, Story quarry, Manegold quarry descriptions in Appendix II). These beds occur within the Racine Dolomite and are Late Wenlockian in age (Boucot, 1970, personal communication). This community occurs in fine-grained, well-bedded dolomite lacking high-energy sedimentary structures.

This community has the highest diversity of any level-bottom community in this area. Most of the fossils are localized in zones, varying from a few inches to over one foot thick, which do not appear to have been concentrated by storm or current activities. These fossil zones are widely spaced and appear to be laterally discontinuous when examined over a large area. The non-trilobite fauna is dominated by a large variety of small brachiopods (see Table 11), with lesser numbers of small rugose corals, fenestrate bryozoans, and gastropods. Orthoconic cephalopods up to several feet in length are scattered throughout the entire section. Scattered fine, disarticulated pelmatozoan debris (mostly piscocrinids) is fairly common in these fossiliferous zones. Horizontal trails and burrows are common to some bedding planes, but vertical burrows are infrequent. Many of the brachiopods are disarticulated, but none appear to be abraded or broken. Overall, the lack of attached organisms, such as tabulate corals and encrusting bryozoans, is conspicuous, as is the high diversity of the trilobite and brachiopod faunas. The sedimentologic and taphonomic evidence of these beds suggests a low-energy environment with a low rate of sedimentation and probably a soft substrate.

The trilobite association in this community is numerically dominated by articulated specimens of Flexicalymene celebra. Tens of thousands of complete specimens of this trilobite have been collected in Wisconsin and Illinois in the past hundred years and specimens can be seen in museums throughout the world. The only other trilobites that are occasionally found in at least a partially articulated state in these beds are "Cheirurus" hydei and Cheirurus cf. niagarensis. Dalmanites and Encrinurus are the most commonly found trilobites after Flexicalymene. See Table 12 for trilobite

Table 11. Composition of the brachiopod fauna of the Flexicalymene celebra association in a Dicoelosia Community (Benthic Assemblage 4-5) from the Hartung quarry (USNM locs. 11167 and 11168) and from glacial erratics in the vicinity of this quarry (USNM locs. 12531 and 17827), Milwaukee County, Wisconsin. See Appendix II for locality details

	11167	11168	12531	17827
Sieberella sp.	42.7%	50.8%	59.5%	61.5%
Resserella sp.	17.1	6.6	5.4	11.3
Leangella sp.	19.4	6.6	8.1	3.7
Dicoelosia sp.	6.6	-	-	4.3
Atrypa "reticularis"	1.4	11.5	5.4	6.1
Cyrtia sp.	2.8	1.6	2.7	4.9
Isorthis sp.	3.3	1.6	-	-
Atrypina? sp.	2.4	-	5.4	-
rhynchonellid	1 4	-	-	1.8
Meristina sp.	0.5	1.6	5.4	1.5
Platystrophia sp.	0.9	3.2	2.7	0.6
Leptaena "rhomboidalis"	0.5	1.6	-	0.3
Plectodonta sp.	0.9	-	-	-
Dolerorthis sp.	-	3.2	-	-
Eospirifer sp.	-	4.9	5.4	-
Coolinia? sp.	-	1.6	-	-
Protomegastrophia sp.	-	4.9	-	-
Amphistrophia sp.	-	-	-	1.5
Anastrophia? sp.	-	-	-	0.6
orthotetacid	-	-	-	0.6
Craniops sp.	-	-	-	0.3
orbiculoid	-	-	-	0.3
Merista sp.	-	-	-	0.6
Number of specimens in each collection	211	61	37	327

Table 12. Composition of the trilobite fauna of the Flexicalymene celebra association in a Dicoelosia Community (Benthic Assemblage 4-5) from the Hartung quarry, Milwaukee County, Wisconsin. See Appendix II for locality details. Column 1: USNM loc. 11167 collection; Column 2: USNM loc. 11168 collection; Column 3: collection from the highest trilobite layer made by the author.

	USNM 11167	USNM 11168	Collection from the highest trilobite layer
Flexicalymene celebra	76.9%	46.2%	83.0%
Dalmanites platycaudatus	-	15.4	4.3
Encrinurus egani	15.4	15.4	2.1
Bumastus cf. cuniculus	-	7.7	-
"Cheirurus" hydei	7.7	7.7	10.6
Sphaerexochus romingeri	-	7.7	-
Percent trilobites of all taxa in collection	5.7	17.3	-
Total number of trilobite individuals	13	13	47

composition of this association.

Weller's (1907) taxonomic description of the trilobites in the Chicago area indicate that a similar trilobite association is present in the vicinity of Lemont, Illinois. This association is found in beds occupying approximately the same stratigraphic position and age as those in Milwaukee County, however, Willman (1973) placed these beds in the Sugar Run Formation. Lowenstam (1948) described some of the taphonomic aspects of this association in the Lemont area and his descriptions indicate that the overall environmental characteristics of these beds seem to resemble those in Wisconsin. Unfortunately, these exposures are no longer accessible and no exact data are available on trilobite species abundance. Examination of museum collections, however, indicates that Flexicalymene celebra is the most common trilobite and that the other trilobite taxa occur in approximately the same numbers as those in Wisconsin (see Table 13 for details). Two notable exceptions are the rarity of "Cheirurus" hydei and the more common occurrence of Trochurus welleri in the Lemont collections; Trochurus welleri is extremely rare in Wisconsin. Little is known about the associated brachiopod fauna at Lemont locality, but it seems to resemble that in Wisconsin although brachiopods are not as common.

At the Lehigh quarry west of Kankakee, Illinois, a similar trilobite association dominated by Flexicalymene celebra is found

Table 13. Comparison of the trilobite composition of the Flexicalymene celebra association in Milwaukee County, Wisconsin, with that in Lemont and Grafton, Illinois. A, C, U, and R is a system of nonquantitative ranking of trilobite occurrence within the trilobite fauna based on field observations and examination of museum collections over the past 15 years. A = abundant, C = common, U = uncommon, R = rare. Abundant indicates that the taxon is predominant among the trilobites, but has no implications of abundance in the entire biota. Common taxa are almost always found in the trilobite fauna. Uncommon taxa are those usually found after diligent search. Rare taxa are those represented by only a few specimens in all collections assembled over a one hundred year period.

Trilobite	Milwaukee Co.	Lemont	Grafton
Acidaspis sp.	R	-	-
Arctinurus sp.	-	R	-
Bumastus cf. cuniculus	R	R	-
Bumastus danielsoni	U	U	C
Bumastus graftonensis	-	-	U
Bumastus n. sp.	R	R	-
Ceratocephala cf. goniata	R	R	R
"Cheirurus" hydei	C	R	C
Cheirurus cf. niagarensis	U	R	U
Dalmanites illinoisensis	U	U	R
Dalmanites platycaudatus	C	C	C
"Dalmanitina" arkansana	-	R	-
Deiphon americanus	R	R	R
Dicranopeltis decipiens	R	R	-
Encrinurus egani	C	C	C
Encrinurus sp.	C	C	C
Eophacops handwerki	U	U	U
Flexicalymene celebra	A	A	A
Hemiarges sp.	-	-	R
Illaenoides triloba	R	R	R
Leonaspis sp.	R	-	-
Otarion sp.	R	-	R
Proetus handwerki	U	R	U
scutelluid	-	-	R
Sphaerexochus cf. romingeri	C	C	C
Staurocephalus obsoleta	R	R	R
Trochurus welleri	R	U	R

near the base of the quarry. Willman (1973) assigned these beds to the Joliet Formation. Fossils are uncommon and lithologically the rock is similar to Lemont, but appears to be slightly more porous. A few small brachiopods, rugose corals, and scattered pelmatozoan debris are the only fossils present besides trilobites. Approximately 50 specimens of Flexicalymene celebra, usually articulated, were found, along with four Dalmanites cephala, one Deiphon cranidium, and two Bumastus cf. graftonensis cranidia.

The upper few feet of rock in the Lehigh quarry are locally fossiliferous with some highly fossiliferous lenses occasionally present. Willman (1973) assigned these beds to the Racine Dolomite. Trilobites and small brachiopods are common, with lesser numbers of fenestrate bryozoans, rugose corals, gastropods, bivalves, and cephalopods. Fine pelmatozoan debris is scattered throughout these layers. The brachiopod fauna is dominated by Leangella, indicating a Benthic Assemblage 4 position, and is similar to the brachiopod community in which the Flexicalymene celebra association is found. The trilobite fauna in these beds is somewhat different than in the Flexicalymene celebra association, however. Dalmanites verruscosus is the dominant trilobite, with lesser numbers of Cheirurus cf. niagarensis, Calymene cf. breviceps, Otarion sp., Bumastus cf. armatus, and other trilobites (see Table 14). Overall, this trilobite association is more closely related to that found in the Waldron Shale

Table 14. Composition of the trilobite fauna in a Dicoelosia Community in the Racine Dolomite at Lehigh, Illinois. Compare with Tables 3 and 13.

	Percent of trilobite fauna
Dalmanites verrucosus	28.9%
Calymene cf. breviceps	15.6
Cheirurus cf. niagarensis	11.1
Bumastus cf. armatus	11.1
Illaenoides sp.	7.8
Ceratocephala sp.	4.4
Dudleyaspis sp.	2.2
Otarion sp.	14.4
Dicarnopeltis sp.	2.2
Decoroproetus sp.	1.1
Arctinurus boltoni	3.3
Total number of individuals	90

at Newsom, Tennessee, and Waldron, Indiana, than to the *Flexicalymene celebra* association. The brachiopod communities of the Waldron Shale at these localities, however, are a Benthic Assemblage 3 *Striispirifer* Community. This may suggest that trilobites are not affected in the same way as brachiopods by environmental factors. An obvious difference to be considered in comparing the disparity between the brachiopod communities and the trilobite associations at these different localities is that the Waldron localities are in shales interbedded with limestones and the Lehigh locality and the various occurrences of the *Flexicalymene celebra* association are in carbonates. At Lehigh well-developed crinoid root systems, like those in the Waldron Shale, are occasionally present some of which appear to have initially developed on trilobite molts.

Approximately 200 miles southwest of Lehigh, at Grafton, Illinois, there is another occurrence of the *Flexicalymene celebra* association. At this locality the trilobite association is like that at Lemont and is placed in the Joliet Formation by Willman and Atherton (*in* Willman *et al.*, 1975). The brachiopod fauna is a typical *Dicoelosia* Community although the brachiopod specimens are not as abundant as in the Milwaukee area.

A few differences are notable in the composition of the trilobite fauna between Grafton and Lemont (see Table 13). Bumastids and cheirurids are more common at Grafton than at Lemont. A number of specimens of scutelluids have been found along with a single specimen of *Hemiarges*? at Grafton. Neither of these two taxa have been found in the *Flexicalymene celebra* association at Lemont or in the Milwaukee area, and this is the only occurrence of *Hemiarges*? in the Silurian of the central United States.

Silurian Level-Bottom Communities of the British Isles

Introduction

A great deal of work has been done on Silurian level-bottom brachiopod-dominated communities in the British Isles, particularly in Wales and the Welsh Borderland, since Ziegler's (1965 initial work. Information is available on community composition for the Llandoverian, Wenlockian, and Ludlovian environments from this area.

The paleogeographic patterns in Wales and the Welsh Borderland remained somewhat similar throughout this time interval (see Ziegler, 1970). In general, northern and central Wales were characterized by offshore basinal environments. To the south and east were emergent areas separated from the basin by shelf deposits which varied in width. A number of transgressions and regressions during the Silurian changed the position and extent of the shelf environment

(Ziegler, 1970). The sediments deposited in this area throughout the Silurian were primarily terrigenous clastics, with coarse-grained sediments deposited nearshore and finer-grained sediments deposited offshore. However, during the Late Wenlockian, carbonate deposition was widespread throughout the shelf area. The presence of similar environments throughout most of the Silurian in this area presents a good opportunity to examine the changes in distribution and composition of various trilobite associations through a long time interval.

Llandoverian Trilobite Associations

Ziegler's (1965) work on Llandoverian communities has been previously mentioned (see Table 1). Bridges (1975) made a detailed study of the depositional features of the Llandoverian in the same general vicinity as Ziegler's study. Bridges found that Ziegler's *Lingula* Community is generally found in restricted marine sandstones. In open marine sandstones *Eocoelia*, *Pentamerus*, or Stricklandia Communities may occur. Mudstones contain either *Pentamerus*, *Stricklandia*, or *Clorinda* Communities; the *Clorinda* Community may also be found in calcarenites.

A number of collections made by Ziegler during his later community work have been examined and the trilobite data are presented in Table 15. Benthic assemblage determinations of these collections were made by A. J. Boucot (1979, personal communication).

Table 15. Trilobite composition of various benthic assemblages (B. A.) of the Llandovery of the British Isles based on representative collections. Numbers at heads of the columns refer to U. S. National Museum localities. All collections are from Wales and the Welsh Borderland except for USNM loc. 10267, which is from Ireland, and USNM loc. 10519, which is from Scotland.

	B. A. 2		B. A. 2-3					B. A. 3		
	10247	10217	10219	10245	10267	10223	10221	10265	10507	10243
Dalmanites sp.	70.0%	58.0%	25.0%	18.0%	-	75.0%	50.0%	-	-	-
proetid	20.0	-	-	18.0	-	-	-	-	-	-
Encrinurus sp.	10.0	42.0	50.0	59.0	50.0	-	50.0	100.0	-	100.0
Calymene sp.	-	-	25.0	-	-	25.0	-	-	-	-
scutelluid	-	-	-	-	16.0	-	-	-	-	-
Stenopareia sp.	-	-	-	6.0	-	-	-	-	-	-
phacopid	-	-	-	-	33.3	-	-	-	-	-
Cheirurus sp.	-	-	-	-	-	-	-	-	100.0	-
Percent trilobites in total fauna	2.2	1.6	1.2	3.0	6.8	0.6	1.0	0.3	0.4	0.3
Number of trilobite individuals	10	36	4	17	6	4	4	1	1	1

Table 15. (Continued)

Trilobite	B. A. 4							B. A. 4-5			
	10262	10519	10226	10220	10459	10215	10253	10270	10257	10218	10232
Dalmanites sp.	-	-	83.0%	40.0%	25.0%	100.0%	-	-	-	-	--
proetids	15.0	-	41.0	-	-	-	50.0	-	-	-	-
encrinurids	45.0	43.0	66.6	60.0	75.0	-	16.6	100.0	33.0	42.8	100.0
Calymene sp.	35.0	25.0	-	-	-	-	16.6	-	-	57.0	-
Otarion sp.	5.0	-	-	-	-	-	-	-	-	-	-
Stenopareia sp.	-	8.0	8.0	-	-	-	-	-	-	-	-
scutelluid	-	4.2	4.1	-	-	-	-	-	-	-	-
phacopid	-	4.2	4.1	-	-	-	-	-	33.0	-	-
Cheirurus sp.	-	-	4.1	-	-	-	-	-	-	-	-
odontopleurid	-	6.2	-	-	-	-	-	-	33.0	-	-
Leonaspis sp.	-	-	-	-	-	-	16.6	-	-	-	-
Percent trilobites of total fauna	2.2	2.2	6.0	1.4	2.1	0.2	0.8	1.6	0.6	0.9	0.2
Number of trilobite individuals	20	16	24	5	15	1	6	3	3	7	1

Table 15. (Continued)

	B. A. 5		
	10260	10272	10259
Dalmanites sp.	-	-	-
proetids	-	-	-
encrinurids	-	-	-
Calymene sp.	83.0	-	-
Otarion sp.	-	-	-
Stenopareia sp.	-	-	-
scutelluid	-	-	-
phacopid	-	-	-
Cheirurus sp.	-	-	50.0
odontopleurid	-	100.0	50.0
Leonaspis sp.	16.6	-	-
Percent trilobites of total fauna	0.8	6.6	0.5
Number of trilobite individuals	6	1	2

No trilobites have been found in the *Lingula* Community in any of the collections assembled by Ziegler or Boucot.

In the Benthic Assemblage 2 communities, *Dalmanites* is the dominant trilobite, with *Encrinurus* occasionally being common. However, only a few collections from this benthic assemblage were available fro study and more are needed for more accurate data. No homalonotids have been found in these collections; this is in sharp contrast with Benthic Assemblage 2 communities in later time intervals. Homalonotids (*Brongniartella*, Lower Llandovery; *Trimerus*, Upper Llandovery) have been found in the Llandovery of Wales, however (Thomas, 1977).

In Benthic Assemblage 2-3 encrinurids are consistently the most numerous trilobite, with *Dalmanites* also being common. *Calymene*, proetids, *Stenopareia*, scutelluids, phacopids, and cheirurids are also found, but are generally rare.

In Benthic Assemblage 3 communities trilobites are poorly represented in available collections. Of three collections, each contain a single specimen of *Encrinurus* and one contains a single specimen of *Cheirurus*. This is similar to other low-diversity *Pentamerus* Community occurrences where rare specimens of *Encrinurus* are usually the only trilobites found. However, high-diversity Benthic Assemblage 3 communities from other areas and time intervals commonly have a higher diversity of trilobites when compared to Benthic Assemblage 2 communities.

Collections from Benthic Assemblage 4 communities have the highest diversity of Llandoverian trilobites from this area. Encrinurus is again the dominant trilobite; Dalmanites and Calymene are also fairly common. Proetids, Otarion, Stenopareia, scutelluids, phacopids, cheirurids and odontopleurids are presnt, but uncommon.

Few collections are present from Benthic Assemblage 4-5 communities, but Encrinurus appears to still be the dominant trilobite. No specimens of Dalmanites are present in these collections. Temple (1970) listed a high-diversity trilobite fauna from a Dicoelosia Community (Benthic Assemblage 4-5) in which Encrinurus cf. mullochensis is the dominant trilobite. Diacalymene and Stenopareia are next most abundant in his collections.

Benthic Assemblage 5 communities appear to have a low trilobite diversity, however, since only a small number of collections, containing only a few trilobites, from Benthic Assemblage 5 are available, the true diversity in these communities is not well known. Odontopleurids appear to be more common than in other benthic assemblages.

Wenlockian Trilobite Associations

Dingle, Ireland. Watkins (1978) described the level-bottom communities found in Wenlockian terrigenous clastics near Dingle, Ireland. He recognized a depositional gradient from offshore silts to nearshore silts and sands. Watkins identified three different brachiopod-dominated associations along this gradient (Table 16).

In the offshore low-energy, calcareous, bioturbated siltstone Watkins identified a Dolerorthis rustica association. He stated that this association is equivalent to Benthic Assemblage 3-4 and similar to Hurst's (1975) Isorthis clivosa community from the Wenlock Limestone of the Welsh Borderland. This association has the highest overall diversity, including trilobites, of Watkins' associations. Encrinurids are the most common trilobites followed by proetids and Hemiarges?

In nearshore, storm-influenced siltstones and sandstones Watkins identified the Sphaerirhynchia wilsoni association, which he assigned to a Benthic Assemblage 2-3 position. Dalmanites is the most common trilobite with some proetids and calymenids also present.

Watkins also identified a Holcospirifer bigugosus association in the same type of sediments as the Sphaerirhynchia wilsoni association, however, he assigned it to a Benthic Assemblage 2 position. A calymenid was the only trilobite found.

Wales and the Welsh Borderland. Wenlockian communities have been described by Calef and Hancock (1974, terrigenous clastic

Table 16. Trilobite composition of Wenlockian "communities" from various benthic assemblages (B. A.) from Dingle, Ireland. Data derived from Watkins (1978), and the numbers at the head of the columns refer to his collections.

Holcospirifer bigugosus association (B. A. 2)

	D7236
calymenid	100.0%
Number of trilobite individuals	1

Sphaerirhynchia wilsoni association (B. A. 2-3)

	D7238	D7239	D7237	D7220
Dalmanites sp.	100.0%	-	100.0%	-
proetid	-	100.0%	-	-
calymenid	-	-	-	100.0%
Number of trilobite individuals	1	1	4	2

Dolerorthis rustica association (B. A. 3-4)

	D7233	D7229	D7228	D7230
lichid	33.3%	-	12.5%	33.3%
encrinurid	33.3	37.5	25.0	33.3
proetid	16.7	62.5	62.5	33.3
odontopleurid	16.7	-	-	-
Number of trilobite individuals	6	8	8	3

communities) and Hurst (1975, carbonate communities).

Calef and Hancock (1974) described five major benthic, brachiopod-dominated communities (which are generally equivalent to Ziegler's, 1965, communities) along a depth gradient. Unfortunately, they presented no trilobite data.

Hurst (1975) recognized four brachiopod-dominated communities in the Wenlockian carbonates. He identified a nearshore, shallow-water Sphaeirhynchia wilsoni community. Hurst believed that the major environmental factor controlling this community was the rate of sedimentation (related to degree of turbulence); he also considered the nature of the substrate to be significant. Proetids are the most common trilobite in this community, but account for an average of only 0.1 percent of the total fauna. Cheirurids and odontopleurids are also present, but rare.

In offshore, deeper-water environments Hurst identified Isorthis clivosa and Eoplectodonta duvalii communities, which he suggested are faunally similar to Ziegler's (1965) Stricklandia and Clorinda Communities, respectively. Boucot (1979, personal communication), however, placed the Isorthis clivosa community in a Benthic Assemblage 3 position as opposed to a Stricklandia Community Benthic Assemblage 4 position. In the Isorthis clivosa community Hurst reported that each trilobite taxon comprised 0.1 percent or less of the total fauna. Dalmanites and Encrinurus are equally common; the only other trilobites he recorded are rarer specimens of undetermined odontopleurids.

In the Eoplectodonta duvalii community trilobites again represent only 0.1 percent of the total fauna, with Encrinurus the only genus reported. Hurst stated that the Woolhope Limestone contains the Eoplectodonta duvalii community in the Malvern Hills area of England. The Woolhope contains the trilobites Bumastus barrensis, Homalonotus sp., and Dalmanites sp. (Penn, 1971, personal communication). At Walsall, the Woolhope Limestone contains the trilobite Bumastus barrensis along with the brachiopods Dicoelosia and Leangella (Bassett, 1974) which would indicate a Benthic Assemblage 4 community. The occurrence of Homalonotus in a carbonate unit and in an offshore, low-energy community is unusual. In the Wenlockian reefs of this area tribolites are poorly represented even though the reefs have been well studied in recent years (see Scoffin, 1971; Abbott, 1976; Penn, 1973). Bumastus and Illaenus, however, have been found in some of the Wenlockian bioherms in the Malvern area (Penn, 1971, personal communication).

Hurst also identified a Visbyella trewerna community, which he interpreted as representing deeper water than previous communities, but no non-brachiopod taxa from this community were mentioned.

The data from Hurst (1975) are supplemented by two additional collections. Watkins and Hurst (1977) listed Calymene and Dalmanites as being rare members of the Dudley crinoid assemblage. They stated that the brachiopods from this assemblage appear to belong to the Sphaerirhynchia wilsoni community. An additional collection (USNM loc. 10222) made by Ziegler from possible Wenlockian terrigenous clastic sediments of the Tortworth Inlier contains a trilobite fauna dominated by Dalmanites and a few Calymene. Boucot (1979, personal communication) assigned this collection to a Benthic Assemblage 3 position.

Thomas (in press) described five trilobite associations in the Wenlock of Wales, the Welsh Borderland, and the English Midlands (Figure 2). He reported that the distribution of the associations was related to lithofacies and position of the paleoslope (from an onshore to offshore position). Thomas considered the trilobite distribution to be more closely related to lithofacies than to depth.

In shallow-water sandstones Thomas (in press) recognized an Acaste/Trimerus association found with infaunal bivalves, tentaculitids, brachiopods, and gastropods. In finer-grained sandstones transitional to the adjacent shale belt, Calymene becomes common, whereas Trimerus becomes rare. Thomas noted that bivalves also become rare in these beds while brachiopods become more common.

Thomas' next association is the Proetus/Warburgella

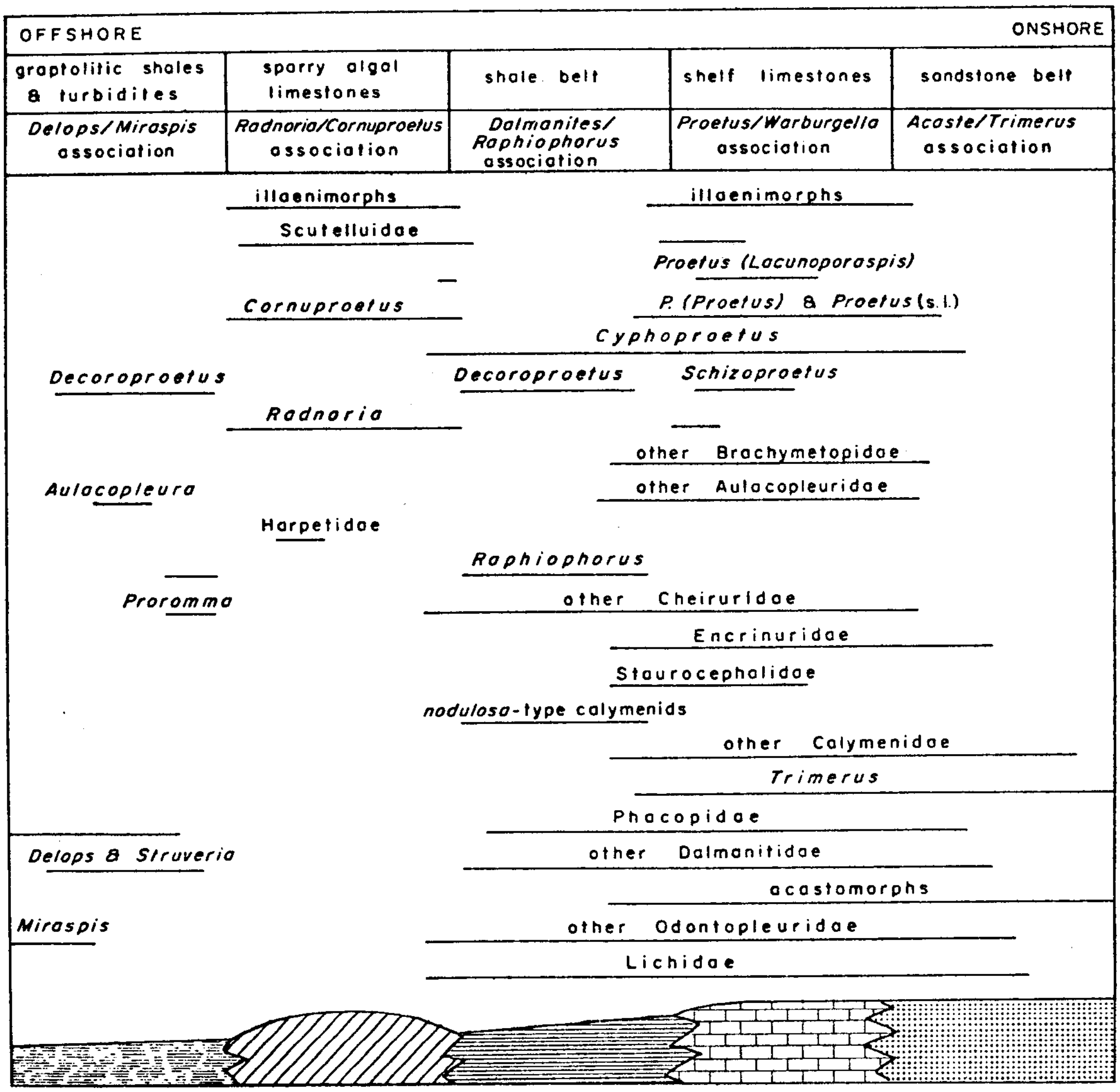


Figure 2. Trilobite distribution in the Wenlockian of the British Isles related to lithofacies, trilobite associations, and position on the paleoslope (onshore to offshore. Modified from Thomas (In press, Figure 2). This figure indicates the range but not the abundance of trilobite taxa.

association, where those two genera are numerically dominant in shelf limestone lithofacies. Illaenomorphs are also common. This association is found in the Barr Limestone, Woolshope Limestone, and Much Wenlock Limestone, usually in beds of impure nodular micrite or in sparry beds. The Proetus/Warburgella association has the highest diversity of any of Thomas' associations. Transitional faunas between this association and the Dalmanites/Raphiophorus association of the shale belt exist in some areas.

The Dalmanites/Raphiophorus association is found in silty mudstones of the shale belt. Dalmanites is numerically dominant although Decoroproetus may also be common. Radiophorus and nodulosa-type calymenids are also present.

Thomas defined the Radnoria/Cornuproetus association as occurring in a sparry algal limestone which is located primarily in two isolated occurrences within the shale belt. This lithofacies developed on Precambrian high areas which appear to be located in a shelf margin position in relation to the basin to the west. The association contains common scutelluids and illaenomorphs besides Radnoria and Cornuproetus.

The Delops/Miraspis association is the final association recognized by Thomas. This association occurs in graptolitic shale beds. Trilobites are uncommon in this association, but Aulacopleura, Struveria, Delops, Miraspis, Decoroproetus, and other trilobites have been found. Faunas transitional with the Dalmanites/ Raphiophorus association are known.

Ludlovian Trilobite Associations

The overall paleogeographic setting of the Welsh Borderland and Wales in the Ludlovian is similar to that found in the earlier Silurian. The sediments are predominantly terrigenous clastics with only minor development of carbonates in contrast to the Upper Wenlock.

Calef and Hancock (1974) described a number of depth-related Ludlow benthic communities from terrigenous clastic environments based on brachiopod associations, however, they presented no trilobite data.

Lawson (1975) reexamined Ludlow brachiopod-dominated communities and reported that Calef and Hancock's (1974) idea that the distribution of communities was controlled by water depth was inaccurate. Instead, Lawson suggested that the nature of the substrate is a major factor in community distribution. He described four communities and listed the trilobites associated with each. These communities will be referred to later in this discussion.

Watkins (1979a) presented a detailed study of the benthic communities of the Ludlow Series along a transect in the Welsh Borderland. His conclusions are based on an integrated examination of the biota and the accompanying sedimentological characteristics of the strata. His data are probably the most detailed for any part of the Silurian in the area of the British Isles under consideration. Watkins found that there are significant changes in the characteristics of the biota and enclosing sediments following a gradient from offshore, low-energy basinal environments to nearshore, high-energy, shallow-water environments. He cited the following sedimentologic evidence for this offshore to nearshore gradient: increase in grain size, decrease in clay content, decrease in bioturbation, increase in storm-deposited beds of laminated silt and shells, and an overall increase in rate of sedimentation. Watkins also noted significant changes in community organization accompanying the sedimentological changes, which include a decrease in species diversity and an increase in opportunistic species towards the unstable, nearshore environment.

Watkins (1979a) described four biotic associations in three main sedimentary facies that he related to environmental changes along the offshore-nearshore gradient. The offshore, low-energy, highly bioturbated beds are characterized by normal marine mudstones with local development of well-laminated shales which he attributed to depletion in the oxygen level. This facies contains the *Glassia obovata* association which is characterized by a high faunal diversity and small size of some of the taxa, particularly the brachiopods. Watkins considered this fauna to be typical of Dicoelosia Parallel Communities which Boucot (1979, personal communication) assigned to a Benthic Assemblage 4-5 position. This association contains the highest abundance of trilobites in Ludlow communities (see Figure 3). Dalmanites makes up 90 percent of the trilobite fauna and occasionally dominates the entire fauna. Leonaspis, Proetus, Calymene, Raphiophorus, Anaspis, and Otarion, in approximately that order of abundance, are also found. Lawson (1975) found a Dicoelosia-Skenidioides Community in the Ludlow approximately equivalent to Watkins' Glassia obovata association. Lawson reported some of the same more common trilobites listed by Watkins, however, he also included rare Encrinurus.

Shoreward from the mudstone facies, Watkins recognized a bioturbated siltstone facies representing a somewhat higher-energy environment that was closer to the sediment source. The facies is characterized by two different associations: the Mesopholidostrophia laevigata association and the lower phase of the Sphaerirhynchia wilsoni association. The Mesopholidostrophia laevigata association is the dominant association in this facies. The Sphaerirhynchia wilsoni association is generally located near the boundary between this facies and the more shoreward facies and will be discussed in connection with the coquinoid siltstone facies. The Mesopholidostrophia laevigata association is the highest diversity Ludlow

Figure 3. Distribution and abundance of trilobites along a transect of Ludlow shelf environments in the Welsh Borderland. The laminated shale facies (4) is an oxygen-poor equivalent of the mudstone facies (3) and was not considered in this study. Go = Glassia obovata association, tr = transitional (treated as part of the Go association); Ml = Mesopholidostrophia laevigata association; uSw = upper phase of the Sphaerirhynchia wilsoni association; lSw = lower phase of the Sphaerirhynchia wilsoni association; Pl = Protochonetes ludloviensis association. From Mikulic and Watkins (In press, Figure 4-2).

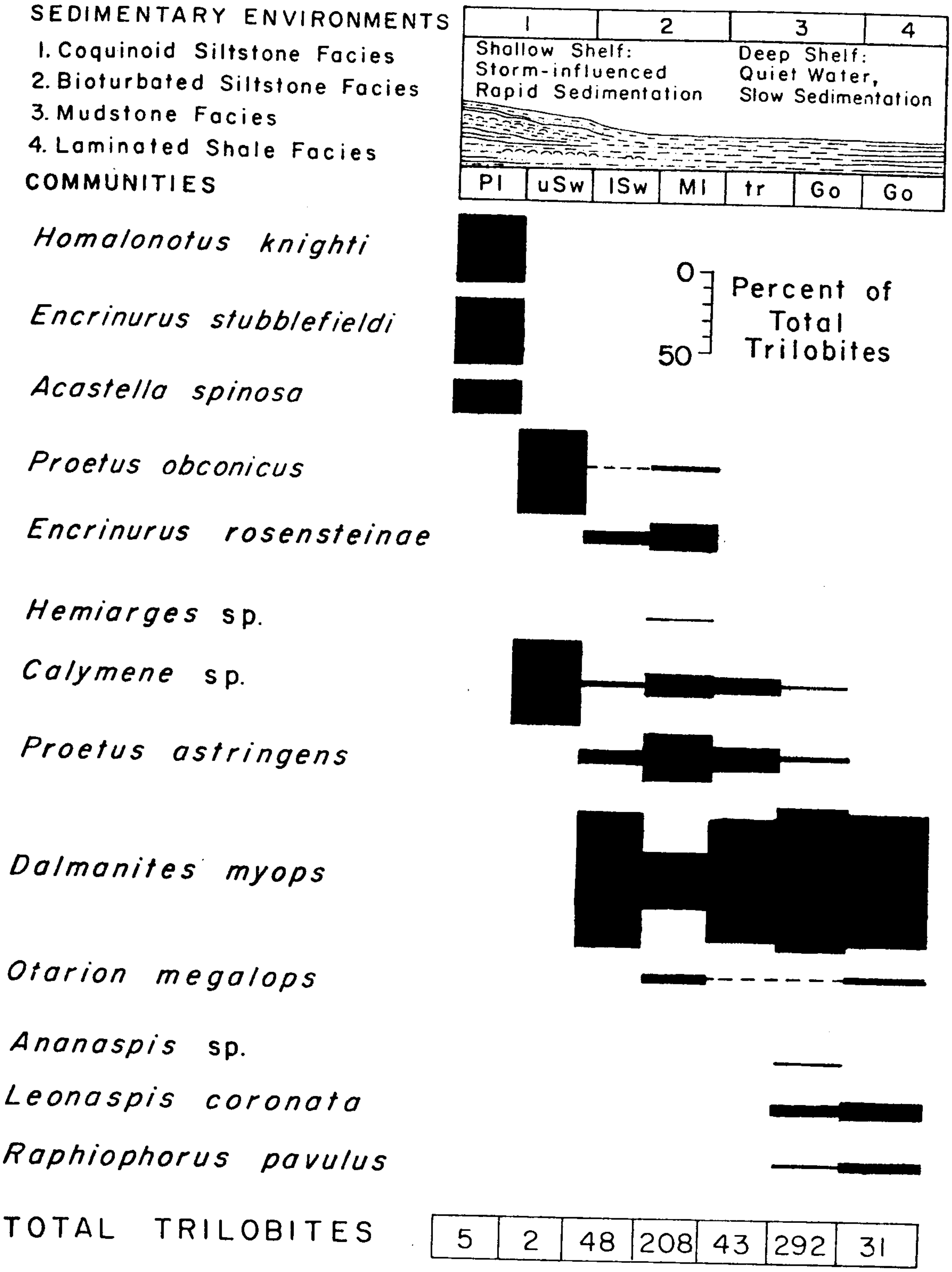

SEDIMENTARY ENVIRONMENTS
1. Coquinoid Siltstone Facies
2. Bioturbated Siltstone Facies
3. Mudstone Facies
4. Laminated Shale Facies
COMMUNITIES
1
2
3
4
Shallow Shelf: Storm-influenced Rapid Sedimentation
Deep Shelf: Quiet Water, Slow Sedimentation
Pl
uSw
lSw
Ml
tr
Go
Go
Homalonotus knighti
Encrinurus stubblefieldi
Acastella spinosa
Proetus obconicus
Encrinurus rosensteinae
Hemiarges sp.
Calymene sp.
Proetus astringens
Dalmanites myops
Otarion megalops
Ananaspis sp.
Leonaspis coronata
Raphiophorus pavulus
0
50
Percent of Total Trilobites
TOTAL TRILOBITES
5
2
48
208
43
292
31

Figure 3

community and is dominated by brachiopods and bryozoans. Watkins considered this association to be typical of Stropheodontid Parallel Communities, which he believed are similar to Stricklandid communities occupying a Benthic Assemblage 4 position. Boucot (1979, personal communication), however, believes that the Stropheodontid Parallel Communities and the Stricklandid Communities are dissimilar, with the former occupying a Benthic Assemblage 3 position. Trilobites are uncommon in the Mesopholidostrophia laevigata association with Dalmanites making up about 40 percent of the trilobite fauna (see Figure 3). Proetus, Encrinurus, and Calymene are also common members of the trilobite fauna in this association; Otarion, Hemiarges, and Cheirurus are rare constituents. Lawson (1975) described the Strophonella-Gypidula Community which appears to be similar to Watkins' Mesopholidostrophia laevigata association. He listed the same dominant trilobites as Watkins, with Dalmanites again being the most abundant with common Calymene and Encrinurus. Encrinurus. Encrinurus reaches its maximum abundance in this community; proetids are rare and Leonaspis is absent.

The shallowest phase of Ludlow deposition is represented by the coquinoid siltstone facies which is a nearshore, high-energy environment characterized by a high rate of sedimentation. The upper phase of the Sphaerirhynchia wilsoni association is primarily developed in the more offshore portions of this facies. Boucot

(1979, personal communication) placed the Sphaerirhynchia wilsoni communities in a Benthic Assemblage 3 position. Trilobites are rare in the Sphaerirhynchia wilsoni association and consist mostly of Dalmanites in the lower phase (bioturbated mudstone facies) and Proetus and Calymene in the upper phase (coquinoid siltstone facies). Lawson (1975) described a Dayia-Isorthis Community which is similar to Watkins' Sphaerirhynchia wilsoni association. He indicated that Calymene and proetids are the most numerous trilobites with rare encrinurids, and that dalmanitids occur rarely near the transition with his Strophonella-Gypidula Community.

The most shoreward association described by Watkins in the coquinoid siltstone facies is the Protochonetes ludloviensis association. This is a low-diversity community dominated by brachiopods and bivalves in a high-energy, shallow-water environment characterized by a high rate of sedimentation; this represents the most unstable environment in theLudlow of this area. Watkins considered this association to be typical of communities of the proximal shelf region, such as Salopina and Eocoelia Communities; Boucot (1975) assigned these communities to a Benthic Assemblage 2 position. Trilobites are rare, but this association contains the distinctive fauna consisting of Homalonotus and Acastella, as well as Encrinurus. Lawson (1975) described a similar community (Protochonetes-Salopina Community) where he recorded rare proetids and Encrinurus transition with his Dayia-Isorthis Community and rare Calymene ranging throughout most of this community.

Between the bioturbated siltstone and coquinoid siltstone facies is the Aymestry Limestone, which is the only major carbonate development in the Ludlow of the Welsh Borderland and Wales. The Kirkidium Beds of the Aymestry Limestone were deposited in a high-energy, possible shelf-margin environment (Lawson, 1975; Watkins, 1979a). Boucot (1975) assigned this type of comjunity to a Benthic Assemblage 3 position. In other areas this type of community contains rare scutelluids and either illaenids or Encrinurus. None of these trilobites has been reported from this portion of the Aymestry Limestone. Shoreward from the high-energy Kirkidium Beds, Watkins identified a low-energy restricted Sphaerirhynchia wilsoni association with only rare Dalmanites representing the trilobites.

Conclusions

A number of trilobite associations can be identified based on a comparison of the occurrences described above (see Figure 4), however, a significant number of the trilobites described from particular communities cannot be placed in recurrent associations. There are several factors which contribute to the difficulty of assigning many trilobires to specific associations. The most significant problem is the lack of adequate samples that indicate the true

Figure 4 . Community frameworks for Silurian level-bottom trilobite associations based on previously discussed examples. L = low energy, M = moderate energy, H = high energy. Diversity, for trilobites in these associations is gradational.

DIVERSITY	LOW ———			HIGH ———		LOW
BENTHIC ASSEMBLAGE	B. A. 1	B. A. 2	B. A. 3	B. A. 4	B. A. 5	B. A. 6
WALDRON SHALE			*Striispirifer* Comm. *Dalmanites-Calymene* *Otarion-Cheirurus* M			
ROCHESTER SHALE		Homalonotid-Acastomorph Association M	*Striispirifer* Comm. *Calymene* *Bumastus* *Arctinurus* M			
IOWA			*Pentamerus* Comm. Illaenid-Scutelluid-Lichid Association M-H	*Stricklandia* Comm. illaenids lichids *Calymene* *Encrinurus* L		
WISCONSIN			*Pentamerus* Comm. *Stenopareia* H	*Dicoelosia* Comm. *Flexicalymene celebra* Association L		
ILLINOIS				*Dicoelosia* Comm. *Flexicalymene celebra* Association *Dalmanites-Calymene-Otarion-Cheirurus* L		
ARISAIG		*Quadrifarius-Protochonetes* Comm. Homalonotid-Acastomorph Association M				
GREAT BRITAIN LLANDOVERIAN		*Dalmanites* *Encrinurus* proetid M	*Pentamerus* Comm. *Encrinurus* H-M	*Encrinurus* *Dalmanites* *Stenopareia* L		
GREAT BRITAIN WENLOCKIAN		Homalonotid-Acastomorph Association M	?	*Dalmanites* *Raphiophorus* *Decoroproetus* *Calymene* L		*Miraspis* *Aulacopleura* L
GREAT BRITAIN LUDLOVIAN		*Protochonetes ludloviensis* Assoc. Homalonotid-Acastomorph Assoc. M	*Mesopholidostrophia* Association *Dalmanites* *Proetus* *Calymene* M	*Glassia obovata* Association *Dalmanites* *Leonaspis* *Calymene* *Raphiophorus* M		

diversity and abundance among the trilobites themselves. An example of this was presented in the discussion on the Hopkinton Dolomite of Iowa. Most samples used in current community work may be accurate for comparing the abundance of the most common taxa and for determining the overall abundance of trilobites in each collection, but since trilobites are rare elements of most Silurian communities, these samples are of limited value in determining trilobite diversity or making comparisons of frequency among the trilobites themselves. Also, the rarity of trilobites in these collections occasionally makes accurate identification of the trilobites difficult. Another problem is the lack of information concerning the sedimentological-lithological relationships of various described communities, or these relationships, when considered, are often oversimplified. Furthermore, the behavior of trilobites is not well known since few have been preserved with appendages or in living positions. Some trace fossils have been interpreted as representing feeding and resting activities of trilobites, but again, these represent only a few taxa. In spite of these limitations, a few trilobite associations have been identified from Silurian level-bottom communities and these will be discussed below.

Homalonotid-Acastomorph Association

The homalonotid-acastomorph association is commonly found in nearshore, high-energy, terrigenous clastic environments having a high rate of sedimentation. This association is found in Benthic Assemblage 1 and 2 communities and is characterized by a low diversity and low abundance of trilobites. Although a few taxa may be locally abundant the entire fauna is of low diversity. Homalonotids and acastomorphs are commonly found with calymenids and encrinurids in this association; Calymene is the most abundant trilobite.

In the Llandoverian of Wales and the Welsh Borderland, homalonotids and acastomorphs appear to be rare or absent in Benthic Assemblage 2 communities, however, Dalmanites and Encrinurus are present. Dalmanites is also present with Trimerus in the Upper Rochester Shale. It appears that Dalmanites may occupy the same functional position as acastomorphs, in their absence, since both have similar morphologic characteristics.

Because of the overall rarity of trilobites in this environment it is difficult to obtain any statistical data, but the co-occurrence of these trilobites is conspicuous in this environment.

Homalonotids are found in nearshore, high-energy, terrigenous clastic environments in Ordovician through Devonian rocks. Homalonotids and acastomorphs are present in this environment in the Ordovician Caradoc Series of Wales and the Welsh Borderland (Hurst, 1979) and Gill (1949) mentioned the occurrence of homalonotids in nearshore, clastic environments in the Devonian of Australia and Germany. Homalonotids (Dipleura) are also present in Benthic Assemblage 2 communities of the Middle Devonian of eastern North America (W. Koch, 1979, personal communication). Eldridge and Ormiston (1979) noted that Silurian-Devonian homalonotids are widespread in this particular environment in the Malvinokaffric Realm. Schrank (1977) stated that homalonotids are most conspicuous in cold-water, terrigenous clastic environments in the vicinity of the South Pole during the Silurian, which is included in the Malvinokaffric Realm.

A carbonate equivalent of this association has not been identified; homalonotids are rare in carbonates. The Woolhope Limestone and its equivalents in Wales and the Welsh Borderland contain a few homalonotids along with more common Bumastus and some Dalmanites, however, Hurst (1975) assigned these beds to an Eoplectodonta duvalii, which is a Benthic Assemblage 4-5 equivalent community.

The trace fossils Rusophycus and Cruziana in the Herkimer Sandstone of New York have been attributed to Dalmanites, Trimerus, and Calymene (Osgood and Drennen, 1975). Since these trace fossils are confined to a nearshore, terrigenous clastic environment (Benthic Assemblage 1-2) it might appear that the trilobites responsible for these traces were similarly limited in their distribution. However, these trilobites, particularly Dalmanites, are commonly found in are commonly found in adjacent offshore environments, and the trace fossils are not found. Therefore, the distribution of the trace fossils probably reflects preservational features and not environmental limitations of their producers. High-energy environments or bioturbation could easily destroy those trace fossils.

Benthic Assemblage 3 Communities

Trilobites are not rare in Benthic Assemblage 3 brachiopod-dominated communities, but trilobite associations are not easily defined. This excludes the reef associations which will be discussed in a later section.

In the low-diversity, rough-water Pentamerus and related communities trilobites are rare and of low diversity. Encrinurus appears to be the most common trilobite, although in carbonate environments with these communities in the central United States illaenids appear to replace Encrinurus as the most common trilobite.

In Sphaerirhynchia communities in the British Isles the trilobite fauna is dominated by Dalmanites, Calymene, and proetids.

Isorthis communities of the same region contain a trilobite fauna dominated by encrinurids and Dalmanites, with calymenids, proetids, and otarionids present as well.

Striispirifer communities contain common Calymene, Dalmanites, Otarion, and Cheirurus in the Waldron Shale of the

United States, but a different trilobite fauna, containing Bumastus, Calymene, and Arctinurus, is present in the Rochester Shale. Encrinurids are absent from these Striispirifer communities.

Dicoelosia Communities

Dicoelosia communities and other communities in a Benthic Assemblage 4-5 range generally contain the most diverse trilobite faunas found in Silurian level-bottom shelf environments. These communities are usually found in environments characterized by low rates of sedimentation and low turbulence. Calymene and Dalmanites are again the dominant trilobites, with phacopids, odontopleurids, Raphiophorus, and Otarion also being commonly found in Great Britain. In the central United States the Flexicalymene celebra association is characteristic of Dicoelosia communities. There Flexicalymene is the dominant trilobite and Dalmanites, Cheirurus, Encrinurus, and Sphaerexochus are also common elements of the trilobite fauna.

As mentioned before, there is some evidence that trilobite associations may be controlled by slightly different environmental factors than brachiopod communities, which is reflected in some apparently conflicting co-occurrences. This is demonstrated by the comparison of trilobites found in the Striispirifer Community in the Waldron Shale with those found in a Dicoelosia-Leangella

Community at Lehigh, Illinois; nearly identical trilobite faunas occur in each.

Benthic Assemblage 5-6 Communities

Trilobite associations from Benthic Assemblage 5-6 communities do not appear to be widespread. Thomas (in press) described the *Delops*/*Miraspis* association, including the genus *Aulacopleura*, from graptolitic shales and turbidites in the Wenlockian of the British Isles. A similar association is known from the Late Wenlockian graptolitic beds (Liteň Formation) near Prague, Czechoslovakia (Horny *et al.*, 1958), which is characterized by a variety of odontopleurids and *Aulacopleura*. In the Holy Cross Mountains of Poland there are Wenlockian graptolitic beds that contain an association similar to both of these. Here *Odontopleura ovata* is the dominant trilobite; this genus also occurs in the Czechoslovakian beds.

Environmental Distribution of Trilobites

A brief examination of environmental distribution would seem to indicate that most trilobites, on a generic or higher level, are not confined to any particular environment. However, upon closer examination, it is apparent that certain groups of trilobites are definitely more abundant and diverse in specific environments.

Based on the previously presented evidence a number of generalizations can be made concerning the environmental preferences of different trilobite groups.

Dalmanites, Encrinurus, calymenids, and proetids are wide-ranging, commonly occurring in Benthic Assemblages 2 through 5 communities (nearshore to offshore). Thomas (in press), however, indicated that proetids are more closely related to specific environments on a generic level; this may also be true for calymenids. Data in Watkins (1979a) and Mikulic and Watkins (in press) indicate that there may be some differences in the environmental occurrence of different species of both Encrinurus and Proetus (see Figure 3) but these differences may also be attributed to evolutionary changes through time.

Differences in environmental distribution on a specific level can be demonstrated by Bumastus. This genus is very common and diverse in Silurian reefs of the Midwestern United States. It is also not rare in surrounding inter-reef environments, but there it is usually represented by a single species which is rare or absent in the reefs.

Encrinurus seems to reach its maximum abundance in some Benthic Assemblage 3 communities.

As described earlier, homalonotids and acastomorphs are generally restricted to nearshore environments characterized by turbulence and a high rate of terrigenous clastic sedimentation. These trilobites are seldom found in carbonate environments or in Benthic Assemblage 4 to 6 communities.

The order Lichida is generally confined to Benthic Assemblage 3 and 4 communities, which commonly occupy a mid-shelf position. No lichids have been observed in Benthic Assemblage 2, 5 or 6 communities. This order seems to reach a maximum diversity and abundance in carbonate buildups.

Illaenids and scutelluids are also found predominantly in Benthic Assemblage 3 and 4 communities. Neither of these groups is particularly common or diverse in environments receiving terrigenous clastic sediments; they are most abundant and diverse in carbonate buildups.

Otarionids and phacopids appear to be more prevalent in Benthic Assemblage 3 and 4 communities, but are not particularly common.

Odontopleurids are more typical and diverse in offshore Benthic Assemblage 5 and 6 communities, with Leonaspis having a slightly different range eing more prevalent in Benthic Assemblage 3 and 4 communities.

Radiophorus is characteristic of Benthic Assemblage 4 and 5 communities, particularly in the British Isles, but appears to be absent from these environments in North America.

Examination of trilobite associations in the central United States shows a significant disparity between the abundance and diversity of proetids compared with similar associations in the British Isles and Gotland. It is particularly noticeable in the trilobite associations described by Thomas (in press) from the Wenlockian of the British Isles where proetids are a major element. He suggested that their absence in the United States may be due to a rarity of suitable environments. However, the environments and associations in which proetids are common in the British Wenlock are present in the North American Silurian. A good example is Thomas' sparry algal limestone containing the *Radnoria*/*Cornuproetus* association in which illaenomorphs and Scutelluidae are common and to which Harpetidae is restricted. Odontopleurids and lichids are also present. This association occurs in rocks that have been described as being in a very shallow, turbulent environment which received very little terrigenous clastic sedimentation and were deposited on a topographic high (Hurst *et al.*, 1978). If the proetids are removed from this list of trilobites the association would be a typical illaenid-scutelluid association characteristic of many North American Silurian reefs and other high-energy carbonates. Many elements of Thomas' shelf limestone association are also found in North American carbonates. The only environment that seems to be poorly represented in the central and eastern United States are the graptolitic shales and turbidites. It seems that the differences in abundance and diversity of proetids are not due to lack of similar environments; they more likely reflect biogeographic differences.

More detailed work in the future should reveal more definite patterns of environmental distribution of trilobites.

TRILOBITE ASSOCIATIONS IN SILURIAN CARBONATE BUILDUPS

Introduction

Trilobite associations found in Silurian carbonate buildups can be more easily recognized than those in level-bottom environments. Literally thousands of Silurian carbonate buildups are known, which furnish a better data base than is available for any particular level-bottom environment. The trilobite associations of most normal marine Silurian carbonate buildups are remarkably similar throughout the world. Silurian carbonate buildups are of several different types, ranging from small byrozoan mounds only a few feet in diameter to coral-stromatoporoid reefs which are several miles in diameter (Heckel, 1974; Wilson, 1975). Many of these buildups are thought to have reached their maximum development in a shallow-water, high-energy environment (Lowenstam, 1957). Coral-, stromatoporoid-, pentamerid-, or pelmatozoan-dominated communities are typical of these buildups, and most of these reefs occupy a Benthic Assemblage 3 position (Boucot, 1975). Some recent work, however has suggested that some Silurian reefs may have developed in a deep-water, below-wavebase environment (Pray, 1976; Lehmann, 1978; McGovney, 1978). These interpretations are based primarily on sedimentologic evidence and contradict much of what is known about the environmental occurrence of the buildup biota. More work will be needed to resolve these apparent discrepancies in the interpretations of the conditions under which these buildups developed.

The main point of this discussion, however, is the notable similarity of the trilobite associations in nearly all of these buildups regardless of whether these structures are considered to be organically or inorganically constructed or regardless of what types of organisms constructed the organic buildups. The only factor that controls the occurrence of these trilobite associations seems to be the presence or absence of a normal marine environment.

Two types of trilobite associations have been described from the Thornton Reef in the Racine Dolomite near Chicago, Illinois (Mikulic, 1976). The primary and most characteristic association found at Thornton is the illaenid-scutelluid-lichid association which is typically found in the core and other high-energy environments of the reef. Trilobites such as the illaenid Bumastus, the scutelluid Kosovopeltis, the lichids Arctinurus, "Lichas," and Dicranopeltis, the cheirurid such as Cheirurus, the odontopleurid such as Ceratocephala, and harpids are characteristic of this association. The second trilobite association, termed the Encrinurus-Sphaerexochus association, is typical of low-energy environments, such as pelmatozoan communities, and is characterized by

Sphaerexochus, calymenids, encrinurids, *Bumastus* (usually different species than in the illaenid-scutelluid-lichid association), and *Dalmanites*. The generic composition of these associations changes to some extent in both time and space, but the morphologic characteristics of the trilobites remain remarkably constant.

Another constant feature of the trilobite associations in Silurian carbonate buildups is the manner of occurrence of the illaenid-scutelluid-lichid association. Trilobites of this association commonly occur in accumulations of disarticulated specimens oriented in a convex-side-down position. These accumulations range up to several feet in diameter, containing thousands of specimens. Nautiloid cephalopods may or may not accompany the trilobites and few other organisms are observed in these accumulations. Excluding the nautiloid specimens, most of the skeletal elements found in these accumulations are characterized by a pronounced concavo-convex, plate- or saucer-like shape, like the cranidia and pygidia of bumastids.

In the following sections various aspects of reef trilobite associations are discussed. Firstly, the composition and distribution of reef trilobite associations are described using a number of examples from various localities, mostly in the central United States. This is followed by a discussion of the possible ways in which trilobite accumulations characteristic of the illaenid-scutelluid-lichid association form based on experimentation and field observation. Another section is devoted to the biogeographic distribution of some Silurian trilobite taxa in reefs of the central United States. And, finally, the conservative morphologic characteristics of trilobite faunas found in Ordovician through Permian carbonate buildups throughout the world are discussed.

Composition and Distribution of Specific Silurian Reef Trilobite Associations

Introduction

This section describes the distribution, composition, and mode of occurrence of Silurian trilobite associations in some specific Silurian carbonate buildups. Most of these examples are from the central United States because of the abundance of these structures in this area. The Silurian carbonate buildups in this area have received more study than Silurian buildups in most other geographic areas and, consequently, much data are available for them. Silurian reefs and carbonate buildups on a worldwide basis are generally confined to the Late Wenlockian through Ludlovian time interval, and in the central United States are found predominantly in the Racine Dolomite and stratigraphically equivalent units. Although there is currently some debate, and long has been for that matter, as to the nature of the environmental conditions under which these buildups developed, this is beyond the scope of this study and will not be discussed in any detail. Again, it should be emphasized that these different environmental interpretations do not change the fact that the trilobite associations are very similar in all these structures.

Horlick Quarry

The Horlick quarry, and surrounding area (see locality 11, Appendix II), at Racine, Racine County, Wisconsin, has been a source of a diverse trilobite fauna for over 100 years. The rocks exposed in this area are all in the Racine Dolomite, and there are a number of reefs visible in the southern two-thirds of the east wall and the southwest corner of the quarry (see Figure 5). All of these reefs have been truncated by post-Silurian erosion. The distribution and abundance of the different trilobite taxa found at this locality have a distinct pattern in relation to the occurrence of the reefs (see Figure 5). Three major environments can be identified in these exposures based on paleontologic and lithologic evidence: the reef core, the reef flank beds, and the inter-reef beds.

The reef core area is characterized by massive, crystalline, locally porous and vuggy, fossiliferous dolomite. Tabulate corals (*Heliolites* and *Halysites*) and stromatoporoids are common, with individual lenticular colonies up to a foot in diameter being present. These colonial organisms are scattered through the core area and

Figure 5. A: Distribution of reef cores, flank beds, and inter-reef beds in the Racine Dolomite at the Horlick quarry (locality 11, Appendix II). Dashed line indicates south quarry wall before construction of swimming beach in 1969.

B: Distribution of various trilobite taxa in this quarry in relation to the reef cores, flank beds and inter-reef beds shown in A. Trilobite-cephalopod accumulations are all confined to reef core areas. 1 - Bumastus sp. A; 2 - Bumastus ioxus; 3 - Kosovopeltis acamus; 4 - Dicranopeltis sp.; 5 - Calymene sp.; 5A - Calymene sp.; 5A - Calymene sp. (complete specimens); 6 - Staurocephalus sp.; 7 - Dudleyospis sp.; 8 - proetids; 9 - Sphaerexochus romingeri; 10 - Dalmanites sp.; 11 - Trochurus nasuta; 12 - Trochurus welleri; 13 - Cheirurus sp.; 14 - Ceratocephala sp.; 15 - Arctinurus sp.

Bumastus sp. A (1) is found throughout the quarry and is not indicated on map; it is, however more abundant in reef core areas.

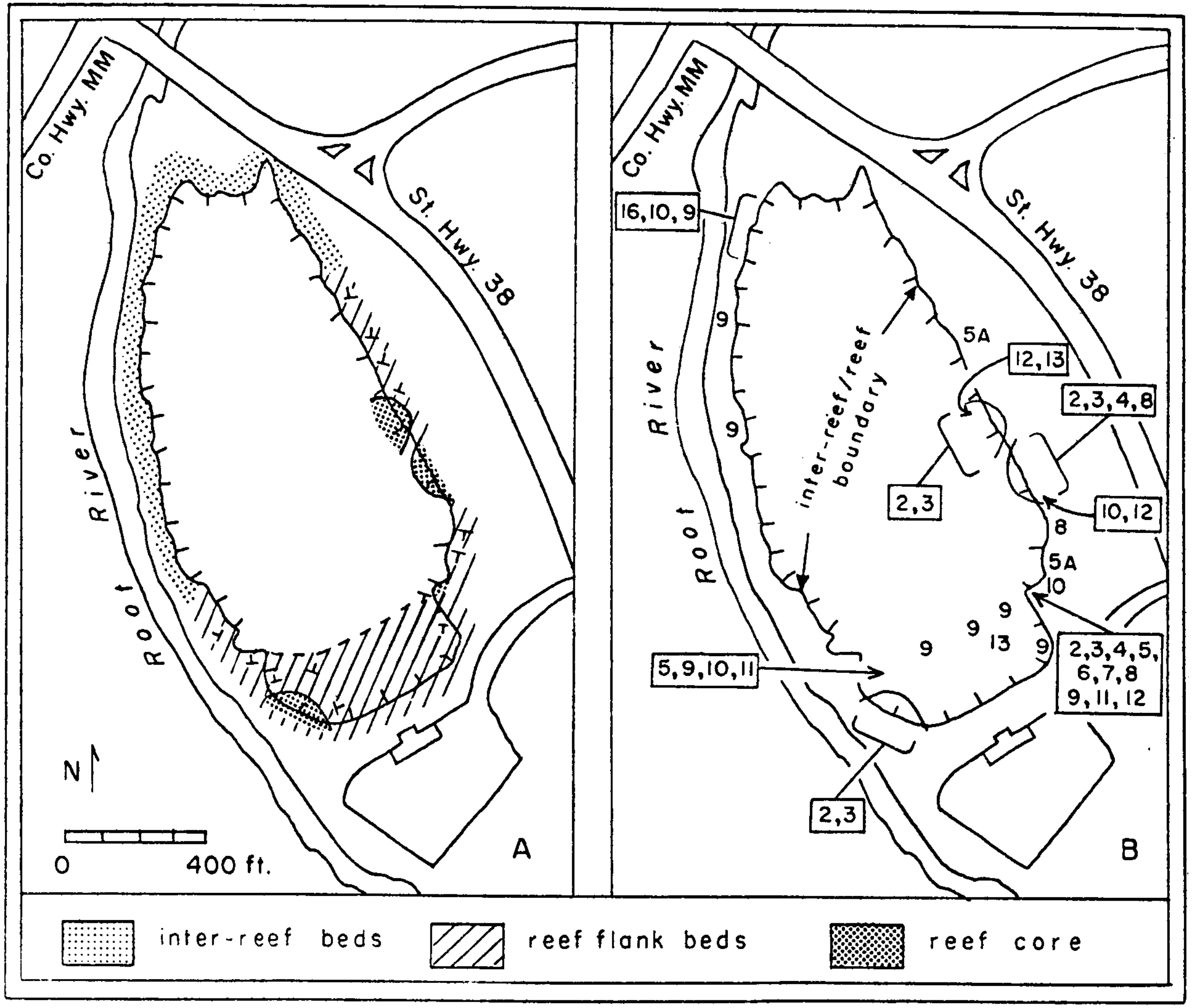

Co. Hwy. MM
St. Hwy. 38
Root River
N
0
400 ft.
A
inter-reef/reef boundary
16,10,9
9
9
5A
12,13
2,3,4,8
2,3
10,12
8
5A
10
9
9
13
9
9
2,3,4,5,
6,7,8
9,11,12
5,9,10,11
2,3
B
inter-reef beds
reef flank beds
reef core

Figure 5

and do not form an observable framework. This is the only environment in which these colonial organisms are common. Pelmatozoans are locally common, occurring as disarticulated fragments in lenses or discontinuous layers with other fossils, but are not as abundant as in the surrounding flank beds. A few scattered pelmatozoan foot systems are present in the reef core, but are not common. Brachiopods are locally abundant and diverse (see Table 17). Gastropods and bivalves ("Amphicoelia") are more common and diverse in the core area than in the other environments. Trilobites of the illaenid-scutelluid-lichid association are locally abundant in the reef core, occurring in accumulations of disarticulated specimens which are oriented in a convex-side-down position. The same trilobites are found outside of these accumulations in the core, but are uncommon; these trilobites are rare or absent in the surrounding flank beds and inter-reef environment.

At least fourteen accumulations have been found in the reef cores at Horlick quarry. These accumulations range in size from less than a foot in width and a few inches in height, containing only a few specimens, to several feet in width and a foot or more in thickness, containing thousands of specimens. It is important to note that regardless of the size of the accumulation the same major trilobite taxa are present. Bumastus ioxus and Kosovopeltis acamus are by far the most abundant trilobites in these accumulations (see

Table 17. Brachiopod composition of collections from the reef core area (Racine Dolomite) at the Horlick quarry, Racine, Racine County, Wisconsin (see locality 11, Appendix II). USNM numbers refer to U. S. National Museum locality numbers. USNM locs. 17385 and 17388 are from the main reef core in the south half of the east wall, and USNM loc. 17387 are from the reef core in the southeast corner of the quarry.

	17385	17388	17387
"Stropheodonta" sp.	12.0%	-	-
Hedeina sp.	4.8	22.6	-
Hedeina cf. H. eudora	-	-	50.0
Leptaena "rhomboidalis"	9.5	3.2	6.3
Coolinia sp.	1.2	-	12.5
Plicanoplia? sp.	2.4	-	-
Eospirifer sp.	14.3	12.9	6.3
Protomegastrophia? sp.	11.9	-	-
Meristina sp.	6.0	-	-
unident. brachiopods	7.1	-	-
Atrypa "reticularis"	15.5	12.9	6.3
rhynchonellids	15.5	19.4	0
Howellella? sp.	-	9.7	6.3
Janius sp.	-	-	12.5
Dalejina sp.	-	9.7	-
Cyrtia sp.	-	6.5	-
Coelospira? sp.	-	3.2	-
Total number of specimens	84	31	16

Tables 18, 19, and 40; Figure 6). Their abundance ratio spans a full spectrum from the near exclusive occurrence of only one of the species to an equal abundance of both. The density of trilobites in these accumulations is occasionally so high that stacks of skeletal elements several inches thick occur, with little intervening sediment. Cephalopods are not common in these accumulations with the trilobites, but two small accumulations of the cephalopod Leurocycloceras have been found. Within some of the trilobite accumulations disarticulated specimens of the bivalve "Amphicoelia" have been found. These bivalve specimens have a very similar shape and texture to bumastid cranidia and pygidia, being concavo-convex, saucer-shaped, and smooth.

An interesting feature of the reef core is the presence of lensoidal, clay-filled cavities overlying nearly all of the trilobite accumulations. The width of these cavities approximately corresponds to the width of the accumulations, but the thickness is quite variable. The largest cavity is at least eight feet wide, three feet high, and extends for more than six feet back into the quarry wall. The rocks exposed under this cavity contain a large volume of non-pelmatozoan fossil debris, but only a small accumulation of trilobites was found along one side. Since this cavity is so large it is possible that trilobites may be found to be more abundant in other unexposed portions, but it is also possible that because of the size different

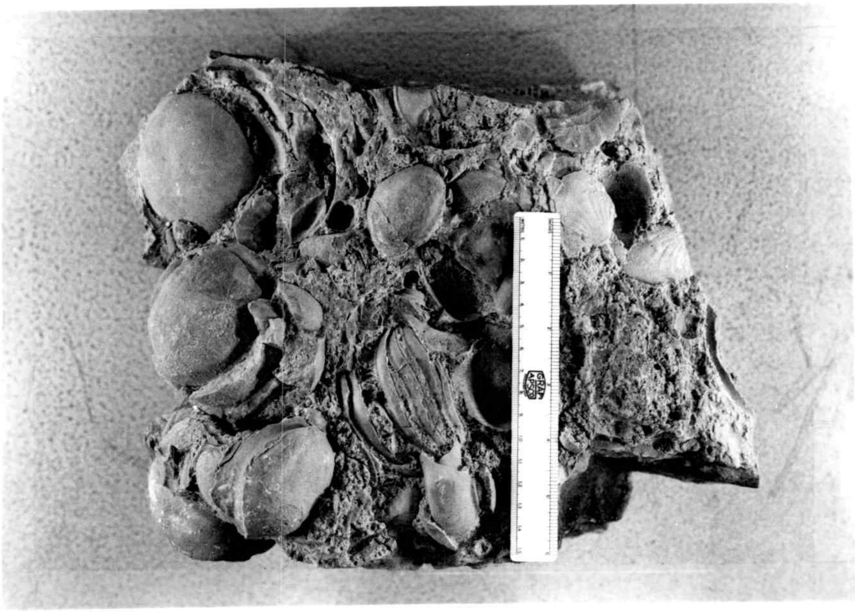
Table 18. Composition of the trilobite faunas in various trilobite accumulations in the reef cores in the Racine Dolomite at Horlick quarry, Racine, Wisconsin (see locality 11, Appendix II). Column 1 is a typical collection from the larger trilobite accumulations in having a greater abundance of Bumastus ioxus; Columns 2-4 represent smaller accumulations showing a wide range of variation in the abundance of Bumastus ioxus and Kosovopeltis acamus. Column 5 shows the trilobite composition of a brachiopod-rich concentration lateral to a more typical trilobite accumulation; trilobites and brachiopods are much smaller than in the main part of the accumulation. Brachiopod composition is given in Table 17. These collections are in the author's possession.

	1	2	3	4	5
Bumastus ioxus	64.0%	17.0%	30.0%	36.0%	4.06%
Kosovopeltis acamus	35.0	74.0	57.0	63.0	38.0
Bumastus sp. A	-	2.1	-	-	35.0
Ceratocephala sp.	-	2.1	3.0	-	2.0
Trochurus welleri	-	2.1	-	-	2.0
Dalmanites sp.	-	2.1	-	-	-
Arctinurus sp.	1.1	-	-	-	-
Cheirurus sp.	-	-	6.0	-	-
Sphaerexochus romingeri	-	-	3.0	-	-
Dicranopeltis sp.	-	-	-	-	17.0
proetid	-	-	-	-	2.0
Number of individuals	89	47	33	19	46

Table 19. The orientation of trilobite parts in the accumulations represented in Columns 1-4 in Table 18 as originally found in place in the rock. Orientations of _Bumastus ioxus_ and _Kosovopeltis acamus_ only were determined. down - convex-side-down; up = convex-side-up.

	1	2	3	4
Bumastus ioxus				
cranidia-up	9.0%	-	10.0%	-
cranidia-down	91.0	100%	90.0	100%
pygidia-up	2.0	12.0	33.0	-
pygidia-down	98.0	88.0	66.0	100.0
Kosovopeltis acamus				
pygidia-up	55.0	43.0	42.0	17.0
pygidia-down	45.0	57.0	58.0	83.0
Total number of specimens	143	54	35	24

Figure 6. The undersides of two slabs from trilobite accumulations from the reef core along the south half of the east wall of the Horlick quarry showing the disarticulated nature of the trilobites (Bumastus ioxus and Kosovopeltis acamus) and the convex-side-down orientation of the Bumastus.
A: part of the accumulation used in Table 19, Column 1;
B: part of the accumulation used in Table 19, Column 4.



A

B

Figure 6

factors may have controlled the types of organisms found underneath it. The origin of these cavities is not known with any certainty but they may have resulted from the overgrowth of depressions in which trilobites were accumulating, or they could have resulted from differential solution of sediments related to the deposition of the trilobite accumulations. In the rocks above some of the cavities large tabulate corals and pelmatozoan roots are present, which may be related to the overgrowth of a depression, but in others the rock is no different from the rest of the core rock. These cavities are not found in non-core rock. The clay that fills these cavities can also be seen in vertical joints extending up to the truncated surface of the reefs, indicating a post-reef origin of the clay. The cavities themselves are only connected to the truncated surface of the reefs by joints found throughout the reef core and not by wide fissures into which trilobites and other fossils could have fallen. This, accompanied by the fact that the same organisms are present in the accumulations and in the surrounding rocks, indicates that the formation of the accumulations was contemporaneous with reef development.

A small exposure of reef core rock is present in the southeast corner of the quarry which contains accumulations of the illaenid-scutelluid-lichid association, as well as a highly diverse fauna of other trilobites. This core rock may represent either a temporary lateral expansion of the reef core at a higher, now-eroded level, or the development of a satellite reef. The upper portion of this core contains several large trilobite accumulations, one of which consists of several thousand specimens, nearly all of which are oriented convex-side-down. Nearly all of these specimens are skeletal elements of Bumastus ioxus (however, several smaller accumulations in the reef cores are more diverse; see Table 18). The lower portion of this core contains a highly diverse brachiopod and trilobite fauna. The brachiopods are dominated by Janius and Hedeina (USNM loc. 17387), which are not common in the other reef cores; most of the other brachiopod taxa are typical of the other reef cores. The trilobites in the lower portion of the core are dominated by Dicranopeltis and represent the most highly diverse trilobite fauna in these reefs (see Table 20). Radiating away from the reef cores are flank beds which dip at 35° near the core. In a lateral direction away from the "cores" the angle of the dip decreases until essentially horizontal inter-reef beds are reached. The flank beds are porous, well-bedded, highly fossiliferous, and coarse-grained. In general, the flank beds near the core are pelmatozoan-rich and, in some places, consist entirely of disarticulated pelmatozoans. Porosity, grain size, and the abundance and diversity of fossils decrease laterally away from the reef cores in the flank beds. The trilobite fauna of the inner reef flank beds has a low diversity. The trilobites are not common and the taxa are different than those generally found in the "core." Sphaerexochus is most common, particularly in pelmatozoan-rich layers, and is associated with Calymene, Trochurus, Cheirurus, Dalmanites, and Bumastus sp. A. It should be noted that Calymene is commonly found as articulated specimens

Table 20. Trilobite composition of the *Dicranopeltis*-dominated trilobite fauna from the lower portion of the reef core in the southeast corner of the Horlick quarry, Racine, Wisconsin (see locality 11, Appendix III). This collection is in the author's possession.

	Percent of trilobite fauna
Dicranopeltis decipiens	41.3%
Ceratocephala sp.	6.5
Trochurus nasuta	3.2
Bumastus sp. A	22.1
proetid	4.9
Kosovopeltis acamus	4.9
Staurocephalus sp.	2.0
Encrinurus sp.	1.2
Dudleyaspis? sp.	0.8
Calymene sp.	2.0
Cheirurus sp.	0.8
Arctinurus sp.	0.4
Bumastus ioxus	9.4
Total number of individuals	244

whereas the other trilobites in all the major environments are most always found disarticulated. The outer reef flank beds are commonly poorly fossiliferous, although a few scattered complete Calymene are present. This general pattern of the flank beds is complicated by the presence of a number of reefs in close proximity and also by upward expansion and development of reefs in now-eroded overlying beds.

The inter-reef beds are highly fossiliferous only in a few localized areas. In general, the biota is similar to the flank beds, but pelmatozoans are not as volumetrically important. Sphaerexochus and Bumastus are scattered throughout these beds. In some localized, more fossiliferous areas, these trilobites occur with Dalmanites, and Encrinurus.

The nearby quarries at Ives (see locality 9, Appendix II) have identical environmentally related trilobite associations (see Figure 7).

Franklin Reefs

The distribution and composition of the trilobite faunas of the Racine Dolomite reefs at Franklin, Milwaukee County, Wisconsin (see locality 70, Appendix II) is nearly identical to that at the Horlick and Ives reefs around Racine. Bumastus ioxus is abundant in accumulations of disarticulated, convex-side-down specimens in reef core rock, along with common Kosovopeltis acamus. Other

Figure 7. Side view of in situ trilobite accumulation in Racine Dolomite reef core along the east half of the south wall of the main Vulcan Materials quarry at Ives, Racine County, Wisconsin (see locality 9, Appendix II). Trilo Trilobites are disarticulated specimens of Bumastus ioxus. Note predominant convex-side-down orientation and close packing of parts. Length of hammerhead approximately 5 inches. Photograph taken 1976.

trilobites occasionally found in these accumulations are Bumastus sp. A, Dicranopeltis decipiens, Cheirurus sp., proetids, and Staurocephalus sp. A distinct trilobite fauna dominated by Dicranopeltis has been found in non-crinoidal reef "core" rock. Besides Dicranopeltis, Bumastus sp. A, some scutelluids, and rare Arctinurus sp., and Dalmanites sp. are found. Rare specimens of Encrinurus have been found in the outer flank beds. Sphaerexochus has not been found at Franklin, which is surprising in view of its common occurrence in pelmatozoan-rich beds in the Racine and other area. Accumulations of orthocones have also been observed in these reefs. Other nearby reef exposures display faunas similar to those at Franklin and Racine; at the airport runway tunnel (see locality 63, Appendix II), a small accumulation of Bumastus ioxus, with some Kosovopeltis acamus, Bumastus sp. A, and Sphaerexochus romingeri was found.

Reefs in the Northern Half of Milwaukee County, Wisconsin

The reefs in the northern half of Milwaukee County have a trilobite fauna different in both composition and manner of occurrence from those in the reefs of the rest of southeastern Wisconsin. These reefs are conspicuous in their lack of pelmatozoans. Various species of Bumastus and Sphaerexochus romingeri are the most common trilobites in this reef.

At the Schoonmaker reef (see locality 74, Appendix II) two distinct trilobite faunas are recognized (see Table 21). The reef core contains common Bumastus cuniculus and Sphaerexochus romingeri, with Hadromerus welleri and a variety of other trilobites. In flank beds (with only rare pelmatozoans) the above trilobites are rare or absent, but scutelluids and Scotoharpes telleri are common. Although thousands of specimens of bumastids have been found at this locality no trilobite-cephalopod accumulations have been observed and only one small sample has been seen in older collections that suggests this type of occurrence. It is not rare to find cranidia, pygidia, and other skeletal elements of a single individual clumped together in a small space.

The Moody reef (see locality 74, Appendix II) has a fauna similar to that of the reef core at Schoonmaker reef, as do other reefs in this vicinity. There is no evidence at any of these reefs for trilobite-cephalopod accumulations.

Halquist Reefs

Three small reefs are present in the Halquist quarry at Sussex, Waukesha County, Wisconsin (see locality 48, Appendix II). The reefs are widely spaced and appear to have begun their development in an unnamed unit beneath the Romeo Beds of the Racine Dolomite (Upper Wenlockian-Ludlovian). One of these reefs appears to have continued developing during thedeposition of the Romeo Beds, but the

Table 21. Trilobite composition for representative Racine Dolomite (Silurian) reefs in the northern half of Milwaukee County, Wisconsin. Column 1 gives a nonquantitative ranking of trilobite occurrence based on examination of museum collections and field observation of the core of the Schoonmaker reef A = abundant, C = common, U = uncommon, R = rare. Column 2 is from collection of reef core at Schoonmaker reef and Column 3 is a collection from the flank beds of that reef. Column 4 is a collection from Moody reef. Column 5 is a collection from the reef exposed in a sewer tunnel at 25th Street and Lloyd Streets (see localities 74, 80, and 84, Appendix II). Collections are in the author's possession.

	1	2	3	4	5
Bumastus cuniculus	A	23. 1%	-	11. 0%	10. 0%
Bumastus dayi	C	-	5. 2	-	-
Bumastus niagarensis	C	1. 0	1. 0	4. 2	-
Bumastus tenuis	R	-	-	10. 4	-
Bumastus sp. B	C	3. 1	-	0. 9	-
Hadromerus welleri	C	4. 2	3. 6	18. 3	20. 0
Sphaerexochus romingeri	A	65. 2	-	40. 0	55. 0
Scotoharpes telleri	R	-	18. 7	3. 3	-
Dicranopeltis greeni	U	-	8. 3	0. 6	-
Arctinurus sp.	R	-	-	-	-
Calymene sp.	C	-	1. 0	2. 7	-
Encrinurus reflexus	U	-	-	-	-
Ceratocephala sp.	U	-	0. 5	1. 8	-
Dudleyaspis sp.	R	-	-	-	-
proetid?	R	2. 1	0. 5	1. 5	-
scutelluid	U	1. 0	42. 1	4. 2	15. 0
odontopleurid	-	-	16. 6	-	-
Deiphon sp.	-	-	-	0. 2	-
Illaenoides sp.	R	-	-	-	-
Dalmanites sp.	R	-	-	0. 2	-
Number of individuals		95	192	442	20

other two seem to have been terminated by Romeo deposition. None of these reefs appears to have had any significant influence on the characteristics of the surrounding inter-reef beds, which are poorly fossiliferous.

The reef which extends into the Romeo Beds is approximately 36 feet wide and 15 feet high, however, it is not well exposed and its lateral contacts with inter-reef beds cannot be examined. In general, the reef rock is massive, fine-grained, poorly fossiliferous dolomite. It is characterized by a number of small trilobite-cephalopod accumulations which are scattered throughout the structure.

The trilobites in these accumulations are predominantly spemens of Bumastus ioxus which are disarticulated and oriented convex-side-down (Figures 8 and 9). The nautiloid cephalopod Dawsonoceras and other orthocones are typical of these accumulations, but are much less common than the trilobites. These accumulations are differentiated from the surrounding reef rock by their fossil content, peculiar vugginess, darker color, and overall more porous nature.

One of these accumulations is particularly noteworthy in that the majority of the orthocones are preserved in an upright position (see Figures 8 and 9). Because of this unusual orientation this accumulation was sampled in detail and the data derived are the basis for this discussion. This trilobite-cephalopod accumulation

Figure 8. Trilobite-cephalopod accumulation in reef core along the north wall of the Halquist quarry (loc. 48), Sussex, Waukesha County, Wisconsin.

A: Accumulation in situ; note the upright cephalopods in lower two-thirds and disarticulated, convex-side-down trilobites (primarily Bumastus ioxus in upper one-third.

B: Same location as A, showing lower two-thirds of accumulation during excavation. Note upright orientation of nautiloid nephalopods and convex-side-down orientation of Bumastus ioxus at top of photo. Photographs taken 1976.

A

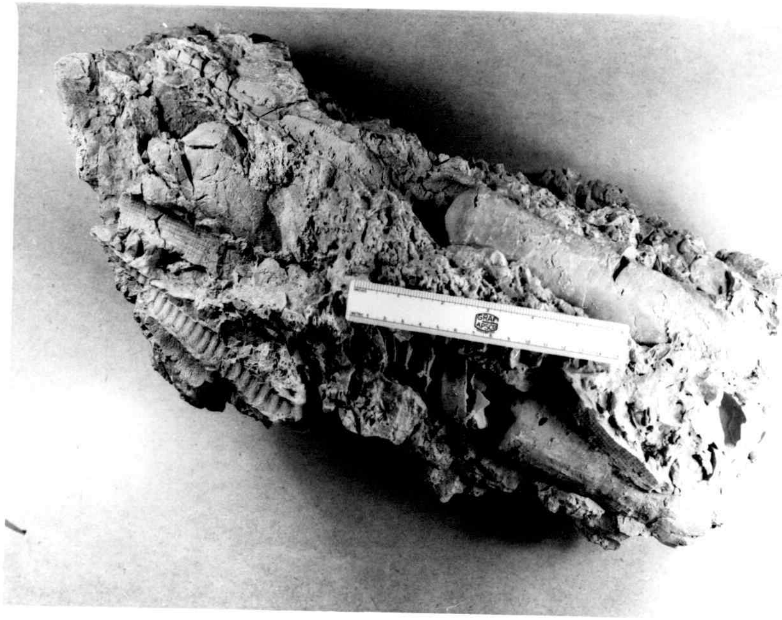
B

Figure 8

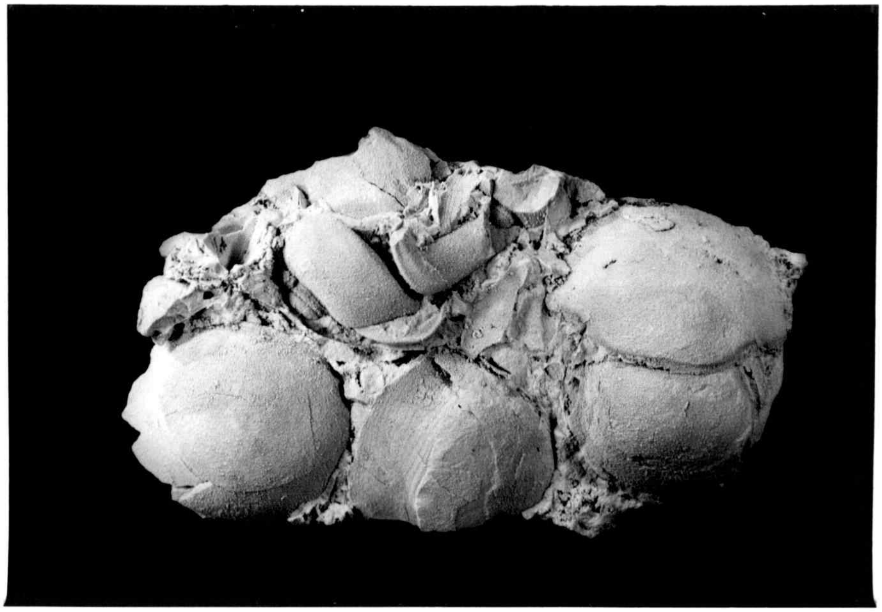
Figure 9. Trilobite-cephalopod accumulation from same locality as Figure 8.

A: Sample showing upright orientation of nautiloid cephalopods. (Photo is arranged so that sample is in approximately its original orientation.)

B: Underside of slab from this accumulation showing the disarticulated nature and predominant convex-side-down orientation of *Bumastus ioxus* parts.



A



B

Figure 9

was somewhat V-shaped, 27 inches high, 18 inches wide at the top narrowing to 10 inches at the bottom, and extended at least 10 inches back into the quarry wall. A large volume of clay is found lying on top of this accumulation which may represent a clay-filled cavity like those at the Horlick quarry, but since most of the rock had been quarried away, it could not be determined whether or not a cavity existed.

The trilobite individuals comprised 79 percent of the organisms found in this accumulation (see Table 22). The dominant trilobite is Bumastus ioxus, which represented 83 percent of the trilobite fauna (see Table 23). Ninety percent of the Bumastus ioxus parts were found in a convex-side-down position (see Table 24). Kosovopeltis acamus represents nine percent of the trilobite fauna with approximately 65 percent of its pygidia in a convex-side-down orientation. See Tables 23 and 24 for information on the rest of the trilobite fauna. The trilobites increased in abundance towards the top of the accumulation (see Figure 8), but there was no difference in their taxic composition or orientation. Each species is generally represented by a limited size range of individuals, indicating some size-sorting prior to deposition. Only one Bumastus ioxus hypostome was found, while four Kosovospeltis and four Dicranopeltis hypostomes were present. Thoracic segments were also noticeably under-represented, however, they could not be accurately counted.

Table 22. Biotic composition of the trilobite-cephalopod accumulation in a reef core at Halquist quarry, Sussex, Waukesha County, Wisconsin (see locality 48, Appendix II).

Taxon	Percent of Biota
Trilobites	79.0%
Cephalopods	6.9
Gastropods	5.7
Brachiopods	4.3
Receptaculitids	3.9
Tabulate corals	0.1
Number of individuals	504

Table 23. Trilobite composition of the trilobite-cephalopod accumulation in the reef core at Halquist quarry, Sussex, Waukesha County, Wisconsin (see locality 48, Appendix II).

	Percent of trilobite fauna
Bumastus ioxus	82.6%
Bumastus sp. A	4.0
Dicranopeltis decipiens	3.5
Kosovopeltis acamus	8.5
Ceratocephala sp.	1.0
Trochurus sp.	0.2
Number of individuals	397

Table 24. Orientation of trilobite skeletal elements in a trilobite-cephalopod accumulation in a reef core at Halquist quarry, Sussex, Waukesha County, Wisconsin (see locality 48, Appendix II). Down = convex-side-down, Up = convex-side-up.

	Percent of trilobites with this orientation
Bumastus ioxus	
cranidia-up	6.4%
cranidia-down	93.5
pygidia-up	5.1
pygidia-down	94.0
free cheek-up	13.8
free cheek-down	70.8
Number of specimens	656
Kosovopeltis acamus	
cranidia-up	27.2
cranidia-down	72.7
pygidia-up	35.2
pygidia-down	64.7
Number of specimens	45

Thirty orthoconic nautiloids were found in this accumulation of which eleven were preserved in an upright position, having an average angle of repose of 45° with a range of 25°-65° (see Figures 9 and 10 and Table 25). The body chambers of these nautiloids are well preserved as internal and external molds due to infilling with sediment. The internal molds of the phragmacones are not well preserved because of incomplete filling of the camerae. The resulting geopetal fabric substantiates the observed angle of repose of the inclined nautiloids and indicates that they are in their original burial position. The horizontally-oriented nautiloids are represented by internal molds of only the lower portions of the body chambers and phragmacones, which indicates they are also in their original burial position. All of the upright nautiloids were located in the lower three-fourths of the accumulation, whereas most of the horizontal specimens were found in the upper one-fourth. Ten of the upright specimens were preserved in an apex-down position, only one was apex-up. Most of the upright specimens were inclined towards the northwest. Table 25 shows that the upright nautiloids, particularly Kionoceras are significantly larger than the horizontally-oriented specimens.

Another peculiar feature of this accumulation is the presence of a number of specimens of the receptaculitid Ischcadites koenigii. These specimens are in a random orientation and do not appear to be

Table 25. Composition, size, and orientation of cephalopods in the trilobite-cephalopod accumulation in the reef core at the Halquist quarry, Sussex, Waukesha County, Wisconsin (see locality 48, Appendix II). Note the predominance of large specimens in an upright position. Size was measured as the maximum average diameter of the living chamber for each taxon.

	Number of upright specimens	Size of upright specimens	Number of horizontal specimens	Size of horizontal specimens
Dawsonoceras	4	1.5 in.	1	-
Kionoceras	7	2.5 in.	7	0.7 in.
smooth unident. orthocone	-		11	0.9 in.
Lechritrochoceratidae	-	-	3	0.3 in.
Oncoceratidae	-	-	2	1.0 in

in life position. Silurian receptaculitids are generally confined to reef environments in the Great Lakes area, but are seldom common, usually occurring as isolated specimens. Receptaculitids are considered to be green calcareous algae and probably lived within the photic zone.

The orientation of the cephalopods in the accumulation suggests that the specimens were deposited in a depression in the reef surface. Small specimens were able to settle in a horizontal position, but the size or shape of the depression was such that large individuals, after falling into the depression, settled in an upright position, leaning against the depression walls.

Menomonee Falls

Pelmatozoan-rich reef flank beds in the Racine Dolomite at Menomonee Falls, Waukesha County, Wisconsin (see locality 59, Appendix II) contain a trilobite association similar to that found in the reef flank and inter-reef beds at the Horlick quarry in Racine. *Sphaerexochus romingeri* is the most abundant trilobite associated with *Bumastus* sp. A, *Calymene* sp., and a variety of other trilobites (see Table 26). No trilobite-cephalopod accumulations were found in this area although older collections contain a predominance of *Bumastus ioxus* and *Kosovopeltis acamus*.

Table 26. Trilobite composition of the pelmatozoan-rich reef flank beds of the Racine Dolomite at Menomonee Falls, Waukesha County, Wisconsin (see locality 59, Appendix II.

	Percent of trilobite fauna
Sphaerexochus romingeri	84.9%
Bumastus sp. A	7.2
Calymene sp.	3.0
Deiphon sp.	0.6
Acidaspis sp.	0.6
Trochurus cf. *nasuta*	0.6
Cheirurus sp.	0.6
Bumastus ioxus	0.6
Dalmanites sp.	0.6
Dicranopeltis cf. *decipiens*	1.2
Number of individuals	166

Germantown

A number of small reefs in the Racine Dolomite are exposed in and around Germantown, Washington County, Wisconsin (see locality 131, Appendix II). A few small accumulations of disarticulated Bumastus ioxus with a convex-side-down orientation have been found in the vicinity of the main Germantown quarries. Core rock at the west quarry contains scattered specimens of Bumastus ioxus, Bumastus sp. A, and Dicranopeltis sp.

Raasch (1973, personal communication) reported finding specimens of Kosovopeltis in the reef core at the nearby Rockfield quarry (see locality 126, Appendix II).

Cedarburg

The Groth quarry in the Racine Dolomite at Cedarburg, Ozaukee County, Wisconsin (see locality 107, Appendix II) contains a number of large trilobite-cephalopod accumulations in a localized area of the reef core. The trilobites include abundant specimens of disarticulated Bumastus ioxus with a convex-side-down orientation, uncommon specimens of Kosovopeltis acamus, and rare Dicranopeltis sp. (see Figure 10). One of the accumulations is associated with a large tabulate coral. Outside of these accumulations trilobites are very rare with Calymene sp. being the only other trilobite known

Figure 10. Trilobite-cephalopod accumulation in Racine Dolomite reef core rock near the center of the north wall in the Groth quarry (loc. 107, Appendix II), Ozaukee Co., Wisconsin. Shows disarticulated nature and convex-side down orientation of the trilobite (Bumastus ioxus) parts. A large tabulate coral (about 2 feet high) is present just above nautiloid on the left side of the photo and continues off the picture. (Photo taken by Stanley Fedderley, 1972)

from this reef.

A short distance to the south, at the Electric Company Quarry (see locality 99, Appendix II) accumulations of Bumastus ioxus have been found in reef beds of the Racine. Dolomite.

Palisades Reef Complex

Philcox (1970, 1971) described the characteristics and development of the Palisades reef complex in the Gower Formation (late Wenlockian-Ludlovian) near Cedar Rapids, Linn County, Iowa. He stated that this reef complex initially began with the development of a number of small pelmatozoan-rich mounds which eventually coalesced into a large mound with upward growth. This larger mound formed an assymetrical structure with a windward and a leeward zone. Philcox stated that coelenterates are scattered throughout the pelmatozoan mounds, but are concentrated in the upper portion of what is interpreted as the above-wavebase, windward size of the reef complex.

Philcox also described a number of penecontemporaneous cave deposits in two of the initial mounds. The distribution of these cave deposits seems to be related to the distribution of the ooelenterate beds. He found the cave deposits to be lithologically distinct from the surrounding rock and irregular in shape (some up to 30 feet wide) and others could be traced upwards to the eroded surface of the reefs.

He recognized three stages of infilling of these cave deposits, some of which he considered to be, in part, contemporaneous with the development of the upper part of the reefs. The lowest stage is composed of coarse sediment or coarse sediment with a layer of nautiloids at the top. The second stage is finer-grained, well-laminated, but irregularly stratified. The third stage is fine-grained, unstratified, and can be traced in vertical fissures to the top of the reef in some places. Philcox found a number of areas where the second stage is associated with "pockets" (several feet across) of what he believed to be "disarticulated nautiloid septa" (see Figure 11). He considered these pockets part of the cave system. Philcox suggested that the caves may have been initiated by "fissures developing by gravitational collapse during mound building" and enlargement by solution may have resulted from subaerial exposure. Philcox (1971, personal communication) suggested that the "nautiloid septa" may possibly be disarticulated trilobites, and an examination of the exposures supports this interpretation.

Trilobite accumulations in this reef complex were first mentioned by Norton in 1895. He stated that "at the lower lime quarry, now abandoned, there are numerous nests of the saucer-like cephalic and tail shields of Illaenus ioxus." The locality of this lower lime quarry is in the vicinity of the pelmatozoan mounds described by Philcox as containing the cave system with the trilobite pockets.

Figure 11. Trilobite accumulation in the Gower Formation at Palisades Reef Complex, Linn Co., Iowa, containing disarticulated, convex-side-down Bumastus ioxus parts. Note large cavity above accumulation. Photograph taken 1975.

An examination of this area shows that there are a number of trilobite accumulations, some of quite large proportions. These accumulations are characterized by disarticulated skeletal elements of Bumastus ioxus preserved in a convex-side-down orientation. The trilobite parts are so agundant thaty they occur in masses of stacked parts several inches thick (see Figure 11). Most of the accumulations are only about a foot wide, however, one mass occurs that is over seven feet wide and two feet thick, containing several thousand trilobite specimens, nearly all of which have a convex-side-down orientation. Most of these accumulations are overlain by cavities approximately the same width as the accumulation and several inches thick. The cavities are similar to the clay-filled cavities overlying the trilobite accumulations at the Horlick quarry, Racine, Wisconsin. Their association with these trilobite accumulations indicates that they are related to the deposition of the trilobites in a depression and may represent a later overgrowth of a partially-filled depression, or may result from modification by solution of some feature of the trilobite accumulation. The trilobite Kosovopeltis acamus is occasionally found with Bumastus ioxus in these accumulations. The only other fossils observed were a few nautiloids and brachiopods. The accumulations contain very little, if any, pelmatozoan debris or other attached benthos found in the surrounding rock. In one of the accumulations a large number of Kosovopeltis pygidia were concentrated at the top of the accumulation, suggesting some possible current-sorting. In Hinman's (1968) study of other Gower reefs in eastern Iowa, he reported finding Bumastus ioxus and Calymene sp. in two other reefs (Mitchell and Sneckloth). The Bumastus were found in disarticulated masses (E. Hinman, 1970, personal communication) as were those described from Palisades reef complex.

Wyoming Quarry

The Wyoming quarry, east of Wyoming, Jones County, Iowa, exposes five to six small reefs. The exact stratigraphic position of the rocks exposed in this quarry is uncertain. Witzke (1976) assigned them to the Hopkinton Dolomite, but there are not stratigraphically useful fossils present and the overall lithology is not readily identifiable with any of the other Hopkinton units. The presence of the illaenid Bumastus ioxus and the absence of the illaenid Stenopareia suggest a Late Wenlockian or younger age for these beds, and the exposures are probably equivalent to parts of the Gower Formation. The inter-reef and reef flank beds are poorly fossiliferous. The reef cores are fossiliferous and contain abundant pelmatozoan debris with some tabulate corals. A number of trilobite-cephalopod accumulations are present in these reefs and large cavity-like structures are present above the accumulations. The accumulations consist primarily of small specimens of Phragmoceras and other nautiloids. Small disarticulated trilobite specimens, primarily Kosovopeltis, are also common. Of particular interest is the occurrence of a number of flat, platy specimens of the brachiopod Megastropheodonta. Overall morphologic characteristics of the valves of this brachiopod are similar to some trilobite parts in both size and shape. The composition of the trilobite fauna of this accumulation is indicated in Table 27 and the composition of all taxa in the accumulation is given in Table 28.

Northwestern Illinois

A number of reefs are known in the Racine Dolomite of northwestern Illinois. In a reef at Cordova, Whiteside County, an accumulation of disarticulated Kosovopeltis acampis with rare Cheirurus sp. was found in association with a tabulate coral (Philcox, 1970, personal communication). Specimens of a species of Arctinurus like that found in the reefs at Racine, Wisconsin, are also present in this reef, but are rare. At Morrison, Whiteside County, Illinois, Kosovopeltis acamus is found with Bumastus sp. A in reef beds. No other data are available from this poorly studied area.

Thornton Reef

The Thornton reef, near Chicago, Cook County, Illinois, is one of the best-exposed and well studied Silurian reefs in the

Table 27. Composition of the trilobite fauna in the trilobite-cephalopod accumulation in the Wyoming quarry, Jones County, Iowa (see Appendix I for locality details).

	Percent of trilobite fauna
Arctinurus sp.	3.4%
Ceratocephala sp.	3.4
Cheirurus sp.	3.4
Dicranopeltis sp.	6.8
Kosovopeltis acamus	51.7
Calymene sp.	6.8
Bumastus sp.	8.6
proetid	5.1
Encrinurus sp.	3.4
Number of trilobite individuals	58

Table 28. Composition of the fauna of the trilobite-cephalopod accumulation in the Wyoming quarry, Jones County, Iowa (see Appendix I for locality details).

Taxon	Percent of total fauna
Trilobites	27.2%
Cephalopods	45.0
Brachiopods	14.5
Tabulate corals	0.4
Stromatoporoid?	0.4
Rugose corals	2.3
Cornulites	2.3
Bryozoans	1.8
Crinoids	0.4
Gastropods	2.8
Bivalves	2.3
Number of specimens	213

Great Lakes area. The reef began development in the Joliet Formation (McGovney, 1978), however, most of its development is located in the Racine Dolomite. The reef ranges in age from Welockian through Ludlovian, and possibly into Pridolian (Shaver, 1976). Bretz (1939) presented the first description of the overall geometry of the reef, recognizing it to be a large structure approximately one mile in diameter. Lowenstam (1948, 1950, 1952, 1957) made a detailed study of the paleoecology of the Thornton reef, which was used as a major example in formulating his ideas on the development of Silurian reefs in the Great Lakes areas. Lowenstam described the Thornton reef as representing a late stage, rough-water phase of development. Ingels (1963) described the reef from a more sedimentological standpoint and divided it into a number of different biosomes. All three of these workers believed that at least the upper, exposed portion of the Thornton reef was organically constructed and developed in a high-energy, shallow-water environment.

A somewhat, different view has recenlty been expressed by Pray (1976) and McGovney (1978). Based primarily on sedimentological evidence they interpreted the Thornton reef as a deep-water carbonate buildup which was inorganically cemented. They suggested that the reef may have reached a high-energy environment in the now-eroded portion of the reef, but they considered current exposures to have primarily developed in a low-energy environment. These interpretations do not adequately explain the biologic characteristics of the Thornton reef, such as the extensive development of the Kirkidium Community (Ingels', 1963, Conchidium and Pentamerus Biosomes) which is usually found in high-energy, shallow-water environments; the localization of corals and stromatoporoids in the center of the reef, possibly indicating higher-energy at that place; and the decrease in diameter of pelmatozoan stems at increasing distances from the center of the reef, indicating possible winnowing.

Mikulic (1976) described the distribution of trilobites in the Thornton reef. Trilobite-cephalopod accumulations, containing disarticulated trilobites oriented convex-side-down, account for most of the trilobites found in the Thornton reef (see Figure 12). These accumulations are usually dominated by either Bumastus insignis or Bumastus cf. springfieldensis, but accumulations dominated by the lichid Arctinurus chicagoensis are also known. Accumulations with predominant small cephalopods and with the lichid Lichas pugnax are also present. Trilobites outside of these accumulations are rare, but the same taxa occur. See Table 39 for general trilobite occurrence. The trilobite accumulations are generally confined to the central reef core and flank beds or are found associated with small "satellite reefs." McGovney (1978) mentioned Bumastus being common in a small satellite reef near the freeway

Figure 12. Trilobite accumulations from the Thornton quarry; see Figure 13 for exact localities.

A: Looking up at an *in situ* accumulation at loc. 11 composed predominantly of disarticulated convex-side-down *Bumastus insignis*. Some orthocones (*Dawsonoceras*) are also present.

B: Underside of slab of trilobite accumulation from loc. 8 containing *Bumastus* cf. *springfieldensis* which are disarticulated and in a convex-side-down orientation.

A

B

Figure 12

bridge. Volumetrically, the trilobite-cephalopod accumulations represent a very small part of the entire reef.

Mikulic (1976) listed trilobites at various locations in the Thornton quarry (see Figure 13 for locations).

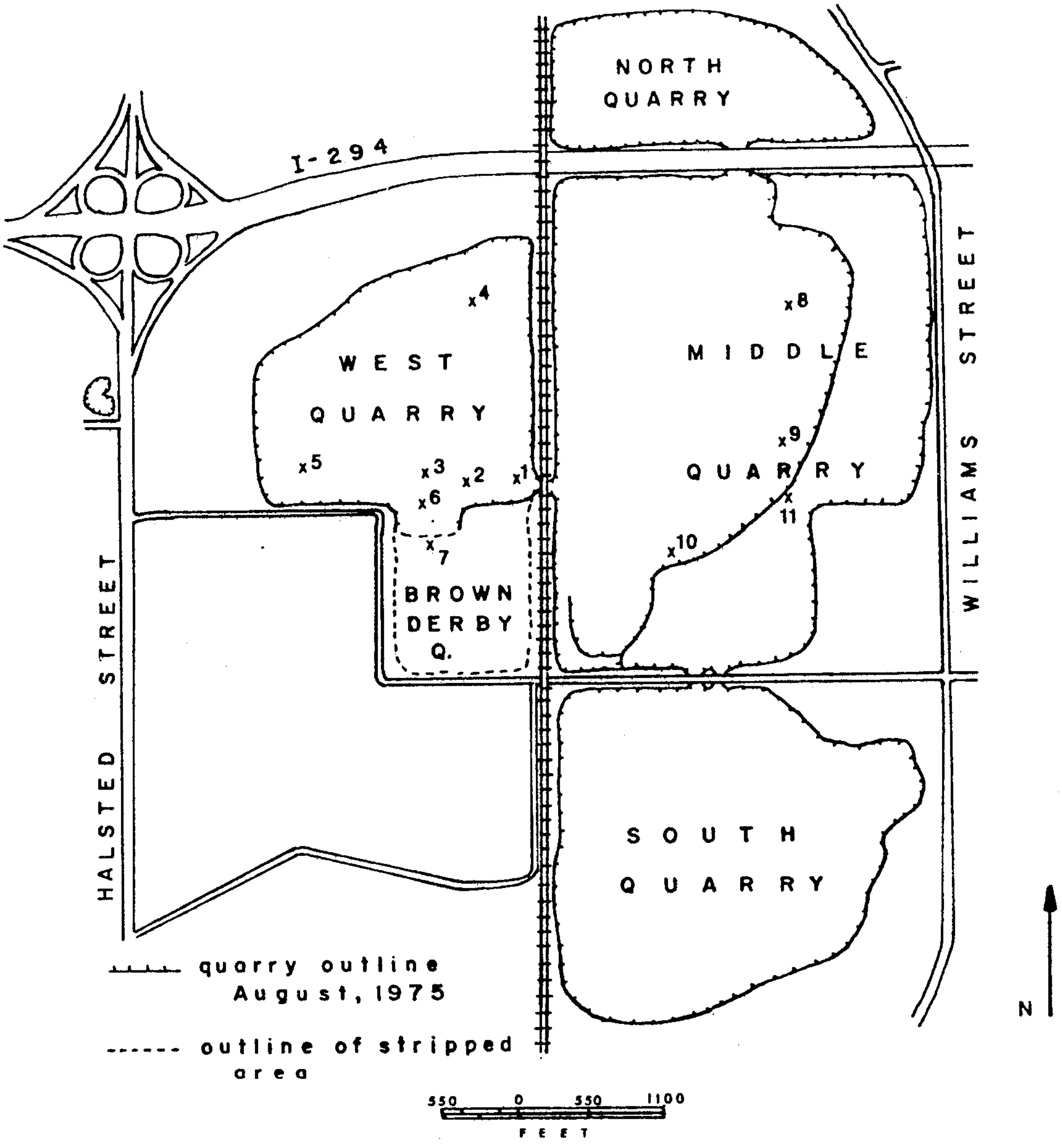
Location 1: In Ingels' (1963) Crinoid Biosome, contained a few *Bumastus*, *Sphaerexochus*, and *Cheirurus*, as isolated specimens.

Location 2: Ingels' samples from his Cephalopod Biosome contained common *Lichas pugnax*, with *Dicranopeltis*, *Ceratocephala*, and abundant small cephalopods.

Location 3: Ingels' Trilobite Biosome contained scattered trilobites and several large accumulations with abundant specimens. The dominant trilobites in these accumulations are *Bumastus* cf. *springfieldensis*, common *Sphaerexochus*, and rare *Calymene*, *Ceratocephala*, *Cheirurus*, and *Encrinurus*. Most *Bumastus* pygidia and cranidia in these accumulations were oriented convex-side-down.

Location 4: Several large accumulations containing a diverse trilobite fauna were found. *Bumastus insignis* is the dominant trilobite with fewer *Ceratocephala*, *Cheirurus*, *Lichas pugnax*, *Arctinurus chicagoensis*, *Calymene*, *Dicranopeltis*, and undetermined scutelluids and proetids. Gastropods, brachiopods, stromatoporoids and corals are common outside of this accumulation. North of this a few *Sphaerexochus* were found in crinoidal rock.

Figure 13. Map of the Thornton quarry, Thornton, Cook Co., Illinois, showing localities in the Racine Dolomite mentioned in the text. Modified from Mikulic (1976, Figure 21). Reef occupies nearly the total area of the diagram. Center of reef is approximately at locality 1.



THORNTON QUARRY
THORNTON, ILLINOIS

Figure 13

Location 5: Scattered specimens of Bumastus, Sphaerexochus, and Calymene were found with more typical core fauna.

Location 6: Scattered specimens of Bumastus insignis and Calymene occur in Ingels' Coral Biosome.

Location 7: A small accumulation of Bumastus insignis with some Cheirurus in association with a tabulate coral was found here.

Location 8: A large number of Bumastus cf. springfieldensis were found associated with scattered Arctinurus chicagoensis. Occasional gastropods and cephalopods were also found. This accumulation may have been associated with a satellite reef.

Location 9: A few Bumastus insignis, Arctinurus, and Cheirurus are associated with several small cavities in a satellite reef.

Location 10: An accumulation of abundant Arctinurus chicagoensis was found; a few Bumastus also present (see Table 29).

Location 11: A large accumulation containing a diverse trilobite fauna dominated by Bumastus insignis is located on the north side of a small satellite reef. Ceratocephala, Bumastus chicagoensis, Lichas pugnax, and Arctinurus chicagoensis are present in this accumulation. Dawsonoceras and other orthocones are fairly common.

Table 29. **Orientation of** parts of the trilobites, number of parts, and composition of the trilobite fauna in **a** trilobite accumulation at Location 10 in the Thornton reef, Thornton, Cook County, Illinois. (See Figure 12 for exact location of Location 10)

	Percent with each orientation	Number of Parts	Percent of trilobite fauna
Arctinurus chicagoensis			91.3%
cranidia-up	28.5%	10	
cranidia-down	71.4	25	
hypostomes-up	-	-	
hypostomes-down	100.0	18	
pygidia-up	31.0	23	
pygidia-down	68.9	51	
free cheek	-	-	
Bumastus sp.			8.6
pygidia-down	100.0	7	

Lemont

Lowenstam (1948) described a trilobite accumulation found in the side of a small reef near Lemont, Cook County, Illinois. At this locality Lowenstam found three reefs which he considered to be embryonic. The top of one of the reefs had been exposed by stripping and was "coffin-shaped," measuring five feet in length and 18 inches in height, with the axis trending east northeast. The enclosing beds arch over and dipped under the reefs and inclined flank beds were lacking. The reef cores consist of structureless, light brown, fine-grained, slightly porous dolomite, and the inter-reef beds are slightly argillaceous with discontinuous shaly green partings. With increased distance from the reefs the inter-reef deposits become slightly cherty, containing partially silicified fossils. Lowenstam reported the following from these reefs (1948, p. 31-32):

> No fossils were located in the exposed reef cores. A few poorly preserved, silicified, colonial corals were found, however, at the periphery of the reefs. Fossils are fairly common in the basal reef near inter-reef deposits. The colonial corals form the main constituent of the assemblages and comprise the same elements that are found in the underlying beds. The coral associated consist of brachiopods, orthoceracone cephalopods, *Loxonema* sp., *Calymene celebra* and *Encrinurus* sp. Coral colonies in overturned positions are not uncommon. The carapace of a *Calymene celebra* specimen was found in the unstable resting position with the ventral side facing upward.
>
> A large assemblage of dismembered trilobite remains occurs locally in the inter-reef strata at the edge of one of the higher reefs, piled up against the clumps of the

> skeletons of colonial corals. The individual carapace elements display random orientation by resting at various angles in the sediments. The accumulation density is variable. The carapace elements are commonly separated from each other by thin partitions of the enclosing sediment, but may occur densely crowded and interwedged in places. The assemblage consists almost entirely of Bumastus remains. Glabellae and pygidia are dominantly represented and are found intermingled with free cheeks and thorax segments. The singular representation of a complete carapace of Calymene celebra and of a Dalmanites cephalon in the Bumastus assemblage is noteworthy. The carapacial elements of the Bumastus assemblage include two distinct species, Bumastus cf. graftonensis and Bumastus cf. armatus; the identification of these remains is unsatisfactory, since the individual skeleton elements could not be freed entirely from the matrix.
>
> With increased distance from the reef, the colonial corals decrease numerically...

An examination of the trilobite specimens collected by Lowenstam show that the skeletal elements are predominantly oriented in a convex-side-down position and occupied an area of about two square feet, being about one to two inches thick. The trilobites are Bumastus cf. graftonensis.

Northeastern Illinois

Diverse trilobite faunas are known from two reefs (Hawthorne, Bridgeport) in the Racine Dolomite of the Chicago area, Cook County, Illinois (see Appendix I for locality details). Both of these reefs can no longer be examined, with the Hawthorne reef being covered and the Bridgeport reef being inaccessible. Examination of specimens in old collections, however, reveals that trilobite accumulations were probably common in these reefs. *Bumastus insignis* was found in the accumulations at Hawthorne, while at Bridgeport *Bumastus armatus*, *Bumastus harrisi*, and *Bumastus transversalis* have been found in separate accumulations (see Table 29 for comparison of the trilobite faunas of these reefs). Accumulations of *Arctinurus chicagoensis* have also been found at Hawthorne.

At McCook, County, Illinois (see Appendix I for locality details) accumulations of *Bumastus insignis* have been found (R. Gutschick, 1977, personal communication; Lowenstam, 1979, personal communication), but little else is known about the trilobite fauna.

At *Conchidium* Hill, near Manteno, Kankakee County, Illinois (see Appendix I for locality details) a reef having the same paleontologic characteristics as Thornton reef is partly exposed. *Bumastus insignis*, *Cheirurus* sp., *Sphaerexochus romingeri*, and *Calymene* sp. are all present, but little information is known about their occurrence.

Indiana

Little detailed information is known concerning the distribution and mode of occurrence of trilobites in the Silurian reefs of Indiana. Reefs of Upper Wenlockian through Ludlovian age are numerous, particularly in north-central Indiana, but few have been studied in any kind of detail.

A number of reefs in northwestern Indiana are faunally and lithologically similar to Thornton reef. At Delphi (see Appendix I for locality details) small accumulations of disarticulated Baumastus insignis have been found in the central core of the reef located in the south quarry (see Shaver, 1976, for location). At Francesville (see Appendix I), Bumastus insignis is found along with Calymene and Sphaerexochus (Mourdock, 1975). C. R. C. Paul (1977, personal communication) reported that accumulations of illaenids are present in this quarry. In the reef at Rensselaer (see Appendix I) Bumastus insignis occurs, but no accumulations have been found. Paul (1977, personal communication) reported finding an accumulation of large orthoconic cephalopods in the reef at Monon (see Appendix I), but no trilobites were present.

To the east, at Montpelier (see Appendix I), Wahlman (1974) reported Bumastus insignis, Cheirurus sp., and Calymene sp. in the fore-reef flank beds. An examination of this area revealed the presence of several small accumulations of disarticulated specimens of Bumastus insignis.

The Pipe Creek Jr. reef has been recently described by Lehmann (1978). Trilobites include Bumastus cf. springfieldensis, as at Thornton, along with Sphaerexochus sp. and Calymene sp.

Western Ohio

At Rockford, Ohio (see Appendix I for locality details) a number of small reefs are exposed in Wenlockian and Ludlovian age rocks (Indiana University Paleontology Seminar, 1976). A diverse trilobite fauna has been found in these reefs, including accumulations of *Arctinurus* sp. and an undetermined illaenid. Other trilobites found in these reefs include *Hadromerus* sp., *Bumastus* cf. *insignis*, *Bumastus* aff. *Harrisi*, *Sphaerexochus* sp., and rare specimens of *Ceratocephala* sp., *Staurocephalus* sp., *Scotoharpes* sp., *Deiphon* sp., and a scutelluid.

A number of small reefs in the same beds as those at Rockford are exposed at Celina, Ohio (see locality details in Appendix I). Accumulations dominated by *Bumastus* cf. *springfieldensis*, with *Hadromerus* sp., *Dicranopeltis* sp., and an undetermined illaenid are not rare. The trilobites in these accumulations are disarticulated and have a preferred convex-side-down orientation. *Bumastus* aff. *harrisi*, *Calymene* sp., *Scotoharpes* sp., *Arctinurus* sp., and *Sphaerexochus* sp. are also present in these reefs.

At Fairborne, Ohio (see Appendix I), accumulations of cephalopods and gastropods occur in Lower Silurian bioherms (D. Kissling, 1976, personal communication).

Irondequoit Bryozoan Mounds

The general depositional environment of the upper Irondequoit Limestone in western New York and eastern Ontario has been described in the discussion on the Rochester Shale trilobite association. Work by Freedenberg (1976) and Brett (1978) has shown this part of the Irondequoit to have developed in a high-energy, above-wavebase environment. A number of small bryozoan mounds are present in the upper few feet of this unit and are dealt with in the following discussion.

Ringueberg (1882) thought these mounds were accumulations of organisms swept together by eddies and currents. Detailed information was presented on the fossils occurring in these mounds by Grabau (1901), but he did not suggest an origin for these structures. Sarle (1901) gave an excellent description of the origin and characteristics of these buildups, having examined over one hundred of these structures. He found that they range in size from two to fifty feet wide and one to fifteen feet thick, but most are rather small. Sarle also observed that nearly all of the buildups are confined to the Irondequoit, but several project up into the overlying Rochester Shale. He found encrusting bryozoans to be abundant in these buildups and believed they were responsible for the development of these mounds. More recently, Freedenberg (1976) described the depositional environment of the Irondequoit based primarily on sedimentological evidence. He stated that the bryozoan mounds began development in the high-energy, above-wavebase, pelmatozoan-rich beds of the Irondequoit. He attributed the development of the mounds to the entrapment of sediment by the baffling effect of the bryozoans and stated that "because of the large amount of fine grained material entrapped and the delicate nature of the entrapping biota" the mounds most likely developed in a below-wavebase environment. This contradicts the high-energy origin of the mounds which he earlier indicated. Freedenberg also thought that the mounds developed before Rochester Shale deposition. He was able to examine only two mounds, both of which projected up into the Rochester Shale, but as indicated by Sarle these are not typical.

Sarle (1901) presented evidence indicating that at least some of these mounds continued development during Rochester deposition. He gave a detailed description of the Niagara Gorge mound located just north of the Niagara Generating Plant as follows:

> All the lenses observed, with possibly four or five exceptions, terminated with the limestone of which basally they are always a part. One exception is the mass at the third watchman's hut (see Figure 14). This starts with a thickening of perhaps the upper two feet of the limestone, of which the capping ten or twelve inches is of darker color and made up of a mass of drifted brachiopod shells and other remains of Niagara type. This stratum is slightly thickened on the right side of the lens and thins out beneath its edge, while on the left side it fuses into the lens. A limestone parting three or four inches thick in the Rochester

Figure 14. Sarle's bryozoan in the Irondequoit Limestone mound, located just north of the Niagara Generating Plant, Niagara Gorge, in New York. Photograph by G. K. Gilbert (No. 1770) U. S. Geological Survey, ca. 1889. Photo courtesy of the U. S. Geological Survey Photographic Library.

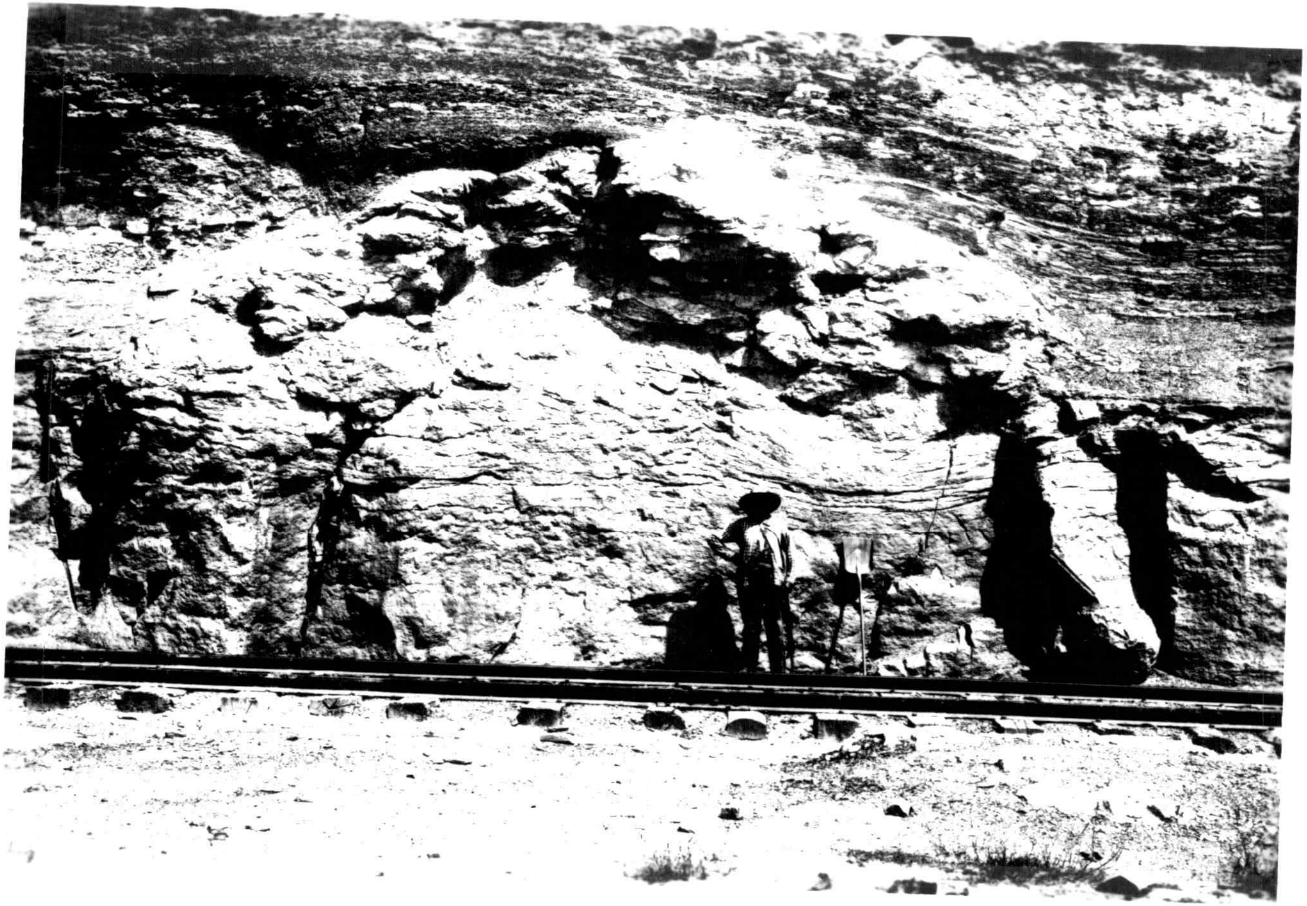


Figure 14

> Shale above and midway on its sides, also fuses into this mass. The lens carries several inclusions of shale, apparently of the same character as that abutting its sides and arching over its dome-shaped top. These may have started as surface pockets like those in the top of the same mass... which might very naturally have become enclosed in the same way had the growth continued longer. These facts point to the growth of the mass contemporaneously with the deposition of the surrounding Rochester shale.
>
> This mass was one surviving the limestone period. The species of brachiopods and bryozoans found are mainly forms to have lived on into the shale period. This limestone dome projecting through the silt flow, probably continued for some time to be the center for attached forms. Brachiopods are remarkably abundant in the basal portion and comparatively rare in the upper. This mass also contains several trilobite pockets. (Figure 15 shows roughly the arrangement of the various elements as displayed in the present section of the mass. From the configuration of the beds beneath on the right side and their slope, it is evident that the portion of the mass broken away extended considerably lower on that side. The extinction of the life of the mass probably occurred about the time the silts reached the level on its sides, indicated by their extension over its top.) (Sarle, 1901, p. 293-294)

Based on Sarle's description and Figure 15 it can be concluded that at least some of this mound was developing during Rochester Shale deposition. Freedenberg (1976) pointed out that the lack of Rochester sediment within normal mound lithology would be illogical if the mound was constructed by sediment baffling and entrapment by bryozoans during Rochester deposition. He found no Rochester sediment in the normal mound lithology. Sarle's mound in Niagara Gorge was in part contemporatneous with Rochester deposition and the lack of Rochester sediment with the normal mound lithology (excluding shale pockets) indicates that there was little or no baffling

Figure 15. Diagram showing the distribution of organisms in Sarle's bryozoan mound in the Irondequoit Limestone (see Figure 15). Note the temporary lateral expansion of mound in Rochester Shale, indicating contemporaneous development of mound with Rochester deposition. Trilobites are disarticulated, convex-down specimens of <u>Bumastus ioxus</u>. Modified from Sarle (1901, p. 293).

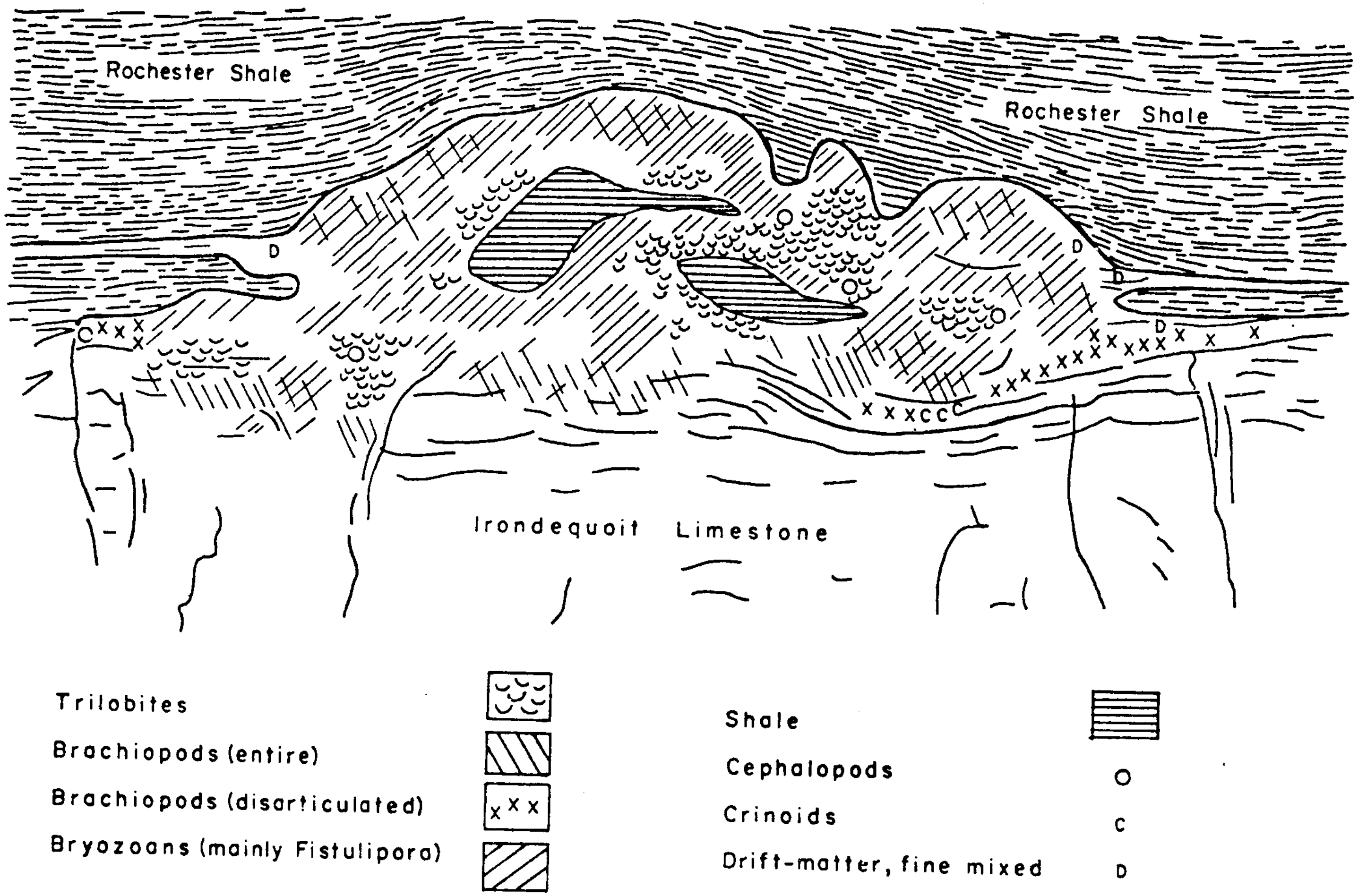

Rochester Shale
Rochester Shale
D
D
D
D
x x x c c
Irondequoit Limestone
Trilobites
Brachiopods (entire)
Brachiopods (disarticulated)
Bryozoans (mainly Fistulipora)
Shale
Cephalopods
Crinoids
C
Drift-matter, fine mixed
D

Figure 15

of sediments by bryozoans. Most of the bryozoans in these mounds are encrusting forms which have little potential for baffling anyway. Furthermore, Brett (1978) observed that a number of mounds had few or no bryozoans present. Therefore, it would seem that most of the sediment of these mounds was generated in place and calcareous algae may have been responsible for most of it, as suggested by Brett.

The baffling concept of organisms in the formation of carbonate buildups is primarily an outgrowth of Ginsburg and Lowenstam's (1958) observations on sediment baffling by _Thalassia_ grass in modern seas. It should be pointed out that grass and filter-feeders, such as bryozoans and pelmatozoans, are radically different organisms. Low-lying bryozoans, but not long-stemmed pelmatozoans, extending no more than an inch or two above the substrate would likely be adversely affected by the baffling of sediments, and instead of mound development isolated vertical growing colonies would be more prevalent, as observed in the overlying Rochester Shale by Brett (1978). Pelmatozoans are likewise adversely affected by large or rapid influxes of sediment (Watkins and Hurst, 1977), and apparently are best adapted to environments with low rates of sedimentation. Baffling by pelmatozoans might be accomplished if the sediment was being transported below their feeding level, but this would be detrimental to filter-feeding organisms at lower levels. The build-up attributed to baffling of other mounds in the geologic record should be re-examined in light of the Irondequoit buildups.

Brett (1978) also found evidence for early lithification of these mounds in the presence of pelmatozoan holdfasts within the mounds, indicating a hard surface, and clasts of lithified mound rock present in the Irondequoit.

A significant feature of these buildups is the large accumulations of disarticulated trilobites, primarily Bumastus ioxus. Hall (1852, Plate A66, Figure 9e) figured a sample of one of these accumulations from an unspecified locality in the Clinton Group of New York, noting that Bumastus occurs in disarticulated, closely packed accumulations in some areas. Ringueberg (1882) in his description of the Irondequoit bryozoan mounds mentioned that (p. 711-712):

> The upper surface is extremely irregular and undulating; having the appearance of being drifted together. This is also corroborated by the position of many of the fossils, which seem to have been swept together by eddies, which at the same time were charges with sedimentary matter by which they were entombed as we now find them.
>
> Thus immense numbers of the cephalic and caudal shields of Illaenus barriensis will be found in the space of perhaps ten or fifteen inches, and outside of this accumulation there will not be any except a stray one or so.
>
> In one vertical section of the stone in my collection, two inches in diameter, the fracture shows thirteen shields of this trilobite crowded one above the other. It also does not seem to have any very regular lines of stratification.

Grabau (1901) described the biota of these mounds, noting that the bryozoan mounds near Lewisburg, New York, were rich in cephalopods and the trilobite Bumastus ioxus. He also reported that Calymene was found rarely with the Bumastus. Sarle (1901, p. 292) discussed the biota of these mounds, stating:

> The favorable conditions are shown by the large size of the trilobites, Calymene and Ceraurus. The head shields of the latter often indicate individuals five or six inches long. In these facts we find an explanation for the occurrence in these lenticular thickenings of communities of brachiopods, for the aggregates of cephalopod shells, for the great numbers of trilobite moultings, and for the abundance of otherwise rare forms.
>
> The manner of occurrence of the trilobites is striking. Their exuviae are commonly found in groups or pockets, sometimes of one speceis, but more often of two or three. They may appear to be entirely absent from some masses, or to occur in two or three parts, or at distinct levels in the same mass. The head and tail shields of Illaenus are almost invariably inverted and generally packed together, one inside the other, like broken egg-shells. These cachements may represent the action of light currents in shifting the tests into depressions in the irregular surface. But the position of some of these moultings suggests that they were left in crannies and silt-lined depressions which were inhabited by trilobites, attracted to these growths by the food supply. Outside of the lenses trilobites are rare.
>
> Cephalopods are not unusual in the surrounding limestone but in the lenses they occur grouped like the trilobites. They are commonest in those masses in which the trilobites are found, and the two forms are frequently comingled.

Sarle indicated that nine genera and ten species of trilobites are present in these reefs, but only five taxa have been observed in this study.

Recent examination of the Irondequoit reefs has supplied more information on the occurrence of the trilobite accumulations. The bryozoan mounds along the old Rome, Watertown, and Ogdensburg

Railroad, near Lewiston Heights, New York are now poorly exposed due to slumping, but a few examples of the trilobite-cephalopod accumulations containing disarticulated *Bumastus ioxus* with rare *Kosovopeltis* sp. and the cephalopod *Dawsonoceras* were found. The Sarle mound in Niagara Gorge has not been significantly altered since his description was made in 1901. Trilobite accumulations composed of abundant disarticulated *Bumastus ioxus* with a common convex-side-down orientation, and rare specimens of *Kosovopeltis* sp. and *Calymene* sp. were found in the same places indicated by Sarle. Just south of the generating plant, a similar mound is located containing the same types of trilobite-cephalopod accumulations (see Table 30). Almost directly across Niagara Gorge from these sites, on the Adam Brook Power Plant access road, in Ontario, is another mound containing accumulations of disarticulated, convex-side-down *Bumastus ioxus* and cephalopods.

Llandoverian Buildups in North America

Llandoverian carbonate buildups in North America are rare and little is known about their trilobite faunas. The Llandoverian buildups in eastern Iowa have already been described in the section on the Hopkinton Dolomite.

At Neda, Wisconsin, a small accumulation of the illaenid *Stenopareia* occurs in a disarticulated state and a convex-side-down

Table 30. Trilobite composition and faunal composition of a trilobite-cephalopod accumulation in an Irondequoit Limestone bryozoan mound on the south side of the Niagara Generating Plant on the New York side of Niagara Gorge. All Bumastus ioxus specimens were oriented convex-side-down.

Taxa:	Percent of trilobite fauna	Percent of fauna
Cephalopods	-	6.6%
Gastropods	-	1.1
Brachiopods	-	5.5
Trilobites	-	86.8
Trilobites:		
Bumastus ioxus	87.3	-
Cheirurus sp.	3.8	-
Illaenoides sp.	1.3	-
Kosovopeltis sp.	5.0	-
Calymene sp.	2.5	-
Total number of trilobite individuals	79	

orientation in the main reef on the north side of the Northwestern Pit, supporting the theory that this is a true carbonate buildup.

At Ashford, Fond du Lac County, Wisconsin, the old railroad cut in Section 2 of Ashford Township, appears to be located in a carbonate buildup belonging to the Schoolcraft Member of the Manistique Formation. Chamberlin (1877, p. 356) mentioned that the rock here is a "soft yellowish dolomite of irregular texture and bedding and is specially interesting for the variety, abundance, and peculiarity of its fauna." He listed (p. 350) a high-diversity fauna from this locality, especially compared to other Schoolcraft (Lower Coral Beds) exposures. The fauna includes a number of gastropods, cephalopods, and illaenids. The exposures are now overgrown, but a few loose blocks can still be found. The matrix and fauna is "reefal" in character. An examination of specimens from this locality in the Greene Museum (University of Wisconsin-Milwaukee) indicates that *Stenopareia* is present.

In the Fiborn Limestone of the Hendricks Member of the Burnt Bluff Formation at the Inland Lime and Stone quarry in Mackinac County, Michigan, several small bioherms occur (Ehlers, 1973). The trilobites include common specimens of the illaenid *Stenopareia*, along with scutelluids, lichids, proetids, and calymenids.

Grawberger (1977) found accumulations of disarticulated "bumastids" in the Manitowaning Bioherm in the Manitoulin Dolomite in Manitoulin Island, Ontario. This accumulation was found in subunit 4, which is an above-wavebase environment (Grawbarger, 1978). The trilobites in this accumulation are predominantly Stenopareia sp. (D. Grawbarger, 1979, personal communication), and specimens of Stenopareia were found in a reef core exposed in a road cut in the same area on Grawbarger's study.

Baltic Area

Gotland. Silurian reefs and carbonate cuildups are common on the island of Gotland, off the coast of Sweden, in the Baltic Sea. They range in age from Late Llandoverian through Ludlovian. A number of different types of buildups are present, ranging from low-energy coral-stromatoporoid mounds to high-energy stromatoporoid reefs. Manten (1971) published an extensive account of the general characteristics and distribution of the Silurian reefs on Gotland.

While many of the Gotland structures are considered to be true reefs, Watkins (1979b) has suggested that the buildups in the Högklint Beds, near the city of Visby, are low-energy mud mounds, composed of an unspecialized level-bottom biota, found along a shelf margin. These bioherms contain stromatoporoids, crinoids, tabulate corals, and calcareous algae, in approximately that order of abundance. Watkins found the brachiopod fauna to represent a low-energy Dicoelosia Community. Upward in the mounds there is a change in the biota, with rhynchonellid and smooth spiriferid brachiopods becoming common and calcareous algae replacing corals and stromatoporoids as most abundant. Beds surrounding these buildups are high-energy deposits dominated by pelmatozoans and common bryozoans. The trilobites found in these bioherms are typical of those found in other Silurian carbonate buildups. Illaenids and lichids are most common and are found in the typical accumulations of disarticulated specimens. Table 31 shows the characteristics of the trilobite fauna found in several of the Högklint mounds. Manten (1971) presented some generalized information on the comparison of trilobites in the Högklint reefs with those of the surrounding crinoidal flank beds (see Table 32). Bumastus is more typical in the reef beds, whereas Encrinurus is more typical of the crinoidal beds.

A number of other reefs were examined in other stratigraphic units on Gotland, but trilobites were seldom observed. At Horsne 4 (see Laufeld, 1974), five proetids and one Calymene were found in lensoidal-like accumulations in a reef in the Halla Beds.

Table 32 presents additional comparison of the trilobite faunas between reefs and surrounding crinoidal flank beds for the Slite and Hense Beds based on Manten (1971). A comparison of these data with that of the Högklint Beds shows that, in general, bumastids are more commonly found in reef environments, whereas encrinurids and calymenids are more typical of the crinoidal beds; however, no

Table 31. Characteristics of trilobite occurrence in various Högklint reefs in the Silurian of Gotland. See Laufeld (1974) for locality information.

Korplinkt 1

Small accumulation of small, disarticulated specimens of *Bumastus* sp. oriented convex-side-down; one accumulation of *Proetus*.

Ireviken 1

Small accumulation containing 4 *Bumastus*, 3 *Arctinurus*, 2 *Calymene*, and cephalopods.

Ireviken 2

Small accumulation of large, disarticulated *Bumastus*.

Galberget 2

Several hundred disarticulated small *Bumastus* found in an accumulation; a few *Arctinurus* also present.

Galgberget

Several small accumulations of disarticulated small *Bumastus* oriented convex-side-down found in biohems in upper 20 feet of Högklint; one accumulation contained a few specimens of *Arctinurus*, another contained a few specimens of *Calymene*.

Table 32. Comparison of the trilobite occurrence in reef cores and surrounding crinoidal flank beds in The Högklint Beds, Slite Beds, and Hemse Beds of the Silurian of Gotland. Numbers represent the number of localities in each unit at which trilobites are found in each environment. Data from Manten (1971).

Trilobites	Högklint Beds		Slite Beds		Hemse Beds	
	Reef core	Crinoidal flank beds	Reef core	Crinoidal flank beds	Reef core	Crinoidal flank beds
<u>Arctinurus</u>	1	1	1	-	-	-
<u>Bumastus</u>	4	2	5	-	3	1
<u>Calymene</u>	3	2	2	7	1	2
<u>Encrinurus</u>	1	3	4	7	2	3
<u>Proetus</u>	1	-	3	1	4	4
<u>Dalmanites</u>	-	-	-	1	1	1
<u>Sphaerexochus</u>	-	-	1	-	2	1
Number of localities of each environment	6	4	10	10	8	5

genera are limited to either environment. Collections from Gotland in the Riksmuseet in Stockholm, show that accumulations of disarticulated specimens of *Bumastus sulcatus* were found in the Slite Beds and accumulations of *Bumastus* cf. *pallens* are also known from an unspecified stratigraphic horizon on Gotland.

Estonia. There a number of small bioherms in the Llandoverian and Wenlockian of Estonia. Männil (*in* Kaljo, 1970) reported that *Arctinurus* is abundant in some of the Upper Wenlockian bioherms. Photographs of samples from these bioherms show small concentrations of disarticulated *Arctinurus* with rare *Calymene*. Männil (1979, personal communication) stated that *Arctinurus* does not occur in dense accumulations, but is quite common in places in some of these bioherms. He added that illaenids occur in great numbers in some Lower Llandoverian bioherms, including disarticulated specimens of *Stenopareia*, associated with tabulate corals.

Kazakhstan

M. Apollonov (1977, personal communication) reported that convex-side-down oriented trilobite accumulations are associated with Silurian bioherms in Kazakhstan.

Greenland

A number of large carbonate buildups are known from the

Llandoverian and Wenlockian of northern Greenland. Mayer (1976) reported Bumastus and Scutellum from Wenlockian? reefs of southern Peary Land. Lane and Thomas (in press) reported a large variety of trilobites from reefs of this area; various scutelluids and cheirurids are most common, along with Stenopareia, Youngia, Calymene, Scharyia, proetids, lichids, and other trilobites.

In northwestern Greenland, reefs of Llandoverian age have produced scutelluids, cheirurids, illaenids, and other trilobites. B. S. Norford (1977, personal communication) stated that some of the trilobites occur in pockets of disarticulated specimens stacked one on top of the other. J. M. Hurst (1977, personal communication) reported having found a piece of a trilobite accumulation from a reef-derived clast in the same area.

Japan

Kobayashi and Hamada (1974) listed a large number of trilobites from a "frontal reef flank" of the Yokokura reef (Ludlovian) at Mt. Yokokura on Shikoku Island, Japan. They reported that Sphaerexochus, Bumastus, Bumastella, Encrinurus, Gerastos, and Cerauroides are most abundant and diverse, while Japanoscutellum, Kosovopeltis, Microscutellum, Illaenoscutellum, Apolichas, Phacops, Bohemiproetus, Decoroproetus, Staurocephalus, Proetus, and Tosacephalus are not as common and less diverse. They noted that Sphaerexochus and Bumastus are gregarious in some places of the reef, suggesting possible accumulations such as those found in other reefs.

Distribution of Non-silurian Trilobite-Cephalopod Accumulations Through Time

Trilobite-cephalopod accumulations in carbonate buildups from periods other than the Silurian (which were previously described), and their distribution through time will be discussed below.

Cambrian

No trilobite-cephalopod accumulations have been reported from the Cambrian, which may, in part, reflect the limited occurrence of carbonate buildups in this period.

Ordovician

Various types of trilobite-cephalopod accumulations are common features of many Ordovician carbonate buildups.

D. Toomey (1978, personal communication) reported finding nautiloid siphuncles in channels cut into the tops of small Lower Ordovician bioherms in southwestern Texas.

The Middle Ordovician bryozoan buildups in New York and Vermont are known to contain trilobite accumulations (R. Flower, 1976; F. Shaw, 1978, personal communication) and nautiloid accumulations (R. Flower, 1976, personal communication). D. Toomey (1979, personal communication) found orthocones here "compressed horizontally into one another for a total length of 12 feet" in cracks or crevasses in the buildups.

Whittington (1963) reported finding disarticulated trilobites in patches in the Middle Ordovician reef at Table Head, Newfoundland. These accumulations are generally a mixture of Bathyurellus, Illaenus, Cydonocephalus, and Apatolichas, which are common. Rarer cephalopods, brachiopods, and gastropods also occur. E. Kindle (1979, personal communication) suggested that these trilobites may have come to the cavities in the reef to molt.

The Middle Ordovician "mud mound" at Meiklejohn Peak in southwestern Nevada contains nests or pockets of nautiloids (Ross et al., 1975), but trilobites, which are common in the rest of the mound, have not been reported in the accumulations.

In the Middle and Upper Ordovician rocks at Dalarna, Sweden, trilobite and cephalopod accumulations are common. Thorslund (in Thorslund and Jaanusson, 1960) stated that nests or lenses of trilobites or brachiopods occur along with rare nests of gastropods and cephalopods. Many of the nests contain specimens of only one species or genus. He mentioned that the trilobites Illaenus, Eobronteus, and Holotrachelus are found in the nests. C. Auton (1977, personal communication) found the trilobites in the Upper Ordovician buildups at Dalarna to occur in fissure-fillings, as well as in depressions and other similar structures. The fissure-filling are not contemporaneous with adjacent rocks. Auton further stated that monospecific accumulations are very rare and that accumulations which appear as such are probably the result of sampling bias. Owens (1979) described a single accumulation containing thousands of specimens of the small trilobite Cyamops stensioei from one of the buildups in this area. These specimens are partially articulated, but nealy all lack free cheeks. Owens suggested that this accumulation was deposited within a sheltered cavity where the trilobites may have gone to molt.

In the Upper Ordovician Keisley Limestone of northern England, accumulations of trilobites and cephalopods are known from carbonate buildups (Reed, 1897).

M. Apollonov (1977, personal communication) stated that trilobite accumulations similar to those in the Silurian reefs of the Great Lakes area are found in Ordovician bioherms of Kazakhstan.

In Upper Ordovician carbonate banks in the Ringerike area of Norway cephalopods are found in localized accumulations (N. Hanken, 1978, personal communication).

Devonian

Trilobite-cephalopod accumulations are found in a number of Devonian reefs and carbonate buildups, but they do not seem to be as prevalent as in the Silurian even though carbonate buildups are more numerous and widespread worldwide in the Devonian. Accumulations in Devonian and later periods contain a more diverse biota than is usually found in the Ordovician and Silurian. Bivalves, brachiopods, gastropods, and other organisms are commonly found with the trilobites and cephalopods, but near-monotaxic accumulations of each of these groups are still common.

In the Lower Devonian Koněprusy reef, near Prague, Czechoslavakia, Chlupáč (1955) has described accumulations of disarticulated exuviae of scutelluids and phyllocarids in basin-shaped depressions. I. Chlupac (1977, personal communication) noted three types of accumulations. One contained only scutelluids; the second contained scutelluids, harpids, proetids, with rare cheirurids and odontopleurids; and the third type contained predominantly phyllocarids with a few scutelluid, harpid, and proetid trilobites. Cephalopods did occur in these accumulations, but were uncommon. More recently, Chlupac et al. (1979), referring to the same accumulations, stated that (p. 139):

> Some trilobites are concentrated in the fillings of the neptunian dykes, and it might be presumed that these species were adapted to living conditions just in the open hollows and caves of the neptunian dykes themselves (e.g. Signatops signatus, Wolayella celox, Quadratroproetus pygolf, Paralejurus dormitzeri dormitzeri).

Accumulations of disarticulated specimens of scutelluids and cheirurids are also known from Lower Devonian reefs in Morocco

(G. Alberti, 1977, personal communication).

Krebs (1974) has described localized brachiopod-molluscan-coral accumulations, which also contain some trilobites, in Middle Devonian reefs of West Germany. These accumulations can be found in "layers, channels, nests, or cave-like depressions at the fore reef slope." Scutelluid trilobites are found in the accumulations (W. Krebs, 1979, personal communication).

The Middle Devonian reef at Lummaton Hill in south Devon, England, contains shell beds of brachiopods, bivalves, gastropods, and trilobites (including scutelluids, harpids, lichids, and odontopleurids) (Scrutton, 1978). These accumulations are about three feet in diameter, contain few cephalopods, and represent infillings of irregularities in the reef (E. B. Sellwood, 1978, personal communication).

In the Upper Devonian reef complex of the Canning Basin, Western Australia, lenticular masses, up to one meter thick, of cephalopods are found. Some disarticulated scutelluids, proetids, and harpids are included (P. Playford, 1978, personal communication).

C. Teichert (1978, personal communication) has also reported cephalopod accumulations from Silurian-Devonian reefs in Pakistan.

Carboniferous

Trilobite-cephalopod accumulations are present in a number of Carboniferous buildups, particularly in the British Isles. Cephalopod accumulations are particularly noticeable; Ford (1965) described such an accumulation from fore-reef beds, concluding that "goniatites accumulated as a result of gentle currents sorting and washing into a hollow such as an inactive surge channel or submarine cave." (p. 190). T. N. Goerge (1978, personal communication) suggested that dead goniatites washed into reef voids or pockets, which could also account for similar occurrences in Ireland and England. He also remarked that abundant brachiopods are also found in accumulations. Broadhurst and Simpson (1973) described the distribution of organisms in the reef in which Ford found the cephalopod accumulation, and it should be noted that this reef complex represents a linear, shelf-edge structure as opposed to the isolated reefs that have been previously discussed. Broadhurst and Simpson found that pockets of brachiopods, molluscs, and other ortanisms occurred at distinct bathymetrically-controlled intervals in the fore-reef area of the buildup (see Figure 16). They stated that "a comparison of the fauna from adjacent pockets can reveal remarkable contrast in the general species represented." They also noted that the shells are usually disarticulated and are tilted to a lesser degree (nearly horizontal) than the

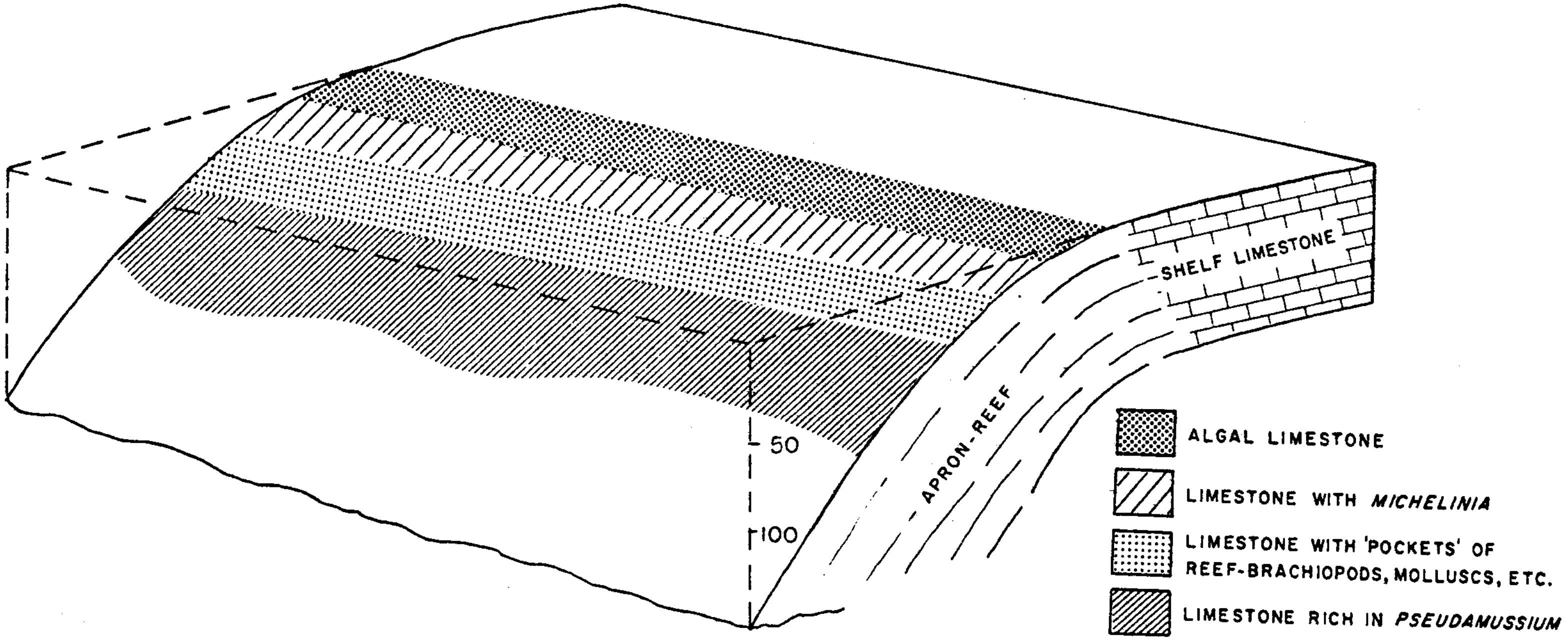


Figure 16. Diagrammatic representation of the carboniferous apron-reef and associated 'shelf' limestone at Treak Cliff, near Castleton, England, to show the distribution of fossils of bathymetric significance. Vertical scale in meters. Modified from Broadhurst and Simpson, 1973, Figure 2.

angle of the dip of the fore-reef slope.

Shaw (1970) described the occurrence of a pectenid (Pseudomusium ellipticum) accumulation from the same reef complex. He found that these bivalves occur in large "concentrated pockets" with up to fifty valves per liter of rock, but are scarce in the surrounding rock. The specimens are generally disarticulated and are oriented in a convex-down position. He suggested that the shells were transported downhill, coming to rest against large objects.

Tilsley (1977) described a diverse trilobite accumulations, approximately in the level with the pockets reported by Broadhurst and Simpson (1973). The trilobites were disarticulated and considered to represent molts. Tilsley believed them to have been transported by "gentle currents into a hollow or fissure within the reef" and rapidly buried (p. 150).

R. Owens (1979, personal communication) stated that "patches" of trilobites are not rare in these types of reefs and that monospecific accumulations are found, containing articulated specimens commonly lacking free cheeks. No other trilobite accumulations have been reported from elsewhere.

Large nautiloids occur in fissures in the Pennsylvanian Yucca mound in New Mexico (J. L. Wilson, 1978, personal communication). And in the Canadian Arctic B. Glenister (1978, personal communication) reported pockets of ammonites in Pennsylvanian bryozoan mounds.

Permian

While no trilobite accumulations are known from post-Lower Carboniferous rocks, cephalopod accumulations are still found in Permian through Jurassic carbonate buildups.

Wilson (1975, p. 233) briefly mentioned the presence of fractures or large cavities filled with thick-shelled nautiloids and echinoids in the Permian reef complex of Texas and New Mexico. He also mentioned that neptunian dykes filled with cephalopods occur in Permian and Triassic buildups. Wilson suggested that these dykes could have resulted from slump, fissuring or solution along joints. Cephalopod accumulations in small depressions in the reef-backreef transition zone have been found in the Permian reef complex of New Mexico (J. Cys, 1979, personal communication; D. Toomey, 1978, personal communication). R. Hewitt (1978, personal communication) reported finding nautiloids occurring in "clusters" within the reef crest in Permian algal reefs in northwest England.

Mesozoic

A few cephalopod accumulations are known from Triassic and Jurassic buildups. J. L. Wilson (1978, personal communication) has observed abundant ammonites in fissures or along reef and mound margins in the Late Triassic of Austria and the Jurassic of Morocco.

It is likely that cephalopod accumulations are also present in Cretaceous reefs, while ammonite are still rather common.

Origin of the Structures in which Trilobite-Cephalopod Accumulations are Found

Most of the trilobite-cephalopod accumulations just described are reported to be associated with cavities, depressions, caves, fissures, or large objects, such as tabulate corals. These structures apparently had a major influence on the concentration of the organisms in localized accumulations, acting as sediment traps for material of a specific size, shape, and density. The evidence for these cavities, and other similar features, is variable, ranging from structures with well-defined walls to those essentially defined by the presence of the trilobite-cephalopod accumulation, having no sharply defined walls. The characteristics of the accumulations are the same regardless of the presence or absence of a well-defined cavity.

The formation of these entrapment structures has not been studied in detail, but a few generalizations can be made. The presence of depressions, cavities, or caves in a carbonate buildup may result from differential rates of development of the buildup surface, from erosion, or from differential rates of sedimentation. The presence of these structures suggests an early subaqueous lithification of the sediment in the buildup, and recent work (Pray, 1976; McGovney, 1978; Lehmann, 1978; Ross et al., 1975) supports this interpretation. Fissures may develop by slumping or settling of the lithified buildup into the underlying soft sediments. Both fissures and caves may result from solution enlargement by subaerial exposure. These methods have been suggested by Wilson (1975). The fossils in these solution-altered structures could be somewhat younger than those in the surrounding buildup.

Formation of the Trilobite-Cephalopod Accumulations

Introduction

The localized accumulations of cephalopods and disarticulated trilobites in a prominent convex-side-down orientation are conspicuous features of Ordovician through Permian carbonate buildups. A number of different processes mentioned in the previous descriptions could account for the formation of these localized accumulations, but none have been considered in detail. These processes will now be discussed in light of the observed characteristics of the accumulations and experimental data.

The occurrence of large numbers of a limited variety of organisms may suggest a living association. It is possible that the trilobites spent all, or part of their lives within depressions or cavities because of a food supply or for shelter. These fossils might then represent molts and/or dead individuals which accumulated over an unspecified period of time. It is also possible that trilobites used these depressions and cavities for protection only during molting. The disarticulated nature of the trilobites could result from bioturbation, scavenging, or current flow through the cavity or depression. A convex-side-down orientation could also result from bioturbation or scavenging (Clifton, 1971). The occurrence of cephalopods in these accumulations may also suggest that the cephalopods lived within these structures; that they were predaceous on the trilobites which may have lived in these structures; or that they were scavengers. However, most of the observable characteristics of these accumulations do not support any of these interpretations.

The accumulations form a continuous spectrum from those containing only trilobites or cephalopods to almost equal numbers of each. This would rule out any interdependence between the two groups, and certainly does not represent a predator-prey relationship.

Cephalopods in some accumulations are too large to have lived within the cavities and depressions in which they are found, and the numbers of specimens in some of the accumulations are too great to represent individuals living in such a small area, as they literally fill the cavities or depressions to the top.

Certain skeletal elements of the trilobites are consistently under-represented in the accumulations. This would seem illogical if the trilobites did indeed live or molt within the cavities. An example may be found in a comparison of the occurrence of various skeletal elements of Bumastus and Arctinurus. Hypostomes of Bumastus are extremely rare in all of the observed accumulations. Cranidia, pygidia, and free cheeks are represented in approximately their proper proportions. Accumulations of Arctinurus chicagoensis, however (see Table 29) contain a fair number of hypostomes, but free cheeks are absent. The free cheeks of Bumastus and the hypostomes of Arctinurus are similar in general shape to the cranidia and pygidia of their respective taxa, which are well-represented in the accumulations. Bumastus hypostomes and Arctinurus free cheeks have a different shape than the other elements of their respective taxa and, therefore, may be absent due to sorting of parts and differential transportation of these parts before deposition. The same is probably true for thoracic segments, which are under-represented in nearly all of the accumulations; however, they are difficult to count and no statistical data are available.

The trilobites in most of the large accumulations are represented by a limited size range of individuals, which may indicate sorting prior to deposition. If trilobites lived in cavities or depressions for any length of time one would expect a wider range of sizes represented.

The possibility that some of these accumulations are associated with large coral colonies suggests that the trilobites and cephalopods were not living in any sheltered areas; this relationship will be described in more detail later in this discussion.

It seems most likely that these accumulations represent sediment traps in which dead individuals or molts accumulated. Dead individuals could have been selectively transported and deposited in cavities or depressions. But the rarity or absence of specific skeletal elements of the trilobites, nearly total disarticulation of the specimens and the well-stacked, convex-side-down orientation indicate that the trilobite specimens were totally disarticulated before reaching the site of deposition. Since the fragile skeletal elements are not broken or abraded it is unlikely that they were subjected to transportation over long distances, predation or scavenging, or exposed on the substrate for very long before deposition and burial.

The fact that bivalve and brachiopod valves, which resemble the shape of certain trilobite parts (such as cranidia and pygidia of Bumastus), are sometimes found in these accumulations would tend to indicate that objects with a particular shape were being selectively transported and deposited at specific sites.

The possibility that these accumulations may represent dead trilobite individuals that were disarticulated and transported to the site of deposition cannot be discounted.

The cephalopods in the accumulations probably represent dead individuals that, due to gas buildup through decomposition or because of gas within the phragmacone, were easily transported to the site of deposition. The absence of most heavy-shelled benthos in the accumulations would seem to indicate that the cephalopods would have had to been buoyant to be transported. This does not mean that the cephalopods had to float as do empty modern Nautilus shells, but just be buoyant enough to be easily transported across the substrate.

It is most likely that the trilobites in the accumulations represent exuviae that were disarticulated and transported to the site of deposition by waves or currents. This interpretation is suggested by the nearly total disarticulation of the trilobites, the absence of certain skeletal elements of particular taxa, the orientation of the skeletal elements, the localized abundance, and the size-sorting.

Experimental Observations

In order to reconstruct the mode of formation of these trilobite accumulations, a number of experiments were conducted utilizing molted exoskeletons from various modern decapods. The carapace of the crab Cancer is similar in shape and size to the pygidia of the trilobite Bumastus ioxus, and it is assumed that molted crab carapaces would probably be of similar density to that of trilobite molts.

Two factors were found to be of prime importance in the transportation, deposition, orientation, and burial of these skeletal elements. The primary factor is the shape of the skeletal element; it was found that similarly-shaped objects behaved in the same way in relation to currents. Secondly, the density of the skeletal element is important. This is demonstrated by comparing the behavior of crab carapaces with single valves of denser, similarly-shaped bivalves (Unio) in relation to currents. The clam shells behaved in a similar manner to that of the crab carapaces, but required stronger currents for movement.

The first experiment performed involved the orientation of concavo-convex shells. Crab carapaces were submerged in a tank in the absence of water movement and were allowed to sink to the bottom. The carapaces were released in three orientations: convex-up, convex-down, and edgewise. Out of 111 trials all the carapaces settled in a convex-side-down orientation. The original orientation of the shells had no effect on the final orientation. Convex-up and edgewise shells, upon release, immediately flipped over into a convex-down position and sank to the bottom (as did those released convex-down) in this orientation. Releasing large numbers of specimens, either individually or in groups, resulted in accumulations similar to the observed trilobite accumulations with many stacks of a number of specimens resting one upon the other.

Further experiments utilizing a constant water flow in a flume tank were performed to determine how accumulations might have formed. Various sizes of crab carapaces were placed at various orientations on the substrate at the bottom of the flume tank and a water current was initiated. On a hard substrate the carapaces were easily transported at low current velocities by sliding across the bottom, saltation, or by being carried in the water column. On soft substrates the same type of transportation occurred, but carapaces in a convex-up orientation stuck on the substrate and were buried. Oscillating currents, simulating wave activity, would resuspend unburied convex-up carapaces on a soft bottom, resulting in further transportation.

Because most of the trilobite accumulations appear to be associated with cavities or depressions, a depression was constructed at the bottom of the flume in order to observe its effect on the carapaces being transported across it. Specimens being moved by sliding across the surface and saltation immediately fell into the depression upon reaching it and settled in a convex-down orientation (see Figure 17). Those specimens being transported within the water column, up to several inches above the substrate, also tended to be deposited within the depression, but by a slightly different method. In Figure 17 the current patterns associated with the depression are indicated. At low current velocities little or no water movement was observed in the depressions, but at high current velocities drag created by the current flowing over the water in the depression resulted in a downward reverse-flow into the depression, producing a circular pattern as indicated in Figure 17. Crab carapaces caught up in this current pattern were transported down and back, being placed into a convex-down orientation at the bottom of the depression.

A bench was also constructed (see Figure 17). Essentially the same types of current pattern and deposition were observed as those associated with a depression.

A number of trilobite accumulations have been found associated with large tabulate corals, so a large object (a fossil coral) was placed on a flat substrate to determine the effort it had on crab carapaces being transported by currents. Very similar types of accumulations to those in the depression were created in the following manner. Flow patterns around the coral are indicated in Figure 17D, E. The currents flowed up and over the top of the coral and around the sides as indicated, producing small backward-flowing eddies in the middle of both the front and the back of the coral, with those on the back side better developed. Crab carapaces being transported past the coral colony were occasionally pushed against the front of the coral, forming small accumulations. The crab carapaces, however, were more often entrapped behind the coral colony, being pushed backwards against the coral by the

Figure 17. Diagram illustrating current flow patterns associated with depression (B), bench (C) and over and around large object (D and E). (A) shows crab carapaces settling into depression in a convex-side-down orientation, as determined by flume experiments.

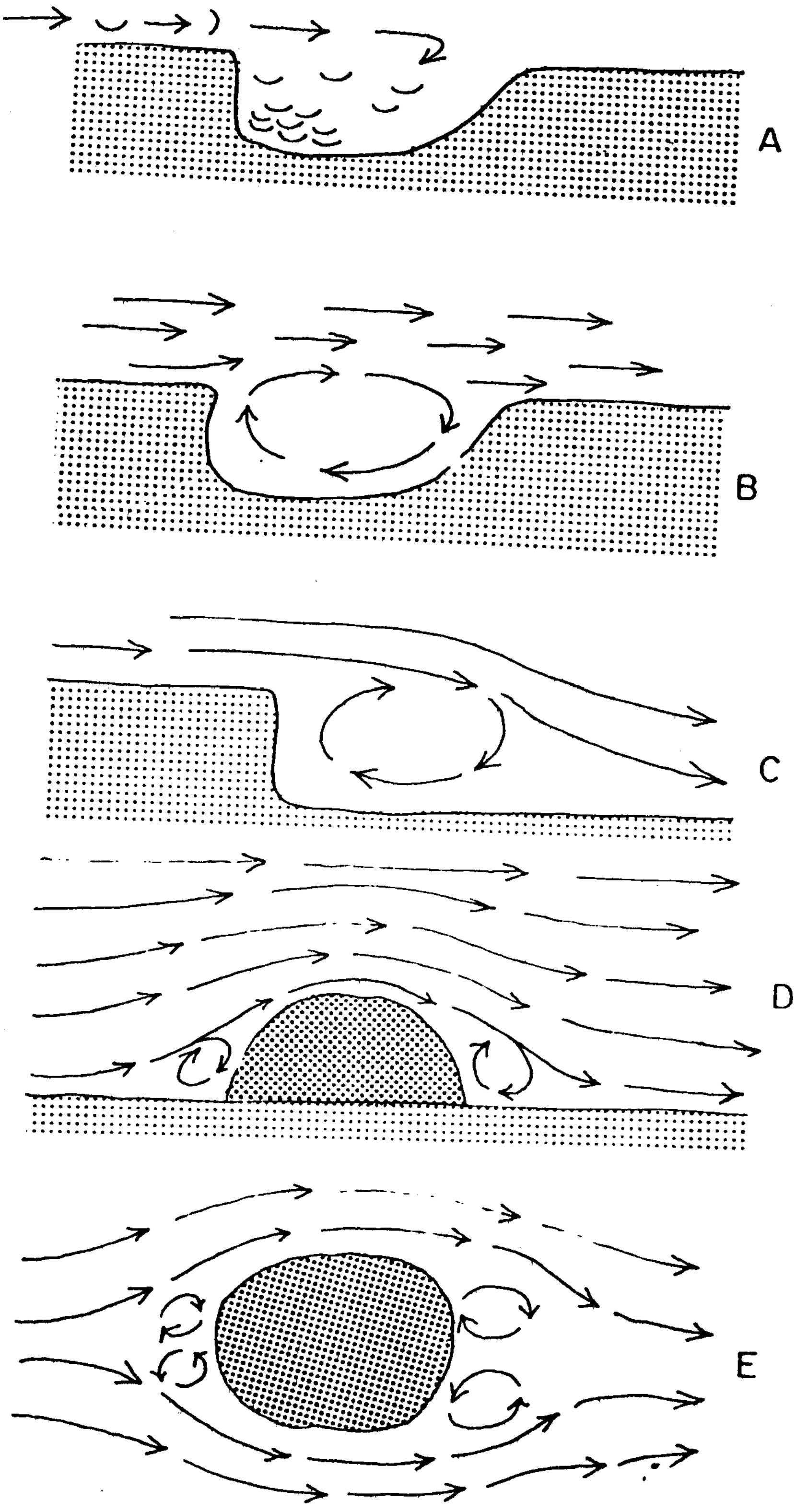


Figure 17

Backward-flowing eddies. This reverse-flow pattern operates in the same manner as that observed in the depression, and produces the same type of convex-side-down orientation.

These experiments demonstrated the following. Carapaces from crab exuviae, simulating disarticulated Bumastus cranidia and pygidia, were best moved on a hard substrate in constant currents; oscillating currents moved them on all substrates. Convex-down orientations were found to be typical of concavo-convex objects settling out in quiet water. Accumulations, like those in which specimens of Bumastus are commonly found, were formed by carapaces being transported over depressions in which the current was too weak to keep them in suspension or by being pulled into the depression by downward reverse-flowing currents. The specimens settled in a convex-down orientation. Accumulations at the foot of a bench were produced in the same manner. Carapaces being transported around large objects were trapped and held in place in a convex-down by back-flowing currents near the center of the backside of the object.

Summary

By comparing the observed characteristics of the trilobite-cephalopod accumulations with the experimental observations several different depositional environments may be inferred.

The predominant convex-side-down orientation of the concavo-convex, saucer-shaped skeletal elements of the trilobites (and some brachiopods and bivalves) indicate that they settled in a quiet-water environment. Objects in a convex-down orientation are unstable in the presence of water movement. This depositional environment could be found in depressions, cavities, caves, fissures, or at the foot of benches in the surface of carbonate buildups. Quiet water areas may also be present behind large objects (such as coral colonies) which project above the substrate.

Evidence indicates that possible stratification of current velocities may cause a zone of accumulation to form around the margins of a buildup (see Figure 17).

It should be pointed out that the trilobites and cephalopods present in these accumulations are almost never found in the surrounding inter-reef beds. This suggests that only the higher parts of the buildups were located in an environment where water movement was sufficient to transport these skeletal elements, that the cephalopods did not float after death as does the modern Nautilus, and that the organisms in the accumulations were endemic to the buildup. All of these indicate that the depositional environment of the trilobite and cephalopod accumulations was localized.

The trilobites found in these accumulations are interpreted as representing disarticulated trilobite exuviae that were transported to the site of deposition. Modern arthropod exuviae are very light and easily transported by currents and trilobite exuviae probably behaved in the same manner. The cephalopods are interpreted as being dead individuals that were transported along the bottom to the site of deposition. The general absence in the accumulations of other organisms found in the surrounding area may indicate that these organisms were too heavy to be transported by the currents responsible for moving the trilobite exuviae and gas-filled cephalopods, that they may have been too firmly attached to the substrate to be moved, or that they were the wrong shape or size to be transported in the same way as the trilobites and cephalopods.

Biogeographic Distribution of Trilobite Faunas in the Silurian Reefs of the Central United States

Differences in the distribution of various Silurian trilobites have long been recognized between southeastern Wisconsin and northeastern Illinois. Day (1877) noted that there are differences in the occurrence of trilobites and other fossils in the reefs of this area. Raymond (1916) observed that the "trilobite fauna of the quarries around Milwaukee and Racine differs considerably from that found in the vicinity of Chicago."

An examination of the distribution of trilobites in the Silurian reefs of the central United States (see Tables 33 and 34, and Figure 18) reveals that there are three distinct biogeographic groupings of

Figure 18. Map showing the distribution of the Bumastus insignis and lichid group; the Bumastus ioxus and scutelluid group, and the Bumastus cuniculus. Specific localities in southeastern Wisconsin may be found in Appendix II. Localities in northeastern Illinois are shown in detail on Figure 19. Numbered localities are as follows: 1 - Palisades-Kepler State Park, Iowa; 2 - Wyoming Quarry, Wyoming, Iowa; 3 - Cordova, Illinois; 4 - Francesville, Indiana; 5 - Delphi, Indiana; 6 - Conner's Mill, Indiana; 7 - Huntington, Indiana; 8 - Montpelier, Indiana; 9 - Celina, Ohio; 10 - Wiarton, Ontario; 11 - Niagara Gorge, New York and Ontario; 12 - Genesee Gorge, New York.

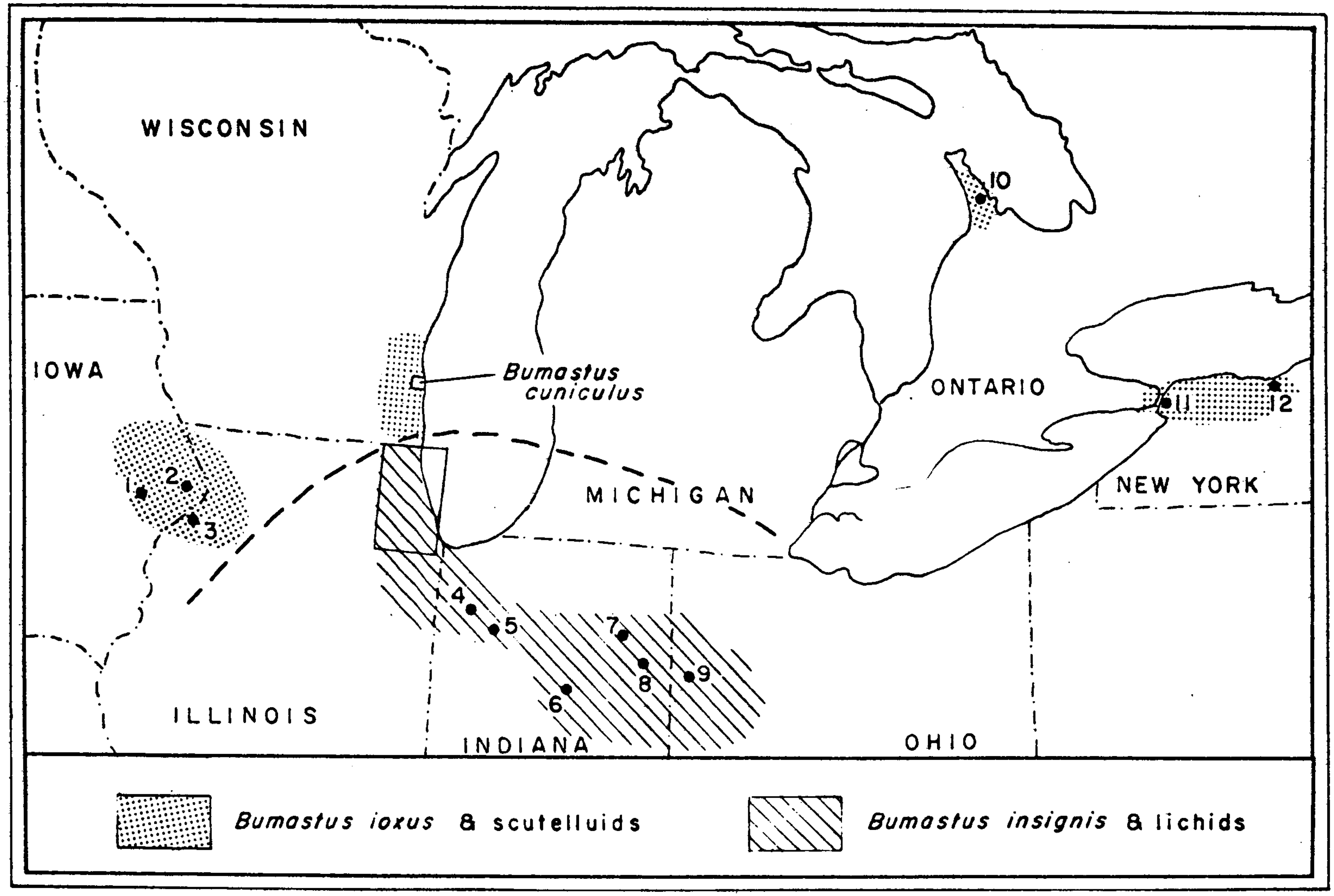

WISCONSIN
IOWA
ILLINOIS
INDIANA
OHIO
MICHIGAN
ONTARIO
NEW YORK
Bumastus cuniculus
1
2
3
4
5
6
7
8
9
10
11
12
Bumastus ioxus & scutelluids
Bumastus insignis & lichids

Figure 18

the trilobite taxa. Two of these groupings have briefly been mentioned by Mikulic (1976). It appears that two of these groupings are independent of variations in age, observable differences in the physical environment, and cannot be attributed to collecting bias or lack of information. The third localized trilobite grouping, however, may be attributed to environmental differences.

Most of the evidence for these biogeographic groupings is based on the distribution of the numerically dominant trilobites (bumastids, scutelluids, lichids) found in the reef environment, as previously discussed. The bumastids under consideration can be divided into different groupings at the specific level. Each of the three groupings is dominated by a single species of bumastid with several subordinate species also being present. The dominant species are seldom, if ever, found outside of their respective geographic areas, but gradation between these groupings cannot be discounted because of a lack of exposures. It also appears that species of the lichid Arctinurus may be divided into the same biogeographic groupings as the bumastids, while other large lichids may not. The scutelluids can be geographically separated only on a generic level probably because of the lack of taxonomic study. Scutelluids and lichids are found in all three geographic areas, but are generally inversely proportional to each other in abundance. Because of their overall morphologic similarities and their nearly identical mode of occurrence the bumastids in the different groupings can be assumed to be occupying the same functional role. The same can be suggested for scutelluids and large lichids, both of which have similar morphologic characteristics, being broad and flat trilobites. The characteristics of these trilobite groupings will now be discussed and reasons for their distribution will be considered.

In southeastern Wisconsin, eastern Iowa, and northwestern Illinois the Silurian trilobite reef faunas are dominated by Bumastus ioxus associated with the scutelluid Kosovopeltis acamus (see Figure 19 and Table 33). Large lichids are rare to absent in these reefs. This grouping may be found in the bryozoan mounds in the Irondequoit Limestone of western New York and eastern Ontario and is also present in the Anabel Formation at Wiarton, Ontario. Bumastids are not particularly diverse in this grouping with only one other species (Bumastus sp. A) being found.

The second grouping is characterized by Bumastus insignis and related species and large lichids (see Figure 18 and Table 34). Scutelluids are rare or absent. This grouping is found in northeastern Illinois, northern Indiana, and western Ohio.

A third grouping is localized in reefs in the northern half of Milwaukee County, Wisconsin, and is characterized by Bumastus cuniculus and related species (see Figure 18 and Table 33). Scutelluids present, but uncommon, and lichids are very rare. The

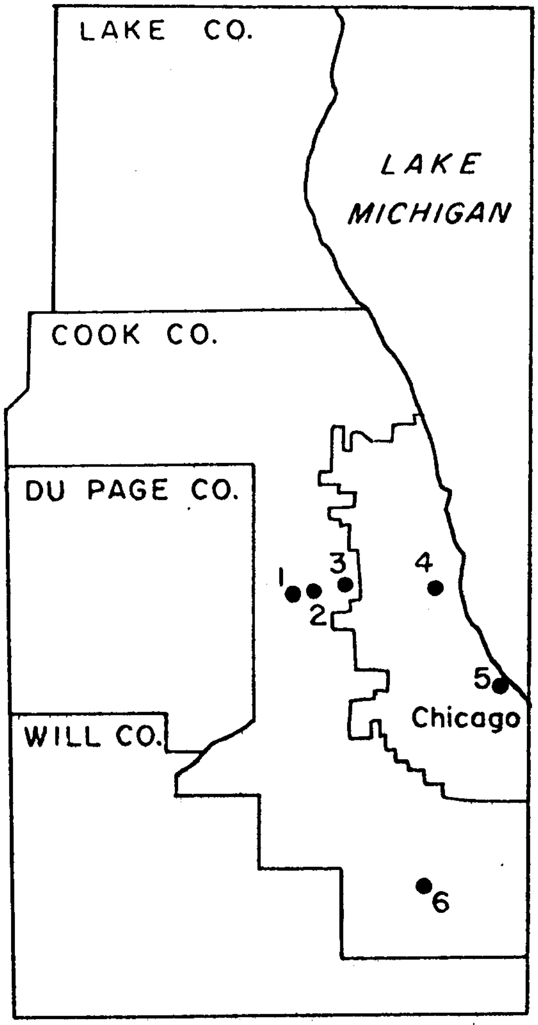


Figure 19. Location of the Silurian reefs in the Chicago area discussed in the text: 1 - McCook; 2 - Lyons; 3 - Hawthorne; 4 - Bridgeport; 5 - Cheltenham; 6 - Thornton.

Table 33. Distribution of trilobites in the Silurian reefs of southeastern Wisconsin and eastern Iowa. A = abundant; C = common; R = rare; this is a non-quantitative ranking system based on field observation and museum collections.

Trilobites	Wisconsin Reefs								Iowa Reefs	
	Horlick	Ives	Franklin	Wauwatosa	26th St.	Germantown	Cedarburg	Thiensville	Pallisades	Wyoming Quarry
Bumastus ioxus	A	A	A	-	-	C	C	C	C	C
Bumastus sp. A	C	C	C	-	-	C	?	-	-	-
Kosovopeltis acamus	C	C	C	-	-	R	?	-	-	R
Arctinurus sp.	R	R	R	-	-	R	?	-	-	-
Bumastus cuniculus	-	-	-	A	C	-	-	-	-	-
Bumastus dayi	-	-	-	C	?	-	-	-	-	-
Bumastus tenuis	-	-	-	R	C	-	-	-	-	-
Bumastus niagarensis	-	-	-	R	R	-	-	-	-	-
Bumastus sp. B	-	-	-	C	R	-	-	-	-	-
Illaenoides sp.	-	-	-	R	-	-	-	-	-	-
Actinobolus americanus	-	-	-	R	-	-	-	-	-	-
scutelluids type 1	-	-	-	R	R	-	-	-	-	-
Trimerolichas sp.	-	-	-	R	-	-	-	-	-	-

predominance of scutelluids over large lichids in this grouping is the same relationship seen in the Bumastus ioxus grouping that surrounds the Bumastus cuniculus grouping.

A few of the reefs under consideration exhibit local variation in the abundance of different species of Bumastus although the reefs are close together, are of the same age, and have the same general environmental characteristics. The best example of this variation is found in a comparison of the trilobite faunas of the Hawthorne and Bridgeport reefs (see Table 34 and Figure 19; Appendix I for locality details) of the Chicago area. The trilobite fauna of the Hawthorne reef is dominated by Bumastus insignis with lesser numbers of Bumastus chicagoensis. Both of these species are found in surrounding reefs in about the same proportions. Five miles to the east, the Bridgeport reef contains several species of Bumastus that are endemic to this locality (Bumastus armatus, Bumastus harrisi, and Bumastus transversalis). Bumastus chicagoensis is absent, while Bumastus insignis is rare at this locality. The differences between the trilobite faunas in these reefs cannot be attributed to obvious lithologic or paleontologic differences like that between the Bumastus ioxus and Bumastus cuniculus groupings in the Milwaukee area. Two other closely-spaced reefs (Schoonmaker and Moody) in the Milwaukee area show an inverse relationship between the abundance of Bumastus cuniculus and Bumastus tenuis.

Table 34. Distribution of trilobites in the Silurian reefs of the Chicago, Illinois, area. A = abundant; C = common; R = rare; this is a nonquantitative ranking system based on field observations and museum collections.

Trilobites	Hawthorne	Bridgeport	Thornton	Other reefs with trilobites as indicated
Bumastus insignis	A	R	A	Lyons, McCook, Cheltenham
Bumastus chicagoensis	C	-	R	
Bumastus armatus	-	C	-	
Bumastus springfieldensis	C	-	A	
Bumastus niagarensis	?	-	C	
Bumastus harrisi	-	C	-	
Bumastus transversalis	-	C	-	
Illaenoides triloba	R	R	-	
Arctinurus chicagoensis	C	R	C	Lyons, McCook
Lichas pugnax	-	R	C	McCook
scutelluids type 1	R	R	R	

A few other organisms found in the reefs under consideration exhibit a similar pattern of distribution to that of the trilobites. This is particularly evident with the pelmatozoans. The cystoid *Holocystites* is common in the highly-diverse pelmatozoan faunas in parts of southeastern Wisconsin, but is rare in high-diversity pelmatozoan faunas in the Chicago area. The crinoids *Periechocrinus* and *Ichthyocrinus* are both common in the same Chicago area pelmatozoan faunas, but are rare in Wisconsin. The opposite is true for *Siphonocrinus* and *Lampterocrinus*. Local variation is also exhibited in the pelmatozoan faunas betwen the Hawthorne and Bridgeport reefs. In the Llandoverian rocks of Wisconsin and Illinois the brachiopods *Virgiana* and *Platymerella* also appear to be geographically confined to two separate areas. These genera appear to be environmentally and stratigraphically equivalent (Ziegler and Boucot, *in* Berry and Boucot, 1970).

The causes for this apparent biogeographic separation of the trilobite faunas in Silurian reefs of this area are not known, but a number of possibilities should be considered.

Collecting biases and lack of information can be excluded as factors in this study. The reefs in this area, particularly in southeastern Wisconsin and northeastern Illinois, have been the source of a prolific fauna for well over one hundred years. Thousands of trilobites from these localities are present in older collections in addition to thousands more collected in this study. All of the accessible reefs in southeastern Wisconsin and northeastern Illinois have been thoroughly examined in conjunction with this study (some having been visited over 100 times) and collecting bias and lack of information in this area are highly improbable. In the other areas under consideration, while not all the reefs have been as extensively examined as those in southeastern Wisconsin and northeastern Illinois, either in the past or for this study, enough is known about these areas to indicate that the observations on these trilobite faunas are accurate.

It has not been possible to develop detailed biostratigraphic zonation in the Silurian reefs of the central United States. However, biostratigraphic variation is not thought to be a factor in the geographic relationships of these trilobites. All of the reefs in this study are found in the Racine Dolomite or its lateral equivalents which range in age from late Wenlockian through Ludlovian, and possibly into Pridolian (Berry and Boucot, 1970). In certain areas (such as Chicago) a number of reefs are known to individually or collectively span nearly this entire time interval, but still contain the same trilobite grouping. This also indicates that the trilobite groupings cannot be attributed to evolutionary changes from within or replacement from outside areas.

Variations in environmental conditions do seem to be responsible for the occurrence of the Bumastus cuniculus grouping. The reefs in which these trilobites are found (and surrounding inter-reef rock) are significantly different lighologically and paleontologically from the reefs containing the Bumastus ioxus grouping (see Milwaukee County, Appendix II and the discussion of the Racine Dolomite). The most noticeable difference is the low diversity and rarity of pelmatozoans in reefs containing the Bumastus cuniculus grouping when compared with the other reefs in southeastern Wisconsin and northeastern Illinois. The cause of this environmental difference has not yet been determined. Environmental variation is not considered to be a factor in the control of the distribution of the Bumastus insignis and Bumastus ioxus groupings. This may not at first be apparent since a structure such as the Thornton reef (Bumastus insignis grouping), may appear to be lithologically and paleontologically different from the Horlick reefs (Bumastus ioxus grouping), for example. This is not an accurate comparison, however, because Thornton reef is a much larger buildup, representing a later stage of reef development than the small reefs at Horlick quarry in Racine, Wisconsin, which accounts for most of the observable differences. Other reefs in the Chicago area (Hawthorne, Bridgeport) containing the same trilobite grouping as the Thornton reef (Bumastus insignis) are also very similar to the Horlick quarry reefs in size, stage of development, and general lithologic and paleontologic characteristics. The type of environmental variation represented in the Chicago area reefs, therefore, has little or no effect on the geographic distribution of the trilobite groupings.

Examination of Figure 18 shows that there are gaps between the data points in which the boundaries of these trilobite groupings have been placed. These gaps represent areas where the Silurian is either completely covered or eroded. Indications suggest that there were no barriers to migration that can be located in these gaps, and they are too small to have been more than minor barriers to larval transportation.

A number of significant factors that may have controlled the distribution of the _Bumastus ioxus_ and _Bumastus insignis_ groupings are difficult to observe in the fossil record. These factors could include subtle differences in water temperature, current pattern, salinity, productivity, and nutrient supply. One or any combination of these factors may have been responsible for the distribution patterns. Whatever effected the trilobite distribution in this area it had no significant effect on the overall composition and distribution of the general communities present in these reefs.

Note: Several significant changes in classification of the bumastids have recently been suggested by Lane and Thomas (1978, _in_ Thomas, 1978). They (Lane and Thomas, 1978) suggested that bumastids should be classified with the Family Scutelluidae as opposed to the Illaenidae, based on similar morphologic characteristics. The (in Thomas, 1978) erected two new genera containing many of the species listed in this discussion under the genus Bumastus. These taxonomic revisions were not incorporated into this study since I consider them to be somewhat preliminary and unproven. Before removing bumastids from the Illaenidae a major restudy of all the illaenids is needed since many of the key morphologic characteristics used by Lane and Thomas to separate these groups are not well known in the majority of non-bumastid illaenids. E. Ludvigsen (1978, personal communication) suggested that the similarities between bumastids and scutelluids can just as easily be attributed to a common origin shared by the illaenids (including bumastids) and the scutelluids. Many of the species listed under Bumastus in this study can be assigned to the new genera proposed by Lane and Thomas, but a few "transitional" forms seem to be present between the proposed genera and, therefore, these genera might more appropriately be considered of subgeneric ranking. The validity of any of Lane and Thomas' designations has little or no effect on the distribution patterns of the trilobite groupings in this discussion. None of the genera they proposed is limited to any one geographic area although two of their genera are inversely proportional to each other in abundance in the same pattern exhibited by the lichids and scutelluids.

Trilobite Associations in Ordovician through Permian Carbonate Buildups

Introduction

In the preceding sections, it has been determined that Silurian carbonate buildups are characterized by several morphologically distinct groups of trilobites. Lane (1972) has observed that many of these same trilobite groups (illaenids, scutelluids, harpids, chierurids) are found in "pure white limestone" from the Middle Ordovician through the Middle Devonian; all but one of his examples are from carbonate buildups. An examination of the trilobite faunas from other carbonate buildups in the Ordovician through Permian indicates that they are all characterized by taxa having similar morphologies. The only major change in the composition of these trilobites is the extinction, during the Devonian, of most of the trilobite taxa present in earlier carbonate buildups. This extinction is followed by a diversification of the proetids in the reef environment.

The trilobite faunas found in Paleozoic carbonate buildups can be divided into several different morphologic groups which persist throughout this interval. This is considered to be a result of conservative behavioral adaptations exhibited by these trilobites. The morphologic groups can be divided as follows:

Illaenid - represented by Illaenus, Bumastus, Stenopareia, Platillaenus and other trilobites of the family Illaenidae. All of these trilobites are characterized by having a smooth carapace, large eyes, and are generally highly convex. This group tends to dominate most Ordovician and Silurian reefs in both abundance and diversity.

Scutelluid- represented by Kosovopeltis, Eobronteus, Scutellum, and other trilobites of the family Scutelluidae. These trilobites generally have a smooth carapace, although not to the same degree as the illaenids. They are broad, usually flat, trilobites with relatively smooth, regular borders and have large eyes. This group is particularly common in Silurian through Devonian carbonate buildups and rare in the Ordovician reefs.

Sphaerexochid- represented by Sphaerexochus, Kawina, Cydonocephalus, and other similar members of the Cheiruridae. These trilobites are characterized by large, smooth and bulbous glabellae and small eyes. The entire body is elongate, the width not significantly exceeding the width of the glabella. With the exception of the glabella, segmentation of the carapace is well-developed. These trilobites are common in Ordovician through Silurian carbonate buildups.

Cheirurid - represented by Cheirurus, Hadromerus, Paraceraurus, Lehua, and other similar members of the Cheiruridae. These trilobites have very spinose borders and unusually large, convex, rounded hypostomes. They are common in Ordovician through Silurian reefs.

Lichid- represented by Arctinurus, Amphilichas, Dicranopeltis, Apatolichas, and other Lichidae. In gross morphology these trilobites are similar to the scutelluids in being flat and broad, but lichids have more strongly defined features (i.e., glabella furrows, pygidial ribs) and radically different hypostomes. Lichids are common in Ordovician and Silurian reefs and are less common in Devonian reefs.

Harpid- represented by Scotoharpes, Harpes, Selenoharpes, and other Harpetidae. These trilobites have conspicuous smooth, horseshoe-shaped cephala which are large in proportion to the rest of the body. The thorax and pygidium are very small and highly segmented. While never abundant, harpids are characteristic of Ordovician through Devonian carbonate buildups.

Odontopleurid- represented by Ceratocephala and other Odontopleuridae. These trilobites are characterized by extreme spinosity. They are characteristic of Ordovician through Devonian carbonate buildups, but are seldom common.

Proetid - represented by Cyamops, Decoroproetus, Cummingella, and other members of the Proetidae. Most of these are characterized by smooth, convex cephala and large eyes. They are found in Ordovician through Permian buildups.

A number of other, unrelated trilobites are present in Ordovician through Devonian carbonate buildups, but are generally limited in their temporal distribution and, therefore, are not considered to be characteristic of buildups through the entire time interval.

The origin of trilobite-reef associations has not yet been determined. While post-Cambrian trilobite faunas in carbonate buildups are well known, there has been no thorough description of the trilobite faunas associated with Cambrian archaeocyathid or stromatolitic buildups. Many Cambrian trilobites have morphologic characteristics similar to later reef-dwellers, but because of the lack of data on their environmental occurrence, none can be directly compared.

Early Ordovician

Fortey (1975) has described an illaenid-cheirurid assemblage from the Early Ordovician of Spitsbergen. *Illaenus*, *Selenoharpes*, and *Ischyrotoma* occur along with Cheiruridae and Bathyuridae in this assemblage, which is found associated with intraformational conglomerates and algal nodules. Fortey suggested that this assemblage was derived from a shallow-water, perhaps reefal, environment. He also stated that there was a similar trilobite assemblage present in the Early Ordovician (Tourmakeady Limestone) of western Ireland (see Table 35).

Table 35. Percentage abundances of trilobites in the Early Ordovician Tourmakeady Limestone of western Ireland, based on 572 specimens. From Fortey (1975, p. 345).

	Percent
Illaenidae (Illaenus)	22.8%
Cheiruridae (aff. Sphaerexochus)	15.0
(Ceraurinella)	1.6
(Kawina)	3.0
Dimeropygidae (Ischyrophyma)	16.2
(Ischyrotoma)	4.2
Bathyuridae	5.6
Glaphuridae (Glaphurus)	5.2
Otarionidae	5.2
Nileidae (Nileus)	3.3
Geragnostidae (Trinodus)	3.1
Proetidae (Decoroproetus)	2.6
Odontopleurida	1.6
Isocolidae (aff. Isocolus)	1.2
Raphiophoridae (Ampyx)	0.2
Pelagic trilobites:	
Telephina	6.6
Opipeuter	2.6

Middle Ordovician

The best known reef trilobite faunas in the Middle Ordovician are found in the Lower Head buildup of western Newfoundland, the Crown Point-Valcour buildups around Chazy, New York, and the Meiklejohn Peak buildup at Bare Mountain, Nevada. The Crown Point and Valcour buildups are thought to be the result of bryozoan, stromatoporoid, tabulate coral, and algal growth (Pitcher, 1964). The carbonate buildups at Lower Head, Newfoundland, and Meiklejohn Peak, Nevada, are largely composed of micrite with no recognizable framebuilders (Whittington, 1963; Ross et al., 1975). The trilobite faunas in all of these structures are very similar and typical of most other buildups in the Ordovician through Devonian. All three are dominated by illaenids (see Tables 36, 37 and 38). The Crown Point-Valcour reefs are different in that they have a variety and abundance of members of the Asaphacea, in addition to the typical trilobite fauna. They are the only reefs in which the Asaphacea are commonly found, although they are occasionally found in other Middle Ordovician reefs. The gross morphology of the Asaphacea is similar to that of the illaenids, which might indicate similar behavioral adaptations; however, the co-occurrence of agundant illaenids would seem to preclude this interpretation. It is also notable that the reefs in all three areas have common to abundant specimens of Glaphurus, which

Table 36. Counts of trilobite parts from reef at tip of Lower Head, western Newfoundland (Middle Ordovician). Data from Whittington (1963).

	Complete Exoskeletons	Cephala or Cranidia	Pygidia
Agnostidae			
Geragnostus	10	12	15
Harpidae			
Selenoharpes		58	1
Remopleurididae			
Remopleurides		7	
Proetidae			
Phaseolops	15	54	3
Isocolidae			
Isocolus	12	108	14
Idiorhapha		1	
Dimeropygidae			
Ischyrotoma	2	9	
Ischyrophyma		17	
Glaphuridae			
Glaphurus		21	
Nileidae			
Nileus		1	1
Bathyuridae			
Bathyurellus	26	135	56
Uromystrum	1	23	8
Goniotelus		50	8
Illaenidae			
Illaenus	24	470	77
Harpillaenus		39	20
Scutelluidae			
Perischoclomus		10	2
Cheiruridae			
Lehua		5	
Heliomera		9	
Heliomeroides		7	
Kawina	1	55	6
Cydonocephalus		283	
Pliomeridae			
Ectenonotus		1	1
Pseudomera		4	3
Colobinion		32	
Odontopleuridae			
Ceratocephala		7	
Lichidae			
Apatolichas	2	272	48

Table 37. Trilobite distribution and abundance in the Crown Point and Valcour Formations reefs (middle Ordovician), Lake Champlain area, New York and Vermont. Collection numbers refer to Shaw (1968). aa = more than 20 specimens; a = 10-20 specimens; c = 5-10 specimens; f = 1-5 specimens; x = genus is present but no abundance data are available. Data from Shaw (1968, Table 5).

	Reef						Calcarenite surrounding reef						
	V151	R8	R3N	R17	V109	R3S	V110	PL4	R14B	R3N	V122	R19	R3S
Calyptaulax													
Ceraurinella	f								f	f			
Paraceraurus		f	a							f			
Heliomeroides													
Glaphurina	c	f	f	f	f	f			f				
Glaphurus	x	a	aa	c	c	x	f	x			f	c	
Remopleurides			x		f								
Hyboaspis			f	f					f				
Isotelus	a		a	a									
Vogdesia					f								
Basiliella													
Nieszkowskia	f								f				
Sphaerexochus	f												
Pliomerops	x		x	f	x						f	f	f
Amphilichas	a		x						x				
Uromystrum		f							x		x	x	
Bumastus	x		x	a	x								
Thaleops					f				c		a		
Platillaenus	c		x	x	x		f		c				
Bumastoides											f		
Eobronteus									f				
Apianurus									f				
Nileoides			x	f					f				

Table 38. Trilobite distribution in Meiklejohn Peak bioherm (Middle Ordovician), Meiklejohn Peak, Nevada. Numbers refer to the number of collections in which each genus is present. Data from Ross (1972). Measurements refer to distance above base of the reef. Numbers in parentheses refer to the number of collections from each location.

	Reef			Flank Beds	
	0-50 ft. (4)	50-65 ft. (2)	130-187 ft. (3)	173-222 ft. (5)	Above reef (2)
Nileus	2	1	1	3	2
Peraspis	1	-	-	-	-
Illaenus	3	2	3	3	-
Lehua	1	-	-	-	-
Bathyurellus	1	1	1	1	-
Kawina	?	2	1	1	1
Carolinites		2	2	2	-
Dimeropyge	-	?	-	-	-
Trinodus	-	1	-	1	1
Endymionia	-	1	1	-	-
Xystocrania	-	1	1	-	-
Glaphurus	-	-	1	-	-
Harpillaenus	-	-	1	-	-
Selenoharpes	-	-	1	1	-
Pliomerops	-	-	1	-	-
Heliomera	-	-	1	-	-
Apatolichas	-	-	1	-	-
Ectenonotus	-	-	2	4	2
Shumardia	-	-	-	1	-
Ischyrophyma	-	-	-	1	-
Pseudohystricurus	-	-	-	1	-
Carrickia	-	-	-	1	-
Miracybele	-	-	-	2	-
Protocalymene	-	-	-	2	1

is limited to reef environments (Shaw, 1968; Ross, 1972). Isocolus and a variety of Dimeropygidea are also conspicuous in some reef faunas. These trilobites are difficult to categorize in a morphologic group because their morphologic characteristics are not as distinct as in other groups, and they are not represented in Silurian or Devonian reefs. The Bathyuridae are diverse and occasionally common in Middle Ordovician buildups. Their general morphology is somewhat similar to that of the scutelluids which are very rare in these reefs, but become common in later buildups after the extinction of the Bathyuridae. Fortey (1975) has suggested that scutelluids filled the niche vacated by the Bathyuridae.

Late Ordovician

Late Ordovician reefs are known primarily from Europe and Kazakhstan. The best known buildups are found in the Boda Limestone around Dalarna, Sweden, the Keisley Limestone in north-central England, and the Chair of Kildare Limestone at Kildare, Ireland. Unfortunately, none of the buildups has been examined in ecologic terms and, therefore, little is known about the detailed trilobite relationships and distribution. The Boda reefs are thought to have been constructed by algae (Thorslund, 1960), however, nothing about the frameworks of the Keisley or Kildare reefs has been published. The trilobite faunas of these reefs are very similar, again being generally dominated by a variety of illaenids with common and diverse lichids and cheirurids. C. Auton (1977, personal communication) reported finding, in the Boda reefs, specimens of Stenopareia or Sphaerexochus in nearly every sample of core material. The scutelluid Eobronteus is common in the Boda reefs, but is not found in either the Keisley or Kildare reefs (Warburg, 1925). Holotrachelus is also common in the Boda reefs and have been also reported in the Keisley and Kildare reefs (Warburg, 1925). This genus is found only in the Late Ordovician and is thought to be related to the illaenids or proetids. It has a broad, convex, smooth cephalon and a relatively smooth thorax and pygidium; these features are typical of many reef-dwelling trilobites. M. Apollonov (1977, personal communication) reported Late Ordovician reefs in Kazakhstan having Illaenus, Stenopareia, Bumastus, Sphaerexochus, Holotrachelus, Amphilichas, "Bronteus," Hadromerus, and Pliomerus, all of which are found in the European reefs.

In summarizing the trilobite contents of the Ordovician buildups it may be stated that all are overwhelmingly dominated by illaenid or illaenid-like trilobites. Lichids and two subfamilies of the Cheiruridae (Cheirurinae and Sphaerexochinae) are usually common in these reefs. Noticeably rare or absent are the Scutelluidae which are common in later reefs. The Ordovician reefs in particular have a variety of other trilobites that become extinct and do not appear to be replaced morphologically by other trilobites in later reef environments.

Silurian

Silurian carbonate buildups are common in North America, including northern Greenland, and are also found in Europe, Soviet Asia, and Japan. The coral-stromatoporoid buildups in the Silurian have trilobite faunas similar to those in Ordovician reefs (Tables 39 and 40). Illaenids are still dominant in all reefs, with cheirurids and lichids again being common and diverse. Scutelluids become common for the first time in Silurian reefs. While a number of Ordovician reef trilobites have become extinct, no new groups of trilobite move into the reef environment. The illaenids show a marked change in the Early Wenlockian: Llandoverian buildups are usually dominated by various species of Stenopareia, Late Wenlockian-Ludlovian buildups are characterized by Bumastus. Both genera are thought to have had similar behavioral adaptations based on similarities in morphology, distribution, and abundance.

The noticeable differences in the distribution of large lichids and scutelluids in North America has already been discussed. Scutelluids are common to abundant in reefs north and west of Chicago, but are rare or absent to the south and east. Large lichids (Arctinurus, Lichas) have an inverse distribution pattern to the scutelluids. Morphologic similarities of both groups and their inverse distribution pattern indicate they probably had similar behavioral adaptations.

Table 39. Trilobite abundance in Thornton reef (Racine Dolomite, Silurian), Thornton, Cook County, Illinois (see Appendix I for locality details). A, C, U, R is a system of nonquantitative ranking of trilobite occurrence based on field observations. A = abundant, C = common, U = uncommon, R = rare.

	Reef Core	Upper Non-crinoidal Flank Beds	Back-reef Trilobite Accumulations
Bumastus cf. springfieldensis	C	-	A
Bumastus cf. niagarensis	C	-	A
Bumastus insignis	R	A	-
Lichas pugnax	C	-	-
Calymene sp.	U	U	-
Dicranopeltis sp.	R	-	-
odontopleurid	R	-	-
Arctinurus sp.	R	R	-
Arctinurus chicagoensis	-	-	C
Ceratocephala sp.	-	R	-
Lichas sp.	-	R	-
Sphaerexochus sp.	U	R	-
Cheirurus sp.	U	C	-
scutelluids	-	R	-
Bumastus chicagoensis	-	R	-

Table 40. Trilobite abundance at Horlick reef (Racine Dolomite, Silurian), Racine County, Wisconsin (see locality Appendix II). A, C, U, R is a system of nonquantitative ranking of trilobite occurrence based on field observations and museum collections. A = abundant, C = common, U = uncommon, R = rare.

	Reef	Inner Flank Beds	Outer-Flank Inter-reef Beds
Bumastus ioxus	A	C	-
Bumastus sp. A	C	R	-
Kosovopeltis acamus	C	R	-
Dicranoeltis decipiens	R	C	-
Arctinurus sp.	R	-	-
Ceratocephala sp.	R	R	-
Calymene sp.	R	R	C
Trochurus nasuta	-	R	R
Sphaerexochus romingeri	-	R	C
Cheirurus sp.	R	R	R
Dalmanites sp.	-	R	C
Encrinurus sp.	-	R	R

However, both groups have radically different hypostomes, indicating they may have had different feeding habits. Examination of the distribution of both groups in Ordovician and Devonian buildups reveals that they are not found in equal numbers in the same reefs, and perhaps they had the same inverse relationships outside of the Silurian. These distribution patterns have to be considered further in light of the earlier suggestion that the Bathyuridae were replaced in the reef environment in the Late Ordovician by the Scutelluidae.

The low diversity and rarity of proetids in Silurian North American buildups compared to Europe has also been discussed. This pattern has also been observed in the level-bottom environments of these two areas. This disparity in distribution changes in the Devonian when a wide variety of proetids appears in the level-bottom environments of North America. Encrinurus may also be more common in Silurian European reefs than in North America, but the evidence is not as conclusive.

The only notable trilobite addition to Silurian reef faunas are the calymenids, which are not particularly abundant, but are found through a large variety of reef environments.

Devonian

Coral-stromatoporoid reefs reach a maximum in distribution and development in the Devonian. They are found throughout Europe, North America, and parts of North Africa and Australia. However, few trilobites have been reported from any of these reefs. Those reported indicate a continuation of most of the major trilobite groups present in Silurian reefs. A major exception is the extinction of all illaenids, which were dominant trilobites in the reef environment through the Ordovician and Silurian, in the Late Silurian. It appears that no trilobites completely filled the niches vacated by the illaenids, at least there are no trilobites that are morphologically similar. Scutelluids might have become a little more diverse and common in the Devonian. Proetids may have filled some of the illaenid niches since they appear to become more diverse and numerous; a few proetid genera have rather large, smooth and convex cephala similar to illaenids. *Sphaerexochus*-like trilobites also become extinct at the end of the Silurian, but some of the Cheirurinae (*Crotocephalus*) appear in the Devonian with a similar morphology and distribution to the Sphaerexochinae. Phacopids also appear to have been important in some reef communities. Because of the small number of trilobite faunas that have been described from Devonian reefs, some information is needed to demonstrate the validity of these observations, with the exception of the illaenid and sphaerexochid extinctions.

The Early Devonian Koněprusy reefs in Czechoslovakia are well known and contain a typical reef trilobite fauna dominated by scutelluids with common harpids, cheirurids, and proetids (Chlupáč, 1958). The framebuilding organisms of these reefs have not been described. The Early Devonian reefs of southeastern Morocco also contain abundant scutelluids, with some cheirurids (G. Alberti, 1977, personal communication). Holzapfel (1895) listed scutelluids, cheirurids, lichids, proetids, harpids, otarionids, and phacopids from reef exposures in the Middle Devonian of Germany. The coral-stromatoporoid reefs of the Middle Devonian of South Devon, England, contain a trilobite fauna dominated by scutelluids, with common lichids, harpids, cheirurids, and odontopleurids (Scrutton, 1978). The Middle Devonian reefs around Formosa, Ontario, have produced a diverse fauna of proetids and a lichid (Fagerstrom, 1961). The Late Devonian reefs of the Canning Basin, Australia, have an associated trilobite fauna of harpids, scutelluids, and proetids (P. Playford, 1978, personal communication). The Canning Basin reefs are the youngest reefs containing a trilobite fauna with harpids and scutelluids.

Carboniferous

With the major Frasnian, Late Devonian, extinction most of the typical Devonian reef trilobites disappeared. A number of Early Carboniferous buildups in the British Isles do have conspicuous trilobite faunas, however, (Tilsley, 1977; Table 41) and a comparison with earlier reef faunas is possible. All of the trilobites in the Carboniferous belong to the superfamily Proetacea, a group which

Table 41. Total number of trilobite parts obtained at a single locality of Visean (Lower Carboniferous) reef limestone at Treak Cliff, Castleton, Derbyshire, England (Data from Tilsley, 1977).

	Cephala	Cranidia	Free Cheeks	Pygidia
Bollandia	1	4	1	5
Eocyphinium	2	1	-	3
Cyrtoproetus	4	18	3	15
Weania	8	20	5	30
Cummingella	25	4	-	24
Carbonocoryphe	-	2	-	8
Brachymetopus ouralicus	50+	-	-	100+
Brachymetopus moelleri	12	-	-	2
Namuropyge acanthina	10	-	-	6
Namuropyge kingi	-	-	-	1
Griffithides	-	1	-	-

first appeared in the Middle Ordovician reefs and became more diverse and common in Devonian reefs. Several genera (Cummingella, Griffithides, Weania, Namuropyge, and Cyrtoproetus) are entirely limited to reefs (R. Owens, 1979, personal communication). Only one trilobite, at this stage, may be directly compared with earlier reef trilobites; Namuropyge is very similar to odontopleurids, such as Ceratocephala, in its gross morphology. Both trilobites are very spinose, not very common, and rather small. Other reef Proetacea have smooth, convex cephala, which are typical of other Ordovician through Devonian reef trilobites, but a direct comparison is not yet possible for each taxon. Proetids remain common in some reefs through the rest of the Paleozoic (Fortey and Owens, 1975).

Ecology and Distribution

The distribution of trilobites is irregular in carbonate buildups, reflecting the complexity of this environment. Unfortunately, few studies have been made with enough precision to accurately plot these patterns. The studies by Shaw (1968) on the Valcour and Crown Point reefs (Table 37) and by Ross (1972) show some variation in the distribution of trilobites in the reef core and surrounding flank beds (crinoidal calcarenite). Information on the Silurian trilobites has been described in more detail earlier in this study, indicating that illaenids, scutelluids, and lichids are more typical of the core area.

Cheiruridae are more typical of the flank beds. Information presented by Manten (1971; see Table 32) on the relationships in some Silurian reefs on Gotland supports these interpretations. Flank bed areas also seem to be the location of most of the rarer atypical reef-dwelling trilobites, such as phacopids. These taxa may be abundant outside of the reefs and probably represent temporary migrants to the peripheral reef environment.

The functional morphology of trilobites is poorly understood. A few suggestions have been made concerning reef-dwelling illaenids. Lowenstam (1957) suggested that their smooth exoskeleton was adapted to a chiton-like existence in the high-energy reef environment. Bergstrom (1973) suggested a burrowing adaptation for the same trilobites. More detailed studies are need (such as those by Clarkson, 1968, on non-reef taxa) to accurately determine trilobite behavior based on morphology.

Carbonate buildups and their associated trilobites in a shore to basin transect have been placed at the shelf edge in both the Middle Ordovician (Shaw and Fortey, 1977) and Silurian (Thomas, in press). This is accurate to some extent, but is over generalized. Many carbonate buildups are indicative of a high-energy, shallow-water environment, receiving little or no terrigenous clastic sedimentation; not a particular position on a shore to basin transect. These reefal environments can be found adjacent to the shore in the manner of modern fringing reef, in barrier reef complexes on shelf edges, as isolated platform or shelf reefs, or as atoll or fringing reefs around islands in open ocean or deep basinal areas (see Figure 20). An example of some of these relationships can be seen in the Silurian rocks of the Michigan Basin and Illinois Basin. These basins contain a number of pinnacle reefs that developed on the shelf slope. On the shelf edge, a barrier reef complex developed and abundant localized reefs are present behind the barrier on the platform or shelf. All three of these types of buildups are characterized by the same general biota (at least in their upper portions). The trilobite faunas of the platform or shelf reefs are dominated by the illaenid-scutelluid-lichid association, but the surrounding inter-reef beds are characterized by different trilobites, such as the Flexicalymene celebra association. Because the pinnacle and barrier reefs are presently known only from subsurface information, little is known about their trilobite faunas, however, a few examples of scutelluids, harpids, and cheirurids have been observed. All these buildups seem to be controlled by similar environmental conditions, resulting in similar biota, and not by the position they occupy.

The illaenid-scutelluid-lichid association is commonly restricted to carbonate buildups, but level-bottom environments with this association are known from the Cyclocrinites Beds of the Hopkinton Dolomite (Llandoverian) of Iowa. This unit is found on the platform or shelf,

Figure 20. Diagram showing the varying positions of reef environments on a hypothetical shelf-basin transect. Non-reefal, high-energy, shallow-water environments can occur nearshore at shelf edge-carbonate bank or at island positions. Platform reefs and nearshore high-energy shallow-water environments or fringing reefs are generally absent in areas with terrigenous deposition. Platform reefs are typical of broad platforms, such as represented by the Racine Dolomite and equivalent units. Diagram indicates that placement of reefs and other carbonate buildups at a shelf edge position is over-simplification of their true occurrences.

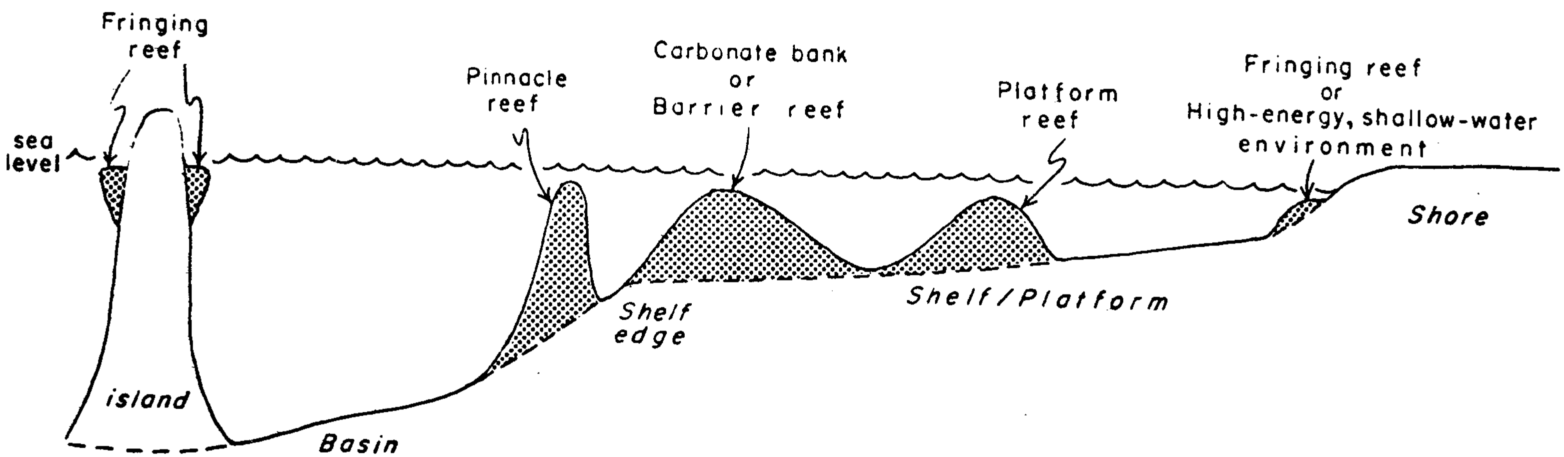

Fringing
reef
sea
level
island
Basin
Pinnacle
reef
Carbonate bank
or
Barrier reef
Shelf
edge
Platform
reef
Shelf/Platform
Fringing reef
or
High-energy, shallow-water
environment
Shore

Figure 20

but is not associated with any buildups.

Summary

Several points should be made concerning trilobite faunas of Paleozoic carbonate buildups:

1. The trilobite faunas of normal marine Ordovician-Devonian buildups are remarkably similar in taxic composition, and in the abundance, diversity, and distribution of the trilobite taxa. These faunas are present in nearly all of these buildups regardless of the size of the buildup, the presence or absence of framebuilders, or the classification of the buildups (such as mudmound, true reef). This indicates that similar environmental conditions were present in all of these structures, regardless of how they have been previously interpreted, or that the trilobites are more tolerant of variation in environmental conditions.

2. The buildups are dominated by only a few morphologically distinct types of trilobites throughout the Middle Ordovician-Devonian. These morphological types may be replaced after extinction by unrelated trilobites bearing a similar morphology.

3. The trilobite faunas of Middle Ordovician-Permian buildups are dominated by only a few major groups (see Table 42). The dominant group is the Suborder Illaenina, which includes the families Illaenidae, Scutelluidae, and the superfamily Proetacea. Recently

Table 42. Importance of trilobite families in Paleozoic reefs demonstrating the dominance of the suborder Illaenina in the reef environment throughout the Paleozoic (the first ten families listed). The only other groups of importance in this time interval are the families Cheiruridae and Lichidae. Bergstrom (1973) erected the order Illaenida, which includes all of the families under the suborder Illaenina listed in the table. Fortey and Owens (1975) have erected a new order Proetida for the proetid trilobites, which were formerly included in the suborder Illaenina. 1, 2, 3, and 4 is a system of ranking based on general abundance in carbonate buildups and the number of reefs in which the trilobites occur. 1 = always present and numerically dominant in the trilobite fauna; 2 = commonly present and common; 3 = commonly present but uncommon; 4 = seldom present and rare.

	Middle Ordovician	Late Ordovician	Silurian	Devonian	Carboniferous	Permian
Illaenidae	1	1	1	-	-	-
Scutelluidae	3	3	2	1	-	-
Bathyuridae	2	-	-	-	-	-
Proetidae	3	3	3	2	1	1
Holotrachelidae	-	2	-	-	-	-
Brachymetopidae	-	-	-	3	1	-
Otarionidae	?	4	4	3	3	-
Dimeropygidae	3	?	-	-	-	-
Glaphuridae	1	-	-	-	-	-
Phillipsiidae	-	-	-	-	2	-
Cheiruridae						
Cheirurinae	2	2	2	3	-	-
Sphaerexochinae	2	2	2	-	-	-
Encrinuridae	4	4	4	-	-	-
Pliomeridae	3	?	-	-	-	-
Harpetidae	3	3	3	3	-	-
Lichidae	2	2	2	3	-	-
Odontopleuridae	3	3	3	3	-	-
Asaphidae	2	-	-	-	-	-
Nileidae	3	-	-	-	-	-
Pterygometopidae	4	4	-	-	-	-
Dalmanitidae	-	-	4	-	-	-
Phacopidae	-	-	4	3	-	-
Calymenidae	4	4	2	-	-	-
Isocolidae	1	-	-	-	-	-
Komaspididae	3	-	-	-	-	-

proposed changes in trilobite classification would result in the Order Illaenida being dominant in Ordovician-Devonian reefs and the order Proetida being dominant in Devonian-Permian reefs. In Ordovician-Silurian buildups the Cheiruridae are next in importance. The Harpetidae, Odontopleuridae, and Lichidae are present in Middle Ordovician-Devonian reefs, but with the exception of the Lichidae, they are seldom common. A large number of other taxa are found in the Ordovician reefs, but they are seldom common and are absent in later reefs. This does not mean that any group is limited to reefs or that all members of a group are found in reefs.

4. The stability of behavioral adaptations of trilobites in the reef environment is demonstrated by the persistence of certain morphologic characteristics throughout the Paleozoic. This is illustrated by the dominance of the illaenids and cheirurids in the Ordovician and Silurian, the abundance of the scutelluids in the Silurian and Devonian, and the dominance of the proetids in the Devonian-Permian buildups. All of these groups are present in Ordovician-Silurian buildups.

5. With the exception of some of the proetids, all major groups of trilobites found in Paleozoic reefs are already present in the Middle Ordovician buildups, with no significant additions.

It is important to emphasize that the reef trilobites are dominated by only one suborder (or two orders based on a newly proposed classification) and two unrelated families throughout the entire Paleozoic. This is highly significant because there are many more families and even orders which are absent or poorly represented in the reef environment despite their contemporaneous abundance elsewhere.

SILURIAN STRATIGRAPHY OF SOUTHEASTERN WISCONSIN

Introduction

Gilbert Raasch (1960, unpublished manuscript) stated that "the Silurian is undoubtedly the most poorly understood system in North America." Since that time, Berry and Boucot (1970) have published a comprehensive correlation of the North American Silurian rocks, alleviating this problem. However, Raasch's statement could still be applied, in part, to the Silurian rocks of eastern Wisconsin, which are probably the most poorly understood Paleozoic unit in the Midwestern United States.

This situation may at first seem surprising since the Silurian exposures in Wisconsin were among the first to be studied after Hall's initial work on the Silurian of New York. The Wisconsin Silurian has been studied by some of the most eminent North American Paleozoic stratigraphers and paleontologists, including T. C. Chamberlin, whose 1877 study of the area was probably the most comprehensive study of Silurian rocks anywhere in North America at that time, and for many years afterward. Unfortunately, much of the information gathered by these early workers has never been published.

The Paleozoic rocks of eastern Wisconsin dip away from a high area of Precambrian rock (the Wisconsin Arch) located primarily in north-central Wisconsin. The general trend is to the east towards the Michigan Basin and successively younger rocks are exposed towards the east. Because of this dip, the oldest Silurian rocks are exposed along the Niagaran Escarpment and the youngest are found along Lake Michigan, with a continuous increase in thickness eastward until a maximum of about 800 feet is reached on the eastern edge of Manitowoc County.

While the Paleozoic rocks of Wisconsin and the surrounding area are structurally uncomplicated, the lack of good exposures makes work in this "layer cake" area difficult at best. The Silurian rocks of eastern Wisconsin are commonly covered by thick deposits of Quaternary sediments. Natural bedrock exposures are usually small, weathered, and are few and far between; the only exception being the Niagaran Escarpment which runs along the western edge of the Silurian from the tip of Door County south to Waukesha County where it disappears beneath the glacial drift. Along the escarpment up to 100 feet of Lower Silurian rocks are exposed. The escarpment is a continuation of the Niagaran Escarpment originating in New York and marking the northern edge of the Silurian rocks of the Michigan Basin. The escarpment is the result of more rapid erosion of the soft, underlying Upper Ordovician rocks and the overall dip of both units. Most of the area to the east of the escarpment in Wisconsin is underlain by Silurian rocks, but natural exposures are limited to a few river cuts and shore exposures. Many of the natural outcrops, particularly those near cities and villages in the eastern part of Wisconsin, had been the site of quarrying activities in the late 19th century and early 20th century. The quarrying resulted in somewhat better exposures than had previously existed, but by the 1930's most of the sites were abandoned, and with the exception of the few still active quarries, exposures have deteriorated.

Unfortunately, there is little hydrocarbon potential in the Silurian of eastern Wisconsin, so almost no cores have been drilled here in contrast to the thousands that have been drilled in the adjacent Michigan and Illinois Basins. The only subsurface information available are water-well logs, which supply only limited data on subsurface Silurian rocks because of variation in the quality of records and difficulty in recognizing stratigraphically useful horizons in the Silurian; even the Silurian-Ordovician boundary is difficult to recognize.

The Silurian of eastern Wisconsin consists primarily of dolomite, which is part of the Dolomite Suite defined by Berry and Boucot (1970) as the dominant lithofacies of the North American platform in the Silurian. A few cherty or more argillaceous intervals are present, most of which are discontinuous over long distances and are, therefore, of limited lithostratigraphic value. The lack of marker beds makes it difficult to be certain of the lithostratigraphic correlation of any exposures unless a large segment of the Silurian section is exposed. Lithostratigraphic correlations are further complicated by the presence of carbonate buildups in the Racine Dolomite which cause the character of the rocks to change rapidly, both vertically and laterally. There is at least one unit that is lithologically conspicuous (Brandon Bridge Beds) which is present in the southern part of the study area, but it is absent throughout most of the rest of southeastern Wisconsin. Cherty units can be used locally for lithostratigraphy.

Biostratigraphic information is scarce for most of the Wisconsin Silurian. Most of the non-reefal exposures produce few, if any, fossils which, when present, are often poorly preserved. Many of the macrofossils present in these rocks are environmentally controlled and are not biostratigraphically useful. A few graptolites have been found in southeastern Wisconsin, but it is unlikely that they will ever be useful for correlation over much of the area because of their rarity. Microfossils, such as conodonts, chitinozoans, and arenaceous foraminiferans, could potentially be extremely valuable for biostratigraphic correlation in this area. A brief search has been made for conodonts (Clark, 1971), but no diagnostic forms were found. Previous attempts to correlate isolated exposures biostratigraphically have led to a significant number of errors due to a lack of understanding of the lithostratigraphy of the area.

It seems, at this point, to be of limited value to assign ages to the various rock units based on dating of isolated exposures. This is particularly true because some of the lithologies have been found to recur both vertically and laterally in different units. It is, therefore, difficult to look at many isolated exposures and place them within a lithostratigraphic framework without supplementary subsurface information. Previous to this study, the relationships between some of the major stratigraphic units were unknown, and the complete sequence of Silurian rocks in any part of the state had not been observed in exposure or in precise subsurface records. It was felt that in this study it was most important to establish a lithostratigraphic framework for the area before further biostratigraphic work could be undertaken.

Another problem in understanding the stratigraphic relationships of the Wisconsin Silurian rocks is the incomplete knowledge of the Silurian in the surrounding area. To the south the Silurian in the Chicago area is well known, but from the northern part of Cook County, Illinois, to Racine, Wisconsin, a distance of about 40 miles, there are almost no exposures. The northernmost exposures of Silurian rocks in eastern Wisconsin are very similar to those in the Upper Peninsula of Michigan and correlation between them is not difficult. The only exception is the upper beds which are poorly exposed throughout most of Wisconsin. To the east, under Lake Michigan, the Silurian units have not been described in any detail, but extensive drilling in that area at present should produce much useful data.

In this study the Silurian lithostratigraphy was examined for Kenosha, Racine, Walworth, Waukesha, Milwaukee, Ozaukee, and the eastern one-third of Washington Counties, Wisconsin. A number of significant new exposures and cores are located in this area, presenting new opportunities to establish a lithostratigraphic framework. Figure 21 shows the distribution of Silurian rocks in Wisconsin and outlines the area of study.

History

As mentioned before, the Silurian rocks of Wisconsin were among the first Silurian units to be studied after Hall's work in New York in the 1840's. Much of the early work were, therefore, attempts to correlate the Wisconsin rocks, unit by unit, with the New York section, first on a lithologic basis and later on a paleontologic basis. The first studies were based mostly on natural exposures and the very small quarries and stone pits that existed at that time. As these quarries increased in size and number they became more important to the understanding of the geology of the area. Quarry activity peaked in the 1930's and most have been abandoned and covered or are water-filled.

For an overview of the history of geologic work in Wisconsin

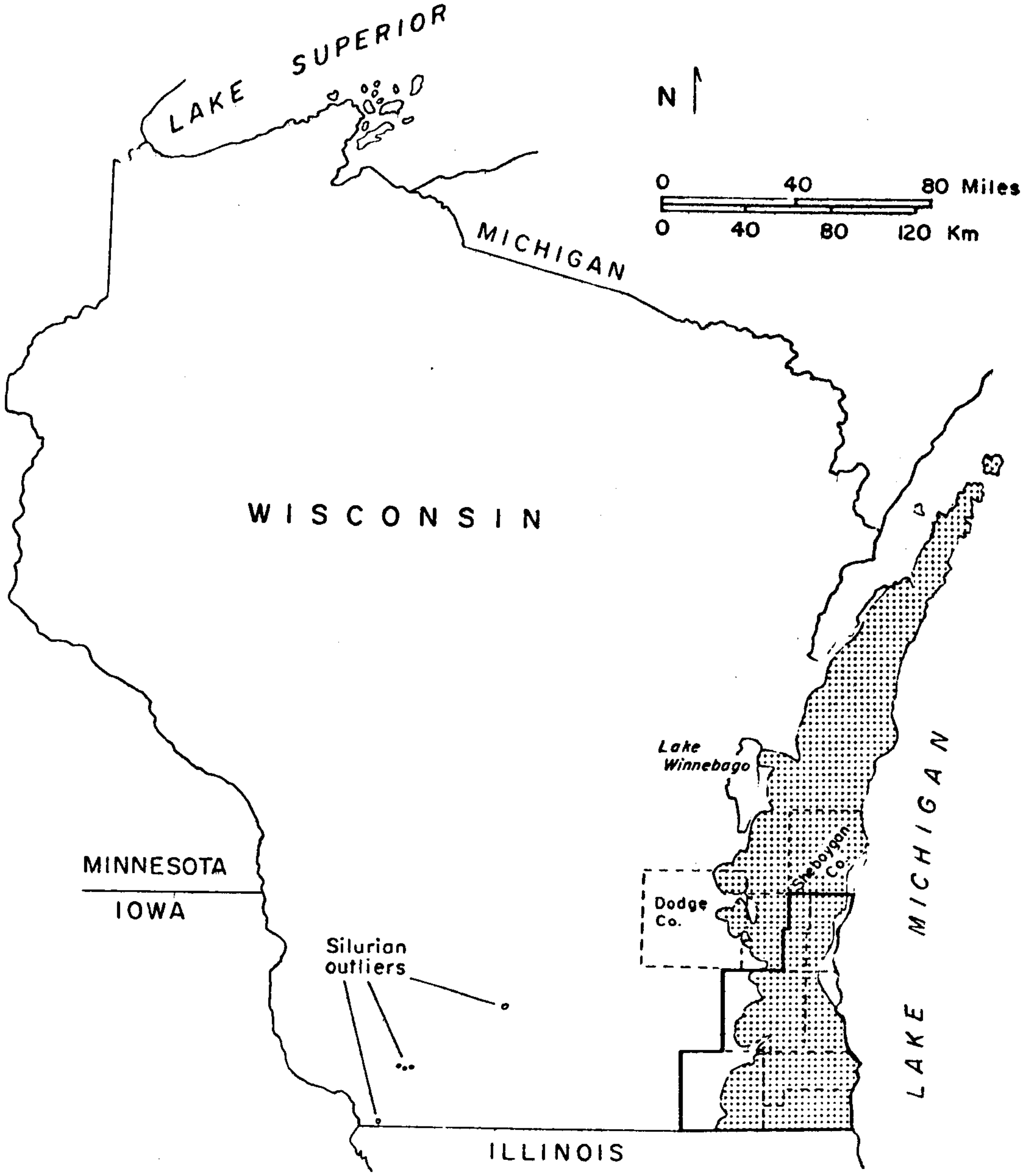


Figure 21. Map of Wisconsin showing the outline of the study area and the distribution of Silurian rocks in the State.

see Bean (1937). The first work on the geology of southeastern Wisconsin was done by I. A. Lapham. He moved to Milwaukee in 1836 and began an examination of the local quarries, making geological observations, besides pursuing his other interests, including map making, meteorology, archaeology, and botany (Scott, 1975). In 1851 Lapham published the first description of the bedrock geology of southeastern Wisconsin (see Table 43) in which he described the rock units including the Waukesha Dolomite, which was the first Silurian stratigraphic unit named in the area. In the same publication James Hall applied his correlation of the New York units to those described by Lapham. Lapham's field notes, manuscripts, and correspondence concerning his work on the geology of eastern Wisconsin are deposited in the Archives of the State Historical Society of Wisconsin in Madison.

J. Percival was the next to make observations on Wisconsin Silurian rocks as part of a survey of the southern part of eastern Wisconsin in 1856. He made no reference to Lapham's earlier work and grouped all of the currently recognized Silurian rocks in eastern Wisconsin into the Mound Limestone (see Table 43), a name derived from the Silurian exposures in southewestern Wisconsin.

After Percival's death in 1856, James Hall was appointed to the Wisconsin Geological Survey along with Daniels and Carr (Bean, 1937), but not much work was done in eastern Wisconsin until 1860

Table 43. Table showing the development of stratigraphic nomenclature in southeastern Wisconsin. See text for details.

LAPHAM (1851)	HALL (1851)	PERCIVAL (1856)	HALL (1862)	LAPHAM (1865)	CHAMBERLIN (1877)	ALDEN (1906, 1918)	ULRICH (1924)	SHROCK (1938)	OSTROM (1967)	BERRY & BOUCOT (1970) SE WIS.	BERRY & BOUCOT (1970) NE ILL.	FREST, ET AL. (1977)	THIS REPORT
UNIT X CORNIFEROUS LIMESTONE OF EATON	UPPER HELDERBERG		UPPER HELDERBERG & HAMILTON GROUPS	DEVONIAN WASHINGTON BRIDGE	DEVONIAN HAMILTON CEMENT ROCK	MILWAUKEE FORMATION	MILWAUKEE FORMATION		DEVONIAN	DEVONIAN			DEVONIAN
UNIT IX SHALY LIMESTONE	ONONDAGA SALT GROUP		ONONDAGA SALT GROUP	MUD CREEK LAYERS	LOWER HELDERBERG LS.	WAUBAKEE FORMATION	WAUBAKEE FORMATION	WAUBAKEE FORMATION	WAUBAKEE	RACINE	RACINE		WAUBAKEE
UNIT VIII GEODIFEROUS LIMESTONE OF EATON OR NIAGARA LS. OF N.Y. REPORTS	NIAGARA	MOUND LIMESTONE	RACINE LIMESTONE	RACINE LIMESTONE	GUELPH BEDS	GUELPH BEDS	GUELPH DOL.	GUELPH	RACINE			RACINE	RACINE
UNIT VII SOFT YELLOW LIMESTONE	NIAGARA & CALCAREOUS PARTS OF CLINTON GROUP			BURLINGTON ILLAENUS BEDS	RACINE BEDS	RACINE BEDS	RACINE DOL.	RACINE				SUGAR RUN? ROMEO	LANNON BEDS ROMEO BEDS
UNIT VI WAUKESHA LS			WAUKESHA LS.	WAUKESHA LS.	WAUKESHA BEDS	WAUKESHA BEDS	WAUKESHA DOL. BYRON DOL.		CORDELL WAUKESHA SCHOOLCRAFT HENDRICKS BYRON	WAUKESHA	CORDELL	WAUKESHA	WAUKESHA
			GEODIFEROUS LIMESTONE OR COPALLINE LS CLINTON GROUP							JOLIET	SCHOOLCRAFT	BRANDON BRIDGE	BRANDON BRIDGE
					MAYVILLE BEDS	MAYVILLE BEDS	MAYVILLE DOL.		MAYVILLE	KANKAKEE	MAYVILLE		LOWER SILURIAN
UNIT V SANDSTONE?	POSITION OF ARENACEOUS PART OF CLINTON MEDINA SS		MEDINA SS						— ? —	EDGEWOOD			
					CLINTON IRON ORE	CLINTON IRON ORE	NEDA		NEDA ?				NEDA
	HUDSON RIVER GROUP	BLUE SHALE	GREEN & BLUE SHALES & LIMESTONES		CINCINNATI SHALES & LIMESTONES	MAQUOKETA SHALE	BRAINARD SH. WHITEWATER LS.		MAQUOKETA FORMATION	MAQUOKETA	MAQUOKETA		MAQUOKETA
UNIT IV GALENA LS		UPPER MAGNESIAN LS	GALENA LS		GALENA LS	GALENA LS			GALENA LS.				

when Hall was more-or-less placed in charge of the Survey. At that time Hall hired T. J. Hale to do field work for him in the Paleozoic rocks of eastern and southwestern Wisconsin. Hale lived for a time in Racine and appears to have been a student at the Univesity of Wisconsin. He also appears to have been interested in fossils and geology prior to 1860. Hale's 1860 field book is preserved in the Archives of the New York State Museum in Albany; it contains the earliest detailed descriptions of Silurian outcrops in southeastern Wisconsin, and indicates that Hale was very familiar with the geology of the area. He is the first to apply the name "Racine" to a number of different exposures, and makes the first reference to a reef in the Milwaukee area. It is not known how much of this reflects possible prior coaching by Hall on the local geology, but Hale's stratigraphic assignments are good. Most of the localities he described were of places not commonly mentioned in publication from this time period, so his descriptions are invaluable. Unfortuantely, a second field book for the 1861 field season might have been made, but it cannot be located, nor can any of Hall's field notes for the area, including those for the Schoonmaker quarry. Hale seems to have left geology after his work for Hall and the only reference to him after this time is by Teller (1911), who described him as an extensive fossil collector in Wisconsin "in a commercial way" during the 1860's who had "furnished Prof. Hall with many fine specimens."

In 1862 Hall published an important description of the Silurian rocks of southeastern Wisconsin (see Table 43) which, unfortunately, contains almost no individual locality data. The only significant exception is that of the important description of the Schoonmaker reef. Hall calls this structure a coral reef; this is the first correct application of this term to a carbonate buildup in North America. This is not the first time Hall used the term in the Silurian since he (1851, p. 159) described some of the coral-rich biostromal beds of the Manistique? Formation as being coral reefs. Hall also presented a more formalized description of the Racine Dolomite, which he had mentioned earlier (1860). Hall's interpretation of the reef clarifies Lapham's earlier usage of the term "geodiferous" for the same beds. Hall's stratigraphic work in Wisconsin ended at this time because the Survey was disbanded by the State Legislature. He did publish some paleontologic papers (1867, 1870).

Lapham (1865, unpublished notes) described a generalized section in Milwaukee, Waukesha, and Racine Counties (see Table 43), which agrees more with Hall's (1862) section, but still includes geodiferous limestone which Lapham shows as an unstratified unit underlying the Waukesha and forming a hill at the same level as the Waukesha. This relationship is undoubtedly based on the Schoonmaker reef, which had been satisfactorily explained by Hall. Lapham also placed the "Burlington _Illaenus_ beds" between the Waukesha and

Racine limestones based on the presence of Burlington-like _Illaenus_ in a thin bed between the Waukesha and Racine at Waukesha. The Wisconsin State Legislature allotted funds for a comprehensive geological survey of the state in 1873 and Lapham became State Geologist, a position which he held until 1875; Chamberlin became State Geologist in 1876.

In 1877 Chamberlin made a significant advance in the knowledge of Silurian rocks in eastern Wisconsin. His was the first comprehensive survey of the area, in which all outcrops were examined and water-well data was used to obtain as complete a picture as possible. Localities were described in detail for the first time. Chamberlin redescribed Lapham's and Hall's units, applied new names where applicable (see Table 43), and, in general described the Silurian rocks in a thorough and systematic manner. His overall stratigraphic succession of Silurian units has not been significantly modified since that time, attesting not to the lack of quality of later work, but to the quality of Chamberlin's. The only significant change in Chamberlin's study has been the placement of the Neda into the Ordovician. The major problems not answered by Chamberlin on the correlation of southeastern Wisconsin with northeastern Wisconsin Silurian has still not been adequately solved, and will not be until subsurface information becomes available. Unfortunately, it appears that all of the original field notes, maps, illustrations, and rock samples for Chamberlin's entire survey have been lost, possibly in the fire at Science Hall, University of Wisconsin, Madison, in 1884 (G. Hanson, 1979, personal communication). The fossils (20, 000 specimens) collected during this field work were distributed among the various colleges at that time (Chamberlin, 1880), but only a couple of dozen can now be located.

In 1897 Buckley studied the building stone quarries in Wisconsin, describing a number of Silurian localities in some detail, but he made no new contributions to understanding the Silurian geology of the area.

W. C. Alden began a survey of the southeastern part of the state in 1898 under the direction of Chamberlin for the U.S. Geological Survey, which continued until 1911 and resulted in two major publications on the geology of the area (1906, 1918). Alden's field notes cover most of the Silurian outcrops, but few localities are described in detail since he was primarily interested in glacial geology. His notes do give extensive coverage of water-well data for the area. Alden's notes, maps, and photographs are preserved in the U.S. Geological Survey Library in Denver, Colorado, and copies of some of the material is in the files of the Wisconsin Geological and Natural History Survey. Alden named the Waubakee beds (see Table 43), but made few other revisions of Chamberlin's work.

Ulrich (1924) published a section for eastern Wisconsin based on work he did in 1914. He made only a few changes in the general section, making the Neda beds the upper member of the Maquoketa (Ordovician) and placed the Byron between the Mayville and Waukesha units.

R. R. Shrock made a very detailed study of the Wisconsin Silurian (see Table 43) from 1930-1935. He visited nearly every exposure in southeastern Wisconsin. His extensive field notes are deposited in the Wisconsin Geological and Natural History Survey, Madison, and rock and fossil specimens are stored in the Milwaukee Public Museum. Photographs of the exposures which he took during his field work, unfortunately, cannot be located. In 1939 Shrock published his classic work on the Silurian bioherms of Wisconsin. A manuscript on Wisconsin Silurian stratigraphy was prepared to be included in a volume on Silurian stratigraphy being edited by C. K. Swartz, but this volume was never published.

G. O. Raasch had studied the Silurian of Wisconsin intermittently since his childhood in Milwaukee around World War I. In the late 1940's and 1950's he prepared a number of manuscripts dealing with the Silurian geology of Wisconsin in which he correlated a number of the units with the section in Illinois. Unfortunately, none of Raasch's Silurian information has been published. Important fossil collections made by Raasch at this time and later by J. Emielity are located in the Milwaukee Public Museum collections.

Ostrom (1967) and Berry and Boucot (1970) have described the general Silurian section in Wisconsin and, in particular, Berry and Boucot, have correlated the units with the British type section.

More recently, Frest _et al_. (1977) have correlated some of the Wisconsin Silurian units with those in the Chicago area.

The Ordovician-Silurian Boundary in Southeastern Wisconsin

The Ordovician-Silurian boundary is marked by a significant unconformity throughout the Great Lakes area, including southeastern Wisconsin. During the Late Ordovician a glacially-controlled eustatic sea-level change resulted in a major regression of the epicontinental seas. A period of intensive erosion was followed by a transgression during the Early Silurian after cessation of glacial activity (Berry and Boucot, 1973; Sheehan, 1973). The resulting erosional topography and available clastic sediment has greatly affected the character of the Lower Silurian rocks. It is, therefore, necessary to closely examine various aspects of the Upper Ordovician rock units in the study area to fully understand the nature of Lower Silurian depositional environments.

The Maquoketa Shale is the youngest Ordovician rock unit in southeastern Wisconsin and the surrounding area. It unconformably underlies the Lower Silurian rocks throughout the Great Lakes area. Because of its nonresistant nature there are few natural outcrops of the Maquoketa Shale in the study area, but its uppermost beds are exposed in a few places along the western edge of the Niagara Escarpment. Information on the Maquoketa Shale in the study area is derived primarily from water-well logs, a few cores, and comparisons with data from the surrounding area. The Maquoketa Shale unconformably overlies the Middle Ordovician Galena Dolomite of the Sinnipee Group in Illinois (Bushbach, 1964; Templeton and Willman, 1963), and possibly in Wisconsin (Ostrom, 1967). Ostrom (1967) reported a one foot conglomerate at the base of the Maquoketa in Sheboygan County, Wisconsin. Although the unconformity is erosional in nature, the amount of relief is not as great or as locally pronounced at that on the upper surface of the Maquoketa. This relationship is reflected in the locally consistent thickness of the lower member (Scales) of the Maquoketa in contrast with the wide fluctuations in thickness of the upper members. The entire Maquoketa ranges in thickness from 180 to 200 feet in Racine and Kenosha Counties, with a general increase towards the east (Hutchinson, (1970). An eastward thickening trend has also been reported in Illinois (DuBois, 1945) and Indiana (Gray, 1973). In Milwaukee and Waukesha Counties the Maquoketa ranges in thickness from 90 to 225 feet (Foley, Walton and Drescher, 1953). A trend in increase or decrease in thickness of the Maquoketa has not yet been determined in Milwaukee County. Alden (1918) reported a range in thickness from 40 to 365 feet for the Maquoketa in eastern Wisconsin, but his information was based on turn-of-the-century well drillers' reports and should be used with some caution.

The Maquoketa Shale is currently divided into three members in southeastern Wisconsin (Ostrom, 1967, see Figure 22), with the Neda Oolite being considered as a fourth and upper member by some authors in Wisconsin (Ulrich, 1924; Rosenzweig, 1951) and in northeastern Illinois and northeastern Iowa. Froming (1971) gives the most current description of the Maquoketa in Wisconsin.

The lowest member of the Maquoketa Shale is the Scales Shale. In the study area, particularly around Milwaukee County, it averages about 55 feet in thickness with a range from 40 to 70 feet. Bushbach (1964) reported a thickness of 90 to 100 feet in northeastern Illinois, while it reaches a thickness of 150.9 feet (Froming, 1971) just north of the study area in Sheboygan County. The Scales Shale is a light green to gray shale with a few dolomitic beds.

The Fort Atkinson Dolomite overlies the Scales Shale throughout the study area, and forms an easily recognizable horizon within the Maquoketa This member is a coarse-grained, brownish, argillaceous dolomite throughout its area of distribution. It ranges in thickness from 5 to 10 feet. At Oostburg, to the north of the study area, it reaches a thickness of 51.8 feet (Froming, 1971). The Fort Atkinson may have been locally removed by pre-Silurian erosion, but this has not yet been definitely established. Bushbach (1964) has

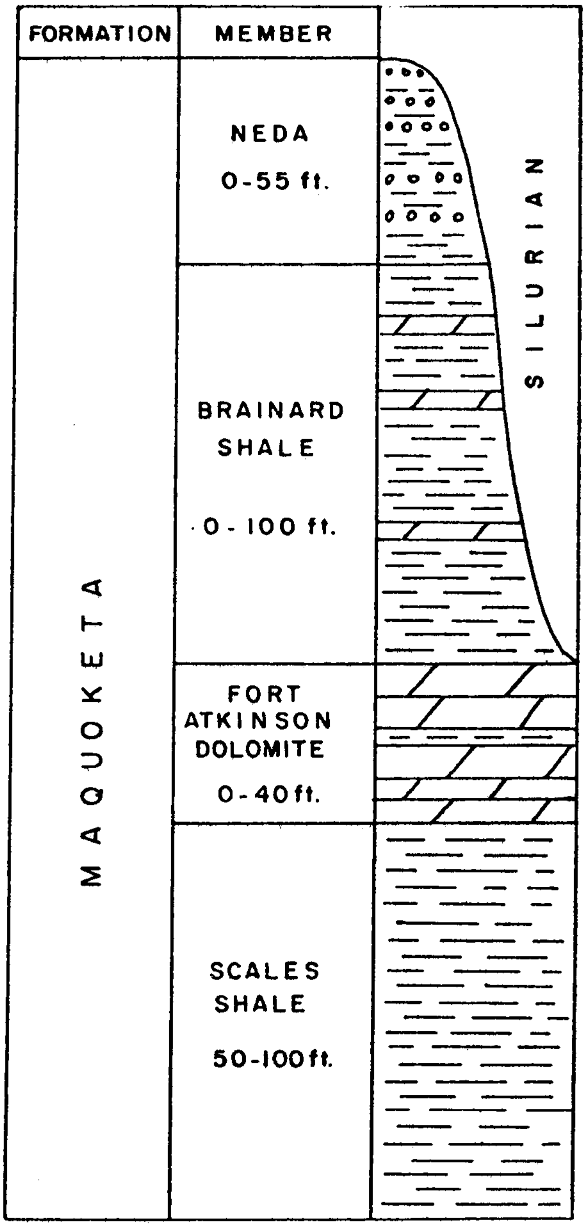


Figure 22. Stratigraphic section of Maquoketa rocks in southeastern Wisconsin. Modified from Ostrom, 1967. Erosional relationships with overlying Lower Silurian rocks is indicated.

suggested that the Fort Atkinson forms a bench, blocking pre-Silurian erosion in northeastern Illinois.

The Brainard Shale overlies the Fort Atkinson Dolomite, and is more variable in composition than the underlying units. It is a green, fossiliferous shale, with common local beds of argillaceous dolomite. It varies considerably in thickness, ranging from 0 to 130 feet. The upper portion of the Brainard Shale is the only part of the Maquoketa exposed in the study area. The variation in thickness of this unit is due primarily to erosion resulting from a Late Ordovician regression. This variation accounts for most of the differences in thickness of the entire Maquoketa.

Because the Maquoketa is seldom well exposed anywhere, the erosional features of its surface are not well known. It is possible that a system of hills and valleys following ancient drainage patterns might exist. What is known is that deep, steep-sided depressions are not rare on the upper surface of the Maquoketa. Mikulic (1977) mentioned the presence of a 120 foot deep "valley" or depression in Section 29, T. 8 N., R. 22 E., Milwaukee County, which demonstrates the rapidly changing differences in topography of the upper surface of this unit. Evidence for hills may be reflected in the patchy distribution of the overlying Neda, which is found only where the underlying Maquoketa is locally at its thickest.

The upper boundary of the Maquoketa is not always conspicuous.

It is probable that Maquoketa sediments were reworked and redeposited during the Early Silurian transgression since the basal Silurian beds exhibit a marked upward decrease in argillaceous content. It is possible that some of the uppermost shale beds of the "Maquoketa" may actulaly be Silurian in age. The age of the Maquoketa Shale is variable throughout Wisconsin. Recent conodont studies (Froming, 1971) shows that the Maquoketa is diachronous across the state, with each member becoming younger from east to west. Froming (1971) attributed this relationship to a transgression across Wisconsin from the northeast to the southwest. It has been similarly found that the Middle Ordovician Platteville Formation is younger in the western part of the state (Atkinson, 1971).

Neda Oolite

The Neda Oolite locally overlies the Brainard Shale in eastern Wisconsin and the Great Lakes area. Major work on the Neda in Wisconsin has been published by Chamberlin (1877), Thwaites (1914), Alden (1918), Savage and Ross (1916), Hawley and Beavan (1934), Rosenzweig (1951), Ostrom (1967), and most recently, Cunningham et al. (1976) and Paull (1977). Papers by Workman (1950) concerning the Neda in Illinois and Brown and Whitlow (1960) and Whitlow and Brown (1963) on the Neda of Iowa are important descriptions of the Neda outside of Wisconsin.

The Neda is predominantly a red, hematitic oolite, with less common beds of maroon or red shale (see Hawley and Beavan, 1934, for petrographic details). It ranges from zero to fifty-five feet in thickness (Thwaites, 1914) in eastern Wisconsin, but is commonly only a few feet thick in its occurrence.

Thwaites (1914) has shown the distribution of the Neda in eastern Wisconsin based on outcrops and well records (see Figure 23). No significant new localities have been found, with the exception of a minor occurrence at Ives in Racine County, and Franklin in Milwaukee County. The "redbeds" area in southern Racine, northern Kenosha, and eastern Walworth Counties described by Thwaites (1914, p. 341-342) and Alden (1918) is not Neda. The Brandon Bridge Beds, which are red highly argillaceous dolomite and shale, are found in the lower one-third of the Silurian throughout this area, and its characteristics match some of the description of the "Neda" given by Thwaites and Alden, accounting for much, but not all, of the "Neda" indicated in this area. Thwaites (1923, p. 536) changed his identification of the Neda in Kenosha County based on similar evidence.

The Neda, and lithologically or stratigraphically similar units, have been reported from northeastern and west-central Illinois (DuBois, 1945; Workman, 1950), northeastern, central, and south-western Iowa (Agnew, 1955; Parker, 1971), the west-central Michigan Basin (Nurmi, 1971), northeastern Indiana (Gray, 1971), eastern

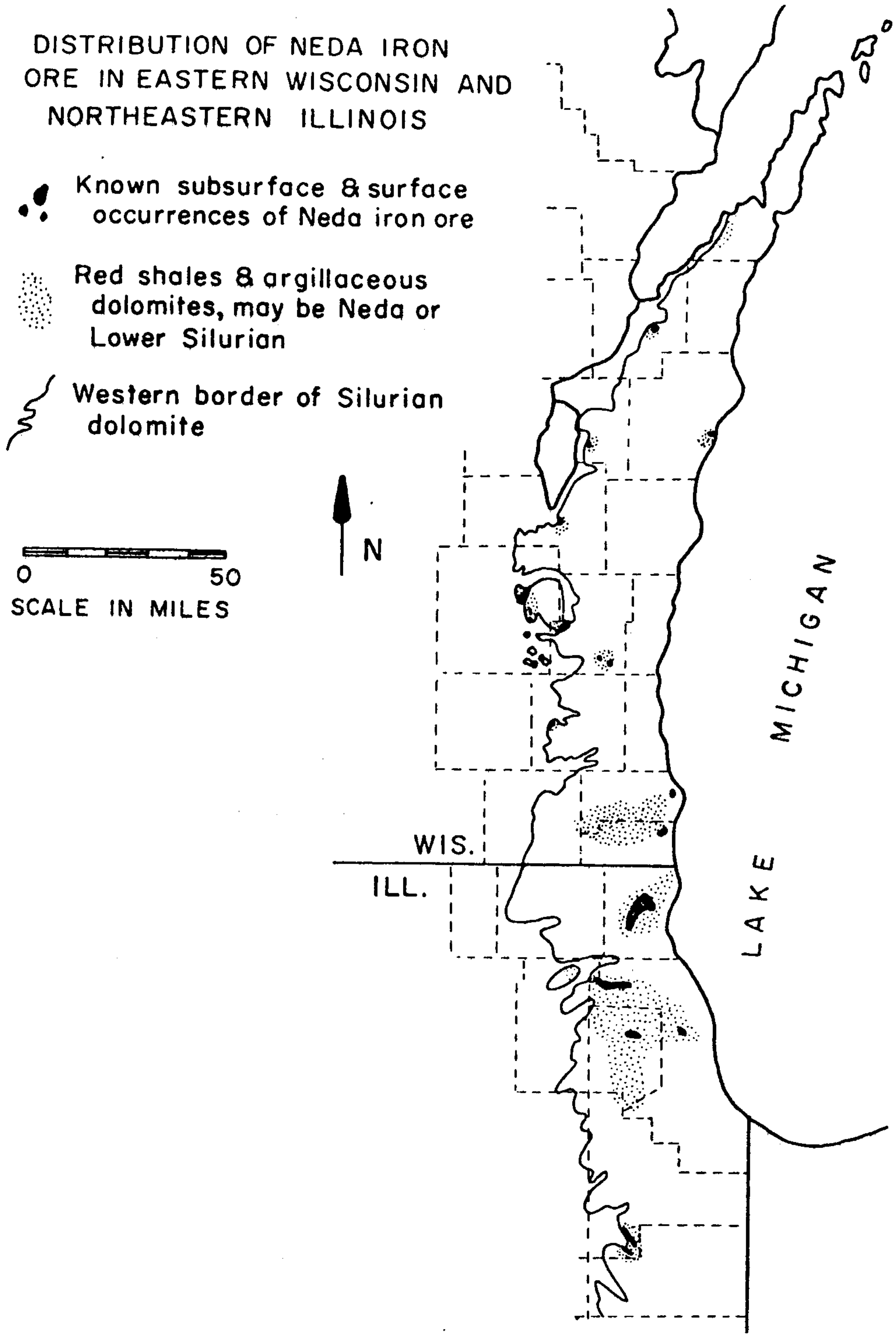


Figure 23. Distribution map of Neda Iron Ore in Eastern Wisconsin and northeastern Illinois. Modified from Thwaites (1914) and Workman (1950).

Kansas (Lee, 1943), southeastern Nebraska (Condra and Reed, 1943), and northwestern Missouri (Crane, 1912).

As stated before, the Neda is commonly found only where the Maquoketa is locally at its thickest, for example, 250 feet in Iowa (Agnew, 1955) and 200 feet in Illinois (DuBois, 1945). It might, however, be more accurate to examine the maximum thickness of only the uppermost member (Brainard) of the Maquoketa to determine what control Maquoketa thickness has on Neda distribution since it is usually the only member to have been subjected to erosion.

The Neda is separated from the underlying Brainard Shale by a slight unconformity (Chamberlin, 1877). DuBois (1945) has suggested that it might overlie different elevations within the Brainard and, therefore, is post-Maquoketa in age.

It is noteworthy that the Upper Ordovician in many areas of the central United States is characterized by a calcareous, non-hematitic oolite which overlies the Maquoketa Shale or similar lithologies of approximately the same age. Examples are the Noix Oolite of northeastern Missouri and west-central Illinois (Amsden, 1974; Thompson and Satterfield, 1975) and southeastern Missouri (Offield and Pohn, 1979); the Leeman Formation of southeastern Missouri (Amsden, 1974; Thompson and Satterfield, 1975); the Pettit Oolite of northeastern Oklahoma (Amsden and Rowland, 1965); the Keel Limestone of south-central Oklahoma (Amsden, 1974); part of the

"Fusselman" Formation of west Texas (Wilson and Majewske, 1960); the Cason Shale of Arkansas (Craig, 1969)(where a calcareous oolitic unit overlies a unit containing some hematitic oolites). Some of these units have been considered Silurian in age, but recent brachiopod (Amsden, 1974) and conodont (Craig, 1969; Thompson and Satterfield, 1975) studies indicate an Ordovician age for a number of these units. Oolitic beds in southeastern Nebraska are assigned to the basal Silurian (Carlson and Boucot, 1967). It is possible that these Upper Ordovician calcareous and hematitic oolitic beds represent the same type of depositional event during the Late Ordovician regression and Early Silurian transgression, with the oolitic beds towards and the north and east being hematitic and those to the south and west being calcareous. These units might not be synchronous in time, but may represent similar depositional environments resulting from a regression or transgression over a surface with major variations in relief. See Figure 24 for distribution of these oolitic beds in the central United States.

The Neda was originally thought to be Silurian in age (Hall, 1861; Chamberlin, 1877; Thwaites, 1914; Alden, 1918) because of its lithologic similarities to the "Clinton" oolitic iron ore of New York and Alabama. This stratigraphic assignment was given in spite of the fact that all these workers knew that the Neda was situated between the Upper Ordovician and the lowest recognized Silurian rocks.

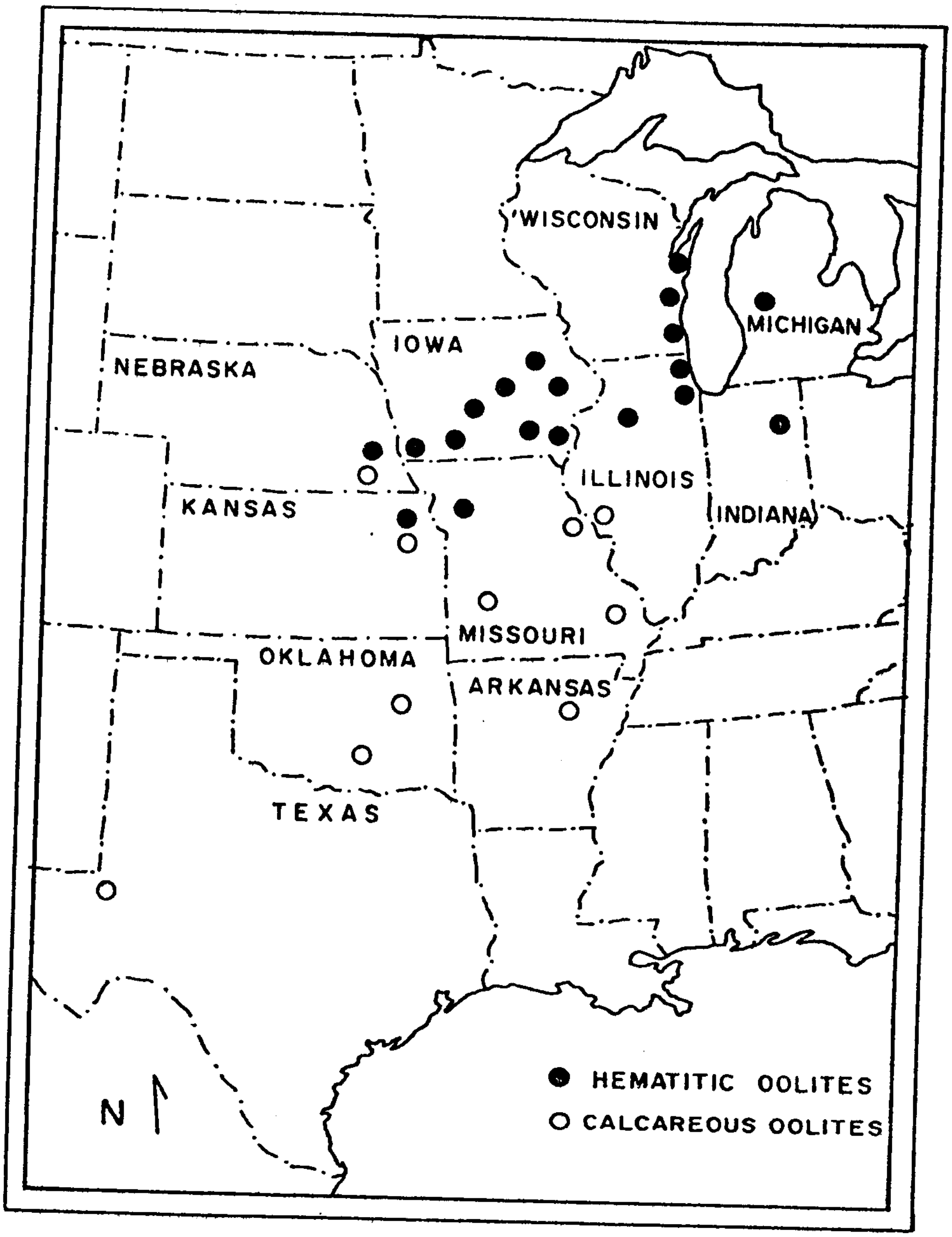


Figure 24. Map showing distribution of calcareous (open circles) and hematitic (closed circles) oolites in the Late Ordovician or Early Silurian of the central United States.

This relationship is quite different from the "Clinton" iron ore in New York and Alabama where it is underlain by substantial thicknesses of older Silurian rocks, some of which are the same age or younger than those immediately overlying the Neda.

Savage and Ross (1916) have assigned the Neda to the Upper Ordovician based on the presence of Upper Ordovician brachiopods that they found in the Neda at Catell Falls, De Pere, Wisconsin. Chamberlin (1877) had also noted the presence of hematitic Ordovician fossils that supposedly came from the Neda at Iron Ridge, Wisconsin; however, he believed that they had probably been Brainard fossils reworked, possibly by glacial activity, intermixed with and stained by weathered Neda. The presence of Ordovician fossils is not definite proof that the Neda is of Ordovician age. These could be Brainard Shale fossils that were reworked during the deposition of the Neda, but the total absence of Silurian fossils does favor an Ordovician age assignment, and it is the only possible age assignment until Silurian fossils are found.

Another factor to be considered in assigning an age to the Neda is the presence of Maquoketa-like sediments overlying the Neda in a few areas. Cores at the Vulcan Quarry, Ives, Racine County, Wisconsin, have shown that the Neda is overlain by 10 inches of Brainard Shale-like rock (Mikulic, 1977). This could be the result of selected erosion of topographically high areas containing Neda and

Brainard with subsequent redeposition in lower areas during Silurian transgression. A water-well log on file at the Wisconsin Geological Survey (ML 569) indicates that in the NW 1/4, SW 1/4, Section 25, T. 5 N., R. 21 E., Franklin, Milwaukee County, beneath the basal Silurian, 20 feet of green-gray and yellow-gray shale overlies 15 feet of orange-gray shale with hematitic pellets. This unit has been called Neda and is underlain by typical Maquoketa. In northeastern Indiana red oolitic beds are overlain by a few feet of Maquoketa Shale (Gray, 1971) and the oolites may be found in different horizons within the upper beds of the Maquoketa.

Another major factor in determining the age of the Neda is the presence of unconformities at its upper and lower surfaces. The unconformities at its upper and lower surfaces. The unconformable contact with the underlying Brainard Shale is not of the same magnitude as the upper unconformity. The upper unconformity is much more pronounced and demonstrates that the Neda beds are not part of the Lower Silurian (Mayville) transgressive depositional sequence. While none of these observations points to a definite Ordovician age assignment, the Neda should continue to be considered Ordovician until Silurian fossils are found.

Northwestern Iron Company Open Pit. While there are a number of important unanswered questions concerning the Neda, its relationships to the depositional environments of the Lower Silurian rocks are known with some certainty. It is, however, necessary to examine, in detail, a Neda exposure outside the study area (the Northwestern Iron Company Open Pit, Neda, Dodge County, Wisconsin) to demonstrate these relationships.

The abandoned open pit mine of the Northwestern Iron Company is located three-fourths mile north of Neda in Dodge County, Wisconsin (Center line between SEE 1/4 and SW 1/4, Section 12, T. 11 N., R. 16 E., Hubbard Township, Horicon 15' quadrangle)(see Figure 25). The pit has been dug into the western face of the Niagaran Escarpment, which is known at this location as Iron Ridge (not to be confused with the village of Iron Ridge, 1.5 miles to the south of the village of Neda). This segment of escarpment is approximately 60 feet high and currently about 40 feet of the Neda Oolite and lower Mayville Dolomite are exposed in the upper two-thirds of the escarpment. The base of the Neda and part of the underlying Brainard Shale have been exposed during mining activities, but both are now covered. The northern two-thirds of the Northwestern Pit are not well exposed so the following description is generally based on exposures around the "lake" in the pit's southern one-third.

Mining began in this area soon after the discovery of the iron ore beds during the late 1840's. The Northwestern Pit began operation around this time, and was first described in the geologic literature by James Hall in 1851. The ease with which the ore was removed

Figure 25. Isopath map of the Neda Iron Ore bodies in the Neda Mining District, Dodge, Co., Wisconsin. After Rosenzweig (1951).

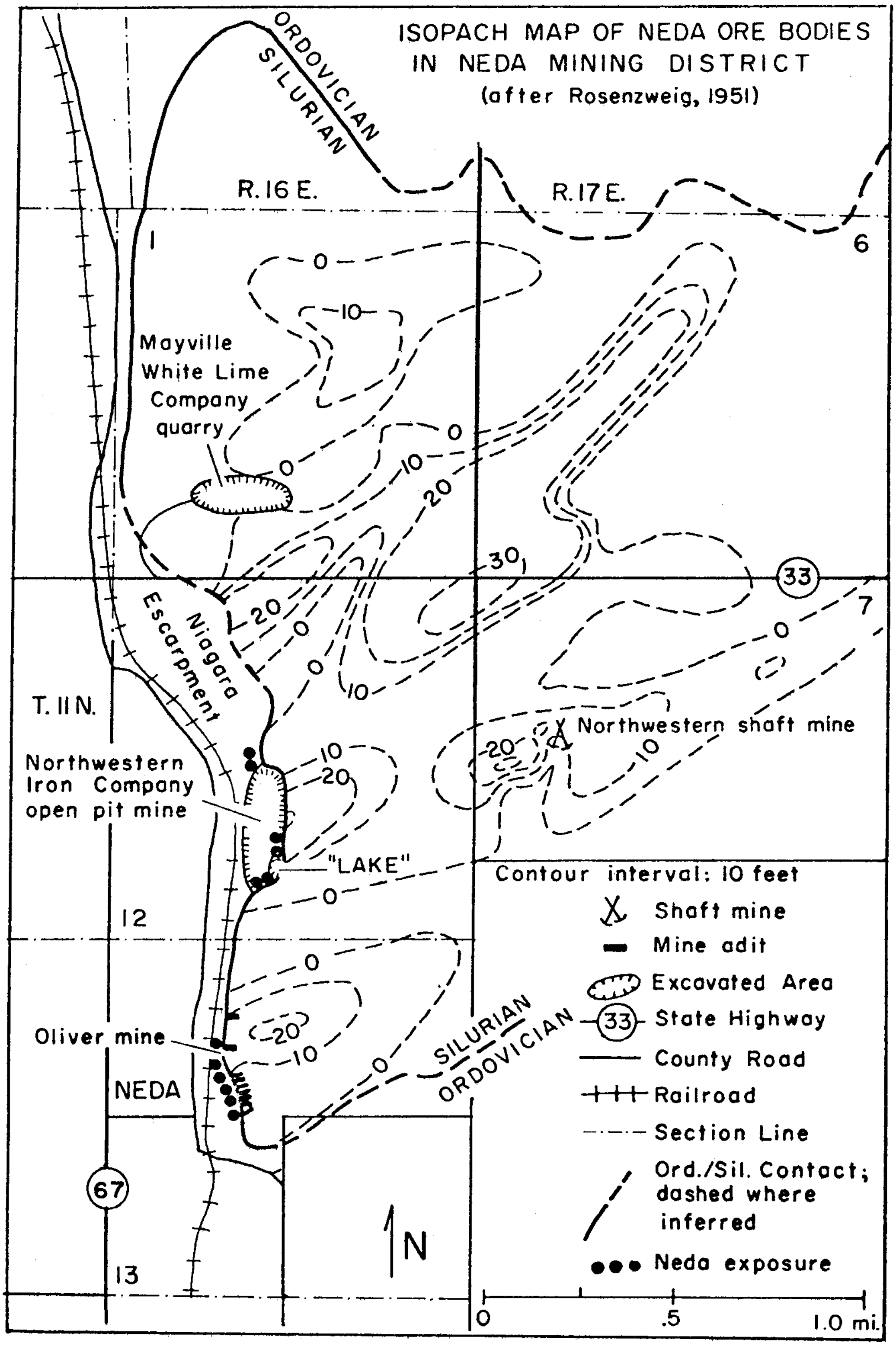

ISOPACH MAP OF NEDA ORE BODIES
IN NEDA MINING DISTRICT
(after Rosenzweig, 1951)
ORDOVICIAN
SILURIAN
R.16 E.
R.17 E.
1
6
7
12
13
T. 11 N.
Mayville
White Lime
Company
quarry
Niagara
Escarpment
Northwestern
Iron Company
open pit mine
"LAKE"
Northwestern shaft mine
Oliver mine
NEDA
33
67
N
0
10
20
30
Contour interval: 10 feet
Shaft mine
Mine adit
Excavated Area
State Highway
County Road
Railroad
Section Line
Ord./Sil. Contact; dashed where inferred
Neda exposure
0
.5
1.0 mi.

Figure 25

and being the closest ore body to the furnace at Mayville ensured continued mining at this locality. The pit was probably abandoned around 1913 when a new shaft mine was opened by the company approximately one mile to the east.

A number of prominent geologists have visited this exposure and it has greatly influenced ideas about the depositional environments of the Neda and the overlying Mayville. Unfortunately, some of the most important descriptions of the pit have not been published in any form, and a number of significant features are no longer visible. Therefore, it is necessary to discuss all of the published and unpublished observations to obtain a full understanding of the geologic relationships present at this locality.

James Hall (1851, p. 156) briefly described the site of the Northwestern Pit as follows:

> ...the superincumbent limestone recedes to the eastward, and in a bend thus formed, an extensive ore-bed has been opened, by simply removing the soil.

Whittlesey (1852, p. 450) had similar observations on the early features of this exposure. He stated that the ore was found throughout the entire 60 feet of the escarpment at this locality and was covered only by soil. He suggested that:

> ...the upper and external parts of the bed have evidently undergone movements, apparently some great diluvial force, from the westward, pushing the outcropping mass up the hill, wherever its face was not too bold.

As evidence, he described "line of deposition" in the ore which were "inclined and curved following the form of the hill up and down its western slope." He found that the ore itself was loose and weathered, with some lumps of clay mixed in. The pit was worked by the Wisconsin Iron Company at the time of Whittlesey's visit, but the name was changed to the Northwestern Iron Company in 1854 and is briefly mentioned by Daniels (1854, p. 68).

The next important description was given by Chamberlin (1877) who stated that this particular pit was known as the Mayville Mine at the time of his visit, and was working what was called the Mayville ore bed. He noted that the dip of the ore at the southern end of the Mayville ore bed was towards the southeast, while farther to the north the dip was northward.

Chamberlin (1877, p.329) also noted that "the thickest portion of the ore occurs at the highest elevation, near the center of the deposit." Even though he implies that thickness and the dip of the ore are related, he went on to suggest that there had been some flexure of strata which would account for the irregularities of bedding. He also observed the Mayville Dolomite overlying undisturbed ore and separated by a layer of hard blue ore with few oolites. Chamberlin's (1877; see Figure 26) diagram of the pit shows that some of the Neda had been pushed to the southeast over undisturbed ore beds (which were first being uncovered at the time of his visit), which

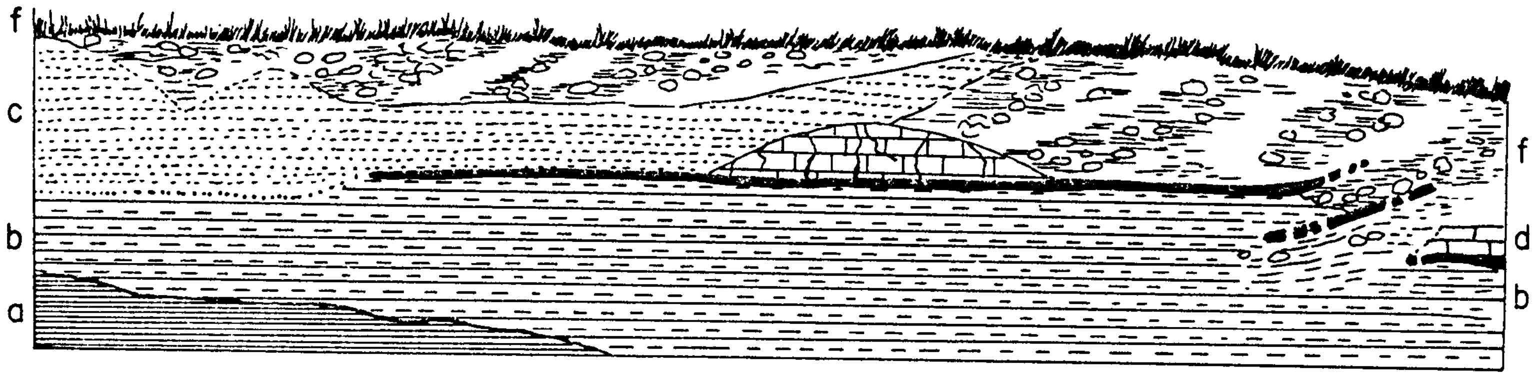


Figure 26. Profile section of the "Mayville Ore Bed" (Northwestern Pit) showing the relations between the (a) Maquoketa Shale, (b) the bedded ore, (c) drift ore, (d) Mayville, and (f) mixed drift. (After Chamberlin, 1877, Figure 41). Note that the bands of drift run obliquely and that the dark ore is peculiarly broken on the right (south).

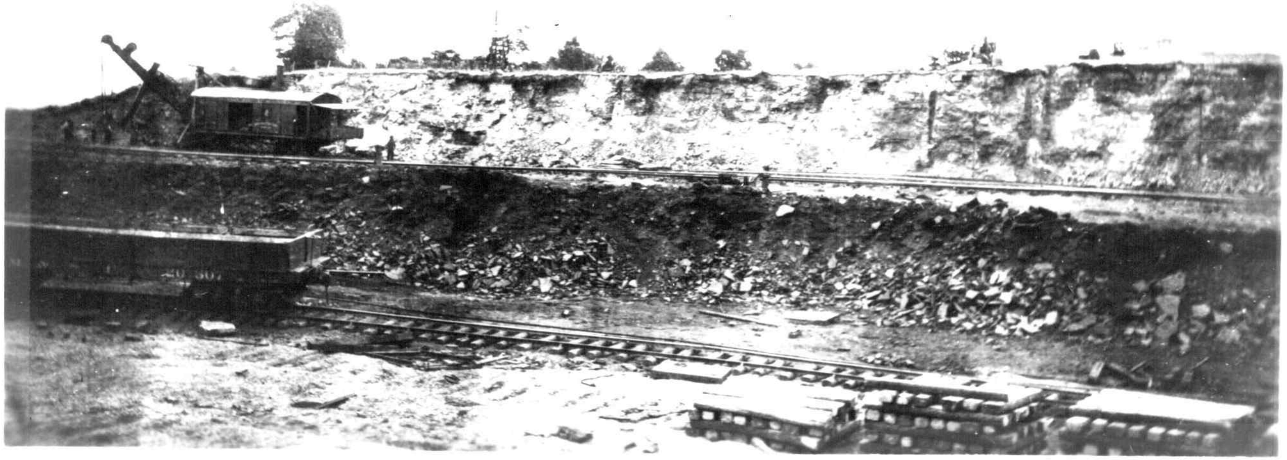


Figure 27. Photograph of Northwestern Pit at Iron Ridge, Wisconsin, looking east, showing the Mayville being stripped off of the Neda Ore. Photographed by W. C. Alden (#418), 1909, courtesy of U. S. Geological Survey Photographic Library.

accounts for the unusual thickness that was observed by Whittlesey (1852). Chamberlin attributed this to Pleistocene glacial activity, which supports Whittlesey's (1852) earlier observations, at least in a mechanical sense. Chamberlin's diagram also shows the underlying "Cincinnatian" (Maquoketa) Shale rising to the north with the Neda uniformly overlying it. As this feature is not discussed in the text (and Chamberlin admits the diagram does not do the exposure justice), it is hard to determine its accuracy, but it could be very important to current ideas on the depositional environment of the Neda.

Alden (1918) described the pit as it appeared during a 1909 visit. He found that the Maquoketa Shale formed the floor of the open cut mine. He states (1918, p. 86):

> ...the lower face of the uppermost shale layer is covered with a very remarkable network of varied and curious forms, which may be of either organic or concretionary origin.

He also gives a detailed description of the Maquoketa-Neda contact (Alden, 1918, p. 88):

> At the bottom of the ore bed and the top of the shale there is a hard purplish layer, partly indurated shale and partly ore. Reference is made above to the remarkable organic or concretionary structures on the lower side of this layer. Just above this the ore appears to be conglomeratic, containing pebble-like nodules of soft ocherous rock.

He found the ore to be 15 to 25 feet thick with 10 to 25 feet of overlying Mayville Dolomite being stripped from above the ore before mining. Alden also found evidence for an unconformity between the ore bed and the overlying Silurian rocks just south of the mine (Alden, 1918, p. 88):

> ...the exposure shows the limestone ore bed, which is about 15 feet in thickness, pinching out a little back of the bluff face (see P. XI, a, p. 81). At the right of the opening the roof of dolomite drops down in a contact wall which lay against the edge of the ore that has been excavated. The lower limestone layers are very irregular and ocherous from the intermixing of the ore with the calcareous sediments; higher up the layers turn up slightly against the slope; and above, the beds rise over the surface of the ore. This appears to be not a relation normal to continuous conformable deposition but an erosional unconformity.

Alden concluded that the limited distribution of the ore was due, in part, to pre-Silurian erosion, which might also account for the significant variation of the underlying Maquoketa throughout southeastern Wisconsin.

E. O. Ulrich visited the Northwestern Pit in August, 1914, accompanied by W. Hotchkiss, E. Steidtmann, and F. Thwaites (all of the Wisconsin Geological Survey). Ulrich and company made a number of important, but brief, notes, including photographs and diagrams. Unfortunately, none of this information was ever published. Ulrich refers to the mine as the old Northwestern Pit, and photos taken at that time indicate it was abandoned when he visited (see Figure 28). Ulrich found that the Brainard Shale-Neda contact seemed to be conformable except for small pebbles of shale mixed in the basal inch or two of the ore. His diagrams (1914, unpublished

Figure 28. Photographs of the northern one-half of the east wall of the "lake" at the Northwestern Pit at Iron Ridge, Dodge Co., Wisconsin. The lower unit is the Neda Ooolite, which is overlain by the Mayville Dolomite. A shows the Mayville overlying a high area in the Neda. B shows the Mayville beds wedging out against the Neda. Photographs courtesy of Wisconsin Geological Survey (A - No. 772, B - No. 775), taken in 1914.

A

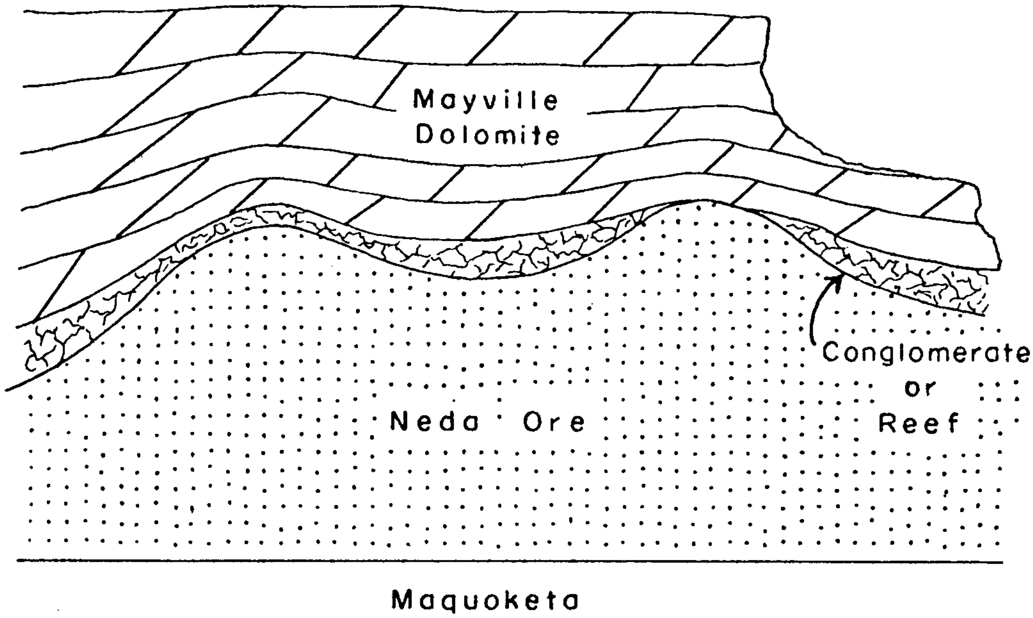
B

Figure 28

field notes; see Figure 28). indicate that the Brainard Shale upper surface was relatively flat with no evidence of shale mounds beneath the mounds of Neda that he observed in the south wall of the pit. He was the first to recognize these mounds or hills in the Neda which seem to project upward into the Mayville Dolomite. In his description of the overlying Mayville Dolomite Ulrich (1914, unpublished field notes) notes that the lower 4 to 5 feet are conglomeratic in appearance, occasionally containing ore pebbles, and a ground-up ore matrix, of well rounded Mayville pebbles up to 3 inches in diameter. Ulrich believed the conglomerate to be intraformational "formed by the breaking up of partly consolidated inclined sediments nearshore by waves." In the lower 6 to 8 feet of the Mayville he found two horizons with lenses a few inches in thickness containing dark red, ferringous clay with oolites. Chemical analysis suggested a "bauxite possibly mixed with kaolin." On the westernmost Neda mound along the south wall, Ulrich found a conglomerate or coral reefs, which contained *Halysites* and *Amplexus*. This is the first reference to the possibility of carbonate buildups being associated with the high areas of the Neda mounds. His notes also indicate that he believed that the irregularities in the topography of the upper surfaces of the Brainard and Neda were more controlled by warping of the strata than by erosion. Ulrich states (1914, unpublished field notes):

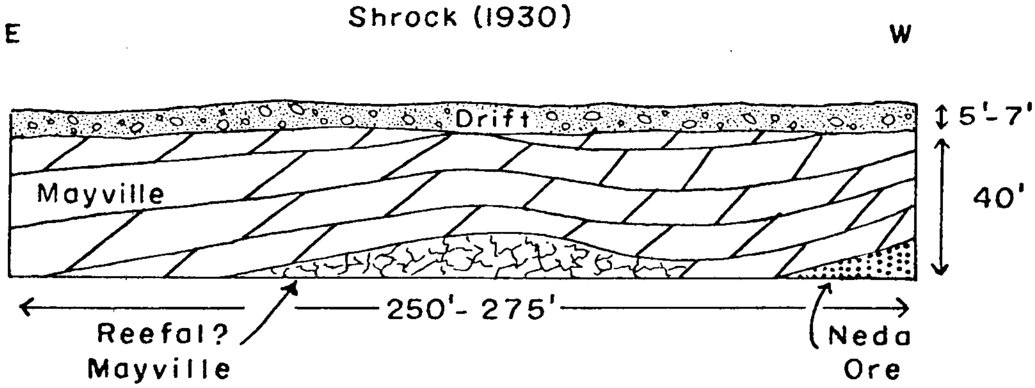
Figure 28. Diagram of the south wall of the "lake" of the Northwestern Pit, Iron Ridge, Dodge Co., Wisconsin, showing relationships between the Neda and the overlying Mayville. A is from Ulrich (1914, unpublished field notes). B is from Shrock (1930, unpublished field notes) and shows relationships after lower beds in the pit had been flooded. Note "mounding" in upper Neda and its influence on the characteristics of the Mayville.

Ulrich (1914)



A

Shrock (1930)



B

Figure 28

> Even though considerable erosion of the top of the ore bed is indicated by contact with the Mayville I do not believe that the ore sheet originally spread widely over east Wisconsin and was removed by erosion prior to Mayville deposition. At Iron Ridge wave work is indicated... The big break came after and not before the ore.

Ulrich (1924) included the Neda as the upper part of the Maquoketa in his Wisconsin geologic column.

Savage and Ross (1916) describe a section at the old ore pit near Neda (Northwestern Pit) based on work done in 1914, and present a photograph of the northern part of the east wall of the "lake" in the pit. They note a break in deposition between the iron ore bed and the Maquoketa. Their section is as follows (Savage and Ross, 1916, p. 189):

Section of strata exposed in an old ore pit near Neda

	Feet
Mayville limestone	
4. Dolomite, gray, crystalline, somewhat vesicular, in layers 1 to 4 feet thick	36
A break in deposition.	
Iron ore bed	
3. Iron ore band, hard, non-oolitic.	2/3 to 1-1/3
2. Iron ore, oolitic, reddish-brown, in rather even layers, with a thin band of iron coated fragments of shaly material, and iron pebbles near the bottom	25-32
A break in sedimentation.	
Maquoketa Shale	
1. Shale, calcareous, bluish-gray, hard, in layers 3 to 8 inches thick; containing shells of <u>Hebertella</u> <u>occidentalis</u>, <u>Platystrophia</u> <u>acutilirata</u> and <u>Rhynchotrema</u> <u>capax</u>	8-10

Savage (1916) presented an abbreviated section similar to that of Savage and Ross (1916), but called both unconformities a break in sedimentation. He noted the presence of zaphrentoid and favositoid corals in the lower Mayveille at the Northwestern Pit and published a somewhat expanded photograph of the same area as that in Savage and Ross (1916) (Savage, 1916, fig. 1).

R. R. Shrock made several visits to the Northwestern Pit from 1930 to 1934. He made detailed notes and diagrams of the outcrops (see Figure 28), including a brief description and diagram in his 1935 manuscript, none of which were ever published. At the time of his visits the lower portions of the pit had been flooded to approximately the current water-level, covering the Brainard-Neda contact. Shrock's observations of the exposure around the "lake" in the pit can be summarized as follows:

1. The Neda forms a number of mounds or hills, including a large mound in the northern two-thirds of the east wall, a smaller mound in the southern one-third of the east wall, and one or two mounds along the south wall.

2. The Neda is well laminated, frequently cross-bedded and ranges in thickness from 1 to 25 feet above the water level.

3. The top of the Neda is marked by a thin (2-4 in.) band of bluish- to steel-gray ore which is massive and occasionally contains oolites.

4. The overlying Mayville Dolomite is characterized by two different lithologies. The first is a nodular reefal and conglomeratic unit

0 to 22 feet in thickness which is only found overlying the Neda mounds. The second is typical in well-bedded Mayville Dolomite, 0-40 feet in thickness, and is thick-bedded, gray to buff, vuggy dolomite with occasional cherty layers.

5. The thickness of the normal upper Mayville Dolomite is inversely proportional to that of the underlying nodular Mayville and Neda. The nodular Mayville is thickest over thick portions of the Neda and rapidly thins out and disappears or merges with the upper Mayville away from the mounds. The upper Mayville thins, drapes over and dips away from the top of the nodular Mayville and the Neda mounds, and it fills the depressions between the mounds where the earliest beds of the upper Mayville wedge out against the nodular beds, indicating they were deposited in an actual depression.

6. Both Mayville lithologies bevel against the Neda which has an irregular surface besides forming the larger scale mounds.

7. The two different types of Mayville beds are separated from each other by a 2 to 4 inch layer of green to maroon colored shale.

8. A 2 to 4 inch layer of sandy dolomite stained yellow and brown, containing some oolites, is found between the Neda and the Mayville.

9. The nodular Mayville is fossiliferous, containing _Favosites_, _Halysites_, _Amplexus_, gastropods, illaenid trilobites (_Stenopareia_) stromatoporoids, and pelmatozoan stems.

In general, Shrock recognized a number of mounds or hills representing pre-Silurian topographic irregularities in the Neda on which nodular or reefy beds of the Mayville were developed. More typical Mayville sediment filled in depressions between these higher areas and later completely covered them. The Mayville and the Neda are separated by a significant unconformity. The relationships which Shrock observed are illustrated in Figure 29.

Rosenzweig (1951) in an unpublished master's thesis on the Neda Oolite described the exposures around the town of Neda, including the Northwestern Pit. He had access to Shrock's and Ulrich's field notes and his descriptions of the pit are similar. Rosenzweig presented an isopach map of the subsurface Neda ore bodies based on borings (see Figure 25). This map shows that there is a very large lens in the middle of the entire Northwestern Pit, which accounts for the northward thickening along the east wall in the vicinity of the "lake" in the southern one-third of the pit. The cross-sections based on these borings show the Neda to be thickest surrounding "hills" in the Maquoketa.

More recently, Paull and Paull (1977) and Paull (1977) have described some of the features at the Northwestern Pit. They also observed that the Neda forms topographic highs on which the Mayville was deposited during an Early Silurian transgression. Also, they note that along the east wall of the "lake" area the Mayville beds thin and disappear as they approach the thickest portions of the Neda.

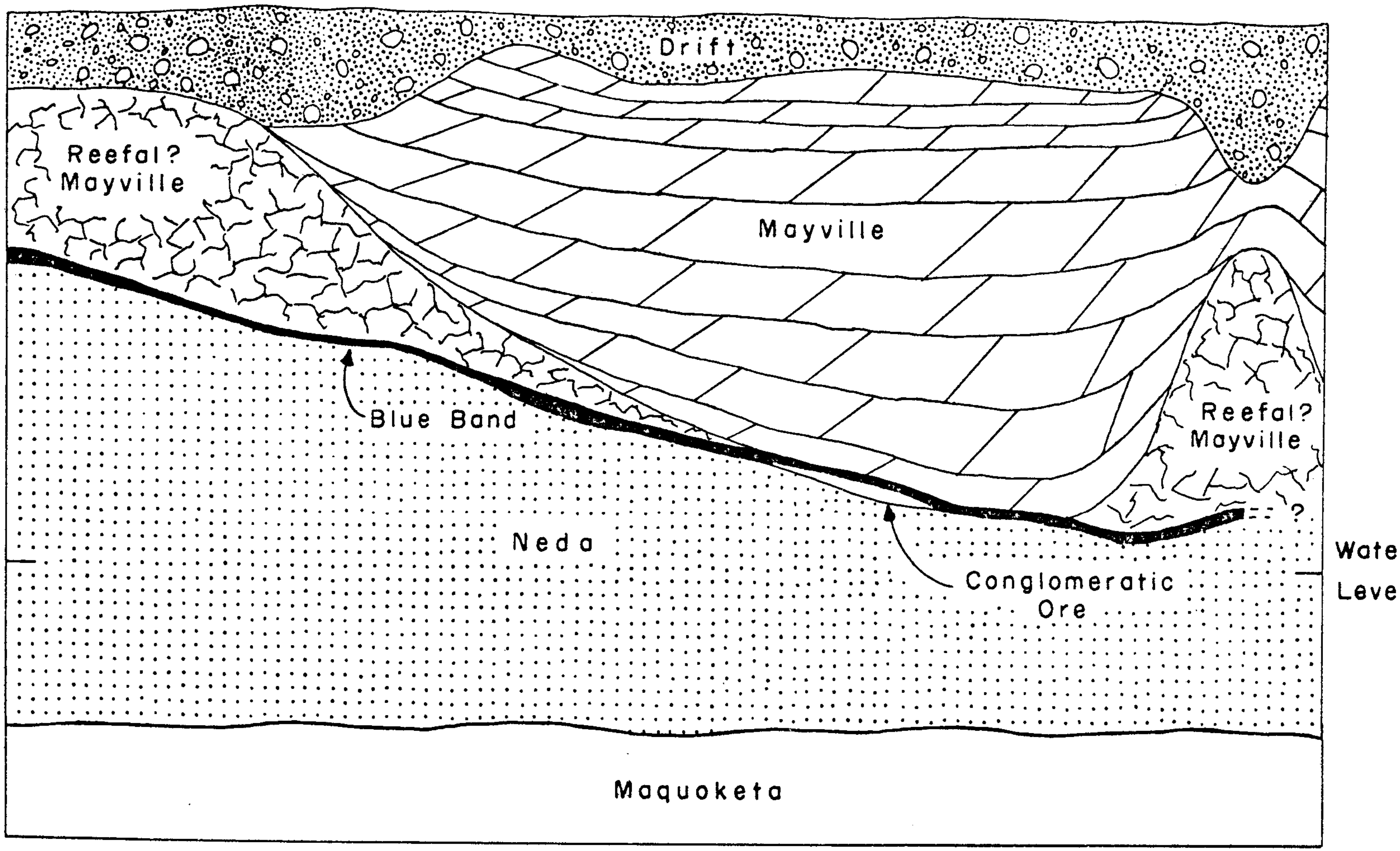


Figure 30. Relationships between the Neda and the Mayville along the east wall of the "lake" at the Northwestern Pit, Iron Ridge, Dodge Co., Wisconsin. Length of walls 425 feet; Height = 32 feet. Data from Shrock (1930, unpublished field notes).

From these descriptions of the Northwestern Iron Company Open Pit a number of important observations can be made about the Neda and Lower Silurian depositional environments in this area. It can be inferred that the same conditions existed in the study area a short distance to the south.

The contact between the Brainard Shale and the overlying Neda Oolite may be unconformable, but there is no evidence for a significant erosional break. Shale clasts in the basal Neda could easily be accounted for by a number of environmental changes of short duration, and not necessarily a major regression or transgression.

The Neda, as a whole, was probably not deposited in a continuous sheet, but may have formed on or around topographic highs of undetermined origin in the Brainard. Paull (1977) gives the most recent theories on the origin of the Neda, but the problem has not yet been satisfactorily solved.

The large Neda ore bodies appear to have formed two types of topographic high areas prior to Silurian deposition. The first and primary type is that which is composed of an entire ore body forming a mound as indicated by Rosenzweig's (1951) isopach map, and the increase in thickness along the east wall of the "lake" in the Northwestern Pit. The second type is the smaller, more localized mounds or hills which can be seen in the upper beds of the Neda in the southern half of the east wall and in the south wall of the "lake" area. The structure of these smaller mounds appears to be independent of the structure of the main ore body. There is a possibility that mounding in the Brainard may be present under the main Neda ore body in the Northwestern Pit which may have some control over the location, topography, and configuration of the Neda. This is suggested by Chamberlin's (1877) diagram, observations made by Shrock (1930, unpublished field notes) that several feet of Maquoketa dipping to the east were exposed above the water level on the west side of the "lake," and by the fact that the floor of the open pit mine (which is supposed to be the top of the Brainard) appears to slope up towards the north paralleling the increasing thickness of the main Neda ore body. Shrock (1934, unpublished field notes) later believed that the shale he observed was not in place and it appears that the outcrop he observed was rubble from mining activity. It should be pointed out that no one actually described a Brainard mounding feature at this locality. Ulrich (1914, unpublished field notes) who probably examined the area when exposures were at their best did not observe this relationship and his diagrams, although somewhat crude, show the Brainard to be flat lying; the overlying complex features were accurately drawn. His diagrams do indicate, however, that the smaller Neda mounds were definitely not controlled by the Brainard.

The Neda appears to have been deposited in a high-energy environment, as indicated by its cross-bedding and oolitic composition, and some local mounding on its upper surface may have been depositionally controlled, as might each entire ore body. An erosional origin for this mounding cannot be discounted since some erosion is indicated on the upper surface of the Neda manifested by the continuous band of hard, blue, homogeneous iron ore with a few oolites forming an irregular surface on a smaller scale; this band was observed by Chamberlin (1877) and nearly all succeeding workers. It does not seem likely that the Neda ore bodies are remnants of a once more continuous, now eroded sheet. Reworked Neda oolites are rare to absent from areas outside of the immediate vicinity of known ore bodies. It is probable that the Neda formed by shoaling on or around pre-existing Brainard highs. This, coupled with the existence of possible Mayville carbonate buildups covered by thin, red shale layers possibly representing eroded Neda and finally normal Mayville deposition covering all of these units, may reflect a series of regressions and transgressions during Late Ordovician-Early Silurian glacial eustatic sea level changes. In any event, the Neda still needs detailed work to establish its true depositional environment.

Lower Silurian

In this study, the Lower Silurian rocks are those found between the Ordovician Maquoketa Shale and the Silurian Brandon Bridge Beds. These pre-Brandon Bridge Silurian rocks are not currently well exposed in southeastern Wisconsin. There are a number of discontinuous natural outcrops in Waukesha, Walworth, Racine, and Washington Counties, but it is difficult to place them in a definite stratigraphic position because of their limited vertical thickness and lack of upper or lower contacts. The deep quarries at Ives (locality 9, Appendix II) in Racine County, and at Waukesha (locality 41, Appendix II) are currently being worked through these beds and supplemented with core material from other areas provide some insight into the nature of these pre-Brandon Bridge units.

Depositional Environment

As previously mentioned, the surface of the Maquoketa was subjected to intensive erosion after the Ordovician regression. As the Silurian seas transgressed across this surface, Maquoketa argillaceous sediments were eroded and incorporated within the Lower Silurian carbonates. The depressions and valleys in the Maquoketa surface were filled in more rapidly than the high areas, resulting in a variable thickness in some of the basal Silurian rock units.

The equivalents of these lower Silurian rock units in Wisconsin are known from northeastern Iowa and northeastern Illinois. Brown and Whitlow (1960) described the basal Silurian units in the Dubuque area of northeastern Iowa. The Lower Silurian Edgewood Formation was found to fill irregularities in theeroded surface of the Mequoketa

Shale. The Edgewood ranges in thickness from nine to 116 feet in that area, and is a gray dolomite with highly argillaceous content at the bottom of the unit which decreases upward. Some chert is present at the top. Brown and Whitlow (1960, p. 36) believed that:

> ...the Edgewood dolomite is a shallow-water marine deposit formed in a sea that transgressed over the eroded surface of the Maquoketa shale. While sediments were being deposited in the low places, Maquoketa shale hills such as the one in this quadrangle were either above sea level or, if covered by the sea, were not receiving sediments. Fragments of the upper part of the Maquoketa shale in local conglomerate layers of the Edgewood dolomite indicate that these hills were being eroded as the Edgewood was being deposited. Much argillaceous material in the lower part of the Edgewood probably was eroded from the hills or islands of Maquoketa shale, and relative purity of the dolomite in the upper member of the formation is a result of the water's clearing after the summits of the Maquoketa shale hills were covered by sediments.

Whitlow and Brown (1963) subsequently describe the Maquoketa-Edgewood contact in Dubuque County, Iowa, as having a basal one foot conglomeratic zone which contains fragments of shale, dolomite, and phosphatic nodules from the Maquoketa set in an argillaceous and dolomitic matrix. Similar zones have been recognized at the Ordovician-Silurian contact in cores from the Vulcan quarries at Franklin (locality 70, Appendix II) and Sussex (locality 49, Appendix II), Wisconsin. However, the absence of this zone should not be considered to indicate a gradational contact between the Maquoketa and the Lower Silurian rocks. The Lower Silurian transgressive features of initial erosion and redeposition of Maquoketa sediments may have masked the original Maquoketa surface.

Willman (1973) described a nearly identical situation to Brown and Whitlow (1960) and Whitlow and Brown (1963) in northeastern Illinois. There the Lower Silurian units are also directly controlled in composition and distribution by the underlying Maquoketa. The lowest unit in the section is the Wilhelmi Formation, a highly argillaceous gray dolomite (Willman, 1973). The unit is occasionally cherty near the top and has a dolomitic shale at its base. Willman (1973, p. 12) states that the wilhelmi:

> ...fills, or nearly fills, channels eroded in the underlying Brainard Shale... The Wilhelmi is as much as 100 feet thick in the deeper channels but is absent or very thin in the areas between the channels.

The Wilhelmi beds found on top of the Neda are composed of 10 1/2 inches of highly argillaceous dolomite containing some oolites.

The Elwood Formation overlies the Wilhelmi and consists of 25 to 30 feet of pure to slightly argillaceous, brownish gray dolomite with common layers of white chert nodules. The Elwood Formation is also largely confined to Maquoketa channels and valleys and it thins and disappears in inter-channel areas.

In some areas the Kankakee Formation directly overlies the Wilhelmi with the Elwood being absent (Willman, 1973).

The Lower Silurian rocks of southeastern Wisconsin probably originated in a very similar depositional environment as those in northeastern Iowa and northeastern Illinois. The Maquoketa does have locally significant variations in releif as in Iowa and Illinois, and the Silurian rocks locally exhibit major differences in thickness, probably resulting from the same inversely proportional relationships between the Upper Ordovician and the Lower Silurian as that described in Iowa and Illinois (Brown and Whitlow, 1960; Whitlow and Brown, 1963; Willman, 1973). The basal Silurian rocks in all three areas are commonly very argillaceous because of the incorporation of reworked Maquoketa Shale. This makes the determination of the exact position of the Ordovician-Silurian boundary difficult to recognize. Moretti (1971) and Paull and Paull (1977) have stated that the Ordovician-Silurian boundary is transitional in eastern Wisconsin. In the water well logs on file at the Wisconsin Geological and Natural History Survey there appears to be a great deal of variation in what is considered to be the boundary, particularly in the older logs, and without examination of the original well cuttings it is difficult to determine the correct position of the boundary. This problem is further complicated by the presence of dolomitic beds in the Brainard and the Fort Atkinson which are not always accurately differentiated lithologically from Silurian dolomites in the logs. I have, therefore, used the last appearance of true shale as the upper boundary of the Maquoketa in the logs since there are no shale beds in the Lower Silurian. This probably involves an error of less than 5 feet where the lithologic descriptions are detailed.

It is probable that erosion and redeposition of Maquoketa sediments during the Early Silurian transgression resulted in some of the initial Silurian beds being lithologically identical to the Maquoketa Shale, but Silurian in age, particularly in the deeper erosional valleys. As suggested by Brown and Whitlow (1960) the decrease in argillaceous content of the Lower Silurian carbonates may be the result of the complete flooding of higher elevations of the Maquoketa.

Lithologic Characteristics and Correlation in Wisconsin

The lithologic characteristics of the Lower Silurian rocks seem to be quite variable, with little lateral continuity over wide areas, in southeastern Wisconsin. This is probably a result of the scarcity of data points and not a real feature. Correlation with surrounding areas has not been entirely successful although the Lower Silurian section at Ives in Racine County is similar to the general section in the Chicago area with the Elwood absent, or at least noncherty, and with a possible, thin section of Wilhelmi present. This correlates with the Lower Silurian at Franklin and with cores in the center of Milwaukee County. At these last two localities a coarse-grained to granular, thick-bedded, vuggy, reddish-brown dolomite composes most of the Lower Silurian section. Towards the west (Waukesha) and northwest (Sussex) core information indicates that the Lower Silurian becomes very cherty from top to bottom, which may, in part, include some equivalent beds of the Elwood Formation of northeastern Illinois. A correlation of these exposures with those of the type Mayville, 30 miles to the northwest, have not as yet been successful, although the general lithologies of the two areas are similar. The poor correlation of these units is due to that lack of data between these localities and the incomplete section at Mayville. The Virgiana bed at the top of the Mayville has not been recognized in the study area. Willman (1973) correlated most of the Mayville and Byron Dolomites with the Kankakee Formation, and also suggested that the overlying Hendricks Formation may be equivalent to the Plaines Member of the Kankakee Formation. It is likely that these units correlate in some manner, but until more information is available precise correlation is impossible. A Byron correlation with higher units cannot be ruled out. Previous workers have correlated the Byron with the Waukesha Dolomite based on similar general characteristics, however, the lithologies of these two units are not really alike and the position of each unit appears to be quite different in the stratigraphic section.

Carbonate Buildups

Silurian carbonate buildups first appear in the pre-Brandon Bridge Beds at Ives, and possibly in equivalent beds at the Halquist quarry (locality 48, Appendix II) near Sussex. These buildups are not well exposed, but appear to be only a few tens of feet high and less than 100 feet in diameter. They are not particularly fossiliferous, but contain Halysites and pelmatozoans at Ives. The buildups contrast sharply with the surrounding beds, being massive and vuggy, and laterally the beds appear to wedge out against the buildups. Underlying beds seem to have been depressed by the buildups. No carbonate buildups are known in the Brandon Bridge and Waukesha unless the buildups in Unit Y at Halquist quarry should prove to belong to the Waukesha.

Brandon Bridge Beds

History of Research, Terminology, and Previous Usage

The name Brandon Bridge Beds, as used in this discussion of Wisconsin exposures, is an informal usage of the name Brandon Bridge Member of the Joliet Formation as described by Willman (1973) in northeastern Illinois. The Wisconsin and Illinois rock units termed Brandon Bridge are lithologically very similar and occupy the same stratigraphic position, however, since a different terminology is used for the overlying rock units in Wisconsin, I feel it is inappropriate to refer to the Brandon Bridge in Wisconsin as a member of the Joliet.

The Brandon Bridge is probably the most lithologically distinct

Silurian unit in southeastern Wisconsin, being characterized by a red, green, dark gray, or maroon color and being rather thin- and irregular-bedded, highly-laminated, highly argillaceous dolomite. These beds have long been exposed in the eastern part of Walworth County, near Burlington, where the bedrock is quite close to the surface (see locality 2, Appendix II). The quarries around Burlington have long been famous for specimens of the trilobite Stenopareia imperator, but the stratigraphic position of these rocks was not well understood. Percival (1856) and Hale (1860, unpublished field notes) correctly suggested that the beds at this locality were part of the Lower Silurian. Lapham (1865, unpublished field notes; see Table 43), however, placed the "Burlington Illaenus Beds" between the Racine Dolomite and Waukesha Dolomite. He had described a two foot thick bed in this stratigraphic position at Waukesha as "Racine Limestone, while more compact with large Illaenus, like those at Burlington, Racine Co." This correlation was apparently based on the presence of similar fossils (Illaenus) and not any lithologic characteristics. Chamberlin (1877, p. 372-376) also considered the rocks exposed west of Burlington as belonging to the Racine Dolomite. He did state (p. 208-209) that these rocks had a character not seen elsewhere, but gave no reason for assigning these beds to the Racine. Thwaites (1912) and Alden (1918) recognized the similarity of these rocks to those exposed in the quarry near Burlington. Thwaites (1923) later stated that the redbeds in that area were not iron ore (Neda).

Brupee (1932) found a distinctive zone of siliceous plane-coiled Foraminifera in insoluble residues from samples collected by Shrock from the Brandon Bridge dolomite in the Voree quarry near Burlington. He was also able to recognize this same zone in water-wells at Burlington, Racine, and Waukesha. Burpee assigned this zone to the Waukesha Dolomite. This assignment is incorrect since the rocks in question are lithologically distinct from the Waukesha and the horizon in which he found the foraminiferans in the water-well logs at Burlington, Racine, and Waukesha is consistent with a placement in the Brandon Bridge Beds beneath the Waukesha Dolomite. Shrock (1935) summarized Burpee's work and assigned the foraminiferan zone to the Byron Dolomite, but information previously presented by Burpee indicates that insoluble residues of definite Byron beds are quite different from those containing the foraminiferans. Karges (1934) was further able to extend Burpee's foraminiferan zone, based on insoluble residues in water-well samples, when he located the zone in Wauwatosa City Well No. 6, west of Schoonmaker reef. Based on patterns of insoluble residues that Burpee presented it is further possible to extend this zone to the Milwaukee Journal well in downtown Milwaukee (east of the Wauwatosa well), and possibly to Cedarburg, although foraminiferans are not present in either of these two wells. Examination of water-wells to the north reveal no similar zone and the insoluble residue patterns are too variable to accurately extend this horizon northward.

Ball (1940) was the first to correlate this unit with exposures outside of Wisconsin, stating that the rocks expsoed in the Burlington quarries were the same as those exposed at Aurora, Illinois. Raasch (1955, unpublished manuscript) further correlated these beds with the lower part of the Joliet Formation in Illinois and subsurface beds in southern Michigan.

Frest et al. (1977) stated that the Brandon Bridge Beds had been uncovered at the bottom of the Ives quarry, north of Racine, which is the first exposure of this unit outside of the Burlington area in Wisconsin. Mikulic (1977) indentified the Brandon Bridge Beds at Franklin and at Waukesha, indicating that the character of this unit is variable to the north.

The first detailed description of the Brandon Bridge was made for the exposures around Joliet, Illinois, where the unit was at one time best exposed. The name Brandon Bridge was first applied to rocks in this area. In 1926, Savage described rocks at Joliet as being the lower part of the Joliet Formation; these rocks are lithologically identical to those of the Brandon Bridge Beds in Wisconsin. He also described the relationship between the Brandon Bridge and the underlying Kankakee Formation, which is a major criterion for identifying the Brandon Bridge Beds. Savage (1942) later separated this unit from the Joliet Formation and gave it the name Rockdale. Dunn (1942) described a large Silurian foraminiferan fauna, including a number of species from the Brandon Bridge around Joliet which are from the same zone described by Burpee (1932) in Wisconsin. Willman (1943) subdivided the Joliet Formation and included Savage's (1942) Rockdale as the lower two units of the Joliet. He later (1973) named these lower beds the Brandon Bridge Member of the Joliet Formation and presented the following description (1973, p. 20-21):

> The Brandon Bridge Member, the shaly zone at the base of the Joliet Formation, is named herein for Brandon Bridge, which crosses the Des Plaines River on the southwest side of Joliet. The type section is in the quarry just south of the bridge (Joliet-Lincoln Quarry Section). The Brandon Bridge is at least partly equivalent to the zone that Savage (1942) removed from the Joliet and named Rockdale. "Rockdale" was preempted, and the name has not been used.
>
> The Brandon Bridge Member is 25 feet thick in the type section and within a foot or two of that in other sections at Joliet and in the deep quarries at Hillside and Elmhurst. It is partly exposed in the Du Page Valley a mile south of Naperville, Du Page County... and in the Fox Valley a mile south of Batavia, Kane County... The Brandon Bridge Member thins southward from the type locality, and it is only 10 feet 6 inches thick in a small ravine on the north side of the Kankakee River, a quarter of a mile east of Warner Bridge in Kankakee County...
>
> In the Joliet area, the Brandon Bridge is separated into two parts by a green to black shale, locally as much as 1 foot thick, slightly above the middle of the member. The lower part is more shaly and contains beds of red crinoidal dolomite and greenish gray, very argillaceous dolomite. Some gray beds are mottled with red. The strata above the shale are less shaly and are largely gray, mottled green and red. The upper contact is placed at the highest strong shaly parting. In other areas, the red

crinoidal beds are less common and some of the very argillaceous beds are dark red, as at Lemont and Elmhurst. The member is thin bedded, and many bedding planes have fucoidal markings. Except for the siliceous foraminifera, the Brandon Bridge is not very fossiliferous, but large specimens of the trilobite Bumastus are occasionally found, particularly in the middle shaly zone.

Lower Contact

An important feature in recognizing the Brandon Bridge is the lower contact with the Kanakakee Formation. This lower contact was not exposed in Wisconsin until recently, but was described by Fisher (1925), Savage (1926), and Willman (1943, 1973) in northeastern Illinois. The upper one and one-half to three feet of the Kankakee Formation is a pure white massive bed of dolomite (Plaines Member) containing specimens of the brachiopods Pentamerus and Microcardinalia (Willman, 1973). Willman also remarked that the upper surface of the Plaines is smooth, with some pitting, and is interpreted as an unconformity or subaqueuos interruption of sedimentation.

Lithologic Characteristics

In southeastern Wisconsin the Brandon Bridge Beds are recognized in Kneosha, Racine, the south half of Milwaukee and Waukesha, and the east half of Walworth Counties (see Figure 31). The thickness ranges from 42 feet at Racine, 54 feet at Franklin, Milwaukee County,

Figure 31. Distribution of Brandon Bridge Beds in southeastern Wisconsin. Known localities exhibiting these beds are indicated by closed circles; localities where the Brandon Bridge is known definitely not to occur are indicated by X. Possible occurrences of Brandon Bridge are indicated by ?

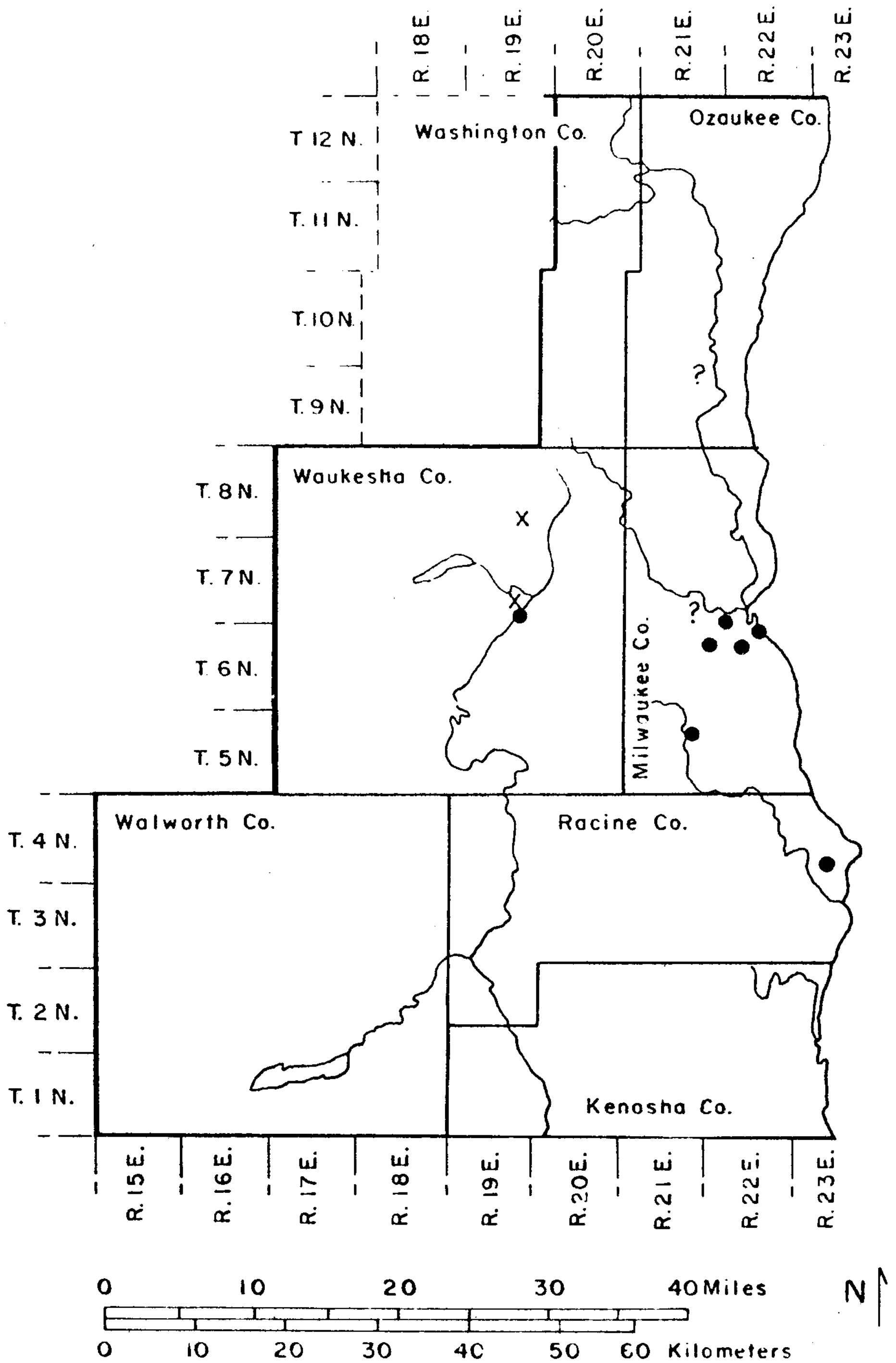

R. 18E.
R. 19E.
R. 20E.
R. 21E.
R. 22E.
R. 23E.
T 12 N.
T. 11 N.
T. 10 N.
T. 9 N.
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
T. 4 N.
T. 3 N.
T. 2 N.
T. 1 N.
Washington Co.
Ozaukee Co.
Waukesha Co.
Milwaukee Co.
Walworth Co.
Racine Co.
Kenosha Co.
?
X
R. 15E.
R. 16E.
R. 17E.
R. 18E.
R. 19E.
R. 20E.
R. 21 E.
R. 22 E.
R. 23 E.
0 10 20 30 40 Miles
0 10 20 30 40 50 60 Kilometers
N

Figure 31

to 26 feet to zero feet at Waukesha. The lithologic characteristics of the Brandon Bridge around Racine and Burlington, Racine County, are very similar to that of the Chicago area. The rock is a highly argillaceous to shaly, thin- to medium-bedded, finely laminated, low porosity dolomite which varies in color from green, pink, red or dark gray. There are more crystalline layers in the upper one-half of the unit. At Franklin, Milwaukee County (locality 70, Appendix II) the rock is less shaly and the prominent red to maroon coloration is absent; the greenish-pink-gray crystalline beds characterize most of the unit here.

In the Chicago area, it has been observed that the more shaly beds of the Brandon Bridge are discontinuous. In the Federal quarry, Materials Service Corporation at 47th Street and East Avenue in McCook, Cook County, Illinois, core information has revealed that shaly Brandon Bridge is present in the eastern one-third of the quarry, but is absent from the western two-thirds. The more typical argillaceous dolomite beds are present throughout this quarry. Cores drilled throughout the Chicago area for the Deep Tunnel Sewer Project have seldom encountered the shaly Brandon Bridge beds (Hartz Engineering, 1975). It is possible, however, that the Brandon Bridge has been included in the Markgraf where the shaly beds are absent. McGovney (1978) indicated that the Brandon Bridge forms a high area under the central core of the Thornton reef, but that it is absent from the surrounding area.

In the city of Milwaukee, the Brandon Bridge Beds have been recognized in a number of recent cores (Mi-1, Mi-2, Mi-7, Mi-12, and possibly Mi-3; see Figure 78) of the Milwaukee Water Pollution Abatement Program. With the exception of M-3, it has similar lithologic characteristics to the quarries to the south. In these cores the Brandon Bridge Beds are easily separated from the reddish-brown crystalline beds in the lower part of the Silurian, but are very similar to a few thin beds just above the Ordovician-Silurian contact. Some maroon-colored rocks have also been found in the Racine Dolomite, so correlation of this unit by color alone is not always reliable, particularly in water-well logs. The position of the Brandon Bridge in these cores agrees with the placement of the Brandon Bridge in the Wauwatosa well and the Milwaukee Journal well based on Karges (1934) data.

Unconformity at Waukesha

West of Milwaukee County, the Brandon Bridge Beds become a dark gray, thin-bedded, finely-laminated, argillaceous, fine-grained dolomite, best exhibited in the south end of the west quarry of the Waukesha Lime and Stone Company (locality 41, Appendix II). Only a few patches of typical grayish-purple rock are found at this locality, but the general lithologic characteristics and stratigraphic position leave no doubt that these beds belong to the Brandon Bridge. In this quarry relationships between the Brandon Bridge and other units are present that cannot be seen elsewhere. Mikulic (1977) briefly described and illustrated these relationships, which were only partially exposed at that time.

At the south end of the west quarry the Brandon Bridge overlies an eight and one-half foot thick, very dense, thick-bedded, light brown dolomite having an almost lithographic texture and breaking with a conchoidal fracture on vertical surfaces. The upper surface of this unit has the same smooth, pitted appearance as the Plaines Member of the Kankakee Formation, which, in addition to its lithologic characteristics, indicates that at least the upper portion of this unit is equivalent to the Plaines. This unit does, however, lack fossils. The surface of this unit gently undulates in some places, having a relief of five inches to one foot. In the east quarry of the Waukesha Lime and Stone Company the upper surface of this unit exhibited an east-west trending, assymetrical ridge, having a relief of up to three feet, with the south side being steeper than the north. The contact between the Plaines and the Brandon Bridge is very sharp.

In the east quarry and the south end of the west quarry the Brandon Bridge has a uniform thickness of 24 to 25 feet and consists of thin-bedded, platy, argillaceous, highly laminated, non-porous dark gray dolomite, becoming thicker-bedded, less argillaceous, and more crystalline towards the top. The lower beds drape over the irregularities in the Plaines. The rock is generally unfossiliferous although the more crystalline beds contain some scattered pelmatozoan debris. The overlying contact with the Waukesha Dolomite is not as sharp as the lower contact. The upper Brandon Bridge Beds become more crystalline and end abruptly being separated from typical Waukesha Dolomite by a prominent bedding plane.

The Brandon Bridge is rather uniform in its characteristics for 1300 feet north along the west wall and 2100 feet north along the east wall from the south end of the west quarry. At these points a thin, cherty conglomerate appears between the Brandon Bridge and the Plaines and continues for some distance northward (see Figure 32). The surface of the Plaines near the conglomerate shows the same characteristics as to the south and also a series of low ridges and troughs with relief of up to one foot are present, appearing to have a northeast-southwest trend. The conglomeratic bed first appears on the northwest side of one of the ridges and also fills in cracks in the surface of the Plaines.

The conglomerate contains abundant chert nodules and fragments, ranging from sand size particles up to four inches in diameter, and some possible glauconite. Silicified fossils are present in the upper surface of the conglomerate, including tabulate corals, pentamerid? brachiopods, pelmatozoan calices, and bryozoans.

Figure 32. Map showing location of sump (x), conglomerate zone (heavy dashed line) and fault (heavy solid line) in the west quarry of the Waukesha Lime and Stone Company (locality 41, Appendix II) Waukesha County, Wisconsin.

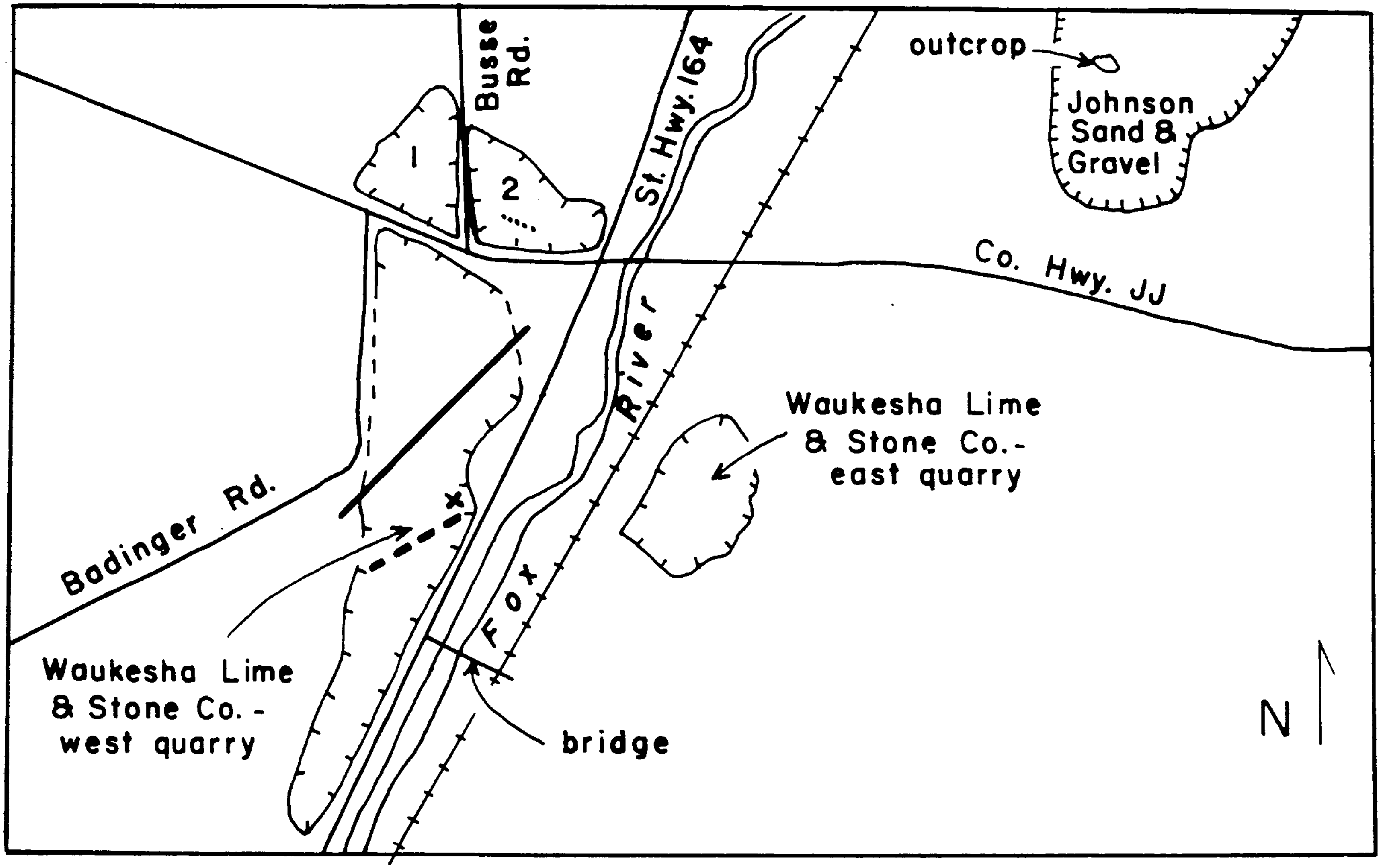

Busse Rd.
1
2
St. Hwy. 164
outcrop
Johnson Sand & Gravel
Co. Hwy. JJ
Fox River
Badinger Rd.
Waukesha Lime & Stone Co. - east quarry
Waukesha Lime & Stone Co. - west quarry
bridge
N

Figure 32

Most of the fossils appear to be worn and some seem to be preserved in a living position. The upper surface of the conglomerate has a platy layer that appears to be cracked and infilled with a greenish-gray clay.

At the sump (see Figures 32 and 33) a more complex development in the relationships between these units is exhibited. The conglomerate locally reaches a thickness of up to three feet. West from this point a now removed quarry face showed the Plaines thickening towards the west with the overall elevation of its upper surface rising to the west-northwest. The Plaines is still characterized by a smooth, pitted surface here, with occasional large depressions. The cherty conglomerate continues to occur between the Brandon Bridge, but 21 feet west of the sump it is only a few inches thick, and the Plaines has thickened an additional one and one-half feet with the Brandon Bridge thinning accordingly. Fourteen feet further west a six inch bed of cherty dolomite appears overlying the Plaines and underlying the Brandon Bridge. Thirty-three feet to the west of this point the cherty dolomite has thickened to three feet and the Brandon Bridge continues to thin. The Plaines is no longer increasing in thickness. Eighty-five feet to the west (153 feet from the point where the Plaines first increased in thickness) the cherty dolomite has increased to ten and one-half feet while the Brandon Bridge continues to thin. Most of this quarry wall, west of the sump, has subsequently been

Figure 33. Unconformity between the Plaines Beds and unnamed cherty dolomite and the Brandon Bridge Beds in the west quarry at Waukesha Lime and Stone Company (locality 41, Appendix II), Waukesha County, Wisconsin.
A: East-west wall, looking north, showing thinning of Brandon Bridge and thickening of underlying Plaines and unnamed cherty dolomite to west (left). Sump is at right. July, 1977.
B: North-south wall, looking east, after removal of most of wall in (A), showing the same relationships. Sump is at right. Lower units are thickening towards the north (left). August, 1977.

A

B

Figure 33

removed, revealing a north-south cut, and the same general relationships just described were present, but over a shorter distance.

A detailed section of the Plaines-Brandon Bridge contact at the sump (see Figure 34) shows the following:

I. Typical Brandon Bridge Beds

II. Conglomerate:

18 in.	Crystalline, laminated, light gray dolomite with uneven surface
2 in.	Dark gray, laminated clay
2-3 in.	Light gray, crystalline dolomite with some chert fragments and vertically oriented clasts
6-7 in.	Cherty conglomerate similar to below, but with large chert nodules
1 1/2-3 in.	Crystalline dolomite filling depressions in underlying unit which accounts for its variable thickness.
1/4 in.	Dark gray clay
1/2 in.	Crystalline, fine-grained, light gray dolomite with irregular surface
1/2 in.	Cherty conglomerate

III. Plaines Beds

About 25 feet north of the west end of the sump the following section is present:

I. Brandon Bridge Beds

II. Conglomerate:

4 in.	Crystalline, light gray dolomite with irregular "domed surface

8 in. Finely laminated Brandon Bridge lithology

7 in. Thin, platy, crystalline dolomite with some pelmatozoan debris interbedded with highly argillaceous layers

9 in. Cherty dolomite with irregular surface covered by thin layer of dark gray shale which fills in depressions

III. Plaines

The Plaines reaches its maximum thickness at the appearance of the overlying cherty dolomite unit and remains at this thickness to the north. The cherty dolomite continues to thicken towards the north as the Brandon Bridge thins. When traced laterally it becomes apparent that layers are being added to the top of the cherty dolomite.

Some of the chert nodules project laterally several inches out of the cherty dolomite unit, appearing to be "undercut." These nodules were later underlain and surrounded by the matrix of the conglomerate, indicating they projected outward in the same manner during deposition of the conglomerate.

Thirty feet farther north the cherty dolomite continues to increase in thickness and the conglomerate becomes discontinuous and is only found filling local depressions. At this point there is a thin, irregular, dark gray shaly layer between the Brandon Bridge and the cherty dolomite. About 30 feet north the quarry face curves to the west (see Figure 34) and the Brandon Bridge thins and disappears while the cherty dolomite continues to increase in thickness. The top

Figure 34. Unconformity between the Plaines Beds and unnamed cherty dolomite and the Brandon Bridge Beds in the west quarry of the Waukesha Lime and Stone Company (locality 41, Appendix II), Waukesha County, Wisconsin. A: Shows unconformable relationships between the Brandon Bridge and underlying unnamed cherty dolomite unit, about 90 feet north of the sump. October, 1977. B: Shows Brandon Bridge Beds wedging out to the north against the underlying, thickening unnamed cherty dolomite unit at the same location as A. Dendroid graptolites and <u>Dalmanites</u> occur in the Brandon Bridge at this location. October, 1977. Wall in background shows Waukesha Dolomite overlain by massive Romeo Beds of the Racine Dolomite.

A

B

Figure 34

16 feet of the Brandon Bridge has been removed by quarrying in this area, but it can be assumed that it continued for some distance to the north and west.

From the sump north as the Brandon Bridge begins to thin, a number of unusual and well preserved fossils have been found. Scattered specimens of disarticulated Stenopareia occur which are typical of the Brandon Bridge in most other localities, but appear to be absent in the southern part of this quarry. Most notable is a fauna of abundant dendroid graptolites. The dendroids occur on a few bedding planes in an extremely dense, fine-grained, well-bedded, highly laminated, light gray dolomite occurring in beds approximately three inches in the lower two feet of the Brandon Bridge, approximately 80 feet north of the sump. This horizon would be about five to six feet above the base of the Brandon Bridge in the southern part of the quarry. In the same vicinity, a number of complete specimens of the trilobite Dalmanites have been found about six inches above the cherty dolomite in a very thin-bedded, highly laminated platy, gray dolomite interbedded with thin, dark gray shale layers. These beds are associated with more crystalline layers that are somewhat irregular in appearance. In the more shaly layers a few monogratids have been found.

In this area the contact between the Brandon Bridge and the underlying cherty dolomite is extremely sharp and well defined with no conglomerate present.

North of the fault (see Figure 32) and about 600 feet north of the sump, the upfaulted cherty dolomite has a thickness of 21 feet and is overlain by about three feet of laminated, argillaceous, light gray to brown dolomite, which may represent the upper beds of the Brandon Bridge. At Halquist (locality 48, Appendix II) and Vulcan (locality 49, Appendix II) quarries four miles to the north, the Brandon Bridge is absent.

In summary, it appears that the upper surface of the Plaines represents an unconformity of undetermined origin and duration.

At least 21 feet of cherty dolomite underlain by the Plaines and three feet of the Plaines itself have been removed in the southern part of the west quarry.

The conglomerate is primarily composed of noncarbonate material derived from the cherty dolomite unit which accumulated in depressions at the base of the slope which reses to the north and west with the thickening of the Plaines and the cherty dolomite.

The upper surface of the cherty dolomite has some of the same characteristics as the surface of the Plaines (smooth, undulating, pitted).

Little or no carbonate material is found in the conglomerate indicating it probably resulted from dissolution of the cherty dolomite beds as opposed to mechanical erosion. A few patches of conglomerate appear to be filling small depressions in the south side of the quarry, but these exposures are inaccessible.

The Brandon Bridge drapes over the Plaines and appears to have infilled the area south of the conglomeratic zone where the cherty dolomite and part of the Plaines have been removed. The Brandon Bridge Beds drape over the cherty dolomite where the conglomerate is absent. The lower Brandon Bridge Beds generally follow the dip of the slope on the surface of the underlying cherty dolomite, but wedge out upslope. This indicates that the apparent relief of the cherty dolomite was real at this time of Brandon Bridge deposition.

The duration of the unconformity is unknown. The upper beds of the Brandon Bridge have produced a few conodonts of an Upper Llandoverian-Lower Wenlockian age (J. Barrick, 1977, personal communication). This age corresponds to that of the upper two-thirds of the Brandon Bridge in northeastern Illinois (Liebe and Rexroad, 1977). The occurrence of the trilobite *Stenopareia* in these beds indicates a Llandoverian-Early Wenlockian age. The graptolite *Monograptus spiralis* indicates a very late Llandoverian age for the Brandon Bridge at this quarry.

Age of the Brandon Bridge

The overall age of the Brandon Bridge in southeastern Wisconsin appears to agree with the Late Llandoverian-Early Wenlockian age assigned to the Brandon Bridge in northeastern Illinois by Liebe and Rexroad (1977). Berry and Boucot (1970) assigned the underlying Plaines Member to a C_1-C_2 position in the Llandovery.

Fauna

With the exception of the fossils found in the Brandon Bridge at Waukesha described above, fossils are rare. The microfossils described by Burpee (1932), Dunn (1942), Gutschick (1941), Ball (1940), and Liebe and Rexroad (1977) are characteristic of this unit. The most characteristic fossil in the Brandon Bridge, however, is the trilobite *Stenopareia imperator*. A few pelmatozoan stem sections and rare orthocones are also present. Vertical and horizontal burrows or trails are common in some of the more shaly layers.

Waukesha Dolomite

Name and Previous Usage

The Waukesha Dolomite was the first Silurian stratigraphic unit to be officially named in southeastern Wisconsin. Unfortunately, the original lack of a designated type section and the inclusion of younger, lithologically similar, rock units in early reports on the Waukesha Dolomite have led to much confusion as to its true stratigraphic relationships.

The name Waukesha Limestone was proposed by Increase A. Lapham (1851, p. 170) for his unit VI in his geologic column for southeastern Wisconsin. Lapham described the Waukesha as being underlain by an unexposed sandstone unit (V) and described the Waukesha as follows (1851, p. 170):

> Throughout the county of Waukesha, is found a hard, white, or bluish-white limestone, which, as it appears to be new, I porpose to call the Waukesha limestone. It forms an excellent and beautiful building material, being disposed in regular layers from a few inches to a foot or more in thickness. It does not, however, receive a good polish, being in many places filled with small, irregular cavities, occasioned probably by the decay of some mineral substance. It contains but few fossils: the most remarkable are two large species of Orthocera. These, with a spiral-chambered shell and a Trilobite, are all that have been discovered. The Waukesha limestone extends eastward along the Menomonee river of lower Wisconsin, to within three miles of Milwaukee, where it is extensively quarried for building purposes in the city. At this point it is only thirty-three feet above the level of Lake Michigan, while at the village of Waukesha, twelve miles west, it has an elevation of about two hundred and fifty feet.

The unit (VII) overlying the Waukesha was described as (Lapham, 1851, p. 170):

> A soft, yellow limestone is found on the Menomonee river of southern Wisconsin, resting immediately upon the Waukesha limestone. The same rock occurs near Racine, and at other points on Root river; also at the Menomonee falls and at the falls of the Milwaukee river in Washington county. It may be considered as only the lower portion of the next rock.

This description has proven to be inadequate in determining the exact rock unit to which Lapham applied the name Waukesha Limestone, but the name has persisted in the geologic literature of the area.

From Lapham's description a number of points about the characteristics of the Waukesha Dolomite, as he viewed it, can be made:

1. The only definite contact that was described between the Waukesha and other units was that with the overlying beds. This overlying unit was described by Lapham as a soft yellow limestone which was later named the Racine Dolomite by Hall (1862). This relationship has been the major determining factor in later identification of the Waukesha.

2. Lithologically the Waukesha is a well bedded, hard, white or bluish-white limestone in layers ranging from a few inches to a foot in thickness. The rock is not very fossiliferous, but is characterized by the presence of orthoconic cephalopods.

3. Lapham describes the Waukesha beds as being an excellent building stone found throughout Waukesha County and along the Menomonee River in Milwaukee County.

Hall (in Foster and Whitney, 1851, pp. 171-172) makes additional comments about the Waukesha Dolomite:

> I am inclined to regard the Waukesha limestone, No. VI, the soft yellow limestone, No. VII, and the geodiferous limestone, No. VIII, as constituting the Niagara, and the calcareous portion of the Clinton Group.
>
> The Waukesha limestone, as I saw it near Milwaukee, is a thin-bedded, argillaceous deposit containing few fossils; I collected from it, however, Orthoceras undulatum, and O. virgatum. I saw the same in Mr. Lapham's cabinet, with another species from this member of the series; also,

> a species of Gomphoceras, like that occurring in the Niagara shale at Rochester and in the limestone at Niagara falls (Pal. N. Y. II., p. 290); also, Spirifer lineata, and a flattened Trochus-like shell, similar to a species occurring in a limestone of this age on Lake Michigan; and a species of Cyrtoceras, and Calymene Blumenbachii, var. niagarensis.

Whittlesey (1852, pp. 448-449, 455) mentions the Waukesha Dolomite in southeastern Wisconsin, however, he presents no new information.

Percival (1856, pp. 65-70) described the Silurian rocks in eastern Wisconsin, including the building stone beds at Waukesha as belonging to the Mound Limestone, a name derived from the Silurian outliers in southwestern Wisconsin. He did not make any mention of Lapham's work.

James Hall (1862) presented a more comprehensive study of the Paleozoic rocks in eastern Wisconsin, including the Waukesha Dolomite. He described the Waukesha as follows (1862, p. 61):

> In the vicinity of Milwaukee, at Waukesha and elsewhere, some of the beds assume an argillaceous character, and are thinbedded with glazed shaly partings, less crystalline than the prevailing character of the rock, and readily quarried, and dressed for building stone.
>
> These beds have been termed the Waukesha limestone, by Mr. Lapham, to distinguish them from the Coralline beds developed in the vicinity of Milwaukee, which he regards as the representative of the Geodiferous limestone of Eaton.
>
> Near Waukesha, and in the section extending from Waukesha to Pewaukie(sic), we have the beds, as shown in the accompanying section, Fig. 7 (p. 62).

While Hall does not give a detailed description of the rock units at

Waukesha the figure by T. J. Hale (in Hall, 1862, p. 62, Figure 7) does show the general stratigraphic relationships at Waukesha (see Figure 35). Hall (1862, p. 63) goes on to describe the "Waukesha" beds at Wauwatosa and their relationship to the reef there; these beds are now known to be part of the Racine Dolomite. In his description of the Racine Dolomite Hall (1862, p. 67) makes some definite statements concerning the stratigraphic relationships between the Waukesha and Racine:

> Lying above the limestone just described, we find a friable yellow or ochreous limestone, readily decomposing on its exposed surfaces, and marked by numerous small cavities. This rock was recognized by Mr. I. A. Lapham, in his original section of the formations of Wisconsin, as a soft yellow limestone, lying above the Waukesha limestone; the position recognized in the section at Waukesha.

It should be noted that unit b (on Hall's Figure 7) was meant to be included in the Waukesha Dolomite but was not clearly indicated as such. Hall (1862, p. 446-448) makes some final comments concerning the Waukesha Dolomite. He mentions (p. 447):

> From observations at this place and elsewhere, I am forced to believe that the 'Geodiferous limestone' of this region lies really below the thin-bedded Waukesha limestone, and the section at Waukesha shows the Racine limestone resting upon that rock.

He goes on to say (p. 448):

> The Waukesha limestone, in its somewhat argillaceous character, and in the presence of Orthoceras undulatus and other Orthoceratites, might be regarded as representing the shale of the Niagara group, while the Racine limestone may represent the upper member of the group as developed in Western New York.

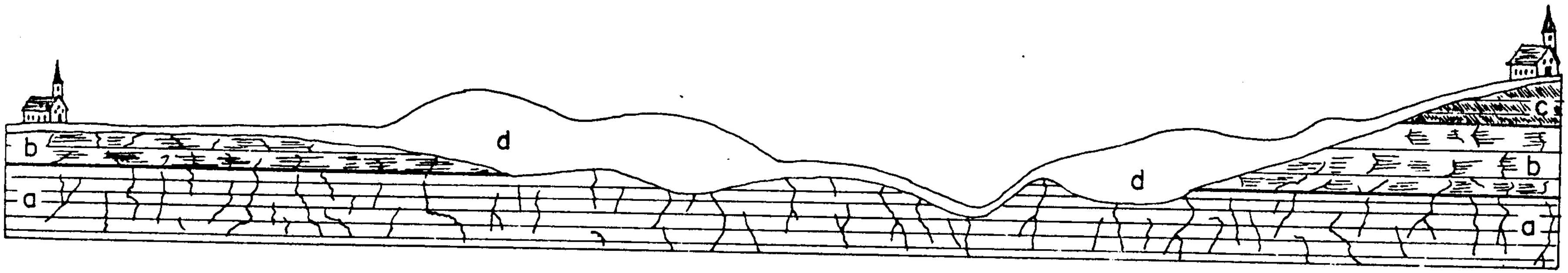


Figure 35. Section of the strata from Pewaukee to Waukesha by T. J. Hale. (a) thin-bedded Waukesha limestone; (b) heavy-bedded limestone of same general character with that below, but less argillaceous; (c) a porous limestone with small cavities and numerous crinoidal remains, recognized as the limestone of Racine; (d) drift (c) is equivalent to the Romeo Beds of the Racine Dolomite (a) and (b) are equivalent to the Waukesha Dolomite. After Hall (<u>in</u> Hall and Whitney, 1862, Figure 7).

It should be pointed out that Hall emphasizes the fact that the Waukesha beds are overlain by a soft, yellow limestone full of small cavities, which he named the Racine limestone and makes references to the section at Waukesha as exhibiting this relationship. As Hall and Lapham knew each other well (as evidenced by Lapham's correspondence in the Archives of the State Historical Society of Wisconsin) it is likely that they were well acquainted with each other's ideas and interpretations concerning he nature of the Waukesha Dolomite and are probably referring to the same outcrops and rock units.

Rominger (1862) made a brief statement concerning the stratigraphic relationships of the "Waukesha" (which is really Racine) near Milwaukee, but contributes no additional information to understanding the nature of the true Waukesha Dolomite.

Lapham (1865, unpublished field notes) described a more detailed section (Figure 36) from the quarries at Waukesha similar to Hall's (1862, Figure 7) more generalized section and consistent with previous descriptions of the Waukesha. He found seven feet of yellow, porous, fossiliferous limestone overlying two feet of white, more compact limestone, both of which he assigned to the Racine. These two units were underlain by four and one-half feet of cherty rock and 10 to 15 feet of regularly bedded, hard, whitish building stone. He assigned both of these units to the Waukesha. Lapham comments that the upper two units (Racine) make good lime while the lower two

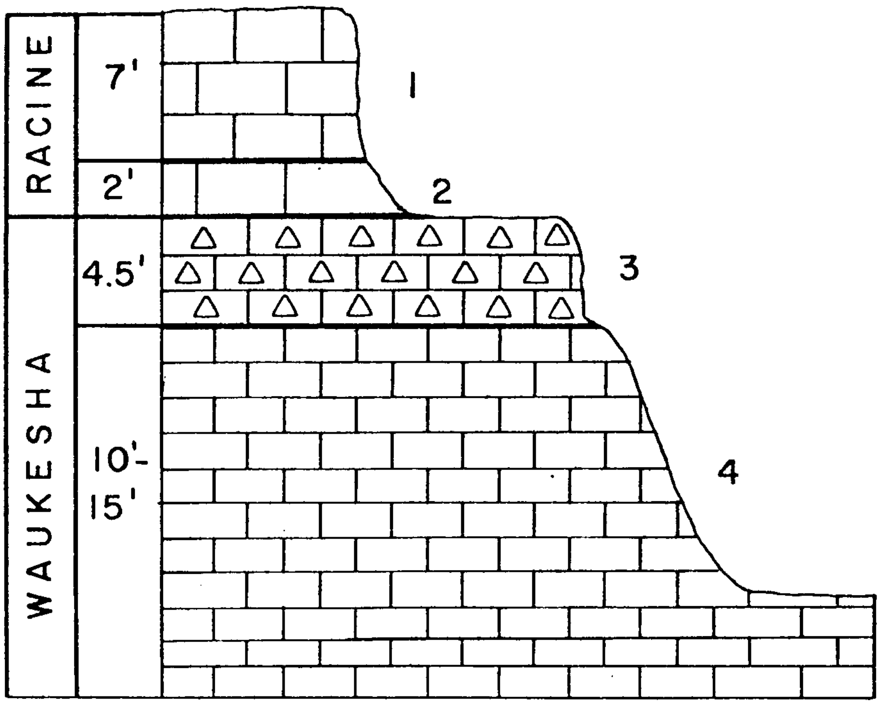


Figure 36. Lapham's (1865, unpublished field notes) section of the exposures in the quarries at Carrol College (locality 26, Appendix II) at Waukesha, Waukesha County, Wisconsin. See text for details.

(Waukesha) do not. This is probably due to the higher argillaceous content of the Waukesha. His description is significant as it is the only detailed description of any Waukesha Dolomite locality given by Lapham and presents his views of the characteristics and relationships of this rock unit.

Hall and Lapham do not give the exact location of the quarries at Waukesha, but they were probably the quarries located at Carroll College (locality 26, Appendix II) since these were the only quarries located in the village of Waukesha. They should not be confused with the quarries (locality 41, Appendix II) located along the Fox River north of town which may not have been operating at that time (see Loerke, 1978, for a discussion of the history of quarries in the area). The Carroll College quarries were then the only ones that exhibited a section as described by Lapham and Hall. Lapham visited the quarries along the Fox River in 1873 (unpublished field notes), but did not assign any of the rock units to either the Waukesha or the Racine. This seems to indicate that these particular quarries played no part in the formation of his ideas on the Waukesha Dolomite.

T. C. Chamberlin was the next individual to study the Waukesha Dolomite as part of his work on the geology of eastern Wisconsin. He (1877, p. 357) designated the Carroll College quarries as the type section of the Waukesha Limestone and presents a fairly detailed description of this locality, nearly identical to Lapham's (1865) description and interpretation, as follows:

> The term Waukesha limestone was selected many years since by Dr. Lapham, to designate the thin bedded strata that occur at Waukesha, and their equivalents elsewhere. This term was also adopted by Prof. Hall, in the report of 1862. It seems therefore desirable to retain a name that has already become fixed in the literature of the subject, although we shall be compelled to restrict its application and to entertain, to some extent, different views as to its relation.
>
> There are at Waukesha three classes of limestone. In the quarry near the college, the upper fourteen feet consist of a soft, yellowish, coarse-textured dolomite, that has been identified with unquestioned correctness, as the equivalent of the Racine limestone. This reposes upon regular, even beds of hard, compact, fine-textured, crystalline dolomite, of gray color and conchoidal fracture. It is characterized by the presence of much chert in the form of nodules, distributed chiefly in layers, coinciding with the bedding joints. These strata abound in Orthoceratites, but contain few other fossils. They constitute the type of the Waukesha beds. The transition to the Racine beds is quite abrupt, but does not correspond to a bedding joint. From three to four inches of the base of a thick layer are of compact rock, like that below, while the remainder has the open texture and fossils of the Racine beds.

Chamberlin was the first to remove the building stone beds along the Menomonee River in Milwaukee County from the Waukesha, placing them in the Racine Dolomite as they are not stratigraphically equivalent to the Waukesha. His designation of the college quarries as the Waukesha type section has been accepted by later workers (Shrock and Raasch) and I support this view for the following reasons:

1. The section exposed at the Carroll College quarries was well known to Lapham, Hall and Chamberlin, all of whom knew each other, and at least Lapham and Chamberlin did some field work

together.

2. These were the only quarries in Waukesha.

3. These were the only quarries known to show the contact of the Waukesha and Racine beds at that time. (Lapham briefly mentions that this contact is present along the Menomonee River in Milwaukee County; he was probably referring to the reef-nonreef contact in the Racine beds at the Schoonmaker Reef, locality 80, Appendix II).

4. Because the unit was named Waukesha it would seem inappropriate to continue using this name in association with the stratigraphically higher beds in Milwaukee County at the expense of the units around Waukesha.

5. Through core information it has been determined that the building stone beds in Milwaukee County are part of the Racine and lie above the upper cherty beds of the Waukesha Dolomite, therefore, they have no part in defining the Waukesha.

The college quarries were abandoned by 1891 (Loerke, 1978, p. 19). After abandonment, the exposures here readily disappeared, as the quarries were used as garbage dumps, and were eventually covered by expansion of Carroll College. Alden visited the site in 1904 (unpublished field notes) and found only an eight to ten foot exposure. In 1905, Kindle (unpublished field notes) described this locality as follows:

> An abandoned quarry in town just south of railroad, showing 7 feet of light creamy colored or nearly white Niagaran limestone in strata 3 inches to 6 inches thick. Fossils scarce; a few fragments of orthoceratites. Across the street from the above mentioned quarry is another exposure of the same beds and also about 15 feet of strata above those seen in quarry no. 1. These upper beds contain a fair number of fossils, but these are difficult to secure.

The last good description of these exposures was made by R. R. Shrock in 1930 (unpublished field notes). He described a section of the cherty Waukesha and overlying Racine beds at the athletic field east of the grandstand on the Carroll College campus (see Figure 38). This description closely matches that of Lapham (1851, unpublished field notes) and Chamberlin (1877). By 1970 only a few feet of the cherty beds were still exposed.

It should also be mentioned that the college quarries were the source of a large number of fossils in the last half of the nineteenth century; nearly every major museum in the eastern United States has some of these specimens (usually labelled just "Waukesha") in their collections. These specimens are not difficult to assign to either the Racine or Waukesha Dolomite based on lithology.

While the type section of the Waukesha Dolomite has largely disappeared, quarries along the Fox River, north of Waukesha, currently have good exposures of some of the same rock units.

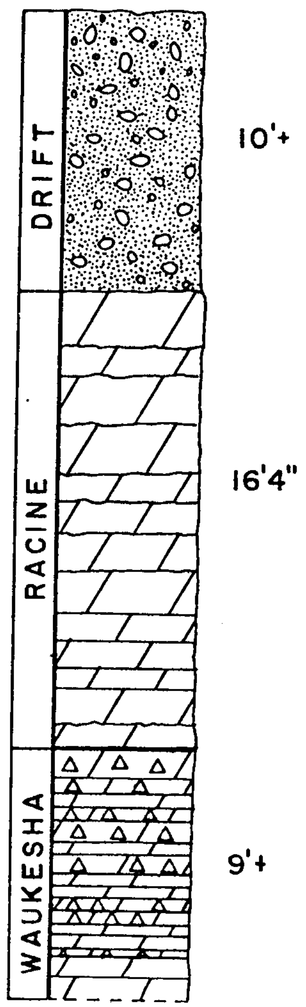


Figure 37. Section in the quarries at Carrol College (locality 26, Appendix II) at Waukesha, Waukesha County, Wisconsin. After Shrock (1930, unpublished field notes).

Lithologic Description at Waukesha

The Waukesha Dolomite is completely exposed in both quarries of the Waukesha Lime and Stone Company (see locality 41, Appendix II), and is rather uniform in its lithological characteristics in both of them. The total thickness of the Waukesha Dolomite is approximately 33 feet. Lapham (1865, unpublished field notes) gave a thickness of 20 feet at the College quarries, however, the lower contact of this unit was not exposed there at that time. This unit is overlain by the lower beds of the Racine Dolomite (Romeo beds) and is underlain by the Brandon Bridge beds. The upper contact is sharp in appearance, but might actually be somewhat gradational. The upper beds of the Waukesha contain abundant chert nodules, which abruptly disappear, but the enclosing dolomite gradually becomes more porous, vuggy, light-colored, and massive in appearance going up in the section. The top of the Waukesha Dolomite is considered to be marked by the top of the chert beds. The lower contact is marked by a prominent bedding plane overlying the last highly argillaceous, well-laminated, dark gray, non-porous, thin-bedded dolomite layer in the Brandon Bridge beds.

The thickness of the upper cherty layers is about nine to ten feet in the Waukesha Lime and Stone Company quarries, and seven feet at Carroll College (Shrock, 1930, unpublished field notes).

Lapham (1865, unpublished field notes) gave a thickness of four and one-half feet for the cherty beds at the Carroll College quarries. These cherty beds are thin-bedded, light brown to gray, fine-grained dolomite with little porosity and abundant chert. The chert is white to gray and appears as rounded nodules and discontinuous layers. The nodules commonly contain a well-preserved fauna. In the northwest corner of the west Waukesha Lime and Stone Company quarry J. Emielity (1965, personal communication) found well-preserved trilobites in the chert nodules in 1940. The chert is most abundant in the upper four feet of this unit although fifteen more widely spaced layers of chert occur in decreasing abundance downward.

Beneath the cherty beds are approximately 23 feet of non-cherty, gray, well-bedded, granular dolomite. From four to six feet below the bottom of the chert beds a zone of scattered orthoconic cephalopods occurs. In general, the rock is gray, thick-bedded, finely porous, mottled dolomite with scattered fine pelmatozoan debris. Approximately 16 feet from the bottom of the chert beds is an additional one foot eight inch thick layer of chert, with a prominent bedding plane running through its center. This chert is comprised of small, soft nodules, in contrast to the well-formed, hard nodules above. This layer is underlain by six feet of fine-grained, thick-bedded, stylolitic gray dolomite containing scattered orthocones, including Dawsonoceras. As mentioned previously, the base of the Waukesha

Dolomite is marked by a prominent bedding plane overlying Brandon Bridge beds.

Description of Other Exposures

Several other complete sections through the Waukesha Dolomite are present in southeastern Wisconsin. At the Vulcan Materials quarry at Ives in Racine County (see locality 9, Appendix II) the Waukesha is 66 feet thick and is a thin- to medium-bedded, argillaceous, highly cherty, gray dolomite. The contact with the overlying Racine Dolomite may be gradational. The upper 16 feet of the Waukesha here is characterized by abundant chert, giving the rock a crumbly appearance throughout the quarry. The rock is poorly fossiliferous, but does contain a few specimens of the trilobite *Stenopareia* and orthocones in the lower beds.

At the Vulcan Materials quarry in Franklin (see locality 70, Appendix II) a similar section of the Waukesha is exposed, but there is no concentration of chert in the upper layers as at Racine and Waukesha. The unit is more fossiliferous in Franklin with small pelmatozoan fragments being common on some bedding planes; the trilobite *Stenopareia* is not rare in the lower layers.

In southeastern Wisconsin water-well logs the approximate position of the Waukesha Dolomite can be determined, if the underlying Brandon Bridge beds are recognized, but the presence of locally abundant chert beneath the Brandon Bridge and some limited chert beds in the upper Brandon Bridge and in the Racine makes correlation based on chert beds alone difficult. Cores and water-well logs indicate that near Lake Michigan most of the chert in the Silurian, including that in the Waukesha, disappears over a short distance towards the east. For example, a core (Mi-7) near the mouth of the Kinnikinic River in Milwaukee shows a typical sequence of cherty Silurian rock, while in another core (Mi-7A), located about 1000 feet northeast of Mi-7, all but five feet of the chert beds disappears. This same relationship can be seen in the cores in the southeastern part of Sheboygan County. It should be noted, however, that a number of the pre-1960's water-well logs are very inconsistent in showing chert beds; some show no chert or significantly less than is known to exist at certain localities.

Lateral Extent

On a lithologic basis the true Waukesha Dolomite correlates with the Markgraf Member of the Joliet Formation in northeastern Illinois (Raasch, 1955, unpublished manuscript). A short distance north of the Waukesha Lime and Stone Company quarries, the Waukesha cannot be identified with any certainty, but may be equivalent to wither Unit C or D under the cephalopod layer. If Unit D is the Waukesha then this would represent the first occurrence of reefs in the Waukesha Dolomite.

Age

The age of the Waukesha Dolomite has not been accurately determined based on biostratigraphic evidence. Boucot and Berry (1970) assigned the Waukesha Dolomite a Wenlockian age based on its position between better-dated units. Liebe and Rexroad (1977) assigned the lower Markgraf in northeastern Illinois a probable Wenlockian age based on conodont evidence. The occurrence of the crinoid *Petalocrinus* and the trilobite *Stenopareia* indicates a possible Llandoverian to Early Wenlockian age in the Franklin quarries, which agrees with graptolite data from these same beds.

Usage Outside of Study Area

The name Waukesha has been used for various stratigraphic units, other than the Markgraf beds, in northeastern Illinois, which has resulted in a great deal of confusion. The problem arose when Savage (1926) applied the name Waukesha to well-bedded building stone beds overlying his Joliet Formation. He thought these beds underlaid the Racine, but, in reality, they were inter-reef beds of the Racine Dolomite. Willman (1943) restricted the name Waukesha to the lower portion of Savage's Waukesha, recognizing that most of the overlying beds were really Racine inter-reef beds. Willman (1973) later abandoned the name Waukesha after determining that the Waukesha was equivalent to part of the Joliet Dolomite.

Racine Dolomite

Introduction

The Racine Dolomite is the most complex Silurian rock unit in southeastern Wisconsin and the surrounding area due to the presence of a large number of reefs and their relationship to the Michigan Basin. The reefs have influenced the characteristics of the Racine on both a local and regional scale. Locally, reefs and the surrounding reef-controlled beds interrupt normal depositional characteristics of the inter-reef beds, making correlation of the subdivisions of the Racine difficult over large areas. The reefs, because of their resistant nature, are the most common exposures of this unit. On a regional scale, reef disturbance is variable although it generally increases towards the east where the thick carbonate bank deposits of the western edge of the Michigan Basin are located. In this area, reefs are common and completely control the characteristics of the inter-reef beds. This can be seen by comparing the Racine beds at Ives (locality 9, Appendix II) with those at Franklin (locality 70, Appendix II) and Waukesha (locality 41, Appendix II).

The Racine is well known for its highly diverse and abundant fauna, which is primarily found in the reef beds. No other Silurian rock unit in the Central United States has as high a faunal diversity as the Racine Dolomite and its equivalents, and some of the first Silurian fossils described in this region were described from the Racine (Hall, 1861a).

It is also interesting to note that the first Paleozoic carbonate buildup in North America to be described as a reef (Hall, 1862) is located in the Racine Dolomite (Schoonmaker reef, locality 80, Appendix II) of this area, and for 80 years the Wisconsin Racine reefs were the classic examples of Silurian reefs throughout the world, a place of importance shared only with those on the island of Gotland in the Baltic Sea.

History of Study

Lapham (1851, in Foster and Whitney) recognized several rock units in southeastern Wisconsin lying above the Ordovician rocks and below his Unit IX ("shaly limestone") (see Table 43). The lowest unit (VI "Waukesha Limestone") has been previously discussed; Lapham considered the building stone beds along the Menomonee River in Milwaukee County to be part of this unit based on lithologic similarities. Overlying the Waukesha was Lapham's Unit VII, "a soft yellow limestone" which could be seen in contact with the underlying Waukesha in several places. Overlying this was Unit VIII "the geodiferous limestone of Eaton, or Niagaran Limestone of the

New York reports." Lapham suggested that Unit VII might be considered to be the lower portion of Unit VIII. Units VII and VIII encompass beds now considered to belong to the Racine Dolomite, but the relationships between these two units were not well understood at that time because of the presence of reefs. Lapham's geodiferous beds are based on the reefs, which rise above the building stone beds in Milwaukee County. Lapham did not understand the nature of these buildups and assumed that they represented a younger stratigraphic unit than the building stone beds.

T. J. Hale (1860, unpublished field notes), who was working for Hall at the time, used the name "Racine Limestone" in his field book, but the name was first published by Hall in 1861 (p. 5). He stated:

> The investigations upon the rocks of the Niagara group and associated strata, have likewise been continued, and I have arrived at certain results fortified by the occurrence of numerous fossils which lead me to conclude that the Racine limestone, mentioned in a former report, is the upper member of the Niagara group, while the heavy bedded mass below is but the expansion of the limestones of the Clinton group. This opinion in regard to the last named rock I advanced some years since, but having until this time no satisfactory evidence of the occurrence of the higher member of the Niagara group, I have been forced to admit that the whole had merged in one great calcareous mass.

The earlier report in which Hall makes mention of the Racine and to which he refers could not be found.

Hall (1862, p. 67-69) formerly designated the Racine Dolomite as a lithostratigraphic unit, describing it as follows:

Lying above the limestone just described, we find a friable yellow or ochreous limestone, readily decomposing on its exposed surfaces, and marked by numerous small cavities. This rock was recognized by Mr. I. A. Lapham, in his original section of the formations of Wisconsin, as a soft yellow limestone, lying above the Waukesha limestone; the position recognized in the section at Waukesha...

This limestone may be regarded as the upper member of the Niagara group; but owing to denudation, or other causes, it is not everywhere present. It is a gray (rarely bluish gray) or buff-colored magnesian limestone, crystalline in texture, very tough and compact in some portions, but extremely porous or carious, either from the removal of fossils or other substances, leaving the cavities lined with an ochreous deposit, which is sometimes granular or pulverulent, and elsewhere has a minute stalagmitic character. The great number of fossils render its texture and fracture extremely uneven.

The rock is known at Racine as its best development; it is seen in the section at Waukesha, and again at Grafton, and can be traced northward along the lake shore.

Examinations have shown this rock to extend from Kewaunee, on the shore of Lake Michigan, southward, with a constantly increasing width, at least as far as Waukesha, and continuing thence to the south line of the State. It may be considered identical with the Leclaire limestone of Iowa, holding precisely the same geological position, and containing some similar if not identical fossils; and both limestones must be regarded as a part of the Niagara group.

This member of the group has not been recognized in the Lead region of Wisconsin.

The investigations regarding this rock, and the subdivisions which may be founded upon both physical and paleontological characters, are still in progress, and the results will be given in a future Report.

The entire thickness of this limestone group is between three hundred and fifty and five hundred feet, in the eastern part of the State; the lower, more compact and less fossiliferous portion, is from two hundred to two hundred fifty feet thick.

He also described the building stone beds in Milwaukee County (1861, p. 61-64). In particular, he mentioned the presence of a reef at Wauwatosa which is surrounded by Waukesha beds. He referred the reef to the coralline or geodiferous limestone as had Lapham in previous years. Rominger (1862, p. 136) described the same locality and found:

> the Waukesha limestone is in reality the superincumbent rock, and that the Niagara limestone only in disseminated spots protrudes by volcanic action in dome-like knobs through the otherwise nearly horizontal or merely undulating strata of the Waukesha limestone.

At Racine, Lapham (1865, unpublished field notes) described a mound of geodiferous rock being overlain by Racine limestone (see Figure 58). His diagram and notes clearly indicate a reef core and flank bed exposure as was later described by Chamberlin (1877). At the same time Lapham made a revised section of the Silurian rocks in southeastern Wisconsin. He now placed the geodiferous beds under the Waukesha doming up to the level of the Racine (his earlier mentioned soft yellow limestone), again this was due to his miscorrelation of the building stone beds in the area and his failure to recognize reefs.

Chamberlin (1877, p. 360-377) gave the first and only detailed description of the "Racine Beds" of the "Niagara Limestone" throughout the state. As previously mentioned, he redefined the underlying Waukesha beds and their relation to the Racine beds (1877, p. 357-360). He also divided the Racine into two parts based on faunal differences and termed the upper part the Guelph Beds (p. 377-380):

> The Guelph limestone constitutes the uppermost subdivision of the Niagara Group in Wisconsin. In its lithological character, it does not differ essentially from the Racine limestone, being in general, a rough, thick bedded, irregular dolomite, usually quite free from impurities, and of buff, gray, or blue color. The distinction between the two subdivisions is a paleontological rather than a physical one. In the latter respect there is less difference between these than either of theother members of the group. There was evidently no marked change in the physical history of the region, but the same conditions continued from the beginning of the deposit of the Racine limestone to the close of the formation of the Geulph beds. In the interval, however, the life underwent a change by the introduction of the species that characterize the Guèlph horizon. This introduction was gradual, so that many localities show a mingling of the two faunas.

Chamberlin (1877, p. 360) described the characteristics and distribution of the Racine as follows:

> Overlying the Waukesha beds at the south, and the Upper Coral beds at the north, is a magnesian limestone to which the term Racine has been applied, from its important development at that point. It has an extent of about 200 miles, reaching from Illinois to near the extremity of the Green Bay peninsula, and attains a surface width of thirty miles. In its southern portion, where it rests upon the Waukesha limestone, it consists of reef-like masses of conglomeratic rock, which, on the denuded surface, appear as mounds or ridges, and which graduate into various kinds of porous, granular, irregularly bedded rock, or into fine grained, compact, even-bedded strata, the whole constituting a formation of exceedingly irregular structure.

Chamberlin's greatest contribution to the understanding of the Racine and other rock units in southeastern Wisconsin is that he recognized the presence of significant lateral variation within the Racine and, therefore, grouped a number of beds that had been previously separated:

> It appears, then, that in the southern counties there are three well marked classes of limestones, with intermediate gradations, one class, consisting of very irregular, often brecciated or conglomeratic dolomite, forming masses that usually appear as mounds, or ridges of rock, of obscure stratification, a second class, formed of pure, soft, granular dolomites, a part of them calcareous sand-rock, and a third class, consisting of compact, fine grained, regular, even beds. We have demonstrated that the three forms change into each other when traced laterally horizontally. They were therefore formed simultaneously.

In this classification Chamberlin included the building stone beds around Milwaukee in the Racine Dolomite, which had previously been considered part of the Waukesha by Lapham, Hall, and Rominger. He also included the reefs along the Menomonee River in the Racine which Lapham and Hall had considered to be exposures of the geodiferous limestone (even though Hall recognized their reefal nature).

Alden (1906) followed Chamberlin's designation of the Racine beds and stated that this unit underlies the drift throughout most of Milwaukee County. He identified all of the Silurian rocks in his chart on artesian wells (p. 12) as Racine, but this appears to have been an oversight.

Alden (1918) gave a similar description of the Racine beds.

Shrock (1938, unpublished manuscript; 1939) followed Chamberlin's earlier definition of the Racine, but did not separate the overlying Guelph beds.

Raasch (1955, unpublished manuscript) recognized that the Romeo beds of the Joliet Formation were the same as the Racine beds overlying the Waukesha Dolomite at Waukesha.

It should be pointed out that the name "Racine Dolomite" was not originally applied to just reefal beds as were a number of equivalent or near-equivalent units in the Midwestern United States. Primary examples are the Leclaire Limestone of eastern Iowa (Hall, 1858) and the Huntington Limestone of northern Indiana (Kindle, 1903). Both of these names were later found to be applicable only to reefal beds, and are no longer used (Pinsak and Shaver, 1964; Hinman, 1968).

Thickness and Upper and Lower Contacts

The upper surface of the Racine is an erosional unconformity. The relationship with the overlying Givetian, Middle Devonian rocks indicates that the Racine was subjected to a major period of erosion before Middle Devonian deposition; the Devonian covers this unit in only a small area along the eastern edge of the study area. The Racine has been further eroded by post-Devonian erosion, including recent Quaternary glacial activity.

The original thickness of the Racine Dolomite is therefore unknown. The Racine, and the Silurian rocks in general, display a thickening towards the northeast which can be demonstrated by comparing the section at Ives (locality 9, Appendix II) in Racine where the Silurian is about 300 feet thick and is overlain by

Quaternary sediments to Milwaukee at core Mi-5 where the Silurian is about 470 feet thick and unconformably overlain by the Middle Devonian and Quaternary sediments. Just north of the study area at Oostburg, Sheboygan County, the Silurian is 610 feet thick and is again overlain by Quaternary sediments. This thickening trend is primarily a result of the increase in thickness of the Racine in relationship to the carbonate bank on the western edge of the Michigan Basin.

The lower contact of the Racine Dolomite has been placed at the highest level of a thick sequence of cherty dolomite, representing the Waukesha Dolomite, in water-well logs. There are some thin chert beds within the Racine, but they are not widespread in the study area. The exposed contact is variable. In areas where reefs are developed the contact is sharp with the underlying cherty and argillaceous Waukesha. In areas where no reefs are present the contact may be slightly gradational, or occur as interbedded Racine and Waukesha lithologies, such as indicated in the Milwaukee cores. Other areas, such as at Franklin (locality 70, Appendix II) and Waukesha (locality 41, Appendix II) the contact is sharp. The elevation of the lower contact is locally quite variable due to compression of the underlying beds by reefs in the Racine.

Inter-reef Beds

The lowest subdivision of the inter-reef beds of the Racine Dolomite are the Romeo Beds. This unit appears to have a gradational contact with the underlying Waukesha in some areas, but it is very sharp in others. The Romeo is a massive, coarse-grained, porous, vuggy, fossiliferous gray dolomite. The unit appears throughout southeastern Wisconsin but is most conspicuous in areas where the overlying Lannon Beds are more argillaceous.

The Romeo is succeeded by the Lannon Beds which are well-bedded, argillaceous, non-porous, fine-grained, poorly fossiliferous dolomite. These beds appear to restrict reef development in some areas, however, in the northern half of Milwaukee County reefs are well developed in this unit. In the Racine area, the Lannon Beds constrict some of the reefs and at Franklin small isolated reefs are terminated by Lannon deposition. At Waukesha no reefs are found in the well developed Lannon Beds. This trend continues north to the Lannon area where over fifty feet of Lannon Beds overlie reefs in the Romeo Beds. To the east of Waukesha and Lannon, Lannon Beds lithology characterizes nearly lall of the Racine inter-reef beds which reach a thickness of at least 150 feet. These are the building stone beds which Lapham and Hall considered to be part of the Waukesha Dolomite. The true cherty Waukesha is present beneath these beds.

The reefs in this area (northern half of Milwaukee County) began their development high in the Lannon Beds and not in the Romeo as elsewhere.

North of Milwaukee and Waukesha Counties, the Racine inter-reef beds are not as well exposed. In the area around Germantown the inter-reef beds are more coarse-grained than typical of the Lannon area, but are more distinctly bedded than the inter-reef beds around Racine and Franklin, however, these beds are stratigraphically higher than those to the south so a direct comparison is not possible. No subsurface information is available for this area.

In the Cedarburg-Grafton area the inter-reef beds are thick-bedded, coarsely crystalline to granular, locally fossiliferous dolomite. Some of these beds contain the "Guelph" fauna first described by Chamberlin (1877).

Farther north the Racine inter-reef is poorly fossiliferous.

Racine Dolomite Reefs

Figure 38 shows the distribution of Racine reefs in the study area. The earliest reefs in the Racine Dolomite appear at the base of the Romeo Beds as seen at Racine, Franklin, and Waukesha. As mentioned before, the Romeo Beds are locally lithologically and paleontologically similar to these early buildups. The distribution

Figure 38. Distribution of Racine Dolomite (Silurian) reefs in the study area. Questionable reefs are not indicated. Closed circles are pelmatozoan-rich reefs, such as those found at Racine (locality 11, Appendix II) and Franklin (locality 70, Appendix II). The pelmatozoan-poor reefs in the northern half of Milwaukee County, such as Schoonmaker reef, are indicated by X.

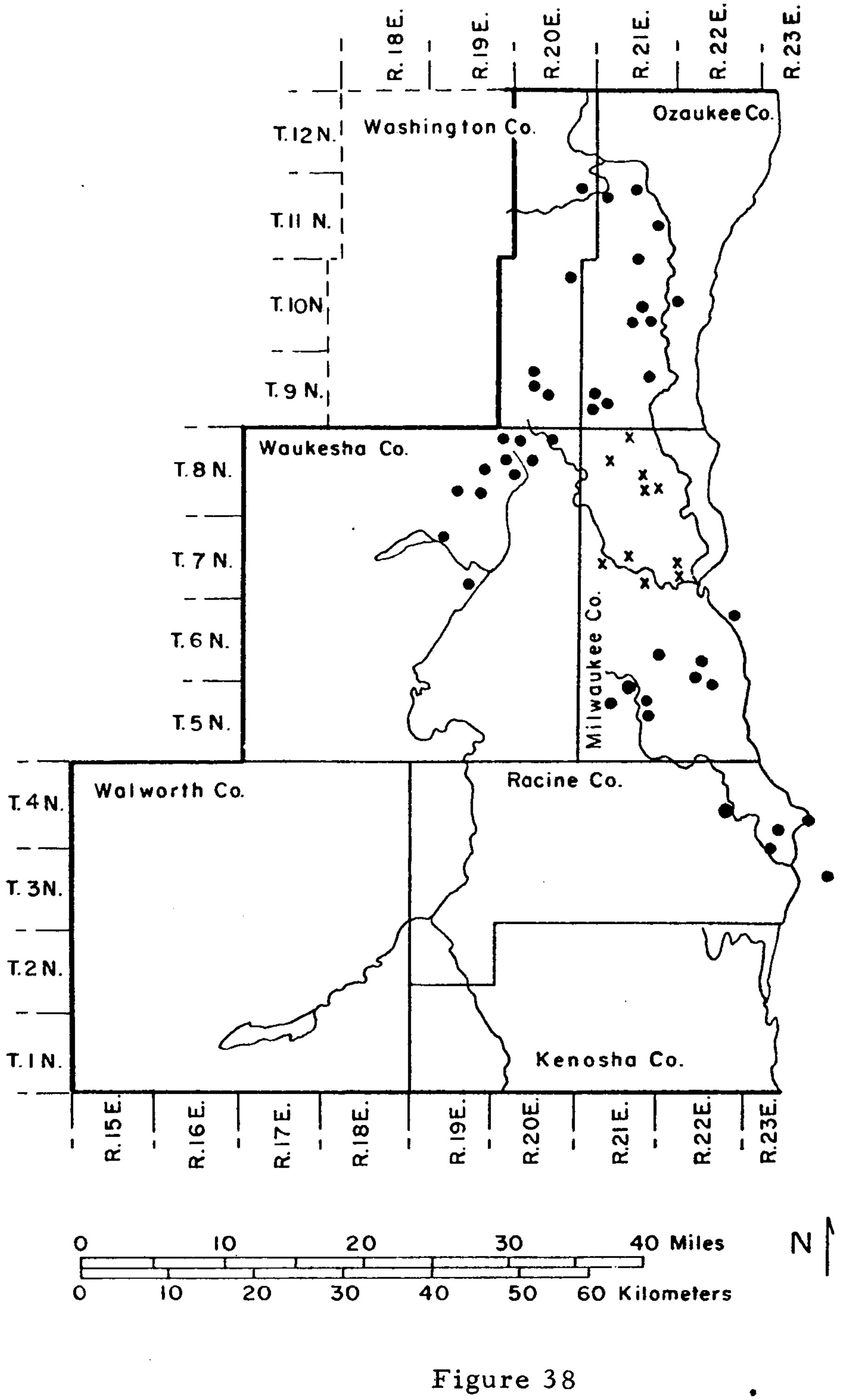

R. 18E.
R. 19E.
R. 20E.
R. 21E.
R. 22E.
R. 23E.
T. 12N.
T. 11 N.
T. 10N.
T. 9 N.
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
T. 4 N.
T. 3N.
T. 2N.
T. 1 N.
Washington Co.
Ozaukee Co.
Waukesha Co.
Milwaukee Co.
Walworth Co.
Racine Co.
Kenosha Co.
R. 15E.
R. 16E.
R. 17E.
R. 18E.
R. 19E.
R. 20E.
R. 21E.
R. 22E.
R. 23E.
0 10 20 30 40 Miles
0 10 20 30 40 50 60 Kilometers
N

Figure 38

of the Romeo reefs is variable. In the quarry at Ives the reefs are common and continue their development through the Lannon Beds. At Franklin to the northwest most of the Racine reefs are localized in the center of the quarry area and continued to develop through Lannon deposition, but a few isolated reefs were terminated by the Lannon beds. At Waukesha, farther to the northwest, only one small buildup has been found in the extensive exposure of the Romeo Beds and it is terminated by Lannon deposition. At this locality, however, the Romeo Beds are nearly identical lithologically to many of the Racine reefs. To the northeast, at Sussex and Lannon, the doming of the Lannon Beds suggests that numerous Romeo reefs underlie these beds and were terminated by Lannon deposition, but had been topographic high areas over which the Lannon beds were draped. In the area around Menomonee Falls and Germantown a number of reefs are exposed at higher levels than those in the Romeo at Lannon; they are similar to the reefs at Ives and Franklin and are surrounded by Lannon Beds, suggesting that they were able to continue their development through the Lannon.

The reefs developing in the Romeo Beds are all characterized by having small structureless cores with well developed pelamtozoan-rich flank beds constituting a major portion of the reef. The rock is vuggy, porous, massive, crystalline dolomite.

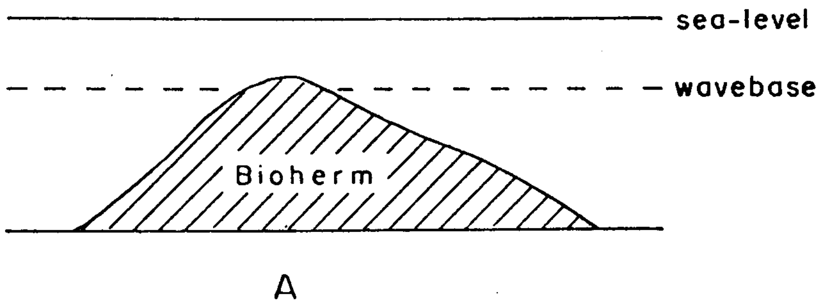
At the close of Lannon deposition the reefs at Racine and

Franklin continued to develop, expanding into large structures. The inter-reef beds surrounding these reefs are coarsely crystalline, thick-bedded, and vuggy, but are seldom fossiliferous. In Ozaukee County a number of reefs are found in the upper beds of the Racine Dolomite; these are not appreciably larger than those at Franklin and Racine and may have started development at a higher level. They differ from the reefs at Racine by the greater abundance of tabulate corals, the limited distribution of pelmatozoans, and the coarse-grained, almost sandy appearance of some of the flank and inter-reef beds. These reefs occupy a position almost 200 feet above the top of the truncated reefs at Racine and are therefore somewhat younger.

Another type of reef is present in a limited area of southeastern Wisconsin. In the center of Milwaukee County the Lannon Beds thicken to over 150 feet and reefs appear with a noticeably different biota and lithologic character. These reefs include the Schoonmaker reef in Wauwatosa and the Moody reef in Milwaukee. These reefs have developed at a horizon up to 100 feet above the base of the Racine as indicated by Shrock (1939). They have a dense, fine-grained texture, being less porous than the reefs around Racine. The core areas of these reefs are larger than the cores of the reefs at Racine and the flank beds are volumetrically not as important. The most notable differences between these two reef types is the biotic composition. The Wauwatosa reefs are conspicuous in the near absence of pelmatozoans while the same nonpelmatozoan genera are found in both reef types although the species of these genera are commonly different. Day (1877) and Chamberlin (1877) both noticed the difference in the biotas of the reefs in this area. The reason for the difference between these two types of reefs is unknown.

The pinnacle reefs of the Michigan Basin show two major stages of development related to their proximity to wavebase (see Figure 39). Gill (1977) defined a lower, crinoid-bryozoan biohermal stage which developed in a low-energy, below-wavebase position. As this bioherm reached wavebase level a gradual change to a higher-energy, above-wavebase coral-algal organic reef stage developed. The Wisconsin reefs appear to represent a below-wavebase stage of development with the possible exception of those reefs in the northern half of Milwaukee County (for example, Schoonmaker reef).

The Silurian reefs formed topographic high areas during their development and after their termination may have remained as high areas which may have been enhanced by erosion of less resistant materials; the reefs because of their dense, massive nature are more resistant to erosion than the surrounding inter-reef beds. The irregular topography of the reefs resulted in doming of the overlying Middle Devonian beds as seen in the Lannon Beds in Waukesha County. Evidence for this is seen in Milwaukee County where the top of the Moody reef is 30 feet higher than the base of the Devonian



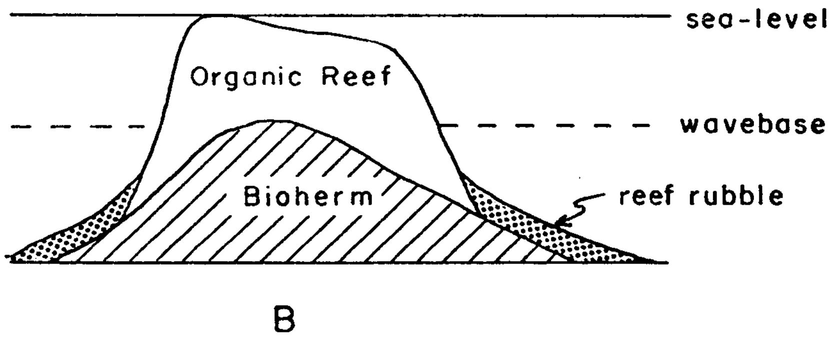


Figure 39. Diagram showing the two major stages of pinnacle reef development in the Michigan Basin Silurian and their relationships to wavebase and sea-level. (After Gill, 1977, Figure 6-1).
(A) shows the development stage of low-energy, below-wavebase bioherm.
(B) shows the above-wavebase, high-energy organic reef stage.

in the vicinity. An examination of the Middle Devonian Milwaukee Formation in Estabrook Park, Milwaukee County (see Figure 40) shows a number of domes similar to those seen at Lannon, which appear to be controlled by underlying Racine reefs. A similar dome is present in the Devonian Lake Church Formation at the Lake Shore Stone Company quarry at Lake Church, Ozaukee County (locality 125, Appendix II) (Mikulic, 1977).

Equivalent Units Outside Wisconsin

The Racine Dolomite has been identified in the Chicago area, where it is lithologically almost identical to exposures in Wisconsin. The Romeo and Lannon beds have been separated from the Racine in this area; the Romeo is considered to be a member of the Joliet Formation (Willman, 1973). Lannon-like beds overlie the Romeo in northeastern Illinois where they are termed the Sugar Run Formation, which is overlain by the Racine (Willman, 1973). The Sugar Run beds are difficult to recognize in the Chicago area subsurface and appear to be absent in many areas (Hartz Engineering, 1975). The rest of the Racine in the Chicago area is very similar to the Racine in Wisconsin. The upper Racine becomes much more argillaceous in this area and cherty units also increase. The largest reefs are also present in this area. To the east, the Racine is equivalent to most of the Wabash Formation and possibly to the Louisville

Figure 40. East wall of old Milwaukee Cement Company quarry at Mill No. 1 along the Milwaukee River, just south of railroad bridge, in Estabrook Park, Milwaukee County, showing doming in the Middle Devonian Milwaukee Formation probably caused by underlying Racine reefs. (B) is just north of (A). Photographs courtesy of the Wilsconsin Geological Survey (A = No. 490; B = No. 491) and were taken probably in the 1920's.

Figure 40 A

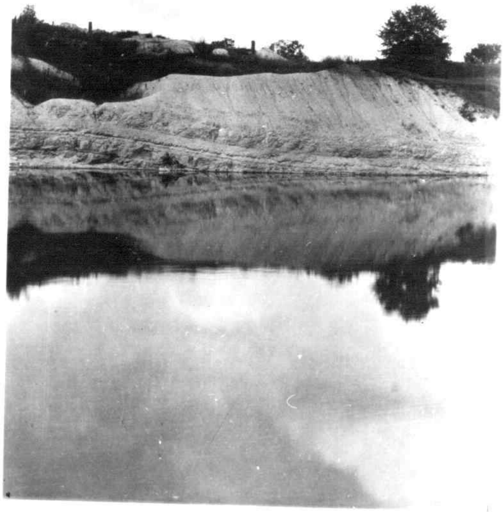


Figure 40 B

Limestone (Willman, 1973).

Age

The age of the Racine Dolomite ranges from Late Wenlockian through Ludlovian (Berry and Boucot, 1970, p. 200). It has been suggested by Shaver (1976, personal communication) that some of the reefs (such as Thornton in Cook County, Illinois) may have existed into the Pridolian. There is no new evidence in Wisconsin on the age of the Racine is post-Early Wenlockian.

Fauna

The Racine Dolomite has a very diverse fauna primarily because of the presence of numerous highly fossiliferous reefs. G. Raasch (1966, personal communication) reported finding over 200 different taxa (not including stromatoporoids, bryozoans, sponges, and micro-fossils) from the Horlick reef at Racine, Racine County, alone. The Racine Dolomite contains one of the largest pelmatozoan faunas found in any single Silurian stratigraphic unit in the world. Most Silurian invertebrate groups are well represented in this unit, however, many of the Racine fossil groups are in need of revision since they have received little attention since the early part of this century. The trilobites are currently being revised.

Waubakee Dolomite

Name and Previous Usage

The Waubakee Dolomite has long been known to geologists working in southeastern Wisconsin who placed it stratigraphically between the "Niagaran" rocks and the Devonian based on its outcrop pattern in Milwaukee County. The earliest mention of the rocks now termed the Waubakee Dolomite was made by Lapham (1851, in Foster and Whitney, p. 170). Lapham described this unit (His Unit IX) as "a shaly limestone. . . found at one locality, representing some of the formations that, in New York, are interposed between the geodiferous and the corniferous limestones." Hall (1851, in Foster and Whitney, p. 173) commented on Lapham's Unit IX as follows:

> . . . the shaly limestone of Mr. Lapham's section represents the Onondaga salt group, which, however, has so far thinned out as to be of little importance. I had no opportunity of seeing the two last members in place; but the specimens of the shaly limestone are very similar to the thin layers of hydraulic limestone in the upper part of the Onondaga salt group of western New York.

In 1862, Hall further described these beds as being equivalent to the Onondaga Salt Group and made the following observations:

> The formation originally represented in the section of the rocks of Eastern Wisconsin, by Mr. I. A. Lapham, as a "shaly limestone," proves, on farther investigation, to be the limestone of the Onondaga-salt group. An examination of the locality has shown that this peculiar granular gray limestone, separated in their laminae by seams of shaly matter, is precisely identical in character

with some of the middle and higher beds of the Onondaga-salt group in western New-York. It likewise holds the same geological position, being above the limestone of the Niagara group and below a limestone which contains fossils similar to those of the Upper Helderberg group of New-York, Ohio and Michigan.

The outcrop of the Onondaga-salt group is in low or level ground, a few miles to the northwest of Milwaukee. In this level country, with accumulations of drift at intervals, it is difficult to trace the line of outcrop for any long distance; but from the known exposures of the rock below and that above, we learn approximately that this formation extends in an irregular curving line from the lake shore at the northern part of Milwaukee northwesterly to the western limits of the township of Granville, and thence bends more abruptly eastward through the township of Mequon to the lake shore below Pierceville.

The rock is a thinbedded and often thinly laminated gray or ash-colored magnesian limestone, the laminae separated by thin seams of tar or black glazed shaly matter. On freshly fractured faces across the lines of bedding, the narrow black lines indicating the shaly partings are clearly visible, and give the rock a peculiar character which I have not observed in any other limestone.

This group has been traced from New-York through Canada West, and, as I have elsewhere shown, the line of its trend extends into Lake Huron to the south of the Manitoulin islands, and it appears in the small islands approaching Mackinac. It forms the base of Mackinac island, and indeed the principal part of the island, except the elevated portions; and it also forms some of the small islands on the north of Mackinac, where gypsum was formerly found; and it continues to Point St. Ignace.

From hence westward, the Onondaga-salt group has been entirely denuded and excavated to form the northern portion of Lake Michigan, while the northern boundary of that lake is in the Niagara group. The line of outcrop, following the course of the Niagara group, shows that the place of this rock would lie along the western shore of Lake Michigan; but it only on approaching the mouth of the Milwaukee river that there appears to be a slight depression of the strata, which allows the outcrop to extend a little to the westward; and by this means has been preserved.

Chamberlin (1877, p. 390-394) identified these beds as belonging to the lower Helderberg Limestone. He gave the first detailed description of the exposures along Mud Creek (locality 87, Appendix II) in Milwaukee County, which was most likely the locality referred to by Lapham and Hall. Chamberlin correlated these beds with previously mentioned exposures just west of Waubeka (localities 122 and 123, Appendix II), Ozaukee County. He also believed that the same rock unit was exposed under the Devonian cement rock in the cement quarries about one mile from the Mud Creek exposures. He also noted that this unit had a patchy distribution and apparently did not form acontinuous belt around the Devonian outcrop area.

Alden (1906, p. 2) described the exposures along Mud Creek and named them Waubakee for the exposures near Waubeka in Ozaukee County. He stated that these beds were equivalent to a "portion of the Cayuga Group of New York."

Cleland (1911, p. 7) followed Chamberlin's example and assigned the beds under the cement rock (Milwaukee Formation) to the Waubakee. He further (p. 8-11) described Waubakee exposures between the Milwaukee Formation and the underlying Silurian in the Lake Shore Stone Company quarry (locality 125, Appendix II) near Lake Church and in the Druecker's quarry (locality 120, Appendix II) near Port Washington, both in the northern part of Ozaukee County. At Lake Church he indicated (his Figure 7) that the "Waubakee" beds are separated from the Silurian by an angular unconformity.

Alden (1918, p. 95-99) gave a more detailed description of the "Waubakee" in Milwaukee and Ozaukee Counties and considered the remaining outcrops were "probably only a very small erosional remnant" of its former distribution.

Raasch (1928, 1929, unpublished field notes; 1935) assigned the "Waubakee" beds at Lake Church, Druecker's, and the cement quarries to the Devonian, stating that "all exposed sub-Devonian contacts are with the Racine beds." Lithologically, he found that none of these former "Waubakee" localities were very similar to the Mud Creek and Waubeka exposures. Raasch identified the rocks immediately underlying the Milwaukee Formation at the old cement quarries as being equivalent to those at Druecker's and Lake Church which belong to the Devonian Lake Church Formation.

Berry and Boucot (1970) suggested that the Waubakee is a local *Lepreditia*-rich facies of the Racine Dolomite.

Klug (1977) summarized past work on the Waubakee and reported that sample he processed from the Mud Creek exposures were barren of conodonts.

Stratigraphic Position and Depositional Environment

Very little is really known about the Waubakee Dolomite. The two outcrop areas are lithologically very similar, but are widely separated, and as such, may represent similar depositional environments that may not be lateral equivalents. The age of outcrops of this unit has not been established because of the total lack of biostratigraphically useful fossils. This is also true for the Thiensville beds in Milwaukee County, which have been identified as with the Waubakee in the past. The Thiensville at the type locality in Ozaukee County does contain Middle Devonian fossils and unconformably overlies the Silurian, however, the assignment of the Thiensville beds in Milwaukee County to the Devonian is based on the assumption that these beds occupy the same stratigraphic position. Evidence for this relationship has recently been discovered in core Mi-5 (Riverside Park, Milwaukee) where a major unconformity separates the Thiensville from the Silurian.

The Waubakee beds are also difficult to interpret since they are not seen in contact with any Silurian or Devonian rocks. As mentioned earlier, Raasch (1935) assigned all the beds formerly termed Waubakee in contact with Silurian and Devonian rocks to different Devonian stratigraphic units. It is possible that some, or all, of the Waubakee beds might be Devonian in age as suggested by Chamberlin (1877), but none of the Devonian units in the area are lithologically similar to the Waubakee, making this interpretation unlikely. It appears that the Waubakee occurs at a horizon below the lowest Devonian rocks.

It is not known if the Waubakee is laterally equivalent to any Racine beds and nothing is known about the nature of the contact if it overlies the Racine. In both areas of its occurrence, the Waubakee is found at lower elevations than nearby or eastward exposures of the Racine Dolomite. This might indicate that the Waubakee is either laterally equivalent to the Racine or that it was deposited in depressions of channels in the surface of the Racine. About 1.5 miles to the southeast of the type section, in the vicinity of Waubeka, Racine Dolomite outcrops about 12 feet lower than the highest Waubakee exposures. Considering the eastward or northeastward dip of the bedrock in this area and the fact that the nearest Devonian is seven miles away, this relation presents difficulties in assigning the Waubakee at the type section to a position overlying the Racine Dolomite. In Milwaukee, Waubakee beds at the West Villard Avenue and North 51st Street sewer tunnel are found approximately 50 feet lower than the outcrops of reefal Racine Dolomite six miles to the northeast. It has been pointed out, however, that there are large-scale, reef-controlled irregularities in the upper surface of the Racine in northeastern Milwaukee County, and that the Middle Devonian beds appear to drape over this surface. It is not unreasonable to assume that the Waubakee beds in this area could be a post-Racine deposit, filling in low areas (see Figure 41). This is not as likely at Waubeka where the nearest Devonian rocks are located

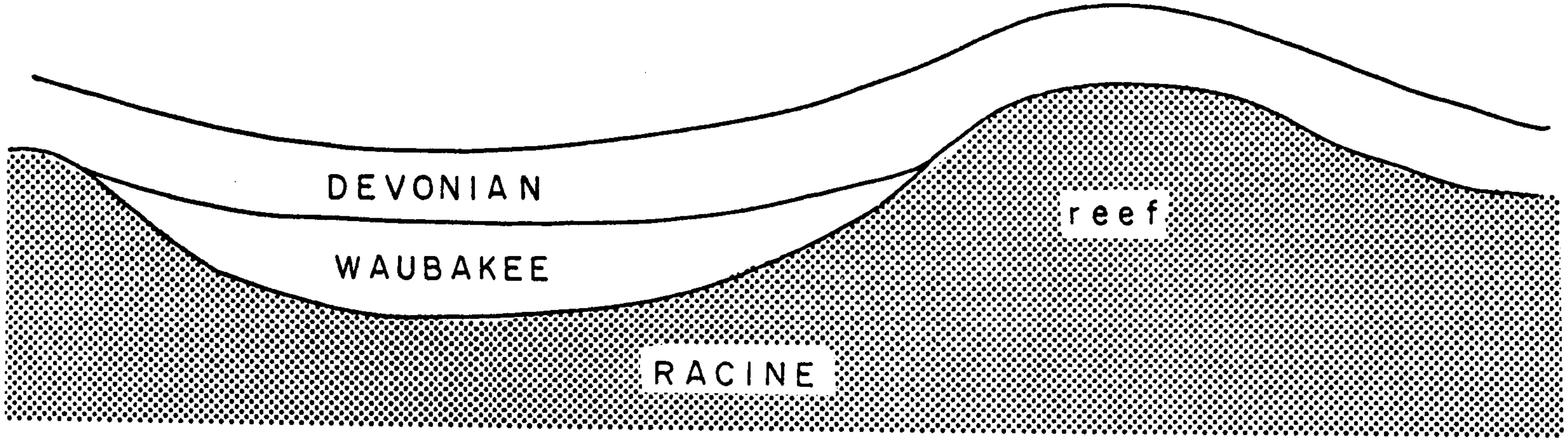


Figure 41. Diagram showing possible relationships of the "Waubakee" beds in Milwaukee County to underlying Racine Dolomite and overlying Devonian rocks. The "Waubakee" may have partially filled low areas in the surface of the Racine; the low areas may have resulted from differential deposition caused by reef growth. The Devonian beds drape over both the "Waubakee" and the Racine.

seven miles to the southeast and presumably Silurian rocks underlie the area in between, and when the dip of the bedrock is considered, it appears that the highest Racine beds would be substantially higher than the horizon of the Waubakee. Berry and Boucot (1970, p. 250) suggested that these beds are too low stratigraphically to be post-Racine unless they have been downfaulted, a condition for which there is no evidence.

Based on the lithologic character and inferred stratigraphic relationships, the Mud Creek beds may be interpreted as having formed in similar depositional environments as the lithologically similar Kokomo Limestone of Indiana and some other "Salina" carbonates of the Michigan Basin. This does not mean that the Milwaukee beds are the same age as the Kokomo or any other speciric Michigan Basin carbonate unit. Shaver et al. (1978) suggested that the Salina beds range in age from Wenlockian through Pridolian and some deposition of these beds was contemporaneous with reef development in the surrounding area. They also indicated that Salina beds are sometimes found at lower elevations than adjacent reefs, but are not necessarily contemporaneous with reef development. The implied depositional history is that reef development resulted in topographically high areas and that a change in salinity may have restricted or terminated reef development, but deposition continued in the lower surrounding inter-reef areas. Since the change in environmental conditions was gradual (Pinsak and Shaver, 1974; Shaver *et al.*, 1978), no unconformity would necessarily be expected in the inter-reef beds, but a sharper contact may be present on top of the reef as they were eventually buried. The evidence in the Milwaukee area is inconclusive, but favors this interpretation. Pre-Middle Devonian erosion may have removed some of the beds over their original area of distribution.

Problems in Silurian Correlation

The problems involved in lithologically correlating the Silurian rocks of eastern Wisconsin have been previously discussed. This study, however, has succeeded in correlating much of the Silurian in Racine, Walworth, Waukesha, and Milwaukee Counties with the Chicago Silurian section. The Brandon Bridge has been correlated through most of this area, but it wedges out against an unnamed cherty dolomite unit in Waukesha County. It has also been demonstrated that the boundary between the Plaines beds and Brandon Bridge Beds is a significant depositional break, but not necessarily of long duration. The overlying Waukesha Dolomite has been redefined and its relationships to the underlying Brandon Bridge and overlying Racine are now well known. The Lower Silurian is not well exposed in the study area and its correlation with specific units in the Chicago area is less certain. All of these advances in correlation have come about because of the availability of core information and deep quarry sections in the last few years. Little progress has been made in correlating the Silurian of the study area with the exposures to the north, mainly due to the lack of exposures in this area. The Lower Silurian is, in part, well exposed in Dodge County, just northwest of the study area, but the complete section of the Mayville is not exposed and this complicates correlations to the south. The lower Silurian beds in the study area is similar to some of the Mayville beds, but is exposed only in isolated outcrops with no upper or lower contacts observable, so their exact position in the sequence is not known. The Byron is also well exposed to the north, but is not found in the study area, although the thin Plaines may be its lithologic equivalent. The Manistique Formation which overlies the Byron can not be correlated with units in the study area with any certainty. The Manistique and Racine beds overlying the Byron are not exposed over much of the state to the north of the study area. Since Chamberlin's (1877) work, it has been apparent that there is a major north-south change in the Silurian rocks of Sheboygan, Dodge and Washington Counties; this area has few exposures and the nature of the transition has not been understood. Until cores, or possibly geophysical information, becomes available for this area few improvements in the correlation of these units will be possible.

Paleogeography

The Silurian paleogeography and depositional environment of the Great Lakes area has recently been reviewed by Shaver et al. (1978) and Mesollella (1978), however, the character of the Llandoverian and Early Wenlockian depositional environments are not well known around Wisconsin. It is likely that the Michigan Basin was a major feature to the east, but there does not appear to be any significant change in the character of these rocks from west to east except for a possible thickening of individual units. During the deposition of the Llandoverian Byron Dolomite (north of the study area) hypesaline, shallow-water conditions existed (Shrock, 1939, 1940; Soderman and Carozzi, 1963), but most of the rest of the Llandoverian and Early Wenlockian units appear to represent normal shallow-water platform environments.

In the late Wenlockian, during early deposition of the Racine Dolomite, a shelf edge barrier reef-carbonate bank complex was built up on the margin of the Michigan Basin. Basinward of the carbonate bank a number of pinnacle reefs developed on the shelf slope. Behind the barrier reef a large number of individual reefs developed on the fairly level platform as those commonly found in the Racine Dolomite of southeastern Wisconsin (see Figures 42 and 43). The "barrier reef" shelf edge complex appears to extend westward from Michigan, reaching the eastern edge of Wisconsin; this is

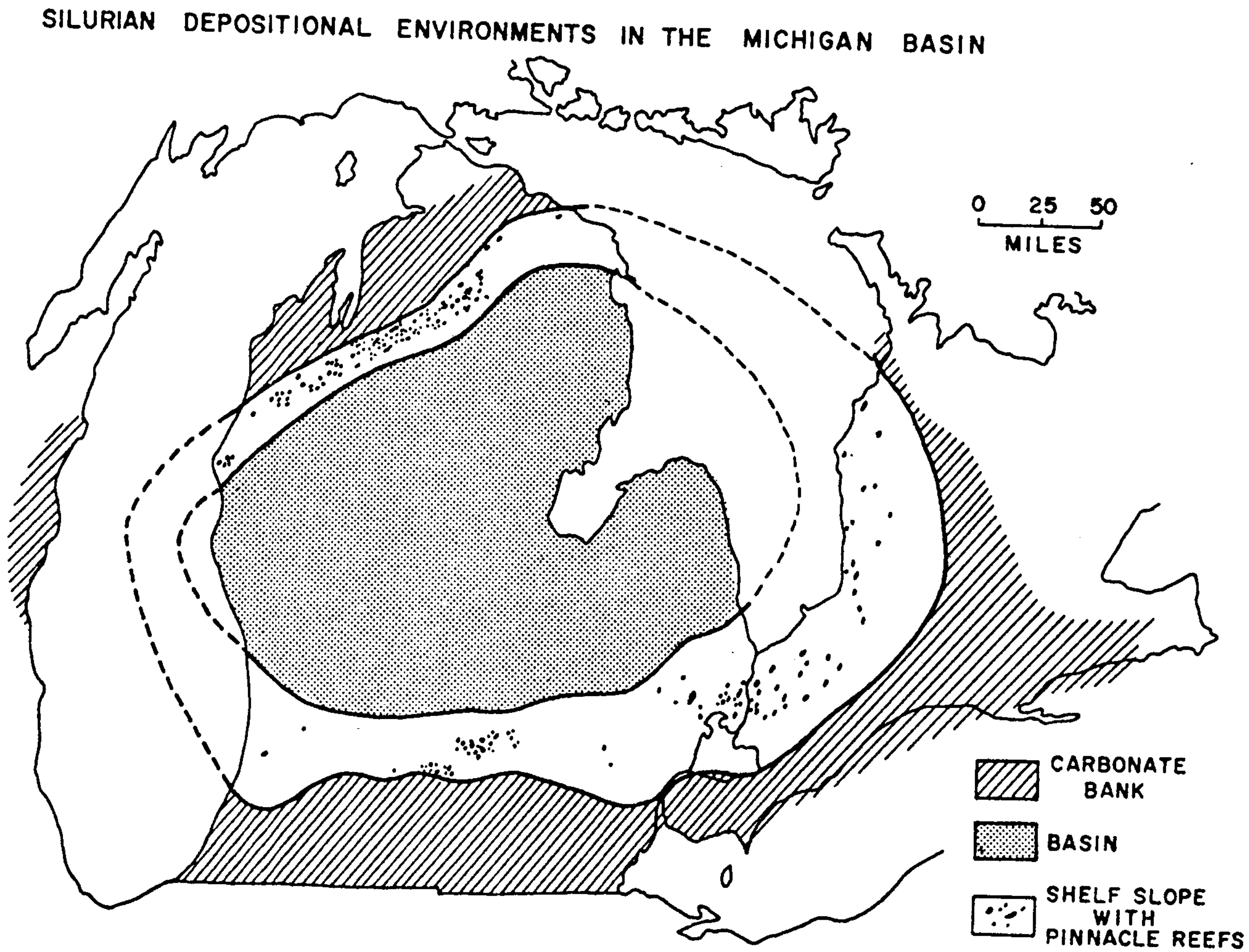


Figure 42. Late Silurian depositional environments in the Michigan Basin (Modified from Gill, 1977, Figure 1-2).

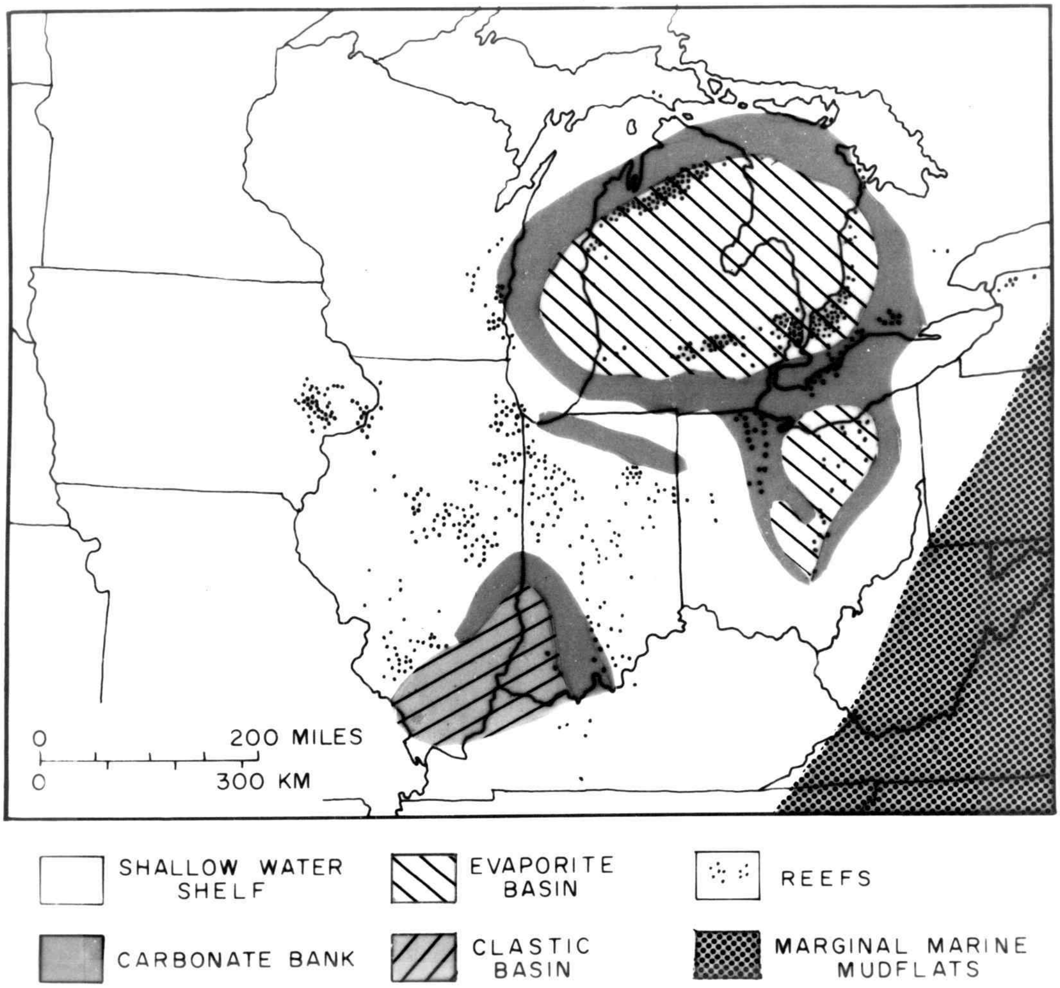


Figure 43. Major depositional environments and reef distribution in the Late Silurian of the central United States. Modified from Shaver et al. (1978) and Mesollella (1978).

indicated by the northeastward thickening trend of the Silurian, as a whole and as individual units, and by the change in composition of lithologic units.

In the Late Silurian a downdrop in sea-level resulted in a restricted circulation pattern in the Michigan Basin and hypersaline conditions developed. Shaver _et al_. (1978) suggested that this may have occurred in the Wenlockian and operated on a cyclical basis, reaching a maximum in the Pridolian.

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APPENDICES

APPENDIX I

Locality Information for Sections on Trilobite Paleoecology

ILLINOIS

Lemont, Illinois

Quarries and drainage canal spoil banks in Sections 20 and 21, T. 37 N., R. 11 E., just east of Lemont, Cook County, Illinois, along the Chicago Sanitary and Ship Canal and the Des Plaines River.

Grafton, Illinois

Grafton Quarry, NW 1/4, NW 1/4, Section 14, T. 6 N., R. 12 W., just south of Grafton, Jersey County, Illinois. See locality 7 in Baxter (1970).

Lehigh, Illinois

Quarry of Lehigh Stone Company at Lehigh, 8 miles west of Kankakee, Kankakee County, NE 1/4, Section 7, T. 30 N., R. 11 E., Illinois. See section 9 in Willman (1973).

Cordova Quarry

SE 1/4, Section 1, T. 19 N., R 1 E., Rock Island County, Illinois.

Thornton Quarry

Active quarry of Material Service Corporation, S 1/2, Section 28, and E 1/2, Section 33, T. 36 N., R. 14 E., Thornton, Cook County, Illinois.

Morrison Quarry

Quarry on the north side of Morrison, Whiteside County, Illinois.

Bridgeport Reef

Abandoned quarry in SE 1/4, Section 29, T. 39 N., R 14 E., Chicago, Cook County, Illinois.

Hawthorne Reef

Filled quarry in NW 1/4, Section 34, T. 39 N., R. 13 E., Cicero, Cook County, Illinois.

Conchidium Hill

SW 1/4, SW 1/4, SE 1/4, Section 20, T. 32 N., R. 12 E., 1.5 miles southwest of Manteno, Kankakee County, Illinois.

McCook Quarry

Active quarry of Vulcan Materials Company, NE 1/4, Section 15, T. 38 N., R. 12 E., McCook, Cook County, Illinois.

INDIANA

Conn's Creek, Indiana

NE 1/4, Section 6, T. 11 N., R. 8 E., south of Waldron, Shelby County, Indiana.

Blue Ridge Quarry

NE 1/4, Section 6, T. 11 N., R. 8 E., 2 km south of Waldron, Shelby County, Indiana.

Ausich locality 21

SE 1/4, SE 1/4, SE 1/4, Section 35, T. 10 N., R. 7 E., gulley exposures at west edge of pig lot on north side of Clifty Creek, 1/2 mile southwest of Hartsville, Bartholomew County, Indiana.

Ausich locality 48

SW 1/4, NE 1/4, SW 1/4, Section 12, T. 9 N., R. 7 E., cut-bank exposure on west bank of Fall Fork, 250 feet below Anderson Falls, 1 3/4 miles south of Hartsville, Bartholomew County, Indiana.

Ausich locality 88

SE 1/4, SW 1/4, NE 1/4, Section 4, T. 11 N., R. 8 E., spoil heaps of active quarry, St. Paul Quarries, Inc., 1/8 mile northwest of St. Paul, Shelby County, Indiana.

Ausich locality 89

NE 1/4, SE 1/4, NW 1/4, and SE 1/4, NE 1/4, NW 1/4, Section 32, T. 11 N., R. 7 E., spoil heaps of active quarry, Norristown Quarry, Cave Stone Company, 4 miles north of Hope, Bartholomew County, Indiana.

USNM loc. 17595

Small exposure on the south side of an abandoned quarry on the east side of Conn's Creek, NE 1/4, Section 6, T. 11 N., R. 8 E., Waldron, Shelby County, Indiana.

Delphi Reef

In the Delphi Limestone Company quarries at the west edge of Delphi, SW 1/4, Section 19, T. 25 N., R. 2 W., Carroll County, Indiana.

Monon Reef

In the active quarry of Monon Crushed Stone Company, Inc. in SE 1/4, NE 1/4, Section 28, T. 28 N., R. 4 W., near Monon, White County, Indiana.

Montpelier Reef

In the Muncie Stone Company quarry at the north edge of Montpelier (SW 1/4, NW 1/4, Section 3, T. 24 N., R. 11 E., Blackford County, Indiana.

Francesville Reef

In Francesville quarry in NE 1/4, SW 1/4, Section 16, T. 29 N., R. 4 W., Salem Township, Pulaski County, Indiana.

Pipe Creek Jr. Reef

In the Pipe Creek Jr. quarry in N 1/2, NE 1/4, Section 12, T. 23 N., R. 6 E., Point Isabel Quadrangle, 16 km southwest of Marion, Grant County, Indiana.

Rensselaer Reef

IOWA

Johnson Section 91-Lang Quarry

Abandoned quarry approximately 0.75 km east off U. S. Hwy. 151 along the Maquoketa River, on the northeast side of Monticello, SE 1/4, NE 1/4, Section 22, T. 86 N., R. 3 W., Jones County, Iowa.

Johnson Section 73.1

Johns Creek Quarry approximately 6.5 km south of Farley on Dubuque County road Y-13 on the east side of the road; SE 1/4, SW 1/4, Section 36, T. 88 N., R. 2 W., Dubuque County, Iowa. Sampled 20 cm above the base of the Cyrtia Beds in the Hopkinton Dolomite.

Johnson Section 73.2

Same locality as above.
Sampled 3.5 m above the base of the Cyrtia Beds in the Hopkinton Dolomite.

Johnson Section 77.1

Exposure along the south bank of the Wapsipinicon River at Massillon; NW 1/4, NW 1/4, Section 13, T. 82 N., R. 1 W., Cedar County, Iowa.

Johnson Section 21.1

Lux Quarry approximately 8 km south of Farley on Dubuque County road Y-13, on the west side of the road; SE 1/4, SE 1/4, Section 2, T. 87 N., R. 2 W., Dubuque County, Iowa.
Sampled 15 cm above the base of the Cyrtia Beds in the Hopkinton Dolomite.

Johnson Section 21/2

Same locality as above.
Sampled 75 cm above the base of the Cyrtia Beds in the Hopkinton Dolomite.

Lux Quarry

Same locality as Johnson Section 21 above.

Johnson Section 43.1

Willms Quarry approximately 9.25 km southeast of Monticello on Iowa Hwy. 38, on the west side of the road; Center of SE 1/4, Section 7, T. 85 N., R. 2 W., Jones County, Iowa.
Sampled just above the base of the Cyrtia Beds.

Johnson Section 43.2

Same locality as above.
Sampled 7.75 m above the base of the Cyrtia Beds in the Hopkinton Dolomite.

Johnson Section 103-Monticello Quarry

Operating quarry (B. L. Anderson, Inc.) approximately 4.75 km west of Monticello on Jones County road D-62; NW 1/4, NW 1/4, Section 24, T. 86 N., R. 4 W., Jones County, Iowa.

Johnson Section 82-Elwood Quarry

Operating quarry (Alpha Crushed Stone) approximately 3 km north of Elwood; Center of NW 1/4, Section 24, T. 86 N., R. 4 W., Clinton County, Iowa.

Wyoming Quarry

NW 1/4, Section 33, T. 84 N., R. 1 W., Jones County, Iowa.

Sneckloth Quarry

Center, Section 4, T. 81 N., R. 6 W., Cedar County, Iowa.

Mitchell Quarry

NE 1/4, Section 24, T. 82 N., R. 5 W., south of Lisbon, Linn County, Iowa.

Palisades Reef Complex

Section 14, T. 82 N., R. 6 W., Linn County, Iowa, in Palisades-Kepler State Park.

NEW YORK

Middleport, New York

Lower Rochester Shale (about 3 m above base of the formation) exposed in a highly weathered cutbank exposure along a north-flowing tributary of Jeddo Creek, about 0.5 km south of N. Y. Tre. 31, and 1.4 km east of Freeman Road, Middleport, Niagara County, New York.

Lockport Gulf, New York

Exposures (now destroyed) of Lower Rochester Shale along the west branch of 18 Mile Creek at Lockport Gulf, 0.8 km north of N. Y. Rte. 31, and 0.3 km west of N. Y. Central railroad tracks, Lockport, Niagara County, New York.

OHIO

Celina Quarry

Quarry of J. W. Karsch Stone Company, about 4 miles west of Celina and half mile south of Ohio Hwy. 29, NE 1/4, Section 5, T. 6 S., R. 2 E., Jefferson Township, Mercer County, Ohio.

Rockford Quarry

Quarry of Rockford Stone Company, 1 1/2 miles northeast of Rockford, Center of northernmost part of Crescent Grant of 1818, T. 4 S., R. 2 E., Dublin Township, Mercer County, Ohio.

Fairborne

Southwestern Portland Cement quarry, south of Ohio Hwy. 235, at Fairborne, Green County, Ohio.

TENNESSEE

USNM loc. 13628

Waldron Shale on both sides of Interstate Hwy. 40, approximately 300 feet east of the McCrory Lane turnoff, Cheatham County, Tennessee.

Quarry at Newsom, Tennessee

Quarry between the railroad and Harpeth River at Newsom Station, Davidson County, Tennessee.

NOVA SCOTIA

USNM loc. 10206

McAdam Brook about 1000 feet upstream from road, Arisaig area, Nova Scotia, Canada.

USNM loc. 10203

McAdam Brook east branch, about 500 feet downstream from road, Arisaig area, Nova Scotia, Canada.

USNM loc. 10835

Ridge east of McLean lake, Pictou County, Nova Scotia.

USNM loc. 10185

Shore 600 feet southwest of McDonald Brook and 300 feet southwest of Red Band of Moydart on Arisaig Shore section, Arisaig, Nova Scotia, Canada.

USNM loc 10189

100 feet southwest of mouth of Stonehouse Brook on Arisaig shore section, Arisaig, Nova Scotia, Canada.

USNM loc. 10205

McAdam Brook about 900 feet upstream from road, Arisaig, Nova Scotia, Canada.

USNM loc. 10184

105 feet southwest of Red Band of Moydart on Arisaig shore section, 440 feet southwest of McDonald Brook, Arisaig, Nova Scotia, Canada.

USNM loc. 10187

725 feet southwest of Red Band of Moydart on Arisaig shore section, 1000 feet southwest of McDonald Brook, Arisaig, Nova Scotia, Canada.

USNM loc. 10910

Arisaig shore section, Arisaig, Nova Scotia.

USNM loc. 10192

750 feet southwest of the mouth of Stonehouse Brook on Arisaig shore section, Arisaig, Nova Scotia, Canada.

USNM loc. 10191

425 feet southwest of the mouth of Stonehouse Brook on Arisaig shore section, Arisaig, Nova Scotia, Canada.

USNM loc. 10188

925 feet southwest of Red Band of Moydart on Arisaig shore section, Arisaig, Nova Scotia, Canada.

BRITISH ISLES

USNM loc. 10247

Slumped outcrop above the large quarries at Nash Scar, Hash, Hereforshire, England. Grid ref. SO/3018 6234.

USNM loc. 10217

Temporary exposure behind new building, 100 feet south of Damery Bridge, near Tortworth, Gloucestershire, England. Damery Beds, 50 feet above base of sequence. Grid ref. ST/7056 9428.

USNM loc. 10219

Stream bed exposure 670 feet north of Hillhouse Farm, Charfield, Gloucestershire, England. Damery Beds, lower half, Grid ref. ST/7267 9206).

USNM loc. 10245

Roadside exposure on north side of Route B 4362, about 1 mile east-northeast of Nash Scar and 690 yards west-southwest of the railway bridge, Nash, Herefordshire, England. Grid ref. SO/3153 6316.

USNM loc. 10267

On shore north of Fox Hill, Kilbride Peninsula, County Mayo, Ireland. Annelid Grit.

USNM loc. 10223

West end of Damery Quarry, near Tortworth, Gloucestershire, England. Basal Damery Beds. Grid ref. ST/7045 9440.

USNM loc. 10221

Roadside exposure 220 feet south of Damery Bridge, near Tortworth, Gloucestershire, England. Damery Beds, about 100 feet above base. Grid ref. ST/7055 9426.

USNM loc. 10265

Loose blocks in stream bed 250 yards northwest of Merrishaw Farm, Harley, Shropshire, England. Pentamerus Beds. Grid ref. SJ/5805 0090.

USNM loc. 10507

Forest Commission roadcut about 1/3 mile northwest of Pen-y-wan and about 5 miles east-northeast of Llandovery, Wales. Grid ref. 845/364.

USNM loc. 10243

Large disused quarry north of Route B 4362 across from Corton House, and 170 yards west-southwest of railway bridge, Wales. Grid ref. SO/3197 6334.

USNM loc. 10262

Disused quarry west of Route A 488 in Hope Valley, 2 1/2 miles southwest of Minsterley, Shropshire, England. Pentamerus Beds. Grid ref. SJ/3551 0208.

USNM loc. 10519

Woodland Point, on coastroad between Girvan and Kennedy's Pass, Scotland. Woodland Limestone.

USNM loc. 10226

Hay Farm Brook section 465 yards west of Hay Farm, northeast side of May Hill, Herefordshire, England. Yarleton Beds. Grid ref. SO/6926 2263.

USNM loc. 10220

Roadside exposure 200 feet south of Damery Bridge, near Tortworgh, Gloucestershire, England. Damery Beds about 90 feet above base. Grid ref. ST/7055 9426.

USNM loc. 10459

About 50-60 yards south of Damery Bridge, near Tortworth, Gloucestershire, England. Damery Beds. Grid ref. 706/943.

USNM loc. 10215

Exposure created by the straightening of Route A 38, 170 feet north of the old A 38 bridge over the Little Avon River, Woodford, Gloucestershire, England. Basal bed of Tortworth Beds. Grid ref. ST/6879 9574.

USNM loc. 10253

Sawdde River section, 500 yards upstream from Bont Fawr, Llangadock Carmarthenshire, Wales. Grid ref. SN/7173 2567.

USNM loc. 10270

Overgrown quarry west of the Llandovery to Myddfai road, about 400 feet northwest of Cefeb-cerig, Llandovery, Carmarthenshire, Wales. Grid ref. SN/7752 3236.

USNM loc. 10257

Roadside exposure on the Llandovery to Myddfai road, 300 yards north of Cefn-cerig, Llandovery, Carmarthenshire, Wales. Grid ref. SN/7752 3257.

USNM loc. 10218

Stream bed exposure 700 feet north of Hillhouse Farm, Charfield, Gloucestershire, England. Damery Beds, lower half. Grid ref. ST/7267 9206.

WSNM loc. 10232

Track-side exposure in Rudge Wood, 370 yards N. 24°W. of Rudge Farm, Woolhope, Herefordshire England. Haugh Wood Beds. Grid. ref. SO/5948 3564.

USNM loc. 10260

Stream section, 470 yards N. 10°E. of Llwyn-Meredith, Myddfai, Carmarthenshire, Wales. Grid ref. SN/7662 3052.

USNM loc. 10272

Overgrown quarry 100 yards northeast of Round Lodge, Llwynywormwood Park, Llandovery, Carmarthenshire, Wales. Grid ref. SN/7689 3237.

USNM loc. 10259

Roadside exposure on the Llandovery to Myddfai road, 200 feet west of Cefn-cerig, Llandovery, Carmarthenshire, Wales. Grid ref. SN/7745 3231.

APPENDIX II

INTRODUCTION

This appendix lists and describes nearly all of the Silurian bedrock exposures in Kenosha, Walworth, Racine, Waukesha, Milwaukee, Ozaukee, and the eastern one-third of Washington Counties. Each locality is indicated on a map and assigned a locality number. Early descriptions of the localities are presented and, when available, new information is added if it contributes to the previous description. Nearly all of the localities were visited, however, a few could not be found and some were inaccessible. A significant effort was made to obtain the older descriptions of the Silurian exposures in the study area for the following reasons:

1. Most of the quarries in the study area, particularly in Milwaukee County, are no longer operating (urban expansion has forced many to close) and many are filled. Since many of the early geological observations made in this area were based on exposures at these old localities, it is important to determine what the rock characteristics and relationships were like especially when no other exposures are close enough to be used as a substitute.

2. The proper individuals deserve to receive credit for both published and unpublished ideas which have often been attributed to the wrong person or are "rediscovered" by someone else at a later date.

3. It is important to clarify what certain exposures were like at the time various ideas (stratigraphic, paleontologic, sedimentologic) were being formulated (for example, see the section on the Waukesha Dolomite.

4. It is necessary to precisely locate the source of the large and valuable collections (Day, Greene, Teller, Milwaukee Public Museum; see Appendix III, since it is impossible to recollect this material in either quality or quantity because most of the localities are no longer accessible. However, by locating the quarries or exposures at which the material was collected, determining both depths at various times and rock characteristics, it has been possible to significantly improve upon the stratigraphic, taxonomic, and ecologic usefulness of these collections.

In this Appendix, information on thickness of Silurian rocks and distribution was derived, in part, from Wisconsin Geological Survey records. Thickness of overburden was derived from Trotte and Cotter (1973) and from Wisconsin Geological Survey well logs. Unpublished maps showing the location of most of the outcrops mentioned in this appendix can be found in the Alden papers in the U.S. Geological Survey Library, Denver, and copies of some of these are on file at the Wisconsin Geological Survey. Most of these localities are also indicated on Alden's (1918, Plate I) map. The Geology Department of the Milwaukee Public Museum has a set of quadrangles giving detailed locations of exposures throughout the study area. These maps were compiled by Gilbert O. Raasch and Ira Edwards during the 1920-1940's. Locality numbers with an "MPM x" prefix refer to the localities on these maps.

Important fossil collections made in the study area are located in the following institutions (see Appendix III):

The F. H. Day collection is located in the Museum of Comparative Zoology at Harvard University. It was assembled in the 1850-1880's and is the finest collection in the quality of the specimens made in the area. It has been divided taxonomically and placed into the general collection so it is no longer possible to study the collection as a whole.

The T. A. Greene collection is located in the Green Museum at the University of Wisconsin-Milwaukee. This collection was assembled from 1800-1894 and is the best intact collection from southeastern Wisconsin.

The E. E. Teller collection is located in the National Museum of Natural History, Washington, D.C. It was assembled from 1880-1910. This collection has also been divided into taxonomic categories and mixed in with the general museum collections. The Field Museum of Natural History-University of Chicago collections contain a large amount of Wisconsin material, including some of Hall's specimens and specimens donated by E. Teller.

The Milwaukee Public Museum contains important collections assembled by G. O. Raasch (1920's-1940's) and J. Emielity (1940's-1960's). Most of this material is accompanied by detailed locality information.

Collections made by I. A. Lapham and the Chamberlin party for the Wisconsin Geological Survey have for the most part been destroyed or lost over the years.

KENOSHA COUNTY

The bedrock surface in Kenosha County is covered by 100 or more feet of glacial drift and soil; Hutchinson (1970) recently has published a map of the bedrock topography. One small area to the northwest of the city of Kenosha in Summit Township has been described as having outcrops (see Figure 44). Schoolcraft (1821) made the first geologic observations in the area, noting that he found a liquid mineral resembling asphaltum in the vicinity of what is now Kenosha County. Ball (1918), however, believed Schoolcraft's observations were of Quaternary features and not bedrock occurrences.

On August 22, 1851, The Telegraph, a Kenosha newspaper, reported the discovery of an outcrop in an article entitled "A Stone Quarry":

> We have learned that an extensive stone quarry has been discovered a few miles north and west of this city. This

Figure 44. Locality map of Kenosha County showing numbered localities discussed in text. Structures located to the right of the county on map may be Silurian reefs present in Lake Michigan. Diagonal lines indicate areas where Silurian has been eroded through to Ordovician bedrock.

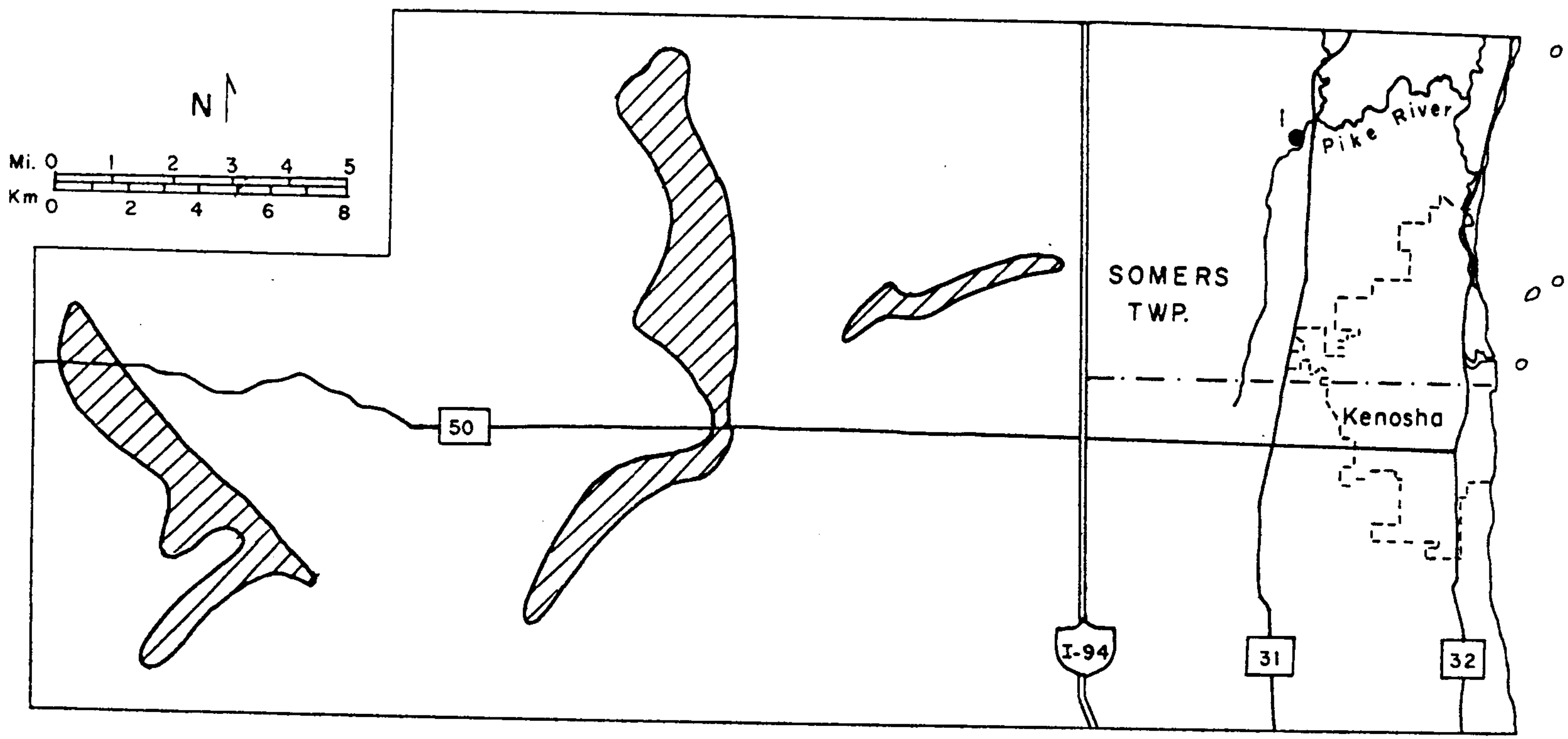

N
Mi. 0 1 2 3 4 5
Km 0 2 4 6 8
50
SOMERS
TWP.
1
Pike River
Kenosha
I-94
31
32

Figure 44

> discovery is of no small value to the citizens of this part of the county, who have always been obliged to go north of Racine for their lime. This stone of of excellent quality for burning. And we hope no long time will intervene before some individual or company will feel the necessity of a little more money, which will compel them to secure the land, and go into business of quarrying stone, and burning lime. There is no end to the amount of stone which would be used in this city if it could be obtained as cheap as bricks are now obtained. And as for lime, thousands and thousands of barrels are every year hauled a distance of thirteen miles from Racine, which would remain these, provided that it could be obtained nearer home. The quarry is in easy access; an excellent road on high ground, leads to it from the city.

Another brief reference in Kenosha County outcrops was made by J. G. Percival (1856) who reported beds of the Mound limestone with layers of bitumen on the south fork of Pine Creek in this county. This occurrence might be related to Schoolcraft's discovery of asphaltum. There is no Pine Creek in Kenosha County, however, the name is probably a misspelling of Pike Creek in the eastern part of the county.

T. J. Hale's 1860 field notebook briefly described a quarry of Racine Limestone on Pike Creek in the SW 1/4, Section 10, T. 2 N., R. 22 E., Kenosha County:

> This is Racine Limestone and is low in the bed of Pike Creek, but a few cords of stone have been taken from it. This is about a miles from the ... mill--a well known object in the vicinity... There is also an untried... ledge on Section 11, SW 1/4; the owner promised to open it.

No other outcrops have been reported in Kenosha County or indicated on maps in the detailed works of Chamberlin, Alden, Hotchkiss and Steidtmann, Shrock, and Hutchinson.

It is probable that the outcrops described in The Telegraph article and mentioned by Percival and Hale are the same. Hale's usage of the name Racine Limestone implies a crinoidal, porous, thick-bedded rock. The presence of bitumin or asphaltum is significant since it is the only occurrence of this material in the Paleozoic of southeastern Wisconsin besides those in the Devonian at Estabrook Park and the Texas Avenue sewer tunnel locality, both in Milwaukee County. A search was made in the southern half of Section 10, along Pike Creek, in 1979, but no outcrops were located. Since the stream bank is heavily overgrown, it is possible that a small outcrop may have been overlooked. Unworn fragments of Silurian dolomite are abundant in many places along the stream, however.

No other outcrops have been reported from Kenosha County. Ball (1918) made a detailed study of the Pike River area of the city of Kenosha, but found no outcrops. In the extreme western part of the country (T. 1 N., R. 19 E., NE 1/4, SW 1/4, Section 3) a water-well reached bedrock within 25 feet of the ground surface and exposures may be present in the area.

WALWORTH COUNTY

Silurian rocks are present in only parts of the eastern half of Walworth County and a small area south of the west end of Lake Geneva (see Figure 45). Exposures of Silurian bedrock are rare because of a thick covering of Quaternary sediments and are located primarily along the eastern edge of the county. Green (1968) and Borman (1976) have both published maps showing the bedrock topography of this county.

The thickness of Silurian rocks ranges from zero feet in the center part of the county to approximately 120 feet along the eastern edge of the county, this variation being due to the eastward dip of the Silurian and older sedimentary rocks. The youngest Silurian rocks exposed belong to the Brandon Bridge beds which are characterized by a conspicuous red, argillaceous lithology. Silurian bedrock exposures are known from only three areas, none of which is currently well exposed. The most important are the old quarries along the White River in Walworth County, just west of Burlington, Racine County. Two other small, old quarries are also known, one along Sugar Creek approximately three miles west of Honey Lake, and another at the southeast corner of Potter Lake in the northeast corner of the county. Unsubstantiated exposures have also been reported near Lyons and Lake Geneva.

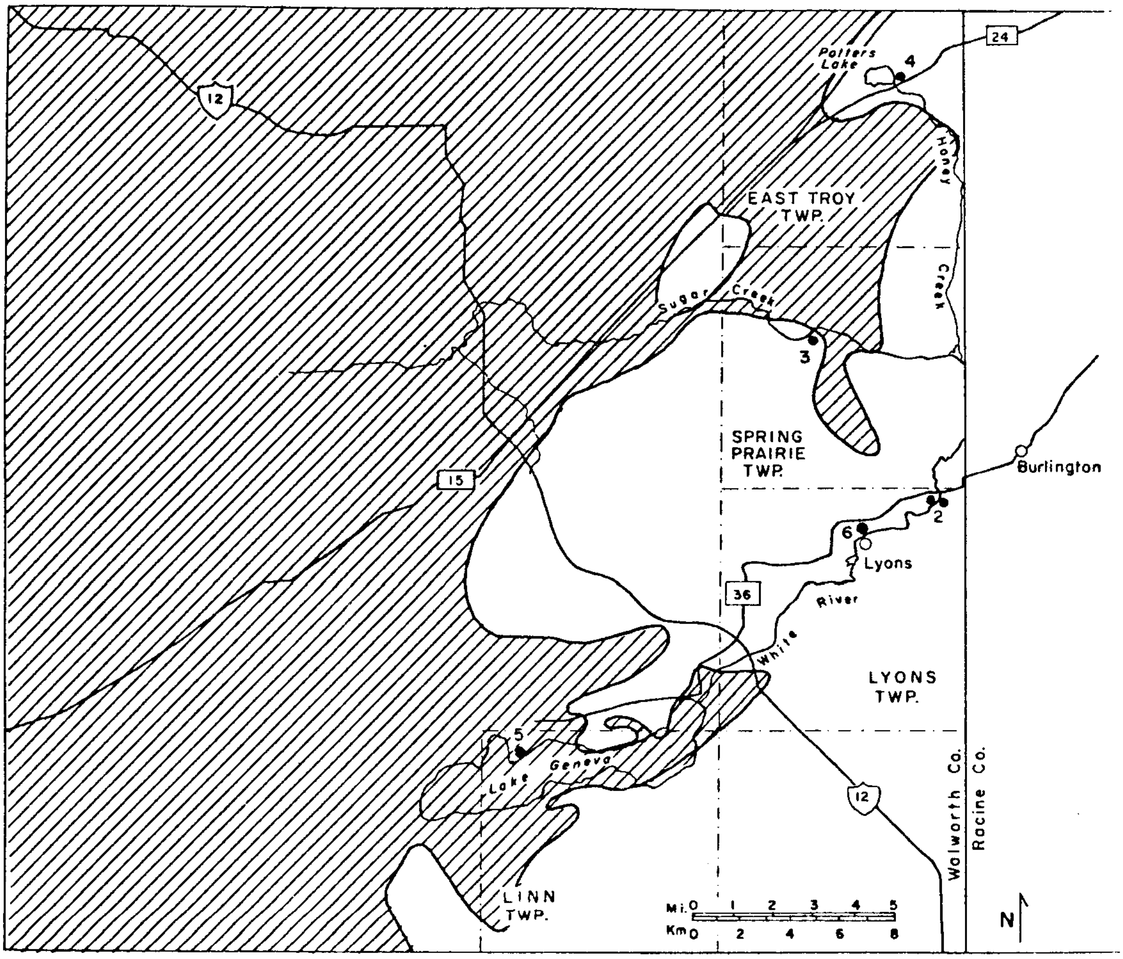


Figure 45. Locality map of Walworth County showing numbered localities discussed in text. Diagonal lines indicate areas where Silurian rock has been eroded through to Ordovician bedrock.

Voree Quarry
Locality 2

NE 1/4, Section 36, T. 3 N., R. 18 E., Spring Prairie Twp., Walworth County

MPM x28.1

elevation: 760 feet

Quarry on the east bank of the White River

The oldest and formerly best exposures of Silurian rock in Walworth County were in the quarries along the White River at the east edge of the county (see Figure 46). These quarries have long been famous for specimens of the trilobite Stenopareia imperator; the locality usually given for these specimens is Burlington because of the close proximity of this Racine County city to the quarries.

This quarry on the east bank of the White River was started around the 1840's at the site of a Mormon settlement. Percival (1856, p. 69-70) was the first to describe the rocks exposed in this quarry as a part of his description of the Mound Limestone in eastern Wisconsin. He stated:

> ...I have observed the rock of the present formation in place only at Waukesha, Casselman's quarry in East Troy and Voree near Burlington. In all these localities the rock has the characters of the lower bed, as it is seen in the mounds and ridges towards the Mississippi. It is the same light colored nearly compact rock, easily dressed, and often admitting a good polish, and when sufficiently thick, is a valuable material for building. This is

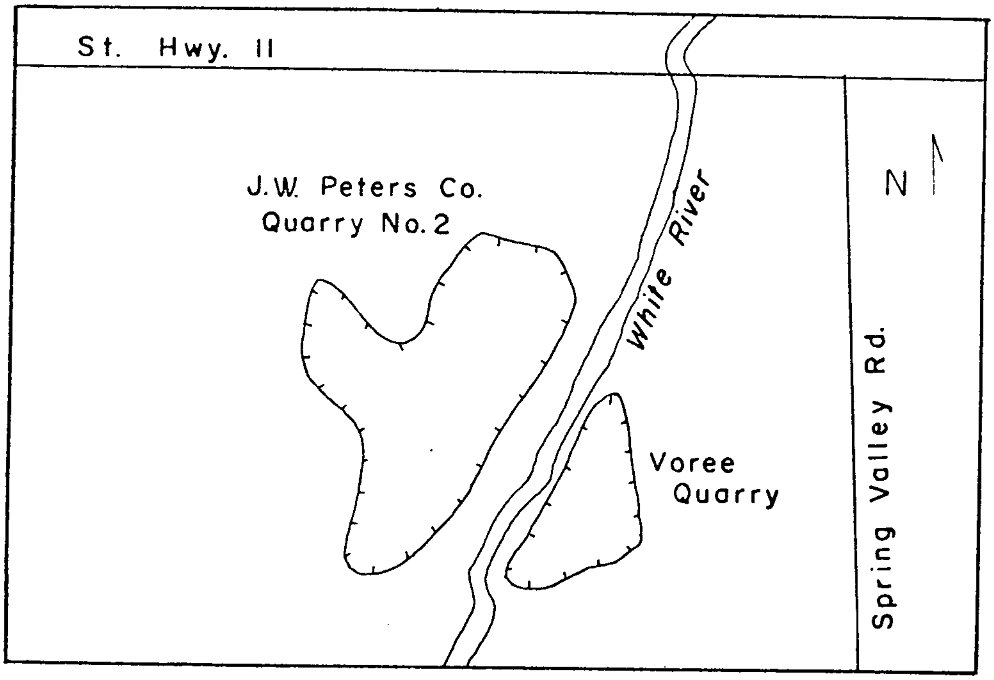


Figure 46. Locality map showing locality 2 in Walworth County. This locality is commonly referred to as Burlington because of its close proximity to that city in Racine County, to the east.

> particularly the case at Waukesha and Casselman's quarry where the rock is thicker and firmer. At Voree it is thinner and softer and alternates with layers of shale, and apparently lies near the base of the formation. In all these localities fossils are unfrequent, but occasional layers occur in which they are more abundant. The rock in all these localities is at a low level, raised but a few feet above Fox River or its branches, to which they are contiguous.

T. J. Hale (1860, unpublished field notes, p. 3-4) described these beds as follows:

> This is a soft-thin bedded form of Niagara unlike that found elsewhere but resembling in some degree that at East Troy 12 miles north.

I. A. Lapham (1873, 1874, unpublished field notes) made a couple of visits to this quarry (which he referred to as formerly Voree's), one with T. C. Chamberlin's field party. He found that the quarry exposed six feet of rock, the surface of which dipped towards the west and was overlain by eight and one-half feet of drift and soil. Only a few fossils were found in the "shaley limestone." He also mentioned finding red, shaley sandstone in the drift in Walworth County that probably belonged to the Clinton or Medinan Group. It is probable that these reddish argillaceous rocks in the glacial drift are actually derived from the Brandon Bridge beds. The presence of these rocks in the drift of southeastern Wisconsin led Lapham to believe that a reddish sandstone (1851, p. 169-170, Unit V) was present between the Galena Limestone and the Waukesha Limestone.

In 1877 Chamberlin (p. 203-204) described the glacial-related phenomena in a Mr. Smith's Quarry (Voree) near Burlington. His description and diagram of the east wall of the quarry indicate that approximately ten feet of rock was exposed, overlain by four to five feet of drift. Chamberlin also mentioned that "on the opposite side of the White River, five or six rods distant" the surface of the bed-rock shows no glacial striae. This indicates that there may have been a natural outcrop in this vicinity. He made additional observations about the quarry in relation to glacial features (p. 208-209):

> Near Burlington there is an exposure of a thin-bedded, rather argillaceous dolomite, different from any seen elsewhere, and containing the Trilobite, Illaenus imperator, in considerable numbers, with but few other fossils. Nothing that could be mistaken for it by a careful observer has yet been found elsewhere in the state. In the Kettle Range southwest of Burlington, large quantities of this rock are found, and at heights very considerably above the present surface of the rock. The blocks are usually somewhat worn, but still subangular. Their identity is put beyond question by the presence of Illaenus imperator.

In his discussion of the Niagaran Limestone he does not describe the quarry or beds exposed there, but he does include them in the Racine Dolomite location in his faunal list for that unit. The following fossils were listed from this locality (p. 372-376):

Buthotrephis und. sp.
Spirifera plicatella var. radiata
Illaenus imperator
Illaenis insignis
Calymene niagarensis

In 1897 Buckley (unpublished field notes) noted that the quarry owned by W. A. Aldrich (Voree) was full of water and had not been operated for some time. His description of the rocks around the quarry indicate that they were of typical Brandon Bridge lithology. In 1898 (p. 326-327) he briefly described these rocks.

Alden (1918) described this quarry as follows:

> In William Aldrich's quarry, a mile west of Burlington, Racine County, red ocherous beds wholly different in character of those seen at any other place are exposed. This deposit has been included in the Niagara dolomite, but it may perhaps represent some of the beds under discussion (Clinton). At the time of the writer's visit the quarry hole was full of water, so that the strata could not be seen in place, but rock that had been taken out was exposed in piles nearby. This rock is impure, thin-bedded, dolomitic limestone, splitting and breaking readily into small pieces. In color it varies from light buff to yellow, reddish yellow, dark red, and purplish red. The red rock, which is softer, than the buff and which disintegrates on exposure to red shaly mud, was said to be from the bottom of the excavation. The rock carries cyrstallized calcite and, especially in the purple layers, abundant fucoidal markings.

R. R. Shrock visited the quarry several times in 1930-1931 as part of his work on the Silurian stratigraphy of eastern Wisconsin. In 1931 (unpublished field notes) he found the quarry was actively operated by J. W. Peters and displayed a 25 foot section (see Figure 47). He made a detailed diagram of the exposures and described them as follows:

> Bed 1. The lower 4 feet are composed of very variable stone. Well stratified, in places gray with reddish, splotches, again a crude stratification is present caused by lenticular masses of red and yellow or gray material. In the south side of the

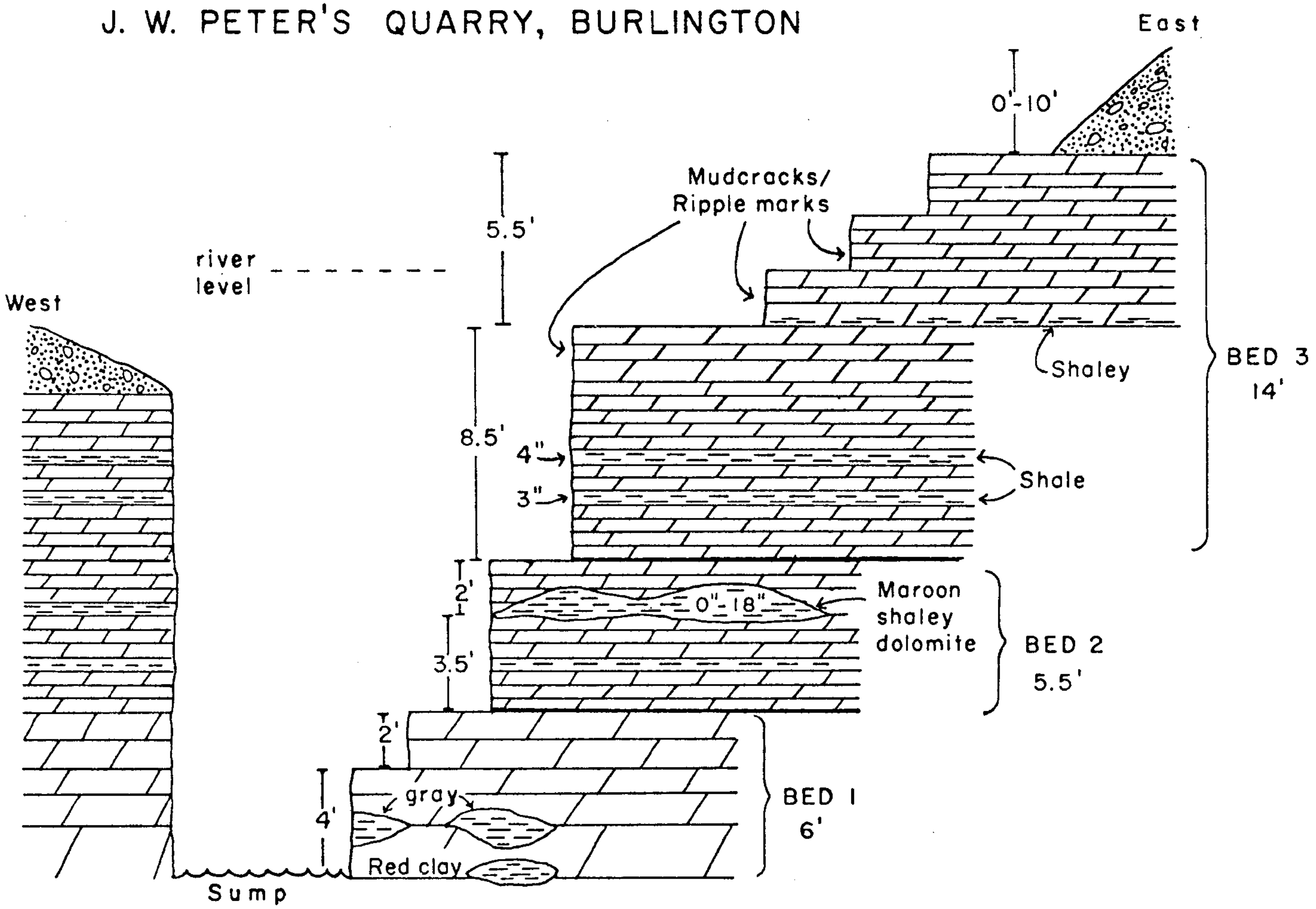


Figure 47. Section of the Brandon Bridge Beds in the Voree (J. W. Peter's) quarry (locality 2). See text for details. After Shrock (1931, unpublished field notes).

sump may be seen several large cavities filled with banded clay-green, gray, reddish, or with very red clay like ochre, apparently from the solution of the argillaceous dolomite. The wall rock near the red clay is a very reddish, clayey dolomite characterized by the lenticular markings described above. This may represent a phase very near the base of the Mayville.

The upper two feet are much like the lower part, except that the rocks forms a more massive layer and is somewhat more crystalline.

The heavier courses of Bd. 1 are used for building purposes. Beds mainly thin however (6"-1 1/2').

Very red clay has small concretions or nodules which seem to be a little more firmly cemented.

Total thickness of Bed 1 . . . . 6 feet

Bed 2. Lower part of variegated reddish or gray crystalline dolomite in thin beds averaging 4" thick. Parts of some layers filled with fucoids used for flagging. Some layers weather clayey.

Middle of bed is a very thinly banded or laminated marroon shale which breaks up into a red mud and is full of seaweeds. Varies in thickness from 0-1 1/2 feet, and appears, where containing most weeds to have been a little mound or ridge. In this case it changes laterally into normal beds like shaley.

Upper part much like lower, but composed of thin slabs or flags 1"-4" thick, dense, crystalline, slightly druzy beds--incipient recrystallization--alternating with "sandy" or shaley beds.

Total thickness of Bed 2 . . . . 5.5 feet

Bed 3. Consists of a series of very fair flaggy beds averaging 2"-4" in thickness, and frequently breaking out blocky. Some beds show incipient recrystallization, and pyrite is common. Not so much red in these beds, the general tend being buff. Quite argillaceous along certain beds, blue and somewhat crystalline in others. Some thin shale zones.

B. imperator very common throughout, at base and top. Several br chiopods noted. Bedding planes near top show mud cracks, very smooth ripple (wave?) marks and many large fucoid and some worm borings probably (latter appear as green material).

Upper 5 1/2 feet is very slabby, 1''-3'', highly weathered, and bears evidence of shallow water deposition by ripple marks, mud cracks or smooth bedding planes. Some layers are covered with fucoidal markings. Weathers to a sandy, buff colored shaley dolomite. More of a blue when unweathered.
Total thickness of Bed 3. . . . . 14 feet

Shrock also noted the following fossils:

<u>Stenopareia imperator</u>
cephalopods
rugose corals
1 graptolite
possible trace fossils

No mention was made of any quarrying activity on the west side of the river at this time.

Burpee (1932) found that rock samples collected by Shrock from the Peters Quarry contained a distinctive fauna of siliceous plano-coiled Foraminifera. He was also able to recognize this microfauna in a water well in Burlington and in one at Waukesha (probably the White Rock well). Burpee assigned these beds to the Waukesha Dolomte for reasons that are unclear. The horizon he identified in the Waukesha well is in reality the Brandon Bridge beds, as are those that produced the Foraminifer fauna around Burlington. He did find Foraminifera in the Racine beds in the upper part of the Waukesha Lime and Stone Quarry north of Waukesha and may have thought that this was the same horizon.

Ball (1940) described this quarry in an attempt to correlate the exposed rocks with lithologically similar units of the lower Mississippi Valley. He reported the quarry to be about 26 feet deep, but only 17 feet were exposed above the water level. He described the east face of the quarry as follows:

Unit 12. Dolomite, in beds averaging 2 1/2 inches in thickness, dense, yellowish gray with faint traces of green and black . . . . 8 inches thick.

Unit 11. Dolomite, in 2 to 3 inch beds, dense, with color bands up to 1/2 inch in thickness, colors faint shades of gray or green. . . . . 2 ft. 2 in. thick.

Unit 10. Dolomite, shaly, colors about the same as in unit above, the shaly portion near the base in large, wavy sheets, bedding surfaces covered with a network of long ridges and furrows, resembling algal remains; small brachiopods. . . . . 8 inches thick.

Unit 9. Dolomite, thin-bedded, indistinct bedding laminae, dense, earthy, deep green with occasional lighter bands, a more purple banding near the base. . .1 ft. 2 in. thick.

Unit 8. Shale, grading laterally into green, platy dolomite, the shale light green, with limonite and manganese stains. . . . . 1/2 inch thick.

Unit 7. Dolomite, shaly, dark green, poorly laminated. . . . . 5 inches thick.

Unit 6. Dolomite, shaly, dull gray, weathering to a deeper greenish color. . . . . .1 1/2 inches thick.

Unit 5. Dolomite, flaggy, laminated, with planes of the laminae showing mottled coloring, pink in an area of green, fossil fragments and solution pits from which fossils have disappeared. . . . . .3 ft. 1 in. thick.

Unit 4. Dolomite, earthy, compact, greenish gray . . . . 6 inches thick.

Unit 3. Dolomite, a somewhat massive bed, compact, resistant, with prominent color bands, greenish gray alternating with pink above, but near the base, in a band 4 1/2 to 5 inches thick, a deep red color appears . . . . 1 ft. 1 in. thick.

Unit 2. Dolomite, thin-bedded, compact colors not vivid, but in bands of faint green, and a less vivid red than above; some concretion centers and calcitic vugs . . . . 2 ft. 2 in. thick

Unit 1. Dolomite, in slightly thicker beds, banded colors of deep red, alternating with bands of yellow, yellowish green and limonite; bedding surfaces show mottled patches of grayish green in a field of red similar to

the Dixon or Bainbridge formations of Missouri
. . . . 5 ft. 10 in. thick.

Ball also noted that his Units 5 and 10 contained microfossils, Unit 10 had a predominance of brachiopods, and that Unit 5 contained a possible fragment of Stenopareia imperator. He mentioned that the quarry workers said that Stenopareia imperator mostly came from beds at or below the then existing quarry floor.

Gutschick (1941) described a collection of ostracodes and other microfossils he obtained from insoluble residues derived from rocks collected in this quarry. The fauna included (p. 164):

> ...arenaceous foraminifera which seem to be abundant throughout most of the section, internal molds of small brachiopods, fragments of small gastropods, abundant bryozoa remains, a few hexaxial sponge spicules, and an abundant ostracode fauna.

The ostracode fauna is comprised of about fifteen species and nine or ten genera, including Kloedenella, Tubulibairdia, Leperditia and Bairdia, all occurring as silicified internal molds.

Raasch (1946, unpublished information) listed the following fossils from the quarry based on Milwaukee Public Museum collections:

Stenopareia imperator-37
Calymene celebra-11
Eophacops handwerki-3
Encrinurus tuberculifrons-?
Enterolasma calyculum?
Dalmanella elegantula-3
"Leptaena rhomboidalis"-1
Barrandella ventricosta-27

Dolerorthis flabellites-1
Fardenia sp. nov.-A
Platyceras sp.-4

A second large quarry was opened sometime after the early 1940's just west of the Voree (Peters) Quarry on the opposite side of the White River. This quarry was also operated by the J. W. Peters Company, but by the early 1960's both quarries were flooded and have not been operated since. However, a few feet of the upper beds are still exposed above water level along the south wall of the Voree Quarry. A loose block of rock collected outside of the quarry on the west side of the river in 1963 contained common Stenopareia imperator parts, in contrast to the scattered occurrence usually reported for this trilobite.

Sugar Creek Quarry
Locality 3

NW 1/4, SE 1/4, SW 1/4, NW 1/4, Section 16, T. 3 N., R. 18 E., Spring Prairie Twp., Walworth County

MPM x28.2

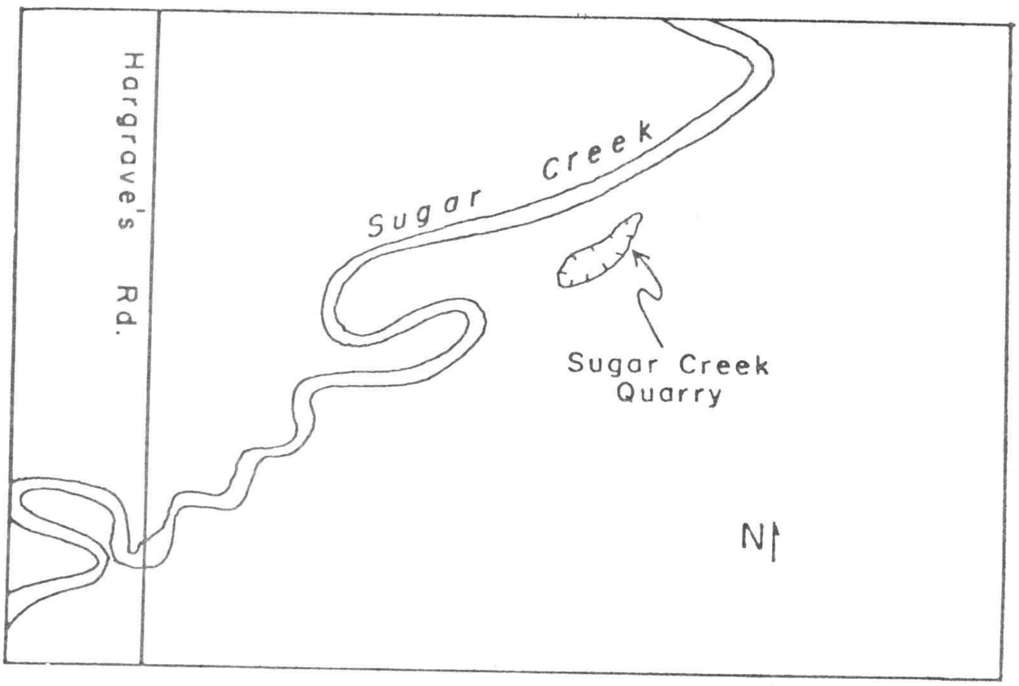
elevation: 810 feet

Agandoned quarry on south side of Sugar Creek

This small abandoned quarry is located on the south side of Sugar Creek at the foot of a northwest-facing hill approximately 1100

Figure 48. Airphoto and locality map of Sugar Creek quarry (locality 3, USNM loc. 11170) Walworth County. Airphoto (A) and diagram (B) showing location of the quarry. Airphoto by Southeastern Wisconsin Regional Planning Commission. Date: 1970.

A



B

Figure 48

feet northeast of the Hargrave's Road bridge crossing Sugar Creek (see Figure 48). The quarry is directly east of a small bend in the creek that turns first sharply to the west and then sharply back to the east. This locality was first indicated by Alden (1918, Pl. I) on his Geologic Map of Southeastern Wisconsin.

The quarry was briefly described by Shrock (1930, unpublished field notes) as two small holes along the slope of a low hill on the south side of Sugar Creek. Slabs of dolomite were common in the soil around the quarries and several thin ledges projected from beneath the soil in the quarries themselves. He noted that the rock was a slabby, gray to buff, earthy to crystalline dolomite, similar to beds exposed in the quarries near Burlington and also those at Casselman's Quarry to the north. A local farmer told Shrock that rock was exposed in the creek bed but none could be found at that time.

G. O. Raasch made a collection from these rocks in the 1940's and found them to contain abundant pentamerids which he correlated with the Schoolcraft Dolomite of northern Wisconsin (1955, unpubl. ms.) A. J. Boucot made a collection (USNM loc. 11170) of this same material in 1964 and correlated it with the Kankakee Formation in northeastern Illinois. He found nine speciments of Pentamerus sp.

An examination of the quarry in 1970 found it to be badly overgrown and slumped over; however, a number of slabs of fossiliferous dolomite were collected from the south wall in a one to two foot exposure. The rock is a fine-grained, dense, non-porous, light brown dolomite and contained the following fossils (brachiopods identified by A. J. Boucot):

Calymene sp. - 1 free cheek
small rugose coral - 1
Antirhychonella sp. - 1 pedicle valve
Pentamerus sp. - 11 pedicle valves, 12 brachial valves
few small pelmatozoan stem sections

Casselman's Quarry - Potter Lake
Locality 4

NW 1/4, SE 1/4, SW 1/4, Section 11, T. 4 N., R. 18 E., East Troy Twp., Walworth County

MPM x33. 1

elevation: approximately 810-820 feet

Small, overgrown quarry in a small ravine a short distance east of the southeast corner of Potter Lake, north of Hwy. 24, and west of Miramar Drive.

Percival (1856, p. 69-70) made the first observation on the nature of the rocks in this quarry (see Voree Quarry).

These rocks were assigned to the lower part of the Niagaran by T. J. Hale (1860, unpublished field notes) and he reported finding a crinoid and the trilobites Bumastus and Calymene, the only fossils

Figure 49. Sections in the Casselman's quarry (locality 4) at Potter Lake, Walworth County. (A) is the section made by T. J. Hale in 1860 Unpublished field notes) (B) locality map after Shrock (1930, unpublished field notes); (C) section made by Shrock (after Shrock, 1930, unpublished field notes).

CASSELMAN'S QUARRY, POTTER LAKE

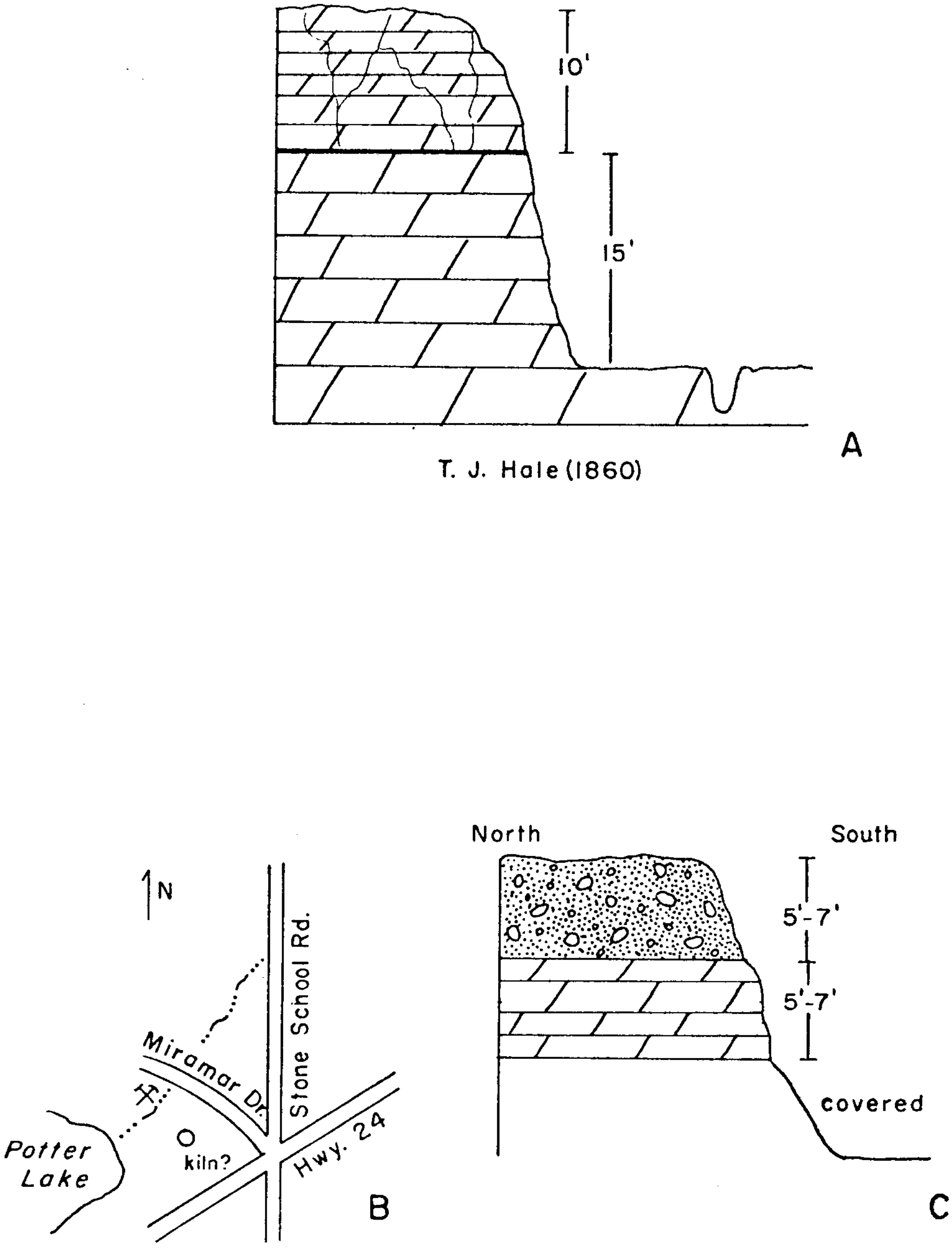


Figure 49

ever reported from this quarry. He described this locality (see Figure 49A) as follows (p. 12):

> This stone resembles that in the hill N. of Geneva Lake. The upper thin beds resemble very much that at Voree. The heavy beds contain some nodules similar to that at Waukesha.

Chamberlin (1877, p. 359) remarked that a "closely allied strata" to the Waukesha beds "occur at Casselman's Quarry... but no distinct fossils were found." He also referred briefly (p. 203-204) to glacial warping of the beds here similar to that found at Burlington.

Alden (1898, unpublished field notes, p. 27) mentioned that the quarry had not been worked for several years since Casselman died and was largely dirt-covered and overgrown. He did, however, find a six foot section exposed along part of the north side showing the rock to be thin-bedded.

In 1930 R. R. Shrock (unpublished field notes) visited this quarry (see Figure 49B and C and described it as follows:

> About 5'-7' of gray and light-buff mottled dolomite, somewhat earthy and in layers from 2"-4" thick are exposed in the small quarry now overgrown and practically hidden in underbrush. Some layers have green films in them.
>
> When weathered the stone becomes sandy and earthy and changes to a pinkish tinged or buff color.
>
> Unless there is a fresh hole where stone has been taken out recently the outcrop would be hard to see because of the gravel from above slumping down over it. The rock, however, can be studied in the walls of several buildings just west of the old quarry.
>
> Apparently this rock was also burned from (sic) lime

for a short distance south along a low bluff numerous pieces of partially calcined lime may be seen. The rock would probably make a fair lime, could be used for ground lime and is fine also for flagging and building stone.

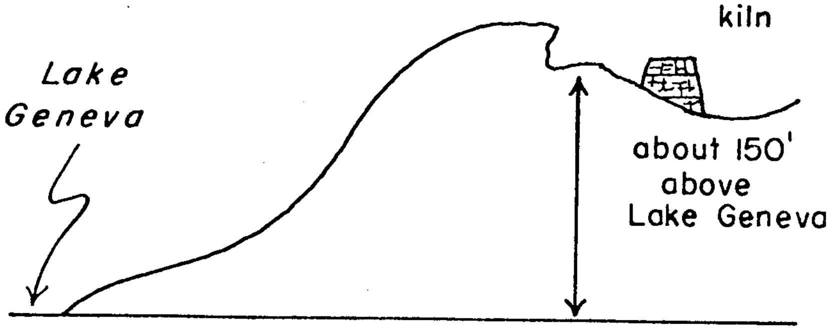
A brief search in 1979 revealed about one foot of rock exposed in the bottom of the stream running west through the ravine. The entire area is heavily overgrown and the quarry walls appear to be completely covered by soil.

Both Casselman's Quarry and the Sugar Creek Quarry are difficult to correlate with known southeastern Wisconsin Silurian rock units. They are thought to occur low in the Silurian; the Sugar Creek exposures are somewhat similar to the Plaines Member exposed at the main quarry at Ives, Racine County. Both exposures are near the outer edge of the Silurian bedrock which would also indicate they are low in the Silurian.

Other Walworth County Localities
Localities 5 and 6

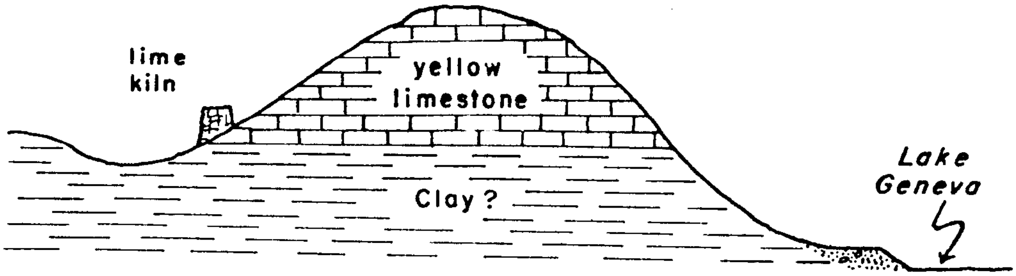
Two other localities in Walworth County have also been mentioned as having outcrops of Silurian. T. J. Hale (1860, unpublished field notes, p. 10-11) described a lime kiln belonging to Thomas Morehead on the north shore of Lake Geneva in Section 5, T. 1 N., R. 17 E., Linn Twp. (locality 5). The kiln was situated on the side of a hill approximately 150 feet high and rock was being excavated from a 35 foot deep pit on the top of the hill (see Figure 50A). Hale

Figure 50. Diagrams showing possible Silurian exposure on the north shore of Lake Geneva, Walworth County (locality 5). (A) diagram after Hale (1860, unpublished field notes); (B) diagram after Lapham (1872-1874, unpublished field notes).



T. J. Hale (1860)

A



I. A. Lapham (1872-74)

B

Figure 50

said that all the rock was in the form of loose, tumbled slabs of dolomite mixed with clay and was similar in appearance to that around Burlington and at Casselman's Quarry. In 1874 Lapham (unpublished field notes) presented a diagram (see Figure 50B) almost identical to that of Hale's and further located this quarry in the E 1/2, NE 1/4, Section 5. Lapham's diagram indicates that he thought the top of the hill to be composed of yellow limestone underlain by clay(?). Chamberlin (1877, p. 342) mentioned that Silurian rocks approach the surface on the north side of Lake Geneva but that they do not outcrop.

Information in the Wisconsin Geological and Natural History Survey files indicate that there is a quarry (locality 6) located along North Road where it crosses a small south-flowing creek near the Center, Section 3, T. 2 N., R. 18 E., one-half mile north of Lyons, Lyons Twp., at an elevation of 817 feet. A brief search of this area revealed no exposures.

RACINE COUNTY

The bedrock surface is generally covered by 100 or more feet of Quaternary deposits in Racine County (Hutchinson, 1970, p. 13). Natural outcrops consist of a few low exposures in the eastern quarter of the county and are confined to areas where stream or lake erosion has uncovered high areas of the bedrock surface. Hutchinson (1970, Pl. 1) shows the bedrock topography and geology of the county. These outcrops are located along the Root River in Section 6, T. 3 N., R. 23 E., Section 26, T. 4 N., R. 22 E., and along the Lake Michigan shore at Wind Point (Section 27, T. 4 N., R. 23 E.). A number of quarries have been opened in and around these outcrops. In the southwestern part of the county around Burlington the bedrock surface is occasionally within a few feet of the ground surface, particularly along the Fox and White Rivers. Natural outcrops have not been reported but a quarry has recently been opened in the bottom of a gravel pit just southeast of Burlington. See Figure 51 for locality map of Racine County.

Because the bedrock dips towards the east the exposure in the western part of the county exhibits older rocks than those in the east. This is well demonstrated by the fact that the quarry southeast of Burlington is mostly in the Brandon Bridge beds with a bedrock elevation of 767 feet, while the main quarry at Ives exposes the same

Figure 51. Locality map of Racine County showing numbered localities referred to in text. Structures to the right of the county on map may be Silurian reefs in Lake Michigan. Diagonal lines indicate areas where Silurian has been eroded through to Ordovician bedrock.

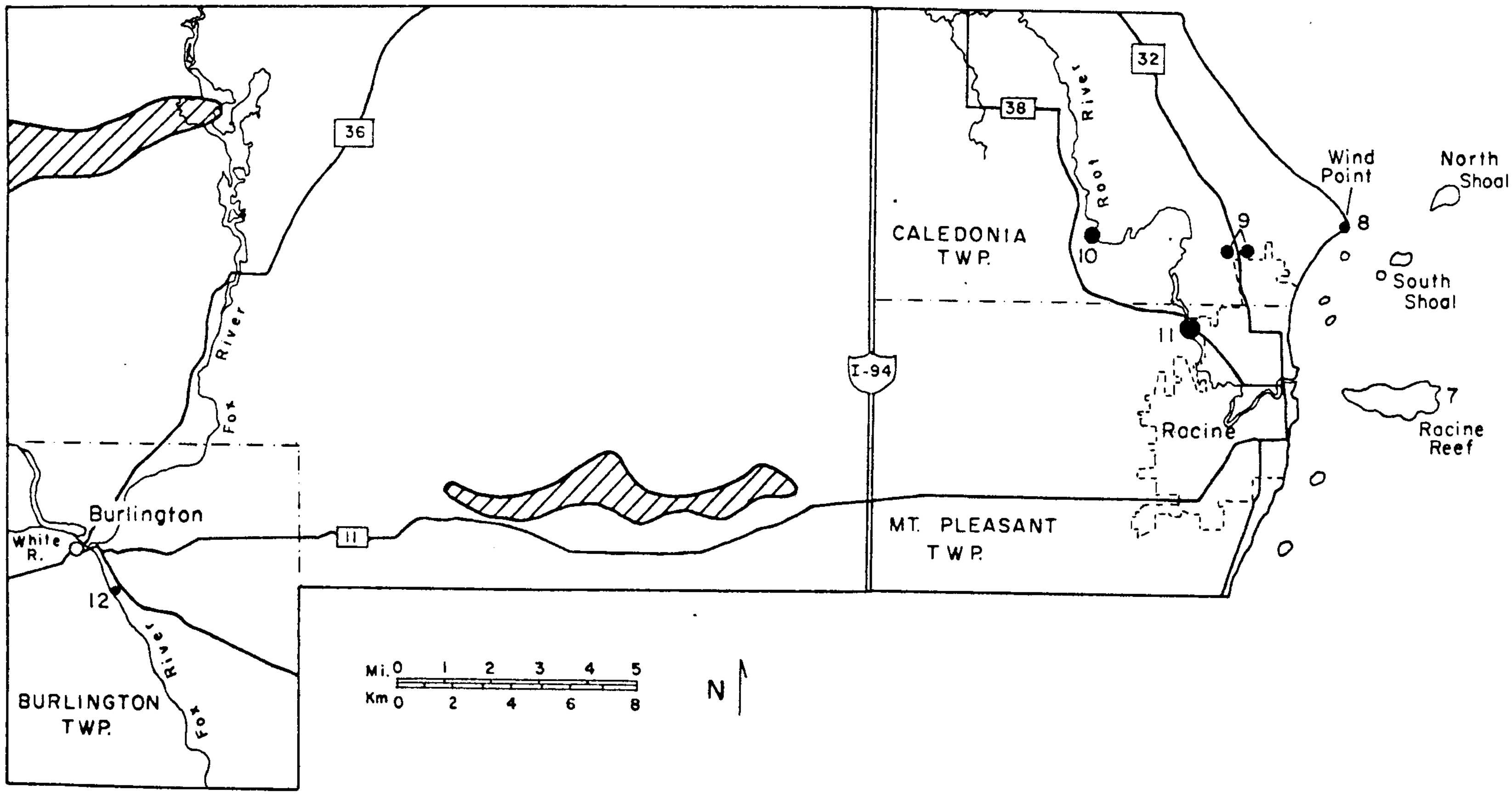

36
32
38
Root River
Fox River
Wind Point
North Shoal
South Shoal
CALEDONIA TWP.
10
9
8
11
I-94
7
Racine
Racine Reef
Burlington
White R.
11
MT. PLEASANT TWP.
12
Fox River
BURLINGTON TWP.
Mi. 0 1 2 3 4 5
Km 0 2 4 6 8
N

Figure 51

unit approximately 150 ft. to 200 ft. below the surface with the bedrock elevation of 645 feet.

The outcrops and quarries in the eastern part of the county are impostant because the type section of the Racine Dolomite is located there, and these exposures have been the source of abundant well preserved fossils for well over a hundred years. Most of these fossils have been found in reefs and reef-associated beds of the Racine Dolomite. Over 80 holotypes of invertebrate fossils have come from the Racine area Racine Dolomite.

Racine Reef (locality 7) and Other Similar Structures in Lake Michigan

A large topographically high structure called Racine Reef is located approximately 0.5 mile east of the shoreline just south of the Racine harbor entrance in Lake Michigan (see Figure 52). It extends over 1.75 miles to the east, having a maximum width of about one mile and rising on its eastern end about 30 ft. above the lake bed to within 10 ft. of the lake surface. Lapham (1846, p. 123) mentions a reef of rocks a mile and a half long and a half of mile wide off of Racine. Martin (1916) described this structure, but was uncertain as to whether it was a bedrock-controlled body or was composed of unconsolidated material.

Racine Reef has been responsible for the sinking of at least

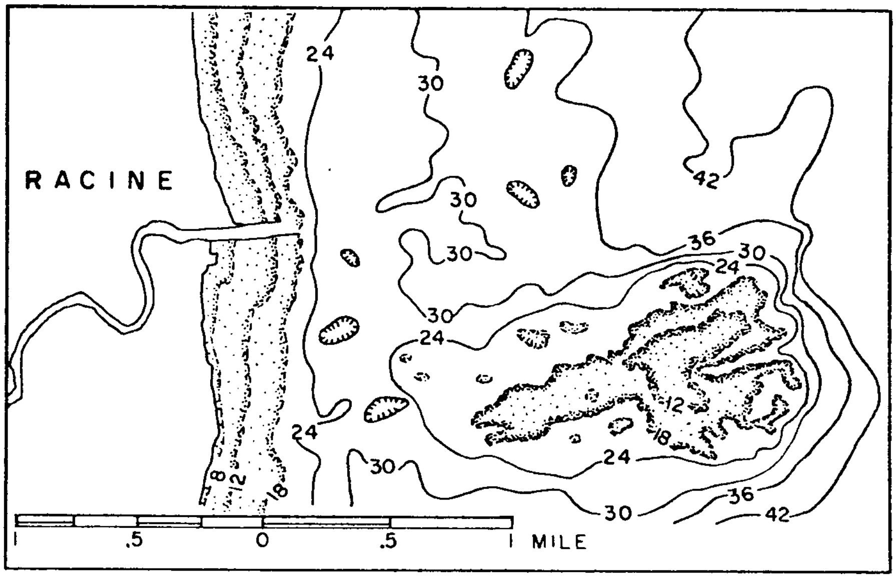


Figure 52. Map showing topography of Racine Reef (locality 7) in Lake Michigan off the shore of Racine, Racine County, Wisconsin (after Martin, 1916, Figure 123).

eleven ships (Racine Sunday Bulletin, June 13, 1954) and, therefore, fits the nautical definition of a tree reef, being a hazard to navigation. The question is, however, whether or not this structure is a Silurian reef as well.

The upper surface of the Reef does exhibit bedrock exposures (Jerry Walsh, 1976, personal communication) and in all likelihood is a Silurian reef. Bretz (1939) described a number of submerged Silurian reefs just off the Chicago shore in southern Lake Michigan, and recent work by the Illinois Geological Survey (Collinson, Norby, and Hansen, 1979) has located over 100 bedrock reefs along the Illinois shore from Indiana to Wisconsin. Most, if not all, of these structures are probably true Silurian reefs.

The topographic expression of these reefs is due to their superior resistance to erosional forces compared to that of the surrounding rock, and as a result, most known Silurian reefs in southeastern Wisconsin appear to be bedrock hills surrounded by glacial debris. Variations in lake level have resulted in the erosion of these surrounding sediments and at least partial exposure of many reefs. The Wind Point reef is currently being exposed in such a manner by shoreline erosion.

Two other smaller, submerged structures (North Shoal and South Shoal) are located about 1.5 miles off the Wind Point shore, both of which are probably also Silurian reefs. There are a number of other small mounds indicated on bathymetric maps of the area and a detailed geophysical survey would probably reveal many more of these structures as indicated by the work done by the Illinois Geological Survey.

Wind Point
Locality 8

NW 1/4, SE 1/4, NW 1/4 Section 27, T. 4 N., R. 23 E.

MPM x31.5

elevation: 582 feet

A number of low outcrops are exposed along the Lake Michigan shore in Shoop Park, Wind Point. These exposures extend for several hundred yards south of the lighthouse and the bedrock surface extends out into the lake for an undetermined distance. A few scattered outcrops may also be present north of the lighthouse.

Alden (1898, unpublished field notes) made a brief description of the outcrops and found the rock to be a very hard, gray, fossiliferous dolomite. Ball (1918) mentions finding a large piece of marcasite along a joint plane at this locality. The outcrops consist of typical, crinoidal, reef-associated Racine Dolomite like that exposed in the quarries around Racine. Only a foot or so of rock is usually exposed above lake level and boulders derived from the outcrop are abundant in the area.

Ives
Locality 9

MPM x31.1

elevation: 649 feet

Several quarries (See Figure 54) are located along Three Mile Road at the intersection of Hwy. 32 at a place formerly known as Ives, just north of the city of Racine (SE 1/4, Section 29; SE 1/4, SW 1/4, Section 29; NW 1/4, NE 1/4, Section 32, T. 4 N., R. 23 E.) (see Figure 53). These quarries were probably opened soon after Racine attracted its first settlers in the early 1800's. The bedrock is within a few feet of the surface and it is possible that natural outcrops were once present but have since been quarried away.

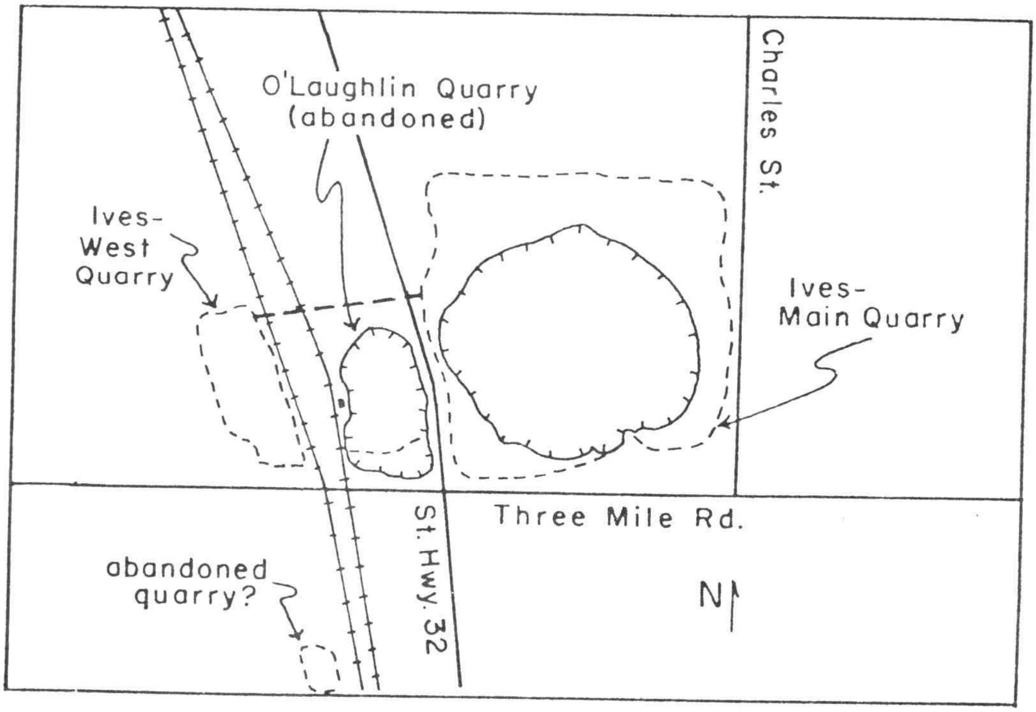
Percival (1856) made the earliest descriptions of the Racine area exposures. At Ives he made the following observations (Percival, 1856, p. 70):

> About three miles north of Racine, at Cooley's and Toes' quarries, beds of limestone rock have been excavated but a few feet, some of the layers of which abound in fossils similar to those at Grafton, and at the rapids of Root river nearly west of these, a similar fossiliferous rock is exposed.

He considered these beds to be part of his Mound Limestone. Both Cooley's (initials probably E.R.) and Toes' quarries were most likely located just to the northeast of the present intersection of Hwy. 32 and Three Mile Road at the current site of the main quarry of Vulcan

Figure 53. Airphoto (A) and locality map (B) of the Ives area (locality 9) of Racine County showing location of quarries discussed in text. Airphoto from National Archives and Records Service, General Services Administration; No. XC-25-2288 Racine County; date: 8-12-37.

A


O'Laughlin Quarry
(abandoned)
Charles St.
Ives-
West
Quarry
Ives-
Main Quarry
Three Mile Rd.
St. Hwy. 32
abandoned
quarry?
N

B

Figure 53

Materials Company.

T. J. Hale (1860, unpublished field notes) "found the quarry on the point 4 miles N. of Racine underwater" a the time of his visit.

Chamberlin (1877) described the area as having a quarry operated by Vaughn (William W.). This quarry was located at the present site of the main quarry of the Vulcan Materials Company. He made the following observations (Chamberlin, 1877, p. 361-362):

> At Vaughn's quarry...the first six or eight feet, as it lies in the beds, is deep yellow in color, verging to orange and red on the one hand, and to pale buff on the other. Below this the color varies from ash-gray to grayish-blue. The upper layers are apparently thinner bedded than those below, though this is probably only the effect of the elements. The lower payers are heavier, but do not often exceed a foot in thickness. The beds are but obscurely defined, so that it is difficult to trace a given one for any considerable distance, or to ascertain the dip with any precision. There is an almost entire absence of shaly partings or laminae of clay, so that the chipstone are comparatively free from the marly or clayey matter common in quarries. This is only true of the lower layers that have not been affected by inwashing from above, and by the immediate action of the surface elements.
>
> The vertical joints are prominent, and in some portions frequent, and are usually smooth, and coated with calcareous and pyritiferous deposits.
>
> The rock is porous and geodiferous; the former condition being largely due to crinoidal remains imperfectly preserved, and the latter perhaps in part to the same cause, also, the portion removed being the calyx. The material filling the geodes is chiefly calcite and pyrite, both of which appear in abundant and beautiful forms. The pyrite takes the tabular form of crystallization to a large extent, and the calcite seems to prefer the form known as dog-tooth spar. Crystals of this an inch or more in length are not uncommon.
>
> The rock is quite brittle and sonorous, and presents a saccharoidal appearance on the freshly fractured surface of the unweathered layers. A bluish-green, argillaceous material is found in obscure, irregular partings.

In fossils, it is far less prolific than the rock at the Rapids.

In 1879 the Horlick Brothers, owners of some of the quarries along the Root River, purchased the Vaughn Quarry.

Some time afterward, John O'Laughlin (operator of quarries in the Chicago area) opened a quarry north of Three Mile Road, between Hwy. 32 and the railroad tracks. The O'Laughlin Quarry was first mentioned by Buckley (1897, unpublished field notes) as having "a vesicular, hard, blue limestone." He also describes the former Vaughn Quarry (operated by the Horlicks at this time) as having a hackly, blue limestone with prominent, irregular breakage occurring in beds running 2-6 inches with an occasional maximum 30 inch thickness. Buckley also mentions these quarries in his 1898 work on the building stones of Wisconsin but did not describe them individually.

Alden visited both these quarries in 1898 and found the O'Laughlin Quarry to be about 50 feet deep with approximately 3 feet of overburden stripped from the bedrock surface. The upper 10-15 ft. (section A, Fig. 54) of the quarry was a buff or yellow, thin-bedded dolomite containing abundant fossils. The lower 30-35 ft. (section B, Fig. 54) was a blue, massive, irregular breaking dolomite with few fossils but good crystals of dogtooth calcite. Pyrite was found in both units. Alden also recorded geologic units penetrated in a water well that was drilled at the quarry site as follows (Alden, 1898, unpublished field notes):

2' drift

300' Niagara Limestone (Silurian)

200' Cincinnati Shale-blue (Maquoketa)

300' Galena Limestone-streaks of shale

25' Trenton Blue shale

60' Sandstone

Alden briefly mentions the Horlick (Vaughn) Quarry as being similar to O'Laughlin's, but the upper, buff dolomite was only 3-10 feet thick with the rock seeming very hard and with fewer fossils than at O'Laughlin's.

A photograph of the south half of the west wall of the O'Laughlin Quarry was published by Buckley in 1903 and was probably taken during his Wisconsin fieldwork in 1897. Figure 55 presents two photographs of the O'Laughlin Quarry.

In 1905 Kindle briefly visited these quarries and made the following observations in his unpublished fieldnotes. The O'Laughlin Quarry was by far the deepest, raching a depth of 84 feet. He describes the rocks in this quarry as follows (Kindle, 1905, unpublished field notes):

> The bedding is distinct and clear on one side of quarry but the rock most places is massive and there is a slight tendency to the "reef" structure in places that in bedding dips away from the massive lumps slightly at times. Fossils throughout but scarce, Illaenus ioxus, crinoid heads, etc.

The Horlick (Vaughn) Quarry was about 37 feet deep and Kindle

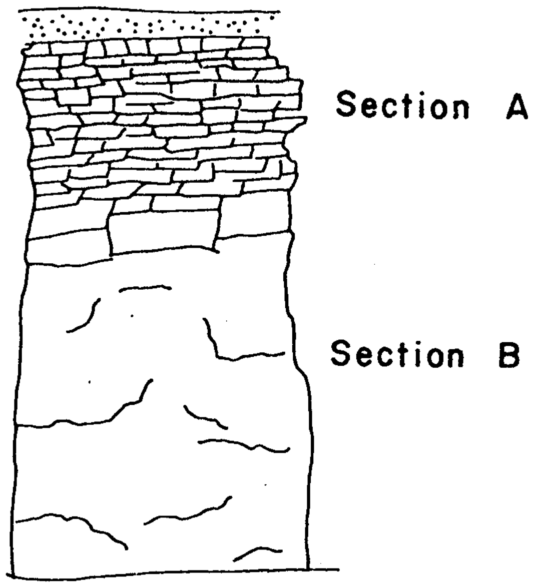


Figure 54. Section in O'Laughlin quarry (locality 9), at Ives, Racine County. See text for details. (After Alden, 1898, unpublished field notes.)

described the rock as a hard, gray dolomite as follows (Kindle, 1907, unpublished field notes):

> Fossils common in spots but most common in upper 1/3 of beds. Over much of quarry fossils are very scarce. Large cephalopods common.
>
> Bedding is slightly irregular--not perfectly horizontal as in many quarries.
>
> A few of the joints are filled with a tenacious blue pyritous clay unlike the glacial clay overlying the locality. Ls. pebbles occur in clay and some vary from a fraction to several inches in width.
>
> The walls of such seams in some are slickened as if they had slipped on each other.

E. O. Ulrich (1914, unpublished field notes) briefly visited the O'Laughlin Quarry and noted that it was about 100 feet deep (this depth might be an exaggeration) and also made a crude sketch of reef structures in one of the walls.

The O'Laughlin Quarry ceased operations around this time and the quarry rapidly filled with water. The quarry was one of the deepest in southeastern Wisconsin, but it is not known if it reached the top of the Waukesha beds which are about 90-100 feet below the surface at this location. Since that time the southern end of the quarry has been partially filled, but a few feet of typical Racine Dolomite can be seen above the water level along the east and west walls.

Shrock visited the former Vaughn Quarry (see Figure 56) in 1931 when it was operated by the Consumer Company. The quarry was over 50 feet deep and exhibited two different lithologies, both within the Racine Dolomite. He describes it as follows (Shrock,

Figure 55. Photographs of the O'Laughlin quarry at Ives (locality 9), Racine County. (A) west wall, looking towards the northwest; (B) looking north along the east wall. Photos courtesy of the Wisconsin Geological Survey, (A) is no. 759, circa 1914; (B) is no. 489, circa 1912.

A

B

Figure 55

Figure 56. Photograph of old Vaughn quarry (Main quarry-Vulcan Materials Company), looking north, taken in the 1920's. Photo courtesy of Milwaukee Public Museum, No. 49682.

unpublished field notes, 1931):

> A lower, buff, fine-grained, dense crystalline rock which is knotty-bedded and has no fossils. Thin and well bedded.
>
> The remainder of the stone is a blue hard cavernous dolomite containing a great deal of marcasite. The dolomite is sometimes druzy, or cavernous; sometimes an inchoate mainly fossiliferous mass and always massively bedded. The blue phase is abundantly fossiliferous, crinoids and brachiopods being quite common at some horizons. Highest beds contain Spirifer.
>
> Dips are somewhat irregular in the quarry.

Rock samples in the Milwaukee Public Museum collections indicate that this quarry had been deepened to the cherty beds of the Waukesha Dolomite no later than 1946. It probably reached its maximum lateral extent during the early 1950's. At this time a large number of fossils were collected in the Racine Dolomite at the old Vaughn Quarry by local amateur collectors. A large collection of fossils, chiefly made by J. Montague, is deposited in the Milwaukee Public Museum. This quarry is currently operated by Vulcan Materials Company who took over the Consumer Company, and in the early 1970's the lower, more argillaceous portion of the Brandon Bridge beds were exposed here.

Frest, Mikulic, and Paul (1977) briefly described the main quarry of Vulcan Materials Company at Ives. Based on 1973 observations the quarry was thought to consist of about only 50 feet of Racine Dolomite overlying about 70 feet of the Joliet Formation, including the uppermost beds of the Brandon Bridge Member. The thickness of the

Racine is now known to be greater than 50 feet.

Sylvester (1977) made a brief study of the Racine Dolomite in the old Vaughn Quarry (which will be referred to as the main quarry in the rest of this discussion) and a small, new quarry west of the railroad tracks and north of Three Mile Road (referred to as the west quarry). She assigned all of the beds above the Brandon Bridge (which she referred to as Byron) to the Racine Dolomite. This included the 65 feet of the cherty, argillaceous Waukesha Dolomite (her Unit B of the Racine Dolomite). Sylvester's Unit A of the Racine is partially equivalent to the Racine Dolomite as defined in this discussion, but she reported only 55 feet of Racine (Unit A) above Unit B, whereas there is approximately 100 feet of Racine Dolomite above the Waukesha Dolomite. This discrepancy cannot be accounted for by her different terminology for the lithologic units exposed in the quarries. Most of Sylvester's observations on the Racine were based on the exposures in the west quarry which was then approximately 45 feet deep. Sylvester also reported a maximum thickness for reefs in the Racine of only 25 feet, whereas most appear to extend through the entire 100 feet of the unit. She was the first to report a fault with 5-8 feet of displacement and a southeast-northwest trend along the east wall of the west quarry.

Mikulic (1977) described both of the operating Ives quarries and the following description is modified from that information.

Main Quarry--Vulcan Materials Company (Vaughn), Ives

This quarry exhibits the thickest section of Silurian rocks in southeastern Wisconsin with over 200 feet of rock currently exposed (see Figure 57A). The quarry exposures are supplemented by a number of cores which have been drilled through the quarry floor and into the upper beds of the Ordovician Maquoketa Shale. This information indicates that the total Silurian is about 290 feet thick in the southwest corner of this quarry; this measurement is close to the 300 feet Alden (1898, unpublished field notes) reported for the O'Laughlin water well, a short distance to the west.

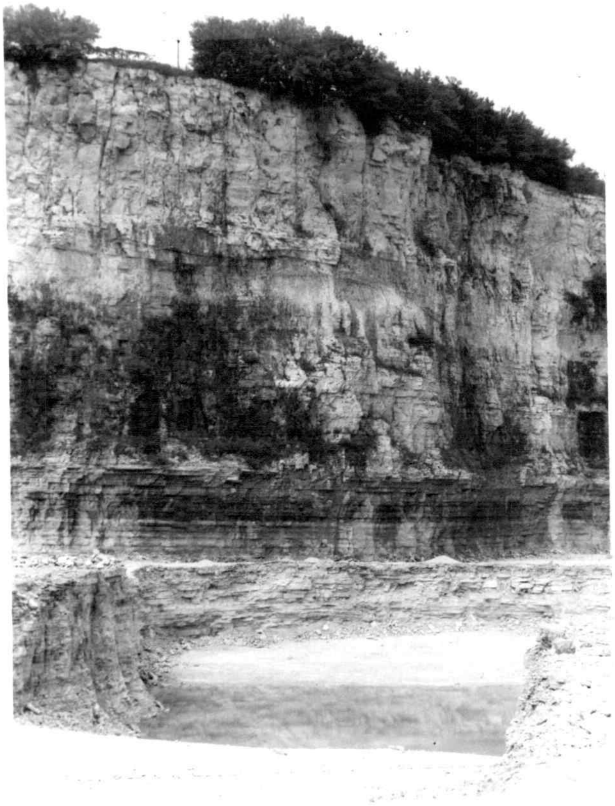
The Racine Dolomite, Waukesha Dolomite, Brandon Bridge beds, and upper 30 feet of the Kankakee(?) Formation are currently exposed in this quarry. The Racine and most of the Waukesha is relatively inaccessible, however, because the upper walls of this quarry are vertical. Quarrying operations in the Brandon Bridge have been slow as the rock is of poor quality.

An interesting feature of this quarry is the presence of large depressions and rises in the quarry floor extending down through at least the Brandon Bridge. These are a result of overlying reef structures in the Racine Dolomite which have depressed the underlying units (see Figure 57B). When power shovels were formerly used in the quarry, attempts had to be made to blast the floor level since it was difficult to operate these machines on the sloping surface (Kjell Oliverson, 1976, personal communication). The distribution of large-scale depressions in the quarry floor indicate that at least six large reefs have been completely quarried away; similar depressions have recently been described from the Silurian of Gotland by Eriksson and Laufeld (1978).

The following description is based on quarry exposures and core information. See Figure 58 for section.

Racine Dolomite. The uppermost stratigraphic unit in the quarry is the Racine Dolomite which has a thickness of over 90 feet. The upper surface is an erosional unconformity covered by Quaternary sediments, so the original thickness of the Racine is unknown. The rock is generally a light to dark gray, medium- to thick-bedded, crystalline, porous dolomite. Bedding is commonly irregular and the rock contains numerous vugs and cavities. The bedding dips up to approximately 30 degrees around reef structures, but is relatively horizontal in non-reef areas. Reefs are relatively common and are up to 90 feet in thickness and 200 feet in diameter. The reefs are well exposed in the north, east, and east half of the south walls, but are accessible along only the east half of the south wall. The reefs are massive in appearance, highly fossiliferous, vuggy and dark gray, and are surrounded by flank beds which radiate away from their centers. Most of the fossils reported from the Racine Dolomite are found in these

Figure 57. Photographs of the Main quarry-Vulcan Materials Company at Ives (locality 9), Racine County. (A) shows the complete exposed section in the Silurian along the west wall of the quarry; (B) shows a Racine Dolomite reef depressing the underlying Waukesha Dolomite beds along the east wall. Photos taken in 1977.



A

B

Figure 57

types of reefs and the faunas here are identical to those collected at the Horlick Quarry, 1.8 miles to the southeast. The fossils occur as internal and external molds.

The contact between the Racine and the underlying Waukesha beds is abrupt in the vicinity of the reefs, but may be more gradational in non-reef areas; unfortunately, this contact is almost completely inaccessible at this time. Several different inter-reef units can be seen in the Racine Dolomite, however, detailed observations are lacking because of the inaccessibility of the lower 50 feet of this unit. The upper 40-50 feet is well exposed in the west quarry and will be described later in the discussion of that quarry.

Waukesha Dolomite. The Waukesha is thin- to thick-bedded, argillaceous, light gray to buff, cherty dolomite. The chert is generally nodular and increases in abundance towards the top of the unit. Bedding planes are occasionally stylolitic and are commonly separated by very thin green clay partings which weather black. As mentioned before, the contact with the overlying Racine Dolomite may be gradational, but it is sharp in the vicinity of the Racine Dolomite reefs. The upper 16 feet of the Waukesha is highly cherty, thin-bedded, white to light gray, crystalline, fine-grained dolomite with little porosity. The chert is white, nodular and contains some crinoidal debris. The chert is white, nodular and contains some crinoidal debris. These beds are conspicuous in the older parts of the quarry

Figure 58. Section through the Silurian at the Main quarry-Vulcan Materials Company at Ives (locality 9), Racine County, based on exposures and core information.

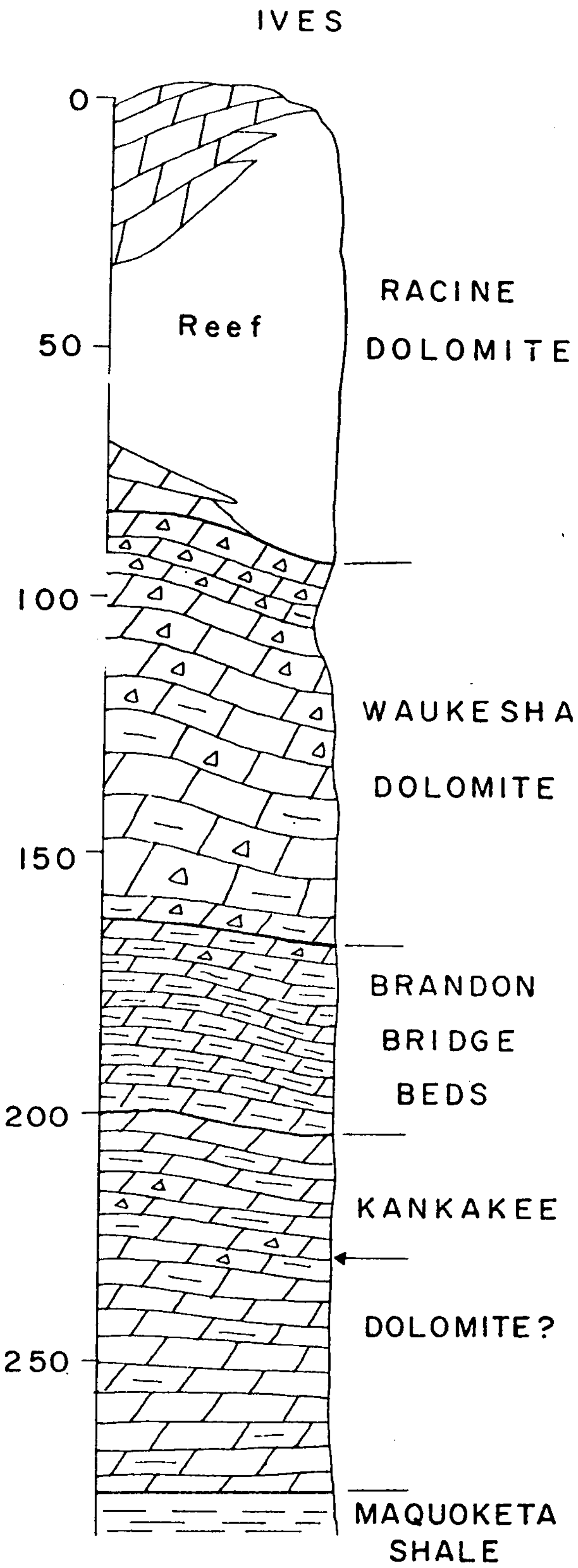

IVES
0
50
100
150
200
250
Reef
RACINE
DOLOMITE
WAUKESHA
DOLOMITE
BRANDON
BRIDGE
BEDS
KANKAKEE
DOLOMITE?
MAQUOKETA
SHALE

Figure 58

as this unit erodes quickly leaving a noticeable, slightly indented, light-colored, rubbly band. The Waukesha is poorly fossiliferous with only a few orthoconic cephalopods, horizontal burrows or trails, and fine disarticulated pelmatozoan debris being present in some areas. The underlying contact with the Brandon Bridge is gradational.

Brandon Bridge Beds. The Brandon Bridge is approximately 42 feet thick, consisting of thin- to medium-bedded, finely laminated, light green to pink, crystalline to argillaceous dolomite. Shaley, argillaceous layers alternate with more crystalline beds, reaching a conspicuous maximum near the middle of the unit. The upper half of the unit becomes less argillaceous and consists of alternating greenish, crystalline layers with beds which become increasingly more Waukesha-like in lithology. The lower half of the unit is much more argillaceous and finely laminated. The highly argillaceous dolomite to shaley beds in the middle of the unit are dark red in color and contain layers of abundant horizontal trails or burrows and some layers of vertical burrows; dessication cracks are also present. Few body fossils are present in this unit. Specimens of the trilobite Stenopareia imperator are particularly conspicuous in the upper beds and may range up into the lower Waukesha. A few orthoconic cephalopods, brachiopods, and pelmatozoan stems are also present. The lower contact of the Brandon Bridge with the underlying beds is very sharp.

Kankakee Dolomite(?). Approximately 76 feet of Silurian rocks are present beneath the Brandon Bridge beds at Ives, but only the upper 40 feet are exposed in the main quarry; however, the rest is known through cores in the quarry floor. The best exposure of these beds is in the sink in the northwest corner of the main quarry.

The upper three feet is a massive-appearing, brown, porous, finely crystalline dolomite which breaks with a conchoidal fracture. Patches of a light-colored, porous, granular material are conspicuous in some places. About ten inches below the top of this unit are locally common, disarticulated specimens of the brachiopod *Pentamerus*; lenticular colonies of the tabulate corals *Favosites* and *Heliolites* are also present. The upper surface is characteristically smooth and slightly undulating, occasionally with small, shallow pits. This three foot bed is similar in appearance to the Plaines Member of the Kankakee Formation in northeastern Illinois as described by Willman (1973).

The exposed underlying beds are highly cherty, medium- to thick-bedded, crystalline to argillaceous, light brown dolomite. Some bedding planes contain a variety of brachiopods and other fossils. Two large lenses of non-cherty, pinkish-brown, vuggy, massive dolomite are conspicuous in the northwest corner of the quarry, although not as yet well exposed. The lenses range up to approximately 60 feet wide and four and one-half feet thick. They are poorly fossiliferous, but some halysitids and pelmatozoan debris are present. Some of the adjacent and overlying cherty beds appear to wedge out against the lenses, but there appears to be little topographic expression of these lenses in the overlying beds. These lenses may represent carbonate buildups. According to the cores, the cherty beds range in thickness from 22 to 51 feet in thickness.

Beneath this is 25 to 50 feet of fine-grained, light gray dolomite, with argillaceous seams, to the top of the Maquoketa Shale. The variation in thickness between the cherty and non-cherty units under the Plaines does not reflect a variation in thickness of the total Silurian rocks in this interval.

Maquoketa Shale. Approximately 200 feet of the Ordovician Maquoketa Shale unconformably underlies the Silurian rocks at Ives. The upper beds of the Maquoketa have been penetrated by cores in the quarry area. Examination of these cores reveals that ten inches of light green shale overlie 14 inches of maroon shale with common hematitic oolites, which is underlain by 13 inches of light maroon to light brown shale without oolites, followed by typical fossiliferous shale of the Brainard Member of the Maquoketa (Mikulic, 1977). The maroon shale beds appear to be equivalent to the Neda. Examination of eight core logs show that the thickness and elevation of the Neda beds are variable. Also, there is a pronounced dip towards the southeast and the Neda appears to be absent in the northeast corner and part of the southwest corner of the quarry. Not all of the cores were examined for this study and there is a possibility that the Neda was overlooked during the original logging.

West Quarry--Vulcan Materials Company, Ives

The west quarry of the Vulcan Materials Company was probably started in the 1950's and has been operated intermittently since then. It is located just west of the railroad tracks and the old O'Laughlin Quarry and north of Three Mile Road. It is rather small in area and had a maximum depth of about 45 feet until 1979. It has recently been connected to the main quarry by a tunnel, and large-scale quarrying operations have just recently started. The tunnel runs under the buildings on the north end of the old O'Laughlin Quarry and is approximately two-tenths of a mile long; it is constructed in approximately the lower half of the Waukesha Dolomite.

At least three small faults, all running northwest-southeast, are present in this quarry and can best be seen in the east wall about 300 to 400 feet north of Three Mile Road. The total amount of displacement is approximately 12 feet with the downthrow to the south (Mikulic, 1977). The highest Racine beds in the area are, therefore, those in the south wall of this quarry. These faults do not appear to be exposed in the main quarry to the east.

The flank beds of two small reefs are exposed in this quarry. One along the south wall in the vicinity of the crusher pit has beds dipping to the northwest and northeast. A second, in the northeast corner of the quarry, is not as well exposed but appears to have beds dipping to the west and south. The beds also appear to dip beneath this reef strucuter.

Most of the exposures in the quarry are of Racine Dolomite inter-reef beds with the exception of the flank beds nare the two reefs. A 44 to 56 foot section of the Racine Dolomite was exposed in this quar quarry in 1977 and these are the highest beds of this unit exposed in the Ives area. The following section was measured primarily along the east wall to the north of the faults.

Unit A. Approximately 16 feet of buff to light brown, thin, irregularly bedded dolomite becoming increasingly gray towards the bottom. The rock is porous and occasionally contains small vugs. It is poorly fossiliferous with disarticulated pelmatozoan columnals of small diameters being most conspicuous. The bottom six feet are darker gray, porous, granular and thicker bedded than above. This lower boundary is gradational with the underlying unit.

Unit B. Eight feet of light gray to whitish, dense fine-grained, non-porous, thick-bedded dolomite. This unit loses its characteristics as it approaches the reef in the northeast corner of the quarry where the rock is darker gray, more vuggy, and massive.

Unit C. Ten feet of dark gray, extremely vuggy, massive, fine-grained dolomite. A number of fossils were observed in this unit including a three foot long orthoconic cephalopod, stropheodontid brachiopods, and larger pelmatozoan stem sections than in Unit A.

Unit D. This unit is approximately 11 feet thick, extending to the bottom of the quarry, and is lithologically similar to Unit B. The upper ten inches is dense, whitish rock underlain by six to fourteen inches of dark, vuggy rock similar to Unit C. This overlies nine feet of whitish to light gray, dense, very fine-grained, crystalline, medium-bedded dolomite. Bedding planes are slightly stylolitic.

In general, the inter-reef beds are poorly fossiliferous (particularly Units B and D), but become more fossiliferous in the vicinity of the reefs. Small crystals of marcasite and calcite are common along joints.

The core drilled along the east wall, near the north corner, shows that there are approximately 90 feet of Racine Dolomite above the highly cherty beds of the upper Waukesha Dolomite.

Directly south of this quarry (south of Three Mile Road) a small quarry is indicated on the 2958 South Milwaukee 15' quadrangle. This is now the site of a construction company with a small "pond" to the south. No rock outcrops can be seen.

Horlick Mills Quarries and Exposures
Locality 11

E 1/2, Section 6, T. 3 N., R. 23 E., Mount Pleasant Twp., Racine Co. MPM x 31.2, x31.9 (quarries on west side of river)
elevation: 630 feet (top of exposure)

There are a number of old quarries and outcrops along both sides of the Root River from the Horlick Mill dam south through the Racine Country Club grounds. Several different quarries were once opeated in this area including the Horlick quarries, Beswick's Quarry and Fox's Quarry. Lapham (1846, p. 123) mentioned that at this location "the river runs over beds of yellowish limestone, forming rapids." Since the 1850's both sides of the river have been quarried and the present exposures may be in part artificial.

It is not known precisely when quarrying began in this vicinity, but in 1853 J. A. Horlick purchased quarry land from Alanson Allen and started a lime and stone operation (Butterfield, 1879). William Beswick purchased the Root River Lime Works in 1856 (Butterfield, 1879) which was located south of the Horlick property. Around the same time Conrad Fox started his quarry which was located on the east side of the river, north of the Horlick porperty, near the mill.

Lapham (1851, p. 170) stated that his Unit VII, a soft yellow limestone, was found near Racine and other points along the Root

River. And in another early description, Percival (1856, p. 70) mentioned that a fossiliferous rock similar to that around Ives was exposed at the rapids of the Root River.

In 1865 Lapham (unpublished field notes) described an exposure in one of the quarries (probably Horlick's) at this locality (see Figure 59):

> Found there a rock (a) very much resembling the 'geodiferous rock' at Milwaukee and Wauwatosa, with beds (b) resting upon it in the same way. The fossils of the two beds are mostly different, the one is blue (a) hard and irregularly bedded; the other (b) is yellow and more evenly bedded with numerous fossil crinoids etc.
>
> The 'Waukesha Limestone' appears to be absent here. It belongs between these two rocks--between a and b.
>
> Numerous large fissures indicate former disturbance of these rocks; perhaps uplifts. These fissures are filled with blue (drift) clay.
>
> Some of the layers (b) are porous yellow, with numerous crinoid stems, like those at Menomonee Falls.
>
> Large quantities of excellent lime is made at these quarries--some of the layers are used for rough masonry.
>
> The fissures extend into both kinds of rock--and have different directions; dip of the layers also irregular and in different directions in different parts of the quarries.

Lapham's type "a" rock is a reef-core and type "b" is flank rock and not the different stratigraphic units he considered them to be.

This same reef structure appears to have been described by Chamberlin (1877, p. 361-362):

> At Racine, whence the formation takes its name, as exposed at at the rapids of the Root River, it is a blue, gray or buff, brittle dolomite, having a somewhat glossy fracture, subcrystalline structure in part, and earthy in part, and contains many geodic cavities, filled with calcite and pyrite, and sometime mammillary deposits. Its texture is uneven, being

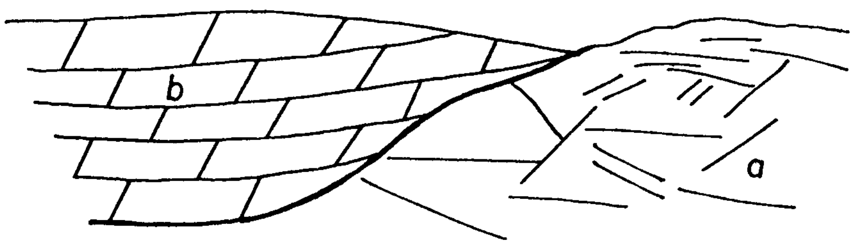


Figure 59. Diagram of exposure at the quarries along the Root River in Racine County, probably at the Horlick quarry (locality 11). Lapham (1865, unpublished field notes) attributed the relationships between (a) and (b) to stratigraphic differences, but it most likely represents a relationship between reef and flank beds. See text for details. After Lapham (1865, unpublished field notes).

> sometimes granular and again brecciated, usually coarse and porous, but sometimes fine and compact. It is frequently stained with iron oxide, and, in places, is quite pyritiferous, especially in the fissures. The bedding is also irregular, but usually rather heavy, ranging from five feet downwards. In the south quarry at this point, belonging to Mr. Horlick, there is a small mound of highly porous blue rock, without visible bedding, full of fossils, from which it doubtless had its origin, after the manner of reef formation. It is surrounded on all sides by bedded rock. The dip at this point is varying in amount and direction... the average dip is to the N. W., a direction opposite to the general dip of the formation. Fossils are very abundant, in the form of imperfect casts.

A plat book from 1887 (Anon.) shows the location of some of the quarries and kilns and also presents sketches of the Fox Quarry and lime kilns; the Horlick Quarry (near the southwest corner of the current Quarry Lake); and the Horlick lime kilns (on the east bank of the Root River under the present Hwy. 38 bridge) (see Figure 60). Figure 62 shows photographs of the Horlick quarry area around this time.

Correspondence between prominent fossil collectors T. A. Greene and P. Hoy from 1880 to 1894 reveals some geologic information at a time when vast numbers of fossils were collected from these localities. Reference to the "Blue Mound" appears several times in their correspondence due to its highly fossiliferous nature; this mound seems to have been located in the SW 1/4 of the main Horlick Quarry on the east side of the river, but has since been quarried away. The letters also indicate that Beswick's Quarry was not being worked and

Figure 60. Map from 1887 plat book showing location of quarries, kilns, and residences along the Root River, Racine County. (Modified from Anonymous, 1887.) Main Horlick quarry (Quarry Lake Park) north of J. A. Horlick's house on the east side of the Root River is not indicated; the quarry was present at that time because it was illustrated on an accompanying lithograph in the plat book.

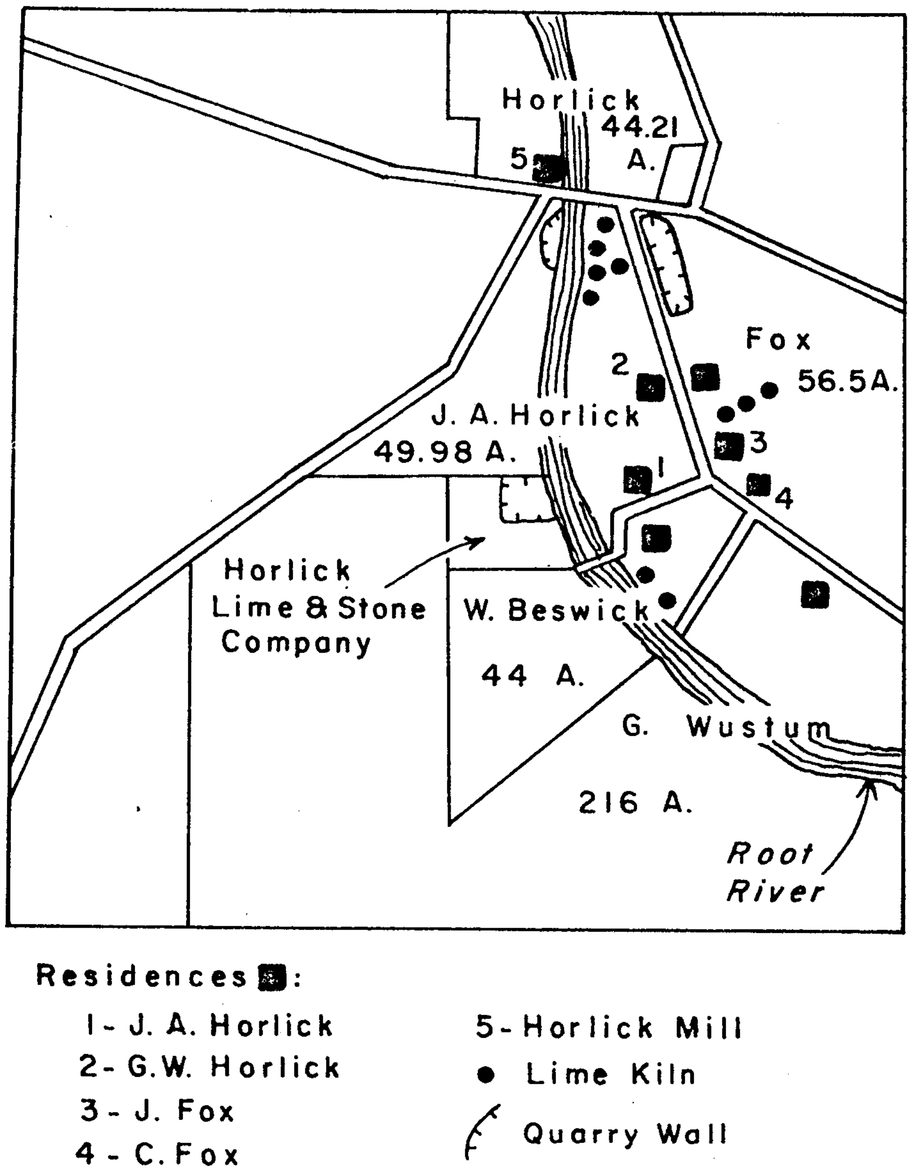

Horlick
44.21
A.
5
Fox
56.5A.
2
J. A. Horlick
49.98 A.
3
1
4
Horlick
Lime & Stone
Company
W. Beswick
44 A.
G. Wustum
216 A.
Root
River
Residences:
1 - J. A. Horlick
2 - G.W. Horlick
3 - J. Fox
4 - C. Fox
5 - Horlick Mill
Lime Kiln
Quarry Wall

Figure 60

Figure 61. Photographs from the Horlick quarry area (locality 11) Racine County circa 1880's. (A) shows quarry west of Root River, north of Quarry Lake Park, looking north toward Horlick Mill along the Root River; (B) looking north along the west wall of the main Horlick quarry (Quarry Lake Park). Photos courtesy of Richard Horlick, Racine, Wisconsin).

A

B

Figure 61

the quarries around Ives and Fox's Quarry were not very fossiliferous. Most of the fossils collected by Greene and others came from the quarries close to the river, on either bank, in the vicinity of the southern end of Quarry Lake.

Buckley (1897, unpublished field notes) described the quarries in this area stating that the Fox Lime and Stone Company Quarry was about 50 feet deep with the rock thicker-bedded at the bottom than at the top, and very vesicular. The Horlick Lime and Stone Company Quarry was large, but only 23 feet deep, and Buckley observed that:

> iron pyrites and marcasite was very plentiful along the seams and weathering out stains the stone brown. Fossils are very abundant throughout all the rock. The natural surface of the rock is pitted from top to bottom with holes of all sizes up to two inches across... The beds dip in this quarry a little to S.W.

In 1898 (p. 327-328) Buckley briefly described these quarries based on these field notes.

Alden (1899, unpublished field notes) presented a more detailed description of these quarries and exposures:

> In sec. 6 the banks of the channel show very much limestone in fragments until the rock beds begin to appear. Just at the middle sec. line is the large quarry of the Horlick Lime & Stone Co. on both sides of the stream. Here the rock is exposed in 10 to 20 ft. sections. It is thin-bedded with the same characters as seen in Fox's Quarry north of the road at the mill. The stream runs in a little rock gorge south as far as the quarries, below the dam. South of the quarry the rock drops down rapidly and is not seen except as indicated in the channel of the stream. To the west the till surface rises quite rapidly.
>
> At the old quarry in the west side of the river the rock

shows but poorly developed bedding. It is mostly massive. Towards the top it inclines more to buff in color and very loose open texture where exposed to weathering, but below it is a hard gray dolomite more or less crystalline in character with abundant pores and little cavities. The rock is highly fossiliferous. There has been more or less quarrying along both sides of the river northward to the dam. Indeed it seems quite notable that the gorge is largely artificial. Much pyrite shows up on the vertical facies. Quite numerous vertical fracture faces are seen through the rock. At the dam and in Fox's Quarry the rock shows much more bedding sloping out in 3 and 4 inch layers of rather uneven surface. At Fox's this is much used for building purposes. Probably 2/3 of this output goes for building and the rest for lime and crushed stone. The bedding has a gentle southward dip.

Horlick Quarry is very large and shows about 20 ft. section. In general the bedding is not very well defined except on the east where more or less defined bedding lines run through the mass and dip to southwest at angle of about 7°. The rock in general is hard gray crystalline dolomite with abundant small cavities, many due to fossils of which only casts remain. There were some regular joints or fractures giving vertical faces or slightly inclined from the vertical. There is really an anticlinal fold with the axis through the middle of the quarry. In NW part dip is 10°W43°N and SE part dip is only seen over the axis at the pitching fold of 7° about 835°W.

In the early 1900's the Horlick quarries were purchased by the Consumer Company and were operated by them until the early 1930's (William Horlick, 1977, personal communciation).

In 1921 Whitbeck (his Fig. 15) published a photograph of the northern kilns on the east side of the Root River at the site of the current Hwy. 38 bridge. See Figures 62 and 63 for photographs of Horlick quarry from this time period.

Shrock (1930, 1931, unpublished field notes) described the main Horlick Quarry (see Figure 64) just prior to cessation of

Figure 62. Photograph of the main Horlick quarry (Quarry Lake Park), looking south along east wall, Racine County (locality 11). Circa 1920's. Photo courtesy of Milwaukee Public Museum, No. 49684.

Figure 62

Figure 63. Photographs of main Horlick quarry (locality 11, Quarry Lake Park), Racine County. (A) shows center of west wall, circa 1920's (photo courtesy of Wisconsin Geological Survey, No. 2461); (B) shows center of east wall exhibiting reef flank beds dipping to north (left), circa 1920's (photo courtesy of Jerry Walsh, Racine, Wisconsin).

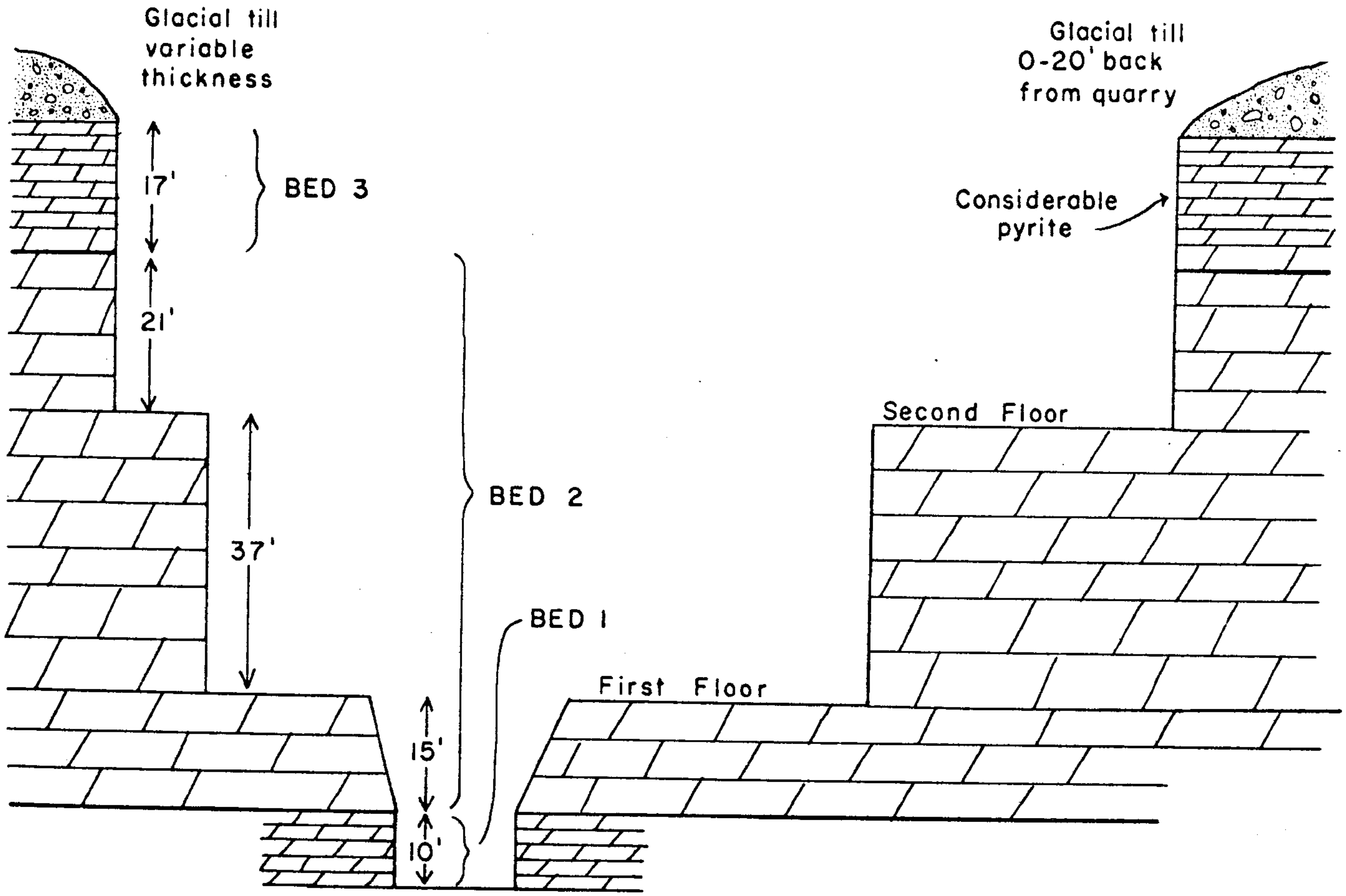
A

B

Figure 63

Figure 64. Section in the main Horlick quarry (Quarry Lake Park, locality 11) after Shrock (1931, unpublished field notes). See text for details.

HORLICK QUARRY, RACINE



after R. R. Shrock (1931)

Figure 64.

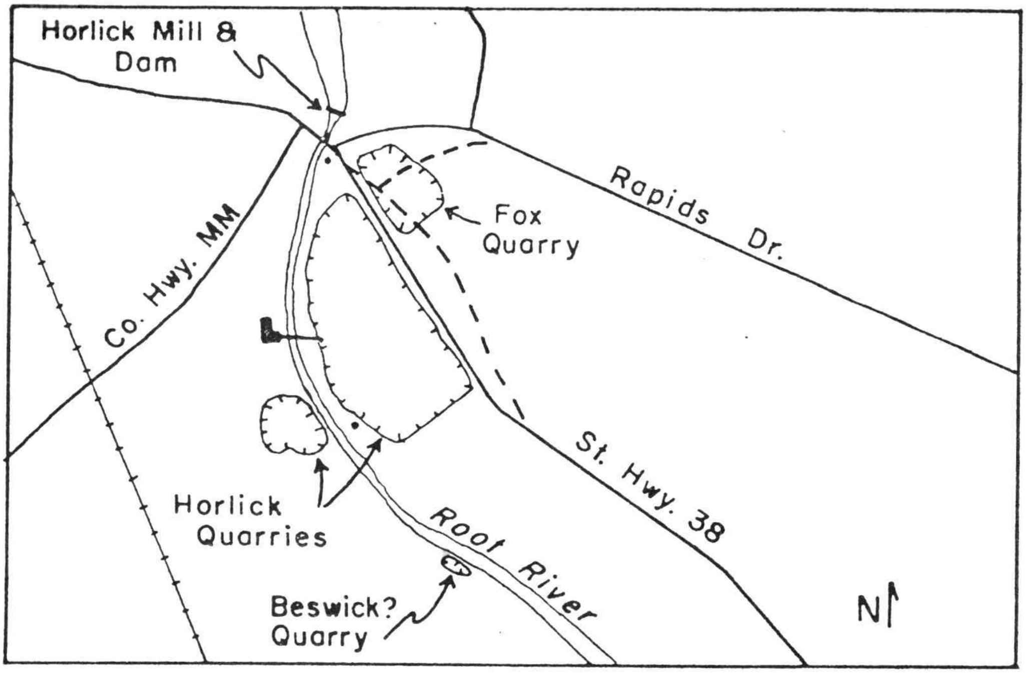
quarrying operations; he also described the Fox Quarry which was already partially filled with water. He gave the following section for the main Horlick Quarry:

> Bed 1. Cream colored, slightly porous, dense crystalline dolomite in beds averaging 4"-12" thick. Breaks semi-conchoidally into irregular blocks. The bedding planes are knotty. Ten feet exposed only in lowest cut, and is distinctly separated from darker, more cavernous dolomite above.
>
> Bed 2. Dark gray to blue mottled cavernous dolomite without any very distinct bedding. Many of the holes, are partly geodized, and some, several inches across, are filled with gray clay. The rock has a hackly fracture and varies considerably in texture, some spots being coarsely crystalline and granular, and porous; other parts (the main ground mass) a little lighter colored and very dense and compact. Fossils are common only above second level. 52 feet from first floor to second; 21 feet more to base of slabby very fossiliferous beds.
>
> Bed 3. Thin-bedded (3"-6") buff, weathered dolomite containing many fossils. Mottled in some places. Some of this rock has smooth even texture, and some has a very open porous granular texture. Some is an inchoate mealy mass of blue, muddy rock composed largely of small fossils. Many of the large blocks are veritable masses of crinoid stems and calices.
>
> In this bed, as in Bed 2, there are many parallel rows of holes. These holes are parallel to bedding and on the weathered surface give the rock a very cavernous appearance. Bedding is brought out best by weathering. Somewhat undulatory in quarry.

Also, he mentioned that about 15 feet of "thin, slabby, yellowish dolomite similar to that exposed in the highest beds of the large quarry" were exposed above water-level in the Fox Quarry. Figure 66 presents a more recent airphoto and locality map of the area.

Figure 65. Airphoto (A) and locality map (B) of the Horlick quarries area (locality 11), Racine County. Airphoto from National Archives and Records Service, General Services Administration, No. XC-25-2342, date: 8-12-37.

A


Horlick Mill &
Dam
Fox
Quarry
Rapids Dr.
Co. Hwy. MM
St. Hwy. 38
Horlick
Quarries
Root River
Beswick?
Quarry
N

B

Figure 65

Figure 66. Airphoto of Quarry Lake Park (main Horlick quarry), locality 11, Racine County, looking northeast. Note smaller Horlick quarry on the west side of the Root River on lower lefthand margin of photo, below pond. Photo taken in 1975.

After abandonment in the 1930's the main Horlick Quarry rapidly filled with water and became a popular swimming and scuba diving site. In 1968 the quarry was purchased by Racine County for use as a recreation area now known as Quarry Lake Park (see Figure 67). During construction of a swimming beach in the park, in 1969, most of the south quarry wall was blasted down and water-level was lowered twice (about ten feet in 1969 and about three feet in 1975). The Quarry had been previously filled in and Hwy. 38 was rerouted over the quarry site. The northern part of the old Horlick Quarry on the west side of the river was covered in the early 1970's, but the rest of this quarry is essentially unchanged from the time quarrying ceased at the turn of the century, although overgrown. No quarry is now known on the former Beswick property nor is any indicated on the 1937 airphotos. A very small quarry was present a little north of the Racine Country Club footbridge on the west side of the river, but this was filled in the early 1970's. Most of Beswick's quarrying activities may have actually been confined mostly to the river banks, or the quarry may have been filled prior to 1937 with the exception of the small quarry by the footbridge.

J. W. Peters & Sons Quarry (Warren Pit)
Locality 12

A small quarry has been opened within the last few years on the west side of Hwy. 43, east of the Fox River, 1.1 miles southeast of Burlington in Racine County. This quarry exposes a section in the Brandon Bridge beds, showing a similar lithology to that exposed in the main quarry at Ives and formerly in the Peters quarries west of Burlington, Walworth County.

WAUKESHA COUNTY

Waukesha County contains more exposures of Silurian rock than any of the surrounding counties (see Figure 67). The Silurian here ranges from zero feet in the western one-third and southeast corner of the county where it has been removed by erosion to 470 feet. Because of the overall dip of the Paleozoic rocks to the east, the Silurian rocks are increasingly younger in that direction. The Quaternary sediments vary considerably in thickness and composition throughout the county. The southern end of the Niagaran Escarpment outcrops in Eagle and Ottawa Townships, marking the western edge of the Silurian in this area. Surface exposures of Silurian range from the basal Silurian in the west to Racine Dolomite in the east and north-east. In contrast to the occurrence of rock exposures in Milwaukee and Racine Counties, there are few bedrock exposures along rivers and streams with the major exception being the outcrops along the Menomonee River at Menomonee Falls in the northeastern corner of the county. The bedrock is close to the surface over a wide area, primarily in a belt running from southwest to northeast through Pewaukee, Lisbon, and Menomonee Falls Townships.

Numerous quarries have been opened in these areas because of the ease with which high quality building stone (Lannon Beds of the Racine Dolomite) can be quarried; however, most of these quarries

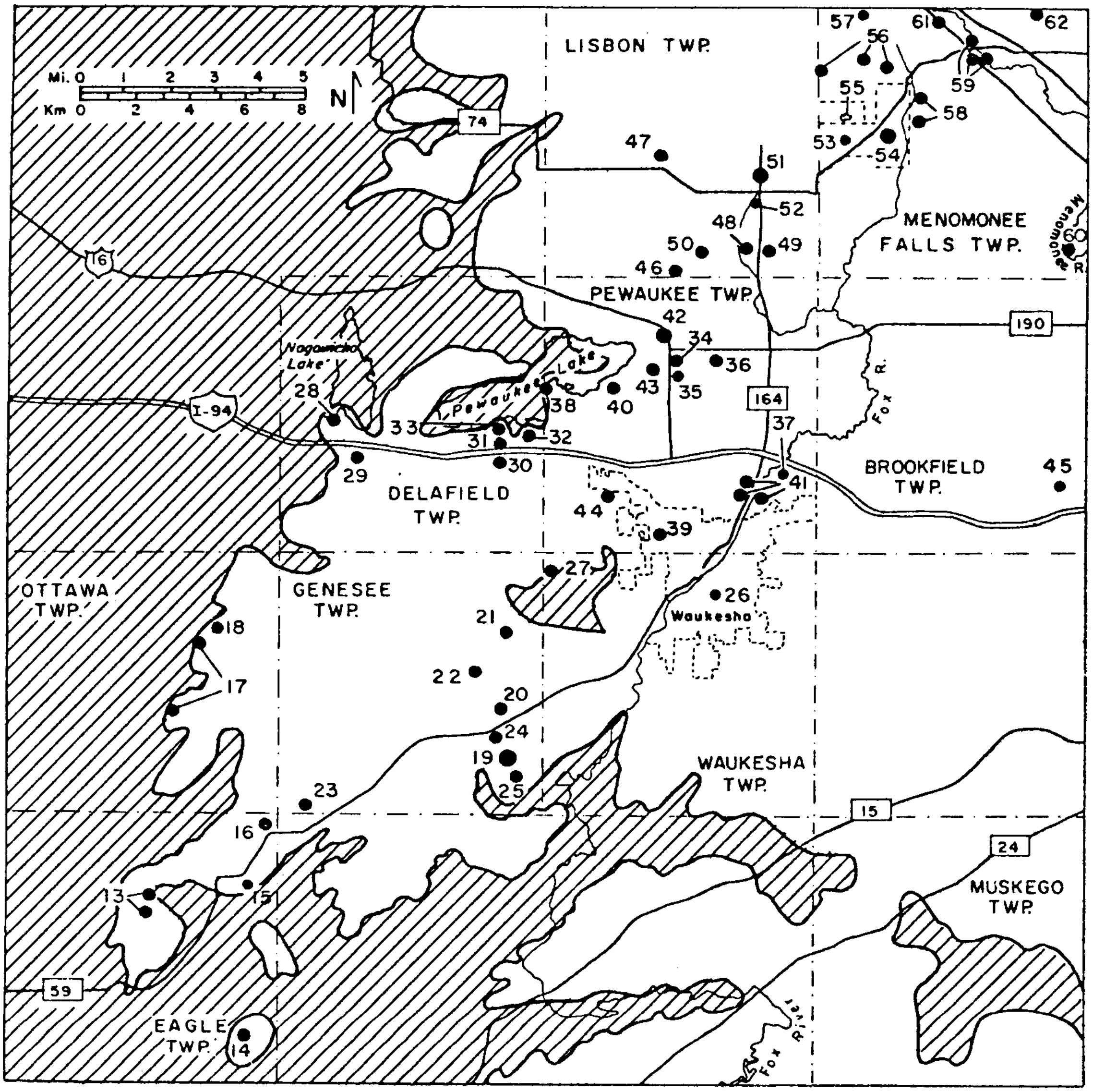


Figure 67. Locality map of Waukesha County showing numbered localities discussed in text. Diagonal lines indicate areas where Silurian has been eroded through to Ordovician bedrock.

are small and shallow. Loerke (1978) has given a good account of quarry history in Waukesha County.

Since there are numerous exposures in this county not all will be described in detail in this study, particularly those in Genessee, Lannon, and Sussex. Large quarries are currently operated north of Waukesha and at Sussex and the section exposed in those places as well as supplementary core information provide a complex section through the Silurian.

Eagle Township
Localities 13-16

SW 1/4, Section 10, T. 5 N., R. 17 E., Eagle Township, Waukesha County.

locality 13

elevation: 900 to 960 feet

Chamberlin (1877, p. 342) described the exposures around Hinckley's quarry as part of his description of the Mayville beds. Overlying the Maquoketa Shale (Ordovician) he found four feet of:

> thin bedded, impure magnesian limestone, having an even fracture and light, yellowish gray color, blotched with green in places, especially between the layers...Above these are nine feet of thicker bedded limestone of coarser and more irregular texture, and marked by walnut-sized cavities, lined with yellow granular matter. These beds, when exposed in natural ledges, as they are in the vicinity, weather to a very rough, ragged exterior, due to the irregularities of their structure.

Chamberlin gave the following faunal list from this locality (1877, p. 340):

> Stromatopora concentrica
> Favosites niagarensis
> Zaphrentis, und. sp.
> Orthis res. O. hybrida
> Leptocoelia planoconvexa
> Ormoceras, prb. O. vertebratum

Alden (1898-1900, unpublished maps) showed the location of a quarry (locality 13) along the bluff straight west of County Highway GN on a geologic map of the Eagle Quadrangle.

In 1930 Shrock (unpublished field notes) visited the area and found a small quarry in the NE 1/4, NW 1/4, Section 10, just across the road from the Hinckley farm. It has been operated by the county in previous years, but was abandoned at that time. Shrock also noted that a low bluff exposing similar beds extended south through the SW 1/4 of Section 10, indicating that Hinckley's quarry had probably been located in that vicinity. This outcrop extends approximately along the 900 foot contour on current topographical maps. Shrock measured the following section in the county quarry across from the Hinckley farm (not the Hinckley quarry):

Drift . . . . 10+ feet

Bed 1. Bluish-gray to buff, druzy or cavernous granular dolomite. Weathers to a very rough, pitted or cavernous surface. Massive with irregular beds. These same beds are found jutting out along the low bluff southwest of the quarry and there form great blocks of float, some standing vertical while others have moved down the slope on the underlying shale and now stand in all positions. The surface is pitted with cavities and the rock is saccharoidal uneven texture ....11 feet

Bed 2. Dense, fairly even-textured, fine crystalline dolomite. Gray mottled with buff...............1.5 feet

Covered interval; contact with Maquoketa Shale marked by seeps.

Alden (1899, unpublished field notes) mentioned a roadcut of Niagara limestone in the middle of the E 1/2 of the N line, Section 16, T. 5 N., R. 17 E., which is a continuation of the outcrops found in Section 10. He (1898-1900, unpublished maps) indicated limestone knolls (1899, unpublished field notes) in the E 1/2, Section 24, along Jericho Creek (locality 14); outcrops along County Highway X (locality 15), just east of the railroad tracks, N line, NE 1/4, Section 12, T. 5 N., R. 17 E.; and slight outcrops (1899, unpublished field notes) of Niagara limestone in the low area northwest of the railroad tracks in the NW 1/4, Section 6, T. 5 N., R. 18 E., about a mile west of North Prairie (locality 16).

Ottawa Township
Localities 17 and 18

T. 6 N., R. 17 E., Ottawa Township, Qaukesha County.

elevation: 900 to 960 feet

In 1860 Hale (unpublished field notes) observed that a westward-facing bluff of Niagara limestone was found running through Sections

11, 14, 22, 27, and 34 of Ottawa Township (locality 17). Hall (1862, p. 61) made reference to Hale's discovery of this outcrop, which Hall referred to as the southernmost exposure of "the ridge" (Niagaran Escarpment) which at this locality extends for five miles at a maximum elevation of 35 feet.

Lapham (1873, unpublished field notes) noted that:

> Limestone is extensively quarried somewhere in the town of Ottawa, (much used for stone fences) character similar to that of Delafield. I found it in place in the bed and north bank of a creek in the road between Sections 13 and 14 in Town 6, Range 17. It is noted by the Government Surveyors on the line between Sections 11 and 14. The rock is here quite similar to that of Delafield and may be of the same age.

Chamberlin (1877, p. 342-343) mentioned outcrops of the Mayville in Sections 11 and 14 of Ottawa Township, which he stated were

> ...characterized by conspicuous nodules of white chert, which are very abundant in some layers.
>
> At Hunter's quarry (Sec. 11, S.E. qr., locality 18), the lower three feet exposed in a moderately hard, compact, gray, magnesian limestone, marked with iron stains. Upon this lies a somewhat peculiar shaly layer, which may be described as chipstone imbedded in a clayey material. Above this are two and a half feet of more solid rock, the upper portion of which is cherty. This is overlaid by another shaly, or chipstone layer, similar to that below, but cherty; and this in turn is surmounted by a few rotten buff layers that complete the exposure. The two chipstone layers are worthy of note, as they may be recognized more than a hundred miles to the northward.

Alden (1898-1900, unpublished maps, Eagle Sheet) showed an outcrop in the bluff throughout the area mentioned by Hale (1860, unpublished field notes). This exposure approximately follows the 900 foot contour in this area, which approximately marks the Ordovician-Silurian contact. Alden reported that the outcrops were occasionally 40 to 50 feet high. He also described the former Hunter quarry (NW 1/4, SE 1/4, Section 11) (1899, unpublished field notes):

> Here Mr. Edward Schultz, formerly Huner Estate, quarry exposes nearly 15 ft. face half way up the slope. The beds are nearly horizontal and considerably broken up. Courses thicken to 6-8 inches or 10 inches. The upper half of the strata are very cherty, very uneven in structure, splitting irregularly. Below these are three quite even grained courses and below again are irregular cherty courses. It is the Niagara limestone as seen near Pewaukee lake.

In addition, Alden indicated small quarries in NE 1/4, SE 1/4, Section 14, and SE 1/4, SE 1/4, Section 11 on his unpublished map of the Eagle Sheet (1898-1900).

Shrock (1930, unpublished field notes) measured the following section in a low bluff along County Highway C at the center of the E line, Section 14, T. 6 N., R. 17 E.:

Gravel and drift . . . . .5+ feet

Buff dryzy, irregularly bedded dolomite. Has a pinkish cast when weathered. Surface rough and ragged . . . . 40 inches

Buff, granular dolomite with chert . . . . 8 inches

Buff, granular dolomite . . . . 8 inches

Irregular-bedded dolomite with chert . . . . 11 inches

Hackly dolomite with chert at top . . . . 13 inches

Fine grained dense dolomite with chert layers 23 inches

Massive druzy dolomite with some chert . . . . . 39 feet

Genesee Township
Localities 19-25

T. 6 N., R. 18 E., Genesee Township, Waukesha County.

elevation: 800 to 860 feet

There are numerous small bedrock exposures in Genesee Township, particularly in the SE 1/4. The first mention of the quarries in this vicinity is made by Lapham (1844, p. 64-65) who stated that "very beautiful grave-stones are manufactured from stone quarried in the town of Genesee."

Loerke (1978, p. 8) mentioned that in the early 1840's Silas Remington operated a quarry in this area which was later purchased by William Johnston.

Hale (1860, unpublished field notes) visited the quarries operated by Stephen Sayles, Patrick Lee, and William Johnson (sic). He gave the location of Sayles' quarry (locality 19) as Section 25, T. 6 N., R. 18 E., and noted that it was excavated in the Waukesha beds on the side of a hill, the hill being capped by "an outlier of Racine not more than 1/2 mile extent."

Chamberlin (1877, p. 359) described Johnson's quarry (locality 20) as follows:

> Johnson's (sic) quarry in the town of Genesee, presents a vertical exposure of more than 25 feet, of a beautiful white,

fine-grained dolomite, in beds of 20 inches thickness and less, having an eastward dip of one foot in sixty. Near the base a layer possesses the mottled color and uneven texture above described. Fossils are rare in this location. A few rods distant on the opposite side of the road, a quarry displays very similar beds, but they are rather more porous in general and abound in chert in certain layers which is rare or absent at the former locality. They are also more fossiliferous, though not abundantly so. The following species were collected: Of Crinoids, Caryocrinus ornatus, Eucalyptocrinus crassus, and E. coelatus; of Brachiopods, Orthis flabellula, Spirifera plicatella, Atrypa reticularis, Rhynchonella indianensis; the Gasteropod, Platycostoma niagarense; of Cephalopods, Orthoceras annulatum, O. alienum, O. columnare, O. medulare, O. n. sp., Cyrtoceras orcas, Gyroceras hercules, and the Trilobite, Illaenus ioxus; a fauna very closely resembling that of Pewaukee.

In the rise of the hill, immediately to the east, the typical, yellow, coarse-grained Racine limestone appears, as it also does in the adjacent ridge on the south. It is probable that many of the prominent hills in this region contain a core of Racine limestone; though deeply overlaid by the almost universally prevalent drift.

Buckley (1898, p. 312-315) described both the Genesee Quarry Company and Lee Brothers quarries, the first having a depth of about 30 feet and the latter about 15 feet.

Alden (1899, unpublished field notes) visited the quarries in this area, including Lee's quarry (locality 19) (middle of E line, Section 16) and the Genesee Quarry Company qaurry, formerly the Johnston quarry (locality 10) (NW 1/4, SW 1/4, Section 24), as well as a small exposure in NW 1/4, SW 1/4, Section 22. Overall, he found the rock to be quite close to the surface in this vicinity. A number of small stone quarries had been opened in rock which was generally horizontally-bedded, even-grained, light buff colored dolomite with some chert beds and few fossils (mainly orthoconic cephalopods). Alden (1918) indicated outcrops in SW 1/4, Section 31 (locality 23), just west of North Prairie (Buckley, 1898, p. 315, mentioned a small abandoned quarry owned by William Zunker at this same location).

Shrock (1930, unpublished field notes) described a number of quarries and exposures in Genesee Township, including a small quarry (MPM x 33.5, locality 24) in SW 1/4, Section 24, just southwest of the intersection of State Highway 59 and County Highway XI, at an elevation of 840 feet, which exposed approximately 14 feet of well-bedded, light gray dolomite with abundant chert nodules in the lower part of the section. Just to the east of this quarry, at the top of the hill, on the south side of State Highway 59, he found a highly fossiliferous granular, porous dolomite which he wasn't sure was a bioherm or a continuous bed. Shrock also described exposures on the northeast bank of Rippling Brook in SW 1/4, NE 1/4, Section 25 (locality 25). In the northeast corner of Section 26 (locality 19), Shrock reported three small quarries having a composite section of 24 feet, the entire section being cherty, light gray, thin-bedded dolomite. He found a number of orthoconic cephalopods in these quarries. On the northern side of State Highway 59 he visited an abandoned lime quarry (MPM x33.3, elevation 840 feet) along the N line of SW 1/4, Section 24 (locality 20), which was partially waterfilled and had less than one foot of overburden; this was the old Johnston quarry (see Figure 68). The top of the hill at this site is presently being quzrried by the R. T. Stone Company for building stone and exhibits ten feet of rock. The lower part of the old quarry is not being worked and most of the wall described by Shrock has been covered with waste from the current operations. The rock exposed is a well-bedded, fine grained, non-porous dolomite. Three to four foot long orthoconic cephalopods are the most common fossils although a few large cranidia and pygidia of the trilobite Bumastus cf. ioxus are also present.

Buckley (1898, p. 315) mentioned a small abandoned quarry (locality 23) at North Prairie, and Alden (1904, unpublished map, Eagle Sheet) indicated on abandoned quarry just west of North Prairie and north of State Highway 59.

College Quarries (Cook)
Locality 26

SE 1/4, SE 1/4, Section 3, T. 6 N., R. 19 E., Waukesha Township, Waukesha, Waukesha County.

MPM x37.26

elevation: 840 to 850 feet (top of bedrock)

There are old quarries located along the northward-facing hill, south of the railroad tracks, north of College Avenue, on both sides of Centre Street on the Carroll College Campus (see Figure 69). This

Figure 68. Section and diagram in the old Johnston quarry (locality 20), Genesee Township, Waukesha County. Diagram shows two small carbonate buildups in the north wall of the quarry. After Shrock (1930, unpublished field notes). See text for details.

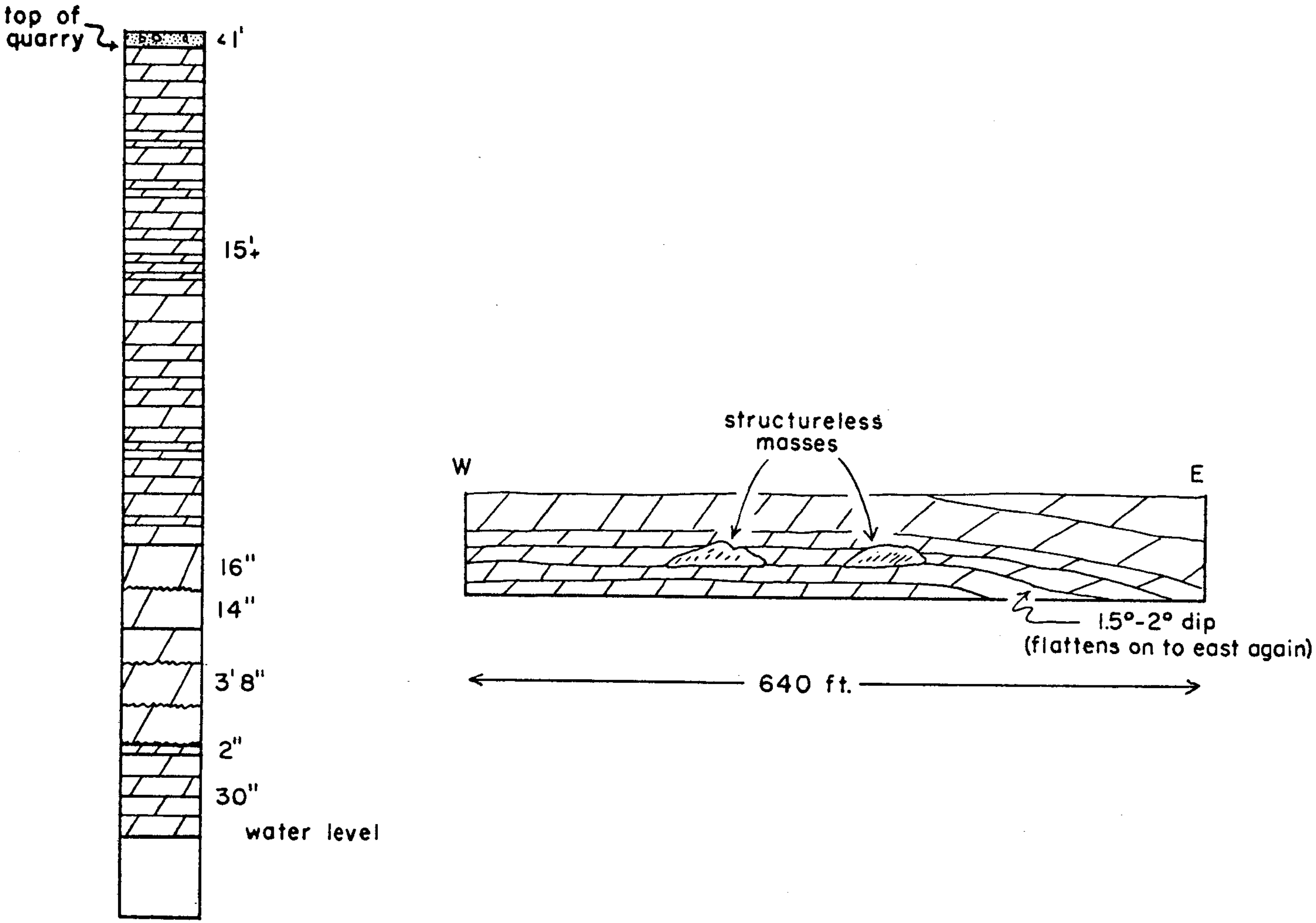
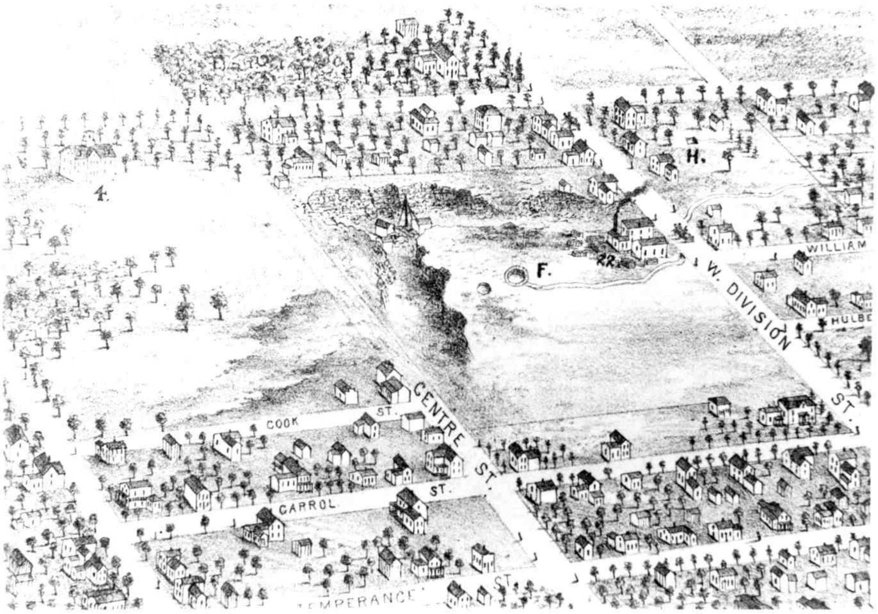

top of quarry
<1'
15'+
16"
14"
3'8"
2"
30"
water level
structureless masses
W
E
1.5°-2° dip
(flattens on to east again)
640 ft.

Figure 68

Figure 69. Quarries at Carroll College (locality 26), Waukesha County. (A) is a lithograph showing the location of quarries at Carroll College; Centre Street runs north-south (south is towards the top of the picture); (B) shows chert nodules in the Waukesha Dolomite at "old quarry near Carroll College" (Photography by W. C. Alden, No. 59, U.S. Geological Survey Photographic Library, Denver, taken on September 17, 1904)


4.
H.
F.
22.
WILLIAM
W. DIVISION ST.
HULBE
CENTRE ST.
COOK ST.
CARROL ST.
TEMPERANCE ST.

A

B

Figure 69

is the location of the type section of the Waukesha Dolomite and formerly exhibited the contact between the Waukesha and overlying Racine Dolomite. Only a small part of the west quarry is still visible along Centre Street on the east side of the athletic field. The quarries at this location originally were opened in the 1840's (Loerke, 1978, p. 8) and operated until 1890; T. D. Cook had retained at least part-ownership of the quarries throughout their years of operation until 1871 when they were sold to Hadfield and Wilkins. (See Loerke, 1978, for details of quarry ownership.)

Descriptions of these quarries presented by Chamberlin, Alden, Kindle, and Shrock are detailed in the section on the Waukesha Dolomite.

In 1964 William Brown (1979, personal communication), a local fossil collector, reported having seen cherty Waukesha beds exposed in an excavation for a gym at Carroll College; he found a few large, poorly preserved orthoconic cephalopods.

Locality 27

NW 1/4, Section 6, T. 6 N., R. 19 E., Waukesha Township, Waukesha County.

Alden (1904, unpublished field notes) briefly described an exposure in Section 6, showing rock was slightly exposed at a spring and found to be thinly covered in the slope.

Delafield Township
Localities 28 and 29

SE 1/4, SW 1/4, Section 17, T. 7 N., R. 18 E., Delafield Township, Waukesha County

elevation: 900 feet

Lapham (1873, unpublished field notes) described a quarry (locality 28) on the south side of Nagawicka Lake:

> A limestone quarry has been opened in the town of Delafiled... just where Bark river leaves Nagawicka Lake. It makes a rough building stone; has some partly decomposed chert; though no fossils were found by which to identify its age, it probably belongs between the Galena and the shales below the Niagara. Depth opened 8 feet.

Chamberlin (1877, p. 343) mentioned that two shaly layers which he thought characteristic of the Mayville Dolomite were present at the quarry near Delafield.

SE 1/4, NE 1/4, Section 20, T. 7 N., R. 18 E.

Lapham (1873, unpublished field notes) described a quarry (locality 29) located on a westward-facing bluff in Delafield Township as follows:

> Another quarry more recently opened for manufacture of lime, is half a mile south of the same lake (Nagawicka Lake)... Graham and Audley, proprietors. Here the layers have considerable thickness and there is an unusual abundance of chert... which being partially decayed gives it a chalky appearance. Drift striae here have the unusual direction of east and west instead of northeasterly. The rock is yellow and

may have the age of the Galena Limestone though no fossils could be found.

Chamberlin (1877, p. 343) in his discussion of Mayville outcrops described this quarry as follows:

> At Audley and Graham's quarry....a few layers of dark gray, crystalline limestone, containing much chert, are burned for lime.

He also presented the analyses of the chemical composition of two rock samples from this quarry (p. 338-339).

Shrock (1930, unpublished field notes) could not locate the quarry at this locality, but he did fina an old lime kiln and a partially filled pit which he believed to be the site of this old quarry.

Exposures and Quarries in the Vicinity of the Roberts Quarry, Pewaukee Lake Localities 30 and 31

T. 7 N., R. 18 E., Delafield Township, Waukesha County.

In a letter of June 28, 1850, Lapham reported that:

> Near the S.E. corner of Section 23 we discovered a quarry (locality 30) of limestone which proved to be quite similar to that at Waukesha. It is regularly stratified, very hard, white, destitute of fossils, and lies at an elevation of 30 or 40 feet above Pewaukee Lake...It is on the land of D. W. Kellogg, Esq.

Later in the same year he visited this same quarry and found that a well had been drilled to a depth of 50 feet below the "limestone," and that layers of limestone and clay similar to that found in the first eight feet of the well were encountered (see Figure 70). He also mentioned that a "half mile north of Roberts there is a limestone cliff from which large masses have fallen leaving large openings and crevices, called caves." He attributed the caves to erosion of the underlying clay.

Chamberlin (1877, p. 317) described the Maquoketa beds which underlie the Silurian at Roberts quarry. He mentioned that the shaft that was drilled in the bottom of the quarry was made in search of coal. He also (p. 343) described the Silurian rocks here as part of the Mayville beds, observing that the rock was "more close textured and siliceous" than exposures to the south and west, and that "the chert is more distinctly arranged in layers along the bedding joints. The exterior of the layers is buff while the interior is blue.

Buell (1882) described the bryozoan fauna of the Maquoketa beds at the Roberts quarry from collections made by the Wisconsin Geological Survey.

Alden (1899, unpublished field notes) described the outcrops and quarries in the vicinity of Roberts quarry as follows:

> At the middle of the west line of Section 24 on Mr. Henry M. Johnson's land, ledges of limestone outcrop in the south slope. The outcrop continues southwest along the slope into Section 23, SE 1/4, to Mr. Wm. Jones' land where there is a small quarry. These ledges are much weathered and split up into irregular thin shelving layers from 1/2 to 3 inches thick. The great blocks are much disturbed and cut up by open joints, as in a driftless region. Above and to the north is a coating of till but these ledges give no evidence of glaciation. Where the rock is freshly exposed in Jones' quarry, the strata are horizontal and undisturbed, though cut by

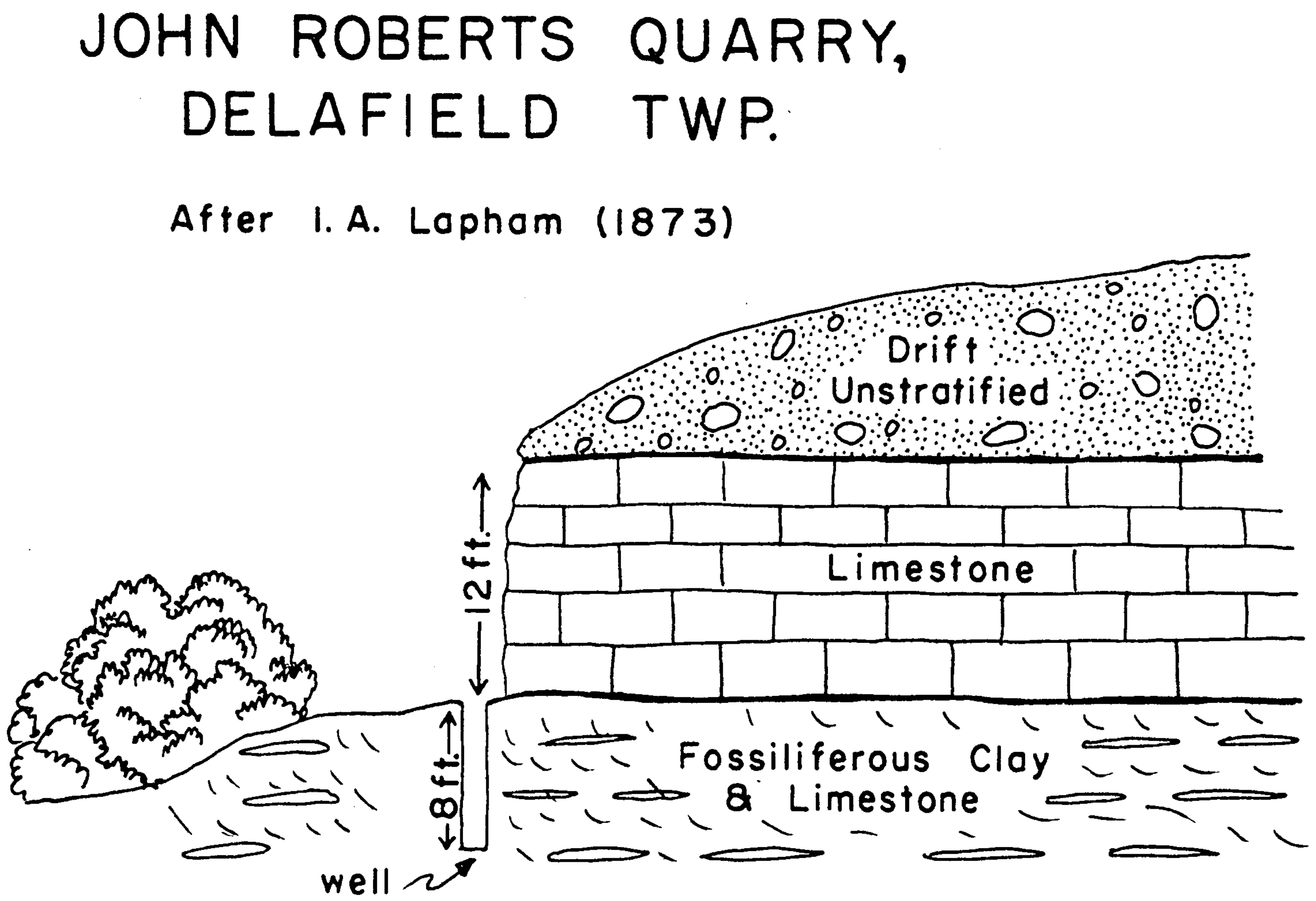


Figure 70. Diagram showing exposures at the Roberts quarry (locality 30), Waukesha County. After Lapham (1873, unpublished field notes).

joints at intervals. The beds thicken from the top downward to 18 or 20 inches. These thicker ones split readily. Two or more lines of chert nodules run continuously across the quarry. About 12 or 15 ft. is exposed in the rock face. In the lower part of the section are horizons with a gray to drab and grayish purple color. The strata have generally rough surfaces. Though I can find no fossils I have no doubt that this rock corresponds in position as in character to that at the uppper Waukesha quarry and at the Genesee Quarry Co.'s near Saylesville.

Allen (1904, unpublished field notes) observed the exposures (locality 30) in the SE 1/4, Section 23 and described them as follows:

Niagara limestone is exposed in bottom of gulley for a few rods west of the raod. East of the road 5 ft. or so is exposed in the ravine and at Roberts (John H.) quarry 12 ft. is exposed. It is regularly bedded in .5 ft. to .9 ft. to 1.5 ft. courses, cut by vertical fractures 1 to 10 ft. apart... The rock is a crystalline dolomite, buff on weathered surface and in thinner parts and more grayish in fresh face of heavier beds. An excellent quality of foundation stone may be and has been taken out. Heavier beds have conchoidal fracture. Some of the layers in the upper third of the exposure carry nodules of white chert. Fracture faces run N. 25°W. and N. 59°E. Bedding nearly horizontal. Surfaces of layers uneven. Lower bed especially, close even textured, except for some little holes. One of the joints is filled with dark red clay. I see no fossils except some cephalopod markings.

Alden observed the same bank of Maquoketa Shale as described by Chamberlin (1877) that had been excavated from the bottom of Roberts quarry in search of coal. He described the Maquoketa as a fine blue clay shale which was highly fossiliferous, containing mostly bryozoans and brachiopods. Alden also visited the Jones' (locality 31) (NE 1/4, SE 1/4, Section 23) at this same time as descr; ibed it as follows:

Wm. Jones' quarry in Niagara limestone exposes 10-12 ft. about same as in Roberts quarry. In upper half are 3 or 4

> nearly continuous bands of chert. Where seen on surface of a bed of limestone the layer is continuous through with frequent holes through it. Not in separate nodules. See no fossils in the Niagara. In floor of quarry near the west side is seen some tough blue clay with Cincinnati Shale (Maquoketa) fossils. Men say it extends up a crevice in the limestone. Shale said to be about one foot below the quarry floor. Rubble and foundation stone for local use are taken out. The limestone is buff on weathered surface and buff to gray on fresh surface. In places slight purplish gray tint. In places pinkish or purplish-gray blotches.

Alden also mentioned that ledges of limestone are exposed in Rocky Dell, to the east of Jones' quarry, and that these ledges have crept down the south slope on the shale.

Alden (1904-1905, unpublished field notes) again visited this area and reported the following:

> In Roberts' quarry (NW 1/4, SW 1/4, Section 24, T. 7 N., R. 18 E.) we found fossils of bryozoa, brachiopods, and one small piece of trilobite taken by an old miner who was searching for coal from the Cincinnati Shale (Maquoketa). The Niagara limestone beneath which the shale is found, as seen in Roberts' and Jones' (just north 1/4 mile) is of grayish color with some yellow. Along certain horizons there are bands (1-2 inches thick) extending about the quarry, especially in Jones'. The limestone is hard and rather brittle, of layers or strata 4 in. to 18 in. in thickness considerable jointing.
>
> In Jones' quarry we saw the heavy, blue, tenaceous Cincinnati Shale (Maquoketa) which has the character of a heavy blue clay. Just west of Jones' quarry 10-20 rds. Rocky Dell. Successive ledges of limestone have moved downslope 10, 12-20 ft. Show no glaciation, have no streams, hence weathering as result of jointing, creep of shale beneath.

Shrock (1930, unpublished field notes) briefly described outcrops (locality 30) in the SW 1/4, SW 1/4, Section 24 (MPM x38.4) exposed both in a stream below bridge of a north-south raod and in slump blocks along the bank of the stream. Maquoketa Shale was exposed in the stream bed and approximately a two foot falls had developed in the stream over the more resistant dolomite. The elevation of the Silurian-Ordovician contact was given as 895 feet. He measured the following section:

> Drift, slump and float . . . . 1-15 feet
>
> Mayville, even-bedded, fine-grained, fine even-textured, buff to light brown dolomitic limestone with layers 2-4 inches thick. . . There are a few sporadic chert nodules, with some along bedding planes. . . . . 5+ feet
>
> Richmond, blue shale with many bryozoans and brachiopods exposed in stream bed.

Shrock also described the old Jones' quarry (SE 1/4, Section 23, MPM x 38.3) giving the following section:

> Thin drift covering . . . . 5+ feet
>
> Weathered buff to light blue, dense, even-textured dolomite in layers 2-4 inches thick, Sporadic chert nodules. Silicified corals. Some stromatoporoid structure. Porous, sandy, some cavities. Like beds at MPM x38.5 and x38.6 . . . . 4 feet
>
> Weathering will break these thicker beds into 2-4 inch beds (rock is otherwise same as above) . . . . 4 feet 4 inches
>
> Bluer, evenly-bedded, even textured dolomite used for building stone, 2-4 inches thick . . . . .3+ feet

Shrock also observed that just northeast of the Jones quarry in Section 24:

> . . . beds similar to the top beds in the quarry may be seen along the low stream bluff. Their weathered surfaces are very much pitted, feel sandy, and have certain patches

which closely resemble stromatoporoid structure but is apparently some inorganic structure.

The Jones quarry, on the west end of Tumblebrook Country Club just east of County Highway G and north of Interstate I-94, currently exhibits approximately an eight foot section similar to that previously described by Alden (1899, 1904, unpublished field notes) and Shrock (1930, unpublished field notes). The beds are massive at the top, cherty in the middle and thin-bedded and argillaceous towards the bottom. The upper layers contain very fine, scattered pelmatozoan debris; stromatolites; rare horn corals and tabulate corals. Piles of weathered Maquoketa Shale are present on the quarry floor.

Outcrops in Interurban Railway Cut
Localities 32 and 33

NW 1/4, Section 24, T. 7 N., R. 19 E., Delafield Township, Waukesha County.

MPM x38.2

elevation: 900 to 905 feet

There is a low cut along the old Interurban Railway (locality 32), just south of County Highway G, along the south shore of Pewaukee Lake.

Raasch (1927, unpublished notes) made the following faunal list for this locality:

Favosites
Strompatopora
Duncanella
crinoids (joints and fragments of arms)
bryozoa? (tubular fragments)
Stictoporoid sp.
Dalmanella _elegantula_ type (11-12 ribs)
Plectambonites
undet. neotremate?
smooth ostracods
Rhynchotreta sp.

Shrock (1930, unpublished field notes) described this exposure as follows:

> In the interurban cut on both sides of the section line about 5-7 feet of thin-bedded, fine-grained, somewhat argillaceous dolomite are exposed. The individual bedding planes are pimply or undulating. Chert nodules occur both within the individual layers and along the bedding planes. There are no continuous layers of chert. The rock also comes to the surface in the field just south of the cut. Appear to be same beds exposed in the quarry 1/2 mile south.

In 1977 shallow excavations made for sewer construction in this vicinity and the adjacent NE 1/4 of Section 23 (locality 33) uncovered a couple of feet of the same kind of rock exposed in the railway cut and the Jones quarry to the south.

Caldwell and Nelson Quarry No. 2-Pewaukee
Localities 34-36

SW 1/4, SW 1/4, Section 10, T. 7 N., R. 19 E., Pewaukee Township, just east of Pewaukee, Waukesha County.

MPM x37.36

elevation: 850 feet

A small abandoned quarry (locality 34) is located on the north side of the Pewaukee River, just east of Pewaukee.

Buckley (1897, unpublished field notes) indicated that this quarry was located about one mile east of Pewaukee, and it was one of two quarries operated by Caldwell and Nelson in the Pewaukee area. He described this quarry as follows:

> The stone is within a foot or two of surface. The upper 4 or 5 feet is not good for much but lime. Below this beds are found from 3 to 6 and 8 inches in thickness which are used for constructional purposes. The stone contains some fossils. It is hard and finely crystalline. It is grayish color on fresh surface but white when weathered.

In 1934 Shrock (unpublished field notes) visited the quarry and described it as follows:

> In a small abandoned quarry along U.S. Highway 19 on the north side of road and just east of where that highway crosses the Pewaukee River, about 4 feet of slabby, gray, smooth-fracturing dense compact dolomite are exposed. The house just east of the quarry is similar to the upper beds at Pewaukee (MPM x38. 1), both at same elevation.

This quarry site is located quite close to the 1979 sewer tunnel excavations along the Pewaukee River.

Loerke (1978) mentioned that a quarry (locality 35) was located just south of this location in Section 15, belonging to H. M. Mills, in 1891.

Chamberlin (1880, p. 32) listed a Harlan's quarry (locality 36), exhibiting Waukesha beds, in Section 12, Pewaukee Township, which is approximately two miles east of this locality.

Johnson Sand and Gravel Company Pit
Locality 37

SE 1/4, NE 1/4, SW 1/4, NW 1/4, Section 25, T. 7 N., R. 19 E., Pewaukee Township, Waukesha County.

elevation: approximately 850 feet

A low exposure of bedrock was uncovered approximately ten to twenty feet below the former ground level in the bottom of the Johnson Sand and Gravel Company pit, approximately 1500 feet north of County Highway JJ and 1750 feet south of the Highway I-94 bridge over the Fox River. About four feet of vertical section was exposed above the water level on the south side of a small pond in the bottom of the pit; no rock could be observed in the pond or towards the south. The southern portion of the bedrock exposure was covered by gravel. The rock is a light gray mottled dark gray, fine-grained, crystalline, very dense, non-porous, hard dolomite which weathers pale orange and occurs in six to eight inch beds with somewhat irregular bedding planes. Fossils are uncommon and scattered, consisting of mostly trilobites of which complete or nearly complete specimens of *Calymene* predominate. A number of *Eucalyptocrinites*-like root systems are also present. These beds are probably equivalent to some of the upper beds (Racine Dolomite) exposed in the Waukesha Lime and Stone Company quarries about one-half mile to the south, but this has not yet been verified.

Outcrops on Shore of Pewaukee Lake
Locality 38

Section 18, T. 7 N., R. 19 E., Pewaukee Township, Waukesha County.

elevation: 850 to 860 feet

T. J. Hale (1860, unpublished field notes) reported outcrops along the south shore of Pewaukee Lake:

> ...appearing at and below the water level, they are evidently the lower part of the Niagara Limestone--heavy bedded, coarse, irregularly stratified, rough and hard, decaying in cavities.

Alden (1899, unpublished field notes) reported outcrops along the south shore of Pewaukee Lake in Section 13, Delafield Twp. (locality 38) where he listed the following dips: "6 °S. 15 ° W., 7 °N. 10 °W., 7 °N. 10 °W., 6 °N. 22 °E., and 3 °E 7 °S" at exposures along:

> ...Rocky Point which just projects into the NE 1/4, Section 13. A few square yards are here exposed rising barely 1 ft. above the water level. There seems to be a sort of perclinal dip in all directions but I judge it is a gentle anticlinal fold pitching gently a little south of east. The rock is an uneven, irregular textured buff dolomite.

Alden found this rock to be unfossiliferous.

Section 13, T. 7 N., R. 18 E., Delafield Township, Waukesha County.

Alden (1899, unpublished field notes) measured dips of 6 °S. 15 °W., 7 °N. 10 °W., 6 °N. 22 °E., and 3 °E. 7 °S. at Rocky Point (which just projects into the NE 1/4, Section 13) at Pewaukee Lake.

He described this exposure as follows:

> A few square yards are here exposed rising barely 1 ft. above the water level. There seems to be a sort of per-clinal dip in all directions, but I judge it is a gentle anti-clinal fold, pitching gentaly a little south of east. The rock is an uneven, irregular textured, buff dolomite which I think must be Niagara limestone though I can find no fossil traces. It looks like the limestone at the upper quarry at Waukesha. The surface of this is striated where water worn.

Siegel's Quarry
Locality 39

NE 1/4, SW 1/4, Section 33, T. 7 N., R. 19 E., Pewaukee Township, Waukesha County.

MPM x38.5

elevation: approximately 900 feet

There is a small abandoned quarry on the north side of U.S. Highway 18 on the west side of the city of Waukesha.

Alden (1904, unpublished field notes) described Siegel's old quarry in the SW 1/4, Section 33. Approximately eight to twelve feet of Silurian rock was exposed which was "hard gray dolomite of rather uneven crystalline texture and irregular fracture." He also observed white chert nodules and noted that the rock surfaces were rough and hackly. In the south part of the quarry floor Alden measured a dip of 3°N. 53°E.

Shrock (1930, unpublished field notes) reported that this quarry was about ten feet deep and had about two to three feet of overburden; he measured the following section:

Till overburden . . . . 2-3 feet or more

Buff, somewhat mottled, druzy dolomite in irregular beds 2-6 inches thick. Numerous irregular flint films and nodules along the bedding planes. Numerous silicified fossils which stick out on the weathered surface . . . . 58 inches

Same as below with numerous silicified corals, etc. Cavernous. Chert contains fossils (*Strophonella* and stromatoporoid) . . . . .24 inches

Chert as irregular nodules along bedding plane . . 1 inch

One massive bed of buff, druzy, granular dolomite. Weathers with a peculiarly pitted rough surface. *H. catenularia*, *Zaphrentis* sp., silicified . . . . 26 inches

A foot or more of rock is in shallow pool.

Locality 40

NE 1/4, Section 17, T. 7 N., R. 19 E., Pewaukee Township, Waukesha County.

MPM x38. 8

A small abandoned quarry is located about one mile east of Waukesha Beach and south of Pewaukee Lake.

Chamberlin (187, p. 31) indicated that Mayville beds were exposed in a Goodyear's quarry located in Section 17.

Shrock (1930, unpublished field notes) described this locality as follows:

> In this small abandoned quarry, several hundred square feet in area, are exposed some five feet of a light buff colored, fine-grained, compact even-textured stone in layers 3-5 inches thick. The bedding is even. Mr. W. Fieldhack stated that the quarry had last been worked 15 years ago, and when worked was about 10 feet deep.

Waukesha Lime and Stone Company Quarries
Locality 41

S 1/2, Section 26, T. 7 N., R. 19 E., Pewaukee Township, Wuakesha County.

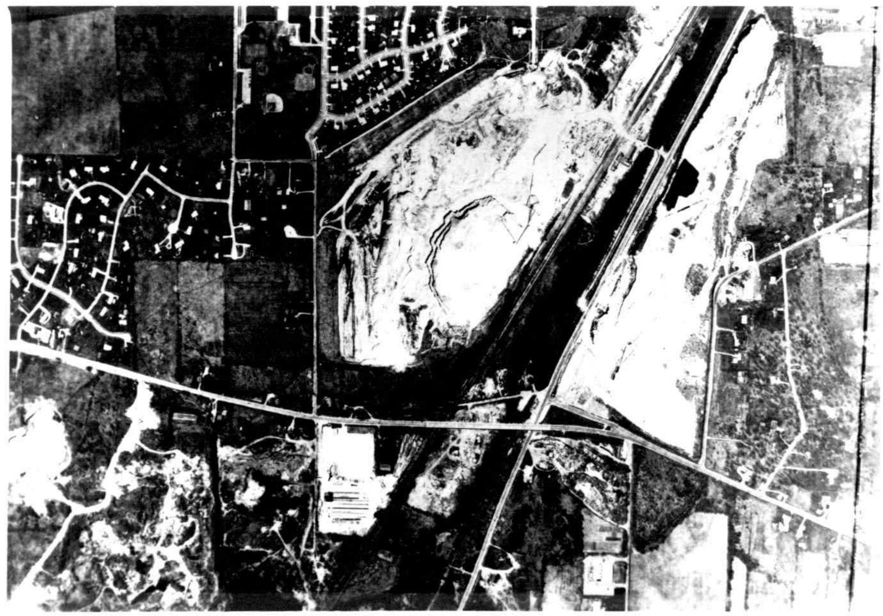
MPM x37.8, x37.9, x37.10, and x37.11

elevation: 840 feet

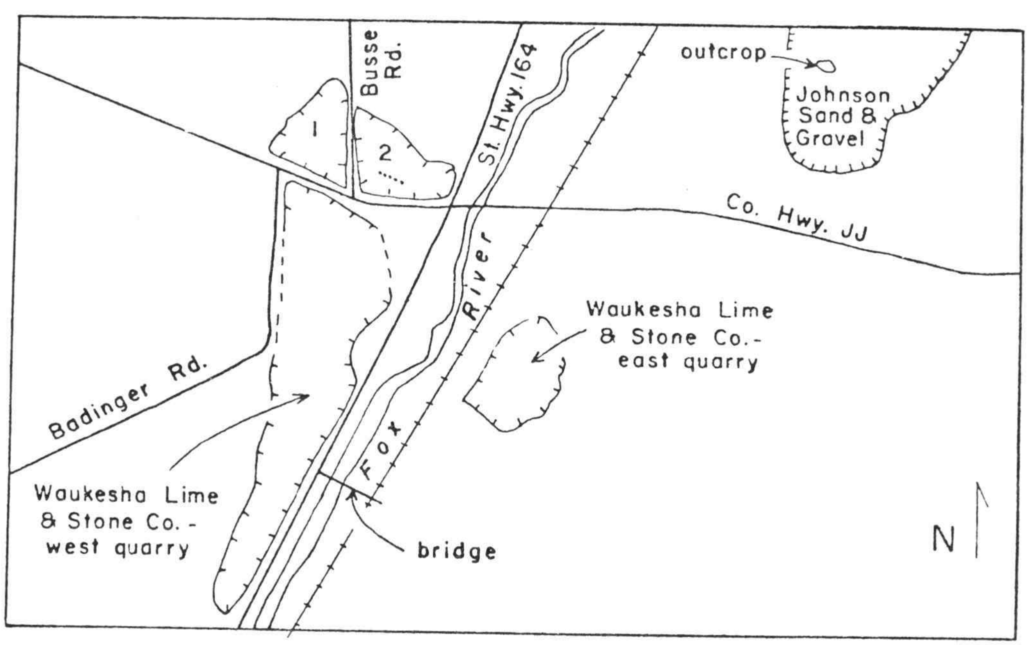
Several quarries are located along the east and west sides of the Fox River, just north of Waukesha (see Figure 71). The Hadfield Company operated some of the quarries on the west side of the river from 1873 until 1891 (Loerke, 1978, p. 16), and the quarries on the east side of the Fox River have been primarily operated by the Waukesha Stone Company.

Lapham (1873, unpublished field notes) mentioned the quarries along the Fox River above Waukesha as having few fossils and the rock being in flat even layers. He stated, however, that "the upper quarry (above the bridge) yields rock that breaks into irregular fragments--not suited for building purposes--but is used for making lime."

Figure 71. Airphoto (A) and locality map (B) of Waukesha Lime and Stone Company quarries (locality 41), Waukesha County. Airphoto from Southeastern Wisconsin Regional Planning Commission.



A


outcrop
Johnson Sand & Gravel
Busse Rd.
St. Hwy. 164
1
2
Co. Hwy. JJ
Fox River
Waukesha Lime & Stone Co.- east quarry
Badinger Rd.
Waukesha Lime & Stone Co.- west quarry
bridge
N

B

Figure 71

Chamberlin (1877, p. 357-358) described the area as follows:

> ...at the lime kilns, two miles above Waukesha, a fine display of the Racine limestone reposing upon similar cherty flags, which forms the sole of the quarry. The transition is accomplished in a manner precisely similar to that described (quite abrupt).
>
> In the road, south of this quarry, the porous Racine rock appears, but one hundred yards beyond, and at the same elevation occurs a light colored, hard, compact, close-grained, subcrystalline dolomite, resembling closely the Waukesha flags, except that chert is absent. A few rods further, a quarry has been opened, exposing these strata more satisfactorily. In addition to the close textured rock, there are layers of mottled blue and white color, and irregular, lumpy structure, such as are associated with the even-bedded rock in the vicinity of the Niagara reefs near Milwaukee. Several openings follow at short intervals, including the main quarry of Mr. Hadfield, all of which exhibit the same character. This is also true of the several quarries on the opposite side of the Fox river. I have elsewhere demonstrated that the coarse, open-textured Racine limestone graduates horizontally into a precisely similar compact rock, and am therefore inclined to consider the weight of evidence as favoring the conclusion that such is the case here. In this view, the flags and thicker even-bedded rock, on either side of the Fox river above Waukesha, would be regarded as belonging to the Racine beds, being the stratigraphical equivalents of the coarse-grained Racine layers. The only undoubted members of the Waukesha beds are, then, the cherty flags near the college and at the kiln.

Buckley (1897, unpublished field notes) visited the quarries in this vicinity and stated that the Hadfield Company "has at one time operated three openings." The first opening, probably the northernmost, was extensively worked for lime and was about 20 feet deep at the time of his visit, with a large floor area; stripping was light. He described the rock as "hackly, very fossiliferous limestone" and "very much fractured," with joints running N. 70°W. and N 15°E.

The second opening was situated a short distance south of the first and was operated for crushed stone. It was not very large and the face was partly covered with talus. The rock here was thin-bedded, badly broken, and corresponded to the rocks in the third opening, to the south. This last opening was extensively developed and furnished a large quantity of dimension stone until the company went into receivership in 1892. This quarry was partly flooded at the time of Buckley's visit with 27 feet of rock exposed above the water level. None of these quarries were operating when Buckley visited them.

The Waukesha Stone Company quarry was also visited by Buckley in 1897 (unpublished field notes). This quarry was operating on the east side of the river. He noted that stripping ranged from five to eighteen feet at the west end of the quarry and that it probably would increase back into the hill (towards the east); the quarry was 34 feet deep at this time. In 1898 (p. 309-311) Buckley presented a description of this quarry based on his earlier visit. He observed that:

> The thickness of the beds varies from 3 to 22 inches. The joints strike about N. 40°E., N. 40°W., and N. 70°E., and occur at sufficient intervals to permit any reasonable dimensions being quarried. The color of the stone differs in the different beds. The color of certain beds is light buff, while others have a bluish tone. The stone is finely crystalline, and largely free from impurities. No drusy cavities or chert were observed. Occasional black or brownish flecks are the only noticeable imperfections.

Alden, (1899, unpublished field notes) described the quarries in this vicinity. On the west side of the Fox River in SW 1/4, NW 1/4, Section 35, T. 7 N., R. 19 E., he found thin-bedded outcrops of "Niagaran" beside the road at an elevation of 810 feet. Just north of this was the Hadfield quarry in which he observed the "rock is well-bedded with dip of 3°S. 19°E. There is a system of joints running S. 27°E. also S. 36°E., dip 5.9° and S. 40°W., beds dip 4°S. 25°E. He also noted that there was 25 to 30 feet of drift over the bedrock surface and that:

> the rock here reaches an elevation of 20 feet above the CM & SP railway about 25 feet above the river or about 830-835 ft. AT. The rock beds show no disturbance and are but little fractured. The strata thicken downward so blocks over 2 feet thick can be removed. About 20-25 feet section is exposed above the water in the quarry.

He also examined the Waukesha Stone Company in Section 35 on the east side of the river in the same year, where he found:

> rock is same as west of river, well-bedded and very little fractured. Beds 1-2 inch thick at top thicken to 27 inches downward. The rock surface on west side of this quarry is about 10 ft. lower than on west side of quarry west of river.

He reported fossils to be uncommon, but orthoconic and cyrtoconic cephalopods and the trilobite *Calymene* were found. He observed 15 feet of gravel overlying the bedrock surface.

In Section 26, going north along the Wisconsin Central Railway, just south of the road, Alden (1899, unpublished field notes) described an old quarry as follows:

> The top thin layers where weathered show something of the granular texture seen at Wauwatosa. River evidently flows in a rock bed all along here. The valley being cut 20-25 feet into the rock.

Alden also described another old quarry on the west side of the Fox River near the middle of the S 1/2 of Section 26:

> The western part of the exposed surface has evidently been subjected to flexure so it is closely cut by parallel vertical fractures running S. 27°W. These fractures are from a fraction of an inch to 4 inches apart so the rock has the appearance of strata turned up on edge. This fractured belt is 15 to 20 feet wide, the fractures becoming farther apart toward the margins.

He goes on to describe a large quarry to the north at the middle of Section 26:

> The rock here is much more open in texture than at the other quarries visited. Fossil fragments are quite numerous and rock especially in the upper part is full of open pores. The surfaces of the strata are uneven in little benches and hollows. Also the beds are much fractured but this may be from blasting. The stratum forming the floor of the quarry is finer in feature and in places bears abundant nodules of chert. The strata are generally not more than 3 or 4 inches thick. At one point a small excavation has been made in the floor of the quarry exposing 2-4 inch strata with very abundant chert nodules evidently too much chert for lime burning so the quarry is no longer worked. The floor of the quarry is gently undulating. The general dip being southeast. At the west side of the quarry the rock is exposed up to 860 ft. A. T. The upper beds are almost entirely made up of crinoidal fragments at some points. At the west side the strata are thicker and of rather more even and closer texture. There is about 8 ft. of till over the rock here.

Hotchkiss and Steidtmann (1914, p. 70) mentioned that the Waukesha Lime and Crushed Stone Company Lime and Crushed Stone Company quarry consisted of about 20 feet of very fine-grained, bluish, thick, even beds that were overlain by 30 feet of gravel. They also presented a photograph (Pl. XV) of this quarry in a view looking east. Steidtmann (1924, p. 93) gave the same description of this quarry.

Ulrich (1914, unpublished field notes) described the Waukesha Crushed Stone and Lime Company quarry, located south of the lime kilns and west of the river, and gave a 70 foot section which included most of the Waukesha Dolomite and all of the Racine Dolomite currently recognized at this locality; it is possible that his section was a composite section from both sides of a fault. His section is as follows: Ulrich also indicated that Thwaites identified the cherty beds of the Waukesha Dolomite at the bottom of the quarry as belonging to the Byron Dolomite. He further mentioned that there were two other large quarries in the vicinity. Ulrich appears to have been the first to recognize the presence of a large fault in this area, even though Chamberlin, Buckley and Alden all recognized significant differences in the rock units in different parts of the area. They all agreed with Chamberlin's original interpretation (1877) that these differences were due to lateral variation in the Racine Dolomite, probably influenced by Chamberlin's reef model. It seems that the fault zone had been previously exposed in the smaller middle quarry on the west side of the river, where in 1899 Alden (unpublished field notes) described

Beginning at bottom of exposure:

Bed I. Byron Dolomite. No fossils obtained except at top. Microfauna of ostracodes, sponges...

Bed II. 22 feet of crinoidal "lime" rock--filled with cavities after fossils--chiefly crinoidal stems and plates. Brachiopods relatively few yet common. Used for manufacture of lime.

Bed III. 14 feet 6 inches. Yellowish to light brownish gray above, light gray in lower half, medium fine grained dolomite--sometimes slightly mottled. Beds 8 inches to 30 inches--few fossils.

Bed IV. Two thin layers blue and yellow mottled, 8 inches.

Bed V. 2 feet 8 inches. Similar to rock above but thicker ledge.

Bed VI. 7 to 8 feet of fine grained, yellowish gray dolomite in 4 inch to 18 inch ledges--breaks somewhat conchoidal under hammer and weather--No fossil observed except cast of one crinoid.

Fault with NE-SW strike and steep dip to SE passes through quarry and drops Bed II to level of Bed I on the east side and Bed III to the level of Bed II. Beds III-VI are therefore seen only in east or SE wall of quarry.

Ulrich also noted details of Bed I according to Thwaites:

Bottom of quarry.
4 feet of heavy bedded (6-15 inches), fine grained gray dolomite. White chert nodules in top 6-8 inch layer. 17 feet of same rock as below but without chert except in basal and top 1 foot. Rock laminated but beds are very heavy (commonly about 5 feet) between main partings. Somewhat lighter colored and denser than below. 2-3 inch layer of gray and yellowish banded and spotted flinty chert.
5 1/2 feet as below but very cherty, chert in small and larger nodules, gray, yellow and white, those at top with interesting microfauna.

Thwaites (1923, unpublished field notes) described a quarry in NW 1/4, SE 1/4, Section 26 "northeast of the road and west of old lime kilns." He noted that there were 15 feet of gray dolomite in one to two foot beds with small cavities. He also stated that there was a faint dip of the strata to the southeast, adding that the overburden was ten to twelve feet thick. He also mentioned that on the south side of the road was the quarry he visited with Ulrich in 1914, the north part of which was now abandoned, and referred to the lower cherty beds as Waukesha instead of Byron. He described the fault zone as being about 15 feet wide with crushed and shattered rock weathering yellow; the strike was noted as N. 47°E., with a 22 foot displacement on the southeast side.

Shrock (1930, unpublished field notes) made a detailed study of the quarry area, measuring several sections. He found the southern end of the quarry (just to the south of the S line, Section 26) abandoned and partly water-filled. His diagram indicates that by this time the two southernmost quarries on the west side of the river mentioned by Chamberlin (1877), Buckley (1897, unpublished field notes), and others, had been joined to form one large quarry which approximately coincides with the area being quarried today. He presented a composite section for this quarry (Waukesha Lime and Stone Co.) as follows:

From top of quarry-

Bed 9. Light gray to blue sometimes mottled, fine-grained, even-bedded dolomite . . . . 11 ft. 8 in.

Even-bedded, fine-grained, bluish gray dolomite . . . . 6 ft. 6 in.

Bed 8. Mottled gray and blue crystalline
dolomite . . . . 37 in.

Bed 7. Very fine-grained, smooth-fracturing
dolomite . . . . 50 in.

Bed 6. Even-bedded, fine-grained dolomite,
beds 4-12 in. thick . . . . 7 ft.

Bed 5. Drab, fine-grained, flinty limestone. . . 8 in.

Bed 4. Blue, fine-grained dolomite, beds
average 13 in. . . . . 4 ft. 6 in.

Bed 3. Buff to blue, porous, granular dolomite,
very fossiliferous in places . . . . 17 ft. 6 in.

Gray, fine-grained dolomite with irregular
bedding . . . . 6 ft.

Bed 2. Cherty dolomite . . . . 11 ft. 10 in.

Bed 1. Buff to blue, fine-grained to slightly
druzy, even-textured dolomite . . . . 6 ft. 4 in.

Mottled blue-gray dolomite. . . . . 4 ft. 6 in.

Very fine-grained, even-textured, gray
dolomite . . . . 8 ft. 6 in.

Shrock assigned Beds 3 through 9 to the Racine Dolomite and Beds 1 and 2 to the Waukesha Dolomite.

In the south end of the Waukesha Lime and Stone Company quarry, along the west wall, Shrock measured a 28 foot section which was comprised of the highest beds exposed in the quarry. He indicated that the elevation of the bedrock surface at this location was about 840 feet. He measured another section in the west face of the northwest corner of this quarry (which is north of the fault). The bedrock surface here is 850 feet and approximately 57 feet of rock were exposed. These beds represent the lowest in his composite section and include the cherty and underlying beds, as well as the overlying massive, granular, porous rock. These two units lie beneath the beds exposed in the previously mentioned section. Shrock measured one additional 58 foot section along the east wall of the quarry at the location of the hoist and sump at that time, south of the fault; this is the approximate present site of the buildings along the east wall. This final section exhibits the upper 11 feet of the cherty beds (Waukesha Dolomite) overlain by 47 feet of Racine Dolomite.

Shrock observed a slight dip in the rocks to the southeast in the southern end of the quarry with the beds leveling out towards the middle of the quarry; this feature can still be seen.

Studying the fault in this quarry in detail Shrock found it to have a strike of about N. 40°E. with a 45 foot displacement and a fracture zone 15 to 25 feet wide comprised of thoroughly weathered and badly broken rock; slickenslide surfaces were also present. He suggested that there may have been some horizontal movement along the fault trend. The area northwest of the fault was not being worked at that time. See Figure 72 for view of fault in northeast corner of quarry.

Shrock also visited the old quarries associated with the lime kilns to the north of County Highway JJ. The quarry (MPM x37.9) at

Figure 72. Fault in the west quarry of the Waukesha Lime and Stone Company. (A) is a diagram of the fault zone in northeast corner of the quarry after Shrock (1930, unpublished field notes); this area is now covered; (B) is photograph of the main fault zone currently exposed near crusher (from Mikulic, 1977, Figure 11). View is looking north.

WAUKESHA LIME & STONE CO.-WEST QUARRY

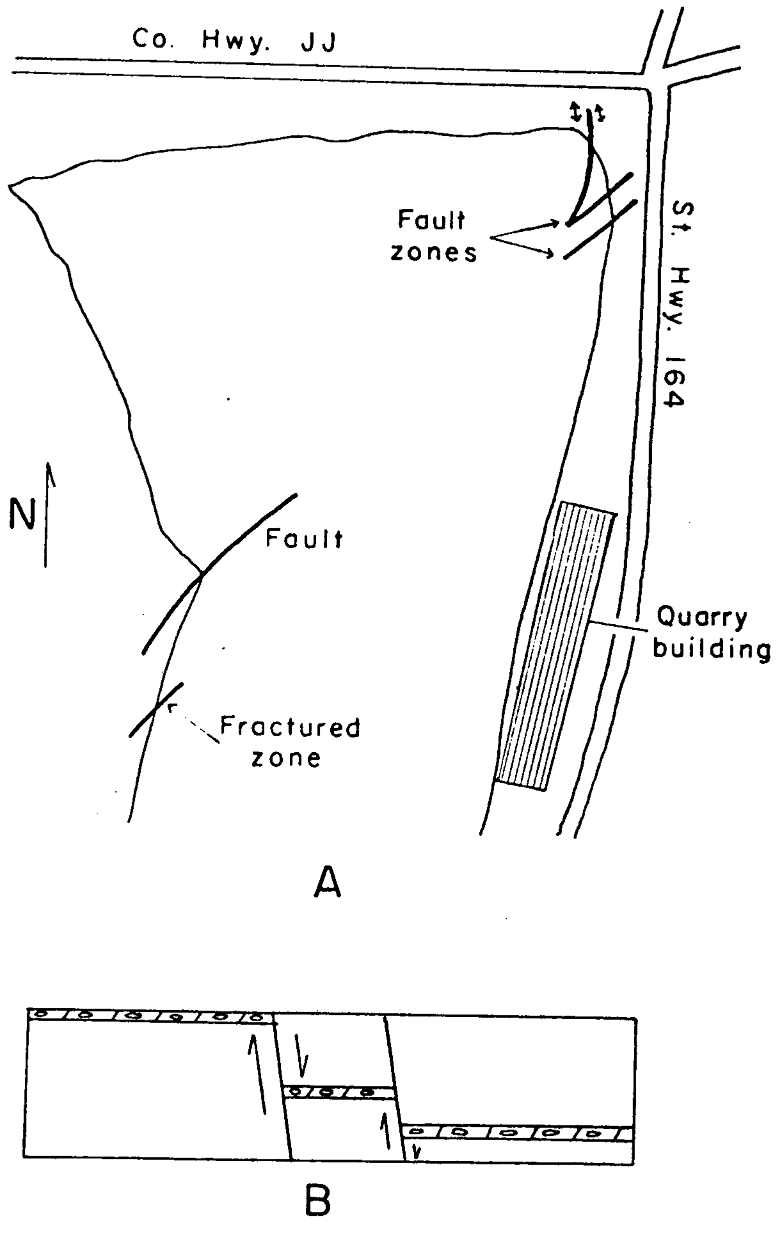


Figure 72

the kilns was no longer being worked, but a crusher was operated there for the manufacture of asphalt; an asphalt plant is still located there today. The shallow quarry west of the kilns, across Busse Road, was also abandoned at this time and Shrock measured a section there; the same beds were exposed at the quarry by the kilns. His section follows:

> Soft to hard, quite porous, buff to light blue dolomite. Massively bedded but upon thorough weathering breaks up into thinner somewhat irregular, but well defined bedding planes. Many of the bedding planes are characterized by stylolitic seams . . . . 18 ft. 2 in.
>
> Floor of the quarry seems to be very close to top of cherty beds. . . . . about 1 ft.
>
> Rock becomes soft on weathering; has a saccharoidal granular texture; takes on a yellowish color and is quite porous.
>
> The upper 5 feet, and even more in places, exhibits beds in places which are almost entirely made up of a mass of crinoid stems, partially dissolved, and brachiopod shells. The porous phases grade up and down as well as laterally into finer-grained dolomite. Some phases resemble very closely the saccharoidal phase of the Huntington Dolomite of Indiana.
>
> The following fossils were noted:
>
> *Orthoceras* sp. (?)
> *Dawsonoceras annulatum*(?)
> *Atrypa reticularis* (casts generally)
> *Strophomena* sp.
> *Trimerella* or *Monomorella* sp.
> crinoids
> *Rhynchotreta*(?) sp.

Shrock also described the abandoned quarry east of the river in the SE 1/4, Section 26. Approximately 13 feet of rock was exposed which appeared to be equivalent to the upper beds of the southern part of the quarry on the west side of the river.

Shrock (1935, unpublished manuscript) gave a general description of the main quarry on the west side of the river based on his 1930 fieldwork.

In 1937 the Tri-State Field Conference visited the Waukesha Lime and Stone Company quarry (Stop 8, Waukesha Quarry) and described it as follows (Thwaites _et al._, 1937, p. 5-6):

> The type exposure of the Waukesha Formation is on the grounds of Carroll College and very little may now be seen. It has been assumed that the formation is represented in the quarry at Waukesha. Crossing the north end of the quarry is a fault with the throw believed to be on the south. The minimum extent of the throw is 40 feet. It may be much greater. It is believed that the strata southeast of the fault may be correlated with the Byron formation. The strata northwest of the fault are thought to represent the lower Byron or Mayville, but it is also possible that they are inter-reef Racine. It seems likely that the strata in the type locality of the Waukesha formation are equivalent to some of those northwest of the fault.

The quarries at this locality were in part described by Mikulic (1977) and the following is modified from that discussion. Rock is no longer exposed in the two quarries, north of County Highway JJ, that were formerly used for lime. The quarry at the kilns has not been completely filled in but the rock face has been covered. The quarry to the west of it has been completely filled in, but a small tunnel between the two quarries, under the north-south road, still connects the two sites. To the south the large quarry of the Waukesha Lime and Stone Company operates on both sides of the fault and extends nearly through the Silurian (see Figure 73). On the east side of the Fox River the former Waukesha Stone Company quarry described by Buckley (1898), Alden (1899, unpublished field notes), and Shrock (1930, unpublished field notes) appears to have been covered over; however, to the north in Section 26 a new quarry has been opened by Waukesha Lime and Stone Company in an area where gravel has been removed from the bedrock surface.

The western quarry of the Waukesha Lime and Stone Company is crossed by a fault having a trend of N. 40°E. and a displacement of approximately 30 feet, with strata on the north side of the fault having been uplifted or the strata on the south side of the fault having been down-dropped. The fault is marked by a highly fractured zone as noted by previous authors, and several smaller faults are located to the south, having a step-like configuration within the overall trend of displacement. The total displacement appears to be approximately 40 feet. Kuntz and Perry (1976) briefly described the length of this fault through southeastern Wisconsin.

The highest strata exposed in the north end of the west quarry are the upper layers of the Romeo Beds and possibly a couple of feet of the overlying well-bedded "Lannon" beds. South of the fault approximately 30 feet of the "Lannon" beds overlie the Romeo beds,

Figure 73. Photograph of quarry wall in the south end of the west quarry of the Waukesha Lime and Stone Company quarries (locality 41), Waukesha County, showing a nearly complete section through the Silurian. Quarry face is approximately 150 feet high and shows the Lannon Beds of the Racine Dolomite at the top of the quarry underlain by massive Romeo Beds of the Racine Dolomite. Unit in middle of photo is the Waukesha Dolomite which is underlain by the Brandon Bridge Beds and the upper part of the Kankakee Beds. Photo taken in July, 1977.

with the bedrock surface at approximately the same level. The lowest beds in the north end of the quarry are those exposed at the crusher, just north of the fault, where 37 feet of "Kankakee" beds underlie the uppermost beds of the Brandon Bridge. South of the fault a continuous section from the "Lannon" beds down nearly into the Maquoketa is currently exposed.

In the east quarry of the Waukesha Lime and Stone Company a section from the top of the "Lannon" beds down to the uppermost "Kankakee" beds is exposed, with the rock units having the same characteristics as those exposed in the south end of the west quarry across the river. The fault apparently passes to the north of the east quarry as there have been no faults observed there.

The following section is a composite of exposures in the east and west quarries, and a nearby water-well log was used to determine the characteristics and thickness of rocks beneath the current exposures in the quarries:

"Lannon" Beds of Racine Dolomite. The highest stratigraphic unit exposed in these quarries is the "Lannon" Beds of the Racine Dolomite, which is approximately 32 feet thick. The upper portion of the "Lannon" Beds have been removed by erosion in this area and, consequently, are much thinner here than they are in the Lannon-Sussex area. At Waukesha these beds are fine-grained, dense, well-bedded, non-porous, light brownish gray dolomite. Fossils are uncommon, but occasional orthoconic cephalopods and *Phragmoceras* are present.

Romeo Beds of Racine Dolomite. Underlying the "Lannon" Beds are 23 feet of Romeo Beds of the Racine Dolomite. The rock is predominantly light gray, vuggy, porous, crystalline, granular, fossiliferous, thick-bedded to massive dolomite. Fossils are mostly pelmatozoan stem fragments with rhynchonellid brachiopods and some other fossils. In the east wall of the west quarry, adjacent to the lime buildings, a carbonate buildup about 20 feet wide can be seen in the Romeo Beds, however, it is inaccessible for close examination. This is the only carbonate buildup reported from these beds in the Waukesha area.

Waukesha Dolomite. Underlying the Romeo Beds are 32 feet 6 inches of the Waukesha Dolomite, having the same characteristics as the exposures of this unit at the type section at Carroll College. The Upper ten feet of the Waukesha Dolomite is highly cherty, thin- to medium-bedded, brownish gray dolomite. The chert is white and fossiliferous, forming layers of well-defined nodules. The lower 27 feet is medium-bedded, light gray dolomite. (See discussion of these exposures in the chapter of the Waukesha Dolomite for details.)

Brandon Bridge Beds. The Brandon Bridge Beds underlie the Waukesha Dolomite forming a conspicuous dark gray unit throughout most of both quarries. This unit ranges in thickness from zero to twenty-six feet and is a thin-bedded, highly laminated, very fine-grained, dark gray, argillaceous dolomite with patches of typical grayish-red-purple coloration as seen in the Brandon Bridge Beds in the southern part of the study area. This unit unconformably overlies, in part, the Plaines Member of the "Kankakee" Beds, but a short distance south of the fault in the W quarry it wedges out against a topographically high unnamed unit above the Plaines which thickens towards the north. (See discussion of these exposures in the section on the Brandon Bridge Beds for details.)

Unnamed Unit. In the northern half of the west quarry the previously mentioned unnamed unit which replaces the Brandon Bridge ranges from zero to twenty-one feet in thickness and is a light brown, thin-bedded, highly cherty, poorly fossiliferous dolomite. The chert takes the form of discontinuous irregular layers, more typical of the underlying "Kankakee" Beds than the well-defined chert nodules in the Waukesha Dolomite.

"Kankakee" Beds. Throughout the southern half of the west quarry and the entire east quarry the Brandon Bridge is underlain by more typical "Kankakee" Beds, the uppermost two feet of which appear to be very similar to the Plaines Member being a dense, thick-bedded, non-porous, fine-grained dolomite which breaks with a conchoidal fracture. A prominent unconformity marks the upper surface of this unit which locally has up to one foot of relief. The same unit underlies the unnamed cherty beds in the north half of the west quarry where the Plaines Member increases to about five feet in thickness.

In both quarries the Plaines Member is underlain by eight feet of similar beds which alternate with more coarse-grained, thin- to thick-bedded dolomite, which breaks with an irregular fracture.

Exposures and water-well logs indicate that approximately 110 feet of generally cherty, coarse-grained, crystalline dolomite lies beneath these and above the Maquoketa (Ordovician).

Pewaukee Quarries and Exposures
Locality 42

SE 1/4, NW 1/4, Section 9 (Ormsby Quarries-Caldwell and Nelson Quarry No. 1) W 1/2, NE 1/4, Section 9 (Pelton-Monitor-Cairneross and Ross Quarries) T. 7 N., R. 19 E., Pewaukee Township, Pewaukee, Waukesha County.
MPM x38. 1
elevation: 850 to 860 feet

T. J. Hale (in Hall, 1862, p. 62, fig. 7) illustrated the stratigraphic relationships between Pewaukie (sic) and Waukeshaw (sic). He indicated that the thin-bedded Waukesha Dolomite was overlain by heavy-bedded dolomite similar to that below, but less argillaceous.

Chamberlin (1877, p. 358-359) gave the most detailed descriptions of the Pewaukee area exposures that have been published to date. He correlated these beds with the Racine and Waukesha Dolomites:

> At Pewaukee, the upper strata consist of a white, fine-grained, but porous crystalline dolomite, having a conchoidal fracture. In this portion occur the crinoids Caryocrinus ornatus, Eucalyptocrinus crassus, E. coelatus, E. n. sp., and the trilobites, Illaenus ioxus and I. pterocephalus, n. sp., in association with several Orthoceratites and other fossils, thus manifesting a noticeable affinity to the Racine fauna.
>
> The lower layers at this point are more argillaceous and siliceous, and of more irregular texture, with patches of cherty material. Halysites, Favosites and Pentamerus occur in these beds. In one portion of Mr. Pelton's quarry a layer is almost entirely composed of a large Pentmaerus oblongus, imbedded in white dolomitic material, forming a rather heavy bedded rock of uneven texture. It lies near the base of the quarry, but from its situation and the undulating nature of the strata, its relation to the impure layers above mentioned are not apparent. It is quite possible that, as suggested by Prof. Whitfield on paleontological evidence, the upper portion belongs to the Racine, and the lower to the Waukesha horizon. The list of fossils, collected at this point, as follows: Stromatopora concentrica, Favosites favosus, Astrocerium venustum, Halysites catenulatus, Zaphrentis, Omphyma, Caryocrinus ornatus, Eucalyptocrinus crassus, E. coelatus, E. n. sp., Streptorhynchus subplanum, Strophomena rhomboidalis, Spirifera nobilis, Meristina maria, Atrypa reticularis, Pentamerus oblongus, P. ventricosus, Orthocera annulatum, P. alienum, O. medulare, O. crebescens, Gyroceras hercules, Gomphoceras nautilus, n. sp., Illaenus ioxus, and I. pterocephalus, n. sp.
>
> An interesting feature of this locality is a mound of rock lying a short distance west of the main quarries which rises ten or twelve feet above its base, and has a diameter of only a few rods. It consists of very irregular beds, coalescing promiscuously with each other and dipping irregularly in all directions. The rock is, for the most part, hard, compact, white, and in some portions, cherty, and contains a few Brachiopods. It evidently owes its origin to irregularities of deposition and not to upheaval.

Buckley (1897, unpublished field notes) briefly described the quarries in this vicinity. At the Cairneross quarry he found a considerable sized opening about six to eight feet deep, having beds two to eight inches thick. The rock was a fine-grained, grayish white, weathering white dolomite, containing a considerable number of fossils and was somewhat porous. The rock was used mostly for lime although some building stone had been produced in the past. He reported that Caldwell and Nelson's quarry (No. 1), in the western part of the village, was about two to eight feet deep and was used for lime. In 1898 Buckley (p. 325) published a brief description of these exposures based on his 1897 observations.

Shrock (1930, unpublished field notes) made the following observations at this location:

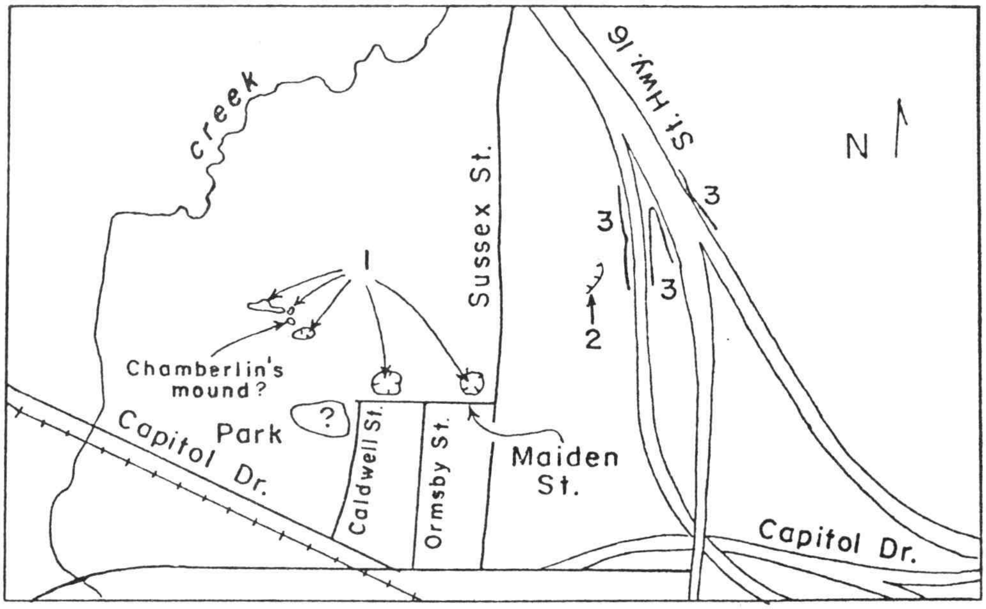
> At the present time there are three small water-filled quarries near Pewaukee, and little stone can be seen. Along the low bluff, however, which rises above the swamp (west of bluff) some 12-15 feet of fine-grained, even-textured, even-bedded light colored dolomite are exposed. The beds are from 2-12 inches thick and are slightly porous... On the east side of the road at the south end of the low bluff a polished striae striking E-W.

Shrock reported that overburden was light and that the cherty rock observed by Chamberlin (1877) was no longer exposed.

The old quarries in this area are no longer well exposed (see Figure 74). However, a good section can be seen in the U.S. Highway 16 roadcuts through the northwest-facing bluff, just east of the old Pelton quarry, made during the 1950's. A 13 foot section of rock

Figure 74. Airphoto (A) and locality map (B) of Pewaukee area quarries and exposures (locality 42), Waukesha County. Airphoto from Southeastern Wisconsin Regional Planning Commission.

A


creek
Sussex St.
St. Hwy. 16
N
3
3
3
1
2
Chamberlin's mound?
Park
?
Capitol Dr.
Caldwell St.
Ormsby St.
Maiden St.
Capitol Dr.

B

Figure 74

is exposed along the westernmost cut as follows:

Unit A: Unit A, at the top of the section, is nine feet thick and consists of light gray, dense dolomite, which is well-bedded in six to eight inch layers. This rock is generally poorly fossiliferous, but fine pelmatozoan debris is scattered throughout these beds and localized in more fossiliferous beds towards the bottom; a few crinoid calices have been found. The lower one foot of this unit contains a number of small orthoconic cephalopods scattered through it, particularly in the southern half of the outcrop. A one foot thick vuggy zone occurs six inches above the bottom of the unit.

Unit B. Unit B is four to five feet thick and is comprised of irregularly bedded, dense, crystalline, light gray dolomite. The lower two feet breaks with a semi-conchoidal fracture. Disarticulated specimens of pentamerids are found scattered through Unit B, and favositids and halysitids are scattered through the upper two feet. Nearly all the fossils appear to be silicified. The character of these beds appears to change laterally, and in the northern one-third of the exposure, apparently equivalent beds become more irregularly bedded, granular, and porous, and highly cherty in the upper two feet. Unfortunately, the transition between these two lithologies is not exposed. The chert is irregular, crumbly, rotten and somewhat lenticular as opposed to well-defined nodules. Pelmatozoan debris seems to be common in the chert. The chert layers appear to thicken to become approximately three feet thick and are overlain by 14 inches of more even-textured rock which in turn is overlain by one foot of more dense rock containing a layer of pentamerids in its upper two inches. The cherty beds at this location appear to be slightly domed, and in the old Pelton quarry, to the west, a dome is apparently present in the floor of the quarry, which may be related to the one here.

The old quarries to the northwest of the intersection of County Highways J and JJ are poorly exposed. The two small, water-filled pits indicated on current topographic quadrangles, south and southwest Pewaukee Mattress Company, had about one to two feet of rock exposed above water level, but were covered over in 1977. The larger pond indicated on quadrangles just to the west has no rock exposed and it is uncertain as to whether or not this is a water-filled quarry.

At the northeast corner of the baseball field in the park to the west of the ponds is a small rock mound, which may have been the one described by Chamberlin (1877). The mound is structureless, approximately five feet high and about 40 feet in diameter. The rock is light gray, vuggy, granular, massive-appearing dolomite. Only a few silicified rhynchonellid(?) brachiopods are present. A small stone pit on the north side of the mound exhibits rock which is finely laminated on weathered surfaces, but more massive or thick-bedded in fresh exposures. A few other small, shallow stone pits can be seen to the north and east of the mount. These pits are largely grassed or slumped over; the rock exposed is light to dark gray, granular, bedded dolomite. It is possible that a few other small stone pits were once located to the west of the mound, but have been covered up by park construction.

In 1968 a sewer tunnel was constructed along the Pewaukee River in S 1/2, Section 9 (locality 42). A large number of disarticulated pentamerids were found in the excavated rock. The following section was measured at this site (William Brown, 1968, personal communication):

Drift	0-4 feet
Cephalopod Beds	4-15 feet
Chert Beds	15-18 feet
Pentamerid Beds	18-10 feet

In 1979 similar rock was exposed in sewer tunnels to the east of the 1968 sewer construction.

Water wells in the area indicate that in Section 9 the Silurian rocks are approximately 170 feet thick and are underlain by about 190 feet of Maquoketa Shale (Ordovician).

A fair-sized collection of Pewaukee area fossils is deposited in the collections of the Greene Museum (University of Wisconsin-Milwaukee). This material was collected during the 1880's and early 1890's, and a number of the specimens are labelled as to the quarries from which they came. Some of the specimens come from a Hine quarry which has not been mentioned in the literature or plat maps.

Locality 43

SE 1/4, Section 29, T. 7 N., R. 19 E., Pewaukee Township, Waukesha County.

elevation: 900 feet

Alden (1904, unpublished field notes) mentioned that there were ledges of Silurian rocks exposed in the east side of the valley here. His 1918 map shows additional outcrops along the 900 foot contour, on the opposite side of the valley, in the SW 1/4, Section 29 and the NW 1/4, Section 32. Alden (1904, unpublished field notes) also observed that rocks were slightly exposed in the NW 1/4, Section 6, T. 6 N., R. 19 E. at a spring and were thinly covered in the slope. His 1918 map indicates that this outcrop is south of County Highway T, along the 900 foot contour.

Shrock (1930, unpublished field notes) described exposures in the SE 1/4, SW 1/4, Section 29 as follows:

> Along the road in a freshly washed gully were exposed some 15 1/2 feet of a buff to light blue, somewhat mottled, fine-grained but druzy dolomite. There are some chert nodules present. The rock is at an elevation of about 885 to 895 feet A. T. and appears to be exactly the same as that found in the abandoned quarry some 1 1/2 miles to the southeast (MPM x38.5). It extends up to the flat bench. Total thickness probably 15 feet.

Locality 44

SE 1/4, Section 29, T. 7 N., R. 19 E., Pewaukee Township, Waukesha County.

Alden (1904, unpublished field notes) reported that ledges of Niagaran limestone were exposed in the east side of the valley in the SE 1/4, Section 29.

Bluemound Road Exposure
Locality 45

NW 1/4, SE 1/4, Section 25, T. 7 N., R. 20 E., Brookfield Township, Village of Elm Grove, Waukesha County.
elevation: 730 feet

In 1973 bedrock was exposed in a shallow excavation for a building near N. 129th Street, on the north side of Bluemound Road. Approximately seven to eight feet of thin-bedded (two to three inch average), flaggy, fine-grained, light gray dolomite with slightly irregular bedding planes was exposed. Fossils were rare, with one *Dawsonoceras*, one *Kionoceras*, and one *Dalmanites*(?) collected. Horizontal trails and burrows were common. The rock becomes light brown on weathering and burrows become rust-colored. In general, the rock and fossils here are very similar to those at the Hartung quarry in Milwaukee county. In the northeast corner of the excavation there was a purplish patch about 2 feet wide which appeared to grade into rock of normal coloration. This purple coloration was also observed in lithologically similar beds excavated in a sewer tunnel in the north-eastern corner of Butler in the late 1960's. There is much iron staining along joints in some places. The bedrock is overlain by four to five feet of glacial drift. Other excavations (small sewer ditches) around W. 129th Street exposed similar rock in 1972. Newspaper articles in the past have mentioned that bedrock is quite close to the surface throughout the surrounding area.

Locality 46

SW 1/4, Section 34, T. 8 N., R. 19 E., Lisbon Township, Waukesha County.

Alden (1904, unpublished field notes) made the following observations of exposures in this vicinity:

> East of big hill the limestone rises in low knolls above the marsh level being barely covered in places. Just west of middle (Section 34) glaciated limestone exposed in road. Just north of middle section corner considerable rock has been sometime quarried. Ruins of old lime kiln here. Freshly stripped rock surface is hard and smoothly polished. Seems to be a sort of glazing in which striae are scratched. Weathering attacks the lime more readily than the glazed surface and to this may be due the peculiar gash-like depressions in some of the weathered surfaces, predominantly in parallel lines but with cross gashes. Striae due west W. 10°N. Rock is hard, dense, white to grayish dolomite bedded in 1 to 8 inch layers. In part the texture is minutely porous. The broad low elevation seems to be due to a low dome-like up curving

in the strata. There are dips of 5°-10° on the east side apparently periclinal.

Locality 47

NW 1/4, NE 1/4, Section 21, T. 8 N., R. 19 E., Lisbon Township, Waukesha County.

elevation: approximately 970 feet

Alden (1904, unpublished field notes) reported an exposure in a railroad cut, showing five to six feet of dense, whitish dolomite, in beds two to four inches thick with even to irregular bedding planes. He mentioned that the rock was considerably fractured, which he considered to possibly be from blasting. The strata dipped east-southeast at a 4° to 10° angle. He further observed "at the east end of cut the rock is a low anticline dipping WNW-SSE. Beds 2-6 inches thick. Rock dense except for some small holes." He also noted that north of the railroad tracks the rock formed a low ridge five to ten feet above the marsh, running for several acres.

Sussex Area Quarries-Lisbon Township

A large number of quarries have been opened in Lisbon Township, primarily along County Highway K, near the intersection with State Highway 164, and in Sussex around the intersection of State Highways 164 and 74. Quarrying began in Lisbon Township (S 1/2, Section 23; 34; 35; W 1/2, Sec. 36, S 1/2, Sec. 26) in approximately 1840, but until the 1950's all of the operations were quite small. Only a few of the more significant quarries will be discussed here.

Halquist Quarry
Locality 48

E 1/2, NW 1/4, and W 1/2, NE 1/4, Section 35, and SE 1/4, SW 1/4, Section 26, T. 8 N., R. 19 E., Lisbon Township, Waukesha County.
MPM x 37.16
elevation: 890 feet (at highest exposure)

This large quarry is located on the east side of a small stream on the north side of County Highway K, west of State Highway 164, one mile south of Sussex (see Figure 75).

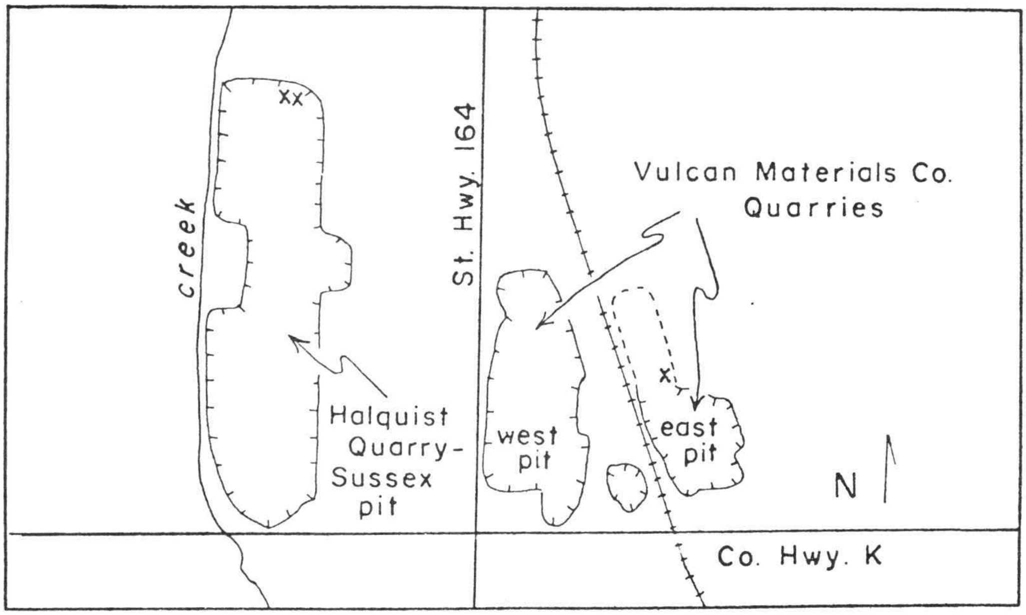
Raasch (1940, unpublished field notes) reported that at that time this quarry was only about 20 feet deep and consisted primarily of well-bedded, gray, fine-grained dolomite.

Frest, Mikulic, and Paul (1977) briefly described the quarry in connection with the occurrence and preservations of cystoids.

Mikulic (1977) presented a more detailed description of this quarry, supplemented by core extending through to the Maquoketa (Ordovician) in the Vulcan quarries to the east (see Figure 76). The following description has been modified from Mikulic (1977).

Figure 75. Airphoto (A) and locality map (B) of the quarries south of Sussex (localities 48 and 49), Waukesha County. Airphoto from Southeastern Regional Planning Commission.

A


creek
xx
St. Hwy. 164
Vulcan Materials Co.
Quarries
Halquist
Quarry-
Sussex
pit
west
pit
x
east
pit
N
Co. Hwy. K

B

Figure 75

Figure 76. Composite section based on the exposures and cores in the Halquist quarry (locality 48) and the Vulcan quarries south of Sussex (locality 49), Waukesha County. After Mikulic (1977, Figure 14) (b) indicates the cephalopod layer. Arrow indicates lowest exposure present in the quarries.

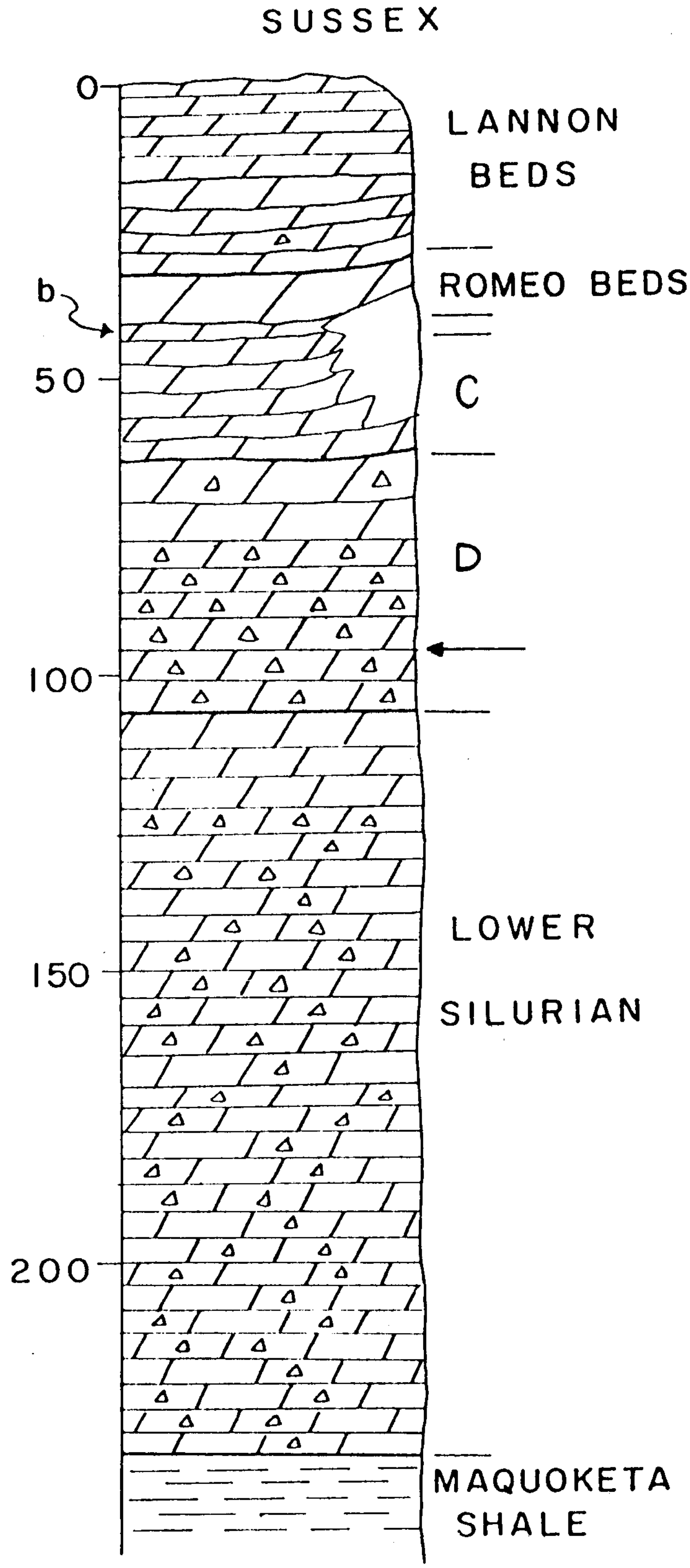

SUSSEX
0
50
100
150
200
b
LANNON BEDS
ROMEO BEDS
C
D
LOWER SILURIAN
MAQUOKETA SHALE

Figure 76

"Lannon" Beds of Racine Dolomite. The uppermost unit in the Halquist quarry consists of 27 feet of "Lannon" Beds of the Racine Dolomite. The rock is light brown to gray, dense, non-porous, medium- and well-bedded dolomite with stylolitic bedding planes. Scattered cephalopods are the only common fossils, although some of the more lithographic lower beds contain a few disarticulated trilobites. The thickest exposure of this unit is found in the southeastern corner of the quarry.

Romeo Beds of Racine Dolomite. Underlying this unit are 12.5 feet of the Romeo Beds of the Racine Dolomite. This unit is thick-bedded to massive, granular, coarsely crystalline, vuggy, fossiliferous, light gray dolomite. The fossils are primarily pelmatozoan fragments with an occasional rhynchonellid brachiopod or other fossil. At the bottom of this unit is a two foot thick bed known as the "Cephalopod Layer." It is light brown, very fine-grained, dense, almost lithographic dolomite, which breaks with a conchoidal fracture. Because of its peculiar lithologic characteristics this bed is very conspicuous in the quarry walls.

Unit C. Below the "Cephalopod Layer" is a 20 foot thick unit that is not easily correlated with beds exposed in the Waukesha quarries to the south, as are the underlying units at this locality. This unit is referred to as Unit C and is thick- to medium-bedded, fine-grained, light gray dolomite with local porous areas of fossiliferous debris.

Several reefs are developed in these beds, most of which appear to have ceased development with the deposition of the "Cephalopod Layer," however, one reef may have projected up into the Romeo Beds (see discussion on trilobite accumulations for details). This unit may correlate with part of the Romeo Beds of the Racine Dolomite or the Waukesha Dolomite.

Unit D. Unit C is underlain by seven feet of cherty, medium-bedded, light gray, fine-grained dolomite, the upper beds of which contain abundant pentamerids and scattered tabulate corals. Beneath this are five feet of thin-bedded, gray, crystalline, non-cherty dolomite, which in turn overlies 30 feet of brownish-gray dolomite containing abundant chert. Several carbonate buildups are present in this lower 30 feet. These are the lowest beds exposed in the Halquist quarry.

Core records from the Vulcan quarries indicate that approximately 125 feet of Silurian rock underlie the floor of this quarry above the Maquoketa Shale (Ordovician). The upper 15 feet of this rock is a fine-grained, dense, light gray dolomite which breaks with a conchoidal fracture. Underlying this is 110 feet of light gray, fine-grained, argillaceous, cherty dolomite.

Vulcan Quarries
Locality 49

E 1/2, NE 1/4, Section 35, and W 1/2, NW 1/4, Section 36, T. 8 N., R. 19 E., Lisbon Township, Waukesha County.

MPM x37.28

elevation: 880 feet

Two large quarries are operated by Vulcan Materials Company on each side of the railroad tracks, just north of County Highway K and east of State Highway 164 (see Figure 75). The exposures in these quarries, in addition to cores drilled to the Maquoketa in the floor of each quarry, give a complete section through the Silurian at this location (see Figure 76). These quarries were briefly mentioned by Mikulic (1977) as part of the discussion of the Halquist quarry. The section exposed in the Vulcan quarries is identical to that in the Halquist quarry.

A carbonate buildup has been uncovered along the east wall of the east Vulcan quarry, opposite the lime buildings on the west side of the railroad tracks. This reef is in the same stratigraphic position (Unit C) as the reefs in the Halquist quarry, and is overlain by the "Cephalopod Layer" and Racine beds, which drape over the buildup.

Locality 50

SW 1/4, SW 1/4, NE 1/4, Section 34, T. 8 N., R. 19 E., Lisbon Township, Waukesha County.

MPM x37.28

elevation: 880 feet

There is a small abandoned quarry exposing a small dome, just north of the interstection of County Highways J and K.

Alden (1904, unpublished field notes) was the first to notice the peculiar doming of the beds just north of the middle of Section 34. He found that considerable rock had been quarried in the vicinity of an old lime kiln. He described it as follows:

> ...hard, dense, white to grayish dolomite bedded in 1 inch to 8 inch layers. In part the texture is minutely porous. The broad low elevation seems to be due to a low dome-like up curving in the strata. There are dips of 5°-10° on the east side, apparently periclinal.

Shrock (1930, unpublished field notes) also visited this locality and described it as follows:

> On the north side of the road is an old lime kiln and nearby a shallow dry quarry where the stone was obtained. The stone is a very white, dense, fine-grained even-bedded limestone. The little hill in which the quarry is located seems to be a small mound with the beds dipping away from the center on all sides. In the small quarry the beds dip east, southeast, north and northeast. Dip is very low, probably never exceeds several degrees. At the east end of the quarry is a very small parasitic mound. The rock is slightly coarser and rougher. These mounds seem to have

> been formed as irregularities on the bottom. There does not seem to be any quarry near the old kiln on the south side of the road.

This quarry has not been altered since Shrock's visit, although it has become overgrown. The rock is thin- to medium-bedded, light gray dolomite. In the northeast corner fine to coarse pelmatozoan debris and scattered brachiopods (pentamerids?) are present.

Sussex Domes
Locality 51

SE 1/4, Section 23, T. 8 N., R. 19 E., Lisbon Township, Waukesha County.

elevation: 900 to 920 feet

There are a number of small shallow quarries and rock outcrops in the SE 1/4, Section 23, on both sides of State Highway 164 (Waukesha Avenue), just north of the intersection with State Highway 74.

Alden (1904, unpublished field notes) visited a quarry in the SE 1/4, SE 1/4, Section 23, at an old lime kiln, just east of the railroad tracks, and described it as follows:

> ...exposes 5 ft. of nearly horizontally bedded, grayish dolomitic limestone. Regularly bedded in thin to 4 inch layers. Rather dense even texture, regular fracture, fine crystalline texture. Fossils not obtained, see none. Excavation in bottom of quarry exposes 4+ ft. of grayish dolomite with rougher, more uneven texture breaking irregularly under the hammer. Old lime kiln seems not to be used now.

Shrock (1930, unpublished field notes) described a number of outcrops and quarries in this vicinity. He mentioned that there was no longer any quarry near the lime kiln; local residents had informed him that it had been covered over by railroad construction. F. H. Keller (Sussex Sun, July 20, 1976) reported that this quarry was filled in 1910 by construction of railroad tracks, but the kiln is still there. Shrock described the rock in this area as:

> ...light-colored, fine-grained, somewhat druzy, even-bedded limestone...on the east side of the road between... the two railroads the stone comes to the surface forming a low bluff. Carlson and Halquist were working a shallow opening here, not over 5 ft. deep. The entire section measured here totaled about 13 ft...

His section is as follows:

Bed 3. Weathered, slabby, thin-bedded, fine-grained, even-bedded dolomite . . . . 5 ft. 6 in.

Bed 2. Mottled, somewhat darker, druzy, irregularly-bedded, hackly, rough dolomite . . . . 2 ft.

Bed 1a. Covered . . . . 1 ft. ±

Bed 1. Thin, somewhat druzy dolomite . . . . . 5 ft. ±

Shrock went on to describe:

> Exposures of the same thin-bedded stone occurs west of the small quarry mentioned across the road...An interesting feature in this exposure, just south of the railroad and west of the road, is the occurrence of two small circular mounds (about 40-60 ft. in diameter) which rise 10-12 feet above the surrounding exposures. The beds dip away from the center in quaquaversal fashion with a very low angle. The surface of the two mounds is marked by sets of intersecting joints which have been enlarged by weathering. These two small mounds probably were caused by

> irregularities on the sea bottom, for they do not seem to be due to upheaval.
>
> Just north of the railroad overhead bridges about 1/4 mile north of Templeton, on the west side of the road is a shallow quarry (5 ft. deep) exposing thin-bedded light-colored, fine-grained dolomite, similar to the rock a short distance south.

The structures described by Shrock appear to be beds overlying buried carbonate buildups as seen in other quarries in the Lannon-Sussex area.

A small quarry operated at the location of these small domes sometime between 1930 and 1959, but is now abandoned. The domes may still be seen here, however.

Templeton Lime and Stone Company Quarry
Locality 52

NW 1/4, NE 1/4, Section 26, T. 8 N., R. 19 E., Lisbon Township, Waukesha County.

MPM x37.27

elevation: 900 feet

Bedrock is quite close to the surface in the vicinity of the intersection of State Highways 164 and 74, in the part of Sussex formerly known as Templeton.

A large, nearly water-filled quarry is located southwest of this intersection and north of County Highway VV. A canning plant has been built on the north side of this quarry which is now used as a swimming beach. This quarry was previously known as the Templeton Lime and Stone Company quarry.

Alden (1904, unpublished field notes) mentioned that this quarry produced only lime and no building stone, and described it as follows:

> Quarry hole is 43 ft. deep. Rock well bedded in regular slightly undulatory layers. At bottom layers are 30-35 inches thick. Some of these lower layers are of very fine dense, even grain and conchoidal fracture and crystalline texture. These are said to give the finest white lime... This grades up and down into finely porous dolomite (which) under glass seems to be composed of rather loosely aggregated dolomite crystals. Saw little or no chert and fossils are not abundant. In upper half of quarry face are layers 2 to 20 inches thick. These are of dense texture, conchoidal fracture some layers are very even grain. Most however show small crystal-lined cavities 1/2 to 1 inch in diameter. One layer 20 inches thick fine even dense rock, color grayish white fresh looking rock. Some layers have rough hackly surface.

In 1916 a fire destroyed many of this company's buildings and the quarry was abandoned and soon filled with water (F. H. Keller, Sussex Sun, Feb. 15, 1977).

Shrock (1930, unpublished field notes) described a foot section of rock exposed above the water level in this quarry:

> Light colored, fine-grained, hard, dense, compact dolomite with semi-conchoidal fracture. The stone is evenly bedded, and the separation planes are almost invariably stylolite seams. In several stylolite seams there are thin films of black, shaly material... The texture of the stone is fairly even and the fracture smooth generally.

The beds range from two to twenty inches in thickness, being thinly bedded at the top and thickening towards the bottom, and are vuggy in places, particularly in the middle four feet of the section and the upper five feet. The upper 20 feet are weathered with a somewhat sandy texture.

A water well (Wk-226) on file at the Wisconsin Geological and Natural History Survey from the SE 1/4, SW 1/4, NE 1/4 Section 26, T. 8 N., R. 19 E. (Alt. 900 feet) shows 25 feet of drift overlying 215 feet of mostly cherty dolomite, which overlies 180 feet of Maquoketa Shale (Ordovician).

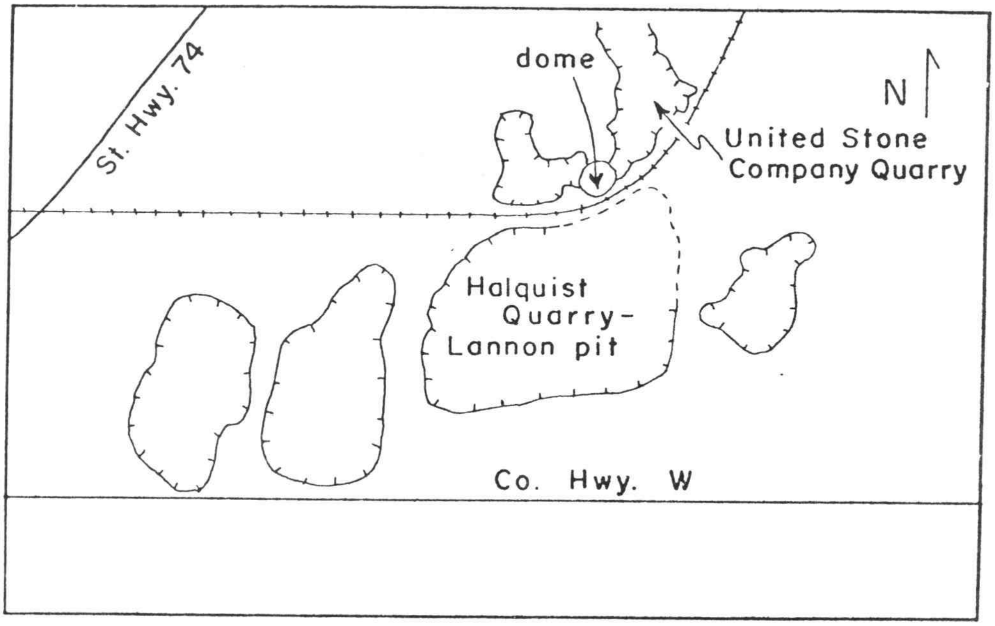
Lannon Area

Section 18
E 1/2, Section 24
S 1/2, Section 17
N 1/2, Section 20
N 1/2, Section 19
all in T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.
elevation: 850 to 910 feet

There are numerous shallow flagstone quarries in the Lannon area of Waukesha County. Bedrock is very close to the surface over a large area and quarries have been operated here at least since the mid-1800's. The rock is well-bedded and makes a fine building stone.

Figure 77. Airphoto (A) and locality map (B) of the United Stone Company dome (locality 54), Waukesha County. Airphoto from Southeastern Wisconsin Regional Planning Commission.

A


dome
St. Hwy. 74
N
United Stone
Company Quarry
Halquist
Quarry-
Lannon pit
Co. Hwy. W

B

Figure 77

Buckley (1897, unpublished field notes; 1898) described most of the quarries in this vicinity in detail, as did Alden (1904, unpublished field notes) and Shrock (1930, unpublished field notes). Since nearly all of the quarries in this vicinity are shallow and show the same features, only a few of the more noteworthy exposures will be described in detail here.

In general the rock is a well-bedded (six to twelve inches thick at the top of the section, thicker at the bottom), fine-grained, non-porous, poorly fossiliferous, even-textured, non-cherty, light gray to very light brown dolomite with common stylolitic bedding planes. Fossils are mostly scattered orthoconic cephalopods and Phragmoceras, a few rare trilobites (Calymene), and on some bedding planes, pelmatozoan stem sections up to one foot long. Fine pelmatozoan stem sections up to one foot long. Fine pelmatozoan debris is sometimes visible on weathered surfaces. The beds are mostly horizontal with a slight dip to the east, except in the vicinity of low domes having a relief of a couple of feet and a diameter of 50 to 200 feet. These domes are particularly common in Sections 18 and 19.

Cawley Quarry
Locality 53

A typical exposure is the Cawley Quarry (SE 1/4, SW 1/4, Section 18, elevation: 890 feet), just north of County Highway W. The quarry is a small two-man operation that began in 1948. The quarry is a small two-man operation that began in 1948. The quarry is about 10 feet deep and is medium-bedded, well-bedded, light gray, fine-grained, non-porous dolomite with stylolitic bedding planes. A bedding surface is the southwest corner of the quarry, approximately three feet down from the bedrock surface, shows a number of slightly curved large pelmatozoan stems one to three feet long, having a random orientation. A few silicified fossils, including Heliolites are also present. At least four low domes are present in the quarry, but no reef structure can be seen. Large-scale polygonal joints as seen by Shrock in his 1930 study of the area are present on the surface of these domes.

United Stone Company Dome
Locality 54

Section 17, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

elevation: 870 feet

This dome is primarily exposed in the United Stone Company quarry (SE 1/4, NW 1/4, Section 17) on the north side of the railroad tracks, and extends into the Halquist Lannon quarry (NE 1/4, SW 1/4, SE 1/4, Section 17), south of the railroad tracks (see Figure 77).

Raasch (1922, unpublished field notes) first observed this dome, stating that "a quarry in the top of the hill shows the same rock as in the surrounding quarries." He also noted that the beds in the sides of the dome dipped downward.

Mikulic (1977, p. A28) described this dome in some detail as follows:

> The dome appears to be somewhat elliptical in shape trending northwest-southeast with dips up to 20 degrees radiating from the center. The rock here is generally fine-grained, dense, thin- to medium-bedded, light gray to white, weathering buff dolomite. Weathered surfaces commonly have scattered pelmatozoan debris.
>
> To the south of the railroad tracks is the Lannon quarry of the Halquist Stone Company. Its northwall is approximately 50 feet high and shows a typical succession of the Lannon beds. At a point just southeast of the United Stone Company Quarry dome the Lannon beds can be seen dipping to the east, west, and south over the nose of the structure that appears in the floor of the Halquist Quarry. It is between 150 to 200 feet from this point to the center of the dome at the United Stone Quarry.

An examination of the "reef" rock exposed in the floor of the Halquist Lannon quarry shows the rock to be massive, irregular breaking, very crystalline (with an almost glassy texture), locally porous, dense, hard, medium- to light-gray dolomite, mottled white-yellowish gray. There are a few scattered fossils which include primarily articulated rhynchellid brachiopods, some pelmatozoan stems, and gastropods. The exposed portion of the "reef" is about 50 feet long and dips to the south. The surface is somewhat irregular with up to one foot of relief. The overlying beds appear to be draped over the "reef." The strata above the "reef" are dense, fine-grained, well-bedded dolomite with a conchoidal fracture.

Lake Shore Stone Quarry
Locality 55

SW 1/4, NE 1/4, Section 18, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

MPM x37.4

elevation: 889 feet (water), 900 feet (outcrop)

There is a large nearly water-filled quarry, approximately 70 feet deep, now used as a swimming beach in Menomonee Park, north of Lannon (see Figure 78).

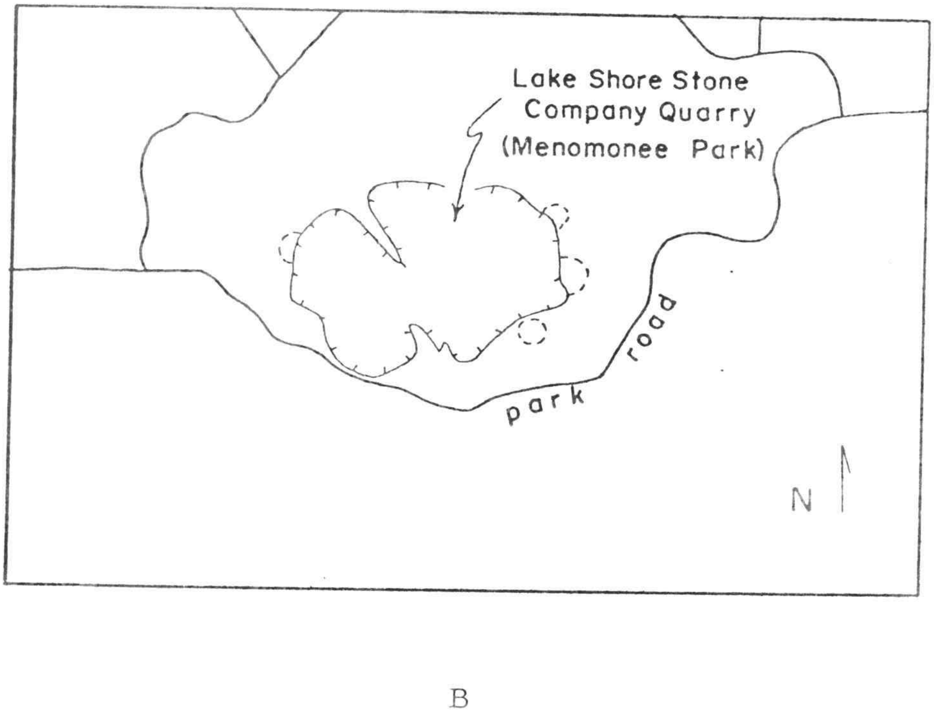
This quarry was once operated by the Hadfield Company in 1891 (see Loerke, 1978, for history).

Alden (1904, unpublished field notes) described a section of this quarry and some glacially-related features in detail. He later (1918) published a similar description of these same features with an accompanying photograph of the quarry.

Raasch (1922, unpublished field notes) described the quarry

Figure 78. Airphoto (A) and locality map (B) of the Lake Shore Stone Company quarry (now Menomonee Park, locality 55). Airphoto from Southeastern Wisconsin Regional Planning Commission. Dashed lines show location of domes.

A



B

Figure 78

as follows:

> The topmost beds exposed in about a four-foot section in the northeastern part of the quarry probably are equivalent to the strats east of the village. Below these and separated from them by a marked unconformity is a second series consisting of light brownish gray dolomite inbeds usually about a foot thick. When damp the rock becomes a much deeper brown. Most of the layers are full of nodules of conspicuous white chert; others contain cavities lined with druzy quartz crystals. At certain horizons fucoidal markings resembling Buthotrophis gracilis occur. Fossils are quite common in the chert nodules. The fauna is unique to this section of the state.
>
> The fossils collected from the chert were as follows: Plant remains 1 sp.; Diplophyllum 1 sp.; Favosites niagarensus; Streptelasma? 1 sp.; Crinoid columns C; Bryozoan 1 sp.; Lichenalia concentrica C; Leptaena rhomboidalis 1 sp.; Plectambonites transversalis C; Bilobites bilobus 2 sp.; Atrypa-like #1, 2; Atrypa-like #2, 1; Spirifer radiatus 1; Meristina 2 sp.; Nucleospira 2 sp.; Calymene? 1 sp. Proetus? C.
>
> The fauna is certainly unlike the Racine or the Waukesha chert faunules.
>
> Below the cherty beds and decidedly unconformable to them is a third set of strata consisting of hard, compact, heavy-bedded dolomite, light gray in color and very fine-grained. The bed was not worked for fossils.
>
> All the strata in this vicinity dip to a marked degree in every direction and tend to form mounds and arches.

Shrock (1930, unpublished field notes) made a detailed study of the quarry and measured the following section (from the bottom of the quarry at the sump):

Bed 1. Gray, dense, compact crystalline dolomite in irregular layers averaging 2-4 inches thick. This unit has numerous small holes 1/2-3 inches across. Breaks with a sem-conchoidal fracture. Separation planes are almost all stylolite seams. Surfaces uneven and somewhat rolling . . . . 11 ft. 6 in.

Bed 2. Dark gray dolomite similar to Bed 1. With many stylolite seams but indistinct layers. Contains several zones of darker colored dolomite characterized by numerous small holes and nodular mottled appearance. . . . . 4 ft. 1 in.

Bed 3. Mottled buff and gray, dense, compact crystalline dolomite with rough splintery fracture. The lower 2 foot bed is characterized by a large number of holes some of which are lined with quartz. . . . . 17 ft. 4 in.

Bed 4. Fairly even-bedded, gray dense compact dolomite with conchoidal fracture. In this unit there are several layers with holes in them. The rock becomes thinner bedded towards the top until the last 4 feet which are reefy. This reefy condition on south face of quarry in places becomes 6-8 feet thick and the overlying thin layers of Bed 5 dome up over it . . . . 18 ft. 2 in. to 26 ft. 8 in.

Bed 5. Flaggy, gray, dense, compact dolomite in layers averaging 4-7 inches thick. Irregularly dipping on flanks of small mounds. Several of the layers have small holes in them. . . . . 6+ ft.

Bed 6. The 1 1/2 feet, called Bed 6 here, are buff-colored, somewhat sandy and in places cavernous. The surface is beautifully striated S. 80°E . . . . 1 ft. 6 in.

Shrock added that:

> In the field north of the quarry are several small dome-like mounds of rock belonging to this unit (Bed 6). The surface of these mounds is cut with solution channels, or widened joints, which cut the rock into large polygonal blocks. Relief 5-8 feet above the flat.
>
> The owner of the quarry reported to us that 75 feet of stone similar to Bed 5, averaging 1-6 in. thick, had been removed from above the present quarry where a large hill was once present.

Sometime after Shrock visit in 1930 the quarry was abandoned and filled with water. In 1960 Waukesha County purchased the quarry as a park site.

Mikulic (1977) briefly described the current exposures at the quarry.

Rock is exposed around nearly all of the quarry above the water level, but less than 10 feet of exposure is present in most areas. Both Shrock and Alden were informed by quarry workers that a large hill of rock was once present at the quarry site, but it was removed before either of their visits.

Several domes and apparent carbonate buildups are still visible in these exposures along the west wall, behind the swimming beach and north of the bath house, a bed can be seen thickening and then thinning from south to north. The overlying beds dome up slightly over this structure, which is only a couple of feet thick at its maximum thickness. No fossils were observed in these beds. Along the east wall several domes can be seen in the bedrock surface. In the south half of the east wall a dome reaches a height of four feet and 200 foot diameter. The quarry wall next to this exposure exhibits a peculiar, very irregular, thick bed (which may be related to the dome) both underlain and overlain by normal, well-bedded strata. Along the east half of the south wall a similar dome having a diameter of about 75 feet and a height of two to three feet is exposed. This dome is described by Mikulic (1977). Around the outer margins of the dome scattered orthocones and curved pelmatozoan stems up to a foot long occur in a random orientation. These pelmatozoan stems increase in abundance towards the dome and possible algal-related structures cover the entire surface and both pelmatozoan stems and cephalopods are absent.

A number of small outcrops are present west and northwest of the quarry in NW 1/4, Section 18, and SW 1/4, Section 7. Some are reefy in appearance and may represent additional carbonate buildups. Shrock also observed these outcrops and described them as follows (MPM x37.30, elevation: 900-920 feet):

> ...there occur a number of small mounds and ridges of a buff, porous crystalline dolomite full of crinoid stems and other fossils. The rock is massive, without distinct bedding, and breaks into large honey-combed or pitted irregular blocks with crumbly fracture. This rock probably represents a facies of the Racine formation. The mounds, usually a hundred feet or more across, rise from 8-20 feet above the surrounding marsh.

Locality 56

Section 7, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

MPM x37.31

elevation: 930 feet

Shrock (1930, unpublished field notes) made the following observations in this area:

Here there occurs a low mound of rather slabby, dense, compact, light colored, earthy dolomite which is very probably the upper part of the Waukesha.

The north-south road runs over the pavement formed by the beds, slightly inclined toward the south.

A short distance northeast at the same elevation two similar mounds occur, partially covered with large glacial boulders.

Farther east still and about the same elevation rock of Racine age is at the surface as indicated by the many fresh slabs and character of the vegetation.

Sections 7 and 8, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

MPM x37.32, x37.33

Shrock described exposures in this area in his unpublished field notes from 1930:

> Along the road, and also in the fields on either side of the road are low rock-strewn mounds of Racine. Their general elevation is between 900-920 feet A. T. (MPM x37.32)
>
> Numerous exposures on either side of the road of a light salmon-colored to buff, porous to cavernous, somewhat slabby to massive dolomite. In the quarry, opened in a small dome, the rock is a nodular appearing, gray to buff, slabby dolomite (2-4 in.) crystalline dolomite. The surface of the dome shows deeply weathered joints which divide the rock into large polygonal blocks. The rock seems to have been quarried for rough masonry stone. It is full of small holes 1/2-1 in. across and is irregularly separated. (MPM x37.33)

Locality 57

NE corner, Section 6, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

MPM x 37.34

elevation: 880-900 feet

Shrock visited this exposure in 1930 and described it as follows (unpublished field notes):

> In the very corner of the section, about 150 yards from the end of the road there is a small surface exposure of a blue crystalline dolomite of rather coarse texture, resembling some phases of the Racine. It appears to be massive and is considerably channeled by solution. Rounded off by glaciers. Weathers into boulders full of pits and cavities. When fresh has a slightly mottled appearance. A few small holes.
>
> About 1/8 mile north there are numerous small mounds or ridges of light salmon colored to buff, porous earthy dolomite which where weathered breaks into large honeycombed blocks or boulders or into slabs 6 inches thick. The rock has a somewhat modular appearance and some of the layers show structures which resemble cross bedding.

Locality 58

W 1/2, Section 9, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

MPM x37. 7

elevation: 885 feet (top of bedrock)

Raasch (1922, unpublished field notes) observed exposures in pastures, woods and roadcuts, one and one-half miles west-southwest of Menomonee Falls and described them as follows:

> Best exposures lie south of the railroad crossing in a wooded pasture to the east of the railroad. Here an outcrop of considerable size shows about a seven foot section of massive, granular dolomite of the Racine beds. Crinoid columns abound as well as numerous brachiopods in a poor state of preservation. The following were found: *Lecanocrinus pisiformis*; *Atrypa reticularis*; *A. nodastriata*, *Rhynchotreta cuneata americana*; *Sprifier radiatus*(?); *Camarotoechia neglecta*(?).... The formation is undoubtedly typical Racine. The strata are heavily bedded, but show no signs of reef structure. The rock is exposed as follows:
>
> (1) mounds in the pasture just mentioned
> (2) mounds in wooded tracts across the tracks from (1)
> (3) mounds in fields about 1/4 mile south of (1)
> (4) about two feet exposed at roadside at schoolhouse about 1/4 mile northwest of (1)
> (5) a foot or so along highway a short distance south of (4)

Menomonee Falls
Locality 59

E 1/2, SE 1/4, SW 1/4, Section 3, and W 1/2, SW 1/4, SE 1/4, Section 3, and NW 1/4, NW 1/4, NE 1/4, Section 10, and NE 1/4, NE 1/4, NW 1/4, Section 10, T. 8 N., R. 20 E., Menomonee Falls Township, Menomonee Falls, Waukesha County.

MPM x37.1 and x37.2

elevation: 830 feet (at dam); 790 feet (south end of exposures); 800-830 feet (Appleton Avenue roadcut); 850 feet (school on Main Street)

There are a number of bedrock exposures from the dam on the Menomonee River, just north of Main Street (State Highway 74), south through Lime Kiln Park (locality 59). Outcrops continue west from Lime Kiln Park along the 800 foot contour to the west side of W. Appleton Avenue; widening of Appleton Avenue formerly exposed bedrock for about .10 mile north of the 800 foot contour. Exposures are also found east of the dam on the north side of Main Street, .15 mile east of Hayes Avenue.

From the distribution and characteristics of these exposures it appears that a bedrock hill (possibly reef-controlled) is located on each side of the Menomonee River at this location.

Quarries and lime kilns were operated from 1845 until 1894 along the river (Loerke, 1978, p. 9).

Lapham (1846, p. 117) described this locality as follows:

> At the place called the Menomonee Falls, 15 miles from Milwaukee, this river passes between perpendicular banks of limestone, sometimes thirty feet in height. There is a fall here of forty-eight feet, in the space of half a mile, and mills have been erected here. There is no perpendicular fall of water. The limestone may be quarried in layers of any desired thickness, and much of it is of an excellent quality for building, and even for ornamental purposes, being hard, and of a uniform texture, resembling marble. Some layers are filled with small cells or cavities, occasioned probably by the decay of some mineral substance that once filled them. This variety is probably the best for the manufacture of lime, requiring less fuel than the more compact variety.

Lapham (1873, unpublished field notes) made a more detailed study of these outcrops along the river and recognized the complexity in the distribution of rock types near the dam, but did not realize a reef was present. His description is as follows:

> There are 3 or 4 different layers of limestone; the lower most abundant constituting the bed at the river the whole distance. It is stratified but the layers much broken by perpendicular joints--no fossils.
>
> The second layer is porous, yellow, and soft; just suited for quarrying and burning for quick-lime. It resembles the rock at Cedarburg.
>
> The third layers is more crystalline, made up largely of joints of crinoids; same that may be seen in the road on Section 8, about two miles southeast from the Falls.
>
> Many loose blocks indicate another layer containing <u>Halysites</u>, <u>Favosites</u>, etc. of the Niagaran limestone. This was not seen in place--but doubtless belongs here.
>
> The varying dip of the rock indicates former disturbances--one of which by telling up the strata has given origin to the Falls.

G. O. Raasch made a collection of fossils from excavations along W. Appleton Avenue (formerly U.S. Highway 41) when the road was widened in the 1920's. The fauna he collected, now in the Milwaukee Public Museum collections, was typical reefal Racine Dolomite, as exposed around Racine.

Shrock (1930, unpublished field notes) described the exposures in this vicinity. At the quarry in the present Lime Kiln Park he observed the following section:

Unit 1. This irregularly bedded, somewhat modular-appearing, gray, dense, to saccharoidal dolomite. The upper and lower parts flaggy-middle a bit modular and massive. Exposed in an old quarry and above in the street.

Unit 2. Even bedded, fairly even-grained, dense, gray dolomite, which breaks into rectangular blocks with smooth fracture. Buff when weathered... lower part cherty.

This area was also briefly described by Mikulic (1977).

Several temporary exposures have been uncovered in the last few years in this vicinity. In 1975 the dam was opened, lowering the water level and exposing rocks on the east side of the river where a small point projects towards the west. This exposure was about five feet high and consisted of flank beds dipping 20° northwest at its southern end, leveling out to horizontal beds on the north. The rock is medium-bedded, light gray, granular, poorly fossiliferous dolomite with scattered small vugs and stylolitic bedding planes. At the southern end of the exposure more reefoidal-appearing rocks were present, consisting of thick-bedded, porous, vuggy, fossiliferous dolomite. From the rock-controlled point to the dam there were no exposures, with the exception of a small exposure adjacent to the dam. This rock was massive, dense, granular, somewhat porous dolomite with pentamerids and other large fossils. On the south side of the dam permanent exposures are present which consist of mainly reefal beds, more massive towards the north and dipping towards the south, at the southern end. From approximately the bridge south few exposures are seen until Lime Kiln Park is reached where a narrow 15 foot deep gorge has been cut by the river through Racine beds having a "Lannon"-like lithology. This exposure continues southward to the old quarry and lime kilns.

In the early 1970's Appleton Avenue was widened from approximately the 800 foot contour north to Garfield Avenue. The rock uncovered was highly fossiliferous, reefoidal Racine Dolomite, the same as was collected by Raasch when the road was widened in the 1920's.

A water-well log (Wk-4), on file at the Wisconsin Geological and Natural History Survey, gives the following information on the entire Silurian sequence a short distance to the northwest of these exposures (SE 1/4, NW 1/4, SW 1/4, Section 3, elevation: 880 feet):

Drift	27 feet
Light gray dolomite	143 feet
Cherty, light gray dolomite	35 feet

Light gray dolomite . . . . 55 feet

White and pinkish dolomite . . . . 20 feet

Light gray dolomite . . . . 15 feet

Gray dolomite, some chert . . . . 20 feet

Light gray dolomite, pink shale . . . . 5 feet

Light and dark gray dolomite . . . . 10 feet

Dark gray dolomite, shaly, with some chert. . . . 20 feet

This is underlain by 160 feet of Ordovician Maquoketa Shale (the log assigns the lower 35 feet of the Silurian to the Maquoketa).

Locality 60

Center N 1/2, Section 36, T. 8 N., R. 20 E., Manomonee Falls Township, Butler and Menomonee Falls Township, Waukesha County.

MPM x37.29

elevation: 710-720 feet

There are a number of low outcrops near the intersection of the Menomonee River and a small, southward-flowing tributary.

Shrock described these outcrops as follows in his 1930 unpublished field notes:

> Flaggy, light-colored dolomite is exposed for several hundred yards along the river's shallow bed and for some distance (200 yards) up the small tributary.
>
> The rock has a roughly conchoidal fracture, and breaks or weathers into lenticular, platy slabs pitted with large shallow depressions made by conchoidal fracture.

The rock is fine-grained, somewhat earthy and probably represents the lower beds of the City Quarry (Currie Park quarry) a short distance southeast.

The river bed for a long ways is filled with shingle from the exposure which nowhere exceeds 5 feet in thickness.

Just to the north of these outcrops, on both sides of the river, and south of Silver Spring Drive, a large amount of rock excavated from various Milwaukee County sewer tunnel projects has been dumped in landfill sites through the 1960's and 1970's.

Locality 61

NE 1/4, Section 4, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

Unpublished locality maps in the Milwaukee Public Museum show outcrops in this vicinity, but they have not been described.

Locality 62

Section 2, T. 8 N., R. 20 E., Menomonee Falls Township, Waukesha County.

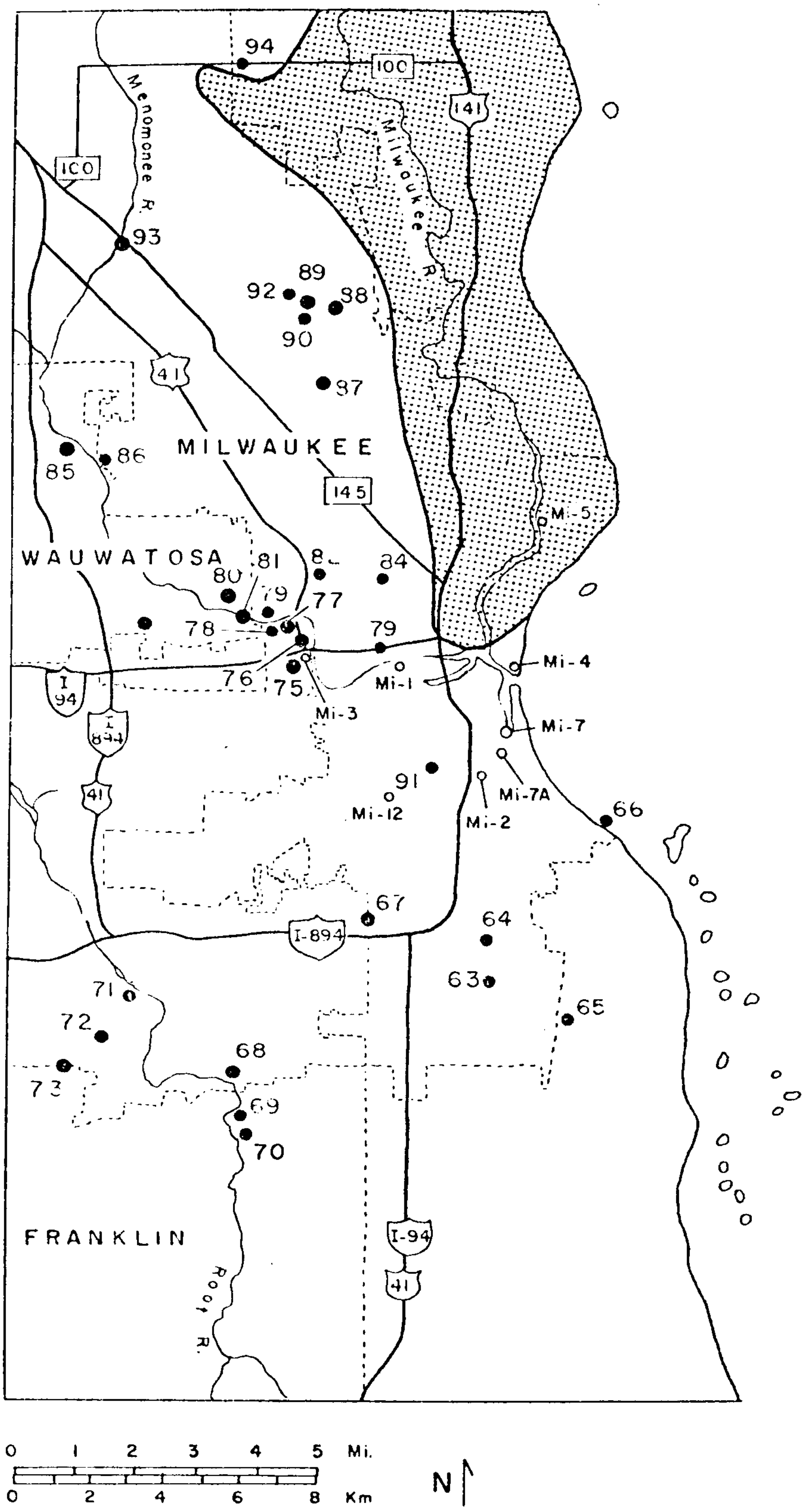
Alden's (1918) map indicates outcrops in this area.

MILWAUKEE COUNTY

The Silurian rocks in Milwaukee County are overlain by zero to 300 feet of Quaternary sediments averaging about 100 feet in thickness. In addition to this, over 150 feet of Devonian rock overlies the Silurian in the northeastern part of the county. In a few restricted areas in the southwestern portion of the county the Silurian has been completely eroded. The thickness of the Silurian increases towards the east-northeast reaching a maximum thickness of about 500 feet, but averaging around 300 feet. Silurian reefs form topographic high areas due to the resistant nature of the reef rock. Because of the Quaternary cover there are few areas with bedrock exposures in the county, only in a small area of the north-central part is bedrock close to the surface. Most natural exposures occur along the Menomonee and Root Rivers and their tributaries. Devonian exposures are found along the Milwaukee River and Lake Michigan. Figure 79 indicates the localities referred to in the text.

Because the county has been the site of urban growth for over 100 years most of the natural outcrops have been quarried for building stone, lime, crushed rock, and other such materials. Most of the quarrying activity occurred in the late nineteenth century and early part of this century. At one time there were over twenty quarries and stone pits in the county, but only two (the adjacent

Figure 79. Locality map of Milwaukee County showing numbered localities referred to in text. Structures to the right of the county on the map are possible Silurian reefs in Lake Michigan.



MILWAUKEE
WAUWATOSA
FRANKLIN
Menomonee R.
Milwaukee R.
Root R.
100
141
41
145
I 94
I 894
I-894
I-94
Mi-1
Mi-2
Mi-3
Mi-4
Mi-5
Mi-7
Mi-7A
Mi-12
0 1 2 3 4 5 Mi.
0 2 4 6 8 Km
N

Figure 79

quarries at Franklin, locality 70) are still operating. Urban expansion has forced most of the other quarries to close and many have been completely covered, and because of the development of the area it is highly unlikely that any new quarries will be opened. However, sewer tunnel construction and other temporary construction-related exposures have and will continue to produce substantial new information on the local geology of the area.

Many of the early observations on Wisconsin Silurian rocks were based on Milwaukee County exposures due to the early quarrying activity in this area. The natural exposures and most of the quarries were in the Racine Dolomite. The Franklin quarries currently exhibit the Waukesha Dolomite and Brandon Bridge Beds underlying the Racine. A number of cores in the center of Milwaukee and also at Franklin present a complete section of the Silurian.

Airport Runway Underpass
Locality 63

SW 1/4, NW 1/4, NW 1/4, Section 33, T. 6 N., R. 21 E., Lake Township, City of Milwaukee, Milwaukee County.

elevation:

In the 1960's the main southwest-northeast runway at General Billy Mitchell Field was extended west across W. Howell Avenue (State Highway 38). An underpass was constructed approximately

20 feet beneath the level of the runway and a few feet of Racine Dolomite were exposed. The rock is typical reefal Racine Dolomite with some inter-reef or pre-reef beds also present. The fauna and lithology are the same as that found in the Racine area quarries. The rock is a dark gray, fine-grained, crystalline, porous, vuggy, massive, fossiliferous dolomite, and the fauna includes Bumastus ioxus, Kosovopeltis acamus(?), Favosites, and pelmatozoan stem sections. Several of these rocks were found with a single, highly polished surface resulting from Pleistocene glacial activity. The excavated material was dumped about one-half mile to the south in a field north of W. Uncas Avenue and S. First Street in Milwaukee.

Howell Avenue Sewer Tunnel
Locality 64

Along the boundary between Sections 21 and 20, T. 6 N., R. 22 E., Lake Township, City of Milwaukee, Milwaukee County.
elevation:

In 1965 a sewer tunnel was constructed along S. Howell Avenue from W. Plainfield Avenue to W. Layton Avenue in Milwaukee. Typical Racine Dolomite was encountered at a depth of 112 feet in a shaft at Plainfield Avenue and in lateral tunnels excavated at a depth of 130 feet. The rock was dumped at a landfill site north of Layton Avenue around S. 9th Street. The rock is a light gray, porous, crystalline, massive, fossiliferous dolomite. Abundant disarticulated pentamerid brachiopods and common pelmatozoan debris (including 1/4 inch diameter stem sections) predominate; small scattered colonies of _Halysites_, _Favosites_, and _Heliolites_ are also present. Lithologically and paleontologically the rock is the same as the Racine Dolomite in the Racine area, and is probably reefal. The following fossils have been identified by A. J. Boucot in U.S.N.M. collection No. 12572 made by William Bode:

Carmanella sp. - 491
Delejina sp. - 4
clorindid - 1
"_Doloerorthis_" _flabellites_ - 2
Coolinia(?) sp. - 1
Monomerella sp. - 3
Dinobolus(?) sp. - 3
Meristina sp. - 2
unidentified brachiopods - 10
Brachyprion (_Protomegastrophia_) _profunda_ - 111
trilobites
Caryocrinites sp.
orthoceroid - 1
Macropleura cf. _eudora_ - 2
"_Poleumita_" sp.

Pennsylvania Avenue Sewer Tunnel
Locality 65

Section 34, T. 6 N., R. 22 E., Lake Township, Cudahy, Milwaukee County.

elevation:

A sewer tunnel was constructed in the mid-1960's along the west side of S. Pennsylvania Avenue between W. College and Grange Avenues, just east of the General Billy Mitchell Field airport. A large amount of typical reefal Racine Dolomite was dumped in fields near the main shaft. Dipping reef flank beds could be seen in the shaft itself (K. G. Nelson, 1967, personal communication). Lithologically the rock is the same as that from the airport runway underpass to the west, but is lighter gray in color. The fossils collected were mostly small, rounded favositids, locally abundant pelmatozoan stem sections, pentamerid brachiopods, a few other brachiopods and gastropods, and the trilobite *Bumastus ioxus*. Lithologically and faunally this rock is the same as that found in the Racine area quarries.

Texas Avenue Reef
Locality 66

SE 1/4, Section 10, T. 6 N., R. 22 E., Lake Township, Milwaukee County.

MPM x31.6

elevation: 578 feet

A low bedrock exposure is located in the bed of Lake Michigan, approximately 100 yards from the shore, under two feet of water at east end of Texas Avenue in Milwaukee. This submerged outcrop was first mentioned by G. O. Raasch (1939, unpublished field notes).

In 1959 construction of the Texas Avenue intake tunnel (which is nine feet in diameter and extends 7600 feet east of the shore) resulted in the excavation of rock from this outcrop. J. Emielity collected some of this material dumped on the beach from about 1300 feet offshore; this collection is now in the Milwaukee Public Museum (No. C1882). This rock is light gray, fine-grained, vuggy dolomite which is stylolitic in places and has an irregular breakage. Calcite, marcasite and asphaltum fill the vugs. There is fine fossil debris some of which might be pelmatozoans, but large pelmatozoans are absent. Some of the pentarmerids appear to be in a denser rock which is possibly layered and not massive. Fossils found in these rocks include: Heliolites and other tabulates in small colonies, stromatoporoids or algae, a rugose coral, a gastropod, and pentamerids.

Wolosin (1972) briefly described the properties of the asphaltum in these samples which was found to be possibly bacterially altered Michigan Basin-type oil. The only other occurrences of asphaltum in southeastern Wisconsin include the questionable occurrence in Kenosha mentioned by Percival (1856), exposures of the Middle Devonian Milwaukee Formation along the Milwaukee River, and a possible occurrence referred to by Alden (1906) in the Currie Park Quarry. Some boulders have been found along the Lake Michigan shore in Grant Park, to the south of this outcrop, which also contain asphaltum. Asphaltum is commonly found in the Silurian reefs of the Chicago area.

A large number of submerged mounds are found offshore from the Texas Avenue exposure south to Oak Creek; these may represent additional submerged Silurian reefs.

1967 Sewer Tunnel Along S. 27th Street Between W. Layton and Howard Avenues Locality 67

Along the boundary between Section 24, T. 6 N., R. 21 E., Greenfield Township, and Section 19, T. 6 N., R. 22 E., Milwaukee County

The rock excavated in this sewer tunnel is lithologically and faunally typical reefal Racine Dolomite as exposed around Racine. The rock is light orange-brown in color, crystalline, porous, vuggy, and massive dolomite which is highly fossiliferous with abundant pelmatozoan stem sections and few calyces, trilobites (chiefly *Sphaerexochus*), a few brachiopods, bryozoans, and variously sized favositid corals. Some typical cherty Waukesha Dolomite was also excavated. Material was collected from a dumpsite located under the present parking lot of the American Automobile Association building at the southwest corner of S. 27th Street and W. Bottsford Avenue, just north of Interstate Highway I-894.

Loomis Road Outcrop
Locality 68

NW 1/4, NE 1/4, Section 3, T. 5 N., R. 21 E., Franklin Township, City of Greendale, Milwaukee County

MPM x31.4

Bedrock outcrops of typical crinoidal Racine Dolomite on the east side of Loomis Road, just northeast of the Root River, have been exposed at various times in the past. Lapham (1874, unpublished field notes) mentioned a Racine Limestone quarry in the NE 1/4 of Section 3 belonging to Reed and one in the SE 1/4 of Section 3 belonging to Schwartz. Alden (1096, p. 2) also mentioned small outcrops and a quarry in this general vicinity, showing their location on his Areal Geology Map. Raasch (1940, unpublished field notes) reported that a small, filled quarry was located near the outcrop. Most recently, road construction in the late 1960's temporarily exposed a few feet of Racine Dolomite in this area.

Hotchkiss and Steidtman (1914, Plate XVI) indicated a quarry or outcrop about one mile northeast of this locality on the east side of Loomis Road (approximately the SW 1/4, NW 1/4, Section 35, T. 6 N., R. 21 E.). There is presently a small pond at this location in Scott Lake Park, but no outcrop can be seen.

Root River Outcrops
Locality 69

SE 1/4, SE 1/4, Section 3, T. 5 N., R. 21 E., Franklin Township, City of Franklin, Milwaukee County.

MPM x31.7

elevation:

A few feet of typical crinoidal Racine Dolomite are exposed in a low bank on the south side of the Root River just north of Rawson Avenue.

Franklin
Locality 70

NE 1/4, Section 10, and NW 1/4, Section 11, T. 5 N., R. 21 E., Franklin Township, City of Franklin, Milwaukee County

MPM x31.3

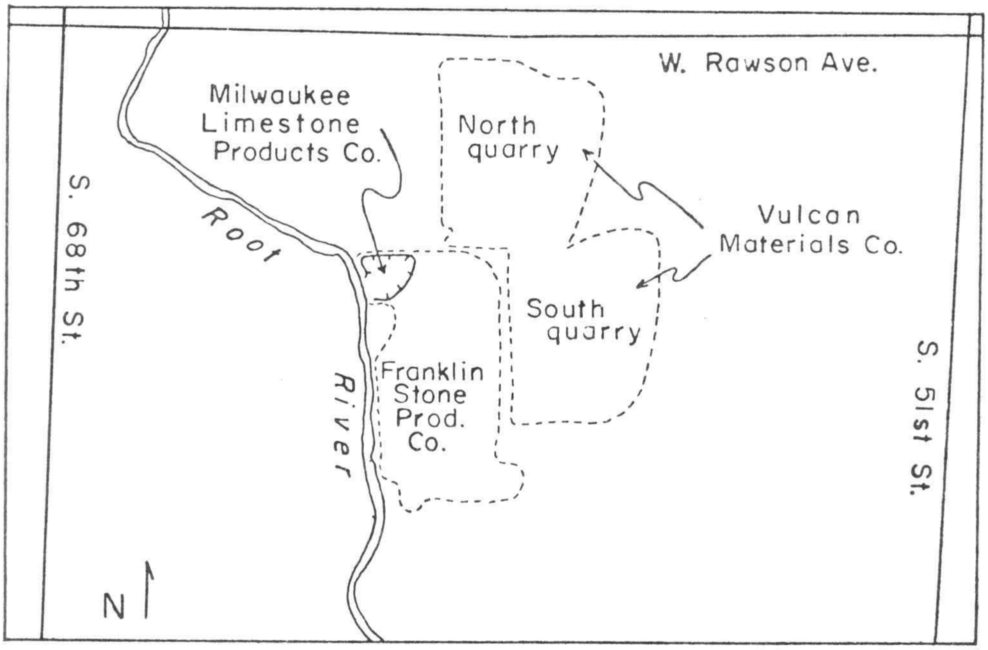
elevation: 710 feet

There are a number of quarries and outcrops exposed along the Root River, south of Rawson Avenue, for approximately .5 mile (see Figure 83).

In his unpublished field notes Hale (1860) mentioned that he was informed by I. A. Lapham that there was a locality of Racine Limestone in Section 10, T. 5 N., R. 21 E.

Figure 80. Airphoto (A) and locality map (B) of the Franklin quarries (locality 70), Milwaukee County. Airphoto from National Archives and Records Service, General Services Administration, No. WX-1B-83, date: 10-45-41.

A


W. Rawson Ave.
Milwaukee
Limestone
Products Co.
North
quarry
Vulcan
Materials Co.
South
quarry
S. 68th St.
Root
River
Franklin
Stone
Prod.
Co.
S. 51st St.
N

B

Figure 80

Lapham (1874, unpublished field notes) stated that there was a Racine Limestone quarry belonging to Leo in the NE 1/4 of Section 10 and also that there was a quarry or outcrop at the bridge on the south line of Section 3.

Alden (1906) reported that there were outcrops along the Root River in this area and showed their location on his Areal Geology Map.

In 1930 Shrock (unpublished field notes) gave the following description of the area:

> In the center of the east 1/2 Section 10 a cliff 8-15 ft. high of slabby, buff, porous dolomite is found at one place on the south side, where it becomes massive with rather indistinct bedding; and on the north side further east where there is a bluff of about 10 ft. of slabby to massive rock of a nodular nature.
>
> Farther south along the stream rock similar to that just described is exposed over several hundred square feet near the stream on the east side.

In 1940 Raasch (unpublished field notes) made a more detailed study of the outcrops in this vicinity prior to the start of quarrying activities. Hs description of the exposures is as follows:

> All outcrops lie in NE 1/4, and extend from the bed of the Root River to the summit of the knolls to NE., and to a maximum height of 30-35 feet above the river level.
>
> The rock is typical Racine dolomite, in several slightly different phases. Most common is a rich buff to light buffy brown, rather fine-grained, moderately porous dolomite, weathering to flat-sided blocks of paving stone size. Also common is a knobby phase, with interspaced porous and hard cryp to crystalline area, causing the rock to weather with a pitted phase. This phase occurs in massive ledges 5-8 feet thick & horizontally bedded. Fossils

> are not common and occur mainly in the highly crinoidal local areas. Noted or collected are the following:
>
> *Favosites* (poor; small masses)
> Stromatoporoid (locally common)
> *Zaphrentis racinensis*
> *Caryocrinus ornatus*
> *Lecanocrinus pisiformis*
> *Collicrinus cornutus*
> *Atrypa reticularis*
> *Leptaena rhomboidalis*
>
> From the highway bridge at the north edge of the section for a distance of 1/8 mile downstream the outcrops are low and confined to the left bank of the stream, where they never rise more than five feet above the water. Most of the fossils come from this area.
>
> One-eighth mile down stream steep crags (rise) vertically 15 to 18 feet above the river, on banks.
>
> From this point, the outcrops decline rapidly on the right bank and gradually on the left bank, disappearing a short distance north of the center line.
>
> In the woods, northeast of the stream, ledges lie extensively at the surface, and the rocky plateau has very thin and sterile soil. The highest beds occur here, but there is no vertical change in lithology and fauna in the entire 30 to 35 feet of exposure.

This last exposure described by Raasch was the site of the first quarrying operation which began sometime after Raasch's visit and August, 1941. This site is in the northwest corner of the present Franklin Stone Products quarry north of the crusher at the north entrance ramp. Air photos from August, 1941, indicate that the quarry was less than 50 feet deep and was located on the north side of a bedrock hill. In 1942 Raasch made several collections (now in the Milwaukee Public Museum collections) from this locality (then called the Milwaukee Limestone Products Company). He referred to these fossils as coming from a gastropod bioherm (MPM No. C1133) and a _Bumastus_ bioherm (MPM No. C1134). Examination of this material indicates that at least the _Bumastus_ bioherm collection is typical Racine Dolomite reef-core rock.

There are currently two large quarries on the east side of the Root River. One, the Franklin Stone Products quarry extends south along the Root River from the original quarry site. The other, Vulcan Materials Company quarry is located directly east and north of the Franklin Stone Products quarry. The quarries are separated by a thin rock wall which is in the process of being removed by quarrying. Both quarries have a maximum depth of approximately 150 feet. The Racine Dolomite, Waukesha Dolomite, and upper Brandon Bridge beds are exposed in both quarries. A core drilled in the floor of the Vulcan Materials quarry reveals that there are over 100 feet of Silurian rocks beneath the exposed units, making a total thickness of approximately 260 feet for the Silurian beds here.

The following description of the Silurian (see Figure 81) at this locality is modified from Mikulic (1977).

Racine Dolomite. The Racine Dolomite is approximately 80 feet thick in the Franklin quarries; an undetermined thickness of Racine has been removed at this locality by post-Silurian erosion and glacial activity. The Racine beds at this locality are faunally and lithologically the same as those exposed around Racine, the only difference

Figure 81. Section through the Silurian at the Vulcan quarry at Franklin (locality 70) Milwaukee County based on exposures and core information.

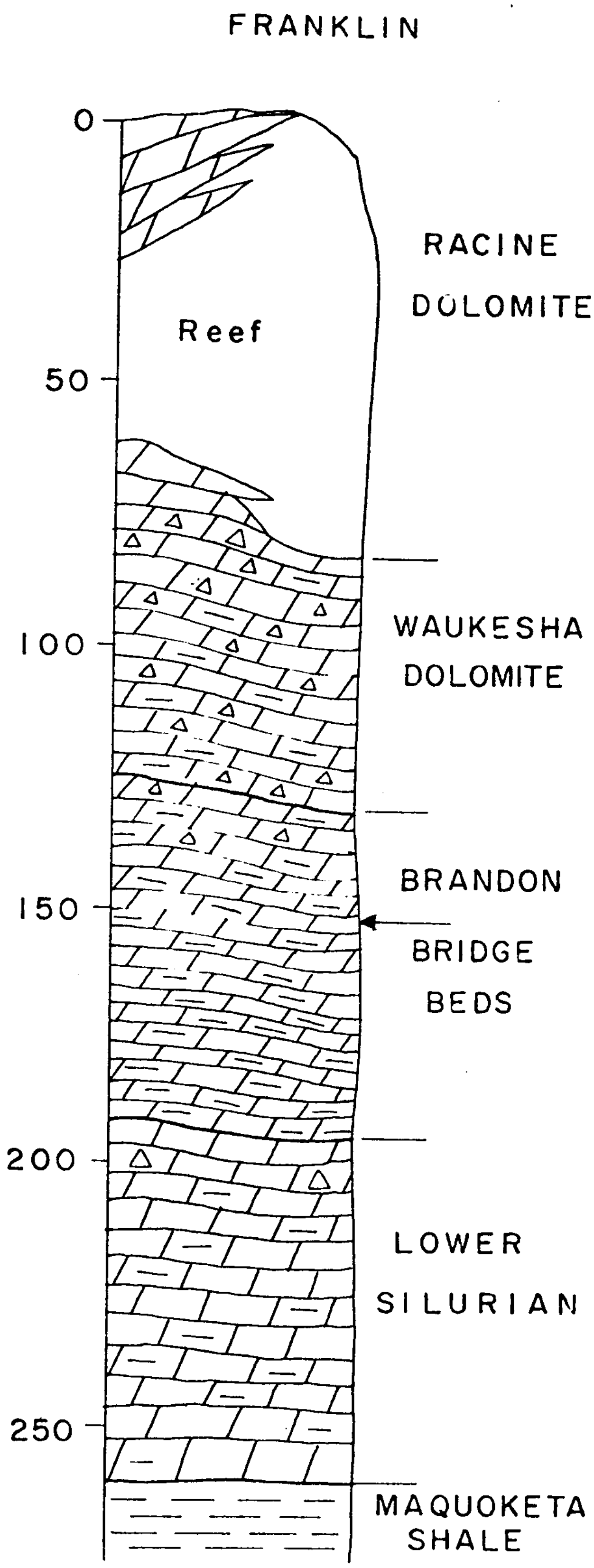

FRANKLIN
0
50
100
150
200
250
Reef
RACINE
DOLOMITE
WAUKESHA
DOLOMITE
BRANDON
BRIDGE
BEDS
LOWER
SILURIAN
MAQUOKETA
SHALE

Figure 81

being a predominant brownish coloration as opposed to gray at Racine.

The Racine beds are composed of both inter-reef and reef rock. The inter-reef beds are located primarily along the south wall and the southern three-fourths of the west wall of the Franklin Stone Products quarry and in the west, north, and east walls of the north pit and the northern two-thirds of the east wall of the south pit of the Vulcan Materials quarry (see Figure 80). A number of reefs are located in the dividing wall of the two quarries (see Figure 82), in the northwest and southeast corners of the Franklin Stone Products quarry and in the south wall of the south pit of the Vulcan Materials quarry. As in the main quarry at Ives, Racine County, these reefs in the Racine Dolomite appear to have compressed the underlying sediments resulting in large depressions and rises in the quarry floor. The relationship between the reefs and this underlying irregular topography is well demonstrated in these quarries. In most of the north pit of the Vulcan quarry where only inter-reef beds are developed the quarry floor is relatively level, with the exception of a slight overall dip to the south. As the reef area along the dividing wall is approached the floor assumes the characteristic large-scale depressions and rises associated with the reefs at Ives. Most of the floor in the Vulcan quarry south pit also exhibits these large-scale irregularities, particularly along the west wall. The Racine

Figure 82. Reef core and inter-reef beds in the Racine Dolomite in the east wall of the Franklin Stone Products quarry (locality 70), Franklin, Milwaukee County. Taken 1969. Reef core on left, inter-reef on right.

inter-reef beds along the west wall of the north pit in the Vulcan quarry appear to have a slight southward dip which may be related to the development of the numerous reefs in the dividing wall to the south.

A general section in the Racine inter-reef beds is as follows:

Unit A. Unit A is 29 feet thick, thick- to thin-bedded, crystalline, vuggy, porous, fossiliferous dolomite which is pale yellowish brown on fresh surfaces and moderate yellow brown on joint surfaces and lining molds of fossils and vugs. Calcite crystals are commonly found lining vugs and joints, but take the form of rhombohedrons as opposed to the dogtooth spar at Ives. Marcasite is rare, also in contrast to the Racine area. Fossils are preserved as internal and external molds and much of the porosity is probably due to external molds of small fossil fragments. The rock becomes lighter in color and thinner bedded towards the bedrock surface. Fossils collected from fossiliferous rock in the upper 30 feet of the northwest corner of the north pit at Vulcan quarry consist of common Eucalyptocrinites and Caryocrinites; common orthoconic cephalopods, including Dawsonoceras; small rugose corals, and rarer Lampterocrinus, Siphonocrinus, Favosites, Halysites, rhynchonellid and atrypid brachiopods.

Unit B. Unit B is 22 feet thick and consists of light gray to tan, medium-bedded, argillaceous(?) dolomite. This unit becomes vuggy towards the top but is conspicuously different from Unit A in its lighter color and by being less porous and crystalline.

Unit C. Unit C is 19 feet thick and is dark gray, crystalline, porous, medium- to thick-bedded dolomite becoming thicker bedded and darker towards the top and vuggy in its upper 12 feet. The vuggy texture is more prominent in areas with no reef development. The contact with the underlying Waukesha Dolomite is makred by a sharp change in lithology and a prominent bedding plane.

It appears that most of the reefs in the Racine began to develop in this unit. It is of interest, however, that at least two carbonate buildups (east half of north wall in north pit and north half of east wall in south pit, Vulcan quarry), isolated from the main area of reef development in the middle of the quarries, appear to stop growing at the onset of Unit B deposition. In the main area of reef development individual reefs continued to grow through Unit B deposition.

Along the dividing wall reef flank beds are locally prominent. They are characterized by common to abundant pelmatozoan stem sections (1/4 in. diameter, several inches long), scattered pelmatozoan calices, 3-4 in. diameter rounded favositid colonies, rhynchonellid brachiopods, and bryozoans.

On the floor of the first level in the southeast corner of the Franklin Stone Products quarry a number of fossils were collected from a very light gray, thick-bedded, crystalline, low porosity dolomite. Fine pelmatozoan debris was present along with one inch diameter Dawsonoceras and other orthocones, a few brachiopods, fenestrate bryozoans and Stenopareia. This represents the highest stratigraphic occurrence of Stenopareia in the Racine-Milwaukee area with the possible exception of the Trimborn quarries. It is not known if these rocks belong to the Racine Dolomite or underlying Waukesha Dolomite.

Waukesha Dolomite. The Waukesha Dolomite is 55 feet thick and is characterized by its highly cherty composition. The beds are thin to medium, argillaceous, non-porous, light gray dolomite. Argillaceous partings are common along some bedding planes giving the rock a thin platy appearance when weathered. Chert is white to light gray in the form of discontinuous bands and irregular nodules averaging one to one and one-half inches thick up to three inches. Some of the larger lenses of chert contain small size pelmatozoan debris. The upper two to three feet of the Waukesha are non-cherty. Fossils are occasionally common on weathered bedding planes, in particular pelmatozoan debris (including Petalocrinus), bryozoans, and brachiopods. A number of graptolites were found approximately 37 feet from the top of the formation; they include Desmograptus sp., Monograptus cf. M. priodon, and a retolitid. Trilobites are also present in at least the lower one-third of the unit and include Stenopareia (most common), Calymene, and Youngia. There are also horizontal burrows and trails found in these beds. The lower beds of the Waukesha Dolomite are gradational with the underlying Brandon Bridge beds.

Brandon Bridge Beds. Approximately 26 feet of the upper portion of the Brandon Bridge beds are exposed in the lower part of the north pit of the Vulcan quarry. The rock is thin- to medium-bedded and alternates between a pinkish-gray, finely laminated, highly crystalline, non-porous dolomite and a light greenish-gray, argillaceous, non-porous dolomite which appears to be thinner bedded. The layers of both rock types appear to be discontinuous and thin, irregular partings of greenish-gray shale are sometimes prominent. A couple of thin layers of white chert nodules are present in the upper 20 feet. Towards the top of this unit the rock alternates between layers of typical Brandon Bridge lithology and beds similar to the overlying Waukesha Dolomite; the top of the Brandon Bridge is considered to be where the last upward appearing bed of Brandon Bridge lithology occurs. A few compressed cranidia and pygidia of *Stenopareia* sp. are present in the exposed portions of the Brandon Bridge. The core in the bottom of this quarry indicates that approximately 28 feet of Brandon Bridge lithology underlie the exposed portion of this unit. The rock becomes more argillaceous towards the bottom with light gray, fine-grained, laminated dolomite with occasional purple beds occurring.

Beneath the Brandon Bridge is approximately eight feet of highly cherty, crystalline, slightly porous, white dolomite. This unit contains some crinoidal debris.

Beneath the chert is 57 feet of crystalline, coarse- to fine-grained, gray dolomite. Several reddish or pinkish horizons are present which are usually associated with vugs. Pelmatozoan debris is the only fossil material observed.

The contact between the Silurian and the underlying Ordovician Mqquoketa Shale is unconformable.

Trimbrogn Quarries-Town of Greenfield
Locality 71

S 1/2, SW 1/4, Section 28, T. 6 N., R. 21 E., Greenfield Township, City of Greendale, Milwaukee County

MPM x32. 1

elevation:

There are a number of small quarries and natural outcrops on the old Trimborn estate and the surrounding area. The bedrock is quite close to the surface over most of the SW 1/4 of Section 28 (south of the Root River), NE 1/4, Section 32, and NW 1/4, Section 33 in Greenfield Township. J. O'Donnel was probably the first to begin quarrying for lime in this area in the 1840's (Zimmerman, 1972, Milwaukee Journal) and Werner Trimborn started his lime business in 1851. Walling's (1858) map shows two lime kilns located in the area of N. Grange Avenue on the land owned by P. Welsh (Walsh). On the south side of Grane Avenue, Timber (Trimborn) and O'Donnell are each shown as owning a lime kiln. Trimborn eventually bought the Walsh and O'Donnell properties and operated a thriving lime business in the area during the 1870's and 1880's.

Hale (1860, unpublished field notes) mentioned many "openings" (quarries) in the vicinity of Section 33, T. 6 N., R. 21 E., but he could find fossils only in a limited portion of one of the quarries. The rock exposed was Racine dolomite.

I. A. Lapham (1873; 1874, unpublished field notes) described the rock as being lithologically and paleontologically the same as at Racine, a predominantly soft yellow limestone. He also reported that a 111 foot deep well located near the Trimborn? house, approximately 30 feet above the level of the Root River, did not reach the bottom of the limestone.

Chamberlin (1877, p. 362) described the exposures at the Trimborn quarries in his discussion of the Racine Dolomite. He found:

> At the quarries belonging to Mr. Trimbone (sic) in the town of Greenfield, Milwaukee County, the rock is chiefly a light buff, porous, granular, brittle dolomite, rather soft, and in some cases almost griable, and at points disintegrating to a calcareous sand. A little calcite in cyrstals, but no pyrite was seen. The fracture is rough, but usually along line indicated by the application of force, the

manner in which the force is applied, rather than the nature of the rock, determining the line of fracture.

But in the southeastern quarry, the rock differs considerably from the rest, being harder, more compact, less brittle, and bluer.

In general, the beds are from 1 1/2 to 3 feet in thickness, but readily split into thinner layers. The beds, though in general regular and somewhat uniform, not infrequently thicken, and curve, or undulate. Indeed, the last feature seems to be a common characteristic when any considerable area is considered, so much as to render any attempt to get the general dip, by local observations, utterly futile. These undulations are not regular, nor do they present a system, as though due to some common cause, as contraction or upheaval, but are in a sense inharmonious with each other. The phenomenon arises, doubtless, in irregularities of deposition, and not in subsequent folding or other disturbance. A little careful study is decisive on this point. One of the clearest illustrations of this is to be found in the southeastern quarry, where the lower bedding joints can be traced in a straight line beneath the apparent folding. The next ones are lost in a thick unbedded mass, over which the upper layers pass on a considerable curve.

Alden (1899, unpublished field notes) stated that the quarries had not been worked since 1889 and gave the following description:

> ...old quarry is found here giving a 10-25 ft. extended section. The rock dips southwest at an angle of 7° hence the valley slope cuts across the edges of the strata and the rock is but thinly covered by till. The rock face is considerably weathered and shows thin beds at top thickening quite rapidly toward the bottom to 1 to 3 ft. Most of the rock is of uneven, open porous texture, and abundantly fossiliferous. In places where most irregular, it appears massive showing little evidence of bedding. The rock has been used principally for lime. The dip is somewhat uneven running as high as 11° S 20°W. In Section 32, NE 1/4 the rock is also exposed in small quarry belonging to Andrew Anderson. Mr. Anderson burns a little lime every year for farmer trade. Stone is rather massive and of open irregular texture as at Trimbones (sic). In Section 33 the rock is seen in small excavations thinly covered.

He (1906) later published a similar description and indicated the location of the quarries on his Areal Geology Map.

Shrock (1930, unpublished field notes) examined the Trimborn quarries and found them to be partly overgrown and water-filled (see Figure 83); he described them as follows:

> Racine dolomite is exposed discontinuously along the south slope of the valley of Root River at the north end of the exposure, flaggy porous granular beds, about 2-4 inches thick outcrop, and have very little dip. To the southeast in a water-filled quarry, the face, about 12-15 feet high shows the same flaggy beds but with a low dip to the west, and south, as though they were riding up on a mound to the northwest where an abandoned kiln is located.
>
> In places these slabbly beds become massive and reefy. These thicker units probably represent the lateral fingers of a reef or the place where the normal-reef-rock change takes place.
>
> Just east of the water-filled quarry are other exposures of the same buff porous, somewhat granular slabby dolomite.
>
> Orthoceratites, brachiopods, and one crinoid or cystid were noted in the slabby beds.
>
> In the meadow northwest of the quarry are numerous small opwining where the slabby porous dolomite has been quarried. Two abandoned lime kilns are present near the stream.
>
> The beds have local dips of 6°-7°, but these seem to be associated with small mounds of structureless rock rather than with anything of regional nature. One of these small mounds 10-11 feet across and 5 feet high had many large coral heads some crinoids, and an Illaenus. A coral something like a Symgopora, but much larger, is very abundant here.
>
> At the greenhouse about 100 yards south of the crossroads and on the east side of the road is a small quarry where heavy to slabby beds of buff porous dolomite are exposed dipping to the southeast about 4°-6°. About 7 feet exposed. About 1/8 mile south of the crossroad on the west side of the road is the old Smith quarry mentioned by Alden. A

Figure 83. Locality map of Trimborn quarries (locality 71) drawn by Shrock (1930). After Shrock (1930, unpublished field notes). See text for details.

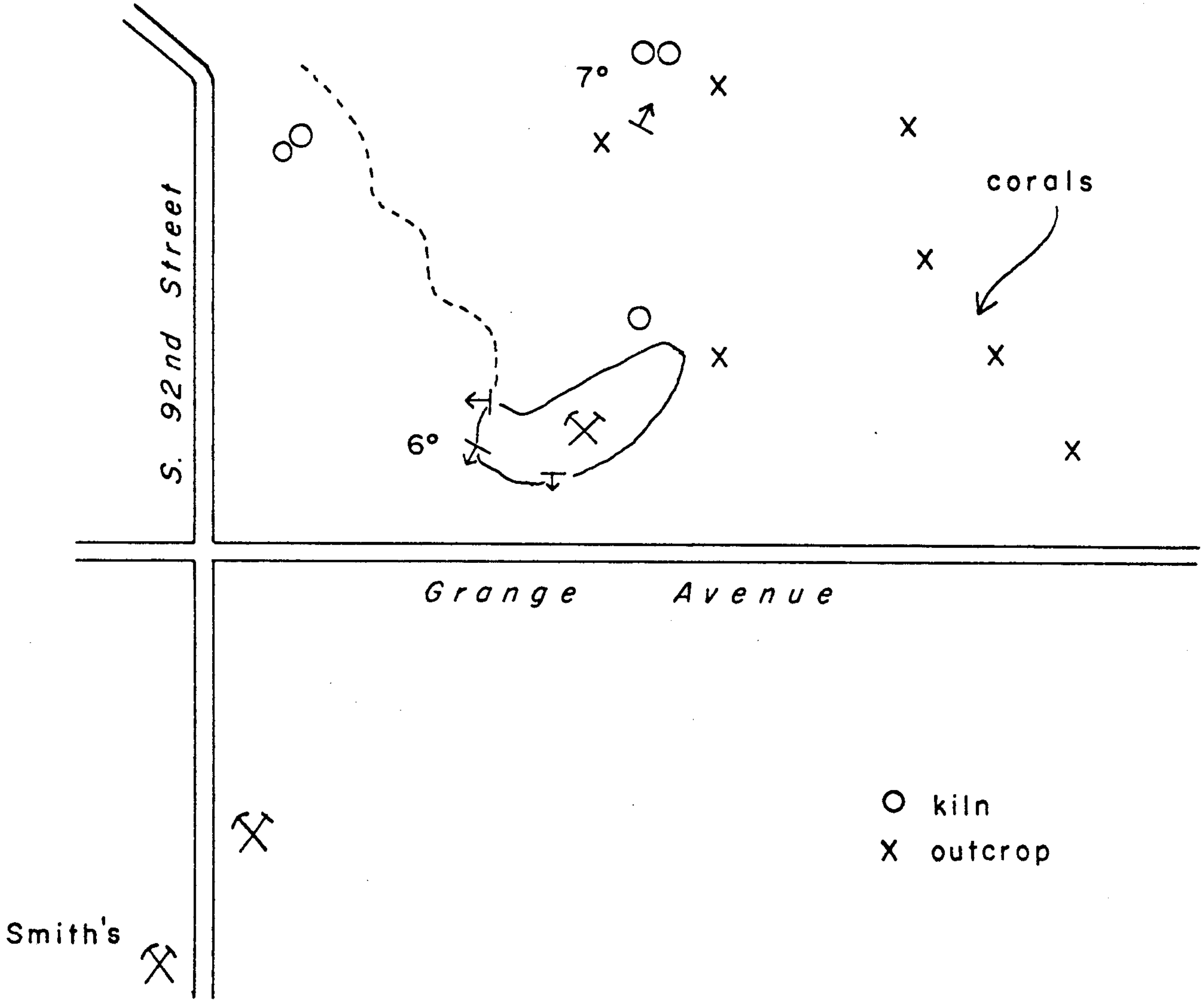

S. 92nd Street
7°
corals
6°
Grange Avenue
O kiln
X outcrop
Smith's

Figure 83

> small hole partially filled with water and rubbish has a face of about 5-7 feet of slabby porous rock similar to that just north. An old kiln stands just west of the quarry.

Some of this information was later (1939) published in his work on Wisconsin Silurian reefs.

Raasch (1940, unpublished field notes) made a detailed study of the Trimborn quarries and the surrounding exposures:

> The rock outcrops at elevation from 6-40 feet above the level of the Root River and is dominantly crystalline granular, porous, cream-buff dolomite in beds from 2 1/2 to 4 feet thick, which in weathered outcrops, breaks into slabs 2 to 5 inches thick. Locally the rock assumes a compact texture with rough cavernous interspaces. The stratification is plane, but not everywhere horizontal. Distinct dips may be observed doubtless a reflection of unseen reefs. For example, the beds the west wall of (A) dip south and somewhat to the west, along (B) the dip is northwesterly; at (D) it is markedly northerly.
>
> A small type of crinoid column is almost universally present but the common large Racine type is scarce. As usual in the detrital phase, good fossils are local in abundance, in colonial rather than biohermal aggregations. The largest numbers of specimens come from a point along the west wall of (B) at an elevation of probably 30-35 feet above the river. A. 15 feet of rock exposed above water level quarry probably not very deep. Exposure 25-40 feet above Root River. A = quarry southwest of square kiln. All detrital limestone. B. Quarry northwest of square kiln. Really a continuation of the upper part of the quarry face of A. All detrital limestone. C. A shallow quarry at the hillside kiln. Rock 30-35 feet above river; Poorly exposed, all detrital limestone. D. Quarry northwest of Curtin House (and on opposite side of road). 25-38 feet above Root River. All detrital limestone. Being worked by government; only quarry in operation. E. Reefs in field from 20-30 feet above Root River and 1/8 mile north of Curtin House. Composed of small rocky knobs composed of little else than Pyncorstylus in compact gray limestone. The westernmost of these is the higher. It summit about 30 feet above river. In many

> places the corallites are in horizontal masses indicating disturbance of the root rock before burial. F & G. Two small quarries in the detrital phase of lying east and west of the parkway, respectively, on the southwest bank of the Root River. F is 16-20 feet above river and G 6-11 feet. Exposures poor. H. Small quarry northeast of Curtin House and on opposite side of road. Detrital phase. Exposure poor; 25-28 feet above River. A very small exposure shows in the north road ditch south of the quarry. Detrital phase and same elevation.

He also described outcrops in Section 33:

> Small quarry behind Curtin House Exposures 8 feet of detrital phase of dolomite, here whiter and more vitreous than in exposures to north (Section 28). Rapidly being filled as dump. Initial dip northeast.

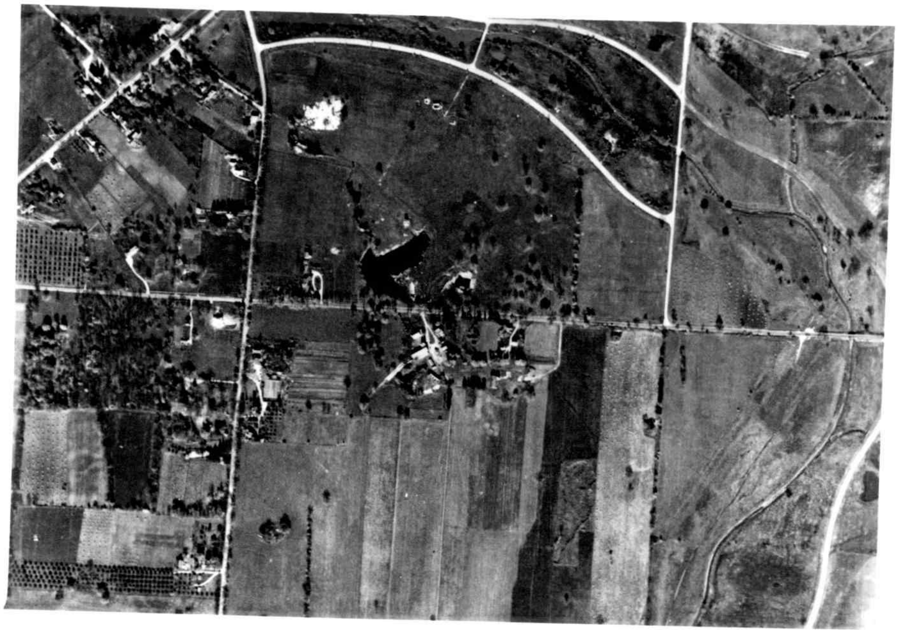
Outcrops in Section 32, NW 1/4, were also mentioned:

> Small quarry hole on west side of road at 16th corner, 1/4 south of section corners. Detrital phase of dolomite in 8 foot face now mostly obscured by dump. Est. 35-43 feet above Root River. Collected "Orthoceras." Original mold is about 16 inches long with young and deflected. Marked by numerous fine longitudinal striae; not fluted. Mold not collected. Also Orthis flabellites, Brachyprion, Zaphrentis racinensis, etc.

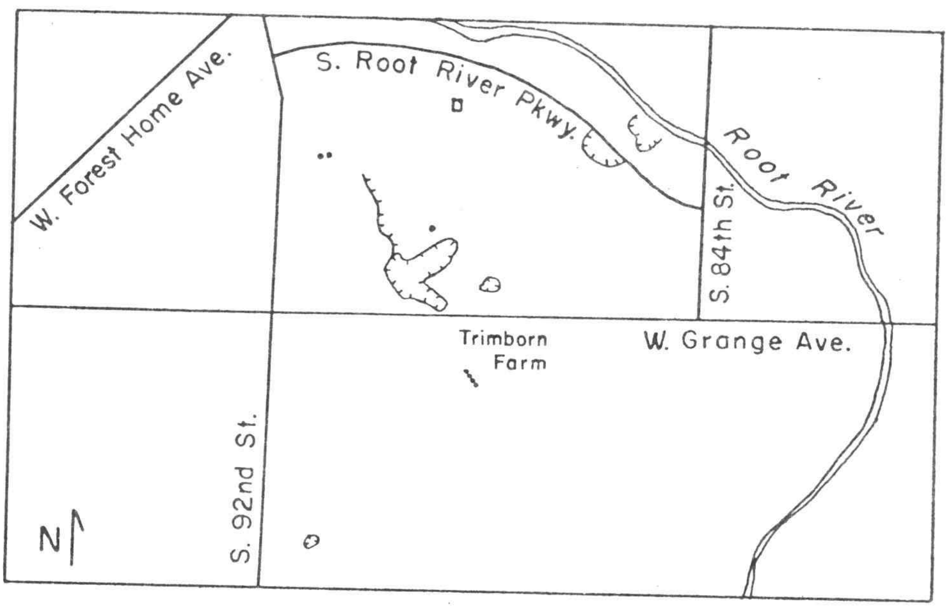
Mikulic (1977) briefly described these quarries.

In 1967 the water was pumped out of the main quarry and its lower 10 feet were visible (see Figures 84 and 85). Two small reefs were seen below the normal water-level, one in the west half of the north wall and the other in the west half of the south wall. The tops of both reefs can be located by the slightly dipping overlying beds exposed above the water-level. The flank beds of the reef along the north wall are cherty which is unusual as chert is seldom

Figure 84. Airphoto and locality map of Trimborn quarries (locality 71), Greendale, Milwaukee County. Dots indicate kilns. Airphoto from National Archives and Recores Service, General Services Administration, Washington, D.C., No. WX-1B-82; date 10-25-41.



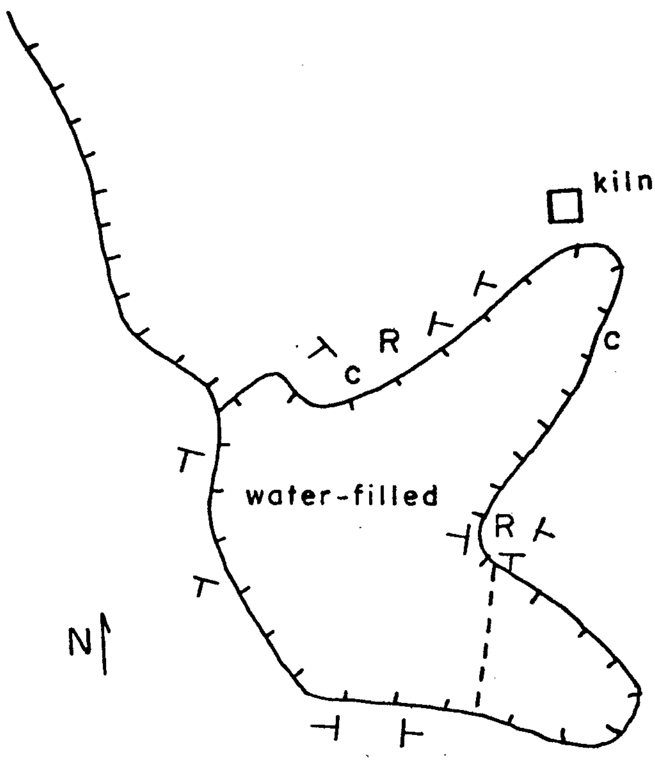
A


W. Forest Home Ave.
S. Root River Pkwy.
Root River
S. 84th St.
W. Grange Ave.
Trimborn Farm
S. 92nd St.
N

B

Figure 84

Figure 85. Diagram of the main Trimborn quarry (locality 71), showing general direction of dip of reef flank beds location of reef cores (R), and location of cherty beds (C).


kiln
c
R
c
water-filled
R
N

associated with any of the reefs in the Silurian of southeastern Wisconsin. The east half of the quarry is generally composed of horizontal or nearly horizontal, medium-bedded dolomite with some chert present near the east end of the south wall. The quarry completely refilled with water again within about a year. The west wall of the quarry is very thick-bedded, fossiliferous, porous, granular to crystalline, light buff dolomite. The beds here dip south-southwest at 10° or less. The rest of the quarry is in more medium- to thin-bedded rock.

The bedrock surface rapidly declines towards the south and east of the Trimborn Farm area. A gravel pit was formerly located southeast of the farm towards the Root River and basement foundations recently excavated in this area encountered no rock. Bedrock has been encountered in basement excavations in the NE 1/4, Section 32, and NW 1/4, Section 33, during the past twelve years.

Large fossil collections were made in the 1870's and 1880's from these quarries, most of which were collected by F. H. Day; this material is now deposited in the Greene Museum at the University of Wisconsin-Milwaukee and the Museum of Comparative Zoology, Harvard University. The highly fossiliferous nature of these exposures is reflected in the fact that Day (in Chamberlin, 1877) listed 121 different fossil species that he identified from these quarries. Additional material was also collected by G. O. Raasch in the 1940's and is now deposited in the Milwaukee Public Museum collections.

Stenopareia is the dominant illaenid trilobite found in these quarries and indicates that the reefs are no younger than Early Wenlockian (Mikulic, 1977). It is possible that the rock exposed in this area is not Racine Dolomite, but an older unit, since *Bumastus*, and not *Stenopareia*, is the type of illaenid found in known Racine Dolomite reefs.

Currently there is an effort to preserve the historic buildings on the Trimborn Farm on the south side of Grange Avenue and it is hoped that the quarries and kiln to the north of Grange Avenue will also be preserved as a historic-geologic park.

Whitnall Park
Locality 72

SE 1/4, SE 1/4, Section 32, T. 6 N., R. 21 E., Greenfield Township, Hales Corners, Milwaukee County.
MPM x32.4
elevation:

A few small exposures of massive Racine Dolomite(?) are located in the north end of Whitnall Park in Picnic Area No. 1 and in the parking lot across the road.

Hales Corners Sewer Tunnel
Locality 73

South line, Section 32, T. 6 N., R. 21 E., Greenfield Township, Hales Corners, Milwaukee County.

elevation:

This sewer tunnel was excavated in 1970-1971 along W. College Avenue between S. 92nd Street and S. 108th Street. The tunnel was 47 feet deep on the east end and 130 feet deep on the west.

Two lithologies were present, one being typical reefoidal Racine Dolomite as found around Racine and southern Milwaukee County. This rock is coarsely crystalline, porous and vuggy, pelmatozoan-rich, massive- to thick-bedded, light gray dolomite with moderate yellowish brown coloration in vugs and fossil molds giving it an overall brownish appearance. Pelmatozoan fossils consist of abundant stem sections and common calices. The following loose specimens were collected from this rock;

Caryocrinites ornata - 874
Lampterocrinus inflatus - 509
Cyathocrinus sp. - 60
Siphonocrinus sp. - 48
Callicrinus sp. - 19
Eucalypotcrinites sp. - 26
Zaphrentis racinensis - less than 10
Lindstroemia - 6
Ptychophyllum stokesi - less than 10

Rhynchonellid brachiopods and small rounded favositids were also common.

Typical Waukesha Dolomite was also excavated in this sewer tunnel, accounting for approximately half the volume of rock at the dumpsite. It is thick-bedded, non-porous, cherty, gray, poorly fossiliferous, argillaceous dolomite.

Rock from this tunnel was dumped in the west half of the parking lot of the Hales Corners Speedway between S. 108th Street and W. Forest Home Avenue in Franklin, Milwaukee County.

At the same time there were other sewer tunnels excavated in Racine and Waukesha Dolomites on the north side of the Root River along the Root River Parkway in the SW 1/4, Section 28, T. 6 N., R. 21 E., north of the Trimborn quarries.

Moody Quarry
Locality 74

SE 1/4, NW 1/4, SW 1/4, Section 30, T. 7 N., R. 22 E., Milwaukee, Milwaukee County.

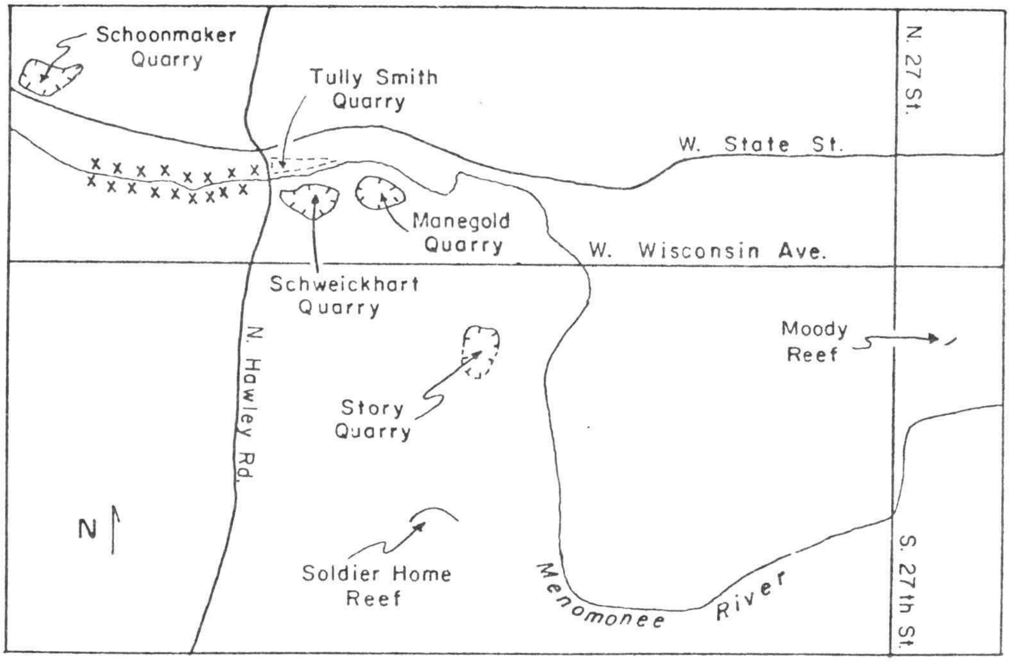
MPM x36.5

elevation: 640 feet

A quarry and outcrop was formerly exposed along the south-facing bluff of the Menomonee River valley just east of N. 25th Street, north of W. St. Paul Avenue and south of W. Clybourn Street (see Figure 86). This exposure was located approximately at the site of

Figure 86. Airphoto (A) and diagram (B) showing location of outcrops and quarries in the Menomonee River valley in the central part of Milwaukee County. Airphoto from National Archives and Records Service, General Services Administration, No. WX-1B-106, date: 10-25-41.

A


Schoonmaker
Quarry
Tully Smith
Quarry
W. State St.
N. 27 St.
Manegold
Quarry
W. Wisconsin Ave.
Schweickhart
Quarry
N. Hawley Rd.
Moody
Reef
Story
Quarry
N
Soldier Home
Reef
Menomonee River
S. 27th St.

B

Figure 86

the present median strip of Interstate Highway I-94 and extended north across the west-bound lanes of the freeway to the bluff. The cement retaining wall that extends east from N. 25th Street marks the covered portion of this exposure which remained after freeway construction.

Lapham (1836, unpublished map) indicated that there was a limestone ledge, but no quarry, approximately in the S 1/2 of center of SW 1/4, Section 30.

Walling (1850) indicated that the land west of 25th Street and south of St. Paul Avenue was owned by W. H. Moody, but no quarry or outcrop is marked in the area.

The first description of this exposure was given by T. J. Hale (1860, unpublished field notes) in his observations of a Niagara reef two miles west of Milwaukee (see Figure 87):

> This is the end of a reef cut off by blasting and exposing the stratification running over the hill; it is the end of a point of land formed by a ravine coming down to the river. It has corals and numerous *Favosites*.

An accompanying sketch of the exposure show it to be dome-shaped, giving an anticlinal appearance to the reef beds. Hale's description is particularly noteworthy in that it is the earliest record of any Milwaukee area carbonate buildup being termed a reef.

Lapham (1873, unpublished field notes) mentioned that Moody's quarry was located in the Milwaukee city limits, the rock being

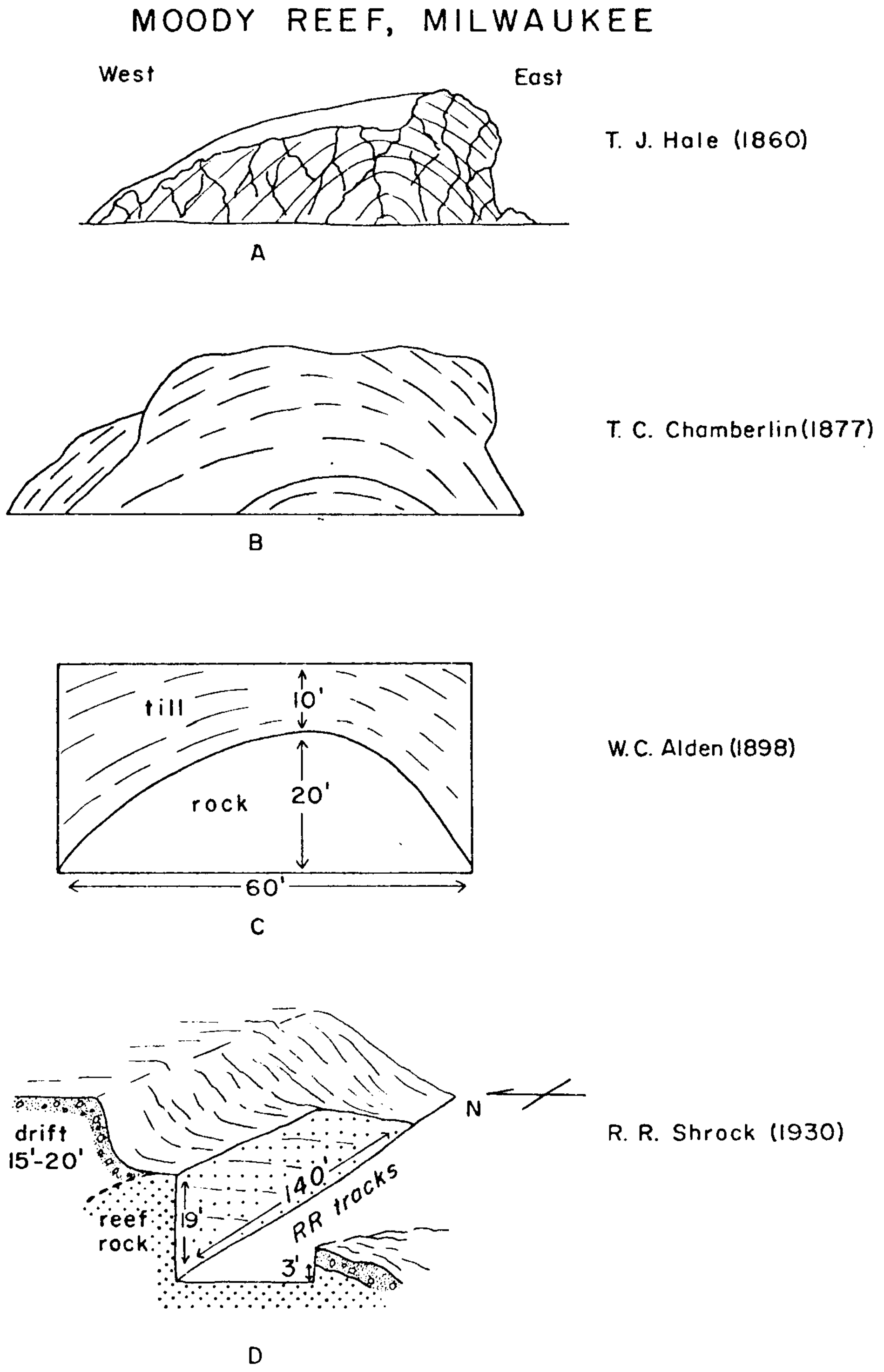


Figure 87. Sketches of the reef structure at the Moody reef (locality 74) by various authors as indicated on diagrams.

formerly burned for lime, but in disuse at the time.

Chamberlin (1877, p. 365) described Moody's quarry as being located in the 4th Ward of Milwaukee on the side of the bluff facing the Menomonee River. He considered the exposure to be a reef in the Racine Dolomite and presented a diagram (his Figure 46) showing its general appearance, similar to Hale's illustration. Chamberlin also mentioned (p. 369) that at this quarry "corals are proportionately more abundant in number of individuals."

F. H. Day (in Chamberlin, 1877, p. 371-377) listed 51 species of fossils he identified from Moody's quarry.

Correspondence between T. A. Greene and Edgar Teller, two local fossil collectors, indicates that the quarry was again active from 1881 to 1885, with most of Greene's fossils having been collected in the early part of this period. Teller made a few domments in a letter to Greene dated November 7, 1884, about the occurrence of fossils:

> I have been to 26th St. several times but outside of corals find very little of anything. They moved a large quantity of stone but owing to its being covered with clay and the moist state of the weather makes it almost impossible to see anything.

In 1898 Alden (unpublished field notes) visited the quarry and described it as follows:

> Just east of the distillery at the 27th, 28th St. in the lower bluff face is the mound of limestone. This is about

20 ft. high and 60 ft. in length east and west. Above the rock is about 8-10 ft. of buff sand and sandy clay. These are laminated and the beds curve up over the rounded surfaces of the rock. At the top the rock dips 27° to 38° in direction N. 35°-38°. In reality it dips down in every direction as far as can be seen. On the west side the rock dips 37° to south 47° to the west.

The surface of the rock on the top and east slope is well glaciated while the west surface seems not to be glaciated (only about one foot of the rock surface is exposed projecting out from the clays).

At one place a curved surface about one square yard is exposed. This is well polished and glaciated. The rock seems to drop down abruptly below the flat, and is not seen at the sides of the exposures.

The limestone is exceedingly irregular in texture and rather coarse grained. It is much broken in places but in the middle is quite solid. On the east slope the rock appears somewhat bedded at the top.

A few fossils were seen at various places but they seem to be rare...

Grabau (1903, p. 342) briefly mentioned the quarry as follows:

This old quarry (Distillery quarry) is at the foot of Twenty-ninth Street. The reef is of the same type as that of the Wauwatosa quarry, but the dips are very steep, averaging 40 degrees towards the east and west and 20 degrees or more southward.

In 1906 Alden (p. 2) published a description of this quarry based on his 1898 field work.

In a letter to Stuart Weller (July 20, 1907) Edgar Teller remarked that the 26th Street locality in Milwaukee was filled in and built over.

Later at least part of the outcrop was uncovered and exposed again in a cut on the Interurban Railroad.

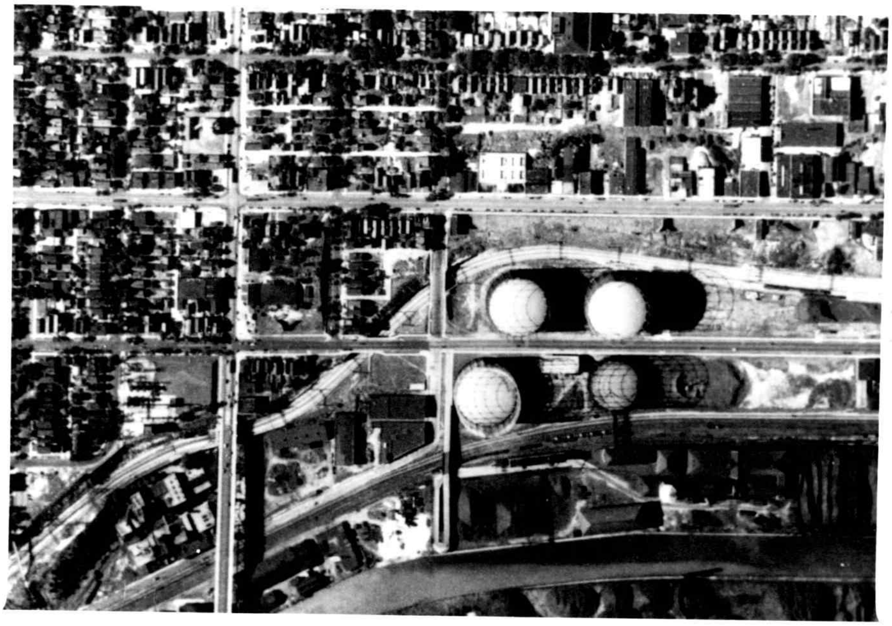
Shrock (1930, unpublished field notes) described this outcrop exposed by the railroad cut as follows:

> The north wall of the cut shows 19 feet of blue to iron-stained reefy dolomite with very irregular uneven texture and in a mound without distinct bedding. Some apparent stratification planes dip east at angle from 35°-40°, but they may not represent true stratification planes.
>
> On the south side of the tracks exposures occur of the same rock. Before the cut was made the rock surface apparently sloped rapidly toward the south.
>
> To the east the surface of the exposure rapidly dips under the drift. To the west the wall of the cut is concreted and what ever was there is now concealed.
>
> The rock is quite fossiliferous carrying corals, and and brachiopods especially.
>
> Glacial striations on east exposure south side--N. 50°E. and N. 80°E. The eastern side of the exposure is beautifully polished and striated showing that the glacier rode over the mound that must be here now beneath the drift.
>
> To the north the rock goes under a covering of 15-20 feet of gravel and till.

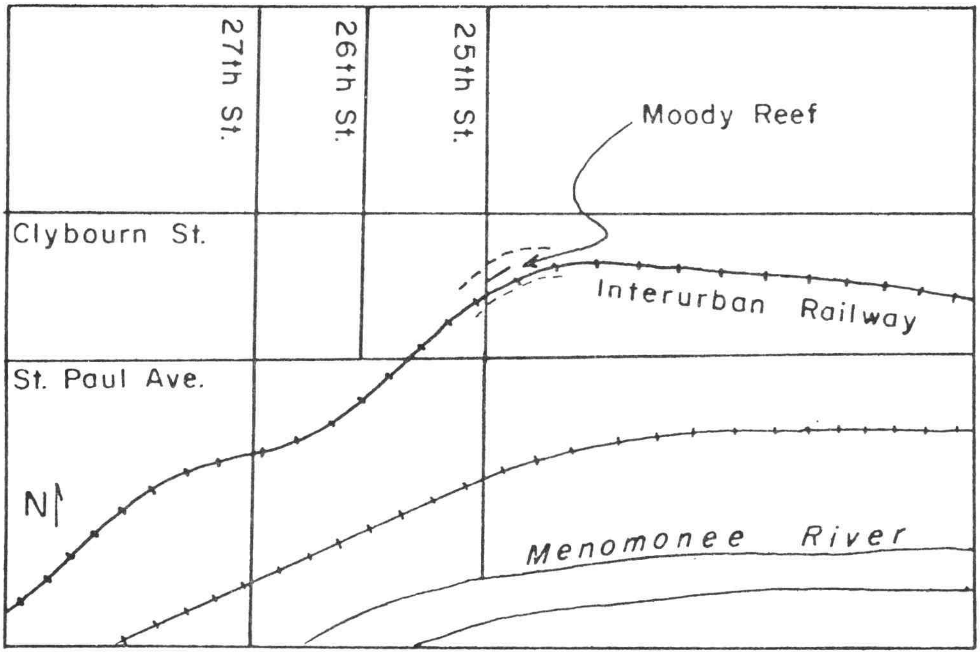
In 1939 Shrock published a brief description of this exposure based on these field notes.

There is quite a bit of variation in the location given for this quarry among these descriptions ranging from 29th Street to east of 25th Street. Local fossil collectors from the late 1800's referred to it as the 26th Street quarry or Moody's quarry and it is possible that the outcrop extended from 25th Street towards 26th Street. However, the dimensions given by Alden (1898, unpublished field notes) are much smaller than those given by Shrock (1930, unpublished field notes) and it seems unlikely that a larger outcrop was ever present. Airphotos taken in 1937 (see Figure 88) place the location of this outcrop in the position that Shrock described, being immediately east

Figure 88. Airphoto (A) and locality map (B) of the Moody Reef (locality 74), Milwaukee County. Dashed line indicates present boundaries of Interstate I-94. Airphoto from National Archives and Records Service, General Services Administration, No. WX-1B-107, date: 10-25-41.



A


27th St.
26th St.
25th St.
Moody Reef
Clybourn St.
Interurban Railway
St. Paul Ave.
N
Menomonee River

B

Figure 88

of the north end of the 25th Street bridge crossing the Interurban Railroad tracks.

Freeway construction in 1957 removed a large part of this outcrop and cemented over the remainder. In 1979 a small quantity of loose rock faunally and lithologically identical to that from the original exposure was found along 25th Street just south of the freeway during further construction.

Two large fossil collections exist from this quarry. One is the T. A. Greene collection at the University of Wisconsin-Milwaukee, and the other is the Edgar Teller collection in the National Museum of Natural History, Washington, D.C. Unfortunately, the Teller collection has been distributed among the general paleontological collections at the National Museum and can no longer be studied as a representative collection from this locality.

The Moody reef was an important exposure because of its similarity, both lithologically and paleontologically, to the Schoonmaker reef 3.75 miles west of Wauwatosa. Although detailed descriptions of this quarry are lacking the information that has been reported indicates it possessed some unique characteristics, including its peculiar anticlinal bedded appearance (as indicated by Hale, 1860, unpublished field notes; Chamberlin, 1877, and Shrock, 1930, unpublished field notes), as well as its prolific coral fauna mentioned by Hale and Chamberlin and manifested by the abundance of coral specimens in the Greene collection.

In 1926 a sewer tunnel struck bedrock at a depth of approximately 112 feet on W. Wisconsin Avenue and N. 26th Street (G. O. Raasch, 1926, unpublished field notes; MPM x36.15). The rock is similar to that from Moody's quarry and was dumped at Watertown(?) and Hawley Roads along the railroad tracks.

Soldiers' Home Reef
Locality 75

Located primarily in SW 1/4, SE 1/4, NW 1/4, NE 1/4, Section 35, T. 7 N., R. 21 E., Wauwatosa Township, Milwaukee County.
MPM x36.6
elevation: 650 feet

There is a natural outcrop in a prominent northward-facing hill just south of Milwaukee County Stadium on the northern edge of Wood Veteran Administration Center The exposure is approximately 30 to 40 feet high, 400 feet long and is covered by 30 to 40 feet of drift. While the outcrop is extensive for the area there is no record of its ever being quarried. A few vertical drill marks and parts of a concrete foundation can be seen near the middle of the outcrop but their purpose is unknown.

Chamberlin (1877, p. 365) mentioned the outcrop on the grounds of the National Military Asylum as one of three Racine Dolomite mounds in the vicinity (the others are Moody's and Schoonmaker's), and he concluded that all three were Silurian reefs (see Figure 86).

The southeast corner of the outcrop was illustrated in an 1875 lithograph of the Soldiers' Home (Beckman, 1978). The view is looking towards the north, and though drawn for its aesthetic rather than geologic qualities, shows that the rock is massive and not bedded.

Alden (1898, unpublished field notes) briefly described the outcrop as follows:

> On the north side of the hill in which the front buildings are located is a ledge of rock exposed 25-30 ft. high. The rock is here massive dolomite, gray of uneven coarse granular texture. No bedding is seen and no traces of fossils except two specimens of Orthoceras.

Bruncken (1900, p. 98-99) briefly discussed the origin of the mound and its relation to glacial activity.

Kindle visited this locality in 1904 (unpublished field notes and described the outcrops as follows:

> At northeast entrance to Soldiers Home is a large outcrop of Niagara limestone--a part of what seems to be a mound of limestone separated from above mentioned quarry by a flat plain and 1/3 mile from it. The beds appear inclined at about 45°. This limestone mound has its base at a level just above top of the Story Bros. quarry and apparently lies at same horizon as the inclined strata noted in the Bridgeport (Chicago) quarries.

In 1906 Alden (p. 2) published a description of this locality:

> One and one-fourth miles west of the mount just described, in the grounds of the National Soldiers' Home, at the bend of the Menominee (sic) Valley, the slope is marked by a prominent drift-capped mound that rises about 80 feet

> above the valley floor. On the northeast side the lower 35 to 40 feet is a vertical section of rock. How much the rock rises under the drift is not known, but a well on the flat to the east is 20 feet deep and does not reach the limestone, and the deep well at the buildings about 100 yards to the west of the slope reaches limestone at a depth of 96 feet--73 feet lower than it is exposed in the slope. This, then, appears to be a second mound, rising considerably above the surrounding rock surface. The rock here is massive gray dolomite of uneven, coarse, granular texture, showing no evidence of bedding.

Shrock (1930, unpublished field notes) visited this outcrop and made the following remarks:

> This exposure...is a partially denuded klint. It is about 300 feet in diameter. 570 feet of the base of the large mound is exposed, the other hidden beneath the drift which is 35-40 ft. thick.
>
> The rock is typical reef rock, with its obscure bedding, cavities, rough, hackly fracture and dense to granular, uneven-textured rock.
>
> On the northeast side, obscure planes of separation simulating bedding planes dip 35°-41° toward the valley in to the southeast...One cannot be certain that these planes are stratification planes, for they change from separation planes to rough, massive rock in places.

In 1939 Shrock restated some of these earlier observations.

The lithology of this reef is similar to parts of the Schoonmaker reef, but its poorly fossiliferous nature seems unusual in view of the large numbers of fossils that have been found at other nearby reefs (Moody's and Schoonmaker's). This lack of fossils probably reflects the fact that this exposure was never quarried and also the possibility that, like the Schoonmaker reef, fossil distribution is irregular and fossils are quite often rare on weathered surfaces. It is also important to note that this reef is at approximately the same elevation as the upper beds of the Story quarry and is probably stratigraphically equivalent to some of these beds, giving some indication of the stratigraphic position and relationships of these reefs to inter-reef strata. See Figure 89 for a photograph of the Soldier Home reef.

Story Brothers Quarry
Locality 76

Located primarily in S 1/2, NE 1/4, SE 1/4, Section 26, T. 7 N., R. 21 E., Wauwatosa Township, City of Milwaukee, Milwaukee County.

MPM x36. 7

elevation: 620 feet

Story Brothers quarry is a filled quarry located in the flat area south of the prominent bluff and W. Bluemound Road, west of N. 44th Street, east of Story Parkway, and just north of the interchange of Interstate Highway I-94 with U.S. Highway 41 (see Figure 86). The Highway 41 freeway runs north-south through the quarry site, the rest of which is a parking lot for Milwaukee County Stadium.

The Story quarry was the first of the Milwaukee building stone quarries to open (William Manegold, 1976, personal communication). Buckley (1898) stated that the quarry opened in 1855, but it probably

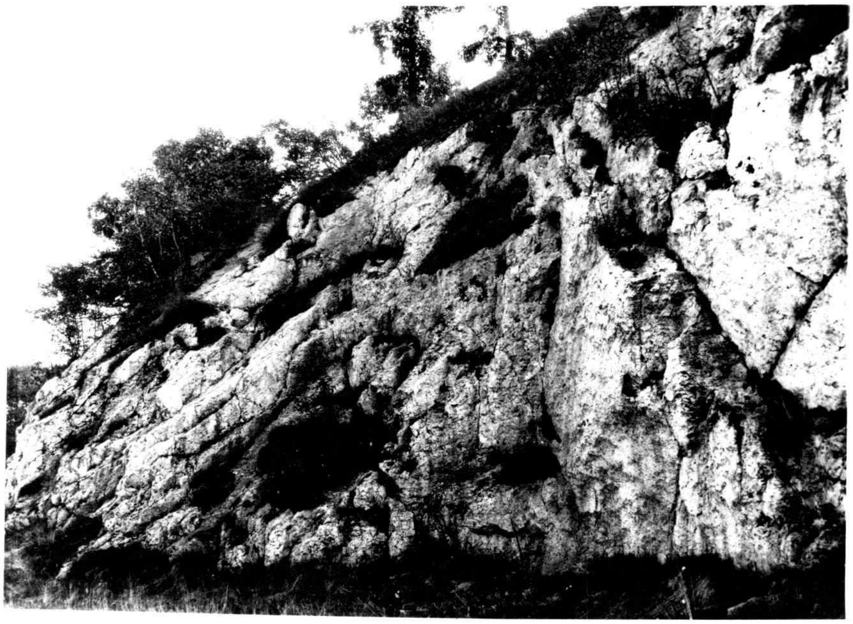


Figure 89. Photograph showing the east side of the Soldier Home reef, looking south (locality 75), Milwaukee County. Photo courtesy of the Milwaukee Public Museum, No. 47368, circa 1920's.

opened as early as the 1840's. There are a number of references to the building stone quarries in Wauwatosa or Milwaukee in early geologic reports of the area (Lapham, 1851; Percival, 1856), probably including the Story quarry, but no specific names or descriptions were given. The first actual mention of the Story quarry is made by Lapham (1874, unpublished field notes) when he discovered "evidence of lateral motion tilting thin layers" in a visit to the quarry with Chamberlin's field party.

Chamberlin (1877, p. 365, 367) briefly mentioned the Story quarry in his discussion of the Racine Dolomite He found the quarry to be in regular-bedded limestone and also mentioned that:

> ...the rock at Storey's (sic) and Schwickhart's (sic) quarries...is closely similar to that in the western part of Busack's quarry, and the same remark may be made of the fossils, which consist mainly of orthoceratites.

Buckley (1897, unpublished field notes) remarked that the three quarries in this vicinity, Story Brothers, Manegold, and Monarch Stone Company (Schweickhart), were marketing all of the stone from their quarries sold in Milwaukee County, jointly, under the name Wauwatosa Stone Company. In 1898 Buckley published a section in the Story quarry based on the building stone characteristics of the rock; he also published a photograph of the north or west wall (Plate XLII, Fig. 2). He stated that the quarry was then 102 to 104 feet deep, with beds dipping at various angles due to "sags" in the quarry floor, but the general dip was toward the south. He also observed small faults with a displacement of only a few inches in the quarry floor and having a trend of N. 50°E. He further reported that most of the trilobites (Calymene) found in the quarry came from the slightly granular upper portion of the 20 inch bed at the bottom of the quarry. He also made the following observations:

> Upper beds are somewhat broken up by weathering. Stripping--to north 30 feet; south and east 5 to 20 feet. The faulting in floor of quarry is along crest and sides of one of the low arches as seen in quarry. The next to the lowest floor shows an uneven rolling surface. In one place a ridge is observed running across the quarry in which the bed is a foot or a foot and a half thicker than elsewhere.

Alden (1898, unpublished field notes) gave the following section for the Story quarry (see also Figure 90):

Section of strata beginning at bottom:

1. Solid even-textured gray dolomite . . . . . . 19 in.
2. Very irregular textured limestone split surfaces being all knobs and hollows of 1 in. elevation . . . . 26 in.
3. Solid, even-textured, taken out in various thicknesses . . . . 66 in.
4. Three layers in places are mostly even-textured with 6-8 in. of rather irregular texture through middle . . . . 42 in.
5. Three layers of quite even texture, in places slightly porous, in places with considerable pyrite coating surfaces of the joints . . . . . 44 in.

These 5 constitute the section of the third or lowest level of the quarry so far as seen fossils are rare (-16 ft. 5 in).

There is a narrow flexure in the top layer of (5) running across the floor of 2nd level of quarry in a general direction E. 25°S. giving a slight fold about 2 ft. high and 40± ft. wide.

6. Rather coarse granular layers pinching out toward center of quarry. . . . . 26-0 in.

7. The section of this second level in middle of quarry is largely less solid limestone with seams of blue clay and blue shale running in between. There are also rounded pockets where the rock seems to have disintegrated to blue clay. This produces sags in the strata. In places this blue clay and shale is highly impregnated with pyrite. Mr. Story says there seems to be a tendency for the coarse granular limestone to pinch out where this clay and shale come in. There are 5 or 6 layers in this section on north and south sides of the quarry the rock seems firmer and less of clay and shale comes in between strata than in middle. -18 ft. Where this clay and shale come in below there are sags in the main floor (39 ft. from bottom). This causes nearly parallel joints in direction S. 50°E. Some of these extend clear across the quarry in remarkable straight lines.

8. Above this main floor comes a heavy even textured course. The top of this course dips 14° E. 3°S as near as can be measured . . . . 5 ft. 9 in.

9. Even grained with one seam 1 ft. from bottom . . . . 7 ft. 3 in.

10. Another coarse granular stratum. This thins out to about 6 in. towards SE which here is a sag . . . . 26 in.

11. Inclines to split into thin layers with rather irregular surfaces with delicate seams of blue clay between . . . . 1 ft. 4 in.

12. Same splitting and clay seams at bottom course taking in delicate pink purple tint . . . . 39 in.

13.	Heavy, even textured coarse, largely well colored with purple tine	5 ft.
14.	Quite even textured coarse, somewhat purple tinted at bottom usually in 2 courses	6 ft.
15.	Coarse granular rock. This on north side is about level with top of quarry at southeast corner	16 in.
16.	3-4 courses of quite even-textured limestone	4 ft. 6 in.
17.	Runs more irregular in grain, inclined to split into 2-3 in. layers	5 ft.
18.	Coarse grained, irregular limestone	2-3 ft.
19.	Rather uneven splitting, thin	1 ft. 6 in.
20.	Coarse granular	3 ft. 4 in.
	Derrick level north side	
21.	Quite even texture	4 ft.
22.	With two coarse granular streaks	5 ft.
23.	5 courses with four coarse streaks	7 ft. ±
24.	4 courses under clays and gravels	5 ft.

Rock at northwest side of quarry under the clays and gravels is nearly 30 ft. higher than at the southeast side under the till. Upper 3 ft. of 24 is coarse, granular, breaks into irregular fragments rather irregular layers.

In addition, Alden described a water well at Mr. Story's house on the bluff to the north of the quarry at an elevation of approximately 680 feet:

Drift	70 feet
elevation of top of Silurian	610 feet
thickness of Silurian	425 feet
top of Maquoketa Shale	185 feet
thickness of Maquoketa Shale	175 feet

However, Alden suspected that this log was inaccurate. The Miller Bewing Company well at Plank Road and 39th Street, about one-half mile northwest of the Story well, at an elevation of 650 feet shows the following section:

thickness of drift	40 feet
elevation of top of Silurian	610 feet
thickness of Silurian	340 feet
elevation of Maquoketa Shale	270 feet
thickness of Maquoketa Shale	160 feet

The thicknesses in this well more closely resemble those from other wells in the vicinity and is probably more accurate than the Story well.

Bruncken (1900, p. 98-99) discussed the glacially-controlled features of the bedrock surface of the Story Brothers quarry, remarking that it formed a low dome that rose towards the west.

In 1904 Kindle (unpublished field notes) visited the quarry and made the following observations:

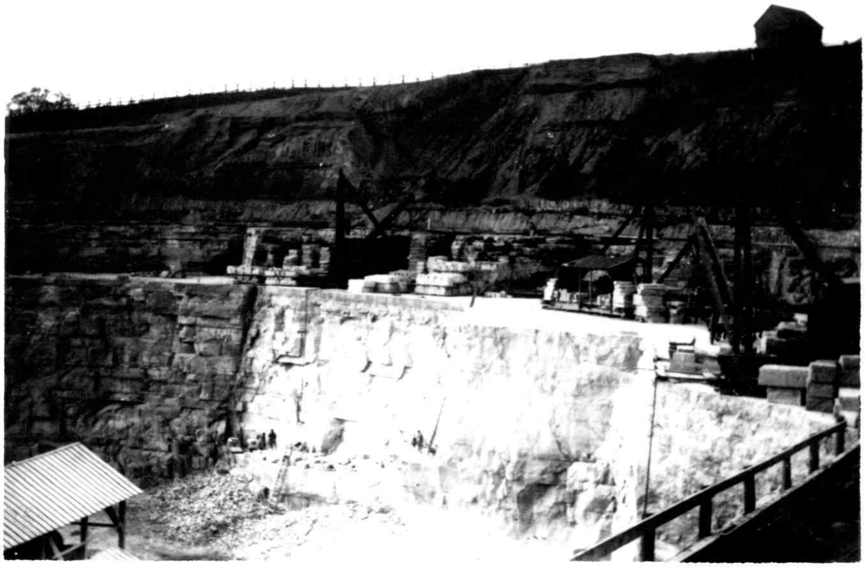


Figure 90. Photograph of the north face of the Story quarry, looking north (locality 76). Photo by W. C. Alden, 1899, No. 114. Photo from U.S. Geological Survey Photographic Library, Denver.

> Northeast of Soldiers Home 1/3 of mile the Niagara limestone is quarried extensively for building stone and for crushed rock for cement. The beds have been quarried to a depth of about 90 feet. The limestone is a light gray (magnesium), very evenly bedded rock usually in strata 8 in.-6 ft. thick. Fossils very scarce.

Alden (1906, p. 2) published a number of his observations on the Story quarry as part of a general description of the Menomonee River valley quarries between Milwaukee and Wawatosa. He showed the location of this quarry on his Areal Geology Map, as well as that of the two wells previously discussed from his 1898 field notes. He found the stone in these quarries to be "distinctly bedded in regular courses, which thicken from the top downward, the thicknesses ranging from 4 to 28 inches." He also stated that the beds alternated between fine- and coarse-grained strata, describing this feature as follows:

> The finer-grained strata are of compact texture, with conchoidal fracture. Alternating with these are beds of more or less irregular, coarse, granular, or lumpy texture. The rock of these beds is peculiar. Under the hammer it breaks into angular lumps or granules, varying size from that of a pea to that of a hazel nut. In some layers a rather loose buff calcareous material fills the interstices between the harder granules. On weathering this filling dissolves, leaving an irregular, open texture. Other layers show an irregular, semilaminate structure, and in these, when the rock is split into building blocks, the bedding surfaces are curiously uneven, with small, irregular knobs and hollows, the knobs having about 1 inch relief. These strata are very hard and do not break readily across the planes of stratification. There are five or six beds of this character in the quarry sections. Between two layers of this kind are several strata of the even-textured, fine-grained rock. Throughout the greater part of the

> formation these different kinds of rocks are arranged in distinct strata, yet at some horizons there are gradations from one type to the other within a single stratum. In some places a thin layer of the coarse, irregular-textured rock runs through the middle of a fine-grained, even-textured stratum with gradations upward and downward. At the quarry of the Story Brothers the coarse-textured layers here and there pinch out laterally and are replaced by soft blue clay.

He also mentioned a distinctive coloration:

> In the quarries of the Monarch Stone Company and of the Story Brothers several courses exposed between the depths of 45 and 60 feet from the surface are mottled with a pink or purplish tint, attributed to the weathering of occastional crystals of iron pyrite.

Buckley (1897, unpublished field notes; 1898) also mentioned these purplish-red beds, and two samples of these beds from the Story quarry are reposited in the Green Museum, University of Wisconsin-Milwaukee. These should not be confused with the Brandon Bridge beds. Alden also reported that:

> In the lower part of Story Brothers' quarry, where the uneven-textured layers pinch out and are replaced by thin beds of soft bluish shaly material, there are other layers of impure argillaceous rock that runs into seams and pockets of soft blue clayey shale. This is highly impregnat ed with iron pyrites. Where these pockets occur the overlying limestone strata have sagged so as to produce fractures.

In 1918 Alden (p. 91-92) summarized parts of his 1906 descriptions.

During the 1920's Ira Edwards measured a section in the Story quarry (G. O. Raasch, 1973, personal communication) and collected rock samples from various beds. The rock samples (MPM Nos.

12627-12639) are in the Milwaukee Public Museum collection, but Edwards' notes have not yet been located.

Shrock (1930, unpublished field notes) measured an 125 foot section in the quarry and described the rock types as follows (see Figure 90 for section):

> Lithology A. Massive, heavy-bedded, gray to white-colored, dense, compact earthy dolomite breaking with smooth, conchoidal fracture. The individual beds separate into thinner units on weathering, and break into angular slabs. Change to buff color when weathered.
>
> Lithology B. Same as A but lavender-colored.
>
> Lithology C. Dense, gray, earthy to slightly crystalline, thin, irregularly bedded dolomite with thin, wavy shale films between the layers. Layers vary from 2 in. - 6 in. in thickness. Fracture is irregular, rarely semi-conchoidal.
>
> Lithology D. Mottled buff and chocolate-colored brecciated dolomite, consisting of angular fragments of gray, dense, crystalline dolomite cemented with a chocolate-colored matrix. Laterally these beds pinch out and a thin shale layer marks the contact between the underlying and overlying beds; the latter of which has thickened to take the place of the brecciated bed. In such cases the shale pockets seem to be over slight ridges and the overlying rocks are sagged down where the shale pocket occurs. Shale pockets also occur in such an association above the place of the brecciated layer within the overlying bed. The shale is a blue to gray, very thinly laminated, gritty (sometimes) rock. Sometimes thin layers of quartz sand occur with the shale pockets. The zones characterized by the shale pockets are quite wavy or billowy, and may represent erosion surfaces.

During the 1930's the quarry was abandoned and used as a garbage dump by the City of Milwaukee and there are currently no

STORY BROTHERS QUARRY, MILWAUKEE

modified from Shrock (1930)

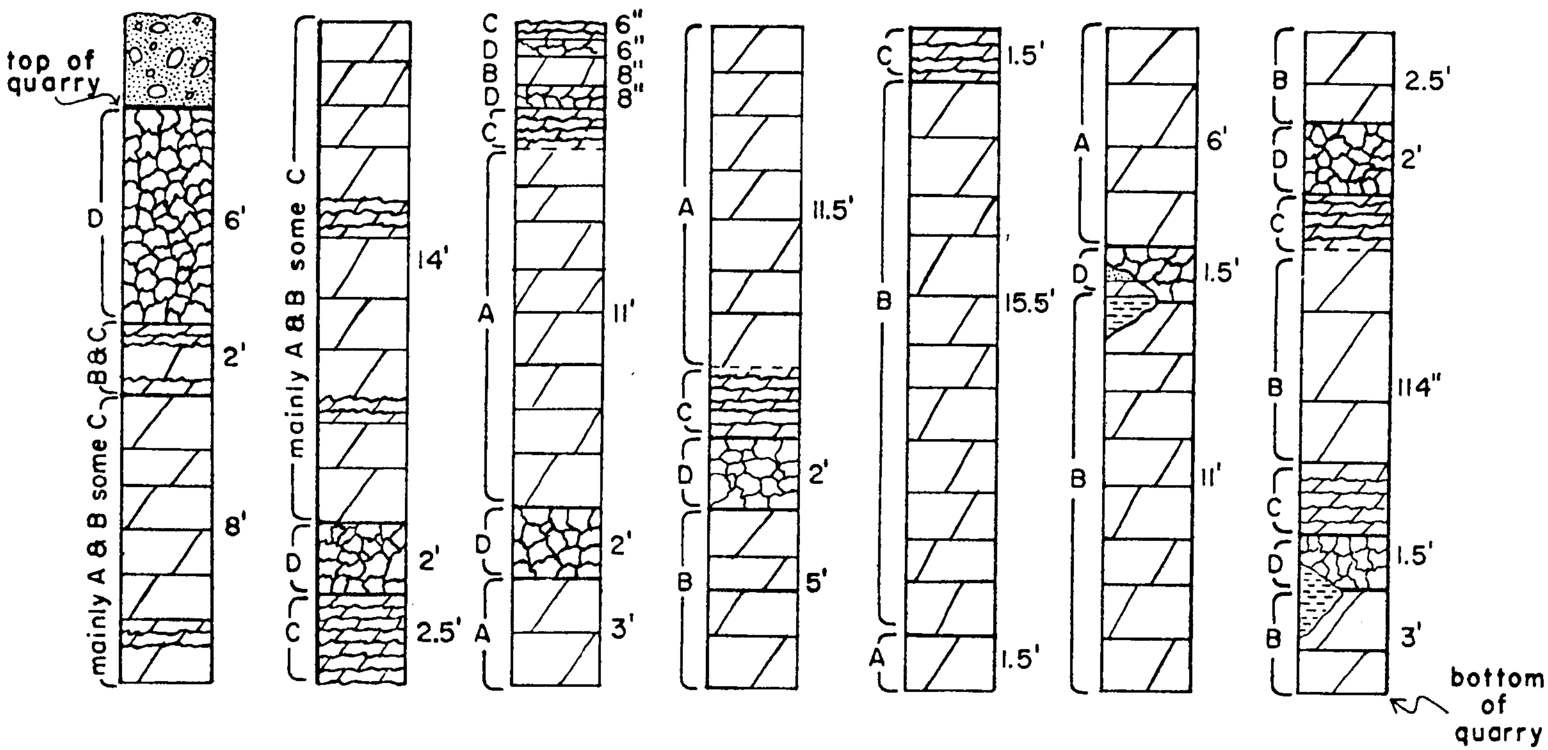


Figure 91. Section in the Story quarry (locality 76) Milwaukee County (after Shrock, 1930, unpublished field notes). See text for details.

exposures at this site.

An examination of fossils in the Greene collection reveals that the following taxa were found in the quar ry during the 1880's and early 1890's:

Flexicalymene celebra (complete specimens) - 104
Dalmanites sp. (thorax and pygidium) - 1
Illaenoides sp. (cranidium) - 1
Sphaerexochus sp. (cranidium) - 1
bumastid (pygidia) - 3
Encrinurus sp. - 1
Dawsonoceras sp. - 46
Phragmoceras sp. - 4
cephalopods (orthocones and Phragmoceras) - 81
"Pleurotomaria perlata" - 7
brachiopods - 6
small rugose corals - 2

This collection is similar, both in composition and lithology, to that of the "Trilobite Beds" in the Hartung and Zimmerman quarries except for the low abundance and diversity of brachiopods.

Manegold Quarry
Locality 77

SW 1/4, NE 1/4, and SE 1/4, NW 1/4, Section 26, T. 7 N., R. 21 E., Wauwatosa Township, City of Milwaukee, Milwaukee County.

MPM x 36.8

elevation: 640 feet

This filled quarry (see Figure 86) is located along a northward-facing bluff between W. Wells Street and the Menomonee River, and between N. 49th and N. 52nd Streets (if these streets were continuous across this area).

The quarry was opened in 1873 by the Manegold family (William Manegold, 1976, personal communication). The original pit (see Figure 92) was located in the northeast corner of the property and was expanded primarily south and west. The pit was used mainly as a building stone quarry in its early years of operation, as were the nearby Story and Schweickhart quarries, but produced primarily crushed stone throughout most of the 1900's.

The approximate location of the quarry is shown on an 1892 lithograph entitled "Wauwatosa and the Western Suburbs of Milwaukee" illustrated in Beckman (1978).

Buckley (1897, unpublished field notes) examined the quarry when it was approximately 55 feet deep and observed that about six feet of drift was stripped from the south side. He found the quarry to be working towards the north and southwest. In 1898 Buckley briefly mentioned the quarry in a general discussion of the building stone industry of this area. He also published a photograph of the east wall (1898, Plate XLII, no. 1).

Alden (1898, unpublished field notes) described the quarry as being 55 feet deep showing "evenly bedded, nearly horizontal dolomitic limestone." He also noted that there were alternating even-grained and granular beds in the section; the even-grained beds being "dense,

Figure 92. Photographs of the Manegold quarry (locality 77) from the late 1800's. (A) Steropticon view looking east towards quarry, circa 1870's; original Miller Brewery is on hill in distance; (B) shows northeast wall of quarry, circa 1890's. Photos courtesy of William Manegold, Wauwatosa, Wisconsin.

A

B

Figure 92

hard, blue gray dolomite limestone becoming of finer grain at the bottom of the pit" with beds up to three feet thick. "The granular courses are of peculiar composition breaking up into angular fragments under the hammer. The beds are quite hard. The beds dip slightly NE 2-3° but are nearly horizontal and very little fractured." Alden (1906, p. 2) mentioned this quarry in his discussion including the Story and Schweickhart quarries (see Story Quarry discussion) and indicated its location on his Areal Geology Map.

In 1914 Ulrich (unpublished field notes) visited the quarry and described an 84 foot section (see Figure 93) and noted that:

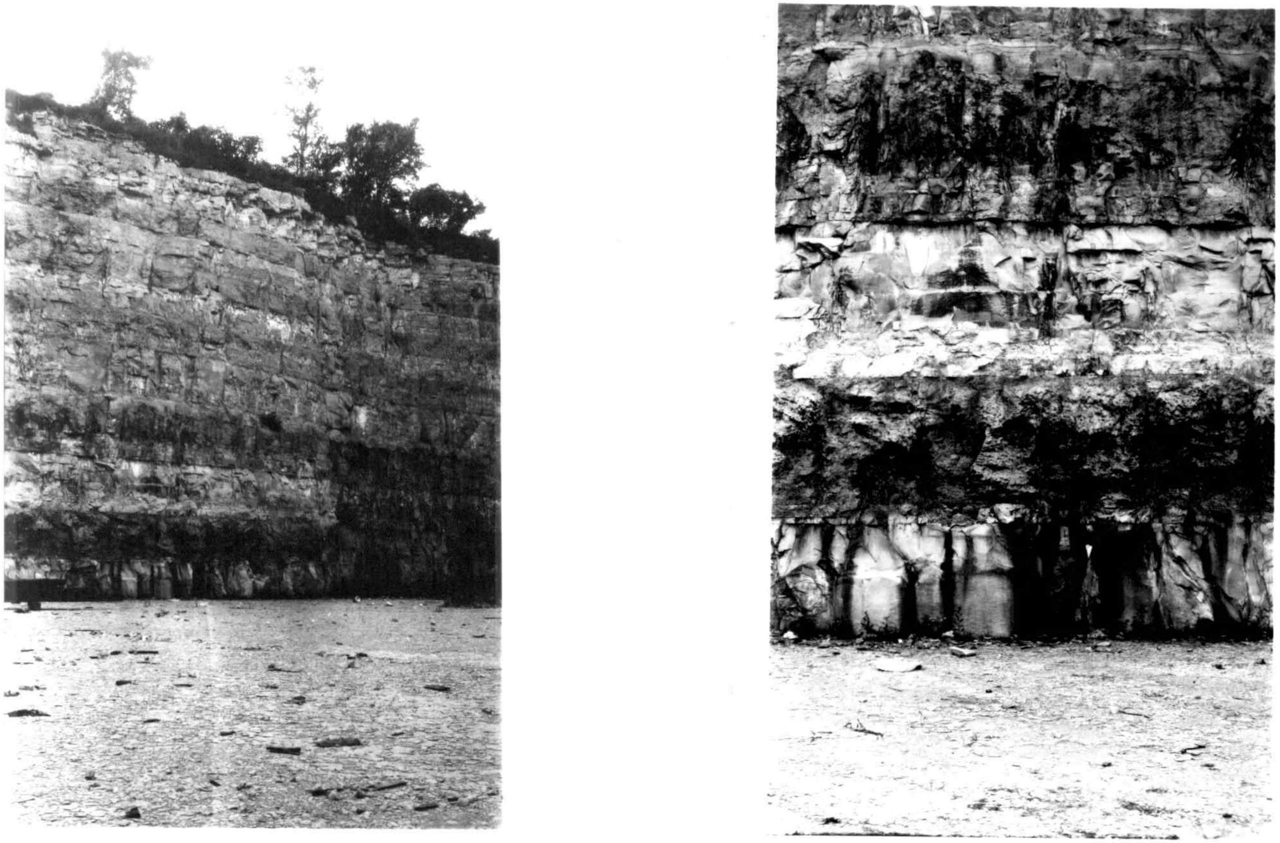
> Fossils are very rare in this quarry. Except fucoids practically none in the light gray beds. The darker cavernous layers have a few.

Alden (1918, p. 204) described the glacial features of the quarry site.

Shrock (1930, 1931, unpublished field notes) gave the following section (See Figures 94 and 95) for this quarry measured upward from the sump:

> Bed 1a. Two feet of gray, dense, argillaceous dolomite like Bed 1 above.
>
> Bed 1b. Three feet of massive, nodular dolomite like Bed 2.
>
> Bed 1. 13.5 feet of very light colored, dense, compact colomite which breaks with conchoidal fracture. Heavy beds 1 1/2 - 3 feet thick which break into thinner units. (The lower) part of the section... is somewhat crystalline and more thinly bedded with the separation planes

Figure 93. Photographs of the Manegold quarry (locality 77) circa 1914. (A) shows entire section of 84 feet; (B) close-up of lower layers. Note contrast between fine-grained, even-bedded building stone layers and coarse-grained, massive, nodular dolomite. Photos by Ulrich, deposited in the Wisconsin Geological Survey, Nos. 764 (A) and 763 (B).



A B

Figure 93

Figure 94. Section in the Manegold quarry (locality 77), Milwaukee county (after Shrock, 1930-31, unpublished field notes). See text for details.

MANEGOLD STONE CO. QUARRY, MILWAUKEE

modified from Shrock (1930-31)

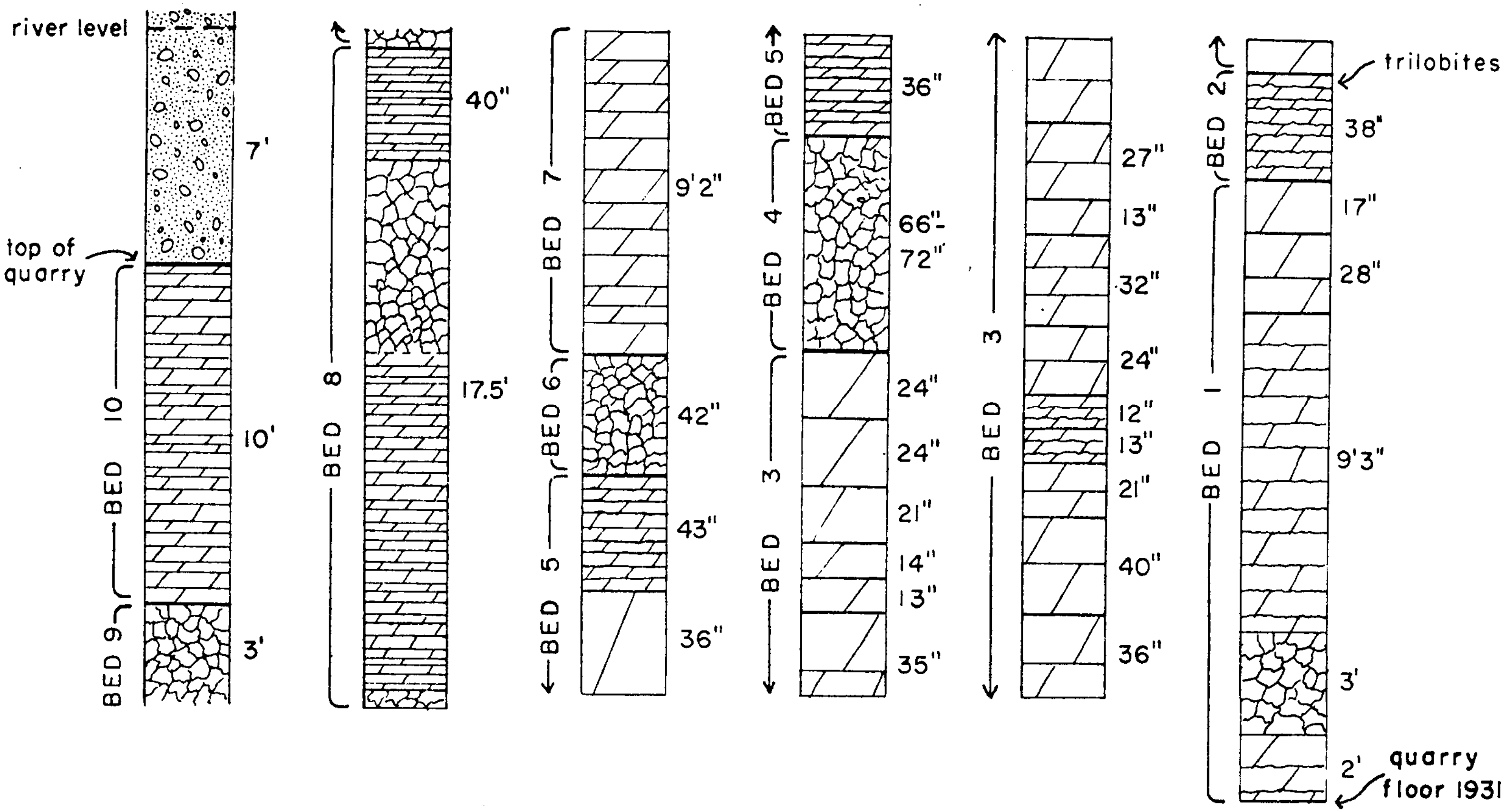


Figure 94

Figure 95. Photograph of northeast corner of the Manegold quarry (locality 77), Milwaukee County, circa late 1930's. Photo courtesy of William Manegold, Wauwatosa, Wisconsin.

slightly irregular and with very thin shale films between the layers.

Bed 2. Gray crystalline dolomite, somewhat porous, in thin irregular layers separated by very thin wavy shale films. Shale blue. Breaks into flaggy beds averaging 2-3 in. thick. Contains numerous cephalopods of the orthoceratite type. Lower 16 in. pinkish and brecciated... In Bed 2 near the top there is a trilobite layer where several dozen specimens were seen. The rock is shaly and the forms not so well preserved. The lower 16 in. is quite granitey looking. (Bed 2 is 38 inches thick.)

Bed 3. Approximately 19 feet of buff to light gray dense compact earthy dolomite which exhibits good conchoidal fracture. Heavy bedded, with the beds breaking into thinner units. The 13 in. and 12 in. layers are more flaggy and separate into thin wavy beds with thin shale films between.

Bed 4. Approximately 6 feet of nodular-looking, bluish gray, crystalline dolomite in thin irregular layers. This rock seems to be a breccia, composed of angular fragments of bluish-gray, crystalline dolomite, cemented with buff earthy dolomite. Breaks with hackly fracture and is conspicuous in the quarry wall because of its rough looking surface.

Bed 5. 9 ft. 7 in. bed of light-colored, light weathering dense, compact dolomite with conchoidal fracture, with beds averaging about 4 in. thick. One bed in the middle is more massive.

Bed 6. Approximately 42 inches of cream-colored, semi-saccharoidal, brecciated dolomite, which on weathering breaks into small irregularly-shaped nodules. Varies from 42-72 in. in parts of the quarry.

Bed 7. 9 ft. 2 in. of bluish-gray, dense, fine-grained, compact dolomite with conchoidal fracture. Beds average 6-12 in. thick. The rock weathers into thin platy slabs and stands out conspicuously in contrast to the rough bed below and the hackly bed above.

Bed 8. 17.5 feet of dark gray, dense compact dolomite which separates into layers averaging 2-4 in. thick and exhibits hackly splintery fracture. Contains one or more brecciated layers like 4 and 6.

Bed 9. Three feet of cream-colored, semi-saccharoidal dolomite which breaks into nodular fragments on weathering. Similar to bed 6. Sometimes also tinged a salmon color.

Bed 10. Ten feet of bluish-gray, dense compact dolomite similar to bed 8. Weathers into thin layers (2-6 in.) with hackly surface.

Shrock also observed a number of shale pockets along the west side of the quarry:

> ...much like those found associated with a similar granitey-looking rock at Story's and at Francey's. The beds are just a bit undulatory and along this zone there has apparently been a bit of solution. Near the sump (northeast) there seems to have been a little faulting with a displacement of several inches.

He also noted that only the lower beds of the quarry were being worked for crushed rock and that the quarry was about 100 feet deep.

Burpee (1932) processed rock samples collected by Shrock for insoluble residues and found the following (bed numbers refer to Shrock's section):

Bed 1a. Silicified oolites and brachiopod tests.

Bed 1b. Brachiopod tests of drusy quartz, sponge spicules of quartz.

Bed 1 lower (massive, gray, crystalline dolomite). Brachiopod tests of drusy quartz, sponge spicules of quartz.

Bed 1 upper (very dense, gray, fine textured dolomite). A quantity of fine quartz.

Bed 2. Crystalline quartz and doloclastic chert.

Bed 3. A large quantity of fine, crystalline quartz.

Bed 4. Crystalline quartz, which is coarser than usual and rhombohedral.

Bed 5. A white residue with crystalline quartz and fossil material.

Bed 6. Brachiopod fragments, sponge spicules, and quartz.

Bed 7. A large quantity of crystalline quartz.

Bed 8. A large quantity of fine crystalline quartz with sponge spicules.

Bed 9. Not tested as it was not collected due to its inaccessibility.

Bed 10. A large quantity of fine crystalline quartz with sponge spicules.

William Manegold (1968, 1976, personal communication) has supplied the following information concerning his quarry. The quarry ceased operation in 1956 and was completely filled by the early 1970's. The quarry had reached a maximum depth of 155 feet and was being worked in abundantly cherty rock in 1956. The bedrock surface was seven feet below river level and was 20 feet lower than the highest exposure at Schweickhart's quarry to the west. Cephalopods were most common near the top of the quarry and some were even observed on the glacially striated surface; a number of specimens collected by Manegold were given to the Milwaukee Public Museum in 1968. By 1963 the only major exposure was along the upper part of the east wall, however, in 1966 a five foot section was measured in the west half of the north wall as follows:

Layer 1. Top. 1.5 feet of light brown, fine-grained dolomite weathering buff, stylolitic bedding planes, glacial striae on surface.

Layer 2. 1.5 feet of nodular, fine-grained, light gray dolomite with very irregular bedding.

Layer 3. 2 feet of light gray, regular-bedded, fine-grained dolomite.

Samples from this section are housed in the Milwaukee Public Museum collections. A large area of the bedrock surface was still exposed with glacial striae trending to the southwest.

Schweickhart Quarry
Locality 78

N 1/2, SE 1/4, NW 1/4, Section 26, T. 7 N., R. 21 E., Wauwatosa Township, City of Milwaukee, Milwaukee County.

MPM x36.9

elevation: 650 feet

This is a filled quarry located along a northward-facing bluff between W. Wells Street and the Menomonee River and N. Hawley Road and the Manegold quarry (see Figure 86).

The quarry was first operated by Hiram T. Rose (Western Historical Company, 1881). Lapham (1873, unpublished field notes) stated that the quarry was first operated by a Mr. Ross (Rose?), and that then a Mr. Chare ran it before it was operated by Schweickhart and Hart. Schweickhart and Hart bought the quarry from J. Hart in 1868 and Manegold succeeded Hart in 1875 (Western Historical Company, 1881). This quarry produced primarily building stone.

In his discussion of the Racine Dolomite Chamberlin (1877, p. 367) briefly mentioned that the rock here was "closely similar" to the rock at Story's and the western part of Busack's quarry. The fossils he found were mostly orthoceratite cephalopods The Greene collection at the University of Wisconsin-Milwaukee contains only a few fossils from Schweickhart's quarry collected in the 1880's and early 1890's, one being the characteristic gastropod of the area, Pleurotomaria perlata, and another the cephalopod, Dawsonoceras sp.

An 1892 lithograph illustrated in Beckman (1978) shows the location of the Schweickhart quarry along Hawley Road in a view of Wauwatosa and the western suburbs of Milwaukee.

Buckley (1897, unpublished field notes) described this quarry as being operated by the Monarch Stone Company, stating that three to eight feet of dirt had been stripped from the surface He mentioned this quarry again in 1898 in his discussion of building stone.

Alden (1898, unpublished field notes) visited this quarry (see

Figure 96) and, in particular, observed that the coarse granular layers like those in the Manegold quarry "split with uneven surface of sharp irregularities. Contain often Calcite and pyrite." He presented the following section:

	Coarse granular, streaks, rather coarse splitting with irregular surface	4 feet
	Quite even but splitting	1 ft. 6 in.
6)	Finer below becoming very coarse granular	3 ft.
	Even grain	10 in.
	Even grain, splitting	3 ft.
	Less irregular than below	1 ft. 3 in.
	Very coarse granular	3 ft.
	Even grain splitting below	8 in.
	Even grain	1 ft.
	Coarse granular	3 in.
	Even grain	10 in.
5)	Very coarse granular, at top finer	5 ft.
	Even	2 ft.
	Even, but coarse through middle	2 ft.
4)	Even below, coarse granular above, irregular	2 ft 6 in.
	More even, coarser above	1 ft

Figure 96. Photograph of the southeast corner of the Schweickert quarry (locality 78), Milwaukee County. Photo by W. C. Alden, No. 114, 1899. Photo from U.S. Geological Survey Photographic Library, Denver.

3) Coarse irregular	1 ft. 4 in.
Dense, even grain, gray	2 ft. 6 in.
Dense, even grain, gray	3 ft.
Dense, even grain, gray	2 ft. 6 in.
2) Coarse granular	2 ft. 6 in.
Coarse granular	1 ft. 4 in.
Coarse granular	8 in.
Coarse granular	3 ft.
Coarse granular	4 in.
Coarse granular	2 ft.
Coarse granular	5 in.
Coarse granular	1 ft.
(All of 2 is largely pinkish in color, mottled or evenly, and penetrated by small pyritized lines like wormholes)	
1) Coarse granular	5 ft. 6 in.
Even grain	5 ft.
Even grain	1 ft.
Even grain, fine gray to pinkish	5 ft.
Water	67± ft.

In 1906 Alden (p. 2) published a description of this quarry in conjunction with the Story and Manegold quarries (see discussion under Story Quarry for details). He (1906, Fig. 12) presented a photograph of the southeast corner of the Schweickhart quarry, and also indicated its approximate location on his Areal Geology Map. Alden (1918, p. 90-92) gave a similar summary of these quarries and reproduced this same photograph (Pl. XII, Fig. A).

Kindle (1904, unpublished field notes) mentioned that:

> The Monarch Stone Co. has a quarry east of Castalia Park 1/4 mile in west part of city. Rock similar to that of the Story Bros. quarry. Used for building stone and crushed for cement. Has been quarried to a depth of about 60 feet.

The quarry was operated by the Monarch Stone Company from the date of purchase in 1891 until it ceased operations in 1914. When it closed the quarry was approximately 98 feet deep; it rapidly filled with water after its abandonment.

Shrock (1930, unpublished field notes) briefly described the rocks exposed above the water level in the quarry (see Figure 97). He found at the north side only a foot of rock exposed, but 10 to 15 feet was exposed along the south wall. He indicated that the rock was the same type as that exposed in the Manegold quarry to the east. Along the east side of the south wall he found the rock dipping steeply 5° to the northeast, and flattening out towards the north. Near the center of the quarry he observed that the rocks dipped towards the northwest about 3° and then flattened out. Shrock suggested that a reef may have been present in the southeast.

In the 1930's the quarry was purchased by the City of Milwaukee and was used as a landfill site until the late 1960's.

Figure 97. Section of rock exposed above water level in the Schweickhart quarry (locality 78) Milwaukee County and diagram showing general dip of beds along south wall of quarry, suggesting a possible reef. (from Shrock, 1930, unpublished field notes).

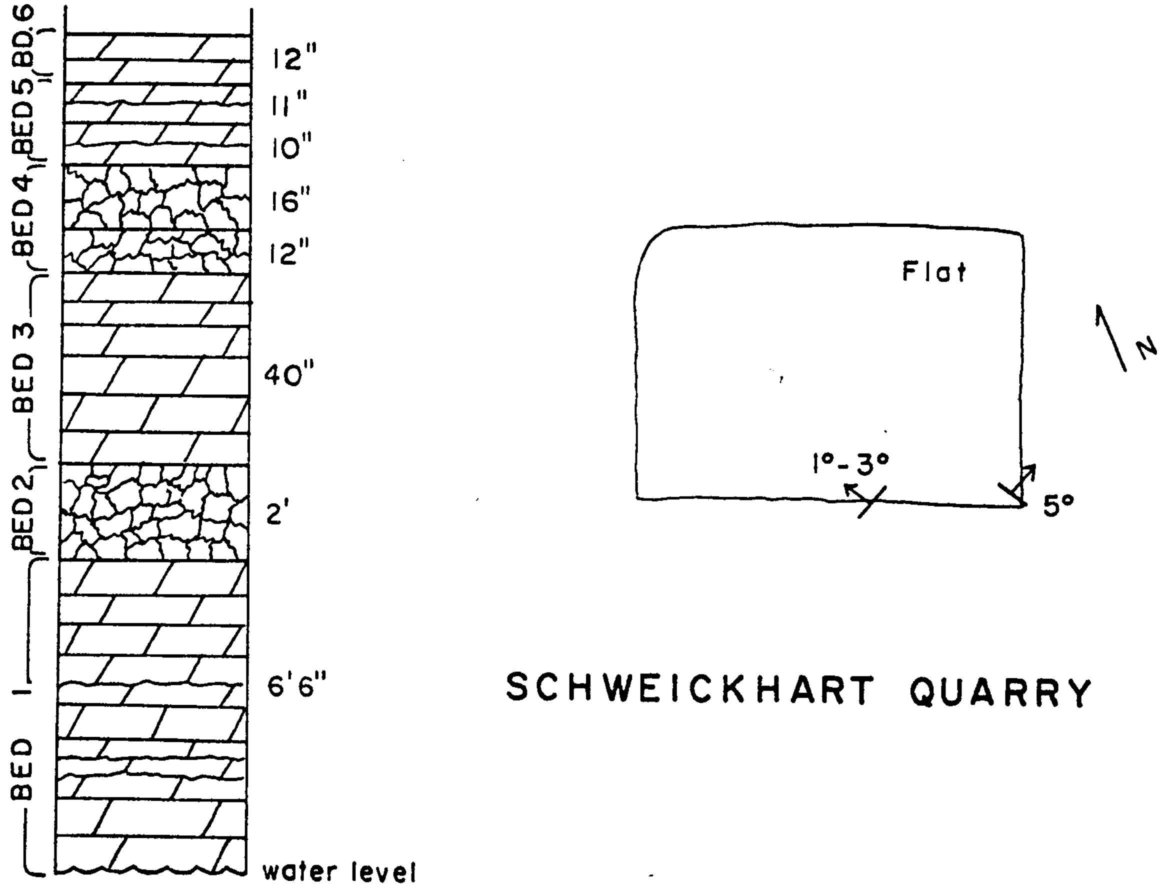

BED 6
BED 5
BED 4
BED 3
BED 2
BED 1
12"
11"
10"
16"
12"
40"
2'
6'6"
water level
Flat
N
1°-3°
5°
SCHWEICKHART QUARRY

Figure 97

Tully Smith Quarry
Locality 79

NW 1/4, Section 26, T. 7 N., R. 21 E., Wauwatosa Township, City of Milwaukee, Milwaukee County.

elevation: 640 feet

A small filled quarry is located on a triangular piece of land west of N. Hawley Road between the Menomonee River and the railroad tracks to the north (see Figure 86). The only information concerning this quarry was obtained from William Manegold (1968, 1976, personal communication). This quarry was operated in the 1880's by Tully Smith and was known as the Irish Quarry. The rock in this quarry is composed of the same Racine Dolomite beds exposed in the Manegold and Schweickhart quarries to the south on the opposite side of the river. Manegold remembers the quarry was full of water in the 1890's, that it had a prominent ledge on its east side, and that the quarry was approximately 12 to 18 feet deep. This quarry was partially filled with large blocks of the thick crystalline beds from the Schweickhart quarry which were unsuitable for building stone. Later the quarry was filled with industrial wastes (asbestos?). This quarry is illustrated in the 1892 lithograph "Wauwatosa and the Western Suburbs of Milwaukee" pictured in Beckman (1978) and appears to have been water-filled at that time.

Schoonmaker Quarry
Locality 80

S 1/2, SW 1/4, SE 1/4, Section 22, extending south into NW 1/4, NE 1/4, Section 27, City of Wauwatosa, Wauwatosa Township, Milwaukee County.

MPM x36.10

elevation: 670 feet

Natural outcrops and a quarry are located in a southward-facing bluff extending from N. 68th Street (8th Avenue) on the west to approximately N. 62nd Street on the east, near the ravine where Schoonmaker Creek once flowed south to the Menomonee River (see Figure 86). This area is bounded by W. State Street. The western portion of the quarry site (termed the Francey quarry) is now occupied by a Jewel food store and the eastern, older portion of the quarry site (Schoonmaker quarry) is occupied by the Western Metals Company.

The Schoonmaker Reef, located here, is the most famous Silurian exposure in eastern Wisconsin. It was the first Paleozoic carbonate buildup in North America to be identified as an organic reef, and has served as a classic example of such a structure, being figured many times. This reef was well exposed for over 100 years and was the source of the diverse and abundant reef faunas collected by the local fossil collectors, such as F. H. Day, in the nineteenth century. It was the best example of a Silurian reef in North America from 1861 until the 1940's.

Quarrying began at this site in 1834 or 1835 by Cyrus Brown and the quarry was later owned successively by Mason Daniels, P. C. Hale, and Green and Watkins until it was finally purchased by John Schoonmaker and Van Schaick in 1857 (Western Historical Co., 1881). Walling's (1858) plat map of the area shows that only the eastern end of the exposure was owned by Schoonmaker and Van Schaick; lime kilns are indicated on this property and it is likely that the quarry began at this end of the bluff and was worked eastward. Schoonmaker later bought out Van Schaick's share and purchased additional land to the east and west.

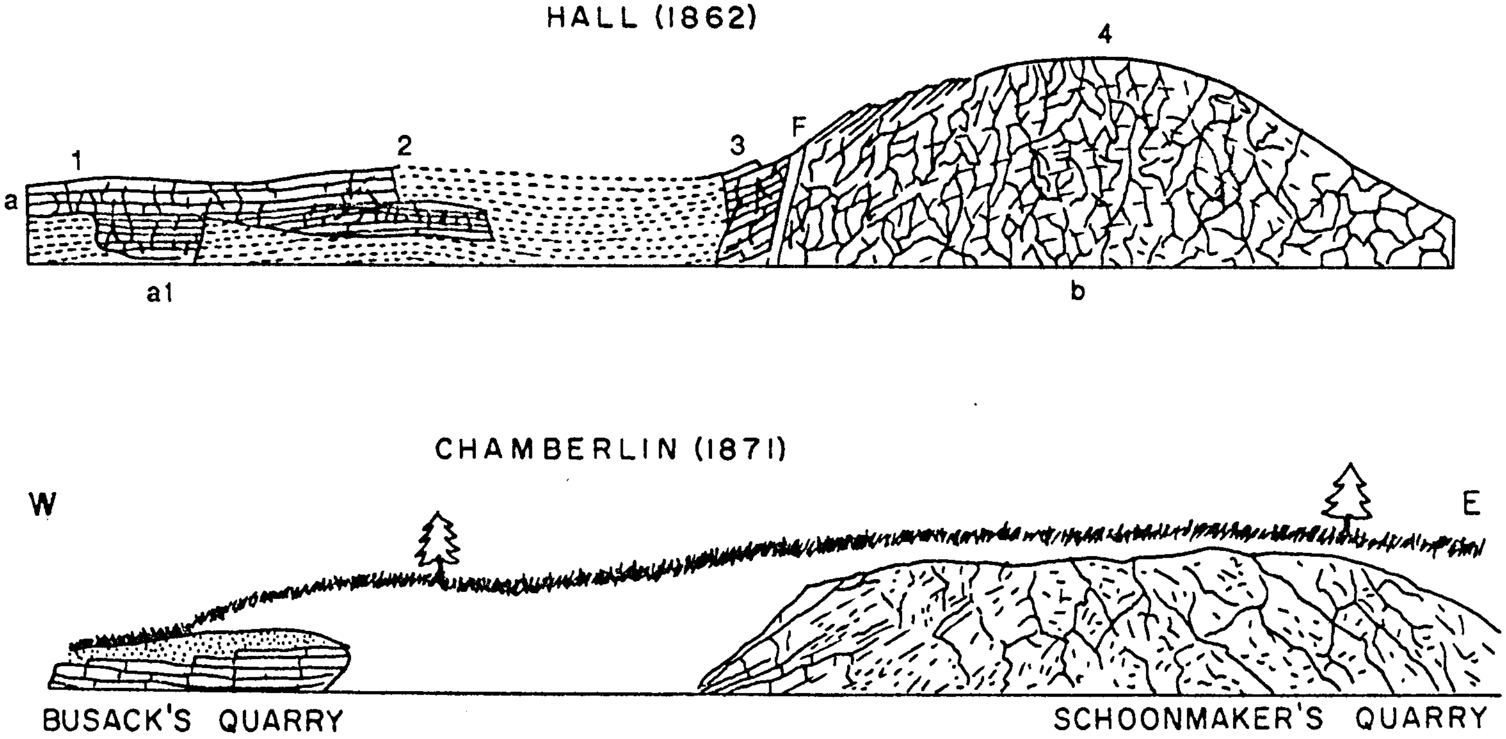
The relationships which exist between the reef rock and surrounding non-reef beds at this locality were the basis for Lapham's (1851) placement of a geodiferous limestone (Unit VIII) in addition to the Waukesha (Unit VI) and Racine (Unit VII) in the local Silurian section, but he did not give a detailed description of the quarry.

Percival (1856, p. 70) mentioned finding a limestone abounding in fossils, including Catenipora, along the Menomonee River west of Milwaukee. He is probably referring to the Moody or Schoonmaker reef, but no details are presented.

Hall (1862, p. 62-64, Figure 8) described the relationships of the different rock units in the quarries at Wauwatosa, which he considered to be in the Waukesha Dolomite (see Figure 98). The east quarry (b) is the Schoonmaker quarry and the western one is Busack's. He stated:

> At Wauwatosa, near Milwaukee, and at other points, there are isolated hills or ridges of Coralline limestone; while the surrounding low flat ground is underlaid by the thin and heavy-bedded Waukesha limestone. At one point in this low ground there is an open quarry, and at a little distance and on the opposite side of the road there is a similar quarry, both exhibiting the thinbedded and the thickbedded portions of the rock. In direct continuation we have the face of a hill of Coralline or Geodiferous limestone, which has been quarried along an extent of several rods. This has been burned into lime, while the other beds are unfit for that purpose.
>
> The connection of the two series of limestone beds, as far as seen, may be understood from the section, Fig. 8; where the continuous lines represent the strata exposed in quarrying and the dotted lines show their supposed continuity along the face of the hill. At b we have a full development of the Coralline limestone, where the lines of bedding are traced with difficulty, and finally not at all.
>
> At the left hand of the section of a and a^1, the even-bedded Waukesha limestone is well exposed, and it is quarried from 1 to 2. At the point of a low hill at 3, the line of bedding are very distinct; but in the centre at 4, and beyond, no lines of bedding can be discerned.
>
> The entire mass appears like a coral reef, where the broken corals and shells are packed in calcareous sand, the whole consolidated as a compact and nearly homogeneous mass; while as we recede from it, the more finely comminuted materials are spread out over the adjacent sea-bottom, and, mingling with a little argillaceous matter, they form the thinbedded argillaceous dolomite of this region. This, at least in the present state of facts, seems to be the only satisfactory explanation which can be offered. That these isolated hills are not outliers of a former continuous mass, would seem to be proved by the sloping strata upon their flanks; and there is no reason to suppose that they have been abruptly elevated in this quiet and undisturbed region; they seem to have been small coral reefs or island, and

Figure 98. Early diagrams showing the structure of the Schoonmaker reef (locality 80), Wauwatosa, Milwaukee County. Note relationships of reef core, on right, to flank beds and inter-reef beds on left. After Hall (1862) and Chamberlin (1877). See text for details.



SCHOONMAKER REEF - WAUWATOSA, WISCONSIN

Figure 98

> are known to exist only over a limited portion of the area occupied by this limestone formation.
>
> It is true that at F there is an obscure break in the continuity of the strata, which may indicate a fault, and if there prove to have been any displacement of the strata, it is still possible that the massive Coralline limestone may not be entirely continuous, or lying directly below the regularly-bedded portion of the rock as it now appears.

This is the first time a North American Paleozoic carbonate buildup was called a reef although Hall (1851, p. 159) referred to the coral-rich biostromal beds of the Silurian in the Upper Peninsula of Michigan as coral reefs.

Rominger (1862) made the following observations based on these exposures:

> In the local description of the Silurian strata exposed in the neighborhood of Milwaukee, a certain calcareous stratum or a complex of such is called Waukesha limestone, and was considered as being the base of the thick bedded fossiliferous lime rocks, considered as synchronous with the Niagara limestones.
>
> A careful examination proves beyond all doubt that the Waukesha limestone is in reality the superincumbent rock and that the Niagara limestone only in disseminated spots protrudes by volcanic action in dome-like knobs through the otherwise nearly horizontal or merely undulating strata of the Waukesha limestone.

Lapham (1873, unpublished field notes) briefly mentioned that the quarry was "extensively worked for lime to supply Milwaukee and Chicago" and that the "stone (is the) same as Moodeys (sic), much broken doubtless former movements of the 'earths crust'."

Chamberlin (1877, p. 365-367) described the relationships between the Schoonmaker quarry and Busack quarry (see Figure 98) to the west in detail:

As the quarries near Wauwatosa furnish the best exposures, are the most fossiliferous, and have been the subject of most discussion, it is desirable that we should enter somewhat into particulars in reference to this interesting locality. If we place ourselves at the extreme western exposure known as Busack's quarry, we shall find a section showing heavy, well defined, nearly horizontal, slightly argillaceous beds, of a rather fine, uniform, compact grain, medium hardness, smooth conchoidal fracture, and bluish gray color. Interstratified with these, are layers having the lumpy nature previously described as occurring in Sec. 36, Germantown. The layers dip eastward to about the middle of the quarry, from which they rise, but not uniformly, for at this point an east and west axis occurs, having the general trend of the ridge farther east, and with which it probably has a definite connection. An east and west section in this part of the quarry shows a dip to the westward, and a north and south section would exhibit the layers curving gently over this axis. But as we trace the rock eastward, it changes in nature. Near the eastern extremity, the upper layer becomes slightly irregular in bedding, and rather soft, and granular in texture.

Below this is a layer from 22 to 24 inches thick, divided into sublayers, somewhat irregularly, and occasionally showing lines of deposition. To casual observation, it appears to be a compact, fine-grained even-textured dolomite, but closer inspection shows it to contain many small cavities, that are angular and sharply defined, and are the result of the removal of minute fossils, in which the rock abounds at this point. Aside from these, the rock is as previously described, with occasional seams of argillaceous material. Below this, the rock is similar to that in the western part of the quarry. In the extreme southeastern portion exposed in connection with this quarry, the rock becomes quite irregular in structure.

There ensues at this point, unfortunately, an interruption of several rods in the exposure, so that this incipient change in structure cannot be traced to its consummation.

Passing this interval, we find at the western extremity of Mr. Schoonmaker's quarry, at the surface, a cellular even textured, regularly bedded rock, similar to that last described, but of lighter color, and more distinctly granular nature. This dips southward at an angle of about 15°. As the face of the quarry curves round to the south, the whole section is composed of similar rock down to and beneath the water that occupies the bottom of the quarry at this point. But these lower layers dip less and less, until they become horizontal, and even slightly incline towards the irregular mass. If we trace these lower layers toward the ridge, their inclination somewhat increases as well as their thickness--this latter sometimes markedly--until they are lost in the obscure structure of the reef, or disappear at the surface.

As we pass eastward along the face of this ridge, now well exposed by quarrying, the dip of the ill-defined layers increases gradually to 54°, when the stratification can no longer be clearly distinguished. This obscurity continues for 80 paces. There are some indications of horizontal bedding in this space, and also some that the dip is to the south, and that the exposure is along the strike of strata, but neither observation is altogether trustworthy.

East of this, blue and lighter colored bands indicate a dip of about 30° eastward. This continues for about 35 paces, the observation at the eastern extremity showing a dip of 31° in a direction E. 10° to 15° S., this being the dip as exposed, not necessarily the full amount of the true dip. The same qualification is true of the other observations made on dip along the face of this exposure.

Ten paces of unexposed face succeeds, followed by 90 paces uncovered, which shows an obscure dip of about 30°E. of S. Again 30 paces are concealed, beyond which a face 40 yards in length succeeds, whose dip is 33°E. of S. After another interruption of 60 paces, we find the last exposure of about 10 paces length, whose very obscure stratification indicates a dip to the S.W. The ridge reaches a height of about 45 feet above the sole of the quarry.

Near the summit of the ridge, at its western extremity, is a slight outcrop apparently in place, and seeming to dip to the northwestward (20° N. 30°W.). If this is reliable, we should infer that the ridge was comparatively narrow, as the exposure lies only 17 paces back from the face of the quarry.

The trend of the ridge, as estimated from the exposures, is a little to the north of east.

Chamberlin accepted the reef hypothesis to explain the origin of the rocks at Schoonmaker's and was the first person to place the building stone quarries and the surrounding reefs into the Racine Dolomite, a placement which has been verified in later work.

Day (*in* Chamberlin, 1877, p. 371-377) listed 125 species of fossils collected by him in the Schoonmaker quarry. Day (1877) made a number of interesting observations concerning the Schoonmaker quarry. Day (1877) made a number of interesting observations concerning the Schoonmaker quarry:

> On one occasion after a recent excavation by blasting at Schoonmaker's quarry, I measured a coral disk about twenty feet in diameter, three feet in height, and more than sixty feet in circumference. The surface was made up of beautiful concentric layers, like the flattened whorls of a gastropod, and were covered by very pretty *Heliolites*. . :
>
> If we examine the lowest depths of the sole of Schoonmaker's quarry, we find the same characteristic rock, containing the Terebratulous fossil, *Gypidean occidentalis*, belonging to the Byron division of the Mayville bed. This formation was quarried to some extent, and formed dressed stones, for bases to gravestones, and window caps and sills.
>
> This stratum terminated abruptly in an ancient river bed, the bottom of which is smooth and polished, grooved and scratched by the drift of the glacial action or era, for huge granite boulders were excavated during the process of quarrying.
>
> Above this stratum, are regular even layers of a glazed, compact, metalic ringing, cherty limestone, of several inches in thickness, which is quarried in regular rectangular forms, and is utilized as a durable pavement on the side walks, or macadamized streets of Milwaukee and Waukesha. This formation was covered with animal life, similar to that, so extensively intermixed in the strata or groups overlying it, and is well exhibited at every exposure of this rock, in all the quarries in Milwaukee, Racine and Waukesha counties. But the fauna which covered the surface of the Waukesha limestone, at Cook's, Hadfield's, and Pelton's in Waukesha county, or Trimbone's (sic), Swan's, Busack's, Schwackhart's (sic) and Story's in Milwaukee county;

or Ive's, Horlick's and others, in Racine county; or Cook and Mc'Henry counties in Illinois, are in an exceedingly compressed stratum, and in many instances the fossils are in such a state as to be of little better than defined, than well marked outlines of the original plant or invertebrate animal.. In several of the quarries, as Story's, Schweickhart's, Busack's, and Cook's, the Bryozoa, Cephalopoda, Gasteropoda, Brachiopoda and Crustacea, are so intensely compressed and distorted and glazened as often to give the appearance of different genera or species.

The Schoonmaker quarry is illustrated in the 1892 lithograph "Wauwatosa and the Western Suburbs of Milwaukee" by Marr and Richards (see Figure).

Alden (1898, unpublished field notes) described the quarry as follows (see also Figure 99):

> In the hillside just north of the railroad the rock has been quarried in the lower slope at Schoonmaker's old quarry and lime kiln. The pit 30-35 feet deep is filled with water, but the rock is exposed in the hill about 25-30 feet and is overlain by blue till grading into buff. The rock here exposed is massive, coarse grained, irregular rock, a hard bluish-gray dolomitic. It is of fragmental appearance and breaks up irregularly. Some places it looks almost like a breccia. At the east end of the exposure the upper part if in places buff, porous, and impure containing much clay. This part is quite fossiliferous...A few fossil traces were noticed at various places in the exposure, but they are quite rare in general. At the west end and in the pit there is more bedding to the rock. There is here quite a strong dip about 30° in a direction S. 47°W. so that a 15 ft. roadcut just west barely exposes the rock...

Grabau (1903) described the reef at this quarry (p. 341-342):

> The quarry was opened in a mound or hillock which undoubtedly owed its preservation to the hard character of the reef mass. At the time of my visit, however, it had been abandoned for a long time, and the walls had become more or less weathered and overgrown, while the deeper portion

Figure 99. Photograph of the south half of the west wall of the Schoonmaker quarry, showing flank beds dipping south and southwest (left) from reef core to north (right). This photo represents the center of the wall in the background under large tree in the frontispiece. Photograph by W. C. Alden, 1899, No. 115, from U.S. Geological Survey Photographic Library.

Figure 99

was filled with water. The same reef is exposed in the eastern part of the quarry, but there are smaller reef-like mounds which may have been subsidiary reefs, or may be merely parts of the larger one. No bedding is visible in the reef portions, which appear to consist mainly of stromatoporoids. These, however, are recognizable as a rule, only on the weathered surfaces, the general aspect of the fresh face being that of extreme massiveness of the rock, with a total absence of stratification. Around the reef, however, the rock is bedded and granular, and it may be seen in many places dipping away from the central reef portion. The highest dips which I observed were 28 degrees, decreasing rapidly to 18 degrees; but Chamberlin mentions a dip of 54 degrees close to the reef, observed while the face was well exposed in quarrying. Other dips mentioned by Chamberlin are 30, 31 and 34 degrees, besides those of lower angles. Chamberlin also mentions the increase in thickness of the sedimentary layers toward the reef, with which they finally merge.

Alden (1906, p. 2) described the exposures here as follows:

...the old quarries of Schoonmaker and Busack. At Busack's quarry the limestone strata are exposed in the valley floor, in a nearly horizontal position. The beds are heavy, well defined, and slightly argillaceous, but of rather fine, even grain, with conchoidal fracture. Interstratified with these are layers having the lumpy structure seen at Story Brothers' quarry. In places the rock is really a conglomerate, in which the pebbles and the matrix are of the same material and blend in solidification. Toward the east the strata begin to rise gently, at the same time dipping laterally at slight angles, as if riding over an east and west axis. At this point there is a break in the section. A point of the hill has been left, so that the clay slope comes down into the valley. The interval is barely 2 rods, but when the rock beds reappear on the east side of this point, they are rising at an angle of 30°, the dip indicating, as before, an east-west axis, over which the beds are deposited. Before the rock passes under this covering of clay a change occurs in character. Near the east end of Busack's quarry the upper layer becomes slightly irregular in bedding and rather soft and granular in texture. At the west end of Schoonmaker's quarry, the stratification of the rock seen emerging from beneath the

> clay covering soon becomes obscure and passes into a massive irregular structure, with no evidence of bedding. This change takes place not only from east to west but from north to south...a north-south section at the west of Schoonmaker's quarry...(shows) the strata rising from south to north and passing into the irregular-textured massive rock that form the body of the mound. When visited by the writer the lower part of the excavation was filled with water, so that the lower beds were not accessible. The upper 25 to 30 feet of the rock is exposed in the valley slope for about 100 yards to the east, except where obscured by clay washed down from above. The rock is a massive, coarse-grained, hard bluish-gray dolomite. In places it appears to be a breccia of angular fragments of limestone in a limestone matrix. Towards the east end the upper part is more nearly buff in color and is impure and porous, containing much clay. The section is evidently that of a elongaged mound or ridge of limestone whose elevation is due not to upheaval and folding of the beds but rather to the mode of formation.

Alden figured the west wall of the Schoonmaker quarry in 1906 (his Figure 10) and used this same photograph in 1918.

Figure 100 shows photographs of the quarry and kilns around the time of Alden's and Grabau's work.

Steidtmann (unpublished field notes) visited the quarry in 1912 and reported the following:

> The quarry appears to be located in the core of a dome (probably coral reef dome) for the beds dip away from the sides of the quarry. Near the core of the dome the beds are very massive while away from it the beds are more distinct and more nearly horizontal. The maximum dip is about 45°. The rock is cavernous and porous and contrasts in this way with the Waukesha Stone. The cavities are frequently lines with rhombohedral crystals. The joints are not as distinct as they are in the more brittle rock at Waukesha...(The height of the west quarry face) is 26 feet (and) seems to be uniform lithologically.

Figure 100. A: Photograph looking east from the top of the west wall of the Schoonmaker quarry (locality 80), Milwaukee County. Kilns are located just right of center; farther right is loading shed and gravel loader. Quarry wall in distance, at center of photo, has remained unchanged and can still be recognized. North wall, to left of center, has been mostly quarried away and buried; circa 2909. B: Photograph of lime kilns in the east enc of Schoonmaker quarry, looking northeast, circa early 1900's. Wall of quarry is hidden by trees in background. Kilns are the ones in background in (A); Western Metals Company building is now located on this site. Photos are courtesy of Mrs. Caroline Timmerman.

A

B

Figure 100

Grabau (1913, p. 418-419) summarizes his earlier (1903) description of this locality but also mentioned that the "genus Clathrodictyon seems to abound." Photographs taken in 1913 during early operations by G. D. Francey are in Figure 101 and frontispiece.

Hotchkiss and Steidtmann (1914, Plate XV) figure the north wall of the Schoonmaker quarry, showing northward dipping flank beds.

Figure 102 shows reef core rock overlying bedded rock in this quarry around 1920.

Steditmann (1924, p. 67) gave the same general information as that supplied by Hotchkiss and Steidtmann (1914) and continued to describe the Schoonmaker and the Wauwatosa Stone and Coal Company quarry (Francey) as two different quarries.

Raasch (1926, unpublished field notes) mentioned that the quarry was then being worked in the reef rock along the northwest and northeast faces (see Figure 103) and stated that "the dip within the reef is well shown at present and is exceedingly varied." He collected a large number of fossils, including trilobites, brachiopods, and bivalves, which are in the Milwaukee Public Museum collections.

Cumings and Shrock (1928, p. 613) "studied the classic reef at the Schoonmaker quarry at Wauwatosa" and stated the following:

> It is a small reef with a very steep flank and down-curved base, so that the entire mass is evidently lens-shaped. The bottom of this reef is now exposed, resting on beds that look

Figure 101. A: Photograph of crusher and screening plant operated by G. D. Francey, circa 1913. View is looking towards the northeast; kilns can be seen at lower right in background. B: Photograph looking southeast toward crusher and screening plant from the north wall, circa 1913. Photos courtesy of Mrs. Bonnie Bliffert.

A

B

Figure 101

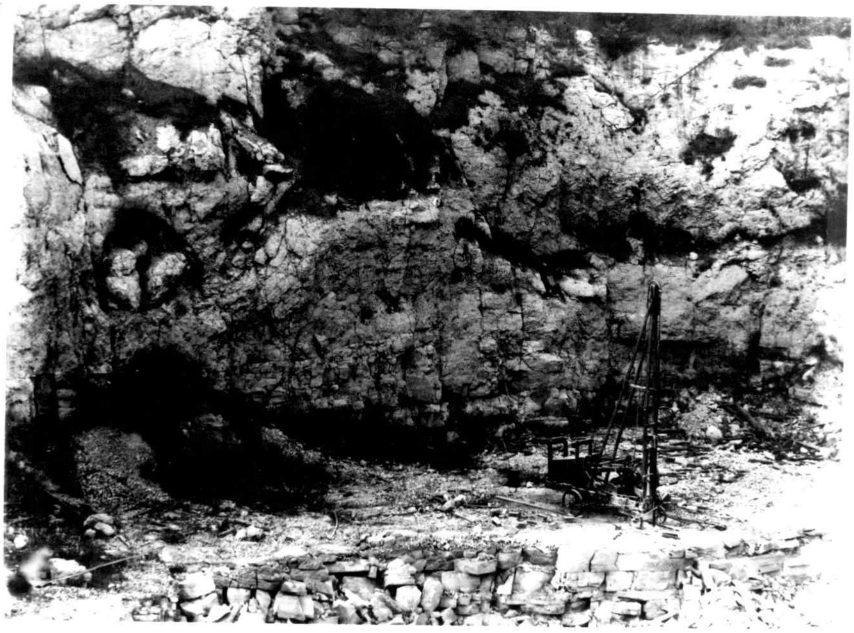
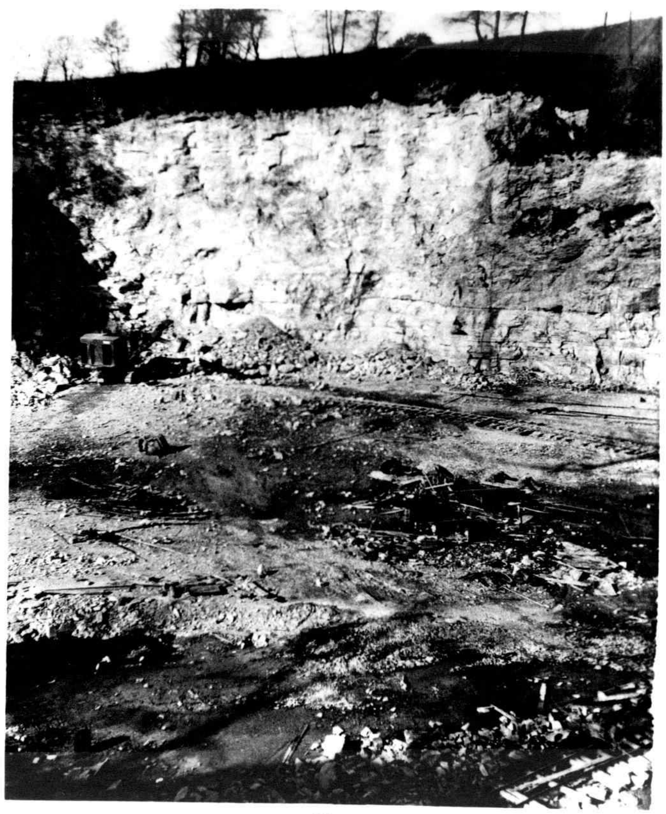


Figure 102. Photograph of reef core overlying bedded rock in the northwest corner of Francey quarry (locality 80), Milwaukee County. Note slight arching of bedded rock in center of photo. Photo courtesy of Milwaukee Public Museum, No. 47367; circa 1920.

Figure 103. A: Photograph showing the east half of the north wall of the Francey quarry, looking north from tip of south wall. Crusher is located to right of picture on south wall and eastern portion of Schoonmaker quarry and lime kilns located to right of picture. Reef rock can be seen overlying bedded rock. Small mound can be seen in basal reef rock at right of picture. Photo courtesy of Milwaukee Public Museum No. 128596.
B: Photograph of west half of north wall, showing reef rock overlying bedded rock. Photo courtesy of Milwaukee Public Museum, No. 128595. Taken in 1926.

A



B

Figure 103

to us like Waukesha. There is evidence of downbending of the foundation, owing to the weight of the reef. The core is very massive and entirely unstratified.

Shrock (1930, 1931, unpublished field notes) visited the quarry and made several sections (see Figure 104). He measured the following section in the middle of the south wall of the Francey (Schoonmaker) quarry in 1930:

Bed 1. Dark gray, dense, compact dolomite of an argillaceous color. Occurs in heavy beds, which weather into thinner units. The units themselves break with smooth conchoidal fracture into angular chip-like blocks or slabs. Weathers to a buff color and exhibits an earthy character. Sharply separated from Bed 2 by a somewhat uneven contact.

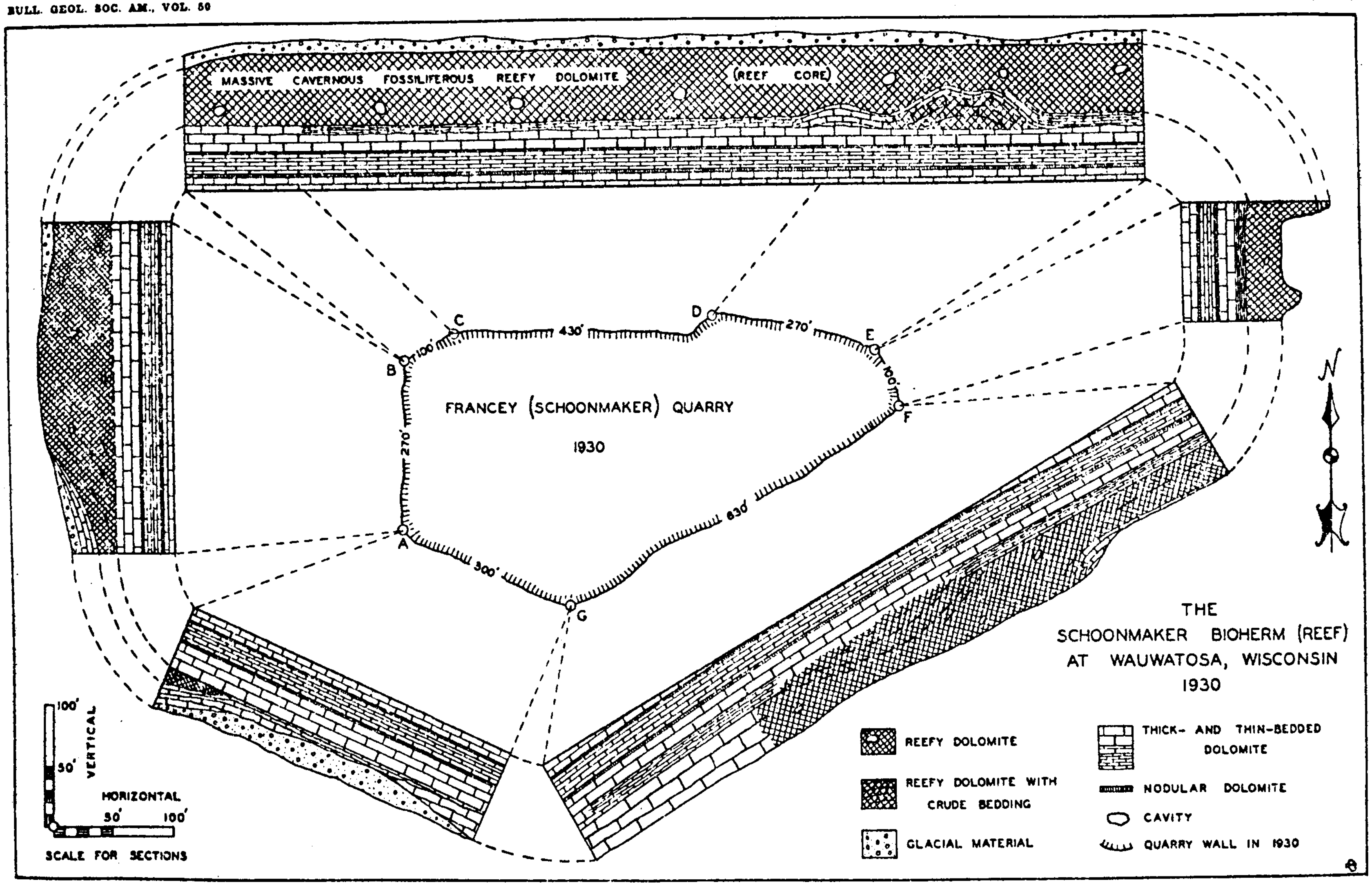
Bed 2. Irregularly bedded, dark gray to light brown brecciated dolomite composed of angular fragments of gray dolomite cemented by a chocolate-colored crystalline matrix. The slightly weathered surface appeared to be mottled and exhibits the brecciated character nicely. Occurs as one massive bed 28-33 inches thick.

Bed 3. Light blue, dense compact argillaceous limestone in heavy beds with smooth conchoidal fracture. The massive beds split into thinner ones on weathering and changes in color to a buff, at the same time becoming somewhat earthy. Laterally, the lower portion of this bed and No. 2 undergo some peculiar relations as illustrated (see Figure 105).

Bed 4. The 4 inch layer consists of a bluish gray crystalline dolomite with wavy shale films. It passes upward into a massive layer of blue, crystalline dolomite with a rough angular fracture (18 inches). The overlying 22 inch layer is bluish-gray slightly earthy dolomite which changes to buff when weathered. The 16 inch layer is a buff to bluish gray semi-crystalline dolomite with rough, angular fracture. Much like the underlying. The 16 inch bed is like the underlying 26 inch layer, but breaks into thin layers more readily.

Bed 5. The 14 inch bed is composed of a pinkish to dirty-gray brecciated dolomite which when fresh has a

Figure 104. Diagram showing general characteristics of the Schoonmaker reef (locality 80) and underlying beds at the Francey quarry (locality 80). From Shrock (1930).



SCHOONMAKER BIOHERM

Figure 104

mottled appearance. Buff fragment and bluish gray areas give the effect. Breaks up like concerete.

The overlying 16 inches is transitional. At the base it closely resembles Bed 6 from which it is separated by a stylolitic seam, and upward it grades into a light-colored, even, heavy-bedded, dense compact dolomite with conchoidal fracture. Some holes as in the 14 inch bed.

Bed 6. Very light colored dense, compact earthy dolomite, which is heavy bedded and breaks with fairly good conchoidal fracture. Tough. Becomes slightly buff colored toward the top.

Bed 7. Fairly thin bedded (4-8 inches) buff-gray mottled cavernous dolomite. In the quarry face these beds are honeycombed weathered. The rock disintegrates to a sandy powder which is yellow. The small holes (2-5 inches across) have shale in them. The upper beds are quite porous and about as earthy as the lower. Laterally these beds thicken towards the reef, ride up toward it and then pass into reef rock.

Shrock observed another unusual structure similar to those in Beds 2 and 3 (Figure 105) in the west face of the quarry (see Figure 106). Shrock also measured a section in the northeast corner of the quarry (see also Figure 107 and 108):

Bed 1. Bluish to dark blue, porous crystalline dolomite, 25 inches.

Bed 2. Heavy-bedded, light-colored, dense compact dolomite with smooth conchoidal fracture, 14 feet 3 inches.

Bed 3. 7 feet 9 inches of hackly, dirty gray, irregularly-bedded dolomite. Breaks into thin irregular layers. The reef rock rests directly on these beds.

Bed 4. 67 feet of hackly, porous, granular to tough blue rock of reefy character.

Shrock went on to describe the faunal distribution at this locality:

Bed 1 carries little in the way of fossils. The black stringers and strap-like markings are very common. An occasional annulated cephalopod may be seen and rarely the

Figure 105. A) Diagram illustrating the relations between Beds 2 and 3 in the south wall of the Schoonmaker quarry, Wauwatosa, Wisconsin (see text for description of section). This situation was found on the south face of the quarry near the west wend well below the reef horizon and represents conditions previous to reef formation. 3a-normal rock of Bed 3 as described in text; 3b-4 inches of yellowish quartz sandstone with some mud in it. Pebbly at base; 3c-62 inches of thinly laminated gray to blue gray shale with little grit; 3d-4 inches of a gray, light-colored earthy dolomite which would break down to a mud; 3e-similar to 3c, 13 inches; 2a- 3e grades downward into a blue, argillaceous dolomite somewhat 1 and 3 beds. Laterally this unit grades either into the basal portion of 3 or Bed 2, depending on its horizon; 3f- found later is very soft blue shale which replaces the 41 inch bed of Bed 3, and comes above the same horizon. It is gritty to a certain extent. Appears to be a large pile of mud, over which the superincumbent beds arch slightly. The 50 inch bed of Bed 3 completely covers over it.

B) Diagram illustrating the conditions along the north face of the quarry near the west end. The beds are slightly flexed downward over this shale pocket.

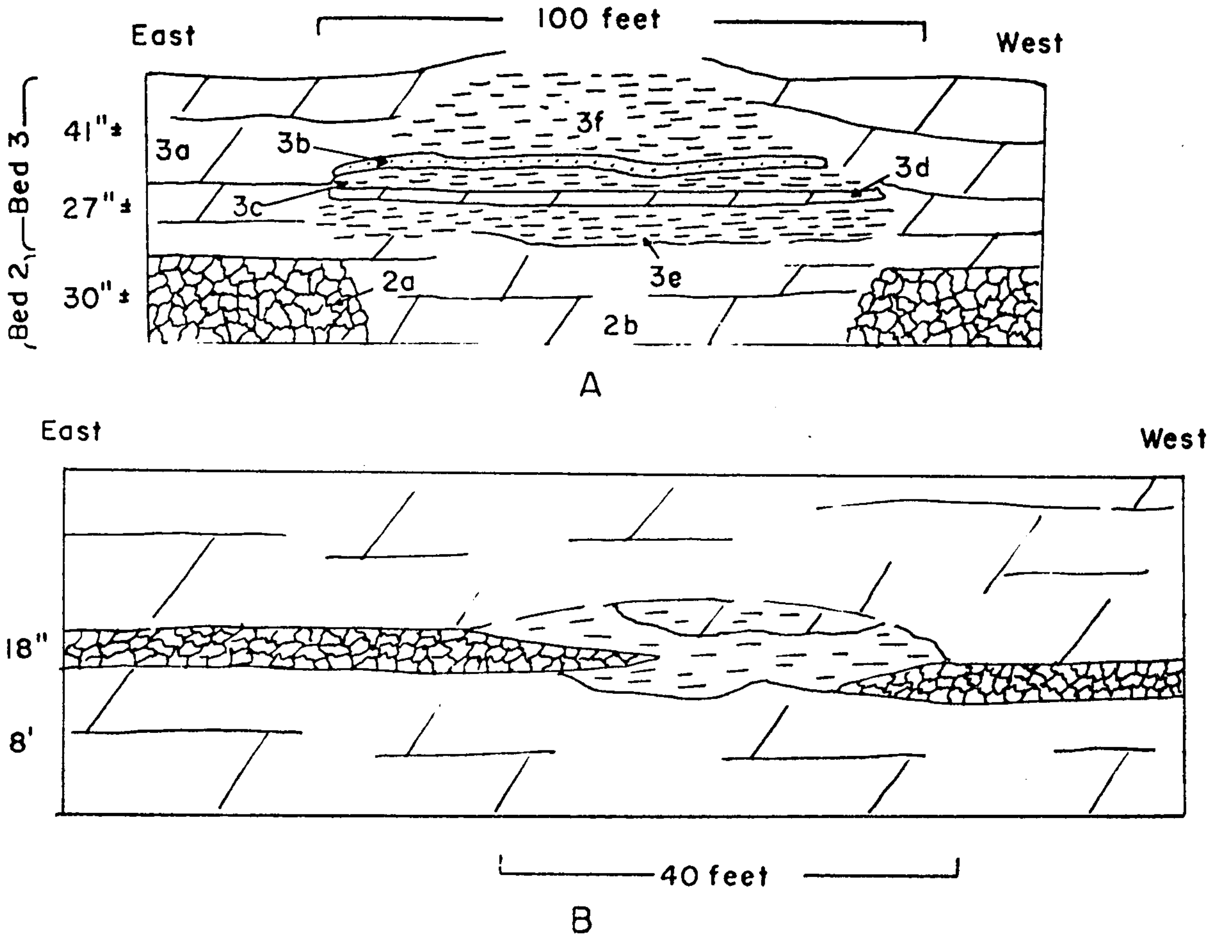

East
100 feet
West
Bed 3
Bed 2
41"±
27"±
30"±
3a
3b
3c
3d
3e
3f
2a
2b
A
East
West
18"
8'
40 feet
B

Figure 105

Figure 106. Diagram illustrating an interesting condition along the west face of the Schoonmaker (Francey) quarry near the northeast corner, Wauwatosa, Wisconsin. The conglomerate or brecciated layer plays out or bevels against the underlying Bed 1. Immediately above it and sometimes lateral to it, comes a bluish-gray laminated shale. The pocket at the south end has a small deposit of quartz sand full of shell fragments in it. The 30 inch bed immediately overlying Bed 2 is partially replaced laterally by blue shale, thin layers a foot or so thick coming both above and below. It is possible that the contact between Beds 1 and 2 represents an unconformity of a local nature for Bed 2 seems to have been laid down on an uneven surface. The sand appears to be a beach sand.

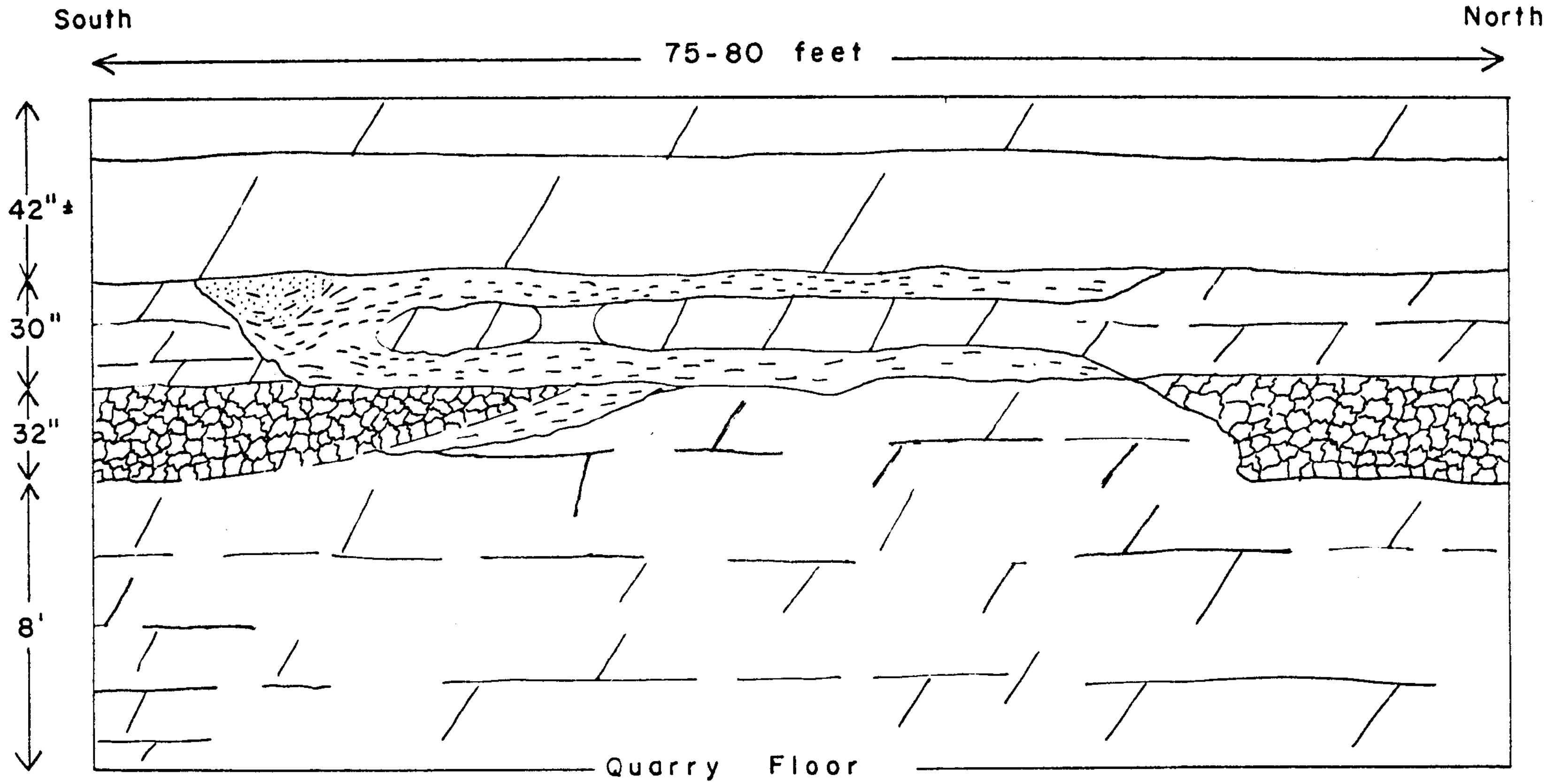


Figure 106

Figure 107. Cross-section of the east face of the Francey (Schoonmaker) quarry, Wauwatosa, Wisconsin. The section is as follows:
Bed 4. Gray to blue, tough, porous, brecciated dolomite from the reef. Bedding generally obscure.
Bed 3. Thin, irregularly bedded gray dolomite with blocky to hackly fracture. Grades upward through indistinct bedding to structureless reef rock.
Bed 2. Massive, light-colored, dense, compact earthy dolomite with conchoidal fracture.
Bed 1. Same as Bed 5 of normal section (see text). Floor of this part of the quarry in Bed 4 of normal section.

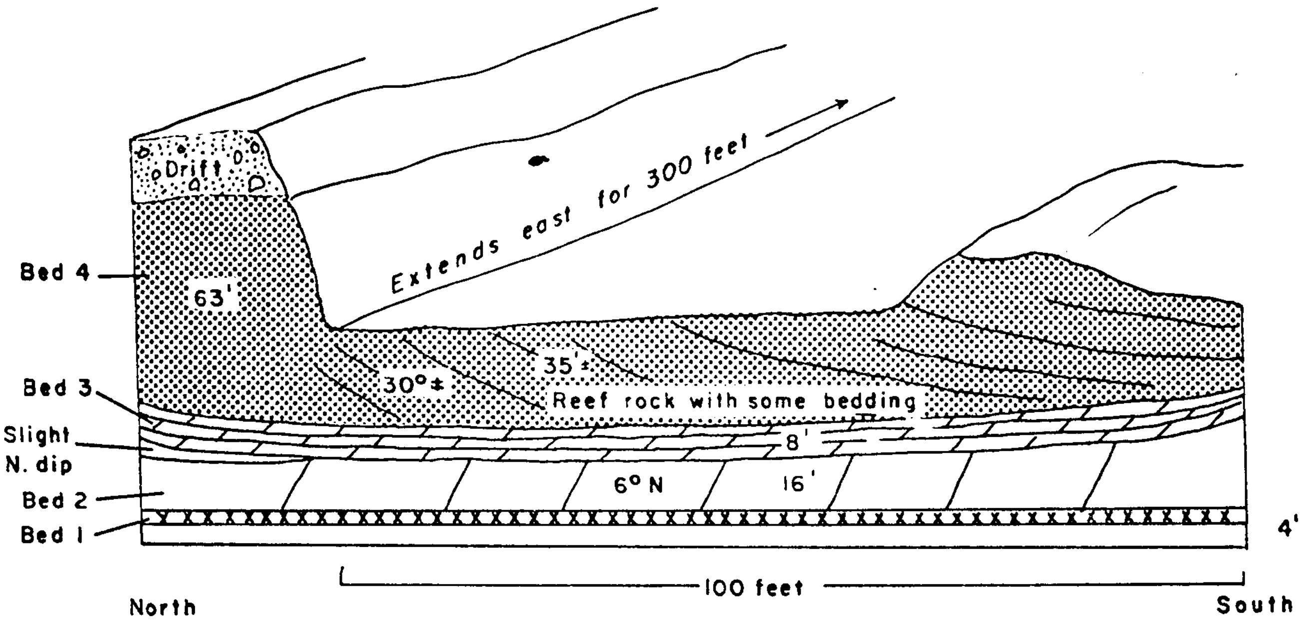

Drift
Extends east for 300 feet
Bed 4
63'
Bed 3
30° ±
35' ±
Reef rock with some bedding
Slight
N. dip
8'
6° N
16'
Bed 2
Bed 1
4'
100 feet
North
South

Figure 107

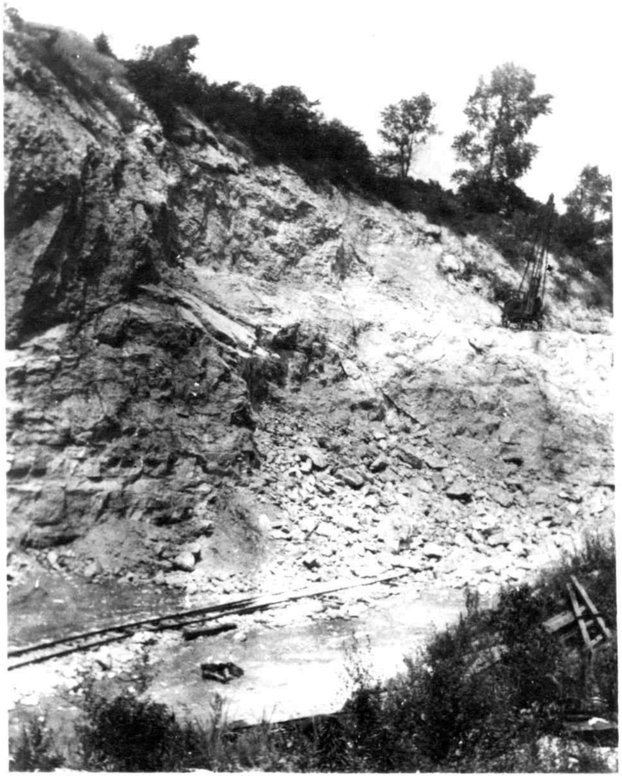


Figure 108. Photograph of northeast corner of Francey quarry (locality 80), Milwaukee County, looking northeast from the south wall. Old east portion of Schoonmaker quarry is to right of photo. Note mounding of basal reef beds in center of photo. Photo courtesy of R. R. Shrock; taken in 1930.

> cast of a brachiopod. One cephalopod was 27 inches long and 1 1/4 to 1 7/8 inches wide, cast only.
>
> The reef facies carries the fauna in this quarry. It is replete with a most interesting fauna of considerable variety. Represented in the fauna are:
>
> Bryozoa
> Brachiopods
> Crinoids
> Cephalopods
> Corals
> Trilobites
>
> Trilobies of the genus Illaenus seem to be quite common, and orthoceratites are the chief representatives of the cephalopods.

And, finally, Shrock (1931, unpublished field notes) made these observations:

> The change from reef lithology to the stratified beds beneath is a change from a dense, compact, argillaceous dolomite to a druzy, blue, hard dolomite, in places saccharoidal...
>
> Of special interest is the change in the rock from the reef phase which is hard and blue through a porous, earthy sandy, slabby dolomite to the normal interreef rock of the normal section. This reef-flank rock is much like the reef flank phase of the Liston Creek in Indiana.

Figure 109 shows close-up of the reef beds in the south wall of the Francey quarry, 1931.

Shrock (1939) published a description of this quarry based on his earlier field observations.

Raasch (1953, unpublished manuscript) noted that:

> ...a large and well developed reef bearing a distinctive fauna, in part rests upon and in part grades laterally into dull, argillaceous, well bedded, minutely crystalline dolomite calciluties...

He also mentioned that in the west wall of the quarry, on the flanks

Figure 109. A and B: Close-up photographs of the center and the south wall of the Francey quarry (locality 80), Milwaukee County, between the doming and the thick-bedded inter-reef beds in Figure 103. Photos taken in 1931 during modernization quarry site by T. Francey. Note massive reef beds overlying well-bedded rocks and rather abrupt lateral transition from massive reef rock to thick-bedded inter-reef rock to the west. Photos courtesy of Mrs. Bonnie Bliffert.

A

B

Figure 109

of the reef

> ...reef washed calcarenites interbedded with the inter-reef calcilutites, bear a fauna of minute brachiopods like those present in the Hartung beds...

W. Manegold (1976, personal communication) remembered that the road (68th Street) ran on bedrock on the west side of Schoonmaker quarry when he was a boy, and F. Babich (1978, personal communication) recalled that the Busack quarry, west of Schoonmaker's, was filled when 69th Street was constructed.

The quarry was purchased from Schoonmaker by G. D. Francey in 1910 and quarrying operations were begun in the western part of the area. In 1931, T. Francey assumed operation of the quarry and erected a new plant, replacing the old tracks and dump cars with trucks. Quarrying during the 1920's and 1930's was carried on primarily to the west and north in the western part of the quarry site. Quarry operations ceased in the early 1950's and the Francey quarry site was used as a dump by the Marchese Brothers Construction Company. The old eastern quarry site (Schoonmaker) was built over by Western Metals Company. Francey quarry was completely filled by 1970 and a food store has been built on this site. The old north wall of the eastern part of the quarry property is still visible and has changed little since Schoonmaker operated his lime kilns. About six feet of the highest portion of the reef in the north wall of the Francey quarry site is exposed for approximately 50 feet just east of the Jewel Food Store.

Although most of the reef and surrounding beds have been covered, a number of characteristics of the reef can be deduced from the older descriptions, old photographs, and current exposures. The eastern part of the reef (behind the Western Metals plant) has changed little since Schoonmaker operated the kilns (Francey did not operate the kilns). The rock appears to be massive reef core with a few possible, vaguely defined beds dipping towards the north-northeast near the center of the exposure. The rock is highly cemented towards the west and is moderately fossiliferous; stromatoporoids, tabulate corals, brachiopods, cephalopods, bryozoans, and the trilobites Sphaerexochus romingeri, Bumastus cuniculus and Hadromerus welleri represent the typical fauna. At the east end of the Francey quarry property (east end of food store parking lot), the rock is covered, but old photographs and previous descriptions (Shrock, 1939) indicate that reef flank beds were dipping towards the southeast and southwest below the present ground level (see Figure 110). Shrock (1930, unpublished field notes; 1939) indicated that two small mounds were present in the north wall at this location, with dips 32° to the south and photographs of the area suggest that the dipping beds are related to these mounds. Shrock also noted that the beds around the old incline to the original crusher at the Francey quarry were about 15-22° towards the south-southeast and were

Figure 110. A: Photograph looking east from top of southwest corner of Francey quarry. Note reef flank beds dipping south-southwest in center of photo. Compare with Figure 100A. Photo taken by A. Riemenschneider in 1934; courtesy of Milwaukee Public Library, No. 22C. B: Photograph looking west from southeast corner of Francey quarry. Reef core has been quarried away along west wall. Compare with Figures 99 and 104. Mounding in basal reef beds seen in north wall (right). Dip towards southwest seen in exposures in lower left of photo; circa late 1930's. Photo courtesy of Mrs. Bonnie Bliffert.

A

B

Figure 110

domed in the reef rock at this location. This part of the dome may be part of, or related to, the mounds in the north wall and all of them probably represent the early stages of reef growth. Presence of small individual mounds has also been observed by Day (1877) and Graham (1903). It is not known if these were satellite reefs or mounds as described above. Chamberlin (1877) reported an eastward dip along most of the eastern part of the outcrop when the north wall had not yet been extended back as far as in later descriptions. The reef rock along the south wall in the Francey quarry continues to the west for 300 feet. Detailed photographs of the area, from the original crusher incline west to the end of the reef rock exposure, indicate that the reef beds have significantly compressed the underlying rock so that it dips towards the northeast on the west side of the dome before it dips southeast near the center of the mound. The whole area around this mound reveals that the underlying rocks have been compressed. To the west of the reef rock in the south wall, inter-reef beds occur almost to the west wall. Along the north wall, to the west of the small mounds, the reef core is uniform in composition, similar to the exposures behind the Western Metals building. About 10 feet of rock is exposed in the present southward-projecting wall just east of the food store; this is the last remaining westward exposure of the reef. The rock here is a highly cemented (J. McGovney, 1978, personal communication) dolomite with a few scattered fossils present that are typical of the core lithology. The rock and fauna is similar to that exposed to the east. Some of the cement appears to be organically controlled. This lithology continued at least 20 feet below the present exposures. Diagrams and photographs of the western portions of the north wall show it to be very similar to reef core rock and unbedded. The base of this reef is relatively horizontal and not depressed into the underlying beds as the reef in the south wall. However, this portion of the wall was blasted back to the west and north during the 1940's and 1950's. Dipping flank beds were uncovered just west of the center of the wall, exposing highly fossiliferous, thick-bedded, porous rock overlying granular, poorly fossiliferous flank beds dipping 10° north-northwest. The highly fossiliferous rock commonly contained badly broken fragments of tabulate corals (Halysites), indicating close proximity to a high-energy environment. The presence of the dipping beds fits the pattern described by Shrock (1939) and Chamberlin (1877) of rock dipping southwest, west, and northwest from the western end of the quarry. Both Hall (1861) and Chamberlin (1877) showed dipping flank beds along the west side of the Schoonmaker quarry when the north wall was probably farther south than when Shrock made his observation in the 1930's. The classic exposure of the reef and flank beds in the west wall has been illustrated by Alden (1906, Figure 10; 1918), showing the flank beds of the reef dipping to the southwest.

Chamberlin's (1877) description of the exposure of the reef-inter-reef transition in this area indicates that the individual flank beds increase in thickness and change in character until they merge into the reef core and can no longer be distinguished. A photograph (see Figure 110B) taken during the late 1930's shows that this wall had been largely removed by quarrying and that the rock farther to the west was well-bedded with only a slight doming towards the upper portion of the middle. This exposure, along with those of the adjacent Busack quarry, indicate that the Schoonmaker reef is an elongate ridge running east-west.

Busack Quarry
Locality 80

SE 1/4, SE 1/4, SW 1/4, or SW 1/4, SW 1/4, SE 1/4, Section 22, T. 7 N., R. 21 E., Wauwatosa, Milwaukee County, Wisconsin
elevation: 650 feet

This is a small filled quarry located just west of the Schoonmaker quarry and N. 68th Street(?) and just north of W. State Street.

Walling (1858) located the quarry just west of the center line of Section 22 on the north side of State Street on land owned by Mr Rorick.

Hall (1862) described the rocks exposed in this quarry in relationship to the Schoonmaker reef, but does not give a name for it (see Hall's description under the discussion of the Schoonmaker quarry).

Lapham (1873, unpublished field notes) briefly mentioned a building stone quarry owned by Carl Busack a little west of Schoonmaker's and mentioned that a spring from the rock surface deposited considerable iron rust, discoloring the ground.

Chamberlin (1877, p. 365-367) described and illustrated the relationships of the Busack and Schoonmaker quarries (see the discussion of the Schoonmaker quarry for details). He also noted that (1877, p. 367):

> The rock at Storey's (sic) and Schwickhart's (sic) quarries, within the triangle before mentioned, is closely similar to that in the western part of Busack's quarry, and the same remark may be made of the fossils, which consist mainly of _Orthoceratites_. But in Busack's quarry, where the strata approach the reef, the fauna is much amplified, and we find _Halysites catenulatus_, an undetermined _Trematopora_, _Streptelasma_ and _Fenestella_, _Stephaocrinus gemmiformis_, _Orthis biloba_, _O. elegantula_, _Strophomena rhomboidalis_, _Streporhynchus subplanum_, _Atrypa reticularis_, _Rhynchonella neglecta_, _Platyceras Niagarense_, _Orthoceras annulatum_, a new species of _Phragmoceras_, found also in the adjoining reef, a _Gomphoceras_, _Calymene Niagarensis_, _Encrinurus ornatus_, and a new species found also at Zimmerman's quarry, _Illaenus Ioxus_, and _Bronteus Acamas_.
>
> From all the foregoing facts, it may be regarded as fairly demonstrated that these horizontal beds were laid down simultaneously with the formation of the mounds. The cellular nature of the rock of the latter, and the uncompressed condition of fragile fossils, are fatal to any theory of upheaval, or other violent action.

A newspaper article (_Milwaukee Sentinel_, May 11, 1874) stated that the Milms Brothers, sons of the late C. T. Milms, have become the proprietors of the Wauwatosa quarry until recently worked by Mr. Carl Busack.

Alden (1898, unpublished field notes) stated that in the S 1/2 of Section 22 "just west of the point of the hill is a quarry hole full of water. The rock is exposed in the west slope of the hill, but about 5 ft. above the flat (nearly horizontal)." Alden (1906) also described this quarry and this description is under the section on the Schoonmaker quarry.

Shrock (1930, unpublished field notes) could find no trace of the Busack quarry.

W. Manegold (1976, personal communication) noted that the quarry was about 150 feet from State Street. He recalled that the Busack quarry was small and very shallow in parts; he remembers seeing a cow standing in it in the flat area west of the hill of Schoonmaker reef. He also recalled that the Schoonmaker quarry had encroached on Wauwatosa city land and had to let the city use part of the quarry as a free dump which was buried with 10-20 feet of dirt.

It is possible that this quarry site was quarried away during westward expansion of the Francey operations in the adjacent Schoonmaker reef, or it could possibly have been covered by the present 68th Street since this road had been angled towards the southwest in the early 1900's and part of the former Busack property was excavated by Francey.

Menomonee River Outcrops
Locality 81

E 1/2, NE 1/4, Section 27, and NW 1/4, Section 26, T. 7 N., R. 21 E., Wauwatosa Township, Cities of Milwaukee and Wauwatosa, Milwaukee County

MPM x36.9

elevation:

There are a number of natureal outcrops along the Menomonee River from the footbridge (approximately N. 64th Street) in Jacobus Park, Wauwatosa, for three-fourths mile east to approximately N. 50th Street, where the bridge to the Manegold quarry crosses the river, in Milwaukee. Rock is exposed in the river bed through most of this area, but approximately six feet of rock is exposed around N. 59th Street to N. 60th Stteet on the south side of the river in the Menomonee River Parkway. The rock in this exposure is thick- to thin-bedded dolomite, nodular in appearance with some dense, fine-grained, well-bedded rock at the highest point. A few poorly preserved Dawsonoceras were found scattered on some of the more irregular bedding surfaces in the upper few feet of the outcrop.

Washington Park Sewer Tunnel
Locality 82

SW 1/4, NW 1/4, Section 24, T. 7 N., R. 21 E., Wauwatosa Township, City of Milwaukee, Milwaukee County.
elevation:

In 2969, a 14 foot diameter sewer tunnel was excavated 600 feet north and 200 feet south from a 50-60 foot deep main shaft located near the swimming pool in the northeast corner of Washington Park (J. Emielity, 1979, personal communication). Bedrock excavated from this tunnel was dumped at Schweickhart quarry landfill site one and one-fourth miles to the southwest. The rock is a light brown, dense, massive, fine-grained, locally porous, vuggy fossiliferous dolomite. It appears to be reefal Racine Dolomite and a number of specimens of the tabulate coral Favosites are present, one of which is an elongate colony; also present are one "Amplexus" coral and one gastropod. Pelmatozoans and fine fossil debris is rare or absent. Material collected from this locality is deposited in the Milwaukee Public Museum.

Milwaukee County General Hospital Addition
Locality 83

NE 1/4, Section 28, T. 7 N., R. 21 E., Wauwatosa Township, Milwaukee County Institutions Grounds, Milwaukee County.
elevation: approximately 700 feet

In 1954 an excavation for an addition to Milwaukee County General Hospital struck bedrock approximately 20 feet below the ground surface. The rock exposed might have been part of a mound-like structure since it was not encountered in all parts of the excavation (J. Emielity, 1979, personal communication). Lithologically and faunally rock for this excavation is similar to that from the Schoonmaker reef and probably represents reefal Racine Dolomite.

Lloyd Street Sewer Tunnel
Locality 84

E 1/2, NW 1/4, NW 1/4, Section 19, T. 7 N., R. 22 E., City of Milwaukee, Milwaukee County.
elevation: 595 feet (top of bedrock)

A sewer tunnel was excavated 150 feet south of W. Lloyd Street and just west of N. 25th Street in 1971. Bedrock was reached at a depth of 65 feet. The rock appears to be reefoidal Racine Dolomite, lithologically and faunally almost identical to that of Schoonmaker and Moody reefs. Two lithologies are present, the most predominant being medium light gray, crystalline, massive, slightly porous, fossiliferous dolomite, breaking with an irregular texture and fracture. Local patches of small fossils, particularly "stick" bryozoans as at Schoonmaker reef, are characteristic of this rock. Other fossils include _Bumastus cuniculus_, _Sphaerexochus romingeri_, _Halysites_, _Favosites_, "_Amplexus_," and _Dawsonoceras_. There is little or no pelmatozoan debris present. The other lithology is a very dense, light olive gray mottled medium light gray, crystalline, massive, irregularly breaking (but with a smooth texture), very fine-grained dolomite with little or no porosity. The only fossils are localized occurrences of the brachiopod. Rock from this sewer tunnel was dumped north of the railroad tracks near the center, Section 22, T. 8 N., R. 22 E., City of Milwaukee.

Currie Park (Zimmerman) Quarry
Locality 85

SE 1/4, NE 1/4, Section 7, T. 7 N., R. 21 E., Wauwatosa Township, City of Wauwatosa, Milwaukee County.

MPM x37.13

elevation: 690-700 feet (top of quarry on north side)

A large, completely filled quarry is located on the south side of the Monomonee River west of State Highway 100 in Currie Park. The quarry was dug into a northeast-facing bluff (see Figure 111). The bedrock is quite close to the surface along parts of the Menomonee River in this general area, but no natural outcrops can be positively identified. Abundant slabs of dolomite are present in the river bed adjacent to the quarry site but they may be, in part, the result of former quarrying operations.

This quarry was first mentioned by T. J. Hale (1860, unpublished field notes) who described it as follows:

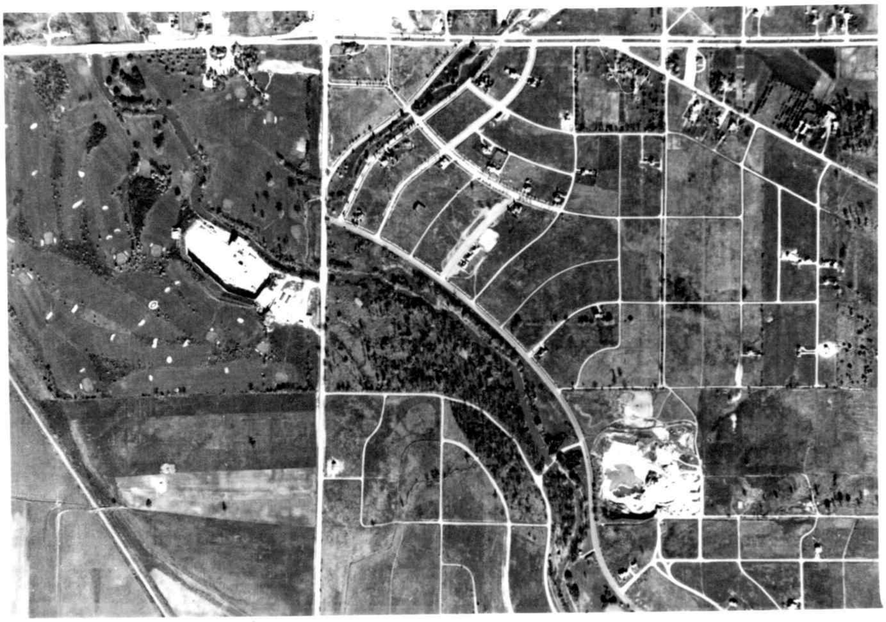
> ...Waukesha Limestone of a softer nature than at Waukesha, and resembles that at Potter's Lake (Castleman's (sic) auarry). The stratification is tin varying from one to two inches in the upper feet of the ledge to 6 inches at the bottom, with an exposure of 18 feet. It is located on the bank of the Menomonee River, is quarried extensively for building and for road material, is owned by Mr. Clark Brookins. A few fossils, slabs are quarried here 4 and 5 feet square but the upper layers are thin and more broken up.

In 1865 I. A. Lapham (unpublished field notes) listed the following fauna from the Zimmermann quarry in the NE 1/4, Section 7:

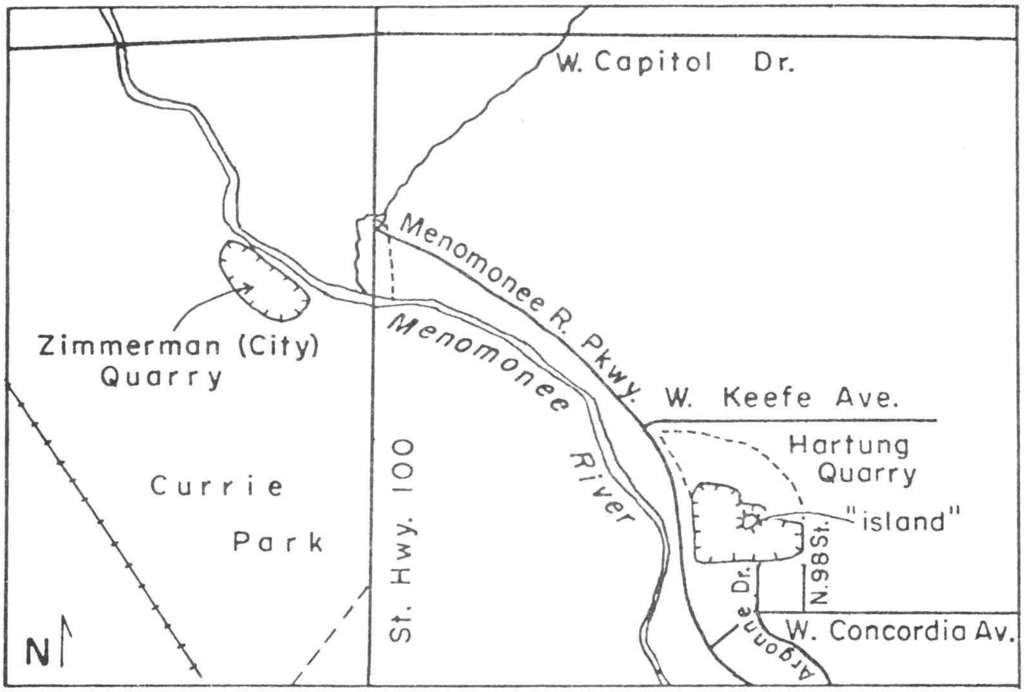
corals
small crinoid
Dalmania vigilans
other trilobites
Atrypa reticularis
Orthocera undulatum

Chamberlin (1877, p. 367) referred to this quarry as Zimmerman's quarry and assigned the exposed strata to the Racine Dolomite. His description is as follows:

Figure 111. Airphoto (A) and locality map (B) of Zimmermann, Hartung quarry, and small outcrop near the intersection of Hwy. 100 and Menomonee River Pkwy. Airphoto from National Archives and Records Service, General Services Administration, No. WX-1B-52; date: 10-25-41.



A



B

Figure 111

...at Zimmerman's quarry, in Section 7, N.E. qr. Wauwatosa, ther is an even-bedded limestone of compact or minutely cellular texture, very similar to that of some layers in the eastern part of Busack's quarry already described, and to which they are equivalent, as shown by the contained fossils. As quarried, the layers are thin, but the true beds are of more considerable thickness, a statement which is true of most or all the flags and apparently thin-bedded strata of this region.

Chamberlin (p. 372-377) also gave a faunal list for this locality. An examination of specimens collected from this locality in the 1880's and early 1890's now housed in the Greene Museum (University of Wisconsin-Milwaukee) indicates that the main trilobite beds, producing abundant specimens of Flexicalymene, had not yet been reached. The following fossils are present in this collection:

Lichenalia - 1
cephalopods - 15
"plants" (=trace fossils) - 10
Dalmanites sp. - 2
Flexicalymene sp. - 1
Encrinurus sp. - 4
brachiopods - 2

In 1898 Alden (unpublished field notes) visited the Zimmermann quarry and described it as follows:

The quarry in the west bank of the Menominee (sic) and shows a 10-25 ft. section. The rock is stripped of 4-6 ft. of buff till on the uphill side. The rock is thin bedded and shelving at the top, thickening downward till 3-6 in. in thickness. The bedding is nearly horizontal and the rock is little disturbed and fractured...The rock is dolomitic... The weathered surface is light buff and the fresh fracture an even gray limestone. The rock is generally even grained and quite easy to dress. In one or two places there is disintegration along a joint to light yellow clay. The rock is not very fossiliferous though some specimens were found...

Minute pores of pitchy asphalt were seen in some places. Glaciation is seen on the stripped surfaces.

Alden (1906, p. 2) published a description of this quarry based on his earlier field work and suggested that these strata belonged to the upper part of the Racine Dolomite. He also located the quarry on his Areal Geology Map.

The Zimmerman Farm was purchased by Milwaukee County in the early 1900's as a park site, however, the quarry was still used extensively for building stone purposes, especially by W.P.A. projects during the 1930's. During this period the quarry was referred to by various names, including Currie Park quarry, City quarry and County quarry (see Figure 112). Rock from this quarry can still be seen lining creek banks in various parts of Milwaukee and large blocks were also dumped as rip-rap along the Lake Michigan shore.

Shrock (1930, unpublished field notes) measured a detailed section (see Figure 113) of the quarry as follows:

Bed 1. The lowest 30 in. are under water but the rock appears to be the same as that above.

The three beds, 10 in., 28 in., and 19 in. are exposed only in the sump. The top of the 19 in. forms the floor of the quarry.

The rock is a dense, fine, even-grained, light-colored dolomite with fairly smooth, conchoidal fracture. The individual layers are separated by thin films of dark blue shale 1/16 to 1/8 in. thick. In the floor of the quarry this shale appears to be composed of peculiar fucoidal, strap-like structures. Throughout the rock occur strap-like and stringer structures

Figure 112. Photographs of the west and south walls of the Zimmermann quarry (locality 85) while being worked by the City of Milwaukee, circa 1920's. Photo courtesy of Milwaukee Public Museum No. 417744 and 417746.

Figure 112

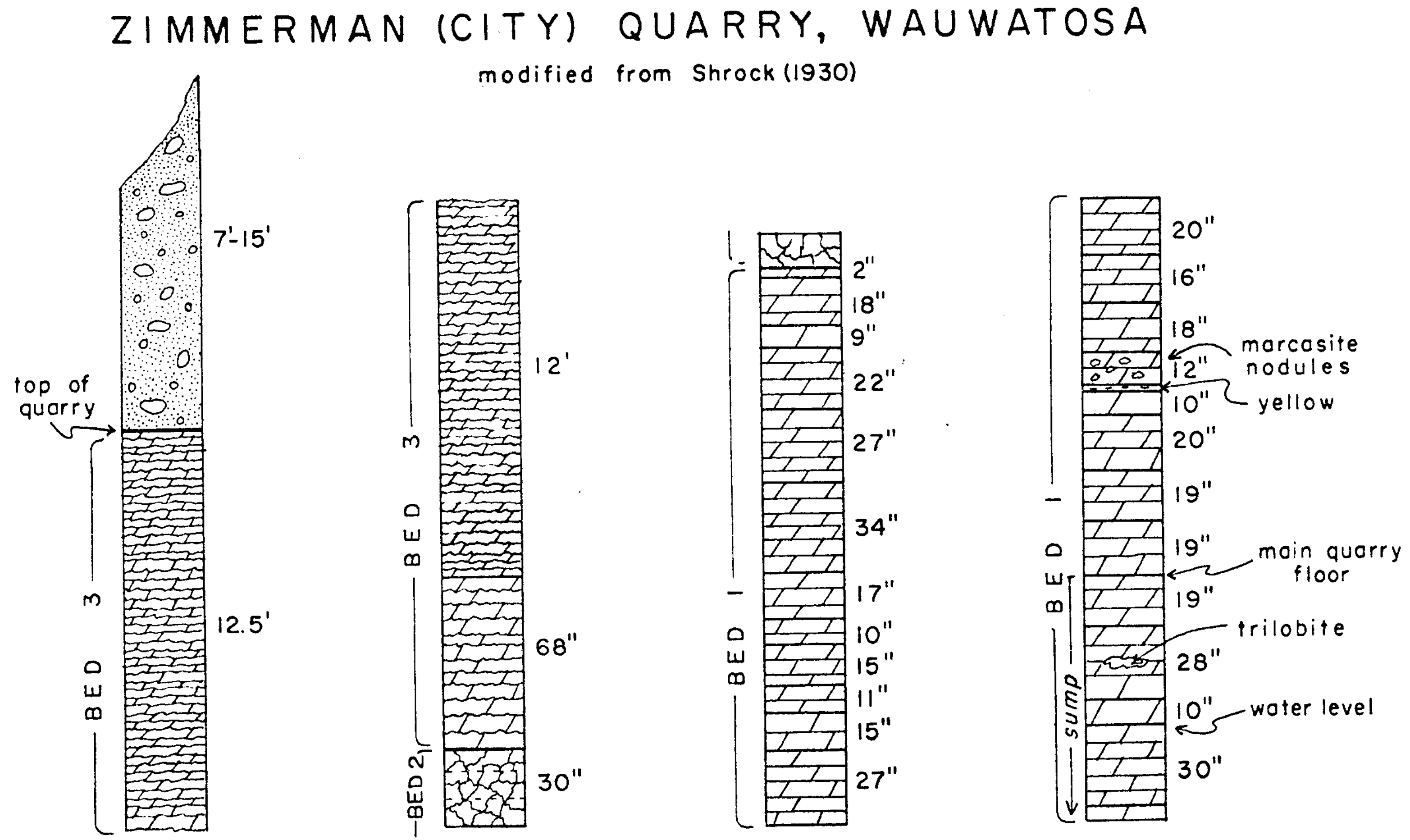


Figure 113. Section in the Zimmermann quarry (locality 85) Milwaukee County (after Shrock, 1930, unpublished field notes).

of black color. They may be sea-weeds. Much like markings of Mississinewa shale, which the rock resembles very closely. A fairly well-preserved Calymene was found in the 28 in. bed.

The individual beds break into wedge-shaped units and exhibit beautiful conchoidal fracture. Small nodules (1/2 in. ±) of marcasite are common in some of the beds, in the middle portion of the section.

The rock is quite homogeneous throughout the entire section, retaining it a blue color, except where changed to buff along the separation planes by weathering, and appearing massive, although breaking into thinner courses when thoroughly weathered.

Bed 2. Lumpy, bluish-gray, dense, dolomite with a very hackly fracture. The rock disintegrates like rotten concrete, but is quite massive in the quarry wall. Upon weathering it seems to be composed of many brecciated fragments enclosed in a matrix much like the material of the fragments. The stone has a light brownish tinge which also sets it apart from the lighter underlying rock. Somewhat porous.

Bed 3. Light-colored, flaggy, porous dolomite. The separation planes are lumpy and sometimes have thin films of dark shale along them. Numerous iron-stained crinoid stems. Several large cephalopods were observed in this section. The rock has an irregular fracture, weathers to an earthy condition and becomes buff-colored.

The lower layers average 4 in.-6 in. or more inches. The upper 8 ft-10 ft. is bluer and somewhat more crystalline.

Flags vary in upper portion from2 in.-4 in. thick.

The upper surface is beautifully striated and polished, with the striae striking in a S62W direction.

During the 1930's the main trilobite bed was reached and large numbers of Flexicalymene celebra and other trilobites and brachiopods were collected by G. O. Raasch and others. The following is a faunal list made by Raasch at that time:

<u>Dictyonema</u>?
<u>Duncanella borealis</u>?
<u>Amplexus</u>?
<u>Favosites</u> (small Maryland form)
crinoid joints and plates
Undet. Bryozoan (discoid growths)
Undet. Bryozoan (fuliform, encrusting)
<u>Fenestella</u> sp.
<u>Semicoscinium</u> sp.
<u>Crania</u> (striate, coarsely)
<u>Crania</u>? (elevated)
<u>Dinobolus</u>? (minute)
"oboloid" (fine muscle scars)
Undet. Neotremate?
<u>Dictyonella reticulata</u>
<u>Dictyonella</u>? (good)
<u>Camarotoechia</u>? sp. (good)
<u>Atrypa reticularis</u>
<u>Atrypa</u>? (fine, sculptured, concentric markings)
Undet. Brach (4)
<u>Spirifer radiatus</u>
<u>Reticularia bicostata</u>
<u>Meristina</u>? sp. 1 (1 good specimen)
<u>Meristina</u>? sp. 2 (2 specimens)
<u>Rhynchospira</u>?
<u>Dalmanella elegantula</u>
<u>Rhipidomella hybrida</u>?
Undet. brach=Dalmanellae?
<u>Orthis flabellites</u> var.
<u>Bilobites bilobus</u>?
<u>Plectambonites</u> sp.
<u>Chlorinda ventricosa</u>?
Undet. pentameroid? (1)
<u>Calymene niagarensis</u>
<u>Cheirurus niagarensis</u>
<u>C. hydei</u>
<u>Phacops handwerki</u>
<u>Sphaerexochus romingeri</u>
<u>Illaenus cuniculus</u>
<u>Illaenus</u> sp.
<u>Encrinurus egani</u>
<u>E. tuberculifrons</u>
<u>Dalmanites platycaudatus</u>

Staurocephalus? sp.
Dalmanites sp. 2
Undet. Odontopleuridae or Lichididae
Undet. part of trilobite
at least 3 species of ostracods

Large collections made by Raasch and other individuals are in the Milwaukee Public Museum and somewhat smaller collections are in the University of Wisconsin Geology Museum and the Museum of Paleontology at the University of Michigan, Ann Arbor. The exact depth of the main trilobite layer is not known, but it was approximately in the middle of the section when the quarry had reached its maximum depth (80-90 feet?) (Raasch, 1973, personal communication; J. Emielity, 1979, personal communication).

In 1937 the quarry was visited as the last stop (Stop #12, City-County Quarry) on the Tri-State Field Conference (Thwaites *et al.*, 1937) and the following description was given:

> The strata exposed in the Currie Park quarry belong entirely to the inter-reef facies of the Racine. The even bedding and the somewhat uniform thickness of the beds makes this rock excellent for building purposes. Most beds contain few fossils but one about 20 feet from the top of the quarry is frequently studded on the surface with tests of *Calymene*.

This measurement of the depth of the main trilobite bed as 20 feet from the top of the quarry was probably made along the river (north) side of the quarry where the surface of the bedrock was some 10 to 20 feet lower than on the south. This would account for the differences in depths reported by Thwaites *et al.* (1937) and Raasch and

Emielity. It is also of interest that the idea for the formation of the National Association of Geological Teachers was conceived at this site on that 1937 Tri-State Field Conference by F. Fryxell, D. Delo, N. Miner, L. Wilson, and M. Wing (F. Fryxell, 1979, written communication).

Eisemann (1940) briefly mentioned this quarry and illustrated the building stone operations there.

Sometime after 1941 the quarry was used as a dumpsite and by the late 1940's only a few feet of rock was exposed (J. Emielity, 1979, personal communication). By 1950 the quarry was completely covered. Essentially the same beds, including the main trilobite later, are still exposed in the Hartung quarry, which is presently a dumpsite.

W line, SW 1/4, NW 1/4, NW 1/4, Section 8, T. 7 N., R. 21 E.,
Wauwatosa Township, City of Wauwatosa, Milwaukee County.
elevation: approximately 690 feet

In the late 1960's bridge construction at the intersection of W. Menomonee River Parkway and W. Grantosa Parkway on the east side of State Highway 100, just east of the Currie Park quarry site, uncovered a few feet of rock (thin- to medium-bedded, light brown dolomite) (see Figure 111) like that exposed in the Hartung quarry and formerly exposed in the Currie Park quarry. At the north end of the bridge on the south side of the stream a foot or so of rock is still exposed.

Hartung Quarry
Locality 86

NE 1/4, SW 1/4, and along the West line of the NW 1/4, SE 1/4, Section 8, T. 7 N., R. 21 E., Wauwatosa Township, Cities of Milwaukee and Wauwatosa, Milwaukee County.

MPM x37.14

elevation: approximately 700 feet (bedrock surface is highest in S 1/2 of the quarry and lowest in the northeast corner)

The quarry is bounded by W. Keefe Avenue on the north, W. Menomonee River Pkwy. on the west, and W. 99th Street on the east. This is the site of the large abandoned quarry which is currently being used as a landfill site by the City of Milwaukee. The quarry was started around 1910 by F. Hartung (W. Manegold, 1976, personal communication). There are no known natural outcrops in this area and the quarry was begun when bedrock was uncovered in a gravel pit. The quarry appears to have been opened in its current southeastern corner and was operated towards the west and north from that location.

Shrock (1930, unpublished field notes) considered this rock to be part of the Racine Dolomite and gave the following section (see

Figure 114):

Bed 1. Light gray to bluish gray, dense, compact earthy dolomite in even beds, which are heavy when fresh, but which break into thin beds when thoroughly weathered. Beds 4-8 inches.
The rock has many strap-like markings of a fucoidal nature, many small black stringers-streaks of black to blue whale very thin, and many marcasite nodules which leave holes and stain the rock when they decompose.
Trilobites occur quite abundantly at certain horizons as indicated and are very well preserved.
The large pocket of shale occurs along the east face of the sump and is composed of laminated or massive shale, sandy shale, etc., all yellow, blue, or green in color.
Some of the bes, and parts of some of the beds, where water circulation has been good, are weathered to a buff color and are a bit earthy to "sandy."

Bed 2. Pinkish to light-chocolate colored, crystalline druzy dolomite, having the appearance of breccia in places. Weathers nodular. Breaks up into thin layers 2-4 inches thick separated by stylolite seams. Hackly fracture.

Bed 3. Flaggy, light colored, dense, even-grained dolomite. Layers average 4-8 inches.
The upper 15 feet of Bed 1 are being quarried for rubble and building stone, the courses running about 4-8 inches thick. Other rock crushed.

Shrock also described the fauna in some detail:

The indicated beds in Bed 1 of the quarry carry a very unusual trilobite fauna, both in numbers and state of observation. Hundreds of trilobites or their casts were seen and many fine specimens collected. On a single slab 8 specimens were found. The trilobite apparently belong to only two species.

Calymene niagarensis
Ceraurus sp.

The former are by far the more prolific of the two. Only two specimens of the latter were collected (or seen). Associated fauna with the trilobites were found-

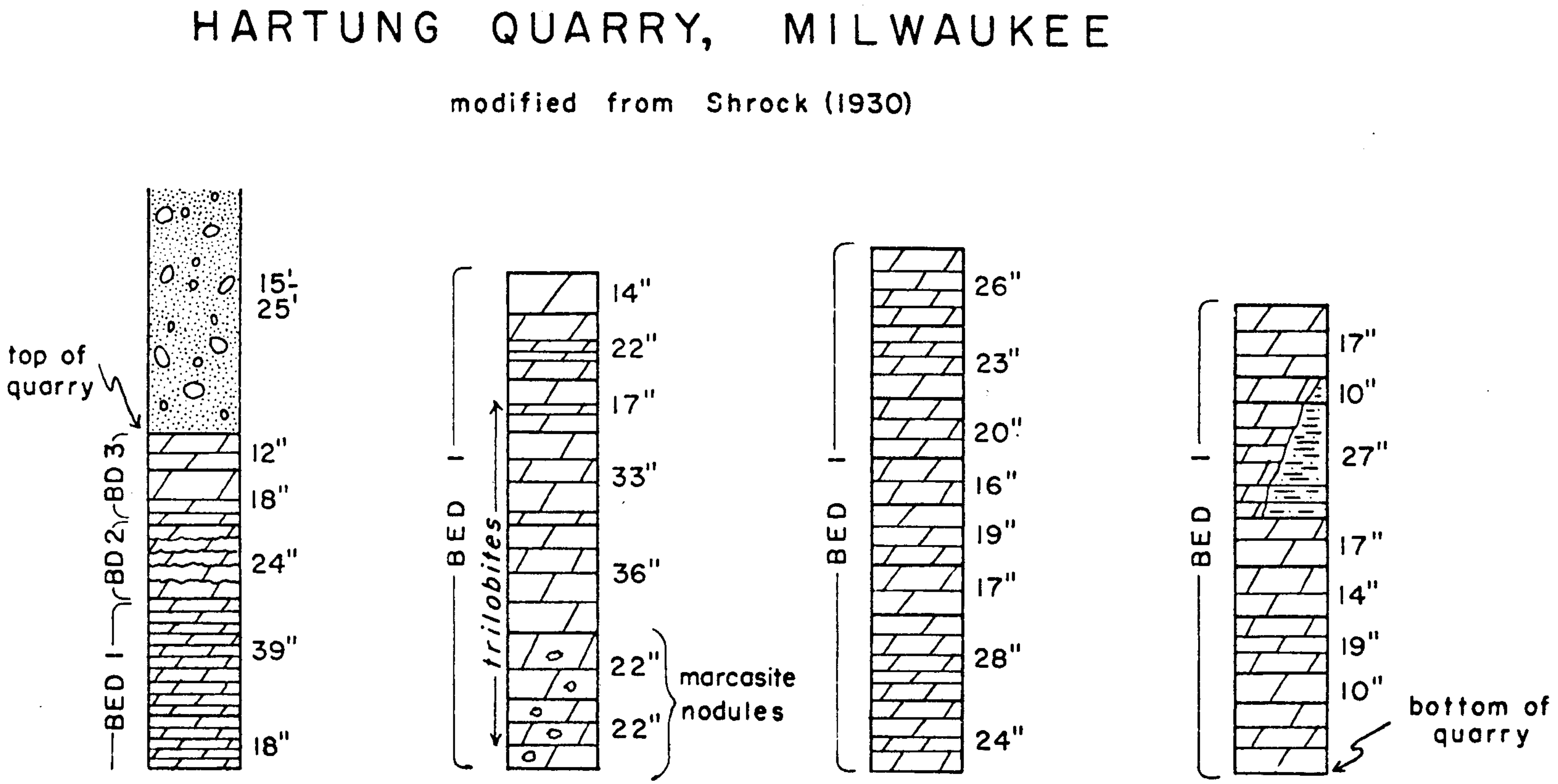


Figure 114. Section in the Hartung quarry (locality 86) Milwaukee County (after Shrock, 1930, unpublished field notes).

Atrypa reticularis
Leptaena rhomboidalis
Gypiula? sp.
a fenestellid bryozoan
a gastropod close to Hormostoma
Camarotoechia? sp.

Where the trilobites are most prolific, however, no other forms were seen. The quarry workers reported that when the trilobite bearing beds were being quarries they saw many of the "bugs."

Bed 2 contains no fossils so far as examination indicated.

Bed 3 carries a cephalopod fauna. No other fossils were seen. The cephalopods are chiefly annulates, several being 12-18 inches in length and 1 1/2-2 inches across. Probably 6-8 specimens were seen but only two were collected.

In addition to the more easily identified forms, there occur throughout the quarry section many minute stem-like markings which are black and in some cases partly pyritized. There are also some large strap-like markings, some of which are several inches long and 1/8-2/3 inch wide. There may be sea weeds. The Mississinewa Shale of Indiana carries a similar fauna.

Large numbers of the trilobite Flexicalymene celebra and the associated fauna have been collected from this quarry, particularly in the 1950's and 1960's, and can still be found after diligent search. A large collection of this material (mostly assembled by J. Emielity) is present in the Milwaukee Public Museum collections.

The quarry was closed in the early 1960's and has been used as a dumpsite since then (see Figure 115); approximately 30 feet of the lowest beds in the section formerly exposed in the quarry have been covered, but 70 feet are still exposed. This lower 30 feet was paleontologically and lithologically very similar to overlying beds.

Figure 115. Photographs of the Hartung quarry (locality 86), Milwaukee County. (A), looking northeast with "island" on the right; (B) looking southwest. Photos courtesy of Milwaukee Public Museum, taken in 1962, Nos. G-114-L (A); G-114-D (B).

A

B

Figure 115

In general, the rock in this quarry is a fine-grained, well-bedded dolomite, with beds averaging 6 inches to one foot in thickness. The rock appears to be massive along large, weathered vertical joints, but in reality it is well-bedded. The predominant color of the rock is very pale yellowish-brown on fresh surfaces and weathers to a light gray. The fossils in these beds are dark yellowish-brown on fresh surfaces and weather to light gray. There are also beds, particularly in the upper part of the section, that are a very pale orange with dark yellowish-brown fossils, with both fossils and matrix weathering to a pale yellowish-brown. Stylolitic bedding planes are common as are dark, very thin, irregular, argillaceous bedding partings. Small fossils are common in a few layers, occurring as numerous minute cavities. Some bedding planes have many dark-colored, horizontal trails and there are occasionally small vertical burrows filled with marcasite.

A section measured in the vicinity of the sump and continuing up along the "island" is as follows:

Unit 1. Five to six feet of very fine-grained, very pale yellowish-brown, thick-bedded-appearing dolomite, with some beds approximately four to six inches thick. Stylolitic bedding planes are occasionally prominent. Some beds are mottled with numerous medium-gray, horizontal trails(?). Fossils are rare.

Unit 2. Unit 2 is 22 inches thick and is conspicuous with a nodular appearance on weathered surfaces. This unit is very pale yellowish-brown mottled with a medium gray. Rock is more crystalline than other units in the quarry. There are some small vugs lined with calcite crystals.

Unit 3. Unit is six feet eight inches thick and is similar to Unit 1, being a dense, fine-grained, very pale yellowish-brown with scattered medium gray horizontal and vertical trails and burrows. The upper one foot contains a three inch fossil layer with common minute fossil fragments and a few scattered larger fossils. The bottom half of this unit contains only a few small fossil fragments. Bedding appears to be massive, but breaks into six to eight inch beds. On vertical faces rock breaks with large-scale conchoidal fracture. Near the middle of this unit some beds become more fossiliferous with a few brachiopods, small rugose corals, and pelmatozoan stem fragments being conspicuous.

Unit 4. Twelve inches. Same as Unit 2.

Unit 5. Eighteen inches. Similar to Unit 3 in appearance with beds four to eight inches thick. There are a number of burrows and trails in this unit and vertical surfaces of the beds appear to have a large-scale conchoidal-like fracture when broken. A 15 inch thick, fossiliferous layer is found four feet two inches from the top of this unit. Small fossils, particularly pelmatozoan fragments, brachiopods, rugose corals, and trilobites, are common in this layer. The largest fossils are usually trilobites, being two to three inches in length; brachiopods are seldom more than one-half inch in diameter. The larger fossils are generally localized in lensoidal-like accumulations. The trilobite *Flexicalymene celebra* is the most common trilobite and is usually found complete. Other trilobites are usually disarticulated with the exception of specimens of "*Cheirurus*" hydei, which are often found partially articulated. This layer contains the highest fossil diversity of any bed in the quarry.

Unit 6. Twenty-five feet of poorly fossiliferous, fine-grained, dense dolomite yellowish-brown at the top with little mottling and some pyritized burrows and trails. Upper two feet is very thin-bedded with irregular bedding planes. Four feet five inches from the top is a layer of small scattered rounded marcadite nodules. Shrock's (1930, unpublished field notes) trilobite beds came from this horizon at approximately the same level as the marcasite band, but are not present at the location of this section. Trilobites are found at this level in other parts of the quarry, particularly the north and west walls.

Unit 7. Thin-bedded dolomite as below which is seven feet six inches thick. At the bottom of this unit is a six inch layer containing small vugs. Four feet from the top is a layer of fossiliferous debris, primarily small pelmatozoan fragments with small rugose corals and brachiopods. No trilobites are present.

Unit 8. This unit is 24 inches thick and the same as Shrock's (1930, unpublished field notes) Bed 2.

Unit 9. This unit is 12 inches thick and the same as Shrock's (1930, unpublished field notes) Bed 3.

There are at least three different trilobite beds in this quarry. A trilobite layer formerly was exposed along the west wall about 10 to 15 feet below the level of the section. This layer contains *Flexicalymene celebra* and other typical fossils of this association. The main trilobite layer has already been described as having the highest fossil diversity of any beds in the quarry. Most of the *Flexicalymene* occur above the main concentration of fossils in this layer. The trilobite bed described by Shrock (1930, unpublished field notes) contains mostly *Flexicalymene* with only a few other fossils present.

Throughout the entire section trace fossils are reasonably common and orthocones up to several feet in length are scattered through many of the beds, including those that appear to be otherwise unfossiliferous.

Petzold's Quarry and Mud Creek Exposures
Locality 87

W 1/2, SW 1/4, NE 1/4, and NE 1/4, SW 1/4, Section 1, T. 7 N., R. 21 E., Wauwatosa Township, City of Milwaukee, Milwaukee County.

MPM x36.11 and x36.12

elevation: 640 feet at easternmost exposures

A number of old quarries and outcrops are located along Lincoln (Mud) Creek in the Lincoln Creek Parkway, just south of the part of Milwaukee known as North Milwaukee. The outcrops extend south from W. Glendale Avenue to W. Congress Street and west along Lincoln Creek Parkway to N. 39th Street. Lincoln Creek has been partially straightened and examination of Alden's (1906) Areal Geology Map shows that outcrops were formerly present along the creek as it continued to the south from its current bend to the west at the center of Section 1 to about W. Hope Avenue (W 1/2, NW 1/4, SE 1/4, Section 1). Additional exposures were located at the former site of the creek between approximately N. 38th Street and N. 39th Street in the vicinity of N. Sercombe Street (SW 1/4, NE 1/4, SW 1/4, Section 1, MPM x36.12). Both of these areas were covered when the stream was straightened. Several feet of the Wausakee are currently exposed along the east bank of the creek and a foot or so is exposed along the west bank, as well as in the creek bed.

Walling (1858) showed that the land in the SW 1/4, SW 1/4, NE 1/4, Section 1 was owned by G. Groose. Two lime kilns were located on each side of the creek on this property.

Hall (1862, p. 70) described beds of the Onondaga-Salt Group and mentioned that the outcrop "is in low or level ground, a few miles to the northwest of Milwaukee." He was probably referring to the Mud Creek locality.

Chamberlin (1877, p. 390-394) in his description of the Lower Helderberg Limestone stated that (p. 390):

> Four miles northwest of the city of Milwaukee--Sec. 7, town of Wauwatosa--in the banks of Mud Creek, are two low exposures of a shaly limestone, that differs in lithological character from both the Niagara limestone, upon which it rests, and the Hamilton cement stone, by which it is overlaid. The rock is a hard, brittle, light gray, magnesian limestone, distinguished by numerous minute, angular cavities, that give it a very peculiar, porous structure. It is thin bedded and laminated, by virtue of which it splits very readily into flags and thin plates, which are, for the most part, too brittle, and too much subject to further splitting, to be serviceable as paving, but which are considered valuable for Macadamizing. A transverse fracture of some of the layers exhibits an alternation of gray and dark colored laminae, peculiarly characteristic of this formation. The rock is nearly pure dolomite...

He also mentioned that the rock under the Hamilton cement stone (Middle Devonian Milwaukee Formation), exposed around the present site of Estabrook Park two miles to the east, was equivalent to the Mud Creek beds, but these beds are now thought to be part of the

Devonian Thiensville Formation. Chamberlin reported that the fossils were very rare in the Lower Helderberg, but he did find one specimen of Meristella nucleolata, an Orthis, and a poor specimen of Meristella or Pentamerus after a long search, apparently collected at the Mud Creek locality.

Alden (1898, unpublished field notes) described Emil Petzold's quzrry (see Figure 116) in Section 1 as follows:

> The limestone is exposed in the creek bed and has been excavated giving a ten foot section. The rock is a hard gray dolomitic rock, finely laminated and very thin bedded in the upper. Splitting in slabs 1/2 inch in thickness. The layers thicken downward to four or five inches but no good foundation rock has been taken out. A crusher has just been put in running probably 50 yds. per day. About one dozen men are employed. The rock was used by Mr. Petzold's father for lime, and is said to have made very strong lime. Beds 2 ft. thick were said to have been removed, but are now under water and not seen. The strata are nearly horizontal. No traces of fossils were seen in the rock. The rock is exposed in the creek bed for about 3/8 of a mile between the two railroad bridges. It shows slight variation in dip of 5° either to north or south.

In 1960 Alden (p. 2) included the Mud Creek exposures in his Waubakee Formation of the Cayuga Group:

> The deposits are best exposed at Mr. Emil Petzold's quarry on Mud Creek, 1 mile south of North Milwaukee. The same beds are exposed one-fourth of a mile further west, on the same creek. The rock is gray to brownish-gray finely laminated magnesian limestone, splitting readily into slabs one-half inch to four inches thick. A thickness of 10 to 12 feet is exposed. The lower strata are more unevenly bedded and contain streaks of blue clay. In general the strata are very nearly horizontal, but at the western exposure they dip 5° toward the east.

Figure 116. Photograph of Emil Petzold's quarry (locality 87), Milwaukee County along Mud (Lincoln) creek looking west. Photo by W. C. Alden, No. 111, 1899.

Alden also located these exposures on his Areal Geology Map. In 1918 Alden (p. 93-95) published the same description.

Raasch (1927, unpublished field notes) described the quarry as follows:

> In the banks of Mud Creek, within the limits of North Milwaukee, beds similar to the upper strata at Waubaka may be seen. At no time of the writer's visits was there ever more than 4 feet of rock visible, but some 12 feet were formerly exposed when the quarries were open.

Shrock (1930, unpublished field notes) visited the quarry, noting the following:

> The Waubakee limestone formation is exposed along the river for over 1/2 mile in section 1. In the south end of North Milwaukee the rock has been taken out of a quarry alongside the stream. The quarry is now filled with water.
>
> About 5 feet are exposed along the edges of the quarry. Several feet are also exposed in the banks of the stream to the east.
>
> The Waubakee is a very thinly laminated gray to bluish gray dolomite which breaks along the laminations more easily than across them, hence a larger block is rather hard to acquire. Some of the layers are banded and some have small cavities. In many respects it is much like the Kokomo.

The above was a description of the exposures in SW 1/4, NE 1/4, Section 1. In the NE 1/4, SW 1/4, Section 1 Shrock found:

> The Waubakee formation, similar to that at the abandoned quarry 1/2 mile northeast is exposed along the east bank of the stream just north of the C. E. Wussow Construction Co.'s building. Dredging has thrown out great quantities of the thinly-laminated, gray dolomite which is piled on either side of the stream. The rock is chiefly in the bed of the stream where it is concealed.

Klug (1977) summarized previous work on the Waubakee beds and reported that samples from the Mud Creek exposures were processed for condonts, but were barren.

A sewer tunnel in 1976 reached rock like that exposed along Lincoln Creek, just south of the center of Section 35, T. 8 N., R. 21 E., at the intersection of N. 51st Street and M. Villard Avenue, in Milwaukee. The rock was dumped at Silver Spring dumpsite in Butler, Waukesha County. C. Klug (personal communication, 1979) related that the bedrock surface was approximately 40 feet below ground level (at elevation of 630 feet) and that about 20 feet of rock was excavated. Near the bottom of the exposure the platy beds alternated with more porous beds about four inches thick.

Silver Spring Sewer Tunnel
Locality 88

North line, NW 1/4, NE 1/4, Section 36, T. 8 N., R. 21 E., Granville Township, City of Milwaukee, Milwaukee County.

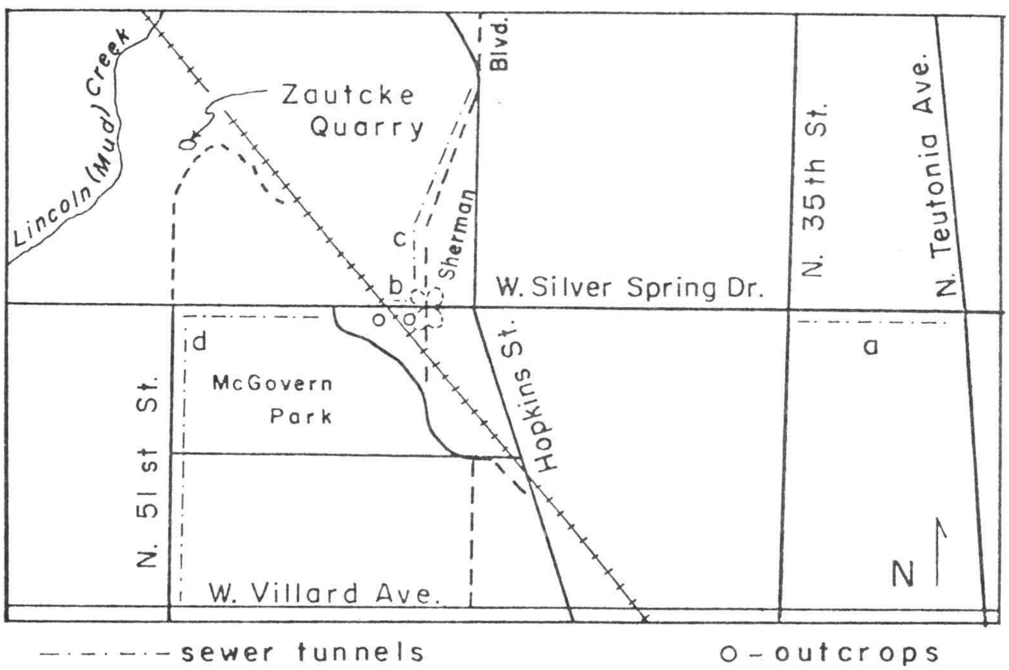
MPM x36.24

elevation: 640 feet (top of bedrock)

In 1952-1954 shallow sewer tunnels were excavated along W. Silver Spring Drive between N. Teutonia Avenue and N. 34th Street (see Figure 117). J. Emielity (1952, unpublished field notes) noted that the tunnel was excavated 25 to 30 feet below the surface and approximately 10 feet of Silurian rocks was cut at the southwest

Figure 117. Airphoto (A) and locality map (B) for localities 88-90, 92, Milwaukee County. Airphoto from National Archives and Records Service, General Services Administration, No. WX-1B-112; date: 10-25-41.

A



B

Figure 117

corner of W. Silver Spring Drive and N. Teutonia Avenue, about 20 feet beneath the surface; at N. 35th Street to N. 34th Street about 15 to 20 feet of rock was cut. Emielity (1968, personal communication) reported that the strata dipped in one direction in one shaft and in another direction in the other shaft. Material collected by Emielity is in the Milwaukee Public Museum collections.

The rock is highly fossiliferous, fine-grained, massive, light olive gray, crystalline, dense dolomite, breaking with an irregular fracture and smooth texture. It has low porosity, but it is vuggy. Lithologically, it is very similar to, and faunally somewhat similar, to the reefoidal Racine Dolomite at the Schoonmaker reef.

Two different faunas are present. One is dominated by large pentamerid brachiopods, many of which are articulated (identified as Pentamerus sp. by Boucot and Johnson, 1979, p. 99), Dawsonoceras cephalopods and Favosites. The other fauna is comprised of abundant and well-preserved Halysites, with Favosites, Syringopora, Heliolites, and Dawsonoceras. There is little or no pelmatozoan debris in either fauna.

Chamberlin (1877, p. 391) reported:

> At Schwartzburg, a mile north of the outcrops on Mud Creek, rock was reached in the excavation of a cellar, which presents all the lithological characteristics of the Niagara Limestone, and contains Pentamerus ventricosus, a Niagara species.

This locality of Chamberlin's appears to have been in the same general vicinity of these sewer tunnels.

Locality 89

SE corner, SE 1/4, Section 26, T. 8 N., R. 21 E., Granville Township, City of Milwaukee, Milwaukee County.
MPM x36.25
elevation: approximately 650 feet

On the north side of W. Silver Spring Drive, east of the railroad tracks, Emielity (1952, unpublished information) reported a sewer tunnel (see Figure 117) approximately 20 feet deep in bedrock. In 1964 another tunnel in the same area, at a depth of about 30 feet, was also excavated in bedrock (Emielity, 1964, unpublished information). The rock is typical Racine Dolomite, reefal in appearance, similar to that at the Schoonmaker reef.

Locality 89

E 1/2, SE 1/4, Section 26, T. 8 N., R. 21 E., Granville Township, City of Milwaukee, Milwaukee County.

In 1966 a sewer tunnel was excavated along the west side of N. Sherman Boulevard (see Figure 117) from approximately N. Hopkins Street south to approximately the intersection of the railroad tracks with W. Silver Spring Drive. The rock is typical reefal Racine Dolomite, as is exposed in the outcrops immediately to the south and in the Schoonmaker reef. At a shaft near the railroad tracks along Silver Spring Drive, rock with a Hartung-like lithology was excavated along with more reefal material. The sewer tunnel turned west from this location along W. Silver Spring Drive to N. 51st Street and then south to W. Villard Avenue, where typical Waubakee rock was being excavated (see Petzold Quarry locality description). Rock from these tunnels was dumped at the dumpsite south of Silver Spring Drive and the west side of the Menomonee River in Butler, Waukesha County.

McGovern Park Outcrop
Locality 90

NW 1/4, NE 1/4, NE 1/4, Section 35, T. 8 N., R. 21 E., Granville Township, City of Milwaukee, Milwaukee County.

MPM x36.23

elevation: 670 feet

An outcrop (see Figure 117) is present just east of McGovern Park on the west and east sides of the railroad tracks, just south of W. Silver Spring Drive. Apparently the rock forms a low hill approximately 10 feet high just south of W. Silver Spring Drive on which the railroad tracks have been laid. The eastern exposures were more extensive until a ramp for the N. Sherman Boulevard overpass was constructed in the 1960's at which time most of the exposed rock was removed. The rock appears to be massive, reefoidal Racine Dolomite like that exposed in the Schoonmaker reef.

Reynolds' Quarry
Locality 91

SE 1/4, Section 6, T. 6 N., R. 22 E., Lake Township, City of Milwaukee, Milwaukee County.

There are several reports of an old quarry operated by John Reynolds in the south part of Milwaukee during the 1860's and 1870's. I. A. Lapham (1865?, unpublished notes) gave a faunal list for a Reynolds' quarry in the 11th Ward (8th Avenue) on the south side of Milwaukee (8th Avenue in this area is not S. 13th Street). The fossils from this locality include:

Syringopora
Halysites calenolaria
Heliolites macrostylus
3 other corals
Pentamerus

This quarry is listed twice in Catalogue B (List of the Localities and Formations from which the Specimes Distributed during the Present Year were collected; Chamberlin, 1880): No. 219 Niagara Formation, John Reynolds quarry; No. 312a Niagara Formation, South Milwaukee, J. Reynolds Quarry, Racine beds, T. C. C. collection. No descriptions of the quarry have been recorded and it has not been mentioned since Chamberlin (1880).

An examination of old plat books and city directories has not revealed what land was owned by John Reynolds in this area. A J. Reynolds is believed to have operated a lime kiln on the Walsh property at the Trimborn quarries in the mid-1800's, and he may have been the operator of the Milwaukee quarry as well.

The available information indicates that the quarry was situated in fossiliferous Racine Dolomite. The dominance of tabulate corals, including Syringopora, at this locality is suggestive of a reef occurrence, such as Moody reef to the north, and not like the reefs to the south af Racine of southern Milwaukee County. It is unfortunate that this quarry cannot be located or that better descriptions cannot be found since it was the only exposure in this area.

Zautcke Quarry
Locality 92

SW 1/4, NW 1/4, SE 1/4, Section 26, T. 8 N., R. 21 E., Granville Township, City of Milwaukee, Milwaukee County.

MPM x36.17

elevation: 660-670 feet

A small filled quarry (see Figure 117) is located approximately 1100 feet almost straight north of the intersection of N. 51st Street and W. Silver Spring Drive, on the west side of the railroad tracks.

Alden was the first to describe this quarry. He (1898, unpublished field notes) reported that Fredrick A. Zautcke had just opened a stone quarry; the rock being a massive, very hard, dolomitic limestone with no stratification and containing much clay. The rock surface was rounded and smooth, particularly on the north and east sides, due to glacial activity, while on the west and southwest sides it was somewhat rough.

In 1904 Alden (unpublished field notes) mentioned that the quarry on Zautcke's estate had not been operated for three years and the whole exposure was "one of the limestone mounds" (reef). On the south side of the quarry was a:

> ...6-7 ft. section of massive, irregular-textured, open porous, hard gray dolomite, many small holes. Fossils seem to be plentiful. Four foot hole in bottom exposes rock with rather more bedding. It is mottled bluish gray, lighter brownish gray, appears very hard, rather rough textured and porous. Fractures rather uneven.

Alden reported specimens of Illaenus (Bumastus) and was told that there were six inch and nine inch beds at bottom.

Alden (1906, p. 2), as part of his discussion on the Racine Dolomite, described this quarry based on his earlier observations adding that there were numerous specimens of Illaenus. The approximate location of this quarry is indicated on his Areal Geology Map.

Raasch (1927, unpublished field notes) visited the quarry, then on the House of Correction grounds, noting that the quarry was full of water and located on a "much glaciated knob of Silurian dolomite." He considered the rock here to be the same type as that at the Schoonmaker reef.

In 1930 Shrock (unpublished field notes) visited the quarry and made the following observations:

> There is a small water-filled quarry... in the reef facies of the Racine Dolomite. The rock is a gray to blue, tough, cavernous dolomite without bedding and in the form of a mound... The rock surface is rolling and has been striated and polished by the movement of glaciers over it.

Drift was five to twelve feet deep over the bedrock surface, and Shrock believed that the quarry was located in a small bedrock mound.

Shrock (1939) briefly mentioned this small, water-filled quarry:

> The rock is massive, uneven-textured, cavernous dolomite, of which only a few feet can now be seen around the edge of the quarry. The surface of the exposure is uneven and has been grooved and polished by the Pleistocene glaciers.

From these descriptions it appears that this exposure was a small mound of reefal Racine Dolomite, lithologically and paleontologically similar to that exposed at Schoonmaker reef.

This quarry was completely filled by the 1950's and no signs of its existence can now be detected.

Granville Exposures
Locality 93

N 1/2, NW 1/4, NE 1/4, Section 29, and SW 1/4, SE 1/4, Section 20, T. 8 N., R. 21 E., Granville Township, City of Milwaukee, Milwaukee County.

MPM

elevation: approximately 710 feet

A number of small outcrops and a small quarry are located along the west side of the Little Menomonee River in the Little Menomonee River Parkway, in the vicinity of its intersection with W. Mill Road.

Chamberlin (1877, p. 365) presented the first description of this locality in his discussion of the Racine Dolomite:

> About four miles to the southeast (middle N line, Section 29, Granville, Milwaukee County), we find a mound of confused, unstratified rock, having a north and south axis. The rock is dirty buff in color, and soft, granular, and almost pulverulent in texture. Eight-five paces to the southeast of this, is a similar, but much smaller, mound, on the north side of which a quarry has been opened in even bedded, rather soft and porous dolomite, the layers of which dip into, or under, the mound at an average angle of about 4°. Pentamerus (Gypidula) multicostata abounds in these layers, and, in the larger mounds, is associated with other Niagara fossils.

Chamberlin (p. 377-380) also mentioned these outcrops in his discussion of the Guelph beds of the Niagara limestone. He stated that the mound at Granville was very similar to the reef structure of the

Racine Dolomite. He also presented a faunal list for exposures in Section 29.

Chamberlin (1880, p. 35) listed a DeWorth's quarry being present in the NE 1/4, Section 29, at Granville.

Alden (1906, p. 2) briefly mentioned the Granville outcrops:

> ...about 3 miles farther north is a small mound of open, porous, much-weathered limestone, containing gastropods, brachiopods, and corals.

He also indicated the approximate location of this locality on his Areal Geology Map.

Shrock (1930, unpublished field notes) described the outcrops of Racine Dolomite at the following exposures:

> 1. A small mound of porous buff to bluish buff dolomite, probably reef facies.
>
> 2. A mound, 5-7 ft. high which contains bedded stone, exposed along the creek, above which is massive, gray, somewhat nodular fossiliferous dolomite which when weathered powders easily.
>
> 3. The road cut through 3 exposes about 5 feet of the porous reefy dolomite facies. On the south side bedded stone of slightly denser character in layers about 2-4 in. thick underlies the reef. Similar bedded stone is exposed under the bridge Soft, buff, porous, cindery-feeling dolomite in the bedded facies. The reef facies weathers to a yellow sand and is quite fossiliferous.

A small mound, showing no stratification, approximately ten feet high, is present on the south side of W. Mill Road. It is fossiliferous in its upper six to seven feet, with fossils including poorly preserved Favosites, brachiopods, small orthoconic cephalopods, gastropods, and rare crinoid stems. This upper rock is buff, granular dolomite with abundant small cavities. The lower three feet is compact, unfossiliferous, granular, white dolomite which is very poorly bedded, having irregular bedding planes, some of which are very stylolitic. Cavities and vugs are nearly absent in these lower layers.

Adjacent to the Little Menomonee River and just south of W. Mill Road is an old, poorly exposed stone pit, approximately six to eight feet deep. The rock here is thin, irregular-bedded, fine-grained dolomite, similar to the lower layers in the mound. This same kind of rock is also found in the river bed adjacent to the stone pit.

North of W. Mill Road there is a small, probably rock-controlled hill. Bedrock is very close to the surface and was exposed in sewer tunnels between W. Mill Road and W. Beale Street in 1971-1972. In the early 1960's construction of the State Highway 145 freeway bridge also exposed rock in the river bed; this rock was dumped at the car dealership to the north.

Brown Deer Exposures
Locality 94

N 1/2, NE 1/4, Section 10, and S 1/2, SE 1/4, Section 3, T. 8 N., R. 21 E., Granville Township, City of Brown Deer, Milwaukee County.

MPM x36.19

elevation: approximately 660-680 feet

Excavations in the vicinity of W. Brown Deer Road from N. 60th Street to N. 68th Street have reached bedrock close to the surface in the past.

Raasch (1928, unpublished field notes) mentioned that two feet of fossiliferous Racine Dolomite were excavated in a cellar between State Highway 100 and a small creek to the south in the NW 1/4, NE 1/4, Section 10.

In 1961 bedrock was excavated in a sewer tunnel at a depth of about 30 feet, approximately at N. 68th Street, and W. Brown Deer Road (State Highway 100) (Emielity, 1961, unpublished notes). The rock from this excavation is massive, dense, fine-grained, light gray, vuggy, fossiliferous dolomite. Tabulate corals are common, including *Favosites* and number small "*Amplexus*," a few cephalopods (*Trochoceras*), and brachiopods are also present. Pelmatozoan debris is rare or absent In general, the rock is reefal Racine Dolomite like that found at the Schoonmaker reef. Similar rock appeared to be quite close to the surface along the creek, west of N. 60th Street, and some was excavated when the creek was straightened in the early 1960's.

In 1973 a sewer tunnel was excavated along the north side of W. Brown Deer Road, east of N. Park Plaza Court (= N. 66th Street), S 1/2, SW 1/4, SE 1/4, Section 3. Bedrock was uncovered close to the surface along the east side of N. Park Plaza Court, near the intersection with W. Brown Deer Road, and for a few hundred feet east along the north side of Brown Deer Road. The rock is a blue-gray to light brown, massive, vuggy, dense, crystalline, fossiliferous dolomite; typical reefal Racine Dolomite like that found in the 1961 sewer tunnel. Most of the fossils are corals, including small irregular hemisphaerical favositids (two inch diameter) and "Amplexus" (one-fourth inch diameter). A few stromatoporoids and rugose corals, brachiopods, gastropods, and the cephalopod "Trochoceras" are also found. Overall the corals are small and characterized by upward, as opposed to horizontal, growth. Pelmatozoan debris is rare or absent.

OZAUKEE COUNTY

The bedrock is close to the surface in many parts of Ozaukee County. Quaternary sediments are seldom more than 150 feet and usually less than 100 feet thick. The bedrock is very close to the surface in the southwestern part of the county in a continuation of the northeast-southwest trend of shallow bedrock which extends north from Waukesha County; this trend continues on northward to Port Washington. There are a number of exposures along rivers and streams (Milwaukee River, Cedar Creek, Sauk Creek) in this county in contrast to Waukesha County. The Silurian is unconformably overlain by Devonian rock along the Lake Michigan shore from Port Washington north to Lake Church and probably south to Milwaukee County, although it is not known if the Devonian is continuous throughout this area. Devonian outcrops are also found along Sauk Creek (north of Port Washington), near Grafton, and north of Thiensville.

The thickness of the Silurian is not well known, but in the southern one-third of the county it ranges from 370 feet, at the western edge of the county, to 540-600 feet around Cedarburg and Grafton. Just north of the study area, near Oostburg, Sheboygan County, the Silurian is 720 feet thick, exhibiting the thickening trend to the north-northeast.

The Silurian rocks in Ozaukee County are all considered to be in the Racine Dolomite, with the exception of the Waubakee Beds. Unfortunately, there are no deep quarries or cores in this county so the nature of most of the Silurian section is known only from water-well logs, which are not reliable for most correlation. Although there are numerous outcrops and abandoned quarries in the county (see Figure 118), only one quarry is actively worked at this time near Cedarburg and since many of the exposures are located near cities there is little likelihood of new operations being started in view of current regulations governing the industry.

Localities 95 and 96

NE 1/4, SE 1/4, SE 1/4, Section 19, T. 9 N., R. 21 E., Mequon Township, Ozaukee County.
MPM x37.20
elevation: 780 feet

Just west of County Highway F (Granville Road), about .2 mile north of State Highway 167 (Mequon Road) a small abandoned quarry (locality 95) is located in a low, bedrock-controlled hill. The locality is indicated as a small gravel pit on current topographic quadrangles.

Raasch (1928, unpublished field notes) described this quarry as a Racine Dolomite reef. He found the exposure very similar to those immediately to the south (MPM x37.19, locality 96). The

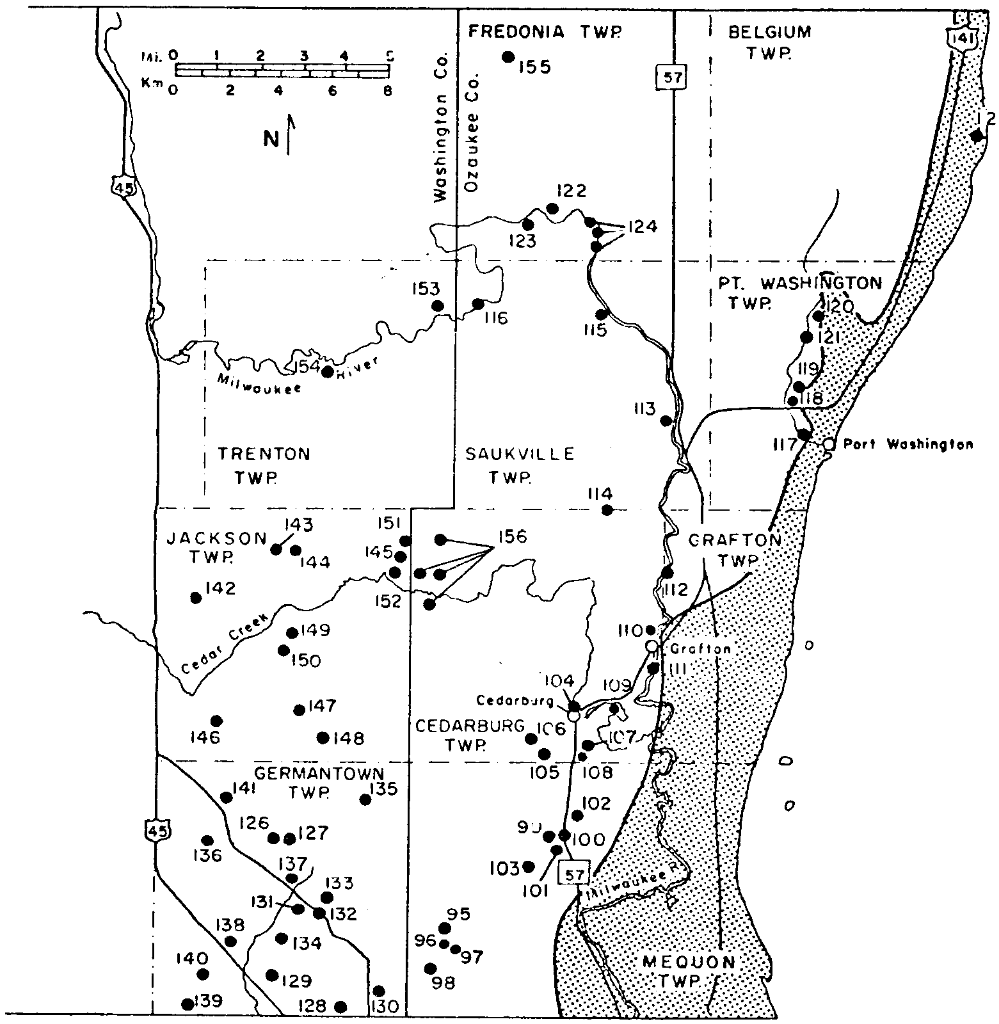


Figure 118. Locality map for Ozaukee and the eastern one-third of Washington Counties showing the numbered localities referred to in the text.

quarry was abandoned and the rock face was badly weathered. Approximately 10 to 15 feet of reef rock was exposed which contained common favositids and conspicuous lenses of pelmatozoan debris. Raasch stated that "the quarry had completely hollowed out an isolated dome."

The quarry is still accessible, but is heavily overgrown in most places. This reef and the exposures at MPM x37.9 are similar, both lithologically and paleontologically, to the reefs in Germantown and Menomonee Falls, to the west, and the reefs around Racine, to the south.

Locality 97

E 1/2, NE 1/4, NE 1/4, Section 30, T. 9 N., R. 21 E., Mequon Township, Ozaukee County.
MPM x37.19
elevation:

A small abandoned quarry and outcrops are located in the hill on the west side of Little Menomonee River, just southeast of the intersection of Mequon Road (State Highway 167) and Granville Road (County Highway F).

Raasch (1928, unpublished field notes) described these reefal exposures of the Racine Dolomite, where he found about 15 feet of semi-stratified reef rock exposed in the then working quarry beside the creek. An additional five feet of rock was present in the hill above the quarry and scattered ledges of a more compact, yellowish rock were exposed in the hillside about another 15 feet above that. In the reef rock, Raasch found lenses of common pelmatozoan debris, colonies of Favosites and stromatoporoids. Brachiopods and crinoid calices were also common.

Alden (1918) indicated the approximate location of this locality of his Geologic Map of Southeastern Wisconsin.

The same exposures are still present at this locality, but the quarry is overgrown and the rocks are very weathered.

Locality 98

Center of S line, SE 1/4, SW 1/4, Section 30, T. 9 N., R. 21 E., Mequon Township, Ozaukee County.

MPM x37.23

elevation: 770 feet

There is a small abandoned quarry (locality 98) located on the north side of Donges Bay Road, just east of a private dirt road running north to a farm, and about 1800 feet east of Wasaukee Road and the west boundary of Ozaukee County. The quarry is indicated as a small depression in a woods on the 1958 Menomonee Falls 7.5 minute quadrangle.

Raasch (1928, unpublished field notes) referred to this quarry as the O'Connell quarry (Sullivan's) and described the Racine Dolomite exposed there as follows:

> The quarry on the north side of the road is remarkable in that the beds show a pronounced dip in the south wall about 20° south and in the north wall about 45° south. This is probably initial dip about a core of reef rock such as rises immediately to the north to a height of about 29 feet above the top of the quarry. The rock is structureless. The rock removed from this quarry was used in the building of part of St. Catherine's church at MPM x37.22, east of Granville.

Small rock exposures can be seen along the private road ascending the hill to the north, which seems to be in part reef-controlled. Rock in the exposures is similar to that in the quarry. The quarry is now overgrown and partly filled with rubbish. In the early 1970's rock from excavations along the north-south road in the new subdivision to the west was dumped in the quarry. This rock was fossiliferous and reefal in appearance; the external mold of a complete Calymene was observed.

Alden (1918) indicated the approximate location of this quarry on his Geologic Map of Southeastern Wisconsin.

Electric Company Quarry (Thiensville)
Locality 99

NE 1/4, SW 1/4, Section 10, T. 9 N., R. 21 E., Mequon Township, Ozaukee County.

MPM x40.3

elevation: 700 feet

An abandoned and water-filled quarry is located about two miles north of Thiensville, on the north side of Pigeon Creek and 700 feet west of the bend around the bluff in State Highway 57. The quarry formerly exhibited 15 feet 10 inches of Devonian rock overlying 35 feet of Silurian rock; only about five feet of Devonian beds are still exposed above the water level.

Devonian outcrops are also exposed in the road cut at the bend in State Highway 57 (locality 100) (the type section of the Thiensville Formation), along Pigeon Creek (locality 101) southeast of the quarry; along the railroad track southeast of the intersection between State Highway 57 and County Highway G (locality 102), .6 mile northeast of this quarry; and there was once possibly Devonian exposed in a small filled quarry (locality 102) between Highway 57 and the railroad tracks, a short distance southeast of this quarry.

Raasch (1928, unpublished field notes) described a section in the quarry and referred the Silurian beds there to the Racine

Dolomite. He found the Devonian to be 15 feet 10 inches thick and the Silurian-Devonian contact to be somewhat unconformable. The highest Devonian rocks were exposed along the middle of the north wall. Raasch measured the following section at this quarry owned by Milwaukee Electric Railway and Light Company:

Bed 1. Silurian-Racine. Dolomite, massive reef rock much of which shows evidences of solvent activity. Rock usually compact, vitreous, light gray, becoming more yellowish toward top, where the beds are penetrated by vast numbers of subangular, parallel, vertical openings, about 1/4 inch in diameter and of unknown significance. Fossils abundant where not destroyed by solution. Fauna similar to that at Grafton, with Monomerellas in great variety and abundance, a small Pentamerois, Atrypa reticularis, Modiolopus, Mytilarca oncoceras, Orthoceras (very small) and numerous gastropods. . . . . . . 35 feet

Bed 2. Lake Church (Ozaukee)-Devonian. Basal reworked zone of varied lithology, never alike at any two points. Where section is taken, about 1 foot of calcareous(?) shale bluish gray in color overlies the massive light colored Racine and is succeeded by a lensing mass of beds, including zones of massive dolomite, calcareous(?) shale, and dolomite conglomerate . . . . 3 feet 1 inch

Bed 3. Devonian. One or two layers of very compact and fine-grained, brittle, dark gray dolomite, very homogeneous with undulating darker and lighter laminae. Local . . . . 1 foot 3 inches

Bed 4. Devonian. Dolomite, mottled light and dark gray and varying in texture, the dark areas being the more compact and resistant. The zone as a whole is compact and well stratified in layers about a foot thick. In the upper part, the bedding planes are covered with bluish shaly material and the rock usually is more argillaceous and less compact than in the lower part. Much marcasite is present throughout and gives a bright yellow color to weathered beds. Joint planes distant.

Fossils are abundant in the upper 5 feet but the fauna is limited and the specimens poorly preserved. The lower part of the fossil zone is a crinoidal limestone, with bands of a large Productella and Stropheodonta demissa type. The highest beds contain principally corals including branching and dumose Favosites, Aceivularia and cup corals. A species of high spired gastropod is occasionally found in the fossil zone. Upper beds weathered into knobby surfaces due to the irregular induration. A large low spired gastropod also fairly common . . . . 11 feet 6 inches

Shrock (1931, unpublished field notes) measured the following section in this quarry (Bed 1 is at the bottom of the quarry):

Bed 1. Buff, generally porous dolomite, with obscure bedding. Upper 10-15 feet more fossiliferous, becoming bluer and better bedded upward. Shaley layer marks uneven contact with bed 2. Upper part has D. conradi, Trimerella, Halysites, a small small corallited Favosites, a few cup corals, pentamerids (rare), gastropods (Diaphostoma and Hormostoma types) and some pelecypods. The brachiopods are very numerous.
The lower part is more like a reef sand, composed in places of nothing but a calcareous sand. In these places large cavernous holes appear. Elsewhere slightly denser . . . . 45 feet

Bed. 2. Bluish gray, dense, fairly well-bedded dolomite, which weathers lighter and breaks conchoidally. Contains considerable pyrite . . . . 10 feet

Bed 3. Impure, rotten, unevenly-bedded dolomite in thin beds. Looks like concrete-matrix chocolate-colored pebbles like material. Nodular. Shaley in thin, uneven, irregular layers . . . . 7 feet

Much of Bed 1 is very much like the fossiliferous beds of the quarries west of Manitowoc, both as to lithology and fauna, and are very likely to be correlated with them.

A specimen in the Milwaukee Public Museum collections (MPM No. 21638) collected from the Silurian at this quarry in 1934 is from a typical cavity- or depression-filling of disarticulated trilobites, which are found in many southeastern Wisconsin Silurian reefs. The trilobites are all specimens of Bumastus ioxus, a species found in quarries to the north and west and also in Racine and the southern half of Milwaukee County. This occurrence indicates that at least some of the Racine beds at this locality are reefal, as suggested by Raasch.

The 1937 Tri-State Field Conference visited this quarry (Stop No. 9, Thiensville Quarry; Thwaites et al., 1937). They draw attention to the Silurian-Devonian contact exposed here, and assign the lower coarse, granular beds to the Racine Dolomite as well as referring the upper formation, overlying the irregular contact, to that Lake Church Formation.

Shrock (1939) observed that some of the upper beds in this quarry resemble some of the beds at the Groth quarry in Cedarburg.

This quarry was abandoned sometime after 1939 and is currently filled with water. In 1970 a proposal to reopen the quarry for a fixed time period after which it would be converted into a park for the City of Mequon was not approved by that city, and the quarry remains abandoned.

Exposures in the Vicinity of Cedarburg

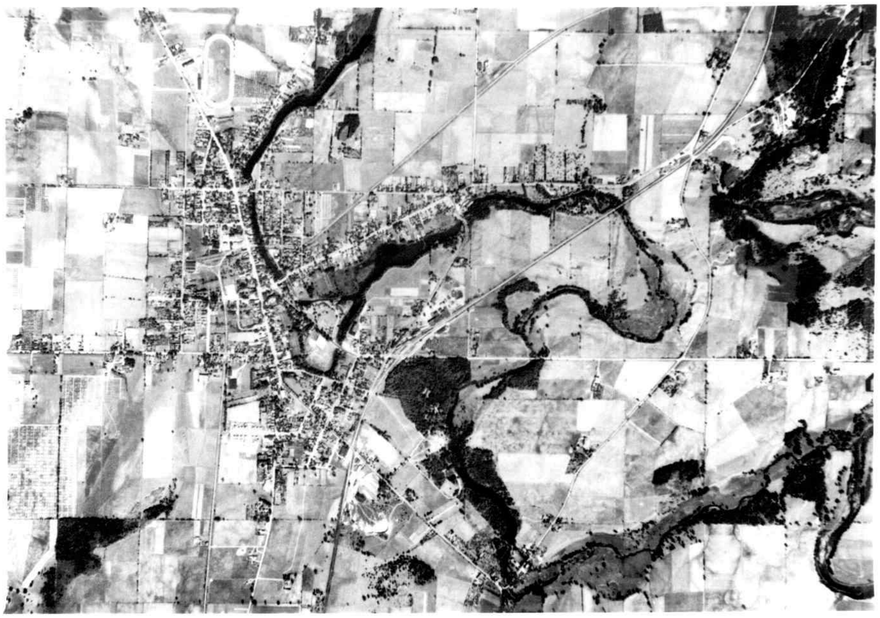
The bedrock is close to the surface throughout most of the Cedarburg-Grafton area and a number of outcrops are present, including those along Cedar Creek in Sections 26, 27 and 35. Several quarries have operated in this area, including Groth's, Anschütz's, and Kreiger's, all of which are now abandoned. A small, but deep, quarry is currently operating just east of the center of Section 22, which opened after bedrock was uncovered in a gravel pit. A brief examination of this quarry showed the rock to be very similar to the reefoidal exposures at Groth's quarry. See Figure 119 for localities.

Chamberlin (1877, p. 362, 377-378) briefly described exposures in the Cedarburg-Grafton area as part of both the Racine and Dolomite and Guelph Beds, assigning most of the exposures around Cedarburg to the Racine. He described these as follows:

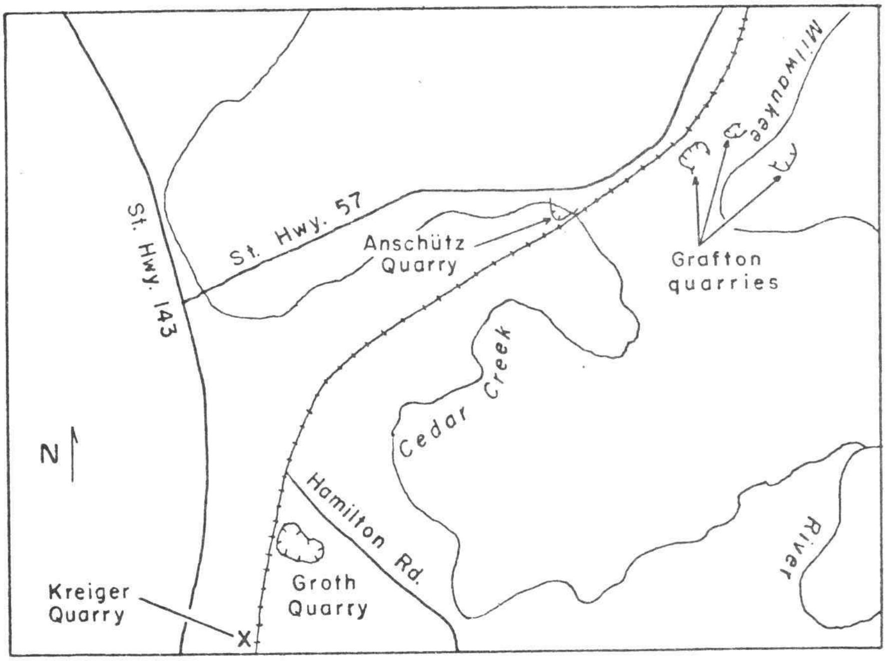
> At the village of Cedarburg, most of the rock is a soft porous, granular, minutely crystalline, dolomite, varying in color from white to light cream. Occasionally, cavities of the size of a walnut or larger appear, but they are not frequent. The beds are from 2 feet to 4 1/2 feet thick, but not well defined nor are vertical fissures regular or prominent. The local dip varies from 1° to 3 1/2° in a southwesterly direction, but is changeable.
>
> Other portions are harder and more compact, some of which, however, when mined back from the exposed surfaces, become softer and more granular, at variance with usual fact.

Some of the outcrops in the Cedarburg area will be described in the following discussion in more detail.

Figure 119. Airphoto (A) and locality map (B) of the Cedarburg-Grafton area, Ozaukee County. Airphoto from National Archives and Records Service, General Services Administration, No. XG-1B-39; date: 9-7-41.



A



B

Figure 119

Locality 103

NE 1/4, SE 1/4, Section 9, T. 9 N., R. 21 E., Mequon Township, Ozaukee County.

MPM x41.4

elevation: approximately 750 feet

There are bedrock exposures along the creek west of County Highway N. Raasch (1928, unpublished field notes) reported a low exposure of Racine Dolomite along the creek, displaying eight feet of typical massive, vitreous, light yellow dolomite with fossils including a Syringopora-like coral, the same as that found at locality MPM x40.3.

Locality 104

SE 1/4, Section 27, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County

Alden (1899), unpublished field notes) described exposures in this area as follows:

> The old meander of the Cedar Creek below the dam follows a 30-35 ft. bluff of stony till. Limestone is seen in the section in the east side just south of the hill and lies near the surface on the flat, which shows very much limestone in the soil.

Locality 105

SW 1/4, SW 1/4, Section 34, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County.

MPM x41.5

elevation: 790 feet

Raasch (1928, unpublished field notes) reported Silurian outcrops at this locality, east of County Highway N, about one mile south-southwest of Cedarburg.

Locality 106

NE 1/4, NE 1/4, SE 1/4, Section 33, T. 10 N., Cedarburg Township, Ozaukee County.

MPM x41.6

elevation: 820 feet

Rock outcrops occur along a rock-controlled hill just west of County Highway N and north of a small creek in Section 33.

Chamberlin (1877, p. 363) described this exposure as follows:

> Near the center of the east line of Section 33, Cedarburg, there is an outlier of rough, coarse brecciated dolomite of light gray color. It is composed of fragments of compact rock, the spaces between which are filled with a yellow pulverulent material. As the rock of the vicinity has been swept away, leaving it about 30 feet higher than its base, it is probable that it was surrounded by the softer granular beds that are prevalent in this neighborhood.

Alden also visited this area and observed the following exposure (1899, unpublished field notes):

> There is here in the land of Jim O'Brien a ledge of limestone outcropping near the east line road and rising 15-20 feet about the marshy strip on the south and east. The rock is rather massive, scarcely showing bedding. It is a dolomitic limestone of very open porous texture and very much weathered. In the more solid part it is bluish gray like the Niagara limestone. Where more loose it is buff and looks like a calcareous sandstone. Some parts have a pinkish tint. It all weathers gray on the surface. The rock is full of minute pores and cavities in the looser parts and is quite cyrstalline. It is quite fossiliferous showing corals, fucoids, brachiopods, gastropods, crinoid stems.. It is undoubtedly Niagara but I can not say if it is Guelph. The surface shows much weathering and no glaciation. The ledge is thinly covered with soil and much limestone pieces.

This 10 foot high hill of massive, reefoidal Racine Dolomite is exposed just west of the road and extends both to the north and west. The rock is lithologically identical to that exposed around Cedarburg.

Groth Quarry
Locality 107

S 1/2, NW 1/4, and N 1/2, SW 1/4, Section 35, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County.

MPM x40.5

elevation: 750 feet

There is a large abandoned quarry southeast of the intersection of Hamilton Road and the railroad tracks and north of Lincoln Boulevard.

Chamberlin (1877, p. 379-380) gave faunal lists for unspecified localities in the NW 1/4 and SW 1/4 of Section 35 in Cedarburg; the locality in the NW 1/4 is probably the Groth quarry locality and that in the SW 1/4 is most likely Kreiger's quarry. These conclusions are based on Alden's observations and on the variety of gastropods and cephalopods found at these localities.

Buckley (1897, unpublished field notes) visited the John Groth quarry at Cedarburg. He found that two irregular-shaped quarries with a depth of 15 to 20 feet were being worked. The western quarry was the most active. He reported:

> The stone is mainly the light porous and fossiliferous rock, similar to that which is found in parts of the Germantown quarries--some of the denser blue stone is found but in much less quantities. The small cavities which make the stone have a fine spongey appearance are largely the casts of fossils. They sparkle in the light due to many small crystals found along the walls.

He later (1898, p. 328) published a similar description of the quarry.

Alden (1899, unpublished field notes) also visited this quarry and made the following observations:

> At the exposure east of railway and just south of Groth's lime kiln the rock is quite solid and more massive in character, broken by vertical and oblique fractures. The rock is considerably broken perhaps due to blasting. It is a gray dolomite weathering grayish and pitted with holes. Is not the loose open texture seen below the dam on Cedar Creek however. Is not so highly fossiliferous as the rock west of Railway. Shows a few gastropods, some large curved cephalopods and favositid corals. I noted no brachiopods or trilobites. Is evidently Niagara perhaps

running westward below the beds seen west of railway... Old quarry just north of kiln not working on account of water. 30+ ft. section. Rock hard gray dolomite above becoming loose, open textured buff limestone below. Upper part much broken into small pieces, lower part in sort of heavy 3-4 ft. courses but really is little evidence of bedding, but rather is massive and considerably fractured. Few fossils seen. Crinoid stems and coral line growths about all. Evidently Niagara limestone. The rock is in the form of a hill, but thinly covered with soil, little or no till. Top part so weathered and fractured as to show no striae. Has rather gentle slope to northeast, other sides may have been quarried. But little building stone has ever been taken out. Not well suited for that. Is poor rock but gives good lime with scarcely any waste. In the newer quarry at present being worked there is about a 40 ft. section. The rock is massive with no evidence of bedding. It is almost entirely the loose open textured buff limestone with many fragments of crinoid stems and some corals but not much else in the fossil line. Below the rock is not much fractured but above on the east side it is all broken up and much weathered. Mr. Groth says there was a surface sag over the quarry and the waters probably percolated down from this. The rock is hand drilled and blasted. There is but a thin coating of soil and till over the rock. Rock too much broken up to show glaciation. A few brachiopods were seen and one (?) trilobite. At one point Orthoceras is abundant. One cast was large as my arm. This is evidently Niagara. No gastropods were seen.

Grabau (1903, p. 342-343) made the following observations at Groth's quarry:

In the vicinity of Cedarburg several quarries show reef characters. Groth's quarry, near the railroad station, is opened in the flanks of a reef which forms a hill, and is shown in the eastern wall of the older, abandoned portion of the quarry. Fossils are numerous in this portion, consisting chiefly of corals, though mollusk shells are also common. The bedding is obsolete here, while stylolite structure is commonly seen. In the western part of the old portion of the quarry bedding is well shown, the strata dipping west and south. Correspondingly, fossils are scarce. The part of the reef exposed is about 30 or 40 feet in thickness, while the length from north to south is perhaps 300 feet. Dolomitization has gone on to a considerable extent, and in many of the bedded strata the corals have been dissolved out. As a result, cavities, either limed with crystals or empty, abound, these usually marking the former position of a stromatoporoid or other coral. In the new portion of the quarry the rocks are all composed of coral, shell, or crinoid sand, and are locally known as sandstones. Fossils are rare, those found being chiefly brachiopods or crinoid fragments, with an occasional cephalopod shell. The succession of bedded strata is as follows:

3. Porous vermicular dolomite, brittle and with stratification poorly developed, full of cavities of dissolved corals . . . . about . . . 20 feet

2. Hard white granular lime rock . about . . . 8 feet

1. Soft friable brown lime sandstone . . . . . . 10 feet

Total . . . . about . . . 38 feet

He later (1913) published a similar description.

Shrock visited the Groth quarry in 1931 and again in 1924, making detailed field notes of the exposures. He (1939) published a detailed description of this locality, based on his earlier observations, including a diagram of the reef exposed there.

The Groth quarry was abandoned in the late 1940's or early 1950's and has partially filled with water. In the mid-1960's extensive exposures up to 30 feet high were present along the walls except in the northwest one-third of the north wall. In the northeast one-third of the north wall a mound of rock at the top of the quarry marked the site of the reef core described by Shrock (1939). Approximately 200 feet west of the northeast corner of the quarry a number of large trilobite-cephalopod accumulations were found in the upper 15 feet of the wall. The trilobites are represented predominantly by Bumastus ioxus, with some Kosovopeltis. The reef core area was fossiliferous, as described by Shrock (1939), with large "Amplexus"-like colonial corals being particularly noticeable in comparison to other reefs in southeastern Wisconsin. Pelmatozoans did not appear to be as common as was reported by Shrock. Along the east wall a gastropod fauna similar to that found around the Grafton area quarries was found in the "nodular beds" mentioned by Shrock. In the late 1960's the east wall and the eastern part of the south wall were blasted down in order to make a gentle slope to the water level. The reef core exposed along the north wall was later covered with fill. The exposures along the west wall and the west one-half of the south remain intact, and an examination of this area suggests that the mound of rock along the south one-half of the west wall may be a reef, possibly the same one that was also exposed in the northeast corner of the quarry.

Frest, Mikulic and Paul (1977) briefly mentioned this quarry and the occurrence of cystoids in it.

Mikulic (1977) mentioned the gastropod beds exposed in this quarry.

Cedarburg City Well No. 5 (Oz-89, elevation: 790 feet) a short distance to the west of the quarry in SW 1/4, SW 1/4, NE 1/4, Section 34, shows the following section:

0-23 feet	Drift
23-205 feet	Yellow gray dolomite
205-230 feet	Cherty dolomite
230-300 feet	Tan to yellow gray dolomite
300-465 feet	Yellow tan to light brown cherty dolomite
465-500 feet	Maroon, tan to pink gray dolomite with little chert
500-580 feet	Gray cherty dolomite
580-705 feet	Ordovician Maquoketa Shale

Krieger Quarry
Locality 108

SW 1/4, Section 35, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County.

Alden (1899, unpublished field notes) visited a Mr. Krieger's quarry and described it as follows:

> There is a small exposure west of the railway in the gentle slope. About 5 ft. are exposed. A little rock has been quarried. The rock is not so very well bedded and is cut up by vertical and oblique jointing. Seems to quarry out quite easily in 4 inch layers. The rock is buff and discolored, seems to become lighter and gray on exposure. The texture is very peculiar as the rock probably Guelph limestone...is very largely made up of gastropods massed together with some Orthoceras, corals and brachiopods. It is highly fossiliferous, but only molds and fragile casts remain and give to the rock a peculiar texture being full of curved and coild and irregular holes. It is difficult to

get out good specimens or even good molds though they are so abundant as the rock breaks anywhere under the hammer, and we can never be sure where it will break. Some crystals of calcite and concretions were found. The rock itself is sometimes hard gray dolomite, but generally loose and friable, weathering readily. A few pieces were seen showing the purplish or lavender tint seen at Wauwatosa. Many of the gastropods are large, over two inches long with cavities as large as my little finger. The rock is thinly covered by soil, no till right at the exposure and so much weathered as not to show glacial striae.

There is no longer any rock exposed in this vicinity.

Anschütz Quarry
Locality 109

N line, NE 1/4, SE 1/4, Section 26, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County.

elevation: 750 feet

This abandoned quarry is located along a northward facing bluff, south of Cedar Creek and adjacent to the railroad crossing of the creek.

Chamberlin (1877, p. 362-363) commented on the nature of the rock here:

> ...near the center of Section 26, a very soft crystalline rock, called sandstone, from its friable and granular nature, occurs, having a strong dip to the westward. Following down the stream a short distance, we find a hard, brecciated and geodiferous rock of bluish cast without apparent stratification.
>
> This gives place almost immediately to granular rock similar to the preceding, but the bedding joints become entirely lost, and, in an exposure of 20 feet, none are

> visible. Vertical seams occur at intervals, which are disposed to change to an angle of 45° with the horizon, and to pass obliquely across to the neighboring fissure.

This last locality is probably the Anschütz quarry. Later Chamberlin (1877, p. 379-380) gave a faunal list for Guelph exposures in the E 1/2, Section 26.

Buckley (1897, unpublished field notes) described the Anschütz quarry as having a 38 to 40 foot high face and observed that the rock was of the "spongey nature" as seen in the Groth quarry. He reported:

> The stone is almost white in color and is free from delitiereous substances. It shows many fossils--the rock being built mainly out of the remains of marine organisms. The crystalline character noted in the previous quarry (Groth's) is the same here.

He further added that the upper beds were hard, being burned for lime, while the lower 15 feet were used as building stone. Two to three feet of overburden had been stripped from the surface.

Alden (1899, unpublished field notes) also visited this quarry and observed the following:

> The quarry shows about 40 ft. section. There is but 3 or 4 feet of till over the rock surface which latter is much weathered. At one point striae were seen W 12°S at another W 37°N, but the surfaces are so weathered either is very doubtful. The rock is somewhat buff above, more grayish below. The rock is the loose open textured, crystalline or subcrystalline limestone. Crumbles under the hammer. Weathers buff, weathers readily. Is quite fossiliferous but only casts or impressions are preserved and these are gotten out with difficulty as the rock breaks up so easily. It is evidently Niagara limestone. Crinoid

stems are abundant, one cast found of cup. Zaphrentis and other corals common. Monomerella(?), Arthothelis subplanum, Strophodonta et al were found. Orthoeras also occurs. Some notably longer slender ones were found. I have one 7-8 in. long but little larger than a lead pencil, is cast of Orthoceras siphuncle. A few gastropods were seen. The fossils on the whole are really rather few.

The rock as whole is massive with but a general sort of bedding on the east side, upper part. The surface slopes down to the river (15°+) probably an erosion slope...

At quarry just west of this nearer the dam is another quarry evidently much more worked for sometime till quite recently. The rock is of the same character but a little more in courses so it can be taken out in courses 2 ft. thick. The dip is 4-7° N 50°E. But few fossils were seen.

In the north bank of Cedar Creek just about the middle of the section ledges are exposed dipping under the water at an angle of 12-15° S 35° to 40°W. There would seem thus to be a gentle fold with NW-SE strile with axis just east of this point.

In 1903 Grabau (p. 343) published a description of this quarry, which he repeated in 1913, as follows:

> Anschütz's quarry, in Cedarburg, is opened in a hill, near the center of which, south of the quarry, occurs a reef, as indicated by the nature and dip of the strata. The dip is 10 degrees northeastward. The limestones of this quarry are all well bedded and uniform, sugary in texture and with few fossils. Those found are chiefly brachiopods. The rock here has the structure of a sandstone, by which name it is familiarly known. Other quarries and natural exposures on the Milwaukee river near Grafton show similar bedded limestones, but no other exposures of reefs were found.

A short distance to the south of Anschütz's quarry on the opposite side of the hill a few low exposures of similar rock are found at the same elevation.

Grafton
Locality 110

SW 1/4, SE 1/4, Section 13, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County.

MPM x40.10

elevation: 760 feet

A shallow roadcut exposes rock along County Highway 0 (formerly State Highway 57) in Grafton.

Raasch (1928, unpublished field notes) reported that three feet of Racine Dolomite, similar to that exposed at MPM x40.3, was here overlain by one foot of Devonian (Ozaukee Member of the Lake Church Formation) rock. The roadcut was fresh in 1927 but was already overgrown by 1928.

Milwaukee River Outcrops-Grafton
Locality 111

E 1/2, Section 24, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County

elevation: 700 to 740 feet

There are outcrops along both sides of the Milwaukee River, south of the north dam to the dam at the northern border of Lime Kiln Park on the S line, NW 1/4, NE 1/4, Section 25. The outcrops along the Milwaukee River in this vicinity have long been known to geologists as they are some of the largest natural exposures in southeastern Wisconsin.

Lapham (1846, p. 105) mentioned that the Milwaukee River, near the mouth of Cedar Creek, "is confined between high perpendicular banks of limestone rock and has a considerable fall." He termed this falls "Milwaukee Falls." Lapham went on to describe Cedar Creek as "a branch of the Milwaukee, entering a little below the falls, and having a similar fall near the junction with same limestone ledge "

Lapham (1851, p. 170) reported that a soft yellow limestone (his Unit VII) that overlies the Waukesha Dolomite is exposed at the falls of the Milwaukee River.

Percival (1856, p. 70) gave the following description of the area:

> At Grafton (Ozaukee county) an extensive range of limestone rock is exposed along the Milwaukee river having the general character of the present formation, the greater part containing very few fossils, but a few layers abounding in them.

He also mentioned that the quarries at Racine had similar fossils and that the rock in both areas belonged to the upper portion of his Mound Limestone.

Hale (1860, unpublished field notes) stated that:

> Grafton presents an extensive outcrop of Racine Limestone divided into two beds. The lower portion rises 20 ft. above the river and is thick bedded and soft.

> Beds 3 to 5 thick, porous; attempts have been made to saw this stone and bring it into market as building material, but it lacks strength and hardness and cannot be very durable.
>
> The upper division is thinner bedded and harder with some fossils. Makes tolerably good lime.
>
> This is the kind seen generally over the country in the vicinity of Grafton. At Saukville both beds occur. The lower is exposed and quarried in a field, while near by on a rise of 15 feet above the same is found the thinbedded stratum with abundance of fossils such as I collected last year at this place.

Hall (1862, p. 67) included the Grafton exposures in his discussion of the Racine Dolomite.

Chamberlin (1877, p. 363) described the outcrops along the Milwaukee River, below Grafton, part of which he assigned to the Racine beds and part to the Guelph horizon. He reported:

> If we pass on eastward about half a mile, we find a rock, at a somewhat higher elevation, of a more earthy structure, belonging to the Guelph horizon, but when we reach the Milwaukee river, below the rapids, we again find the granular rock, as before, but distinctly bedded and dipping northward. In a few rods, the layers become harder and are almost as soon lost in a brecciated, unstratified mass, whose superior hardness has given rise to the rapids. This mass is made up of fragments of rock cemented by continued debris of a dolomitic character, which renders the distinction of the fragments from the matrix often obscure. This breccia graduates almost imperceptibly into hard, compact layers, as we proceed up the river, and these in turn soon give place to granular rocks again, the strata dipping northwad for a distance, and then rising...
>
> At the dam near the south line of the SE qr, Section 24, Grafton, the granular dolomite is developed in its most characteristic form, becoming a well marked calcareous sandrock.

Most of his observations were made in Section 25. He further commented on these exposures (p. 378) and presented lists of Guelph fossils collected in Sections 24 and 25 (p. 379-380). A list of Racine fossils collected at Grafton in Section 25 was given also (p. 372-377).

Buckley (1898, p. 329) described the quarry of the Milwaukee Falls Lime Company, located about one mile south of Grafton. The quarry opened in 1892 and was about 40 feet deep, 800 feet long, and 400 feet wide at the time of his visit.

Alden (1899, unpublished field notes) visited this area and observed the following:

> From the sharp bend in the Milwaukee River from north-south to east-west northward to Grafton the river flows in a sharp little gorge evidently almost entirely due to erosion though the river's course was evidently determined by the gentle little till valley. The river has now cut down through the till and into the rock about 20-30 ft. The rock stands in little cliffs along the water and with the evergreen covered lower slopes makes a very pretty little valley. The rock evidently rises in the slopes on either side but is covered by buff stony till with many surface boulders.
>
> There are two quarries in N 1/2, Section 25, and one large lime kiln at the northern one. There is a sag across in E 2/3, in Section 25 from the Milwaukee River valley to Cedar Creek valley or partly across. The streams are here 1/4 mile apart but there is probably 20 ft. of limestone in height between covered till. The Milwaukee River evidently was turned eastward down into the broader till valley off the rock and has not cut into the rock so there is no tendency to change its course.

He also made some observations in Section 24:

> There are two dams in E 1/2 in Grafton and rapids where the water falls over the rock ledges of the channel on the west side.

Alden also described a quarry owned by Henry Loell in the N 1/2 of Section 25:

> At Mr. Loell's quarry the rock is somewhat firmer in texture still quite open and porous and of much the same character. It is buff in color. Has not a very well defined bedding yet it runs in courses. These dip about 8° in a direction N 35° to 45°E. The rock is considerably broken up and can hardly be taken out in courses. Seems to be very few fossils, at least I saw but a single polyp coral. There is about 20 ft. exposed thinly covered with soil much broken at top so as to show no striae. Effervesces very readily.
>
> At the quarry about 100 yds. north of this the rock is much firmer, harder, denser more dolimitic, more like the Racine limestone. Used also for lime, is quite fossiliferous. Found Pentamerus oblongus. Somewhat more buff and loose at top.

At the Milwaukee Falls Lime Company he made the following observations:

> The quarry here shows about 35 ft. section. Toward the top the rock is more buff with many holes filled with blue clay which washes out leaving a cavernous surface. Below the rock is hard, gray dolomite like the Racine limestone. It is of subcrystalline texture with many cavities showing crystals of calcite. I carefully examined ths sides of the quarry and much of the loose stuff in the bottom but found a single cast of Pentamerus beside traces of corals and crinoid stems. Probably repeated search would show fossils, but they are surely not abundant. The rock is much fractured and shows a not very well defined bedding. The northeast quarry shows a gentle anticline with strike N 50°E as near as I could read it. This gives dips to NW and SE of 8-18°. It is noted that the axis of this fold is about at right angles to the direction of the fold notes to the southwest on Cedar Creek west of Auschuetz Quarry.

Continuing his examination of the exposures in this area, Alden reported the following from Section 24:

> Going north along the west side of the river a short distance below the middle dam there is a dip 15-17° N 50°-50°E. The rock along this bank shows many crinoid stems.

> Found one Pentamerus also. Is the same gray dolomite.
>
> Going northward from the middle dam the rock becomes even more hard. It is gray crystalline dolomite like the Racine limestone. It seems to become rather more fossiliferous also. Gastropods being not infrequent though not abundant as south of Cedarburg. Not much else but corals and crinoid stems have been seen.
>
> At the old quarry in the west valley slope at one place a few yards of the upper rock surface are stripped and show striae of several sets.

Raasch (1928, unpublished field notes) examined the Grafton quarries in Section 25 for Devonian rocks, but found none. He described the Silurian rocks exposed as follows:

> The newer of the two quarries, now idle, was examined. The walls rise to as high as 40 feet or more and on the north side consist of massive dolomite with no continuous bedding and irregular reef-like masses. The south wall as well as the older quarry to the south-west is in a very light yellow, soft, granular rock, well bedded, and having a clastic appearance.
>
> The massive reef-rock contains an abundant fauna.

He presented the following faunal list for this locality:

Favosites sp. (common)
Zaphrentis, very elongate
Gastropod, low coiled, revolving striae (common)
Gastropod, smooth, cone shaped
Gastropod, moderately low, strong growth lines
Gastropod, large turreted
Gastropod, marked pleurotomarid band
Orthoceroid, Kionoceras
Orthoceroid, long air chambers
Orthoceroid, wauwatosense type
Orthoceroid, large short air chambers
Trochoceras
Oncoceras (small)
Cyrtoceras (large)

Shrock (1934, unpublished field notes) described the exposures at an abandoned quarry on the east side of the Milwaukee River, about 150 yards south of the dam at the south end of Grafton (see Figures 120-122): The quarry contained a mound which Shrock observed as follows:

> The structureless mound, which is without either definite bedding or jointing, is composed of massive, hackly, uneven-textured, gray to light tan dolomite containing some holes. Few fossils noted though I did see some echinoderm columnals and some hemispherical tabulate coral heads. The rock is in some places massive and dense compact texture; elsewhere it has a brecciated appearance and seems to be composed of several different kinds of material, so that a weathered surface has such an appearance. There are numerous large holes head size and smaller and some of these are filled with dolomite laminae some of which are at high angles. Similar masses of laminae are found throughout the reef core. The rock weathers to a gray or dirty-colored, ragged, rough surface, with bulging rounded surface, in contrast to block appearance of overlying bedded material.
>
> The bedded rock is in massive layers 3-4 ft. or more thick, but these tend to break into thinner layers on weathering. This rock is a cream-colored, saccharoidal porous dolomite similar to that seen an interreef at Cedarburg.
>
> As nearly as I can determine the bedded rock grades laterally into the reef as well as passing over it.

Shrock (1934, unpublished field notes) also described the exposures at the lower dam on the east side of the river, near the quarry, one mile south of Grafton (MPM x40. 11):

> On the east side of the dam there is an abandoned pot-holed, run-around in the bottom and walls of which are exposed dipping layers of coralline sugary dolomite as shown on the diagram. The rock is quite reefy and cavernous in appearance and reminds me of the reef cave at Cedarburg.
>
> One large mound very near the east end of the dam rises more than 10 ft. above the water and seems to be connected with a mass at the west end of the dam, but separate

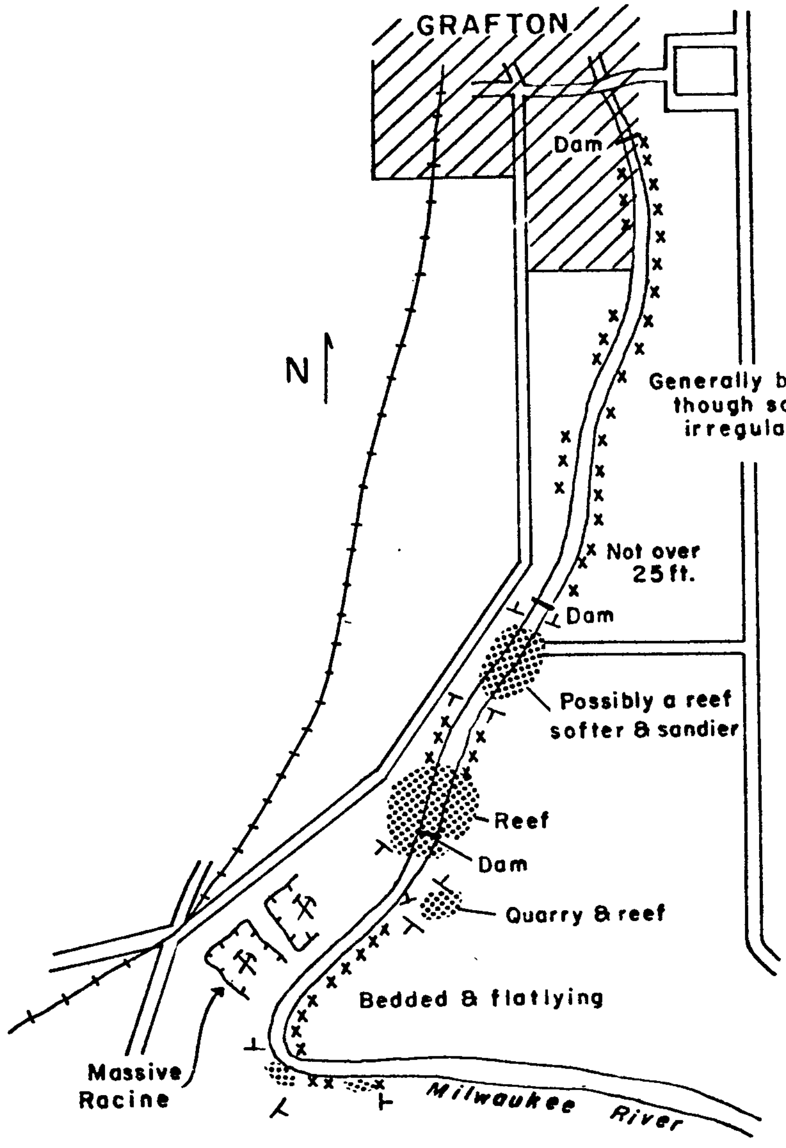


Figure 120. Diagram showing location of exposures along the Milwaukee River, south of Grafton, Ozaukee County. After Shrock (1934, unpublished field notes).

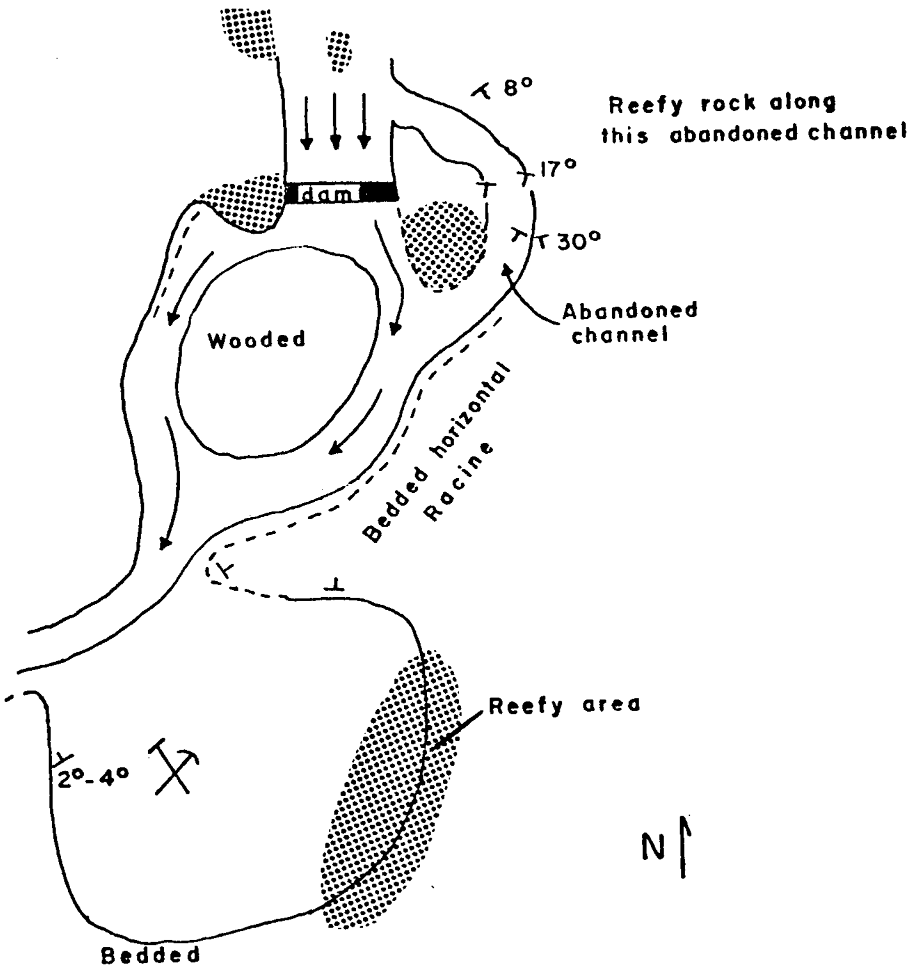


Figure 121. Diagram of exposures around the south dam along the Milwaukee River, south of Grafton, Ozaukee County. After Shrock (1934, unpublished field notes).

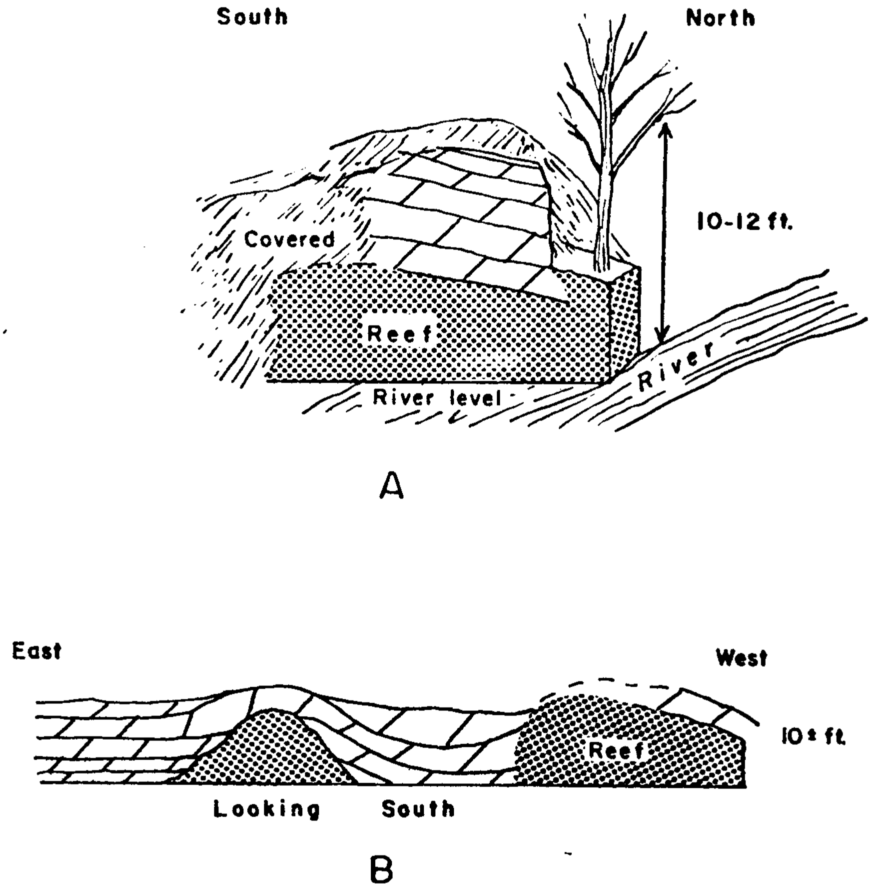


Figure 122. Diagram detailing the exposures at the south bend of the Milwaukee River, south of the main quarries at Grafton, Ozaukee County. After Shrock (1934, unpublished field notes).

from the larger mass to the north upward against which the dipping layers are leaning. This small mound contains some brachiopods, and has several large heads of a tabulate coral reminding one of Syringopora. They look like boring on superficial examination.

At locality MPM x40. 8, a quarry on the west side of the Milwaukee River, one mile south of Grafton, Shrock (1934, unpublished field notes) measured the following section:

Bed 1. Irregularly bedded and unevenly textured gray finely saccharoidal fossiliferous dolomite much like that at Manitowoc and to some extent like the Milwaukee and Racine exposures. The following fossils, usually poorly preserved, were found . . . . 10-15 feet

Favosites
Halysites (2)
Pycnostylus
Wilsonia sp.
Dinobolus conradi(?)
gastropods 5 sp.
cephalopods
small tubular corals
stromatoporoids

Bed 2. Massively-bedded, even-textured, creamy saccharoidal dolomite . . . . 20-25 feet

In the upper unit there are reefy mounds which differ little from the enclosing rock except in lacking bedding. They are really bioherms, and the rock is very fossiliferous. The fossils are poorly preserved.

In 1939 Shrock published a brief description of the area based on these earlier field notes; he also figured one of the mounds in the vicinity (1939, Pl. 1, Fig. A).

The quarries on the west side of the river, now part of Lime Kiln Park, were briefly discussed by Mikulic (1977).

A water well (Oz-79) in SW 1/4, NW 1/4, NE 1/4, Section 13,

T. 10 N., R. 21 E., Cedarburg Township (elevation approximately 770 feet) located about one mile north of the north dam on the Milwaukee River displays the following section:

Drift	31 feet
Gray dolomite	369 feet
Gray, cherty dolomite	30 feet
Buff and gray dolomite which becomes argillaceous and red towards the bottom	170 feet
Ordovician Maquoketa Shale	175 feet

Locality 112

NW corner, SW 1/4, Section 7, T. 10 N., R. 22 E., Grafton Township, Ozaukee County.

Outcrops in this vicinity are indicated on Alden's (1918) map.

Saukville
Locality 113

NE 1/4, Section 26, T. 11 N., R. 21 E., Saukville Township, Ozaukee County.

MPM x40. 15

elevation: 770 to 800 feet

Small overgrown quarries are located in a woods just west of the railroad tracks, south of Cold Spring Road, north of Saukville.

Chamberlin (1877, p. 369) mentioned this locality:

> At Noessen's quarry near Saukville, where there is a mingling of Racine and Guelph faunas, some portions of the rock are little more than a mass of coral specimens imbedded in calcareous sand.

He described the quarry in more detail in his discussion of the Guelph beds (1877, p. 378):

> At Noessen's quarry, north of Saukville... there is a limited opening upon an ancient reef, exposing a rock of varying character, a portion of its being very soft and coarsely granular, while other portions are compact and fine-grained. Some portions are made up almost wholly of Crinoid stems and Corals, while others are brecciated. In color the rock is buff, weathering to a deeper and more reddish hue. Corals and Crinoids are abundant, and only extensive quarrying is needed to make this locality valuable to the collector. The fauna shows a mingling of Guelph and Racine species. The locality is rather to be regarded as Racine than Guelph.

Chamberlin (1877, p. 379-380) also presented a faunal list for this locality.

Alden (1899, unpublished field notes) briefly mentioned this locality:

> The limestone rises with slope and outcrops in Section 26 west of railway. Is the same Niagara dolomite as seen in all the other exposures. Shows crinoid stems and some gastropods. The two exposures are very slight.

Raasch (1928, unpublished field notes) reported exposures and old stone pits in the fields approximately one mile north of Saukville. He described the exposures as follows:

> Racine Dolomite exposed in rocky knobs and numerous small stone pits, so old that elm trees up to 9 inches in diameter have found rest in the quarry floors. Over 20 ft. of beds

exposed. Mostly massive reef limestone or granular bedded rock with initial dip. On the west side of the railroad track, in the marshy pasture, are outcrops of distinctly crinoidal rock containing an unusual coral fauna (including Cystiphyllum) besides several species of Crinoids (Eucalyptocrinus ornatus, Cyathocrinus, Callicrinus). It seems to grade laterally into massive reef rock. The more granular rock as well as the reef rock has gastropods and the small celled Favosites of Grafton, etc. for its most predominant fossils.

The highest rock exposed is Racine limestone perforated by the striking vertical parallel openings described in connection with locality MPM x40.3 where it is restricted to the upper 10 ft. of the Silurian. This rock forms the edge of the flat-topped terrace which lies at about 795 ft. The native rock plowed up in the fields upon this terrace have been thrown together in a large rock pile which consists largely of unglaciated boulders to two kinds: a lesser quantity of the peculiar Silurian rock just described and a much larger quantity of dirty gray rough weathering dolomite like the basal Devonian at localities MPM x40.3, x40.12, x40.2, etc. and full of subangular pebbles.

Shrock (1934, unpublished field notes) visited this locality and presented the following description:

> ...there are several small mounds or ridges of a gray, open-textured, saccharoidal dolomite of "Racine" type.
>
> In the three easternmost exposures, where the stone has been burned for lime, the rock is full of crinoid columnals and an occasional calyx (one specimen is probably Eucalyptocrinus). The mounds which are mainly masses of weathered dolomite boulders may be small bioherms of crinoids, or crinoid gardens.
>
> Columnals are very abundant and throughout the rock the calcite plates of the column and calyx still retain their calcitic cleavage, hence a fractured surface glistens still. Further west on a north-south ridge of which MPM x40.16 is a northern extension the stone is harder and denser and is not so fossiliferous.
>
> The rock is exposed at MPM x40.16 on the north side of the road, but not to a thickness sufficient to warrant an examination.

Shrock (1939) published a brief description of this locality based on these earlier observations.

Saukville Klint
Locality 114

Section 34, T. 11 N., R. 21 E., Saukville Township, and Section 1, T. 10 N., R. 21 E., Cedarburg Township, Ozaukee County.
MPM x40.22

Shrock (1934, unpublished field notes) described a 20 foot high dolomite mound in a swamp one and one-half miles southwest of Saukville. His description of the exposure is as follows:

> An examination of the stone shows it to be a gray saccharoidal dolomite which is soft, and which breaks irregularly with crumbly fracture. A weathered surface is mainly a dolomitic sand. A weathered surface has a rough pinnacled appearance due to considerable weathering along joints. The beds appear massive, but may be heavily bedded. Not over 5 to 6 ft. were seen anywhere around the mound which is largely covered by weathered boulders of the formation.
>
> The highest beds exposed just east of the barn on the north side of the east-west road appear a little more dense and of closer and of closer and finer texture.
>
> Fossils found included Favosites, Halysites and a Hormotoma-like gastropod, The former seem to be most abundant, though sparsely scattered through the rock.
>
> The rock reminds me of certain phases of the Huntington dolomite and also certain phases of the interreef rock as developed at Cedarburg. In the present exposure, however, there are no large holes as at Cedarburg.

Shrock also mentioned that most of this area was underlain by "the same gray, sugary, saccharoidal, crumbly dolomite" but due to the thickness of the glacial drift there were only scattered exposures where erosion had stripped off the till.

Shrock (1939) briefly described this klint from his earlier observations.

Locality 115

SE 1/4, SE 1/4, Section 10, T. 11 N., R. 21 E., Saukville Township, Ozaukee County.

MPM x40. 19

Silurian outcrops occur along the west side of the Milwaukee River and east of County Highway 0 in Section 10, four miles north-northwest of Saukville.

Raasch (1929, unpublished field notes) described these exposures as follows:

> Low knolls of massive dolomite, the base about 5 ft. above the stream and several hundred feet from the water's edge. Fauna recalls that of locality MPM x40. 15 which likewise is in crinoidal Racine rock. The outcrop has a relief of from 5 to 10 feet, the rock lies probably about 25 ft. below the top of the Racine.
>
> Fauna includes: Favosites (large corallites, radiatrum, C) Zaphrentis?, Caryocrinus ornatus, Eucalyptocrinus nodulosus, Fenestella, Atrypa reticularis, Spirifer radiatus, plicate Spirifer, Rhynchotreta, Strophonella? (very flat), Parastrophia, Orthis cf. flabellites, "Pleurotomaria occidens"?, Cephalopod fragment, Illaenurus cf. armatus (large size), Arctinurus, etc.

Locality 116
Riveredge Nature Center Outcrops

SE 1/4, Section 6, and center N 1/2, Section 7, T. 11 N., R. 21 E., Saukville Township, Ozaukee County.

elevation:

Silurian bedrock is exposed at the Audobon Society's Riveredge Nature Center on the south bank of the Milwaukee River.

Rachel Paull (1970, p. 42-44) described these outcrops on the Riveredge property:

> The Riveredge property is located in an area of shallow bedrock, with the bedrock lying within twenty feet of the surface...
>
> The Racine Formation outcropping at the northern edge of the Riveredge property exhibits medium-thick, irregular bedding with the small, twelve to fifteen foot thick exposure. The dolomite is gray to buff, dense to sugary, with some relatively porous beds. The fauna appears to be limited to cephalopods, solitary corals, and crinoid stems, and most likely represents an interbiohermal facies as described by Shrock (1939).
>
> Stylolitic surfaces are abundant in the Riveredge outcrop. They are irregular interlocking columns that project in opposite directions and meet along an uneven surface, producing a cross-section similar to a steeply angular graph...An insoluble, argillaceous material coast the stylolitic surfaces...
>
> In addition to the Racine Dolomite exposed along the Milwaukee River, test borings for a water well, immediately north and west of the naturalist's office at the "castle" revealed the presence of dolomite bedrock at depths of ten to nineteen feet...A very small exposure of dolomite is present twenty-five feet north of the "castle," but it is questionable as to whether this is *in situ* or is an ice transported block.

Rachel Paull (1969, personal communication) further reported that the cephalopods at this locality were found in a localized accumulation; this may represent a debris-filled depression in a reef.

Sauk Creek
Locality 117

NE 1/4, NE 1/4, Section 29, T. 11 N., R. 22 E., Port Washington Township, Ozaukee County.

MPM x40. 12

elevation: 620 to 650 feet

Outcrops occur along Sauk Creek for about one-fourth mile south from the N line of Section 29, just east of County Highways KK and RR (locality 117).

Alden (1899, unpublished field notes) made the following observations about these outcrops:

> In NE 1/4 Section 29 along the creek there is a very interesting rock exposure. Along the west bank from the way on road crossing of the railway for 75 to 100 yds. limestone is exposed in 8-10 ft. section. This hard gray dolomite evidently Niagara. It is rather thin-bedded, 2-4 inch, not very even or continuous strata. The rock is rather open, porous, and full of small holes. It is quite fossiliferous showing internal and external casts. The fossils seen are favosite corals and principally gastropods... This may be Guelph beds(?) The beds dip 7°N 50°E, at another place 5°N 55°E. The ledges reach about 675-680 ft. A. T. or nearly 100 ft. above lake so there must be a very rapid drop toward the north of the valley. The gastropods seem to be confined principally to one horizon. This rock surface also lowers probably from erosion down the stream at the south end of

> the exposure so the creek has a fall of 8-10 ft. over the rock bed in about 100 yds. While the exposure on the west stands 8± ft. above the water on the west. On the east the beds dip down and 2-3 feet of more bluish rock overlies the hard gray dolomite. This is evidently a different bed. The change in color and texture is quite noticeable. This higher rock resembles the Hamilton in texture and color and from its lithological character and stratigraphic position together with the relations of the two limestone formations as shown in wells at Port Washington I think we are safe in inferring that there is here a contact between Niagara and Devonian limestone formations. Yet, with careful search, I could find no fossils in the blue limestone. A few hundred yards down the creek a loose piece of rock having about the same texture and appearance gave abundant Hamilton fossils... This may not however be from this formation. This bluish limestone has rather indefinite bedding and apparently conforms to the rather irregular surface of the Niagara below so the surface passes below the creek bed in 50 yds. down the stream. Its surface shows glaciation with striae W 5°N. to due West.

Ulrich (1914, unpublished field notes) presented an illustration of this locality.

Raasch visited this locality in 1928 and made the following observations (unpublished field notes):

> Rock is exposed in the bed of the stream for a distance of about 1/4 mile. The lower 10 ft. or so of the section are in the uppermost beds of the Racine in rock very similar to MPM x40.3, Thiensville, with which it agrees in the abundance of Monomerella and gastropods, in the evidence of solution and deposition in fossil cavities, and in the presence of parallel vertical openings of unknown origin. On the upper surface the dolomite bears peculiar curved worm burrows of two sizes, the former thicker than a finger, the latter about 3/16 of an inch thick, often with several inside one of the first type.
>
> The yellowish, vitreous, fossiliferous rock of the Silurian is overlain by dirty, dull gray barren Devonian dolomite, distinctly conglomeratic at base, and more or less so throughout. The pebbles are angular and of the

Silurian rock. Patches of conglomerate adhere to the top surface of the Silurian which is slightly irregular, but not markedly so. The Devonian rock is massive and heavily bedded much like the associated Silurian.

Structure is very marked at this point owing to a maximum dip of at least 20° in a southeasterly direction. This makes the fall of the strata greatly exceed the fall of the creek (which flows at right angles to the strike) so that the Devonian only may be seen on the downstream end, while the Silurian alone is exposed on the upper end. In all there is a relief of 20-30 degree in the bedrock at this point, but the stratigraphic section is much less (15 ft.).

Shrock (1934) described this locality as follows:

...there is exposed some 5 ft. of "reefy" Racine with what appears to be bedding dipping 8°-10° southeast. These beds are exposed in the river bed and bank from the section line south for some distance. The cause of the local dip is not apparent.

No fossils were seen...

Locality 118

SE 1/4, SE 1/4, Section 20, T. 11 N., R. 22 E., Port Washington Township, Ozaukee County.

MPM x40. 13

elevation: 670 to 680 feet

Several small abandoned quarries are situated in the westward-facint hill east of Sauk Creek, just west of Grant Street in Port Washington. One of these quarries is indicated as a gravel pit on current topographic quadrangles.

Raasch (1928, unpublished field notes) found a twelve foot exposure of Racine Dolomite which was mostly covered; he collected the brachiopod Rhynchotreta(?).

Shrock (1934, unpublished field notes) visited this locality and described it as follows:

> ..."Racine" rock is exposed on a hillside in tow shallow pits, in the walls of which are exposed 4-5 ft. of gray, semi-saccharoidal dolomite, similar to that seen in other localities north and west. This rock was once burned for lime...

Locality 119

SE 1/4, NE 1/4, Section 20, T. 11 N., R. 22 E., Port Washington Township, Ozaukee County.

MPM x 40.18

Bedrock outcrops along the east bank of Sauk Creek, southwest of Knellsville.

Raasch (1929, unpublished field notes) reported approximately three feet of Racine Dolomite exposed for several hundred feet along the creek bank, west of the railroad tracks. A small overgrown, long abandoned quarry was also present.

Druecker Quarry
Locality 120

SE 1/4, NW 1/4, Section 9, T. 11 N., R. 22 E., Port Washington Township, Ozaukee County.

MPM x40.2

elevation: 740 feet (on east), 725 feet (on west)

A filled quarry is located just east of the railroad tracks and Sauk Creek and west of County Highway KW.

Lapham (1872, unpublished field notes) briefly described the exposures at John Druecker's quarry. Approximately 15 feet of rock was exposed, of which the upper few feet Lapham thought belonged to the Devonian.

Alden (1899, unpublished field notes) reported that this quarry was about 60 feet deep and that it had not operated much in recent years. He added that a well on the hill (elevation 770 feet?) struck rock at 90 feet and one in the NE 1/4, Section 4 reached rock at 100 feet. He described the quarry as follows:

> The rock shows very few fossil traces. I was able to find but 2 or 3 specimens of corals in a 2 hour careful search. The main part of the quarry is said to be about 40 feet deep. Though in one part it has been run down to about 60 ft. On the east or uphill side about 35 ft. is exposed in nearly horizontal beds. There is about 5 ft. of stony till lying upon the glaciated surface. Below this on east side is 5 to 8 ft. much broken, rather thin bedded rock. This passes downward into regular courses running 1 to 5 ft. in thickness. These heavy beds are massive not laminated. The rock is

> a rotten loose open granular dolomite, breaking easily under the hammer with quite regular fracture. It is not nearly so hard as the hard blue dolomite of the Racine limestone beds. This is said to run softer below. West of the tracks some has been quarried but it is softer here breaking down into crystalline sand on exposure and melting down in the sun. The rock is of a light buff color. On long exposure this becomes gray and in general hardens with exposure to the air, so that parts of the quarry which have been exposed for 6 or 8 years are gray and hard on the surface.
>
> Some building stone has been taken out but only for local demand, e.g. the Druecker's stone house on the hill to east of quarry and St. Mary's church in Port Washington.
>
> In the northwestern part of the quarry the good limestone into an irregular poor lot of stuff. Under 6 or 7 ft. of rock is a streak nearly 10 ft. of blue clay and shaly clayey rock. The solid rock is bluish and very hard and brittle, breaking irregularly. There are hard streaks in it like cherty layers. The bedding is here uneven and irregular. These hard bluish layers are seen running back into the good limestone beds in the north section. It is said 20 ft. south of this irregular section was well bedded limestone like the rest of the quarry. This is evidently a local impure deposit. No fossils were seen here either.

Cleland (1911, Plate B) illustrated the east wall of the quarry which showed the Silurian-Devonian contact. He reported that six feet of Devonian rock unconformably overlaid two feet of thin-bedded Waubakee Formation, which in turn unconformably overlaid light-colored Racine Dolomite.

In 1928 Raasch (unpublished field notes) visited Druecker's quarry and described the exposure as follows:

> Druecker's quarry three miles north of Port Washington shows some 12 feet of rather hard, light brown, fossiliferous dolomite in persistent courses of moderate thickness. The fauna compares favorably only with that of similar beds at Lake Church. An interesting structure in the Racine beds

accompanied by a Devonian unconformity might prove of interest as outlined in the following notes.

The Lake Church formation has an outcrop ranging through 12 feet of beds on the east wall of the quarry, where it overlies 44 feet of Racine dolomite plus about 15 feet under water at time of visit; with a basal unconformity of at least 4 feet. The Devonian rock is abundantly fossiliferous except a foot or two from the base in which the rock is gray, coarse and dirty, in contrast to the clean light brown above. Pebbles of the underlying Racine dolomite are abundantly incorporated in the base of the Devonian formation and in some places are found even in the fossiliferous rock. The lowest Devonian bed has its surface covered with very fine examples of mud cracks. A band containing Gypidula and Atrypa occurs about 4 feet above the base. The rock as a whole is compact and moderately thickbedded. Stylolites are frequent. The fauna is identical with that of the lower beds at Lake Church.

The Silurian in the east wall of the quarry is practically horizontal dipping slightly southward. At the northeast corner a very pronounced monoclinal fold on the north wall drops the strata about ten feet and then is lost under slumped soil in the northeast corner of the east wall. This slump may conceal a fault zone. The Silurian rock from top to base throughout the quarry is highly dolomitized and all fossils are destroyed. The rock consists of horizontal bands about 1/4 inch thick of alternating compact and porous rock as at Lake Church. The bedding is very heavy and well defined.

In the west face of the quarry, a deep and steep-sided depression in the Silurian, extending downward to within 13 feet of water level, is filled with dirty and unfossiliferous Devonian sediments. The Silurian rock along the contacts is deeply weathered and stained. Very long stylolites mark the surface in some places.

The Devonian section in the center of the depression, which is about 100 yards wide in a north-south direction is as follows:

Bed 1, Post Racine filling of depression. Probably subaerial. Dirty structureless rock, mottled light and dark gray, in some places indurated and in others almost a clay or marl. 6 ft. 6 in.

Bed 2, Base of marine Devonian filling. Blue gray shales. Crumbling. 6 in.

Bed 3, Devonian. Indurated, bluish gray, dirty dolomite, weathering to a buff. Lensing. Pebbels near the side walls. 7 ft.

Bed 4, Devonian. Well indurated and compact, distinctly bedded dolomite of light gray color, on weathered surfaces light brown. Broken by weather into angular blocks. Dirty and unfossiliferous. 1 ft. 6 in.

Base of exposure 13 feet above water. Top of exposure 28 feet 6 inches above water level. Base of Lake Church rock on east side of quarry about 740 feet to 40 to 44 feet above water.

This strange occurrence is interpreted at present as a post-Niagaran pre-Devonian slump, probably along an open fault which may extend through the north end of the quarry. It is more likely that Bed 1 is pre-Devonian fill in this depression, while Beds 2-4 are of Devonian age. The former is unstratified and a good line can be established at the base of the shale (Bed 2). While the rock of Beds 2-4 is of a Devonian aspect, it was deposited under such unusual and turbulent conditions that no fossils are incorporated and closer correlation is impossible.

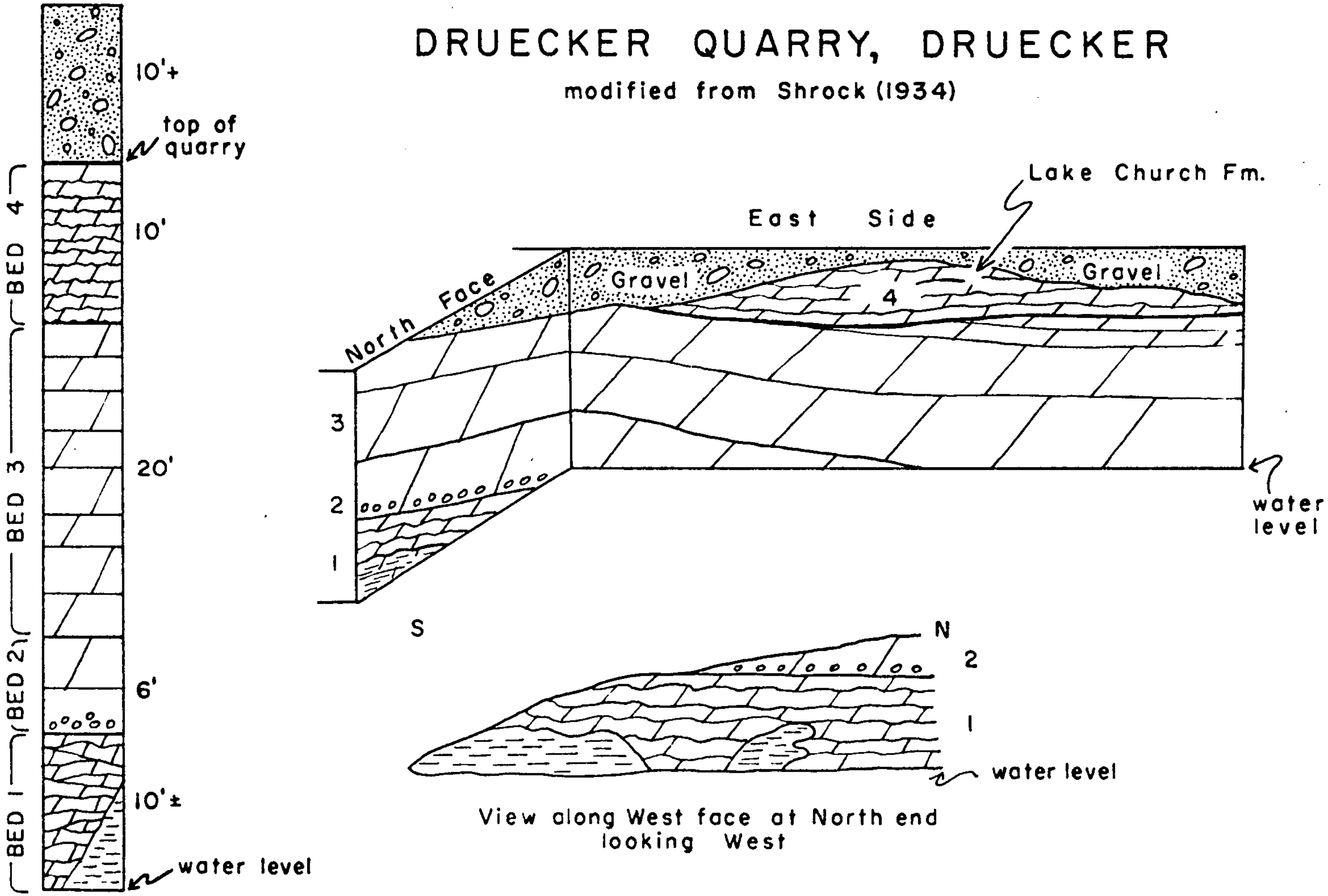
Shrock (1934, unpublished field notes) made the following description of the quarry (see also Figure 123):

> The structure in the quarry is monoclinal, with the lower beds rising rather sharply in the northwest corner of the quarry.
>
> The slabby, nodular beds on top appear to bevel the underlying heavy beds, and it is thought they may be Devonian...
>
> This quarry has not been operated for many years according to a native of the village. Lime was once burned, but only tumble down ruins now remain, and irregularly.

Shrock also observed about four feet of thin-bedded, sugary dolomite, similar to the lower beds in the quarry, a short distance to the south of the quarry in a small pit in the field.

Shrock measured the following section at Druecker's quarry:

Figure 123. Silurian-Devonian section and relationships of strata at Druecker's quarry (locality 120), Ozaukee County. Beds 1-3 are Silurian, Bed 4 is Devonian. After Shrock (1934, unpublished field notes).



DRUECKER QUARRY, DRUECKER
modified from Shrock (1934)
10'+
top of quarry
BED 4
10'
BED 3
20'
BED 2
6'
BED 1
10'±
water level
Lake Church Fm.
East Side
North Face
Gravel
Gravel
4
3
2
1
water level
S
N
2
1
water level
View along West face at North end looking West

Figure 123

Gravelly bouldery drift . . . . 10+ feet

Bed 1. Fine and even-textured, argillaceous dolomite containing many fossils. The bedding is quite irregular and the weathered surface is nodular and rough. Probably Devonian. Appears to bevel underlying beds . . . . 10 feet

Bed 2. Gray, very saccharoidal dolomite which weathers to a sandy dolomitic sand. The unit is well-bedded in units of considerable thickness (1-3 ft.). These beds are somewhat thinner at the top and a little more dense in texture . . . . 20 feet

Bed 3. Same lithology as above but with many walnut-sized holes in lower 1. Rests on underlying irregularly bedded dolomite . . . . 6 feet

Bed 4. Very irregularly-bedded, unevenly textured saccharoidal dolomite, becoming on some parts a dolomitic shale or mud. (only on west side visible). Has dipped under east . . . . 10.5 feet

No fossils were noted in the section except in the upper 10 ft. unit. The lower 36 feet probably belong to the so-called Racine. They have the same lithology observed to the south at localities MPM x40.17, x40.16, x40.15, and x40.22.

The quarry has been completely filled with ash from the Wisconsin Electric Power Company plane in Port Washington by the 1950's.

Between the quarry and the railroad tracks are a few low exposures of Silurian rock like that described from Druecker's quarry by previous workers.

Locality 121

SE 1/4, SE 1/4, Section 9, T. 11 N., R. 22 E., Port Washington Township, Ozaukee County.

Outcrops along Sauk Creek are indicated on Alden's (1918) map in this area.

Waubeka Quarry
Locality 122

NE 1/4, SE 1/4, Section 29, T. 12 N., R. 21 E., Fredonia Township, Ozaukee County.

MPM x41.2

elevation: 792 feet

Exposures of Silurian rock are found in an old quarry on the north side of the Milwaukee River, on River Drive, three-fourths mile west of Waubeka; this is the type section of the Waubakee Dolomite.

Chamberlin (1877, p. 392-393), in his discussion of the Lower Helderberg Limestone, was the first to describe exposures in this vicinity, as follows:

> About one mile above the village of Waubakee (sic), in the town of Fredonia, Ozaukee county, in the bed of the Milwaukee river, and the vicinity, is a formation that deserves ourconsideration in this connection. On the north side of the river is a quarry in which the following section

is exposed:

1. Light gray, thin bedded, shaly dolomite resembling that above described as occurring at Mud creek, but less porous. The surfaces of some of the layers are covered with large numbers of Leperditia, undistinguishable from Leperditia alta . . . . 2 feet
2. A layer of hard dolomite, containing cavities, some 5 or 6 inches in diameter, which are usually filled with large crystals of calcite. Leperditia occurs occasionally in this layer . . . . 10 inches
3. Alternating thin and thicker beds similar to No. 1 in lithological character, but some layers are marked with a dark, rusty coating . . . . 2 ft. 2 in.
4. Similar to No. 2 . . . . 1 ft. 2 1/2 in.
5. Moderately thick beds somewhat shaly, intermediate in character between the thinner and thicker beds above . . . . 1 ft.

Total . . . . 7 ft. 2 1/2 in.

The remains of Leperditia, found at this locality, are very abundant, literally covering the surface of some layers, and, to a greater or less extent, disseminated through the mass of some of the beds, but unfortunately the state of preservation is poor. A careful examination and comparison of a large number of specimens leaves no doubt that the fossil is Leperditia alta, or a very closely related species.

Chamberlin also mentioned exposures in the river bed in the vicinity:

In the bed of the river a little above this locality, very thin beds of a softer, dark dolomite, colored by carbonaceous matter, are found. Some of the layers are marked by numerous black or dark brown carbonaceous laminate, which give to the rock an appearance quite peculiar. This carbonaceous matter is evidently derived from the remains of plants, many indications of which are present, among them forms resembling Sphenothallus. In addition to these, two species of Orthis are found, one resembling Orthis oblata, and the other closely similar to Orthis subcarinata, but smaller. Pterinea aviculoidea, or a very closely allied, if not absolutely identical, species, an imperfect Orthoceras, and a doubtful Inocaulis, are also present.

Alden (1906, p. 2) named the Waubakee Formation (following Chamberlin's misspelling) presumably for the exposure in this quarry, but did not present any new information about these rocks.

Alden (1918) mentioned this quarry, repeating Chamberlin's description.

Raasch (1928, unpublished field notes) presented the following section for this quarry:

Bed 1, Covered above river level . . . . 3 ft.
Bed 2, Single layer of dolomite similar to Bed 2, at MPM x41. 7. Large slabs. Expised in road ditch . . . . 5 in.
Bed 3, Covered by talus . . . . 8 ft.
Bed 4, White banded dolomite in layers about 3 inches thick with several partings in each layer which allow the rock to split into thin slabs. The intervening rock is very compact. Leperditia covers some partings and is present throughout . . . . 4 ft.

Residual blocks of similar character occur 3 to 4 feet above the top of Bed 4. Rock similar to Bed 2 is barely exposed in a small pit on the south bank of the river a short distance upstream at about the same level as at MPM x41. 2. The water of the river was very high at date visited. The generalized section at Waubeka is as follows:

Bed 1, Brown, bituminous dolomite, with Athyris. Base not shown . . . . 2 ft.
Bed 2, White dolomite, moderately thick bedded, slabby . . . . 4 ft. 6 in.
Bed 3, Banded whitish dolomite, thinbedded, lensing . . . . 7 ft.
Covered interval . . . . 2 ft.
Bed 4, Thinbedded whitish dolomite with Leperditia. Top not shown . . . . 7 ft.

Total thickness of exposed Beds 1-4 equals 22 feet six inches. The upper beds of the Racine outcrop in the river two miles below the Waubeka exposures, and it also appears likely that the Niagaran is near the surface a short distance up the river from the outcrops at Waubeka.

Klug (1977) republished Chamberlin's (1877) section as part of a discussion of the Upper Silurian of Wisconsin.

The quarry is now largely covered; only a bed or two is exposed.

Phyllocarid Quarry
Locality 123

Along W line, SW 1/4, NW 1/4, SE 1/4, Section 29, T. 12 N., R. 21 E., Fredonia Township, Ozaukee Coi nty.

MPM x41. 7

elevation: 795 feet (top of quarry)

On the south side of the Milwaukee River, about 300 feet east of the northward turning bend, a small abandoned quarry is located approximately one mile west of Waubeka.

Chamberlin (1877, p. 393) briefly observed what was probably this quarry:

> ...a quarry has been opened which exhibits a more compact, close textured rock, and one intermediate in lithological character between these and the Niagara limestone. No fossils were found in it, and its relationship is uncertain. Its most striking peculiarity is the strong undulation of its strata, which allies it rather with the Niagara than with the formation under consideration (Lower Helderberg Limestone), whose beds have never been observed otherwise than as horizontal and perfectly plane.

Whitfield (1896) described a number of fossil phyllocarid specimens that were found by Edgar Teller and Charles Monroe in "the present bed of the quarry in a layer used for building stone and flagging."

Alden (1899, unpublished field notes) reported that:

> Mr. Petsch's (Julius Klessig) quarry 1 1/2 miles west of Waubakee (sic) shows thin-bedded dolomite limestone with somewhat anticlinal dips. On the north side the dip is 15°N 28°-30°E. On the east side 14°N 70°E. At the top the beds are thin coming out in flags from 4 inches to a fraction of an inch in thickness. The rock is not much broken. At the top it is grayish to light buff in color in places where weathered rather soft but generally hard and brittle. It much resembles the Lower Helderberg Limestone at Mud Creek south of North Milwaukee in being so thin-bedded. About 7 ft. section is exposed. From a lower hole has been thrown out a hard brittle thin laminated more bluish rock. It is though cement rock. Can be taken from below as a whole, it seems not very fossiliferous but crustacean specimens and small brachiopods were found by me in what seems to have come from this lower part. I saw nothing in the top beds. The rock is thought to be Lower Helderberg. The quarry is not much worked only some rubble taken out.

Alden's phyllocarid specimens are currently in the National Museum of Natural History collections, deposited with his Devonian fossils.

Alden (1918), presented a more detailed description of this quarry:

> A little farther west, on the south side of the stream, a small quarry about 7 feet deep has been opened in the flat on land which when visited by the writer belonged to Julis Klessig. The rock as exposed is a very brittle, hard buff to grayish, thinly laminated, impure dolomite, quarrying out in layers varying in thickness from a fraction of an inch to 4 inches. On the north side of the excavation the beds

dip 15°N. 30°E., and on the east side they dip 14°N 70°E. Material thrown out from the lower part of the hole, now filled, is more bluish and somewhat fossiliferous. E. E. Teller and C. E. Monroe, of Milwaukee, collected from this material thrown out specimens of three species of fossil shrimps described and named by R. P. Whitfield (Entomocaris telleri, Ceratiocaris monroei, and C. poduriformis). The writer also collected from this material fragments of Ceratiocaris monroei, numerous caudal spines and mandibles of the same genus but specifically undeterminable, and much flattened specimens of a brachiopod comparable if not identical with Rhynchonella? hydraulica Whitfield.

In 1928 Raasch visited this locality and made the following description, including a section:

> In the northwestern part of Ozaukee County near the Village of Fredonia (the type locality of the Waubakee (sic) Formation) are two exposures of Magnesium limestone on opposite sides of the stream and about one half mile apart. The lowest beds are exposed in the west quarry on the right bank where the following section was obtained.
>
> Bed 1, Not seen in place. Exposed only below water at depth of approximately 3 feet. Brown bituminous dolomite some layers rendered shaly by carbonaceous partings, other layers several inches thick, compact, fine-grained and very resistant, exactly like certain beds beneath Zone A at Port Washington Road bridge. The only identifiable fossils are a species of Athyris.
>
> Bed 2, Resembles Bed 3 from which it differs as follows: thicker and more evenly bedded, not conspicuously laminated, contains occasional openings about the size of an acorn . . . . 2 ft. 8 in.
>
> Bed 3, White to light gray laminated dolomite not regularly bedded, but with more massive lenses, thinning laterally. Very thin bedded at base and less so at top. Fine-grained. Breaks in some zones into thin fissile slabs . . . . 7 ft.
>
> Structure very undulating, but without any definite trend. Bottom of quarry about 3 feet above river level (latter about 792 feet). The section on the left bank runs somewhat higher and is recorded under MPM x 41.2

Klug (1977) also mentioned this quarry in his review of the Upper Silurian of Wisconsin.

Fredonia Township
Locality 124

E 1/2, and NW 1/4, Section 34, T. 12 N., R. 21 E., Fredonia Township, Ozaukee County.

MPM x40.17

elevation: 775 to 785 feet

Numerous Silurian bedrock outcrops occur along the Milwaukee River in Section 34 of Fredonia Township.

Chamberlin (1877, p. 393-394) mentioned a Smith's quarry two miles southeast of the Waubeka quarries in the center of E 1/3, Section 30, Fredonia. He described the rock here as "very soft, porous, granular, friable, cream colored dolomite, belonging, undoubtedly, to the Niagara formation." However, Section 30 of Fredonia Township is one-half mile west of the Waubeka quarries, not two miles southeast as reported by Chamberlin; he probably mistakenly located this quarry in Section 30 when it should really have been Section 34, at the same elevation as the Waubeka quarries.

Alden (1899, unpublished field notes) described the exposures at the quarry of John Schmidt along the river bank:

> The ledges of limestone were exposed 10-15 ft. above the river. At the north end the thicker beds are exposed a

> loose textured, soft buff dolomitic limestone. This hardens somewhat on exposure. Going south thinner upper beds are exposed at a higher level. These lie almost horizontally in 2 to 4 inch layers, thickening somewhat below. These are rather soft above but harden below. Still farther south near the half section line thicker beds are again seen of the same. Where weathered toward the top it is loose and soft but is harder below. The rock seems to show few fossils, at least, I saw no traces of any. They may occur in the harder part below. Very little stone has been taken out. No lime has been made. Mr. Schmidt says the same rock is seen just across the river.

Raasch visited the exposures at this locality in 1928 and described the outcrops of Racine Dolomite as follows (unpublished field notes):

> Granular dolomite of the Grafton type is shallow exposures on both banks and in the bed of the river. A cliff on the east bank reaches a height of ten feet or so and puts the highest rock at an elevation of about 785 ft. Gastropods were the most common fossils observed; all forms are rather infrequent. Outcropping about water level in the lower part of the section, a bed of dolomite showing a very peculiar type of weathering the surface being reticulated by small pits all about 1/4 inch in diameter.

Shrock (1934, unpublished field notes) visited one of the exposures along the east bank of the Milwaukee River where it turns south; he described it as follows:

> About 5-6 ft. of heavy-bedded, gray to cream colored, beautifully saccharoidal dolomite similar to that at Locality MPM x40.2, x40.15, x40.16, and x40.22, and probably belongs to the "Racine" formation.

Lake Church
Locality 125

Center, W 1/2, Section 19, T. 12 N., R. 23 E., Belgium Township, Ozaukee County.

MPM x 40.

elevation: 600 feet (top of bedrock)

A large, water-filled quarry is located west of the Lake Michigan shore in Harrington Beach State Park. Silurian and Devonian rocks were formerly exposed at this locality, however, only the upper 12 feet of the exposure are now visible.

Alden visited the quarry in 1899 (unpublished field notes) and later (1918, p. 98-99) described the quarry based on these earlier observations; he also illustrated the unconformable relations between the Devonian and Silurian (1918, Figure 4).

Cleland (1911, p. 8-9) described the rocks at this quarry based on his 1904-1905 field work and provided illustration of the quarry as well (1911, Figs. 2, 3; Plate B, fig. 4).

Raasch (1928, unpublished field notes) described the exposures at the Lake Shore Stone Company and shore exposures, one mile east of Lake Church:

> The quarry is filled with water so that the basal layers of the Devonian are the lowest rocks visible. Some 40 feet of Racine dolomite like that at Loc. MPM x40.2 are known to be present near the surface.

The section from the base of the Devonian to the top of Bed 3 is taken on the north side of the quarry at the point where the small stream cascades over a rock ledge into the quarry lake. From Bed 3 through to Bed 6 the section has been taken from the south and west sides of the quarry.

The excessive local undulation makes a general dip reading difficult. The structure is highest near the middle of the north side and lowest near the middle of the west side of the quarry.

The top surface of the hard dolomite is everywhere beautifully polished by glacial action, the striae funning a few points north of east.

The section of the Devonian strata is as follows:

Bed 1, Basal zone of reworking. Light colored, thinly laminated, dirty dolomite with no constant bedding. (Waubakee Formation of Cleland). Now inaccessible except by boat, but examined by writer in former years. . . . . 2 1/2 feet

Bed 2, Massive, brown to gray dolomite in two thick courses, the lowest barren and laminated. Accessible with difficulty. 3 ft. 8 in.

Bed 3, Chonetes Zone. Thinbedded dolomite chocolate brown when fresh, readily weathering to an earthy light yellow brown. The zone is abundantly fossiliferous with the fossils distributed in bands or patches. A large variety of forms has been collected from this horizon but a certain large Chonetes far outnumbers all other fossils . . . . 2 feet

Bed 4, Massive resistant dolomite dark chocolate color in layers 2-3 ft. thick. The rock is extensively stylolited and cavities filled with rhombohedrons of calcite are common. Fossils of poorly preserved forms; on the bedding planes which have been polished by glacial ice are to be seen many cross-sections of a large flat coiled gastropod approaching 3 inches in diameter. These do not appear in the freshly fractured rock. Large crinoid joints . . . . 5 feet

Bed 5, Thickbedded dolomite similar to Bed 4 but with numerous corals particularly Acervularia, except in the uppermost stratum. Some of the Acervularia colonies are 5 inches in diameter, lined with calcite crystals. Besides this, Favosites, Cyathophylloids, Fenestella, Stropheodonta halli var., Pholidostrophia, Chonetes and the gastropod and large crinoid joints of Bed 4 occur. Fossils in general, however, are not particularly common . . . . 9 ft. 6 in.

Bed 6, Light colored brown dolomite with ichre tints. The glacially polished surface appears mottled. More porous than beds below; cavities lined with calcite druses, not microscopic crystals as in Bed 5 and 6. The few poorly preserved fossils are forms which are also found in beds below (Strophodonta, Pholidostrophia, etc.). Corals are not conspicuously present . . . . 6 feet (top of quarry)

Mikulic (1977) mentioned the presence of a low dome in the Devonian exposures along the lake shore just northeast of the quarry. It seems possible that this dome is controlled by a buried Silurian reef.

The quarry area was purchased by the State of Wisconsin and was incorporated into a state park in the early 1970's.

WASHINGTON COUNTY

Only the eastern townships (Germantown, Jackson, and Trenton) of Washington County are included in this study since outcrops and information on the Silurian are lacking for the rest of the area (see Figure 118). In the southernmost two of the eastern townships (Germantown and Jackson) the bedrock is close to the surface and apparently represents a continuation of the northeast-southwest trend of shallow bedrock in Waukesha County. Many of these exposures appear to be reef-controlled in contrast to those in Waukesha County.

The Quaternary cover ranges from less than 50 feet in Germantown and Jackson Townships to over 100 feet in Trenton Township where the exposures are all found along the Milwaukee River.

Silurian bedrock thickness in the county ranges from zero in the west to over 370 feet to the east along the southern border. Most of the exposures are in the Racine Dolomite.

Quarries were formerly operated in Germantown Township, but all are now abandoned, and a quarry has recently been opened in Jackson County (locality 152).

Rockfield Quarry and Outcrops
Locality 126

NE 1/4, SE 1/4, Section 9, T. 9 N., R. 20 E., Germantown Township, Washington County.

MPM x41. 1

elevation: 900 feet (top of quarry)

Alarge, abandoned, partially water-filled quarry is located southwest of the intersection between Division Road (County Highway G) and Rockfield Road, and west of the railroad tracks (see Figure 124). The west side of the quarry is developed in a partially rock-controlled hill. There is also an outcrop in the road ditch 300 feet south of the quarry (elevation 880 feet).

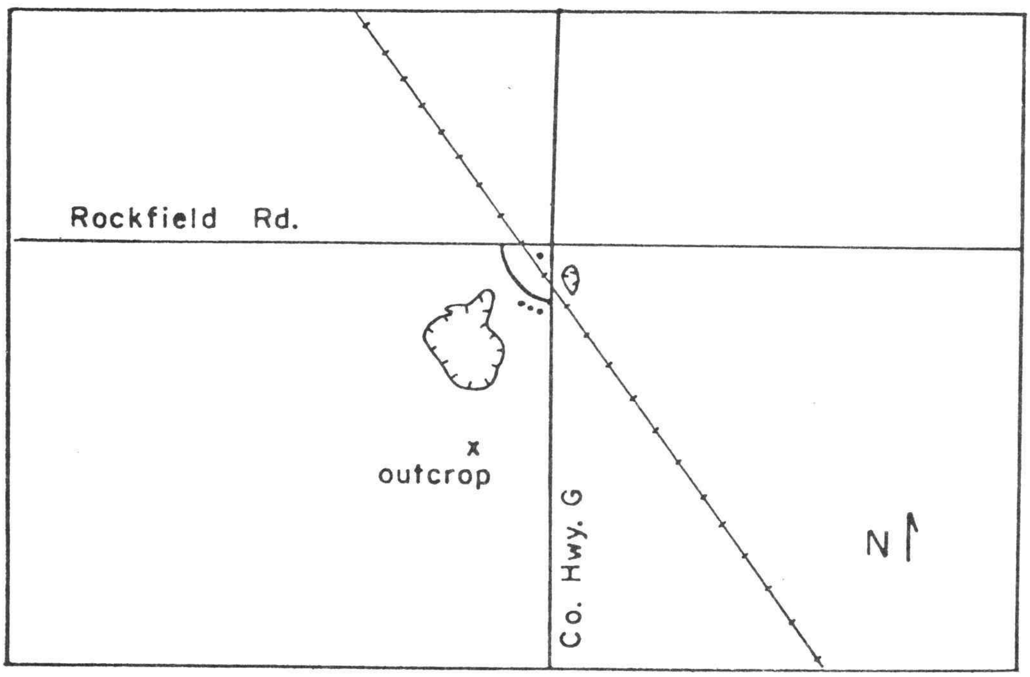
Alden (1904-1905, unpublished field notes) reported that this quarry (Mace Lime Company) was then 10 to 15 feet deep and described the rock exposed there as follows:

> Stone porous gray dolomite in thin somewhat uneven layers mostly about 4 inches thick, some 6 inches to 1 ft. The thicker layers contain irregular cavities 1 to 4+ inches in long diameters. Rock breaks irregularly. See no chert or fossils. Few said to occur. Some thin beds wedge out laterally every few feet.
>
> Rock overlain by 1 to 3 ft. of clay till.

The quarry is now partially water-filled, but approximately 20 feet of Racine Dolomite is exposed along the west, north, and south walls; however, only a couple of feet can be seen along the east wall (see Figure 125). A reef is well exposed in the west wall and a

Figure 124. Airphoto (A) and locality map (B) of Rockfield quarry (locality 126), Washington County. Airphoto from National Archives and Records Service, General Services Administration. No. XH-2B-153; date: 8-28-41.

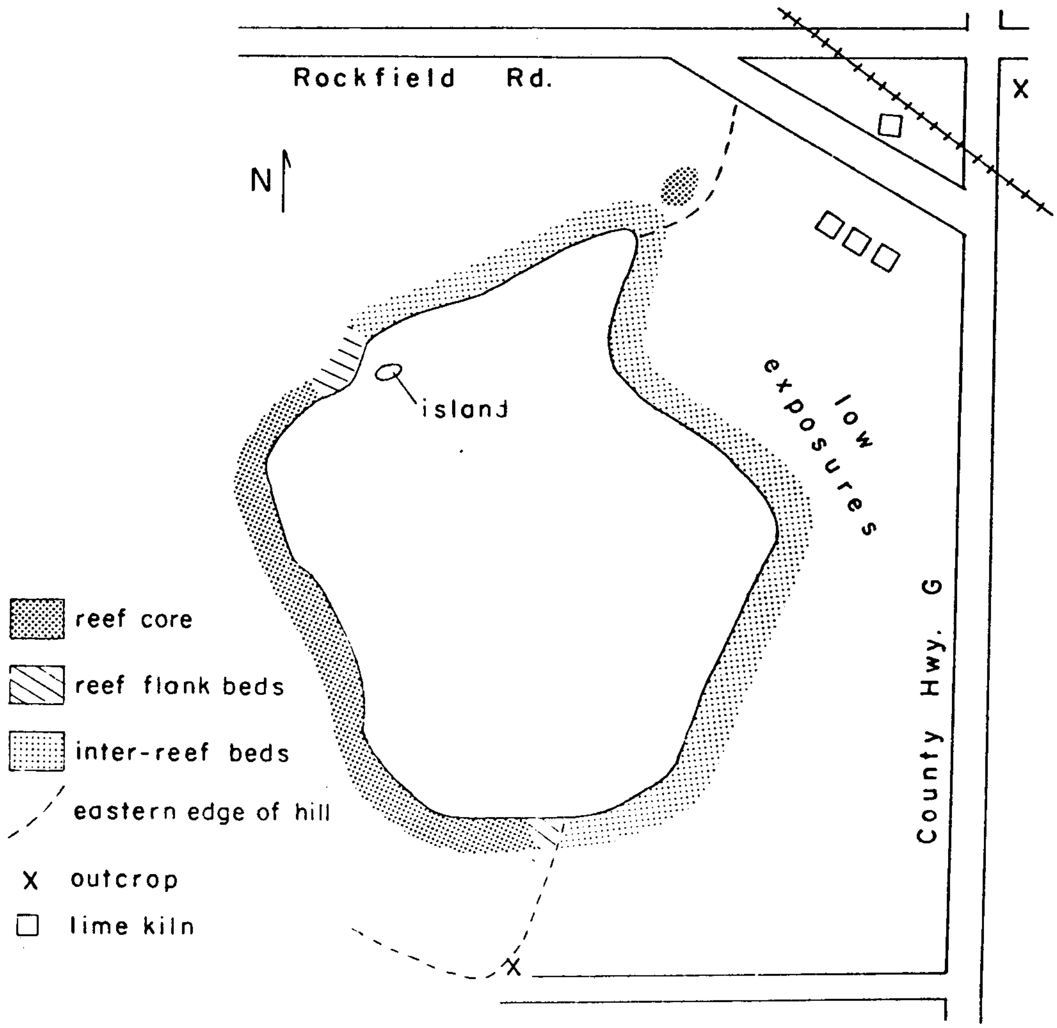
A



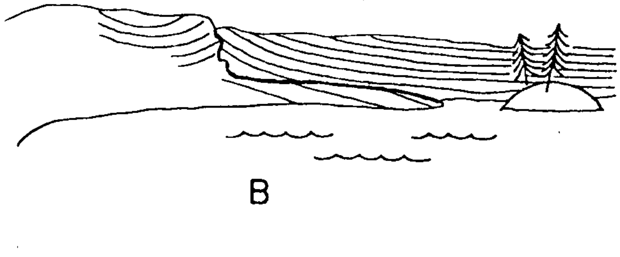
B

Figure 124

Figure 125. Diagrams of the Rockfield quarry (locality 126) Washington County. (A) is map showing exposures around the quarry. Reef core in hill along west wall; inter-reef beds form low area along east wall. (B) shows details of flank beds in northwest corner of quarry; flank beds dip to northeast (right) away from massive core rock (left). These represent current quarry exposures.



A



B

Figure 125

possible reef outcrop is also located near the incline to the lime kilns north of the quarry. Horizontally-bedded inter-reef rock is well exposed along part of the north wall, occurring in beds six inches thick. The rock is dense, poorly fossiliferous, non-porous, light gray dolomite. Fine pelmatozoan debris is present. Towards the west, the beds appear to dip away from the northwestern corner of the quarry, at first gently but increasing towards the west (see Figure 125B and 126B). Before the west wall is reached the beds become massive, but are still poorly fossiliferous. Along the northern one-third of the west wall the rock is massive, porous, granular, vuggy, light gray dolomite; this is typical reef core rock. Many two to three inch diameter cavities are present and appear to represent external molds of tabulate corals and stromatoporoids. Small rugose corals are common and pelmatozoan stem fragments are locally abundant. Only a few large tabulate coral colonies are scattered along the entire west wall core area. The center of the west wall is generally not well exposed, but the rock appears to be similar to that exposed to the north. At approximately the center of the wall is a five foot by ten foot mass of dense, poorly fossiliferous, non-porous dolomite surrounded by more typical fossiliferous dolomite. In the southern one-third of the wall sections of large pelamtozoan stems are abundant, along with common, small spherical favositid colonies. There is also a large variety of cephalopods

Figure 126. Photographs of reef-inter-reef transition in the Rockfield quarry (locality 126), Washington County. (A) is transition in the southwest corner of the quarry, inter-reef beds at left (south), reef core at right (north); (B) transition in the northwest corner, inter-reef beds at right (east), reef core at left (west) (see also Figure 109B). Photos taken 1975.

A

B

Figure 126

and brachiopods, including rhynchonellids. To the south, the transition from reef to inter-reef beds is well exposed (see Figure 126A). Nearly horizontal inter-reef beds similar to those along the north wall rise up towards the north, rapidly thickening and becoming massive within about 10 feet, at which point typical reef core rock is exposed. The rocks along the east wall are essentially horizontal inter-reef beds, as in the north wall. This reef is lithologically and faunally like those exposed around Germantown, Menomonee Falls, and Racine.

Locality 127

NW 1/4, SW 1/4, Section 10, T. 9 N., R. 20 E., Germantown Township, Washington County.

MPM x41.10

elevation:

A small, filled quarry is located southeast of the intersection of County Highway G and Rockfield Road. A small bedrock exposure is present at ground level.

Alden (1904-1905, unpublished field notes) visited this old quarry and found a ten foot section of a porous, fairly well-bedded dolomite which he compared to rock at Germantown quarries. The rock weathered buff and dipped gently to the south 10° at the south side of the quarry. Beds were six to twelve inches thick.

Chamberlin's Germantown Locality
Locality 128

Chamberlin (1877, p. 363-364) described, in detail, a reef exposure "near the south line of the SW 1/4 of Section 35, Germantown" in a quarry of "considerable lateral extent," but only eight feet deep. The exposure consisted of a reef core in the southwest and horizontal, non-reef beds in the northeast. Alden (1904-05, unpublished field notes) indicated the presence of a quarry (Schmidt's) in this approximate location. Only a few surface exposures are present at this location today and there is some question as to the true location of Chamberlin's quarry. He (1880) mentioned only one fossil collection from Germantown (No. 223, Niagaran Formation, Germantown, Section 25, SW 1/4, S line, Racine beds, south side of road). No outcrops have ever been located in this section. Alden (1918) indicated outcrops in the NW 1/4, and SW 1/4, Section 36 (locality 129), and NE 1/4, Section 33 (locality 130), however.

Germantown-West Quarry
Locality 131

Section 22, T. 9 N., R. 20 E., Germantown Township, Washington County.

MPM x37.17

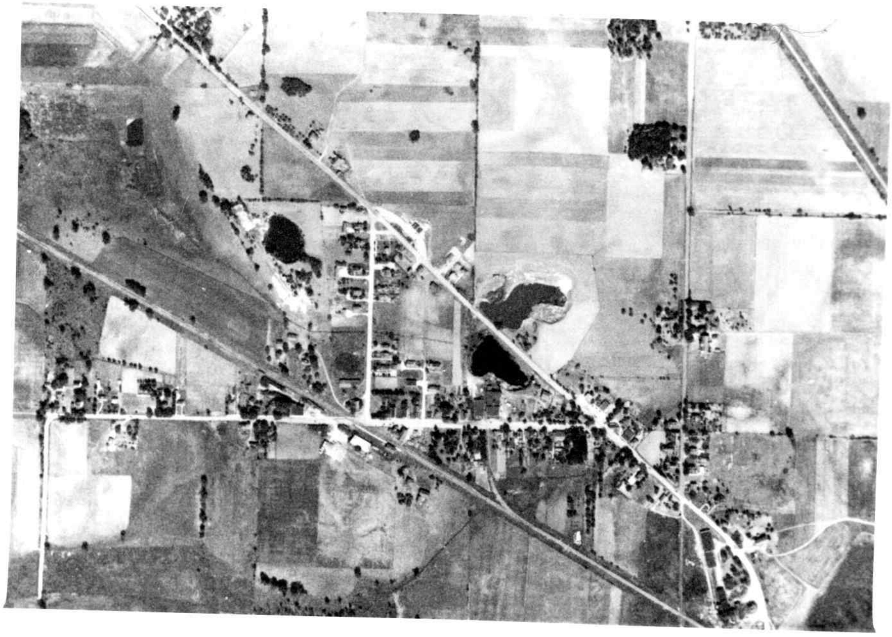
elevation: 670 feet (top of bedrock)

A small, partially water-filled quarry is situated south of State Highway 145 and north of the railroad tracks on the northwest side of Germantown (see Figure 126). The quarry has been dug into the west side of a low hill which rises toward State Highway 145 (northeast). To the southeast of the quarry is a small, localized hill which has been partially quarried away and appears to be a reef. To the southwest is a flatland with no rock exposures.

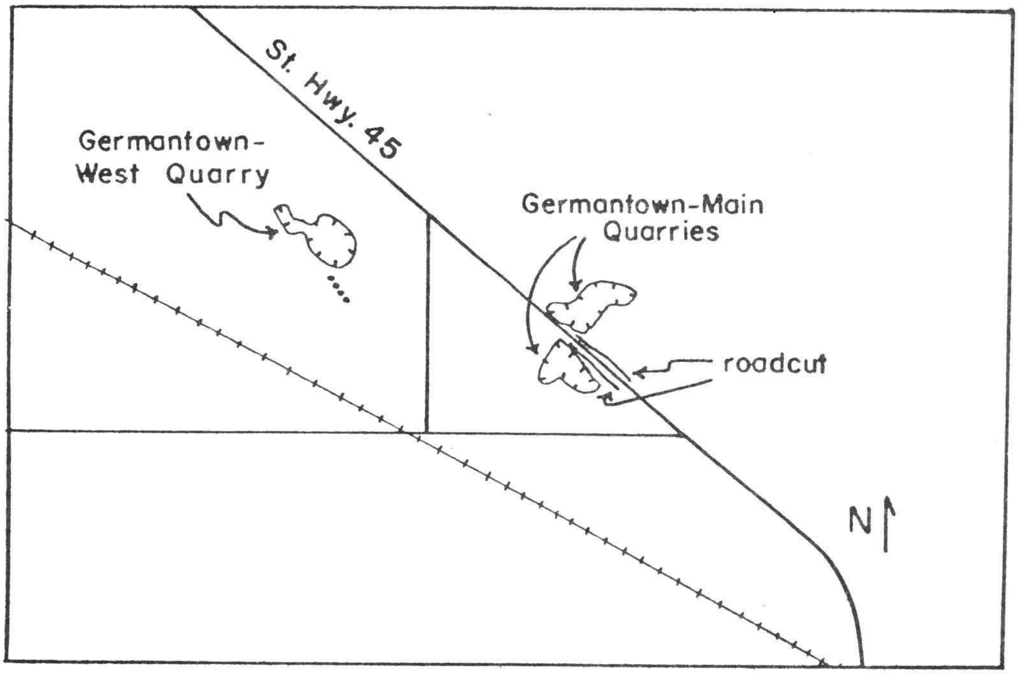
Shrock (1930, unpublished field notes) visited this quarry and described it as follows:

> At this locality there is a water-filled quarry with the southeast face cut into a ridge. There are 37 feet of rock exposed. Low abandoned lime kilns stand just south of the quarry.
>
> The lower 5 feet are a light colored to buff, evenly grained, very porous massive dolomite which shows no bedding. It contains many small crinoid stems.
>
> The upper 32 feet are composed of a blue to gray, dense, to cavernous, very unevenly-textured dolomite which has rough hackly fracture.
>
> The quarry seems to be a deep one from the length of time required for a boulder to reach the bottom.

Figure 127. Airphoto (A) and locality map (B) of Germantown area quarries and outcrops. Airphoto from National Archives and Records Service, General Services Administration, No. WH-28-165; date: 8-28-41.



A



B

Figure 127

No exposures can be seen along most of the west wall of this quarry at the present time; to the east the rock face increases from approximately five feet to twenty-five feet near the southeast corner of the quarry (see Figure 128). There are a number of scattered, low outcrops north of the quarry along the slope of the hill going up to State Highway 145. The quarry is old and most of the exposures are weathered and overgrown; solution pits and cavities are conspicuous on some weathered surfaces. Fossils occur as internal and external molds. Stylolitic bedding planes are common, particularly in well-bedded areas. The depth of the quarry below the water level is unknown.

The west half of the north wall exposes about five to ten feet of medium-bedded, horizontal, light gray, dense, non-porous dolomite. The rock is poorly fossiliferous with only small pelmatozoan fragments present. About ten feet of rock is exposed above water level on the east half of the north wall. The rock appears to be well-bedded, but has a slight dip to the west. The lower two-thirds of this wall grades into a thicker-bedded dolomite lithologically similar to the western exposures. The upper one-third of the wall is more porous, fossiliferous, and thinner-bedded. Large pelmatozoan stem sections are present and fossils in general increase in abundance throughout the entire section toward the east. The north half of the east wall is poorly exposed, but appears to be lithologically similar

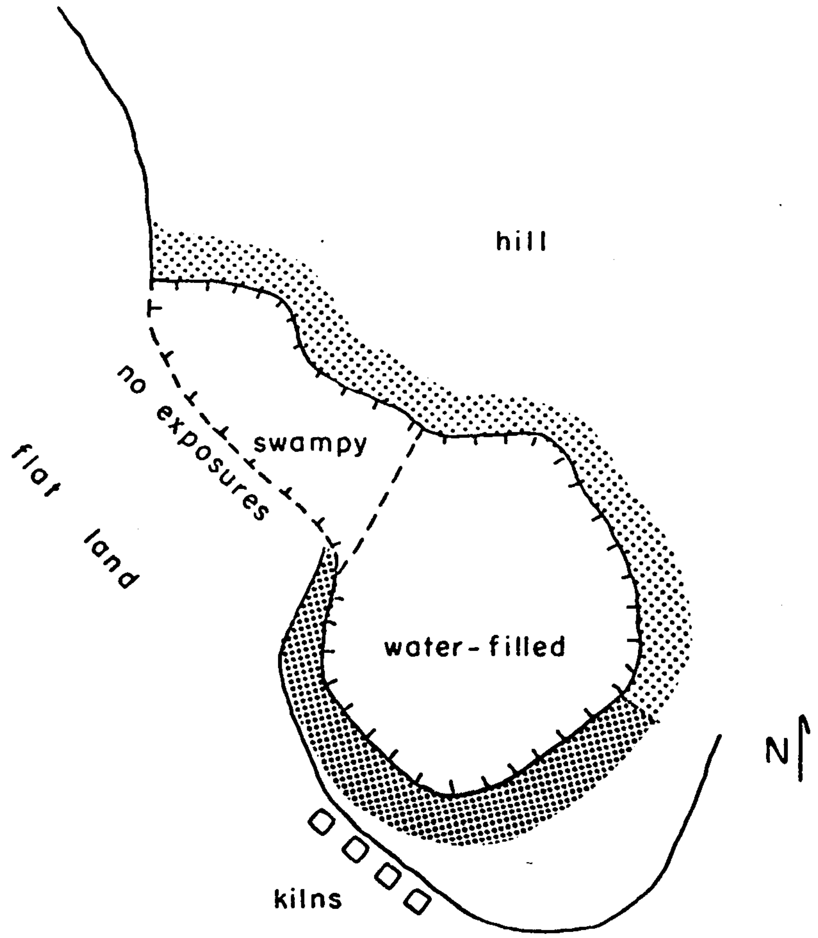


Figure 128. Diagram showing general characteristics of the west quarry (locality 131) at Germantown. Reef core occupies south and east walls. Bedrock hill between quarry and kilns is reef-controlled. See text for details.

to the adjacent beds described from the north wall. Fossils are more common and the height of the quarry face increases to 20 feet above the water level. Along the south wall and the south half of the east wall the outcrop reaches a maximum thickness of about 25 feet (southeast corner). To the southeast is the small hill previousl mentioned. To the south and west of the quarry the rock surface rapidly drops down to the flat area.

In general the rock is massive, highly fossiliferous, light gray, finely granular, and porous dolomite. Fine pelmatozoan debris is common, with larger fossils found in lenses. Sections of large pelmatozoan stems are common, as are tabulate corals, rugose corals, and rhynchonellid brachiopods. Molds of tabulate corals and stromatoporoids commonly appear as vugs and cavities one-half inch to four inches in diameter. This reef is lithologically and paleontologically similar to other Racine Dolomite reefs in Washington and Racine Counties.

Germantown-Main Quarries
Locality 132

Section 22, T. 9 N., R. 20 E., Germantown Township, Washington County.

MPM x37. 18

elevation: 880 feet

The center of Germantown, along State Highway 145, in the NE 1/4, Section 22, is underlain by a number of bedrock-controlled hills; outcrops are common. A number of old quarries are located in the vicinity and the basements of many nearby buildings are excavated in bedrock. Many of these bedrock hills appear to be reef-controlled and exposures of typical, reefoidal beds of Racine Dolomite are common (see Figure 127).

Shrock (1930, unpublished field notes) described the exposures in this vicinity as follows:

> There is a quarry on either side of the road. Both are filled with water.
>
> In the north quarry there are 14 feet of homogeneous massive, open textured, yellowish granular dolomite with a domed surface. The overlying beds are irregularly separated, full of holes, nodular-looking, and much harder and bluer than the underlying beds.
>
> The top beds, 6-10 ft. thick, are inclined to the south at an angle of 4-6°.
>
> On the south side the beds dip to the west at an angle of 10±°. There are about 29 feet of the massive homogeneous rock exposed in the quarry on the south side.
>
> There seems to be a dome to the east of the quarries upon which the overlying beds are laid, dipping generally to the west and north.

There seems to be some local irregularity in the dip of the overlying beds.

The exposures examined by Shrock are still partly visible, however, both quarries have been nearly filled. Based on Shrock's observations and recent examination of this locality, it appears that the exposures represent the western portions of a reef which controls the topography in the area.

The quarry on the south side of State Highway 145 has been partially filled, and only the upper part of the east wall, adjacent to the road cut, is still exposed. The rock here consists of a very thick-bedded to massive, granular, non-porous, unfossiliferous dolomite, most of which has recently been covered. This is overlain by several feet of medium-bedded, somewhat vuggy, granular, light gray dolomite with beds dipping south and east.

Parts of the north and east walls of the northern quarry remain and are composed of well-bedded dolomite as described by Shrock.

At the east end of the southern road cut a <u>Bumastus</u> accumulation was found in massive rock, indicating the proximity of a reef. In general the rock at this road cut is somewhat thick-bedded, fossiliferous, reefal dolomite which dips to the west.

A water-well (Wn-351) in the SE 1/4, SE 1/4, NW 1/4, Section 21 (elevation 875 feet) about one mile west of the quarries gives the general characteristics of the subsurface Silurian in this vicinity:

Drift . . . . 12 feet

Gray dolomite with rare chert

near top and about 70 feet down. . . . . . . 148 feet

Gray, cherty dolomite becoming reddish

in the lower 100 feet . . . . 215 feet

Ordovician Maquoketa Shale . . . . 135 feet

Total thickness of the Silurian here is 363 feet.

Alden (1918) indicated on his Geologic Map of Southeastern Wisconsin that outcrops were present in the NW 1/4, Section 23, along the railroad tracks (locality 133), and in the SE 1/4 and NW 1/4, Section 21, NW 1/4, Section 27, and NE 1/4, Section 28, T. 9 N., R. 20 E., Germantown Township, Washington County, (all at locality 134).

Miscellaneous Germantown Localities

Alden (1918) indicated the following localities from T. 9 N., R. 20 E., Germantown Township, Washington County on his Geologic Map of Southeastern Wisconsin:

S 1/2 of line between Sections 1 and 2 (locality 135)

SW 1/4, Section 5 (locality 136)

NW 1/4, SW 1/4, Section 10 (locality 137)

SE 1/4, SW 1/4, Section 10 (locality 137)

NW 1/4, Section 23 (locality 133)

E 1/2 of line between Sections 21 and 28 (locality 134)

NW 1/4, Section 27 (locality 134)

NE 1/4, Section 28 (locality 134)

NE 1/4, Section 29 (locality 138)

SE 1/4, Section 31 (locality 139)

NW 1/4, Section 32 (locality 140)

Alden (1904-1905, unpublished field notes) reported a small quarry on Leasenfeller's land in the SE 1/4, Section 5, T. 9 N., R. 20 E. (locality 141), Germantown Township, and also mentioned that rock was exposed one-fourth mile north of Kraelisch.

Exposures in Jackson Township
Locality 142

NE 1/4, NW 1/4, Section 17, T. 10 N., R. 20 E., Jackson Township, Washington County.
elevation: approximately 860 feet

Alden (1904-1905, unpublished field notes) mentioned finding large block of limestone at a low knoll as though they were part of a limestone ledge, however, he did not find any of the rock *in situ*.

Locality 143

SE 1/4, Section 4, T. 10 N., R. 20 E., Jackson Township, Washington County.

elevation: approximately 860 feet

Alden (1904-1905, unpublished field notes) reported that rock was exposed in the creek bed at W. J. Groth's barnyard, and that in the SE 1/4, SE 1/4, Section 4, limestone rose to the surface in a low ridge.

Locality 144

SW 1/4, SW 1/4, Section 3, T. 10 N., R. 20 E., Jackson Township, Washington County.

elevation: 860-880 feet

In his 1904-1905 unpublished field notes Alden indicated that rock was close to the surface here and was only thinly covered by soil.

Locality 145

NE 1/4, Section 12, T. 10 N., R. 20 E., Jackson Township, Washington County.

elevation: 880-900 feet

According to Alden (1904-1905, unpublished field notes) the west slope of Lemke's farm was "said to stand in limestone." He also reported that he was informed that rock was near the surface in the NE 1/4, Section 2.

Locality 146

S line, Section 29, T. 10 N., R. 20 E., Jackson Township, Washington County.
elevation: approximately 900 feet

Alden (1904-1905, unpublished field notes) reported that limestone was exposed in the road at this location.

Location 147

E 1/2, SW 1/4, Section 27, T. 10 N., R. 20 E., Jackson Township, Washington County.
elevation: 900 feet

A ledge of roughly weathered limestone having a relief of six feet or more on the east, north and south sides was reported by Alden (1904-1905, unpublished field notes).

Locality 148

Section 34, T. 10 N., R. 20 E., Jackson Township, Washington County.

Alden (1904-1905) observed rock exposed in the road here.

SW 1/4, NW 1/4, Section 35, T. 10 N., R. 20 E., Jackson Township, Washington County.

elevation: 880-900 feet

Alden (1904-1905, unpublished field notes) reported that limestone was exposed in and near the road at this locality.

Locality 149

SW 1/4, Section 15, T. 10 N., R. 20 E., Jackson Township, Washington County.

elevation: approximately 860 feet

Alden (1904-1905, unpublished field notes) reported that limestone was exposed near the barn here.

Locality 150

NE 1/4, Section 21, and NW 1/4, Section 22, T. 10 N., R. 20 E., Jackson Township, Washington County.

elevation: approximately 840-860 feet

Alden (1904-1905, unpublished field notes) thought that limestone was exposed at one point in the road.

Locality 151

Near center of E line, Section 1, T. 10 N., R. 20 E., Jackson Township, Washington County.

elevation: approximately 880-900 feet

Alden (1918) indicated an outcrop at this location on his Geologic Map of Southeastern Wisconsin.

Jackson Quarry
Locality 152

Center Section 12, T. 10 N., R. 20 E., Jackson Township, Washington County

elevation: 880 feet

In the last few years a large quarry has been opened in the southwest corner of an apparently bedrock-controlled hill rising to the east of Cedar Creek. The quarry exposes approximately feet of granular, thick-bedded, non-porous, light gray dolomite having beds that dip from northeast corner of the quarry and level out to the west. A reef is probably located towards the northeast, but has not yet been uncovered. The rock appears to be Racine Dolomite.

Newburg
Locality 153

NE 1/4, SW 1/4, NE 1/4, Section 12, T. 11 N., R. 20 E., Trenton Township, Washington County.

MPM x41.3

elevation:

A small old quarry is situated on the north bank of the Milwaukee River north of the road, just west of Newburg.

Chamberlin (1877, p. 394) mentioned rock at Newburg and described it as being "one of the more common varieties of the Niagara limestone."

Raasch (1922, unpublished field notes) described this locality as follows:

> Exposure just west of Newburg along the river showed about a seven foot section consisting of reef or mound with stratified layers overlapping.
>
> The stratified beds consist of light colored, compact dolomite with many small openings due probably to the dissolving away of minute fossils. The rock is fairly hard and resists erosion well.
>
> Interbedded with the above are similar strata, but more compact harder and light grayish in color.
>
> When the beds first appear they are dipping quite sharply away from the reef. As they approach the reef, however, they assume a more nearly horizontal position.
>
> The reef itself consists of hard, nodular limestone of a light gray color. The rock resembles some of the horizons of reef rock in the vicinity of Milwaukee.
>
> Both the reef and the adjoining strata yield numerous fossil remains, notably brachiopods. These occur as internal casts which show many of the internal characters of the

shells. Unfortunately many of the fossils have been partially removed by eolution.

The fauna of the stratified beds is unlike any other so far discovered in this section of the state. It consists largely of brachiopods and corals, the former being represented by *Whitfieldella*, *Meristina*, *Orthis* (*flabellites*?), *Camarotoechia* (res. *C.* *acinus*). The only form common to the Racine or Guelph of this area is the widespread *Leptaena* *rhomboidalis*.

The corals are not distinctive.

Building excavations in a housing subdivision a short distance northeast of the quarry uncovered similar rock in 1975.

Myra
Locality 154

S 1/2, Section 15, T. 11 N., R. 20 E., Trenton Township, Washington County.

elevation: approximately 860 feet

A small quarry is thought to have operated south of the Milwaukee River near the town of Myra.

Kohler
Locality 155

S.W. 1/4, S.E. 1/4, Section 6, and NW 1/4, NE 1/4, Section 7, T. 12 N., R. 21 E., Ozaukee County.

elevation: approximately 820 feet

MPM x256.1

Raasch (1929, unpublished field notes) reported a limestone ridge with a relief of 30 feet two miles north of Kohler. Fossils were scarce because of the granular and dolomitized rock, but Raasch found Favosites, Zaphrentis, and Illaenus cf. armatus near the middle of the section. He also noted local doming in lower layers near the creek. Fossils were also reported from near the top of the exposure in a reef-like mass. A small amount of quarrying was carried on, but no more than a few feet of strata are exposed in any one place. The exposure extended for more than a quarter of a mile in a southerly direction but soon disappeared under drift to the north of the road.

Locality 156

Sections 6 and 7, T. 10 N., R. 21 W., Cedarburg Township, Ozaukee County.

Scattered outcrops of Silurian occur in this area.

APPENDIX III

PROMINENT FOSSIL COLLECTORS IN SOUTHEASTERN WISCONSIN

Introduction

Since many of the classic southeastern Wisconsin Silurian localities are now either poorly exposed or inaccessible, the older fossil collections assembled by a number of nineteenth century "gentlemen paleontologists" are very important for taxonomic, biogeographic, and ecologic studies. Fortunately, a number of these collections are preserved reasonably intact and are accompanied by information in correspondence and notes as to when and where the fossils were found. Most of these individuals had little or no scientific training, but were well educated and interested in many aspects of natural history. Some, such as Day and Greene, were wealthy and were able to devote a fair amount of both time and money to obtaining specimens for their "cabinets." These individuals expanded their collections by exchanges made with other collectors and professional geologists throughout the country and specimens of the more common taxa from southeastern Wisconsin can now be found in museums throughout the United States because of this activity.

Fossil collecting in the nineteenth century was quite different than it is today. Most of the quarries were small and shallow and exposures changed little over long periods of time. This is in contrast to today where quarries, such as that at Thornton (near Chicago, Illinois) produce a million tons of rock a month and exposures disappear overnight. In the 1800's all of the rock was picked up and placed in carts by hand; blocks too big to be handled were broken with sledgehammers. Few fossils would pass unnoticed, especially since there was a ready market for them. Quarry workers were more than happy to save fossils for the gentleman paleontologists since it could mean a few extra dollars a week which, considering their low wages, was a sizable sum; they could even double their wages. This also contrasts with collecting today since it would be rather difficult to double the wages of a modern quarry worker. It is safe to assume that few good fossils escaped the quarry workers or the collectors themselves.

The following are brief biographical sketches of several of the notable Silurian fossil collectors from southeastern Wisconsin.

Increase A. Lapham (1811-1875)

The first individual to assemble a large collection of southeastern Wisconsin fossils was probably I. A. Lapham. He was Wisconsin's first scientist and was interested in virtually all aspects of natural history, including archaeology, botany, zoology, geology, and meteorology (Winchell, 1894).

Lapham first came to Wisconsin in 1836 and began mapping the Milwaukee area and studying its geology. By the 1850's he had gained a fair knowledge of the basic geology of the area (see section on Silurian stratigraphy of southeastern Wisconsin for some of his contributions).

Lapham's diverse interests did not allow him a great deal of time to devote to geology and paleontology, but his small number of publications in these fields should not be interpreted as meaning his knowledge in these areas was limited. This is demonstrated by the fact that he and James Hall at one time worked on a monograph of North American paleontology, which appears to have been planned to cover all invertebrate fossils known from North America at that time.

Lapham's geologic work in the state culminated with his appointment as Director of the Wisconsin Geological Survey in 1873.

Unfortunately, almost nothing remains of Lapham's collections. In 1876, his collection, which included "some 10, 000 fossils, minerals, shells, meteorites, and Indian relics, " primarily from Wisconsin was purchased by the state for the University of Wisconsin (Scott, 1975). However, the Science Hall fire in December of 1884 destroyed this entire collection (Scott, 1975). A few of Lapham's specimens were purchased by T. A. Greene, a Milwaukee collector and Lapham did supply a few specimens to Hall for his paleontologic work (some of these are now type specimens in the American Museum of Natural History). Teller (1912) reported that the few specimens Lapham had at the time of his death were donated to the Milwaukee Public Museum by his family.

Another early fossil collector, Mr. Sherman of Milwaukee, was mentioned in T. J. Hale's field notebook as having a large collection of fine trilobites and other fossils from the Milwaukee area; according to Hale he purchased fossils from quarry workers. Nothing else is known about Sherman.

Fisk Holbrook Day (1826-1903)

F. H. Day was born in New York in 1826 and moved to Wauwatosa, Wisconsin, in 1854 (Western Historical Co., 1881). He was a physician in Wauwatosa and held the position of Milwaukee County Physician for many years (Lansing Journal, 1903). Day was also a naturalist, like Lapham, being interested in all phases of natural science, including archaeology and geology, but primarily paleontology. Unfortunately, none of Day's notes or correspondence has been preserved with the exception of letters he wrote to individuals at Harvard University (now in the Archives of the Museum of Comparative Zoology) and letters between him and T. A. Greene (now in the Greene files in the Archives at the University of Wisconsin-Milwaukee Library).

Day began collecting fossils shortly after his arrival in Wauwatosa. Most of the material he collected was obtained from the nearby Schoonmaker quarry, but he also collected extensively at the Trimborn quarries in Greenfield Township and Horlick quarries in Racine, as well as most of the other operating quarries in the area. Day also purchased specimens, as did most of the gentlemen paleontologists of the day. Day was good friends with P. R. Hoy, T. A. Greene, and E. E. Teller, as well as other local geologists. He supplied specimens and information to both James Hall and T. C. Chamberlin during the course of their work on the geology and paleontology of southeastern Wisconsin. Besides Chamberlin and Hall, Day corresponded with other prominent scientists, including Charles Doolittle Walcott He (1877) wrote at least one scientific paper on the geology and paleontology of the area, demonstrating thorough knowledge of these subjects and some rather original thinking. Although he had no formal training in geology he did not hesitate to present ideas contrary to those held by such eminent scientists as Hall. He also mentioned working on a paper about the general characteristics of trilobites, but it was never published.

As far as quality is concerned, Day assembled the best collection of Silurian fossils from southeastern Wisconsin. This includes many spectacular specimens of trilobites and cephalopods from the Schoonmaker quarry. Day was once offered $100 for a single specimen consisting of two complete trilobites, one of which later became the holotype for Bumastus dayi. For reasons no longer known, Day decided to sell his collection in 1880. He offered the collection to the University of Wisconsin through T. C. Chamberlin and also to Harvard University. Most of the collection was purchased by Alexander Agassiz in 1880 and was donated to the Museum of Comparative Zoology at Harvard the following year. It may at first seem unfortunate that the collection left the State at that time, however, if it had been purchased by the University of Wisconsin it would probably have been destroyed with the rest of the collections in the Science Hall fire of 1884. Day's collection at Harvard has been dispersed among the general collections and it is next to impossible to determine the size of the original collection.

Day continued to collect fossils for the rest of his life and in 1884 he sold a large collection to T. A. Greene for $100; this material cannot be identified in Greene's collection now, but considering the price paid, it probably represents a large portion of Greene's Wauwatosa material and other fossils. In 1893 Day retired from his medical practice and moved to Lansing, Michigan. He died in 1903 and a collection of several thousand specimens in his possession at that time was supposed to have been given to the Milwaukee Public Museum, however, it was eventually sold to the University of Michigan where it is now located. Unfortunately, most of the original locality labels appear to have been lost for this material.

Recently, an interesting account of Day's life was given by

H. Russell Zimmermann (1979).

Philo Romayne Hoy (1816-1892)

Dr. Phil R. Hoy was born in 1816 in Mansfield, Ohio, and moved to Racine, Wisconsin, in 1846 where he remained for the rest of his life (McMynn, 1893). Hoy was a medical doctor and also a naturalist, having diverse interests including paleontology. According to T. A. Greene correspondence, Hoy was interested in collecting fossils only around Racine and he accompanied Greene to the quarries there on numerous occasions. Hoy gave many specimens to Hall and other interested individuals (Teller, 1912). Teller (1912) also stated that Hoy gave the last of his specimens to F. H. Day and the now-defunct Racine College. The Racine County Museum has a number of stuffed birds from Hoy's collections, but no fossils.

Thomas A. Greene (1826-1894)

Thanks to the foresight of his family, much of T. A. Greene's correspondence, library, and most importantly, his collection have been preserved in Milwaukee, and therefore, more information is known about his paleontological activities than about any of the other local collectors.

Greene was born in 1826 in Rhode Island and moved to

Milwaukee in 1848 (Greacen and Ball, 1946). After reaching Milwaukee he purchased a drugstore and later established a successful pharmaceutical supply house with Henry H. Button. His business success allowed him to pursue his interest in mineral collecting which he had acquired as a child (Greacen and Ball, 1946). Greene was well known to his contemporary gentlemen paleontologists of southeastern Wisconsin, including Day, Teller, and Hoy, as indicated by his extensive correspondence with them. He also corresponded with many of the leading invertebrate paleontologists in North America, such as James Hall, Charles Wadsworth, and J. Newberry, all of whom examined his collection at various times and borrowed a number of specimens for their research.

Greene began collecting fossils about 1877 and in 16 years had assembled a large and valuable collection. He had acquired a good knowledge of fossil identification, but apparently he was not interested in publishing any scientific papers. There is only a limited amount of geologic information in his correspondence and notes. Most of the information deals with general conditions of quarries for collecting fossils, but occasionally information about where fossils were being found in particular quarries can be discerned. Greene was able to purchase a large number of specimens from quarry workers. The workers were more than happy to save fossils for Day, Greene, and other potential customers, as the prices they received for good specimens could more than double their weekly salaries. Greene had a somewhat aggressive personality and his fossil collection became somewhat of an obsession, as indicated by his correspondence to and from other collectors. His letters are generally confined to asking individuals what he could obtain from them to the point where most people told him they were no longer interested in trading with him. He seldom revealed any information on the occurrence of fossils to other collectors and, in his correspondence, it would seem that the collecting was always better a few years before at all the localities. He was very possessive of his fossils and after one scientist had permanently borrowed some of his specimens, he went to extremes to keep track of what he loaned out. The following quote from one of F. H. Day's letters to Greene gives further insight into Greene's personality (letter, October 23, 1889):

> I was sorry to hear of your nervous attack yesterday and sincerely hope nothing serious will result--but serve simply as a precaution to keep that go-a-head-activeness of yours well in hand and not overdo.

As with many other gentlemen paleontologists of the day, much of Greene's collection was a result of purchases from quarry workers and other parties. A notable figure in this regard is A. G. Warner of Chicago. The only information on Warner is in Greene's correspondence and it appears that he earned his living by purchasing fossils from quarry workers (primarily in Chicago) and selling them to wealthy collectors. Warner shows up early in Greene's correspondence to P. Hoy, having raided the quarries at Racine on a number of occasions. Many of Warner's specimens ended up in the collection of Dr. J. Kennicott of Chicago and when Greene purchased Kennicott's collection in 1885 he also acquired the services of Warner. For the remainder of his life Greene purchased specimens from Warner on a regular basis, often receiving several boxes of fossils a week during the summer months. It is interesting to note that Greene would almost invariably pay less than Warner's asking price for the fossils, there was seldom any bargaining, and it is difficult to determine whether Warner was always overcharging or Greene was always underpaying. As a result of his transactions with Warner, the Greene collection contains the best collection of Silurian fossils from Chicago area reefs assembled in the 1800's. Most of these specimens are from the Hawthorne and Bridgeport quarries, old localities in the Chicago area, and most of Greene's locality data is still with the specimens. Because there were many restrictions placed on the examination and loan of specimens by Greene's heirs in the past, the collection is still in good shape. A number of measures, however, should be adopted to insure its usefulness to future research. Firstly, cataloguing of the collection should be completed. And secondly, the entire collection of Silurian-Devonian fossils, minerals, and rock samples should be kept intact since this is the only collection now available from which it is possible to obtain data, such as approximate species abundance, from the old classic localities, and also the collection is large enough to study variations in characteristics of different species.

Edgar E. Teller (1845-1923)

Teller was born in Buffalo, New York, in 1845 and moved to Milwaukee in 1875, where he became interested in fossils by walking through a quarry (the Moody quarry) on his way to work (Teller, 1924). He became a member of the Wisconsin Natural History Society in 1875 and was an influential member until he left Milwaukee in 1915. Teller was the most prolific writer of the gentlemen paleontologists in the Milwaukee area. His main interest was Devonian fossils of the Milwaukee area and he wrote several papers about them. A number of both vertebrate and invertebrate fossils were named in his honor. He also made large collections from the Silurian Moody quarry and the Wisconsin Cambrian. He donated many of his fossils to the Milwaukee Public Museum, the American Museum of Natural History, the University of Chicago-Field Museum, and the Buffalo Society of Natural Science. In 1915 he moved back to Buffalo and after his death his collection and library were donated to the U.S. National Museum in 1924. His collection has since been divided into different biologic and stratigraphic units and can no longer be studied intact.

There are two other collectors from the Milwaukee area around the turn-of-the-century about whom little is known. Teller (1912) mentioned that Mr. F. L. Horneffer of Milwaukee made a collection of fossils during the 1890's which became part of the Teller collection. Most of this material was Devonian, but some specimens from the Silurian Moody reef were also included.

Mr. Charles E. Monroe of Milwaukee made a large collection of Devonian fossils from the area which he later donated to the Milwaukee Public Museum. Little else is known about these individuals.

Location of Various Silurian-Devonian Fossil Collections from Southeastern Wisconsin

Most of I. A. Lapham's collection was destroyed by the Science Hall fire at the University of Wisconsin in 1884. A few of his specimens probably exist in the James Hall collections at the American Museum of Natural History and the University of Chicago-Field Museum, and possibly in other collections, but individual specimens cannot be attributed to him.

James Hall's type specimens from Wisconsin are located primarily in the American Museum of Natural History collections. The bulk of his non-type Wisconsin material is in the University of

Chicago-Field Museum collections, but some may be located in the New York State Museum in Albany.

Most of T. J. Hale's collections were probably incorporated into Hall's collections and no specimens can be directly attributed to Hale.

Whatever fossil specimens that were collected by the Wisconsin Geological Survey prior to the 1873 Wisconsin survey were stored in Science Hall and destroyed in the 1884 fire. The specimens from the 1873-1879 survey were, in part, stored in Science Hall and, therefore, also destroyed; this included the lithologic samples and one of 12 collections of about 1700 specimens of fossils. The fossils, numbering around 20,000, collected by this survey were, according to law, divided among 12 incorporated colleges and state normal schools and the Wisconsin Academy of Sciences, Arts, and Letters, which existed at that time. At that time Chamberlin (1880) published a locality register for the entire rock and fossils collection. Unfortunately, only one or two dozen fossils have been relocated and it appears that the collections have been lost for the mostpart. The type specimens (primarily described by R. P. Whitfield) were originally given to the Wisconsin Academy of Sciences, Arts and Letters, but after the Science Hall fire they were transferred along with the non-type material at the Academy to the University of Wisconsin. The types were not well curated and in the 1930's G. O. Raasch, then at the University of Wisconsin, found a number of the types in the teaching collection which he segregated and stored separately (G. Raasch, 1973, personal communication). These specimens were later transferred to the U. S. National Museum (Batten, 1960) where they are now located Non-type figured specimens have been distributed among the general biologic collections at that institution. Whitfield appears to have illegally retained a large number of Survey type and figured specimens which he sold to the University of California-Berkeley in 1886; this collection has been catalogued (Peck and MacFarland, 1954). Some of the type specimens cannot be located in any collections. The loss of the Survey collections, field notes, and maps is most unfortunate.

Other nineteenth century collections have already been discussed under the various collectors.

W. C. Alden assembled some collections in his work on the geology of southeastern Wisconsin. The Devonian material he collected is in the U. S. National Museum along with the Silurian phyllocarid material he collected near Waubakee (locality), which is included with the Devonian fossils. The rest of his Silurian specimens cannot be located.

A. W. Grabau's collections, made at the time of his brief study of the area reefs, are now in the collections of the American Museum of Natural History having been recently transferred from Columbia

University (J. Golden, 1979, personal communication).

Much of H. F. Cleland's collection was also transferred to the U. S. National Museum, but there does not appear to be any Silurian material with his Wisconsin Devonian fossils. R. R. Shrock's collection of fossils and rock samples assembled during his work in Wisconsin during the 1930's is now in the Milwaukee Public Museum collections. The Milwaukee Public Museum also contains large collections of Wisconsin Paleozoic fossils assembled by G. O. Raasch collected from around the time of World War I until the 1940's; another large collection of fossils was assembled by J. Emielity from the 1940's to 1970's.