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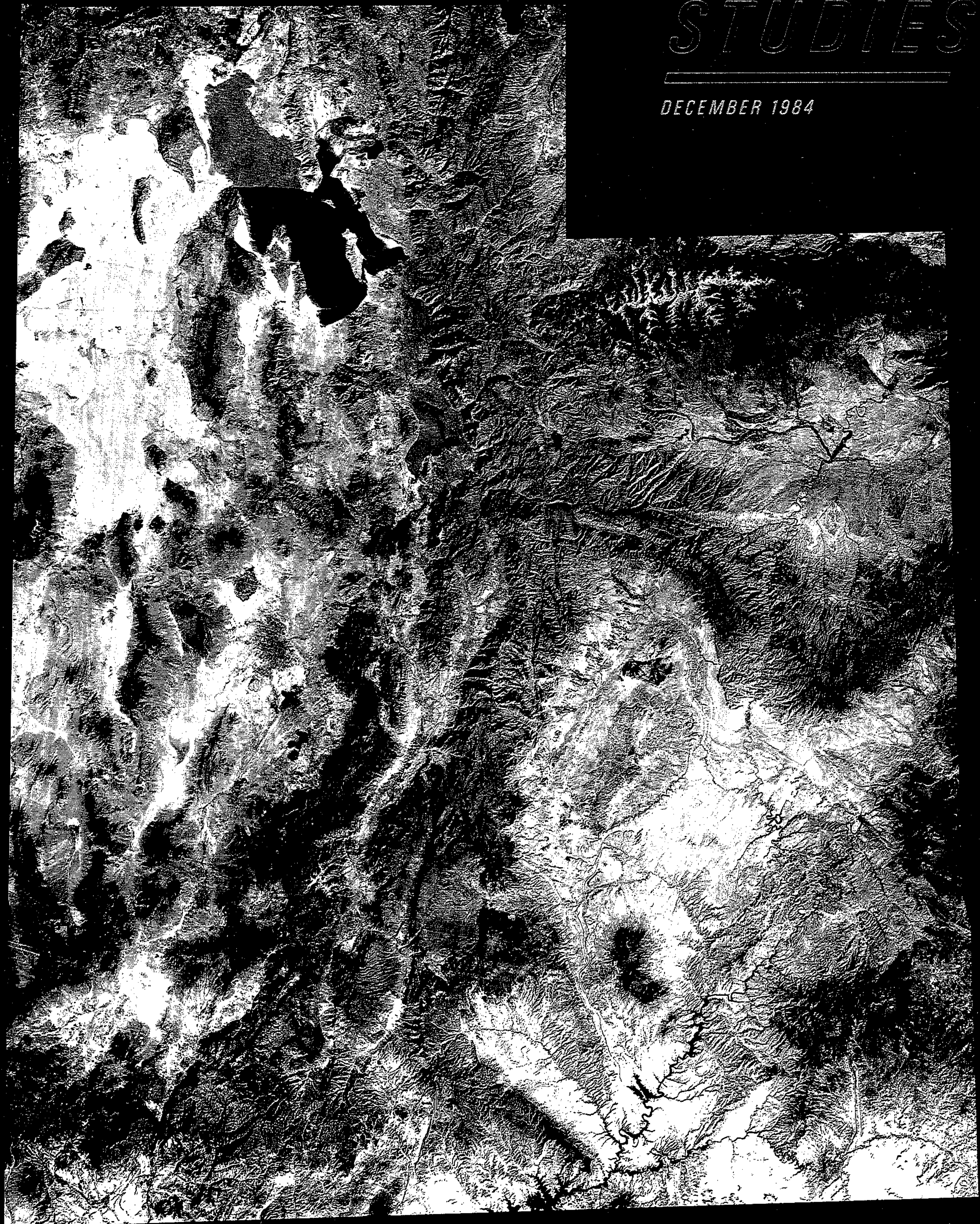
GEOLOGY STUDIES

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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Carbonate Petrology and Depositional Environments of Carbonate Buildups in the Devonian Guilmette Formation near White Horse Pass, Elko County, Nevada*

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Thesis chairman: HAROLD J. BISSELL

ABSTRACT

The Guilmette Formation contains major carbonate buildups, near the White Horse Pass area, that are best described as carbonate banks on the basis of biostromal growth form and nonrigid skeletal communities that show subtle lateral faunal changes. These very thick bedded, dominantly packstone rocks generally rest on medium-bedded wackestone and mudstone with interbedded dolomite platform carbonates.

Open-marine conditions prevailed during a major period of platform subsidence that allowed carbonate bank and interbank pelletal shoals to form. Quiet, restricted conditions generally existed prior to the formation of carbonate banks.

Occurrence of the guide fossils *Stringocephalus* and *Manticoceras,* within the carbonate banks and in genetically related units, indicates bank formation took place from Givetian through Frasnian time.

INTRODUCTION

In Alberta, Upper Devonian reefs, such as the Leduc and Nisku, have been prolific hydrocarbon producers and thus have been intensively studied. Devonian carbonates in the Great Basin have not shown similar potential at present, but carbonate buildups do exist which deserve serious attention. Examples of carbonate buildups in the Devonian Guilmette Formation have been noted but not studied in detail. Good exposures of these buildups occur in the Goshute Mountains directly west of the Nevada/Utah border in the southeast corner of Elko County, Nevada. These buildups were deposited in a variety of shallow-marine environments, and represent an excellent opportunity to study facies changes with possible economic results.

The primary focus of this study is to describe and interpret the lithofacies that compose the buildups and those that are genetically related. A secondary objective is to petrographically determine the porosity and permeability of these facies in order to highlight possible petroleum entrapment potential.

LOCATION

The study area is located in the central part of the Goshute Mountains approximately 18 km from the Nevada/Utah border in the southeast corner of Elko County, Nevada (fig. 1). Four of the five measured sections are exposed in dry canyons on the east flank of the range, north of White Horse Pass, and the remaining section is located on the north flank of Sugar Loaf Peak.

U.S. 50 runs diagonally southwest of Wendover, Nevada, to White Horse Pass, a distance of 45 km. The Dead Cedar Spring, Ferguson Mountain, and Felt Wash sections are reached from jeep trails intersecting a maintained dirt road that parallels Dead Cedar Wash and connects with U.S. 50 near the Blue Lake junction 1.5 km south of the Ferguson Springs Maintenance Station. Figure 1 shows the location of each measured section. All are found in T. 28, 29, and 30 N, R. 68 E.

METHODS AND NOMENCLATURE

Five stratigraphic sections of the Guilmette Formation containing carbonate buildups were measured with a 30-m steel tape and Brunton compass. The Guilmette Formation has been divided into two members (Reso 1959), but reliable marker beds are hard to find. Sections were measured from the first dolomitic sandstone occurrence below the buildups, which provided the best field correlation possible in the absence of detailed conodont zonation studies. An additional limestone unit containing the im-

*A thesis submitted to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Master of Science, April 1983.

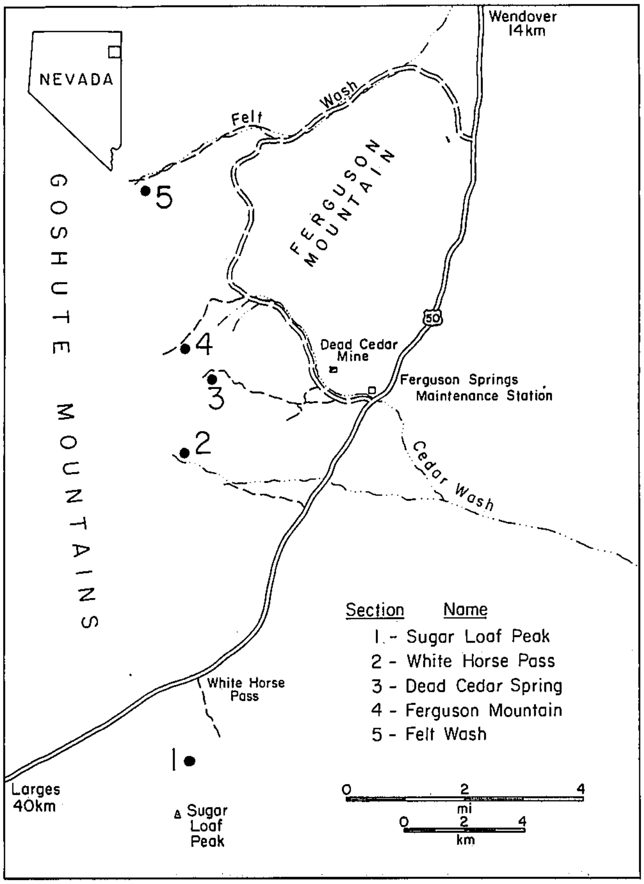


FIGURE 1.—*Index map.*

portant guide fossil *Manticoceras,* located just below the dolomitic sandstone, was included in the Felt Wash section. With color, bedding, cement type, fossil content, sedimentary structures, and geomorphic expression as parameters, each section was subdivided into units on the basis of common lithologic character. Samples were collected from (1) each distinct lithologic unit less than 3 m thick, or (2) from every 3-m interval in units thicker than 3 m. This twofold approach was used to prevent error resulting from failure to recognize subtle facies changes common in carbonate rocks.

More than 250 thin sections were subsequently prepared from these hand samples for analysis under petrographic and binocular microscopes. Selected slides were stained using Alizarin Red S (Friedman 1959) to determine calcite/dolomite ratios.

Terminology used in this study is based on Dunham's (1962) classification scheme with the addition of crystalline fabric modified after Dean (1981). This modification is necessary to accommodate the abundant secondary dolomites encountered in association with the carbonate buildups that have obliterated or obscured original textures. Figure 2 summarizes nomenclature used for rock-specimen identification.

The term *pellet* is used without the size constraints imposed by Folk (1962). The catch-all term *peloid,* which does not imply mode of origin, is used as conservatively as possible and is also irrespective of size. Calcispheres, whose origin is still much debated, are placed in three categories (Stanton 1963) based on the nature of the cell wall: the prismatic wall type, spinose wall type, and the transitional wall type. Stylolites are classified on the basis of geometry after Park and Schott (1968; fig. 3).

PREVIOUS WORK

The Guilmette Formation was first used with reference to a body of rock exposed in Guilmette Gulch, Gold Hill region, by T. B. Nolan (1935), where the sequence of rocks is dominantly thick-bedded dolomite and limestone with some lenticular siltstones. Nolan differentiated the Guilmette Formation from the underlying Simonson Dolomite on the basis of a greater limestone-to-dolomite ratio. The Guilmette Formation was divided by Westgate and Knopf (1932) into the Silverhorn Dolomite and West Range Limestone in their study of the Pioche District, Nevada. Kellogg (1963) recognized correlation between the Silverhorn Dolomite and certain facies of the Guilmette Formation as part of a stratigraphic study in the southern Egan

<table>
<tr><td colspan="5">Limestones and Dolomites - Depositional Texture recognizable</td></tr>
<tr><td colspan="4">Original components not bound together during deposition</td><td rowspan="4">Original components were bound together during deposition</td></tr>
<tr><td colspan="3">Contains mud (particles of clay and fine silt size)</td><td rowspan="3">Lacks mud and is grain supported</td></tr>
<tr><td colspan="2">Mud - supported</td><td rowspan="2">Grain supported</td></tr>
<tr><td>Less Than 10% grains</td><td>More Than 10% grains</td></tr>
<tr><td>MUDSTONE</td><td>WACKE-STONE</td><td>PACK-STONE</td><td>GRAIN-STONE</td><td>BOUND-STONE</td></tr>
<tr><td colspan="5">Dolomites - Depositional Texture not recognizable</td></tr>
<tr><td colspan="5">Crystalline Fabric</td></tr>
<tr><td>less than .03mm</td><td>.03-.1mm</td><td colspan="2">.1mm-.2mm</td><td>more than .2mm</td></tr>
<tr><td>DOLOMICRITE</td><td>FINE CRYSTALLINE DOLOMITE</td><td colspan="2">MEDIUM CRYSTALLINE DOLOMITE</td><td>COARSE CRYSTALLINE DOLOMITE</td></tr>
</table>

FIGURE 2.—*Classification scheme used in the text for carbonate rocks, modified after Dunham (1962) and Dean (1981).*

Range. Bissell (1955) incorporated relationships expressed in the Guilmette Formation with paleotectonics of the Great Basin and recommended the continued use of the term *Guilmette Formation.* Reso (1959, 1963) believed the lower units of the Guilmette Formation in the Pahranagat Range of southeastern Nevada to be equivalent to the Beaverhill Lake Formation in Alberta, whereas the upper units of the lower Guilmette Formation were considered equivalent in age and depositional environment to the Cooking Lake Formation. Reso further correlated carbonate buildups in the lower part of the upper Guilmette Formation with the Leduc reef. Schaeffer and Anderson (1960) measured and described a total thickness of 680 m (2,229 ft) for the Guilmette Formation on Silver Island, northeast of Wendover, Utah. They described the Guilmette Formation as follows:

Black limestone predominated in the lower 1,340 feet of the formation, whereas medium-gray limestone which weathers light to gray predominated in the upper 890 feet of the formation. A shaly, calcareous, argillaceous, arenaceous dolomite is present from 300–350 feet below the top of the Guilmette Formation on Silver Island.

As part of his thesis work with Devonian strata of central Utah, Petersen (1956) made a petrologic and petrographic analysis of the Guilmette Formation. He alluded to petroleum entrapment potential in the western part of the state, such as the Desert Range near Wendover, where much of the rock in the formation emits a petroliferous odor when the rock is fractured.

Guilmette faunas have been studied for some time. Devonian formations of North America were correlated on the basis of *Stringocephalus* by Cooper (1943), who observed their occurrence near the base of the Guilmette Formation in the Great Basin. Waines (1964) described and studied the distribution and biostratigraphy of stromatoporoid faunas of the Guilmette Formation and other Devonian formations in Nevada. Using brachiopod zonation, Boucot and others (1968) did detailed work on the biostratigraphy of the Guilmette Formation. Nadjmabadi's (1967) paleoenvironmental study, along with Luke's (1978) study of several species of corals in the western part of the Leppy Range, north of Wendover, implied that a warm, shallow, quiet to slightly agitated environment existed to produce the Guilmette Formation. Hoggan's (1975) paleoecological study summarized the Guilmette Formation in eastern Nevada and western Utah as consisting of limestone, dolomite, and sandstone deposited in a shallow north–south-trending miogeosyncline, which contained two separate basins of accumulation. He also concluded that massive carbonate buildups in the Guilmette Formation are not reefs but simply carbonate bank deposits. More recent work has been done on the biostratigraphy and paleoecology of the Guilmette Formation in eastern Nevada by Niebuhr (1980). He suggested that a wide belt of stromatoporoidal buildups existed in eastern Nevada during early Frasnian time bordering a carbonate platform and enclosing a lagoon.

A petrologic analysis of carbonate buildups in the Guilmette Formation located in the Pequop Mountains is currently being done by Williams (1984) and is the most recent related work nearest the study area.

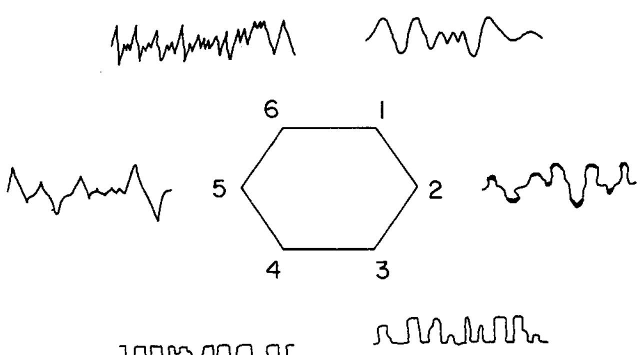


FIGURE 3.—*Classification of stylolites after Park and Schott (1968): (1) Simple or primitive wavelike type, (2) sutured type, (3) up-peak type, (4) down-peak type (rectangular type), (5) sharp-peak type (tapered and pointed), (6) seismogram type.*

ACKNOWLEDGMENTS

The writer extends appreciation to Dr. H. J. Bissell, chairman, for encouragement and assistance throughout preparation of the manuscript. I am also grateful to Dr. J. Keith Rigby, committee member, who aided interpretation of the thin sections. Dr. W. K. Hamblin gave helpful suggestions on preparation of illustrations and reviewed the manuscript. Sincere thanks is extended to Dr. M. S. Petersen for field assistance and fossil identification. I am thankful for help provided by Dr. W. R. Phillips in making photomicrographs of selected thin sections. The writer is grateful to Winston Williams, fellow graduate student, for help in measuring and describing sections. Special thanks are reserved for my wife, Lynda, who offered constant encouragement and untiring assistance in typing the manuscript.

GEOMETRY AND CARBONATE PETROLOGY OF LITHOFACIES

In order to best illustrate the nature of major carbonate buildups in the Guilmette Formation near White Horse Pass, rocks of the five measured sections were divided into seven lithofacies, A through G, in ascending order. The Sugar Loaf Peak, White Horse Pass, and Dead Cedar Spring sections are readily broken down into lithofacies A through E. Unfortunately, large parts of the Ferguson

Mountain section have covered slopes that greatly hinder discernment of the presence or absence of lithofacies A through E. The Felt Wash section is also obscured by covered slopes and includes two additional lithofacies (F and G). Figure 4 shows the positions of the various lithofacies.

Parameters for description include rock types, geomorphic expression, fossil content, and sedimentary structures. Where appropriate, lithofacies are divided into subfacies to facilitate more detailed petrologic parameters.

LITHOFACIES A

Lithofacies A consists of light olive gray to grayish orange dolomitic sandstones with occasional light gray dolomite interbeds that form small slopes between sandstone ledges. It makes up a small percentage of most measured sections, with the thickest occurrence comprising approximately 12% of the Dead Cedar Spring section. The basal contact is sometimes covered by float but is usually easily distinguished from darker limestone or dolomite lithologies. This contact is believed to represent an approximately equivalent time line; it provided the best horizon for rough correlation between measured sections.

The diagnostic features of lithofacies A are ubiquitous well-rounded, bimodally sorted quartz and absence of fossil content. Smaller quartz grains average 0.1 mm, and the larger grains are generally 0.5 to 0.8 mm. Also common are round peloids replaced with medium to coarse subhedral dolomite crystals. A dark dolomicrite, sometimes grading into a fine crystalline dolomite, usually forms the matrix.

Though the abundance of quartz suggests a higher-energy regime, cross-bedding is not present. The thin-bedded nature does, however, impart a laminated character to sandstone units (fig. 5).

LITHOFACIES B

The rocks of lithofacies B form 3–20% of the five measured sections. These light gray dolomites most commonly occur as medium-bedded units that form ledges, small cliffs, and slopes. Upper and lower contacts are either covered or gradational. Lithofacies B was not observed in the Ferguson Mountain section but may exist beneath covered slope. Gradation between lithofacies A and B is gradual and sometimes marked with a transitional dolomicrite unit.

Three subfacies occur, including an alternating light and dark gray "spaghetti" dolomite, a homogeneous dolomite, and a heterogeneous dolomite. The alternating light and dark "spaghetti" dolomite subfacies can be differentiated in the field, but the others must be distinguished petrographically (fig. 6).

Alternating Light and Dark "Spaghetti" Dolomite Subfacies

This subfacies is characterized by alternating light gray and dark gray layers of dolomite (fig. 7). *Amphipora* is most abundant in the dark layers and imparts a spaghettilike appearance to these rocks (fig. 8). The subfacies composes 50%–90% of lithofacies B in the White Horse Pass and Dead Cedar Spring sections but was not observed in any of the other sections.

Petrologically, the dolomites are cloudy, fine to coarse crystalline, and exhibit a xenotropic texture. There is no difference between the light and dark layers that can be discerned in thin sections.

Amphipora is the most abundant fossil and is usually seen as remnant skeletal ghosts, now nearly obliterated by dolomitization. A few ostracode(?) valves were also seen as ghosts. Isolated cabbage-size stromatoporoids were noted in unit 3 of the White Horse Pass section.

Light and dark layers are commonly separated by stylolites, which provide high contrast to the suturelike patterns in outcrop (fig. 9). Thin sections reveal that dissolution surfaces are stained, mostly with limonite and occasionally with hematite. Amplitudes range from 1 to 3 cm. Limonite-stained microstylolites, with amplitudes less than 1 mm, can be seen separating fine and coarse patches of dolomite in many thin sections.

Homogeneous Dolomite Subfacies

Dolomite units that comprise the homogeneous subfacies range from 10% of lithofacies B in the White Horse Pass section to 100% of lithofacies B in the Sugar Loaf Peak section. This kind of dolomite is not present in the Dead Cedar Spring section.

Composition consists of cloudy, medium, or coarse crystalline dolomite. The most diagnostic feature of the homogeneous subfacies is the uniform crystal size of the xenotopic or hypidiotopic fabric (fig. 10). In the Felt Wash section the homogeneous subfacies includes fine quartz grains (less than 0.05 mm) scattered throughout a fine crystalline xenotopic fabric.

Fossil content is dominated by *Amphipora,* though it is not so abundant as in the alternating light and dark "spaghetti" subfacies and is more poorly preserved. A few dolomitized rugose corals and isolated bulbous stromatoporoids are present in horizons of this subfacies in the White Horse Pass section. Other skeletal ghosts can be observed but are not identifiable.

Heterogeneous Dolomite Subfacies

Rocks comprising the heterogeneous dolomite subfacies range from 10%–15% of lithofacies B in the White Horse

Pass and Dead Cedar Spring sections. Such dolomite is not present in lithofacies B of the other sections.

Petrologically, they are the same as dolomites of the alternating light and dark "spaghetti" dolomite subfacies. *Amphipora* is more common than that found in the homogeneous dolomite subfacies and is replaced by hypidiotopic textured dolomite.

The only sedimentary structures seen in outcrop are irregular to ovoid calcite-filled vugs 3–12 cm in diameter (fig. 11). They occur in unit 9 of the Dead Cedar Spring section and unit 4 of the White Horse Pass section. An organic origin is likely, perhaps stromatoporoidal, but diagenetic processes cannot be ruled out.

LITHOFACIES C

Outcrops of lithofacies C range from thin- to medium-bedded limestones and dolomites to occasional thick to very thick bedded units. Dolomites form some small cliffs but generally are slope-forming units. Limestones also form small cliffs but usually crop out as ledges. The first limestone ledge encountered above lithofacies B marks the base of lithofacies C.

Many of the limestones are partially dolomitized, exhibiting patches of fine to coarse, crystalline, xenotopic fabric as well as good dolorhomb development. Lithofacies C is the thickest of the lithofacies and comprises at least 30% of each measured section, except in the Felt Wash section, where it makes up approximately 10%. Much of what is believed to be lithofacies C in the Ferguson Mountain section consists of covered slope, which prohibits description. Unfortunately, this same kind of cover exists in the Felt Wash section, where these rocks appear to form a much thinner proportion (15%–20%) than in other measured sections.

Limestones of lithofacies C are made up of nearly equal amounts of wackestone and packstone with much less grainstone and mudstone. Six subfacies are defined in the lithofacies, including (1) pelletal packstone/grainstone subfacies, (2) *Amphipora* packstone and wackestone subfacies, (3) pelletal packstone and wackestone subfacies, (4) skeletal packstone and wackestone subfacies, (5) peloidal wackestone and mudstone subfacies, and (6) heterogeneous and homogeneous dolomites.

Pelletal Packstone/Grainstone Subfacies

The pelletal packstone/grainstone subfacies occurs only in the Ferguson Mountain and Felt Wash sections as limestone ledges underlain and capped by covered slopes. The subfacies composes 5%–15% of these two sections.

Dark pellets, which range from 0.05 to 0.3 mm in diameter, are the characteristic feature of the subfacies. Composite pellet intraclasts up to 0.7 mm across may also be present. One unit in the Felt Wash section has a unique occurrence of many oblong pellets up to 0.5 mm long. Both packstone and grainstone textures are commonly observed in the same rock (fig. 12).

Fossils seen petrographically include green and blue-green algae, ostracodes, low-spired gastropods, uniserial foraminifera, and rare calcispheres, with prismatic walls. Skeletal constituents, as a whole, are not abundant though bioturbation is evidenced by burrows filled with pellets.

Amphipora *Packstone and Wackestone Subfacies*

The medium gray to dark gray limestones that make up the *Amphipora* packstone and wackestone subfacies comprise up to 20% of lithofacies C in the Sugar Loaf Peak section but were not observed in the Ferguson Mountain and Felt Wash sections.

Both packstone and wackestone textures contain abundant *Amphipora* generally well preserved. *Amphipora* coenostea do not exhibit evidence of baffling but rather are oriented parallel to bedding. Blue-green algae are commonly found encrusting *Amphipora* fragments and may also be found as separate entities (fig. 13). Infrequent occurrences of other stromatoporoids, including massive and bulbous types, are found. Less common fossils, seen only in thin sections, include gastropods, ostracodes, and calcispheres. Also noted are two occurrences of *Solenopora.*

Pellets (0.1 mm), if present, are a minor constituent of the subfacies and generally have a "fuzzy" appearance, likely a result of recrystallization. Neomorphic overprints have also produced other unidentifiable allochems which may simply be related to disarticulation of algae.

Pelletal Packstone and Wackestone Subfacies

Approximately 6% of the Ferguson Mountain section and 25% of the Sugar Loaf Peak section of lithofacies C consist of pelletal packstone and wackestone subfacies. The subfacies, if present in the Felt Wash section, is buried beneath covered slopes.

Compositionally, the subfacies consists of abundant dark pellets ranging from 0.05 to 0.3 mm, with a median of about 0.1 mm. The pellets are cemented either into sparry packstone textures or into micritic wackestone fabric, with a wide spectrum between. Neomorphic overprints commonly blur the pellet boundaries causing a fuzzy appearance. Rather than random arrangement, the pellets seem to occur mostly in patches. In both packstone and wackestones, partial dolomitization has produced scattered dolorhombs in the limestone fabric (fig. 14).

Many kinds of fossils occur in the subfacies, but none are abundant. They include *Amphipora,* ostracodes, gastropods, calcispheres, uniserial foraminifera, and very

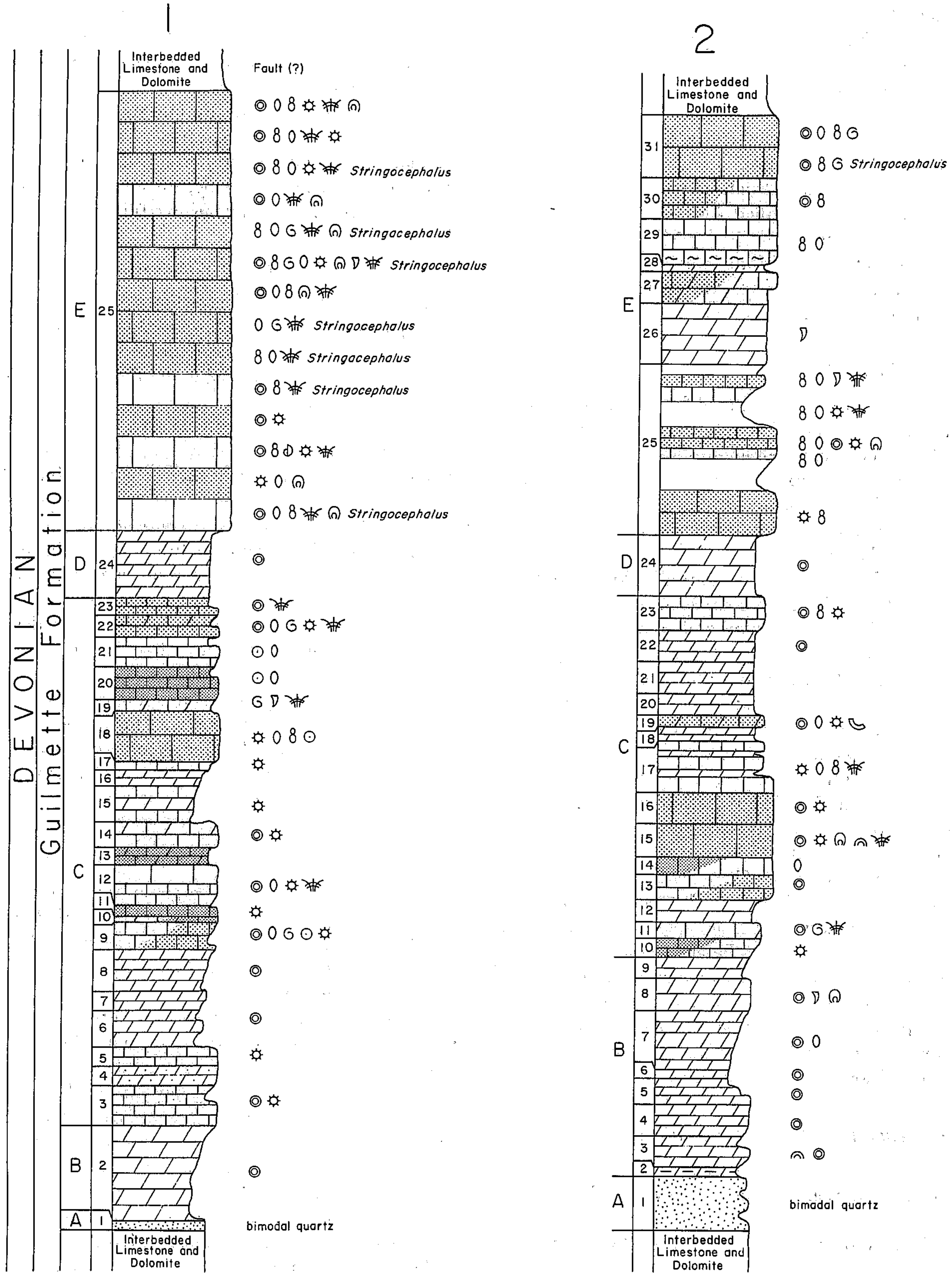
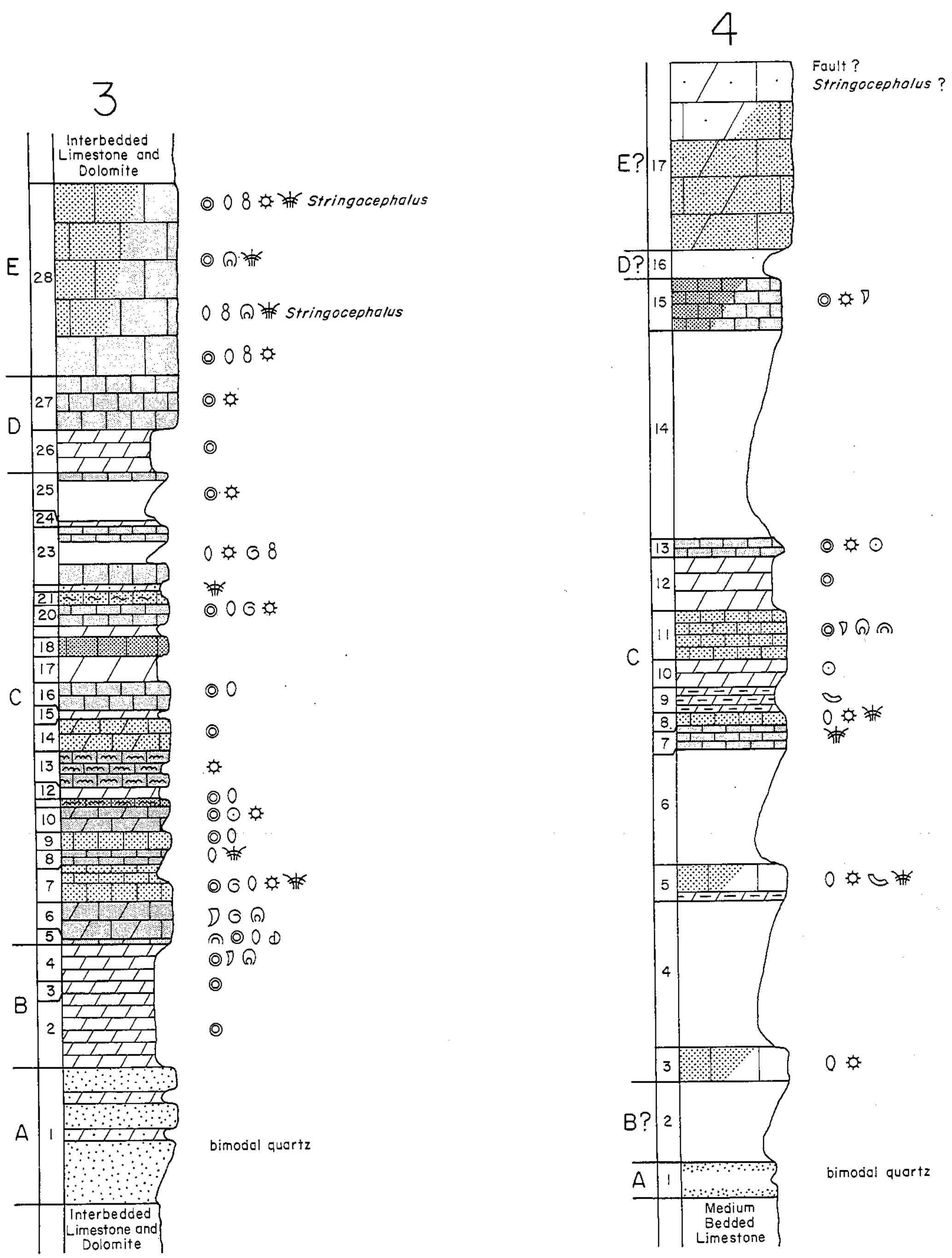
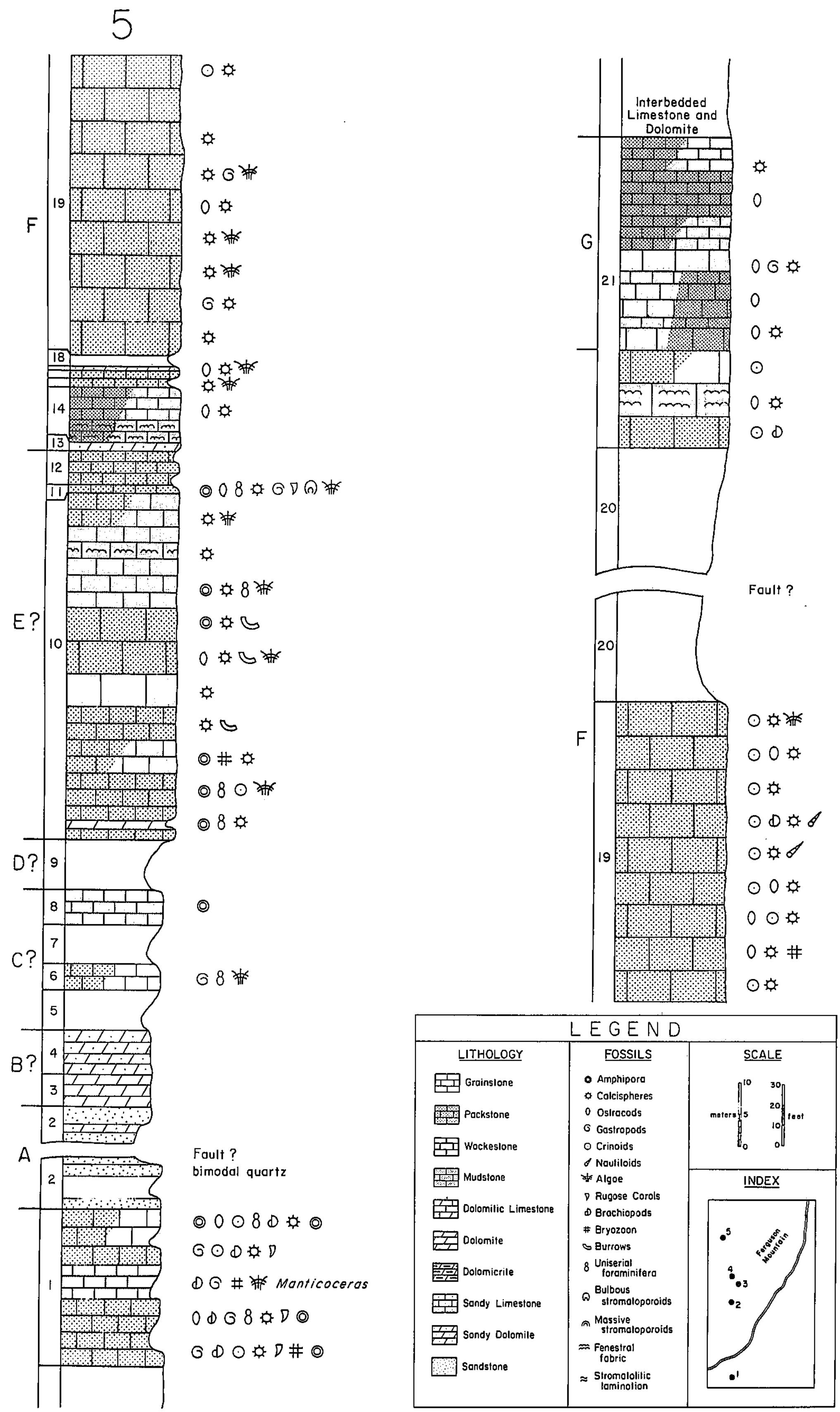


FIGURE 4.—*Stratigraphic columns of measured sections.*


3
Interbedded Limestone and Dolomite
Stringocephalus
Stringocephalus
E
D
C
B
A
bimodal quartz
Interbedded Limestone and Dolomite
4
Fault ?
Stringocephalus ?
E?
D?
C
B?
A
bimodal quartz
Medium Bedded Limestone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2
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Fault ?
bimodal quartz
Manticoceras
Interbedded Limestone and Dolomite
G
21
20
Fault ?
20
F
19
LEGEND
LITHOLOGY
Grainstone
Packstone
Wackestone
Mudstone
Dolomitic Limestone
Dolomite
Dolomicrite
Sandy Limestone
Sandy Dolomite
Sandstone
FOSSILS
Amphipora
Calcispheres
Ostracods
Gastropods
Crinoids
Nautiloids
Algae
Rugose Corals
Brachiopods
Bryozoan
Burrows
Uniserial foraminifera
Bulbous stromatoporoids
Massive stromatoporoids
Fenestral fabric
Stromatolitic lamination
SCALE
meters
feet
INDEX
Ferguson Mountain

rare crinoid debris. Calcispheres have mainly prismatic walls, but a few have transitional wall types.

The only sedimentary structure worthy of note is found in unit 7 of the Ferguson Mountain section. Contorted fine laminae in the middle of the unit appear to be algal(?) related and may contain dead oil.

Skeletal Packstone and Wackestone Subfacies

Ledges containing the skeletal packstone and wackestone subfacies comprise up to 15% of the Dead Cedar Spring and Felt Wash sections. However, the subfacies was not observed in the White Horse Pass section.

Both packstone and wackestone texture are found in these rocks. Regular patches of blocky calcite have replaced unidentifiable skeletal fragments, but most spar cementing the allochems is micritic to fine crystalline. Dark, idiotopic to hypidiotopic, textured dolomite is present in minor amounts throughout the subfacies. Peloids 0.3–0.4 mm across are also rare constituents.

Most characteristic of the subfacies is the abundant fossil content. Besides *Amphipora,* other stromatoporoids include bulbous cabbage-size varieties which are believed to be in growth position (fig. 15). However, the thickest

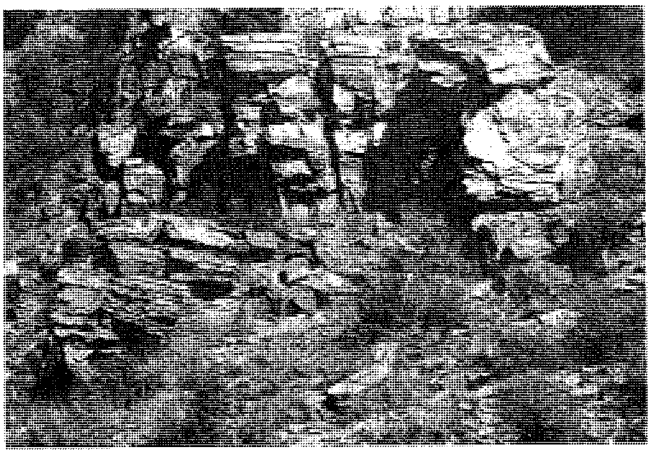

FIGURE 5.—*Laminated character of lithofacies A, White Horse Pass section, view to the north.*

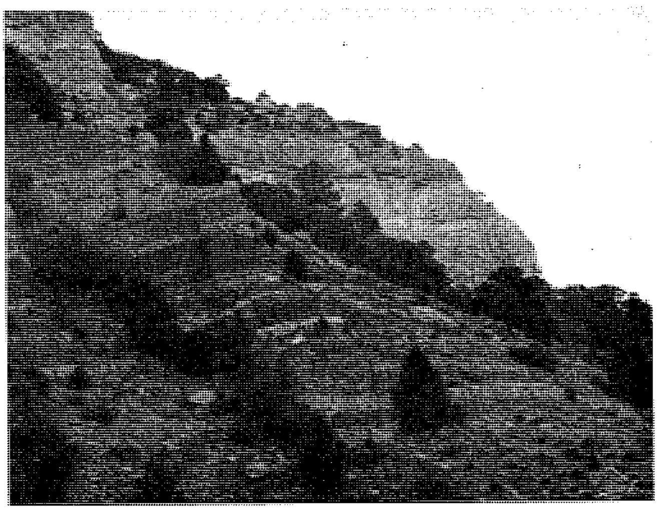

FIGURE 6.—*Alternating light and dark "spaghetti" subfacies, lithofacies B, White Horse Pass section, view to the northeast.*

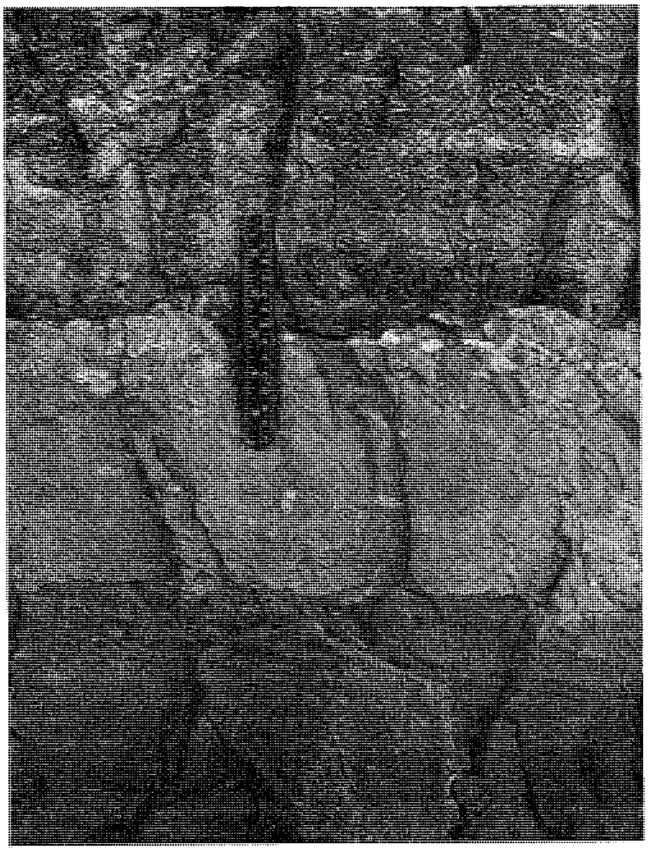

FIGURE 7.—*Closeup of alternating light and dark "spaghetti" subfacies, unit 7, White Horse Pass section.*

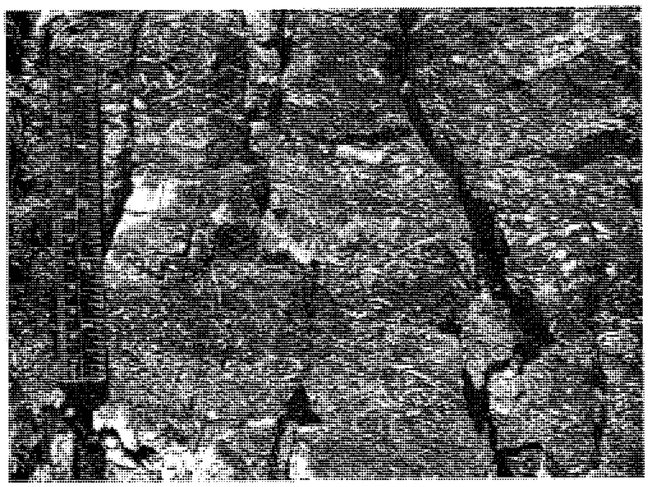

FIGURE 8.—*"Spaghetti" dolomite, unit 12, Ferguson Mountain section.*

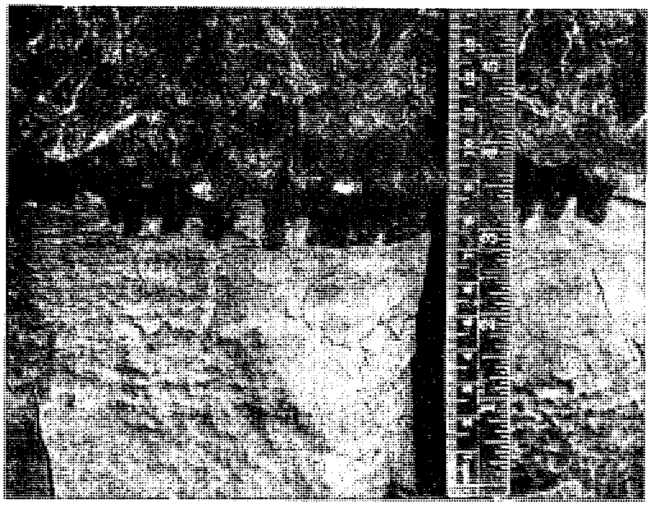

FIGURE 9.—*Stylolites separating light and dark dolomite, unit 7, White Horse Pass section.*

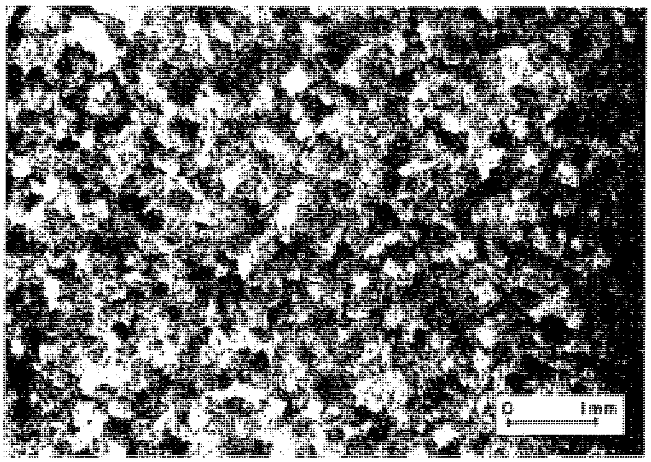

FIGURE 10.—*Xenotopic dolomite, unit 24, Dead Cedar Spring section.*

FIGURE 11.—*Replaced stromatoporoids(?), unit 3, Dead Cedar Spring section.*

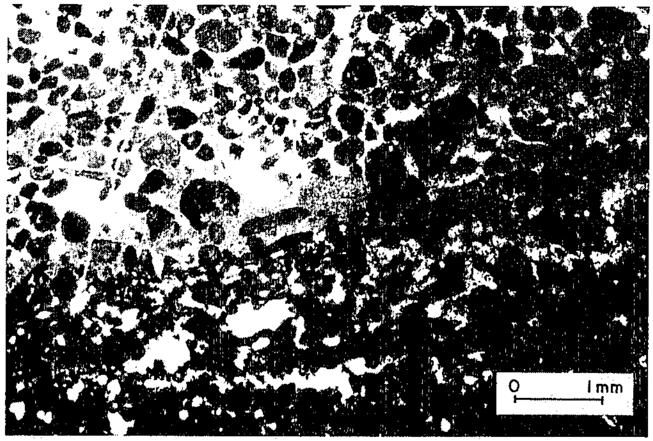

FIGURE 12.—*Grainstone/packstone, unit 16, Felt Wash section.*

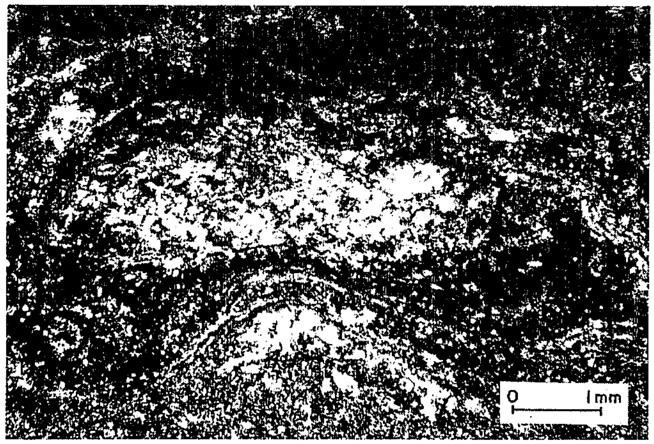

FIGURE 13.—Amphipora *encrusted with blue-green(?) algae, unit 19, Sugar Loaf Peak section.*

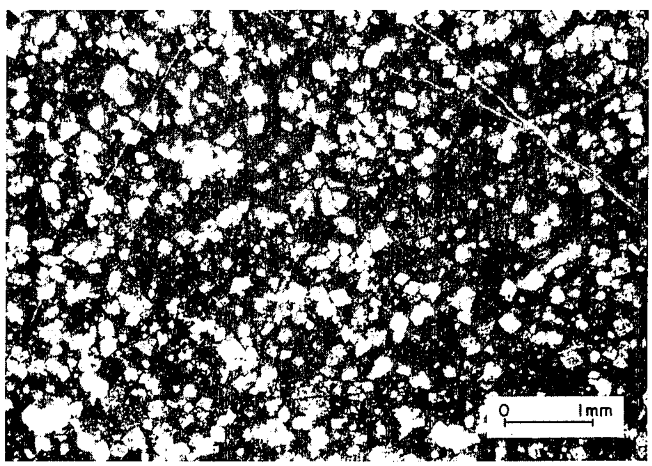

FIGURE 14.—*Scattered dolorhombs in wackestone fabric, unit 14, Sugar Loaf Peak section.*

FIGURE 15.—*In situ bulbous stromatoporoids, unit 5, Dead Cedar Spring section.*

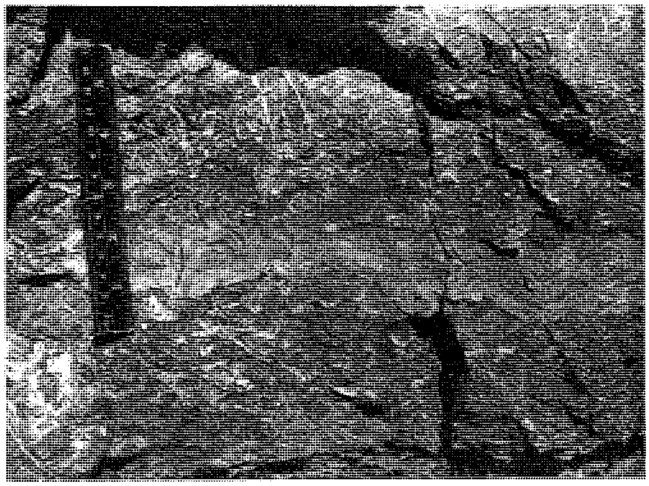

FIGURE 17.—*Tabular stromatoporoid, unit 13, Ferguson Mountain section.*

occurrence is only 0.3 m, found in unit 5 of the Dead Cedar Spring section. Smaller species have been ripped up and are oriented upside down (fig. 16). Isolated tabular (fig. 17) genera also occur in the subfacies, but are generally not in growth position.

Algae present are dominantly blue-green varieties and usually encrust *Amphipora* coenostea (fig. 13). A few occurrences of possible *Vermiporella*(?) were observed in the Ferguson Mountain section (fig. 18).

Fossils observed in outcrop include low-spired gastropods and rugose corals. Thin sections reveal fragments of brachiopods, ostracodes, and rare crinoid ossicles. Prismatic-, spinose-, and transitional-wall-type calcispheres are also present in the subfacies (figs. 19, 20).

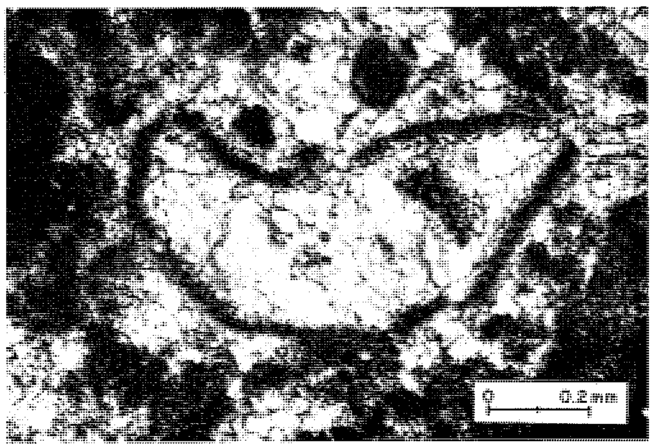

FIGURE 18.—Vermiporella, *unit 5, Ferguson Mountain section.*

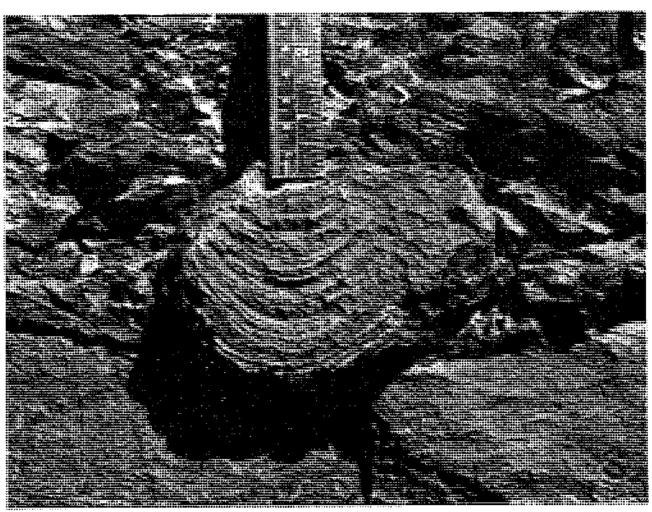

FIGURE 16.—*Upside-down stromatoporoid biscuit, unit 13, Ferguson Mountain section.*

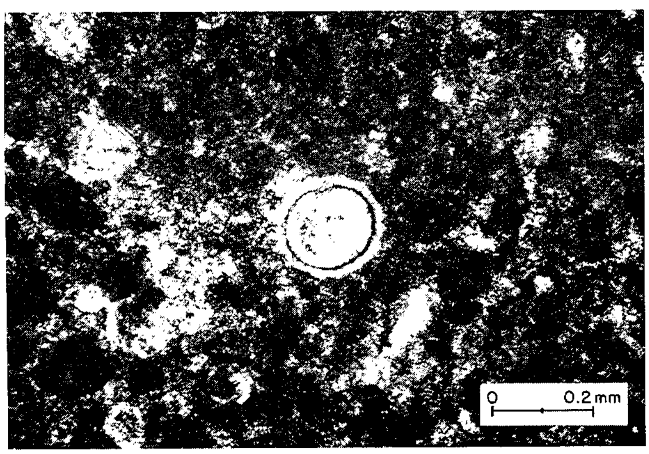

FIGURE 19.—*Prismatic-wall-type calcisphere, unit 10, Felt Wash section.*

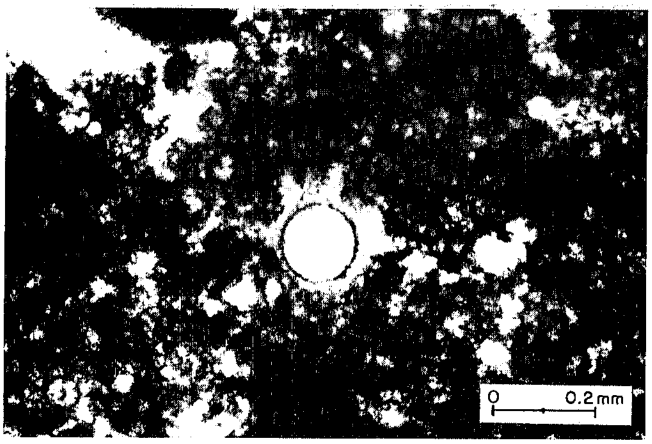

FIGURE 20.—*Spinose-wall-type calcisphere, unit 10, Felt Wash section.*

Peloidal Wackestone and Mudstone Subfacies

Rocks of the peloidal wackestone and mudstone subfacies that make up 15%–25% of lithofacies C in the Sugar Loaf Peak, White Horse Pass, and Dead Cedar Spring sections were not observed in the Ferguson Mountain or Felt Wash sections. These rocks form both dark gray ledges and slopes.

Recrystallization of micrite to microspar obscures both wackestone and mudstone fabrics of the subfacies. Dark, ferruginous, idiotopic textured dolomite may be found in irregular patches along with small amounts of silt-size quartz. Peloids (0.7 mm) which have a fine "fish-egg" appearance are diagnostic and may have algal origin. "Fuzzy" pellets (0.05 mm) are rare in the subfacies.

Of minor importance in the subfacies are fossils. Microscopic fossils observed in thin section float in a micrite matrix and include ostracodes, prismatic-wall-type calcispheres, and isolated fragments of *Amphipora* coenostea. Megascopic fossils were not observed in outcrop.

Fenestrallike structures are common in mudstone textures of the subfacies (fig. 21). Many of the vugs are geopetal, containing fine internal sediment or hypidiotopic textured dolomite. Iron-stained microstylolites of various geometry, including types 2, 4, 5, and 6 of Park and Schott (1968), are found in most of the thin sections (fig. 3).

Heterogeneous and Homogeneous Dolomites

Heterogeneous and homogeneous dolomites comprise from 4%–35% of lithofacies C, and have formed recesses, reentrants, or slope-forming units. These olive to light medium gray rocks are similar, petrologically, to those of lithofacies B.

Heterogeneous dolomites are cloudy or dark, fine to coarse crystalline, and usually exhibit a xenotopic texture. Coarser fractions of euhedral dolomite mostly replace *Amphipora* or, more rarely, fragments of crinoid columnals. Peloid ghosts of unidentifiable allochems may also be observed in some thin sections. Poorly sorted quartz (0.05–0.6 mm) is noted in the Dead Cedar Spring and Ferguson Mountain sections.

Iron-stained microstylolites (type 2) wander throughout many of these dolomites. In units 9 and 10 of the Ferguson Mountain section these "wandering" stylolites surround fragments of replaced *Amphipora* and are stained with dead oil. Algal(?) laminae ghosts also occur in part of unit 9.

Homogeneous dolomites are medium to coarse crystalline, clear or slightly cloudy, with xenotopic to hypidiotopic fabrics. The xenotopic texture of these rocks appears to be a mature stage of dolomitization which has precluded any evidence of fossils or sedimentary structures.

LITHOFACIES D

Prominent limestone cliffs of upper units measured in the Guilmette Formation near White Horse Pass are underlain by the heterogeneous dolomites of lithofacies D. These rocks make up 6%–12% of the Sugar Loaf Peak, White Horse Pass, and Dead Cedar Spring sections, but are either covered or not present in the other measured sections.

Lithofacies D consists of alternating medium light gray and dark gray layers of dolomite. They are in essence the same kinds of rocks as those in lithofacies B. However, no megascopic fossils besides *Amphipora* were observed.

LITHOFACIES E

Medium gray, very thick bedded to massive limestones of lithofacies E form the prominent 20–40-m cliffs in the Guilmette Formation near White Horse Pass and are the carbonate bodies that first attracted the author to the area (fig. 22). Unlike lower lithofacies these rocks are composed mainly of packstones with lesser amounts of grainstone and wackestone. Lithofacies E comprises only 9% of

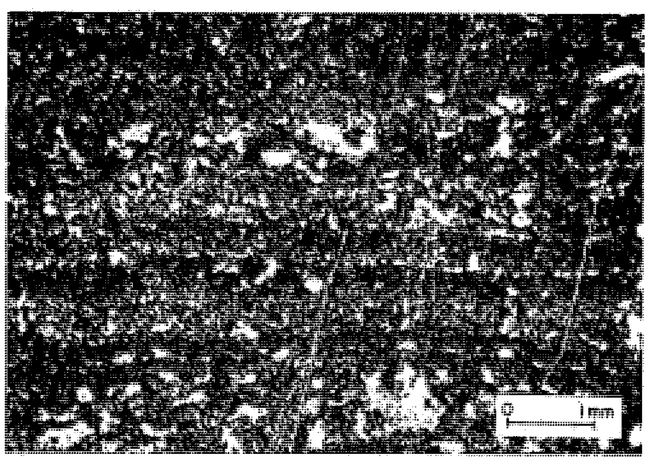

FIGURE 21.—*Fenestral fabric, unit 11, Sugar Loaf Peak section.*

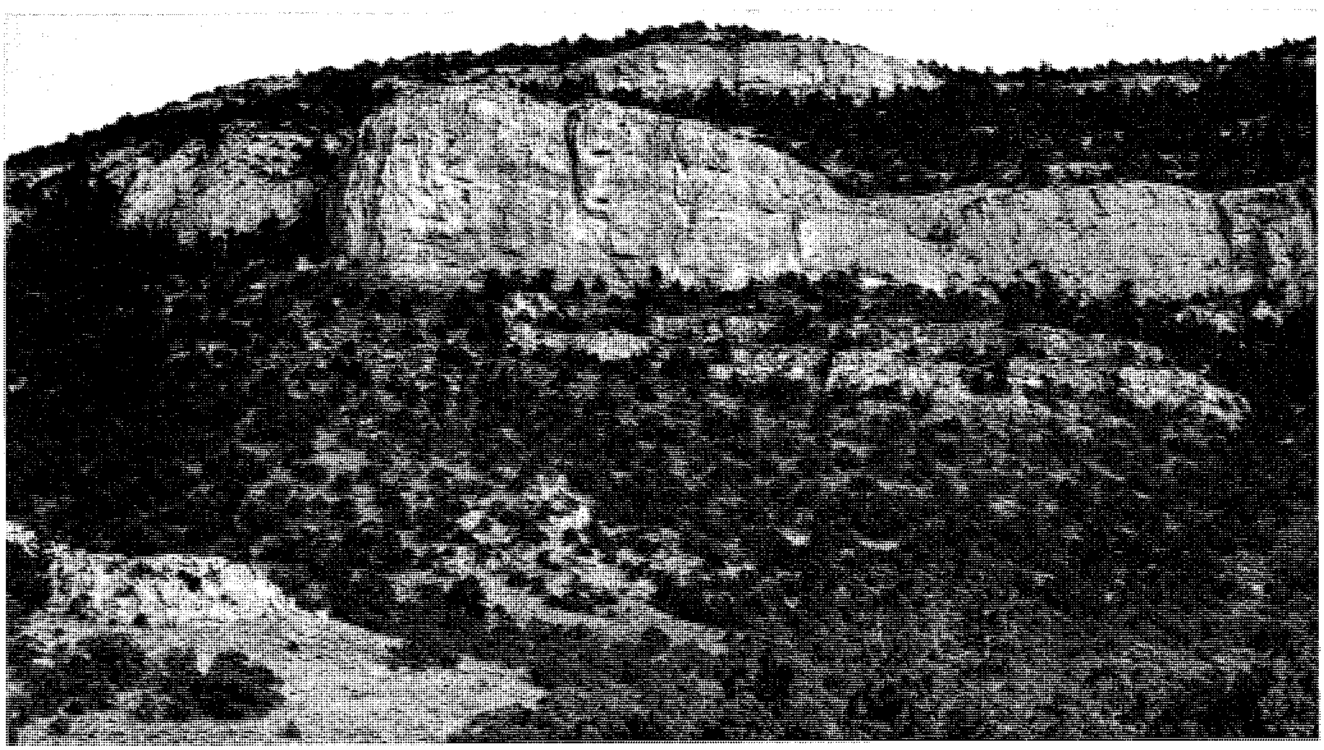

FIGURE 22.—*Prominent exposure of lithofacies E, Sugar Loaf Peak section, view to the southeast.*

the Felt Wash section but ranges up to nearly 40% for the Sugar Loaf Peak and White Horse Pass sections. Petrographically, three subfacies are defined: a pelletal grainstone and packstone subfacies, a skeletal pelletal packstone and wackestone subfacies, and a pelletal packstone and wackestone subfacies.

Pelletal Grainstone and Packstone Subfacies

Rocks that make up the pelletal grainstone and packstone subfacies comprise 100% of lithofacies E in the Ferguson Mountain section. This subfacies was not observed in any of the other sections and is placed in lithofacies E on the basis of *Stringocephalus* occurrence, perhaps representing a major facies change.

The subfacies is composed exclusively of fecal pellets and well-rounded quartz grains, which may range from 0.1 to 0.9 mm but are usually well sorted. Dolomitization has obscured the pelletal fabric in lower units so that pellets appear as faint relict ghosts. Good preservation of both dark and light varieties of pellets produces a good grainstone texture that predominates in upper units of the subfacies. Quartz grains may contribute up to 30% of the rock fabric and produce grayish orange sandy stringers in outcrop. No evidence of cross-bedding was seen.

A unique 0.8-m bed of brachiopod shells occurs near the top of the subfacies (fig. 23). They are believed to be a smaller species of *Stringocephalus* than those observed in the Sugar Loaf Peak, White Horse Pass, and Dead Cedar Spring sections. Unfortunately, it is impossible to extract identifiable specimens because of the friable sandy matrix. The valves have been disarticulated and appear to be mostly oriented convex side upward. No other fossils were observed in outcrop or under the microscope.

Skeletal Pelletal Packstone and Wackestone Subfacies

Rocks that compose the skeletal pelletal packstone and wackestone subfacies generally occur toward the top of lithofacies E. They usually make up the largest proportion of lithofacies E in most of the measured sections, except the Felt Wash section where they comprise only 30%.

Packstone textures are more dominant than wackestone textures, but both rock types exhibit abundant skeletal and pelletal constituents. Pellets range from 0.05 to 0.5 mm but average approximately 0.12 mm. Usually they are recrystallized and surrounded with micrite or microspar. Dolomitization has produced pelletal ghost fabrics in the subfacies only in the White Horse Pass section.

Most diagnostic of the subfacies is the occurrence of the large brachiopod *Stringocephalus* (fig. 24). It is most abundant in the Sugar Loaf Peak and Dead Cedar Spring sections and may be found in beds up to 2 m thick. Algae are not common but include *Solenopora* (fig. 25), *Ortenella*(?), *Vermiporella*(?), and unidentifiable genera of probable blue-green algae. *Amphipora* is present in most units of the subfacies along with scattered bulbous stromatoporoids. Most of the latter resemble *Trupetostroma*(?).

Less common to the subfacies are gastropods and isolated rugose corals, as well as microscopically observed ostracodes, prismatic-wall-type calcispheres, and uniserial

FIGURE 23.—*Oriented* Stringocephalus *in grainstone, unit 17, Ferguson Mountain section.*

FIGURE 24.—Stringocephalus, *unit 25, Sugar Loaf Peak section.*

foraminifera. Endothyrid foraminifera were noted in the White Horse Pass section. Bryozoan and crinoid fragments are extremely rare.

Limonite-stained microstylolites (types 2, 5, and 6; fig. 3) weave through many of the limestone fabrics and sometimes surround *Amphipora* fragments or other skeletal grains. Burrows are not generally observed, but the abundance of pellets suggests much bioturbation has taken place. Such sediment interface destruction of bedding planes may partially account for the very thick bedded to massive nature of much of lithofacies E.

Pelletal Packstone and Wackestone Subfacies

Rocks that make up the pelletal packstone and wackestone subfacies form 70% of lithofacies E in the Felt Wash section. In the Sugar Loaf Peak and White Horse Pass sections the subfacies comprises 15%–30%.

Rock textures of the pelletal packstone and wackestone subfacies are similar to the skeletal pelletal packstone and wackestone subfacies of lithofacies E. The major difference is the noticeable absence of fossil content. *Amphipora* fragments, calcispheres, uniserial foraminifera, and ostracodes may be present but only in minor numbers. Secondly, pellets are more abundant and generally smaller (0.05–0.1 mm). Composite pellet intraclasts (up to 2 mm) are rarely observed and apparently form as a result of agglutination. Graded, turbiditelike sequences of pellets suggest that intermittent periods of higher energy occurred during deposition of the lower units of lithofacies E in the Felt Wash section.

LITHOFACIES F

Lithofacies F is found only in the Felt Wash section and crops out as the second of three prominent medium gray cliffs of the Guilmette Formation in the area (fig. 26). It is composed almost entirely of very thick bedded limestone,

FIGURE 25.—Solenopora, *unit 25, Sugar Loaf Peak section.*

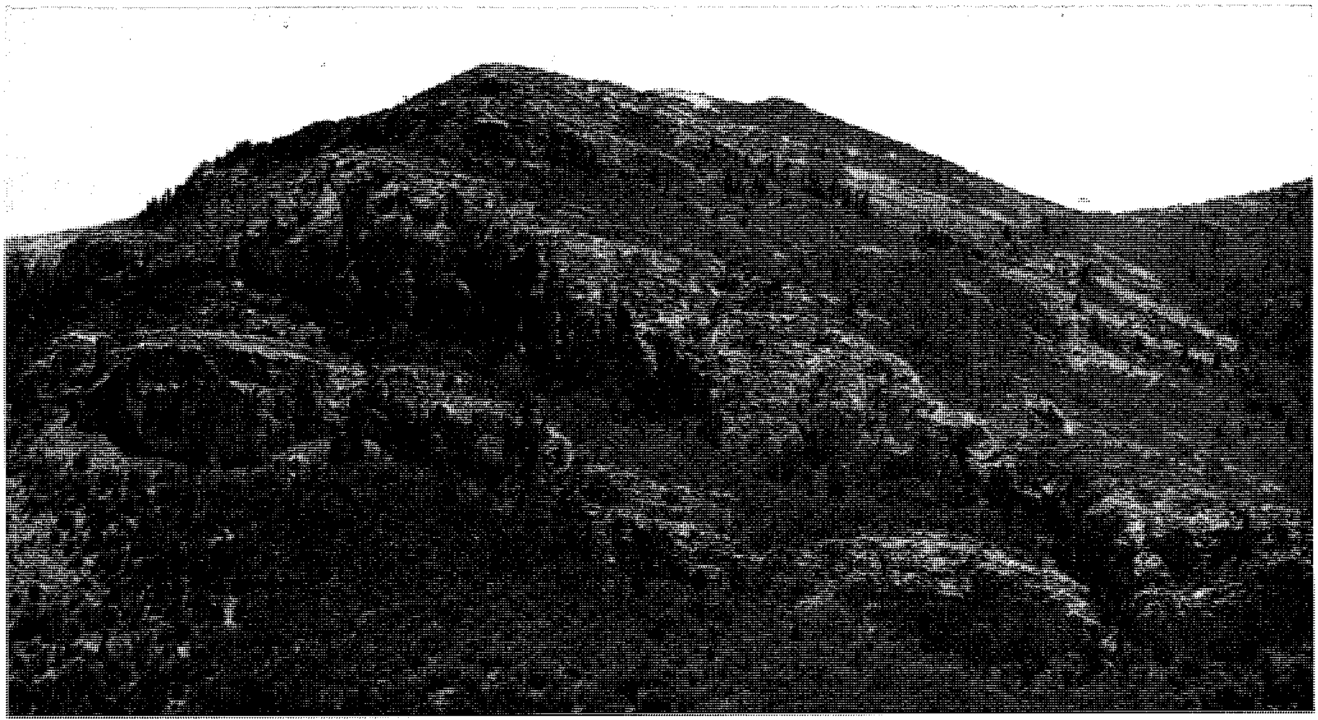

FIGURE 26.—*Felt Wash section, view to the southeast.*

predominantly packstone. Included in the lithofacies is a thin sequence of medium-bedded limestone and minor dolomite that underlies the cliff. A faulted section may occur near the top of the lithofacies but is disguised under a covered slope. Rocks that make up lithofacies F are divided into three petrologic subfacies: the peloidal-pelletal packstone subfacies, the fenestral wackestone and mudstone subfacies, and the sandy dolomite subfacies.

Peloidal-Pelletal Packstone Subfacies

The peloidal-pelletal packstone subfacies comprises approximately 60% of lithofacies F and forms most of the second prominent cliff in the Felt Wash section. Rocks of the subfacies are essentially all packstones with minor grainstones and wackestones.

They are made up of pellets and peloids in varying ratios. Pellets range from 0.05 to 0.2 mm in diameter but peloids may reach 2–3 mm. Composite pellet intraclasts were observed up to 10 mm in diameter. Some of the larger oblong peloids may be fecal. Other peloids appear to have algal genesis. Recrystallization has obscured many of the rocks of the subfacies with microspar overprints. Differentiation between packstone and grainstone texture is difficult in a few thin sections where neomorphic spar has replaced micrite, giving the appearance of primary coarse calcite.

Presence of crinoid fragments and the conspicuous absence of *Amphipora* is characteristic of the subfacies (fig. 27). Prismatic-wall-type calcispheres are more abundant than any other microscopic fossils, including ostracodes, gastropods, and extremely rare brachiopod fragments. *Solenopora* intraclasts encased in micrite were occasionally observed. A unique occurrence of *Renalcis*-like foraminifera was found in the top units of the subfacies. Isolated nautiloids were the only megascopic fossils seen in the outcrop (fig. 28).

Fenestral Wackestone and Mudstone Subfacies

Dark gray rocks composing the fenestral wackestone and mudstone subfacies are found at the bottom and also near the top of lithofacies F. The subfacies comprises only 8% of lithofacies F.

Fenestral-like structures occur in both wackestone and mudstone textures. Many of the vugs are partially filled with internal sediment forming geopetal structures. Pellets (0.05–0.1 mm across) are common but blend into the micrite matrix. Microfossils that also float in this muddy matrix include ostracode clusters, spicules, and rare prismatic-wall-type calcispheres (fig. 29).

Sandy Dolomite Subfacies

Light olive gray rocks of the slightly sandy dolomite subfacies form less than 2% of lithofacies F and are concentrated as very thin bedded units near the bottom of the lithofacies.

Petrographically, these rocks are composed of dark, fine crystalline, xenotopic-textured dolomite, with minor patches of coarse hypidiotopic fabric and dolomicrite. No evidence of relict fabrics or fossils was observed. Silt-size quartz is scattered throughout the subfacies, forming approximately 5–10% of the matrix.

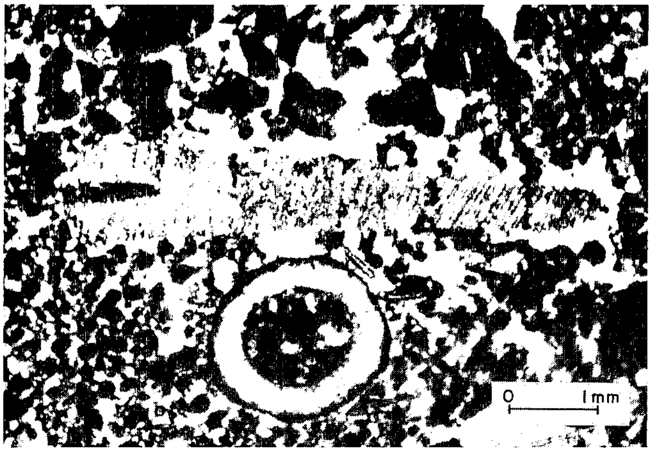

FIGURE 27.—*Crinoid columnal, unit 19, Felt Wash section.*

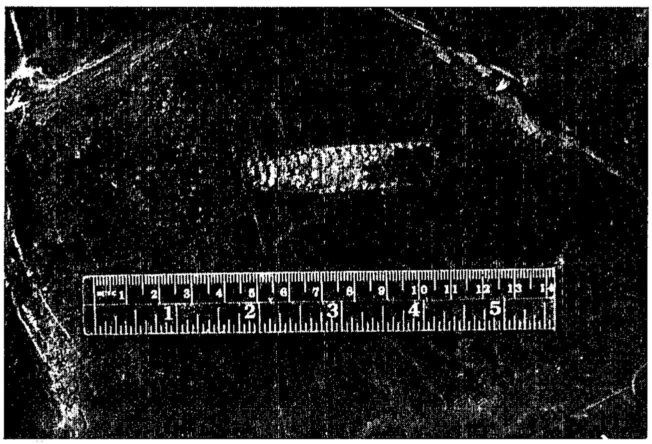
FIGURE 28.—*Nautiloid, unit 19, Felt Wash section.*

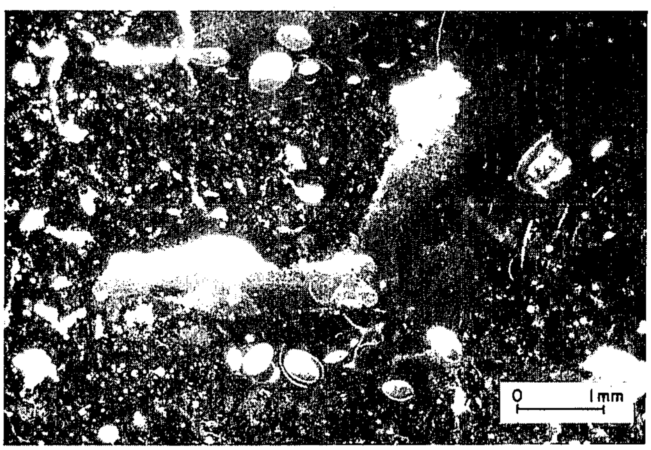

FIGURE 29.—*Ostracode clusters, unit 21, Felt Wash section.*

LITHOFACIES G

Lithofacies G comprises approximately 10% of the Felt Wash section but was not observed in any of the other sections. These medium- to thick-bedded dark gray limestones form the upper two-thirds of the uppermost prominent cliff measured in the section.

The lithofacies is characterized by mudstone texture that may border on wackestone with increasing fossil and/or pellet content. Petrographically, lithofacies G is similar to the fenestral wackestone and mudstone subfacies of lithofacies F but exhibits less fenestral fabric. There is also a greater abundance of spicules observed in lithofacies G as well as a greater range in pellet size (0.05–0.3 mm).

PALEONTOLOGY

Fossils are not common in measured sections of the Guilmette Formation in the study area and, where found, are generally poorly preserved. Those that are identifiable generally represent a shallow, restricted to open-marine assemblage.

The ammonoid *Manticoceras,* worldwide indicator of the Frasnian age, was collected from unit 1 of the Felt Wash section. According to Petersen (personal communication 1982), *Manticoceras* has usually been noted in the uppermost beds of the Guilmette Formation in the Great Basin. However, nearly 190 m of the Guilmette Formation were measured above this fossiliferous horizon. Other unique fossils collected from beds associated with *Manticoceras* included the dasycladacean algae *Receptaculites.* Various spiriferid brachiopods, mostly *Atrypacea,* are also abundant in this zone.

Stringocephalus, found near the top of lithofacies E in all measured sections but the Felt Wash section, is considered by Boucot and others (1966) to be upper Givetian in age (fig. 24). Cooper (1943) correlated Devonian formations on the basis of *Stringocephalus* that occur near the base of the Guilmette Formation in the Great Basin. However, in the sections of the Guilmette Formation measured in the study area, it appears to be found in middle to upper beds.

The branching stromatoporoid, *Amphipora,* is by far the most common fossil encountered (fig. 30). It is found in lithofacies B, C, D, and E but is most abundant in lithofacies C. Many of the coenostea appear to be overgrown by algae, but Stearn (1963) found that different species may grow upon each other, producing one coenosteum between them. In many units its abundance may impart a "spaghetti"-like appearance to the rock.

Other stromatoporoids were placed in three categories for field description: massive, bulbous, and tabular after the usage of Hoggan (1975). Massive refers to generally cabbage-size shapes with flat bases; bulbous refers to any size with a light bulb to sometimes dumbbell-like form; tabular is used to describe stromatoporoids which have much greater lateral than vertical extent, irrespective of thickness. All these varieties are found in the study area, but massive and bulbous varieties are the most common (figs. 15, 16). They are found only in lithofacies C and D, where they are minor elements. In situ occurrences are found in both of these lithofacies, as well as in beds containing transported specimens. Tabular stromatoporoids were noted only in unit 11 of the Ferguson Mountain section (fig. 17). Thin sections of massive and bulbous forms reveal presence of these possible genera: *Trupetostroma*(?), *Hammatostroma*(?), and *Actinostroma*(?) (figs. 31, 32).

Isolated rugose corals occur locally in lithofacies B, C, and E (fig. 33). The colonial coral *Billingsostrea nevadensis* was observed in lithofacies C in the Ferguson Mountain sections and below the *Manticoceras* zone of the Felt Wash section. Also, cuplike corals, possibly *Aveolites*(?) and *Thamnopora,* were found in float in the covered slope above unit 11 of the same section. *Thamnopora* was also noted in unit 3 of the Dead Cedar Spring section.

Petrographically observed fossils include ostracodes, gastropods, foraminifera, crinoids, and calcispheres. Both low- and high-spired gastropods were found in isolated occurrences in lithofacies C, E, F, and G. Uniserial foraminifera are present in varying degrees of abundance in lithofacies E but are noticeably scarce in lithofacies C (figs. 34, 35). Endothyrids were found only in unit 25 of the White Horse Pass section and unit 1 of the Felt Wash section (fig. 36). Possible encrusting foraminifera resembling the green algae *Renalcis* were observed only in the upper beds of lithofacies F. Except for lithofacies F, crinoids occur rarely. Calcispheres are dominated by the prismatic cell wall types, while spinose- or transitional-cell-wall types were found occasionally in some thin sections (figs. 19, 20). These probable algal spores (Wray 1967) are ubiquitous in all hospitable facies, excepting lithofacies A, B, and D.

DIAGENESIS

Diagenetic processes have obscured original rock fabrics of most of the lithofacies and, in some cases, have totally obliterated them. These processes are divided into those of recrystallization and those related to dolomitization. Though the results of dolomitization may be observed in the field, most diagenetic overprints affecting rocks in the study area are best seen in thin section.

RECRYSTALLIZATION

Pellets are the most abundant allochem subjected to recrystallization, which results in a "fuzzy" appearance as

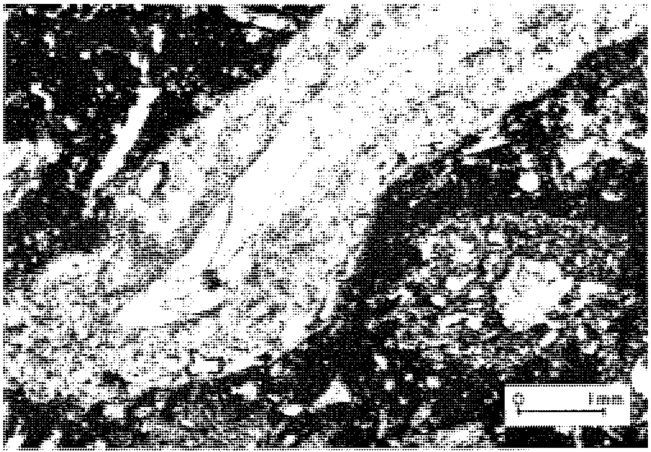

FIGURE 30.—*Longitudinal and transverse sections of* Amphipora, *unit 12, Sugar Loaf Peak section.*

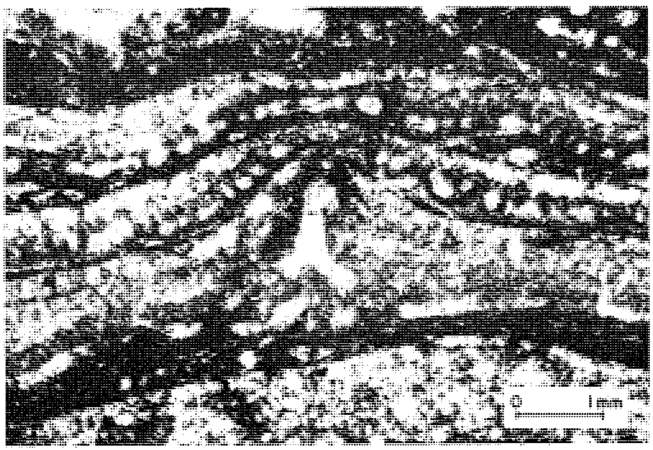

FIGURE 31.—Trupetostroma*(?), unit 6, Dead Cedar Spring section.*

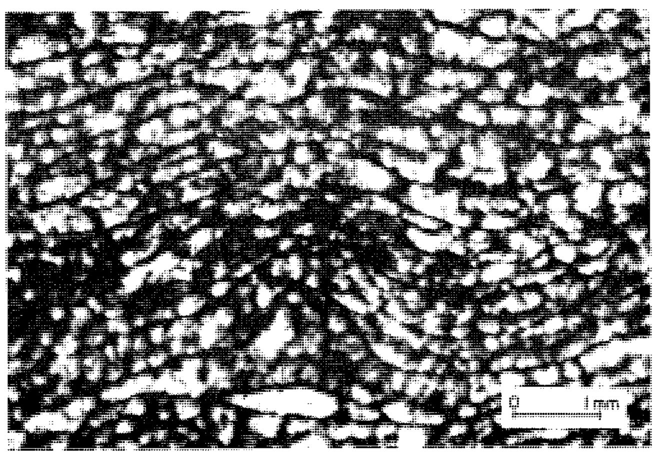

FIGURE 32.—Hammatostroma*(?), unit 8, Dead Cedar Spring section.*

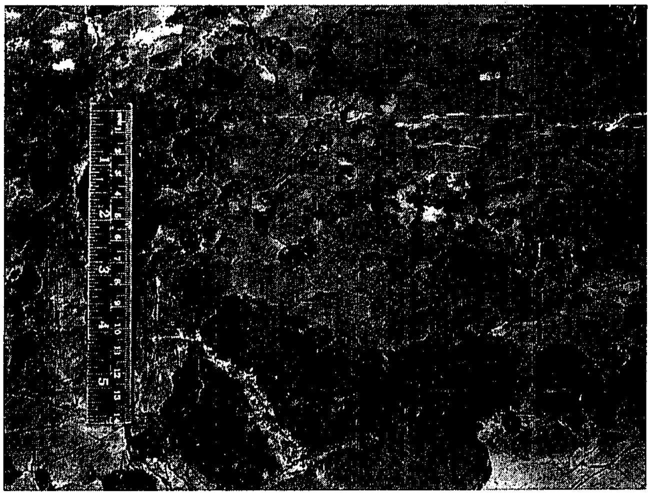

FIGURE 33.—*Rugose corals, unit 17, White Horse Pass section.*

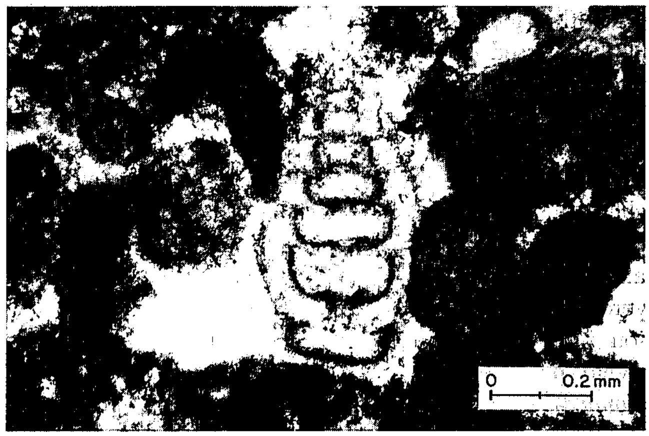

FIGURE 35.—*Nodosinelled, unit 10, Felt Wash section.*

their micritic texture is converted to microspar. Skeletal grains, such as gastropods, ostracodes, or calcispheres, are replaced with a coarser spar.

Brachiopod shell fragments commonly show original fibrous structures. However, *Stringocephalus* invariably is replaced with a blocky spar that has preserved little original skeletal texture.

Ascertaining recrystallization of matrix is difficult in many cases but critical to identification of original rock texture. Many of the packstones of lithofacies C, E, and F have been subjected to an exchange of pseudospar for micrite. This is evidenced in thin section by the dirty nature of the uniformly crystalline spar and fuzzy contacts between allochems and matrix. This neomorphic process may mimic normal pore-fill calcite, causing a rock to be classified as a grainstone when it should be called a packstone (Folk 1965).

DOLOMITIZATION

Dolomite composes at least 50% of each measured section. Results of primary dolomitization may be observed in rocks of the study area, but those of secondary dolomite are dominant.

Dolomicrites are considered to have been produced penecontemporaneously, as evidenced by preservation of microcrystalline textures and laminate form. These rocks comprise minimal amounts of lithofacies B and C. Algal mat structures, which may be partially ripped up, are also present in the upper beds of lithofacies A. They are interpreted as having formed under restricted supratidal or tidal conditions.

Lithofacies B and C are dominated by secondary dolomitization overprints. Lack of associated evaporite minerals or solution features and no evidence for subaerial exposure preclude sabkha diagenesis. Selective dolomitization of certain beds and not others in lithofacies C may be related to control by the sediment-water inter-

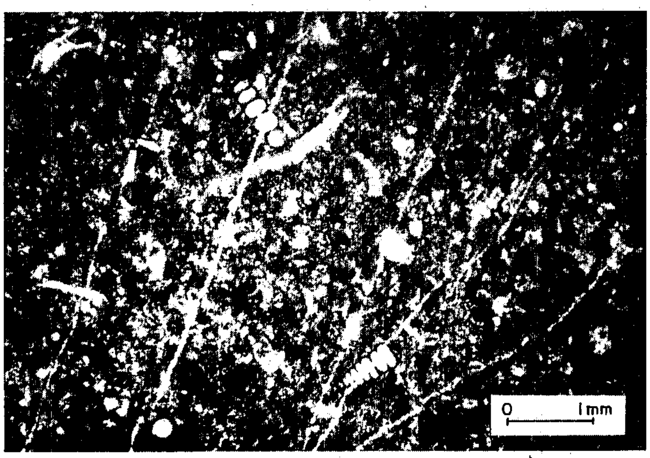

FIGURE 34.—*Uniserial foraminifera, unit 25, White Horse Pass section.*

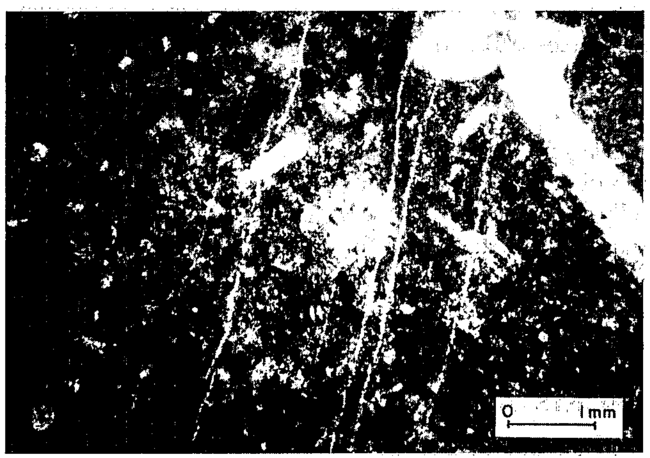

FIGURE 36.—*Endothyrid, unit 25, White Horse Pass section.*

face during, or shortly after, deposition. Beales (1965) suggested this as a viable conclusion if limestone alternated with dolomite over a thick vertical section. However, deep-burial diagenesis of selected limestone units may also be attributed to dolomitizing Mg-rich connate fluids traveling along preferred conduits, as proposed by Mattes and Mountjoy (1980). Both models could have produced the coarse crystalline, hypidiotopic to xenotopic dolomite generally found in lithofacies B and C. This dolomitization took place after lithification, as evidenced by relict peloid and skeletal ghosts seen in some thin sections. Many of these dolomites also contain stylolites, suggesting dolomitization occurred before or during stylolitization. Stylolites may form at different stages during diagenesis but are generally considered to be a late-stage feature whose amplitude represents the minimum amount of material carried away in solution.

Fine crystalline, dark to cloudy patches of idiotopic textured dolomite are found predominantly in wackestones in contrast to absence in packstones of lithofacies C (fig. 14). Inden and Koehn (1979) suggest that such a pattern may be a result of an early semilithified stage forming in packstone fabrics that are able to resist dolomitization. Wackestones, on the other hand, were less lithified at this stage, in their model, and contained more magnesium in high-magnesium calcite, mixed layer illites, and chlorite, as well as fine grains of detrital dolomite which may have acted as seed crystals. A whole spectrum of dolomitization exists between these idiotopic patches and the xenotopic fabrics previously discussed, suggesting that small dolorhomb patches are an incipient stage of growth compared with more mature sucrosic development (figs. 10, 14).

DEPOSITIONAL ENVIRONMENTS OF CARBONATE LITHOFACIES

Deposited in a variety of shallow marine settings, lithofacies A through G represent sedimentation on a carbonate platform. Lithofacies B, C, and D were formed in broad, somewhat restricted regions of the platform, such as lagoons, that produced mostly wackestones and mudstones. Thick carbonate banks, represented by lithofacies E and F, were built on these platform sediments in response to more open-marine conditions, perhaps as a result of increased subsidence. Slightly higher energy conditions are reflected in the packstone and grainstone textures of these rocks, as well as in the increased fauna observed in the bank deposits compared to the underlying platform sediments.

LITHOFACIES A

The clastic component in a dominantly carbonate sequence makes lithofacies A unique in comparison with the other lithofacies. The well-rounded, bimodally sorted quartz that characterizes the lithofacies could have come from three possible sources: the Antler orogenic belt to the northwest, the Stansbury Uplift to the northeast, or sediments derived from the craton to the east.

Sandberg and others (1982) imply that the Antler orogenic highland was not a positive feature and thus not a major contributor of sediment until earliest Mississippian time. Bissell (personal communication 1983) suggests more flexibility in dating the event and does not preclude the possibility of clastic sediment being swept for some distance from the Antler highland during Late Devonian time. Though the absence of cross-bedding prevents any determination of source direction, bimodality implies intermittent energy fluctuations, likely related to tidal currents.

The dolomicrite matrix, which is sometimes algal(?) laminated, is suggestive of shallow, restricted, supratidal conditions. Terrigenous pulses from any of the three sources could have produced the contorted, in some cases partially ripped up, algal mat caused by invasion of clastic sediment.

LITHOFACIES B

Dolomites of lithofacies B signify the return to deposition of carbonate rocks. Dark layers of alternating light and dark "spaghetti" dolomites are most likely caused by the abundance of *Amphipora* disseminated throughout their matrix compared to the light layers, which largely lack *Amphipora*. Unfortunately, the almost complete obliteration of original fabric clouds interpretation. Before dolomitization, these rocks could have been lagoonal-type mudstones and *Amphipora* wackestones, as the abundance of *Amphipora* would suggest. Additionally, *Amphipora* coenostea are oriented in similar fashion to the mudstones and wackestones of lithofacies C.

Niebuhr (1980) described an alternating dolomite and a "spaghetti" dolomite lithofacies, similar to the alternating light and dark "spaghetti" dolomite subfacies of lithofacies B. However, he found the presence, in his study area, of interlocking evaporite minerals within the dolomite fabric. No evidence of evaporite minerals or dessication features were observed in rocks composing the subfacies in this study area.

The homogeneous dolomite subfacies is similarly diagenetically disguised. However, isolated, seemingly in situ, occurrences of rugose corals and bulbous stromatoporoids found in the White Horse Pass section reflect a higher-energy, possibly intertidal influence.

Rocks of the heterogeneous subfacies contain both abundant replaced *Amphipora* and small, bulbous stromatoporoids(?) (fig. 11) that seemingly represent an environment intermediate between the other two subfacies. This restricted to intertidal environment would produce the range of salinities and conditions necessary to produce both types of stromatoporoids.

LITHOFACIES C

Pelletal Packstone/Grainstone Subfacies

The pelletal packstone/grainstone subfacies reflects the highest energy conditions of lithofacies C (fig. 12). Unfortunately, beds above and below that would offer better clues to its origin are covered. It appears, however, that strata of this subfacies may be small pelletal shoals that formed in response to local higher-energy conditions. Noticeable lack of fauna suggests water turbulence was not great, at least not enough to promote growth of stromatoporoids or other sessile wave resistant organisms. An alternative notion is that the shifting substrate of these pelletal shoals was too loose for organisms to occupy.

Amphipora *Packstone and Wackestone Subfacies*

Amphipora, though ubiquitous throughout most lithofacies except F and G, is most abundant in the muddier limestones of lithofacies C. This abundance is characteristic of the *Amphipora* packstone and wackestone subfacies and is indicative of more restricted, higher-than-normal saline conditions. Lack of open-marine shelly fauna also suggests poor circulation, along with other inhospitable conditions. Quiet, muddy, lagoonal-type conditions of deposition are evidenced by the horizontal, irregular attitudes of *Amphipora* coenostea surrounded by dark micrite. Furthermore, *Amphipora* coenostea are commonly encrusted with blue-green(?) algae, which is suggestive of very shallow water, perhaps less than 2 m deep. Amphiporids have been equated with quiet, back-reef, lagoonal deposition by most workers since the first major paleoecological studies of Devonian reef tracts in the 1950s.

Pelletal Packstone and Wackestone Subfacies

Most pellets of the pelletal packstone and wackestone subfacies are likely of fecal origin. Abundance of fecal pellets suggests extensive bioturbation. Depositionally, these rocks could be found in a wide range of environments. Indeed, pelletal fabric, to a greater or lesser degree, is found in almost all limestones of the study area. Lack of fauna may point to a turbid setting but one that allowed sediment-eating organisms to survive.

Skeletal Packstone and Wackestone Subfacies

Besides *Amphipora,* bulbous and tabular stromatoporoids characterize the skeletal packstone and wackestone subfacies (figs. 15, 17). These in situ occurrences represent the nearest approach to biohermal growth that could have produced wave-resistant carbonate bodies. However, they form units usually less than 50 cm thick and are thus a minor feature of lithofacies C. The presence of rugose corals, though isolated, indicates better circulation, while brachiopods and gastropods suggest more open-marine conditions than that indicated by *Amphipora* alone.

Isolated occurrences of algae, such as *Vermiporella,* attracted by a higher-energy regime, suggest still relatively inhospitable turbid growing conditions, as they are found only rarely.

Calcispheres were found by Stanton (1963) to be most abundant in pelletal lime muds in association with *Amphipora* in back-reef facies of the Redwater and South Sturgeon Lake Reefs, Alberta.

Peloidal Wackestone and Mudstone Subfacies

Wackestones of the peloidal wackestone and mudstone subfacies contain roughly 15% peloids. Many of the peloids have a "fish-egg" appearance and may be algal intraclasts, perhaps indicative of disrupted stromatolite beds. Most, however, have indeterminate internal structure.

Mudstones, as well as wackestones of the subfacies, that exhibit fenestral fabric, may have resulted from algal activity. Vuggy bird's-eye texture viewed in thin section, complete with geopetal structures, does not often appear the same in hand sample. Thus, this texture may also be related to inorganic diagenetic process.

Heterogeneous and Homogeneous Dolomites

Secondary heterogeneous and homogeneous dolomites yield little information concerning their original nature. Allochem ghosts that are recognizable commonly are *Amphipora,* implying a similar origin as that of lithofacies B.

LITHOFACIES D

Rocks of lithofacies D are essentially the same as lithofacies B and thus likely had similar origins and evolution. They do, however, mark a transition zone from dominantly lower-energy wackestone and mudstone to higher-energy packstone and grainstone.

LITHOFACIES E

Pelletal Grainstone and Packstone Subfacies

This unique subfacies, found only in the Ferguson Mountain section, represents a local, inner-platform, sandy, pelletal shoal sequence. The well-rounded, well-sorted quartz grains and pellets suggest some of the highest energy conditions in the study area, even though cross-bedding is not evident.

Source for the well-rounded quartz could be any of those described in lithofacies A, whereas the pellets were likely locally derived clastic carbonate grains.

A variety of *Stringocephalus,* near the top of the subfacies, shows evidence of mechanical orientation in response to the shoaling-upward conditions (fig. 23).

Skeletal Pelletal Packstone and Wackestone Subfacies

Thick-bedded to massive limestones that form skeletal pelletal packstone and wackestone subfacies are the rocks that form the major carbonate buildups of the study area. They are best described as carbonate bank deposits consisting of open (nonrigid) skeletal communities that form locally extensive biostromal deposits.

Abundant *Stringocephalus* beds suggest open-marine conditions. This is complemented by the presence of minor amounts of solenoporacean, dasycladacean, and codiacean algae indicative of warm, shallow-marine origin. Bulbous stromatoporoids occur more frequently in lithofacies E than in lithofacies C and reflect an overall higher-energy environment. This energy shift is also reflected in a comparison of rock textures which shows that packstones are more dominant in lithofacies E than in C.

Pelletal Packstone and Wackestone Subfacies

Although it appears to be slightly less bioturbated, the pelletal packstone and wackestone subfacies of lithofacies E generally represents the same environments as the pelletal packstone and wackestone subfacies of lithofacies C.

LITHOFACIES F

Peloidal-Pelletal Packstone Subfacies

Lithofacies F is a carbonate banklike deposit similar to lithofacies E, though not characterized by an abundance of nonrigid skeletal remains. Crinoids are present in the peloidal-pelletal packstone subfacies, which suggests a slightly more open marine environment than that of lithofacies E. This is further supported by the absence of *Amphipora.* Also noticeably absent are uniserial foraminifera, which seemed to have been replaced with a "*Renalcis*-like" form. Calcispheres are more abundant in lithofacies F than in any other lithofacies but are not diagnostic of a particular environment.

Higher-energy conditions consistent with a more open-marine regime are suggested by the occasional solenoporacean algal intraclast. Many of the peloids of the subfacies, in fact, may be algal related. Composite peloid-pellet intraclasts, that may reach 10 mm in diameter, offer evidence of the competence of the higher-energy medium.

Fenestral Wackestone and Mudstone Subfacies

Rocks of the fenestral wackestone and mudstone subfacies formed under quiet, restricted conditions. This is evidenced by the lack of a megafauna and a generally bioturbated fabric. Microfossils consist mainly of ostracodes. Limestones of the lower portion of lithofacies F are similar to fenestral wackestones which partially comprise the peloidal wackestone and mudstone subfacies of lithofacies C.

Sandy Dolomite Subfacies

The sandy dolomite subfacies, represented by two thin units near the base of lithofacies F, records the deposition of terrigenous sediment from a distant clastic source. Silt-size quartz forms no more than 10% of these rocks and seems to suggest a milder invasion onto the carbonate platform than that documented by lithofacies A.

LITHOFACIES G

Dark gray rocks of lithofacies G, which forms the third prominent cliff seen in the Felt Wash section (fig. 26), exhibit fenestral fabric like that observed in the fenestral wackestone and mudstone subfacies of lithofacies F but are interpreted to have been deposited in a deeper platform-edge environment. Quiet, muddy conditions are suggested by a greater occurrence of observed spicules that float in a micrite matrix.

CONCLUSIONS

Major carbonate buildups of the White Horse Pass area, lithofacies E and F, are best described as very thick bedded to massive carbonate bank deposits. These carbonate banks have local, lateral extent and poorly developed nonrigid skeletal communities showing subtle lateral faunal changes. Lithofacies E and F represent these rocks that formed under prevalent open-marine conditions, likely due to a major period of platform subsidence (III., fig. 37). Lithofacies B, C, D, and G are interpreted as shallow, muddy platform carbonates formed generally under quiet, restricted conditions with brief periods of subsidence that produced areas of slightly more open marine conditions (II., fig. 37). Lithofacies A represents a clastic influx onto the platform that interrupted a dominantly carbonate sequence (I., fig. 37). Figure 37 summarizes these depositional relationships.

The grainstone shoals of lithofacies E and sandstones of lithofacies A have the best potential as reservoirs in the study area. The timing of migration of hydrocarbons, versus cementation and subsequent diagenesis of these lithofacies, is critical. Most of the rocks encountered in the study area, however, are nonporous. Diagenetic over-

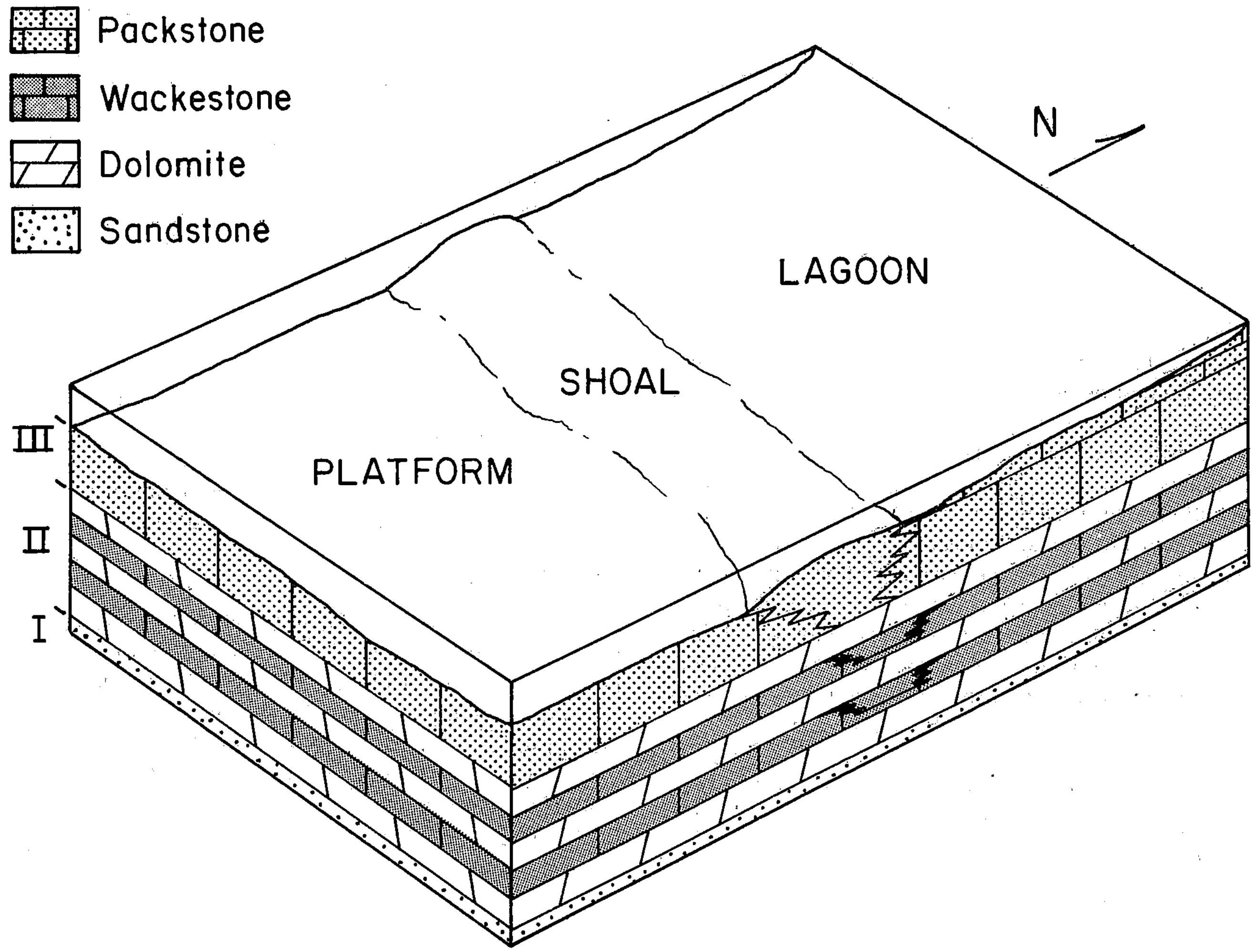

FIGURE 37.—*Diagram showing relationship of depositional environments and generalized vertical sequence of rocks; I.—Sandstones of lithofacies A, II.—Medium-bedded, muddy platform carbonates of lithofacies B, C, D, and G; III.—Very thick bedded carbonate bank and pelletal shoal deposits of lithofacies E and F.*

prints have destroyed most, if not all, primary porosity. Petrographic analysis reveals minimal porosity in some of the "spaghetti" dolomites that resulted from leaching of *Amphipora*. A petroliferous odor is given off when fresh surfaces of these rocks are broken.

Rocks of the Sugar Loaf Peak, White Horse Pass, and Dead Cedar Spring sections are assigned a Givetian age on the basis of the occurrence of *Stringocephalus*. Those of the Felt Wash section are considered Frasnian in age because of the occurrence of *Manticoceras*.

Correlation of lithofacies based on the marker dolomite sandstone used in the field is valid for the Sugar Loaf Peak, White Horse Pass, and Dead Cedar Spring sections. Covered slopes of the Ferguson Mountain section make correlation efforts difficult, but the occurrence of *Stringocephalus* is evidence for its validity. The Felt Wash section is most questionable. Faulting in lower units may have repeated section, but such repetition is not evident in the results of the study. Paleontological evidence suggests that these rocks be placed stratigraphically above the remaining sections.

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