DEPOSITION AND DIAGENESIS OF A MIDDLE TO UPPER DEVONIAN CARBONATE BUILDUP, KAYBOB SOUTH AREA, ALBERTA

DONNA L. HANNESON

THE UNIVERSITY OF MANITOBA LIBRARIES

THE UNIVERSITY OF MANITOBA

DEPOSITION AND DIAGENESIS OF A MIDDLE TO UPPER DEVONIAN CARBONATE BUILDUP, KAYBOB SOUTH AREA, ALBERTA

BY

DONNA L. HANNESON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF EARTH SCIENCES

WINNIPEG, MANITOBA

MAY, 1981

DEPOSITION AND DIAGENESIS OF A MIDDLE TO UPPER DEVONIAN CARBONATE BUILDUP, KAYBOB SOUTH AREA, ALBERTA

BY

DONNA L. HANNESON

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

© 1981

Permission has been granted to the LIBRARY OF THE UNIVERSITY OF MANITOBA to lend or sell copies of this thesis, to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film, and UNIVERSITY MICROFILMS to publish an abstract of this thesis.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

ABSTRACT

The Devonian Swan Hills Formation of the Beaverhill Lake Group (Late Givetian to Early Frasnian) encountered in core study of the Kaybob South area consists of a maximum of 150 meters (500 feet) of organic carbonate buildup sediment. Four informal stages of carbonate deposition are recognized within two organic banks, as a result of hydrodynamic processes and sediment accumulation which produced four major regressive cycles during the southwesterly transgression of the Beaverhill Lake sea. Green shale and/or tidal flat facies, micrite crusts, and abrupt lateral facies shifts mark major stage boundaries. Each stage is identified by variable development of: 1) algal facies in the tidal flat environment, 2) Amphipora, bulbous stromatoporoid, Euryamphipora and pelleted facies in the lagoon environment, 3) branching stromatoporoid and Euryamphipora facies in the open shelf environment, 4) hemispherical stromatoporoid, tabular stromatoporoid and oolite facies in the shelf margin environment, 5) tabular stromatoporoid, branching stromatoporoid, skeletal-peloid, Euryamphipora and pelleted facies in the fore reef environment, and 6) massive and laminated micrite, echinoid-brachiopod and pelleted facies in the north-south off reef channel between the banks. Isolated stromatoporoid reefs occur along the windward (east) margins of both banks.

Submarine diagenetic modifications to bank sediments include: 1) occlusion of porosity by submarine silt and by precipitation of calcite rim cements of bladed isopachous,

irregular, equant isopachous, syntaxial, and micritic habits, and 2) micritization of allochems by biological activity. Subaerial exposure of bank sediments led to formation of green shale and micrite discontinuity surfaces, to dissolution of allochems and cement resulting in porous zones beneath discontinuity surfaces, and to precipitation of vadose, bladed to fibrous micro-stalactitic and meniscus calcite cement and phreatic, bladed or equant isopachous calcite cement. Equant ferroan or zoned-ferroan calcite cement, commonly occurring after an initial rim cementation episode, may be of phreatic or later subsurface origin. The pre-lithification process of pressure-solution formed stylolites and some dolomite. Widespread dolomitization of the west bank may have been a late subsurface diagenetic phenomenon. High porosity values exist in zones of the dolomitized west bank where late subsurface coarse calcite spar does not occlude vuggy porosity. On both banks, zones of good porosity occur where large skeletal allochems are most abundant; that is, in open shelf, shelf margin, and less commonly, in lagoonal and fore reef environment facies. Some discriminative dolomitization may be an earlier replacement process which occurred at the periphery of a phreatic lens.

TABLE OF CONTENTS

List of Figures v

List of Tables vi

CHAPTER I INTRODUCTION

1.1 Introduction and Purpose of Study ... 1
1.2 Regional Geology 2
1.3 Local Geology 5
1.4 Previous Work 9
1.5 Methods and Terminology 10
1.6 Acknowledgements 15

CHAPTER II MODEL OF CARBONATE DEPOSITIONAL ENVIRONMENTS

2.1 Introduction 17
2.2 Recent and Pleistocene Carbonate Deposition 18
2.3 Devonian Carbonate Deposition 21
2.4 A Model of Carbonate Deposition 23

CHAPTER III CARBONATE DEPOSITION AT KAYBOB SOUTH

3.1 Introduction 28
3.2 Lithofacies 29
Hemispherical Stromatoporoid Facies . 29
Tabular Stromatoporoid Facies 30
Branching Stromatoporoid Facies 32
Amphipora Facies 33
Euryamphipora Facies 35
Bulbous Stromatoporoid Facies 36
Algal Facies 37
Skeletal-peloid Facies 39
Pelleted Facies 40
Oolite Facies 42
Echinoid-Brachiopod Facies 44
Micrite Facies 45
Green Shale Facies 49
3.3 History of Carbonate Deposition 51

CHAPTER IV DIAGENESIS

4.1 Introduction 63
4.2 Submarine Diagenesis 64
4.3 Subaerial Diagenesis 73
4.4 Subsurface Diagenesis 83
4.5 Dolomitization 87
4.6 Porosity 102

CHAPTER V	SUMMARY AND CONCLUSIONS	106
	REFERENCES	112
	PLATES	129
APPENDIX A	Kaybob South Area Core Study Summary.	148
APPENDIX B	Compilation of Devonian Fossil Distribution Based on Previous Work .	150
APPENDIX C	Insoluble Residue Data	154
APPENDIX D	Point Count Data	155
APPENDIX E	Core Descriptions	157

LIST OF FIGURES

Figure		
1	Beaverhill Lake Paleogeography	3
2	Stratigraphy, Swan Hills Area	4
3	Carbonate Buildups, Swan Hills Area	6
4	Isopach of Swan Hills Formation, Kaybob South area	8
5	Morphological Stromatoporoid Classification	13
6	Distribution of Organisms in Devonian Depositional Environments	22
7	Model of Carbonate Depositional Environments	14
8	Lithofacies, West Bank (Kaybob South), Section A-B	Figs.8-13 in pocket
9	Lithofacies, East Bank, Section C-D	
10	Lithofacies, Channel, Section E-B	
11	Environments, West Bank, Section A-B	
12	Environments, East Bank, Section C-D	
13	Environments, Channel, Section E-B	
14	Schematic Cross-section, Swan Hills Area .	53
15	Composite Cross-section, Kaybob South Area	55
16	Porosity, Dolomite, and Calcite Cement Distribution Beneath Three Surfaces of Unconformity	97

LIST OF TABLES

Table		
1	Classification of Limestones	12
2	Descriptive Terminology of Carbonate Buildups	14
3	Point Count Data of Dolomite and Calcite Cement Distribution Above and Below Three Horizontal Micrite Surfaces	99
4	Point Count Data Summary of Mud and Dolomite Distribution Below Three Unconformity Surfaces	100

CHAPTER 1

INTRODUCTION

1.1 Introduction and Purpose of Study

Oil and gas reservoirs in carbonate buildups of the Devonian Swan Hills Formation of the Beaverhill Lake Group (Late Givetian to Early Frasnian) contribute significantly to the total production of oil and gas in Alberta. Research describing and interpreting the physical contrasts that delineate reservoirs in these ancient carbonate complexes is aided by continuing observations of processes of carbonate deposition and diagenesis in modern carbonate environments.

This study focuses on the Beaverhill Lake Group in the vicinity of the Kaybob South gas field of Central Alberta, Twp. 58 to 63, Rge. 18 to 20 West of the Fifth Meridian (54°00'N to 54°25'N and 116°30'W to 117°00'W) (Figure 1). The objectives of the study are:

1. To interpret the history of carbonate deposition and the relationship of carbonate buildup to off-reef sedimentation in the Kaybob South area.
2. To interpret the effects of diagenesis during exposure of the carbonate sequence to successive diagenetic environments.

1.2 Regional Geology and Stratigraphy

The area under study is located in the western sedimentary basin in the Interior Plains physiographic province of Canada. During the Devonian Period the area was located in a marine tropical climatic belt, approximately 30° north of the paleo-equator (Bain, 1963).

During the late Middle Devonian (Givetian) three positive areas--the Peace River landmass to the north, the Western Alberta Ridge, and the Canadian Shield to the East--restricted circulation in the central Alberta epeiric sea (Figure 1). Deposition of evaporites of the Fort Vermilion Formation (Figure 2) occurred over both shallow water and deltaic clastic sediments of the Watt Mountain Formation of the Elk Point Group. The three positive areas were at least partly emergent during the Middle to Upper Devonian (Givetian to Frasnian) transgression which followed. This transgression was accompanied by development of extensive carbonate complexes of the Swan Hills Formation on a carbonate platform or shoal adjacent to the submerging landmasses (Figure 1). Adjacent basins accumulated argillaceous limestones and shales. The basinal shales commonly transgressed over the carbonate banks but occasionally carbonate bank deposition was continuous into the overlying Upper Devonian Woodbend Group (Hemphill, et al., 1970). Grayston, et al. (1964), Bassett and Stout (1967) and Douglas, et al. (1970) may be consulted for an expanded account of the geological history of the area.

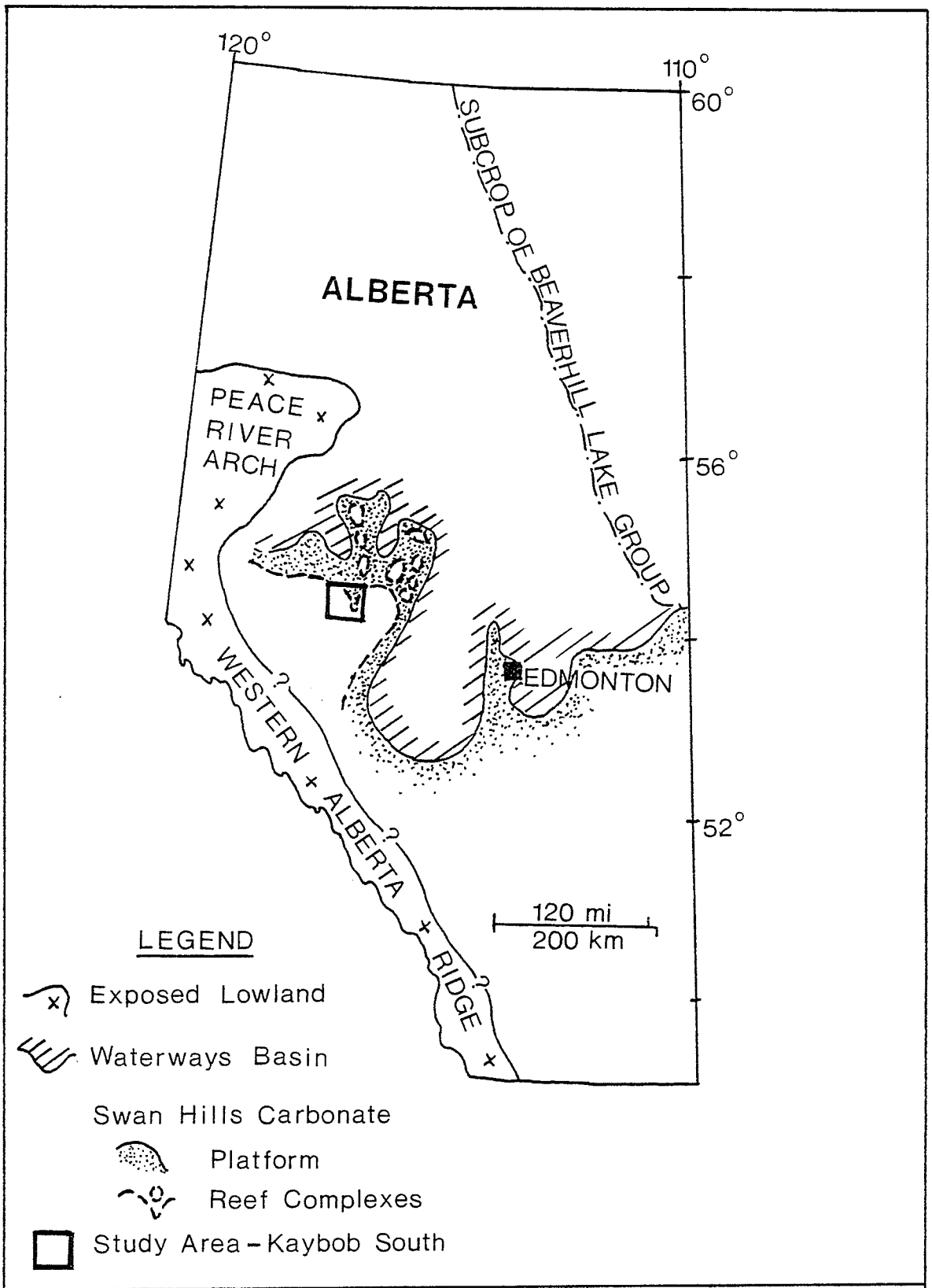


Figure 1. Beaverhill Lake paleogeography, Alberta. (After Fischbuch, 1968 and Leavitt, 1968.)

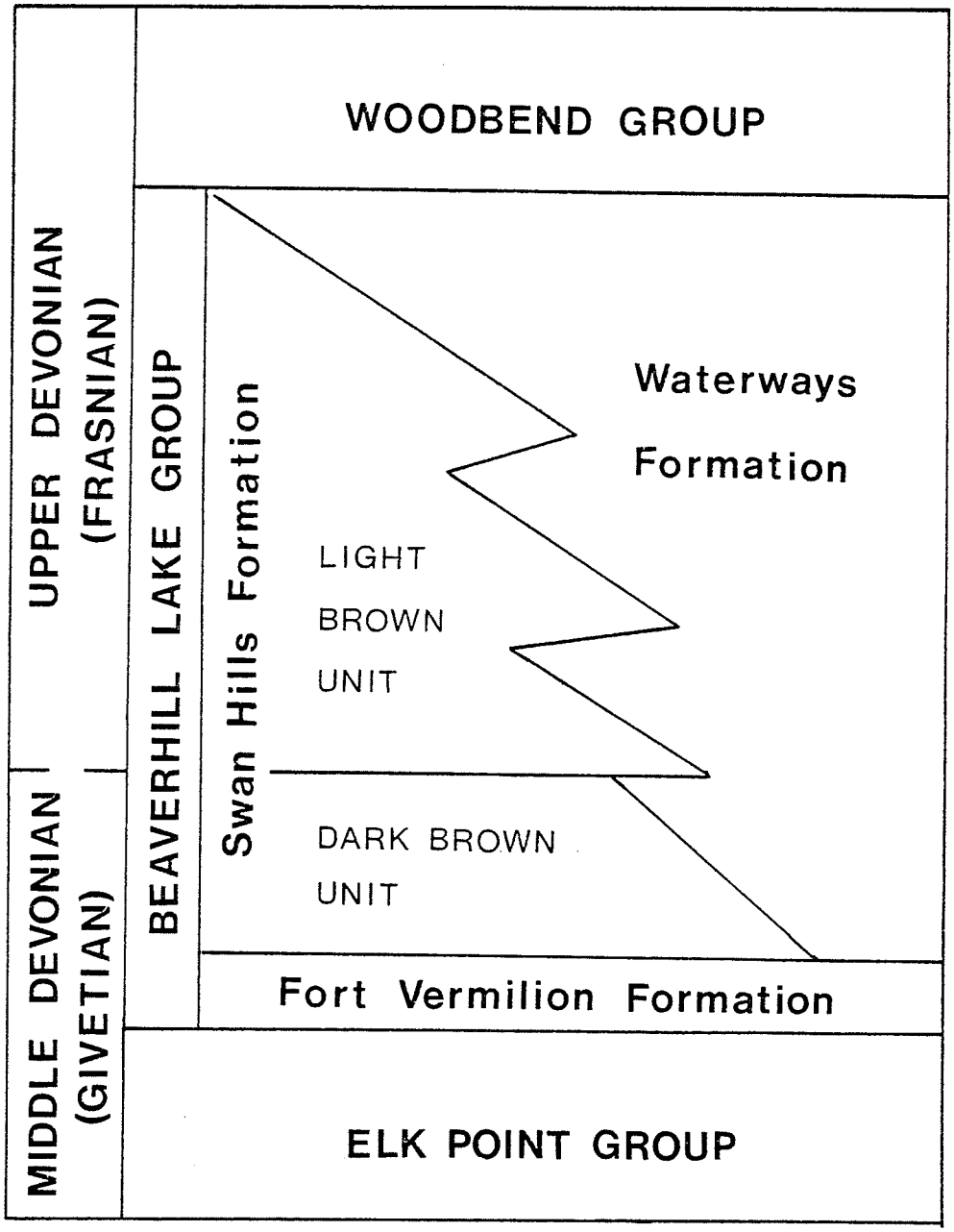


Figure 2. Stratigraphy, Swan Hills area.
(After Leavitt and Fischbuch, 1968.)

Middle to Upper Devonian stratigraphy in the Swan Hills area is shown in Figure 2. The Swan Hills Formation consists of the hydrocarbon-producing carbonate unit, while nodular off-reef shales, limestones, and thinly laminated argillaceous limestones constitute the Waterways Formation. The uncertainty in the exact age of the units is discussed by Leavitt and Fischbuch (1968). Hemphill, et al. (1970) assigned a Late Devonian age to the entire Beaverhill Lake Group. Jansa and Fischbuch (1974) suggested a Middle Devonian age for the lower part of the Swan Hills Formation, equivalent to Divisions I to IV of Fischbuch (1968) and the dark brown unit of Fong (1959). The dark and light brown units (Fong, 1959) are not recognizable as distinct units throughout the Swan Hills area. The upper part of the Swan Hills Formation, considered to be Upper Devonian, is correlated with part of the Waterways Formation (Jansa and Fischbuch, 1974). The Flume Formation of the Rocky Mountains is considered equivalent in age to the Beaverhill Lake Group (Kobluk, 1975).

1.3 Local Geology

The distribution of the Lower Swan Hills marginal reef-bank complexes (Fischbuch, 1968, Divisions I-IV) and the Upper Swan Hills solitary reef complexes (reef terminology of Jansa and Fischbuch, 1974, p. 46) is shown in Figure 3. The extent of solitary reef complexes south of Township 63 is uncertain. The maximum thickness of the Swan Hills Formation is approximately 152 meters (500 feet).

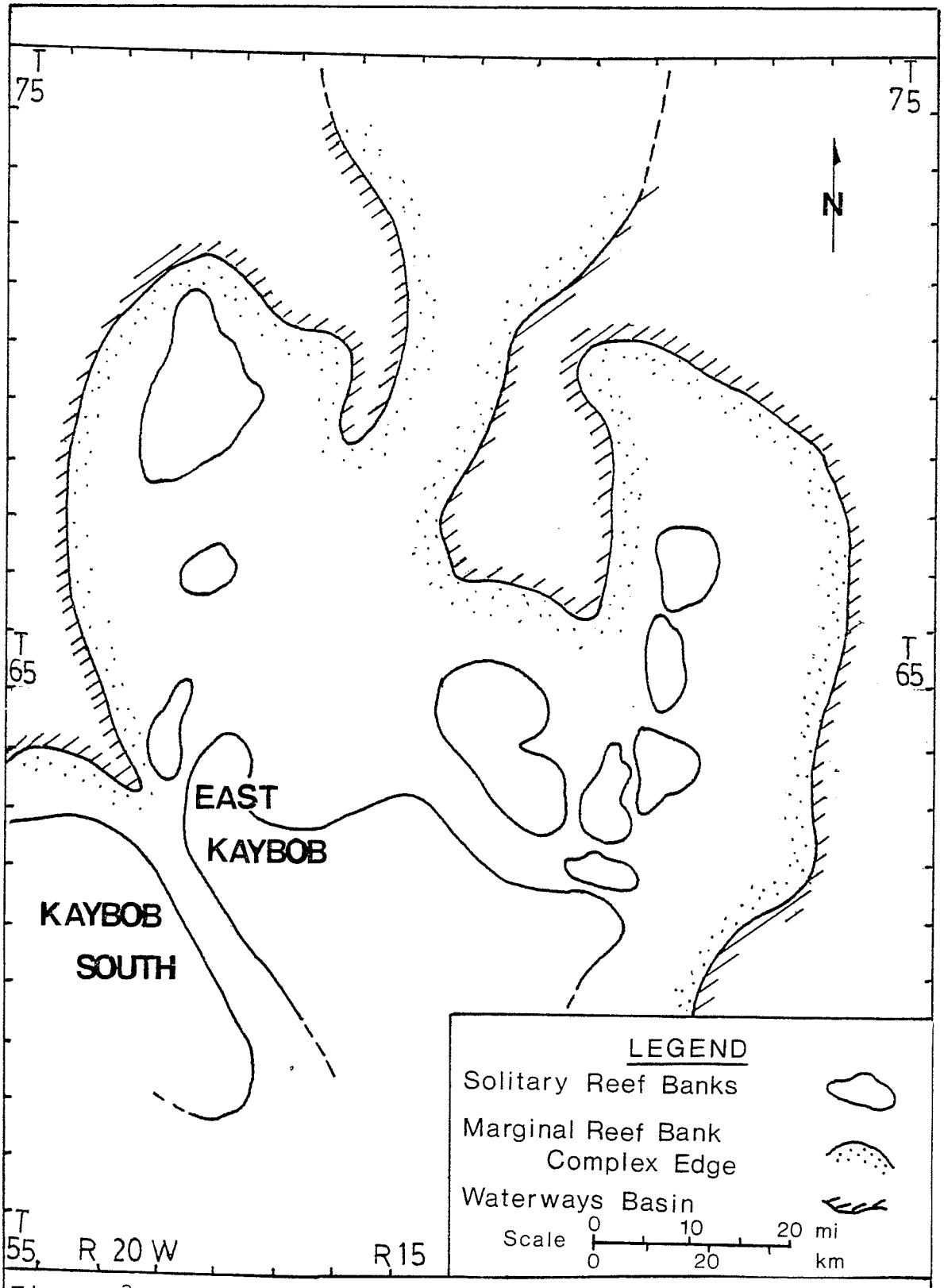
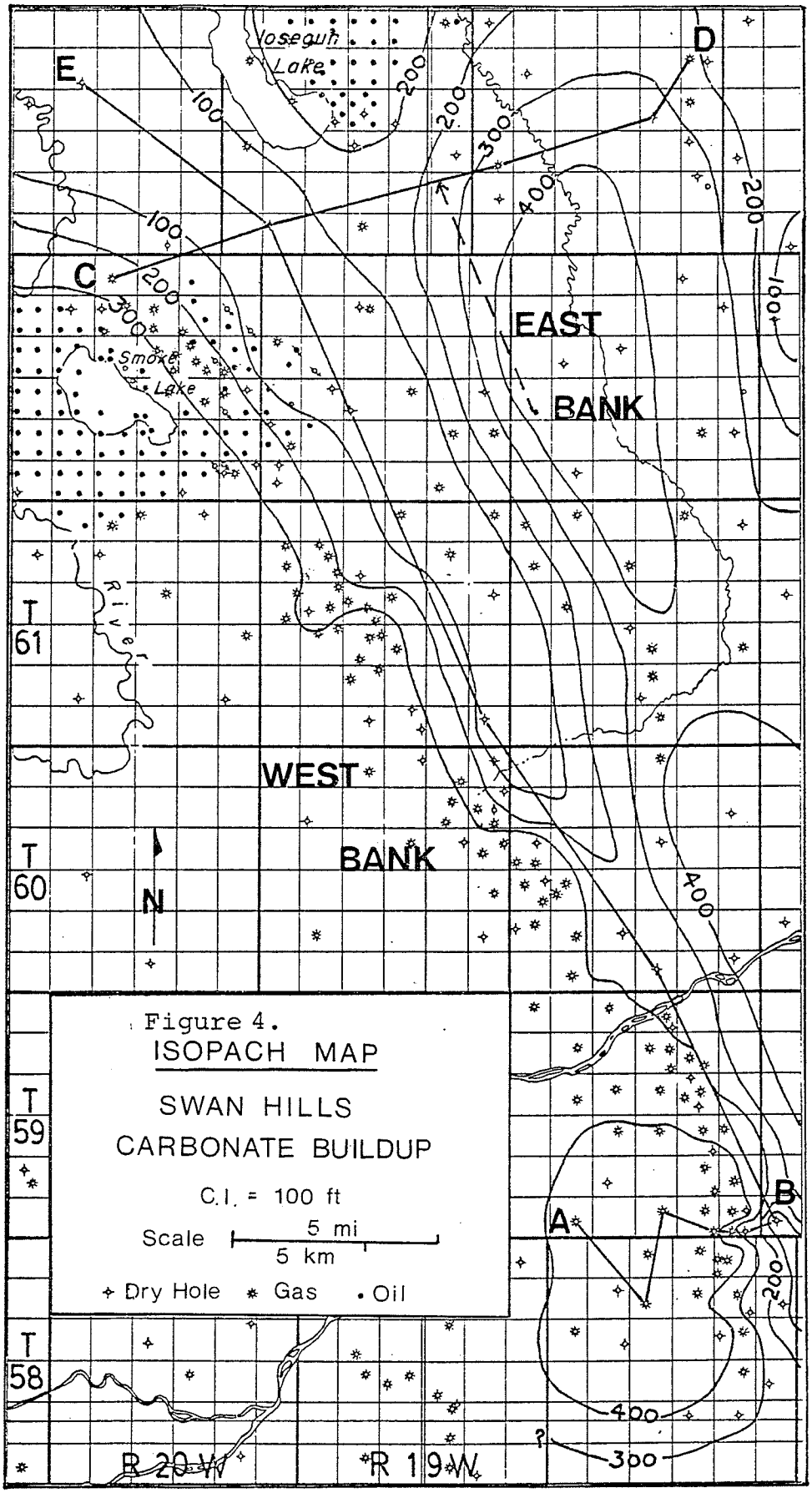


Figure 3.
Distribution of carbonate buildups, Swan Hills area. (Solitary reef banks and marginal reef bank complexes of Jansa and Fischbuch, 1974.)

The isopach (Figure 4) outlines the thickness of the Swan Hills Formation limestone and dolomite in the study area. The off-reef carbonate units, although considerably more calcareous than the off-reef shales that typify the Waterways Formation (Leavitt and Fischbuch, 1968) are not included in the carbonate isopach and are relegated to the Waterways Formation. The Swan Hills Formation is a hydrocarbon-producing unit, while the off-reef carbonate units of the Kaybob South area and the Waterways shales surrounding other Swan Hills reefs perform similar hydrocarbon-trapping functions.

In the Kaybob South area the regional dip of the Beaverhill Lake Group is approximately 9.4 meters/kilometer (50 feet/mile), S 60°W (Schultheis, 1976). During deposition of the Beaverhill Lake Group sediments, the regional dip would have been approximately east to north-east, towards the axis of the Beaverhill Lake basin located by Hemphill, et al. (1970). The trend of the Kaybob South carbonate complex margin and the adjacent channel-like extension of the off-bank facies east of the complex extends for approximately 45 kilometers (28 miles) S 30°E.

Tectonic activity in the area is suggested by faulting of the Swan Hills platform at the Kaybob carbonate complex to the north (Schultheis, 1976). Keith (1970) noted that an orthogonal pattern of sharp elongated folds at the base of the Kaybob reef, tending northeast-southwest and northwest-southeast, were controlled by large scale basement


Joseguin Lake
Smoke Lake
River
EAST BANK
WEST BANK
N
T 61
T 60
T 59
T 58
R 20 W
R 19 W
A
B
C
D
E
100
200
300
400
?
Figure 4.
ISOPACH MAP
SWAN HILLS
CARBONATE BUILDUP
C.I. = 100 ft
Scale 5 mi
5 km
Dry Hole
Gas
Oil

structures associated with the Western Alberta Ridge. Martin (1967) related linear trends and Devonian reefs of the Sturgeon Lake-Windfall area to fault systems on the Peace River Arch.

1.4 Previous Work

Following the discovery of oil in the Swan Hills area in 1957 and the first description of the type section of the Beaverhill Lake Formation by Fong (1959, 1960), considerable effort has resulted in numerous published reports pertaining to the carbonate buildups of the Swan Hills area. Petrologic and paleontologic studies, frequently centred on one of the isolated limestone reef complexes, began to characterize the various facies of the reefal carbonates, and endeavoured to interpret the geologic history of the Swan Hills buildups. Notable reports include work by Edie (1961) on Swan Hills, Murray (1966) on Judy Creek, Leavitt (1968) on Carson Creek, Jenik and Lerbekmo (1968) on Goose River, Havard (1974) on Snipe Lake, and Schultheis (1976) on Kaybob. Studies encompassing several isolated buildups were published by Thomas and Rhodes (1961), Fischbuch (1968), Hemphill, et al. (1970) and Jansa and Fischbuch (1974). Jansa and Fischbuch (1974) dealt more specifically with the evolution of the Lower Swan Hills Formation. Investigations of Devonian reef complexes in Australia (Playford and Lowry, 1966), Belgium (Tsien, 1971) and in Central Europe (Krebs, 1974) also contributed to understanding facies variations

in carbonate buildups. Descriptions of the zonation of various Devonian organisms within the reef complexes, especially the abundant stromatoporoid species or morphological types, have been contributed by Fischbuch (1962, 1968, 1969), Klovan (1964), Noble (1970), Corneil (1969), Jamieson (1969) and Kobluk (1975).

Stages or cycles of reef growth were recognized to some extent in most studies of the Swan Hills area. Havard (1974) confined her study to backreef sediments at Snipe Lake, recognized several sedimentary cycles, and conducted the most detailed diagenetic study to date.

The petrology and depositional history of the off-reef Waterways Formation at Judy Creek was described by Murray (1965). In the vicinity of the Swan Hills field, Sheasby (1971) defined several units in the Waterways Formation and interpreted depositional environments and sediment source.

1.5 Methods and Terminology

A list of locations and cored intervals of wells selected for this study in the Kaybob South area is included in Appendix A. Cores were examined at the Energy Resources Conservation Board Core Research Centre, Calgary. Group I, Appendix A, contains cores logged in detail using a binocular microscope and sampled for later thin section observations. These wells appear on the stratigraphic cross-sections, located on Figure 4. Note that well location

2-18-62-18 W5 was projected to line of cross-section C-D. The resulting proximity of this well to the well at location 2-18-63-18 W5 illustrates the facies relations inferred by the core study. Group II, Appendix A, contains additional wells that were not part of the detailed study. Unit descriptions of detailed core intervals and short descriptions of Group II cores are included in Appendix E.

The majority of thin sections and slabs prepared for acetate peels were stained with Alizarin Red-S and potassium-ferricyanide, according to Dickson (1965), to distinguish ferroan and non-ferroan calcite and dolomite.

Insoluble residue and total organic carbon determinations conducted by Mobil Laboratory, Calgary, are summarized in Appendix C.

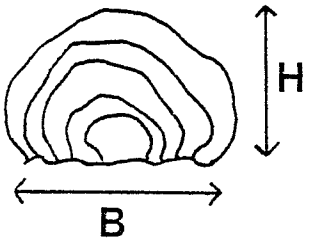
The carbonate classification used throughout this study was modified from the depositional classification of Dunham (1962) by Embry and Klovan (1971), and is suited to classification of carbonates in organic buildups (Table 1). The classification of pores and pore systems of Choquette and Pray (1970) aided in porosity identification. Stromatoporoids were identified by morphological types as defined by Kobluk (1975) (Figure 5), except the genera Amphipora and Euryamphipora.

The terms used for carbonate buildups in this study follow the definition and refinement of buildup classification and descriptive terminology for carbonate buildups proposed by Heckel (1974) (Table 2). According to Heckel

TABLE 1

Classification of Limestones According to
Depositional Texture
(after Embry and Klovan, 1971)

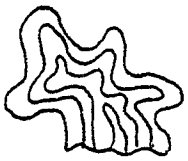
<table>
<tr><td colspan="6">Allochthonous Limestones - Original Components
not organically bound during deposition</td><td rowspan="3">Autochthonous Limestones
Original components organically
bound during deposition</td></tr>
<tr><td colspan="4">Less than 10% > 2 mm components</td><td rowspan="2">Greater than
10% > 2 mm
components</td><td rowspan="2"></td></tr>
<tr><td colspan="3">Contains lime mud (<.03 mm)</td><td>No
lime mud</td><td rowspan="2">Matrix
Supported</td><td rowspan="2">>2 mm
Component
Supported</td></tr>
<tr><td colspan="2">Mud Supported</td><td colspan="2" rowspan="2">Grain
Supported</td><td rowspan="2"></td></tr>
<tr><td>Less than
10% grains
>.03 mm
< 2 mm</td><td>Greater
than 10%
Grains</td><td>MUD-
STONE</td><td>WACKE-
STONE</td><td>PACK-
STONE</td><td>GRAIN-
STONE</td><td>FLOAT-
STONE</td><td>RUD-
STONE</td><td>BOUND-
STONE</td></tr>
</table>



Hemispherical $H \leq B$

Bulbous $H > B$

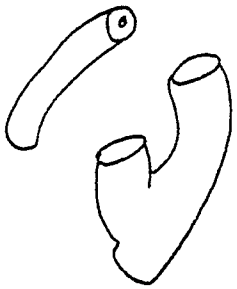
Tabular $H \ll B$



Irregular



Encrusting



Branching

Thick = Stachyodes type

Thin = Amphipora type

Figure 5. Morphological classification of stromatoporoids.
(After Kobluk, 1975.)

TABLE 2

Descriptive Terminology for Carbonate Buildups
(after Heckel, 1974)

PREDOMINANT CONSTITUENTS	Skeletal Grains	Lime Mud	Nonskeletal Grains
DOMINANT ROCK TYPES	Boundstone Rudstone Floatstone Packstone Grainstone	Wackestone Mudstone	Over 70% Nonskeletal Grains
GENERAL TERM	Skeletal Buildup	Lime-Mud Buildup	Oolite (etc.) Buildup
DISTINCTION AS TO SHAPE	Mound, Knoll, Atoll, etc.	Mound, Bar	Mound, Bar
DISTINCTION AS TO TYPE OF SKELETAL MATERIAL	Example: Coral Stromatoporoid Reef		

(1974, p. 91), a carbonate buildup is defined as "a carbonate mass or a local portion of a carbonate unit which: 1) differs in nature to some degree from equivalent deposits and surrounding and overlying rocks; 2) is typically thicker than equivalent carbonates; and 3) probably stood topographically higher than the surrounding sediment during some time in its depositional history." A reef is defined as "a buildup that displays: 1) evidence of potential wave resistance or growth in turbulent water which implies wave resistance, and 2) evidence of control over surrounding environment" (Heckel, 1974, p. 96). If no evidence of turbulent water or potential wave resistance is apparent, the term 'bank' is used.

1.6 Acknowledgements

This thesis was supported by a National Research Council of Canada Scholarship and a Chevron Standard Fellowship to the author. The author wishes to gratefully acknowledge consultation and access to data and core during initial thesis development at Mobil Oil Canada Ltd., Amoco Canada Ltd., and Chevron Standard Ltd., Calgary. Core logging and sampling was aided by the cooperation of the Energy Resources Conservation Board of Alberta, Calgary. Major drafting problems were overcome thanks to Mr. Ken Gibson. Expert typing was done by Beryl Logan.

Special thanks are extended to Dr. R. S. Harrison, initial thesis supervisor, for guidance and discussion

throughout the research period and to Dr. R. J. Elias for his help as advisor towards the conclusion of the thesis. Helpful informal discussions with other members of the carbonate research group at the University of Manitoba were also greatly appreciated.

Finally, I wish to thank my good husband, Jim, for his support and encouragement.

CHAPTER II

CARBONATE DEPOSITIONAL ENVIRONMENTS - A MODEL

2.1 Introduction

Models depicting marine carbonate depositional environments are essentially based on partition of the continuously varying hydraulic energy across an idealistic bottom profile, as described by Irwin (1965). This partitioning or zoning across a carbonate shelf model, into units of more or less homogeneous energy, facilitates the description and discussion of depositional environments and their interrelationships in any modern or ancient carbonate buildup. The characterization of these units or facies depends on observed variations of the sediments and organisms in response to energy variations and other parameters that also control the distribution of organic communities in a carbonate environment.

This chapter will summarize some important previous studies detailing the variations in sediments and organisms across modern and ancient (Devonian) carbonate buildups and

will conclude with a description of the model that is applied to this particular study.

2.2 Recent and Pleistocene Carbonate Deposition

Reef configuration is strongly influenced by the location of positive relief features on the initial substrate; features that are controlled by some combination of tectonic (Maxwell, 1968), hydraulic (Maiklem, 1970), or solution (Stanley and Swift, 1968; Purdy, 1974) processes. An atoll, barrier or fringing reef develops, depending on adjacent bathymetric restrictions. Regardless of the form of the reef mass, the biotic community of the living reef builds upward if continuous or discontinuous subsidence or sea-level rise occurs. Organisms occupy various ecological niches created by variations in water turbulence, illumination, temperature, salinity, substrate, and sediment accumulation on the reef and the surrounding buildup.

Several specific examples of organism response to environmental factors have been observed. Wells (1957) related hermatypic coral growth-form to the environment, especially water turbulence. Delicate, branching corals are suited to deeper water, quiet lagoons, or well-protected areas of the reef. More massive, encrusting, or stout branching forms can survive in the more exposed, turbulent water zones. Some species exist in more than one form to adapt to the water conditions or to more successfully compete with other organisms (Wells, 1957). Kornicker and Boyd (1962)

observed the branching coral Acropora cervicornis to vary from stout branches in turbulent water to thin branches in quiet water. In areas of relatively high sedimentation rates, branching forms are more likely to survive than domal heads.

Zonation of reef fauna with increasing depth or decreasing wave energy has been documented in several examples from the Recent: Great Barrier Reef (Maxwell, 1968), Jamaica (Goreau, 1959; Hartman and Goreau, 1970), Yucatan (Logan, et al., 1969), Great Bahama Bank (Bathurst, 1971), and Barbados (Stearn and Riding, 1972). Kobluk (1975, p. 252) has produced a diagrammatic compilation of coral and hydrozoan morphological and species variations across the Great Barrier Reef Complex. An example of depth control is observed on the Yucatan shelf, where the stout branching coral Acropora palmata characterizes the high energy environment above wave base, to a depth of 9.1 meters (30 feet) (Logan, et al., 1969). An intermediate energy environment from below wave base to storm wave base at 21.3 meters (70 feet) is characterized by massive heads of the corals Diploria and Montastrea and stubby branching or massive Porites. Below the storm wave base a leafy coral Agaricia and Montastrea dominate the quiet, low energy community. The high surface area to mass ratio of Agaricia colonies is an adjustment to the decrease in light intensity at greater depth. Mesolella, et al. (1970) described a similar species trend from the Pleistocene reef tracts of Barbados.

Concerning the evolution of corals and the extrapolation of Recent observations to the ancient record, Scoffin (1975, p. 29) stated: "The functional morphology of the skeletal structure, the relationships of one skeleton to another and to its matrix, and the nature of the sediments associated with the reef may give more useful information on the environments of growth than the mere presence of a particular reef building organism." Ladd (1970, p. 1273) has estimated that "more than 90 percent of a three dimensional reef complex (consisting of fore reef, reef, back reef or lagoon, and beach deposits) is composed of sediments." Within the reef facies of the Pleistocene Barbados reef tracts, Mesolella, et al. (1970) estimated that 50 percent of the facies consisted of sediment in framework interstices. Lateral textural changes in these volumetrically important sediments in the reef and adjacent depositional environments reveal changing energy conditions across the buildup profile. Sediment textures, then, are as important as organism adaptations in interpreting environmental conditions.

Published reports on sediment and lithofacies distribution in several Recent carbonate environments encompass the Great Bahama Bank (Newell, et al., 1959; Purdy, 1963), the Alacran reef complex (Kornicker and Boyd, 1962), Florida Bay (Ginsburg, 1956, 1964), Bermuda (Ginsburg and Garrett, 1969), Shark Bay in Australia (Davies, 1970), and the Persian Gulf (Kendall and Skipwith, 1969).

2.3 Devonian Carbonate Deposition

As previously indicated (Section 1.4), several studies of Devonian carbonate buildups have described fossil-sediment distributions and interpreted energy environments based on the fabric and fossil content of the rocks. Morphological analogies between Paleozoic stromatoporoids and Recent corals have resulted in similar interpretations of environmental parameters. Although it is possible that stromatoporoids may be extinct sponges (Stearn, 1972), the analogy with corals has enabled the visualization of a 'living' Devonian carbonate buildup (Fischbuch, 1968, Figure 22).

The summary of previous studies included in Figure 6 is based on a simple profile of four major environments: off reef, fore reef, organic reef, and back reef (lagoon). This juxtaposition has formed the basic profile on which the distribution of organisms and sediments of the majority of studies has been placed. The designated stromatoporoid morphologies of Kobluk (1975) that appear in this figure postdate several studies, and therefore the terminology of previous studies is conflicting where these terms were defined (or ill-defined) previously. In these studies the terminology was compared carefully with the terminology of Kobluk (1975) to maintain consistency within the Figure. In addition to the tabulated summary, Tsien (1971) described the morphological and structural adaptations of tabulate and rugose corals to different environments in more detail than can be included in this summary. Murray (1966), Jamieson

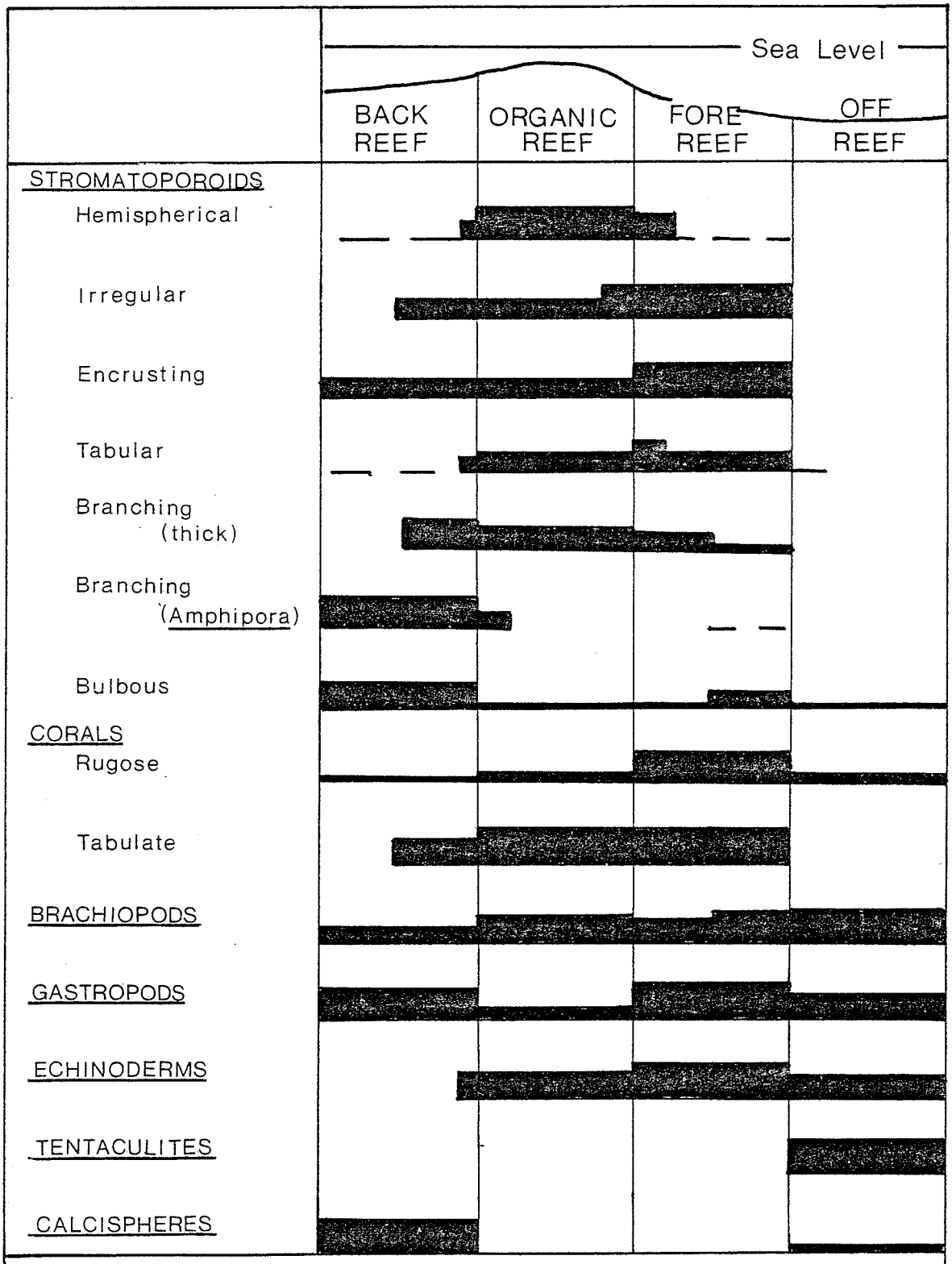


Figure 6.

Distribution of organisms in Devonian depositional environments. Relative abundances based on frequency of occurrence in literature (Appendix B).

(1969), Tsien (1971), and Machielse (1972) described the preferred environments of several families of calcareous algae. Sedimentary fabrics and structures in European Devonian carbonate environments are summarized in Krebs (1974).

2.4 A Model of Carbonate Deposition

While it is obvious from the compilation of Figure 6 that the distribution of organisms and stromatoporoid morphological types is not always definitive, certain types frequently recur in certain environments. Although the boundaries are as gradual as the energy environments they divide, the following model of carbonate depositional environments (Figure 7) is adopted for this study. Organism and sediment characteristics of each environment are summarized.

Shelf Margin

The shelf margin environment is the highest energy environment and the location of the most extensive organic reef development in a carbonate buildup. To resist turbulent wave energy, organic binding into local or extensive rigid frameworks occurs. The sediment within the interstices of the framework is generally poorly sorted; the inter-reef sediment is characteristically grain-supported. In this environment, hemispherical stromatoporoids dominate as primary framebuilders, while subsidiary fauna includes tabular, thick-branching, and irregular or encrusting stromatoporoids and minor corals, brachiopods, gastropods, echinoderms, and Amphipora. Stromatoporoids may be in situ or

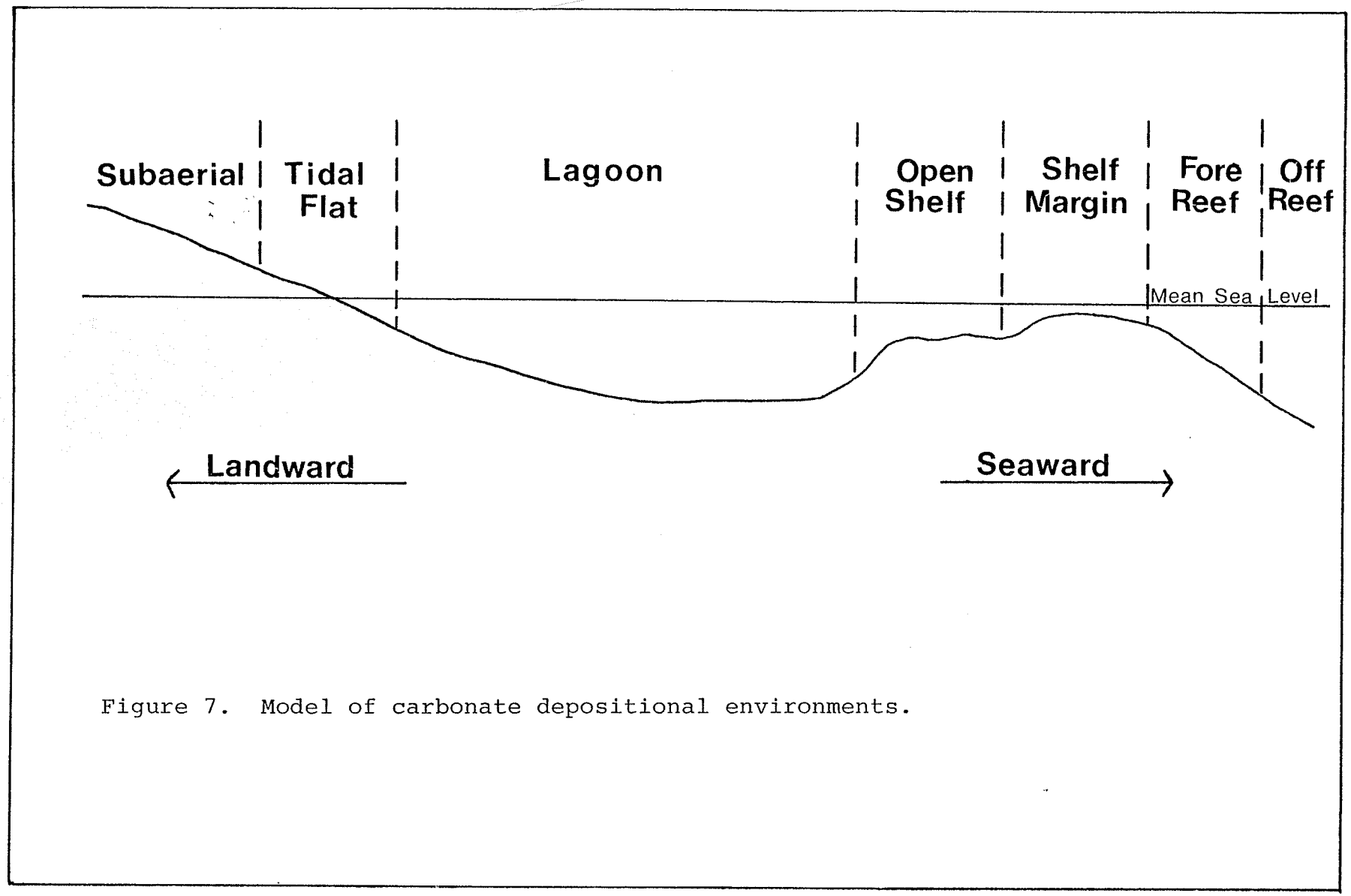


Figure 7. Model of carbonate depositional environments.

overturned in the shallow, turbulent water. Ooliths may also be found in this environment.

Fore Reef

The fore reef environment extends outward from the shelf margin to the deeper basin, with a decrease in wave energy accompanying the increase in water depth. The sediment encompasses a wide range of grain sizes as a result of derivation from the adjacent shelf margin and from local fore reef slope sedimentation and organisms. Sediment movement in channels or grooves between fore reef framework buildups or spurs, extends coarse sediment into the lower energy, deeper fore reef. A wide variety of stromatoporoid morphologies is found, although Amphipora is generally rare. Corals, brachiopods, echinoderms and gastropods are common.

Off Reef

The off reef environment is the low energy environment that surrounds the carbonate buildup and is characterized by fine grained or argillaceous sediments. The fauna consists predominantly of echinoderms, brachiopods, gastropods, Tentaculites, and cephalopods, with minor occurrences of bryozoans, ostracods, and bulbous stromatoporoids.

Open Shelf

The open shelf environment occupies the position immediately in the lee of the shelf margin, and is therefore part of the back reef environment. The open shelf is a

relatively high to intermediate energy environment compared with the low to intermediate energy of the more distal back reef or lagoon. The sediments are characteristically grain supported and better sorted and more rounded than those of the shelf margin environment. Local pockets of skeletal fragments from the adjacent shelf margin result in poorly-sorted sediment. Thick branching stromatoporoids dominate the fauna. Amphipora, calcispheres, and bulbous stromatoporoids are accessory skeletal components. Oncolites or algal-encrusted skeletal fragments (Jamieson, 1969; Leavitt, 1968; Jansa and Fischbuch, 1974), grapestones and hardened pellets are also present in this environment.

Lagoon

The lagoon environment is the lowest energy environment on the carbonate buildup, although varying water depths within the lagoon produced by small patch reefs or shoals are 'islands' of a higher energy regime. Depending on the effectiveness of the shelf margin and open shelf barrier in restricting circulation to the back reef lagoon, salinities can rise above normal marine values. Sediments are characteristically fine-grained and mud supported. Amphipora and bulbous stromatoporoids are the dominant fauna, with minor brachiopods, gastropods, ostracods, and rare stromatoporoids of several morphological types. Calcispheres and pellets are common.

Tidal Flat

The tidal flat environment is adjacent to the lagoon environment and is located in the intertidal to supratidal zone. Sediment is predominantly sand and mud, with sand enrichment at the low-water line and major mud deposition near the high-water line (Reineck and Singh, 1975). Skeletal constituents are commonly calcispheres, Amphipora and gastropods. Mud cracks, flat-pebble breccias and evaporites may form in the supratidal zone (Roehl, 1967). Air bubbles trapped in sediment left by the swash produce a bubble sand structure (Reineck and Singh, 1975) labelled 'keystone vugs' by Dunham (1970). Laminated algal mats (Machielse, 1972) and birdseye or fenestral structure (Shinn, 1968; Read, 1973) are also characteristic of this environment. Burrows may be abundant, although tidal channels and compaction may destroy them.

Subaerial

The subaerial environment is effectively beyond marine influence and, as a diagenetic environment, can be superimposed on any of the previous environments of the model. Several epigenetic fabrics can develop in this environment at the sediment/rock interface, such as microkarst terrains, caliche, soil development and green shales. Subaerial fabrics will be discussed in detail in Chapter IV.

CHAPTER III

CARBONATE DEPOSITION AT KAYBOB SOUTH

3.1 Introduction

In this chapter the depositional history of sedimentation in the Kaybob South area is reconstructed following interpretation of depositional environments of the cored sediments, based on the model developed in the previous chapter. Neomorphism and replacement, including secondary dolomitization of some sediments on the west bank, allowed only vague interpretations of the original fabrics, especially the matrix of some units. The description, outline of vertical and lateral distribution, and environmental interpretation of each lithofacies distinguished by paleontologic and petrographic constituents and sediment fabrics is followed by a summary of the history of carbonate deposition. The distribution of lithofacies is shown in Figures 8, 9 and 10, and environmental interpretation is found in Figures 11, 12 and 13 (back pocket).

3.2 Lithofacies

Hemispherical Stromatoporoid Facies

The hemispherical stromatoporoid facies (Plate I, A) is characterized by *in situ*, complete, and fragmented hemispherical stromatoporoids comprising 10 to 80 percent of the rock. Other associated fossils include irregular, tabular, and thick-branching stromatoporoids, fragments of stromatoporoids that cannot be ascribed to any one morphological type , branches of the tabulate coral *Thamnopora*, and minor (notably large) gastropods, brachiopods and echinoids. The hemispherical stromatoporoids rarely attain heights of 25 centimeters but are commonly larger than core diameter (8 to 10 cm).

The rock types associated with this facies include light to dark brown rudstones and floatstones with minor framestones. Matrices in the rudstones and floatstones are predominantly grainstones and packstones consisting of skeletal grains, peloids, and lime mud or silt (now micrite or microspar). Floatstone matrices are also grainstones and packstones, but wackestones are not uncommon. In some dolomitized sections in the west bank, the core or central portion of the organic skeletons has frequently been removed Dark brown units have a high ratio of micrite to light-coloured macro-fossils and may also be stained by bituminous residue.

The hemispherical stromatoporoid facies is inter-

spersed or gradational with the tabular stromatoporoid facies and the branching stromatoporoid facies. The maximum unit thickness of the facies is approximately 9.1 meters (30 feet). Thinner 0.3 to 0.6 meter (1 to 2 foot) intervals of this facies occur interbedded with the Amphipora facies. The facies is volumetrically most important on the west bank and on the east margin of the east bank. Its maximum development is restricted vertically to the later (upper) stages of the carbonate buildup development.

The hemispherical stromatoporoid facies is interpreted as a high energy environment indicator. The massive hemispherical morphology is suited to the high current and wave energy of the shelf margin (Figure 6). Large organisms reflect the optimum nutrient and light conditions that exist in this environment. Thicker accumulations indicate shelf margin framework reefs and inter-reef debris, while thinner units interbedded with Amphipora units represent small 'patch reefs' in the back reef lagoon.

Tabular Stromatoporoid Facies

The tabular stromatoporoid facies (Plate I, B, C; Plate II, A) is characterized by 10 to 80 percent tabular stromatoporoids. Also common in this facies are stromatoporoid-algae consortia (Klovan, 1964), thick-branching stromatoporoids, solenoporoid algae, rugose corals, Thamnopora (up to 55 percent), irregular and overturned hemispherical stromatoporoids, Amphipora, echinoids, brachiopods,

and gastropods. Bulbous and encrusting stromatoporoids are rare. Fragmented stromatoporoids are common.

The rocks of this facies are predominantly medium to dark brown rudstones and floatstones with less common tabular stromatoporoid boundstones. Matrices in rudstones and floatstones vary from grainstones to mudstones. Matrix grains are predominantly skeletal. If bulbous stromatoporoids are accessories to the tabular stromatoporoids, the matrix is commonly a wackestone or mudstone.

The tabular stromatoporoid facies is well developed in both the east and west banks. The facies is interspersed with the hemispherical stromatoporoid facies of the shelf margin and the skeletal-peloid, echinoid-brachiopod, and micrite facies of the distal fore reef and off reef environments. There is also interbedding with the bulbous stromatoporoid facies in the lower developmental stage of the carbonate buildup. Units of the facies are thinner in the early stages (maximum 3.0 meters (10 feet)) relative to the later stages (maximum 9.1 meters (30 feet)) of development.

The tabular stromatoporoid morphology has been found to adapt both to the high energy of the shelf margin and the deeper, quieter waters of the fore reef (Figure 6). Klovan (1964) described tabular stromatoporoid-algae consortia from the fore reef of the Leduc Redwater reef complex. Nodular solenoporoid algae was placed in the reef or fore reef environment by Machielse (1972).

The mud-supported rocks of this facies are inter-

preted as representing lower energy conditions than the grain-supported rocks, and therefore more likely to occur in a more distal fore reef position with respect to the shelf margin than the grain-supported sediments. Mudstone matrices are also common in the units that are part of the quiet water, initial or platform stage of development.

Branching Stromatoporoid Facies

The branching stromatoporoid facies (Plate II, B, C, D, E) is characterized by fragments and *in situ* colonies of thick-branching stromatoporoids (*Stachyodes* type) comprising up to 45 percent of the rock. Colonies are up to 10 cm (4 inches) in height. Other fossils present include overturned and fragmented irregular, hemispherical, and encrusting stromatoporoids, up to 30 percent *Amphipora*, and minor brachiopods and large gastropods. Oncolites and algal-coated allochems are also characteristic of this facies.

Light to medium brown rudstones and floatstones are the major rock types of the branching stromatoporoid facies. Matrices are commonly grainstones or packstones and consist predominantly of skeletal grains and peloids. Wackestone matrices are less common. Bafflestones with grainstone matrices are rare. Darkest brown units contain disseminated bitumen.

The branching stromatoporoid facies occurs adjacent to the shelf margin hemispherical stromatoporoid or tabular stromatoporoid facies and the *Amphipora* facies of the back

reef lagoon. The facies is present along the shelf margin in both the east and west banks in the Kaybob South area. Along the west margin of the east bank the facies is volumetrically more important than the hemispherical stromatoporoid facies.

The organisms of this facies are characteristic of either the open shelf environment of the model or an intermediate energy zone of the fore reef. In a situation of overall quieter water conditions, as on the leeward margin of an 'atoll-type' buildup, the facies may also occupy the shelf margin position. Oncolites and branching stromatoporoids were found to be similarly distributed by Jansa and Fischbuch (1974) and Leavitt (1968). Branching stromatoporoid 'patch reefs' occur in the lagoon.

Amphipora Facies

The Amphipora facies (Plate III A, B, C) is characterized by fragmented Amphipora skeletons comprising 10 to 85 percent of the rock. The cylindrical fragments of the coenoestea are commonly oriented with the cylinder axis in a horizontal attitude. The diameter of the skeleton is usually 3 to 5 mm but depauperate Amphipora with diameters of 1 to 2 mm predominate in some units. Micritization of skeletons is common locally. Other common macrofossils in this facies include thick-branching stromatoporoids, gastropods, and brachiopods. Rarely present are other stromatoporoid morphologies, Euryamphipora and ostracods. Sand-sized calci-

spheres, peloids, pellets, skeletal grains and micrite are the matrix constituents.

Rock types associated with this facies are rudstones and floatstones with matrices that vary from grainstones to mudstones. The maximum thickness resulting from the interbedding of the various lithologic units is approximately 20 meters (65 feet). Colour of the units is light to dark brown; the dark brown colour usually associated with the finer grained matrices and more bituminous or argillaceous material. In several dark brown Amphipora limestone samples tested by Murray (1966), an indication of hydrocarbon compounds was found. Evidence of burrowing is suggested by irregular patches of contrasting colour.

The Amphipora facies is interbedded with the algal facies of the tidal flat and the open shelf branching stromatoporoid facies. The Amphipora facies is located centrally in the east bank, west of the shelf margin in the west bank, and is volumetrically the most important facies in the carbonate buildups of the Kaybob South area as the major facies indicative of the lagoon environment. The dark brown units predominate in the early (lower) stage of carbonate buildup development while the light brown units predominate in the later stages. Units containing depauperate Amphipora are absent to rare in the later stages of buildup development but common in the early stage dark brown units.

The light to dark brown colour variation in the rocks of this facies is interpreted as a reflection of oxygenation

conditions at the time of deposition in the lagoon. Thus, in the early dark brown platform units, or lower Swan Hills marginal reef bank complex of Jansa and Fischbuch (1974), reducing conditions were predominant, while during later deposition, predominating light brown units indicate better oxygenated conditions.

Euryamphipora Facies

The Euryamphipora facies (Plate III D) is characterized by the tabular, 1 to 3 mm thick stromatoporoid species Euryamphipora (first described by Klovan, 1966) comprising 10 to 40 percent of the rock. Other common fossil constituents include Amphipora, thick-branching stromatoporoids, fragmented stromatoporoids, fragmented gastropods and brachiopods. Skeletal grains, calcispheres and micrite are the matrix constituents.

Rock types associated with this facies include boundstones and floatstones with wackestone or mudstone matrices. Colour varies from dark to light brown as the percentage of macrofauna increases. The maximum and average thicknesses of units of this facies are 6.1 meters (20 feet) and 3.0 meters (10 feet) respectively.

Distribution of the Euryamphipora facies is similar to the bulbous stromatoporoid facies in the early developmental stage of the carbonate buildup. The facies is interbedded with the bulbous stromatoporoid and Amphipora facies. Euryamphipora preferred a moderate energy environment with

low sedimentation rates to prevent burial of the thin tabular organisms. They could therefore be found in the fore reef, open shelf or lagoon environments of the carbonate depositional model.

Bulbous Stromatoporoid Facies

The bulbous stromatoporoid facies is characterized by 5 to 35 percent bulbous stromatoporoids reaching a maximum height of 18 centimeters. The organisms are often overturned. Other common fossil constituents of the facies are Amphipora, Euryamphipora and encrusting stromatoporoids. Minor echinoid, gastropod, and brachiopod grains and branching stromatoporoid fragments are also present. Peloids, pellets, skeletal grains and micrite are the matrix constituents.

Rock types associated with the facies include dark brown rudstones and floatstones with wackestone and mudstone matrices. The maximum unit thickness is 4.6 meters (15 feet) and intervals of 0.6 meters (2 feet) or less are common.

The bulbous stromatoporoid facies is interbedded with the Euryamphipora, Amphipora, tabular stromatoporoid and skeletal-peloid facies in the early (lower) stage of the carbonate buildups. The association of bulbous stromatoporoids with Amphipora and muddy sediments indicates a preference for the low energy environment of the lagoon or quiet zones in an early, deep water platform stage. While some

of the organisms may have been partly buried rather than fully exposed (Kobluk, 1975), many were overturned, possibly under higher energy storm conditions.

Algal Facies

The algal facies (Plate IV A, B, D) is characterized by 0.2 to 6.0 mm thick micrite laminae, fenestral porosity, abundant calcispheres and rare skeletal fragments with commonly micritized margins. A filamentous algal mass, possibly Girvanella, was noted in one sample. Peloids, up to 0.6 mm in size, constitute a maximum of 95 percent of the rock in grainstones. Fine peloid grainstones (0.04 to 0.1 mm peloids) merge into the 'structure grumeleuse' of Cayeux (1935) and superficially resemble mudstones. The thickest micrite laminae, absent in samples with 'structure grumeleuse', are commonly fractured or bored. Intraclasts, a maximum of 2.1 mm in size, are common in the coarse peloid grainstones.

The predominantly light brown units of this facies are less than 3.0 meters (10 feet) thick and occur interbedded with the Amphipora or branching stromatoporoid facies. The algal facies appears more frequently on the east bank, but its absence on the west bank is possibly a result of the destruction of facies characteristics by dolomitization, rather than original non-deposition on the west bank. In the well at location 7-5-59-18 W5, a unit assigned to this facies exhibits laminae, less than 1 mm thick, of 0.2 to 0.4 mm dolomite euhedra alternating with calcite micro-

spar, possibly analogous to the dolomite laminations in stromatolites described by Gebelein and Hoffman (1973).

The algal facies is interpreted as an intertidal to supratidal deposit of the tidal flat environment, formed by elevation of lagoonal or open shelf sediments into very shallow water by some tectonic or mechanical process, or climatic variation affecting the position of sea level. The absence of extensive bank-wide units supports a more locally restricted mechanism for this environment transposition. Havard (1974) noted that sediment accumulation to the point of emergence in the back reef environment could account for the repeated intertidal or supratidal sediment development observed in the Snipe Lake Reef complex. Fenestral porosity (birdseye) and fractured or cracked crusts of micrite are interpreted as resulting from desiccation in the supratidal environment. Stalactitic cements in fenestral pores and dolomite associated with micrite laminae are suggestive of supratidal or subaerial diagenesis as described by Shinn, et al (1965) in the hammocks of Andros Island. The presence of algae is indicated by the abundant calcispheres, possibly reproductive cysts of dasycladacian algae (Rupp, 1967), considered inhabitants of an environment subject to extremes in salinity and Eh (oxidation potential) by Jamieson (1969). Other algal activity may be indicated by the merging of peloids into structure grumeleuse, perhaps triggered by algal photosynthesis, as suggested by Bathurst (1971).

Skeletal-Peloid Facies

The skeletal-peloid facies (Plate IV E) is characterized by 0.03 to 2.0 mm grains of fragmented brachiopods, gastropods, echinoderms, calcispheres, stromatoporoids, unidentified skeletal constituents, and 20 to 85 percent peloids. Micritic peloids are subangular to subrounded, moderately well to poorly sorted grains ranging from 0.06 to 0.7 mm in size. Allochems larger than 2.0 mm include traces of stromatoporoids, commonly algal-coated, or lithoclasts up to 4.5 mm in size. The matrix contains from 0 to 25 percent micrite.

Rock types associated with the skeletal-peloid facies are light to dark brown grainstones and packstones. Intervals of equigranular, euhedral to subhedral dolomite crystals in peloid-size range, lacking vuggy porosity, may also belong to this facies. Darkest units are found in the earliest stages of carbonate buildup development. Packstones and grainstones are commonly interbedded. The units are not commonly graded, but a graded grainstone unit was found interbedded with rudstones and floatstones of the tabular stromatoporoid facies.

The skeletal-peloid facies is commonly interbedded with the echinoid-brachiopod facies in the fore reef or off reef environment, rarely with other facies. Thickness of the units varies from 0.2 to 3.0 meters (0.5 to 10 feet).

The fine sand deposits represented by the rocks of this facies indicate deposition in an intermediate to high

energy environment. The source of grains is both degradation of the carbonate buildup organisms and skeleton production by the off reef benthonic community. Intraclasts may have been produced during one of the periods of subaerial exposure of part of the carbonate buildup, but no direct evidence of the formation of skeletal-peloid units coincident with subaerial exposure was observed. The graded grainstones interbedded with the tabular stromatoporoid facies are interpreted as fore reef groove or channel deposits between stromatoporoid reef spurs. The lack of large organisms in this facies indicates sands too unstable to allow growth for any significant length of time. Extension of these fore reef sands into the off reef environment required an energy impulse for the initiation of movement. This impulse may have taken the form of tectonic activity related to earthquakes or faulting, or abnormal storm wave action. Sliding or viscous flowage of the bank sands would account for the lack of erosion or scouring of the underlying sediment (Dott, 1963).

Pelleted Facies

The pelleted facies (Plate III F) is characterized by well-sorted, rounded or elliptical, 0.07 to 0.15 mm pellets comprising 30 to 90 percent of the rock. The pellets have no internal structure and consist of micrite. The shape and sorting of the grains suggest a faecal origin for the pellets. They also fall within the size limitation of Folk

(1962) for distinguishing faecal pellets. Micritized grains or peloids of no particular size or origin (McKee and Gutschick, 1969) are also generally more poorly sorted and angular. Deformed pellets are common in pellet-supported fabrics. Allochems larger than 2.0 mm comprise less than 10 percent of the rock and include echinoid, brachiopod, bryozoa, Amphipora and pelecypod fragments. Small fragments of these fossils and calcispheres are present as grains. Not more than 15 percent micrite is present in the matrix.

Rocks of the pelleted facies are grainstones and packstones; dark brown and commonly thinly laminated. The horizontal laminae, 1 to 2 mm thick, are produced by sorting of grain sizes. Average unit thickness of this facies is approximately 1.5 meters (5 feet).

The pelleted facies is interbedded or interlaminated with the micrite and echinoid-brachiopod facies. The distribution of the facies in the Kaybob South area is restricted to within 9.1 m (30 feet) of the top of the carbonate buildup or within 1.5 meters (5 feet) of the base of the Swan Hills Formation within the early stages of 'platform' deposition. The apparently small volume occupied by this facies in the buildups of the Kaybob South area may reflect the tendency of pellets to be more usually destroyed by compaction, resulting in micrites with clotted textures. These clotted micrites often surround brachiopod, gastropod or cephalopod shells that contain recognizable pellets.

Pellets are common in a low energy environment and

have been previously described as a matrix constituent of the lagoon environment (p.26). Rocks of the pelleted facies were found in the fore or off reef environments.

Oolite Facies

The oolite facies (Plate III E) is characterized by 10 to 80 percent circular to ovoid ooliths 0.08 to 0.5 mm in diameter and averaging 0.2 mm in diameter. Nuclei are commonly pellets. The oolith coating of radially fibrous calcite is less than 0.1 mm thick. Individual lamellae are separated by discontinuous micrite envelopes, possibly representing some algal activity. Other constituents of this facies include pellets, well-rounded lithoclasts (up to 1.7 mm in size) of micrite and skeletal grains, and fragments of foraminifera, pelecypods, brachiopods, gastropods and echinoids. Micrite constitutes less than 10 percent of the rock.

Rock types associated with the oolite facies are dark brown grainstones and packstones. The maximum thickness of the unit is 0.8 meters (2.5 feet). The facies is interbedded with the echinoid-brachiopod skeletal-peloid, or pelleted facies. The facies is restricted to within 12.2 meters (40 feet) of the base of the Swan Hills Formation and was observed in only three wells (6-6-59-17, 2-18-62-18 and 2-28-63-20 W5) although ooliths have been reported in 12-5-63-19 W5 by Canadian Stratigraphic Services logging of samples. The lateral distribution of the oolite facies out-

UNIVERSITY OF MANITOBA LIBRARIES

lines a trend that parallels the Kaybob South stromatoporoid buildup, occurring where the channel is defined northeast of the Kaybob South trend.

The oolite facies represents a high energy environment in the early stages of carbonate sedimentation in the Kaybob South area. It is possible that the ooliths were transported into the channel from a nearby shoal where they were originally formed; however, no ooliths were found in the banks on either side of the channel at any later stage in buildup development. The absence of stromatoporoids in this high wave and current energy environment in which hemispherical stromatoporoids may have been able to flourish indicates that other controls on organism distribution are effective here. Unstable substrate conditions may have prevented the establishment of stromatoporoid colonies, or perhaps increased salinities corresponding to long sea water residence times (Broecker and Takahashi, 1966) may have produced unsuitable chemical conditions for living stromatoporoids. Carbonate deposition in the entire early 'platform' stage in the Kaybob South area could have been widely restrictive, although not as restricted an environment as in the preceding Fort Vermilion depositional stage. Only certain organisms, such as Amphipora, bulbous stromatoporoids (Edie, 1961) and possibly tabular stromatoporoids, are thought to have been tolerant of abnormally high salinities. Such high salinities would occur in waters that were infrequently replaced by only slightly fresher water, and only these few

organisms could inhabit this early, widespread 'lagoon'.

Echinoid-Brachiopod
Facies

The echinoid-brachiopod facies (Plate V A, B, C) is characterized by 0.03 to 2.0 mm grains of fragmented echinoids, brachiopods, ostracods, gastropods, Tentaculites, bryozoa, pelecypods, cephalopods, and foraminifera. Pellets, peloids and stromatoporoid fragments are rare. Gastropods, cephalopods, and brachiopods larger than 2.0 mm are also rare. Pyrite is common. Chert locally replaces allochems, especially echinoid ossicles. Rare skeletal grains are black.

The facies may be divided into two subfacies: i) grainstones and packstones, and ii) wackestones.

i) Echinoid-Brachiopod Grainstones/Packstones. Echinoids and brachiopods, up to 50 and 30 percent respectively, are the most abundant skeletal fragments in this subfacies. Micrite constitutes a maximum of 30 to 35 percent of the matrix.

Dark brown grainstones or packstones are 0.3 to 1.2 meters (1 to 4 feet) thick and are interbedded with the wackestone subfacies or the laminated micrite subfacies in the channel wells.

ii) Echinoid-Brachiopod Wackestones. This subfacies is characterized by skeletal fragments of echinoids (up to 30 percent), brachiopods (up to 20 percent), gastropods (up to 20 percent) and 35 to 90 percent micrite. Horizontal

stylolites are common. Shale partings are rare. Beds are commonly massive, rarely nodular.

Dark brown wackestone units of maximum thickness of 4.6 meters (15 feet) are interbedded with the echinoid-brachiopod grainstone/packstone subfacies and the micrite facies in the off reef channel wells or with the fore reef tabular stromatoporoid or skeletal-peloid facies.

The observed fossil assemblage combined with the lack of stromatoporoids places this facies in the off reef environment of the model (Figure 6 and 7). Although gastropods tolerate a wide range of salinity and Eh, other organisms in this facies are indicative of normal marine conditions. Murray (1965) noted that the abundance of echinoids tends to decrease away from the reefs, although echinoderm and bryozoa fragments can be easily transported. Although typically well oxygenated, the presence of pyrite and blackened skeletal grains, also recognized in sediments by Jansa and Fischbuch (1974), indicate local reducing conditions following or generating the demise of flourishing communities.

Micrite Facies

The dark brown micrite facies (Plate V B, D, E, F) is characterized by less than 10 percent 0.03 to 2.0 mm grains and less than 10 percent allochems larger than 2.0 mm. Micrite or microspar is the main constituent. Allochems larger than 2.0 mm include gastropod, cephalopod, brachiopod (to 1.5 cm) or stromatoporoid fragments. Grains include fragmented

echinoids, brachiopods, ostracods, Tentaculites, pellets and peloids. Pyrite is common in the form of cubes, lenses, veins and disseminations in the micrite and pyritization of fossils is common. The insoluble residue content of the mudstones is not more than 10 percent (Appendix C, Samples 3 to 7 inclusive), except where stylolites and thick residual seams are concentrated (Sample 1). Clays, pyrite, and authigenic silica constitute the insoluble fraction. The organic carbon content of the samples analyzed averages 0.27 percent.

The facies can be divided into two subfacies: 1) massive or nodular micrite and ii) laminated micrite.

i) Massive (nodular) Micrite. In addition to the above characteristics, this subfacies is identified by the massive to nodular structure of the mudstones, described by Murray (1965) in the Waterways Formation at Judy Creek, and frequently referred to as 'sedimentary boudinage' (McCrossan, 1958). Wedge-shaped cracks filled with calcite spar, narrowing inwards from the borders of nodules or lenses, were previously described and interpreted by McCrossan as tension cracks formed in less plastic limey beds under the stress of compaction. Burrows filled with bioclastic debris are present in this subfacies but not common. Irregular lenses of fine skeletal debris are common. Stylolites parallel to the horizontal bedding are common and have amplitudes of up to 5 cm. Vertical stylolites up to 30 cm long and of low amplitude are rare. Black bituminous material, clays

and sulphides are concentrated along stylolite seams. Where horizontal shale partings are abundant (less than 1 cm apart), the nodular structure is absent.

Coarse calcite spar occurs in veins, vugs, fossil molds and interiors, and rare vertical fractures. Rare vugs (fossil molds) are lined with calcite, dolomite or quartz crystals. Chert occurs as nodules up to 13 cm thick, containing dolomite rhombs or ghosts of skeletal debris. Chert rarely replaces brachiopod and echinoid grains and constitutes less than 5 percent of the rock.

The massive micrite subfacies is widely distributed in the channel wells and is interbedded with the laminated micrite subfacies and the echinoid-brachiopod facies in the off reef environment and with the skeletal-peloid limestones in the fore reef. Massive mudstones also occur in beds commonly less than 3.0 meters (10 feet) thick, interbedded with the Amphipora, bulbous stromatoporoid, and tabular stromatoporoid facies.

ii) Laminated Micrite. The laminated micrite subfacies (Plate V D) consists of thinly laminated dark brown mudstones and light brown fine skeletal limestones that are wackestones, packstones, or grainstones. This facies is included as a subfacies of the micrite facies because of the invariable presence of micrite laminae while the texture of other laminae varies considerably. Variations in grain size and in the concentration of micro-stylolites in lamina impart a varve-like texture to the sediments. Pyrite is rarely concentrated in

laminae. The thickness of the lamina is variable, commonly 0.05 to 3.5 mm but lamina of pelleted packstone may be up to 2.0 cm thick. Laminae either extend the width of the core or occur more discontinuously as lenses. Tentaculites is abundant in the thinnest skeletal laminae. Other fossil debris occurs in thicker laminae. Pellets are locally common.

The laminated micrite subfacies ranges from 0.3 to 4.3 meters (1 to 14 feet) in thickness, is interbedded with the massive micrite subfacies and the echinoid-brachiopod facies of the off reef environment, and is rarely in contact with the skeletal-peloid or pelleted facies. In the well at location 7-5-59-18 W5 the laminated subfacies occurs interbedded with massive mudstones 9.1 meters (30 feet) above the base of the Swan Hills Formation, but otherwise the facies is restricted to wells penetrating the channel. One laminated interval can be correlated from the most northern well on the channel cross-section, 2-28-63-20 W5 (Figure 10) to the 6-6-59-17 well in the south, a distance of approximately 48 kilometers (30 miles). Other intervals can be correlated between two or three wells. The vertical distribution of the laminated intervals indicates the restriction of this subfacies to the wells located closest to the open basin to the north during the later episodes of off reef sedimentation.

The presence of a benthonic fauna indicates oxygenated bottom water conditions during much of the period of deposition of the micrite facies. The abundant lime mud originating from the mechanical or biological destruction of organism

skeletons living on the adjacent buildup was carried into the off reef channel by off-bank currents. Pellets, preserved in fossil interiors, may have been more abundant in the matrix than can now be recognized, and therefore also a 'source' of lime mud when their outlines are obscured during compaction.

The preservation of laminae in the laminated subfacies indicates an absence of infauna which would have destroyed the structure by bioturbation. The absence of infauna as well as the presence of pyrite reflects poorly oxygenated water conditions. Thin laminae of pelagic organism skeletons suggest that inhospitable conditions caused an increase in mortality following some variation, perhaps seasonal, in the organic productivity of the basin. Thin laminae may also have resulted from episodic storm deposition.

Green Shale Facies

The green shale facies (Plate IV C, VI D) is characterized by non-fossiliferous, laminated to massive beds of green pyritic and dolomitic or calcareous shale. Laminations are produced by an alternation of thin lenses containing varying amounts of green shale (clays), dolomite and pyrite. Laminae are commonly horizontal but were observed in one instance to dip at approximately 30 degrees. Green shale occurs in beds up to 0.9 meters (3 feet) thick and along stylolitic seams or lenses in limestone or dolomite for up to 3 meters (10 feet) beneath the thickest green shale beds. Pale green shale and dolomite also occurs in fenestral or solution cavities.

Green shale beds commonly include lithoclasts of the underlying carbonate rocks or intraclasts of green shale. Rocks underlying the shale beds are occasionally brecciated and often mottled (Plate VI E) in appearance. Fractures in the underlying rocks are filled with green shale and widen or increase in number upward to merge into green shale beds with scattered lithoclasts. Pyrite (or marcasite) occurs as fine disseminations and coarse crystal aggregates and euhedra in the green shale or concentrated along the sharp contact of the green shale with the underlying rock or included lithoclast. A stained thin section along a green shale seam showed the presence of iron-rich calcite spar, both cement and neomorphic spar, adjacent to the seam. Composition of the green shale has been found to be illite, pyrite, quartz, dolomite and rare chlorite (Murray, 1966; Havard, 1974).

Green shales have been recognized in most of the Swan Hills buildups in central Alberta and were found by Fischbuch (1968) to occur at, or near, divisional boundaries separating stages of reef growth. Both Murray (1966) and Leavitt (1968) interpreted the green shale as a residue left in ponds following a relative lowering of sea level. Havard (1974) also connected the shales with subaerial weathering processes: brecciation and solution of the exposed bank with possible soil development. A reducing environment created by the next transgressive event would have transformed the typically red oxidized soils into green shales. A submarine origin for the shales is unlikely since: 1) shallow water lagoonal, open

shelf or algal facies occur below and above the green shales, 2) there is considerable difference between the mineralogy, chemistry and associated fabrics of the green shales and previously described off reef shales (Murray, 1965), and 3) brecciation, dissolution, and extensive cementation and recrystallization of fabrics resemble karst topographic features in limestone terrains. The clays are probably residue from solution of limestones. The degree to which aeolian transport may be responsible for soil formation, as in the paleosoils of Bermuda (Bricker and Mackenzie, 1970) is unknown.

3.3 History of Carbonate Deposition

A reconstruction of the depositional history of the Kaybob South area under study is possible by analysis of facies and environments of deposition (Figures 8 to 13, in pocket) and with reference to the model developed in Chapter II (Figure 7). Four informal stages of development are recognized in the carbonate buildups based on similarities in the characteristics and spatial relationships of facies within a given stage. In addition, stage boundaries indicating important discontinuities during deposition of the buildups are recognized by one or more of the following: 1) green shale and/or tidal flat development, 2) micrite crust development (discussed in detail in Section 4.3), and 3) abrupt lateral facies shifts. Minor divisions within each stage of development, indicated by discontinuities that can only be correlated locally, are not defined within the limits of this study.

Initiation of the carbonate buildup in the Kaybob

South area was undoubtedly controlled by the same factors which influence the location of modern reefs, namely bathymetry (Stanley and Swift, 1968; Purdy, 1974), hydrology and ecology. Although Jansa and Fischbuch (1974, p. 83) suggested that the location of subsequent Swan Hills carbonate buildups was most influenced by the topography of the inorganic plateau that existed at the end of Fort Vermilion time, neither the Kaybob South linear trend (west bank) or the east bank carbonate buildups were shown to be strongly influenced by this factor (Jansa and Fischbuch, 1974, Figure 41). A structural control over the location of the buildup trends, established by faulting related to the Peace River Uplift (Martin, 1967) is possible, although no evidence of faulting was observed in the cores studied.

Since the regional dip in the Swan Hills area was approximately east to northeast during deposition of the carbonate buildups, growth of discontinuous carbonate buildups as the Beaverhill Lake sea transgressed south-westerly over the Swan Hills area can be visualized as presented in Figure 14. The most favourable location for prolific organism development is first in the northeast (sea level 1), later shifting to the west to southwest with the following marine transgression (sea level 2). In this situation the east bank area would have been a prime location for flourishing stromatoporoid growth before similar conditions existed on the west bank. The west bank would be suitably located to continue to host stromatoporoid growth after the east bank colonies had been

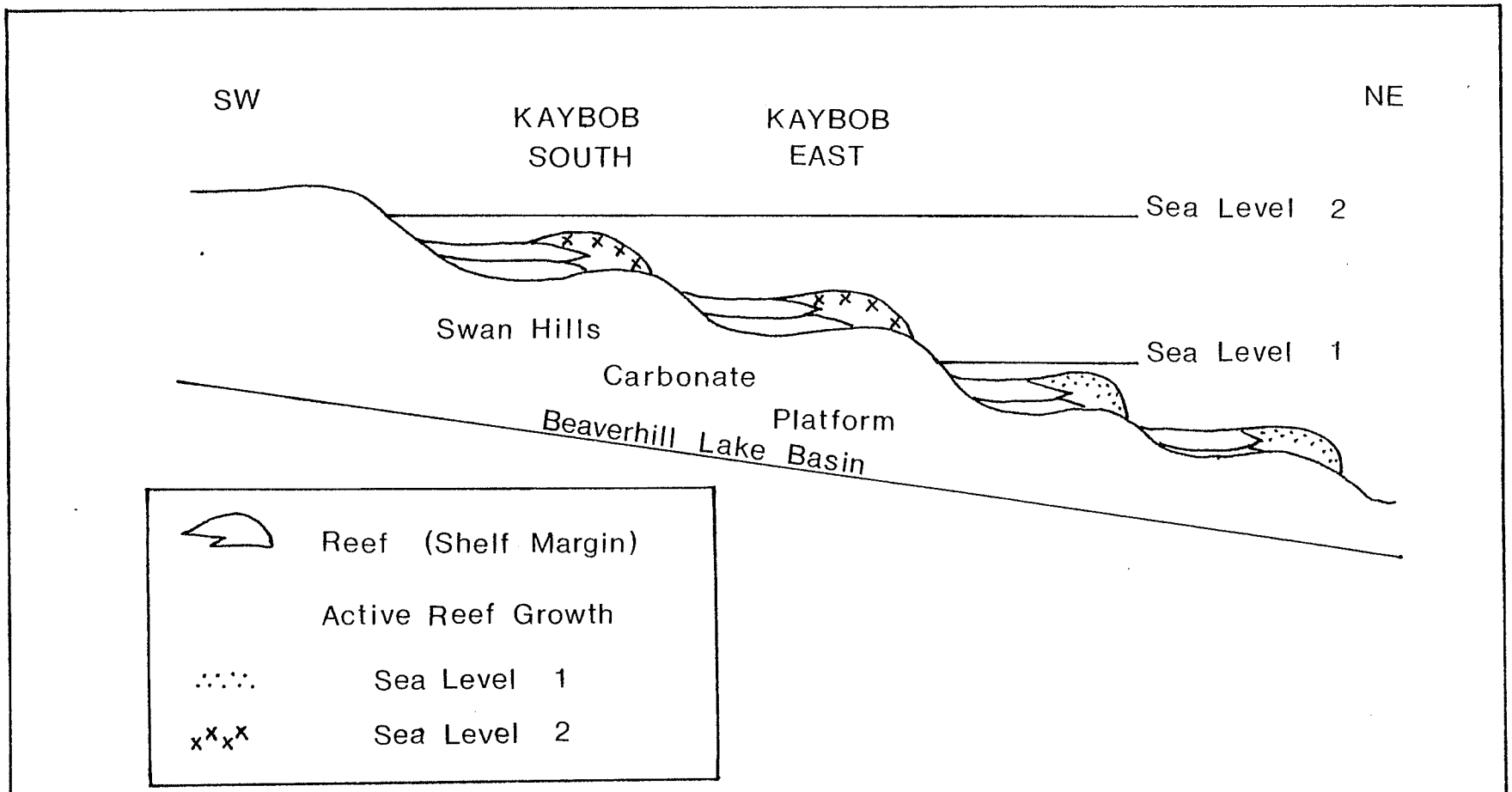


Figure 14. Schematic cross-section along line approximately N 45° E, perpendicular to Beaverhill Lake basin shore, Swan Hills area.

destroyed by drowning. Figure 15, a composite cross-section of the west and east banks, with the green shale at the top of Stage 1 as a datum, is believed to represent the best interpretation of the spatial relationship of the two banks. Stromatoporoid growth on the west bank continues after east bank growth is terminated. Both west and east banks show shelf margin and open shelf facies shifting to the west during the last stage of carbonate buildup deposition.

Characteristics of the stages of development in the depositional history of carbonate buildup are described and interpreted as follows:

Stage 1 Platform-Biostrome Development. The platform stage of development reaches a maximum thickness on the west and east banks of 30 to 34 meters (100 to 110 feet) and 43 to 55 meters (140 to 180 feet) respectively. Predominantly dark brown units contain generally not more than 30 percent fossil material, although locally Amphipora skeletons may compose 40 to 50 percent of the rock. The Amphipora lithofacies is widespread and depauperate Amphipora are most common in this stage. Bulbous stromatoporoid, Euryamphipora, and tabular stromatoporoid lithofacies are rarely present. Oolite, skeletal-peloid, and pelleted lithofacies are locally developed. The branching stromatoporoid lithofacies is present near the upper boundary of the stage. Matrix-supported rocks are more common than grain-supported rocks and, except on the east margin of the east bank, mud is the predominant constituent of the matrix. Algal boundstones

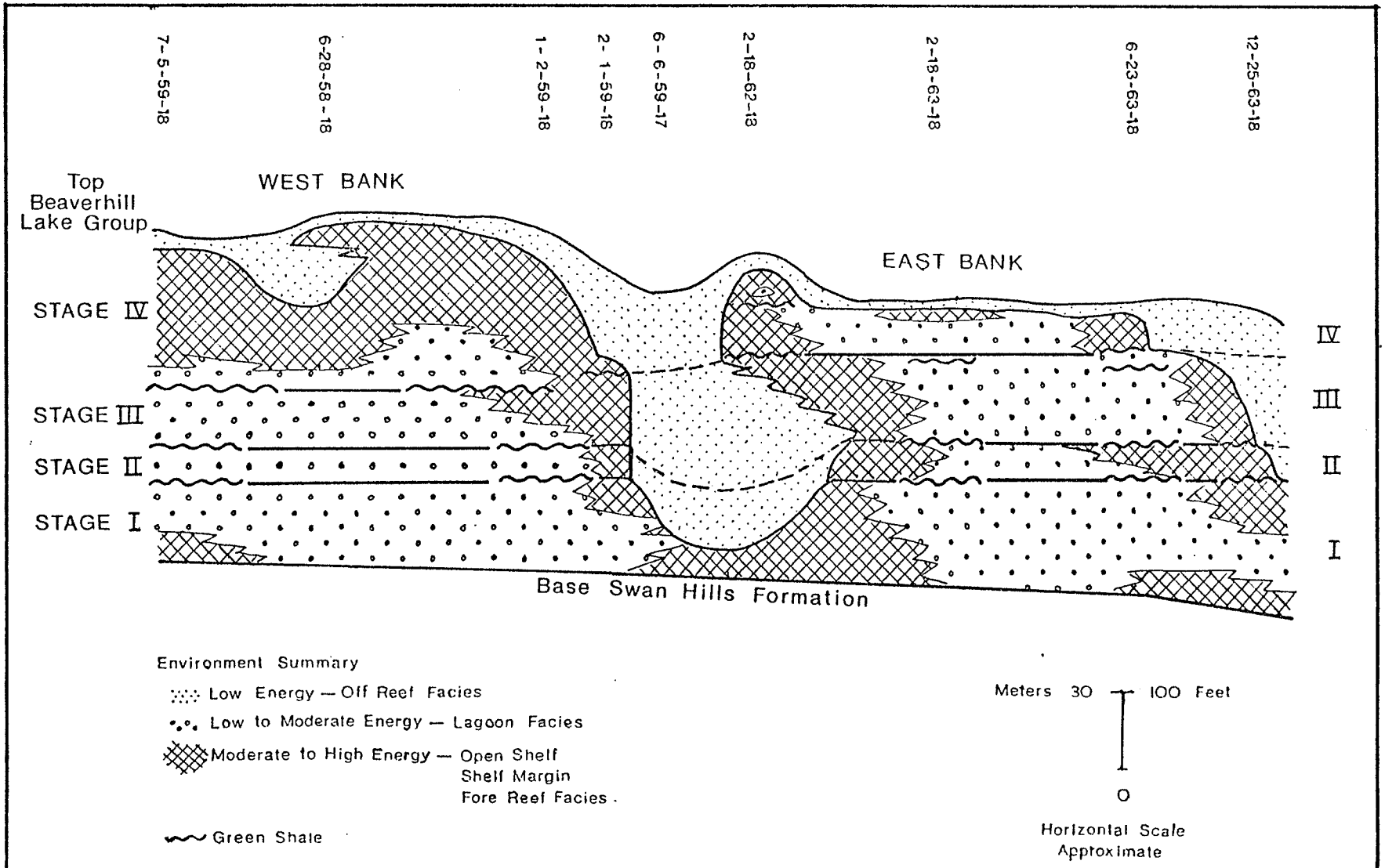


Figure 15. Composite cross-section, Kaybob South area.

are rare. Green shale marks the upper boundary of the stage.

In this initial biostrome or bank stage, limited facies development indicates relatively uniform environmental conditions across the carbonate buildup during the marine transgression. In comparison with the zoned model (Figure 7), the bank at this time most resembles the widespread lagoonal environment, with local patch reefs of encrusting, tabular and branching stromatoporoids. Branching stromatoporoid mounds on the east margin of the east bank near the end of Stage I deposition indicate well-aerated conditions in this windward location (Jansa and Fischbuch, 1974; Schultheis, 1976). Abundant dark brown units indicate predominantly reducing conditions in existence during Stage I. Local episodes of shallowing occurred during the main transgression. Green shale deposited at the end of this stage indicates subaerial exposure of the platform on the east and west banks. Lack of green shale overlying the platform in channel wells suggests that the channel 'bottom' may not have been exposed, and that this deeper channel or inlet between the carbonate banks was in existence and maintained from the earliest stage of carbonate bank deposition. The possibility that a soil (green shale) was present in channel wells at this stage but later removed by continued erosion is not favoured as no petrographic evidence of diagenesis related to subaerial exposure (presented in Chapter IV) was observed in the channel rocks. Evidence of oolite buildups and/or stromatoporoid growth in the platform sediments in channel wells is support-

ing evidence that strong currents, whether wind or tidal induced, were in existence in the channel during Stage I.

Stage II. The second stage of carbonate bank development is 12 to 15 meters (40 to 50 feet) thick. Growth resumed on the east and west carbonate banks with an increase in the diversity of growth habits of stromatoporoids. Fossil abundance is noticeably increased over Stage I. On the east bank, grain-supported rocks dominate over matrix-supported rocks, while on the west bank mud-supported rocks are still common. The branching stromatoporoid lithofacies is widespread on the east bank and occurs with the hemispherical stromatoporoid, tabular stromatoporoid, skeletal-peloid, and Amphipora lithofacies. Although the facies are easily separable on the east bank, they are not as easily defined on the west bank. Green shale or micrite crust (discussed in detail in Section 4.3) development defines the upper boundary of this stage.

The widespread open shelf facies and generally light coloured rocks indicate that well-aerated and moderately turbulent conditions prevailed on the east bank during the Stage II marine transgression. West bank deposition was still characterized by lagoonal environments with Amphipora patch reefs on the lime mud bank. Irregular topography created by subaerial erosion at the end of Stage I is possibly partly responsible for isolating and encouraging shelf margin or open shelf-type environments and producing a buildup profile that exhibits the zoned aspect of the model (Figure 7).

Subaerial exposure termined the transgression of Stage II.

Stage III. The third stage of deposition in the Kaybob South area averages 24 meters (80 feet) thick on the west bank and 34 to 37 meters (110 to 120 feet) thick on the east bank. Both west and east banks are characterized by well-developed and varied facies, abundant fossils, and light coloured units darkening towards the base of the stage. Buildup deposition is areally less extensive on the east bank and facies exhibit shifting to the west. Branching stromatoporoid, Amphipora and tabular stromatoporoid lithofacies predominate on the west bank while Amphipora, skeletal-peloid, tabular stromatoporoid and hemispherical stromatoporoid lithofacies predominate on the east bank. Matrix-supported fabrics predominate on both banks, and increase significantly in mud content towards the west margin of the east bank. Matrices on the west bank are recrystallized, mud content is not easily determined, and trends are therefore ill-defined. On both banks algal boundstones and green shale or micrite crust developments dominate the upper 12 meters (40 feet) of Stage III. Green shale or algal boundstones mark the termination of Stage III.

The third stage of carbonate buildup deposition is characterized by a great variability in depositional environments, with the complete range of environments shown in the model profile (Figure 7) present for much of this stage. The volumetric significance of the open shelf and shelf margin organisms along the east margins of the carbonate buildups

is not clearly defined by the cores studied. However, the existence of a barrier and its influence on carbonate sedimentation across the buildup is substantiated by observations of the leeward cores. Although framework reefs (definition of Heckel, 1974) and sediment bafflers (branching stromatoporoids) formed an effective barrier, skeletal sediment predominated over framework patch reefs along the windward shelf margins. In the lagoon adjacent to the shelf margin, grains dominate the matrix constituents, while mud predominates over grains in the matrix in the more leeward lagoon. Shallow subtidal conditions were prevalent during this transgression; the turbulent conditions commonly fragmenting fossil skeletons. Intertidal to subaerial conditions, widespread during the latter period of this stage and finally terminating buildup growth at the end of Stage III, may have coincided with increased carbonate sediment supply to the off reef. Fifteen meters (50 feet) of skeletal-peloid grainstones to wackestones west of the east bank may have been deposited during the erosive periods. When Stage IV growth began, interbank sedimentation had progressed to the point where the surface of the carbonate bank of Stage III was only slightly elevated above the surrounding off reef carbonate sediments.

Stage IV. The final stage of carbonate buildup deposition in the Kaybob South area reaches maxima of approximately 60 meters (190 feet) and 40 meters (125 feet) on the west and east banks respectively. In response to a shift in currents, tectonic adjustment, and/or the erosive topography

of Stage III, shelf margin and open shelf facies shifted significantly to the west and the range of buildup deposition decreased. Branching stromatoporoid and tabular stromatoporoid lithofacies are common on both banks. The hemispherical stromatoporoid lithofacies is developed on the west bank. Amphipora lithofacies is present on the east bank. Fossils are abundant and grainstone matrices dominate on the east bank where sediments are both matrix and grain-supported. Matrix-supported fabrics predominate on the west bank, but matrices are largely recrystallized and it is therefore difficult to interpret original fabrics.

The presence of tidal flat sediments and green shale on the east bank indicates an interval of shallowing to exposure that is interpreted as a local event, as no correlative evidence for exposure was observed on the west bank. It was noted during the study that green shales tend to be better developed, or perhaps better preserved, in back reef lagoonal environments rather than shelf margin or open shelf environments. The predominance of the latter environments over the former on the west bank could explain the apparent lack of green shale and the lack of recognition of another major boundary in the carbonate buildup.

Stage IV represents a period of relatively shallow-water deposition in the depositional history of the Kaybob South area. Grain-supported textures, abundant large hemispherical stromatoporoids,and widespread development of lithofacies of the highest energy environment support this inter-

pretation. Electrical logs indicate that carbonates with increased argillaceous content surround the rocks of this stage, suggesting that off reef carbonate sedimentation rates may have been lower during Stage IV than during previous stages, and that the bulk of off reef sedimentation surrounding the Stage IV carbonate banks occurred after bank sedimentation ceased.

The cause of the termination of carbonate deposition on the east bank is not obvious from the study of the available cored intervals. Deposition may have been terminated by drowning: the inability of vertical growth to keep up with the subsidence rate or relatively rapid sea level rise, or shallowing: organism growth limited by sea level and unable to maintain the existence of the bank by lateral growth. On the west bank the author suggests that deposition continued upward beyond the level of temination of east bank deposition (Figures 14 and 15). Core recovery through the top of the thickest carbonate buildup sections on the west bank indicate shallowing may be responsible for terminating buildup deposition. Units of fractured and fragmented fossils, and truncated fossils in abrupt and often stylolitic contact with overlying off reef sediments form the last deposits of Stage IV on the west bank. Lack of green shale at the top of these units indicates either the absence of a long period of subaerial erosion that marked other stage boundaries or an extensive period of erosion that removed the previously formed green shale. With a rapid increase in water

depth accompanying the marine transgression that followed, conditions hostile to organism growth were established and buildup deposition never resumed.

Each stage of carbonate deposition in the Kaybob South area defines a major marine transgression. Shallowing, either by sea level lowering or by growth of the buildup into shallow water at a rate that surpassed the subsidence rate, was accompanied by deposition of a regressive carbonate sequence, often terminating the stage with emergence into the subaerial environment. A new increase in water depth initiated the next depositional cycle. The extent to which regional or local tectonic movements or climatic changes are responsible for the adjustments in relative sea level at the time of deposition are unknown. As Jansa and Fischbuch (1974) and Havard (1974) suggest, regressing carbonate cycles may form in a continuously subsiding basin or transgressing sea by hydrodynamic processes and sediment accumulation around a shelf margin barrier. These processes could also account for the major and minor regressive stages of carbonate deposition in the Kaybob South area.

CHAPTER IV

DIAGENESIS

4.1 Introduction

The purpose of this chapter is to describe and illustrate the petrographic features of diagenetic environments interpreted by thin section study of the cores of the Kaybob South area. Studies of modern and ancient carbonate sequences, combining petrographic and chemical techniques, have identified diagenetic modifications to original carbonate sediments beginning while these sediments lie in their original submarine environments and continuing until their burial in the subsurface. In addition there exists the possibility of elevation of the sediments into the subaerial regime and the development of ephemeral or persistent fresh water lenses. All diagenetic processes affect the original depositional fabric, including the distribution of porosity (Matthews 1974).

Diagenetic features observed in this thin section study are described and interpreted under three major divi-

sions or environments:

a) submarine

b) subaerial

c) subsurface

Dolomitization is discussed in Section 4.5. This chapter concludes with a discussion of porosity trends in the Kaybob South area.

4.2 Submarine Diagenesis

Cement

Four calcite cement fabrics are interpreted to be of submarine origin: 1)irregular, discontinuous rim with micro-stalactitic protuberances, 2)bladed isopachous rim, 3)equant isopachous rim, and 4)syntaxial rim.

Irregular rim cement consists of diverging subcrystals of non-ferroan calcite discontinuously rimming pores. Long axes of crystals are perpendicular or sub-perpendicular to pore walls and slightly curved. Inter-crystalline boundaries are ragged. This cement exhibits a brush or undulatory extinction described by Havard (1974) in some cements in the Snipe Lake reef complex (Plate VII A, B and Plate VIII C). Crystals up to 3.8 mm long contain either thin laminae of micritic inclusions or bands of 1 to 2 micron 'dust', marking growth episodes (Plate VIII C). Where the cement is found on the base of shelter or interparticle pores, it is overlain by fine-grained or silty fossiliferous marine sediment. This

cement occurs in fore reef rudstones and floatstones.

The irregular rim cement is interpreted to be submarine in origin based on the observations: 1) it occurs in shelter and interparticle pores which were present immediately following deposition (classified as primary pore systems by Choquette and Pray, 1970), 2) it is associated with pore-filling marine sediments and occurs in rocks of the fore reef facies, 3) it is not associated with vadose fabrics of subaerial diagenesis, such as dissolution porosity or vadose silt, 4) it resembles the 'fan-druses' of aragonite fibres described by Shinn (1969) in the interstices of subtidal sands in the Persian Gulf, or the botryoidal aragonite described by Ginsburg and James (1973) in Holocene reefs of Belize. James and Kobluk (1978) found non-ferroan calcite, first generation cement with sweeping extinction in Lower Cambrian reefs of southern Labrador and interpreted it as synsedimentary in origin. Davies (1977) described botryoidal calcite from Upper Paleozoic reefs in the Arctic and interpreted the cement as a neomorphic replacement of an original fibrous to acicular magnesian calcite cement. Mazzullo and Cys (1979) described divergent radial mosaics of pseudospar with undulatory extinction as representative of former marine aragonite botryoids. As Havard (1974) suggests, the brush extinction of the rim cements may be a relic of fibrous crystal structure, but the original mineralogy cannot be deduced from only petrographic study.

Bladed, isopachous rim cement, (Plate VIII B, E) with straight to undulatory extinction is also non-ferroan calcite. With a relatively uniform thickness about the pore wall, reaching a maximum thickness of 2.0 mm or completely filling smaller pores, the isopachous rim cement displays up to three variations in colour and clarity over the continuous growth of one isopachous rim. In the Plate VIII E example, initially the rim cement is yellow and clear, then colourless and cloudy with inclusions, and finally brown and cloudy with inclusions. Minor irregularities in thickness occur in cement rims on the bases rather than upper surfaces of pores. Fossiliferous marine sediment, including ostracod fragments and silt, or a second generation of cement overlies the isopachous rim. This cement is found in interparticle, intraparticle, shelter and fenestral pores in fore reef grainstones and floatstones.

The argument supporting a marine origin for the bladed isopachous rim cement is similar to that supporting the interpretation of the irregular rim cement: occurrence in primary pores, association with marine sediments in the fore reef environment, and dissociation from vadose fabrics. Micrite coatings on unabraded Amphipora and gastropod shell margins preliminary to bladed rim cement may be analogous to examples of rinds of magnesian calcite micrite cement to bladed spar, as described by James, et al (1976) in modern Belize reefs. However, differentiation between micritization

of allochem margins by biological activity or by cementation is not possible here. The unabraded nature of the fossil skeletons supports the interpretation of early preservation of ornamentation by early cementation - the skeletons not being susceptible to further abrasion when secured by cement. The undulatory extinction of the cement could be relic of former acicular or fibrous crystal structure, similar to the structure of isopachous fringes in Jamaican reefs (Land and Goreau, 1970).

Equant isopachous rim cement consists of clear or cloudy and colourless, 0.02 to 0.20 mm non-ferroan calcite crystals (Plates III F; VII C,D; VIII F). Acicular or bladed 'ghost' crystals are rarely identified in the equi-dimensional crystals of the relatively uniformly isopachous cement. Thin micrite laminae, less than 0.01 mm thick, are uncommonly interlayered with cement (Plate VIII F, VII C). The cement is found in the interparticle pores of rudstones, grainstones and packstones of off reef skeletal, oolite, and pelleted facies.

The equant isopachous rim cement is interpreted as a product of the subtidal environment. As in the case of the previously described cements, this cement occurs in primary pores. Fenestral porosity typical of the intertidal environment is absent, so the cement is most likely to be of subtidal rather than intertidal 'beachrock' origin. Radial-fibrous to equigranular fabrics of aragonite or high-magnesian calcite

cements in Persian Gulf submarine hardgrounds and isopachous acicular rim cements present in modern beachrock ('druse' of Shinn, 1969) may both petrographically resemble the above ancient submarine cements after recrystallization (summary in Bathurst, 1971, p.371-373, and several articles in Bricker, 1971). Interlayered micritic laminae may owe their origin to the precipitation of micrite cement between equant cement rims or to the accumulation of micrite sediment. Since these laminae are not restricted to sites determined by gravitational settling of sediment, but occur on all surface attitudes, the former origin is the most likely interpretation.

Syntaxial rim cement consists of an overgrowth of calcite on echinoid grains in crystallographic continuity with the echinoderm fragment, producing single crystals up to 2.0 mm (Plate VII E). The syntaxial rims are interparticle in off reef packstones and grainstones. As pointed out by Bathurst (1971), syntaxial cement rims and syntaxial neomorphic rims are very similar and not always easily distinguished. In this instance the syntaxial rim appears to be a cement. Found as an overgrowth on echinoid grains in packstones or grainstones, it is not present on echinoid grains in interbedded wackestone units where these grains are mud-supported. Interstitial dolomite retains former structures of pellets and peloids that infilled interparticle pores after growth of the syntaxial rim, while relic structures are absent in syntaxial rims. In addition, intercrystalline boundaries are

planar and the percentage of enfacial junctions is greater than that typical of neomorphic calcite spar (Bathurst, 1971). There are no vadose or dissolution fabrics present with the syntaxial rim cements to suggest the over-growth occurred in any but the subtidal marine environment.

Submarine Sediment (Silt)

Submarine sediment, as discussed under diagenesis, refers to that sediment which modifies porosity by infilling subsequent to an initial episode of cementation and commonly preceding additional cementation episodes. Contrasting in colour with the host rock sediment, the commonly light brown sediment of well-sorted calcite crystals less than 6 microns in size contains minor fragmented ostracod valves, 0.07 to 0.15 mm in length. Commonly, as in the interparticle pore of a fore reef rudstone (Plate VIII B), the sediment forms a geopetal fabric with a succeeding generation of cement occluding the remainder of the pore space. In the example shown in Plate VIII A, the sediment occurs in solution-enlarged pores (note dissolution of Amphipora skeleton) of an intertidal beachrock. A dolomitized equivalent of this geopetal silt fabric may be the example shown in Plate XI A, in the fenestral pore of an intertidal grainstone. In spite of the change in composition, the similarity of the dolomitized fabric of 6 to 8 micron crystals overlain by significantly coarser 0.5 mm crystals (Plate XI A) to the undolomitized geopetal fabric (Plate VIII B) is striking.

The diagenetic silt is interpreted to be of marine origin rather than vadose origin, as interpreted for crystal silts described by Dunham (1969a). The diagenetic silt contains fossil skeletons and exhibits colour characteristics similar to the burrow structures in subtidal Amphipora wackestones and floatstones. The diagenetic silt differs in being better sorted and containing fewer, smaller ostracod valves, differences that would be expected after the winnowing process which would transport the silt to new pore systems. Similar to Dunham's crystal silts, the diagenetic silts are geopetal. However, the upper surface is invariably horizontal, whereas crystal silt surfaces described by Dunham were commonly inclined. Shinn (1969) found internal sediments in submarine sediments of the Persian Gulf to be similarly fine-grained and well-sorted (5 to 10 microns), and noted their resemblance to Dunham's vadose silts. In the Kaybob South area, the diagenetic silt is characteristically found in primary pores in fore reef or intertidal facies rocks. One exception (Plate VIII A) is a rare occurrence of the silt in a solution-enlarged pore. Possibly this example indicates resubmergence after an emergent interval which was responsible for dissolution and initial gravitational cementation (described under Section 4.3, subaerial diagenetic features).

Biological Diagenesis

The contribution of organisms to diagenesis in the reef complex environment is seen in bored and micritized

skeletons, grains, and micrite surfaces. Both micro- and macroborings are present in the Kaybob South complex. The process of micritization, the development of micrite envelopes or cryptocrystalline rinds on skeletal grains, was detailed by Bathurst (1966) and attributed to algal activity. Fungi also are bio-erosive borers, their characteristic bores distinguished from those of algae by Bromley (1975). More recently, Kobluk and Kahle (1978) described the widespread effects of endolithic (boring) microphytes (algae and fungi), including the formation of constructional and destructional micrite envelopes, total grain micritization, and even grain binding or cementation, previously described as important in the formation of Bahamian grapestone (Winland and Matthews, 1974). Calcified algal filaments that have grown outward from their borings, less than 0.1 mm long, infesting Amphipora skeletons in a lagoonal rudstone, resemble the components of the constructional envelope described by Kobluk and Kahle (1978). Other possible algal or fungal infestations are shown on a gastropod (Plate X C) and in infected circular or 'doughnut' shaped zones in stromatoporoids (Plate X B). Micritization from thorough boring of skeletal grains has probably contributed to the formation of peloids throughout the reef complex. Unknown organisms are responsible for macroborings with diameters from 0.1 to 0.5 mm and lengths up to 5 mm. These are found in stromatoporoid skeletons, in micrite surfaces (Plate VI A), and in micrite crusts or layers

in algal facies grainstones (Plate X A).

Beachrock

Discussion of beachrock fabrics could as easily occur in the next section on subaerial diagenesis as here, since derivation of the cement to lithify the sediments is from both sea water and meteoric water which can invade the intertidal environment (Bathurst, 1971; Moore, Jr., 1973; Milliman, 1974). One may also expect to observe fabrics reflecting both vadose (above water table) and phreatic (below water table) regimes in the presence of fluctuating tidal conditions.

The beachrock sediments identified at Kaybob South are grainstones and occasionally rudstones. Indurated crusts or layers in grainstones are 0.7 to 1.8 mm thick, and are composed of grains less than 0.1 mm in size cemented with micrite and fine equant calcite (Plate X A). Micrite is most abundant adjacent to the undulating to relatively planar upper and lower surfaces of the layers. Fenestral porosity is filled with equant to bladed calcite cement. The layers are fractured and bored (Plate X A). Sediment grains fine enough to pass through the interparticle pores of the coarser inter-crust grainstone units have accumulated on top of the underlying crust, resulting in inter-crust grainstone beds that appear more poorly sorted at the base of the grainstone unit. From the lower surface of the indurated layers, dusty, stalactitic, fibrous cement may hang (Plate IX D). Gravita-

tional cements associated with beachrock grainstones are described in the following section on subaerial diagenesis.

Holocene beachrock cements are extremely variable in composition and morphology. As summarized by Milliman (1974, Table 72, p.280) and Bathurst (1971, p.369), and described by Moore, Jr. (1973), acicular, bladed-equant, and micritic textures are all present. The petrographic fabrics described for the indurated layers in this study are very similar to the description given by Bathurst (1971). Rounded lithoclasts in a grainstone unit overlying an indurated crust, and the accumulation of fine-grained sediment on top of an indurated crust underlying a grainstone unit may both owe their presence to marine (wave) influences, while distinct gravitational (vadose) fabrics are not definitive of water composition. Mixed marine and meteoric conditions were most likely present, as suggested by Moore, Jr. (1973).

4.3 Subaerial Diagenesis

With the elevation of parts of the carbonate platform into the subaerial environment by any of the methods discussed in Section 3.3, a new, fresh water diagenetic environment will develop. Seasonal fresh water lenses form in tidal flat beach ridges or channel bank sediments on Andros Island. Only a small height and area of exposure is necessary to establish a lens, while Todd (1959) predicts that the hydrostatic equilibrium between fresh water and salt water will ensure that salt water will occur at a depth below sea level

equal to forty times the height of the fresh water table above sea level. Subaerial diagenesis ('subaerial' since it requires subaerial exposure of at least part of the subtidal carbonate sediments) may be divided into two sub-environments: the vadose zone of air-filled sediment pores above the groundwater table, and the phreatic zone of water-filled sediment pores below the groundwater table. There is also a zone of mixing of phreatic and marine waters near the limits of the fresh water lens, possibly an important zone of dolomite formation (Badiozamani, 1973). As determined by Steinen, et al (1978) for Barbados, one would expect the fresh water lens to vary spatially and temporally, bringing chemically new environments into contact with previously chemically stable carbonate. One expects significant diagenesis to occur, and in fact Land (1970) and Steinen and Matthews (1973) found diagenesis to be more rapid in the phreatic fresh water zone than in the vadose or beachrock zones.

Vadose Fabrics

Cementation in the vadose zone reflects the incomplete filling of pores by water. Cements suggesting the downward gravitational movement of water in this zone are micro-stalactitic (Plates IX D; VIII A, D), hanging from lower surfaces of larger grains or lithoclasts, or upper surfaces of pores (Purser, 1969), in grainstones or rudstones or beneath indurated crusts. The micro-stalactitic calcite cements are less than 2.0 mm thick and 'dusty' with tiny in-

clusions. Bladed or fibrous crystals display undulatory extinction. Also present in interparticle pores of 'beachrock' units are possible meniscus-type cements (Dunham, 1969 b) which are deposited around points of grain contact where water is localized above the water table (Plate IX A). Known as 'pore-rounding cement', the clear, equant crystals less than 0.01 mm are difficult to recognize after succeeding cement generations mask their presence. This example (Plate IX A) resembles a similarly interpreted Mississippian fabric identified by Harrison and Steinen (1978, Figure 9E).

Micrite surfaces (Plate VI A, B, C), up to 1.0 mm thick, are relatively planar discontinuity surfaces, and are distinctly marked by colour change between units. A micrite surface truncates skeletal allochems in the unit on which it develops (Plate VI C). Fractures (Plate VI B) and/or boring (Plate VI A) may be present, producing a somewhat pitted and irregular surface on a microscopic scale. Point count data indicate an increase in the amount of calcite spar below the micrite surface compared to the overlying unit in two samples, while a third sample showed a slight decrease (Table 3). Calcite cement occurs in irregular and roughly circular fenestral pores, shelter pores, and channel, fracture, and vug pores usually less than 1.0 cm in largest dimension. A dusty, bladed cement similar to the micro-stalactitic cement described in beachrocks occurs in both micro-stalactitic and isopachous habit in all pore types found. A clear, equant

calcite cement fills some pores entirely or the remainder of pores containing a first generation of the bladed cement. Beneath the thin micrite surface, micrite is common as peloids, micritized grain margins and matrix.

The micrite discontinuity surfaces are either subaerial exposure surfaces or submarine hardgrounds. The author favours the former explanation for the following reasons: 1) The presence of vadose-type cements in primary and secondary (post-depositional) pores. One would not expect to find secondary pores formed by dissolution containing gravitational cements if the unit had not been exposed to the subaerial environment. 2) Lack of encrusting fauna in growth position on the surface. This feature is typical of submarine hardgrounds, according to Purser (1969) and Bathurst (1971). Shinn (1969) however, pointed out that encrustation, along with boring, only occurs near shore in Holocene Persian Gulf sediments, not seaward where the hardground may be protected from encrustation by overlying sediment. 3) Lack of internal marine sediments in pores. Geopetal marine sediment as described earlier (p.69) is absent beneath the micrite surfaces, but highly characteristic of hardgrounds, according to Bathurst (1971).

Havard (1974) described a type of micrite surface, in back-reef sediments at Snipe Lake, which also exhibited a dense upper 1 to 2 mm thick micrite layer with subaerial fabrics beneath (dissolution pores, molds of root tubules,

cements, crystal silt accumulations). A comparison was made to the Holocene laminated crusts (caliche) of Multer and Hoffmeister (1968) and James (1972). As an analogue for this type of diagenetic feature, the micrite surfaces at Kaybob South must represent only the most rudimentary stage of development. Conditions suitable for developing more extensive caliche profiles as described by the above authors, and also Harrison (1974) and Walls, et al (1975), did not exist.

Green shale horizons, previously described and interpreted in Section 3.2 (p.29), are another indicator of the subaerial environment. The contact between the green shale and underlying carbonate (Plate VI E) is comparable to the micrite surface in its sharpness, and differs in being more fractured and brecciated. In addition, pyrite and, more rarely, dolomite, occur along and below the green shale contact and along the green shale seams beneath the major shale horizon (Plate VI F). Dissolution of skeletal components and formation of enlarged moldic and vuggy dissolution porosity is more common below green shale than beneath micrite surfaces. Geopetal dolomite fabrics (Plate XI B) may reflect original fabrics such as vadose internal sediment or crystal silt, if the crystal size of replacement dolomite in any way reflects the size of the original calcite (further discussion in Section 4.5).

Anhydrite, occurring as nodules up to 1.3 mm in size,

in beds up to 1.0 cm thick, and interbedded with finely laminated fine (0.03 to 0.05 mm) dolomite, may represent diagenetic products of the supratidal zone (Plate XII A). The nodules are composed of felted anhydrite laths (maximum to minimum length ratio 20:1) with maximum lengths commonly less than 0.5 mm. Some laths are fractured and bent. Kinsman (1969) described nodular anhydrite displacively growing interstitially in host sediments in Persian Gulf sabkhas (salt flats inundated by marine water only occasionally). In such an environment, increased salinities, caused by evaporation of interstitial sea water brines, are accompanied by precipitation of gypsum and anhydrite, and dolomitization of fine-grained carbonate sediment (Kinsman, 1969). The absence of gypsum in the example at Kaybob South is not surprising since it could have been replaced by anhydrite. As Kinsman (1969) points out, other ephemeral mineral phases such as halite can be removed by later flooding, and all minerals once present in the sabkha may not be preserved. Broken and bent crystals suggest that growth of later anhydrite laths physically displaced and ruptured earlier formed crystals. The fabric of the anhydrite nodules differs from the other occurrences of anhydrite at Kaybob South. Elsewhere it occurs as large (up to 4.5 mm), often poikilitic crystals in stromatoporoid floatstones, skeletal packstones or oolite grainstones (Plate V C), or as smaller equant, anhedral crystals associated with dolomite in moldic poros-

ity. These examples are clearly later features of subsurface diagenesis. Since dolomite is extensive for hundreds of feet vertically about the location of the anhydrite nodules, it is difficult to estimate the amount of dolomite which might be penecontemporaneous, but the fine-grained laminated dolomite interbedded with the anhydrite nodules may possible be of such origin. Kinsman (1969) noted dolomitization of fine-grained sediment occurred in the Persian Gulf sediments.

Phreatic Fabrics

Three cement fabrics are interpreted to be of phreatic origin. The first is an isopachous calcite rim cement in fenestral, fracture and dissolution porosity (Plate IX C, E, F). It is composed of bladed crystals, commonly with fibrous 'ghosts', up to 1.8 mm thick, and dusty with inclusions. A second isopachous rim cement is composed of equant, clear calcite and is less than 0.1 mm thick (Plate IX B). This cement is found in irregular and laminar fenestral porosity. Both cement types completely fill smaller pores and are common in Amphipora facies grainstones and rudstones. The third type of phreatic cement fabric is a ferroan calcite or zoned-ferroan calcite cement occurring as clear equant crystals up to 2.5 mm in size. Sometimes growing in optical continuity with the rim cement (Plate IX F), it commonly completely occupies the centres of pores already rimmed by a cement of non-ferroan calcite. It also occurs in fractures, fenestral pores, and intraparticle pores that have no previous cement rim,

and in moldic porosity of gastropods, brachiopods, and pelecypods in off reef skeletal packstones and wackestones.

The two isopachous rim cement fabrics are interpreted to be of phreatic origin because of their presence in secondary pores and their tendency to form isopachous rims, indicating fluid-filled pores. These cement types occur in Amphipora facies units subject to subaerial diagenesis below green shale horizons or micrite surfaces, although they were not themselves elevated above the groundwater table.

The ferroan calcite cement was probably precipitated in the phreatic zone where reducing conditions (low Eh (oxidation potential)) of the interstitial water allowed incorporation of the Fe^{++} ion into calcite lattices (Neal, 1969). Zoning of iron content within single crystals is due to fluctuating chemical conditions, perhaps near the vadose/phreatic boundary. Pyrite below green shale horizons and included in rim cement may form in the phreatic environment if hydrogen sulphide is supplied by decaying organic matter (Neal, 1969). However, Love (1967) documented pyrite formation in muds in a reducing environment just below the marine sediment surface. Later, deeper subsurface waters may be responsible for precipitating the ferroan calcite in molds in off reef skeletal units, although, at times when the adjacent carbonate buildup was exposed, a phreatic lens may have invaded these subtidal sediments. Oldershaw and Scoffin (1967) interpreted pressure-solution along stylolites or clay seams as a source of calcite and ferrous ions for ferroan

calcite. Adjacent to stylolites beneath green shales in stromatoporoid rudstones, ferroan calcite is found within a few centimeters of the stylolite in a predominantly non-ferroan calcite stromatoporoid skeleton. Whether or not pressure-solution is a significant source of ferrous ions for all the ferroan calcite cement is unknown.

Dissolution occurs under conditions of subaerial exposure, especially in the phreatic zone (Steinen and Matthews, 1973; Land, 1970; Pingitore, Jr., 1976). Evidence of dissolution at Kaybob South includes the development of secondary solution-enlarged, irregular, channel, vuggy and moldic porosity, as well as partial dissolution of skeletons and rim cements. Solution features may be associated with pyrite, as in the dark 'halo' of pyrite surrounding a roughly circular vug in the wackestone matrix of an Amphipora floatstone beneath a green shale horizon (Plate XI B). Amphipora skeletons beneath green shale horizons (Plate VIII A) and at micrite surfaces (Plate VI B,C) show evidence of partial dissolution. Partial dissolution of rim cement in a fenestral pore is shown in Plate IX E. Complete dissolution of some gastropods, brachiopods and pelecypods has occurred, leaving micrite-rimmed molds filled with ferroan calcite.

Neomorphism

Neomorphism as defined by Folk (1965), includes transformation of aragonite to calcite and recrystallization without change in mineralogy. Aggrading neomorphism (Folk, 1965)

describes the process of producing coarser crystal mosaics from finer ones, and Bathurst (1971) described criteria for distinguishing such neomorphic spar from sparry cement. Cements themselves in ancient carbonates are subject to neomorphism (Davies, 1977). James (1974) described two major solution-precipitation processes affecting Pleistocene aragonite coral skeletons in the subaerial environment. One of these processes operating on a fine scale, produces a neomorphic fabric that preserves original coral microstructure. Occasionally stromatoporoid skeletons, especially Amphipora (Plate X F) display relic fibrous microstructure at Kaybob South. Pingitore, Jr. (1976) distinguished neomorphic mosaics of vadose-altered Pleistocene corals from phreatic-altered corals. In fabric-selective mosaics of vadose-altered corals, boundaries of primary voids serve as crystal boundaries of the calcite mosaic replacing the coral skeleton. In cross-cutting mosaics of phreatic-altered corals, the calcite crystals replacing the coral skeleton extend into the void-filling cement (Pingitore, Jr., 1976, Figure 4 and 5). Better preservation of microstructure occurs in the vadose-altered corals than phreatic-altered corals. However, James (1974) pointed out, such Pleistocene diagenetic environmental indicators should be very cautiously applied to similar textures exhibited by organisms in more ancient rocks, such as these Devonian stromatoporoids.

Other examples of neomorphic fabrics include: a) cal-

cite of a gastropod skeleton and rim cement, where calcite crystals with curved or interlocking crystal boundaries and few enfacial triple junctions (less than 5 percent) contain traces of shell microstructure and patterns of dusty inclusions of a first generation of cement (Plate XC), and b) microspar peloids surrounded by pseudospar (coarser neomorphic spar of Folk (1965)) of crystals of irregular size with non-planar crystal boundaries. The pseudospar does not exhibit a fabric characteristic of cement fabrics (Bathurst, 1971) and could therefore be a neomorphic fabric of carbonate mud, as described by Folk (1965).

4.4 Subsurface Diagenesis

Modifications to carbonate sediments in the subsurface diagenetic environment occur beneath the zone under the influence of surficial processes, in the mesogenetic time-porosity zone of Choquette and Pray (1970). Evidence that some processes, such as stylolitization and dolomitization, were most probably operating before sediments entered the mesogenetic zone of diagenesis, and continued for some time during the relatively long period of time spent by the sediments in the subsurface, is presented as each feature is discussed below.

Stylolites

With reference to the stylolite classification of Park and Schot (1968), based on stylolite geometry and attitude

with respect to the bedding plane, the stylolites found in the rock units at Kaybob South area are commonly horizontal, less commonly interconnecting, and rarely vertical. The geometry is commonly of suture type, with thick residue concentrations in wave crests and valleys (Plates I C, II D, V F), and of the sharp-peak type (Plate VI A), occurring between stromatoporoids and within units. Residual clay seams, a variation of the simple wave type, commonly also occur in off reef facies (Plate V B), sometimes with considerable accompanying green shale (Plate VI F). In addition to the clay minerals of the green shale, pyrite, bitumen, dolomite, quartz, ferroan calcite and twinned or strained non-ferroan calcite may occur along residual seams and stylolites. Stylolites are present in every rock type, but are noticeably abundant in mudstone and wackestone matrices of floatstones.

Presumably pressure solution during compaction of the sediments, promoted by inhomogeneities in fabric and/or composition, concentrates the insoluble minerals along stylolitic seams. As Park and Schot (1968) suggest, the majority of stylolites are probably of pre-lithification origin - the solution providing a source of ions for pore-filling cement. More recently, Wanless (1979) identified three types of pressure-solution products that characterize units of certain clay or platy silt content and certain ability to resist stress. One of these solution types is invariably a source of dolomite, and will be discussed further (p.90).

Silica

Silica is present as quartz and chert in all facies of the Kaybob South complex. Euhedral to subhedral crystals of quartz, usually less than 0.2 mm in size, occur along stylolites and scattered in matrix or micritized grains, and amount to less than 1 percent of the rock. More commonly silica appears as single or coalesced spherulites in hemispherical or branching stromatoporoids, or Amphipora consisting either of calcite that preserves skeletal microstructure (Plate VII C) or very coarse calcite with no skeletal structure preserved. The spherulites, commonly less than 0.6 mm, consist of radiating fibrous to bladed aggregates of quartz that become coarser further from the spherulite centre. Often the marginal quartz is clear while the interior quartz is either uniformly dusty with inclusions or alternatingly dusty and clear in concentric rings. Microcrystalline chert occurs in nodules and lenses larger than core diameter in size, and in veins in off reef facies mudstones and wackestones (Plate V E). On a larger scale, microcrystalline chert may replace entire skeletal grainstone or wackestone units and preserve as 'ghosts' the primary texture of the sediment (Plate XII D). Rarely quartz occurs as concentric laminae alternating with pyrite and calcite in roughly circular concentrations less than 2.5 mm across in units massively replaced by microcrystalline chert (Plate XII D).

Silica dissolves in strongly alkaline solutions (pH>9) (Dapples, 1959). Such chemical conditions have been found in modern reefs and beachrock (Davies and Kinsey, 1973; Friedman, Amiel and Schneidermann, 1974), where silica spicules of sclerosponges in reef sediments have been dissolved (Land, 1976). Krauskopf (1959) noted that the rate of precipitation of silica increases markedly when solutions changed from slightly acidic to slightly basic. The dissolved silica would be deposited from solutions moving through porous and permeable sediments, replacing calcite preferentially over dolomite (Pittman, Jr., 1959). The stromatoporoid skeletons may have provided suitable sites for spherulite precipitation due to their ability to retain better porosity and permeability than surrounding matrix sediments. Whether or not there was silica present within their skeletons to act as nucleation sites is unknown. Concentrically laminated quartz, such as the example in Plate XII D, appears to be void precipitation, as no pre-silicification texture can be seen. The chert-replaced skeletal units indicate precipitation and replacement on a fine scale to preserve 'ghosts' of primary texture, although the fabric of rim cement is not preserved (Plate XI E). Dolomite euhedra and subhedra are often contained within the chert (Plate XI E), indicating that some chert is post-dolomitization in origin. The unreplaced calcite laminae in a chert unit (Plate XII D) may represent areas that were impermeable to silica solutions due to early

cementation, while interlaminated grainstones were still porous and permeable.

Calcite

Very coarse, non-ferroan calcite crystals, up to 2.0 cm in size, occur in fracture, vuggy and moldic porosity in completely dolomitized units on the west bank (Plate XII B). Rarely yellowed by sulphur inclusions, they more commonly contain dolomite euhedra or chert spherulites. This coarse calcite differs from previously described cements in its crystal size and occurrence in secondary pores in completely dolomitized samples. The occurrence in post-dolomitization porosity, the association with sulphur, and the coarse crystal size atypical of early cement (Folk, 1974), all suggest that this calcite is a product of late stage diagenesis.

4.5 Dolomitization

Distribution of Dolomite

The distribution of dolomite in the Kaybob South complex is uneven. The west bank is largely dolomite while the east bank is largely limestone. Dolomite distribution on the west bank coincides approximately with the distribution of carbonate buildup facies, although dolomitic limestones and dolostones can be found up to 6.3 meters (20 feet) above the buildup top in off reef facies. The carbonate buildup encountered in channel wells is dolomitized in two locations (10-3-60-18 and 11-1-61-19 W5). On the east bank dolomitic lime-

stones are less common, as dolomite contributes to less than 20 percent of the rock. Dolomite shows no preference for any particular facies in either bank. One finds three types of dolomite occurrence in the Kaybob South complex: a) in limestones, discriminative dolomite replacing only certain fabric elements, b) indiscriminant dolomite that has replaced all fabric elements, and c) dolomite in vuggy porosity in dolostones.

An example of the first type of occurrence is dolomite replacing ferroan or zoned-ferroan calcite in the centres of fenestral, intraparticle, interparticle, and dissolution (channel and vug) pores (Plate III B, D; Plate IV B, D; Plate IX C, and Plate XI C). The coarse crystals, up to 4 mm in size, are commonly inclusion-rich and exhibit curved crystal faces and undulose extinction. Where dolomite replacing ferroan calcite incompletely fills some intraparticle pores, the strained curved crystal faces may be easily seen. Rarely, 'ghosts' of ostracods can be seen in the dolomite in the lowermost part of the pore. Crystals commonly appear to originate from the base of a pore with pyramidal crystal terminations against unreplaced ferroan calcite near the top of the pore (Plate IX F). In some cases the dolomite is much finer (less than 0.2 mm) towards the base (Plate IX F). This gravitationally lower equant dolomite commonly has associated intercrystalline calcite or pyrite. The crystal size difference between the lower and upper dolomite is com-

monly distinct, rather than gradational, and in thin section the linear boundary between the two sizes is either horizontal or slightly inclined. (Plate XI A, B).

Another example of discriminative dolomite replacement is a linear distribution of equant dolomite crystals in calcite microspar (Plate XI D). Laminae of coarse, strained, equant dolomite, from 0.07 to 0.8 mm in size, are less than 1.0 mm thick. Abundant 1 to 2 micron inclusions are concentrated in the centres of laminae. Alternating with dolomite laminae are microspar (6 to 10 micron calcite) layers. Predominantly horizontal, the dolomite laminae coalesce occasionally, and laterally vary in concentration (within core diameter), almost to the exclusion of calcite microspar.

Gebelein and Hoffman (1973) interpreted ancient dolomite and limestone interlaminations to be analogous to Recent laminations formed by non-skeletal, intertidal to supratidal or subtidal blue-green algal mats (stromatolites). The dolomite laminae, analogous to Recent algal-rich laminae, are relatively uniform layers less than 1 mm thick with bituminous residue and micro-stylolitic seams present in the dolomite where organic material would occur in algal-rich layers. Interlaminated calcite analogous to Recent sediment layers, is of variable thickness, lacks bituminous residue, contains thread-like stringers of dolomite, and has an epiclastic texture (Gebelein and Hoffman, 1973). Their experiments determined that a 2 mm thick algal mat layer contained enough mag-

nesium to produce a 1 mm thick dolomite layer.

An alternate explanation for the origin of the dolomite/limestone interlaminations is suggested by the work of Wanless (1979) on pressure solution and dolomitization. Of his three major types of solution, two have micro-stylolitic textures with associated dolomite rhomb growth. In clean Ordovician limestones (little significant clay or platy silt), he describes the lateral transition from micrite to micritic dolomite by very fine micro-stylolitic seams. Largest dolomite rhombs tend to be zoned with clear cores and ferroan dolomite rims. It is possible that algal material (Gebelein and Hoffman's interpretation) could have supplied the magnesium for later dolomite formation along pressure-solution stylolites (Wanless's mechanism). In some Kaybob South examples where ferroan calcite crystals are replaced by dolomite in fenestral pores, stylolites are observed between the base of the dolomite and the rim cement (Plate IV B, Plate VIII E), so that dolomite of pressure-solution origin is not uncommon elsewhere in Kaybob South rocks.

Other examples of discriminative dolomite include:
1) A patchy dolomite distribution in mudstone (Plate V F). No relic primary textures are visible in the dolomite.
2) Dolomite occurring immediately beneath horizontal micritized laminae with laminar fenestral porosity in grainstones, replacing the interparticle cement in semi-circular drop-like or 'festoon' areas extending not more than 4 mm beneath

the micritic laminae (Plate IV A, near scale arrow).
3) Strained dolomite replacing peloids inside cephalopod and brachiopod shells while surrounding peloid matrix remains as calcite (Plate V C). 4) Dolomite replacing matrix, or matrix and allochem margins (Plate XII C) in more extensively dolomitized rocks. Dolomite replacing stromatoporoid skeleton margins is commonly coarser (0.15 to 1.5 mm size range) than dolomite replacing matrix constituents (0.02 to 0.15 mm).

Indiscriminant replacement of all fabric elements by dolomite is commonly seen in textures from the west bank. In hand sample, allochems are commonly easily distinguished from matrix and cement by colour (Plate II C, Plate III C). In thin section the distinction is less clear, but dolomite crystal size and shape, and intercrystalline boundary characteristics are found to vary where dolomite has replaced different calcite fabric elements. In the example shown in Plate XII E, comparing thin section to hand sample one finds replacement of a) stromatoporoid by equant dolomite of relatively uniform size (averaging 0.1 mm), b) rim cement by bladed dolomite crystals (averaging 0.6 mm in longest dimension), with long axes perpendicular to stromatoporoid margins and interlocking intercrystalline boundaries, and c) later pore filling cement by equant crystals of varying size (0.2 to 0.6 mm). In some instances the dolomite crystal fabric does not vary significantly between allochem and matrix for example, but extremely fine detail may appear to be preserved

by colour. The shape of stromatoporoid fragments or grains may be preserved by brown stain patterns, with colourless dolomite replacing probable cement surrounding the allochems. In other instances stromatoporoid allochems are replaced by colourless dolomite with few inclusions, while matrix dolomite is brown and often contains dark micro-stylolites. Rarely dolomite crystals are uniform throughout a sample, or vary in one aspect, size for example, but have no second characteristic, such as colour, from which primary textures can be deduced.

The third type of occurrence of dolomite in vuggy or moldic porosity in dolostones (Plate III C) is characterized by coarse (up to 3.0 mm) white crystals, completely or partially filling vug or mold. Crystals have undulatory extinction and curved crystal faces and dusty, micron-sized inclusions, occasionally distributed in a zonal pattern. Coarse crystalline calcite (p.87) may fill the remaining pore space of the vug or mold.

Environment and Mechanisms of Dolomitization

Several hypotheses concerning mechanisms and chemical environments of dolomite crystallization have been formulated following the recognition of dolomite in certain Recent environments. Dolomite in hypersaline waters was described by Illing, et al (1965) from the Persian Gulf sabhka, and by Shinn, et al (1965, 1969) from Andros Island supratidal flats. Hypersaline interstitial waters arise either through mechan-

isms of supratidal flooding by saline water or capillary evaporation. Deffeyes, et al (1965) described a dolomite-forming mechanism of seepage reflux of dense brines beneath hypersaline lagoons, although their hypothesis was questioned by Hsu and Siegenthaler (1969) who decided a reverse process, which they called evaporative pumping, was operating beneath tidal flats. A theory of dolomite formation in mixed meteoric/marine water was postulated by Badiozamani (1973) from a study of Middle Ordovician rocks. His dolomitization model was named 'Dorag'. In Jamaica, Land (1973 a, b) suggested that mixing of meteoric groundwater and sea water formed phreatic dolomite in Pleistocene carbonates. Hanshaw, et al (1971) hypothesized that groundwater might be responsible for dolomitization in Florida and Yucatan, with magnesium supplied by sea water or reflux brines. Folk and Siedlecka (1974) gave the name 'schizohaline' to that environment characterized by fluctuating hypersaline to freshwater conditions, as in shallow, hypersaline lagoons occasionally flooded by heavy rains, where dolomite could form. Behrens and Land (1972) believed to have found an example of dolomite precipitated directly from subtidal interstitial water, although they acknowledged that slightly hypersaline solutions may have been present and replacement may have taken place. The role of organisms in supplying magnesium for dolomite is summarized by Milliman (1974). Dolomite associated with algal mats (Gebelein and Hoffman, 1973) and pressure-solution fea-

tures (Wanless, 1979) has already been described.

The effectiveness of dolomitization on a limestone unit depends on the availability of dolomitizing fluids (this depending partly on the mechanism and length of time it is operational and the physical and chemical character of the sediment or rock (Murray and Lucia, 1967). The extent to which pre-dolomitization interstitial waters have reduced porosity and permeability through cementation and neomorphism or, on the other hand, increased porosity and permeability by dissolution, will decrease or increase the effectiveness of dolomitization, provided a mechanism for dolomitization and an ion source for dolomitizing solutions is established.

At Kaybob South, the character of dolomite distribution seems to suggest that the large scale dolomitization of the west bank may have been a later, subsurface diagenetic phenomenon. Lithification of predominantly muddy, off reef sediments, perhaps with calcite cement being supplied by pressure-solution during compaction (Bathurst, 1970), may have produced less porous and permeable units in the off reef when extensive dolomitization occurred in the carbonate buildup facies unit. The off reef sediments may have been a source of the magnesium ions for dolomitization as solutions migrated from the off reef into the more porous and permeable buildup facies, as Leavitt (1968) suggested. Even within the buildup facies, examples of dolomite associated with stylolites have been described (p.90). Perhaps

the fact that all fabric elements are dolomitized (allochems, all cement generations present, and matrix) is a clue that all these elements were equally susceptible to dolomitization when dolomitizing solutions arrived. Schmidt (1965) noted discriminative dolomitization first of matrix, then aragonite bioclasts, then magnesium calcite bioclasts, in Jurassic sediments where dolomitization preceded mineral stabilization. Incomplete dolomitization of some stromatoporoid skeletons in totally dolomitized matrix at Kaybob South may reflect the contrast in mineralogical stability of stromatoporoid margins compared to stromatoporoid interiors. The suggestion here would be that stromatoporoid interiors were first stabilized to low magnesium calcite, and perhaps this 'inside out' process is analogous to stabilization of scleractinian coral skeletons in the subaerial environment as described by James (1974).

Evidence for supratidal, hypersaline dolomitization is not present at Kaybob South. Except for a few occurrences of anhydrite nodules (p.77), coarse, poikilitic anhydrite is a later diagenetic feature, not the sulphate precipitation common in sabkha-type environments. On Andros Island, however, supratidal dolomite occurs without accompanying evaporites (Shinn, et al, 1965). There is a possibility that, though once present, the evaporite minerals could have been dissolved by heavy rains for example. Neither is there evidence for dolomitization in the schizohaline environment,

which according to Folk and Siedlecka (1974), takes the form of evaporite minerals, poikilitic calcite and limpid dolomite in birdseye vugs and fractures, and length-slow chalcedony. Dolomite of possible organic origin has been previously described (p.89).

Of all the possible mechanisms of 'early' dolomitization, mixing of meteoric and sea waters at the periphery of a fresh water lens seems most likely to have formed early dolomite in the Kaybob South area. Phreatic dolomite was described by Land (1973 a, b) in micrite, replacing red-algal allochems, and as drusy linings in primary intraparticle pores or secondary dissolution pores. In the Kaybob South area, dolomite is similarly found in micritic matrices, and in moldic pores originating from dissolution of cephalopod, brachiopod, and gastropod skeletons. The susceptibility of mud or fine-grained sediment to dolomitization was attributed to its greater surface area by Murray and Lucia (1967). Dolomite appearing below green shale horizons in solution channels, vugs and fractures at Kaybob South may have replaced fine-grained sediment where a geopetal dolomite texture is now seen.

Extensive dolomitization of the entire rock does not occur immediately beneath green shale horizons (to a few centimeters depth), as reported at Snipe Lake (Havard, 1974) (Figure 16, Sections B and C, for example). In Figure 16, Sections A, B, and C, which actually occur vertically adja-

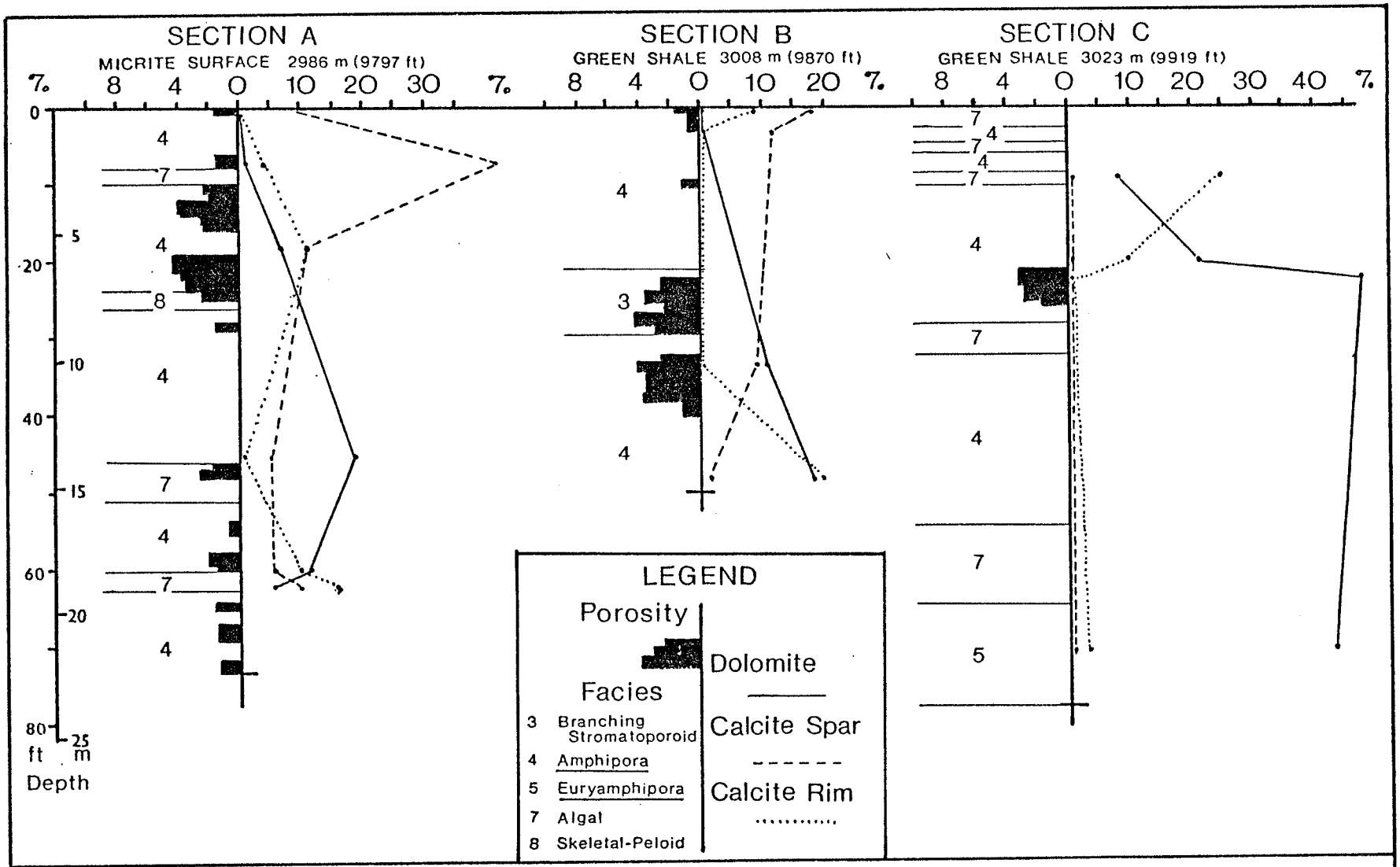


Figure 16. Porosity, dolomite, and calcite cement distribution beneath three surfaces of unconformity.

cent in the well located at 2-18-63-18 W5 (Figure 9, in pocket), are shown with unconformity surfaces adjusted to one datum. As seen in Table 3 and Figure 16, Section A, dolomite is not common immediately below micrite surfaces. It may be that the earliest subaerial calcite cements (also shown in Table 3) thoroughly plug porosity to later arriving dolomitization solutions immediately below micrite surfaces. Dolomite is usually more common with increasing depth below green shale horizons or micrite surfaces (Figure 16 and Table 4).

Table 4 also shows the lack of a strong correlation between percentages of mud and dolomite in a sample. Rather, this table shows that dolomite appears more predictably to vary (increase) with depth beneath an unconformity. Amphipora floatstones and rudstones with 33 to 58 and 16 to 35 percent mud respectively in wackestone matrices contain 0 to 18 percent dolomite, while floatstones and rudstones with 13 to 17 and 2 to 11 percent mud in packstone matrices contain 0 to 48 percent dolomite. Samples SN 10 and SN 11 are grainstones with micrite laminae containing 3 and 27 percent mud and 6 and 12 percent dolomite. Although there appears to be a correlation between mud and dolomite percentages in these last two examples, in fact the majority of the dolomite in these two samples does not occur in the micrite layers but in fracture, interparticle or fenestral pores.

Dolomite found in intraparticle and moldic pores at

TABLE 3

Dolomite and Calcite Cement Distribution
Above and Below Three Horizontal
Micrite Surfaces

LOCATION OF SURFACE		2-18-63-18 2986 meters (9797 feet)	12-25-62-18 3026 meters (9927 feet)	12-25-63-18 2923 meters (9589 feet)
DOLOMITE	ABOVE SURFACE	0%	2.5%	1%
	BELOW SURFACE	0	0	0
CALCITE CEMENT	ABOVE SURFACE	10	11	8
	BELOW SURFACE	8	22	19

SAMPLE		DEPTH BELOW UNCONFORMITY m (ft)	MUD (%)	DOLOMITE (%)	LITHOLOGY
SECTION A (Fig. 16)	SN5(b)	<0.03 (0.1)	13	0	Amphi. floatstone, packstone matrix
	SN 6	2.1 (7)	33	1	Amphi. floatstone wackestone matrix
	SN 7	5.5 (18)	65	7	peloidal wackestone
	SN 9	13.7 (45)	58	18	Amphi. floatstone, wackestone matrix
	SN 10	18.3 (60)	27	12	grainstone
	SN 11	18.9 (62)	3	6	grainstone
SECTION B	SN 12	<0.03 (0.1)	58	trace	Amphi. floatstone, wackestone matrix
	SN 13	0.9 (3)	35	0	Amphi. rudstone, wackestone matrix
	SN 15	10.1 (33)	30	11	Amphi. rudstone, wackestone matrix
	SN 16	14.6 (48)	16	18	Amphi rudstone, wackestone matrix
SECTION C	SN 17	2.7 (9)	40	8	Amphi. floatstone, wackestone matrix
	SN 18	6.1 (20)	11	22	Amphi. rudstone, packstone matrix
	SN 19	6.7 (22)	17	48	Amphi. floatstone, packstone matrix
	SN 20	21.3 (70)	2	44	Amphi. rudstone packstone matrix

TABLE 4: Point count data summary of mud and dolomite distribution below three unconformity surfaces in well at location 2-18-63-18 W5.

Kaybob South does not form isopachous rims, as Land (1973 a, b) described, and never precedes calcite when occurring with calcite in a void, but always seems to have preferred to replace ferroan-zoned calcite. Neal (1969) noted that lime-mud matrix and ferroan calcite spar cement seemed most susceptible to dolomitization in Pennsylvanian limestones, and that ferroan calcite spar was consistently replaced by ferroan dolomite. Neal (1969) suggested that the presence of the ferrous ion in the calcite lattice was enough to cause chemical instability, thus promoting dolomitization of ferroan calcite over non-ferroan calcite.

Dolomite occurring beneath micrite laminae with laminar fenestral porosity in a drop-like pattern may represent precipitation in the zone of mixing of sea water and meteoric water in a beachrock. Again the dolomite appears to replace a calcite cement. This dolomite may represent the initial stage of formation of an intertidal dolomitic crust, similar to those forming in Recent Florida tidal flats (Atwood and Bubb, 1970).

Strained dolomite crystals, with curved crystal faces and twisted crystal axes, exhibiting undulose extinction under crossed-nicols, were named 'baroque' dolomite by Folk and Assereto (1974). In addition to its occurrence at Kaybob South, it has also been documented by Corneil (1969), as euhedral crystals lining vugs; by Mossler (1971), as saddle-shaped crystals lining open burrows; by Havard (1974), as fer-

roan dolomite crystals replacing equant calcite or fine-grained sediment deposited in solution vugs below green shale horizons, and by Mazzullo and Cys (1979), as replacing divergent radial mosaics of calcite pseudospar (after aragonite) or matrix mudstone. Dana (1947, p.516) describes dolomite rhombohedral faces as being "... commonly curved or made up of sub-individuals, and thus passing into saddle-shaped forms (Fig. 787).". The strained dolomite crystals in Kaybob South only rarely show finer, parallel sub-crystals along crystal margins. It is not clear from the literature which chemical and physical parameters are responsible for development of the strained dolomite over more commonly unstrained rhombs, since these dolomites have been interpreted to be of phreatic (Havard, 1974) or subsurface (Mazzullo and Cys, 1979) origin. Folk and Assereto (1974) thought the fabric might result from crystallization from waters of low salinity in the presence of sulphates.

4.6 Porosity

Having described the diverse sediment textures of the lithofacies of the Kaybob South reef complex in Chapter III, and the various diagenetic fabrics thus far in Chapter IV, a discussion of observed trends in porosity as related to sedimentation and diagenesis now follows.

Several workers have noted the dependence of porosity on facies. In their study of several isolated limestone Swan Hills buildups, Thomas and Rhodes (1961) found that the

best reservoir units were vuggy, organic lattice (= boundstones ?) and fragmented organic material in grainstone matrices along reef fronts or buildup margins, especially on the eastern (windward) margins of buildups. The central zone (lagoon) of these atoll-like buildups was without effective porosity. McGillivray and Mountjoy (1975) determined that highest porosity was developed in marginal grain-supported subtidal massive stromatoporoid and skeletal calcarenite rocks of the isolated limestone Golden Spike reef-complex (Leduc Formation). Flank or fore reef, and interior or lagoonal rocks were found to have unpredictable and generally poor porosity. Schultheis (1976), in a study of the Kaybob oil field north of Kaybob South, also found the most effective reservoir in the marginal organic reef facies. Porosity types present are vug, intraorganic (in stromatoporoids), and intrafragmental (in calcarenite matrices). Most recently, Fischbuch and Havard (1977) indicated that although reservoir character in most Swan Hills reef complexes is facies dependent, substantial post-depositional modification (including early and late diagenesis, tectonic activity, and dolomitization) may produce reservoir quality inconsistent with that predicted by facies association alone.

On comparing commercial core lab porosity analyses and visual estimates with facies at Kaybob South, one finds the same general trend that others (Thomas and Rhodes, 1961; Schultheis, 1976) have observed. Porosity is best where

large skeletal components are most abundant, as in the stromatoporoid rudstones in the shelf margin and open shelf environments, or Amphipora rudstones in the back reef lagoon. Another recognizable trend is that porosity values are much higher on the extensively dolomitized west bank than on the east bank. Porosity types on the dolomitized west bank are predominantly vuggy, moldic, fracture and inter-crystalline, while on the east bank moldic, intraparticle, interparticle and fenestral porosity types predominate. The vuggy porosity on the west bank is derived largely from partly to completely leached stromatoporoids in shelf margin, open shelf and fore reef environment facies, and intervals of 10 to 20 percent porosity are common. On the east bank, in hemispherical, branching or tabular stromatorporoid facies, intraparticle stromatoporoid porosity is commonly less than 10 percent and vuggy and moldic porosity are rare. Moldic Amphipora porosity may reach as high as 12 percent in dolomitized units, while on the east bank porosities are seldom higher than 7 percent. Although high porosities exist in west bank units, the porosity values drop considerably (to 1 to 2 percent) where coarse, sparry calcite or dolomite fills vugs, molds or fractures.

Figure 16 illustrates the distribution of porosity (core lab analyses) beneath three unconformity surfaces (one micrite (Section A) and two green shale horizons (Sections B and C)). To the right of the vertical axes are plotted dolo-

mite, calcite rim cement, and calcite spar cement from point count analyses of samples listed in Table 4. To the left the porosity values from analyses and the facies encountered are indicated. It may be seen from this figure that zones having highest porosity begin 3.0 to 6.2 meters (10 to 20 feet) beneath the unconformity. Porosity in these intervals is largely interparticle and intraparticle, with minor fracture and fenestral porosity present. Intraparticle, interparticle, fracture and fenestral pores outside the porous zone are filled with a first-generation, dusty, bladed or fibrous micro-stalactitic or isopachous rim cement, and commonly a second-generation of coarser, ferroan-zoned calcite cement. These cements have been interpreted as products of vadose (p.74) and phreatic (p.79) or beachrock diagenesis. Commonly, where dolomite incompletely fills dissolution porosity, the dolomite crystal/air boundaries are smooth, whereas calcite/air boundaries are jagged or irregular from solution effects, not smooth, uninhibited growth surfaces. In terms of diagenetic history, based on these samples, the best porosity zones seem to exist where phreatic solution has occurred and where dolomite precipitation was unable to continue to fill available pores, possibly due to loss of effective porosity (reduced permeability) or passage into non-dolomitizing interstitial solutions by subsidence beyond the zone of fresh water/sea water mixing.

CHAPTER V

SUMMARY AND CONCLUSIONS

Devonian Swan Hills carbonate deposition in the Kaybob South area occurred on two organic carbonate buildups, separated by an interbank channel during much of the depositional period. Isolated reefs of hemispherical, tabular, and branching stromatoporoids existed along the east (windward) margins of both the east and west banks. Sediments, rather than organic framework, predominated in the shelf margin environment. As the Beaverhill Lake sea transgressed southwesterly over the area, the high-energy zone of most abundant organism growth in open shelf and shelf margin positions also shifted to the southwest. Leeward of the open shelf and shelf margin facies, near-normal marine conditions existed in the Amphipora lagoons. Locally, sediment accumulation resulted in the formation of tidal flat deposits. Windward of the shelf margin, tabular and branching stromatoporoids locally formed organic framework reefs in the fore reef, which was otherwise characterized by large fragmented organism skeletons and finer sediment debris. Normal marine

conditions were present in the interbank channel during much of the period of off reef deposition. Less hospitable, perhaps widespread, reducing conditions occurred intermittently

Four informal stages of development are present in the carbonate buildups. Each stage is a regressive carbonate sequence accompanying periods of relative shallowing of water over the banks during the slow subsidence of the Beaverhill Lake basin. Stage I, a platform or biostrome stage, 30 to 34 meters (100 to 110 feet) thick, was characterized by a widespread lagoonal-type environment, with local patch reefs of encrusting, tabular and branching stromatoporoids. Subaerial exposure of both carbonate banks, but not channel sediments, ended this first stage of development. Stage II of carbonate bank deposition, 12 to 15 meters (40 to 50 feet) thick, was marked by an increase in the diversity of stromatoporoid growth habits and organism abundance over Stage I. Fore reef, shelf margin, open shelf, and lagoonal environments could be recognized on the east bank, but much of the west bank was predominantly a lagoonal-type environment, with few patch reefs. Subaerial exposure terminated Stage II deposition. Stage III of deposition, averaging 24 meters (80 feet) thick on the west bank and 34 to 37 meters (110 to 120 feet) on the east bank, was accompanied by a noticeable shift of shelf margin, open shelf and fore reef facies to the west, and a decrease in the range of deposition on the east bank. A profile across the Kaybob South area carbonate banks during Stage III would most resem-

ble a model profile of possible environments across a carbonate bank, with deposition occurring in tidal flat, lagoon, open shelf, shelf margin, fore reef and off reef environments. The upper 12 meters (40 feet) of Stage III was characterized by shallow-water and intertidal conditions, and eventual exposure terminated this depositional stage. Deposition of off reef carbonate sediment was probably never far behind carbonate bank sedimentation, but by the end of Stage III interbank sedimentation had advanced significantly. Stage IV deposition (58 meters (190 feet) and 38 meters (125 feet) on the west and east banks respectively) began with a significant shift of bank environments to the west, over interbank sediment. Abundant and diverse organisms characterized various environments as in Stage III. This last stage of deposition was probably terminated by shallowing conditions.

Diagenetic alterations occurred while the carbonate sediments were still in the submarine environment. Precipitation of bladed isopachous calcite rim and irregular calcite rim cements occurred in shelter, interparticle, intraparticle and fenestral pores of fore reef rudstones, floatstones and grainstones. Equant isopachous calcite rim cement was precipitated in interparticle pores of off reef skeletal rudstones, and oolitic and pelleted grainstones and packstones. Syntaxial calcite cement rims grew on echinoid fragments in off reef packstones and grainstones. Submarine sediment (silt) occluded primary porosity in some fore reef

and intertidal rudstones. Biological activity produced micritized margins or zones, on or in skeletal allochems, macroborings in skeletal fragments and micrite crusts or layers, and probably contributed to the production of peloids.

During local or widespread episodes of subaerial exposure, ephemeral or persistent fresh water lenses developed. Green shale horizons and micrite discontinuity surfaces formed during subaerial exposure. Thin, 1.0 cm beds of anhydrite nodules, interbedded with finely laminated dolomite, may have formed in a supratidal zone. In the zone of vadose diagenesis, bladed to fibrous, micro-stalactitic and meniscus calcite cements precipitated in the interparticle pores of intertidal algal grainstones and rudstones. In the fresh water phreatic zone, bladed or equant isopachous calcite rim cements were precipitated in fenestral, fracture and dissolution pores in Amphipora grainstones and rudstones. A coarse, ferroan calcite or zoned-ferroan calcite cement often occluded the remaining pore space partly occupied by a rim cement, or precipitated in moldic, fracture, fenestral, and intraparticle pores where no rim cement was previously precipitated. Neomorphism appears to have preserved the microstructure of some stromatoporoids. Stylolites, either of pre-lithification or early subsurface origin, may have been responsible for some dolomite formation. The zone of mixing of meteoric water and sea water at the periphery of the phreatic lens is the most probable chemical environment

of early 'Dorag' dolomitization at Kaybob South.

Dolomite, occurring extensively on the west bank, its distribution approximately coincident with buildup facies, was probably a subsurface diagenetic event. Dolomite has indiscriminately replaced allochems, cements and matrix, but has commonly preserved primary textures that can be identified by colour patterns of inclusions and by variations in the crystal size, shape and intercrystalline boundary characteristics. On the east bank where dolomite is less common, dolomitization discriminatively replaced ferroan or zoned-ferroan calcite of phreatic origin, matrix, stromatoporoid margins, mudstone, possible geopetal sediment, and laminae of possible algal affinity. Dolomite is found to be more common with increasing depth beneath micrite surfaces and green shale horizons. Discriminative dolomitization was probably controlled by variations in the chemical stability of mineralogy and grain size present at the time of arrival of dolomitizing solutions. Very coarse dolomite crystallized in vuggy or moldic porosity in dolostones.

Zones of good porosity are found where large skeletal components are most abundant, in stromatoporoid rudstones of open shelf, shelf margin, and, less commonly, lagoonal and fore reef environmental facies. Porosity on the west bank is more variable than on the east bank, attaining highest values (10 to 20 percent not uncommonly) where vuggy porosity is concentrated, and lowest (1 to 2 percent) where vuggy porosity is filled with coarse calcite spar. Beneath unconformity

surfaces (micrite or green shale), good porosity zones begin 3 3.0 to 6.2 meters (10 to 20 feet) below the unconformity, where phreatic dissolution has occurred, and where dolomitization did not completely fill all available pores before the sediments passed beyond the dolomitizing environment.

REFERENCES

Atwood, D. K. and Bubb, J. N., 1970, Distribution of dolomite in a tidal flat environment, Sugarloaf Key, Florida: Jour. Geology, V. 78, p. 499-505.

Badiozamani, K., 1973, The Dorag dolomitzation model - application to the Middle Ordovician of Wisconsin: Jour. Sed. Petrology, V. 43, p. 965-985.

Bain, G. W., 1963, Climatic zones throughout the ages. In: Munyan, A. C. (ed.), Polar Wandering and Continental Drift, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. No. 10, p. 100-131.

Bassett, H. G. and Stout, J. G., 1967, Devonian of western Canada. In: Oswald, D. H. (Ed.) International Symposium on the Devonian System, Alta. Soc. Petrol. Geol., p. 717-752.

Bathurst, R. G. C., 1966, Boring algae, micrite envelopes and lithification of molluscan biosparites: Geol. Jour., V. 5, p. 15-32.

_____, 1970, Problems of lithification in carbonate muds: Geol. Association London Proc., V. 81, p. 429-440.

_____, 1971, Carbonate sediments and their diagenesis: Elsevier, New York, 620 pp.

Behrens, E. W. and Land, L. S., 1972, Subtidal Holocene dolomite, Baffin Bay, Texas: Jour. Sed. Petrology, V. 42, p. 155-161.

Bricker, O. P., (ed.), 1971, Carbonate cements: Johns Hopkins Press, New York, 360 pp.

Bricker, O. P. and Mackenzie, F. T., 1970, Limestones and red soils of Bermuda: Discussion, Geol. Soc. Amer. Bull., V. 81, p. 2523-2524.

Broecker, W. S. and Takahashi, T., 1966, Calcium carbonate precipitation on the Bahama Banks: Jour. Geophysical Research, V. 71, p. 1575-1602.

Bromley, R. G., 1975, Trace fossils at omission surfaces. In: Frey, R. W. (Ed.), The Study of Trace Fossils, Springer-Verlag, New York, p. 399-428.

Cayeux, L., 1935, Les roches sedimentaires de France; Roches carbonatées: Masson, Paris, 463 pp.

Choquette, P. W. and Pray, L. C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: Bull. Amer. Assoc. Petrol. Geol., V. 54, p. 207-250.

Corneil, B. D., 1969, A paleoecological study of the Ante Creek reef, Middle to Late Devonian in age, west central Alberta: M.Sc. Thesis, Univ. of Alberta, 112 pp.

Dana, J. D., 1947, Textbook of mineralogy: Ford, E. W. (ed., 4th edition), Wiley and Sons, New York, 851 pp.

Dapples, E. C., 1959, The behavior of silica in diagenesis. In: Ireland, H. A. (Ed.), Silica in Sediments, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 7, p. 36-54.

Davies, G. R., 1970, Carbonate bank sedimentation, eastern Shark Bay, Western Australia. In: Carbonate Sedimentation and Environments, Shark Bay, Western Australia, Amer. Assoc. Petrol. Geol. Memoir 13, p. 85-168.

_____, 1977, Former magnesian calcite and aragonite submarine cements in Upper Paleozoic reefs of Canadian Arctic; a summary: Geology, V. 5, p.11-15.

Davies, J. and Kinsey, D. W., 1973, Organic and inorganic factors in Recent beachrock formation, Heron Island, Great Barrier Reef: Jour. Sed. Petrology, V. 43, p. 59-81.

Deffeyes, K. S., Lucia, F. J. and Weyl, P. K., 1965, Dolomitization of Recent and Plio-Pleistocene sediments by marine evaporite waters on Bonaire, N. Antilles. In: Pray, L. C. and Murray, R. C. (eds.), Dolomitization and Limestone Diagenesis, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, p. 71-88.

Dickson, J. A. D., 1965, A modified staining technique for carbonates in thin section: Nature, 205, p. 587.

Dott, Jr., R. H., 1963, Dynamics of subaqueous gravity depositional processes: Bull. Amer. Assoc. Petrol. Geol. V. 47, p. 104-128.

Douglas, R. J. W. and others, 1970, Geology of Western Canada. In: Geol. Surv. Can. Economic Rept. No. 1, p. 392-399.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture. In: Ham, W. E. (ed), Classification of Carbonate Rocks, Amer. Assoc. Petrol. Geologists, Memoir 1, p. 108-121.

Dunham, R. J., 1969a, Early vadose silt in Townsend Mound (reef) New Mexico. In: Friedman, G. M. (ed.), Depositional Environments in Carbonate Rocks, Society Econ. Paleontologists and Mineralogists Spec. Pub. No. 14, p. 139-181.

_____, 1969b, Meniscus cement, Bermuda Biol. Station Rept. 3, p. 314-316.

_____, 1970, Keystone vugs in carbonate beach deposits: Bull. Amer. Assoc. Petrol. Geol., V. 54, p. 845.

Edie, R. W., 1961, Devonian reef reservoir, Swan Hills oilfield, Alberta: Can. Min. Metal. Bull., V. 54, p. 447-454.

Embry, A. F. and Klovan, J. E., 1971, A Late Devonian reef tract on northeastern Banks Island, N.W.T.: Bull. Can. Petrol. Geol., V. 19, p. 730-781.

Fischbuch, N. R., 1962, Stromatoporoid zones of the Kaybob reef Alberta: Jour. Alta. Soc. Petrol. Geol., V. 10, p. 62-72.

_____, 1968, Stratigraphy, Devonian Swan Hills reef complexes of central Alberta: Bull. Can. Petrol. Geol., V. 16, p. 446-587.

_____, 1969, Devonian stromatoporoids from central Alberta, Canada: Can. Jour. Earth Sci., V. 6, p. 167-185.

_____ and Havard, C. J., 1977, Facies - porosity relationships and diagenetic processes which modify them, Swan Hills area, Alberta. In: McIlreath, I. A. and Harrison, R. S. (eds.), The Geology of Selected Carbonate, Oil, Gas

and Lead-Zinc Reservoirs in Western Canada, Can. Soc. Petrol. Geol. Core Conference Guide Book, p. 41-65.

Folk, R. L., 1962, Spectral subdivision of limestone types. In: Ham, W. E. (ed.), Classification of Carbonate Rocks, Amer. Assoc. Petrol. Geol. Mem. 1, p. 62-84.

_____, 1965, Some aspects of recrystallization in ancient limestones. In: Pray, L. C. and Murray, R. C. (eds), Dolomitization and Limestone Diagenesis; A Symposium, Soc. Econ. Paleontologists and Mineralogists, Spec. Pub. 13, p. 14-48.

_____,1974, The natural history of crystalline calcium carbonate: effect of magnesium content and salinity: Jour. Sed. Petrology, V. 44, p. 40-54.

_____ and Assereto, R., 1974, Giant aragonite rays and baroque white dolomite in teepee-fillings, Triassic of Lombardia, Italy: Soc. Econ. Paleontologists and Mineralogists Ann. Mtg. Abs., San Antonio, p. 34-35.

_____ and Siedlecka, A., 1974, The schizohaline environment: its sedimentary and diagenetic fabrics as exemplified by Late Paleozoic rocks of Bear Island, Svalbard: Sedimentary Geology, V. 11, p. 1-15.

Fong, G., 1959, Type section Swan Hills Member of the Beaverhill Lake Formation: Jour. Alta. Soc. Petrol. Geol., V. 7, p. 95-108.

_____, 1960, Geology of Devonian Beaverhill Lake Formation, Swan Hills area, Alberta: Bull. Amer. Assoc. Petrol. Geol., p. 1807-1825.

Friedman, G. M., Amiel, A. J. and Schneiderman, N., 1974, Submarine cementation in reefs: example from the Red Sea: Jour. Sed. Petrology, V. 44, p. 816-825.

Gebelein, C. D. and Hoffman, P., 1973, Algal origin of dolomite laminations in stromatolitic limestones: Jour. Sed. Petrology, V. 43, p. 603-613.

Ginsburg, R. N., 1956, Environmental relationships of grain size and constituent particles in some south Florida carbonate sediments: Bull. Amer. Assoc. Petrol. Geol. V. 40, p. 2384-2427.

_____, 1964, South Florida carbonate sediments, Guidebook for Field Trip No. 1, Geol. Soc. Amer. Convention 1964, New York, 72 pp.

_____ and Garrett, P., 1969, Seminar on organism - sediment interrelationships: Bermuda Bio. Station Research Spec. Pub. 2, p. 1-151.

_____ and James, N. P., 1973, Botryoidal aragonite in Holocene reef-wall limestone, Belize: Synsedimentary 'stromatactis', Geol. Soc. Amer. Abstracts, V. 5, p. 635-636.

Goreau, T. F., 1959, The ecology of Jamaican coral reefs, I. Species composition and zonation: Ecology, V. 40, p. 67-90.

Grayston, L. D., Sherwin, D. F. and Allan, J. F., 1964, Middle Devonian. In: McCrossan, R. G. and Glaister, R. P. (eds.), Geological History of Western Canada, Alta. Soc. Petrol. Geol., p. 45-59.

Hanshaw, B. B., Back, W. and Deike, R. G., 1971, A geochemical hypothesis for dolomitization by groundwater: Econ. Geol. V. 66, p. 710-724.

Harrison, R. S., 1974, Near-surface subaerial diagenesis of Pleistocene carbonates, Barbados, W. I.: Ph.D. Thesis, Brown University, 333 pp.

_____ and Steinen, R. P., 1978, Subaerial crusts, caliche profiles, and breccia horizons: comparison of some Holocene and Mississippian exposure surfaces, Barbados and Kentucky: Geol. Soc. Amer. Bull., V. 89, p. 385-396.

Hartman, W. D. and Goreau, T. F., 1970, Jamaican coralline sponges: their morphology, ecology and fossil relatives: Symp. Zool. Soc. London, No. 25, p. 205-243.

Havard, C. J., 1974, Sedimentary and early diagenetic cycles, Snipe Lake reef complex, Alberta: M.Sc. Thesis, Univ. of Calgary, 125 pp.

Heckel, P. H., 1974, Carbonate buildups in the geologic record: a review. In: Laporte, L. F. (ed), Reefs in Time and Space: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 18, p. 90-154.

Hemphill, C. R., Smith, R. I., and Szabo, F., 1970, Geology of Beaverhill Lake reefs, Swan Hills area, Alberta: Amer. Assoc. Petrol. Geol. Mem. 14, p. 50-90.

Hsü, K. J. and Siegenthaler, C., 1969, Preliminary experiments on hydrodynamic movement induced by evaporation and their bearing on the dolomite problem: Sedimentology, V. 13, p. 11-25.

Illing, L. V., Wells, A. J. and Taylor, J. C. M., 1965, Penecontemporary dolomite in the Persian Gulf. In: L. C. Pray and R. C. Murray (ed.), Dolomitization and Limestone Diagenesis; a Symposium, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, p. 89-111.

Irwin, M. L., 1965, General theory of epeiric clear water sedimentation: Bull. Amer. Assoc. Petrol. Geol., V. 49, p. 445-459.

James, N. P., 1972. Holocene and Pleistocene calcareous crust (caliche) profiles: criteria for subaerial exposure: Jour. Sed. Petrology, V. 42, p. 817-836.

_____, 1974, Diagenesis of Scleractinian corals in the subaerial vadose environment: Jour. Paleo., V. 48, p. 785-799.

_____, Ginsburg, R. N., Marszalek, D. S. and Choquette, P. W., 1976, Facies and fabric specificity of early subsea cements in shallow Belize (British Honduras) reefs: Jour. Sed. Petrology, V. 46, p. 523-544. .

_____ and Kobluk, D., 1978, Lower Cambrian patch reefs and associated sediments; southern Labrador: Sedimentology, V. 25, p. 1-35.

Jamieson, E., 1969, Paleoecology of Devonian reefs in western Canada: Proc. North Amer. Paleo. Conv., Sept. 1969, Pt. J. p. 1300-1340.

Jansa, L. F. and Fischbuch, N. R., 1974, Evolution of a Middle Devonian sequence from a clastic coastal plain-deltaic complex into overlying carbonate reef complexes and banks, Sturgeon-Mitsue area, Alberta: Geol. Surv. Can. Bull. 234, 105 pp.

Jenik, A. J. and Lerbekmo, J. F., 1968, Facies and geometry of Swan Hills Reef Member of Beaverhill Lake Formation (Upper Devonian), Goose River Field, Alberta: Bull. Amer. Assoc. Petrol. Geol., V. 52, p. 21-56.

Keith, J. W., 1970, Tectonic control of Devonian reef sedimentation: Amer. Assoc. Petrol. Geol. Abst. of Ann. Conv., Calgary, p. 854.

Kendall, C. G. St. C. and Skipwith, P. A. D.'E., 1969, Holocene shallow-water carbonate and evaporite sediments of Kor al Bazam, Abu Dhabi, southwest Persian Gulf: Bull. Amer. Assoc. Petrol. Geol. V. 53, p. 841-869.

Kinsman, D. J. J., 1969, Modes of formation, sedimentary associations and diagnostic features of shallow water and supratidal evaporites: Bull. Amer. Assoc. Petrol. Geol., Vol. 53, p. 830-840.

Klovan, J. E., 1964, Facies analysis of the Redwater reef complex, Alberta: Bull. Can. Petrol. Geol., V. 12, p. 1-100.

_____, 1966, Upper Devonian stromatoporoids from the Redwater reef complex, Alberta, Canada: Bull. Geol. Surv. Can. 133, p. 1-33.

Kobluk, D., 1975, Stromatoporoid paleoecology of the southeast margin of the Miette carbonate complex: Bull. Can. Petrol. Geol., V. 23, p. 224-277.

_____ and Kahle, C. F., 1978, Geological significance of boring and cavity-dwelling marine algae: Bull. Can. Petrol. Geol., V. 26, p. 362-379.

Kornicker, L. S. and Boyd, D. W., 1962, Shallow-water geology and environments of Alacran reef complex, Campeche Bank: Bull. Amer. Assoc. Petrol. Geol., V. 46, p. 640-673.

Krauskopf, K. B., 1959, The geochemistry of silica in sedimentary environments. In: Silica in Sediments, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 7, p. 4-19.

Krebs, W., 1974, Devonian carbonate complexes of central Europe. In: Laporte, L. F. (ed.), Reefs in Time and Space, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 18, p. 166-208.

Ladd, H. S., 1970, Existing reefs-geological aspects: Proc. North Am. Paleon. Conv., 1969, p. 1273-1300.

Land, L. S., 1970, Phreatic versus vadose meteoric diagenesis of limestones; evidence from a fossil water table: Sedimentology, V. 14, p. 175-185.

Land, L. S., 1973a, Contemporaneous dolomitization of Middle Pleistocene reefs by meteoric water, N. Jamaica: Bull. Marine Sci., V. 23, p. 64-92.

_____, 1973b, Holocene meteoric dolomitization of Pleistocene limestones, N. Jamaica: Sedimentology, V. 20, p. 411-424.

_____, 1976, Early dissolution of sponge spicules from reef sediments, N. Jamaica: Jour. Sed. Petrology, V. 46, p. 967-969.

_____ and Goreau, T. F., 1970, Submarine lithification of Jamaican reefs: Jour. Sed. Petrology, V. 40, p. 457-562.

Leavitt, E. M., 1968, Petrology, paleontology, Carson Creek North reef complex, Alberta: Bull. Can. Petrol. Geol. V.16, p. 296-413.

Leavitt, E. M. and Fischbuch, N. R., 1968, Devonian nomenclature changes, Swan Hills area, Alberta: Bull. Can. Petrol. Geol. V. 16, p. 288-297.

Logan, B. W., Harding, J. L., Ahr, W., Williams, J. D. and Snead, R. G., 1969, Carbonate sediments and reefs, Yucatan Shelf, Mexico: Amer. Assoc. Petrol. Geol. Mem. 11, Menasha, 198 pp.

Love, B. C., 1967, Early diagenetic iron sulphide in Recent sediments of The Wash (England): Sedimentology, V. 9, p. 327-352.

Machielse, S., 1972, Devonian algae - their contribution to the western Canadian sedimentary basin: Bull. Can. Petrol. Geol., V. 20, p. 187-237.

Maiklem, W. R., 1970, Carbonate sediments in the Capricorn Reef complex, Great Barrier Reef, Australia: Jour. Sed. Petrology, V. 40, p. 55-80.

Martin, R., 1967, Morphology of some Devonian reefs in Alberta - a paleogeomorphological study. In: Oswald, D. H. (ed). International Symposium on the Devonian System, V. 2, Alta. Soc. Petrol. Geol., p. 365-385.

Matthews, R. K., 1974, A process approach to diagenesis of reefs and reef associated limestones. In: Laporte, L. F. (ed.) Reefs in Time and Space, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 18, p. 234-256.

Maxwell, W. G. H., 1968, Atlas of the Great Barrier Reef, Elsevier, Amsterdam, 258 pp.

Mazzullo, S. J. and Cys, J. M., 1979, Marine aragonite seafloor growths and cements in Permian phylloid algal mounds, Sacramento Mts., N. Mexico: Jour. Sed. Petrology, V. 49, p. 917-936.

McCrossan, R. G., 1958, Sedimentary boudinage structures in the Upper Devonian Ireton Formation: Jour. Sed. Petrology, V. 28, p. 316-320.

McGillivray, J. G. and Mountjoy, E. W., 1975, Facies and related reservoir characteristics, Golden Spike reef complex, Alberta: Bull. Can. Petrol. Geol., V. 23, p. 735-809.

McKee, E. D. and Gutschick, R. D., 1969, History of the Redwall limestone of N. Arizona: Geol. Soc. Amer. Mem. 114, 726 pp.

Mesolella, K. J., Sealy, H. A. and Matthews, R.K., 1970, Facies geometries within Pleistocene reefs of Barbados, W.I.: Bull. Amer. Assoc. Petrol. Geol. V. 54, p. 1899-1917.

Milliman, J. D., 1974, Marine Carbonates, Springer-Verlag, New York, 375 pp.

Moore, Jr., C. H., 1973, Intertidal carbonate cementation, Grand Cayman, W. I.: Jour. Sed. Petrology, V. 43, p. 591-602.

Mossler, J. H., 1971, Diagenesis and dolomitization of Swope Formation (Upper Pennsylvanian), Southeast Kansas, Jour. Sed. Petrology, V. 41, p. 962-970.

Multer, H. G. and Hoffmeister, J. E., 1968, Subaerial laminated crusts of the Florida Keys: Geol. Soc. Amer. Bull., V. 79, p. 183-192.

Murray, J. W., 1965, Stratigraphy and carbonate petrology of the Waterways Formation, Judy Creek, Alberta: Bull. Can. Petrol. Geol., V. 13, p. 303-326.

_____, 1966, An oil-producing reef-fringed carbonate-bank in the Upper Devonian Swan Hills Member, Judy Creek, Alberta: Bull. Can. Petrol. Geol., V. 14, p. 1-103.

Murray, R. C. and Lucia, F. J., 1967, Cause and control of dolomite distribution by rock selectivity: Geol. Soc. Amer. Bull., V. 78, p. 21-36.

Neal, W. J., 1969, Diagenesis and dolomitization of a limestone (Pennsylvanian of Missouri), as revealed by staining: Jour. Sed. Petrology, V. 39, p.1040 1045.

Newell, N. D., Imbrie, J., Purdy, E. G. and Thruber, D. L., 1959, Organism communities and bottom facies, Great Bahama Bank: Bull. Amer. Museum Nat. Hist. 117, No. 4, p. 177-228.

Noble, J. P., 1970, Biofacies analysis, Cairn Formation of Miette reef, Jasper Park. In: Davies, G. R. (ed.) Devonian Reef Complexes II, Can. Soc. Petrol. Geol. Reprint Series, p. 145-196.

Oldershaw, A. E. and Scoffin, T. P., 1967, The source of ferroan and non-ferroan calcite cements in the Halkin and Wenlock limestones: Geol. Jour., V. 5, p. 309-320.

Park, W. C. and Schot, E. H., 1968, Stylolites - their nature and origin: Jour. Sed. Petrology, V. 38, p. 175-191.

Pingitore, Jr., N. E., 1976, Vadose and phreatic diagenesis: processes, products and their recognition in corals: Jour. Sed. Petrology, V. 46, p. 985-1006.

Pittman, Jr., J. S., 1959, Silica in Edwards Limestone, Travis County, Texas. In: Silica in Sediments, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 7, p. 121-134.

Playford, P. E. and Lowry, D. C., 1966, Devonian reef complexes of the Canning Basin, Western Australia: Geol. Surv. Western Australia, Bull. 118, 150 pp.

Purdy, E. G., 1963, Recent calcium carbonate facies of the Great Bahama Bank, 1. Petrography and reaction groups: Jour. Geol., V. 71, p. 334-355. 2. Sedimentary Facies: Jour. Geol. V. 71, p. 472-497.

_____, 1974, Reef configurations: cause and effect. In: Laporte, L. F. (ed.) Reefs in Time and Space, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 18, p. 9-76.

Purser, B. H., 1969, Syn-sedimentary marine lithification of Middle Jurassic limestone in the Paris Basin: Sedimentology, V. 12, p. 205-230.

Read, J. F., 1973, Paleo-environments and paleogeography, Pillara Formation (Devonian), Western Australia: Bull. Can. Petrol. Geol. V. 21, p. 344-394.

Reineck, H.-E. and Singh, I. B., 1975, Depositional Sedimentary Environments: Springer-Verlag, New York, 439 pp.

Roehl, P. O., 1967, Stony Mt. and Interlake facies analogs of Recent low energy marine and subaerial carbonates, Bahamas: Bull. Amer. Assoc. Petrol. Geol., V. 51, p. 1979-2032.

Rupp, A., 1967, Origin, structure and environmental significance of Recent and fossil calcispheres: Geol. Soc. Amer. Spec. Paper 101, p. 186 (abstract).

Schmidt, V., 1965, Facies, diagenesis and related reservoir properties in the Gigas Beds (Upper Jurassic), northwestern Germany. In: Pray, L. C. and Murray, R. C. (eds.) Dolomitization and Limestone Diagenesis; A Symposium, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, p. 124-168.

Schultheis, N. R., 1976, Kaybob Oil Field, Alberta, Canada. In: Amer. Assoc. Petrol. Geol. Mem. 24, p. 79-90.

Scoffin, T. P., 1975, The Geology of Reefs: Can. Soc. Petrol. Geol. Seminar notes, Univ. of Calgary Div. of Continuing Education.

Sheasby, N. M., 1971, Depositional patterns of the Upper Devonian Waterways Formation, Swan Hills, Alberta: Bull. Can. Petrol. Geol., V. 19, p. 377-404.

Shinn, E. A., 1968, Practical significance of birdseye structures in carbonate rocks: Jour. Sed. Petrology, V. 38, p. 215-223.

Shinn, E. A., 1969, Submarine lithification of Holocene carbonate sediments in the Persian Gulf: Sedimentology, V. 12, p. 109-144.

_____, Ginsburg, R. N. and Lloyd, R. M., 1965, Recent supratidal dolomite from Andros Island, Bahamas. In: Pray, L. C. and Murray, R. C. (eds.) Dolomitization and Limestone Diagenesis; a Symposium, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, p. 112-123.

_____, Lloyd, R. M. and Ginsburg, R. N., 1969, Anatomy of a modern carbonate tidal flat, Andros Island, Bahamas: Jour. Sed. Petrology, V. 39, p. 1202-1228.

Stanley, D. J. and Swift, D. J. P., 1968, Bermuda's reef-front platform; bathymetry and significance: Marine Geology, V. 6, p. 479-500.

Stearn, C. W., 1972, The relationship of the stromatoporoid to the sclerosponges: Lethaia, V. 5, p. 369-388.

_____ and Riding, R., 1972, Distribution of forms of Millepora (hydrozoa) on a recent coral reef, Barbados (Abst.): Bull. Amer. Assoc. Petrol. Geol. V. 56, p. 655.

Steinen, R. P. and Matthews, R. K., 1973, Phreatic versus vadose diagenesis; stratigraphy and mineralogy of a cored borehole on Barbados, W. I.: Jour. Sed. Petrology, V. 43, p. 1012-1020.

_____, _____ and Sealy, H. A., 1978, Temporal variation in geometry and chemistry of the fresh water phreatic lens; the coastal carbonate aquifer of Christchurch, Barbados, W.I.: Jour. Sed. Petrology, V. 48, p. 733-742.

Thomas, G. E. and Rhodes, H. S., 1961, Devonian limestone bank-atoll reservoirs of the Swan Hills area, Alberta: Bull. Alta. Soc. Petrol. Geol. V. 9, p. 29-38.

Todd, D. K., 1959, Groundwater Hydrology, Wiley and Sons, New York, 336 pp.

Tsien, H. H., 1971, The Middle and Upper Devonian reef complexes of Belgium: Petrol. Geol. Taiwan, no. 8, p. 119-173.

Walls, R. A., Harris, W. B. and Nunan, W. E., 1975, Calcareous crust (caliche) profiles and early subaerial exposure of Carboniferous carbonates, northeastern Kentucky: Sedimentology, V. 22, p. 417-440.

Wanless, H. R., 1979, Limestone responses to stress; pressure solution and dolomitization: Jour. Sed. Petrology, V. 49, p. 437-462.

Wells, J. W., 1957, Corals: Geol. Soc. Amer. Mem. 67, p. 1087-1104.

Winland, H. D. and Matthews, R. K., 1974, Origin and significance of Grapestone, Bahama Islands: Jour. Sed. Petrology, V. 44, p. 921-927.

PLATES

PLATE I

FACIES

A. Hemispherical stromatoporoid facies. Hemispherical stromatoporoid colonies in a boundstone. Core slab, 12-25-63-18 W5, depth 2928.5 meters (9,608 feet). Scale in centimeters.

B. Tabular stromatoporoid facies. Tabular stromatoporoids alternating with brachiopods in a rudstone; brachiopods with internal geopetal fabric. Core slab, 12-25-63-18 W5, depth 2938 meters (9,640 feet). Scale in centimeters.

C. Tabular stromatoporoid facies. Stylolitic contacts between colonies in a tabular stromatoporoid boundstone. Core slab, 12-25-63-18 W5, depth 2914 meters (9,561 feet). Scale in centimeters.

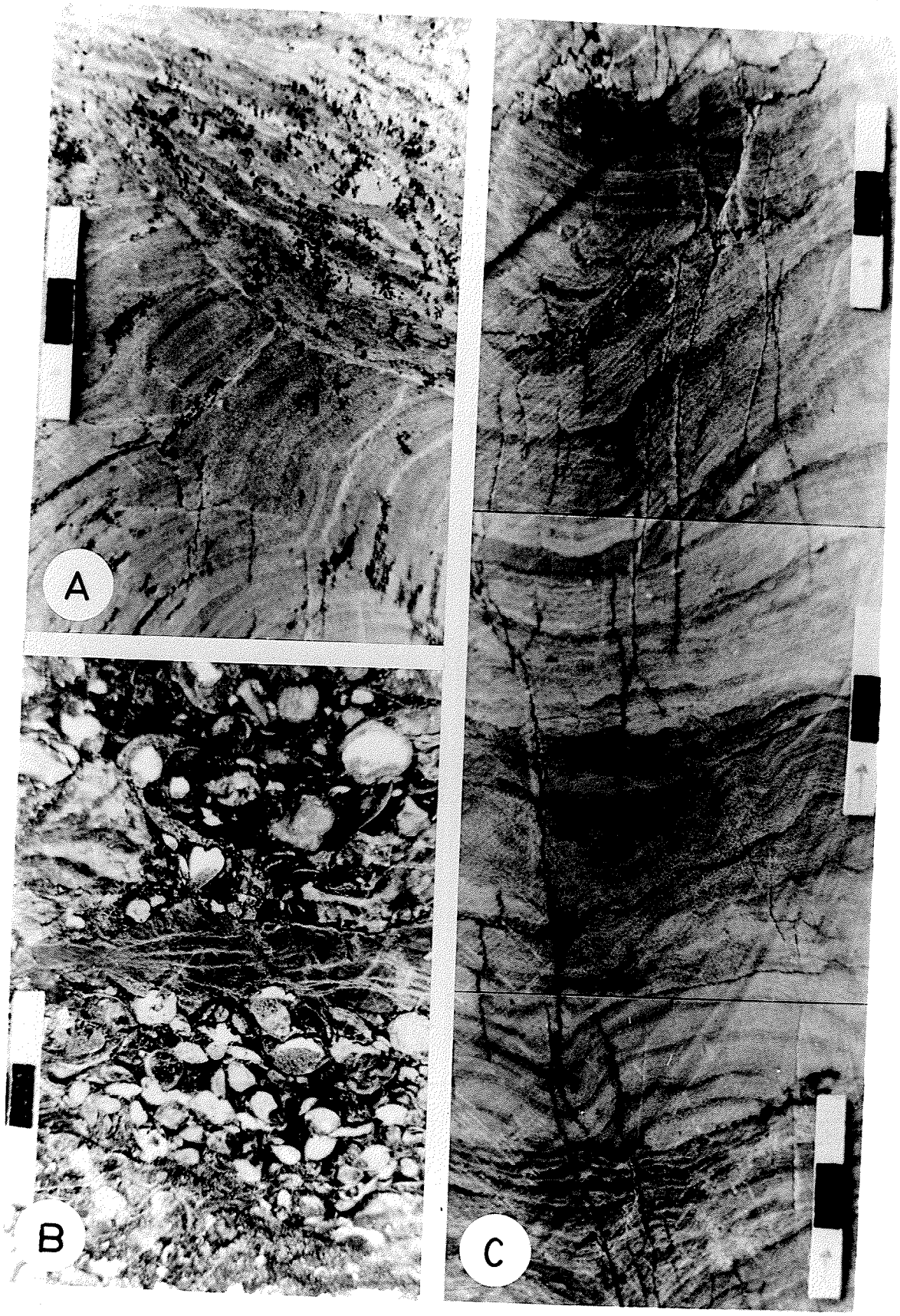

A
B
C

PLATE II

FACIES

A. Tabular stromatoporoid facies. Tabular stromatoporoid boundstone with skeletal grainstone matrix. Core slab, 12-25-62-18 W5, depth 3041.5 meters (9,979 feet). Scale in centimeters.

B. Branching stromatoporoid facies. Branching stromatoporoid colony with interframework bitumenous grainstone. Core slab, 12-25-62-18 W5, depth 3033.5 meters (9,953 feet). Scale in centimeters.

C. Branching stromatoporoid facies. Dolomitized branching stromatoporoid rudstone; interparticle isopachous and stalactitic rim cements. Core slab, 6-33-62-20 W5, depth 3,191 meters (10,470 feet). Scale in centimeters.

D. Branching stromatoporoid facies. *In situ* branching colony. Core slab, 12-25-62-18 W5, depth 3034.5 meters (9,956 feet). Scale in centimeters.

E. Branching stromatoporoid facies. Branching stromatoporoids, gastropods and *Amphipora*; interparticle dolomite spar (white). Core slab, 2-18-63-18 W5, depth 3014.5 meters (9,890 feet). Scale in centimeters.

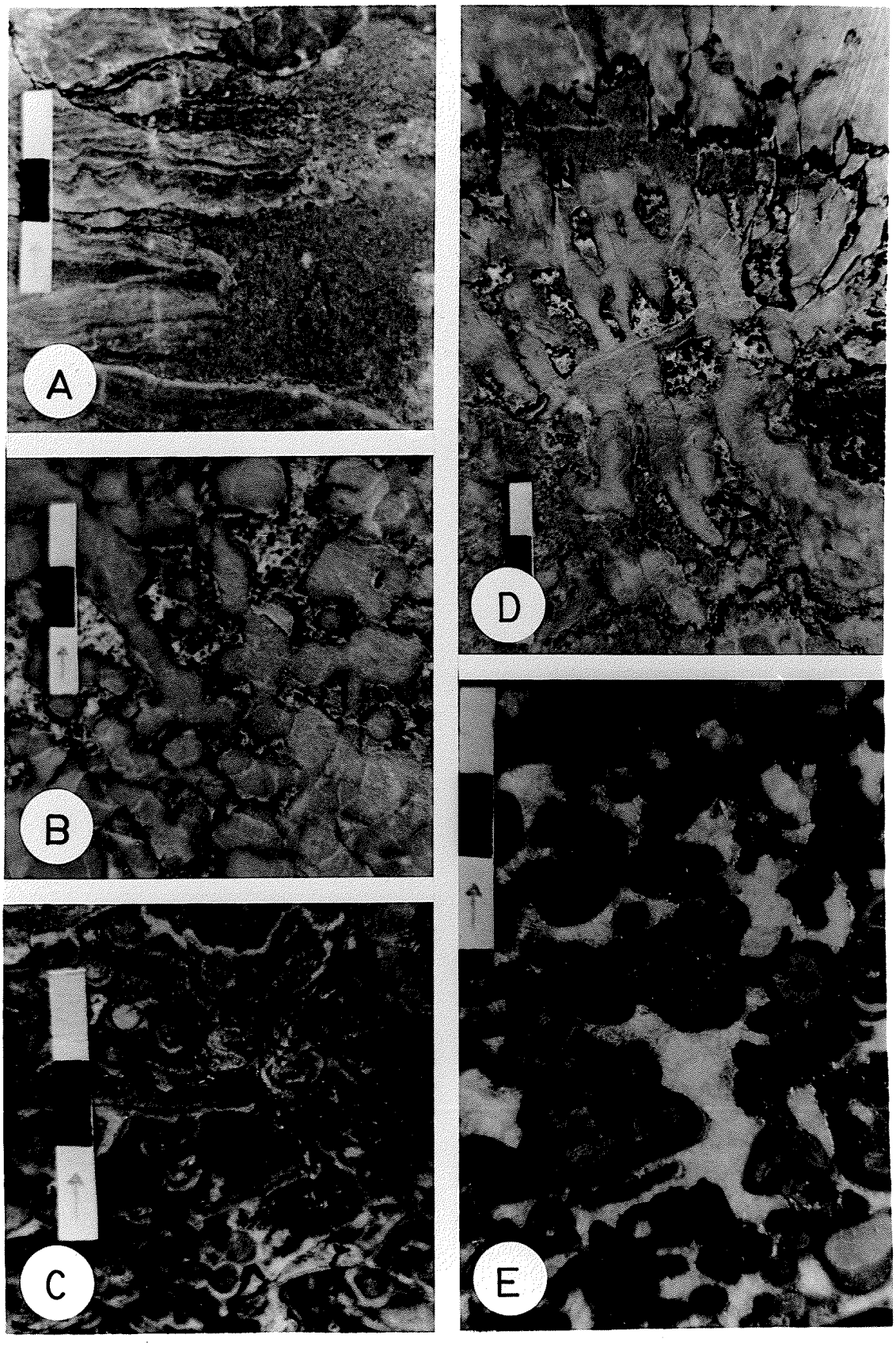

A
B
C
D
E

PLATE III

FACIES

A. Amphipora facies. Light brown Amphipora rudstone; calcite in Amphipora intraparticle pores. Core slab, 2-18-63-18 W5, depth 3017.5 meters (9,900 feet). Scale in centimeters.

B. Amphipora facies. Medium brown Amphipora rudstone; dolomite (white) and calcite in intraparticle pores. Core slab, 2-18-63-18 W5, depth 2999 meters (9,839 feet). Scale in centimeters.

C. Amphipora facies. Dolomitized dark brown Amphipora rudstone; partly moldic Amphipora. Core slab, 2-1-59-18 W5, depth 3415 meters (11,205 feet). Scale bar = 1.0 cm.

D. Euryamphipora facies. Euryamphipora with intraparticle dolomite (white). Core slab, 2-18-63-18 W5, depth 3043.5 meters (9,985 feet). Scale in centimeters.

E. Oolite facies. Radial-fibrous calcite and thin micrite layers on peloid nuclei. Thin section, 6-6-59-17 W5, depth 3469 meters (11,382 feet). Scale bar = 0.1 mm.

F. Pelleted facies. Deformed pellets cemented by calcite spar. Thin section, 2-28-63-20 W5, depth 3189 meters (10,463 feet). Scale bar = 0.1 mm.

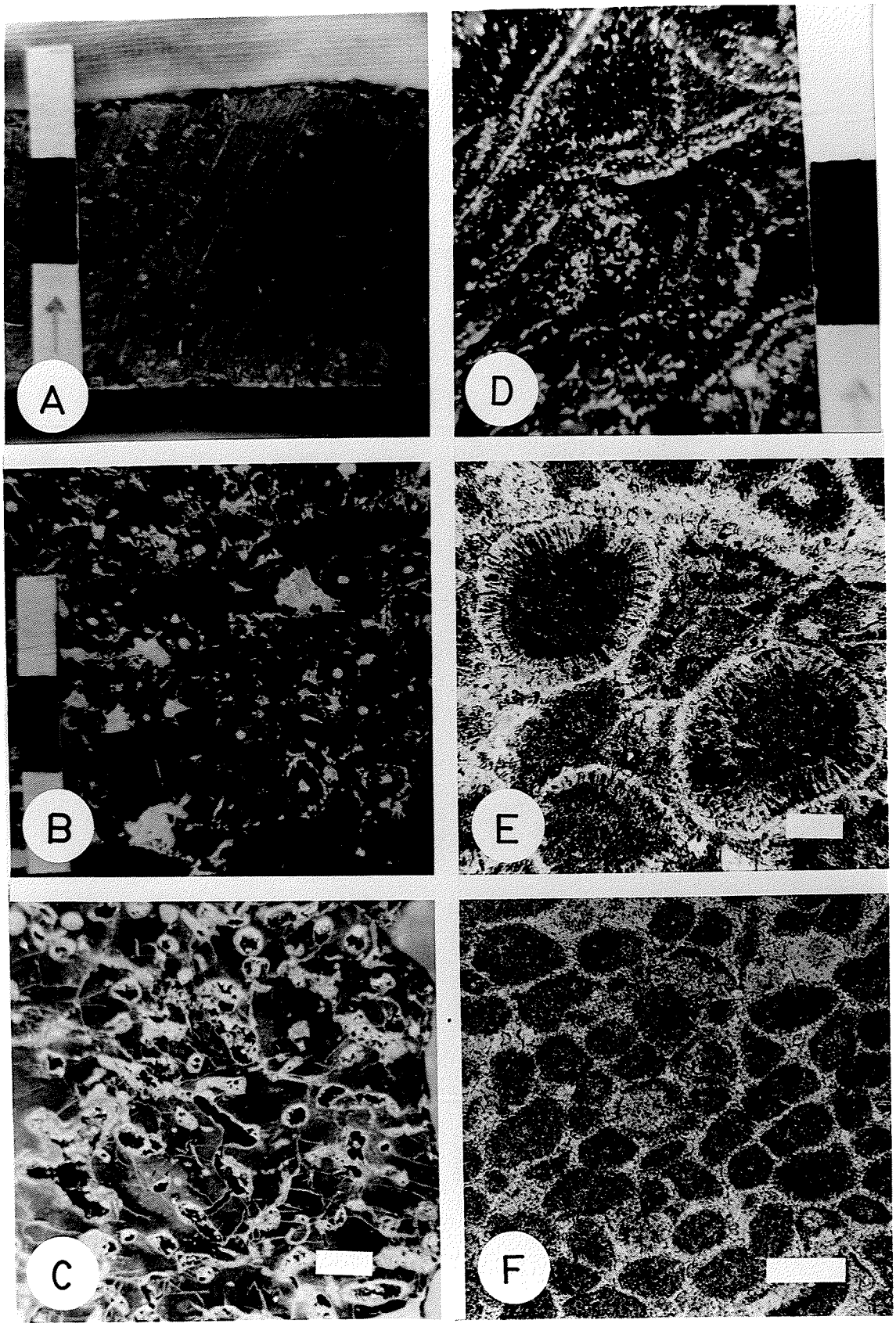

A
D
B
E
C
F

PLATE IV

FACIES

A. Algal facies. Peloidal grainstone with micritic laminae; coarse white dolomite in fenestral pores and beneath micrite laminae (finer dolomite near arrow head). Core slab, 2-18-63-18 W5, depth 3003.5 meters (9,854 feet). Scale in centimeters.

B. Algal facies. Scattered Amphipora in peloidal wackestone; calcite spar fills or rims fenestral pores; coarse white dolomite replaces coarse calcite in centres of largest fenestrae. Core slab, 2-18-63-18 W5, depth 3025 meters (9,925 feet). Scale in centimeters.

C. Green shale facies. Laminated green shale overlying mottled, dolomitized and brecciated rock. Core slab, 2-25-60-19 W5, depth 3359 meters (11,020 feet). Scale bar = 1.0 cm.

D. Algal facies. Peloidal grainstone with irregular and laminar fenestral porosity filled with geopetal dolomite (white) (see also Plate XI A); large, scattered algal-coated allochems or oncolites. Core slab, 12-25-62-18 W5, depth 3046 meters (9,993 feet). Scale in centimeters.

E Skeletal-peloid facies. Micritized grains, larger composite grains and skeletal fragments of echinoids and

calcispheres. Thin section, 2-18-62-18 W5, depth 3182 meters (10,439 feet). Scale bar = 0.5 mm.

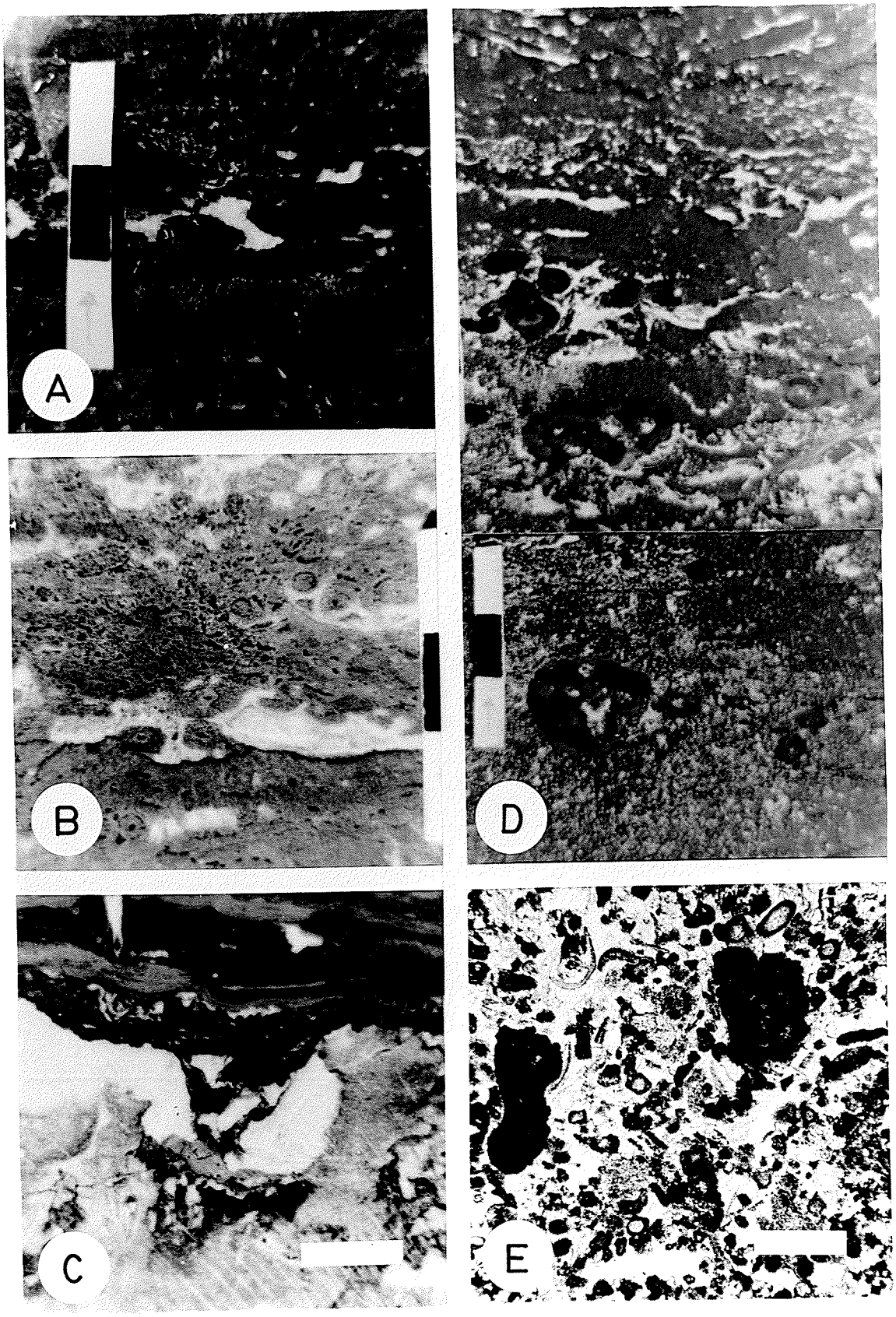

A
B
C
D
E

PLATE V

FACIES

A. Echinoid-brachiopod facies. Echinoid and bryozoa grainstones; incomplete replacement by dolomite (white). Core slab, 6-6-59-17 W5, depth 3416.5 meters (11,209 feet). Scale bar = 1.0 cm.

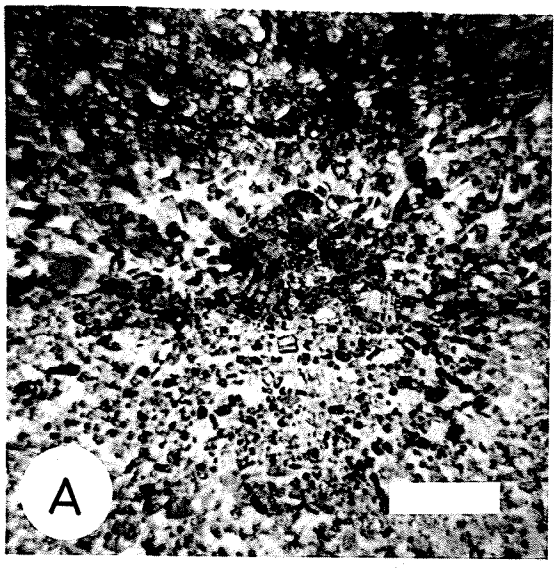
B. Massive micrite and echinoid-brachiopod facies. Insoluble residue seam (black) at contact of upper mudstone with lower wackestone. Core slab, 6-6-59-17 W5, depth 3444.5 meters (11,301 feet). Scale bar = 1.0 cm.

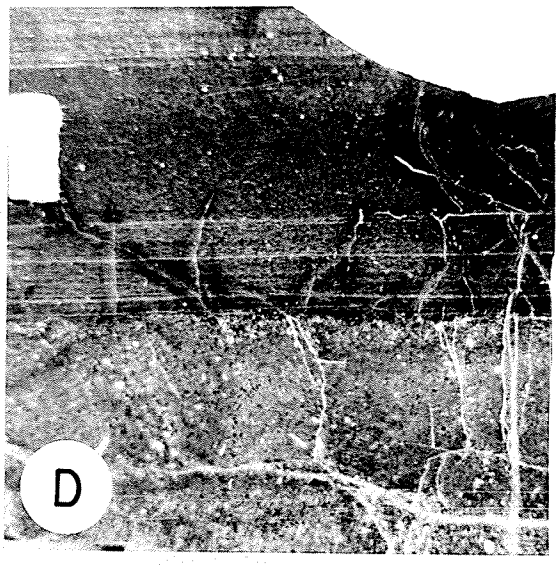
C. Echinoid-brachiopod facies. Cephalopod, brachiopod, gastropod, and echinoid fragments; replacement of peloids in cephalopod chamber by dolomite (grey); coarse crystalline anhydrite (white) in cephalopod chamber. Core slab, 2-28-63-20 W5, depth 3169 meters (10,397 feet). Scale in centimeters.

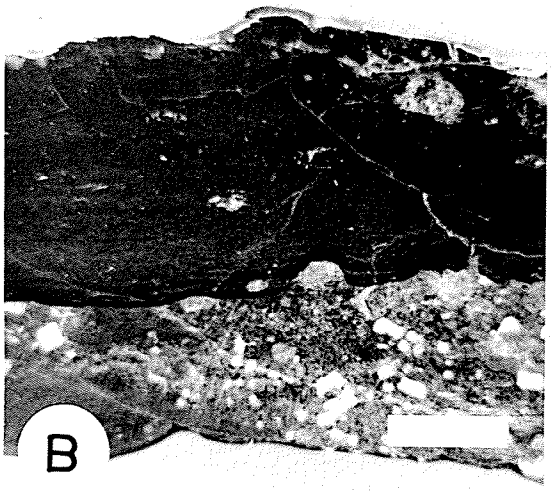
D. Laminated micrite facies overlying skeletal-peloid facies. Core slab, 6-6-59-17 W5, depth 3442 meters (11,292 feet). Scale bar = 1.0 cm.

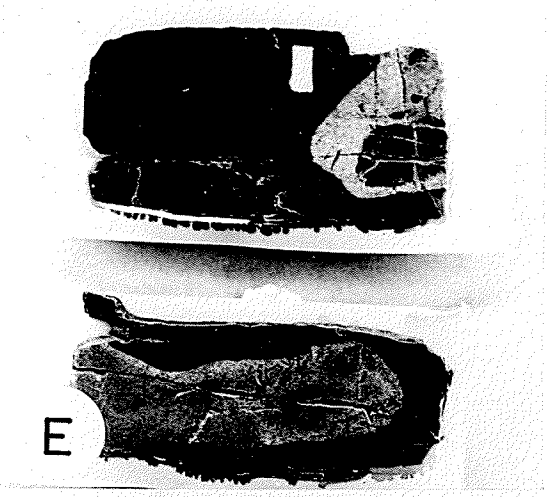
E. Massive micrite facies. Chert nodules containing dolomite euhedra in mudstone. Core slabs, 6-6-59-17 W5, depth 3432 meters (11,260 feet) (upper slab) and 3433.5 meters (11,265 feet) (lower slab). Scale bar = 1.0 cm.

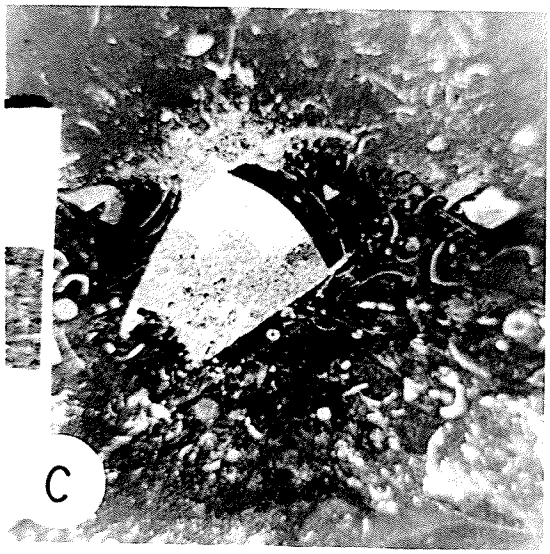
F. Massive micrite facies. Incomplete dolomitization (light grey) of mudstone (dark grey); insoluble residue concentrated along large amplitude stylolite. Core slab, 8-28-61-18 W5, depth 3179 meters (10,429 feet). Scale in centimeters.


A


D


B


E


C

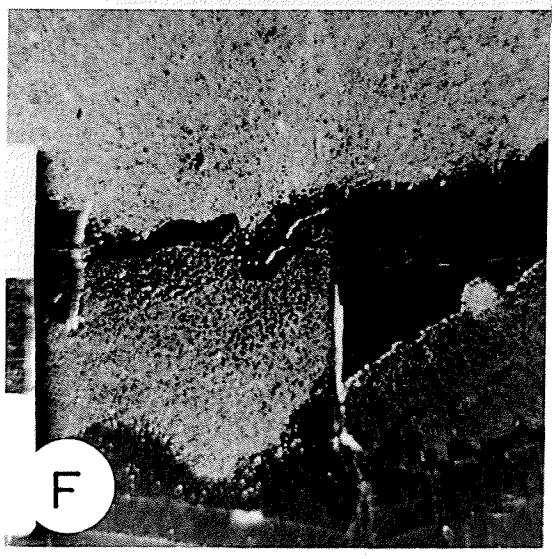

F

PLATE VI

DIAGENESIS - UNCONFORMITY

A. Micrite surface. Boring (centre, right) of discontinuity surface. Core slab, 12-25-62-18 W5, depth 3025.5 meters (9,927 feet). Scale in centimeters.

B. Micrite surface. Fractured micrite surface; fenestral porosity below surface filled with calcite. Thin section, location as in A. Scale bar = 1.0 mm.

C. Micrite surface. Truncated Amphipora fragment; fenestral porosity and cement as above (B). Thin section, 12-25-63-18 W5, depth 2922.5 meters (9,589 feet). Scale bar = 1.0 mm.

D. Green shale horizon. Poorly laminated green shale (dark grey) containing anhedral to subhedral dolomite (light grey) and disseminated pyrite (black). Thin section, 7-5-59-18 W5, depth 3510 meters (11,515 feet). Scale bar = 0.5 mm.

E. Green shale horizon. Contact of dolomitic green shale with underlying dolomitic limestone; pyrite (black) concentrated along contact and euhedra dispersed through green shale and underlying Amphipora floatstone; partial replacement by dolomite (light grey). Thin section, 7-5-59-18 W5, depth 3511 meters (11,519 feet). Scale bar = 0.5 mm.

F. Green shale horizon. Green shale containing pyrite euhedra (black) along stylolite seam in mottled dolomitic limestone. Thin section, location as above (E). Scale bar = 0.5 mm.

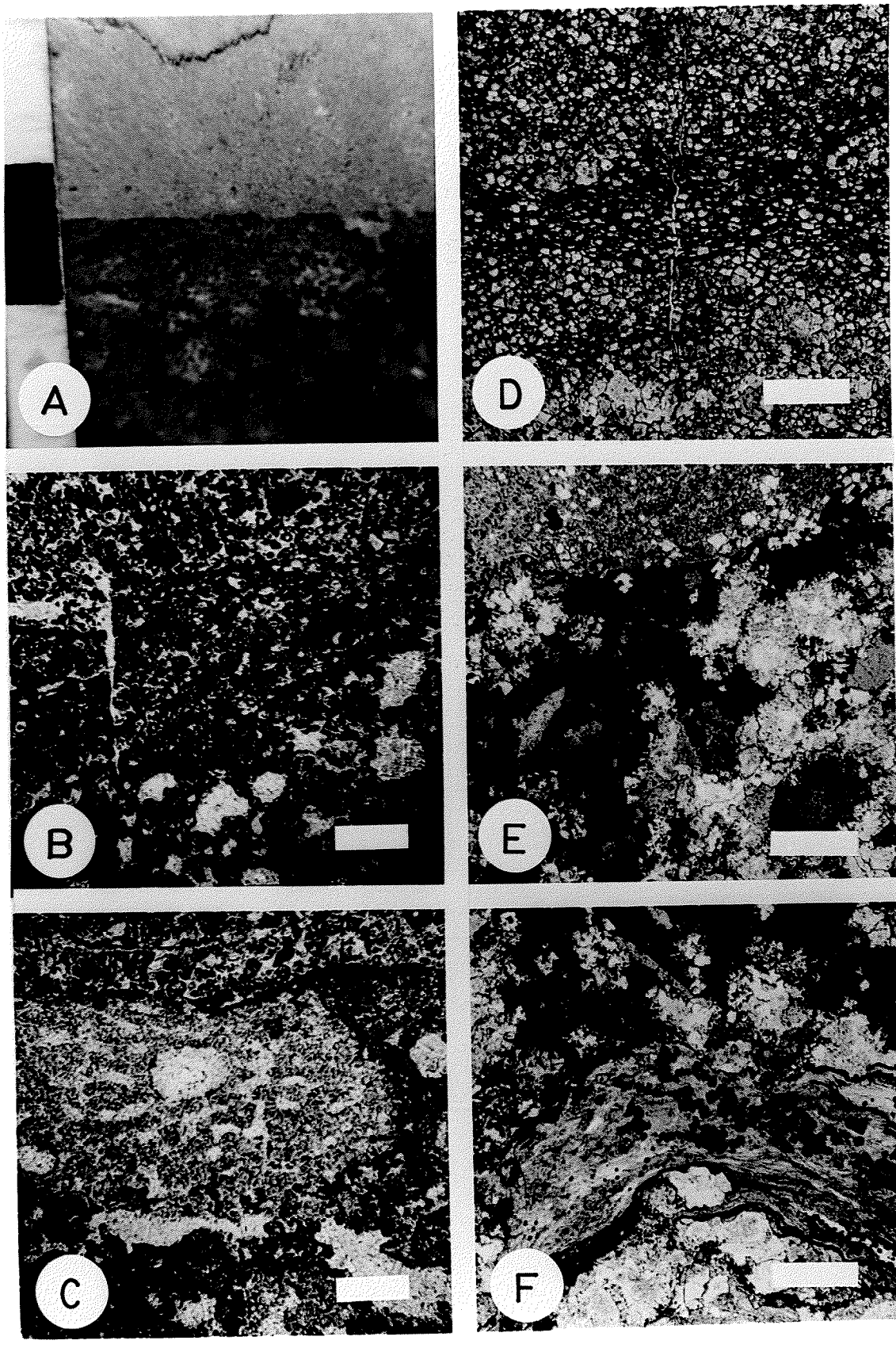

A
D
B
E
C
F

PLATE VII

DIAGENESIS - CEMENTS

A. Irregular calcite rim cement 'stalagmite' in a shelter cavity later infilled with skeletal sand and silt. Thin section, 12-25-62-18 W5, depth 3012.5 meters (9,884 feet). Scale bar = 0.5 mm.

B. Diverging subcrystals of rim cement. Thin section, x-nicols, 12-25-62-18 W5, depth 3012 meters (9,883 feet). Scale bar = 0.5 mm.

C. Pelleted micrite cement (black) on Amphipora overlain by equant calcite rim cement. Coarse, iron-zoned calcite crystal in centre, lower. Chert spherulite (white) in Amphipora. Thin section, 6-23-63-18 W5, depth 2958.5 meters (9,706 feet). Scale bar = 0.5 mm.

D. Neomorphic interparticle calcite with discernible equant calcite rim cement in oolite (?) grainstone. Partly leached grains contain dolomite or anhydrite crystals or hydrocarbon residue (black). Thin section, 2-28-63-20 W5, depth 3178.5 meters (10,428 feet). Scale bar = 0.1 mm.

E. Syntaxial rim cement on echinoid ossicles. Incomplete replacement of calcite by chert (C). Thin section, 12-5-63-19 W5, depth 3147 meters (10,324 feet). Scale bar = 0.5 mm.

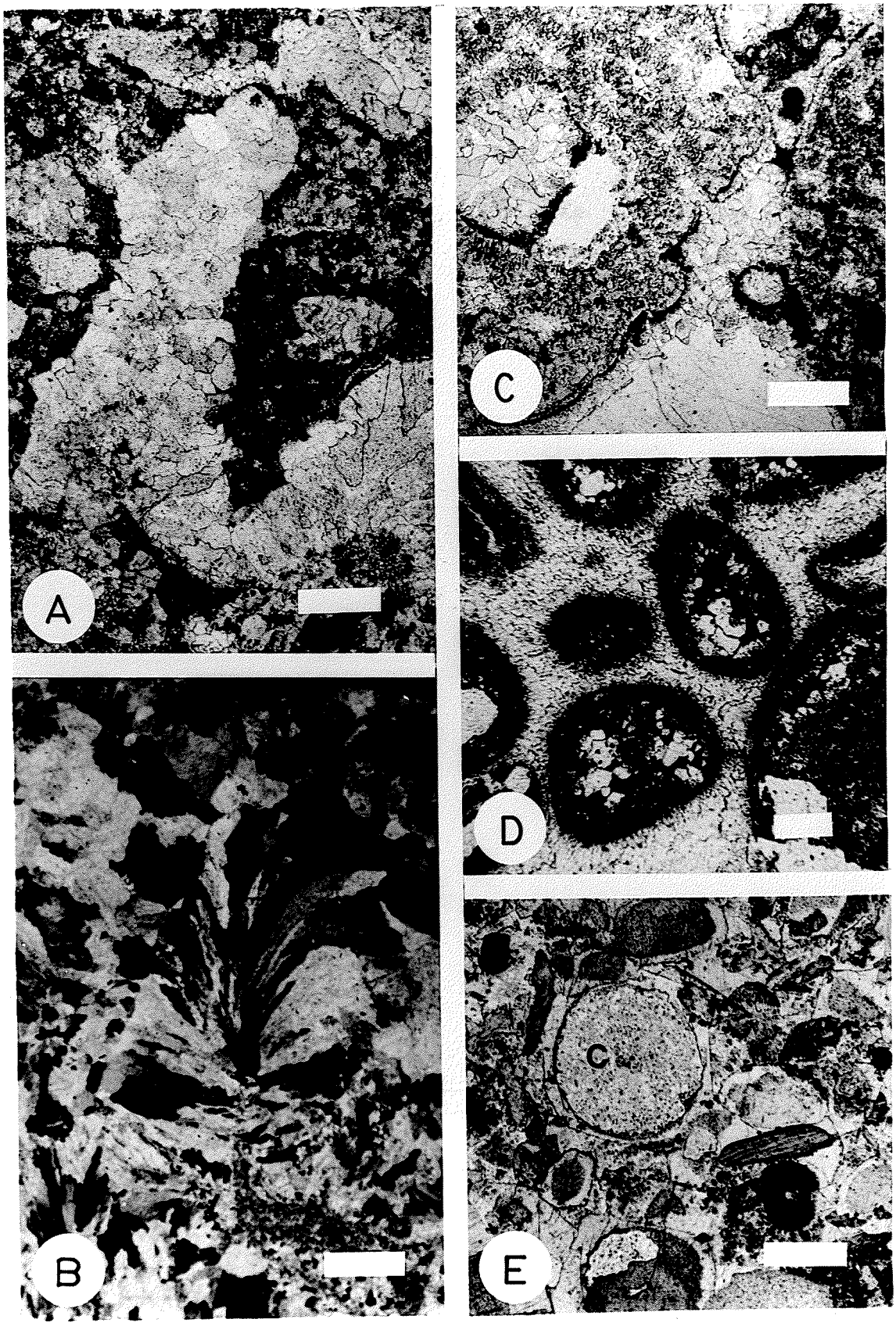

A
B
C
D
E

PLATE VIII

DIAGENESIS - CEMENTS

A. 'Stalactitic' calcite rim cement on Amphipora fragments; thinly bedded silt (centre, left) with scattered ostracods in solution-enlarged interparticle pore. Thin section, 2-18-63-18 W5, depth 2979 meters (9,774 feet). Scale bar = 1.0 mm.

B. Calcite rim cement in interparticle pore; incomplete pore filling of scattered ostracods in silt. Transition from rim cement (R) to pore-filling calcite cement (E) marked by decrease in inclusion content. Thin section, 6-23-63-18 W5, depth 2917.5 meters (9,572 feet). Scale bar = 0.5 mm.

C. Diverging subcrystals of calcite rim cement on upper surface of shelter pore; episodes of growth marked by lines of micritic inclusions. Coarse iron-zoned equant calcite (C) partly replaced by dolomite (D). Thin section, 6-23-63-18 W5, depth 2913 meters (9,558 feet). Scale bar = 0.5 mm.

D. Location and scale as in A, x-nicols. Note 'brush' extinction of cement crystals diverging from lower surfaces of Amphipora fragments and upward from upper surface of silt at left.

E. Calcite rim cement (R), thickest on upper surface of interparticle pore, with three growth stages contrasted by inclusion content and colour. Coarse, iron-zoned calcite filling pore is partly replaced by dolomite (D). Thin section, 6-23-63-18 W5, depth 2917.5 meters (9,572 feet). Scale bar = 0.5 mm.

F. Equant rim cement (R) with discontinuous thin micrite laminae (upper centre) on stromatoporoid fragments (S). Equant, iron-zoned calcite partly replaced by coarse, strained dolomite fills remainder of interparticle pores. Thin section, 6-23-63-18 W5, depth 2958.5 meters (9,706 feet). Scale bar = 1.0 mm.

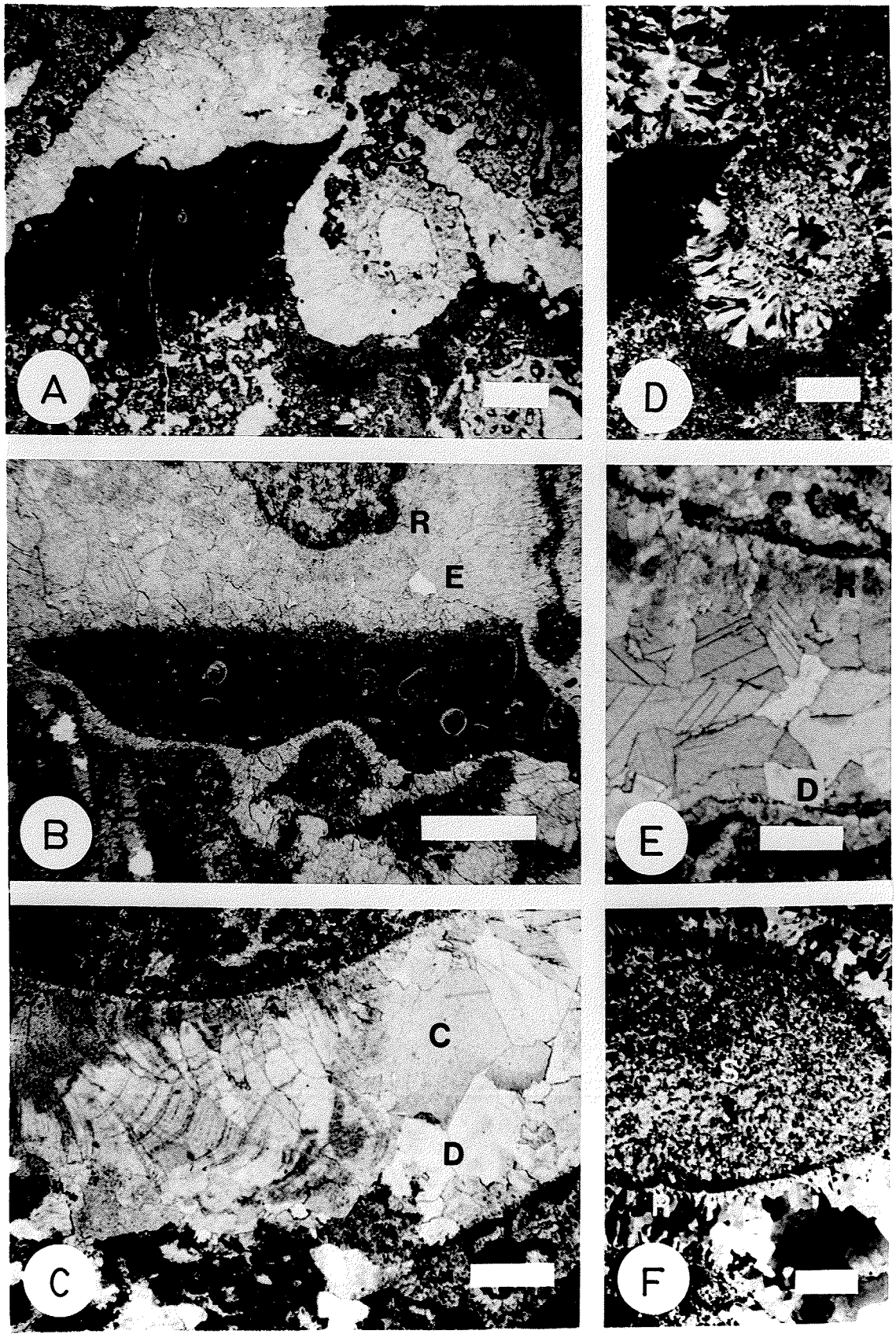

A
D
R
E
B
R
D
E
C
D
C
F

PLATE IX

DIAGENESIS - CEMENTS

A. Equant calcite rim cement at grain contacts, followed by coarser, iron-zoned equant calcite cement in interparticle pores of a micritized grainstone. Thin section, 2-18-63-18 W5, depth 3005 meters (9,859 feet). Scale bar = 0.1 mm.

B. Equant calcite rim cement followed by coarse, iron-calcite cement in fenestral pore. Thin section, 2-18-63-18 W5, depth 2980 meters (9,777 feet). Scale bar = 0.5 mm.

C. Isopachous rim cement (light grey) in larger pores, completely filling smaller pores. Iron-zoned dolomite (white) partly replacing equant calcite in larger pores (see also Plate IX, F). Core slab, 6-23-63-18 W5, depth 2929.5 meters (9,612 feet). Scale bar = 1.0 cm.

D. Stalactitic inclusion-rich cement of diverging subcrystals beneath an indurated crust (C) (see also Plate X, A). Overgrowths of inclusion-free crystals in optical continuity with rim cement replace grains beneath rim cement (arrow). Thin section, 2-18-63-18 W5, depth 3005 meters (9,859 feet). Scale bar = 0.5 mm.

E. Isopachous rim (R) of inclusion-rich diverging calcite subcrystals in a fenestral pore. Evidence of dissolution between rim cement and overlying geopetal calcite

microspar (M). Coarse, iron-zoned dolomite (D) replacing coarse, iron-zoned calcite crystals (C). Thin section, 2-18-63-18 W5, depth 2991.5 meters (9,815 feet). Scale bar = 0.5 mm.

F. Same location as C. Strained, iron-zoned dolomite (D) replacing equant, iron-zoned calcite (C). Thin section. Scale bar = 1.0 mm.

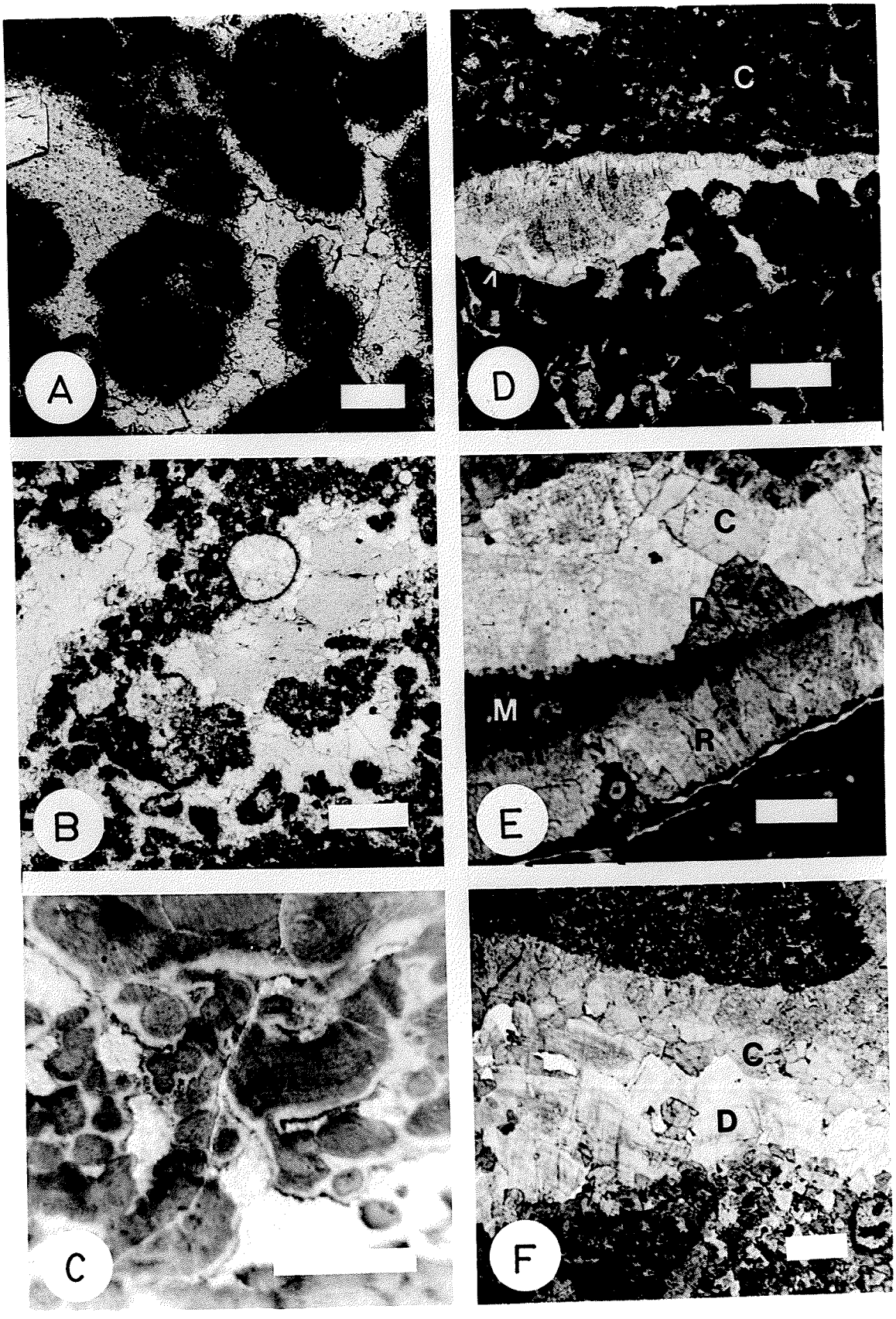

A
C
D
B
C
D
M
R
E
C
D
F

PLATE X

DIAGENESIS - NEOMORPHISM AND BIOLOGICAL DIAGENESIS

A. Vertical boring through an indurated crust (C) (micritic layer) into an underlying grainstone bed. Thin section, 2-18-63-18 W5, depth 3005 meters (9,859 feet). Scale bar = 0.5 mm.

B. Micritized zone of algal or fungal origin in a stromatoporoid. Thin section, 12-25-63-18 W5, depth 2920 meters (9,580 feet). Scale bar = 0.5 mm.

C. Irregular micritization (black) of algal (?) origin on a gastropod. Finer neomorphic calcite of former gastropod shells (S) and rim cement (R) is marked by inclusions and relict fibrous structure, compared to coarser iron-zoned calcite of former internal cavity. Thin section, 2-18-63-18 W5, depth 3045 meters (9,991 feet). Scale bar = 0.5 mm.

D. Microspar of former peloids (P) as distinct from coarser neomorphic spar (S) (iron-calcite) of former cement. Thin section, 2-18-62-18 W5, depth 3101.5 meters (10,175 feet). Scale bar = 0.1 mm.

E. Amphipora skeleton (S) replaced by neomorphic calcite with relic fibrous structure. Very coarse calcite spar occludes intraskeletal pores. Thin section, 2-18-63-18 W5, depth 3008 meters (9,869 feet). Scale bar = 0.1 mm.

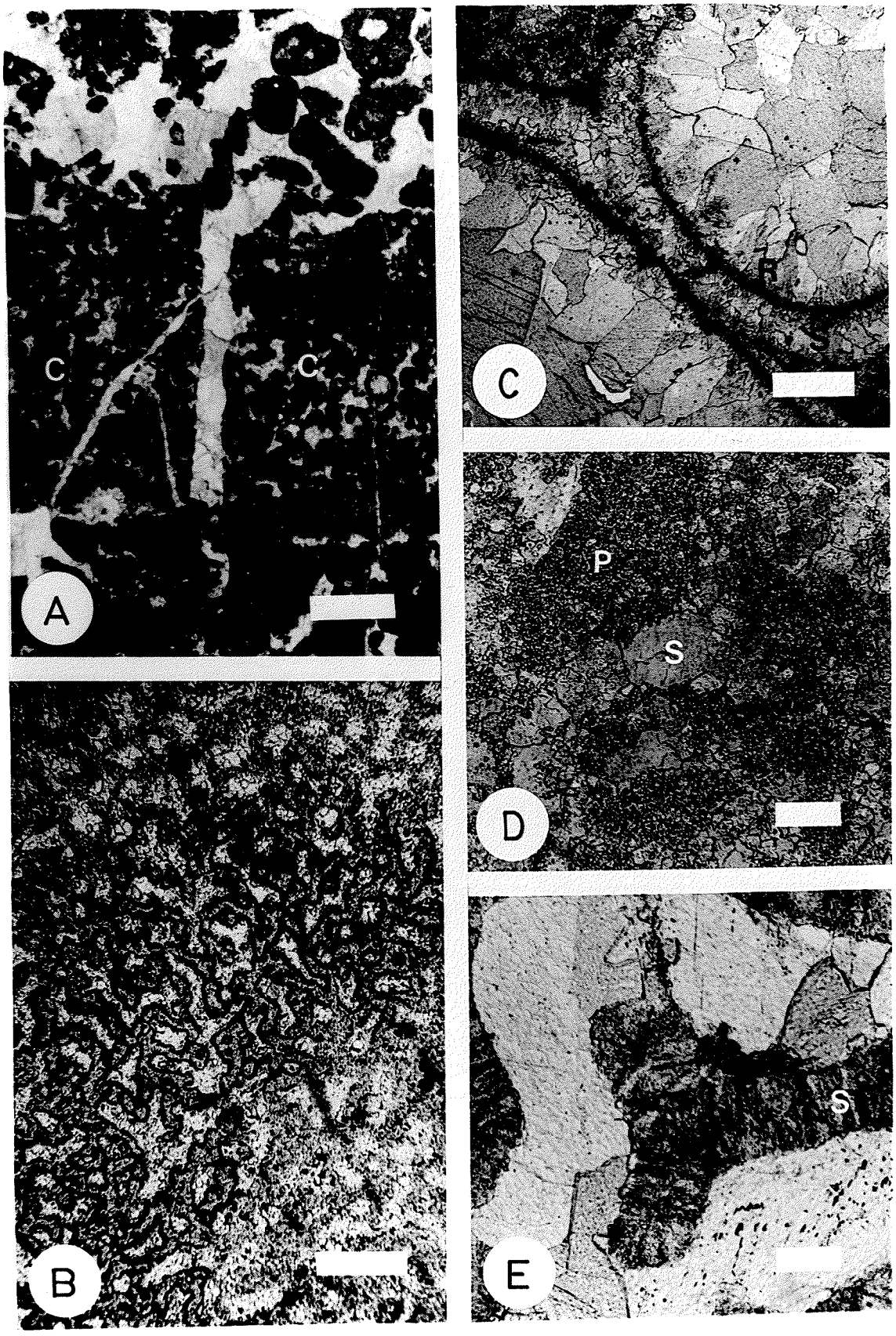

C
C
A
C
P
S
C
P
S
D
S
E

PLATE XI

DIAGENESIS - DOLOMITE

A. Dolomitized geopetal fabric in former fenestral pore in sekeletal-peloid grainstone. Fine crystalline dolomite with intercrystalline calcite lower-most in pore. Coarse, strained, inclusion-rich dolomite replaces coarse calcite spar uppermost in pore. Thin section, 12-25-62-18 W5, depth 3046 meters (9,993 feet). Scale bar = 0.5 mm.

B. Dark pyritic halo around dolomitized geopetal fabric in solution cavity in wackestone. Thin section, 6-23-63-18 W5, depth 2952 meters (9,685 feet). Scale bar = 0.5 mm.

C. Large dolomite crystal (black) in intraparticle Euryamphipora pores. Euryamphipora skeleton (neomorphosed) partly replaced by dolomite. Thin section, x-nicols, 2-18-63-18 W5, depth 3043.5 meters (9,985 feet). Scale bar = 0.1 mm.

D. Linear pattern of dolomite euhedra (light grey) in calcite microspar. Concentration of dark, 1 micron particles in central zones of dolomite horizons (arrows). Thin section, 7-5-59-18 W5, depth 3511.5 meters (11,521 feet). Scale bar = 0.5 mm.

E. Dolomite euhedra (white) in wackestone partly replaced by chert (black) (lower half of photo). Equant to bladed calcite of gastropod shell (S) and interior (A) partly replaced by chert adjacent to wackestone matrix. Thin section, x-nicols, 6-28-58-18 W5, depth 3303.5 meters (10,838 feet). Scale bar = 0.5 mm.

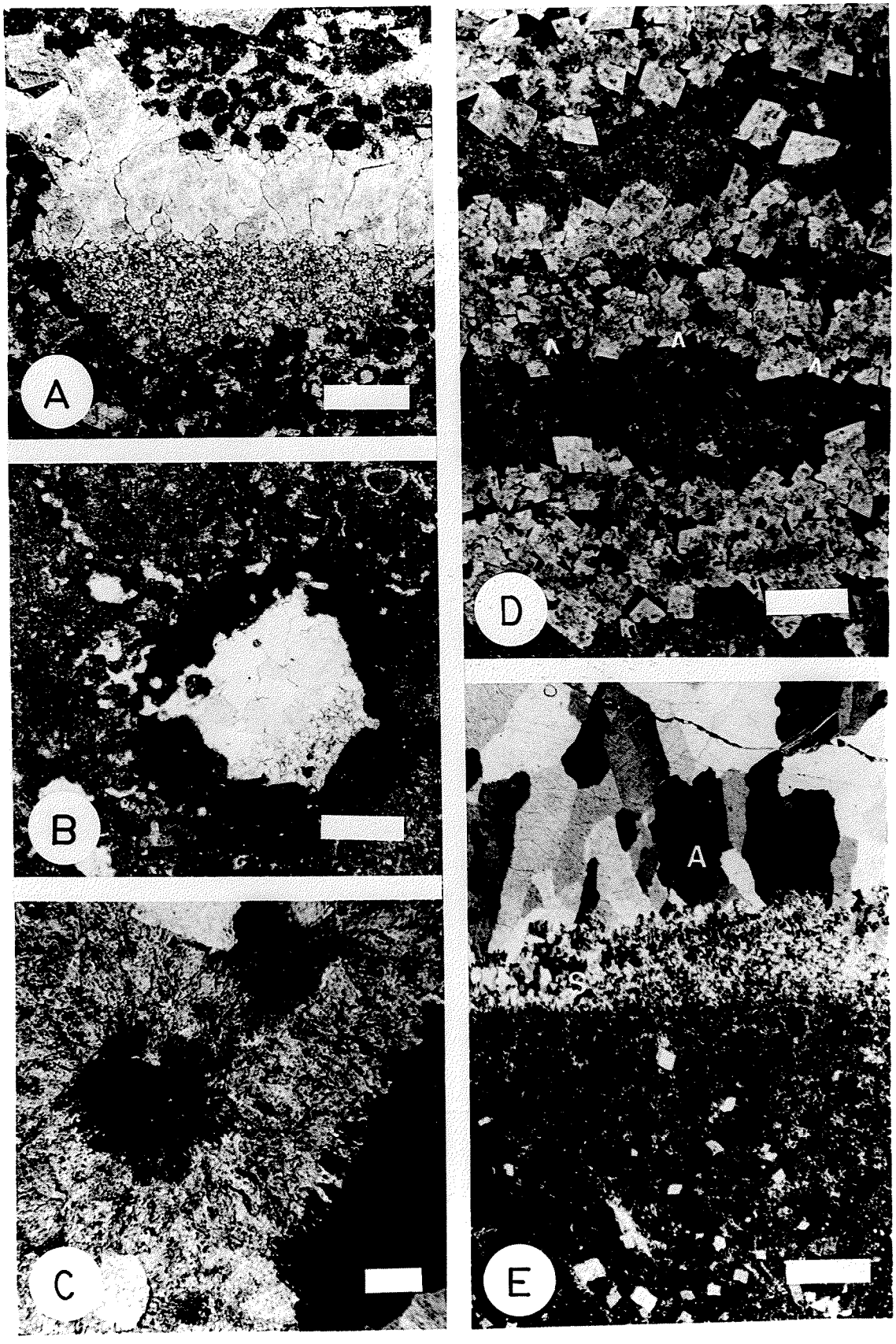

A
B
C
D
A
A
A
E
A

PLATE XII

DIAGENESIS - DOLOMITE

A. Nodules of anhydrite laths in dolomite. Thin section, 7-5-59-18 W5, depth 3563 meters (11,690 feet). Scale bar = 0.5 mm.

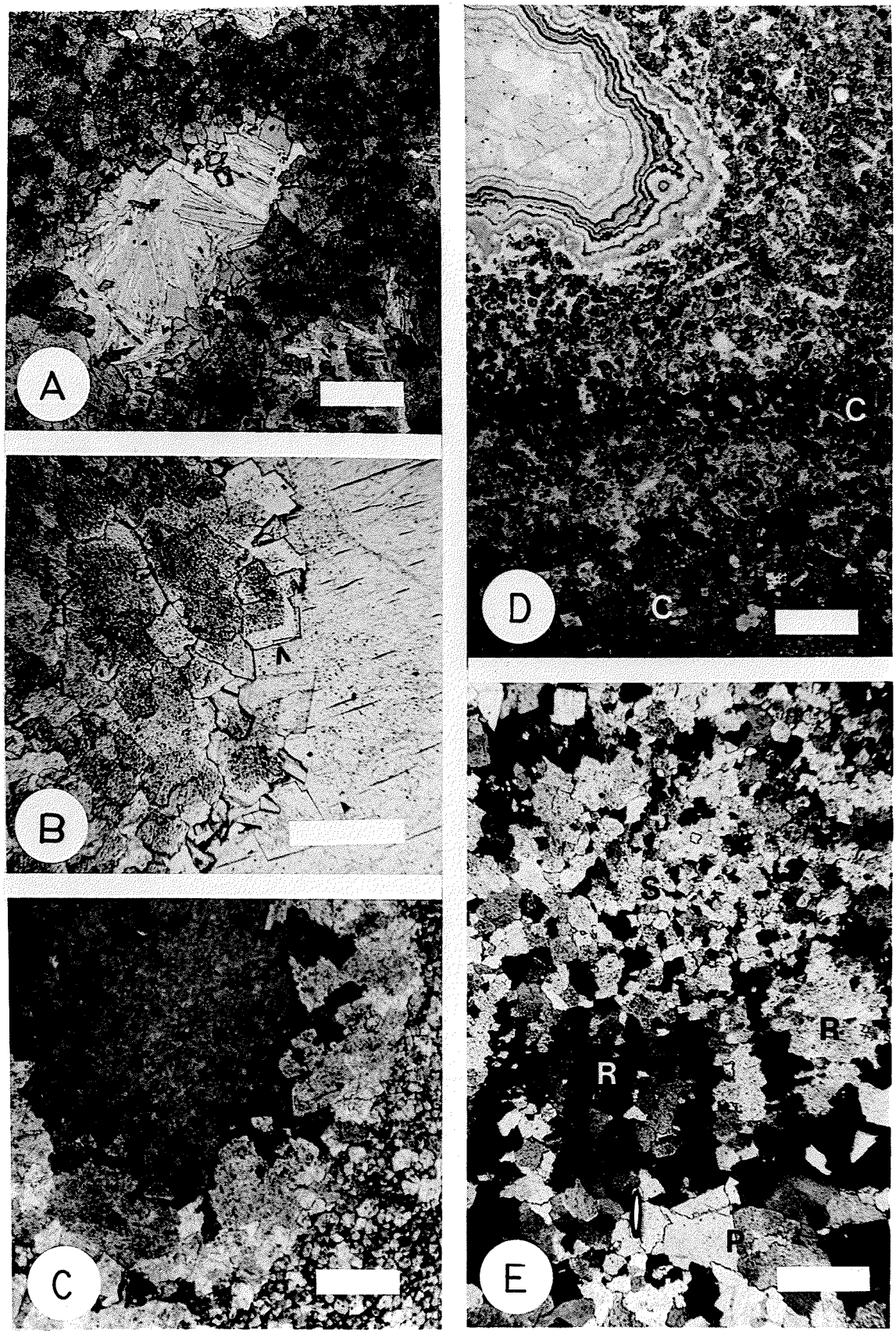
B. Limpid margins (arrow) on inclusion-rich dolomite crystals adjacent to very coarse calcite crystal (right). Thin section, 7-13-60-19 W5, depth 3292 meters (10,802 feet). Scale bar = 0.5 mm.

C. Dolomite replaced a) matrix with fine crystals (lower right and b) stromatoporoid margin with coarse crystals (light grey to white). Stromatoporoid interior is calcite (dark grey). Thin section, 6-28-58-18 W5, depth 3291.5 meters (10,799 feet). Scale bar = 0.5 mm.

D. Calcite laminae (C) with scattered dolomite euhedra (white) (bottom of photo) in a chert-replaced grainstone. Bladed quartz, thin layers of calcite, pyrite, and quartz fill geode-like cavity (upper left). Thin section, 6-6-59-I7 W5, depth 3438.5 meters (11,281 feet). Scale bar = 0.5 mm.

E. Dolomite replaced a) stromatoporoid with equant crystals of uniform size (S), b) rim cement (R) with 'bladed' crystals, with interlocking crystal boundaries with long axes of crystals perpendicular to stromatoporoid margin and c) pore filling cement (P) with equant crystals of

less uniform crystal size. Thin section, x-nicols, 6-33-62-20 W5, depth 3191 meters (10,469 feet). Scale bar = 0.5 mm.


A
B
C
D
C
C
E
S
R
R
R
P

APPENDIX A

KAYBOB SOUTH AREA CORE STUDY SUMMARY

Well Location and Name, Date			Cored Interval (Ft.)
Group I - Detailed Core Study			
2-28-63-20 W5	Calstan BA Kaybob W.	1960	10,304-10,470
12- 5-63-19 W5	Calstan BA Iosegun	1958	10,150-10,352
4-16-62-19 W5	Calstan BA Kaybob	1959	10,400-10,626
11- 1-61-19 W5	Chevron Fox Creek	1967	10,482-10,871
10- 3-60-18 W5	HB-Amoco-Fina Kaybob S.	1969	10,300-10,413
6- 6-59-17 W5	Amoco et al. H-1 Kaybob S.	1969	11,200-11,386
6-33-62-20 W5	HBBL Gas Unit 1 Kaybob S.	1966	10,408-10,508
2-18-62-18 W5	Calstan BA Kaybob	1959	10,060-10,458
2-18-63-18 W5	Phillips Kaybob	1959	9,709-10,035
6-23-63-18 W5	Pacific et al. Kaybob	1971	9,546- 9,789
12-25-63-18 W5	Pacific et al. E. Kaybob	1973	9,553- 9,796
7- 5-59-18 W5	SOBC Clark	1968	11,320-11,759
6-28-58-18 W5	SOBC Clark	1970	10,785-10,951
10- 3-59-18 W5	Mobil et al. Kaybob S.	1969	10,614-10,750 10,780-10,833
1- 2-59-18 W5	Chevron BL Unit 3 Kaybob S.	1970	10,709-11,040
2- 1-59-18 W5	Chevron BLG U3 Kaybob S.	1970	10,948-11,222
Group II - Reconnaissance Core Study			
7- 5-60-18 W5	Chevron Clark	1968	10,380-10,583 10,593-10,701
7-13-60-19 W5	HB-Pan Am-Fina Kaybob S.	1969	10,710-10,830
4-19-60-18 W5	Triad Can. Sup. Kaybob S.	1969	10,775-10,915

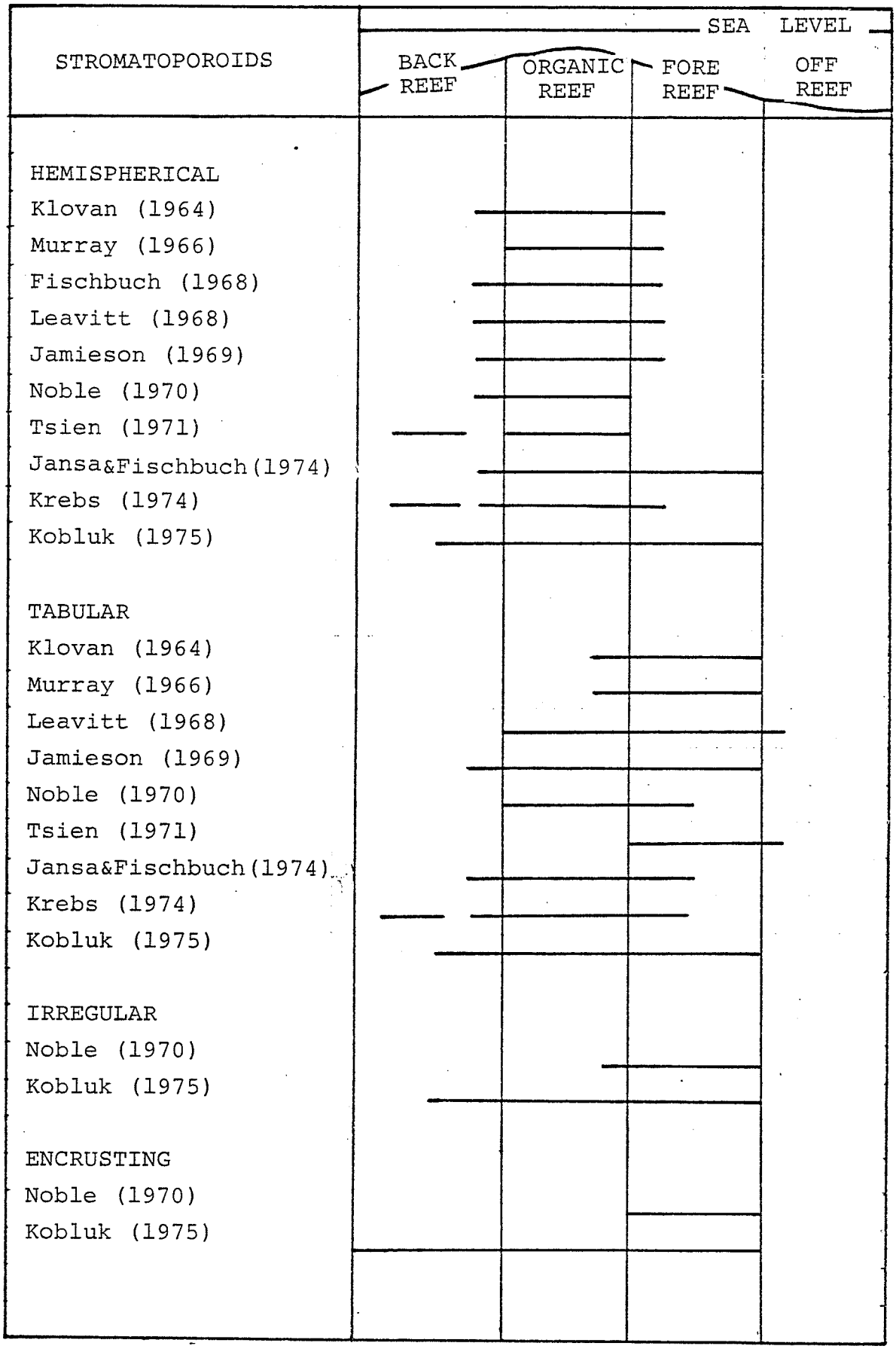
Group II (contd.)

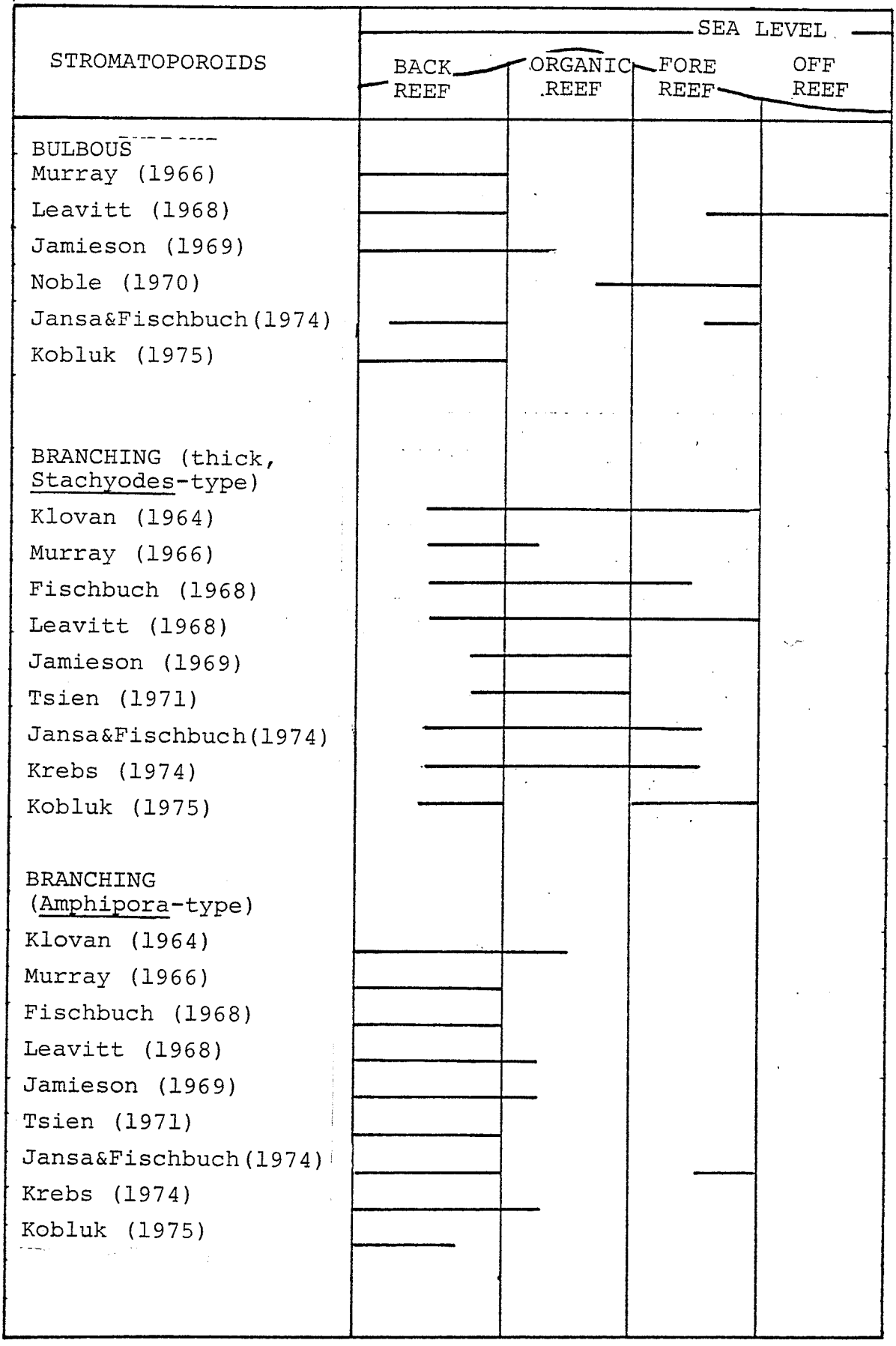
2-25-60-19 W5	HB BL Gas Unit 2 Kaybob S.	1969	10,960-11,139
8-28-61-18 W5	HB Union Kaybob	1960	10,350-10,400 10,405-10,437
1-22-62-20 W5	HB BL Gas Unit 1 Kaybob S.	1968	10,571-10,662
12-25-62-18 W5	Chevron Gulf E. Kaybob	1973	9,876- 9,996
4-24-62-20 W5	HB Union Kaybob	1960	10,636-10,686

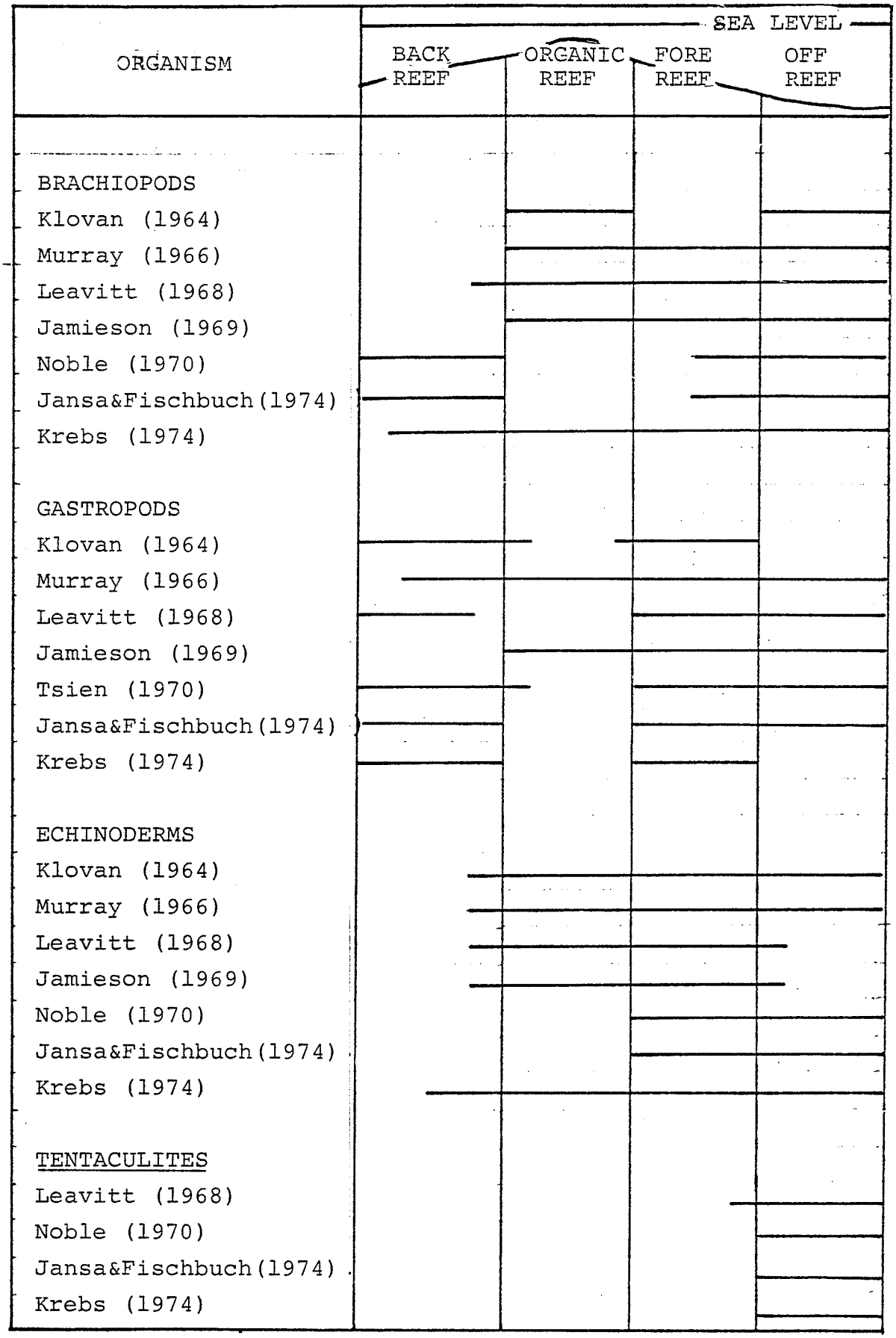
APPENDIX B

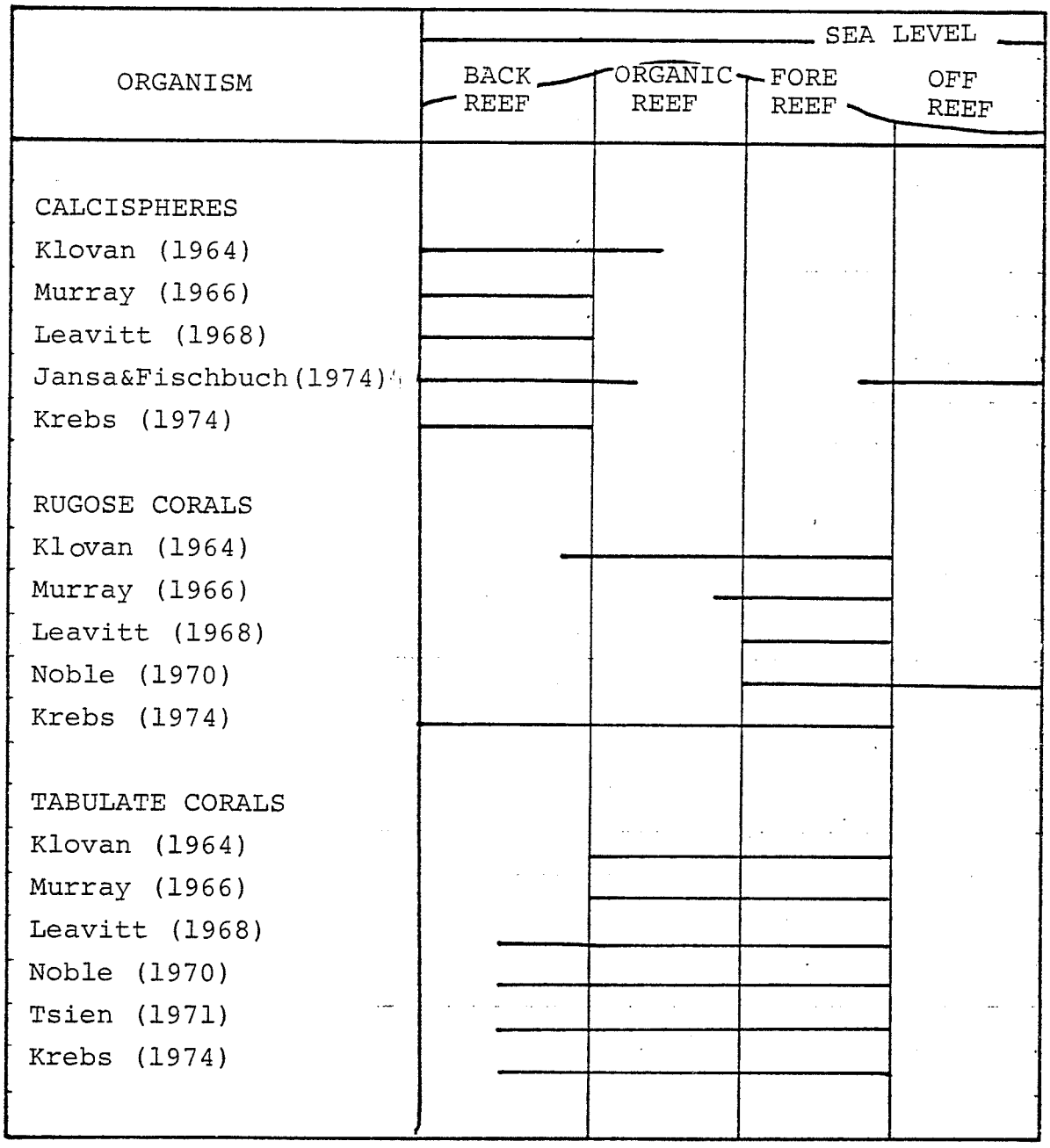
COMPILATION OF DEVONIAN FOSSIL DISTRIBUTION

BASED ON PREVIOUS WORK


STROMATOPOROIDS
SEA LEVEL
BACK REEF
ORGANIC REEF
FORE REEF
OFF REEF
HEMISPHERICAL
Klovan (1964)
Murray (1966)
Fischbuch (1968)
Leavitt (1968)
Jamieson (1969)
Noble (1970)
Tsien (1971)
Jansa&Fischbuch(1974)
Krebs (1974)
Kobluk (1975)
TABULAR
Klovan (1964)
Murray (1966)
Leavitt (1968)
Jamieson (1969)
Noble (1970)
Tsien (1971)
Jansa&Fischbuch(1974)
Krebs (1974)
Kobluk (1975)
IRREGULAR
Noble (1970)
Kobluk (1975)
ENCRUSTING
Noble (1970)
Kobluk (1975)


STROMATOPOROIDS
SEA LEVEL
BACK REEF
ORGANIC REEF
FORE REEF
OFF REEF
BULBOUS
Murray (1966)
Leavitt (1968)
Jamieson (1969)
Noble (1970)
Jansa&Fischbuch(1974)
Kobluk (1975)
BRANCHING (thick, Stachyodes-type)
Klovan (1964)
Murray (1966)
Fischbuch (1968)
Leavitt (1968)
Jamieson (1969)
Tsien (1971)
Jansa&Fischbuch(1974)
Krebs (1974)
Kobluk (1975)
BRANCHING (Amphipora-type)
Klovan (1964)
Murray (1966)
Fischbuch (1968)
Leavitt (1968)
Jamieson (1969)
Tsien (1971)
Jansa&Fischbuch(1974)
Krebs (1974)
Kobluk (1975)


ORGANISM
SEA LEVEL
BACK REEF
ORGANIC REEF
FORE REEF
OFF REEF
BRACHIOPODS
Klovan (1964)
Murray (1966)
Leavitt (1968)
Jamieson (1969)
Noble (1970)
Jansa&Fischbuch(1974)
Krebs (1974)
GASTROPODS
Klovan (1964)
Murray (1966)
Leavitt (1968)
Jamieson (1969)
Tsien (1970)
Jansa&Fischbuch(1974)
Krebs (1974)
ECHINODERMS
Klovan (1964)
Murray (1966)
Leavitt (1968)
Jamieson (1969)
Noble (1970)
Jansa&Fischbuch(1974)
Krebs (1974)
TENTACULITES
Leavitt (1968)
Noble (1970)
Jansa&Fischbuch(1974)
Krebs (1974)


ORGANISM
SEA LEVEL
BACK REEF
ORGANIC REEF
FORE REEF
OFF REEF
CALCISPHERES
Klovan (1964)
Murray (1966)
Leavitt (1968)
Jansa&Fischbuch(1974)
Krebs (1974)
RUGOSE CORALS
Klovan (1964)
Murray (1966)
Leavitt (1968)
Noble (1970)
Krebs (1974)
TABULATE CORALS
Klovan (1964)
Murray (1966)
Leavitt (1968)
Noble (1970)
Tsien (1971)
Krebs (1974)

APPENDIX C

INSOLUBLE RESIDUE DATA

SAMPLE, LITHOLOGY, FACIES	WELL LOCATION	DEPTH (ft)	INSOLUBLE RESIDUE %	TOTAL ORGANIC CARBON %
1 mudstone Massive Micrite	11-1-61-19	10,724	43	.29
2 mudstone, Tabular strom.	11-1-61-19	10,863	5	.50
3 mudstone, Massive Micrite	4-16-62-19	10,434	8	.38
4 mudstone, Massive Micrite	12-5-63-19	10,174	7	.15
5 mudstone, Massive Micrite	12-5-63-19	10,344	10	.19
6 mudstone, Ech.-Brach.Wackestone	2-18-63-20	10,324	9	.20
7 mudstone, Massive Micrite	2-18-63-20	10,366	6	.18

APPENDIX D

POINT COUNT DATA

	<.03mm MUD	<2mm SAND	>2mm	SH	Py	ϕ	D1	D2	CC RIM	CC SPAR	TOTAL
SN 5a	87.1	-	2.7	-	-	-	-	-	-	10.3	600
5b	13.0	67.1	12.4	-	-	-	-	-	-	7.5	599
SN 6	33.2	-	20.5	-	-	-	1.3	-	3.5	41.9	797
SN 7	65.3	3.4	1.7	-	-	-	7.1	-	11.8	10.7	968
SN 9	57.9	0.1	19.3	-	0.1	-	17.7	-	0.4	4.5	820
SN 10	26.7	46.0	-	-	-	-	11.6	-	9.5	6.2	792
SN 11	2.9	64.7	1.1	0.2	-	-	5.6	-	16.4	9.1	824
SN 12	57.1	2.8	13.0	0.1	-	-	0.1	-	9.2	17.7	823
SN 13	35.3	10.2	42.2	-	-	-	-	-	-	12.3	892
SN 15	29.1	2.1	48.2	-	-	1.4	10.8	-	-	8.3	844
SN 16	15.9	28.1	16.2	0.4	-	-	17.6	-	19.9	2.0	801
SN 17	39.5	23.2	3.1	-	-	-	8.1	0.5	24.6	1.1	818
SN 18	11.4	18.4	36.1	-	-	-	22.0	-	11.5	0.5	801
SN 19	16.8	0.9	30.7	-	-	3.6	4.3	13.6	-	-	814
SN 20	1.7	10.1	37.1	-	4.5	-	25.3	8.9	2.4	-	800
SS 6a	3.5	82.7	0.3	-	-	-	2.5	-	-	10.9	603
6b	12.9	61.5	3.3	-	-	-	-	-	22.2	-	603
SY 5a	54.5	35.1	1.4	-	-	-	1.0	-	6.1	1.9	624
5b	49.4	9.6	21.5	-	-	-	-	-	17.3	2.1	613

Sh = shale
Py = pyrite
ϕ = porosity
D1 = dolomite in intra-,interparticle or fenestral pores.
D2 = dolomite in matrix only
CC RIM = calcite rim cement
CC SPAR = calcite spar cement
TOTAL = total points counted (other values are percentages)
(See core descriptions for sample locations.)

APPENDIX E

CORE DESCRIPTIONS

2-28-63-20 W5

10,304-10,314' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids 5 to 10%, brachiopods 5 to 15%, trace bryozoa, ostracods, and Tentaculites. Pyrite finely disseminated in allochems and matrix. Wackestone, minor mudstone. Echinoid-brachiopod facies.

10,314-10,324' - Nodular limestone, dark brown; trace dolomite shale and pyrite. Echinoids 5%, brachiopods 5%, trace ostracods and Tentaculites. Mudstone. Micrite facies.

10,324-10,326' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids 10%, brachiopods 10%, ostracods and Tentaculites. Mudstone, wackestone, rare packstone. Echinoid-brachiopod facies.

10,326-10,337' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids (trace to 5%), brachiopods (trace to 10%), ostracods and Tentaculites. Mudstone, minor wackestone. Micrite facies.

10,337-10,343' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids 5% , brachiopods 10% , trace Amphipora, ostracods and Tentaculites. Wackestone, minor mudstone. Echinoid-brachiopod facies.

10,343-10,347' - Nodular limestone, dark brown; dolomite (to 5%), trace pyrite and shale. Brachiopods 10%, gastropods (trace to 10%), peloids 15 to 30%, trace echinoids, ostracods and Tentaculites. Peloidal wackestone and packstone, minor mudstone.

10,347-10,370' - Nodular limestone. Laminated limestone from 10,385 to 10,362. Dark brown; trace dolomite, shale and pyrite. Brachiopods 5%, trace echinoids, ostracods, and Tentaculites, . Mudstone. Micrite facies.

10,370-10,374' - Nodular limestone, dark brown; trace dolomite shale and pyrite. Brachiopods 10%, trace echinoids, rugose corals, ostracods, and Tentaculites. Mudstone, minor wackestone. Micrite facies.

10,374-10,383' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 5%, trace echinoids, ostracods, and Tentaculites. Mudstone. Micrite facies.

10,383-10,386' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 5 to 10%, trace echinoids, gastropods, ostracods, Tentaculites, and 20% pellets. Packstone and wackestone. Echinoid-Brachiopod facies.

10,386-10,396' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 5%, trace echinoids, ostracods, and Tentaculites. Sparry calcite (from dewatering?). Mudstone, minor wackestone. Micrite facies.

10,396-10,398' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 10%, gastropods 5%, trace echinoids, ostracods, Tentaculites, cephalopods, and Amphipora. Dolomite in allochems. Packstone, minor wackestone, Echinoid-Brachiopod facies. Packstone, minor wackestone. Sample SX 1 at 10,397 feet.

10,398-10,424' - Nodular limestone, laminated from 10,408 to 10,410 feet. Dark brown; trace dolomite, shale and pyrite. Brachiopods 5 to 10%, trace echinoids, ostracods, Tentaculites

and gastropods. Mudstone, minor wackestone. Micrite facies.

10,424-10,426' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 10%, trace echinoids, ostracods and Tentaculites. Burrows (1 to 2 cm) filled with bioclastic debris. Mudstone, packstone in burrows. Micrite facies.

10,426-10,432' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 5 to 10%, trace echinoids, ostracods, Tentaculites, Amphipora and branching stroms. Oolites 35 to 80%. Grainstone and packstone, minor mudstone and wackestone. Oolite facies. Samples SX 2 at 10,427.5 feet, SX 3 at 10,428 feet and SX 4 at 10,428.5 feet.

10,432-10,438' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 10%, trace Amphipora, echinoids and ostracods, minor Tentaculites. Wackestone and mudstone. Echinoid-Brachiopod facies.

10,438-10,440' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 10%, trace Amphipora, ostracods and Tentaculites. Oolites 40%. Packstone. Oolite facies.

10,440-10,447'- Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 5%, gastropods (trace to 5%) echinoids (trace), trace ostracods and Tentaculites. Wackestone and mudstone. Echinoid-Brachiopod facies.

10,447-10,452' - Limestone, dark brown; trace dolomite, shale and pyrite. Encrusting stroms. (strom/algal) 10 to 20%, gastropods and brachiopods. Tension (?) fracture

filled with dolomite. Peloids 20 to 25%. Strom. boundstone and floatstone with grainstone to wackestone matrix. Minor peloidal packstone. Tabular stromatoporoid facies.

10,452-10,458' - Limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 5%, trace gastropods, trace to 25% oncolites. Mudstone and oncolite floatstone with packstone to wackestone matrix. Micrite facies.

10,458-10,462' - Limestone, dark brown; trace dolomite, shale and pyrite. Echinoids 5 to 20%, brachiopods (trace to 25%), trace gastropods, foraminifera, ostracods, and Tentaculites. Well-preserved 2 cm brachiopod. Packstone, minor wackestone. Echinoid-Brachiopod facies.

10,462-10,464' - Limestone, dark brown, trace to 5% dolomite, shale and pyrite. Trace brachiopods, possible algae. Pellets up to 90 percent. Grainstone and packstone, minor mudstone. Samples SX 5 at 10,462.5 feet, SX 6 at 10,463.5 feet. Pelleted facies.

10,464-10,466' - Laminated limestone, dark brown; 10% dolomite, trace pyrite. Mudstone. Micrite facies.

10,466-10,470' - Fort Vermilion Formation: limestone and anhydrite.

10,470-10,472' Watt Mt. Formation: shale, limestone and dolomite.

12-5-63-19 W5

10,150-10,153' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Trace brachiopods, echinoids, ostracods and Tentaculites. Mudstone. Micrite facies.

10,153-10,160' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Tentaculites to 35%, brachiopods 10 to 25%, trace echinoids and ostracods. Packstone, minor wackestone. Echinoid-Brachiopod facies.

10,160-10,163' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 10%, trace echinoids, ostracods and Tentaculites. Wackestone. Echinoid-Brachiopod facies.

10,163-10,181'- Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods (trace to 5%), trace ostracods, Tentaculites, echinoids, and cephalopods. Mudstone. Micrite facies.

10,181-10,194' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Trace echinoids, brachiopods, ostracods, and Tentaculites. Mudstone and wackestone. Micrite facies.

10,194-10,209' - Nodular limestone. Laminated limestone at 10,199 feet. Dark brown; trace dolomite, shale and pyrite. Trace echinoids, ostracods, Tentaculites, and brachiopods. Mudstone. Micrite facies.

10,209-10,212' - Laminated limestone, dark brown; trace brachiopods, ostracods and Tentaculites. Dolomite (trace to 5%). Trace pellets. Mudstone and wackestone. Micrite facies.

10,212-10,222' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Trade brachiopods, Amphipora, branching stroms., ostracods and Tentaculites. Mudstone. Micrite

facies.

10,222-10,226' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Trace echinoids, brachiopods, Amphipora, ostracods and Tentaculites. Mudstone and wackestone. Micrite facies.

10,226-10,235' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids (trace to 10%), brachiopods, 50 to 10%, trace gastropods, ostracods and Tentaculites. Wackestone, minor mudstone. Echinoid-Brachiopod facies.

10,235-10,250' - Nodular limestone, laminated at 10,249 feet. dark brown; trace dolomite, shale and pyrite. Echinoids (trace to 5%), brachiopods 10%, trace gastropods, ostracods, and Tentaculites, Amphipora and pellets. Mudstone, minor wackestone. Micrite facies. (Core missing 10,238 to 10,240 feet.)

10,250-10,260' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids 5 to 10%, brachiopods 10%, trace ostracods and Tentaculites. Peloids 50%. Wackestone and packstone. Skeletal-peloid facies.

10,260-10,274' - Nodular limestone, dark brown; trace to 10% dolomite, trace shale and pyrite. Echinoids 5 to 15%, brachiopods 5 to 10%, trace gastropods, ostracods, and Tentaculites. Peloids 10 to 20%. Vertical fracture filled with calcite spar. Wackestone, minor mudstone. Echinoid-Brachiopod facies.

10,274-10,280' - Nodular limestone, dark brown; trace to 5% dolomite, trace shale and pyrite. Echinoids 5%, brachiopods (trace to 5%), trace ostracods and Tentaculites.

Wackestone, minor mudstone. Echinoid-brachiopod facies.

10,280-10,284' - Nodular limestone, dark brown; trace to 5% dolomite, trace shale and pyrite. Echinoids 5%, brachiopods 5 to 10%, trace gastropods, ostracods and Tentaculites. Brachiopod with geopetal fabric. Possible burrows. Packstone and wackestone. Echinoid-brachiopod facies.

10,284-10,290' - Laminated limestone, dark brown; trace dolomite shale, and pyrite. Echinoids (trace to 10%), brachiopods 5 to 10%, ostracods and Tentaculites. Packstone to grainstone and mudstone laminae. Sample SW 1 at 10,285 feet.

10,290-10,292' - Core missing.

10,292-10,307' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods 5 to 10%, trace echinoids, Amphipora, ostracods, and Tentaculites. Large 3 to 4 cm brachiopod. Wackestone, minor mudstone, rare packstone. Echinoid-brachiopod facies. Sample SW 2 at 10,299 feet.

10,307-10,320' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Brachiopods (trace to 5%), trace echinoids, ostracods and Tentaculites. Mudstone. Micrite facies.

10,320-10,324' - Limestone, dark brown; 5 to 10% dolomite in matrix and chert replacing allochems. Echinoids 40 to 50%, trace brachiopods, ostracods and Tentaculites. Packstone and wackestone. Echinoid-brachiopod facies. Samples Sw 3 at 10,324 feet, SW 4 at 10,320 feet.

10,324-10,340' - Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids (trace to 5%), brachiopods

(trace to 5%), trace gastropods, ostracods and Tentaculites. Mudstone. Micrite facies.

10,340-10,344' - Nodular limestone, dark brown; trace chert, dolomite, shale and pyrite. Chert nodules. Trace echinoids, brachiopods, ostracods and Tentaculites. Mudstone. Micrite facies.

10,344-10,352' - Nodular limestone, dark brown; trace dolomite shale and pyrite. Brachiopods (5 to 10%), echinoids (trace to 5%), ostracods and Tentaculites. Wackestone and mudstone. Echinoid-brachiopod facies.

4-16-62-19 W5

10,400-10,412' - Nodular limestone, dark brown; trace shale and pyrite. Trace brachiopods, ostracods and Tentaculites. Mudstone. Micrite facies.

10,412-10,460' - Nodular limestone, dark brown; trace to 5% dolomite, trace shale and pyrite. Echinoids (trace to 2%), brachiopods (trace to 5%), trace ostracods, Tentaculites, rare braching stroms. and Amphipora. Mudstone. Micrite facies.

10,460-10,474' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Trace brachiopods, ostracods, Tentaculites and rare Amphipora. Mudstone and wackestone. Micrite facies.

10,474-10,484' - Limestone, dark brown; trace dolomite, shale and pyrite. Shale partings. Trace echinoids, brachiopods, ostracods and Tentaculites. Mudstone. Micrite facies.

10,484-10,486' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Trace brachiopods, ostracods and Tentaculites. Mudstone, packstone and grainstone. SV 1 at 10,485 feet.

10,486-10,490' - Limestone, dark brown; trace dolomite, shale and pyrite. Echinoids, brachiopods, gastropods, cephalopods, ostracods and Tentaculites, and carbon-replaced fossil fragments. Packstone and wackestone. Echinoid-brachiopod facies. Samples SV 2 at 10,489 feet, SV 3 at 10,489.5 feet.

10,490-10,494' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Trace echinoids, brachiopods, ostracods and Tentaculites. Mudstone and wackestone. Micrite facies.

10,494-10,500' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Echinoids trace to 5%, brachiopods trace to 5%, ostracods and Tentaculites. Laminae of packstone and grainstone with sparry calcite cement in mudstone. Minor carbon-replaced fossil fragments. Micrite facies.

10,500-10,504' - Nodular limestone, dark brown; dolomite trace to 5%, trace chert, shale and pyrite. Chert in allochem interior. Brachiopods 5 to 10%, echinoids 5%, trace Amphipora gastropods, ostracods and Tentaculites, and spines (echinoid or brachiopod). Peloids 5 to 20%. Packstone, wackestone and mudstone. Skeletal-peloid facies. Sample SV 4 at 10,502 feet.

10,504-10,507' - Laminated limestone, dark brown; trace dolomite shale and pyrite. Laminae with variations in organic and pyrite content. Brachiopods 5%, echinoids (trace) and trace ostracods, Tentaculites and spines. Mudstone and wackestone. Micrite facies.

10,507-10,520' - Nodular limestone, dark brown; trace dolomite shale and pyrite. Echinoids (trace to 15%), brachiopods 5%, trace gastropods, Amphipora, ostracods, and Tentaculites. Mudstone. Micrite facies.

10,520-10,530' - Nodular limestone, dark brown; trace dolomite shale and pyrite. Echinoids 5 to 10%, brachiopods 5%, trace gastropods, Amphipora, ostracods, and Tentaculites. Wackestone, minor mudstone. Echinoid-brachiopod facies. (Core missing from 10,522 to 10,526 feet).

10,530-10,532' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Echinoids 5%, brachiopods 5%, trace ostracods and Tentaculites. Mudstone and wackestone. Micrite facies.

10,532-10,577' Nodular limestone, dark brown; trace dolomite, shale and pyrite. Echinoids (trace to 5%), brachiopods (trace to 10%), trace ostracods, Tentaculites, and echinoid or brachiopod spines. Mudstone, minor wackestone. Micrite facies.

10,577-10,598' - Laminated limestone, dark brown; trace dolomite, shale and pyrite. Trace echinoids , gastropods, brachiopods, ostracods and Tentaculites. Mudstone and wackestone. Micrite facies.

Lost Core: remaining two feet recovered are: Limestone, dark brown, trace dolomite, shale and pyrite. Carbon-replaced fossil fragments. Packstone and wackestone. Sample SV 5 at 10,599 feet.

11-1-61-19 W5

10,490-10,524' - Shaly limestone, dark brown; pyrite accessory. Abundant shale partings. Rare large brachiopod (1.5 cm) and gastropod. Pyritized shells. Trace ostracods and Tentaculites. Mudstone. Micrite facies.

10,524-10,540' - Shaly limestone; dark brown. Pyrite accessory. Abundant shale partings. Brachiopods trace to 5%, trace ostracods and Tentaculites. Irregular lenses of fine skeletal debris rare. Mudstone. Micrite facies.

10,540-10,560' - Shaly limestone, dark brown. Pyrite accessory, abundant shale partings. Trace brachiopods, ostracods and Tentaculites throughout. Mudstone. Micrite facies.

10,560-10,578' - Nodular limestone, dark brown. Trace shale and pyrite. Nodular (boudinage) structure with horsetail stylolites. Traces of echinoids, brachiopods, ostracods and Tentaculites. Irregular concentrations of sparry calcite. Mudstone. Micrite facies.

10,578-10,580' - Nodular limestone, dark brown. Trace shale and pyrite. Echinoids 10%, trace brachiopods, ostracods and Tentaculites. Mudstone and wackestone. Echinoid-brachiopod facies.

10,580-10,616' - Nodular limestone, dark brown. Trace shale, pyrite and dolomite. Trace to 10% echinoids, gastropods and trace brachiopods, ostracods and Tentaculites. Mudstone, minor wackestone. Micrite facies.

10,616-10,620' - Nodular limestone, dark brown. Trace shale, dolomite and pyrite. Chert nodules 2 to 5%. Trace to 2%

echinoids, trace brachiopods, ostracods and Tentaculites. Mudstone. Micrite facies.

10,620-10,632' - Nodular limestone, dark brown. Trace shale, dolomite and pyrite. Echinoids trace to 2%, trace brachiopods, ostracods and Tentaculites. Mudstone. Micrite facies.

10,632-10,634' - Nodular limestone, dark brown. Trace shale, pyrite and dolomite. Chert nodules 2% Echinoids 2%, trace brachiopods, ostracods and Tentaculites. Mudstone. Micrite facies.

10,634-10,714' - Nodular limestone, dark brown. Trace shale, pyrite and dolomite. Trace echinoids, brachiopods, ostracods and Tentaculites. Mudstone. Micrite facies. (10,641 to 10,645 feet core missing.)

10,714-10,718' Nodular limestone, dark brown. Trace dolomite, pyrite and shale. Echinoids (trace to 5%), brachiopods (trace to 5%), trace gastropods, ostracods, Tentaculites, algal-coated Amphipora, corals. Interbedded wackestone and mudstone. Echinoid-brachiopod facies.

10,718-10,722' - Nodular limestone, dark brown. Trace pyrite, dolomite and shale. Echinoids 5 to 15%, brachiopods 10%, trace Amphipora, corals, ostracods and Tentaculites. Wackestone. Echinoid-brachiopod facies.

10,722-10,726' - Nodular limestone, dark brown. Trace pyrite, dolomite and shale. Echinoids 5%, brachiopods 5%, trace Amphipora, ostracods and Tentaculites. Mudstone. Micrite facies.

10,726-10,728' - Nodular limestone, dark brown. Trace pyrite, dolomite and shale. Echinoids 15%, brachiopods 5%, trace corals, ostracods and Tentaculites. Wackestone. Echinoid-brachiopod facies.

10,728-10,740'- Nodular limestone, dark brown. Trace pyrite, dolomite and shale. Trace echinoids (to 5%), brachiopods to 5%, trace ostracods and Tentaculites. Mudstone. Micrite facies.

10,740-10,745' - Laminated limestone, dark brown. Trace pyrite, dolomite and shale. Echinoids 5%, brachiopods 5 to 10%, trace ostracods and Tentaculites. Wackestone and mudstone. Micrite facies.

10,745-10,768' - Nodular limestone, dark brown. Trace pyrite, dolomite and shale and chert. Chert in Amphipora interior. Pyritized fossils. Echinoids trace to 5%, brachiopods trace to 5%, trace Amphipora, ostracods and Tentaculites. Mudstone. Micrite facies.

10,768-10,770' - Shaly limestone, dark brown. 5% dolomite (scattered). Echinoids, brachiopods, ostracods and Tentaculites in wackestone, minor packstone. Echinoid-brachiopod facies.

10,770-10,774' - Shaly limestone, dark brown. Shale partings, 5% dolomite, trace pyrite. Trace cephalopod. Echinoids, brachiopods, ostracods and Tentaculites in a packstone. Echinoid-brachiopod facies.

10,774-10,782' - Shaly limestone, dark brown. Shale partings, 5% dolomite, trace pyrite. Echinoids, brachiopods,

ostracods and Tentaculites in wackestone and packstone. Echinoid-brachiopod facies.

10,782-10,792' - Laminated limestone, dark brown. Trace pyrite, dolomite and shale. Trace echinoids, brachiopods, ostracods, Tentaculites, and Amphipora. Mudstone and wackestone. Micrite facies.

10,792-10,794' - Limestone, dark brown; 5% dolomite, trace pyrite and shale. Echinoids 10%, brachiopods 10%, ostracods and Tentaculites. Wackestone. Echinoid-brachiopod facies.

10,794-10,798' - Laminated limestone, dark brown. Dolomite 5 to 10%, trace pyrite and shale. Echinoids 25 to 30%, brachiopods 30%, trace Amphipora, ostracods and Tentaculites, foraminifera and bryozoa. Carbon replacement of rare allochems. Packstone and laminated mudstone. Micrite facies. Sample SU 1 at 10,794 feet.

10,798-10,810' - Dolomitic limestone and calcitic dolomite. Trace pyrite and shale. Stylolites. Dolomite in matrix and filling fractures. Echinoids 10 to 20%, brachiopods 5 to 10%, trace gastropods, Amphipora and algal-coated brachiopods. Large brachiopods. Cephalopod fragments 5 cm long. Wackestone. Echinoid-brachiopod facies.

10,810-10,834' - Dolomite, medium brown. Anhydrite trace to 5%, trace pyrite and shale. Stylolites in interval to 10,820 feet; shale partings 10,820 to 10,834 feet. Hemispherical (20%) and tabular (10%) stroms. in top two feet. Rare to 15% stroms. and Amphipora scattered throughout. Echinoids (trace to 5%), brachiopods (trace to 10%), trace

gastropods. Anhydrite and dolomite spar in former strom. sites. Fragmented stroms. Porosity averages good, intercrystalline. Rare intraparticle (strom), vuggy, and moldic (Amphipora or branching strom) porosity. Rudstone at top of interval. Floatstone and possible wackestone (matrix indistinct). Hemispherical stromatoporoid facies.

10,834-10,845' - Dolomite, medium brown. Trace shale, anhydrite and pyrite. Shale partings. Trace echinoids, brachiopods, gastropods, cephalopods. Mudstone. Micrite facies.

10,845-10,850' - Dolomite, medium brown. Trace anhydrite, pyrite and shale. Stylolites. Fragmented and overturned hemispherical (2 to 5%), bulbous (2%), and tabular stroms. (trace to 2%), partly filled with white dolomite spar, to 10%. Brachiopods 5%, trace Amphipora, echinoids, and gastropods. Floatstone, probably mudstone to wackestone matrix. Hemispherical stromatoporoid facies.

10,850-10,858' - Dolomite, medium brown. Trace anhydrite, shale and pyrite. Stylolites. Tabular stroms (trace to 20%), and bulbous stroms 5 to 10%, and 5 to 15% brachiopods. Trace to 2% gastropods and trace Amphipora. Floatstone, minor rudstone with mudstone matrix. Sample SU 2 at 10,857.5 feet.

10,858-10,860' - Dolomite, medium brown. Trace anhydrite, shale and pyrite. Stylolites. Bulbous stroms. 30%, trace tabular stroms. and Amphipora. Brachiopods 5%, trace echinoids and gastropods. Sparry calcite and dolomite in

vuggy Floatstone with mudstone matrix. Bulbous stromatoporoid facies.

10,860-10,871' - Dolomite, medium brown. Trace anhydrite, shale and pyrite. Stylolites Tabular (15 to 25%), branching (trace) and bulbous (trace-10%) stroms., trace Amphipora, trace to 2% echinoids, and trace to 5% brachiopods. Floatstone and rudstone with mudstone matrix. Tabular stromatoporoid facies.

10-3-60-18 W5

10,300-10,318' - Limestone, dark brown; trace dolomite and pyrite. Amphipora (trace to 10%), irregular, hemispherical, and branching stroms in trace amounts. Echinoids 5-15% and trace barchiopods and gastropods. Shale partings and rare stylolites. Wackestones and mudstone. Echinoid-brachiopod facies.

(10,306 to 10,308 ft core missing.)

10,318-10,324' - Limestone, dark brown; dolomite at 10,323 ft. Trace pyrite. Echinoids 10%, trace to 5% brachiopods, trace gastropods. Shale partings. Mudstone and wackestone. Micrite facies.

10,324-10,339' - Dolomite, dark brown; trace anhydrite, pyrite. Anhydrite in vug. Echinoids trace to 5%, trace brachiopods and gastropods. Intercrystalline porosity poor. Mudstone. Micrite facies.

10,339-10,356' - Dolomite, dark brown; trace pyrite. Laminated zone at bottom of interval. Depauperate Amphipora 5 to

15%, trace branching and hemispherical stroms, trace to 5% echinoids and brachiopods, trace gastropods. Wackestone. Echinoid-brachiopod facies.

10,356-10,376' - Dolomite, dark brown; trace pyrite. Trace Amphipora and hemispherical stroms. Vugs originate from leached Amphipora and branching stroms. Matrix undeterminable. Porosity good intercrystalline and moldic, vugs to 5%. Floatstone. Amphipora facies.

10,376-10,386' - Dolomite, medium brown; trace pyrite. Amphipora 25 to 35%, trace-2% bulbous stroms. Sparry dolomite. Moldic porosity very good. Rudstone and floatstone, undertermined matrix. Amphipora facies. Sample ST 1 at 10,379'.

10,386-10,400' - Dolomite, medium brown; trace pyrite. Amphipora 10 to 15%, trace hemispherical stroms. Interbedded tight and (moldic) porous intervals. Sparry dolomite 'cement' in Amphipora beds. Moldic porosity good. Interbedded floatstone, wackestone and mudstone. Amphipora facies.

10,400-10,410' - Dolomite, medium brown; trace pyrite. Hemispherical (trace to 10%) and branching (trace to 15%) stroms. Amphipora 10%. Floatstone with undetermined matrix. Open shelf facies.

10,410-10,413' - Dolomite, light brown, trace pyrite. Euryamphipora 5 to 20%, hemispherical stroms. (trace to 10%), branching stroms. (trace to 15%) and tabular stroms. (trace to 5%). Trace Amphipora. Coarse dolomite spar in vugs. Floatstone with undetermined matrix. Euryamphipora facies.

6-6-59-17 W5

11,200-11,205.5' - Limestone, dark brown. Scattered branching stroms., echinoids, algal rimmed rugose corals (trace to 5%). Abundant shale partings, horizontal stylolites Mudstone. Micrite facies. Sample SA 1 at 11,205.5 ft.

11,205.5-11,209.5' - Limestone, dark brown. Echinoid and bryozoan fragments. White sparry calcite cement and intergranular pryrite. Where grains are least abundant, stylolites are present. Skeletal allochems 50 to 70%. Grainstone and packstone. Echinoid-brachiopod facies. Sample SA 2 at 11,209 ft.

11,209.5'-11,259' - Limestone, dark brown. Rare echinoid fragments; three ft interval of up to 10% echinoid fragments. Gastropods to 1%. Abundant shale partings, stylolites and locally, boudinage structure. Mudstone. Micrite facies.

11,260-11,286' - Limestone, dark brown. Brachiopods (filled with dolomite spar) up to 1.5 cm. Rare large gastropods. Chert lenses and clasts, laminated with calcite. Mudstone, minor grainstone. Micrite facies. Samples SA 3 at 11,260.5 ft , SA 4 at 11,265 ft , SA 5 at 11,271 ft , SA 6 at 11,281 ft.

11,286-11,290' - Limstone, dark brown; one low amplitude, 30 cm long vertical stylolite. Brachiopod, branching strom. and unidentified fragments. Mudstone. Micrite facies.

11,290-11,293' - Limestone, dark brown. Laminated. Stylolitic contact with underlying unit. Mudstone. Micrite

facies. Samples SA 7 at 11,292 ft , SA 8 at 11,292.5 ft.

11,293-11,307' - Limestone, dark brown. Laminated intervals from 11,293.5 to 11,294.5 ft., 11,302 to 11,304 ft. Amphipora (trace to 5%), echinoids (trace to 10%), trace brachiopods (filled with white sparry dolomite.) Vertical fracture filled with calcite cutting Amphipora fragments. Skeletal-peloid grainstone for top 0.5 ft. Wackestone and mudstone Samples SA 9 at 11,293 ft., SA 10 at 11,293.3 ft., SA 11 at 293.5 ft. and SA 12 at 11,301.5 ft.

11,307-11,320' - Limestone, dark to medium brown. Amphipora and Euryamphipora (trace to 10%), encrusting stroms. (trace to 5%), brachiopods (less than 5%) with internal geopetal fabric. Algal coatings on nuclei of brachiopods or Amphipora, up to 2 cm in diameter. Trace echinoids and gastropods. Floatstones with mudstone matrix. Amphipora facies. Sample SA 13 at 11,313 ft.

11,320-11,332' - Limestone, dark brown. Bulbous stroms. (up to 3 cm) 5%, trace to 2% branching stroms., trace to 2% Amphipora. Strom. fragments encrusted with algae. Mudstone, minor floatstone. Bulbous stromatoporoid facies. Samples SA 14 at 11,324 ft., SA 15 at 11,327.5 ft. (11,332-11,334' Missing).

11,334-11,343.5' - Limestone, dark brown. Mottled from 11,338 to 11,344 ft. Amphipora (trace to 20%), bulbous stroms. (trace to 5%); trace brachiopods and gastropods (filled with pellets). Rudstone has largest stroms. (>4 cm), and white sparry calcite in matrix. Stylolites common. Floatstone with mudstone matrix and rudstone with packstone matrix.

Amphipora facies. SA 16 at 11,339 ft. (11,345.5-11,346' Missing)

11,346-11,352' - Limestone, dark to medium brown. Bulbous stroms. 5 to 35%. Fragmented stroms. Large vugs filled with anhydrite. Rudstone and floatstone. Bulbous stromatoporoid facies.

11,352-11,367' - Limestone, dark to medium brown. Bulbous (trace to 5%), tabular (trace to 55%), and fragmented stroms. Rare hemispherical stroms. with base larger than core diameter. Dolomite in matrix. Stroms. in stylolitic contact. Matrix contains rare Amphipora, trace to 15% brachiopods with geopetal internal fabric, and 5% echinoid debris. Large masses of anhydrite, grains of pyrite and anhydrite and dolomite occur in fractures in stroms. and solution? voids. Samples SA 17 at 11,353 ft , SA 18 at 11,355.5 ft , SA 19 at 11,359.3 ft , SA 20 at 11,359.5 ft , and SA 21 at 11,363.5 ft. Floatstone, rudstone, wackestone and mudstone matrix. Tabular stromatoporoid facies.

11,367-11,375' - Limestone, dark brown. Trace to 5% brachiopod fragments, 5% echinoid fragments. Rare large gastropod and brachiopod with coarse calcite spar shells. Pyrite concentrations in the matrix. Stylolites and shale partings. Wackestone. Echinoid-brachiopod facies. Sample SA 22 at 11,374 ft.

11,375-11,382.5' - Limestone, dark brown. Trace to 5% gastrpods, trace brachiopods, trace to 30% echinoid fragments. Coarse dolomite spar, pyrite in seams and matrix, 2-3%. Pyrite replaced

shells. Stylolites. Oolite grainstone 11,380-11,382.5 ft. Mudstone to wackestone. Echinoid-brachiopod and oolite facies. Sample SA 23 at 11,382.4 ft.

11,382.5-11,386' - Watt Mt.: Shale and laminated dolomite.

6-33-62-20 W5

10,408-10,456' - Limestone, dark brown. Nodular mudstone with trace echinoid and brachiopod skeletal fragments. Pyrite throughout. Mudstone and wackestone. Micrite facies.

10,456-10,458' - Limestone, dark brown. Laminated. Mudstone. Micrite facies.

10,458-10,468' - Dolomite, dark brown. Echinoid, brachiopod, and gastropod fragments. Wackestone and packstone. Echinoid-brachiopod facies.

10,468-10,478' - Dolomite, light brown. Green shale at top of interval. Hemispherical (5 to 10%) and branching (30 to 45%) stromatoporoids. Isopachous cements. Moldic and vuggy porosity poor to good. Rudstone and floatstone, possible grainstone matrix. Branching stromatoporoid facies. Samples SM 1 at 10,469.5 ft , SM 2 at 10,471 ft , and SM 3 at 10,472 ft.

10,478-10,484' - Dolomite, medium brown. Dolomite spar partly fills small vugs. Peloids. Grainstone or mudstone? Possibly skeletal-peloid facies.

10,484-10,508' - Dolomite, medium brown. Anhydrite in vugs. Amphipora 10 to 25%. Porosity good to poor, moldic, vuggy and intercrystalline. Floatstone, interbedded possible

grainstone. Amphipora facies. Sample SM 4 at 10,485 ft.

2-18-62-18 W5

10,060-10,072' - Limestone, light brown; 30% dolomite in matrix. Hemispherical 5 to 15%, encrusting 2 to 10%, and branching 10 to 20% stroms. Amphipora (trace to 5%), rugose corals (trace to 5%), and brachiopods (trace to 5%). Encrusting stroms on corals. Floatstone and rudstone with grainstone and packstone matrix. Minor porosity. Branching stromatoporoid facies.

10,072-10,074' - Limestone, light brown. Fine grainstone. 10% dolomite interparticle. Porosity poor. Skeletal- peloid facies.

10,074-10,080' - Limestone, dark brown; dolomite 15% in matrix. Branching stroms. (trace to 30%), Amphipora 10 to 30%, and trace to 5% brachiopods. Possible pellets. Interbedded rudstone and floatstone with mudstone. Branching stromatoporoid facies.

10,080-10,086' - Limestone, dark brown; 10 to 15% dolomite in matrix. Branching stroms. 20%, and Amphipora 15%. Trace brachiopods. Oncolite and algal-coated allochems. Floatstone with wackestone matrix. Branching stromatoporoid facies.

10,086-10,096' - Limestone, dark brown; dolomite less than 10% in matrix. Irregular (trace) and branching (5%) stromatoporoids, Amphipora 5 to 20%, and trace brachiopods. Micritized grains, algal-coated allochems. Floatstone with grainstone and packstone matrix. Amphipora facies.

10,096-10,100' - Limestone, dark brown. Irregular (5%), and branching (10%) stroms., Amphipora 10%, trace brachiopods and gastropods. Algal-coated allochems. Floatstone with wackestone matirx. Branching stromatoporoid facies.

10,100-10,102' - Limestone, dark brown. Branching stroms 5%, Amphipora 10%, brachiopods (trace). Algal-coated allochems. Grainstone and floatstone with grainstone matrix. Skeletal-peloid facies.

10,102-10,110' - Limestone, dark to medium brown. Green shale at top of interval, pyrite throughout. Amphipora 15% and trace branching stroms and brachiopods. Calcite cement. Algal boundstone 10,102 to 10,104 ft. Floatstone with packstone and wackestone matrix. Amphipora and algal facies.

10,110-10,114' - Limestone, dark brown. Amphipora 55 to 60%. Rudstone with wackestone to mudstone matrix. Amphipora facies.

10,114-10,118' - Limestone, dark brown; dolomite less than 10%. Branching stroms 15 to 20%, Amphipora 10%. Trace hemispherical stroms. and brachiopods. Floatstone. Branching stromatoporoid facies.

10,118-10,126' - Limestone, dark brown; dolomite trace to 10%. Amphipora 10 to 15%, branching stroms 10%. Trace brachiopods. Floatstone. Amphipora facies.

10,126-10,130' - Limestone, dark brown; trace to 10% dolomite. Branching stroms 25%, Amphipora 10%, trace hemispherical stroms., trace corals and brachiopods. Floatstone, minor

rudstone, with wackestone and mudstone matrix. Branching stromatoporoid facies.

10,130-10,140' - Limestone, dark brown. Irregular (trace to 10%) stroms., branching stroms. (10 to 30%), Amphipora (5 to 10%), and trace brachiopods and gastropods. Oncolites at top of interval. Algal-coated allochems. Calcite cement. White dolomite spar. Floatstone with wackestone to grainstone matrix. Branching stromatoporoid facies.

10,140-10,148 - Limestone, medium brown; dolomite less than 10%. Irregular (5%) and branching (trace to 30%) stroms, 10% Amphipora, and trace brachiopods and gastropods. Algal-coated allochems. Algal boundstone 10,140 to 10,142 ft. Floatstone and minor rudstone, with grainstone to wackestone matrix. Algal and branching stromatoporoid facies.

10,148-10,152' - Limestone, medium brown. Amphipora 15%, trace branching stroms, brachiopods, and gastropods. Algal-coated allochems. Grainstone, minor floatstone with grainstone matrix. Amphipora facies.

10,152-10,171' - Limestone, medium brown. Hemispherical and irregular stroms (trace to 5%), branching stroms. 5 to 15%, Amphipora (trace to 25%), and trace brachiopods and gastropods (Missing core 10,162-10,166 ft.) Bored stroms, geopetal and dolomite internal fabrics. Rudstone and floatstone with wackestone matrix. Branching stromatoporoid facies. Sample SQ 1 at 10,152.5 ft.

10,171-10,178' - Limestone, light brown. Green shale at top

of interval and stringers throughout. Pyrite throughout. Mottled dolomitic limestone, originally rudstone with packstone matrix beneath shale. Branching (trace to 15%), encrusting stroms. (trace), Amphipora (trace to 15%), trace to 5% rugose corals, trace brachiopods and gastropods. Peloidal packstones 10,174-10,176 ft. Rudstone interbedded with grainstones. Branching stromatoporoid facies. Samples SQ 2 at 10,173 ft , SQ 3 at 10,175 ft , SQ 4 at 10,177 ft.

10,178-10,191' - Limestone, light brown. Trace hemispherical and branching stroms. and brachiopods. Micritized grains. Abundant stylolites. Irregular discoloured patches (burrows). Grainstone. Skeletal-peloid facies.

10,191-10,194' - Limestone, light to dark brown. Trace branching stroms., Amphipora 5%, trace echinoids, 10% brachiopods. Interbedded grainstone and wackestone. Skeletal peloid facies.

10,194-10,200' - Limestone, light brown. Trace branching stroms, Amphipora, and brachiopods (some algal-coated), and peloids. Grainstone. Skeletal-peloid facies.

10,200-10,206' - Limestone, light brown. Trace branching stroms. Amphipora, and brachiopods, peloids. Grainstone and packstone. Skeletal-peloid facies.

10,206-10,218 - Limestone, dark and medium brown. Trace branching stroms., Amphipora and brachiopods. Interbedded grainstones, packstones and wackestones. Skeletal-peloid facies.

10,218-10,222' - Limestone, dark to medium brown. Trace encrusting and branching stroms., trace brachiopods, 5 to 10% Amphipora. Coarse floatstone debris beds (with algal-coated stroms.). Grainstones. Skeletal-peloid facies.

10,222-10,230' - Limestone, medium to dark brown. Trace encrusting and branching stroms., trace brachiopods, trace to 10% Amphipora, trace to 10% gastropods. Trace algae-encrusted stroms. Packstone and wackestone interbedded, minor grainstone. Skeletal-peloid facies.

10,230-10,234' - Limestone, medium and dark brown. Trace Amphipora, brachiopods, and gastropods. Mudstone, minor wackestone. Micrite facies.

10,234-10,244' - Limestone, dark brown. Chert nodules and lenses with calcite. Some fossils replaced by pyrite and silica. Trace brachiopods, gastropods, echinoids and Tentaculites. Mudstone, wackestone, minor packstone from 10,242 to 10,244 ft. Micrite and skeletal-peloid facies. Sample SQ 5 at 10,243.5 ft.

10,244-10,274' - Limestone, dark brown. Chert nodules and lenses and irregularly disseminated in matrix. Echinoids (trace to 5%), and trace brachiopods and gastropods. Echinoids to 3 mm partly replaced by silica. Chert concentrated in skeletal beds. Mudstone and wackestone. Micrite facies. Sample SQ 6 at 10,259 ft.

10,274-10,286' - Limestone, dark brown. Trace brachiopods. Stylolites. Dolomite (trace). Wackestone and mudstone.

Echinoid-brachiopod facies. (Core missing 10,276 to 10,278 ft.)

10,286-10,290' - Limestone, dark brown. Brachiopods 10%, trace echinoids, gastropods, and Amphipora. Trace dolomite. Wackestone and mudstone. Echinoid-brachiopod facies.

10,290-10,300' - Limestone, dark brown. Trace dolomite. Trace brachiopods and gastropods. Mudstone. Micrite facies.

10,300-10,326' - Limestone, dark brown. Brachiopods (trace to 15%), trace gastropods, Amphipora, and branching stroms. Spines. Mudstone, minor wackestone. Micrite facies.

10,326-10,346' - Limestone, dark brown. Trace dolomite. Brachiopods 5 to 10%, trace echinoids and gastropods. Amphipora trace to 5%. Peloids and algal-coated Amphipora in upper 8 ft of interval. Wackestone, minor peloidal packstone and mudstone. Skeletal-peloid and echinoid-brachiopod facies.

10,346-10,370' - Limestone, dark brown. Trace dolomite. Brachiopods 10 to 20%, echinoids 2 to 15%, gastropods trace to 5%, trace Amphipora and branching stroms. Spines. Wackestone, minor mudstone. Echinoid-brachiopod facies.

10,370-10,406' - Limestone, dark brown. Trace dolomite. Brachiopods (trace to 15%), echinoids (trace to 10%), trace gastropods, Amphipora, and branching stroms. Trace algae-coated lithoclast. 3 to 4 cm brachiopods with geopetal internal fabric. Dolomite scattered in matrix and intraparticle pores. Wackestone and mudstone. Echinoid-brachiopod facies.

10,406-10,424' - Limestone, dark brown. Trace dolomite, trace anhydrite at 10,420 ft. Brachiopods 10 to 20%, echinoids (trace to 20%), gastropods 5 to 10%, and trace Amphipora. Peloids 50 to 70%. Dolomite interparticle. Peloidal packstone and wackestone, minor grainstone. Skeletal-peloid facies.

10,424-10,430' - Limestone, dark brown. Trace dolomite. Brachiopods 10%, gastropods 10%, oolites (0.25 mm. average diameter) 10 to 25%, peloids 50 to 70%. Sparry calcite cement in oolite beds. Peloidal packstone and grainstone with oolite grainstone interbeds. Sample SQ 7 at 10,425 ft.

10,430-10,434' - Limetone, dark brown. Dolomite 5%. Tabular (5%), irregular (5%) and encrusting (5%) stroms. Trace Amphipora. Brachiopods 10 to 15%, trace echinoids and gastropods. Algal-strom. consortia fragments. Floatstone with wackestone matrix. Tabular stromatoporoid facies.

10,434-10,442' - Limestone, dark brown; dolomite 5%, trace anhydrite at 10,438 ft , gypsum at 10,436 ft. Irregular and encrusting strom. (trace to 10%) and trace Amphipora. Brachiopods 10 to 15%, trace to 5% gastropods, trace echinoids. Gypsum in sparry calcite line vug. Peloids 20% and trace intraclasts. Floatstone and wackestone, minor grainstone. Echinoid brachiopod facies. Sample SQ 8 at 10,439 ft.

10,442-10,448' - Limestone, dark brown; dolomite 5%. Irregular and encrusting stroms. (trace to 10%) and trace Amphipora. Brachiopods 5 to 15%, gastropods (trace to 5%), and

trace echinoids. Trace to 85% peloids. Minor grain aggregates. Packstone, minor floatstone and wackestone. Skeletal-peloid facies.

10,448-10,452' - Limestone, dark brown; dolomite 5%. Trace anhydrite. Irregular and encrusting strom. (trace to 10%). Brachiopods 5 to 10%, 5% gastropods. Wackestone. Echinoid-brachiopod facies.

10,452-10,458' - Limestone, dark brown; dolomite 5%. Trace anhydrite. Brachiopods 5 to 10%, gastropods 5%, trace echinoids and irregular stroms. Algal-coated gastropods. Rare cephalopod. Peloids 25 to 30%. Packstone and wackestone. Skeletal-peloid facies. Samples SQ 9 at 10,455 ft.

2-18-63-18 W5

9,712-9,727' - Limestone, dark brown. Hemispherical (rare), irregular (5 to 15%), encrusting (trace to 5%) and branching (5 to 10%) stromatoporoids and trace to 30% Amphipora. Brachiopods and gastropods in trace amounts. Oncolites and algal-coated allochems. Overturned and fragmented stroms. Amphipora canals filled with calcite or dolomite spar. Also irregular blebs of dolomite spar in matrix. Trace dolomite disseminated in matrix. Rudstone and floatstone with grainstone matrix. Branching stromatoporoid facies.

9,727-9,733' - Limestone, dark to medium brown. Branching stroms. (trace to 20%), Amphipora (trace to 5%), and trace brachiopods and gastropods. Irregular blebs of dolomite in grainstone. Floatstone, minor rudstone with grainstone mat-

rix. Branching stromatoporoid facies.

9,733-9,751' - Limestone, dark to medium brown. Hemispherical (trace), irregular (trace to 5%) and branching (trace to 15%) stroms. and 10 to 35% Amphipora. Trace brachiopods and gastropods. Algal-coated allochems and small oncolites. Grains commonly micritized. Gastropods to 1.5 cm in size. Floatstone, minor rudstone, with grainstone matrix. Amphipora facies.

9,751-9,757' - Limestone, dark brown. Hemispherical (trace) and branching (trace to 10%) stroms. Amphipora 40 to 45%. Trace brachiopods and gastropods. Amphipora canals empty or filled with white dolomite spar. Floatstone, minor rudstone, with gainstone matrix. Amphipora facies. Sample SN 1 at 9,755.5 ft.

9,757-9,763' - Limestone, dark brown. Branching stroms 10%, and Amphipora 10 to 20%. Trace encrusting strom. on branching stroms. Algal boundstone for one foot at top and bottom of interval. Mudstone with birdseye calcite. Strom. floatstone with mudstone matrix. Amphipora facies. Sample SN 2 at 9,758 ft.

9,763-9,773' - Limestone, light brown. Branching stroms. (trace to 5%) and Amphipora 5 to 10%. Trace rugose corals. Trace intercrystalline porosity and bitumen stain on crystal faces in recrystallized mudstone. Coarse calcite spar in fenestral pores and as rounded and irregular blebs. Algal mudstone from 9,765 to 9,767 ft. Mudstone and floatstone with

mudstone matrix. Algal and Amphipora facies.

9,773-9,788' - Limestone, light brown. Green shale and pyrite at top of interval. Amphipora 10 to 25%. Algal boundstone, laminated, with birdseye calcite. Geopetal silt with ostracods. Fractures lined with bituminous residue. Algal mudstone inter-bedded to 9,782 ft , and floatstone and rudstone with mudstone matrix. Algal and Amphipora facies. Samples SN 3 at 9,744 ft , SN 4 at 9,777 ft.

9,788-9,800' - Limestone, light brown. Amphipora 5 to 15%. Micrite surface at 9,797 ft. Peloid grainstone and packstone over Amphipora floatstone. Skeletal-peloid facies. Sample SN 5 at 9,797 ft. (5a:above micrite surface, 5b: below.)

9,800-9,821' - Limestone, light brown. Branching stroms. (trace) and Amphipora 5 to 20%. Calcispheres and fenestral (birdseye) calcite in irregular blebs. Intraparticle (Amphipora) and intercrystalline porosity poor to good. Microstalactitic and isopachous calcite cement in fenestral pores. Wackestone and floatstone with wackestone matrix. Algal boundstone from 9,805 to 9,807 ft. Algal and Amphipora facies. Samples SN 6 at 9,804 ft and SN 7 at 9,815 ft.

9,821-9,823' - Limestone, light brown. Calcispheres in finely laminated mudstone. Algal boundstone.

9,823-9,831' - Limestone, light brown. Amphipora (trace to 20%). Dolomite scattered through matrix, filling Amphipora canals and vesicles. Geopetal silt, stalactitic cement (cal-

cite). Amphipora floatstone with grainstone and wackestone matrix, and grainstone (9,823-9,824 ft.). Amphipora and skeletal-peloid facies.

9,831-9,841' - Limestone, light to dark brown. Dolomite crystals in matrix. Hemispherical (trace to 5%) and branching (trace) stroms. Trace to 15% Amphipora, trace corals and brachiopods. Micrite coated grains. Dolomite fills Amphipora canals and vesicles. Geopetal fabrics and stalactitic cements. Floatstone, matrix from wackestone to grainstone. Amphipora facies. Sample SN 8 at 9,836 ft.

9,841-9,857' - Limestone, light brown. Amphipora 20 to 35%. Algal-coated allochems. Birdseye fabric. Dolomite in matrix. Floatstone with packstone to mudstone matrix. Algal boundstone interbedded 9,843 to 9,848 ft. Sample SN 9 at 9,842 ft. Algal and Amphipora facies. (Core missing 9,848 to 9,850 ft.)

9,857-9,870' - Limestone, light to medium brown. Amphipora 20 to 40%. Algal boundstone, laminated grainstone, from 9,857 to 9,879 ft. Stalactitic and isopachous calcite cements in fenestral and interparticle pores. Amphipora rudstone to to floatstone with grainstone to mudstone matrix. Algal and Amphipora facies. Samples SN 10 at 9,857 ft , and SN 11 at 9,859 ft.

9,870 to 9,891' - Limestone, light to dark brown. Green shale at top of interval. One 35 cm massive strom., trace branching stroms., 20 to 35% Amphipora and ostracods 5%. Amphipora float in light coloured ostracod-rich silt in bur-

rowed mud. Isopachous calcite cement in largest pores and calcite in fractures. Dolomite in Amphipora canals. Floatstone, minor rudstone, packstone and minor wackestone matrix. Amphipora facies. Samples SN 12 at 9,870 ft., SN 13 at 9,872.5 ft. (Missing core 9,885-9,870 ft.)

9,891-9,901' - Limestone, medium to dark brown. Dolomite in matrix. Branching stroms. (trace to 20%) Amphipora (1 to 2 mm smaller) 15-25%, gastropods 5%, and trace brachiopods. Rudstone, grainstone matrix. Branching stromatoporoid facies.

9,901-9,919' Limestone, light to dark brown. Dolomite in matrix. Amphipora 20 to 25% (5% in bottom 6 ft), trace brachiopods, gastropods, ostracods and calcispheres. Calcite and dolomite spar in Amphipora canals and vesicles. Calcite spar, stalactitic cement and silt in fenestral pores for bottom 6 ft. Floatstone, minor rudstone, with wackestone to packstone matrix. Amphipora facies. Samples SN 15 at 9,903 ft and SN 16 at 9,918 ft.

9,919-9,933' - Limestone, light brown. Green shale at top of interval, and green shale stringers below. Trace encrusting and trace to 5% branching stroms. Amphipora 5 to 30%, trace brachiopods and gastropods. Isopachous white calcite spar, dolomite, and silt in fenestral pores. Burrows filled with lighter coloured sediment. Algal boundstone interbedded to 9,929 ft. Floatstone with fine packstone to wackestone matrix. Algal and Amphipora facies. Sample SN 17 at 9,928 ft.

9,933-9,945' - Dolomitic limestone and calcite dolomite; light brown. Amphipora (trace to 35%), trace brachiopods and gastropods. Dolomite in matrix. Rare intraparticle Amphipora porosity. Other intraparticle Amphipora pores filled with calcite matrix. Amphipora facies. Samples SN 18 at 9,939, SN 19 at 9,941 ft.

9,945-9,963' - Dolomitic limestone, minor calcitic dolomite; light brown. Amphipora 10 to 20%, encrusting stroms. (trace to 10%), trace branching stroms., and trace brachiopods and gastropods. Trace oncolites. Geopetal fabric in stromatactis cavity. Birdseye fabric. Algal boundstone from 9,947 to 9,951 ft. Amphipora floatstone with fine grainstone to mudstone matrix. Amphipora and algal facies.

9,963-9,967' - Limestone, dark brown. Amphipora 20 to 25%, trace brachiopods and gastropods. Algal-coated depauperate Amphipora. Interbedded Amphipora packstone and peloidal grainstone. Amphipora facies.

9,967-9,973' - Limestone, dark to light brown. Amphipora (3 to 5 mm) 25 to 40%. Trace brachiopods. Amphipora canals filled with calcite spar. Amphipora floatstone and rudstone with mudstone matrix. Amphipora facies.

9,973-9,983' - Limestone and dolomitic limestone; dark brown. Amphipora (trace to 10%). Fenestral fabric. Dolomite along algal layers. Algal boundstone (grainstone). Algal facies.

9,983-9,996' - Limestone and dolomitic limestone. Trace to 10% hemispherical, irregular, encrusting and branching stroms. Trace to 45% Euryamphipora, trace to 10% Amphipora. Trace to 10% brachiopods, trace to 5% gastropods, and trace calcispheres. Fragmented stroms. Dolomite and calcite along axial canals of Amphipora and Euryamphipora and in matrix. Pellets. Amphipora diameter 1 mm. Rudstone and floatstone with mudstone matrix, Euryamphipora boundstone, minor wackestone and packstone matrix. Euryamphipora facies. Samples SN 20 at 9,988.5 ft , and SN 21 at 9,994 ft. (Core missing 9,986 to 9,988 ft.)

9,996-10,012' - Limestone, dark brown. Trace to 10% Amphipora. Oncolites common (with Amphipora nuclei). Mudstone, wackestone. Micrite facies.

10,012-10,019 - Limestone, light brown. Hemispherical stroms. and strom. fragments trace to 30%. Amphipora and Euryamphipora 10%. Coarse dolomite spar in strom. void. Rudstone. Hemispherical stromatoporoid facies.

10,019-10,023' - Limestone, dark brown. Brachiopods, gastropods and Tentaculites. Wackestone. Echinoid-brachiopod facies.

10,023-10,033' - Limestone, dark brown. Trace irregular stroms., strom./algae consortium 5%, trace Amphipora, brachiopods, and gastropods. Interbedded wackestone and mudstone. Echinoid-brachiopod facies.

10,033-10,038' - Limestone, dark brown. Trace Amphipora,

10% brachiopods, 5% gastropods, 60% unidentified fine skeletal grains (largely echinoid spines, calcispheres, peloids). Interbedded grainstone to packstone and wackestone. Skeletal peloid facies. Sample SN 22 at 10,036.5 ft.

6-23-63-18 W5

9,546-9,557' - Dolomitic limestone, medium brown. Hemispherical (trace to 2%), irregular (5 to 15%), encrusting (trace to 5%), and branching (5 to 15%) stroms., trace to 5% brachiopods and trace gastropods. Dolomite in matrix. Algal-coated allochems and strom/algae consortium. Dolomite in matrix. Interparticle and intraparticle porosity poor. Floatstone with packstone and grainstone matrix. Tabular stromatoporoid facies.

9,557-9,576' - Dolomitic limestone, medium to dark brown. Hemispherical (trace to 5%), irregular (5 to 10%), encrusting (trace to 10%), and branching (trace to 25%) stroms., Amphipora (trace to 35%), brachiopods and gastropods (trace to 5%). Algal-coated allochems. Algal/strom. consortium. Bored stroms. with geopetal fabric in cavities. Spar cements, isopachous cements. Floatstone, minor rudstone, with grainstone matrix. Porosity poor. Tabular stromatoporoid facies. Samples SP 1 at 9,558.5 ft , SP 2 at 9,572 ft.

9,576-9,590' - Limestone, light brown. Green shale at top of interval, stringers for 10 feet. Dolomite in channels. Amphipora 5 to 15%; trace brachiopods and gastropods. Algal-coated allochems. Fenestral porosity plugged with calcite

spar. Large stylolites (low amplitude). Algal boundstone (grainstone) from 9,576 to 9,578 ft and 9,582 to 9,586 ft. Floatstone with grainstone matrix. Amphipora facies.

9,590-9,596' - Limestone, light brown. Trace hemispherical stroms., Amphipora 10 to 15%; trace brachiopods and gastropods. Stylolites. Bored stroms. Amphipora floatstone with grainstone matrix. Amphipora facies.

9,596-9,607' - Limestone, light brown. Green shale at top of interval, stringers for 4 feet. Amphipora 20 to 35%, branching stroms. (trace to 5%), and trace brachiopods. Floatstone and rudstone with grainstone and packstone matrix. Amphipora facies.

9,607-9,614' - Limestone, light to medium brown. Branching stroms. (5 to 15%), Amphipora (20 to 35%), algal-coated allochems. Calcispheres in laminated algal boundstone. Stalactitic and dolomite 'cement' zone. Algal boundstone from 9,610 to 9,611 ft. (mudstone). Floatstone and rudstone with packstone and grainstone matrix. Algal and Amphipora facies. Sample SP 3 at 9,612.5 ft.

9,614-9,624' - Limestone, medium brown. Amphipora 10 to 15%. Irregular and branching stroms. less than 5%. Trace vertical fractures, geopetal fabrics. Moldic and intraparticle (gastropod and Amphipora) porosity begins at bottom of interval. Algal boundstone from 9,168 to 9,620 ft. Floatstone with wackestone and packstone matrix. Samples SP 4 at 9,617 ft , SP 5 at 9,623.5 ft.

9,624-9,632' - Limestone, medium brown. Dolomite in matrix. Trace vertical fractures. Intraparticle (Amphipora), intercrystalline and minor moldic porosity is poor to good. Amphipora 15 to 20%. Floatstone with packstone and wackestone matrix. Amphipora facies.

9,632-9,640' - Limestone, medium brown. Dolomite less than 10%. Amphipora 30 to 40%. Intraparticle and fracture porosity good. Floatstone with mudstone and wackestone matrix. Amphipora facies.

9,640-9,650' - Limestone, medium brown. Hemispherical and branching stroms. (trace to 5%), Amphipora 25 to 35%. Vertical fractures. Dolomite in Amphipora canals but not vesicles. Floatstone and rudstone with packstone matrix. Intraparticle porostity poor to good. Amphipora facies. Sample SP 6 at 9,647.5 ft.

9,650-9,658' - Limestone, medium brown. Amphipora 20 to 35%. Hemispherical stroms. to 20% in one 2 foot interval. Strom. fragments 10%. Intraparticle porosity poor to good. Dolomite trace to 5%. Floatstone and rudstone with packstone and grainstone matrix. Amphipora facies.

9,658-9,670' - Limestone, dark to medium brown. Dolomite in canals and vesicles of Amphipora. Amphipora 25 to 35%. Floatstone, minor rudstone, with mudstone matrix. Amphipora facies. (Missing core, 9,664 to 9,667 ft.)

9,670-9,680' - Limestone, dark brown. Dolomite, trace to 10%. Amphipora 20 to 45%. Rudstone and floatstone with

grainstone matrix. Amphipora facies.

9,680-9,690' - Limestone, dark brown. Amphipora 20 to 25%. Dolomite in Amphipora canals and irregular blebs. Algal boundstone from 9,680 to 9,681 ft.. Floatstone with mudstone matrix. Amphipora facies.

9,690-9,698' - Limestone, dark to medium brown. Green shale at top of interval, dolomite below shale in Amphipora canals and irregular patches. Trace hemispherical and branching stroms., 10 to 25% Amphipora and trace brachiopods. Floatstone and rudstone with mudstone matrix. Amphipora facies. Sample SP 7 at 9,691 ft.

9,698-9,702' - Limestone and dolomitic limestone, medium brown. Hemispherical (2 to 25%) and branching (trace to 10%) stroms., Amphipora 20 to 35%, and trace brachiopods. Stroms. bored. Dolomite in matrix. Algal boundstone from 9,692 to 9,694 ft. Floatstone and rudstone with wackestone matrix. Hemispherical stromatoporoid and algal facies. Sample SP 8 at 9,698 ft.

9,702-9,714' - Dolomitic limestone, medium brown. Dolomite in matrix and spar cement. Branching stroms. 10 to 40%, Amphipora (trace to 15%), trace brachiopods, trace to 20% gastropods. Siderite in foram. test. Dolomite spar 'cement' in rudstone. Porosity poor to good intraparticle (gastropod), interparticle and fenestral. Rudstone and floatstone with packstone and grainstone matrix. Branching stomatoporoid facies. Samples SP 9 at 9,705 ft , SP 10 at 9, 706 ft , and SP 11 at 9,708 ft.

9,714-9,725' - Limestone, medium brown. Dolomite trace to 10% in Amphipora canals. Rare large hemispherical strom., trace to 5% branching stroms., 15 to 35% Amphipora, and trace brachiopods. Intraparticle Amphipora porosity poor. Rudstone and floatstone with packstone and wackestone matrix. Amphipora facies. Sample SP 12 at 9,714 ft.

9,725-9,728' - Limestone, dark brown. Depauperate (1 to 2 mm) Amphipora 40%, trace brachiopods. Dolomite in Amphipora canals. Rudstone, minor floatstone with packstone to grainstone matrix. Amphipora facies. Sample SP 13 at 9,725 ft.

9,728-9,752' - Dolomitic limestone and limestone, light brown. Green shale at 9,730' on logs, absent in core. Amphipora 25 to 40%, trace branching stroms., trace brachiopods, gastropods, and calcispheres. Dolomite spar in former fenestral, channel, and fracture porosity. No dolomite visible in matrix. Porosity good, intraparticle Amphipora and gastropod; minor moldic porosity. Floatstone with grainstone and packstone matrix. Amphipora facies.

9,752-9,758' - Limestone, light brown. Amphipora 25 to 40%, trace branching stroms, trace brachiopods and calcispheres. Dolomite in matrix, rarely in Amphipora vesicles. Dolomite and calcite in Amphipora canals. Amphipora floatstone, minor rudstone with wackestone matrix. Poor intraparticle porosity. Amphipora facies.

9,758-9,770' - Limestone and dolomitic limestone, light to medium brown. Amphipora 20 to 40%, branching stroms. (trace

to 5%), trace hemispherical stroms., brachiopods and calcispheres. Dolomite in fenestral porosity. Dolomite and calcite in Amphipora canals. Porosity poor. Minor algal boundstone from 9,758 to 9,762 ft. Floatstone, minor rudstone, with wackestone and packstone matrix. Algal and Amphipora facies.

9,770-9,772' - Limestone, light brown. Amphipora 25%. Peloidal packstone. Skeletal-peloid facies.

9,772-9,778' - Limestone, medium brown. Amphipora (less than 2 mm) 30%, trace branching stroms. and brachiopods. Oncolites and algal-coated Amphipora. Interbedded rudstones and floatstones with peloid matrix. Amphipora facies.

9,778-9,782' - Limestone, medium brown. Amphipora 25% and trace brachiopods. Fenestral pores and rare Amphipora canals plugged with dolomite. Algal boundstone with minor floatstone and rudstone with packstone matrix. Algal facies.

9,782-9,789' - Limestone, medium brown. Amphipora 20 to 25%. Trace branching stroms. and brachiopods. Algal-coated Amphipora. Trace fenestral porosity. Floatstone with wackestone matrix. Amphipora facies.

12-25-63-18 W5

9,552-9,572' - Limestone, light brown. Tabular (trace to 80%), hemispherical (trace to 20%) and branching (trace to 20%) stroms., tabular strom/algal consortium, trace to 2% rugose corals, trace to 5% brachiopods, trace gastropods. Calcite spar cement in matrix. Vertical fractures and frac-

tured stroms. lined with bitumen. Porosity poor to good; interparticle and intraparticle. Boundstone, floatstone and rudstone with grainstone matrix. Samples SY 1 at 9,566 ft , SY 2 at 9,569 ft. Tabular stromatoporoid facies.

9,572-9,578' - Limestone, light brown; trace pyrite. Branching stroms. 5 to 10%, Amphipora 5%, brachiopods 5%, and trace gastropods. 10 to 15% strom. fragments. Micrite coatings on allochems. Vertical fractures lined with bitumen. Floatstones with packstone matrix. Porosity poor to good; interparticle and intraparticle. Tabular stromatoporoid facies.

9,578-9,580' - Limetone, light brown; trace dolomite in matrix. 5% strom. fragments, trace branching stroms. Peloids. Packstone. Skeletal-peloid facies. Samples SY 3 at 9,579 ft and SY 4 at 9,580 ft.

9,580-9,588.5' - Limestone, light brown. Hemispherical (trace to 20%), branching (5 to 20%) and tabular (trace to 10%) stroms.; trace Amphipora, rugose corals, and brachiopods. Strom. fragments to 20%. Silt and sparry calcite geopetal fabric. Vertical fractures. Porosity poor to good; interparticle and intraparticle. Floatstone and rudstone with grainstone to packstone matrix. Hemispherical stromatoporoid facies.

9,588.5-8,597' - Limestone, light brown; trace dolomite and pyrite in matrix. Microkarst and bleached zone at top of interval. Coated grains and calcite spar cement. Branching stroms. 5 to 15%, trace encrusting and possible bulbous

strom., 5 to 15% Amphipora, trace brachiopods. Floatstone with grainstone and packstone matrix. Branching stromatoporoid facies. Sample SY 5 at 9,588.5 ft. (5a:above micrite surface, 5b:below surface)

9,597-9,604' - Limestone, light brown; trace dolomite and pyrite. Hemispherical (trace to 15%), branching (10 to 40%), trace encrusting and bulbous stroms., trace to 15% Amphipora and trace brachiopods. Interparticle porosity good. Bafflestone (boundstone), rudstone, and floatstone with grainstone matrix. Hemispherical stromatoporoid facies. Sample SY 6 at 9,598'.

9,604-9,608' - Limestone, light brown; 5% dolomite in matrix, trace pyrite. Hemispherical (trace to 20%), tabular (5 to 10%) and branching (15 to 25%) stroms. Boundstone and rudstone, packstone matrix. Interparticle porosity good. Tabular stromatoporoid facies. Sample SY 7 at 9,607 ft.

9,608-9,614' - Limestone, light brown; 5% dolomite in matrix, trace pyrite. Branching stroms. 15 to 20%; 20 to 25% strom. fragments. Rudstone with grainstone to packstone matrix. Porosity good; interparticle and intraparticle. Branching stromatoporoid facies.

9,614-9,623' - Limestone, light brown; 5% dolomite in matrix, trace pyrite. Branching stroms. 20 to 45%, encrusting stroms. 10 to 15%, trace to 5% brachiopods. Matrix recrystallized. Porosity good to very good; intraparticle and intercrystalline. Rudstone and floatstone, minor bafflestone (bound-

stone), probable grainstone to packstone matrix. Branching stromatoporoid facies.

9,623-9,632' - Limestone, light brown; 5% dolomite in matrix. Green shale at top of interval, trace pyrite. Encrusting (10 to 20%) and branching (10 to 15%) stroms; trace bulbous stroms., rugose corals, and brachiopods. Matrix recrystallized. Interparticle and intercrystalline porosity. Boundstone and floatstone. Branching stromatoporoid facies. Samples SY 8 at 9,623, SY 9 at 9,626.5 ft.

9,632-9,649' - Limestone, medium brown; 10% dolomite in matrix, trace pyrite. Tabular (trace to 30%) and branching (trace to 15%) stroms., trace rugose corals, trace to 15% brachiopods, trace to 2% gastropods. Strom-algal consortium. Porosity poor to very good; intraparticle and intercrystalline. Rudstone and floatstone with grainstone to wackestone matrix. Tabular stromatoporoid facies.

9,649-9,652' - Limestone, medium brown; 5% dolomite in matrix, trace pyrite. Trace gastropods, trace to 20% brachiopods. Peloids. Grainstone and packstone. Skeletal-peloid facies.

9,652-9,655' - Limestone, light and medium brown; 5% dolomite in matrix, trace pyrite. Hemispherical (5 to 15%) and branching (15%) stroms, Amphipora (5%), and trace to 10% brachiopods. Dolomite 'cement'. Rudstone and floatstone with packstone to wackestone matrix. Branching stromatoporoid facies.

9,655-9,666' - Limestone, light brown; 5 to 10% dolomite,

trace pyrite. Branching 5 to 35%, encrusting (trace to 5%), irregular (trace), and hemispherical (trace to 15%) stroms. Trace Amphipora, brachiopods, and gastropods. Porosity good to very good; interparticle and/or intraparticle porosity in grainstone and packstone matrix; intraparticle porosity with packstone to wackestone matrix. Floatstone and rudstone, grainstone to wackestone matrix. Sample SY 10 at 9,665.5 ft.

9,666-9,680' - Limestone, light brown; trace dolomite in matrix. Amphipora 25 to 30%, trace encrusting and branching stroms., trace brachiopods and trace to 5% gastropods. Sparry calcite in irregular concentrations and common in Amphipora canals. Porosity poor to very good; intraparticle and interparticle. Floatstone and rudstone with grainstone and packstone and minor wackestone matrix. Amphipora facies. Samples SY 11 at 9,667', SY 12 at 9,671', and SY 13 at 9,672 ft.

9,680-9,700' - Limestone, light to medium brown, trace to 5% dolomite in matrix, trace pyrite. Amphipora 15 to 40%, trace branching stroms., brachiopods, gastropods, and calcispheres. Calcite and dolomite spar fill irregular fenestral porosity and Amphipora canals. Micrite coatings on allochems. Silt. Algal boundstone from 9,682 to 9,684 ft. Porosity (intraparticle) poor to good. Amphipora floatstone, minor rudstone with grainstone to packstone matrix. Algal and Amphipora facies. Sample SY 14 at 9,685 ft.

9,700-9,723' - Limestone, light to dark brown; trace dolomite and pyrite. Amphipora (15 to 55%), brachiopods (trace to

5%), trace gastropods. Grains micritized. Calcite spar in grainstone. Floatstone, minor rudstone, with packstone to wackestone and minor grainstone matrix. Amphipora facies.

9,723-9,726' - Limestone, light to dark brown; trace dolomite and pyrite. Amphipora 20 to 35%. Laminated algal facies at top of interval, micritized grains. Floatstone with grainstone matrix, rudstone with packstone matrix. Algal and Amphipora facies. Sample SY 15 at 9,723 ft.

9,726-9,736' - Limestone, light to dark brown; trace dolomite and pyrite. Amphipora 10 to 25%, trace gastropods. Amphipora slightly smaller, to 1 mm. Fenestral porosity filled with calcite spar. Algal boundstone (micritized grainstone) from 9,730 to 9,736 ft. Rudstone and floatstone with grainstone matrix. Algal and Amphipora facies.

9,736-9,740' - Limestone, dark brown; trace dolomite and pyrite. Amphipora 10%, trace brachiopods and gastropods. Floatstone with wackestone matrix. Amphipora facies.

9,740-9,752' - Limestone, dark brown; trace dolomite and pyrite. Amphipora (trace to 25%), bulbous stroms. (trace to 2%), brachiopods (trace to 5%), and trace gastropods. Rudstone and floatstone with packstone and wackestone matrix. Amphipora facies.

9,752-9,754' - Limestone, medium to dark brown; trace dolomite and pyrite. Trace Amphipora. Algal boundstone (laminated grainstone) with sparry calcite in fenestral pores. Packstone and wackestone. Algal facies.

9,754-9,757' - Limestone, medium to dark brown; trace dolomite and pyrite. Depauperate Amphipora 10 to 20%. Sparry calcite fills former fenestral voids. Algal boundstone (grainstone) and interbedded Amphipora floatstone. Algal facies.

9,757-9,767' - Limestone, medium to dark brown; trace dolomite and pyrite. Amphipora (trace to 5%), trace brachiopods. Thin bedded wackestone and packstone. Amphipora facies.

9,767-9,769' - Limestone, medium to dark brown; trace dolomite, pyrite and anhydrite. Bulbous (15%), encrusting (10%), and trace branching stroms. Trace to 5% Amphipora. Rudstone and floatstone with wackestone matrix. Bulbous stromatoporoid facies.

9,769-9,776' - Limestone, medium to dark brown; 5% dolomite, trace to 5% anhydrite, trace pyrite. Trace Amphipora. Thin bedded packstone and wackestone. Skeletal-peloid facies.

9,776-9,782' - Limestone, medium to dark brown; 10% dolomite, trace anhydrite and pyrite. Thin bedded grainstone and peloidal packstone. Skeletal-peloid facies.

9,782-9,784' - Limestone, dark brown; 10% dolomite, trace pyrite, anhydrite. Hemispherical (20%) and branching (10%) stroms., 15% Thamnopora, 10% Amphipora. Rudstone with wackestone matrix. Hemispherical stromatoporoid facies.

9,784-9,788' - Limestone, dark brown; 10% dolomite, trace pyrite and anhydrite. Bulbous stroms. (15 to 20%), branching stroms. (10 to 15%) and Amphipora 5%. Thamnopora 2%. Float-

stone, minor rudtone with wackestone matrix. Bulbous stromatoporoid facies. Sample SY 16 at 9,787 ft.

9,788 to 9,796' - Limestone, dark brown; 10 to 15% dolomite, trace pyrite, anhydrite. Hemispherical (10 to 20%), and branching (5 to 15%) stroms., Amphipora 5%. Floatstone, minor rudstone with wackestone matrix. Hemispherical stromatoporoid facies. Samples SY 17 at 9,788', SY 18 at 9,792.5', SY 19 at 9,795'.

7-5-59-18 W5

11,324-11,332' - Limestone, dark brown. Laminated. Echinoid and brachiopod skeletal grains. Pyrite replaces pellets in 1 ft pelleted grainstone at bottom of interval. Mudstone and wackestone. Micrite and pelleted facies. Sample SC 1 at 11,331 ft.

11,332-11,352' - Dolomitic limestone and dolomite; light brown. Hemispherical and irregular (10 to 50%) and branching (5 to 10%) stromatoporoids, rugose corals (1 to 2%) and traces of fragmented brachiopods. Stroms. fractured and brecciated with white calcite spar along fractures and infilling strom. interiors. Eroded, flat strom. on top. Porosity poor to locally good, small vuggy porosity. Dolomite in matrix. Rudstone and floatstone with possible wackestone and grainstone matrix. Hemispherical stromatoporoid facies. Sample SC 2 at 11,332 ft.

11,352-11,364' - Dolomitic limestone and dolomite; dark brown. Hemispherical and irregular (5 to 10%) and branching

5 to 15%) stroms. and traces of Amphipora, brachiopods and gastropods. Large stroms. to 17 cm and strom. fragments. Stroms. partly leached, porosity poor. Dolomitized matrix may be packstone or mudstone. Stromatoporoid floatstone. Hemispherical stromatoporoid facies. Sample SC 3 at 11,360 ft.

11,364-11,374' - Calcitic dolomite and dolomite; dark brown. Hemispherical (trace to 5%) and branching (trace to 5%) stroms. and trace of Amphipora, brachiopods, and gastropods. White dolomite spar fills fractures in brecciated rock. Wackestone and mudstone. Echinoid-brachiopod facies. SC 4 at 11,368 ft.

11,374-11,384' - Dolomite, dark brown. Hemispherical (5 to 10%) and branching (5%) stromatoporoids and 10 to 20% Amphipora. Strom. interiors leached and partly to completely filled with white dolomite spar. Dolomite spar also in fractures. Vuggy and moldic porosity. Floatstone with possible mudstone and wackestone matrix. Hemispherical stromatoporoid facies.

11,384-11,394' - Dolomite, dark brown. Hemispherical, tabular and irregular (5 to 15%) stroms., trace to 10% Amphipora, and traces of echinoids and brachiopods. Amphipora canals filled with dolomite. Porous dolomite patches in tight dolomite. Floatstone with possible wackestone matrix. Hemispherical stromatoporoid facies.

11,394-11,398' - Dolomite, dark brown. Amphipora (10%) and

trace echinoderm and brachiopod fragments, minor strom. fragments. Shale partings. Wackestone and mudstone. Echinoid-brachiopod facies.

11,398-11,420' - Dolomite, dark brown. Hemispherical (10 to 20%) and irregular and branching stroms. (5 to 15%) and Amphipora (trace to 5%). Stroms. to 10 cm , extremely large vugs from leached stroms., partly to completely filled with coarse sparry dolomite. Stroms. and Amphipora have intraparticle porosity. Porosity good. Floatstone with possible wackestone and mudstone matrix, 2 to 4 ft. wackestone bed. Hemispherical stromatoporoid facies. Samples SC 5 at 11,400 ft , SC 6 at 11,404 ft , SC 7 at 11,406 ft , SC 8 at 11,408 ft.

11,420-11,432' - Dolomite, dark brown. Tabular stroms. (5 to 30%) leached and partly filled with coarse dolomite. Branching stroms. (5 to 10%) and Thamnopora (trace to 5%). Trace brachiopods. Vuggy and intraparticle porosity is good. Tabular stromatorporoid rudstone and floatstone with mudstone matrix.

11,432-11,442' - Dolomite, dark brown. Branching stroms. 20 to 40%. Floatstone, minor rudstone with possible wackestone matrix. Branching stromatoporoid facies.

11,442-11,454' - Dolomite, dark brown. Hemispherical and irregular (trace to 15%) and branching (20 to 30%) stroms. Rugose corals (trace to 5%), Amphipora (trace to 20%), and brachiopods (trace). Larger stroms. are fragmented. White

dolomite spar 'cement' as irregular patches and horizontal concentrations in rudstone and in strom. interiors and fractures. Rudstone and floatstone with wackestone and mudstone matrix. Branching stromatoporoid facies. Sample SC 9 at 11,446 ft.

11,454-11,478' - Dolomite, dark brown. Hemispherical and irregular (trace to 5%) and branching (5 to 20%) stroms., 0 to 10% Amphipora and 0 to 2% brachiopods. White dolomite spar fills allochem molds. Floatstone and wackestone interbeds. Branching stromatoporoid facies. Samples SC 10 at 11,454 ft , SC 11 at 11,458 ft , SC 12 at 11,465 ft , SC 13 at 11,474 ft.

11,478-11,492' - Dolomite, dark brown. Hemispherical and irregular (5 to 25%) and 10 to 20% branching stromatoporoids. Amphipora (trace to 10%) and trace brachiopods. Smaller stroms. than previous interval. Strom. fragments. Intraparticle and vuggy porosity poor. Floatstone, minor rudstone with wackestone and mudstone matrix. Hemispherical stromatoporoid facies. Sample SC 14 at 11,488 ft.

11,492-11,496' - Dolomite, dark brown. Hemispherical and irregular stroms. (trace to 20%), branching stroms. (trace to 2%), and trace Amphipora, brachiopods and gastropods. Mudstone, wackestone, and floatstone with mudstone matrix. Hemispherical stromatoporoid facies.

11,496-11,504' - Dolomite, dark brown. Irregular (trace to 5%) and branching (2 to 5%) stroms., 5 to 15% Amphipora and

trace brachiopods and gastropods. Algal oncolites 5%. Floatstone with mudstone matrix. Minor rudstone. Amphipora facies. Sample SC 15 at 11,532 ft.

11,504-11,516' - Dolomite, dark brown. Amphipora (10 to 45%) strom. fragments (trace to 5%), and brachiopods (trace to 5%). Bottom 15 cm may be grainstone. Trace sulphur. Floatstone and rudstone with wackestone matrix. Amphipora facies. Sample SC 16 at 11,508 ft , SC 17 at 11,515 ft.

11,516-11,519' - Shale, green; laminated with dolomite. Dolomite with small shale lithoclasts. Trace pyrite. Samples SC 18a at 11,516.5 ft , SC 18b at 11,518 ft.

11,519-11,524' - Limestone and dolomitic limestone; medium to light brown. Amphipora 5 to 30%, trace small hemispherical stromatoporoids. Coarse dolomite crystals in matrix and dolomite spar in irregular voids. Floatstone with grainstone? and mudstone matrix. Amphipora facies. Sample SC 19 at 11,519 ft.

11,524-11,570' - Calcitic dolomite and dolomite; light brown. Trace green shale at 11,554 ft. Interbedded algal boundstone, Amphipora (5 to 80%) skeletal layers, and possible grainstones. Geopetal fabrics in stromatactis-like cavities. Fenestral and moldic (Amphipora) porosity poor to very good. Algal units from 11,524 to 11,525 ft , 11,541 to 11,545 ft , 11,548 to 11,550 ft , and 11,562 to 11,564 ft. Floatstone and rudstone with packstone matrix. Samples SC 21 at 11,532', SC 22 at 11,534ft,SC 23 at 11,541 ft , SC 24 at 11,545 ft ,

SC 25 at 11,561 ft , and SC 26 at 11,569 ft. Algal and Amphipora facies.

11,570-11,594' - Dolomite, medium to dark brown. Amphipora 10 to 50%. 10 cm. algal? mound with 15° inclination of laminations. Overlying Amphipora floatstones also inclined 15° for one foot above mound. Amphipora canals are filled with white dolomite spar. Sulphur crystals and disseminated sulphur in white calcite spar. Floatstone and rudstone with packstone and mudstone matrix. Mudstone from 11,592 to 11,594 ft. Amphipora and micrite facies. Sample SC 27 at 11,572 ft.

11,594-11,614' - Dolomite, light brown. Dolomitization has all but obliterated primary textures. Vug shapes suggest allochem shapes. Green shale occurs along a stylolitic seam and interparticle 'cement' in horizontal trends. Sulphur crystals in vugs. Possible floatstone with minor rudstone. Mudstone for lower 2 feet. Amphipora and micrite facies.

11,614-11,642' - Dolomite, dark brown. Amphipora 5 to 30%, average 1.0 mm diameter. Strom. boundstone for 33 cm. Anhydrite fills strom interior. Sulphur crystals. Fenestral and birdseye concetrations of white dolomite spar. Packstone and rudstones interbedded with floatstones. Mudstone and wackestone increase toward bottom of interval. Amphipora facies. Sample SC 28 at 11,625 ft.

11,642-11,644' - Shale; green. Trace Pyrite.

11,644-11,657' - Dolomite, medium to dark brown. Amphipora 10 to 30% and fragmented stroms. 1 to 10%. Fenestral voids with geopetal fabric and irregular blebs of dolomite spar in 2 ft interval below shale. Amphipora molds. Porosity poor to good; moldic and trace vuggy. Floatstone and minor rudstone, mudstone interbeds increase at bottom of interval. Amphipora facies.

11,657-11,666' - Dolomite, trace shale; dark brown. Amphipora trace to 10% and trace fragmented stroms. Mudstone and wackestone, minor floatstone. Mircrite facies.

11,666-11,692' - Dolomite, dark brown. Amphipora 10 to 45%. Bottom 4 ft contain small, 1 mm diameter Amphipora. Floatstone and rudstone with mudstone matrix. Laminated mudstone interbeds with anhydrite. Amphipora facies. Sample SC 29 at 11,690 ft.

11,692-11,709' - Dolomite, dark brown. Hemispherical (5 to 10%) stroms., Euryamphipora (5 to 20%), and Amphipora (trace to 10%). Strom. interiors filled with anhydrite. Trace vuggy porosity. Floatstone, minor rudstone, with mudstone and wackestone matrix. Euryamphipora facies.

11,709-11,720' - Dolomite, dark brown. Branching stroms. 5 to 10%, trace Amphipora. Anhydrite in vugs and fossil molds. Mudstone and wackestone, minor floatstone. Micrite facies.

11,720-11,733' - Dolomite, dark brown. Trace anhydrite. Bulbous stroms. trace to 10%. Trace Euryamphipora and Amphipora. Four foot laminated interval; mudstone and grainstone.

Bulbous stromatoporoid facies and micrite facies.

11,733-11,739' - Dolomite, dark brown. Trace anhydrite. Bulbous stroms. (trace to 10%), brachiopods (trace to 15%), and gastropods (trace to 10%). Abundant fractures filled with coarse dolomite. Large stroms. up to 18 cm. Floatstone and mudstone. Bulbous stromatoporoid facies. Samples SC 30 at 11,733 ft , and SC 31 at 11,737 ft.

11,739-11,748' - Dolomite, dark brown. Trace anhydrite. Tabular stroms. (trace to 10%), trace bulbous stroms. and fragments. Echinoids 5 to 10%, and brachiopods trace to 5%. Floatstone with wackstone and mudstone matrix. Tabular stromatoporoid facies.

11,748-11,757' - Dolomite, dark brown. Echinoid and brachiopod fragments 5 to 15%. Trace pyrite. Wackestone and mudstone and trace laminated mudstone. Echinoid-brachiopod facies.

11,757' Watt Mt. : green shale.

6-28-58-18 W5

10,785-10,814' - Calcitic dolomite, light to medium brown. Hemispherical and irregular stromatoporoids and strom. fragments 15 to 80%, trace to 15% branching stroms., trace to 15% Amphipora, and trace echinoids and brachiopods. Four foot interval of skeletal-peloid grainstone. Stroms. are calcite in interiors, dolomite on rims (less than 1 cm thick). Echinoids up to 5 mm in diameter. Intraparticle and moldic porosity generally poor, locally good. Floatstone and rud-

stone with wackestone and packstone matrix and interbeds. Hemispherical stromatoporoid facies. Samples SE 1 at 10,796 .5 ft , SE 2 at 19,799.5 ft.

10,814-10,824' - Limestone, light brown. Stromatoporoids and coral fragments coated with algae (5 to 10%). Birdseye-type patches of dolomite. Mudstone and wackestone. Micrite facies.

10,824-10,840' - Dolomitic limestone and dolomite; dark brown. Trace Amphipora, brachiopods and gastropods. Chert occurs as irregular concentrations and lenses. Dolomite in irregular patches. Minor intercrystalline porosity. Mudstone and wackestone. Micrite facies. Samples SE 3a at 10,825 ft , SE 3b at 10,830 ft , and SE 4 at 10,838 ft.

10,840-10,844' - Calcitic dolomite and limestone; dark brown. Branching and hemispherical stromatoporoids and fragments, 5 to 15%, and trace to 10% Amphipora. Trace of rugose corals and brachiopods. Chert along lamellae of strom. fragments. Floatstone with mudstone matrix. Tabular stromatoporoid facies.

10,844-10,880' - Limestone, slightly dolomitic; dark brown. Large, 2 to 3 cm gastropods and smaller gastropods in rare gastropod wackestone beds. Echinoids and rare echinoid wackestones. Rare stromatoporoid fragments, including one 15 cm stromatoporoid. Trace brachiopods. Mudstone. Micrite facies.

10,880-10,894' - Dolomitic limestone and dolomite; dark brown.

Minor boudinage. Trace echinoids, brachiopods, gastropods. Mudstone. Micrite facies.

10,894-10,904' - Dolomite; dark brown. Extremely well-rounded and angular stromatoporoid fragments 5 to 10% for 10 feet. Traces of echinoids, brachiopods, and gastropods. Minor intercrystalline and intraparticle porosity. Wackestone and minor floatstone with wackestone matrix. Echinoid-brachiopod facies.

10,904-10,908' - Dolomite; dark brown. Hemispherical stroms. 5 to 10%, branching stroms. (trace to 5%), trace Amphipora and brachiopods. Intraparticle porosity in stroms. Floatstone with possible wackestone matrix. Hemispherical stromatoporoid facies.

10,908-10,910' and core from 10,910 to 10,951', (Rec. 19 ft.) Dolomite, medium to dark brown. 8 ft medium brown. Trace to 10% hemispherical stroms., branching stroms. 10 to 20%, Amphipora 10 to 15%; trace brachiopods. Minor intraparticle and moldic, vuggy and intercrystalline porosity. Floatstone and rudstone with mudstone matrix. Branching stromatoporoid facies. 4 ft tabular stroms. 5 to 10%, branching stroms. (trace to 5%), and Amphipora 5 to 15%. Minor intraparticle porosity. Floatstone and rudstone with possible mudstone matrix. Tabular stromatoporoid facies. 10 ft hemispherical (5 to 10%), branching (2 to 10%) stroms., and trace to 5% Amphipora. Trace brachiopods. Stroms vuggy or filled with dolomite spar. Poor to good intraparticle and vuggy porosity.

Floatstone with possible mudstone and wackestone matrix. Hemispherical stromatoporoid facies.

10-3-59-18 W5

Core recovery:	10,614-10,665'	Rec. 41'	Core 1
	10,665-10,683'	Rec. 2'	Core 2
	10,683-10,694'	Rec. 4.5'	Core 3
	10,694-10,750'	Rec. 32'	Core 4
	10,750-10,780'	Rec. 2'	Core 5
	10,781-10,833'	Rec. 15.5'	Core 6

Core 1

17 ft. Limestone; dark brown, trace of dolomite and shale. Strom. fragments and thin tabular stroms. 5 to 10%, branching stroms. 5 to 20%; trace Amphipora, brachiopods and trace to 5% gastropods. Allochems coated by algae. Dolomite in matrix. Floatstone and rudstone with grainstone and mudstone matrix. Tabular stromatoporoid facies. Sample SD 1 at 10,624' approx.

9 ft. Limestone; dark brown, trace of dolomite in matrix. Strom. fragments less than 15%, Amphipora less than 15%, and trace Thamnopora and brachiopods. Gastropods 2 to 10%. Algal-coated allochems. Floatstone with possible wackestone matrix. Possible hemispherical stromatoporoid facies. Sample SD 2 at 10,636 ft. approx.

15 ft. Limestone, dark brown; trace of dolomite in matrix. Branching stromatoporoids 5 to 15%, Amphipora trace to 10%, strom. fragments 1 to 10%. Some algal-coated fragments..

Floatstone with wackestone and mudstone matrix. Sample SD 3 at 10,648 ft. approx.

Core 2

2 ft. Limestone; dark brown. Hemispherical and branching strom. Floatstone. Possible hemispherical stromatoporoid facies.

Core 3

4.5 ft. Dolomite; dark brown. Hemispherical and branching stroms. Minor moldic porosity. Floatstone, mudstone matrix.

Core 4

4 ft. Dolomite; dark brown. Hemispherical stroms. 15 to 20%, branching stroms 5%, trace Amphipora and brachiopods, and trace to 10% gastropods. Large stroms. with calcite interiors. Intraparticle porosity poor. Rudstone and floatstone. Hemispherical stromatoporoid facies. Samples SD 4 a, b at 10,694' approx., SD 4c at 10,696'.

12 ft. Dolomite, dark brown. Branching stroms. 0 to 20%, Amphipora 5 to 10%, and brachiopods and gastropods less than 10%. Poor moldic and intraparticle porosity. Floatstone with possible mudstone matrix. Branching stromatoporoid facies.

16 ft. Dolomite, dark brown to light brown. Branching stroms. 5 to 30%, Amphipora 5 to 15%. Trace to 5% brachiopods and gastropods. Hemispherical stroms. most abundant in upper 12 ft. Minor intraparticle porosity. Floatstone and rudstone with grainstone and mudstone matrix. Branching

stromatoporoid facies. Sample SD 5 at 10,718 ft. approx.

Core 5

2 ft. Dolomite; dark brown. Amphipora 20%, branching stroms. 10%; trace rugose corals and brachiopods. Large concentrations of white dolomite spar. Poor moldic porosity. Floatstone. Branching stromatoporoid facies.

Core 6

15.5 ft. Dolomite, light to medium brown. Amphipora 5 to 20%. Interparticle, intraparticle and intercrystalline porosity. Floatstone. Amphipora facies.

1-2-59-18 W5

10,720-10,726' - Dolomite, medium to light brown. Gastropods 5 to 20%, Amphipora trace to 5%, trace brachiopods. Moldic intercrystalline and vuggy porosity. Possible wackestone, minor floatstone. Echinoid-brachiopod facies.

10,726-10,728' - Dolomite, light brown. Hemispherical stroms. (some larger than 7 cm) 25%; trace branching stroms., brachiopods and gastropods. Vuggy porosity. Floatstone. Hemispherical stromatoporoid facies.

10,728-10,736' - Dolomite, light to medium brown. Branching (10 to 20%), and irregular (trace to 5%) stroms., trace to 5% Amphipora, trace gastropods, Moldic and intercrystalline and vuggy porosity. Floatstone. Branching stromatoporoid facies.

10,736-10,740' - Dolomite, light brown. Hemispherical (trace to 25%) and branching (trace) stroms.; trace gastropods.

Stromatactis-like cavities lined with dolomite spar. Moldic, intercrystalline and vuggy porosity. Wackestone and floatstone. Hemispherical stromatoporoid facies.

10,740-10,750' - Dolomite, light to medium brown. Branching (10 to 15%) and irregular (trace) stroms.; trace Amphipora, trace to 5% gastropods. Moldic, intercrystalline and vuggy porosity. Floatstone. Branching stromatoporoid facies.

10,750-10,763' - Dolomite, dark brown; rare stylolites. Branching (trace to 15%), and hemispherical (trace to 2%) stroms., Amphipora (trace to 10%), and trace to 5% gastropods. Coarse dolomite spar fills large strom. interiors. Brecciation. Porosity moldic, intercrystalline, fracture and vuggy. Floatstone and wackestone. Branching stromatoporoid facies.

10,763-10,772' - Dolomite, dark brown; trace pyrite. 1 to 2 cm dolomite crystals in vugs. Hemispherical (10 to 15%), tabular (trace to 5%), and branching (trace to 10%), stroms., trace Amphipora, rugose corals, gastropods and brachiopods. Fragmented stroms. Porosity vuggy, moldic, intercrystalline, and fracture. Floatstone. Hemispherical stromatoporoid facies.

10,772-10,782' - Dolomite, dark brown; stylolites common. Tabular (trace to 10%), hemispherical (trace to 10%), and branching (5 to 15%) stroms. Trace to 10% rugose corals, trace to 5% brachiopods, trace gastropods. Calcite crystals to 2 cm inside stroms. vugs. Moldic, intercrystalline and

vuggy porosity. Floatstone and rudstone. Tabular stromatoporoid facies.

10,782-10,790' - Dolomite, dark brown; stylolites common. Brachiopods 5 to 10%, trace branching stroms., Amphipora, rugose corals, and gastropods. Intercrystalline, moldic and vuggy porosity. Wackestone, minor floatstone. Echinoid-brachiopod facies.

10,790-10,806' - Dolomite, dark brown; stylolites common. Branching (5 to 15%), and hemispherical (trace to 10%) stroms. Trace to 5% rugose corals, trace Amphipora, trace to 5% brachiopods, trace gastropods. Coarse dolomite spar. Abundant hairline fractures filled with white dolomite near bottom of interval. Vuggy porosity. Floatstone and wackestone. Branching stromatoporoid facies.

10,806-10,812' - Dolomite, medium to dark brown; stylolites common. Intercrystalline porosity. Possible wackestone.

10,812-10,820' - Dolomite, medium to dark brown; stylolites common. Hemispherical (trace to 20%), and branching (10 to 15%) stroms; trace to 5% rugose corals, trace to 5% Amphipora, trace brachiopods and gastropods. Strom. fragments. Breccia. White dolomite spar in fractures and strom. interiors. Moldic, vuggy and intercrystalline porosity. Floatstone. Hemispherical stromatoporoid facies.

10,820-10,836' - Dolomite, dark brown; stylolites common. Branching (5 to 15%) and hemispherical (5 to 10%) stroms. Amphipora (trace to 5%), trace brachiopods. Vuggy, moldic

and intercrystalline porosity. Floatstone, and wackestone. Branching stromatoporoid facies. Sample SZ 1 at 10,827'.

10,836-10,840' - Dolomite, dark brown; stylolites common. Hemispherical (trace to 5%) and branching (trace) stroms. Amphipora 5%, trace brachiopods. Vuggy porosity. Wackestone. Echinoid-brachiopod facies.

10,840-10,852' - Dolomite, dark brown; trace anhydrite, stylolites common. Hemispherical (trace to 15%) and branching (5%) stroms.; trace to 10% Amphipora, trace brachiopods. Coarse dolomite spar in strom-originated vugs. Some vugs later filled with anhydrite. Vuggy, moldic and intercrystalline porosity. Floatstone and wackestone. Hemispherical stromatoporoid facies.

10,852-10,862' - Dolomite, dark brown; trace anhydrite. Branching (10 to 25%) and hemispherical (trace) stroms.; 5% Amphipora, trace brachiopods and gastropods. Anhydrite breccia. Abundant fractures lined with dolomite spar and filled with anhydrite. Intercrystalline and vuggy porosity. Floatstone, minor rudstone. Branching stromatoporoid facies.

10,862-10,866' - Dolomite, dark brown; trace anhydrite. Depauperate Amphipora 40 to 45%. Branching (trace to 5%) and hemispherical (trace) stroms., and trace brachiopods. Vugs filled with coarse calcite spar. Porosity moldic and vuggy. Rudstone and floatstone. Amphipora facies.

10,866-10,876' - Dolomite, dark brown; trace anhydrite. Amphipora (trace to 25%), brachiopods (trace to 5%), gastropods

(trace to 5%), branching stroms. (trace to 5%). Breccia; dolomite and anhydrite along fractures. Wackestone, minor floatstone. Echinoid-brachiopod facies.

10,876-10,880'- Dolomite, dark to light brown; trace to 5% anhydrite, trace green shale. Trace to 30% Amphipora, trace to 5% branching stroms., trace brachiopods. Breccia as above. Trace vuggy porosity. Floatstone, minor rudstone. Possible grainstone. Amphipora facies.

10,880-10,881' - Dolomite, light brown, and bedded (30 to 35°) green shale. Sample SZ 2 at 10,881'.

10,881-10,894' - Dolomite, light brown; trace anhydrite and green shale. Texture and allochems almost indistinguishable. Hemispherical and branching stroms. and Amphipora present. Possible floatstone with coarse calcite spar and geopetal silt fabric.

10,894-10,898' - Dolomite, light brown; trace green shale. Grainstone, possible floatstone.

10,898-10,928' - Dolomite, light brown; trace to 25% anhydrite. Anhydrite in large masses and fractures in breccia. Moldic, intercrystalline and fracture porosity. Probable floatstone. Sample SZ 3 at 10,907 ft.

10,928-10,932' - Dolomite, light brown. Branching stroms. 20%, Amphipora 20 to 25%. Moldic porosity. Rudstone and floatstone. Branching stromatoporoid facies.

10,932-10,952' - Dolomite, light brown; trace shale and shale partings. Amphipora 10 to 30%. Dolomite spar rarely lines

moldic porosity. Minor to good intercrystalline and moldic porosity. Floatstone and rudstone. Amphipora facies.

10,952-10,973' - Dolomite, light and medium brown. Green shale at 10,960 ft on log. Amphipora 15 to 35%. Dolomite spar along fractures and filling molds. Porosity moldic, intercrystalline and vuggy. Floatstone and mudstone. Amphipora facies.

10,973-10,988' - Dolomite, medium to light brown; 20% green shale for 4 feet. Stylolites common. Amphipora 15 to 30%. Mottled dolomite and shale. Coarse dolomite and calcite spar cement in vugs. Vuggy and moldic porosity. Possible grainstone from 10,973 to 10,974 ft. Floatstone, minor rudstone. Amphipora and skeletal-peloid facies.

10,988-11,006' - Dolomite, light to medium brown; stylolites common. Branching (trace to 15%) and hemispherical (trace) stroms., trace to 25% Amphipora. Birdseye and geopetal fabrics. Coarse calcite spar partly to completely fills vugs. Isopachous cement lines rare vug. Moldic and vuggy porosity. Floatstone. Amphipora facies.

11,006-11,012' - Shale, green; and dolomite (to 80%), light brown. Green shale with fragments of rudstone and floatstone. Amphipora 10 to 20%. Amphipora facies.

11,012-11,017' - Dolomite, light brown; trace green shale and abundant stylolites. Amphipora 10 to 35%, trace to 10% hemispherical stroms., trace brachiopods. Moldic and vuggy porosity. Floatstone and rudstone. Amphipora facies.

11,017-11,022 - Dolomite, light brown; trace green shale, stylolites common. Amphipora 25%. Irregular solution channels and fenestrae with dolomite spar and geopetal fabric. Possible floatstone. Amphipora facies.

11,022-11,040' - Laminated dolomite, light to medium brown; stylolites common. Green shale in solution cavities. Sparry dolomite lining irregular vugs and molds. Amphipora 15 to 25%. Moldic and vuggy porosity poor to good.

2-1-59-18 W5

11,008-11,018' - Limestone, medium gray. Nodular structure. Rare brachiopods. Stylolites. Pyrite veins, coarse crystalline calcite in veins, irregular fractures, vugs and molds. Mudstone. Micrite facies. Sample SB 1 at 11,012.8 ft.

11,018-11,028.5' - Limestone; medium gray. Trace echinoid, gastropod and Amphipora fragments. Geopetal internal fabrics in gastropod. Vugs filled with sparry calcite. Nodular structure, stylolites and residual seams. Mudstone. Micrite facies.

11,028.5-11,031' - Core Missing.

11,031-11,035' - Limestone, medium gray. Nodular structure. Trace brachiopods. Stylolites. Vertical fractures filled with coarse calcite. Mudstone. Micrite facies.

11,035-11,044.5' - Dolomite, medium gray. Nodular structure. Trace to 10% brachiopods, trace echinoid, gastropod and Amphipora fragments. Stylolites with up to 2 cm amplitude. Pyrite seams and shale partings. Vugs lined with calcite, then

dolomite. Mudstone. Micrite facies.

11,044.5-11,046' - Core Missing.

11,046-11,057' - Dolomite, medium gray. Trace to 10% echinoids, trace to 10% brachiopods, and trace Amphipora. Geopetal fabrics. Vugs lined with dolomite and containing quartz crystals. Irregular concentrations of calcite spar near bottom of interval. Stylolites and shale partings. One 15 cm bed of 10% echinoid wackestone Mudstone. Micrite facies.

11,057-11,064' - Stylolite contact at 11,057 ft. Dolomite, light gray to brown; minor pyrite and shale seams. Trace to 30% branching stroms. Trace to 30% Amphipora, trace to 15% massive hemispherical stroms. Some mottled fabric. Moldic to vuggy porosity partly filled with white dolomite spar. Residue seams of green shale and pyrite. Floatstone and rudstone, minor mudstone. Branching stromatoporoid facies and micrite facies. Sample SB 2 at 11,058.5 ft , SB 3 at 11,059 .1 ft , SB 4 at 11,059.7 ft , and SB 5 at 11,063.7 ft.

11,064-11,066' - Dolomite, light gray to brown. Uniform, 1 mm size dolomite. Stylolites. Intercrystalline porosity. Appears to be 15° bedding. Possible grainstone, and skeletal-peloid facies. Sample SB 6 at 11,065.5'.

11,066-11,076' - Dolomite, light gray to brown. Trace to 10% tabular stroms., trace to 5% Amphipora, trace Thamnopora and trace brachiopods. Vuggy and moldic porosity poor to good. Dolomite and calcite lining vugs and filling fractures.

Burrows are filled with grains and partly leached. Trace green shale at 11,075 ft. Floatstone and mudstone. Tabular stromatoporoid facies. Samples SB 7 at 11,066.5 ft., SB 8a at 11,067 ft. and SB 8b at 11,075 ft.

11,076-11,090' - Dolomite, dark brown. Thamnopora trace to 35%. Trace brachiopods, gastropods and Amphipora. Thamnopora sticks horizontal. Pyrite in veins and cubes. Moldic and vuggy porosity. Floatstone with mudstone matrix and mudstone.

11,090-11,104.5' - Dolomite, dark brown. Trace pyrite nodules. Trace to 5% gastropods, echinoids, brachiopods, Amphipora, and branching stroms. Intraclasts. Burrows filled with skeletal debris and small gastropods. Dolomite in vertical fracture and gastropods. Dolomite in vertical fracture and gastropod molds. Minor vuggy porosity. Stylolites. Mudstone. Micrite facies.

11,104.5-11,106' - Dolomite, dark brown. Echinoids, brachiopods, Amphipora, solitary corals and gastropods. Vugs and molds. Pyrite crystals, thin residue seams and stylolites. Wackestone. Echinoid-brachiopod facies. Sample SB 9 at 11,104.5 ft.

11,106-11,124.5' - Dolomite, dark brown. Trace to 20% tabular stroms., trace to 10% echinoids, and trace Amphipora. Trace brachiopods and gastropods. Stroms. leached and partly to completely filled with white dolomite spar. Vugs lined with dolomite spar. Vuggy and moldic porosity. Wackestone

or possible mudstone matrix in floatstone. Tabular stromatoporoid facies. Sample SB 10a at 11,116 ft.

11,124.5-11,128' - Dolomite, dark brown. Echinoids 20%. Thin, vertical fractures filled with white sparry calcite. Minor vugs. Stylolites and pyrite. Wackestone. Echinoid-brachiopod facies. Sample SB 10b 11,127.5 ft.

11,128-11,132' - Dolomite, medium brown. Trace echinoid and brachiopod fragments. Sparry calcite filled vugs. Moldic porosity. Mudstone. Micrite facies.

11,132-11,139' - Dolomite, medium brown. Pyrite concentrated at stylolites. Large vugs and moldic porosity. Possible grainstone. Dolomite crystal size very uniform (1 to 2 mm) Sample SB 11 at 11,138 ft.

11,139-11,140' - Core missing.

11,140-11,150' - Dolomite, mottled light and medium brown. Partly leached hemispherical stroms. and branching strom fragments. Minor brachiopods. Porosity vuggy, moldic and intraparticle. Possible floatstone with mudstone matrix. Hemispherical stromatoporoid facies. Sample SB 12 at 11,143 ft.

11,150-11,160' - Dolomite, medium to light brown (mottled). Tabular stroms. trace to 5%. Hemispherical stroms. trace to 30%. Trace brachiopods and gastropods. Irregular patches of white dolomite spar. Moldic, vuggy and intraparticle porosity. Possible floatstone. Hemispherical stromatoporoid facies. Samples SB 13 at 11,151 ft., SB 14a at 11,158 ft.

11,160-11,170' - Dolomite, medium to light brown. Hemispherical and irregular stroms. trace to 10%; tabular stroms. trace to 10%. Calcite spar in some vugs. Moldic and vuggy porosity. Floatstone, possible packstone and mudstone matrix. Tabular stromatoporoid facies. Sample SB 14b at 11,169 ft.

11,170-11,180.5' - Dolomite, dark brown. Tabular stroms. 10 to 30%, branching stroms. 10 to 20%, trace coral fragments, brachiopods. Stylolitic contacts between stroms. Some fragments leached and filled with white sparry calcite. Moldic, intraparticle and vuggy porosity. Stylolites common. Floatstone and rudstone, possible mudstone and wackestone matrix. Tabular stromatoporoid facies. Sample SB 15 at 11,173 ft.

11,180.5-11,189' - Dolomite, dark brown. Trace echinoid and branching strom. fragments. Allochems leached and filled with sparry dolomite and calcite. Stylolites and shale partings. Mudstone to wackestone, minor floatstone. Micrite facies. Sample SB 16 at 11,185.5 ft.

11,189-11,196' - Dolomite, dark brown. Trace to 10% echinoid fragments. Stylolites and shale partings. Mudstone, minor wackestone. Micrite facies.

11,196-11,206' - Dolomite, dark brown. Branching stroms. and Amphipora 30%. Fragments of stroms. White calcite spar fills some molds completely. Dolomite in fractures, molds, and intraparticle pores. Stylolites and residue seams. Moldic and vuggy porosity. Floatstone, possible mudstone matrix. Sample SB 17 at 11,199 ft , SB 18 at 11,204.5 ft , and

SB 19 at 11,205.5 ft.

11,206-11,209.5' - Dolomite, medium brown. Uniform, fine-grained dolomite. Moldic and intercrystalline porosity. Possible grainstone. Sample SB 20 at 11,207.5 ft.

11,209.5-11,217.5' - Dolomite, dark brown; pyrite along stylolite. Brachiopods, possible Amphipora. Wackestone and possible mudstone. Echinoid-brachiopod facies. Sample SB 21 at 11,214 ft.

11,217.5-11,222' - Dolomite. Possible oncolites. Trace brachiopods. Molds and vugs filled with white sparry calcite and dolomite. Stylolites and pyrite. Moldic porosity. Mudstone. Micrite facies. SB 22 at 11,218.5 ft.

7-5-60-18 W5

10,380-10,426' - Limestone, dark brown. Echinoid-brachiopod mudstones, wackestone, packstones, and grainstones.

10,426-10,448' - Limestone and dolomitic limestone, dark to medium brown. Minor green shale at 10,440 ft. Hemispherical irregular and branching stroms. Amphipora. Algal-coated grains and stroms. Fractured and brecciated stroms. Sparry calcite in fenestral porosity. Good moldic and intraparticle porosity. Rudstones and floatstones. Samples SF 1 at 10,426 ft., SF 2 at 10,441 ft.

10,448-10,508' - Dolomite, dark brown. Irregular and branching stroms., Amphipora and echinoid and brachiopod grains. Moldic, intercrystalline and vuggy porosity. Floatstone.

10,508-10,551' - Dolomite, light brown. Green shale, fractured and brecciated stroms. at top of interval. Coarse crystalline dolomite with porous and tight intervals. Few vugs and moldic Amphipora. Possible grainstone.

10,551-10,568' - Dolomite, medium to dark brown. Green shale and birdseye calcite geopetal fabric in 1 foot laminated interval. Amphipora to 2 mm in size, minor branching stroms. Poor moldic porosity. Floatstone and rudstone.

10,568-10,688' - (from 10,593 to 10,609' Rec. 10.5') Dolomite, dark to light brown. Amphipora (5 to 6 mm in size) are 1 to 2mm in size for bottom 4 feet of interval. Green shale along stylolites from 10,593 to 10,605'. Irregular concentrations of white dolomite spar. Moldic porosity poor to good. Floatstones and rudstones. Sample SF 3 at 10,685 ft.

10,688-10,701' - Dolomite, dark brown. Euryamphipora, minor irregular and branching stroms. (bored) and echinoid grains. Floatstone. Sample SF 4 at 10,694 ft.

7-13-60-19 W5

10,710-10,732' - Limestone, dark brown. Echinoids, brachiopods and gastropods. Mudstone, minor wackestone.

10,732-10,750' - Limestone, dolomite in matrix; dark brown. Hemispherical, irregular and branching stroms.; Amphipora, brachiopods, echinoids, gastropods and rugose corals. Algal-coated allochems, oncolites. Overturned and fragmented stroms. Floatstone and rudstone.

10,750-10,774' - Calcitic dolomite and limestone, medium brown. Hemispherical, branching and irregular stroms.; minor Amphipora, brachiopods and gastropods. Stroms. with dolomite rims, calcite interiors. Floatstone and rudstone.

10,774-10,792' - Dolomite, dark brown. Branching stroms., minor hemispherical and irregular stroms., Amphipora and brachiopods. Good vuggy porosity. Floatstone, minor rudstone.

10,792-10,804' - Dolomite, dark brown. Amphipora and minor hemispherical, branching, and irregular stroms. and brachiopods. Dolomite in some strom interiors. Moldic and vuggy porosity poor. Rudstone and floatstone. Samples SG 1 and SG 2 at 10,802 ft.

10,804-10,828' - Dolomite, light brown. Green shale lenses in top four feet. Amphipora. Porosity (intercrystalline and moldic) poor to very good. Rudstone and floatstone, possible grainstone. Sample SG 3 at 10,810 ft.

4-19-60-18 W5

10,775-10,806' - Limestone, dolomitic limestone and dolomite. Dark brown. Echinoids, brachiopods, gastropods, trace ostracods and Amphipora. Pyrite. Mudstone and wackestone.

10,806-10,810' - Dolomite, dark brown. Thamnopora, minor fragmented stroms., echinoids, brachiopods, gastropods. Floatstone and wackestone.

10,810-10,825' - Dolomite, medium to light brown. Green shale residue seams and pyrite. Fractured, brecciated stroms.

Dolomite spar in fractures and leached stroms. Poor to good vuggy porosity. Stromatoporoid floatstone and rudstone. Samples SH 1 at 10,815 ft and SH 2 at 10,821 ft.

10,825-10,870' - Dolomite, light to medium brown. Green shale at 10,836 ft ; mottled fabric beneath shale. Pyrite along fractures. Amphipora. Porosity good; moldic and intercrystalline. Floatstone, minor rudstone. Samples SH 3 at 10,839 ft , SH 4 at 10,841 ft , and SH 5 at 10,849 ft.

10,870-10,915' - Dolomite, medium brown. Green shale at top of interval; mottled dolomite beneath. Dolomite spar in fractures and irregular voids. Amphipora. Porosity good; moldic, intercrystalline and fracture. Floatstone and rudstone, minor wackestone. Sample SH 6 at 10,872 ft.

2-25-60-19 W5

10,960-11,019' - Limestone, dark brown. Echinoid, brachiopod and gastropod fragments. Rare strom. fragments at bottom of interval. Mudstone, minor wackestone.

11,019-11,042' - Dolomite, light brown. Green shale at top of interval. Amphipora. Intercrystalline and moldic porosity below 11,024 ft. Floatstone, possible grainstone. Samples SJ 1 at 11,020 ft , SJ 2 at 11,021 ft , SJ 3 at 11,022 ft.

11,042-11,070' - Dolomite, light brown. Green shale at 11,060 ft. Hemispherical and branching stroms. Minor Amphipora. Porosity good to very good; moldic, vuggy (after stroms.), fracture and intercrystalline. Floatstone, minor

rudstone. Samples SJ 4 at 11,051 ft , SJ 5 at 11,059 ft.

11,070-11,140' - Dolomite, light to medium brown. Trace sphalerite. Amphipora and trace stroms. or strom. fragments. Porosity good to very good; moldic, intercrystalline, vuggy and intraparticle. Floatstone.

(Core from 11,101 to 11,110 ft. Rec. 5 ft.)

8-28-61-18 W5

10,350-10,400' - Rec. 11 ft. 10,425-10,437' - Rec. 29 ft.

11 ft. Limestone, medium to dark brown. Hemispherical, encrusting, and branching stroms., Amphipora, brachiopods and gastropods. Floatstone, grainstone and wackestone.

29 ft. Limestone, dark brown. Dolomite 5 to 20%. Minor Amphipora, echinoids, brachiopods, gastropods, rugose corals, and branching stroms. Stylolites and nodular structure. Wackestone and mudstone. Samples SR 1 and SR 2.

1-22-61-20 W5

10,571-10,587' - Limestone, dark brown. Minor echinoids, brachiopods and gastropods. Mudstone, minor wackestone.

10,587-10,591' - Calcitic dolomite and dolomite, light brown. Hemispherical and branching stroms. Strom fragments. Breccia with green shale stringers, pyrite. Algal (spaherocodium) colony on reef top. Floatstone. Samples SL 1 at 10,587 ft , SL 2 at 10,587.5 ft.

10,591-10,662' - Dolomite, light to medium brown. Green shale at 10,620 ft and 10,636 ft. Sphalerite in vug at 10,647 ft.

Amphipora. Porosity poor to good; moldic, intercrystalline and vuggy. Floatstone, possible grainstones.

12-25-61-18 W5

9,876-9,906' - Limestone, light to dark brown. Hemispherical, branching and tabular strom., solitary corals, large brachiopods and gastropods. Graded skeletal sand at 9,889 ft. Rim cements, vertical fractures. Intraparticle porosity poor to good. Floatstone and rudstone with grainstone and packstone matrix. Samples SS 1 at 9,883 ft , SS 2 at 9,884 ft , SS 3 at 9,891 ft , and SS 4 at 9,894.5 ft.

9,906-9,918' - Limestone, light brown. Trace dolomite. Hemispherical and branching stroms, minor tabular strom., solitary corals, brachiopods and gastropods. Isopachous rim cements and coarse calcite spar. Rudstone and floatstone, grainstone to wackestone matrix, minor wackestone and packstone. Sample SS 5 at 9,907 ft.

9,918-9,924' - Limestone, light brown. Amphipora and gastropods. Calcite spar in fenestral porosity. Floatstone with mudstone matrix, algal boundstone.

9,924-9,926' - Limestone, light brown. Trace dolomite in matrix. Branching and hemispherical stroms., minor Amphipora and brachiopods. Floatstone with wackestone matrix.

9,926-9,928' - Limestone, light to medium brown. Micrite surface at 9,927 ft. Grainstone. Sample SS 6 at 9,927 ft. (6a refers to that part of sample above micrite surface, 6b to that part below the micrite surface)

9,928-9,931' - Limestone, light brown. Dolomite in matrix. Hemispherical and branching stroms., minor Amphipora, brachiopods. Minor intraparticle porosity. Floatstone with wackestone matrix, and grainstone.

9,931-9,938' - Limestone, light brown. Dolomite in matrix. Amphipora, minor branching stroms. and brachiopods. Floatstone, grainstone matrix.

9,938-9,964' - Limestone, light brown. Branching strom. colonies, hemispherical strom.; minor Amphipora, brachiopods and gastropods. Fragmented stroms. Vertical fractures. Calcite spar cement; minor birdseye calcite. Minor intraparticle, interparticle and vuggy porosity. Rudstone, bafflestone (boundstone), and floatstone, with grainstone to wackestone matrix. Sample SS 7 at 9,953 ft and SS 8 at 9,956 ft.

9,964-9,980' - Limestone, light brown. Dolomite in matrix. Tabular and branching stroms., minor hemispherical stroms., rugose corals, brachiopods, solenoporoid algae, gastropods. Rudstone and floatstones, possible grainstone matrix. Sample SS 9 at 9,967 ft , SS 10 at 9,979 ft.

9,980-9,988' - Limestone, medium to light brown. Branching, hemispherical and tabular stroms., rugose corals and brachiopods locally abundant. Overturned stroms. Grainstone and floatstone with grainstone matrix, minor packstone to wackestone.

9,988-9,996' - Limestone, light brown. Laminated green shale (dolomitic) with lithoclasts of rudstone at bottom of inter-

val. Branching stroms., minor brachiopods, gastropods and Amphipora. Rudstone and floatstone with grainstone to wackestone matrix, minor algal boundstone (grainstone). Sample SS 11 at 9,993 ft.

4-24-62-20 W5

10,636-10,664' - Limestone, calcitic dolomite in lower 4 feet; dark brown. Echinoid and brachiopod grains. Pyrite in cubes, lenses, horizontal laminae. Mudstone, laminated for lower 4 feet. Minor wackestone.

10,664-10,686' - Dolomite, dark brown. Coarse porous dolomite patches. No recognizable allochems. Samples SK 1 at 10,682 ft , SK 2 at 10,685 ft.

EAST

D

PACIFIC ET AL

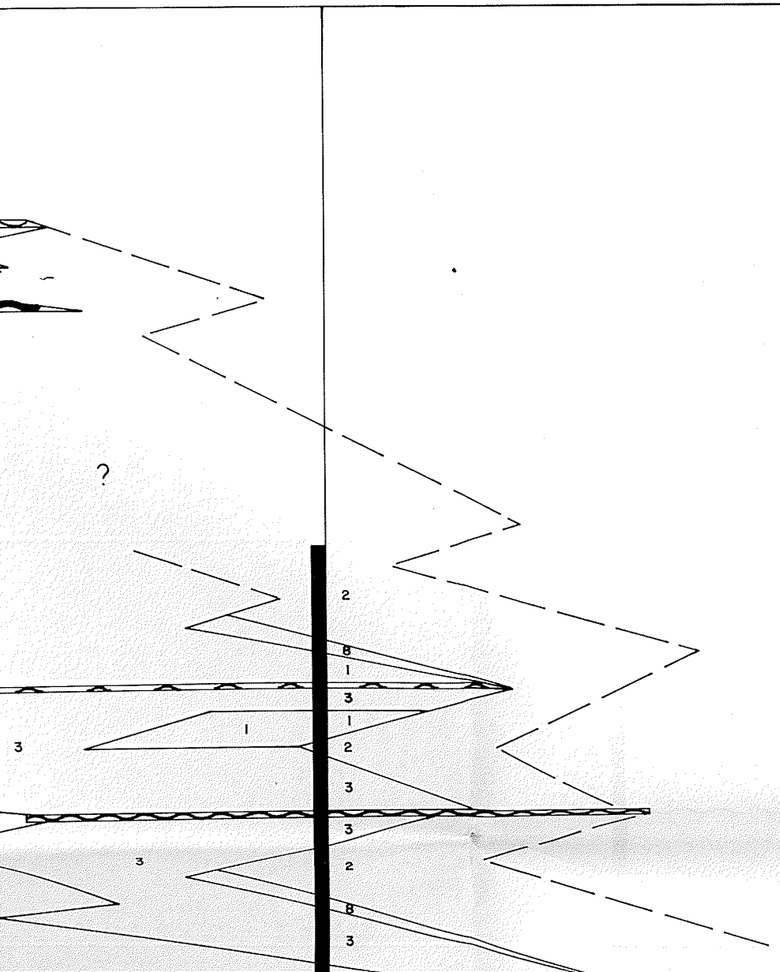
E. KAYBOB

12-25-63-18

W5M

9,410 FT.

DATUM: TOP OF BEAVERHILL LAKE GROUP



FACIES

1	HEMISPHERICAL STROMATOPOROID
2	TABULAR STROMATOPOROID
3	BRANCHING STROMATOPOROID
4	AMPHIPORA
5	EURYAMPHIPORA
6	BULBOUS STROMATOPOROID
7	ALGAL
8	SKELETAL - PELOID
10	OOLITE
11	ECHINOID - BRACHIOPOD: GRAINSTONE - PACKSTONE
12	ECHINOID - BRACHIOPOD: WACKESTONE
13	MICRITE: MASSIVE
14	MICRITE: LAMINATED
~	GREEN SHALE
~	UNCONFORMITY (GREEN SHALE ABSENT)

CORE RECOVERY

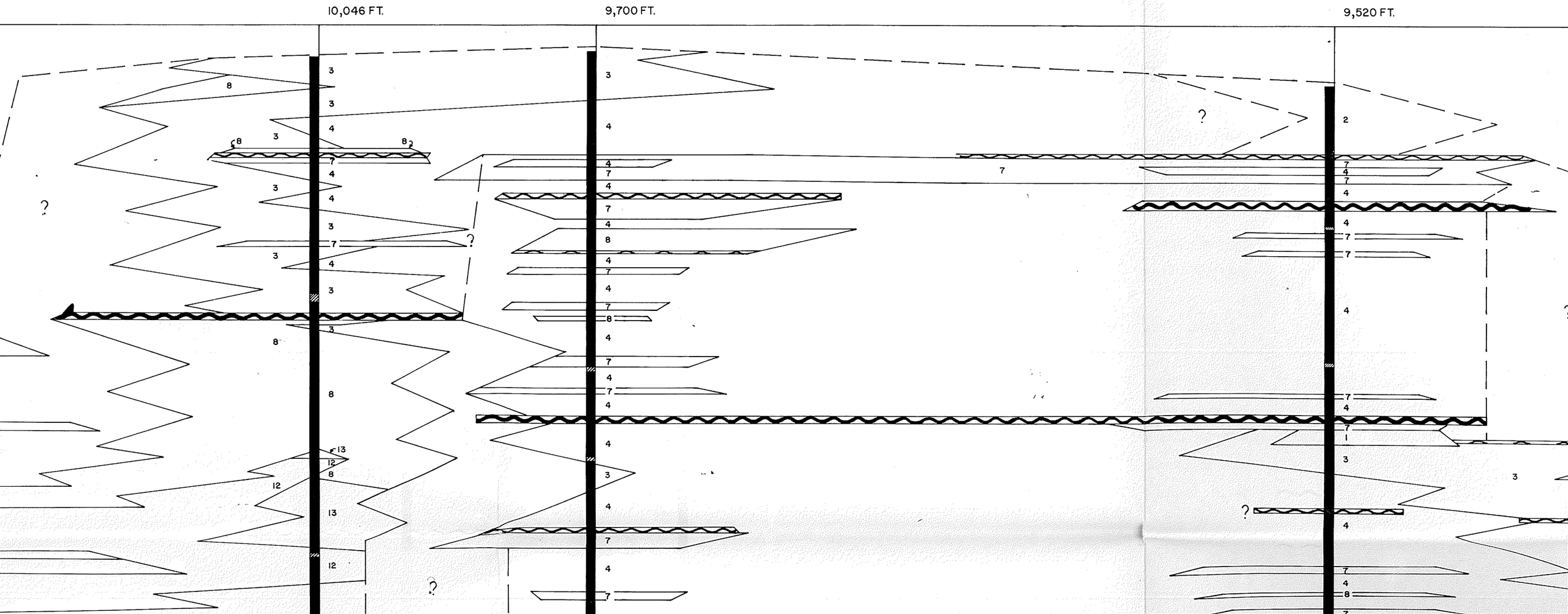
COMPLETE

INCOMPLETE

CALSTAN-BA
KAYBOB
2-18-62-18
W5M

PHILLIPS
KAYBOB
2-18-63-18
W5M

PACIFIC ET AL
KAYBOB
6-23-63-18
W5M



WEST

C

HB
KAYBOB S.
6-33-62-20
W5M

CALSTAN-B A
IOSEGUN
12-5-63-19
W5M

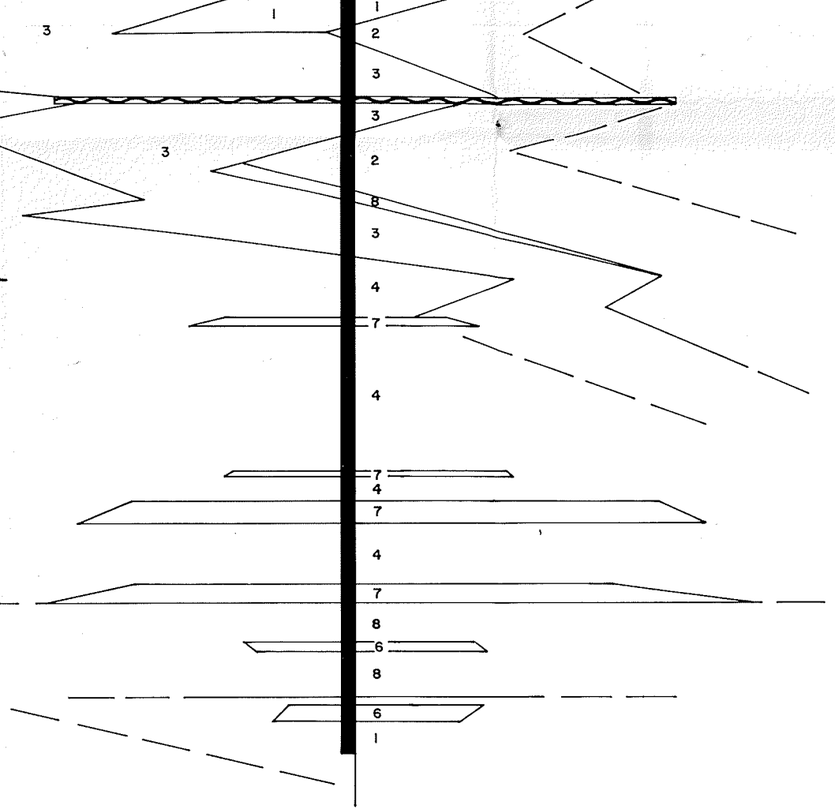
DEPTH

10,396 FT.

13
14
12
3
8
4

10,050 FT.

13
11
12
13
14
13
14
13
14
13
14
12
13
14
8
12
11
14
12



14 MICRITE : LAMINATED

GREEN SHALE

UNCONFORMITY (GREEN SHALE ABSENT)

METERS FEET

30 100

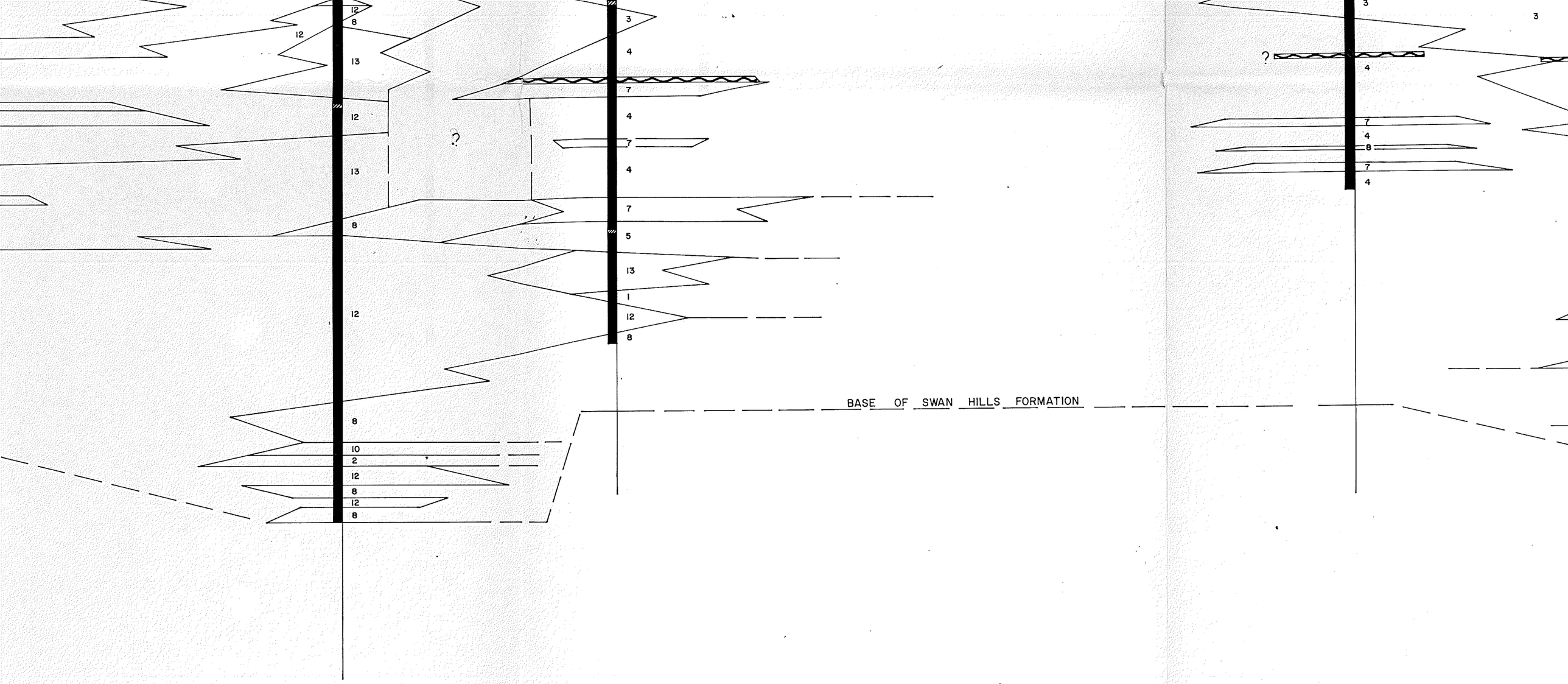
0 0.5 1.0 MILES

1.0 KILOMETERS

NOTE: HORIZONTAL SCALE APPROXIMATE

SECTION C-D
LITHOFACIES
KAYBOB SOUTH AREA - EAST BANK

FIGURE 9


12
8
12
13
12
13
8
12
8
10
2
12
8
12
8
?
3
4
7
4
7
4
7
5
13
1
12
8
BASE OF SWAN HILLS FORMATION
?
3
3
4
7
4
8
7
4

12
8
12
13
12
13
8
12
8
10
2
12
8
12
8
3
4
7
4
7
4
7
5
13
1
12
8
?

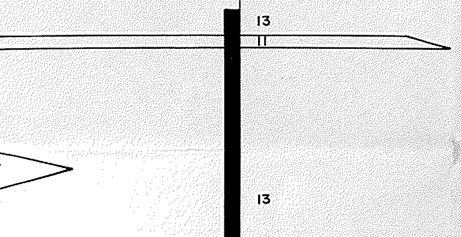
EAST

B

AMOCO ET AL H-1
KAYBOB S.
6-6-59-17
W5M

11,020 FT.

DATUM : TOP OF BEAVERHILL LAKE GROUP



FACIES

1	HEMISPHERICAL STROMATOPOROID
2	TABULAR STROMATOPOROID
3	BRANCHING STROMATOPOROID
4	AMPHIPORA
5	EURYAMPHIPORA
6	BULBOUS STROMATOPOROID
7	ALGAL
8	SKELETAL - PELOID
9	PELLETED
10	OOLITE
11	ECHINOID - BRACHIOPOD : GRAINSTONE - PACKSTONE
12	ECHINOID - BRACHIOPOD : WACKESTONE
13	MICRITE : MASSIVE
14	MICRITE : LAMINATED
~~	GREEN SHALE

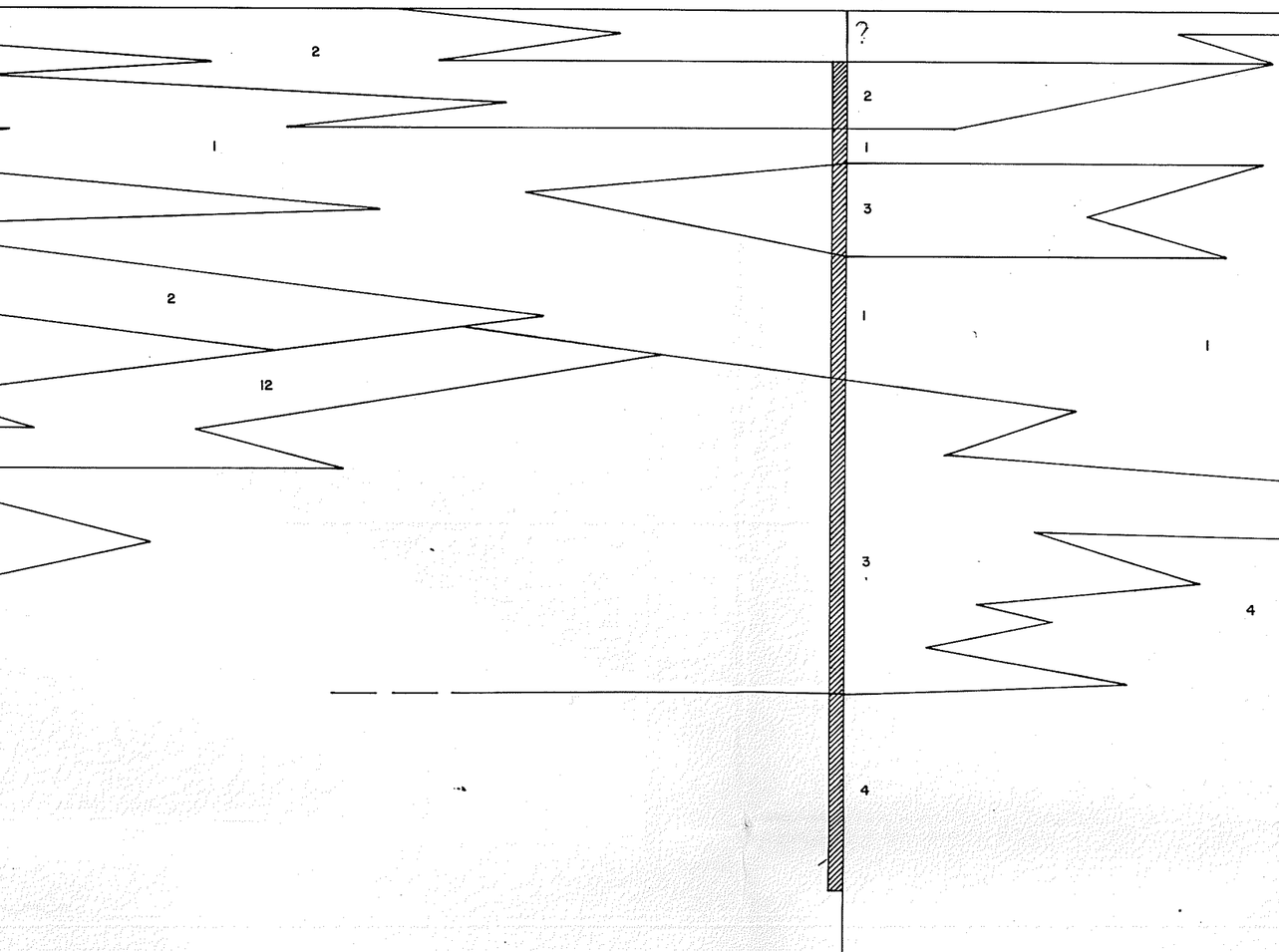
CORE RECOVERY

COMPLETE

INCOMPLETE

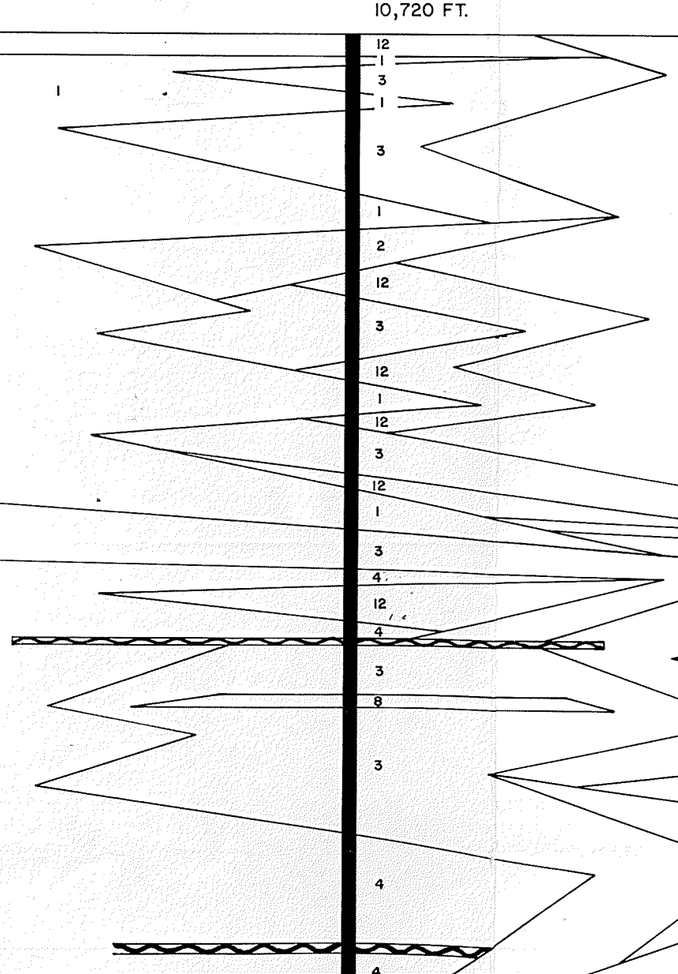
MOBIL ET AL
KAYBOB S.
10-3-59-18
W5M

10,600 FT.



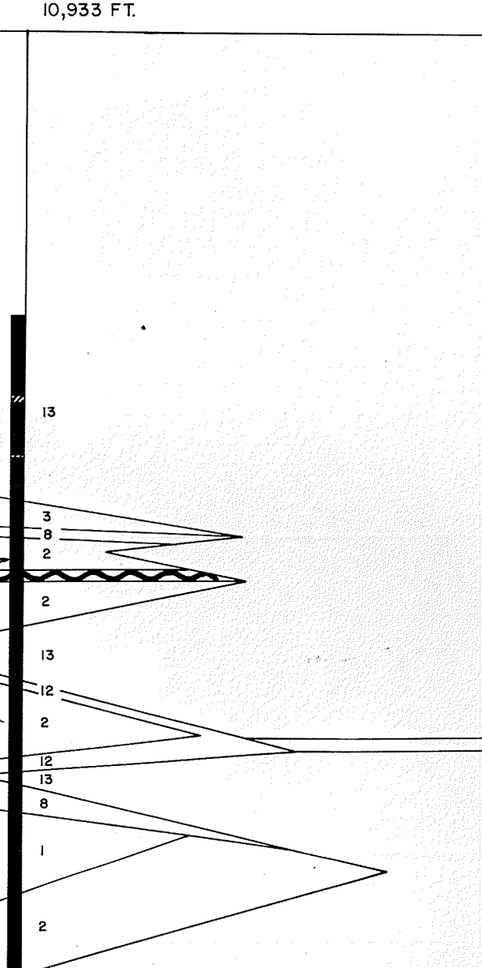
CHEVRON
KAYBOB S.
1-2-59-18
W5M

10,720 FT.



CHEVRON
KAYBOB S.
2-1-59-18
W5M

10,933 FT.



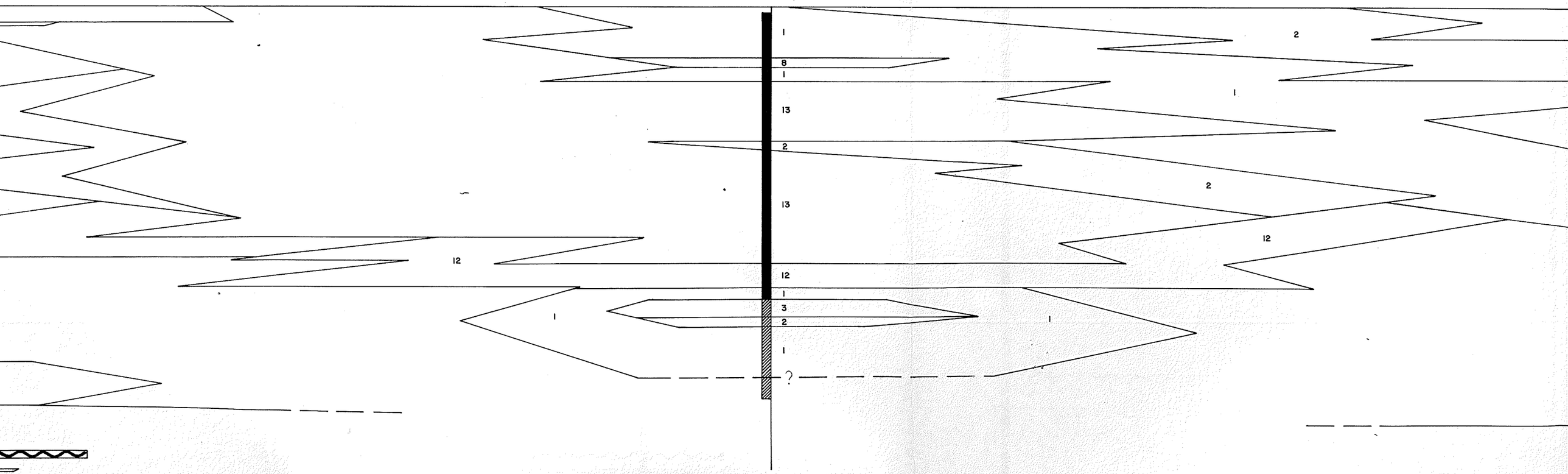
AMO
K
6

SOBC

CLARK

6-28-58-18

W5M

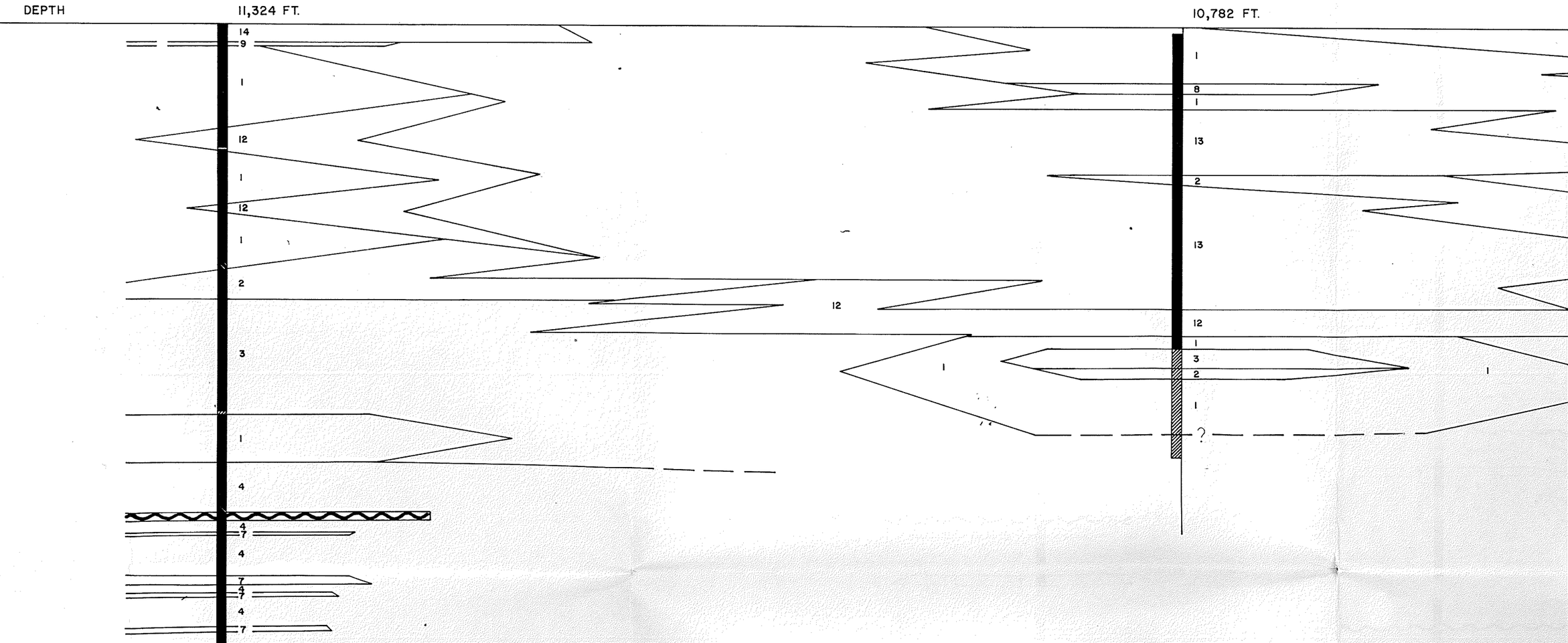


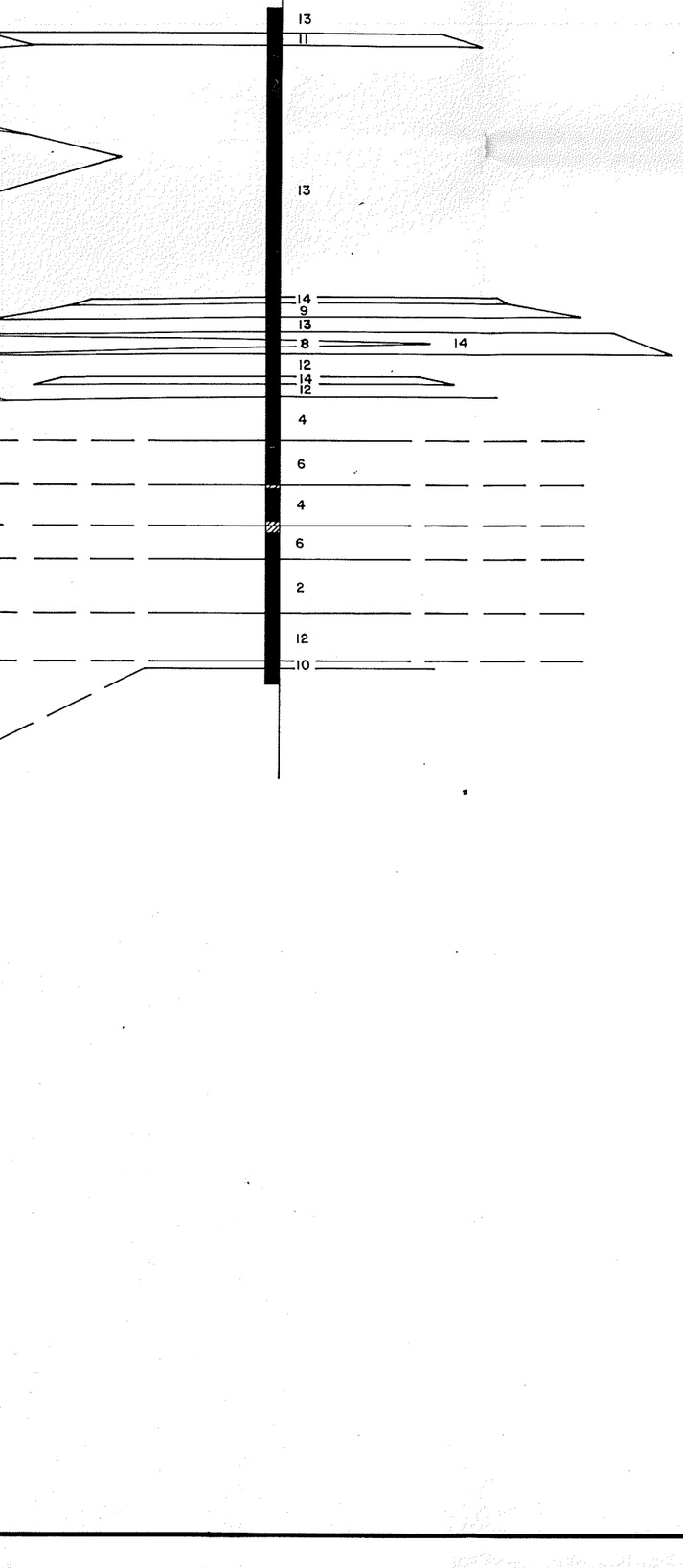
WEST

A

SOBC
CLARK
7-5-59-18
W5M

SOBC
CLARK
6-28-58-18
W5M





12	ECHINOID - BRACHIOPOD : WACKESTONE
13	MICRITE : MASSIVE
14	MICRITE : LAMINATED
	GREEN SHALE

METERS FEET

30 100

0.25 0.5 MILES

0 0.5 1.0 KILOMETERS

NOTE : SEE ISOPACH FOR SECTION LOCATION

SECTION A-B

LITHOFACIES

KAYBOB SOUTH AREA - WEST BANK

FIGURE 8

4

3

4

4

8

4

3

4

2

12

13

8

1

2

13

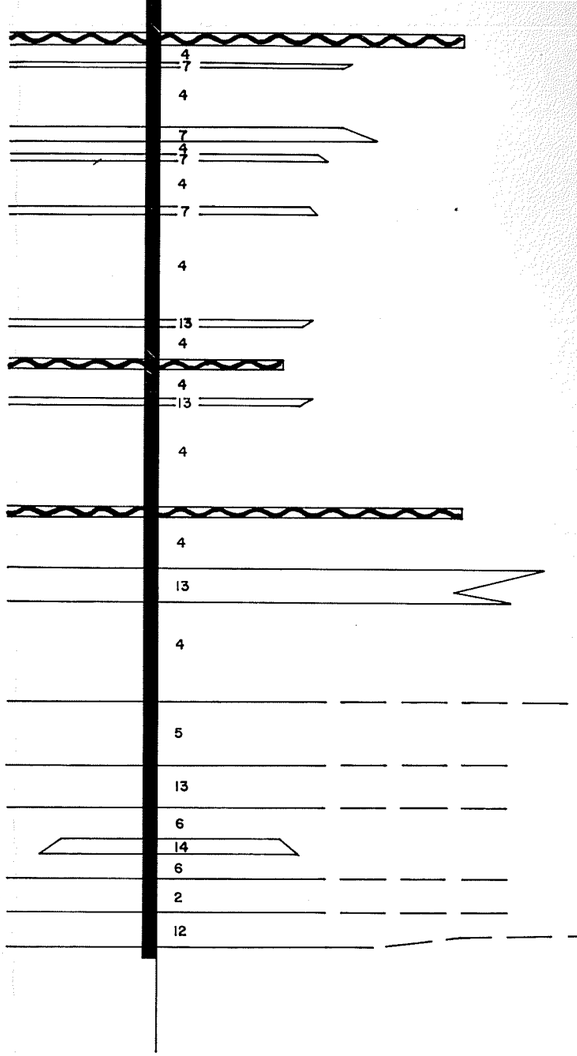
2

8

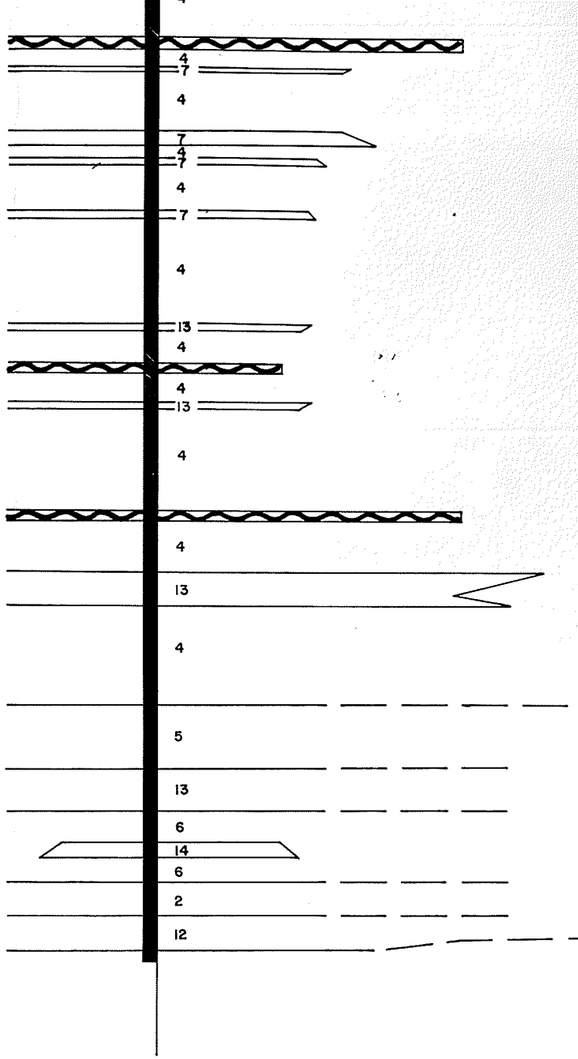
12

13

FORMATION



BASE OF SWAN HILLS FORMATION



BASE OF SWAN HILLS FORMATION

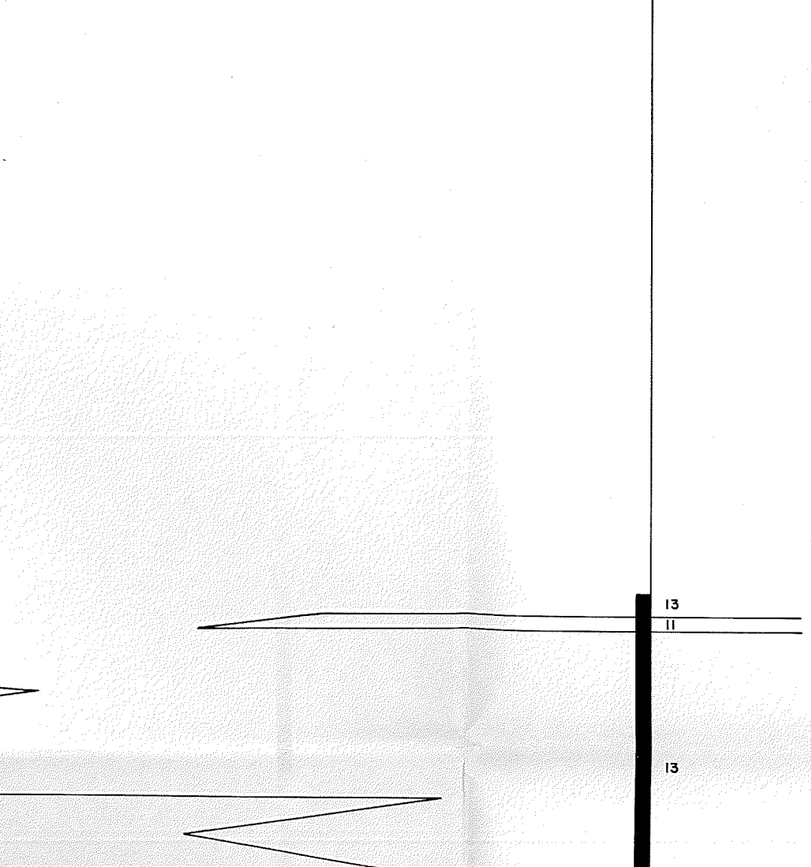
SOUTH

B

AMOCO ET AL H-1
KAYBOB S.
6-6-59-17
W5M

11,020 FT

DATUM : TOP OF BEAVERHILL LAKE GROUP



FACIES

1	HEMISPHERICAL STROMATOPOROID
2	TABULAR STROMATOPOROID
3	BRANCHING STROMATOPOROID
4	AMPHIPORA
5	EURYAMPHIPORA
6	BULBOUS STROMATOPOROID
8	SKELETAL - PELOID
9	PELLETED
10	OOLITE
11	ECHINOID - BRACHIOPOD : GRAINSTONE - PACKSTONE
12	ECHINOID - BRACHIOPOD : WACKESTONE
13	MICRITE : MASSIVE
14	MICRITE : LAMINATED

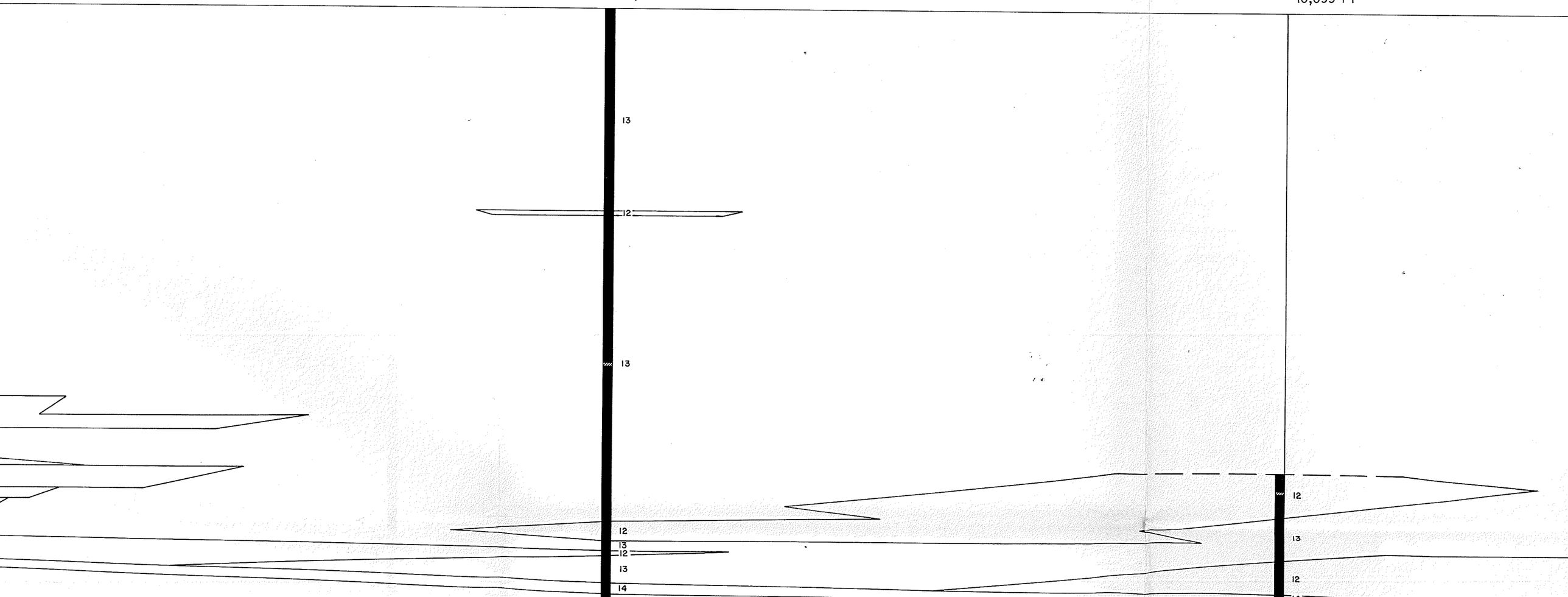
CORE RECOVERY

COMPLETE

INCOMPLETE

CHEVRON
FOX CREEK
11-1-61-19
W5M

HB - AMOCO - FINA
KAYBOB S.
10-3-60-18
W5M



NORTH

E

CALSTAN - BA
KAYBOB W.
2-28-63-20
W5M

CALSTAN - BA
IOSEGUN
12-5-63-19
W5M

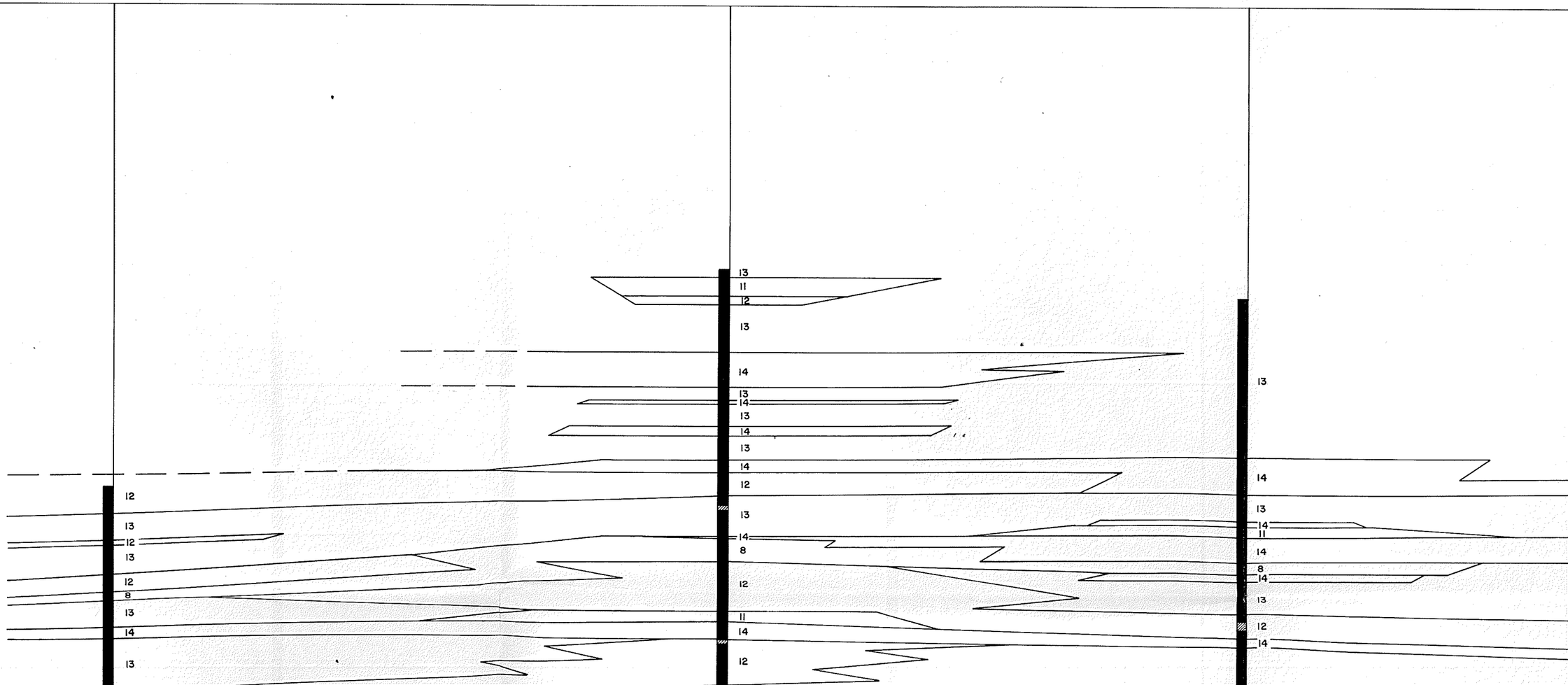
CALSTAN - BA
KAYBOB
4-16-62-19
W5M

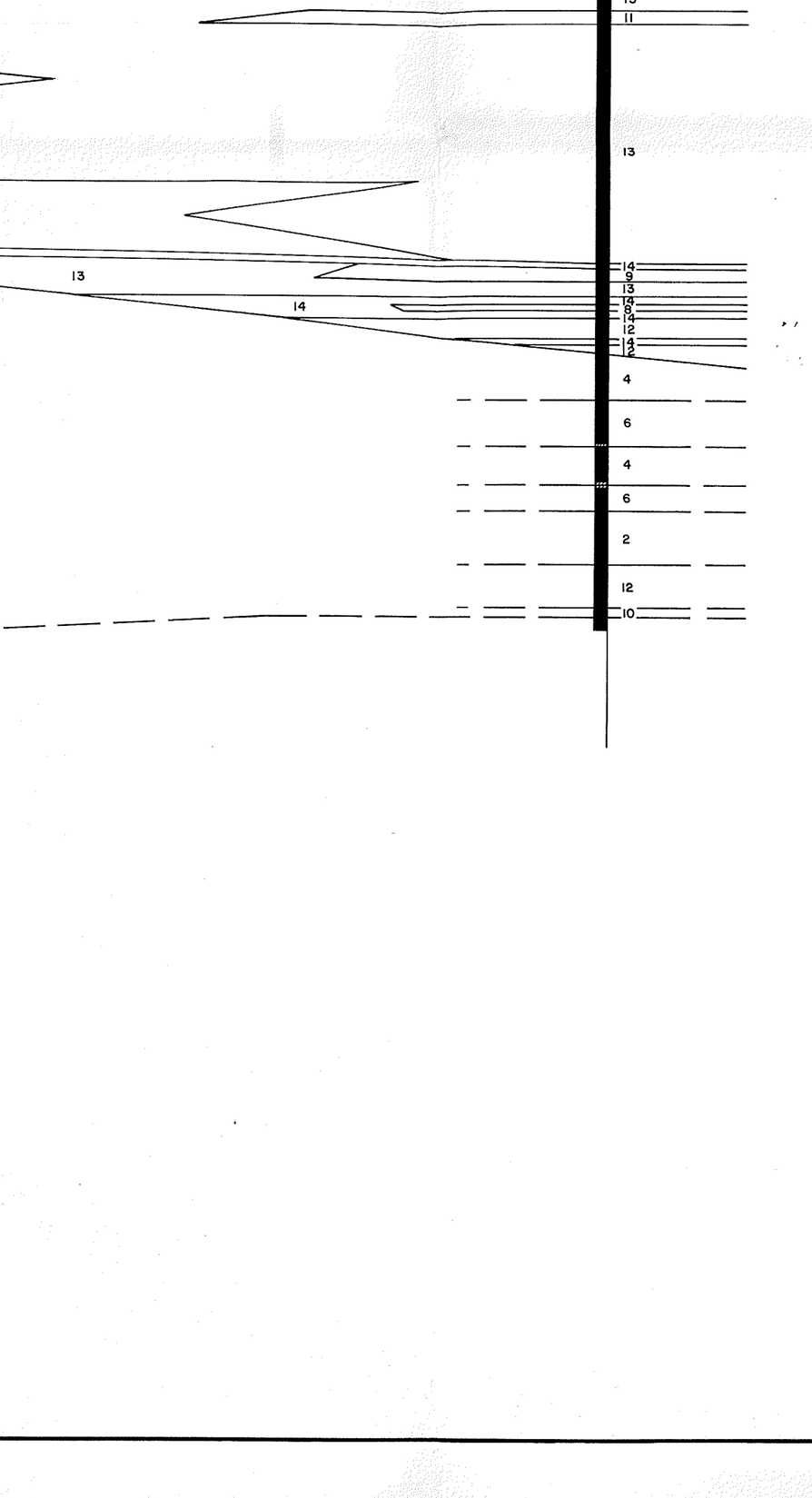
DEPTH

10,121 FT

10,050 FT

10,290 FT





14	MICRITE : LAMINATED

METERS FEET

30 — 100

0 1 2 3 KILOMETERS

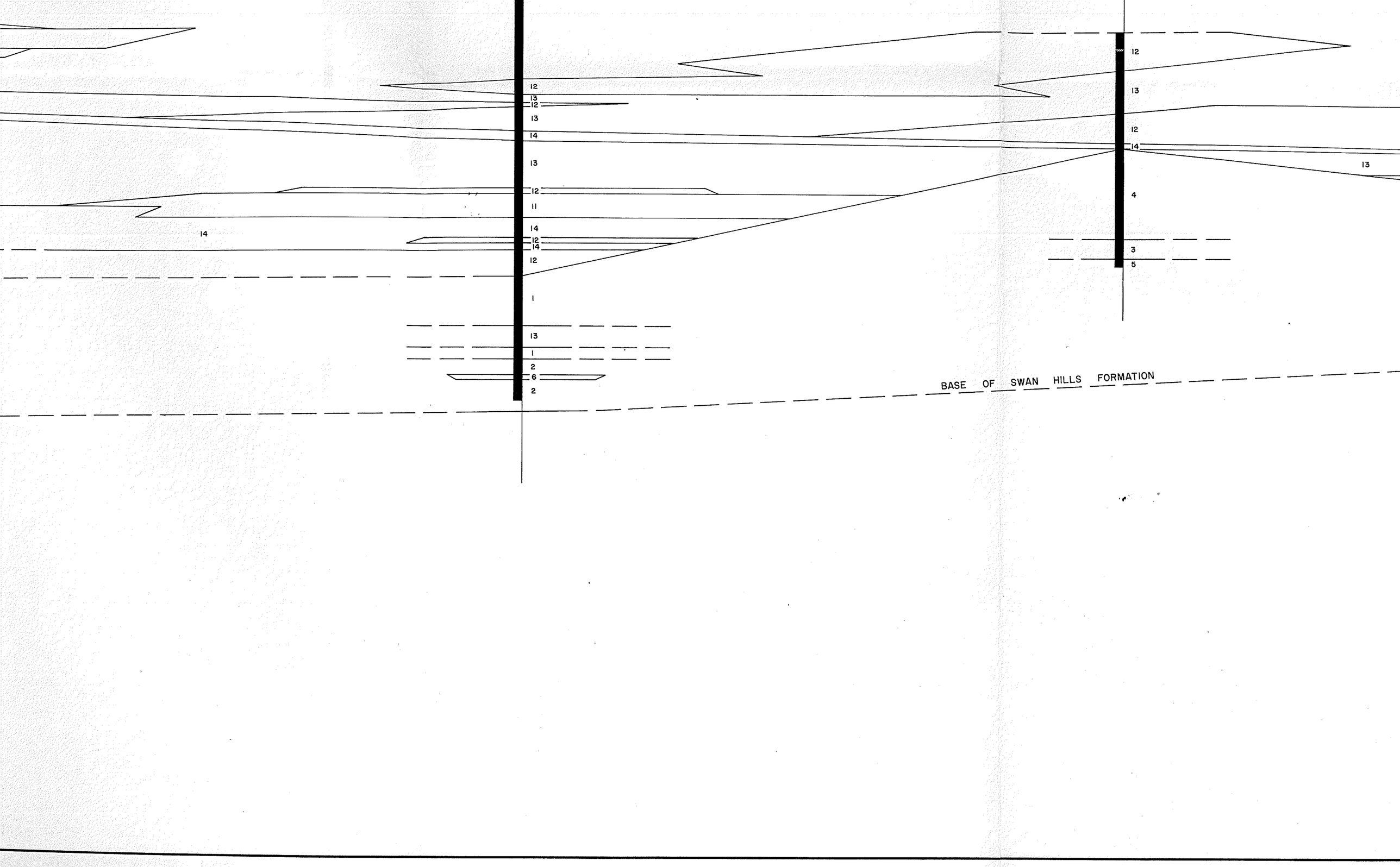
1 2 MILES

SECTION E-B

LITHOFACIES

KAYBOB SOUTH AREA - CHANNEL

FIGURE 10


12
13
12
13
14
13
12
11
14
12
14
12
1
13
1
2
6
2
14
12
13
12
14
4
3
5
13
BASE OF SWAN HILLS FORMATION

13
12
13
12
8
13
14
13
12
13
11
13
14
13
10
12
10
12
2
13
11
9
14

13
14
8
12
11
14
12
13
11
13
12

13
14
11
14
8
14
13
12
14
13
14

EAST

B

6-6-59-17

W5M

DATUM : TOP OF BEAVERHILL LAKE GROUP

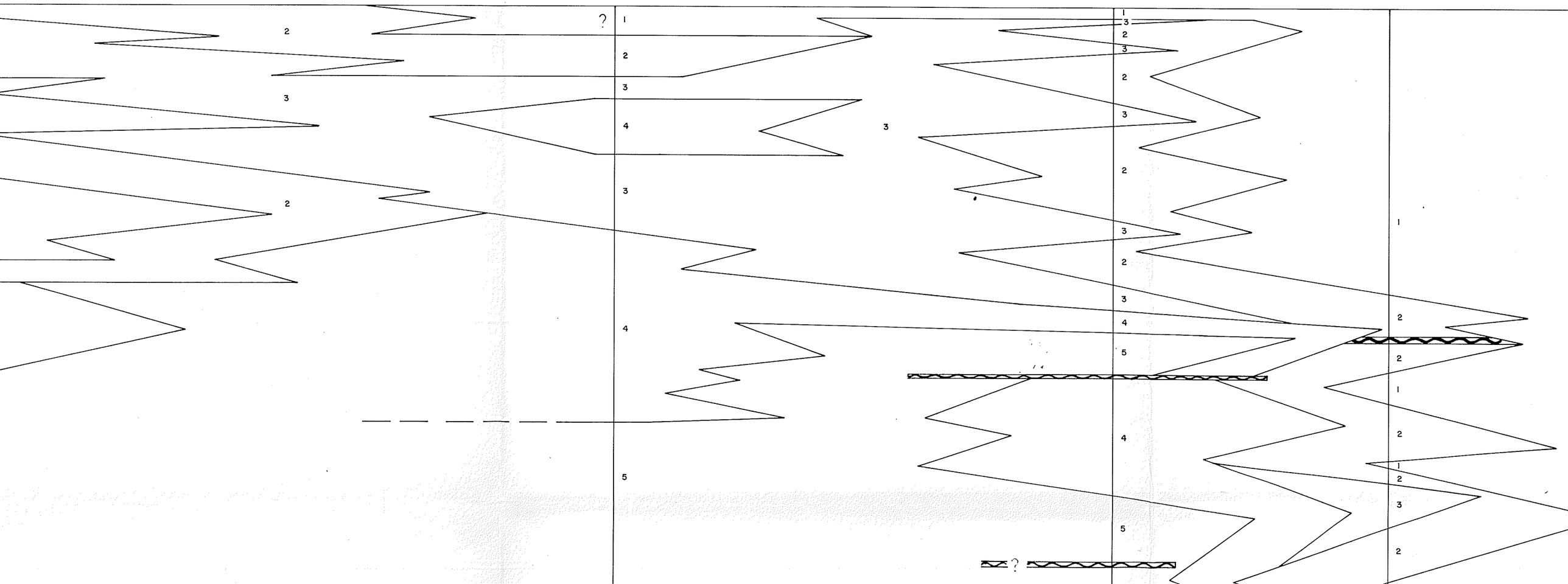
ENVIRONMENTS

1	OFF REEF
2	FORE REEF
3	SHELF MARGIN
4	OPEN SHELF
5	LAGOON
6	TIDAL FLAT
~	GREEN SHALE

10-3-59-18
W5M

1-2-59-18
W5M

2-1-59-18
W5M

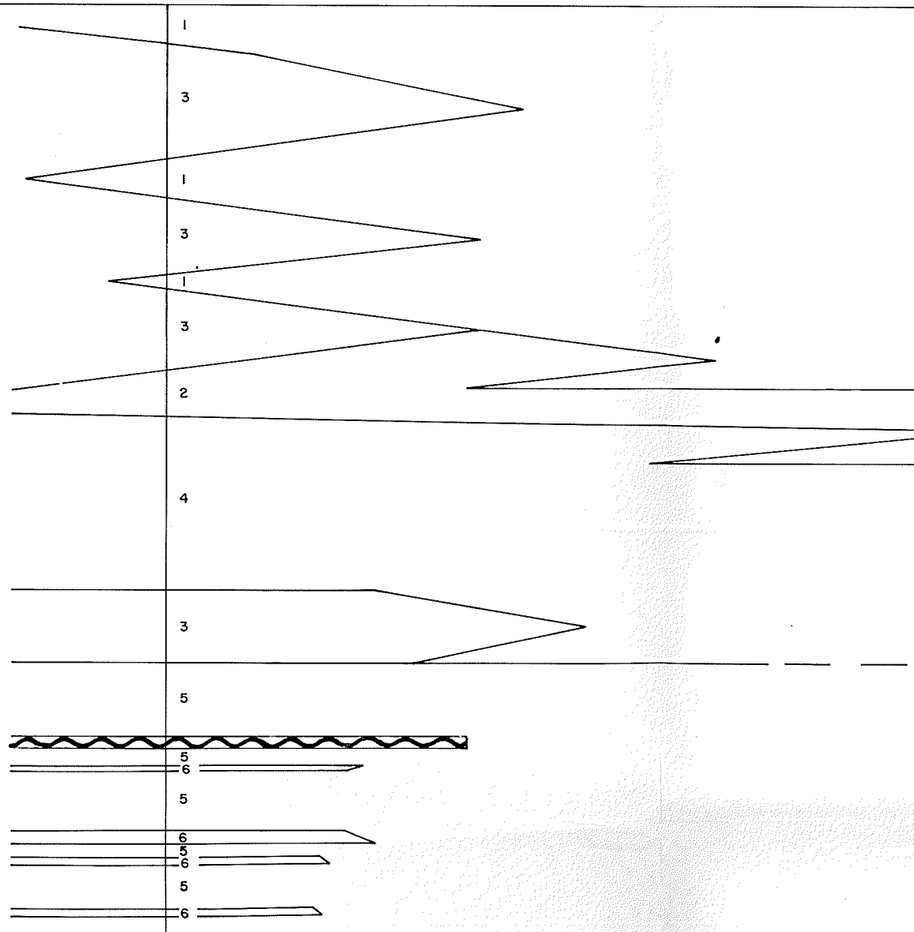


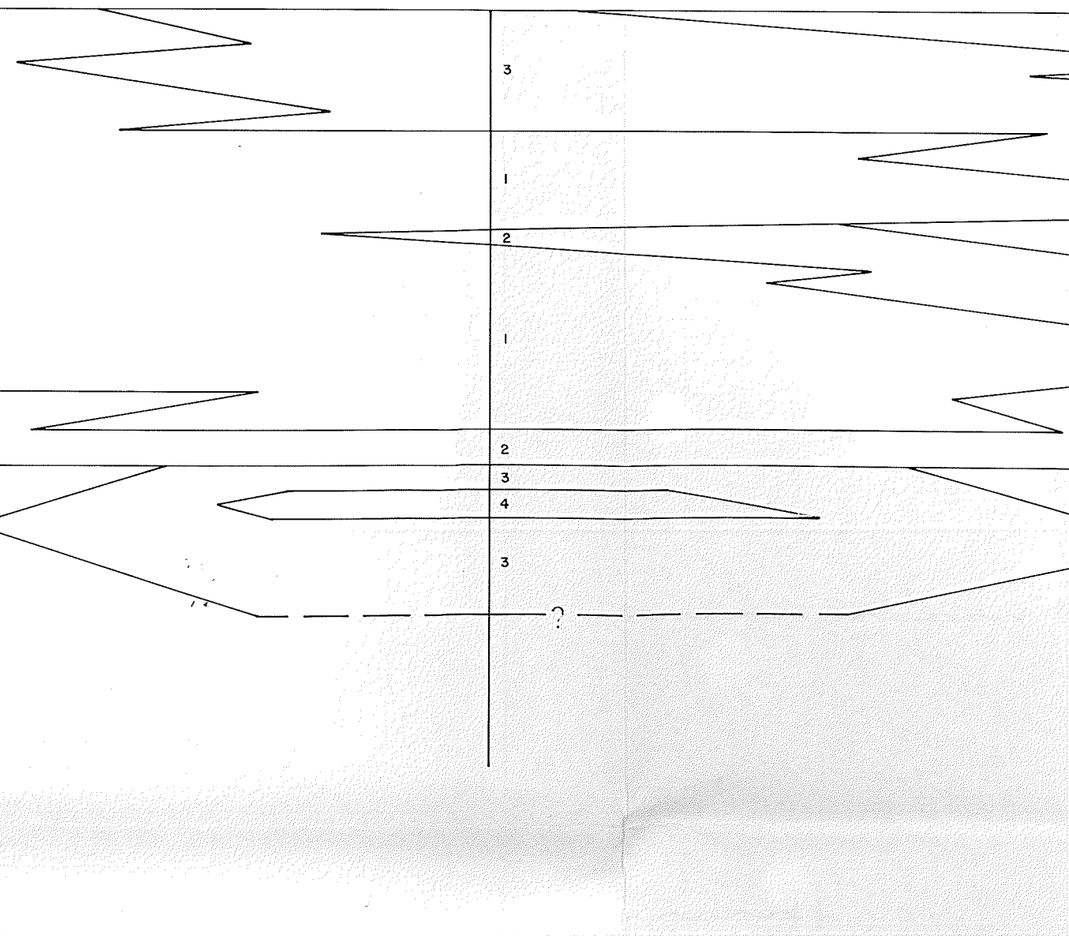
WEST

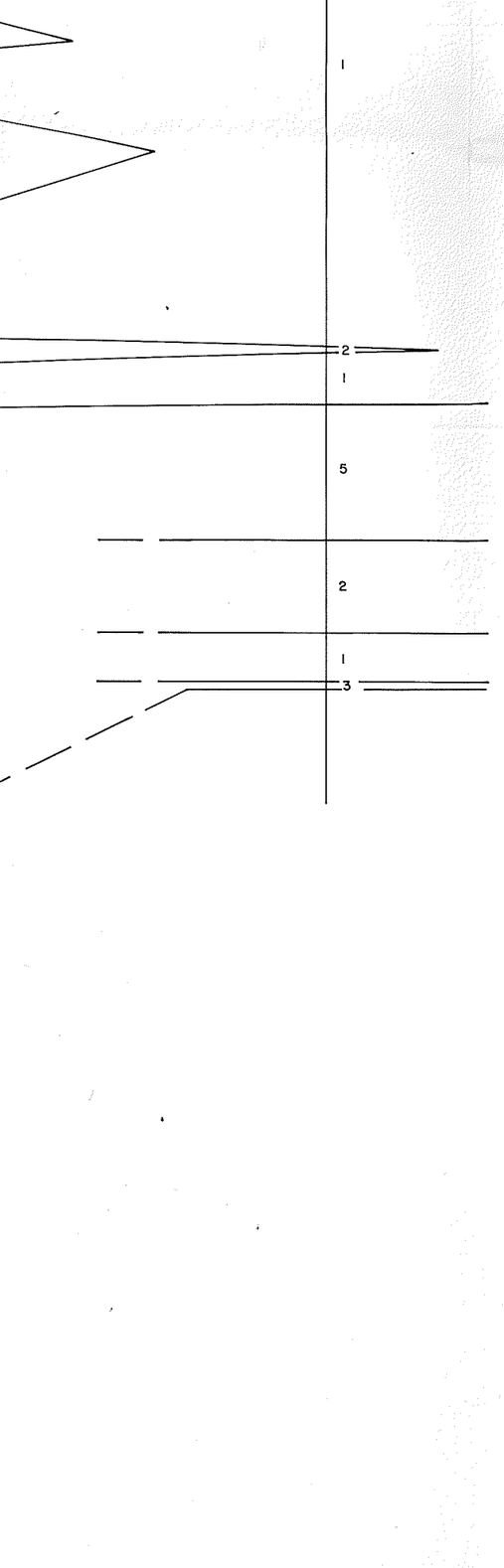
A

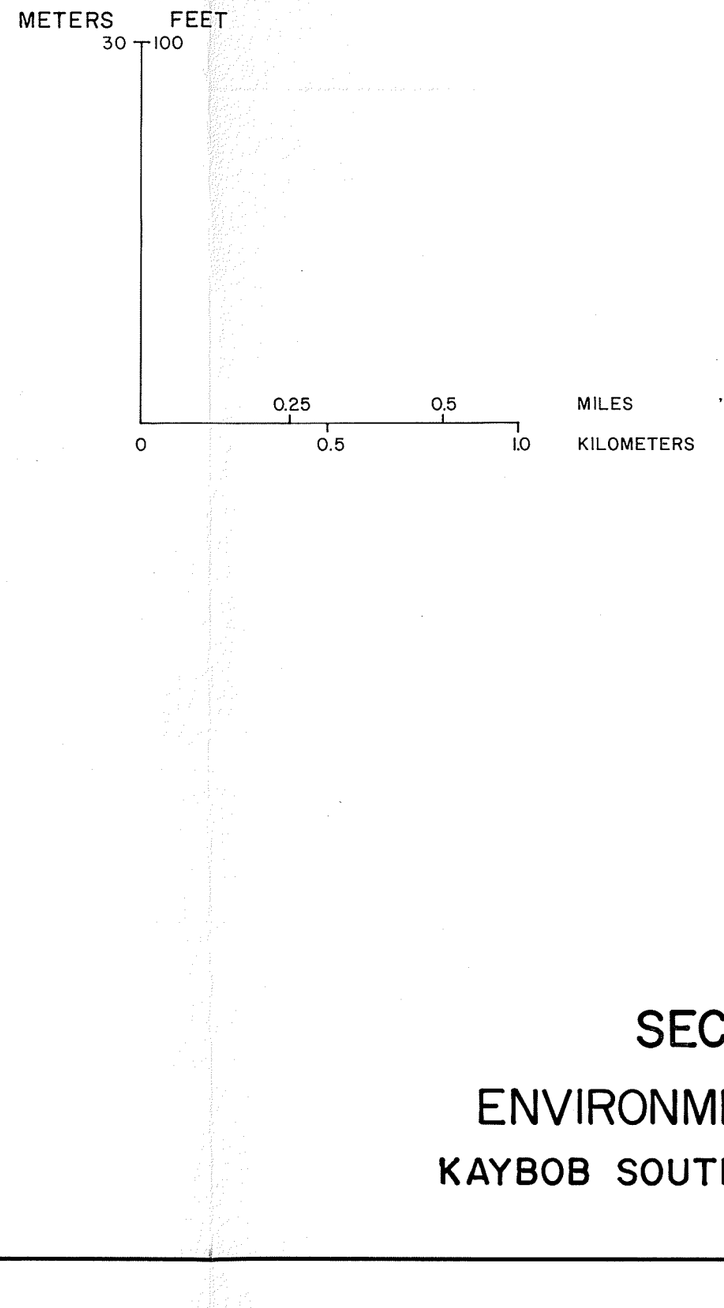
7-5-59-18
W5M

6-28-58-18
W5M









SECTION A-B

ENVIRONMENT SUMMARY

KAYBOB SOUTH AREA - WEST BANK

FIGURE II

5

4

2

1

2

3

5

2

?

1

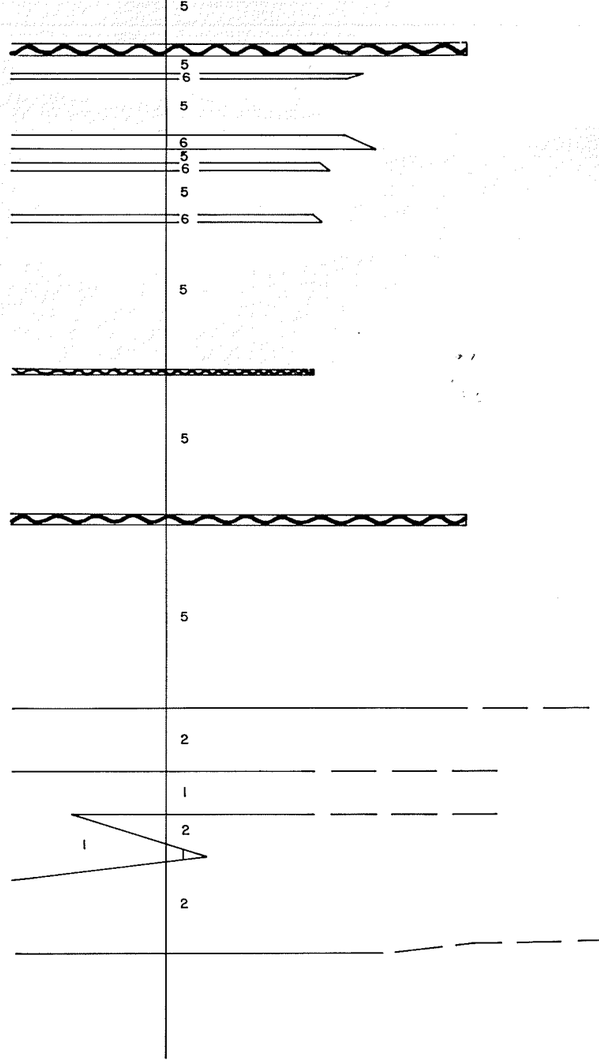
5

2

1

5

ORMATION



BASE OF SWAN HILLS FORMATION

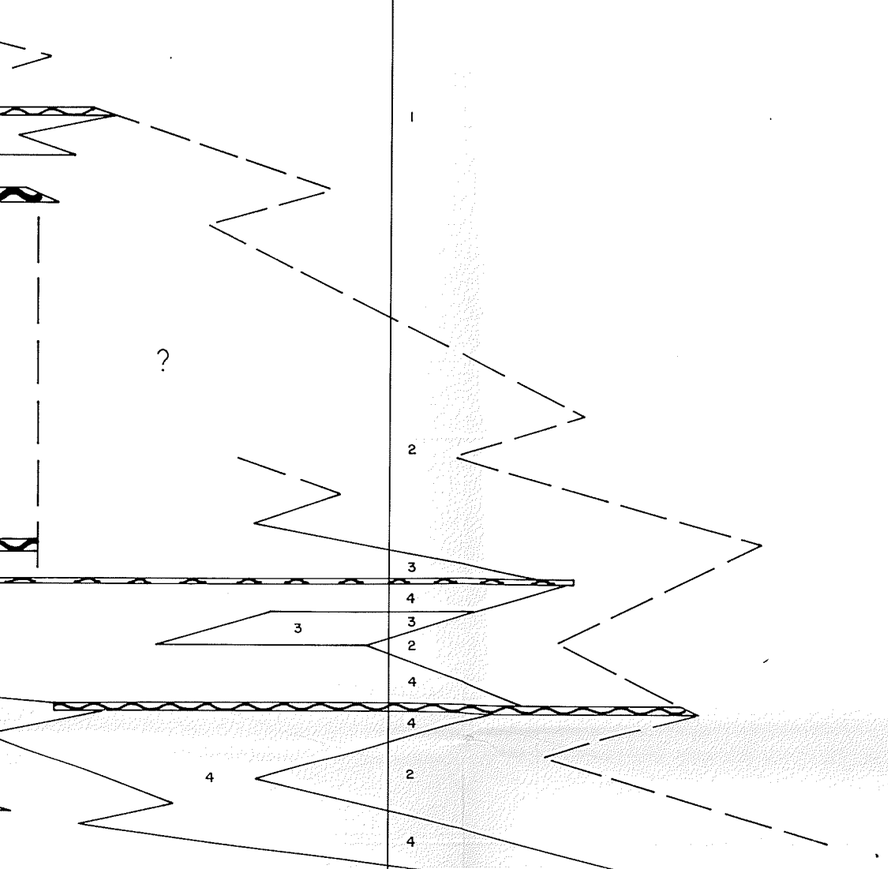
EAST

D

12-25-63-18

W5M

DATUM: TOP OF BEAVERHILL LAKE GROUP



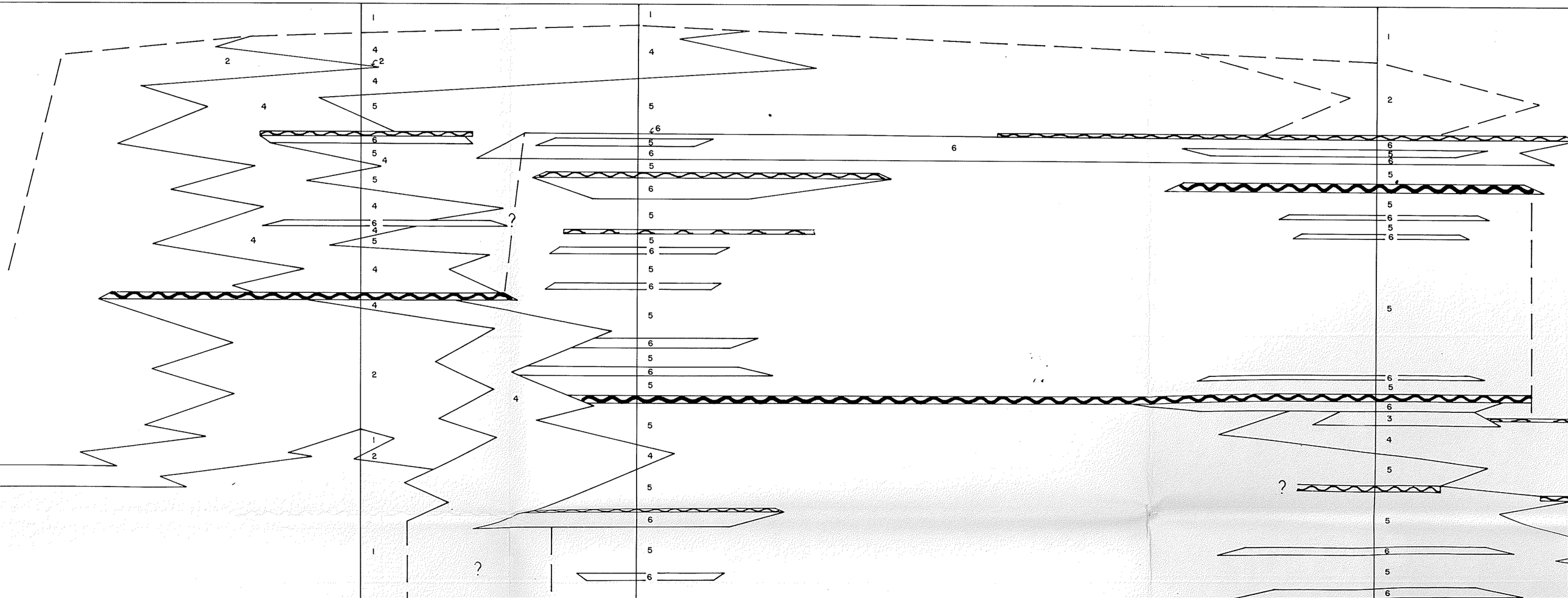
ENVIRONMENTS

1	OFF REEF
2	FORE REEF
3	SHELF MARGIN
4	OPEN SHELF
5	LAGOON
6	TIDAL FLAT
~~	GREEN SHALE
~ ~	UNCONFORMITY (GREEN SHALE ABSENT)

2-18-62-18
W5M

2-18-63-18
W5M

6-23-63-18
W5M

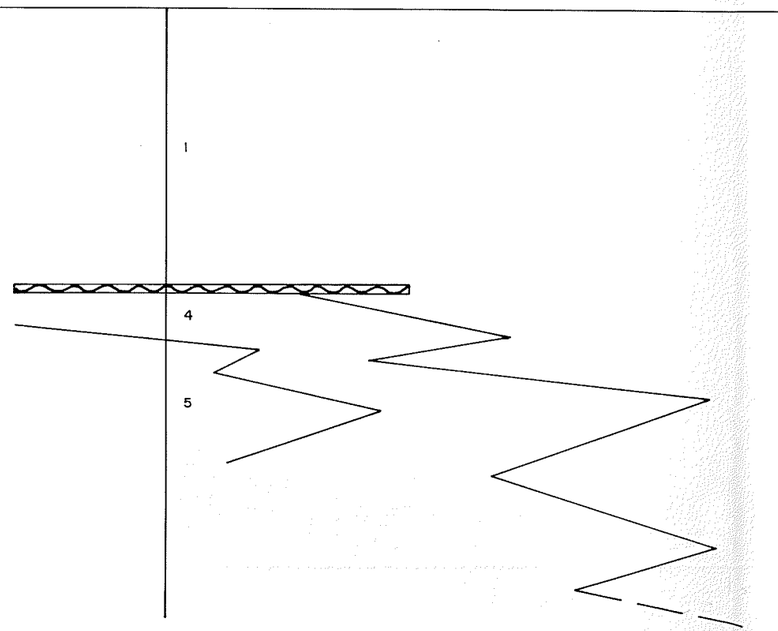


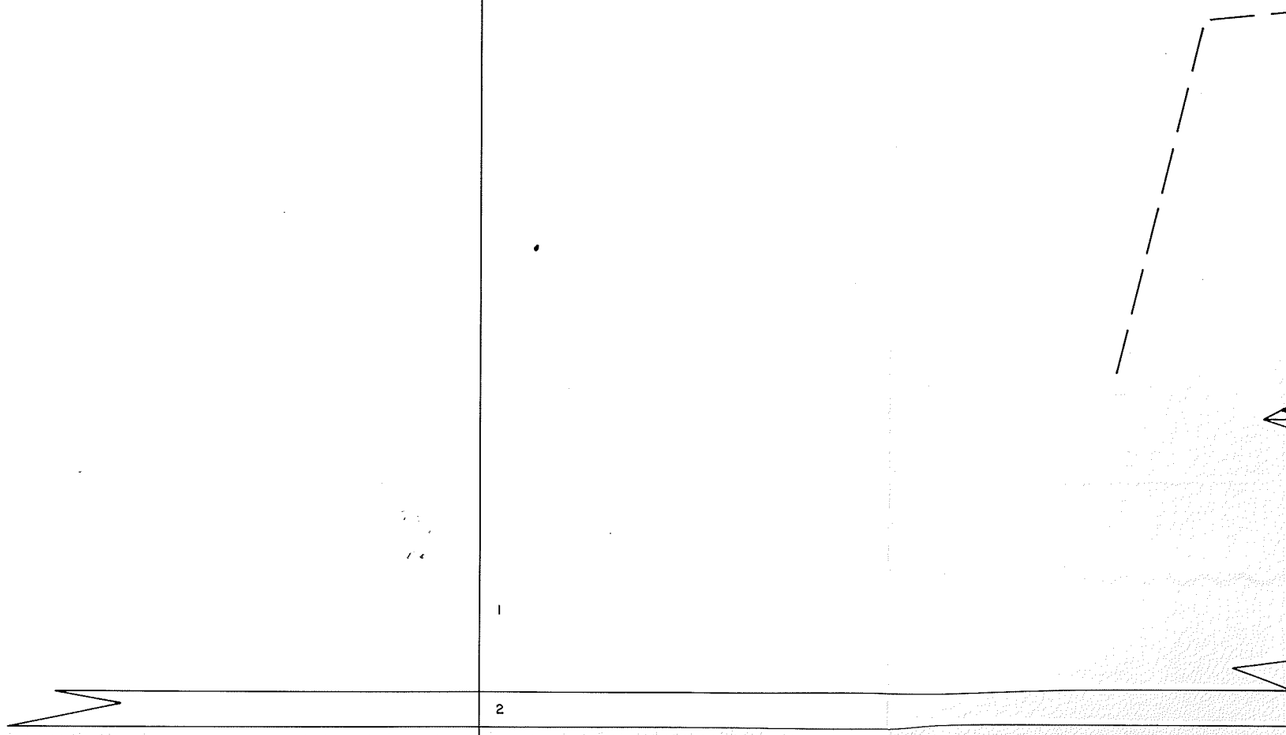
WEST

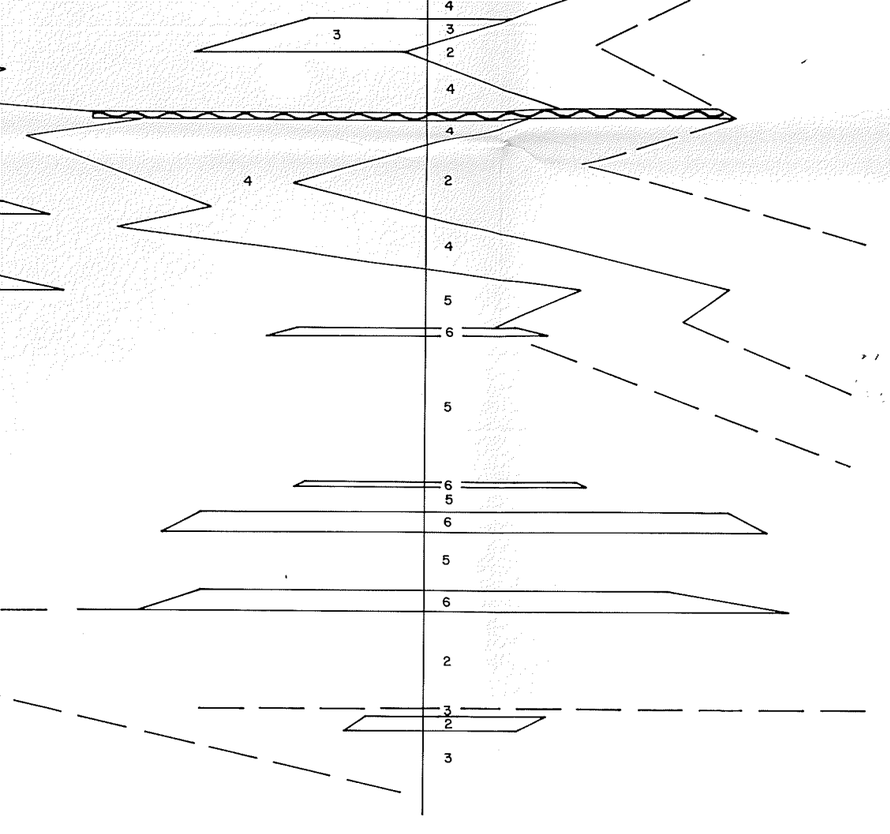
C

6-33-62-20
W5M

12-5-63-19
W5M







METERS FEET

30 100

NOTE: HORIZONTAL SCALE APPROXIMATE

0 0.5 1.0 MILES

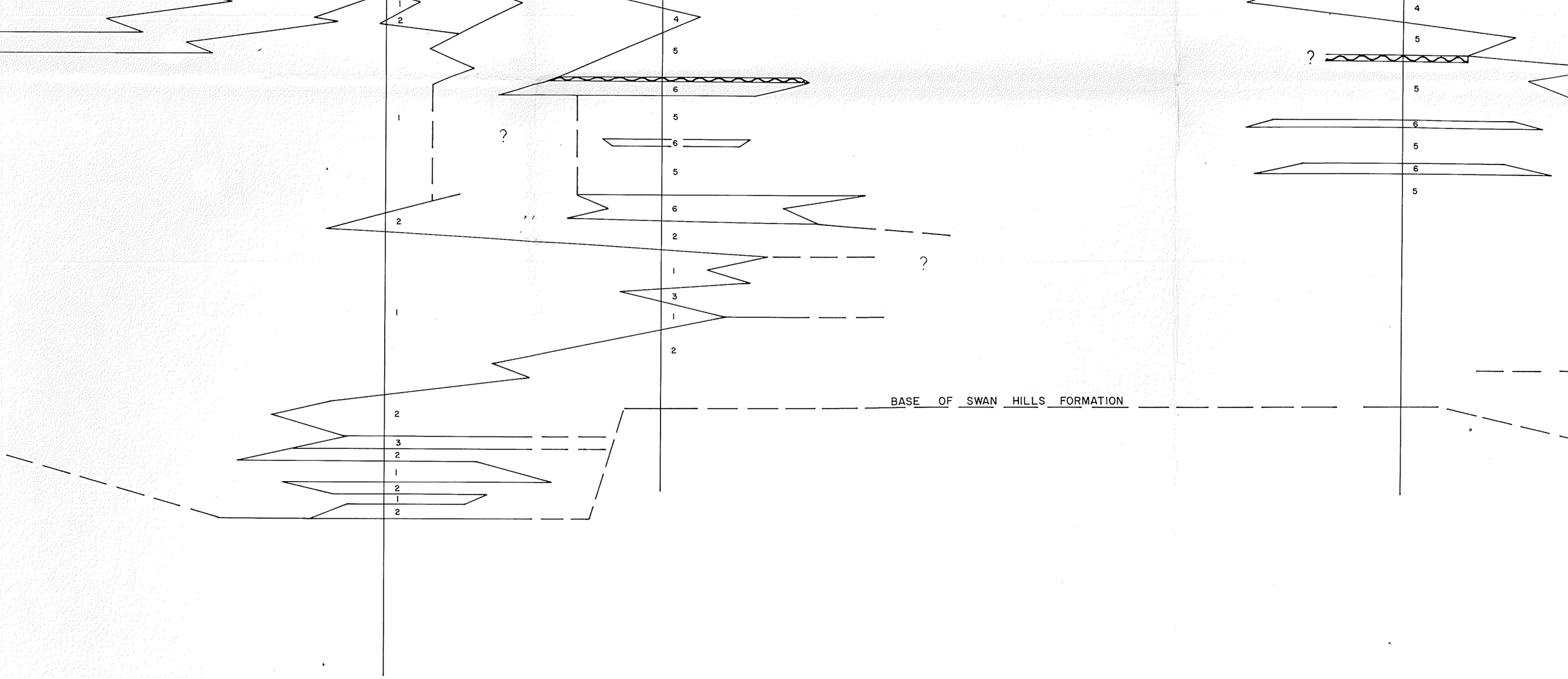
1.0 KILOMETERS

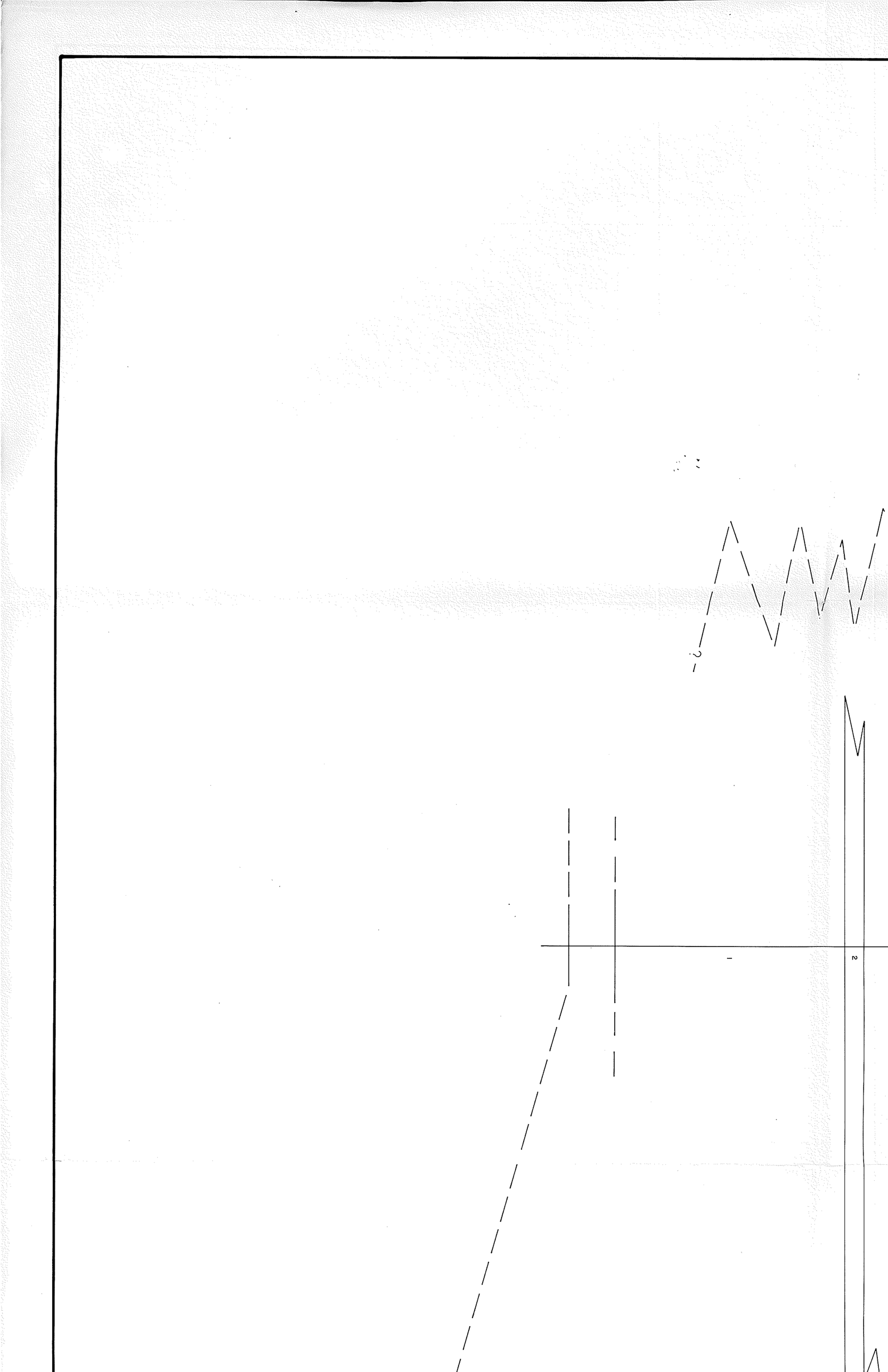
SECTION C-D

ENVIRONMENT SUMMARY

KAYBOB SOUTH AREA - EAST BANK

FIGURE 12


BASE OF SWAN HILLS FORMATION



SOUTH

B

6-6-59-17

W5M

DATUM: TOP OF BEAVERHILL LAKE GROUP

ENVIRONMENTS

1	OFF REEF
2	FORE REEF
3	SHELF MARGIN
4	OPEN SHELF
5	LAGOON

11-1-61-19
W5M

10-3-60-18
W5M

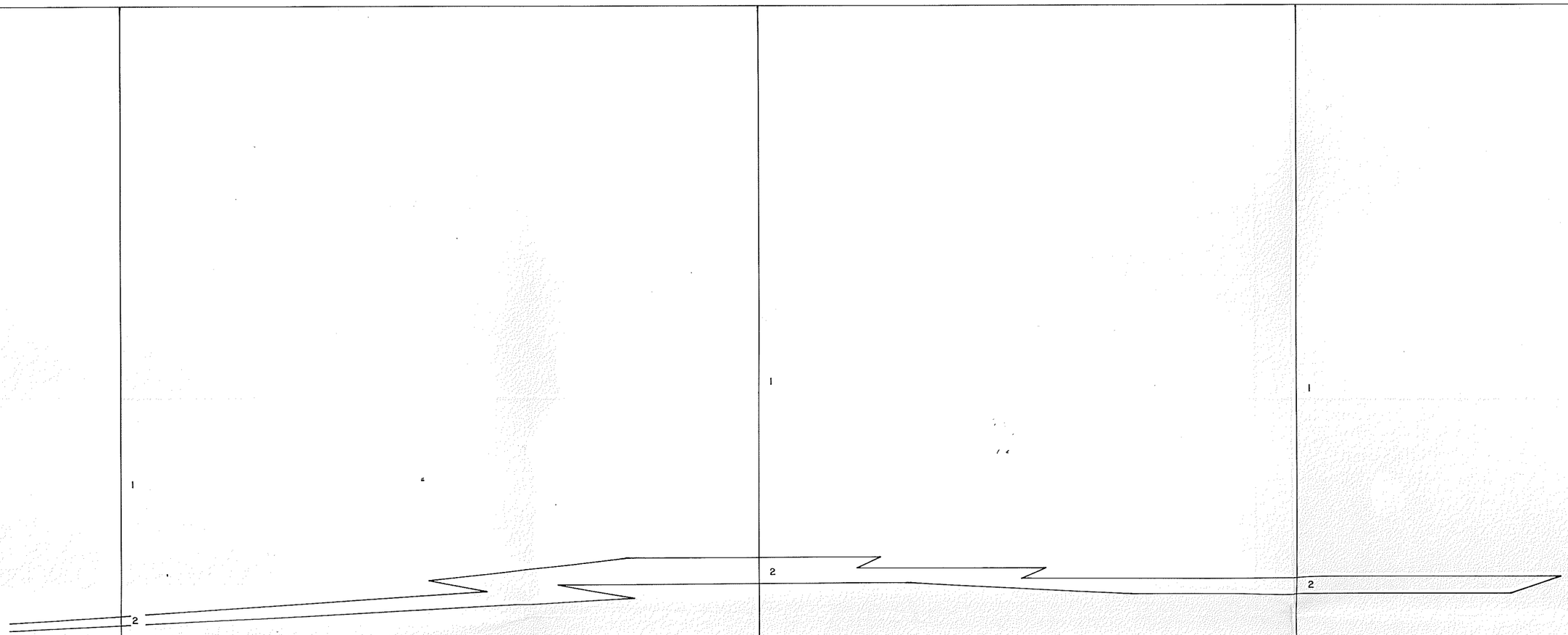
NORTH

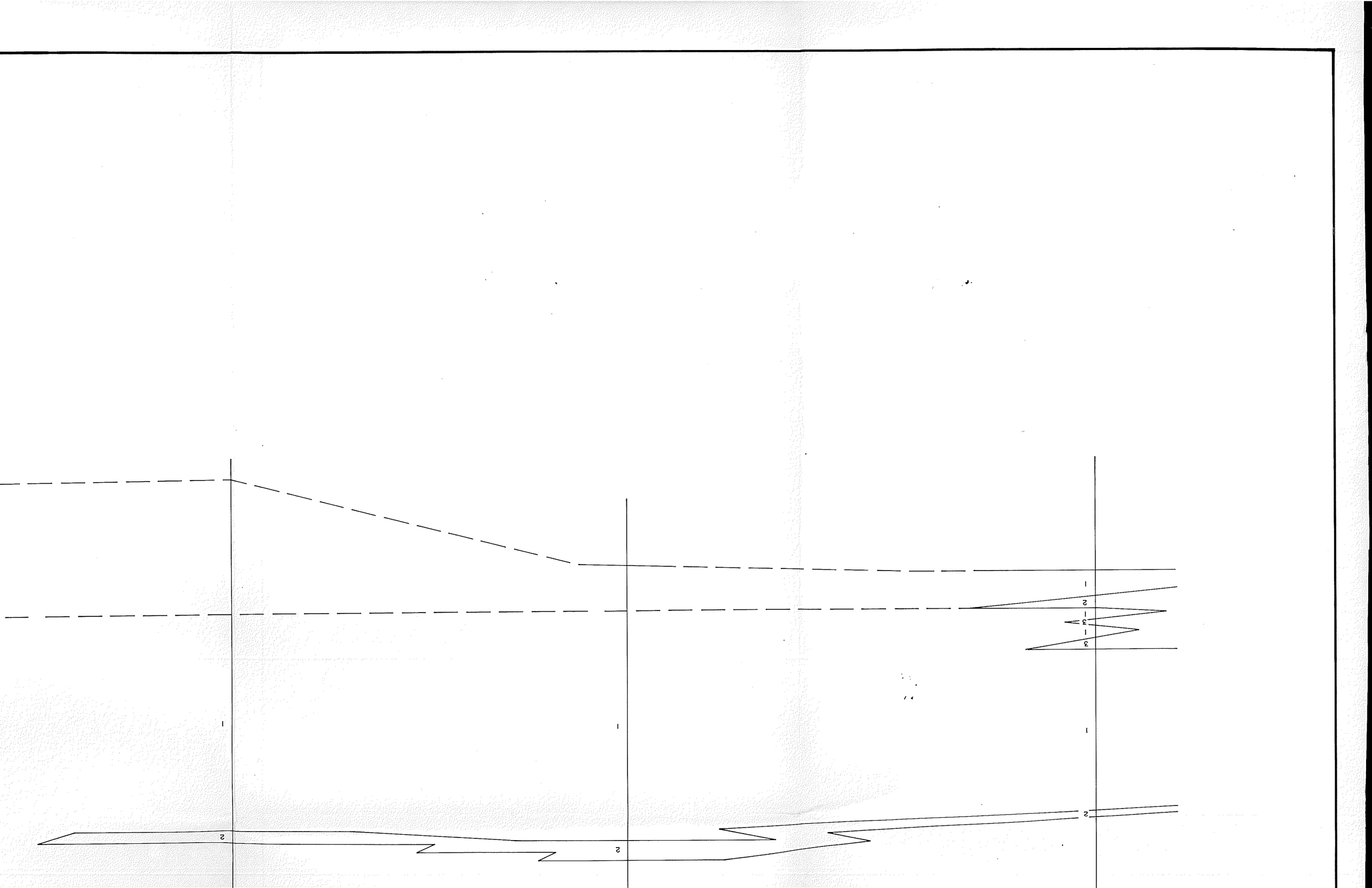
E

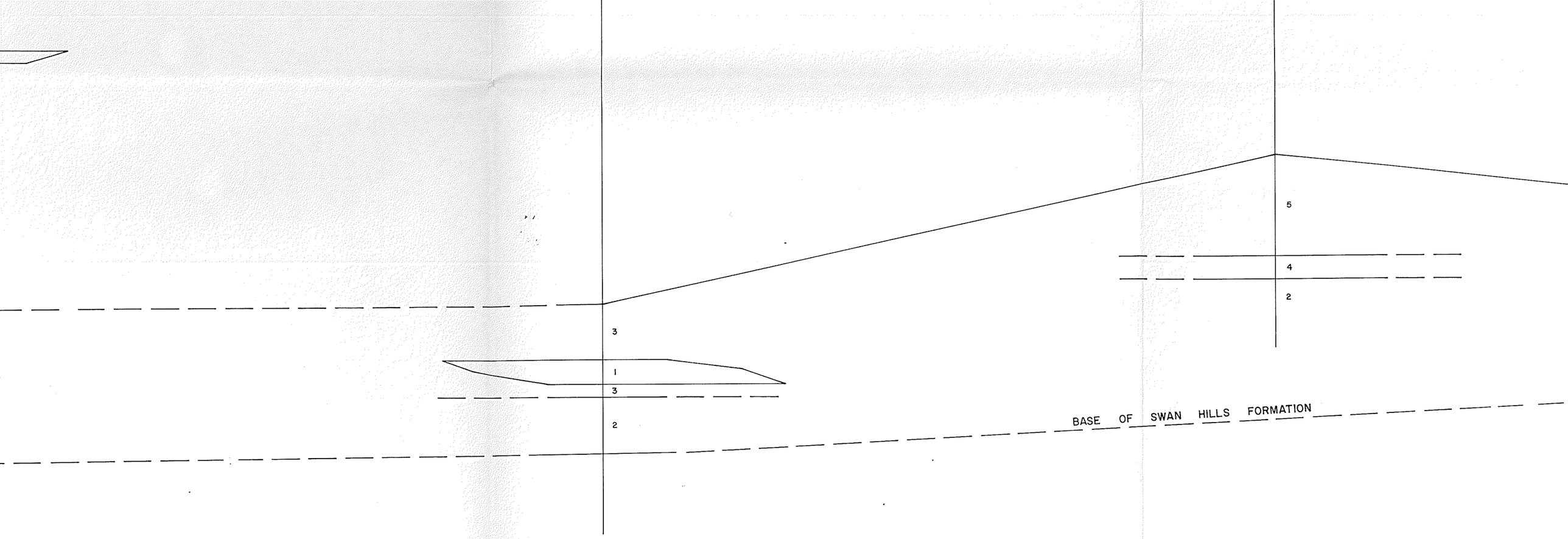
2-28-63-20
W5M

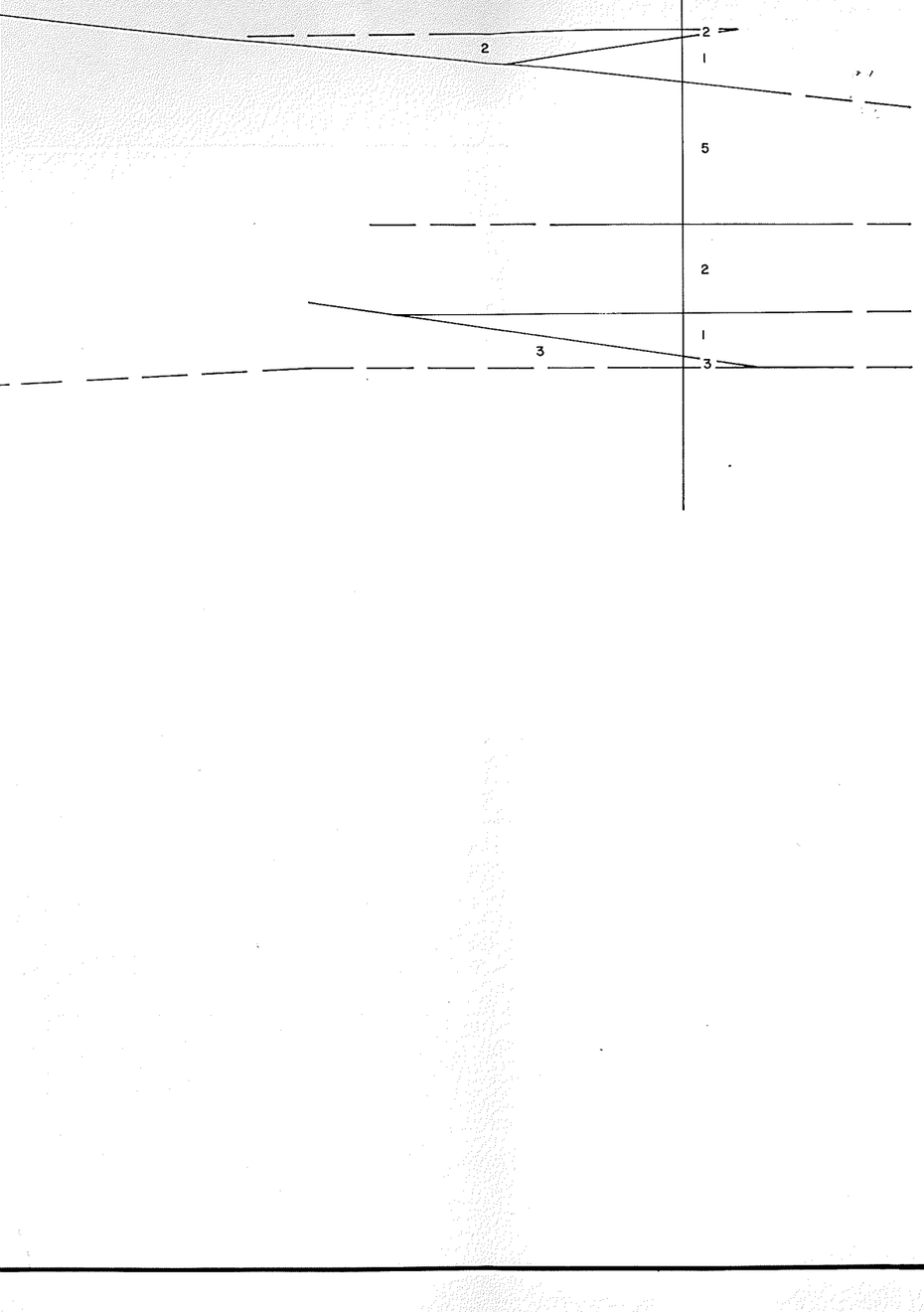
12-5-63-19
W5M

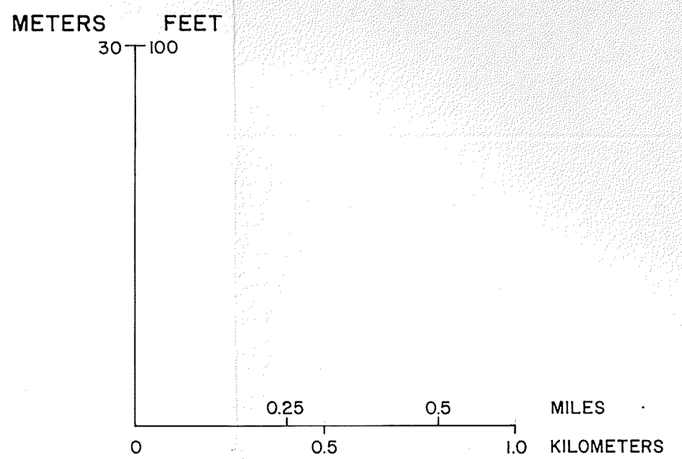
4-16-62-19
W5M




1
2
1
3
1
3
1
1
1
2
2
2


5
4
2
3
1
3
2
BASE OF SWAN HILLS FORMATION





SECTION E-B

ENVIRONMENT SUMMARY

KAYBOB SOUTH AREA - CHANNEL

FIGURE 13