DEPOSITION AND DIAGENESIS OF THE UPPER MOUNT HEAD FORMATION (LOOMIS, MARSTON AND CARNARVON MEMBERS), PLATEAU MOUNTAIN, ALBERTA

A Thesis

Submitted to

The Faculty of Graduate Studies

The University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Scott Raymond Smith

February, 1978

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ABSTRACT

The Loomis, Marston and Carnarvon Members of the Upper Mount Head Formation were studied in detail from a stratigraphic section at Plateau Mountain, Alberta. Depositional environments and diagenetic processes, their occurrence, relative timing and origin are considered in the present study.

At Plateau Mountain, the Loomis Member represents moderate to high energy barrier complex sedimentation. The Lower Marston Member as exposed at Plateau Mountain, accumulated within a tidal flat complex whereas the Upper Marston Member was deposited within a lagoon. Lagoonal conditions persisted throughout the deposition of the Carnarvon Member. Periodically and locally, sedimentation built up to the intertidal and low supratidal zones within the shallow lagoon.

Biological alteration, micritization and burrowing, and an early dolomitization event are the earliest diagenetic processes. Micritization altered grains only within the moderate to high energy barrier complex. Burrowing occurred within the lagoonal sediments and possibly banks and sand flats of the barrier complex. Early dolomitization, facies related, affected predominantly shallow subtidal to intertidal carbonate muds.

Drusy and syntaxial rim calcite cements were

penecontemporaneously precipitated into primary interparticle, shelter, intraparticle, burrow and fenestral pores and into secondary moldic pores. These cements are considered to have been precipitated in a shallow subsurface environment. First generation blocky calcite cement of shallow or deep subsurface origin occluded most of the remaining primary and secondary porosity.

A later dolomitization event post-dates the syntaxial rim cement and pre-dates the first generation blocky cement. Silicification also occurred prior to precipitation of the first generation blocky cement and after dolomitization. Second generation blocky calcite cement has precipitated into fractures developed by thrust faulting of the Mississippian strata.

Cementation, dolomitization and silicification destroyed almost all primary and secondary porosity. Fractures associated with thrust faulting provide the best visible porosity. However, in the Lower and Upper Marston Member first generation blocky cementation and silicification have not completely destroyed primary and secondary pores. Consequently minor visible porosity is preserved.

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CHAPTER I - INTRODUCTION

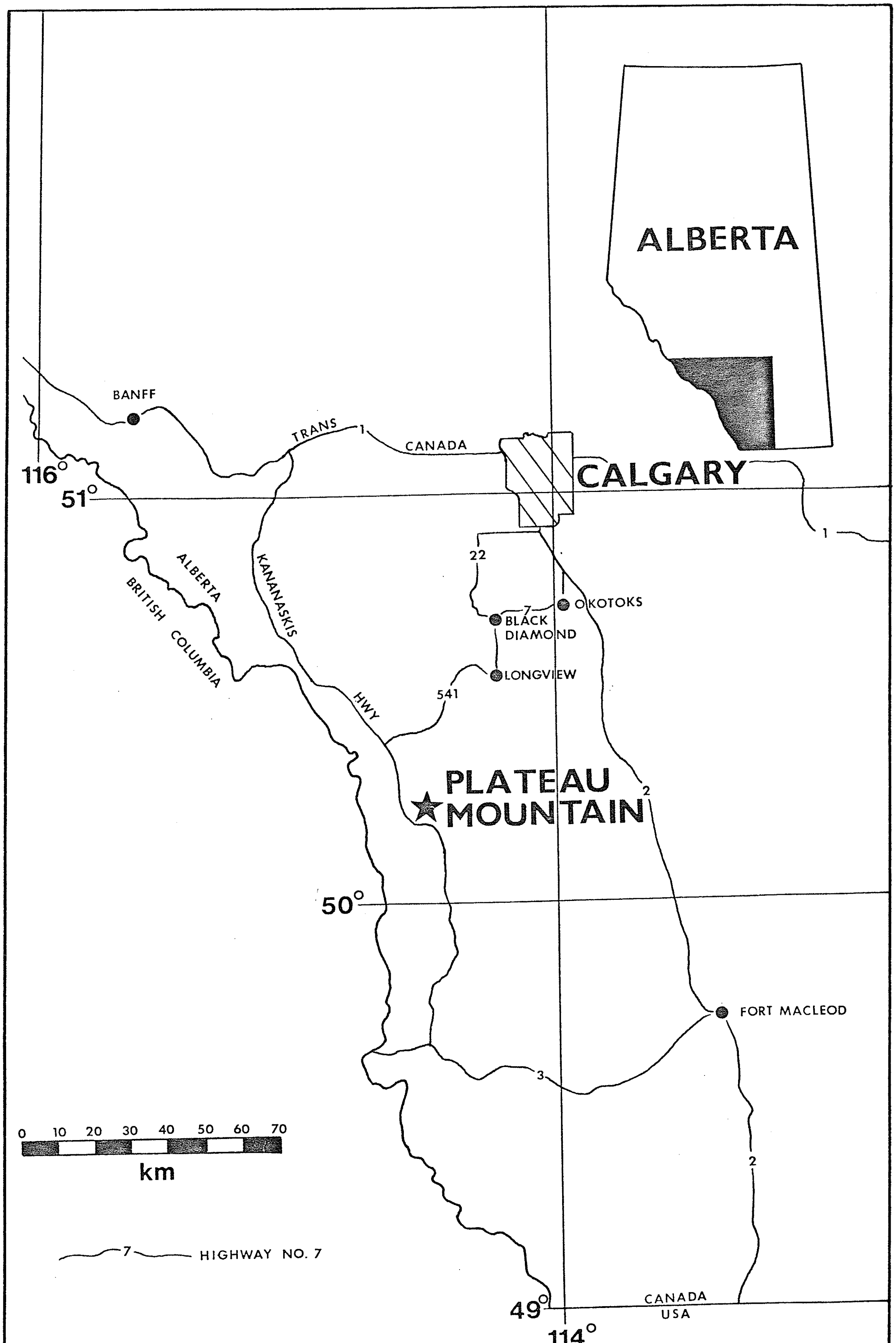
General Introduction

The Front Ranges and the Foothills of the Rocky Mountains in Alberta are of economic importance due to the gas and oil occurrences at Turner Valley, Jumping Pound, Savanna Creek, and numerous other fields. Thrust faulting has produced fault traps for mainly gas accumulations in Mississippian subsurface strata (Fox, 1959).

Insight into the Mississippian subsurface strata can be obtained from the extensive Mississippian exposures in the Front Ranges. Previous studies have dealt largely with the stratigraphy and sedimentation of the Mississippian sequence and little work has been published on diagenesis. Yet diagenetic processes have to some extent determined whether or not these rocks are favorable for hydrocarbon accumulation.

Good exposures of the Mississippian Upper Mount Head Formation are present at Plateau Mountain, Alberta. Plateau Mountain, where the Savanna Creek gas field occurs, is located approximately 85 km southwest of Calgary, Alberta (Figure 1). This thesis is a study of deposition and diagenesis of the Loomis, Marston and Carnarvon Members of the Mount Head Formation at Plateau Mountain.

Figure 1: Location Map of Plateau Mountain, Alberta


ALBERTA
BANFF
TRANS 1 CANADA
CALGARY
1
116°
51°
22
7
OKOTOKS
BLACK DIAMOND
LONGVIEW
541
KANANASKIS HWY
ALBERTA
BRITISH COLUMBIA
PLATEAU MOUNTAIN
2
50°
FORT MACLEOD
3
2
0 10 20 30 40 50 60 70
km
7 HIGHWAY NO. 7
49°
114°
CANADA
USA

Structural Setting

The Eastern Cordilleran Fold and Thrust Belt extends from Montana to the Yukon, and consists of northwesterly striking folds and thrust sheets. Cambrian, Devonian and Carboniferous carbonates have moved over relatively incompetent Triassic, Jurassic and Cretaceous clastic rocks to form the northwesterly striking, westward dipping series of subparallel fault slices that are bounded by gently dipping thrust faults in the Eastern Ranges of the southern Rocky Mountains (Wheeler, 1970).

At Plateau Mountain, the Savanna Creek gas field structure consists of at least four thrust plates of Mississippian carbonates that have folded Upper Devonian to Upper Cretaceous rocks into a doubly-plunging anticline three miles wide and at least twelve miles long (Hennessey, 1975).

Previous Work

McConnell (1887) divided the Mississippian carbonate strata into the "Lower Banff Shales" and the "Upper Banff Limestones". Kindle (1924) renamed these the Banff and Rundle Formations respectively, with the Rundle Formation being raised to Group status by Douglas (1953, 1958). In the Front Ranges, the Rundle Group consists of three

Formations: Livingstone, Mount Head and Etherington. The Mount Head Formation was divided into six Members: Wileman, Baril, Salter, Loomis, Marston and Carnarvon (Douglas, ibid).

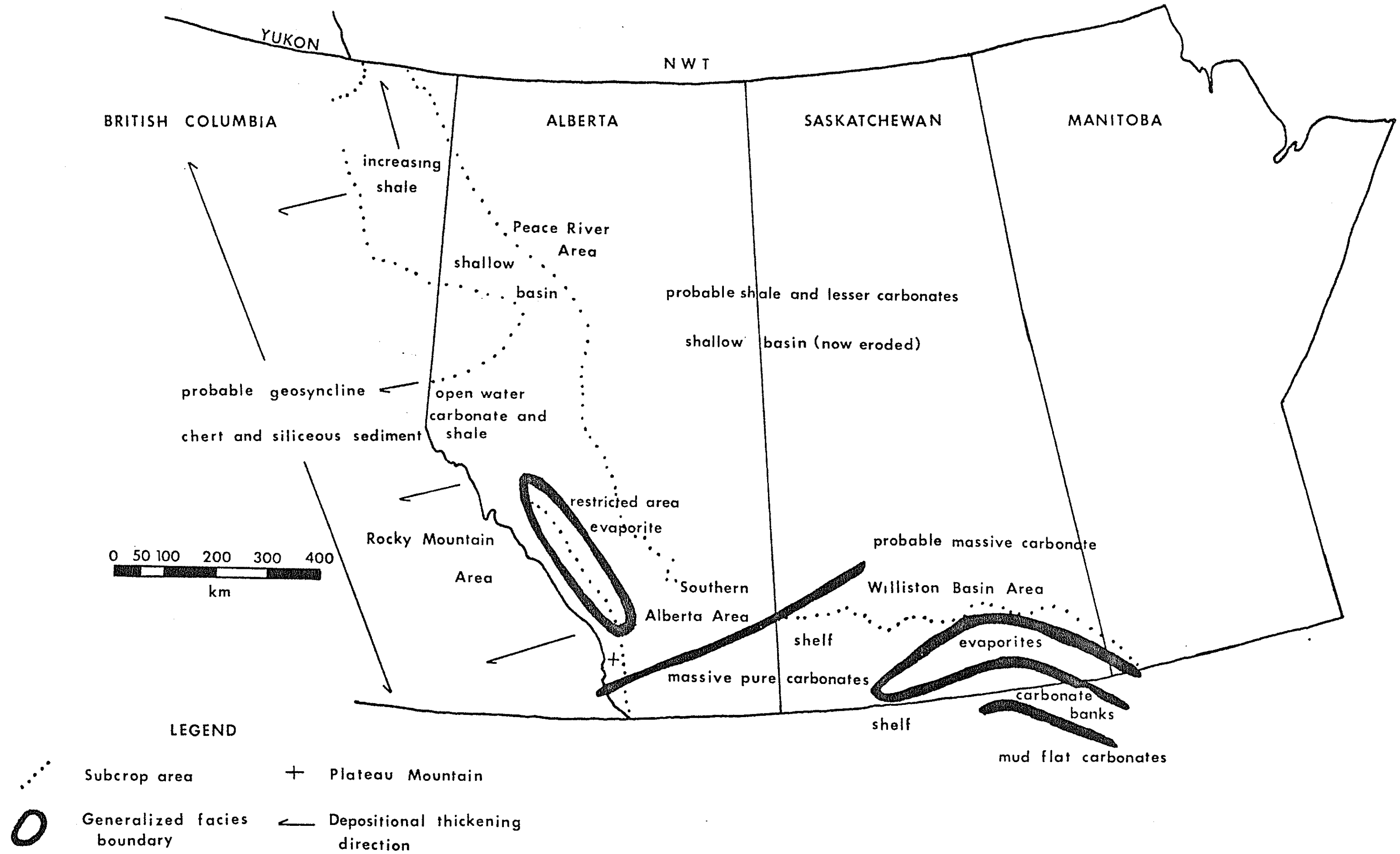
Macqueen and Bamber (1968) documented the regional stratigraphy and depositional history of the Mount Head Formation. In addition to proposing a new member, the Opal Member, they developed a Mississippian depositional model. Although early diagenesis is part of the model, it is limited and confined to dolomitization. A review of the previous stratigraphic work is contained in the paper.

The Plateau Mountain area was mapped by Norris (1958a,b). Scott (1953), Scott et al (1957), Fox (1959), and Hennessey (1975) have dealt with the Plateau Mountain structure and the Savanna Creek gas trap.

Regional Stratigraphy

During the Mississippian in Western Canada there were four major areas of sediment deposition: Peace River, southern Alberta, Rocky Mountains and Williston Basin (Figure 2). These areas appear to have been connected at that time but a major erosional event at the end of the Paleozoic separated them. Procter and Macauley (1968) suggested this connection on the basis of the following observations: 1) westward thickening of the strata into the Cordilleran geosyncline, 2) a south to north increase

Figure 2: Generalized Depositional Environments during Middle and Upper Mississippian (Osage and Meramec) in Western Canada (modified after McGrossan and Glaister, 1964).


YUKON
NWT
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
increasing shale
Peace River Area
shallow basin
probable shale and lesser carbonates
shallow basin (now eroded)
probable geosyncline
chert and siliceous sediment
open water carbonate and shale
restricted area evaporite
Rocky Mountain Area
0 50 100 200 300 400
km
Southern Alberta Area
probable massive carbonate
Williston Basin Area
shelf
evaporites
massive pure carbonates
carbonate banks
shelf
mud flat carbonates
LEGEND
Subcrop area
Plateau Mountain
Generalized facies boundary
Depositional thickening direction

in the thickness of the strata, 3) a facies change from near shore sediments in the south to more open marine sediments in the north. On a regional scale, facies changes were from the evaporitic to shallow water carbonates of the Williston Basin, to shallow water carbonates in southern Alberta and the Rocky Mountains, to more open marine carbonates in the Peace River area.

The Mount Head Formation (Figure 3) in southern Alberta and the Rocky Mountains is correlated with the Upper Debolt Formation in northern Alberta and northeastern British Columbia, the Poplar Formation in southeastern Saskatchewan, and the Charles Formation in Montana and North Dakota (Procter and Macauley, 1968). These formations are of Meramec age. The Upper Debolt Formation consists of shales and argillaceous limestones, whereas interfingering carbonates and evaporites occur in the Poplar and Charles Formations (ibid). The carbonates of the Mount Head Formation are discussed in more detail below.

Local Stratigraphy

The Mount Head Formation in the southern Rocky Mountains of Alberta was discussed by Macqueen and Bamber (1968) and Macqueen et al (1972). The following summary is based upon their work.

In the subsurface of southern Alberta (Figure 4) the Mount Head Formation is undivided and, where not removed by

Figure 3: Subsurface Carboniferous Stratigraphy of Western Canada (modified after Procter and Macauley, 1968).

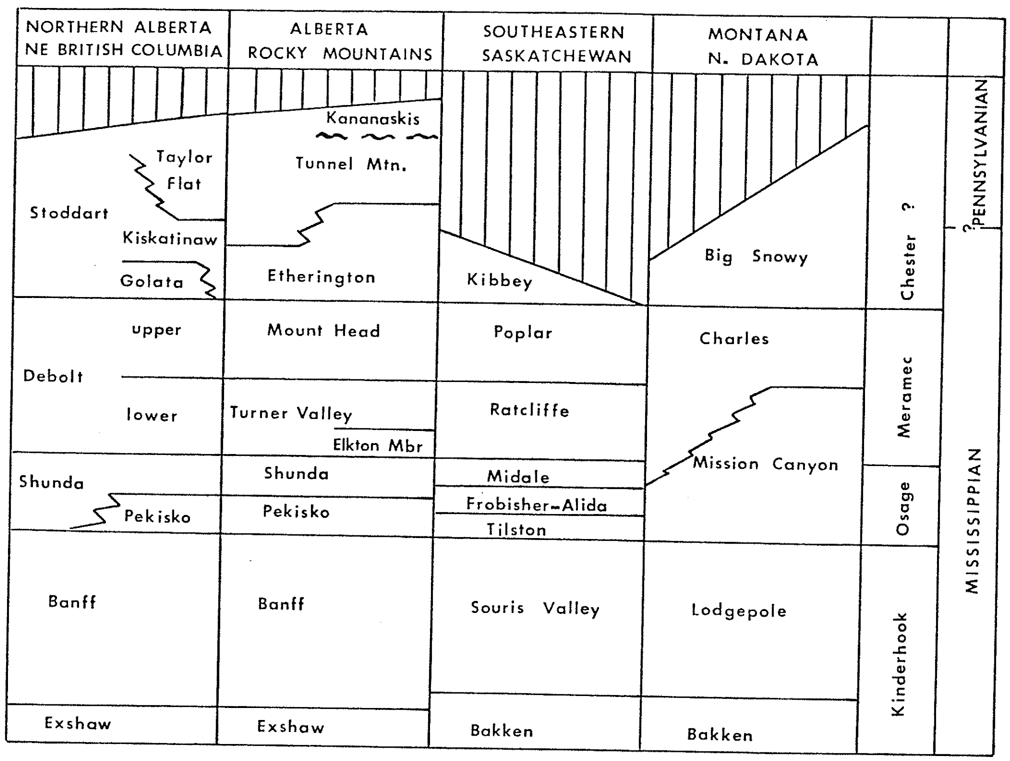
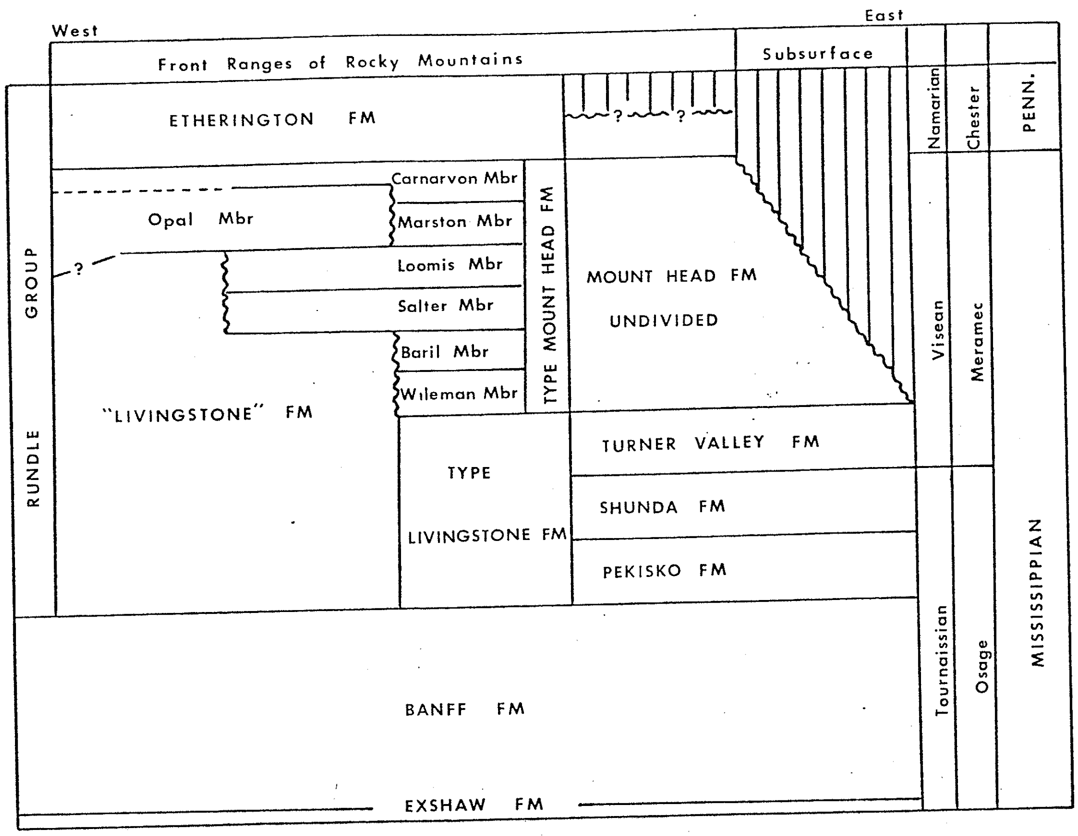

NORTHERN ALBERTA
NE BRITISH COLUMBIA
ALBERTA
ROCKY MOUNTAINS
SOUTHEASTERN
SASKATCHEWAN
MONTANA
N. DAKOTA
Kananaskis
Taylor
Flat
Tunnel Mtn.
Stoddart
Kiskatinaw
Golata
Etherington
Kibbey
Big Snowy
upper
Debolt
lower
Mount Head
Turner Valley
Elkton Mbr
Poplar
Ratcliffe
Charles
Mission Canyon
Shunda
Pekisko
Shunda
Pekisko
Midale
Frobisher-Alida
Tilston
Banff
Banff
Souris Valley
Lodgepole
Exshaw
Exshaw
Bakken
Bakken
Chester ?
Meramec
Osage
Kinderhook
PENNSYLVANIAN
?
?
MISSISSIPPIAN

Figure 4: Outcrop and Subsurface Carboniferous Stratigraphy of Southwestern Alberta (Modified after Macqueen, Bamber and Mamet, 1972).


West
East
Front Ranges of Rocky Mountains
Subsurface
ETHERINGTON FM
Carnarvon Mbr
Opal Mbr
Marston Mbr
Loomis Mbr
Salter Mbr
Baril Mbr
Wileman Mbr
"LIVINGSTONE" FM
TYPE MOUNT HEAD FM
MOUNT HEAD FM
UNDIVIDED
TYPE
LIVINGSTONE FM
TURNER VALLEY FM
SHUNDA FM
PEKISKO FM
BANFF FM
EXSHAW FM
RUNDLE GROUP
Namarian
Visean
Tournaissian
Chester
Meramec
Osage
PENN.
MISSISSIPPIAN

erosion, overlies the Turner Valley Formation. The Etherington Formation may have overlain the Mount Head Formation but the erosional event at the end of the Paleozoic has removed the Etherington Formation from subsurface localities.

In the Front Ranges, the Mount Head Formation is underlain by the Livingstone Formation and overlain by the Etherington Formation. In southwestern Alberta, the Mount Head Formation consists of alternating recessive and resistant limestone, dolomite, calcareous and/or dolomitic shale, and local solution breccia. From oldest to youngest, the six members of the type Mount Head Formation are:

1) Wileman Member - a recessive, yellowish brown, thin-bedded silty and sandy dolomite with minor limestone. Interpreted environment is an evaporitic coastal sabkha.

2) Baril Member - a resistant, light grey, thick-bedded limestone, locally dolomitic and cherty, representing tidal flats, and shallow marine lagoons and shoals,

3) Salter Member - a recessive, yellowish brown to light grey, thin-to thick-bedded dolomite, limestone and local solution breccia indicating a return to coastal sabkha conditions,

4) Loomis Member - a resistant, light grey, thick-bedded,

cherty, oolitic limestone representing oolitic shoals,

5) Marston Member - a recessive, brownish grey, thin-bedded cyclic sequence of dolomite, limestone and calcareous shale representing alternation of lagoon and sabkha conditions,

6) Carnarvon Member - a resistant, light grey, thick-bedded cyclic sequence of limestone with minor amounts of dolomite and calcareous shale indicating an extensive lagoon system.

Stratigraphic and time equivalents of the Wileman, Baril, Salter and Loomis Members are included in the upper part of the "Livingstone" Formation in the western-most Front Ranges (Figure 4). The "Livingstone" Formation consists of resistant, light grey, thick-bedded, echinoderm-bryozoan limestones, partly dolomitized, and representing shallow water carbonate banks. The Marston and the Lower and Middle Carnarvon Members correlate with the Opal Member: a recessive, dark grey, thin-to-thick-bedded sequence of limestone, dolomitic limestone and calcareous shale. The Opal Member represents an open marine environment with barrier shoals. The Upper Carnarvon Member overlies the Opal Member.

Objectives of Study

The Loomis, Marston and Carnarvon Members of the Mount Head Formation at Plateau Mountain were studied to:

1) interpret depositional facies and environments,

2) identify diagenetic fabrics, their relative time of formation and origin,

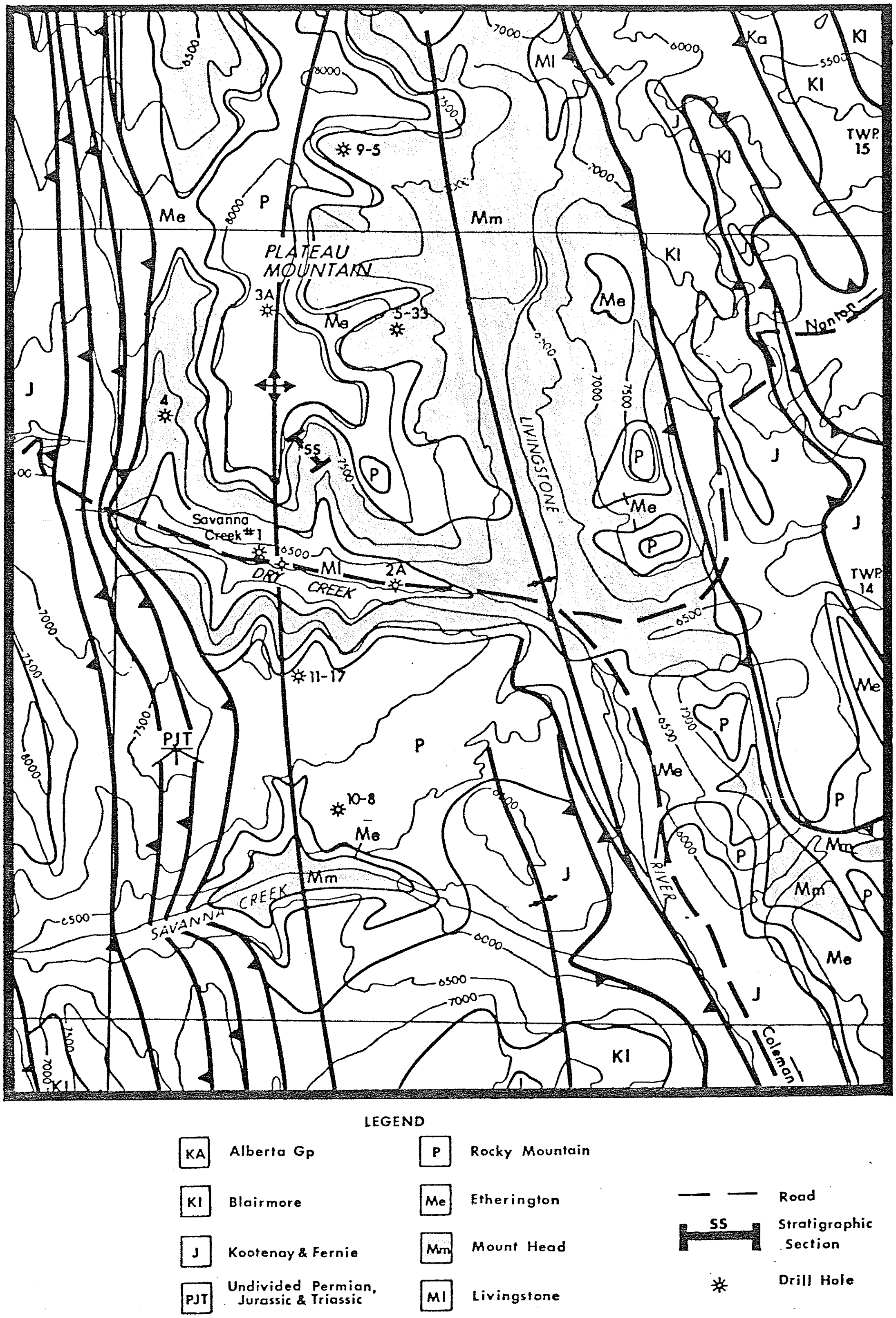
3) investigate possible relationships between diagenetic fabrics and depositional environments.

Method of Study

Field work was carried out in the fall of 1975 by measuring a stratigraphic section, approximately 145 meters thick, of the Upper Salter, Loomis, Marston and Carnarvon Members of the Mount Head Formation in a cirque on the south side of Plateau Mountain (Figure 5; Plate 1A). Subsequent follow-up work was carried out in the fall of 1976.

One hundred and forty-seven samples were collected and slabbed. From these slabs, one hundred and fourteen thin sections and twenty-six acetate peels were prepared by standard methods. Most of the thin sections were stained either wholly or partly using Dickson's method (1965) to determine non-ferroan and ferroan calcite and dolomite.

Figure 5: Surface Geology and Location of the Stratigraphic Section Measured at Plateau Mountain, Alberta (taken from Norris, 1958a, b).



PLATEAU MOUNTAIN
LIVINGSTONE RIVER
DRY CREEK
SAVANNA CREEK
Savanna Creek #1
Nanton
Coleman
TWP. 15
TWP. 14
9-5
3A
3-33
4
SS
2A
11-17
10-8
PJT
LEGEND
KA Alberta Gp
Kl Blairmore
J Kootenay & Fernie
PJT Undivided Permian, Jurassic & Triassic
P Rocky Mountain
Me Etherington
Mm Mount Head
Ml Livingstone
Road
SS Stratigraphic Section
Drill Hole

Fifty samples were point counted from the Upper Salter, Loomis, Marston and Carnarvon Members (Appendix B).

A few samples were x-rayed (Appendix C) for identification of unknown minerals or semi-quantitative determination of calcite and dolomite percentages.

Acknowledgements

This thesis is part of a continuing research program at the University of Manitoba under the direction of Dr. R.S. Harrison. The program involves the study of depositional and diagenetic aspects of Mississippian strata in the Front Ranges and Foothills of Alberta.

The author would like to thank the Department of Earth Science, the University of Manitoba, for financial assistance and the use of the diffractometer, photographic facilities, petrographic instruments and thin section equipment.

The field work was ably assisted by K.S. Glenday in 1975 and W.K. Mysyk in 1976. Some thin sections were prepared at the University of Manitoba by I. Berta.

A special thanks to W.K. Mysyk for his assistance and advise with the X-ray diffraction work.

The author would especially like to acknowledge Dr. R.S. Harrison for many hours of advice, criticism and encouragement throughout the study. The author thanks Dr.

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Special thanks are due to my mother, Mrs. R.R. Smith, for her time and patience in typing the first draft. The second draft was typed by Mrs. E. Keele. Mrs. J. Engelsjord typed the final draft.

CHAPTER 2 - FACIES

Introduction

The Loomis, Marston and Carnarvon Members of the Mount Head Formation at Plateau Mountain are made up of carbonates, limestone and dolomite, with some chert nodules. The carbonate classification scheme used is that of Dunham (1962). The facies (Table 1) are based upon the following depositional textures: 1) type and percentage of sand size grains, 2) percentage of the original carbonate mud, and 3) sedimentary structures. Unless otherwise noted, the percentages were determined by point counting (Appendix B).

Depositional Components

The depositional components are defined as grains, >20μ in size and carbonate mud of clay and fine silt size (Dunham, 1962). The most abundant grains are echinoderm fragments, ooids, pelletoids, bivalves and "superficial" ooids. The echinoderm fragments, 0.1 to 4.0 mm in size, are plates, ossicles and spines. Pelletoids (Bathurst, 1971, p. 547) are equant to oblate, micritic grains that vary from 0.05 to 0.8 mm in size. They may be either faecal pellets or micritized grains that were formed by boring algae. Bivalves, varying from 0.5 to 4.0 mm in length, consist primarily of brachiopods and ostracodes with a few

Table 1: Summary of Facies and Depositional Environment Interpretation of the Upper Mount Head Formation, Plateau Mountain, Alberta.

FACIES	DOMINANT GRAIN	NUMEROUS GRAINS	MINOR GRAINS	MUD & DOLOMITE	DOLOMITE	ORIGINAL ROCK	SEDIMENTARY STRUCTURES	DEPOSITIONAL ENVIRONMENT
Oolite	ooid (40-55%)	echinoderm bryozoa bivalve pelletoid	foraminifera calcisphere gastropod lump algae	< 10%	Tr	grainstone	massive	high energy subtidal; adjacent to an ooid shoal
"Superficial" oolite, pelletoid	"superficial" ooid (50%)	pelletoid	bivalve echinoderm	10-20%	5%	packstone	massive	moderate energy subtidal
Echinoderm grain	echinoderm (20-75%)	ooid bryozoa pelletoid bivalve	foraminifera calcisphere algae lump gastropod	20-50%	2-25%	packstone	massive horizontal lamination tabular cross-beds - - - - - finely laminated	moderate to high energy subtidal banks and their reworked detritus - - - - - moderate to high energy shallow subtidal to intertidal
Echinoderm mud	echinoderm (15-35%)	pelletoid bivalve calcisphere algae	intraclast ooid	50-80%	Tr-35%	wackestone	massive horizontal lamination vertical burrows thin shale beds	low to moderate energy subtidal banks and their reworked detritus
Skeletal mud	bivalve (1-8%)		pelletoid calcisphere echinoderm algae ooid	> 70%	5-60%	mudstone to wackestone	massive vertical burrow thin shale beds	low energy, restricted subtidal
Mud			echinoderm bivalve	> 95%	85-100% or 5-10%	mudstone	massive finely laminated vertical, horizontal burrows fenestral lamination	very low energy shallow subtidal to intertidal to low supratidal
Pelletoid evaporite	pelletoid evaporite length-slow chalcedony		bivalve intraclast	10-60%	0-Tr	evaporitic wackestone to packstone	finely laminated	evaporitic supratidal
Breccia	clasts micritic chalcedony megaquartz			100% ?	0%	evaporitic mudstone ?	none	evaporitic supratidal

molluscs. Ooids, 0.1 to 0.7 mm in diameter, have cores of dominantly either pelletoid or echinoderm grains and rarely bivalves, foraminifera, bryozoa and lumps. Ooids have radial and tangential laminations which vary from 0.01 to 0.14 mm thick. "Superficial" ooids, 0.07 to 0.2 mm in diameter, have a pelletoid core with only one radial lamination which ranges from 0.02 to 0.04 mm thick.

Other grain types found in minor amounts are: 1) calcispheres and algae, 0.02 to 1.0 mm in diameter, 2) foraminifera, 0.1 to 1.0 mm in diameter, 3) bryozoa, 0.5 to 4.0 mm in length, 4) lumps, 0.5 to 2.0 mm in diameter, 5) gastropods, 0.5 to 1.0 mm in diameter, and 6) intraclasts, 0.5 to 50.0 mm in length.

The original carbonate mud and micritic grains are no longer composed of micrite, 1 to 4 μ in size, but now consist of microspar, 4 to 10 μ in size, due to neomorphism (Folk, 1965). For convenience, the author has retained the terms, carbonate mud and micritic grains.

The amount of carbonate mud now seen in these rocks is lower than when the sediments were originally deposited. The carbonate mud has been replaced to varying degrees by dolomite during diagenesis. Although micritic grains have been dolomitized, dolomitization is generally confined to the outer portion of the grain. The author estimates that of the depositional components affected by dolomitization in the Upper Mount Head Formation, eighty percent was original carbonate mud. Therefore, the total of carbonate mud plus dolomite is a more accurate measurement of the original carbonate mud. The carbonate mud plus dolomite total is used in this study to determine the amount of carbonate mud originally deposited.

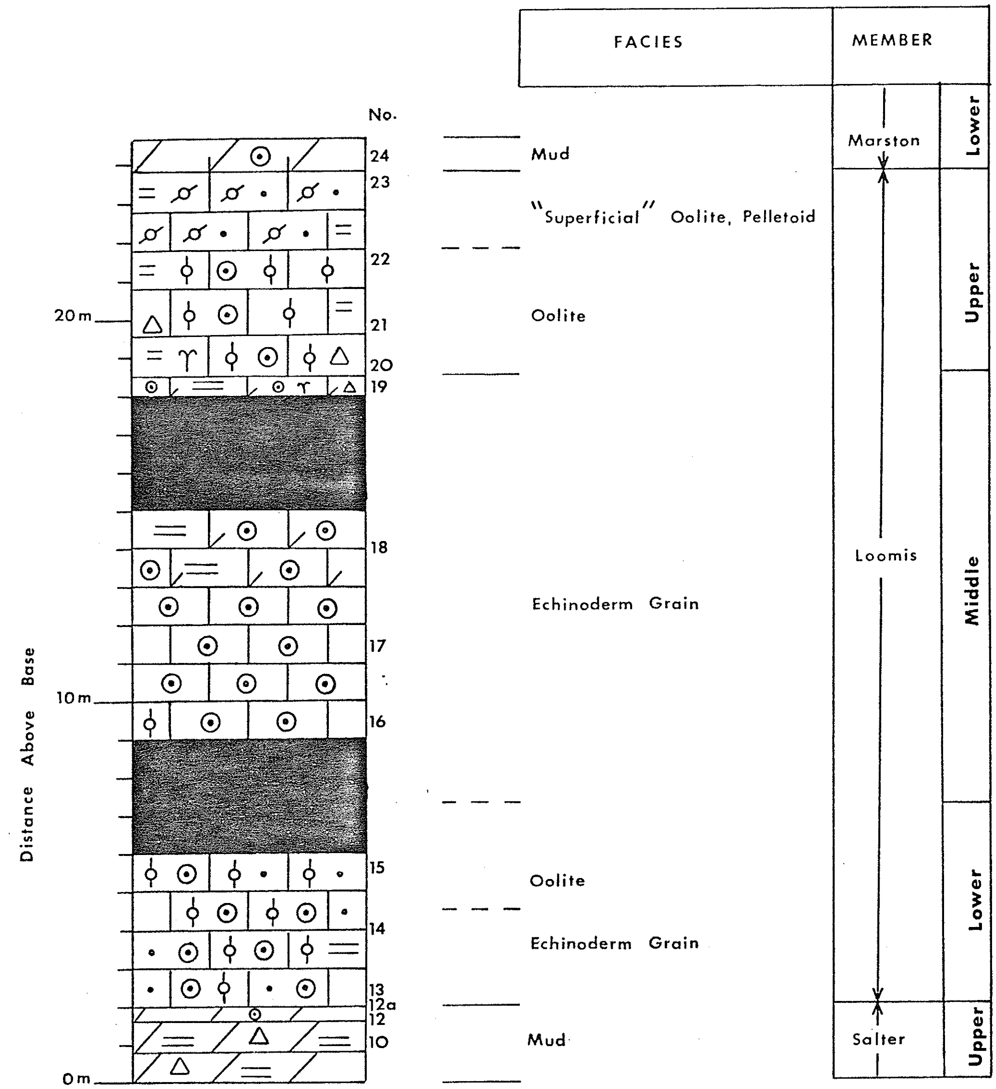
Oolite Facies

Description

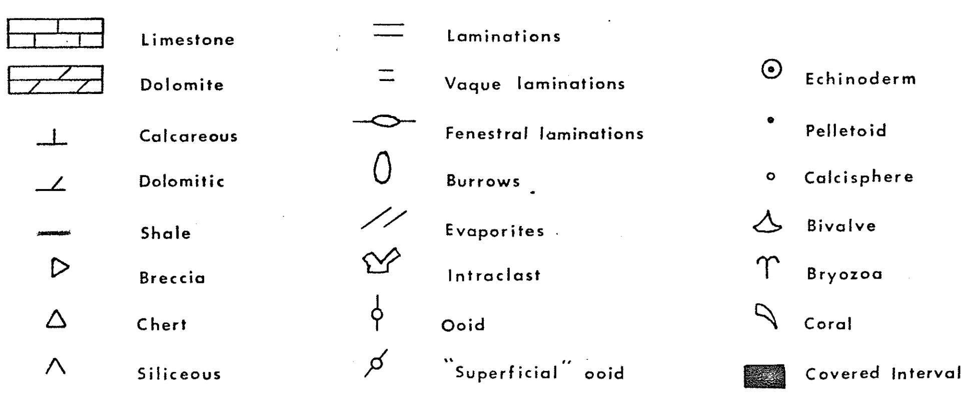
The oolite facies is a resistant, light grey, medium grained, massive, oolitic grainstone (Plate 1B). This facies was recognized only in the Loomis Member (Figure 6). In the Lower Loomis Member, the facies underlies the echinoderm grain facies. The contact is covered. In the Upper Loomis Member, it sharply overlies the echinoderm grain facies. At both intervals, the facies is approximately 3 meters thick. Weathering and the small size of the ooids make it difficult to recognize the ooids in outcrop.

Grains (Plate 2A) comprise over 90% of the depositional components. The original carbonate mud (mud and dolomite) is less than 10% with the dolomite occurring in trace amounts. The dominant grains are ooids which vary in abundance from 50 to 55%. Echinoderm, 15-25%, bryozoa, 0-25%, pelletoid, 8-25%, and bivalve, 0-3%, grains are also present. Foraminifera, gastropods, algae, calcispheres and lumps are

Figure 6: Stratigraphic Section of the Loomis and Upper Salter Members of the Mount Head Formation, Plateau Mountain, Alberta.


FACIES
MEMBER
No.
24
23
22
21
20
19
18
17
16
15
14
13
12a
12
10
20 m
10 m
0 m
Distance Above Base
Mud
"Superficial" Oolite, Pelletoid
Oolite
Echinoderm Grain
Oolite
Echinoderm Grain
Mud
Marston
Loomis
Salter
Lower
Upper
Middle
Lower
Upper

LEGEND


Limestone
Dolomite
Calcareous
Dolomitic
Shale
Breccia
Chert
Siliceous
Laminations
Vaque laminations
Fenestral laminations
Burrows
Evaporites
Intraclast
Ooid
"Superficial" ooid
Echinoderm
Pelletoid
Calcisphere
Bivalve
Bryozoa
Coral
Covered Interval

minor grains.

Most of the echinoderm grains have a micritic envelope that partly or completely surrounds the grain. These envelopes are also present on echinoderm grains that are the ooid nuclei.

Interpretation

The high proportion of grains and the paucity of original carbonate mud indicate a high energy subtidal environment in which currents deposited abundant grains and winnowed out the carbonate mud. The oolite facies was deposited close to an ooid forming environment due to the high percentage of ooids.

Modern ooid shoals in the Persian Gulf and the Bahamas contain almost 100% ooids and have cross-bedding and/or ripple marks (Loreau and Purser, 1973; Gebelein, 1974). Stablilized sand flats adjacent to the ooid shoals in the Bahamas are massive, ooid-rich sediments with numerous skeletal and non-skeletal grains (Gebelein, 1974). The lack of cross-bedding and/or ripple marks, and the high proportion of other grain types in the ooid-rich rock at Plateau Mountain suggest that the oolite facies was not the ooid forming environment but an area adjacent to it, similar to a stabilized sand flat.

"Superficial" Oolite, Pelletoid Facies

Description

The "superficial" oolite, pelletoid facies is a resistant, dark grey, fine grained, vaguely horizontally-laminated "superficial" ooid, pelletoid packstone (Plate 1B). The vague laminations are due to discontinuous concentrations of echinoderm grains. The facies which occurs only at the top of the Loomis Member (Figure 6), is approximately 2 meters thick.

"Superficial" ooids (Plate 2B) constitute approximately 50% of the depositional components. Pelletoids, 23%, occur in moderate proportions while bivalve, 3%, and echinoderm, 1%, grains are minor. All of the cores of the "superficial" ooids consist of pelletoids. The original carbonate mud (mud and dolomite) varies from 10 to 20% with 5% being dolomite.

Interpretation

Due to the abundance of grains, 80-90%, and the paucity of original carbonate mud, 10-20%, the "superficial" oolite, pelletoid facies is interpreted as a moderate energy subtidal environment. The "superficial" ooids may not have been formed in this environment since they constitute only 55% of the depositional components. The facies also lacks sedimentary structures, cross-bedding and ripple marks, associated with modern ooid forming environments (Gebelein, 1974). However, the single lamination may indicate that there were only periodic energy influxes sufficient to produce a single lamination around the pelletoid grain. The abundance of pelletoid-cored "superficial" ooids and pelletoids suggests that this facies is transitional between an ooid shoal and the lagoon or open marine shelf environment.

Echinoderm Grain Facies

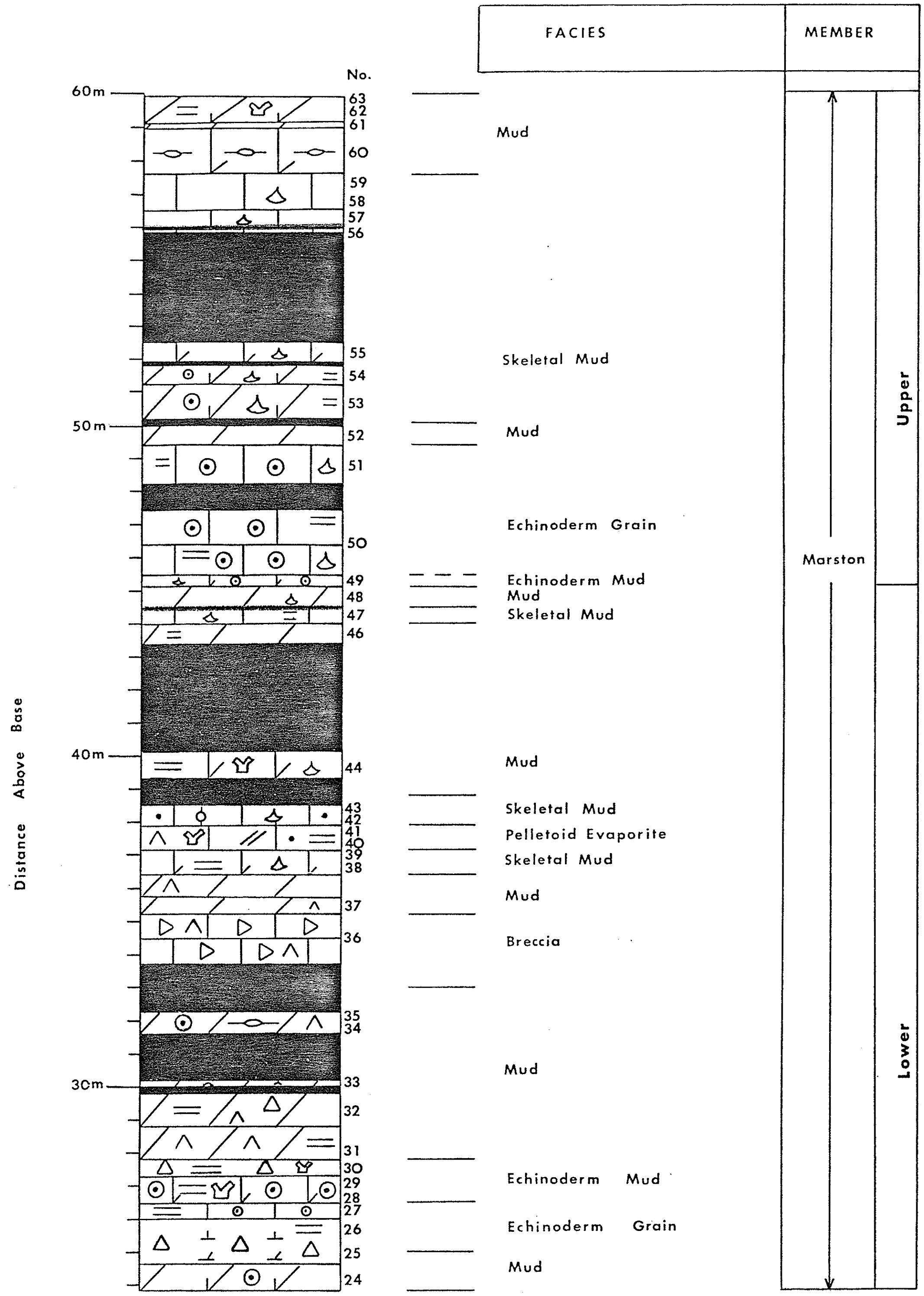
Description

The echinoderm grain facies is a resistant, light grey, fine to coarse grained, massive to laminated echinoderm packstone (Plate 1C). Individual units range from 1.5 to 11 meters thick. The facies is present in the Loomis (Figure 6) and Marston (Figure 7) Members. In outcrop echinoderm, brachiopod and coral fragments are visible.

Echinoderm grains (Plates 2E and 2F) vary from 20 to 70% of the depositional components. Ooids, 0-20%, bryozoa, 1-20%, pelletoids, 5-25%,and bivalves, 0-8%, are the other grains present in appreciable amounts. The bivalves are mostly brachiopods with a few mollusc shells. Lumps, foraminifera, algae and gastropod grains occur in trace amounts. The original carbonate mud (mud and dolomite) ranges from 25 to 45% with dolomite varying from 2 to 25%.

Within the Upper Mount Head Formation there are three

Figure 7: Stratigraphic Section of the Marston Member of the Mount Head Formation, Plateau Mountain, Alberta (legend located in Figure 6).


FACIES
MEMBER
No.
60m
50m
40m
30m
Distance Above Base
63
62
61
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
Mud
Skeletal Mud
Mud
Echinoderm Grain
Echinoderm Mud
Mud
Skeletal Mud
Mud
Skeletal Mud
Pelletoid Evaporite
Skeletal Mud
Mud
Breccia
Mud
Echinoderm Mud
Echinoderm Grain
Mud
Marston
Upper
Lower

distinct occurrences of the echinoderm grain facies:

(1) In the Loomis Member, (Figure 6) the facies can be massive (Plate 2D), cross-bedded (Plate 2C) or horizontally-laminated. Individual units range from 3 to 11 meters thick. The echinoderm grain facies is overlain sharply and underlain by the oolite facies (Figure 6). The Loomis-Salter contact in the field is sharp with the echinoderm grain facies overlying the mud facies of the Salter Member. Echinoderm grains (Plate 2E), which commonly have a micritic envelope partly or completely surrounding the grains, constitute from 20 to 55% of the facies. A large diversity of grains such as ooids, bryozoa, pelletoids, and bivalves constitute 25 to 45% of the sediment.

(2) In the Upper Marston Member (Figure 7), individual units are 4 meters thick and horizontally-laminated due to concentrations of coral, brachiopod and echinoderm detritus. The echinoderm grain facies gradationally overlies the echinoderm mud facies whereas the contact with the overlying mud facies is sharp. Echinoderm grains (Plate 6E) which range from 50 to 75% do not have any micritic envelopes. Other grains are bivalves, 3-8%, and pelletoids, 1-4%.

(3) In the Lower Marston Member, the facies is a thinly-bedded, 1.5 meter thick sequence consisting of non-laminated

beds interbedded with finely laminated beds. The echinoderm grain facies is underlain by the mud facies. The contact is obscured by the extensive development of chert. The contact with the overlying echinoderm mud facies is sharp, stylolitic and erosional (Plate 3A). Angular to subrounded intraclasts of the echinoderm grain facies have been ripped up. The 2-3 mm thick fine laminations are low angle cross-beds and/or ripple marks. The laminations are due to alternation of echinoderm-rich and echinoderm, pelletoid-rich laminae. The echinoderm grains (Plate 2F) lack micritic envelopes and range from 53 to 63% while pelletoids, 9-12%, are the only other significant grain.

Interpretation

The echinoderm grain facies of the Loomis and the Upper Marston Members is interpreted to be a moderate to high energy subtidal environment due to the relative abundance of grains, 55-75%, and the moderate amount of original carbonate mud, 25-45%. In the Loomis Member, the association with the oolite facies, the diversity of grains, tabular cross-bedding and horizontal-laminations indicate that this facies occurred in an area with abundant currents, close to ooid shoals and echinoderm banks. Channels within barrier complexes in the Persian Gulf (Purser and Evans, 1973) and the Bahamas (Gebelein, 1974) have similar characteristics. The massive units may be banks of prolific growth of organisms, in particular echinoderms. The organisms were fragmented by the moderate to high energy currents.

In the Upper Marston Member, the echinoderm grain facies was probably an echinoderm bank within the lagoon or open marine shelf environment. This interpretation is based upon the association with the echinoderm mud and mud facies, and the abundance of echinoderm grains.

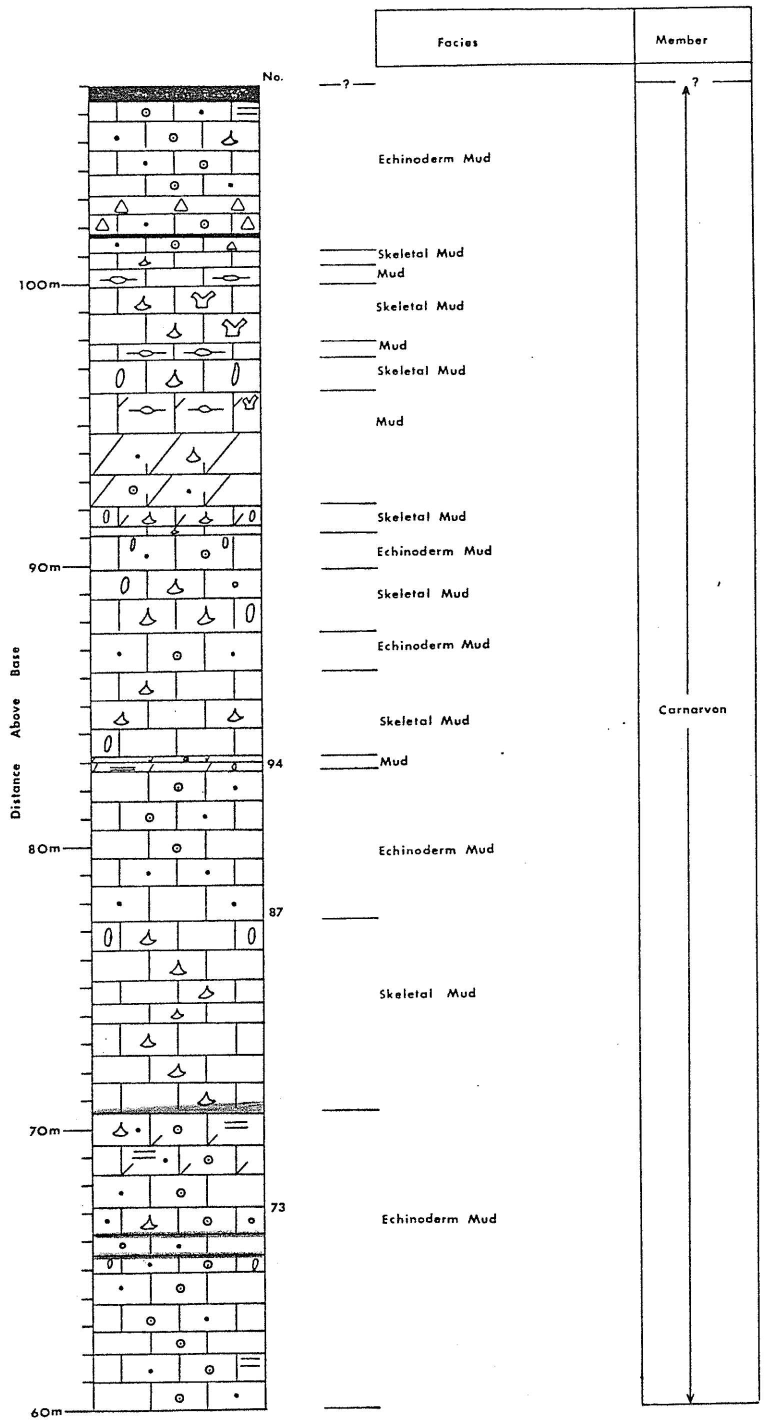
In the Lower Marston Member, low angle cross-beds and/or ripple marks indicate that the echinoderm grain facies was deposited in a shallow subtidal to intertidal environment under the influence of moderate to high energy currents.

Echinoderm Mud Facies

Description

The echinoderm mud facies consists of resistant, medium to dark grey, lithographic to medium grained, massive to horizontally-laminated echinoderm wackestone (Plate 1F). Individual units vary from 0.4 to 10.6 meters thick. In the field, brachiopods and corals may be observed but they are minor. Horizontal-laminations occur and are up to 2 centimeters thick. The echinoderm mud facies occurs in the Marston Member (Figure 7) but is most abundant in the Carnarvon Member (Figure 8).

Figure 8: Stratigraphic Section of the Carnarvon Member of the Mount Head Formation, Plateau Mountain, Alberta (legend located in Figure 6).


Facies
Member
No.
?
?
Echinoderm Mud
Skeletal Mud
Mud
100m
Skeletal Mud
Mud
Skeletal Mud
Mud
Skeletal Mud
Echinoderm Mud
90m
Skeletal Mud
Echinoderm Mud
Distance Above Base
Skeletal Mud
Carnarvon
94
Mud
80m
Echinoderm Mud
87
Skeletal Mud
70m
73
Echinoderm Mud
60m

Echinoderm grains (Plate 3B) that have no micritic envelopes comprise 15 to 35% of the depositional components. Other grains are pelletoids, 0-10%, calcispheres and algae, 0-3%, and bivalves, 1-9%. Ooids, intraclasts and foraminifera grains occur in minor proportions. The original carbonate mud (mud and dolomite) varies from 50 to 80% with dolomite ranging from trace to 35%.

Minor vertical burrows, outlined by spherical areas of calcite cement, occur in the Carnarvon Member near the contact with the skeletal mud facies. Grey, fissile calcareous shale beds (Plate 1F), 1-2 centimeters thick, occur either within the echinoderm mud facies, or at the contact with the skeletal mud facies. The contacts are sharp or gradational over a centimeter.

In the Marston Member (Figure 7), the echinoderm mud facies is overlain by the mud facies but the contact is obscured by the extensive development of chert nodules. The contact between the echinoderm mud facies and the underlying mud facies is sharp. The echinoderm mud facies gradationally underlies the echinoderm grain facies in the Upper Marston Member. In the Lower Marston Member, there is an erosional contact (Plate 3A) where the echinoderm mud facies overlies the non-laminated to finely-laminated echinoderm grain facies.

In the Carnarvon Member (Figure 8), the echinoderm mud facies sharply overlies and underlies the skeletal mud facies, and sharply underlies the mud facies.

Interpretation

The relative abundance of original carbonate mud, 50-80%, and the moderate amount of grains, 10-50%, indicate a low to moderate energy subtidal environment. The depositional environment was lower in energy than that of the echinoderm grain facies which resulted in a decrease of echinoderm growth and an increase in the original carbonate mud deposition.

The echinoderm mud facies is associated with the echinoderm grain and skeletal mud facies in the vertical sequence. The facies represents an intermediate area between the moderate to high energy currents of the echinoderm grain facies and the very low energy currents of the skeletal mud facies. Current activity was sufficient to produce horizontal laminations that are locally disrupted by burrowing.

The calcareous shale beds indicate periodic influxes of argillaceous sediment. Deposition was under low energy, subtidal conditions due to its association with the echinoderm mud, skeletal mud and mud facies. The source area could possibly have been the emergent Canadian Shield to the east (Macqueen and Bamber, 1968).

Rodriguez and Gutschick (1970) summarized characteristics of modern and ancient carbonate analogues.

According to them, vertical burrows are confined to the intertidal zone. Therefore, vertical burrows suggest localized build up to sea level of the echinoderm mud facies.

Skeletal Mud Facies

Description

The skeletal mud facies is a relatively recessive, dark grey, lithographic, massive mudstone to wackestone (Plate 1E). Individual units vary from 1.4 to 7.6 meters thick. The skeletal mud facies occurs in the Marston (Figure 7) and Carnarvon (Figure 8) Members.

The facies underlies and overlies the echinoderm mud facies sharply, the mud facies sharply, and the pelletoid evaporite facies gradationally.

Less than 30% of the depositional components consist of grains (Plate 3C). The original carbonate mud (mud and dolomite) is greater than 70% with dolomite ranging from 5 to 60%. The dominant grains are brachiopod and ostracod bivalves, 1-8%. Echinoderm grains are generally less than 1% but may constitute up to 15% of the depositional components. Pelletoids, 0-20%, calcispheres and algae, 0-3% and trace ooids are minor grains.

Vertical burrows have diameters ranging from 2 to 7 mm and are up 20 mm in length. The burrows (Plate 4D) have pelletoids, skeletal debris and carbonate mud in the lower portion and calcite cements in the upper portion. The sediment in the burrow is very similiar to some echinoderm mud facies sediment.

Grey, fissile calcareous shale beds, 1-2 cm thick, occur within the skeletal mud facies and occasionally at the echinoderm mud facies contact. The contact can be sharp or gradational over a few centimeters. In some cases, these beds grade out laterally.

Interpretation

The skeletal mud facies is interpreted as a low energy subtidal environment due to the high original carbonate mud content. This facies is characterized by bivalves, brachiopods and ostracodes, but other grains such as echinoderms and/or pelletoids may reach appreciable amounts. Where this facies contains only bivalves as grains, the depositional environment is believed to have been restricted with very little current circulation. With less restriction and more current circulation, organisms such as echinoderms will start to thrive. Therefore, it would grade into the echinoderm mud facies.

As in the case of the echinoderm mud facies, the calcareous shale beds represent periodic influxes of argillaceous sediment that were deposited under low energy, subtidal conditions. The emergent Canadian Shield to the east was probably the source area (Macqueen and Bamber, 1968).

That the skeletal mud facies locally built up to intertidal levels is suggested by the presence of vertical burrows which only occur in this zone (Rodriguez and Gutschick, 1970).

Mud Facies

Description

The mud facies is a recessive, yellowish brown to dark grey, lithographic to fine grained, massive to finely laminated carbonate mudstone. Individual units range from 0.6 to 5.2 meters thick. Much of the facies has been completely dolomitized. The mud facies occurs in the Marston (Figure 7) and Carnarvon (Figure 8) Members. The facies sharply overlies and underlies the echinoderm grain, the echinoderm mud, and the skeletal mud facies. In the Upper Carnarvon Member, a grey, fissile shale bed, 2 cm thick, occurs within the mud facies.

Grains constitute less than 5% of the depositional components and are generally echinoderm detritus, 0-5%, with trace amounts of bivalve grains (Plate 3E). In the Lower Marston Member, angular to subrounded, equant to bladed detrital quartz grains, 0.02 to 0.05 mm in size, constitute up to 6% of the sediments with trace clay minerals (illite?). The original carbonate mud (mud and dolomite) varies from

95 to 100% with dolomite being either 5 to 10% or 85 to 100%. The facies is either highly dolomitized (Plate 3E) or slightly dolomitized (Plate 3G).

The mud facies may be massive or finely laminated. The massive units are comprised of both slightly and highly dolomitized sediments. The highly dolomitized sediments may have minor argillaceous seams, 0-1 mm thick, skeletal debris, 0-5%, or fenestral pores filled by secondary quartz (Plate 7E). The slightly dolomitized sediments have fenestral pores filled by calcite cements (Plates 3F and 3G). The fenestral pores are generally horizontally aligned, but they may form at various angles to the horizontal. The pores, 0.1 - 0.3 mm in length, are usually lenticular but also have irregular shapes.

Laminations within the highly dolomitized, finely laminated sediments, are due to argillaceous material, or binding of sediments by algal mats (?) (Plate 3D). Laminations vary up to 1 mm thick. The algal mat (?) laminations consist of light and dark zones in dolomite. Laminae have straight, wavy or crumpled forms. Minor small burrows occur within argillaceous laminated sediments (Plate 5B). The burrows which are vertical to sub-vertical and horizontal may or may not transect the laminations.

Interpretation

The paucity of grains and the abundance of original carbonate mud indicates that the mud facies represents a very low energy environment. The presence of either fenestral pores or possible algal mats (?) indicates an intertidal to low supratidal environment. Shinn et al (1969) and Logan et al (1974) have found similar characteristics within these environments in the Bahamas and Shark Bay, West Australia, respectively. Scarce skeletal debris such as echinoderms, and vertical and horizontal burrows suggests very shallow, restricted subtidal to intertidal environments. Therefore the mud facies represents a range from very shallow subtidal through intertidal to low supratidal environments. The distinction between these three contrasting environments rests upon the successful recognition of diagnostic sedimentary structures.

Pelletoid Evaporite Facies

Description

The pelletoid evaporite facies is a relatively resistant, dark grey, lithographic to medium grained, massive to finely laminated, siliceous, pelletoid wackestone to packstone (Plate 4A). The facies occurs as a single unit in the Marston Member (Figure 7). The pelletoid evaporite facies (Figure 7) is overlain and underlain gradationally by the skeletal mud facies.

Abundant siliceous nodules which are up to 2 mm in size, define the laminations in this 0.75 meter thick unit. The siliceous nodules occur at the top and the bottom of the unit. The occurrence of celestite ($SrSO_4$) strontianite ($SrCO_3$) and length-slow chalcedony indicate that evaporites were previously more abundant. Length-slow chalcedony is formed by the replacement of evaporites (Folk and Pittman, 1971).

Alternating carbonate mud and secondary quartz-bearing horizons accentuate the laminations, 1-4 mm thick. In the secondary quartz-bearing horizons, the quartz is megaquartz (>20μ in width), opal (Plate 4C) and/or length-slow chalcedony (Plate 4D). The celestite, which occurs at the base of the facies and was identified by X-ray diffraction (Appendix C) is considered to be primary. The celestite crystals are confined to the horizontal laminations which have a wavy to crinkly form (Plate 4A) and do not transect depositional textures. Length-slow chalcedony has partly replaced some celestite crystals (Plate 8F). The carbonate mud areas consist of pelletoids, 20-35%, and carbonate mud, 31-63%, with trace amounts of bivalve grains and dolomite. The pelletoid grains seemingly merge into the carbonate mud. In the upper part of the facies, round oblate intraclasts (Plate 4D) are similar to the surrounding pelletoid-carbonate mud sediment. The intraclasts are aligned with their long dimension parallel to bedding.

Interpretation

The pelletoid evaporite facies represents an evaporitic supratidal environment similar to the modern Persian Gulf (Kendall and Skipwith, 1969a) as indicated by the lack of organisms and the presence of evaporites. Celestite, strontianite and length-slow chalcedony strongly suggest that evaporites were much more abundant than at present. Pelletoids and carbonate mud were deposited in the supratidal area during storms. The round, oblate intraclasts were formed by lithification and dessication of supratidal sediments and then the transportation of these clasts during storms. Similar intraclast breccias associated with evaporites, gypsum and halite, are forming within the supratidal at Shark Bay, West Australia (Logan, 1974).

Breccia Facies

Description

The breccia facies is a recessive, mottled light grey and greyish yellow, fine grained, vuggy breccia (Plates 1D and 4E). The unit occurs only in the Marston Member (Figure 8) and is approximately 2.2 meters thick. The breccia facies overlies and underlies the highly dolomitized mud facies.

Irregular to horizontal lenticular pores, up to 4 mm in size, are present.

The facies is comprised of approximately 20-30% clasts, 70-80% calcite cements and 5% pores (visual estimate). The clasts are angular to round micrite, length-slow chalcedony and megaquartz which are cemented by finely crystalline blocky calcite (Plate 4D). In larger pores, the crystal size increases to coarsely crystalline calcite cement. The micrite clasts commonly contain length-slow chalcedony. Limonite and minor hematite are disseminated throughout the micrite clasts. Limonite commonly occurs lining the coarsely crystalline calcite cement.

Interpretation

The breccia facies is interpreted to be a solution breccia which originally contained abundant evaporites in a carbonate mud sediment. The evaporites were dissolved out, leaving micrite and secondary quartz clasts which were later lithified by calcite cement. The formation of the solution breccia occurred after silicification and prior to blocky calcite cementation. The only remnant of these evaporites is the length-slow chalcedony which Folk and Pittman (1970) suggested is formed by the replacement of evaporites. The original depositional environment of the breccia facies represents an evaporitic supratidal environment. Similarly, in the modern Persian Gulf (Kendall and Skipwith, 1969a) evaporites are forming in the supratidal environment.

Summary

The eight facies recognized in the Upper Mount Head Formation at Plateau Mountain are summarized in Table 1. These facies represent various energy levels in sedimentation:

1) the oolite facies - a high energy subtidal environment adjacent to ooid shoals; similar to a stablilized sand flat;

2) the "superficial" oolite, pelletoid facies - a moderate enery subtidal environment transitional between ooid shoals and lagoons or open marine shelves;

3) the echinoderm grain facies - a) a moderate to high energy subtidal environment; echinoderm banks and their reworked detritus, b) a moderate to high energy, shallow subtidal to intertidal environment;

4) the echinoderm mud facies - a low to moderate energy subtidal environment; echinoderm banks and their reworked detritus;

5) the skeletal mud facies - a low energy, restricted subtidal environment;

6) the mud facies - a very low energy, shallow subtidal to intertidal to low supratidal environment;

7) the pelletoid evaporite facies - an evaporitic supratidal environment;

8) the breccia facies - an evaporitic supratidal environment.

CHAPTER 3 - DEPOSITIONAL INTERPRETATION

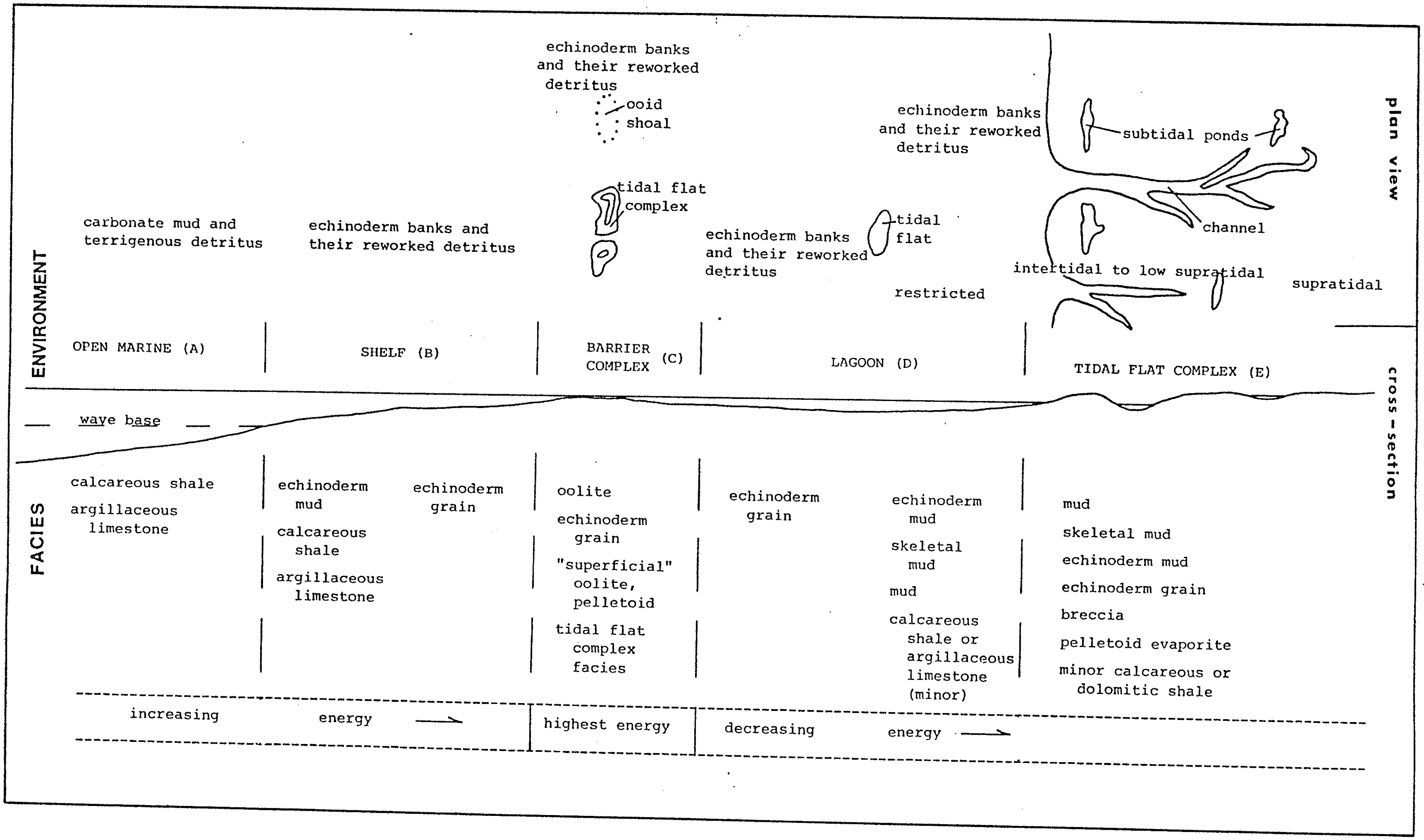
Mississippian Depositional Model

During the Mississippian, an epeiric sea existed in Western Canada, adjacent to the emergent, but topographically low Canadian Shield (Macqueen and Bamber, 1968; Procter and Macauley, 1968). An epeiric sea is an extensive continental area with shallow-water marine sediments accumulating in zones tens to hundreds of kilometers wide and on slopes less than 0.2 meters per kilometer (Irwin, 1965).

Although not on the same scale as the ancient epeiric seas, modern carbonate sedimentation does have similar sedimentary processes and sediments as the Mississippian carbonates of Western Canada. The Mississippian depositional model used in the present study is essentially the same as the one proposed by Macqueen and Bamber (1967, 1968). The model (Figure 9) was modified to illustrate the complexities within the depositional environments identified at Plateau Mountain. The major characteristics of the model are similar to the modern Persian Gulf and the Bahamas.

Calcareous shale and argillaceous limestone of the open marine environment (A) (Figure 9) were deposited below wave base under low energy conditions (Illing, 1959; Macqueen and Bamber, 1968). High argillaceous and low skeletal content characterize this area similar to the modern central Persian

Figure 9: Mississippian Depositional Model (modified after Macqueen and Bamber, 1968) not to scale.


echinoderm banks and their reworked detritus
ooid shoal
tidal flat complex
echinoderm banks and their reworked detritus
subtidal ponds
plan view
channel
tidal flat
carbonate mud and terrigenous detritus
echinoderm banks and their reworked detritus
echinoderm banks and their reworked detritus
intertidal to low supratidal
supratidal
restricted
ENVIRONMENT
OPEN MARINE (A)
SHELF (B)
BARRIER COMPLEX (C)
LAGOON (D)
TIDAL FLAT COMPLEX (E)
wave base
cross-section
FACIES
calcareous shale
argillaceous limestone
echinoderm mud
calcareous shale
argillaceous limestone
echinoderm grain
oolite
echinoderm grain
"superficial" oolite, pelletoid
tidal flat complex facies
echinoderm grain
echinoderm mud
skeletal mud
mud
calcareous shale or argillaceous limestone (minor)
mud
skeletal mud
echinoderm mud
echinoderm grain
breccia
pelletoid evaporite
minor calcareous or dolomitic shale
increasing energy
highest energy
decreasing energy

Gulf (Wagner and van der Togt, 1973).

The shelf environment (B) (Figure 9) shallows landward towards the barrier complex. This shallowing results in the following gradational changes: 1) the energy conditions increase from low to moderate to high energy, 2) the skeletal content, in particular echinoderms, increases and 3) the argillaceous content decreases (Walpole and Carozzi, 1961; Macqueen and Bamber, 1967). In the landward portion, echinoderm banks and their current-sorted detritus are more abundant. Progressing seaward, these banks and their reworked detritus decrease in abundance and calcareous shale and/or argillaceous limestone increase. Similar trends are also characteristic of the modern Persian Gulf (Wagner and van der Togt, 1973). Using the facies classification in this thesis, the seaward portion would have the echinoderm mud facies interbedded with calcareous shale and/or argillaceous limestone. The echinoderm grain facies would characterize the landward, shelf environment.

Neither the open marine nor the shelf environments are represented in the Upper Mount Head Formation at Plateau Mountain. This observation is based upon the regional studies of previous workers (Douglas, 1953, 1958; Macqueen and Bamber, 1968; Macqueen et al, 1972) and the present detailed facies study.

The barrier complex environment (C) (Figure 9) was a mixture of "islands, beaches, shoals, deltas, reefs, bars, splits, tidal channels, etc." (Macqueen and Bamber, 1967). This environment was similar to the ooid-rich zone in the modern Persian Gulf and the Bahamas. High energy ooid shoals and tidal bars within channels occupy only a small area but the ooids are dispersed over a broad region into channels, tidal deltas and stabilized sand flats (Loreau and Purser, 1973; Gebelein, 1974). The tidal bar and shoal sediments have abundant cross-bedding and/or ripple marks, and are almost 100% ooids (ibid; 1973, 1974). Skeletal-rich sediments can occur within the channels as moderate to high energy banks or their current-sorted detritus (ibid; 1973). Since this environment is very close to sea level, tidal flats with similar facies to the tidal flat complex environment may develop. The barrier complex environment is represented by the oolite, echinoderm grain and possibly the "superficial" oolite, pelletoid facies of the Loomis Member (Figures 6 and 10).

The lagoon environment (D) (Figure 9) is situated landward of the barrier complex environment which restricts or semi-restricts water circulation (Illing, 1959; Macqueen and Bamber, 1967). Modern analogues are found in the Bahamas and the Persian Gulf. The lagoonal area just behind the barrier complex has sediments similar to those of the landward, shelf environment. Moderate to high energy echinoderm banks and their current-sorted detritus are abundant but decrease landward (Loreau and Purser, 1973; Gebelein, 1974). The echinoderm grain facies at the base of the Loomis Member and the "superficial" oolite, pelletoid facies at the top of the Loomis Member (Figures 6 and 10) possibly may represent this part of the lagoon.

Progressing shoreward, the energy decreased, as water circulation in the lagoon became more restricted. Highly restricted areas had low fauna content, mostly ostracod and brachiopod bivalves. With increased water circulation, more organisms, especially echinoderms and foraminifera, colonized the lagoon. The restricted, skeletal mud and semi-restricted, echinoderm mud facies represent these parts of the lagoon, respectively. The floor of the relatively shallow lagoon periodically built up to sea level, as indicated by shallow subtidal to intertidal to low supratidal sediments of the mud facies. Argillaceous influxes, presumably from the land, produced thin calcareous shale beds within the lagoon. Semi-restricted to restricted lagoonal sedimentation occurs in the Upper Marston (Figures 7 and 10) and Carnarvon (Figure 8) Members.

The tidal flat complex environment (E) (Figure 9) has been described by previous workers (Illing, 1959; Macqueen and Bamber, 1967, 1968) as supratidal sedimentation in which high salinities have developed conditions for penecontemporaneous dolomite and evaporite development (anhydrite, now represented by solution breccia). In the Bahamas, the Persian Gulf, and Shark Bay, West Australia, modern tidal flat sedimentation is similar to the Mississippian tidal flats. In these areas, the tidal flat complex comprises intertidal to supratidal pelletoid-mud rich sediments with low fauna content (Shinn et al, 1969). They are cut by channels in the seaward portion . Subtidal ponds may form within the supratidal environment. Evaporites and penecontemporaneous dolomite are common constituents of these sediments (Kendall and Skipwith, 1969a; Hagan and Logan, 1973).

A tidal flat complex occurs in the Lower Marston Member (Figures 7 and 9). The echinoderm mud facies may represent a channel which was developed by erosion of previously deposited strata. Moderate to high energy current sorting within the intertidal environment produced the finely laminated echinoderm grain facies. Subtidal ponds within the supratidal setting are represented by the skeletal mud facies. The mud facies represents environments ranging from shallow subtidal to intertidal to low supratidal; sediments are highly dolomitized. Evaporitic supratidal sediments are the pelletoid evaporite and breccia facies.

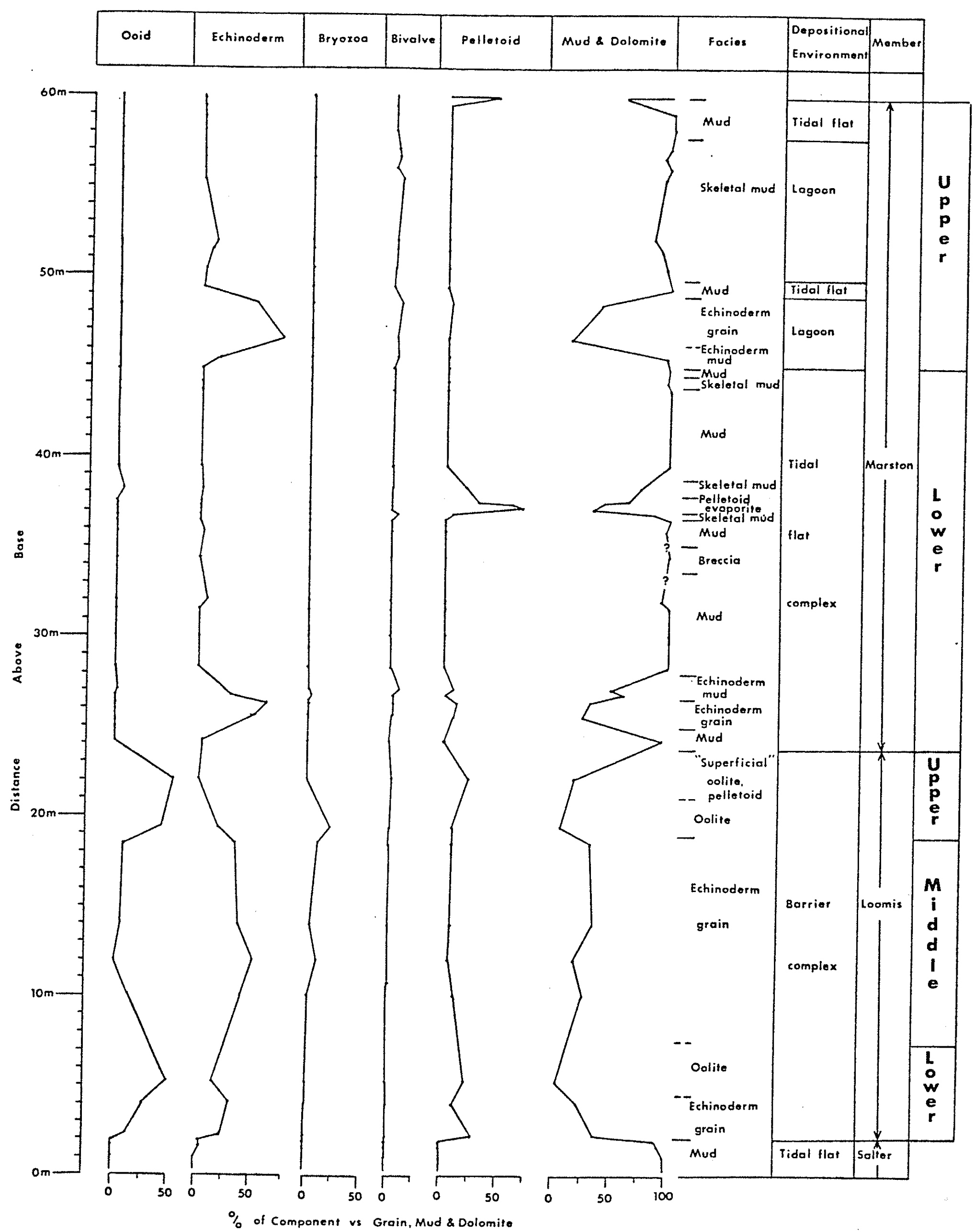
Depositional History of the Upper Mount Head Formation

Loomis Member

A major transgression within the Mount Head Formation occurred at the end of Salter time (Macqueen and Bamber, 1968). Widespread shallow marine, high energy oolite shoals of the Loomis Member were developed in the east and grade westward into the current-sorted skeletal, echinoderm-bryozoa, banks of the Upper "Livingstone" Formation (ibid). At Plateau Mountain, the Loomis Member comprises the echinoderm grain, oolite and "superficial" oolite, pelletoid facies (Figures 6 and 10).

The Salter-Loomis contact is sharp but it represents a gradational, not erosional, change from the tidal flat complex environment of the Salter Member to the barrier complex environment of the Loomis Member. The basal, massive, moderate energy echinoderm grain facies probably indicates an echinoderm bank developed on the near shore part of the barrier complex, as suggested by the numerous echinoderm and pelletoid grains (Figure 10). The bank is overlain gradationally by the tabular cross-bedded, moderate to high energy echinoderm grain facies with numerous echinoderm and ooid grains, followed by the massive, high energy oolite facies. Respectively, they represent current-sorted detritus from echinoderm banks and ooid shoals, and

Figure 10: Depositional Component Trends and Facies Relationship in the Loomis and Marston Members.



Ooid
Echinoderm
Bryozoa
Bivalve
Pelletoid
Mud & Dolomite
Facies
Depositional Environment
Member
60m
50m
40m
30m
20m
10m
0m
Distance Above Base
Mud
Skeletal mud
Mud
Echinoderm grain
Echinoderm mud
Mud
Skeletal mud
Mud
Skeletal mud
Pelletoid evaporite
Skeletal mud
Mud
Breccia
Mud
Echinoderm mud
Echinoderm grain
Mud
"Superficial" oolite, pelletoid
Oolite
Echinoderm grain
Oolite
Echinoderm grain
Mud
Tidal flat
Lagoon
Tidal flat
Lagoon
Tidal flat complex
Barrier complex
Tidal flat
Marston
Loomis
Salter
Upper
Lower
Upper
Middle
Lower
0 50
0 50
0 50
0
0 50
0 50 100
% of Component vs Grain, Mud & Dolomite

high energy sand flats next to ooid shoals within the barrier complex environment. The Lower Loomis Member indicates a gradual increase in energy conditions as suggested by a relative decrease in the original carbonate mud content as compared with the top of the Salter Member (Figure 10).

A covered interval masks the oolite-echinoderm grain facies contact between the Lower and Middle Loomis Member but it appears to be gradational (Figure 10). In the Middle Loomis Member, the massive echinoderm grain facies is gradationally overlain by the tabular cross-bedded to horizontally-laminated echinoderm grain facies. Up-section, echinoderm grains decrease whereas bryozoa and carbonate mud slightly increase (Figure 10). Bryozoa and bivalve grains are larger and less fragmented in the upper portion. This suggests an overall decrease in energy and a facies change from a moderate to high energy echinoderm bank to moderate energy current-sorted detritus off echinoderm-bryozoa banks. The Middle Loomis Member is overlain sharply by the oolite facies of the Upper Loomis Member.

The Upper Loomis Member is a gradational sequence from the massive oolite facies to the massive "superficial" oolite, pelletoid facies. This sequence seems to represent a change from high energy ooid sand flats within the barrier complex to moderate energy lagoonal sediments due to: 1) an increase in the original carbonate mud content (Figure 10).

2) the "superficial" ooids have a pelletoid core with only one lamination 3) numerous pelletoid grains and 4) the overlying tidal flat complex environment.

Marston Member

In the west, high energy shoals and tidal flats have produced the oolitic and skeletal sands of the Lower Opal Member (Macqueen and Bamber, 1968). These shoals and tidal flats are barriers which permitted development of lagoons in the eastern part of the area (ibid). Cyclic calcareous muds, lime muds and sand, and microdolomite of the Marston Member represent alternating lagoon and sabkha conditions (ibid).

The Lower Marston Member at Plateau Mountain is a thick sequence of tidal flat complex sediments (Figures 7 and 10). The shallow subtidal to intertidal to low supratidal mud facies is the most abundant facies. Much of the mud facies was probably very restricted, subtidal lagoon sediments which have been subsequently dolomitized. In the lower part, the moderate to high energy, current-sorted intertidal echinoderm grain facies is overlain sharply by the massive, low to moderate energy echinoderm mud facies. Intraclasts of the underlying echinoderm grain facies occur at the base of the echinoderm mud facies. The echinoderm mud facies is felt to represent a channel within the tidal flat complex. Both facies are bordered sharply by the dolomitized mud facies. The slightly dolomitized skeletal mud facies is interbedded with the highly dolomitized mud facies and is thought to represent subtidal ponds within a supratidal setting. Evaporitic supratidal conditions have produced the breccia and pelletoid evaporite facies in the middle of the Lower Marston Member.

Lagoonal conditions existed in the Upper Marston Member (Figures 7 and 10). Prolific echinoderm growth, echinoderm mud and echinoderm grain facies, within the lagoon environment built up to sea level, resulting in the shallow subtidal to intertidal to low supratidal mud facies. The restricted lagoonal skeletal mud facies occurs in the upper part of the Marston Member. It also built up to sea level producing the mud facies. Periodic argillaceous influxes into the lagoon have deposited thin beds of calcareous shale.

Carnarvon Member

Regionally, the Lower and Middle Carnarvon Member has cyclic lime muds and skeletal sands of the lagoon environment in the east (Macqueen and Bamber, 1968). The skeletal content increases westward towards the barrier complex environment. Further west, the Upper Opal Member has micritic or micritic skeletal limestone and calcareous shale interbedded indicating the open marine environment (ibid). The Upper Carnarvon Member represents an extensive lagoon in which lime mud and skeletal mud accumulated over the area (ibid).

Only two samples were point counted from the Carnarvon Member. Petrographic identification of the echinoderm mud, skeletal mud and mud facies, and the recognition of their facies relationship in the lagoon environment suggested that for the present study, no additional information would be provided by point counting.

At Plateau Mountain, the Carnarvon Member (Figure 8) contains abundant lagoonal sediments of the restricted, skeletal mud and the low to moderate energy echinoderm mud facies. They are overlain commonly by the shallow subtidal to intertidal to low supratidal mud facies where localized sediment built up to sea level. Thin calcareous shale beds were occasionally deposited within the lagoon.

In general, (Figure 8), there is a decrease in the thickness of echinoderm mud and skeletal mud facies and an increase in the occurrence of the skeletal mud and mud facies higher in the section. This change suggests that more restrictive and possibly more landward lagoonal sedimentation occurred.

The top of the Carnarvon Member has a cleaner and thicker echinoderm mud facies which may mean more open and less restrictive lagoonal deposition.

CHAPTER 4 - DIAGENESIS

Introduction

Diagenesis is defined as all processes, biological, physical and chemical, acting upon a sediment after its initial deposition and until the sediment is subjected to metamorphic temperatures and pressures (Blatt et al p.456). The present study examines the following diagenetic processes in the upper three members of the Mount Head Formation at Plateau Mountain: biological alteration, cementation, dolomitization, silicification and the development of porosity. The diagenetic processes are discussed in terms of their occurrence, relative timing and possibly origins.

Biological Alteration

Micritization

Micritization is the process in which a carbonate grain is altered to microcrystalline carbonate (Bathurst, 1966, 1971). Bathurst (ibid) described a centripetal replacement of irregular borings into skeletal grains, a process taking place in the Bimini Lagoon, Bahamas. The boring and colonization by algae produce a hole which is later filled with micritic aragonite or high-Mg calcite by an unknown process. With continued algal boring, the grain would develop a micritic envelope.

Algal micritization has been documented in the Persian Gulf by Kendall and Skipwith (1969b) and in Australia by Swinchatt (1969). Kendall and Skipwith (1969b) suggested that boring algae will completely alter carbonate grains if they are exposed to sunlight for sufficient time. Swinchatt (1969) stated that an abundance of algal-bored grains represents deposition in less than 40 meters of water and probably less than 15 to 18 meters unless the grains have been transported to deeper depths.

Most workers consider micritization as a destructive process. However, Kobluk (1976) proposes a process in which partial destruction of the grain occurs and then is followed by a constructional process in which the grain is enlarged. In modern reef and reef channels, endolithic algae bore into the substrate and become calcified (ibid). The algal filaments bore into the outer surface of the substrate and develop a mass of filaments that are calcified with continued growth. These filaments will then grow out beyond the surface into the pores and become possible sites of cement precipitation.

Micritization in the Upper Mount Head Formation at Plateau Mountain appears to be confined to the oolite and echinoderm grain facies of the Loomis Member. A brownish-grey, microcrystalline, iron-poor calcite occurs as: 1) elongate tubules, 0.01 to 0.1 mm long and 0.01 to 0.06 mm wide, perpendicular to the skeletal grain margins (Plate 6D), 2) partly developed envelopes on the outer portion of skeletal grains (Plate 6D), and 3) completely developed envelopes around the outer portion of skeletal grains (Plate 2E). The base of the envelope is commonly irregular but may be straight. The thickness of the micritized area is variable depending upon the degree of alteration. Where a complete envelope has developed it can vary from a thin micritic zone to a thick micritic zone with only a small core remaining.

Micritization commonly occurs on echinoderm and bivalve grains. Mollusc shells are recognized by a micritic envelope which preserves the original shell outline (Plate 6C). Echinoderm grains which are ooid cores commonly have a micritic envelope developed prior to the ooid laminae deposition.

The three occurrences of micritization represent the various stages of alteration of a grain towards a completely micritized grain as inferred by Kendall and Skipwith (1969b). The micritic envelopes occur only in the moderate to high energy barrier complex environment representing ooid sand flats, echinoderm banks and reworked bank detritus. In the barrier complex environment, the moderate to high energy currents winnow out the carbonate mud and rework the grains so that the grains are exposed to sunlight for longer periods and are not rapidly buried by mud, favouring abundant algal growth.

The lack of micritic envelopes within the other environments may indicate either: 1) sediment deposition was below the photic zone such that boring algae could not live (Swinchatt, 1969), or 2) rapid sedimentation has buried the grains so they are not exposed to sunlight. The author favours the rapid sedimentation interpretation as lagoonal sedimentation characterizes much of the Marston and Carnarvon Members, and modern lagoons are very shallow and within the photic zone (Gebelein, 1974).

Burrowing

Burrows, endolithic lebensspuren (Teichert, 1975), by unknown organisms are preserved within the Marston and Carnarvon Members. Vertical to sub-vertical burrows (Plate 5D) range from 2 to 7 mm in diameter and are up to 10 mm in length. In the field, these burrows are commonly recognized by spherical areas filled by fine to coarse crystalline calcite cements (Plate 5A). The lower part has pelletoids, skeletal debris and carbonate mud cemented by iron-poor calcite. The upper portion is completely filled by iron-poor calcite cements. These burrows are common at either the top of the echinoderm mud or skeletal mud facies.

A mottled branching vertical burrow (Plate 5C) within the skeletal mud facies is completely occupied by pelletoids, skeletal debris and carbonate mud. Calcite cements were precipitated into primary pores.

Vertical burrows are confined to the intertidal zone according to Rodriguez and Gutschick (1970). Water movement during tides causes burrowing organisms to be scarcer in the intertidal zone. Sediments would not be as bioturbated as subtidal sediments which have abundant burrowing organisms. The skeletal mud and echinoderm mud facies were stabilized and organisms burrowed downward from the intertidal zone. The branching form seems to represent a burrowing organism which lived completely within the stabilized skeletal mud facies sediment.

The highly dolomitized mud facies has vertical to sub-vertical and horizontal burrows. They are 1 to 5 mm in diameter and vary up to 22 mm in length. Carbonate mud completely filled the burrows and was subsequently dolomitized. These burrows characterize the shallow subtidal to intertidal zone (Rodriguez and Gutschick, 1970).

The sediment infilling the vertical burrows is very similar to some of the echinoderm mud facies sediments. These sediments are interpreted to have been extensively burrowed. Abundant burrowing is common within modern subtidal environments (Gebelein, 1974).

The massive echinoderm grain facies is interpreted to represent an echinoderm bank. Burrowing organisms in this area of prolific faunal growth would have destroyed any laminations. The relatively low carbonate mud content of these sediments makes it difficult to identify any burrowing. The massive character suggests burrowing may have been a major process. However, the massive character may result from rapid accumulation or continuous sedimentation without any breaks.

Cementation

Introduction

The cement types identified in the Upper Mount Head Formation at Plateau Mountain are drusy, syntaxial rim and blocky. A detailed description of their morphology and habit is presented below. Relative time of formation and possible diagenetic origin are also discussed. The cement percentages are based upon the total sample point counted (Appendix B). The porosity classification scheme used is that of Choquette and Pray (1970).

Drusy Cement

The drusy cement is a clear, equant, iron-poor calcite rimming interparticle, intraparticle, shelter, fenestral, burrow and moldic pores. The calcite crystals vary from 0.01 to 0.09 mm in length and grew perpendicularly outward from the pore wall. Length to width ratios are generally less than 1.5:1. Some crystals have dogtooth terminations.

The drusy cement forms as either a discontinuous or continuous fringe lining the void. The fringe varies from a single crystal to a mosaic. Drusy mosaic commonly forms in intraparticle, interparticle and moldic pores of relatively small dimensions. In some cases, the cement has completely occluded the pore.

The abundance of drusy cement is related primarily to the abundance of interparticle and shelter porosity. In the Loomis Member, the echinoderm grain, oolite and "superficial" oolite, pelletoid facies had high original interparticle and shelter porosity. Drusy cement occurring within interparticle, shelter, intraparticle and moldic pores ranged from 7 to 15%. The echinoderm grain, echinoderm mud and skeletal mud facies of the Marston and Carnarvon Members had low original interparticle and shelter porosity. These facies have 1% or less drusy cement in interparticle, shelter, intraparticle, burrow and moldic pores. The mud facies has 1% or less drusy cement in fenestral pores. Drusy cement is not present in the pelletoid evaporite and breccia facies.

However, the shallow subtidal to intertidal echinoderm grain facies of the Lower Marston Member had a high original interparticle and shelter porosity but contains only 1 to 2% drusy cement. Abundant syntaxial rim cement has developed around echinoderm grains that have no micritic envelopes.

Syntaxial Rim Cement

Syntaxial rim cement occurs in the echinoderm grain, echinoderm mud, oolite, skeletal mud, mud and "superficial" ooid, pelletoid facies. This cement varies from 1 to 25%.

The syntaxial rim cement is a clear, iron-poor calcite that forms a single crystal in optical continuity with its host echinoderm grain. It occurs in interparticle (Plate 6D, E, F) intraparticle, burrow, shelter (Plate 6A) and moldic pores. No syntaxial rim cement has been observed on grains where a micritic envelope completely surrounds the grain or where the grain is in contact with carbonate mud or another grain. A syntaxial rim cement may form if only a small segment of the grain has not developed a micritic envelope (Plate 6D). One or more grains may be encompassed in a poikilotopic manner by the syntaxial rim cement (Plate 6F). Some moldic pores are partly filled with syntaxial rim cement from adjacent echinoderm grains.

Because echinoderm fragments are the only host grain, the amount of syntaxial rim cement present depends upon the abundance of echinoderm grains. The presence or absence of micritic envelopes also influences syntaxial rim cement abundance. In the Middle Loomis Member where micritic envelopes on echinoderm grains are common, a sample from the subtidal echinoderm grain facies has 52% echinoderm grains and 7% syntaxial rim cement. In the Lower Marston Member where the echinoderm grains do not have any micritic envelopes, the shallow subtidal to intertidal echinoderm grain facies has 53% echinoderm grains and 16% syntaxial rim cement. In the Upper Marston Member where no micritic envelopes are present, the subtidal echinoderm grain facies has 50% echinoderm grains and 12% syntaxial rim cement. Thus the presence of micritic envelopes decreases the abundance of syntaxial rim cement.

First Generation Blocky Cement

The first generation blocky cement is clear, equant, iron-poor calcite that occludes most pores not filled by the drusy and syntaxial rim cements. These pores may be interparticle (Plate 6B, C), intraparticle (Plate 6B), shelter (Plate 6A), moldic (Plate 6C), breccia (Plate 4F), burrow or fenestral. The length to width ratios are generally approximately 1:1. The crystal size varies from 0.03 to 0.20 mm in diameter. The blocky cement may be a single crystal or a mosaic filling the void. Within a particular pore, drusy and first generation blocky cement are distinguished by the distinct contrast in size and habit. The first generation blocky cement is coarser and overlies the drusy cement.

The first generation blocky cement occurs in all facies but is generally less than 25% of the total rock. Similar to the drusy cement, the first generation blocky cement is more abundant in the facies with high original interparticle and shelter porosity. The Loomis Member had high original interparticle and shelter porosity in the echinoderm grain, oolite and "superficial" oolite, pelletoid facies. First generation blocky cement ranges from 2 to 21%. The lower values are due to a greater degree of syntaxial rim cement development. In the Marston and Carnarvon Members, the echinoderm grain, echinoderm mud, skeletal mud, mud and pelletoid evaporite facies vary from low to no original interparticle and shelter porosity. First generation blocky cement varies from 0 to 5%. Syntaxial rim cement has greatly reduced what little original interparticle and shelter porosity was present.

In the breccia facies, the cement (Plate 4F) comprises approximately 88% of the rock due to the dissolution of evaporites and later precipitation of the first generation blocky cement around the clasts. The sample consists of approximately 76% first generation blocky cement with 1:1 length to width ratios and approximately 12%

first generation blocky cement with length to width ratios ranging from 1:1 to 1.5:1. The more elongated form overlies the equant form which has lithified the clasts together. Approximately 5% porosity (visual estimate) is present.

Second Generation Blocky Cement

The second generation blocky cement occurs throughout the Upper Mount Head Formation as clear, equant, iron-poor calcite in fractures (Plate 3F). Calcite crystals form a mosaic and range from 0.03 to 0.20 mm in diameter. Length to ratios are approximately 1:1.

Cement Relationships

The drusy and syntaxial rim cements were the first cements precipitated on the depositional components. The relative timing between these cements seems to be penecontemporaneous. Plate 6D illustrates an interparticle pore in which the drusy cement has formed a discontinuous fringe on a thin micritic envelope of an echinoderm fragment. The syntaxial rim cement whose host grain is the echinoderm fragment has completely obliterated the remaining interparticle pore space. The above relationship suggests the drusy and syntaxial rim cements formed at the same time. The syntaxial rim cement started to grow on parts of the echinoderm fragment with no micritic envelope whereas the drusy cement developed on the micritic envelope portions of the fragment. Syntaxial rim cement will form at a faster rate since it is a single crystal precipitated on an echinoderm fragment composed of only one crystal. In contrast, the drusy cement consists of a number of crystals competing against each other. The micritic envelope has abundant microspar crystals which act as the nuclei for the drusy cement. The more rapid growth of the syntaxial rim cement results in the pore space being occluded by the syntaxial rim cement.

Blocky cements were precipitated at two different times. The first generation blocky cement overlies both the drusy and syntaxial rim cements. Interparticle, shelter, intraparticle, burrow, fenestral, breccia and moldic porosity has been almost completely occluded by this blocky cement.

Fractures related to thrust faulting transect all depositional and diagenetic fabrics. The second generation blocky cement has partly or completely filled these fractures.

Diagenetic Timing

Evidence in the Lower Marston Member suggests that cementation occurred early in the diagenetic history. The Lower Marston Member has shallow subtidal to intertidal echinoderm grain facies overlain by subtidal echinoderm mud facies within a tidal flat complex environment (Figure 8). The echinoderm mud facies sharply overlies the echinoderm grain facies with the contact being stylolitic. Approximately 2 cm above the contact are subrounded to angular intraclasts of the underlying echinoderm grain facies. The echinoderm mud facies is interpreted to be a subtidal channel deposit which has dissected the tidal flat complex.

All three cements drusy, syntaxial rim and first generation blocky, are present in the shallow subtidal to intertidal echinoderm grain facies and within the echinoderm mud facies' intraclasts. Syntaxial rim cement, 16 to 25%, is the dominant cement type. The drusy and first generation blocky cements occur in minor amounts, less than 2%. The paucity of drusy and first generation blocky cements, and the abundance of dolomite along the periphery of the intraclasts make it difficult to determine precise diagenetic relationships.

However, the angularity of the intraclasts and the truncation of the syntaxial rim cements along the periphery of the intraclasts strongly suggest that some degree of cementation had taken place prior to erosion.

Rare compaction features within the Upper Mount Head Formation are compression of grains against one another and dissolution of grains at grain-grain contacts. These features are thought to have occurred prior to cementation.

The above evidence indicates that early cementation by the penecontemporaneous drusy and syntaxial rim cements has formed an indurated sediment resistant to compaction. The first generation blocky cement may represent either an early or late diagenetic fabric that developed prior to stylolitization. Stylolites cross-cut the drusy, syntaxial rim and first generation blocky cements.

The thrust faulting fractures in which the second generation blocky cement is present, cross-cut the stylolites. The second generation blocky cement is a very late diagenetic fabric.

Diagenetic Environments

The precipitation of the drusy, syntaxial rim and first generation blocky cements occurred in one or more of the following diagenetic environments: 1) submarine, 2) vadose, 3) shallow subsurface, or 4) deep subsurface.

Common criteria used in the identification of vadose diagenesis are meniscus cement (Dunham, 1971), gravitional cement (Muller, 1971) and vadose silt (Dunham, 1969). These diagenetic fabrics were not observed within the Upper Mount Head Formation at Plateau Mountain. Although the author does not negate the possibility of vadose cementation, no diagnostic evidence for vadose cementation was found.

The lack of major compaction within the sediments prior to cementation suggests that at least the drusy and syntaxial rim cements could not have formed in the deep subsurface. However, the first generation blocky cement may have formed in the deep subsurface or possibly in another diagenetic environment.

Early lithification by the drusy and syntaxial rim cements, the lack of vadose diagenetic fabrics and the lack of major compaction favor initial cementation in the submarine and/or the shallow subsurface diagenetic environment.

Modern submarine cements are acicular aragonite, and acicular high-Mg calcite (Ball, 1967 ; Shinn, 1969; Taylor and Illing, 1969; Land and Goreau, 1970; James et al, 1976). If during later neomorphism the original morphology was retained, the cement would be bladed to acicular calcite. No studies have proven whether the original morphology would be preserved or whether it would change to a more equant morphology. The crystal size might also be either reduced or enlarged.

Two criteria used in modern and ancient studies to recognize submarine cementation are: 1) borings which have transected grains and cements (Evamy and Shearman, 1969; Purser, 1969; Shinn, 1969; Land and Goreau, 1970), and 2) internal marine sediment overlying the submarine cement in a geopetal fashion (Land and Goreau, 1970).

Cotter (1966) and Myers (1974) found their submarine cements to be "cloudy" while the shallow subsurface cements were "clear". Cotter (1966) suggested that the "cloudiness" was due to the depositing medium being seawater. Seawater contains more minute particles than meteoric water. During crystal formation, these minute particles become trapped within the crystal giving the cloudy appearance.

The modern and ancient shallow subsurface cements are clear, equant, low-Mg calcite (Folk, 1974). A common product of modern shallow subsurface diagenesis is the dissolution of aragonite grains forming moldic porosity (Gavish and Friedman, 1969; Steinen, 1974; Friedman, 1975). Myers (1974) used iron-rich and iron-poor zonation to identify probable flucuating solution compositions within an ancient shallow subsurface environment.

The characteristics described above for shallow subsurface diagenesis are also characteristics of the vadose and deep subsurface diagenetic environments.

Diagenetic Origin

The following observations bear on the origin of the penecontemporaneous drusy and syntaxial rim cements:

1) The sediments lack major compaction prior to cementation,

2) Diagnostic vadose features such as meniscus cement,

gravitational cement and vadose silt were not observed,

3) The drusy cement is "clear", equant, iron-poor calcite,

4) The syntaxial rim cement is "clear", iron-poor calcite in optical continuity with its host echinoderm grain,

5) Moldic porosity although minor has mainly drusy cement forming a discontinuous or continuous fringe within the pore. The syntaxial rim and/or the first generation blocky cements have occluded the remaining moldic pore space,

6) No marine sediment was observed overlying the cements,

7) No borings transecting grains and cements were observed,

8) The drusy cement precipitated into interparticle shelter, intraparticle, burrow, fenestral and moldic pores. The syntaxial rim cement precipitated into interparticle, shelter, burrow and moldic pores.

9) In the Lower Marston Member, drusy and syntaxial rim cements had partly lithified the sediments prior to erosion by a channel in the tidal flat complex.

Although the observations are not conclusive, the combination of the observations presented above suggests that the penecontemporaneous drusy and syntaxial rim cements were formed in the shallow subsurface diagenetic environment.

As previously mentioned, the first generation blocky cement was precipitated slightly after the drusy and syntaxial rim cements within the shallow subsurface environment or possibly in the deep subsurface prior to stylolitization.

The second generation blocky cement was formed by subsurface or modern near-surface fluids percolating along the fractures developed after the thrust faulting of the Mississippian sequence.

Dolomitization

Description

In outcrop, the very fine to fine crystalline dolomitic rocks weather yellowish brown when dolomite is abundant. Sedimentary structures such as burrows (Plate 5B) and laminations (Plate 3D) have been preserved.

Dolomitization has affected all facies to some extent. The shallow subtidal to intertidal mud facies has been extensively dolomitized. Abundant dolomite occurs as discrete conformable layers varying from 5 cm to 4.0 m thick. The contact between both the underlying and overlying units is either sharp or gradational within a few centimeters. The dolomite content decreases very rapidly.

Within the other facies, the dolomite content does not exceed 50% but may approach this value when an extensively dolomitized interval overlies and/or underlies the facies. Very slightly dolomitized facies may also overly or underly the highly dolomitized mud facies.

Point counting of some dolomite layers indicate 100% dolomite. X-ray analysis of dolomite to calcite ratios (Appendix C) shows that the 100%, point counted, dolomite samples actually varied from 84 to 100 wt %. The highest x-rayed dolomite value, 100%, occurred in the Lower Marston Member where the thickness of the dolomitized interval is 4.0 meters. In the other x-rayed samples, the calcite content is either carbonate mud that was not affected by dolomitization or calcite cement that was precipitated into intercrystalline pores formed after dolomitization of the carbonate mud. Petrographic identification is difficult since it occurs at a submicroscopic level.

In the mud facies, iron-rich or iron-poor euhedral dolomite rhombs (Plate 7B) as determined by staining, form a crystalline mosaic. The dolomite rhombs vary from 0.01 to 0.06 mm in size but are generally between 0.02 and 0.04 mm in size. The crystals either have a dusty appearance or are zoned. The dusty appearance is due to numerous inclusions of argillaceous or organic material or carbonate mud incorporated within the crystal. The zoned crystals have a dark dusty core with a clear outer rim. Some small dolomite rhombs have a large dolomite rhomb overgrowth (Plate 7C). The larger dolomite rhomb grew on the upper portion of the small dolomite rhomb.

Within a particular interval, the dolomite composition is constant. The composition seems to be related to the composition of the original carbonate mud. Iron-rich dolomites will develop from iron-rich carbonate mud. The iron within the carbonate mud could have possibly come from detrital iron minerals (Berner, 1971). These minerals might have been in the form of an argillaceous component within the sediment. Bacterial or inorganic processes could release the iron into solution.

In facies other than the mud facies, dolomite crystals are iron-poor, clear to slightly dusty, euhedral rhombs. Four occurrences of dolomite rhombs were observed: 1) isolated to numerous euhedral rhombs replacing carbonate mud (Plate 7A, E), 2) isolated to numerous euhedral rhombs replacing micritic envelopes or the outer portion of micritic grains (Plate 7D), 3) isolated euhedral rhombs replacing parts of skeletal grains (Plate 7A), 4) isolated euhedral rhombs replacing drusy and syntaxial rim cement (Plate 6D, E, F).

Distribution

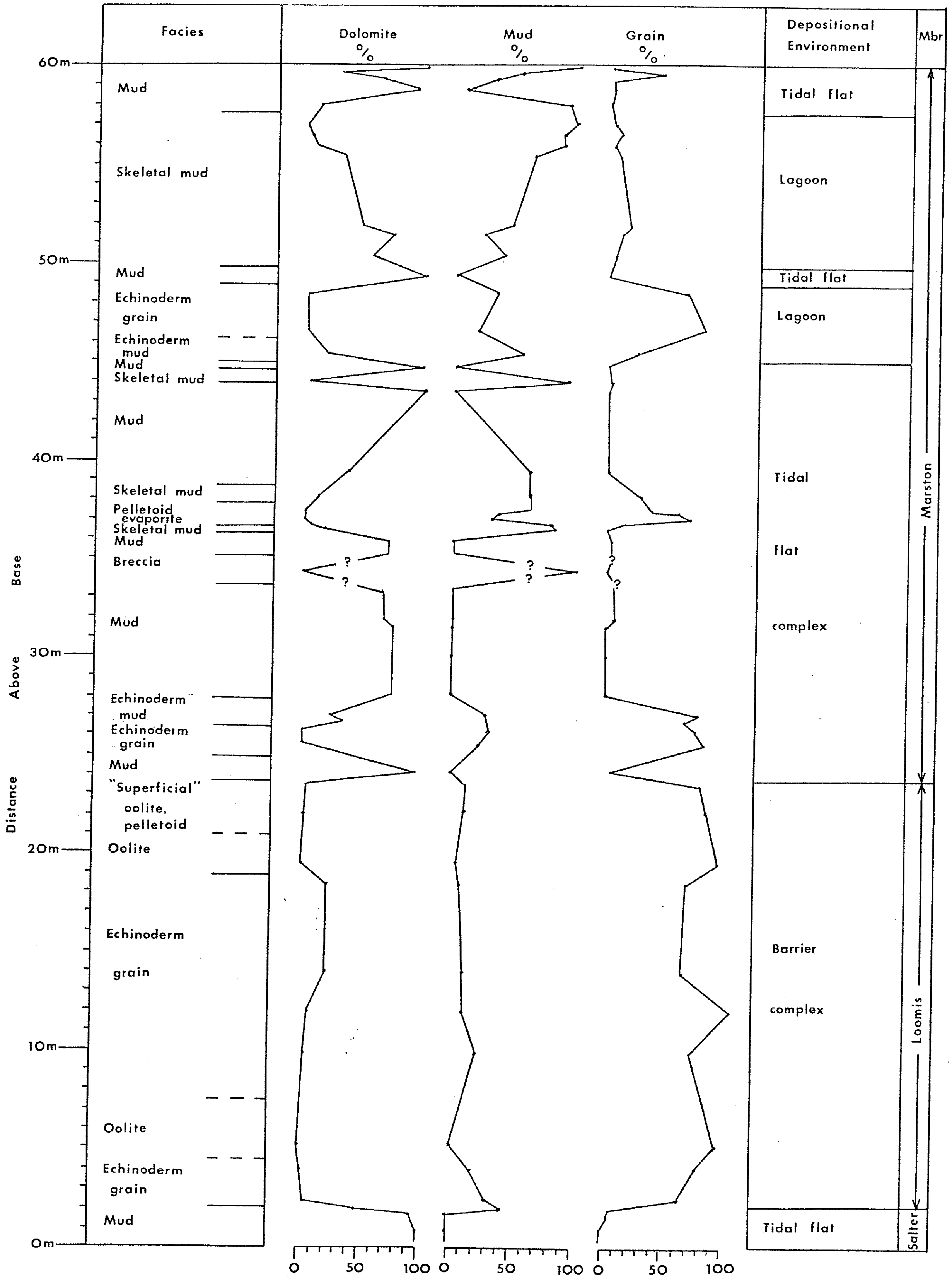
Throughout the Mount Head Formation at Plateau Mountain, dolomite beds occur as discrete conformable layers within the shallow subtidal to intertidal mud facies. The dolomite content within these layers decreases rapidly at the contact with the overlying and underlying limestone.

The values discussed below are based upon point count data (Appendix B).

At the Salter-Loomis contact (Figure 11), the intertidal to shallow subtidal mud facies of the Salter Member sharply overlies the moderate energy subtidal echinoderm grain facies of the Loomis Member. However, within approximately 50 cm the dolomite content has decreased from 100% in beds of the uppermost Salter Member to 5% in beds of the basal Loomis Member. The decrease was not solely a function of the original carbonate mud content since within the mud facies, dolomite declined from 95% to 49%. Abundant carbonate mud, 43%, was still present. The packstone just above the Salter-Loomis contact also contains 32% carbonate mud but only 5% dolomite.

Within the Marston Member, figure 11 shows a sharp reduction in the dolomite content at the mud facies contacts with the adjacent facies. The carbonate mud content is relatively high in these other facies but dolomitization has not affected the sediments to the same degree as the mud facies. The distribution of dolomite beds within the Carnarvon Member (Figure 8) has similar characteristics.

Figure 11: Dolomite, Mud and Grain Relationships to Facies and Environments in the Loomis and Marston Members.



Facies
Dolomite %
Mud %
Grain %
Depositional Environment
Mbr
60m
50m
40m
30m
20m
10m
0m
Distance Above Base
Mud
Skeletal mud
Mud
Echinoderm grain
Echinoderm mud
Mud
Skeletal mud
Mud
Skeletal mud
Pelletoid evaporite
Skeletal mud
Mud
Breccia
Mud
Echinoderm mud
Echinoderm grain
Mud
"Superficial" oolite, pelletoid
Oolite
Echinoderm grain
Oolite
Echinoderm grain
Mud
Tidal flat
Lagoon
Tidal flat
Lagoon
Tidal flat complex
Barrier complex
Tidal flat
Marston
Loomis
Salter
0 50 100
0 50 100
0 50 100

At the top of the Marston Member (Figure 7), the mud facies overlying the skeletal mud facies has fenestral laminations and 10% dolomite rhombs. A highly dolomitized mud facies interval sharply overlies it. Within the Carnarvon Member (Figure 8), the fenestral laminated mud facies also has a low dolomite content, less than 15% (visual estimate). Fenestral laminations are formed in the intertidal to low supratidal zone (Logan et al, 1974).

The characteristics of dolomite distribution within the Upper Mount Head Formation are: 1) abundant dolomite forms discrete, conformable layers, 2) the layers consist of greater than 84% dolomite, 3) these layers represent the shallow subtidal to intertidal mud facies, 4) a rapid decrease in dolomite content occurs at the contact with the adjacent facies, 5) adjacent facies have less than 50% dolomite, 6) abundant carbonate mud is not the sole factor in dolomite distribution since some facies with abundant carbonate mud may be only slightly dolomitized, 7) the fenestral laminated mud facies is slightly dolomitized.

The above characteristics lead the author to believe that there was an early dolomitization event that was related to the mud facies. A later dolomitization event was superimposed on the early dolomitization as indicated by dolomite in the other facies.

Diagenetic Timing

The dolomite distribution suggests at least two dolomitization events. The early dolomitization, facies related, was confined mainly to the shallow subtidal to intertidal mud facies. The late dolomitization occurred primarily in the subtidal facies.

Two types of crystal zoning within the highly dolomitized mud facies support the contention of at least two dolomitization events: 1) large dolomite rhombs have formed overgrowths on small dolomite rhombs, and 2) some dolomite rhombs have a dusty core with a clear outer rim. The early dolomitization produced small dusty rhombs while the late dolomitization formed larger, clearer rhombs. The late dolomite rhombs range from 2 to 28% within the subtidal facies.

Petrographic observation of the late dolomite rhombs has provided information on diagenetic timing. Isolated individual dolomite rhombs or groups of dolomite rhombs clearly replace grains (Plate 7D), drusy (Plate 7D, E) and syntaxial rim cements (Plate 7D, F). Dolomite rhombs were not found with the first generation blocky cement completely surrounding them. The last stage of the first generation blocky cementation has not been observed to contain dolomite. The late dolomitization post-dates drusy and syntaxial rim cementation and pre-dates the first generation blocky cement.

However, the initial first generation blocky cement (Plate 7D, E) may possibly have been dolomitized or dolomite has grown into a void which was later occluded by the first generation blocky cement. The initial first generation blocky cementation and the late dolomitization may overlap in time.

Dolomitization Models

The occurrence of dolomite has been a problem to geologists due to: 1) its rarity in Recent and Pleistocene sediments as compared to ancient rocks, and 2) the inability to synthesize it at ordinary temperatures and pressures. Dolomite is generally found as a secondary replacement, representing reaction of solutions with previously deposited carbonate sediments, rather than primary, direct precipitation from solutions. The secondary replacement origin of the dolomite in the upper three members of the Mount Head Formation is interpreted as due to the presence of the "ghost" textures of laminations, burrows, and minor grain borders. The four models for dolomitization at the present time are evaporative reflux, evaporative pumping, mixing of shallow subsurface meteoric water and seawater, and the deep subsurface.

The evaporative reflux theory (Figure 7A) was proposed by Deffeyes et al (1965) and is a modified version of

Adams and Rhodes (1960) seepage refluction theory. Seepage refluction occurs in a very restricted evaporitic lagoon whereas evaporative reflux develops in a supratidal lake. Evaporative reflux occurs in an area of restriction in which the water becomes hypersaline due to evaporation. The Mg/Ca ratio and the solution density increase such that the solution will migrate downward and dolomitize the sediment. The restricted area is replenished by sea water that either flows underground or was deposited in the basin during storms.

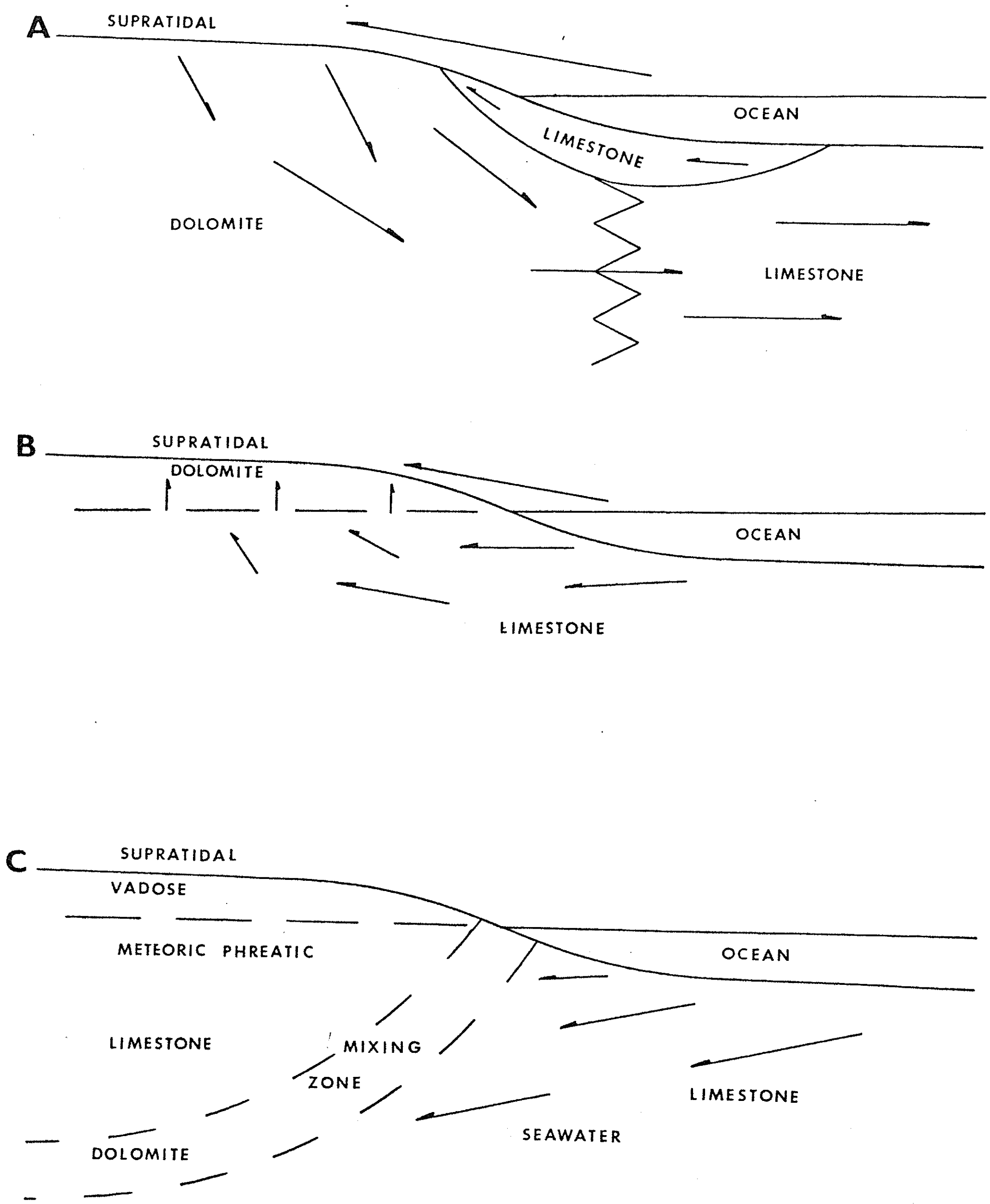
The evaporative pumping theory (Figure 7B) was developed from modern dolomite occurrences in the Persian Gulf and the Bahamas. In the Bahamas (Shinn et al, 1965), dolomite, less than 3µ in size, occurs on supratidal mud flats in pelleted muds which contain laminations, stromatolites and mud cracks. Up to 80% dolomite rhombs may develop at or near to the surface just above the mean high tide level. In the Persian Gulf (Illing et al, 1965), dolomite rhombs, 1 to 5µ in size, occur on the sabkha surface in aragonite mud between the grains. Dolomite abundance increases landward such that when the process is completed a cryptocrystalline to microcrystalline dolomite is formed with the resistant skeletal fragments remaining. Dolomitization occurs in the top 2 to 3 feet and alters sabkha and intertidal sediments. Algal laminations are

Figure 12: Dolomitization Models

(A) Evaporative Reflux (modified after Deffeyes et al, 1965)

(B) Evaporative Pumping (modified after Shinn et al, 1965)

(C) Mixing of Shallow Subsurface Meteoric Water and Seawater (modified after Hanshaw et al, 1970).


A
SUPRATIDAL
OCEAN
LIMESTONE
DOLOMITE
LIMESTONE
B
SUPRATIDAL
DOLOMITE
OCEAN
LIMESTONE
C
SUPRATIDAL
VADOSE
METEORIC PHREATIC
OCEAN
LIMESTONE
MIXING
ZONE
LIMESTONE
DOLOMITE
SEAWATER

preserved. Evaporative pumping involves the upward movement of interstitial water of marginal marine sediments and evaporation at the sediment-air interface (Friedman and Sanders, 1967). As in evaporative reflux the Mg/Ca ratio increases and dolomitization results. Water is replenished by lateral movement of sea water through the sediments from the adjacent marine environment or by flooding through storm action.

The theory of dolomitization by mixing of shallow subsurface meteoric water and sea water (Figure 7C) was proposed by Hanshaw et al (1970) (ground water theory) and Badiozamani (1973) (Dorag dolomitization model). Dolomitization is thought to occur in the zone of mixing between meteoric water and sea water when the Mg/Ca ratio exceeds 1 (Hanshaw et al, 1970). With 30% mixing of meteoric water the solution is undersaturated with respect to calcite but dolomite saturation increases continuously (Badiozamani, 1973).

Land (1973) in examining Pleistocene carbonate sediments in north Jamaica identified Ca-rich dolomite occurring as: 1) randomly oriented, euhedral rhombs, 8 to 25μ in size, replacing micrite, 2) replacement of high-Mg calcite red algal allochems, and 3) isopachous drusy linings of either primary or secondary pores. Land suggested that the dolomite was forming in the mixing zone where meteoric infiltration rates are slower and magnesium can be derived from seawater.

Very little is known about the deep subsurface environment. Folk and Land (1975) reported that "subsurface waters show an extremely wide range in composition", from low to high salinities. The salinity increases deeper into the subsurface. Subsurface waters commonly have a low Mg/Ca ratio. In order for dolomite to form, the Mg/Ca ratio must exceed 1:1 in the shallow subsurface and 5:1 in the deep subsurface due to the increasing salinity with depth.

Diagenetic Origin

Macqueen and Bamber (1968) interpreted the microdolomites occurring in the Mount Head Foramtion to be penecontemporaneous dolomite within supratidal sabkhas similar to the modern Persian Gulf. The present study found that the early dolomitization was related to the shallow subtidal to intertidal mud facies. Hypersaline solutions derived from supratidal sabkhas may have percolated downward and laterally, dolomitizing the underlying shallow subtidal and intertidal sediments. Alternatively, the evaporative conditions within supratidal sabkhas may have drawn interstitial water upward causing hypersaline solutions to develop and dolomitize the shallow subtidal and intertidal sediments. Therefore, the early dolomitization could have resulted from either the evaporative reflux or the evaporative pumping mechanism of dolomitization.

Supratidal sabkhas have played a role in producing the hypersaline solutions but very few of the supratidal sediments at Plateau Mountain were dolomitized. The evaporitic supratidal pelletoid, evaporite facies and the intertidal to low supratidal fenestral laminated mud facies contain less than 10% dolomite. The author can not be certain whether these dolomite rhombs are from the early or late dolomitization. Early dolomite rhombs are favored due to their facies occurrence and their small size. Early dolomitization although related to supratidal sakbhas did not dolomitize the supratidal sediments to the same extent as the underlying shallow subtidal to intertidal sediments.

Macqueen and Bamber (1968) considered the dolomite within the other facies to have formed later than the penecontemporaneous dolomite. An electron microprobe analysis of magnesium distribution from some Loomis Member samples (Macqueen and Ghent, 1970) identified minute dolomite crystals in echinoderm grains. The crystals are 1 to 10μ in size and average 5μ. Macqueen and Ghent (1970) interpreted these dolomite rhombs to have an exsolution origin. Magnesium was derived from echinoderm grains and their pore-filling calcite cements during neomorphism (ibid).

An alternative explanation for the magnesium could be that micritic high-Mg calcite mud occupied the intraparticle pores of the echinoderm fragment. During neomorphism, the high-Mg calcite mud was inverted to low-Mg calcite releasing magnesium. At Plateau Mountain, carbonate mud filling intraparticle pores of echinoderm grains is common. Macqueen and Ghent's (1970) interpretation suggests that the echinoderm fragments and the syntaxial rim cement were originally high-Mg calcite. Syntaxial rim cementation would have occurred within the submarine environment. However, the present cementation study has inferred that the syntaxial rim cement was more likely to have formed from shallow subsurface meteoric water. Meteoric water produces low-Mg calcite cement not high-Mg calcite cement (Folk, 1974). The data collected in the present cementation study favor the alternative explanation that magnesium was derived from high-Mg calcite mud within intraparticle pores.

The late dolomitization post-dates the drusy and syntaxial rim cement but pre-dates the first generation blocky cement. Since the blocky cement may have precipitated in either the shallow subsurface or deep subsurface environments, the late dolomitization was either a shallow subsurface meteoric water - seawater mixing origin or a deep subsurface origin.

The early dolomite has served as sites of later dolomite growth resulting in the mud facies being almost totally dolomitized. Land (1973) suggests that Mg-rich hosts, micrite and algal allochems, are important to dolomite nucleation. In the Loomis Member, micritic envelopes, micritic grains and micrite are prime sites of dolomitization. Minor dissolution and the selective dolomitization indicate these depositional components were probably original high-Mg calcite. The neomorphic conversion of the unstable high-Mg calcite to the stable low-Mg calcite may have provided magnesium necessary for dolomitization. Additional magnesium could be provided from seawater or deep surface connate solutions. The late dolomitization ceased upon the completion of this neomorphic process.

Gavish and Friedman (1969) suggested high-Mg calcite is converted to low-Mg calcite very early, 7,000 to 10,000 years, within Recent to Neogene carbonates of Israel. If neomorphism has occurred early, the late dolomitization may result from mixing of shallow subsurface meteoric water and seawater. However, the deep subsurface origin can not be excluded.

Silicification

Description

Silicification in the Upper Mount Head Formation occurs in a variety of forms. Megascopically, silicification forms are: 1) isolated spherical chert nodules varying from 2 to 10 cm thick and up to 2 meters long (Plate 8A), 2) conformable beds, up to 1.5 meters thick, of abundant spherical chert nodules with some carbonate remaining (Plate 8B), and 3) small spherical siliceous nodules, less than 2 mm diameter, in 1 to 4 mm thick laminations (Plate 4D). The nodules weather white to light grey and are accentuated by differential weathering.

The chert nodules have a sharp, commonly stylolitic undulatory contact with the surrounding carbonate. The contacts are parallel to sub-parallel to bedding but do transect sedimentary laminations (Plate 8A).

The chert nodules are microcrystalline, anhedral, equant quartz crystals that may show increasing crystal size, up to 0.07 mm. Argillaceous and/or organic material seems to limit the crystal size to less than 0.01 mm. Grain outlines of ooids, bivalves and pelletoids are preserved by argillaceous and/or organic material.

At the top of the Carnarvon Member, a chert nodule has an outer rim with 40 to 50% (visual estimate) unaltered limestone and 40 to 50% (visual estimate) chert (Plate 8D). The crystal size of the chert increases outward from the unaltered limestone. Colloform and/or massive, iron hydroxide (?) occurs between the unaltered limestone and the microcrystalline quartz, lining the unaltered limestone.

Carbonates adjacent to a zone of chert nodules may contain microcrystalline, equant, anhedral quartz mosaic; chert. The quartz mosaic has uniform crystal size and commonly replaces parts of echinoderm and bivalve grains. Within intraparticle pores of foraminifera, calcisphere and echinoderm grains, the quartz mosaic shows crystal size increasing toward the pore centre. Within interpreted fenestral pores (Plate 8E) only slight variation in the crystal size occurs in the quartz mosaic.

Equant to bladed, anhedral to subhedral, isolated quartz crystals, megaquartz (Folk and Pittman, 1971), vary from 0.04 to 0.07 mm in size and commonly replace micritic grains. Rarely, the megaquartz grows from one micritic grain into another micritic grain or into an interparticle pore. Euhedral prismatic crystals with rhombohedron terminations are rare.

The small siliceous nodules in the thin laminations

(Plate 4A) are 1) equant to bladed, anhedral to subhedral megaquartz crystals, 0.10 to 0.50 mm in size with numerous inclusions, and/or 2) massive opal (Plate 4) in the laminations and isolated patches, and/or 3) spherulitic length-slow chalcedony (Plate 4D).

Distribution

A zone of numerous chert nodules occur at the base of the high energy subtidal oolite facies and the top of the moderate energy, current-sorted subtidal echinoderm grain facies in the Upper Loomis Member (Figure 7). Minor isolated megaquartz crystals are present throughout the Loomis Member.

The Lower Marston Member (Figure 8) has abundant secondary quartz development. Abundant chert nodules have formed layers within the echinoderm grain and echinoderm mud facies. In the mud facies, interpreted fenestral pores are partly or completely filled by microcrystalline quartz mosaic (Plate 8E). The pelletoid evaporite facies contains thin laminations of siliceous nodules consisting of megaquartz, chalcedony and opal. Megaquartz and chalcedony clasts occur within the breccia facies.

At the top of the Carnarvon Member (Figure 9), isolated chert nodules, abundant chert nodule layers and microcrystalline quartz mosaic in intraparticle pores are present within the echinoderm mud facies.

Diagenetic Timing

Plate 8F shows a length-slow chalcedony nodule partly replacing a celestite crystal. Folk and Pittman (1971) have stated that length-slow chalcedony is formed by the replacement of evaporative minerals under high pH conditions. Strontianite (Plate 4B) occurs as: 1) alteration along celestite crystals, 2) veins cutting across laminations and megaquartz crystals, and 3) veins encompassing megaquartz crystals. West (1973) suggested that the occurrence of length-slow chalcedony and strontium minerals are indicative of former evaporites. Strontianite at Plateau Mountain was formed by the dissolution of the celestite crystals and then precipitation after silicification.

Silicification post-dates dolomitization. Dolomite rhombs are still present within chert nodules occurring in the subtidal facies. A few rhombs have partly corroded borders. In the mud facies, a megaquartz crystal has partly replaced a dolomite rhomb developing an embayment within the rhomb.

Silicification pre-dates the first generation blocky cement since in the breccia facies, length-slow chalcedony and megaquartz clasts are cemented by the first generation blocky cement.

Diagenetic Origin

A replacement origin as opposed to a primary precipitation origin of silicification is indicated by the following observations: 1) chert nodules transect laminations, 2) the nodules are not entirely chert but contain unaltered dolomite and limestone, 3) although nodules are parallel to bedding, their shape may be irregular, 4) nodule lobes, transecting laminations, have down warped the adjacent and underlying laminations (Plate 8A), 5) echinoderm fragments, bivalves, micritic grains and dolomite are partly replaced by megaquartz, 6) argillaceous and/or organic material outline "ghost" grains, and 7) chalcedony replaces celestite.

Replacement is the simultaneous capillary dissolution and precipitation of a new mineral. The increasing crystal size within intraparticle pores and chert nodules is similar to increasing crystal size of calcite cement towards the center of a pore. In some cases, the dissolution of carbonate, calcite and dolomite and the precipitation of the various forms of quartz must have had a distinct void stage. Thus, silicification was not entirely a replacement process. Some silica forms may have formed as a pore-filling cement or more likely as a combination of both processes.

The source of the silica may have been either siliceous organisms or detrital quartz. Siliceous sponge spicules and radiolaria are present in the open marine and shelf environments of the Carboniferous carbonates in Western Canada (Mamet, 1976). Minor spicules occur within the lagoon environment. No siliceous organisms were observed within the facies at Plateau Mountain.

In the Lower Marston Member at Highwood River, K.S. Glenday (1976, personal communication) has identified shale and argillaceous siltstones with detrital quartz. At Plateau Mountain, minor detrital quartz occurs in the highly dolomitized mud facies of the Lower Marston Member.

High pH conditions are necessary for dissolution of quartz (Friedman et al, 1976). Two possible means of raising the pH so quartz can dissolve are biological agents and supratidal sabkhas. Biological agents are dissolving quartz sponge spicules within modern reefs of north Jamaica (Land, 1976) and the Red Sea (Friedman et al, 1976). Supratidal sabkhas in Australia produce high pH solutions capable of dissolving detrital quartz (Peterson and von der Borsch, 1965). Therefore, the initial stage of silica formation may be very early in the diagenetic history.

Extensive silicification in the Lower Marston Member is associated with the tidal flat complex environment. The evaporitic conditions would produce high pH solutions capable of dissolving detrital quartz or siliceous organisms.

Silicification in the Upper Loomis Member and the Upper Carnarvon Member does not appear to be related to tidal flats. These zones may have contained abundant siliceous organisms. Biological activity or another process would raise the pH and dissolve the siliceous organisms. With a reduction in pH, silica would precipitate.

Porosity

Within the Upper Mount Head Formation at Plateau Mountain, cementation, dolomitization and silicification have destroyed most of the primary and secondary porosity. Primary porosity consisted of interparticle, shelter, intraparticle, burrow and fenestral pores. Secondary porosity was moldic, breccia, fracture and possibly intercrystalline pores.

Selective dissolution of some gastropods, bivalves and ooids, presumably originally composed of aragonite, developed minor moldic porosity. Selective dissolution of evaporites produced moldic porosity within the pelletoid evaporite facies and breccia porosity within the breccia facies. Thrust faulting of the Mississippian sequence has developed fracture porosity throughout the section.

The conversion of aragonite or calcite to dolomite results in a 6% or 13% volume decrease, respectively. Intercrystalline porosity may have developed from dolomitization. Although dolomitization may have increased porosity, the late dolomitization used the early dolomite rhombs as nuclei and occluded any intercrystalline pores.

Visible porosity except for fracture porosity is confined to the Lower Marston Member. The pelletoid evaporite facies has up to 12% moldic porosity. Voids are only partly occluded by megaquartz, opal and chalcedony. In the breccia facies, the first generation blocky cement has not completely occluded the breccia pores leaving 4% porosity. The highly dolomitizated mud facies, overlying and underlying the breccia facies, has up to 5% (visual estimate) moldic porosity. Dissolution after dolomitization while these rocks were still buried or surficial weathering may have selectively removed calcite echinoderm grains. Rare interparticle and shelter porosity (Plate 6E) occurs in the subtidal echinoderm grain facies in the Upper Marston Member. The porosity results from the syntaxial rim cement not occluding all of the primary pores and the first generation blocky cement not being precipitated into these voids.

Fracture porosity is the most abundant visible porosity in the Upper Mount Head Formation. The second generation blocky cement has not completely occluded all of the fractures.

CHAPTER 5 - SUMMARY AND CONCLUSIONS

Within the Upper Mount Head Formation at Plateau Mountain, the depositional environments varied from barrier complex to lagoon to tidal flat complex.

The Loomis Member was a barrier complex environment as represented by:

1) the oolite facies - high energy subtidal, adjacent to an ooid shoal; possibly sand flats;

2) the echinoderm grain facies - moderate to high energy subtidal banks and their reworked detritus; and

3) the "superficial" oolite, pelletoid facies - moderate energy subtidal, transitional between ooid shoal and lagoon or open marine shelf sediments.

The Lower Marston Member was a tidal flat complex comprised of:

1) the mud facies - very low energy, shallow subtidal to intertidal;

2) the skeletal mud facies - low energy, restricted subtidal;

3) the echinoderm mud facies - low to moderate energy subtidal (channel ?);

4) the echinoderm grain facies - moderate to high energy shallow subtidal to intertidal;

5) the pelletoid evaporite facies - evaporitic supratidal; and

6) the breccia facies - evaporitic supratidal.

The Upper Marston and the Carnarvon Members were a lagoon environment as represented by:

1) the echinoderm mud and echinoderm grain facies - low to moderate energy subtidal banks and their reworked detritus;

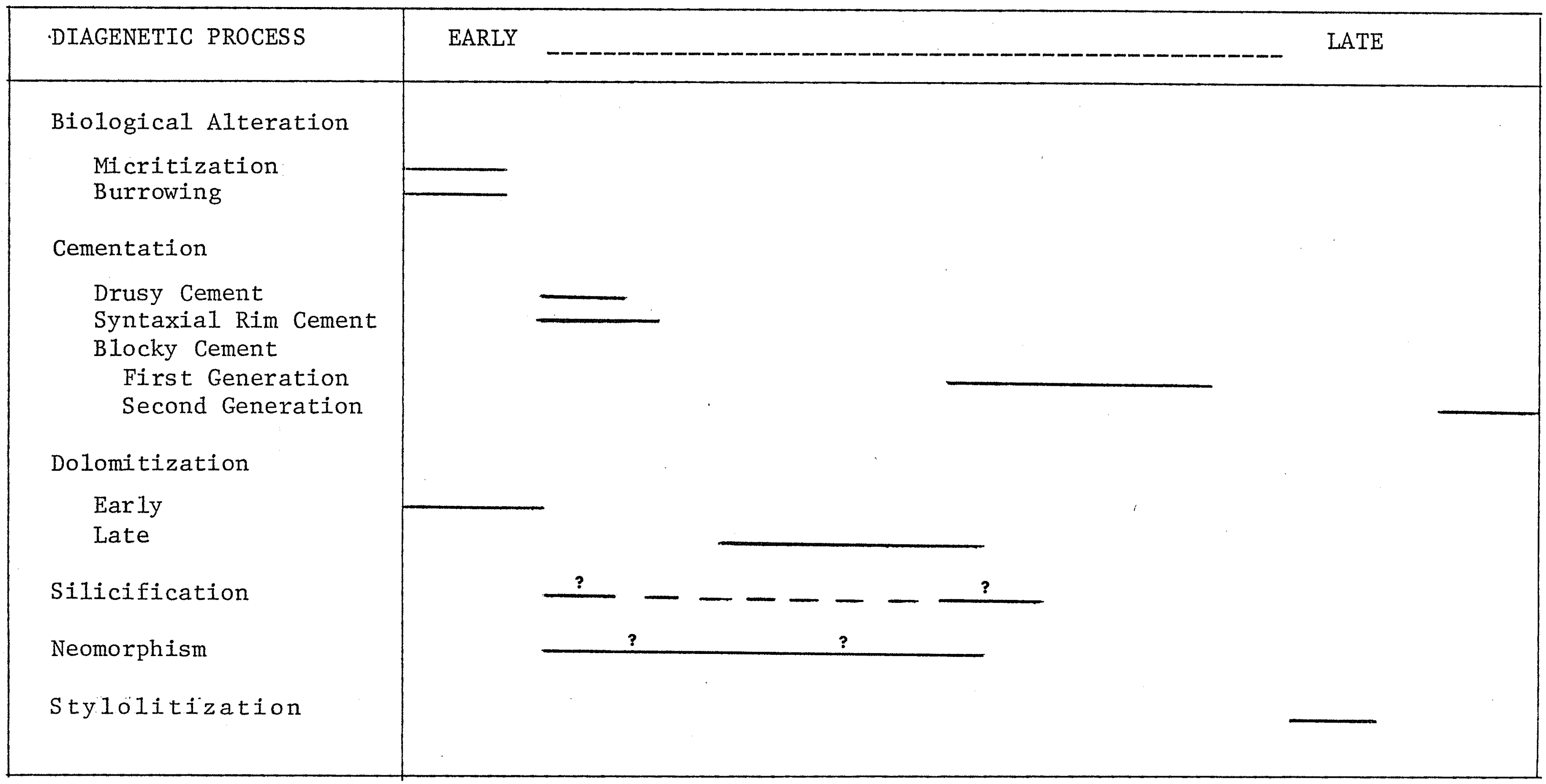
2) the skeletal mud facies - low energy, restricted subtidal; and

3) the mud facies - very low energy, shallow subtidal to intertidal to low supratidal.

The relative timing of the diagenetic processes are presented in Table 2. The conclusions regarding the diagenetic processes, their timing and origin are summarized below:

1) Micritization of grains by boring algae was confined to the oolite and echinoderm grain facies within the barrier complex environment of the Loomis Member. The moderate to high energy conditions winnowed out the carbonate mud and reworked the grains. The grains received maximum sunlight exposure, favoring boring algae growth. Within the lagoon and tidal flat complex facies, the grains were buried rapidly; thereby not favoring micritization.

Table 2: Relative Timing of Diagenetic Processes in the Upper Mount Head Formation, Plateau Mountain, Alberta.


DIAGENETIC PROCESS
EARLY
LATE
Biological Alteration
Micritization
Burrowing
Cementation
Drusy Cement
Syntaxial Rim Cement
Blocky Cement
First Generation
Second Generation
Dolomitization
Early
Late
Silicification
?
?
Neomorphism
?
?
Stylolitization

2) Burrowing occurs predominantly within the lagoon environment. Parts of the subtidal echinoderm mud facies were extensively burrowed. Vertical burrows indicate periodic exposure to the intertidal zone while horizontal and vertical burrows represent the shallow subtidal to intertidal zone. Banks and sand flats adjacent to ooid shoals of the barrier complex environment may have been extensively burrowed due to their massive character.

3) Drusy and syntaxial rim cements were precipitated penecontemporaneously into primary interparticle, shelter, intraparticle, burrow and fenestral pores and into secondary moldic pores. The absence of major compaction prior to cementation, vadose fabrics and submarine fabrics, the presence of minor moldic porosity and intraclasts which were partly lithified by syntaxial rim cement prior to erosion, suggest that these cements may have precipitated in the shallow subsurface meteoric environment. The first generation blocky cement has occluded most of the remaining primary and secondary porosity within either the shallow subsurface or the deep subsurface. Fractures produced by the thrust faulting of the Mississippian strata are filled partly by the second generation blocky cement. Subsurface or modern near surface meteoric water percolated downward along the fractures.

4) Two dolomitization events have occurred in the Upper

Mount Head Formation. The early dolomitization, facies related, affected predominantly the shallow subtidal to intertidal mud facies. Evaporitic conditions developed on supratidal sabkhas produced solutions capable of dolomitizing the sediments by either evaporative pumping or evaporative reflux. The late dolomitization post-dates the syntaxial rim cement and pre-dates the first generation blocky cement. Subtidal facies with greater porosity and permeability were affected the most. In the highly dolomitized mud facies, early dolomite rhombs were used as nuclei for the late dolomites. Late dolomitization could have originated within either the seawater - shallow subsurface meteoric water mixing zone or the deep subsurface. Some magnesium was derived from the high-Mg calcite depositional components during the neomorphic change to low-Mg calcite.

5) Silicification pre-dates the first generation blocky cement and post-dates dolomitization. In the Lower Marston Member, abundant silicification seems related to the tidal flat complex environment. Evaporative conditions could have raised the pH producing solutions capable of dissolving detrital quartz or siliceous organisms. Length-slow chalcedony has replaced at least the evaporative mineral celestite. In the Upper Loomis and Upper Carnarvon Members, silicification may be related to zones with abundant siliceous

organisms.

6) Cementation, dolomitization and silicification have occluded almost all primary and secondary porosity. The best visible porosity occurs in the fractures related to thrust faulting. In the Lower and Upper Marston Member, minor visible porosity remains because either the first generation blocky cement or secondary quartz has not completely occluded primary or secondary porosity. Selective dissolution of evaporites in the pelletoid evaporite and breccia facies have produced secondary moldic and breccia porosity, respectively. Megaquartz, chalcedony and opal have not occluded all moldic pores in the pelletoid evaporite facies while in the breccia facies, the first generation blocky cement has not totally filled the breccia pores. Selective dissolution of calcite grains has resulted in moldic porosity within the highly dolomitized mud facies. Primary interparticle and shelter porosity remains within the subtidal echinoderm grain facies due to the absence of first generation blocky cement.

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PLATES

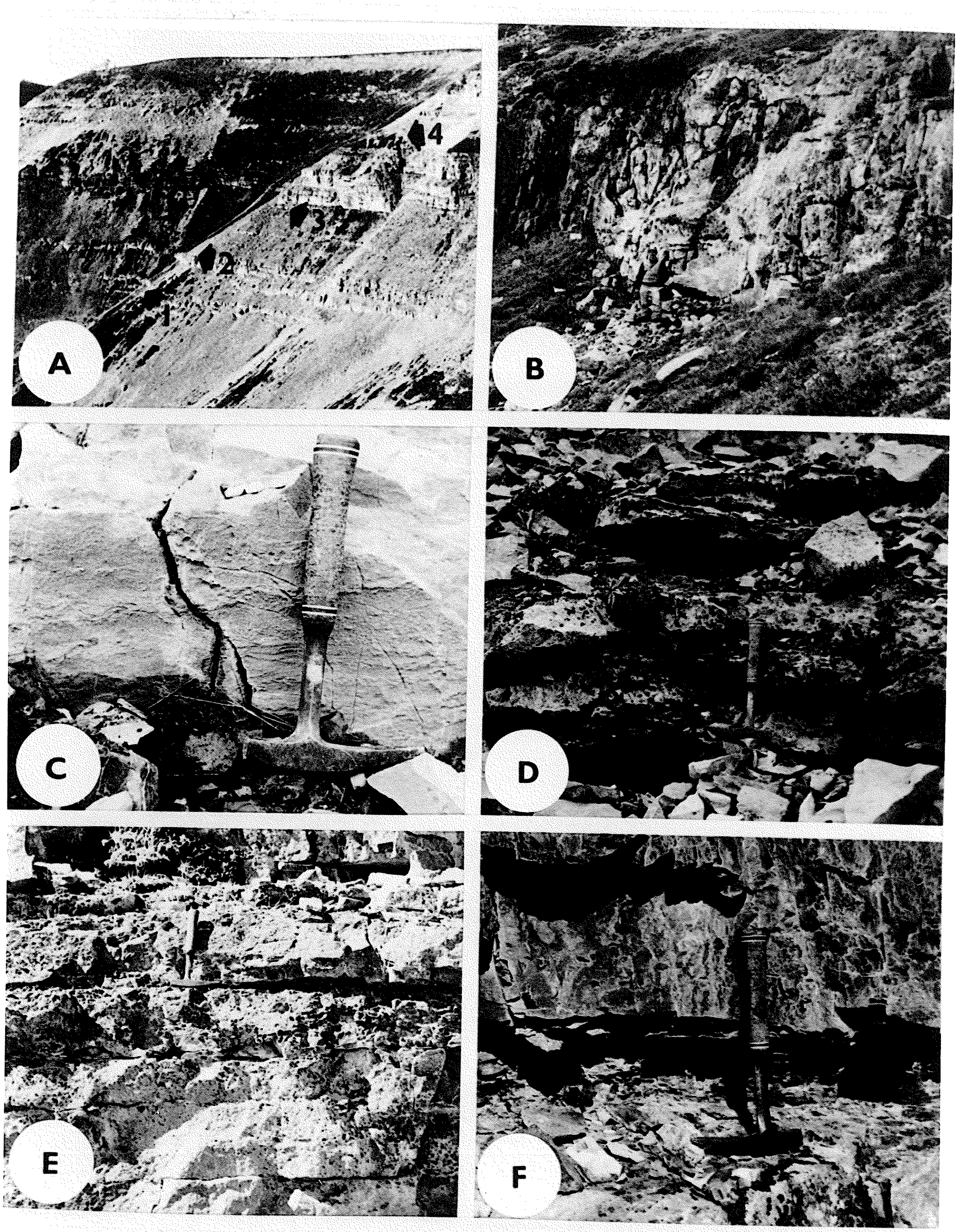
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PLATE 2 FACIES - OOLITE, "SUPERFICIAL" OOLITE, PELLETOID AND ECHINODERM GRAIN FACIES

A Oolite Facies - Loomis Member
Ooid-rich grainstone with echinoderms, pelletoids, bivalves and bryozoa had a high primary interparticle porosity. Ooid cores are pelletoids, echinoderms and bryozoa grains. On the right side an echinoderm grain has a micritic envelope completely developed around the grain. Thin section, bar, 0.5 mm.

B "Superficial" Oolite, Pelletoid Facies - Loomis Member
"Superficial" ooid-rich packstone has numerous pelletoids. The "superficial" ooid cores are all pelletoid grains. Thin section, bar, 0.5 mm.

C Echinoderm Grain Facies - Loomis Member
Echinoderm packstone is tabular cross-bedded. Hand sample, bar, 1 cm.

D Echinoderm Grain Facies - Loomis Member
Echinoderm packstone illustrates massive character. Hand sample, bar, 1 cm.

E Echinoderm Grain Facies - Loomis Member
Echinoderm-rich packstone with bryozoa, pelletoids and bivalves had high primary interparticle and shelter porosity. Echinoderm grains show various stages of micritic envelope development. Micritic envelope (ME) has almost completely altered the echinoderm grain. Thin section, bar, 1 mm.

F Echinoderm Grain Facies - Marston Member
Echinoderm-rich packstone with numerous pelletoids has no micritic envelopes developed on the echinoderm grains. Cloudy areas represent the echinoderm grains (E) and the clear areas are syntaxial rim cement (R). Thin section, bar, 0.5 mm.

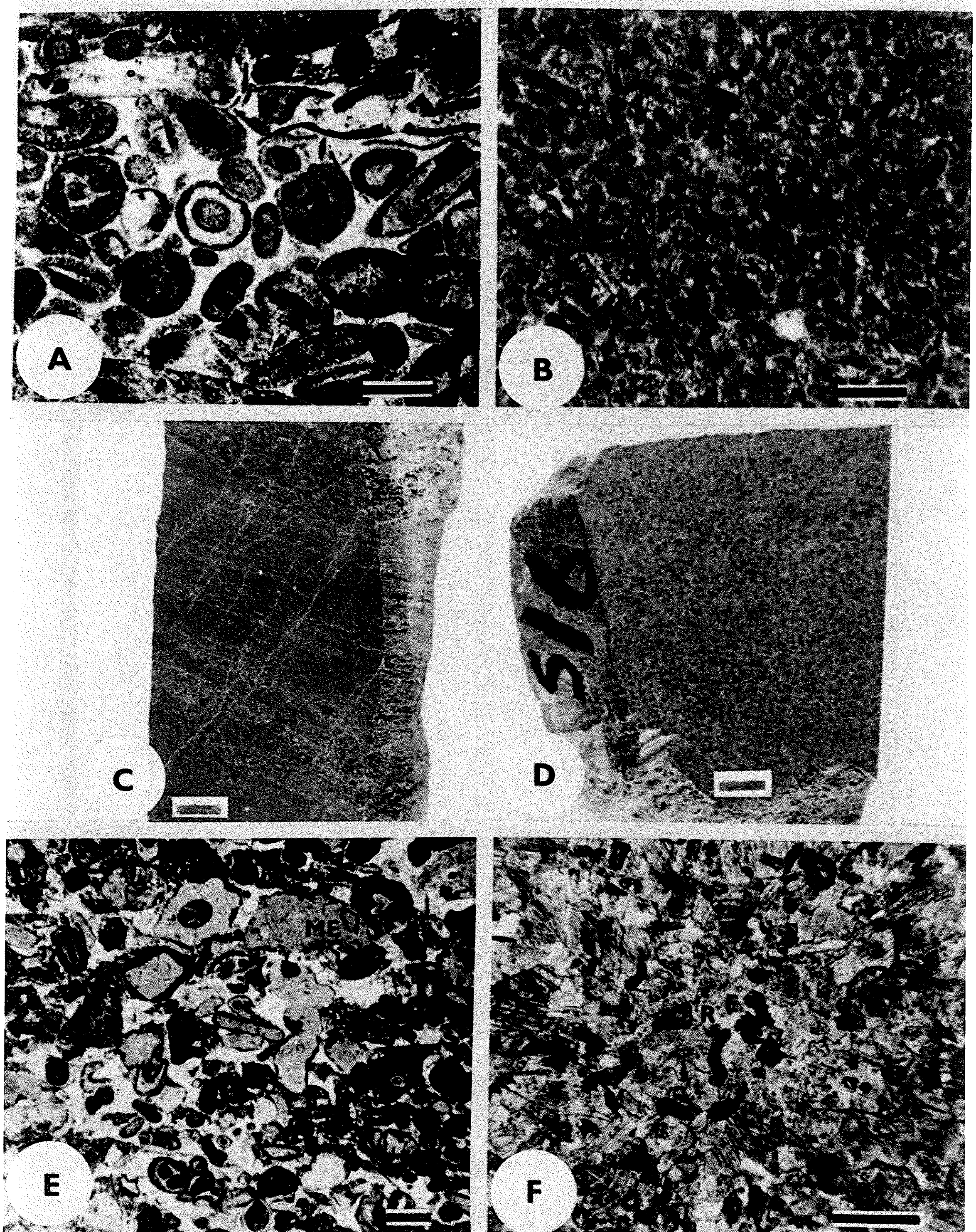
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PLATE 3 FACIES - ECHINODERM MUD, SKELETAL MUD AND MUD

A Echinoderm Mud Facies - Marston Member
The echinoderm mud facies sharply overlies the echinoderm grain facies. Angular to subround echinoderm grain intraclasts were eroded and deposited within the echinoderm mud facies. The change from dark to light shading reflects increasing dolomite content up from the contact. Hand sample, bar, 1 cm.

B Echinoderm Mud Facies - Marston Member
Echinoderm-rich wackestone with some pelletoids has no micritic envelopes developed on the echinoderm grains (E). Thin section, bar, 1 mm.

C Skeletal Mud Facies - Marston Member
Mudstone has scattered bivalve fragments. Thin section, bar, 1 mm.

D Mud Facies - Salter Member
The finely laminated sediment is highly dolomitized. The laminations are thought to be of algal origin. Hand sample, bar, 1 cm.

E Mud Facies - Marston Member
The sediment is highly dolomitized with calcite echinoderm grains. Thin section, bar, 1 mm.

F Mud Facies - Carnarvon Member
Horizontally aligned primary fenestral porosity is filled by calcite cements. Numerous fractures associated with thrust faulting transect depositional and diagenetic fabrics and are filled by second generation blocky cement. Hand sample, bar, 1 cm.

G Mud Facies - Marston Member
A slightly dolomitized mudstone has numerous primary fenestral porosity filled by calcite cements. Thin section, bar, 1 mm.

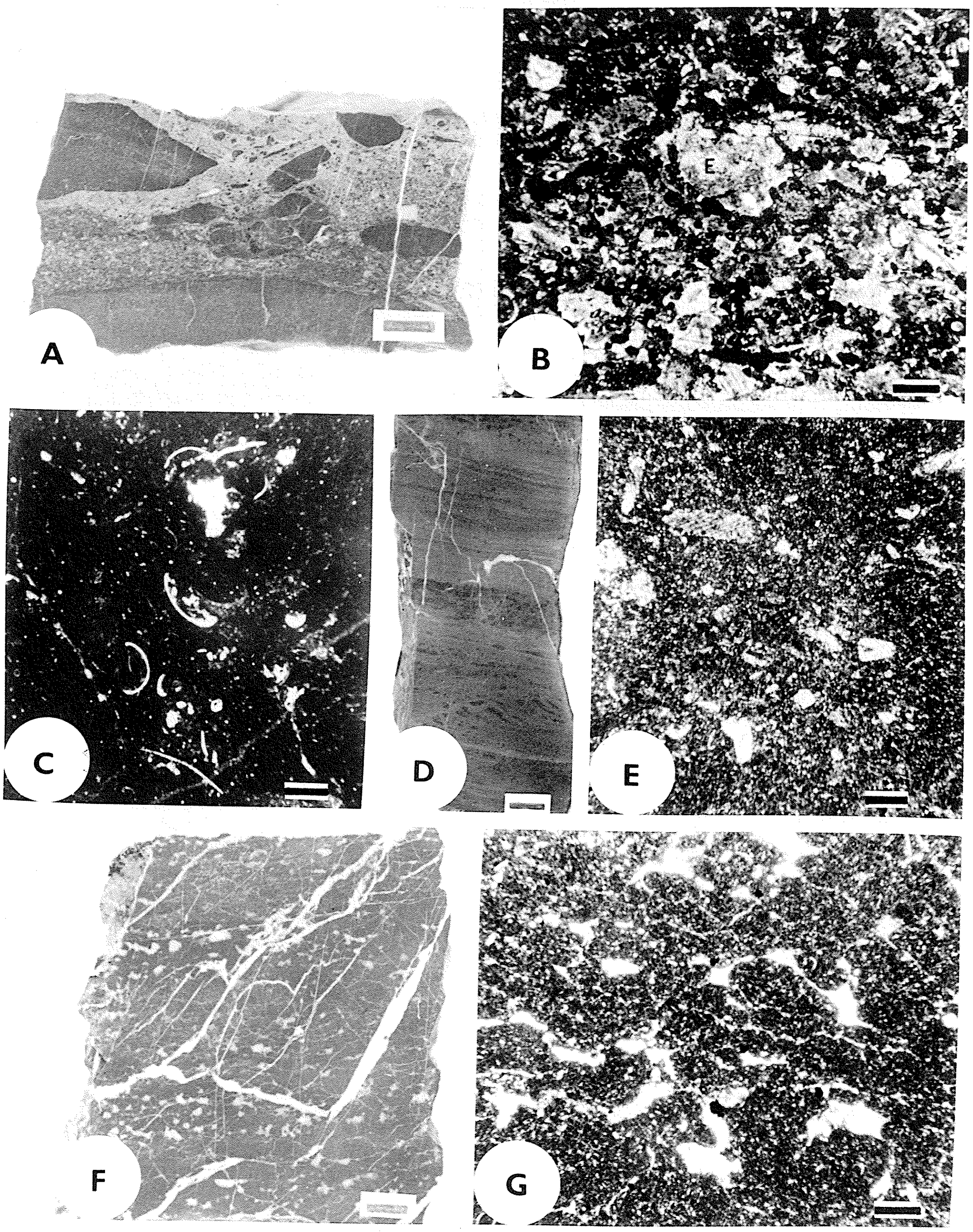
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PLATE 4 FACIES - PELLETOID EVAPORITE AND BRECCIA

A Pelletoid Evaporite Facies - Marston Member
Alternation of secondary quartz-rich (white) and mud-rich (dark) zones produces the finely laminated character. The secondary quartz-rich zones were formerly evaporites. Celestite still occur within some zones (see 4B). Hand sample, bar, 1 cm.

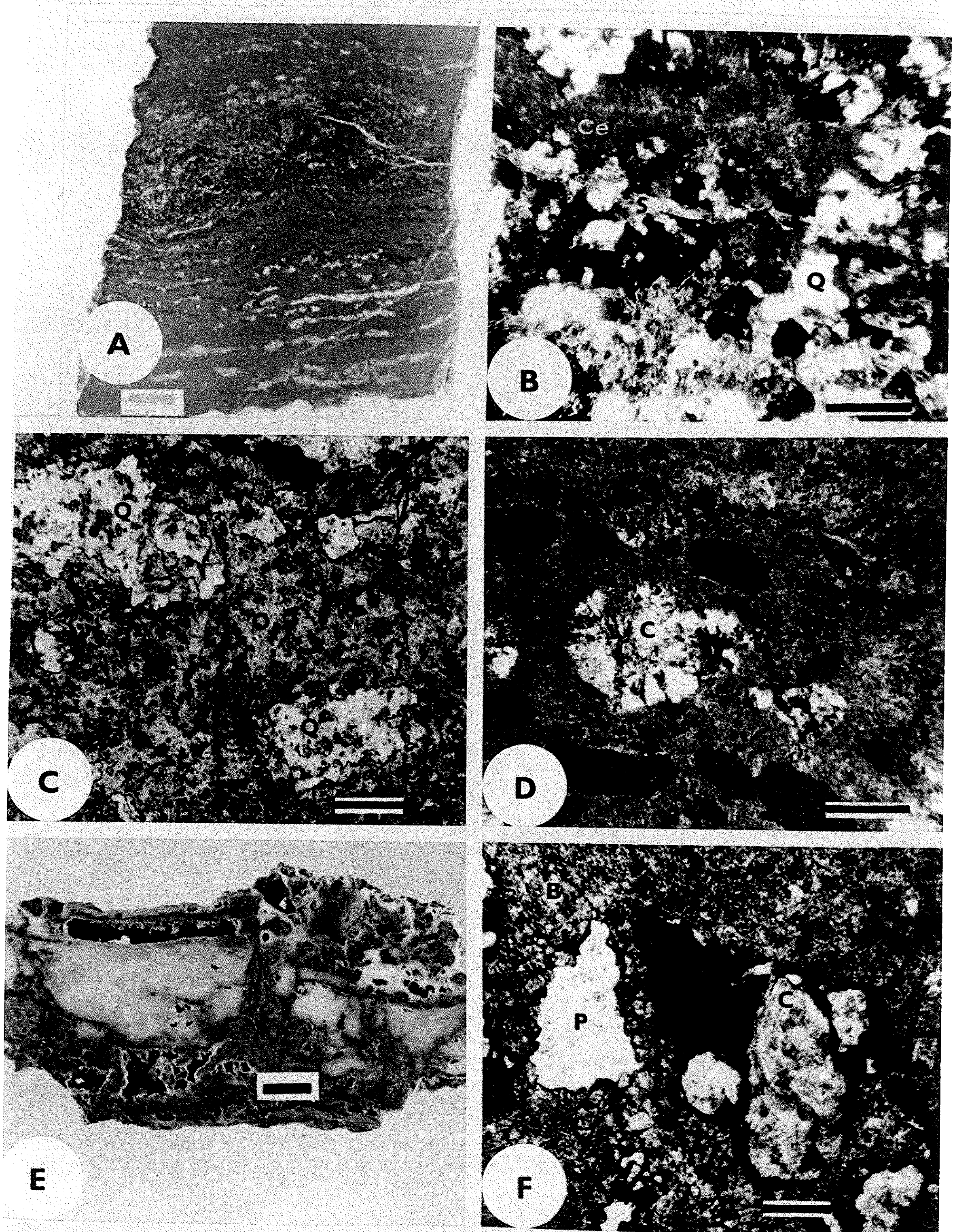
B Pelletoid Evaporite Facies - Marston Member
The quartz-rich zone has celestite (Ce), megaquartz (Q) and strontianite (S). Strontianite occurs in veins transecting celestite and megaquartz. Thin section, cross-nicols, bar, 0.5 mm.

C Pelletoid Evaporite Facies - Marston Member
The quartz-rich zone has megaquartz (Q) and opal (O). Thin section, bar, 0.5 mm.

D Pelletoid Evaporite Facies - Marston Member
Length-slow chalcedony nodule (C) is in an intraclastic wackestone. The micritic intraclasts are round, elongate and generally horizontally aligned. Thin section, cross-nicols, bar, 0.5 mm.

E Breccia Facies
Clasts (dark) are cemented by first generation blocky calcite cement (white). The secondary breccia porosity has not been occluded by the cement leaving some porosity. Selective dissolution of evaporites is interpreted to have caused the breccia porosity. Thin section, bar, 1 cm.

F Breccia Facies
A micrite clast (dark) has spherulitic chalcedony forming in it. Disseminated limonite and hematite produce the dark appearance of the clast. First generation blocky calcite cement (B) has cemented the clasts. The crystal size increases at the pore space (P). Thin section, bar, 1 cm.


A
Ce
S
Q
B
Q
C
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D
B
P
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E
F

PLATE 5 BURROWS

A Spherical vertical burrows within the skeletal mud facies of the Carnarvon Member are outlined by calcite cements (white). Field photo.

B Vertical and horizontal burrows are within the highly dolomitized mud facies of the Upper Marston Member. Field photo.

C A branching vertical burrow (arrow) (light) is within the skeletal mud facies (dark) of the Carnarvon Member. Hand sample, bar, 1 cm.

D A vertical burrow in the skeletal mud facies of the Carnarvon Member has pelletoids, carbonate mud and skeletal debris in the lower portion. The upper part of the burrow is filled by calcite cements. Thin section, bar, 1 mm.

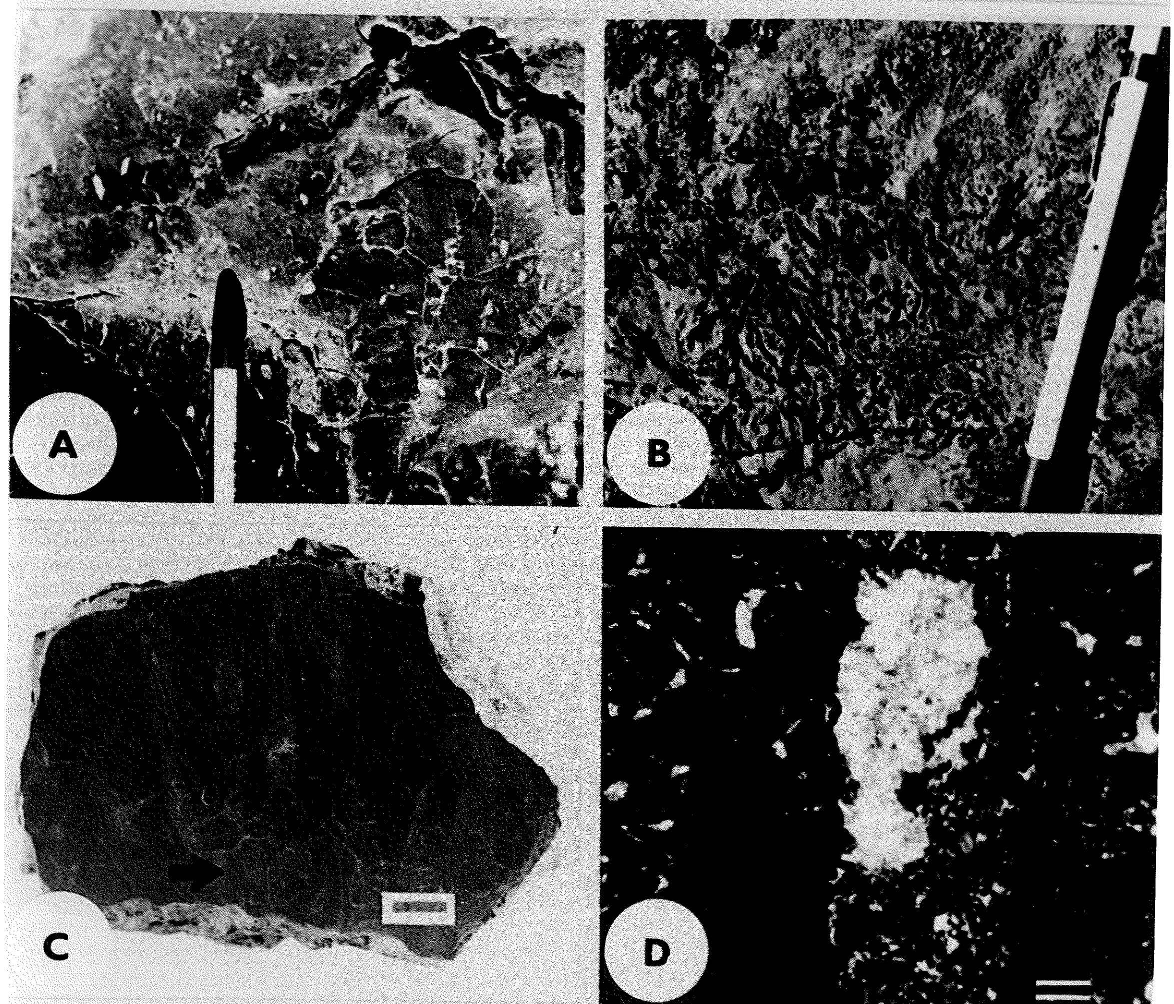
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PLATE 6 CEMENTATION

A Drusy cement (D) is a discontinuous fringe along bivalve and bryozoa grains in a primary shelter pore. Micritic envelope has developed around the bivalve grain prior to cementation. Syntaxial rim cement (R) from an echinoderm grain out of the picture overlies the drusy cement and occludes most of the pore. First generation blocky cement (B) has precipitated into the remaining pore space. Thin section, bar, 0.5 mm.

B Drusy cement (D) occurs as: 1) a continuous fringe in a primary intraparticle pore of a foraminifera grain; partly or completely occluding the pore, 2) a discontinuous fringe in primary interparticle pores. First generation blocky cement (B) has occluded the remaining pores. Thin section, bar, 0.5 mm.

C Drusy cement (D) occurs as: 1) a fringing mosaic in secondary moldic pores that have retained their original shape by development of a micritic envelope, 2) a fringing mosaic in primary interparticle pores. First generation blocky cement (B) occludes the remaining interparticle and moldic pore space. Thin section, cross-nicols, bar, 0.5 mm.

D On the right, micritic tubules (T) have developed along the margin of an echinoderm grain (E). On the left side, a thin micritic envelope has developed partly around the margin of an echinoderm grain (E). Discontinuous drusy cement (D) lines the primary interparticle pore on the micritic parts. The remaining pore space has been filled by syntaxial rim cement (R), in optical continuity with its host echinoderm grain (dark). Thin section, cross-nicols, bar, 0.1 mm.

E Abundant syntaxial rim cement (R) developed on echinoderm grains (E) with no micritic envelope. Minor primary interparticle porosity (P) remains when the syntaxial rim or first generation blocky cement did not occlude the pore space. Thin section, bar, 1 mm.

F Syntaxial rim cement (R) has encompassed several grains in a poikilotopic manner. Single megaquartz crystals (Q) has replaced a pelletoid grain. Thin section, cross-nicols, bar, 0.5 mm.

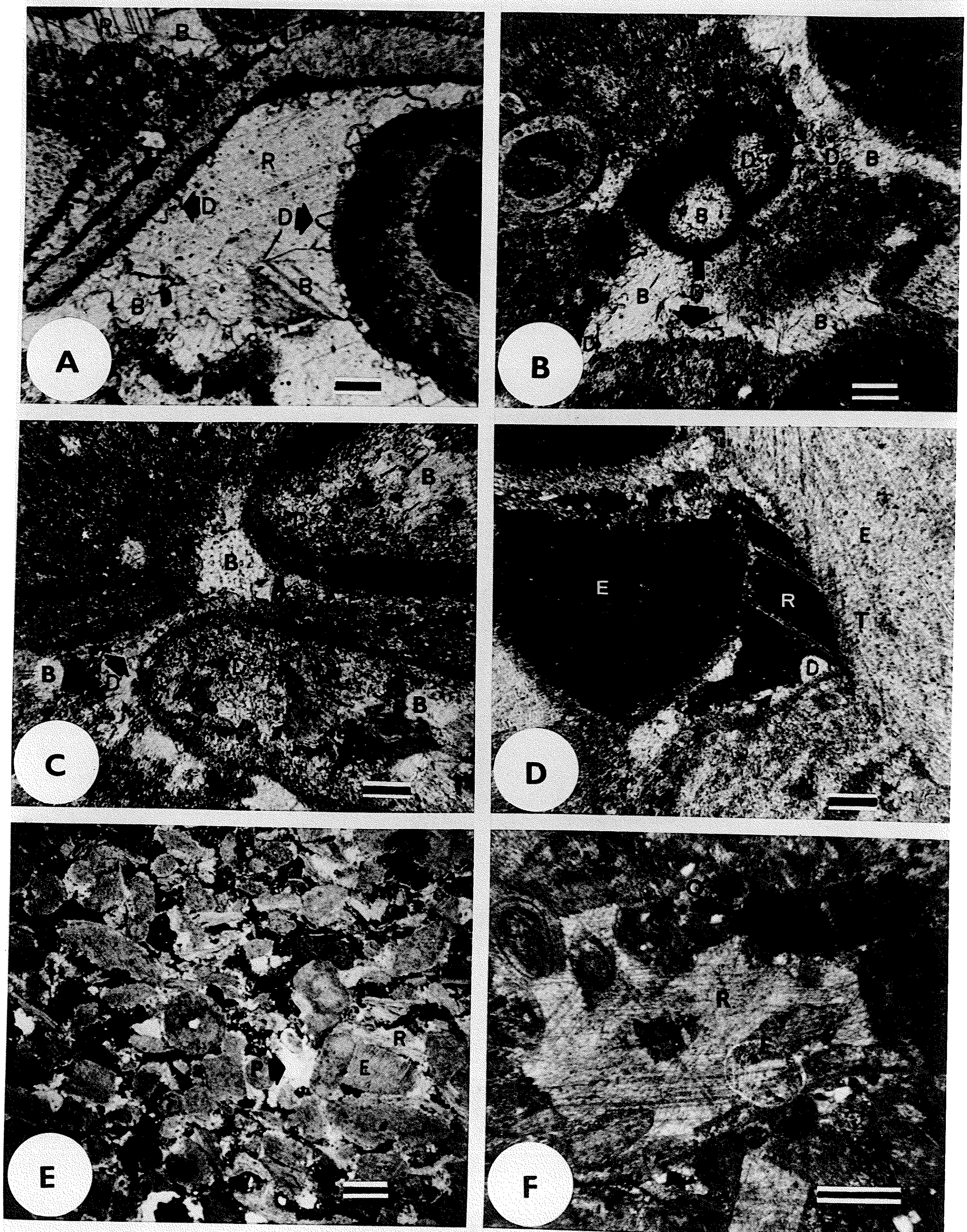
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PLATE 7 DOLOMITIZATION

A The upper part shows a dolomite mosaic (Do) which has completely replaced the carbonate mud matrix. A few echinoderm grains (E) remain with only the margin of the grain replaced by dolomite. The lower part consists of a few scattered dolomite rhombs replacing the carbonate mud. Both units represent the mud facies. The contact between the units is sharp. Thin section, bar, 0.5 mm.

B The dusty dolomite mosaic (Do) within the mud facies has a few zoned dolomite rhombs. The zoned rhombs have a dusty core and a clear outer rim. Thin section, bar, 0.5 mm.

C Large dolomite rhombs have replaced the carbonate mud matrix (M) within the mud facies. Two small dolomite rhombs have a large dolomite rhomb overgrowth. Thin section, bar, 0.1 mm.

D Large dolomite rhombs (Do) have replaced the edge of a pelletoid and the drusy cement (D). "Ghost" outline of the grain and the cement can be observed within the rhomb. Syntaxial rim cement (R) and first generation blocky cement (B) have occluded the interparticle pore space. The rhomb may have replaced the first generation blocky cement or the cement was formed after dolomitization. Thin section, bar, 0.1 mm.

E Large dolomite rhombs (Do) have replaced: 1) the carbonate mud (M), 2) the drusy cement (D) and 3) the syntaxial rim cement (R). "Ghost" outline of the cements is present in the dolomite rhomb. Thin section, bar, 0.1 mm.

F A dolomite rhomb has replaced the syntaxial rim cement (R) of an echinoderm grain (E). Thin section, bar, 0.1 mm.

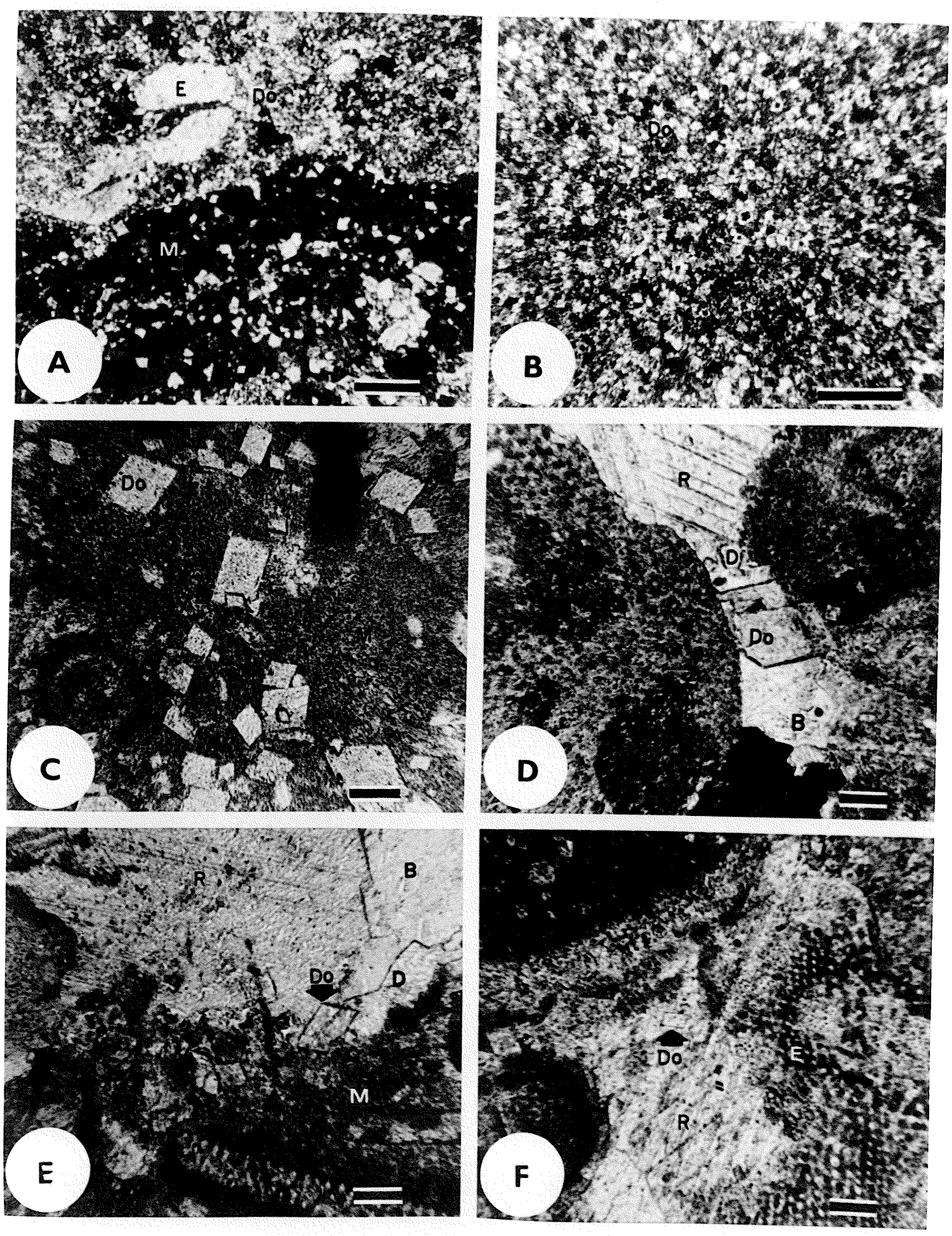
E
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PLATE 8 SILICIFICATION

A The chert nodule (Q) in the Upper Salter Member is parallel to bedding but a lobe has cut across the laminations of the underlying dolomite (Do). The underlying laminations are downwarped. Laminations are retained within the chert nodule. Field photo.

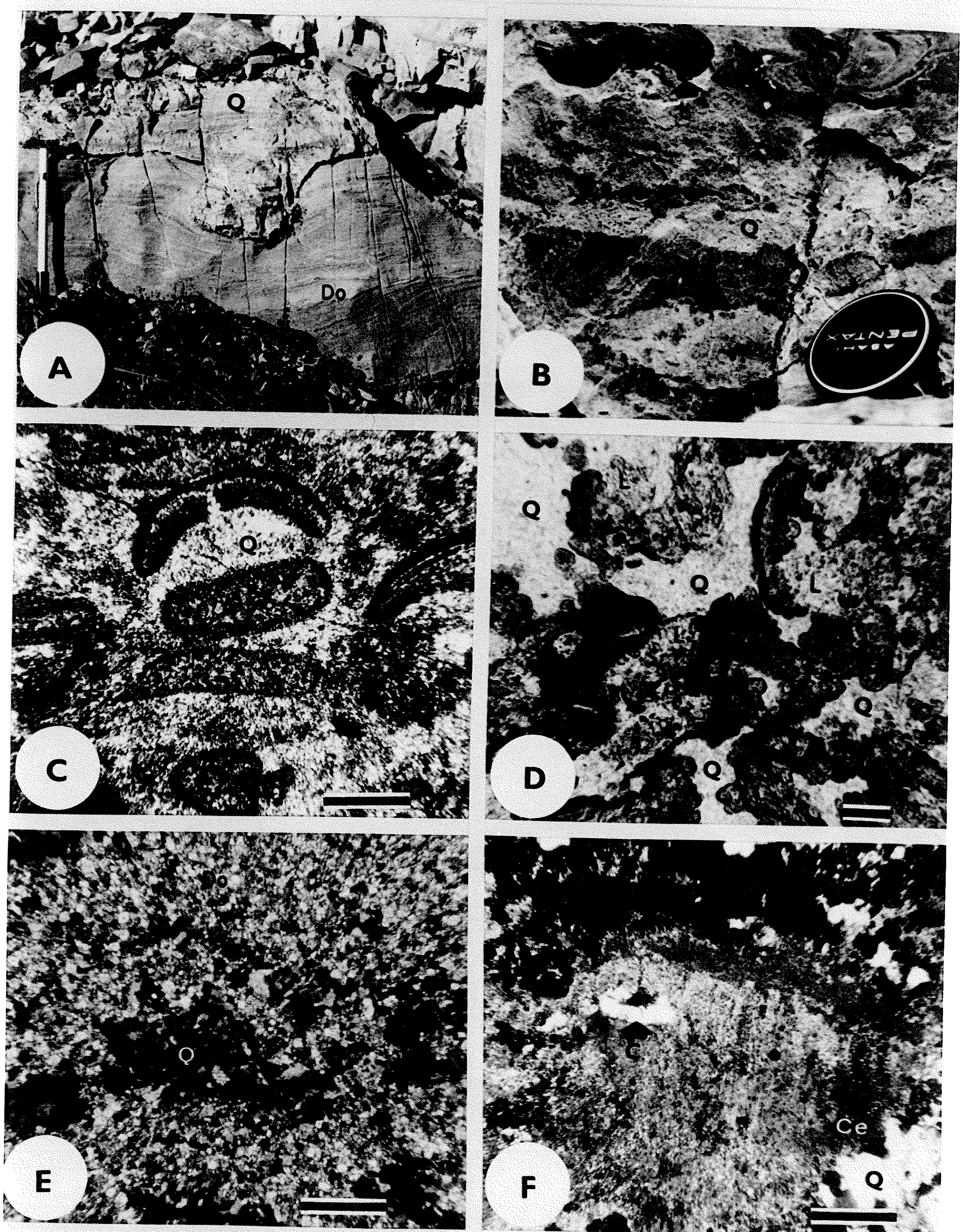
B A massive chert (Q) interval in the Lower Marston Member has preserved the original laminated character. Unaltered limestone nodules (L) are present within the chert. Field photo.

C Chert nodules are comprised of microcrystalline quartz mosaic. Argillaceous and/or organic material have preserved ooid and bivalve grain outlines. The microcrystalline quartz shows some increasing crystal size. Thin section, bar, 0.5 mm.

D The outer part of a chert nodule contains unaltered limestone (L). Massive or colloform iron hydroxide (?) (dark) overlies the limestone. The voids are filled with microcrystalline quartz mosaic similar to Plate 8C. Thin section, bar, 0.5 mm.

E Microcrystalline quartz is filling an interpreted fenestral pore within a dolomite mosaic (Do) of the mud facies in the Lower Marston Member. Thin section, cross-nicols, bar, 0.5 mm.

F Length-slow chalcedony (C) has partly replaced a celestite crystal (Ce) within the pelletoid evaporite facies of the Marston Member. The light areas in the celestite crystals are minute strontianite crystals replacing the celestite. Megaquartz (Q) is surrounding the celestite crystal. Thin section, cross-nichols, bar, 0.5 mm.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APPENDIX A

Field Description of the Upper Mount Head Formation at Plateau Mountain, Alberta

Appendix A - Field Description of the Upper Mount Head Formation Section at Plateau Mountain, Alberta

Meters above base	Thickness (meters)	Description
		Mount Head Formation
		Salter Member (upper part)
1.6	1.6	Dolomite - fresh surface medium grey, weathers yellowish brown, fine grained, finely laminated, calcareous, numerous chert nodules in the lower part which have relict laminations (some of the underlying laminations are downward), rare cross-bedding (20^{o}), overlying contact sharp.
2.0	0.4	Dolomite - weathers yellowish brown, fresh surface medium grey, fine grained, massive, calcareous, few unidentified fossils, overlying contact sharp.
		Loomis Member
6.0	4.0	Limestone - weathering and fresh surface light grey, medium to coarse grained, massive, possible increase in grain size up section (?), packstone to grainstone, middle part tabular cross-sets (laminae up to 8cm thick).
9.0	3.0	Covered Interval
15.0	6.0	Limestone - weathering and fresh surface light grey, coarse grained packstone, slightly dolomitic abundant echinoderms with possible oolites, at the base vaguely

Meters above base	Thickness (meters)	Description
		laminated, going up section becoming more laminated, (coarse grained material alternating with finer grained material), beds 1-2cm thick at top of unit, within beds fine laminations, at top tabular cross-beds.
18.0	3.0	Covered Interval
18.5	0.5	Limestone - weathering light grey, fresh surface medium grey, medium grained packstone, few echinoderms, finely laminated, numerous chert nodules (1m by 0.03cm) (10%) which are planar and parallel to bedding, overlying contact sharp and stylolitic.
23.8	5.3	Limestone - weathering medium grey, fresh surface dark grey, medium grained packstone, few echinoderms, rare brachiopods, mostly vaguely laminated but in places is laminated, chert nodules (2-5cm wide and 1-2cm long) occur in lower portion (appear massive), fossils decrease going up section, overlying contact appears sharp since it broke along a joint (may be gradational).
	Marston Member	
24.65	0.85	Dolomite - weathers yellowish brown, fresh surface medium grey, medium grained, calcareous, few corals, numerous skeletal debris (echinoderms?). matrix has been dolomitized with the fossils still calcite, overlying contact sharp.
26.05	1.4	Chert - massive and convolute

Meters above base	Thickness (meters)	Description
		lamination, relict portion of the original carbonate (dolomite and limestone) occur as spherical nodules, 90% chert, 10% relict carbonates, finely laminated (low angle cross-beds and/or ripple marks).
26.50	0.45	Limestone - weathering and fresh surface medium grey, fine grained packstone, finely laminated.
27.3	0.8	Limestone - weathering and fresh surface medium grey, fine grained wackestone, at the base are angular intraclasts of the underlying unit, upper part has more coarse grained material (fossils?), the base is massive and the upper part laminated (1-2cm thick), brachiopods present, dolomitic, overlying contact sharp.
27.8	0.5	Chert - abundant chert nodules (80%), up to 0.5m by 0.2m by 0.1m, parallel to bedding, weathers white to grey, 20% weathering and fresh surface medium grey, medium grained, wackestone with few intraclasts and finely laminated, overlying contact sharp.
29.8	2.0	Dolomite - weather yellowish brown, fresh surface dark grey, fine grained, finely laminated, at top a bed with abundant chert (0.2m thick).
30.0	0.2	Covered Interval
30.2	0.2	Dolomite - weathers yellowish brown, fresh surface, dark grey, fine grained, appears massive.
31.6	1.4	Covered Interval

Meters above base	Thickness (meters)	Description
32.3	0.7	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, massive, at top (3cm) numerous vugs due to surficial leaching of fossils (?).
33.7	1.4	Covered Interval
35.2	1.5	Solution Breccia - weathers light grey and yellow mottling, fresh surface white and yellow mottling, fragments in calcite matrix, vuggy 10%, overlying contact sharp.
36.4	1.2	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, massive, overlying contact sharp, vugs 2%.
36.6	0.2	Limestone - weathering and fresh surface dark grey, fine grained mudstone, dolomitic, finely laminated, overlying contact sharp.
37.1	0.5	Limestone - weathering and fresh surface dark grey, lithographic mudstone, highly fractured, overlying contact sharp.
37.2	0.1	Limestone - weathering and fresh surface dark grey, lithographic mudstone, finely laminated due to quartz-rich laminations, overlying contact gradational.
37.6	0.4	Limestone - weathering and fresh surface dark grey, lithographic mudstone, massive, overlying contact sharp.
37.9	0.3	Limestone - weathering and fresh surface medium grey, medium grained mudstone, finely laminated due to

Meters above base	Thickness (meters)	Description
		quartz-rich laminae, minor chert nodules at top of unit, overlying contact sharp.
38.5	0.6	Limestone - weathering and fresh surface dark grey, lithographic mudstone, finely laminated at the top, few fossil debris.
39.3	0.8	Covered Interval
40.1	0.8	Limestone - weathering and fresh surface dark grey, fine grained mudstone, dolomitic, finely laminated, numerous intraclasts, burrows (?), few fossil debris (brachiopods) along laminations.
43.4	3.3	Covered Interval
44.5	1.1	Dolomite and Limestone - at the base weathers light brown, fresh surface dark grey, fine grained dolomite with vague fine laminations, at the top weathering and fresh surface dark grey, fine grained mudstone with vague fine laminations, gradational contact, more fragments in upper part, overlying contact sharp, pyrite nodules occur in the middle.
44.52	0.02	Shale - grey, fissile, overlying contact sharp.
45.12	0.6	Dolomite - weathers yellowish brown, fresh surface medium grey, fine grained, massive, few brachiopods (?), vuggy 2% due to leaching of fossils, overlying contact sharp.
45.52	0.4	Limestone - weathering and fresh surface medium grey, fine grained

Meters above base	Thickness (meters)	Description
		wackestone, massive except for a few brachiopods along a particular zone, dolomitic, overlying contact gradational.
47.52	2.0	Limestone - weathering and fresh surface light grey, coarse grained packstone, abundant brachiopods, corals, and possibly echinoderms, laminated.
48.02	0.5	Covered Interval
49.22	1.2	Limestone - weathering and fresh surface light grey, coarse grained packstone, vaguely laminated abundant fossil debris (brachiopods), overlying contact sharp.
49.82	0.6	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, massive.
50.02	0.2	Covered Interval
51.02	1.0	Dolomite - weathers yellowish brown, fresh surface medium grey, fine grained, calcareous, slightly laminated, few fossils (brachiopods, echinoderms), overlying contact sharp.
51.62	0.6	Dolomite - weathers yellowish brown, fresh surface medium grey, fine grained, massive (vaguely laminated), numerous fossils (echinoderms, brachiopods).
51.72	0.1	Covered Interval
52.37	0.65	Limestone - weathering and fresh surface medium grey, fine grained,

Meters above base	Thickness (meters)	Description
		wackestone, slightly laminated, few skeletal debris, dolomitic.
55.67	3.3	Covered Interval
55.77	0.1	Limestone - weathering and fresh surface dark grey, fine grained mudstone, massive, few skeletal debris, scattered pyrite, dolomitic overlying contact sharp.
55.79	0.02	Shale - grey, fissile.
56.39	0.6	Limestone - weathering and fresh surface dark grey, lithographic mudstone, massive, vugs 2%, upper 0.3m highly fracture, overlying contact sharp.
57.39	1.0	Limestone - weathering and fresh surface dark grey, lithographic, mudstone, few fossil debris, few disseminated pyrite crystals, overlying contact sharp.
58.79	1.4	Limestone - weathering and fresh surface dark grey, lithographic mudstone, few sparry calcite, massive.
58.94	0.15	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained mudstone, massive, small burrows preserved, overlying contact sharp.
59.74	0.8	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, massive, numerous intraclasts, calcareous.
59.79	0.05	Dolomite - weathers yellowish brown, fresh surface dark grey, fine

Meters above base	Thickness (meters)	Description
		grained, slightly laminated, few intraclasts, calcareous, overlying contact sharp, few pyrite crystals disseminated.
	Carnarvon Member	
63.79	4.0	Limestone - weathering and fresh surface dark grey, fine grained wackestone, generally massive but finely laminated at the top, few unidentified fossils, few pyrite crystals disseminated, highly fractured, overlying contact sharp.
65.39	1.6	Limestone - weathers medium grey, fresh surface dark grey, lithographic (at the base) to fine grained (at the top) wackestone, massive, burrows, overlying contact sharp.
65.4	0.01	Shale - grey, fissile, overlying contact sharp.
65.45	0.05	Limestone - weathers medium grey, fresh surface dark grey, lithographic wackestone, few brachiopods (very small), overlying contact sharp.
65.46	0.01	Shale - grey, fissile, overlying contact sharp.
66.06	0.6	Limestone - weathering and fresh surface medium grey, lithographic wackestone, massive, overlying contact sharp.
66.07	0.01	Shale - grey, fissile, overlying contact sharp.
68.17	2.1	Limestone - weathering and fresh

Meters above base	Thickness (meters)	Description
		surface medium grey, fine grained wackestone, massive, overlying contact sharp.
70.37	2.2	Limestone - weathers medium grey, fresh surface dark grey, fine grained wackestone, finely laminated, dolomitic, overlying contact gradational.
70.55	0.0-0.18	Shale - grey, fissile, calcareous, pinches out laterally, overlying contact gradational.
73.55	3.0	Limestone - weathering and fresh surface dark grey, lithographic wackestone, massive, few brachiopods, overlying contact sharp.
75.05	1.5	Limestone - weathering and fresh surface light grey, lithographic wackestone, burrows, massive, overlying contact sharp.
77.15	2.1	Limestone - weathers medium grey, fresh surface dark grey, lithographic wackestone, massive, at top (0.6m) burrows (?) filled with calcite, overlying contact sharp.
81.5	4.35	Limestone - weathers medium to dark grey, fresh surface dark grey, lithographic wackestone, massive, overlying contact sharp.
81.8	0.3	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, finely laminated, few small burrows (?).
82.0	0.2	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, massive, few burrows at

Meters above base	Thickness (meters)	Description
		the top, few skeletal debris, matrix preferentially dolomitized, calcareous.
85.0	3.0	Limestone - weathering and fresh surface dark grey lithographic wackestone, massive, slightly argillaceous in places, very few fossils, minor burrows filled with sparry calcite, overlying contact sharp.
86.4	1.4	Limestone - weathering and fresh surface dark grey lithographic wackestone, massive, overlying contact sharp.
86.41	0.01	Shale - grey, fissile, overlying contact gradational.
86.44	0.03	Limestone - weathers yellowish brown to medium grey, fresh surface dark grey, fine grained wackestone, dolomitic, generally massive but dolomite stringers give slightly laminated appearance, overlying contact gradational.
86.45	0.01	Shale - grey, fissile, overlying contact gradational.
88.65	2.2	Limestone - weathering and fresh surface dark grey, lithographic wackestone, massive, minor vertical burrows (?) filled with sparry calcite, at the top few shaly bands (0.5cm), overlying contact sharp.
89.9	1.25	Limestone - weathering and fresh surface dark grey, fine grained wackestone, massive, slightly argillaceous at the bottom, numerous burrows at the top, overlying contact sharp.

Meters above base	Thickness (meters)	Description
90.2	0.3	Limestone - weathering and fresh surface dark grey, lithographic wackestone, massive, overlying contact sharp.
90.85	0.65	Limestone - weathers yellowish brown, fresh surface dark grey, fine grained wackestone, few skeletal debris (brachiopods?), massive, dolomitic, matrix is partially dolomitized, overlying contact sharp.
91.25	0.4	Limestone - weathering and fresh surface dark grey, lithographic wackestone, massive, numerous burrows, overlying contact sharp.
92.0	0.75	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, slightly argillaceous in places, calcareous, few skeletal debris left, matrix dolomitized, overlying contact sharp.
92.01	0.01	Shale - grey, fissile, calcareous.
93.46	1.45	Dolomite - weathers yellowish brown, fresh surface dark grey, fine grained, massive, calcareous, pyrite crystals disseminated, overlying contact sharp.
94.96	1.5	Limestone - weathering and fresh surface dark grey, lithographic mudstone, massive, upper 0.1m dolomitic with a few round intraclasts, overlying contact sharp.
96.14	1.18	Limestone - weathering and fresh surface dark grey, lithographic wackestone, massive, few burrows

Meters above base	Thickness (meters)	Description
		filled with sparry calcite, overlying contact sharp.
96.64	0.5	Limestone - weathering and fresh surface medium grey, lithographic mudstone, laminations due to fenestral voids (?) filled with sparry calcite, overlying contact sharp.
97.84	1.2	Limestone - weathering and fresh surface light grey, at the base, dark grey at the top, lithographic wackestone, at the top rounded intraclasts, massive, overlying contact sharp.
98.39	0.55	Limestone - weathering and fresh surface dark grey, lithographic wackestone, massive, few round intraclasts at the base, pyrite crystals disseminated, overlying contact sharp.
99.44	1.05	Limestone - weathering and fresh surface light grey, lithographic mudstone, massive, numerous sparry calcite, few pyrite crystals disseminated, overlying contact sharp.
100.04	0.6	Limestone - weathering and fresh surface light grey, lithographic wackestone, massive, overlying contact sharp.
100.54	0.5	Limestone - weathering and fresh surface light grey, fine grained wackestone, massive, chert nodules (5cm by 3cm) in upper portion.
100.74	0.2	Covered Interval

Meters above base	Thickness (meters)	Description
101.44	0.7	Limestone - weathering and fresh surface light grey, lithographic wackestone, massive, few chert nodules, overlying contact sharp.
102.04	0.6	Chert - abundant nodules, overlying contact sharp.
103.74	1.7	Limestone - weathers medium grey, fresh surface medium grey and dark grey mottling, fine grained wackestone, massive, overlying contact sharp.
103.76	0.02	Shale - grey, slightly fissile, calcareous, overlying contact sharp.
104.66	0.9	Limestone - weathering and fresh surface light grey, fine grained wackestone, massive, few brachiopods, overlying contact sharp.
105.36	0.7	Limestone - weathers medium grey, fresh surface medium grey and dark grey mottling, fine grained wackestone, massive.
145.36	40.0?	Covered Interval

Etherington Formation

APPENDIX B

Point Count Data

1) Raw Data
2) Percent of Depositional Component to Total of Grains, Mud and Dolomite
3) Percentage of Cements, Porosity and Quartz in Total Sample

Appendix B - Point Count Data

The stratigraphic position of the thin sections point counted are found in Figure 6 for the Upper Salter and Loomis Members, Figure 7 for the Marston Member and Figure 8 for the Carnarvon Member. Approximately 600 points in each thin section were counted at 0.5 mm spacing using the Glagalev-Chayes modal analysis method (Galehouse, 1971). The depositional components counted are ooids, echinoderms, bryozoa, bivalves, pelletoids, intraclasts, other grains, mud, dolomite, drusy cement, blocky cement, syntaxial rim cement, secondary quartz, pyrite and voids.

LEGEND

Ech - Echinoderm
Oo - Ooid
Bry - Bryozoa
Biv - Bivalve
Int - Intraclast
Oth - Other Grains
Dol - Dolomite
Dr - Drusy Cement
S R - Syntaxial Rim Cement
Bl - Blocky Cement
Qtz - Quartz
Pyr - Pyrite
Por - Porosity

* strontianite

** celestite

1) Raw Data

No.	Ech	Oo	Bry	Biv	Pel	Int	Oth	Mud	Dol	Dr	S R	Bl	Qtz	Pyr	Por
10	0	0	0	0	0	0	0	0	600	0	0	0	0	0	0
12	31	0	0	0	0	0	0	0	569	0	0	0	0	0	0
12a	28	1	2	5	1	0	8	253	284	3	4	10	4	0	0
13	116	6	2	7	138	0	30	155	21	29	46	28	1	0	0
14	118	98	7	4	42	0	32	75	3	55	24	109	0	0	0
15	72	226	3	2	101	0	34	15	1	58	0	88	0	0	0
16	186	65	10	5	50	0	23	105	13	66	43	34	0	0	0
17	262	8	51	5	35	0	52	58	31	44	40	14	0	0	0
18	193	28	21	7	43	0	11	80	116	42	29	20	0	0	0
19	174	42	51	2	44	0	33	44	111	41	37	23	0	0	0
20	90	160	94	8	40	0	35	24	0	67	23	59	0	0	0
22	5	197	0	11	87	0	18	44	18	91	1	128	0	0	0
24	25	0	0	2	0	0	5	0	555	11	0	0	0	0	0
26	253	0	2	11	36	0	6	92	2	8	149	15	21	0	5
27	244	0	7	14	54	0	8	138	1	13	98	9	13	0	0
28	163	7	14	16	9	4	4	159	167	2	6	2	37	0	0
29	114	8	9	37	41	0	0	135	98	25	62	32	5	1	1
31	0	0	0	0	0	0	0	0	506	0	0	0	70	17	7
33	0	0	0	0	0	0	0	0	562	0	0	0	33	5	0
34	0	0	0	0	0	0	0	0	560	0	0	0	36	4	0
35	0	0	0	0	0	0	0	0	552	0	0	0	40	8	0
36	0	0	0	0	0	0	0	39	0	0	0	529	9	0	23
37	0	0	0	0	0	0	1	0	567	0	0	9	0	0	23
38	0	0	0	0	0	0	2	499	99	0	0	0	0	0	0
39	0	0	0	35	45	0	7	475	31	3	0	4	0	0	0
40	5*	33**	0	0	134	0	0	60	0	0	0	0	367	0	0
41	0	0	0	1	206	0	0	142	0	0	0	9	173	0	69
42	0	0	0	0	131	43	1	293	0	0	0	0	104	0	28
43	6	26	2	10	101	0	7	341	62	8	0	37	1	0	0
44	0	0	0	1	0	0	4	363	215	15	0	0	0	2	0
46	0	0	0	0	0	0	0	0	595	0	0	0	2	3	0
47	0	0	0	8	0	0	9	560	20	3	0	0	0	0	0
48	6	0	0	2	0	0	0	0	591	0	0	0	0	0	1
49	98	0	0	20	3	8	7	326	117	1	0	8	22	0	1
50	416	0	0	18	1	3	5	108	11	2	33	2	2	2	13
51	255	0	1	39	20	0	10	170	16	3	77	3	10	0	1
52	0	0	0	0	0	0	0	0	599	0	0	0	0	0	1
53	9	0	0	8	0	0	11	243	328	0	0	10	0	1	0
54	49	0	0	9	0	0	4	92	437	0	0	7	0	2	0
55	72	0	1	14	0	0	14	242	250	1	1	3	0	2	0
56	0	0	0	38	0	0	3	376	175	0	0	0	0	4	0
57	0	0	0	14	0	0	8	522	53	0	0	0	0	1	2
58	3	0	0	26	0	0	26	509	21	0	0	7	0	7	1
59	0	0	0	17	0	0	6	573	0	4	0	0	0	0	0
60	0	0	0	0	0	0	1	511	54	1	0	25	0	0	0
61	5	0	0	1	0	0	0	46	535	0	0	0	0	10	2
62	3	0	0	3	0	0	7	190	390	0	0	6	0	0	0
63	0	0	0	3	248	0	2	173	169	3	0	2	0	0	0
73	50	0	0	3	59	0	10	425	0	13	8	32	0	0	0
87	73	0	0	14	59	0	12	317	1	29	10	99	0	0	3

2) Percent of Depositional Component to Total of Grains, Mud and Dolomite

No.	Oo	Ech	Bry	Biv	Pel	Mud+ Dol	Dol	Grains
10	0	0	0	0	0	100	100	0
12	0	5	0	0	0	95	95	5
12a	<1	5	<1	<1	<1	92	49	8
13	13	24	<1	2	29	37	5	63
14	27	32	2	1	12	21	1	79
15	50	16	1	<1	22	4	<1	96
16	14	41	2	1	11	26	3	74
17	2	52	10	1	7	18	6	82
18	6	39	4	1	9	35	23	65
19	8	35	10	<1	9	31	22	69
20	42	20	21	2	9	5	0	95
22	52	1	0	3	23	16	5	84
24	0	4	0	<1	0	95	95	5
26	0	63	<1	3	9	23	<1	77
27	0	53	2	3	12	30	<1	70
28	1	30	3	3	2	60	31	40
29	2	24	2	8	9	49	21	51
31	0	0	0	0	0	100	100	0
33	0	0	0	0	0	100	100	0
34	0	0	0	0	0	100	100	0
35	0	7	0	0	0	93	93	7
36	0	0	0	0	0	100?	0	0
37	0	4	0	0	0	96	96	4
38	0	0	0	0	0	100	17	0
39	0	0	0	6	8	85	5	15
40	0	0	0	0	69	31	0	69
41	0	0	0	<1	59	41	0	59
42	0	0	0	0	28	63	0	37
43	5	1	0	2	18	73	11	27
44	0	0	0	<1	0	99	37	1
46	0	0	0	0	0	100	100	0
47	0	0	0	1	0	97	3	3
48	0	1	0	0	<1	99	99	1
49	0	17	0	4	<1	76	20	24
50	0	74	0	3	<1	21	2	79
51	0	50	0	8	4	36	3	64
52	0	0	0	0	0	100	100	0
53	0	2	0	1	0	95	55	5
54	0	8	0	2	0	90	74	10
55	0	12	0	2	0	83	42	17
56	0	0	0	6	0	93	30	7
57	0	0	0	2	0	96	9	4
58	0	<1	0	4	0	91	4	9
59	0	0	0	3	0	96	0	4
60	0	0	0	0	0	100	10	0
61	0	1	0	<1	0	99	91	1
62	0	<1	0	<1	0	98	66	2
63	0	0	0	<1	42	57	28	43
73	0	9	0	<1	11	78	0	22
87	0	15	0	3	12	67	<1	33

3) Percentage of Cements, Porosity and Quartz in Total Sample

No.	Tot. Cem.	Dr	S R	Bl	Por	Qtz
10	0	0	0	0	0	0
12	0	0	0	0	0	0
12a	4	1	1	2	0	1
13	22	7	8	7	0	< 1
14	31	9	4	18	0	0
15	24	10	0	15	0	0
16	24	11	7	6	0	0
17	16	7	7	2	0	0
18	15	7	5	3	0	0
19	17	7	6	4	0	0
29	24	11	4	10	0	0
22	37	15	< 1	21	0	0
24	2	2	0	0	0	0
26	29	1	25	3	0	5
27	20	2	16	2	0	3
28	1	Tr	1	Tr	0	6
29	19	4	10	5	Tr	1
31	0	0	0	0	1	12
33	0	0	0	0	0	6
34	0	0	0	0	0	6
35	0	0	0	0	0	7
36	88	0	0	88	4	2
37	0	0	0	0	0	0
38	0	0	0	0	0	0
39	2	1	0	1	0	0
40	0	0	0	0	0	62
41	2	0	0	2	12	29
42	0	0	0	0	5	17
43	7	1	0	6	0	Tr
44	3	3	0	0	0	Tr
46	0	0	0	0	Tr	0
47	1	1	0	0	0	0
48	1	0	0	1	Tr	0
49	1	Tr	0	1	Tr	4
50	5	Tr	Tr	5	2	Tr
51	14	1	12	1	Tr	2
52	0	0	0	0	Tr	0
53	2	0	0	2	0	0
54	1	0	0	1	Tr	0
55	1	Tr	0	Tr	0	0
56	0	0	0	0	0	0
57	0	0	0	0	Tr	0
58	1	0	0	1	0	0
59	1	1	0	0	0	0
60	4	Tr	0	4	1	0
61	0	0	0	0	Tr	0
62	1	0	0	1	0	0
63	1	1	0	Tr	0	0

APPENDIX C

X-Ray Data

Appendix C - X-ray Data

X-ray diffraction analysis for the percentage of dolomite and calcite and the identification of unknown minerals used a nickel filtered copper radiation at 400/1/0 (counts per second/time constant/zero suppression). It was run at $1^{o}2\theta$ per minute.

Semi-quantitative determination of dolomite and calcite percentages was done on dolomites, 100% dolomite by point counting, from the Upper Salter (10, 12), Marston (37, 46) and Carnarvon Members (94) using the intensity ratios from the diffrogram's dolomite $30.98^{o}2\theta$ peak and calcite $29.49^{o}2\theta$ peak (Royse et al, 1971). Four or five oscillatory runs from 27^{o} to 33^{o} were averaged and then plotted on Royse et al's (1971) graph to determine the dolomite weight percent (±6% with .95 confidence interval).

The stratigraphic location of samples' 10 and 12 from the Upper Salter Member and samples' 37 and 46 from the Marston Member are plotted on Figures 6 and 7 respectively. Sample 94 from the Carnarvon Member is found in Figure 8.

Sample Number	Dolomite Intensity (cm)	Calcite Intensity (cm)		Do / Do+Ca	Dolomite Wt % (from graph)
10	22.8	2.9		0.89	
	24.2	3.0		0.89	
	24.1	3.1		0.89	91
	23.7	3.1		0.88	
	23.9	2.5		0.91	
			Av.	0.89	
12	22.7	3.9		0.85	
	23.2	4.0		0.85	86
	22.3	4.2		0.84	
	22.5	4.6		0.83	
			Av.	0.84	
37	All dolomite peaks went off the diffrogram and calcite peaks are just visible				100
48	21.1	1.6		0.93	
	20.4	1.4		0.94	
	21.2	1.2		0.95	96
	21.5	1.1		0.95	
	20.9	1.4		0.94	
			Av.	0.94	
94	15.0	1.8		0.89	
	15.1	2.0		0.88	91
	14.8	1.8		0.89	
	14.9	1.8		0.89	
	14.3	1.9		0.88	
			Av.	0.88	

X-ray analysis from 6^{o} to $60^{o}2\theta$ was used to positively identify celestite, strontianite and quartz in a few Marston Member samples. The chart below compares the major celestite and strontianite d spacing values (highest intensity) with the major d spacing values (high intensity) of the unknown minerals.

Major unknown mineral's d spacing values	Major celestite d spacing values from x-ray powder file no. 5-593
2.98	2.97
3.31	3.30
2.05	2.04
3.18	3.18
2.74	2.73
2.68	2.67

Major unknown mineral's d spacing values	Major strontianite d spacing values from x-ray powder file no. 5-418
3.53	3.54
1.94	1.95
3.43	3.45
2.05	2.05
2.44	2.44
2.98	3.01