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The Geology of the Adair Marble Quarry Wiarton, Ontario

Julian V. Kanarek

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Julian V. Kanarek

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Conference Desk and Credenza
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Amabel Marble Quarried and Sawn
by
Angelstone Limited,
Cambridge, Ontario. 1981.

ABSTRACT

The Adair Marble Quarry is located 14 kilometres North of the Town of Wiarton on the East side of the Bruce Peninsula. This area is on the eastern margin of the Michigan Basin and the Middle Silurian dolostone extracted at the quarry is part of the concentric belts of Paleozoic formations that ring the Basin. The regional structure of the area is related to the Algonquin Arch, a basement feature attributed to progressive compressional and extensional stresses that are also responsible for the joint and fracture systems of the area. The present surface physiography was modified by the Wisconsin glaciation and post-glacial hydrology has produced an extensive karst system. The quarry has been operated at the present location by the Arriscraft Corporation of Cambridge, Ontario since 1979.

Dolostone of the Wiarton Member of the Amabel Formation is currently extracted at the quarry. Approximately 6 metres below the present quarry surface the Wiarton Member grades into the Transition Zone between the Wiarton and Colpoy Bay Members. Differences occur between these two units and also within each unit. The Wiarton Member is typically a medium-grained , porous, blue-grey mottled, light grey and white dolostone while the Transition Zone Beds are fine-grained to dense, dark blue-grey mottled, buff to buff-grey dolostone. The mineralogy is essentially constant between the units and consists predominately of dolomite with calcite, chalcedony, clay minerals, organic material and metallic minerals. An increase in chalcedony, clay minerals and metallic minerals occurs at depth. A change in the type of stylolites occurs with the individual, well defined type in the Wiarton Beds replaced by swarms of microstylolites in the Transition Zone Beds. The variations noted between the units can be attributed to a change in the original carbonate. The Wiarton Member represents a shallow, low energy shelf facies while the Transition Zone Beds are a more basinal facies.

Within the units variations in the amount and type of mottling are due to the organic content of the rock and the type of dolomitization. Areas of higher organic content have a darker colour and are comprised of incipient dolomicrite formed through a sulphate reduction process. Lighter coloured and white areas are comprised of a dolomite mosaic formed through freshwater/seawater mixing. The one constant feature of the rock is the presence of sub-horizontal fractures. These fractures can be accurately mapped by ground probing radar to a depth of 10 metres as an aid to quarry planning. All of these features vary in a random fashion and the characteristics of the rock cannot be ascertained before extraction.

ACKNOWLEDGEMENTS

The writer would like to express his appreciation of the contributions made by the following individuals. My advisor, Dr. C.G. Winder, for his advice, support and humour. Bern Feenstra of the Ministry of Natural Resources for providing funds for geochemical analysis and my parents for providing the remainder of the funds necessary for the completion of this report. Lastly I would like to thank Bevan Ratcliffe and Randy White of the Arriscraft Corporation for generously allowing access to the Adair Marble Quarry, which was the least they could do.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction and Previous Work

The Adair Marble Quarry is extracting Middle Silurian dolostone from the Amabel Formation of the Bruce Peninsula of Ontario. The Bruce Peninsula area consists of flat-lying Paleozoic carbonate strata ranging in age from Ordovician to Devonian, on the eastern flank of the Michigan Basin. These strata have been extensively studied in both outcrop and subsurface in the Bruce Peninsula area, Manitoulin Island, Southwestern Ontario and Michigan and adjoining States. The major surface feature of the area is the Niagara Escarpment.

Williams (1919) published a comprehensive report and geological map that included the Silurian of the Bruce Peninsula. In the 1940's, J.F. Caley commenced systematic stratigraphic studies in the district culminating in a preliminary map of the Owen Sound area in 1945. This program of field study was continued in the late 1940's by B.A. Liberty who extended the studies northward to Manitoulin Island and eastward into Lake Simcoe area (Liberty, 1957 and 1969). Bolton (1957) studied the Niagara Escarpment from Niagara Falls northward into the Bruce Peninsula and produced a detailed stratigraphic and paleontological paper on the Silurian of the Niagara Escarpment. B.A. Liberty and T.E. Bolton (1971) combined their efforts and published the first comprehensive report of the Paleozoic Geology the Bruce Peninsula area (a benchmark reference for the area). Detailed study of the lithostratigraphy of the Wiarton road cut (type section of the Amabel Formation) was performed by Mosher et al. (1978). The most recent work on the area is A.L. Smith and J.A. Legault's (1985) paper concerned with the preferred orientations of the Middle Silurian reefs of Southern Ontaio.

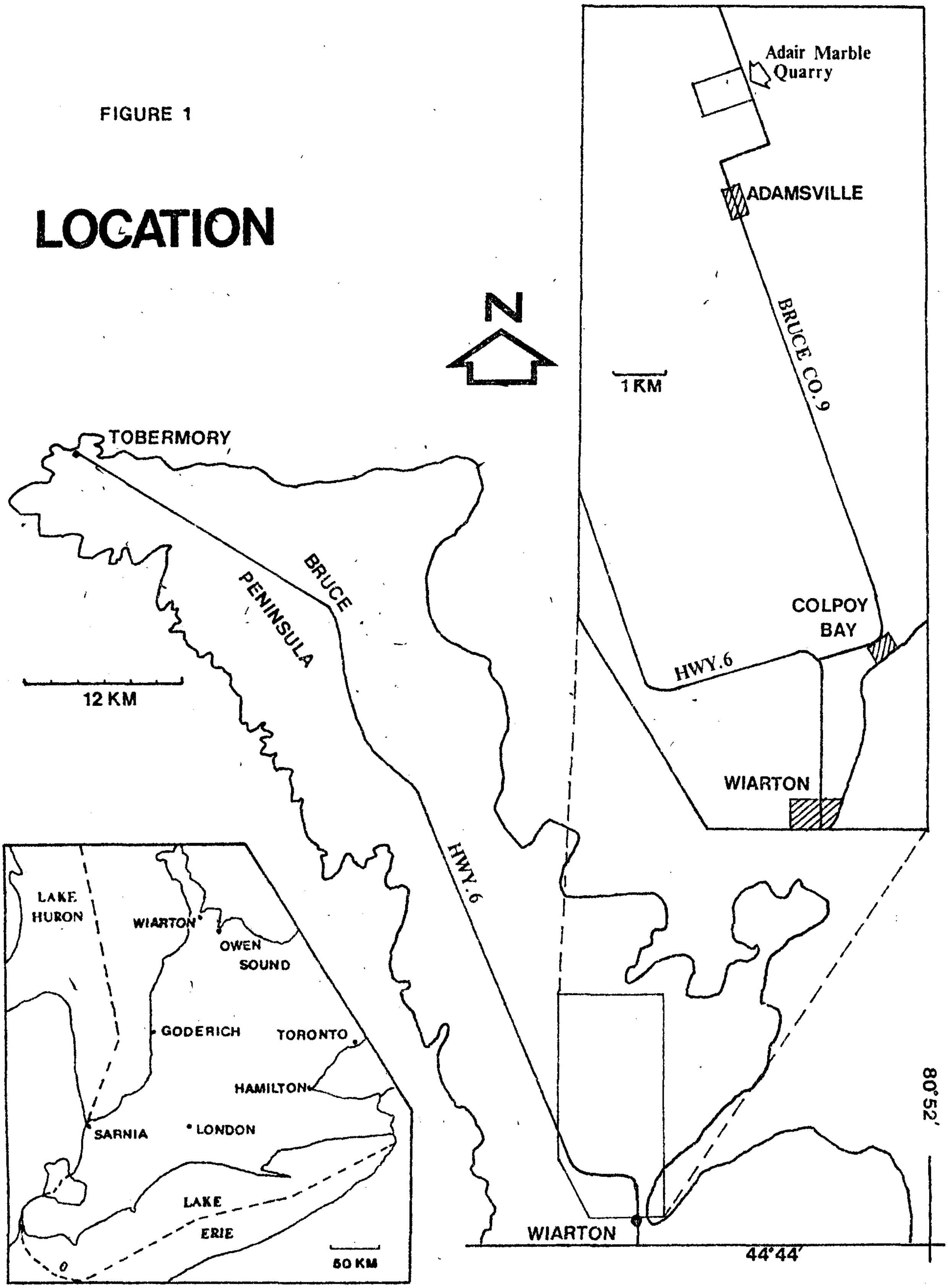
On a broader scale, the Paleozoic geology of Southern Ontario has been extensively studied in both outcrop and subcrop and many publications produced (Evans, 1950; Sanford, 1969; Sanford and Winder, 1972). Since the Bruce Peninsula area is considered to be part of the Michigan Basin, many reports concerning the origin and development of the Basin include details of the Bruce Peninsula (Lowenstam, 1950; Shelden, 1963; Shaver, 1977), and the Michigan Basin Geological Society has produced much useful information (Briggs and Briggs, 1976; Mosher et al., 1978; Barnes et al., 1978).

1.2 Location and Access

The Adair Marble Quarry is located (on the eastern side of the Bruce Peninsula) 14 kilometers North of Wiarton. Specifically the quarry is on Lots 7 and 8, Concession VIII, Albermarle Township, Bruce County, latitude 44° 52' 45" north and longitude 81° 10' 00" west. The quarry can be reached from Wiarton by following Ontario Highway 6 North to Bruce County Raod 9, and following this County Road through Colpoy Bay and Adamsville. Lots 7 and 8 are on the West side of the road just North of Adamsville (Figure 1).

FIGURE 1

LOCATION



1.3 A Brief History of the Quarry and Its Methods

The Adair Marble Quarry is owned and operated by the Arriscraft Corporation of Cambridge, Ontario, a wholly Canadian owned and operated company that has been developing, manufacturing and marketing high quality building stone from Ontario raw materials since 1924. The corporation consists of two major divisions; the Angelstone Division that manufactures sandstone by a proprietary process unique to North America, and the Adair Marble Quarries Division which extracts and converts quarry stone blocks into numerous natural building stone products. Arriscraft products are widely distributed throughout Eastern Canada and the Northeastern United States. Projects that have utilized "Adair Marble" include: the construction of a desk for the Prime Minister of Canada in 1981, the restoration of the first three locks of the Rideau Canal at Ottawa and the repaving of street sections in old Quebec City. "Adair Marble" is currently being considered for use in the construction of the new Canadian Chancery in Washington, D.C.

Dolostone of the Amabel Formation was chosen to become the "Adair Marble" because of its white colour and attractive blue-grey mottling, ease of extraction and plentiful supply. The Amabel Formation crops out on the eastern side of the Bruce Peninsula. Until the end of 1979, Amabel dolostone was quarried, at a rate of 15,000 tons per year, at Lot 4, Con. VIII, Albermarle Twp. When this site was exhausted the present "Adair Marble Quarry" was opened at Lots 7 and 8, Con. VIII with a potential of 6,000,000 tons of quarriable material on some 140 acres.

The Adair Marble is quarried through a combined process of drilling and blasting (Plate 2). Firstly, a closely spaced series of vertical holes are drilled to delineate blocks of stone of about 1 m X 1 m X 2 m. The "web" between the closely spaced holes is broken (broaching) using explosive detonating cord. The positioning of the explosives also forms horizontal fractures which eliminate the need for horizontal drilling. In some areas of the quarry the natural, sub-horizontal fractures in the rock delineate the bottom of the blocks. Once the blocks are extracted, they are weighed, numbered and inspected for fractures, vugs and other undesirable features. Blocks that meet the requirements are trucked to Arriscraft's Cambridge facility where they are stored until required for specific projects. The stone is cut into slabs with a one meter diameter diamond saw (Plate 3), then passed through a line of special continuous cutting, breaking and polishing equipment that, like the manufactured sandstone plant, was designed and built by the Arriscraft engineering department. The finished products range from; sills, coping, hearth slabs and paving blocks to furniture and other polished products.

The Arriscract Corporation is constantly researching and developing new extraction, processing and finishing methods and actively seeking new products.

1.4 Purpose and Methods of Investigation

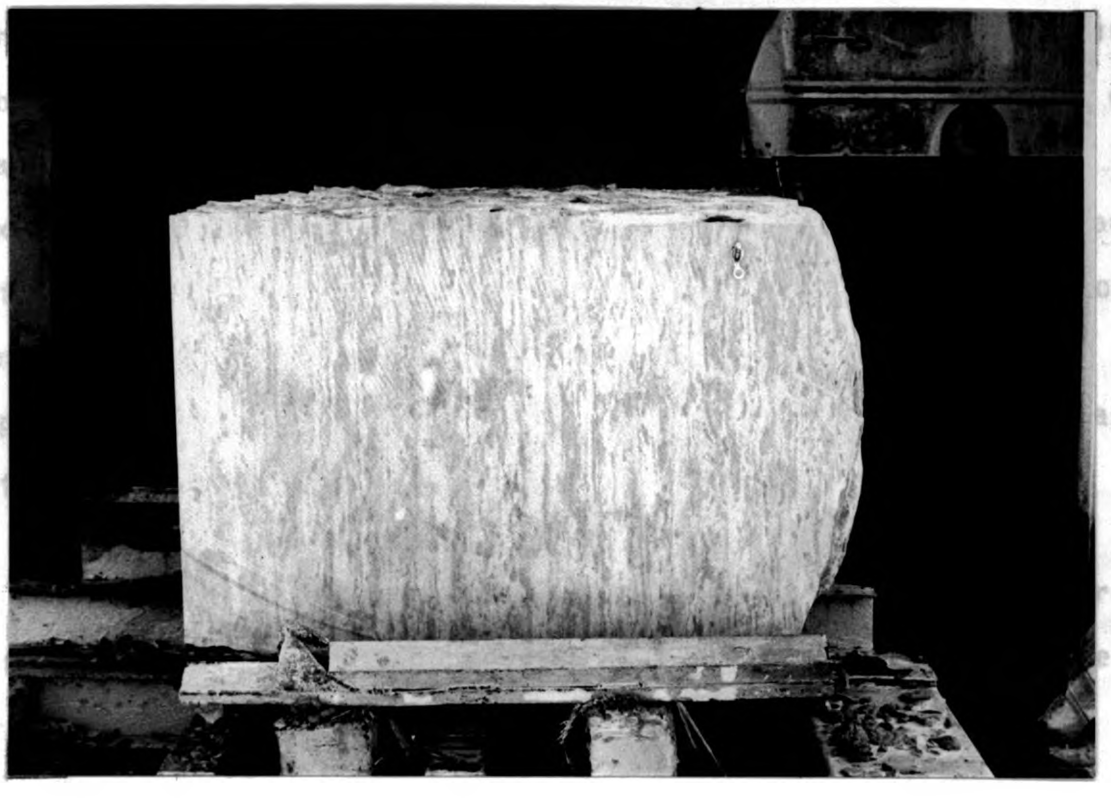
Amabel dolostone is quarried for the attractive blue-grey mottling, the form and abundance of which varies greatly over short

PLATE 2. The Adair Marble Quarry

PLATE 3. Adair Marble quarry block being cut with a 1 metre diameter diamond saw at Arriscrafts Cambridge facility.

PLATE 2

PLATE 3



distances. Variations are also seen in the porosity, mineralogy and chemical composition of the rock.

It is the purpose of this study to produce a synthesis of previous and original work that will provide some insight into the general trends and history of these variations and how they may effect the structural and aesthetic qualities of the rock. Also included in this study is the correlation of experimental geophysical data, provided by the A^3 Geophysics Company of Mississauga, with the rock record as an aid to long and short term quarry planning (see Chapter Six).

The study began with four days of field work at the quarry and in the surrounding area; Hope Bay, the Wiarton road cut and the old quarry at Lot 4, Con. VIII. The drilling and broaching methods used to remove the stone tend to obscure much of the fine detail on the quarry face and observations were limited to general features. Measurements of macroscopic features such as joints and fractures were made along with an extensive search through the rubble piles, where some features were more visible. Some hand specimens were taken, along with 10 meters of diamond drill core from A^3's August 1985 geophysical survey. Further hand specimens were collected during a visit to Arriscraft's cutting and finishing operation in Cambridge.

The majority of detailed work was carried out from the 10 metres of core which was first carefully logged and the breaks in the core were examined to determine which were true fractures and which were artifacts of the drilling (see Chapter 6). The core was then cut into 10 centimetre lengths and slabbed. The slabbed core was carefully examined with a binocular microscope and areas were selected for further study on the basis of unusual or distinctive features. These areas were chosen from the entire length of the core with the aim of establishing variations with respect to depth. Ten of these areas were used for the preparation of thin sections and the chips from which the sections were cut were stained with Alizarin Red-S (Allman and Lawrence, 1972) as a quick indication of the amount of calcite. The thin sections were used with a petrographic microscope for such things as mineralogy, grain size and texture. Because of the variability in the characteristics of the rock most observations were made with the aim of establishing trends and overall characteristics, although some specific features were studied.

In addition to microscopic examination, eight sections of the core were selected for geochemical analysis. These sections were chosen from different depths in the core and were also chosen as "pairs"; one piece showing predominately light colour and the other predominately darker colouration. Once chosen, these samples were pulverized and ground to less than 200 microns. All eight powdered samples were subjected to x-ray diffraction analysis (XRD) to determine calcite to dolomite ratios. Four of the samples were analyzed for their major oxide content using X-ray flourescent mass-spectromety (XRF), and all eight of the samples were analyzed by XRF for their trace element concentrations. The XRF analysis was performed to establish any geochemical reasons for the colour variation in the rock and to allow correlation with the geochemical analysis of the type section (Mosher et al., 1978).

From a more qualitative standpoint, several stratigraphic cross-sections were produced from water well records to provide correlation of the quarry with the type section and to determine the stratigraphic interval covered by the drill core.

CHAPTER TWO REGIONAL GEOLOGY

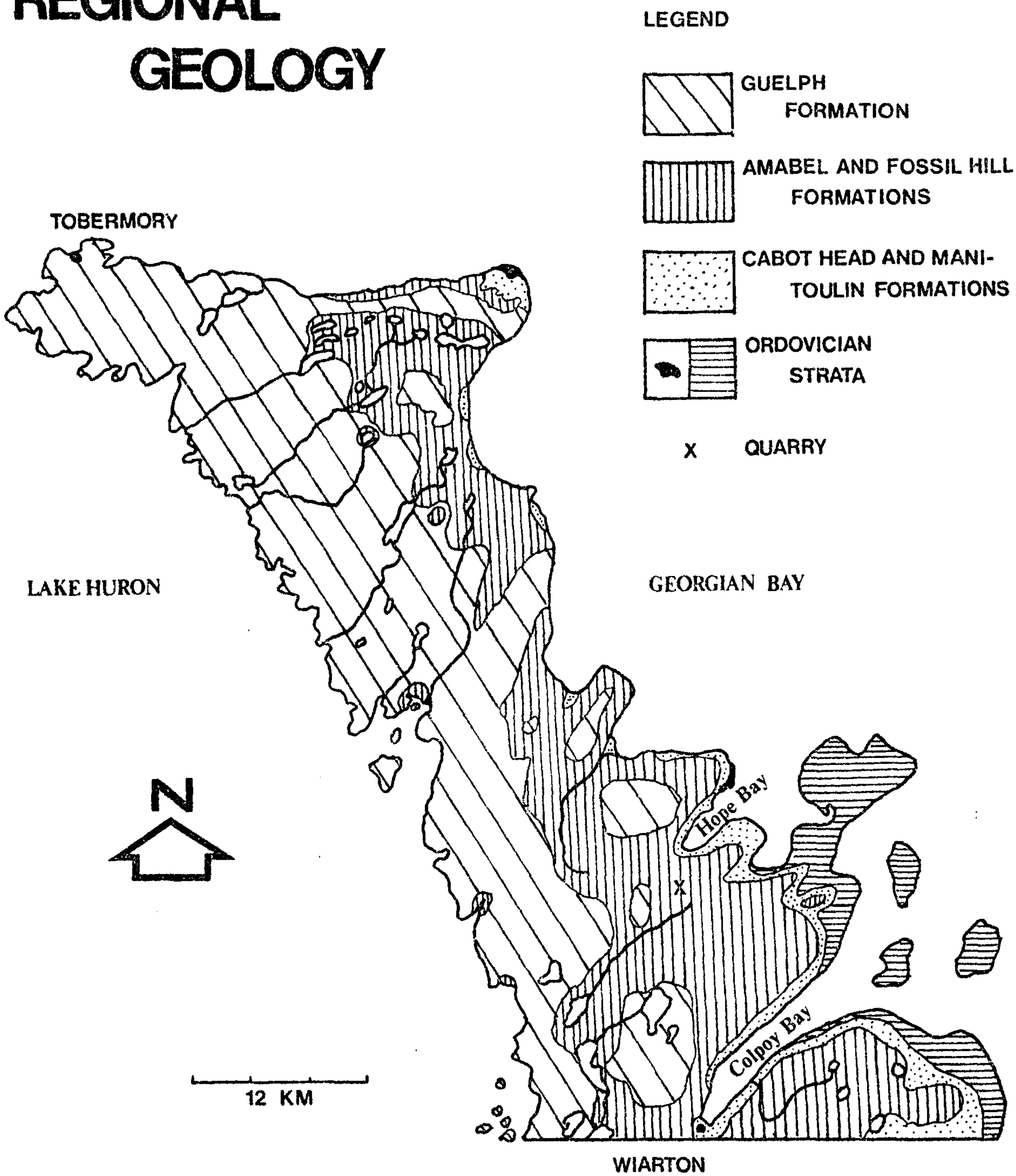
2.1 Introduction

The Bruce Peninsula area is underlain by strata that range in age from Ordovician to Devonian (Figure 2). These undeformed stata form part of the concentric belts of Paleozoic formations that dip toward the centre of the Michigan Basin. The major physiographic feature of the Bruce Peninsula is the Niagara Escarpment and for the most part the area lies above this cuesta with only a thin belt following its base along the eastern shore. The lowlands to the east of the escarpment are made up of Cambrian and Ordovician strata up to 600 meters thick. The escarpment comprises rocks of Middle Silurian age and to the west a column of Cambrian, Ordovician, Silurian and Devonian strata reaches a maximum thickness of 1,525 meters near Sarnia, Ontario. All formations from the Upper Ordovician Whitby outcrop within the Bruce Peninsula area and the presence of older rocks is known from subsurface studies (Evans, 1950).

The primary structural feature of this part of the Michigan Basin is a broad, positive basement lineament known as the Algonquin Arch. By plotting the contours of the Precambrian basement it can be seen that this arch trends in a southwesterly direction from Owen Sound towards Lake St. Clair (Liberty and Bolton, 1971). The Bruce Peninsula lies on the Northwest flank of the Algonquin Arch and the Paleozoic rocks of the area dip westward from the Arch at approximately 5 meters per kilometer.

FIGURE 2

REGIONAL GEOLOGY



AFTER LIBERTY AND BOLTON (1971)

Other more localized structural features are recognized in the area but, for the most part, the Paleozoic strata are undeformed.

The entire area has been glaciated and thickness of drift varies from a few meters on the main peninsula to more than fifty meters south of Wiarton and Owen Sound (Sharpe and Jamieson, 1982). Since the last retreat of ice from the area, around 12,000 years ago, ground water circulation on the eastern side of the peninsula has produced one of the most mature assemblages of Karst landforms of Postglacial age in eastern Canada (Cowell and Ford, 1979).

2.2 Stratigrapy

The Amabel Dolostone extracted by the Adair Marble Quarry is of Wenlockian age and is therefore the part of the extensive Silurian system. This system has been studied in detail by many authors (Williams, 1919; Bolton, 1953, 1957; Sanford, 1969; Liberty and Bolton, 1971) and several stratigraphic classifications have been developed (Figure 3). The classification scheme best suited to this report is that of Bolton (1957) and the following sequence of stratigraphic units is based on his scheme. This report deals specifically with two members of the Amabel Formation, but for reasons of continuity the entire Niagaran sequence will be described.

Clinton Group

This group comprises a great variety of sediments ranging in age from the end of Alexandrian (Lower Silurian) sedimentation to the

FIGURE 3

STRATIGRAPHY

SERIES	BOLTON (1957)			SANFORD (1969)		LIBERTY AND BOLTON (1971)		
NIAGARAN	GUELPH FM		ALBEMARLE GP	GUELPH FM		GUELPH FM		
	ERAMOSA MB	AMABEL		ERAMOSA MB		MEMBER 3	c	LOCKPORT FM
	WIARTON MB			WIARTON MB	AMA-BEL		b	
	COLPOY BAY			COLPOY BAY MB				
	LIONS HEAD			LIONS HEAD MB			a	
	FOSSIL HILL FM		CLINTON GROUP	FOSSIL HILL FM		MEMBER 2		
						MEMBER 1		
	ST EDMUND FM			ST EDMUND FM	CATARACT GROUP	ST EDMUND MB	CABOT HEAD FM	CATARACT GROUP
	WINGFIELD FM			WINGFIELD FM		WINGFIELD MB		
	DYER BAY FM			DYER BAY FM		DYER BAY MB		
ALEXANDRIAN	CABOT HEAD FM		CATARACT GROUP	CABOT HEAD FM		CABOT HEAD MB		
	MANITOULIN FM			MANITOULIN FM		MANITOULIN FM		
	WHIRLPOOL FM			WHIRLPOOL FM		WHIRLPOOL FM		

stratigraphic break that occurs in the middle of the Niagaran series.

Dyer Bay Formation: The name Dyer Bay was applied by Williams (1919) to an impure dolostone lense that disconformably overlies the Alexandrian Cabot Head shales at Dyer Bay. The Dyer Bay has been traced from north of Owen Sound, through the Bruce Peninsula and Manitoulin Island into Michigan (Sanford, 1978). The formation is everywhere a thin-bedded, brownish grey to blue-grey, finely crystalline to dense dolostone, with numerous green to grey shale partings (Liberty and Bolton, 1971). Toward the base of the formation the beds become thicker, grey to brown, finely crystalline to dense dolostone with thin intraformational conglomerate lenses present. The formation is of a fairly uniform thickness that averages 5 meters (Bolton, 1957).

Wingfield Formation: The Wingfield (Williams, 1919) is separated by a sharp lithological break from the underlying Dyer Bay dolostones. The formation is characterized by green to greenish grey shales and interbedded green to brown, dense, argillaceous dolostones (Bolton, 1957). The vertical extent of this unit varies irregularly although in the Hope Bay area it is a uniform 4.5 meters.

St. Edmund Formation: The term St. Edmund was proposed by Williams (1919) for the thin unit of thin-bedded, brown, fine grained to dense dolostones that overlie the Wingfield Formation. The lower contact of this formation is not seen in the area but its thickness is estimated at 2.5 meters (Bolton, 1957).

Fossil Hill Formation: The St. Edmund dolostones grade into the Fossil Hill Formation (Bolton, 1953) which is the uppermost unit of the Clinton Group. This formation is a uniform, thin and unevenly bedded, brown, fine grained to crystalline dolostone, further distinguished by the abundance of the brachiopod Pentamerus oblongus (Bolton, 1957). The base of the formation has a fairly high argillaceous content and the upper 0.5 meters contain chert lenses and nodules. The formation has a thickness of between 3 and 4 meters in the Wiarton area and is easily distinguished from the overlying Amabel Formation.

Albemarle Group

This group is comprised of the remaining dolostones of the Niagaran, the Amabel and Guelph Formations. The lower units of this group produce the upper cliffs of the Niagara Escarpment and can be traced from central New York State across Ontario and Manitoulin Island into Northern Michigan (Bolton, 1957).

Amabel Formation: Bolton (1953) proposed this name for the main mass of dolostones that overlie the Fossil Hill Formation and underlie the Guelph Formation. At the Wiarton road cut, the type section for this formation, 40 meters of Amabel dolostones are visible and can be divided into four distinct lithological units. This four-fold division is visible throughout the Bruce Peninsula and as far south as Waterdown where the Amabel Formation grades laterally into the Lockport Formation. The Lockport is correlated with the Amabel and forms the crest of the Niagara Escarpment from Waterdown south into New York State.

Lions Head Member: This is the lowest member of the Amabel Formation and the contact with the underlying Fossil Hill Formation appears to be a sharp lithological break in some areas and a gradational contact in others. Because the lithology of the Lions Head Member is more closely allied to that of the Amabel dolostones is it included in this formation. The member consists of blocky, hard, conchoidal fracturing, dense, dark brown dolostone with an average thickness of 2.5 meters (Bolton, 1957).

Colpoy Bay and Wiarton Members: These two members form the stratigraphic interval in which the Adair Marble Quarry is located. Bolton (1953) proposed the name Colpoy Bay for the thick series of dolostones separating the Lions Head Member from the Wiarton Member. He also stated that the Colpoy Bay is the most constant stratigraphic unit in the Amabel Formation, and can be identified along the crest of the Niagara Escarpment from Georgetown to Cabot Head. Sanford (1969), on the other hand, states that the Colpoy Bay is a transitional facies between the Lions Head and Wiarton Members and that the Wiarton is the dominant facies throughout the entire length of the escarpment. Both the Wiarton and Colpoy Bay Members can be seen in the Wiarton road cut, the type section for the Members. The following lithology is visible.

The lower contact of the Colpoy Bay Member with the underlying Lions Head Member is gradational and the lower 4 metres of the Colpoy Bay contain thin, grey argillaceous partings and lenses. The rest of the Colpoy Bay is typically a massive, porous, fine-grained to dense, buff weathered, white to light grey to blue-grey dollostone. The presence of a minor fossil assemblage and of vugs containing gypsum has also been noted (Bolton, 1957). The Wiarton Member is characteristically a massive, porous, coarse-to fine-grained, blue-grey mottled, light grey, crinoidal dolostone, weathering white to buff, with purple mottled basal beds. Bioherms are known to exist in this member and the interbiohermal beds contain chert nodules and vugs lined with crystalline calcite (Bolton, 1957).

The contact between the Colpoy Bay and Wiarton members is gradational and Bolton (1953) separated them at the level above which the rocks are predominately blue-grey mottled, crystalline, fossiliferous dolostones. Later studies by Mosher et al (1978), of the Wiarton road cut, attempted to fix the position of the contact by a variety of methods. The results of this study show a distinct transition zone between the two members with a thickness of 4.0 or 7.1 metres depending upon the method of analysis.

Eramosa Member: The upper contact of the Wiarton Member with the overlying Eramosa and Guelph dolostones is also the subject of some controversy. The Eramosa Member (Willims, 1919) of the Amabel Formation is a unit of varied thickness, lithology and stratigraphic position which is occasionally completely absent. Generally the Eramosa is a thin bedded, dark brown, fine-grained to sugary, highly bituminous dolostone containing thin coral biostromes and lenses of crystalline dolomite (Bolton, 1957). This unit usually occurs between the Amabel and Guelph Formations but in some localities it is bounded above and below by definite Wiarton beds or grades laterally into massive Wiarton bioherms. In other areas, the Eramosa is completely absent with the Guelph Formation resting directly on the Wiarton. These variations are attributed to the depositional environment present at the close of Amabel sedimentation. The Eramosa was deposited as interreef lagoonal or flank sediments and its development is directly related to biohermal accumulation at the close of Wiarton sedimentation (Liberty and Bolton, 1971).

Guelph Formation: The Guelph Formation (Williams, 1919) is the upper-most of the Middle Silurian formations in the Bruce Peninsula area. The typical Guelph lithology is a buff and brown, fine and medium crystalline dolo stone that omits a distinct petroliferous odour when broken. Locally it may be greyish, tan, or dark brown, fine-to medium-grained, lithograpic to sub-lithographic and fine-to course-crystalline dolostone (Liberty and Bolton, 1971). The Guelph Formation is a reefal complex, with a much higher proportion of biohermal material than the underlying Amabel Formation, that varies in thickness from 30 to 52 metres in the Bruce Peninsula area (Bolton, 1957).

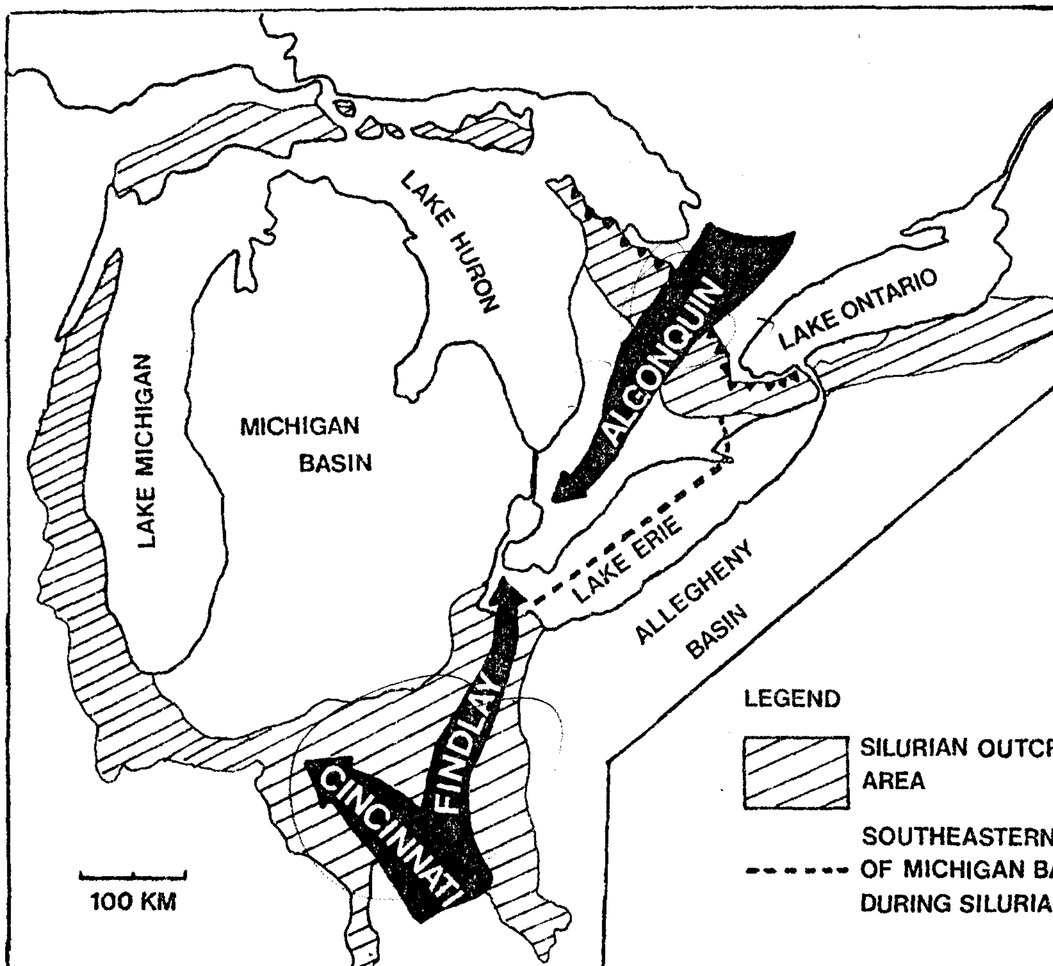
2.3 Structural Geology

The topography of the Bruce Peninsula is bedrock controlled, except where glacial drift is exceptionally thick. The major feature of the area is the Niagara Escarpment which exposes continous outcrop over long distances. Because of the low regional dip of the area, little structural data can be obtained from outcrop mapping. The major structural controls on the Paleozoic sedimentation of the area are related to the topography of the Precambrian basement. The Bruce Peninsula is on the northwest slope of a wide, low, south-westerly plunging area of the basement complex known as the Algonquin Arch (Brigham, 1972).

This feature has been in existence since the beginning of the Paleozoic as is evident by the arching of Cambrian sediments. The Algonquin Arch separates two major negative areas of the basement; the Michigan Basin and the Appalacian Basin (Figure 4), and is not so much a positive feature but a less negative feature between these basins (Brigham, op cit.). The second major structural control is the subsidence of the Michigan Basin which occurred mainly during the Late Silurian and Middle Devonian. Sanford et al. (1985) see the development of the Algonquin Arch and Michigan Basin as being controlled by compressional and extensional stresses, activated by plate tectonic motion and associated orogenic events operative beyond the margins of the North American craton. The abnormally high stress fields generated by plate tectonics are believed to have triggered basement arch rejuvenation and the inception and progressive development of the Michigan Basin. The attitudes of the Paleozoic strata, relative to the basement, are those of

STRUCTURAL GEOLOGY

FIGURE 4



LEGEND

SILURIAN OUTCROP AREA

SOUTHEASTERN MARGIN OF MICHIGAN BASIN DURING SILURIAN TIME

NIAGARA ESCARPMENT

BASEMENT ARCH

AFTER SANFORD (1969)

FIGURE 5

DISTRIBUTION OF JOINT PATTERNS

AFTER BRIGHAM (1972)

initial depositional angle (Liberty and Bolton, 1971).

As the Michigan Basin subsided, a series of "rolls" occurred on the northern flank of the Algonquin Arch. These radial linear folds plunge toward the centre of the Michigan Basin in the same way that a circular filter paper will fold, at the edges, when it is placed in a funnel. The prominent inlets and headlands on the eastern side of the Bruce Peninsula are believed to be related to these "rolls", with the anticlines underlying the headlands and the synclines underlying the inlets. These "rolls" also play an important part in the Middle Silurian with reefs forming along the crests of the anticlines and inter-reffal material collecting in the synclines (Liberty and Bolton, 1971). Figure 6 shows structural lows in the subsurface that correlate with inlets on the eastern shore of the peninsula. The position of the Adair Marble Quarry in a shallow depression, that corresponds with Sydney Bay, suggests that the quarry is located in an inter-reef area and that the higher ground to the north and south may represent reef masses. Sanford et al. (1985) suggest that the above-mentioned "rolls" may be caused by vertical rotation (tilting) of individual fault bounded "megablocks" created by continued positive motion of the Algonquin Arch.

In the quarry area the important secondary structural features are joints and fractures. Field observations show that the joints are vertical with an average bearing of 260 degrees. Just east of the quarry, beyond Bruce County Road 9, some minor northerly trending joints were noted. These trends are consistent with Brighams (1972) analysis of joint systems in the area (Figure 5). The joints outcrop as solution widened fissures that narrow rapidly with depth (Plate 4) and are of various lengths. The development of these joint systems is believed, by Sanford et al. (1985), to be related to the movement of the Bruce tectonic megablock, and the joints represent the surface manifestation of a major fault system. Associated with some of these joints are sets of sub-horizontal, sub-parallel fractures (Plate 5). These fractures are not parallel to the bedding and do not have great lateral extent. Some of the fractures are open and contain clay and brecciated rock debris while others are closed and show only minor disruption of the adjacent rocks. The brecciation seen in some of the fractures, but not the fractures themselves, is most likely an artifact of the quarrying techniques since, in some of the fractures the brecciation is present only above the line of the fracture.

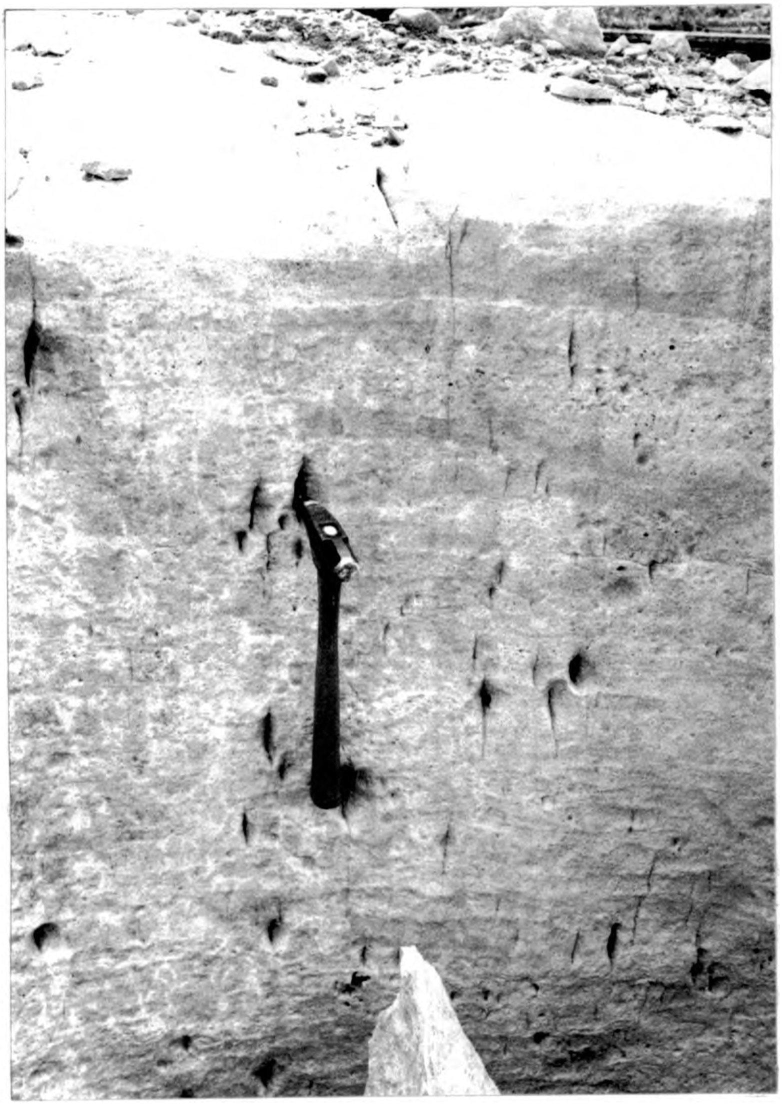
The joint and fracture systems are important to the quarrying operation because they can limit the size of the blocks being removed. One aim of the experimental geophysical surveys carried out in the quarry is to determine the location of fractures in the subsurface as an aid to quarry planning (Chapter Six).

2.4 Stratigraphic Interval of the Adair Marble Quarry

One of the aims of this study is to locate the stratigraphic position of the Adair Marble Quarry. Several stratigraphic cross

PLATE 4. Vertical joint surface exposed at the quarry.

PLATE 4



sections were constructed using water well drilling reports (Ontario Ministry of the Environment, 1979). The water well records give the surface elevation of the drill hole, a brief description of the rock types and the depth of the contacts between them. One section (Figure 6) was constructed along a line from the quarry to the type section at Wiarton to allow the correlation of studies performed at the type section with the quarry. The uncertainty and possible inaccuracy of the water well data prevents detailed correlation over the fourteen kilometers but the cross section does show the general subsurface trends.

The second cross section constructed (Figure 7) is a more detailed section from the old quarry, at Lot 4, Con VIII, to just south of the present quarry. The precise elevation of the quarry surface is known from the Ministry of Natural Resources site plan and this enabled the location of the A^3 drill hole, from which the core for this report was taken, to be plotted accurately. It can be seen from Figure 7 that the core samples the bottom of the Wiarton Member, the transition zone between the Wiarton and Colpoy Bay Members and possible the very top of the Colpoy Bay Member. This will be discussed at greater length in the consideration of Geochemistry (Chapter Five) and Sedimentology (Chapter Four).

2.5 Pleistocene Geology

With the exception of the prominant bedrock escarpment, the present surface physiography of the Bruce Peninsula is a reflection of

REGIONAL CROSS-SECTION

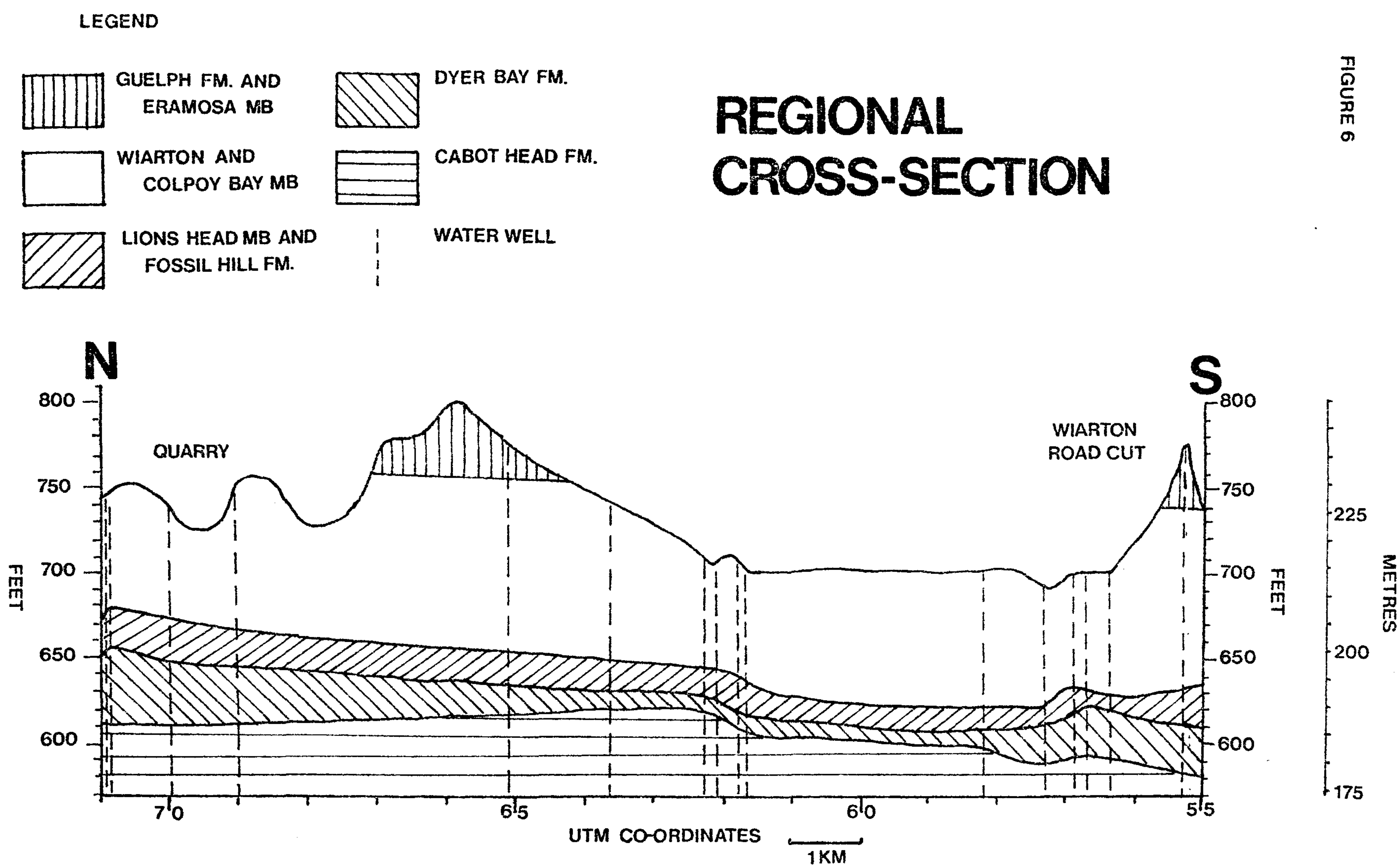
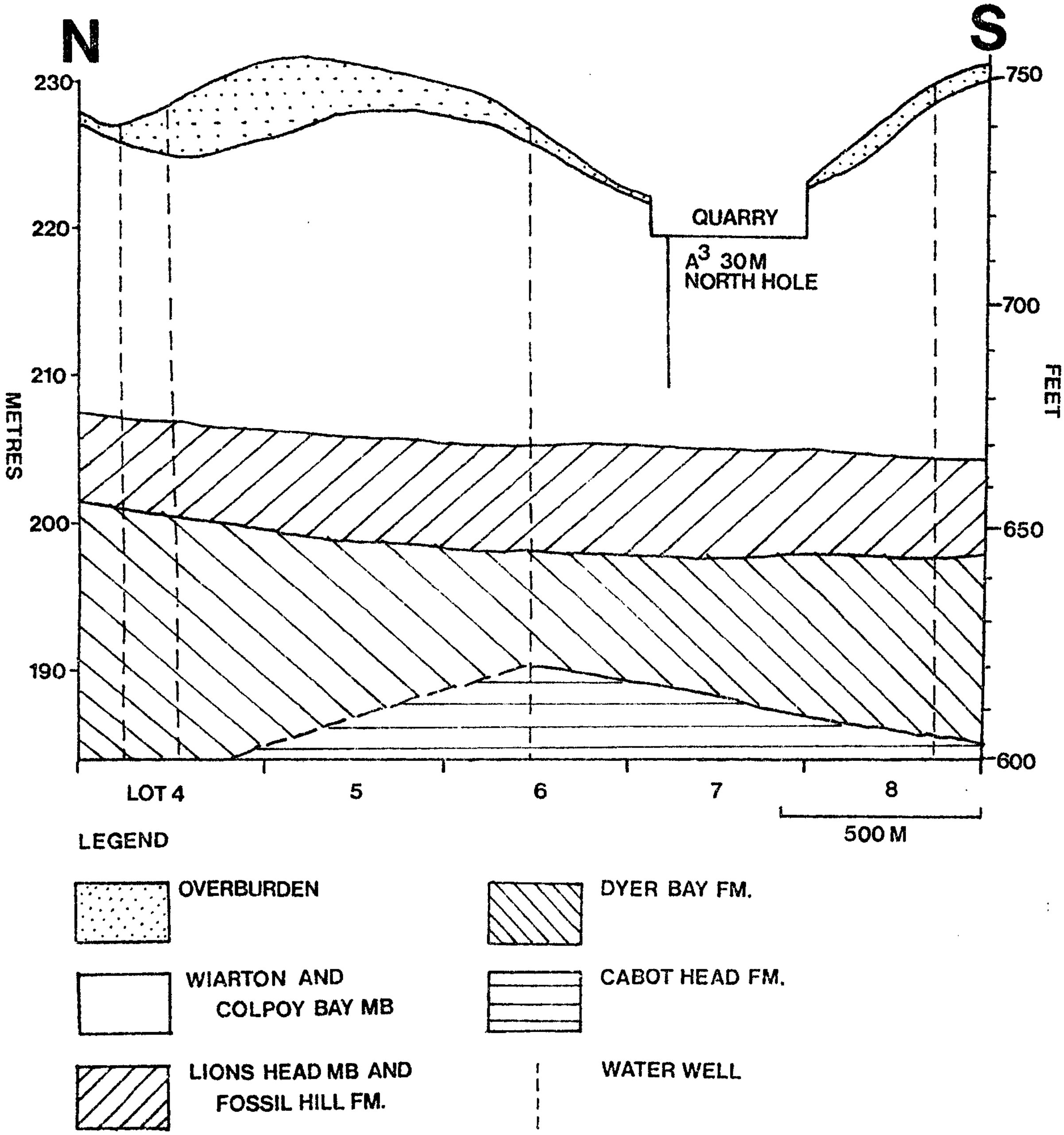


FIGURE 7

DETAILED CROSS-SECTION



glacial deposition. The Wiarton area features a prominant, drumlinized till plain that has been cut into by a series of glacial lakes. In the northern part of the area the till plain occurs intermittently on the flat lying Silurian carbonates west and south of the escarpment. At the escarpment edge and in the area of the quarry, the bedrock surface outcrops and glacial striae are visible, paralleling the northeast-southwest joint set. Cowell and Ford (1979) suggest that this joint system played a prominant role in guiding the glacial scour as the ice advanced from the northeast.

Further west and toward the south the till plain is more continuous and is crossed by a series of small end moraines and ribbed moraines. The till plain is made up of a compact to loose stoney, gravelly, sandy silt till, that is yellowish brown in colour (Plate 6). The till has an abundant dolostone content (52% of the total carbonate) derived from active glacial ice that eroded and abraded the underlying Paleozoic rocks (Sharpe and Jamieson, 1982). All the glacial features of the Wiarton area are the product of the Wisconsin Stage of glaciation, initiated about 100,000 years ago with the ice retreating from the area about 12,000 years ago.

In the quarry area the depth to bedrock varies greatly. In some areas the Amabel Dolostone is exposed at the surface and in others it is covered by substantial amounts of glacial drift. The drift is removed

PLATE 5. Vertical joint (A) and associated horizontal fracture (B). The regular vertical lines (C) are produced by the drilling process. Bar Scale = 1 m.

PLATE 6. Varved clay overburden before removal from the quarry area.

PLATE 5

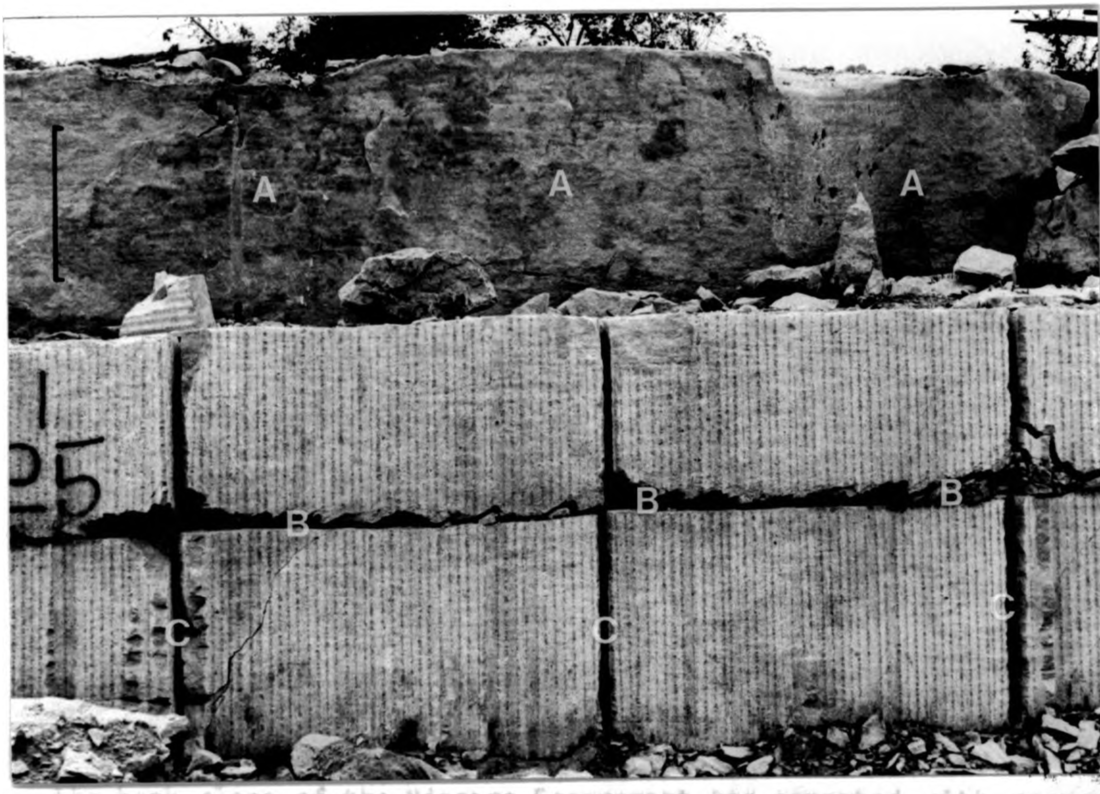
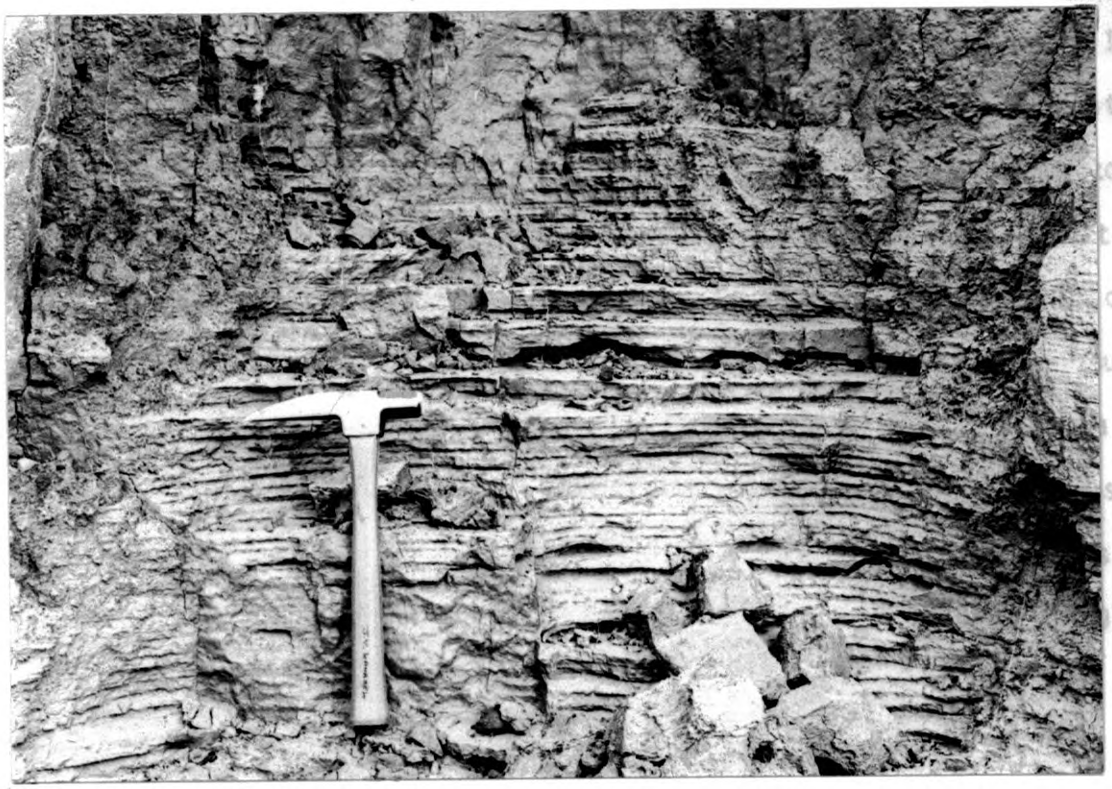


PLATE 6



from the quarry site by backhoes and bulldozers and is piled to form an earth beam around the active quarry workings.

2.6 Hydrogeology

Solution is quite common in the carbonate rocks of the Bruce Peninsula. Dolostone solution pavements, formed by surface runoff, enhance the joint patterns of the area to produce grikes (solution fissures). The joint sets of the area also control the flow of ground water down to the shales of the Wingfield and Dyer Bay Formations that act as the regional aquiclude.

Since the retreat of the Wisconsin ice, normal channel drainage on the back slope of the Niagara Escarpment has competed with ground water drainage to the scarp foot resulting in the progressive karstification of the underlying carbonates. Near the scarp face, and underlying 13% of the surface area of the peninsula, is a zone of holokarst dominated by vertical drainage and lacking normal surface channels. This zone of holokarst extends up to 3 kilometers westward from the cuesta and includes the area of the Adair Marble Quarry. The remainder of the peninsula has surface flow draining to sinkholes and normal surface drainage westward to Lake Huron. The relative immaturity of the karst is indicated by the presence of numerous intermittent springs as opposed to a few perennial springs at the foot of the escarpment, thus, the holokarst areas have non-integrated drainage (Cowell and Ford, 1980).

In an earlier study by Cowell and Ford (1979) an interesting feature of the ground water chemistry was noted. The total hardness (Ca^{2+} and Mg^{2+} as $CaCo_3$ in solution) of the ground water is higher at the springs of the underground drainage than at the sinks. These ground waters were already saturated with respect to calcium and magnesium and the increased total hardness is attributed to the addition of even harder subsoil seepage. At the springs a notable depletion of Ca^{2+} occurs in spite of the overall increase in hardness. This depletion is attributed to incongruent solution of dolomite which occurs when, following saturation of water wth respect to calcite and dolomite, a further solution of calcium rich dolomite accompanies precipitation of calcite. This process may explain the presence of crystalline calcite lining the vugs seen at the Adair Marble Quarry.

Other evidence of solution weathering seen at the quarry includes; solution pavements (Plate 7) and grikes on those surfaces that outcrop, channel features noted along the vertical sides of exposed joints (Plate 8) and channels on the horizontal fracture planes of blocks exposed in the rubble pile (Plates 9 and 10).

• PLATE 7. Solution pavement surface at the quarry.

PLATE 8. Solution features on a vertical joint surface exposed at the quarry. Bar scale = 20 cm.

PLATE 7

PLATE 8

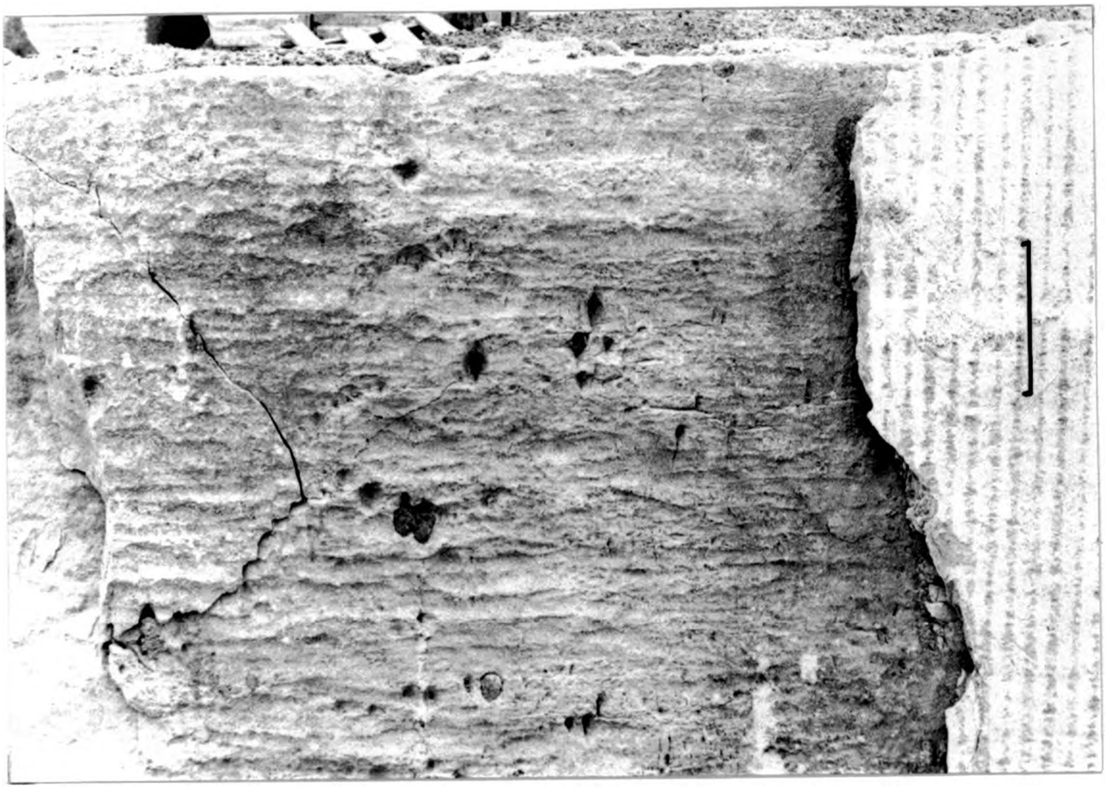


PLATE 9 and PLATE 10. Solution channel features seen on the horizontal surfaces of blocks in the rubble pile at the quarry.

PLATE 9

PLATE 10

CHAPTER THREE LITHOLOGY AND PETROGRAPHY

3.1 Introduction

The entire length of the slabbed care, as well as hand specimens, were examined in detail and lithologic features such as colour, porosity, macroscopic mineralogy and bedding were noted. For petrographic examination ten thin sections were prepared, nine from various positions in the core and one from a hand sample collected at the quarry. The rock chips from which the sections were cut were stained with Alizarin Red-s as a quick indication of calcite in each sample. Alizarin Red-s stains calcite and arogonite red while dolomite remains colourless.

3.2 Lithology

The 10 meters of drill core were slabbed, wetted and carefully logged. Attention was paid to such features as colour differences, macroscopic mineralogy and depositional or post-depositional features. Bolton (1957) described the Wiarton member as "a massive, porous, course-to fine-grained, blue-grey mottled, light grey, crinoidal dolostone, weathering white to buff...Bioherms are well displayed... mounds 6 to 15 feet high, 80 feet wide and 50 feet apart...separated by dipping and truncated interreef, thin-bedded, bituminous, slightly petroliferous dolostone". The basal beds of the Wiarton Member (the transition zone of Moser et al. (1978)) are described as "purple mottled and massive". On the basis of these descriptions and other observations the core used in this report can be divided into two lithologic units, definite Wiarton Beds and Transition Zone Beds. The division between these occurs at approximately 6 meters depth with the Wiarton Beds above 6 meters and the Transition Zone Beds below.

3.2.1 Wiarton Beds

These beds are characteristically medium-grained, porous, blue-grey mottled, light grey to white dolostone. Field observations at the Adair Marble Quarry reveal that the Wiarton Beds are massive with no evident bedding. At Hope Bay however, some evidence of bedding was seen in the form of differential weathering of beds (Plate 11). The grain size of the Wiarton Beds is relatively constant although some decrease in size is evident with increasing depth. The upper few meters of dolostone in the Wiarton Beds show a sugary texture while the lower areas are more massive.

Field observations and core analysis show the blue-grey mottling of the Wiarton Beds to have several forms. The colour of the mottling varies form a light blue-grey to a darker, more blue colour. The light blue-grey colour is due to more transparent aggregates of dolomite crystals while the darker blue colour appears to be related to finer grained dolomite with a higher bituminous content. Several different forms of mottling were noted. Irregular, sub-parallel, sub-horizontal bands are common and vary in thickness from a few millimetres to tens of centimetres. The lateral continuity of these bands is highly variable with some bands traceable for several metres and others tapering off after only a few centimetres. Many of the thicker bands of colouration are made up of smaller, irregular bands. Elongate, ovoid lenses of blue-grey colouration are also present in the rock, these vary in size form a few millimetres to several centimetres and most are oriented with their long axes sub-horizontal. These lenses occur either as groups forming irregular bands or as randomly distributed individual lenses, some of which appear to be fossil outlines (Plate 12). The concentration of colouration in the rock is also variable. Some layers of the core and exposed quarry faces are almost free of colouration while others are almost completely coloured. The boundaries between strongly coloured areas and uncoloured areas can be sharp or gradational (Plate 13).

Both the quarry faces and the slabbed core show a view of the rock cut perpendicular to the "bedding". At the Arriscraft cutting plant in Cambridge several pieces of Amabel Dolostone could be seen cut parallel to the bedding and showed features that were not observed at the quarry or in the core. Colouration that appears as sub-horizontal and planar in cross section is actually much more irregular. The bedding plane view shows many circular areas of colouration that correspond to "highs" in the layers of colouration (Plate 14). One block of stone seen

PLATE 11. Beds of the Amabel Formation exposed on the cliffs at Hope Bay. Bedding is evident in the Formation by differential weathering. The cliffs are approximately 60 metres in height.

PLATE 12. Typical Wiarton Beds showing the variation in the type and amount of blue-grey mottling.

PLATE 11

PLATE 12

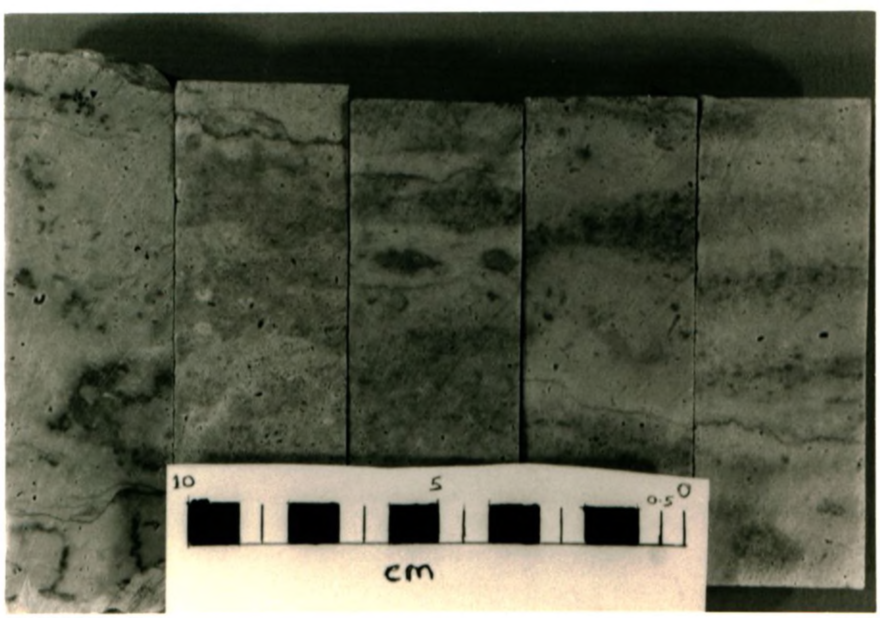


PLATE 13. Gradational contact between an area of light, sparse colouration (A) and an area of darker, profuse colouration (B).


A
B
L
R

PLATE 14. A slab of Amabel Dolostone cut parallel to the bedding, showing circular patterns of colouration.

PLATE 14

in the rubble pile at the quarry showed another feature only visible in cross section. The side of the block cut perpendicular to the bedding showed typical colouration bands and lenses (Plate 15). The side cut parallel to the bedding showed a profusion of fossil casts that were not visible on the vertical sides of the block (Plate 16). This shows a relationship between the biological characteristics of the rock and the colouration.

Fossil molds are an important contributing factor in the porosity of the rock. Most pores are irregular in both size and shape but some are definitely casts of crinoid stems or brachiopods (Plate 17). The other major primary porosity, seen at the quarry and in the core, is vugs. These void spaces are elongated ovoids with their longest dimensions ranging from 1 centimetre up to 15 centimetres (Plate 18). The vugs, orientated with their long axes horizontal, occur in horizontal bands and one such band was penetrated by the core at 3.3 metres (Plate 19). All the vugs seen at the quarry and in the core are lined with well developed calcite crystals (Plate 20) and when tested with hydrochloric acid many of the smaller pores in the rock effervesced vigorously. This suggests that many of the smaller void spaces in the rock are also lined with calcite. Vugs are only seen in the upper part of the Wiarton Beds. Another important feature of the Wiarton Beds is fractures which are described in detail in Chapter 6. Associated with these fractures, in the upper part of the Wiarton Beds, is an orange colouration. The

PLATE 15. A block of Amabel Dolostone cut perpendicular to the bedding, showing bands and lenses of colouration.

Bar Scale = 5 cm.

PLATE 16. Bedding plane view of the above block, showing abundant fossil casts.

Bar Scale = 5 cm.

PLATE 15

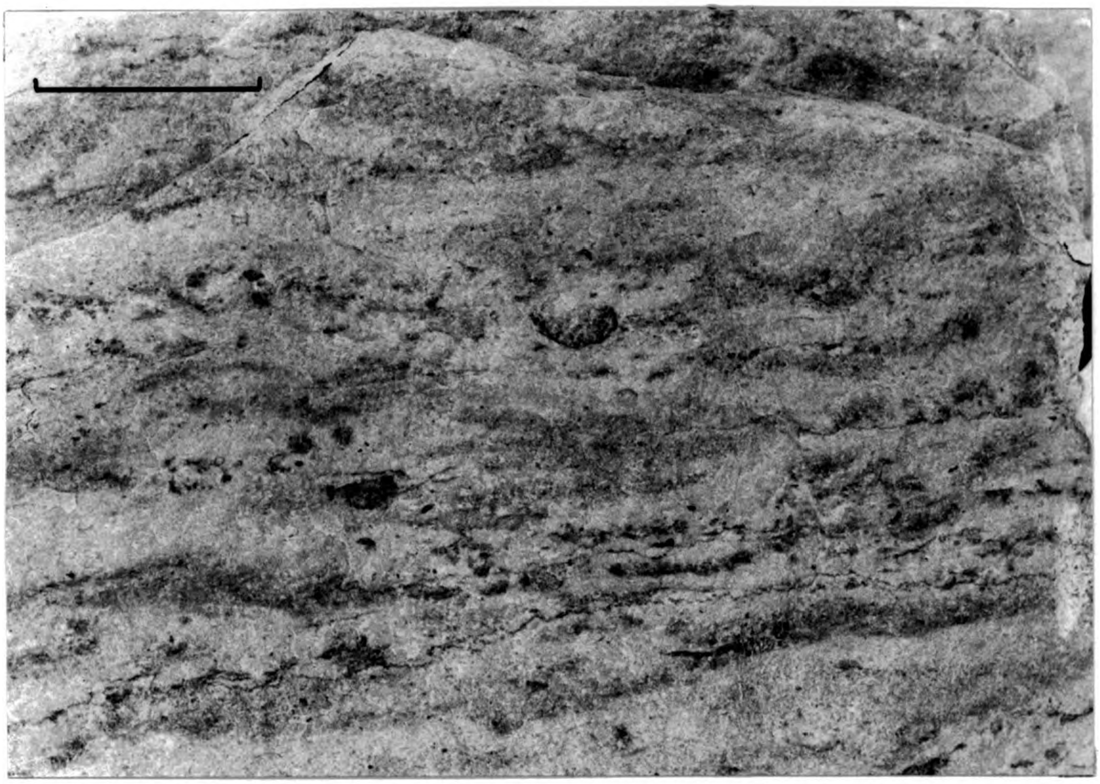


PLATE 16

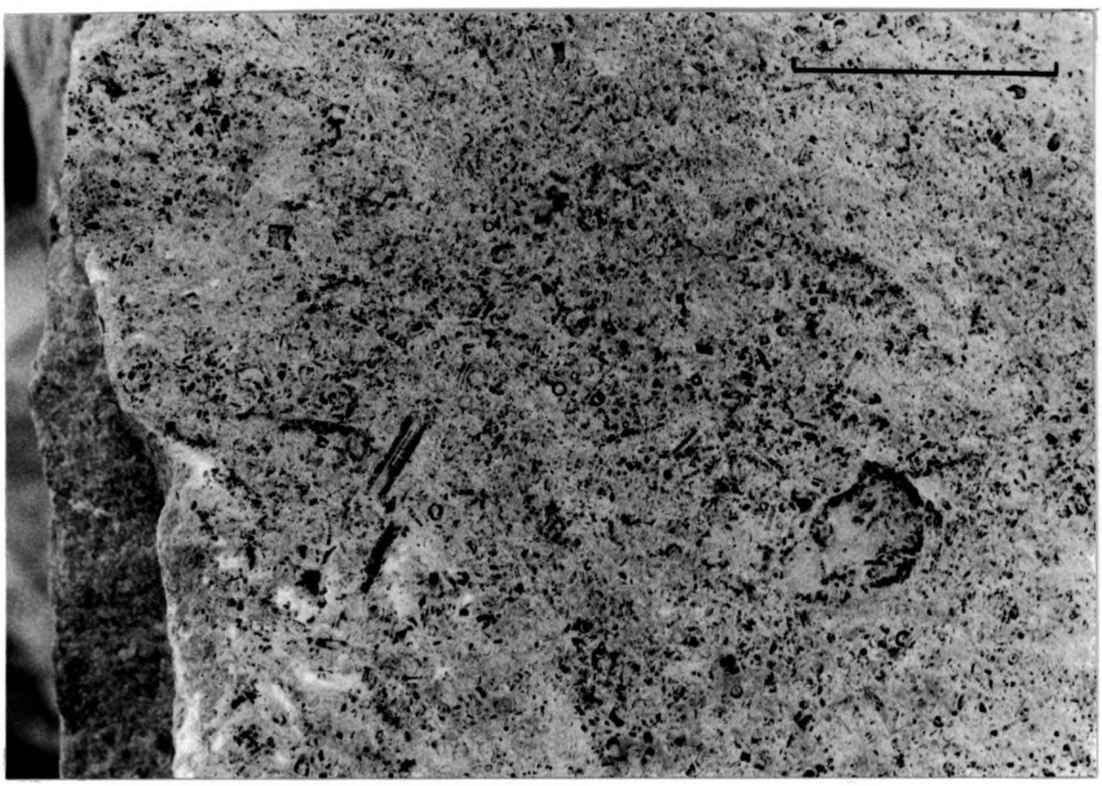


PLATE 17.. Fossil casts seen in the core.

A. Cross section of a crinoid column.

Bar Scale = 1 cm.

B. Cross section of a brachiopod showing ribbing.

Bar Scale = 1 cm.

PLATE 17A

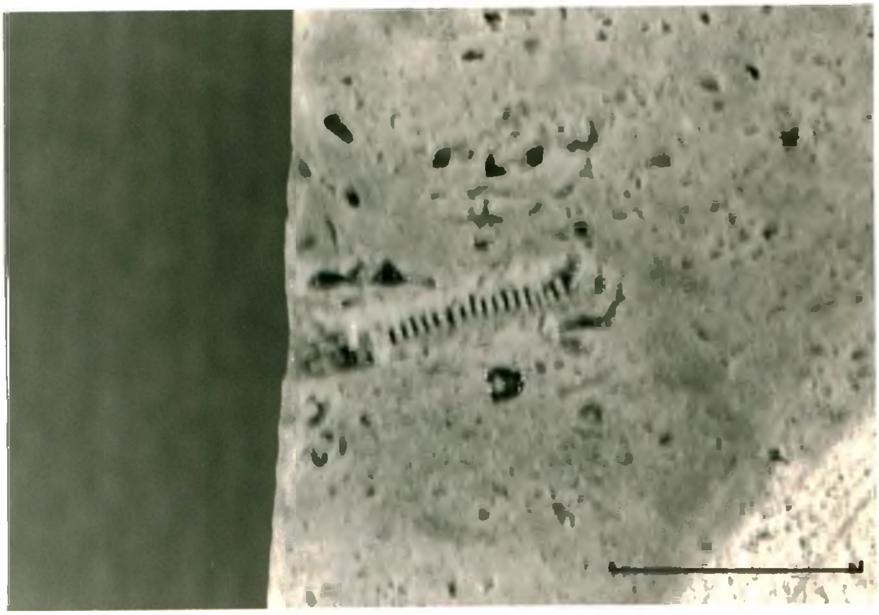


PLATE 17B

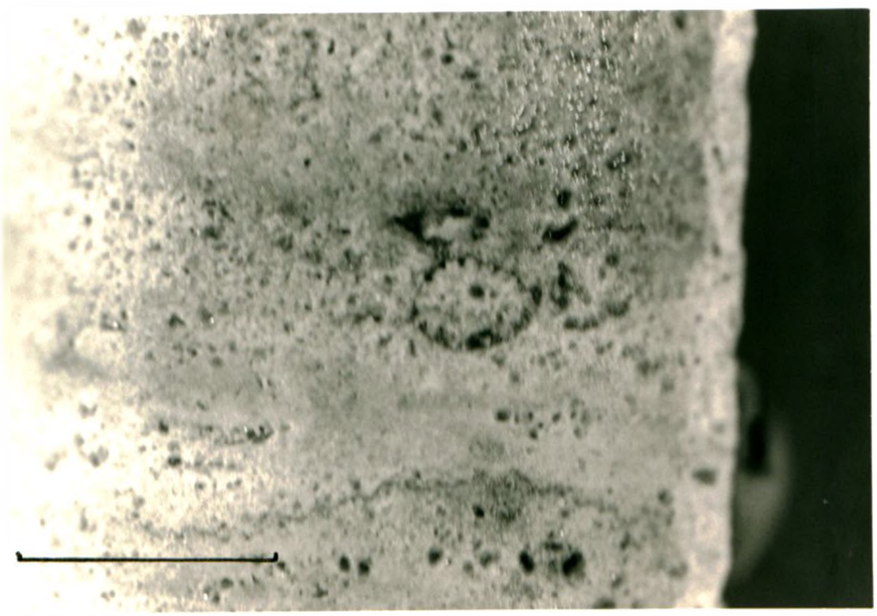
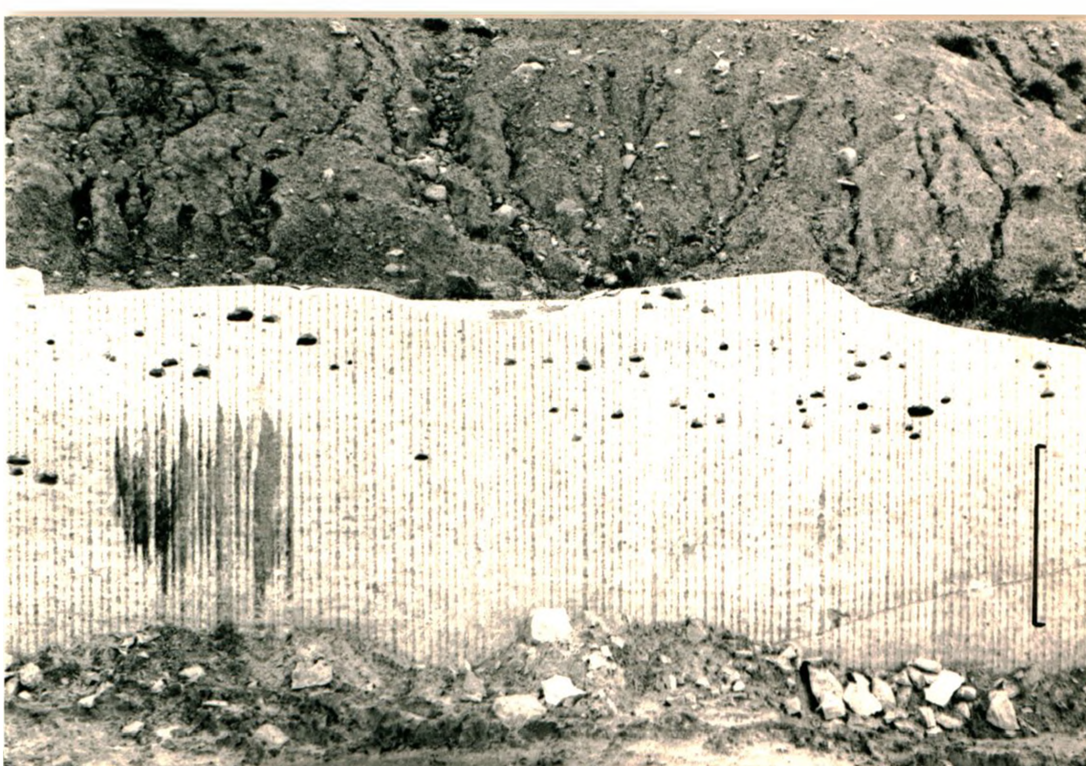


PLATE 18. Large vug, lined with calcite crystals.

PLATE 19. "Band" of vugs exposed along the quarry face.
Bar Scale = 1 m.

PLATE 18

PLATE 19



colouration does not extend more than a few centimetres beyond the fractures and is derived from glacial material washed into the fractures from the surface. Both the fractures and the orange colouration can be considered post-depositional features as can the calcite crystals lining the vugs.

Other post-depositional features seen in the Wiarton Beds are stylolites. These are formed by pressure solution and result in the formation of thin seams of insoluable material that are visible with the naked eye. In the Wiarton Beds the stylolites are well developed with an average amplitude of 3 millimetres (Plate 21). Bands of blue-grey colouration are often truncated by stylolites and in some cases the porosity of the rock is lower in the vicinity of a stylolite. A very small number of vertical tension cracks can be seen in the Wiarton Beds and hydrochloric acid testing shows them to be filled with clear, crystalline calcite (Plate 22).

3.2.2 Transition Zone Beds

The contact between the Wiarton Beds and underlying Transition Zone Beds is gradational but occurs over a relatively short distance. The division was drawn at 6 meters depth because of changes in a number of features in the rock. The Transition Zone Beds are generally fine-grained to dense, dark blue-grey mottled, blue to blue-grey dolostone. As shown by this description the most obvious change between the Wiarton Beds and the Transition Zone Beds is colour. The rock becomes buff-grey rather than grey-white and the abundance and type of

PLATE 20. Inside surface of a vug showing the crystalline calcite lining. Bar Scale = 1 cm.

PLATE 21. Typical Wiarton Bed stylolite. Scale in cm.

PLATE 20

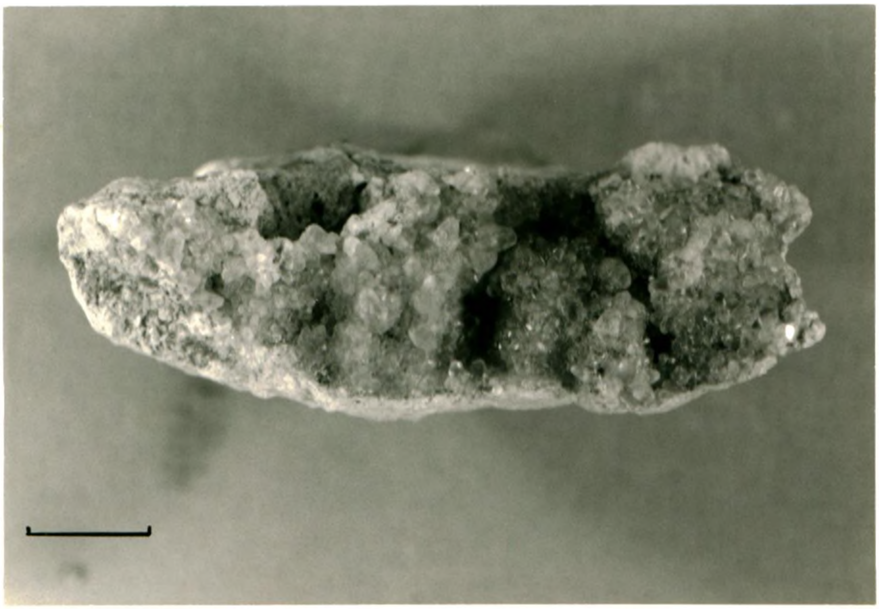
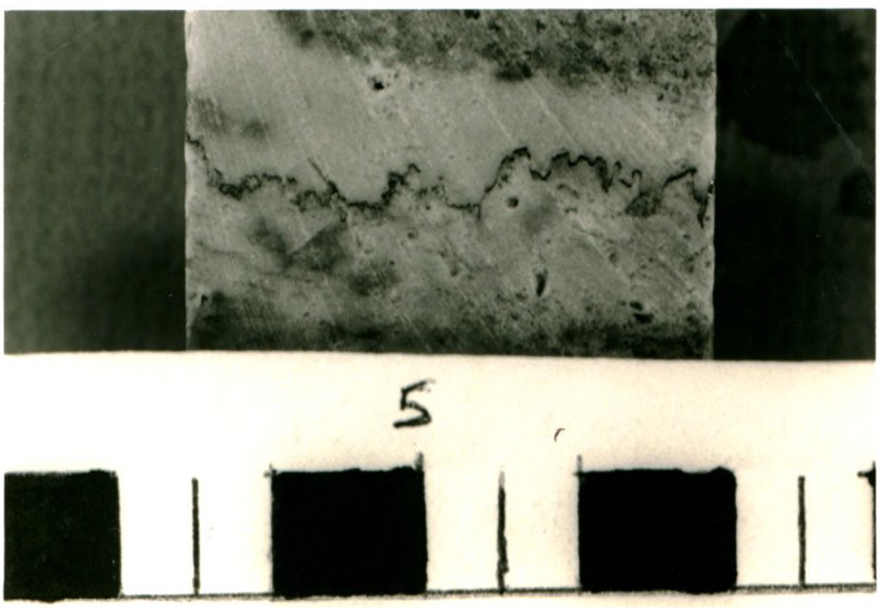


PLATE 21



changes. In the meter of core directly below the contact there is less than 5 percent blue-grey colouration, and where the colouration becomes more abundant it is a much darker blue-grey than in the Wiarton Beds (Plate 23). The contacts between the areas of colouration and the rest of the rock are more sharply defined in the transition Zone Beds. The grain size of the dolomite becomes progressively finer with depth below the contact with a reduction in porosity. Vugs and fossil molds are absent below 6 meters and many of the pores that are present are filled with white, very fine-grained chalcedony. This pore filling chalcedony first appears at 6 meters and increases in abundance to a depth of 9 meters below which it is absent, most likely due to the decreased porosity in the lowest part of the core.

Fratures and tension cracks are still evident in the Transition Zone Beds with the only change being the absence of orange staining in the areas of fracture. This is due to a lack of glacial clay penetrating to this depth. The other major difference between the Transition Zone Beds and the Wiarton Beds is the nature of the stylolites. In the Transition Zone the well defined, sutured stylolites are replaced by swarms of microstylolites (Plate 24). Wanless (1978) attributes this change to an increase in the amount of insoluable and platy material in the rock. The material concentrated in the microstylolites has an orange brown colour and this suggests a concentration of iron oxide into the stylolites from the surrounding rock. It is therefore assumed that the buff colouration in the rock is due to an increase in the amount of iron in the dolomite.

PLATE 22. Vertical tension cracks filled with calcite (A) associated with a stylolite (B). Scale in cm.

PLATE 23. Typical Wiarton Bed (A), Contact area between Wiarton Member and Transition Zone (B), Transition Zone Beds just below contact (C) and typical Transition Zone Bed (D). Scale in cm.

PLATE 22

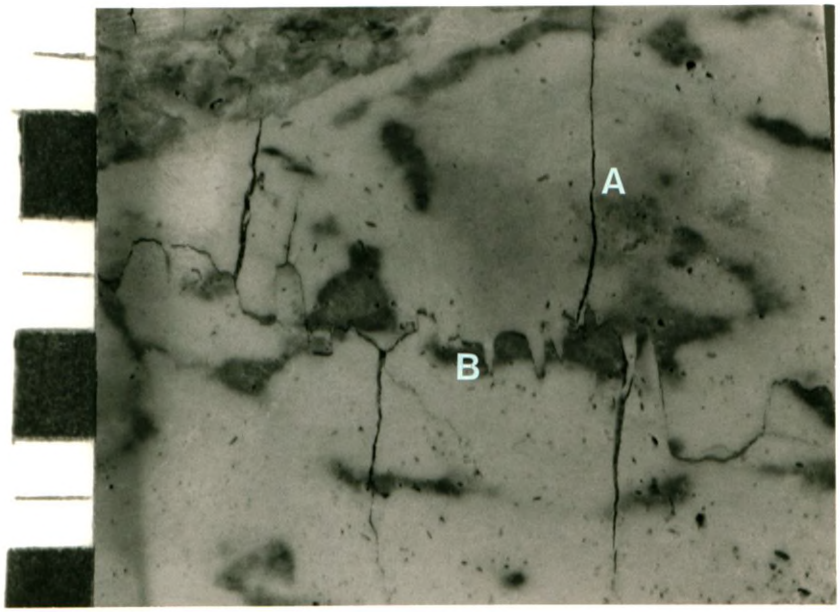


PLATE 23

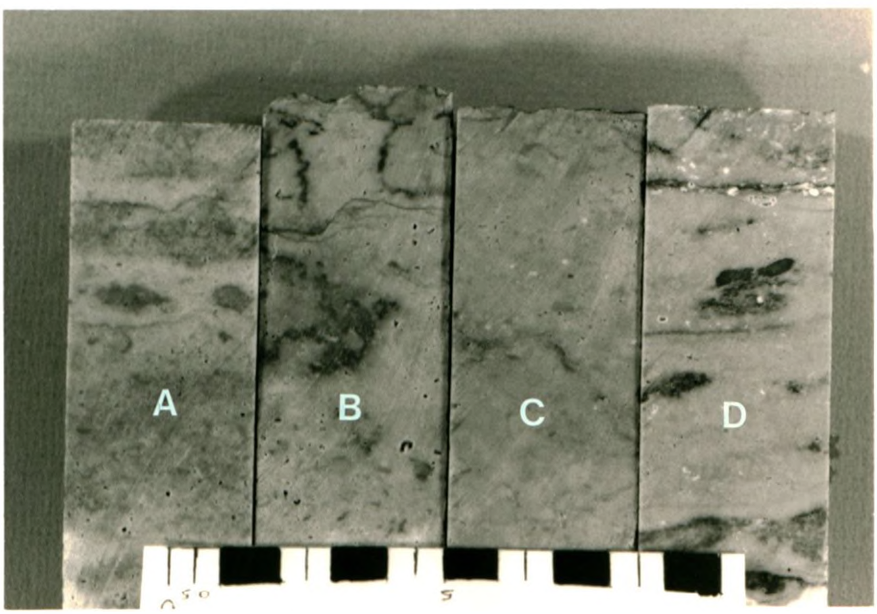
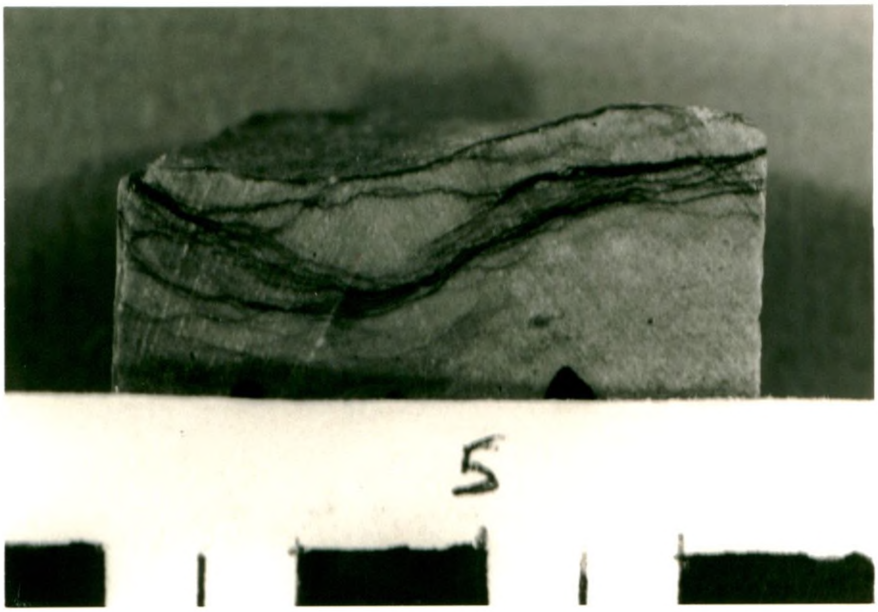


PLATE 24. Typical Transition Zone microstylolite swarm. Scale in cm.

PLATE 24



It can be seen that as depth increases below 6 meters the typical Wiarton lithology undergoes a gradual change towards the typical Colpoy Bay lithology described by Bolton (1957) as "massive, porous, fine-grained to dense, buff weathered, white to light grey to blue-grey dolostone".

3.3 Petrography

3.3.1 Mineralogy

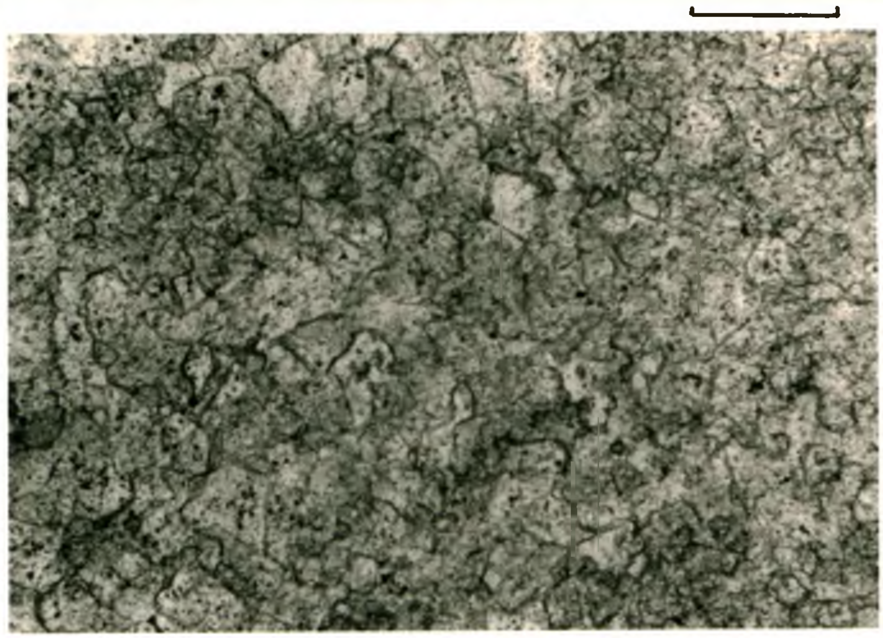
Microscopic examination of the thin sections show that this part of the Amabel Dolostone is composed almost entirely of carbonate minerals. After staining with Alizarin Red-s the rock showed no significant colouration which indicates that the carbonate mineral is dolomite. The core from which the sections were cut represents only a very small amount of the Amabel Formation and qualitive tests performed on the core and in the field show that a small amount of the carbonate in the formation is calcite. Another major mineral component of the rock is quartz which occurs in two different forms. The most abundant form is the cryptocrystalline variety known as chalcedony which occurs as pore fillings and silicified fossil fragments. The second occurrence of quartz is as very fine crystals scattered sparsely throughout the rock. The chalcedony is considered authigenic, formed from solution, while the fine, individual grains are thought to be of terriginous origin and transported by wind. The concentration of quartz varies through the rock with amount ranging from less than one percent up to five percent in some areas.

The other minerals are clays, organic (bituminous) material and metallic minerals. These constituents are disseminated through the rock and are too fine for detailed analysis. In regions of the rock where pressure solution has formed stylolites, the insoluable constituents have been concentrated into thin seams and are more readily identified.

3.3.2 Textures

The dolomite of the Amable Dolostone is a mosaic of subhedral and anhedral grains of various sizes. Individual grain sizes vary from less than 0.05 millimetres up to 1.0 millimetres, with an average size of 0.25 millimetres. The dolomite can be divided into three textural types on the basis of grain size. The medium grained xenotropic mosaic that makes up approximately 70 percent of the rock consists of very closely packed grains showing little intergranular porosity (Plate 25). Little cement can be seen between grains, although some very thin isopachous crusts occur. The boundaries between individual grains are sharply defined with some showing sutured or enfacial boundaries. No evidence of primary sedimentary features, such as bedding, are visible in this mosaic in thin section and grain elongation or preffered orientation was not seen. The general appearance of this dolomite mosaic is slightly cloudy and the cleavage is poorly defined.

PLATE 25. Thin section photomicrograph, plane polarized light. Dolomite mosaic showing scattered opaque material. Bar Scale = 0.2 mm.



The second textural type of dolomite has been termed "dolomicrite" for the purposes of this report. It consists of very fine-grained, less than 0.01 mm to 0.03 mm, cloudy masses of anhedral crystals which are extremely closely packed without intergranular porosity (Plate 26). The dolomicrite is usually found as lensoidal aggregates that have very sharp boundaries with the surrounding dolomite mosaic. The Lensoidal shape of many of these aggregates is suggestive of primary sedimentation. Dolomicrite also occurs as thin bands dispersed between the coarser grains of the mosaic and in some cases there is gradational contact between the fine and coarser grains. The lenses of dolomicrite are elongated with their long axes horizontal, the thin bands of dolomicrite are also oriented sub-horizontally.

The third type of dolomite has been termed "dolospar" and has a coarser grain size, 0.4 to 1.0 mm. These grains are subhedral to euhedral and transparent with well defined cleavage (Plate 27). Dolospar is found in porosity in areas of the rock and partially or completely fill some of the pores. In some areas the dolospar forms thin, irregular, discontinous bands running through the mosaic that are filled elongate void spaces. The concentration of dolospar is also higher in areas adjacent to some of the stylolites. Since the dolospar grains are larger and more euhedral they are not as closely packed as the grains of the mosaic resulting in a higher degree of intergranular porosity. The

PLATE 26. Thin section photomicrograph, plane polarized light. Lense of dolomicrite showing high organic content (A) and micritized envelope (B). Bar Scale = 1 mm.

PLATE 27. Thin section photomicrograph, crossed polars. Coarse grained, euhedral dolospar (A) in contact with finer grained, subhedral mosaic (B). Bar Scale = 1 mm.

PLATE 26

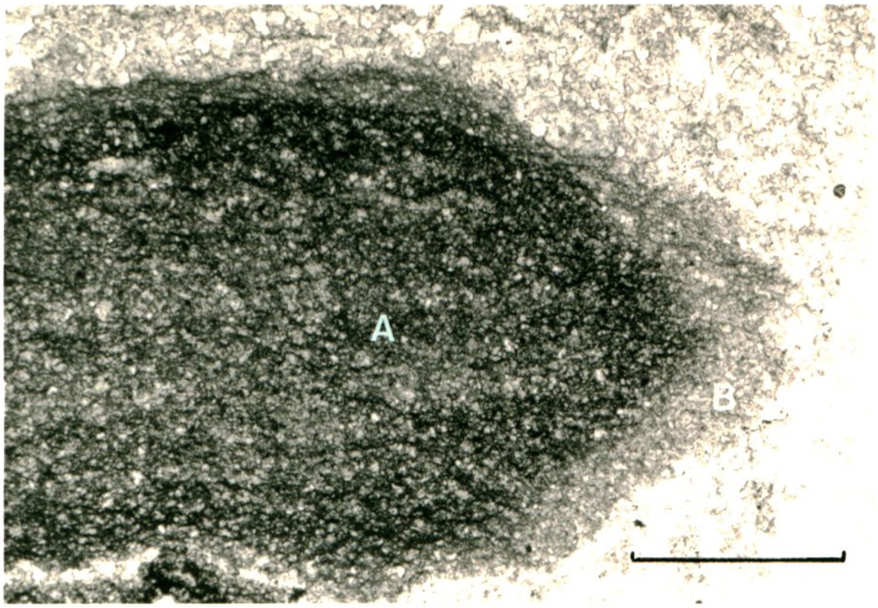
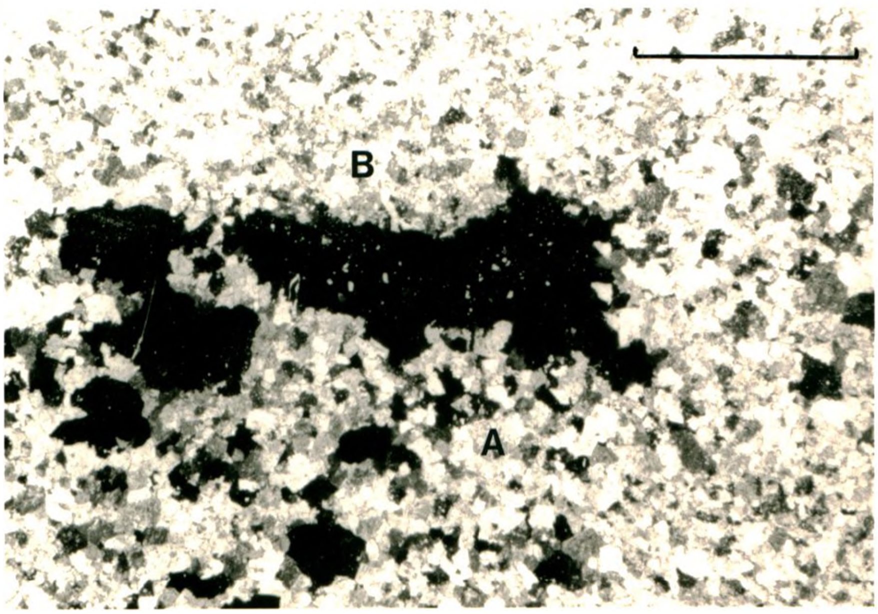


PLATE 27



boundaries between the dolospar grains and the adjacent mosaic or dolomicrite are sharply defined and in some cases the dolospar appears to have grown slightly into the surrounding dolomite. The dolospar does not show any features, such as bedding, and takes its shape from the shape of the pores it formed in. All three textural types of dolomite show a consistent decrease of grain size with depth which becomes more pronounced below a depth of 6 meters.

Chalcedony is the most abundant type of quartz and occurs in two different textures. Most of the chalcedony fills, partially or completely, some pores. Where the pores are completely filled the chalcedony occurs as radial fibrous aggregates that are clear under plane polarized light, although a few grains show a slight reddish brown tint. Under crossed polars the chalcedony displays a distinctive extinction cross (Plate 28). In partially filled pores the chalcedony occurs as a thin lining around the inside of the pore. This pore filling chalcedony first appears at the depth of approximately 6 meters in the core and is sometimes concentrated in the vicinity of stylolites. The second textural type of chalcedony was only noted at approximately 1.2 meters depth. In this area the chalcedony is in the form of silicified crinoid ossicles. These are hexagonal aggregates of five quartz crystals ranging from 0.5 to 1.0 mm. These aggregates have pentameral symmetry with evidence of a central canal in some of them (Plate 29).

The second type of quartz is extremely fine, with single grains

PLATE 28. Thin section photomicrograph, crossed polars. Pore filled with radial fibrous chalcedony. Bar Scale = 0.2 mm.

PLATE 29. Thin section photomicrograph, crossed polars. Silicified crinoid columnal. Bar Scale = 0.2 mm.

PLATE 28

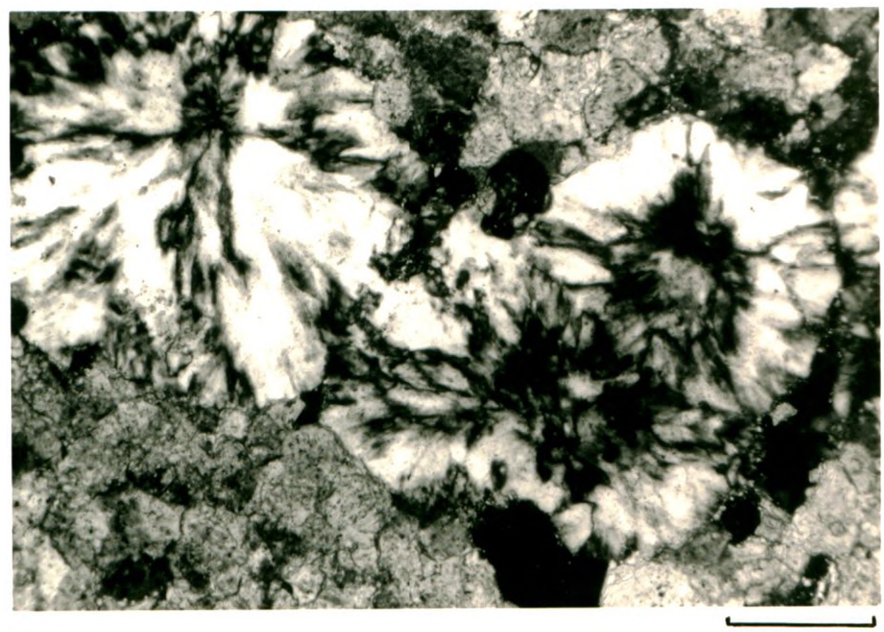
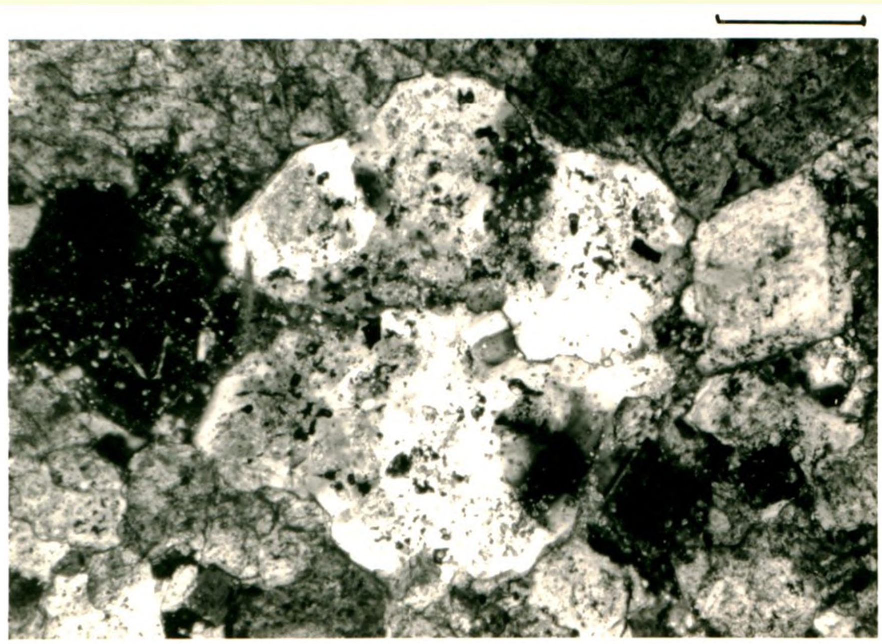


PLATE 29



less than 0.02 mm in size. These grains are well rounded and in most cases are completely surrounded by the dolomite mosaic. Although scarce these grains are found throughout the rock and in some cases are concentrated near stylolites.

The remaining cons tituents of the rock are clay minerals, metallic minerals and organic material which are scattered throughout the rock and concentrated as thin seams in the stylolites. The composition of a stylolite in a certain area of the rock is a good indication of the type of insoluable material in that area. Shelden (1963) conducted an analysis of the insoluble content of the Amabel Formation of Manitoulin Island and found that the Dolostone contained quartz silt, dark brown carbonaceous material, fossils, ooliths, platy siliceous material and sulphides. All but one of these constituents, ooliths, were found in the samples examined in this report. Dark brown and black carbonaceous material occurs as very small rounded blebs that are scattered through the rock, concentrated in stylolites and concentrated in lenses of dolomicrite (Plate 26). The carbonaceous material also occurs as thin films lining some of the void spaces in the rock. The platy siliceous material is too fine grained for more specific identification but Wanless (1979) identified some possible constituents such as mica flakes, insoluable silt and illitic clay. In areas of the rock where stylolites have concentrated the insoluable material, the colour of the stylolite seams is a good indication of the type of insoluble material. The stylolite seams have a black and dark green colour where organic and siliceous material are dominant. The presence of iron oxide in the rock is shown by the rust brown colour of stylolite seams in areas of the core that have buff coloured dolomite. The iron in the dolomite structure, which produces the buff colouration, is released by pressure solution and concentrated into a stylolite seam. The other metallic mineral in the rock is pyrite. Shulka and Friedman (1983) note the presence of framboidal pyrite in the Lockport formation of New York State and it is thought that the pyrite in the Amabel Formation occurs in this form. The individual framboids are extremely small, rounded grains and are indistinguishable from organic material in thin section. The framboids, when subjected to weathering, will rust or discolour.

The insoluable content of the Amabel Dolostone is important in the production of stylolites. Wanless (1979) noted that as the amount of platy insoluable material increases the type of stylolite will change from well defined, sutured stylolites to swarms of microstylolites. This change is seen at depth below 6 meters in the core, implying that a higher proportion of platy insoluable material occurs below this depth. Sections cut form the upper part of the core show individual, well sutured stylolites with an average amplitude of 3 mm (Plate 30). The dominant colour of the insoluable material in these stylolites is black. Below 6 meters the stylolites become less well defined with lower amplitudes and as depth increases swarms of these microstylolites appear (Plate 31). The colour of these microstylolites is reddish brown and dark green. In several sections of the core vertical tension cracks are associated with stylolites of both types (Plate 32). These cracks are less than 2mm wide and up to 6cm long and in hand specimen are filled with crystalline calcite.

Another important textural feature in the thin sections is the porosity. Every section showed some porosity although they do not all show the same amount. Within any particular section the size, shape and orientation of the pores is highly variable. The two types of porosity were; 1, primary porosity in the form of fossil casts and 2, secondary intergranular porosity. The latter are of irregular shapes and in some areas they are elongated with their long axes horizontal. The primary porosity produced by the removal of fossil material is also occasionally oriented so that the longest dimension of the cast is horizontal. Both types of pores are randomly distributed through the rock although some areas show a higher overall porosity than others. A general trend

PLATE 30. Thin section photomicrograph, plane polarized light. Typical Wiarton Bed stylolite. Bar Scale = 1 mm.

PLATE 31. Thin section photomicrograph, plane polarized light. Typical Transition Zone microstylolite swarm. Bar Scale = 0.2 mm.

PLATE 30

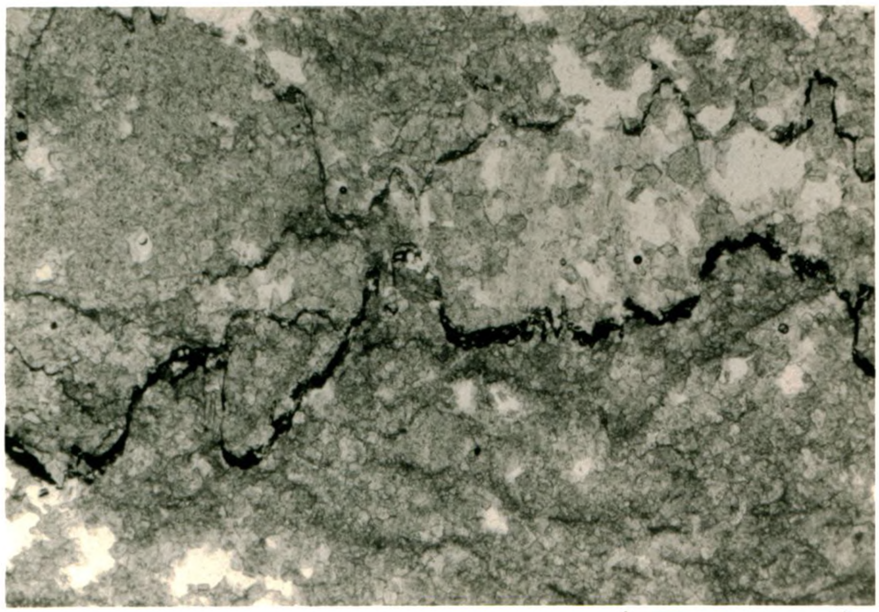
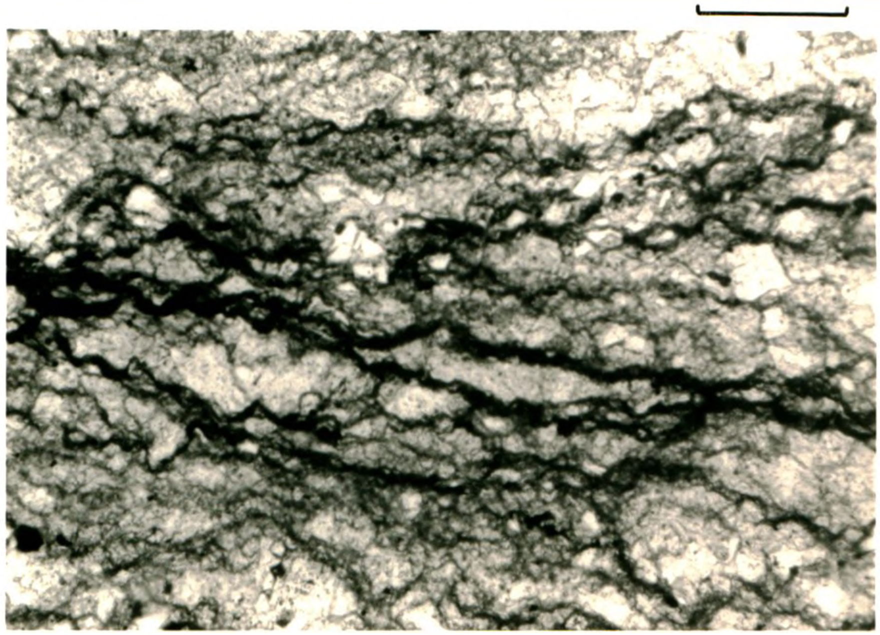


PLATE 31



towards a reduction of porosity with depth becomes more pronounced below approximately six meters. Above 6 meters the majority of the pores are empty and the remainder are partly or completely filled with dolospar. Below six meters many of the pores contain partial or complete fillings of radial fibrous chalcedony or a combination of chalcedony and dolospar (Plate 33).

In general the trends with respect to depth are:

1. A decrease in grain size.
2. A decrease in porosity.
3. An increase in the silica content.
4. An increase in the insoluable content.
5. A change in the type of stylolites.

PLATE 32. Thin section photomicrograph, plane polarized light. Vertical tension crack (A) associated with stylolite (B). Bar Scale = 1 mm.

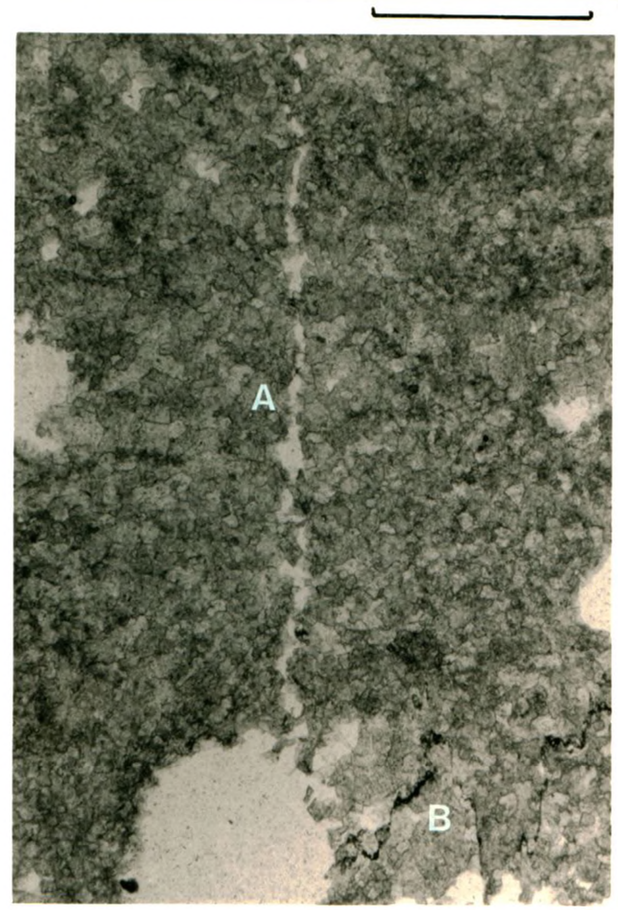

A
B

PLATE 33A (i). Thin section photomicrograph, plane polarized light. Fossil cast filled with chalcedony (clear under plane polarized light). Bar Scale = 1 mm.

PLATE 33A (ii). Thin section photomicrograph, crossed polars. As above showing chalcedony. Bar Scale = 1 mm.

PLATE 33A (i)

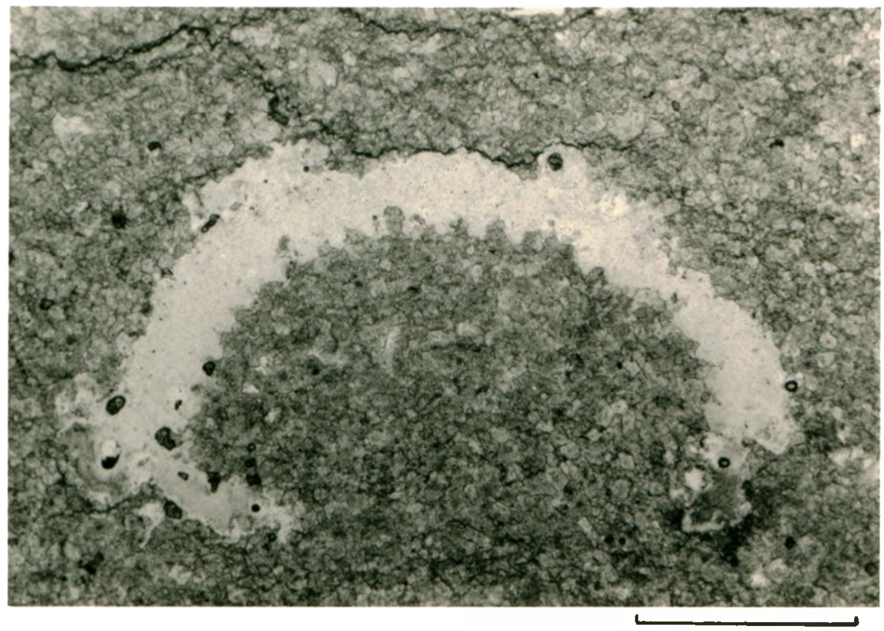


PLATE 33A (ii)

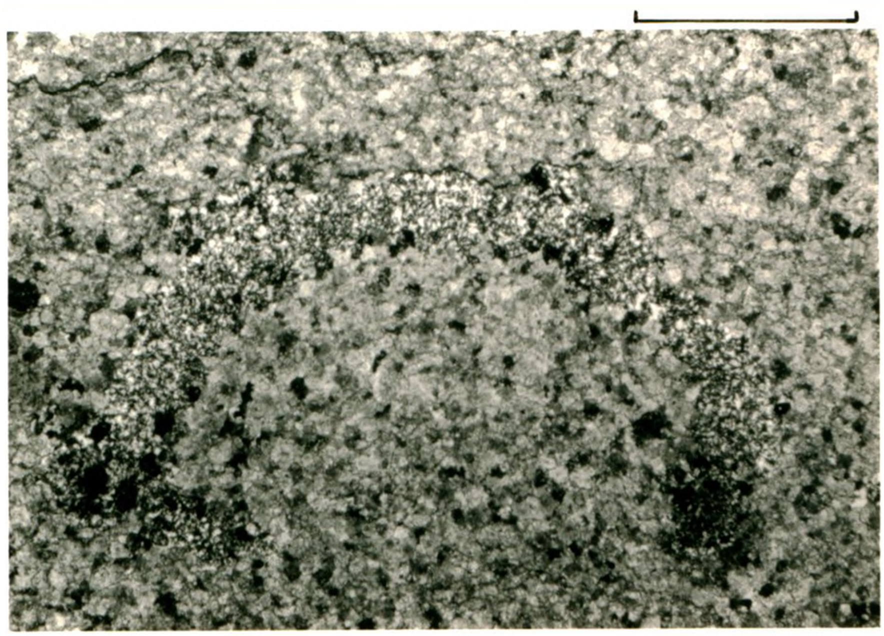


PLATE 33B. Thin section photomicrograph, crossed polars.

Pore filled with coarse, euhedral dolospar (A).

Bar Scale = 1 mm.

PLATE 33C. Thin section photomicrograph, plane polarized light.

Pores lined with opaque, bituminous material (A).

Bar Scale = 0.2 mm.

PLATE 33B

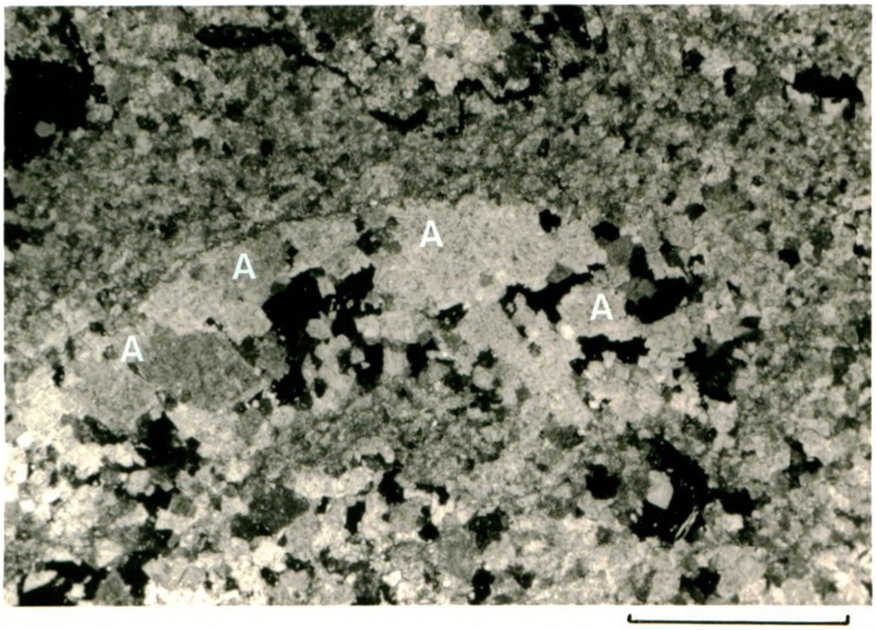
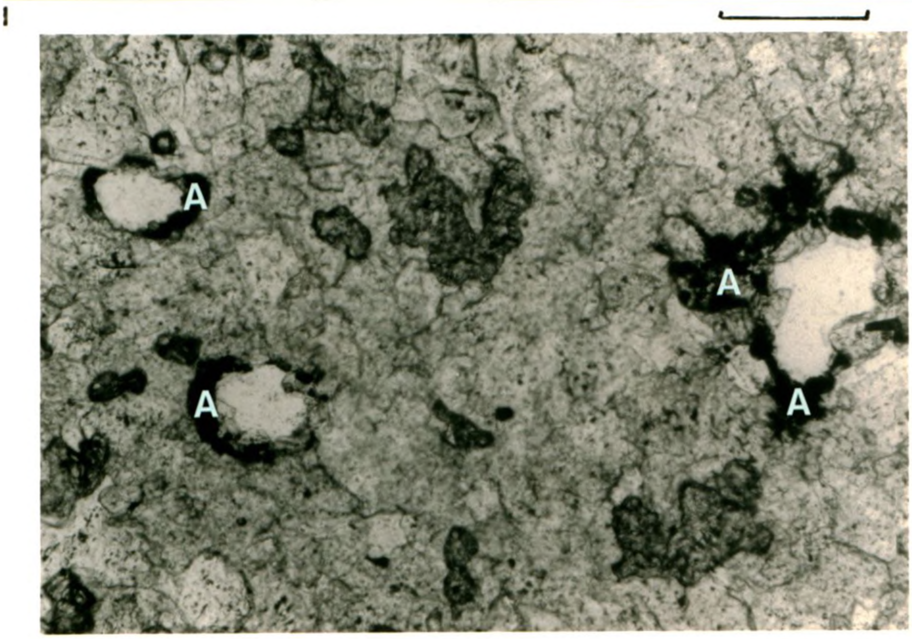


PLATE 33C



CHAPTER FOUR SEDIMENTOLOGY

4.1 Regional History

During the Silurian the Michigan Basin was largely a carbonate and evaporite basin. Throughout the Great Lakes region of Canada and the United States, the Middle and Late Niagaran were a time of major reef development as the area was located between 10 and 20 degrees south of the paleo-equator (Shaver, 1977). Sheldon (1963) has interpreted the entire Niagaran sequence from the top of the Clinton Group as one large transgressing littoral-lagoonal-barrier reef association. Within this overall sequence several smaller fluctuations can be identified. At the end of the Clinton erosional forces were in effect, this was followed by a transgression and the deposition of the first significant reef deposits in the area, the Fossil Hill Formation. This was the first stage in the development of a series of complex biostromal deposits that formed around the stable margins of the Michigan Basin and make up Manitoulin Island, the Bruce Peninsula and extend southward across the Algonquin Arch into the subsurface beneath Lake Erie.

Following the deposition of the Fossil Hill Formation a minor regression occurred and an erosional surface was formed. The next stage of the transgressive sequence was the encroachment of the Amabel Sea into Southwestern Ontario. A complex variety of facies developed, a clean carbonate rocks of shallow marine origin which give way to more basinal carbonates to the West (Sanford, 1969). The initial transgression of the

Amabel Sea produced a significant increase in sea level over the Bruce Peninsula and resulted in the deposition of relatively deep water carbonates, the Lions Head and Colpoy Bay Members. There followed a sudden shallowing of the sea which provided a suitable environment for the crinoidal bank development of the Wiarton Member. During the final phase of Wiarton deposition, the structural axis of the Michigan Basin shifted southward (Sanford, 1969). This caused the crinoidal bank facies to migrate southwestward along a broad arc from the Algonquin Arch to central Lake Erie, then westward to northern Ohio to form the present known rim of the Michigan Basin.

4.2 Depositional Environment and Diagenesis

Detailed facies analysis of the Amabel Formation in the area of the Adair Marble Quarry is not possible due to the destruction of most primary features by dolomitization. The general lithologic characteristics of the rock provide some evidence of the environment of deposition and the secondary features such as dolomitization allow for fairly comprehensive interpretation of diagenesis.

The more basinal environment of the Colpoy Bay Member is evident from the finer grain size, higher proportion of siliceous and bituminous material and sparse fauna shown by the Transition Zone Beds. The general form of the Colpoy Bay and the rare biohermal mounds seen (Bolton, 1957) fit the deep water carbonate slope environment described by James (1984). This environment consists almost entirely of lime mud with occassional, widely separated, mud mounds. About one quarter of the material in these mounds is fossil fragments such as crinoid stems and sponge spicules without large skeletons. The remaining constituent of the mounds is lime mud indistinguishable from the surrounding shelf. The authigenic chalcedony found in the Transition Zone Beds at the quarry was derived from the tests of minute organisms and sponge spicules which were disseminated throughout the carbonate, later dissolved and reprecipitated in the pore spaces (Mosher et al., 1978).

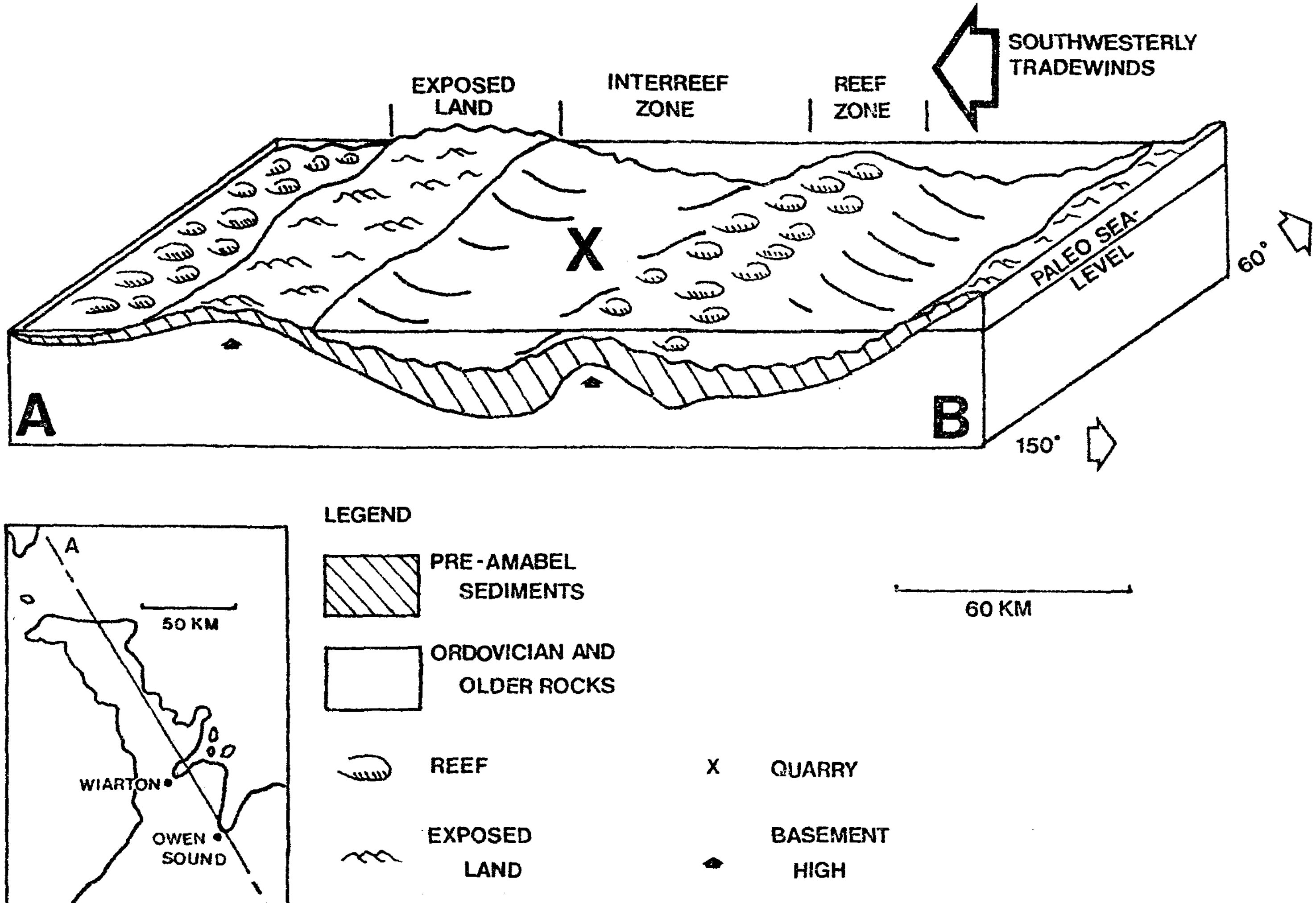
The following reduction in sea level produced a shallow, subtidal environment which was conducive to a more abundant fauna and a second type of reef mound. The shape of the mounds can vary from flat lenses to conical piles of poorly sorted bioclastic lime mud with minor amounts of organic bindstone. They are clearly formed in quiet water environments and appear to occur in preferred locations in tranquil lagoons or wide shelf areas. The internal structure of the mounds consist of a basal bioclastic lime mud pile, a lime mudstone or bafflestone core and a mound cap of encrusting, domal or hemispherical organisms. The mounds are flanked by massive, commonly well-bedded, carbonates comprised of lime mud and fossil debris. In many cases, volumetrically, these flank beds may be greater than the core of the mound itself.

The Wiarton Member, as seen and described in the quarry area, is consistent with James' (1984) model in the following ways. The study of Amabel reef mounds by Smith and Legault (1985) shows that they formed in shallow, quiet waters behind the structural "rolls" of the Bruce Peninsula which acted as breakwaters. The orientation of the reef mounds, their spatial distribution and the paleo-wind direction all suggest that the quarry is situated in the flanking or interreef area behind a line of reef mounds that formed on a structural high (Figure 8). The composition of the flanking deposits described by James (1984) is very similar to that seen in areas of the Wiarton Member where dolomitization has not destroyed the primary features. In the quarry area itself the generally fine grained nature of the rock and the more abundant fossil casts support this similarity. The absence of definite biohermal beds in the quarry area also suggest a flanking or interreef environment.

As time progressed and the transgression proceeded to the point where deepening water eliminated the low energy, shallow water, Wiarton environment, deposition of the interreefal Eramosa Member and the deeper water, Guelph Formation began. The Wiarton Member and underlying Transition Zone were buried and diagenesis began. At some point after burial fresh water was introduced into the Wiarton Beds and this combined with the marine water already present to allow marine/freshwater diagenesis. The diagenesis formed such features as micritized shells, micrite envelopes and very thin crusts of isopachous, blocky calcite cement. The grain supported fabric produced by subtidal deposition and a slow rate of mineral nucleation are responsible for the thinness and sparseness of these crusts (Shulka and Friedman, 1983). The next stage of diagenesis in the rock was incipient dolomitization. This type of dolomitization is fabric selective and occurred first in the areas of

FIGURE 8

PALEOENVIRONMENT



AFTER SMITH AND LEGAULT (1985)

biomicrite such as fossils. The presence of brownish to black bituminous material in the micrite gives these area their dark colour and may also be responsible for their dolomitization, since the reduction of sulphate is believed to produce dolomite (Bathurst, 1975). As the Wiarton and Transition Zone Beds were buried a change from an oxidizing environment to a reducing environment occurred and the sulphate in trapped marine water and organic material was reduced. The organic material in the dolomicrite sheaths many of the individual dolomite rhombs formed by this first stage of dolomitization. This suggests that the dolomite rhombs grew and pushed the organic material aside. In some areas organic material, and possibly framboidal pyrite, occurs as inclusions in the dolomite and this lends credence to the reduction of sulphate being responsible for the dolomitization.

Shulka and Friedman (1983) noted three types of dolomitization in their study of the Lockport Formation of New York State. Two of these dolomitization fabrics can be seen in the Amabel Formation. Type 2 fabric occurs when both the allochems and groundmass of the rock are dolomitized but there is some preservation of the shape and structure of the allochems. Type 3 dolomitization results in a mosaic of dolomite crystals which contain no clues regarding the identity of the precursor sediment. The dolomitization of the Wiarton and Transition Zone Beds is a combination of Types 2 and 3. In the type 2 fabric microstructures are preserved due to a reduction in the rate of dolomitization. This rate reduction is controlled by a number of factors including porosity, permiability and organic content (Shulka and Friedman, 1983). In some areas of the Wiarton Beds areas of darker colouration can be seen to have the shape of primary allochems but are not composed of dolomicrite. The organic material in these areas slowed the rate of dolomitization, producing varying degrees of structure preservation and colouration.

Type 3 dolomitization fabric makes up the remainder of the dolomite mosaic in the Wiarton and Transition Zone beds. Dolomite crystals transect allochem boundaries and obscure the primay features. A hypidiotropic fabric results from the growth of the dolomite crystals and sutured grain boundaries are a common result of close packed growth. This fabric occurs in areas of higher porosity and permiability and lower organic content and is therefore uncoloured.

Both the Type 2 and Type 3 mosaic fabrics were produced by the same process of dolomitization. Badiozamani (1973) proposed a model of dolomitization known as the Dorag Model. This involves dolomitization during shallow burial diagenesis through the mixing of fresh water and sea water. If sea water makes up 5 to 30 percent of the mixture, a solution is produced that is saturated with respect to dolomite but undersaturated with respect to calcite. This mixture will produce dolomitization through the solution of calcite and precipitation of dolomite. The absence of sodium in the Wiarton and Transition Zone Beds is consistent with this model (Veizer et al , 1978) as is the low strontium concentration (Sears and Lucia, 1980) (See Chapter 5).

The dolospar fabric seen in the Wiarton Beds was produced through a different process. As the rock was more deeply buried, pressure solution of the existing dolomicrite and mosaic dolomite began. The dolomite released into solution was transported by pore waters and reprecipitated in the void spaces in the rock. Since these dolomite rhombs had ample space in which to develop, they grew to be larger and more euhedral than the other fabrics noted.

To reiterate, the timing and types of dolomitization seen in the Wiarton and Transition Zone Beds are: Firstly, incipient, syngenetic dolomitization of micrite by sulphate reduction producing dolomicrite. Secondly, diagenetic replacement of preexisting limestone or lime sediment by a slower, shallow burial, dissolution-precipitation process (the Dorag Model), resulting in Type 2 and 3 fabrics. Finally, the generation of dolospar by pressure solution and subsequent precipitation in void spaces. The grain sizes noted for the various fabrics in this report are consistent with the values obtained by Shulka and Friedman (1983), dolomicrite, less than 0.02mm and Type 2 and 3 fabric between 0.04mm and 0.3mm.

Other post-depositional features seen in the Wiarton and Transition Zone Beds occurred at various times relative to the dolomitization. Primary porosity, vugs and fossil casts, was preserved, in some cases, in the following way. The calcitic material originally making up the fossils was replaced by Type 2 dolomitization in such a way as to leave the void spaces of the fossil empty. Those areas of porosity that were filled during burial were dolomitized to form dolomicrite but those areas that were empty were preserved as void spaces. Secondary porosity developed during the dissolution-precipitation dolomitization that produced the Type 2 and 3 fabrics. The volume of dolomite is 12 percent less than that of calcite, as calcite is dissolved and dolomite precipitated this volume reduction produces intergranular pores. The pore filling chalcedony seen in the Transition Zone Beds was derived from the tests of minute organisms and sponge spicules scattered through the rock (Mosher et al, 1978). This silica was dissolved, transported and reprecipitated in primary and secondary pores. It appears that this chalcedony precipitation occurred before stylolitization, and precipitation of dolospar, because the concentration of chalcecony filled pores is near some of the stylolites. The silicification of crinoid fragments seen in the Wiarton Beds most likely occurred before the Type 2 and 3 dolomitization had a chance to destroy the structure of these fragments. Silicification of calcite is more likely to occur than the silicification of dolomite, therefore the crinoid fragments were silicified before the replacement of calcite (or aragonite) by dolomite.

The last process related to burial that effected the Wiarton and Transition Zone Beds was pressure solution. The production of both types of stylolites seen in the rock occurred after the incipient and Type 2 and 3 dolomitization since all of these fabrics have been effected. The load of the overlying sediments became sufficient for pressure solution to occur and a reduction of thickness in the Wiarton and Transition Zone Beds resulted. The difference between the two types of stylolites reflects the more basinal nature of the Transition Zone Beds. Being depositied in deeper water these beds received larger amounts of very fine siliciclastic clay and silt than the shallower water Wiarton Beds.

The calcite crystals lining the pore spaces, especially the larger vugs, are not a product of burial diagenesis. Once the Amabel Formation was returned to the near surface by erosion, fresh ground water moving through the rock began dissolving dolomite and precipitating calcite. This process is still occurring (see Chapter 2).

CHAPTER FIVE GEOCHEMISTRY

5.1 Introduction

X-ray Fluorescent Mass Spectrometer (XRF) and X-Ray Diffraction (XRD) analysis ware performed on various samples of the drill core. The aim of this analysis was to establish the chemical characteristics of the rock andrelate these characteristics to observed petrographic and lithologic features. For instance; a chemical explanation was sought for the various colour differences, and through correlation with previous geochemical work (Mosher et al , 1978; Sears and Lucia, 1980) a better understanding of the stratigraphic position and history of the rock was sought. Samples were selected from the entire length of the core with emphasis placed mainly on the dominant colour of the sample. Eight samples were selected, with four subjected to XRF analysis of their major oxides, eight subjected to XRF analysis of their trace element concentrations and eight subjected to XRD analysis to determine their calcite/dolomite ratio.

5.2 X-Ray Fluorescence

5.2.1. Analytical Procedures and Limitations

XRF analysis was done by a Philips PW-1450 Automatic Sequential Spectrometer at the University of Western Ontario with the assistance of Dr. T. Wu of the Geology Department. Samples for major oxide analysis were prepared following the method of Norrish et al. (1969). Samples for trace element analysis were prepared by a similar method to that of Nisbet et al. (1979). The major oxide analysis was calibrated against the N.B.S. 88a rock standard which represents an ideal dolomitic limestone. The accuracy of the major oxide results was checked by preparing duplicates of all the samples using different initial weights of each sample. The accuracy of all the samples was better than 10 relative percent, taking into account machine and sample preparation errors. The only major inaccuracy occurred in the preparation of pressed pellets for the trace element analysis. The grinding of the samples introduced anomalously high values of cobalt, an element not expected to be abundant in the rock.

5.2.2. Major Element Distribution

The major oxide compositions of the samples tested are presented in Table 1. Trends of some of the chemical elements are plotted in relation to their stratigraphic positions in Figure 9. By far the largest component of all the samples was the volatiles, which include water and carbon dioxide. These components are driven off during the initial baking of the samples and are listed under LOI (loss on ignition) in Table 1. A high proportion of volatiles is expected in a rock that is mostly carbonate since the initial baking removes all the carbon dioxide from the carbonate minerals.

The most abundant oxide in the samples is calcium, followed by magnesium and the ratio of Ca^{2+}/Mg^{2+} is approximately 3/2 for all the samples tested. The abundances of these elements change with depth, calcium decreasing and magnesium increasing (Figure 9). Petrography and

TABLE 1

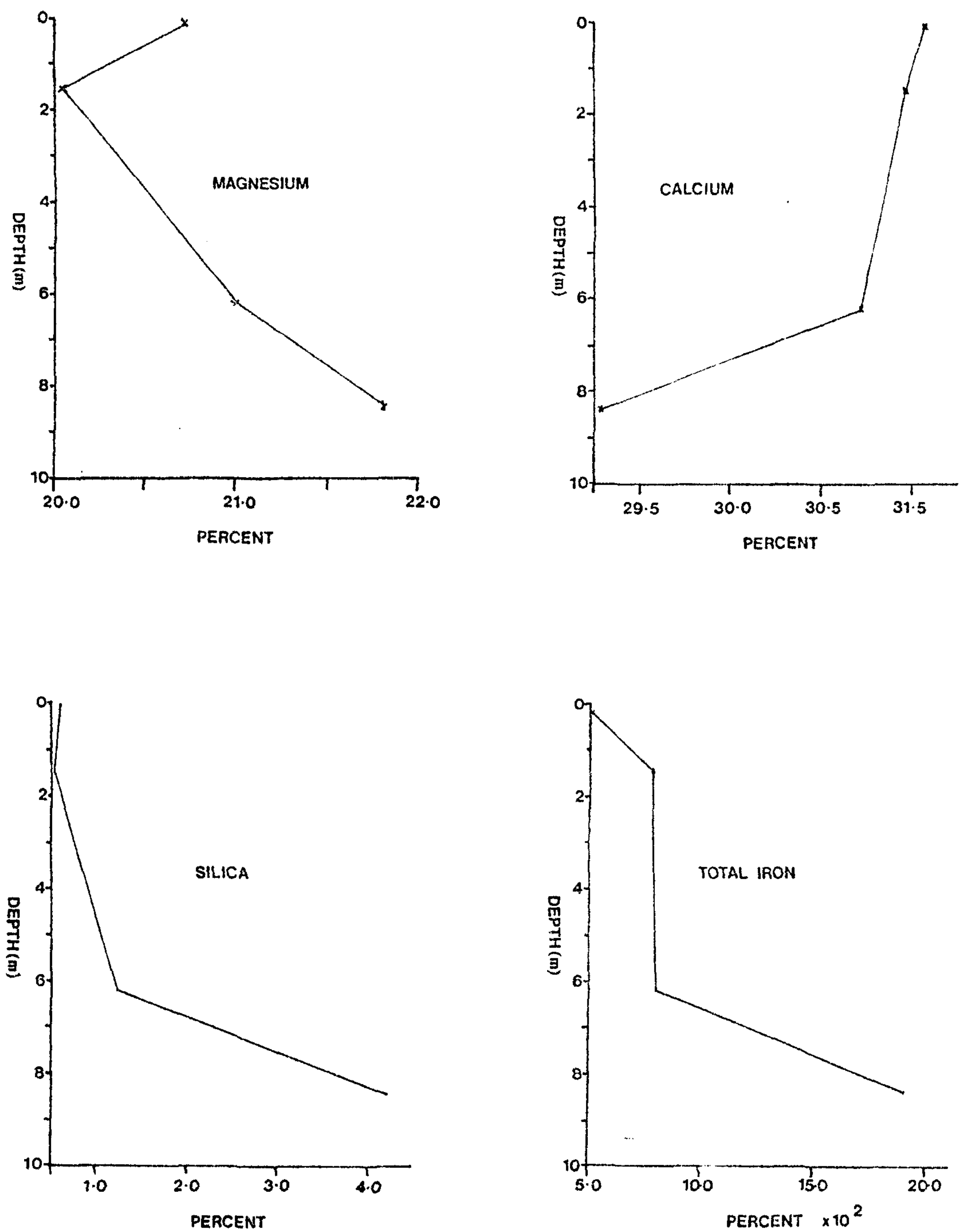
MAJOR ELEMENT CONCENTRATIONS

SAMPLE		MAJOR ELEMENT PERCENTAGES											
#	DEPTH	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	K_2O	Na_2O	P_2O_5	LOI	TOTAL
C1a	0.01m	0.55	0.00	0.00	0.05	0.00	20.73	31.07	0.00	0.00	0.00	47.40	99.80
C6d	1.50m	0.51	0.01	0.00	0.08	0.01	20.02	30.99	0.01	0.00	0.00	48.10	99.73
C33a	6.20m	1.24	0.02	0.00	0.08	0.01	21.01	30.74	0.02	0.00	0.04	46.70	99.59
C52b	8.40m	4.24	0.02	0.00	0.19	0.01	21.81	29.29	0.09	0.00	0.00	44.80	100.45

FIGURE 9

GEOCHEMISTRY

MAJOR ELEMENT ABUNDANCE vs STRATIGRAPHIC POSITION



XRD analysis show that the carbonate in these samples is entirely dolomite with calcite occurring only as minor pore lining crystals.

The next most abundant oxide is SiO_2 which also shows an increase in abundance with depth. At the top of the core, in the quarried rocks, the SiO_2 concentration is only 0.55% but, at a depth 8.4 meters, the SiO_2 concentration increases to 4.24%. This is significant because the diamond saws used by the quarry are designed to process rock with less than 5% SiO_2. Total iron, measured as Fe_2O_3 , is the next most abundant element and it also shows an increase with depth. Other significant major oxide trends are seen in the concentrations of TiO_2 and K_2O which both increase with depth. The absence of Na_2O , Al_2O_3 and P_2O_5 is also considered to be significant.

5.2.3 Trace Element Distribution

The trace element concentrations of the samples tested are in Table 2. Trends of some of the trace element concentrations are plotted in relation to their stratigraphic depth in Figure 10. The most abundant trace element is sulphur and it is the only element to occur in concentrations of more than 100 ppm. In the top meter of the core the sulphur concentration is below the detection limit of the spectrometer but it increases with depth to a value of 1543 ppm at a depth of 9.2 meters. Petrographic analysis suggests that the majority of the sulphur is concentrated in the bituminous material scattered through the rock although one occurrence of pyrite (FeS_2) is near the base of the

TABLE 2

TRACE ELEMENT CONCENTRATIONS

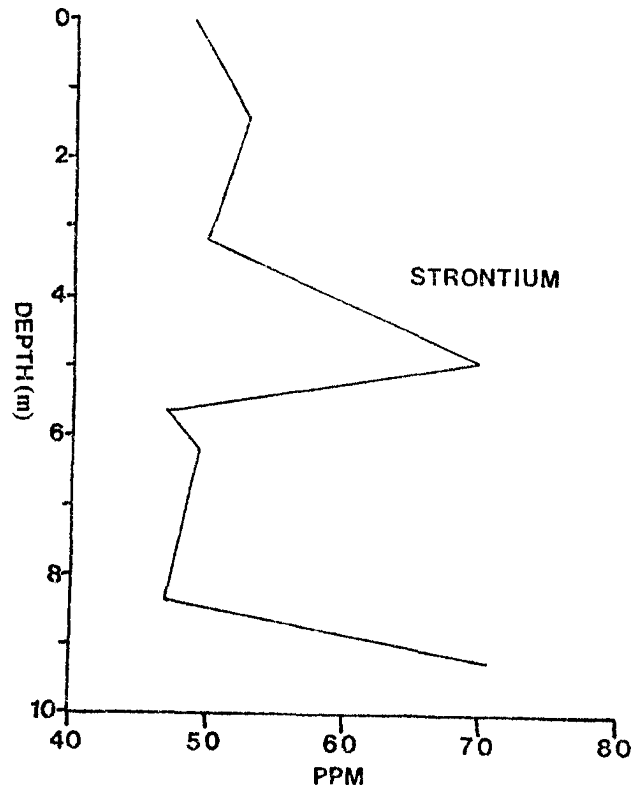
SAMPLE		TRACE ELEMENT CONCENTRATION IN PARTS PER MILLION											
#	DEPTH	Nb	Zr	Sr	Rb	Pb	Zn	Cu	Ni	Cr	Ba	S	Ga
C1a	0.10m	--	--	49	--	14	--	14	1	20	23	--	5
C6d	1.50m	3.3	--	53	--	--	13	8	--	4	--	335	6
C12	3.20m	--	--	50	2	--	--	9	--	48	--	135	6
C21	4.87m	--	6	70	2	--	--	11	1	39	30	501	6
C27b	5.70m	3.5	5	47	--	--	--	14	--	16	--	448	6
C33a	6.20m	3.0	4	49	--	--	13	8	--	32	3	258	7
C52b	8.40m	3.0	13	47	6	--	--	13	1	9	10	1045	5
C58b	9.23m	3.5	40	71	13	--	--	15	1	89	105	1543	5

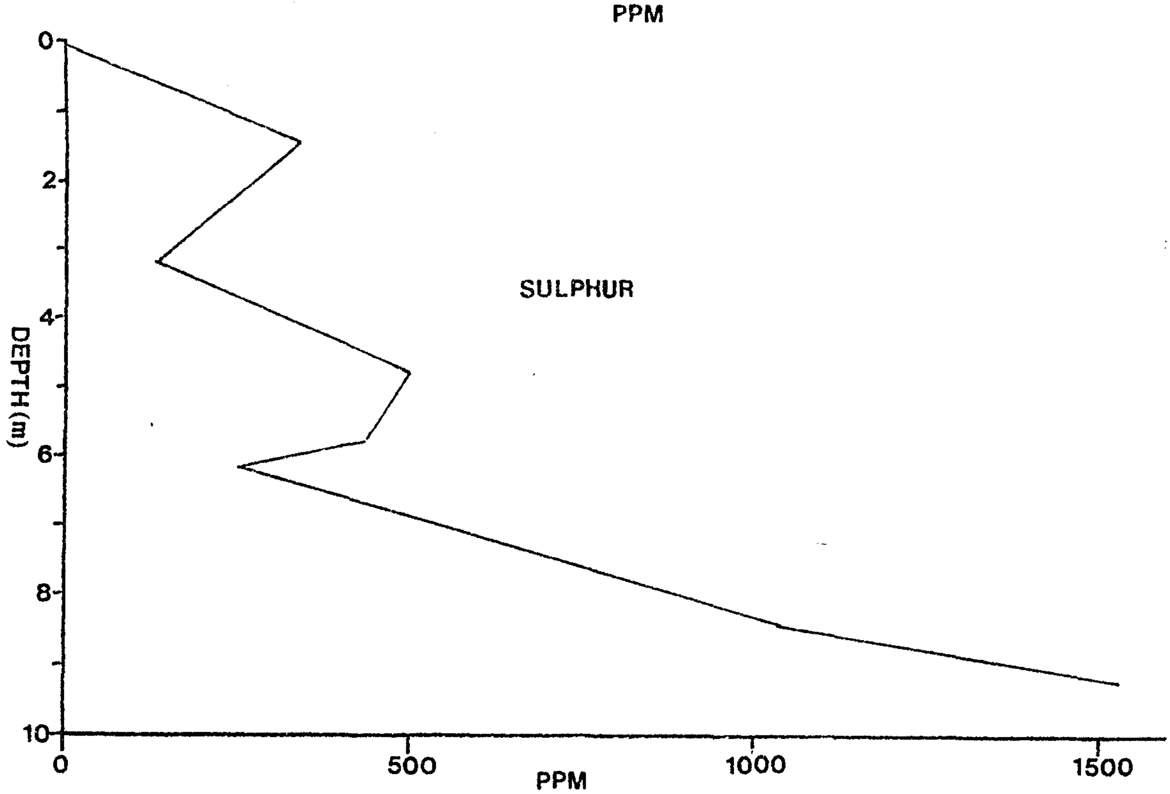
* Elements Yttrium and Vanadium were tested for but were below the detection limit of the equipment. Cobalt was also tested for but produced anomalous values due to contamination.

FIGURE 10

GEOCHEMISTRY

TRACE ELEMENT ABUNDANCE vs STRATIGRAPHIC POSITION





core. Another possible source of sulphur is the mineral gypsum ($CaSO_4$) which was noted in the Colpoy Bay Member by Bolton (1957) but was not positively identified in this report.

Other significant trace elements occurring in the samples tested are strontium, copper, chromium and barium. The remaining trace elements were either below the detection limit of the equipment or over abundant due to contamination.

5.3 X-Ray Diffraction

5.3.1 Analytical Procedures

Standard X-ray diffraction powder methods were used to determine the calcite to dolomite ratio in eight samples of the core. The samples were analysed by a Rigaku Geigerflex Diffractometer at the University of Western Ontario with the assistance of Y. Cheng of the Geology Department. The samples were crushed to less than 300 mesh and mounted on glass slides that were loaded individually into the diffractometer. Each sample was scanned from 28.00 to 32.00 degrees 2θ to record the 104 calcite and 112 dolomite reflections occurring at 29.43 and 30.99 degrees 2θ respectively. This method of calcite to dolomite ratio determination was devised by Tennant and Berger (1957) and revised by Gulbrandsen (1960). It is based on the correlation between the amount of calcite and dolomite in each sample and the number of Geiger counts of the X-rays diffracted from their surfaces. To aid in interpretation the number of radiation counts was plotted against the number of degrees 2θ, for each sample, to produce "peaks" corresponding to the calcite and dolomite reflections.

5.3.2 Results

The charts showed, for each sample, a pronounced peak coinciding with the 112 dolomite reflection and no discernible peak for the 104 calcite reflection. Further analysis of the data was unnecessary since it was obvious that the carbonate in all the samples analysed was mostly dolomite. The presence of some calcite is still possible since it may have been below the detection limit of the equipment, or interference from the strong dolomite reflection may have masked the calcite reflection.

5.4 Interpretation

Graphical presentation of the major oxide and trace element concentrations show that the rate of increase or decrease of concentrations for certain elements show a significant change at approximately 6.2 meters depth. Those elements showing an increase with depth (iron, potassium, sulphur, silica) increase more rapidly below 6.2 meters and calcium, which decreases with depth, shows a more rapid decrease below 6.2 meters. This change in the chemical nature of the rock corresponds with the lithologic change at this depth in Chapter 3.

The changes noted in the concentrations of calcium and magnesium are most likely due to a change in the composition of the dolomite.

Ideal dolomite has the formula $CaMg(CO_3)_2$ which gives a one to one ratio of Ca^{2+} to Mg^{2+}. It has been noted however, that dolomite can contain up to five percent excess Ca^{2+} in its structure (Deer et al, 1982). Ca^{2+} in the form of calcite, is also known to occur as pore lining crystals in the Amabel Dolostone and although the amount of calcite was below the detection limit of the XRD equipment the reduction of Ca^{2+} with depth may correspond to the reduction of porosity with depth.

The next major oxide trend is exhibited by SiO_2 . The Sio_2 occurs in the form of chalcedony which was precipitated from solution in some of the pore spaces of the rock. The increase in the occurrence of chalcedony with depth may indicate a change in the chemical characteristics of the rock that produced an environment more favourable for SiO_2 precipitation (see Chapter 4). The concentration of iron in the rock is of concern to the quarry operators because, when iron is incorporated into the dolomite structure it produces a buff colouration in the rock. The increase in the amount of iron in the rock with depth explains the change in colour noted in Chapter 3. Some evidence, from field observations, reveals that the iron content of the rock changes laterally as well as vertically. In several areas of the quarry extracted blocks have had to be discarded due to their unwanted buff colouration. In many cases the buff colouration is not noticeable until the rock has been extracted and exposed to the atmosphere, allowing oxidation of the iron, and it is this phenomenon that is of concern to the quarry operators. If a structure is constructed of Adair Marble blocks with different iron contents, differential colouration may occur and spoil the aesthetic qualities of the structure.

The majority of trace elements in the samples can be attributed to the organic material present throughout the rock and the clay minerals associated with the stylolites. Strontium is the exception since it can be incorporated into the structure of dolomite. A number of authors (Veizer et al, 1978; Sears and Lucia, 1980) have indicated that trace element studies of ancient carbonate rocks may be useful indicators of paleosalinity and diagenesis. The most important indicator elements are Na^{+} and Sr^{2+}. The lack of Na^{+} in the Amabel Dolostone suggests that it formed in normal saline marine waters or possibly fresh water (Veizer et al., 1978). The strontium content of carbonate rocks may be indicative of their depositional and/or early diagenetic history. A large reduction in Sr^{2+} concentration, to approximately 75ppm, is attributed to fresh water diagenesis and later dolomitization (Sears and Lucia, 1980). The Sr^{2+} concentrations of the Amabel Dolostone range from 47 ppm to 71 ppm. The full significance of this is discussed in Chapter 4.

The lithostratigraphy of the Wiarton road cut was studied in detail by Mosher et al. (1978). Through the use of insoluable residue, atomic absorption and chemical analyses they attempted to fix the position of the contacts between the lithologic units present in the road cut. Two different sets of analysis generated slightly different stratigraphic interpretations. Both the atomic absorption/insolubles analysis and the chemical analysis show the contact between the Wiarton Member and the underlying Transition Zone to be in the same place. But the two different analyses give different thicknesses of the transition zone and consequently two different positions for the contact between the Transition Zone and the Colpoy Bay Member. The atomic absorption/ insolubles data assigns a thickness of 4 meters to the Transition Zone while the chemical analysis shows a thickness of 7.1 meters.

In an attempt to determine the stratigraphic position of the core used in this report, certain data from Mosher et al (1978) were graphed and compared with data from this report (Figure 11). The common reference point for this comparison was the contact between the Wiarton member and the Transition Zone. The data from this report show this contact at approximately 6.2 meters depth while Mosher et al. (1978) have the contact occurring at 18 meters above the base of the road cut.

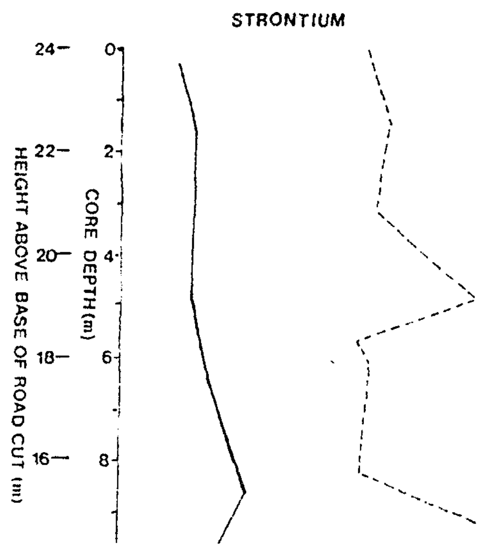
Figure 11 shows that little correlation exists between the data of this report and that of Mosher et al (1978), either quantitatively or qualitatively. Some possible trends do exist but on the whole the chemical composition of the Amabel Dolostone appears to change laterally as well as vertically between the type section and the quarry.

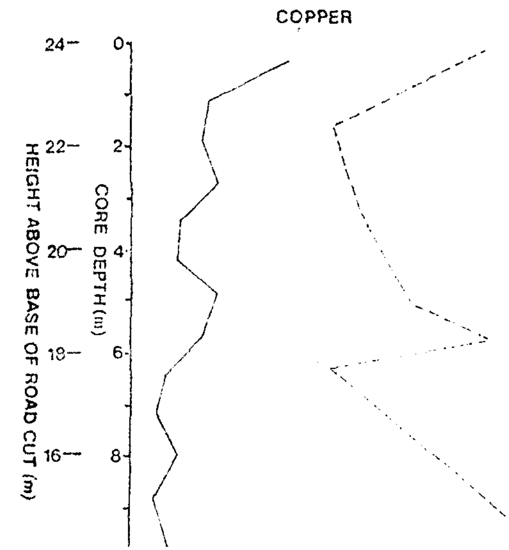
In their conclusions, Mosher et al, (1978), note that the concentrations of iron, strontium and zinc are much more variable in the

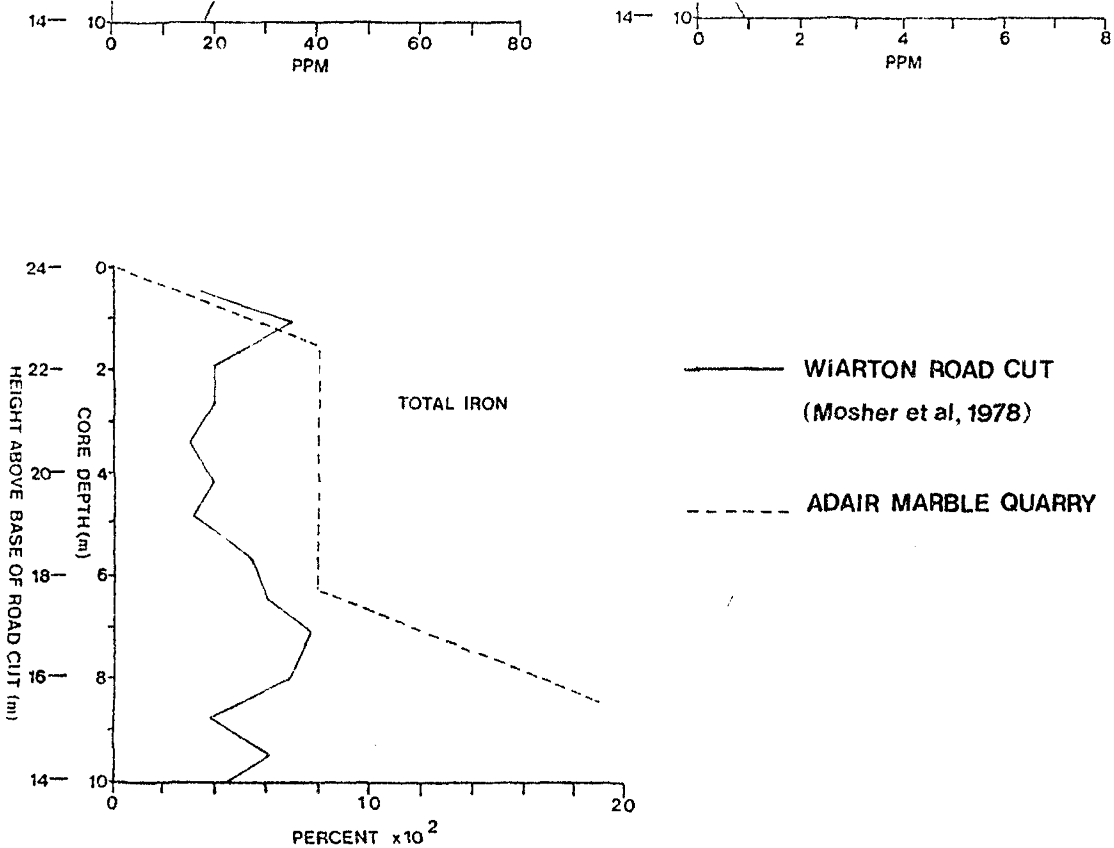
FIGURE 11

GEOCHEMISTRY

ADAIR MARBLE QUARRY vs WIARTON ROAD CUT







14
10
0
20
40
60
80
PPM
14
10
0
2
4
6
8
PPM
24
22
20
18
16
14
HEIGHT ABOVE BASE OF ROAD CUT (m)
0
2
4
6
8
10
CORE DEPTH (m)
TOTAL IRON
0
10
20
PERCENT x10 2
WiARTON ROAD CUT
(Mosher et al, 1978)
ADAIR MARBLE QUARRY

Colpoy Bay Member than the Wiarton Member with the reduction in variability occurring at 18 meters above the base of the road cut. They also noted that the average concentrations of certain elements were greater in the Colpoy Bay Beds than in the Wiarton Beds. Similar conclusions can be drawn from the data in this report, many elements show a definite increase in abundance below the contact between the Wiarton Beds and the Transition Zone. One major difference between the Amabel beds of the type section and those of the quarry is the concentration of sulphur. The qualitative tests for sulphur conducted by Mosher et al, (1978) were negative whereas this report found high concentrations of the element.

CHAPTER SIX GEOPHYSICS

6.1 Introduction

The technical information contained in this chapter is courtesy of J.L. Davis, Research Physicist at A[3] Geophysics Inc., Mississauga, Ontario.

Long term planning at quarry sites presently consists of diamond drill coring. The drilling data are satisfactory if the bedding planes are uniform. In areas where the bedding planes are not parallel then either a great number of boreholes are necessary for good quarry planning or nothing more than short term planning can be expected.

Considering the capital and labour costs involved today, a much better return of investment can be assured if proper site investigations are carried out for long term planning. A[3] Geophysics and the Adair Marble Quarry conducted two sets of tests with ground probing radar equipment at the quarry with the objective of determining whether radar can map major fractures or anomalies in the rock.

Ground probing radar has been used in the past to map fractures in bedrock for mining, geotechnical and hydrogeological applications from the surface, in tunnels and in boreholes, and signal penetration of up to 60 meters has been achieved. Fractures of less than 1 millimeter thickness have been detected at a range of 3 meters and changes in rock type have also been mapped using radar techniques.

6.2 Equipment and Procedure

The radar sends a short pulse of radio frequency energy into the ground. Part of the pulse energy is reflected whenever it encounters a change in the electrical properties in the ground. The amount of reflected energy is dependent on the electrical contrast and size of the reflector. In rock, air or water filled cracks as small as a few millimeters wide represent a large electrical contrast to the radar signal. Clay and rock filled fractures on the order of a few centimeters thick appear to be satisfactory radar reflectors.

The radar equipment consists of two antennae, a control unit, a cassette tape recorder, a graphic display unit and batteries. The antennae, one transmitting and one receiving, are pulled over the surface. The signals from the ground travel to the control unit where they are amplified, processed and formatted for recording or display. Two sets of antennae are used, each with different operating parameters. The 2 nanosecond (ns) antennae are used for high resolution, shallow penetration soundings. They are able to detect thick bedding planes, up to 6 meters depth, and also thin air filled cracks, of about 1 millimeter thickness, at a depth of 2 meters. The second set of antennae, 10 ns, are used for deeper, medium resolution soundings. Reflections to a depth of at least 10 meters can be mapped using the 10 ns antennae.

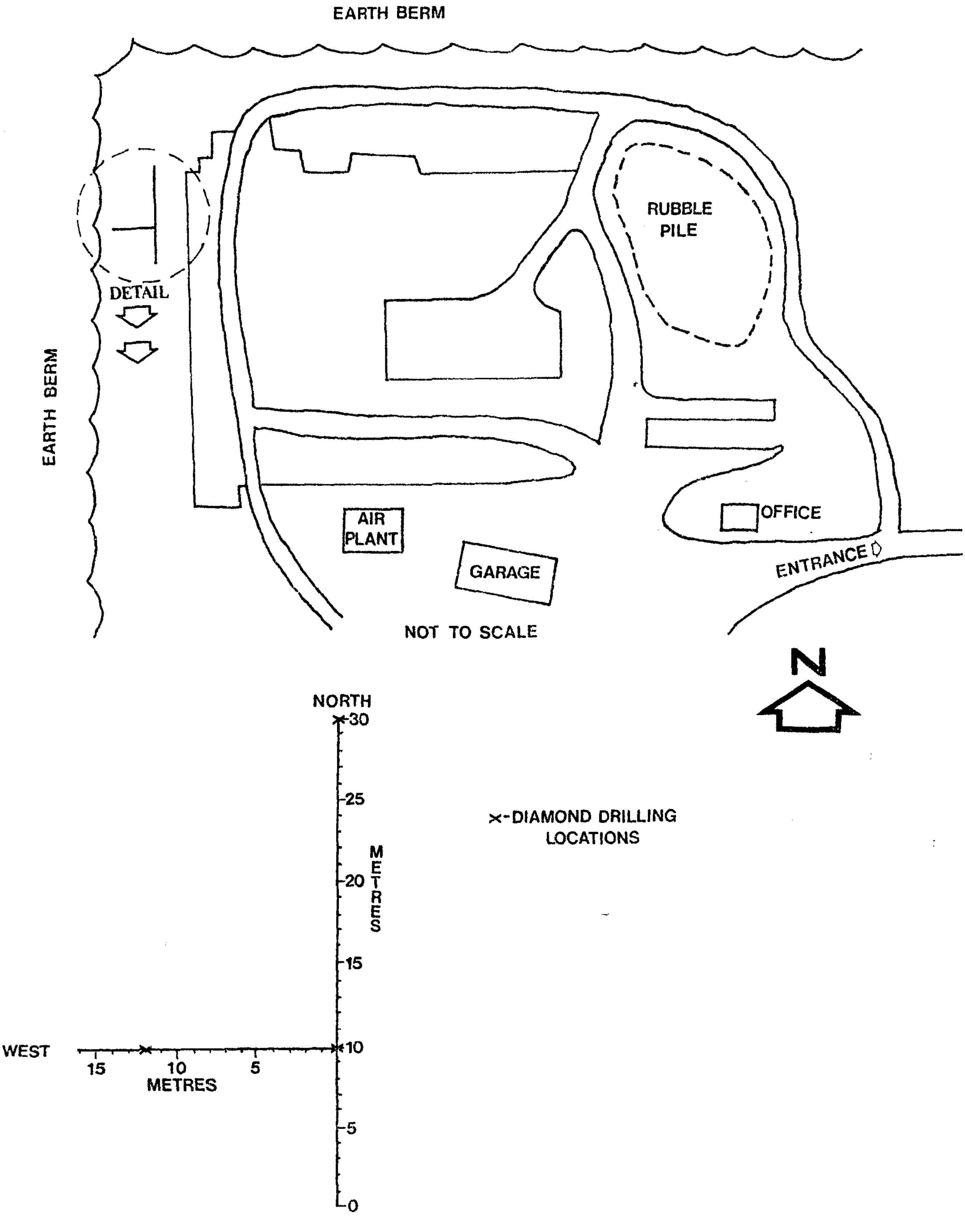
The systems control unit amplifies the received signals which are then recorded on an analog cassette recorder. The recorded data are used as a permanent record and can also be further processed if required. The amplified data can also be displayed immediately on a gray-level electrostatic plotter in the field. This plotter displays strong signals in black and weaker signals in gray on a white background. A strong radar reflection is usually plotted as three black bands.

Radar tests were carried out at the Adair Marble Quarry on July 17, 1985 and August 27, 1985. The July tests consisted of four separate surveys conducted along various lines throughout the quarry. First a velocity sounding was performed to determine the velocity of the radar signal in the rock. Once this velocity is known the depths to the reflectors on the subsequent profile records can be calculated. It was assumed that the signal propogation velocity remains constant in the rock throughout the quarry. The other surveys conducted in July attempted to map thick beds in complicated ground up to 6 meters deep and thereby determine the scanning capability of the equipment, scan one layer at high resolution to find thin beds and horizontal fractures, and scan some unexcavated areas to find the depth to bedrock and evidence of beds beneath the overburden.

Since most of these tests were carried out along the top of the exposed quarry faces it was possible to correlate the radar profile records directly with the rock record. Correlation was generally good but it was decided to run a second series of tests with controlled perpendicular survey lines and diamond drill coring at selected points of the control grid. The area for these tests was situated in the north-west corner of the quarry where no drilling or broaching had occurred (Figure 12). Two survey lines were marked out; one running North-South for 30 meters, and the other running West from the North-South line for

FIGURE 12

GEOPHYSICS A^3 AUGUST 1985 TEST GRID



16 meters and intersecting the North-South Line at 10 meters North. Both of these lines were surveyed using the 2 ns and 10 ns antenna arrays giving two profiles for each line, one to 4 meters depth and the other to 10 meters depth. Since these surveys were performed in an unexcavated area, correlation between the radar profile records and the subsurface was achieved through diamond drill coring at the 12 meter West, 10 meter North and 30 meter North grid points. Ten meters of core from the 30 meter North drill hole was examined in detail to ascertain the position of fractures in the subsurface and to identify any changes in the rock that may produce radar reflections.

6.3 Results

Photoreduced copies of the radar profile records of the 2 ns and 10 ns soundings in the 30 meter North area are shown in Figure 13. These records were examined in detail by A^3 Geophysics and the strong and weak reflectors located. A diagram of the radar data and the detailed core examination is shown in Figure 14. The core was broken in many places and during examination the breaks were categorized in three ways: Fracture; the ends of the core on either side of a break show evidence of weathering and do not fit back together. Possible; the ends of the core on either side of a break do not fit back together but do not show obvious signs of weathering. Fresh: the ends of the core on either side of a break fit together, therefore the break is an artifact of the drilling.

FIGURE 13

GEOPHYSICS

RADAR PROFILES FROM N-S LINE, AUGUST 1985

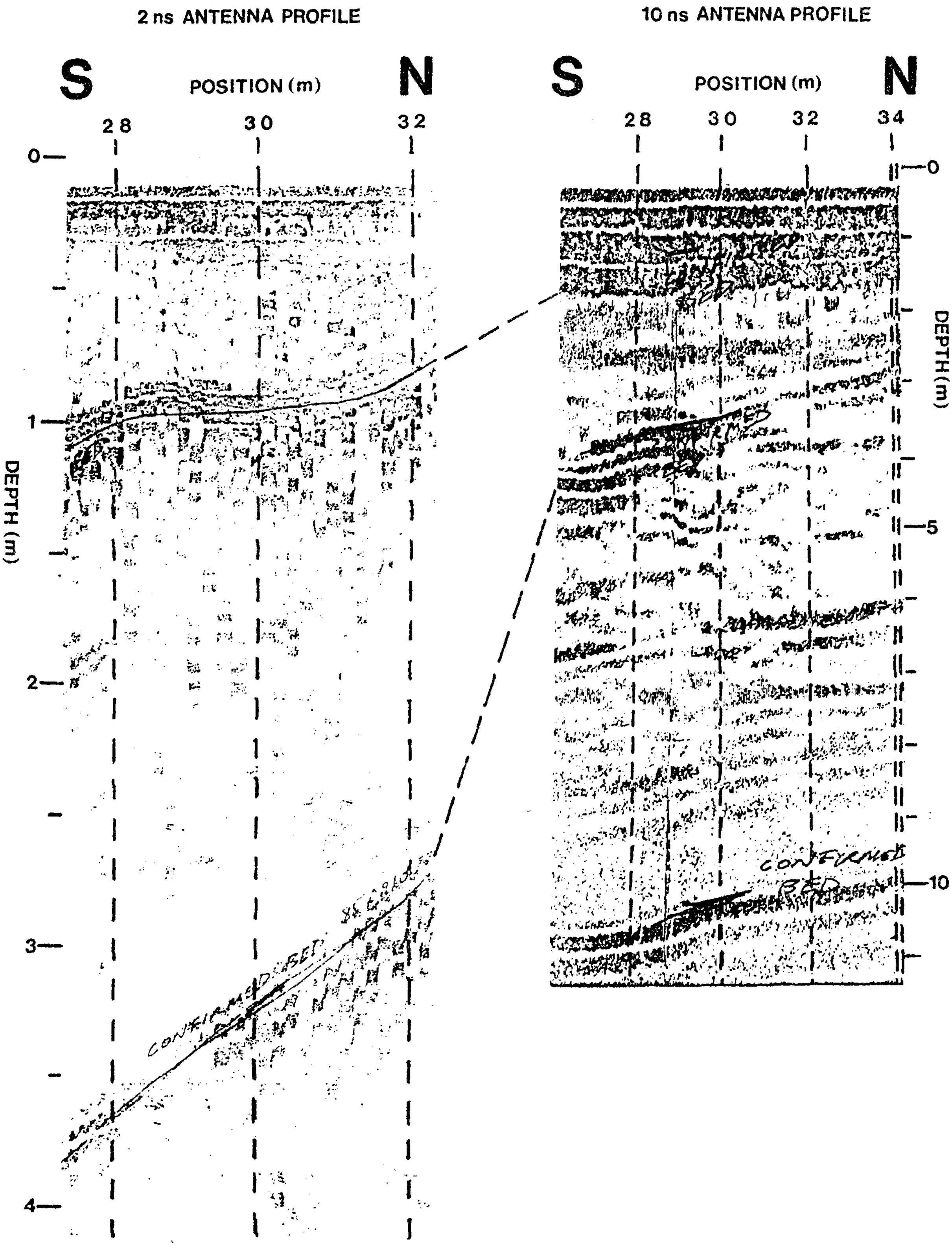
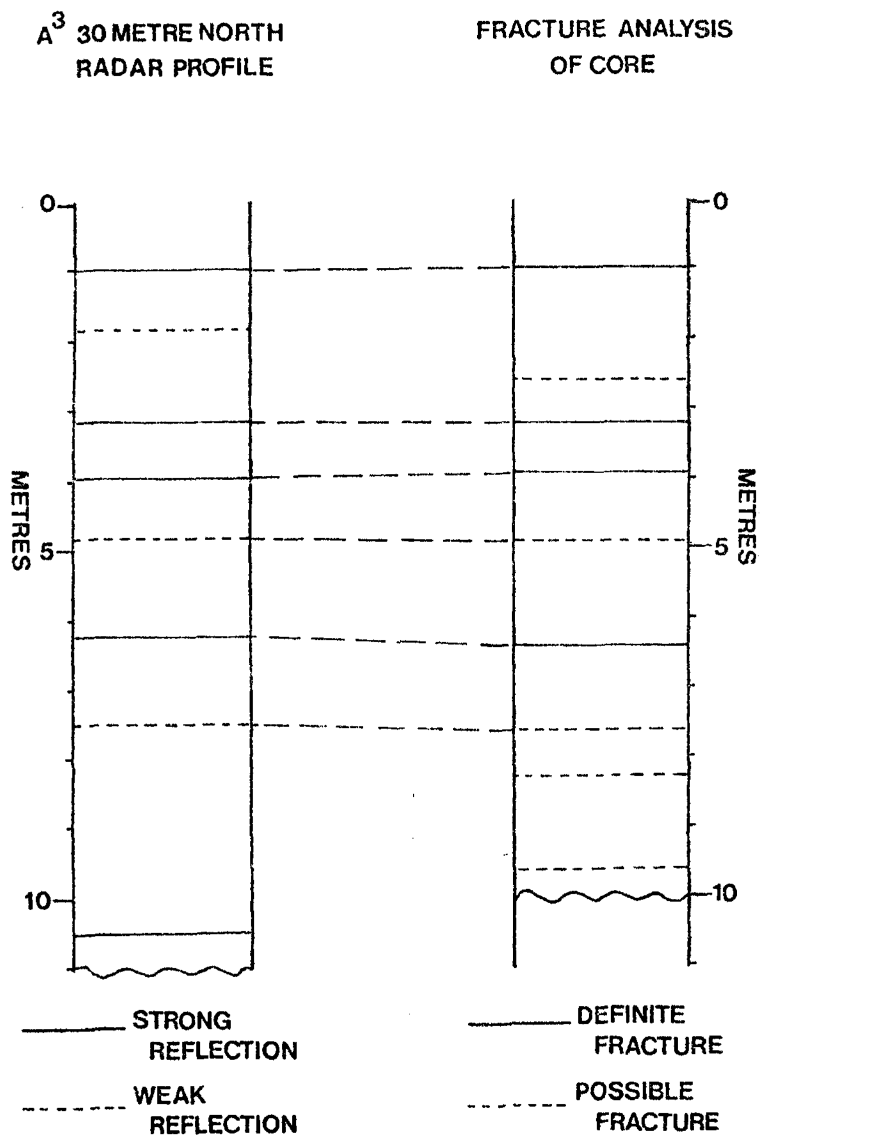


FIGURE 14

GEOPHYSICS RADAR REFLECTION CORRELATION



Some of the fresh breaks occur along stylolites which suggest that, even though a fracture was not present in the subsurface, the thin seams of clay minerals and other insolubles in the stylolite may produce radar reflections. The presence of breaks along stylolites also shows that they are zones of weakness in the rock. In some areas of the core several fractures occur within 20 centimeters of each other, these have been plotted as one fracture for the sake of clarity. When the core is removed from the ground the space between the pieces of core on either side of a fracture is lost, therefore it is not known how wide the fracture was and precise location of the position of the fracture is not possible. It is also not known what, if any, material was filling each fracture since this is also lost during drilling and extraction.

6.4 Correlation and Interpretation

As can be seen from Figure 14 generally excellent correlation exists between the radar reflectors and the fractures in the rock. The strong reflectors recorded correspond to definite air or water filled fractures in the core. Weaker reflections correspond to smaller clay or rock filled fractures. The presence of two possible fractures at 8.3 and 9.6 meters in the core that did not register or the radar profile may be too small to be resolved by the 10 ns antennae needed to sample this depth. During A^3's July survey, unexplained weak reflections occurred in some of the profiles. It was suggested that these reflections may be due to changes in the high frequency electrical properties of the rock, colour differences due to chemical changes in the rock or changes in the density or structural properties of the rock.

Changes do occur in the porosity of the rock and in the chemical composition. These changes do not occur rapidly or systematically and it is doubtful that they would produce anomalous reflections. The high frequency electrical properties of the rock were not tested. In some areas of the core, a profusion of stylolites may effect the radar sounding but since the individual stylolites are less than 1 millimeter thick, this would only be a factor in the upper few meters of the profile. The generally good correlation between the radar reflectors and fractures in the rock suggest that reflections on the profile are due solely to these fractures and the other factors mentioned above probably only contribute "noise" to the data.

The ability of ground probing radar to detect major fractures to a depth of 10 meters and minor fractures to a depth of 4 meters shows that it is a useful aid in quarry planning. The radar not only shows the depth of the fractures, but also their orientation with respect to the surface and each other. This is very useful in determining the size of quarry blocks that can be removed from the surveyed area. Arriscraft had hoped to determine the type and amount of colouration in the rock, before removal, using the radar. The lack of solid evidence relating the colouration to the radar data makes this unlikely.

CHAPTER SEVEN

CONCLUSIONS

The geology of the Adair Marble Quarry is of interest to Arriscraft from the aspect of rock quality. The characteristics of the rock most desired by Arriscraft are the abundance and form of the blue-grey mottling, low porosity and the absence of fractures and lines of weakness such as stylolites. At the present time the rock must be extracted before these characteristics can be assessed. It was hoped that a detailed geologic study would provide information about the qualities of the rock in the quarry before extraction. Ideally a uniform pattern of colouration, porosity and fractures would be developed to aid in quarry planning. If the location of high quality rock was known before extraction, it would greatly reduce wastage and improve efficiency.

It can be seen from this report that no uniform pattern can be established at the quarry. The desirable and undesirable characteristics of the rock vary laterally and with depth in a random fashion. The variations seen in the lithology, petrography and geochemistry are due to the depositional environment in which the rock was formed. The major environmental variation is the facies change between the basinal Transition Zone and the shallow shelf Wiarton Member. This change is responsible for many of the changes that occur in the rock with increasing depth. These changes include the increase in iron, silica and sulphur which in turn are responsible for changes in the colour, texture and mineralogy.

Variations also occur on a much smaller scale within the Transition Zone and Wiarton Beds. The amount and type of blue-grey mottling is controlled by the different types of dolomite and the amount of organic material which results in rapid, non-systematic changes in colouration. The porosity also varies greatly depending on the amount of primary porosity (vugs and fossil casts) and the generation of secondary porosity during dolomitization. The formation of stylolites, along which the rock may break, depends on the relative resistance to pressure solution of individual areas in the rock which is again controlled by deposition and diagenesis. The only property of the rock that can be predicted before extraction is the presence of fractures. Ground probing radar has shown its ability to locate and map fractures in the subsurface with sufficient accuracy to aid quarry planning.

The comparison of the rock at the quarry and the type section at Wiarton suggests that the Amabel Formation varies throughout its aereal and vertical extent. This does not mean a significant change in the gross lithology of the rock but rather many small scale changes that effect the building stone properties of the rock. Amabel Dolostone could be extracted from any location or the Bruce Peninsula and show the same variability as seen at the Adair Marble Quarry. It is highly unlikely that large areas of uniformly high quality stone are present in the area and the present quarry methods are the best possible in this situation.

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