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THE PETROLOGY AND PALAEOLOGY
OF THE METHY FORMATION

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Thesis
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ABSTRACT

The Methy Formation is exposed along the Clearwater River and is recognized in cores of eight wells in the Waterways area. A detailed megascopic examination was made of the core sections, from which important petrographic, textural, and structural data were obtained. Twenty thin sections were also examined under the petrographic microscope, which yielded additional information. In one slide, a mineral believed to be brucite was found. So far as is known, this is the first recognition of this mineral in an evaporite series.

Sedimentation and metasomatism of the formation are discussed. The theory, distribution and criteria for recognition of reef structures are considered. Brecciation in its different forms is treated.

Porosity and permeability tests were tried on two core sections, and porosity alone on two others. Structural relationships of the formation are outlined.

Fossils obtained from the formation were identified as Middle Devonian in age. Correlation with other Middle Devonian formations in western and northern Canada is attempted.

Finally, the possible economic value of the formation is discussed.

FRONTISPIECE

Polished vertical section from Bear Vampire #1, 2088 feet, illustrating mottling in reef flank beds due to argillaceous matter. Note well-rounded ends of broken crinoid column, contrasting with the angular corners of those in Slide 50-90, Plate VII(b). Brachiopod shell fragments may also be seen. Dense, white areas may be algal growths.

About three-quarters actual size.

THE UNIVERSITY OF ALBERTA

THE PETROLOGY AND PALAEOLOGY OF THE METHY FORMATION

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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- FIGURE 1 -

Surface Outcrops of Methy Formation xxx

INTRODUCTION

Nomenclature of the Methy Formation.

The term, "Methy Formation," was first applied by geologists of Pacific Petroleum Ltd. to a formation encountered below the Elk Point Evaporites in the Waterways area, and found in outcrops on the Clearwater River. It is best exposed along the Clearwater River close to the famous Methy Portage. The latter made an important link in the water highway of early northern explorers, for it connects the easterly-flowing Churchill River drainage with that of the northerly-flowing Mackenzie Basin.

Relationship to Associated Formations.

In the Athabaska River-Clearwater River area of northeastern Alberta, the Methy Formation overlies the claystones, shales and red beds which in turn rest unconformably on the ancient Precambrian crystalline granites and gneisses. The dolomite is overlain by the thick Elk Point Evaporites, and may best be considered the earliest deposit in the widespread Elk Point Basin. (Figure 2)

Sediments which formed beds of the Methy Formation were deposited in the shallow waters of the Middle Devonian seas spreading down from the north, and overlapping onto the stable Shield area to the east. The deep Upper Devonian seas deposited the Waterways Formation above the evaporites. After a long interval of erosion, Cretaceous shales and sandstones were laid down, and, finally, Pleistocene glacial deposits complete the rock sequence. (Figure 3)

Thickness and Distribution.

In thickness, the Methy Dolomite varies from about 148 feet at Bear Rodeo #2, to about 227 feet at Bear Westmount #1. It exhibits

Approx. Limits of
Rock Salt Deposition — — — —

the great variation in thickness usually associated with formations of a reef nature.

In distribution, ~~the~~ ^{the Methy} ~~the~~ Formation with its correlatives has great lateral extent. Near Lake Winnipeg it seems to be equivalent to the Winnipegosis Formation; on Great Slave Lake, the Presqu'ile Dolomite probably corresponds to it; and still further north down the Mackenzie River it may correlate with the Ramparts limestone. ~~However,~~ The Methy Formation also is found in wells on the Plains to the southwest,-- at Imperial Clyde #1, Imperial Darling #1, Imperial Irma #1, Imperial Provost #1, and elsewhere.

For this work, the study of the Methy Formation is largely limited to the northeast section of Alberta, where Pacific Petroleum have kindly provided the use of cores from eight wells and information regarding surface exposures. The wells are: Bear Rodeo 1 & 2, Bear Vampire 1 & 2, Bear Westmount 1 & 2, Bear Biltmore 1, and Christina River-Hardy 1.

Previous Work.

The Clearwater River, on which the Methy Dolomites are best exposed, was first surveyed by David Thomson in 1799. Later, most of the early explorers traversed this stream on their way west or north. In 1875, J. Macoun of the Geological Survey of Canada examined the Clearwater River exposures of Devonian age. He merely stated that they "....resemble Niagaran limestones of Owen Sound." Whether this remark included the Methy Dolomites, or only the later Waterways limestone is not clear. (18)

In 1890, R.G. McConnell, also of the Survey, traversed up the

Clearwater River and "Perbina" River (now the Christina) as far as it was navigable. He would not encounter formations below the evaporites there, nor does he mention exposures further up the Clearwater, where the dolomites outcrop. (19)

J.C. Sproule, who traversed the Clearwater River in 1930, states, "the massive dolomites and thinly banded arenaceous and argillaceous limestone at Cascade Rapids, sec. 8, tp. 89, range 2 and eastward, that yield a limited number of poorly preserved gastropods, pelecypods, and brachiopods, are probably Silurian. Below this point, the rocks are thinly banded limestones and shales and imperfectly bedded, rubbly, argillaceous limestones with zones containing an abundant Hamilton brachiopod fauna.Massive Silurian(?) dolomites are responsible for the treacherous series of rapids between Edwin creek and the 4th meridian. At various points, notably at the mouth of Gypsy creek, dolomitic erosion remnants, appearing as irregular vertical "pipes," dot the broad valley, standing above the trees. It is estimated that the largest of these remnants rises 150 feet above the river." (22)

Even at that time, Sproule appears doubtful about placing the dolomites in the Silurian. This was a doubt that had lingered since the days of the drilling of the McMurray No. 1 Salt Well in 1920 (2). No fossils were obtained below the salt at that time, hence the presence of Middle Devonian strata was not recognized.

The discovery of the Leduc Devonian oil pool in 1947 stimulated the interest of oil companies in the Palaeozoic formations of the Great Plains. Detailed geological surveys down the Clearwater River from the Precambrian contact to the Athabaska Forks were made by Imperial Oil Ltd., in 1948, and by Bear Oil Co. Ltd., in 1949.

I (a)--Scarp of dolomite at Contact Rapids. Bedded chert approximately at ten-foot mark. Fossils were taken from talus of this outcrop; they are believed to belong to the upper section shown in photograph. Note that this is bedded throughout.

I (b)--Small klint by foot of Pine Portage. This gives an excellent view of part of reef overlain by some layered dolomite. Fossils were collected from the foot of this pinnacle.

Geologists of the latter company named the first dolomitic formation overlying the basal detrital zone "Methy Dolomite." This formation was recognized almost simultaneously in a number of wells south and west of Fort McMurray.

Acknowledgments.

The writer wishes to thank all members of the faculty and staff of the Department of Geology at the University of Alberta for their unstinting help rendered in the preparation of this thesis.

Particular thanks are due Dr. P.S. Warren, under whose guidance this work was done. His kindness in making palaeontological determinations was invaluable.

Mr. F. Trollope, who did geological field work for Standard Oil Co. of California, contributed information regarding outcrops on the Clearwater and Firebag Rivers.

The Department of Petroleum Engineering of the University of Alberta kindly permitted use of equipment in conducting porosity and permeability tests.

The writer is also indebted to Pacific Petroleums Ltd. and its geological staff for permission to examine their well cores, well logs and reports. Dr. P.E. Coté, who traversed the Clearwater River for that company, particularly gave freely of his time and assistance. Photographs along the Clearwater River are Dr. Coté's.

PETROGRAPHY

As used in this thesis, the term, "Petrography," is that defined by Dr. F.F. Grout: "the systematic and descriptive side of the study of rocks." Petrology is more comprehensive, including not only the

description but theories of rock origin and interpretation of petrographic facts. The term also includes porosity and permeability.

The preponderant rock type found in the Methy Formation is dolomite. Also present are limestone, chert, anhydrite, gypsum, shale, and rock salt.

Megascopic Examination.

Dolomite:

Commonly, the dolomite is cryptocrystalline to crystalline, varies from light buff to dark brown or dark grey in colour, and is either somewhat bedded or else some kind of a fragmental or breccia.

In chemical composition, the dolomites vary principally in the amounts of argillaceous matter contaminating them. It is noteworthy that gradational mixtures such as 'calcitie dolomite,' 'dolomitic limestone,' etc. are extremely rare. They are, however, present in a gradational zone between the lower limestones and overlying dolomite at Bear Rodeo #1 and Bear Westmount #1. At other places, where the rock is fossiliferous, the fossils may retain their calcitic composition while the main rock mass is dolomitized.

Chemical analysis was made of a dark brown ^{limestone} ~~dolomite~~ sample from Christina River-Hardy #1 well. The following results were obtained from Mr. J.A. Kelso of the Alberta Provincial Laboratory:

Silica	.51 %
Iron Oxide	.20 %
Alumina	.25 %
Calcium Oxide	41.45 %
Magnesium Oxide	9.96 %
Loss on ignition	<u>47.55 %</u>

or,

II (a)--This photograph illustrates the flaggy appearance of "flow" type dolomite on weathering.

II (b)--This picture shows "flow" type structure of the layered dolomite. See text for possible explanation of structure.

Silica	.51 %
Iron Oxide	.20 %
Alumina	.25 %
Calcium Carbonate	74.02 %
Magnesium Carbonate	20.81 %
Organic Matter	<u>4.13</u> %

(Note: Analysis on salt-free sample.)

Although this analysis was mainly ^{undertaken} ~~done~~ to determine the organic content, it may be noted that the carbonates present are those of a dolomitic limestone, rather than a pure dolomite. (Pettijohn (20, p. 314) gives Magnesium Oxide 7.07%, Calcium Oxide 45.65%, in a dolomitic limestone analysis he cites.) The high percentage of organic matter may account for the slow reaction with acid.

The layered dolomites are mostly of the finely-granular kind. No primary precipitates of dolomites were recognized, although such may occur. (The criterion used was the cryptocrystalline, almost amorphous, nature of the precipitated carbonate.) Bedded dolomites were most prevalent in the uppersections of the Methy. They appear to have originated as layered fragmentals.

Brecciated and 'fragmental' dolomites are most common.

Limestone:

Limestone in any amount is found only in two wells: Bear Ro-deo #1 and Bear Westmount #1. The intervening well, Bear Westmount #2 has no dolomitic lower section to correspond, thus the distribution of limestone seems to be quite erratic. (See Cross Section A-B.) One possible explanation for this is that given with regard to "dolomitization" (page 21), namely, that the environmental range of

dolomite replacement is a narrow one, and a short lateral distance may witness the two different petrologic types being deposited contemporaneously.

Some significance may also attach to the fact that the limestones are at the base of the Methy. At that time it is logical to suppose that the seas were less saline and less favourable to dolomitization than later on, when they became magnesia-rich.

The limestones present are predominantly brown-coloured, argillaceous, and fossiliferous.

Fossils are generally better preserved than in the dolomite. Their broken remains yield fine to coarse "coquinoid" fragmental zones. Sometimes the fragments are rounded through wave action. Evaporite-solution brecciation, on the other hand, is less common in the limestone zones. This is to be expected, for the conditions that produce evaporite interbeds are also those conducive to dolomitization.

The enhanced porous nature of limestones which have been dolomitized has not been outstanding in the Methy core sections examined. The estimated porosity appears to be much the same in both the dolomitized and non-dolomitized rocks.

Chert:

Chert, which, according to Terr (13), is a dense, cryptocrystalline rock, composed mineralogically of chalcedony and cryptocrystalline quartz, is found principally in two wells: Bear Biltmore #1 and Bear Vampire #2 (Appendix I and Cross Section A-B). In both places, the chert occurs as interbeds or local lenses, not as nodules or cavity fillings.

These chert beds pinch and swell and bifurcate irregularly--

and typically. Petrographically, the chert is a bone white to bluish grey, cryptocrystallin material. In the Biltmore well, the lower chert beds become porous and friable, probably due to recrystallization processes. Fossils are rather well preserved in this type of "chert."

Shale:

Although argillaceous dolomites and limestones are common in the Methy Formation, genuine shale beds are almost lacking. Most commonly, the shale occurs as thin partings or thin beds in the layered zones, or as lenticular or irregular concentrations in the breccias other than those of the evaporite-solution type. These breccias are those associated with slumping on the reef flanks, and thus may possess an angular bedding. Undoubtedly, the mud acted as a lubricant in the slumping process.

The shale present in the Methy dolomites is usually fissile, black to dark brown or dark grey in colour, has a fetid odour on fresh fracture, and often gives an oily smell on heating. A reducing environment of deposition is indicated, therefore, which is further supported by the occasional presence of pyrite crystals. When found in limestone, the shaly partings are usually calcitic, but in a dolomite section they give no reaction with acid and are called "dolomitic." Fossil ^{fragments} ~~parts~~ are well-preserved in the shale, and consist mostly of crinoid stems and brachiopod shells.

Shale is considered a part of the back-reef facies (1). Reducing conditions probably resulted from the abundant decomposing organic remains present on the lagoon-like sea floor. The vertical circulation necessary for oxidation would also be largely confined

to a shallow surface zone, in these sheltered waters.

Anhydrite and Gypsum:

Anhydrite and its hydrated equivalent, gypsum, are typical associates, with dolomite, found in evaporite basins. In the wells studied, the Methy Formation is usually followed in sequence by anhydrite beds. Some anhydrite also precedes deposition of the Methy, but in much less amounts. Another typical occurrence of both anhydrite and gypsum is as irregular 'blebs' in the main dolomite section. Sometimes these may be recognized as simple crystalline vug fillings, at other times they are less obviously of this origin, and may be penecontemporaneous with the deposition of the host rock. Anhydrite also is present as fillings in small vertical diagenetic cracks near the top of the formation.

In at least two wells, Christina River-Hardy and Biltmore #1, the order of precipitation to be expected in the waters of an evaporating enclosed basin was followed: i.e., dolomite, then anhydrite or gypsum, and lastly, rock salt.

In appearance, the anhydrite is commonly grey or bluish-grey, finely-crystalline and massive.

Rock Salt:

This mineral is present only as vug fillings in the Methy Formation, although large thicknesses overlie it in many wells. Its occurrence appears to be restricted to those wells which have rock salt deposits overlying the Methy. Solution and reprecipitation by underground waters will account for the vug fillings.

The size of the halite crystals is, of course, dependent upon

PLATE III

III (a)--This picture shows differential weathering of "flow" type dolomite. Main portion is massive. Note tripod at base.

III (b)--Illustrates local steep dip of draping layered dolomite. Hammer handle is vertical.

the size of the openings. Quite often they are up to 3 inches across, but in other places small, paper-thin crystals have been observed.

Clay:

A light grey to white clay is intimately associated with the chert. It is friable and soft, and under the microscope has a cryptocrystalline mosaic texture. This clay has not been recognized, other than with the chert.

Microscopic Examination.

Twenty thin section mounts were obtained for use in the microscopic examination of certain Methy core sections. It was hoped that the worth of this method in determining the petrogenic history and fossil constituents as well as the mineral content of the rock could be evaluated. What is the nature and genesis of certain "irregular structures?" Was the original rock before dolomitization a "fragmental" (i.e., coquina), or a breccia? What is the cause of the "flow structures" which are so common in the Methy dolomites? What part, if any, did the algae play in building the postulated bioherms? These were some of the questions for which answers were sought.

Textures:

The largest number of thin sections studied were finely-crystalline and granoblastic. (This, of course, applies mainly to the ground mass, for most of the specimens examined were breccias or fragmentals.) The carbonate crystals were generally anhedral and presented a typical mosaic appearance.

A porphyroblastic, or uneven-grained, texture is also quite common. Although no relationship between this type of texture and

the degree of dolomitization could be seen, it is believed that the manner and time of metasomatic replacement will induce a hiatal grain size. Penecontemporaneous dolomitization should produce grano-blastic textures, for the conditions producing the original deposit would still be present when dolomitization processes appeared. If, however, metasomatism followed lithification, no connection between the grain size of the original sediment and that of the replacing medium need exist, and porphyroblastic textures may result. The breccia in Slide 50-73 is representative of this.

It is interesting to note, as well, that post-contemporaneous growth in this fashion seems to be conducive to euhedral crystal forms, at least in the early stages of replacement. It is here suggested that this may offer a criterion for post-contemporaneous dolomitization in its early stages.

Structure:

The twenty thin sections were primarily made with the hope of finding out more about various structures of the formation:

(a) Some hand specimens, such as the core from which Slide 50 -83 was made, appeared to be originally fragmentals. Microscopic study often revealed a contrasting textural and structural variation between the fragments and their matrix, which was not visible to the unaided eye, and enabled them to be definitely classified as 'fragmentals.'

(b) The top of the Nethy Formation at Bear Westmount #1 had structures which ~~that~~ looked like oolites or spherulites ~~structures~~ in the core section. Under the microscope, no radial or concentric features could be seen in these, ^{structures} hence the rock was ^{considered} ~~found~~ to be of a granular type. (Slides

50-79 and 50-80, Plates VI (b) and VII (a))

(c) Dolomitization destroys fossil and ^{sedimentary} ~~other~~ structures. It was found that the outlines of the original forms were more apparent megascopically than microscopically, in most cases. When the fossil remains were very small, however, the microscope proved a valuable aid in identifying the forms. (For example, Slide 50-81, Plate VI (a), where the gastropod shells were noticed in thin section, but not in ^{megascopically} the core.)

Stromatoporoids and crinoids seem to resist dolomitization best, perhaps because they are calcitic. Aragonitic gastropod shells and brachiopod shells, which are largely aragonite, are more easily dolomitized.

Palimpsest fossil or breccia forms are believed to create the "irregular structures" seen in many core sections and mentioned in the well logs (Appendix I).

(d) Stylolite structures were observed in Slide 50-75. A concentration of argillaceous matter with a little fine quartz was seen on one solution surface, which is quite typical. The usefulness of stylolites ^{for sedimentary diagnosis} is limited: (1) they indicate that post-depositional solvent fluids were present, and, (2) they could be used to determine the top of a member.

Mineral Composition:

Dolomite and calcite cannot be readily differentiated optically. Hence, no important data pertaining to dolomitization effects could be obtained microscopically. However, the two minerals can sometimes be told apart by inference, as, for instance, in a highly dolomitized fossiliferous rock, the fossils may safely be considered

to constitute the remaining calcitic ingredient. A different grain size may then be apparent. In this way could the metasomatic replacement of crinoid stems from the inside out be observed (Slide 50-90, Plate VII (b)).

One thin section of a chertified dolomite was made. The chert had a typical cryptocrystalline mosaic appearance. An interesting feature was the presence of numerous euhedral calcite or dolomite rhombs enclosed in the chert. As they could hardly have grown in the indurated chert, it seems they must have done so while the chert was still a colloidal gel, probably on the sea floor.

Anhydrite in small amounts was observed in a few slides. Very often it had a fibrous habit, when viewed microscopically.

Argillaceous material is present in varying amounts in nearly all thin sections.

A mineral believed to be brucite, $Mg(OH)_2$, was found occurring intergranularly in Slide 50-79 (Plate VI (b)). Of fairly low birefringence, the mineral displays excellent micaceous cleavage, and is of positive uniaxial character.

After crushing, the lighter brucite(?) was separated from the dolomite portion by flotation in bromoform. Unfortunately, the micaceous nature of the mineral yielded only minute fragments. However, this feature also aided in bracketing the index of the ordinary ray (perpendicular to the basal cleavage). This index lies between 1.5646 and 1.5695. That for brucite is 1.566.

Seen as pore fillings in the hand specimen, the mineral has a pearly lustre, like brucite.

So far as is known, this is the first recognition of brucite in an evaporite series. Generally, brucite is formed by the thermal metamorphism of magnesian rocks,---a genesis incompatible with the

history of the Methy Formation. Recently, other magnesian minerals of similar association have been recognized in evaporite beds. Magnesite (MgCO_3), and talc ($\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 4\text{SiO}_2$) were observed in an east Yorkshire boring (24). In that well, bedding was not well developed, and was often indicated by strings of dolomite granules. The talc was always associated with halite, as thin ragged plates along the cleavages. F.H. Stewart suggests a mechanical rather than chemical replacement for it. The tabular magnesite was formed, with anhydrite, at the expense of dolomite. Both minerals were considered secondary.

Its occurrence between dolomite granules suggests a secondary nature for the brucite found here. As metamorphic genetic agents are ruled out, some chemical reaction is suggested for its formation. The difficulty in obtaining an adequate amount of the suspected mineral prohibited chemical analysis. It is useless to chemically analyze the entire rock, in view of the presence of magnesium in the dolomite grains. X-ray diffraction methods might prove of value in further confirming the mineral. Unfortunately, the necessary equipment is not available.

The group of minerals which are uniaxial and have a positive sign is very small; no others can be made to apply in this environment. This fact, together with the evidence of the index of refraction, constitutes quite good proof for calling the mineral brucite.

Metasomatism:

As this topic is more fully discussed in the "Petrology" section, no detailed discourse is given here. It should be mentioned,

however, that the microscope is of limited value in distinguishing degrees of dolomitization. Calcite cannot be told from dolomite in thin sections.

Fauna:

Fossils

~~These~~ appear much the same as in the hand specimen. Gastropod spires were recognized in one slide (Plate VI (a)) and a scolecodont(?) in another.

No evidence pointing to the presence of algae in reef formation could be gained by microscopic study of the slides.

Other Features:

(a) In determining the reefal relationships of a core--for example, whether reef wall, fore reef, reef flank, etc.--thin section study has limited value. It is felt that careful study of the actual cores is of greater worth.

(b) The "fly" structure" so common in the Methy Formation did not yield the secret of its genesis to the microscope. The typical angular layering is caused by the accumulation of argillaceous material along planes. But whether separation was effected by life forms, slumping on the reef flanks, is a feature of the bedding, or is due to some other means is unknown. The topic is discussed more fully elsewhere (page 37).

(c) In estimating porosity and permeability quantitatively, thin section study is of little aid, especially when the pores are of large size. For determining the cause of the porosity they are sometimes useful,--for instance, stromatoporoid growths can often be found microscopically.

(d) Evidence for the primary precipitation of dolomite was not obtained, unless the finely-crystalline, granoblastic nature of

some specimens is considered as such.

PETROLOGY

Sedimentation.

Pre-Methy:

The Methy dolomites were deposited upon a detrital group of beds which lie in turn upon the Precambrian basement rocks. This detrital zone is believed to be a true regolith or mantle rock. In ascending order, it consists of (a) a fresh, massive, crystalline granite or gneiss or porphyry; (b) an arkosic sandstone, grading upwards into finer siltstones; (c) red sandy or shaly beds, probably representing an ancient weathered surface; (d) claystones. Some dolomitic and anhydritic interbeds occur throughout and are more common near the base of the Methy (frequently referred to as the "Second Evaporite").

A shallow Middle Devonian sea came down from the north and overlapped onto the ancient peneplained Precambrian Shield to the east. Upon that peneplain, the twin processes of disintegration and decomposition had created a regolith of variable thickness, which filled-in the depressions to create what must have been a monotonous topography of low relief.

Methy Sedimentation:

The Middle Devonian sea was widespread and shallow. Coming down from the north, it spread onto the forelands of the Precambrian craton to the east. The gradual submergence in low areas was not balanced by any pronounced uplift on the positive flanking areas, hence deposits were of the calcareous type. The warm shallow seas bred a prolific fauna capable of organic precipitation of limestones

However, the initial spread of the sea was relatively short-lived. Intense evaporation took place in shoreward arms and embayments: a magnesia-rich sea occupied these areas. Fringing or barrier reefs further fostered evaporation in back reef areas. In short, the warm, shallow, highly-saline waters immediately replaced the early limestones with dolomite. Undoubtedly some primary deposition of dolomite occurred, as well.

Corresponding to the marine environment described above, there exist lithologic and faunal counterparts. Initial encroachment of the sea deposited a thin, rather well-bedded, argillaceous dolomite or limestone. With these transgressive, relatively fresh, marine waters appeared numerous crinoid colonies, bryozoa, and brachiopods. These persisted until well past mid-Methy time, probably until the environment became too saline. Siliceous(?) sponges also lived in early Methy time.

This lowest zone was succeeded by a more massive dolomite, which often has 'flow' structures. Solution brecciation also is widespread. At the base, this zone is sometimes highly chertified. Besides crinoid columnals and brachiopods, a few corals and stromatoporoids make their appearance here.

Reef growth flourished as this stage developed. Coral and stromatoporoid colonies built upwards and outwards from slightly higher parts of the ocean floor. Fragments of these colonies, as well as broken and comminuted brachiopod shells and crinoid stems filled the interstices of the reef wall. Interdigitation of reef rubbles and coral sands can be identified in this section in many wells.

The latest sedimentation in the Methy, as the evaporites began

to dominate, features well-bedded, light buff or grey dolomites with occasional interbeds of anhydrite or gypsum.

As would be expected from the high salinity of the waters of this period, no faunas are to be found in this latest stage.

Post-Methy:

Gradually, the entire trough area, now occupied by the Elk Point Formation (Fig. 2) became an evaporite basin. Perhaps tectonic movements restricted egress to the open sea, perhaps super-abundant reef growth caused the same result--as it did, for instance, in the Capitan of the Texas Permian (1). In any case, the rate of inflow from the open sea exceeded that of outflow, and evaporation eventually exceeded both. At first, beds of salt, anhydrite, and gypsum interbedded with the dolomites, but, as time went on, they predominated. Finally, the entire evaporite basin dried up, and erosion went on until the Upper Devonian seas came down from the north in Waterways time.

Metasomatism.

Dolomitization:

Dolomitization is the conversion of diverse rock types, usually other carbonates, to dolomite. Theories as to the origin of dolomite may be grouped into three categories: (1) primary (chemical) precipitation of the dolomite; (2) selective leaching of calcite from an original mixture of calcite (or aragonite) and dolomite, and (3) replacement of an original calcitic limestone. (20, page 316)

Evidence supporting the first two concepts is meagre, whereas

that for replacement is overwhelming. Data from the Funafuti boring somewhat support the leaching hypothesis. This theory finds less favour today, however, than it did in the past. There is as yet no proof of the direct precipitation of dolomite from the sea (23). Some fine-grained dolomites suggest this possibility, however, and it may be much more common than is generally supposed.

The process of replacement of ^{other} carbonates by dolomite may be divided into two principal methods, namely, (a) that contemporaneous or penecontemporaneous with the deposition of the original sediment, and (b) post-depositional thereto. There is, of course, overlapping between the two methods.

(a) Contemporaneous or penecontemporaneous replacement (Halmyrolysis).

These are chemical replacements and changes occurring while the original sediment is being slowly precipitated on the sea floor (20, page 477). It is generally agreed that dolomite forms best when the following environmental conditions are met (23 and 27):

(1) Marine rather than non-marine surroundings. Experimentally, dolomite has been formed at ordinary temperatures by solutions comparable to sea water, but not by carbonate solutions similar to underground waters. Furthermore, many Tertiary coral reefs are dolomitized, where the only agent could be sea water (23).

(2) Shallow, rather than deep, waters.

(3) Increase in salinity, especially of magnesia salts, stimulates dolomitization. This condition finds its maximum expression in enclosed basins or arms of the sea.

(4) Warm temperatures. A condition which is notable, as well,

for an optimum faunal development.

(5) Reducing conditions probably generally exist where dolomitization is active.

The question may here be asked: How are two such incompatible environmental conditions as shallow, inshore waters and reducing conditions to exist conjunctively? It is the writer's belief that the answer lies in the favourable conditions existing for the production of life, in these shallow, warm seas. A high life incidence means a high death incidence, hence upon the sea floor, where actual conditions of sediment deposition are the most important, dead and decomposing organisms are extremely abundant. Reducing conditions will therefore prevail at shallower depths, where such decay occurs, than in places where it is not present.

In the change to dolomite, there is the possibility that the rotting and sulphurous organic compounds may act as catalysts, as well. As far as is known, no experimental data are available on this point.

(b) Post-depositional replacement.

Dolomites formed by replacements through underground circulation of water form a minority. They may be recognized by their relation to fissures, faults and other secondary openings. They may, therefore, be expected to be more local in nature than those in the first group.

In the replacement process of limestone by dolomite, a porous reservoir may be created when the rate of solution exceeds that of precipitation. This type of vugginess is of local character, as might be expected from a correct interpretation of its cause (15).

Local dolomitization of this kind depends for its kind and degree on temperature and pressure conditions, the character and concentration of percolating solutions, and the character of the rock being replaced. (10)

Now, turning to the dolomite formation at present under study, it can be seen how closely it meets the conditions required for the neoecontemporaneous replacement formation of dolomite. In the Methy, dolomitization is widespread, rather than local; a marine evaporite basin follows the dolomite sequence, indicating a high salinity; it contains an abundant fauna, including the warm, shallow-water coral types. Even some indications of reducing conditions are offered by (a) occasional pyrite crystals, and (b) by the fact that at least in one well the high organic matter content is present as carbon, not hydrocarbons (see page 44). In addition, the very presence of widespread reef zones indicates a warm, shallow-water environment.

Steidtmann pointed out that the critical state between the formation of a limestone or dolomite is a narrow one (23). This means that failure of one or more environmental factors in the replacement process whereby dolomite is formed will result in limestone deposition, not in some intermediate carbonate mixture. If, for example, the sea waters have a low saturation of magnesia, or are too deep, dolomite formation will not be favoured. Yet at the same time, and at no great distance therefrom--in a shallow embayment, for instance, where evaporation is more intense--dolomite replacement or deposition may be actively taking place. This explanation will account for the presence of limestone instead of

dolomite in the lower sections of Bear Rodeo #1 and Bear Westmount #1 wells, while adjacent wells (Rodeo #2, Westmount #2) contain only a dolomite facies. (Comparison may also be noted with the dolomitized D3 reef at Ieduc, while at Bedwater, about 45 miles distant, the reef is non-dolomitized.)

Effect of Dolomitization on Textures and Structures:

Whatever the full story of dolomitization, its effect on the original fossils and other structures is profound. The results of dolomitization are too well-known to need detailed repetition here. What were cognate fossil forms in the original limestone remain merely as palimpsests, or else they are obliterated entirely. Bedding, which, at least in the dolomite at present under study, is related to horizontal argillaceous banding, fares somewhat better. The same is true for argillaceous breccia types. However, when the original limestone was quite pure, or when no great compositional difference existed between the breccia fragments and their matrix--as, for instance, in many solution breccias--the elastic texture of the original rock may be quite lost. This is undoubtedly one source of the "irregular structures" described in many well cores. (See Appendix I, and Cross Sections A-B and C-D.)

Hatch and Restall state: "Dolomite has a strong tendency to form idiomorphic crystals, even when growing within a solid limestone, and for this reason dolomitisation largely obliterates any structures depending upon the original grouping of calcite or aragonitic crystals. ...Small fossils and oolitic (radial or concentric) structures are obliterated during metasomatism." (9)

Complete recrystallization produces a fine- to coarsely-crystalline rock composed of dolomite euhedra. Incomplete conversion to dolomite, however, produces a porphyroblastic texture. The metacrysts, in this case, are rhombic euhedra of dolomite embedded in a matrix of calcite. (20)

Interpretation of petrologic and lithologic types in these highly-dolomitized rocks requires an experienced eye able to "see through" the dolomitization back to the original sediment that was deposited, or that would have been deposited, had not dolomitization processes taken over.

Chertification.

Modern theories as to chert origin may be classified as follows: (20)

I. Syngenetic Origin.

1. Clastic quartz.

m 2. Chemical silica.

- (a) Biochemical precipitate.
- (b) Chemical precipitate.
- (c) Magmatic precipitate.

II. Penecontemporaneous silica.

III. Epigenetic silica.

- 1. Precipitation in the zone of cementation.
- 2. Precipitation in the zone of weathering.

Evidence supporting both the syngenetic and epigenetic theories is considerable. For the purpose in hand, it is perhaps sufficient to note the following points:

1. Gruner (8) postulates a tropical or sub-tropical, humid climate, and a low form of plant life to aid in dissolving the iron and silica. The colloidal silica was later precipitated by electro-

lytes of the sea waters. Such an environment is also theorized for Methy time. We know, for instance, that an abundant fauna existed. Why not also an abundant low form of flora, such as algae, which may also have helped to build the reef structures?

2. Trefethen (28) found that diagenetic cracks in chert were filled with limestone which was continuous with the limestone in the rest of the formation. Silica gets buried in limy sediments and undergoes dehydration and hardening at the same time as the lithification of the limy ooze. In places the limy ooze hardens first and squeezes the gel into it; in other places the gel hardens first.

3. Tarr (27), besides agreeing with the chemical weathering and colloidal transportation ideas, also postulates low-lying, especially peneplained, source areas, where chemical erosion can predominate over mechanical erosion. Precipitation was effected by the action of alkalic salts in the sea water. The tendency of colloids is to aggregate in globular shape; burial makes the body assume a lens shape. Fossils falling into these gel masses, Tarr further states, would be perfectly preserved.

The low-lying peneplained Shield area upon which the shallow Methy sea lapped, the highly alkaline waters, the lenticular nature of the chert bedding, even the preservation of fossils, are features of the chert present in the formation under study.

Cherts are said to increase basinward (1). Certainly Bear Biltmore #1 is located in what is considered to be a basin-facies theatre. (See Contour Map, Fig. 7.)

An interesting feature of the chert beds is the excellent

porosity of the crystallized 'chert.' Such a rock type could undoubtedly act as a reservoir or carrier bed for petroliferous fluids.

Biohermal Development.

Theoretical Considerations:

A bioherm, or organic reef, has been defined and described very well by Wilson (29): "A reef is a sedimentary rock aggregate, large or small, composed of the remains of colonial-type organisms that lived near or below the surface of water bodies, mainly marine, and developed relatively large vertical dimensions as compared with the proportions of adjacent sedimentary rocks. The organisms, generally corals and algae and less commonly crinoids and bryozoans, creating the essential features of a reef, lived their mature lives on it and their hard parts remain in place there after death. Reefs tend to develop as mounds or ridges but also grow in irregular, asymmetrical forms. In all, however, a rigid framework develops that does not compact under weight of overburden. This framework enables a reef margin to grow upward and outward at much steeper angles (even vertical) than is the case with sedimentary clastic rocks. Reefs are commonly characterized by lack of well developed stratification. Differential settling in rocks adjacent to them usually causes draping of strata over reefs."

The many theories as to the origin of bioherms have been classified as follows: (11)

1. Those which require a change of sea level relative to the reef foundation:

(a) Darwin (5) proposed a subsiding foundation and consequent rising sea level. Under these conditions, organic growth

would transform a fringing reef into a barrier and finally into an atoll.

(b) Daly's Glacial Control Theory (4) explains how organic reefs could have originated on the banks left close to sea level at a time when the sea level was low because of the removal of water to form glacial ice on the land. Later, as the glaciers melted, the reefs grew upward with the rising sea level.

2. Those that hold that reefs may develop without a change in sea level relative to the reef foundation:

(a) Hoffmeister and Ladd (11) presented the Antecedent Platform Theory, which holds that, "any bench or bank located within the circumequatorial coral reef zone can be considered a potential coral reef foundation, and that, if ecological conditions permit, a reef could grow up to the surface without any change in the sea level."

Typically, a bioherm consists of a massive, unbedded, central core of uneven-textured, fossiliferous carbonate rock surrounded by a relatively narrow reef flank zone made up of well-bedded, granular or brecciated, and sparsely fossiliferous strata which lap against and grade into the core and show steep dips away from it. Distal flanking beds grade into the horizontal and relatively unfossiliferous rock of the interbiohermal region. (20, page 297)

Fundamentally, reefs are expressions of intense biologic activity. They require a structure-building potential, and must have (a) frame-building, (b) sediment-binding, and (c) detritus-

catching elements. (17) However, most authorities agree with Fairbridge that, "in both living and ancient reefs, the proportion of actual colonial corals grown in situ is extremely small in relation to the enormous quantities of "coralline" sedimentary debris." (6) Reef-builders form a subordinate part of the whole. The reef structure may make up only 5% to 10% of the reef mass.

A sharp differentiation in faunal types must occur between assemblages on and off the structures. Greater density and varieties of species and larger forms occur on the reefs. The reef flanks are built up from bioclastic debris derived from the central core.

The tops of Niagaran bioherms of the Great Lakes area are covered by layered bioclastics. (17)

A barrier reef such as the Capitan of the southwestern United States, breaks the area in which it grows into two parts: one in front and the other behind the reef. A trifold division in facies is thus possible: the reef wall proper, separating fore-reef and back-reef provinces, away from and toward the basin area respectively.

The back-reef facies is highly fossiliferous, has shale and silt beds, anhydrite crystals and some pisolitic and pyrite crystals.

The fore-reef facies features steeply-dipping bedding, boulder breccia from the reef, with lime-mud and lime-sand lenses. It grades into the finer bedding of bottom-set beds. Basinal limestones and dolomites, with some chert, are grey or brown near the margins, but become dark and dense basinward. (1)

Link (16) applied the principles of transgression and regression of epi-continental seas to bioherm development. Reefs growing during transgression are told from those growing during retreat of

PLATE IV

IV (a)--Small reef growth, showing bedded 'floor' sediments, structureless core, and arching in overlying beds. This may be principally an algal growth. These structures form the many cascades in Long and Cascade Rapids (below Pine Rapids).

IV (b)--Island made up of "flow" type dolomite at Long Rapids, looking north. It shows the largest flexure observed in this vicinity. Its crest is at left edge of photograph. Dip is 20 degrees east.

a sea by the associated sediments, for the latter are found with evaporites. Criticism of this view is made on the grounds that an individual reef in its lifetime may have undergone development during transgression as well as regression. It may have been fringing, barrier, and atoll, at different stages. Seldom is a clear-cut differentiation possible, for any individual reef.

Present Application:

Structures which have been interpreted as reefs have been observed in field outcrops of the Methy Formation along the Clearwater River. Besides this, in seven of the eight wells examined, rock sections believed by the writer to be intimately associated with bioherms were obtained.

On the Clearwater River, where the Methy dolomites outcrop, signs of biohermal development have been remarked at Whitemud and Pine Rapids. (Plates I (b), IV (a), and V) The structureless central cores, with rather steeply-dipping flanking beds draping away from them, together with the presence of such reef-building colonial elements as corals and stromatoporoids are evidence for the acceptance of these as true organic reefs.

The evidence for the presence of bioherms in the well cores is of a somewhat different and necessarily less complete nature. The closest two wells are about 8 miles apart: in the intervening distance a bioherm the size of the Marine Reef of Illinois--a classic structure, outlined completely by subsurface methods--could be lost. Thus each well core had to be judged almost on its own, in its possible relations to reef facies.

A reef grows outwards, as well as upwards from its base. A drill bit may penetrate its vertical "axis," pass through a top bioclastic layered zone into the structureless, fossiliferous, and vuggy heart of the reef, and, finally, enter the platform upon which growth originated. On the other hand, drilling just to one side, a part of the expanded reef top may be struck, be passed through into the draping flank beds and down to the pre-reef floor sediments. Other variations are numerous. For this reason, it was early felt by the writer that a set of reef criteria were needed. The following are diffidently suggested as a tentative basis:

1. As reefs, above all, grow upwards from the bottom, any thickening of the suspected formation or strata may indicate reefal development. If this thickening is somewhat erratic in distribution, and appears not to be merely associated with depositional "wedging" of the members, added evidence is provided.

In the Bear Wells, thicknesses of the Methy Formation vary from 113 feet at Rodeo #1 to 227 feet at Westmount #1 (see Figures 4, 5, and 6). The former location is in a pre-Methy depression, where thicker sedimentation would normally be expected.

2. Klints, or reef cores, are notably lacking in stratification.

In the wells examined, unlayered or 'structureless' sections were found in many places. A good example of this was in Westmount #2 (Figure 4). While undoubtedly some of this is due to massive types of sediments, in many places it is combined with other features in such a way as to suggest reef cores.

3. Strata with high-angle dips which cannot be accounted for by regional structure point to the presence of a local reef formation of some sort. Differential compaction of surrounding beds, added to the talus-like slope of the original reef breccia accounts for the steep dips.

Such reef flank strata are common in the Methy well cores. Dips of over 40 degrees have been seen. This, in combination with reef-wall breccias and fossil fragments suggests flanking beds (see Frontispiece and Plate III (b)). It is possible, as well, that the common flow structures are related to reef-flank slumping.

4. An abundant and varied fauna is an essential criterion for biohermal growth. Colonial reef-building forms--corals, stromatoporoids and algae--are particularly necessary, but other faunal types, which contribute fossil debris to the structures, are also important.

Methy time was extremely favourable to vital growth. Corals, stromatoporoids, grinoids, and brachiopods were very numerous. Bryozoans and sponges were less so; algal growths are not recognizable, but may have been extremely important as reef-builders.

In situ corals of the reef wall can be differentiated from fragmental ones by their generally upright position, according to Dr. Stelck.^V They have been noticed in this position in cores from Westmount #2, at 620 feet, and (less definitely) elsewhere.

Grinoid columnals are important contributors to the bioclastic

^V Stelck, C.R., personal communication.

debris around reefs. In normal sediments they are not generally rounded as they are in the turbulent reef zones. (Contrast Slide 50-90, Plate VII (b), with the Frontispiece.)

In brief, the mere presence of colonial types of corals and stromatoporoids is enough to make one suspect that there has been reef-building. The question then is simply the degree of vertical growth achieved by them.

6. While vuginess in itself is no criterion for a reef, recognition of the vugs as molds of reef-building fossils may be. Stromatoporoids, even when dolomitized, usually retain an excellent fine vuginess. Algae, on the other hand, are recognized by their extreme density.

In the Methy, vuginess and porosity correspond with other criteria in the postulated reef facies (see Appendix I and Cross Section A-B, Fig. 4). Coarse vuginess is a reef-wall attribute; medium to fine vugs dominate in reef flank zones. Thus on-reef and off-reef zones may be theorized to some degree by the degree and kind of porosity.

7. "Fragments" found in rock sections sometimes provide another criterion for reef development. As no evidence for uplift or other diastrophic movements which might account for the production of breccias and fragmentals in Methy time was found, these must have resulted either (a) by erosion of elevated parts, such as reefs, occurring in the deposition area, or, (b) by solution-brec-ciation methods (see page 34).

The fact that much of the broken material is fragmental-- that is, made up of pieces of fossils, rather than pieces of rock,

as in true breccias--points to an origin in a fossil-rich source, such as a bioherm.

8. A zone of layered bioclastics overlying the reef proper may be a distinct reef element. Such a cover was found everywhere on the Marine Pool reef cited before. Lowenstam considered it to be the fossil analogue of a modern detrital reef surface (17).

As can be seen from the cross sections (Figs. 4 and 5), a layered bioclastic blanket overlies the postulated reef at West-mount #2 and elsewhere. Reef builders are present but are no longer building upwards. They occur instead as layered clastics.

The environment is not unlike that present during active reef development, but increasing evaporation conditions caused these differences:

(a) Recession of the sea basinward uncovered the reef tops and subjected them to the sorting action of surface waters.

(b) Increasing salinity was more than the crinoids and brachiopods could bear; only the hardy stromatoporoids and corals remained to provide material for the blanketing detritus.

9. Proximity to a shoreline may give cause to suspect barrier or fringing reefs. Likewise, recognition of a suitable elevation or antecedent platform on which a reef could be built may be an added criterion for such a structure.

In the Waterways area, it is logical to suppose that the Middle Devonian sea lapped upon the Precambrian positive mass just to the east. As pointed out previously, that sea was probably shallow and warm, comparing with that in the present-day regions of the Austra-

PLATE V

V--Mesas of Methy dolomite on valley floor at Pine Rapids. All show reef rock in their lower portions, hence may also be termed klints. View looking north.

lian Barrier Reef.

10. Both regressive and transgressive reefs will concentrate on steeper slopes of the sea floor (16), hence thickening of the suspected reef member at such places provides a criterion for reefs.

Such increased thickening occurs at Westmount #1 and Westmount #2 where the pre-Methy bottom sloped rather sharply upwards towards the southeast (see Figures 6 and 7).

11. Concentration of light fluids such as petroleum and/or gas may sometimes be attributed to their accumulation in an arch or dome over a reef.

Notable concentrations of those products have not as yet been found in the Methy.

12. Reef-wall rock sometimes possesses fluorescent properties (1). Such a specimen from the Methy Formation was no exception (see below).

13. Finally, combinations of the above criteria will accentuate belief that a reef exists.

Brecciation and Fragmentation.

When the fragments in a breccia are ^{identified as} ~~seen to consist of~~ pieces of broken fossils or agglomerations of fossils the rock is termed a "fragmental." Hence, in the Methy Formation, with its abundant fossils, the "breccias" are more truly fragmentals.

In various forms, fragmental rocks are most common in the Methy, as can be seen by reference to the cross sections (Figs. 4

and 5). Less common are the evaporite-solution breccias. In a formation where reef development is abundant, fragmentation will abound. As we have seen, the reef core itself averages only about 10% of in situ coralline material, while the rest is detrital; reef-flank beds are built up from detritus; layered bioclastics blanket the reef. It is not surprising, therefore, to find that the Methy Formation has relatively few bedded deposits, while breccias and fragmentals abound. (See Cross Sections, and Appendix I.)

An important genetic type is a solution breccia. These are created when the intervening soluble evaporites--salt, anhydrite, gypsum, etc.--are dissolved away, letting the carbonate beds crush under the weight of overlying sediments. An extremely angular collapse breccia results, in which the matrix is of essentially the same material as the rock fragments.

Sloss and Laird (21) have used the term "evaporite-solution breccias" for these, and apply it to breccias which "can be demonstrated to have resulted from the removal of evaporites. It seems probable that such breccias are to be found in most areas where evaporite-bearing strata crop out."

These writers state further that, assuming ground-water circulation was necessary for solution of the anhydrite, widespread regional uplift occurred in the Montana area studied by them. To postulate similar uplift in the region around Waterways is untenable, hence one may conclude that the "ground-water circulation" is not always a necessary condition for the production of evaporite-solution breccias.

PLATE VI

VI (a)--Slide 50-81. Gastropod shells in a fine fragmental calcitic matrix.

Plain light, 20X.

VI (b)--Slide 50-79. Brucite(?), occurring in pores between grains of dolomite. The mineral's eminent basal cleavage is well illustrated, in this slide. Black areas are open space.

Crossed nicols, 60X.

These solution or collapse breccias can, with careful examination, be separated from other fragmentals:

(a) The bedded granular type, more common at the top of the Methy, has been mentioned above. A sorting of clastic materials in layers is pronounced.

(b) Less sorting affected detritus around the immediate reef flank. In this other important breccia type, large-sized fragments of coral and stromatoporoids in rubble interdigitate with a finer, often friable, earthy, coral sand. The breccia fragments in this case are usually less angular than in the solution breccia. They may even be somewhat rounded by wave action. Bear Rodeo #2, 840-860 feet, offers a typical example of this interdigitation.

The importance of differentiating between 'solution breccias' and 'reef-edge breccias' in seeking petroleum pools will be apparent, for from the latter the presence of a reef structure in the vicinity may be predicted.

Porosity and Permeability.

Except for four core samples for which exact percent porosities were obtained, the kind and quantity of porosity present in the Methy was only estimated (Appendix I).

Rock pores are mostly of the intergranular type. Little credit is given to dolomitization processes in the creation of the openings. Rather, the macroporosity represents a residuum from the original openings after cementation and other diagenetic processes.

For the most part, these original openings were present as spaces between and in the fossil fragments which made up the rock.

Fossil molds have been seen to form coarse vugs, as well. Stromatoporoids, in particular, resist dolomitization and retain a very good fine porosity. Solution brecciation occasionally was important in forming openings, especially in Vampire #1, where the vugs are filled with rock salt. Finally, the bedded fragmentals in the upper sections of the formation usually yield a good fine to pinpoint porosity.

Intermediate porosity, or that which has no direct relationship to the grain properties of the rock, is a result of solution by ground water. Its effects are seen to work both favourably and adversely to the overall porosity of the rock:

(a) Small vugs in dolomite are very frequently lined with calcite crystals. These were undoubtedly precipitated from ground waters. Their effect is to decrease porosity.

(b) Fossil molds indicate that solvent fluids have carried away the original skeletal matter of the fossils. Brachiopod shells, which are largely composed of aragonite, are especially vulnerable. The effect, in this case, is to increase porosity.

Porosity is related to reef facies. Estimates indicate that the reef cores have the coarsest vugs and best porosity, flanking beds less, and normal sediments least of all. In order to partially check this thesis, and also the relative merits of limestone versus dolomite, four cores were subjected to quantitative tests, using a Ruska Porosimeter and Permeameter. The results follow:

Westmount #1:

(1) Core 60, 1489 feet (Reef-wall dolomite).

Porosity: 21.5%

Permeability: 15 to 64 millidarcys (varying in different 'plugs').

PLATE VII

VII (a)--Slide 50-80. Fine limestone grains in a dolomitic matrix, from upper bedded zone. Some anhydrite also is present.

Crossed nicols, 60X.

VII (b)--Slide 50-90. Crinoid columns of calcite in a dolomitic matrix, from a bedded interbiohermal dolomite. Contrast angularity of these crinoid parts with rounding of those shown in the Frontispiece, which is from the reef flank. Dolomitization of crinoid sections proceeding from inside out may be seen in fragment at lower right.

Crossed nicols, 60X.

(2) Core 64, 1529 feet (probably reef-flank dolomite).

Porosity: 12.3%

Permeability: 11 to 16 millidarcys.

(3) Core 67, 1555 feet (bedded limestone).

Porosity: 1.2%

Westmount #2:

(1) Core 78, 765 feet (bedded dolomite).

Porosity: 3.2%

(As the last two samples were extremely dense, permeability results were negligible.)

The porosity of the reef-wall sample is exceptionally high. (Analogous cores from the Redwater oil field average about 13% porosity.) The reef-flank sample also has excellent porosity. Of the bedded carbonate rocks, both are 'tight,' but the dolomite is slightly more porous than the limestone.

"Flow" Structures.

As seen in well cores, "flow" structures exhibit an argillaceous layering of varying dip and uneven thickness. The most natural interpretation from a study of these is that they are a product of reef flank movements, with considerable lubrication provided by the muds present.

In the field occurrences, however, the relationship of flow structures to a reef facies is less evident, according to Dr. Côté.^{II} He offered three other possible explanations:

^{II} Côté, P.E., personal communication.

(1) They may be a product of dolomitization processes.

(2) They may be due to algal growths.

(3) They may be caused by the deposition of closely-interlayered limes and marls, with subsequent partial leaching of the marls prior to dolomitization.

In the present writer's opinion, one other likely explanation exists, namely, that the structures may simply be features created during the deposition of the sediment--a kind of bedding. They may have been modified by the various sizes of fragments present, slope of the sea floor (e.g., whether on or off a reef flank), quantity of argillaceous matter present, etc.

Fluorescence.

Three cores from Westmount #1 were subjected to ultra-violet rays: (a) one believed to be from a reef core, (b) one from angularly-bedded flanking beds, (c) one from well-bedded dolomites.

Only the reef-core rock exhibited a faint fluorescence and phosphorescence. This is in keeping with other known reef facies, notably the Capitan Reef of Texas, where it was noted that fluorescence increased reefward (1, page 307).

STRUCTURE

The Waterways area, in which the Methy Formation is found, lies on the east limb of the Alberta Syncline. The formation of that structure is usually associated with mountain-building movements which created the Rocky Mountains in Tertiary time. In the

- FIGURE 6 -

Middle Devonian, therefore, the Alberta Syncline was non-existent, and, for the most part, constituted a foreland area. A shallowly-dipping Precambrian basement inclined to the west. With the creation of the Alberta Syncline, this dip was considerably increased.

In order to get a truer picture of the topography of the pre-Methy sea floor, the area was, figuratively speaking, rotated about an axis paralleling the strike of the basement rocks until only a shallow easterly dip remained. Contours were then drawn on the base of the Methy (Figure 7). (The regional strike and dip were obtained by solution of a three-point problem, using the three most widely-separated wells.)

Important features derived from the resulting contour map, and possible interpretations of them, are:

(a) No prominent elevations or depressions appear, hence the area was probably one of low relief--a typical peneplain.

(b) Low areas lie to the southwest and northeast of an arch or 'nose' just west of the axis of rotation. It is believed that this arching is, to some extent, a false one. The Precambrian basement rocks found in well cores close to the strike axis give definite indications of faulting, together with some mineralization. It is suggested, therefore, that a "hinge zone" occurs just east of the strike axis, probably one of many associated with diastrophic movements forming the Alberta Syncline.

(c) A slope to higher elevations with an east-west trend is to be seen paralleling the Clearwater and Athabaska Rivers. As noted before, reef development was good on this slope.

A possible explanation for this is that a culmination in the

- FIGURE 7 -

Precambrian basement occurs, with an axis extending somewhere south of the two rivers, in that area, and at right angles to the regional strike of those early formations.

An isopach map was drawn of the Methy Formation as well (Figure 6). Wells with the best evidence for reef development have the thickest formation. Bear Rodeo #1, in which reef indications were poor, has the thinnest Methy.

PALAEONTOLOGY

The following collections of fossils were made in the field by Dr. Coté of Pacific Petroleum Ltd., and identified by Dr. P.S. Warren of the University of Alberta:

(1) At Contact Rapids, on the Clearwater River:

(Columnaria?) disjuncta Whiteaves.
Favosites cf. alrenensis Winchell.
F. limitaris Rominger.
Aulopora (?) sp.
Coenites (Cladopora) (?) sp.
Atrypa reticularis var. A Whiteaves.
Atrypa 3 species.
Stropheodonta cf. deniss^a Hall.
Strineocephalus burtini deFrance.
Gammatoechia sp.

(2) At Whitemud Falls and Pine Portage, on the Clearwater River:

Sphaerospongia tessellata Phillips.
Favosites cf. goldfussi Castelnau.
Alveolites cf. cryptodens Billings.
Gypidula cf. comis Owen.
Gypidula cf. occidentalis Hall.
Atrypa reticularis var. A Whiteaves.
Strineocephalus burtini deF.

Of this fauna, Dr. Warren states: "They are Middle Devonian and may be correlated with the Presqu'île Dolomite."

From the well cores, the following were obtained:

Westmount #1:

<u>Synartophyllum</u> sp.,	about 1475 feet.
<u>Actinostroma</u> sp.,	de Blainville. " 1485 " .
<u>Favosites</u> cf. <u>cervicornis</u> ,	" 1516 " .
<u>Atrypa</u> cf. <u>arctica</u> Warren,	" 1548 " .
" " " " ,	" 1558 " .
" " " " ,	" 1568 " .
Gastropod,	" 1558 " .
<u>Cyridula</u> cf. <u>coris</u> ,	Owen " 1568 " .
<u>Martinisella</u> cf. <u>sublineata</u> ,	Mæek. " 1579 " .
<u>Atrypa</u> sp.,	" 1578 " .
<u>Cyridula</u> (?) sp.	" 1578 " .

Westmount #2:

<u>Actinostroma</u> sp.,	about 618 " .
" " ,	" 645 " .
<u>Atrypa</u> cf. <u>arctica</u> Warren,	" 676 " .
<u>Atrypa</u> sp. (coarse-ribbed),	" 676 " .
Sponge spicules,	" 676 " .
<u>Fenestella</u> sp.,	" 691 " .

Podeo #1:

<u>Cyridula</u> (?) sp.,	about 888 and 935 feet.
<u>Atrypa</u> sp.,	" 889 " 935 " .
" " (coarse-ribbed),	" 901 feet.
<u>Actinostroma</u> sp.,	" 912 " .
<u>Atrypa arctica</u> Warren.	" 949 " .

Biltmore #1:

<u>Prismatophyllum</u> sp.,	about 2587 feet.
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Vampire #2:

Sponge spicules,	about 773 feet.
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Dr. Warren says: "The cores from which Cyridula and Atrypa arctica were identified are probably from the base of the Winnipeg-sen dolomite. The other specimens cannot be tied in, but are undoubtedly Middle Devonian."

In addition to these, F. Trollope collected fossils typical of the Methy Formation at the confluence of the Rochers and Slave Rivers, near Lake Athabaska. Among these were:

Atrypa arctica Warren.
Gvuidula cf. comis Owen.
Martinionsis sp.

Crinoid columnals, brachiopod shells, stromatoporoids and corals are abundant in most of the well cores. Often they are dolomitized and poorly preserved, hence are seldom identifiable.

Correlation.

The Methy Formation correlates with the Winnipegosis Formation of Manitoba, the Presqu'île of Great Slave Lake, and the Ramparts in the Norman Wells area. The best evidence for correlation is in the faunal assemblages. However, petrological resemblances are often striking as well, as can be seen from the following brief summaries:

(e) The Winnipegosis of Manitoba (3, 14):

Fauna: Strimoccephalus burtini^{de France}, Sphaerospongia tessellata^{Phillips}, and others.

Lithology: The formation is 250 feet thick. Baillie notes two rock types: a massive bioherm facies, and a bedded, saccharoidal "normal facies." The normal facies is a grey, unevenly-bedded, sugary dolomite, with poor porosity. It is poorly fossiliferous, and contains large crinoid columnals, poorly-preserved brachiopods and scattered corals. Beds are a few inches to 3 feet thick. The bioherm facies makes cliffs 15 to 40 feet high of thick-bedded to

massive dolomite. (Comparing with exposures represented in Plates I, IV (a), and V.) It is highly fossiliferous, with abundant corals and stromatoporoids. Baillie thought the aligned vugs might be due to lime-secreting algae. Part of the rock is a tightly-cemented concretion.

(b) The Presqu'ile of the Great Slave Lake Area, N.W.T. (12):

Fauna: Stringocephalus burtini^{de F.}, Gynidula cf. comis^{Owen}, Actinostroma cf. nodulatum Nicholson, Gladopora sp., and others.

Lithology: A brown, light grey or mottled dolomitic limestone, with some bituminous and recrystallized dolomite and shaly limestone. The total thickness is 375 feet.

(c) The Ramnarts Formation of the Norman Wells Area, N.W.T.

(12, 13):

Fauna: Stringocephalus burtini^{de F.}, Gladopora sp., Prismato-

Lithology: Compact, grey, bedded to knobby limestones, with thin-bedded, buff sandstones at the top.

(d) Alberta Plains Area:

Argillaceous dolomites and limestones believed to be equivalent to the Methy Formation have been struck in certain deep borings on the Alberta plains. Crinoid columnals were the only macrofossils found. Thicknesses are similar to those of the Methy Formation in the Waterways area. (See Appendix I, pp. 14-15.)

ECONOMIC POSSIBILITIES

There is little doubt but that the Methy reef dolomites may contain oil. The correlative Presqu'ile Formation on Great Slave Lake has long been known to contain petroleum-filled vugs. Indeed, it would be strange if such a porous reef rock did not contain some hydrocarbons or other fluids, either created in situ from the abundant organisms present, or brought in by migration from nearby source beds.

Some core sections were exceptionally dark brown in colour. In order to determine the nature of the colouring agent, a quantitative chemical analysis of a sample was obtained from the Alberta Provincial Laboratory (see analysis, pages 5 and 6).

An exceptionally high carbon content is noted (4.13%). In order to find out whether this carbon was present in the form of hydrocarbons or as the element, 31 grams of the powdered rock were treated with boiling carbon tetrachloride. Only 0.015 grams were removed in solution--a negligible amount. It is concluded, therefore, that the chocolate colour is due to finely-disseminated elementary carbon.

As we have seen, reef development was extremely widespread in Methy time, providing domes and ridges favourable for oil accumulation. What is lacking, however, is a good capping rock. While evaporite beds such as anhydrite and rock salt will effectively seal-in fluids, their method of formation is sufficiently slow to permit the greater part of any fluids to escape. A blanket of shale, on the other hand, not only provides an effective seal, but smothers

the bioherm and its abundant life quickly.

In the area studied, a shale bed overlying the Methy was not discovered. But it is entirely possible that such a member may be locally present elsewhere. Nor is it impossible to suppose that petroliferous fluids concentrated in the porous reefs after migration from down-dip areas. For these, the evaporites would still provide an adequate cap rock.

Large thicknesses of shales and other rocks which could provide an abundant source for petroleum are lacking in the Waterways area, where the beds in immediate sequence are the evaporites. However, possible source beds are intimately associated with the equivalent formations on Great Slave Lake and possibly even closer at hand.

As to where a future search would be most favourable, the writer has two suggestions:

1. Continuing northwesterly parallel to the Shield, an area where oil is known to occur (in the Prescu'ile) is approached. The evaporite basin is skirted; somewhere to the northwest it pinches out, perhaps where reefal growth was superabundant (as was the case with the Capitan Reef of the Texas Permian (1)). Thicknesses of shales and limestones, which might prove to be good source rocks, increase in that area, as well (12).

Remaining fairly close to the Shield, (a) shale beds are perhaps more likely to occur, being closer to the source of the sediments, and (b) depths to favourable horizons, such as the Methy, would be shallower.

2. Undoubtedly a culmination in the Precambrian basement

trends southwesterly, with its axis somewhere south of Waterways. Reefal development may be expected to be strong on the flanks of this arch.

The writer is convinced that the Methy Formation with its equivalents is one of the most favourable horizons in Western Canada in which to seek for accumulations of oil in commercial quantities.

SUMMARY OF CONCLUSIONS

The Methy Formation is of Middle Devonian age, as indicated by its faunal content. Correlation with the Winnipegosis of Manitoba, the Presqu'île of Great Slave Lake, and the Ramparts Formation of the Lower Mackenzie River is possible.

The formation is overlain by the Elk Point evaporite series, in the Waterways area. Dolomite is the predominant rock present, with limestone, chert, shale, anhydrite, gypsum, and rock salt in lesser amounts. Some clay and disseminated argillaceous matter are also present. The mineral brucite(?) has been identified, as well.

An abundant fauna is found in the formation, hence a warm, shallow, marine environment is postulated for Methy time. Bioherm growth was widespread, and occurred throughout deposition of the formation. Stromatoporoids, corals and probably algae were active reef-builders, with crinoid columnals, brachiopod shells and other fragments providing abundant detritus.

All types of reef facies are present in the formation. Careful examination of cores enabled a set of criteria for the recognition of these facies in subsurface well sections to be formulated.

Structural study indicates that the Methy was deposited on an erosional surface of low relief.

Dolomitization processes have been intense. It is concluded that by far the greater amount of replacement occurred contemporaneously or penecontemporaneously with deposition of the sediments. Calcitic shell fragments are less vulnerable to this metasomatism than aragonitic fossils.

The lenticular chert interbeds were believed to be precipitated by electrolytic action as colloidal gels. The silica had its source in the low-lying peneplained Shield area to the east. Cherts are representative of the basinal facies.

Breccias and fragmentals are common and are related to reef-flank and reef-wall facies. Some evaporite-solution breccias also occur.

Great thicknesses of source rocks for petroleum are lacking in the Waterways area. However, the Methy Formation may provide a good potential reservoir for these fluids, for it is often very porous.

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-- WELL LOGS --

BEAR WESTMOUNT #2

Location
9-36-88-8 W4

'K.B.' El. 837

NOTE: The complete log of this well is given here, as being typical for the entire group. For all other wells, only descriptions of the Methy Dolomite sections are included.

The writer wishes to acknowledge his indebtedness to Dr. P.E. Côté Of Pacific Petroleum Ltd. for the use of his core descriptions, and permission to amplify and abridge them as desired for this work.

- 5' - 43' Limestone, light grey to light buff, cryptocrystalline, argillaceous, massive, occasionally rubbly; cut by numerous dark grey shaly and silty bands, fairly regular ($\frac{1}{4}$ "); crinoid stems, a few brachiopods; tight.
- 43' - 44' Limestone, marked break, dark grey, argillaceous, interbanded with buff, granular limestone and dark grey calcareous shale.
- 44' - 45' Shale, greenish grey, calcareous.
- 45' - 46' Limestone, dark grey, highly fossiliferous, granular breaks.
- 46' - 62' Shale, greenish grey, calcareous, with occasionally limy bands.
- 62' - 68' Core lost.
- 68' - 71' Shale, as above.
- 71' - 75' Limestone, mainly, grey, argillaceous, mottled in black, highly fossiliferous at top, occasionally rubbly, due to numerous shaly bands; pyrite.
- 75' - 78' Argillaceous limestone, locally grading to shale, many shaly bands; 0.2' coquinoid (brachiopods) at 77'.
- 78' - 123' Shale, greenish-grey, calcareous, locally almost an argillaceous limestone, fair parting, some pyrite.
- 123' - 138' Limestone, cryptocrystalline to crystalline, irregular texture due to fossil parts, looks very much like fine fragmental, tight, some granular concentrations locally, pyrite, silty, some brachs.
- 138 - 146' Limy silty shale, green, almost a silty limestone, some brachiopods.

- 146 - 191' Limestone, buff, looks like fragmental at top, generally with irregular thin argillaceous breaks, cryptocrystalline, occasionally interbedded with limy shale bands to 2' thick. Some crinoid stems and brachiopods, slightly silty, tight.
- 191 - 217' Highly argillaceous Limestone, almost a shale, greenish grey, silty, locally grading to a definitely shale, many brachiopods, massive, tight.
- 217 - 283' Shale, mostly, green, calcareous, with some limy concentrations and silt; some brachiopods at top and in thin coquinaoid limestone beds below. Some pyrite. Becomes increasingly interbedded with limestone below.
- 283 - 318' Argillaceous limestone and limy shale, grey with green argillaceous bands, a few brachiopods, mat to microgranular.
- 318 - 342' Shale, green, calcareous, some brachiopods.
- 342 - 347' Limestone, rubbly, argillaceous, with shale bands.
- 347 - 379' Shale, grey to greenish-grey, good fissility locally, some limy concentrations. Lingula sps. present.

TOP OF ELK POINT EVAPORITES

- 379 - 383' Siltstone, green grey, calcareous, interbanded with shale as above.
- 383 - 407' Shale and limestone, closely interbanded in one to two foot layers; shale as above; limestone, grey, cryptocrystalline to microgranular, possibly silty.
- 407 - 408' Silty claystone, grey, calcareous, to dolomitic.
- 408 - 412' Limestone, buff to light brown, silty, massive, some breccia.
- 412 - 415' Claystone, siltstone and dolomite, interbanded; claystone is silty and dolomitic; dolomite is buff, others are grey.
- 415 - 418' Claystone, mainly, grey, silty, dolomitic, with gypsum bands.
- 418 - 426' Gypsum, mainly, with many bands of silty claystone.
- 426 - 429' Dolomite, buff, mat to microgranular, finely layered, cut by numerous gypsum bands and concentrations.
- 429 - 441' Siltstone and silty claystone, interbanded with shale and some limestone; greenish grey, dolomitic, with some gypsum.
- 441 - 449' Claystone, grey to buff, dolomitic, silty, with numerous thin layers of dolomitic silt, and gypsum bands and stringers.
- 449 - 462' Gypsum, mostly, some green shale at top, numerous dolomite stringers.
- 462 - 468' Dolomite, buff, bedded, argillaceous, with some gypsum concentrations.

- 468 - 477' Gypsum, grey, mottled in black with many shale bands.
- 477 - 494' Gypsum and anhydrite; anhydrite is highly brecciated and altered to gypsum; some shaly contamination.
- 494 - 527' Anhydrite, brecciated in part and altered to gypsum containing shaly impurities; also contains some dolomitic bands.
- 527 - 528' Dolomite, light buff, microgranular.
- 528 - 562' Anhydrite, with numerous dolomite "stringers," brecciated. Only locally.

TOP OF METHY DOLOMITE

- 562 - 564' Dolomite, buff, cryptocrystalline to microcrystalline, layered, anhydritic, silty. Anhydrite filling vertical fractures.
- 564 - 569' Anhydrite, grey, crystalline, massive.
- 569 - 570' Gypsum, grey, with much dolomite at top.
- 570 - 581' Dolomite, light grey to buff, microgranular, in part recrystallized, mostly dense at top, excellent fine vugginess lower down, probably due to stromatoporoids, indistinct evidence of coral; irregular layering; shaly locally; vertical anhydrite stringers at top.
- 581 - 585' Dolomite, greenish grey, irregular fine vugginess (due to stromatoporoids?), microgranular, slightly argillaceous.
- 585 - 595' Dolomite, light grey, microcrystalline, massive, generally tight, some evidence of corals, indistinct layering locally.
- 595 - 605' Dolomite, buff to grey, to greenish grey, microcrystalline, very finely vuggy throughout. vugs locally up to $\frac{1}{2}$ " , layered throughout, locally shaly. Vugs lined with calcite crystals.

TOP OF REEF

- 605 - 617' Dolomite, buff to greenish grey as above, some breccia, a few irregular structures, locally shaly, probably reef.
- 617 - 630' Dolomite, as above, definite irregular structures, definite coral, probably reef, vugginess generally poor; brecciated near bottom. Also some limy phases, with stylolites.
- 630 - 640' Dolomite and dolomitic limestone, as above, irregular structures, much evidence of corals (some only partly dolomitized) and coral sand; calcite-filled vugs up to $\frac{3}{4}$ ".
- 640 - 658' Dolomite, as above, crystalline, stromatoporoids and corals and crinoid stems; locally fragmental (some coral sand); fair to good vugginess, with vugs to 1" in diameter.

BASE OF REEF

- 653 - 670' Dolomite, brownish grey, layered at approximately 25° to horizontal (flow type layering), contains some corals, many paper-thin brownish-black bituminous shale layers, some limy films and anhydrite blobs. Dolomite has sugary texture, fair to good microporosity. Possibly a few corals and brachiopods.
- 670 - 671' Dolomite, breccia, buff matrix and brown coarse fragments somewhat layered, fine local vugginess. Coquinoid, with corals, stromatoporoids, brachiopods and crinoid(?) fragments.
- 671 - 674' Dolomite, dirty brown, sugary texture, finely layered, possibly a fragmental; vugs up to 1½" in diameter.
- 674 - 678' Dolomite, limy dolomite, near the bottom, brown, brecciated, some coralline matter, stromatoporoids, crinoid stems, and brachiopods. Considerable amounts of finely-broken organic matter.
- 678 - 694' Dolomite, dirty brown becoming greenish grey, microcrystalline, locally shaly, fair to good vugginess to 1", some breccia, good coral evidence and bryozoans (Fenestella?); shaly partings. Possibly reefal?
- 694 - 704' Dolomite, greenish grey, becoming mottled with buff, some breccia, fair to good vugginess, has crinoid stems present.
- 704 - 730' Dolomite, sometimes limy, dark grey becoming mottled and compact at base, microcrystalline, fair vugginess, irregular layering at high angle. Crinoid stems, stromatoporoids, bryozoans and brachiopods. A definite breccia, especially below.
- 730 - 732' Dolomite, grey, irregularly layered and argillaceous, fair vugginess; coarser vugs filled with gypsum.
- 732 - 737' Argillaceous dolomite, dark grey, finely bedded, slightly silty, dense, many crinoid stems.
- 737 - 757' Dolomite, very argillaceous, dark brown to dark grey, finely bedded, a few brachiopods, many crinoid stems, scattered coarse gypsum-filled vugs, becoming massive and tight below and indefinitely layered. Some bryozoans (Fenestella?).
- 757 - 768' Dolomite, green at top, becoming dark brown, then buff at base, slightly layered at top, microcrystalline, massive, many small anhydrite inclusions, a few crinoid stems; bottom 6" shows no structures.
Shale, greenish grey dolomitic, with fair to good parting, and fractures filled with dolomite from above marks base.

BASE OF METHY DOLOMITES

- 768 - 775' Shale, anhydrite and dolomite, interbanded, with many gypsum stringers.
- 775 - 787' Dolomitic claystone mainly, olive green, locally interbanded with dolomite or anhydrite, occasionally brecciated, some gypsum.

TOP RED BEDS

- 787 - 805' Claystone and dolomitic claystone, greenish grey to buff to green, some argillaceous dolomite and gypsum, slightly silty.
- 805 - 807' Claystone as above, but mottled in red, top of Red Beds.
- 807 - 848' Red Beds, dolomitic claystone above, becoming increasingly arenaceous and silty below; local gypsum concentrations.
- 848 - 858' Red beds, sandstone of rounded quartz grains, some arenaceous claystone; gypsum concentrations throughout.
- 858 - 884' Red beds, arenaceous claystone, rusty red and green, silty, with gypsum concentrations.
- 884 - 908' Red beds, argillaceous breccia, dolomitic, rusty red, fragments up to 1", some siltstone and sandstone; gypsum.
- 908 - 936' Feldspar-hornblende-gneiss, highly-weathered at top, gypsiferous. Bottom of well.

BEAR WESTMOUNT #1

Location
14-9-86-7 W4

'K.B.' El. 1627

1416'

TOP OF METHY DOLOMITE

- 1416-1424' Dolomite, buff, granular, indistinctly layered, oolitic, vertical anhydrite-filled cracks, anhydrite "sand crystals."
- 1424-1428' Anhydrite, blue grey, fairly pure, altered in part to gypsum, especially at base; some dolomite also present at base.
- 1428-1460' Dolomite, buff, granular, layered throughout, very fine fragmental probably, brownish black shaly films, fair to good very fine vuginess, bottom 3' become very compact.
- 1460-1465' Dolomite, greenish grey, layered, microcrystalline to granular, very finely vuggy locally.

TOP OF REEF

- 1465-1480' Dolomite, buff, microgranular, irregular structures throughout, vugs to $\frac{1}{2}$ ", coarse gypsum concentrations; some rubble at base; abundant evidence of corals and stromatoporoids.
- 1480-1501' Dolomite, buff, crumbly, earthy lustre locally, otherwise microcrystalline, irregular structures, some local layering due to shaly films, vugs to $\frac{1}{2}$ ", considerably brecciated, with abundant corals, brachiopods, and stromatoporoids.
- 1501-1511' Dolomite, buff, microcrystalline, some earthy crumbly sections, (coral rubble?), vugs up to 1", brownish shaly films, some gypsum concentrations and pyrite; locally coquinooid, recognizable corals and stromatoporoids.

- 1511-1532' Dolomite, brown, flow layered, microcrystalline, fair microporosity and vugginess, dark shaly films; corals, stromatoporoids and brachiopods; probably coquinoid rubble.
- 1532-1542' Dolomitic limestone, dark brown to almost black, bedded throughout, argillaceous, microcrystalline, many black-brown shaly films; crinoidal, brachiopods and corals (Syringopora?).
- 1542-1553' Limestone to dolomitic limestone, dark brown, indistinct layering, microcrystalline, mainly argillaceous, massive, tight; coarse-ribbed Atrypas, other brachiopods, crinoid stems. (Atrypa cf. arctica Warren.)
- 1553-1583' Limestone, dark brown, massive, indistinct layering, microcrystalline, argillaceous, tight, abundant brachiopods and crinoids. Atrypa arctica Warren, Gypidula cf. comis, Martinio-opsis cf. sublineata Meek, coarse-ribbed Atrypas, an indeterminate gastropod. Slickensiding common in shaly phases.
- 1583-1593' Limestone, dark brown, massive, tight, very argillaceous, indistinct layering, few fossils than above.
- 1593-1638' Limestone, becoming more dolomitic at base, dark brown, argillaceous, dappled in brown (due to fossils and irregular distributions of argillaceous matter, probably); many brachiopods, crinoids, becoming fewer at base; massive, tight.
- 1638-1648' Calcitic dolomite, brown, some irregular structures, massive, vugs to $\frac{1}{4}$ " filled with anhydrite, argillaceous, finely silty; contains a few brachiopods.

TOP OF SECOND EVAPORITE.

BEAR RODEO #1

Location
89-9 W4.

'K.B.' El. 822

842'

TOP OF MEXICAN DOLOMITE

- 842 - 853' Dolomite, buff to brown, microcrystalline, with good to excellent fine porosity, locally finely vuggy, slightly argillaceous; some pyrite; salt encrusted; vertical joints, often filled with anhydrite; some indefinite coral forms.
- 853 - 861' Dolomite, similar to above, but marked by fine speckling due to small elongate buff forms, generally in alignment; probably a breccia; fine porosity; corals, brachiopods, and crinoid stems in evidence; becomes reddish-brown at base.
- 861 - 885' Dolomite, brown, microgranular to crystalline, finely porous, salt encrusted. Probably originally a breccia, as above; could be reef; irregular structures; locally layered; slightly argillaceous, moreso at base; a few brachiopods.

- 885 - 888' Limestone, light buff, microcrystalline, microporous, probably fine fragmental; crinoidal, perhaps.
- 888 - 889' Argillaceous dolomite, dark brown and buff, a breccia. Cypidula(?) sp.
- 889 - 891' Limestone, buff, as above; quite pure. Atrypa sp. Crinoidal.
- 891 - 893' Calclitic dolomite, dark brown argillaceous, brecciated; brachiopods.
- 893 - 898' Limestone, breccia, buff and dark brown; coarse, irregular, buff limestone fragments in a dark brown argillaceous matrix. A coarse fragmental, with some fine porosity, some anhydrite infilling. Brachionods.
- 898 - 899' Shale, black, calcareous. Brachiopods.
- 899 - 900' Limestone, breccia, as above.
- 900 - 903' Limestone and shale, limestone as above, shale dark brown to dark grey, calcareous. Brachiopods and crinoid stems. Coarse-ribbed Atrypas.
- 903 - 922' Limestone, coarse fragmental, fragments of coralline and other limestones, buff, angular, locally rounded, contained in dark brown dolomitic argillaceous ground mass, the latter having definite oil smell when heated. Crinoid stems, brachionods, stromatoporoids (Actinostroma sp.), and corals; the latter especially at the base.
- 922 - 925' Dolomitic shale, brownish black, looks like oil shale (as above), a few limestone concentrations; crinoid stems.
- 925 - 944' Limestone and dolomitic(?) shale, limestone as buff-coloured fragments in dark brown oil(?) shale; a breccia or rubble originally, probably. Brachiopods (coarse-ribbed Atrypas, Cypidula), crinoid stems, corals.
- 944 - 955' Limestone, brown, dense, argillaceous, massive, tight; becomes increasingly dolomitized at base; some shaly anhydrite blobs; fine-ribbed Atrypas,--Atrypa arctica Warren.

TOP SECOND EVAPORITE

BEAR RODEO #2

Location
5-17-91-9 WA

'K.B.' El. 803

730'

TOP OF METHY DOLOMITE

- 730 - 743' Dolomite, light brown, granular, poor bedding, finely crystalline.

- 743 - 753' Dolomite, light brown, massive, granular, as above, but with corals.
- 753 - 783' Dolomite, light brown, granular, massive, anhydrite blebs, becoming increasingly argillaceous towards base.
- 783 - 793' Dolomite, brown to dark brown, generally crystalline, locally argillaceous, poorly bedded, anhydrite-filled vugs, brachiopods and crinoid stems observed.
- 793 - 796' Dolomite, dark brown, bedded to irregularly laminated, thin, dark, argillaceous bands locally; anhydrite-filled vugs; crinoid stems.
- 796 - 807' Dolomite, light brown, generally granular, crumbly, massive, locally argillaceous; crinoidal and coralline (reef?).
- 807 - 809' Dolomite, well layered, light brown granular as above, inter-banded with dark brown argillaceous phases--flow layered; pyritic, brachiopods (*Atrypa (arctica?)*, *Martinionsis* sp.).
- 809 - 829' Dolomite, dark brown becoming light brown toward base, where argillaceous content is on decrease; locally finely layered to bedded; mottled; probably originally a coquina breccia; pyritic; coralline and crinoidal: some "coral sand."
- 829 - 834' Dolomite, light brown, granular, as above, but with brachiopods near the top.
- 834 - 839' Dolomite, dark brown, argillaceous locally, strongly mottled, locally well bedded; local bands of crystalline dolomite; a breccia with brachiopods, at the base.
- 839 - 865' Dolomite, brown to dark brown, a rubble breccia, mostly, hence granular to crystalline texture: layering almost absent, better at base, where more argillaceous matter occurs: porosity varies from excellent to poor; stylolites and slickensiding common; indistinct coralline evidence, becomes crinoidal towards base. This zone may represent interdigitation of rubble and chemical precipitates around reef edge.
- 865 - 878' Dolomite, greenish grey to buff, finely crystalline, argillaceous, indistinct layering, massive, some anhydrite-filled vugs, becomes shaly towards base.

TOP SECOND EVAPORITES

BEAR VAMPIRE #1

Location
7-28-87-12 W/

'K.B.' El. 1545

1914'

TOP METHY DOLOMITE

1914-1917' Dolomite, mainly, brown, argillaceous, locally finely layered, some anhydrite, finely vuggy, silty, microcrystalline.

1917-1921' Dolomite, argillaceous, dark greenish grey, with disseminated anhydrite and as beds to 0.4' thick.

1921-1922' Anhydrite.

1922-1944' Dolomite, dark brown, finely crystalline, coarse vugs with coarse crystals of salt, massive, indistinct layering, some indications of breccia, contains some anhydrite, --a bed 1.5' in thickness at the base.

TOP OF REEF

1944-1947' Dolomite, dark grey, finely crystalline, coarse vugs filled with salt, otherwise massive, anhydritic content on decrease downwards.

1947-1957' Dolomite, dark grey, microcrystalline, irregular reef structures, fair to good vugginess, mainly filled with salt, apparently brecciated, definite coral development at base. Pyrite.

1957-1960' Dolomite, as above, anhydritic, coarsely vuggy, mainly filled with salt; brachiopods and corals present.

1960-1968' Dolomite, dark grey, finely granular, irregular structures in top half, somewhat layered below; shows definite brecciation of the once-solid dolomite; contains some anhydrite and pyrite.

1968-1978' Dolomite, dark grey to brown, salt-filled vugs, irregular structures, may be breccia; anhydritic; probably corals at base.

1978-1988' Dolomite, dark brown almost black, irregular structures locally, salt-filled vugs, a breccia; stromatoporoids at centre section, also crinoids and possibly corals.

1988-2008' Dolomite, buff to dark brown, irregular structures, brecciated and fractured locally, medium to coarse salt-filled vugs; crinoids, bryozoans and some coral at 1993'.

2008-2018' Dolomite, brown, irregular structures, locally brecciated, somewhat layered, coarse salt-filled vugs, massive finely granular; corals, brachiopods, and crinoids in evidence.

2018-2022' Dolomite, light brown, irregular structures, brecciated (of coral-rubble and-sand type), coarse salt-filled vugs to 3", some crinoids seen.

BASE OF REEF

2022-2028' Dolomite, buff to brown, irregularly layered, shaly breccia, dolomitic fragments contained in dark green shale, layering at about 20°, local thin beds of crystalline dolomite.

2028-2038' Dolomite, buff to dark green mottled, flow type breccia, fair vugginess; layered at about 20 degrees from horizontal.

BEAR VAMPIRE #1

- 2038-2043' Dolomite, greenish-grey, mainly with buff layers; flow layered, dark dolomite has some shale, fair to good vugginess; some brachiopods and crinoids.
- 2043-2068' Dolomite, grey to buff, irregular structures, some thin shaly partings, anhydritic, coarse vugs due to brecciation, probably; mostly salt-filled.
- 2068-2078' Dolomite, buff to grey, flow-type layering at about 20 degrees, sucrose, shaly partings, decreasing vugginess from above, some brachiopods and possibly bryozoans.
- 2078-2088' Dolomite, as above, but denser and with numerous stylolites.
- 2088-2092' Dolomite, buff to grey, flow-type layered, medium salt-filled vugs, dense, mottled, some large crinoid stems.
- 2092-2125' Dolomite, dark brown to dark grey, dense, strongly argillaceous, much irregular layering, crinoidal, shaly streaks.
- 2125-2135' Dolomite, brown, massive, finely vuggy towards base, with vugs filled with salt crystals, sharp break at base.

TOP SECOND EVAPORITE

BEAR VAMPIRE #2

Location
4-32-93-10 W4

'K.B.' El. 799

604'

TOP METHY DOLOMITE

- 604 - 640' Dolomite, buff to brown, coarse anhydrite concentrations, decreasing downwards, has distinct layering throughout, mostly tight, locally argillaceous towards base, some pyrite, occasional shale partings, slickensiding, possibly diastems.
- 640 - 654' Dolomite, light buff, quite massive, tight, locally layered between fragmental sections; suggest "resorbed" breccia; large stromatoporoid growths and (horizontal) corals, either in place or as fragments.
- 654 - 673' Dolomite, buff, microcrystalline, a fragmental, coarse and argillaceous at the base; stromatoporoids, possibly corals.
- 673 - 683' Dolomite, buff, as above, fragmental, but has some fairly horizontal bedding; originally some coral and crinoid coquina breccia.
- 683 - 695' Dolomite, buff to brown as above, fragmental, some layering, large vugs; coarse-ribbed Atrypas and crinoid stems in breccia.
- 695 - 719' Dolomite, buff, massive, irregularly-layered granular, dark bituminous shale partings, a few coarse vugs, "coral sand" type, with crinoid stems.

- 719 - 732' Dolomite, buff to brown, massive, flow layered, dark black shaly partings, anhydrite concentrations in old vugs; crinoid and brachiopod coquina type of fragmental.
- 732 - 770' Dolomite, shaly to argillaceous, well-layered, some bands of black bituminous shale, some salt, anhydrite and gypsum concentrations, small to medium vugs, local narrow chertified zones; numerous crinoid stems, also brachiopods.
- 770 - 780' Argillaceous dolomite, dark brown, layering not marked, gypsum concentrations, finely crystalline, a few vugs, salt-encrusted; crinoid stems and brachiopods and sponge spicules.
- 780 - 790' Argillaceous dolomite, as above, increase in argillaceous matter and in brachiopods, decrease in layering, in porosity and in gypsum and salt encrustation.
- 790 - 801' Dolomite, brown, massive, argillaceous, irregular structures, possibly due to diagenesis rather than life growths, some irregular layering, some vugs small to medium, microcrystalline, some anhydrite vug fillings; a few crinoids.
- 801 - 807' Dolomite, as above, but believed to be a breccia, originally, probably microporous.
- 807 - 808' Argillaceous dolomite, cryptocrystalline, dense, tight, structureless.

BOTTOM METHY DOLOMITE.

BEAR BILTHORE #1

Location
7-11-87-17 W4

'K.B1' El. 1445

2467'

TOP OF METHY DOLOMITE

- 2467-2470' Dolomite, brown microgranular, finely layered, some dark brown shaly partings; finely vuggy in layers; vertical anhydrite-filled cracks.
- 2470-2471' Anhydrite, grey, finely crystalline, fairly pure.
- 2471-2475' Dolomite, as above, but some granular patches.
- 2475-2480' Anhydrite, massive, as above, locally dolomitic.
- 2480-2491' Dolomite, as above, with anhydrite layers up to 1' thick; thin shale partings; one foot breccia at base.
- 2491-2501' Dolomite, brown, microgranular, flow type layering at top, mostly dense, irregular structures (due to stromatoporoids or corals?) start at 2496'. Possibly part of reef.

- 2501-2521' Dolomite, brown, microgranular as above, rather dense, irregular structures with occasional coarser vugs, filled with anhydrite or salt; shaly partings; some breccia in lower parts; brachiopod at 2511'; possibly reef.
- 2521-2530' Dolomite, dark brown, microgranular, locally argillaceous, irregular structures, with some coarse vugs, filled with salt and anhydrite, mostly dense; probably reef.
- 2530-2540' Dolomite, brown, granular and locally crystalline, irregular structures, rather dense to finely vuggy, some coarse, anhydrite-filled vugs, some dark shaly films; corals, probably reefal.
- 2540-2545' Dolomite, light to dark brown, as above, developing flow-type layering down. May represent base of reef?
- 2545-2559' Dolomite, light to dark brown, light brown due to crypto-crystalline irregular structures; dark brown part is more crystalline and irregularly-layered, probably due to argillaceous content, at angle of about 40 degrees; mostly dense; some crinoid stems. Probably represents a brecciated section.
- 2559-2569' Dolomite, dark to light brown, as above, irregularly layered, mostly granular, some recrystallized, mostly massive and dense; locally vuggy with gypsum infilling; less brecciated than above; crinoidal and coralline.
- 2569-2589' Dolomite, light grey or brown, flow layered, dense, occasionally finely vuggy; shaly partings; crinoidal and coralline (Prismatophyllum sp., near base).
- (Top of Chertified Zone.)
- 2589-2599' Dolomite, brown, with chert interbands irregularly layered, salt-filled vugs to 2". Chert is often sugary, porous to finely vuggy, probably represents coralline and other growth. Dolomite is generally crystalline, locally vuggy; somewhat brecciated below; crinoidal.
- 2599-2621' Dolomite, brown, with white chert interbands, porous and sugary. Dolomite is dense and irregularly layered with shaly films, --"layered breccia" type. Brachiopods present (one 3" across at 2605' was pyritized.).
- (Base of chertified zone.)
- 2621-2629' Dolomite, dark brown, massive, granular, small irregular structures, probably due to resolution or dolomitization. Mostly dense, finely vuggy locally, sometimes anhydrite infillings.
- 2629-2640' Dolomite, as above, but crinoidal.

- 2640-2658' Dolomite, brown, massive, dense, some irregular structures at top (fragmental?), mostly microgranular, some recrystallization, some vugginess, some evaporite infilling.
- 2658-2660' Dolomite, light brown to grey, black mottling due to some argillaceous matter.

BOTTOM METHY DOLOMITE

CHRISTINA RIVER-HARDY #1

Location
14-25-77-9 W4

'K.B.' EL. 1895

2510-2520' TOP OF METHY DOLOMITE

- 2510-2520' Dolomite, buff, some layering throughout, but nevertheless believed to represent a brecciated section, friable to crumbly with earthy lustre locally (coral sand?), microgranular to crystalline, sugary, fair to fine vugginess, some coarse vugginess, in part infilled with salt, anhydrite and gypsum; slightly argillaceous.
- 2520-2530' Dolomite, as above, less crumbly, good layering at top, indistinct layering below, upper part fragmental. Texture microcrystalline, sugary; some salt-filled vugs; bottom 3' fractured.
- 2530-2545' Dolomite, buff as above, but no layering, locally crumbly, a few thin layers of bituminous(?) shale, some irregular structures; crinoids; originally a coral sand and rubble, probably.
- 2545-2553' Dolomite, buff to dirty brown, indistinctly layered, argillaceous, massive, dense, microcrystalline, salt-encrusted.

TOP OF REEF(?)

- 2553-2560' Dolomite, brown to dirty brown as above, but with irregular structures at top, also is very coarsely vuggy throughout. Vugs are filled with salt or gypsum. Dolomite is microcrystalline, somewhat argillaceous: has some indistinct fossils.
- 2560-2570' Dolomite, dark brown as above, microcrystalline, cavernous, looks like breccia; coarse vugs (2" plus), often salt-filled; thin black irregular bituminous(?) shale partings; a few small anhydrite concentrations. Stylolites occur in the shale.
- 2570-2580' Dolomite, dark brown as above, but coarser anhydrite concentrations; a few indefinite irregular structures; only part of coarse vugs are filled with salt. Looks like breccia, cavernous.
- 2580-2600' Dolomite, dark brown as above, coarsely vuggy, more spotty, less so at bottom; vugs more infilled with salt, more irregular structures, cavernous, probably reef. Looks like breccia, but dolomitization obscures fossils and other structures.

2600-2607' Dolomite, brown, tough, massive, structureless, many salt-filled vugs; cavernous, brecciated-looking.
(Bottom of Methy unattained.)

IMPERIAL PLAIN LAKE #1

Location
1-11-53-12 W4

'K.B.' El. 2282

4605' (?)

TOP OF METHY DOLOMITE

Dolomite, grey-brown, microcrystalline to sucrose, occasionally earthy, pin-point porosity, with some anhydrite and salt casts.

5010' (?)

BOTTOM OF METHY DOLOMITE

IMPERIAL GROSSMONT #1

Location
13-17-67-23 W4

'K.B.' El. 2066

5035'

TOP OF METHY DOLOMITE

Limestone and argillaceous limestone, some dolomite, brown to buff, finely-crystalline, dense to very finely-crystalline. Crinoids.

5285'

BOTTOM OF METHY DOLOMITE

IMPERIAL DAPP #1

Location
5-29-62-1 W5

'K.B.' El. 2086

6280'

TOP OF METHY DOLOMITE

Dolomite, dark brown, argillaceous, crystalline to sucrose, some vugs; crinoids.

6380' (?)

BOTTOM OF METHY DOLOMITE.

IMPERIAL CLYDE #1

Location
9-29-59-24 W4

'K.B.' El. 2065

5750'

TOP OF METHY DOLOMITE

Limestone and dolomite, buff; crinoids and Saracella.

5850' (?)

BOTTOM OF METHY DOLOMITE.

IMPERIAL IRMA #3

Location
6-14-46-9 W4

'K.B.' El. 2312

4715'

TOP OF METHY

Dolomite and limestone, grey to brown, dense, argillaceous;
Sarcocolla, Trochiliscus.

4900' (?)

BOTTOM OF METHY

IMPERIAL PROVOST #1

Location
1-33-37-3 W4

'K.B.' El. 2420

4980'

TOP OF METHY

Dolomite, light grey to brown, finely-crystalline, anhydri-
tic, dense.

5270' (?)

BOTTOM OF METHY

-- THIN SECTION DESCRIPTIONS --

Slide 50-71

Westmount 2, Core 66, 641'

Hand specimen Description:

A greyish, fossiliferous, crystalline dolomite.

Microscopic Study:

Texture: Anhedral, equi-sized, crystalline, with small vugs.

Structure:

Original: A fossil fragmental.

Secondary: Dolomitized fossil forms, which remain as palimpsests.

Mineral Composition: Dolomite, with argillaceous matter.

Metasomatism: Dolomitization processes have been intense; the matrix and much of the fossil parts have been replaced with dolomite.

Fauna: Crinoids, corals(?).

Other Features:

Slide 50-72

Westmount 2, Core 63, 618'

Hand Specimen Description:

A greyish, rather pure coralline, argillaceous dolomite, with stromatoporoids.

Microscopic Study:

Texture: Microcrystalline, with dolomite(?) crystals in fine vugs.

Structure:

Original: A fragmental.

Secondary: Structures somewhat destroyed by dolomitization.

Mineral Composition: Dolomite, with argillaceous matter.

Metasomatism: Original fragments are replaced by dolomite.

Fauna: Stromatoporoids, corals.

Other Features: Thought to be part of the reef wall through megascopic examination, in thin section the fragmental nature of the rock was found to predominate. This, however, may be a local feature.

Slide 50-73

Westmount 2, Core 69, 676'

Hand Specimen Description:

A brownish, brecciated, argillaceous, replacement(?) dolomite, with numerous brachiopod shell fragments, corals, and stromatoporoids.

Microscopic Study:

Texture: Finely-crystalline. Anhedral, porphyroblastic (i.e., uneven-grained) dolomite.

Structure:

Original: "Fragmental," i.e., fossil coquinoid.

Secondary: Dolomitized fossil forms--"palimpsest."

Mineral Composition: Dolomite, with argillaceous matter.

Metasomatism: A completely dolomitized rock. No signs of fossil forms remain, except stromatoporoids. They are seen, however, in the hand specimen as moulds.

Fauna: Stromatoporoids, corals, brachiopods.

Other Features: This rock may represent brecciation and slumping close to the reef wall.

Slide 50-74

Westmount 2, Core 70, 688'

Hand Specimen Description:

A greyish, rather coarsely/fragmental limestone, with concentrations of argillaceous matter around the fossil fragments.

Microscopic Study:

Texture: Microcrystalline, granoblastic, in matrix.

Structure:

Original: Limestone fragmental.

Secondary: Well-preserved fossil fragments, surrounded by a rather argillaceous matrix.

Mineral Composition: Limestone fragments in a dolomitic argillaceous matrix.

Metasomatism: This specimen appears to be only weakly dolomitized.

Fauna: Grinoid stems, brachiopods, corals.

Other Features: The fragmentation, abundant fauna, and relationship of the argillaceous matter may point to an origin in the reef flank.

Slide 50-75

Westmount 2, Core 63, 619'

Hand Specimen Description:

Grey, unlayered, fossiliferous, calcitic dolomite, with fine stylolites.

Microscopic Study:

Texture: Fine-grained, porphyroblastic matrix.

Structure:

Original: Rather large fossil forms, possibly in situ.

Secondary: Stylolites, with typical concentration of argillaceous matter along their surface, on one side.

Mineral Composition: Dolomite, with argillaceous matter;
Faunal remains are calcite.

Metasomatism: An early stage in the dolomitization process is probably represented.

Fauna: Stromatoporoids, corals.

Other Features: The core section from which this specimen was taken may represent reef wall. The stylolitic "breaks" indicate that circulation of solvent fluids took place.

Slide 50-76

Westmount 2, Core 66, 644'

Hand Specimen Description:

Greyish, fragmental, calcitic dolomite, with stromatoporoids and corals.

Microscopic Study:

Texture: Finely-crystalline, granoblastic (i.e., equigranular).

Structure:

Original: Fragmental.

Secondary: Fossil structures are poorly-preserved.

Mineral Composition: Dolomite and calcite, rather pure;
some disseminated argillaceous matter;
a few rounded quartz grains.

Metasomatism:

Dolomitization has been intense.

Fauna: Stromatoporoids, corals.

Other Features:

Slide 50-77

Westmount 2, Core 73, 714'

Hand Specimen Description:

Mottled greyish and buff, irregularly-layered, fragmental dolomite.

Microscopic Study:

Texture: Finely-crystalline, porphyroblastic.

Structure:

Original: Rather coarse fragmental.

Secondary: Stromatoporoids and crinoid stems are fairly well-preserved.

Mineral Composition: Mostly dolomite; rudaceous brachiopods and stromatoporoids are somewhat calcitic. Crinoid stems show rhombohedral twinning, and are replaced by dolomite from centre out, in the case of the crinoids.

Metasomatism: Dolomitization is well advanced.

Fauna: Crinoid stems, brachiopods, stromatoporoids.

Other Features:

Slide 50-78

Westmount 2, core 75

Hand Specimen Description:

Irregularly-layered, dark brown, argillaceous dolomite.

Microscopic Study:

Texture: Finely-crystalline, granoblastic.

Structure:

Original: Primary dolomite deposit?

Secondary: Most fossil forms remain as palimpsests, except some crinoid stems. Argillaceous matter is in microlayers.

Mineral Composition: Dolomitization may have been contemporaneous or penecontemporaneous with deposition.

Fauna: Crinoid stems, sponge spicules(?).

Other Features: Crinoid stems seem to be most resistant to dolomitization. They may also imply an original environment with sorted clastics.

Slide 50-79

Westmount 1, Core 53, 1418' (Plate VI (b))

Hand Specimen Description:

Granular or oolitic(?) buff-coloured dolomite, with anhydrite or gypsum intergranularly and in fine fissures.

Microscopic Study:

Texture: Clastic, granular.

Structure: The well-rounded dolomite grains do not possess any concentric or radial features, hence are not true oolites.

Mineral Composition: The thin section consists of dolomite grains, with the pores between filled with a mineral believed to be brucite, $Mg(OH)_2$. The mineral had an index of 1.56 to 1.58, was uniaxial positive, possessed moderate birefringence, and had good cleavage. In the hand specimen it had a pearly lustre. (See page 13, text.)

Metasomatism: The original rock was probably a dolomite clastic; not much replacement of the dolomite grains took place. Whether the brucite(?) replaced some earlier pore filling is unknown.

Fauna: Nil.

Other Features:

Slide 50-80

Westmount 1, Core 54, 1420' (Plate VII (a))

Hand Specimen Description:

Granular or oolitic(?), buff-coloured, calcitic dolomite, with anhydrite-filled fine cracks.

Microscopic Study:

Texture: Clastic, granular.

Structure:

Original: A granular dolomite or limestone clastic.
Secondary: Nil.

Mineral Composition: Fragments are rather limy; matrix is dolomitic.

Metasomatism: The matrix, perhaps also the grains, are being replaced by dolomite.

Fauna: Nil.

Other Features:

Slide 50-81

Westmount 1, Core 66 (Plate VI (a))

Hand Specimen Description:

Cryptocrystalline, argillaceous, fossiliferous, brownish, dolomitic limestone.

Microscopic Study:

Texture: Finely-crystalline, granoblastic.

Structure:

Original: Fine fragmental--"calclutite"--probably.
Secondary: Fossil forms remain only as palimpsests.

Mineral Composition: Dolomite, with disseminated argillaceous matter.

Metasomatism: The rock has only been mildly dolomitized.

Fauna: Gastropods, sponge spicules(?).

Other Features: Gastropod spires can be quite definitely recognized in thin section. Other fossil forms have been dolomitized; only their outlines remain.

Slide 50-82

Rodeo 1, Core 86, 870'

Hand Specimen Description:

Brownish, microgranular, porous, dolomitic limestone, probably part of a reef wall.

Microscopic Study:

Texture: Finely-crystalline, granoblastic, except for medium-sized (calcite?) crystals lining the vugs.

Structure:

Original: Fine fragmental?
Secondary: Original discrete, probably organic, particles have lost their boundaries.

Mineral Composition: Dolomite, with the vugs lined with calcite crystals, apparently; scattered, disseminated argillaceous matter.

Metasomatism: The rock has been intensely dolomitized, with the calcitic vug linings brought in later.

Fauna: Nothing recognizable.

Other Features:

Slide 50-83

Rodeo 1, 850'

Hand Specimen Description:

Buff coloured, calcitic dolomitic rock, with irregular, light buff specks. May be a fragmental.

Microscopic Study:

Texture: Microcrystalline, granoblastic, except for larger crystals lining the vugs.

Structure:

Original: Fine fragmental?

Secondary: Boundaries of the fragments become quite fuzzy.

Mineral Composition: Dolomite, with argillaceous matter, and calcite vug linings.

Metasomatism: Dolomitization had apparently been complete.

Fauna: Stromatoporoid, scolecodont(?)

Other Features: The high porosity of this rock was probably a pre-dolomitization feature, and related to the postulated fragmental nature of the rock.

Slide 50-84

Rodeo 1, Core 88, 897'

Hand Specimen Description:

Brownish, crystalline limestone, with numerous brachiopod shell fragments.

Microscopic Study:

Texture:

Structure: Microcoquinoid.

Mineral Composition: Dolomite, with abundant disseminated argillaceous matter.

Metasomatism: None recognized.

Fauna: Brachiopods, crinoid stems.

Other Features: The rock is apparently an unreplaced limestone.

Slide 50-85

Rodeo 1, Core 89, 917'

Hand Specimen Description:

Brownish, calcitic crinoid fragments in a dolomitic, argillaceous matrix.

Microscopic Study:

Texture: Anhedral, porphyroblastic, finely-crystalline.

Structure: Fragmental or brecciated. In places, sutured.

Mineral Composition: Calcite, dolomite, some argillaceous matter and anhydrite.

Metasomatism: There may be some calcitic replacement along fissures.

Fauna: Crinoid stems, stromatoporoids.

Other Features: Calcite crystals sometimes show rhombohedral twinning.

Slide 50-86

Rodeo 1, Core 93, 939'

Hand Specimen Description:

Chertified, dull grey limestone and dolomitic shale.

Microscopic Study:

Texture: Porphyroblastic--cryptocrystalline chert with euhedral dolomite or calcite rhombs.

Structure: Brecciated limestone fragments in a chertified, shaly matrix.

Mineral Composition: Chert, limestone, dolomitic shale.

Metasomatism: In part, this rock is dolomitized, in part, chertified. The chert seems to be of the bedded type, however.

Fauna: Brachiopods.

Other Features: Dolomitization seems to be later than chertification, for a brachiopod shell in the chert is unreplaced by dolomite and well-preserved.

Slide 50-87

Rodeo 1, Core 87, 888'

Hand Specimen Description:

Light buff-coloured, fine-grained fragmental limestone.

Microscopic Study:

Texture: Porphyroblastic: euhedral calcite rhombs in a microcrystalline groundmass, and especially in fine vugs.

Structure: Fine-grained fragmental.

Mineral Composition: Calcite, rather pure, some argillaceous matter.

Metasomatism: The rock is unreplaced.

Fauna: None recognized.

Other Features: The fine pores are probably related to the fragmental nature of the rock.

Slide 50-88

Rodeo 1, Core 88, 898'

Hand Specimen Description:

Greyish-brown, argillaceous, limestone breccia, with brachiopod shell fragments.

Microscopic Study:

Texture: Brecciated, with anhedral, granoblastic matrix.

Structure: Brecciated, or fragmental.

Mineral Composition: Limestone, with argillaceous matter. One medium-sized, well-rounded quartz grain is present in the slide.

Metasomatism: The specimen is unreplaced.

Fauna: Brachiopods.

Other Features:

Slide 50-89

Vampire 2, Core 73, 664'

Hand Specimen Description:

A rather pure, buff-coloured, fragmental calcitic dolomite.

Microscopic Study:

Texture: Anhedral, porphyroblastic.

Structure: Fine-grained fragmental.

Mineral Composition: Dolomite, calcite, a very little argillaceous matter.

Metasomatism: Dolomitization has not been too intense, in this specimen.

Fauna: Stromatoporoids, others not recognizable.

Other Features:

Slide 50-90

Vampire 2, Core 86, 776' (Plate VII (b))

Hand Specimen Description:

Dark grey, crinoidal, fine-grained, argillaceous, calcitic dolomite.

Microscopic Study:

Texture: Finely-crystalline, anhedral.

Structure: Fossil forms are rather well-preserved.
Crinoidal.

Mineral Composition: Dolomite, calcite, some finely-disseminated argillaceous matter.

Metasomatism: Fossil fragments are relatively unaltered.

Fauna: Crinoids, brachiopods, sponge spicules, stromatoporoids(?).

Other Features: The matrix consists of some of the most finely-crystalline dolomite seen in the thin sections.

SCALED SECTION - BEAR BILTMORE I TO PINE RAPIDS.

SHOWING RELATIONSHIP OF METHY

SCALE: HORIZONTAL 1 inch = 4 miles
VERTICAL 1 inch = 400 feet.

IDS. SHOWING RELATIONSHIP OF METHY DOLOMITE TO ASSOCIATED FORMATIONS.

SCALE: HORIZONTAL 1 inch = 4 miles
VERTICAL 1 inch = 400 feet.

28' removed

Bottom of Upper Bedded Zone

METHY FORMATION

SUBSURFACE CROSS SECTION A-B

— WATERWAYS AREA —

WITH TENTATIVE CORRELATIONS

Scale: Horizontal 1" = 5 miles
Vertical 1" = 20 feet

Datum: Base of Methy

1st Column:
PETROLOGY

2nd Column:
BEDDING, ETC.

3rd Column:
FAUNA

Christina River - Hardy 1
(Base of Methy
unattained.)

Dolomite

Argillaceous
Dolomite Cherty
Dolomite

Limestone

Anhydrite &
Gypsum

Shale

Bioherm

Pyrite

Bedded

Poorly
Bedded Indefinitely
Bedded Flow-
Layered

Brecciated

Unbedded
or Massive Irregular
Structures Rubby and
Granular

Corals

Stromatoporeids

Crinoids

Brachiopods

Bryozoans

Sponge
Spicules COLOUR

Buff

Grey

Brown

B

Westmount 1

1st Column:

PETROLOGY

Dolomite	
Argillaceous Dolomite	
Cherty Dolomite	
Limestone	
Anhydrite & Gypsum	
Shale	
Bioherm	
Pyrite	

2nd Column:

BEDDING, ETC.

Bedded	
Poorly Bedded	
Indefinitely Bedded	
Flow-Layered	
Brecciated	
Unbedded or massive	
Irregular structure	
Rubblly and granular	

COLOUR

Buff	
Grey	
Brown	

3rd Column:

FAUNA

Corals	
Stromatopora	
Crinoids	
Brachiopods	
Bryozoans	
Sponge Spicules	

METHY FORMATION
SUBSURFACE CROSS SECTION C-D
— WATERWAYS AREA —

WITH TENTATIVE CORRELATIONS

Scale: Horizontal 1 inch = 5 miles

Vertical 1 inch = 20 feet

Datum: Base of Methy

Bottom of Upper Bedded Zone

Bottom of Upper Bedded Zone

Top of Stromatopora?

Top of Lower Crinoidal

Top of Lower Crinoidal

Top of Basal Bedded Zone

Base of Lower — ? Crinoidal

Biltmore 1

Vampire

Westmount 2

D

B29761