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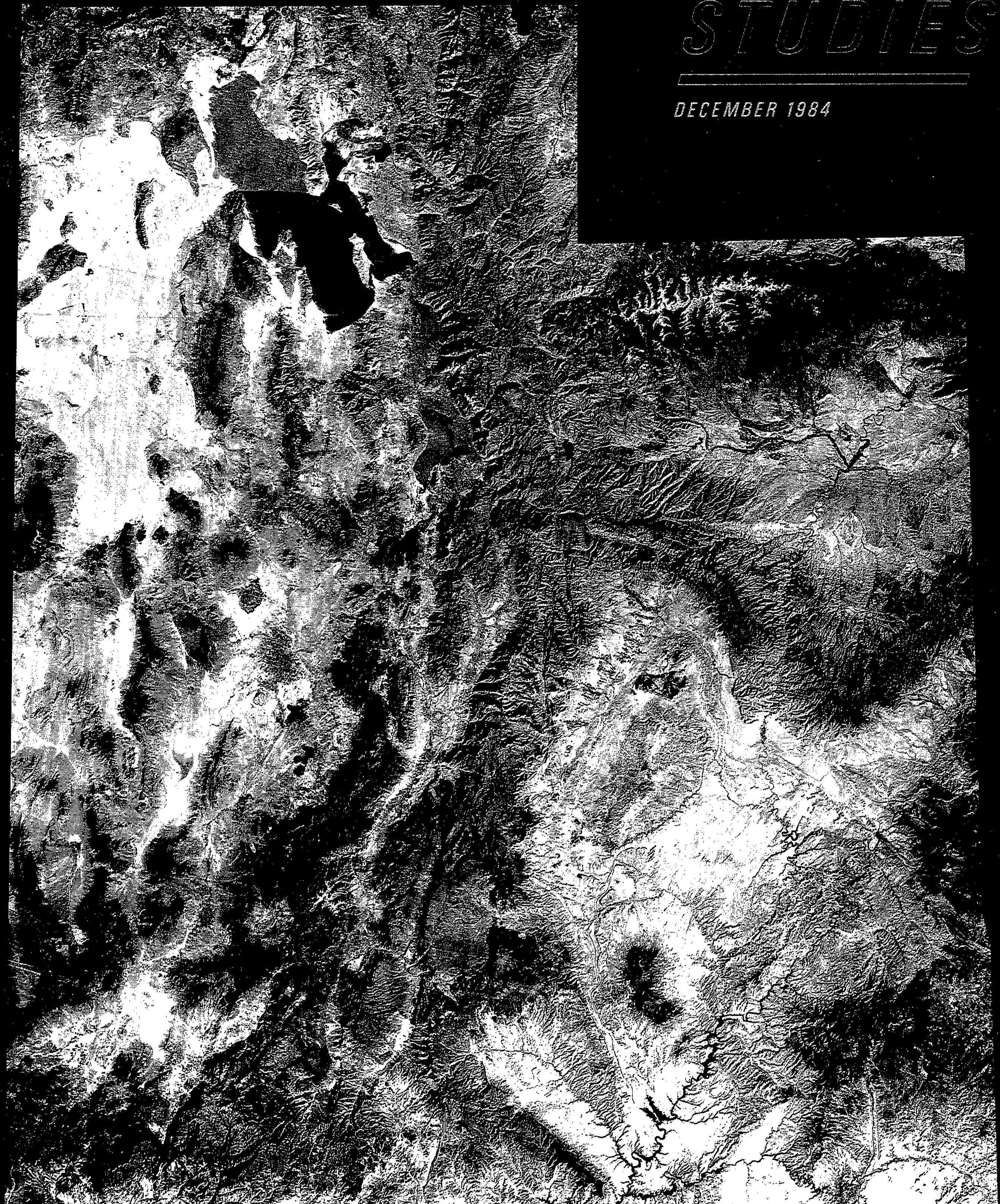
DECEMBER 1984



VOLUME 31, PART 1

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

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CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

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CONTENTS

Figures

Petrography and Microfacies of the Devonian Guilmette Formation in the Pequop Mountains, Elko County, Nevada*

WINSTON L. WILLIAMS

Department of Geology, Louisiana State University, Baton Rouge, Louisiana 70803

Thesis chairman: HAROLD J. BISSELL

ABSTRACT

The Guilmette Formation contains thick-bedded to massive limestone units that have often been called "reefs." Approximately 58 km (36 mi) west of Wendover, Utah-Nevada, one of these Guilmette Formation "reefs" is well exposed in the northern Pequop Mountains and was studied in detail. Petrographic analysis of the microlithofacies and paleontology, combined with data from sections measured in the field, revealed the presence of a mound and some proto-mounds, surrounded by shallow shelf back-reef sediments. This mound is not a reef, as previously supposed, and differs from mounds described in the literature in the following ways: (1) lack of diagenetic stromatactis structures, and (2) lack of obvious baffling organisms in the main body of the mound. Above this mound is an erosional unconformity which, dated by conodonts and some diagnostic stromatoporoids, shows that rocks of the Famennian stage (uppermost Devonian) are missing, which represents a period of about 5 million years.

Cementation and neomorphic diagenesis have combined to greatly reduce permeability. However, dolomitic zones and a sandstone unit exhibit good hydrocarbon reservoir potential. This reservoir potential is dependent upon early hydrocarbon migration prior to cementation.

INTRODUCTION AND LOCATION

Devonian carbonate buildups have been the subject of intense study in Canada, Europe, and Australia. These buildups have true organic "reef" character and in Canada are prolific producers of hydrocarbons. Devonian carbonate buildups in the western United States have been studied by few workers; their work has been equivocal. Reso (1959), after some preliminary work, concluded that the Guilmette Formation carbonate buildups in the Pahranagat Range of east central Nevada were actual reefs, comparable to the reefs in Alberta. Hoggan (1975, p. 145) reported that much unpublished work, some of which was done by Stanton in the same area, contradicted Reso's conclusions. To date, no unequivocal reef has been described from the Guilmette Formation.

The objective of this study is to define what type of carbonate buildup is represented by the Devonian upper Guilmette Formation in the northern Pequop Mountains (fig. 1). It was accomplished by tracing the vertical and horizontal microlithofacies and fossil organism changes throughout the entire areal extent of the outcrop in the study area. The outcrop covers an area of approximately 3 km^2 located in the central to southeast quarter of T. 37 N, R. 65 E, Elko County, Nevada. From fieldwork and the definition of microlithofacies as seen in thin section, conclusions are drawn determining what type of carbonate buildup is present in the area and how it relates to Devonian reefs found in other parts of the world. In addition, the economic potential of the buildup is determined for both economic minerals and hydrocarbons.

ACKNOWLEDGMENTS

The writer extends sincere thanks and appreciation to Dr. Harold J. Bissell, who served in all of the various aspects of thesis chairman. Dr. Morris Petersen and Dr. J. Keith Rigby, committee members, are thanked for having made valuable contributions to this study in terms of discussions, assistance in microslide and paleontologic identi-

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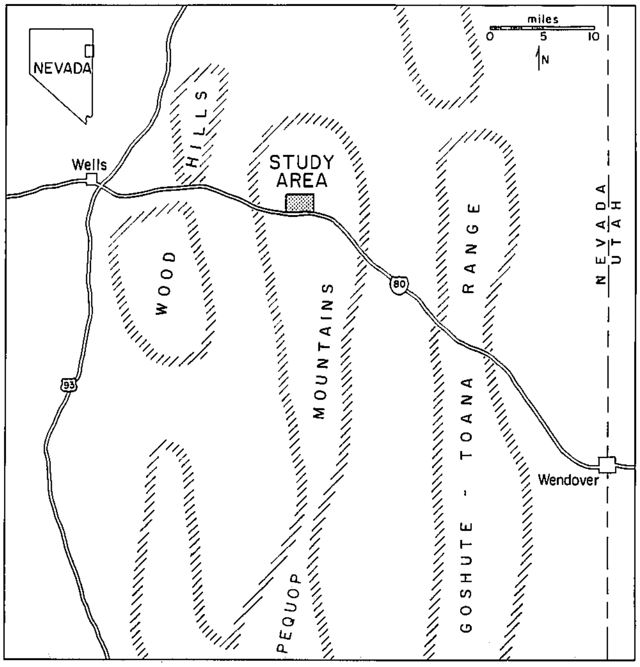

FIGURE 1.—*Index map showing location of study area.*

fications, and useful criticisms. The writer is indebted to John S. Berge, who provided the majority of the financial support for this thesis, and also to Drs. Joseph St. Jean, John Wray, and Charles Sandberg for paleontological identifications.

Also appreciated are the Marathon Oil Company geologists, Drs. Richard Rawson, David Beach, and Wilson Herrod, who provided stimulating discussions concerning the rocks in this study. Thanks are extended to Steve Smith and my brother, Winslow Williams, for helping with the fieldwork. Last, but not least, thanks to my friends Anne Eberhardt and Sid Petersen for help in preparing the manuscript.

PREVIOUS WORK

Nolan (1935, p. 20) named the Guilmette Formation as follows:

> *The Guilmette formation, named after Guilmette Gulch, on the west side of the Deep Creek Mountains, forms the westernmost exposures of the range from Simonson Canyon northward to Sheridan Gulch, except for a few small areas occupied by the younger Woodman formation.*

Since Nolan, work on the Guilmette Formation can be divided into two areas, (1) descriptive and correlative work, and (2) efforts to interpret the environment of deposition, including defining the types of carbonate buildups present, such as reefs. This study deals with the problem of defining a carbonate buildup, and so only works of the latter category will be described here.

Three workers, Petersen (1956), Nadjmabadi (1967), and Niebuhr (1980), have made interpretations on the depositional environment of the Guilmette Formation. Petersen (1956, p. 17) studied the Guilmette Formation in central Utah, and—on the basis of the number of clastics present, the absence of shale, and the presence of microstructures—concluded that the environment of deposition there was a stable shelf near sea level. Nadjmabadi (1967), working in the Leppy Range north of Wendover, Utah-Nevada, concluded that sediment deposition there occurred in a warm, shallow, open-marine environment. He also found evidence in the rocks of fluctuations of wave-base depth, indicating variations in sea level. Niebuhr (1980), who measured sections in the Egan and Southern Egan Ranges (southeastern Nevada), divided the rocks there into three facies, lagoonal, stromatoporoidal bioherms, and shallow open marine.

Four workers, Reso (1959), Stanton (unpublished, reported in Hoggan 1975), Hoggan (1975), and Dunn (1979), concentrated at least a part of their work on interpreting carbonate buildups. Reso (1959, p. 1661; 1963, p. 909), after doing some preliminary work in the Pahranagat Range (south central Nevada), reported similarities between the Guilmette Formation "reefs" in the Pahranagat Range and Mount Irish to Devonian reefs in Alberta. Subsequently, many geologists did unpublished work in the Pahranagat Range with the intent of finding petroleum reserves. One of these, Stanton, was reported by Hoggan (1975, p. 145) to have concluded that the supposed reefs in the Pahranagat Range and Mount Irish had no similarities to the Devonian reefs in Alberta.

Although Hoggan's (1975) study was directed around demonstrating the differences between the Guilmette Formation "reefs" and the Devonian reefs in Alberta, he measured only one section in the Pahranagat Range, where the "reefs" had previously been reported. He measured seven other sections of Guilmette Formation, one in each of the following ranges: Pequop Mountains (northeastern Nevada), Leppy Range (northeastern Nevada), Confusion Range (southwestern Utah), Snake Range (east central Nevada), Egan Range (southeastern Nevada), and two in the Douglas Hills (southeastern Nevada). He concluded that carbonate buildups in the Guilmette Formation were best referred to as pelletal or lime mud banks, even though he found one small reeflike buildup (3.7 m or 12 ft thick) in the southern Douglas Hills.

Recently, Dunn (1979) did a more detailed study of the "reef" in Mount Irish previously described by Reso (1963, p. 909). She concluded that it was a bioherm which was located upon a local high created by debris flows, in contrast to Reso's (1963, p. 909) description of it as a "reef" which formed on a foundation biostrome.

METHODS

Seven detailed stratigraphic sections were measured on the main buildup (fig. 2), and one other, section 8, in the ledges and cliffs below the southwest corner of the main buildup. Of the seven sections, three (sections 2–4) were measured on the west side of the buildup, three (sections 5–7) on the south side, and one (section 1) on the north side. The distances between the measured sections are as follows: 1–2 = 600 m, 2–3 = 700 m, 3–4 = 215 m, 4–5 = 100 m, 5–6 = 350 m, 6–7 = 2,816 m. The section farthest east on the south side, section 7, was selected mainly for its distance from the main body of the buildup.

Because of the cliffs composing the sides of the buildup, rappelling methods and equipment (rope, figure eight, and a set of jumars) were used in measuring four of the sections. Inasmuch as the entire buildup was almost all peloidal limestone, differentiating units on lithologic changes was not possible. Units were chosen and samples collected every 3.2 m (10 ft) or less, to insure complete tracking of the microlithofacies changes, except on the first two sections measured, sections 3 and 5.

In the laboratory, standard 2″ × 3″ thin sections were prepared. Two hundred twenty of them were studied with both a petrographic microscope and a binocular microscope, to determine paleontology, diagenesis, and microlithofacies. Standard staining techniques with Alizarin Red S were used to help distinguish the dolomitic portions of the rock (Friedman 1959).

GEOLOGIC SETTING

During Frasnian time, the western edge of the North American craton was located so as to divide the present state of Utah into east and west halves. The position of this edge of the ancient North American craton corresponds roughly to Sandberg and Poole's Mesozoic Sevier thrust system (1977, p. 7–8). The ancient continental shelf extended westward from this line, and included what is presently western Utah and eastern Nevada, and was bounded on the west by the Antler orogenic belt. Deposition of shelf sediments was influenced by both the Taghonic onlap (late Givetian, early Frasnian) which left a broad, shallow shelf (Johnson and Sandberg 1977, p. 137), and also by early tectonism in the Antler orogenic belt.

Hoggan (1975, p. 178–89) indicated that this continental shelf west of the ancient North American craton contained two subsiding basins within a north–south-trending miogeosynclinal trough. Stewart and Poole (1974, p. 29) prefer the term *miogeocline* for this area to emphasize its nonsynclinal wedge shape. It seems to be a more accurate term inasmuch as Sandberg and others (1982, p. 117) date the initial Antler "welt" at 3 million years after the end of the Devonian, thus demonstrating that there was actually open sea west of the continental shelf during the Devonian, instead of a typical eugeosynclinal/miogeosynclinal environment.

At present, the outcrop is exposed as a horst in the northern Pequop Mountains as a result of basin-and-range faulting. Several north–south-trending normal faults are located on the west side of the outcrop. At least one east–west-trending normal fault displaces the main buildup, and there is another which is located below the southwest corner of the main buildup, but it does not extend through the main buildup. Because of the fault-controlled stream valley to the south of the outcrop (in which Interstate 80 is presently located), the outcrop horst is isolated on four sides and thus has the appearance of a butte or small mesa.

MICROLITHOFACIES

One of the major objectives of this study is to trace the microlithofacies changes, both vertically and horizontally, in this seemingly homogeneous body of peloidal limestone (fig. 3) throughout its areal extent. There are actually five rock types, which are, in decreasing order of relative abundance, packstone, wackestone, sandstone,

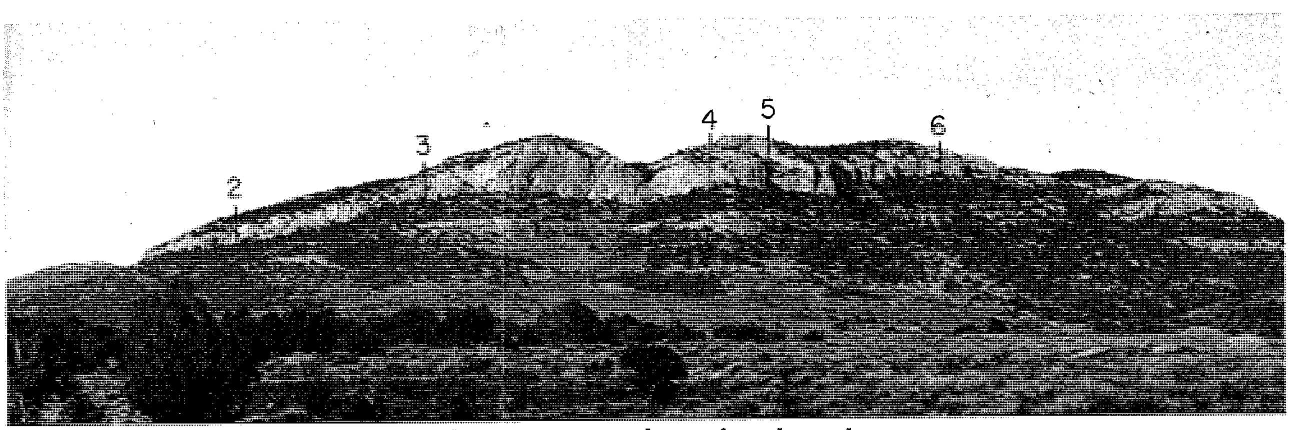

FIGURE 2.—*Photograph of main buildup with sections measured, view from the southwest.*

dolomite, and stromatolitic boundstone. Dunham's (1962) classification is followed here with two modifications: (1) rocks that are grain supported but are surrounded by neomorphic spar are called packstones, assuming the neomorphic spar was originally carbonate mud, and (2) rocks which contain more than 10% peloids but which are still not grain supported are called wackestones, whether the matrix is carbonate mud or neomorphic spar.

Changes in the microlithofacies which occur are subtle and are significant in indicating both local currents and a regional transgression/regression cycle. These changes are reflected in the rock names chosen for the units and are based on the following parameters: (1) number of peloids (packstone or wackestone), (2) whether or not the carbonate mud has altered to neomorphic spar (sparry or muddy), and (3) whether or not intraclasts are present (uniform or mixed fabric). One other facies change is the occasional inclusion of quartz sand grains, which seems to have minor significance.

PACKSTONE

Uniform Packstone

Uniform packstone is characterized by peloids of uniform size, about 0.1 mm but also has a minor fraction of peloids ranging from 0.05 to 0.3 mm. Intraclasts are either nonexistent or are less than 5% in the entire microslide. If less than 50% of the mud matrix has recrystallized to neomorphic spar, it is considered to be a "uniform muddy packstone"; otherwise, it is a "uniform sparry packstone" (figs. 4, 5).

Mixed Packstone

Peloids range in size from 0.05 to 0.7 mm. There is no dominant size, but rather a spectrum of sizes. Intraclasts are common and range up to 30 mm long, but are generally in the range of 0.5–3.0 mm. If less than 50% of the matrix has recrystallized to neomorphic spar, it is considered to be a "mixed muddy packstone"; otherwise, it is considered to be a "mixed sparry packstone" (figs. 6, 7).

WACKESTONE

Uniform Muddy Wackestone

Of approximately 200 units, only two, units 2.0 and 5.5, are a uniform muddy wackestone microlithofacies. Laterally, unit 2.0 changes to fine-grained dolomite with euhedral crystals, and unit 5.5 is 20%–30% euhedral dolomite crystals. Both are characterized by small mud allochems about 0.05 mm in diameter and by crystals contained in a mud matrix. Unit 2.0 contains calcite crystals, whereas unit 5.5 contains dolomite crystals (fig. 8).

Mixed Wackestone

Peloids range from 0.06 to 0.7 mm in diameter, and intraclasts are up to 20 mm. There is no real dominant size of the peloids, but there is a range of sizes. If less than 50% of the matrix has recrystallized to neomorphic spar, it is

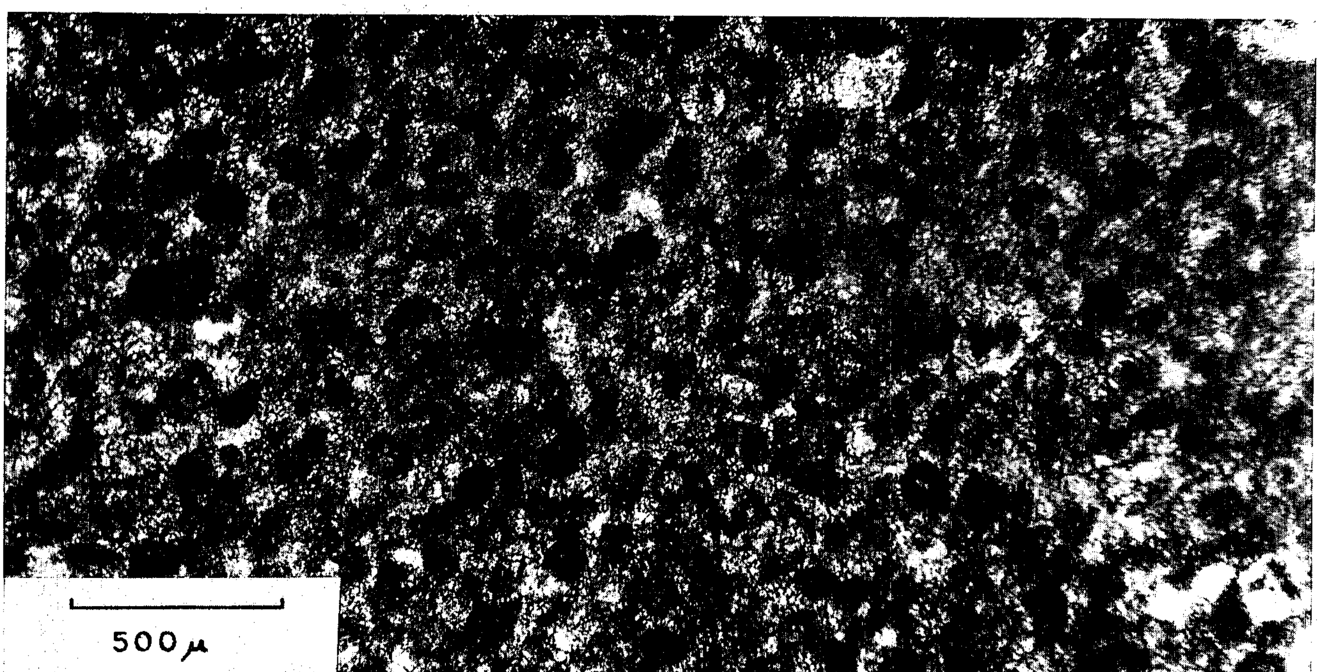

FIGURE 4.—*Photomicrograph of uniform sparry packstone from unit 3.5; transmitted light, X25.*

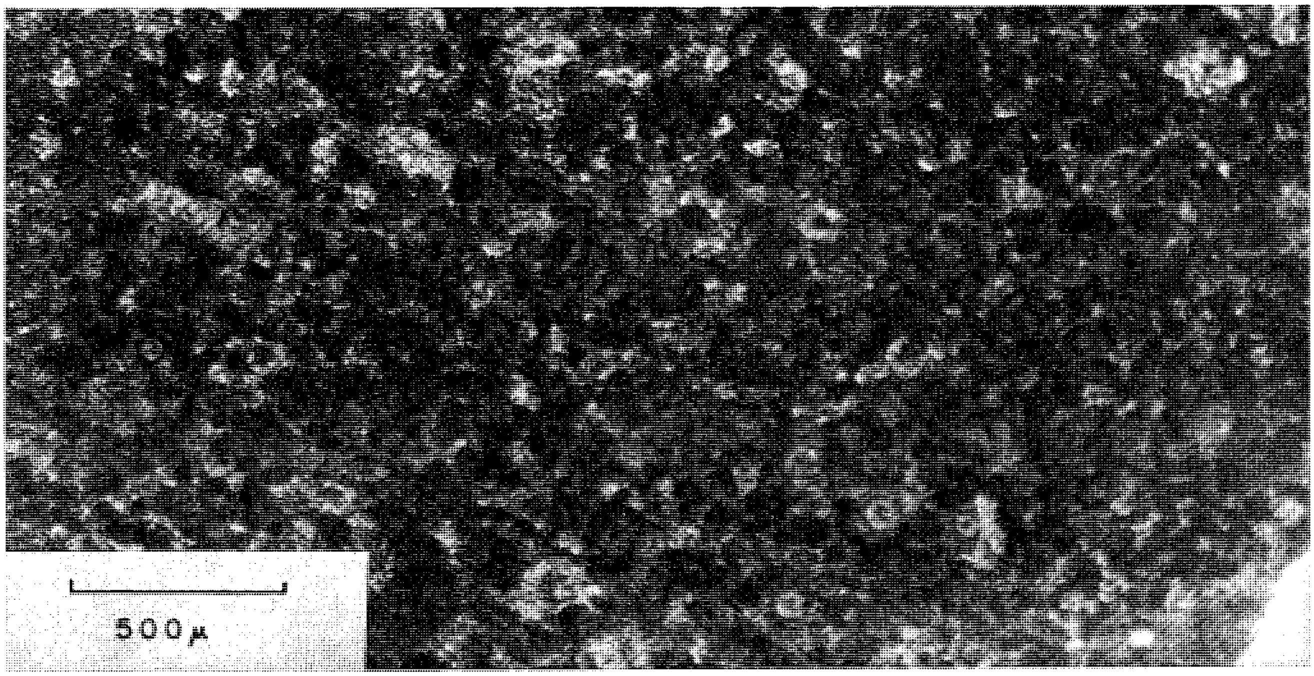

FIGURE 5.—*Photomicrograph of uniform muddy packstone from unit 6.19; transmitted light, X25.*

then considered to be a "mixed muddy wackestone"; otherwise, it is a "mixed sparry wackestone" (figs. 9, 10).

SANDSTONE

Only one quartz sandstone unit occurs in the outcrop studied; it is well exposed as the basal unit of sections 4 and 5, a cross-bedded quartz sandstone approximately 2 m thick. The sand grains are well rounded, and their size distribution is roughly bimodal; the two modes range from 0.05 to 0.4 mm (medium grained) and 0.7 to 2.5 mm (coarse to very coarse grained) (fig. 11). The grains are fractured, and the cement is calcareous. It is interpreted to be a very mature sand, possibly representing an ancient sand shoal.

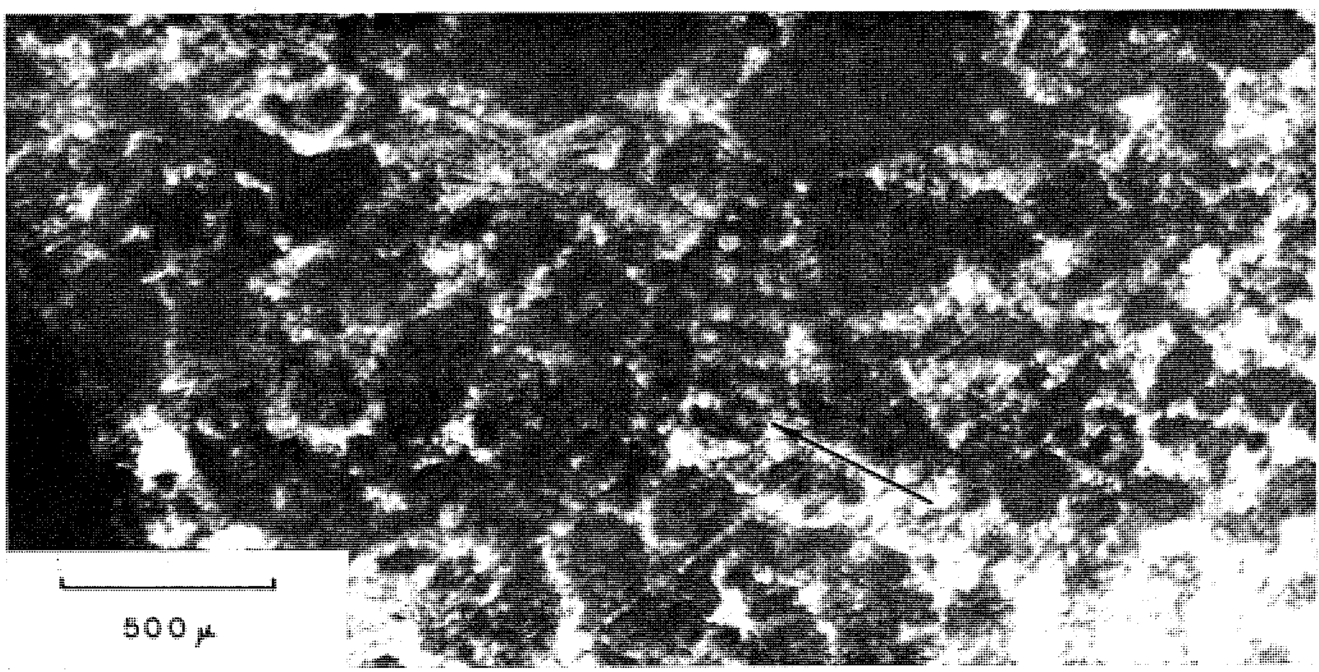

FIGURE 6.—*Photomicrograph of mixed sparry packstone from unit 1.24; transmitted light, X25. Arrow points to a foraminifera.*

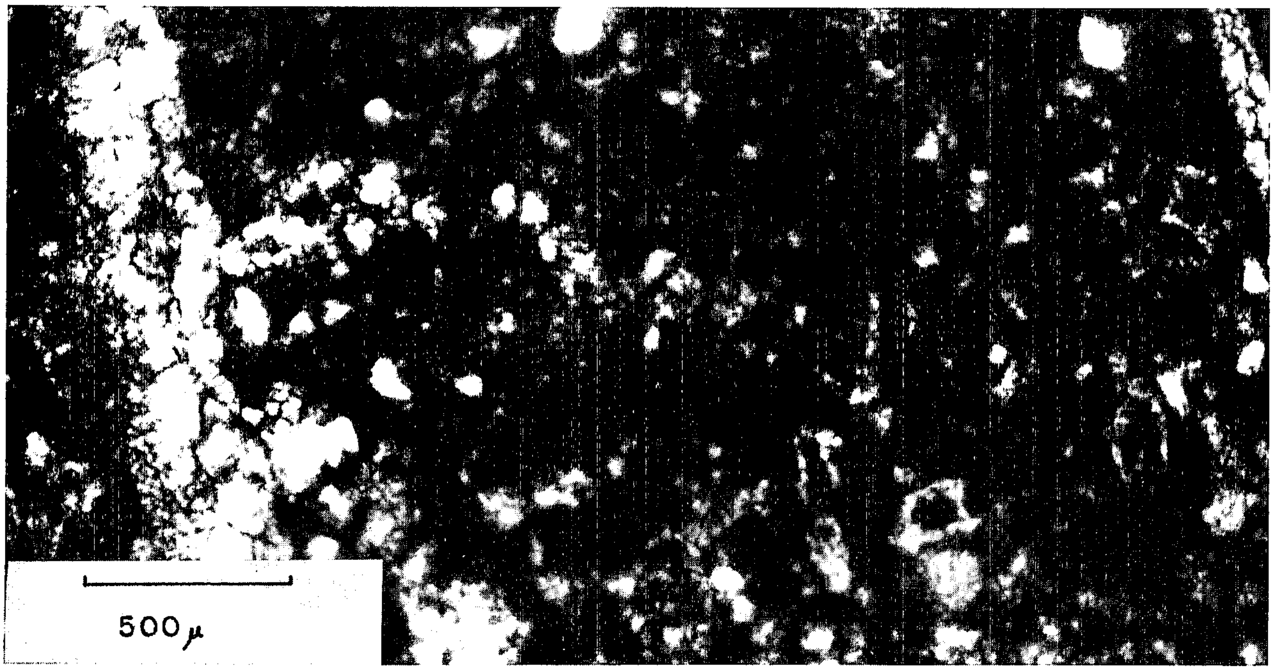

FIGURE 7.—*Photomicrograph of mixed muddy packstone from unit 5.2; transmitted light, X25.*

STROMATOLITIC BOUNDSTONE

The stromatolitic boundstone unit is exposed at the top of sections 1, 2, and 3. The extensive weathering and diagenetic effects have obscured all traces of the stromatolitic lamination on the surface of the rock, but this facies is easily recognized in thin section. As with other reported occurrences of stromatolitic boundstone, the algae are not preserved, but layers of sediment trapped by the algae have been preserved in a laminated, fenestral fabric. Peloids present in the laminae range from 0.1 to 0.4 mm; intraclasts range up to 20 mm in diameter (fig. 12).

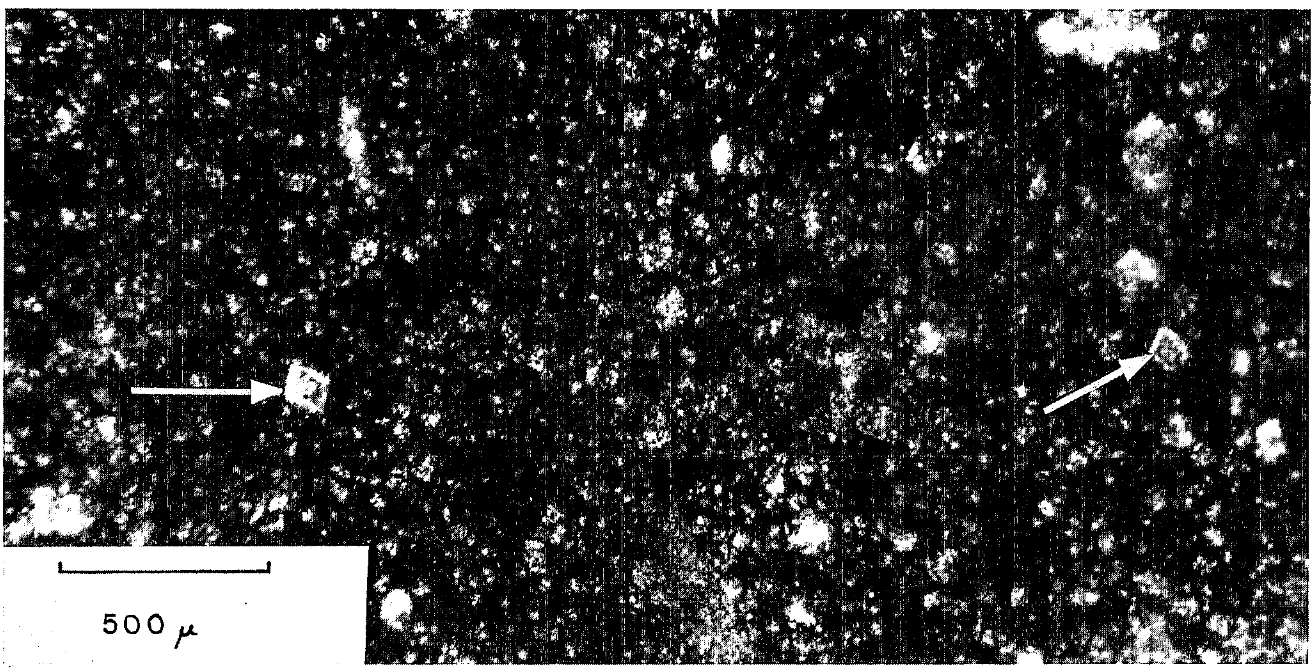

FIGURE 8.—*Photomicrograph of dolomitic uniform muddy wackestone from the top of unit 5.5; transmitted light, X25. Arrows point to zoned dolomite crystals.*

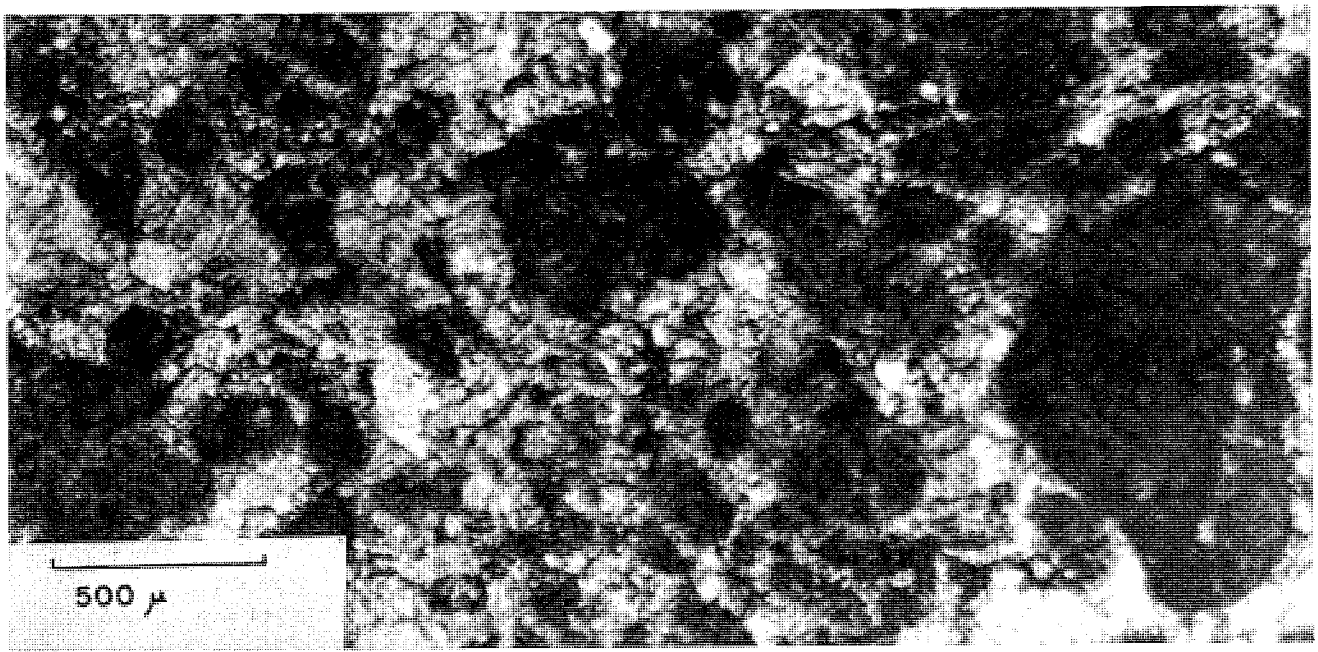

FIGURE 9.—*Photomicrograph of mixed sparry wackestone from the top of unit 5.7; transmitted light, X25.*

DOLOMITE AND DOLOMITIC UNITS

The main dolomite unit is a thin bed about 0.6 m thick, which, upon a weathered surface, resembles a quartz sandstone. This bed is easily correlated in the field between sections 2, 3, 4, 5, and 6. Sections 1 and 7 contain dolomitic units which, when studied in thin section, seemingly correlate well with this main dolomite bed. The dolomite crystals are often euhedral and sometimes zoned, ranging in size from 0.05 to 0.2 mm long (fig. 13).

Zoned crystals indicate several periods of growth. Each of these periods of growth can be interpreted to have been associated with fluids that actively replaced limestone surrounding each crystal with dolomite. This inter-

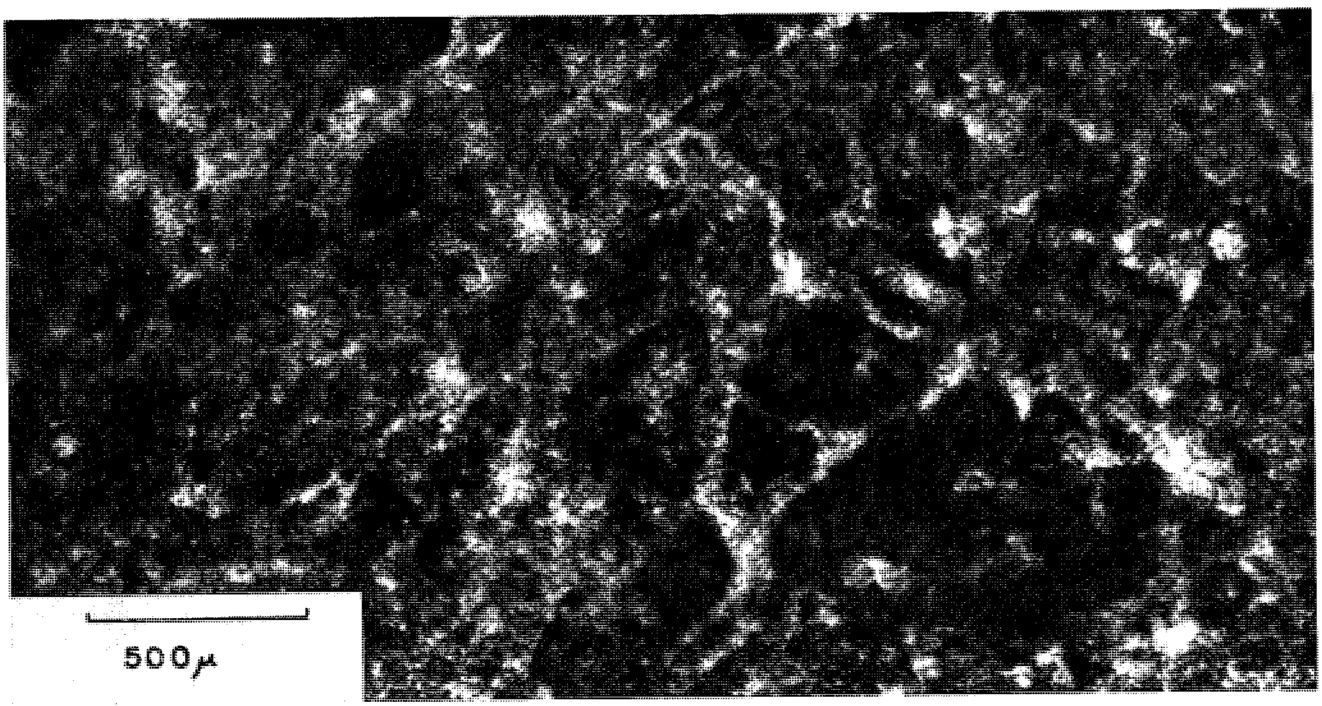

FIGURE 10.—*Photomicrograph of mixed muddy wackestone from unit 6.15; transmitted light, X25.*

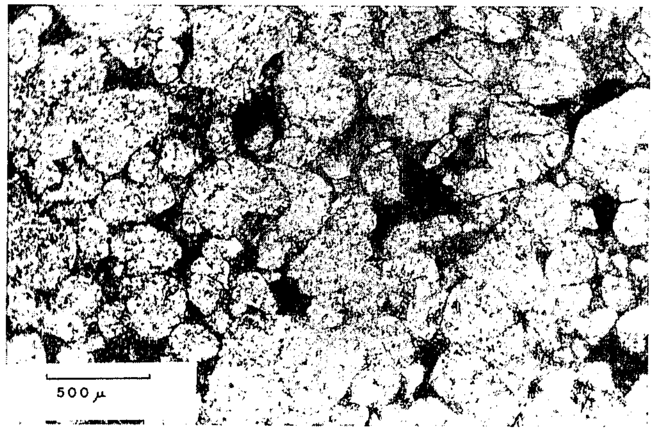
FIGURE 11a.—*Photomicrograph of cross-bedded sand unit from unit 4.0, also found at base of section 5. Transmitted light, X12.5.*

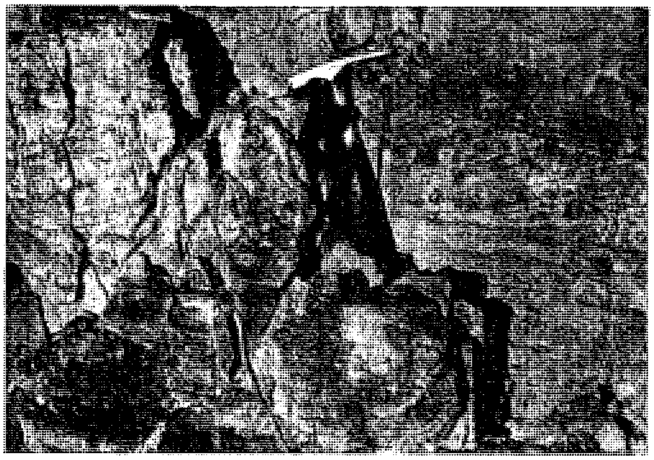

FIGURE 11b.—*Cross-bedded sand unit, unit 4.0. Also found at base of section 5.*

pretation is supported by a facies change that occurs in the main dolomite bed in unit 2.0. Unit 2.0 is a uniform muddy wackestone, but laterally it changes to a fine-grained dolomite. This facies change indicates that the entire main dolomite bed was originally a uniform muddy wackestone but has since been replaced by dolomite in all but a few places. The only other occurrence of a uniform muddy wackestone, unit 5.5, is about 20%–30% dolomite (fig. 8) for a thickness of about 3 m. This is an area which has been only partially replaced by dolomite. Close association of dolomite with the two occurrences of uniform muddy wackestones implies that the uniform muddy wackestones are the most susceptible to dolomitization.

Other occurrences of dolomitic units are restricted to the units directly above and below the key dolomite bed. In some sections dolomitization has spread, but most have not been completely replaced as has the correlation dolomite unit.

PALEONTOLOGY

Weathering, diagenesis, lichen, and Recent dissolution have all combined to reduce the exterior of outcrops in Pequop Pass to a nondescript meringuelike surface. Consequently, megafossils were found more frequently as fragments in thin section than as entire entities in outcrop. Common megascopic fossils found in outcrop include gastropods (generally planispiral, although one exceptional 15-cm high-spired specimen was found), straight nautiloids, algal oncoids, and both hemispherical and ramose stromatoporoids.

This study was of rocks too young to include the Givetian *Stringocephalus* brachiopod described by many who have done previous work with the Guilmette Formation. Also, the writer did not find the tetracorals and crinoid columnals Hoggan (1975, p. 181–82) recorded at the top of his measured section in the Pequop Mountains. However, they were found in the overlying Lower Mississippian rocks.

UPPER DEVONIAN

The most useful fossils collected were the hemispherical stromatoporoids, four of which were identified by St. Jean (personal communication 1982) as follows: two specimens of *Stromatopora cygnea*, one of *Talaeostroma steleforme* (fig. 14a,b,c), and one of ?*Trupetostroma*. On the basis of these fossils, Dr. St. Jean placed the age of this portion of the Guilmette Formation as Frasnian (personal communication 1982).

St. Jean also pointed out that the stromatoporoids have microdiastems in their coenostea (fig. 15), indicating that at times the environment was less than ideal for stromatoporoid growth, and that the stromatoporoids were forced to recommence growth over layers of sediment deposited within their coenostea. The abundant carbonate mud (most of which has altered to neomorphic spar) found in the thin sections indicates that the environment was relatively turbid. Lecompte (1956, p. F126) described the preferred habitat of hemispherical stromatoporoids as clean, without a muddy bottom.

Hemispherical stromatoporoids are generally found as reef builders in Givetian and Frasnian rocks in other parts of the world (Klovan 1964, Playford and Lowry 1966, Krebs 1974). Hemispherical stromatoporoids are similar to many reef organisms in that they apparently thrived best in turbulent, sediment-free water. They are commonly found in association with calcareous algae which help bind the reef into a solid mass.

In this study, several types of calcareous algae were found. A preliminary sampling of the algae was submitted to Dr. John Wray, who verified the presence of solenoporacean algae in the few samples sent. For subsequent iden-

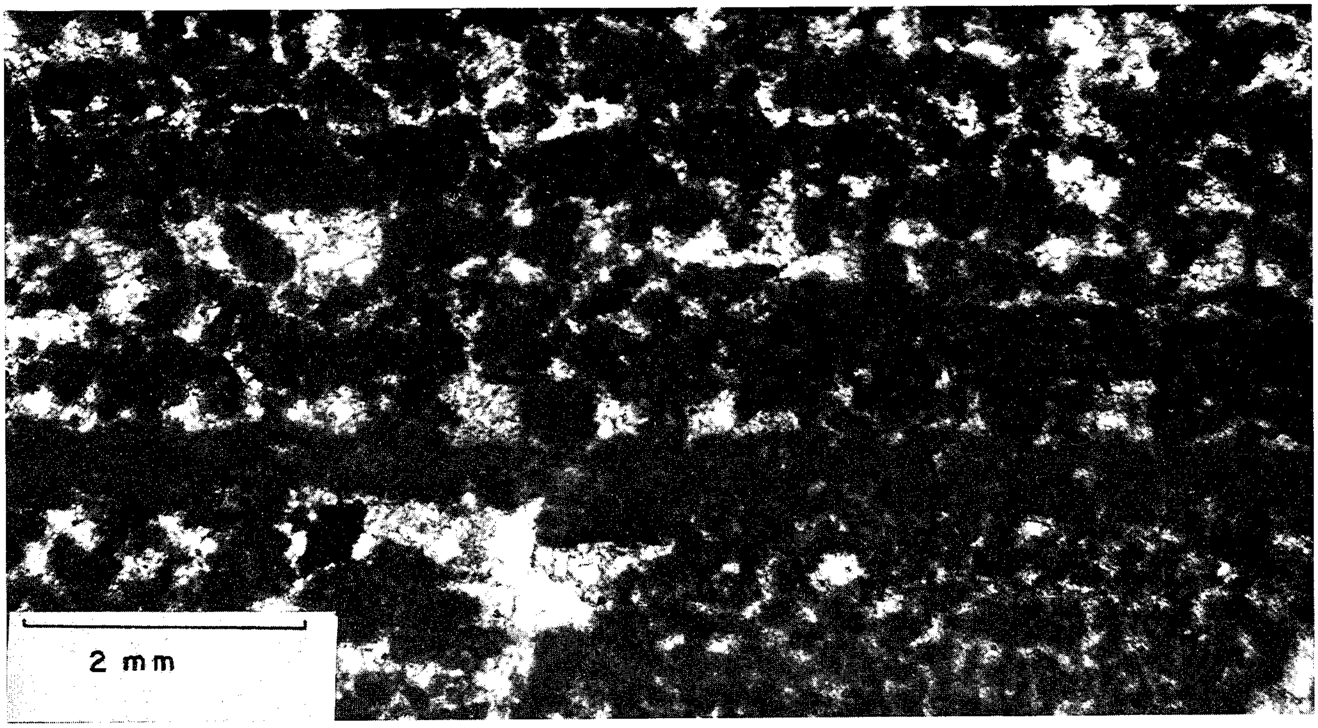

FIGURE 12.—*Photomicrograph of stromatolitic boundstone (algal mat) from the top of unit 3.9; transmitted light, X10.*

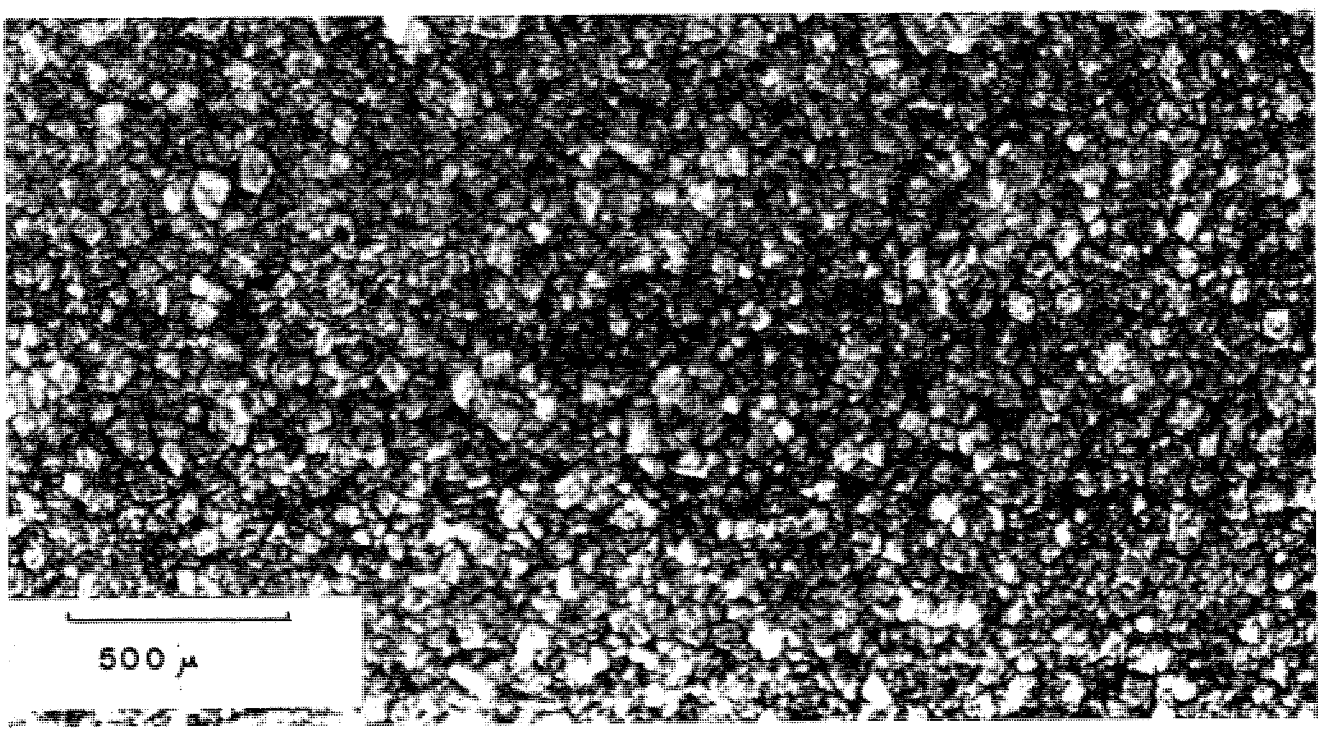

FIGURE 13.—*Photomicrograph of "correlation" dolomite unit, unit 4.2.9; transmitted light, X25.*

tifications of calcareous algae, the writer used Wray's (1967) publication on Australian Devonian calcareous algae from the Canning Basin.

The samples are (fig. 16a,b,c,d,e,f) tentatively identified as follows: (1) Rhodophycophyta (red algae), five genera: *Solenopora*? sp., *Parachaetetes*? sp., *Stenophycus*? sp. (fig. 16a), *Keega*? sp. (fig. 16b), and *Tharama*? sp. (fig. 16e); (2) Chlorophycophyta (green algae), two genera: *Litanaia*? sp. (fig. 16c) and *Ortonella*? sp. (fig. 16d); and (3) unknown, two specimens (fig. 16f). Playford (1980, p. 8, 9) described algae as being major reef constituents in the Canning Basin during the Givetian and Frasnian, and as being the dominant reef constituent during the Famennian.

Wray (1967, p. 9, 10) discussed the distribution of these genera in the various reef-associated facies. Though they all occur in a variety of facies, their major occurrences are as follows: *Solenopora*, fore-reef, reef, and back-reef; *Parachaetetes*, reef and back-reef; *Litanaia*, reef; *Ortonella*, post reef; *Tharama*, reef; *Keega*, reef. Many of the algae found in the Pequop Mountains are found as intraclasts, indicating transport from their original growth site. There is no organized pattern in which the algae oc-

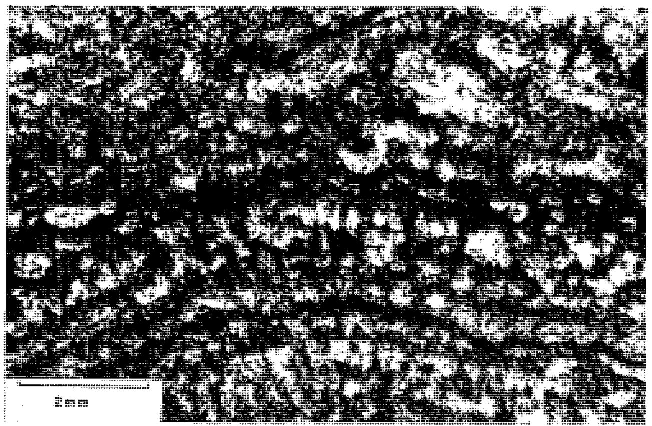

FIGURE 14a.—*Photomicrograph of* Stromatopora cygnea *from unit 4.16; transmitted light, X5.*

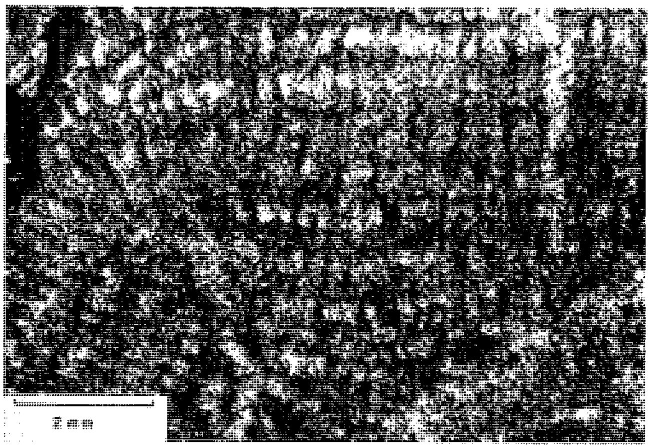

FIGURE 14b.—*Photomicrograph of* Talaestroma steleforme *from unit 5.6; transmitted light, X5.*

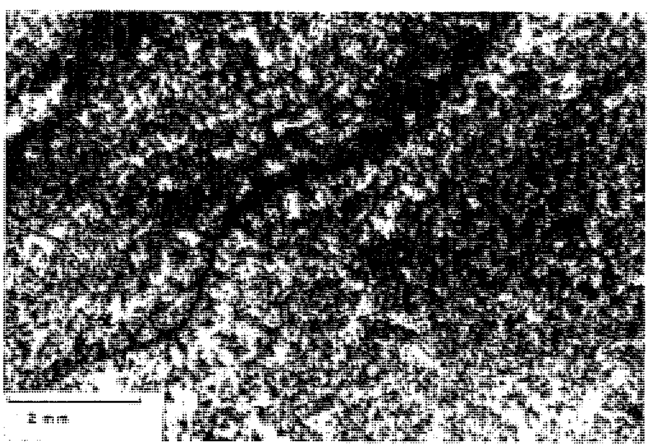

FIGURE 14c.—*Photomicrograph of* ?Trupetostroma *sp. from unit 1.21; transmitted light, X5.*

FIGURE 15.—*Photomicrograph of diastem contained within a stromatoporoid's coenostea, demonstrating marginal adaptability to the environment, unit 4.17; transmitted light, X7.5.*

cur here, an indication that the algae were not localized into specific communities but grew wherever conditions temporarily permitted.

Amphipora sp. are found in great abundance in the section measured below the main buildup. Krebs (1974, p. 187, 188), Klovan (1964, p. 33), and Playford and Lowry (1966, p. 49, 50) all discussed *Amphipora* as characteristic of the back-reef facies. On the basis of the great abundance of *Amphipora* in the lower ledges, the writer interprets those limestone units as representative of back-reef, lagoonal environments.

Calcispheres are common in the rocks and are easily

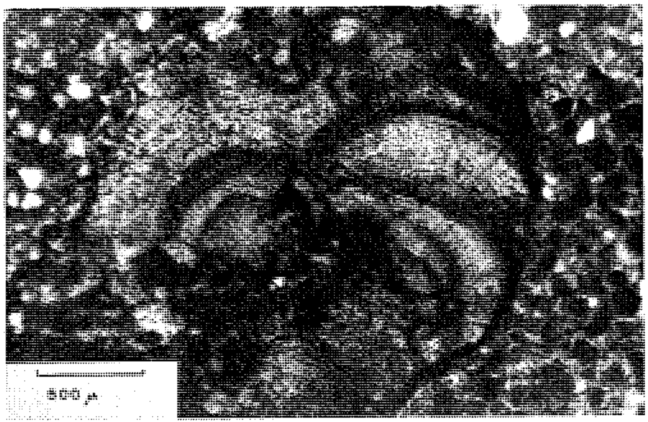

FIGURE 16a.—*Photomicrograph of calcareous alga* ?Stenophycus *sp. from unit 5.2; transmitted light, X12.5.*

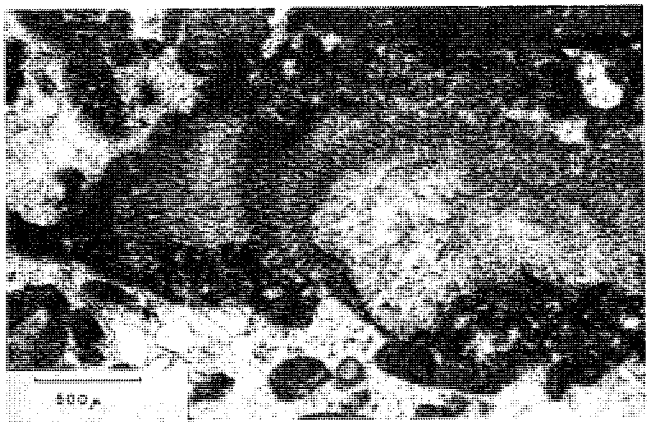

FIGURE 16b.—*Photomicrograph of calcareous alga* ?Keega *sp. from unit 4.7; transmitted light, X12.5.*

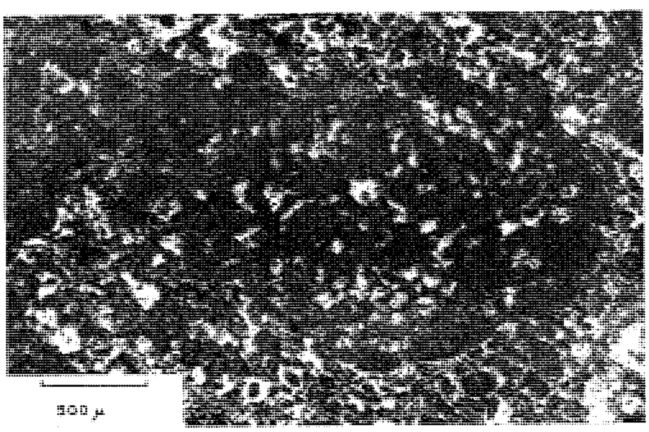

FIGURE 16c.—*Photomicrograph of calcareous alga* ?Litanaia *sp. from unit 5.18; transmitted light, X12.5.*

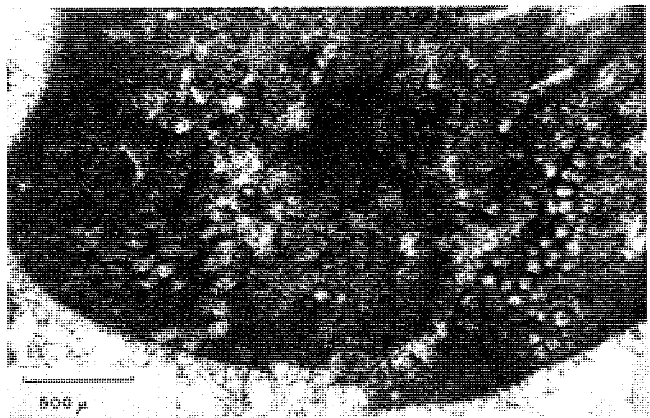

FIGURE 16d.—*Photomicrograph of calcareous alga* ?Ortonella *sp. from unit 6.18; transmitted light, X12.5.*

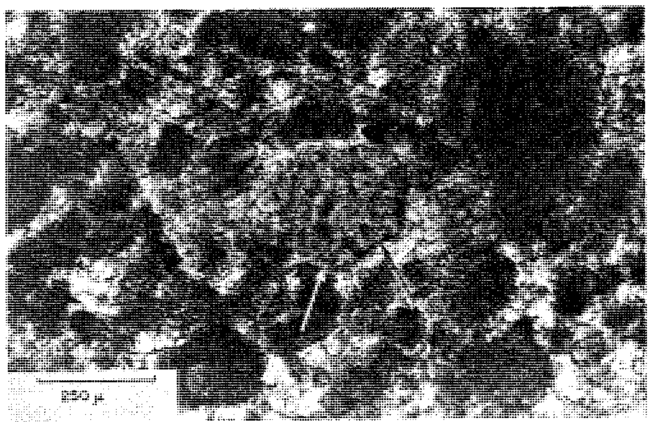

FIGURE 16e.—*Photomicrograph of calcareous alga* ?Tharama *sp. from unit 1.14; transmitted light, X31.5.*

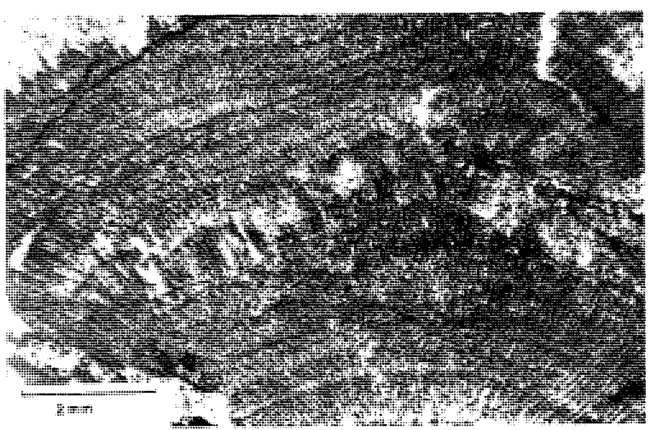

FIGURE 16f.—*Photomicrograph of calcareous alga of unknown genus from unit 5.7; transmitted light, X5.*

recognized. In general, calcispheres are problematical as to their affinities, but Stanton (1963, p. 417) suggested that they are a type of plant spore or reproductive body. Stanton (1963, p. 415) stated that the fossils characteristically associated with calcispheres are *Amphipora* and *Paratharammina.* Because of this association, many workers infer that the presence of calcispheres indicates back-reef facies. However, the small, spherical shape of this organism suggests easy transport, and so it is probably unreliable as a specific facies indicator. In this study of the Guilmette Formation, they are found both with and without *Amphipora,* so no facies interpretation is based on them.

Foraminifera and straight nautiloids are also easily transported. Not much literature is available on facies distribution of Devonian straight nautiloids or foraminifera. The writer interprets the presence of these organisms in the study area as indicating that the animals possibly floated in from deeper water.

Brachiopods and gastropods in the sections were not found preserved well enough to permit much detailed paleontologic work to be done with them, although elsewhere Merriam (1940) found abundant, well-preserved faunas. In this study, the presence of brachiopods and gastropods is interpreted as indicating intertidal to subtidal water depth. Crinoid ossicles were also found in limited numbers and are also poorly preserved. They suggest environments of normal-marine salinity. The presence of stromatolitic algal mats at the top of sections 1, 2, and 3 also generally indicates an intertidal to subtidal water depth. Because of the intense weathering, these algal units were not easily recognized in the field but are apparent in thin section. Stromatolitic algal mats are usually interpreted as indicative of intertidal to subtidal water depth. One exception has been found in rocks of the same age in Western Australia by Playford and Cockbain (1969). They reported some forms that grew on fore-reef depositional slopes in water at least 45 m deep. Stromatolitic units from the Guilmette Formation are interpreted as indicative of subtidal water depth.

Sections of the Guilmette Formation in this area contain a significant number of very large algal oncoids. They range from 10 mm to about 12 cm in diameter. In thin section, only micritic layers alternating to a lesser degree with peloidal layers are preserved. The layers are not crinkly (see Flugel 1982, p. 138). According to Wilson (1975, p. 69), oncoids which occur in a micrite are characteristic of a shallow-water, back-reef environment. Guilmette Formation oncoids are sometimes associated with sediments which are muddier than the sediments above and below. Playford (1976, p. 9, 10), described the facies of the Upper Devonian reef complex in the Canning Basin, Western Australia, and listed oncoids in both the bank and the back-reef subfacies. He also noted that the oncoids in the back-reef subfacies occur mainly where the reef is absent or weakly developed. In addition to these occurrences, he also noted (Playford 1976, p. 19) that the oncoids form on top of the reef and cascade down the sides, forming deposits of oncoids in the flanking beds. Oncoids are also often associated with deposits that show evidence of currents (Flugel 1982, p. 144).

Finally, the ostracodes in this study were found only as cross sections in the microslide thin sections. They are fairly ubiquitous and range from fresh and brackish water to normal-marine environments, and also occur at a great variety of depths. However, they seem to be most abundant in shallow seas of the shelf areas (Benson 1961, p. Q60). Because of their ubiquitous nature, not much can be said about them in relation to this study. However, Benson (1961, p. Q58, Q62) indicates that most fossil ostracodes were crawlers, burrowers, and near-bottom swimmers, and that Recent ostracodes are often associated with sediment-trapping grasses such as *Thalassia* and *Zostera.* Therefore, even though these grasses are not preserved in the rock record, it is possible that the presence of ostracodes implies that sediment-trapping grasslike plants (e.g., algae comparable to modern *Halimeda* or *Pennicilus*) may have been present.

LOWER MISSISSIPPIAN

Conodonts were found in the unit overlying the Guilmette Formation, which has been mapped as Joana Limestone (Thorman 1970, Hope and Coats 1976), but may be the Tripon Pass Formation (Charles Sandberg personal communication 1983).

Conodont identifications were verified by Dr. Charles Sandberg (personal communication 1983); those identified were *Polygnathus* sp., *Polygnathus longiposticus, Siphonodella quadruplicata, Siphonodella isosticha, Polygnathus inornatus, Bispathodus* sp., *Hibbardella* sp., and *Polygnathus communis* (fig. 17). This assemblage is of Kinderhookian (Lower Mississippian) age.

DEPOSITIONAL MODEL

Section 5 has several distinguishing characteristics that differentiate it from other sections in the study area. Measured from the top of a bed found in the base of both sections (the "correlation" dolomite), section 5 is 6 m thicker than section 4, which is only 100 m distant (see fig. 3). Also, it has a greater abundance of stromatoporoids than any of the other sections, and it has flanking beds that lap onto it from the south (fig. 18). In common with section 4, it is also overlain by a paleomicrokarst unconformity (fig. 19), it is underlain by a cross-bedded sandstone unit (fig. 11), and the majority of the upper part of the section is composed of wackestone rather than packstone.

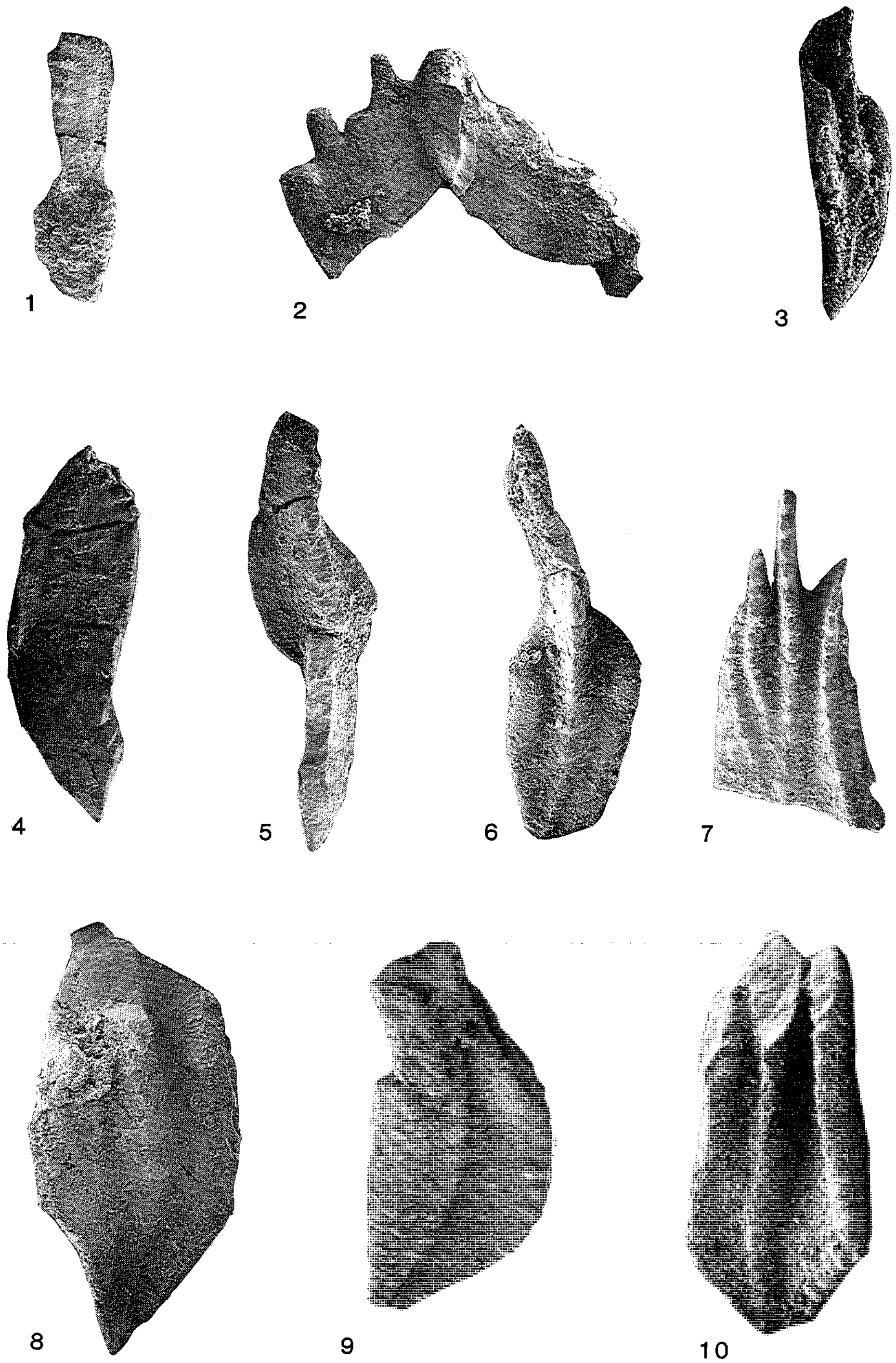

FIGURE 17.—*SEM photomicrographs of Kinderhookian conodonts taken from the Joana Limestone, which unconformably overlies the Guilmette Formation: (1)* Polygnathus *sp., X50; (2)* Hibbardella *sp., X45; (3)* Polygnathus longiposticus, *X50; (4)* Bispathodus *sp., X45; (5)* Bispathodus *sp., X50; (6)* Polygnathus communis, *X80; (7)* Siphonodella quadruplicata, *X50; (8)* Polygnathus inornatus, *X100; (9)* Siphonodella isosticha, *X50; (10)* Polygnathus inornatus, *X50.*

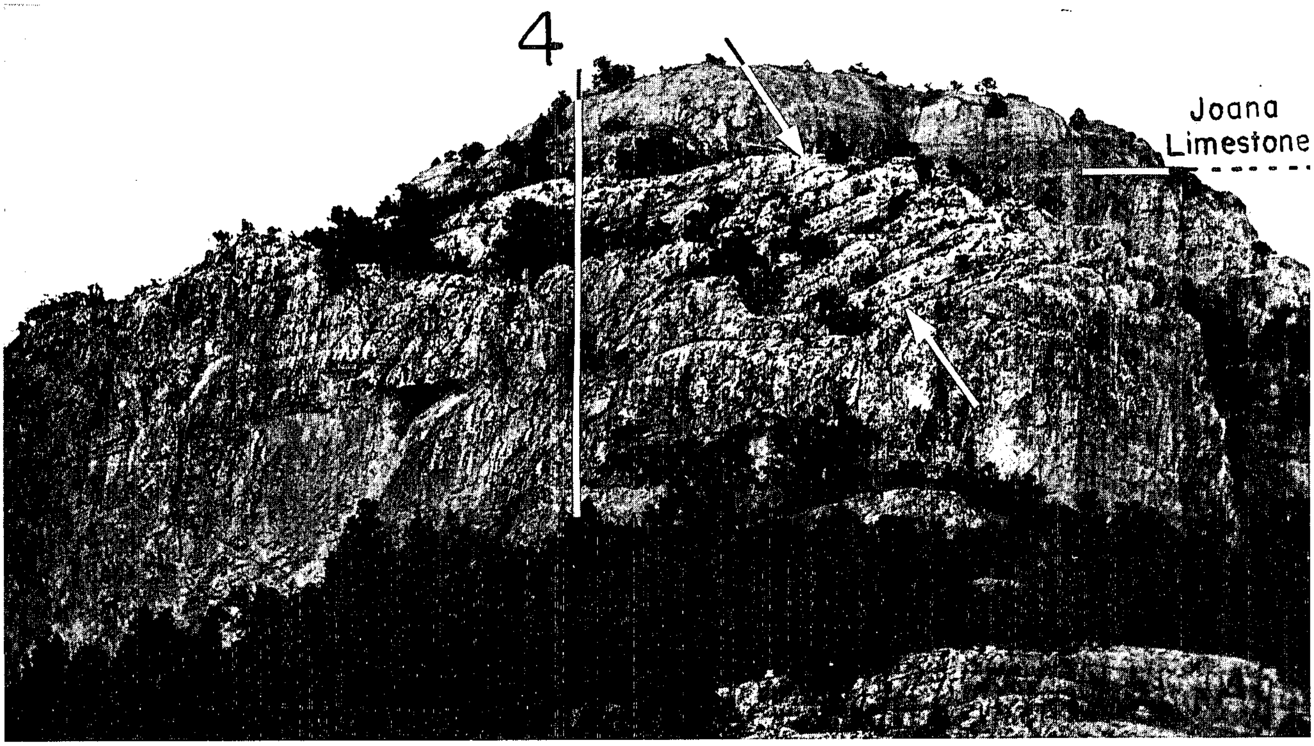

FIGURE 18.—*Photograph of flanking beds on mound (between arrows). View from the southwest, section 4 to the north.*

These characteristics are similar to many of those listed by Wilson (1975, p. 364–69) and James (1978, p. 20–22) as representative of a mound. Wilson (1975, p. 364) included banks in his definition of mounds though some prefer to make this distinction: a bank may have a more tabular shape, and a mound a more hemispherical shape (James 1978, p. 20, 21; Heckel 1974, p. 93–96).

Important characteristics of a mound are listed by James (p. 21). They include stage 1, basal bioclastic lime mudstone to wackestone pile; stage 2, lime mudstone or bafflestone core; and stage 3, mound cap—thin layer of encrusting or lamellar forms, occasional domal or hemispherical forms, or winnowed lime sands. In discussing why such mounds grow from deeper, quieter water upward to above wave base, Wilson (1975, p. 366–67) gave the following reasons: (1) mechanical accumulation of both fine and coarse sediment through current and wave action (probably the most important process localizing mound growth); (2) trapping and baffling of carbonate sediment produced locally at higher than normal rates (probably the most important process contributing to the growth of the mound); (3) stabilization of sediment by surface encrustation so that normal processes of marine erosion do not remove it; (4) protection by a veneer or wall of frame-building organisms at a late stage in its development; and (5) protection by cementation. In lime mud deposited and remaining in the marine environment, cementation commonly is often very slow (unless early submarine cementation occurs). In shallow-water banks, where chances of subaerial exposure are better, lithification of lime mud is more effective.

Wilson (1975, p. 367), in discussing the bioclastic wackestone at the base of the mound, stated, "The origin of these piles cannot be generally understood; presumably they are heaped up by gentle currents." Also, in evaluating mound origins (1975, p. 365–66), he discussed how the base of the mound, along with its underlying beds, is usually the least studied. Therefore, the presence of considerable fossil debris in the basal wackestone is an element commonly associated with mounds, but the presence of fossils does not seem to be a critical element. Jamieson (1971, p. 1309–11), in her study of the Devonian reefs in Canada, demonstrated that existence of a "gravel" bed of fossil debris is necessary for later growth of reef organisms. Some fossil debris exists at the base of the "mound" in section 5. Stromatactis is another element commonly found in mounds that is not well understood. Early workers felt that it represented evidence of soft-bodied organisms that had not been preserved. Now it is thought to be a result of diagenesis (Burchette 1981, p. 130). No stromatactis is found in the mound in section 5.

The major difference between an idealized mound and the "mound" in section 5 is the lack of fossil evidence of obvious baffling organisms that trapped mud. Most

FIGURE 19.—*Unconformable contact between the Guilmette Formation and the Joana Limestone (arrow), with paleomicrokarst topography upon the Guilmette Formation; view from the south. Independence Valley in the background.*

mounds have a significant amount of fossil debris which obviously acted as a baffling agent and trapped sediment, thereby building up the mound into a morphological high. According to the list that Wilson (1975, p. 368) gave, an idealized mound in the Devonian should have a significant amount of bryozoan debris mixed throughout the muddy wackestone core. However, large Mississippian Waulsortian mud mounds lack major numbers of large organisms. They commonly contain only small percentages of crinoid and bryozoan debris that constitute no more than 20% of the rock. According to James (1978, p. 22), the development of most mounds can be explained in terms of a combination of baffling organisms, encrusting organisms, and possible shaping by currents and storms. Waulsortian mounds present a special situation in that they display topographic relief above the ancient sea floor but lack fossil evidence that explains why such muddy sediments were able to accumulate in such relief.

The low mound at section 5 (approximately 7 m thick) is a little like the enigmatic Waulsortian mud mounds in that it seems to have had topographic relief above surrounding sediments, as evidenced by the flanking beds and thicker section. However, it lacks obvious fossils that could have acted as baffles to trap sediment into a local mound. There are a few possible explanations that might help explain why sediments accumulated into a mound in section 5. First, there are considerably more stromatoporoids in section 5 than in other sections. However, fieldwork completed to this point suggests that there were not enough to create a small, muddy reef. Second, this mound could have been built by sediments localized by currents. The cross-bedded sand shoal (fig. 11) at the base of the section indicates that at an earlier time, currents were significant in localizing inorganic sediments. Third, there could have been a baffling organism trapping sediment, which, after it died, left no fossil evidence of its existence.

Baars (1963, p. 120–27) discussed the ability of modern-day sea grasses, such as *Thalassia testudinum,* to baffle and trap sediment in the Florida Bay, thereby creating banks. As was discussed earlier, modern marine ostracodes are not often found inhabiting sea floors which are simply mud, but are commonly found in association with sea grasses such as *Thalassia.* Even though the ostracodes are not abundant throughout the study area, their presence suggests the possibility of the existence of some sort of ancient grasslike plant that may have acted to baffle and trap sediment.

A fourth possibility, though a fairly new concept, is the possibility of early submarine cementation. Playford (1980, p. 819–20, 830–33) discussed the significant role that early submarine cementation played in the formation of the Late Devonian reefs of the Canning Basin, Australia. Schmidt (1971, p. 209–15) discussed early cementation in the Middle Devonian bioherms of Canada. Ginsberg (1971), Land (1971), and Shinn (1971) all discussed early marine cementation. Throughout the study area, there are occasional evidences that early cementation may actually have occurred. These include isopachous rim ghosts (fig. 20), geopetal structures, and non-compacted sediment and fossils. At this point, it is difficult to say which, if not all, of these played a part in making it possible for sediment in the top of section 5 to accumulate to be a topographically higher mound than the surrounding sediment.

Finally, the mound grew up above wave base into an environment more suited for stromatoporoids, a little less muddy and a little more turbulent, and was capped by a stromatoporoid colony (fig. 21). Sections 1 and 6 show similar moundlike characteristics at the same stratigraphic level as section 5, a series of wackestones capped by stromatoporoids, but on a much smaller scale. These sections show no evidence of relief above the surrounding sediments, so they do not seem to be actual mounds; however, they could probably be considered as proto-mounds.

One of the most influential factors on deposition in this area was a worldwide transgression throughout the Frasnian, with a worldwide regression at the end of the Frasnian (Playford 1980, p. 826; Johnson 1974). Guilmette Formation stratigraphic columns show (fig. 3, esp. sections 2 and 6) local effects of the transgression. Sections begin with deposits characteristic of shallow, high-energy water, such as peloidal limestone with both mixed and uniform fabrics. The main difference between these two peloidal limestones is the inclusion of small intraclasts in the mixed fabric. These small intraclasts probably indicate minor, local variations in the energy on the Devonian continental shelf, possibly due to current action. Wackestones above these units become increasingly more common and thicker, and probably represent deeper water, but possibly not more than 20 m deep. Mounds, proto-

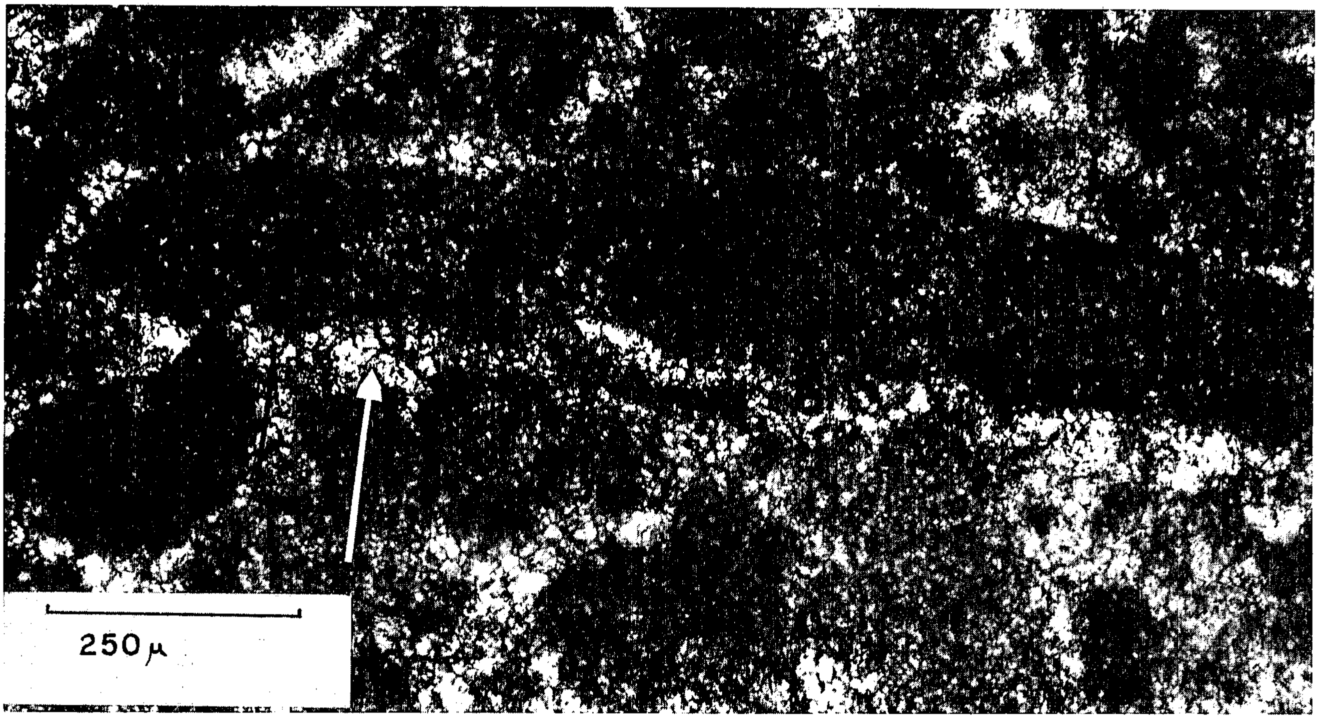

FIGURE 20.—*Long intraclast indicated by arrows has a possible ghosted isopachous rim, unit 2.7; transmitted light, X25.*

mounds, and oncoids are associated with these wackestone units. This wackestone facies demonstrates characteristics of back-reef facies found in the rocks of the same age in other parts of the world. To date, no actual reef has been substantiated in the Guilmette Formation, so it is not strict usage to call this a back-reef facies, though it is similar. Another zone of peloidal packstone occurs above the wackestone and represents a return to shallower water and higher energy conditions during the regression. It was during this time that the stromatolitic algal mats developed. This event had two effects in this area, (1) development of a microkarst topography upon the surface of the area near sections 4 and 5, and (2) growth of algal mat as the sea shallowed in the areas of sections 1, 2, and 3.

DIAGENESIS

It is beyond the scope of this paper to describe the entire diagenetic history of the Guilmette Formation in this study area. However, several interesting postdepositional features will be discussed. The most recent events are the emplacement of chert and the intrusion of iron-bearing solutions. Chert generally occurs in ribbons from 1 to 7.5 cm wide and several meters long. It cuts across bedding and seemingly follows fault-related joints, especially in the overlying Lower Mississippian rocks. Because of their fault relationships, they are interpreted to have been emplaced during or after the Laramide orogeny.

The iron-bearing solutions have selectively traveled along fault breccias and have mineralized these zones, leaving gossans in some places. Since these iron-bearing solutions are also fault controlled, they were probably introduced in the Cretaceous or later.

Syndepositional iron also occurs as limonite pseudomorphs after pyrite. These pseudomorphs do not have any pattern of occurrence but are disseminated in different parts of the sections as both euhedral and anhedral crystal forms 0.05 mm to 0.06 mm across. In spite of the usual association of pyrite with deep-water limestones, this pyrite was formed in shallow water, similar to that studied by Lambert in the Moenkopi Formation in southern Utah (Ralph Lambert personal communication 1938).

There are two occurrences of dolomite in the study area. The major occurrence is in the "correlation" dolomite (fig. 13) found near the base of most of the sections. Associated with the "correlation" dolomite are minor dolomitic units that may occur either above or below that distinctive bed. The other occurrence is in unit 5.5 of section 5 (fig. 8).

Although dolomite interfingers with limestone in places, suggesting a syndepositional origin, the best model to explain the origin of these dolomites is that proposed by Mattes and Mountjoy (1980, p. 272–75) for the dolomitization (type 2) of the upper Devonian Miette buildup in Alberta. They suggested that, after burial, brines from the adjacent basin sediments circulated through the sediments in question and selectively dissolved and replaced limestone matrix. For the Guilmette Formation, the brines would have been derived from the underlying lagoonal sediments. The writer feels that this is the best model to explain the formation of dolomite in the Guilmette Formation for the following reasons: (1) dolomite in unit 5.5 (fig. 8) is zoned, implying a long-term dolomitization process; (2) dolomite in the "correlation" unit replaces the existing rock, being more strongly replaced in some areas than others, but is missing at the base of section 2, implying that some portions of the rock are more resistant to dissolution than others, or that permeability was absent; and (3) there was no nearby source of fresh water to create the brine refluxing to which many workers attribute dolomitization.

The most significant aspect of the diagenesis in these rocks is the occurrence of neomorphic spar. The major criterion used in this study for differentiating neomorphic spar from cement spar was the presence of inclusions in the neomorphic spar, giving it a "dirty" look. In addition, the neomorphic spar occurs adjacent to muddy areas which have not been replaced. Bathurst's guidelines of neomorphic spar characteristics (1975, p. 484–91) and cement fabrics (1975, p. 417–20) were also used.

All of the sparry matrix in the rocks in this area is neomorphic spar. Such abundant neomorphic spar makes it difficult to determine whether or not early cementation has taken place. Early cementation is generally characterized by the presence of isopachous rims of aragonite or high Mg calcite, which normally invert later to low Mg calcite. Neomorphic spar disguises these isopachous rims (see possible rim ghost, fig. 20), and makes it difficult to determine whether the rims actually existed. After careful inspection of areas where neomorphism was less intense, it was concluded that early submarine cementation probably did not play a major role in the diagenetic history of these rocks.

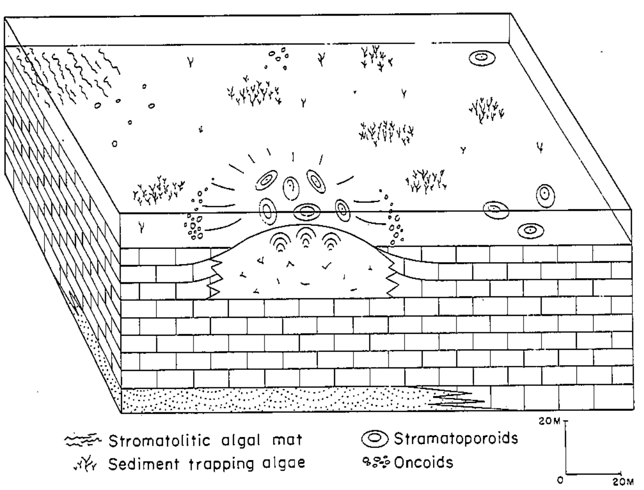

FIGURE 21.—*Idealized depositional model of mound and surrounding shelf sediments, view from the southwest.*

In addition to the aggrading neomorphism of the carbonate mudstone to neomorphic spar, strained calcite occurs in minor amounts. However, no evidence was found to indicate neomorphic recrystallization of the strained calcite to a more stable form (see Bathurst 1975, p. 475–84). The straining of the calcite in figure 22 could have been caused by (1) late crystal growth or (2) compaction of overlying sediments.

Stylolites are also significant, though not abundant; they also occur occasionally as microstylolites. Bathurst (1975, p. 465, 470) concluded that stylolitization must take place after cementation, because it transects cemented matrix, but must occur before cementation is entirely finished in order to give the dissolved calcite a place to go. He stated (1975, p. 470) that material removed by stylolitization is actually a good source of cement in the rock, and that cementation by stylolitization represents the end of porosity. Essentially, the low porosity and permeability of the rocks of this study may be due in part to stylolitization.

ECONOMIC SIGNIFICANCE

Beds of similar age to the Guilmette Formation are prolific hydrocarbon producers in Alberta, Canada. In evaluating the rocks of this area as potential hydrocarbon producers, one must take several parameters into consideration. Is this formation a source rock? What characteristics does this formation have as a reservoir? Is there an effective seal to trap hydrocarbons?

It is necessary for rocks to contain at least 3% organic material on a dry weight basis to be able to generate hydrocarbons (Bissell personal communication 1983). Regional work by the writer and others demonstrates that the Guilmette Formation does have a potential for at least 3% organic carbon in some areas, a good portion of it being produced by algae. Other potential source rocks in the area include the Mississippian Joana Limestone, which was a source to the currently producing volcanic tuffs in Railroad Valley (Doug A. Sprinkel, Placid Oil Co., oral communication 1983). Although the Joana Limestone unconformably overlies the Guilmette, occurrences of source rocks overlying host rocks have been reported (Pye 1958, p. 196).

In this area, the Guilmette Formation has two types of potential reservoir units within it, (1) the sandstone shoal and (2) dolomitic units. In order for these units to serve as reservoir rocks, migration and entrapment of hydrocarbons would have had to occur previous to complete cementation. As indicated by the zoned dolomite and the presence of stylolites, permeability existed at some point.

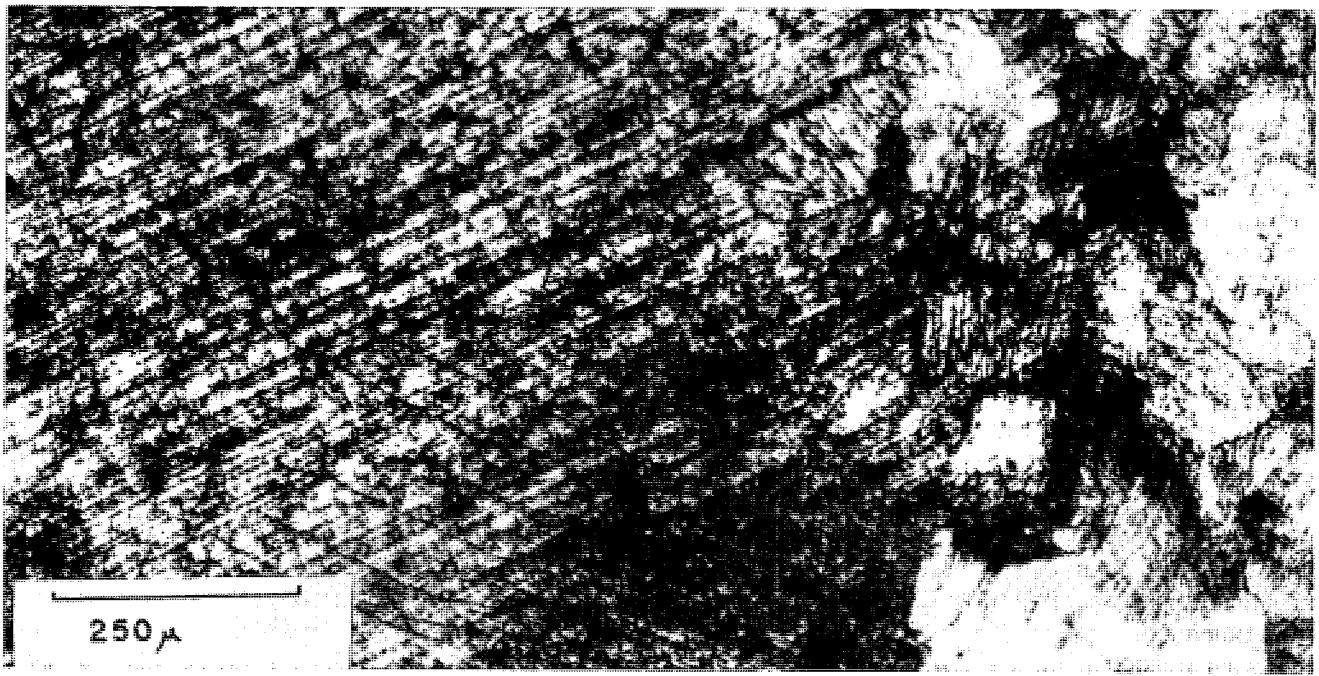

FIGURE 22.—*Strained calcite from unit 2.7; transmitted light, X63.*

If the proper source rock (or even if the Guilmette Formation itself acted as a hydrocarbon source) was adjacent to one of these units at the proper time, these units could serve as reservoir rocks.

It is not entirely clear if the mounds could serve as host rocks. In unit 5.5 there is a wackestone similar to that which makes up the core of the mound. This unit is about 20%–30% zoned dolomite, indicating that permeability existed during dolomitization. If the core of the mound were dolomitized, which does not seem unlikely, it could serve as a reservoir rock. The fact that the dolomitizing solutions flowed through the wackestone previous to dolomitization indicates that permeability existed in the wackestone, so the mounds could possibly be reservoir rocks.

The only potential seal found was simply the facies difference between the "correlation" dolomite unit and the surrounding rock, which implies a difference in permeability. The surrounding rock was only partially dolomitized, perhaps because of a number of factors. If, however, it was simply because of a difference in permeability, that facies change might serve as an effective trap for hydrocarbons.

Also, while the mound in section 5 was in a late period of development, algal mats were forming contemporaneously just a short distance away because of the regression which was occurring. Anhydrite is often associated with algal mats, and if it overtook the mound in some other area of mound development, it would then serve as an effective trap. In addition, in some areas the Guilmette Formation is overlain by the Famennian Pilot Shale. If this shale were found in a mound-producing area of the Guilmette Formation, it too could serve as an excellent seal because of its high impermeability.

Other than hydrocarbon potential, the Guilmette Formation has some economic mineral potential. As was previously discussed, iron-rich solutions have mineralized some fault breccias in the area. The writer fire-assayed a sample of one of these zones for gold, silver, and platinum. No measurable amounts of noble metals were found. In addition, section 7 was fire-assayed by Dr. Willis Brimhall for microscopic noble metals. Unit 2 of section 7 contains about $10.00/ton of microscopic gold and silver.

CONCLUSIONS

The Guilmette Formation has been studied by various workers in an effort to find similarities between it and characteristic Devonian reef formations throughout the world. Because hydrocarbons are commonly found in association with these characteristic reef facies, much of the work done by petroleum companies on the Guilmette Formation has not been published. Nevertheless, up to this point, no well-documented reef has been discovered in the Guilmette Formation.

This study indicates that during the continental shelf deposition of Nevada in Frasnian time, conditions existed that permitted growth of mounds in an environment similar to the back-reef facies of Frasnian-age reefs in other parts of the world. These mounds are similar to those described in the literature but have the following minor differences: (1) lack of diagenetic stromatactis structures and (2) lack of obvious fossils which acted as baffling organisms in the main body of the mound. Regression followed mound deposition, with a resulting erosional unconformity, producing the sequence Frasnian Guilmette Formation overlain by Kinderhookian Joana Limestone. The period of time not represented by the rock column is about 5 million years.

Diagenesis is a major determinant of the economic potential of the rocks in this study. The Guilmette Formation has potential both as a reservoir and a source rock of hydrocarbons, with algae contributing greatly to the 3% dry weight carbon necessary for hydrocarbon production. In the area studied, maturation of organic carbon had not taken place, and cementation and neomorphic alteration of carbonate mud have effectively destroyed permeability. However, interbedded dolomite units and sandstone beds occur, which, under conditions of early hydrocarbon migration, could serve as excellent reservoirs. Stylolites and zoned dolomite crystals indicate that the rocks were permeable for a period of time.

REFERENCES CITED

Baars, D. L., 1963, Petrology of carbonate rocks: In Bass, R. O., Sharps, S. L. (eds.), Four Corners Geological Society Guidebook, p. 101–29.

Bathurst, R. G. C., 1975, Carbonate sediments and their diagenesis: Elsevier, New York, 658p.

Benson, R. H., 1961, Ecology of ostracode assemblages: In Moore, R. C. (ed.), Treatise on invertebrate paleontology, part Q, Arthropoda 3: Geological Society of America, p. Q56–Q63.

Burchette, T. P., 1981, European Devonian reefs: a review of current concepts and models: In Toomey, D. F. (ed.), European fossil reef models: Society of Economic Paleontologists and Mineralogists Special Publication 30, 546p.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture: In Ham, W. E. (ed.), Classification of carbonate rocks: American Association of Petroleum Geologists Memoir 1, p. 108–27.

Dunn, M. J., 1979, Depositional history and paleoecology of an upper Devonian (Frasnian) bioherm, Mount Irish, Nevada: Master's thesis, State University of New York at Binghamton, 133p.

Flugel, E., 1982, Microfacies analysis of limestones: Springer-Verlag, New York, 633p.

Friedman, G. M., 1959, Identification of carbonate minerals by staining methods: Journal of Sedimentary Petrology, v. 29, p. 89–97.

Ginsberg, R. N., 1971, Recent synsedimentary cementation in subtidal Bermuda reefs: In Bricker, O. P. (ed.), Carbonate cements: Johns Hopkins University Studies in Geology, no. 19, p. 54–58.

Heckel, P. H., 1974, Carbonate buildups in the geologic record: a review: In Laport, L. E. (ed.), Reefs in time and space, selected examples from the recent and ancient: Society of Economic Paleontologists and Mineralogists Special Publication 18, p. 90–154.

Hoggan, R. D., 1975, Paleoecology of the Guilmette Formation in eastern Nevada and western Utah: Brigham Young University Geology Studies, v. 22, part 1, p. 141–99.

Hope, R. A., and Coats, R. R., 1976, Geologic map of Elko County: U.S. Geological Survey Open File Report no. 76-779.

James, N. P., 1978, Facies models, 10, Reefs: Geoscience Canada, v. 5, no. 1, p. 16–26.

Jamieson, E. R., 1971, Paleoecology of Devonian reefs in western Canada: In Yochelson, E. L. (ed.), Proceedings of the North American Paleontological Convention, part J: Allen Press Inc., Lawrence, Kansas, p. 1302–40.

Johnson, J. G., 1974, Extinction of perched faunas: Geology, v. 2, p. 479–82.

Johnson, J. G., Sandberg, C. P., 1977, Lower and Middle Devonian continental-shelf rocks of the western United States: Symposium on the Western North American Devonian: University of California Riverside Campus Museum Contribution, no. 4, p. 121–42.

Klovan, J. E., 1964, Facies analysis of the Redwater Reef Complex, Alberta, Canada: Bulletin of Canadian Petroleum Geology, v. 12, no. 4, p. 1100.

Krebs, W., 1974, Devonian carbonate complexes of central Europe: In Laport, L. E. (ed.), Reefs in time and space, selected examples from the recent and ancient: Society of Economic Paleontologists and Mineralogists Special Publication 18, p. 155–208.

Land, L. S., 1971, Submarine lithification of Jamaican reefs: In Bricker, O. P. (ed.), Carbonate cements: Johns Hopkins University Studies in Geology, no. 19, p. 59–62.

Lecompte, M., 1956, Stromatoporoidea: In Moore, R. C. (ed.), Treatise on invertebrate paleontology: Geological Society of America, p. F107–F127.

Mattes, B. W., Mountjoy, E. W., 1980, Burial dolomitization of the Upper Devonian Miette buildup, Jasper National Park, Alberta: In Zenger, D. H., Dunham, J. B., Ethington, R. L. (eds.), Concepts and models of dolomitization: Society of Economic Paleontologists and Mineralogists Special Publication 28, p. 259–94.

Merriam, C. W., 1940, Devonian stratigraphy and paleontology of the Roberts Mountains region, Nevada: Geological Society of America Special Paper 25, 114p.

Nadjmabadi, S., 1967, Paleoenvironment of the Guilmette Limestone (Devonian) near Wendover, Utah: Brigham Young University Geology Studies, v. 14, p. 131–42.

Niebuhr, W., 1980, Biostratigraphy and paleoecology of the Guilmette Formation of eastern Nevada: Ph.D. dissertation, University of California at Berkeley, 242p.

Nolan, T. B., 1935, The Gold Hill district, Utah: U.S. Geological Survey Professional Paper 177, 172p.

Petersen, M. S., 1956, Devonian strata of central Utah: Brigham Young University Research Studies, v. 3, no. 3, 37p.

Playford, P. E., 1976, Devonian reef complexes of the Canning Basin, Western Australia: 25th International Geological Congress Excursion Guide 38A, 39p.

__________, 1980, Devonian "Great Barrier Reef" of Canning Basin, Western Australia: American Association of Petroleum Geologists Bulletin, v. 64, no. 6, p. 814–40.

Playford, P. E., and Lowry, D. C., 1966, Devonian reef complexes of the Canning Basin, western Australia: Geological Survey of Western Australia Bulletin, v. 4, no. 118, p. 1–141.

Playford, P. E., and Cockbain, A. E., 1969, Algal stromatolites: deposition forms in the Devonian of western Australia: Science, v. 165, p. 1108–10.

Pye, D. P., 1958, Oil in Great Plains and Rocky Mountains: In Weeks, L. G. (ed.), Habit of oil, a symposium: American Association of Petroleum Geologists, Tulsa, Oklahoma, 1384p.

Reso, A., 1959, Devonian reefs in the Pahranagat Range, southeastern Nevada: Geological Society of America Bulletin, v. 70, p. 1661.

———, 1963, Composite columnar section of exposed Paleozoic and Cenozoic rocks in the Pahranagat Range, Lincoln County, Nevada: Geological Society of America Bulletin, v. 74, p. 901–18.

Sandberg, C. A., and Poole, F. G., 1977, Conodont biostratigraphy and depositional complexes of Upper Devonian cratonic-platform and continental-shelf rocks in the western United States: Symposium on the Western North American Devonian: University of California, Riverside Campus Museum Contribution, no. 4, p. 144–82.

Sandberg, C. A., Gutschick, R. C., Johnson, J. G., Poole, F. G., and Sando, W. J., 1982, Middle Devonian to Late Mississippian geologic history of the Utah hingeline and overthrust belt region, western United States, a summary: In Nielson, D. L. (ed.), Overthrust belt of Utah: 1982 Symposium and Field Conference, Utah Geological Association Publication, no. 10, p. 116–18.

Schmidt, V., 1971, Early carbonate cementation in middle Devonian bioherms, Rainbow Lake, Alberta: In Bricker, O. P. (ed.), Johns Hopkins University Studies in Geology, no. 19, p. 209–15.

Shinn, E. A., 1971, Holocene submarine cementation in the Persian Gulf: In Bricker, O. P. (ed.), Johns Hopkins University Studies in Geology, no. 19, p. 63–65.

Stanton, R. J., 1963, Upper Devonian calcispheres from Redwater and south Sturgeon Lake Reefs, Alberta, Canada: Bulletin of Canadian Petroleum Geology, v. 11, no. 4, p. 410–18.

Stewart, J. H., and Poole, F. G., 1974, Lower Paleozoic and uppermost Precambrian Cordilleran miogeocline, Great Basin, western United States: In Dickinson, W. R. (ed.), Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 22, p. 28–57.

Thorman, C. H., 1970, Metamorphosed and nonmetamorphosed Paleozoic rocks in the Wood Hills and Pequop Mountains, northeast Nevada, Geological Society of America Bulletin, v. 81, no. 8, p. 2417–47.

Wilson, J. L., 1975, Carbonate facies in geologic history: Springer-Verlag, New York, 471p.

Wray, J. L., 1967, Upper Devonian calcareous algae from the Canning Basin, Western Australia: Professional Contributions of the Colorado School of Mines, no. 3, 76p.