STRATIGRAPHY AND FACIES OF THE MIDDLE DEVONIAN DUNDEE FORMATION, SOUTHWESTERN ONTARIO

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OF THE

MIDDLE DEVONIAN DUNDEE FORMATION,

SOUTHWESTERN ONTARIO

By

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ABSTRACT

The Middle Devonian Dundee Limestones of Southwestern Ontario accumulated in the Michigan and Appalachian Basins, with deposition in part being controlled by the proximity to the Findlay and Algonquin arches. Six lithofacies were recognized in the Dundee Formation during detailed core and outcrop studies. Stratigraphic relations indicate that, prior to deposition of Dundee carbonates, a major regression exposed underlying Detroit River sediments adjacent to the arches. Subsequent transgression deposited reworked sands and shallow shelf, bioclastic limestones in most areas of the adjoining basins while in westernmost regions of the Appalachian Basin Columbus Formation sediments were accumulating adjacent to the Findlay Arch.

Transgression became interrupted during middle Dundee time and a thick unit of lagoonal muds was deposited in the Appalachian Basin. A regionally well-developed firmground capping these mudstones indicates that a significant episode of non-deposition ensued. The equivalents of these muds in the Michigan Basin are pulses of coarse, reworked grainstones and rudstones indicating that substrates there were shallower and above wave base. Evidence of subsequent renewed transgression is preserved as middle to outer shelf moderately fossiliferous mudstones and wackestones overlying shallow shelf facies.

Well-developed traceable 'packages' of firmgrounds commonly occur in middle to outer shelf facies and record step-like transgressive conditions with relative sea level rise interrupted by episodes of stillstand and non-deposition. These firmgrounds developed adjacent to paleotopographic highs and have distributions similar to hardgrounds documented in modern, shallow epicontinental seas of the Persian Gulf. Uppermost Dundee strata in the Appalachian Basin suggest a final transgressive episode with deposition of deep water argillaceous mudstones; however, upper Dundee strata in the Michigan Basin document a period of sea level stillstand, winnowing and reworking.

ACKNOWLEDGEMENTS

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At McMaster University, Jack Whorwood deserves special thanks for developing photographs and providing advice on thesis presentation. His patience and prompt service allowed me to beat many critical deadlines. Len Zwicker is also to be thanked for producing all thin sections. Craig Johnston and Peter Lloyd deserve recognition for being excellent assistants both in the field and in the lab.

Many friends, too many to mention here, made my stay at McMaster an enjoyable one. Mac wouldn't have been the same without the numerous challenges and imaginative adventures in which these people were always willing to participate. Francois Brissette, Bruce Willmer, Randy Meecham, Stu Miller, Steve Beneteau and other members of the Rockbusters Football and Aureoles Baseball teams provided continuous entertainment both on and off of the sports field. Their dedication and light-hearted approach allowed me to maintain a respectable degree of sanity throughout my studies.

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CHAPTER 1 - INTRODUCTION

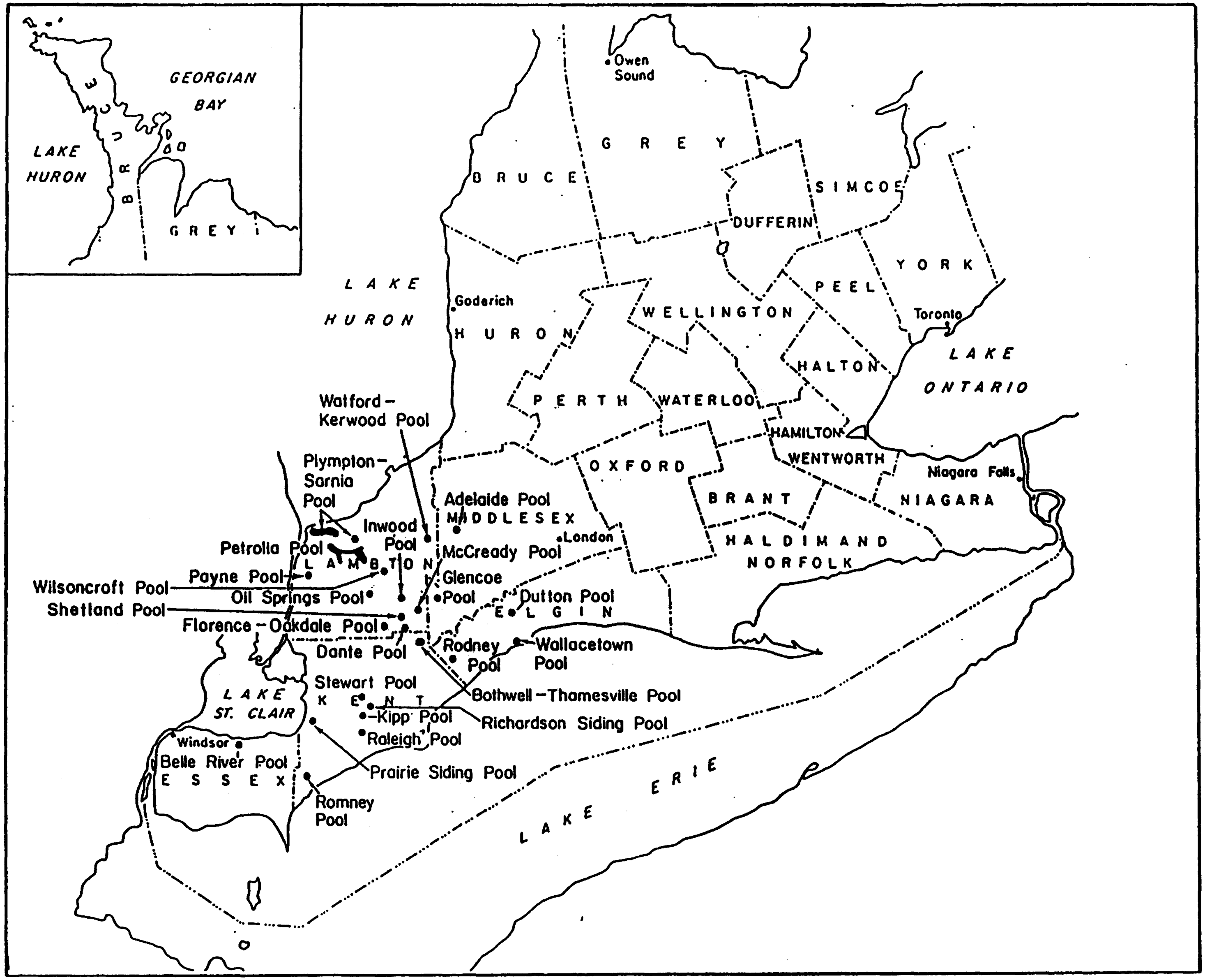
1.1 Introduction

In southwestern Ontario, Dundee Formation and underlying Detroit River Group carbonates have produced nearly 6.3 million cubic meters of oil from a variety of traps (Bailey and Cochrane, 1985). Certain Devonian traps in parts of southwestern Ontario occur in uppermost Detroit River and lower Dundee sandy limestones, while other pools produce from bioclastic limestones in uppermost Dundee strata (Fig. 1.1). The primary control on these traps is structural but many of these traps are found within different lithofacies. Although the Dundee Formation has been the largest oil producing formation in southwestern Ontario, little research has been carried out on this unit in the subsurface. Previous interpretations and lithofacies schemes developed for the Dundee Formation are based primarily upon limited outcrop exposures (Best, 1958; Diffendal, 1971). This study looks at most outcrop locations and available drill cores of Dundee and immediately underlying rocks in the southwestern Ontario area.

1.2 Study Area and Methods

The Dundee Formation in Ontario occurs southwest of an imaginary line running from the town of Goderich, on the Lake Huron shoreline, through St. Marys to the Port Dover area on

Figure 1.1 Location of Devonian pools in southwestern Ontario (after Bailey and Cochrane, 1985).

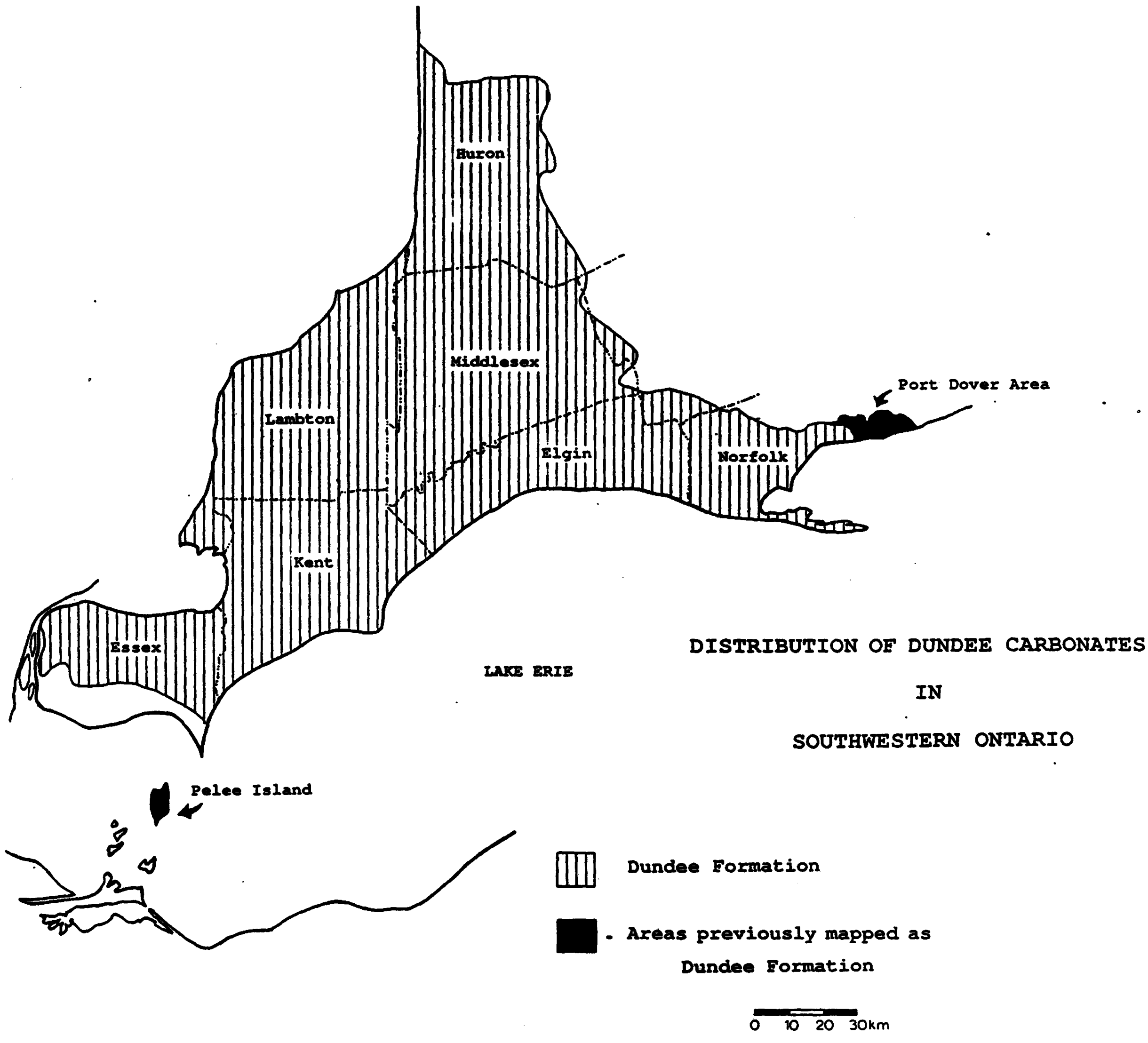


GEORGIAN BAY
LAKE HURON
BRUCE
GREY
Owen Sound
GREY
BRUCE
SIMCOE
DUFFERIN
YORK
PEEL
LAKE
HURON
Goderich
HURON
WELLINGTON
Toronto
LAKE ONTARIO
HALTON
PERTH
WATERLOO
HAMILTON
WENTWORTH
Niagara Falls
NIAGARA
OXFORD
BRANT
HALDIMAND
NORFOLK
Watford-Kerwood Pool
Plympton-Sarnia Pool
Adelaide Pool
MIDDLESEX
London
Inwood Pool
Petrolia Pool
LAMBTON
McCready Pool
Payne Pool
Glencoe Pool
Wilsoncroft Pool
Oil Springs Pool
Dutton Pool
Shetland Pool
ELGIN
Florence-Oakdale Pool
Dante Pool
Rodney Pool
Wallacetown Pool
Stewart Pool
KENT
Bothwell-Thamesville Pool
LAKE ST. CLAIR
Kipp Pool
Richardson Siding Pool
Raleigh Pool
Windsor
Belle River Pool
ESSEX
Prairie Siding Pool
Romney Pool
LAKE ERIE

the north shore of Lake Erie (Fig. 1.2). Dundee strata have also been mapped as underlying parts of the Windsor - Essex area and as forming the bedrock of Pelee Island in Lake Erie (Uyeno et al., 1982). Outcrop locations of Dundee and underlying strata previously mapped and described by other authors were logged in detail (Best, 1953 ; Sanford, 1958 ; Diffendal, 1971 ; Telford and Tarrant, 1975 ; Telford and Hamblin, 1980 ; Uyeno et al., 1982 ; Sparling, 1983 ; Bjerstedt and Feldmann, 1985). The most complete outcrop sections of Dundee strata occur in the quarry of the St. Mary's Cement Company Limited at St. Marys and along the Maitland River near Goderich.

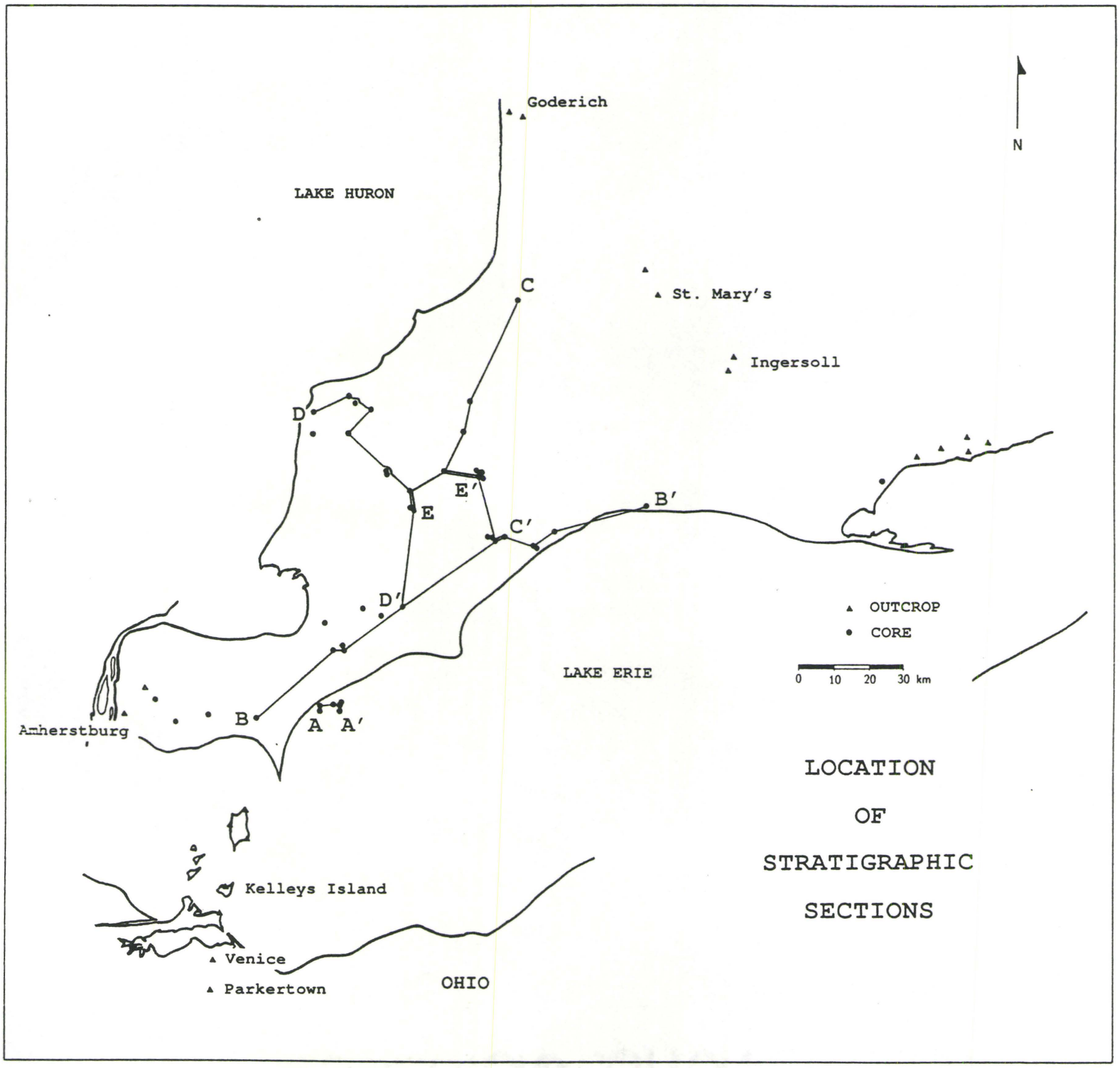
This study is also based on the examination and correlation of 86 drill cores listed by the Ministry of Natural Resources as penetrating parts of the Dundee Formation (Fig. 1.3). These cores are stored at the Petroleum Resources Laboratory of the Ministry of Natural Resources in London, Ontario. Many of the cores come from within small areas of producing fields. Consequently, for these small areas all cores were examined but only the most complete core was logged. Cored sections which were logged but not included in drafted core cross sections are available from the author. Samples representative of facies and faunal variations from outcrop and subsurface cores were collected. Polished slabs, acetate peels and thin sections stained with Alizarin Red-S

Figure 1.2 Distribution of Dundee carbonates in southwestern Ontario (after Sanford, 1958, 1969 ; Telford and Tarrant, 1975 ; Telford and Hamblin, 1980 ; Uyeno et. al., 1982). Areas previously mapped as Dundee Formation which have been re-evaluated in this study are shown in black. Boundaries of counties discussed in this study are also shown.



DISTRIBUTION OF DUNDEE CARBONATES
IN
SOUTHWESTERN ONTARIO

Figure 1.3 Location of outcrop and subsurface drill cores examined in this study. Orientations of stratigraphic sections constructed from logged cores also shown.



LOCATION OF STRATIGRAPHIC SECTIONS

and potassium ferricyanide solutions were later prepared from these samples.

1.3 Study Objectives

Many problems still exist as to the nature of the lower formation contact of the Dundee Formation and the lateral relationships of the Dundee with adjacent strata in Ohio, Michigan and western New York. In parts of southwestern Ontario, intervals of sandy limestone containing lenses of clean porous sandstone have commonly been included within the Dundee succession (Dutton, 1985). Other authors, however, suggest that similar sandy units belong in an underlying member of the Detroit River Group (Uyeno et al., 1982). These sandy intervals have, in the past few decades, been called 'Columbus' sands, a term adopted from Ohio where a unit of dolomitic, fossiliferous limestone (called the Columbus Formation) occurs approximately at the lower Dundee contact. The Columbus problem is further complicated by the fact that American geologists recently have mapped bedrock on Pelee Island, in Lake Erie, as Columbus Formation while Canadian geologists have mapped these rocks as Dundee Formation (Uyeno et al., 1982 ; Bjerstedt and Feldmann, 1985). Facies relationships of Dundee strata have not been precisely determined between Ontario, Ohio and Michigan.

One of the main problems dealt with in this study is defining the lower formation contact and developing a lithofacies scheme for the Dundee Formation in this region of southwestern Ontario. By developing a facies scheme, it is hoped that some of the problems regarding placement of these sandy and dolomitic limestones can be resolved. As well, regional facies relationships incorporated into a depositional model may be useful both for exploration purposes and for interpreting porosity and permeability trends in existing Dundee reservoirs.

CHAPTER 2

REGIONAL SETTING AND STRATIGRAPHY

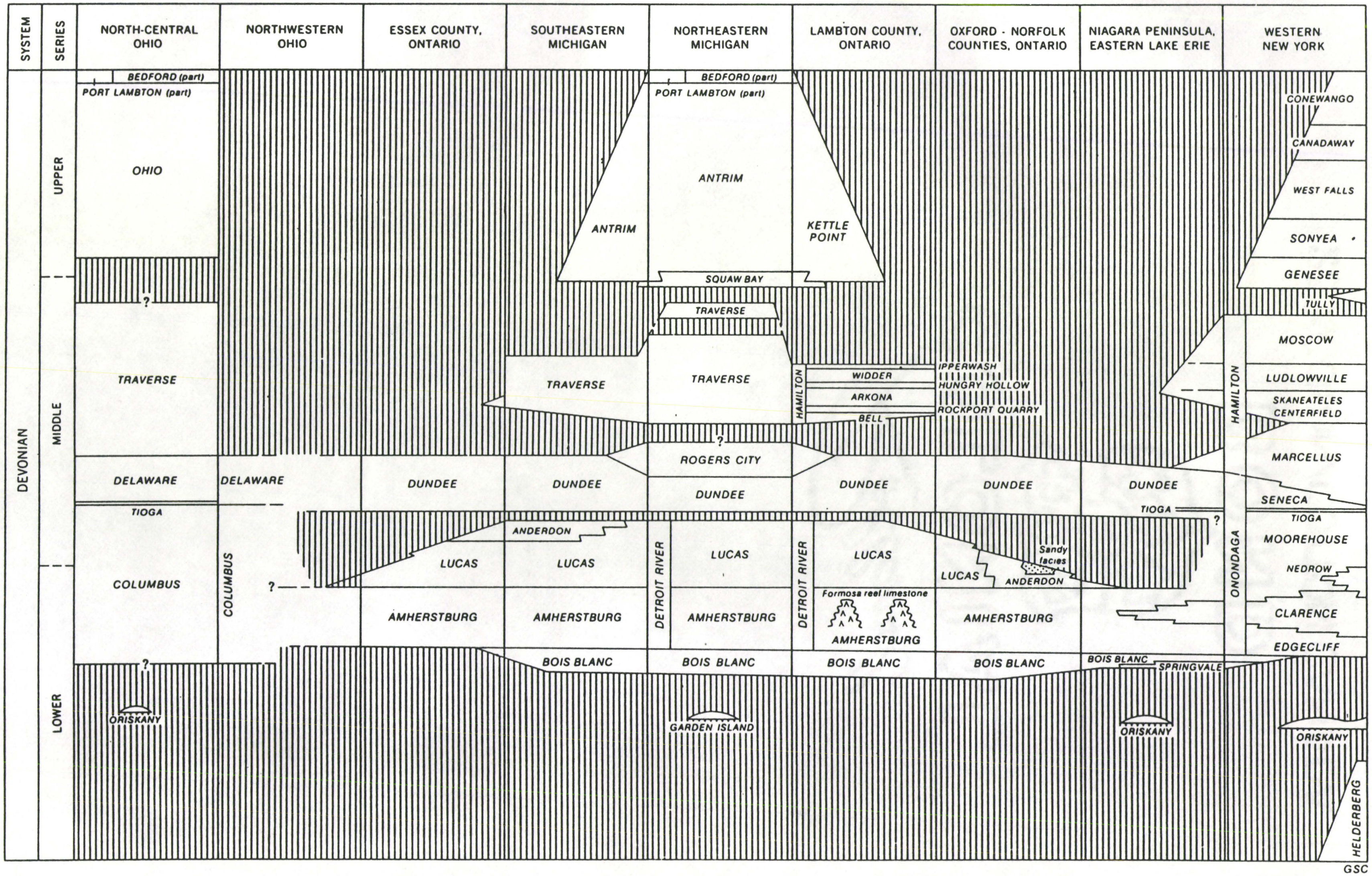
2.1 Introduction

There has been much discussion over the past century regarding the lateral relationships and nomenclature of Middle Devonian rocks in Ontario, Ohio, Michigan and New York. Much of this discussion has stemmed from the fact that outcrops of Middle Devonian rocks are relatively scarce and widely separated. Where outcrops do occur, they are commonly small, vertical exposures which are only traceable laterally over short distances. Correlation of these sections has proven difficult due to lateral facies variations, the lack of good biostratigraphic control and the absence of traceable lithologic markers. Recent integration of subsurface data has aided in understanding stratigraphic relationships (Sanford, 1968 ; Uyeno et al., 1982) however, an absence of published subsurface information from the southwestern Ontario area has left many stratigraphic problems unresolved. Some of these problems will be dealt with in this study.

2.2 Middle Devonian Stratigraphy

Detailed summaries of previous work on the Middle Devonian of Ontario, Ohio, Michigan and New York have recently been documented by several researchers (Oliver, 1976 ; Uyeno et al., 1982 ; Sparling, 1988). Figure 2.1 shows the presently

Figure 2.1 Formational nomenclature and correlation of the Devonian succession in southwestern Ontario and adjoining areas (after Uyeno et. al., 1982).

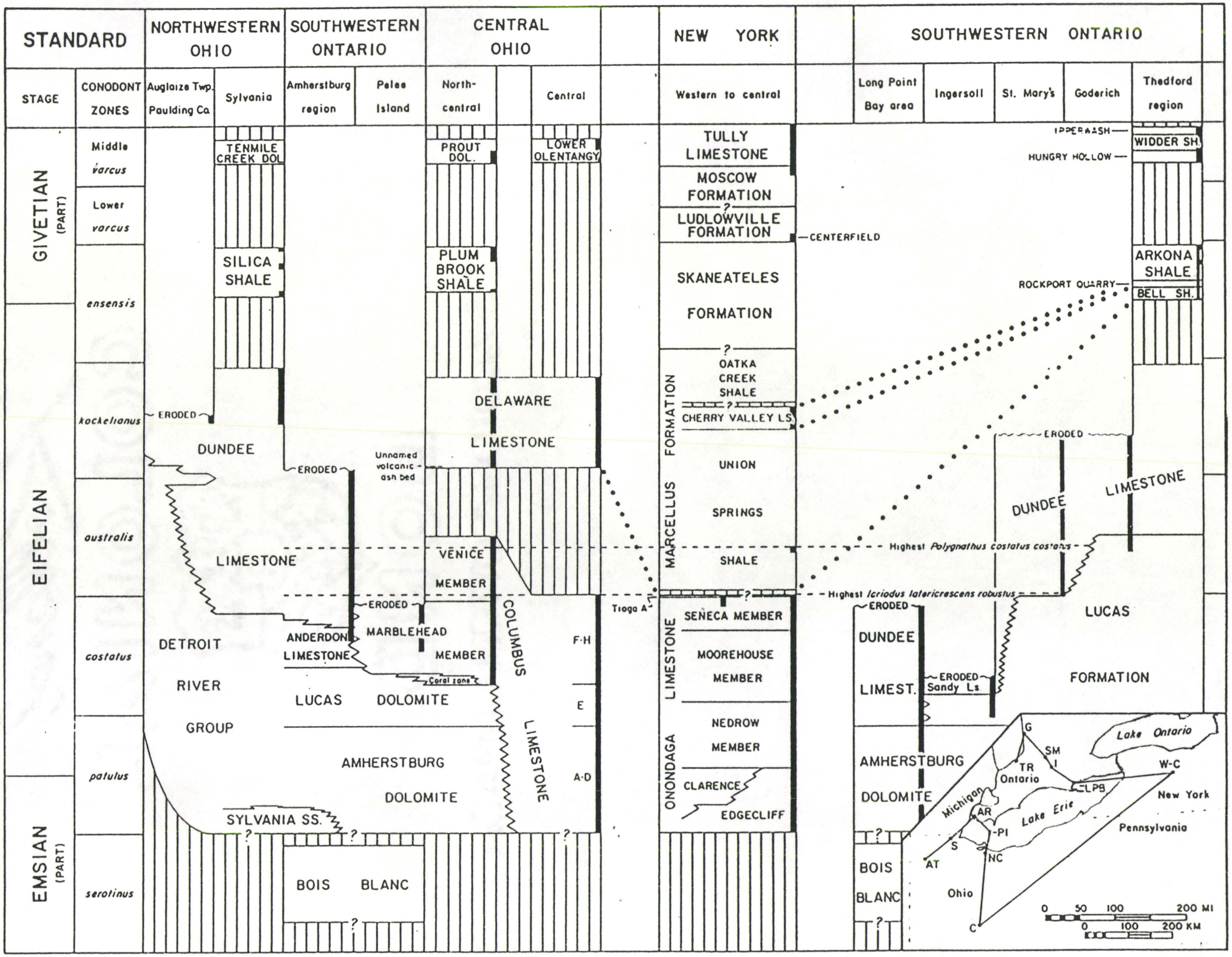

SYSTEM
SERIES
NORTH-CENTRAL OHIO
NORTHWESTERN OHIO
ESSEX COUNTY, ONTARIO
SOUTHEASTERN MICHIGAN
NORTHEASTERN MICHIGAN
LAMBTON COUNTY, ONTARIO
OXFORD - NORFOLK COUNTIES, ONTARIO
NIAGARA PENINSULA, EASTERN LAKE ERIE
WESTERN NEW YORK
DEVONIAN
UPPER
MIDDLE
LOWER
BEDFORD (part)
PORT LAMBTON (part)
OHIO
BEDFORD (part)
PORT LAMBTON (part)
ANTRIM
ANTRIM
KETTLE POINT
SQUAW BAY
TRAVERSE
CONEWANGO
CANADAWAY
WEST FALLS
SONYEA
GENESEE
TULLY
?
TRAVERSE
TRAVERSE
TRAVERSE
HAMILTON
WIDDER
ARKONA
BELL
IPPERWASH
HUNGRY HOLLOW
ROCKPORT QUARRY
MOSCOW
LUDLOWVILLE
SKANEATELES
CENTERFIELD
HAMILTON
?
ROGERS CITY
MARCELLUS
DELAWARE
DELAWARE
DUNDEE
DUNDEE
DUNDEE
DUNDEE
DUNDEE
DUNDEE
SENECA
TIOGA
TIOGA
TIOGA
?
ANDERDON
MOOREHOUSE
LUCAS
LUCAS
LUCAS
LUCAS
Sandy facies
LUCAS
ANDERDON
NEDROW
ONONDAGA
COLUMBUS
COLUMBUS
?
DETROIT RIVER
DETROIT RIVER
Formosa reef limestone
AMHERSTBURG
AMHERSTBURG
AMHERSTBURG
AMHERSTBURG
AMHERSTBURG
CLARENCE
EDGECLIFF
?
BOIS BLANC
BOIS BLANC
BOIS BLANC
BOIS BLANC
BOIS BLANC
SPRINGVALE
ORISKANY
GARDEN ISLAND
ORISKANY
ORISKANY
HELDERBERG
GSC

accepted formational nomenclature and correlation of the Devonian succession in southwestern Ontario and adjoining areas. Over the last few years research on Middle Devonian strata in these areas has largely centred on conodont biostratigraphy and the relationships of the Dundee Formation with adjacent strata (Sparling, 1983, 1984, 1985, 1988 ; Rickard, 1985 ; Uyeno et al., 1982). A composite conodont-based correlation of Middle Devonian strata for the Lake Erie region is shown in figure 2.2 (Sparling, 1988). Since one of the main objectives of this study is to define better the Dundee Formation in southwestern Ontario, a brief introduction to the lithologies of adjacent strata is given here. More complete formation descriptions are given in Best (1953), Oliver (1966), Uyeno et al. (1982), Bjerstedt and Feldmann (1985) and Sparling (1988).

2.2.1 Detroit River Group

In most of southwestern Ontario the Dundee Formation overlies upper Detroit River Group strata. The Detroit River Group consists of the Amherstburg Formation and overlying Lucas Formation, although it is the Lucas Formation which most commonly underlies Dundee strata in this area. The contact of the Detroit River Group with the Dundee Formation is a sharp disconformity and will be discussed in more detail in a later section. Uyeno et al. (1982) describe three main lithologies of the Lucas Formation in southwestern Ontario.

Figure 2.2 Conodont-based correlation of Middle Devonian strata in the Lake Erie region. Wide vertical lines indicate intervals from which conodonts have been previously studied (Sparling, 1988).


STANDARD
STAGE
CONODONT ZONES
NORTHWESTERN OHIO
Auglaize Twp. Paulding Co.
Sylvania
SOUTHWESTERN ONTARIO
Amherstburg region
Pelee Island
CENTRAL OHIO
North-central
Central
NEW YORK
Western to central
SOUTHWESTERN ONTARIO
Long Point Bay area
Ingersoll
St. Mary's
Goderich
Thedford region
GIVETIAN (PART)
EIFELIAN
EMSIAN (PART)
Middle varcus
Lower varcus
ensensis
kockelianus
australis
costatus
patulus
serotinus
TENMILE CREEK DOL.
SILICA SHALE
ERODED
DUNDEE
LIMESTONE
DETROIT RIVER GROUP
SYLVANIA SS.
ERODED
ANDERDON LIMESTONE
LUCAS DOLOMITE
AMHERSTBURG DOLOMITE
BOIS BLANC
Unnamed volcanic ash bed
PROUT DOL.
PLUM BROOK SHALE
DELAWARE LIMESTONE
VENICE MEMBER
ERODED
MARBLEHEAD MEMBER
Coral zone
COLUMBUS LIMESTONE
LOWER OLENTANGY
F-H
E
A-D
Tioga A
TULLY LIMESTONE
MOSCOW FORMATION
LUDLOWVILLE FORMATION
CENTERFIELD
SKANEATELES FORMATION
MARCELLUS FORMATION
OATKA CREEK SHALE
CHERRY VALLEY LS.
UNION SPRINGS SHALE
ONONDAGA LIMESTONE
SENECA MEMBER
MOOREHOUSE MEMBER
NEDROW MEMBER
CLARENCE
EDGECLIFF
Highest Polygnathus costatus costatus
Highest Icriodus latericrescens robustus
IPPERWASH
HUNGRY HOLLOW
WIDDER SH.
ARKONA SHALE
ROCKPORT QUARRY
BELL SH.
ERODED
DUNDEE LIMESTONE
LUCAS FORMATION
ERODED
DUNDEE LIMEST.
ERODED
Sandy Ls.
AMHERSTBURG DOLOMITE
BOIS BLANC
Lake Ontario
G
SM
I
TR
Ontario
LPB
W-C
New York
Michigan
AR
PI
Lake Erie
Pennsylvania
S
NC
AT
Ohio
C
0 50 100 200 MI
0 100 200 KM

These are 1) the undifferentiated Lucas Formation, 2) Anderdon Member and 3) the sandy limestone facies of the Anderdon Member. The most readily identifiable facies is that of the undifferentiated Lucas Formation. This facies consists of thin to medium bedded, tan to grey brown, finely crystalline, poorly fossiliferous dolostone with dark bituminous laminations. Algal domes are commonly found associated with this facies which has been interpreted as representing deposition in a shallow evaporitic setting (Best, 1953). This typical Lucas facies is exposed at the base of the St. Mary's Cement Company Limited quarry at St. Marys and along the Maitland River near Goderich, Ontario.

The Anderdon Member of the Lucas Formation is comprised of sparsely fossiliferous, often peloidal, mottled micritic limestone interbedded with thick beds of coral and stromatoporoid-rich bioclastic limestones. Colonial rugose coral fragments, Amphipora sticks, tabular and domal stromatoporoids are particularly abundant in the upper parts of this facies at the Amherst quarry near Amherstburg, Ontario. Facies of the Anderdon Member are best found in the subsurface of Ontario directly underlying the Dundee Formation in parts of Kent, Lambton and Middlesex counties.

The sandy limestone facies of the Anderdon Member includes brown, thick to massive bedded, moderately fossiliferous sandy limestones interbedded with lenses of orthoquartzitic sandstone (Uyeno et al., 1982). Sandstone lenses are commonly planar laminated or cross-stratified and occasionally interfinger with typical Anderdon Member facies. This sandy facies has in the past been designated as the 'Columbus sand' by local geologists and drillers. It was suggested by Ehlers and Stumm (1951) that outcrop of this facies near Ingersoll, Ontario was in fact equivalent to the upper part of the Columbus Formation from Ohio. This suggestion has since been disproven (Sanford, 1968).

2.2.2 Columbus Formation

In north-central Ohio, the Lucas Formation is conformably overlain by the Columbus Formation which in turn is relatively conformably overlain by the Delaware Formation (Sparling, 1988). The Delaware Formation of Ohio is equivalent to part of the Dundee Formation in southwestern Ontario (Uyeno et al., 1982) although exact facies relationships have not been precisely determined until this study. A diagrammatic summary of the history of the stratigraphic nomenclature for Middle Devonian carbonates in Ohio is given by Bjerstedt and Feldmann (1985). Typically, the Columbus Formation is made up of light brown, moderately fossiliferous, medium grained, bioclastic dolomitic limestones. Chert is commonly present and well rounded, frosted quartz grains are common in the lower part of the formation. Ehlers and Stumm (1951) and Best (1953) both identified Columbus Formation sediments in a quarry near

Ingersoll, Ontario. Oliver (1976) agreed with this designation based upon the coral fauna present there but these rocks were later shown to be a facies of the Lucas Formation (Sanford, 1968 ; Uyeno et al., 1982). Carbonates on Pelee Island in Lake Erie have also been mapped as Columbus Formation sediments (Fagerstrom, 1982 ; Bjerstedt and Feldmann, 1985) although Sanford (1968) and Uyeno et al (1982) mapped these rocks as Dundee Formation. This problem will be discussed in more detail in a later section of this thesis.

2.2.3 Onondaga Formation

Sanford (1968) has suggested that the lowermost Edgecliff Member of the Onondaga Formation is equivalent to the Amherstburg Formation of southwestern Ontario (Fig. 2.1). He also states that the Dundee Formation of Ontario grades eastward into the upper Moorehouse and overlying Seneca Members of the Onondaga Formation in the Niagara Peninsula region. The Moorehouse Member consists of medium-bedded, dark grey or purplish-brown, fine- to coarse-grained, moderately fossiliferous bioclastic limestone. Chert beds and argillaceous seams are common in this member which has corals, stromatoporoids, brachiopods and bryozoa as the dominant fossils. The Seneca Member is similar lithologically but is sparsely fossiliferous in comparison to the underlying Moorehouse Member. The Seneca becomes more argillaceous upwards and is dominated by a brachiopod fauna. Three to four ash beds have been identified throughout a large area of the Appalachian Basin in these upper members of the Onondaga Formation (Rickard, 1984). These may be excellent marker horizons and an important aid to correlations.

In western and central New York an ash bed, previously called the Tioga bentonite, separates the Moorehouse and Seneca Members (Oliver, 1976). This ash bed (called the Tioga B by Rickard) has been correlated with an ash bed at the Columbus - Dundee Formation contact at the Venice quarry in Ohio. Consequently, the Delaware Formation of Ohio has been correlated with the upper Dundee Formation of Ontario and in part with the Seneca and Moorehouse Members of the Onondaga of New York (Oliver et al., 1968). Sanford (1968) has documented the occurrence of an ash bed at a consistent stratigraphic position above the base of the Moorehouse Member from subsurface wells in Norfolk and Oxford counties, and in parts of Lake Erie. As noted by Sanford, the Tioga B ash bed of Ontario and Michigan should be in the middle of the Dundee limestone. In this study, no other ash beds have been positively identified at this stratigraphic position from the Dundee Formation in southwestern Ontario, however, an occasional 2 - 3 cm thick, bluish clay seam has been found in middle to upper Dundee strata. This clay seam may be similar to one described by Bassett in the Dundee Formation from a quarry near Dundee, Michigan (Rickard, 1984 p. 824).

2.2.4 Hamilton Group

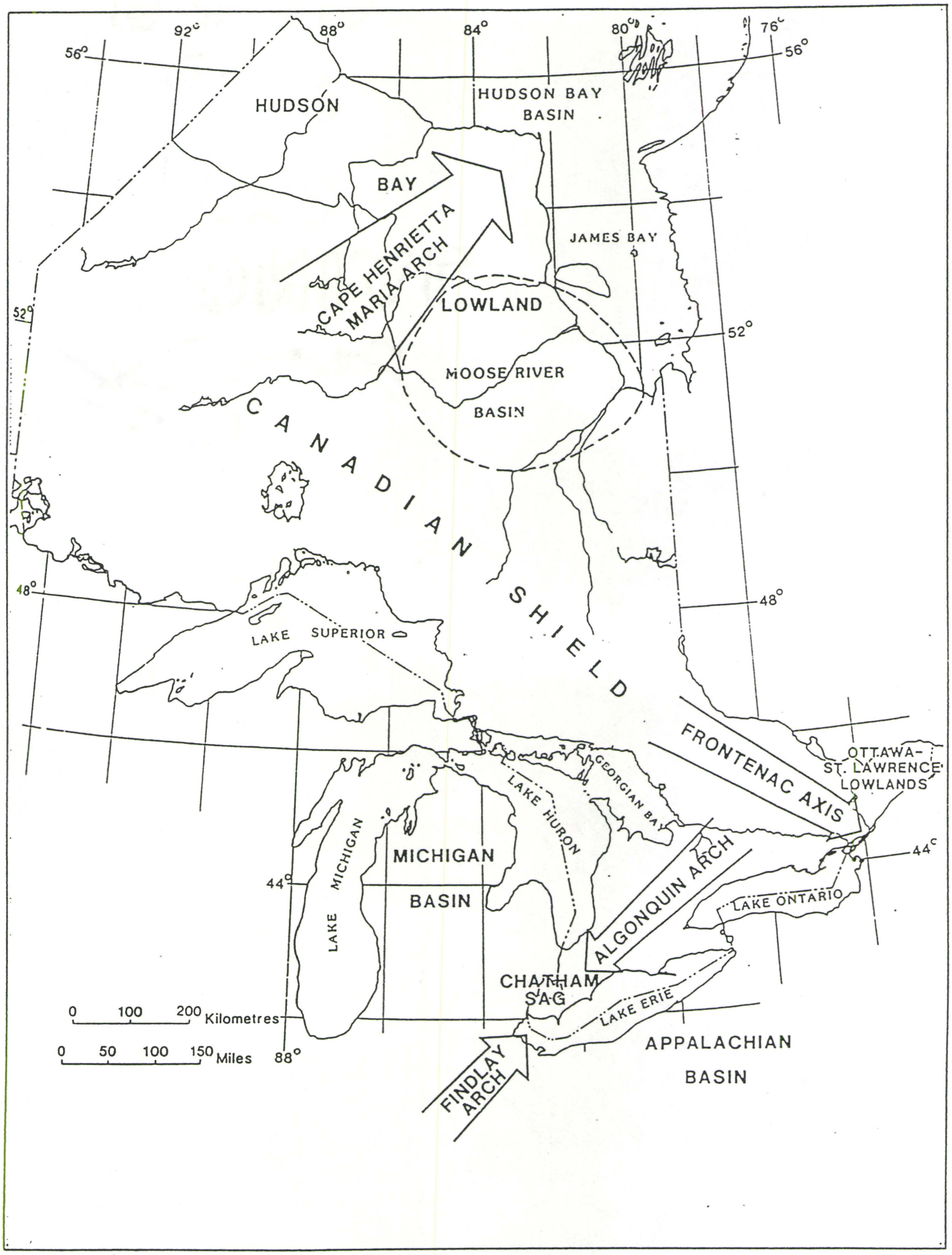
The Hamilton Group overlies the Dundee Formation and in most of southwestern Ontario comprises, in ascending order, the following formations: Bell, Rockport Quarry, Arkona, Hungry Hollow, Widder and Ipperwash (Uyeno et al., 1982). The lithology of the Hamilton Group is predominantly a moderately fossiliferous, fine-grained, marine clastic unit with interbeds of limestone. As shown in figure 2.1, the Marcellus Formation, which has been included in the Hamilton Group of western New York, overlaps the Seneca Member of the Onondaga Formation. Black, bituminous Marcellus shales have a thin basal zone of alternating shale and dark brown, argillaceous limestone gradational with the underlying Seneca Member (Sanford, 1968). The Marcellus shales are not exposed in Ontario but Sanford (1969) suggests that they underlie parts of Lake Erie, Norfolk and Elgin counties.

Oliver (1954) summarized arguments which state that the contact of the Onondaga with the overlying Marcellus Formation is relatively conformable and that evidence for a significant episode of erosion following Marcellus time is sparse. The limestone - black shale contact is apparently younger to the west and older to the east (Oliver, 1966). Recent work has shown, however, that a widespread unconformity does in fact exist across the cratonic interior (Sparling, 1988). In southwestern Ontario, the Dundee - Hamilton contact has been described as a sharp disconformity (Sanford, 1968) although Rickard (1984) believes that this disconformity may represent a hiatus of relatively short duration.

2.3 Regional Setting

Middle Devonian carbonates of southwestern Ontario occur within and between the Michigan and Appalachian basins on the flanks of two major structural highs which are developed on the Precambrian basement (Fig. 2.3). The Algonquin Arch trends northeast-southwest through the southwestern Ontario peninsula and the Findlay Arch trends roughly north-south through southeastern Indiana, western Ohio and the extreme western regions of southern Ontario. These arches are separated by a structural low called the Chatham Sag. This depression apparently resulted from differential subsidence of the Michigan and Appalachian basins and did not have a significant influence on sedimentation until Late Silurian time (Brigham, 1972). Brigham (1972) argues that the Algonquin and Findlay arches are part of the same continuous structural feature, while Sanford (pers. comm. in Brigham, 1972) earlier believed that the two arches were not tectonically related and that the Findlay Arch was raised independently of the Algonquin Arch during Late Middle and Upper Devonian time. These structural features appear to have played an important role in deposition of carbonates during the Middle Devonian. Both arches had been partially exposed in early Dundee time (Sanford, 1968) and the

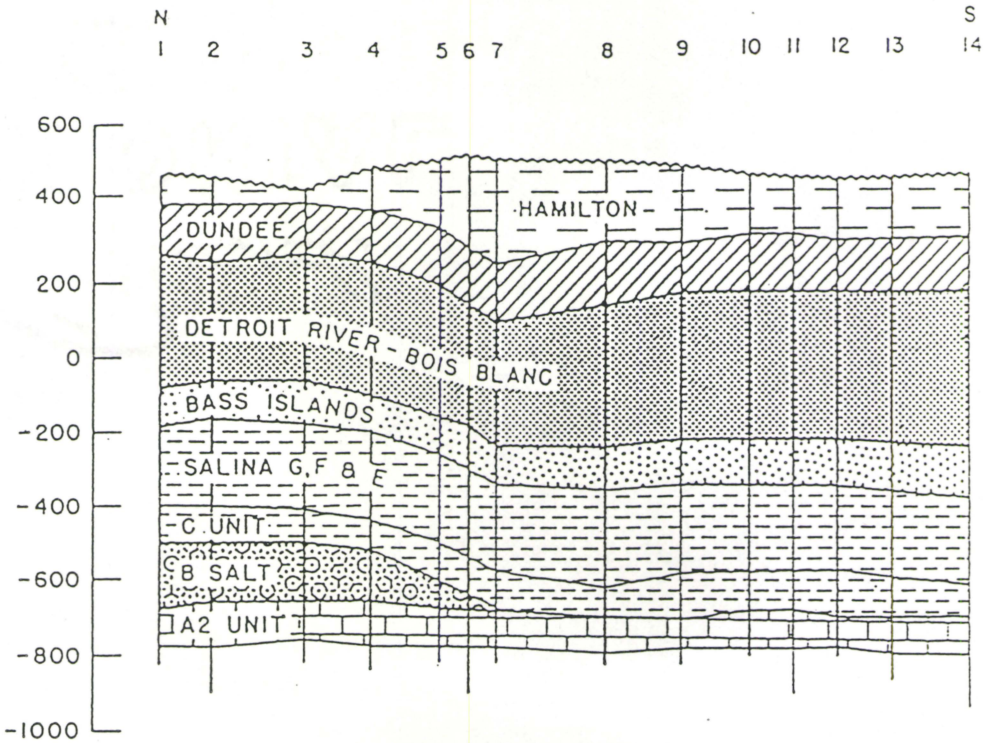
Figure 2.3 Major structural features of Paleozoic rocks in Ontario (courtesy of the Ontario Geological Survey).

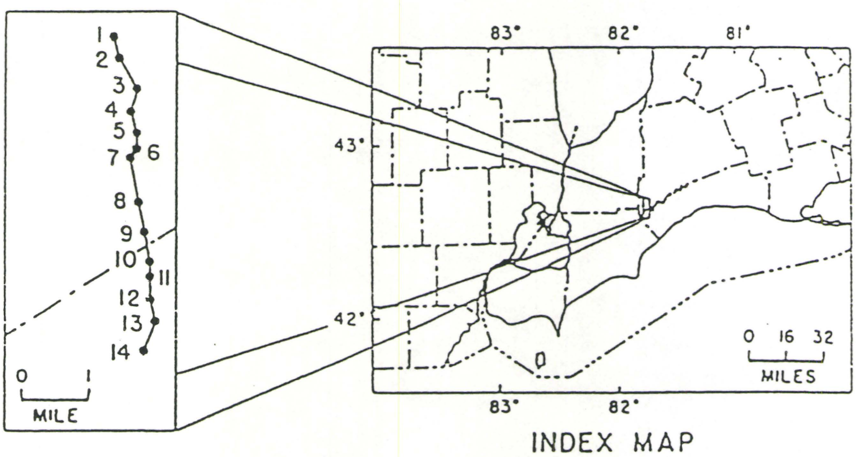

92°
88°
84°
80°
76°
56°
52°
48°
44°
HUDSON
BAY
HUDSON BAY
BASIN
JAMES BAY
CAPE HENRIETTA
MARIA ARCH
LOWLAND
MOOSE RIVER
BASIN
CANADIAN SHIELD
LAKE SUPERIOR
FRONTENAC AXIS
OTTAWA-
ST. LAWRENCE
LOWLANDS
GEORGIAN BAY
LAKE HURON
LAKE MICHIGAN
MICHIGAN
BASIN
ALGONQUIN ARCH
LAKE ONTARIO
CHATHAM
SAG
LAKE ERIE
APPALACHIAN
BASIN
FINDLAY
ARCH
0 100 200 Kilometres
0 50 100 150 Miles

Chatham Sag may have acted as a trap for lower Dundee sediments. The significance of these structures will be discussed in a later section.

Another important structural influence on Devonian sediments in southwestern Ontario is the presence and / or absence of underlying Silurian salts. Brigham (1972) developed a model which shows that during the early Paleozoic several episodes of salt leaching have removed parts of the Upper Silurian Salina Formation. As a result of these episodes of leaching, collapse structures formed such that thickening and thinning of overlying sediments has occurred locally adjacent to these areas. Figure 2.4 shows that leaching of the Silurian B-Salt has resulted in the downwarping of overlying Silurian and Devonian strata. Brigham (1972) contends that two major periods of salt dissolution occurred; the first from Lower to early Middle Devonian (during Bois Blanc to the close of Detroit River sedimentation) and the second during and after deposition of the Upper Devonian Kettle Point Formation. This thesis looks at certain paleotopographic structures which may have resulted due to salt leaching at the end of Detroit River time and suggests that these topographic highs may have influenced Dundee sedimentation.

Figure 2.4 North-south structural cross section through the Wardsville Silurian Field (after Brigham, 1972). Note the localized absence of the Silurian B-salt unit in southernmost wells and corresponding collapse of overlying strata.


N
S
1 2 3 4 5 6 7 8 9 10 11 12 13 14
600
400
200
0
-200
-400
-600
-800
-1000
HAMILTON
DUNDEE
DETROIT RIVER - BOIS BLANC
BASS ISLANDS
SALINA G, F & E
C UNIT
B SALT
A2 UNIT


1
2
3
4
5
6
7
8
9
10
11
12
13
14
0 1
MILE
83°
82°
81°
43°
43°
42°
0 16 32
MILES
83°
82°
INDEX MAP

CHAPTER 3

FACIES DESCRIPTIONS AND INTERPRETATIONS

3.1 Introduction

Six distinct lithofacies have been identified in Dundee strata of southwestern Ontario. These facies were defined mainly on the basis of lithology, texture and sedimentary structures using Dunham's classification scheme as modified by Embry and Klovan (1971). The presence or absence of fossil materials, abundance, size and degree of sorting were noted but fossils were not identified in great taxonomic detail. Most outcrop locations and all subsurface drill cores (available at the Ministry of Natural Resources Core laboratory in London, Ontario) previously mapped as Dundee rocks were examined (Appendix I). Approximately 150 polished slabs, 80 thin sections and 30 acetate peels representing Dundee and adjacent strata were made to complement outcrop and subsurface descriptions. Facies are described in an idealized sequence from the lower through to the uppermost facies within the Dundee succession.

3.2 Facies Descriptions

3.2.1 Lithofacies 1 : Bioturbated Dolomitic Sandy Wackestones

Facies 1 is composed dominantly of slightly argillaceous, moderately bioturbated, sandy dolomitic wackestones

(Fig. 3.1). This lithofacies makes up the significant oil producing interval at the Rodney pool in Elgin County where average porosities and permeabilities are 18 % and 424 md respectively (Bailey and Cochrane, 1985). Pinpoint vuggy and fabric selective porosities commonly occur. Quartz grains usually make up 20 to 50 % of this facies with a decreasing quartz content upwards. Quartz may occur rarely as well rounded, frosted, medium grained sand which may have silica rims, or commonly as subangular fine sands. Dolomite rhombs make up less than approximately 30 % of grains. Bioclastic fragments of pelmatozoan material (dominantly crinoidal), brachiopod valves and solitary rugose corals make up most of the remaining constituent grains.

Uncommon bioclastic packstone pulses are found at the base of this lithofacies and an increasing proportion of crinoidal material is evident upwards in this facies. Common 0.5 to 1.5 cm diameter subhorizontal burrows occur in upper sediments of this facies, corresponding with the decrease in quartz and increase in bioclastic fragments upwards. Sandy wackestone beds are generally up to 50 cm thick and are fairly massive.

Interpretation :

This facies represents marginal marine conditions above storm wave base where sands became fairly well sorted. Fauna preserved in the basal bioclastic packstones record normal

Figure 3.1

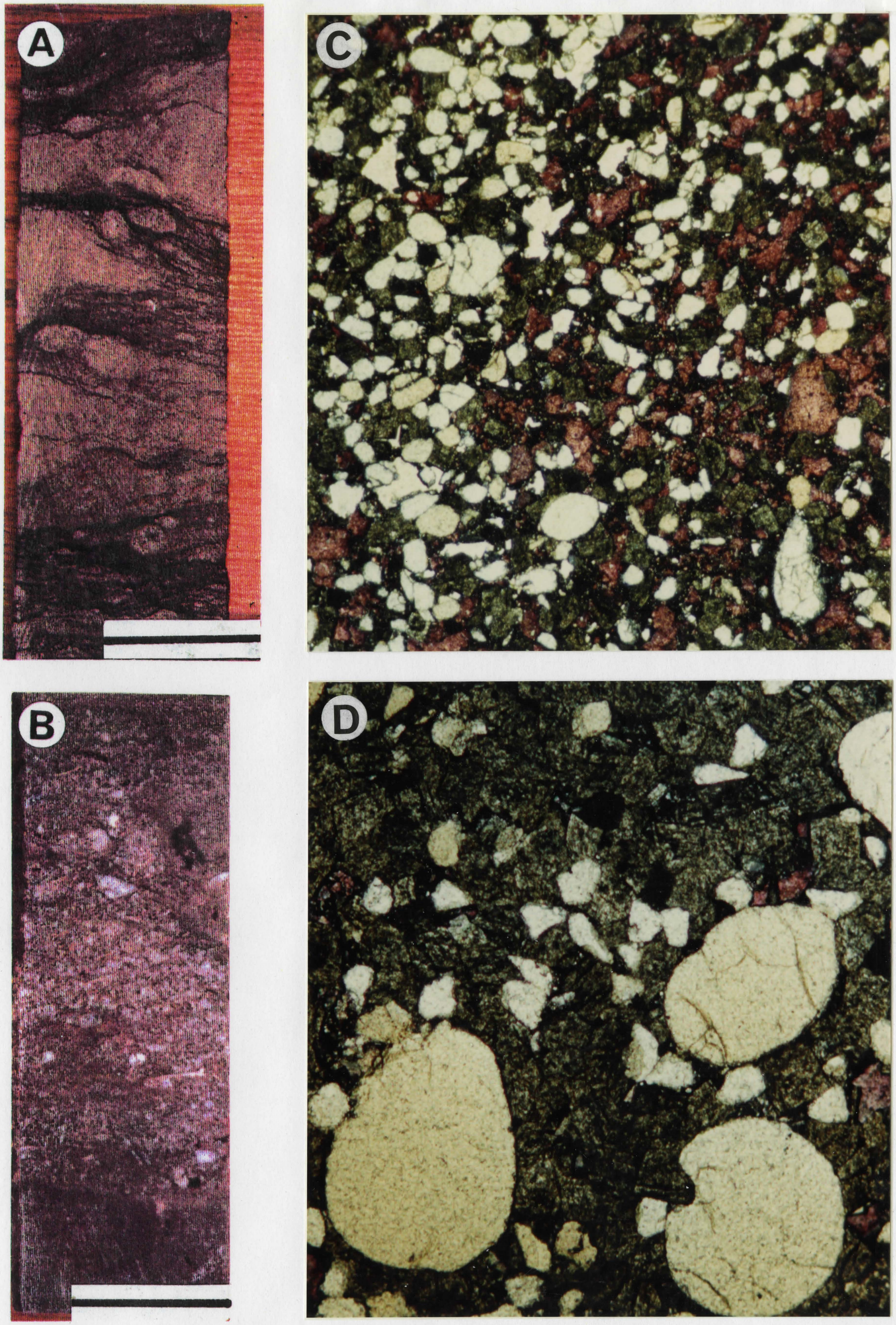
Lithofacies 1 : Bioturbated, dolomitic sandy wackestones

A. Dolomitic mudstone with common rounded subhorizontal burrows. I.O.E Felmont, Elgin Co., 160.02 - 159.86 m. Scale bar = 3 cm.

B. Sandy crinoidal dolomitic wackestone. Rodney 6 - 15, Elgin Co., 122.08 - 121.92 m. Scale bar = 3 cm.

C. Thin section photomicrograph of dolomitic sandy wackestone facies showing common rounded and subangular quartz grains. Rodney 6-15, Elgin Co., 120.1 m. Stained thin section, plane polarized light, 25X magnification. Field of view = 2.5 X 2.5 mm.

D. Thin section photomicrograph showing large rounded and small subangular quartz grains in lithofacies 1. Dunwich 5-VIII, Elgin Co., 162.3 m. Stained thin section, plane polarized light, 63X magnification. Field of view = 1.0 X 1.0 mm.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marine conditions while the only evidence of an in situ fauna higher up in this facies are the horizontal burrows. Evidence from quartz grains suggests two possible sources for the sands: medium grained, well rounded sands may have been reworked from underlying Detroit River sandy carbonates while finer grained, subangular quartz grains may have originated from a more proximal source possibly adjacent to the Algonquin Arch. Summerson and Swann (1970) suggest that some of these well rounded, frosted quartz grains may have had an aeolian origin.

3.2.2 Lithofacies 2 : Cherty Bioclastic Facies

Common, thin bioclastic pulses set in a cherty wackestone matrix make up much of the lower Dundee Formation in southwestern Ontario. Bioclastic pulses are lenticular packstones to floatstones which are generally less than 3 cm thick and laterally discontinuous. These poorly sorted pulses are most commonly made up of broken fenestrate bryozoans, crinoidal fragments and disarticulated brachiopod valves. Bioclastic lenses are set in a dominantly crinoidal, slightly argillaceous, bioturbated wackestone matrix which may be partly dolomitic (Fig. 3.2). Light brown crinoidal wackestone beds are up to approximately 50 cm thick and exhibit a pseudonodular texture. This texture appears to have resulted from bioturbation and pressure dissolution of slightly argillaceous wackestones and is similar to nodular textures

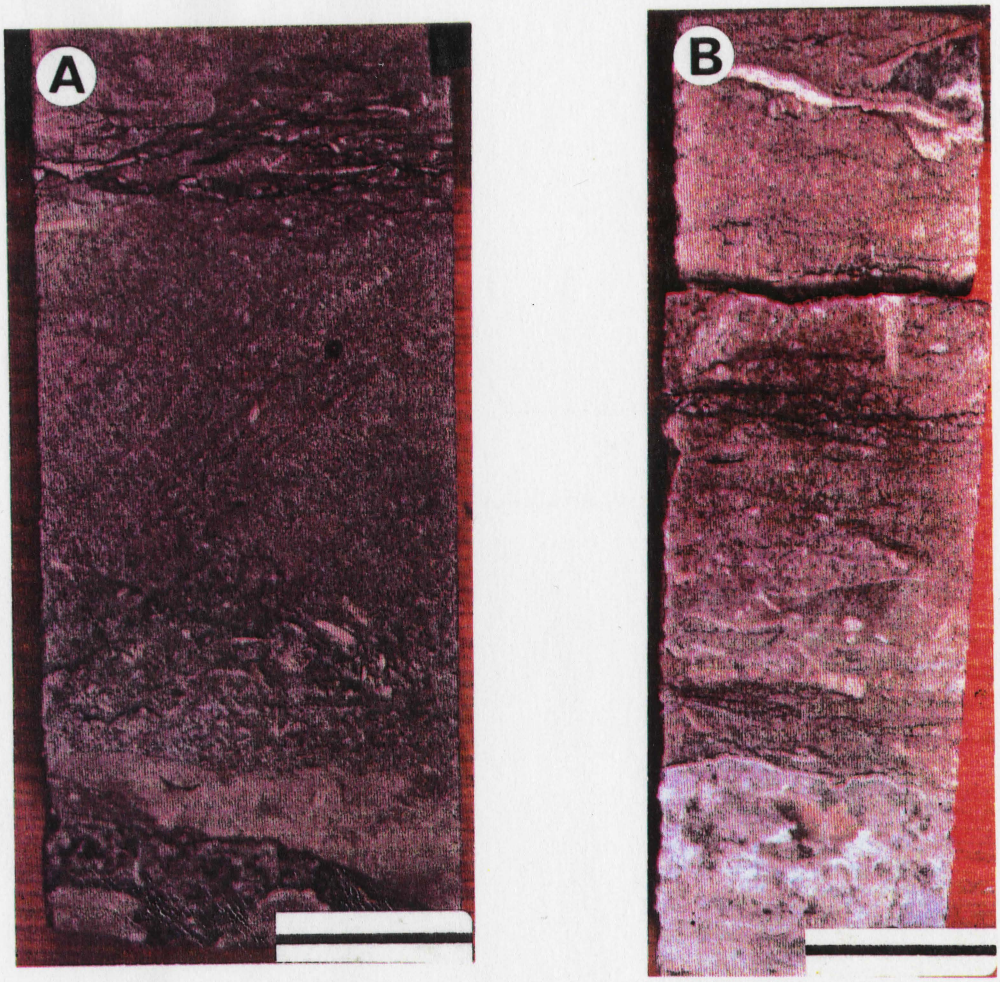
Figure 3.2

Lithofacies 2 : Cherty bioclastic facies

Scale bar = 3 cm.

A. Possible graded bed in facies 2. OGS 82-2, Kent Co., 150.64 - 150.8 m.

B. Facies 2. Consumers 33409, Kent Co., 108.33 - 108.13 m.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described by Choquette and James (1986). Certain beds have coarse packstone pulses which grade upward into crinoidal wackestones. Light brown to whitish chert nodules comprise up to 15 % of this facies with a decreasing chert content observed upwards. Chert nodules usually have diffuse, bioturbated edges. Horizontal burrows with spreiten are commonly preserved in the chert. This facies reaches a thickness of approximately 15 metres in the Imperial Felmont well of Elgin County. This well is situated, within the study area, the furthest distance south of the approximate axis of the Algonquin Arch indicating that this facies thickens into the Appalachian Basin.

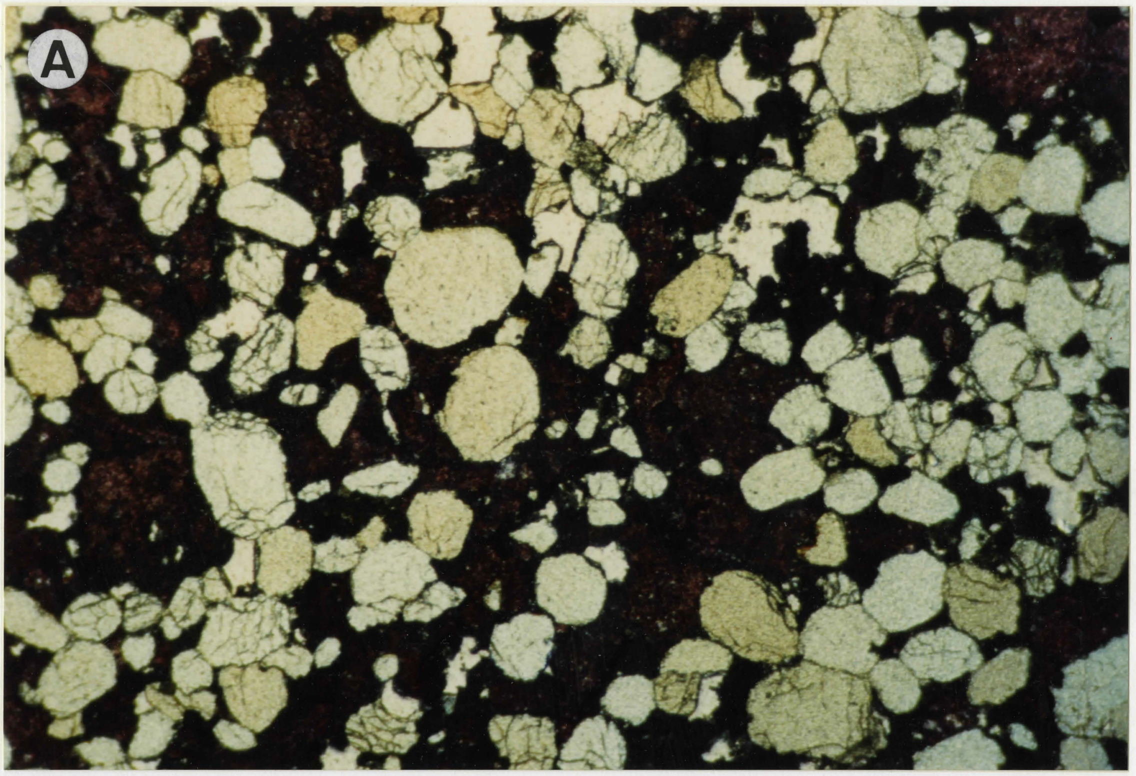
Basal sediments in this facies are commonly sandy with well rounded, frosted < 1.0 mm diameter quartz grains comprising up to 10 % of the lower few metres of this facies. Along the Maitland River near Goderich coarse crinoidal, sandy grainstones overlie Detroit River Group laminated dolomites. Basal quartz sands occur here as reworked, fractured cemented aggregates commonly displaying undulose extinction or as individual rounded and subangular grains (Fig. 3.3). Individual grains may be eroded fragments of larger grain aggregates. Reworked Detroit River carbonate clasts are commonly found interspersed with quartz sands and coarse basal grainstones. This facies is most commonly found erosively overlying Detroit River Group carbonates, however, it may also

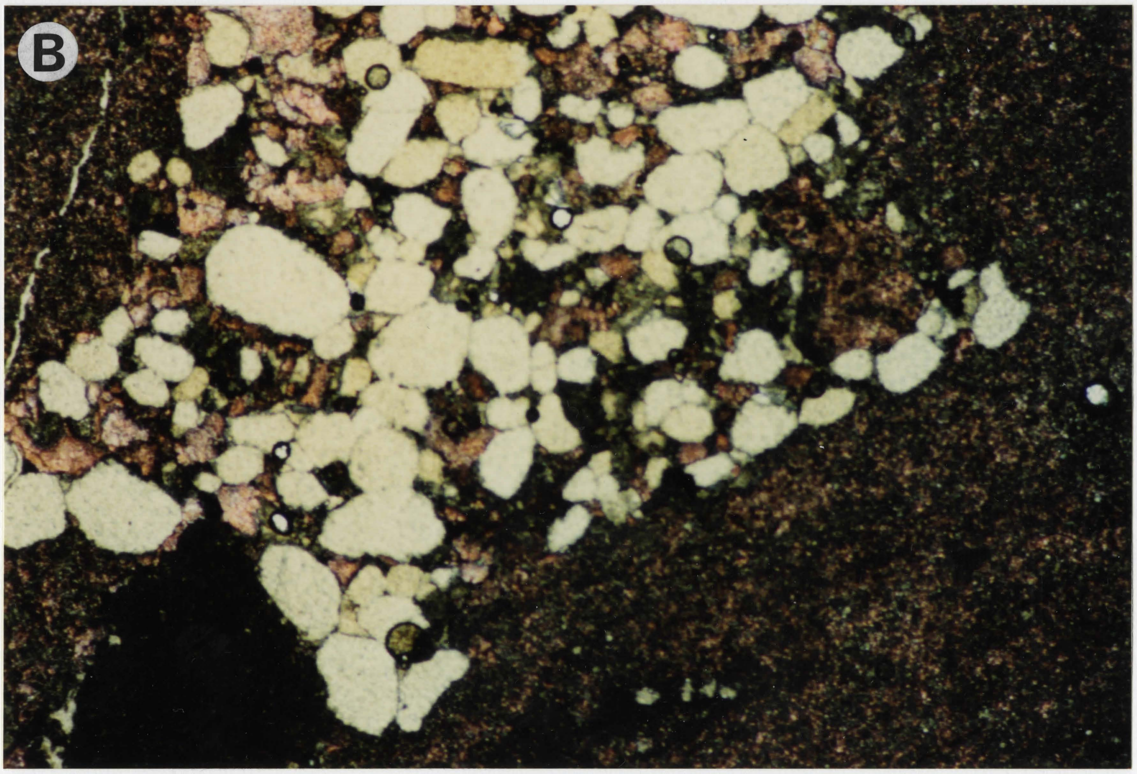
Figure 3.3

Lithofacies 2 : Cherty bioclastic facies

A. Thin section photomicrograph of reworked cemented quartz grains set in crinoidal wackestone matrix of lithofacies 2; Maitland River near Goderich. Note eroded edges of grains and tangential grain contacts. Stained thin section, plane polarized light, 25X magnification. Field of view = 2.5 X 4.0 mm.

B. Thin section photomicrograph showing rounded quartz grains set in a crinoidal wackestone matrix overlying fine-grained Lucas Formation dolomites; Maitland River near Goderich. Stained thin section, plane polarized light, 25X magnification. Field of view = 2.5 X 4.0 mm.





gradationally overlie either dolomitic sandy wackestones of lithofacies 1 or Columbus Formation sediments.

Amber coloured spore cases (Protosalvinia of Best, 1953 ; Tasmanites of Uyeno et al., 1982) are common in this facies and have been used in some instances as an indication of Dundee strata (Dutton, 1985). This proposal will be discussed in chapter 4. Other fossils commonly found in this facies include trilobites, gastropods, cricoconarids (Tentaculites), solitary rugose and domal tabulate corals. Fragments of thin tabular stromatoporoids, ramose bryozoa, colonial rugose and thamnoporid corals are uncommon.

Interpretation :

Common, thin bioclastic pulses composed of marine fossils set in a bioturbated, cherty wackestone matrix suggest that these sediments were deposited in an open shelf environment near or below storm wave base (Wilson, 1975). Thin packstone to floatstone pulses grading upward into a wackestone matrix is evidence of episodic, possibly storm-influenced deposition. Disarticulated brachiopod valves commonly found in a stable convex up position with shelter void cements also support this interpretation (Kreisa and Bambach, 1982). Basal sandy wackestones and crinoidal grainstones / floatstones with reworked Detroit River clasts suggest that these lower sediments are possibly a transgressive lag deposit.

3.2.3 Lithofacies 3 : Cherty Mudstone Facies

Dark brown, thinly bedded to massive mudstones make up this readily identifiable facies which gradationally or sharply overlies the cherty bioclastic facies. Cherty mudstones occur near the middle of the Dundee sequence and reach a maximum thickness of approximately 6 metres. Individual mudstone beds are generally less than 50 centimetres thick and may be separated by thin, black carbonaceous seams (Fig. 3.4). A single example of faintly rippled? muds was documented from the well Consumers 33409 (depth of approximately 110.0 metres). This facies contains fewer fossils than underlying sediments but certain macrofossils such as brachiopods, solitary rugose corals and crinoid fragments are found. The cricoconarid Tentaculites and amber coloured spore case Tasmanites are common to abundant constituents of these sediments.

Chert nodules have sharp edges and may comprise up to 50% of this facies. Individual nodules may be laminated, massive or bioturbated and preserve subhorizontal mining structures with excellent spreiten (Fig. 3.4b). Certain chert nodules are fractured and it is evident in one subsurface core that the chert has lithified earlier than surrounding muds. Fractures such as that observed in the well OGS 82-2 have been infilled by sparry calcite and surrounding muds (Fig. 3.4d).

Interpretation :

Figure 3.4

Lithofacies 3 : Cherty mudstone facies

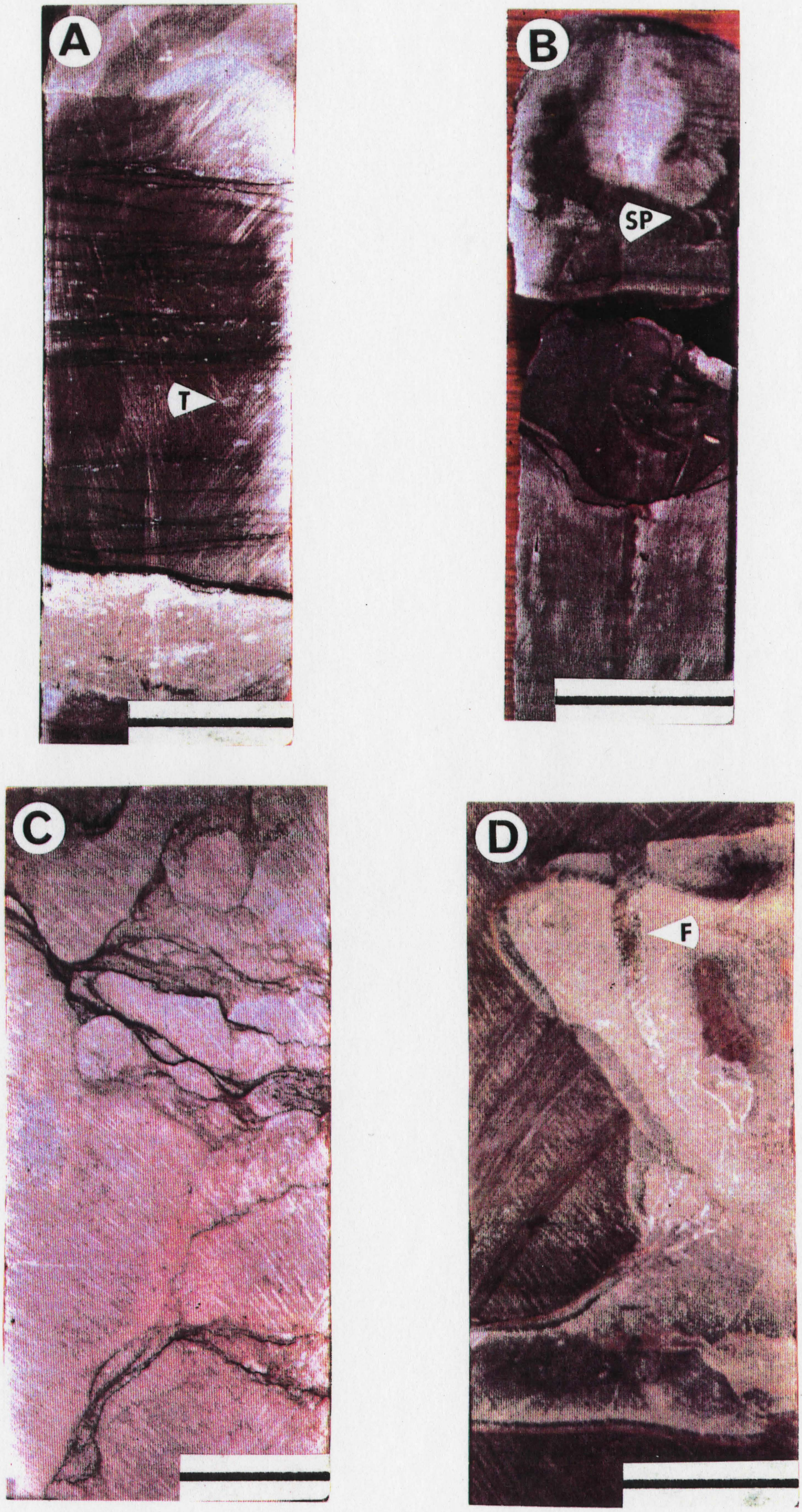
Scale bar = 3 cm.

A. Dark brown, cherty mudstone with common carbonaceous seams, Tentaculites (T) and Tasmanites. Consumers 33409, Kent Co., 104.12 - 103.95 m.

B. Subhorizontal mining structure with spreiten (SP) preserved in dark brown chert nodule. Brett-Onaco, Elgin Co., 126.87 - 126.72 m.

C. Bioturbated Tasmanites-rich mudstone. OGS 82-2, Kent Co., 136.23 - 135.99 m.

D. Fractured chert nodule (F) in facies 3. Note surrounding muds infilling fracture. OGS 82-2, Kent Co., 133.55 - 133.3 m.


A
T
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SP
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F

The abundance of well preserved spore cases (Tasmanites) in dark brown mudstones suggests a quiet water, possibly dysaerobic, restricted lagoonal environment. The lack of marine suspension and filter feeding organisms, commonly found in adjacent facies, supports this interpretation. The occurence of thin, black carbonaceous seams also hints at a restricted lagoonal interpretation. The abundance of Tentaculites in this possibly dysaerobic facies implies a possible nektonic mode of life for these organisms away from oxygen minimum levels that might be found at deeper water levels.

3.2.4 Lithofacies 4 : Crinoid - Brachiopod Firmground Facies

Coarse grainstones and rudstones grading upward to dark grey crinoidal wackestones with well developed firmgrounds generally characterize this facies which reaches a thickness of approximately 12 metres (Well OGS 82-2). Grainstones and rudstones commonly found at the base of this facies are 5 - 15 cm thick and consist primarily of reworked brachiopods plus fragments of solitary rugose corals and crinoids (Fig. 3.5a). Other fossils present may include trilobites, rare thamnoporid and small domal tabulate corals. Fenestrate bryozoans are rare to absent in this facies. Some grainstone to rudstone pulses are relatively well sorted and in places appear biostromal. One of the best examples of biostromal development in this facies occurs at the St. Mary's Cement

Figure 3.5

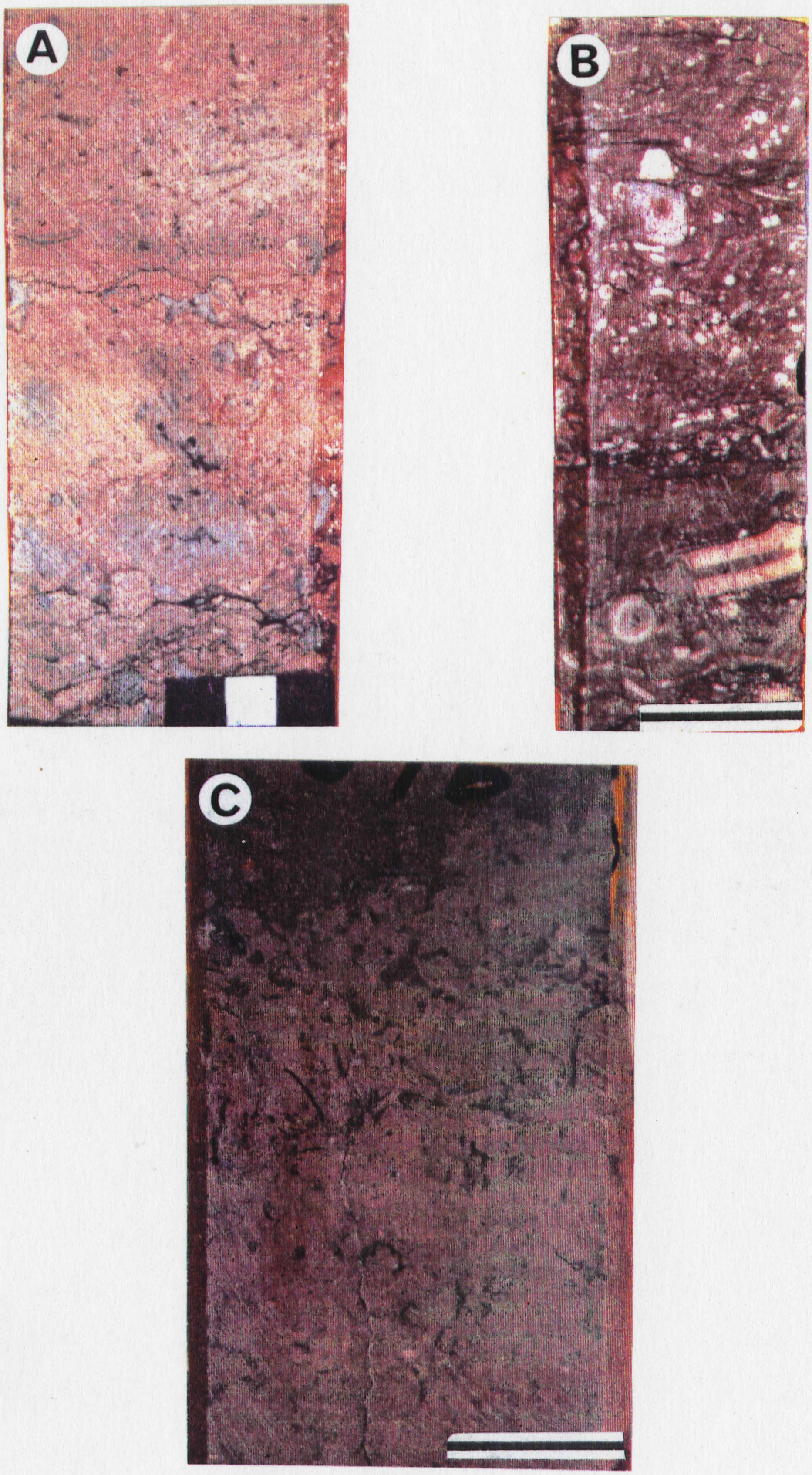
Lithofacies 4 : Crinoid-brachiopod firmground facies

Scale bar = 3 cm.

A. Pyritic coral-brachiopod packstone to rudstone pulse at the base of facies 4. Consumers 33408A, Kent Co., 96.57 - 96.39 m.

B. Coarse crinoidal wackestone in upper part of facies 4. Leesa Imperial 18-XIII, Lambton Co., 86.66 - 86.54 m.

C. Well-developed bioturbated firmground with dark overlying mud infilling burrows. Ram #77, Lambton Co., 120.87 - 120.7 m.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Company quarry where a 25 cm thick, coral-rich bed occurs near the base of this facies which gradationally overlies facies 2.

As observed in the quarry at St. Marys and in many subsurface wells, facies 2 is gradationally overlain by facies 4. In some of these wells two to three coarse grainstone to rudstone pulses occur near the top of facies 2 and the base of facies 4 (Leesa Imp. 19-XIII). In other wells where facies 3 is present, a well-developed firmground separates facies 3 from overlying facies 4. This firmground has been eroded in places and mudstone clasts of facies 3 may be found in the lowermost few centimetres of facies 4. No borings or encrusting organisms were documented at this firmground surface. The significance of this surface will be discussed in a later section.

Above the basal grainstones and rudstones in this facies are massive, dark brown, sparsely fossiliferous wackestones with well developed firmgrounds (Fig. 3.5c). Firmgrounds may be overlain by thin, well sorted packstones to grainstones. Further descriptions and significance of firmgrounds will be discussed in a later section. Coarse crinoid fragments set in a mudstone to wackestone matrix commonly occur near the top of this facies (Fig. 3.5b). Unlike facies 2 this facies does not exhibit a pseudonodular texture and can further be distinguished from facies 2 by the occurence of thick fossiliferous grainstone to rudstone pulses, an absence of chert and an upwards increase in mud content .

Interpretation :

This facies appears to have been deposited during deeper water, open shelf conditions in contrast to underlying facies. Basal grainstones and rudstones with common abraded marine fossils are interpreted as being evidence of biostrome development and episodic reworking. A decrease in the abundance of coarse allochems and a corresponding increase in carbonate mud upwards suggests a deepening of waters and / or a decrease in the energy level. The existence of firmground discontinuity surfaces in upper muddy wackestones implies that several episodes of non-deposition must have occurred during deposition of this facies. There is no evidence to support a subaerial exposure interpretation for these firmground surfaces.

3.2.5 Lithofacies 5 :

Argillaceous, Brachiopod-rich Mudstones to Wackestones

Lithofacies 5 is made up of massive to medium bedded, pervasively bioturbated, argillaceous mudstones to wackestones. Two to ten centimetre thick, dark grey argillaceous seams with common subrounded horizontal burrows interbedded with 20 - 40 cm thick massive mudstone to wackestone beds are diagnostic of this facies (Fig. 3.6a,b). Mudstone to wackestone beds are dark brown to purplish in colour and commonly appear mottled. Mottles are dark grey to

Figure 3.6

Lithofacies 5 : Argillaceous, brachiopod-rich mudstones to wackestones

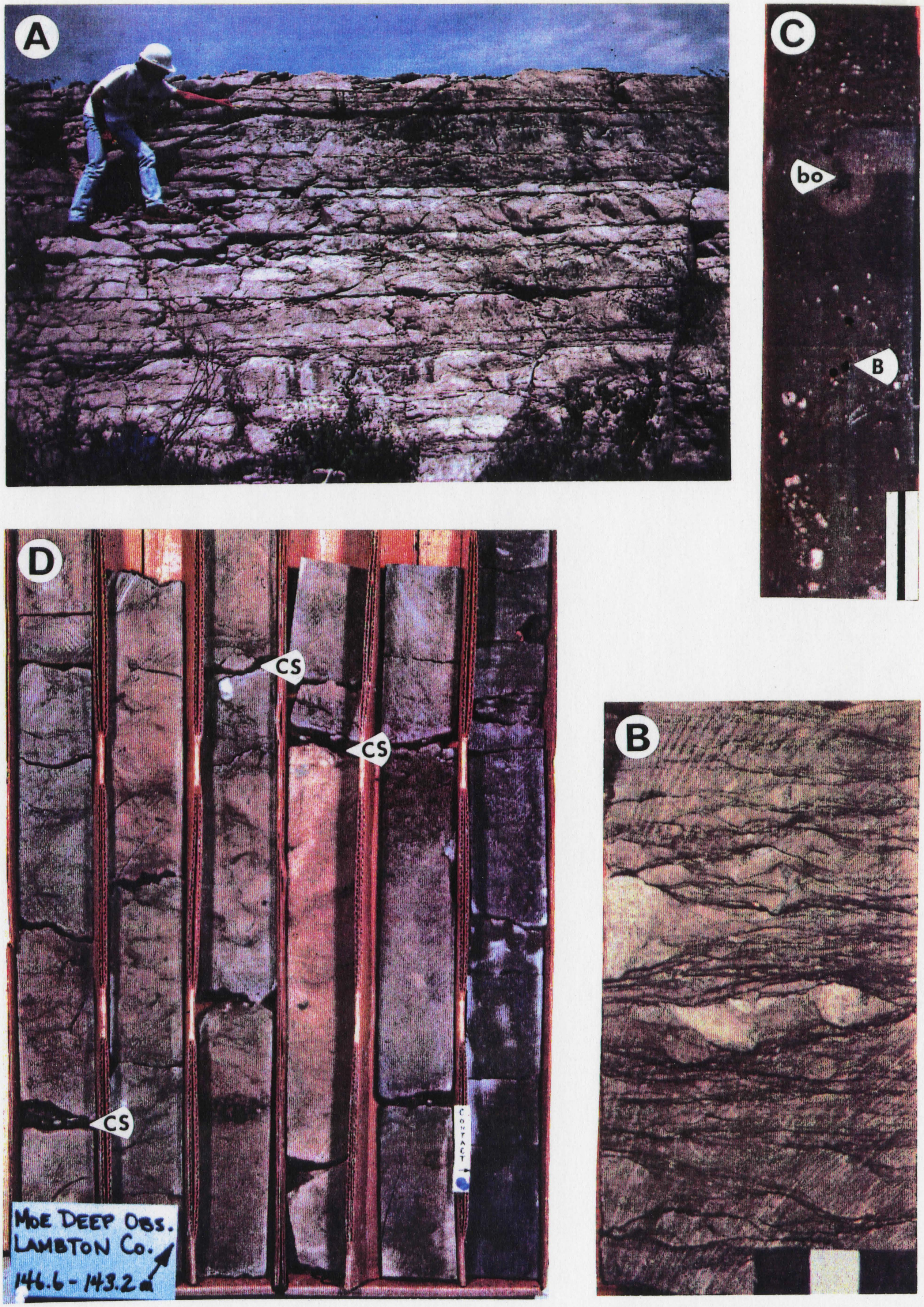
A. Medium bedded, argillaceous mudstones and wackestones; St. Mary's Cement Co. operating quarry, St. Marys.

B. Bioturbated, argillaceous pulse in facies 5; MOE Deep Obs. #1, Lambton Co., 159.22 - 159.1 m. Scale bar = 3 cm.

C. Hardground contact of facies 5 with overlying Hamilton shales. Note millimetre-size phosphatic bone fragments (B) infilling vertical boring? (bo) in center of core. Scale bar = 2 cm.

Lithofacies 6 : Muddy, bioturbated wackestones to packstones

D. Facies 6 with thin, dark brown carbonaceous seams (CS). Subvertical mud-lined burrows are common below muddy seams. MOE Deep Obs. #1, Lambton Co., 146.6 - 143.2 m. Top of core to right.


A
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CONTACT
MOE DEEP OBS.
LAMBTON CO.
146.6 - 143.2
B

bluish, generally less than one centimetre in diameter and appear to be a result of bioturbation. Horizontal to subhorizontal mining structures are the most common type of burrow observed.

Body fossils are much less common than in underlying facies and packstone, grainstone and rudstone beds are essentially absent. Thin 1 - 2 cm diameter disarticulated brachiopod valves are abundant in argillaceous pulses and articulated brachiopods are also commonly found. Crinoidal fragments and 2 - 3 cm diameter solitary rugose corals are scattered throughout these sediments. Thin valved ostracods frequently occur within argillaceous pulses and rare tabular stromatoporoids are present. A 10 - 20 cm thick argillaceous mudstone bed with common rugose corals (Cystiphyllum) and coarse crinoidal fragments commonly occurs near the top of this facies. Excellent intraskeletal porosity occurs within Cystiphyllum and hydrocarbons commonly ooze from these corals. Firmgrounds are uncommon in this facies but can be identified both in core and outcrop. Examples of these can be seen in the well MOE Deep Obs. # 1 in Lambton County and at the St. Marys quarry, respectively.

Interpretation :

The occurence of argillaceous pulses interbedded with sparsely fossiliferous, pervasively bioturbated mudstone to wackestone beds suggests middle shelf, deep water conditions and soft substrates. Occasional firmgrounds indicate that episodes of non-deposition must have occurred locally during deposition of these sediments. Black, argillaceous pulses near the top of this facies in southeastern parts of the study region have abundant brachiopods and closely resemble precursor pulses of Hamilton shales.

3.2.6 Lithofacies 6 :

Muddy, Bioturbated Wackestone to Packstones

Capping the Dundee succession in parts of southwestern Ontario are light brown, 'clean', well-sorted, dominantly crinoidal wackestones with common thick packstone pulses. This facies exhibits good microcrystalline porosity and has been a significant producing interval in parts of the Lambton County area. Approximately 10 to 40 cm thick beds of fine grained wackestones and packstones are separated by thin 1 - 2 cm dark brown carbonaceous muddy seams (Fig. 3.6d). Commonly found within beds below these dark carbonaceous seams are distinctive 1 - 2 cm diameter mudlined subvertical burrows. Some of these burrows are concentrically lined (Asterosoma) while others have knobby mudlined walls (Ophiomorpha).

The fauna in this facies is similar to that in facies 5 with brachiopod and crinoid fragments as the dominant allochems. Tabular stromatoporoids are uncommon and firmgrounds are rare in these sediments. Massive, bioturbated brachiopod rich beds typical of facies 5 are gradationally overlain by facies 6 sediments. Fine crinoidal fragments become more common upward in this facies. Facies 6 is sharply overlain by Hamilton Group limestones and black shales with the upper Dundee contact commonly being a distinct, often pyritized hardground (Fig. 3.6c).

Interpretation :

The lack of argillaceous material in this facies and the degree of sorting of fine crinoidal material suggests that these sediments may represent an episode of winnowing and reworking of nearby shallow shoal-type sediments. Subvertical mudlined burrows are characteristic of shallow intertidal settings (Rhoads, 1967) and the presence of muddy, carbonaceous seams would support this suggestion.

CHAPTER 4

STRATIGRAPHIC PROBLEMS

4.1 Introduction :

Prior to discussing the distribution of Dundee lithofacies in southwestern Ontario, it is necessary to address some of the stratigraphic problems which exist with regard to the Dundee and adjacent formations in surrounding areas (Fig. 1.2). The first problem concerns use of the term 'Columbus' which has been used to describe sandy intervals present near the lower Dundee contact, as well as dolomitic limestones of the Pelee Island area. A second problem concerns the absence of typical Lucas Formation facies in the vicinity of Port Dover and the possibility that a correlative facies has been misidentified as the lower part of the Dundee Formation.

4.2 The Columbus problem :

In the southwestern Ontario area, orthoquartzitic sandstone lenses present near the Detroit River - Dundee contact have previously been designated as 'Columbus sands'. The term Columbus has been applied to these sandy intervals since Ehlers and Stumm (1951) suggested the possible correlation of sandy limestones at Ingersoll, Ontario with brown, fossiliferous dolomitic limestones of the Columbus Formation in Ohio. The Columbus limestone, typically exposed in the Columbus, Ohio region, had not been identified from outcrop in Ontario prior to this time. Recently, it has been shown that these sandy limestones at Ingersoll are more likely a facies of the Anderdon Member (Sanford, 1968).

Although the term Columbus has been discarded for the Ingersoll section, some controversy still remains. Fossiliferous dolomitic limestones on Pelee Island and in the subsurface of the Lake Erie area, although closely resembling upper Columbus Formation sediments of Ohio, have been designated Dundee Formation by Canadian geologists (Sanford, 1968; Uyeno et al., 1982). Sanford (1968) stated that Columbus limestones of Pelee Island are the basal coarse clastic limestone facies of the Dundee Formation and have stratigraphic continuity with the Dundee Formation of southeastern Michigan and Ontario. American geologists, however, have continued to call Pelee Island limestones an upper Columbus Formation equivalent (Fagerstrom, 1982 ; Sparling 1983 ; Bjerstedt and Feldmann, 1985). The problem of designating formation status to Pelee Island carbonates can be resolved by detailed facies analysis as carried out in this study.

4.3 Columbus facies and markers, Pelee Island area :

Bjerstedt and Feldmann (1985) describe a pelmatozoan wackestone-packstone-grainstone facies that is well exposed in the northern Ohio and Pelee Island areas. Winnowed packstone and grainstone layers within an overall dolomitic wackestone matrix are characteristic of this facies. On Pelee Island, well-developed coral biostromes are also present, especially at the Erie Sand and Gravel quarry on the northeast corner of the island. These sediments host an abundant and diverse fauna which include brachiopods, cryptostome bryozoans, trilobites, bulbous stromatoporoids, planispiral gastropods, solitary and colonial rugose corals, nautiloids and a variety of tabulate corals. This facies has been interpreted as representing a well aerated, medium to high energy, nutrient rich subtidal shoal environment (Bjerstedt and Feldmann, 1985).

Uyeno et al. (1982) state that on Pelee Island "lenses of pseudo-oolitic limestone enclosing bioclastic debris are occasionally present". The author believes that the 'pseudo-oolitic' material described by Uyeno et al. has been misidentified and in fact is an abundance of calcified charophyte oogonia (Fig. 4.1). This charophyte material is common to abundant in upper Columbus Formation sediments on Pelee and Kelleys islands, as well as at quarries in Venice and Parkertown in Ohio. In contrast to Columbus Formation sediments, charophyte oogonia are rare to absent in the overlying Delaware Formation (= Dundee equivalent) and these microfossils may be used to differentiate Columbus and Dundee facies.

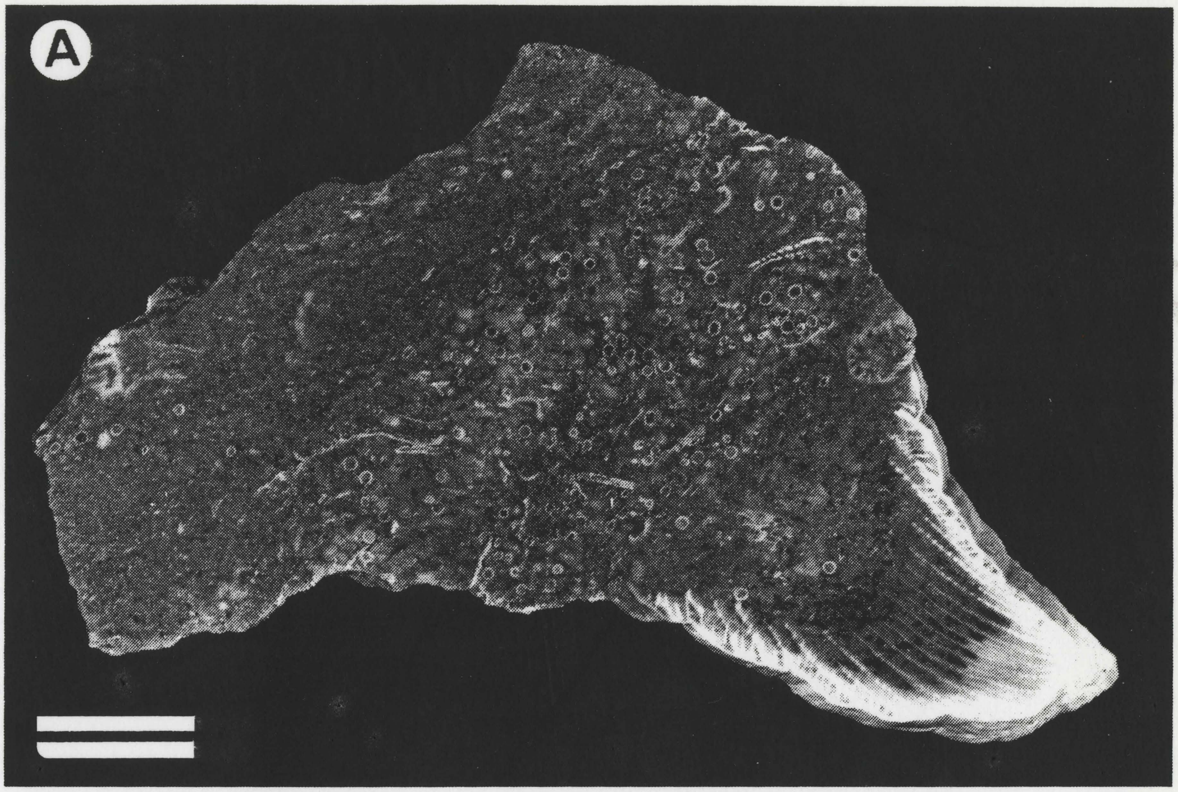
These millimetre-size, calcitic oogonia have been

Figure 4.1

Moellerina greenei?

A. Polished slab of Columbus Formation dolomitic limestone with common hollow, calcitic charophyte oogonia identified as *Moellerina greenei*. Note also common black *Tasmanites* infilling rugose calyx. Scale bar = 1 cm.

B. Thin section photomicrograph of *Moellerina* showing well preserved ornamentation. Unstained thin section, plane polarized light, 63X magnification. Scale bar = 400 microns.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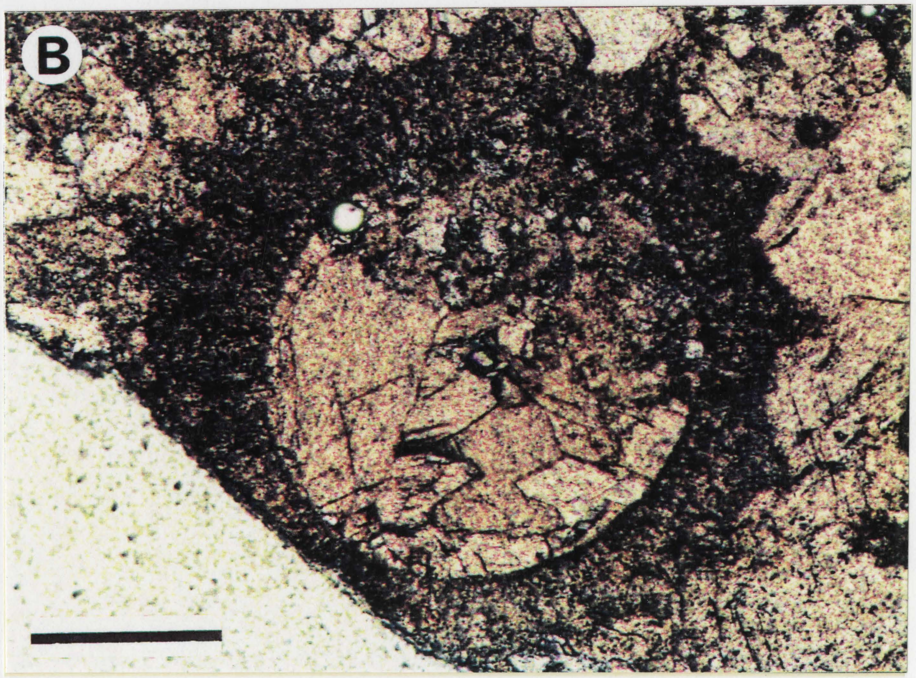
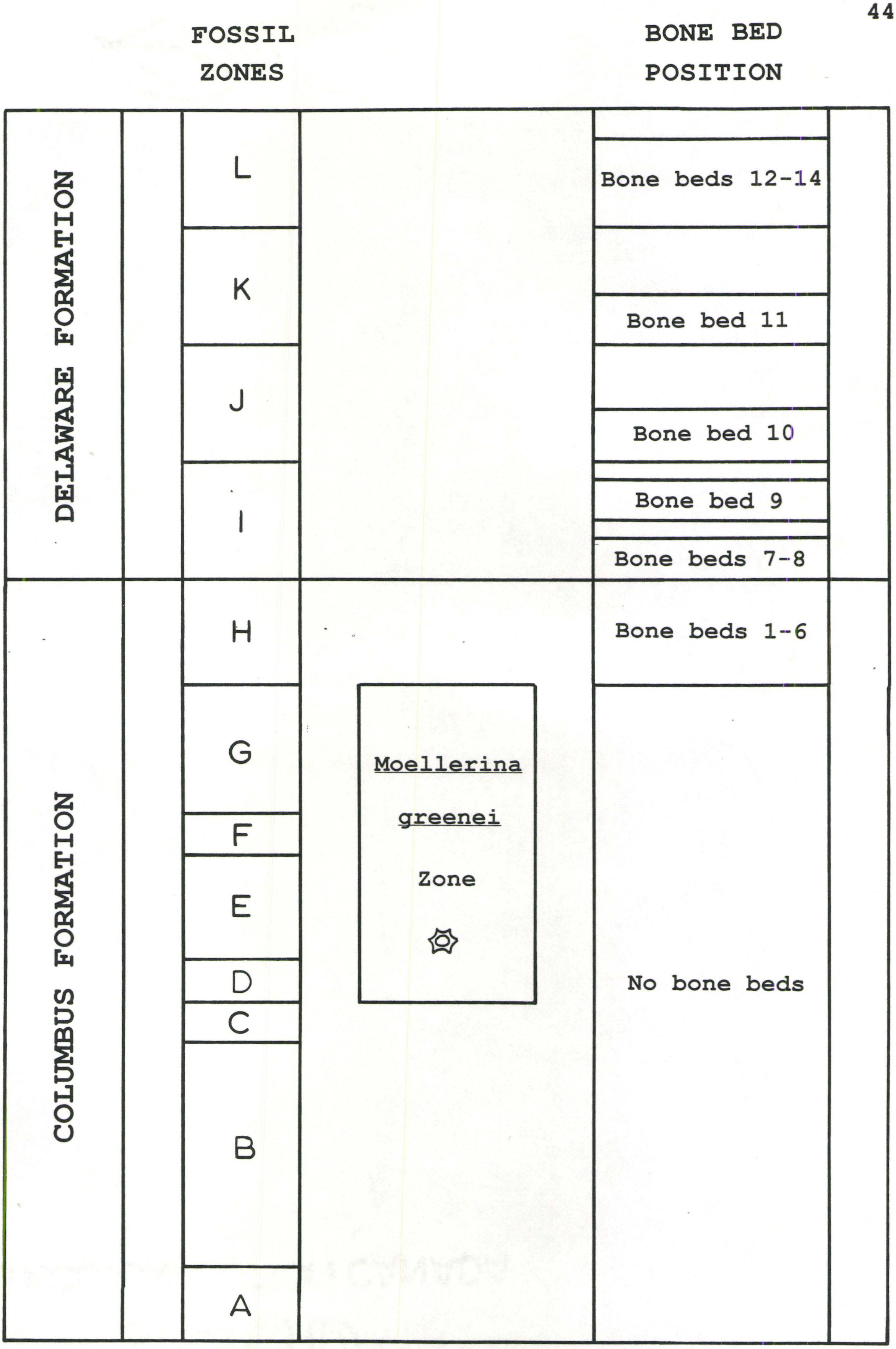

B

documented as occurring within Columbus Formation sediments at other locations in Ohio and have been identified as Moellerina greenei (Peck and Morales, 1966 ; Conkin et al., 1970 ; Bjerstedt and Feldmann, 1985). Conkin et al. (1970) have described a one to two foot thick interval of common to abundant Moellerina in the upper Columbus Formation and proposed that this may be part of a biostratigraphic zone traceable in the areas of Jefferson County, Kentucky, southern Indiana and Columbus, Ohio (Fig.4.2). The abundance of Moellerina observed in upper Columbus Formation sediments in Ohio and on Pelee Island, Ontario hinted that these microfossils may be identified in the subsurface of Ontario as an indicator of upper Columbus Formation facies.

4.4 Distribution of Columbus facies :

Using the lithofacies scheme developed for the Dundee Formation in southwestern Ontario and Moellerina as a possible marker of Columbus Formation sediments, a number of wells in the southernmost parts of Ontario were examined to describe the relationship of the Columbus and Dundee formations. Subsurface drill cores proximal to the Pelee Island area occur east of Point Pelee in Lake Erie and also in the Essex County region. Eight of fifteen closely spaced Lake Erie cores penetrating part of the Columbus - Dundee succession were logged in detail. It was observed in all cases that common to abundant Moellerina could in fact be identified and that the

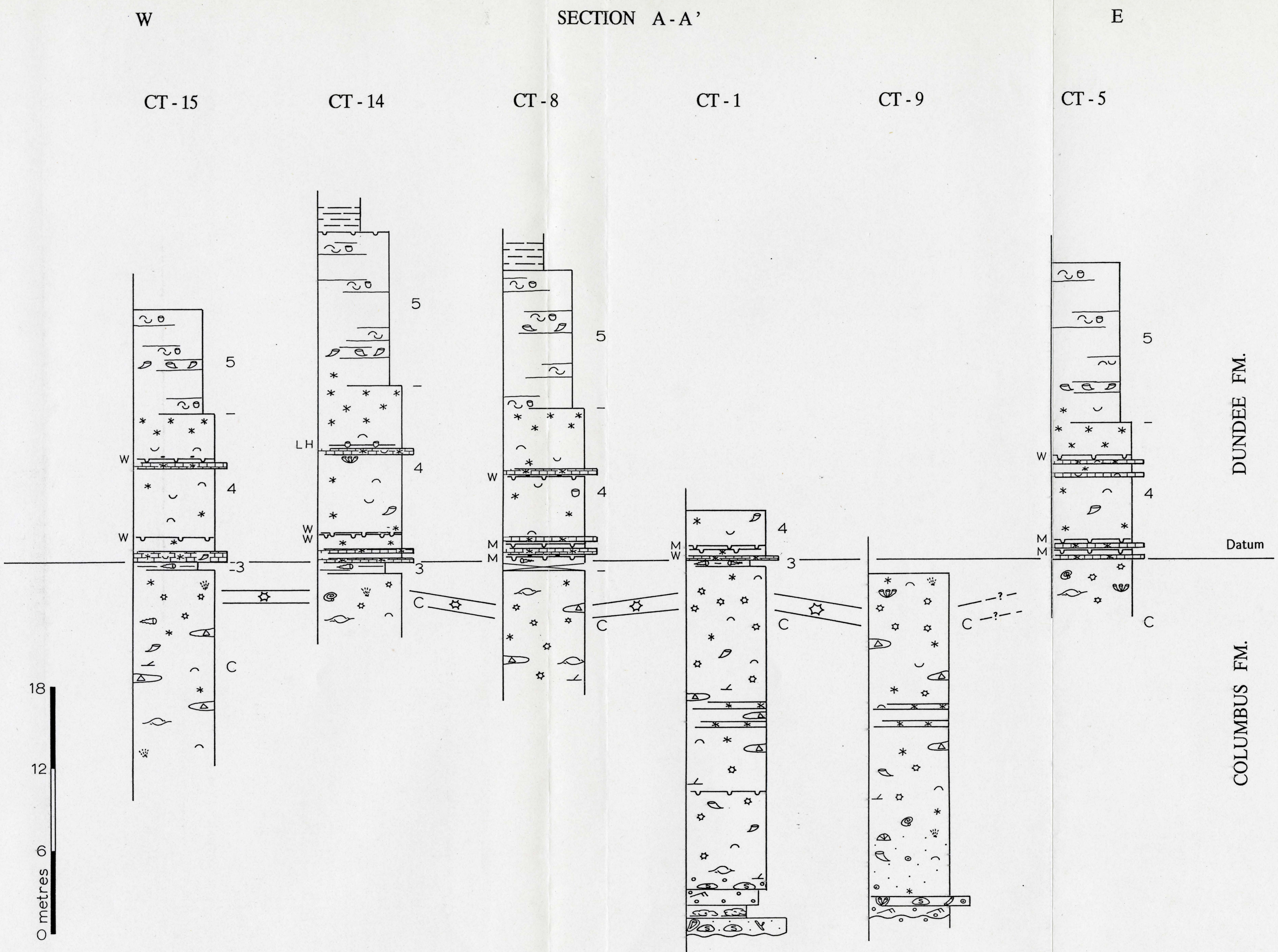
Figure 4.2 Approximate position of _Moellerina greenei_ biostratigraphic Zone in Middle Devonian strata of Ohio (after Conkin et al., 1970). Fossil zones are those defined by Stauffer (1909) while bone beds are those identified in the Ohio area from the Columbus and Delaware formations (Wells, 1944 ; Westgate and Fischer, 1933 ; Conkin and Conkin, 1975).


FOSSIL ZONES
BONE BED POSITION
DELAWARE FORMATION
COLUMBUS FORMATION
L
K
J
I
H
G
F
E
D
C
B
A
Moellerina greenei Zone
Bone beds 12-14
Bone bed 11
Bone bed 10
Bone bed 9
Bone beds 7-8
Bone beds 1-6
No bone beds

sediments in which they occurred closely resembled Columbus facies similar to those observed on Pelee Island and described by Bjerstedt and Feldmann (1985). Moellerina are virtually absent from facies sharply overlying the charophyte-rich strata. Stratigraphic cross section A-A' (Figs. 4.3, 4.4) shows that the Columbus and Dundee formations have been differentiated on the basis of facies and the microfossil Moellerina. In all of these wells, Moellerina are commonly found in the upper 6 to 10 metres of the Columbus Formation and are abundant within a 30 to 50 cm thick interval approximately 2 to 3 metres below what are more typically upper Dundee Formation sediments. This thin, charophyte-rich interval may be equivalent to the Moellerina greenei biostratigraphic zone proposed by Conkin et al. (1970).

As mentioned in a previous section, the occurence of orange or amber coloured spore cases referrable to the genus Tasmanites has been suggested as an indicator of Dundee strata (Uyeno et al., 1982 ; Dutton, 1985). In this study, Tasmanites were noted to be common in upper Columbus Formation sediments. Subsurface wells of the Lake Erie region (Well CT-1) show that Tasmanites can be found down to approximately 19 metres below the Columbus - Dundee contact. Similarly, these spore cases can be identified to at least 3 metres below the contact at quarries in Venice and Parkertown, Ohio. Tasmanites is not a good indicator of Dundee strata especially when

Figure 4.3 Stratigraphic section A-A′ from subsurface cores of Lake Erie showing relationship of the Columbus Formation (labelled C) to overlying Dundee Formation facies. See figure 1.3 for location of section. A thin unit of common to abundant charophyte oogonia (Moellerina) in upper Columbus Formation strata may be correlatable with the Moellerina greenei biostratigraphic Zone described by Conkin et al. (1970). Base of Dundee lithofacies 4 used as datum. See figure 4.4 for legend of symbols.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SECTION A - A'
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COLUMBUS FM.
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Figure 4.4 Legend for stratigraphic sections constructed in this study.

LEGEND

	Fenestrate bryozoan
	Brachiopod
	Solitary rugose coral
	Strom. encrusted rugosa
	Colonial rugose coral
	Domal tabulate coral
	Thamnoporid coral
	<u>Aulopora</u>
S	Domal, tabular or bulbous stromatoporoid
	<u>Amphipora</u>
	Pseudonodular texture
	Fenestral texture
	Bioturbation
	Sandy
	Dolomitic
	Medium to coarse gnd. packstone – grainstone
	Erosive contact
	Shale
X	No core
	Phosphatic fish? fragments
	Planispiral gastropod
	Charophyte oogonia
	Tentaculitid
* *	Crinoidal debris
A	Algal material (Leiosphaerids)
P	Peloidal material
	Chert nodules
	Oolites
	Anhydrite
	Ripples
	Mudcracks
	Carbonate clasts
	Firmground with vertical burrows
W	– Well developed
M	– Moderately developed
P	– Poorly developed
LH	Lithified horizon

differentiating Columbus and Dundee formations. Tasmanites may only be useful as a marker when both the Columbus and Dundee formations are considered as a single unit as is proposed by other authors (Sanford, 1968 ; Uyeno et al., 1982).

Moellerina appears to be more useful for differentiating these two formations. These microfossils are visible to the naked eye and can be identified in drill cuttings as well as in core and outcrop. Fritz (1939) was able to distinguish a fossil zone containing common trochaliscids (= Moellerina of Conkin et al., 1970) from drill cuttings in Kent County. These fossils, although referred to the Onondaga Formation by Fritz, are almost certainly from the Columbus Formation.

4.5 Port Dover Area :

In the Long Point Bay area near Port Dover, Ontario (Fig. 1.2) Dundee Formation sediments have been mapped as disconformably overlying what has been called the Onondaga (Oliver, 1966 ; Telford and Tarrant, 1975) or Amherstburg Formation (Sanford, 1968). Uyeno et al. (1982) have noted that the reason for the absence of the Lucas Formation in this area could be due to non-deposition, a facies change, or both. Based on conodont evidence, Dundee strata in this area are laterally equivalent to middle and upper Onondaga limestones of western to central New York (Uyeno et al., 1982 ; Sparling, 1985) .

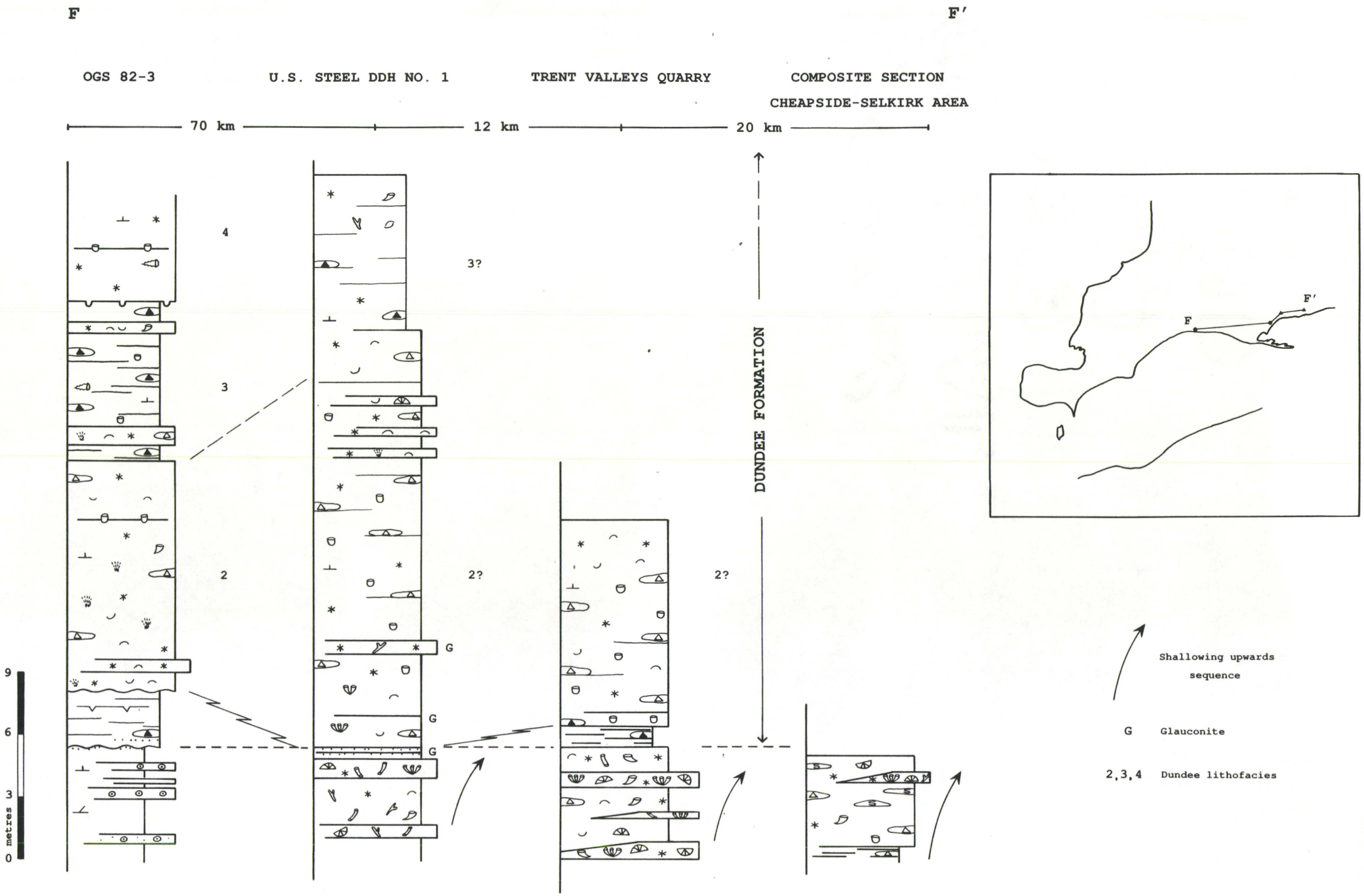
At outcrop sections near Cheapside and Selkirk grey to purplish brown, thinly bedded to massive, partly cherty, moderately fossiliferous mudstones have been mapped as Dundee sediments. Best (1953) and Diffendal (1971) both mapped these sediments as being facies equivalents to upper Dundee sediments similar to that found at the St. Mary's quarry, Ontario. In the Port Dover area coral-stromatoporoid biostromes are commonly developed in these strata while no biostromes are present in upper Dundee sediments at St. Marys. Chert, commonly found in Port Dover area carbonates, is also absent in upper Dundee carbonates at St. Marys. Coral and stromatoporoid-rich biostromes are, in contrast to Dundee sediments elsewhere, commonly developed within the Onondaga Formation. What then is the relationship of these fossiliferous units in the Port Dover area with surrounding areas of Ontario? Examination of two cores from Elgin and Norfolk counties has assisted in interpreting outcroppings near Port Dover.

In the Steel Company of Canada Limited quarry near Nanticoke, Ontario, Telford and Hamblin (1980) identified Dundee Formation sediments disconformably overlying the very fossiliferous Onondaga (= Amherstburg) Formation. These authors also identified two marker beds composed of dark brown to black, very fine grained, very bituminous limestone that occur approximately 80 and 360 cm above the lower Dundee contact. At other locations in the area, these marker beds can be identified and allowed Telford to map the Onondaga - Dundee contact near the village of Sandusk. Telford (pers. comm., 1990) noted that the contact of the Onondaga and Dundee formations used to be exposed in a sump at the Trent Valleys quarry approximately three kilometres north of the town of Port Dover. Korec (1979) however, placed the lower Dundee contact three metres up from the base of the Trent Valleys quarry.

The lowermost six metres of the Trent Valleys quarry (Fig. 4.5) is dominantly a dark brown, sparsely cherty, fossiliferous dolomitic mudstone to wackestone facies. Occasional 30 to 75 cm thick, coral and stromatoporoid-rich rudstone to bafflestone lenses occur within the mudstone to wackestone matrix. These fossiliferous pulses contain a fauna similar to that found in the Moorehouse Member of the Onondaga Formation at other locations east of Port Dover. Solitary and colonial rugose corals are common in these lenses, as are a variety of tabulate corals and stromatoporoids. Along Sandusk Creek and near the towns of Cheapside and Selkirk, biostrome development represents the final stage in a thin, shallowing upwards sequence (Fig. 4.5). No other diagnostic shallowing upwards sequences are found in any other Dundee facies at other localities in Ontario.

Overlying this fossiliferous facies in the Trent Valleys quarry is a 90 cm thick unit of dark brown, thinly bedded

Figure 4.5 Stratigraphic section in the Elgin and Norfolk County areas showing the lower Dundee formation contact at outcrop and subsurface locations. In the OGS 82-3 well the Dundee Formation overlies Detroit River Group facies while in eastern locations the Dundee Formation overlies more typical Onondaga Formation facies. See figure 4.4 for legend of symbols.


F
F′
OGS 82-3
U.S. STEEL DDH NO. 1
TRENT VALLEYS QUARRY
COMPOSITE SECTION
CHEAPSIDE-SELKIRK AREA
70 km
12 km
20 km
4
3
2
3?
2?
2?
G
G
G
DUNDEE FORMATION
9
6
3
0
metres
Shallowing upwards sequence
G Glauconite
2,3,4 Dundee lithofacies

cherty mudstones. This may be the upper marker bed proposed by Telford and Hamblin (1980) for the Dundee Formation. Approximately 10 metres of cherty, moderately fossiliferous wackestones overlie the cherty mudstone unit in the Trent Valleys quarry. The lower contact of these cherty mudstones with underlying fossiliferous wackestones is sharp and appears to be a diastemic surface. Sparse rounded quartz grains and chert granules are commonly found above this surface. This may actually be the lower Dundee contact. Biostromal facies underlying the cherty mudstone unit would therefore be a Detroit River Group equivalent. The cherty mudstone interval overlying this contact is very similar lithologically to a 225 cm thick unit which erosively overlies Lucas Formation facies in the well OGS 82-3, Elgin County.

In a well approximately 10 kilometres east of Port Dover (United Steel Co. DDH #1), it is extremely difficult to locate the lower Dundee contact. Neither of the thin marker horizons suggested by Telford can be identified. Uyeno et al. (1982, p. 24) placed the Dundee contact at a depth of 96.62 metres, thereby including several very fossiliferous biostromal units in lower Dundee sediments. This interpretation is consistent with Telfords placement of the contact at the base of the Trent Valleys quarry near Port Dover. Several thin, sandy glauconitic horizons occur in this well, at a depth of approximately 90.2 metres, immediately above the coral-rich biostromal lenses (Fig. 4.5). These sandy horizons may be equivalent to the diastemic surface noted at the Trent Valleys quarry at the base of the thin, dark brown mudstone unit. This correlation would suggest that a previously misidentified facies is present in the Port Dover area. This may be correlative to either Lucas Formation sediments documented to the west, or upper Onondaga Formation facies mapped to the east. By suggesting this correlation the Dundee contact is not only moved higher stratigraphically but outcroppings in the vicinity of Cheapside and Selkirk would be excluded from the Dundee Formation. Dundee equivalent sediments in the Selkirk - Cheapside area may therefore be missing due to erosion.

The purpose of this thesis is not to document facies in formations underlying the Dundee Formation. Considerable facies variation exists within the uppermost part of the Onondaga Formation and it would take a detailed study of Onondaga facies in the Port Dover area to adequately address the problems discussed here. New placement of the lower Dundee contact excludes rocks previously mapped as Dundee Formation, which contain an abundant and diverse fauna dissimilar to fauna in typical Dundee facies described from other parts of Ontario. Further detailed facies work is required in the Port Dover area in order to answer questions regarding facies relationships of Dundee, Detroit River and Onondaga formations.

CHAPTER 5

FACIES DISTRIBUTIONS AND THE DETROIT RIVER - DUNDEE CONTACT

5.1 Introduction

Previous depositional models proposed for the Dundee Formation in the study area were based on limited outcrop and subsurface information (Best, 1953 ; Diffendal, 1971 ; Dutton, 1985). Lack of a thorough knowledge of facies variations throughout the southwestern Ontario area, both within the Dundee and underlying formations, has resulted in confusion regarding regional facies relationships. Upon sorting out some of the previous stratigraphic problems and documenting a new Dundee lithofacies scheme, the distribution of Dundee sediments begins to make more sense. This section discusses the distribution of Dundee facies and describes the contact of the Dundee with underlying formations.

5.2 Vertical facies sequence :

Facies sequences vary considerably depending upon the position within the Michigan and Appalachian Basins. Three simplified sequences are proposed which represent most of the facies variations in areas of the basins represented by this study.

5.2.1 Sequence 1 :

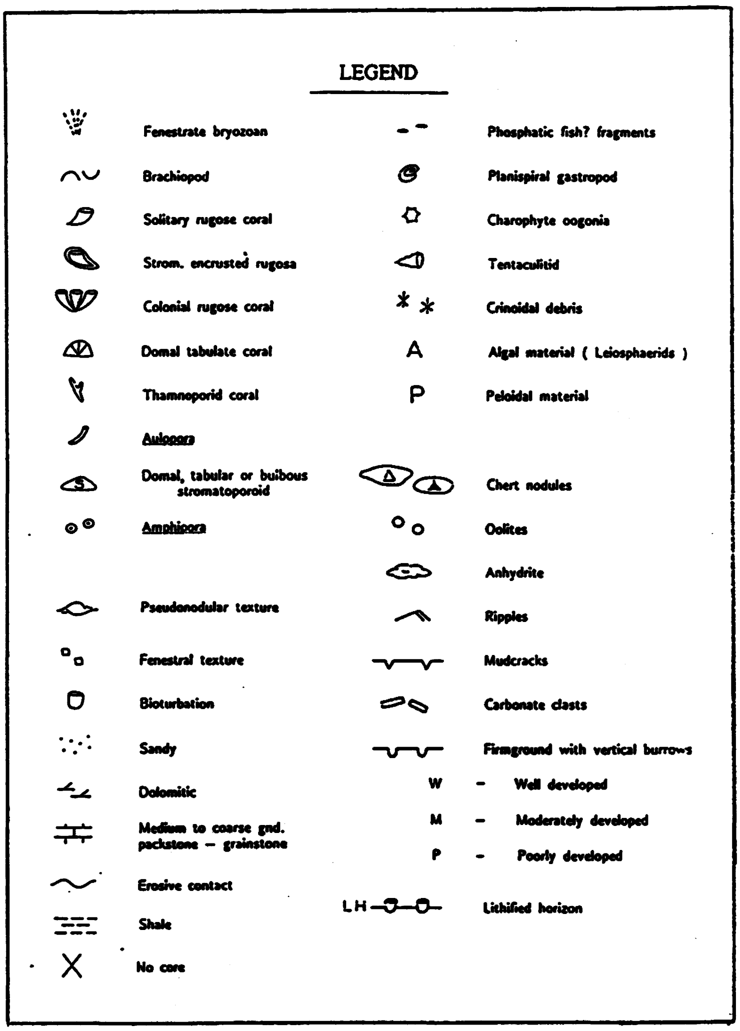
In the southwesternmost parts of the study area within the Appalachian Basin, the Columbus Formation has been shown to underlie Dundee Formation sediments (Chapter 4). Flanking the Findlay arch, the Columbus Formation as suggested by Sparling (1988) thins northward and actually pinches out in the study area. Columbus strata are gradationally overlain by Dundee facies 2, 3 or 4. The most complete sequence here, in ascending order, includes facies 2, 3, 4 and 5 overlying Columbus sediments (Fig. 5.1). A 15 to 80 cm thick pulse of facies 3 may occur near the middle of a much thicker unit of facies 2 sediments.

Figure 5.2 shows the approximate northern limit of the Columbus Formation, as defined in this study, and the immediately overlying Dundee facies. Northeast of the Pelee Island area, facies 2, 3 and 4 overlap upper Columbus sediments. Sparling (1988) noted that in north-central Ohio the top of the Columbus was disconformable. This is not the case in southwestern Ontario and may be due to the top of the Columbus becoming younger northward (Sparling, 1988) and westward.

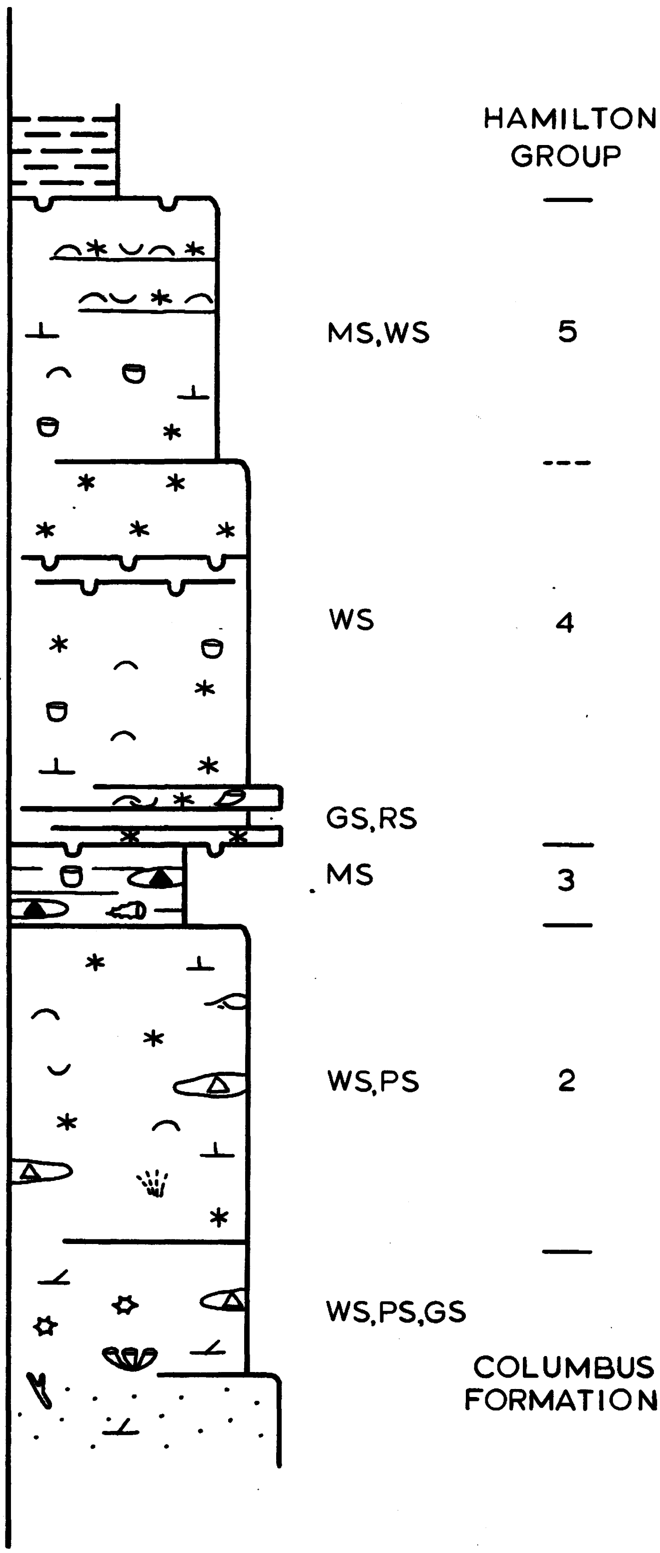
5.2.2 Sequence 2 :

This sequence is represented by most wells in the Kent and Elgin county areas where Columbus Formation sediments are not present at the base of the Dundee. Most wells in Elgin County were drilled within or adjacent to the Rodney field and no core is available over roughly a 30 kilometre distance

Figure 5.1 Idealized facies sequence for the Dundee Formation in the southwesternmost parts of the study region. In parts of Lake Erie, Essex and Kent counties, Columbus Formation sediments are conformably overlain by Dundee facies 2,3,4 and 5.

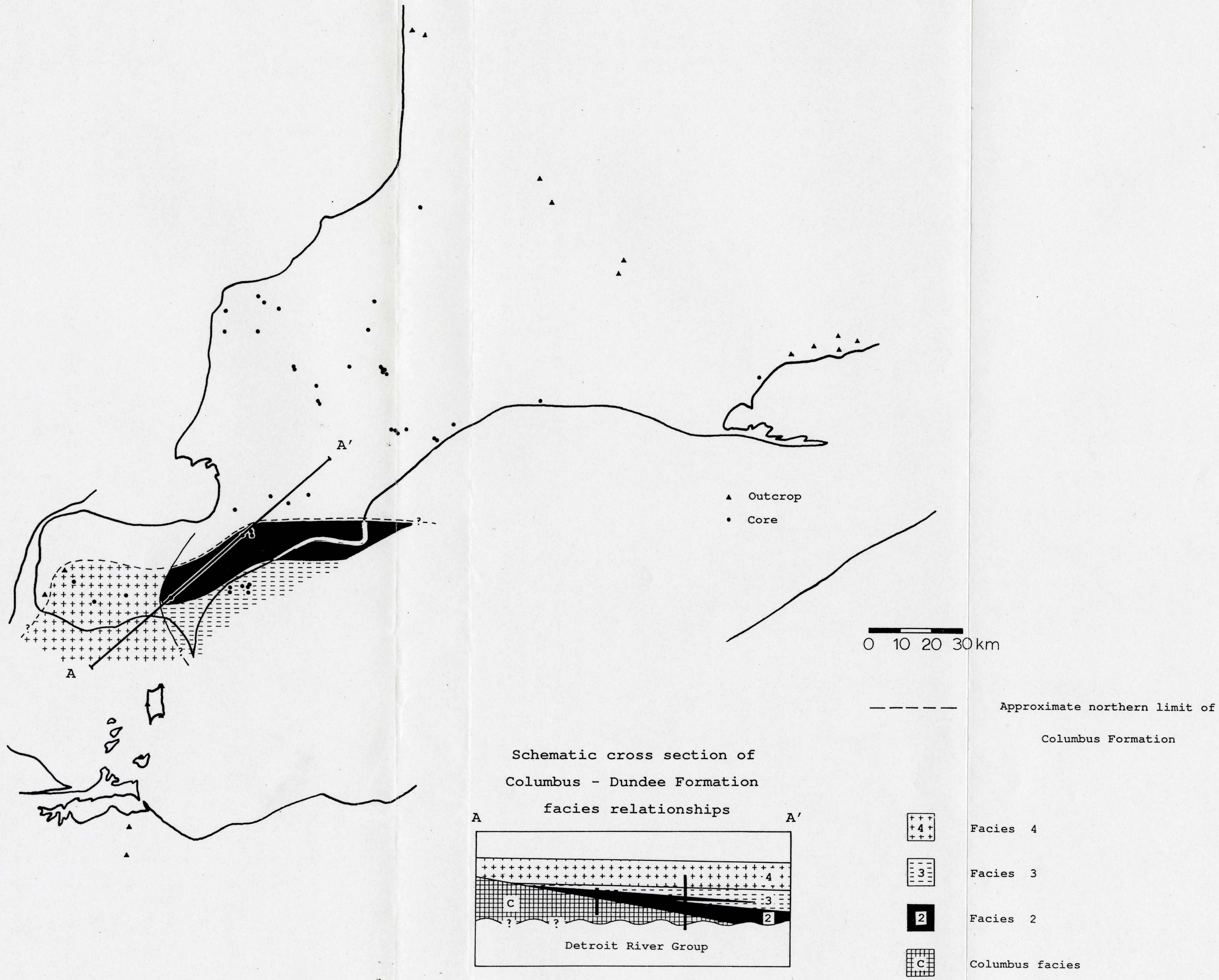


SEQUENCE 1



RS	RUDSTONE
GS	GRAINSTONE
PS	PACKSTONE
WS	WACKESTONE
MS	MUDSTONE

Figure 5.2 Map showing the approximate northern extent of Columbus Formation sediments with immediately overlying Dundee facies. Facies distributions are derived strictly from logged drill cores. The schematic cross section shows the pinch out of the Columbus Formation to the northeast and overlap of Dundee lithofacies 2, 3 and 4.

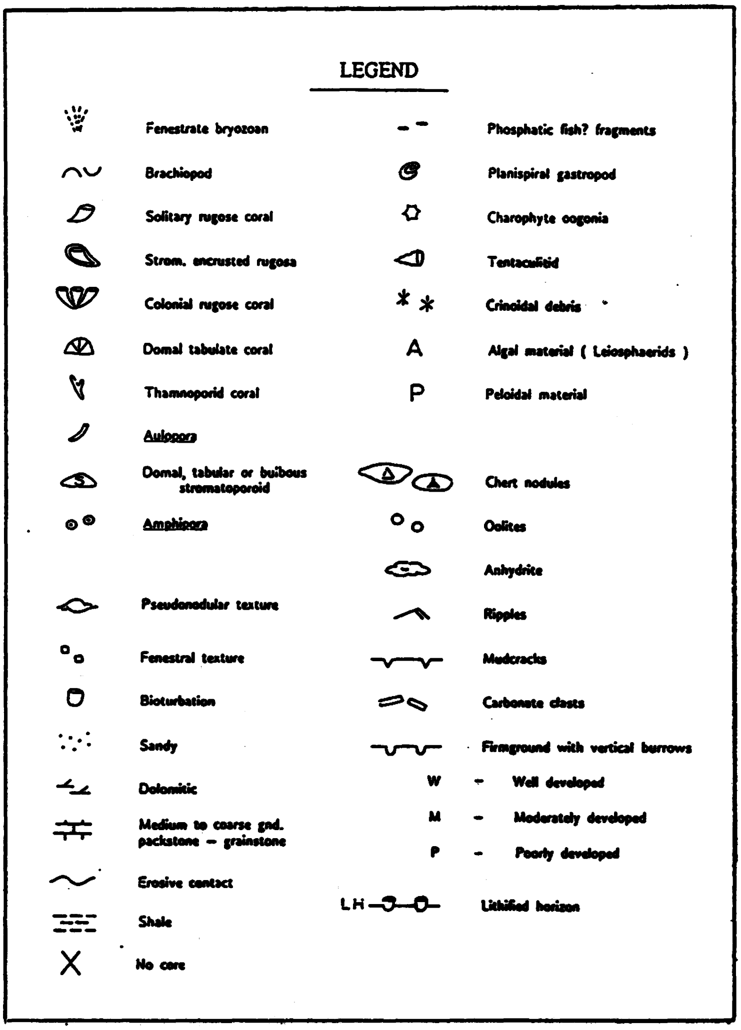

A
A′
Outcrop
Core
0 10 20 30 km
Approximate northern limit of
Columbus Formation
Schematic cross section of
Columbus - Dundee Formation
facies relationships
A
A′
4
3
C
2
Detroit River Group
4
Facies 4
3
Facies 3
2
Facies 2
C
Columbus facies

between the Rodney field and the nearest well in Kent County (Well OGS 82-2). In all cored wells of this area, Dundee facies sharply and / or erosively overlie typical Lucas Formation laminated fenestral dolomites (Fig. 5.3). Two wells, OGS 82-2 and Brett-Onaco, best represent the vertical facies relationships of sequence 2.

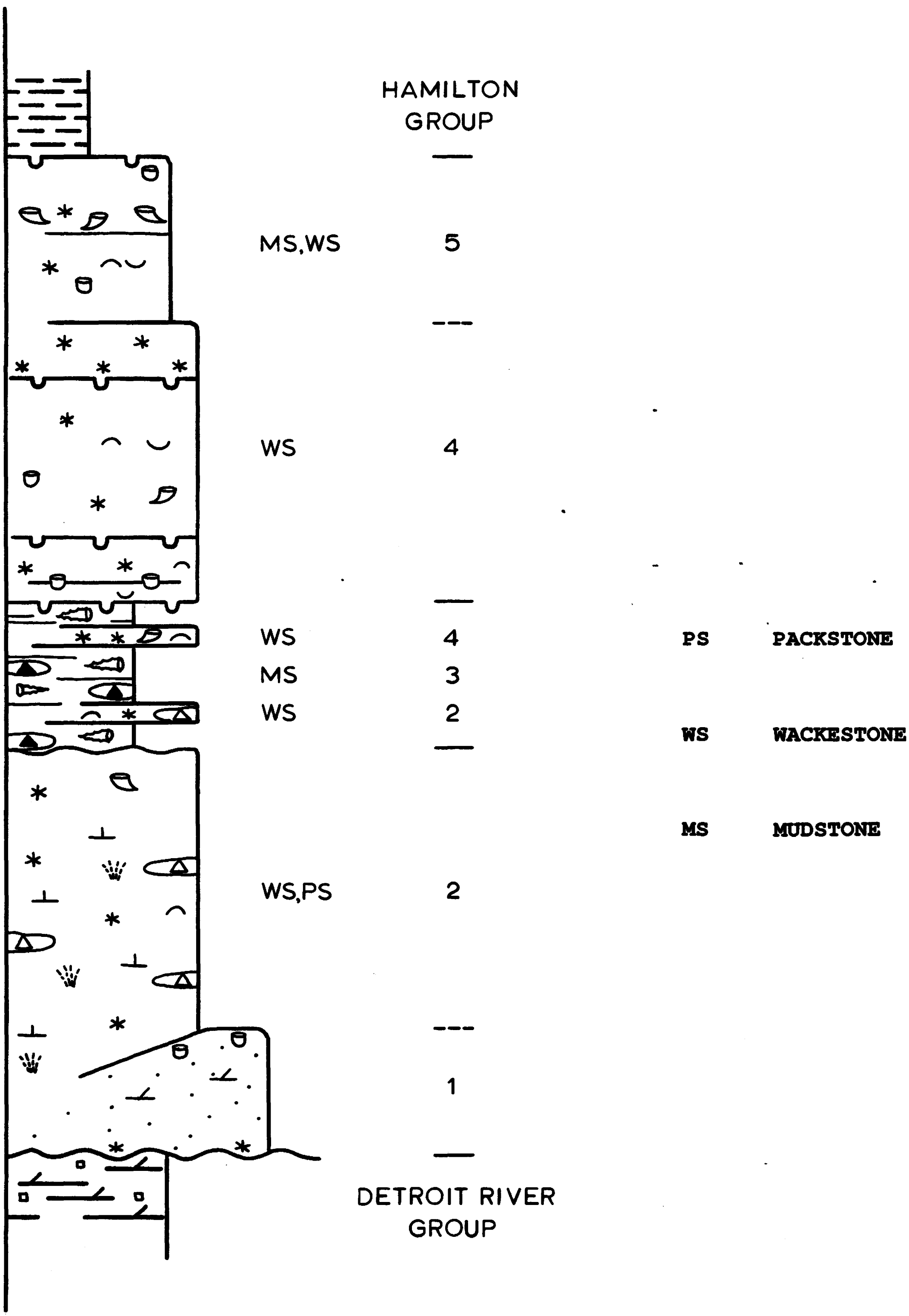
In the vicinity of the Rodney field (Fig. 1.1), 5 metres of lithofacies 1 (dolomitic sandy wackestone) occurs above the Detroit River - Dundee contact. Invariably, facies 2, 3, 4 and 5 overlie facies 1. Thin pulses of facies 2 and 4 occur at the base and near the top respectively, within a 5 to 6 metre thick unit of cherty mudstones (facies 3). The cherty mudstone facies is restricted to the Appalachian Basin since it is found only within wells south of a line parallel to the approximate axis of the Algonquin Arch. The restriction of this facies to the Appalachian Basin suggests that the Michigan and Appalachian basins may have been partially separated until middle Dundee time.

Wells in the Kent County area show a similar facies sequence to that described for parts of Elgin County but the lower dolomitic sandy wackestone facies is not present. The cherty bioclastic facies erosively overlies Detroit River Group facies with the lower few centimetres of facies 2 in this area commonly being quartz-rich. In the well OGS 82-2 the

Figure 5.3 Idealized facies sequence for the Dundee Formation in the vicinity of Elgin and Kent counties, southwestern Ontario. In this sequence sandy dolomites and dolomitic limestones of facies 1 are locally developed and pulses of facies 2 and 4 are observed within a thicker unit of facies 3. Dundee strata disconformably overlie Detroit River Group facies.



SEQUENCE 2


HAMILTON GROUP
MS,WS
5
WS
4
WS
4
MS
3
WS
2
WS,PS
2
1
DETROIT RIVER GROUP
PS PACKSTONE
WS WACKESTONE
MS MUDSTONE

lower 3 cm of facies 2 is a dark grey sand-rich unit (Fig. 5.4a) while in a nearby well, Putnam Sterling #1, a 12 cm thick sandy interval contains abundant, well rounded quartz grains, rounded micrite and sandy limestone clasts as well as typical Lucas dolomite clasts (Fig. 5.4b). One angular Lucas dolomite clast in this interval is approximately 7 cm thick and sits in the quartz-rich, sandy limestone. The contacts of Detroit River and Dundee sediments in these two wells are possible examples of subaerially exposed surfaces. In the OGS 82-2 well, further support for a subaerial exposure interpretation comes from underlying supratidal dolomites of the Lucas Formation. A number of fenestral, laminated dolomite beds capped by 1 to 3 centimetre thick carbonaceous seams appear to represent thin shallowing upwards sequences. The association of supratidal dolomites, thin organic-rich layers, eroded carbonate clasts and well rounded, quartz grains indicates the possibility of subaerial exposure of upper Detroit River strata in this area. This interpretation will be expanded upon in the discussion of the next sequence.

5.2.3 Sequence 3 :

This stratigraphic sequence is common to Dundee sediments flanking the northern side of the Algonquin Arch in the Michigan Basin. This includes wells in Lambton and Middlesex counties as well as outcroppings in the St. Marys and Goderich areas. The main difference between this sequence and that of

Figure 5.4

A. Detroit River - Dundee contact ; OGS 82-2, Kent Co., 151.21 - 150.94 m. Note 3 cm thick grey sand-rich horizon erosively overlying laminated dolomites of the Lucas Formation. Scale bar = 1 cm.

B. Erosive, brecciated sandy Detroit River - Dundee contact ; Putnam Sterling #1, Kent Co., 122.86 - 122.68 m. Note large angular clast of typical Lucas Formation lithology (L) and subrounded sandstone clast (S) in a sand-rich crinoidal limestone matrix. A calcite-filled fracture crosscuts the core. Scale bar = 2 cm.


A

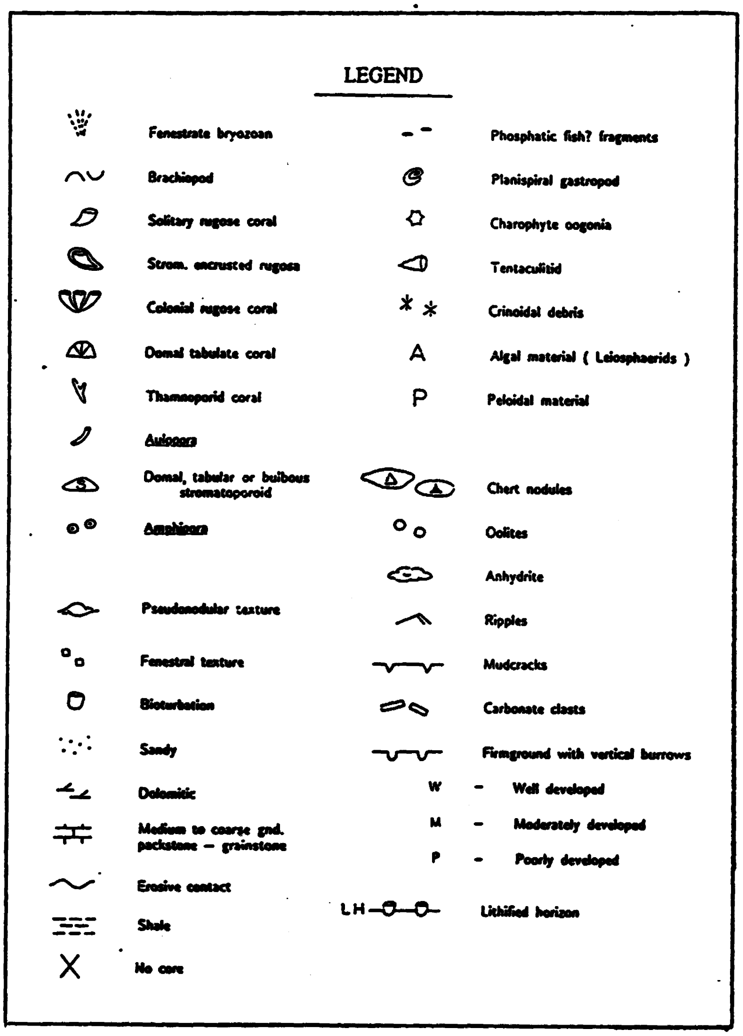

B
S
L

sequences 1 and 2 is that the basal dolomitic sandy wackestones (facies 1) and cherty mudstones (facies 3) are not present (Fig. 5.5). As well, facies 6 is unique to this region and is best developed in the northwestern part of Lambton County.

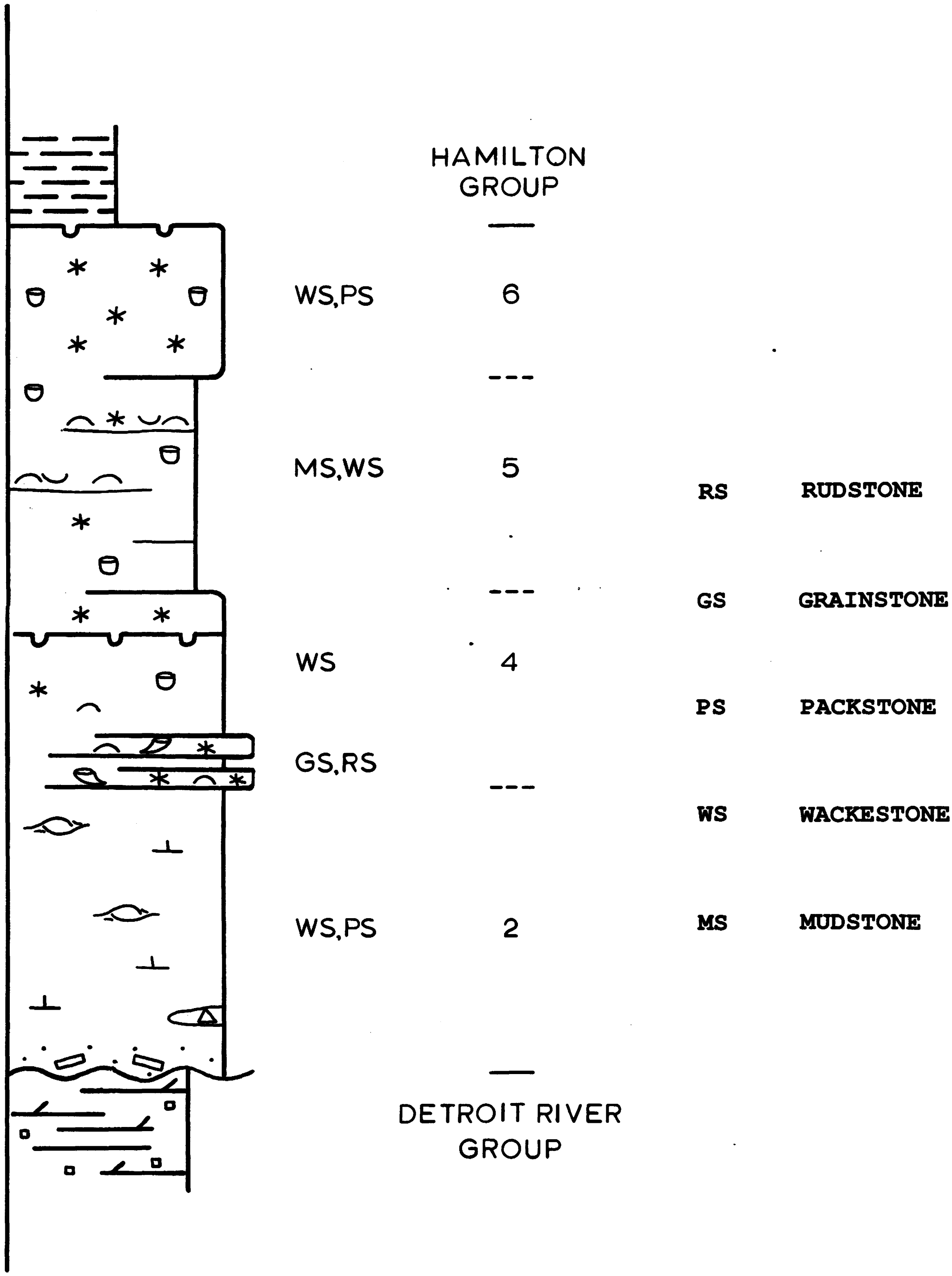
The cherty bioclastic facies sits erosively upon Detroit River Group carbonates and it is in parts of this region that some confusion has arisen as to the placement of sands near the lower Dundee contact. In ascending order, the vertical facies succession includes facies 2 overlain by facies 4, 5 and 6. Facies 6 was not identified in outcrop at St. Mary's or Goderich but this facies may have been removed by erosion. All facies are gradationally overlain by the next facies and interfinger to such a degree that it becomes difficult in places to distinguish facies. Coarse packstone, grainstone and rudstone pulses of facies 4, composed of rugose corals, crinoid fragments and brachiopods, are locally well developed and at the St. Mary's quarry have been interpreted as coral bank deposits (Upitis, 1964).

The contact of facies 2 with underlying Detroit River Group carbonates varies considerably within this area such that certain styles of contacts must be considered independently. Examples of the Detroit River - Dundee contact will be described here for the Maitland River area, the St. Mary's Cement quarry and also from Middlesex County in the

Figure 5.5 Idealized facies sequence for Dundee carbonates in the Michigan Basin region of the study area. In ascending order Dundee lithofacies 2, 4, 5 and 6 disconformably overlie Detroit River Group strata. Lithofacies 1 and 3 are not present in this sequence.



SEQUENCE 3



HAMILTON GROUP
WS,PS
6
MS,WS
5
WS
4
GS,RS
WS,PS
2
DETROIT RIVER GROUP
RS RUDSTONE
GS GRAINSTONE
PS PACKSTONE
WS WACKESTONE
MS MUDSTONE

vicinity of the Glencoe pool. Characteristics of contacts at other locations in this region can be incorporated into these three styles to provide a simpler description of the contacts observed in the region.

A> Maitland River area -

Approximately 2 kilometres east of the mouth of the Maitland River near Goderich is an example of an erosive, brecciated Detroit River - Dundee contact. Facies 2 erosively overlies laminated dolomites of the Lucas Formation such that pebble to cobble size, rounded to tabular Lucas clasts are common in the lower few metres of the Dundee Formation. A channel, approximately 100 metres wide and 75 cm deep, cuts into upper Lucas Formation carbonates at one location along the Maitland River. The contact here is brecciated with common tabular Lucas clasts sitting in a sparsely fossiliferous, sandy wackestone matrix (Fig. 5.6).

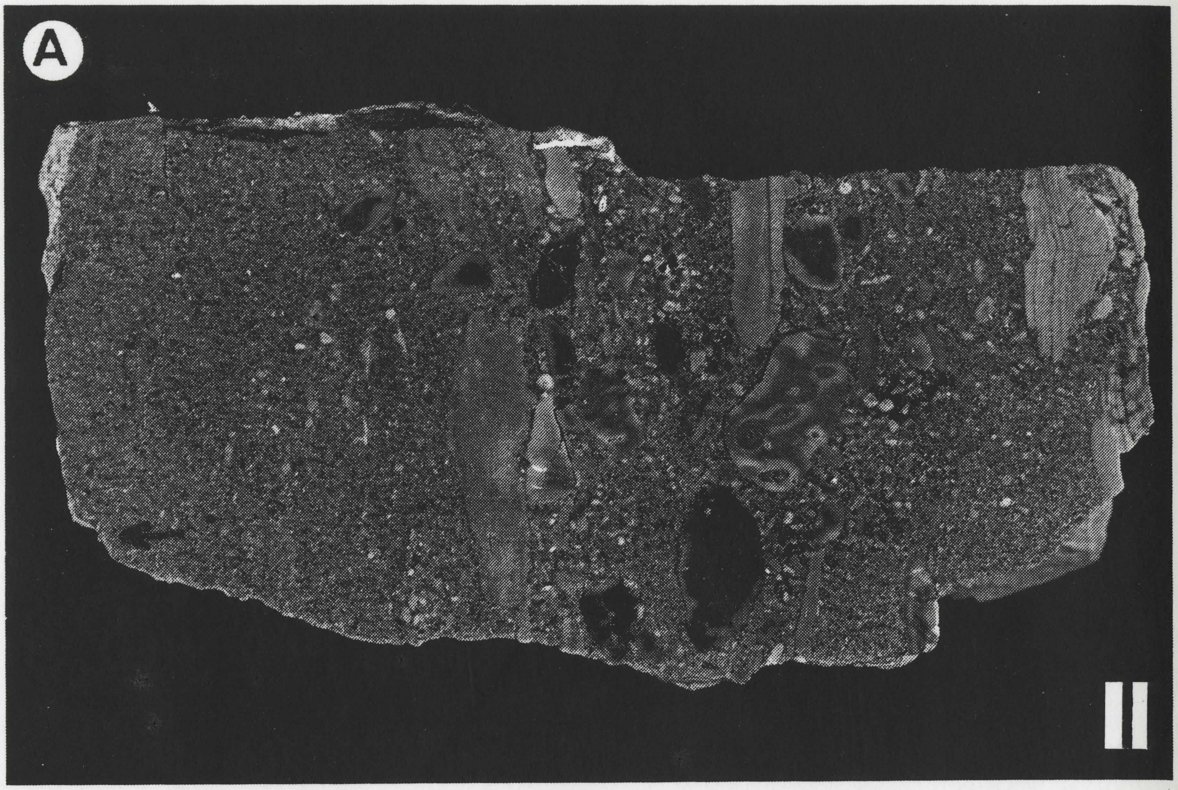
Overlying this basal brecciated zone is a 1.5 metre thick sandy, coarse crinoidal floatstone with excellent intercrystalline and vuggy porosities. Quartz in the lowermost few metres occurs as well rounded, medium grains and cemented aggregates of rounded grains. Reworked thamnoporid coral fragments and domal tabulate corals are present in this basal floatstone. This basal floatstone grades upwards into more typical facies 2 sediments.

In wells from the Lambton County area, similar crinoidal

Figure 5.6

A. Sandy crinoidal floatstone in lower Dundee facies, Maitland River area, Goderich. The contact of the Dundee with the Lucas Formation occurs at the base of this sample. Note angular and rounded Lucas clasts in lower Dundee sediments. Arrow on core indicates way up. Scale bar = 1 cm.

B. Brecciated contact of Detroit River Group with the Dundee Formation, Maitland River. Angular Lucas clasts floating in a dark brown, sandy crinoidal wackestone matrix characterizes the infill of a channel cut into uppermost Detroit River strata.


A


B

floatstones and rudstones, 10 to 30 cm thick, sit erosively upon Lucas Formation carbonates. Laminated dolomites within 10 to 20 cm below the contact are commonly partially dissolved and have been infilled by well rounded, fine to medium grained quartz sands (Fig. 5.7a) and crinoidal wackestones. Dissolution of upper Detroit River carbonates, brecciation and infilling by rounded quartz sands suggests a subaerial exposure interpretation similar to that described for sequence 2.

B> St. Marys section -

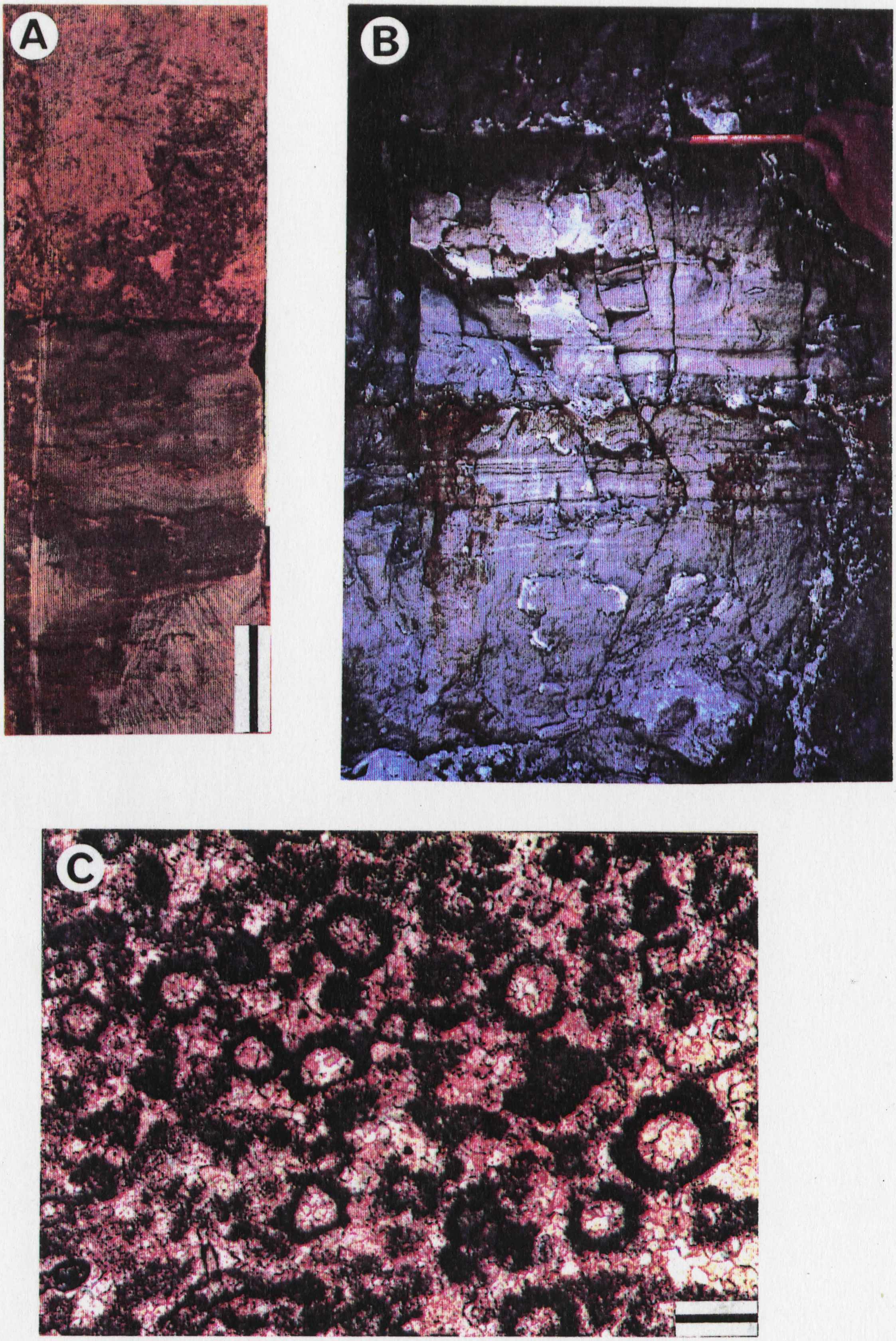
The location of the Detroit River - Dundee contact at the St. Mary's Cement Company quarry has been questioned by several authors (Upitis, 1964; Ferrigno, 1968). Following Ferrigno (1968), I have placed the contact approximately 15 cm above a thin bed of intraformational breccia which is conformable with lithologies above and below. Breccia clasts are typically laminated Lucas lithology and are set in a buff coloured, algal-rich, peloidal grainstone matrix (Fig. 5.7b). B. Taylor (in Uyeno et al., 1982) noted one-celled algae identified as Leiosphaeridia spp. to be present in the Dundee Formation, however, none were documented within Dundee strata in this study. Leiosphaerids have been found to be abundant in upper Detroit River strata interbedded with micritic limestones and laminated dolomites. In the St. Mary's east quarry (old quarry) the algal-rich interval immediately below

Figure 5.7

A. Detroit River - Dundee contact ; Leesa Imperial 18 - XIII, Lambton Co., 102.62 - 102.49 m. Note sandy crinoidal grainstone overlying and infilling dissolved Detroit River Group strata. Scale bar = 2 cm.

B. Algal-rich grainstone in Lucas Formation immediately below the lower Dundee contact, St. Mary's Cement Company quarry. Pencil marks the Lucas - Dundee contact. Clasts of Lucas Formation lithology have been outlined.

C. Thin section photomicrograph of algal-rich grainstone from the Lucas Formation, St. Mary's Cement quarry. Stained thin section, plane polarized light, 63 X magnification. Scale bar = 200 microns.


A
B
C

the Dundee contact is hematitic and appears as a dark, purplish-brown band.

Sharply overlying this algal-rich bed is a thick unit of facies 2 sediments with common well-rounded quartz grains in the lower few metres. Landes (1951) suggested that the occurrence of rounded quartz grains in the basal part of the Dundee in Michigan was characteristic of the Dundee Formation. Rounded quartz sands have been identified in upper Detroit River Group sediments at several locations including the St. Mary's quarry (Upitis, 1964) and cannot be used as a guide to lower Dundee strata. This contact style shows that unlike the brecciated, disconformable contact along parts of the Maitland River, thin brecciated zones can also occur immediately below the Dundee contact.

C> Glencoe pool region -

The Glencoe pool, located in the southwest corner of Middlesex County (Fig. 1.1), has been described as producing from bioclastic Dundee limestone as well as from porous sands and sandy reefal carbonates of the Columbus Formation (Bailey and Cochrane, 1985). This study, as discussed in a previous section, has attempted to clarify some of the problems which have existed in the past regarding use of the term "Columbus". Although detailed facies relationships have not been looked at for upper Detroit River strata, the name Columbus as previously used for sands present near the lower Dundee contact should not be applied to the Glencoe pool area. These sands and sandy carbonates are most likely present within the Anderdon Member of the Detroit River Group. Dutton (1985) included these sands and sandy carbonates within the Dundee Formation, however, most of his sedimentologic interpretations were based on five drill cores penetrating lower Dundee and upper Detroit River sediments. I would suggest that only Dutton's uppermost lithofacies F should be included within the Dundee Formation.

Although only a few incomplete cores are available from the Glencoe region, facies identified in adjacent areas provide sufficient information for recognition of the lower Dundee contact. An excellent example of the contact and facies present at this area can be found in the Leesa-Imperial Brooke 1-13-I well. Dundee facies 2 is most commonly sharply underlain by one of two different facies. The first type of sediments underlying the cherty bioclastic facies are grey to tan coloured, laminated fenestral dolomicrites which may be interbedded with thin beds of tan coloured, algal-peloidal packstone to grainstone pulses similar to those described at St. Marys. The second type of sediments underlying facies 2 are stromatoporoid and coral-rich floatstones. These floatstones have common fragments of colonial rugose, thamnoporid and tabulate corals (Aulopora) as well as a variety of stromatoporoids. Laminar, tabular and bulbous stromatoporoids are common and Amphipora sticks may be abundant in places. Stromatoporoids are commonly found encrusting coral fragments. This facies is very similar to sediments of the Anderdon Member exposed in the uppermost part of the Amherst quarry near Amherstburg, Ontario (Fig. 5.8).

The contact of Detroit River carbonates with facies 2 of the Dundee Formation is sharp and occasionally erosive. Placement of this contact can be difficult since many of the cores available for this region are very fragmented and a great deal of core is missing from some wells. Sediments above and below the contact may also have similar wackestone lithologies, however the fauna is noticeably different. Proper identification of the Dundee contact shows that thick, massive to cross-stratified porous sands and sandy, 'reefal' carbonates exist below the Dundee contact and are most likely a facies equivalent of the Anderdon Member, more commonly found in the Amherstburg area.

Bailey and Cochrane (1985) generated gross sand isopach maps from drill cuttings without differentiating sands in upper Detroit River strata from those at the base of the Dundee Formation. A regional sand isopach map compiled from Bailey and Cochrane's maps for each county of southwestern Ontario is shown in figure 5.9. Based upon facies evidence and placement of the lower Dundee contact from outcrop and core, it is suggested that this map includes sands present at the

Figure 5.8 Anderdon Member facies

A. Domal and tabular stromatoporoids ; Sandy Anderdon Member, Amherst quarry, Amherstburg.

B. Amphipora sticks (Am) and Aulopora (Au) common in Anderdon Member facies, Amherst quarry.

C. Laminar stromatoporoids and stromatoporoid-encrusted colonial rugose coral fragments in a sparsely crinoidal wackestone to bindstone lithology. Walker 502, Middlesex Co., 109.2 - 109.1 m. Scale bar = 3 cm.

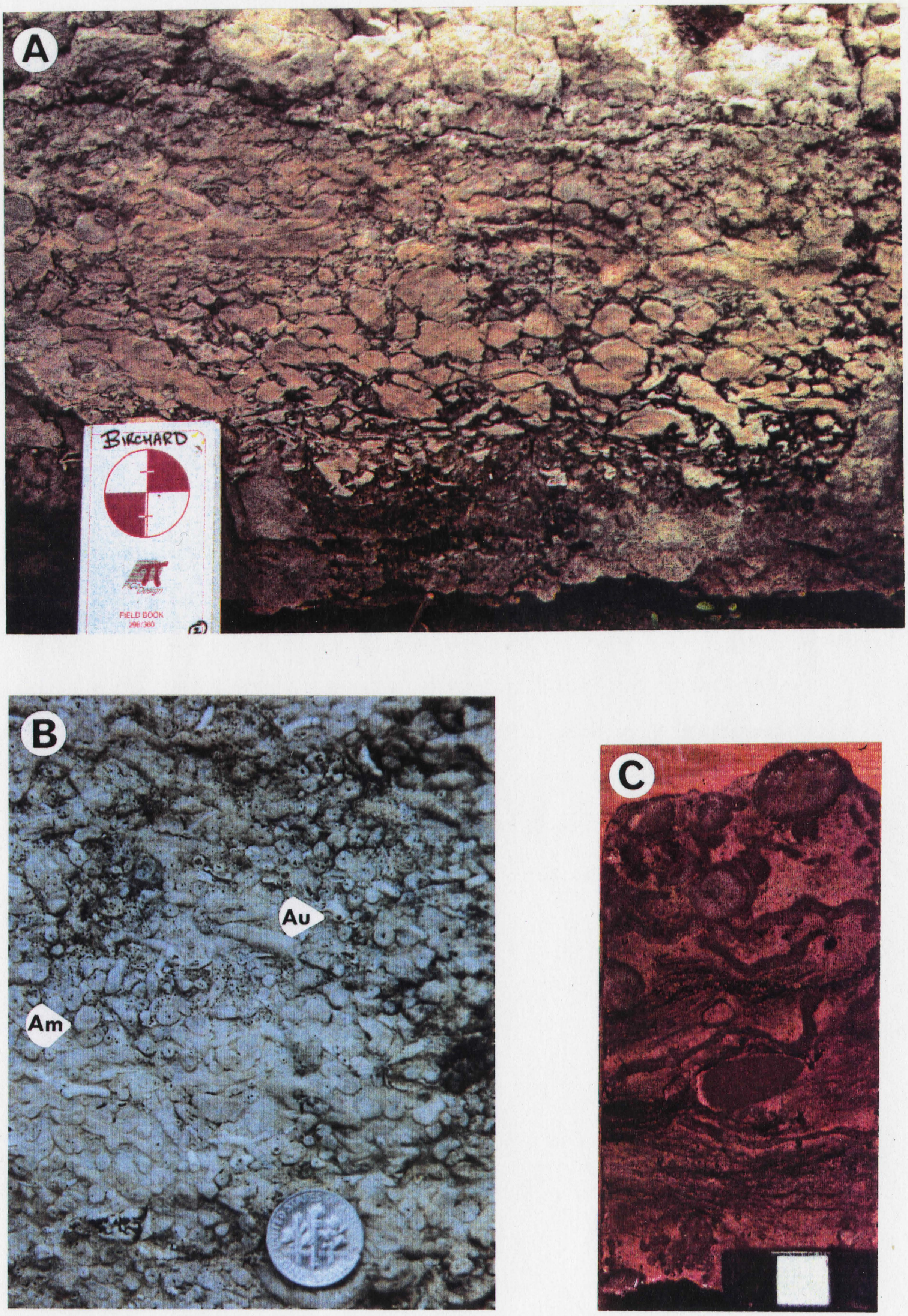
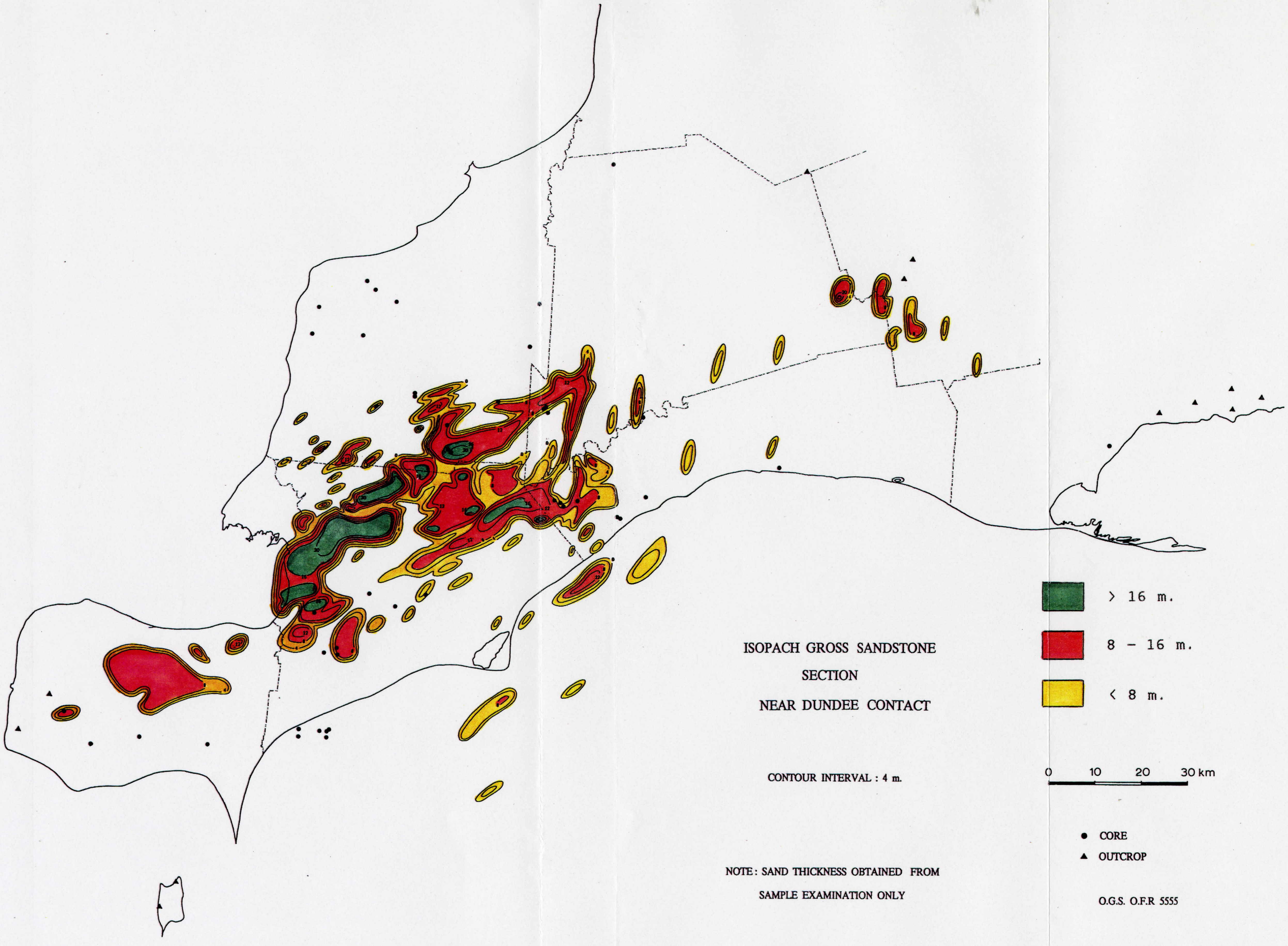

A
BIRCHARD
FIELD BOOK
298/380
B
Au
Am
C

Figure 5.9 Isopach of the gross sandstone section near the Dundee contact . This isopach includes sands in the Columbus Formation, the Detroit River Group and also sands at the base of the Dundee Formation. Sand thicknesses were obtained from examination of drill cuttings only, and a minimum cutoff of 10% sand was used (after Bailey and Cochrane, 1985). Note the localized concentration of sands in the area of the Chatham Sag along the periphery of the Michigan and Appalachian basins.



ISOPACH GROSS SANDSTONE
SECTION
NEAR DUNDEE CONTACT

CONTOUR INTERVAL : 4 m.

NOTE : SAND THICKNESS OBTAINED FROM
SAMPLE EXAMINATION ONLY

O.G.S. O.F.R 5555

base of the Columbus Formation, in the Anderdon Member of the Detroit River Group and also at the base of the Dundee Formation. Most of these sands rest within the area of the Chatham Sag between the southwestern nose of the Algonquin Arch and the northern end of the Findlay Arch. This localized concentration suggests that there may have been a regional structural control upon deposition of these sands. This will be looked at further when discussing regional cross sections. Proper designation of these sands is important to understanding regional facies relationships and would be critical for any future exploration in this stratigraphic interval.

CHAPTER 6

DISCONTINUITY SURFACES IN DUNDEE LIMESTONES

6.1 Introduction :

Earlier models proposed for deposition of Dundee sediments were based primarily upon facies observed from limited outcrop exposures in both the Michigan and Appalachian Basins (Best, 1953 ; Diffendal, 1971). No lithologic markers have been identified from Dundee strata which can be used for regional correlations. Although the Tioga ash bed may be useful for correlations elsewhere (Rickard, 1984), it has not been identified in the subsurface of Ontario. The purpose of this chapter is to look at the characteristics, distribution and importance of two types of discontinuity surfaces found in Dundee strata and to suggest that these may be correlatable into adjacent regions of Michigan and Ohio.

6.2 Lithification on the sea floor

Much recent research has stemmed from Shinn's excellent documentation of submarine lithification of recent carbonates in the Persian Gulf (Shinn, 1969). Within the last twenty-five years there have been a variety of papers published documenting synsedimentary lithified horizons in carbonate successions throughout the Phanerozoic rock record (Read and Grover, 1977 ; Dravis, 1979 ; Wilkinson et al., 1982 ; Brett and Brookfield, 1984). In the past, certain lithified horizons in carbonates have been previously misinterpreted as 'emersion' surfaces formed by subaerial exposure of shallow marine limestones in close association with meteoric waters (Chamberlin, 1882 ; Moore, 1964). Many of these horizons, however, have no associated paleosoils, karst features or adjacent supratidal sediments. Detailed description of discontinuity surfaces and adjacent facies is required to ensure a correct interpretation for such surfaces.

Fischer and Garrison (1967) published one of the earliest accounts of carbonate lithification on the sea floor at depths between 200 and 3500 metres and argued that, contrary to widespread opinion, calcite could in fact be precipitated chemically in seawater. A few years later Shinn (1969) identified large areas of the sea floor in the Persian Gulf composed of lithified carbonate sediment, with cementation occurring essentially contemporaneously within the submarine environment. Detailed documentation of characteristics of Persian Gulf 'lithified horizons' and their sedimentologic significance subsequently has led to some reinterpretation of similar horizons in the rock record.

Purser (1969) identified bored surfaces in Middle Jurassic limestones in the Paris Basin and interpreted them as being the result of slow carbonate sedimentation and synsedimentary lithification of the sea floor at the end of a regressive episode prior to subsequent transgression. Rose

(1970) re-evaluated the sedimentologic significance of discontinuity surfaces in the Lower Cretaceous Edwards Formation of Texas and suggested an origin similar to those in the Paris Basin. Shinn (1969) documented submarine lithification occurring in the Persian Gulf, a shallow epicontinental sea, at relatively normal salinities and temperatures in depths down to approximately 30 metres. Several interesting observations were made by Shinn of hardgrounds characterized as having bored and encrusted surfaces. Firstly, hardgrounds were developed on the windward flanks and crests of offshore highs. Secondly, these Holocene hardgrounds cover hundreds of square miles in the Persian Gulf and commonly occur as multiples of bored beds. At one location Shinn documented four cemented horizons within a 50 cm thick vertical interval. Thirdly, submarine lithification of shallow, marine carbonate sands ceased upon progressive rise in sea level when deeper basinal marls covered shallow hardgrounds.

Lundstrom (1963) and Bromley (1965) produced estimates of the time required to form ancient hardground surfaces. Lundstrom calculated that a hardground surface in Ordovician calcilutites of southern Sweden may have been exposed at the sea floor for approximately 200,000 years. Bromley calculated a similar possible time of exposure for a hardground surface in Cretaceous chalks of England. These hardground surfaces therefore may represent a significant episode of non-deposition in the rock record.

6.3 Traceable hardground surfaces

Even though many factors can cause variations in lithification over short distances, in some instances lithified horizons have been used as regional markers. Bathurst (1971) states that "a lithified deposit is a hardground only if its upper surface has been bored, corroded or eroded (by abrasion), if encrusting or other sessile organisms are attached to the surface or if pebbles derived from the bed occur in the overlying sediment". Only a few papers have shown that hardgrounds can be traced over great distances. These examples are summarized in table 6.1.

Shinn (1969) describes an area of the Persian Gulf sampled by grab sampler and bomb corer that extended 700-800 kilometres in length by 100-150 kilometres wide. Much of this area was covered by what may be an almost continuous sheet of submarine cemented sediment. In another modern example, Dravis (1979) suggested that hardground formation takes place on a high energy carbonate platform in the Bahamas from the near shelf margin, bankward for a distance of 17 kilometres.

Documentation of traceable ancient hardgrounds is relatively sparse. Jaanusson (1961) noted that a particular bored surface separating the Cambrian and Ordovician could be traced for approximately 400 kilometres in Sweden from

Table 6.1.

Traceable modern and ancient lithified surfaces

Author	Formation and age	Location	Traceable distance (kilometres)
Shinn (1969)	Modern sed's	Persian Gulf	Local 10 km.
			Regional 70000 km^2
Dravis (1979)	Modern sed's	Bahamas	15 - 17 km.
Rose (1970)	Edwards / Cretaceous	Texas	300 km.
Jaanusson (1961)	Ontikan / Camb. - Ord.	Sweden	400 km.
This paper	Dundee / Devonian	Ontario	Local to 23 km.
			Regional to 110 km.

Ingermarland to Western Estonia. Rose (1970) showed that a zone of mappable "hardgrounds" occurs over a distance of approximately 180 miles (300 km) within the Lower Cretaceous Edwards Formation of Texas. What had been previously mapped as a single discontinuity surface was found by Rose to be 2 to 3 surfaces within a thin vertical interval. Very few examples detailing the lateral extent and significance of hardgrounds occur in the literature, in part due to the fact that the significance of such surfaces has not been realized and also because in outcrop weathered surfaces can be extremely difficult to identify. Many papers simply describe hardgrounds by documenting paleoecological interpretations associated with the hardground i.e. faunal community, sedimentology, etc., (Halleck, 1973; Wilkinson et al., 1982 ; Brett, 1988 ; Brookfield and Brett, 1988) without noting the significance of the surface in a regional depositional interpretation.

Shinn's description and interpretation of hardground surfaces in the Persian Gulf suggests that the significance of discontinuity surfaces in ancient carbonates has not yet been realized. If some of Shinn's observations are correct for the Persian Gulf, a shallow epicontinental sea, then perhaps a more detailed examination of ancient shallow epeiric sea sediments may provide important sedimentologic evidence preserved in the form of submarine lithified horizons.

6.4 Lithified surfaces in Dundee carbonates

Two types of discontinuity surfaces were identified from Dundee carbonates both at outcrop locations and in 28 of the available subsurface drill cores. Using Bathurst's definition of a hardground as a reference, discontinuity surfaces most commonly occurring in the Dundee Formation have been classified as 1) lithifed horizons and 2) firmgrounds. True hardgrounds are rare in Dundee strata.

6.4.1 Type 1 : Lithified horizons

These surfaces were first identified in outcrop of the upper Columbus Formation at the Parkertown quarry in Ohio where five distinct lithified horizons were documented within a 5 to 6 metre thick interval directly below the Dundee contact (Fig. 6.1a,b). At this quarry, some lithified horizons were traceable laterally for a distance of several hundred metres along the quarry wall. Other horizons were locally developed and could only be traced over a distance of tens of metres.

Lithified horizons are commonly found in medium to coarse grained packstones and grainstones with similar sediments overlying the surfaces. Sharp, smooth upper contacts commonly have been indurated and exhibit a 'rind' of opaque minerals and / or dolomite. Some lithified horizons have been eroded and have slightly undercut surfaces. Lithified clasts may also be found overlying these horizons (Fig. 6.1c). Well-sorted allochems, rare rounded quartz grains and rare glauconite? may also be found above these surfaces. Dolomite-filled fractures (Fig. 6.2a) were seen to penetrate down from the upper surface and rare thin stromatoporoids were identified encrusting lithified horizons. No borings were found to penetrate these surfaces. Commonly, however, large 2-3 cm diameter by 5-10 cm deep burrows were observed. These burrows are generally vertical and most likely represent a dwelling type of structure (Fig. 6.2b). Westgate and Fischer (1933) describe similar U- or V-shaped depressions in an undulating surface at the Columbus - Delaware contact from a quarry in central Ohio. Only 10 lithified horizons were identified from wells

Figure 6.1

A. Columbus-Delaware Formation transition, Parkertown quarry, Ohio. Upper medium-bedded, grey, argillaceous limestones are Delaware Formation.

B. Two lithified horizons (LH) in upper Columbus Formation strata, Parkertown quarry, Ohio. Note dark grey indurated upper surfaces and lighter coloured subvertical burrows?.

C. Brecciated lithifed horizon in core ; OGS 82-3, Elgin Co., 122.30 - 122.15 m. Scale bar = 1 cm.

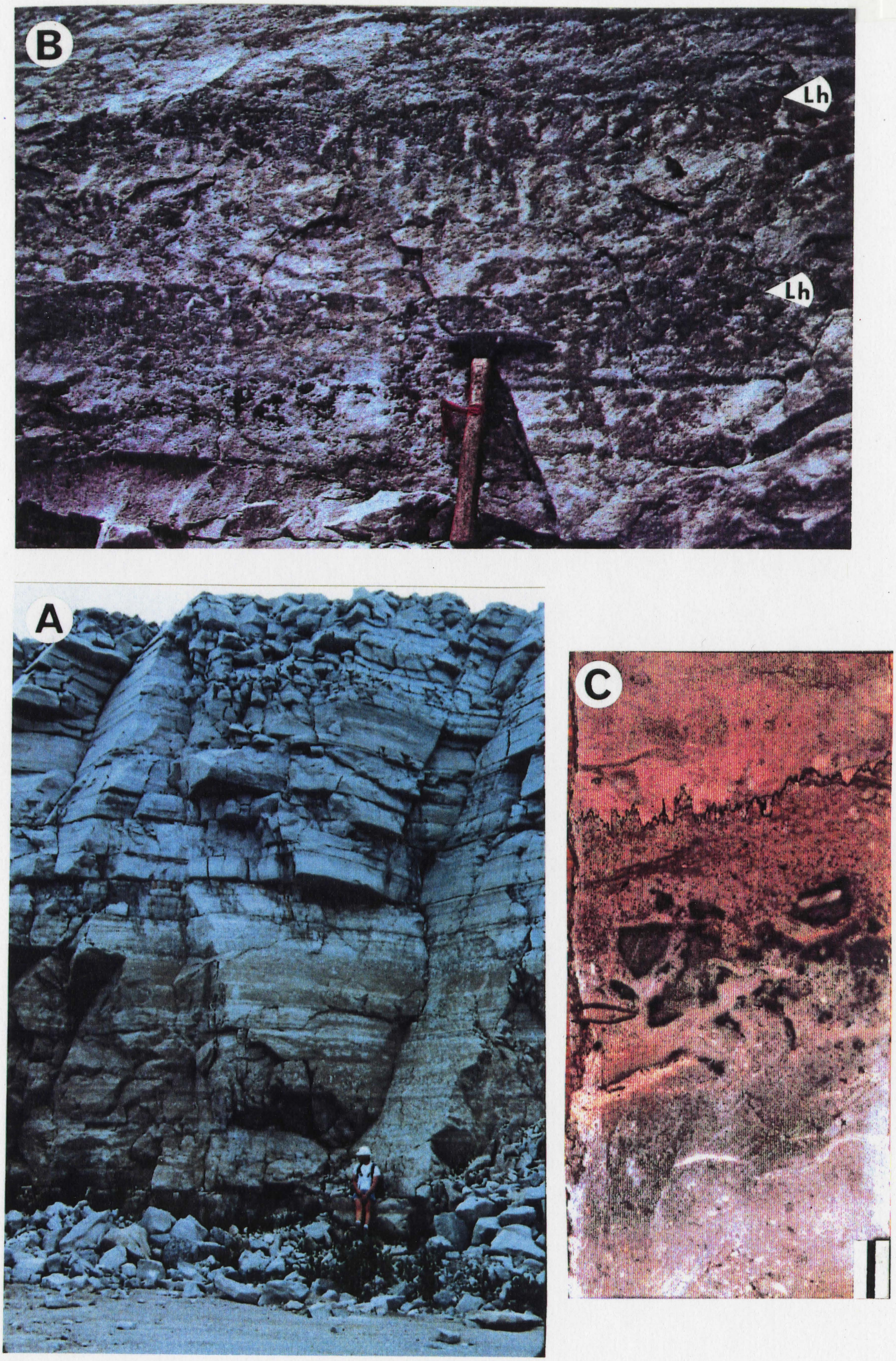

B
Lh
Lh
A
C

Figure 6.2

A. Thin section internegative photomicrograph of lithified horizon ; OGS 82-3, Elgin Co., 128.37 - 128.32 m. Note sharp, undercut pyritized and dolomitized upper surface with thin, vertical dolomite-filled fracture (F). Coarse crinoidal material overlies lithified horizon. Scale bar = 1 cm.

B. Close up of lithified horizon at the Columbus-Dundee contact, Parkertown quarry. Note well preserved subvertical and U-shaped burrows? penetrating indurated surface.


A
F


B

penetrating the Dundee Formation. These horizons are believed to be laterally discontinuous and appear to represent episodes of non-deposition, winnowing and reworking followed by submarine lithification. Continued reworking caused erosion and the lithified surface was subsequently blanketted with a layer of well sorted, usually crinoidal grainstone. Lithified horizons are most commonly found in packstone and grainstone pulses of facies 2 and 4.

6.4.2 Type 2 : Firmgrounds

The term 'firmground' is used here to describe the second, more common type of discontinuity surface found within Dundee sediments. These surfaces have been subdivided into poorly, moderately and well-developed firmgrounds depending on the degree of development of these horizons with regard to the following described characteristics. Firmgrounds most commonly occur in fine-grained, slightly argillaceous mudstones and wackestones and have a sharp, irregular upper surface that may be undercut. Upper surfaces are commonly pyritized and / or dolomitized. The key distinguishing characteristic of firmgrounds in Dundee strata are the presence of thin (2-3 mm diameter), often pyritized vertical burrows which penetrate the upper surface to depths of approximately 10 cm (Figs. 6.3, 6.4). True hardground development was rarely achieved, since only a few examples were observed where grains were cut at the margins of borings. The lack of cut grains may be in part due

Figure 6.3

A. Well-developed firmground in facies 5 ; MOE Deep Obs. #1, Lambton Co., 151.65 m. Sharp, irregular upper contact with thin vertical burrows infilled by dark, overlying muds. Convex up brachiopod valve (left of center) is not cut by vertical burrow.

B. Polished slab of a well-developed firmground from the lower part of the Delaware Formation, Parkertown quarry, Ohio. Burrows are partially pyritized and penetrate downwards to a depth of approximately 10 cm. Scale bar = 1 cm.

C. Well-developed firmground in Dundee facies 4 ; Lake Erie CT-8, 234-N, 67.06 m. Scale bar = 2 cm.

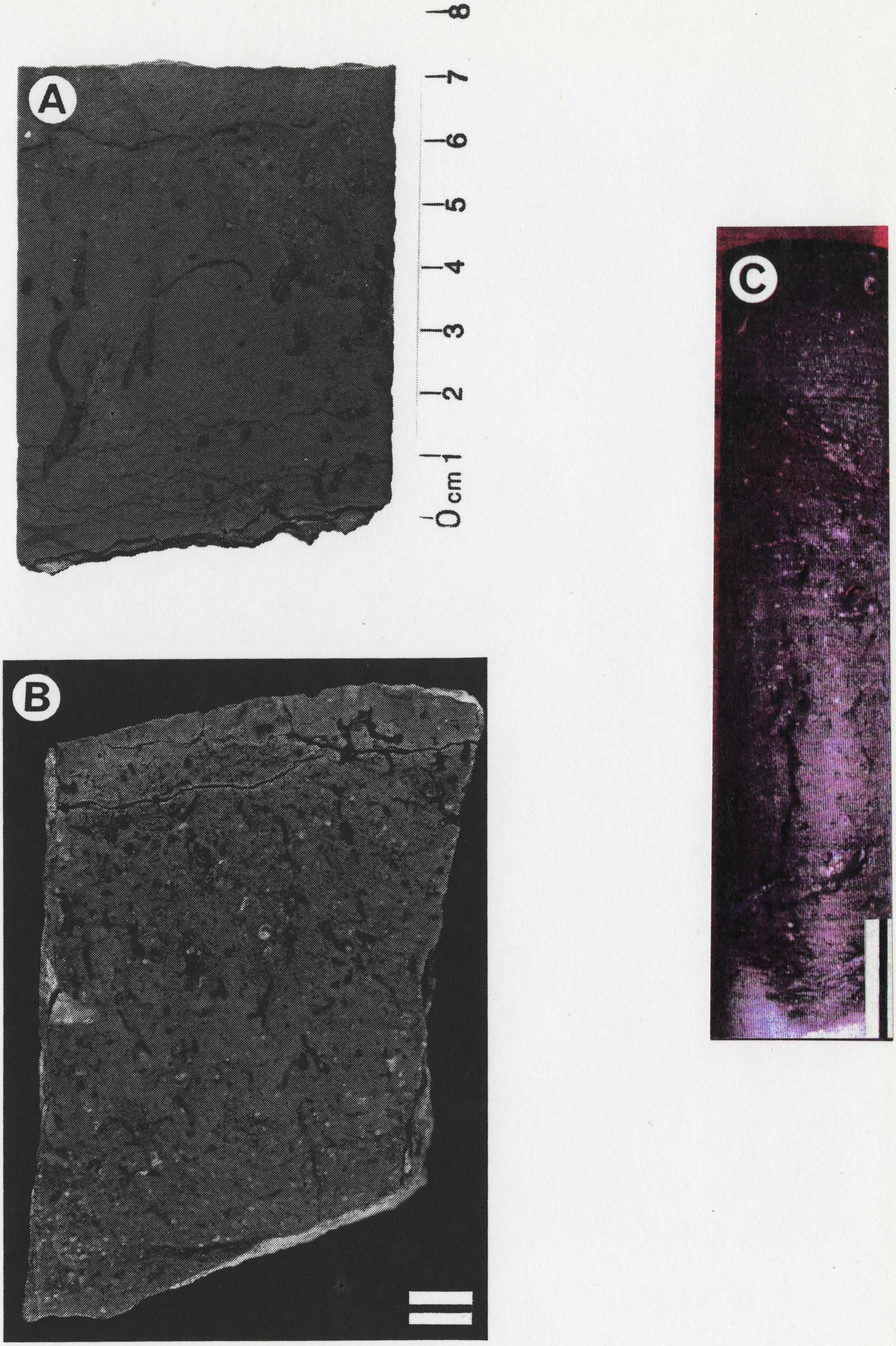
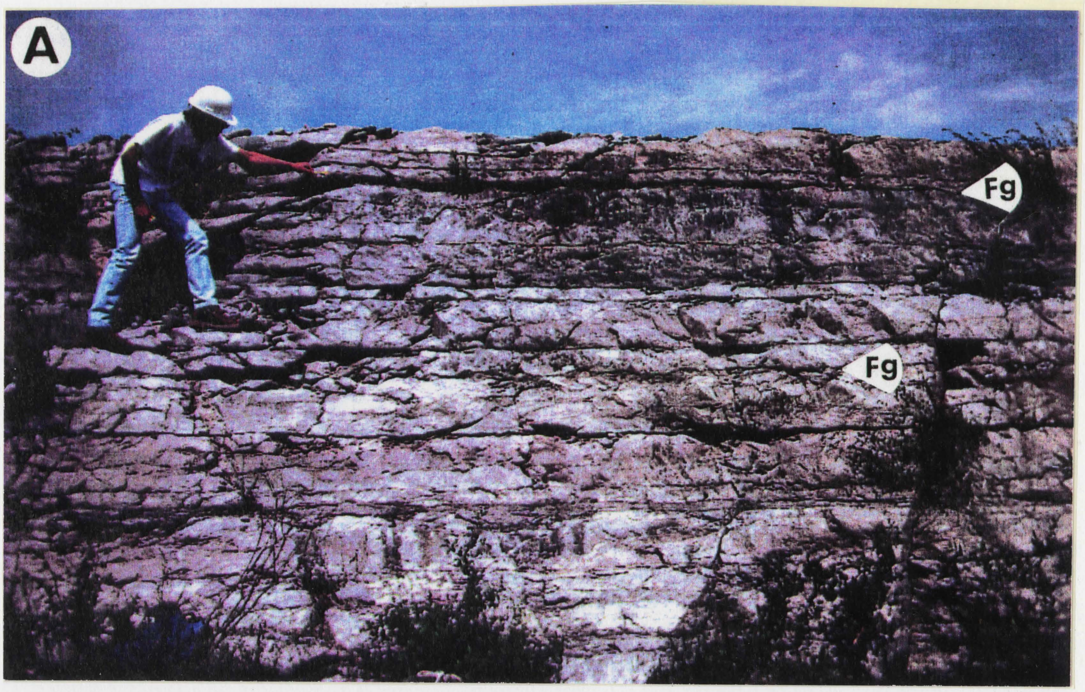
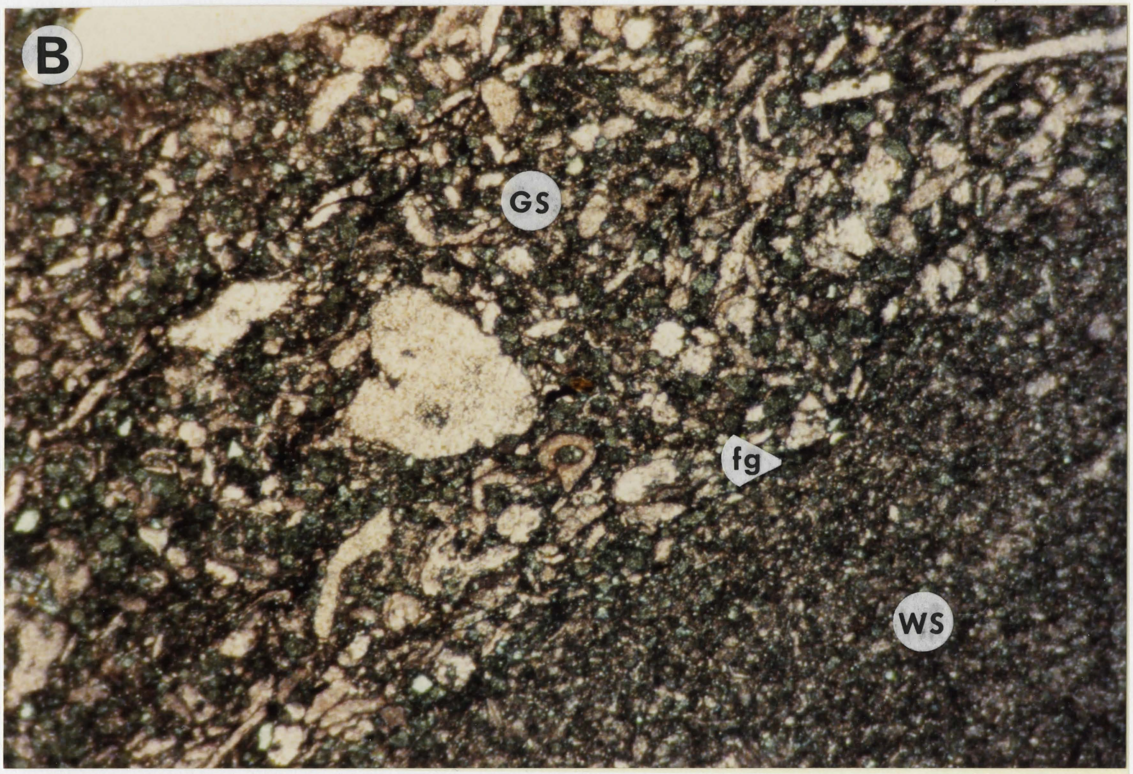

A
B
C
0 cm 1 2 3 4 5 6 7 8

Figure 6.4

A. Traceable moderately developed firmgrounds in upper Dundee strata (facies 5) at the entrance ramp of the St. Mary's Cement Company operating quarry. Note slightly undulatory nature of firmground surfaces.

B. Thin section photomicrograph of firmground surface (FG) in facies 4; Note coarser well-sorted crinoidal grainstone (GS) overlying a fine grained wackestone (WS) lithology; Lake Erie CT-5, 234-R, 58.9 m. Stained thin section, plane polarized light, 63X magnification Field of view = 1.0 X 1.5 mm.


A
Fg
Fg


B
GS
fg
WS

to the fine grained nature of the sediments in which these surfaces are most commonly found. Seventeen thin sections and ten peels were made in order to help distinguish and classify these surfaces. These represent more than half of all firmgrounds identified. Burrows commonly are infilled by overlying sediments which are either fine grained, dark carbonate muds or coarse, well sorted crinoidal packstones and grainstones. Phosphatic bone fragments, approximately 1-3 millimetres in size, were commonly observed directly overlying firmground surfaces and infilling burrows. These phosphatics are most commonly found associated with well-developed horizons. Eroded clasts occasionally occur above firmgrounds and thin tabular stromatoporoids rarely encrust moderately to well-developed surfaces.

The term hardground has not been used to describe these surfaces mainly due to the absence of borings and the general lack of encrusting organisms. Preservation of burrows is likely due to the fact that these structures were formed after partial lithification of sediments. Grains are not cut at the margins of these structures and in some cases burrows bypass brachiopod valves. Evidence of partial lithification is suggested by 1) overlying muds infilling burrows and 2) coarser, sorted fossil fragments occasionally in a sparry matrix also infilling burrows.

6.5 Dundee bone beds

Conkin and Conkin (1975) have identifed eight bone beds at various intervals in the Delaware Formation (= Dundee) of central Ohio (Fig. 4.2). They have also suggested that bone beds can be used as keys for differentiation and correlation of stratigraphic intervals within the Middle Devonian of Ohio. One well-developed bone bed has commonly been used to separate the Columbus and Delaware formations in parts of Ohio (Westgate and Fischer, 1933 ; Wells, 1944 ; Conkin and Conkin, 1975 ; Sparling, 1988). These beds vary in development, being absent at some localities and up to approximately 60 centimetres thick at others. Bone beds consist of clastic accumulations of crinoidal debris, scales, plates, teeth and bones of fishes, conodonts, ostracods, relatively few macrofossils, mixed with rounded sand grains and a small amount of clay-size constituents (Wells, 1944). No similar bone beds have been identified in stratigraphically equivalent formations in Ontario and Michigan. Wells (1944) suggests the reason for this is that bone beds found in the vicinity of north-central Ohio formed in close proximity to the Cincinatti Arch. As well, bone beds did not form to the north in the Ontario area because the sea bottom there rarely attained wave base for more than brief intervals.

The bone fragments which commonly occur above well-developed firmgrounds in Dundee sediments of Ontario are most likely from fish (Figs. 6.5, 6.6). Some of the firmgrounds documented in the Dundee Formation of Ontario may be correlatable with bone beds of Ohio. Conkin and Conkin (1975) describe bone bed 7 at the base of the Delaware Formation as being underlain by a gray interval, a few inches thick which has common worm burrows. This description sounds very much like the dark, mud-filled vertical burrows which are diagnostic of well-developed Dundee firmgrounds in Ontario. Wells (1944) suggests that bone beds from Ohio represent lag concentrates accumulated during diastems resulting from fluctuations with respect to wave base of the very shallow sea bordering the Cincinatti Arch. A similar interpretation may be surmised for the development of firmgrounds in shallow waters of Dundee seas in the southwestern Ontario area.

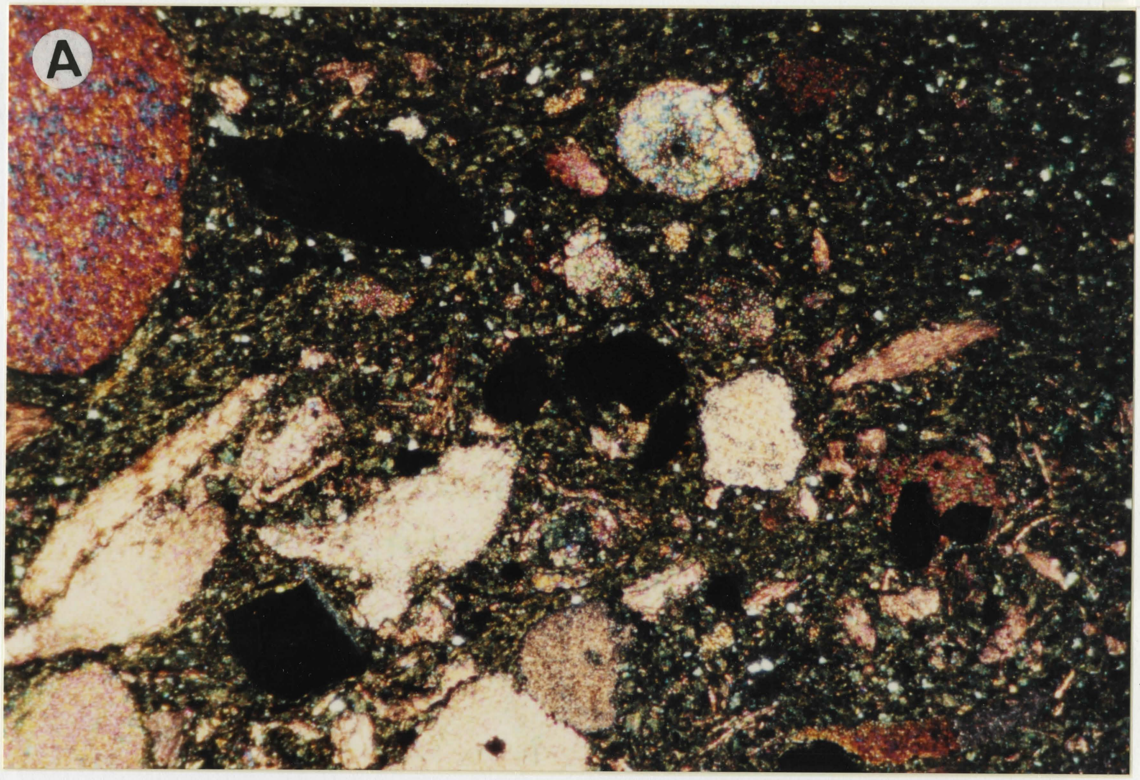
6.6 Distribution of firmgrounds

Fifty individual firmgrounds were identified from twenty-eight of the cores examined in this study. Three other firmground surfaces were observed in outcrop: two in uppermost sediments at the St. Mary's quarry and one just above the Columbus - Dundee contact in the Parkertown quarry in Ohio. At these quarries, firmgrounds appear to be traceable for several hundred metres. The degree of firmground development was assessed for all surfaces depending on characteristics of firmgrounds listed earlier and surrounding lithofacies were noted. Part of the problem studying the Dundee Formation was

Figure 6.5 Thin section photomicrographs of millimetre-sized phosphatic fish? fragments found in the Dundee Formation.

A. Phosphatic fragments and pyrite (both are black) as seen under cross polarized light. Stained thin section, 25X magnification.
Field of view = 2.5 X 4.0 mm.

B. Same as in (A) but plane polarized light. Pyrite (black) can be distinguished from phosphatics which are commonly a brownish colour.


A

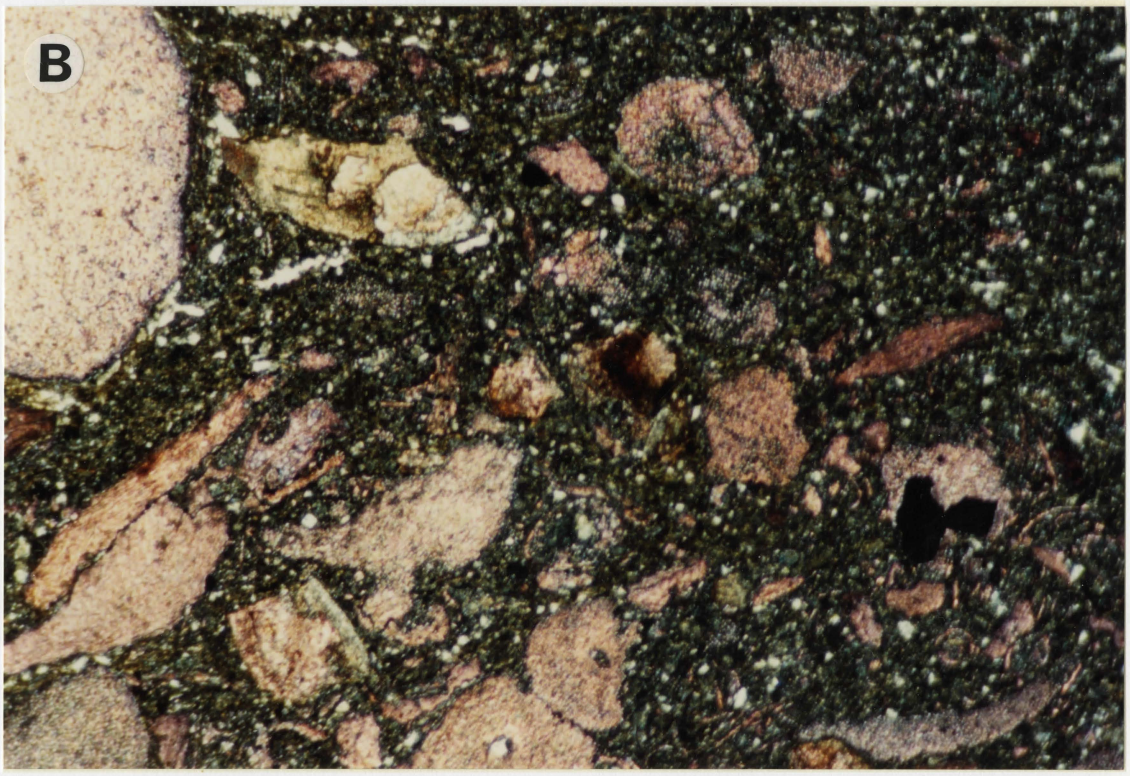
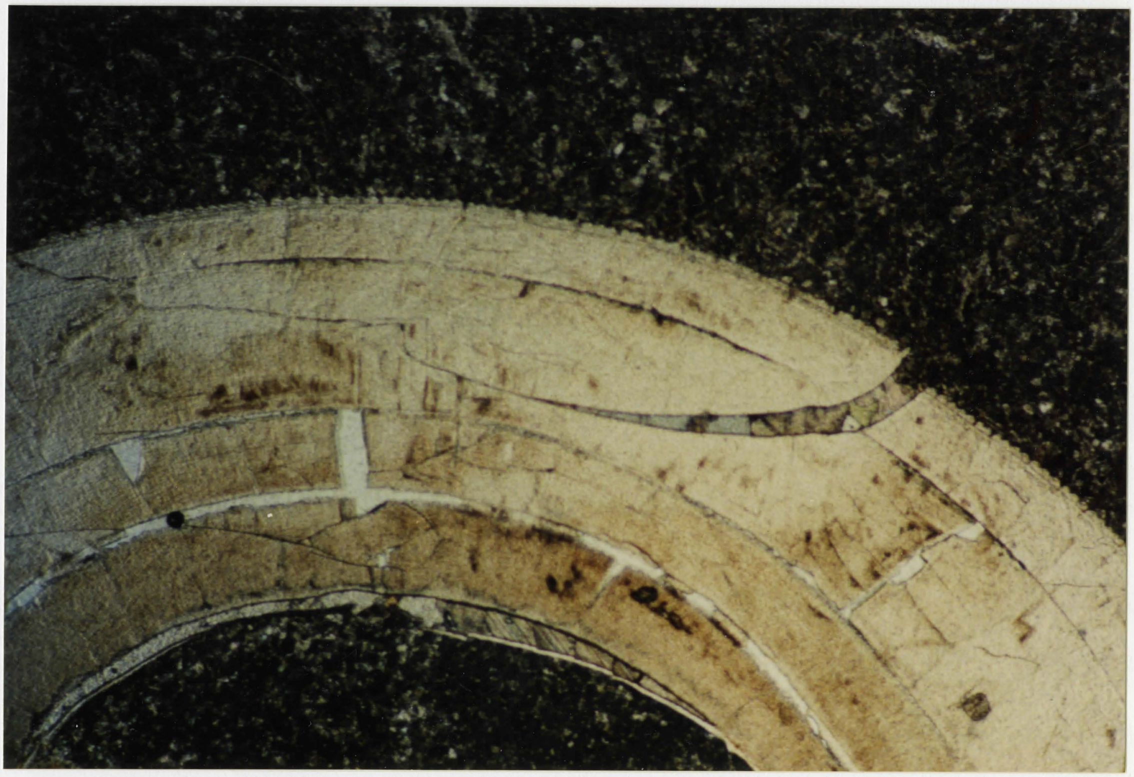

B

Figure 6.6 Large phosphatic bone? fragments occasionally found overlying well-developed firmgrounds. Note hollow centre and serrated edges of phosphatics. Unstained thin sections, cross polarized light, 25X magnification.

Fields of view = 2.5 X 4.0 mm.



that both the lower and upper formation contacts are disconformable and there were no readily identifiable internal lithologic markers previously described. Many of the lithofacies grade upwards into the overlying facies and Dundee facies in the Michigan Basin are different from those in the Appalachian Basin. Therefore, it is difficult to choose markers that can be used as datum planes in order to construct both local and regional stratigraphic cross sections.

Stratigraphic cross section A-A′ (Fig. 4.3), covering a horizontal distance of approximately 8 kilometres, shows that the Columbus and Dundee formations can be differentiated using facies evidence and Moellerina as a Columbus facies marker. This section uses the base of Dundee facies 4 as a local datum plane and shows that Dundee facies 3, 4 and 5 can be separated from underlying Columbus strata. A number of moderately and well-developed firmgrounds are present in these wells and occur at roughly the same stratigraphic positions at the base and near the middle of facies 4 sediments. Although individual surfaces do not appear to be traceable here, 'packages' of surfaces are found at similar horizons.

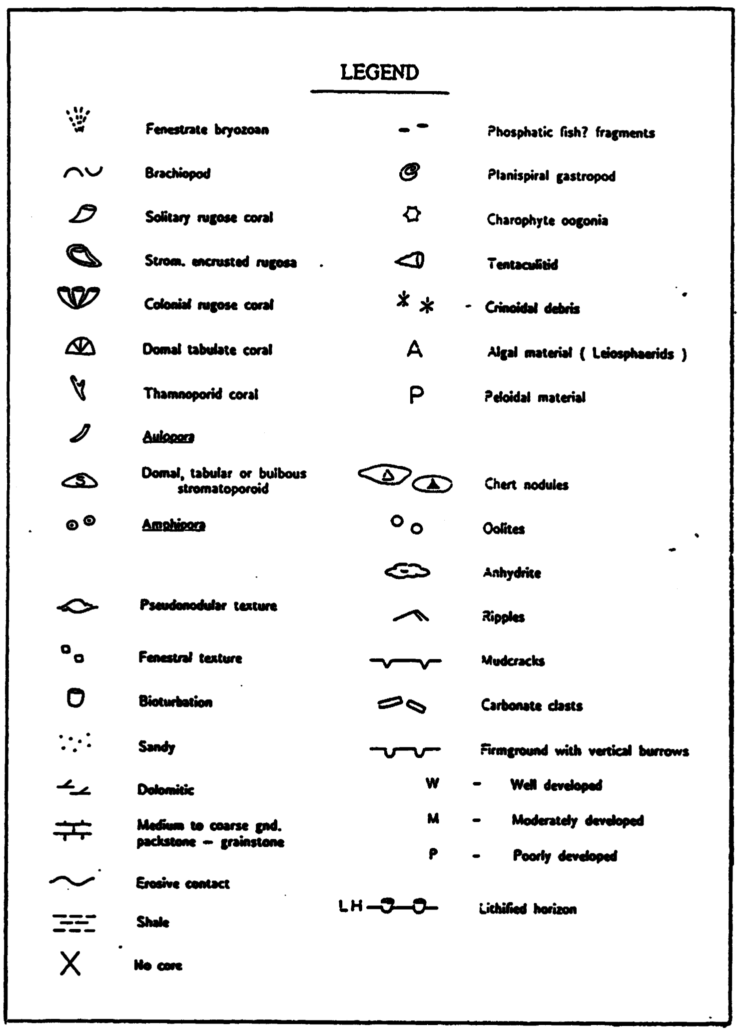
Firmgrounds were also found to be common in facies 4 sediments of the Michigan Basin region. At a slightly larger scale than cross section A-A′ previously discussed, five cores in the southern part of the Michigan Basin were correlated using the uppermost firmground in facies 4 as a local datum

(Fig. 6.7). Two to three firmgrounds occur at roughly the same stratigraphic position over a maximum straight line distance of approximately 23 kilometres. Choosing the upper or lower firmground in this 'package' as a datum would not significantly affect the cross section.

Several interesting observations can be made from section E-E'. Firstly, a paleotopographic high occurs on the lower Dundee contact and the overlying cherty bioclastic facies appears to thin over this structure. It is believed that the datum probably was not a flat surface but due to the thinning of facies 2 it seems that a paleotopographic high does occur at the lower Dundee contact. This topographic high may be a relict feature caused in part by dissolution of underlying Silurian salts as modelled by Brigham (1972). Assuming a constant gradient, the slope at the Dundee contact between wells 27-XIII and 19-XIII is calculated to be roughly 1.5 metres per kilometre (8 ft. per mile). Secondly, the greatest number of firmgrounds within a thin vertical interval and the best development of firmgrounds occurs proximal to this topographic high. Well-developed firmgrounds are found near the crest of this structure while moderately developed firmgrounds are located further away on the flanks. Lack of core precludes the identification of transitional lithified surfaces further away from the paleotopographic high.

These observations from section E-E' suggest that

Figure 6.7 Stratigraphic section E-E′ constructed along the southeast part of the Michigan Basin (see fig. 1.3 for location). The uppermost firmground in facies 4 is used as the datum. Lithofacies numbers are shown beside schematic sections.



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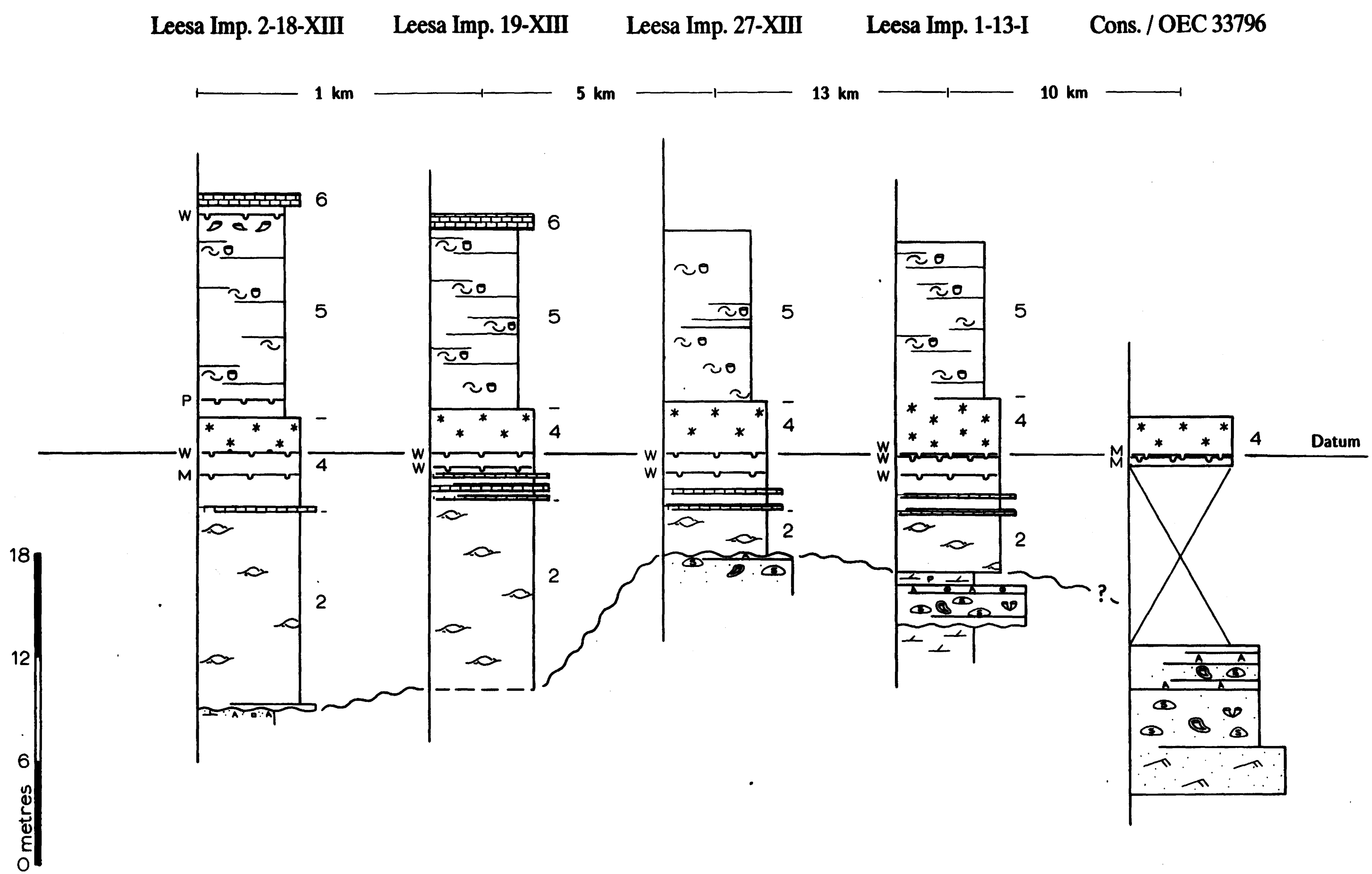
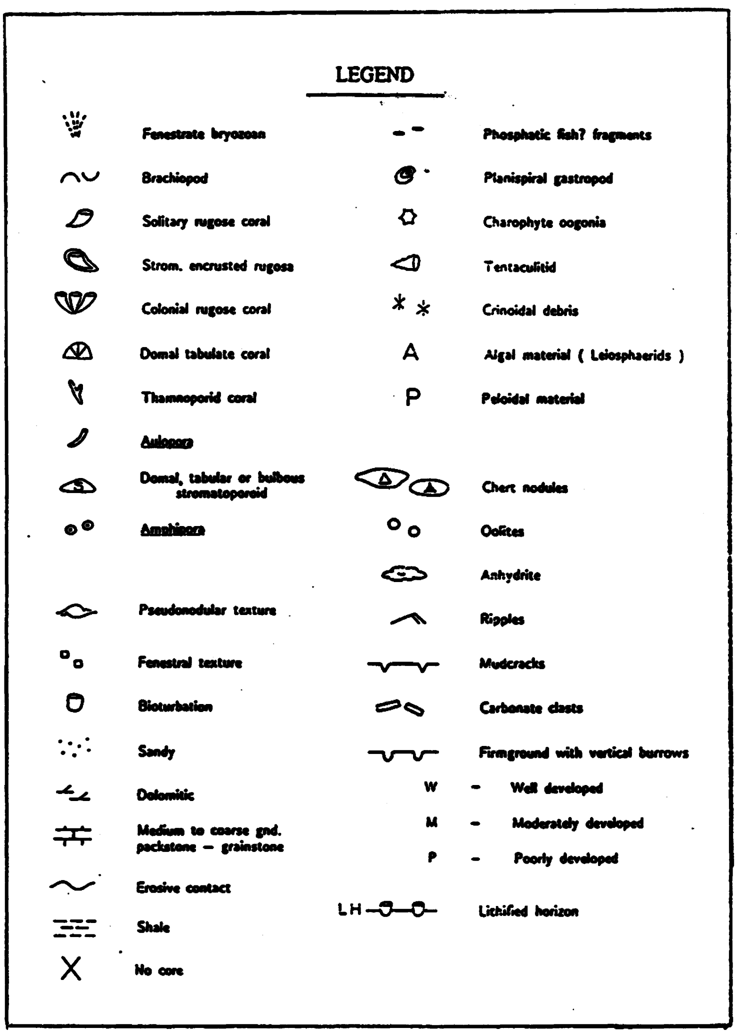
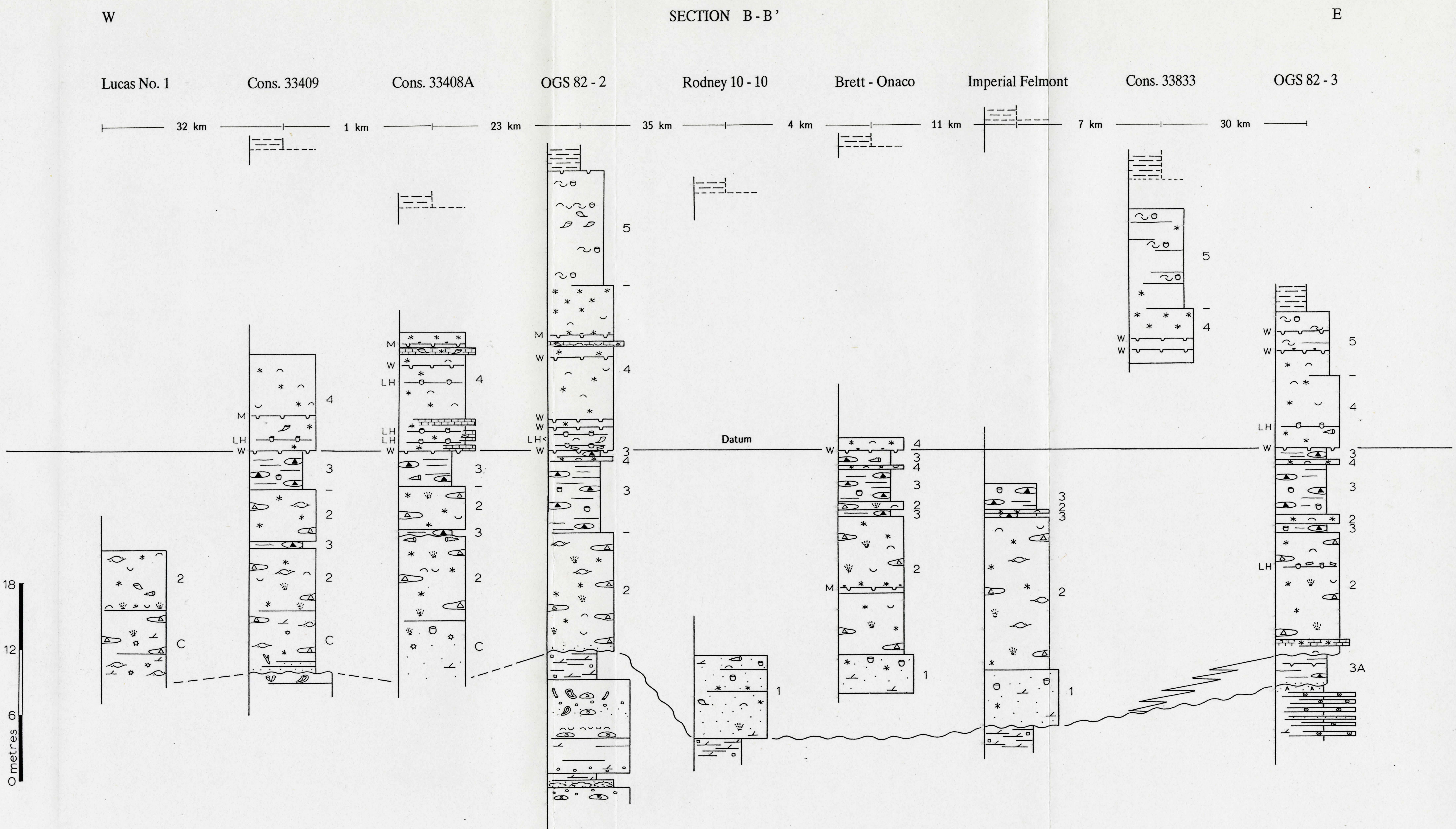


although individual surfaces do not appear to be traceable, firmground 'packages' may be correlatable within Dundee strata and may in fact be used as regional markers. Similar observations to those described for section E-E' were made by Shinn (1969) for hardgrounds in the Persian Gulf where hardgrounds were most common near the crests of offshore highs (as many as 4 were observed) with hardgrounds becoming thinner, softer and eventually pinching out with depth.

On a regional scale, a number of cores along the northern margin of the Appalachian Basin show that certain discontinuity surfaces in middle Dundee strata can in fact be used as regional markers (Fig. 6.8). Lithofacies 3 is a readily recognizable dark brown, sparsely fossiliferous cherty mudstone representing deposition in what may have been a dysaerobic lagoonal environment. This lithofacies is bounded below and above by normal marine fossiliferous wackestones, packstones and grainstones, and the top of lithofacies 3 in these wells is a well-developed firmground. This surface has occasional overlying mud clasts and some burrows are partially filled by sparry calcite and coarse crinoidal fragments. This particular firmground surface is traceable along the northern margin of the Appalachian Basin for a distance of approximately 110 kilometres. Lithofacies 3 pinches out northward, therefore this surface cannot be traced north into the Michigan Basin.

Figure 6.8 Stratigraphic cross section B-B′ constructed across the northern margin of the Appalachian Basin (see fig. 1.3 for location). The top of the readily identifiable cherty mudstone facies is used as a datum. The contact of facies 3 with facies 4 is commonly a well-developed traceable firmground. Note the pinchout of Columbus Formation sediments (labelled C) to the east. Dundee lithofacies numbers are shown beside schematic sections. The approximate position of the Dundee - Hamilton contact is shown for individual wells as determined from geophysical logs.




W
SECTION B - B'
E
Lucas No. 1
Cons. 33409
Cons. 33408A
OGS 82 - 2
Rodney 10 - 10
Brett - Onaco
Imperial Felmont
Cons. 33833
OGS 82 - 3
32 km
1 km
23 km
35 km
4 km
11 km
7 km
30 km
Datum
18
12
6
0 metres

Several firmgrounds and lithified horizons occur in strata overlying the laterally extensive traceable firmground at the top of facies 3. Many of these discontinuity surfaces occur at similar stratigraphic positions within facies 4 sediments of different wells. This suggests that basinwide responses to changes in sedimentation occurred in the Appalachian Basin during this episode of the Middle Devonian.

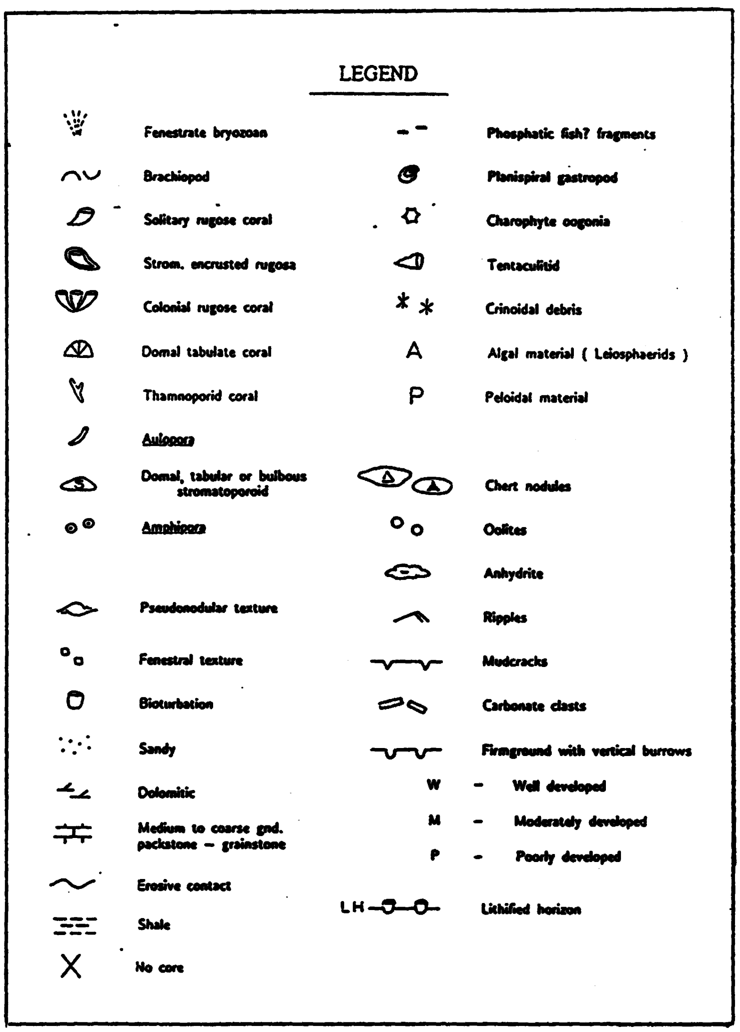
6.7 Intrabasin correlation of firmgrounds

Correlation of 'packages' of firmgrounds between the Michigan and Appalachian basins is difficult at best and can be attempted only in conjunction with detailed lithofacies interpretation. As discussed in chapter 5, facies sequences are different between the two basins. The readily identifiable cherty mudstone facies of the Appalachian Basin region and the regionally correlatable firmground at the top of this facies are not present in adjacent areas of the Michigan Basin. Packages of firmgrounds are present within facies 4 sediments of both the Michigan and Appalachian basins and may in part be correlative.

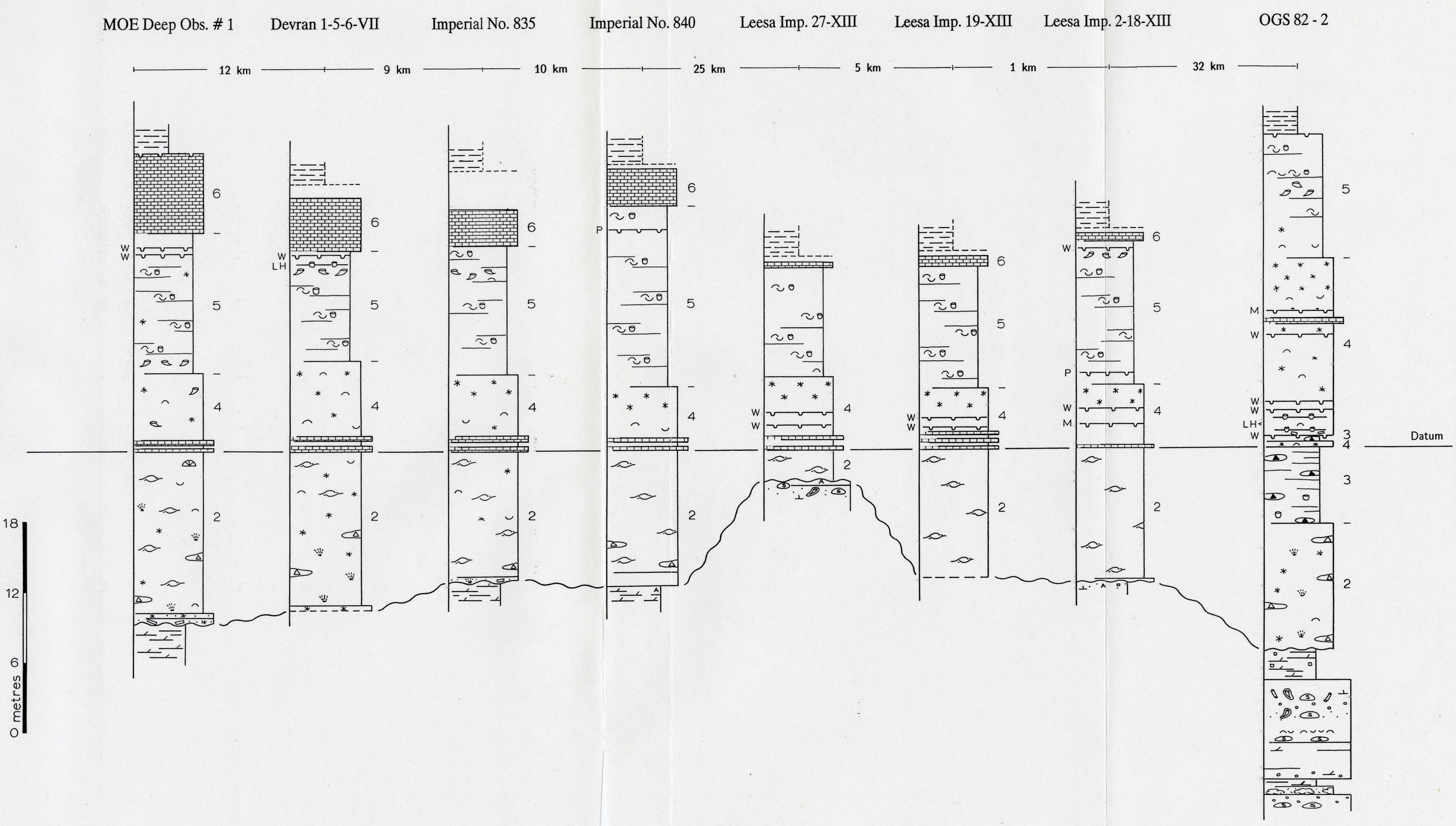
In the Michigan Basin region of this study area, the cherty bioclastic facies is gradationally overlain by facies 4. Occasionally, two to three coarse, basal grainstone or rudstone pulses occur in the lower few metres of facies 4 and possibly represent episodes of sea level stillstand, winnowing and reworking. At the St. Marys Cement quarry, one of these coarse pulses has been interpreted as a coral bank deposit (Upitis, 1964). Correlative units in the Appalachian Basin region could include the regionally traceable firmground at the top of facies 3, coarse basal pulses and / or firmgrounds within facies 4.

Stratigraphic section D-D′ is constructed perpendicular to the trend of the Algonquin Arch from the Michigan Basin into the Appalachian Basin and uses the base of facies 4 as a datum (Fig. 6.9). This section shows that strata overlying the datum appear to be flat lying. As previously noted for section E-E′, a paleotopographic high appears to exist at the lower Dundee contact in the vicinity of the Leesa Imperial 27-XIII well. The southern slope of this contact is approximately 1.5 metres per kilometre (8 ft. per mile) while the slope on the northern side is only 0.3 metres per kilometre (1.6 ft. per mile). Section D-D′ shows the differences in thickness of facies between the two basins. This may be a result of differential subsidence between the two basins. As a result of this observation it is suggested that firmgrounds within facies 4 of the Michigan Basin are more likely correlative with facies 4 firmgrounds identified higher up in facies 4 of Appalachian Basin sediments. If this is the case, then coarse basal grainstone and rudstone pulses to the north are possible time equivalents of facies 3 and / or lower facies 4 sediments.

Figure 6.9 Stratigraphic cross section D-D′ constructed roughly perpendicular to the axis of the Algonquin Arch (see fig. 1.3 for location). The base of facies 4 is used as a regional datum. The disconformable Detroit River Group - Dundee contact is shown and the approximate position of the Dundee - Hamilton contact, as determined from geophysical logs, is also shown. Dundee lithofacies numbers are shown beside the schematic log for each well.



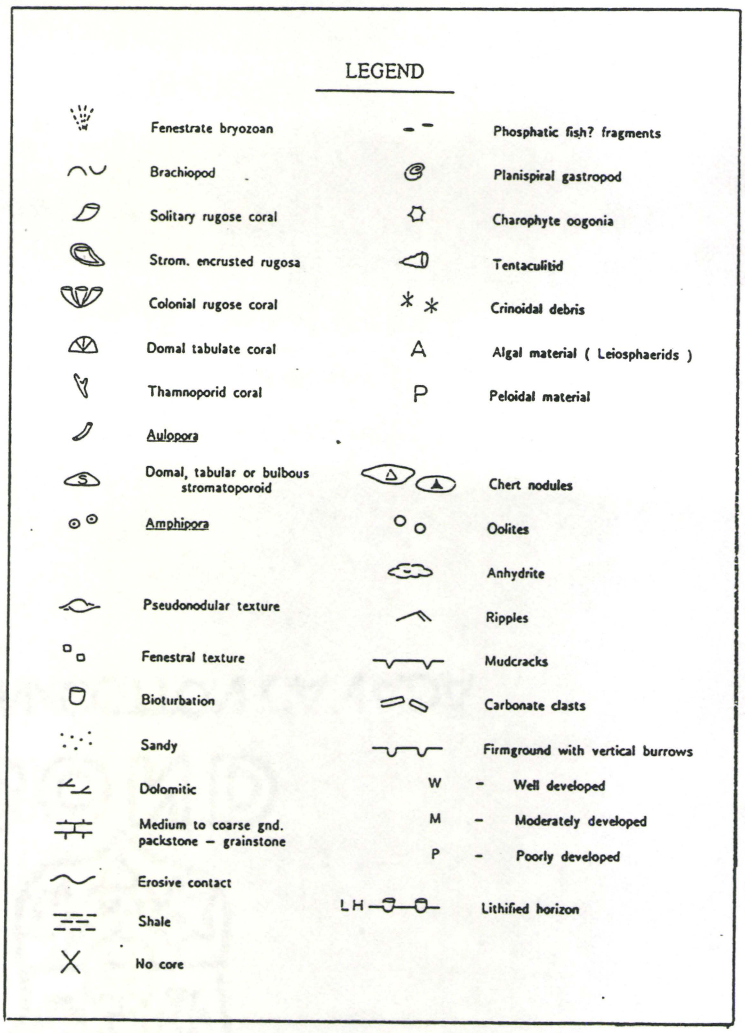
N SECTION D - D' S

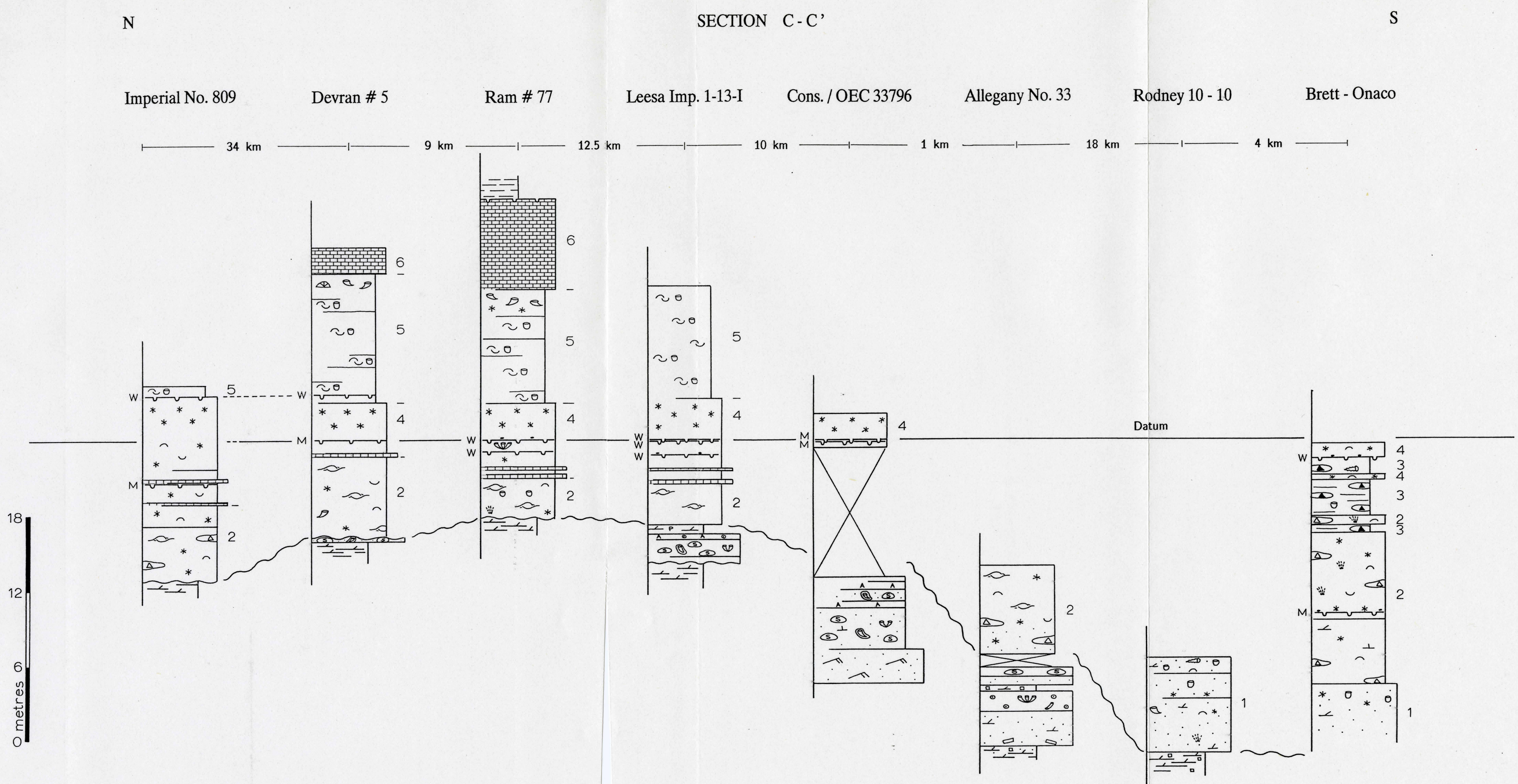


Stratigraphic section C-C′ is similarly constructed roughly perpendicular to the orientation of the Algonquin Arch from the Michigan Basin southward into the Appalachian Basin (Fig. 6.10). Choosing the upper firmground within a traceable firmground package in facies 4 as a datum reveals a number of observations similar to those previously discussed for section E-E′. Firstly, a slight paleotopographic high occurs at the lower formation contact and the overlying facies 2 thins over this structure. Thinning of facies 2 supports the idea that a topographic high, as shown in section C-C′, is in fact present. Assuming a constant gradient, the average slope along the Detroit River - Dundee contact, from the crest of the high southward into the Appalachian Basin, can be calculated to be approximately 0.6 metres per kilometre (3 ft. per mile). In contrast, the slope into the Michigan Basin is roughly 0.12 metres per kilometre (0.7 ft. per mile). Thirdly, the maximum number of firmgrounds and their greatest degree of development appears to be coincidental with the crest of the topographic high, with both the number and degree of development decreasing basinward, most noticeably into the Michigan Basin. These interpretations are again similar to those made by Shinn for certain hardgrounds in the Persian Gulf.

In summary, it can be seen that firmground packages are traceable within middle to upper Dundee strata both within and between the Michigan and Appalachian Basins. Although the data

Figure 6.10 Stratigraphic cross section C-C′ constructed roughly perpendicular to the axis of the Algonquin Arch from the Michigan Basin southward into the Appalachian Basin (see fig. 1.3 for location). The uppermost firmground in facies 4 is used as a datum. Dundee lithofacies numbers are shown beside the schematic log for each well.




N
SECTION C - C'
S
Imperial No. 809
Devran # 5
Ram # 77
Leesa Imp. 1-13-I
Cons. / OEC 33796
Allegany No. 33
Rodney 10 - 10
Brett - Onaco
34 km
9 km
12.5 km
10 km
1 km
18 km
4 km
Datum
18
12
6
0 metres

set is limited by the number and spacing of available cores, it appears reasonable to suggest that firmgrounds are concentrated near the crests of paleotopographic highs with the greatest degree of development of firmgrounds possibly also occurring near the crests of these structures. Firmgrounds have distributions similar to those observed on offshore highs in the Persian Gulf where horizons "become progressively thinner, softer, discontinuous and eventually disappear seaward" (Shinn, 1969). These interpretations, for the distribution and development of Dundee firmgrounds, are similar to the interpretation for the development of bone beds of Ohio which were found to have formed proximal to the tectonically positive Cincinatti Arch.

Although the topography of Dundee highs cannot be accurately established due to poor core control and the extreme difficulty of using geophysical logs to define lithofacies, it appears that these structures are similar in size to offshore highs documented by Shinn (1969) from the Persian Gulf. Submarine-cemented layers on offshore highs in the Dohat Hussain lagoon of the Persian Gulf were traced for over 500 metres down a slope of approximately 2 metres per kilometre (Shinn, 1969). The slopes of Dundee paleotopographic highs documented in this study range from 0.12 m/km, on the northern side of the highs, to 1.5 m/km on the southern flank of the highs. Firmgrounds, located on the crests of Dundee topographic highs, should be traceable downslope for distances at least comparable to that documented for cemented layers in the Persian Gulf. Cemented layers on shallow, lower angle slopes may even be traceable for significantly greater distances.

Mapping of discontinuity surfaces such as these may be important for reservoir development. Packages of firmgrounds occur within a thin vertical interval near the middle of the Dundee sequence. Many of these Dundee firmground surfaces were noted to have been partially pyritized and / or dolomitized to a depth of several centimetres. Laterally continuous, well developed firmgrounds with indurated surfaces may act as barriers to fluid flow thereby reducing the vertical permeability of the rock. Identification of these discontinuity surfaces as possible vertical barriers to fluid migration could be an important aspect of understanding the characteristics of certain Devonian reservoirs in this area.

CHAPTER 7

DEPOSITIONAL MODEL

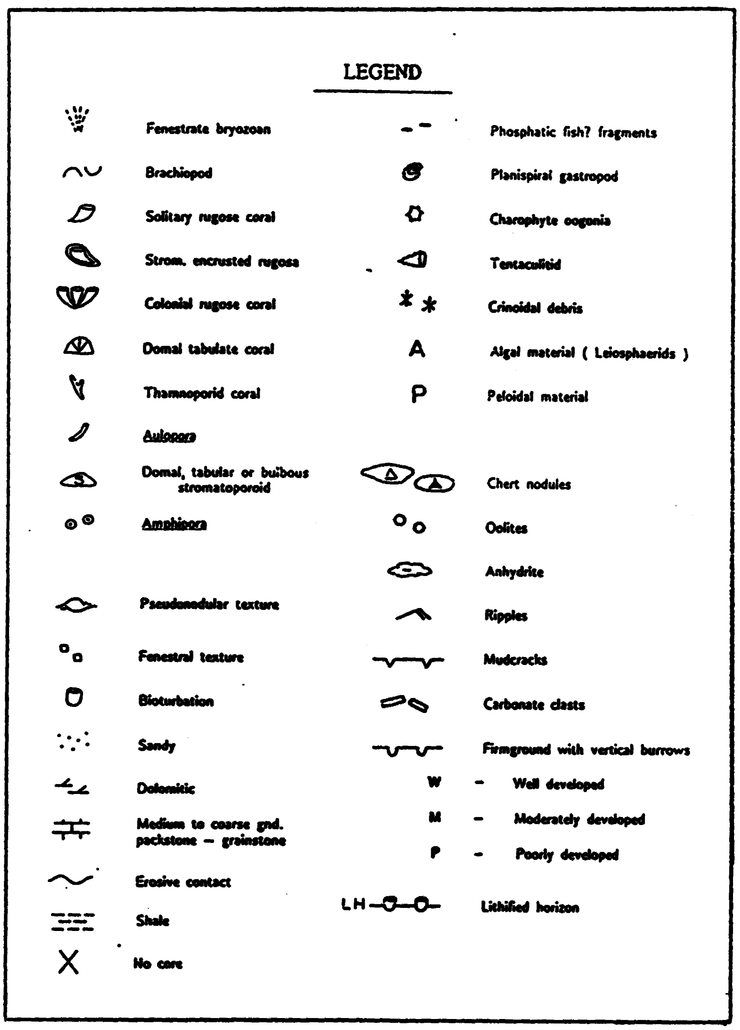
7.1 Introduction

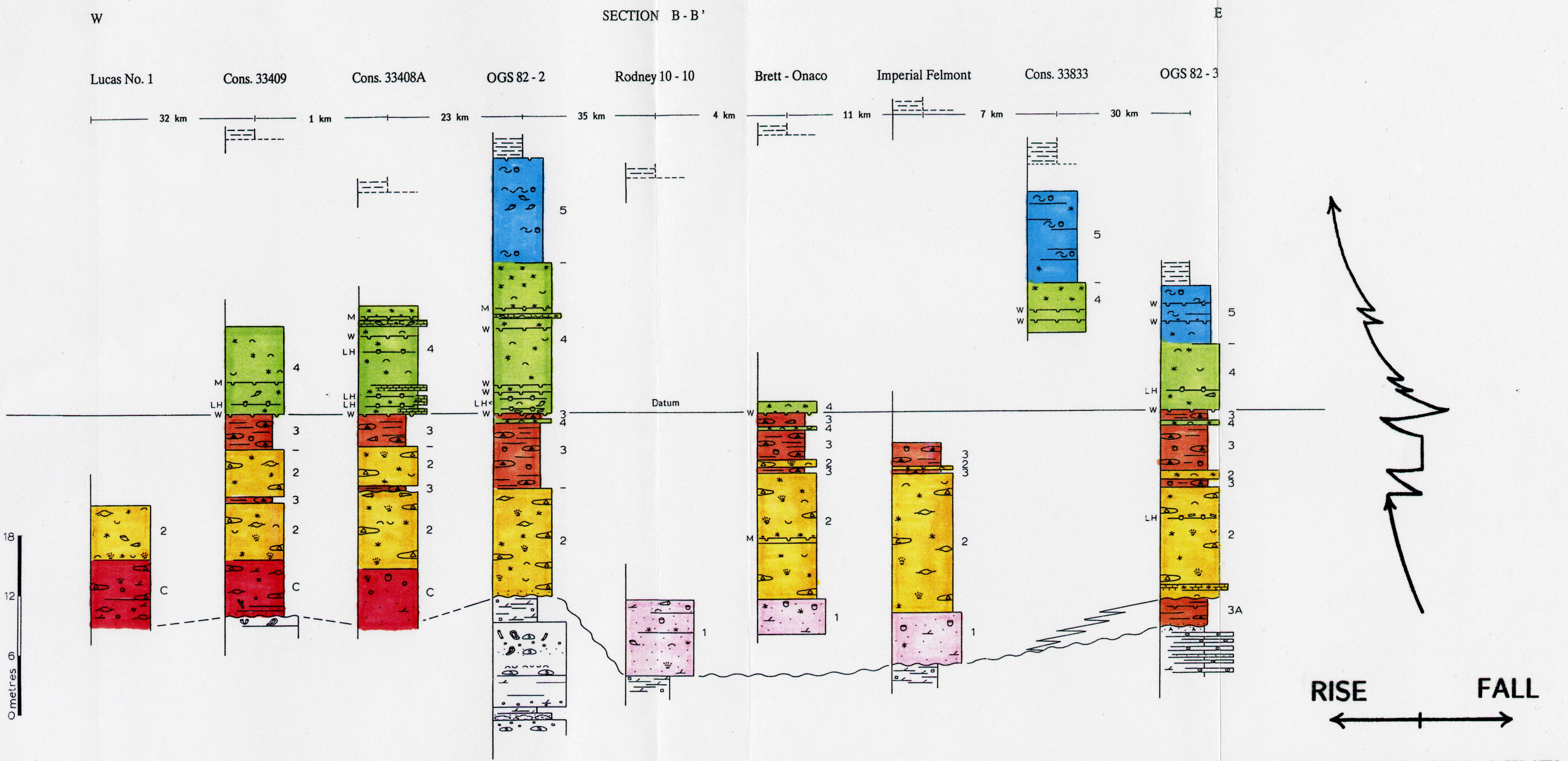
Based upon information derived from outcrop and subsurface cores it can be postulated that evidence of a number of sea level fluctuations has been preserved within Dundee and equivalent sediments. Firmgrounds and diagnostic marker facies can be recognized within cores, but recognition of these markers on geophysical logs is virtually impossible. Diffendal (1971) proposed that the Dundee Formation in Ontario represents a single time-transgressive package. The present study suggests that the lower part of the Dundee is time-transgressive and that minor relative sea level falls interrupted transgression during middle Dundee time. Upper Dundee strata seem better to reflect a time-stratigraphic deposition in which the Michigan and Appalachian basins were responding to similar depositional controls.

7.2 Depositional history of Dundee limestones

Stratigraphic section B-B′ best illustrates the vertical facies relationships that are present within the Dundee Formation (Fig. 7.1). Detailed lithofacies examination and interpretation have led to the conclusion that a relative sea level rise followed subaerial exposure and erosion at the end of Detroit River time. Maximum degree of exposure and erosion

Figure 7.1 Stratigraphic section B-B′ showing Dundee facies relationships observed for the Appalachian Basin. A relative sea level curve developed for the Dundee Formation of southwestern Ontario is also included.




W
SECTION B - B'
E
Lucas No. 1
Cons. 33409
Cons. 33408A
OGS 82 - 2
Rodney 10 - 10
Brett - Onaco
Imperial Felmont
Cons. 33833
OGS 82 - 3
32 km
1 km
23 km
35 km
4 km
11 km
7 km
30 km
Datum
18
12
6
0 metres
RISE
FALL
RELATIVE SEA LEVEL

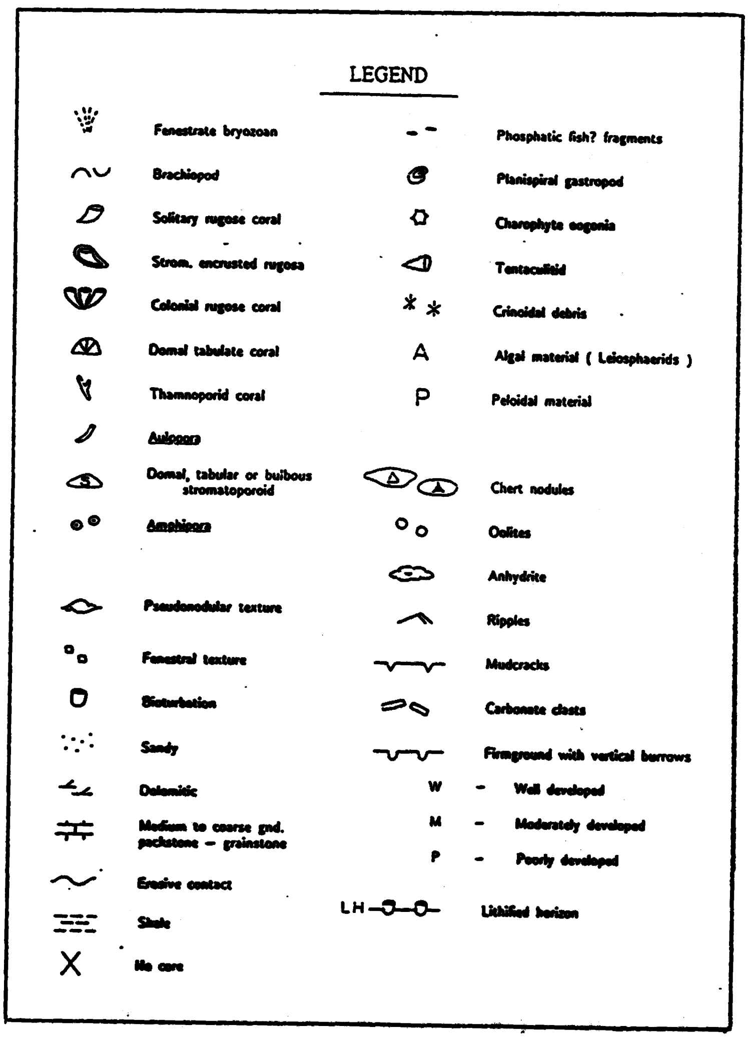
of Detroit River Group sediments occurred proximal to the Findlay and Algonquin arches. Baltrusaitis (1974) similarly noted that post-Detroit River emergence and erosion was confined to the edges of the Michigan Basin and did not affect the central areas of that basin. Appalachian seas subsequently transgressed over Detroit River carbonates, in a northwesterly direction (Lillienthal, 1978), depositing Columbus Formation and lower Dundee sediments. Columbus Formation sediments onlapping Detroit River carbonates are thickest towards the center of the Appalachian Basin, thin northwards and pinch out in the vicinity of Kent County, Ontario. As Sanford (1968) correctly stated, the Columbus limestones of Sandusky, Ohio and Pelee Island, Ontario are equivalent in part to the basal coarse clastic limestone facies of the Dundee Formation in other parts of southwestern Ontario.

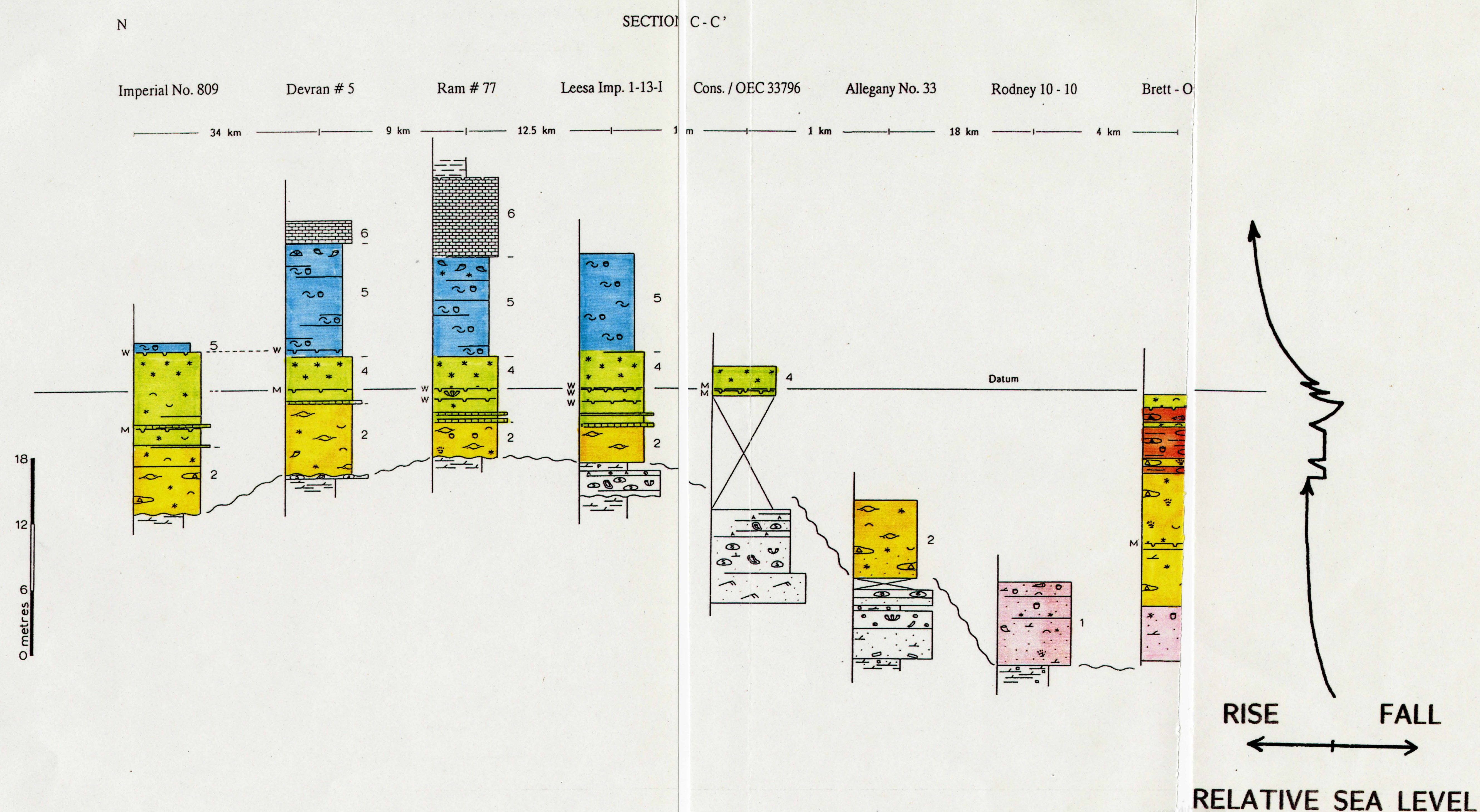
Lower Dundee sediments locally developed along the northern margin of the Appalachian Basin are dolomitic sandy wackestones. These dolomitic sandy limestones represent a stage of transgressive reworking of sands and sandy limestones most likely from the Anderdon Member of the Detroit River Group. Sanford (1968) suggests that some of these sands may have had an aeolian origin. Basal dolomitic sandy limestones accumulated locally in parts of the Chatham Sag between the Michigan and Appalachian basins. The presence of a structural depression is evidenced by the attitude of the Detroit River -

Dundee contact as shown in section B-B′ between wells OGS 82-2 and OGS 82-3. It was previously shown that the distribution of the cherty mudstone facies indicated that the two basins may have been somewhat restricted until middle Dundee time. Both the basal sandy wackestone and cherty mudstone facies are shown in section C-C′ to pinch out towards the topographic high defined by the Detroit River - Dundee contact (Fig. 7.2). Lower Dundee sands may have been reworked and deposited as relatively thick accumulations at a change in slope defined by the lower formation contact between the two basins. Free mixing of waters between the basins did not occur and transgressive sands were developed to maximium thicknesses on the southern flank of this paleotopographic high in the Appalachian Basin. Thin pulses of reworked sands are also present to the north of this paleotopographic high at the base of the Dundee Formation in the Michigan Basin.

The cherty bioclastic facies was next to be deposited in what was most likely an open shelf environment above storm wave base. This facies is common to both the Michigan and Appalachian basins, however, chert is more abundant in Appalachian than Michigan Basin facies. This distribution of chert further supports the suggestion that there was little mixing of waters between the two basins during early Dundee times. Liberty and Bolton (1971) postulated that seas depositing Dundee strata contained vast quantities of silica

Figure 7.2 Stratigraphic cross section C-C′ showing the Dundee facies relationships between the Appalachian and Michigan Basins. A relative sea level curve developed for the Dundee Formation of southwestern Ontario is also included.




N
SECTION C - C'
Imperial No. 809
Devran # 5
Ram # 77
Leesa Imp. 1-13-I
Cons. / OEC 33796
Allegany No. 33
Rodney 10 - 10
Brett - O
34 km
9 km
12.5 km
1 km
1 km
18 km
4 km
Datum
18
12
6
O metres
RISE
FALL
RELATIVE SEA LEVEL

in gel form. If this were true and if waters were freely mixing between the Michigan and Appalachian basins, the proportions of chert in lower Dundee sediments of the two basins would be similar, contrary to what is observed.

Transgression was interrupted during middle Dundee time and a dysaerobic, lagoonal mudstone facies was deposited in the Appalachian Basin. An episode of relative sea level stillstand is proposed for deposition of this facies. The lack of marine suspension and filter feeding fauna found commonly in bounding facies suggests that restricted conditions were present. The dark brown colour of mudstones, the presence of black, carbonaceous seams and abundant well preserved spore cases further supports a dysaerobic, lagoonal interpretation. Thin pulses of middle shelf bioclastic facies are present within the cherty mudstone facies and possibly represent an interfingering of laterally adjacent facies. The top of this mudstone facies is commonly a well-developed, regionally correlatable firmground. This firmground surface represents a significant episode of non-deposition during middle Dundee time.

The cherty mudstone facies and upper firmground are not present within the Michigan Basin region of the study area. Correlation of strata between the two basins, as discussed in section 6.7, shows that thick, coralliferous grainstone and rudstone pulses present at the base of facies 4 in the

Michigan Basin are possibly correlatable with the cherty mudstone facies. These coarse pulses are interpreted as representing episodes of winnowing and reworking during a relative sea level stillstand. In some instances coral banks or biostromes were developed such as that described from the St. Mary's quarry (Upitis, 1964). Although the cherty mudstone interval is not found in the Michigan Basin, Janssens (1970) has described a light-grey and brown, pelletal, unfossiliferous lithographic limestone which is present near the middle of the Dundee Formation in northwestern Ohio. Janssens interprets this lithographic limestone in northwestern Ohio as being a lime ooze deposited in a protected nearshore environment such as a restricted lagoon. This unit may be equivalent to the cherty mudstone facies described in this study.

The top of the cherty mudstone facies marks a point during Dundee time after which waters were probably freely intermixing between the Michigan and Appalachian basins. A crinoid and brachiopod-rich wackestone facies sharply overlying the lagoonal cherty muds marks renewed transgression and deposition of middle to outer shelf sediments. The shift to deeper water deposition is evidenced by the fact that facies 4 sediments become muddier upwards; there is an absence of chert and fewer bioclastic pulses as compared to underlying facies. In both the Michigan and Appalachian basins, coarse packstone, grainstone and rudstone pulses are found at the base of facies 4. Several lithified horizons and firmgrounds can also be identified near the base of this facies. These coarse pulses, lithified horizons and firmgrounds are locally developed and may have been formed by shallow water processes acting as a result of basinal subsidence and / or due to brief episodes of relative sea level stillstand during renewed transgression. The greater thicknesses of facies in the Appalachian Basin region suggest that the rate of basin subsidence may have been greater there than in the Michigan Basin at this time. A step-like rather than an abrupt and continuous rise in relative sea levels is inferred from the observed vertical distribution of these features within the lowermost few metres of facies 4 (Fig. 7.1).

A number of moderately and well-developed firmgrounds occur in upper facies 4 mudstones and wackestones. Although individual firmgrounds do not appear to be traceable, firmground packages can be correlated (Section 6.6). These discontinuity surfaces formed during episodes of non-deposition and submarine lithification. Transgression of Dundee seas, as suggested for basal facies 4 coarse pulses and diastemic surfaces, may have been interrupted by brief episodes of sea level stillstand such that firmgrounds were able to develop. Well-developed firmgrounds commonly have millimetre-sized, phosphatic bone fragments immediately overlying surfaces and infilling burrows. These firmgrounds may be correlatable with bone beds documented at various intervals in the Delaware Formation of north-central Ohio.

As seas became deeper over the southwestern Ontario area, middle to outer shelf mudstones and wackestones were deposited. This facies is sparsely fossiliferous as compared to underlying facies and bioclastic pulses are essentially absent. Brachiopods and crinoids are the dominant faunal constituents. Beds in this facies are fairly massive, pervasively bioturbated and become more argillaceous upwards. This is consistent with an outer shelf interpretation (Wilson and Jordan, 1983). Firmgrounds are occasionally developed in this facies but are not regionally traceable. These firmgrounds most likely represent diastemic surfaces formed locally under conditions of restricted circulation and non-deposition of sediment. Pyrite is commonly associated with these firmgrounds in upper Dundee strata and indicates restricted conditions.

Uppermost Dundee sediments in the Michigan Basin are dominantly well sorted, crinoidal wackestones and packstones. Thin dark brown, carbonaceous mud seams cap crinoidal wackestone beds and mud-lined subvertical burrows are commonly preserved below these muddy seams. The 'clean', well sorted nature of crinoidal wackestone and packstone beds and the lack of argillaceous material suggests a shallow shoal type depositional environment as compared to upper Dundee facies of the Appalachian Basin. The occurrence of thin dark brown, carbonaceous muddy seams supports a nearshore interpretation for these sediments. Rhoads (1967) suggests that subvertical mud-lined burrows are characteristic of modern, shallow intertidal settings. Thin, tabular stromatoporoids are occasionally found in packstone beds suggesting that stable substrates were present for stromatoporoid growth.

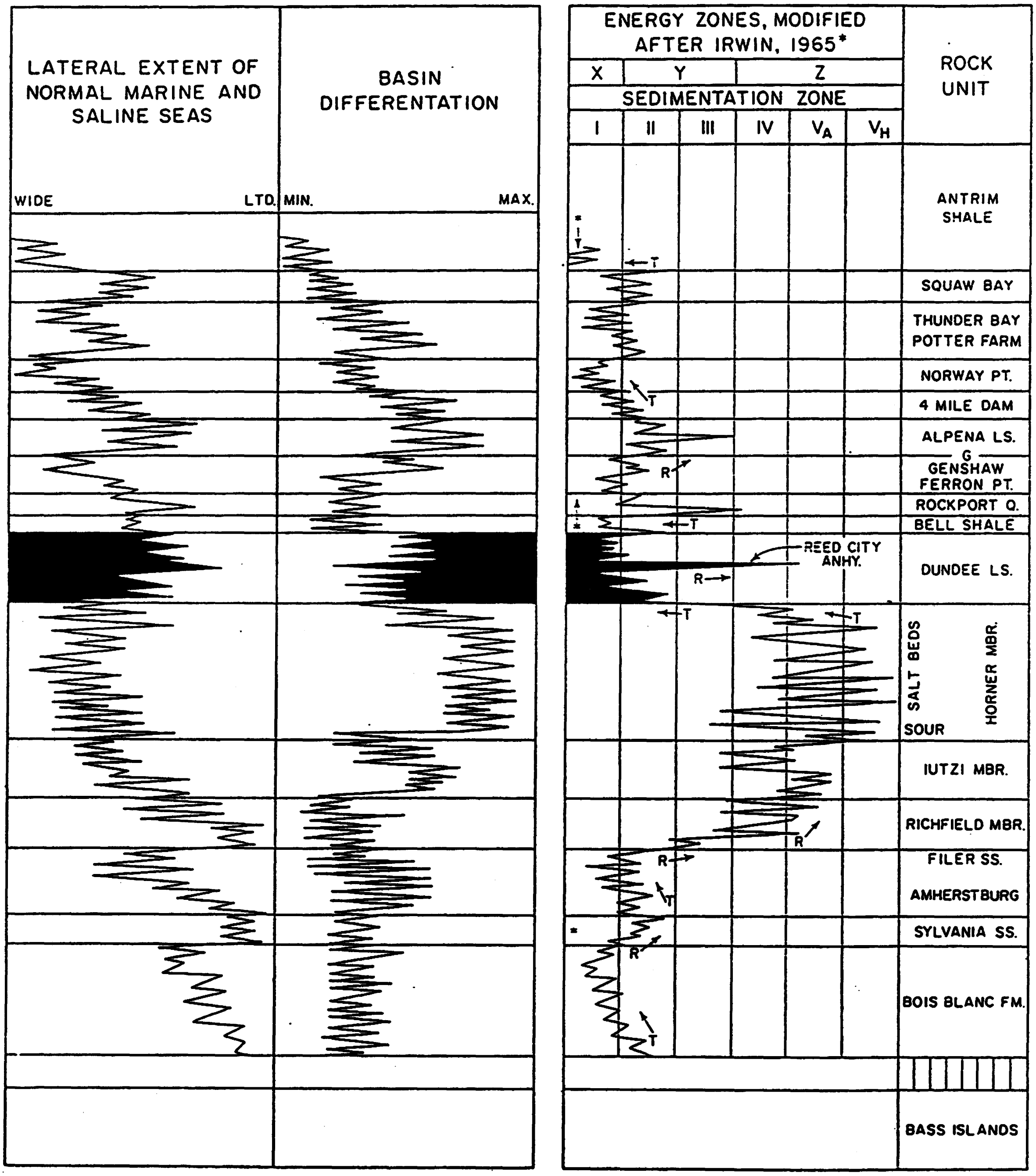
This Michigan Basin facies may have been deposited as transgressive conditions waned. As a result of these changing conditions, shallow crinoidal shoals developed due to episodic winnowing and reworking. Preservation of carbonaceous muddy seams and subvertical mud-lined burrows indicates that episodes of reworking were occasionally interrupted by condition of quieter waters. The increased thickness of facies 6 towards the northwestern part of the study region suggests that maximum shoal development occurred in that area. Several well developed firmgrounds and lithified horizons can be identified immediately below facies 6 sediments in northwesternmost wells of this study area (MOE Deep Obs. #1 and Devran 1-5-6-VII). It has previously been suggested that discontinuity surfaces in Dundee strata may have formed due to decreased sedimentation, reworking and submarine lithification in shallow waters. The firmgrounds and lithified horizons here may have formed similarly on the flanks of a nearby paleotopographic high. No biostromes or bioherms were identified in Dundee cores of this area, however, it is possible that these may occur nearby in the offshore Lake Huron region or in upper Dundee strata of southeastern Michigan.

Facies 6 sediments are not present in the Appalachian Basin. This may be due to the fact that substrates did not penetrate wave base possibly as a result of greater subsidence rates in the Appalachian Basin. Thick, brachiopod-rich, argillaceous pulses are common in upper Dundee facies 5 strata of the Appalachian Basin. These argillaceous beds are similar lithologically to overlying Hamilton shales and appear to be precursors to deep water, Hamilton conditions.

7.3 Regional and global significance of model

Certain models have been proposed which show that sea level fluctuations have significantly influenced deposition of Devonian sediments (Gardner, 1974; Johnson et al, 1985). The depositional model proposed in this study agrees quite well with existing regional and global models. Gardner (1974) has constructed a diagrammatic representation of the transgressive - regressive history for the Devonian of the Michigan Basin based upon regional facies relationships (Fig. 7.3). In Gardner's model, lower Dundee carbonates mark transgressive conditions following maximum differentiation of the Michigan and adjacent basins during Detroit River time . Gardner

Figure 7.3 Diagrammatic representation of the transgressive - regressive history of the Devonian of the Michigan Basin (after Gardner, 1974). Dundee interval shown in black.



X = low energy calcisiltites
Y = high energy skeletal calcarenites
Z = low energy syngenetic dolomites and evaporites
V_A = anhydrite zone; V_H = halite zone

T = transgressive trend of normal marine waters
R = regressive trend of normal marine waters
* Terriginous effects are not included in Irwin's model.

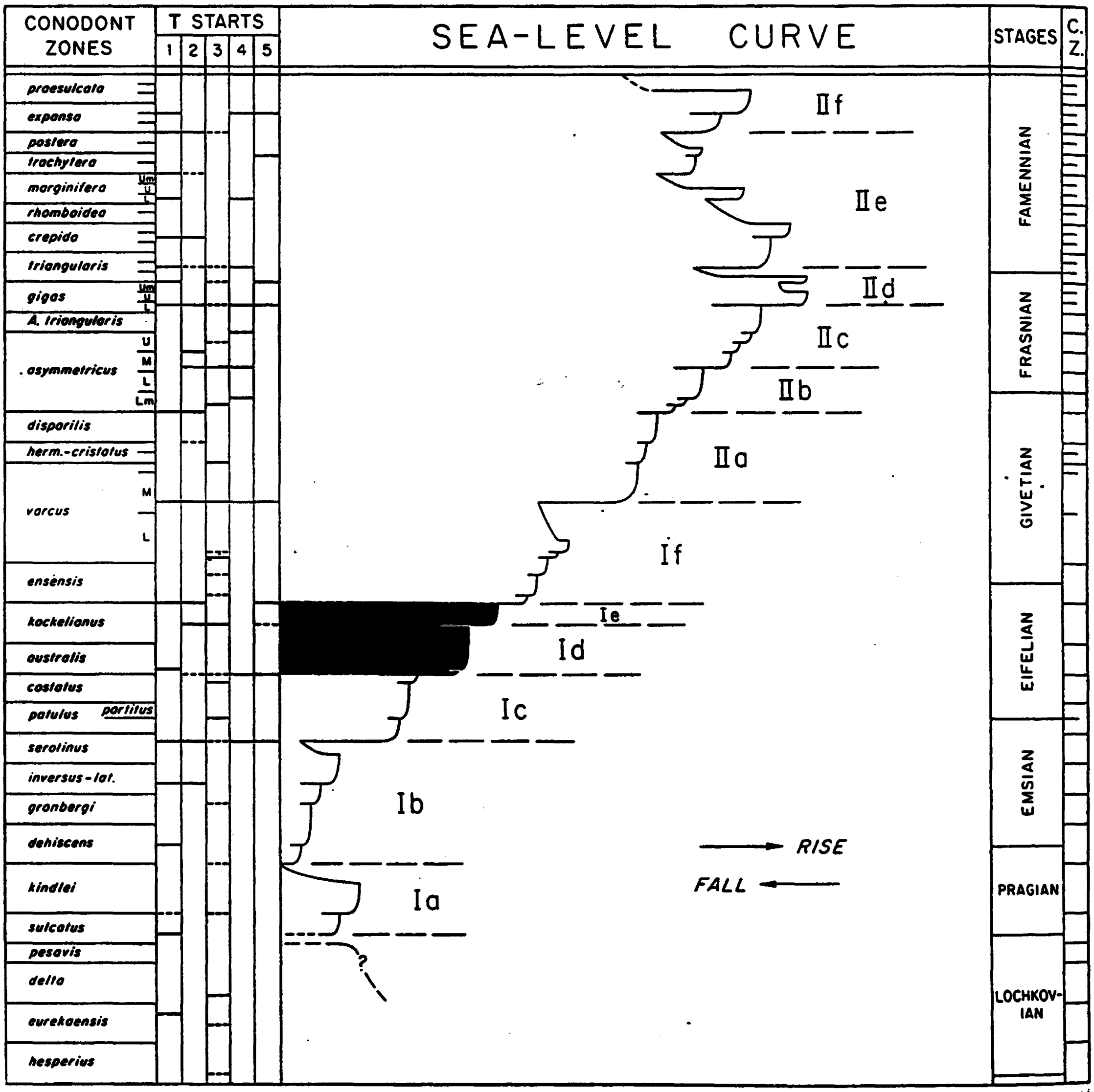
suggests that a regressive episode interrupted transgression during middle Dundee time and is preserved as the regionally traceable Reed City anhydrite. Lilienthal (1978) notes that this unit has been variously interpreted as part of the Dundee limestone or part of the Detroit River Group but places it within his definition of the Dundee Formation, similar to Gardner's designation. Following this regressive episode, Gardner suggests that a final transgressive stage continued to the end of Dundee time. The model described for the Dundee Formation in southwestern Ontario, like Gardner's model, includes an episode of relative sea fall or stillstand during middle Dundee time bounded by episodes of transgression.

Montgomery (1986) has documented facies development in the Buckeye oil field of Michigan. Although the exact stratigraphic relationships of the rocks described by Montgomery to those in southwestern Ontario are not known, a similar depositional interpretation can be envisaged for Dundee sediments there. Coral and stromatoporoid reefs present in middle Dundee strata of the Buckeye oil field are interpreted by Montgomery to have developed due to a lowering of sea level. A subsequent increase in subsidence rate or major sea level rise then caused deeper water, open marine deposition to cover the Buckeye reefs. This interpretation can be easily incorporated into the model of relative sea level changes for middle and upper Dundee strata in southwestern

Ontario.

Johnson et al. (1985) developed a qualitative eustatic curve for the Devonian showing transgressive and regressive cycles and their relationship to conodont zones (Fig. 7.4). This curve is based upon facies relationships at locations in western United States, western Canada, New York state, Belgium and Germany. Based upon conodont zonations defined by Sparling (1983) and Uyeno et al. (1982), the Dundee interval in southwestern Ontario is represented by cycles Id and Ie of Johnson et al. Cycle Ic represents Detroit River Group strata while cycle If represents deposition of Hamilton Group sediments in Ontario. In the Dundee Formation of southwestern Ontario, cycle Id is equivalent to Columbus Formation and lower Dundee sediments. The deepening event marking the end of cycle Id is suggested by Johnson et al to be a possible equivalent of the hiatus between the Columbus and Delaware formations in Ohio. The physical evidence of this hiatus in Ohio is the well known bone bed described at the base of the Delaware Formation (Johnson et al., 1985). It has previously been shown (chapter 6) that this hiatus separating the Columbus and Delaware formations is equivalent to the episode of relative sea level stillstand modelled for middle Dundee sediments in Ontario. This global model for eustatic changes therefore is quite similar to the model proposed here for the Dundee where relative sea level rise is interrupted by

Figure 7.4 Eustatic sea level curve developed for the Devonian of Euramerica (after Johnson et. al., 1985). The Dundee Formation, as determined by conodont zonations, is equivalent to stages Id and Ie of Johnson et al. Dundee interval shown in black.


CONODONT ZONES
T STARTS
1 2 3 4 5
SEA-LEVEL CURVE
STAGES
C. Z.
proesulcata
expansa
postera
trachytera
marginifera
rhomboidea
crepida
triangularis
gigas
A. triangularis
asymmetricus
disparilis
herm.-cristatus
varcus
ensensis
kockelianus
australis
costatus
patulus
partitus
serotinus
inversus-lat.
gronbergi
dehiscens
kindlei
sulcatus
pesavis
delta
eurekaensis
hesperius
IIf
IIe
IId
IIc
IIb
IIa
If
Ie
Id
Ic
Ib
Ia
RISE
FALL
FAMENNIAN
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN
PRAGIAN
LOCHKOV-IAN

stillstand or sea level fall and a subsequent stage of relative sea level rise.

In summary, the depositional model proposed in this study for the Dundee Formation in the southwestern Ontario area agrees quite well with regional and global models. Regionally, this model agrees with Gardner's transgressive - regressive model for the Devonian of the Michigan Basin, however, this is dependent upon placement of the Reed City anhydrite within Dundee strata. Globally, the Dundee model agrees quite well with distinct episodes of eustatic sea level fluctuation. Further work needs to be done regionally on relative sea level changes in Columbus and Dundee strata of Ohio and Michigan to confirm the vertical facies relationships described in this study.

7.4 Economic significance of model

The depositional model proposed here may be extremely useful for exploration and development of reservoirs from Dundee and equivalent sediments in southwestern Ontario and adjacent areas. Although the primary control on many existing Dundee reservoirs in Ontario is structural, significant stratigraphic controls also exist. Proper identification of the Detroit River Group - Dundee Formation contact is, first of all, crucial in order to gain an understanding of the lateral continuity of porous sandstone and dolomitic sandy limestone reservoirs present near the lower Dundee contact.

Massive sandstones and sandy 'reefal' carbonates present in the Anderdon Member of the Detroit River Group must be clearly differentiated from dolomitic sandy limestones which are locally developed at the base of the Dundee Formation in parts of the Appalachian Basin. The disconformable nature of the Detroit River - Dundee contact shows that a paleotopographic high, separating the Michigan and Appalachian basins, developed at the end of Detroit River time. Thick dolomitic sandy limestones of the Dundee Formation accumulated due to the transgressive reworking of underlying sands and sandy limestones. These sediments were deposited on the southern flank of the paleotopographic high within a structural depression defined by the Chatham Sag.

Another important stratigraphic oil-producing interval is the 'bioclastic' unit in upper Dundee strata of the Lambton County area. The model proposed here suggests that this bioclastic facies thickens to the northwest and represents deposition in what may have been a shallow intertidal region adjacent to a reef or well developed shoal. Such a shoal or reef may be present in the offshore Lake Huron region or in southeastern Michigan. Application of this model, which incorporates relative and eustatic sea level changes for the Dundee Formation in southwestern Ontario, will hopefully aid in developing depositional models for adjacent regions and help to correlate similar stratigraphic units.

Finally, this model documents the significance of discontinuity surfaces in marine carbonates which have been interpreted as being deposited in shallow epeiric Dundee seas. Firmgrounds were found to have developed proximal to offshore highs with the greatest degree of development occurring near the crests of these structures. Several of these surfaces occur within a thin vertical interval and these firmgrounds commonly have indurated surfaces. 'Packages' of firmgrounds adjacent to these offshore highs have been correlated over a distance of several tens of kilometres. These characteristics of ancient firmgrounds are similar to those documented for modern regionally traceable cemented surfaces from the Persian Gulf (Shinn, 1969). The significance of these packages of indurated surfaces is that they may be vertical permeability barriers to fluid flow. Identification of firmgrounds as vertical permeability barriers may help in better understanding the characteristics of existing Dundee reservoirs and reservoirs in carbonates deposited similarly in other shallow epeiric seas.

CHAPTER 8 - CONCLUSIONS

1. Detroit River carbonates were exposed subaerially near the topographically high Algonquin and Findlay arches. Dundee sediments, in southwestern Ontario, were disconformably laid over the Detroit River during subsequent Middle Devonian transgression.

2. In parts of the Appalachian Basin, Dundee carbonates conformably overlie dolomitic limestones of the Columbus Formation. The term Columbus Formation, as used by American geologists, should be adopted in Canada to describe those rocks cropping out on Pelee Island and subcropping in the subsurface of parts of western Lake Erie, Essex and Kent counties. The lithology and fauna of Columbus Formation facies , in these areas, are distinctly different from those within facies of the Dundee Formation.

3. Millimetre-sized calcitic microfossils identified as charophyte reproductive bodies (Moellerina greenei?) are common to abundant in upper Columbus Formation carbonates but are essentially absent in the overlying Dundee Formation. A thin unit of abundant Moellerina in upper Columbus facies in southwestern Ontario may be correlatable with the Moellerina greenei biostratigraphic Zone of Kentucky, Indiana and Ohio.

4. Six facies were identified in the Dundee Formation based upon lithological and biological characteristics:

Facies 1: Dolomitic sandy wackestones

Facies 2: Cherty bioclastic facies

Facies 3: Cherty mudstones

Facies 4: Crinoid-brachiopod firmground facies

Facies 5: Argillaceous, brachiopod-rich mudstones and wackestones

Facies 6: Muddy, bioturbated wackestones and packstones. Facies 1 and 3 are restricted to the Appalachian Basin while facies 6 is found only in the Michigan Basin.

5. Where Columbus Formation facies are not present, the most complete Dundee facies sequence observed includes facies 1 overlain by facies 2, 3, 4 and 5. In the Michigan Basin, facies 2 is gradationally overlain by facies 4, 5 and 6. These sequences represent an overall transgression which was interrupted by episodes of relative sea level stillstand during middle Dundee time.

6. Two types of discontinuity surfaces have been identified in Dundee carbonates: 1) lithified horizons and 2) firmgrounds. Firmgrounds commonly have irregular, pyritized and / or dolomitized upper surfaces with thin, vertical burrows penetrating to a depth of several centimetres. These firmgrounds occur in "packages" with two to three surfaces occurring within a small vertical interval. Firmgrounds are excellent markers in middle Dundee strata and represent significant episodes of non-deposition. These discontinuity

surfaces may be correlatable with distinctive bone beds documented from Dundee-equivalent sediments in parts of Ohio.

8. Stratigraphic cross sections constructed using firmgrounds and facies as local and regional datum planes show that certain discontinuity surfaces may be traced for distances up to 110 kilometres. Packages of firmgrounds may be correlated over several tens of kilometres and appear to have developed adjacent to paleotopographic highs developed at the Detroit River - Dundee contact. Well-developed surfaces occur near the crests of these highs with the degree of development and number of firmgrounds in a "package" decreasing with increased depth. These characteristics of firmground distribution in Dundee strata are similar to those described for modern submarine-cemented surfaces in areas of the Persian Gulf.

9. Dundee facies relationships suggest that lower Dundee sediments represent time-transgressive deposition. Episodes of relative sea level stillstand are preserved in middle Dundee strata as reworked packstone and grainstone pulses, lagoonal muds and discontinuity surfaces. Middle and upper Dundee facies better represent a time-stratigraphic deposition with renewed transgression following the episode of relative sea level stillstand.

10. The depositional model, incorporating relative sea level changes, developed for the Dundee Formation of

southwestern Ontario is similar to a model proposed for the Dundee of the Michigan Basin. The relative sea level changes which explain Dundee facies relationships can also be correlated in part with eustatic sea level changes proposed for this part of the Devonian.

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Appendix I

List of subsurface cores logged in detail for this study. Cores examined for this study that were not logged are listed in a core index published by the Ministry of Natural Resources (Carter and Trevail, 1989). Core number refers to the catalogue number given by the MNR.

Well Name	Lot	Conc.	Core #	Depth Logged (metres)
Elgin County				
Aldborough Township				
Rodney 1-16	5	IV	911	128.9 - 124.0
Rodney 6-15	5	V	912	123.2 - 119.0
Rodney 5-29	5	V	866	120.1 - 111.1
Rodney 10-10	5	VI	865	131.4 - 122.3
Brett - Onaco	9	Gore	299	146.6 - 120.7
Cons./ OEC 33833	16	XII	892	107.3 - 93.6
Cons./ OEC 33828	17	XII	893	107.4 - 98.4
Cons./ OEC 33831	17	XIII	906	109.6 - 100.2
Dunwich Township				
Imper. Bluewater #904	21	II	166	87.5 - 78.9
I.O.E Felmont	5	VIII	443	166.4 - 141.4
Yarmouth Township				
OGS 82-3	9	I	861	137.8 - 98.1
Essex County				
Anderdon Township				
Lucas #3	4	VIII	881	29.3 - 7.6

Well Name	Lot	Conc.	Core #	Depth Logged (metres)
Colchester South Township				
Lucas #2	11	V	882	29.6 - 15.8
Mersea Township				
Lucas #1	6	IV	883	32.1 - 20.0
<u>Kent County</u>				
Harwich Township				
OGS 82-2	25	IECR	860	164.8 - 108
Raleigh Township				
Stevenson #2	1	I	872	77.7 - 55.8
Putnam Sterling #1	23	IVEB	828	123.1 - 118.9 82.0 - 76.2
Putnam Bedosti #1	25	VIII	827	123.7 - 111.6
Tilbury East Township				
Consumers 33407	1	IX	759	93.7 - 82.5
Consumers 33409	4	IX	751	122.6 - 91.6
Consumers 33408A	2	X	772	126.9 - 94.
<u>Lambton County</u>				
Brooke Township				
Leesa-Imperial	13	I	546	114 - 99.4
Ram #77	24	X	880	127.7 - 100.5
Dawn Township				
Leesa-Imperial	18	XIII	559	103.6 - 73.2
Leesa 19-XIII	19	XIII	383	103.6 - 73.2

Well Name	Lot	Conc.	Core #	Depth Logged (metres)
Leesa Imperial	27	XIII	590	126.5 - 107.3
Moore Township				
Imperial #840	3	X	602	151.8 - 116.4
Plympton Township				
Imperial #835	6	II	155	163.1 - 129.2
Sarnia Township				
MOE Deep Obs. #1	12	R4	954	186.1 - 143.2
Devran 3-2-3-VI	3	VI	871	140.0 - 104
Devran 1-5-6-VII	6	VII	878	143.8 - 108.5
Warwick Township				
Devran #5	26	VSER	941	138.7 - 113.4
Middlesex County				
McGillivray Township				
Imperial #809	5	XIX	220	53 - 37.9
Mosa Township				
Cons./ OEC 33796	6	V	949	115.5 - 107.0 96.6 - 93.8
Dominion Petroleum - Stanley Gillies No. 10	7	V	282	115.3 - 102.5
Mitchell #3	7	V	358	122.8 - 113.1
Allegany #33	6	VI	256	114 - 94.5
Walker 502	6	VI	895	114.6 - 102.1
Secord 601	6	VI	894	113.4 - 98.1
Dominion Petroleum - J.A. Walker No. 19	6	VI	260	115.5 - 98.1

Well Name	Lot	Conc.	Core #	Depth Logged (metres)
Sloan and Zook - N. Gillies No. 10	7	VI	281	114 - 98.1
<u>Norfolk County</u>				
Charlotteville Township				
U.S. Steel DDH #1	21	I	100	91.4 - 54.9
<u>Lake Erie</u>				
CT-1	234-M		117	65.1 - 32.6
CT-5	234-R		118	70.4 - 44.5
CT-8	234-N		127	84.7 - 46.3
CT-9	234-M		135	65.8 - 39.6
CT-14	233-L		128	88.7 - 51.8
CT-15	233-S		133	91.4 - 54.9