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A BIOFACIES AND LITHOFACIES STUDY OF THE
RAMPARTS FORMATION, MOUNTAIN-GAYNA
RIVER REGION, NORTHWEST TERRITORIES., CANADA

by

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A thesis submitted to the Faculty of
Graduate Studies in partial fulfilment
of the requirements for the degree of
Master of Science

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ABSTRACT

A biofacies and lithofacies analysis was made of the Ramparts Formation, a Middle Devonian (Givetian) and Upper Devonian (Frasnian) carbonate unit that crops out along an escarpment between the Mountain and Gayna Rivers, approximately sixty miles west of Norman Wells, Northwest Territories, Canada. The objective of the study was to interpret the paleoenvironments and the history of the reef complex. An attempt was also made to investigate the various diagenetic changes that are evident in the rocks.

For this study thin sections and cellulose peels, as well as the polished surfaces of hand specimens, gathered from sixteen surface sections, were studied.

The Ramparts Formation can be divided into two informal members, the lower (platform) member (incorporating the Carcajou marker), and the upper (reef) member. On the basis of lithologic and paleontologic criteria the members can be further subdivided into facies and units. The platform member consists of three laterally contiguous facies, from east to west, the platform edge, platform, and shallow shelf facies.

The reef member can be divided into seven laterally contiguous facies, from east to west, the off-reef, fore-reef, organic-reef, back-reef, marginal-shoal, organic-shoal, and sublittoral facies.

Diagenetic processes that have affected the Ramparts Formation can be divided into seven stages. In order in which they have affected the rocks these are: processes preceding first generation calcite cementation; first generation calcite cementation; processes following first generation and preceding second generation calcite cementation; processes following second generation cementation and preceding stylolitization; and processes synchronous with and following stylolitization.

The Ramparts Formation is interpreted to have three stages of development:

a) Stage I. During Stage I the Givetian sea gradually became shallower. In response, widespread, scattered biostromes and bioherms and more localized bioherms and biostromes developed.

b) Stage II. During Stage II the Givetian sea underwent a rapid deepening. This was accompanied by

the development of organic shoals.

c) Stage 111. Stage 111 can be subdivided into two substages: 1) During Substage 1 the sea, possibly of Upper Devonian (Frasnian) age, continued to deepen at a decreased rate. The nucleus of a large, laterally zoned reef complex developed on the platform. In the marginal areas an organic-shoal, a sublittoral, and an off-reef facies developed.

11) During Substage 11 a further decrease in the rate of water level rise occurred and was accompanied by a pronounced lateral expansion of the reef complex.

The growth of the reef complex ceased when the rate of increase of the water depth in the basin overtook the rate of upward growth.

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Drafting of figures was done by L. A. Williams of Carleton University and by my wife.

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INTRODUCTION

A) General Statement

Most of the petroleum and natural gas produced in Western Canada comes from Devonian stromatop-
oroid reef complexes. Many of the detailed surface and subsurface reef studies have dealt with reef complexes of Upper Devonian (Frasnian) age. This study concerns that part of the Ramparts Formation exposed in an escarpment west of Norman Wells (Figures 1 and 2, p.2&4). Here the Ramparts Formation is a reef complex of late Middle Devonian (Givetian) to early Upper Devonian (Frasnian) age. Excellent exposure, relatively easy access and relatively minor secondary alteration of the rocks make this location an ideal study area.

B) Objective

This study is essentially a biofacies and lithofacies analysis of the Ramparts Formation exposed along the escarpment with the objective of interpreting the paleo-environments, and the history of the reef complex.

FIGURE 1
INDEX MAP SHOWING LOCATION
OF THE STUDY AREA

C) Methods

An attempt was made:

- a) to identify the fossils, describe their distribution, and suggest their significance in petrogenesis,
- b) to identify the rock types and their relationship to depositional environment,
- c) to investigate the various diagenetic changes that have occurred in the rocks since their deposition as sediments.

For this study approximately four hundred hand specimens were gathered from sixteen surface sections exposed along the escarpment (Figure 2,p.4). All specimens were cut, polished, and etched with dilute hydrochloric acid. The polished surfaces were coated with mineral oil and examined optically using a low power binocular microscope. Two hundred and seventy-seven thin sections and two hundred and twenty cellulose peels were prepared from the hand specimens. Of these, one hundred thin sections and fifty cellulose peels were stained with the combination stain, Alizarin Red-S and potassium ferricyanide to aid in differentiation of ferroan from non-ferroan calcite and dolomite. Most of the thin sections were stained with Alizarin Red-S alone. The thin sections and the peels were examined using a low power binocular microscope and a petrographic binocular microscope.

More detailed descriptions of the methods are outlined in Appendix Two, p. 204.

D) Location and Access

The Ramparts Formation crops out along an escarpment between Mountain and Gayna Rivers, sixty miles west of Norman Wells, Northwest Territories (Figures 1 and 2, p. 2 & 4). The escarpment is approximately twenty miles long and lies between $65^{\circ} 17' N$ and $65^{\circ} 18' N$, and $128^{\circ} 47' W$, and $129^{\circ} 28' W$.

The escarpment area is accessible by fixed-wing aircraft or by helicopter from Norman Wells. Air service connects Norman Wells with Yellowknife and Edmonton. Barge service is provided on the Mackenzie River, linking Norman Wells and Hay River.

Outcrops are most easily reached where streams cut through the escarpment. In most other places the escarpment face is too steep for climbing without mountaineering techniques.

HISTORY OF RESEARCH ON THE RAMPARTS FORMATION

A) Previous Work

Numerous stratigraphic and paleontologic studies of the Ramparts Formation have been published. A complete literature review is not attempted, but a table is provided showing the history of Middle and Upper Devonian nomenclature (Table 1, p. 7). Major works concerning the region include in chronological order, those of: Kindle and Bosworth (1921), Hume and Link (1945), Warren and Stelck (1949), Hume (1954), Crickmay (1960), Bassett (1961), Lenz (1961), House and Pedder (1963), Caldwell (1964), Braun (1969), Tassonyi (1968), James (1969), Statham (1969), Crickmay (1970), MacKenzie (1970), and Law (1971). The works by Tassonyi (1968) and Crickmay (1970) give good reviews of the contributions made by most of the previously mentioned authors.

James (1969) made a petrographic study of the Bell Creek section (KK of this study). The major rock components were identified and the section was divided roughly into units.

Statham (1969) examined both core and hand specimens from the Kee Scarp Formation in the subsurface

KINDLE and BOSWORTH, 1921	HUME and LINK 1945	WARREN and STELCK, 1950	BASSETT 1961	BRAUN 1966	CRICKMAY 1970	MACKENZIE 1970	THIS REPORT
UPPER DEVONIAN	BOSWORTH SS. and SIL.	BOSWORTH	IMPERIAL F.M.	IMPERIAL F.M.	IMPERIAL F.M.	IMPERIAL F.M.	IMPERIAL F.M.
	FORT CREEK SH.	SILTY SH. BIT. SH. KFF SCARP LOWER FT. CREEK SIL.					
	IMPERIAL F.M.	BEAVERTAIL LS.	CANOL F.M.	CANOL F.M.	CANOL F.M.	CANOL F.M.	CANOL F.M.
	IMP. F.M.	RAMPARTS	UNNAMED BEDS	UNNAMED BEDS	BEAVERTAIL SHALE F.M. (argillaceous Rock)	BEAVERTAIL F.M.	BEAVERTAIL F.M.
	U. NON BIT. SIL.	RAMPARTS LS.	KFF SCARP F.M.	KFF SCARP F.M.	RAMPARTS F.M.	RAMPARTS F.M.	RAMPARTS F.M.
	BIT. SH.	HARE IND. SH.	HARE INDIAN F.M.	HARE INDIAN F.M.	HARE INDIAN F.M.	HARE INDIAN F.M.	HARE INDIAN F.M.
	RIFT LS.	RAMPARTS SH.	HUME F.M.	HUME F.M.	HUME F.M.	HUME F.M.	HUME F.M.
	LOWER SHALE						
	UPPER LS. MEMBER						
	MIDDLE SIL. MEMBER						
	LOWER LS. MEMBER						
MIDDLE DEVONIAN	RAMPARTS F.M.						
	BEAVERTAIL LS.						
	RAMPARTS LS.						
	HARE INDIAN RIVER SHALE						

TABLE I
HISTORY OF NOMENCLATURE
(THIS IS NOT A CORRELATION CHART)

at Norman Wells and at a quarry a few miles to the northeast. On the basis of petrographic and paleontologic criteria the Kee Scarp Formation was divided into two informal members, a lower platform member and an overlying massive member, termed the reef complex. Most of the rocks of the platform member were included in a coral packstone facies, (P. 40). The reef complex was divided laterally into a fore-reef zone, characterized by the stromatoporoid and fine pellet packstone facies, into an organic reef zone characterized by the massive stromatoporoid grainstone facies, and into the back-reef zone characterized by the fine pellet packstone and Amphipora packstone facies. The division of the reef complex was based on an environmental interpretation of stromatoporoids.

Crickmay (1970), in an examination of eight stratigraphic sections from the Norman Wells-Fort Good Hope region, separated the Beavertail from the Ramparts Formation and proposed the existence of a regional disconformity at the base of the Beavertail Formation. In addition it was demonstrated that most of the Beavertail Formation was of Upper Devonian (Frasnian) age.

MacKenzie (1970) studied the Middle and Upper Devonian carbonate succession in the vicinity of Powell Creek (Figure 2, p. 4, sections KJ and KL of this study). He suggested that the succession

can be divided (from top to bottom) into three units: limestone turbidites, allochthonous reef debris, and reef margin carbonates of the Ramparts Formation (Table 1, p. 7). Upper Devonian brachiopods and conodonts were collected from the allochthonous reef debris unit suggesting an Upper Devonian (Frasnian) age for the two units overlying the Ramparts Formation of MacKenzie.

B) Nomenclature

Much confusion exists over nomenclature in the study region. Formational nomenclature has been reviewed in a number of publications, the latest and most complete treatment being that of Caldwell (1964).

In this thesis the terminology proposed by Tassonyi (1968) is adopted.

FIGURE 3
PHYSIOGRAPHIC SETTING
(Bostock, 1970)

REGIONAL GEOLOGY

A) Physiographic Setting

The study area lies within the northwestern portion of the Mackenzie Plain of the Cordilleran physiographic region (Bostock, 1970). The Mackenzie Mountains lie to the west, the Peel Plateau and Peel Plain to the north, the Franklin Mountains to the north and west, the Great Slave Plain to the west and south, and the Liard Plateau to the south and east (Figure 3, p. 10).

B) Tectonic Setting

The study area is located on the eastern side of the Mackenzie Arch in the western border zone of the Mackenzie Trough which with the Canadian Shield, were principal tectonic elements during Middle Devonian (Givetian) time (Gabrielse, 1970). Figure 4, p. 12 shows these elements.

C) Stratigraphy

The general geology of the study area is shown in Figure 7, (in pocket).

a). Formation Descriptions

Brief descriptions of all formations are presented in Table 2, p. 14. Detailed descriptions of

FIGURE 4
TECTONIC SETTING
(Gabrielse, 1970)

the Middle Devonian Hare Indian and Middle and Upper Devonian Ramparts Formation as well as the Upper Devonian Canol Formation are discussed here.

1) Hare Indian Formation

The name Hare Indian Formation applies to the shales underlying the Ramparts Formation as proposed by Kindle and Bosworth (1921). The total thickness of the Formation ranges from one hundred feet to seven hundred and seventy-two feet (Tassonyi, 1968, p. 73).

The Formation can be divided into two shale units (Tassonyi, 1968). The lower, thinner unit consists of dark brown to black, bituminous, calcareous and non-calcareous shale. This shale contains scattered trilete spore cases, rare fragments of Tentaculites and Styliolina, rare pyrite nodules, and poorly preserved brachiopod shells, in the upper part. The thickness of this unit ranges from thirty to fifty feet.

The upper unit of the Hare Indian Formation is predominantly shale with generally less than ten percent of interbedded, calcareous siltstone and argillaceous or silty limestone. This unit, (from one hundred and ten feet to seven hundred and thirty feet thick,) contains spore-case fragments, rare trilete spore cases, brachiopod fragments, rare ostracods, and some crinoid fragments.

TABLE OF FORMATIONS
AFTER TASSONYI (1968)

TABLE 2

FRA	PERIOD OR EPOCH	STAGE	FORMATION	THICKNESS (feet)	LITHOLOGY DESCRIPTION
PALEOZOIC	UPPER DEVONIAN	FRAS	IMPERIAL FORMATION	0 1750	Sandstones and siltstones underlain by grey, partly calcareous shales; sandstones, calcareous, non-glauconitic, fine-grained, cemented, argillaceous.
			LOCAL UNCONFORMITY		
			CANOL FORMATION	100 400	Shale, black to chocolate brown, hard; siliceous, partly pyritic, generally unfossiliferous.
	REGIONAL DISCONFORMITY WEST AND NORTH OF FORT GOOD HOPE				
	MIDDLE DEVONIAN	GIVERTIAN	RAMPARTS FORMATION	0 825	Carbonate reef complex and associated shelf carbonates <u>Reef member</u> 0 590' light grey-buff coloured limestones, commonly massively bedded, containing numerous corals, stromatoporoids, algae, brachiopods and ostracods. <u>Platform member</u> 0 190' well-bedded, brown to medium dark grey, limestones, containing <i>Stringocephalus</i> , <i>Rensselandia</i> , corals, stromatoporoids, ostracods, molluscs and trilobites.
		FIFELIAN	HARE INDIAN FORMATION	100 - 772	Shale, greenish grey to dark grey, calcareous, flaky, interbedded with calcareous siltstones and limestones containing brachiopods, ostracods, crinoid fragments, and rare spore cases.
			HUME FORMATION	213 525	Limestone, grey, containing corals and stromatoporoids, alternating with shale, grey and greenish grey containing brachiopods and ostracods. (Divided into three informal members)
			LOCAL DISCONFORMITY POSSIBLE IN THE NORMAN WELLS AREA AND IN THE SOUTHEASTERN SECTOR		
		BEAR ROCK FORMATION	400 1,115	<u>Brecciated member</u> 100 440' dolomite, brown, brecciated and non-brecciated, finely crystalline partly anhydritic. <u>Evaporate member</u> 1000' + predominately anhydrite, minor gypsum and interbedded dolomite.	

The contact of the Hare Indian Formation with the overlying Ramparts Formation is sharp in most cases. In others the Hare Indian Formation grades laterally and vertically into the lithology of the Ramparts platform member. In such cases the boundary between the Hare Indian Formation and the Ramparts Formation is placed arbitrarily where limestones typical of the Ramparts platform member predominate over Hare Indian shales.

ii) Ramparts Formation

The Ramparts Formation (Kindle and Bosworth, 1921; emended by Caldwell, 1964) includes the limestones lying above the Hare Indian Formation and below the Canol Formation. It incorporates the Ramparts-Beavertail sequence of Kindle and Bosworth, (1921) (Table 1, p. 7). The type section for the Ramparts Formation is located at the Ramparts gorge.

The Ramparts Formation is present in outcrop and in the subsurface near Norman Wells, Powell Creek, Imperial Hills, the northern Franklin Mountains, and Fort Good Hope. It has not been reported north of latitude 68° N, unless the reefal beds in the Anderson River region are of the Ramparts Formation. Thickness ranges from zero to eight hundred feet in exposures in the study area (James, 1969).

Two carbonate units are differentiated within the

Ramparts Formation, termed the platform (lower) and the reef (upper) members (Tassonyi, 1968, p. 80). The Carcajou marker (Tassonyi, 1968, p. 81) at the top of the platform member in most sections assists in making this subdivision.

The platform member consists predominantly of well-bedded, brown to medium-dark grey, brown-weathering, argillaceous, partly bituminous, slabby (2" to 6") to flaggy ($\frac{1}{4}$ " to 2") limestones with irregular partings of dark brown, platy ($\frac{1}{10}$ " to $\frac{1}{4}$ " to papery (less than $\frac{1}{10}$ ") argillaceous limestone. The amount of argillaceous and bituminous material decreases upward and strata become more massive and lighter in colour. Dolomitization is absent or negligible. This member is characterized by a fauna including Stringocephalus, Rensselandia, corals, stromatoporoids, ostracods, molluscs, and trilobites. The thickness of the platform member ranges from seventy to one hundred and sixty feet in the Norman Wells region to three hundred feet in the thesis area.

The Carcajou marker consists of a maximum of twenty-one feet of interbedded dark limestones and shales. This unit is characterized by a prolific fauna including Leiorhynchus castanea. Typical rocks of the platform member grade vertically into the

Carcajou marker wherever it is present. The contact between the Carcajou marker and the overlying reef member is placed at the top of the highest shaly bed. Where the Carcajou marker is absent the contact between the platform member and the reef member is based on the change in bedding and lithology.

The reef member consists of light grey to light buff-coloured limestones, commonly unevenly and massively (greater than 4') bedded. It contains abundant digitate and tabulate corals, stromatopoids, algae, brachiopods, and ostracods. Fossil content, massive bedding, and field relationships suggest that these are reef limestones (Tassonyi, 1968, p. 80). The thickness of the reef member ranges from three hundred feet in the Norman Wells region to five hundred feet in the thesis area.

Contact relationships between the Ramparts Formation and younger Devonian rocks differ from place to place in the study area as follows (Tassonyi, 1968, p. 84):

1. The Canol Formation disconformably overlies the Ramparts Formation as a result of pre-Canol uplift and subsequent erosion that affected the Fort Godd Hope - Point Separation region.
2. The Imperial Formation unconformably overlies the reef member where the Canol Formation is absent as a result of either non-deposition or post-Canol

erosion due to local uplift. The latter suggestion seems more likely. This type of contact is observed only in the Imperial Whirlpool No. 1 well (Figure 2, p. 4).

3. Various authors, including Warren and Stelck (1949) and Braun (1966), have postulated a hiatus of variable magnitude between Givetian (Ramparts reef member and basinal equivalents) and Frasnian rocks in the thesis region. Warren and Stelck (1949) cited pronounced faunal breaks in various sections as evidence in support of the hiatus. In the Norman Wells area the Canol Formation was, in some successions, thought to lie directly over sediments progressively older than the Ramparts limestones. Lenz (1961) supported the idea of a hiatus in the eastern, but not in the western, parts of the area. Braun (1966) reported a distinct ostracod faunal break between the Ramparts limestones and the Canol Formation. Tassonyi (1968), p. 84) suggested that in the Norman Wells area "the relationship of the thickness of the members of the Canol Formation over the top of the Norman Wells Pool to the thickness on the reef flanks indicates that the reef was the site of non-deposition (or erosion) during the initial

stage of deposition of the lower member of the Canol Formation. Although limited subaerial exposure of this or other reef tops can be accepted, bevelling (if any) of the reef tops could have been the result of marine abrasion resulting from progressive, gentle uplifts instead of a major regression of the Middle Devonian sea."

The hiatus proposed by Warren and Stelck (1949) may exist locally in the Norman Wells-Fort Good Hope region, but it is not as profound as was first suggested, and probably affected only the topographically highest parts of the Ramparts Formation.

4. On the reef flanks near Norman Wells, and in parts of the Mackenzie Trough, deposition was probably continuous. A basinal time equivalent to the Ramparts reef member and platform member should therefore exist in these areas.

iii) Canol Formation

Bassett (1961, p. 494) proposed the name Canol Formation for "the black shale unit that directly overlies the Kee Scarp" (Ramparts Formation). Thickness of the Formation ranges from zero at Imperial Whirlpool No. 1 to four hundred feet in the Norman Wells area.

The Canol Formation is informally divided into

EPOCH	STAGE	FORMATION LOWER MACKENZIE REGION	FORMATION GREAT SLAVE LAKE REGION
UPPER DEVONIAN	FRASNIAN	CANOL	HAY RIVER
		RAMPARTS	SLAVE POINT
MIDDLE DEVONIAN	GIVETIAN	HARE INDIAN	SULPHUR POINT
			PRESQUILLE
			PINE POINT
			CHINCHAGA
	EIFELIAN	HUME	

FIGURE 5
CORRELATION OF LOWER MACKENZIE VALLEY AND GREAT SLAVE LAKE
FRASNIAN, GIVETIAN, AND EIFELIAN FORMATIONS
(BASED IN PART ON CALDWELL, 1967)

upper, middle, and lower members (Tassonyi, 1968, p. 90). The lower member consists of black to dark chocolate-coloured, very hard, siliceous, non-calcareous shales. The middle member consists of grey to dark grey, slightly calcareous and non-calcareous, and partly bituminous shales. The upper member is commonly grey to black, and slightly to moderately bituminous. The members can be separated easily in subsurface on the basis of mechanical logs. The lower member ranges in thickness from fifty to four hundred feet, the middle member from twenty-five to ninety feet, and the upper member from seventy to one hundred feet.

The Canol Formation has the following relationships with the underlying strata:

1. It is absent, as in Imperial Whirlpool No. 1 where the Imperial Formation is in contact with the reef member of the Ramparts Formation.
2. It directly overlies the Ramparts Formation (Contact relationships have been described in the section on the Ramparts Formation, p. 15).
3. It directly overlies basinal equivalents of the Ramparts Formation. In some places the Formation is very thick where it overlies the relatively thin Hare Indian Formation and may include the shaly time equivalents of the

FIGURE 6

THICKNESS RELATIONSHIPS OF THE PLATFORM AND REEF MEMBERS OF THE RAMPARTS

FORMATION IN THE NORMAN WELLS - FORT GOOD HOPE REGION

(BASED ON WELL LOGS AND JAMES, 1969)

Ramparts Formation (Tassonyi, 1968, p. 93).

b) Regional Middle and Upper Devonian Correlation

Figure 5, p. 20 shows the correlation of the Middle and Upper Devonian Formations in the Lower Mackenzie River region and in the Great Slave Lake region. Figure 6, p. 22 shows the correlation of the lower (platform) and upper (reef) member of the Ramparts Formation in the Norman Wells, Fort Good Hope region.

i) Correlation of the Ramparts Formation

Stringocephalus, the Givetian index fossil has been found in the lower (platform) member of the Ramparts Formation at the following locations: the Ramparts gorge, the Mountain - Gayna River escarpment, several localities north of the Hare Indian River, Carcajou Ridge, and several wells in the Norman Wells oil field. Givetian goniatites have been discovered in the upper part of the Ramparts Formation, exposed at Carcajou Ridge (House and Pedder, 1963) and Braun (1966, p. 252) discovered a Givetian ostracod fauna in an Ramparts Formation exposed at West Powell Creek (section KJ this study). Mackenzie (1970, p. 478)

discovered Upper Devonian (Frasnian) brachiopods and conodonts at the top of the Ramparts Formation exposed at Powell Creek (section KL this study).

Thus sufficient evidence is present to correlate the Ramparts Formation with the Givetian and Frasnian stages.

Several authors have suggested a correlation of the Ramparts Formation with the Slave Point limestones and the underlying Presqu[^]ile dolomites in the Great Slave Lake region. According to Bassett (1961, p. 492) the lower Ramparts Formation can be correlated with the Presqu[^]ile dolomites exposed at Presqu[^]ile Point on Great Slave Lake at times of low water. Caldwell's (1967) study of the regional stratigraphic distribution of ambocoeliid brachiopods supports this correlation and suggests the correlation of the Ramparts Formation with the upper Pine Point Formation, Sulphur Point Formation, and the Slave Point Formation. The lower portion of the Hay River Formation and the upper part of the Ramparts Formation may be correlative. The respective parts of these formations both contain Upper Devonian (Frasnian) fauna (Mackenzie, 1970 p. 478; House and Pedder, 1963).

D) Structure

The major structural elements in the study region are related to the Laramide Orogeny (Gabrielse, 1970). A series of anticlines and synclines whose axes strike approximately east-west (roughly parallel to the strike of the MacKenzie Mountains in this region) are the dominant structural features (Figure 7, in pocket). The Ramparts Formation exposed in the Mountain - Gayna River escarpment, having an average dip of 20° to 30° , forms part of the northern limb of the southernmost anticline. An anticline in the centre of the region forms the Imperial Hills; other anticlines located north of the MacKenzie River form Carcajou Ridge and West Mountain.

Numerous normal faults of relatively small displacement are present in the region. One group trends predominantly northwest - southeast a second group, northeast - southwest.

REEFS - DEFINITIONS, CLASSIFICATION AND ORIGIN

A) Definitions

The following terms used in this study are definitions of Klován (1964, p. 11):

Reef Complex - the aggregate of reef limestones and related carbonate rocks.

Reef - rigid carbonate structure with vertical dimensions significantly larger than those of the contemporaneous sediments, composed, at least in part, of organisms able to build and maintain the structure as a topographic feature on the sea floor, potentially in the zone of wave action.

Organic reef - that portion of the reef which is or was built directly by organisms, and is responsible for the reef's wave - resistant character.

Bank - a skeletal carbonate deposit formed by organisms that do not form a rigid, wave - resistant structure.

B) Classification and Origin

According to Teichert (1958), three types of organic carbonate accumulations exist in modern oceans:

1) Shallow water hermatypic coral reefs

This type of accumulation is composed chiefly of

anthozoans, coralline algae, encrusting foraminifers, and various vagile components (Logan, 1969, p. 144) which have the ability to raise organic sedimentary structures above the bottom and into the surface waters. According to Logan (1969, p. 144), "emergent reefs may be viewed as part of a growth spectrum ranging from thin biostromal veneers and including submerged biostromes, submerged reef-banks, and fully emergent reef knolls and reef-wall complexes."

In hermatypic coral reefs most frame-builders are anthozoans. Most coralline algae and encrusting foraminifers are frame-binders, that is, they encrust pre-existing skeletal frames and in the process commonly create a rigid skeletal framework.

Water circulation, illumination, temperature and salinity (Kinsman, 1964, p. 1280) limit the growth of these accumulations:

- a) Water circulation. Relatively vigorous water circulation is required to ensure the necessary oxygen and nutrient supply.
- b) Illumination. Reef corals generally live in water depths of less than fifty meters, and most vigorous growth takes place in depths of less than twenty meters. The depth control is a reflection of the depth to which light, sufficient to maintain the metabolic process of the zooxanthellae, may penetrate.

- c) Temperature. Corals flourish best in the range of mean annual temperatures of 25° - 29° C. They can withstand limited exposure to temperatures as low as 16° - 17° C, and the maximum temperature for survival appears to be 36° C.
- d) Salinity. Reef corals flourish best within the range 34-36 parts per thousand. However, they can tolerate dilution to 27 parts per thousand or concentration to 40 parts per thousand.

Shallow water hermatypic coral reefs are generally found with 30° of the equator.

2) Ahermatypic Coral accumulations

This type of accumulation, composed of ahermatypic corals (without symbiotically associated zooxanthellae) flourishes at depths from 60 to 300 metres in waters with a temperature range of 4° - 8.5° C (Allen and Wells, 1962, p. 391). Such accumulations tend to grow in non-rigid thickets in temperate and polar seas.

3) Banks of Coralline algae

This type of accumulation grows in banks in the cold waters in many parts of the world, including areas around Norway, Iceland, and Greenland but mostly in shallow water (Johnson, 1961, p. 25).

Lithologic and biologic composition of the Ramparts limestones exposed in the Mountain-Gayne River

TABLE 3
DISTRIBUTION OF FOSSILS

Unit	Hemistomatopora	Stomatopora	Tabular	Bulbous	Stomatopora	Stachyodes	Amphipora	Alveolites	Coccolites	Thamnopora	Rugose	Brachiopods	Bryozoa	Crinoids	Echinoids	Gastropods	Pelecypods	Parahumeralia	Bryozoa	Tikheila	Echinoids	Interpretation	Legend	Vermipores	Ctenidia	Remnants	Algal Coating	Calcareous	Ostracods	Trilobites	Tentaculites	Sponges
A																																
B																																
C																																
D																																
E																																
F																																
G																																
H																																
I																																
J																																
K																																
L																																
M																																
N																																
O																																
P																																
Q																																
R																																
S																																
T																																
U																																
V																																
W																																
X																																
Y																																
Z																																

Note:
1. X - Present, But not Quantified
2. All Digits refer to percentages

escarpment area shows similarity to the modern shallow water hermatypic coral reefs. Details will be presented later, p. 174.

PETROGRAPHY

A) Description of Rock Components

a) Fossils

Table 3, p. 29 shows the distribution and abundance of fossils.

Fossils include organisms in growth position and skeletal grains.

Hemispherical and tabular stromatoporoids, and tabular Alveolites (see p. 41 for description of these organisms) are often found in what is interpreted to be original position. These organisms appear to encrust the substrate (Plate 1, figures 1 & 2 p.184). In most cases the base of the encrusting organism tends to follow the irregularities of the surface being encrusted.

Skeletal grains include both fragmented and whole shells or hard parts of stromatoporoids, corals, brachiopods, bryozoans, echinoderms, molluscs, foraminifers, algae, ostracods, trilobites, Tentaculites and sponges. (Carbonate particles, either single or aggregate, having a diameter greater than 0.03 mm. are called grains. Skeletal grains as well as intraclasts, pellets, and coated grains are included in this category.) The criteria used to identify the skeletal

grains are those of Johnson (1951), Klován (1964), and Majewske (1969). Numerous indeterminate skeletal grains, consisting of a variety of infilled (with sparry calcite and micrite) and empty, spherical to ramose organic remains of uncertain affinity, are present. Some indeterminate skeletal grains may be the remains of worm tubes, spores, spore cases, algae, and foraminifers. As the size of the grain diminishes, identification becomes less certain, and thus a number of indeterminate skeletal grains are probably fossil fragments of the taxa present in the succession.

Diagenetic obliteration of detail in skeletal grains also causes identification problems.

Illustrations of skeletal grains are presented in Plates I to VI p. 184 - 189.

b) Intraclasts

Intraclasts are "fragments of penecontemporaneous, usually weakly consolidated carbonate sediment that have been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment" (Folk, 1959, p. 4). In some cases intraclasts show internal structure such as laminations or skeletal fragments, but more often they are composed of structureless, homogeneous light to dark brown-grey micrite and microspar. (Plate II and XII, figures 1 and 2, p. 185 & 195). Intraclasts are common constituents of the Ramparts limestones (Table 4, p. 31).

TABLE 4

SUMMARY OF FIELD DESCRIPTION AND LITHOLOGIC ANALYSIS

Bedding Units			Bedding Character		Bedding Type		Colour		Rock Components										Texture Rock Classification										Grain Size						
Unit	Resistant	Moderate	Weakly	Sharp	Uneven	Nodular	Massive	Blocky	Slabby	Flaggy	Platy	Papery	Colour	Total Fossils	Intracasts	Pellets	Microspar	Spar	Dolomite	Quartz-Detrital	Silica Authigenic	Pyrite	Marcasite	Iron Oxides	Argillaceous	Porosity	Random	Mottled	Laminated	Wackestone	Packstone	Grainstone	Shale	Sandstone	Grain Size
W	Xpr	X		X	Xpr		X	X	X	X			Med. Bn.	12 P	?	P	P	P	P	P	P	P	P	<1	P	f	X	X		X	X		X	Very-Fine-Med.	
V	X				X		X	X	X	X			Lt.Med.Gy-Bn.	53 P	?	P	P	P	P	P	P	P	P	<1	P	po	X		Xpr	X			Fine-Medium		
U	X				X		X	X	X	X			Lt.Med.Gy-Bn.	37 P	P	P	P	P	P	P	P	P	P	P	P	po	X		X	X			Fine-Medium		
T	Xpr	X			X		Xpr	X	X	X			Lt. Gy.	68 P	P	P	P	P	P	P	P	P	P	P	P	po	Xpr	X		X	X			Fine-Medium	
S	X				X		X	X	X	X			Lt. Gy.	32 P	P	P	P	P	P	P	P	P	P	P	P	po	X		Xpr	X			Micro-Medium		
R	X				X		Xpr	X	X	X			Med. Bn. Gy.	71	15	3	1	5						<1	<1	9	X		X	X	X			Med.-Extremely Coarse	
Q	X				X		X	X	X	X			Med. Lt. Bn.	65	?	P	P	P	P	P	P	P	P	<1	f	X		X	X	X			Fine- U. Coarse		
P	Xpr	X			X		Xpr	X	X	X			Lt.-Dk. Gy.-Bn.	56	8	1	8	33	4	<1	<1	<1	<1	<1	<1	po	Xpr	X	X	X	X			Micro-Coarse	
O	Xpr	X			X		X	X	X	X			Lt.-Med. Bn.-Gy.	50	8	5	21	29	4	<1	<1	<1	<1	<1	<1	po	Xpr	X	X	X	X			Micro-Medium	
N	X				X		X	X	X	X			Med. Gy.	99			P	P	P	P	P	P	P	P	P	po	X		X	X	X			Med.-Extremely Coarse	
M	X				X		X	X	X	X			Lt.-Med. Gy.-Bn.	55	P	P	P	P	P	P	P	P	P	P	P	po	X		X	X	X			Fine-Coarse	
L	Xpr	X			Xpr		Xpr	X	X	X			Med. Gy.	55	?	1	30	14	1	10	?	?	?	<1	<1	po	X		X	X	X			Fine-Coarse	
K	X				X		X	X	X	X			Bl.-Dk. Bn.	?	P	?	P	P	P	P	P	P	P	P	P	po	X		X	X	X			Micro-Coarse	
J	X	Xpr	X		X		X	X	X	X			Lt.-Dk. Gy.	30	P	?	P	P	?	P	P	P	P	P	P	po	X		X	X	X			Micro-Coarse	
I	Xpr	X			X		X	X	X	X			Lt.-Dk. Gy.	40	10	?	13	42	1	P	P	P	P	P	P	po	X		X	X	X			Micro-Medium	
H	X				Xpr		X	X	X	X			Med.-Dk. Gy.-Bn.	48	3	P	25	38	5	<1	1	<1	<1	<1	3	po	X		X	X	X			Micro-Medium	
G	X				Xpr		X	X	X	X			Med. Gy.	29	<1	<1	40	15	4	<1	<1	<1	<1	<1	1	po	X		X	X	X			Fine-Medium	
F	Xpr	X			X		X	X	X	Xpr			Med.-Dk. Gy.-Bn.	83	5		26	5	<1	<1	<1	<1	<1	<1	<1	po	X		X	X	X			Fine-Medium	
E	X				X		X	X	X	X			Med.-Dk. Gy.-Bn.	23	13		21	38	4	<1	?	?	?	<1	po	X		X	X	X			Micro-Fine		
D	X				Xpr		X	X	X	X			Med. Bn.-Dk. Bn.	66	3	2	27	2	<1	<1	<1	<1	<1	<1	po	Xpr		X	X	X			Medium-Coarse		
C	X				X		X	X	X	X			Lt. Med. Bn.-Gy.	24	3		24	44	1	<1	?	?	?	3	po	X		X	X	X			Micro-Fine		
B	X	Xpr			Xpr		X	X	X	X			Lt.-Dk. Gy.-Bn.	42	2	<1	39	13	<1	<1	<1	<1	<1	<1	po	Xpr	X	Xpr	X	X			Micro-Coarse		
A	X	Xpr	X		Xpr		X	X	X	X			Dk. Gy.-Bn.	10	<1	<1	20	42	9	<1	?	?	?	2	po	Xpr	X	X	Xpr	X			Micro-Fine		

NOTE:

1. Sum of Rock Components does not always equal 100% because of averaging

2. All digits refer to percentages

3. • Micrite plus Microspar

4. pr - Predominant

5. po - poor, f - fair, g - good

<2% 2-5% >5%

6. P - Present but not Quantified

c) Pellets

Irregular to ovoid grains classified as pellets, consisting predominantly of micrite and/or microspar, are devoid of significant internal structure. Two morphologic pellet types are present in the Ramparts limestones (Plate XIX, figure 4, p. 202). The predominant type consists of pellets that are characteristically .05 to .3 mm. in size, well-sorted, irregular to ovoid, and composed of homogeneous dark brown micrite or microspar. The second type consists of pellets .5 to .6 mm. in size, very well-sorted, almost always ovoid, and composed of inhomogeneous light brown micrite and fine skeletal grains. This latter type is found spatially related to burrows.

A gradation often exists between distinct pellets and distinct intraclasts. Some intraclasts may actually be deformed pellets. Some pellet-rich limestones appear to merge in an irregular manner with dense structureless mudstones. In addition, islands of pelletal material commonly occur within these mudstones, suggesting that compaction of poorly consolidated pellets has produced mudstones bearing only remnants of the original pellet textures.

d) Coated Grains

The term "coated grain" as used in this study includes all grains having an outer sheath produced by algal corrosion (Plate XV, figure 5, p. 198). (This

process and the results of the process will be discussed on p. 142). Oololiths are absent in the Ramparts limestones.

e) Micrite

Micrite is defined as "calcite grains 1-4 microns in diameter, generally subtransparent with a faint brownish cast in thin-section. In hand specimen, this is the dull and opaque, ultra fine-grained material that forms the bulk of lithographic limestones, and the matrix of chalk, and may vary in color from white through grey, bluish and brownish grey, to nearly black" (Folk, 1959, p. 8; plate VII, figure 1, p. 190).

A polygenetic origin has been suggested for lime mud. Of the numerous hypotheses for lime mud formation, three appear to be important:

a) Chave (1960), and more recently, Matthews (1965) have suggested that the abrasion of skeletal material into finely comminuted mud may be an important process. This suggestion is supported by the fact that many modern lime mud deposits consist of three calcium carbonate polymorphs. They are low-magnesium calcite, high-magnesium calcite, and aragonite, the three common constituents of invertebrate skeletons (Chave, 1954; Stehli and Howes, 1961; Matthews, 1965).

b) Black (1933) and Cloud (1962) suggest that extensive lime mud deposits are precipitated either inorganically by agitation, salinity changes and

temperature changes, or organically by biochemical processes of bacteria, etc..

c) Lowenstam and Epstein (1957) propose that lime mud may be the result of algal disintegration. The aragonite needles composing the calcareous muds in modern carbonate sediments are similar to those secreted in the tissues of several different types of blue-green algae, including Penicillus and Halimeda.

These three processes are all important in the production of lime mud. Which process will dominate depends on many factors including the presence or absence of organisms, type of organisms, and the physiochemical nature of the environment.

It is generally agreed that for micrite to be produced, lime mud must be converted by physicochemical processes. Folk (1965, p. 35) gives an excellent account of the possible processes.

The abundance of lime mud is probably the best index of the lack of turbulence in a depositional environment. Skeletal grains and pellets can be formed or sedimented in quiet water, but lime mud cannot ordinarily be deposited in turbulent water or in energetic environments (Folk, 1959; Dunham, 1962, p. 111; Klován, 1964).

f) Microspar

Microspar is defined as microcrystalline calcite having size limits of 4 to about 30 microns, as arbitrarily set by Folk (1965, p. 37). Microspar is

interpreted to be the result of neomorphic alteration of micrite (Plate XLX, figure 7, p. 202).

g) Sparry Calcite

Sparry calcite includes both pore-filling calcite cement and neomorphic calcite. Pore-filling calcite results when calcite is precipitated in voids. Neomorphic calcite or pseudospar (Folk, 1965) can form in two ways. First, it can form by the inversion of molluscan aragonite to stable low-magnesium calcite. Second, it forms by neomorphism of carbonate mud to form crystals that are coarser than microspar and usually have different morphology from microspar (Plates XVlll and XLX, figures 8, p; 2 to 9 excluding 7, p. 200 & 202).

Criteria to differentiate these two forms of sparry calcite are discussed by Folk (1965, p. 44).
h). Dolomite.

Dolomite (Plate XVlll, figures 1 to 6, p. 201) is present as an authigenic mineral that is readily recognized in thin sections that have been stained with Alizarin Red-S and potassium ferricyanide solution. It shows distinctive rhomb form, and if ferroan, stains a distinctive peacock-blue colour. (For details of the staining process see Appendix Two, p. 204). Dolomite can be recognized in peels by its characteristic rhomb shape and relief.

i) Quartz

Quartz is present both as detrital (Plate XLV,

figure 3, p. 197) and as authigenic quartz, both chaledony and lutecite (See Wilson, 1966, p. 1038) (Plates XVI and XVII, figures 7 to 9; 1 to 6, p. 199 and 200). Detrital quartz occurs both in the lower (platform) member and in the upper (reef) member of the Ramparts Formation (Table 4, p. 33).

j) Pyrite and Marcasite (Plate XVI, figures 1 to 6, p. 199).

k) Argillaceous and Bituminous Material.

Both argillaceous and bituminous material are present in the platform member of the Ramparts Formation and bituminous material also occurs sporadically throughout the reef member. Argillaceous and bituminous material is dispersed evenly throughout the limestones, is concentrated in stylolites and voids, and coats sparry calcite pore-filling crystals and pseudospar crystals (Plate XX, figures 2 to 4, p. 203).

l) Porosity

Visible porosity is variable throughout the Ramparts Formation. Table 4, p. 31 shows the distribution of porosity in that portion of the formation studied. Much of the primary porosity has been destroyed as a result of diagenetic alterations, especially by cementation and recrystallization.

Microspar, sparry calcite, dolomite, quartz, pyrite and marcasite are more thoroughly discussed on p. 144. Table 5, p. 140 shows the distribution of the effects of diagenetic processes.

B) Rock Classification Scheme

The classification scheme adopted for this study (Figure 8, p. 40) is a modified version of the scheme proposed by Dunham (1962).

The author selected this particular scheme on the basis of applicability to the Ramparts limestones.

*MODIFIERS	ORIGINAL COMPONENTS NOT BOUND				BOUND
1. GRAIN SIZE	CONTAINS MUD .03 mm.			LACKS MUD	B O U N D S T O N E
2. GRAIN NAME					
3. COLOUR	MUD SUPPORTED		GRAIN SUPPORTED		
4. MAIN ORGANIC CONSTITUENTS	<10% GRAINS	>10% GRAINS	P A C K S T O N E	G R A I N S T O N E	
5. IMPURITIES (INCLUDING DOLOMITE, QUARTZ, PYRITE, ARGILLACEOUS AND BITUMINOUS MATTER)	M U D S T O N E	W A C K E S T O N E			

* ONE OR MORE OF THESE MAY MODIFY ANY TEXTURAL CATEGORY

FIGURE 8
CLASSIFICATION SCHEME
(MODIFIED DUNHAM, 1962)

MM.	SIZE CATEGORY
2.0	EXTREMELY COARSE - GRAINED
	VERY COARSE - GRAINED
1.0	COARSE - GRAINED
0.50	MEDIUM - GRAINED
0.25	FINE - GRAINED
0.12	VERY FINE - GRAINED
.0625	MICRO - GRAINED

FIGURE 9
GRADE SCALE
(MODIFIED WENTWORTH, 1922)

PALEONTOLOGY AND PALEOECOLOGY

In modern coral reefs, organisms are closely related to their environment. On the one hand, the distribution and abundance of organisms is controlled by many environmental factors (See p. 26). On the other hand, the organisms influence the nature of the environment around them. In order to understand the many different paleoenvironments represented in the rocks of the Ramparts Formation, it is necessary to study the distribution and abundance of fossil organisms, and the relationship between organisms and their enclosing sediments.

Whole and fragmented fossils constitute a large portion of the Ramparts Formation. Identification of these fossils has been attempted to the genus level where possible. Organisms are discussed in decreasing order of abundance.

Table 3, p. 29 shows the distribution of fossils and their relative abundance in each unit of the Formation.

A) Stromatoporoids

Stromatoporoids are the most abundant organisms in that part of the Ramparts Formation studied. Hemispherical, tabular, bulbous, and dendroid forms are

present. Actinostroma has been tentatively identified in tabular form (Plate X, figure 7, p. 193). No attempt was made to divide the hemispherical and bulbous forms into genera.

a) Hemispherical Stromatoporoids.

The description of hemispherical stromatoporoids given here is based mostly on field observations and to a lesser degree on hand specimen examination.

Hemispherical stromatoporoids are dome-shaped or subspherical with the width of the base approximately equal to, or slightly less than, the height.

Hemispherical stromatoporoids interpreted to be in growth position are enclosed in sediment containing little argillaceous and bituminous material and consisting of medium to coarse-grained packstone and grainstone (Figure 8, p. 40; Tables 3 and 4 p. 29 and 31). Associated organisms include other stromatoporoids, principally tabular and hemispherical forms (Table 3, p. 29).

Most of the hemispherical stromatoporoids studied were not in growth position. They are commonly randomly oriented and fragmented (Plate XI, figure 4, p. 194).

The nature of the sediment enclosing those hemispherical stromatoporoids interpreted to be in growth position, suggests that this stromatoporoid form flourished under relatively high energy conditions.

On the basis of the medium-to coarse-grained nature of the enclosing sediment consisting largely of skeletal remains, and on the strongly abraded, commonly fragmented and randomly oriented nature of the hemispherical stromatoporoids themselves, Iecompte (1956) Klován (1964) and Fischbuch (1968), suggest that hemispherical stromatoporoids were adapted to turbulent, high energy water conditions. Fischbuch (1968, p. 64) further suggests that this type of environment "could be encountered only in the near-surface zone of continuous wave action."

It should be emphasized that in using hemispherical stromatoporoids or any other organism as an indicator of the particular environment in which the organism grew, observations should be made on those organisms that are in growth position or on those that have not been transported far after death. Randomly oriented, strongly abraded and fragmented organisms may have been moved into an environment different from that normally inhabited.

b) Tabular Stromatoporoids

Tabular stromatoporoids are flat, "pancake-like" or laminar in form. A number of the tabular stromatoporoids examined consisted of several alternating stromatoporoid and micrite layers (thought to be of algal origin)(Flates 1, figure 1, p. 184). The stromatoporoid most commonly composing the layers is tentatively identified as Actinostroma. The micrite

layers interpreted as algal layers are composed of dark grey to black micrite similar to that found coating skeletal grains which are thought to have been corroded by algae (Plate XV, figure 5, p. 198). Perhaps the stromatoporoids were encrusted by algae and subsequently overgrown by additional layers of stromatoporoid. As a result of later diagenetic processes the algal structure was destroyed (See p. 142 for further discussion).

Tabular stromatoporoids, interpreted to be in growth position, are enclosed most commonly in wackestone and packstone sediments. Associated fossils include: hemispherical stromatoporoids, colonial tabulate corals (Alveolites, Thamnopora, and Coenites), bryozoans, brachiopods, and crinoid ossicles (Table 3, p. 29.) Tabular stromatoporoids are sometimes bored (Plate XV, figure 2, p. 198).

The nature of the surrounding sediment and the association of algae suggest that the tabular stromatoporoids grew in moderately shallow, moderately turbulent and energetic water conditions. Tabular stromatoporoids not only grew in the same environment as hemispherical stromatoporoids, as evidenced by the association of both types, but also in slightly deeper water and in a less turbulent and energetic water environment than did the hemispherical stromatoporoids. This study would indicate that they were more common in the latter environment. In other studies of

Devonian reef complexes, Klován (1964, p. 37), Murray (1966, p. 17) and Leavitt (1968, p. 234) have come to similar conclusions. Murray (1966, p. 17) suggests that tabular stromatoporoids may have grown in the lower part of the zone of vigorous photosynthesis whereas the hemispherical stromatoporoids grew in the upper part of the zone.

c) Bulbous Stromatoporoids

According to Murray (1964, p. 20) bulbous stromatoporoids include all spherical and oblate forms ranging from 20 to 60 mm. in diameter (Plates I and XII, figures 3 and 1, p. 184 & 195).

Bulbous stromatoporoids of the Ramparts Formation are occasionally composed of alternating, roughly concentric layers of micrite and stromatoporoid. As in the case of the tabular stromatoporoids the layers are composed of dark grey to black micrite and probably have undergone similar diagenetic alteration. The maximum diameter of this form ranges from 6 mm. to 30 mm. The nucleus of the bulbous stromatoporoids is occasionally a fragment of Stachyodes or of a dendroid coral (Plate XII, figure 1, p. 195).

Bulbous stromatoporoids commonly show evidence of abrasion and fragmentation (Plate I, figure 3, p. 184). The surrounding sediment varies considerably from mudstone to very coarse-grained grainstone. Associated fossils include: the dendroid stromatoporoids

(Amphipora and Stachyodes), the dendroid corals (Coenites and Thamnopora), algae, foraminifers, and crinoid ossicles (Table 3, p. 29). Many bulbous stromatoporoids are bored (Plate XV, figure 3, p. 198).

The variable nature of the surrounding sediment and the faunal associations suggest that the bulbous stromatoporoids inhabited and were sedimented in many different environments. On the one hand the spherical, commonly abraded and fragmented form, and the coarse-grained grainstone enclosing sediment suggest fairly high energy conditions. On the other hand the association with Amphipora, algae and foraminifers, and the mudstone-wackestone enclosing sediment suggest lower energy conditions.

On the basis of the characteristic well-rounded form, the absence of a means of attachment, and the common algal-micritic coatings, Leavitt (1968, p. 325) suggests that bulbous stromatoporoids may have lived in turbulent water environments and after death were transported in some instances into lower energy environments. Fischbuch (1968, p. 502) also suggests that the bulbous stromatoporoids appear to have been unattached and may have rolled during growth.

d) Dendroid Stromatoporoids

Dendroid stromatoporoids have a digitate, occasionally branching form. Included in this category are Stachyodes and Amphipora.

- 1) Stachyodes (Plates X, XI and XII, figures

1; 2, 3; 4, p. 193 & 195).

James (1969, p. 35) identified three types of Stachyodes from the Bell Creek section (KK): Stachyodes spongiosum Stearn, S. costulata Lecompte, and S. Thomasclarki Stearn. Of these three S. costulata occurred rarely. No attempt was made in this study to identify additional genera.

The Stachyodes coenostea present in the Ramparts Formation are fragmented, and commonly bored and corroded by algae. No coenostea were found in original position. The sediment containing Stachyodes varies from a very coarse-grained grainstone to a fine-to medium-grained wackestone. The coenostea are predominantly found in a medium-to coarse-grained packstone or grainstone associated with bulbous stromatoporoids. Other associated fauna include: Amphipora, tabular stromatoporoids, Thamnopora, Coenites, crinoid ossicles, and brachiopods (Table 3, p. 29).

The variable nature of the sediments in which Stachyodes is found would suggest that it was sedimented in both turbulent and high energy environments, and in relatively low energy environments. The association with bulbous stromatoporoids might indicate that both types of organisms occupied similar environments.

2) Amphipora (Plates 1, XI, and XII; figures 4

and 5; 1 to 4; 2 and 3; p. 184, 194 & 195).

James (1969, p. 34) has identified three types of Amphipora from the Bell Creek (KK) section: Amphipora ramosa Phillips, A. pervesiculata Lecompte, and A. angusta Lecompte. Both A. ramosa and A. pervesiculata are fairly common. A. angusta is quite rare. No new genera were identified in this study.

Small juvenile and large adult forms of A. pervesiculata are present (Plate 1, figure 4, p. 184).

Amphipora coenostea are both abraded and non-abraded. The abraded forms do not have intact marginal vesicles (Plate XII, figure 3, p. 195). Specimens with intact marginal vesicles, (Plates 1 and XII, figures 5, 2, p. 184 & 195) contained in relatively fine-grained sediments probably have not been moved very much since death and may have been sedimented in the environment in which they grew. The sediments containing Amphipora vary from fine-grained wackestones to coarse-grained grainstones. Packstones are the most common type of sediment. Associated fossils include: foraminifers, algae, Stachyodes, bulbous stromatoporoids, Thamnorora, Coenites and gastropods (Table 3, p. 29). Some Amphipora coenostea are encrusted by Girvanella and possibly by blue-green algae.

The nature of the enclosing sediments, and the associated fossils suggest that Amphipora was

sedimented in at least two different environments: one, a low energy environment, and the other a higher energy environment. Leavitt (1968, p. 326) states that Amphipora thrived and grew in abundance only in relatively quiet, sheltered waters." According to Fischbuch (1968, p. 66) "a flexible holdfast may have allowed the animal to bend with the wash of currents coursing through the lagoons. Upon death the holdfast decayed, and the skeletons were rolled and winnowed over shorter or longer distances, dependant on the strength of bottom currents." The amphiporids were probably swept into a number of high and low energy environments that they would not normally inhabit.

Klovan (1964, p. 38) and Leavitt (1968, p. 326) suggest that Amphipora reached its maximum occurrence in the back reef areas of the Redwater and Swan Hills reef complexes, respectively. On the basis of this study this is true of the Mountain-Gayna River reef complex as well.

B) Corals

Corals are common in the Ramparts Formation.

Alveolites, Coenites, Thamnopora, Hexagonaria, Favosites, and several rugose corals have been identified.

a) Colonial Tabulate Corals

1) Alveolites (Plates 1, figure 6, p.184).

Alveolites occurs in irregularly

shaped, massive, and in flat-tabular forms. The tabular form has a thickness ranging from 10 mm. to 15 mm..

Numerous specimens have been found in what is interpreted to be growth position. Others are randomly oriented and fragmented. These are interpreted as having been moved to their place of sedimentation. Medium-to coarse-grained wackestone, packstone and grainstone sediment encloses those corals that are interpreted to be in growth position. Medium-grained packstone is the predominant enclosing sediment. Associated fossils include: Thamnopora, Coenites, tabular stromatoporoids, brachiopods, crinoid ossicles, and gastropods, (Table 3, p. 29). Alveolites is occasionally bored and corroded by algae.

The nature of the enclosing sediment of some of the 'in situ' Alveolites specimens suggests a moderately high energy, perhaps turbulent water habitat for Alveolites. The close association of Alveolites with the dendroid corals and tabular stromatoporoids might also suggest that all of these organisms lived relatively close together.

2) Coenites (Plates VIIl, IX and XIV, figures 2 and 4; 4; 2, p. 191 , 192 & 197).

Coenites is considered to be a dendroid coral; that is, it has a digitate form.

All of the Coenites specimens examined are fragmented. Coenites has not been found in growth position. Fine-grained wackestones, medium-to coarse-grained packstones, and coarse-grained grainstone contain Coenites fragments. Most of the Coenites fragments are found in packstones. Associated fossils include: Thamnopora, Alveolites, Stachyodes, bulbous and tabular stromatoproids, Amphipora, brachiopods, small gastropods, crinoid ossicles, algae, and foraminifers (Table 3, p. 29).

The nature of the sediment containing Coenites fragments indicates that Coenites was sedimented in both low and high energy environments. Very little can be said about the nature of the environment where Coenites grew.

3) Thamnopora (Plates 1, VIII, XIII and XIV, figures 7 and 8; 4; 4; 2, p. 184, 191, 196 & 197).

Thamnopora, like Coenites, is a dendroid coral.

All of the Thamnopora specimens examined were fragmented. No specimens have been found in growth position. Thamnopora fragments are contained in medium-to coarse-grained wackestones, and in medium-to coarse-grained packstones and grainstones. Most of the fragments are found in the packstones and grain-

stones. Closely associated fossils include: Alveolites, Coenites, bulbous and tabular stromatoporoids, Stachyodes, Amphipora, crinoid ossicles and brachiopods (Table 3, p. 29).

The nature of the sediment containing Thamnorora fragments indicates, as in the case of Coenites, that Thamnorora was sedimented in both low and high energy environments.

4) Hexagonaria and Favosites (Plate 1, figure 9, p. 184).

Fragments of both Hexagonaria and Favosites have been tentatively identified from the lower part of the platform member. Little can be said about the environment in which they lived. Both are minor constituents of the Ramparts Formation.

b) Rugose Corals

Several rugose corals have been identified from the reef member and from the platform member, but they are minor constituents of the Ramparts Formation (Table 3, p. 29; Plate XI, figure 3, p. 194).

C) Brachiopods (Plate 11, figures 1 and 2, p. 185).

Articulated and disarticulated brachiopod valves, valve fragments, and spines are relatively common constituents of the Ramparts Formation. No attempt was made to study brachiopods in detail. In James's (1969) p. 39) study, Spinatrypa, Schizophoria, Emanuella, and Stringeocerhalus were identified from the Bell Creek

(KK) section.

In general, small, thin and smooth-valved brachiopods are more abundant in rocks interpreted to be representative of low energy, fairly deep water conditions. The larger, thick-valved, coarsely ribbed brachiopods are more abundant in rocks interpreted to be representative of high energy, shallow water conditions.

Stringocephalus, a Givetian index fossil, has been identified from the lower platform member. Mackenzie (1970, p. 478) reports Upper Devonian brachiopods in the Powell Creek area.

D) Bryozoans (Plate 11, figures 3 to 7, p. 185).

Bryozoans are relatively minor constituents of the Ramparts Formation. Of the five different bryozoans recognized, Fenestella and Polypora have been tentatively identified (Mason, 1969, personal communication). For the purposes of this study the three unnamed forms are referred to as bryozoan A, B and C. (Plate 1, figures 3 to 5, p. 184).

The bryozoans occur in fine-to coarse-grained wackestones and packstones, and are frequently fragmented. No organisms in growth position are present. Closely associated fossils include: tabular stromatoporoids, Alveolites, Thamnopora, Coenites, brachiopods, crinoid ossicles and gastropods (Table 3, p. 29).

The nature of the sediment containing the fragments would suggest that the bryozoans were sedimented

in a moderately energetic environment. Bryozoan fragments found in relatively fine-grained wackestones may have been sedimented in the environment in which they grew.

E) Echinoderms

Crinoid ossicles, calices, and fragments, as well as echinoid plates and fragments are relatively minor constituents of the Ramparts Formation (Plate 11, figures 8 to 10, p. 185).

Echinoderms occur in every rock type of the Ramparts Formation (Tables 3 and 4, p. 29 & 33). Closely associated fossils include: brachiopods, Coenites, Thamnopora, Alveolites, and tabular stromatoporoids.

Crinoid ossicles are porous and as such have a low density. Because individual ossicles are hydraulically equivalent to dense skeletal grains of much smaller size it would not be uncommon for the ossicles to be swept, after the death of the crinoid organism, into environments different from the one normally inhabited (Jamieson, 1968, p. 170). Their widespread distribution and common fragmentation suggest considerable transportation, and sedimentation in many environments.

The distribution of echinoid spines and fragments roughly parallels that of crinoids.

F) Molluscs

(Included are gastropods and pelecypods).

a) Gastropods (Plate 111, figures 1 to 3, p. 186).

A large variety of gastropods is present in the Ramparts Formation. No attempt has been made to identify the different gastropods, but for this study the gastropods are divided into two categories, a large, relatively coarse-shelled type, and a small relatively thin-shelled type. The smaller type generally requires the use of a microscope for identification.

Gastropod valves have undergone inversion from aragonite to calcite, partial to complete dissolution, and subsequent cementation. These aspects are discussed on p. 159.

Gastropods are contained in mudstones, wacke-stones, packstones and grainstones, but are most abundant in the packstones. Closely associated fossils include: bulbous stromatoporoids, Amphipora, Stachyodes, Coenites, Thamnopora, and Alveolites (Table 3, p.29).

The variety of sediments in which the gastropods are contained suggests sedimentation in both high and low energy environments.

Most authors including Klován (1964, p. 41) and Jamieson (1968, p. 169) agree that like their modern relatives, the Devonian gastropods occurred in many

environments and were tolerant of a wide range of environmental conditions.

b) Pelecypods (Plate XVIII, figure 4, p. 196).

Abraded and fragmented pelecypod shells occur sporadically throughout the Ramparts Formation.

Pelecypod shells, like gastropod valves, have undergone inversion, partial to complete dissolution and subsequent cementation.

Because no pelecypods have been found in what is interpreted to be growth position and because so few fragments were found, little can be said about either their habitat or place of sedimentation.

G) Foraminifers (Plate III, figures 4 to 20, p. 186).

Foraminifers are relatively common constituents of the Ramparts Formation (Table 3, p. 29). Because of their small size a very low volume percentage may represent a fairly large number of individual organisms.

Seven different foraminifers are tentatively identified: Parathuramina, Bisphaera, Tikhinella, Evlania, Irregularina, Eonodosaria, and the lagenid-like form of Toomey (1965). Specimens of Paratikhinella may also be present (Plate III, figure 20, p. 186). Classification of the foraminifers is based on the descriptions of Toomey (1965) and Toomey et al. (1970).

The foraminifers are found in almost every rock

type (Tables 3 and 4, p. 29 & 33). They are most abundant, however, in fine-to medium-grained wackestones and packstones. Hand specimens of these rock types characteristically have a sublithographic texture (Plate X, figures 3 and 4, p. 193). In outcrop these rocks are sharply bedded in one to four inch beds. Commonly associated fossils include: algae, Amphipora, Stachyodes, Coenites, bulbous stromatoporoids, and numerous indeterminate skeletal organisms (Table 3, p. 29).

The nature of the sediment containing the foraminifers suggests that they were sedimented in a low energy, possibly moderately shallow-water, environment.

Both Parathurammina and Bisphaera are quite long ranging. Both genera have been reported in rocks ranging in age from Middle Ordovician to Lower Carboniferous (Tournaisian) (Tooney et al. 1970, p. 972). Tikhinella, Irregularina, the lagenid-like form, Evlania, Partikhinella, and Eonodosaria have only been reported from Upper Devonian (Frasnian) rocks (Toomey et al. 1970, p. 972-978). Parathurammina, Tikhinella and Irregularina have been identified from the lower (platform) member of the Ramparts Formation. All of the rest of the foraminifers are found only in the upper (reef) member. This would suggest that either the time range of Tikhinella and Irregularina should

be extended or that part of the lower (platform) member may be Upper Devonian (Frasnian) in age.

H) Algae (Plate IV, figures 1 to 11, p. 187).

Both green and blue-green algae are present in the Ramparts Formation. The dasycladacean alga Vermiporella is the only green alga present. Blue-green algae include: Girvanella, Renalcis, (Plate VI, figure 2, p. 189), algal coatings and borings, and radiosphaerid calcispheres.

a) Vermiporella and Girvanella

Several different forms of Vermiporella are recognized (Plate I, V, figures 1 to 8, p. 184). Vermiporella occurs throughout the Ramparts Formation in most rock types (Tables 3 and 4, p. 29 & 33).

Girvanella is present in the Ramparts Formation as spaghetti-like clumps (.2 mm. to .4 mm. maximum diameter) dispersed throughout the matrix of the enclosing sediment (Plate IV, figures 10 and 11, p. 187), and as encrustations on bryozoans, Coenites, Thamnopora and Amphinora (Plate IV, figure 9, p. 187).

Toomey et al. (1970, p. 964) suggest that the tubules penetrate mud intraclasts. This study suggests that the clumps of Girvanella found in the rock matrix have been derived by fragmentation of Girvanella encrusted organisms.

Like Vermiporella, Girvanella is found in most rock types of the Ramparts Formation (Tables 3 and 4,

p. 29 & 33). This suggests that both organisms were sedimented in both high and low energy environments.

b) Algal Coatings and Borings (Plate XV, figures 2 to 5, p. 198).

Algal coatings and borings are well distributed throughout the Ramparts Formation. Algal coatings are present in the form of micrite layers occurring between successive stromatoporoid layers, and as irregular micrite crusts on skeletal grains and framebuilders. The micrite layers in stromatoporoids have been previously discussed (p. 44). The irregular micrite crusts are composed of dark grey-brown to black, dense, homogeneous micrite often with what appears to be fine filaments in some parts of the crust (Plate XV, figures 5, p. 198). These crusts are attributed to the corroding action of blue-green algae. Skeletal grains are commonly bored. Small tubules extending from the grain surface penetrate the skeletal structure. These tubules are attributed to the boring action of blue-green algae. The processes of algal corrosion and boring, as well as their paleoecological significance will be discussed further on p. 142.

Algal-coated and bored skeletal grains occur throughout the platform member and the reef member. A large amount of coated and bored material probably underwent these processes before being sedimented.

c) Radiosphaerid Calcspheres (Plate IV, figures 12 to 17, p. 187).

Toomey (1970, p. 965) describes radiosphaerid calcispheres as "discrete spherical bodies composed of an inner chamber of variable diameter bounded by a relatively thick calcite wall. The outer wall is made up of radially arranged spines and/or pores".

In the Ramparts Formation radiosphaerid calcispheres vary in form from those with short, stubby spines to those with fairly long, fibrous spines.

Radiosphaerid calcispheres are found in most parts of the Ramparts Formation, in both the lower (platform) and upper (reef) members (Table 3, p. 29).

Stanton (1963, p. 415) interprets calcispheres to represent some form of marine plant spore or reproductive structure. Radiosphaerid calcispheres are not strictly algae, but the author follows Toomey et al. (1970) in classifying them with algae.

Specimens of radiosphaerid calcispheres have been reported to range in age from the Upper Devonian (Frasnian) to the Lower Carboniferous (Toomey et al., 1970, p. 967). Their occurrence in both the lower (platform) and upper (reef) members of the Ramparts Formation either extends their time range to include the Middle Devonian (Givetian) or part of the platform member may be Upper Devonian (Frasnian) in age.

I) Ostracods (Plate IV, figures 18 and 19, p. 187).

Ostracod shells and shell fragments are widely distributed throughout the Ramparts Formation (Table 3, p. 29). Braun (1966) identified both Givetian and Frasnian ostracod assemblages from the Powell Creek succession (section KJ of this study); Givetian faunal assemblages "e", to "f" as well as the Frasnian faunal assemblage "g" were identified in the Powell Creek succession (section KL of this study) (Braun, 1966, p. 249). No attempt was made in this study to identify the ostracods.

J) Trilobites (Plate IV, figure 20, p. 187).

Trilobite shell fragments, spines, and rare pygidia are randomly distributed throughout the Ramparts Formation (Table 3, p. 29). Trilobites probably inhabited many different environments in the Ramparts Formation, and after death their carapaces were broken up and distributed over a large area.

K) Tentaculites

Tentaculites (Plate V, figures 1 and 2, p. 188), a minor rock constituent, occurs both in the lower (platform) and upper (reef) members of the Ramparts Formation (Table 3, p. 29).

L) Sponge Spicules

Sponge spicules are minor rock constituents the lowest part of the platform member (Table 3, p. 29).

The sponge spicules may originally have been silica, now replaced by calcite. Sections through the spicules show them to be composed of a core of blocky, sparry calcite crystals with rims of bladed, sparry calcite crystals (Plate V, figure 3, p. 188).

M) Indeterminate Skeletal Organisms

Numerous regular - and irregular - shaped forms, .1 mm. to 2 mm. in largest dimension, occur in the Ramparts Formation. Most of these forms show some evidence of internal organization and are interpreted to be skeletal organisms of uncertain affinity (Plates V and VI, figures 4 to 11; to 19, p. 188 & 189).

One organism occurs throughout both the platform and reef members, occasionally composing up to ten percent of the total rock volume. This organism generally has a cylindrical form. Branching forms have been identified, but are rare. Numerous chambers, separated from each other by calcite plates that are perpendicular to the cylinder walls, are found in the interior of the organism (Plate V, figure 4, p. 188). This organism is similar to an organism identified by Leavitt (1968, Plate 13, figure 40, p. 395) as Tikhinella. Toomey (1970, p. 975) states this is an organism of uncertain affinity rather than a foraminifer.

Many of these unidentified organisms are probably algae and foraminifers. Their identification and re-

cognition in rocks of similar age may aid in zonation of the Middle Devonian (Givetian) and early Upper Devonian (Frasnian).

STRATIGRAPHIC ANALYSIS AND ENVIRONMENTAL INTERPRETATION

Figure 12 (in pocket) shows the correlation of the units in both platform and reef members. Tables 3, 4, and 5, p. 29, 33 & 140 show the distribution of fossils, summary of field description and lithologic analysis and diagenetic alteration, respectively.

A) Platform Member

The platform member can be divided on the basis of lithologic and paleontologic criteria into three laterally contiguous facies, from west to east, the shallow shelf, platform, and platform edge facies, which can be subdivided vertically into Units A to I. Units A and B are found in all three facies. Units C to H are found only in the platform facies, whereas Unit I is found only in the platform edge facies (Figures 10, and 11, p. 66 & 95; Figure 12, in pocket).

Thickness of the platform member ranges from approximately ten feet in sections KX-68 and KT-68, where Units A and B are present, to approximately one hundred and ninety feet in section KK-68, where Units A to H are present (Figure 12, in pocket).

The contact of the base of the platform member,

Unit A, with the underlying Hare Indian Formation is gradational. It is placed where the amount of limestone first exceeds the amount of shale present. The contact of the top of the platform member (from west to east Units B, H and I) with the overlying reef member is also gradational. This position coincides with a change in fauna from corals, brachiopods, crinoid ossicles, and tabular stromatoporoids to Amphipora, Stachyodes, bulbous stromatoporoids, foraminifers and algae. It also corresponds to a change in colour from dark grey-brown to medium brown, and generally to a change in bedding characteristics (Figure 12, in pocket).

a) Unit A

1) Distribution and Lithology

Unit A, (Figures 10 and 12, p. 62, in pocket) is present throughout the escarpment area. Thickness ranges from five feet in section KX-68 and KT-68 to fifteen feet in section KK-68. The lower contact has previously been described. The contact of Unit A with Unit B is gradational. It is placed where total skeletal material becomes a major (greater than twenty five percent of the total rock volume) rock constituent.

Rocks of this unit are bituminous, argillaceous and dark grey brown in colour. Beds $\frac{1}{2}$ " to 4' thick show weakly resistant to resistant weathering characteristics. Bedding planes are uneven to sharp. Those that are sharp generally correspond to an increase in

FIGURE 10
PLATFORM MEMBER UNITS A TO H,
SECTION KK-68

the amount of argillaceous material present. Shale interbeds sometimes constitute up to fifty percent of the total rock volume.

2) Petrography

In hand specimen the rocks are crudely laminated, mottled or homogeneous in texture. (Plate VII, figure 1, p. 190). Laminae are the result of alternating concentrations of coarse and fine material. Mottling is the result of either bioturbation, where rock components show evidence of having been moved after deposition (laminae are disrupted, skeletal grains are re-oriented into complex swirls, and pellets are present) or aggrading neomorphism of the micrite in the rock matrix. (Plate XV, figures 1 p. 198 See also p. 139).

The main rock constituents are microspar, micrite, skeletal grains, sparry calcite, and quartz clasts (Table 4, p. 33).

Microspar constitutes up to ninety percent, with an average of forty-two percent of the rock. Microspar is the result of aggrading neomorphism of micrite. (Plate XIX, figure 7, p. 202. See also p. 156). Micrite constitutes an average of twenty percent of the rock.

Skeletal grains compose an average of ten percent of the rock. In decreasing order of volumetric abundance skeletal grains include: brachiopod shell fragments and spines, Coenites fragments, and assorted

fragments of Amphipora, bryozoans, crinoids, gastropods, pelecypods, Parathurammina, Girvanella, ostracods, trilobites, Tentaculites, and sponge spicules (Table 3, p. 29). Crinoid ossicles and Coenites fragments have undergone selective degrading neomorphism (See p. 156). Parts of the skeletal architecture have been altered to dense micrite, and microspar. In addition some of the crinoid ossicles have undergone incongruent dissolution (Land, 1967), (Plate XLX, figure 7, p. 202; See P. 161). Ostracod shells are commonly crushed.

Sparry calcite, composing an average of nine percent of the rock, occurs as non-ferroan and ferroan cement filling fractures and cavities, and as pseudo-spar occupying the centres of aggrading neomorphism. (Plate XVIII, figure 8, p. 201).

Angular quartz grains, ranging in size from .01 mm. to .1 mm. and constituting an average of seven percent of the rock volume, are dispersed randomly throughout the rock matrix. Inclusions of calcite (possibly authigenic) are commonly contained within the grains. Overgrowths, some of them well terminated, occur around certain grains. (See p. 146).

Pyrite and bituminous and argillaceous material, each composing an average of two percent of the rock volume, and intraclasts, pellets, dolomite, and authigenic quartz, each composing an average of less than one percent of the rock volume, are minor constituents

(Table 4, p. 33).

Pyrite occurs as euhedral crystals and crystal aggregates distributed randomly throughout the rock matrix and as sooty coatings on brachiopod shell fragments and inside Tentaculites.

Bituminous and argillaceous material is dispersed throughout the matrix and concentrated along with pyrite and quartz grains in stylolites (Plate XX, figure 2, p. 203). Intercrystalline bituminous material is also found in sparry calcite filled fractures and in cavities. (Plate XX, figure 1, p. 203).

Intraclasts from .03 to .12 mm., and pellets, from .03 mm. to .20 mm., are randomly distributed throughout the rock matrix.

Dolomite occurs as non-ferroan dolomite selectively replacing parts of the matrix and parts of fossils.

Rocks of this unit are classified as fragmental-quartzose-bituminous, and argillaceous mudstones, wackestones and packstones, and as shales. (Plate VII, figure 1, p. 195). The matrix is micro-to-fine grained.

3) Interpretation

The rocks of this unit are interpreted as having been formed on a relatively broad and open marine shelf. The fine-grained character of the rocks, their dark colour due to the abundance of argillaceous and

bituminous material, the frequent shale interbeds, and the absence of shallow water fossils suggest deposition in a relatively low-energy, poorly oxygenated, and moderately deep-water environment.

The large amount of quartz may have originated from an area to the west, possibly from an exposed portion of the Mackenzie Arch. The quartz may have been either blown into the shelf area from beaches or swept up and deposited by waves and currents generated by storms.

b) Unit B.

1) Distribution and Lithology

Unit B is present throughout the escarpment area. (Figure 10, p. 62 and 12, in pocket). The thickness of the unit ranges from five feet in sections KY-68, KX-68, KW-68, KT-68, and KJ-68, to thirty feet in section KK-68. Unit B directly overlies Unit A. The lower contact has been previously discussed; the upper contact with Unit C is gradational and is placed where skeletal material falls below twenty-five percent of the rock volume.

Rocks in this unit are bituminous, argillaceous and light to dark grey-brown. In outcrop, beds range in thickness from less than $\frac{1}{10}$ " to greater than 4', and are commonly moderately resistant to weathering. Shale interbeds are commonly intercalated with limestone beds.

2) Petrography

The main rock constituents are fossils, micrite and microspar and sparry calcite (Table 4, p. 33). Fossils compose an average of forty-three percent, micrite and microspar an average of thirty-nine percent, and sparry calcite an average of thirteen percent of the rock volume.

Alveolites and tabular stromatoporoids (none of which are in growth position) are common constituents of this unit. In decreasing order of abundance skeletal grains include fragments and tests of: Thamnopora, large crescentic and small brachiopod valves (including Stringocephalus), Stachyodes, crinoid ossicles, bryozoans, gastropods, rugose corals, Coenites, echinoid spines, calcispheres, Amphinora, Parathuramina, Vermiporella, Girvanella, ostracods, trilobites and numerous indeterminates (Table 3, p. 29).

Many of the skeletal grains show the effects of degrading neomorphism, algal boring and corrosion (Plate XV, figure 5, p. 198). Brachiopod shell fragments

and ostracods are commonly crushed.

Sparry calcite occurs as non-ferroan and ferroan sparry calcite cement infilling fractures, fossil cavities, gastropod moulds, and forming syntaxial cement rims on brachiopod shells and crinoid fragments, and as pseudospar occupying the centres of neomorphic patches.

Minor rock components include intraclasts, pellets, dolomite, detrital quartz, authigenic quartz, pyrite, iron oxides, and argillaceous and bituminous material (Table 4, p. 33). Intraclasts compose an average of two percent, whereas the remaining components less than one percent, of the rock volume.

Intraclasts from .5 mm. to 3 mm., and pellets are randomly distributed throughout the matrix.

Non-ferroan and ferroan dolomite occurs as anhedral to euhedral crystals: partially replacing crinoid ossicles and other skeletal grains, selectively replacing parts of the matrix, growing in the dilatant areas of stylolites, and growing in the cavities of fossils, especially those of bryozoans and Alveolites.

Angular quartz grains, from .01 mm. to .3 mm., (some of which have well-terminated overgrowths), are present (Plate XVI, figures 7, p. 199). Colloform silica is found in the cavities of Stachyodes

(Plate XVII, figure 8, p. 200).

Pyrite is present as euhedral crystals and crystalline aggregates dispersed in the matrix, as euhedral crystals selectively replacing parts of brachiopod, trilobite, and bryozoan skeletal parts, and as a fine sooty coating on bryozoans (Plate XVI, figure 1 and 3, p. 199). Some of the pyrite has been oxidized as evidenced by crystals of limonite with cubic forms.

Bituminous and argillaceous material is dispersed throughout the matrix and is concentrated in stylolites.

In a number of specimens of this rock type the long axes of the constituents show a preferred alignment. Burrows and mottled fabrics, probably the result of bioturbation, are common in Unit B.

Rocks of Unit B are classified as wackestones, packstones, grainstones, and shales (Plate VII, figure 2, p. 190). The rock matrix is micro-grained to extremely coarse-grained (Figure 9, p. 40).

3) Interpretation

Rocks of Unit B are interpreted as having been formed in a slightly higher energy, and possibly a slightly shallower marine environment than the rocks of Unit A. On one hand, the extremely coarse-grained nature of the sediment and the alignment of the long axes of constituents indicate moderately energetic water conditions. On the other hand, the abundance of shale beds, and the random orientation of relatively fine-grained skeletal grains and micrite, indicate somewhat

lower energy conditions. Skeletal debris was derived from organic shoals scattered over the shelf during possible frequent periods of increased higher energy generated by storms. During periods of lower energy conditions, between storms, shales and argillaceous carbonates accumulated.

The reduction of quartz grains in Unit B from Unit A may be the result of a decrease in the amount of quartz introduced into the basin, or of decreased circulation within the basin caused by an increase in organic shoal barriers on the shelf or of dilution of the quartz with an increased amount of carbonate sediment.

Skeletal grains showing the effects of algal boring and corrosion were probably derived from contemporaneous shallower original environments.

The association of calcite, pyrite, and bituminous material suggests conditions of pH and Eh similar to those of Unit A.

c) Unit C

1) Distribution and Lithology

Unit C is present in sections KK-68 and KM-68. Although the interval where it is expected is covered it is probably present in KQ-68 (Figure 10, p. 66, and 12, in pocket). Thickness ranges from ten feet in section KK-68 to fifteen feet in section KM-68. The

lower contact has been previously described; the upper contact with Unit D in section KK-68 is sharp, coinciding with a change in bedding from thinly bedded (2" to 6"), moderately resistant argillaceous limestones to massively bedded greater than 4', resistant, relatively pure limestones. It also coincides with a change in fossil content from algae, foraminifers, and many indeterminate skeletal fragments, to abundant stromatoporoids.

Rocks composing this unit are argillaceous, and bituminous, and medium to dark grey in colour. In outcrop, beds of this rock type range in thickness from 2" to 6", and are generally moderately resistant to weathering. Bedding surfaces are sharp. Thin shale partings (less than 2") are common.

2) Petrography

Micrite, microspar and skeletal grains are the main rock constituents (Table 4, p. 33).

Micrite composes an average of twenty-four whereas microspar, an average of forty-four percent of the rock volume. The large amount of microspar is the result of patchy aggrading neomorphism of the original micrite.

Skeletal grains, composing an average of twenty-four percent of the rock volume, include in decreasing order of abundance: indeterminate skeletal grains, brachiopod shell fragments and spines, crinoid ossicles and fragments, Parathuramina, Girvanella, radiosphaerid

calcispheres, and possibly examples of Evlania, Renalcis, Coenites and Thamnopora, (Plate VI, figure 2, p. 189 ; Table 3, p. 29).

Intraclasts, argillaceous and bituminous material, sparry calcite, and detrital quartz are minor rock constituents (Table 4, p. 33).

Intraclasts, from .03 mm. to .3 mm., occur randomly throughout the rock matrix and compose three percent of the rock volume.

Argillaceous and bituminous material also composing an average of three percent of the rock volume, is dispersed through the matrix giving it a 'speckled' appearance in hand specimen.

Sparry calcite composes an average of one percent of the rock volume. It occurs as non-ferroan cement filling fractures and cavities and forming overgrowths on brachiopods, and as pseudospar. Pseudospar occupies the centres of neomorphic patches.

Silica, composing less than one percent of the rock volume, occurs only as angular quartz grains .03 mm. to .04 mm..

Rocks of this unit are classified as algal, foraminiferal wackestones and packstones (Plate VII, figure 3, p. 190). The matrix is typically micro-to fine-grained. (Plate VII, figure 3, p. 190).

3) Interpretation.

Rocks of Unit C are characterized by their micro- to fine-grained matrix, by the presence of shale partings, and by the presence of algae and foraminifers.

Most of the sediment was formed under conditions that were amenable to the accumulation of mud and inhospitable to benthonic organisms. Water depths were probably similar to those postulated for Unit B whereas water conditions were less energetic than in Unit B.

The presence of shale partings and quartz grains indicates periodic influxes of terrestrial sediment into the basin.

The microfossils and skeletal fragments were probably transported from nearby organic shoals.

d) Unit D

1) Distribution and Lithology

Unit D is present in sections KQ-68, KM-68, and KK-68, and is probably present in section LA-68, although the lower (platform) member was not measured in this section. In section KK-68 the unit has a thickness of twenty feet. Part of the unit is covered in sections KQ-68 and KM-68. The lower contact has been previously described; the upper contact with Unit E in section KK-68 is sharp, coinciding with a change in bedding from resistant, massive-bedded (greater than 4') fairly pure limestones to resistant, medium-bedded (2" to 4'), argillaceous and bituminous limestones.

It also coincides with a change in fossil organisms from stromatoporoids and corals to Amphipora, algae and foraminifers.

Rocks of this unit are light to medium brown-grey. In outcrop, beds are generally greater than 4', are resistant to weathering and have uneven bedding surfaces.

2) Petrography

Fossils and microspar are the main rock constituents (Table 4, p. 33).

Fossils compose an average of sixty-six percent of the rock volume. Tabular Actinostroma stromatoporoids, and tabular Alveolites are in growth position. Skeletal grains in decreasing order of abundance include: bulbous stromatoporoids, brachiopod valve fragments, Stachyodes, Thamnopora, crinoid ossicles and fragments, Amphipora, echinoid fragments, pelecypod shell fragments, Parathurammina, Vermiporella, ostracods, trilobites, and indeterminate skeletal grains. The brachiopod valve fragments are commonly bored and corroded by algae. Numerous skeletal grains are crushed.

Microspar composes an average of twenty-seven percent of the rock whereas micrite an average of only two percent. This is largely as a result of neomorphism.

In addition to micrite, intraclasts, sparry calcite, dolomite, detrital quartz, authigenic quartz, pyrite and argillaceous and bituminous material are minor components (Table 4, p. 33). Sparry calcite composes

an average of two percent, whereas the remainder less than one percent of the rock volume.

Intraclasts from .06 mm. to .12 mm. are distributed randomly throughout the matrix.

Sparry non-ferroan and ferroan calcite cement fills cavities and fractures, and forms syntaxial overgrowths on some of the brachiopod fragments. Calcite pseudospar occupies the centres of aggrading neomorphism patches in the rock matrix (Plate XIX, figure 8, p. 202). Some of the sparry calcite has been subjected to strain recrystallization (See p. 157).

Non-ferroan dolomite selectively replaces parts of the rock matrix and parts of Amphipora coenostea and brachiopod valve fragments.

Angular quartz grains .02 mm. to .03 mm. are randomly dispersed throughout the rock matrix.

Parts of brachiopod valve fragments and Amphipora and Stachyodes coenostea have been replaced by chalcedony and lutecite patches (Plate XVII, figure 1, p. 200).

Pyrite occurs as euhedral crystals and crystalline aggregates dispersed throughout the matrix.

Bituminous and argillaceous material is dispersed throughout the matrix, and is concentrated in stylolites.

The rocks composing this unit are classified as medium-to coarse-grained stromatoporoid and coral

wackestones, packstones (Plate VII, figure 4, p. 190) and boundstones.

3) Interpretation

The abundant fossils, especially the tabular stromatoporoids and Alveolites (many of which are in place) and the medium-to coarse-grained matrix are characteristic of this unit.

Unit D rocks are interpreted as having been part of an organic shoal. They formed in moderately shallow, well oxygenated, and fairly energetic water conditions. The presence of algae suggests that the water was relatively clear.

The change in lithology from Unit C to Unit D indicates a further shallowing over the shelf. This may have been caused by a general marine regression.

The amount of detrital quartz is less than in Unit C. This is probably the result of decreased circulation on the shelf as a result of the growth of numerous organic-shoal barriers in response to the shallowing.

e) Unit E

1) Distribution and Lithology

Unit E is present in section KK-68, and, although the interval where it is expected is covered, is probably present in sections KQ-68, and LA-68 (Figure 10, p. 66, and 12, in pocket). In section KK-68 Unit E is ten feet thick. The lower contact has been

described; the upper contact with Unit F is gradational, and is placed where Amphipora, algae and foraminifers give way upwards to tabular stromatoporoids, Alveolites, and dendroid corals.

Rocks composing the unit are argillaceous, bituminous, and are medium brown to dark brown. In outcrop, beds are separated by sharp contacts, range in thickness from 2" to 4', and are resistant to weathering.

2) Petrography

Micrite and microspar, skeletal grains, and pellets and intraclasts are the main rock constituents (Table 4, p. 33).

Microspar composes an average of thirty-eight, whereas micrite an average of twenty-one percent of the rock volume. Much of the microspar is the result of aggrading neomorphism and perhaps of the destruction of pellets and/or intraclasts. Vague pelletoid outlines are commonly visible within the microspar and micrite. Compression, the result of load pressure, may have caused much of the pelletoidal material to coalesce, destroying individual **particle outlines**. For this reason it is sometimes quite difficult to measure **exactly** the amounts of micrite, microspar and pellets present in the rocks of this unit.

Skeletal grains, composing an average of twenty-three percent of the rock volume, include in decreasing order of abundance: Amphipora (up to forty percent of

the rock), brachiopod shell fragments, crinoid ossicles, Parathurammina, Irregularina, Vermiporella, ostracods, and indeterminate skeletal grains (Table 3, p. 29).

Amphipora coenostea have undergone extensive degrading neomorphism causing partial to total obliteration of skeletal architecture. Ostracod shells and crinoid fragments have undergone degrading neomorphism. Some of the skeletal grains are crushed.

Fellets and intraclasts from .04 mm. to .12 mm., composing an average of thirteen percent of the rock volume, are randomly distributed throughout the rock matrix.

Minor rock constituents include sparry calcite, dolomite, detrital quartz, and argillaceous and bituminous material (Table 4, p. 33). Sparry calcite composes an average of four percent, whereas the remaining constituents less than one percent of the rock volume.

Sparry calcite occurs as non-ferroan cement filling cavities and fractures, and as pseudospars occupying the centres of aggrading neomorphic patches.

Widely dispersed angular grains of quartz less than .03 mm. occur with dolomite crystals in the matrix of the rocks, along with bituminous and argillaceous material.

Rocks of this unit are classified as micro-to

fine-grained Amphipora wackestones and packstones (Plate VIII, figure 1, p. 191).

3) Interpretation

This unit is characterized by the abundance of Amphipora, pellets and intraclasts, by the occurrence of algae and foraminifers, and by the fine-grained nature of the rock matrix.

Rocks of Unit E are interpreted as having formed in a moderately shallow, reasonably well-oxygenated, and relatively quiet water environment.

It seems probably that at the time of formation of Unit E, the organic shoals of Unit D had in some cases evolved into "proto-reefs" each with its own environmentally controlled lateral zonation. The rocks of Unit E may have formed in the lee of one or more of the "proto-reefs."

The minor amount of detrital quartz and argillaceous material in the rocks indicates that very little terrigenous detritus was being deposited in the "proto-reef" environment. Most of the sediment was generated by the reef complexes.

f) Unit F

1) Distribution and Lithology

Unit F occurs in sections KQ-68 and KK-68, although the interval where it is expected is covered, it is probably present in sections KM-68 and LA-68

(Figure 10, p.66 and 12, in pocket). In section KK-68 the unit is thirty feet thick. The lower contacts have been described; the upper contact with Unit G is gradational, placed where there is a change from Coenites, Alveolites, and tabular stromatoporoids (some of which are in place), to a mixture of assorted, randomly oriented, skeletal grains.

Rocks composing this unit are bituminous, argillaceous, and medium to dark grey-brown in colour. Bedding thicknesses range from 2" to 4'. Beds are weakly resistant to resistant to weathering. Weakly resistant beds tend to contain more argillaceous material than do the more resistant beds. Bedding surfaces are nodular to sharp.

2) Petrography

Fossils, micrite, microspar and intraclasts, are the main rock constituents (Table 4, p. 33).

Fossils compose an average of eighty-three percent of the rock volume. Actinostroma tabular stromatoporoids (some of which are in growth position) and tabular and irregularly-shaped Alveolites are the most prominent fossils in the unit. In decreasing order of abundance skeletal grains include: Coenites, crinoid ossicles and fragments, Stachyodes, Amphipora, brachiopod valve fragments, bryozoans, echinoid fragments, Parathurammina, ostracods, indeterminate

skeletal fragments, and possibly Thamnopora fragments and Tentaculites (Table 3, p. 29).

Alveolites, Coenites, crinoid fragments and ossicles and brachiopod valve fragments have undergone degrading neomorphism (Plate XLX, figure 1, p. 202).

'In situ' tabular stromatoporoids are more prevalent along with rare tabular Alveolites at the base of the unit. 'Coenites' and irregularly-shaped Alveolites occur in the middle of the unit, whereas Coenites is prevalent towards the top of the unit.

Micrite composes an average of twenty-six, whereas microspar an average of five percent of the rock volume. Relatively little aggrading neomorphism has taken place.

Intraclasts from .03 mm. to 7 mm. are scattered throughout the matrix and compose an average of five percent of the rock volume.

Minor rock constituents include in decreasing order of abundance: sparry calcite, dolomite, detrital quartz and argillaceous and bituminous material (each composing an average of less than one percent of the rock volume).

Sparry calcite occurs as non-ferroan cement infilling cavities and fractures, and forming bladed crystal crusts on skeletal grains.

Dolomite occurs as euhedral to anhedral crystals

from .03 mm. to .15 mm. growing in the cavities of Coenites and partially replacing the adjacent skeleton. (Plate XVIII, figure 5, p. 201).

Angular quartz clasts from .01 mm. to .02 mm., some with authigenic silica overgrowths, are distributed randomly throughout the matrix.

The rocks of this unit are classified as Coenites packstones, and tabular stromatoporoid boundstones (Plate VIII, figure 2, p. 191). There is a general decrease in the matrix grain size from medium-grained at the bottom to fine-grained at the top of the unit. Some of the specimens show a pronounced alignment of the long axes of skeletal grains. In a few specimens there is evidence of crude lamination caused by a subtle grading of constituents.

3) Interpretation

Unit F is characterized by the presence of in-place tabular stromatoporoids, by Coenites and Alveolites corals, and by the decreasing grain size from the bottom to the top of the unit.

This unit is interpreted as having formed in deeper water and under more turbulent, more energetic and less oxygenated water conditions that did the previous unit. The change from tabular stromatoporoids at the base of the unit through Alveolites to Coenites at the top of the unit accompanied by the grain size

change, is interpreted as evidence of general deepening of the water on the shelf. As the water deepened the tabular stromatoporoids were no longer able to survive and were replaced in turn by Alveolites and Coenites.

g) Unit G

1) Distribution and Lithology

Unit G is present in sections KK-68 and KM-68, and is also probably present in section KQ-68 (Figure 10, p. 66 and 12, in pocket). In section KK-68 Unit G is thirty feet thick. The lower contact has been described; the upper contact with Unit H, the Carcajou marker, is relatively sharp, being placed where Coenites and Thamnopora compose more than twenty percent of the rock volume. The contact also coincides with a change in bedding from beds less than $\frac{1}{10}$ " to $\frac{1}{4}$ " to beds $\frac{1}{2}$ " to 2' in thickness, and a change from weak to moderate resistance to weathering.

Rocks composing this unit are moderately argillaceous and bituminous, and are dark brown to black in colour. In outcrop beds are commonly $\frac{1}{10}$ " to 6", and are moderately to weakly resistant. Bedding surfaces are characteristically sharp and interbedded shale is common in the middle and top of the unit.

2) Petrography

The main rock constituents are micrite, microspar, and skeletal grains (Table 4, p. 33).

Micrite composes an average of forty percent, whereas microspar an average of fifteen percent of the rock volume.

Skeletal grains compose an average of twenty-nine percent of the rock volume and include in decreasing order of abundance: Alveolites fragments, Coenites, brachiopod valve fragments, crinoid ossicles and fragments, bryozoans, Stachyodes, echinoid spines, gastropods, Parathurammina, Tikhinella, Girvanella, radiosphaerid calcispheres, ostracod fragments, trilobite fragments, and possibly fragments of Thamnopora, Tentaculites, and Evlania (Table 3, p. 29).

Minor rock components include: sparry calcite (composing an average of four percent of the rock volume), argillaceous and bituminous material (composing an average of one percent of the rock volume), and intraclasts, pellets, dolomite, detrital quartz, authigenic quartz and pyrite (each composing an average of less than one percent of the rock volume).

Sparry calcite occurs only as non-ferroan cement, infilling fossil cavities and fractures.

Argillaceous and bituminous material is dispersed randomly throughout the matrix.

Intraclasts, pellets and angular grains of quartz, are randomly dispersed throughout the matrix.

Non-ferroan dolomite occurs both as euhedral to subhedral crystals replacing parts of the rock matrix

and parts of skeletal grains, and as euhedral crystals filling portions of cavities in skeletal grains (Plate XVlll, figure 2, p. 201).

Authigenic silica is present in the form of lutecite and chalcedony replacements of brachiopod valve fragments and other skeletal grains.

Pyrite occurs as euhedral crystals replacing parts of skeletal grains and as microcrystalline pyrite scattered throughout the rock matrix.

Some of the sediment in this unit shows alignment of the long axes of skeletal grains. Rocks are classified as wackestones, packstones, grainstones, and shales (Plate Vlll, figure 3, p. 191). The matrix is generally fine-to medium-grained. Whereas packstone and grainstone sediments are predominant at the base of the unit, wackestone sediments are predominant in the middle and at the top of the unit along with interbedded shale.

3) Interpretation

Rocks of Unit G are characterized by the abundance of skeletal grains, by their moderately bituminous and argillaceous character, and by the change from packstone sediments at the base of the unit to wackestone sediments and shale at the top.

These rocks are interpreted as having formed in deeper water that was less oxidizing and in an environ-

ment of less energetic and turbulent conditions than for Unit F. This environment is very similar to that postulated for Unit B. The rocks of both Unit F and Unit G indicate a progressive decrease in the energy of the environment, probably caused by an increase in the depth of water over the shelf. In response to the changing environment the organisms sought habitats where conditions were more amenable for their existence. Those that were not suited to the deeper water conditions simply stopped growing.

h) Unit H

1) Distribution and Lithology

Unit H, the Carcajou marker, is present in sections KP-68, KQ-68, KM-68, KK-68, and LA-68. It is only weakly developed in section KP-68; it is probably present in section LB-68, but does not crop out there. Unit H is present in those sections where the platform member is overlain by Units Q, O, L and M of the reef member (Figures 10, p. 66, and 12, in pocket). Thickness ranges from zero in sections KS-68 and KJ-68 to forty-five feet in section KQ-68. The lower contact has been described previously; the upper contact with the reef member generally coincides with a change in bedding and with a change in fossils from Coenites and Thamnopora corals, and crinoid ossicles to Amphinora, foraminifers and algae (Figure 12, in pocket). (In section

LA-68 the upper contact is only tentatively placed because of the difficulty in defining it).

The rocks composing Unit H are strongly bituminous, argillaceous, and medium to dark grey-brown. Beds range in thickness from 6" to 4', and are weakly to highly resistant to weathering. Bedding surfaces are uneven, and interbedded shale beds are common.

2) Petrography

The main rock constituents are fossils, and micrite and microspar (Table 4, p. 33).

Fossils compose an average of forty-eight percent of the rock volume. Alveolites and tabular stromatopora (both of which are commonly in growth position) are abundant in the upper part of the unit (in section KK). In decreasing order of abundance, skeletal grains include: Thamnopora, Coenites, Stachyodes, brachiopod valve fragments, bryozoans, crinoid ossicles and fragments, echinoid spines, gastropods, Parathurammina, Tikhinella, Girvanella, radiospherid calcispheres, ostracod fragments, trilobite shell fragments, Tentaculites and sponge spicules (Table 3, p. 29).

Whereas tabular stromatopora and Alveolites are abundant in the upper part of the unit (in sections KP, KQ and KK-68) Coenites and Thamnopora are more abundant, often to the exclusion of both tabular stromatopora and Alveolites in the middle and lower parts of the unit.

Numerous skeletal grains, especially Coenites and Thamnopora have been subjected to degrading neomorphism, boring activity and corrosion by algae. Crushing of skeletal grains is common.

Microspar composes an average of thirty-eight, whereas micrite, twenty-five percent of the rock volume. Aggrading neomorphism is not extensive in rocks that have relatively large amounts (greater than 3 percent) of bituminous and argillaceous material.

Minor rock constituents include: sparry calcite, (an average of five percent of the rock volume) intraclasts and bituminous and argillaceous material (each an average of three percent of the rock volume); and dolomite, detrital quartz, authigenic quartz, pyrite and iron oxides (each one percent or less of the rock volume) (Table 4, p. 33).

Sparry calcite occurs as both non-ferroan and ferroan cement infilling cavities and fractures and forming bladed crystal crusts on skeletal grains.

Intraclasts from .04 mm. to .45 mm. are distributed randomly throughout the matrix.

Bituminous and argillaceous material is dispersed throughout the matrix, and concentrated in stylolites.

Dolomite is present in the form of: anhedral non-ferroan crystals selectively replacing crinoid ossicles and stromatoporoids; euhedral non-ferroan crystals occupying the cavities of corals; subhedral and anhedral

non-ferroan crystals selectively replacing the matrix; and anhedral ferroan crystals replacing ferroan calcite cement in gastropod moulds.

Angular quartz grains from .03 mm. to .05 mm. are randomly dispersed throughout the rock matrix. Some of the grains have overgrowths on them.

Thamnorora fragments and brachiopod valve fragments are selectively replaced by chalcedony and lutecite. Mosaic quartz (Plate XVI, figure 9, p. 199) occupies some of the pores of Alveolites in section KG-68.

Pyrite occurs as euhedral crystals (.01 mm. to .03 mm.) and crystal aggregates (.13 mm. to .3 mm.) selectively replacing parts of Thamnorora, Coenites, brachiopod valve fragments, crinoid fragments, echinoid spines, and stromatoporoids (Plate XVI, figure 2, p. 199). The border zone and the area immediately adjacent to body cavities of Thamnorora and Coenites are most commonly affected. In addition euhedral crystals (.06 mm. to .15 mm.) occupy part of the matrix. Some of these crystals have a rim of bladed spar crystals around them (Plate XVI, figure 4, p. 199). A large amount of the pyrite has been oxidized.

Rocks of this unit are classified as micro-to medium-grained Thamnorora and Coenites wackestones, packstones, grainstones and shales (Plate VIII, figure 4, p. 191). There is a general increase in grain-size and a corresponding change from wackestones intercalated with shales, to packstones, grainstones

and boundstones, from the bottom to the top of the unit (Figure 10, p. 66). The long axes of skeletal grains are commonly aligned in the rocks of the upper part of the unit.

3) Interpretation

Rocks of Unit H are characterized by an abundance of Thamnopora and Coenites, by the variety of skeletal grains in the matrix, by the bituminous and argillaceous nature of the matrix, and by the change in both grain-size and rock type from the bottom to the top of the unit.

The fine-grained wackestones and shales at the bottom of the unit indicate a fairly low-energy depositional environment. In contrast, the packstone and grainstone rocks, and the alignment of the long axes of skeletal grains at the top of the unit suggest a more energetic environment.

The rocks composing the unit are interpreted as having been formed under progressively shallower, more energetic, water conditions. The progression of Thamnopora, Alveolites and tabular stromatoporoids (many of which are in place), from the bottom to the top of the unit is a result of the changing conditions. The presence of algae in the middle and upper parts of the unit support a shallow water environment, and indicate that the water was probably relatively clear.

FIGURE 11
PLATFORM MEMBER UNITS A, B
AND I, SECTION KJ -68

i) Unit I

1) Distribution and Lithology

Unit I is present in sections KJ-68 and KL-68 (Figures 11, p. 95, 12 in pocket, and 13, p. 101). Thickness of the unit ranges from eighty feet in section KJ-68 to forty feet in section KL-68. In section KJ-68 the lower contact with Unit B is gradational. It is placed where skeletal grains compose more than thirty percent of the rock volume. In section KL-68 the lower contact with Unit A is sharp, coinciding with a change in bedding from moderately resistant beds 6" to 4' thick to resistant beds 2" to 6" thick. The upper contact with Unit J of the reef member in section KL-68 is sharp. The contact is placed at the base of a shale unit which forms the base of Unit J.

2) Petrography

Microspar and micrite, skeletal grains, and intra-clasts are the main rock constituents (Table 4, p. 33).

Microspar composes an average of forty-two, whereas micrite an average of thirteen-percent of the rock volume. Moderate aggrading neomorphism has resulted in the formation of the microspar.

Skeletal grains compose an average of forty percent of the rock volume, and include fragments of: bulbous stromatoporoids, Stachyodes, Amphipora, Coenites, Thamnopora, brachiopod valves, bryozoans, crinoid ossicles, trilobites, Tentaculites, and sponge

spicules (Table 3, p. 29).

Crinoid ossicles and fragments have been subjected to degrading neomorphism. Many of the skeletal grains are partially corroded by algae.

Minor rock constituents include sparry calcite, dolomite, detrital quartz, authigenic quartz, pyrite, marcasite, iron oxides and argillaceous and bituminous material (Table 4, p. 33).

Sparry calcite occurs: as non-ferroan cement forming bladed crystal crusts on grains and filling cavities and fractures, as ferroan cement filling cavities and fractures, and as pseudospar occupying the centres of aggrading neomorphism patches. Fractures filled with ferroan calcite commonly cut across cavities and fractures filled with non-ferroan calcite.

Dolomite occurs as euhedral non-ferroan crystals selectively replacing the matrix, as non-ferroan anhedral crystals replacing parts of sparry calcite in fractures, and as subhedral crystals replacing parts of crinoid fragments (Plate XVIII, figure 1, p. 201).

Angular quartz clasts (.02 mm. to .03 mm.) are distributed randomly throughout the matrix. Some of these have simple and well-terminated overgrowths.

Authigenic silica is present as spherulitic lutecite, replacements of brachiopod valves (Plate XVII, figure 4, p. 200), as chalcedony and lutecite patchy

replacements of Stachyodes coenostea, and as colloform cement in the pores of some of the Stachyodes.

Pyrite occurs as euhedral crystals and crystal aggregates occupying parts of the matrix, as euhedral crystals and crystal aggregates that have selectively, in places totally, replaced brachiopod shells, Stachyodes coenostea, Tentaculites, and crinoid fragments.

The former presence of marcasite is inferred from the numerous (in places) cuneiform crystals of hematite that are dispersed throughout the matrix. It is probable that the marcasite underwent oxidation to hematite (Plate XVI, figures 5 and 6, p. 199).

Bituminous and argillaceous material is distributed randomly throughout the matrix.

Rocks of this unit are classified as skeletal, intraclastic mudstones, wackestones, packstones and grainstones (Plate IX, figure 1, p. 192). The matrix is commonly fine-grained.

Some beds of this unit are graded. Medium-grained, light coloured skeletal grains and intraclasts at the bottom of such a bed grade into fine-to micro-grained dark coloured intraclasts and mud at the top. The contact between beds is sharp and occurs where the medium-grained portion of one bed meets the fine-to micro-grained portion of another. Some beds are also burrowed and show micro-faulting.

3) Interpretation

Graded beds, the abundance of a wide assortment

of relatively fine-grained skeletal grains, and the abundance of very fine-grained intraclasts are characteristic of this unit.

Unit I is thought to be the lateral (eastern) platform edge equivalent of Units C to H in the central part of the platform member. The rocks of this unit are interpreted as having been formed in relatively deep water, under poorly oxidizing and quiet water conditions. Most of the skeletal grains were derived from the organic shoals that existed in the central and western part of the platform member and were transported to their place of deposition possibly by turbidity currents. A similar origin has been postulated for the rocks of Units J and K which overlie Unit I (Mackenzie, 1970).

The Tentaculites, sponge spicules, and small, smooth, thin-shelled brachiopods may be indigenous fossils.

This type of deposit will be discussed further in conjunction with Units J and K, p. 102.

B) Reef Member

The reef member can be divided into seven laterally contiguous facies on the basis of lithologic and paleontologic criteria. From east to west these are the: off-reef, fore-reef, organic-reef, back-reef, marginal-shoal, organic-shoal, and sublittoral facies (Figure 12, in pocket).

Thickness of the reef member ranges from approximately ten feet in the sublittoral facies, section KK-68 to five hundred and seventy-five feet in the back-reef facies, section KK-68.

The contact of the reef member with the platform member has been previously described. The contact of the reef member with the overlying Canol Formation is sharp in sections KY-68, KX-68, KW-68 and KL-68. In section KL-68 it is gradational, and is placed where the reef member is overlain by the distinctive yellow-and-orange-weathering, dark brown to black, siliceous, fissile shale of the Canol Formation.

1 Off-Reef Facies

The off-reef facies is present in sections KL-68 and KJ-68. The off-reef facies grades laterally into the fore-reef facies on the west, probably somewhere between sections LB-68 and KJ-68. The lower contact has been described. The upper contact with the Canol Formation in section KL-68 is sharp (Figure 13, p. 101).

KL-REEF

Dark brown to black shales and intercalated beds of micro-to coarse-grained skeletal mudstones, wackestones and packstones. Fossils include brachiopods, crinoids and Tentaculites. Beds show grading.

Light to dark grey micro-to coarse-grained wackestones, packstones, grainstones and shales. Black chert, slump structures and beds composed of angular blocks of limestone are common. Fossils include ostracods, brachiopods, corals, crinoids, gastropods, Tentaculites, and stromatoporoids.

FIGURE 13

REEF MEMBER UNITS J AND K,
SECTION KL-68

The off-reef facies is divided vertically into Unit J and Unit K.

Mackenzie (1970) gives a detailed account of the lithology and petrography of the off-reef facies. A brief description and discussion of the way this facies relates to the remainder of the reef member is given here.

a) Unit J

1) Distribution, Lithology and Petrography

Unit J is present in sections KL-68 and KJ-68. In section KL-68, Unit J is the lower unit with a thickness of approximately twenty feet (Figures 12 and 13, p. 101). Only part of Unit J is present in section KJ-68 (Figure 11, p. 95). The contact between Unit J and Unit K is disconformable, and is placed where the limestones of Unit J are in contact with the shales of Unit K.

The rocks of this unit are light to dark grey. In outcrop beds are less than $\frac{1}{10}$ " to 6" in thickness and are weakly resistant to resistant to weathering. Bedding surfaces are sharp. Interbeds of shale and beds composed of large, angular blocks of limestone are common as are black chert nodules, and slump structures.

Skeletal grains noted in the rocks include fragments of: ostracods, Tentaculites, gastropods, crinoid ossicles, bryozoans, brachiopod valves, Thamnopora, Coenites, Alveolites, Stachyodes, and possibly bulbous stromatoporoids (Table 3, p. 29; Plate XVll and XVlll,

figures 6; and 6, p. 200 & 201).

These rocks are classified as wackestones, packstones, grainstones and shales (Plate 1X, figure 2, p. 192).

2) Interpretation

Interpretation is considered with Unit K, below.

b) Unit K

1) Distribution, Lithology and Petrography

Unit K is approximately thirty feet thick and overlies Unit J in section KL-68.

The rocks of this unit are dark brown to black. In outcrop beds are less than $\frac{1}{10}$ " to 2" thick and are weakly resistant to weathering. Bedding surfaces are sharp and interbeds of shale and crinoid limestone are common.

The beds are commonly graded. Skeletal grains and intraclasts (with an average size of .70 mm.) at the bottom of the beds grade into micrite-sized material at the top of the beds.

Skeletal grains in the rock include: brachiopod valve fragments, crinoid ossicles and fragments, Tentaculites, and possibly some echinoid plates and sponge spicules (Table 3, p. 29).

These rocks are classified as shales and as skeletal mudstones, wackestones and packstones (Plate 1X, figure 3, p. 192).

2) Interpretation

According to MacKenzie (1970, p. 476) the rocks of Unit J are interpreted as allochthonous reef debris, whereas those of Unit K are limestone turbidites.

The rocks of both units were deposited in relatively deep and quiet water, possibly in a euxinic environment. Unit J rocks were formed by periodic mass sliding of reef-derived material into the shale basin, whereas Unit K rocks were formed when loose sediment containing skeletal grains, especially crinoid fragments, was transported into the basin and deposited by periodic turbidity flows.

The abrupt change in sediment type from allochthonous reef debris to black shale and turbidites presumably is a reflection of changes in current patterns or, locally, perhaps a result of slumping of reef material (MacKenzie, 1970, p. 483). The present author suggests that the changes in current patterns may be the result of a deepening of the water in the basin. Evidence for such deepening is present in other facies.

The source of the allochthonous debris and the skeletal grains in the two units is presumed to be the organic-reef and the fore-reef facies which lie to the west.

11 Fore-Reef Facies

The fore-reef facies is present in sections LA-68 and LB-68 (Figure 12 in pocket, and 13, p. 101). Fore-reef facies limestones grade laterally into the organic-reef facies on the west and into the off-reef facies

on the east. In section LA-68 the lower fore-reef facies unit overlies the Carcajou marker, Unit H, with a gradational contact; the upper contact is not exposed. Neither the lower nor the upper contacts are exposed in section LB-68.

The fore-reef can be divided into a lower unit, Unit L, and an upper unit, Unit M.

a) Unit L

1) Distribution and Lithology

Unit L, the lowermost unit of section LA-68, with a thickness of one hundred and fifty feet, is overlain by a tongue of the organic-reef facies, Unit N (Figure 12, in pocket, and 14, p. 106). A gradational contact separates these units.

Rocks of this unit are medium grey. In outcrop beds are greater than 4' thick and are resistant to weathering. Bedding surfaces are uneven.

2) Petrography

The main rock constituents are fossils, micrite and microspar, dolomite, and intraclasts (Table 4, p. 33).

Fossils compose an average of fifty-five percent of the rock volume. Tabular stromatoporoids and Alveolites (both of which are commonly in place) are present. Tabular stromatoporoids are progressively more abundant from the middle to the top of the unit, whereas the abundance of Alveolites decreases. Skeletal grains include in decreasing order of abundance:

LA-68-REEF

FIGURE 14
REEF MEMBER UNITS L, M, AND N,
SECTION LA-68

bulbous stromatoporoids. Coenites, Stachyodes, Thamnopora, crinoid ossicles and fragments, brachiopod valve fragments, 'lagenid' foraminifers, radiosphaerid calcispheres, ostracods and trilobites (Table 3, p. 29).

Many of the grains, especially Coenites and Thamnopora, have undergone degrading neomorphism, especially around the edges of skeletal cavities.

Coenites and Thamnopora are more abundant in the lower and middle parts of the unit whereas bulbous stromatoporoids are prevalent at the top of the unit.

Micrite composes an average of thirty percent, whereas microspar fourteen percent of the rock volume.

Dolomite composes an average of ten percent of the rock volume, and occurs as euhedral to anhedral crystals replacing portions of the rock matrix.

Intraclasts from .05 mm. to .2 mm. and composing an average of seven percent of the rock volume are distributed randomly throughout the matrix.

Minor rock constituents include: pellets, and sparry calcite (each composing an average of one percent of the rock volume); and bituminous and argillaceous material composing less than one percent of the rock volume (Table 4, p. 33).

Pellets are distributed randomly throughout the rock.

Sparry calcite occurs as non-ferroan and ferroan calcite filling cavities and fractures.

Bituminous and argillaceous material is dispersed

randomly throughout the matrix and concentrated in stylolites.

Rocks of this unit are classified as fine-to coarse-grained stromatoporoid packstones and boundstones (Plate IX, figure 4, p. 192).

3) Interpretation

Rocks of Unit L are characterized by an abundance of Coenites, Thamnopora, Alveolites, and tabular stromatoporoids.

This unit is interpreted as having formed in a progressively shallower, more energetic and oxygen-rich environment. The gradual change from a dendroid coral, brachiopod and crinoid assemblage at the base of the unit through an Alveolites and tabular stromatoporoid assemblage in the middle of the unit to a tabular and bulbous stromatoporoid assemblage at the top of the unit, accompanied by a general increase in grain-size, indicates this.

Bituminous and argillaceous material is only a minor constituent of the unit. This is manifested by the light colour of the limestones composing the unit. The minor amount of bituminous material indicates fairly well-oxygenated waters. The minor amount of argillaceous material is caused by the presence of the reef barrier to the west. Terrigenous sediment was prevented from entering the basin by this barrier.

Unit L formed on the basin edge of the organic-reef barrier.

b) Unit M

1) Distribution and Lithology

Unit M is present in sections LA-68 and LB-68 (Figure 12, in pocket, and 14, p. 106). In section LA-68 it forms two tongues, a lower tongue fifty feet thick and an upper tongue thirty-five feet thick. In section LB-68 the whole thickness of the section, one hundred and seventy-five feet, is composed of Unit M rocks. In section LA-68 the lower and upper contacts of the tongues are gradational. Neither of the contacts is present in section LB-68.

Rocks of Unit M are light to medium grey-brown. In outcrop beds are 2' to greater than 4' thick and are resistant to weathering. Bedding surfaces are uneven.

2) Petrography

Skeletal grains, composing an average of fifty-five percent of the rock volume, are the main constituents (Table 4, p. 33). In decreasing order of abundance these include: Stachyodes, bulbous stromatoporoids, crinoid ossicles and fragments, Thamnonora, rugose corals, brachiopod valve fragments, echinoid plates, radiosphaerid calcispheres, ostracod fragments, trilobite fragments, and possibly Parathurammina and Vermiporella (Table 3, p. 29).

Many of the skeletal grains have been bored and corroded by algae. Brachiopod valves and ostracods are commonly crushed.

Other constituents which have not been quantified in an examination of this unit include: intraclasts, pellets, micrite, microspar, sparry calcite, dolomite, pyrite, marcasite, iron oxides, and argillaceous and bituminous material.

Intraclasts and pellets from 1 mm. to .5 mm. are distributed randomly throughout the matrix.

Sparry calcite occurs as ferroan and non-ferroan cement filling cavities and fractures and forming syntaxial overgrowths on crinoid ossicles, and as pseudospar. Most of the cavity space in what would normally be a very porous rock is occluded by sparry calcite cement.

Dolomite occurs as euhedral crystals growing in the skeletal cavities of stromatoporoids and corals, and as subhedral to euhedral crystals selectively replacing portions of the matrix.

Pyrite occurs as euhedral crystals and crystal aggregates selectively replacing brachiopod valves, crinoid ossicles, bulbous stromatoporoids and Stachvodes coenostea. The presence of marcasite is inferred by numerous hematite cuneiform crystals distributed randomly throughout the matrix and occupying the pores of crinoid ossicles.

Bituminous and argillaceous material is dispersed throughout the matrix and is concentrated in stylolites. Very little is present in this unit.

Rocks of this unit are classified as Stachyodes and bulbous stromatoporoid packstones and grainstones (Plate X, figure 1, p. 193). The matrix is fine-to coarse-grained and is moderately well-sorted.

3) Interpretation

Rocks of Unit M are characterized by an abundance of Stachyodes and bulbous stromatoporoids, and by their moderately well-sorted packstone-grainstone nature.

This unit is interpreted as having been formed under moderately shallow, fairly energetic and oxygen-rich water conditions. The prevalence of algal corrosion suggests 'in situ' corrosion, and this indicates relatively clear and fairly shallow water conditions (See page 143). The packstone-grainstone nature of the sediments, and their moderate sorting suggest fairly energetic conditions. The relative lack of bituminous and argillaceous material in the rocks, manifested by their light colour, suggests an oxygen-rich environment where bituminous material was rapidly oxidized.

Unit M formed on the basin side (to the east) of the organic-reef facies.

111 Organic-Reef Facies

A portion of the organic-reef facies is present in section LA-68 (Figure 12 in pocket, and 14, p. 106). The organic-reef facies limestones grade laterally into the back-reef facies on the west and into the fore-reef facies on the east. In section LA-68 two tongues

of the organic-reef facies are present. Tongues of the fore-reef facies (Unit M) lie between the organic-reef tongues and over the upper organic-reef tongue. The lower tongue overlies Unit L of the fore-reef facies. Contacts are gradational.

a) Unit N

1) Distribution and Lithology

The description of Unit N is based on the description of the two tongues of the unit present in Section LA-68. The major portion of Unit N probably lies to the west of section LA-68.

Rocks of this unit are medium grey. In outcrop beds are generally greater than 4' thick, and are resistant to weathering. Bedding surfaces are uneven.

2) Petrography

Because only a few hand specimens of rocks from this unit have been examined, the description that follows is based mostly on field examination.

Hemispherical and tabular stromatoporoids compose up to one hundred percent of the rock volume. Many of the stromatoporoids are in growth position. Both types of stromatoporoids encrust each other and other stromatoporoids of the same type, and appear to form a fairly stable framework. Other fossils present include: bulbous stromatopoids, Stachyodes, brachiopod valves and crinoid ossicles.

Medium-to extremely coarse-grained skeletal sediment is present around the stromatoporoids.

Rocks of this unit are classified as stromatoporoid packstones, grainstones, and boundstones (Plates 1 and X, figures 2 and 2, p. 184 & 193).

3) Interpretation

Unit N is characterized by the abundance of hemispherical and tabular stromatoporoids that commonly form fairly stable frameworks.

The rocks of Unit N are interpreted as having formed in a fairly energetic, oxygen-rich environment. The association of hemispherical stromatoporoids and skeletal grains derived from the stromatoporoids, the lack of bituminous material in the rocks, and the nature of the sediment indicate this.

The organic-reef facies was probably composed of isolated mounds of stromatoporoids that together formed a barrier. This barrier probably started to grow at the beginning of the formation of the reef member and continued to move to the east, growing over the fore-reef facies and extending the area of the platform (Figure 12, in pocket).

Skeletal debris derived from the organic-reef facies was swept into the fore-reef and off-reef facies.

IV Back-Reef Facies

The back-reef facies is present in sections KQ-68, KM-68, and KK-68 (Figures 12 and 15, p. 115). Back-reef facies limestones probably grade laterally into the marginal shoal facies on the west somewhere between

sections KQ-68 and KP-68, and into the organic reef facies on the east. In all three sections the back-reef facies overlies the Carcajou marker, Unit H.

The back-reef facies can be divided vertically into a lower unit, Unit O, and an upper unit, Unit P.

a) Unit O

1) Distribution and Lithology

Unit O is present in sections KQ-68, KM-68, and KK-68. Thickness ranges from two hundred and forty-five feet in section KM-68 to two hundred eighty-five feet in section KK-68. The contact of Unit O with the overlying Unit P is gradational.

Rocks of Unit O are medium to light grey-brown. In outcrop beds range in thickness from 6" to greater than 4', and are weakly resistant to resistant to weathering. Bedding surfaces are sharp to nodular.

2) Petrography

The main rock constituents are: skeletal grains, microspar and micrite, and intraclasts and pellets (Table 4, p. 33).

Skeletal grains compose an average of fifty percent of the rock volume and include in decreasing order of abundance: tabular stromatoporoid fragments, bulbous stromatoporoids, Amphipora, Stachyodes, Coenites, Thamnopora, brachiopod valve fragments, crinoid ossicles, echinoid plates, gastropods, Parathuramina, Bisphaera, Tikhinella, Evlania, Irregularina, 'lagenid'-type for-

KK-Reef

Contact not evident

Light to dark grey-brown, micro-to coarse-grained, stromatoporoid, coral packstones, grainstones and boundstones (most common), Amphipora wackestones, packstones, and grainstones, and intrapel, foraminiferal, algal wackestones and packstones. Fossils include Amphipora, bulbous stromatoporoids, Stachyodes, Thamnopora, foraminifers and algae.

Medium to light brown, micro-to medium-grained, intrapel, foraminiferal, algal wackestones and packstones (common), Amphipora wackestones and packstones (common), Amphipora and Stachyodes packstones and grainstones, and stromatoporoid, coral packstones and grainstones. Fossils include Amphipora, Stachyodes, algae and foraminifers.

REEF MEMBER UNITS O AND P,
SECTION KK-68

FIGURE 15

aminifers, Vermiborella, Girvanella, Renalcis, radiosphaerid calcispheres, ostracods, trilobite fragments, and indeterminate skeletal grains (Table 3, p. 29).

Most skeletal grains have undergone some degree of degrading neomorphism. The skeletal architecture of Amphipora is commonly obliterated. (Plate XIX, figure 3, p. 202). Some skeletal grains show evidence of algal boring and corrosion (Plate XV, figure 2, p. 108). Girvanella rarely coats Amphipora coenostea.

Microspar composes an average of twenty-nine percent, whereas micrite twenty-one percent of the rock volume. Most of the microspar is the result of aggrading neomorphism.

Pellets from .03 mm. to .16 mm., composing an average of five percent of the rock volume, and intra-clasts from .09 mm. to 8 mm., composing an average of eight percent of the rock volume, are distributed randomly throughout the rock matrix (Plate XIX, figure 4, p. 202).

Minor rock constituents include: sparry calcite (composing an average of four percent of the rock volume) and dolomite, authigenic silica, pyrite, iron oxides and argillaceous and bituminous material (each composing less than one percent of the rock volume) (Table 4, p. 33).

Sparry calcite occurs as cement, infilling cavities

and fractures and forming bladed crystal crusts on skeletal grains, and as pseudospar (Plate XIX, figure 2, p. 202).

Dolomite occurs as subhedral to euhedral non-ferroan crystals selectively replacing parts of the matrix, replacing parts of skeletal grains, and occupying cavities of skeletal grains (Plate XVIII, figure 3, p. 29).

Authigenic silica occurs as chalcedony and lutecite replacing portions of Amphipora and other stromatoporoids.

Pyrite, partially if not wholly oxidized to hematite, occurs as euhedral crystals and crystal aggregates (.04 mm. to .05 mm.) randomly dispersed throughout the matrix.

Argillaceous and bituminous material is dispersed randomly throughout the matrix and is concentrated in stylolites (Plate XX, figure 3, p. 203).

Rocks of Unit 0 are classified as: intrapel-foram-algal wackestones and packstones, Amphipora wackestones and packstones, Amphipora and Stachyodes packstones and grainstones, and as stromatoporoid-coral, packstones and grainstones (Plates X and XI, figures 3 and 4; and 1 and 2, p.193-94). The first two rock types are characteristic of the unit and most abundant. The rock matrix is micro-to medium-

grained.

3) Interpretation

Interpretation is given with the interpretation of Unit P, below.

b) Unit P

1) Distribution and Lithology

Unit P overlies Unit O in sections KQ-68, KM-68, and KK-68. Thickness is at least two hundred and ninety feet in section KK-68, the upper part of which is covered.

Rocks composing the unit are light to dark grey-brown, and bedding is similar to that of Unit O (Table 4, p. 33).

2) Petrography

Skeletal grains composing an average of fifty-six percent of the rock volume, microspar composing an average of thirty-three percent of the rock volume, and micrite and intraclasts, each composing an average of eight percent of the rock volume, are the main constituents. (Table 4, p. 33).

Skeletal grains include in decreasing order of abundance: Amphipora, bulbous stromatoporoids, Stachyodes, Thamnopora, tabular stromatoporoid fragments, Coenites, rugose corals, brachiopod valve fragments, crinoid ossicles and fragments, gastropods, Parathurammina, Bisphaera, Tikhinella, Evlania, Irregularina,

'lagenid'-type foraminifers, Vermiporella, Girvanella, radiosphaerid calcispheres, ostracods, trilobites fragments, and indeterminate skeletal grains (Table 3, p. 29).

Microspar is mainly the result of aggrading neomorphism.

Intraclasts from .03 mm. to .3 mm. are distributed throughout the matrix.

Minor rock constituents include in decreasing order of abundance: sparry calcite (composing an average of four percent of the rock volume); pellets (composing an average of one percent of the rock volume); and dolomite, authigenic silica, pyrite, iron oxides and argillaceous and bituminous material (each composing less than one percent of the rock volume) (Table 4, p. 33 ; Plate XVII, figures 3 and 5, p. 200).

Each of the minor constituents in this unit has a mode of occurrence similar to that found in Unit 0.

Rocks of this unit are classified as: stromatoporoid-coral packstones, and grainstones; Amphipora wackestones, packstones and grainstones; and intrapel-foram-algal wackestones and packstones, (Plates XI and XII, figures 3 and 4; 1 to 3, p. 194-95). Rare boundstones are also present.

Stromatoporoid-coral packstones are diagnostic of the unit and are by far the most prevalent rock type. The rock matrix is micro-to coarse-grained.

3) Interpretation

The rocks of Units O and P are quite similar and probably formed under similar conditions. The rocks of Unit O have a finer matrix size, have more widespread foraminifers, algae, and indeterminate skeletal grains and contain more micrite and microspar than do the rocks of Unit P.

The intrapel-foram-algal wackestones and packstones are characterized by the abundance of micrite and microspar (and are consequently fine-grained), and by the relative abundance of radiosphaerid calcispheres, foraminifers, and algae. This rock type is interpreted to have formed in a relatively low energy environment.

The Amphipora wackestones and packstones are characterized by the abundance of Amphipora (which commonly has its marginal vesicles intact), by the relatively fine-grained matrix, and by the abundance of calcispheres, foraminifers and algae. This rock type is quite similar to the previous rock type with the exception that Amphipora is a constituent. This rock was formed in a low energy environment similar to that of the previous rock type. However, conditions were right for the growth of Amphipora. (The intact marginal vesicles on the Amphipora coenostea are interpreted to mean that the Amphipora grew in the immediate vicinity and were not transported very far, if at all, before sedimentation).

The Amphipora and Stachyodes packstones and grainstones are characterized by the abundance of Amphipora and Stachyodes coenostea, and by a medium-to coarse-grained matrix. This rock type is interpreted as having formed in a more energetic environment than the previous two.

The stromatoporoid-coral packstones and grainstones are characterized by the association of Coenites, Thamnopora, bulbous stromatoporoids, Stachyodes, and Amphipora, as well as by a medium-to coarse-grained matrix. A moderately energetic environment is postulated for its formation.

As was stated previously the first two rock types are characteristic of Unit O, whereas the last rock type is characteristic of Unit P. In general, the rocks of Unit O formed in perhaps deeper and/or more restricted and lower energy conditions than the rocks of Unit P.

The back-reef facies developed behind the organic-reef which was located to the east, and in front of the marginal shoal facies which was located to the west. Both of these facies served as barriers for the back-reef facies. The full effect of storms generated in the deep basin east of the organic-reef was minimized by the organic-reef barrier.

The back-reef area was probably dotted by small patch-bank communities consisting of laterally and vertically zoned organisms (in response to environ-

mental controls). In the low energy areas between banks, where water movement is minimal, the intrapel-foram-algal wackestones and packstones, and Amphipora, wackestones were sedimented. In higher energy areas, where water currents were fairly pronounced, the Amphipora and Stachyodes packstones and grainstones and stromatoporoid-coral packstones and grainstones were sedimented.

V Marginal-Shoal Facies

The marginal-shoal facies is present in section KP-68 (Figure 12 in pocket, and 16, p. 124). The limestones of this facies grade laterally into the organic-shoal facies on the west and into the back-reef facies on the east. The marginal-shoal facies overlies the Carcajou marker, Unit H, and is thought to have developed on the western edge of the carbonate platform. The contact with the Canol Formation is not present in section KP-68.

The marginal-shoal facies can be divided into a lower Unit Q and an upper Unit R.

a) Unit Q

1) Distribution and Lithology

Unit Q is approximately eighty feet thick. The contact with Unit R is gradational. Rocks of this unit are medium brown to medium-light brown. In outcrop beds are greater than 4' thick and are resistant to weathering. Bedding surfaces are generally uneven,

and a few beds are nodular.

2) Petrography

The main constituents are skeletal grains, composing an average of sixty-five percent of the rock volume. Skeletal grains include in decreasing order of abundance: Amphipora, Stachyodes, bulbous stromatoporoids, Coenites and Thamnonora fragments and crinoids (Tables 3 and 4, p. 29 to 33). Some of the skeletal grains show evidence of corrosion.

Sparry calcite, micrite and microspar, argillaceous and bituminous material, and possibly intraclasts are minor constituents (Table 4, p. 33).

Sparry non-ferroan and ferroan calcite cement fills cavities, forms bladed crystal crusts on skeletal grains, and forms syntaxial overgrowths on crinoid ossicles.

Rocks of this unit have fair porosity, and are classified as fine-to very coarse-grained wackestones, packstones and grainstones (Plate XII, figure 4, p. 195). Fine-to medium grained packstones predominate. The matrix commonly has moderate sorting.

3) Interpretation

The fine-to medium-grained matrix, the moderate sorting, and the abundance of skeletal grains in a packstone rock, are characteristic of rocks of this unit.

Unit Q rocks formed in a moderately energetic

KP -68-REEF

Medium grey-brown, medium-to coarse-grained, moderately well-to well-sorted, packstones, grainstones, and boundstones. Wide variety of fossils including hemispherical, bulbous and dendroid stromatoporoids, brachiopods and crinoids.

Medium to medium-light brown, fine-to medium-grained, moderately sorted, wackestones, packstones and grainstones. Fossils include Amphipora, Stachyodes, bulbous stromatoporoids, Coenites, and crinoids.

FIGURE 16
REEF MEMBER UNITS Q AND R,
SECTION KP-68

environment. The absence of dispersed bituminous material might suggest fairly well-oxygenated water as well. The rocks of Unit Q are similar in fossil composition to those of Unit P in the back-reef facies. However, the rocks of Unit Q probably formed under more agitated, possibly shallower water conditions.

The marginal shoal facies developed on the western edge of the platform. In this area numerous Stachyodes, Amphipora and bulbous stromatoporoid banks were growing. Storms and normal attrition caused the organisms to be broken up and added to the sediment. The normal wash over the shoal probably removed some of the finer sediment, leaving a fine-to medium-grained sediment with moderate sorting.

b) Unit R

1) Distribution and Lithology

Unit R, with a thickness of approximately three hundred and ten feet, overlies Unit Q.

Rocks of this unit are medium grey-brown in colour. Beds are generally greater than 4' thick and are resistant to weathering. Bedding planes are uneven.

2) Petrography

The main constituents are skeletal grains, intraclasts and sparry calcite (Table 4, p. 33).

Skeletal grains compose an average of seventy-

one percent of the rock volume and include in decreasing order of abundance: hemispherical stromatoporoids, Amphipora, bulbous stromatoporoids, Stachyodes, brachiopod valve fragments, crinoid ossicles, Parathuramina and Evlania, radiosphaerid calcispheres, ostracods, and possibly trilobite fragments (Table 3, p. 29).

Many of the skeletal grains have been subjected to intense algal boring and corrosion (Plate XIII, figure 2, p. 191). The result is that sometimes it is difficult to differentiate grains altered by algae from intraclasts which have a similar shape and composition. Some of the grains have a single micrite layer coating them. This may be an algal coating, or it could be an incipient oolite.

Intraclasts, from .06 mm. to approximately 2 mm., compose an average of fifteen percent of the rock volume, and are randomly distributed throughout the matrix.

Non-ferroan and ferroan sparry calcite cement compose an average of five percent of the rock volume. The mode of occurrence is similar to Unit Q (Plate XVIII, figure 9, p. 201).

In decreasing order of abundance minor constituents include micrite and microspar, iron oxides and argillaceous and bituminous material (Table 4, p. 33).

Micrite composes an average of 3 percent, whereas microspar one percent of the rock volume.

Bituminous and argillaceous material, composing an average of less than one percent of the rock volume, is dispersed throughout the matrix, is concentrated in stylolites, and forms intercrystalline coatings.

Hematite, probably the oxidation product of pyrite, composes less than one percent of the rock volume.

The rocks are classified as medium-to coarse-grained, moderately well-to well-sorted packstones, grainstones, and boundstones (Plate XIII, figure 1, p. 191). Packstones and grainstones predominate, whereas boundstones are found rarely.

3) Interpretation

Rocks of Unit R are characterized by the abundance of skeletal grains (commonly coated and corroded by algae), by the abundance of intraclasts, and by the medium-to coarse-grained, moderately well to well-sorted matrix. Unit R rocks were sedimented in a more energetic, more turbulent, and possibly shallower water environment than the rocks of Unit Q.

VI. Organic-Shoal Facies

a) Unit S

1) Distribution and Lithology

Unit S is present in sections, KU-68, KT-68,

KS-68-REEF

Light grey, fine-to medium-grained, Thamnopora, Coenites and Alveolites packstones, grainstones and rare boundstones. Packstones are found at the base of the unit, whereas, grainstones and boundstones at the top of the unit. Fossils include Thamnopora and Coenites (at base), and Alveolites (at top).

Light grey, micro-to medium-grained wackestones, packstones and grainstones. Fossils include Stachyodes, Amphipora, tabular stromatoporoids, Coenites, brachiopods, bryozoans, and crinoids.

FIGURE 17
REEF MEMBER UNITS S AND T,
SECTION KS-68

and KS-68. The unit is approximately ten to fifteen feet thick and has a gradational contact with Unit T.

Rocks of this unit are light grey. Beds range in thickness from 2" to greater than 4', and are moderately resistant to resistant to weathering.

2) Petrography

Skeletal grains compose an average of thirty-two percent of the rock volume. In decreasing order of abundance these include: Stachyodes, Amphipora, tabular stromatoporoids, Coenites fragments, brachiopod valve fragments, bryozoans, crinoids, pelecypods, Farathuramina, Vermiporella, Girvanella, ostracods, and possibly Thamnopora fragments (Table 3, p. 29).

Many of the skeletal grains have been corroded and bored by algae, and have undergone degrading neomorphism.

Intraclasts from .03 mm. to 1.5 mm. and pellets from .03 mm. to .5 mm. are distributed randomly throughout the matrix.

Micrite and microspar, sparry calcite, dolomite, detrital quartz and argillaceous and bituminous material are all minor constituents (Table 4, p. 33).

Angular quartz clasts (.03 mm. to .08 mm.), composing less than one percent of the rock volume, are distributed randomly throughout the matrix.

Burrows and mottled fabrics (possibly the result of bioturbation) are common features in the rocks.

Rocks of this unit are classified as wackestones,

packstones and grainstones (Plate Xlll, figure 3, p. 196). The matrix is micro-to medium-grained.

3) Interpretation

Rocks of Unit S are characterized by an association of Stachyodes, Amphinora, and stromatoporoids, and by their predominant packstone nature.

The rocks of Unit S are interpreted as having been sedimented under conditions similar to those of Unit P.

b) Unit T

1) Distribution and Lithology

Unit T is present in sections KU-68, KT-68, and KS-68. Thickness ranges from thirty-one feet in section KU-68 to at least forty-two feet in section KT-68 (Figure 17, p. 128).

The rocks composing the unit are light grey. Beds are moderately resistant to resistant to weathering and are 6" to greater than 4' thick. Bedding surfaces are uneven.

2) Petrography

Fossils compose an average of sixty-eight percent of the rock volume. In decreasing order of abundance they include: Alveolites, Thamnonora, Coenites, Amphipora, brachiopod valve fragments, bryozoans, crinoids, echinoid plates, gastropods, paleocypods, Parathurammina, Vermiporella, radiosphaerid calcispheres, and ostracod shell fragments (Table 3, p. 29).

Thamnopora and Coenites are common at the base of the unit, whereas Alveolites is common at the top of the unit.

Crinoid ossicles and fragments are commonly corroded and bored by algae, and Thamnopora grains are altered by degrading neomorphism.

Other rock components include: intraclasts, pellets, micrite and microspar, sparry calcite, dolomite, detrital quartz, authigenic silica, pyrite, and bituminous and argillaceous material (Table 4, p. 33).

Sparry calcite occurs as non-ferroan and ferroan calcite filling cavities and fractures, and as pseudospar.

Dolomite occurs as euhedral crystals growing in cavities of Alveolites.

Angular quartz grains from .03 mm. to .08 mm. are dispersed throughout the matrix.

Pyrite occurs as slightly oxidized euhedral to subhedral crystals selectively replacing parts of the matrix, and as anhedral to subhedral crystals replacing parts of skeletal grains.

Burrows filled with material different from the surrounding matrix and framework, and mottled fabrics, are quite common.

The rocks of this unit are classified as Thamnopora, Coenites, and Alveolites packstones, grainstones and boundstones (Plate XLII, figure 4, p. 196).

Boundstones are rare. Packstones are predominant at the base, whereas grainstones and boundstones are predominant at the top of the unit. The matrix is fine-to medium-grained.

3) Interpretation

Rocks of Unit T are characterized by the assemblage Alveolites, Thamnopora, and Coenites, and by the vertical change from packstone to grainstone and boundstone sediments.

The rocks of Unit T were sedimented in moderately energetic water conditions. The vertical change in fossils from Thamnopora and Coenites at the base of the unit to Alveolites at the top of the unit and the corresponding change in sediment may indicate an increase in water energy upwards.

The organic-shoal facies formed over parts of a moderately shallow open water trough that existed between the sublittoral facies on the west and the marginal shoal facies on the east. (Water depths over the organic shoal facies exceeded those over the marginal shoal facies). The basin does not appear to have been restricted as there is no evidence of evaporites or of fossils indicative of such an environment.

VII Sublittoral Facies

The sublittoral facies is exposed in sections KZ-68, KY-68, KX-68, and KW-68. The rocks of the sublittoral facies grade laterally into the limestones of

the organic-shoal facies to the east (Figure 12, in pocket, and 18, p. 134). The facies disappears to the west. The sublittoral facies overlies Unit B of the platform member with a gradational contact. The upper contact has been described (p. 100).

This facies can be subdivided vertically into three units. In ascending order these are Unit U, Unit V, and Unit W.

Rocks of the sublittoral facies are characteristically quartz-rich.

a) Unit U

1) Distribution and Lithology

This unit appears in sections KY-68, KX-68, KW-68 and KV-68. It is approximately five to ten feet thick. The contact with Unit V is gradational (Figure 18, p. 134).

The rocks composing the unit are light to medium grey-brown. Beds are resistant to weathering and are 6" to greater than 4' thick. Bedding surfaces are uneven.

2) Petrography

Unit U is very similar to Unit S of the organic-shoal facies with several differences:

i) Skeletal grains compose an average of thirty-seven percent of the rock volume. In decreasing order of abundance skeletal grains include: brachiopod valve fragments, Amphipora, Stachyodes, bryozoans, ossicles, echinoid spines, Parathurammina, Vermiporella,

KW-68

FIGURE 18
REEF MEMBER UNITS U, V, AND W,
SECTION KW-68

ostracods, and trilobite fragments (Tables 3 and 4, p. 29 & 33; Plate XV, figure 4, p. 198).

ii) Both pyrite and iron oxides derived from its oxidation are present.

iii) Angular grains of quartz compose up to fifteen percent of the rock volume. (This is the main difference).

Rocks of this unit are classified as quartzose Amphipora and Stachyodes wackestones and packstones (Plate XLV, figure 1, p. 197).

3) Interpretation

Unit U is interpreted as having formed under conditions similar to those proposed for the formation of Unit S. The quartz in the unit may have been derived from the west, or south, possibly from an exposed portion of the Mackenzie Arch. A western or southern source is indicated by the increase of quartz in the sediments in these directions.

b) Unit V

1) Distribution and Lithology

This unit is present in sections KX-68, KW-68 and KV-68. The unit ranges from ten to twenty feet in thickness (Figure 18, p. 134).

The rocks composing the unit are light to medium brown-grey. Beds are resistant to weathering and are 6" to greater than 4' thick. Bedding surfaces are uneven.

2) Petrography

Unit V is similar to Unit T with several exceptions:

i) Skeletal grains compose an average of fifty-three percent of the rock volume. Skeletal grains include in decreasing order of abundance: Thamnopora, Alveolites, Coenites, brachiopod valve fragments, Stachyodes, Amphipora, crinoids, echinoid spines, gastropods, ostracods, trilobites, and possibly fragments of pelecypods and Tentaculites (Tables 3 and 4, p. 29 & 33).

ii) Both pyrite and hematite, possibly derived from the oxidation of pyrite are present in the unit.

iii) Angular quartz clasts from .03 mm. to .1 mm. constitute up to thirty percent of the rock volume.

Rocks of Unit V are classified as quartzose Thamnopora, Coenites, and Alveolites packstones and grainstones (Plate XIV, figures 2 and 3, p. 197).

3) Interpretation

Unit V is interpreted as having formed under conditions similar to those of Unit T.

c) Unit W

1) Distribution and Lithology

Unit W is present in sections KZ-68, KY-68, KX-68, and KW-68 (Figures 12 & 18, p. 134). Thickness ranges from eight feet in sections KW-68 and KZ-68 to seventeen feet in section KY-68. Unit W overlies Unit S in section KY-68, and Unit U in sections KX-68

and KW-68 with gradational contacts.

Rocks in this unit are medium brown. Beds are moderately resistant to resistant to weathering and are 2" to 4' thick. Bedding surfaces are sharp to uneven. Interbeds of quartz sandstone are common.

2) Petrography

Skeletal grains compose an average of twelve percent of the rock volume. In decreasing order of abundance skeletal grains include: Alveolites fragments, bryozoans, crinoid ossicles and fragments, ostracods, trilobite fragments, and possibly fragments of Coenites and Thamnopora (Tables 3 and 4, p. 29 to 33). Articulated brachiopods commonly contain sediment different from that of the enclosing matrix. Brachiopods are most abundant in the more carbonate-rich beds. The uppermost three to five feet of the unit are very rich in brachiopods.

Other constituents include: intraclasts, micrite, microspar, sparry calcite, detrital quartz, and argillaceous and bituminous material (Table 4, p. 33).

Angular quartz grains from .02 mm. to .1 mm. and rare plagioclase grains compose up to sixty percent of the rock volume. The quartz content of the unit varies from bed to bed.

Porosity in this unit ranges from poor to fair (less than two to three percent). The sandstone units are more porous than the skeletal carbonates.

Burrows and mottled fabrics are common. The rocks of this unit are classified as very fine-to medium-grained quartzose carbonates and sandstones (Plate XIV, figure 4, p. 197).

3) Interpretation

The large amount of detrital quartz, the numerous burrows, and the abundance of brachiopods, are characteristic of this unit.

Unit W is interpreted as having formed in a shallow, moderately turbulent and relatively high energy environment. The skeletal grains have probably been derived from the organic-shoal facies to the east. The quartz grains may have been derived from either the west or south. The alternation of sandstones with the skeletal carbonates suggests that there was periodic introduction into the area of terrestrially-derived sediment or alternatively of sediment derived from the organic shoals.

The water in the basin was probably shallower during the formation of Unit W than it was during the formation of Unit T.

DIAGENESIS

The term diagenesis is used in this thesis to include all biochemical and organic, physicochemical, and physical processes that modify sediments between deposition and lithification at low temperatures and pressures characteristic of surface and near surface environments (modified after Chilingar et al., 1967, p. 180).

Locally, the effects of the various diagenetic processes have been severe enough to obliterate the primary fabrics and textures of the Ramparts Formation limestones. More commonly, however, diagenetic alterations have only slightly altered the rocks so that the effects of individual processes can be studied and related in a paragenetic sequence.

Table 5, p. 140 shows the distribution of diagenetic alterations in the Ramparts Formation.

A) Biochemical and Organic Processes

These processes include: organic mixing, organic burrowing, aggregation, particle size reduction, boring, and corrosion.

a) Organic Mixing, Organic Burrowing, Aggregation, and Particle Size Reduction.

TABLE 5
DIAGENETIC ALTERATION

Unit	Physicochemical										Physical			
	Replacement										Neomorphism			
	Cementation										Inversion			
	Dedolomitization										Aggrading Re-crystallization			
Organic	Dolomitization										Ferroan			
	Non-Ferroan										Non-Ferroan			
Burrows	Pyritization										Styolites			
	Spheralitic										Cavity Filling			
Boring	Brachiopod Replacement										Spar Cement Replacement			
	Mosaic Quartz										Dedolomitization			
A	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
B	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			
C	Brachiopod Replacement										Styolites			
	Mosaic Quartz										Dedolomitization			
D	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
E	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			
F	Brachiopod Replacement										Styolites			
	Mosaic Quartz										Dedolomitization			
G	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
H	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			
I	Brachiopod Replacement										Styolites			
	Mosaic Quartz										Dedolomitization			
J	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
K	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			
L	Brachiopod Replacement										Styolites			
	Mosaic Quartz										Dedolomitization			
M	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
N	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			
O	Brachiopod Replacement										Styolites			
	Mosaic Quartz										Dedolomitization			
P	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
Q	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			
R	Brachiopod Replacement										Styolites			
	Mosaic Quartz										Dedolomitization			
S	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
T	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			
U	Brachiopod Replacement										Styolites			
	Mosaic Quartz										Dedolomitization			
V	Colliform										Strain Recrys-tallization			
	Overgrowths										Degradation Re-crystallization			
W	Pyritization										Ferroan			
	Spheralitic										Non-Ferroan			

NOTE: X - Present
*No data available

These four processes are related. In modern marine sediments numerous organisms churn the unconsolidated sediment. As a result, mixing of the sediment occurs causing the destruction of primary bedding structures, the re-arrangement of skeletal fragments, and the development of mottled fabrics (Winder, 1968, p. 174) (Plate VII, figure 1, p. 190). Where bottom conditions permit and where the substrate sediment is favorable, discrete burrows are formed (Plate XV, figure 1, p. 198). These are frequently mud-lined cylindrical tubes filled with micrite and pellets and/or skeletal debris (Tebbutt, 1967, p. 59).

In the course of forming burrows the organisms ingest large amounts of sediment including sand-sized skeletal debris (Ginsburg, 1957, p. 83). The result of ingestion is the formation of fecal matter in the form of subspherical, ellipsoidal and rod-shaped pellets, and the size reduction of sediment by both chemical and mechanical means (Ginsburg, 1957, p. 83).

Examples of the products of these processes are common in the Ramparts Formation. Mottled fabrics are particularly common in the lower part of the platform member (Unit A), as well as in the back-reef facies (Units F, G and H) of the reef member (Table 5, p. 140). Two types of pellets are common (Plate XIX, figure 4, p. 202). In addition to micrite, microspar, pseudospar, sparry calcite cement and skeletal grains,

pellets commonly occur in burrows.

Pellets are frequently coated with a crust of bladed non-ferroan sparry calcite cement. Burrows are occasionally filled with both a lining of non-ferroan and ferroan sparry calcite cement. Presumably the blocky ferroan calcite filled the pore space that remained after the non-ferroan calcite was precipitated.

b) Boring and Corrosion

Two types of boring are widespread in the Ramparts Formation. The first type results in "burrow-like" structures ranging in diameter from 1 mm. to 3 mm. This type of boring is common in stromatoporoids and colonial corals (Plate XV, figures 2 and 3, p. 198). The bores are filled with micrite, microspar, pseudo-spar, sparry calcite cement, pellets and skeletal grains. In modern marine sedimentary environments, Cliona, the boring sponge, and lithophagous pelecypods produce similar boring (Tebbutt, 1967, p. 60). The second type results in a network of minute tubular boring ranging in diameter from 4 microns to 10 microns (Plate XV, figure 4, p. 198). This type of boring has been attributed to filamentous blue-green algae (Ginsburg, 1957, p. 84). Numerous fossils have been subjected to this type of boring.

Skeletal grains are frequently coated by irregular micrite envelopes. The micrite envelope often grades imperceptibly into the unaltered skeletal struc-

ture of the grain. In some cases only a tiny remnant, if any, of the grain is visible. This type of alteration is probably related to algal boring and is referred to as algal corrosion (Wolf, 1963; Plate XV, figure 5, p. 198).

Algae are known to bore into chemically and corrode limestones from high-tide level to a depth of a few hundred feet below sea level. Swinchatt (1969, p. 1391) states that algal boring is abundant in recent shallow shelf carbonates from the Florida-Bahamas region, but comparatively rare in recent deeper shelf carbonates from a part of the Great Barrier Reef of Australia. Available evidence suggests an abrupt decrease in abundance of algal boring at a depth of sixty feet.

Blue-green algae can dissolve calcium carbonate possibly by the use of oxalic acid or by indirectly acidifying the surrounding water during respiration. At night the algae give off CO_2 into their microenvironment, thereby causing a decrease in the pH. Calcium carbonate can be created by the reverse process (photosynthesis) which occurs during the daytime (Chilingar et al., 1957, p. 193). Possibly as a result of these processes, skeletal material may be destroyed and dense microcrystalline amorphous micrite envelopes created.

In Tebbutt's (1967, p. 63) study of the diagenesis

of Ambergris Cay, he concluded that "no other single organic agency (blue-green algae), nor perhaps any inorganic process, has had such a long-sustained effect upon the final rock product."

All of the biochemical and organic processes are thought to have occurred very early in the diagenetic history of the Ramparts Formation.

B) Physicochemical Processes

Physicochemical Processes include: replacement, cementation, neomorphism, and dissolution.

a) Replacement

Three types of replacement are important. These are: pyritization, silicification and dolomitization.

1) Pyritization (including the formation of marcasite).

Three forms of pyrite occur in the Ramparts Formation.

The first form consists of micro-grained sooty-dusty pigmentation and impregnation pyrite (Plate XVI, figure 1, p. 199). Pyrite crystals are generally less than 2 microns in size. This type of pyrite selectively replaces parts of fossils and coats the exteriors and cavities of fossil skeletons.

The second form consists of aggregates of pyrite crystals that are dispersed randomly throughout the matrix (Plate XVI, figure 2, p. 199). Size of the

aggregates ranges from 10 microns to 15 microns. The aggregates are occasionally coated with crusts of non-ferroan bladed sparry calcite crystals, the long axes of which are oriented perpendicular to the surface of the aggregate.

The third form consists of euhedral crystals and crystal aggregates of pyrite that selectively replace parts of fossils (Plate XVI, figures 3 and 4, p. 199). The euhedral pyrite crystals have a cubic crystal form and range in size from 5 microns to 150 microns with an average of 60 microns.

The crystal aggregates frequently grow up to 1 mm. in longest dimension, and they replace the peripheral areas of fossils, particularly those of Thamnopora and Stachyodes.

The first and second forms of pyrite compose one generation of pyrite. Non-ferroan sparry calcite cement coats pyrite crystals of this generation. The third form of pyrite composes the second generation. Euhedral pyrite crystals partially replacing fossil organisms appear to be inhibited in their growth into the cavities of these organisms by non-ferroan calcite crystals that occupy the cavities.

Pyrite most commonly occurs in the platform member, and the back-reef facies of the reef member (Table 5, p. 140). Much of the pyrite in the back-reef facies is oxidized.

Recent investigations by Berner (1970) reveal that the major steps in the formation of sedimentary pyrite are:

1. bacterial sulphate reduction,
2. reaction of H_2S with iron minerals to form iron monosulphides,
3. reaction of the iron monosulphides with elemental sulphur to form pyrite.

The most important factor limiting pyrite formation in marine sediments is the availability of organic matter that can be metabolized by sulphate reducing bacteria (Berner, 1970).

The presence of marcasite is inferred by numerous lath-like crystals of hematite which are interpreted to be hematite pseudomorphs after marcasite. (Plate XVI, figures 5 and 6, p. 199)(Schmidt, 1965, p. 154).

Marcasite is produced under neutral to acid conditions (pH generally less than 7.0) whereas pyrite is favored by slightly alkaline conditions (Fairbridge, 1966, p. 54). Whether pyrite or marcasite is produced may be a function of the permeability of the sediment. Marcasite tends to form in more permeable sediments whereas pyrite forms in the more impermeable sediments.

2) Silicification

Both cementation and replacement silica are present in the Ramparts Formation. The classification of silica fabrics is based in part on the classification scheme of Wilson (1966, p. 1038).

Cementation fabrics include:

- i) Simple and well-terminated overgrowths on quartz clasts (Plate XVI, figure 7, p. 199). The overgrowths are commonly colourless. An irregular line of inclusions commonly marks the boundary between clast and overgrowth.
- ii) Colloform fabrics (Plate XVI, figure 8, p. 199). Colloform fabrics are controlled by the shape of the fossil organism cavities that the colloform silica occupies. The colloform fabrics range in maximum dimension from .3 mm. to .8 mm. Under plane-polarized light the fabrics consist of roughly concentric bands of yellow-brown to dark brown, inclusion-filled silica. Under crossed nicols the fabrics consist of alternating lutecite (See Wilson, 1966, p. 1038) and chalcedony fibres radiating from centres within the fabric.
- iii) Mosaic quartz fabrics (Plate XVI, figure 9, p. 199). Mosaic quartz fabrics are commonly colourless. The fabric is composed of interlocking equigranular to anhedral quartz grains. Like the colloform fabrics, the mosaic quartz fabrics occupy the cavities of fossils.

The overgrowth fabrics and the mosaic quartz fabrics are most commonly found in the platform member (Table 5, p. 140). The colloform fabrics are found in the back-reef and off-reef facies of the reef member.

Replacement fabrics include:

i) Patches of lutecite and chalcedony (Plate XVll, figures 1 and 2, p. 200). The patches are commonly colourless to light brown with numerous inclusions. The chalcedony patches commonly have an irregular outline whereas the lutecite patches have a pseudo-hexagonal outline. The patches range in longest dimension from .22 mm. to .85 mm..

ii) Spherulitic lutecite (Plate XVll, figures 3 to 5, p. 200). Spherulitic lutecite is generally colourless to light brown. It is subspherical in form, commonly with smooth and jagged outlines. Spherulitic lutecite occurs in aggregates of fibres which appear to have a common centre. Under crossed nicols the fibre orientation is such that a pseudouniaxial extinction cross is produced. The bars of the cross are sharply defined where the plane of section passes through the centre of the spherulite. Spherulites commonly range from .15 to .25 mm. in diameter.

iii) Patchy chalcedony and lutecite replacement of brachiopods (Plate XVll, figure 6, p. 200). This fabric is similar to the first silica replacement fabric with the exception that the orientation of the silica fibres is controlled by the orientation of the calcite fibres composing the brachiopod valve.

Silica replacement is most common in the platform member and the back-reef and off-reef facies of the reef member (Table 5, p. 140). Black nodules of

chert are common in the off-reef facies which has undergone the most intense silicification.

Silica-replacement fabrics are most commonly developed in fossils that have undergone fairly intense degrading neomorphism.

The fossils record a definite order of susceptibility to silicification of the original organisms. Arranged in order of decreasing susceptibility the organisms include: Thamnopora and Coenites, Stachyodes and bulbous stromatoporoids with a similar skeletal architecture, Actinostroma, Amphipora, and brachiopods.

There appear to be two generations of silica as evidenced by textural relationships. The colloform silica and the mosaic quartz appear to have been formed before the precipitation of the non-ferroan sparry calcite cement. These silica fabrics occupy cavities in fossils where no remnants of the non-ferroan sparry calcite cement are present. There is a possibility that if the cement was present it may have been dissolved before silica formation, but since evidence of this process is lacking elsewhere, it seems unlikely.

The other silica fabrics appear to have formed before fracturing and subsequent infilling by ferroan calcite cement. Fractures filled with ferroan calcite commonly cut through silica fabrics.

Evidence that silica formed both before and after dolomitization is present. In some cases numerous unaltered and partially replaced dolomite crystals are contained within silica fabrics (Plate XVlll, figure 6, p. 201). This would suggest the silica formed after the dolomite. In other cases, dolomite crystals selectively replace parts of the silica fabrics. Inclusions common to the silica fabrics are contained within the dolomite crystals. This would suggest dolomite formed after the formation of silica. Walker (1962) suggests that such reversible silica-carbonate replacements may occur in response to variations in pH or in response to variations in temperature of the sediments which are deeply buried.

The silica contained in both the cementation and replacement fabrics may be organically derived. Sponge spicules are common skeletal grains in both the lower part of the platform member and in the off-reef facies of the reef member. All of these spicules are now composed of calcite. It is possible that the calcite may have replaced the original silica. Wilson (1966, p. 1048) suggests a similar source of silica in the Upper Jurassic limestones of Southern England.

3) Dolomitization

Dolomite is present in the Ramparts Formation as non-ferroan and ferroan dolomite. The following modes of occurrence are recognized for dolomite:

1) Non-ferroan dolomite replacing skeletal

grains and framebuilders (Plate XVlll, figures 1 and 2, p. 201). Parts of bryozoans, crinoid ossicles and fragments, brachiopod valve fragments, and stromatoporoids are replaced by euhedral to anhedral crystals.

ii) Non-ferroan dolomite replacing the matrix (Plate XVlll, figure 3, p. 201). This is the most common mode of occurrence. The degree of dolomitization varies from single euhedral crystals scattered throughout the matrix to anhedral crystal aggregates replacing large patches of the matrix. The line between intensely dolomitized and non-dolomitized portions of the matrix is commonly a sharp line outlined by a bituminous residue.

iii) Ferroan and non-ferroan dolomite replacing sparry calcite cement. Anhedral to subhedral crystals of dolomite frequently replace both the ferroan calcite in mollusc shells and the non-ferroan calcite cement in fractures (Plate XVlll, figure 4, p. 201). Ferroan dolomite generally results in the replacement of the mollusc shell cements whereas non-ferroan dolomite always results in the replacement of the fracture cements.

iv) Non-ferroan dolomite crystals growing in the cavities of fossils (Plate XVlll, figure 5, p. 201). Euhedral crystals of non-ferroan dolomite commonly occur in the cavities of bryozoans, Alveolites, Coenites and certain tabular stromatoporoids, commonly

replacing portions of the fossils.

v) Ferroan dolomite associated with stylolites.

Anhedral crystal aggregates of ferroan dolomite occasionally replace ferroan calcite occupying the limbs of stylolites.

The rock constituents show a relative susceptibility to dolomitization in decreasing order as follows: micrite and microspar, ferroan calcite cement, non-ferroan calcite cement, and non-ferroan calcite skeletal grains. This sequence is similar to those of Schmidt (1965) and Neal (1969).

Dolomite is a relatively rare constituent of the Ramparts Formation. It occurs sporadically in both the platform and reef members (Table 5, p. 140). No stratigraphic or structural control is apparent.

Most of the dolomite in the reef complex appears to have formed at the same time. The minor amount of dolomite, the relatively low intensity of dolomitization when dolomite is present, and the general increase in porosity in the most severely dolomitized rocks suggest that Mg^{++} was derived locally. Murray (1966) refers to this type of dolomite as local source dolomite. It is quite probable that the source of Mg^{++} is connected with the stabilization of the $MgCO_3$ -rich fossils. This will be discussed in conjunction with magnesium carbonate stabilization.

Dolomite appears to have formed after the dissolution of aragonite from mollusc shells and in some

cases after their subsequent infilling by ferroan calcite cement, and because dolomite rhombs are frequently partially dissolved in stylolites, before stylolitization.

b) Dedolomitization

Dedolomitization rarely occurs in the Ramparts Formation (Table 5, p. 140, Plate XVIII, figure 7, p. 201). Where it does occur, both non-ferroan and ferroan crystals of dolomite are wholly and partially replaced by non-ferroan calcite. When ferroan calcite is replaced iron oxide coats the newly formed replacement crystals and parts of the surround matrix. Evamy (1969, p. 790) has described an identical occurrence. He suggests that "oxidizing conditions in the weathering zone cause the new generation of calcite to precipitate without incorporating ferrous iron." The iron oxide coating is probably "formed from the oxidation of the ferrous iron excluded from the carbonate lattice during the replacement" (Evamy, 1969, p. 790).

Von Morlot (see Cayeux, 1935, p. 429) suggests the following equation for dedolomitization:

Evamy (1963, p. 168) suggests that sulphate ions are liberated during the oxidation of pyrite and that the sulphate ions in combination as calcium sulphate and ferrous sulphate then caused dedolomitization.

b) Cementation

At least three types of sparry calcite cement are present in the Ramparts Formation (Table 5, p. 140).

1) Non-Ferroan Calcite

Non-ferroan calcite occurs as bladed crystal crusts on skeletal grains, as incipient cavity and fracture fillings, and as monocrystalline overgrowths on brachiopod valve fragments, crinoid ossicles and fragments, and echinoid spines (Plate XVIII, figures 8 and 9, p. 201).

From textural evidence the formation of this cement follows the formation of sooty pyrite and precedes the the filling of moldic porosity created by the dissolution of aragonite from molluscan shells.

2) Strongly Ferroan Calcite

Strongly ferroan calcite occurs as blocky to equant crystals filling pore space not occupied by the first generation cement, and rarely as monocrystalline overgrowths on skeletal grains (Plates XVIII and XIX, figures 7 and 8, p. 201-02).

The formation of this cement follows the formation of some fractures and their infilling by the first generation cement, and follows the dissolution of aragonite in mollusc shells. It precedes the formation of stylolites. Fractures filled with the second type of cement cross-cut cavities and fractures filled with the first type of cement. Mollusc shells are frequently filled with the second generation cement,

and fractures filled with this cement are cross-cut by stylolites.

3) Weakly Ferroan Calcite

Weakly ferroan calcite occurs in fractures that displace stylolites (Plate XLX, figure 9, p. 202). It might also be present as a cavity filling, but would be difficult to differentiate from the second type of cement.

The zone of partial aeration above the water table is principally an oxidizing medium, whereas the zone below the water table is principally an alkaline and reducing medium (Garrels and Christ, 1965, p. 383). Evamy (1969, p. 791) suggests that carbonate cements precipitated in the zone of partial aeration should generally be free of ferrous iron and therefore should be non-ferroan, in contrast to carbonate cements precipitated below the water table, which should be ferroan.

Thus it seems probable that most of the non-ferroan calcite probably formed above the water table whereas most of the ferroan calcite formed below the water table.

Below the water table where local oxidizing conditions may exist as a result of high rates of water flow (Garrels and Christ, 1965, p. 383), or where there is a local absence of iron, non-ferroan calcite cements can be precipitated (Evamy, 1969, p. 791).

Some of the first type of non-ferroan calcite may be formed under these conditions.

c) Neomorphism

The term neomorphism was introduced by Folk (1965) to include the following diagenetic processes: inversion, recrystallization, strain recrystallization and Folk's "unknown process" for the increase in grain size of micrites.

1) Inversion

The aragonite in the skeletons of organisms can be stabilized either by inversion or by dissolution.

Inversion is defined as the spontaneous reaction of skeletal aragonite to calcite. Land (1967, p. 914) suggests that the reaction takes place without the production of discernable void space, and in addition reduces originally aragonitic skeletons to a characteristic sparry calcite mosaic (Plate III, figures 2 and 3, p. 186). Because aragonite is removed and calcite deposited within the same bodies, the process of inversion is, strictly speaking, a replacement process (Tebbutt, 1967, p. 83).

Most of the micrite and microspar in the Ramparts Formation may have been originally aragonitic lime mud. If this assumption is true, the conversion of the mud to micrite may have been the result of inversion. Some of the molluscan aragonite may also have been subjected to this process. The shell material in both

gastropods and pelecypods is now a sparry calcite mosaic. No trace of former shell fabrics is visible.

2) Recrystallization

Recrystallization is defined as a diagenetic alteration involving a change in crystal size, shape and arrangement, but not in mineralogy (Folk, 1965, p. 22). Recrystallization probably proceeds in unstrained material driven by the surface tension energy of curved grain boundaries (Folk, 1965, p. 18).

Both aggrading (an increase in crystal size) and degrading (a decrease in crystal size) recrystallization occur in the Ramparts Formation (Table 5, p. 140; Plate XIX, figures 1 to 4, p. 202). Skeletal grains and framebuilding organisms show a variable susceptibility to this process. The skeletal organisms listed in order of decreasing susceptibility to recrystallization include: Coenites and Alveolites, Thamnopora, ostracods and trilobites, crinoid ossicles and echinoid spines, brachiopods, Stachvodes, Amphinora and stromatoporoids with a similar skeletal architecture.

There appears to be no obvious structural or stratigraphic control to the occurrence or intensity of recrystallization. Recrystallization textures occur sporadically throughout the Ramparts Formation.

3) Strain Recrystallization

This type of recrystallization is similar to the process of recrystallization with the exception

that textures are strained (Plate XIX, figures 5 and 6, p. 202). This is probably caused by the fact that this type of recrystallization was driven by strain energy (Folk, 1965, p. 23).

Both aggrading and degrading strain recrystallization textures occur in the Ramparts Formation. Numerous irregular sparry calcite patches often with islets of matrix material are present. Some of the sparry calcite crystals possess bent or intersecting twins, and are frequently located close to stylolites. Ostracod shells have been reduced to sparry calcite mosaics where they have been bent presumably by compaction pressure.

The same pressure that is responsible for the formation of stylolites may produce the strain recrystallization textures.

4) "Unknown Process"

The result of this process is a grain size increase of the matrix micrite. This is similar to "grain growth" as used by Bathurst (1958) and Voll (1960).

A large amount of the matrix in limestones of the Ramparts Formation is microspar and pseudospar that probably resulted from a progressive increase in grain size caused by this "unknown process" (Plate XIX, figures 7 and 8, p. 202).

Friedman (1964) and Tebbutt (1967) report that

much of the aragonite in Pleistocene carbonate rocks has undergone inversion from aragonite to calcite. It seems probable, and textural evidence from this study supports this, that inversion was a relatively early diagenetic event. It appears to have taken place either before or synchronous with aragonite dissolution and subsequent ferroan calcite cementation. Fractures filled with ferroan calcite commonly cut across mollusc shells that have undergone inversion. Strain recrystallization is probably related to tectonic pressures. Islets of patchy lutecite and chalcedony have been found inside the centres of some of the strain recrystallization sparry calcite mosaics. This would suggest that some of the silica formed before strain recrystallization. Both the unknown process and recrystallization have proved impossible to date in relation to other diagenetic events.

d) Dissolution of Aragonite

When skeletal organisms undergo dissolution, aragonite is dissolved and moldic porosity remains. Later in the diagenetic history calcite cement may be precipitated in the void left by dissolution.

Numerous examples of dissolution and subsequent infilling by sparry ferroan calcite cement are present in the Ramparts Formation. Parts of gastropod valves and pelecypod shells are filled with ferroan calcite (Plates XVlll, and lll, figures 4 and 1, p. 201 & 186).

Frequently non-ferroan calcite is also present in the shell. The boundary between the two mineralogical types of calcite is generally irregular. This texture is interpreted in the following manner. Part of the shell underwent dissolution, and moldic porosity was created. The remaining aragonite underwent inversion. Some time later the moldic porosity was filled with ferroan calcite cement. If inversion occurred synchronously or shortly after dissolution, and before the ferroan calcite cementation, no ferroan iron would be expected in the calcite lattice. The resulting calcite would be non-ferroan calcite. If however, inversion occurred shortly before or synchronously with the ferroan calcite cementation the reverse should be true. The resulting calcite would be ferroan calcite. Dissolution of aragonite should occur in preference to inversion if the surrounding solution is under-saturated with respect to CaCO_3 provided that the solution is in contact with the aragonite. If the surrounding solution is saturated with respect to CaCO_3 inversion probably would occur.

In any case dissolution occurs before the precipitation of ferroan calcite cement.

The process of dissolution is an important process in that in addition to stabilizing aragonite in skeletal organisms, it probably provides a considerable amount, if not most, of the CaCO_3 needed in cementation.

Both the first and the second generations of cement could result from dissolution. Non-ferroan calcite cement would form above the water table when the CaCO_3 released by dissolution collected and became locally supersaturated, under reducing conditions.

e) Incongruent Dissolution of Magnesium Calcite

Organisms whose skeletons are composed of high magnesium calcite are stabilized by the process of incongruent dissolution. When the skeletons are converted to a stable form of calcite, magnesium ions are lost to an aqueous solution while the skeleton retains its original geometry (Land, 1967, p. 214).

This process has undoubtedly occurred in the Ramparts Formation. Several examples of crinoid ossicles and brachiopod shells have been observed that are composed of ferroan calcite (Plate XLX, figure 9, p. 202). This phenomenon is difficult to explain unless perhaps, during the process of incongruent dissolution ferrous iron is substituted for magnesium ions in the crystal lattice, instead of calcium ions for magnesium ions. This suggests that at the time of incongruent dissolution the surrounding environment was probably reducing and that iron was present in the environment.

Incongruent dissolution is probably an early to intermediate diagenetic event occurring coevally with and after the dissolution of aragonite.

The magnesium ions liberated in the process of

incongruent dissolution may constitute the major portion of the magnesium found in the dolomite of the Ramparts Formation. Textural evidence indicates that dolomite forms in some cases after the formation of ferroan calcite. It may be that the formation of dolomite is synchronous with the release of magnesium ions during incongruent dissolution.

C) Physical Processes

These processes include: desiccation and shrinkage, slumping and boudinage, and compaction.

Numerous examples of desiccation and shrinkage are present in the back-reef facies of the Ramparts Formation.

Slumping and boudinage are common in the lower part of the platform member.

Desiccation and shrinkage, and slumping and boudinage are probably quite early diagenetic events occurring before the sediment was lithified.

The process of compaction manifests itself in several ways: a) Crushing

Ostracod and brachiopod shells have been frequently subjected to crushing. Textural evidence indicates that most of the crushing occurred after the formation of non-ferroan calcite cement and before the formation of ferroan calcite cement. Crushing is probably the result of lithostatic pressure caused by loading.

b) Pressure Solution

Examples of pressure-solution are common. Skeletal grains in mutual contact and in contact with non-skeletal grains show pressure-solution contacts. One grain preferentially dissolves the other (Plate XX, figure 1, p. 203).

Stylolites outlined by bituminous and argillaceous material, as well as by pyrite, dolomite, and quartz grains, are common (Plate XX, figures 3 and 4, p. 203). The stylolites are late diagenetic.

D) Paragenesis

Table 6, p. 164 shows the temporal relationships among diagenetic events. Temporal relationships have been worked out by interpreting the textures created by the effects of one or more diagenetic processes on primary textures.

TABLE 6

DIAGENETIC PARAGENESIS

THE DEPOSITIONAL HISTORY OF THE RAMPARTS FORMATION

During the Middle Devonian (Givetian) large areas of Western Canada were inundated by a sea that transgressed to the interior of the continent by way of the Mackenzie Trough. The Hare Indian Formation shales were deposited when the depth of the sea was at its maximum, and toward the end of deposition of the Hare Indian Formation, the sea began to recede. This recession is evidenced by the appearance of thin, widespread, limestone beds which are intercalated with shale beds of the Hare Indian Formation, and by the development of the limestone beds of the Ramparts Formation.

The Ramparts Formation exposed in the Mountain-Gayna River area is interpreted to have three stages of development.

A) Stage 1

Stage 1 is represented by Units A to E and by part of Unit I of the platform member.

Units A to E indicate a gradual shallowing of the Givetian sea. This shallowing is evidenced by a progression from widespread, scattered biostromes and

bioherms (Units A and B) to the more localized, abundant bioherms and biostromes (Units C, D, and E) each with its own crude lateral zonation. These flourished in parts of the shelf area where environmental conditions permitted. This progression is also marked by a vertical succession of organisms from dendroid corals through Alveolites and tabular stromatoporoids to hemispherical stromatoporoids.

Units C to E are not present in the westernmost portion of the study area, indicating that as the sea continued to shallow, the highest parts of the sea floor (in this case the upper part of the shelf) were gradually exposed. The bioherms (parts of Units C, D and E) began growth on that part of the shelf where conditions were optimal, probably in the vicinity of section KF-68, and moved eastward as the shallowing continued, to always inhabit an environment of moderately shallow turbulent-water. Unit I on the eastern side of the study area was formed in fairly deep water from skeletal grains and intraclasts that were derived from the bioherms to the west and transported by turbidity currents to the site of deposition.

B) Stage 11

Stage 11 is represented by Units F to H and part of Unit I of the platform member, and parts of Units S and U of the reef member.

After the formation of Unit E, the Givetian sea

began to deepen gradually. This is indicated in the central portion of the study area by a progression from bioherms (Units C, D and E) to a widespread organic shoal (Units F, G, and H), and by an accompanying succession of fossils ranging from hemispherical stromatoporoids to dendroid corals (the inverse of the succession in the underlying units).

As the sea level rose, the western part of the area was gradually flooded. A widespread lagoon (part of Unit U) characterized by the abundance of Amphipora, and a shoal area (part of Unit S) developed, similar to that of Units C, D, and E. In the eastern portion of the area deposition of Unit I continued.

C) Stage III

Stage III, represented by Units J to W of the reef member, can be divided into two substages.

Stage III began after a shallowing of the sea.

a) Substage 1.

During the first substage, represented by Units L, O, Q, and parts of J, R, S, T, U, V, and W, the nucleus of a large, laterally-zoned reef complex developed on the platform. In the areas on the periphery, the organic-shoal (parts of Units S and T) and the sublittoral facies (parts of Units U, V, and W) formed to the west, and the fore-reef (Unit L) and the off-reef (part of Unit K) facies formed to the east.

On the eastern edge of the platform, on the basin-

side of the organic-reef facies, a coral shoal area (Unit L) developed. Farther to the east at the beginning of substage 1 the off-reef facies (Unit J) formed. Skeletal and lithic debris derived from the organic and fore-reef facies was periodically transported by mass sliding and turbidity currents into this area.

At the beginning of Substage 1 in the western part of the study area, the lagoon and shoal area (parts of Units S and U) continued their formation.

As the water level continued to rise in the basin, and as the reef complex continued to grow vertically in response to this rise, the water in the marginal areas became progressively deeper. Sedimentation rates were greater on the platform than they were on the edges or in the basin. Consequently, in the western area the shallow-water lagoon and shoal environment (represented by parts of Units S and U) gradually evolved into an organic shoal area where the deeper water dendroid corals were in abundance (lower parts of Units T and V), and a sublittoral area (Unit W). In the eastern area, Unit J, lithology characterized by reef debris, gave way to Unit K lithology characterized by finer-grained sediments including shales.

b) Substage 2

During the second substage, represented by Units M, P, and parts of K, N, R, T, V, and W, the rise in

water level slowed. As a result the reef complex went through a period of pronounced lateral expansion. The organic-reef facies (part of Unit N) and the upper part of the fore-reef facies (part of Unit N) and the upper part of the fore-reef facies (Unit M) grew over the lower unit (Unit L) of the fore-reef facies. The water in the back-reef facies was not as deep as it had been previously. A large shoal area with Amphipora, Stachyodes, and bulbous stromatoporoids developed. The marginal shoal facies (Unit R) probably overgrew part of the organic shoal (Unit T); however, this is not revealed in the sections measured.

In the eastern part of the study area Unit K of the off-reef facies continued to form. In the western part stromatoporoids began growing in the upper part of the organic shoal (Unit T), and the sublittoral facies (part of Unit W), began forming over a portion of the organic shoal facies (Unit V).

The growth of the Ramparts Formation ended when the rate of increase of the water depth in the basin overtook the rate of upward growth of the reef complex. When the water depth became too great, the organisms died. These organisms would in turn be replaced by other organisms that could tolerate the environmental conditions, until finally no organisms could live. At this point the Canol Formation began to form.

It is not known exactly when the Givetian ended

and the Frasnian began in the Ramparts Formation. The presence of Frasnian brachiopods and ostracods in Units J and K of the off-reef facies indicates that this boundary probably occurs within substage 1 of Stage III.

CONCLUSIONS

1. The Ramparts Formation, exposed in the Mountain-Gayna River area, can be divided into two members, the lower (platform) member, and the upper (reef) member. These members can be further subdivided into facies and units on the basis of lithologic and paleontologic criteria. The platform member is composed of three laterally contiguous facies, from east to west, the platform edge, platform, and shallow shelf facies, which can be subdivided into Units A to I. The reef member is composed of seven laterally contiguous facies, from east to west, the off-reef, fore-reef, organic-reef, back-reef, marginal-shoal, organic-shoal, and sublittoral facies. Each facies can be divided into units, and together these are Units J to W.

2. In decreasing order of abundance, fossils in the Ramparts Formation include: stromatoporoids, corals, brachiopods, bryozoans, echinoderms, molluscs, foraminifers, algae, ostracods, trilobites, Tentaculites, sponge spicules, and numerous indeterminate skeletal elements. In some units there is a commonly repeated vertical sequence of stromatoporoids and corals. In order of appearance the fossils composing the sequence are: Coenites and Thamnopora, Alveolites, tabular

stromatoporoids, bulbous stromatoporoids, and hemispherical stromatoporoids. In some units corals appear at the base and stromatoporoids are at the top, whereas in other units the sequence is reversed. The first sequence with Coenites and Thamnorora at the base and stromatoporoids at the top is interpreted as representing growth in progressively shallower waters. A similar sequence from dendroid corals to massive stromatoporoids occurs in parts of the Alexandra Reef Complex (Jamieson, 1968).

3. Six stages of diagenetic processes affected the Ramparts Formation:

- i) Processes preceding first-generation calcite cementation. These include aggregation, organic mixing, organic burrowing, particle size reduction, boring and corrosion by algae, desiccation and shrinkage, slumping, and boudinage, "sooty" pyritization and possibly some silica cement.
- ii) First generation cementation
- iii) Processes following first generation cementation and preceding second generation cementation. These include crystalline replacement pyritization, the major period of silicification, inversion of molluscan aragonite, dissolution of molluscan aragonite, incongruent dissolution of high magnesium carbonate, recrystallization, "unknown" neomorphism, and fracturing.
- iv) Second generation cementation.
- v) Processes following second generation cementation

and preceding stylolitization. These include dolomitization and possibly some desilicification.

vi) Processes synchronous with and following stylolitization.

- a) Processes synchronous with stylolitization are other pressure solution phenomena and strain recrystallization.
- b) Processes following stylolitization include fracturing, subsequent cementation of weakly ferroan calcite, local dedolomitization and desilicification.

Hydrocarbon migration, evidenced by bitumen in pores and fractures probably took place at the same time as, or slightly before, stylolitization.

4. The Ramparts Formation can be divided into three stages of development.

i) Stage 1

Stage 1 (Units A to E, and part of Unit I), represents a gradual shallowing of the Givetian sea accompanied by the development of bioherms and biostromes.

ii) Stage 11

Stage 11, (Units F to H, and parts of Units I, S, and U), represents fairly rapid deepening of the Givetian sea accompanied by the development of organic shoals inhabited chiefly by corals.

iii) Stage 111

Stage 111 can be subdivided into two substages:

Substage 1, (Units L, O, Q, and parts of J, R, S, T, U, V, and W), represents a gradual deepening of a sea, possibly an Upper Devonian (Frasnian) sea, accompanied by the development of a laterally zoned reef complex.

Substage 11, (Units, M, P, and parts of K, N, R, T, V and W) represents a decrease in the rate of water level rise within the basin, accompanied by a pronounced lateral expansion of the reef complex.

The growth of the Ramparts Formation ceased when the rate of increase of the water depth in the basin overtook the rate of upward growth of the reef complex.

5. In a general way the Ramparts Formation reef complex resembles modern, shallow-water hermatypic coral reefs.

1) According to Logan (1969, p. 144) "emergent reefs may be viewed as part of a growth spectrum ranging from thin biostromal veneers and including submerged biostromes, submerged reef-banks, and fully emergent reef knolls and reef-wall complexes." The growth of a single emergent reef does not normally proceed in an orderly manner from a biostromal veneer unless certain conditions such as a static sea level are present. The biostromal veneers, biostromes and bank deposits are preserved in the rocks of Unit A to E of the platform member. These

deposits give way upward through Units F to I, to the organic-reef facies Unit N, of the reef member. This facies is probably comparable to a modern emergent reef. As has been previously explained, a rapid rise in sea-level interrupted the ideal growth spectrum of the reef complex when Units F to I of the platform member were deposited.

ii) Modern reef complexes commonly show a lateral zonation of litho-and biofacies which are established in response to differing conditions of the physical environment. The reef member of the Ramparts Formation is divided into seven facies on the basis of lithologic and paleontologic criteria. Each of these facies was established, as well, in response to the conditions of the physical environment.

iii) In modern reefs the anthozoan communities, the Acropora palmata and Diploria-Montastrea-Forites communities are partly responsible for frame-building (Logan, 1969, p. 186). The Acropora palmata community forms the reef wall in a zone of relatively high energy and turbulence, whereas the Diploria-Montastrea-Forites community forms structures on the open shelf in a lower energy environment. Hemispherical stromatoporoids and bulbous stromatoporoids, the organisms that dominate Unit N of the reef member in the Ramparts Formation are probably analogous to the Acropora palmata community, whereas Alveolites, tabular stromatoporoids, Coenites and Thamnonora are

analogous to the Diploria-Montastrea-Porites community.

6. The Ramparts Formation studied in the Mountain-Gayna River area appears to be similar to the Kee Scarp Formation studied in the Norman Wells area by Statham (1969). In both localities the formations can be divided into a lower platform and an upper reef member. The reef member can be further subdivided laterally into facies. The lithologies of both the reef and platform members in both localities are similar as well. Statham (1969) suggests that the reef complex in the Norman Wells area is 'atoll-like'. The reef complex exposed in the Mountain-Gayna River area and studied here, is probably part of a larger north-south trending fringing reef complex of Middle and Upper Devonian age (Law, 1971, p. 466).

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APPENDIX ONE

		DESCRIPTION OF PLATE 1	
SAMPLE NUMBER	PHOTOGRAPH NUMBER	STROMATOPORCIDS AND CORALS	
KK-63	1	Unit O. Tabular stromatoporoid in growth position, composed of alternating stromatoporoid (S) and algal (A) layers. Note <u>Stachyodes</u> coenostea fragments both above and below. X1	
LA-3	2	Unit N. Tabular stromatoporoid in growth position encrusting substrate consisting mainly of crinoid (C) and <u>Stachyodes</u> (S) fragments. X1	
KQ-17	3	Unit P. Section through abraded bulbous stromatoporoid. Note fragments of <u>Stachyodes</u> (S) <u>Amphipora</u> (A) and <u>Coenites</u> (C) around the bulbous stromatoporoid. X2.3	
KK-83	4	Unit O. Juvenile growth forms of <u>Amphipora pervesiculata</u> . X4.5	
KK-113	5	Unit P. Assortment of <u>Amphipora angusta</u> coenostea cut randomly. Note absence of axial canals, and intact marginal vesicles (in most cases). X4.5	
KT-9	6	Unit T. Random section through <u>Alveolites</u> . X2	
KK-41	7	Unit H. Longitudinal section through <u>Thamnopora</u> . X4.5	
KK-40	8	Unit H. Transverse section through <u>Thamnopora</u> .	
KK-18	9	Unit B. Random section through a colonial tabulate coral. X20	

PLATE 1

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PLATE 1

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DESCRIPTION OF PLATE 11

SAMPLE NUMBER	PHOTOGRAPH NUMBER	BRACHIOPODS, BRYOZOANS, AND ECHINODERMS
KJ-61	1	Unit O. Random sections through several different types of brachiopod valve. Note pellets and intraclasts in the matrix. X30
KK-16	2	Unit B. Cross section through a brachiopod spine. Part of the spine is replaced by pyrite. (P). X60.
KK-18	3a, b	Unit B. a) Longitudinal section through bryozoan A. b) Transverse section through a juvenile (?) form of bryozoan A. X40.
KK-19	3c	Unit B. Transverse section through bryozoan A. X40
KK-36	4	Unit G. Transverse section through bryozoan B. X20
KK-19	5	Unit B. Transverse section through bryozoan C. X80.
KK-17	6	Unit B. Random section through <u>Fenestella</u> . X30
KK-12	7	Unit A. Random section through <u>Polynora</u> . X25
KP-1	8	Unit B. Section through a crinoid ossicle. Note crinoid fragments, other skeletal grains and intraclasts in the sediment around the ossicle. Several of the skeletal grains show evidence of algal corrosion. X30
KK-33	9	Unit F. Random section through an echinoid spine. X50
KK-40	10	Unit H. Random section through an echinoid spine. X40

PLATE 11

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3b

3c

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PLATE 11

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3c

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DESCRIPTION OF PLATE 111		
SAMPLE NUMBER	PHOTOGRAPH NUMBER	GASTROPODS AND FORAMINIFERS
KK-18	1	Unit B. Random section through a large gastropod. Shell is composed of a mosaic of calcite crystals. X25
KM-1	2	Unit A. Section through a small gastropod. X30
KK-38	3	Unit G. Section through a small gastropod. X30
KK-60	4	Unit O. <u>Parathurammia</u> . X90
KK-132	5	Unit P. <u>Parathurammia</u> . X90
KK-12	6	Unit A. <u>Bisphaera</u> . X200
KK-81	7	Unit O. <u>Tikhinella</u> fragment. X90
KQ-3	8	Unit P. <u>Tikhinella</u> fragment. X90
KK-60	9	Unit O. <u>Tikhinella</u> fragment. X90
KK-124	10	Unit P. <u>Tikhinella</u> fragment. X90
KK-14	11	Unit A. <u>Evlania</u> X90
KM-3	12	Unit O. <u>Evlania</u> X50
KK-26	13	Unit E. <u>Irregularina</u> X30
KK-71	14	Unit O. <u>Irregularina</u> X30
KK-78	15	Unit O. <u>Irregularina</u> X30
KK-122	16	Unit P. <u>Irregularina</u> X30
KK-38	17	Unit G. <u>Eonodosaria</u> X90
KK-40	18	Unit H. <u>Eonodosaria</u> X90
KK-132	19	Unit P. Lagenid-type X90
KM-2	20	Unit O. <u>Paratikhinella?</u> X50

PLATE 111

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PLATE 111

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DESCRIPTION OF PLATE 1V

SAMPLE NUMBER	PHOTOGRAPH NUMBER	ALGAE, RADIOSPHAERID CALCISPHERES, OSTRACODS AND TRILOBITES	
KK-22	1	Unit D. <u>Vermiporella</u> .	X30
KK-27	2	Unit E. <u>Vermiporella</u> .	X50
KK-26	3	Unit E. <u>Vermiporella</u> .	X25
KK-27	4	Unit E. <u>Vermiporella</u> .	X50
KK-100	5	Unit C. <u>Vermiporella</u> .	X50
KK-78	6	Unit C. <u>Vermiporella</u> .	Note circular unknown. X50
KK-134	7	Unit F. <u>Vermiporella</u> .	X50
KK-122	8	Unit F. <u>Vermiporella</u> .	X25
KK-12	9	Unit A. <u>Girvanella</u> .	X90
KK-19	10	Unit B. <u>Girvanella</u> , encrusted on a bryozoan.	X90
KK-39	11	Unit G. <u>Girvanella</u> .	X90
KK-21	12	Unit C. Radiosphaerid calcisphere	X50
KK-38	13	Unit G. Radiosphaerid calcisphere	X50
KY-84	14	Unit O. Radiosphaerid calcisphere	X50
KK-51	15	Unit C. Radiosphaerid calcisphere	X50
KK-86	16	Unit C. Radiosphaerid calcisphere	X50
KK-132	17	Unit F. Radiosphaerid calcisphere	X50
KK-49	18	Unit O. Ostracod.	X25
KK-47	19	Unit O. Ostracod.	X25
KK-19	20 21	Unit B. a) trilobite shell fragment, plane polarized light; b) crossed nichols	X50

PLATE 1V

PLATE IV

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DESCRIPTION OF PLATE V

SAMPLE NUMBER	PHOTOGRAPH NUMBER	<u>TENTACULITES</u> , SPONGE SPICULES AND INDETERMINATE SKELETAL ORGANISMS
KL-20	1	Unit A. Longitudinal and transverse sections through <u>Tentaculites</u> . X20
KK-17	2	Unit B. Transverse section through <u>Tentaculites?</u> X20
KM-1	3	Unit A. Section through sponge spicules. X30
KK-38	4	Unit G. Unknown. Note pyrite (P) crystals inside the organism. X90
KK-12	5	Unit A. X90 (Photograph numbers 5 to 11 are indeterminate skeletal elements).
KK-14	6	Unit A. X90
KK-17	7	Unit B. X90
KK-17	8	Unit B. X50
KK-21	9	Unit C. X90
KK-21	10	Unit C. X50
KK-21	11	Unit C. X90

PLATE V

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PLATE V

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DESCRIPTION OF PLATE VI
INDETERMINATE SKELETAL ORGANISMS

SAMPLE NUMBER	PHOTOGRAPH NUMBER		
KK-21	1	Unit C. <u>Renalcis?</u>	X90
KK-21	2	Unit C. <u>Renalcis?</u>	X90
KK-21	3	Unit C.	X50
KK-26	4	Unit E.	X90
KK-26	5	Unit E.	75
KK-26	6	Unit E.	X90
KK-27	7	Unit E.	X50
KK-33	8	Unit F.	X50
KK-51	9	Unit O.	X50
KK-78	10	Unit O.	X30
KK-73	11	Unit O. Notice the sparry calcite infilling.	X30
KK-71	12	Unit O.	X30
KK-51	13	Unit O. <u>Vermiporella?</u>	X50
KK-51	14	Unit O.	X50
KK-89	15	Unit O.	X50
KM-5	16	Unit P.	X30
KQ-4	17	Unit P.	X50
KM-5	18	Unit P.	X50
KV-2	19	Unit U.	X30

PLATE VI

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PLATE VI

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DESCRIPTION OF PLATE VII

UNITS A TO D

SAMPLE NUMBER	PHOTOGRAPH NUMBER	(Unless otherwise stated for Plates VII to XIV inclusive, thin section photographs are negative prints. Hand specimens magnification X2; thin section magnification X4. a=hand specimen; b=thin section).
KK-13	1a,b	Unit A. Mudstone. Note disrupted laminae in a).
KK-17	2a,b	Unit B. Skeletal packstone. Note brachionod (B) crinoid (C) fragments. b) X6.
KK-21	3a,b	Unit C. Algal-foraminiferal packstone.
KK-23	4a,b	Unit D. Stromatoporoid-coral packstone. Note the <u>Stachyodes</u> , <u>Coenites</u> , and <u>Amphipora</u> fragments.

PLATE VII

1a

b

2a

b

3a

b

4a

b

PLATE VII

1a

2a

3a

4a

4b

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE VIII
		UNITS E TO H
KK-26	1a,b	Unit E. <u>Amphipora</u> packstone.
KK-31	2a,b	Unit F. <u>Coenites</u> packstone. Note the <u>Coenites</u> fragments (C). Note the <u>Stachyodes</u> (S) fragments in a) and the crinoid (Cr) fragment in b). Part of the matrix is dolomitized.
KK-36	3a,b	Unit G. Skeletal packstone. Note the crinoid, (C) brachiopod, (B) <u>Amphipora</u> (A) and bryozoan (Br) fragments in a) and b).
KK-41	4a,b	Unit H. <u>Thamnonora-Coenites</u> packstone.

PLATE VI11

1a

b

2a

b

3a

b

4a

b

PLATE VI11

2a

b

3a

3b

4a

4b

DESCRIPTION OF PLATE IX

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE IX UNITS I TO L
KJ-63	1a,b	Unit I. Skeletal-intraclastic mudstone. Note the mottling in the hand specimen.
KL-10	2a,b	Unit J. Skeletal wackestone-packstone. Lighter coloured beds consist of intraclasts and skeletal debris and are classified as packstones. Darker coloured beds consist of intraclasts, skeletal debris, micrite and microspar, and are classified as wackestones. a) X1.75
KL-6	3a,b	Unit K. Skeletal wackestone-packstone. Note finely-bedded wackestone beds and relatively thick crinoidal-packstone unit. (b) Negative peel print a) X1.75
LA-2	4a,b	Unit L. Coral packstone. Note the <u>Coenites</u> coral fragments and brachiopod valve (B) fragments in both hand specimen and thin section.

UNITS I TO L

PLATE 1X

1a

b

2a

b

3a

b

4a

b

PLATE 1X

1a

2a

3a

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE X
		UNITS M TO O
LB-2	1a,b	Unit M. <u>Stachvodes</u> packstone. Note the <u>Stachvodes</u> fragments in both hand specimen and thin section. a) X1.75
LA-3	2a,b	Unit N. <u>Actinostroma</u> ? boundstone. (b) positive thin section photograph.
KK-60	3a,b	Unit O. Intrapel-foram-algal wackestone. Note ostracods (C) and foraminifers (F) in thin section. Note also mottling in thin section.
KQ-25	4a,b	Unit O. Intrapel-foram-algal wackestone. Note <u>Amphipora</u> fragments and sparry calcite 'eyes' (E) in hand specimen.

PLATE X

1a

b

2a

b

3a

b

4a

b

PLATE X

1a

2a

3a

SAMPLE		DESCRIPTION OF PLATE XI	
NUMBER	PHOTOGRAPH NUMBER	UNITS O AND P	
KK-51	1a,b	Unit O. <u>Amphipora</u> wackestone-packstone. Note <u>Amphipora</u> coenostea, crinoid (C) and other skeletal fragments.	
KK-81	2a,b	Unit O. <u>Amphipora-Stachyodes</u> wackestone-packstone. Note <u>Amphipora</u> and <u>Stachyodes</u> coenostea in the hand specimen and other skeletal elements in the thin section.	
KK-130	3a,b	Unit P. Stromatoporoid-coral grainstone. Note the <u>Amphipora</u> and <u>Stachyodes</u> fragments in both the hand specimen and thin section. Note also the stromatoporoid encrusting <u>Coenites</u> coral fragments in the hand specimen, and the rugose coral in the thin section.	
KK-119b	4	Unit P. Stromatoporoid-coral packstone. Note the assortment of stromatoporoid. <u>Coenites</u> , <u>Amphipora</u> and stromatoporoid encrusted coral fragments.	

PLATE XI

1a

b

2a

b

3a

b

4

PLATE XI

1a

2a

3a

DESCRIPTION OF PLATE XII		
SAMPLE NUMBER	PHOTOGRAPH NUMBER	UNITS P AND Q
KK-119a	1a,b	Unit P. Stromatoporoid-coral packstone. Note the bulbous stromatoporoid with the <u>Coenites</u> fragment as a nucleus.
KK-138	2a,b	Unit P. <u>Amphipora</u> wackestone-packstone. Note the <u>Amphipora</u> coenostea with intact marginal vesicles.
KK-102	3a,b	Unit P. <u>Amphipora</u> packstone. Most of the <u>Amphipora</u> do not have intact marginal vesicles.
KP-3	4a,b	Unit Q. Skeletal packstone.

PLATE XI1

1a

b

2a

b

3a

b

4a

PLATE XII

2a

3a

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE XIII
		UNITS R, S AND T
KP-5	1a,b	Unit R. <u>Stachyodes</u> grainstone. Note the <u>Stachyodes coenostea</u> in both a) and b), and the sparry calcite cement in the matrix of b).
KP-6	2	Unit R. Thin section photograph of a packstone-grainstone rock showing intraclasts and skeletal grains both corroded and non-corroded by algae. (Positive print) X25
KS-4	3a,b	Unit S. Skeletal packstone.
KT-10	4a,b	Unit T. <u>Thamnonora</u> packstone. Note the <u>Thamnonora</u> fragments in both a) and b). The matrix is composed mostly of <u>Thamnonora</u> fragments.

PLATE XIII

1a

b

2

3a

b

4a

b

PLATE XIII

1a

2

3a

4a

		DESCRIPTION OF PLATE XIV
SAMPLE NUMBER	PHOTOGRAPH NUMBER	UNITS U, V, AND W
KV-1	1a,b	Unit U. Quartzose skeletal packstone. Note the <u>Amphipora</u> (A) fragments in a).
KV-3	2a,b	Unit V. Quartzose coral packstone-grainstone. Note the <u>Coenites</u> and <u>Thamnobora</u> fragments in both a) and b). a) X1.5
KX-5	3	Unit V. Thin section of a quartzose coral packstone showing coral fragments and quartz clasts in the matrix of the rock. X25 (Positive print).
KX-7	4a	Unit W. Quartzose carbonate. Note brachiopod valve fragments.
KY-3	4b	Unit W. Quartzose carbonate. (Positive print of a thin section) X2

PLATE XLV

1a

b

2a

b

3

4a

b

PLATE XIV

1.

2.

3.

4.

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE XV
		BIOCHEMICAL AND ORGANIC PROCESSES
KK-14	1	Unit A. Mottling, possibly the result of burrowing organisms. (Negative thin section print) 1.5X
KK-69	2	Unit O. Boring in a tabular stromatoporoid. X2
KQ-14	3	Unit P. Boring in a bulbous stromatoporoid. Pellets (P) are present within the larger structure. X2
KX-4	4	Unit U. Boring along the edge of a brachiopod valve fragment. X25
KP-1	5a,b,c	Unit B. Algal corrosion of skeletal grains. X25
KK-58	6	Unit O. Serpulid worm tubes. X25

PLATE XV

1

2

3

4

5a

b

c

6

PLATE XV

1

2

3

4

5a

5b

5c

5d

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE XVI
		PYRITIZATION AND SILICIFICATION
KK-17	1	Unit B. Micro-grained (M) and crystal aggregate pyrite coating and replacing parts of a bryozoan. X25
KK-43	2	Unit H. Aggregate of pyrite crystals rimmed by calcite crystals. X5
KK-18	3	Unit B. Euhedral crystal of pyrite replacing part of a bryozoan. X25
KQ-34	4	Unit H. Crystal aggregates of pyrite replacing parts of a <u>Thamnopora</u> fragment. X25
KJ-63	5	Unit I. Limonite after marcasite? X25
KJ-65	6	Unit I. Limonite after marcasite? X25
KJ-59	7	Unit B. Well-terminated overgrowths on quartz grains. X100
KJ-59	8a,b	Unit B. Colloform silica in <u>Stachyodes</u> cavities. In b) note dolomite rhombs (D) replacing the silica. a) X25, b) X50
KQ-32	9	Unit H. Mosaic quartz crystals occupying the pores of <u>Alveolites</u> . (crossed nichols). X25

PLATE XVI

4

7

PLATE XVI

1

2

3

4

5

6

7

8a

b

9

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE XVII
		SILICIFICATION
KK-23	1	Unit D. Patchy lutecite replacing part of <u>Stachyodes</u> fragment. Note hexagonal form of several of the patch branches, and remnants of skeletal carbonate in the centre of the patch. X60
KQ-17	2	Unit P. Patchy chalcedony replacing part of a stromatoporoid. X50
KQ-17	3a,b	Unit P. Spherulitic lutecite replacement of a stromatoporoid fragment. Note jagged outline. a) plane polarized light; b) crossed nichols. X50
KJ-66	4	Unit I. Spherulitic lutecite replacement of a brachiopod valve fragment. Note smooth outline. (crossed nichols) X50
KQ-17	5a,b	Unit P. Spherulitic lutecite replacement of a stromatoporoid fragment. Upper replacement may have started as a patchy replacement. a) plane polarized light; b) crossed nichols. X50
KL-10	6a,b	Unit J. Chalcedony and lutecite replacement of a brachiopod valve fragment. Orientation of silica is controlled by brachiopod valve structure. a) plane polarized light; b) crossed nichols. X50

PLATE XV11

1

2

3a

b

4

5a

b

6a

b

PLATE XVII

1

2

3a

b

4

5a

b

6a

b

SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE XVlll
		DOLOMITIZATION, DEDOLCMITIZATION AND CEMENTATION
KJ-66	1	Unit I. Non-ferroan dolomite replacing part of a crinoid fragment. (Medium grey area) X6.7
KK-38	2	Unit G. Non-ferroan dolomite replacing part of a crinoid fragment. X100
KK-52	3	Unit O. Non-ferroan dolomite replacing part of the matrix. X50
KU-10	4	Unit T. Ferroan dolomite replacing ferroan calcite infilling pelecypod? shells (P). Most of the dolomite (D) occurs along the edges of the calcite infilling. X40
KK-31	5	Unit F. Non-ferroan dolomite crystals growing in the cavities of <u>Coenites</u> and partially replacing parts of the surrounding skeleton. X25
KJ-76	6	Unit J. Non-ferroan dolomite replacing both non-ferroan calcite of a <u>Stachvodes</u> fragment (s) and silica(Si). Note the pyrite (black) crystals replacing the silica as well. X40
KJ-59	7	Unit B. Dedolomitization. Ferroan dolomite has been replaced by non-ferroan calcite. Note the outline of the dolomite rhomb (R) in the patch of ferroan calcite. Note also the iron oxide coating on the skeletal grains. X25
KL-20	8	Unit A. Non-ferroan (N) and ferroan (F) calcite inside <u>Tentaculites</u> . X25
KP-5	9	Unit R. Non-ferroan syntaxial cement rim around a crinoid fragment. X25

PLATE XVIII

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PLATE XVIII

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SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE XIX
		NEOMORPHISM
KK-33	1	Unit F. Degrading recrystallization of a <u>Coenites</u> coral fragment. Part of the skeleton has been altered to micrite. X25
KQ-25	2	Unit O. Degrading and aggrading recrystallization. Ostracod? skeletal structure has undergone degrading recrystallization producing micrite and has later been subjected to aggrading recrystallization which is responsible for the generation of the sparry calcite (pseudospar). X25
KK-52	3	Unit O. Part of the internal skeletal architecture of <u>Amphipora</u> has been destroyed by aggrading recrystallization. X50
KQ-27	4	Unit O. Two kinds of pellets and intraclasts that have undergone partial aggrading recrystallization. X25
KK-65	5	Unit O. Intersecting twin lamellae in sparry calcite. Note that some of the lamellae are bent. Product of strain recrystallization. X25
KK-17	6	Unit B. Both coral fragment and matrix material have been affected by some neomorphic process. Strain recrystallization? X25
KJ-57	7	Unit A. Microspar and pseudospar. X4
KK-23	8	Unit D. Aggrading neomorphism. Note the islets of partially altered matrix material in the sparry calcite. Possibly the result of the 'unknown' process. X25
KM-1	9	Unit A. Incongruent dissolution. Crinoid ossicle has been altered to a mosaic of weakly ferroan calcite crystals. A fracture containing strongly ferroan calcite cuts the crinoid. X30

PLATE XIX

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PLATE XIX

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SAMPLE NUMBER	PHOTOGRAPH NUMBER	DESCRIPTION OF PLATE XX
		PHYSICAL PROCESSES
KK-33	1	Unit F. Pressure-solution contact of two crinoid fragments. One is preferentially dissolved in favour of the other. X30
KK-12	2	Unit A. Pore in sparry calcite filled cavity is filled with bitumen. Note also that bitumen occurs throughout the sparry calcite crystals around the central bitumen filling. X30
KK-81	3	Unit O. Stylolite, outlined by bitumen, between matrix and coral fragment. X25
KK-12	4	Unit A. Part of a stylolite outlined by quartz (Q), pyrite and bitumen. X30

PLATE XX

1

2

3

4

PLATE XX

1

2

3

4

APPENDIX TWO

METHODS OF INVESTIGATION

Section Measuring and Sampling Procedure

Sixteen sections of the Ramparts Formation exposed along stream cuts in the Mountain-Gayna River escarpment were measured, described and sampled in the course of field work for the Chevron Standard Company of Calgary during the summer of 1968.

The sections were described in five foot intervals according to the Chevron Standard carbonate field description chart. Results of the description are tabulated in Appendix Three, p. 208. All of the measuring was done using a five foot long "pogo" stick.

Representative lithologic samples were collected at five foot intervals in sections KL, KJ, KH, KS, KT, KU, KV, KW, KX, and KY. In the remaining sections rock samples were collected to illustrate the main lithologic types present.

Specimen Preparation

Approximately four hundred hand specimens were collected from the surface sections. All of the specimens were cut and polished. The polishing was first done using a 220 grade grinding powder and then with a 600 grade powder. The ground surfaces were etched for 5 to 10 seconds in dilute (10 percent by volume) hydrochloric

acid. After rinsing and drying a mixture of glycerin and water (a 1:1 mixture) was then spread sparingly over the surface of the polished sections in preparation for the initial petrographic examination.

Initial Petrographic Examination

Each of the polished surfaces was examined briefly using a low powered zoom microscope. During this examination specimens were selected both for the preparation of thin sections and for cellulose peels. Major constituents present in the hand specimens, as well as any major diagenetic features or structural features were recorded during this examination.

Thin Section and Peel Section Preparation

Two hundred and seventy-seven thin sections and two hundred and twenty cellulose peels were prepared from the selected specimens. The peels were prepared according to the method of Davies and Till, (1966). Most of the thin sections and peels were random slices through the hand specimens. Of the sections prepared approximately one hundred thin sections and fifty cellulose peels were stained with the combination stain, Alizarin red-S and potassium ferricyanide in order to differentiate ferroan calcite and dolomite from nonferroan calcite and dolomite. The combination stain was prepared and applied according to the method of Dickson (1965). Most of the

remainder of the thin sections were stained with alizarin red-S alone to differentiate calcite from dolomite.

Detailed Petrographic Examination

All of the thin sections and peel sections were examined using both a low powered zoom microscope and a Leitz polarizing binocular microscope with transmitted light.

A number of thin sections were selected for point counting. The sections were representatives of the major rock types present in the reef complex. In each of the thin sections counted the whole surface of the section was covered using a grid of at least 100 points. The number selected was based on several factors:

- 1) Numerous trial counts were made on a wide variety of lithologic types to select the minimum number of points to give a reasonable amount of reproducibility of results on successive counts of the same specimen. The degree of reproducibility ranged from 5 to 15 percent using 100 points.
- 2) In view of the large number of thin sections that could be point counted and considering the amount of time needed for each count it was decided to keep the number of points to a minimum in order to point count as many of these as were possible in the allotted time. 103 point counts were made in the study.

3) A large degree of variation often exists in the amounts of various constituents present within individual hand specimens and within areas of individual thin sections. It was felt that counting additional points to achieve a higher degree of reproducibility was not necessary.

The results of the petrographic examination of hand specimens, thin sections, and peel sections are presented in Appendix Three, p. 224.

APPENDIX THREE

[illegible]

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	COMMENTS
80				X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Cabbage Stroms Nodular Stroms
79			X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
78			X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
77			X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
76					X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
75				X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
74				X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
73				X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
72				X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
71				X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
70				X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
69												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
68												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
67												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
66												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
65												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
64												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
63												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
62												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
61												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
60												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
59												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
58												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
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56												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
55												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
54												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
53												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
52												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
51												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
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49												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
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42												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
41												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
40												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
39												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
38												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
37												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
36												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

COVERED - 5'

Base of Yellow Streaked Unit

Shale Interbeds Tabular Stroms
" " "

Shale Interbeds

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Table D

224

DIAGENETIC ALTERATION

Physicochemical																															
Replacement																Physical															
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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
J KL 8-11					X		X		X		X		X		X		X					X		X		X		X				
KJ 76-77					X																X											
I KL 12-19				X	X		X		X		X		X		X		X					X		X		X		X				
KJ 60-75				X	X		X		X		X		X		X		X					X		X		X		X				
H LA*																																
KK 40-46					X		X								X		X					X		X		X		X				
KM*																																
KO 32-34					X		X		X						X		X					X		X		X		X				
KP*																																
G KK 34-39					X		X								X		X					X		X		X		X				
KM*																																
F KK 28-33																																
KQ*																																
E KK 26-27																																
D KK 22-25				X	X										X		X					X		X		X		X				
KM 2							X								X		X					X		X		X		X				
KQ*																																
C KK 21					X		X															X										
KM*																																
B KJ 59					X		X		X		X										X		X		X		X		X			
KK 15-20						X									X		X					X		X		X		X				
KM*																																
KP 1					X		X								X		X					X		X		X		X				
KS 1-2					X		X								X		X					X		X		X		X				
KT 2					X		X								X		X					X		X		X		X				
KU 5-6					X																											
KW 2-3																																
KX 3																																
KY 1																																
A KL 20-21				X			X																									
KJ 57-58					X		X		X													X		X		X		X				
KK 12-14				X		X	X															X		X		X		X				
KM 1					X										X		X					X		X		X		X				
KT 1							X															X		X		X		X				
KU 4																						X		X		X		X				
KV 1																						X		X		X		X				
KW 1																						X		X		X		X				
KX 2																						X		X		X		X				

NOTE: 1. X - Present 2. * - Thin Sections or Feels not Available

CRETACEOUS

K Undifferentiated Cretaceous
(includes Little Bear etc. Formations)

UPPER DEVONIAN

Di Imperial Formation

Dfc Canal Formation

MIDDLE DEVONIAN

Ramparts Formation

Dhi Hare Indian Formation

Dh Hume Formation

Dbr Bear Rock Formation

SILURIAN

Sr Ronning Formation

CAMBRO-ORDOVICIAN

EO Undifferentiated Cambrian and Ordovician

Anticline.....
Syncline.....
Bedding.....
Fault.....

Figure 7 GEOLOGICAL MAP OF THE THESS REGION
(From A Chevron Standard Co. Base Map, 1968)

FOR HORIZONTAL SCALE SEE FIGURE 2, P. 4

SECTIONS KS, KT, KU, KV, KW, KY and KZ
SAME VERTICAL SCALE

REMAINING SECTIONS SAME VERTICAL
SCALE AS KP.

FOSSIL DISTRIBUTION

[illegible]

NOTE:

1. All digits refer to Percentages
2. P - Present
3. Data presented in this Table are from Field Notes, Hand Specimen and Thin Section Analysis
4. AB - Abundant, not quantified

FOSSIL DISTRIBUTION

Unit	Section	Sample Number	Av. Total Fossils	Av. Hemispherical Sponges	Av. Tubular Stroms	Av. Bulbous Stroms	Av. Stachyodes	Av. Amphipora	Av. Alveolites	Av. Coscinot	Av. Thamnospira	Av. Rugosa	Av. Brechs	Av. Bryozoans	Av. Crinoids	Av. Echinoids	Av. Gastropods	Av. Pelecypods	Av. Foraminifera	Av. Bivalves	Av. Trilobites	Av. Tentaculites	Av. Sponges	Unit
W	KW	10-8	5																					W
	KX	7-8	17																					
	KY	3-5	14																					
	KZ																							
V	KV	3-6	61																					V
	KW	6-7	80																					
	KX	5-6	17																					
U	KV	1-2	27																					U
	KW	4																						
	KX	4	20																					
	KY	2	65																					
T	KS	5-8	70																					T
	KT	5-12	63																					
	KU	9-15	70																					
S	KS	3-4	10																					S
	KU	3-4	78																					
	KV	7-8	7																					
R	KP	4-6	71	25	9	9	15																	R
Q	KP	2-3	65		15	50	30																	Q
P	KK	101-158	52	<1	<1	10	5	19	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	P
	KM	5	10																					
	KQ	1-23	59		1	1	1	15	<1	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
O	KK	47-100	48		7	5	9		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	O
	KM	3-4	53		46		2																	
	KQ	24-31	52		10	28	1	4	<1															
N	LA	3	99	99	P	P	P																	N
M	LB	1-8	54		9	36			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	M
	LA	4	55		20	30																		
L	LA	1-2	55		P	25	3																	L
K	KL	2-7																						K
J	KL	8-11																						J
	KJ	76-77	30		59	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	
I	KL	12-19																						I
	KJ	60-75	40		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
H	LA																							H
	KK	40-46	43		4		4																	
	KM																							
	KQ	32-34	53																					
	KP																							
G	KK	34-39	29																					G
	KM																							
F	KK	28-33	83		59		1	<1	P	8				<1	2	<1								F
	KQ																							
E	KK	26-27	23																					E
D	KK	22-25	76		25	25	9	1	P					8	<1	<1								D
	KM	2	55																					
	KQ																							
C	KK	21	24																					C
	KM																							
B	KJ	59	60																					B
	KK	15-20	52		16																			
	KM																							
	KP	1	55																					
	KS	1-2	25																					
	KT	2	30																					
	KU	5-6	23																					
	KV	2-3	25																					
	KK	3	50		15																			
	KY	1	65																					
A	KL	20-21																						A
	KJ	57-58	17																					
	KK	12-14	12																					
	KM	1	19																					
	KT	1	3																					
	KU	4																						
	KV	1	4																					
	KX	2	5																					

NOTE:

- All digits refer to Percentages
- P - Present
- Data presented in this Table are from Field Notes, Hand Specimens and Thin Section Analysis
- AB - Abundant, not quantified

SUMMARY OF FIELD DESCRIPTION AND LITHOLOGIC ANALYSIS

Unit	Section	Sample No.	Bedding Units		Bedding Character		Bedding Type		Colour		ROCK		COMPONENTS		Texture		Classification		Unit																					
			Resistant	Moderate	Weakly	Sharp	Uneven	Nodular	Messive	Blocky	Slabby	Flaggy	Platy	Papery	Colour	Grain	Av. Intracasts	Av. Pellets	Av. Micrite	Av. Microspar	Av. Spar	Av. Dolomite	Av. Detrital Quartz	Av. Authigenic Silica	Av. Pyrite	Av. Mercansite	Av. Iron Oxides	Av. Argillaceous Material-Bitumen	Av. Forams	Random	Mottled	Laminated	Mudstone	Wackestone	Packstone	Grainstone	Boundstone	Shale	Sandstone	
W	KW	8-10	X			X				X-X					DL.Gy.	5	?	P	P	P	P		P					P	F		X				X		X		W	
	KX	7-8	X				X			X					Med. Bn.	17		P	P	P	P		P					P	Po	X				X-X		X		X		
	KY	3-5	X-X				X			X-X					Med. Bn.	14	P		P	P	P							P	F	X-X				X-X		X		X		
	KZ		X				X			X-X					Med. Bn.													P	F									X		
V	KV	3-6	X				X		X						Lt. Gy.	61	P		P	P	P		P				<1	Po	X						X-X					V
	KW	6-7	X				X			X					Med. Gy. Bn.	30	?	?	?	P	P		?	?				P	Po	X					X					
	KX	5-6	X				X								Med. Gy. Bn.	17	P		P	P	P		?	?				P	Po	X					X-X					
U	KV	1-2	X				X		X	X-X					Lt. Gy.	27	P	P	P	P	P		P					P	Po	X					X-X					U
	KW	4	X				X			X					Med. Gy. Bn.				P	P	P		P					P	Po	X					X					
	KX	4	X				X			X					Med. Gy. Bn.	20	P		P	P	P		P					P	Po	X					X					
	KY	2	X				X			X					Med. Gy. Bn.	65			P	P	P							P	Po	X										
T	KS	5-8	X				X		X						Lt. Gy.	70	P	P	P	P	P		P					<1	Po	X					X					T
	KT	5-12	X				X		X	X-X					Lt. Gy.	63	<1		P	P	P	P	P	?				P	Po	X-X				X-X		X				
	KU	9-15	X-X				X		X	X-X					Lt. Gy.	70	P		P	P	P		P					P	Po	X-X					X		X			
S	KS	3-4	X				X		X						Lt. Gy.	10	P	P	P	P	P		P					Po	X						X					
	KT	3-4	X				X			X-X					Lt. Gy.	78	P		P	P	P		P					P	Po	X					X-X					
	KU	7-8	X-X				X		X	X-X					Lt. Gy.	7	P		P	P	P		P					P	Po	X					X					
R	KP	4-6	X				X		X	X-X					Med. Gy. Bn.	71	15		3	1	5						<1	<1	G	X				X-X						
Q	KP	2-3	X				X		X	X-X					Med. Li. Bn.	65	?		P	P	P							F	X					X-X						
P	KM	101-158	X-X				X		X	X-X					Med. Dk. Gy. Bn.	52	9	<1	9	31	3		<1			<1	<1	Po	X-X					X-X						
	KM	5	X-X				X		X	X-X					Med. Gy. Bn.	10	10	<1	27	46	6						<1	<1	Po	X					X					
	KO	1-23	X-X				X		X	X-X					Lt. Gy.	59	6	2	7	34	5		<1			<1	<1	Po	X					X-X						
O	KK	47-102	X-X				X		X	X-X					Med. Li. Bn.	48	7	3	17	34	5		<1			<1	<1	Po	X-X					X-X						
	KM	3-4	X-X				X		X	X-X					Med. Gy.	53	5	3	8	5							<1	<1	Po	X					X					
	KO	24-31	X-X				X		X	X-X					Lt. Gy.	52	9	6	25	33	3		<1			<1	<1	Po	X-X					X-X						
N	LA	3	X				X		X	X-X					Med. Gy.	99			P	P	P														X-X					
M	LB	1-8	X				X		X	X-X					Lt. Gy.	54	P	P	P	P	P		P				Po	X							X-X					
	LA	4	X				X		X	X-X					Lt. Med. Gy. Bn.	55	P	P	P	P	P						Po	X							X					
L	LA	1-8	X-X				X		X	X-X					Med. Gy.	55	7	1	30	14	1		10				<1	<1	Po	X					X-X					
K	KL	2-7	X-X				X		X	X-X					Med. Bn.	?	?	?	P	P	P							P	Po	X				X-X						
J	KL	8-11	X-X				X		X	X-X					Med. Bn.	?	?	?	P	P	P							P	Po	X				X-X						
	KJ	76-77	X				X		X	X-X					Lt. Gy.	30	P		P	P	P		?					P	Po	X					X-X					
I	KJ	12-19	X-X				X		X	X-X					Lt. Gy.	40	16	?	13	42	1		P				P	Po	X					X-X						
	KJ	60-75	X				X		X	X-X					Lt. Gy.	40	16	?	13	42	1		P				P	Po	X					X-X						
H	KE	40-46	X-X				X		X	X-X					DL. Bn.	43	1		41	6	5		<1			<1	<1	5	Po	X				X-X						
	KM	X-X					X		X	X-X					DL. Gy. Bn.																									
	KQ	33-34	X-X				X		X	X-X					DL. Gy. Li. Gy.	53	4	P	8	70	P		1		<1	<1	<1	<1	Po	X				X-X						
	KP	X-X					X		X	X-X					Med. Gy. Bn.																									
G	KK	34-39	X-X				X		X	X-X					Med. Gy.	29	<1	<1	40	15	4		<1	<1	<1	<1	<1	7	Po	X				X-X						
	KM	X					X		X	X-X					Med. Gy.																									
F	KK	28-33	X-X				X		X	X-X					Med. Gy. Dk. Bn.	83	5		26	5	<1		<1				<1	Po	X					X-X						
	KQ	X					X		X	X-X					Med. Gy.																									
E	KK	26-27	X				X		X	X-X					Med. Bn. Dk. Bn.	23	13		21	38	4		<1	<1	?			<1	Po	X				X-X						
D	KK	22-25	X				X		X	X-X					Lt. Bn.	76	6		4	37	2		<1	<1	<1		?	<1	Po	X				X-X						
	KM	2	X				X		X	X-X					Med. Gy.	55			P	P	P		<1	<1	<1									X-X						
	KQ	X					X		X	X-X					Lt. Gy.																									
C	KK	21	X				X		X	X-X					Med. Gy.	24	3		24	44	1							3	Po	X				X-X						
	KM	X					X		X	X-X					DL. Gy.																									
B	KJ	59	X				X		X	X-X					Lt. Gy.	60	P		P	P	P		P					P	Po	X					X					
	KK	15-20	X-X				X		X	X-X					Med. Gy.	52		<1	P	P	?		<1	<1	<1		<1	<1	Po	X				X-X						
	KM	X					X		X	X-X					DL. Med. Gy.																									
	KP	1	X				X		X	X-X					DL. Gy.	55	7	<1		6	32		<1	<1				<1	Po	X					X					
	KS	1-2	X				X		X	X-X					DL. Gy.	25	<1		<1	<1	<1							P	Po	X					X-X					
	KT	2	X				X		X	X-X					Lt. Gy.	30	P		P	P	P		P					P	Po	X					X					
	KU	5-6	X				X		X	X-X					DL. Gy.	23			P	P	P							P	Po	X					X-X					
	KW	2-3	X				X		X	X-X					DL. Med. Gy.	25	P		P	P	P		P					P	Po	X					X-X					
	KX	3	X				X		X	X-X					Lt. Gy.	50	P		P	P	P							P	Po	X					X					
	KY	1	X				X		X	X-X					Med. Gy. Bn.	65	2		P	P	P							P	Po	X					X					
A	KL	20-21	X				X		X	X-X					DL. Gy.		P		P	P	P		P					P	Po	X-X					X					
	KJ	57-58	X				X																																	