DOLOMITE WITHIN THE ST. GEORGE GROUP (LOWER ORDOVICIAN), WESTERN NEWFOUNDLAND

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DOLOMITE WITHIN THE ST. GEORGE GROUP (LOWER ORDOVICIAN), WESTERN NEWFOUNDLAND

by

© Douglas Wayne Haywick, B.Sc.

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FRONTISPIECE: Cathodoluminescence photomicrograph of a metamorphosed dolostone from the Curling Group (Cambrian to Middle Ordovician) of western Newfoundland. These rocks are composed of brecciated brightly luminescing dolomite annealed by weakly luminescent (dark) dolomite. The brecciation and the annealing processes are probably a result of the metamorphism. A weakly luminescent calcite fracture (yellow) runs the length of the photograph. Field of view, 1 centimetre by 0.75 centimetres.

ABSTRACT

Seven varieties of dolomite and dolostone, the products of four stages of dolomitization, are recognized within the St. George Group (Lower Ordovician) of western Newfoundland.

Dololaminites are syngenetic, formed in a tidal flat environment, characterized by prominent shallow water sedimentary structures, local bioturbation, $\delta^{18}O$ values of -4 to -8 o/oo and composed of anhedral, very finely crystalline, uniformly luminescent dolomite rhombs. Siliciclastic minerals are subordinate.

Early-diagenetic (eogenetic) dolomitization, possibly initiated by the presence of mucopolysaccharides and controlled spatially by permeability, has resulted in three varieties of dolomite and dolostone. $\delta^{18}O$ values range between -4 and -10 o/oo. Mottle dolomite selectively replaces body and trace fossils and is localized along pressure solution seams. Rhombs of matrix dolomite are evenly distributed in mudstones and wackestones and range in abundance from trace quantities to 80 percent. Both varieties are characterized by finely crystalline, well zoned, idiotopic to xenotopic dolomite. Though initially nucleated during early- diagenesis, they have undergone a prolonged period of growth continuing at least until the onset of pressure solution.

Pervasive A dolostones are mottled rocks characterized by bimodal crystallinity; finely crystalline dolomite in mottles, medium crystalline dolomite between mottles. Both are xenotopic and uniformly luminescent to moderately zoned. These rocks are coincident with early phases of mottle/matrix dolomitization and may have developed due to the mixing of meteoric and marine waters. They have not been subjected to late-diagenetic periods of growth.

Hydrothermal alteration, probably related to tectonics during initial phases of the Taconic Orogeny (Middle Ordovician), is a late-diagenetic (mesogenetic) event and in the northern portion of the study area (Great Northern Peninsula), has developed two extensive field varieties. Pervasive B dolostones are bimodal rocks resulting from overprinting of a dolomite-mottled limestone. Saddle dolomite is a void and fracture filling cement and is associated with sphalerite mineralization near Daniel's Harbour, Newfoundland. Both varieties are composed of coarsely crystalline, uniformly luminescent and strained dolomite rhombs (commonly with curved crystal outlines), and are characterized by $\delta^{18}O$ values ranging from -8 to -12 o/oo.

Hydrothermal dolomitization in the southern portion of the study area (Port au Port Peninsula) is rare. This variety of matrix dolomite is restricted to the intergranular (matrix) areas of wackestones and packstones.

It is similar both petrographically and isotopically to saddle dolomite.

<u>Cavity-filling dolostone</u> has filled dissolution voids in pre-existing dolostones formed during periods of subaerial exposure and is characterized by $\delta^{18}O$ values ranging from -6 to -9 o/oo. The dolomite is very finely crystalline, uniformly luminescent and anhedral. Accessory minerals are diverse and abundant.

KEYWORDS: St. George Group, Lower Ordovician, western Newfoundland, dolomite, dolomitization, diagenesis, isotope geochemistry, cathodoluminescence, petrography.

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Last (and definitely least), I would like to thank my fellow students along "DECADENCE ALLEY". You made my stay in Newfoundland memorable and opened my eyes to an entirely new aspect of literature: cartoons.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF PLATES

LIST OF PLATES (CONTINUED)

CHAPTER ONE

INTRODUCTION

1.1 PURPOSE:

The St. George Group is a sequence of shallow water carbonate rocks deposited during Early Ordovician time along the western continental margin of the Proto-Atlantic (Iapetus) Ocean (Levesque, 1977, Williams, 1978, Pratt, 1979, James and Stevens, 1982, Pratt and James, in press).

Over the past several years these rocks have been the subject of many studies, with emphasis on their sedimentology and stratigraphy (Levesque, 1977, Knight, 1977a,b, 1978a,b, 1980, Pratt, 1979, Pratt and James, in press), economic potential, (Cumming, 1968), conodont biostratigraphy (Barnes and Tuke, 1970, Fahraeus, 1970, 1977, Stouge, 1980, 1982) and palaeontology (Flower, 1978, Fortey, 1979, Boyce, 1979, Stouge and Boyce, 1983). Little is known, however, about the dolomite and dolostone which accounts for approximately one third of the St. George Group.

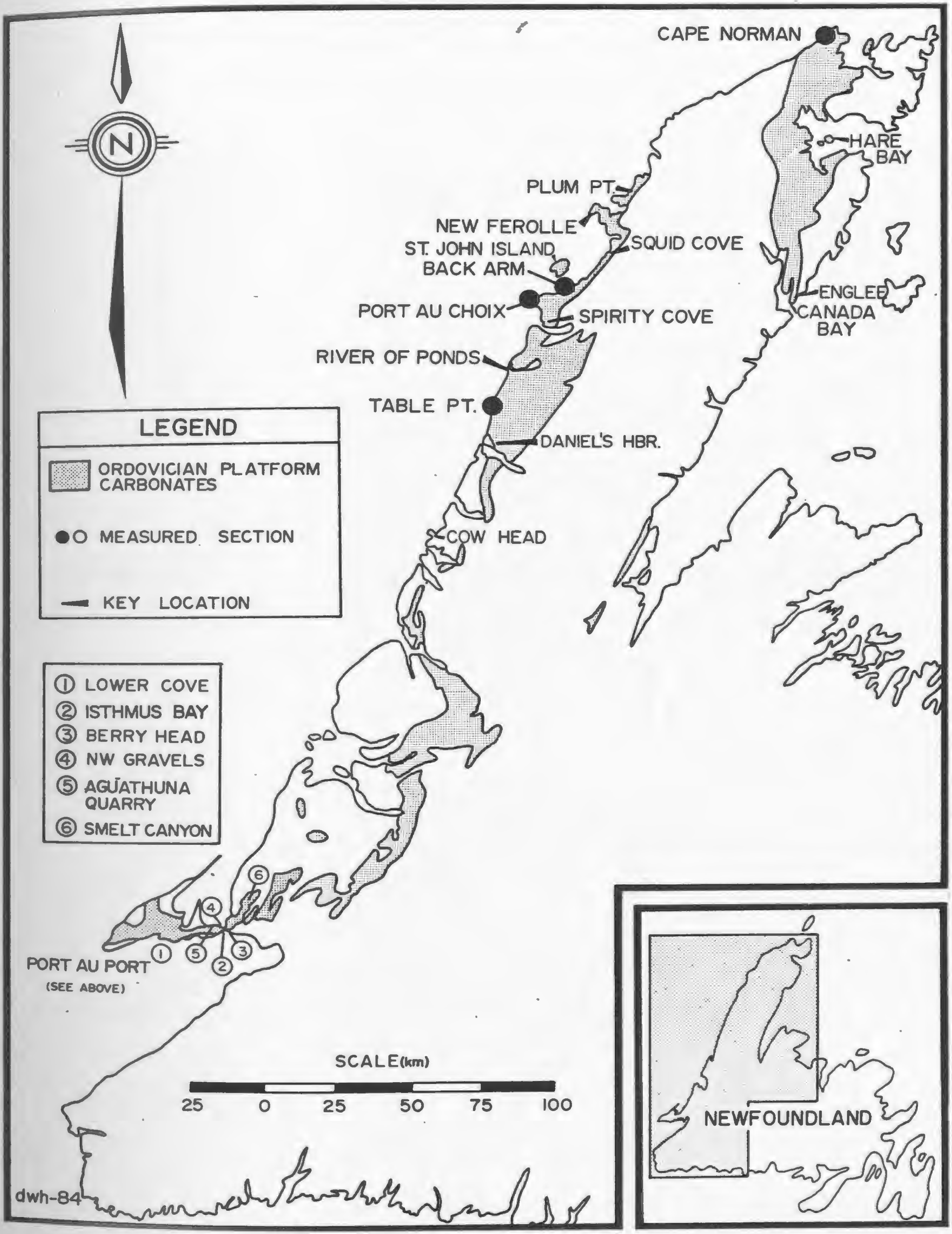
The main goal of this study is to classify and characterize the different varieties of dolomite and dolostone in the St. George Group, by integrating detailed field study with petrographic and geochemical analyses. The stratigraphic and geographic distributions of the different varieties, as well as their paragenetic succession will be determined and suggestions for possible mechanisms of dolomitization will be offered.

1.2 LOCATION AND METHODS:

This study is concentrated along the west coast of Newfoundland where the sedimentology, stratigraphy and palaeontology of the St. George Group have previously been documented (Levesque, 1977, Knight, 1977b, 1980, Pratt, 1979, Smyth, 1982a,b,c, Pratt and James, in press.). Ten stratigraphic sections were studied during the summer of 1983; six in the vicinity of the Port au Port Peninsula and four along the west coast of the Great Northern Peninsula (figure 1.1). In addition, several "key locations" which contained interesting dolomite relationships, but where sections could not be measured because of uncertainty in the stratigraphic position of the outcrop, were also studied. These other locations include; Daniel's Harbour, Plum Point, River of Ponds, Spirity Cove, New Ferolle, Squid Cove, Canada Bay and Hare Bay (figure 1.1). Taken together, the measured sections and the key locations cover all known aspects of stratigraphy, sedimentology and dolomitization found within the St. George.

Each of the ten sections was measured by a combination of range pole and steel tape. Detailed descriptions of colour, grain size, lithology, sedimentary structures and macro-palaeontology were made in the field

FIGURE 1.1: Map of the study area indicating the distribution of Lower Ordovician platform carbonates (St. George Group) and the positions of measured sections or key locations discussed in the text.


CAPE NORMAN
HARE BAY
PLUM PT.
NEW FEROLLE
SQUID COVE
ST. JOHN ISLAND
BACK ARM
PORT AU CHOIX
SPIRITY COVE
ENGLEE
CANADA BAY
RIVER OF PONDS
TABLE PT.
DANIEL'S HBR.
COW HEAD
LEGEND
ORDOVICIAN PLATFORM CARBONATES
MEASURED SECTION
KEY LOCATION
① LOWER COVE
② ISTHMUS BAY
③ BERRY HEAD
④ NW GRAVELS
⑤ AGUATHUNA QUARRY
⑥ SMELT CANYON
PORT AU PORT
(SEE ABOVE)
SCALE(km)
25 0 25 50 75 100
NEWFOUNDLAND
dwh-84

for all lithologies (refer to appendix A). The classification scheme of Dunham (1962) was employed to describe the limestones.

Particular emphasis was placed upon the description of dolomite and dolostone. In addition to the characteristics outlined previously, the crystal size, localization, fabric preservation and the amount of dolomite (visually estimated) within each litho-stratigraphic unit were also noted.

Approximately 450 samples were collected from the ten measured sections and key locations and 375 polished thin sections were made from these samples. All thin sections were stained with a combination of Alizarian Red-S to differentiate calcite and dolomite, and potassium ferricyanide to qualitatively estimate iron content. One hundred and forty five thin sections were re-polished and examined by cathodoluminoscope. These analyses were supplemented with electron microprobe data.

Selective dolomite and dolostone samples were processed for X-ray diffraction analysis to identify the insoluble non-carbonate fraction and to characterize the host carbonate. Scanning electron microscopy was also used to characterize the different varieties of dolomite and dolostone.

Carbon - oxygen stable isotope analysis was performed on 50 representative limestone, dolomite and dolostone samples. Duplicates of these samples were analysed by atomic absorption to determine Sr^{2+} concentrations.

1.3 REGIONAL SETTING:

The island of Newfoundland, which marks the northern terminus of the North American Appalachians, has been divided into four tectono-lithographic zones by Williams (1978, 1979). From west to east, these are the Humber, the Dunnage, the Gander and the Avalon (figure 1.2).

The St. George Group is wholly confined within the Humber zone, which is interpreted as the ancient continental margin of the Proto-Atlantic Ocean.

Sedimentation within the Humber zone began during Early Cambrian time following rifting of Grenvillian aged basement (ca. 1.0 billion years; Williams and Stevens, 1974, James and Stevens, 1982). Rift facies clastics pass upward into clastic shelf deposits of the Labrador Group and then into the predominantly carbonate deposits of the Middle - Upper Cambrian Port au Port Group (figure 1.3). Apart from a few minor? breaks, this stable carbonate shelf sedimentation continued through Early Ordovician time (St. George deposition) and into Early Middle Ordovician time (Table Head deposition) (James and Stevens, 1982). The lower portion of the Table Head passes upward into deep water carbonates, shales and finally flysch recording the collapse of the stable continental margin (Klappa et al.,

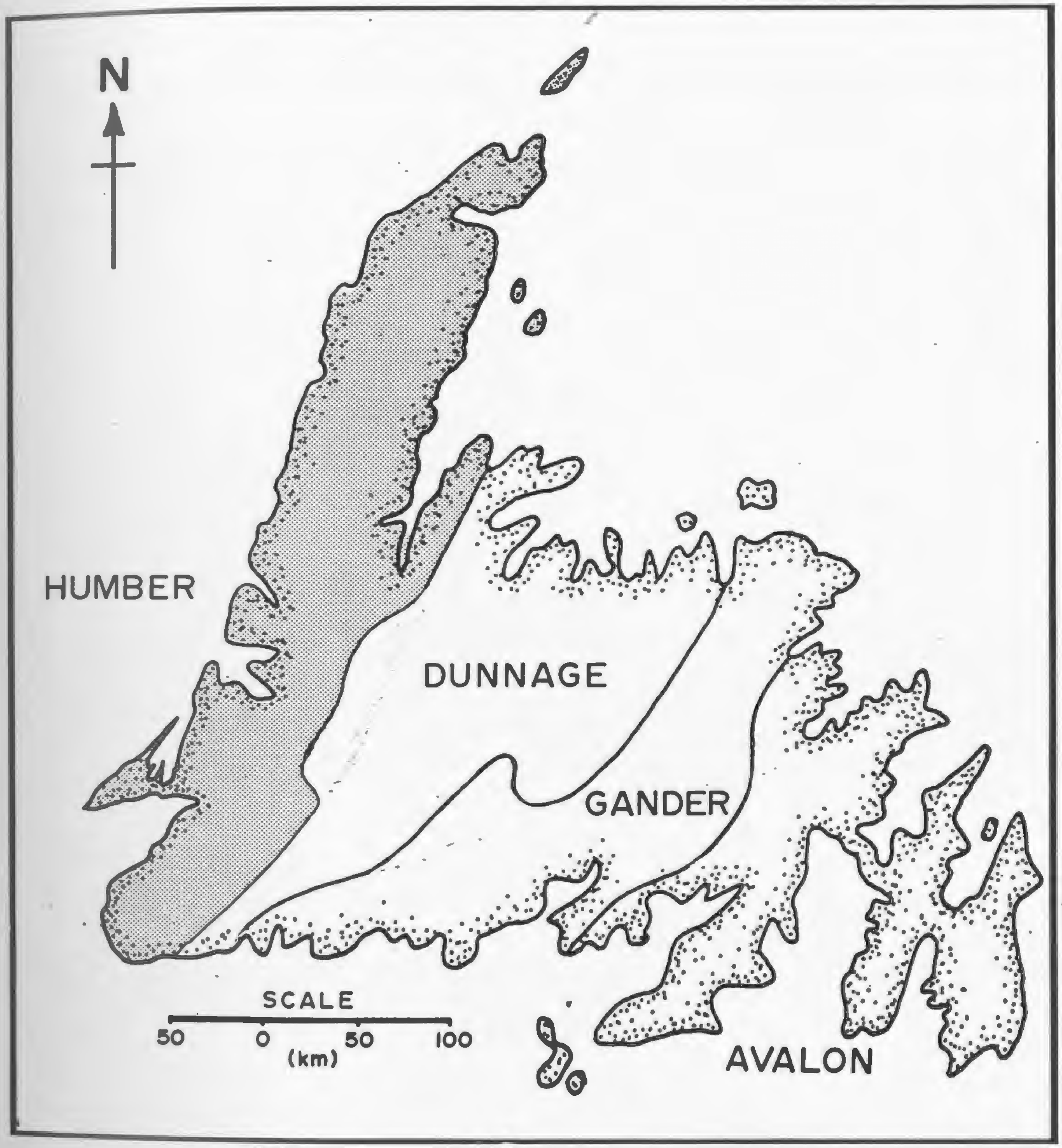
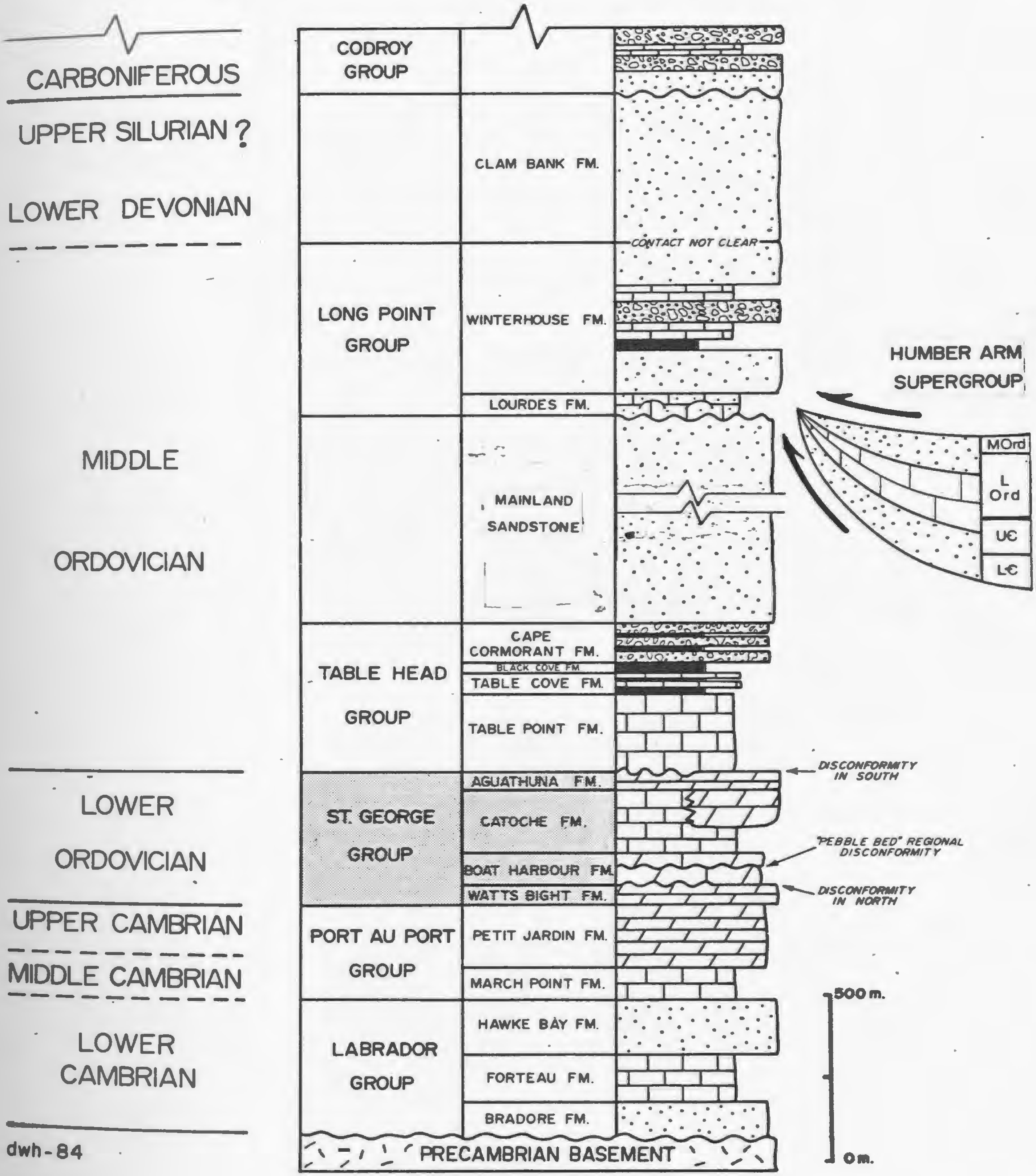


FIGURE 1.2: Tectono-stratigraphic zones of Newfoundland. The St. George Group is localized within the Humber Zone (stippled) (After Williams, 1979).

FIGURE 1.3: Authochthonoous stratigraphy of the Humber Zone. The position of the St. George Group is indicated by the stippled pattern. Important disconformities within the St. George are also identified (modified from Knight, 1977b, James and Stevens, 1982 and Lane, 1984). Allochthonous sediments of the Humber Arm Supergroup were emplaced during the Middle Ordovician.


CARBONIFEROUS
UPPER SILURIAN ?
LOWER DEVONIAN
MIDDLE
ORDOVICIAN
LOWER
ORDOVICIAN
UPPER CAMBRIAN
MIDDLE CAMBRIAN
LOWER
CAMBRIAN
CODROY GROUP
CLAM BANK FM.
CONTACT NOT CLEAR
LONG POINT GROUP
WINTERHOUSE FM.
LOURDES FM.
MAINLAND SANDSTONE
TABLE HEAD GROUP
CAPE CORMORANT FM.
BLACK COVE FM
TABLE COVE FM.
TABLE POINT FM.
ST. GEORGE GROUP
AGUATHUNA FM.
CATOCHE FM.
BOAT HARBOUR FM.
WATTS BIGHT FM.
PORT AU PORT GROUP
PETIT JARDIN FM.
MARCH POINT FM.
LABRADOR GROUP
HAWKE BAY FM.
FORTEAU FM.
BRADORE FM.
PRECAMBRIAN BASEMENT
HUMBER ARM SUPERGROUP
MOrd
L Ord
UC
LC
DISCONFORMITY IN SOUTH
"PEBBLE BED" REGIONAL DISCONFORMITY
DISCONFORMITY IN NORTH
500 m.
0 m.
dwh-84

1980). Subsidence proceeded emplacement of allochthonous strata (Humber Arm Supergroup) derived from the east and transported westward (Williams, 1978, James and Stevens, 1982; figure 1.3).

In the Port au Port region (figure 1.1), these allochthonous strata are overlain by the neoallochthonous upper Middle Ordovician Long Point Group, by the Upper Silurian? - Devonian Clam Bank Formation and the Carboniferous Codroy Group (James and Stevens, 1982, Dix, 1982; figure 1.3).

CHAPTER TWO

STRATIGRAPHIC AND SEDIMENTOLOGICAL FRAMEWORK

2.1 PREVIOUS WORK:

Carbonate rocks which crop out along the west coast of Newfoundland have been studied regularly since the initial stratigraphic investigation carried out in 1861 by Sir James Richardson (published in Logan, 1863). Since that time, numerous studies involving some aspect of the Lower Ordovician carbonates, (or carbonates that would later be assigned an Early Ordovician age), have been published. Those of interest to this study are summarized briefly in table 2.1.

Many of the previous studies summarized in table 2.1 were primarily concerned with fitting these rocks into a stratigraphic framework. The name St. George has been retained since its initial usage by Schuchert and Dunbar (1934), but at various times, the St. George carbonates have been assigned formational status (Kindle and Whittington, 1965, Whittington and Kindle, 1966, Smit, 1971, Collins and Smith, 1975, Levesque, 1977), or group status (Sullivan, 1940, Besaw, 1972, 1973, 1974, Knight, 1977b, Pratt and James, in press.). The most recent reassessment of stratigraphic nomenclature, and the scheme that shall be used in this study, is that proposed by Knight and James (in prep.). They assign Group status to

TABLE 2.1: Summary of major previous studies concentrating on the St. George Group.

PUBLICATION	SUMMARY OR IMPORTANT CONCLUSIONS
JUKES (1842)	FIRST PERSON TO EXAMINE THE GEOLOGY OF WESTERN NEWFOUNDLAND.
RICHARDSON (1861) (IN LOGAN, 1863)	FIRST COMPREHENSIVE STUDY OF THE STRATIGRAPHY OF THE WEST COAST OF NEWFOUNDLAND DESCRIBED AND NAMED THE POTSDAM GROUP (UNITS A TO C), AND THE QUEBEC GROUP (UNITS D TO R). MISTAKENLY IDENTIFIED CAMBRO-ORDOVICIAN STRATA AS LOWER SILURIAN IN AGE.
MURRAY (1866)	EXAMINED SIMILAR CARBONATES IN CANADA BAY AND HARE BAY (GREAT NORTHERN PENINSULA) ASSIGNING THEM EARLY ORDOVICIAN (LLANDEILO) AGE.
SCHUCHERT & DUNBAR (1934)	REDEFINED MUCH OF CAMBRO-ORDOVICIAN STRATIGRAPHY. RE-ASSIGNED RICHARDSON'S (1861) POTSDAM GROUP TO THE UPPER CAMBRIAN LABRADOR SERIES; DIVISIONS D TO I OF THE QUEBEC GROUP TO THE LOWER ORDOVICIAN ST. GEORGE SERIES, DIVISIONS K TO N TO THE TABLE HEAD SERIES; DIVISION O TO THE LONG POINT SERIES; DIVISION P TO THE COW HEAD GROUP AND DIVISION Q TO THE GREEN POINT AND HUMBER SERIES (ALL MIDDLE ORDOVICIAN). PLACED THE TYPE SECTION OF THE ST. GEORGE SERIES AT THE GRAVELS ON THE PORT AU PORT PENINSULA. SUGGESTED THAT THE ST. GEORGE-TABLE HEAD CONTACT WAS UNCONFORMABLE.
COOPER (1937)	EXAMINED THE HARE BAY AREA (GREAT NORTHERN PENINSULA) RECOGNIZING THREE LIMESTONE UNITS. THE SOUTHERN ARM AND BRENT ISLAND LIMESTONES ARE CORRELATIVE WITH THE ST. GEORGE SERIES; THE HARE ISLAND LIMESTONE IS CORRELATIVE WITH THE MIDDLE ORDOVICIAN TABLE HEAD SERIES.
BETZ (1939)	EXAMINED CAMBRO-ORDOVICIAN CARBONATE OUTCROPS IN THE CANADA BAY AREA AND IN SO DOING, DEFINED FOUR NEW UNITS. THE CHIMNEY ARM FORMATION WAS CORRELATIVE WITH THE ST. GEORGE SERIES; THE REMAINING THREE WERE CORRELATIVE WITH CAMBRIAN OR MIDDLE ORDOVICIAN STRATA.
SULLIVAN (1940)	STUDIED THE GEOLOGY OF THE PORT AU PORT AREA AND ASSIGNED THE ST. GEORGE GROUP STATUS. SUGGESTED THAT THE ST. GEORGE WAS IN FAULT CONTACT WITH THE UNDERLYING CAMBRIAN ROCKS AND THAT SUBSTANTIAL FAULTING HAD AFFECTED SCHUCHERT AND DUNBAR'S (1934) TYPE SECTION OF THE ST. GEORGE.
TROELSON (1947)	EXAMINED THE BONNE BAY AREA AND DIVIDED THE ST. GEORGE INTO FIVE NUMBERED UNITS. SUGGESTED THAT THE BASAL PORTION WAS CAMBRIAN IN AGE.
JOHNSON (1949)	PRODUCED A REGIONAL DESCRIPTION OF THE ST. GEORGE GROUP. DISCOUNTED SULLIVAN'S (1940) SUGGESTION THAT THE CAMBRIAN AND ORDOVICIAN WERE IN FAULT CONTACT ON THE PORT AU PORT PENINSULA.
WALTHIER (1947, 1949)	PROPOSED THAT THE BASAL UNITS OF THE ST. GEORGE WERE EQUIVALENT TO QUARTZITES FOUND WITHIN UPPER CAMBRIAN STRATA.
OXLEY (1953)	MAPPED THE GEOLOGY OF THE PARSON'S POND - ST. PAUL'S AREA ON THE GREAT NORTHERN PENINSULA FOCUSING MOSTLY ON ORDOVICIAN STRATA.
JOHNSON (1954)	STUDIED STRONTIUM ORE DEPOSITS LOCALIZED IN PRE-CARBONIFEROUS TOPOGRAPHIC LOWS WITHIN ST. GEORGE STRATA IN THE PORT AU PORT AREA.
NELSON (1955)	MAPPED THE GEOLOGY OF THE PORTLAND CREEK-PORT SAUNDERS AREA (INCLUDES ST. GEORGE ROCKS) OF THE GREAT NORTHERN PENINSULA.
WOOD ARD (1957)	DESCRIBED THE "RECRYSTALLIZED" DOLOSTONES OF THE ST. GEORGE GROUP FROM THE PORT AU CHOIX - CASTOR RIVER AREA OF THE GREAT NORTHERN PENINSULA.
LILLY (1961)	STUDIED THE HUMBER GORGE AND GOOSE ARM AREAS OF WESTERN NEWFOUNDLAND AND SUBDIVIDED THE ST. GEORGE GROUP INTO THE HUGHES BROOK AND CORNER BROOK FORMATIONS. FIRST (PUBLISHED) DETAILED PETROGRAPHIC AND GEOCHEMICAL ANALYSES PERFORMED ON ST. GEORGE DOLOMITES AND DOLOSTONES.
RILEY (1962)	STUDIED THE STEPHENVILLE MAP AREA (PORT AU PORT PENINSULA). REPORTED PREVIOUSLY UNPUBLISHED DATA AND WAS THE FIRST PUBLISHED STUDY DISCUSSING MAGNETIC ANOMOLIES DETERMINED FROM AN AEROMAGNETIC SURVEY.
KINDLE & WHITTINGTON (1965) WHITTINGTON & KINDLE (1966)	REDUCED THE ST. GEORGE TO FORMATIONAL STATUS. DISCOVERED CAMBRIAN TRILOBITES IN STRATA PREVIOUSLY INTERPRETED AS LOWER ORDOVICIAN IN AGE BY SCHUCHERT AND DUNBAR (1934).
CUMMING (1967)	DISCOVERED AN EROSIONAL CHANNEL CUT INTO DOLOSTONES AT THE ST. GEORGE-TABLE HEAD CONTACT AT AGUATHUNA QUARRY ON THE PORT AU PORT PENINSULA. THIS CONFIRMED SCHUCHERT AND DUNBAR'S BELIEF THAT THE CONTACT WAS UNCONFORMABLE AT THIS LOCALITY.
CUMMING (1968)	DISCUSSED THE ROLE OF THE ST. GEORGE-TABLE HEAD UNCONFORMITY ON SPHALERITE MINERALIZATION IN THE DANIEL'S HARBOUR AREA OF THE GREAT NORTHERN PENINSULA.
TUKE (1968)	EXAMINED TWO PACKAGES OF CAMBRO-ORDOVICIAN ROCKS IN THE PISTOLET BAY AREA (NEAR THE NORTHERN TERMINUS OF THE GREAT NORTHERN PENINSULA). THE FIRST PACKAGE, AN AUTOCHTHONOUS SUITE OF CLASTIC AND CARBONATE STRATA, WERE CORRELATIVE WITH THE CAMBRIAN AND LOWER TO MIDDLE ORDOVICIAN (INCLUDES THE ST. GEORGE GROUP). THE SECOND PACKAGE WAS INTERPRETED AS ALLOCHTHONOUS AND IS COMPOSED OF GREYWACKES, VOLCANIC AND ULTRA BASIC ROCKS. DETERMINED THAT THE ST. GEORGE-TABLE HEAD CONTACT WAS CONFORMABLE AT THIS LOCATION.

TABLE 2.1: Continued

PUBLICATION	SUMMARY OR IMPORTANT CONCLUSIONS
BARNES & TUKE (1970)	STUDIED CONODONTS FROM THE ST. GEORGE FORMATION AND ASSIGNED THEM A LOWER ARENIG AGE.
WHITTINGTON & KINDLE (1969)	REDEFINED THE STRATIGRAPHY OF THE CAMBRO-ORDOVICIAN ROCKS IN THE LIGHT OF THEIR TRILOBITE DISCOVERIES MADE SEVERAL YEARS EARLIER.
FÅHRAEUS (1970)	EXAMINED CONODONTS FROM THE ST. GEORGE GROUP AND DETERMINED THAT THEY COULD BE USED TO CORRELATE THE ST. GEORGE WITH BALTO-SCANDIAN EQUIVALENTS.
SMIT (1971) SWETT AND SMIT (1972)	STUDIED THE CAMBRO-ORDOVICIAN CARBONATES WITH RESPECT TO THEIR SEDIMENTOLOGY AND PETROGRAPHY. LATER, (SWETT AND SMIT, 1972), COMPARED THE NEWFOUNDLAND STRATA WITH SIMILAR ROCKS IN NORTHWEST SCOTLAND AND GREENLAND. THEY SUGGEST COMMON DEPOSITIONAL AND DIAGENETIC HISTORIES FOR ALL THESE AREAS.
BESAW (1972, 1973, 1974)	EXAMINED THE PORT AU PORT PENINSULA IN AN ATTEMPT TO LOCATE AND MAP METALLURGICAL GRADE CARBONATE DEPOSITS TO BE USED IN THE STEEL INDUSTRY OF NOVA SCOTIA. REASSIGNED GROUP STATUS TO THE ST. GEORGE CARBONATES. DEFINED FIVE LITHOLOGICAL UNITS TO THE ST. GEORGE GROUP; THE LOWER COVE, PIGEON HEAD, FINE TREE, WHITE HILLS AND PORT AU PORT. THE BASAL LOWER COVE WAS LATER DETERMINED AS CAMBRIAN IN AGE.
DEGRACE (1974)	INVESTIGATED THE LIMESTONE RESOURCES OF NEWFOUNDLAND AND LABRADOR (INCLUDING THE ST. GEORGE GROUP.
DAVENPORT ET AL., (1975)	STUDIED STRONTIUM AND LEAD DISTRIBUTION IN STREAM SEDIMENTS ON THE PORT AU PORT PENINSULA.
KLUYVER (1975)	STUDIED THE ST. GEORGE GROUP IN THE PORT AU CHOIX AREA AND DIVIDED IT INTO THREE FORMATIONS. IN ASCENDING ORDER THESE ARE; THE BARBACE POINT, THE CATOCHE AND THE PORT AU CHOIX.
COLLINS & SMITH (1975)	EXAMINED THE ST. GEORGE IN THE DANIEL'S HARBOUR AREA, AGAIN REDUCING IT TO FORMATIONAL STATUS. SUBDIVIDED THE ST. GEORGE FORMATION ON THE BASIS OF DIAMOND DRILL CORE INTO THREE UNITS; THE LOWER LIMESTONE, THE DARK GREY DOLOMITE AND THE CYCLIC DOLOMITE.
LEVESQUE (1977)	STUDIED THE STRATIGRAPHY AND THE SEDIMENTOLOGY OF THE ST. GEORGE FORMATION IN THE PORT AU PORT AND PORT AU CHOIX AREAS. IDENTIFIED THREE MEMBERS, THE LOWER CYCLIC MEMBER, THE MIDDLE LIMESTONE MEMBER AND THE UPPER CYCLIC MEMBER.
KNIGHT (1977A,B, 1978, 1980) KNIGHT AND SALTMAN (1980)	REDEFINED THE STRATIGRAPHIC NOMENCLATURE OF THE ST. GEORGE GROUP ON THE GREAT NORTHERN PENINSULA. IN ASCENDING ORDER THEY DEFINED; THE UNFORTUNATE COVE FORMATION, THE WATTS BIGHT FORMATION, AN UNNAMED UNIT (LATER NAMED THE BOAT HARBOUR FORMATION, KNIGHT, 1980), THE CATOCHE FORMATION, (WITH THE LAIGNET POINT MEMBER LOCALIZED AT THE TOP), DIAGENETIC CARBONATES AND THE SILICEOUS DOLOMITE FORMATION. THE NAME UNFORTUNATE COVE WAS DROPPED BY KNIGHT (1980) WHEN THE WATTS BIGHT FORMATION WAS REDEFINED. THE WATTS BIGHT AND BOAT HARBOUR FORMATIONS ARE APPROXIMATELY EQUIVALENT TO THE BARBACE POINT FORMATION (KLUYVER, 1975) AND THE DIAGENETIC CARBONATES AND SILICEOUS DOLOMITE FORMATION ARE APPROXIMATELY EQUIVALENT TO THE PORT AU CHOIX FORMATION (OP. CIT.).
FLOWER (1978)	STUDIED ST. GEORGE AND TABLE HEAD CEPHALOPOD ZONATION IN WESTERN NEWFOUNDLAND.
BOYCE (1978, 1979) STOUGE AND BOYCE (1983)	STUDIED TRILOBITE BIOSTRATIGRAPHY OF THE CAMBRO-ORDOVICIAN ROCKS OF WESTERN NEWFOUNDLAND.
FORTEY (1979)	STUDIED TRILOBITE FAUNAS FROM THE CATOCHE FORMATION OF THE ST. GEORGE GROUP.
KNIGHT (1983) SNOW AND KNIGHT (1979) KNIGHT AND BOYCE (1984)	SUMMARIES OF A REGIONAL MAPPING PROJECT ON THE GREAT NORTHERN PENINSULA.
PRATT (1979) PRATT AND JAMES (1982) PRATT AND JAMES (IN PRESS)	STUDIED THE ST. GEORGE GROUP FROM PORT AU PORT TO CAPE NORMAN CONCENTRATING UPON THE CRYPTALGAL STRUCTURES, THE SEDIMENTOLOGY AND THE DIAGENETIC HISTORY OF THE ROCKS. THE FORMER TOPIC WAS DISCUSSED IN PRATT AND JAMES (1982). INTRODUCED THE NAME AGUATHUNA FORMATION FOR THE UPPER MOST DIVISION OF THE ST. GEORGE GROUP (EQUIVALENT TO KNIGHT'S SILICEOUS DOLOMITE FORMATION). SUGGESTED A TIDAL FLAT - ISLAND DEPOSITIONAL MODEL TO EXPLAIN FACIES DISTRIBUTION WITHIN THE ST. GEORGE GROUP.
STOUGE (1980, 1982)	EXAMINED CONODONTS WITHIN THE ST. GEORGE GROUP FROM OUTCROPS ON THE GREAT NORTHERN PENINSULA AND DETERMINED A ZONATION SCHEME POSSIBLY APPLICABLE TO THE ENTIRE ST. GEORGE GROUP.
LANE (1984)	STUDIED CARBONATE BRECCIAS ASSOCIATED WITH SPHALERITE MINERALIZATION AT DANIEL'S HARBOUR.
HAYWICK AND JAMES (1984)	GROUPED THE DOLOMITE AND DOLOSTONE FOUND WITHIN THE ST. GEORGE GROUP INTO SEVEN DISTINCT VARIETIES.

the St. George and recognize four formations. In ascending order, these are: the Watts Bight, the Boat Harbour, the Catoche and the Aguathuna (figure 1.3).

In contrast to the voluminous amount of stratigraphic literature that has been published, very little data has been gathered with respect to the dolomites within the St. George. The earliest studies simply stated that dolomite made up a significant proportion of the lithology and briefly described the textures that could be observed in the field (Schuchert and Dunbar, 1934, Sullivan, 1940, Walthier, 1947, 1949, Oxley, 1953, Woodard, 1957).

Petrographic and bulk chemical analyses of laminated dolostones were integrated with field observations by Lilly (1961) as part of his study of the geology of the Hughes Brook - Goose Arm areas. He was, however, not concerned with the chemistry of the dolostone, but was more interested in determining the relationships between dolostone and limestone (Lilly, 1961).

Other studies which investigated dolostones within the St. George Group did so for economic reasons. Johnson (1954) was interested in strontium deposits associated with pre-Carboniferous topographic lows within St. George dolostones in the Aguathuna Quarry area of the Port au Port Peninsula. Besaw (1972, 1973, 1974) was interested in locating and mapping metallurgical grade carbonate deposits in the Port au Port area to be used in the steel industry of Nova Scotia. His studies relied heavily upon bulk chemical analysis of both limestones and dolostones.

The discovery of sphalerite mineralization in the area of Daniel's Harbour which was associated with "white sparry" dolomite sparked many studies to understand these deposits (Cumming, 1968, Collins and Smith, 1975, Lane, 1984), and to look for other deposits elsewhere (e.g. Kluyver, 1975). The "white sparry" dolomites have been documented in Lower Ordovician strata from the Table Point area to Cape Norman on the Great Northern Peninsula (Nelson, 1955, Woodard, 1957, Tuke, 1968, Kluyver, 1975, Levesque, 1977, Knight, 1977a,b, 1978, 1980, 1983, Snow and Knight, 1979, Pratt, 1979, Knight and Saltman, 1980, Haywick and James, 1984).

Studies by Levesque (1977) and Pratt (1979) examined outcrops from the Port au Port Peninsula to Cape Norman. Levesque recognized three varieties of dolomite which Pratt later confirmed. In approximate paragenetic sequence, these varieties were classified as; syngenetic, diagenetic and epigenetic.

2.2 MEASURED SECTIONS:

The stratigraphic sections measured at each of the ten principle areas investigated as part of this study are presented graphically in appendix A (back pocket). Each section displays general lithologies (Dunham, 1962), sedimentary structures, macroscopic faunal content, stromatolitic and thrombolitic buildups, secondary mineralization, and the degree of bioturbation (refer to figure A1, back pocket). Selective dolomitization or silicification of fauna or ichnofossils are denoted by a subscript d or s respectively. The presence of abundant pressure solution seams or stylolites, chert pebbles and other components, and the bitumin content are also indicated.

The amount of dolomitization within each lithostratigraphic unit (visually estimated as between 0 and 100 percent of the unit), is schematically summarized by way of a histogram on the left side of each section. The variety of dolomite or dolostone (discussed in chapter three) is also shown on this scale.

2.3 WATTS BIGHT FORMATION:

The Watts Bight Formation lies conformably upon dolostones of the Upper Cambrian Petit Jardin Formation (figure 1.3). The type section of the Watts Bight Formation at Watts Bight, (near Cape Norman on the western side of the Great Northern Peninsula), is approximately 80 metres thick. It is composed of dark grey to black, fine to coarsely crystalline, burrow mottled, vuggy, often cherty, stromatolitic and thrombolitic dolostones (Knight, 1977b, 1978, 1980, Knight and James in prep.).

The preservation of the stromatolites and thrombolites is often spectacular, due mainly to colour variations in the dolostone and selective dolomitization (plate 2.1a,b). The growth forms of the stromatolites vary between SH-C, columnar and digitate SH-V types (as defined by Logan, et al., 1964), stacked hemispheroids and cryptalgal laminations (Knight, 1977b). Cryptalgal structures in the St. George have been discussed by Pratt (1979).

The basal part of the Watts Bight Formation contains finely crystalline, laminated dolostones (dololaminites of Wanless, 1975 and Haywick and James, 1984), with abundant cryptalgal laminations and chert.

On St. John Island (between Port au Choix and New Ferolle; figure 1.1), Knight and Boyce (1984) have identified partially dolomitized stromatolitic mudstones that may be equivalent to the dolostones of the Watts Bight Formation elsewhere on the west coast of the Great Northern Peninsula. The exact correlation is not yet well established and trilobite remains found in the limestone suggest possible equivalence with the overlying Boat Harbour Formation (Knight and Boyce, 1984).

On the eastern side of the Great Northern Peninsula in the area of Canada Bay (Figure 1.1), most of the Watts Bight Formation is composed of bioturbated lime mudstone and wackestone. The thickness of the stromatolite interval decreases from 80 metres to 17 metres and the dolostones that are prevalent on the western coast of the peninsula, are confined to the basal 7 to 17 metres of the formation (Knight and Saltman, 1980).

PLATE 2.1: STRATIGRAPHY AND SEDIMENTOLOGY OF THE WATTS BIGHT FORMATION.

A) Columnar thrombolites preserved in dolomitized strata; Cape Norman. These algal structures are recognizable because of selective dolomitization and colour differences. Hammer is 30 cm in length.

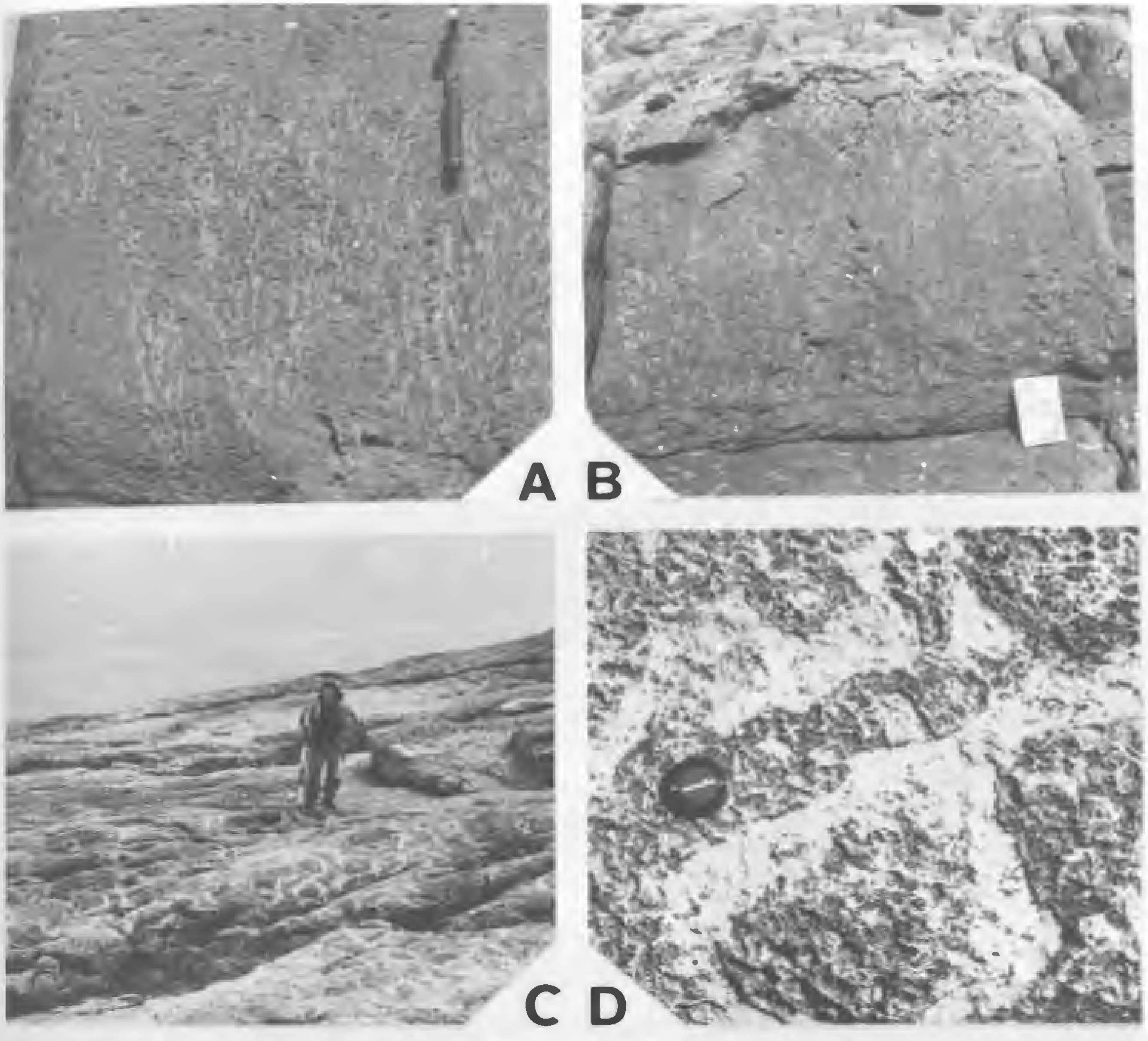
B) As above. Field book is 19 cm long.

C) A bedding-plane view of cerebral structure in partially dolomitized thrombolite mounds within the "Green Head Bioherm"; Isthmus Bay.

D) Detailed plan view of the dolomitized thrombolites pictured above. Here, dolomite has selectively replaced the matrix between the thrombolites rather than the algal structures themselves. Lens cap is 6 cm in diameter.

E) Contact between dolostone (dolo) and limestone (lime); Isthmus Bay. Both lithologies are mottled by abundant ichnofossils.

F) Breccia bed marking the contact between the Watts Bight and Boat Harbour Formations; Cape Norman. This horizon has been interpreted as a disconformity surface by Knight, (1980). Wide divisions on scale bar are 25 cm in length.


A
B
C
D
dolo
lime
E
F

Dolostone is the dominant lithology of the Watts Bight Formation in the eastern Port au Port area. Partially dolomitized stromatolites and thrombolite are again abundant and commonly form prominent mound complexes such as the "Green Head Bioherms" at Isthmus Bay on the Port au Port Peninsula (Pratt, 1979, James and Stevens, 1982, Pratt and James, 1982; figure 2.1, plate 2.1c,d). The medium crystalline dolostone weathers buff to medium grey and is locally chert rich.

"Remnant" limestone that has apparently escaped regional dolomitization, is a common component of the Watts Bight Formation in the Port au Port area and is usually of a mudstone or wackestone texture. Recently, conodonts obtained from limestones that crop out along the southern shore of the Port au Port Peninsula have yielded Early Ordovician (Early Canadian) ages (N. P. James, pers. comm.). These limestones may represent non-dolomitized equivalents of the Watts Bight Formation.

Bioturbation is ubiquitous in the Watts Bight giving a mottled appearence to both the dolostones and the limestones (plate 2.1e). Gastropods (eg. Maclurites), cephalopods (eg. Clarkoceras, Ectenolites and Diaphragmoceras; B. Stait, pers. comm.), brachiopods and trilobites are common in these rocks. Crinoids and corals are present but only rarely.

The contact between the Watts Bight and the overlying Boat Harbour Formation along the western coast of the Great

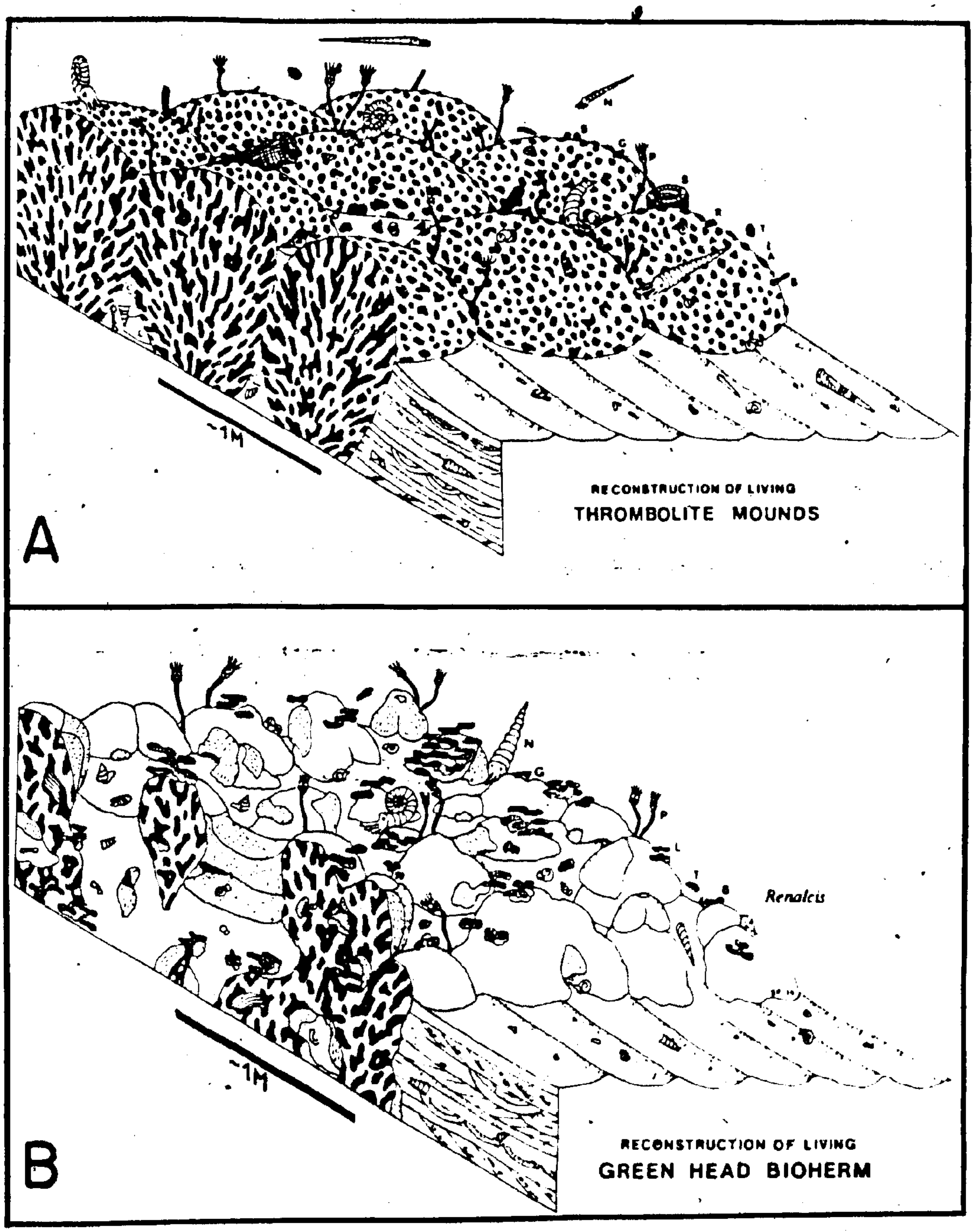


FIGURE 2.1: Reconstructions of the living surface of mound buildups in the St. George Group.
A) Thrombolite mounds.
B) Lichenaria-Renalcis mounds.

Thrombolites are coloured black. Other fauna include unspecified species of : sponges (S), trilobites (T); rostroconchs (R), nautiloids (N), gastropods (G), Lichenaria (L) and pelmatozoans (P). (From Pratt and James, 1982).

Northern Peninsula is marked by a limestone, dolostone and chert clast breccia (plate 2.1f). Breccia filled fractures also penetrate down into the top of the Watts Bight. Knight (1980) interprets this horizon to represent a disconformity that predates deposition of the Boat Harbour rocks. This disconformity may be localized to the Great Northern Peninsula as the contact appears conformable south in the Port au Port area (Haywick and James, 1984).

2.4 BOAT HARBOUR FORMATION:

The type section of the Boat Harbour Formation is located at Boat Harbour near Cape Norman on the Great Northern Peninsula (Knight and James, in prep.),(figure 1.1). It is approximately 120 metres thick and is predominantly composed of bioturbated mudstones and wackestones. These limestones are locally stromatolitic (plate 2.2a,b), grainy and are commonly interbedded with finely crystalline dololaminites (Knight, 1977b, 1980, Pratt, 1979; plate 2.2c).

The lithology of the Boat Harbour Formation is similar to the east in the Canada Bay area, and to the south in the region of Port au Port. In the east, however, the typical interbedded limestone - dololaminite lithology has a strong stromatolite, thrombolite and primative-coral mound component (Pratt, 1979, Knight, 1980, Knight and Saltman, 1980, Pratt and James, 1982).

The limestones and dololaminites in all areas are

PLATE 2.2: STRATIGRAPHY AND SEDIMENTOLOGY OF THE BOAT HARBOUR FORMATION.

A) Hemispheroidal stromatolites within thin bedded limestones; Isthmus Bay. Fine carbonate mud is draped between the two stromatolites. Hammer is 25 cm long for scale.

B) LLH stromatolitic mudstone in cross-section; Isthmus Bay. Lens cap is 6 cm in diameter.

C) Finely crystalline dololaminite ~~inter~~bedded with limestone; Isthmus Bay. Divisions on scale bar are 25 cm in length.

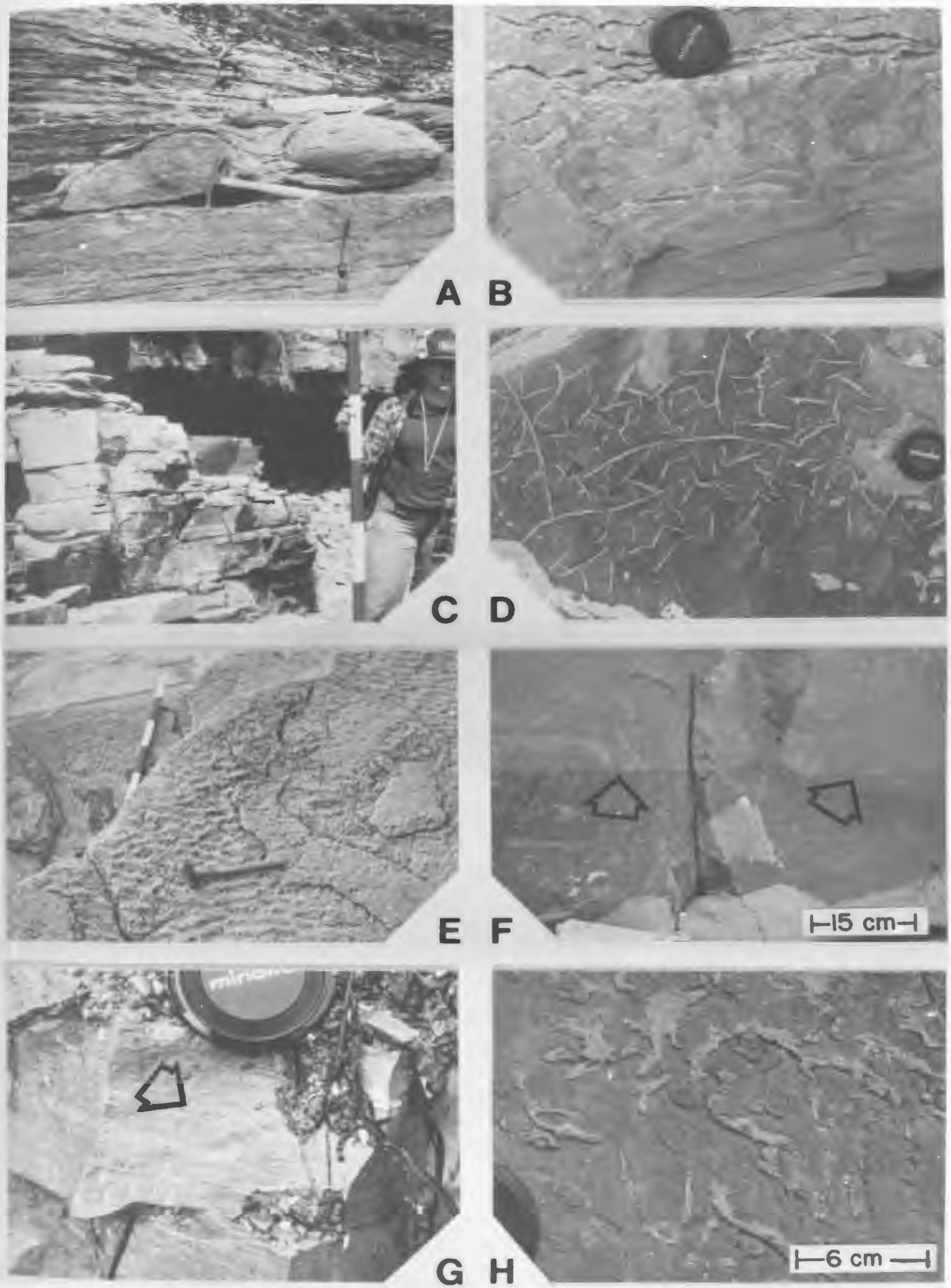
D) Shrinkage cracks atop lime mudstone; Isthmus Bay.

E) Bifurcating, symmetrical wave ripples, (trending approximately parallel to the hammer) atop a wackestone bed; Isthmus Bay. The lower bed is characterized by wave ripples of a different form (straight crested) and orientation (approximately parallel to the measuring pole), compared to those on the upper bed.

F) Flat bottomed grainstone channels (arrows) cut into a hardground within a thrombolitic mudstone; Isthmus Bay.

G) Poorly developed stromatolite (arrow) within dololaminite, Isthmus Bay.

H) Preferentially dolomitized ichnofossils in a wackestone bedding plane; Port au Choix.


A
B
C
D
E
F
⊢15 cm⊣
G
H
⊢6 cm⊣

characterized by a wide spectrum of shallow water sedimentary structures and components. The most abundant in in the limestones include desication cracks (plate 2.2d), bifurcating and symmetrical wave ripples (plate 2.2e). Lenticular to laterally continuous, cross-bedded oolite beds, hardgrounds (plate 2.2f) and herringbone cross-stratification are present, but are not as common. Grainstone horizons range from continuous to lenticular and may surround or fill topographic depressions around cryptalgal mound structures (Levesque, 1977, Pratt, 1979).

Dololaminites are characterized by desiccation cracks, prism cracks, tepee structures, intraformational breccias and poorly developed, small stromatolites (plate 2.2g). These dolostones are frequently of a limited lateral extent and may grade into stromatolitic / thrombolitic horizons or mudstones (Levesque, 1977, Pratt, 1979, Pratt and James, in press.).

Stylolites and pressure solution seams, usually marked by an accumulation of dolomite, are a common component of most Boat Harbour limestones. Ichnofossils are also very abundant and are often preferentially dolomitized (plate 2.2h). The combination of the stylolites and the ichnofossils gives rise to the characteristic dolomitic mottling so prevalent in St. George limestones. These mottles had previously been interpreted as "fucoids" by Schuchert and Dunbar (1934).

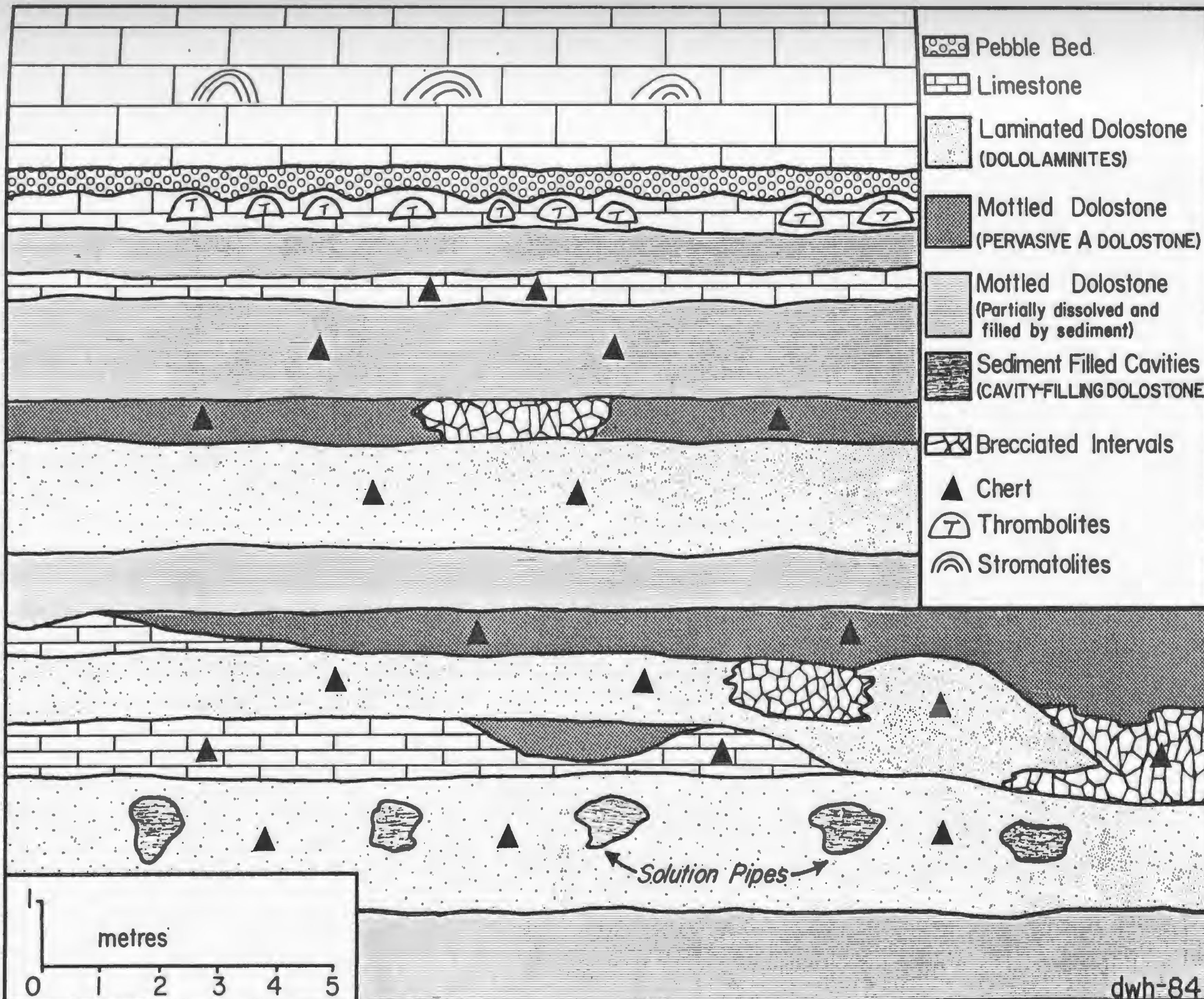
Argillaceous, dolomitic shales, some of which contain rounded quartz silt, are present within the Boat Harbour Formation in the Port au Port area, but are minor.

Towards the top of the Boat Harbour Formation is a horizon characterized by quartz, chert and dolostone pebbles. This "pebble bed" is correlative from the western side of the Great Northern Peninsula south to the Port au Port Peninsula and is generally regarded as an disconformity (Knight, 1977b, 1980, Pratt, 1979, Stouge, 1980, 1982, Haywick and James, 1984). An erosional surface exposed northwest of Canada Bay which may be equivalent to the pebble bed (Knight and Saltman, 1980, Stouge, 1980, 1982) strongly suggests that this exposure horizon is of widespread, regional extent.

The pebble bed is well exposed on the Port au Port Peninsula where it overlies 14 metres of chert rich, mottled dolostone. This dolostone is punctuated by numerous cavities that are filled with finely crystalline dolostone which Pratt (1979) interprets as karst solution pipes formed, and filled during sub-aerial exposure (figure 2.2). Above ~~the~~ pebble bed, stromatolitic and burrow mottled limestone with very little chert or dolostone, is the dominant rock type.

Stouge (1980, 1982) sampled the Boat Harbour Formation across the pebble bed in the Cape Norman area and found it to yield a "meagre" conodont fauna. Nevertheless, he did observe an abrupt change in fauna across the horizon suggesting the presence of a hiatus in deposition. Boyce

FIGURE 2.2: Schematic representation of the "pebble bed" and underlying strata at Isthmus Bay on the Port au Port Peninsula (for location, refer to figure 1.1). The rocks beneath the pebble bed are extensively dolomitized, locally brecciated (possibly by solution collapse) and are rich in chert. Solution pipes, localized in a horizon approximately 10 metres beneath the pebble bed, are filled with fine grained sediment. In comparision, rocks above the pebble bed are mostly limestones with few diagenetic alterations. Names given in parentheses are specific varieties of dolostone defined and described in later chapters. (Drawn to scale).


Pebble Bed
Limestone
Laminated Dolostone
(DOLOLAMINITES)
Mottled Dolostone
(PERVASIVE A DOLOSTONE)
Mottled Dolostone
(Partially dissolved and filled by sediment)
Sediment Filled Cavities
(CAVITY-FILLING DOLOSTONE)
Brecciated Intervals
Chert
Thrombolites
Stromatolites
Solution Pipes
1
metres
0 1 2 3 4 5
dwh-84

(1979) and Stouge and Boyce (1983) have also reported the absence of trilobite zone G1 at the pebble bed near Cape Norman further supporting this conclusion.

Samples collected from just above and below the pebble bed at Port au Port as part of this study failed to yield significant numbers of conodonts preventing any biostratigraphic determination of a hiatus in this location.

2.5 CATOCHE FORMATION:

The Boat Harbour is conformably overlain by the Catoche Formation, a sequence of bioturbated, fossiliferous limestones which are locally extensively dolomitized. The most complete section crops out at Port au Choix on the Great Northern Peninsula where 100 metres of limestone pass upward into 50 metres of medium to coarsely crystalline dolostone (Knight, 1980). This prominent dolostone is found everywhere north of Table Point (figure 1.1). In more southerly regions (such as the eastern Port au Port Peninsula and Smelt Canyon), this upper interval lacks the coarsely crystalline component, but does contain lenticular to continuously bedded, cherty, burrow mottled, medium crystalline dolostones, interbedded with lime mudstones (plate 2.3a).

The limestone in all regions is predominantly thin to medium bedded (1 centimetre to 1 metre) mudstone and wackestone. Grainstone beds are less common and are

PLATE 2.3: STRATIGRAPHY AND SEDIMENTOLOGY OF THE CATOCHE FORMATION.

A) Mottled, and locally cherty dolostones interbedded withi limestones; Smelt Canyon.

B) Thinly bedded mudstones characterized by numerous tepee structures (arrow) in the basal Catoche; Isthmus Bay.

C) Bioclastic floatstone bed containing abundant brachiopods, trilobites and spiral and coiled gastropods; Lower Cove. Divisions on scale bar are 5 cm in length.

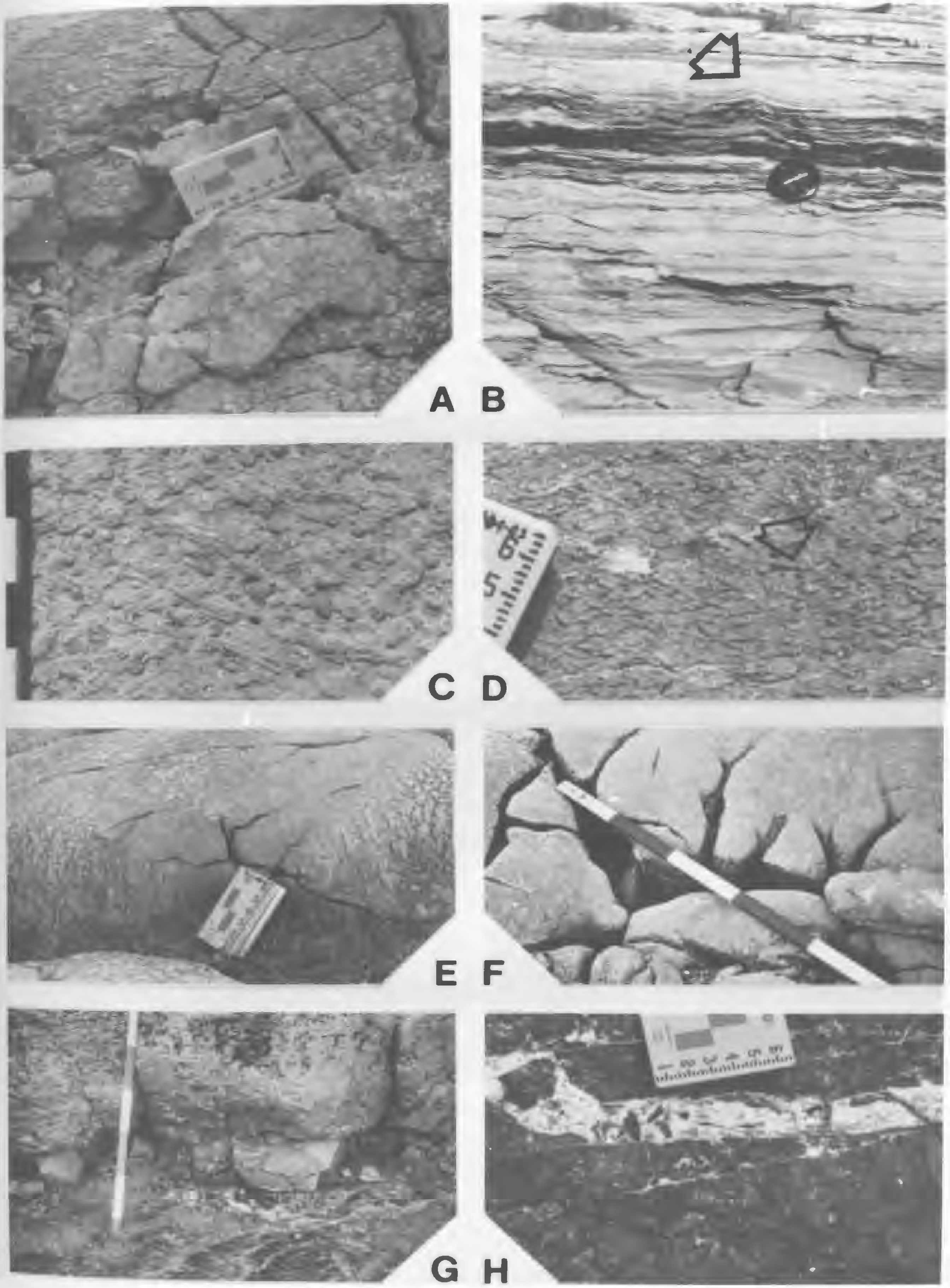
D) Stylolites (arrow), marked by an accumulation of dolomite within a wackestone bed; Smelt Canyon. This is a common form of mottling within the Catoche Formation at this location. Viewed in vertical section.

E) Partially dolomitized thrombolite mounds; Aguathuna Quarry.

F) Solution enlarged joint patterns atop fenestral mudstones; Aguathuna Quarry. The age of the solution enlargement is likely Carboniferous.

G) Interbedded dull grey and cream coloured dolostone; Back Arm. Together these rocks make up a prominent dolostone horizon found near the top of the Catoche Formation everywhere north of Table Point.

H) Coarsely crystalline dolomite localized to fractures within dolostone; Table Point. This sparry dolomite is associated with sphalerite mineralization at Daniel's Harbour.


A
B
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H

typically lensoidal. Limestones in the basal portions of the formation are locally mudcracked (plate 2.3b) and may contain bifurcating and symmetrical wave ripples.

Sponge, stromatolite and thrombolite mounds are present in all areas but are especially common in the Canada Bay and Hare Bay regions. Shelly fossils are abundant everywhere in the formation and include trilobites (Boyce, 1979, Fortey, 1979, Stouge and Boyce, 1983), brachiopods, crinoid ossicles, coiled and spiral gastropods and cephalopods (Flower, 1978) (plate 2.3c). As in the lower formations of the St. George, stylolites are usually marked by the accumulation of dolomite (plate 2.3d). Body and trace fossils are less commonly dolomitized in these rocks.

Towards the top of the Catoche Formation in the Port au Port area (Aguathuna Quarry section), a poorly exposed, mottled dolostone horizon passes upward into a partially dolomitized thrombolite mound interval (plate 2.3e) and finally into 20 metres of fenestral mudstone. The exposed mudstones are characterized by Carboniferous solution enlarged joint patterns (N.P. James pers. comm.) (plate 2.3f). Fine dolomite laminated intervals become more numerous toward the top of the Catoche and eventually coalesce into discrete dololaminite beds of the overlying Aguathuna Formation.

The prominent dolostone horizon found north of Table Point is composed of alternating sequences of dull grey, medium crystalline dolostone and cream coloured coarsely crystalline dolostone (plate 2.3g). Both varieties of dolostone are mottled by a finer, darker dolomite and can be very porous and bituminous (Knight and Saltman, 1980). White sparry dolomite crystals up to 15 millimetres in size are common and are localized in vugs and as fracture fill cements (plate 2.3h). This dolomite is also associated with sphalerite mineralization in the Daniel's Harbour area (Cumming, 1968, Collins and Smith, 1975, Lane, 1984).

2.5 AGUATHUNA FORMATION:

Knight (pers. comm. 1984) has recently found what he believes to be a disconformity at the Catoche- Aguathuna contact on St. John Island. At its type section at Table Point on the Great Northern Peninsula, the contact appears conformable. Here, the Aguathuna Formation is 60 metres thick and composed primarily of finely crystalline dololaminites (Levesque, 1977, Knight, 1977b, Pratt, 1979, Lane, 1984). Burrow mottling is prevalent in the medium crystalline dolostones, more so in the lower portion of the formation than near the top (Knight, 1977b). Shelly fossils are notably rare in the Aguathuna Formation and are usually confined to burrow-mottled.

The Aguathuna Formation is much less dolomitic in the Hare Bay and Port au Port areas and limestones make up a significant proportion of the rocks. The limestones on the

Port au Port Peninsula contain a sparse shelly fauna (gastropods, rare trilobite and orthocones), but many oncolites and stromatolites. The stromatolites are distinctly LLH in appearence (cf. Logan et al., 1964, Pratt, 1979). Ichnofossils are also present, but are less commonly replaced by dolomite than limestones in other formations.

The Aguathuna thins away from the type section at Table Point. Near Hare Bay, Stouge (1980, 1982) estimates that the formation measures approximately 35 metres in thickness. On the Port au Port Peninsula, it measures 50 metres in thickness, while near Port au Choix, it is only 10 metres thick and consists of only a few dololaminite beds (Pratt, 1979, Knight, 1980, Haywick and James, 1984).

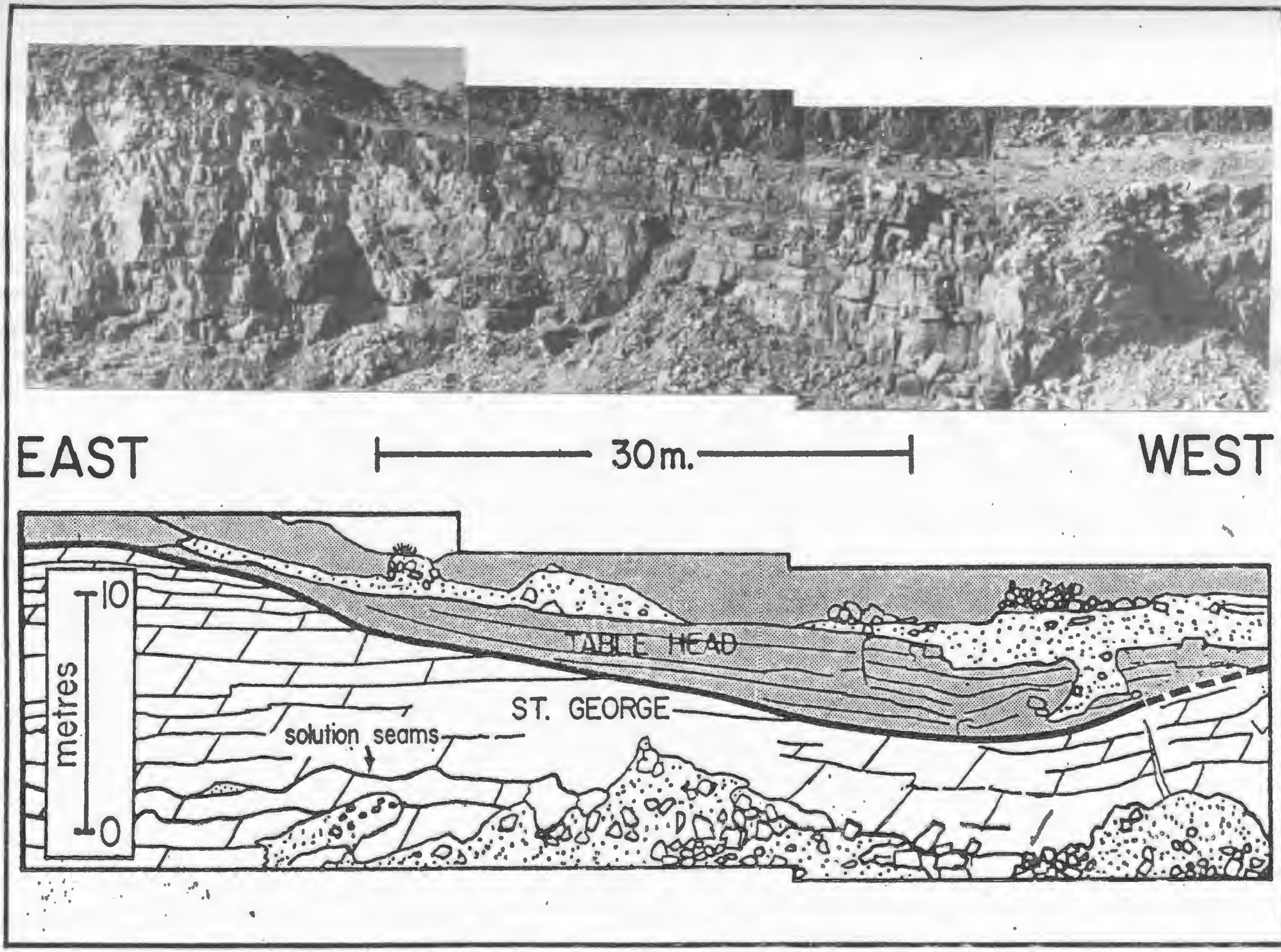
Approximately 20 metres below the Aguathuna - Table Head contact at Table Point, a thin dolomite cemented lithic arenite bed approximately 20 centimetres thick, is interbedded with thick dololaminites. The dominant components of this sandstone bed include well rounded to angular chert, quartz and feldspar grains, reworked dololaminite intraclasts, detrital zircons and a silicified oolite nodule. Several fine grained, argillaceous and/or dolomitic shale beds also punctuate the section, not only at Table Point, but also in the south on the Port au Port Peninsula.

Chert is a common component of the Aguathuna Formation in all parts of the study area and occurs as discrete nodules, in pebble horizons and in breccias (Stouge, 1982, Lane, 1984). Entombed sulphate crystallites have been found in some nodules from the Port au Port Peninsula (James and Stevens, 1982) and from Smelt Canyon (this study) which suggests that evaporite minerals may have existed in these rocks. It is possible therefore, that many of the chert breccias were formed through the dissolution of these minerals and subsequent collapse (discussed in Knight, 1977b). Other workers feel that these breccias may actually be related to sub-aerial exposure (Collins and Smith, 1975). Stouge (1982) has identified a change in conodont faunas across a prominant breccia bed 10 metres above the Catoche - Aguathuna contact at Table Point. Although the breccia bed does occur within a barren zone, Stouge feels that the faunal change is real and that the breccia corresponds to a sub-aerial exposure horizon.

The contact between the Aguathuna Formation and the overlying Middle Ordovician Table Head Formation (Table Head Group) is unconformable on the Port au Port Peninsula and is marked by an erosional channel up to 9 metres deep at Aguathuna Quarry (Schuchert and Dunbar, 1934, Cumming, 1967, Levesque, 1977, Pratt, 1979; plate 2.4). The upper surface of the Aguathuna Formation is pitted and is locally marked by an accumulation of chert clasts and nodules, which Pratt (1979) interprets as a silcrete horizon developed during sub-aerial exposure. Elsewhere on the Great Northern Peninsula, the contact appears conformable

PLATE 2.4: STRATIGRAPHY AND SEDIMENTOLOGY OF THE AGUATHUNA FORMATION.

Panoramic photograph and interpretive sketch of the St. George - Table Head disconformity at Aguathuna Quarry on the Port au Port Peninsula. Rocks of the Table Head Group fill a nine metre deep erosional channel cut into the St. George dololaminites. The disconformity surface in the sketch is highlighted.


EAST
30m.
WEST
metres
10
0
TABLE HEAD
ST. GEORGE
solution seams

or is too poorly exposed for an accurate determination (Pratt, 1979, Haywick and James, 1984).

Approximately 5 metres beneath the Table Head - St. George contact at Aguathuna Quarry and northwest of The Gravels, two irregular bedding planes are marked by an accumulation of red and green argillaceous shales. These surfaces may be correlative with two red limestone beds cropping out on the western side of the Port au Port Peninsula (B. Stait, pers. comm., 1984) and are interpreted here as solution seams resulting from pressure solution of the limestone (plate 2.4). Pressure solution in other parts of these sections commonly results in thin, laterally discontinous limestone beds truncated at their margins by large stylolites (10 centimetre amplitude).

2.7 FACIES INTERPRETATION:

The palaeoenvironments in which the four formations of the St. George Group were deposited have been discussed by Levesque (1977), Pratt (1979) and Pratt and James (in press).

The rocks of the St. George Group were deposited in a stable shelf environment. The stromatolitic and thrombolitic-rich, burrow-mottled limestones and dolostones of the Watts Bight Formation suggest that prior to regional dolomitization, these rocks were mostly subtidal shelf deposits (Levesque, 1977, Knight, 1977b, 1980, Snow and Knight, 1979, Pratt, 1979, Pratt and James, in press). The

Catoche Formation, dominated by lime mudstones and wackestones and regionally overprinted by dolomitization near the top, is also thought to have been deposited during generally subtidal conditions.

The Boat Harbour and Aguathuna Formations are thought to have been deposited in shallower-water than the other formations because they contain abundant dololaminite beds. These dolostones have been interpreted as an upper intertidal-supratidal facies (Levesque, 1977, Pratt, 1979) similar to those presently forming in modern tidal flat environments (Illing et al., 1965, Deffeyes et al., 1965, Shinn et al., 1965, Wanless, 1975, MacKenzie et al., 1980, Shinn, 1983). The desiccation cracks, tepee structures, cryptalgal and millimetre scaled laminations, the lack of significant numbers of body fossils and evidence of nodular evaporite minerals within these dolostones attests to their very shallow water origin.

Interbedded dololaminite - limestone lithologies typical of the Boat Harbour and Aguathuna Formations, have been interpreted in the rock record by some as the result of repeated shoaling upward cycles in a shoreline-tidal flat environment (Bathurst, 1975, Wanless, 1975, Levesque, 1977, Knight, 1977b, 1980, Snow and Knight, 1979; figure 2.3). The variation observed in the lithology of the limestones (for example, from mudstone to grainstone) has been explained by Levesque (1977) as the periodic winnowing of subtidal muds, possibly through the action of storms.

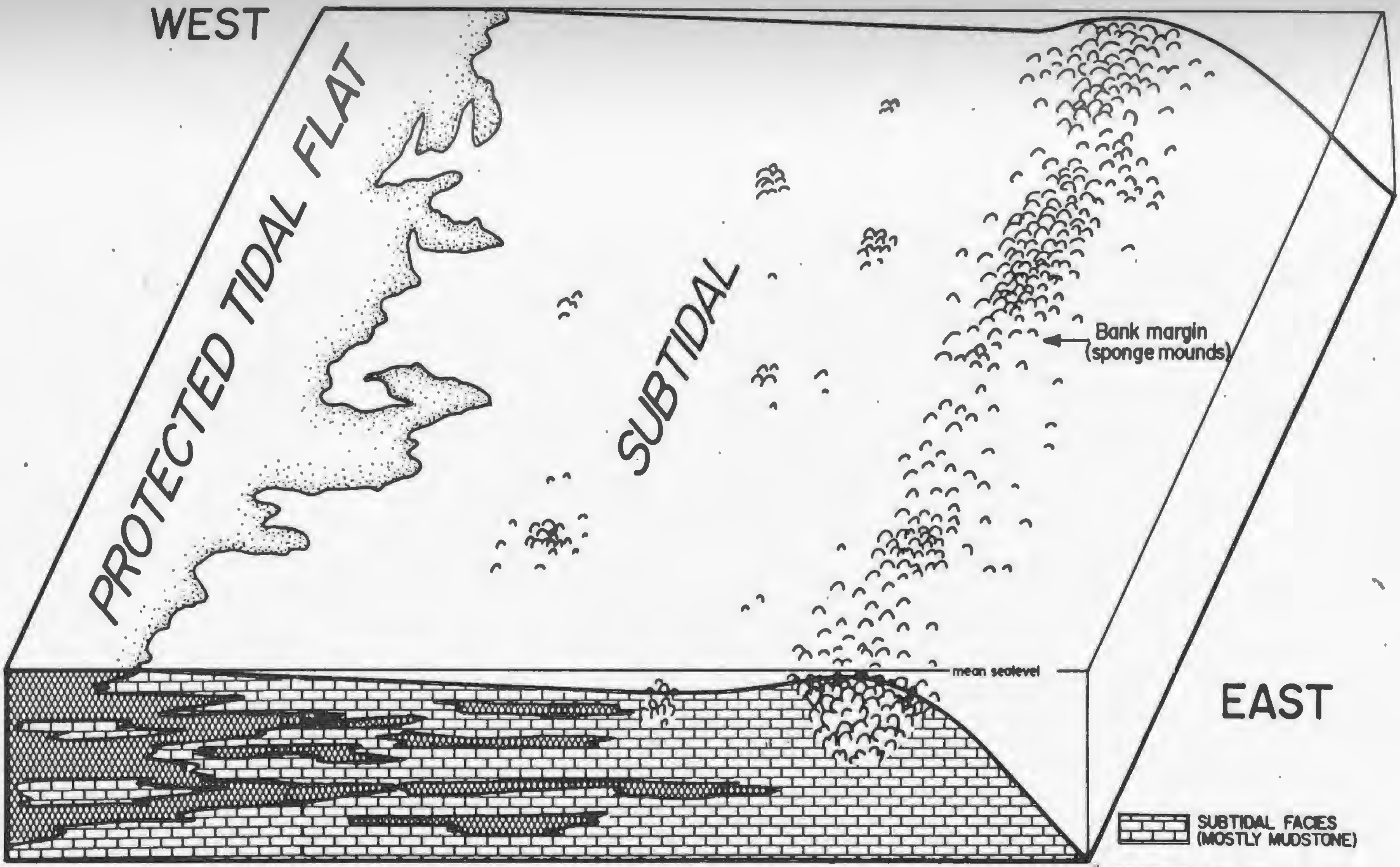


FIGURE 2.3: Schematic stable shelf sedimentation model proposed by Levesque (1977) for the St. George Group during Boat Harbour - Catoche deposition. (No vertical or horizontal scale implied)

This is thought to result in laterally discontinuous grainstone beds which interdigitate with nearby mudstones or wackestones. A complete shoaling upward cycle would therefore consist of subtidal stromatolitic or thrombolitic burrow mottled and fossiliferous lime mudstone (with occasional lensoidal grainstone beds), grading upward into burrow mottled rocks of the intertidal zone and finally into supratidal dololaminites (Levesque, 1977). The complete cycle is however, rarely preserved.

To the east, in the vicinity of Canada Bay and Hare Bay, the shallow shoreline deposits of the Boat Harbour Formation pass gradually into subtidal stromatolitic and thrombolitic mound banks (Levesque, 1977, Knight, 1977b, Pratt, 1979, Pratt and James, 1982). These mounds are thought to represent high energy buildups at, or near, the edge of the carbonate platform. During Catoche time, the thick mound sequence continued to fluorish along the eastern margin of the shelf developing a pronounced mound barrier (Knight, 1977b, Pratt, 1979, Pratt and James, 1982; figure 2.3).

Knight (1977b, 1980), Snow and Knight (1979) and Stouge (1980, 1982) regard the St. George Group as recording two "mega-cycles" of deposition on the Lower Ordovician carbonate platform. This is a continuation of a trend first started during the deposition of the Middle - Upper Cambrian Port au Port Group (Knight, 1980). The development of the first mega-cycle in the Early Ordovician was initiated when the subtidal Watts Bight Formation was deposited atop the dolostones of the Upper Cambrian Petit Jardin Formation. This marked a regional transgression (Knight, 1977b, 1980, Snow and Knight, 1979, Stouge 1980, 1982). The Boat Harbour Formation, itself composed of numerous smaller "cycles", represents a regressive phase of deposition. A transgression again proceeded the deposition of the subtidal Catoche Formation followed by another regression and deposition of the Aguathuna Formation. Regional and localized sub-aerial exposure horizons within the Boat Harbour and Aguathuna Formations occur within these regressive deposits.

The rare siliciclastic components of the St. George Group are confined to the regressive phases of deposition. The paucity of non-carbonate lithologies suggests that shelf sedimentation took place at a great distance from any land masses (Levesque, 1977, Pratt, 1979). This makes the thin lithic arenite bed found in the Aguathuna Formation at Table Point rather disquieting. It occupies a stratigraphic position similar to that of a thick siliciclastic sequence found in the lower portion of the Mingan Formation (equivalent to the Aguathuna Formation) in Quebec (A. Desrochers, pers. comm., 1984) and contains quartz grains characterized by numerous inclusions of tourmaline and possibly acicular rutile needles. If some inclusions are indeed rutile, one can speculate that the source rock of these quartz grains was granitic (Blatt et al., 1972).

The origin of the zircons in the arenite is uncertain. They are of a consistent size, shape, colour and luminescence which suggests a common provenance (Blatt et al., 1972), however, this provenance is difficult to determine. Zircons can be metamorphic or igneous or, because they are exceedingly stable, they may even be derived from reworked sedimentary rocks (Blatt et al., 1978, Folk, 1974b).

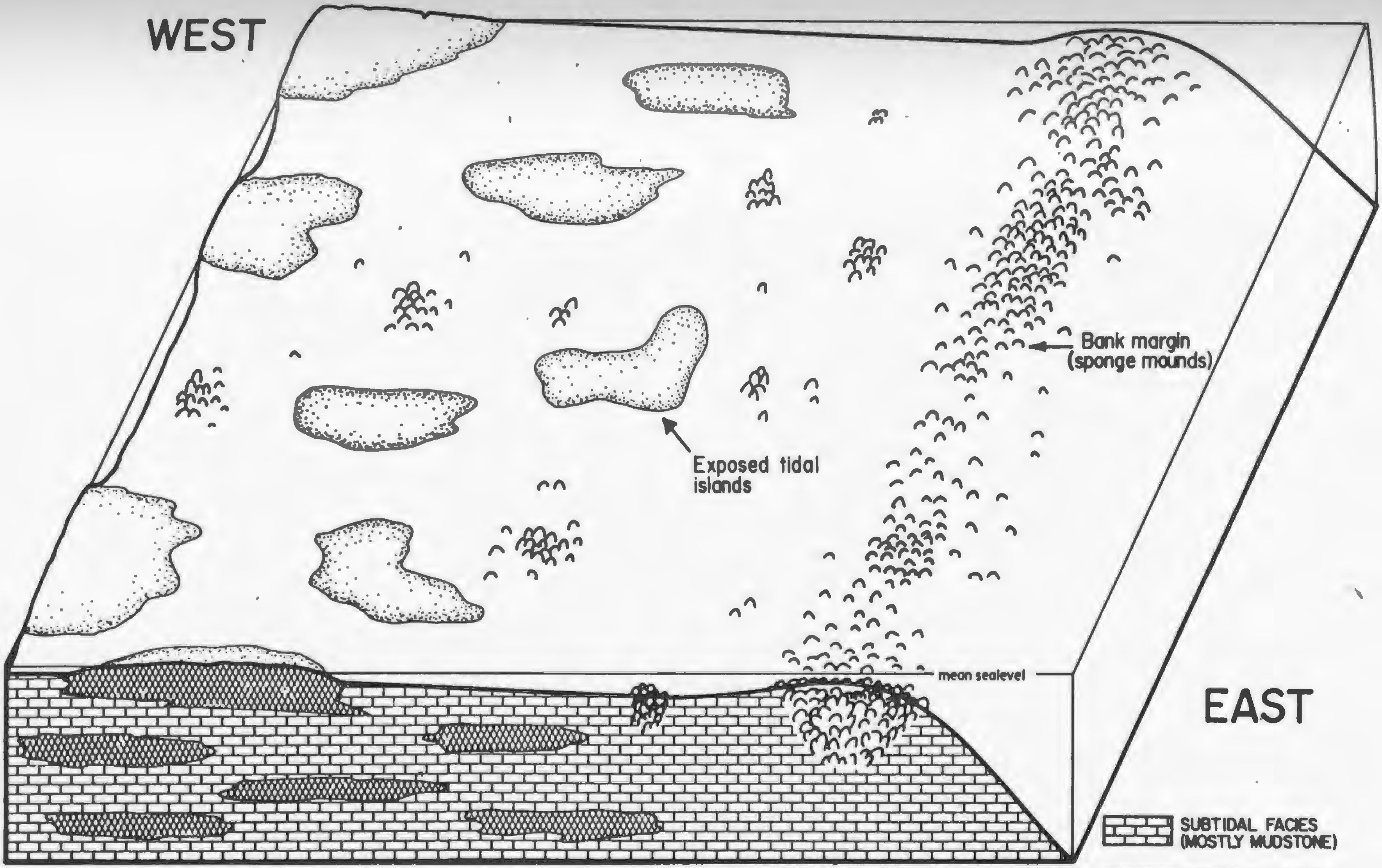
The most likely source of the siliciclastic components of the arenite is a stable shield area, but to date, this source area has not been identified. The reworked dololaminite clasts and the silicified oolite nodule are probably from a more local source(s).

The silt-sized quartz grains found "floating" within the shales of the Boat Harbour Formation were likely transported to the shelf by wind during the regressive phases of sedimentation (Levesque, 1977); however, as in the lithic arenite in the Aguathuna Formation, the source area has not been found.

The quartz grains are very well rounded (classification scheme of Powers, 1953) spherical and when examined under a petrographic microscope, are clearly "frosted". Characteristics such as these were originally assumed to be indicative of an aeolian provenance (Cailleux, 1941) but other circumstances such as sudden temperature drops (LeRiBault, 1977) and/or chemical dissolution (Kuenen, 1960, Kuenen and Perdok, 1962) are also capable of frosting grains. Scanning electron microscopy has had some success in determining the provenance of quartz grains (Krinsley and Takahashi, 1962, Krinsley and Doornkamp, 1973, Le Ribault, 1977, Krinsley and McCoy, 1978, Rogerson and Hudson, 1983); however, when viewed with a scanning electron microscope, most of the surface of the Boat Harbour quartz grains are pitted and lack the fine surface features necessary for an accurate provenance determination. Subramanian (1975) and Friedman et al. (1976) suggest that pitting of quartz may be a result of chemical dissolution during carbonate precipitation. This diagenetic alteration prevents any determination of the provenance of the quartz grains. All that can be concluded with any degree of confidence, is that the rounding and high degree of sphericity of the quartz grains probably resulted from prolonged abrasion prior to deposition with the shales of the Boat Harbour Formation.

The processes which control the smaller scaled cycles within the Boat Harbour and Aguathuna Formations are not fully understood. Some consider cyclic deposition to be the result of episodic subsidence and/or sedimentation rates (see discussion in Bathurst, 1975). Subsidence is a regional phenomenon and if it were the principle parameter dictating deposition, regionally correlative limestones and dololaminites should result (Pratt, 1979). For the most part, individual dololaminites are not tracable over large areas, nor are grainy limestones. In fact, these lithologies often grade laterally into other limestone facies (Levesque, 1977, Pratt, 1979, this study). It is likely therefore, that episodic subsidence alone did not cause the facies variation observed in the Boat Harbour and Aguathuna Formations (Pratt, 1979, Pratt and James, in press).

An alternative to the shoreline model has been proposed by Pratt (1979) and Pratt and James (in press). They envision tidal flats accreting as "cyclic" deposits on a gently subsiding sea floor punctuated by numerous low relief, tidal flat islands (figure 2.4). Dololaminite deposition took place in the supratidal zone on the islands and subtidal deposition took place in the subtidal zone between the islands. Facies variations were primarily controlled by local fluctuations in the rate of sedimentation. During deposition of the Watts Bight and Catoche Formations, the tidal flat areas were predominantly subtidal and very few (or no) islands developed. The Boat Harbour and Aguathuna Formations reflect times when islands were much numerous and subsequently, dololaminite deposition was much more extensive (Pratt, 1979, Pratt and James, in press.).



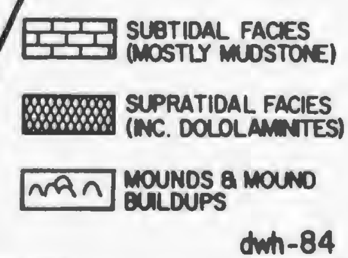


FIGURE 2.4: Schematic island-tidal flat sedimentation model proposed by Pratt (1979) for the St. George Group during Boat Harbour - Catoche deposition. (No vertical or horizontal scale implied) (Adopted from Pratt and James, in press).

CHAPTER THREE

FIELD CLASSIFICATIONS OF DOLOMITE AND DOLOSTONE

3.1 INTRODUCTION:

Four varieties of dolostone (rocks composed of greater than 50 percent dolomite) and two varieties of dolomitic limestone (rocks composed of less than 50 percent dolomite) are recognized in the St. George Group. The four dolostones are referred to as: 1) dololaminites, 2) pervasive A dolostone, 3) pervasive B dolostone and 4) cavity-filling dolostone (Haywick and James, 1984). The two varieties of dolomitic limestone are referred to as either matrix dolomite or mottle dolomite. A seventh variety which fills void space and fractures in pre-existing rocks is referred to as saddle dolomite.

Parameters used to distinguish one type from another include: 1) crystal size, 2) proportions of dolomite within a lithostratigraphic unit, 3) faunal content, or lack of it, 4) degree of (and the nature of) mottling, 5) sedimentary structures, 6) colour and 7) localization. These characteristics are summarized in table 3.1. The stratigraphic and geographic distributions of the seven varieties are summarized in table 3.2. and are shown schematically on the ten measured sections (appendix A) and in figures 3.1 and 3.2.

TABLE 3.1: Summary of the main characteristics of the seven varieties of dolomite and dolostone found in the St. George Group.

VARIETY	CRYSTAL SIZE	COLOUR	DISTINGUISHING CHARACTERISTICS
1) DOLO-LAMINITES	VERY FINE	BUFF TO WHITE	DOLOSTONE: CONTAINS ABUNDANT SHALLOW WATER SEDIMENTARY STRUCTURES (I.E. PRISM CRACKS, MUDCRACKS, LAMINATIONS).
2) MATRIX DOLOMITE	0.1 MM.	BUFF	DOLOMITIC LIMESTONE: REPLACES MATRIX BETWEEN ALLOCHEMS, BODY FOSSILS AND TRACE FOSSILS. VARIES IN AMOUNT FROM 5 TO 40% OF THE HOST, RARELY 85%.
3) MOTTLE DOLOMITE	0.1 MM.	BUFF TO DOVE GREY	DOLOMITIC LIMESTONE: SELECTIVELY REPLACES ICHNOFOSSILS MARGINS AND SOME MOLLUSCS. LOCALIZED ALONG PRESSURE SOLUTION SEAMS. RANGES IN AMOUNT FROM TRACE QUANTITIES TO 40% OF THE HOST.
4) PERVASIVE A DOLOSTONE	0.1 & 0.3 MM.		DOLOSTONE: FINER CRYSTALLINE DOLOMITE IS LOCALIZED TO MOTTLES. COARSER CRYSTALLINE DOLOMITE IS LOCALIZED BETWEEN MOTTLES. STROMATOLITES, THROMBOLITES, MOLLUSCS AND SOME TRACE FOSSILS ARE COMMONLY PRESERVED. OFTEN BITUMINOUS.
5) PERVASIVE B DOLOSTONE	0.1 TO 0.3 MM. & 1.0 MM.	MEDIUM GREY TO WHITE	
6) CAVITY-FILLING DOLOSTONE	VERY FINE	BUFF TO GREEN	DOLOSTONE: USUALLY GEOPETAL. FILLS IN OPEN CAVITIES AND VOID SPACE IN PRE-EXISTING PERVASIVE A AND B DOLOSTONES.
7) SADDLE DOLOMITE	0.5 TO 15.0 MM.	WHITE TO PINK	DOLOSTONE: COMPOSED OF SADDLE-SHAPED DOLOMITE RHOMBS WHICH FILL IN FRACTURES AND VOIDS WITHIN PRE-EXISTING PERVASIVE B DOLOSTONES.

TABLE 3.2: Distribution, abundance and extent of the seven varieties of dolomite and dolostone found within the St. George Group.

VARIETY	DISTRIBUTION		ABUNDANCE AND EXTENT
	STRATIGRAPHIC	GEOGRAPHIC	
1) DOLO-LAMINITES	AGUATHUNA AND BOAT HARBOUR FORMATIONS, BASAL WATTS BIGHT.	WIDESPREAD	ABUNDANT. PACKAGES OF DOLOLAMINITES ARE CORRELATIVE OVER SEVERAL KMS.
2) MATRIX DOLOMITE	BOAT HARBOUR AND WATTS BIGHT FORMATIONS	LOCALIZED OCCURRENCES ON PORT AU PORT AND GREAT NORTHERN PENINSULAS	RARE. BEDS OF MATRIX DOLOMITE ARE CROSSCUTTING AND ARE OF LIMITED VERTICAL AND LATERAL EXTENT.
3) MOTTLE DOLOMITE	WIDESPREAD	WIDESPREAD	VERY ABUNDANT. THICK PACKAGES OF DOLOMITE MOTTLED LIMESTONES ARE CORRELATIVE OVER REGIONAL DISTANCES.
4) PERVASIVE A DOLOSTONE	WIDESPREAD	WIDESPREAD	ABUNDANT. INDIVIDUAL DOLOSTONES ARE STRATA-BOUND. THICK PACKAGES ARE CORRELATIVE OVER REGIONAL DISTANCES.
5) PERVASIVE B DOLOSTONE	WIDESPREAD	GREAT NORTHERN PENINSULA ONLY.	VERY ABUNDANT. SINGLE DOLOSTONES MAY BE CROSSCUTTING. THICK PACKAGES ARE CORRELATIVE OVER REGIONAL DISTANCES.
6) CAVITY-FILLING DOLOSTONE	BOAT HARBOUR AND WATTS BIGHT FORMATIONS	LOCALIZED OCCURRENCES ON PORT AU PORT AND GREAT NORTHERN PENINSULAS	VERY RARE. CAVITIES ARE SMALL AND ARE NOT LATERALLY OR VERTICALLY CONTINUOUS.
7) SADDLE DOLOMITE	WIDESPREAD	GREAT NORTHERN PENINSULA ONLY.	COMMON. VEINLETS OF SADDLE DOLOMITE ARE CROSSCUTTING. PACKAGES OF ROCK CONTAINING SADDLE DOLOMITE MAY BE CORRELATIVE OVER SHORT DISTANCES.

FIGURE 3.1: Regional distribution of dolomite and dolostone varieties from Port au Port to Cape Norman.

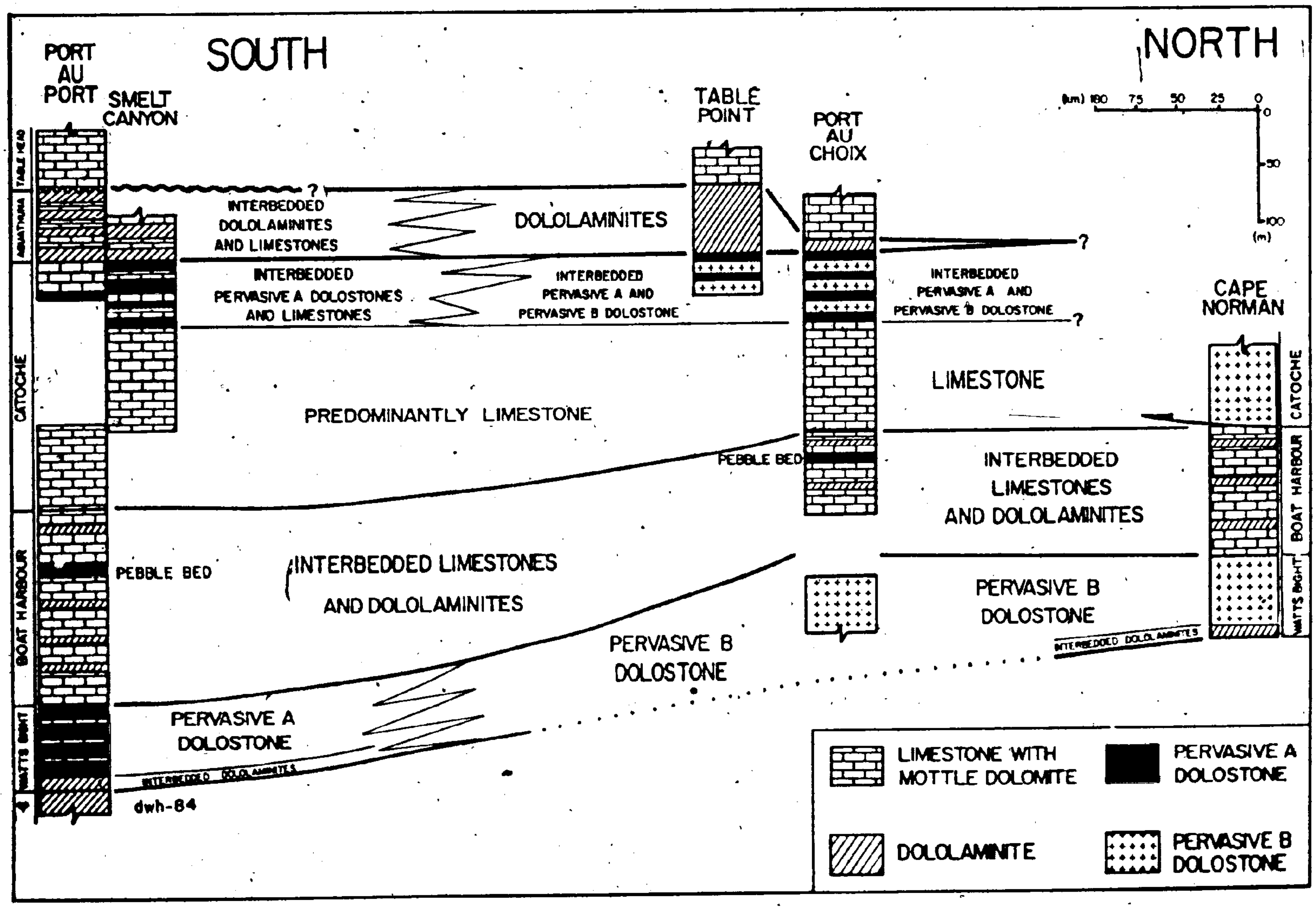
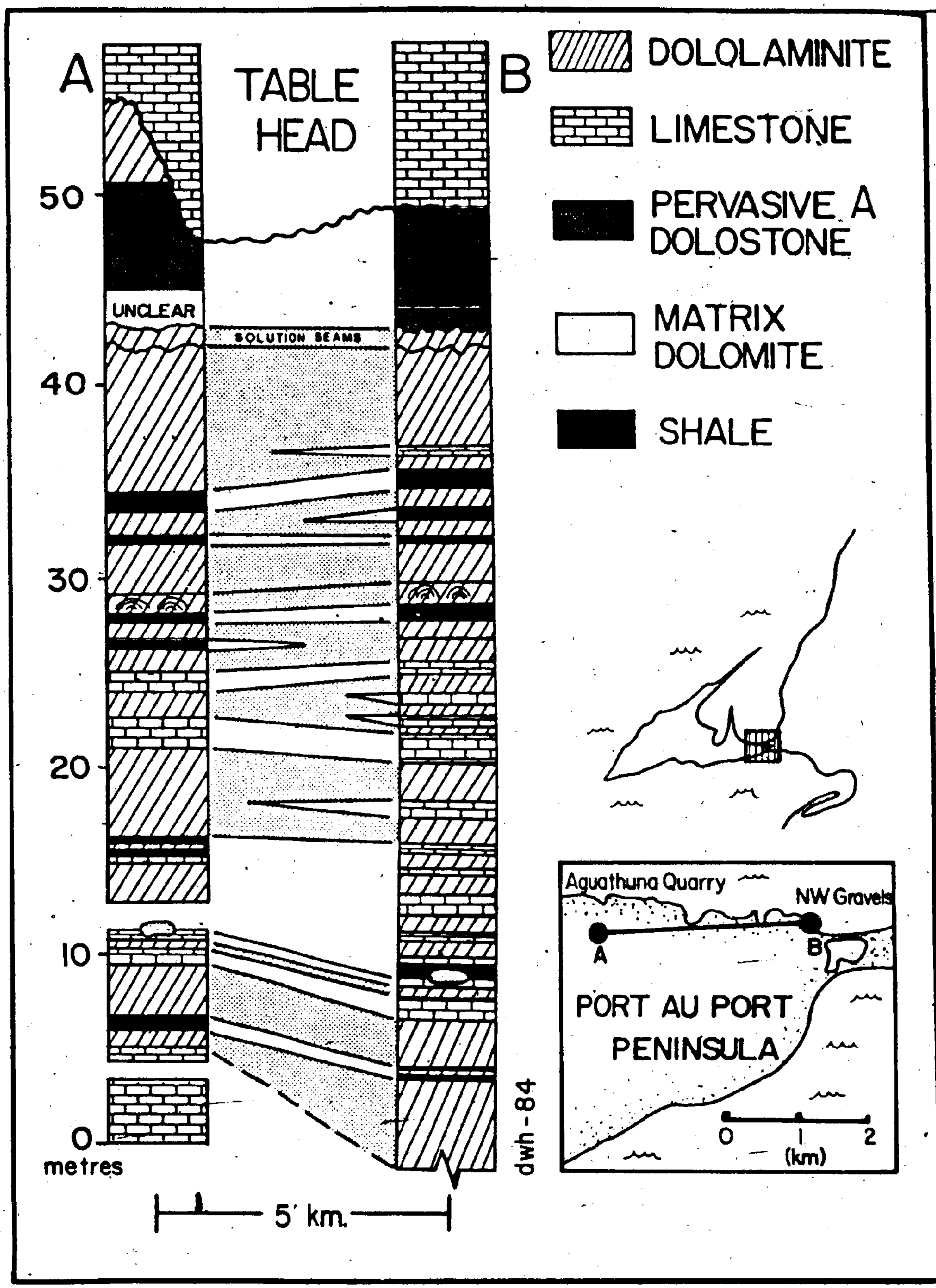

SOUTH
NORTH
PORT AU PORT
SMELT CANYON
TABLE POINT
PORT AU CHOIX
CAPE NORMAN
(km) 100 75 50 25 0
0
50
100
(m)
TABLE HEAD
AGUATHUNA
CATOCHE
BOAT HARBOUR
WATTS BIGHT
INTERBEDDED DOLOLAMINITES AND LIMESTONES
DOLOLAMINITES
INTERBEDDED PERVASIVE A DOLOSTONES AND LIMESTONES
INTERBEDDED PERVASIVE A AND PERVASIVE B DOLOSTONE
INTERBEDDED PERVASIVE A AND PERVASIVE B DOLOSTONE
LIMESTONE
PREDOMINANTLY LIMESTONE
PEBBLE BED
INTERBEDDED LIMESTONES AND DOLOLAMINITES
PEBBLE BED
INTERBEDDED LIMESTONES AND DOLOLAMINITES
PERVASIVE B DOLOSTONE
PERVASIVE B DOLOSTONE
PERVASIVE A DOLOSTONE
INTERBEDDED DOLOLAMINITES
INTERBEDDED DOLOLAMINITES
dwh-84
LIMESTONE WITH MOTTLE DOLOMITE
PERVASIVE A DOLOSTONE
DOLOLAMINITE
PERVASIVE B DOLOSTONE

FIGURE 3.2: Lithostratigraphic correlation of dolomite and dolostone varieties between two measured sections on the Port au Port Peninsula (location Map in inset). Thin units are generally non-correlative over the five kilometres between the sections, whereas thick packages are. The datum for the correlation are two prominent solution seams which are present in both sections.


A
TABLE HEAD
B
DOLOLAMINITE
LIMESTONE
PERVASIVE A DOLOSTONE
MATRIX DOLOMITE
SHALE
UNCLEAR
SOLUTION SEAMS
50
40
30
20
10
0
metres
5 km.
dwh-84
Aguathuna Quarry
NW Gravels
A
B
PORT AU PORT PENINSULA
0
1
2
(km)

3.2 DOLOLAMINITES

DEFINITION AND DESCRIPTION:

The definition and the general characteristics of dololaminites have been briefly discussed in chapter two. The majority of these dolostones are characterized by fine, often cryptalgal, laminations which are prominent because of the accumulation of dark organic rich, insoluble material (plate 3.1a). Ripple scaled crosslaminations, tepee structures (plate 3.1a), desiccation cracks (plate 3.1b), prism cracks and intraformational breccias (plate 3.1c) are also abundant.

Cryptalgal laminations may pass vertically or laterally into dicontinuous centimetre to metre scaled, burrow mottled intervals (plate 3.1d) or into thin (less than one metre), poorly developed, LLH stromatolite horizons. Rarely, no structures whatsoever are preserved in these rocks, possibly as a result of intense bioturbation. Despite this variability, all of these dolostones are essentially the same. All are composed of the same buff to black weathering, microcrystalline to very finely crystalline dolomite. They frequently contain fenestrae and chert nodules with entombed evaporite minerals and may be hosts to centimetre-scale, calcite spar-filled vugs. Some vugs contain internal sediment displaying geopetal texture, and pseudomorphs of calcite after gypsum. It would appear that textural variability, (on a very localized scale), is itself a characteristic of dololaminites, and subsequently, further

PLATE 3.1: FIELD CHARACTERISTICS OF DOLOLAMINITES.

A) Fine millimetre scaled laminations and tepees (arrow) viewed in vertical section; Aguathuna Formation, N.W. Gravels. Divisions on scale bar are 5 cm in length.

B) Polygonal desication cracks (arrow) atop a dololaminite; Boat Harbour Formation, Port au Choix.

C) Rip up pebble breccia localized within the basal portion of a dololaminite bed; Boat Harbour Formation, Isthmus Bay.

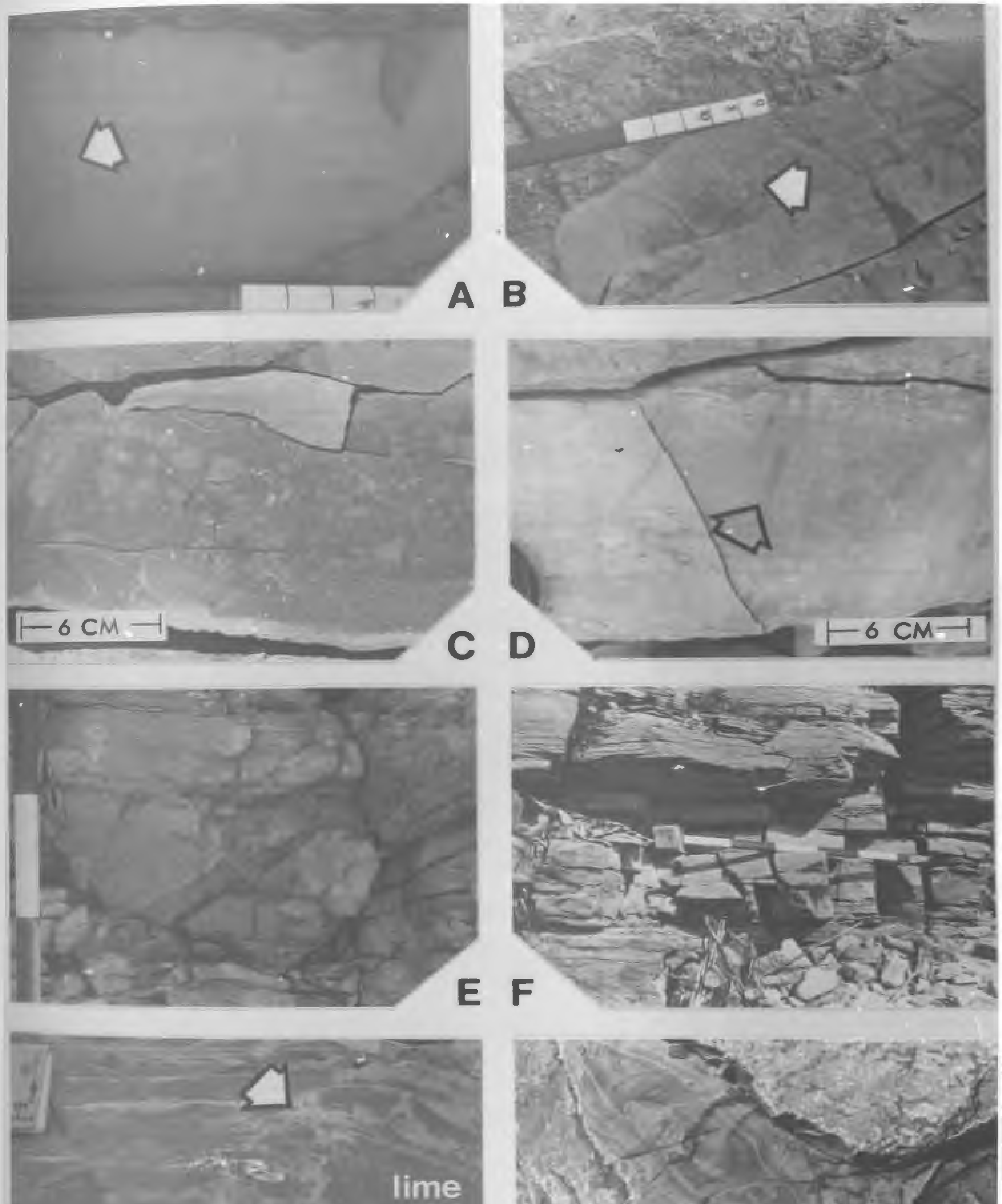
D) Cross-section of burrow mottling (arrow) within a dololaminite; Aguathuna Formation, N.W. Gravels. Bioturbation has destroyed the fine texture of the dolostone in this interval

E) Badly fractured dololaminite; Aguathuna Formation, Aguathuna Quarry. The broken blocks have sharp, jagged edges and concoidal fracture. Divisions on scale bar are 25 cm in length.

F) Dololaminite (behind measuring pole) interbedded with lime mudstones; Boat Harbour Formation, Isthmus Bay. The contacts between the two lithologies in this example are very sharp, but others can be more gradual.

G) Breciated contact between a dololaminite and a limestone (lime); Watts Bight Formation, Berry Head. The fractures which penetrate into the limestone (arrow) are filled with light coloured dolomite from the overlying dololaminite.

H) Liesegang bands developed within a dololaminite. This colour alteration developed adjacent to fractures as a result of oxidizing pore fluids migrating along the fractures.


A
B
C
D
6 CM
6 CM
E
F
lime
G
H

subdivision of this variety is unnecessary.

Dololaminite beds range in thickness from a few centimetres to a maximum of three metres. Frequently, many descrete beds coalesce into intervals 10, or more metres in thickness.

Stylolites and pressure solution seams are rare within dololaminite beds but commonly mark their boundaries with other lithologies. Body fossils are also rare components of these dolostones.

Dololaminites are frequently fractured and this is responsible for the rubbly appearence of some beds (plate 3.1e). The broken blocks have sharp, jagged edges and concoidal fractures. Contacts with limestones are usually sharp to stylolitic (plate 3.1f), but on occasion, are brecciated (plate 3.1g) or gradual.

Many dololaminites on the Port au Port Peninsula are stained a distinctive red colour, commonly with the development of Liesegang bands adjacent to vertical fractures that pass upward into the overlying Carboniferous Codroy Group (plate 3.1h). This colouration is secondary, and probably occurred as a result of oxidizing fluids passing along these fractures after the deposition of the red siliciclastic Codroy sediments (Dix, 1982).

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION:

Dololaminites are confined to the Boat Harbour and Aguathuna Formations and to the basal portion of the Watts

Bight Formation. They are found in all parts of the study area.

Individual dololaminites beds are generally not correlative over large or regional distances (Pratt, 1979; figure 3.1); however, packages of dololaminites a metre or more in thickness can be traced approximately 5 kilometres between measured sections on the Port au Port Peninsula (figure 3.2).

Bioturbated intervals are best developed within the Aguathuna Formation northwest of The Gravels on the Port au Port Peninsula and at Table Point on the Great Northern Peninsula.

3.3 MATRIX DOLOMITE

DEFINITION AND DESCRIPTION:

This variety of dolomite selectively replaces the matrix or intergranular areas in packstones and grainstones. Grains, allochems, cements, body and trace fossils, are usually unaltered; however, occasionally dolomitization is more extensive and these components may also be replaced.

Dolomite rhombs are medium crystalline (200 to 300 micrometres), white to medium grey weathering and range in proportion from approximately 5 percent to about 40 percent, depending upon the extent of replacement (plate 3.2a). Rarely, matrix dolomite may replace up to 85 percent of the precursor limestone.

PLATE 3.2: FIELD CHARACTERISTICS OF MATRIX DOLOMITE.

A) Matrix dolomite (arrow) within a packstone; Watts Bight Formation, Isthmus Bay. The dolomite replacement is very "patchy," and parts of the limestone are preferentially replaced over others. Lens cap is 6 cm in diameter.

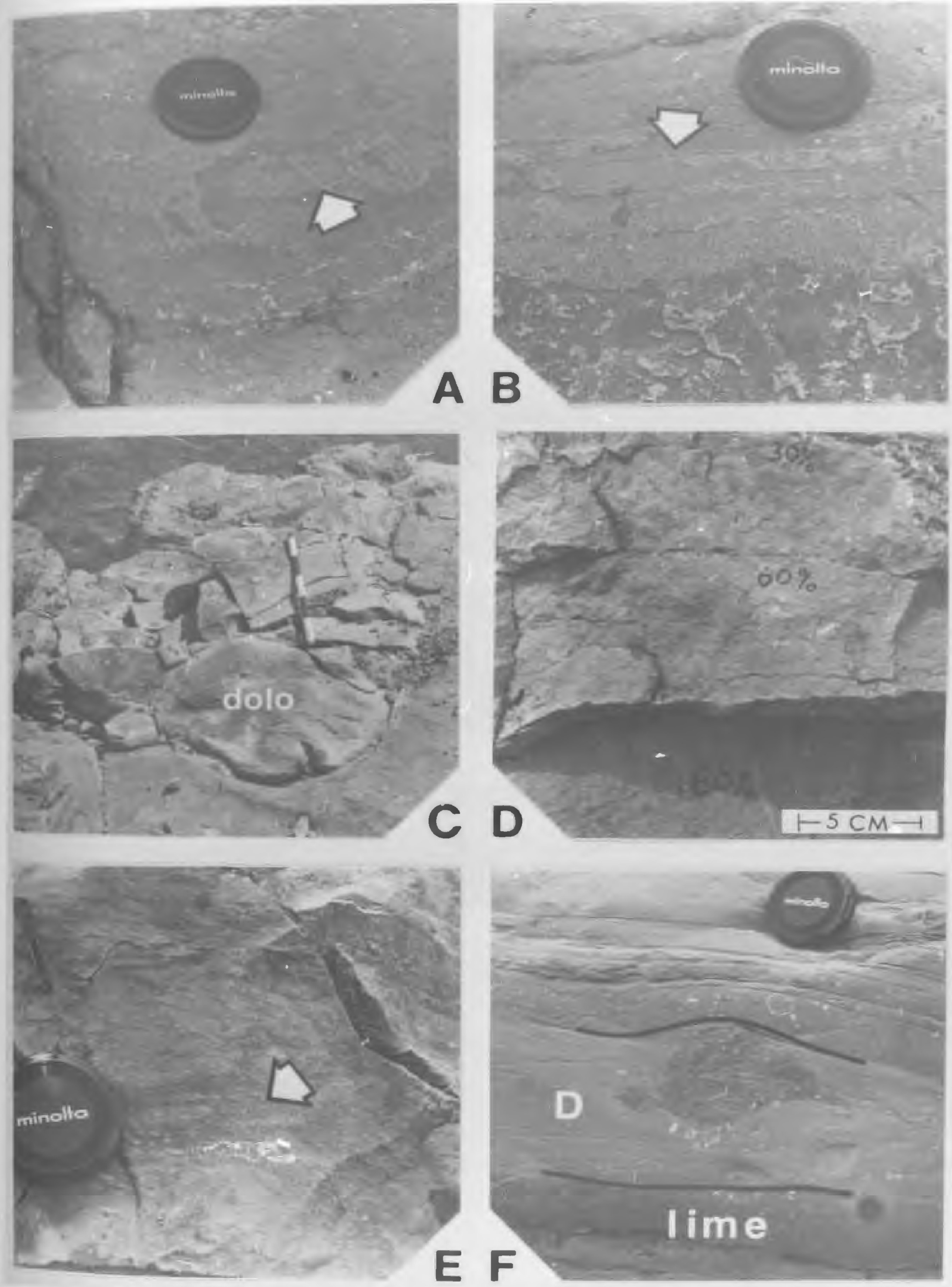
B) Stylolites (arrows) marking the contacts between matrix dolomite - rich (lighter areas) and matrix dolomite - poor intervals (darker areas); Watts Bight Formation, Isthmus Bay. This rock is also in sharp contact with the underlying lithology; a dolomite mottled limestone.

C) "Pod" of matrix dolomite (dolo) within a lime mudstone; Aguathuna Formation, N.W. Gravels. This occurrence of matrix dolomite is characterized by sharp lateral and vertical contacts resulting in a "concretionary like" appearence to the pod.

D) Gradual transition from matrix dolomite "rich" to matrix dolomite "poor" limestones; Watts Bight Formation, Isthmus Bay. The numbers painted on the side of the rock are approximate percentages (visually estimated) of dolomite within the limestone.

E) Black, organic rich bands (arrow) within a matrix dolomite - rich interval; Watts Bight Formation, Isthmus Bay.

F) Small stromatolite preserved within matrix dolomite - rich" interval (ca. 80 percent dolomite; D) in a mudstone (lime); Watts Bight Formation, Isthmus Bay.


minolta
minolta
A
B
dolo
30%
60%
⊢5 CM⊣
C
D
minolta
minolta
D
lime
E
F

Matrix dolomite is also found in some mudstones or wackestones. Rhombs of dolomite are evenly distributed throughout the rock (as opposed to being fabric selective), are finely crystalline (100 micrometres) and buff weathering. The degree of replacement is similar to that observed in coarse grained limestones (ranges from 5 to approximately 40 percent).

Matrix, dolomite-rich intervals (those containing more than 50 percent dolomite) are of very limited vertical extent and are usually seperated from matrix dolomite-poor intervals (those containing less than 50 percent dolomite) by stylolites. The contacts between limestones containing matrix dolomite and other lithologies is also usually sharp and stylolitic (plate 3.2b). In rare mudstones, lateral transitions are also sharp and this results in concretionary-looking pods of matrix dolomite (plate 3.2c). Gradational variations in the proportion of matrix dolomite, both laterally and vertically, are much less common (plate 3.2d).

In coarse grained limestones, matrix dolomite-rich intervals may be up to 1 metre in thickness, are buff to rust coloured and contain abundant intercrystalline porosity, late calcite pore filling calcite cement and black, (organic rich?), material. This gives rise to a conspicuous dark and "wispy" appearance to some of the beds (plate 3.2e). A prominent bituminous odour on fresh surfaces is due to intercrystalline gaseous hydrocarbons *.

The original fabric of matrix dolomite rich limestones is seldom preserved. Occasionally though, the dolomite replaces some portions of the limestone bed over others thus preserving a portion of the original fabric. Stromatolites appear to be especially resistent and can be found "floating" in these intervals (plate 3.2f).

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION:

Matrix dolomite is uncommon and accounts for no more than one or two percent of the total dolomite within the St. George Group. It is best developed in packstones of the Watts Bight and Boat Harbour Formations in the Port au Port area (Isthmus Bay and Berry Head sections; appendix A). Most of these occurrences cut across bedding rather than being confined to individual beds. Pods of matrix dolomite are contained within a mudstone bed in the Aguathuna Formation northwest of the Gravels and at Aguathuna Quarry (figure 3.2).

Matrix dolomite can also be found in minute quantities in the Boat Harbour and Catoche Formations on the Great Northern Peninsula. Here however, it is more difficult to recognize because of additional phases of dolomitization which have overprinted the rocks.

* A powdered sample of this rock yielded 0.43 milligrams of soluble organic extract per gram of rock. These organics are highly biodegraded and contain no normal alkanes (R. Quick, pers. comm.).

3.4 MOTTLE DOLOMITE

DEFINITION AND DESCRIPTION:

This variety of dolomite was originally referred to as intramuros (Latin for "within the walls") by Haywick and James (1984). Subsequent study has demonstrated that this term is too restrictive, and hence, it has been dropped in favor of mottle dolomite.

Mottle dolomite replaces specific components within limestones. The dolomite is usually buff to light grey and is finely crystalline (ca. 100 micrometres). The most commonly selected components are ichnofossils (plate 3.3a,b), stylolites (plate 3.3c) and the shell walls of coiled and spiral gastropods (especially Maclurites; plate 3.3d). Nautiloids, and the outer shell wall of other cephalopods are less commonly replaced.

Mottle dolomite often has a "salt and pepper" appearence due to the combination of light coloured dolomite crystals and dark, intercrystalline porosity. Lichen, perhaps taking advantage of the increased porosity, preferentially grow within the mottles on the upper surfaces of limestones.

Trace fossils are not very diverse in St. George limestones, but nevertheless, are abundant. The most abundant varieties, and those most frequently dolomitized, are the branching burrow systems; Palaeophycus, Thalassinoides and Spongeliomorpha (G. Narbonne, pers. comm.). Other less common trace fossils that are

PLATE 3.3: FIELD CHARACTERISTICS OF MOTTLE DOLOMITE.

A) Preferentially dolomitized ichnofossils (Palaeophycus?) atop a limestone bedding plane; Boat Harbour Formation, Isthmus Bay.

B) Cross-section of preferentially dolomitized ichnofossils; Boat Harbour Formation, Isthmus Bay. Some of these trace fossils have been strung out horizontally, due to compaction and pressure solution (arrow).

C) Cross-section of a polished rock slab mottled extensively by preferentially dolomitized burrows (arrow) and solution seams; Catoche Formation, Smelt Canyon. The dolomite is light coloured in comparison to the dark limestone.

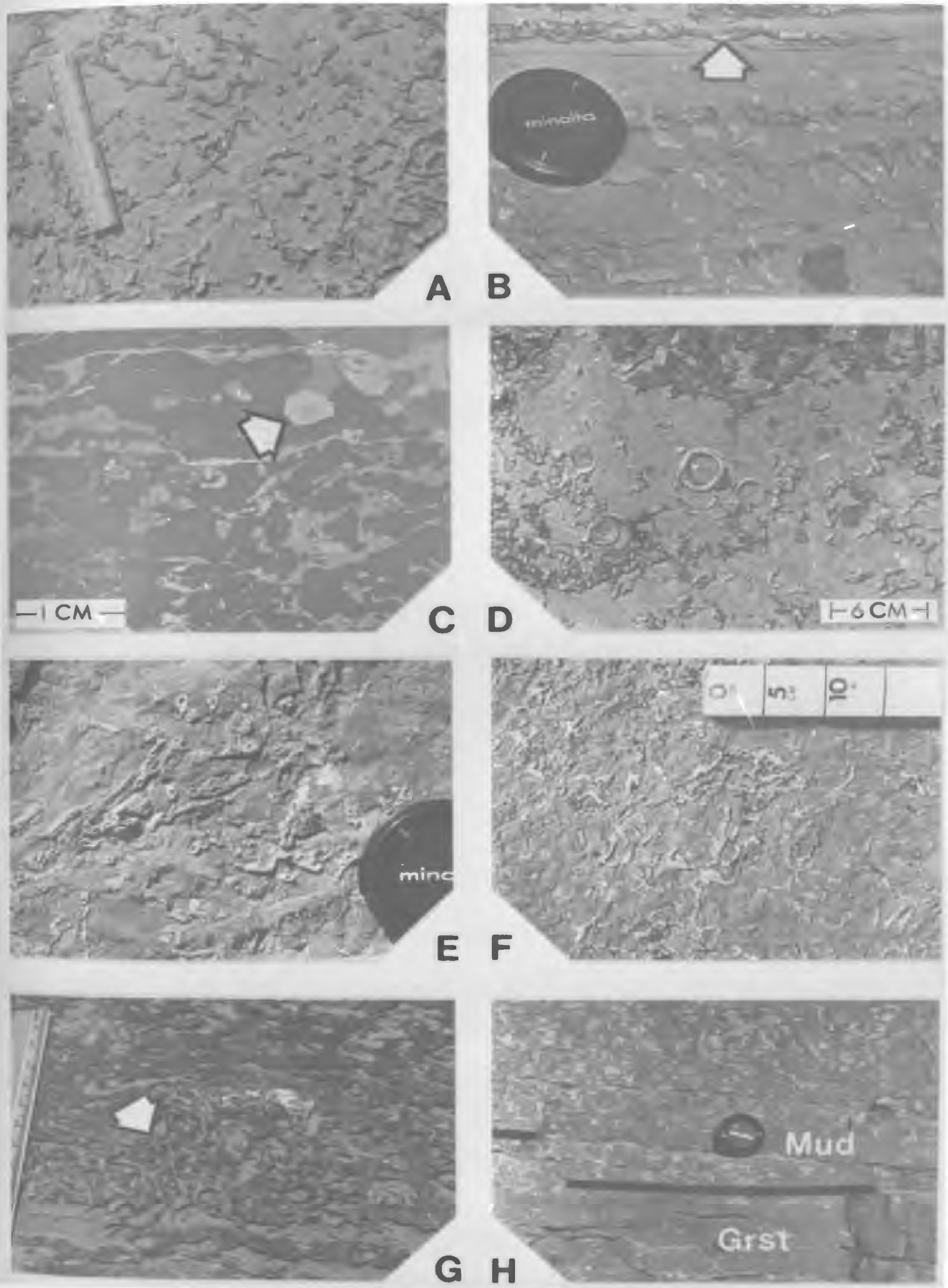
D) Preferentially dolomitized gastropods atop a limestone bedding plane; Boat Harbour Formation, Hare Bay. Only the shell walls have been replaced by dolomite.

E) Preferentially dolomitized ichnofossils atop a limestone bedding plane; Boat Harbour Formation, Isthmus Bay. In this example, only the margins of the trace fossils are replaced; the cores remain free of dolomite.

F) Preferentially dolomitized ichnofossils atop a limestone bedding plane; Boat Harbour Formation, Isthmus Bay. Unlike those pictured above, these trace fossils are completely replaced by dolomite.

G) Extensively dolomitized trace fossils viewed in cross-section; Boat Harbour Formation, Isthmus Bay. In this example, mottle dolomite has spread out from the confines of the trace fossils and into the neighbouring limestone. The original character of the mottles is no longer apparent although some ichnofossils are still recognizable (arrow). The majority of the mottles are also strung out horizontally due to physical compaction and/or pressure solution (as at the bottom of the photo).

H) Variations in the amount of mottle dolomite within different textures of limestone; Watts Bight Formation, Berry Head. The mudstone (Mud) contains approximately 20 percent mottle dolomite whereas the grainstone (Grst) contains only a trace.


A
B
minolta
C
D
1 CM
6 CM
E
F
minc
0
5
10
G
H
Mud
Grst

preferentially dolomitized include; Trichnichus, Chondrites and the lined burrow Diplocraterion (G. Narbonne, pers. comm.). Skolithos burrows are rare and are not normally replaced by dolomite. Burrows and burrow systems range in length from less than one, to approximately 15 centimetres.

Replaced ichnofossils and shelly fossils are most readily identifiable on bedding surfaces. In cross-section, many of these mottles are "strung out" horizontally in response to physical compaction (plate 3.3b).

The amount of dolomite associated with these components is variable. In some limestones, only the margins of ichnofossils are replaced and the cores remain free of dolomite (plate 3.3e), whereas in other limestones, the burrows are completely replaced (plate 3.3f). Occasionally, the dolomite is not wholly confined to the margins of body fossils and trace fossils, and some of the adjacent limestone is also replaced (plate 3.3g). It is not possible solely on the basis of field relationships to determine whether this variation represents different intensities of the same dolomitization event, (in which case the dolomite would be the same in all mottles), or if it represents intial nucleation in the walls of the features followed by later replacement of the surrounding medium (in which case the dolomite in the margins would differ from the dolomite around the margins; figure 3.3).

In many limestones, mottle dolomite is localized

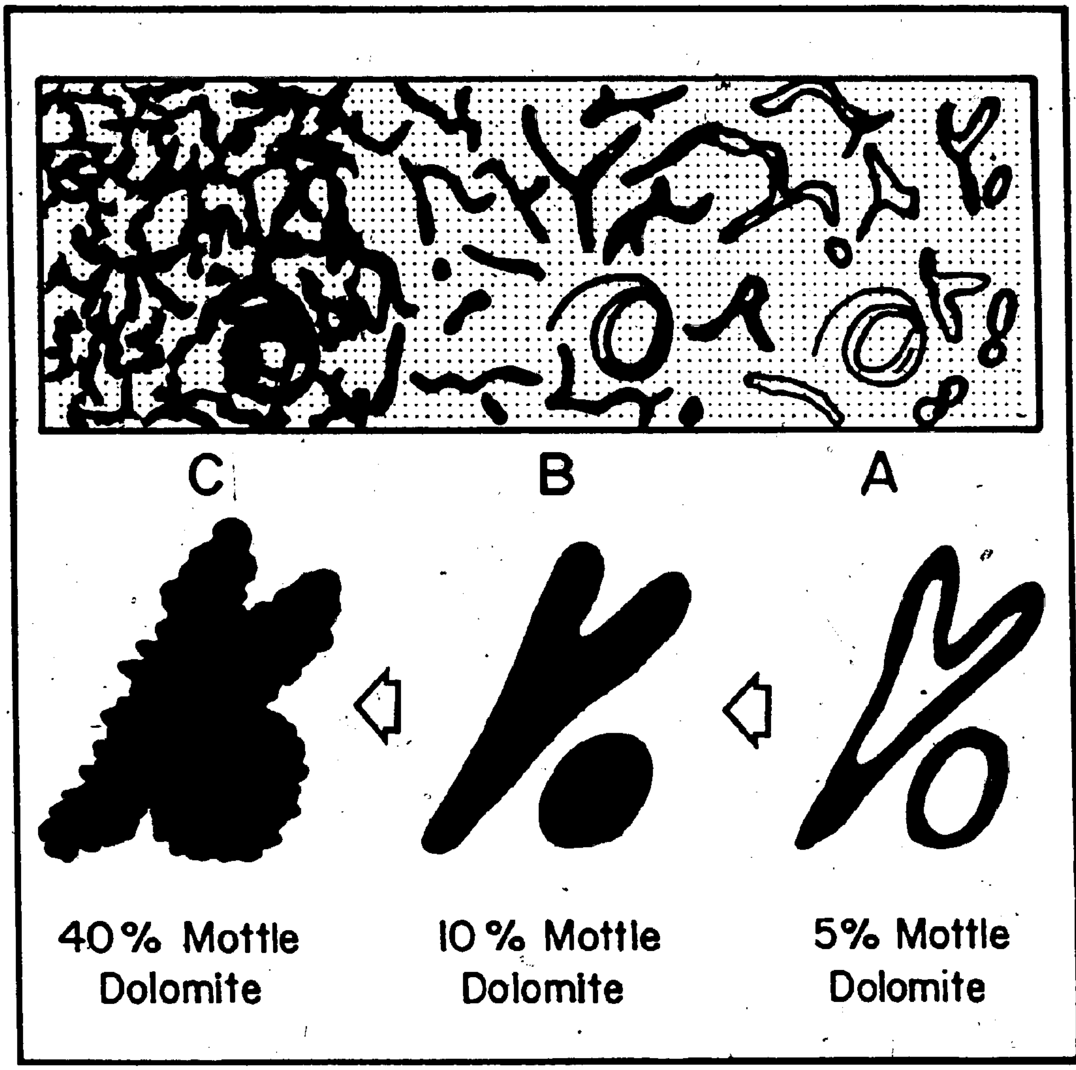


FIGURE 3.3: Variations in the amount of mottle dolomite (coloured black) observed atop a hypothetical St. George limestone bed (stippled). Mottle dolomite can be localized along the margins of ichnofossils, or within the shell walls of some shelly fossils (as in A), or it can completely replace these components (B). Occasionally, some of the surrounding limestone is also replaced making the identification of the individual components difficult (C). This entire range of replacement can occur within a single limestone bed, but the transitions are more gradual than illustrated here.

partially or entirely along pressure solution seams and stylolites (refer to plate 3.3c). These components range in size from one to five centimetres in length and are associated with planar to subplanar, anastomosing stylolites (hummocky to anastomosing configuration of Logan and Semeniuk, 1976).

The amount of mottle dolomite within limestones is variable and ranges from trace quantities to a maximum of approximately 40 percent. The amount within individual limestones is normally fairly constant, but vertical and lateral variations are not uncommon. There may be a marked increase in the number of dolomitized ichnofossils upward if the overlying lithology is a dolostone. Variations in the amount of dolomite along stylolites appears to be related to the number of pressure solution seams.

Dolomite crystals that are responsible for the mottles within St. George limestones are identical in size, crystallinity and colour regardless as to the principle component of the mottles. The only significant difference is that stylolite mottles are more recessive than ichnofossil mottles and may contain an appreciable clay content.

Limestones which contain the most mottle dolomite are usually fine-grained mudstones and wackestones. Grainstones are seldom host to more than five percent of this variety (plate 3.3h). Stylolites are common in grainstones, but are of a columnar to peaked-high amplitude (to 2 centimetres) configuration (Logan and Semeniuk, 1976), not the planar configuration that appears to be the locus for dolomitization along most stylolites.

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION:

Mottle dolomite is the most widespread variety within the St. George Group. With the possible exception of grainstones, it is present in almost every limestone bed and in every formation throughout the study area. Limestones containing mottle dolomite are laterally continuous on a regional scale (figure 3.1).

Most of the occurrences of mottle dolomite are due to a combination of ichnofossils and stylolites. Limestones which contain exclusively one or the other of these two end members are less common. "Burrow-only" mottles occur in the Watts Bight Formation at Berry Head and Isthmus Bay (Port au Port area), within the Boat Harbour Formation at Isthmus Bay and Lower Cove (Port au Port Peninsula) and at Port au Choix, Back Arm and Cape Norman (Great Northern Peninsula). They can also be found within the upper Catoche Formation at Lower Cove, Port au Choix and Back Arm.

"Stylolite-only" mottles are best developed within the Catoche Formation at Smelt Canyon and near Cape Norman.

3.5 PERVASIVE DOLOSTONES

DEFINITION AND DESCRIPTION:

Pervasive dolostones are rocks that have a distinctive mottled appearence to them. Two subtypes, A and B, are recognized within the St. George and in both, the mottled areas are composed of darker, more finely crystalline dolomite than are the interareas. Both varieties commonly preserve stromatolitic and thrombolitic structures

The two subtypes differ enough from each other to warrant sêperate classification and discussion. They are distinguished from one another principally by the nature of the dolomite in the interareas between mottles.

<u>Pervasive</u> <u>A</u> <u>Dolostone</u>:

The dolomite in the interareas in these dolostones is medium crystalline (averages 300 micrometres in size) and dove grey weathering. Mottles are darker imparting a medium grey colour to the rock. Interareas, because of the coarser dolomite crystal size, are more porous than the mottled intervals and as a result, may contain minor amounts of pore filling calcite cement. The rock emits a slight to strong bituminous odour when freshly broken.

Mottles account for between 50 and 80 percent of the volume of pervasive A dolostones and are usually non-descript (plate 3.4a). Those that can be identified are exclusively ichnofossils.

PLATE 3.4: FIELD CHARACTERISTICS OF PERVASIVE A DOLOSTONE.

A) Non-descript mottling within pervasive A dolostone; Boat Harbour Formation, Isthmus Bay. Mottles are composed of a finer crystalline dolomite than are the intermottle areas. Lens cap is 6 cm in diameter.

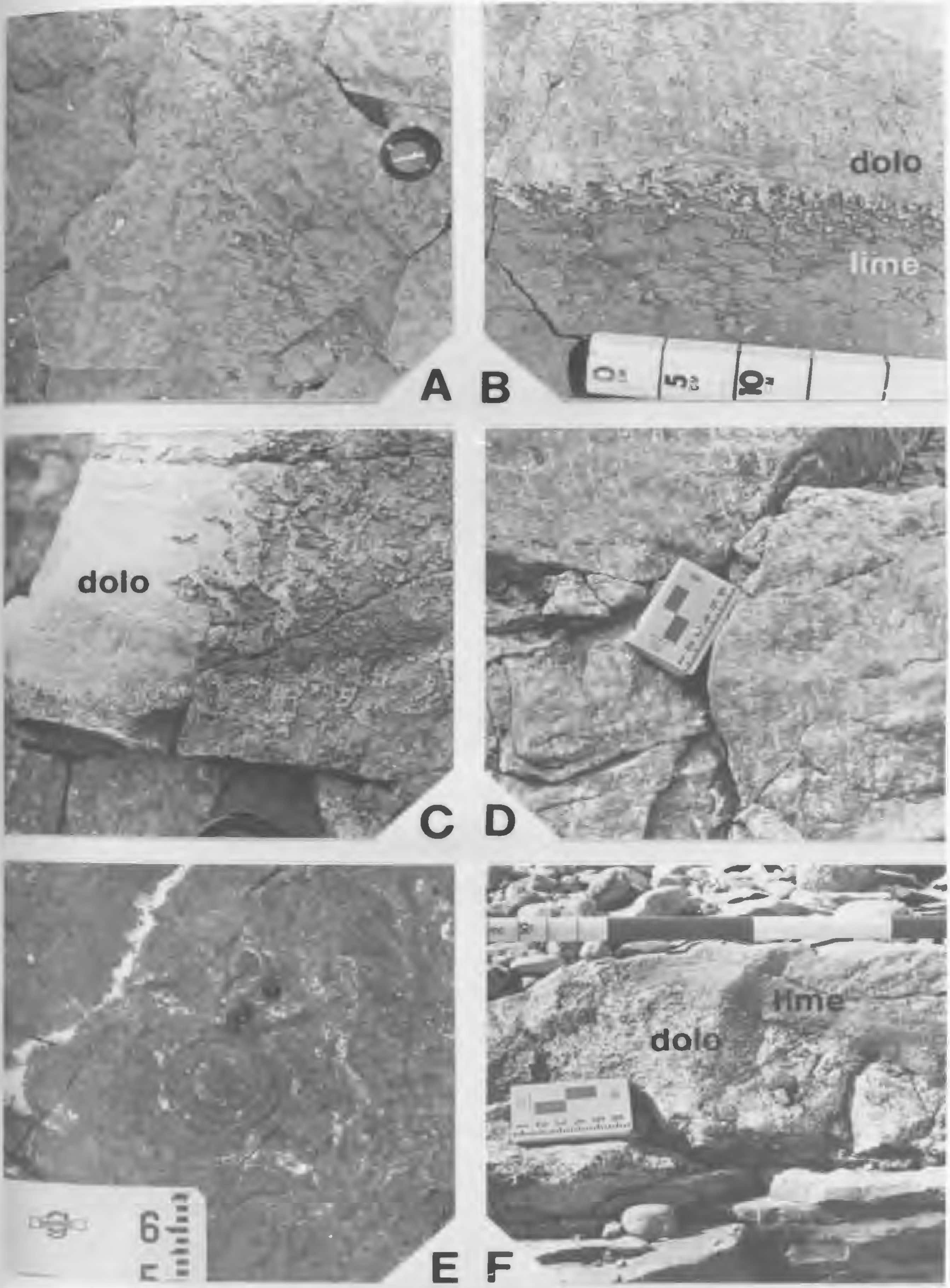
B) Sharp vertical transition from limestone (lime) to pervasive A dolostone (dolo); Watts Bight Formation, Berry Head. The mottles within the limestone are stylolitic; however, the mottles that are recognizable within the dolostone are usually ichnofossils.

C) Lateral transition from pervasive A dolostone (dolo) to burrow mottled limestone; Boat Harbour Formation, Isthmus Bay.

D) Digitate stromatolites (or thrombolites) preserved within pervasive A dolostone of the Green Head Bioherm; Watts Bight Formation, Isthmus Bay.

E) Gastropods atop pervasive A dolostone; Boat Harbour Formation, Back Arm. The gastropods are preferentially replaced by the same fine dolomite that is found within the mottles.

F) Pervasive A dolostone (dolo) developed beneath the pebble bed and cutting across a lime wackestone; Boat Harbour Formation, Isthmus Bay.


A
B
dolo
lime
C
dolo
D
E
F
lime
dolo

Pervasive A dolostones commonly grade vertically or laterally into dolomite mottled limestones. The transition is accompanied by a decrease in the amount of dolomite within, and between the mottles until a point is reached (normally well into the limestone), when individual components become identifiable. Most frequently, these components are ichnofossils (plate 3.4b,c, figure 3.4).

Stromatolitic or thrombolitic horizons, especially within the Green Head Bioherm (Watts Bight Formation, Isthmus Bay section), are readibly identifiable because of their characteristic shapes (plate 2.1b,c, 3.4d). Bioturbation between the mounds prior to lithification (and dolomitization) is suggested by the mottled appearance of these intervals.

Dolomitization of mounds and bioherm buildups (especially thrombolites) is variable. In rocks composed of less than about ninety percent dolomite, only sediment between the thrombolites has been dolomitized while the algal mound itself is unaltered. Elsewhere, individual mounds within limestones are preferentially dolomitized.

Spiral and coiled gastropods and rare orthocones are preserved in these dolostones and easily recognized because their shell walls are composed of the same dark, finely crystalline dolomite that is localized within the mottles (plate 3.4e). Apart from these body fossils (and algal structures), no other fauna or fabrics are preserved in pervasive A dolostones.

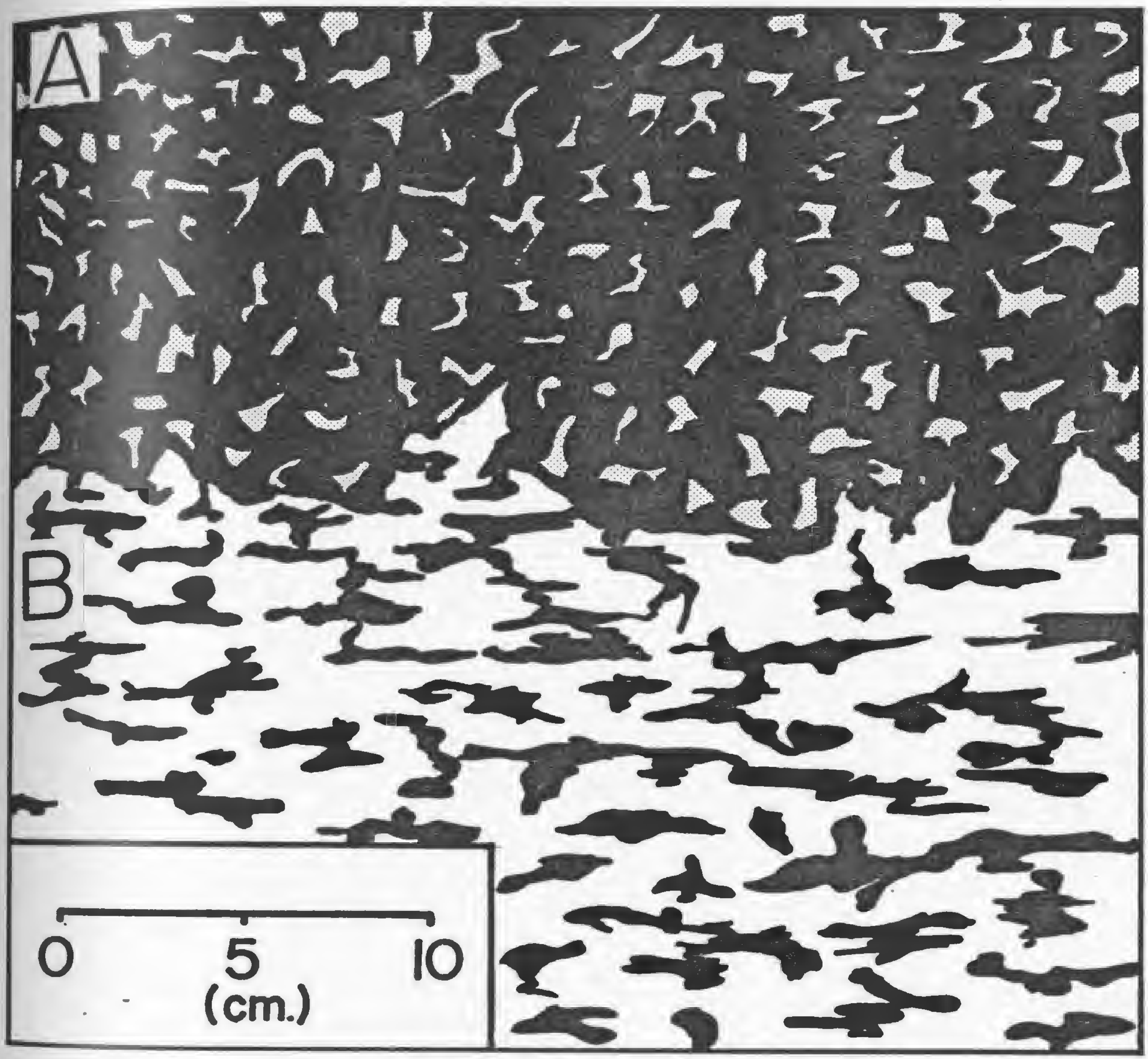


FIGURE 3.4: A sketch illustrating the transition between pervasive A dolostone (A) and dolomite mottled limestone (B). The proportion of finely crystalline mottles (black) is much higher in the dolostone than in the limestone (white) making their identification subjective. Intermottle areas within the dolostone (stippled) are composed of a more coarsely crystalline dolomite than are the mottles. Only in the limestone can the mottles be identified, in this example as trace fossils smeared out along stylolites.

Single pervasive A dolostone beds range in thickness from 30 centimetres to approximately 2 metres, but sequences can be up to 15 metres thick without a change in the lithology.

Most pervasive A dolostones are stratabound, confined to distinct beds and although they may be laterally discontinuous (as in plate 3.4c), only rarely do they cut across or truncate other lithologies (plate 3.4f).

Pervasive B Dolostone:

The interareas between mottles in pervasive B dolostones are composed of white to pink, coarsely crystalline dolomite (ranges from 1 to 5 millimetres), imparting a light pink to grey colour to this rock.

Unlike pervasive A dolostone, the proportion of the dark mottles seldom exceeds 40 percent of the host and if well exposed on bedding plane surfaces, they can clearly be identified as ichnofossil traces (plates 3.5a,b). In cross-section however, burrows are not recognizable and mottles are noticably "strung-out" along stylolites (plate 3.5c). Coiled and spiral gastropods are conspicuous on bedding planes because the shell walls are composed of the same dark, finely crystalline dolomite as is found within the trace fossils and mottles (plate 3.5d). Stromatolites and thrombolites in mound intervals are replaced by the coarser, lighter coloured dolomite rather than the finer, darker dolomite (refer to plate 2.1a,b).

PLATE 3.5: FIELD CHARACTERISTICS OF PERVASIVE B DOLOSTONE.

A) Ichnofossils (Palaeophycus?; arrow) atop a pervasive B dolostone bedding plane: Catoche Formation, Table Point. The dark mottles stand out clearly from the rest of the light coloured rock.

B) As above. The margins of these ichnofossils are preferentially replaced by a finely crystalline dolomite. Compare this photo with the mottle dolomite depicted in plate 3.3e).

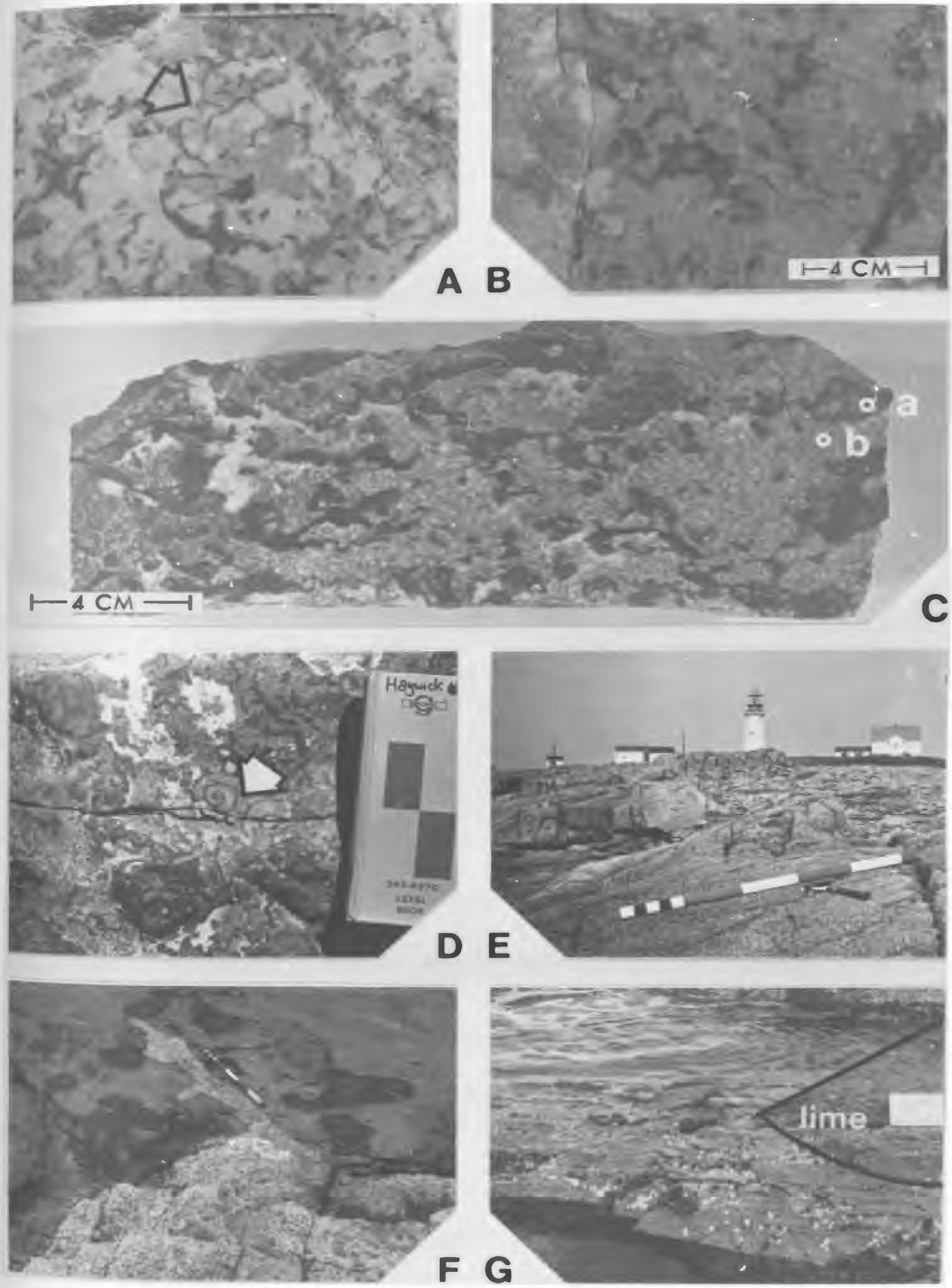
C) Cross-section of a polished rock slab showing the appearence of the mottles in cross-section; Catoche Formation, Table Point. All of these mottles are strung out along stylolites. The letters a and b refer to sites sampled for isotopic analysis (sample TPii; chapter five and appendix B).

D) Gastropods (arrow) preserved atop a pervasive B dolostone bedding plane; Catoche Formation, Table Point. These gastropods are composed of the same finely crystalline dolomite as are the mottles. Compare this photo with the gastropods preserved by mottle dolomite pictured in plate 3.3d.

E) Continuous and extensive pervasive B dolostone beds; Watts Bight Formation, New Ferolle. Large divisions on scale bar are 25 cm in length.

F) Discontinuous "pan" of pervasive B dolostone in sharp contact with lime wackestones, Catoche Formation, Cape Norman.

G) "Remnant" limestone (lime) within pervasive B dolostones; Catoche Formation, Table Point.


A B
4 CM
a
b
4 CM
C
Haywick
LEVEL BOOK
D E
lime
F G

Interareas between mottles exhibit abundant intercrystalline porosity. Pore space is often filled by calcite, chert, fluorite or euhedral quartz. Much of the intercrystalline pore space in the interareas is also filled by a black bituminous material. Geochemical analysis of a sample of this dolostone yielded 0.26 milligrams of soluble organic extract per gram of rock. The original character of the hydrocarbon is indeterminent. It contains no no mal paraffins and is likely strongly biodegraded (R. Quick, pers. comm., 1984).

Pervasive B dolostone is exceedingly variable in extent. Some beds are laterally continuous over hundreds of metres of section and coalesce with others into widespread terranes (plate 3.5e), whereas other beds come and go over distances as short as a few metres (plate 3,5f). It is this variability that is responsible for "remnant" limestone intervals found localized within otherwise pervasively dolomitized strata (plate 3.5g). In almost all cases, the contacts between pervasive B dolostone and adjacent limestones are sharp and usually planar (plate 3.6a,b). There are no clues within the remnant limestones to explain why they have not been dolomitized or why the contacts with the dolostone are so sharp. There does not appear to be any lithological variation in the limestone and most are either homogeneous mudstones or wackestones.

Pervasive B dolostone is also confined to distinct equidimensional "pods" or flat-lying "pans" within

PLATE 3.6: FIELD CHARACTERISTICS OF PERVASIVE B DOLOSTONE.

A) Sharp contact between pervasive B dolostone (dolo) and a dolomite mottled limestone (lime); Boat Harbour Formation, Port au Choix.

B) Sharp contact between pervasive B dolostone (B), pervasive A dolostone (A) and limestone (lime); Catoche Formation, Cape Norman. Large divisions on scale bar are 25 cm in length.

C) Localization of pervasive B dolostone (D) along a vertical fracture (highlighted); Boat Harbour Formation, Cape Norman.

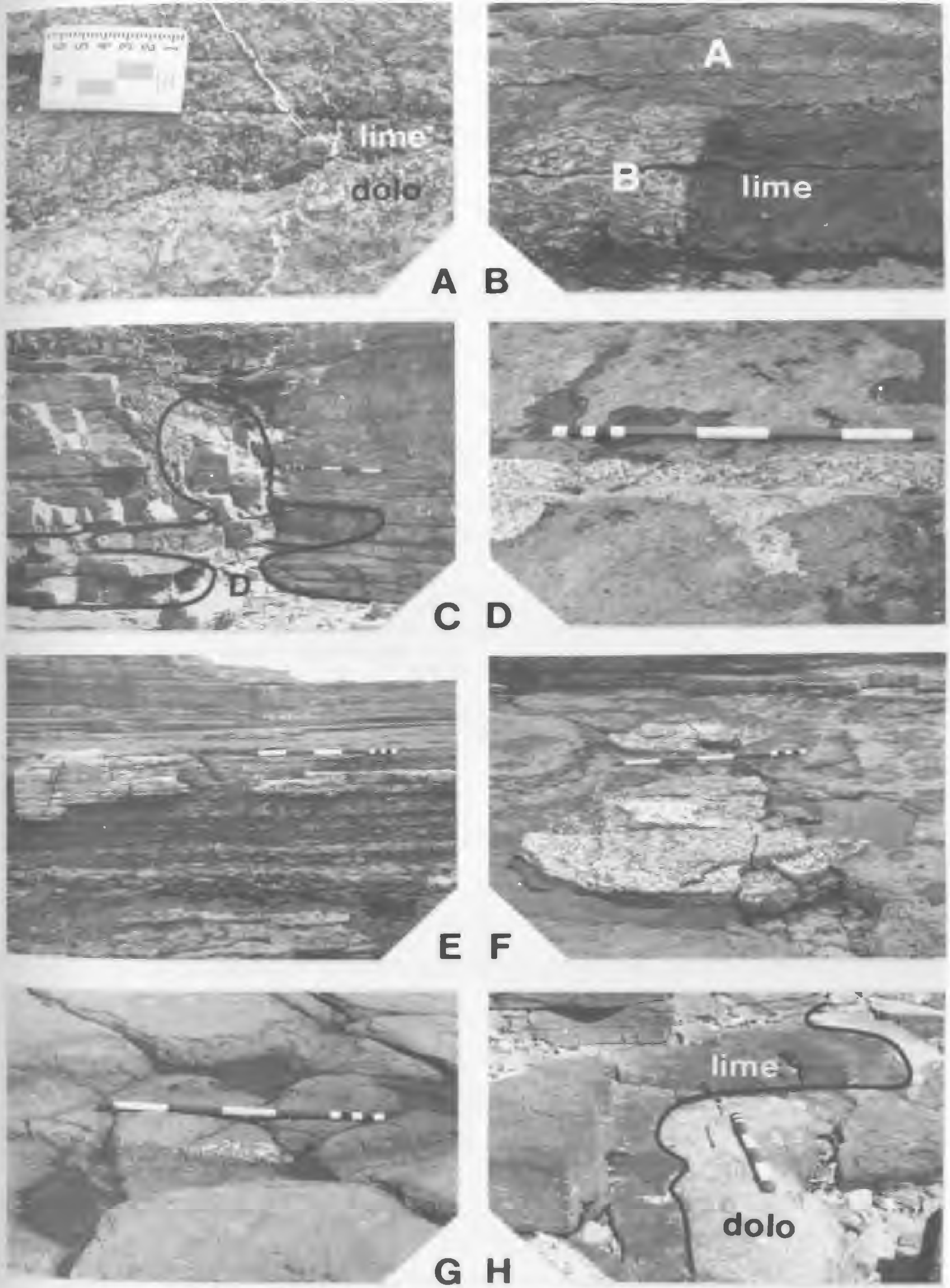
D) Localization of pervasive B dolostone along horizontal, white sparry dolomite filled fractures; Catoche Formation, Cape Norman.

E) Strata bound, equidimensional "pod" (left) and flat lying "pan" (right) of pervasive B dolostone within lime mudstones; Catoche Formation, Cape Norman. These occurrences do not appear to have any association with fractures.

F) Strata bound, flat lying "pans" of pervasive B dolostone, Catoche Formation, Cape Norman. As in the photo above, these occurrences of this dolostone do not appear to be associated with any fractures or veins.

G) Pervasive B dolostone localized within a single thrombolite (or stromatolite) mound ; Boat Harbour Formation, Back Arm.

H) Pervasive B dolostone (dolo) localized along a fault in lime mudstones; Boat Harbour Formation, Plum Point. The fault lies to the right of this photo.


lime
dolo
A
B
lime
A B
D
C D
E F
lime
dolo
G H

limestones. The pods and pans also have sharp contacts and are localized either along vertical or horizontal fractures and joints (plate 3.6c,d), or are strata - bound without any obvious association with fractures (plate 3.6e,f). Some of these latter occurrences may be preferentially dolomitized stromatolite or thrombolite mounds (plate 3.6g).

The area immediately adjacent to faults is also commonly altered to pervasive B dolostone (plate 3.6h).

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION:

Pervasive A dolostone is very widespread both stratigraphically and geographically. It is found in all formations, and in every outcrop studied (figure 3.1).

The Watts Bight Formation is predominantly composed of this dolostone in the Port au Port area, but only contains a few beds in other parts of the study area.

The Boat Harbour Formation is occasionally punctuated by pervasive A dolostone beds in all outcrops, particularly beneath the "pebble bed" on sections on the Port au Port Peninsula (figures 2.2 and 3.1).

The upper portion of the Catoche Formation contains regionally correlative pervasive A dolostones in all sections studied (figure 3.1). Minor beds of pervasive A dolostone are occasionally present in lower portions of the Catoche Formation.

The Aguathuna Formation in all exposures contains pervasive A dolostone beds. In the Port au Port area, these rocks are most abundant towards the upper part of the formation and are developed just below the St. George-Table Head disconformity (figure 3.2).

In contrast to type A, pervasive B dolostones are restricted entirely to outcrops on the Great Northern Peninsula (figure 3.1). Stratigraphically, the distribution is quite widespread and pervasive B dolostones are found within all four formations of the St. George Group.

This dolostone is the dominant lithology in all sections of the Watts Bight Formation on the Great Northern Peninsula. It is much less abundant within the Boat Harbour Formation and tends to be restricted to areas adjacent to faults and fractures or as discrete pods and pans. Pods and pans are also found within the Catoche Formation. Towards the top of the Catoche, thick sequences of pervasive B dolostone coalesce and become interbedded with the pervasive A dolostones. This dolostone package, (the "diagenetic dolomites" of Knight, 1977b, 1980 and Pratt, 1979), occurs everywhere on the Great Northern Peninsula and is regionally correlative (figure 3.1). In the southern portion of the study area, pervasive A dolostone is interbedded with limestone.

Pervasive B dolostone is rare in the Aguathuna Formation, but can be found interbedded with dololaminites in the basal part of the outcrop at Table Point.

3.6 SADDLE DOLOMITE

DEFINITION AND DISTRIBUTION:

This variety of dolomite is localized to fractures, veins (plate 3.7a) and vugs (plate 3.7b) within other rocks. The dolomite crystals are white to pink in colour, are very coarsely crystalline (1 to 15 millimetres in size) and usually possess curved, or distorted crystal faces. This variety of dolomite has been referred to as "white sparry" (Mattes and Mountjoy, 1980), "baroque" (Folk and Assereto, 1974) or "saddle" (Friedman, 1980) and in Newfoundland, is related to sphalerite mineralization at the Newfoundland Zinc Mines near Daniel's Harbour (Cumming, 1968, Collins and Smith, 1975, Coron, 1982, Lane, 1984). In this study, this variety is referred to as saddle dolomite because of the diagnostic "saddle shape" of some of the crystals.

Saddle dolomite, whether in vugs , veins or fractures, contains abundant intercrystalline porosity which may be filled by bituminous material, calcite or chert. The centres of vugs and fractures are even more porous and may contain open voids up to 1 centimetre in diameter. Quartz, fluorite or gypsum mineralization is occasionally localized here.

Saddle dolomite is extensive in the vicinity of Newfoundland Zinc Mines where it commonly develops a fabric referred to as "pseudobreccia" (Collins and Smith, 1975,

PLATE 3.7: FIELD CHARACTERISTICS OF SADDLE DOLOMITE.

A) Fractures filled by saddle dolomite (white) within pervasive A dolostone; Catoche Formation, Table Point.

B) Saddle dolomite confined to spherical vugs within pervasive A dolostone; Boat Harbour Formation, Port au Choix.

C) "Pseudobreccia"; Boat Harbour Formatión, Cape Norman. The dark, finely crystalline dolostone clasts within these rocks, show a strong horizontal imbrication and are generally insitu within the rocks.

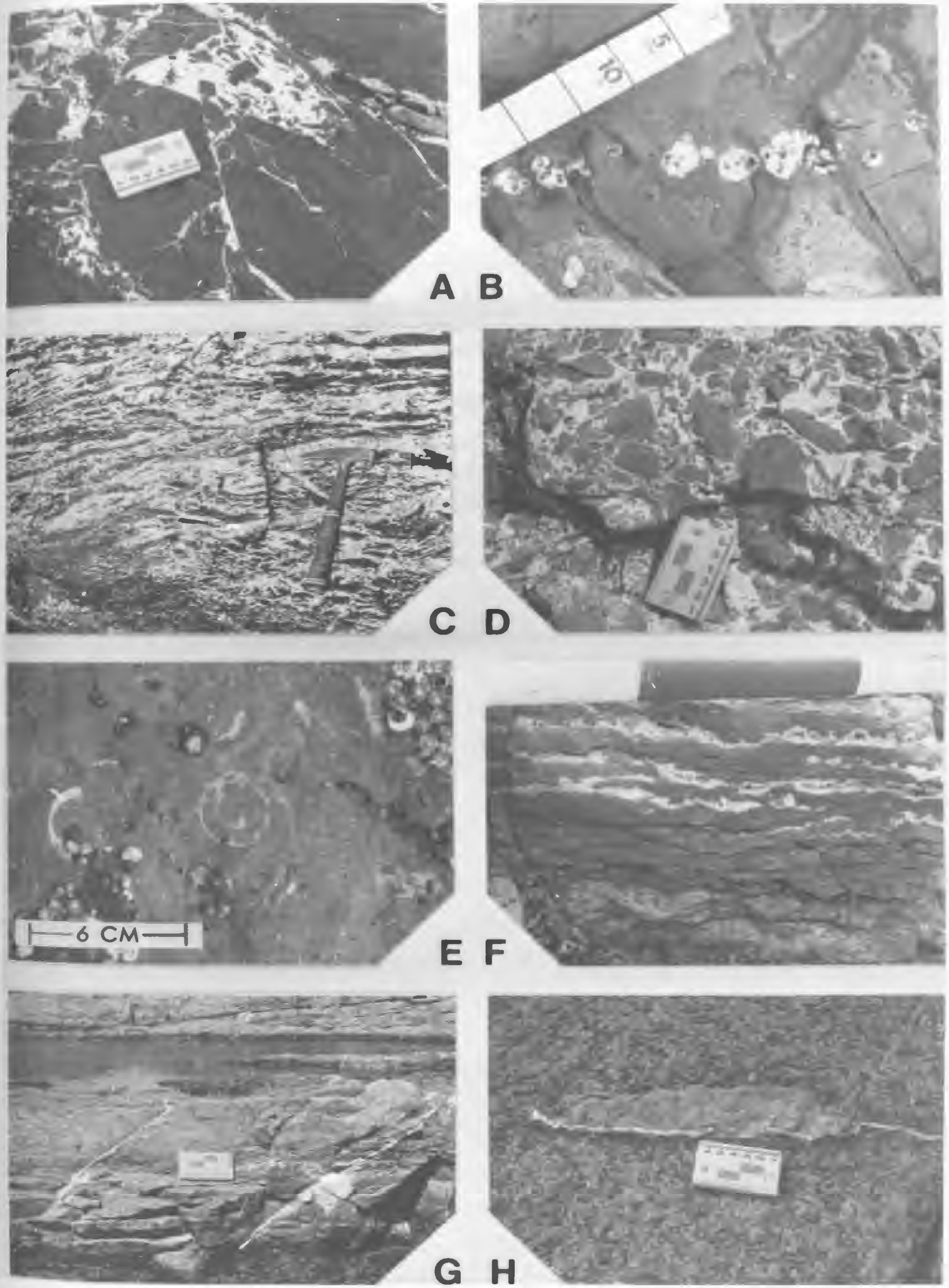
D) "True spar breccia"; Catoche Formation, Newfoundland Zinc Mine, Daniel's Harbour. This breccia differs from the pseudobreccia pictured above because the dark clasts have clearly been displaced and rotated within the host rock.

E) Gastropod shell preferentially replaced by saddle dolomite atop a pervasive A dolostone; Watts Bight Formation, New Ferolle.

F) Saddle dolomite preferentially replacing the coarsely crystalline dolomite between mottles in pervasive B dolostone; Boat Harbour Formation, Back Arm.

G) Fine veinlets of saddle dolomite passing through pervasive A dolostone; Catoche Formation, Table Point. The veinlets do not appear to have diagenetically altered the host dolostone.

H) Thin veinlet of saddle dolomite passing through a fine grained limestone; Catoche Formation, Table Point. Unlike the veinlets which cut through the dolostones pictured above, minor dolomitization in the vicinity of the veinlet has occurred. The resulting dolostone is identical in appearence to pervasive B dolostone.


5
10
A B
C D
6 CM
E F
G H

Lane, 1984). Pseudobreccias (plate 3.7c) are rocks composed of horizontally oriented, dispersed and angular patches of mottle dolomite "floating" in a saddle dolomite cement. The saddle dolomite makes up from 5 to 80 percent of the rock (Lane, 1984).

Lane (1984) distinguishs between true spar breccias and pseudobreccias. Clasts within the true spar breccias (plate 3.7d) have clearly been displaced and rotated, whereas the clasts in the pseudobreccias are generally insitu. Both are present in the mine area and when overlapping, are very difficult to distinguish from one another (Lane, 1984).

Saddle dolomite appears to grow from the margins of open spaces inward toward the centre. Subsequently, fractures and vugs were probably open prior to being filled by the dolomite and therefore, this variety can be regarded as pore filling.

Saddle dolomite also replaces part of the country rock adjacent to fractures or the finely crystalline dolomite within gastropod shells (plate 3.7e). Lane (1984) observed that saddle dolomite locally replaces the finely crystalline dolomite that is the matrix to some breccias near the mine (his "fine rock matrix breccias"). The coarser crystalline interareas of pervasive B dolostone are also commonly replaced by saddle dolomite (plate 3.7f).

Thin veinlets and fractures pass cleanly through dololaminites and pervasive A dolostones without an appreciable effect on the host rock (plate 3.7g). In pervasive B dolostones, veinlets may pass through the whole rock, or may merge into the coarsely crystalline dolomite of the interareas.

The effect of saddle dolomite veins and fractures upon limestones is more dramatic. Small veins may cut across the limestones without visable effect or may cause minor, localized dolomitization (plate 3.7h). The resulting patch of dolostone is identical to pervasive B dolostone pods and pans described from elsewhere on the Great Northern Peninsula. Intense fracturing and "pseudobrecciation" are unknown in limestone lithologies.

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION:

Saddle dolomite is located principally within pervasive B dolostone-rich intervals on the Great Northern Peninsula. It is a common component of the Watts Bight and Boat Harbour Formations and is abundant in the upper third of the Catoche Formation (especially at Table Point and Daniel's Harbour). Saddle dolomite is also found within the Aguathuna Formation at Table Point, but is not common.

There is one very minor occurrence of saddle dolomite in the southern portion of the study area associated with a vertical fault that cuts across a pervasive A dolostone sequence at Isthmus Bay.

3.7 CAVITY - FILLING DOLOSTONE

DEFINITION AND DESCRIPTION:

This variety of dolostone is best described as cavity-filling (Haywick and James, 1984). It occurs in small (less than 30 centimetres), irregularly shaped cavities within pre-existing pervasive A and B dolostones (plate 3.8a,b,c,d). It is buff to green in colour, very finely crystalline (less than 50 micrometres) and usually geopetal. It makes up less than about ten percent of the volume of the host dolostone.

Laminations commonly drape over irregularities at the bottom of the cavities suggesting that fine sediment has rained down upon the floor of an open hole.

The cavities clearly cut across cryptalgal laminations and mottles within the host dolostone (figure 3.5); however, in pervasive B dolostones, veinlets of saddle dolomite are not cut. Occasionally, geopetal cavities are developed, in association with the finely crystalline mottles of these dolostones. Saddle dolomite may fill the void space at the top of the cavities (as in plate 3.8b).

Beneath the "pebble bed" on the Port au Port Peninsula, scalenohedral calcite spar crystals are localized within open pore space near the top of the cavities. These calcite crystals contain abundant, minute pyrite and bitumen inclusions. A breccia, composed of chert and pervasive A dolostone clasts is associated with the cavity - filling dolostone at this location.

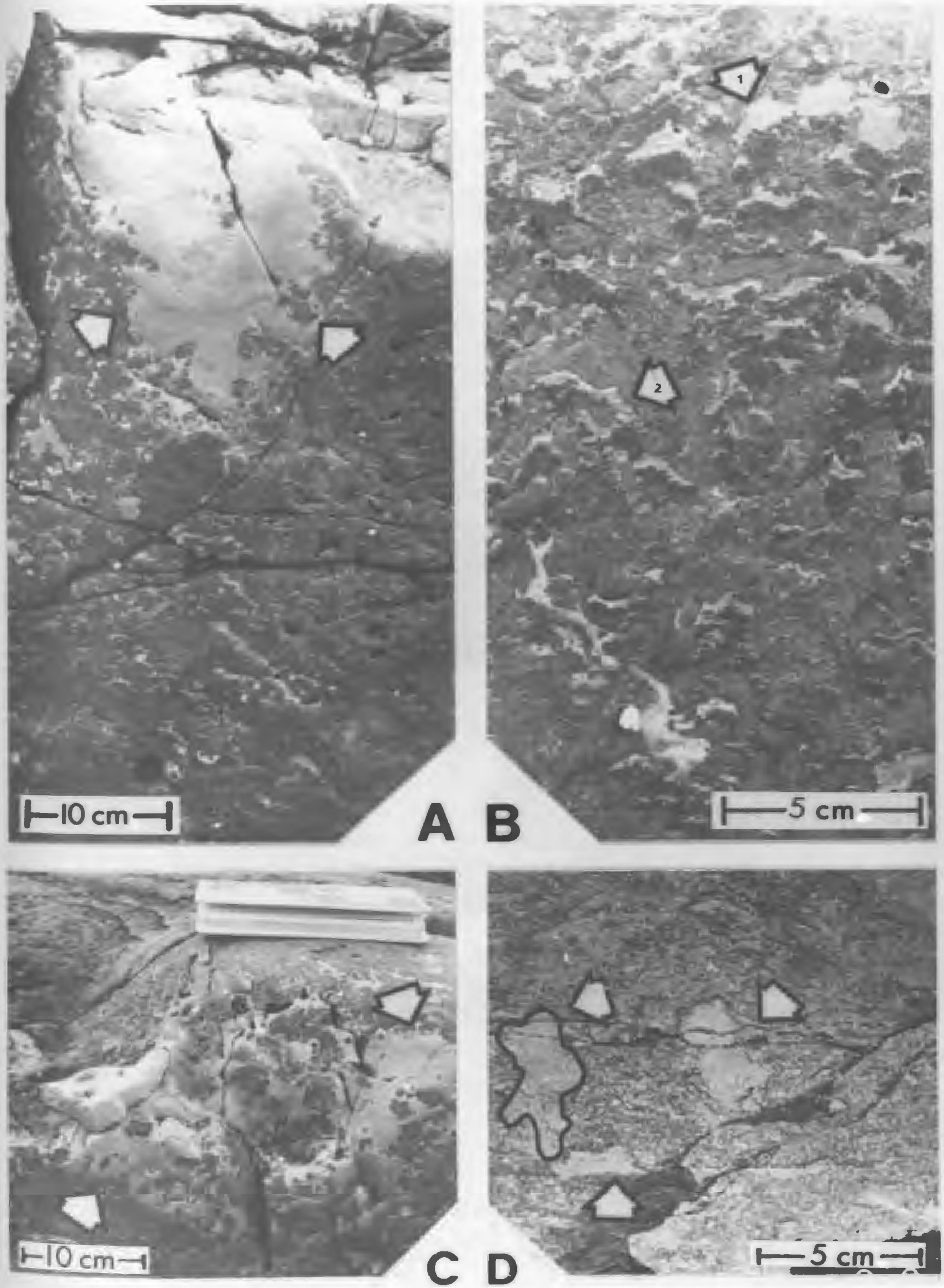
PLATE 3.8: FIELD CHARACTERISTICS OF CAVITY-FILLING DOLOSTONE.

A) Cavity - filling dolostone confined to a large cavity (arrows) within a pervasive B dolostone; Watts Bight Formation, Cape Norman. The sediment which fills the cavities is buff to green, argillaceous and is characterized by convex-down, faint laminations.

B) As above. In this example, the dolostone is filling cavities that have apparently only developed in association with the dark mottles (arrow 1). Some sediment is geopetal and saddle dolomite fills the void space at the top of the cavity (arrow 2).

C) As above.

D) Cavity-filling dolostone (highlighted and arrows) confined to suspected solution pipes (Pratt, 1979) beneath the pebble bed; Boat Harbour Formation, Isthmus Bay.


10 cm
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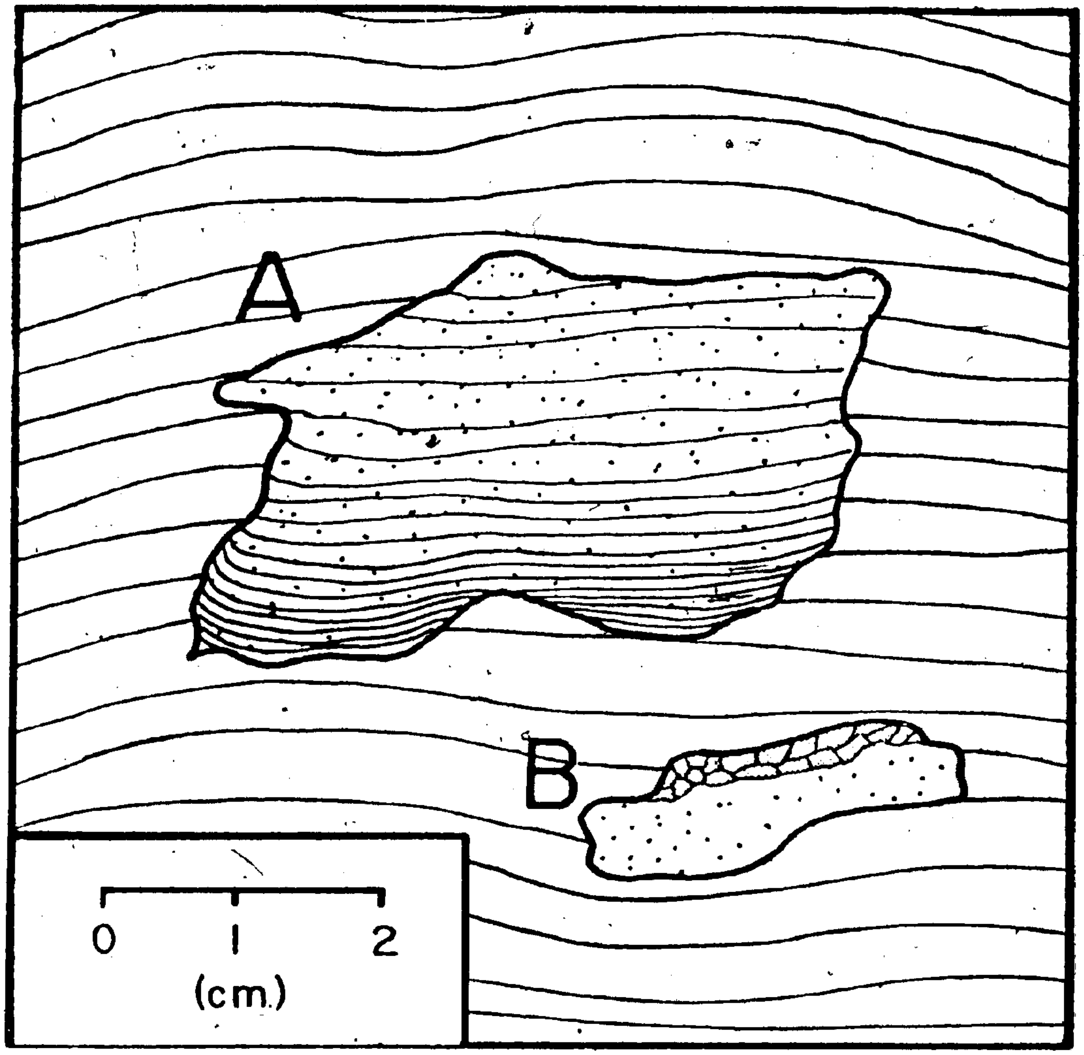


FIGURE 3.5: Schematic representation of cavity-filling dolostone within stromatolitic pervasive dolostone. The margins of the cavities clearly truncate the laminations of the stromatolites indicating that cavity formation and filling postdates lithification and dolomitization. The fine geopetal sediment which fills the cavities may be either laminated (A) or homogeneous (B). Saddle dolomite may fill the void space at the top of geopetal cavities in pervasive B dolostones (as in B).

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION:

Cavity - filling dolostone is the least abundant (volumetrically) of any variety of dolomite or dolostone within the St. George.

The best examples are associated with the stromatolite-thrombolite mound rich pervasive B dolostones of the Watts Bight Formation at Cape Norman and on New Ferolle Peninsula (figure 1.1). Cavity- filling dolostone has not been identified in any other formation in this region.

In the southern portion of the study area, cavity-filling dolostone is confined to possible karst solution pipes beneath the pebble bed within the Boat Harbour Formation at Lower Cove and Isthmus Bay (refer to figure 2.1). There is also a minor occurrence within a pervasive A dolostone in the Catoche Formation at Smelt Canyon.

CHAPTER FOUR

PETROGRAPHY, CATHODOLUMINESCENCE AND PARAGENESIS

4.1 INTRODUCTION:

In this chapter, the petrography, cathodoluminescence and interpreted paragenesis of the seven varieties of dolomite and dolostone are outlined and discussed. A summary of these data are presented in table 4.1.

For each variety, the diagenetic relationships between the dolomite and the other components within the rock are assessed and when possible, are integrated with the diagenetic history of neighbouring limestones. The overall paragenetic history of the limestone and dolomite is summarized in figure 4.1.

4.2 CATHODOLUMINESCENCE OF CARBONATES:

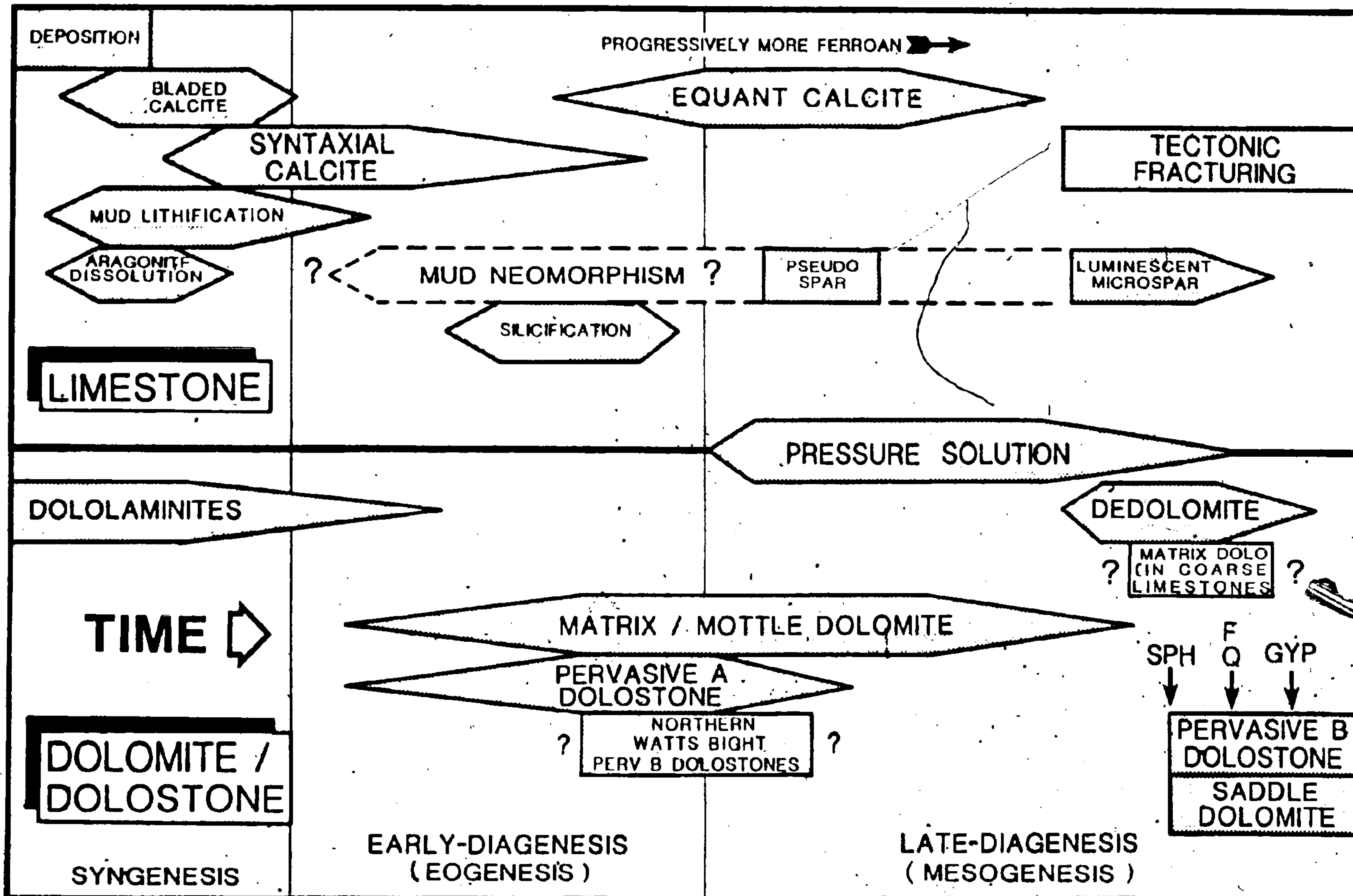
Cathodoluminescence was performed using a Wild microscope equipped with a Nuclide ELM 24 vacuum stage and power source. An operating voltage of from 12 to 18 kilovolts at a beam current of 60 microamps was used for all analyses.

Cathodoluminescence results from bombarding a suitable sample (one that is capable of luminescing), with a concentrated electron beam (Pierson, 1981). Substituted trace elements in a crystal system can either activate luminescence (in which case they are refered to as

TABLE 4.1: Summary of petrography and luminescence characteristics and paragenesis of the seven varieties of dolomite and dolosotne recognized in the St. George Group.

VARIETY	PETROGRAPHIC & LUMINESCENCE CHARACTERISTICS OF DOLOMITE	TIMING OF DOLOMITIZATION
1) DOLO-LAMINITES	-CRYSTALS ARE CLEAR TO TURBID, ANHEDRAL TO EUHEDRAL AND USUALLY FORM XENOTOPIC FABRICS. -LUMINESCENCE IS UNIFORM OR CRYSTALS ARE WEAKLY ZONED (THREE ZONES MAXIMUM).	SYN-SEDIMENTARY.
2) MATRIX DOLOMITE	MUDSTONES: CRYSTALS ARE CLEAR, EUHEDRAL AND OFTEN CONTAIN CLOUDED CORES. DEDOLOMITIZATION IS VERY COMMON. RHOMBS ARE WELL ZONED (2 TO 8 INTERLAYERS).	EARLY TO LATE DIAGENESIS
	PACKSTONES: CRYSTALS ARE ANHEDRAL (XENOTOPIC) TURBID AND DISPLAY STRAINED EXTINCTION. LUMINESCENCE IS A UNIFORM BUT DULL PURPLE TO RED COLOUR. ZONATION IS ONLY POORLY DEVELOPED.	LATE
3) MOTTLE DOLOMITE	-CHARACTERISTICS ARE VARIABLE. CRYSTALS RANGE FROM EUHEDRAL TO ANHEDRAL, (IDIOTOPIC TO XENOTOPIC FABRICS), AND ARE CLEAR TO CLOUDED. LUMINESCENCE IS EQUALLY VARIABLE AND RANGES FROM DULL TO BRIGHT. ZONATION IS OFTEN SPECTACULAR (MORE THAN 20 ZONES MAY BE DEVELOPED IN SOME CRYSTALS).	EARLY TO LATE DIAGENESIS
4) PERVASIVE A DOLOSTONE	-MOTTLES AND INTERMOTTLES ARE SIMILAR BOTH PETROGRAPHICALLY AND IN THEIR LUMINESCENCE. -CRYSTALS ARE CLEAR AND DEVELOP XENOTOPIC FABRICS, LUMINESCENCE IS NORMALLY A UNIFORM AND MODERATE RED COLOUR. ZONATION IS BEST DEVELOPED IN THE INTERAREAS SUGGESTING LATER PERIODS OF GROWTH IN THESE AREAS THAN IN THE MOTTLES.	EARLY
5) PERVASIVE B DOLOSTONE	MOTTLES: SIMILAR TO UNIFORMLY LUMINESCENT EXAMPLES OF MOTTLE DOLOMITE AND PERVASIVE A DOLOSTONE.	EARLY TO LATE DIAGENESIS
	INTERMOTTLES: CRYSTALS ARE LARGE, ANHEDRAL TO EUHEDRAL AND ARE CHARACTERIZED BY STRAINED EXTINCTION. LUMINESCENCE IS USUALLY A UNIFORM, MODERATE TO BRIGHT RED COLOUR. LATER GENERATIONS ARE COMMONLY MORE FERROAN THAN EARLIER ONES.	LATE
6) SADDLE DOLOMITE	-SIMILAR TO THE INTERMOTTLE DOLOMITE IN PERVASIVE B DOLOSTONE	LATE
7) CAVITY-FILLING DOLOSTONE	-DOLOMITE IS VERY FINELY CRYSTALLINE, ANHEDRAL AND LUMINESCES UNIFORM COLOURS (RED TO ORANGE). LUMINESCENCE IS DULL TO MODERATE. -FELDSPAR, QUARTZ, MICA, PHOSPHATE, CLAYS AND INSOLUBLES ARE COMMON ACCESSORY MINERALS.	ASSOCIATED WITH SUB-AERIAL EXPOSURE

FIGURE 4.1: Summary illustrating the paragenetic history of the St. George Group as suggested through petrography and cathodoluminescence. Events primarily associated with limestones are summarized in the upper portion of the diagram whereas those events primarily associated with dolomites and dolostones are summarized in the lower half of the diagram. The distinction between syngenetic, early and late diagenetic events are also indicated. Cavity - filling dolostone is related to periods of subaerial exposure and is not included on this diagram.
Secondary mineralization; SPH - sphalerite, F - Fluorite, Q - quartz, GYP - Gypsum.


DEPOSITION
PROGRESSIVELY MORE FERROAN
BLADED CALCITE
EQUANT CALCITE
SYNTAXIAL CALCITE
TECTONIC FRACTURING
MUD LITHIFICATION
ARAGONITE DISSOLUTION
? MUD NEOMORPHISM ?
PSEUDO SPAR
LUMINESCENT MICROSPAR
SILICIFICATION
LIMESTONE
PRESSURE SOLUTION
DOLOLAMINITES
DEDOLOMITE
? MATRIX DOLO (IN COARSE LIMESTONES ?
TIME
MATRIX / MOTTLE DOLOMITE
SPH
F Q
GYP
PERVASIVE A DOLOSTONE
? NORTHERN WATTS BIGHT PERV B DOLOSTONES ?
PERVASIVE B DOLOSTONE
SADDLE DOLOMITE
DOLOMITE / DOLOSTONE
SYNGENESIS
EARLY-DIAGENESIS (EOGENESIS)
LATE-DIAGENESIS (MESOGENESIS)

"activators") or inhibit luminescence (in which case they are refered to as "quenchers"). It is the changes in concentration of the activating and quenching elements that causes variations in luminescence and optical zonation in crystals. Several cations, (including Ti^{2+}, Pb^{2+} and many rare earth elements) are activator elements; however, the most common activator in carbonate rocks is generally considered to be Mn^{2+} (Pierson, 1981). The most common inhibiting cation in carbonate rocks is usually Fe^{2+} (Sommer, 1972, Pierson, 1981, Amieux, 1982).

The luminescence emission of dolomite is concentrated within the spectral range of 620 to 690 nanometres (orange to deep red) and peaks at approximately 650 nanometres (Pierson; 1981). Sommer (1972) states that the variety of colours may be due to the distance between atoms; shorter bond lengths giving deeper reds than longer bond lengths. The valence state of manganese has also been stated as a cause (Pierson, 1981). Pierson concluded that Mn^{2+} concentrations of from 80 to 100 parts per million were sufficient to develop luminescence in dolomite. He also reported that .1 weight percent of Fe^{2+} was sufficient to inhibit luminescence, regardless of Mn^{2+} concentration. Frank (1981) however, suggested that it was the Fe^{2+}/Mn^{2+} ratio rather than the absolute amounts, that caused the luminescence he observed in dolomite rhombs from the Taum Sauk limestone, Missouri. He found that luminescence was promoted in specific zones which were characterized by Fe^{2+}/Mn^{2+} ratios of less than 7.5, whereas luminescence was quenched when the Fe^{2+}/Mn^{2+} ratio exceeded 7.5.

In this study, the Mn^{2+} and Fe^{2+} concentrations of select samples of dolomite and dolostone were determined by electron microprobe in order to explain the luminescence characteristics of the crystals.

4.3 LIMESTONES:

In order to fully understand the diagenetic events responsible for dolomite and dolostone within the St. George Group, the paragenetic history of the limestones must be established as accurately as possible. To accomplish this, observations made on limestones during the course of this study are combined with those made in studies more concerned with limestone diagenesis (eg. Smit, 1971, Swett and Smit, 1972, Pratt, 1979).

Diagenetic events which affected St. George limestones can be divided into three stages; 1) syngenetic (or synsedimentary), 2) early-diagenetic and 3) intermediate to late-diagenetic (Mattes and Mountjoy, 1980). Choquette and Pray (1970) in their study of carbonate porosity termed the first two stages eogenesis and the third mesogenesis. They also recognized a telogenetic stage which they defined as the period of time during which long-buried carbonate rocks are infuenced by processes associated with subaerial exposure. Mattes and

Mountjoy equate telogenesis with tectonic and post-tectonic events.

CEMENTS:

At least three generations of calcite cement are recognized within St. George limestones (Smit, 1971, Pratt, 1979) (figure 4.2).

Radial bladed calcite cement predates pore filling by lime mud (plate 4.1a), forms isopachous fringes around carbonate grains (plate 4.1b) and is non-ferroan and non-luminescent. These characteristics suggest that this cement precipitated out of well-oxygenated seawater during, and/or immédiately after depostion (Bathurst, 1975, Grover and Read, 1983). Radial bladed calcite can therefore be regarded as syngenetic (Pratt, 1979).

Syntaxial calcite spar is restricted to overgrowths around echinoid fragments and fabric preserving ooids. It, like radial bladed calcite, is non-ferroan and non-luminescent and is a first stage, possibly syngenetic, cement in some ooid grainstones (plate 4.1c). Syntaxial overgrowths around echinoids commonly abut into radial bladed calcite cement implying either cogenetic, or later growth than the radial bladed calcite. Syntaxial calcite sparry cement is therefore best interpreted as a syngenetic to early diagenetic cement.

Equant calcite is the most abundant cement in St. George grainstones (plate 4.1d) and is a common second

FIGURE 4.2: Simplified sketches illustrating the diagenetic history of St. George wackestones (A1 to A6) and grainstones (B1 to B6).

WACKESTONES:

A1 - Deposition

A2 - Syngenetic events; lithification and dissolution of skeletal aragonite. Shell molds are filled with micritic sediment (1).

A3 - Early diagenetic events; continued dissolution of skeletal aragonite with the creation of pore space (2) and possible microspar neomorphism (3).

A4 to A6 - Late diagenetic events; equant calcite cement filling of pore space (4), pressure solution (5), pseudospar neomorphism (6) and tectonic fracturing (7). Microspar generation may have occurred at anytime during late diagenesis; however, luminescent microspar appears genetically related to periods of tectonic fracturing.

GRAINSTONES:

B1 - Deposition

B2 - Syngenetic events; internal sedimentation (1) postdating a period of isopachous radial-bladed calcite cement (2). Syntaxial calcite spar cement may also be a syngenetic event when associated with ooids (3).

B3 - Early diagenetic events; syntaxial calcite spar around echinoid fragments (4) and selective silicification (5).

B4 to B6 - Late diagenetic events; equant calcite cement filling of pore space (6), pressure solution (7), microspar neomorphism of micritic components (8) and tectonic fracturing (9).

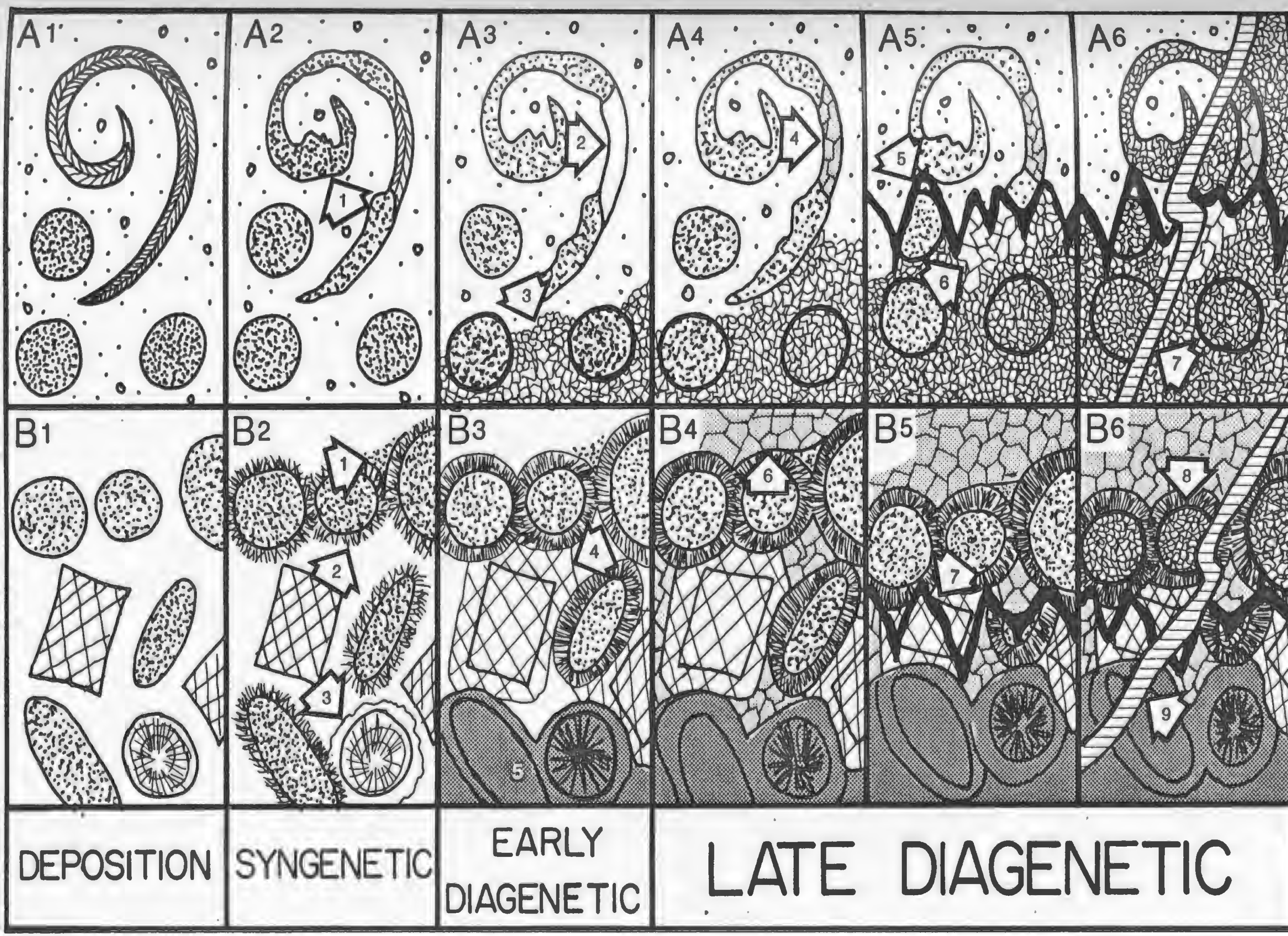

A1
A2
A3
A4
A5
A6
B1
B2
B3
B4
B5
B6
DEPOSITION
SYNGENETIC
EARLY DIAGENETIC
LATE DIAGENETIC

PLATE 4.1: PETROGRAPHY AND CATHODOLUMINESCENCE PHOTOMICROGRAPHS OF ST. GEORGE LIMESTONES.

A) Isopachous bladed calcite cement around peloids and ooids; Boat Harbour Formation, Isthmus Bay. After the initial cementation, fine grained sediment (arrow) percolated into the rocks to fill part of the porosity. Equant calcite cement has filled in the remaining porosity. Plane polarized light.

B) Isopachous calcite cement; Boat Harbour Formation, Lower Cove. This cement predates a second phase of equant calcite spar. Plane polarized light.

C) Syntaxial calcite cement in optical continuity with ooids (arrow); Boat Harbour Formation, Isthmus Bay. Plane polarized light.

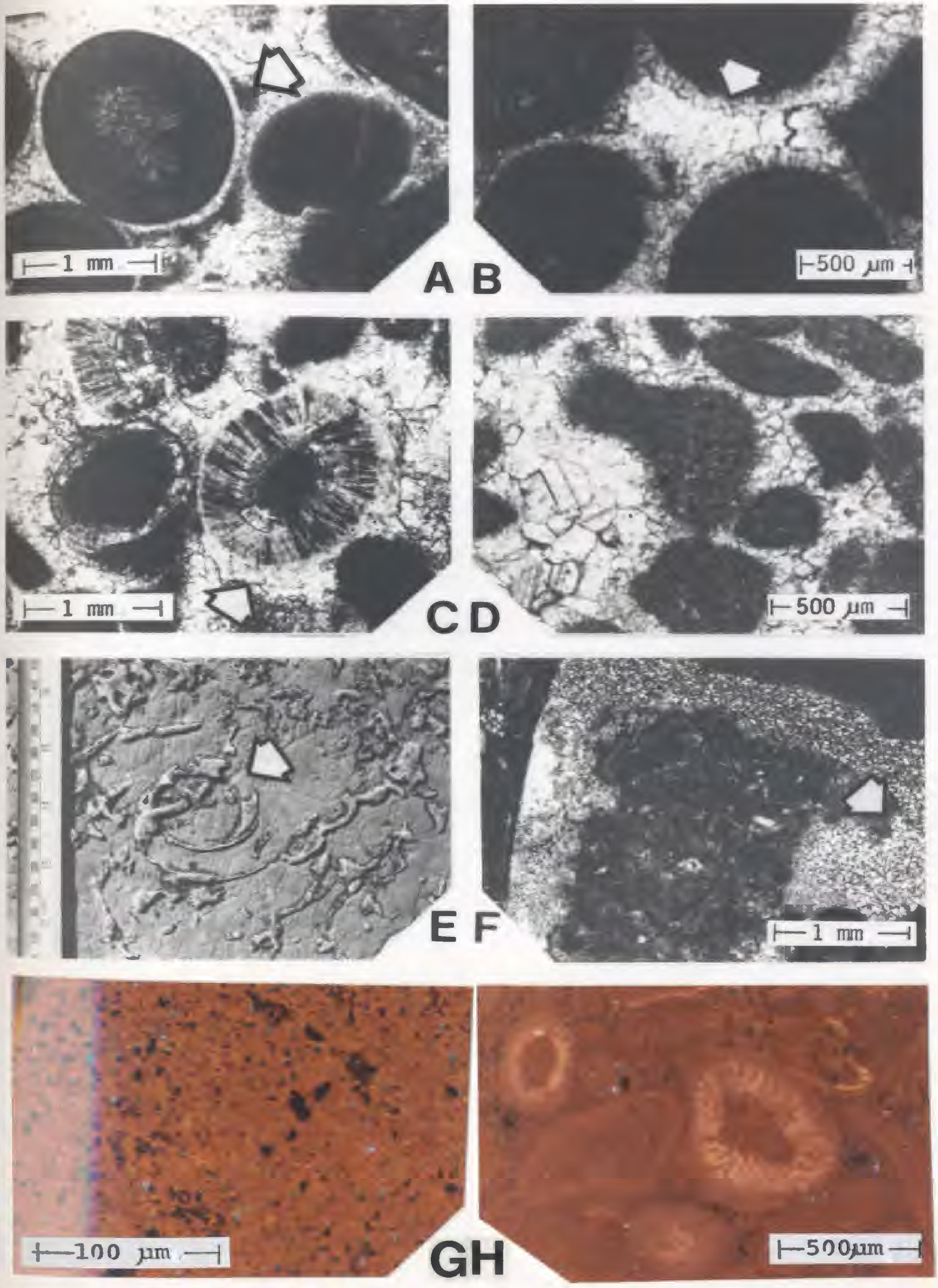
D) Equant calcite spar cementing peloids; Catoche Formation, Smelt Canyon. This texture of cement is the most abundant variety found in St. George limestones. Plane polarized light.

E) Gastropod shell, now preferentially replaced by dolomite, penetrated by burrows (arrow); Boat Harbour Formation, Isthmus Bay.

F) Gastropod shell which has been preferentially dissolved and filled by fine grained calcite sediment in a sponge wackestone; Catoche Formation, Smelt Canyon. The shell outline is very irregular and suggests that dissolution may have penetrated into the surrounding sediment as well. The fine grained calcite is usually selectively replaced by dolomite (arrow). Plane polarized light.

G) Cathodoluminescence of microspar; Catoche Formation, Port au Choix. The centres of many of the microspar crystals are dark and suggest that the luminescent calcite grew syntaxially around non-luminescent cores. The large dark grains are detrital quartz and the bright blue luminescent grains are detrital feldspar.

H) Cathodoluminescence of algal grains (Nuia?); Boat Harbour Formation, Lower Cove. In these examples, the internal structures of the organisms are more luminescent than other parts of the grains or the surrounding rock.


1 mm
A B
500 µm
1 mm
C D
500 µm
E F
1 mm
100 µm
GH
500µm

stage cement to grainstones cemented previously by radial bladed and/or syntaxial calcite cements (Pratt, 1979). It also fills pores (some of which are fossil molds), in all textures of limestones.

Crystals range from 30 to 200 micrometres in size and are normally non-ferroan but do occassionally become more ferroan towards the centres of pores (Pratt, 1979). This cement is generally non-luminescent, though some examples do contain thin (5 to 10 micrometre) luminescent bands interlayered in thicker (to 200 micrometres) non-luminescent intervals.

In a recent study, Wilkinson et al. (1982) have documented modern equant syngenetic cements and have inferred that some ancient examples may also be syngenetic. The majority of equant calcite in the St. George is interpreted as a mesogenetic, burial cement precipitated from phreatic pore waters (Pratt, 1979) rather than a syngenetic cement. This interpretation is based upon its petrographic and luminescence character and the fact that it postdates both radial bladed and syntaxial cements.

The fluctuations from weakly luminescent calcite to non-luminescent (ferroan) calcite suggest precipitation from predominantly reducing conditions, perhaps with minor fluctuations in redox potential or in pH (Evamy, 1969, Hem, 1972, Grover and Read, 1983).

ARAGONITIC COMPONENTS:

The majority of aragonite body fossils appear to have been affected by an episode of dissolution while within striking distance of burrowing organisms on, or near, the seafloor. This is suggested by burrows (not bores) which penetrate shell molds (Pratt, 1979; plate 4.1e) and by internal sediment which fills molds (plate 4.1f). The outline of the mold is frequently irregular because the lime mud in contact with the shell walls was also prone to dissolution (as in plate 4.1d). Calcitic fossils such as echinoids, trilobites and brachiopods were not subjected to this early event.

Kendall (1977) in his study of Palaeozoic limestones of Saskatchewan and Manitoba similarly observed gastropods penetrated by burrows and also favoured early dissolution of aragonite body fossils. He argued convincingly that the lack of geopetal structures (partial fills) ruled out passive infiltration of sediment during compaction or after burial. Instead, Kendall suggested that the lime mud was introduced into the void space by the churning of sediment during bioturbation. This is also a reasonable explanation to account for sediment-filled gastropods in the St. George.

Replacement of aragonitic body fossils by non-fabric preservative, equant calcite spar is also frequent and indicates dissolution of the shell after lithification, but prior to cementation (Bathurst, 1975). Replacement of these components with the preservation of the original fabric is, however, rare. This suggests that either the neomorphic conversion of aragonite to calcite (concommitant dissolution and precipitation) was not a significant event in the St. George or (more likely), most of the skeletal aragonite was dissolved prior to the onset of neomorphism.

Overall, the diagenesis of aragonite body fossils appears to have been restricted to syngenetic or early diagenetic dissolution (figure 4.2).

SILICIFICATION:

Silicification of limestones is common, and is generally an early-diagenetic event (Pratt, 1979) (figure 4.2). It often preserves the original fabrics of grains and cements, especially radial bladed cements.

MUDSTONE LITHIFICATION AND MICROSPAR GENESIS:

Lithification of lime mud in mudstones and wackestones appears to have been a relatively early-diagenetic event because most cross-sectional trace fossils are only slightly (plate 3.3b,g), or are not compacted at all. Some burrows however, are very compacted (Pratt, 1979, 1982) and this variability may reflect sporadic lithification of the mud prior to compaction. The fact that molds remained opened during infiltration of marine sediment (as opposed to collapsing) and that dissolution of aragonite has frequently penetrated into the surrounding lime mud (plate 4.1f) also implies that some mud was lithified (or at least consolidated) on or near the seafloor. This is consistent with the conclusion arrived at by Kendall (1977) for Palaeozoic carbonates of Saskatchewan and Manitoba. Kendall observed that the ichnofossils were often "re-burrowed" by successive generations of burrowing organisms. He suggests that early lithification of lime mud forced the burrowers to selectively "mine" the more permeable, unlithified ichnofossils and sediment filled gastropod molds.

Much of the micrite in these fine grained limestones as well as the micrite in peloids, intraclasts, burrow linings and some calcitic fossils (trilobites or brachiopods), is commonly altered to microspar. Microspar is finely crystalline (5 to 20 micrometres), of an interlocking to equant habit (Folk, 1965) and in the St. George, is exclusively non-ferroan. It may be non-luminescent, or brightly luminescent (plate 4.1g).

The origin of microspar is somewhat of an enigma in the diagenesis of carbonates. Most microspar fabrics, with the possible exception of geopetal deposits (Bathurst, 1975), are generally considered to be recrystallization products (Folk, 1965). In the St. George, luminescent microspar appears to be a syntaxial overgrowth of "bright" calcite around a dark "core" (plate 4.1g). This implies recrystallization in waters of a reducing environment where the Fe^{2+}/Mn^{2+} ratio was small enough to promote luminescence (ie. a phreatic environment; Grover and Read, 1983). Colour and intensity of luminescence is similar to that exhibited by some of the calcite in fractures cutting across the microspar and intuitively, suggests luminescent microspar was generated during late-diagenetic periods of tectonic fracturing (figure 4.2). Fluids introduced via the fractures, may have penetrated into the micrite along minute intercrystalline boundaries and at the expense of some of the micrite, precipitated out luminescent calcite in optical continuity with that of the core. Most microspar is however, non-luminescent, not crossed by tectonic fractures and therefore cannot be explained by this process.

There are a number of other explanations for microspar generation. Folk (1974a), in his study of Mg^{2+} inhibition on calcite precipitation, suggested that Mg^{2+} is retained within the sediment after lithification and forms a "cage" around each micritic calcite crystal preventing growth beyond a few micrometres. Only after the Mg^{2+} has been flushed away by fresh-water can recrystallization to coarser crystalline microspar take place.

Bertrand et al., (1983) have suggested that at least some of the coarser crystalline fabrics observed in mudstones (including microspar) could evolve during thermal maturation of the rock. This mechanism would operate during later periods of limestone diagenesis.

Independant studies in the modern by Steinen (1978, 1982) and Lasemi and Sandberg (1984) support Folk's (1974a) suggestion that freshwater is an important factor in microspar development. They believe that microspar is produced directly from lime mud (in their case predominantly aragonite) and does not first pass through a lithification stage as Folk contends; micrite and microspar form at the same time (Lasemi and Sandberg, 1984). The conversion is thought to involve dissolution of aragonite and precipitation of calcite in the resulting micro-pores and through displacive calcite crystallization (Steinen, 1982). This is essentially the same process outlined by Land (1967) to explain the Pleistocene limestones of Bermuda. Skeletal aragonite is dissolved in contact with freshwater, and provides the necessary ions for cementation of the remaining sediment by calcite.

The composition of ancient marine sediments and ultimately, of ancient seawater, is much too complex an issue to attempt to resolve in this study; however, burrowed, sediment filled gastropod molds do suggest that skeletal aragonite during St. George sedimentation was prone to dissolution while essentially on or near the sea floor. It is questionable therefore whether aragonite was a major component of St. George muds and whether or not the conversion of aragonite to calcite was the driving force for microspar generation. If the majority of mud deposited during Early Ordovician time was calcite (or magnesium calcite) rather than aragonite, the early diagenetic evolution of microspar via the method proposed by Steinen (1978, 1982) and Lasemi and Sandberg (1984) is difficult to envision. Calcite and Mg-calcite (containing less than 12 mole percent $MgCO_3$) could not produce the ions necessary for cementation of the mud because they are less reactive than aragonite when affected by freshwater (Bathurst, 1975).

In the St. George Group, mud appears to have been lithified very early, perhaps while still on the seafloor. If microspar formed directly from unlithified mud as suggested by Steinen (1978, 1982) and Lasemi and Sandberg (1984) then it must be an early-diagenetic product. On the other hand, at least some microspar, (the luminescent variety), appears to be related to late- diagenetic periods of tectonic fracturing. Microspar in the St. George may have been generated several times during the paragenetic history of limestones (early- to late-diagenesis; figure 4.2).

ALGAL COMPONENTS:

Dascycladaceans and problematic algae (for example, <u>Renalcis</u> and <u>Nuia</u>) commonly luminesce more brightly than the background calcite (plate 4.1h) and often, a non-descript peloid can be identified as an algal clot simply by examining it with a cathodoluminoscope. The reason(s) for luminescence of these components is not clear. There is not an obvious diagenetic alteration of the algae (for example, it has not been altered to microspar), and since not all the algae luminesce, it seems unlikely that luminescence is caused by primary trace element geochemistry. It is clear however, that cathodoluminescence can be a valuable tool in determining the identity of some questionable grains.

PRESSURE SOLUTION AND TECTONIC FRACTURING:

Pressure solution results in a variety of stylolite forms and can locally develop "pseudospar", (a neomorphic alteration of micrite to calcite greater than 30 micrometres in size; Folk, 1965, Bathurst, 1975), in limestones immediately adjacent to stylolites. Pressure solution is a late-diagenetic event (figure 4.2) and is discussed further in this chapter and in chapter seven.

Apart from dolomitization, the final diagenetic event of significance in these rocks is tectonic fracturing and fill by a variety of ferroan and non-ferroan calcites. Fracturing occurred several times during the alteration of limestones (early- to late-diagenesis), but is commonly the last diagenetic event (figure 4.2). In the Port au Port area, they are as young as Carboniferous, as demonstrated by fractures filled with Codroy Group sediments that extend out from sinkholes .

SYNOPSIS:

The paragenesis of St George limestones is grouped into synsedimentary (syngenetic), early-diagenetic (eogenetic; Choquette and Pray, 1970) and late-diagenetic events (mesogenetic; opt. cit.) (figures 4.1 and 4.2). Some St. George grainstones were cemented while on the sea floor by synsedimentary marine cements (radial-bladed and possibly syntaxial cements) and at the same time, skeletal aragonite was dissolved. Lime mud may also have been lithified while on the seafloor.

Syntaxial calcite spar cement continued to precipitate around echinoids and some ooids during periods of early-diagenesis and second stage burial cements began to fill the remaining pore space in the grainstones. Silicification of some limestones also occurred during this period.

Late-diagenetic events include; 1) continued cementation of pore space by increasingly iron rich equant calcite spar cement, 2) pressure solution 3) local development of pseudospar and 3) tectonic fracturing. Dolomitization occurred throughout the diagenetic history of limestones. In the following sections, it is placed in its proper paragenetic context.

4.4 DOLOLAMINITES

PETROGRAPHY AND CATHODOLUMINESCENCE:

These rocks are composed of closely packed, clear to turbid dolomite rhombs (plate 4.2a). Iron content varies from 0.13 to 0.87 weight percent FeO as determined by electron microprobe and atomic absorption.

Crystals in most dololaminites from the southern portion of the study area are either uniformly luminescent (non-zoned; plate 4.2b) or are poorly zoned (plate 4.2c). If zoned, they contain no more than 3 interlayers; the innermost one being more luminescent than the outer two. Contacts between zones are diffuse. In some rocks, rhombs are cemented by a ferroan calcite cement. They are however, seldom dedolomitizated.

Dololaminite crystals range from less than 10 to about 50 micrometres though some may reach 100 micrometres. Larger crystals are euhedral and are commonly localized along laminations (plate 4.2d) or as cement between clasts in intraformational breccias. Zonation in larger crystals is only slightly better developed than in smaller ones (plate 4.2e). Rare dololaminites are composed almost exclusively of this coarser dolomite but do not differ outwardly from the finer crystalline equivalents.

Detrital feldspar and quartz silt are ubiquitous and range in abundance from trace quantities to approximately 5 percent. They are 20 to 60 micrometres in size, are angular to rounded, and are commonly distributed parallel to the

PLATE 4.2: PETROGRAPHY AND CATHODOLUMINESCENCE PHOTOMICROGRAPHS OF DOLOLAMINITES.

A) Closely packed, xenotopic mosaic of finely crystalline, angular dolomite crystals in a typical dololaminite; Boat Harbour Formation, Lower Cove. Plane polarized light.

B) Cathodoluminescence of the same dololaminite sample depicted in A. The dolomite in this sample is essentially uniformly luminescent and non-zoned.

C) Poorly developed zonation within dolomite rhombs in a well laminated dololaminite; Boat Harbour Formation, Hare Bay. Detrital feldspar (blue luminescence) is very abundant in these rocks and is commonly concentrated along laminations. Cathodoluminescence.

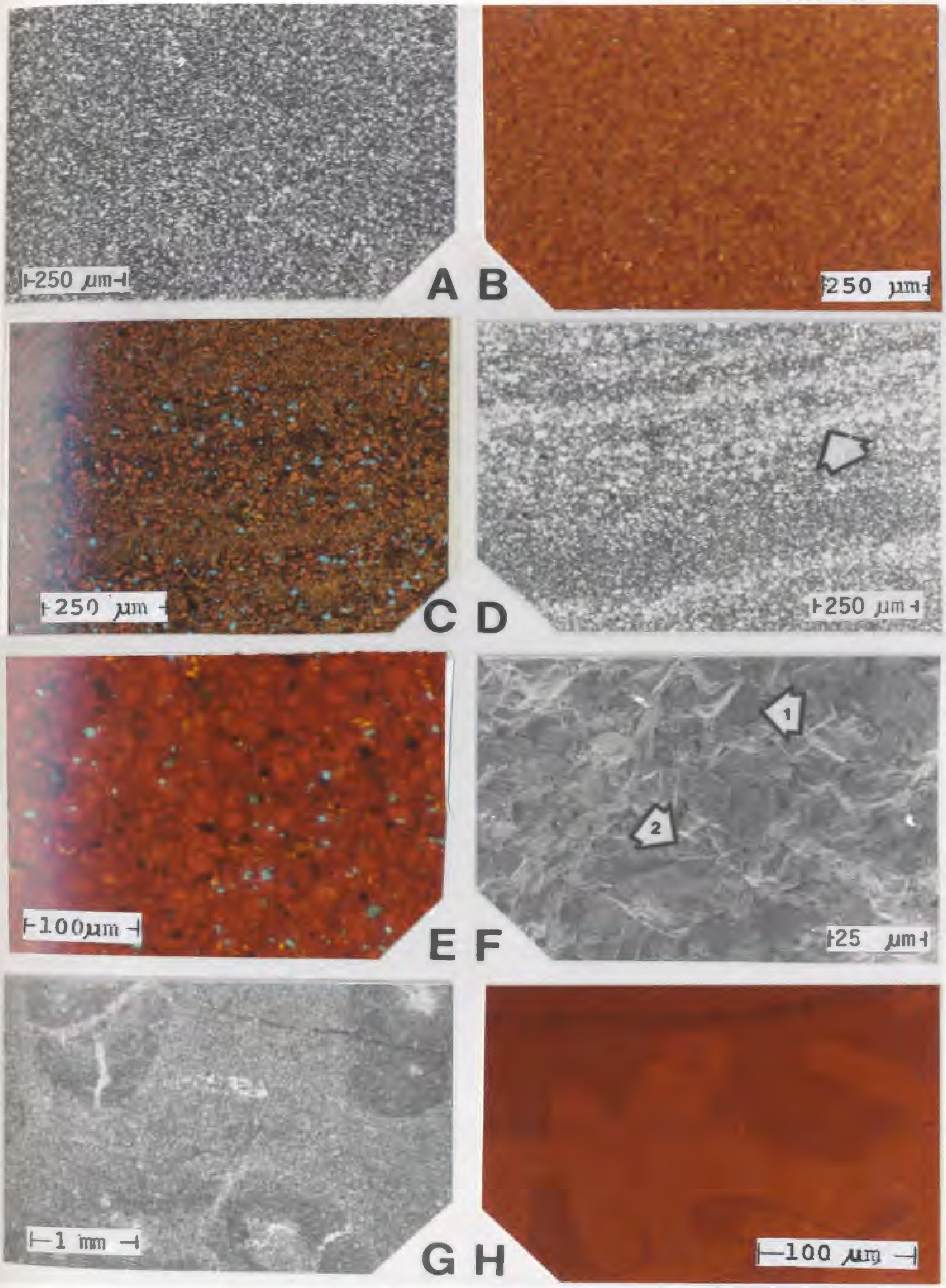
D) Euhedral dolomite crystals developed along and between laminations (arrow); Aguathuna Formation, NW Gravels. Plane polarized light

E) Zonation developed in coarsely crystalline dolomite crystals; Boat Harbour Formation, Isthmus Bay. Despite the larger crystal sizes, the zonation is still quite weak and seldom are more than three interlayers developed. Cathodoluminescence.

F) Scanning electron photomicrograph of a dololaminite; Aguathuna Formation, Aguathuna Quarry. In this sample, as in most dololaminites, the intercrystalline pore space (2) between dolomite crystals (1) is filled by dark organic rich material (2). This material is also commonly concentrated along laminations.

G) Burrow mottled dololaminite; Aguathuna Formation, NW Gravels. These rocks do not differ petrographically from other dololaminites except for the presence of trace fossils. Plane polarized light.

H) Pseudomorphs of calcite after gypsum; Boat Harbour Formation, Lower Cove. These pseudomorphs are from a cavity developed in a dololaminite after dissolution of an evaporite nodule. Cathodoluminescence.


A
⊢250 µm⊣
B
250 µm
C
⊢250 µm⊣
D
⊢250 µm⊣
E
⊢100µm⊣
F
1
2
25 µm
G
⊢1 mm⊣
H
⊢100 µm⊣

laminations (refer to plate 4.2c).

Silica nodules are common (Pratt, 1979). They are composed of a variety of quartz and chalcedony fabrics, although replacement of evaporite nodules appears to have been exclusively by euhedral mega-quartz or flamboyant quartz (Pratt, 1979).

Laminations, if not marked by an accumulation of coarser crystalline dolomite, are marked by an abundance of dark, amorphous, insoluble material (refer to plate 4.2d). This same insoluble material is also localized in intercrystalline pore space (plate 4.2f). Examples from the northern portion of the study area are normally "cemented" by a red, moderately luminescent dolomite which locally replaces the dark, insoluble material between the crystals.

Burrow-mottled dololaminites are petrographically similar to laminated equivalents; however, burrow walls are darker than the host rock because of insoluble material in intercrystalline areas (plate 4.2g).

PARAGENESIS:

By direct comparison to laminated dolomite forming in modern supratidal environments (for example the Tunisian Coast), the initial dolomitization of St. George dololaminites probably occurred penecontemporaneously with sedimentation (figure 4.1). The coarseness and the zonation of some of the crystals also suggests that dolomite growth also continued after burial. Early dolomitization had been suggested earlier by Pratt (1979) who found microdolomite intraclasts trapped within a silicified dololaminite-grainstone. He argued that the pre-chert formation of the dolomite supported penecontemporaneous precipitation of dolomite during supratidal sedimentation. Early dolomitization and lithification is also supported by intraformational breccias and fracturing around replaced evaporite nodules. The fractures, from 10 to 75 micrometres wide, are filled by slightly ferroan calcite and appear to have developed because of the brittle nature of the rock during compaction around the nodule. After dolomitization and lithification, the evaporites were dissolved and the pore space was partially filled with geopetal calcite sediment preserving possible pseudomorphs of calcite after gypsum (R.G.C. Bathurst, pers comm, 1984; plate 4.2h).

Rare dololaminites appear to have been compacted prior to extensive lithification (and dolomitization?). In these rocks, compaction has caused unlithified portions of the bed to flow around lithified portions resulting in a "concretionary" look to these horizons.

Apart from the silicification of evaporite nodules and tectonic fracturing, dololaminites do not appear to have been greatly affected by post-dolomitization events.

4.5 MATRIX DOLOMITE

PETROGRAPHY AND LUMINESCENCE:

The matrix dolomite in fine grained limestones differs from that in coarse grained limestones and therefore, the two will be discussed seperately.

Fine Grained Limestones:

Within mudstones and wackestones, matrix dolomite is clear, euhedral, non-ferroan, finely crystalline (100 micrometres) and commonly partially dedolomitized. Crystals are zoned and can contain from 2 to 20 internal layers. Cores are more luminescent than outer zones and commonly, a thin, strongly ferroan band (containing up to 5.0 weight percent FeO), is developed near the midpoint or terminus of the rhomb (plate 4.3a). Contacts between individual zones are sharp in rhombs composed of more than three or four zones but are transitional in rhombs composed of fewer than three. Transects of several dolomite crystals by electron microprobe suggest that these zones are developed in response to fluctuations in total iron content rather than in changes in Mn^{2+} concentration (figure 4.3). The concentration of iron is often great enough to impart a blue colouration to the zones, (especially the very ferroan outer zone), in stained thin sections.

There are no visable nuclei at the cores of the rhombs (ie. peloids, allochems or crystallites of calcite or dolomite) suggesting that dolomite growth was around

PLATE 4.3: PETROGRAPHY AND CATHODOLUMINESCENCE PHOTOMICROGRAPHS OF MATRIX DOLOMITE.

A) Well developed zonation within matrix dolomite rhombs; Boat Harbour Formation, Lower Cove. A prominent non-luminescent is developed near the terminus of the majority of the crystals. Cathodoluminescence.

B) Coarsely crystalline matrix dolomite localized between peloids in a packstone; Watts Bight Formation, Isthmus Bay. These occurrences are characterized by very irregular crystal outlines. Plane polarized light.

C) Cathodoluminescence photomicrograph of the same portion of the sample depicted in B. Luminescence of the dolomite is a dull and uniform purple to red.

D) Matrix dolomite (dolo) partially extinct postdating an earlier phase of pore lining equant calcite spar cement; Watts Bight Formation, Isthmus Bay. Crossed nichols.

E) Scanning electron microphotograph of a portion of a matrix dolomite-rich interval; Watts Bight Formation, Isthmus Bay. Intercrystalline porosity is very common in these samples.

F) Secondary porosity in a matrix dolomite "rich" interval, Watts Bight Formation, Isthmus Bay. Dolomite crystals in contact with the pores have been partially dissolved. Plane polarized light.

G) Dedolomitization of matrix dolomite crystals; Aguathuna Formation, NW Gravels. The majority of the dedolomitization is concentrated near the central portion of the crystals (arrow). Cathodoluminescence.

H) Dedolomitization of matrix dolomite crystals; Watts Bight Formation, Berry Head. The quilt-like mosaic of these rhombs is caused by the combination in luminescence of two phases of calcite and the original dolomite. Cathodoluminescence.

I) Tectonic fractures filled by brightly luminescent calcite; Watts Bight Formation, Berry Head. This same calcite also surrounds (arrow) or partially dedolomitizes the dolomite crystals. Cathodoluminescence.

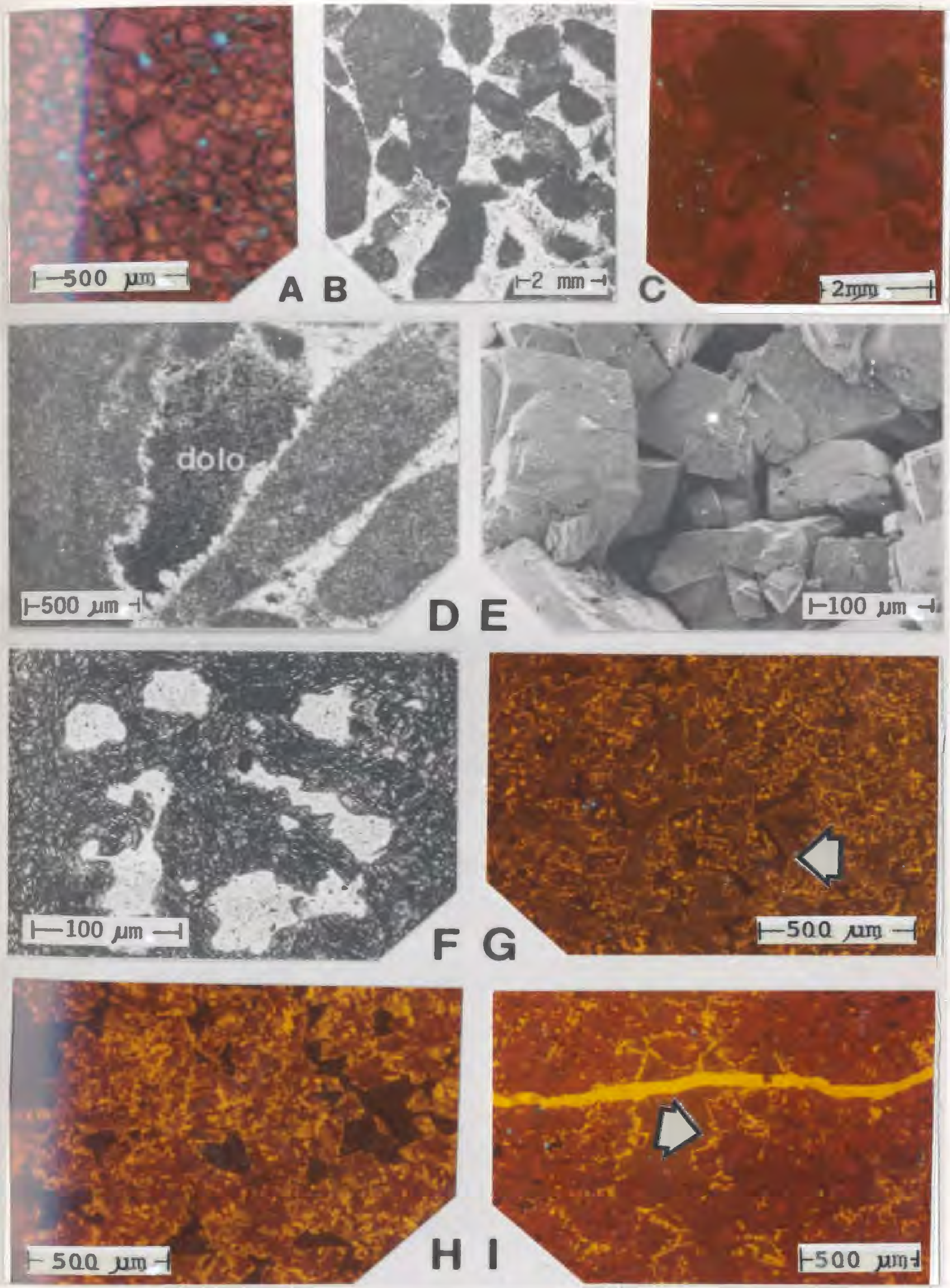
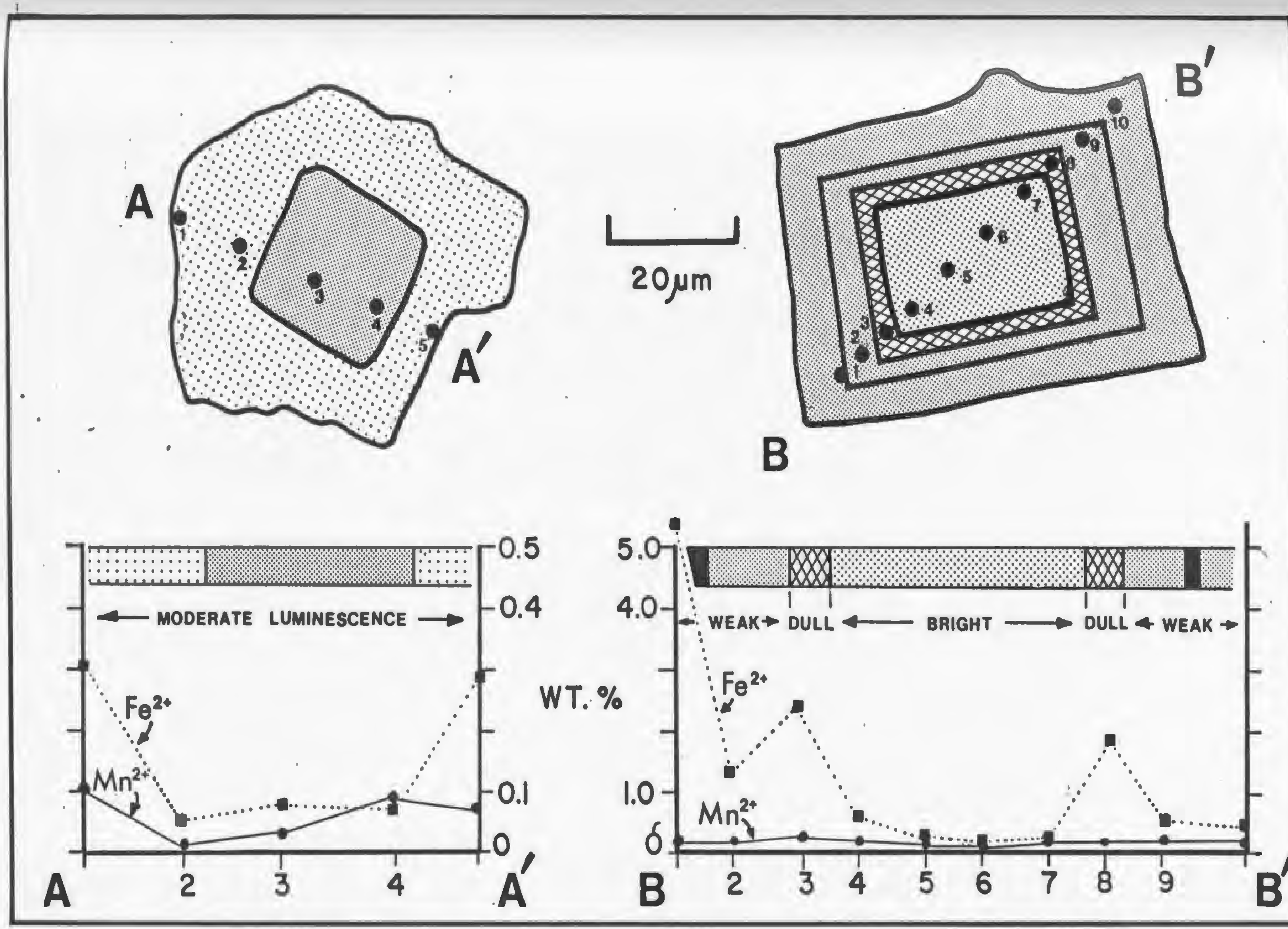

500 μm
A
B
2 mm
C
2mm
dolo
500 μm
D
E
100 μm
100 μm
F
G
500 μm
500 μm
H
I
500 μm

FIGURE 4.3: Schematic representation of matrix dolomite zonation correlated with electron microprobe traverses. Traverse A - A' is across a weakly zoned rhomb whereas traverse B - B' is across a well zoned rhomb. In both examples, the zonation results from variations in the concentration of iron rather than variations in the concentration of manganese.


A
A′
B
B′
20μm
MODERATE LUMINESCENCE
WEAK
DULL
BRIGHT
DULL
WEAK
WT. %
Fe^{2+}
Mn^{2+}
0.5
0.4
0.1
0
5.0
4.0
1.0
0
A 2 3 4 A′
B 2 3 4 5 6 7 8 9 B′

microscopic nuclei.

Coarse Grained Limestones:

Matrix dolomite in grainstones and packstones is coarser (200 to 500 micrometres) and has very irregular crystal outlines where it abuts against grains or earlier cements (plate 4.3b). In plane polarized light, rhombs are faint brown, turbid, strongly pleochroic and characterized by strained extinction. Luminescence is dull, uniform and ranges in colour from purple to red (plate 4.3c). Zonation is poorly developed and is usually a non-luminescent zone surrounding a weakly luminescent core. The transition between the two zones is always gradual. The dolomite is pore-filling in grainstones, postdating non-ferroan equant calcite cement (plate 4.3d).

Occasionally, replacement of the limestone has gone almost to completion and has resulted in the matrix-dolomite rich intervals described in chapter three. These intervals are composed of the same dolomite that is in packstones and grainstones, but the dolomite is better crystalline (developing idiotopic mosaics; Friedman, 1962) (plate 4.3e) and the intervals are characterized by abundant primary intercrystalline and secondary dissolution porosities (plate 4.3f). Non-ferroan calcite void-filling spar is localized to primary intercrystalline pores suggesting that secondary dissolution postdates late phases of calcite cementation. Stylolites and tectonic fractures are not present within these intervals.

PARAGENESIS:

Petrographic and field evidence suggests that matrix dolomite in fine grained limestones is the product of an early- to late-diagenetic event(s) (figure 4.1). Rarely, rhombs are etched by microspar and or by non-ferroan, equant calcite cement implying that at least some growth predates neomorphic conversion of micrite to microspar and equant calcite cementation. On the basis of arguements to be given shortly, it is likely that dolomitization proceeded up until the start of dedolomitization which in these rocks, accompanied tectonic fracturing.

Crystal zonation in fine grained limestones suggests growth during numerous fluctuations in pore water chemistry, (that is, in Mn^{2+} and Fe^{2+} concentration), and intuitively suggests a prolonged period of dolomitization. Chemical variations appear to have been local as the zonation in the rhombs is not consistent everywhere. The partition coefficient of Mn^{2+} in dolomite is much greater than that for Fe^{2+}, and because the residence time of fluid flowing through fine grained rocks is long compared to that of fluid flowing through coarser grained rocks, initial dolomite precipitates would be relatively Mn^{2+} rich (and more luminescent). Later precipitates would be Fe^{2+} rich and correspondingly less luminescent. This may explain the patern of zonation found in fine grained rocks (D.W. Morrow, pers. comm., 1984).

Matrix dolomite in grainy limestones is petrographically different from the dolomite in fine grained limestones and is the result of a later diagenetic event (figure 4.1). It postdates equant calcite cementation and because it is not cross-cut by stylolites or tectonic fractures, may also postdate these late diagenetic events. Lack of zonation in the rhombs implies growth from fluids of a fairly constant trace element composition or alternatively, a rapid dolomite growth rate.

The intervals which were more intensely dolomitized (matrix dolomite-rich intervals) have been affected by later periods of calcite spar cementation, secondary dissolution and gaseous hydrocarbon accumulation, probably because of the high intercrystalline porosity developed during and/or after dolomitization.

DEDOLOMITIZATION IN FINE GRAINED LIMESTONES:

Dedolomitization of matrix dolomite in mudstones and wackestones occurs in one of three fashions (figure 4.4): 1) in the cores of the crystals (plate 4.3g); 2) within the more ferroan and therefore, most unstable zones (refer to plate 4.3b); 3) randomly in the crystals. The last mode of replacement is the most common and imparts a "quilt-like" appearance to the dolomite crystals (plate 4.3h).

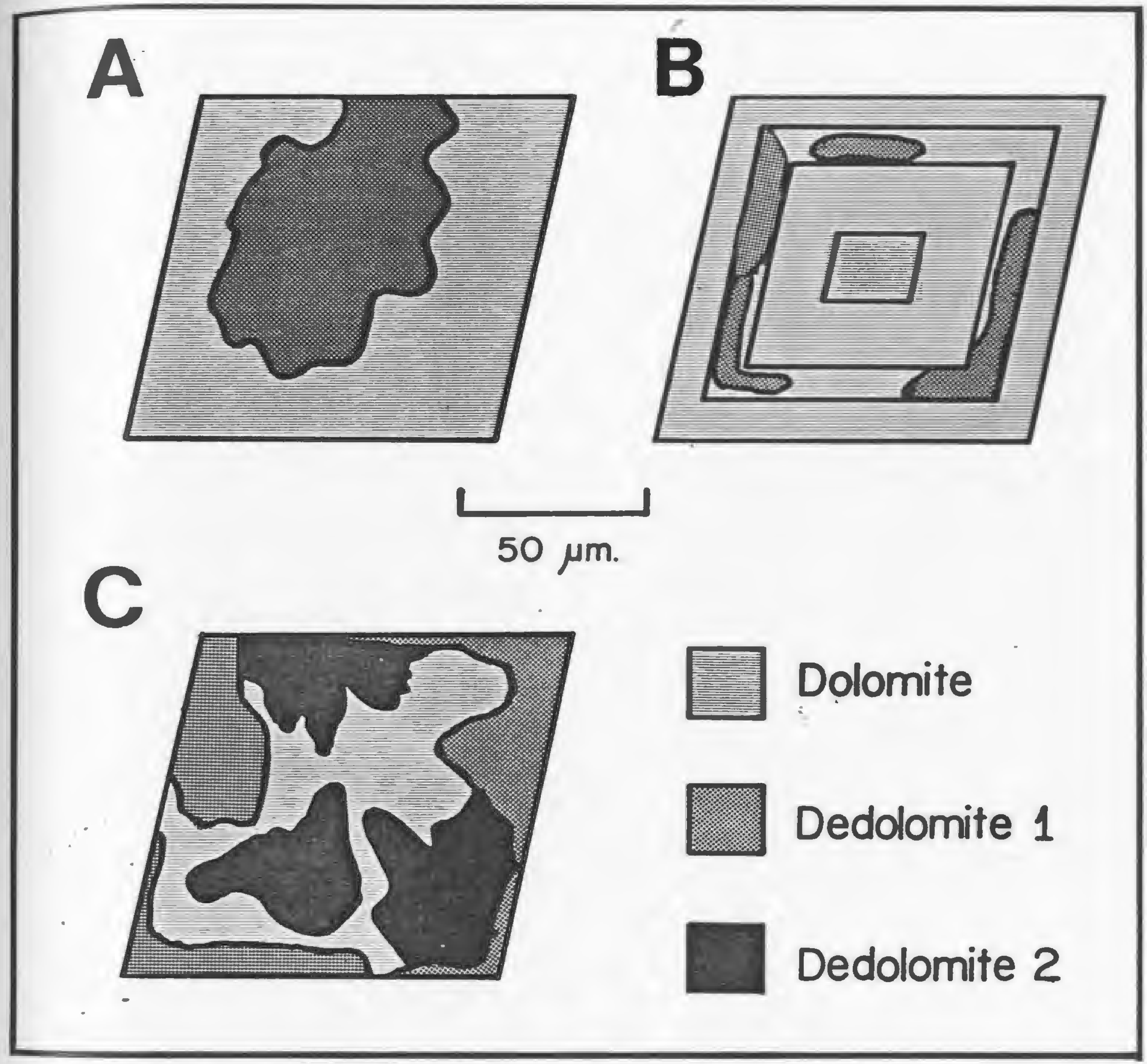


FIGURE 4.4: Common fabrics of dedolomitization observed through cathodoluminescence of matrix dolomite rhombs.

A) Dedolomitization of crystal core.
B) Dedolomitization of specific zones (usually the most ferroan)
C) "Quilt-like" mosaic caused by two phases of dedolomite.

Fluids were introduced into the limestone via very fine to microscopic late-diagenetic fractures (1 to 50 micrometres) (figure 4.5). In one particularly good example of dedolomitization, three phases of calcite can be distinguished by their different luminescent properties and crosscutting relationships. The earliest phase is non-luminescent and non-ferroan and while it cuts across the limestone and dolomite, it replaces neither. The second phase of calcite is slightly ferroan and brightly luminescent*. It encircles dolomite crystals (plate 4.3i, figure 4.5), replaces both the dolomite and the host limestone and has filled the intercrystalline pore space of equant calcite spar cement.

The final phase of calcite is moderately luminescent, non-ferroan and also causes some dedolomitization, however, it <u>does</u> <u>not</u> surround dolomite rhombs. It is the combined luminescence of the two phases of "dedolomite" and the remaining dolomite that develops the quilt-like mosaic of the crystals when viewed under cathodoluminescence (refer to plate 4.3g).

It is likely that matrix dolomite grew by concomitant dissolution and precipitation. The brightly luminescent calcite surrounding the dolomite crystals appears to have

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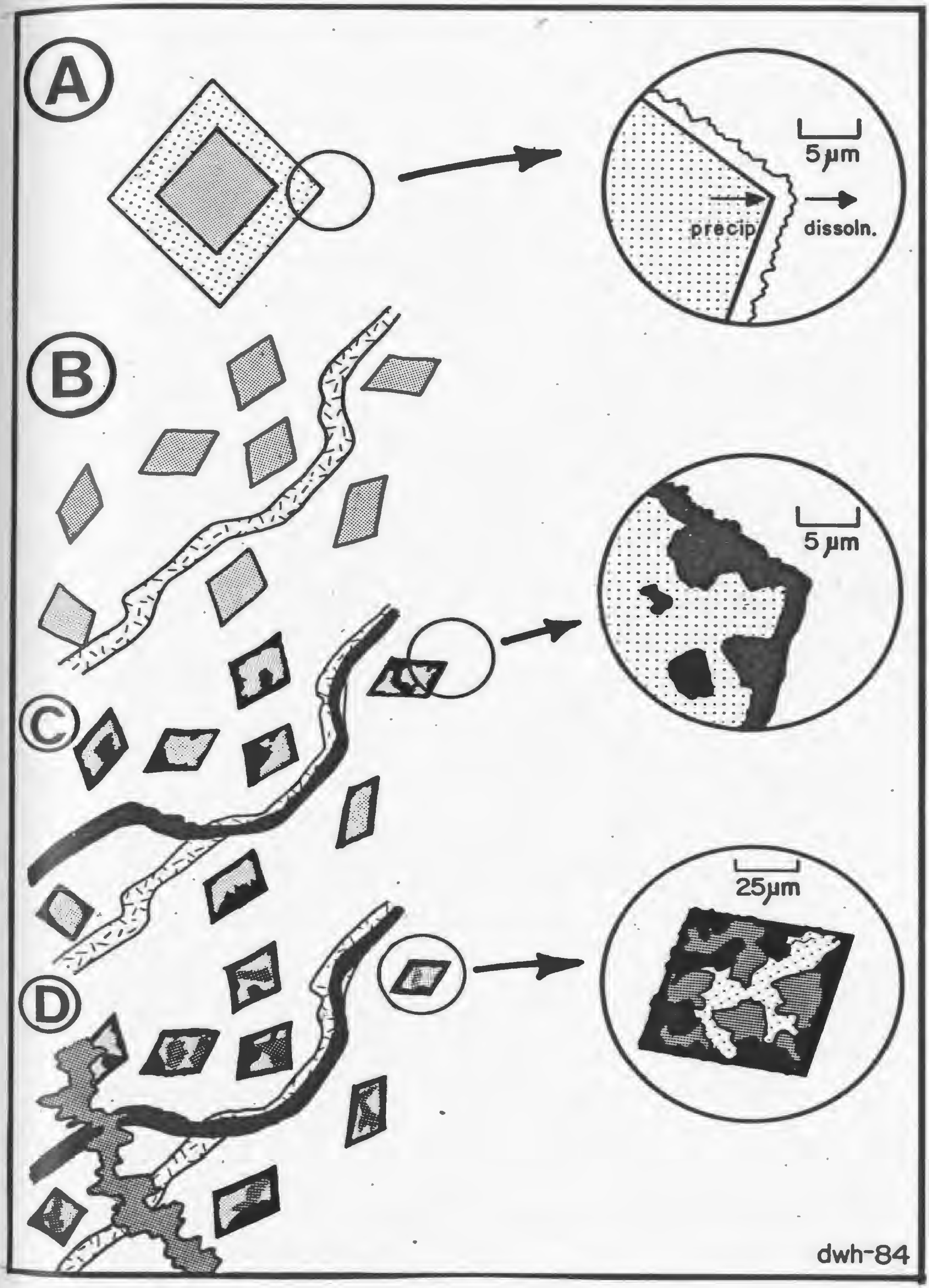
* Electron microprobe analysis of this calcite shows it to contain 0.20 weight percent FeO and 0.70 weight percent MnO; Fe^{2+}/Mn^{2+} = 0.29).

FIGURE 4.5: Origin of the "quilt-like" luminescence observed within some matrix dolomite crystals. Matrix dolomitization initially proceeds through the dissolution of host limestone and the precipitation of dolomite on a microscopic scale (A). Following the majority of dolomite growth, tectonic fractures begin to penetrate the host limestone. The first phase of calcite fracture filling cement is non-luminescent and causes little or no dedolomitization of the rhombs (B). A second generation of fracturing partially utilizes the pathways provided by the first generation and is filled by brightly luminescent calcite. This phase of calcite fills in the thin layer of porosity associated with the dolomitization and causes significant dedolomitization of the rhombs (C). A third generation of fractures, this time filled by moderately luminescent calcite also partially dedolomitizes the crystals (D) and it is the combination of of both phases of calcite and the original dolomite which results in the "quilt-like" mosaic of the crystals when viewed under cathodolumninescence.


A
5 µm
precip
dissoln.
B
5 µm
C
25µm
D
dwh-84

been introduced by fluids moving along the microporosity accompanying the dissolution/precipitation process and effectively sealed the void space. The last phase of moderately luminescent calcite does not surround the rhombs because the intercrystalline pore space had been filled previously. Cementation of the microporosity by brightly luminescent calcite may be the mechanism by which dolomitization was terminated.

4.6 MOTTLE DOLOMITE

PETROGRAPHY AND CATHODOLUMINESCENCE:

The petrographic and luminescent properties of this variety of dolomite are varied. Rhombs are fine to medium crystalline (50 to 500 micrometres), idiomorphic to xenotopic (Friedman, 196?), non-zoned to exceptionally well zoned and range in luminescence from dull purple to bright red. This entire range in character can occur over an interval as small as one or two metres and commonly, one limestone bed immediately overlying another, may contain a completely different dolomite even though the mottles look identical in outcrop.

There are however, many generalities that can be made about this variety. Rhombs are commonly dedolomitized in a fashion similar to that of matrix dolomite (figure 4.4) and most, about eighty percent of the total, are zoned by three or more discrete layers. Zonation is more common in mottle dolomite from the southern portion of the study area. In the north, rhombs are usually uniformly luminescent.

Crystals from the southern portion commonly contain a strongly ferroan zone, (to 5.4 weight percent FeO), near their midpoint or terminus (plate 4.4a). Zonation in these crystals, as in matrix dolomite, is a result of changes in total iron content rather than Mn^{2+} concentration (figure 4.6). The vast majority of crystals must have grown around microscopic nuclei because in only one example (plate 4.4b), were fine nuclei (10 micrometre calcite grains) observed.

Intercrystalline pore space is dark and composed of organic-rich insoluble detritus. The distinct impression is that this material has been "pushed out of the way" and concentrated into intercrystalline pore space, during dolomitization. This is similar to porphyroblastic growth in metamorphic rocks. The detritus is locally replaced by moderately luminescent dolomite in limestones on the Great Northern Peninsula.

Detrital feldspar and quartz are sparse accessory minerals in both the limestone host rock and the mottles. These minerals are, however, very abundant within stylolite-mottles (plate 4.4c).

Mottle dolomite is commonly preserved in diagenetic silica nodules or in silicified fine grained limestones (Pratt, 1979).

PLATE 4.4: PETROGRAPHY AND CATHODOLUMINESCENCE PHOTOMICROGRAPHS OF MOTTLE DOLOMITE.

A) Zonation within mottle dolomite crystals; Boat Harbour Formation, Lower Cove. Most crystals have a very pronounced ferroan (non-luminescent) zone developed near the midpoint or terminus of the rhombs. Cathodoluminescence.

B) Dolomite rhombs containing bright orange luminescing calcite cores, Catoche Formation, Smelt Canyon. The central location of these grains suggests that they acted as nuclei for dolomite growth. Cathodoluminescence.

C) Portion of a pressure solution seam containing an abundance of detrital feldspar (blue luminescence) and dolomite (weak luminescence): Catoche Formation, Smelt Canyon. One can visually gauge the amount of pressure solution that affected the limestone by comparing the amount of feldspar along the stylolite with that in the surrounding rock. Cathodoluminescence.

D) Portion of a trace fossil that has been completely replaced by well zoned dolomite; Boat Harbour Formation, Isthmus Bay. Cathodoluminescence.

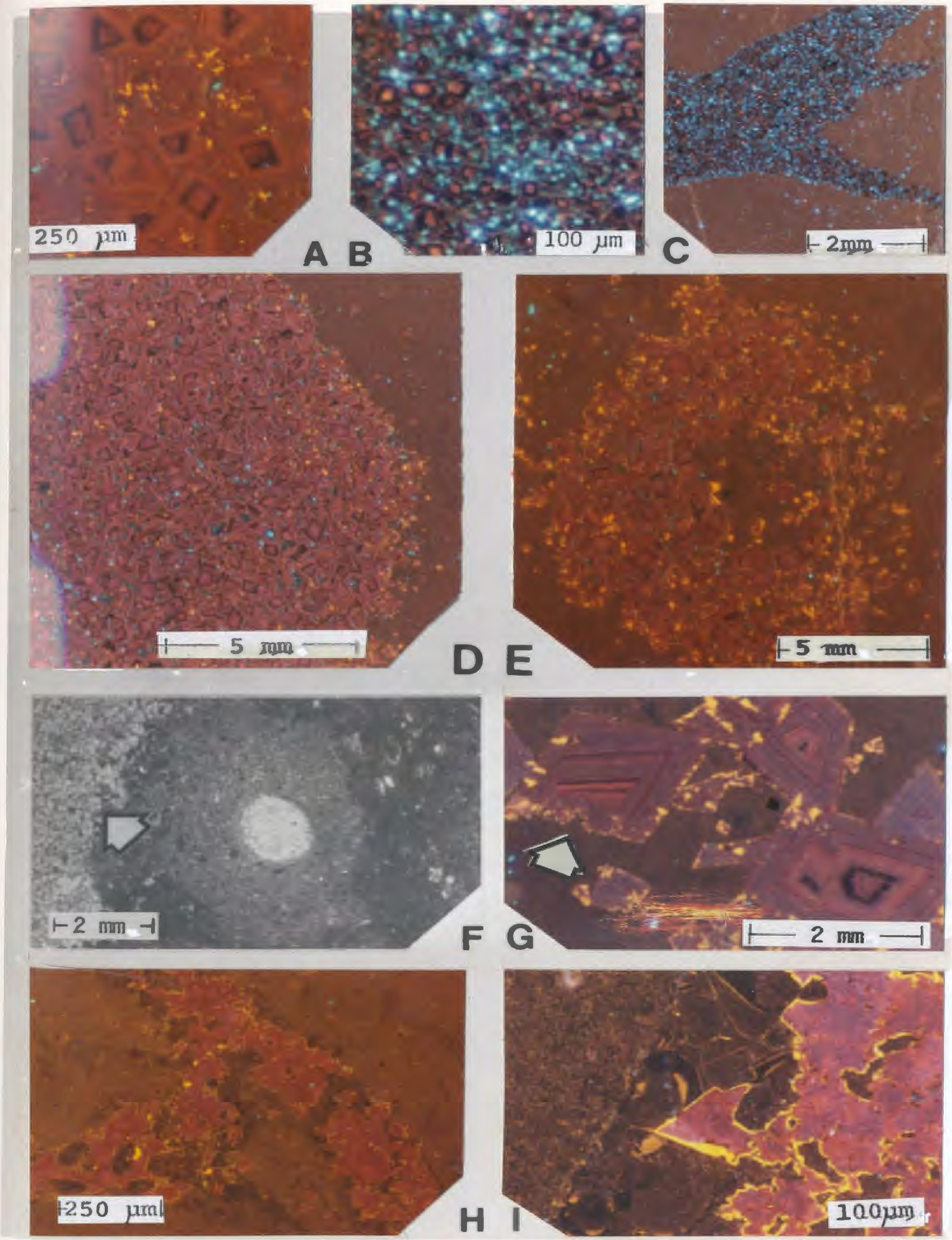
E) Ichnofossil partially replaced by dolomite; Boat Harbour Formation, Isthmus Bay. In this example, which is from the same thin section as D, dolomite is localized to the margins of the ichnofossil. The core has been filled in by a later phase of slightly ferroan calcite. Cathodoluminescence.

F) Ichnofossil whose margin has been converted to microspar; Boat Harbour Formation. No dolomite is localized to this burrow but dolomite is found in another adjacent to it (arrow). This ichofossil is in the same thin section as D and E. Plane polarized light.

G) Well zoned dolomite crystals etched by the neomorphic conversion of micrite to microspar (arrow); Catoche Formation, Aguathuna Quarry. After the neomorphism, the remaining porosity between the dolomite and the microspar was penetrated by fluids which precipitated brightly luminescent calcite (yellow). This calcite also partially dedolomitized part of the rhombs. Cathodoluminescence.

H) Dolomite (red) preferentially replacing the fine grained sediment (dark) which has filled a gastropod shell wall after dissolution of the aragonite; Catoche Formation, Smelt Canyon. Cathodoluminescence.

I) Dolomite (purple) abuting against and partially replacing a calcite filled gastropod shell; Catoche Formation, Smelt Canyon. Dolomite crystals are surrounded and are partially dedolomitized by brightly luminescent calcite. Cathodoluminescence.


250 µm
A
B
100 µm
C
2mm
5 mm
D
E
5 mm
2 mm
F
G
2 mm
250 µm
H
I
100µm

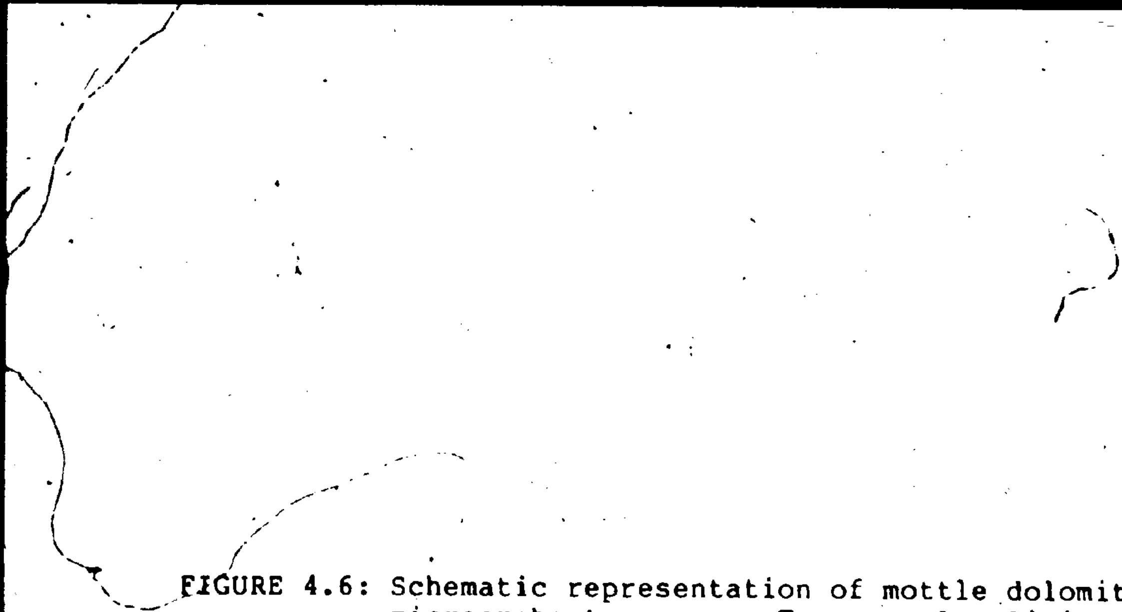
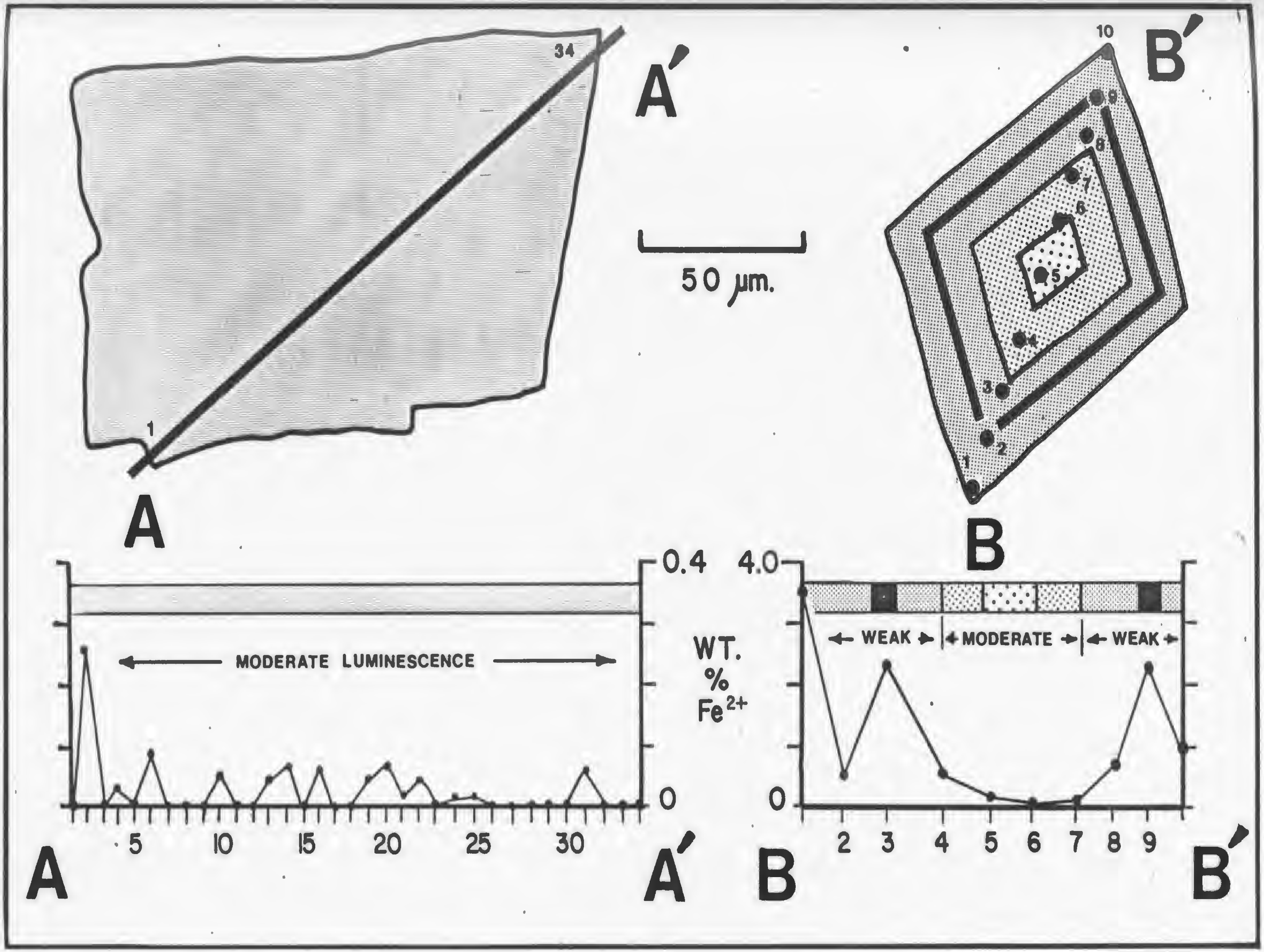


FIGURE 4.6: Schematic representation of mottle dolomite zonation correlated with electron microprobe traverses. Traverse A - A' is across a large, uniformly luminescent crystal. The concentration of both manganese (not shown on this figure) and iron are essentially below the limits of detection of the microprobe. Traverse B - B' is across a well zoned dolomite crystal and as in matrix dolomite, zonation appears to be a response to fluctuations in iron content. The concentration of manganese in this example is below the limit of detection of the microprobe.


34
A'
1
A
50 µm.
10
B'
9
8
7
6
5
4
3
2
1
B
0.4
4.0
MODERATE LUMINESCENCE
WT.
%
Fe^{2+}
0
0
WEAK
MODERATE
WEAK
5
10
15
20
25
30
A
A'
B
2
3
4
5
6
7
8
9
B'

PARAGENESIS:

As discussed in chapter three, the replacement of ichnofossils by mottle dolomite is variable. Some burrows are completely replaced (plate 4.4d), others are only partially replaced (plate 4.4e), and some have no dolomite asssociated with them at all (plate 4.4f). In several thin sections, all degrees of replacement are present enabling the following conclusions to be made;

1) There is no petrographic difference between the dolomite in partially replaced, or completely replaced ichnofossils (compare plates 4.4d and e). This implies that nucleation and growth took place in all parts of a burrow at the same time and that burrows completely replaced by dolomite are not the result of an additional phase(s) of dolomitization on those that were only partially replaced.

2) The cores of burrows that have had only their margins replaced by dolomite are filled with slightly to moderately ferroan (averages 0.24 weight percent FeO), pore-filling, equant calcite cement. This calcite locally replaces or etches some of the dolomite.

3) The margins of burrows that are not replaced by dolomite are composed of microspar (refer to plate 4.4f). Rhombs are occasionally etched in contact with the microspar (plate 4.4g).

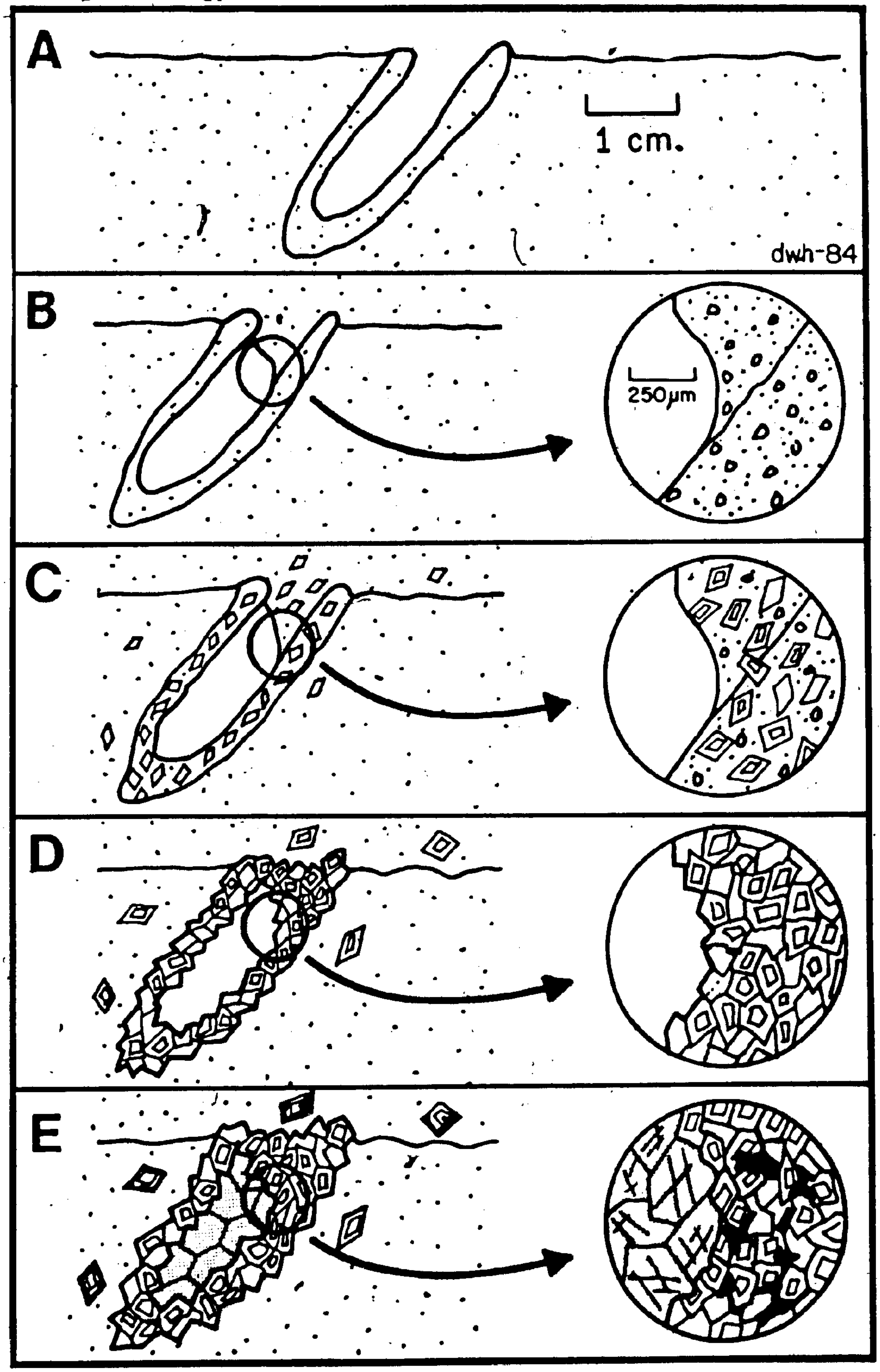
4) Compaction of burrows is variable and predates dolomitization in all examples. This is the reason for the strung-out appearence of many of the burrows when viewed in cross section.

Palaeophycus is the most commonly dolomitized ichnofossil in the St. George Group and it is likely that most of the ichnofossils encountered in thin section are of this genus. This trace fossil has a packed wall and remains open during occupation by the burrowing organism (G.

Narbonne, pers. comm. 1983; figure 4.7). After the death of the animal, some burrows must have been filled with sediment, but others, (those whose cores would later be filled by pore filling calcite), must have remained "empty". After lithification of the host mud, but before periods of silicification, dolomite began to replace the material in, and lining the burrows. Initial phases of mottle dolomite must therefore be regarded as the products of early diagenesis or eogenesis (Choquette and Pray, 1970). Those burrows filled entirely with sediment were eventually completely replaced, whereas the empty burrows had only their margins replaced (figure 4.7). Dolomite growth appears to have been continuous but affected by changes in the pore water chemistry as displayed by zonation. These changes were local because the zonation is not constant everywhere. In many examples, crystal size and zonation patterns (especially the prominent ferroan zone), are similar to those of the matrix dolomite in nearby fine grained limestones. This strongly suggesting that at least some matrix dolomite and mottle dolomite formed over the same period of time and as a result of the same event(s) (figure 4.1).

The etching of some of the dolomite crystals by microspar (plate 4.4g) and by ferroan, pore- filling equant calcite cement suggests that dolomitization was interupted on occasion by the conversion of micrite to microspar and by periods of late-diagenetic burial cementation (figure

FIGURE 4.7: Schematic summary illustrating the process whereby mottle dolomite replaces the margins of ichnofosssils. Many of the trace fossils, especially those identified as Palaeophycus, are characterized by packed margins (A) and may have remained open after they were overlain by sediment (B). After lithification of the enclosing lime mud, dolomite selectively replaced the margins and the sediment which percolated into the open burrows (C), eventually forming an xenotopic mosaic (D). After dolomitization, ferroan calcite spar cement (stippled) filled the void space at the core of the burrow (E). Selective dolomitization (black) is a later diagenetic event.


A
1 cm.
dwh-84
B
250μm
C
D
E

4.7). Most rhombs however, are not altered by these events suggesting that dolomite growth was also continuous after microspar formation and burial cementation. This is also like matrix dolomite in fine grained limestones.

It is evident that mottle dolomite has undergone a prolonged period of growth and must be regarded as a product of early- to late-diagenesis (mesogenesis of Choquette and Pray, 1970) (figure 4.1). Dedolomitization and termination of dolomite growth may have occurred during periods of tectonic fracturing in a similar fashion to that postulated for matrix dolomite (figure 4.5).

Events responsible for the replacement of aragonite body fossils are essentially the same as those summarized above with but one important addition. Aragonite body fossils (especially gastropods) were subjected to dissolution prior to the start of lithification (figure 4.1) and the shell molds were filled by fine sediment. Dolomite preferentially replaced this fine grained sediment. Rhombs are petrographically identical to the dolomite in nearby ichnofossils (plate 4.1f).

Fossils that have been filled or replaced by calcite spar rather than sediment are less commonly dolomitized suggesting that in some cases, equant calcite cementation of aragonite shell molds predates dolomitization. The embayment of cement in contact with dolomite (plate 4.4i) further supports this conclusion.

The role that pressure solution has played in these rocks is variable. Frequently, stylolites cut across mottles, are deflected around them, or are nucleated along the contacts between the mottles and the limestone indicating that pressure solution postdates mottle dolomitization. In many limestones however, dolomite has nucleated in, and grown wholly within the confines of the stylolites. It has not simply been collected during pressure solution.

It is possible to visually guage the amount of pressure solution that has affected a rock by comparing the amount of detrital feldspar localized along stylolites with the amount found scattered in the limestone (for example, refer to plate 4.4c). If the dolomite is compared in a similar manner, it becomes clear that there is just not enough in the host rock to account for the amount localized along the stylolites; dolomite must either postdate pressure solution, or must have accompanied it.

Many dolomitized ichnofossils as well as matrix dolomite-rich intervals in fine grained limestones are transected or, abut against stylolites. Given that the fluids which passed along the solution seams during and/or after pressure solution could have promoted dolomitization, it is not unreasonable to assume that they too were subjected to this late-diagenetic period of dolomite growth. This further implies that mottle (and some matrix) dolomitization is a long lived event.

4.7 PERVASIVE A DOLOSTONE

PETROGRAPHY AND CATHODOLUMINESCENCE:

The dolomite that is responsible for the mottling in these rocks is to all intents and purposes, identical to the dolomite between the mottles. Crystals in both areas are clear, anhedral and form xenotopic mosaics. Luminescence is normally a uniform moderate red colour. The only apparent difference between the mottles and the intermottle areas is a difference in crystal size; this being most apparent when the samples are examined under polarized light (plate 4.5a).

Mottles can occasionally, be resolved into individual ichnofossils and as in mottle dolomite, the finer dolomite is localized to the margin of the burrow (plate 4.5b). When viewed under cathodoluminescence however, resolution is much more difficult because of similarities in colour and intensity (plate 4.5c).

Approximately twenty percent of the pervasive A dolostone samples examined with cathodoluminescence are composed of zoned dolomite. Zonation within the dolomite that makes up the mottles is poor, and seldom are more than one or two layers developed around a central core of dull red luminescing dolomite. The intermottle rhombs are usually better zoned and have additional outer layer(s) of non-luminescent dolomite (plate 4.5d,e). The core to these crystals is commonly larger than the dolomite found in the mottles, but luminesce in an identical fashion.

PLATE 4.5: PETROGRAPHY AND CATHODOLUMINESCENCE PHOTOMICROGRAPHS OF PERVASIVE A DOLOSTONES.

A) Bimodal dolomite crystal size within a pervasive A dolostone; Boat Harbour Formation, Isthmus Bay. Crossed nichols.

B) Transverse section through an ichnofossil (arrows); Boat Harbour Formation, Cape Norman. Trace fossils are only recognizable in these rocks by the localization of finely crystalline dolomite to their margins. Plane polarized light.

C) Cathodoluminescence of the ichnofossil shown in B (arrows are in the same position as they are in B). In general, the rhombs within the margin of the burrow luminesce the same colour and intensity as the dolomite between the burrows. The intercrystalline boundaries of the dolomite crystals have been penetrated by a later phase of moderately luminescent dolomite. This is typical of all samples from the northern part of the study area.

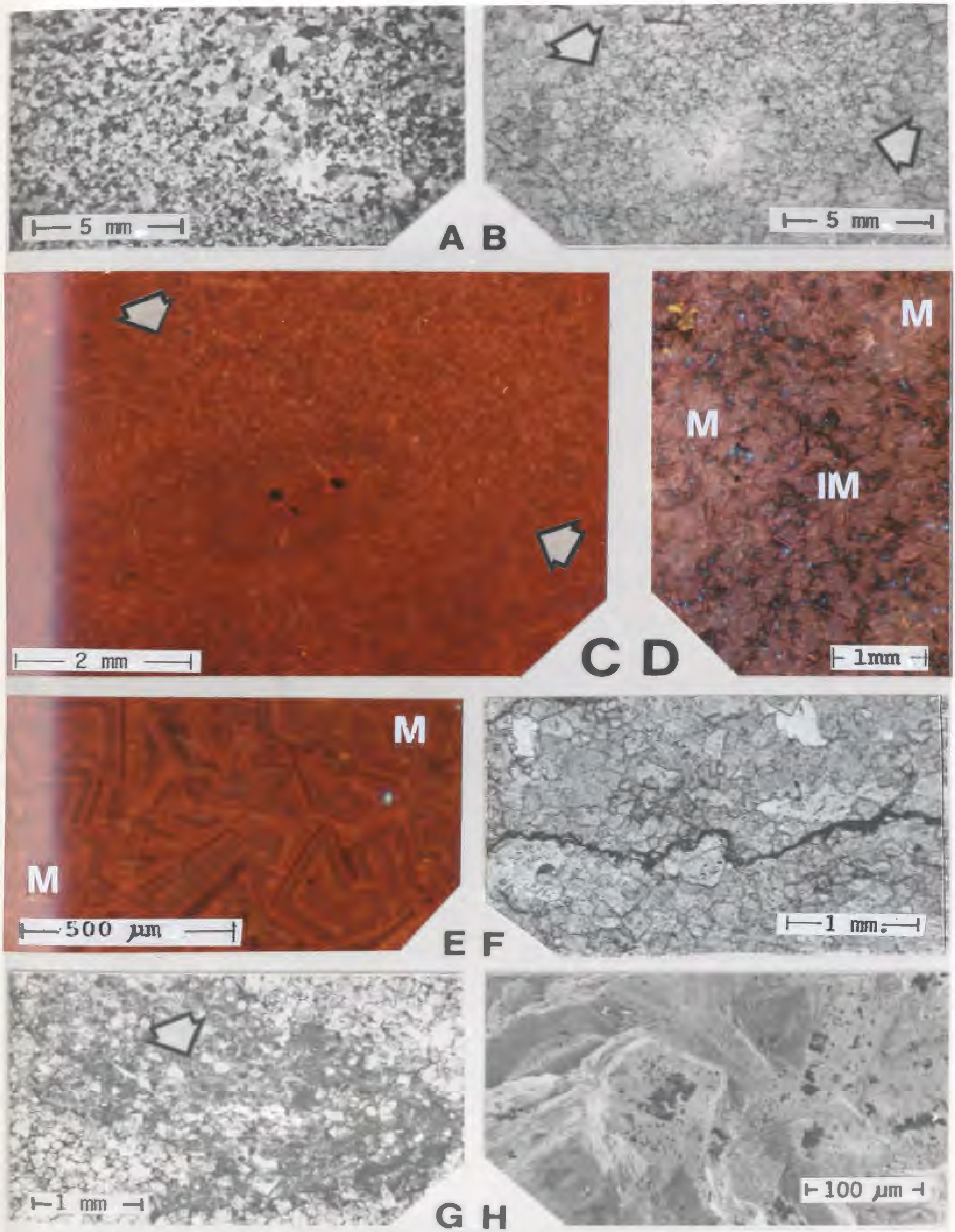
D) Mottles (M) and intermottle areas (IM) within a pervasive A dolostone; Catoche Formation, Smelt Canyon. The intermottle areas are composed of dolomite that is better zoned and has additional outer zones than the dolomite confined to the mottles. Cathodoluminescence.

E) Exceptionally well zoned dolomite crystals within the intermottle area of a pervasive A dolostone; Catoche Formation, Hare Bay. Part of the intermottle dolomite has nucleated around the mottles which suggests continual dolomite growth in these areas after dolomitization had terminated in the mottles (M). Cathodoluminescence.

F) Dark insoluble material localized along a stylolite (arrow); Boat Harbour Formation, Cape Norman. Despite the fact that the stylolite is only poorly developed, this indicates that pressure solution postdates pervasive A dolomitization. Plane polarized light.

G) Individual dolomite rhombs localized in the interareas between mottles in a wackestone close to a pervasive A dolostone - limestone contact; Boat Harbour Formation, Isthmus Bay. Plane polarized light.

H) Scanning electron photomicrograph of a partially dedolomitized pervasive A dolostone; Boat Harbour Formation, Isthmus Bay. Prior to examination, this sample was etched in a weak acid solution to selectively remove the calcite. Dedolomitization is concentrated at the cores of the rhombs.


5 mm
5 mm
A B
M
M
IM
2 mm
1mm
C D
M
M
500 µm
1 mm
E F
1 mm
100 µm
G H

Three samples out of a total of twenty seven examined differ from the "standard" dolostones discussed above. These rocks contain mottles that are composed of a clearly different dolomite than makes up the intermottle areas and is not simply the addition of a few different layers of dolomite on top of the same core. The mottles are made up of moderately luminescent dolomite whereas the intermottles are composed of non-luminescent dolomite with occasional and thin (less than 50 micrometres), bright bands. These different dolostones are scattered both geographically and stratigraphically; one is from Smelt Canyon (Catoche Formation), one is from Port au Port (Boat Harbour Formation) and one is from Hare Bay (Catoche Formation). They appear to be interbedded with the more typical or "standard" pervasive A dolostones.

Feldspar is a common but sparsely distributed accessory mineral in pervasive A dolostones and is likely inherited from the former limestone. Stylolites are also common, though poorly developed. Rather than the sharp seams marked by the accumulation of siliciclastic minerals, stylolites in the majority of these dolostones are usually marked by brecciation (on a microscopic scale), grinding of the dolomite and the accumulation of dark insolubles (plate 4.5f). Intercrystalline pore space is marked by the accumulation of dark insoluble material and this is locally replaced by bright red luminescing dolomite on the Great Northern Peninsula (refer to plate 4.5c).

PARAGENESIS:

Before summarizing the paragenetic history of pervasive A dolostones as suggested by petrographic and field observations, it is first necessary to outline some important conclusions that can be made (or deduced) about these rocks. It seems likely that the mottles and intermottle areas within most pervasive A dolostones formed from fluids of the same trace element composition and probably at the same time. This conclusion is based upon the identical luminescence of dolomite in the mottles and intermottles for the majority of the examples. Samples that are composed of zoned dolomite also support this conclusion, but the fact that there are additional zones added to the intermottle dolomite suggests further growth after the rhombs had coalesced in the mottles. This is best explained by advocating a more rapid, or intense, nucleation rate within the margins of the ichnofossils than between them. The three exceptions suggest a secondary dolomitization and will be addressed shortly.

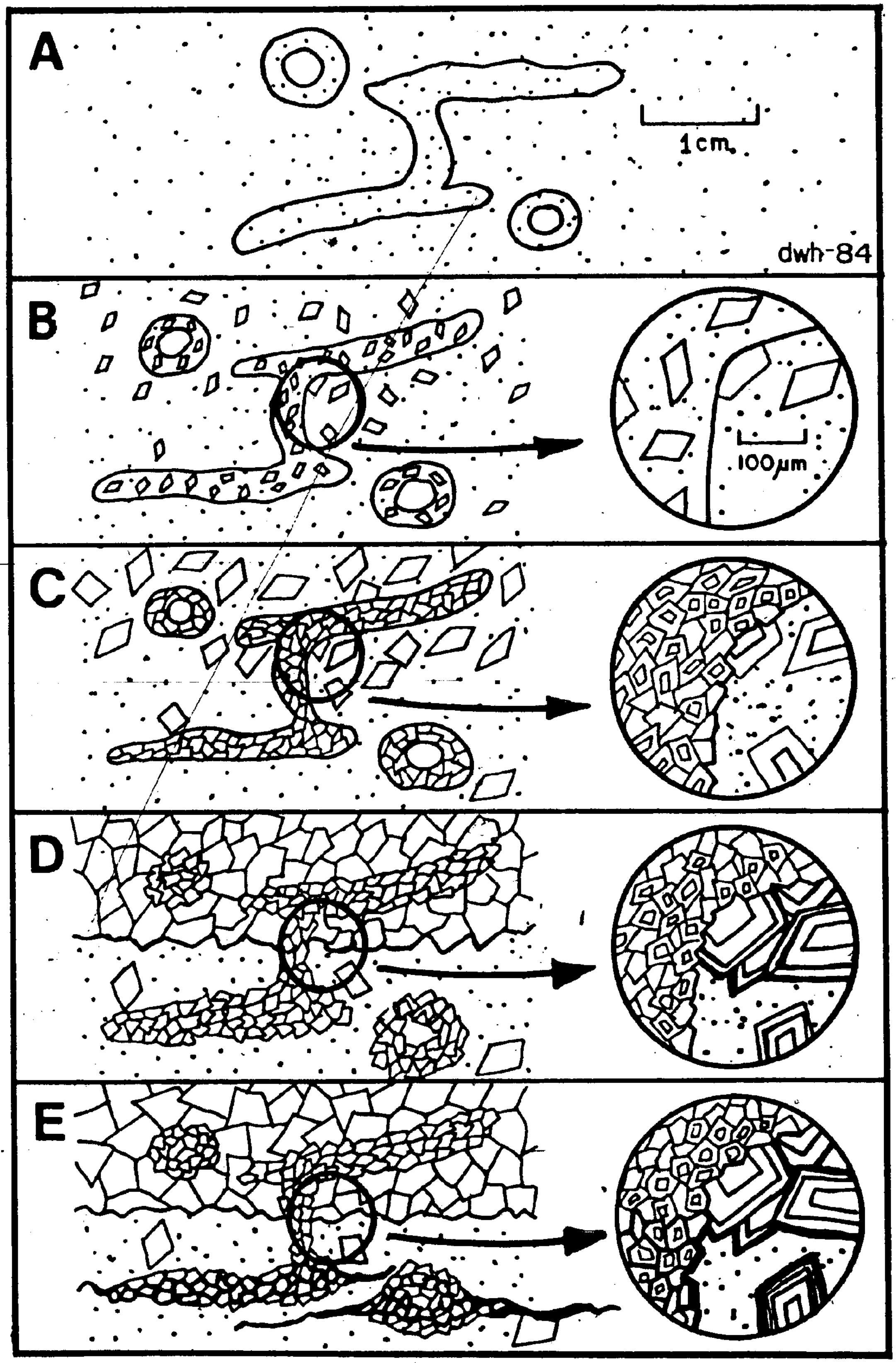
The relationship between mottles in the pervasive A dolostones and in adjacent limestones is not straight forward. Pervasive A dolostones share many common characteristics with dolomite mottled limestones: 1) they commonly abut against, or grade into one another (plates 3.4b,c), 2) mottles can be traced from one lithology into the other and 3) both contain gastropods and ichnofossils whose walls are preferentially replaced by finely crystalline dolomite (compare plate 4.5b with plate 4.4e). These common characteristics suggest that pervasive A dolostones and mottle dolomite in limestones must be closely related. Rhombs in the limestone, however, differ petrographically from those within the adjacent dolostones. The central portion of the mottle dolomite crystals are similar to those in the dolostone; they are uniformly luminescent if the adjacent pervasive A dolostone is composed of uniformly luminescent dolomite (the usual case), or are zoned if the adjacent pervasive A dolostone is composed of zoned dolomite (rare occurrences). In almost all examples however, the mottle dolomite has additional zones superimposed on this central portion which suggests further dolomite growth within the limestone after dolomitization had been completed in the dolostone. It can also be deduced that crystal growth was more rapid in the dolostone than in the limestone because bands within the former are usually thicker than are corresponding bands in the latter.

Mottles in limestone and in dolostones also differ in their accessory mineral composition. Mottle dolomite is commonly strung out along stylolites and contains abundant feldspar, quartz and clays. No where in any of the dolostones are there concentrations of this "stylocumulate", in fact, the stylolites that are present brecciate the dolomite crystals. These observations indicate that pervasive A dolostone predates all phases of pressure solution.

Although very sharp in outcrop, contacts between the two lithologies in thin section is usually gradational. The transition from limestone to dolostone is accompanied by a increase in the amount of dolomite rhombs within the intermottle areas (plate 4.5g), eventually coalescing into xenotopic mosaics in the intermottle areas of the dolostone. In the limestone, dolomite rhombs are only sporadically distributed.

These field and petrographic observations are best explained by the following sequence of events. Ichnofossils in both the limestones and the dolostones must have begun to be preferentially dolomitized at about the same time (figure 4.8). Rhombs probably nucleated and grew quickly, (but also coalesced quickly), near the margins of the ichnofossils in the dolostone as evidenced by their fine crystallinity and xenotopic habit. Growth may have been less rapid in the limestone as dolomite crystals here are less commonly intergrown and the central portion of the crystals is smaller than corresponding crystals in the dolostone. Differences in nucleation and growth rates may also explain why the transition from limestone to dolostone is also accompanied by a sharp increase in the proportion of mottle dolomite (refer to the discussion in chapter three and figure 3.4). At the same time, individual dolomite rhombs nucleated between the mottles and also grew rapidly (figure 4.8). Because they were more sparsely distributed initially, they had more room to grow and

FIGURE 4.8: Paragenesis of pervasive A dolostones and its relationship to mottle dolomite. Following bioturbation (A), dolomite nucleation and growth began (B). In some areas (upper half of diagram), dolomite growth was pervasive. In other portions (lower half of diagram), dolomite growth was restricted to the burrows. Nucleation appears to have been very rapid in the ichnofossils and subsequently, dolomite crystals coalesced quicker in the ichnofossils than between them (C). Dolomite growth in the areas between the ichnofossils proceeded for a longer period of time and this resulted in coarser crystals with additional outer zones (D) Pervasive A dolostones were not subjected to a later phase of dolomite grow along stylolites that affected the mottle dolomite (E).


A
1cm
dwh-84
B
100μm
C
D
E

therefore, became larger before finally coalescing. Additional zones may, or may not, be more ferroan reflecting changes in pore water chemistry during these later phases of growth (refer to plate 4.4d). The transition from bioturbated limestone to pervasive A dolostone took place relatively early diagenetically and in most examples, predates the onset of additional phases of zonation within the mottle dolomite in adjacent limestones. Pervasive A dolomitization is therefore primarily the result of an early-diagenetic event and is coincident with early phases of mottle/matrix dolomite (figure 4.1).

The three samples of pervasive A dolostone which contain a different dolomite in the intermottles than found in the mottles suggests overprinting of a dolomite mottled limestone by a second later period of dolomitization. These instances must have been the result of several different, and very localized events as these rocks are so few in number and are widely distributed both geographically and stratigraphically. Timing these secondary dolomitization events is difficult and little apart from stating that they postdate the initial dolomitization responsible for the mottles, and that they may have accompanied periods of pressure solution can be safely concluded.

Post-dolomitization events are similar to those in previously described varieties. Ferroan and non-ferroan calcite cementation of pore space, followed by chert replacement of this cement is common, as is tectonic fracturing. Selective dedolomitization (plate 4.5h), and late stage pore filling ferroan dolomite are less common events.

4.8 PERVASIVE B DOLOSTONE AND SADDLE DOLOMITE PETROGRAPHY AND CATHODOLUMINESCENCE:

Unlike pervasive A dolostone, the mottles and intermottles of pervasive B dolostone are bimodal and warrant separate discussions. The dolomite within the intermottle areas of these rocks is petrographically identical to saddle dolomite in fractures and vugs, and therefore, these two varieties will be discussed together.

Mottles:

Dolomite within mottles in pervasive B dolostones is medium crystalline (100 to 200 micrometres), non-ferroan, anhedral, forms xenotopic mosaics (plate 4.6a) and normally luminesce uniform hues of red or purple (plate 4.6b). Zonation is rarely developed. Ichnofossils and gastropods are exceptionally well preserved (plate 4.6c).

In all cases, mottles have been dragged out horizontally along stylolites (refer to plate 3.5c) and commonly abundant detrital feldspar is associated with them (refer to plate 3.6a). Stylolites usually do not continue into intermottle areas.

Dolostones from the Watts Bight Formation are composed of dolomite which luminesce in a similar fashion

PLATE 4.6: PETROGRAPHY AND CATHODOLUMINESCENCE PHOTOMICROGRAPHS OF PERVASIVE B DOLOSTONE.

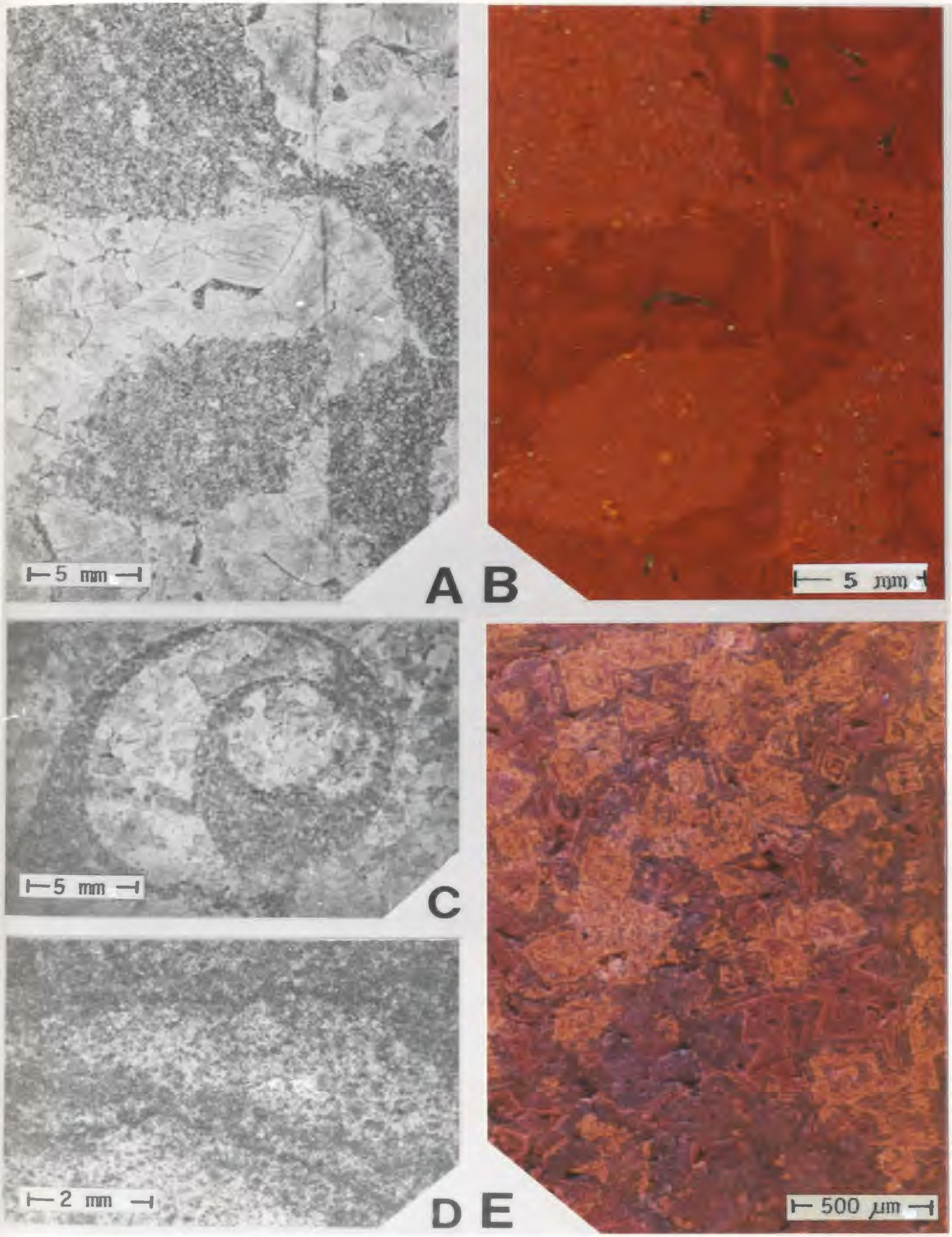
A) Finely crystalline dolomite localized in mottles within a pervasive B dolostone; Catoche Formation, Table Point. The dolomite within the interareas is much more coarsely crystalline and is characterized by curved crystal outlines, and strained extinction. Plane polarized light.

B) Cathodoluminescence of the same portion of the pervasive B dolostone shown in A. The dolomite within the mottles has clearly different luminescence than the dolomite between the mottles.

C) Gastropod preserved within a pervasive B dolostone; Watts Bight Formation, Cape Norman. The finely crystalline dolomite that is localized to the shell is the same as the dolomite found in ichnofossils. Plane polarized light.

D) Cryptalgal laminations preserved within a pervasive B dolostone; Watts Bight Formation, Back Arm. Plane polarized light.

E) Recrystallization of dolomite within a pervasive B dolostone; Watts Bight Formation, Cape Norman. The contact between the replacement dolomite (red luminescence) and the original dolomite (purple luminescence) is very irregular indicating that the luminescence characteristics of this example is not the result of zonation. Cathodoluminescence.



5 mm
A
B
5 mm
5 mm
C
2 mm
D
E
500 µm

to that of the mottle dolomite but preserves, albeit poorly, cryptalgal laminations (plate 4.6d). Rhombs are also more coarsely crystalline ranging from 300 to 750 micrometres in size. This characteristic more closely resembles the intermottle dolomite than it does the mottle dolomite. As in other pervasive B dolostones, mottles are usually dragged out along stylolites; however, in these rocks, the stylolites also cut across the intermottles.

Intercrystalline pore space of the dolomite within all mottles, as in most other varieties of dolomite and dolostone on the Great Northern Peninsula, is filled by dark, organic rich insoluble material which is locally penetrated and replaced by red, moderately luminescent dolomite. This same red luminescing dolomite also replaces part of the original dull-purple luminescing dolomite in some Watts Bight dolostones. The contact between the two different dolomites is very patchy and irregular suggesting that it is a replacement rather than simple zonation (plate 4.6e). These are the only clear-cut examples of dolomite recrystallization found in the St. George.

INTERMOTTLES AND SADDLE DOLOMITE:

Rhombs from between mottles in pervasive B dolostone and in saddle dolomite are turbid, show sweeping or hour glass extinction (plate 4.7a), can be very coarsely crystalline, (saddle dolomite crystals in fractures can measure to 15 millimetres), and range in shape from

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B) Cathodoluminescence of the same portion of the pervasive B dolostone shown in A. The dolomite within the mottles has clearly different luminescence than the dolomite between the mottles.

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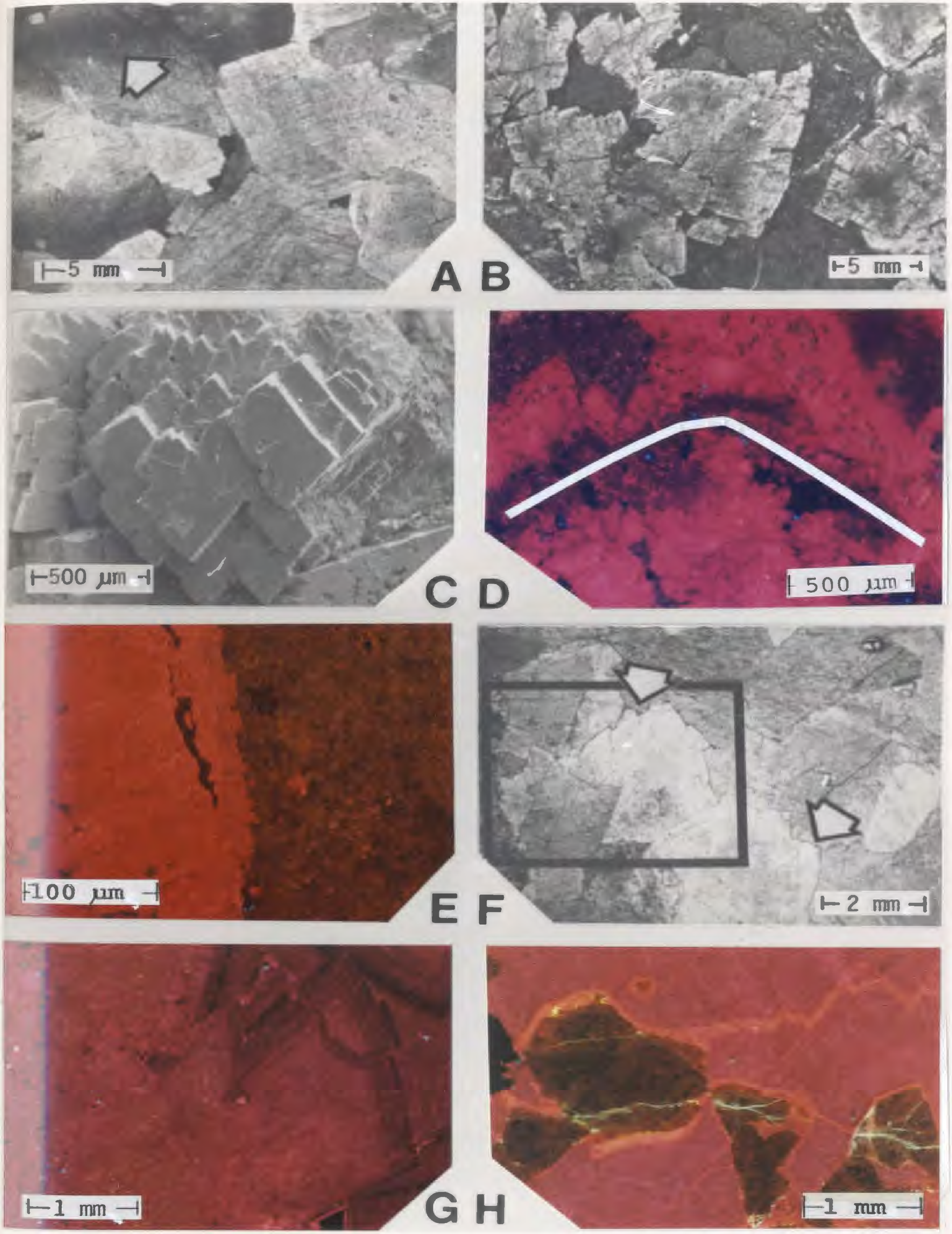
D) Cryptalgal laminations preserved within a pervasive B dolostone; Watts Bight Formation, Back Arm. Plane polarized light.

E) Recrystallization of dolomite within a pervasive B dolostone; Watts Bight Formation, Cape Norman. The contact between the replacement dolomite (red luminescence) and the original dolomite (purple luminescence) is very irregular indicating that the luminescence characteristics of this example is not the result of zonation. Cathodoluminescence.


5 mm
5 mm
A
B
500 µm
500 µm
C
D
100 µm
2 mm
E
F
1 mm
1 mm
G
H

anhedral - intergrown to rhombohedral and strongly curved (plate 4.7b). Pore-filling saddle dolomite crystals nucleated along both sides of the fractures and grew with their optic, or C axes, oriented perpendicular to the fractures. Cleavages are also commonly curved and large crystal faces are composed of smaller rhombs which are identical in appearence to the stepped or disrupted surfaces described by Radke and Mathis (1980) (plate 4.7c).

The dolomite is usually non-ferroan, rarely zoned and uniformly luminescent (moderate to bright red) (refer to plate 4.6a). It is this dolomite that occupies intercrystalline pore space in all other dolomite and dolostone varieties on the Great Northern Peninsula. Exceptions to this luminescence do exist, particular within pore filling saddle dolomite. Successive generations are commonly more ferroan, (increases from 0 weight percent FeO to 2.5 weight percent FeO are not uncommon), and are correspondingly less luminescent.

Intercrystalline pore space in the intermottle areas of pervasive B dolostone is occupied by either dark insoluble material, or microcrystalline chert. The intercrystalline pore space preserved in the saddle dolomite-filled fractures and vugs is either empty, or contains megacrystalline, non-ferroan calcite, euhedral quartz or rarely, gypsum and fluorite.

PARAGENESIS:

The paragenetic relationships between saddle dolomite, pervasive B dolostone and the surrounding country rocks are complex. Because of petrographic and luminescence similarities, it is likely that most saddle dolomite and pervasive B dolostones were derived from fluids of similar character. It is clear however, that all the pervasive B dolostone and saddle dolomite did not form at the same time. There are different events of both as evidenced by:

1) Veins of saddle dolomite that cut across some beds of pervasive B dolostone which also nucleate pervasive B dolomitization in nearby limestones (refer to plate 3.8h),

2) Saddle dolomite veinlets which do not cut completely across pervasive B dolostones, but instead, merge into the intermottle dolomite,

3) Saddle dolomite which locally replaces the intermottle dolomite within pervasive B dolostones (refer to plate 3.8f).

With the possible exception of the Watts Bight Formation, there is no doubt that pervasive B dolostones are products of late diagenetic events (figure 4.1) and were caused by a second phase of dolomitization overprinting a dolomite mottled limestone. This conclusion is substantiated by several petrographic and field observations:

1) Mottles in the dolostone look similar to mottles in nearby limestones (both have the same uniform luminescence) and commonly, they grade into one another. Unlike pervasive A dolostones, mottles in both lithologies have been dragged out by pressure solution.

2) Pods of pervasive B dolostone are common within limestones on the Great Northern Peninsula but never in any other lithology.

3) In some remnant limestones, saddle dolomite nucleates around pre-existing dolomite crystals in mottles and along stylolites (plate 4.7d). In all cases, this phase of dolomitization postdates all diagenetic alterations of the limestone (including compaction, cementation, neomorphic conversion of micrite to microspar and pressure solution).

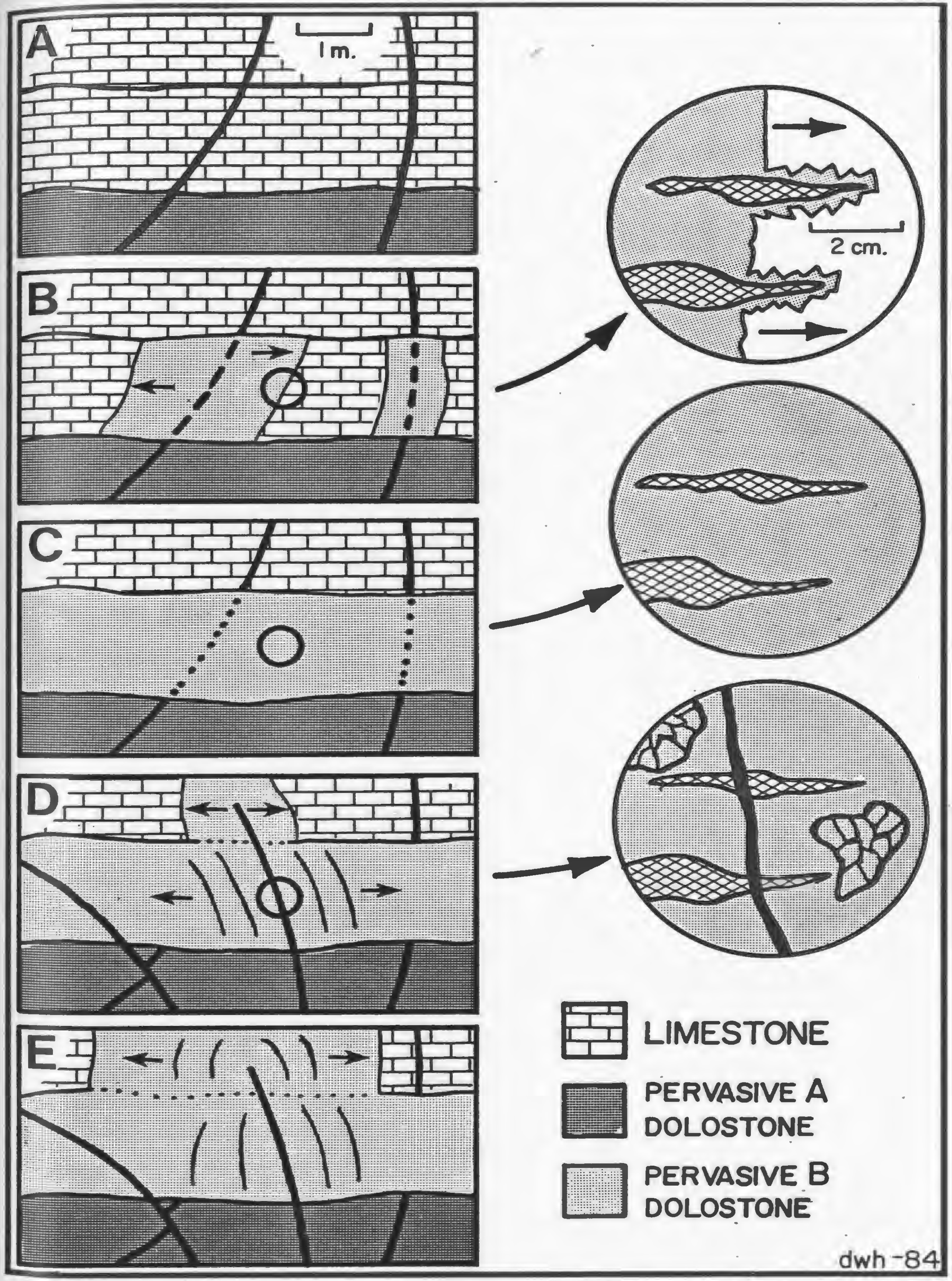
Pervasive B dolostone in the Watts Bight Formation differs from dolostones in stratigraphically higher formations: 1) it preserves cryptalgal laminations, 2) is not characterized by two distinctly different dolomites, 3) is cut by stylolites and 4) is (rarely) recrystallized (plate 4.6e). It is this latter characteristic that is most important as it suggests that an earlier phase of dolomite was replaced by late-diagenetic dolomite. Rather than overprinting a limestone, pervasive B dolomitization in the Watts Bight Formation may have overprinted a pre-existing dolostone. Overprinting may also explain why, given the prominence of zonation in most southern examples of mottle dolomite, mottles in northern limestones and pervasive B dolostone are composed of uniformly luminescent crystals. This may either reflect original differences in character (that is, the rhombs were never zoned), or destruction of zonation by overprinting. Given that the one example of recrystallization was at the expense of <u>zoned</u> crystals, this latter possibility is entirely feasible.

The replacement of limestone by intermottle dolomite must have been accomplished by dissolution and precipitation along a very sharp front and on a microscopic scale rather than large scale dissolution prior to dolomitization. There is no other way to account for the sharp contacts which often occur between pervasive B dolostones and limestones. These contacts appear sharp even in thin section (plate 4.7e). Had the dolomitization been preceded by large scale dissolution, the mottles would not be expected to be insitu and many examples of solution collapse would be expected. With the exception of the Newfoundland Zinc Mines (discussed shortly), solution collapse is not a major component in the paragenetic history of these rocks.

Pervasive B dolomitization was probably initiated during the earliest phases of tectonic fracturing. Fluids passing up the fractures migrated into surrounding rocks where they developed the first generations of pervasive B dolostone (figure 4.9). The replacement of the intercrystalline material in the other dolostones is also likely to have occurred during the passage of these fluids.

As these limestones were being dolomitized, new generations of saddle dolomite either utilized the previous fractures or filled new ones. These fractures, and still later generations, cut cleanly through the dololaminites, and the pervasive A and B dolostones but locally caused pervasive B dolomitization when limestones were encountered (figure 4.9). The "pods" and "pans" described in chapter three are probably products of this dolomitization.

FIGURE 4.9: Probable origin of pervasive B dolostones. Initially, country rocks (limestones and dolostones) were subjected to tectonic fracturing and fill by saddle dolomite (A). From these sites, stratabound dolomitizing fluids passed into limestones along a sharp dissolution/precipitation front (B). Dolomite growth may also have nucleated along the pre-existing crystals that were localized to mottles (inset). Whole limestone beds were replaced in this manner (C). Later generations of fractures cut through the dolostones and nucleted dolomitization in other limestones. Replacement of the intermottle areas by later generations of saddle dolomite also occurred during this time as the aggressive solution continued to pore out from the fractures (D). Limestones could again be completely replaced, or only partially replaced. The latter results in stratabound pods or pans (E).


A
1m.
B
C
D
E
2 cm.
LIMESTONE
PERVASIVE A DOLOSTONE
PERVASIVE B DOLOSTONE
dwh-84

Fracturing is most intense in the area of the Newfoundland Zinc Mine where true spar breccias and pseudobreccias are locally developed. The upper portion of the Catoche Formation underwent local dissolution prior to deposition of Table Head sediments and this subsequently caused collapse (Collins and Smith, 1975, Lane, 1984). Elsewhere on the Great Northern Peninsula, the rocks in this part of the section are composed of interbedded pervasive A and pervasive B dolostones. Collapse at the mine appears to have resulted from selective dissolution of limestone interbeds during, or instead of, pervasive B dolomitization. This can be concluded because the pervasive A dolostone beds, which are referred to as "dark grey dolomites" (T. Lane, pers. comm., 1983), are preserved in the mine.

After collapse, sediment filled in the depression, and saddle dolomite precipitated out as a cement for the breccias and into fractures which extended into the country rock. The precipitation must have been exceedingly rapid because saddle dolomite can account for up to about sixty percent of the volume of the rock in true spar breccias and it seems unlikely that an unstable mass such as this could have existed very long without cementation.

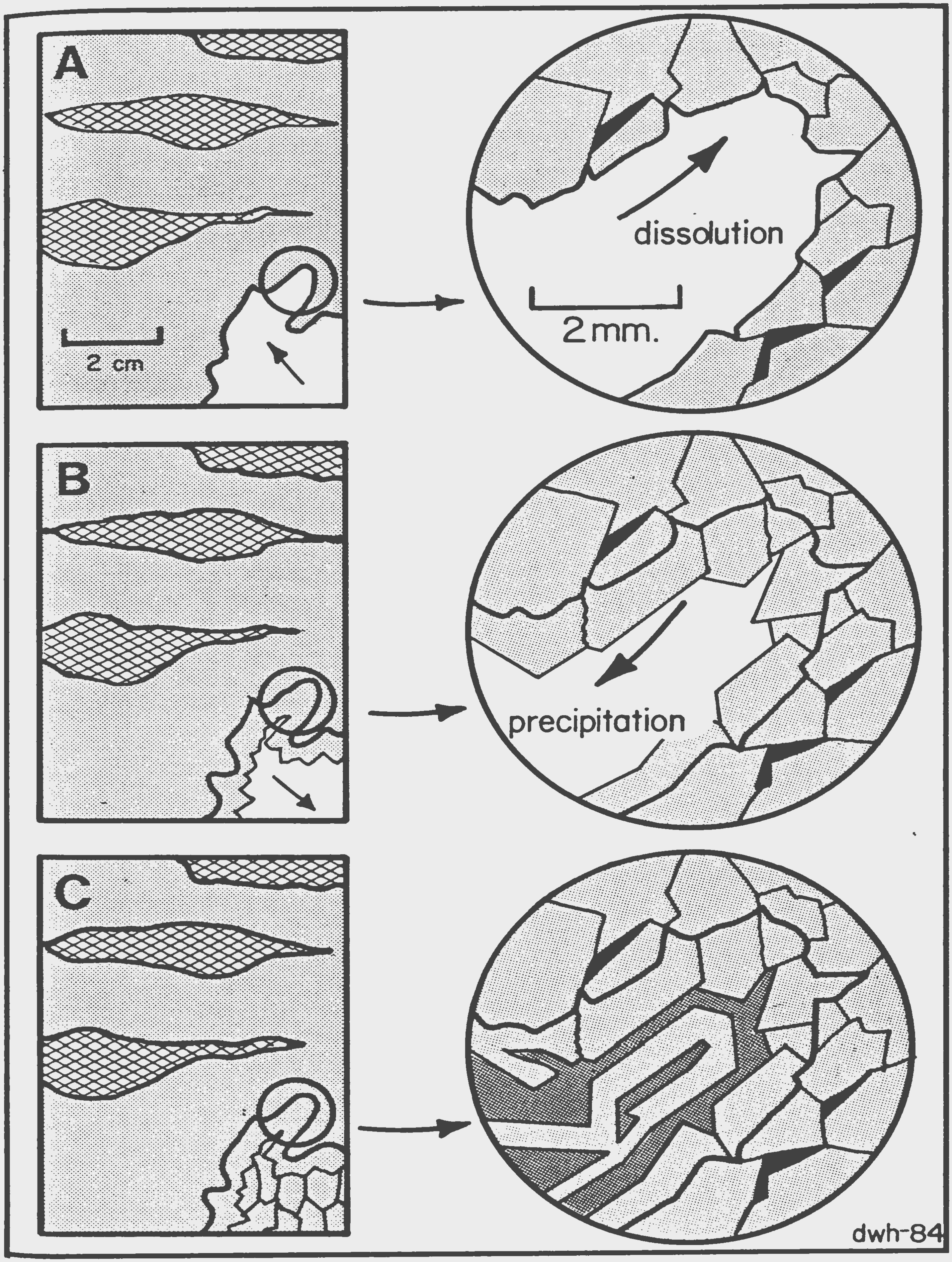
Saddle dolomite also replaces portions of the surrounding host rocks (especially the intermottles of pervasive B dolostone). This replacement is partially responsible for pseudobreccia development (refer to plate

3.8c) and for patches of saddle dolomite within pervasive B dolostones (refer to plate 3.8d). Replacement appears to have been caused by sharp fronts that passed through the dolostones in a similar fashion to how pervasive B dolostones formed (figure 4.9). In fact, it is likely that the fluids responsible for replacement, originated from the same fractures that were the source of pervasive B fluids and relatively speaking, almost at the same time (figure 4.9). These were very aggressive fluids and appear to have been capable of replacing dolomite that had just formed.

Although replacement is very clear in outcrop, it is difficult to resolve in thin section because of petrographic similarities between the dissolution front and the normal intercrystalline contacts (plate 4.7f). Early phases of the replacement dolomite commonly have similar optical and luminescent properties to the pre-existing dolomite and grow syntaxially around it (plate 4.7g). Later phases of saddle dolomite are more ferroan (less luminescent) and occasionally fill fine fractures which cut across the early dolomite (figure 4.10).

Sphalerite mineralization is complex at Newfoundland Zinc Mines and Lane (1984) has identified as many as four stages of precipitation which he distinguishes from one another on the basis of colour differences. In this study, sphalerite mineralization was investigated only in a cursory fashion, but most appears to have predated or accompanied early phases of saddle dolomite precipitation

FIGURE 4.10: Replacement of intermottle dolomite by saddle dolomite in pervasive B dolostones. The replacement is first preceded by dissolution (A) which at least partially follows the crystal outlines of the dolomite crystals. After dissolution, dolomite began to precipitate out in optical continuity with the pre-existing crystals. Usually the luminescence character of the new dolomite is the same as the pre-existing dolomite, and the dissolution front becomes very difficult to recognize in thin section (B). Later generations of saddle dolomite (in this example of a different luminescence character), fill in the remaining pore space of the rock (C).


A
2 cm
dissolution
2 mm.
B
precipitation
C
dwh-84

(plate 4.7h). This is in agreement with the conclusions of Lane (1984).

The timing and the duration of pervasive B and saddle dolomitization in the Catoche Formation can be estimated by examining the overlying Table Head Group. The lowest part of these limestones are pervasively dolomitized in the mine area, at River of Ponds (refer to figure 1.1) and at Port au Choix. If pervasive B dolomitization began around the time of solution collapse of the Catoche Formation, it can be speculated that the dolomitization(s) occurred over the interval represented from the deposition of the Aguathuna Formation (Valhallan; Stouge, 1980) to at least earliest Middle Ordovician time (White Rock; Stouge, 1980).

It is likely that the scattered occurrences found within the Boat Harbour Formation also formed at the same time. This is suggested by saddle dolomite fractures which extend from the Boat Harbour into the Catoche at Port au Choix, Back Arm and Cape Norman.

The association of pervasive B dolostone with some faults suggests that dolomitization proceded up until at least the onset of regional tectonism. Along the west coast of Newfoundland, faulting is thought to have begun during the Middle Ordovician (H. Williams, pers. comm., 1984). Other periods of faulting occurred during the Devonian and the Carbonifereous (H. Williams, pers. comm., 1984). Intuitively, one would expect that the phases of faulting associated with this dolomitization are early (Middle Ordovician) as pervasive B dolostones are confined to the lower Table Head Group and have not yet been recognized in stratigraphically younger rocks. This is coincident with early phases of the Taconic Orogeny. This conclusion however, must remain tentative until further structural and biostratigraphic data is collected.

Possible overprinting of the Watts Bight Formation and crosscutting by saddle dolomite-filled fractures must also have occurred during this time. This conclusion is, however, less conclusive because there is little relating Watts Bight examples to those of stratigraphically higher formations (for example, saddle dolomite veins crossing from the Watts Bight into the Boat Harbour). There is also the question of the nature of the pre-existing dolostone overprinted by late dolomitization. As will be demonstrated shortly, the occurrences of cavity- filling dolostone in these rocks strongly suggests that they formed from an earlier event, probably before the deposition of the overlying Boat Harbour Formation. The fact that they preserve cryptalgal structures suggests that they may have been very similar to pervasive A dolostones prior to overprinting.

4.9 CAVITY - FILLING DOLOSTONE

PETROGRAPHY AND CATHODOLUMINESCENCE:

The sediment that fills cavities within pre-existing dolostone is finely crystalline (10 to 100 micrometres) and is composed of a wide variety of minerals including anhedral dolomite, feldspar, micas, phosphate grains (collophane), insoluble organics and clays (plate 4.8a). Dolomite is by far the most abundant mineral but the other accessory minerals can account for up to 15 percent by volume, of the fill. Laminations are very prominent and as observed in outcrop, commonly drape over irregularities at the base of the cavity (plate 4.8a,b).

Dolomite crystals luminesce weakly from orange to red (plate 4.8c) and zonation is seldom developed. Samples from different parts of the study area differ from one another both in their luminescence (in colour and in intensity), and in the abundance of the accessory minerals. Quartz and feldspar is especially abundant in the cavities beneath the pebble bed on the Port au Port Peninsula whereas micas, phosphates and quartz is common in many of the examples from the Watts Bight Formation on the Great Northern Peninsula. The lone example from the Catoche Formation at Smelt Canyon contains abundant clays and insoluble material, but little quartz or feldspar.

Cements are diverse and include a second phase of dolomite or chert (Great Northern Peninsula) and clays? or calcite (Smelt Canyon). The sediment filled cavities beneath the pebble bed on the Port au Port Peninsula are extremely friable and are only weakly cemented by dolomite.

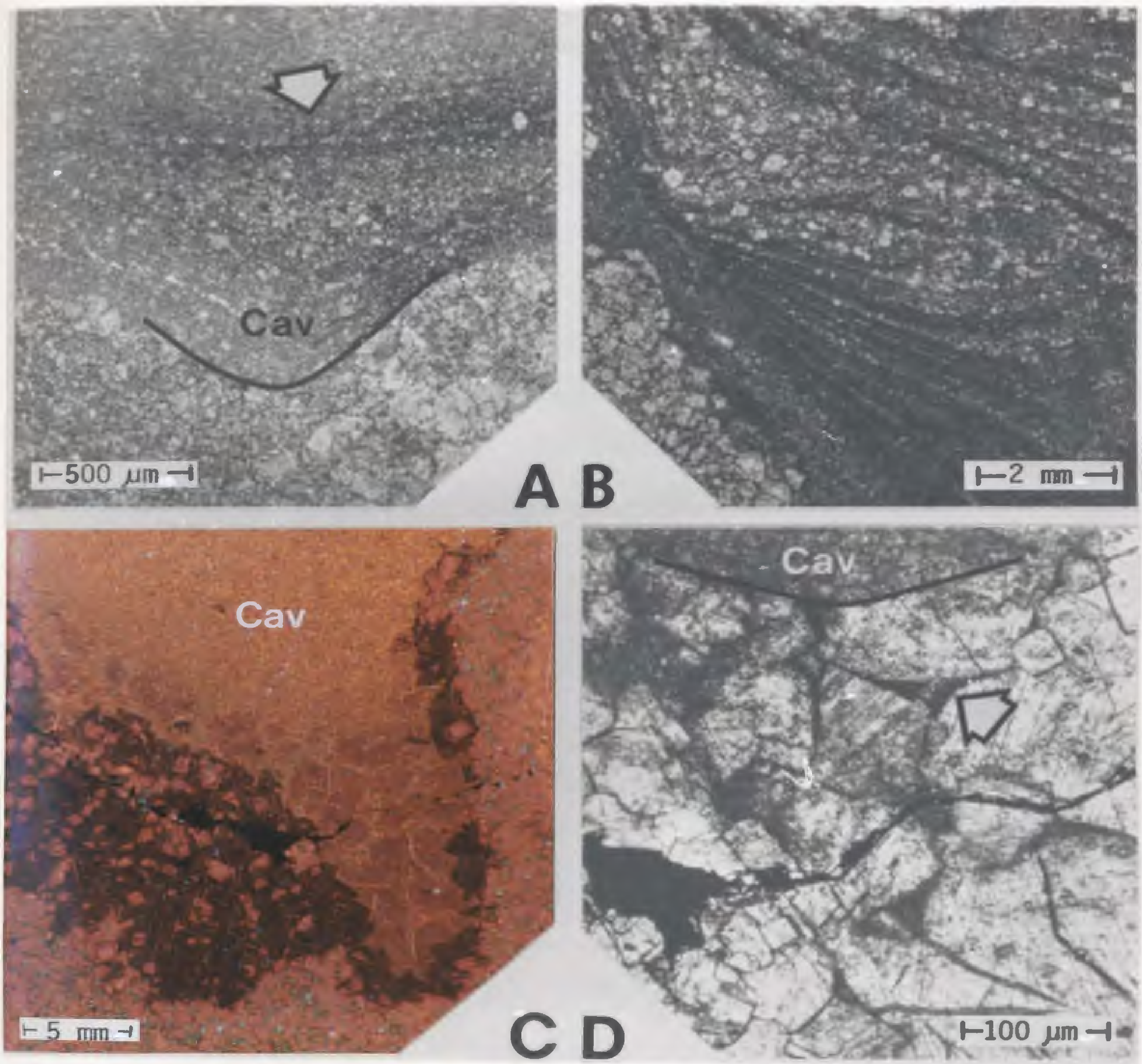
PLATE 4.8: PETROGRAPHY AND CATHODOLUMINESCENCE PHOTOMICROGRAPHS OF CAVITY-FILLING DOLOSTONE.

A) Cavity-filling dolostone (Cav) drapping over a depression in a pervasive B dolostone; Boat Harbour Formation, Isthmus Bay. Laminations (arrow) are prominent in this example. Plane polarized light.

B) Laminations within cavity-filling dolostone; Watts Bight Formation, New Ferolle. The dolostone is characterized by anhedral to euhedral dolomite crystals and a variety of accessory minerals including; quartz, feldspar, collophane, organics and clays. Plane polarized light.

C) Cavity-filling dolostone (Cav) is usually uniformly luminescent and is seldom zoned as in this example; Catoche Formation, Smelt Canyon. Sediment has rained down into the cavity after a phase of pore rimming ferroan (non-luminescent) dolomite growth. The dolomite nucleated along the margin of the cavity atop of pre-existing pervasive A dolostone crystals. Cathodoluminescence.

D) Cavity-filling dolostone (Cav) penetrating into the intercrystalline pore space of pre-existing rhombs in a pervasive A dolostone. This is the same thin section depicted by cathodoluminescence in C. Plane polarized light.


Cav
⊢500 μm⊣
A
B
⊢2 mm⊣
Cav
⊢5 mm⊣
C
D
Cav
⊢100 μm⊣

PARAGENESIS:

Paragenetically, it is clear that cavity-filling postdates pervasive A dolomitization as the sediment often penetrates into the rock by way of the intercrystalline boundaries of the dolomite rhombs (plate 4.8d). In the example from the Catoche Formation at Smelt Canyon, sediment filling postdates a period of pore lining ferroan dolomite growth (plate 4.8c). This dolomite nucleated around pre-existing dolomite crystals at the margin of the cavity and grew inward prior to, and probably immediately after, sediment spilled into the cavity.

Cavity-filling dolostone also cross-cuts algal structures in pervasive B dolostones of the Watts Bight Formation (indicating that it postdates initial dolomitization), but is never observed cutting veins of saddle dolomite (chapter three). This, plus the fact that saddle dolomite often fills void space at near the top of geopetal cavities, suggests that cavity-filling predates saddle dolomite. This is consistent with the suggestion made earlier in this chapter that pervasive B and saddle dolomitization may have overprinted a precursor mottled dolostone.

Though composed predominantly of finely crystalline dolomite rather than fine grained calcite, the habit of these cavities and the characteristics of the internal sediment is not unlike the "vadose silt" described by Dunham (1969) and Bathurst (1975). This sediment is thought to result from "winnowing" or erosion of host rock by moving ground water in the vadose zone. Differences in host rock composition would be reflected in the make up of the sediment, and this may explain the petrographic variations observed in cavity-filling dolostone.

All the known occurrences of this dolostone seem to be localized beneath documented (or suspected) exposure horizons. For example, cavity-filling dolostone is abundant immediately beneath the pebble bed on the Port au Port Peninsula, but no where else on the Port au Port Pennisula. Knight (1977b) suspects a disconformity at the Watts Bight - Boat Harbour contact on the Great Northern Peninsula and it is beneath this horizon that cavity-filling dolostone is found. Knight (pers. comm.) has also recognized a disconformity seperating the Catoche Formation from the Aguathuna Formation on parts of the Great Northern Peninsula. Unfortunately, the contact is not exposed at Smelt Canyon or on the Port au Port Peninsula and it is not possible at the present time to assess the significance of Knight's observation for the southern portion of the study area. If an exposure horizon does exist in this stratigraphic position, then the lone example of cavity-filling dolostone found in the upper part of the Catoche Formation at Smelt Canyon may be associated with it. Otherwise, it may be related to the erosional unconformity at the St. George - Table Head contact, an estimated 50 metres above its position.

On the basis of stratigraphic position and petrographic character of the sediment, it seems likely that cavity-filling dolostone is directly related to subaerial exposure.

4.10 DOLOMITE AND DOLOSTONE IN OTHER ROCKS:

As part of this study, dolomite and dolostone in rocks of similar age to the St. George outcroping along the coastal region of western Newfoundland were examined in a cursory fashion. It was felt that by examining these rocks, the different varieties recognized within the St. George Group would be better placed in their stratigraphic context and other additional varieties not present within the St. George might be identified.

Only three varieties of dolomite or dolostone found within the St. George Group are found in other rocks. As discussed earlier, pervasive B dolostone is locally developed within parts of the lower Table Head Group at the Newfoundland Zinc Mines, River of Ponds and at Port au Choix. These rocks are petrographically identical to the equivalents in the St. George Group.

Dololaminites are a dominant component of the Upper Cambrian Petit Jardin Formation and mottle dolomite is a sparse component of the Upper Cambrian and lower Table Head Group. These varieties do not differ significantly from those of the St. George Group.

Mottle dolomite is also found within certain breccia clasts in the Middle Cambrian to Middle Ordovician Cow Head Group near Cow Head (figure 1.1). These rocks are interpreted as slope debris shed partially from the adjacent stable shelf (the site of St. George deposition; James and Stevens, 1982). The mottles are strung out, are wholly confined to the clasts and do not cross into the matrix or into other clasts. Preliminary conodont analysis of the dolomite mottled clasts have yielded only sparse data which is insufficient to determine their ages (S. Pohler, pers. comm., 1984). Should these clasts prove to be derived from St. George rocks, it would reaffirm that initial mottle dolomitization and compaction was early, as it must have preceded their transport into the slope area.

The Table Head Group at Table Point and the Cow Head Group at "The Arches" (35 kilometres northeast of Table Point) are punctuated by linearly trending, dolomitized bodies. The dark grey dolostone appears to be associated with faults at Table Point as limestones on either side of the bodies dip at different angles and the trends of the dolostone (032 - 212°) are roughly parallel to that of regional faults. The Cow Head occurrence is somewhat more speculative because with the exception of the dolostone, the rocks in the immediate area are not exposed. The linear trend, however, also parallels the regional fault pattern, and once again suggests an association with tectonics.

In thin section, the dolomite is characterized by anhedral or sutured crystal outlines, strained extinction and uniform luminescence (dull red to purple). It is medium crystalline (200 to 500 micrometres), transected by numerous stylolites of all orientations and has been affected by a late period of dissolution and ferroan calcite cementation. This dolomite, although superficially resembling saddle dolomite or the interareas of pervasive B dolostone (eg. strained extinction), has different luminescent properties and has undergone a different paragenetic history. After cursory examination, it seems likely that the Cow Head and Table Head fault related dolostones are unique to these rocks and may be due to later periods of faulting than those associated with pervasive B dolostones in Lower Ordovician strata. Further study will reveal if this supposition is correct or not.

In the vicinity of Englee, Newfoundland (figure 1.1), metamorphosed shales and limestones of the allochthonous Cambrian to Middle Ordovician Curling Group contain numerous lenticular beds and diseminated blocks of yellow weathering dolostone. These rocks are composed of brecciated bright red luminescent dolomite, annealed by a non-luminescent dolomite (frontispiece). This is unlike any other variety in the St. George and much of it, especially the brecciation and annealing process appears to be related to metamorphism.

4.11 DOLOMITIZATION SYNOPSIS:

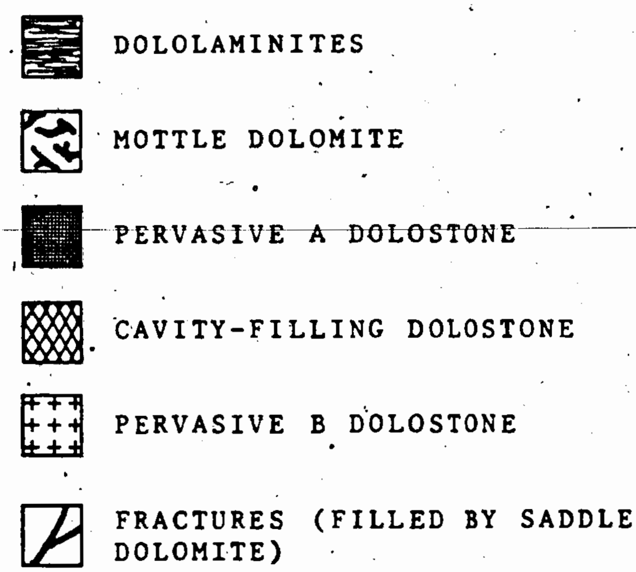
Four different generations of dolomite make up the seven field varieties recognized in the St. George Group.

Dololaminites are syngenetic and formed during deposition in tidal flat environments (figure 4.11). They are composed of finely crystalline, uniformly luminescent anhedral dolomite. Continued growth after burial is suggested by coarser, better zoned crystals in some dololaminites.

Matrix dolomite in fine grained limestones and mottle dolomite are the result of long lived (early- to late-diagenetic) events. Pervasive A dolostones are coincident with earlier phases of these varieties (figure 4.11). Petrographic and luminescence character of the dolomite in these varieties is diverse and appears to reflect local water chemistry.

Matrix dolomite in coarse grained limestones, saddle dolomite and the intermottle dolomite in pervasive B dolostones are late-diagenetic events. They are characterized by coarsely crystalline, uniformly luminescent, and strained dolomite crystals. Pervasive B dolostones overprint pre-existing dolomite mottled limestones, or in the Watts Bight Formation, may instead overprint a pre-existing (pervasive A ?) dolostone. This event(s) is related to tectonics, perhaps coincident with early phases of the Taconic Orogeny.

FIGURE 4.11: Schematic representation, arranged in chronological order (A to J), illustrating the paragenetic relationships between the different varieties of dolomite and dolostone recognized in the St. George Group. Refer to text for details.



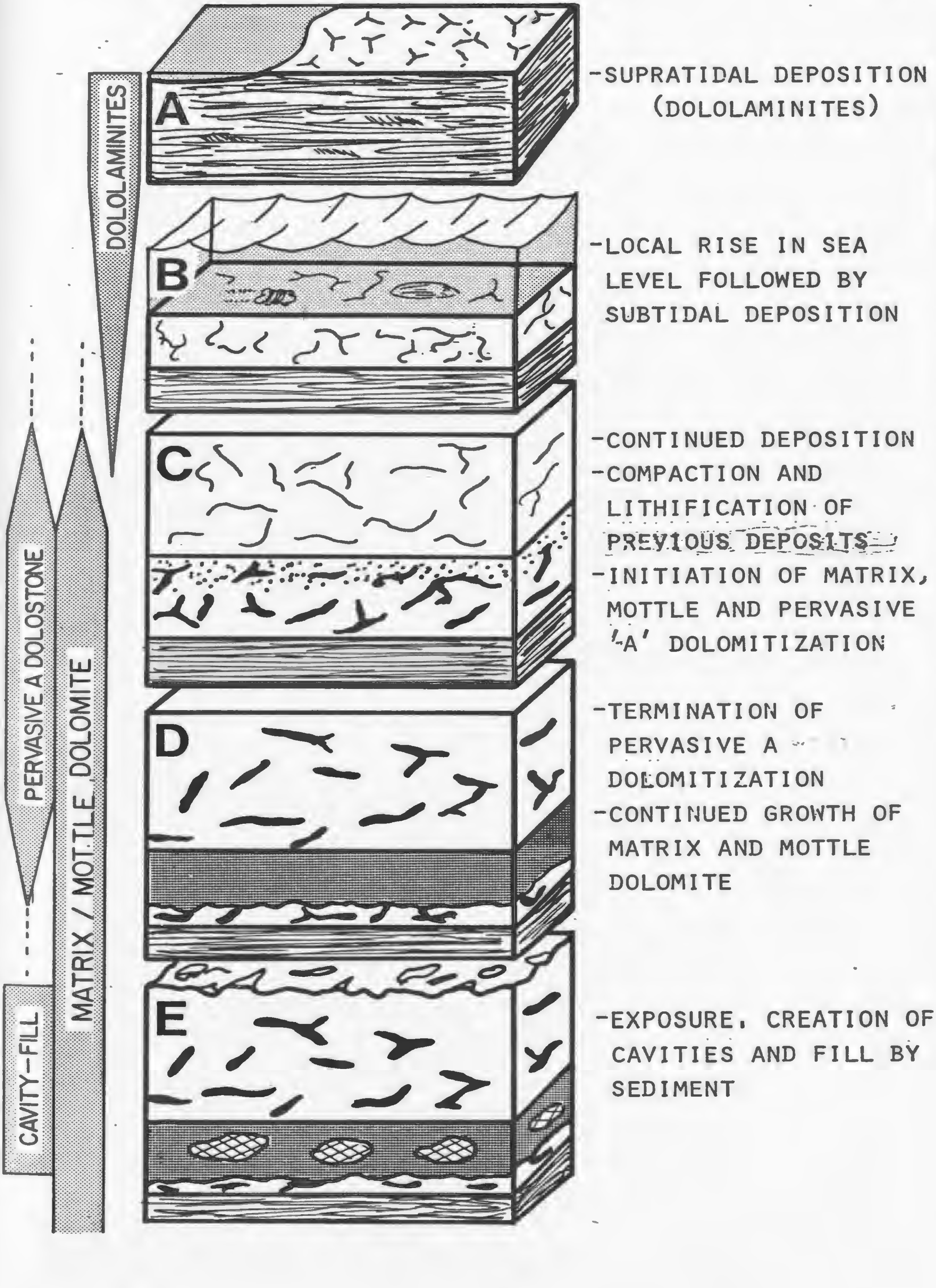
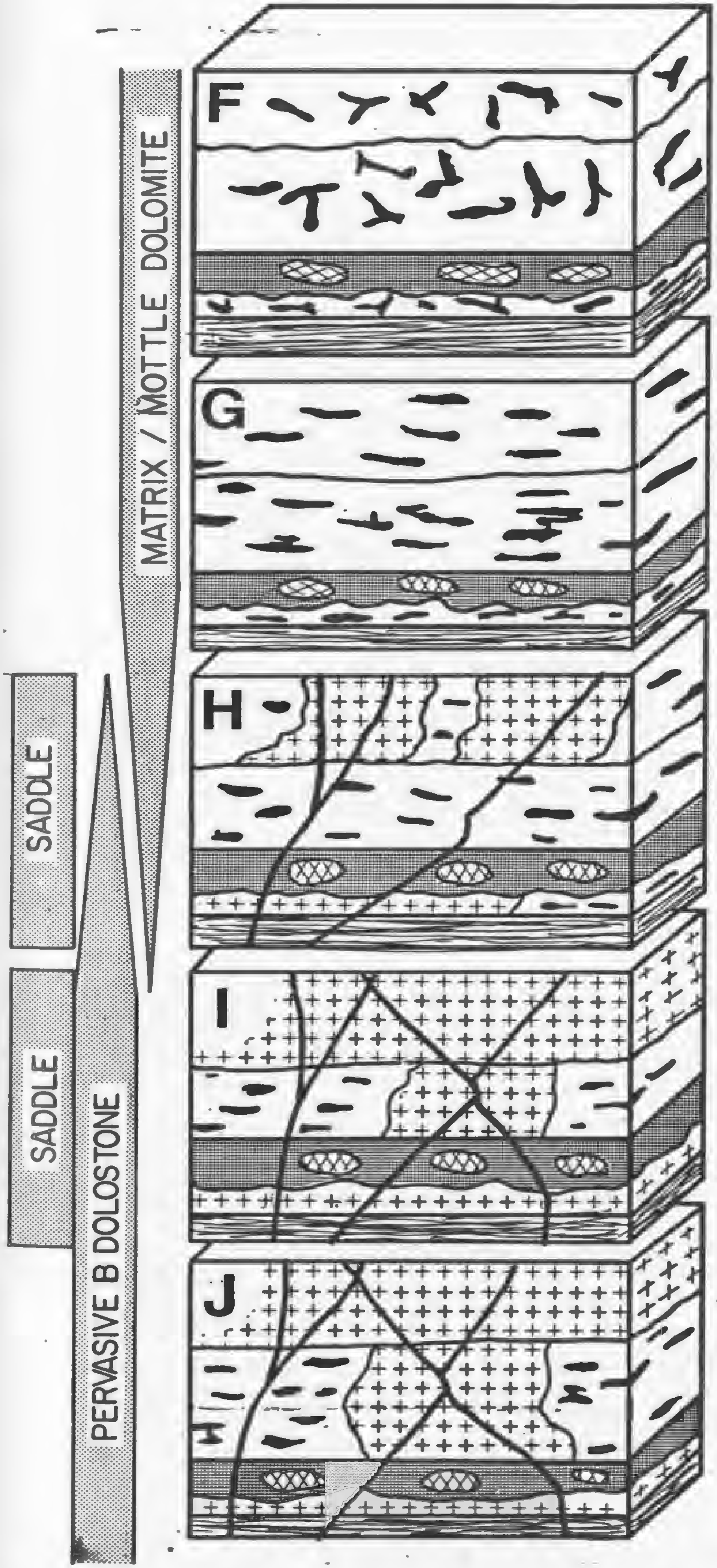

DOLOLAMINITES
PERVASIVE A DOLOSTONE
MATRIX / MOTTLE DOLOMITE
CAVITY-FILL
A
-SUPRATIDAL DEPOSITION (DOLOLAMINITES)
B
-LOCAL RISE IN SEA LEVEL FOLLOWED BY SUBTIDAL DEPOSITION
C
-CONTINUED DEPOSITION
-COMPACTION AND LITHIFICATION OF PREVIOUS DEPOSITS
-INITIATION OF MATRIX, MOTTLE AND PERVASIVE 'A' DOLOMITIZATION
D
-TERMINATION OF PERVASIVE A DOLOMITIZATION
-CONTINUED GROWTH OF MATRIX AND MOTTLE DOLOMITE
E
-EXPOSURE, CREATION OF CAVITIES AND FILL BY SEDIMENT

FIGURE 4.11 Continued



-SUBMERGENCE, DEPOSITION OF OVERLYING SEDIMENT
-LITHIFICATION AND INITIATION OF MATRIX AND MOTTLE DOLOMITIZATION IN EARLIER DEPOSITS

-SIGNIFICANT BURIAL DEPTHS REACHED
-BEGINNING OF PRESSURE SOLUTION. CONTINUED MOTTLE DOLOMITE GROWTH ALONG STYLOLITES

-TECTONIC FRACTURING AND FILL OF FRACTURES BY SADDLE DOLOMITE
-START OF PERVASIVE B DOLOMITIZATION

-CONTINUED TECTONICS AND PERVASIVE B DOLOMITIZATION

-CONTINUED TECTONICS AND PERVASIVE B DOLOMITIZATION.

Cavity-filling dolostone fills cavities created during periods of subaerial exposure (figure 4.11). The sediment is characterized by finely crystalline, anhedral and uniformly luminescent dolomite rhombs and a wide spectrum of accessory minerals (feldspars, quartz, clays, phosphates and micas).

CHAPTER FIVE

CARBON AND OXYGEN STABLE ISOTOPE AND TRACE ELEMENT GEOCHEMISTRY

5.1 INTRODUCTION:

Carbon and oxygen stable isotope geochemistry has been employed successfully in numerous studies dealing with limestones in an attempt to supplement or provide data regarding diagenesis (Dickson and Coleman, 1980), palaeogeothermometry (Bottinga and Javoy, 1973) and in assessing palaeoenvironments (Allen et al., 1973). These isotopes are equally useful in the study of fluids including hydrocarbons (Stahl, 1979), marine and fresh waters (Craig, 1961, Chase and Perry, 1972) and ground and pore waters (Deines et al., 1974) making them valuable tracers of low temperature fluid-rock interactions (Longstaff, 1983).

In this study, carbon and oxygen stable isotope geochemistry is used primarily as a means of characterizing the different varieties of dolomite and dolostone and to determine whether the classification scheme devised in the field and through petrographic analysis, is supported by chemical data. Isotopic analysis may also resolve the question as to whether the vast quantity of dolomite within the St. George Group is the result of one or many, different events.

5.2 ANALYTICAL PROCEDURE:

The samples chosen for isotopic analysis are considered the most representative of the seven varieties of dolomite and dolostone. They were selected from all formations of the St. George Group and from all areas where sections were studied.

The rocks were washed with distilled water and methanol prior to diasggregation with an ultrasonic probe to reduce possible contamination by foreign or loose material. As individual crystals could not be isolated, all data constitute bulk mineral analyses.

Powdered aggregates were taken from both the mottles and the interareas between mottles for samples of dolomite mottled limestones and the pervasive dolostones to determine whether the mottles differ geochemically and/or isotopically from the rest of the host rock. Interareas of dolomite-mottled limestones, composed of lime mudstone or wackestone, are used to estimate the Lower Ordovician marine isotopic signature.

In total, 50 powdered mineral aggregates from 36 rock samples were forwarded to Teledyne Isotopes (New Jersey) for isotopic analysis. Three hundred to 500 milligram samples were reacted with 100 percent phosphoric acid at 50 C°. The liberated CO_2 gas was passed directly to a mass spectrometer to determine the isotopic ratios of carbon and oxygen. All reactions were run to completion so that any powder present in the sample was completely dissolved. The completion of the reaction was checked visually and by thermocouple gauge.

These data are expressed by way of the delta notation (Faure, 1977);

$$^{13}C(dolo) = \frac{((^{13}C/^{12}C)dolo-(^{13}C/^{12}C)ref)}{(^{13}C/^{12}C)ref} \times 10^{3} \quad (5.1)$$

$$^{18}O(dolo) = \frac{((^{18}O/^{16}O)dolo-(^{18}O/^{16}O)ref)}{(^{18}O/^{16}O)ref} \times 10^{3} \quad (5.2)$$

These are relative difference functions whereby the isotopic composition of a sample (dolo) is compared to a standard reference (ref). In this study, the reference used to report variations in both the oxygen and carbon isotopic ratios is the PDB standard; a belemnite (Belemnitella americana) from the Cretaceous Peedee Formation of southern Carolina (Faure, 1977).

Duplicate powdered samples (1.0 to 1.5 grams) were placed in 25 ml of dilute HCl solution (approximately 8% volume/volume; M. Coniglio, pers. comm., 1984) until most of the carbonate component was dissolved; an average of 90 minutes. The leachate was filtered using pre-weighed filter paper and brought to 50 ml of solution by washing in distilled water. The solutions were analysed with an atomic absorption spectrophotometer for Sr^{2+} concentration by G. Andrews of Memorial University.

5.3 RESULTS:

$\delta^{13}C$ for all 50 samples analysed in this study is clustered between -0.50 and -4.01 o/oo (table 5.1, figure 5.1). Values of $\delta^{18}O$ are much more variable and range from -4.74 to -12.73 o/oo (table 5.1, figure 5.2). Sr^{2+} concentration ranges from a minimum of 40 to a maximum of 320 ppm. A complete listing of $\delta^{13}C$, $\delta^{18}O$ and Sr^{2+} for the 50 samples as well as their stratigraphic and geographic positions are contained in appendix B.

5.4 BACKGROUND:

The stable isotope geochemistry of dolomite is poorly understood. Dolomite has yet to be synthesized in experiments that approximate near surface conditions, and therefore, fundamental relationships necessary to interpret these data, (such as the relationship between temperature and oxygen isotope fractionation that exist between dolomite and water), can only be inferred from successful hydrothermal syntheses (Land, 1980, Arthur et al., 1983). Several different relationships have been determined for the system dolomite - water:

$$1000 \ln\alpha = 3.2 \times 10^{6}T^{-2} - 2.00 \qquad (5.3)$$
(Northrup and Clayton, 1966)

$$1000 \ln\alpha = 3.34 \times 10^{6}T^{-2} - 3.34 \qquad (5.4)$$
(O'Neil and Epstein, 1966)

$$1000 \ln\alpha = 3.23 \times 10^{6}T^{-2} - 3.29 \qquad (5.5)$$
(Sheppard and Schwarcz, 1970)

$$1000 \ln\alpha = 2.78 \times 10^{6}T^{-2} + 0.11 \qquad (5.6)$$
(Fritz and Smith, 1970)

DOLOMITE / DOLOSTONE		$\delta^{13}C$ (‰) RANGE	$\delta^{13}C$ (‰) AVG.	$\delta^{18}O$ (‰) RANGE	$\delta^{18}O$ (‰) AVG.
DOLOLAMINITES		-0.50 to -4.01	-1.99	-4.78 to -7.94	-6.31
MATRIX DOLOMITE		-1.62 to -1.85	-1.74	-9.03 to -9.72	-9.38
DOLOMITE MOTTLED LIMESTONES	MOTTLES	-1.27 to -1.99	-1.67	-5.47 to -10.34	-7.77
	INTERMOTTLES (L)	-1.56 to -2.30	-1.89	-7.95 to -10.31	-8.95
PERVASIVE DOLOSTONES — PERVASIVE 'A'	MOTTLES	-1.18 to -2.05	-1.52	-4.74 to -10.58	-7.36
	INTERMOTTLES	-1.19 to -1.82	-1.54	-5.36 to -11.16	-8.34
PERVASIVE DOLOSTONES — PERVASIVE 'B'	MOTTLES	-0.78 to -1.31	-1.07	-8.47 to -9.38	-8.93
	INTERMOTTLES	-0.62 to -1.66	-1.30	-8.18 to -12.73	-10.89
CAVITY-FILLING DOLOSTONE		-0.61 to -1.78	-1.41	-6.45 to -8.93	-7.28
SADDLE DOLOMITE		-0.89 to -1.57	-1.35	-9.04 to -10.47	-9.61

(L)- denotes limestone samples

TABLE 5.1: Summary of carbon and oxygen isotopic data for St. George limestones (L) and dolostones. A complete listing is given in appendix B.

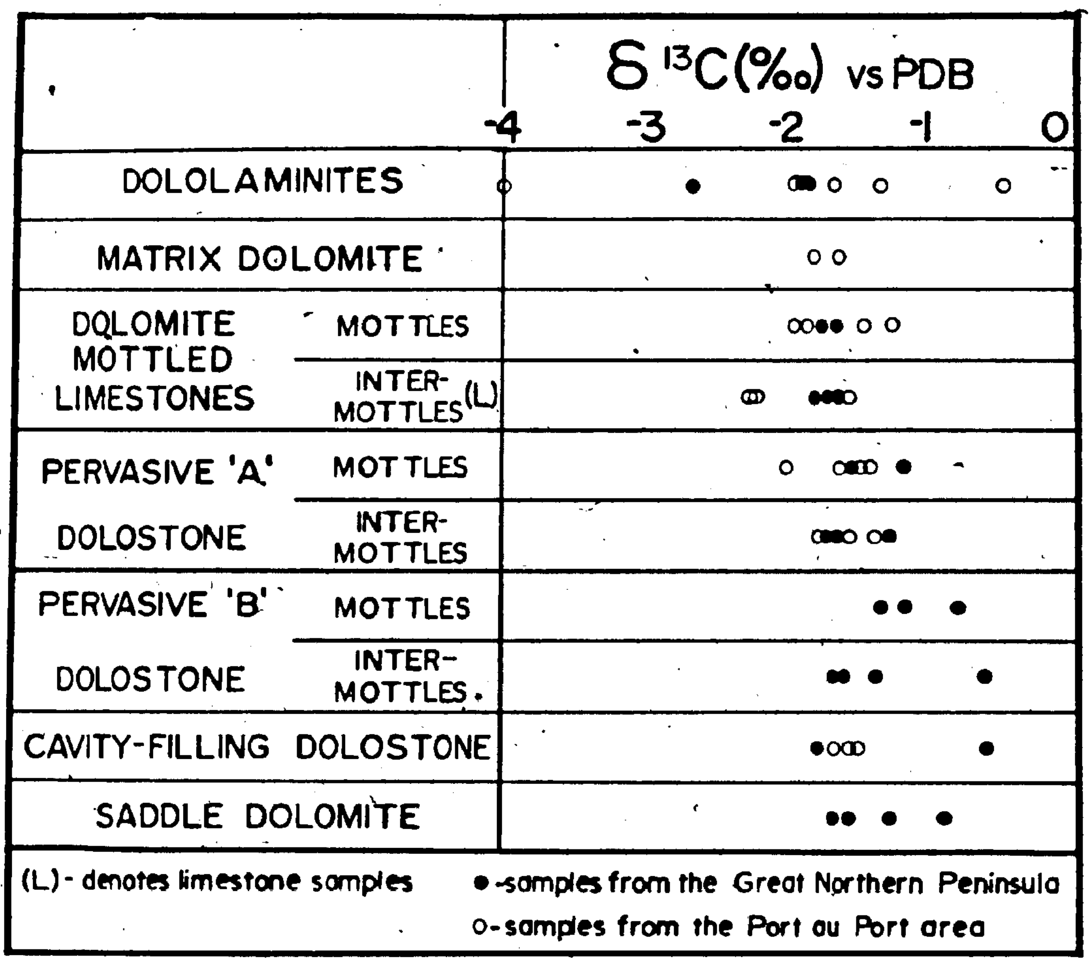


FIGURE 5.1: Schematic representation of carbon stable isotope data for the seven field varieties of dolomite and dolostone observed within the St. George Group.

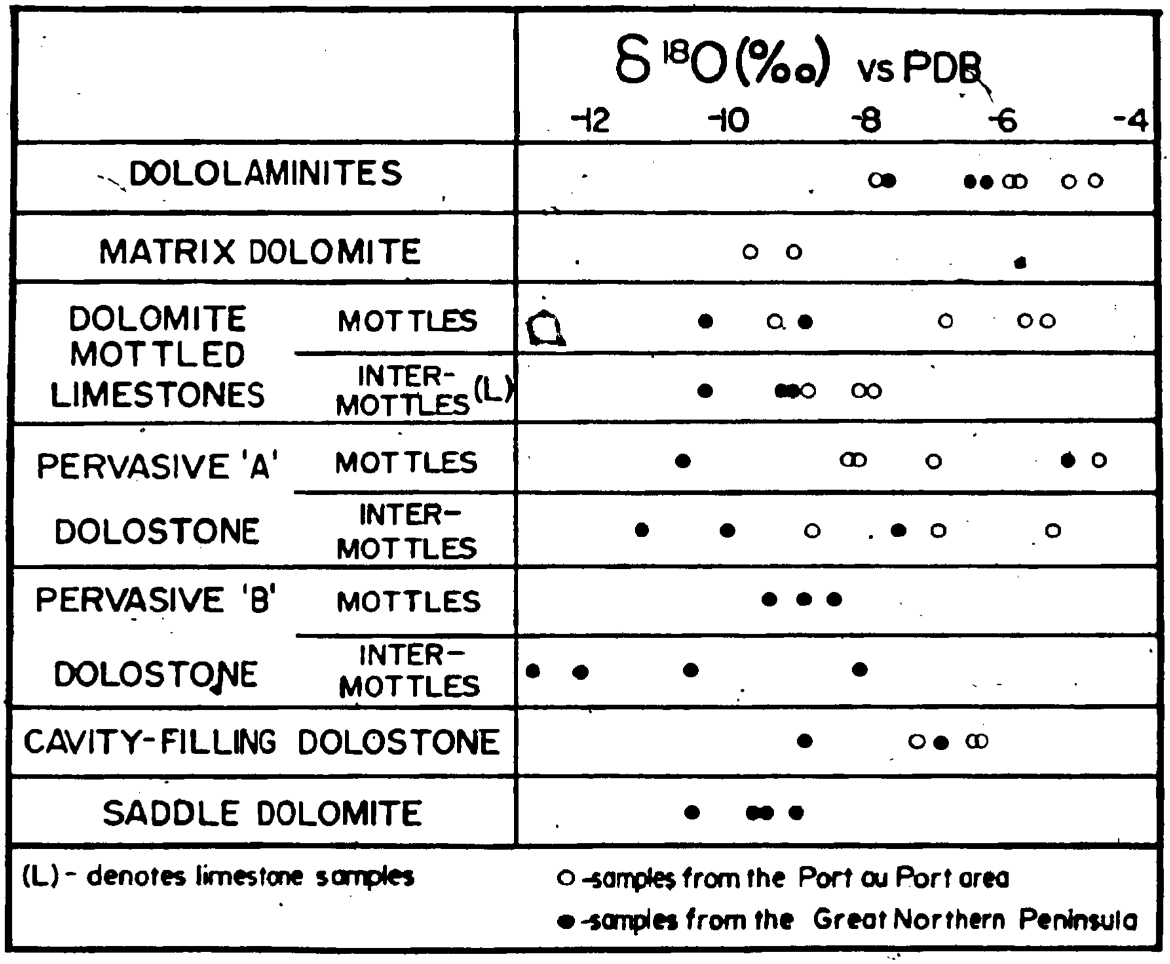


FIGURE 5.2: Schematic representation of oxygen stable isotope data for the seven field varieties of dololmite and dolostone found within the St. George Group.

where (α) is the fractionation factor between dolomite and water at a temperature (T). Land (1980) has discussed the problems with this approach and most authors now recognize the limitations of these relationships. They are qualitative at best for low temperature conditions (Northrup and Clayton, 1966). Plots of these expressions may be found in Arthur et al. (1983) (their figure 4.1).

As most dolomite appears to be the replacement product of a precursor limestone, there has also been considerable interest in establishing the oxygen isotope fractionation for the system dolomite - calcite. Unfortunately, this relationship is just as poorly understood. Most experimental results suggest that dolomite should be enriched in heavy oxygen by +5 to +7 o/oo relative to calcite, whereas heavy carbon should be only slightly enriched in the dolomite (Schwarcz, 1966, Sheppard and Schwarcz, 1970). One study by Degens and Epstein (1964) suggests that syngenetic dolomite and calcite are isotopically similar. Land (1980) has criticized this conclusion because some of the co-existing dolomite - calcite pairs were not cogenetic. For example, some of the data Degens and Epstein obtained was based upon Holocene lime muds which contained windblown, detrital dolomite.

The shift in $\delta^{18}O$ between "cogenetic" limestone and dolomite that is actually observed in nature is somewhat less than that predicted by experimentation. Dolomite now forming penecontemporaneously with calcite in sabkhas (for example, the Persian Gulf, McKenzie et al., 1980), in other hypersaline environments (Baffin Bay, Texas, Behrens and Land, 1972; Coorong, southern Australia, Muir et al., 1980; Deep Spring Lake, California, Clayton et al., 1968) and in deep water environments (Enewetak Atoll, equatorial Pacific Ocean, Saller, 1984) are enriched in ^{18}O by only 2 to 4 o/oo relative to the calcite. This discrepancy between what is predicted by experimentation and what is actually observed has caused much speculation. Recent dolomite precipitates as a poorly ordered, metastable mineral ("protodolomite" of Gaines, 1977) and some authors (Fritz and Smith, 1970, Katz and Matthews, 1977) have suggested that the protodolomite - water fractionation is less than that of dolomite - water. Later, when the protodolomite is recrystallized to ordered dolomite, the isotopic signature is simply transferred to the "new" mineral. Land (1980) argues convincingly against this reasoning and presently, the issue is not resolved.

The isotopic signature of other dolomites and dolostones, those not forming penecontemporaneously with calcite, would be expected to vary depending upon when, or how, they formed during the diagenetic history of the rock. Before these can be discussed however, the isotopic signature of the Lower Ordovician limestones must be established. This gives a starting, or reference point from which to recognize trends exhibited by the dolomite.

5.5 LIMESTONE AND THE EARLY ORDOVICIAN MARINE SIGNATURE:

Limestones of the St. George Group are characterized by $\delta^{13}C$ values similar to those observed in Holocene equivalents (Hudson, 1977). These "normal" values indicate that sulphate reduction (resulting in an isotopically light carbon signature) and organic fermentation (resulting in an isotopically heavy carbon signature) did not play major roles during limestone formation or diagenesis (Irving et al., 1977). So little is known about carbon stable isotope geochemistry, however, that little more can be said about these data (Land, 1980).

Ancient limestones are severely depleted in $\delta^{18}O$ compared to those of Holocene age. To a lesser extent, this secular trend is also apparent within the Ordovician Period (figure 5.3) and at the present time, three explanations have been proposed to explain this;

1) The concentration of ^{18}O in ocean water was less in the past (Knauth and Epstein, 1976, Brand and Veizer, 1981),.

2) The temperature of ocean water during carbonate precipitation was higher in the past resulting in less "heavy" oxygen being incorperated into the rocks (Perry, 1967, Perry and Tan, 1972),

3) There has been steady post-depositional exchange (re-equilibrium) with water of a lighter isotopic composition (i.e. of a meteoric origin), or water of a higher temperature (Degens and Epstein, 1964, Dickson and Coleman, 1980).

No one explanation has received unanimous support, but more and more evidence is being gathered

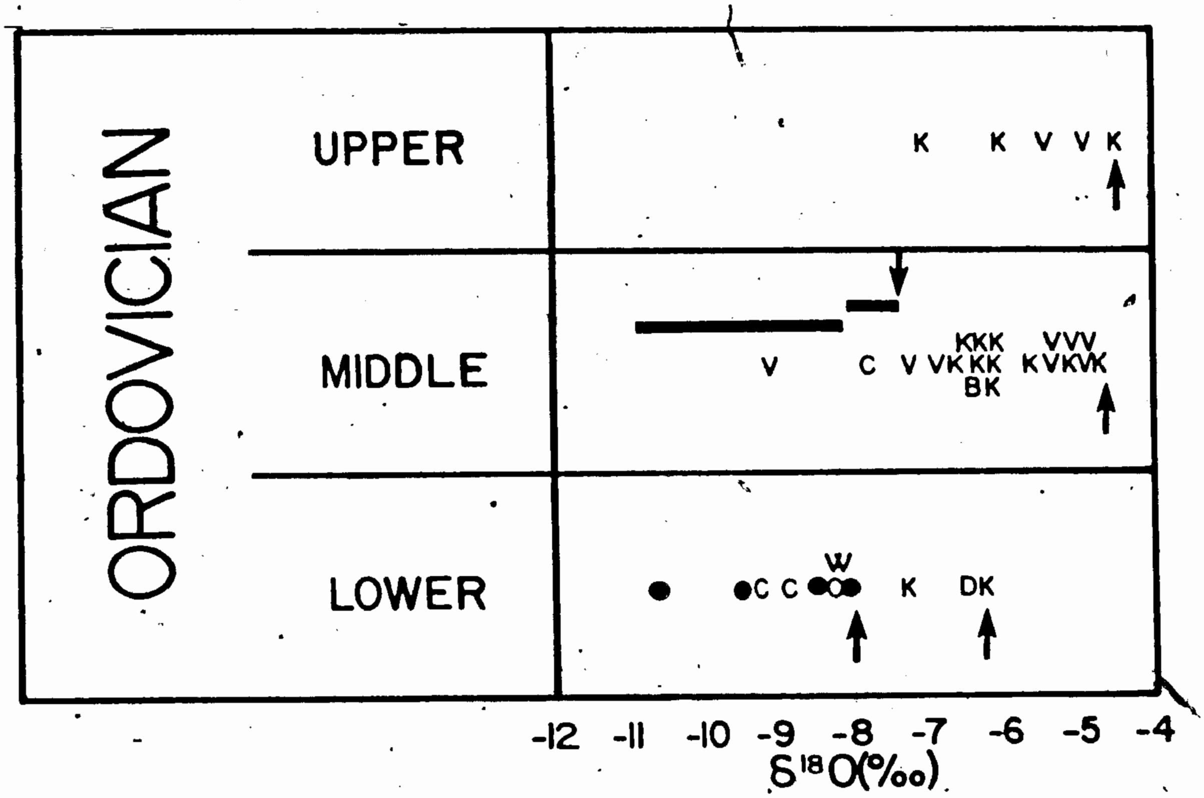


FIGURE 5.3: Summary plot of $\delta^{18}O$ values for Ordovician marine limestone from this, and other studies. All data, with the exception of that obtained by Ross et al., (1975) and this study were derived through bulk rock analysis. The most likely limestone isotopic signatures for each major study are indicated by an arrow. Data from Keith and Weber (1964)-K; Degens and Epstein (1964)-D; Badiozamani (1973)-B; Ross et al., (1975)-▬; Veizer and Hoels (1976) - V; Coron (1982)-C; and this study - ●.

favouring the first proposal; that ocean waters have varied in ^{18}O composition throughout the Phanerozoic (James and Choquette, 1983). The last proposal (3) is also an important consideration in assessing the isotopic composition of the limestone. Most diagenetic reactions involve meteoric water, and would therefore shift $\delta^{18}O$ within a limestone toward lighter values. In siliciclastic poor sequences, only a reaction with water of a strong (or exclusive) marine character could shift ^{18}O toward heavier values. For this reason, the "heaviest" samples are usually the least diagenetically altered (James and Choquette, 1983). This was first suggested by Choquette (1968) and also appears to be true for the limestones analysed in this study. The two limestones (both wackestones) which cluster at -7.95 and -8.15 o/oo show few diagenetic alterations and both the matrix and peloids remain micritic. The sample which deviates the most, a peloidal wackestone close to a pervasive B dolostone front on the Great Northern Peninsula, has been completely converted to moderately luminescent microspar suggesting recrystallization in a freshwater phreatic environment (Grover and Read, 1983).

The other limestone samples that lie between these end members are either partially converted to microspar, or are traversed by many fine fractures filled by very brightly luminescent calcite. These diagenetic alterations probably account for the depletion in ^{18}O relative to the heavier limestones.

The unmodified $\delta^{18}O$ signature of the Lower Ordovician limestones is most likely to be closest to the two heaviest analyses. These values compare favorably to the heaviest isotopic data collected on the same rocks by Coron (1982) in western Newfoundland and on other Lower Ordovician limestones analysed by Veizer and Hoffs (1976) from Tasmania (figure 5.3). They do not however, compare favorably with Lower Ordovician limestones analysed from Pennsylvania and Sweden by Keith and Webber (1964) or from Illinois by Degens and Epstein (1964) (figure 5.3). Perhaps most significantly, the data obtained in this study are comparable to that obtained by Ross et al., (1975) for lowest most Middle Ordovician mudmounds in Nevada. Their study is the most detailed of any focusing upon Ordovician carbonates. Selective sampling of both calcilutites and marine cements, none of which appeared to have been affected by meteoric diagenesis, led Ross and his co-workers to conclude that the basal Middle Ordovician limestone signature was approximately -9.00 o/oo (relative to PDB). If one assumes that the heaviest analyses are the closest to the true marine signature, this value is closer to -8.00 o/oo. It is likely that the Lower Ordovician signature is similar to this value and therefore, the best representation of the oxygen isotopic signature of St.

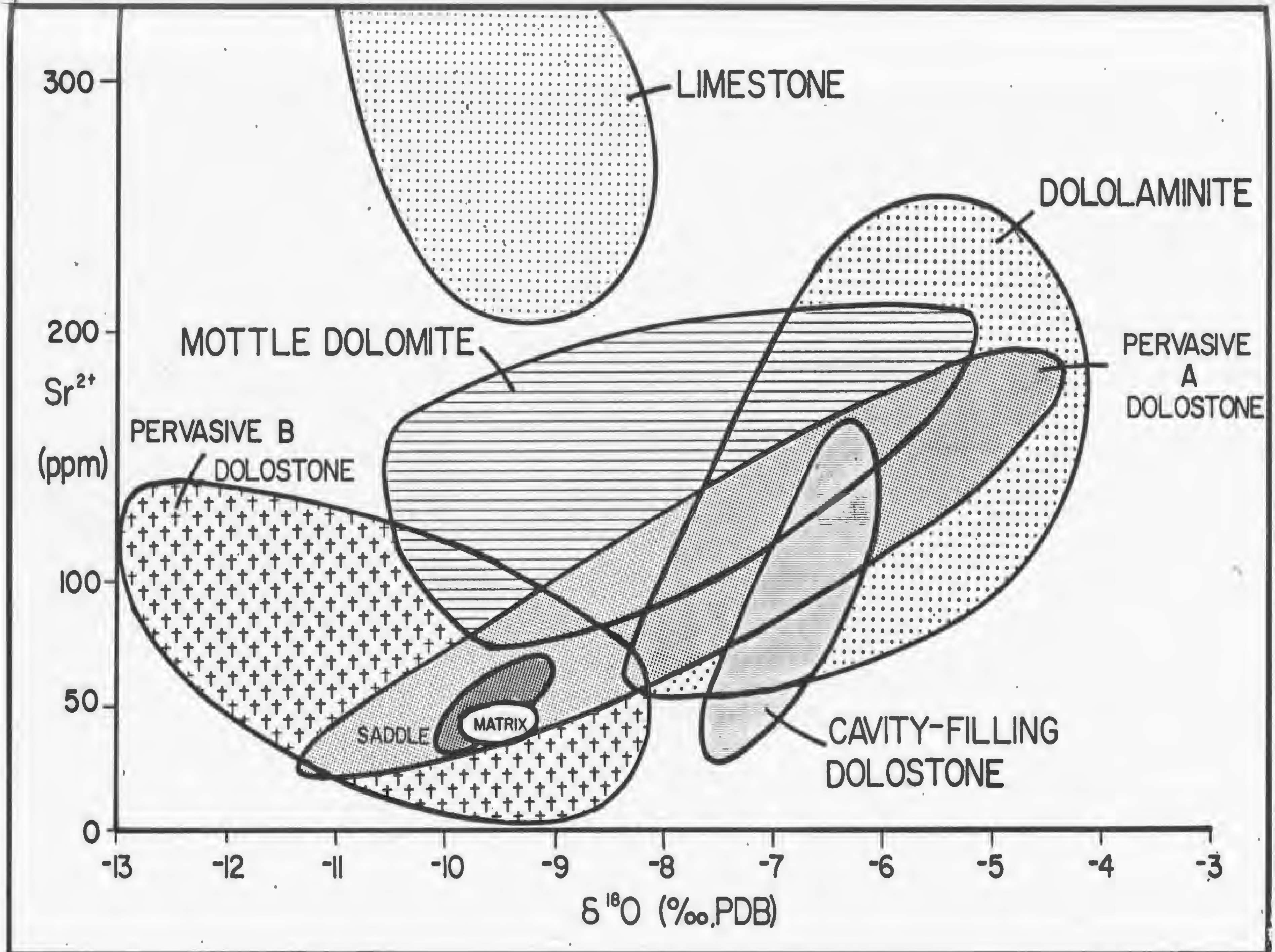
George limestones is considered to be approximately -8.00 o/oo (relative to PDB).

5.6 DOLOMITES AND DOLOSTONES:

The carbon isotopic ratios of the different varieties of dolomite and dolostone are clustered within a narrow range and are essentially identical to those of the limestones. Subsequently, the arguements put forward for the limestones are equally applicable here. In general, there is a trend towards heavier $\delta^{13}C$ with later dolomitization events (figure 5.1). Two dololaminite analyses are noticably depleted in $\delta^{13}C$ relative to the others. This depletion is not strong enough to advocate a 100 percent organic origin to the carbon, but as the dolomite crystals in these samples are zoned, it is possible that dolomitization proceeded long enough to incorporate an organic signature in some of the (outer most?) zones. Re-equilibration with migrating fluids is unlikely because the dolomite crystals are well zoned (that is, unaltered) and because dolomite is fairly isotopically stable with respect to carbon. (Once established, $\delta^{13}C$ does not appear to be modified by later diagenetic processes; Fritz, 1967, Land, 1980).

$\delta^{18}O$ of the seven varieties of dolomite and dolostone is quite varied, and with the exception of the four saddle dolomite and two matrix dolomite samples, no

FIGURE 5.4: Plot of Sr^{2+} concentration (in parts per million) versus $\delta^{18}O$ for the seven varieties of dolomite and dolostone recognized within the St. George Group. In general, samples with lighter oxygen isotope ratios contain less strontium than do samples with heavier ratios. Late varieties, such as saddle dolomite and pervasive B dolostone are significantly lighter and contain less strontium than do earlier varieties.


LIMESTONE
DOLOLAMINITE
MOTTLE DOLOMITE
PERVASIVE A DOLOSTONE
PERVASIVE B DOLOSTONE
SADDLE
MATRIX
CAVITY-FILLING DOLOSTONE
Sr^{2+} (ppm)
300
200
100
50
0
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
$\delta^{18}O$ (‰,PDB)

variety is characterized by a distinctive oxygen isotopic composition (figure 5.2). There is also considerable overlap when the $\delta^{18}O$ values are plotted against Sr^{2+} concentrations (figure 5.4). Veizer et al., (1978) found that dolostones in a Lower Paleozoic carbonate sequence in Arctic Canada could be grouped into 3 strontium populations: low, intermediate and high. Low-Sr^{2+} (66 +/- 45 ppm) dolostones were usually the products of a late phase of dolomitization; intermediate-Sr^{2+} (180 +/- 66 ppm) dolostones were products of penecontemporaneous-early dolomitization. Celestite rich dolostones formed the high-Sr^{2+} statistical group. In this study, dololaminites contain on average the most strontium and would be grouped within the intermediate-Sr^{2+} population, whereas saddle dolomite and pervasive B dolostones contain the least and would be grouped within the low-Sr^{2+} population. These conclusions are similar to those determined by Veizer and his co-workers. The fact that the intermottle dolomite in pervasive B dolostones and saddle dolomite contain the least amount of Sr^{2+} intuitively implies that the dolomitization fluids had a low Sr^{2+}/Ca^{2+} ratio..

The other varieties of dolomite and dolostone are characterized by Sr^{2+} concentrations that fall between these two end members. High-Sr^{2+} dolostones are rare in the St. George Group. These results strongly suggest that in the St. George Group, later phases of dolomitization or dolomite growth are characterized by lower concentrations of strontium.

$\delta^{18}O$ data fall into two diffuse groups on the basis of where they were sampled geographically. Stratigraphic position does not appear to be a factor. Most samples from the north are depleted in $\delta^{18}O$ relative to southern equivalents and this is unquestionably the result of the additional dolomitization events responsible for northern occurrences of saddle dolomite and pervasive B dolostone. Saddle dolomite and pervasive B intermottle dolomite are essentially the same isotopically; both characterized by very negative $\delta^{18}O$ (-8.18 to -12.73 o/oo). This is within the range of hydrothermal dolomite discussed by Engel et al., (1958) and Mattes and Mountjoy (1980) (figure 5.5) andit is probable that the saddle dolomite in veins and fractures (Coron, 1982) and the intermottle dolomite in pervasive B dolostone owe their origin to hydrothermal fluids.

It is possible to estimate the precipitation temperature of saddle dolomite and the dolomite between mottles in pervasive B dolostones by substituting $\delta^{18}O$(dolo) into the following expression:

$$T = 31.9 - 5.55\,(\delta(\text{dolo}) - \delta(w)) + 0.17(\delta(\text{dolo}) - \delta(w))^2$$

(Fritz and Smith, 1970, Dickson and Coleman, 1980).

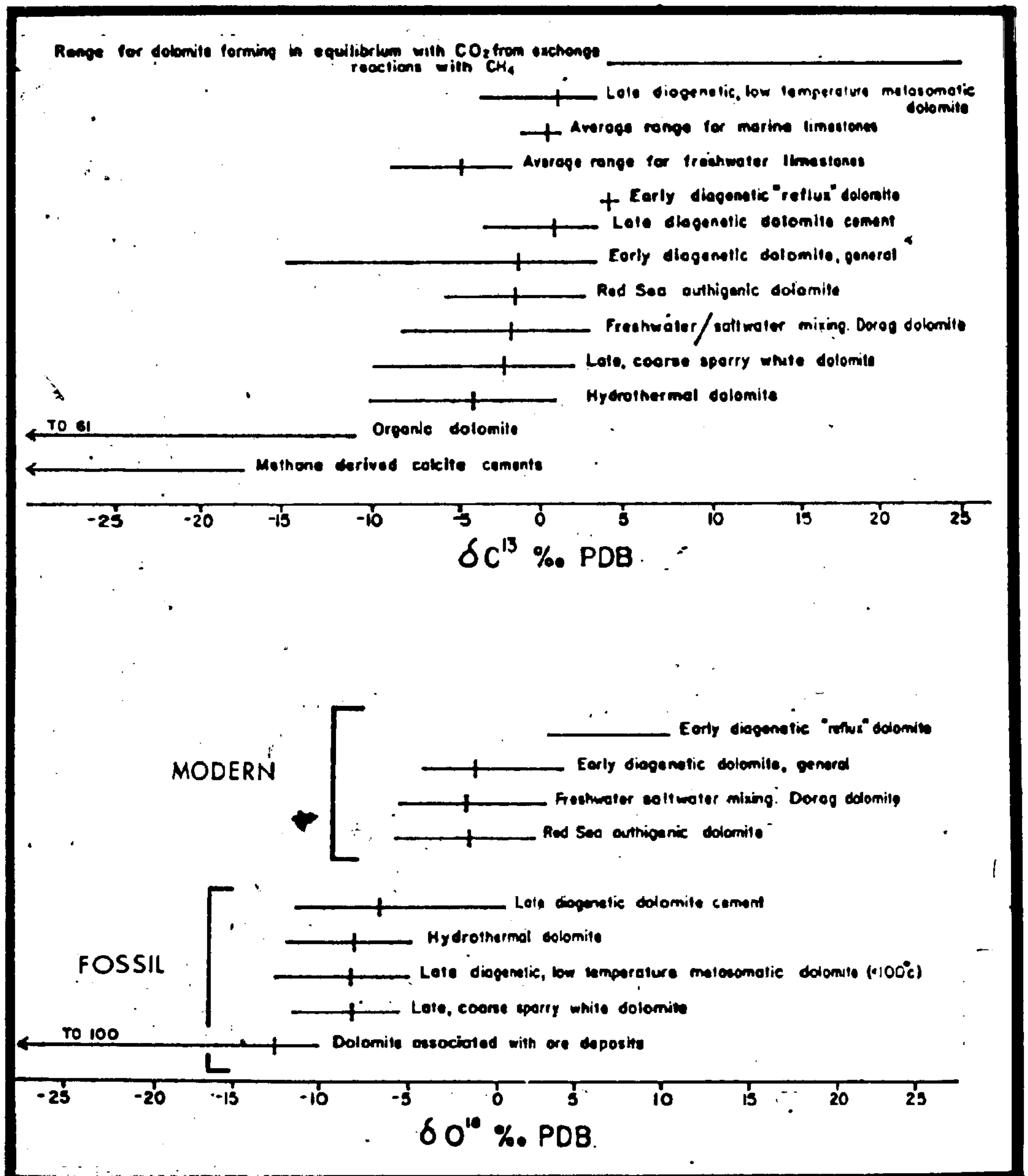


FIGURE 5.5: Bar graphs for $\delta^{13}C$ and $\delta^{18}O$ for a variety of fossil and modern dolomites.
(From Mattes and Mountjoy, 1980)

Assuming a $\delta^{18}O$ for water of -8.00 o/oo (δ(w)), precipitation temperatures range from 37°C (δ(dolo)= -9.0) to 64°C (δ(dolo) = -13.0). These temperatures are significantly cooler than temperatures deduced by Radke and Mathis (1980) (60 to 150°C) but are still within the hydrothermal range.

In chapter four, it was demonstrated that saddle dolomite were the latest stage dolomites, often nucleated on, and intruded into the intercrystalline pore space between pre-existing dolomite crystals (refer to plates 4.5c). The majority of the northern isotopic analyses must therefore be regarded as "masked" or "contaminated" by a later hydrothermal- related overprint. Interpretation of the isotopic character of the remaining varieties of dolomite and dolostone is best made on samples from the south.

Diagenetic overprinting also explains some of the $\delta^{18}O$ variations within seperate dolomite types, both in the north, and in the south. For example, dololaminites, the deposits of hypersaline tidal flat environments (discussed in chapters two and three), should be enriched relative to limestones by 2 to 4 o/oo, providing fractionation during Early Ordovician time was similar to what is observed at present (Land, 1980). The oxygen isotopic signature of St. George limestones is approximately -8.00 o/oo (PDB) and therefore, $\delta^{18}O$ for the dololaminites should fall within the range -4.00 to -6.00 o/oo. All of the dololaminites are shifted toward a more positive $\delta^{18}O$ compared to St. George limestones, but only four of the analyses (all from the south) fall within the predicted $\delta^{18}O$ field. These dololaminites are composed of uniformly luminescent, very finely crystalline dolomite crystals. The dololaminites that do not fall within the predicted field have been affected by later diagenesis. Some, those that deviate most strongly, are composed of more coarsely crystalline zoned dolomite crystals (to 100 micrometres), whereas others, those that are close to the predicted field, contain a second phase of dolomite as a cement (figure 5.6). These samples do not fall within the predicted dololaminite range because only a portion of the dolomite crystals, the cores, are the product of a hypersaline environment. The rest of the dolomite crystals are later overgrowths. As a general rule, the larger the dolomite crystals, the larger the diagenetic overprint, and subsequently, the stronger the depletion in $\delta^{18}O$ (Fritz and Jackson, 1971, Land et al, 1975, Morrow, 1982a). This also explains the trend observed in Sr^{2+} concentration versus ^{18}O (figure 5.4). Strontium is highest in those dololaminites showing the least diagenetic growth, and lowest in those dololaminites showing the most diagenetic growth. As concluded earlier, later stages of dolomite growth, even if restricted to dololaminites, are characterized by lower concentrations of Sr^{2+}. This

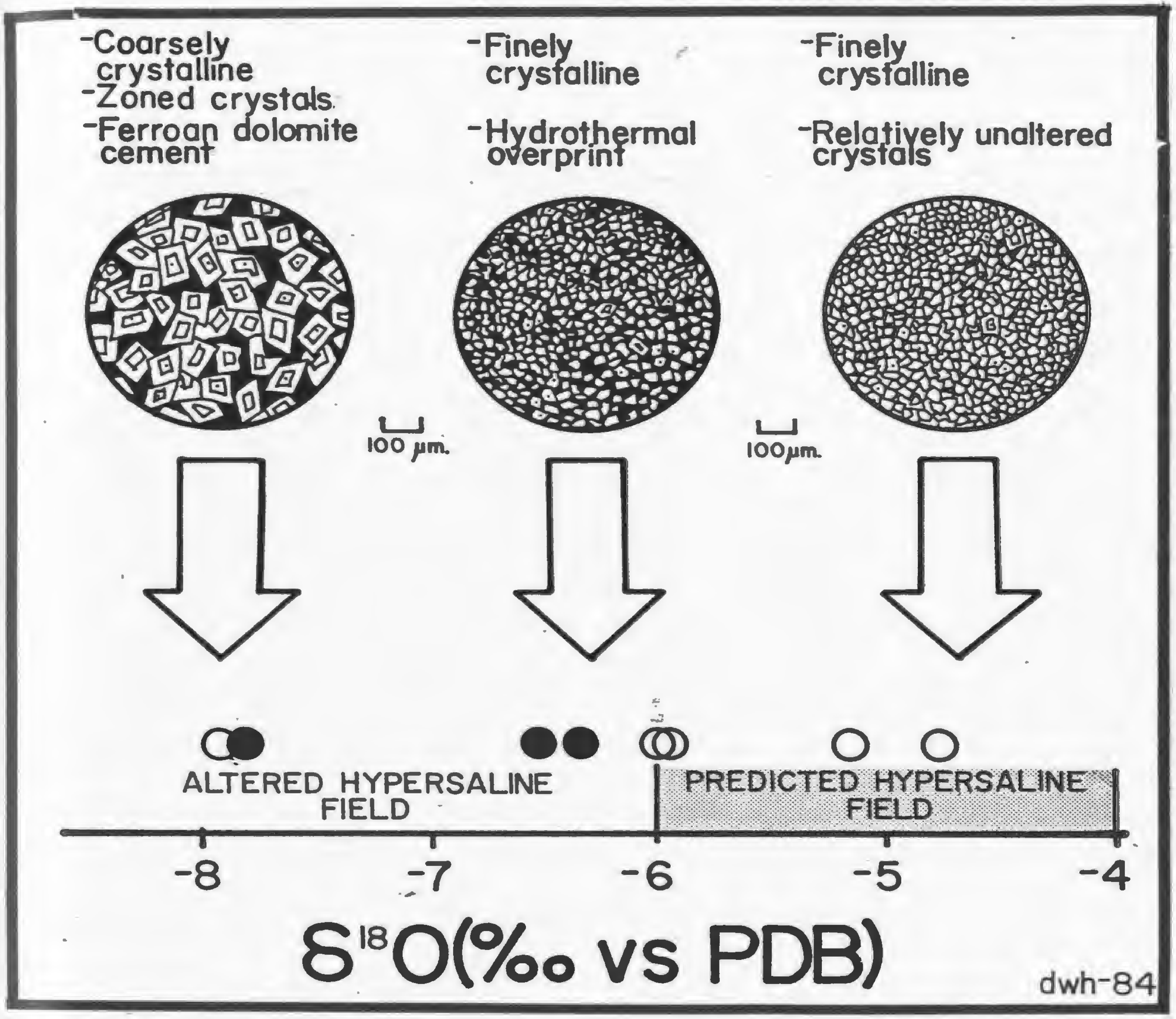


FIGURE 5.6: Petrographic and $\delta^{18}O$ characteristics of dololaminites. The four dololaminite samples from the southern portion of the study area (open circles) that fall within the predicted hypersaline field are characterized by very fine crystallinity and appear relatively unaltered diagenetically. The two samples from the northern part of the study area (solid circles) are finely crystalline, but are cemented by a second "hydrothermal" phase of dolomite. The sample most removed from the predicted hypersaline field is composed of coarsely crystalline, zoned dolomite and is cemented by ferroan dolomite suggesting significant diagenetic growth after deposition.

conclusion is equally applicable to all varieties of dolomite and dolostone (figure 5.4).

The isotopic relationship between mottle dolomite and host limestone is inconclusive as there is no consistent isotopic fractionation between them. In some samples, dolomite is enriched in $\delta^{18}O$ relative to the host limestone, whereas in others, it is depleted (figure 5.7). This is partially explained by the fact that the mottle dolomite varies petrographically from sample to sample. Some mottles are composed of zoned crystals whereas others are composed of non-zoned crystals, but neither the uniformly luminescent, nor the zoned crystals are characterized by a unique fractionation compared to the limestones. For example, two different samples, both composed of petrographically identical dolomite may show completely opposite trends (refer to figure 5.7). The nature of the mottles also does not seem to be a factor. Those mottles that are characterized by a strong ichnofossil component are just as variable as those mottles that are characterized by a strong stylolite component. Given the prolonged growth period of this variety and the likely hood of local aquifers, it is not surprising that mottle dolomite is not characterized by a unique $\delta^{18}O$ (or petrographic) signature.

Similar variability is also observed for the mottles within southern examples of pervasive A dolostone. In these rocks, the mottles and intermottles have similar isotopic

FIGURE 5.7: Fractionation trends for dolomite - calcite pairs in dolomite mottled limestones from the southern portion (open symbols) and the northern portion (solid symbols) of the study area. Plots that are joined are analyses from the same samples. There is no unique fractionation between dolomite and calcite pairs. The two limestone analyses from the south that fall within the "unaltered limestone field" are characterized by dolomites of very different character even though the dolomite in both of them appear petrographically identical. Dolomite - calcite pairs from the northern portion of the study area are all shifted toward more negative oxygen values because of hydrothermal alterations. See text for discussion. All data is compared to the PDB Standard.

FIGURE 5.8: Fractionation trends between dolomite mottles and host rock for neighbouring dolomite mottled limestones and pervasive A dolostones. Symbols are as described in figure 5.7. The southern samples are all clustered within a narrow range suggesting that mottle dolomite and pervasive A dolostones all formed together from fluids of the same isotopic composition. The northern samples are much more widespread, most likely a result of hydrothermal alteration.

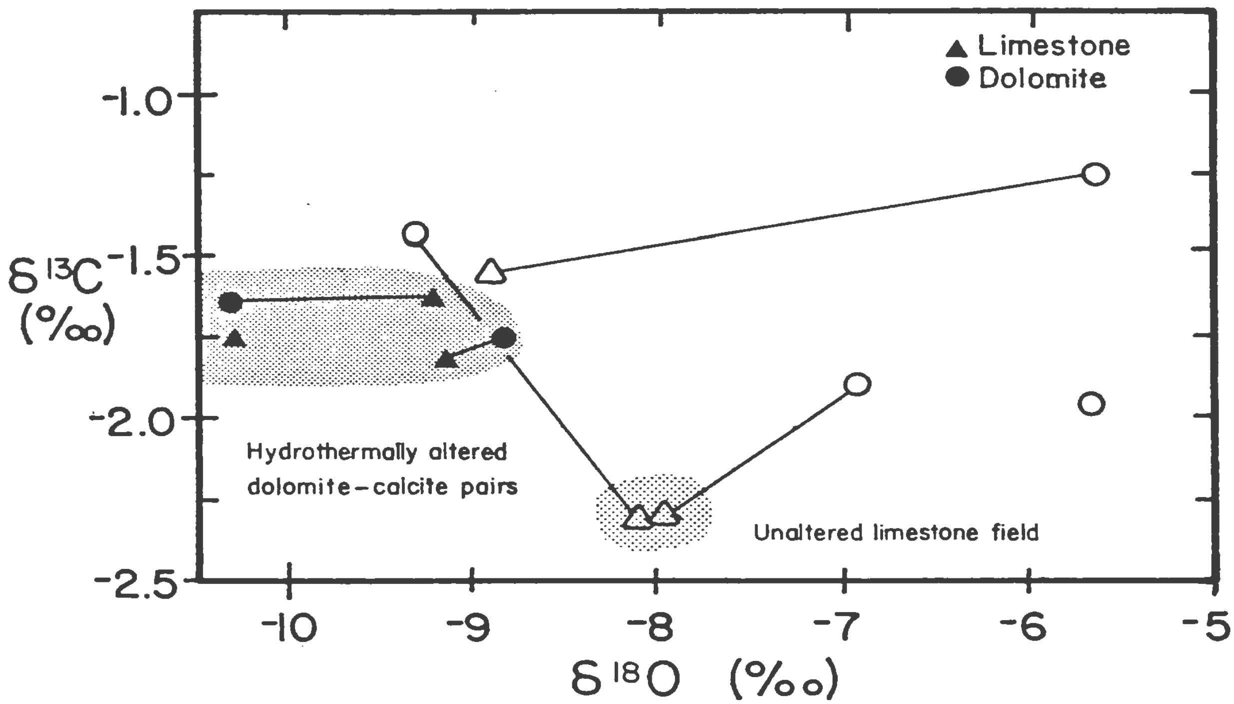


Figure 5. 7

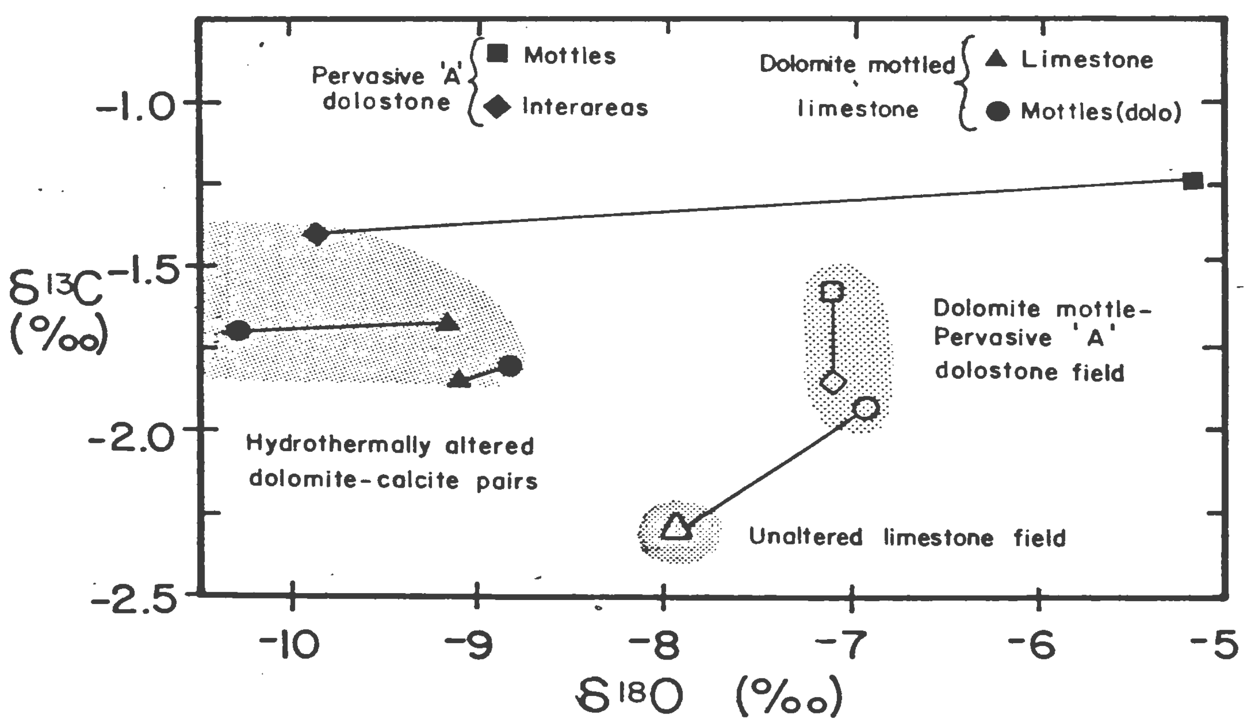


Figure 5.8

compositions (appendix B, figure 5.8) suggesting cogenetic origin. The $\delta^{18}O$ values of pervasive A dolostone are also very similar to the $\delta^{18}O$ values of mottle dolomite obtained from neighbouring limestones (figure 5.8) which further suggests that early mottle dolomite and pervasive A dolostone originated from fluids of the same isotopic character and probably at the same time. These conclusions agree with those made earlier during petrographic and cathodoluminescence analysis.

Any interpretation of the isotopic character of northern examples of pervasive A dolostone and the mottles within pervasive B dolostone is more speculative because of the later hydrothermal dolomitization overprint. It seems probable on the basis of paragenetic relationships and petrography that they also had a similar isotopic composition to the nearby mottle dolomite prior to hydrothermal overprinting.

The two analyses of matrix dolomite were carried out on packstones from the southern portion of the study area that were matrix dolomite-rich (greater than 50 percent dolomite) because of difficulties in obtaining sizable quantities from matrix dolomite-poor (less than 50 percent) limestones. As discussed in chapters three and four, coarse grained limestones contain a different matrix dolomite than do fine grained limestones and therefore, these two analyses are not representative of all examples of matrix dolomite within St. George limestones. One of the samples analysed contained gaseous hydrocarbons (R. Ouick, pers. comm., 1984), but "normal" $\delta^{13}C$ values for both of the analyses indicate that the organics did not play a significant role in this matrix dolomitization.

The two samples are among the lightest with respect to $\delta^{18}O$ of any analysis in the south, and further implies that they are the result of a different dolomitization event than those responsible for the other varieties. The analyses are similar isotopically to saddle dolomite and the intermottle dolomite within pervasive B dolostones and fall within the fields delineated by these two varieties in a plot of Sr^{2+} concentration versus $\delta^{18}O$ (figure 5.4). On the basis of these observations, it is likely that the matrix dolomite in packstones and grainstones which crop out in the southern portion of the study area is a hydrothermal product, but not necessarily the same one that developed the pervasive B dolostones.

Two cavity-filling dolostones were analysed from beneath the pebble bed on the Port au Port Peninsula, two samples were analysed from the Watts Bight Formation on the Great Northern Peninsula and one sample was analyzed from the Catoche Formation at Smelt Canyon. Despite this stratigraphic and geographic distribution, all but one of these analyses, (one from the Great Northern Peninsula), plot within a narrow range of $\delta^{18}O$. These are similar values to those reported by Badiozamani (1973) for dolostones in Wisconsin which he attributed to mixed water dolomitization. Evidence has been given in previous chapters which suggests that this dolostone is directly related to subaerial exposure and though not entirely conclusive, $\delta^{18}O$ values also favors the supposition that meteoric waters contributed to the dolomitizing fluids.

CHAPTER SIX

X-RAY DIFFRACTION

6.1 INTRODUCTION AND LABORATORY METHODS:

X-ray diffraction has been employed successfully for many purposes including the determination of mineral crystallographic parameters, mineral identification and mineral chemistry. The principles behind this form of analysis are discussed in Cullity (1956).

X-ray diffraction was employed in this study for two purposes: 1) to characterize the seven different field varieties of dolomite and dolostone and 2) to identify the clay minerals that may be associated with them. This study is primarily concerned with the identification of the clay and accessory minerals rather than their absolute abundances and therefore, quantitative measurements were not made on any of the analyses.

Representative samples, a minimum of two from each dolomite or dolostone variety, were crushed and ground with mortar and pestle. The less than 50 micrometre fractions were mixed with a small quantity of ground sodium chloride or fluorite (as internal standards) and were examined by powder x-ray diffraction. For the two varieties of pervasive dolostone, seperate analyses were run on mottle and intermottle samples. In total, 27 analyses were performed.

Duplicate powdered samples were allowed to settle out of a water column for four hours and the still-suspended fraction (ca. less than 2 micrometres) was centrifuged, transferred to filter paper, and finally to a glass slide in preparation for analysis.

All analyses were performed on a Phillips X-ray diffractometer with Cu-K_{α} radiation at a scanning speed of 1^{o} 2^{θ}/minute.

Clay mineralogy samples were also exposed to saturated ethylene glycol vapours to detect the presence of montmorillonite and mixed layer clays.

6.2 RESULTS AND DISCUSSION:

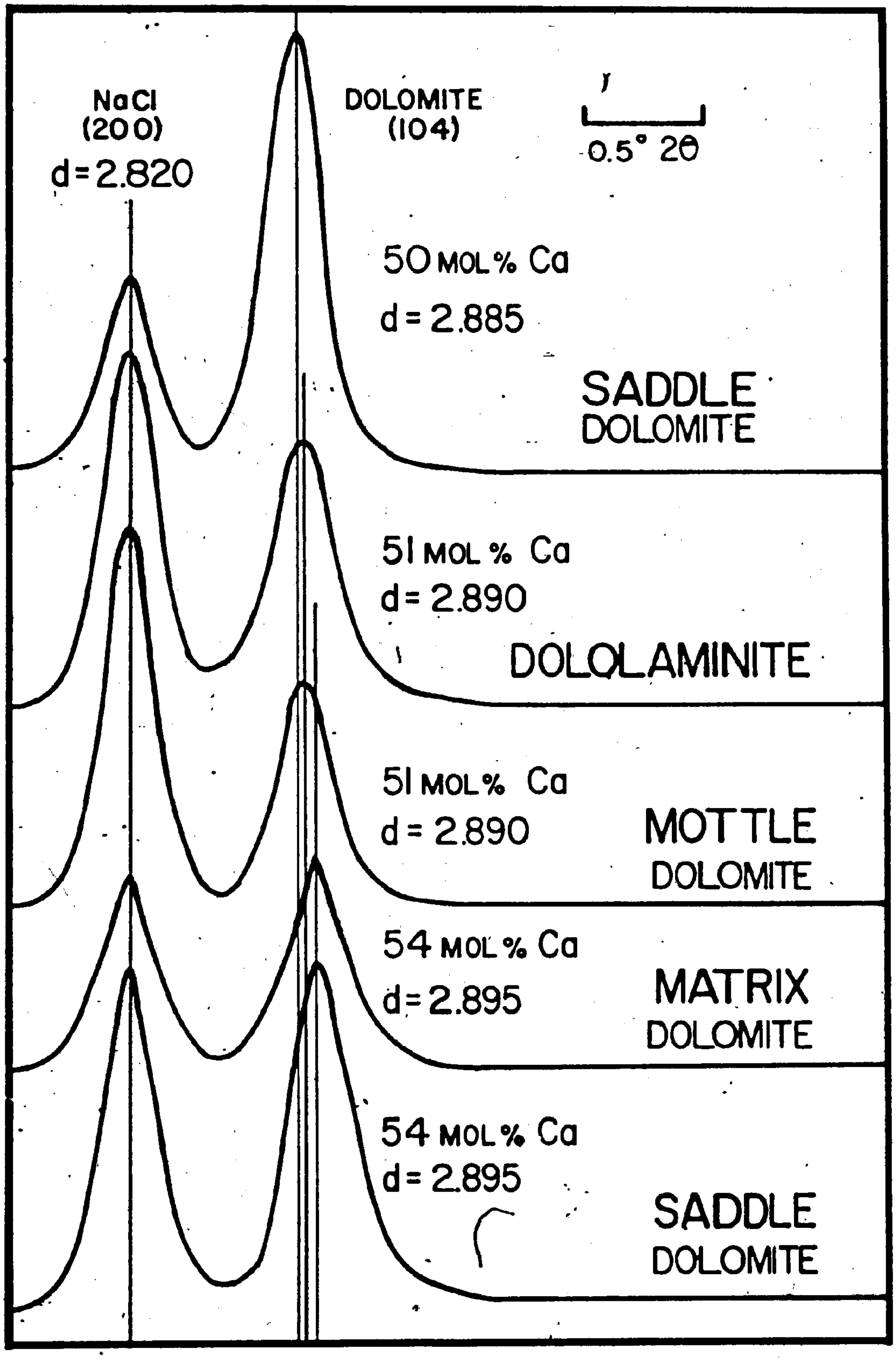
DOLOMITE AND DOLOSTONE:

The proportions of $MgCO_3$ and $CaCO_3$ within dolomite can be determined by assuming a linear relationship between $d_{(104)}$ and the substitution of $MgCO_3$ into the carbonate lattice (Goldsmith and Graf, 1958a). By this argument, Goldsmith et al., (1961) established a curve which allowed for rapid determination of $MgCO_3$ and $CaCO_3$ content in naturally occurring and synthetic carbonates. Blatt et al., (1972) found that by using sodium chloride as an internal standard, they could determine stoichiometry right from the diffractometer trace with an precision of 0.02 mol % magnesium. In the St. George Group, all dolomite is calcium rich. Representative samples of dololaminites, mottle dolomite, pervasive A dolostone and cavity-filling dolostone contain from 51 to 52 mole percent $CaCO_3$ whereas matrix dolomite, saddle dolomite and the intermottles in pervasive B dolostone are slightly more enriched with respect to $CaCO_3$; 53 to 54 percent (figure 6.1). These data suggest that hydrothermal phases of dolomite are enriched in $CaCO_3$ relative to other varieties and this probably explains the curved crystal faces and sweeping extinction exhibited by the rhombs (Radke and Mathis, 1980). Exceptions to this conclusion do exist. The most notable are some strongly curved saddle dolomite crystals from the Newfoundland Zinc Mines. These crystals are strained and strongly curved, yet are stoichiometric (figure 6.1).

The presence of strong "superstructure reflections" within the diffractometer traces (for example the 10.1, 10.5 and 02.1 peaks; Lippmann, 1973), and through direct comparison with samples analysed by Goldsmith and Graf (1958b), indicates that all of the St. George dolomites analysed in this study are very well ordered (figure 6.2 and 6.3). "Protodolomite" (poorly ordered dolomite of Gaines, 1977) does not exist in these rocks.

The most apparent difference between the diffractometer traces in figures 6.2 and 6.3 is their bulk mineralogy. Dololaminites, mottle dolomite, pervasive A and B dolostones (both mottles and intermottles) and cavity-filling dolostone are characterized by subordinate siliclastic peaks, presumably because they inherit these

FIGURE 6.1: Determination of the stoichiometry of representative dolomite and dolostone samples following the method outined by Blatt, Middleton and Murray (1972). A sample of saddle dolomite (sample DH-1) from the area of Daniel's Harbour is stoichiometric; however, most saddle dolomite (sample CN-25) and the intermottle dolomite of pervasive B dolostones is calcium rich (averages 54 mol % calcium). A sample of coarsely crystalline matrix dolomite (PP-117) is also enriched in calcium. Other varieties, including dololaminites (sample LC-2), mottle dolomite (sample PP-112C), pervasive A dolostone and cavity-filling dolostone are only slightly calcium rich (averages 51 to 52 mol %).
Relative peak hights reflect variations in the proportions of dolomite and sodium chloride in each analysis.


NaCl
(200)
d=2.820
DOLOMITE
(104)
0.5° 2θ
50 MOL% Ca
d = 2.885
SADDLE
DOLOMITE
51 MOL % Ca
d = 2.890
DOLOLAMINITE
51 MOL% Ca
d = 2.890
MOTTLE
DOLOMITE
54 MOL % Ca
d = 2.895
MATRIX
DOLOMITE
54 MOL% Ca
d = 2.895
SADDLE
DOLOMITE

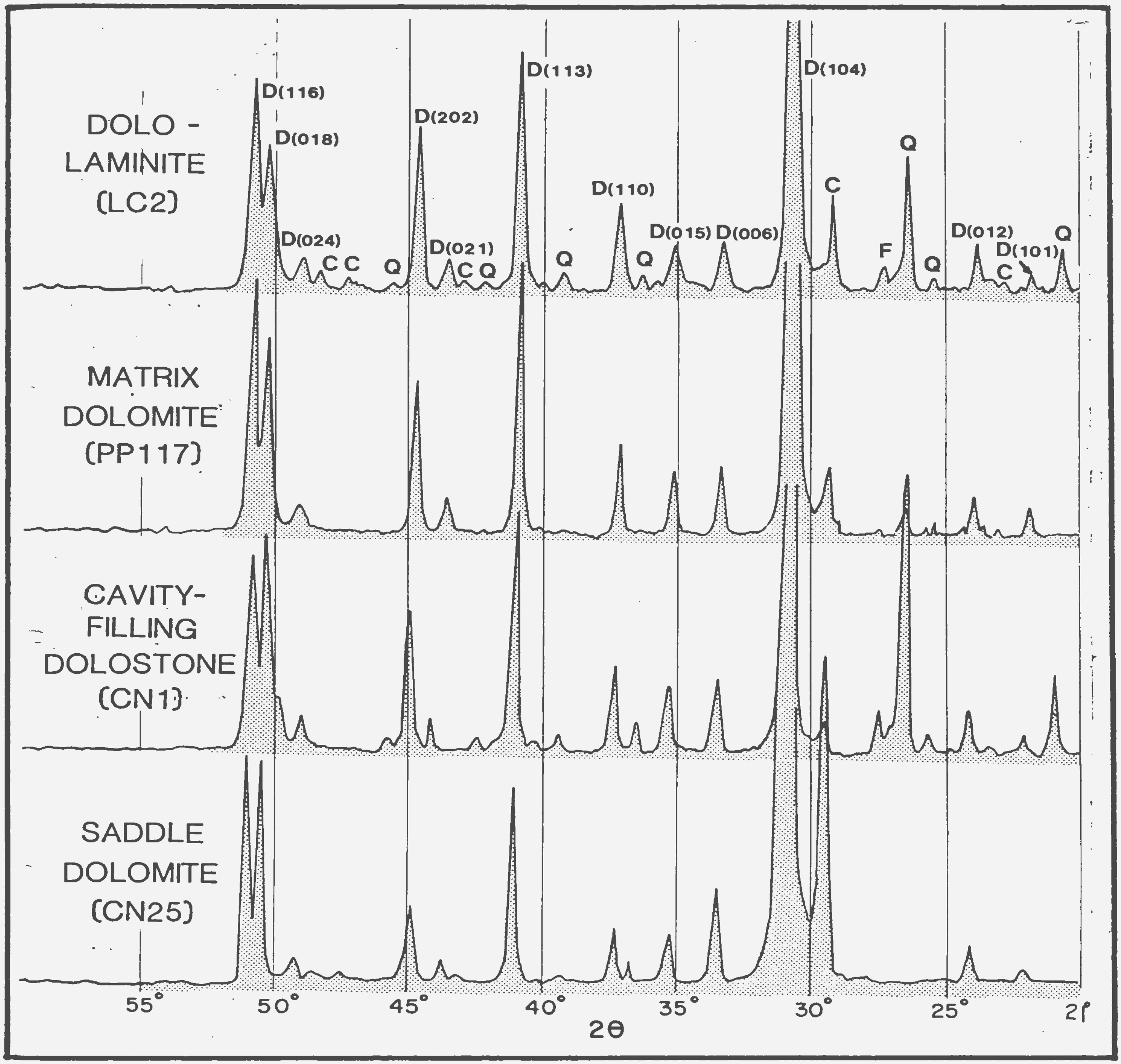


FIGURE 6.2; Portions of diffractometer traces taken with Cu radiation of a representative sample of dololaminite, matrix dolomite (coarse grained limestone), cavity-filling dolostone and saddle dolomite. The peaks in the top trace are identified as either dolomite (D), calcite (C), quartz (Q) or feldspar. The hk.1 indices for dolomite are also indicated. The flourite internal standard peak has been removed from these samples.

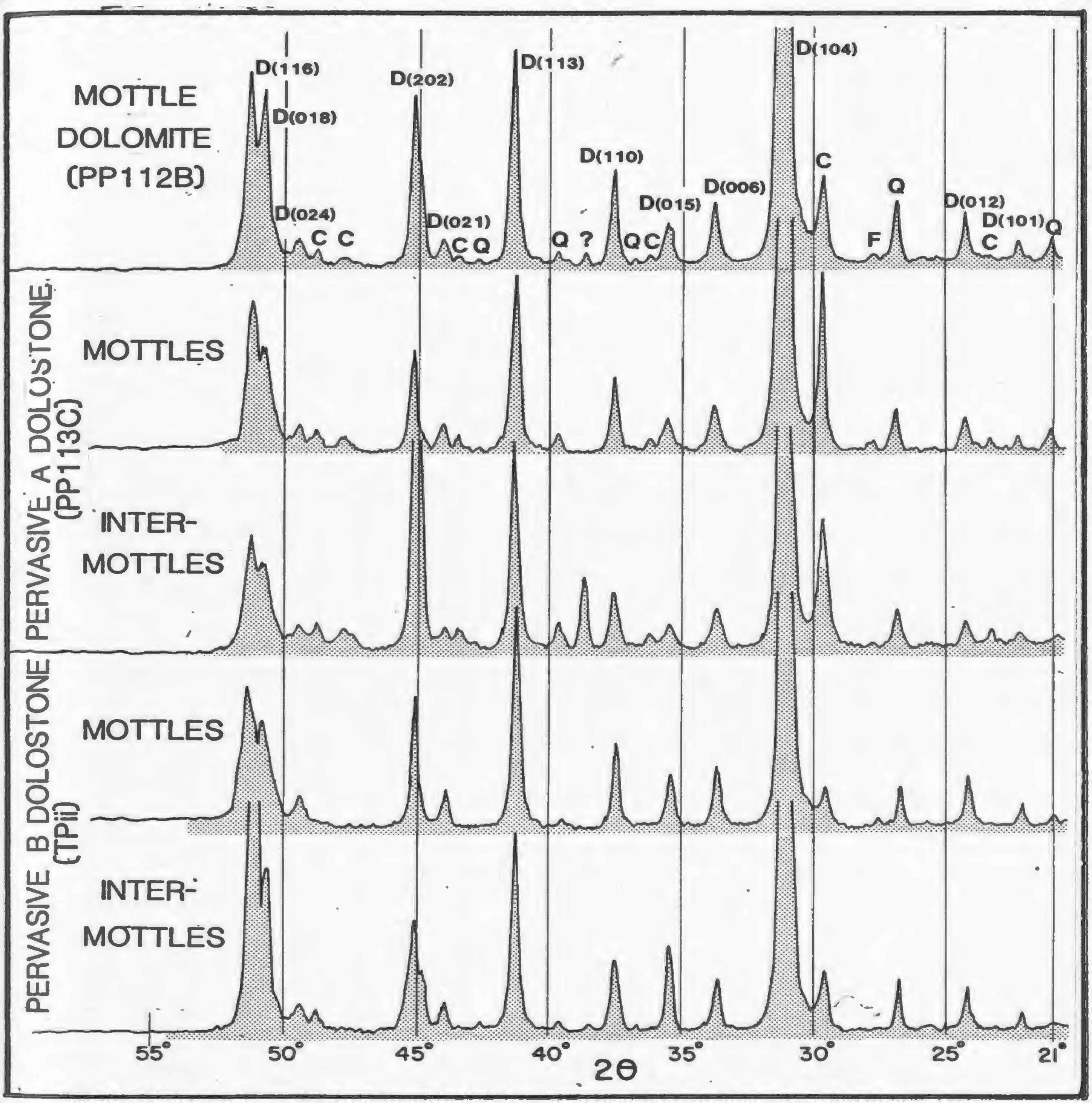


FIGURE 6.3: Portions of diffractometer traces for representative samples of mottle dolomite, pervasive A and pervasive B dolostones. Refer to figure 6.2 for explanation of peak identifications.

minerals from the pre-existing limestones. Saddle dolomite which is pore-filling, does not.

CLAY MINERALS:

The less than 2 micrometre fraction of 24 of the 27 samples analysed were found to contain only illite with subordinate chlorite. Three samples of saddle dolomite do not contain significant quantities of clay minerals.

Illite was identified in the diffractometer traces by its basal reflection at 10 Å and chlorite by its basal reflections at 7 and 14 Å. Neither illite nor chlorite was affected by exposure to ethylene glycol (figure 6.4).

Wood (1983) analysed shale samples from Cambrian and Lower Ordovician rocks of the Port au Port Peninsula and also found them to contain mostly illite (77 to 99 percent) and chlorite. She argues that this suite of clay minerals is likely detrital rather than diagenetic by citing two lines of evidence;

> 1) A diagenetic suite of illite and chlorite can only be generated if burial temperatures exceeded $200^{\circ}C$. The colour indices of conodonts from nearby limestones suggest that temperatures never exceeded $60^{\circ}C$.
>
> 2) The illite is poorly crystalline as indicated by the diffuse 10 A peaks and this is indicative of a detrital rather than diagenetic source (Wood, 1983).

By these same arguments, it is likely that the clay minerals associated with the dolomite and dolostone are also detrital and were probably transported by wind onto

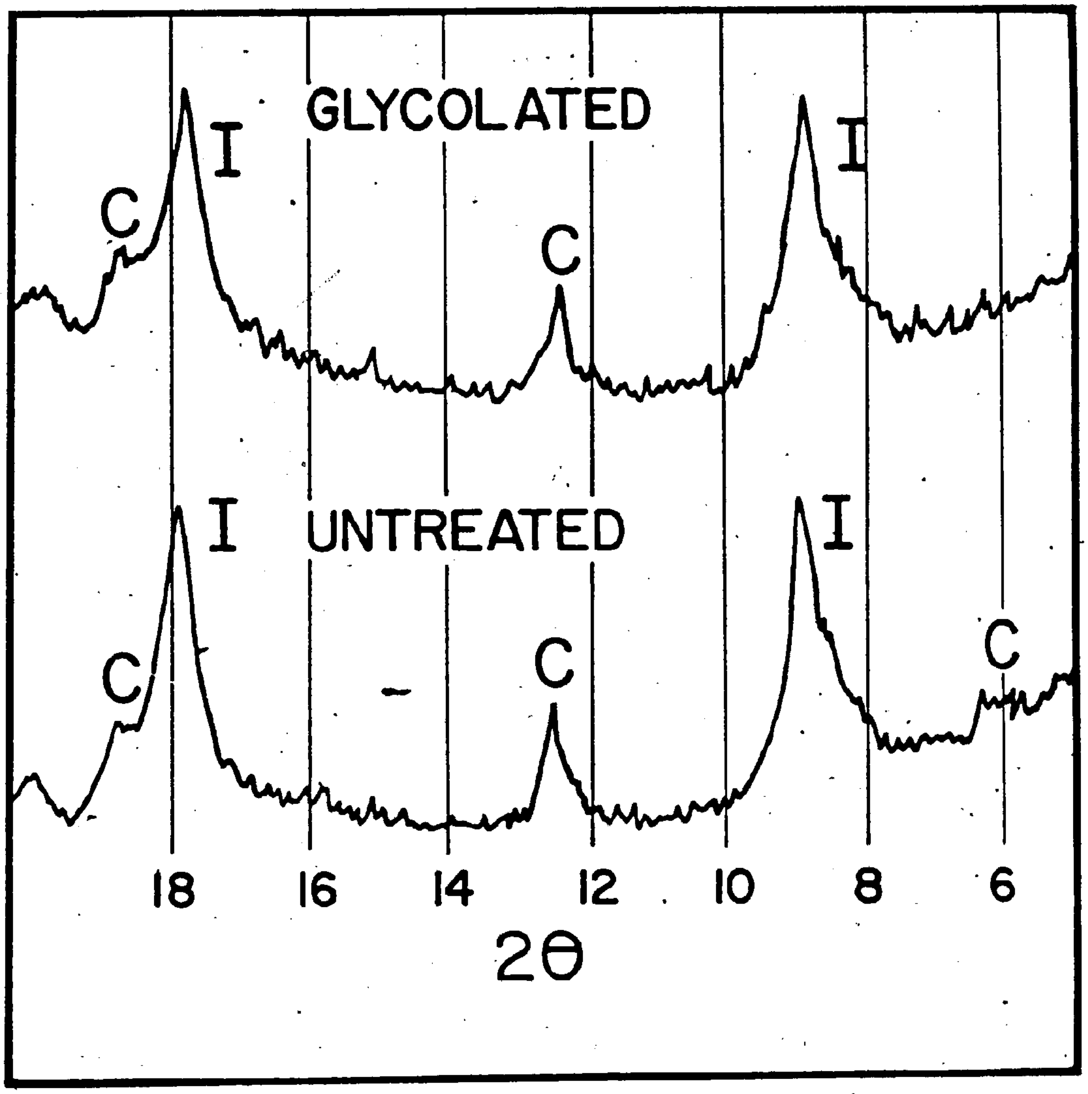


FIGURE 6.4: Portion of diffractometer traces of the less than 2 micrometre fraction of a dololaminite sample. The only clay minerals that are present are illite (I) and chlorite (C), neither of which are affected by gycolation.

the carbonate shelf during deposition of the Lower Ordovician sediments. Wood speculates that both the illite and chlorite were probably derived through the weathering of granitic rocks.

As was discussed in chapters three and four, mottle dolomite characterized by a strong or exclusive stylolite component (refer to plate 3.3c), also contains significant quantities of clay minerals and oxides. If the clays are detrital rather than diagenetic, it must be concluded that their localization along the stylolites is purely the result of the accumulation of insoluble minerals during periods of pressure solution.

CHAPTER SEVEN

MECHANISMS OF DOLOMITIZATION AND CONCLUSIONS

7.1 INTRODUCTION:

Dolomite is still one of the most perplexing problems in the field of carbonate geology. Despite numerous studies, it is still not clear why dolomite, given its abundance in the rock record, is not a more common component in modern sediments, or what the exact mechanisms of dolomite growth are (two aspects of the so called "dolomite problem"; Land, 1980).

To resolve these and other problems, sedimentologists have searched for an all encompassing dolomitization model and to date, many have been proposed (Morrow, 1982b). The most popular include; seepage refluxion (Adams and Rhodes, 1960, Deffeyes et al., 1965), capillary evaporation (McKenzie, et al., 1980), cannibalization (Goodell and Garman, 1969), mixed water, or Dorag (Hansaw et al., 1969, Badiozamani, 1973, Land, 1973, Folk and Land, 1975), burial compaction (Mattes and Mountjoy, 1980), pressure solution (Wanless, 1979) and hydrothermal alteration (Lovering, 1969).

Dolomite grows under a variety of conditions (this is in part responsible for the many different models) and as this study has demonstrated, dolomitization may be reactivated many times, and for many different reasons during the diagenetic history of a rock.

In this chapter, possible mechanisms responsible for syngenetic, early- and late-diagenetic dolomitization are discussed and applied to proposed sedimentation models devised for the St. George Group. As earlier generations of dolomite commonly act as nuclei for later growth, particular emphasis is place upon initial nucleation. Suggestions for further study to resolve some tentative conclusions are also offered.

7.2 MECHANISMS OF DOLOMITIZATION

SYNGENETIC DOLOMITE - DOLOLAMINITES:

Dolomitization of limestone or lime sediment is basically a hydrological process (Land, 1983). On modern sabkhas, the best documented environments where dolomite forms syngenetically, hydrological parameters are reasonably well understood. Seawater is pushed onto the flat-lying sabkhas by the action of storms (McKenzie et al., 1980, Patterson and Kinsman, 1981, 1982) and evaporates, increasing both the ionic strength and ^{18}O of the remaining brine (Adams and Rhodes, 1960, Craig et al., 1963, Illing et ál., 1965, McKenzie, et al., 1980). Fluids circulate through the sediment due to increased hydrostatic head caused by flood recharge, capillary evaporation and evaporative pumping. These three factors represent a complete hydrological cycle (McKenzie, et al., 1980).

Dolomitization on sabkhas is thought to be controlled by a number of factors: 1) high Mg^{2+}/Ca^{2+} ratios* (McKenzie, et al., 1980, Patterson and Kinsman, 1981, 1982), 2) gypsum precipitation (a sink for Ca^{2+}) (Patterson and Kinsman, 1982), 3) low SO_4^{2-} concentrations. Recent experimental studies by Baker and Kastner (1981) and Kastner (1984) have demonstrated that dolomite replacement of aragonite can be inhibited by SO_4^{2-} concentrations greater than 5 to 7 percent that found in seawater (28 mMol). Gunatilaka et al. (1984) also suggested that this is a principle factor dictating subtidal dolomitization of aragonite sediments in a saline lagoon in Kuwait. These studies advocate removal of sulphate by reduction, a process which Baker and Kastner claim further promotes dolomitization by increasing alkalinity and producing NH_4^+ (ammonium ions can exchange with complexed Mg^{2+} ions, releasing them and increasing the Mg^{2+}/Ca^{2+} ratio). It is not entirely clear if such a mechanism is responsible for St. George dololaminites. They likely originated from very shallow water because of the abundance of sedimentary structures (chapters two and three); but, these features need not have formed in a Persian Gulf-like sabkha environment. Oxygen

---

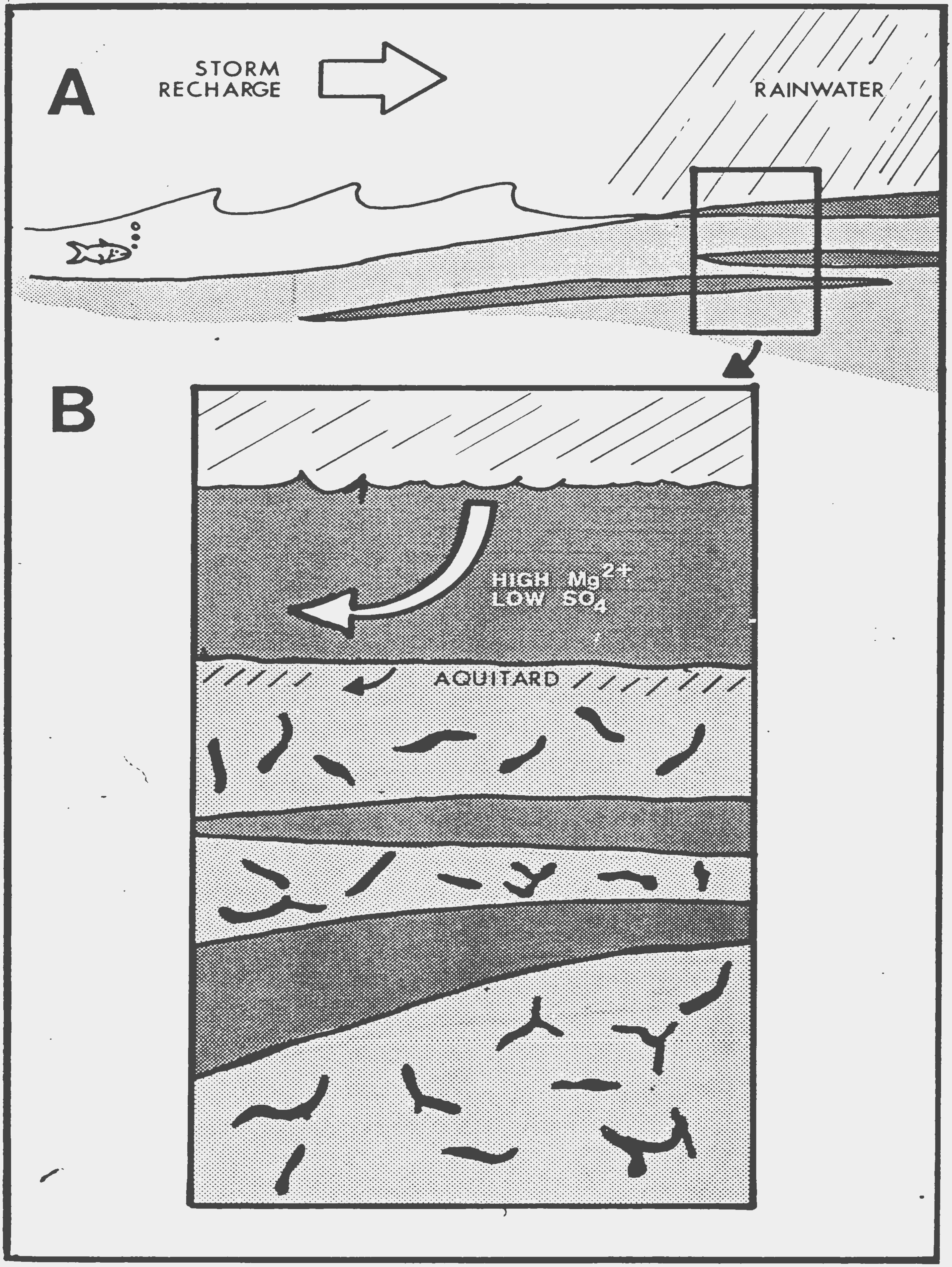
* Mg/Ca ratios as high as 27 have been observed in some parts of the Persian Gulf (McKenzie et al., 1980). In comparison, normal seawater has a Mg/Ca ratio of 5.3 (Kastner, 1984).

isotopes suggest $\delta^{18}O$ enrichment of the dololaminites compared to seawater (consistent with a rapid evaporational setting, Craig et al., 1963); however, extensive evaporites are not present in these rocks. Dololaminites also differ from modern sabkhas in that they are well laminated, whereas most sabkhas are not (Patterson and Kinsman, 1982).

Aragonite, the dominant component of modern sabkhas, is normally easier to dolomitize than is either calcite or Mg-calcite (less than 12 Mol% $MgCO_3$) (Baker and Kastner, 1981). Evidence given in an earlier chapter suggested that St. George tidal flats were composed primarily of calcitic mud, not aragonitic mud. Given favorable conditions (i.e. high Mg^{2+}/Ca^{2+} ratios, low SO_4^{2-} concentrations; figure 7.1), dolomitization of the tidal flats could (and did) occur. It may have been a slower process than that observed on modern aragonitic tidal flats and may have only produced finely crystalline nuclei. Xenotopic fabrics caused by the coalescence of rhombs could be a shallow burial feature. Later zones of dolomite around some cores may represent this phase of dolomite growth.

Most dololaminite beds are thin and stratabound between intertidal or subtidal limestones. Evidence has been given earlier suggesting that lithification of lime mud was commonly early and possibly syngenetic. It is possible therefore, that early lithification caused the underlying substrate to act as a barrier, or aquitard, to the fluids which were initiating dolomite growth in the

FIGURE 7.1: A sketch illustrating a possible mechanism of dololaminite formation. Seawater is pushed onto tidal flats by storm surges (A). After precipitation of evaporite minerals and/or the dilution of the seawater of meteoric water, the Mg-rich, SO_4^{2-} poor fluids began to dolomitize the permeable (unlithified) sediments (B). Lime mud that was lithified early acted as a barrier to the fluids (Aquitard) and subsequently, escaped dolomitization.


A
STORM
RECHARGE
RAINWATER
B
HIGH Mg2+
LOW SO4
AQUITARD

overlying, more permeable intervals (figure 7.1). Intuitively, this implies dolomitization of unlithified sediments.

EARLY DIAGENETIC DOLOMITIZATION - MOTTLE DOLOMITE, MATRIX DOLOMITE (FINE LIMESTONES), PERVASIVE A DOLOSTONE:

In addressing early diagenetic dolomitization, two questions must be answered: 1) the mechanism of dolomite nucleation and 2) the nature of the fluids responsible for crystal growth.

1) Nucleation:

The most important clue in solving this problem is the selective replacement of burrow linings and the sediment which has filled burrows or fossil molds because these components were especially susceptible to dolomitization. In previous studies of Palaeozoic dolomite mottled limestones, the general consensus has been that ichnofossils were more permeable than the enclosing limestone (Beales, 1953, Kendall, 1977, Morrow, 1978a). Permeability is without question, an important factor in dolomitization of St. George ichnofossils. Some burrows remained open until after dolomitization as evidenced by etched rhombs in contact with pore-filling calcite cement. These trace fossils must have acted as "mini-pipelines" transporting fluids through the rock.

Kendall (1977) suggested that sediment within ichnofossils and gastropod molds remained unlithified after lithification of the surrounding lime mud. This he felt, could explain the selective burrowing of sediment-fill within the gastropods (as in plate 4.1e). Petrography demonstrated that at least some mottle dolomite formed during periods of early-diagenesis and it is possible that it selectively replaced the unlithified (more permeable) components. By this same arguement, unlithified mud intervals or beds may have been the predecessors of pervasive A dolostones. Lateral and vertical transitions into burrow-mottled limestones may simply reflect gradations from permeable sediment into aquitards (lithified sediment).

Localization of dolomite to Palaeophycus margins suggests that the organic lining may have been influencial to dolomitization; at least in nucleation. This may also explain why mottles in pervasive A dolostones are composed of finer crystalline dolomite than the intermottles. In chapter four, it was suggested that this reflected different nucleation rates; mottles (burrows) were sites of more intensive nucleation than were intermottles.

There are two possible ways in which organics can aid (or promote) dolomitization; 1) by removing sulphate during biogenic decay (reduction) (Lippmann, 1973, Kastner, 1984) or 2) by concentrating Mg^{2+} through organic complexing (Gebelein and Hoffman, 1973).

Dolomite which has formed as a result of sulphate reduction (referred to as "organic" dolomite by Lippmann, 1973) should be characterized by deficient heavy carbon provided that it has grown primarily while reducing conditions have prevailed (Arthur et al., 1983). As Lippmann states however;

> "When sulphate reduction is no longer active, i.e. due to consumption of utilizable organic matter, a normal isotopic composition may be restored for the carbonate species dissolved in the interstitial solution." (Lippmann, 1973, p186).

Despite the fact that St. George dolomites are not characterized by enrichment of light carbon (chapter five) it is still possible that some of the dolomite ultimately owes its origin to biogenic decay and sulphate reduction. The nuclei for further growth could have been established during early reduction of the organic burrow linings.

Organic complexing of magnesium was suggested by Gebelein and Hoffman (1973), in their study of algal mats. They postulated that Mg^{2+} concentrated into algal sheaths during growth was released into the rock during burial and biogenic decay (reduction). This inturn, initiated dolomitization. The resulting dolomite should also be depleted in $\delta^{13}C$.

Chloride ions, SO_4^{2-} and CO_3^{2-} all form ion pairs with most common anions; however, apart from Gebelein and Hoffman's study, the role of organic complexing (for example chelation by amino acids or aromatic molecules in mucopolysaccharides), in carbonate diagenesis has not been fully addressed. It is not known what (if any) cations are capable of being complexed or if other dissolved species (for example SO_4^{2-}) are involved. Biologists have studied mucopolysaccharides secreted from marine organisms (i.e. crustaceans, Ehrlich, et al., 1981; foraminifera, Spindler, 1978; and advanced invertebrates, Patel et al., 1980), however, few studies have examined the chemistry of mucopolysaccharides associated with ichnofossils. The most relevant of these to date is a study by Trench (1973). He examined the mucopolysaccharides secreted by the marine slug Tridachia crispata and determined it to be of large molecular weight, acidic, sulphated and composed of glucose, glucuronic acid, glucosamine, galactosamine and traces of galactose. It is not possible in this study to accurately assess the effects these compounds would have on the sediment or seawater, but it is worth while to speculate. If some of the organics in ancient mucopolysaccharides were capable of complexing with sulphate ions (in light of Trench's finding that some modern mucopolysaccharides are sulphated, it becomes a distinct possibility), a mechanism of dolomite nucleation without requiring reducing conditions may exist.

Following bioturbation and lithification of the surrounding lime mud, sulphate complexing could have removed SO_4^{2-} from the area enclosed by the organic lining. This is either the packed margin of the ichnofossils, or in the case of sediment-filled burrows and shell molds, the unlithified internal sediment. Dolomite nucleation (essentially from oxidized seawater) would occur probably as sub-micron sized crystallites. These would be the substrates for early- and late-diagenetic growth.

Morrow (1978b) considered the possibility that organics influenced dolomite growth in Palaeozoic rocks of the Canadian Arctic Archipelago, but rejected it because he believed that the bioturbated matrix material should have also have been replaced. This argument does not apply to the St. George Group for two reasons; 1) matrix material is often dolomitized (witness pervasive A dolostones and matrix dolomite in fine grained limestone); 2) St. George mud was lithified early. This latter characteristic makes it unlikely that dolomite would grow within the lithified mud, even if dolomite crystallites were pervasively distributed.

After nucleation, dolomite growth continued whenever (and wherever) fluids and conditions favorable for dolomitization occurred. This is responsible for the variable petrographic and isotopic character of mottle dolomite and matrix dolomite within fine grained limestones.

2) Nature of Dolomitizing Fluids:

After nucleation, dolomitization would begin in earnest once favorable fluids began to pass through the rocks. Growth was by concomitant dissolution and precipitation.

The possible chemical nature of the fluids have been addressed by Kendall (1977) and Morrow (1978b). Kendall suggested that dolomitizing fluids which affected Ordovician limestones of Saskatchewan and Manitoba were derived from an overlying evaporite sequence and advocated refluxion of Mg^{2+}-rich brines through the burrow networks as a probable cause. In the St. George, this is feasible only for limestones interbedded with dololaminites in the Aguathuna and Boat Harbour Formations. It cannot explain the occurrences of dolomitized ichnofossils in the predominantly subtidal Catoche or Watts Bight Formations.

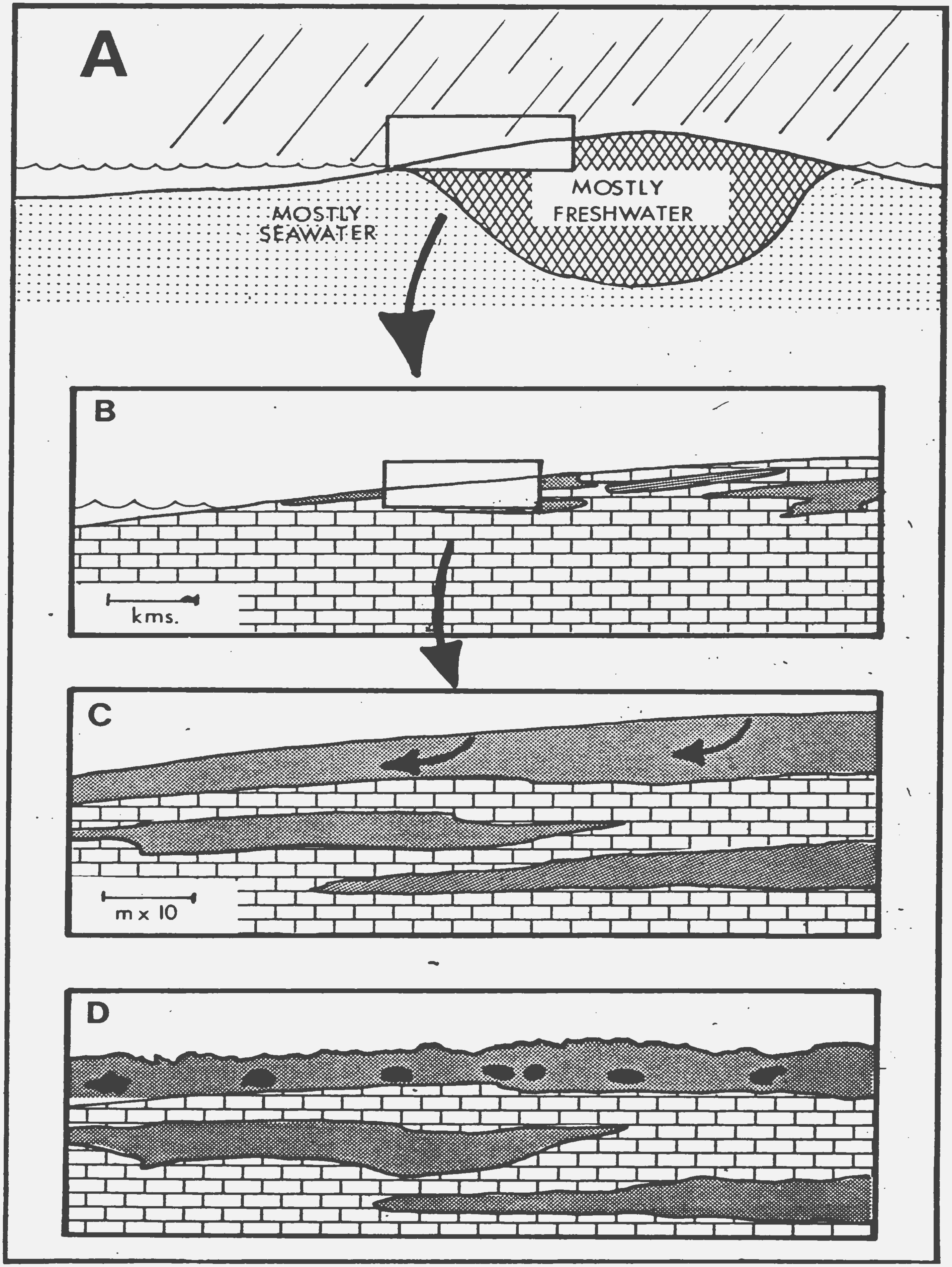
Morrow's (1978b), study area is free of evaporites and therefore, he endorses a different process. He suggested that initial dolomitization of the burrow-filling sediments was the result of salinity fluctuations in overlying shelf water and cites fresh water dilution as the probable cause. Dolomitization is thought to have been promoted through the diffusion of Mg^{2+} from seawater into the permeable burrows. By way of mathematical arguement, Morrow demonstrated that a significant portion of an ichnofossil could be replaced in a very short time, perhaps in just 100 years.

Mixed water dolomitization is an attractive option to explain early-diagenetic dolomitization in the St. George Group; especially for pervasive A dolostones. By mixing meteoric water with seawater, the ionic strength and soluble sulphate are both reduced factors which have been cited as possible causes of dolomitization (Folk and Land, 1975, Kastner, 1984). Mixed water dolomitization could also explain the localization of pervasive A dolostones beneath suspected or documented subaerial exposure horizons. If dolomitization was caused by mixing together of seawater with meteoric water, the resulting dolomite would be expected to reflect the combined isotopic signature of the fluids.

Predicting the isotopic composition of Early Ordovician meteoric water is speculative, but comparisons can be made to the modern. Rainwater in coastal tropical areas is depleted in $\delta^{18}O$ relative to seawater by approximately 2 to 4 o/oo. This depletion is very much dependant upon land mass configurations, wind directions and/or temperatures and can be greater (or lesser) in some coastal regions (J. Whelan, pers. comm., 1984). Badiozamani (1973) suggested dolomitization would be favored when seawater was diluted with from 30 to 95 percent freshwater. Assuming modern rainwater is depleted by 4 o/oo relative to seawater, the resulting solution would have $\delta^{18}O$ values ranging from approximately -1 o/oo to almost -4 o/oo. Extrapolating to the St. George examples, it is very possible that some of the isotopic variation observed in pervasive A dolostones is a result of mixing seawater with freshwater in different proportions. Not all of the variation can be explained in this manner. There must be other local factors as well.

The actual mechanism of pervasive A dolomitization may be very similar to that proposed for the dololaminites. Both probably developed because occasionally, unlithified sediments were subaerially exposed. The only difference between them is in the composition of the dolomitizing fluids and in the exposure time. Dololaminites formed in areas where recharge was frequent and pore fluids were predominantly seawater, whereas pervasive A dolostones formed in areas where meteoric water contributed significantly to the pore fluids (figure 7.2). The development of exposure horizons atop sequences of pervasive A dolostone (for example, the St. George Table Head contact, Port au Port), commonly with the development of dissolution voids filled with cavity-filling dolostone (for example; beneath the "pebble bed", Port au Port; Watts Bight - Boat Harbour contact, Great Northern Peninsula [later overprinted by pervasive B dolomitization]) implies that occasionally, longer periods of exposure occurred with partial dissolution of the previously dolomitized strata (figure 7.2). In retrospect, stratabound pervasive A dolostones with no evidence of overlying disconformities may imply shorter periods of exposure.

FIGURE 7.2: A sketch illustrating a possible mechanism for Pervasive A dolomitization. Pervasive A dolostones are commonly developed beneath disconformities or interbedded with dolo-laminites suggesting that they may be caused by mixing seawater with freshwater (A) The dolomitizing fluids may have preferentially replaced unlithified sediments (B) but not the early-lithified mudstones. These dolomite-mottled limestones acted as aquitards to the fluids (C). After prolonged exposure, disconformities may develop, punctuated by voids and cavity-filled dolostone. Scale in all sketches is generalized.


A
MOSTLY SEAWATER
MOSTLY FRESHWATER
B
kms.
C
m x 10
D

Pressure solution and dolomitization of the St. George Group had been questioned previously by Pratt (1982) in response to a paper published earlier by Wanless (1979). Wanless argued that three styles of pressure solution response prevailed in Palaeozoic rocks of Arizona, western Maryland and southeastern Kansas. Sutured-seam solution developed common stylolites and grain contact sutures. Non-sutured-seam solution developed microstylolite swarms (or anastomosing stylolites), and were commonly the locus of dolomitization. Non-seam solution results in the pervasive thinning of a limestone and frequently caused widespread dolomitization. Pratt (1982) argued against pressure solution as a cause of widespread, stratigraphic burial dolomite in the St. George (pervasive A dolostones). The results of this study are in agreement with his conclusions. His rebutal to Wanless' suggestion of dolomitization along stylolites is not necessarily correct. Some mottle dolomite in the St. George has grown wholly along stylolites (chapter four, plate 4.4c) and may have accompanied pressure solution. Magnesium-bearing fluids passing along stylolites could have reacted with calcium released during solution of the limestone (Logan and Semeniuk, 1976, Wanless, 1979, Mattes and Mountjoy, 1980). Anastomosing (or microstylolitic) swarms (Wanless, 1979) appear to be the locus of this dolomitization which may have been aided significantly by the presence of any dolomite crystals or crystallites collected during limestone solution.

LATE-DIAGENETIC DOLOMITE: PERVASIVE B DOLOSTONE, SADDLE DOLOMITE, MATRIX DOLOMITE (COARSE LIMESTONES):

There is no doubt that the occurrences of pervasive B dolostone and saddle dolomite on the Great Northern Peninsula are the result of a late diagenetic event involving hydrothermal fluids. The field characteristics, as well as petrographic and isotopic properties are all consistent with this interpretation.

Matrix dolomite associated with packstones and grainstones in the south, are similar both petrographically and isotopically to saddle dolomite and are also likely related to hydrothermal dolomitization. They are however, much more limited in extent.

Models involving hydrothermal fluids have been actively sought because of their economic potential when associated with Mississippi Valley Type ores (Lovering, 1969, Collins and Smith, 1975, Beales and Hardy, 1980, Coron, 1982, Sangster, 1983, Barnes, 1983). Fluids are thought to be derived through the de-watering of basinal sediments during burial metamorphism (Barnes, 1983). As suggested earlier, these fluids were probably depleted in Sr^{2+}. Temperatures of the dolomitizing fluids are usually less than 250°C, commonly in the range of 60 to 150°C (Radke and Mathis, 1980, Morrow, 1982b). Precipitation temperatures determined via isotopic analysis for St. George saddle dolomite and pervasive B dolostones are in the range of 37 to 64°C. Fluid inclusions, although abundant in saddle dolomite and the intermottle dolomite within pervasive B dolostones, are not clearly primary in the St. George samples examined preventing an estimation of formation temperatures. In coexisting fluorite however, primary fluid inclusions from Port au Choix have yielded consistent minimum formation temperatures of from 135 to 150 ^{0}C (J. Maloney, pers. comm., 1984). These data are similar to the minimum formation temperatures determined by Pratt (1979) on fluorite samples from the Cape Norman area (120 to 160^{o}C). The difference between these temperature estimates and those derived through isotopes either indicates that fluorite precipitated out from hotter solutions, or (more likely), the isotopic composition of the dolomitizing solution ($\delta(w)$) was significantly different than -8.00 o/oo.

Temperatures the order of 100^{o}C have been used to successfully synthesis dolomite in laboratories (refer to chapter five) and it seems likely that this condition would favor more rapid rates of dolomite precipitation. This property may explain the cementation of unstable breccia masses by saddle dolomite near Daniel's Harbour (before stabilization occurred; chapter three) and the uniform luminescence or diffuse zonation in the rhombs (precipitation was more rapid than were changes in porewater chemistry. Higher temperatures may also be capable of sidestepping some of the problems encountered in near surface conditions, such as nucleation.

The common association of saddle dolomite with sphalerite mineralization near Daniel's Harbour suggests that they are the products of the same major event (Coron, 1982). Two schools of thought exist on the transport of the metals. One group contends that the ore is the result of mixing two solutions, one rich in Zn^{2+} and the other rich in sulphide (possibly through the reduction of sulphate by organics). The other group feels that the aqueous metal ions possibly complexed by organics, and the sulphide must have been carried together in the same solution (Barnes, 1983). Whatever the exact transport mechanisms are, it is clear that they were of local extent compared to the widespread nature of the pervasive B dolostones and saddle dolomite.

7.3 DOLOMITIZATION AND PROPOSED SEDIMENTATION MODELS:

Two models of sedimentation have been proposed in previous studies for the St. George Group; 1) stable shelf sedimentation (Levesque, 1977, Knight, 1977b) and 2) island-tidal flat sedimentation (Pratt, 1979, Pratt and James, in press). Dolomitization mechanisms suggested in this study are equally applicable for both; however, the island-tidal flat model better explains the spatial distribution and variable petrographic and isotopic characteristics of some varieties of dolomite and
7 dolostone. In an island setting, local aquifers of different water chemistry (mostly meteoric beneath exposed

islands and mostly marine beneath tidal flats) would be developed. Such a model would also explain the lateral discontinuity of some dolostones (especially dololaminites; Pratt, 1979). Dolomitization in relation to stable shelf and island-tidal flat sedimentation is schematically illustrated in figures 7.3 and 7.4.

7.4 RECOMMENDATIONS FOR FURTHER STUDY:

Some of the conclusions proposed in this thesis are tentative pending further collection of data and assessment by other studies. The following topics will test some of the suppositions made in this thesis and are recommended for further study:

1) A detailed palaeontological study (especially focusing upon conodonts) of the Catoche to Table Head portion of the stratigraphic section north of Table Point in necessary to accurately establish the timing and duration of pervasive B and saddle dolomitization.

2) A study of the association of faults with pervasive B and other dolostones, perhaps including core obtained from the Gulf of St. Lawrence and the Strait of Belle Isle, will better assess the role of tectonics on pervasive B dolomitization and may

FIGURE 7.3: Dolomitization mechanisms and stable shelf sedimentation. Dolominities form on tidal flat environments whereas pervasive A dolostones form beneath exposed surfaces. Mottle dolomite forms during early-diagenesis in lithified mudstones. Later phases of dolomitization (eg. Pervasive B dolostone, saddle dolomite) overprint these earlier generations. No scale implied.

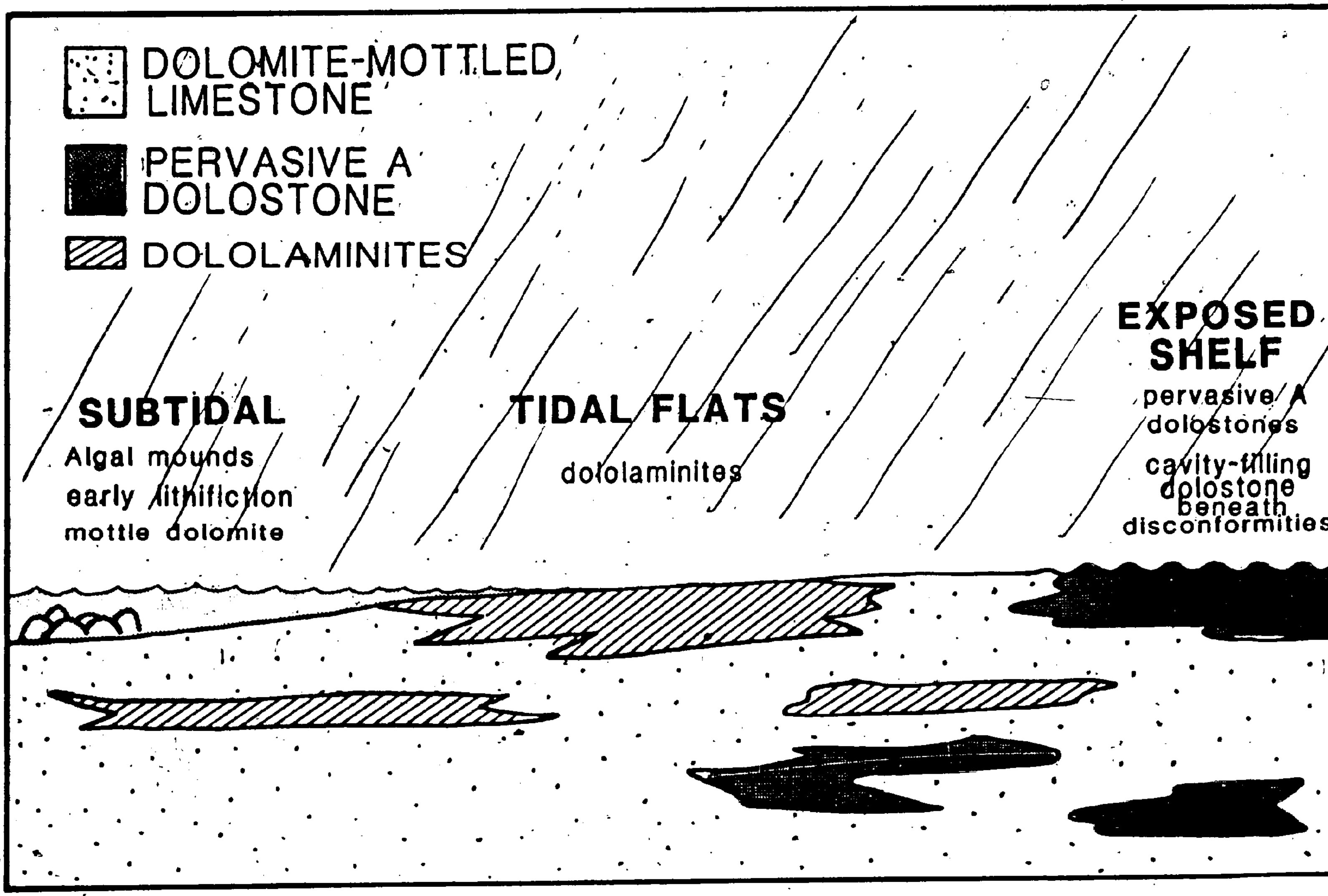
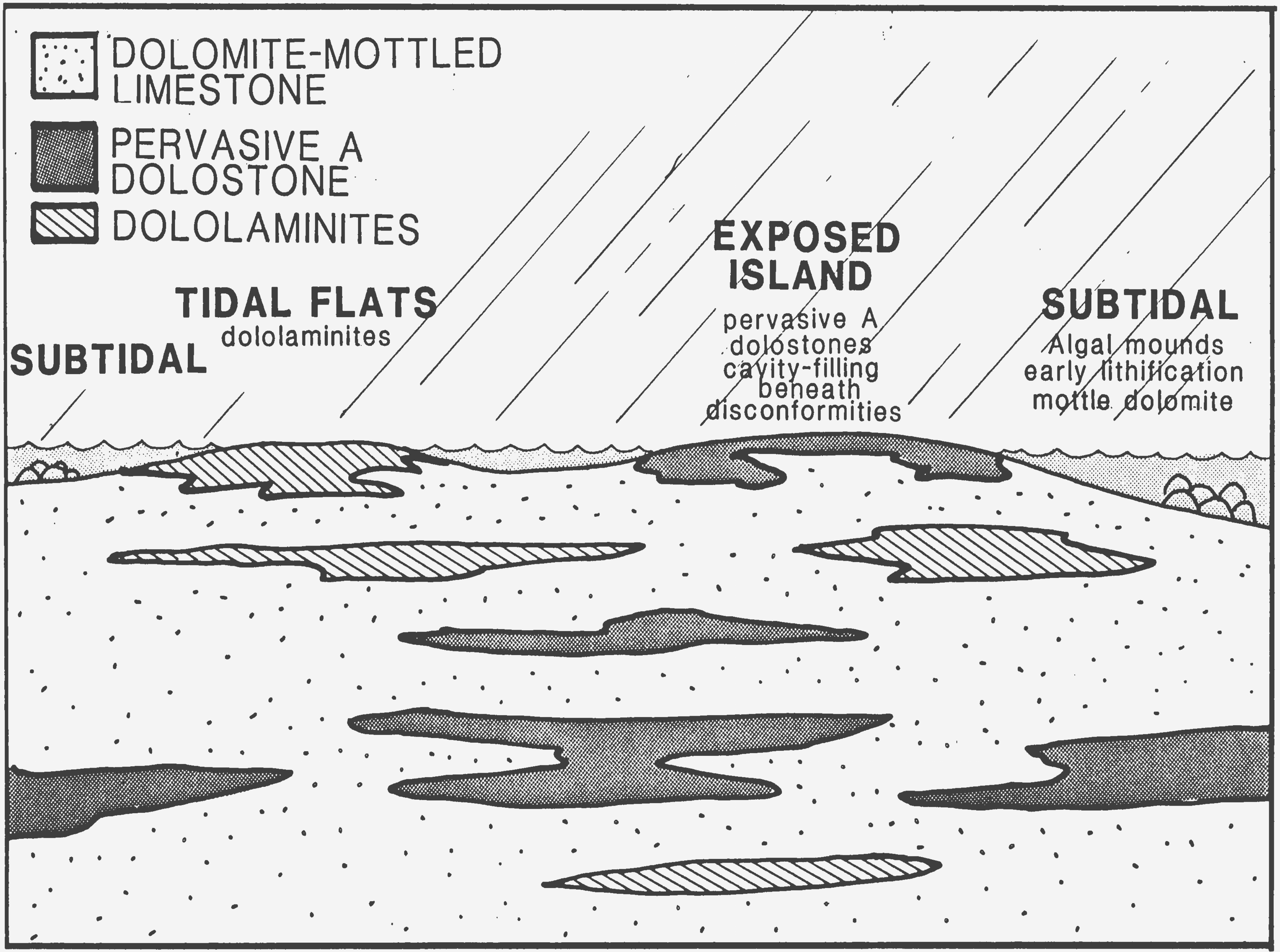

DOLOMITE-MOTTLED LIMESTONE
PERVASIVE A DOLOSTONE
DOLOLAMINITES
SUBTIDAL
Algal mounds
early lithification
mottle dolomite
TIDAL FLATS
dololaminites
EXPOSED SHELF
pervasive A dolostones
cavity-filling dolostone beneath disconformities

FIGURE 7.4: Dolomitization mechanisms island-tidal flat sedimentation. Dololaminites form on tidal flat environments whereas pervasive A dolostones form beneath exposed surfaces. Mottle dolomite forms during early-diagenesis in lithified mudstones. Later phases of dolomitization (eg. Pervasive B dolostone, saddle dolomite) overprint these earlier generations. No scale implied.


DOLOMITE-MOTTLED LIMESTONE
PERVASIVE A DOLOSTONE
DOLOLAMINITES
TIDAL FLATS
dololaminites
SUBTIDAL
EXPOSED ISLAND
pervasive A dolostones cavity-filling beneath disconformities
SUBTIDAL
Algal mounds early lithification mottle dolomite

explain its localization to the northern part of the study area.

3) Further work must be done to discover the nature of the alledged Watts Bight - Boat Harbour disconformity on the Great Northern Peninsula. This may better explain the origin of the pervasive B dolostones in the Watts Bight Formation and whether they are actually overprinted pervasive A dolostones.

4) A biochemical study of mucopolysaccharides associated with modern ichnofossils, especially in regards to the complexing ability of the various organics, is long overdue to determine the role that these compounds play in the diagenesis of modern rocks and through inference, the role that they may have played in the rock record.

7.5 CONCLUSIONS:

The Lower Ordovician St. George Group is a sequence of carbonates that were deposited in a stable shelf environment subject to periodic exposure. Dolomite makes up approximately one third of these rocks and seven field varieties are distinguished.

1) Dololaminites are common components of the Aguathuna and Boat Harbour Formations in all parts of the

study area. They are buff to grey, stratabound, laminated dolostones characterized by diverse and abundant shallow water sedimentary structures (including desiccation cracks and tepees), lack of body fossils, chert nodules with rare entombed evaporites and local bioturbation. $\delta^{13}C$ and $\delta^{18}O$ values range from -0.5 to -4.01 o/oo. and -4.78 to -7.94 o/oo (relative to PDB) respectively. Sr^{2+} varies from 75 to 240 ppm.

Petrographically, dololaminites are composed of uniformly luminescent to poorly zoned, very finely crystalline and non- to slightly ferroan xenotopic dolomite. Windblown feldspar and quartz silt are subordinant.

2) Two varieties of matrix dolomite are recognized. In mudstones and wackestones, rhombs are buff weathering, euhedral, finely crystalline, very well zoned and distributed evenly within the limestone. A prominent non-luminescent (ferroan) zone is commonly developed near the mid-point or terminus of the crystals.

Amounts of this variety range from trace quantities to 100 percent and usually, matrix dolomite-rich intervals (those containing more than 50 percent dolomite) are separated from matrix dolomite-poor intervals (those containing less than 50 percent dolomite), by stylolites. Dedolomitization is frequent.

Matrix dolomite in packstones and grainstones weathers buff to white, and is usually restricted to intergranular areas but may on occasion, expand to replace the whole rock. Rhombs are medium crystalline, anhedral, non-ferroan and uniformly luminescent. Two analyses yielded $\delta^{13}C$ values of -1.62 and -1.85 o/oo and $\delta^{18}O$ values of -9.03 and -9.72 o/oo. Sr^{2+} concentration in both samples is 40 ppm.

Intercrystalline and secondary dissolution porosity is abundant in extensively dolomitized intervals and is filled with either dark insoluble (organic rich) material, gaseous hydrocarbons or calcite cement.

Both varieties of matrix dolomite are rare and are best developed within the Watts Bight and Boat Harbour Formations in the Port au Port area.

3) Mottle dolomite is buff to light grey and is localized to ichnofossils, body fossils and pressure solution seams. This variety is abundant both stratigraphically and geographically and may account for up to 40 percent of the volume of a rock.

The petrographic properties of mottle dolomite are variable. Rhombs are fine to medium crystalline, uniformly luminescent to well zoned, idiotopic to xenotopic and are characterized by $\delta^{13}C$ values of -1.27 to -1.99 o/oo, $\delta^{18}O$ values of -5.71 to -10.34 o/oo and Sr^{2+} concentrations of 70 to 195 ppm. Dedolomitization in a fashion similar to that observed in some matrix dolomite is common.

4) Pervasive A dolostones are bimodal, mottled rocks. Mottles (occasionally identified as ichnofossils or gastropods), account for between 50 and 80 percent of the rock and are composed of finely crystalline rhombs, whereas the intermottles are composed of medium crystalline rhombs. Both are xenotopic, non-ferroan, uniformly to moderately zoned and are characterized by $\delta^{13}C$ and $\delta^{18}O$ values of from -1.18 to -2.05 o/oo and -4.74 to -11.16 o/oo respectively. Sr^{2+} ranges from 35 to 185 ppm. Similarity with respect to these properties for the mottles and the intermottles suggests that they were dolomitized at the same time. Additional zones occasionally superimposed around cores in the intermottles suggests later periods of growth in these areas. Dedolomitization is rare in these rocks.

Pervasive A dolostones are common components of all formations of the St. George Group and are also widespread geographically. They are particularly well developed immediately beneath subaerial exposure horizons.

5) Pervasive B dolostones are also mottled rocks characterized by bimodal crystallinity. They are widespread on the Great Northern Peninsula but are especially common in the Watts Bight Formation and the upper portion of the Catoche Formation. Pervasive B dolostones frequently abut sharply against, or form equidimensional "pods" or flat-lying "pans" within dolomite-mottled limestones.

Mottles are dark, organic rich, finely crystalline and on bedding planes, are clearly recognizable as ichnofossils or body fossils. In cross-section, all mottles have been dragged out along stylolites.

Intermottle areas are white to pink and are composed of coarsely crystalline, strained, calcium-rich (to 54 mol % Ca^{2+}) and uniformly luminescent dolomite rhombs. Crystal faces are commonly curved. Rhombs are usually non-ferroan, but occasionally may contain up to 2.5 weight percent FeO. $\delta^{13}C$, $\delta^{18}O$ and the concentration of Sr^{2+} in the intermottle dolomite varies from -0.62 to -1.66o/oo, -8.47 to -12.73 o/oo and from 35 to 135 ppm respectively.

Saddle dolomite is a pore-filling cement localized to voids or fractures and also replaces portions of pre-existing dolostones (especially body fossils and intermottle areas in pervasive B dolostones). It is similar both petrographically and isotopically to the intermottle dolomite in pervasive B dolostones. The stratigraphic and geographic distribution is also the same.

Cavity-filling dolostone fills small (less than 30 centimetre) dissolution voids in pre-existing dolostones, is commonly geopetal, laminated and is characterized by buff to green, very finely crystalline dolomite with subordinate feldspar, quartz, phosphate, micas, clays and insoluble (organic-rich?) material. Dolomite rhombs are anhedral, uniformly luminescent and contain from 45 to 165 ppm Sr^{2+}. $\delta^{13}C$ varies from -0.61 to -1.78 o/oo and

$\delta^{18}O$ ranges from -6.45 to -8.93 o/oo. This variety is rare in the St. George Group and is restricted to intervals beneath documented or suspected disconformity surfaces.

The seven varieties of dolomite and dolostone are the result of four generations of dolomitization. Later generations frequently overprint earlier generations and in so doing, modify both the petrographic and isotopic character of the original dolomite.

Dololaminites are syngenetic products formed during deposition of supratidal sediments in a tidal flat environment. Dolomitization may have been nucleated due to high Mg^{2+}/Ca^{2+} ratios and/or low SO_4^{2-} which prevailed on the tidal flats. Continued growth after burial is suggested by additional zones superimposed on some rhombs.

Matrix dolomite in fine grained limestones and mottle dolomite are the result of the same long lived (early- to late-diagenetic) events. They initially nucleated after lithification of lime mud, possibly due to the presence of mucopolysaccharides associated with bioturbation and grew by concomitant dissolution and precipitation. These dolomites were also subjected to further growth during periods of pressure solution.

Pervasive A dolostones are coincident with early phases of matrix/mottle dolomitization and predate pressure solution. Their localization beneath documented or suspected subaerial exposure horizons suggests that they may be due to mixed water dolomitization.

Matrix dolomite in fine grained limestones, mottle dolomite and pervasive A dolostones have been affected by late-diagenetic periods of tectonic fracturing and dedolomitization.

Pervasive B dolostones are the result of late-diagenetic hydrothermal events which have overprinted dolomite mottled limestones. They probably evolved at the start of the Taconic Orogeny and were generated by fluids passing along tectonic fractures and into susceptible limestones. Fractures and void space were simultaneously filled with saddle dolomite.

Southern examples of matrix dolomite (those occurrences within packstones and wackestones) are also due to hydrothermal alteration but not necessarily the same one responsible for pervasive B dolostone or saddle dolomite.

Cavity-filling dolostone is similar to vadose silt (Dunham, 1969, Bathurst, 1975) and may have been derived in a similar fashion, that is, through the mechanical erosion of host rock by moving ground water in the vadose zone. This variety is directly related to subaerial exposure.

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APPENDICES

APPENDIX A:
MEASURED STRATIGRAPHIC SECTIONS

The stratigraphic sections measured at each of the ten principle areas investigated as part of this study are drafted on a scale of 1 centimetre to 2 metres. They display the general lithologies, the variety, and estimated proportions of dolomite or dolostone within the lithostratigraphic unit, sedimentary structures, secondary mineralization, the estimated bitumen content and palaeontological and/or other components (refer to legend, back pocket). The ten sections are also located in the back pocket.

APPENDIX B

CARBON AND OXYGEN ISOTOPE AND SR^{2+} GEOCHEMICAL ANALYSES OF REPRESENTATIVE LIMESTONE AND DOLOSTONE SAMPLES FROM THE ST. GEORGE GROUP (LOWER ORDOVICIAN) OF WESTERN NEWFOUNDLAND

DOLOLAMINITES:

SAMPLE #	LOCATION	FORMATION	$\delta^{18}O$(PDB)	$\delta^{13}C$(PDB)	Sr^{2+}(ppm)
PP172A	IB	BOAT HBR.	-5.17	-1.38	85
LC 2	LC	BOAT HBR.	-7.94	-4.01	75
CN30	CN	BOAT HBR.	-6.33	-1.88	240
PC 9	PC	BOAT HBR.	-6.54	-2.70	185
SC25	SC	AGUATHUNA	-4.78	-0.50	90
PC32	PC	AGUATHUNA	-7.83	-1.86	85
PP 134	NWG	AGUATHUNA	-5.98	-1.89	85
PP 212	NWG	AGUATHUNA	-5.96	-1.66	160

MATRIX DOLOMITE:

SAMPLE #	LOCATION	FORMATION	$\delta^{18}O$(PDB)	$\delta^{13}C$(PDB)	Sr^{2+}(ppm)
PP 117	IB	WATTS BIGHT	-9.72	-1.62	40
PP 119	IB	WATTS BIGHT	-9.03	-1.85	40

DOLOMITE MOTTLED LIMESTONES:

SAMPLE #	LOCATION	FORMATION	$\delta^{18}O$(PDB)	$\delta^{13}C$(PDB)	Sr^{2+}(ppm)
PP 112C	IB	WATTS BIGHT			
MOTTLES			-9.31	-1.44	70
LIMESTONE			-8.15	-2.30	165
SC 16	SC	CATOCHE			
MOTTLES			-5.71	-1.27	190
LIMESTONE			-8.87	-1.56	235
CN 42	CN	CATOCHE			
MOTTLES			-8.86	-1.74	165
LIMESTONE			-9.21	-1.78	290
CN 43	CN	CATOCHE			
MOTTLES			-10.34	-1.67	175
LIMESTONE			-9.18	-1.67	275
PP 113B	IB	WATTS BIGHT			
MOTTLES			-6.94	-1.89	150
LIMESTONE			-7.95	-2.30	235
PP35A	IB	BOAT HBR.			
MOTTLES			-5.47	-1.99	195
PC37	PC	BOAT HBR.			
LIMESTONE			-10.31	-1.75	320

PERVASIVE A DOLOSTONE:

SAMPLE #	LOCATION	FORMATION	$\delta^{18}O$(PDB)	$\delta^{13}C$(PDB)	Sr^{2+}(ppm)
PP 113B	IB	WATTS BIGHT			
MOTTLES			-7.10	-1.54	140
INTERMOTTLES			-7.09	-1.82	130
SC 12	SC	CATOCHE			
MOTTLES			-4.74	-1.40	175
INTERMOTTLES			-5.36	-1.64	185
PP112	IB	WATTS BIGHT			
MOTTLES			-8.33	-1.37	105
INTERMOTTLES			-8.77	-1.72	75
CN 41	CN	CATOCHE			
MOTTLES			-5.15	-1.18	140
INTERMOTTLES			-9.99	-1.37	55
PC 35	PC	BOAT HBR.			
MOTTLES			-10.58	-1.59	35
INTERMOTTLES			-11.16	-1.51	35
PP48D	IB	BOAT HBR.			
MOTTLES			-8.24	-2.05	100
CN 12	CN	WATTS BIGHT			
INTERMOTTLES			-7.65	-1.19	70

PERVASIVE B DOLOSTONE:

SAMPLE #	LOCATION	FORMATION	$\delta^{18}O$(PDB)	$\delta^{13}C$(PDB)	Sr^{2+}(ppm)
TP 11	TP	CATOCHE			
MOTTLES			-8.94	-1.13	80
INTERMOTTLES			-10.51	-1.35	85
CN 42	CN	CATOCHE			
MOTTLES			-9.38	-1.31	90
INTERMOTTLES			-12.09	-1.59	75
PC18B	PC	CATOCHE			
MOTTLES			-8.47	-0.78	15
INTERMOTTLES			-8.18	-0.62	35
PC 37	PC	BOAT HBR.			
INTERMOTTLES			-12.73	-1.66	135

SADDLE DOLOMITE:

SAMPLE #	LOCATION	FORMATION	$\delta^{18}O$(PDB)	$\delta^{13}C$(PDB)	Sr^{2+}(ppm)
CN 5	CN	WATTS BIGHT	-9.04	-0.89	70
CN25	CN	BOAT HBR.	-9.48	-1.57	65
PC10	PC	CATOCHE	-10.47	-1.69	not run
DH 1	DH	CATOCHE	-9.45	-1.26	40

CAVITY-FILLING DOLOSTONE:

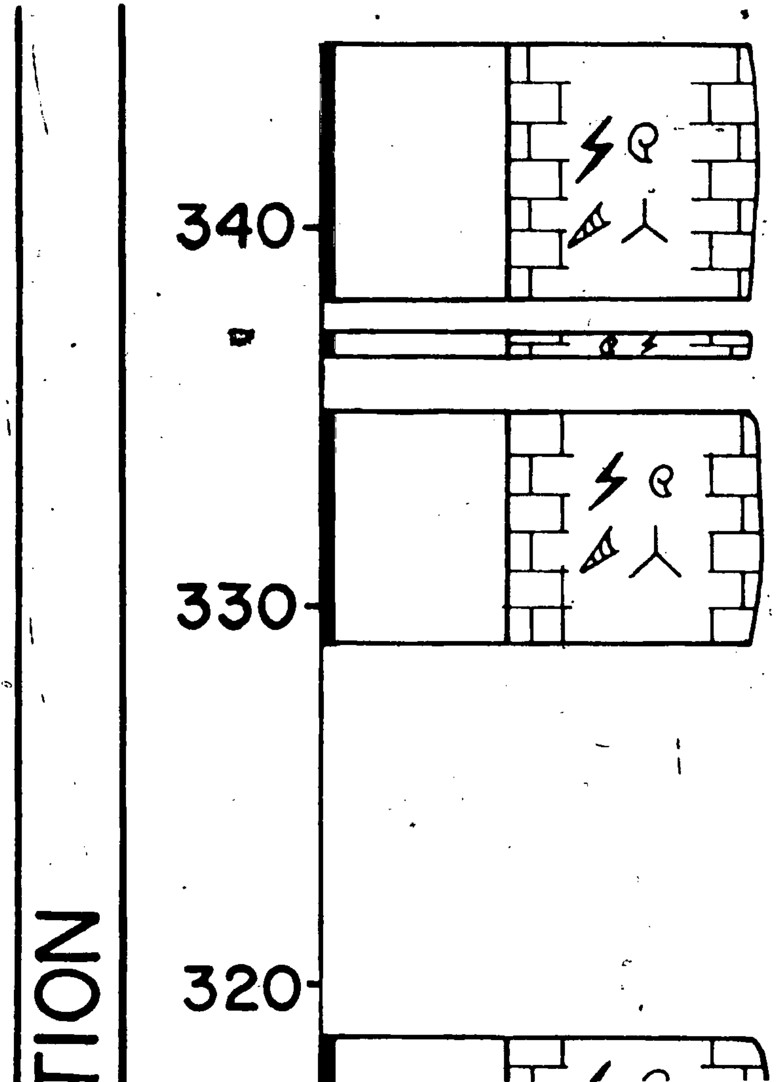
SAMPLE #	LOCATION	FORMATION	$\delta^{18}O$(PDB)	$\delta^{13}C$(PDB)	Sr^{2+}(ppm)
CN 1	CN	WATTS BIGHT	-7.08	-0.61	45
CN14	CN	WATTS BIGHT	-8.93	-1.78	50
PP 43B	IB	BOAT HBR.	-7.38	-1.53	65
PP 48D	IB	BOAT HBR.	-6.57	-1.50	85
SC13	SC	CATOCHE	-6.45	-1.62	165

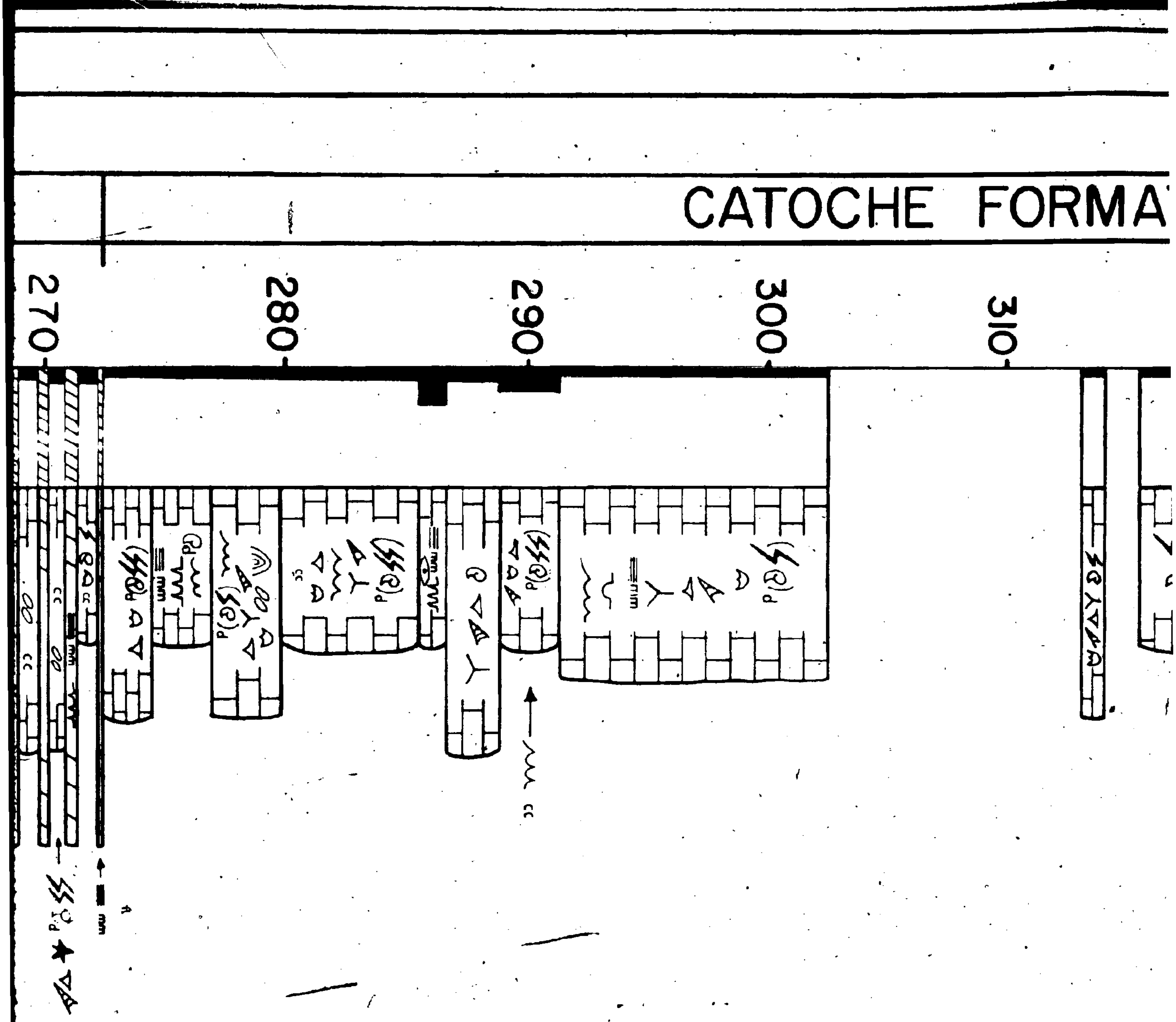
Analytical uncertainty is one standard deviation and varies from a minimum of 0.01 to a maximum of 0.08 parts per mil. Locations: IB, Isthmus Bay; LC, Lower Cove; NWG, Northwest Gravels; SC, Smelt Canyon; DH, Daniel's Harbour; TP, Table Point; PC, Port au Choix; CN, Cape Norman.

ISTHMUS BAY

(PORT AU PORT PENINSULA)

1 OF/DE

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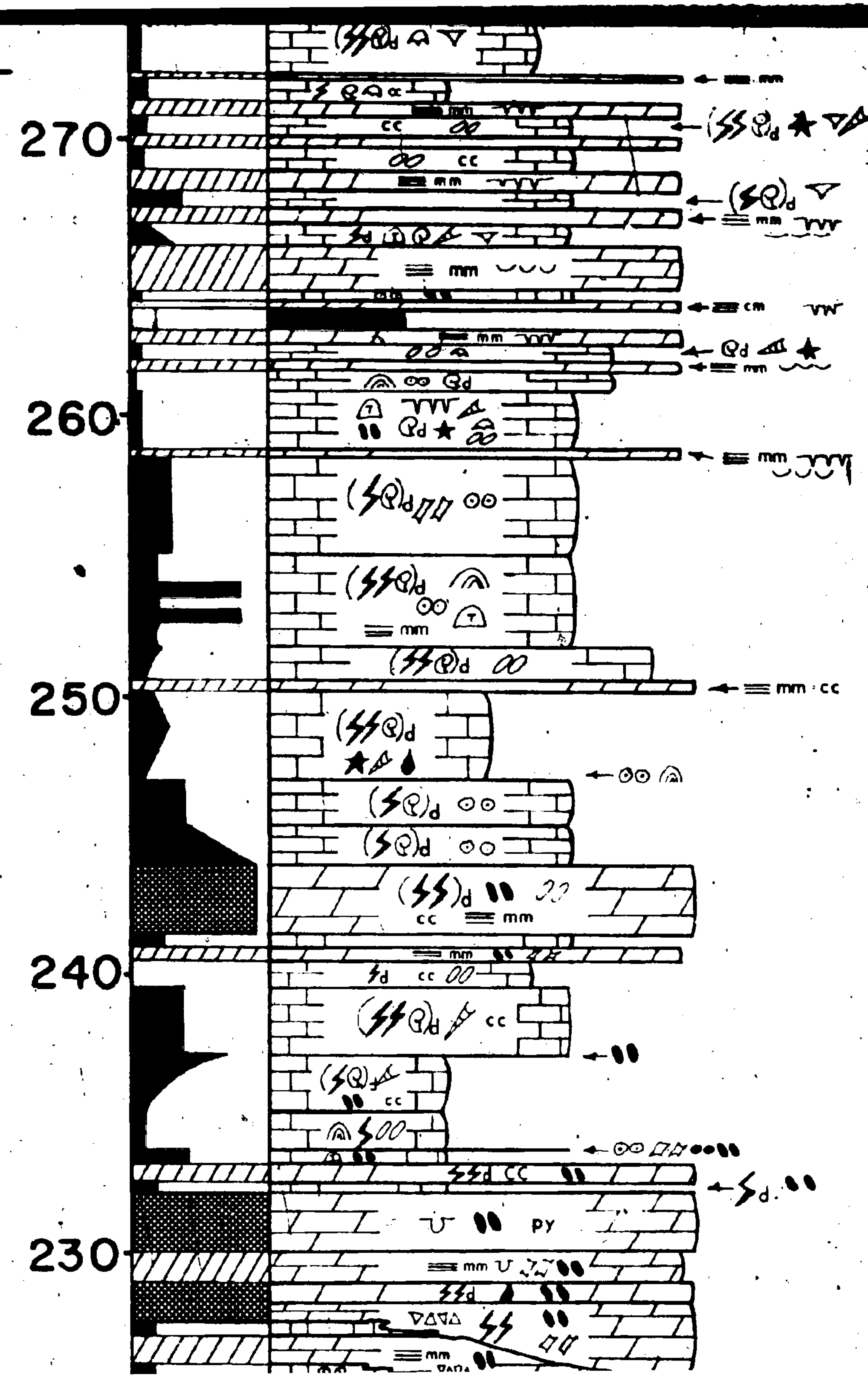
300
310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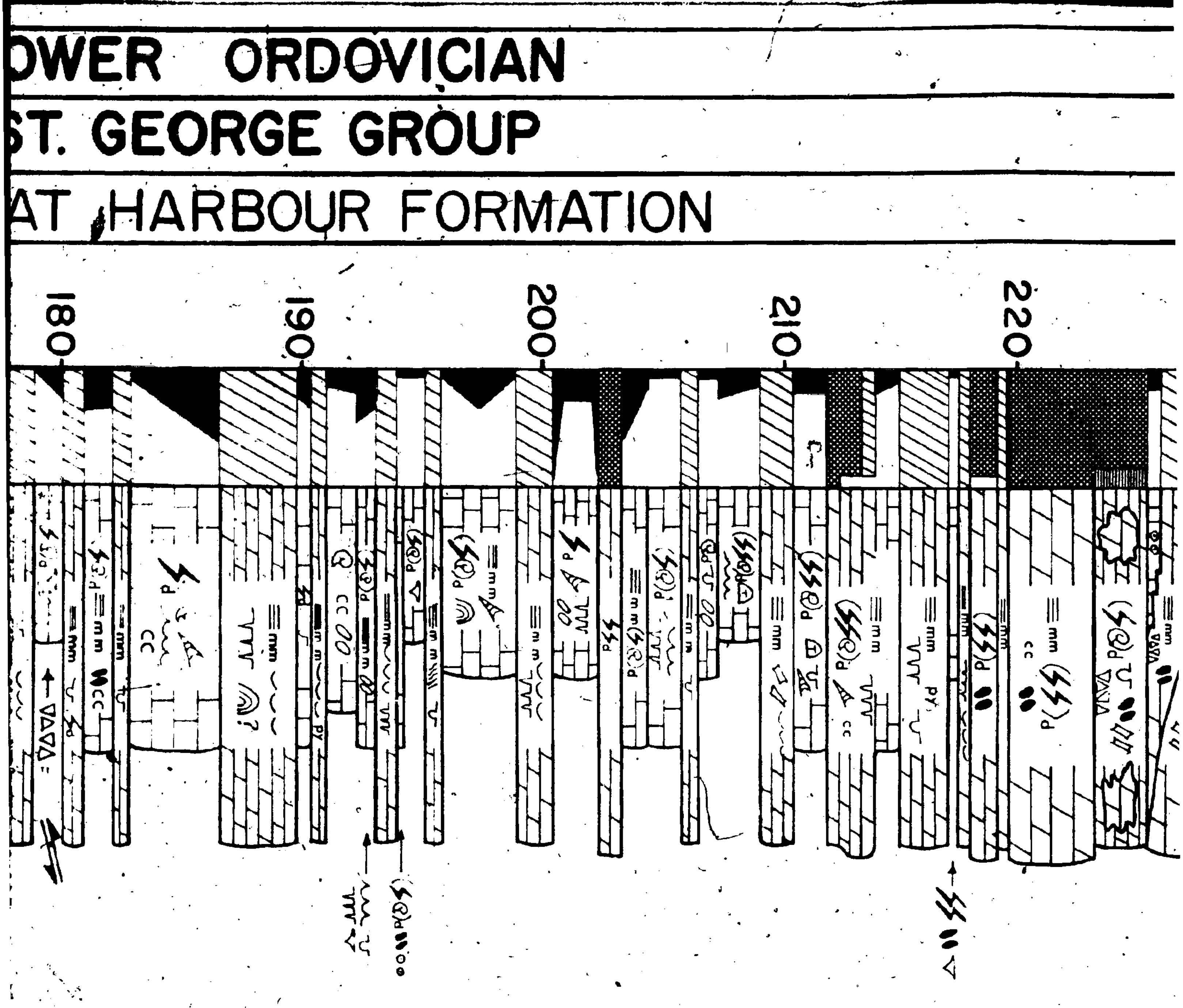

OWER ORDOVICIAN
ST. GEORGE GROUP
AT HARBOUR FORMATION
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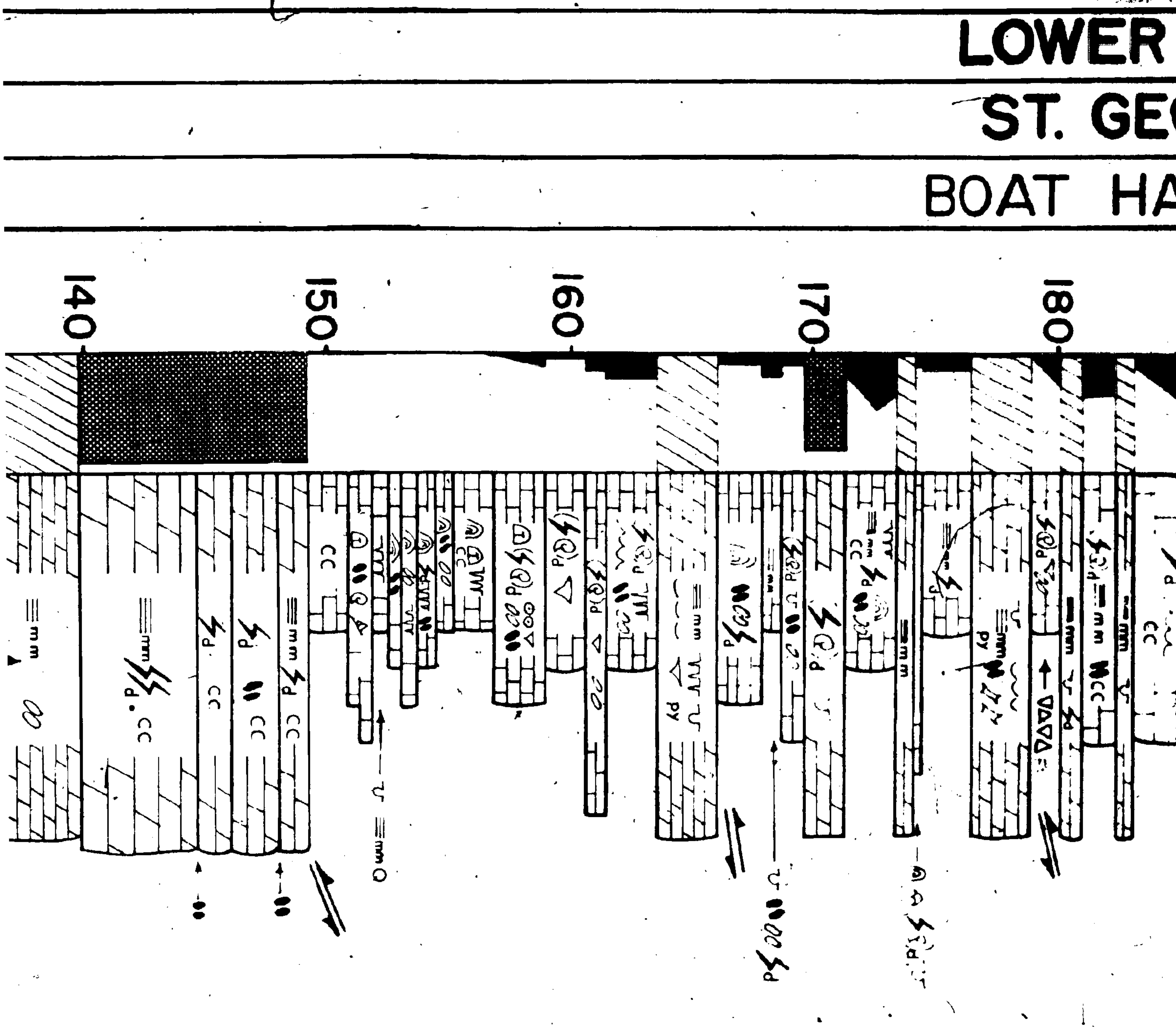
200
210
220



LOWER
ST. GE
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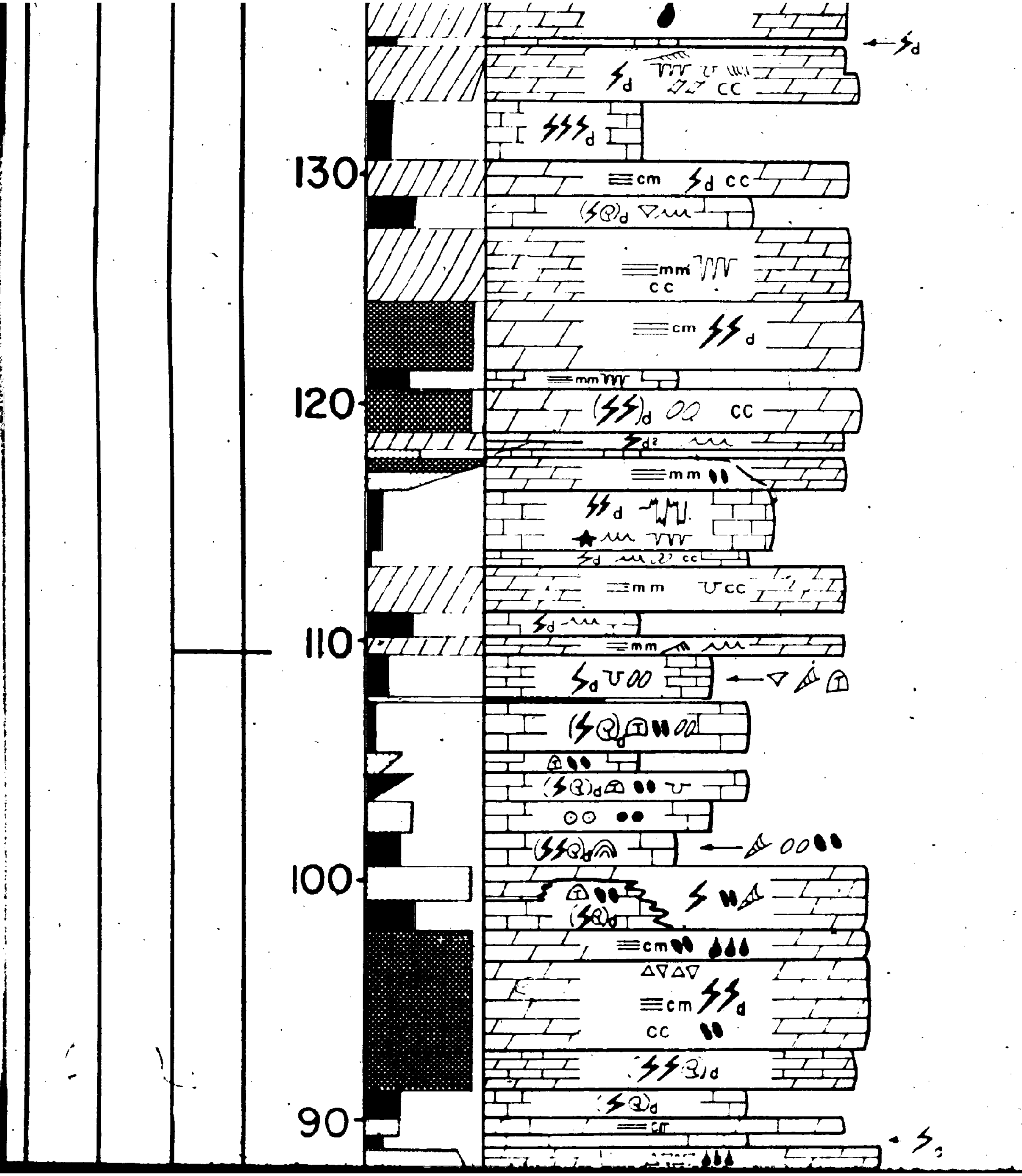
170
180



130
120
110
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90
cm
mm
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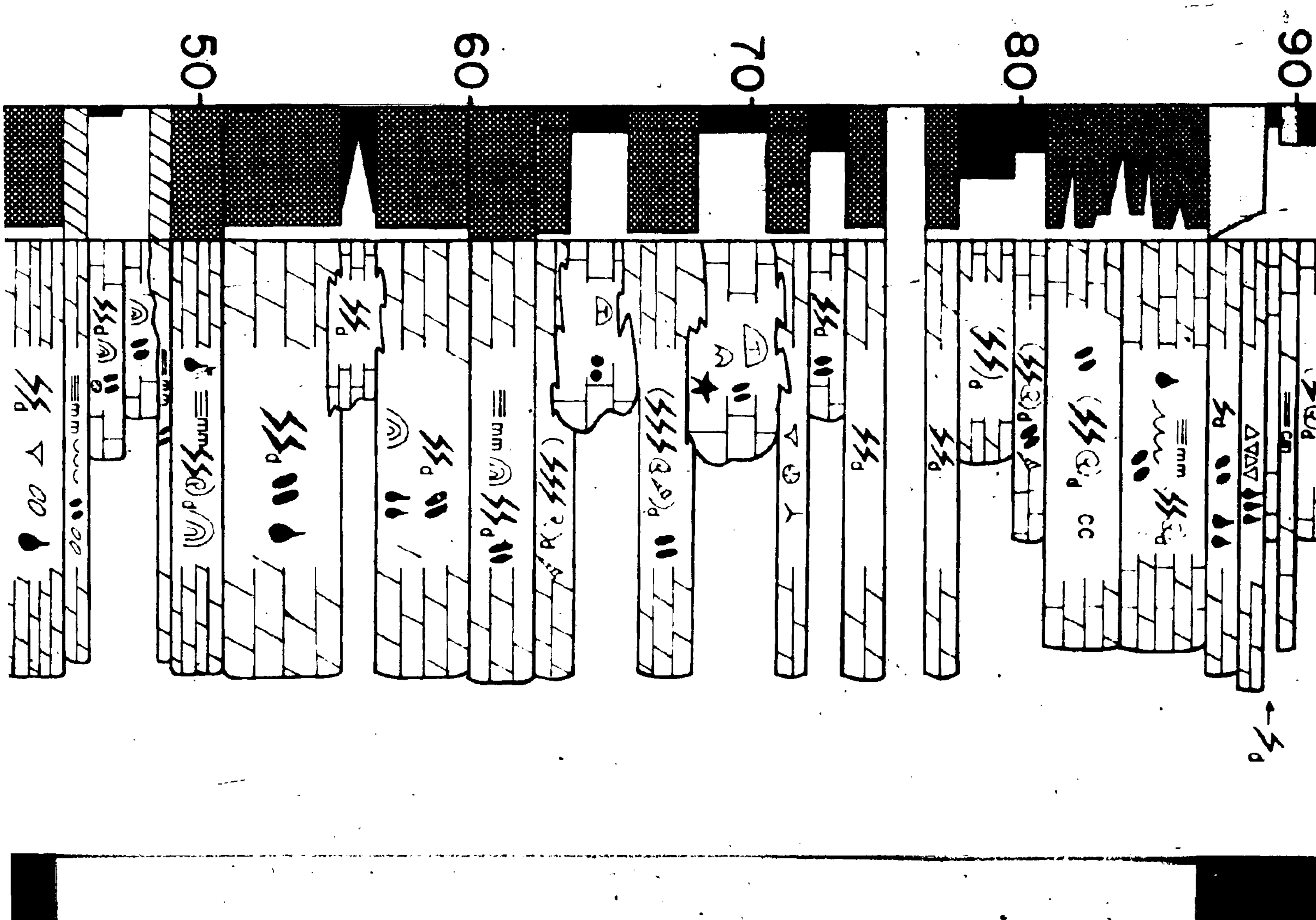
WATTS BIGHT FORMATION



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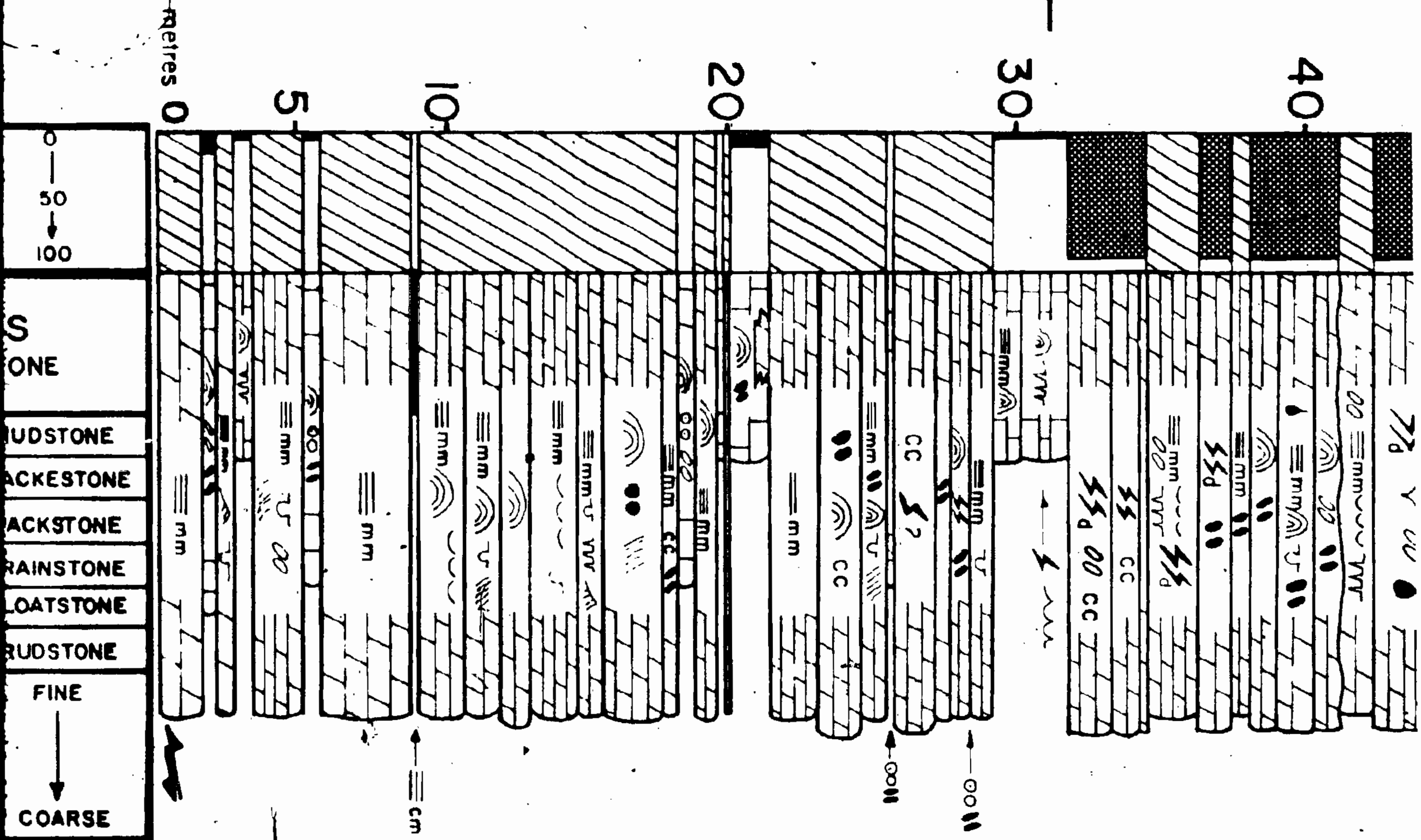
UPPER CAMBRIAN

PORT AU PORT GROUP

PETIT JARDIN FORMATION



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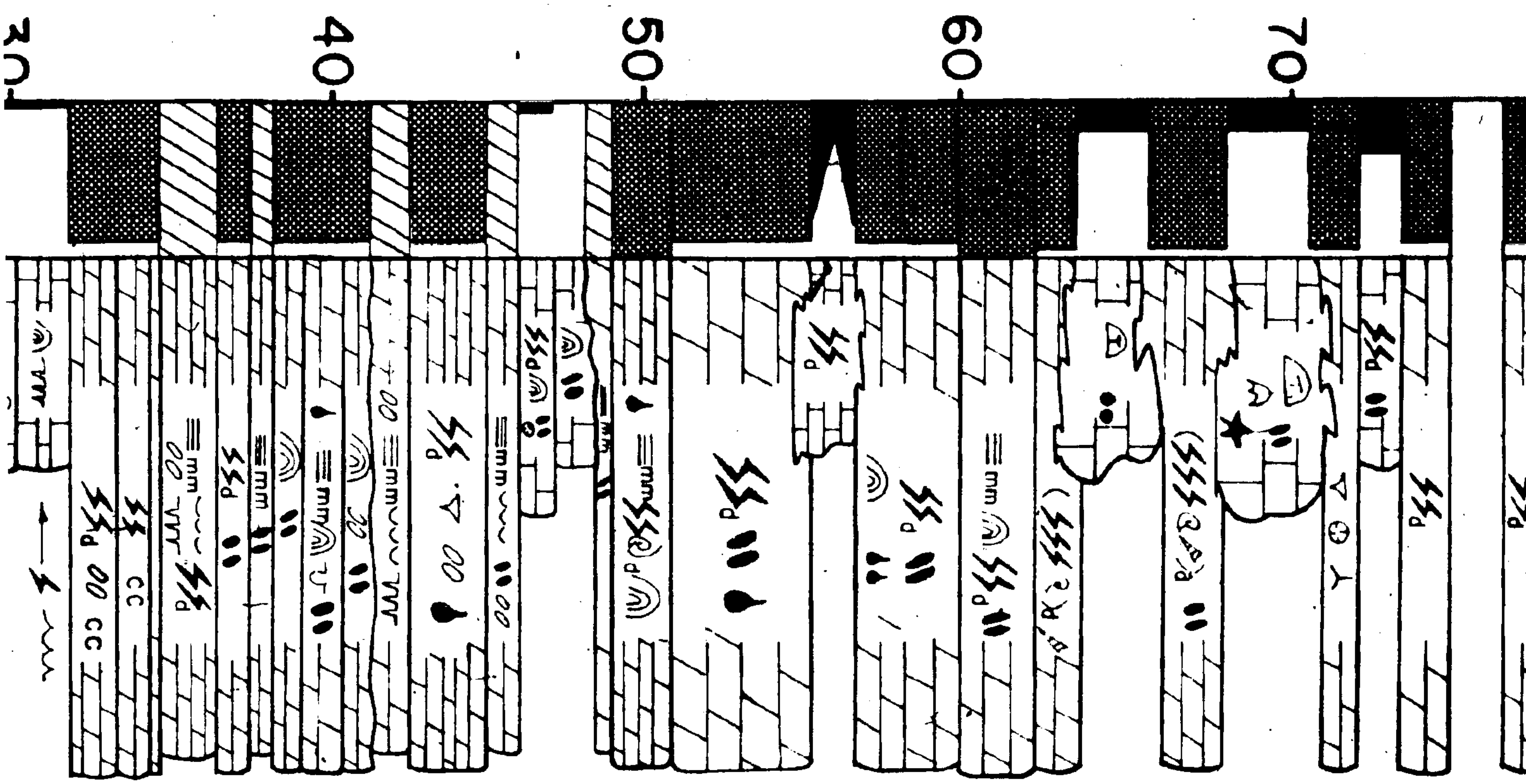

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UPPER CAMBRIAN

PORT AU PORT GROUP

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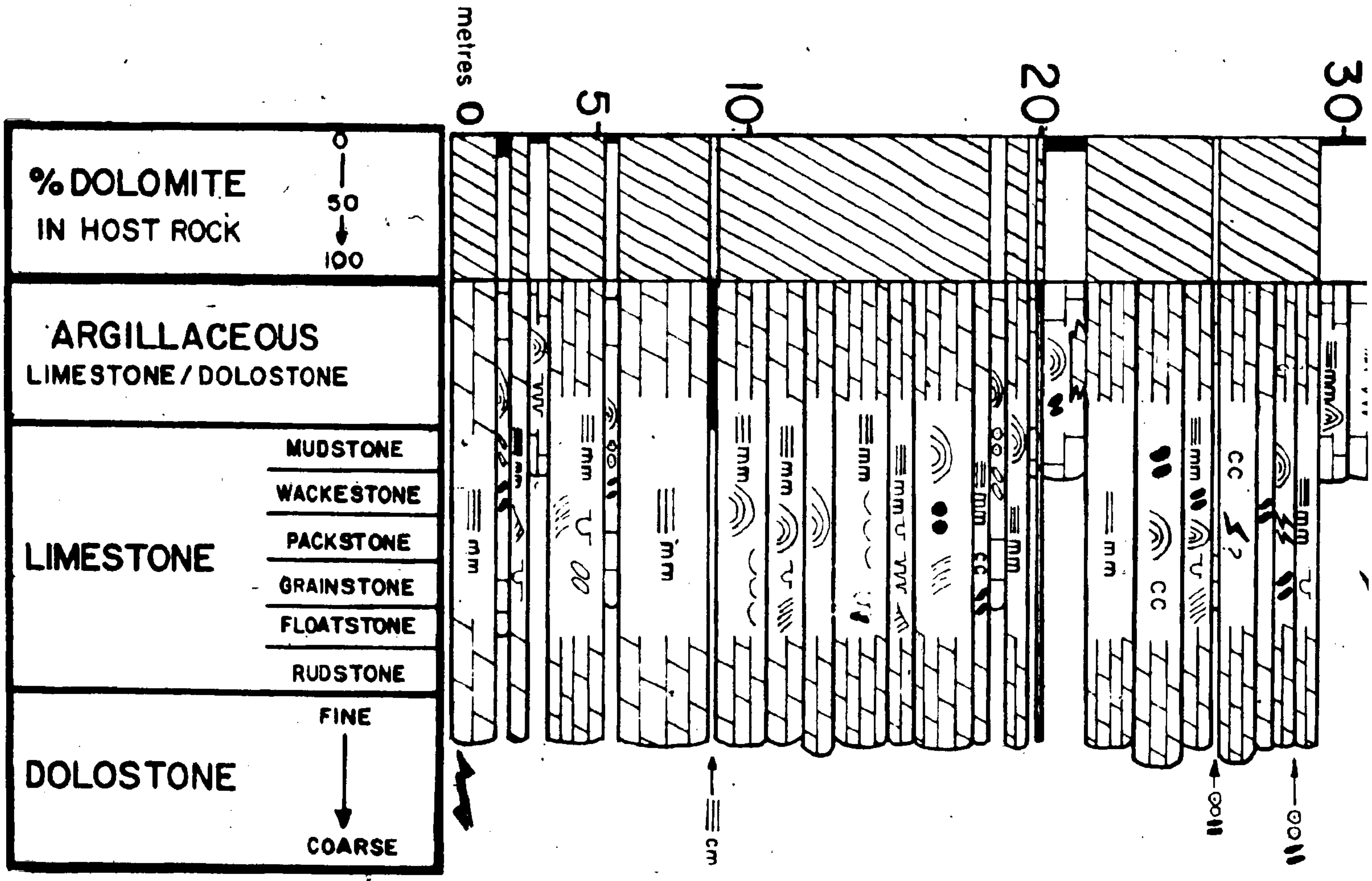
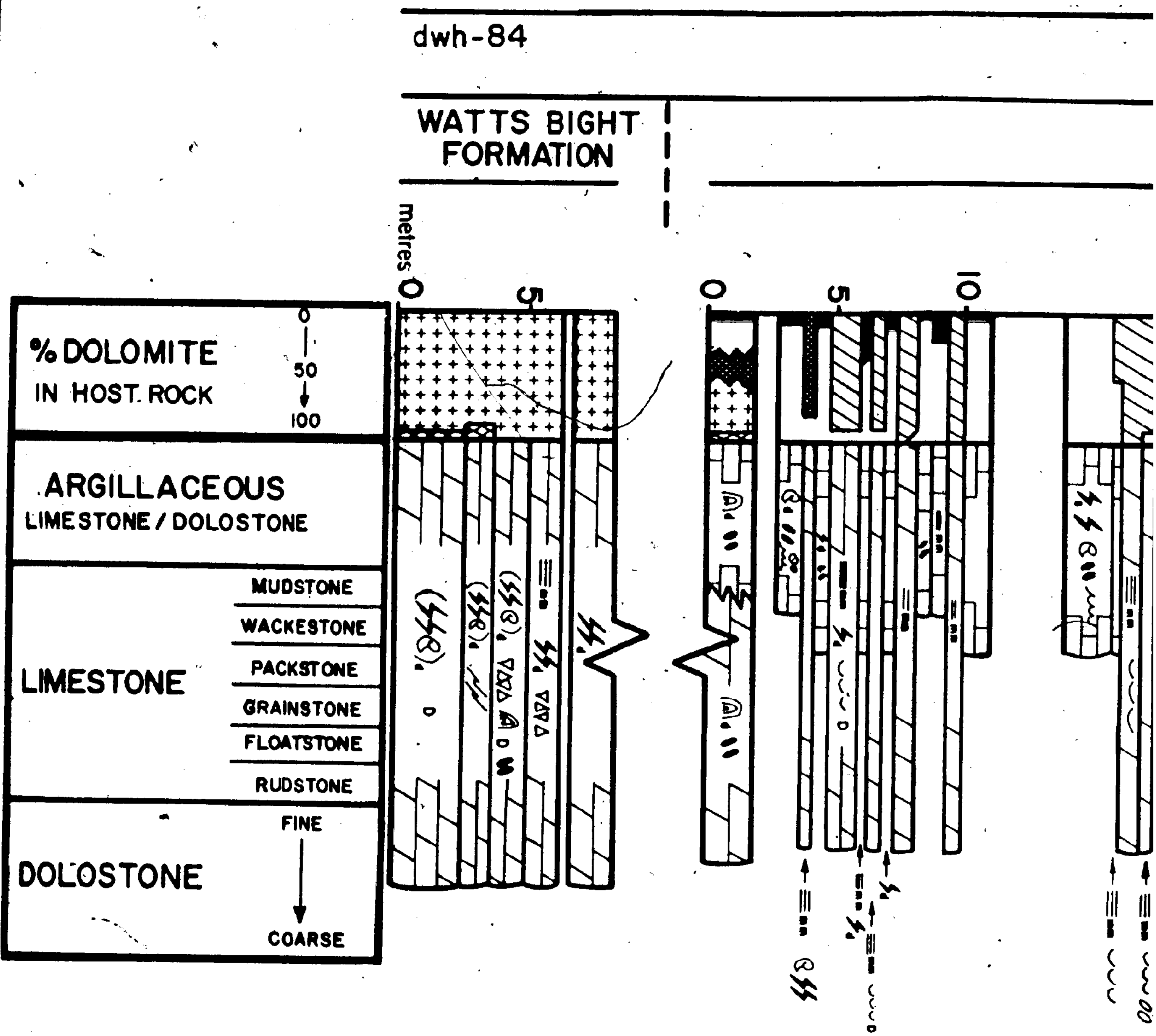
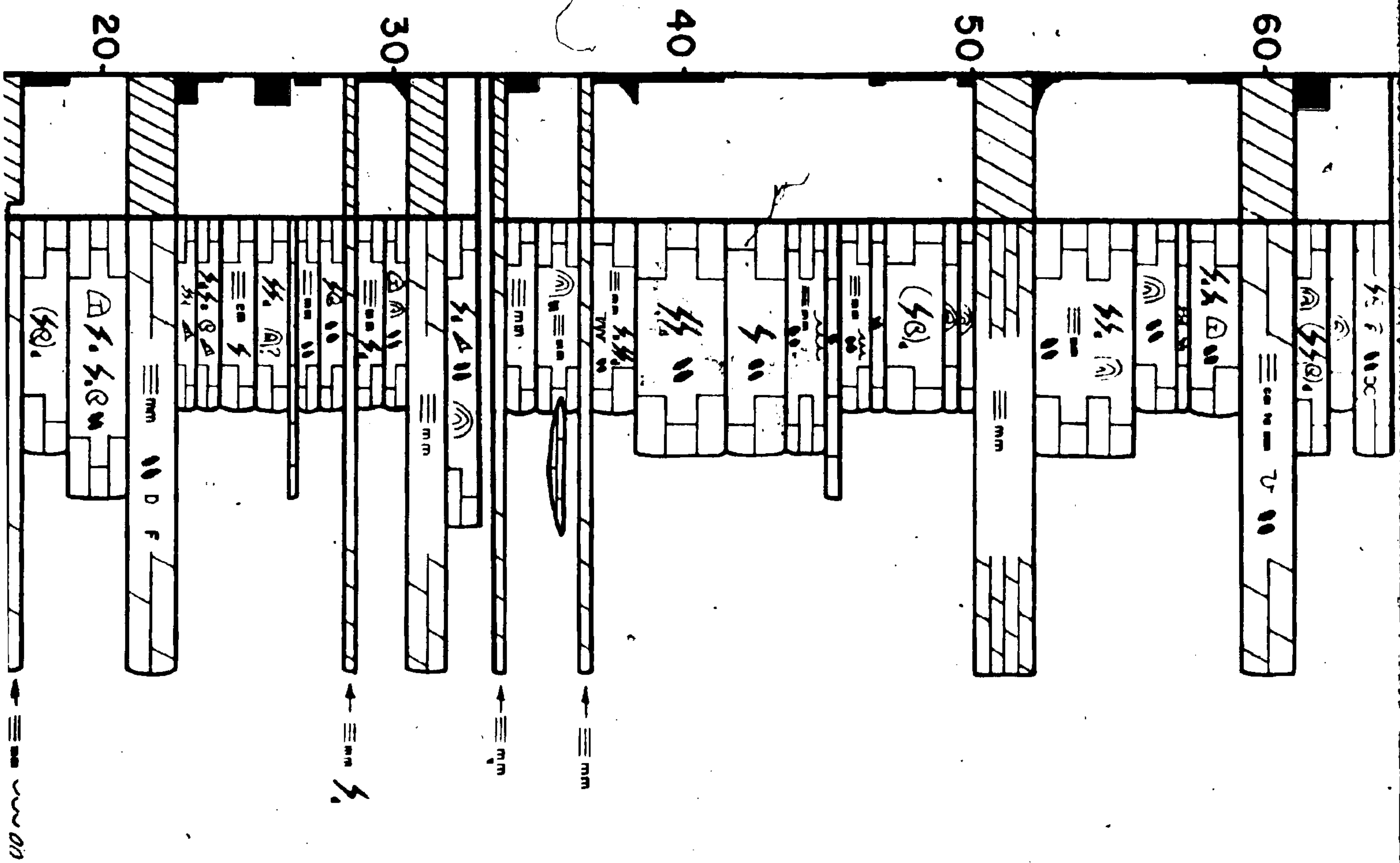
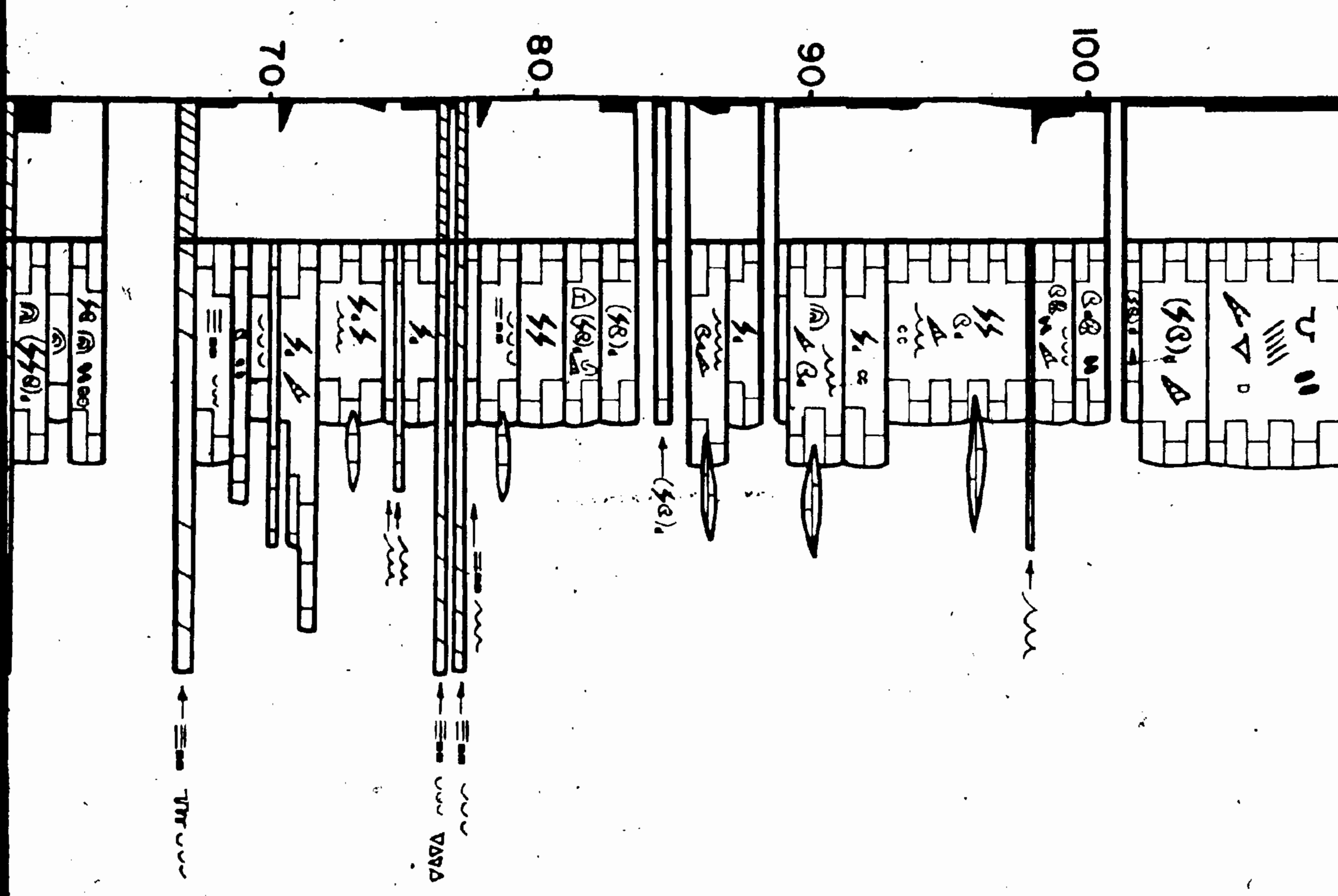



dwh-84
WATTS BIGHT FORMATION
metres
0
5
0
5
10
% DOLOMITE IN HOST ROCK
0
50
100
ARGILLACEOUS LIMESTONE / DOLOSTONE
LIMESTONE
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
FLOATSTONE
RUDSTONE
DOLOSTONE
FINE
COARSE

BOAT HARBOUR FORMATION

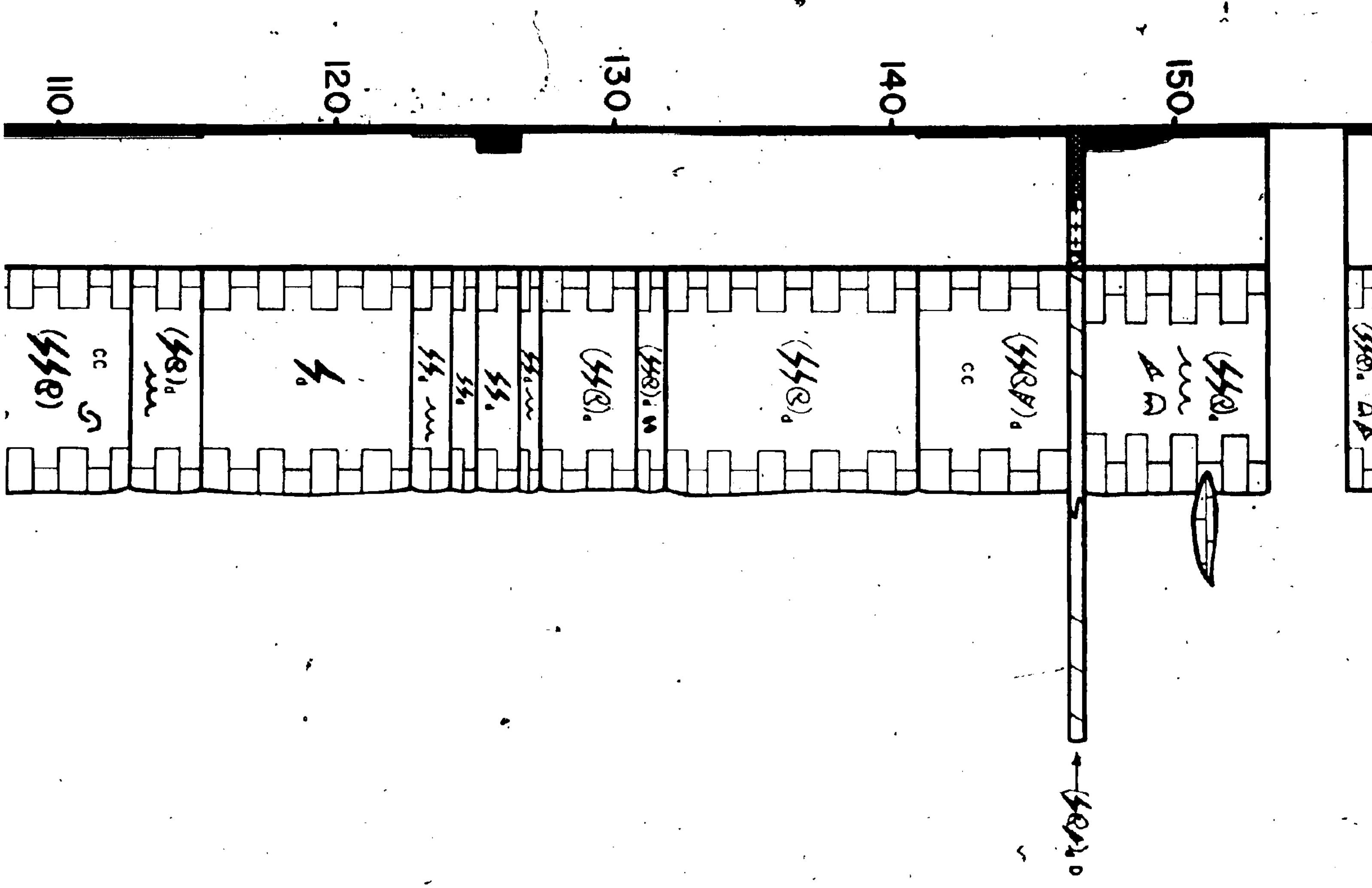


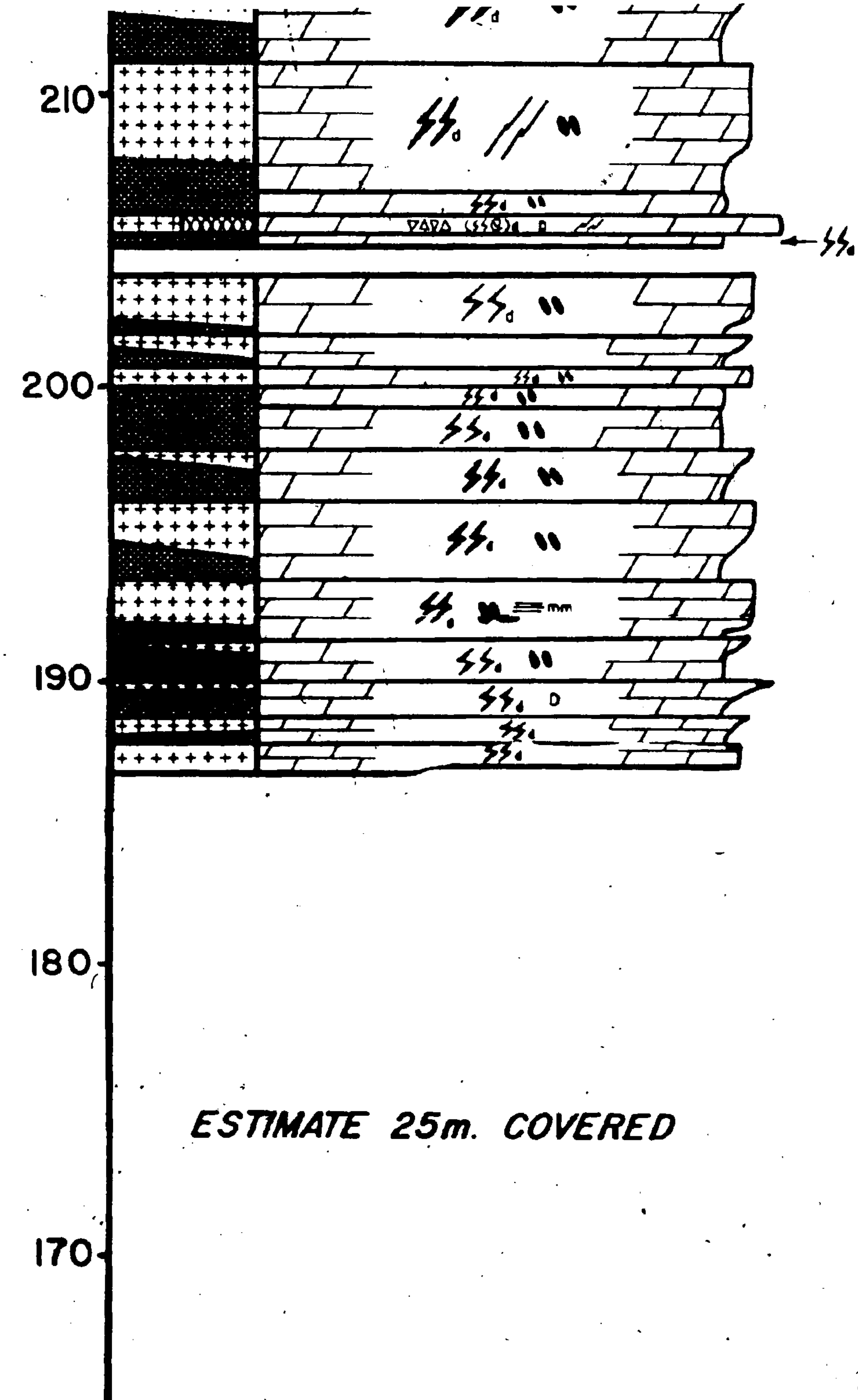
LOWER ORDOVICIAN ST. GE(



EORGE GROUP

CATOCHE FORM

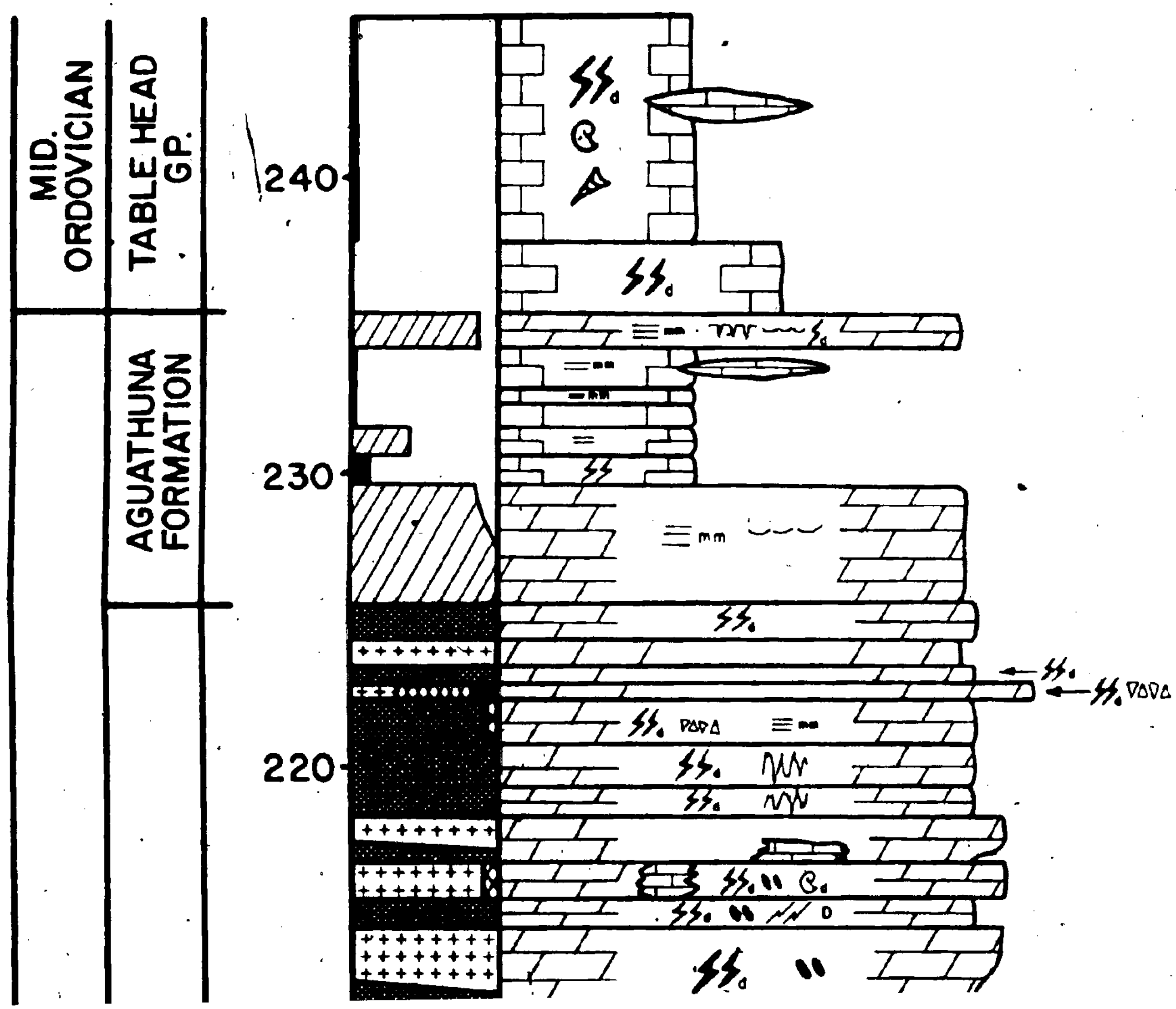




3 OF/DE 3

BACK ARM

(GREAT NORTHERN PENINSULA)



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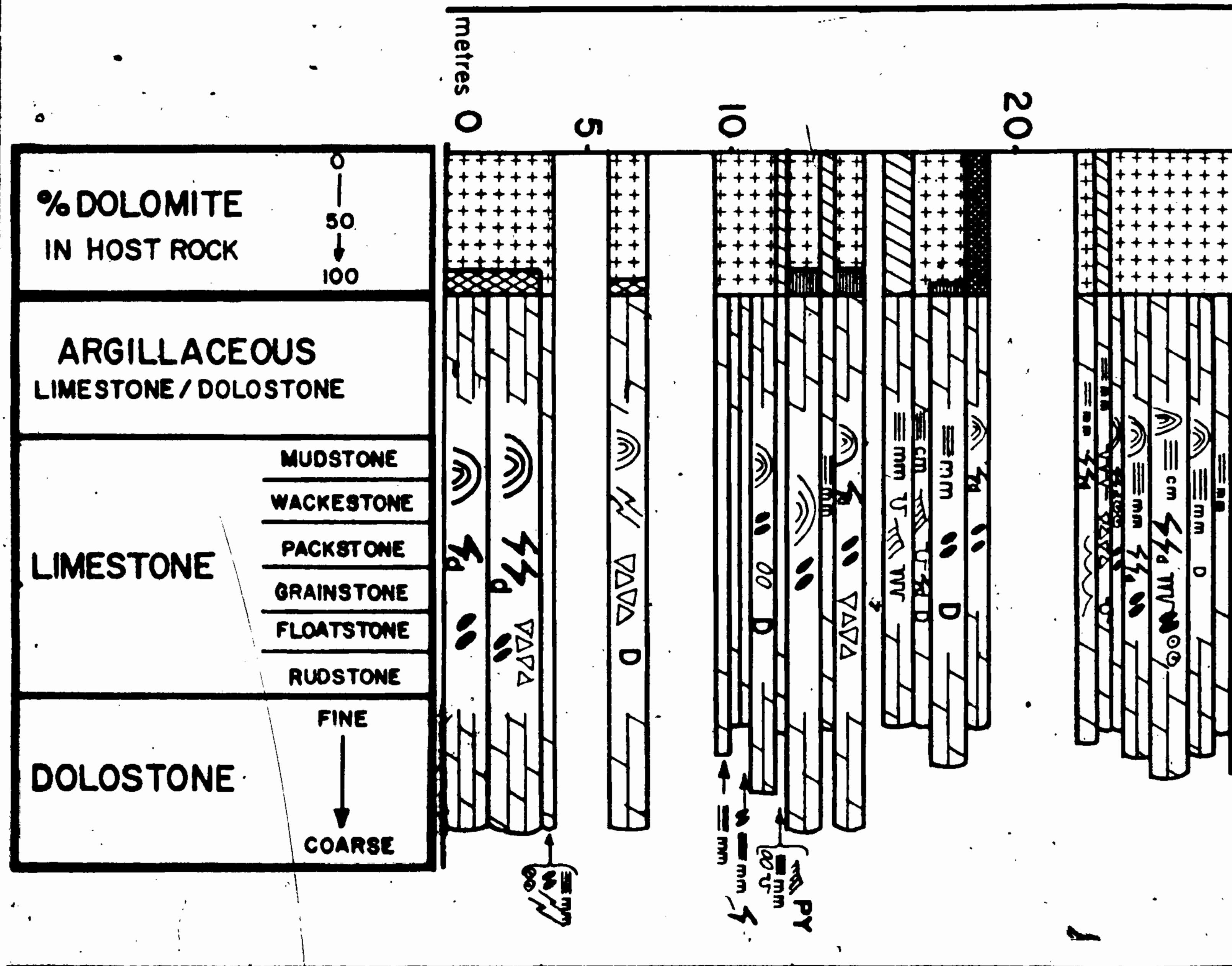
WATTS


metres
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% DOLOMITE IN HOST ROCK
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ARGILLACEOUS LIMESTONE / DOLOSTONE
LIMESTONE
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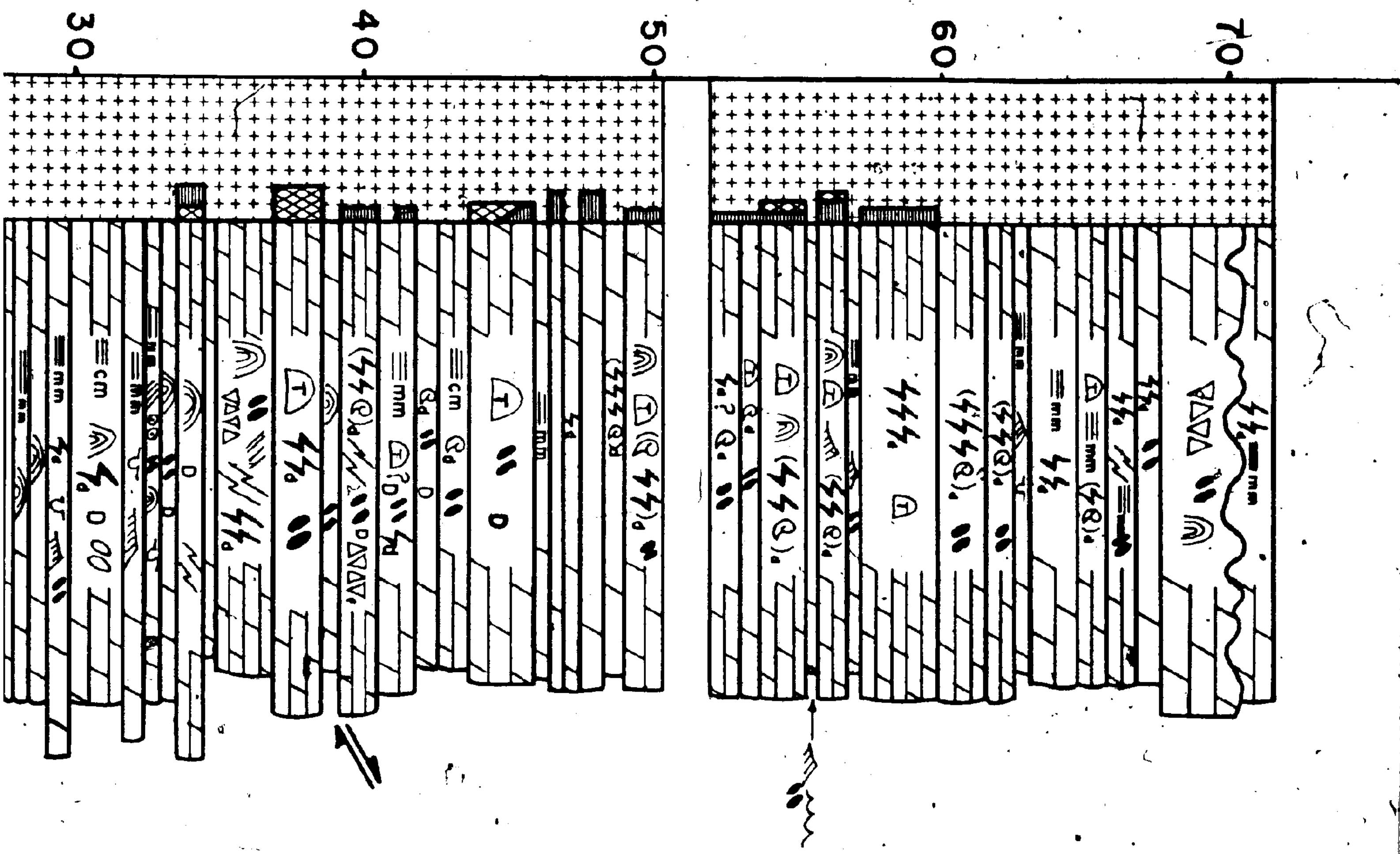
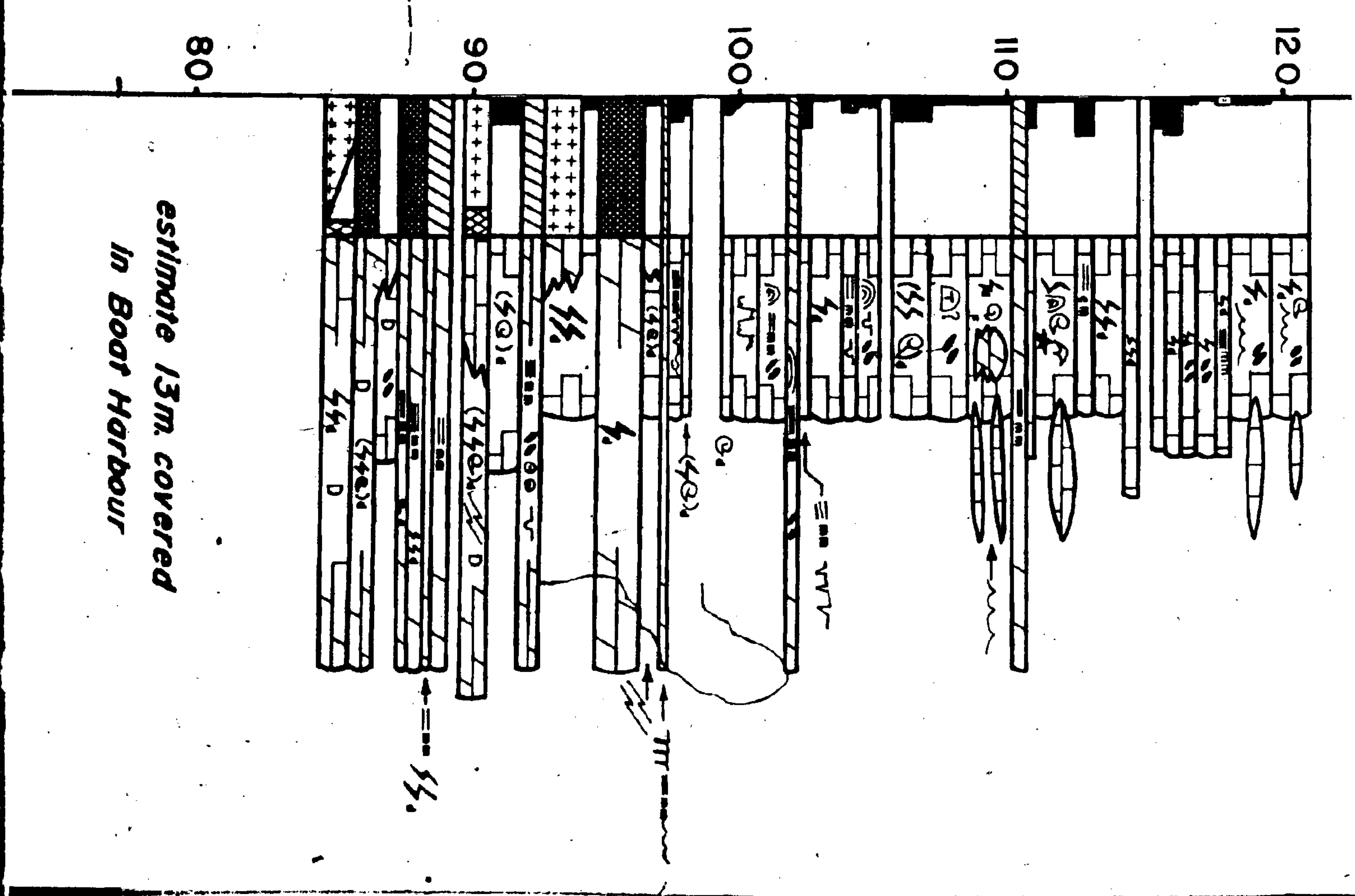
PACKSTONE
GRAINSTONE
FLOATSTONE
RUDSTONE
DOLOSTONE
FINE
COARSE
PY

BIGHT FORMATION



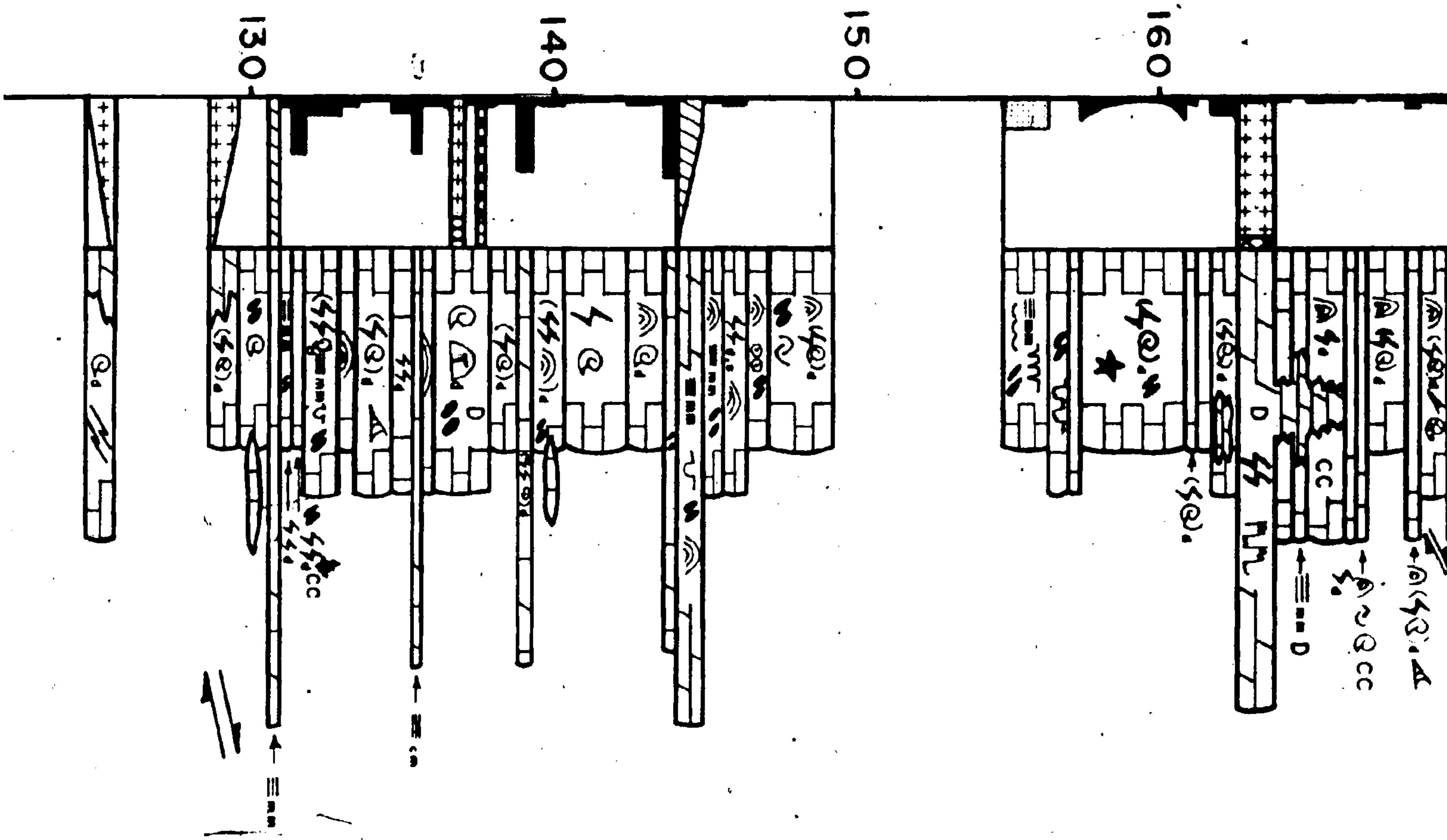
LOW

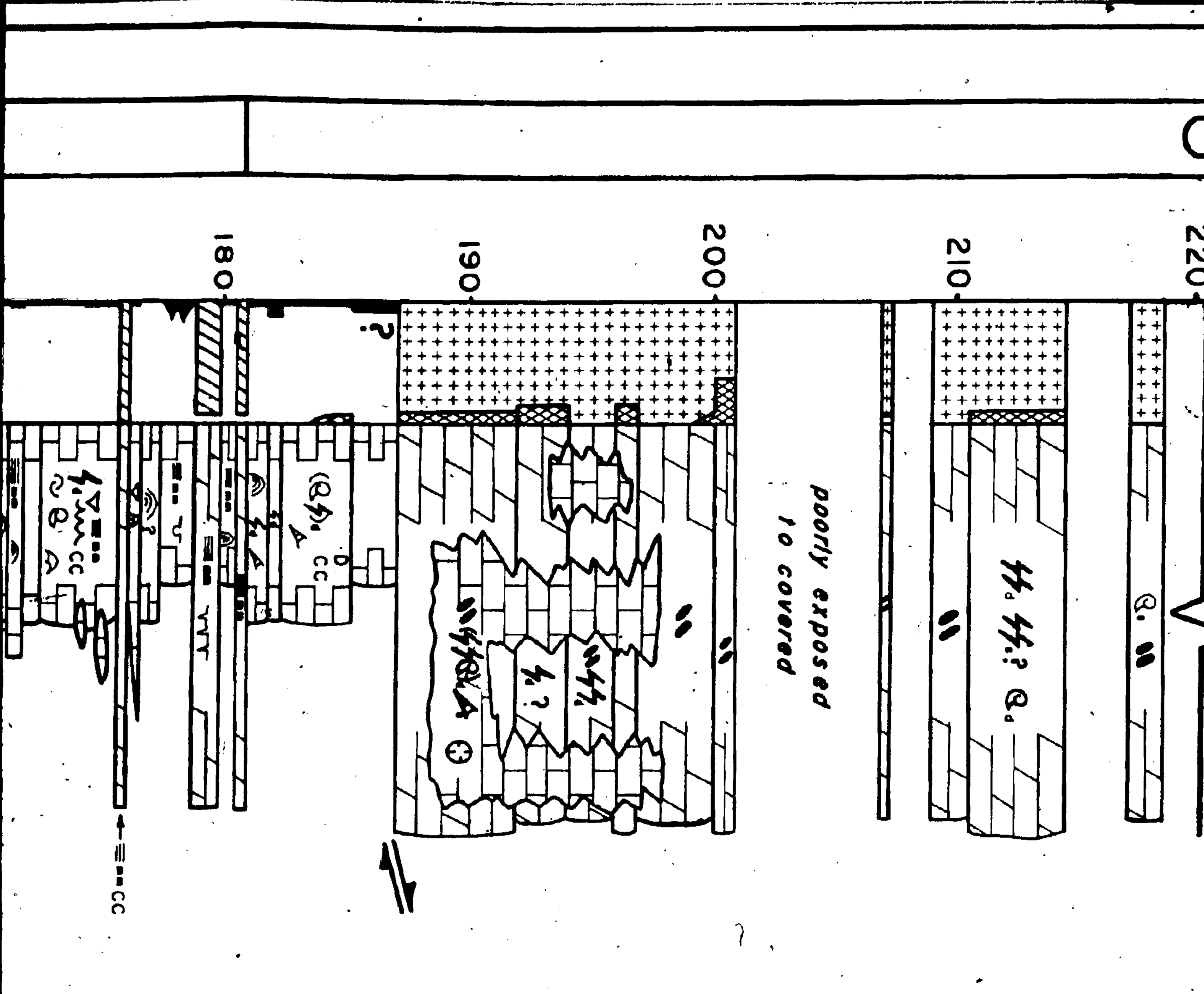
BOAT HARB



'ER ORDOVICIAN ST. GEORGE GROUP

BOUR FORMATION




180
190
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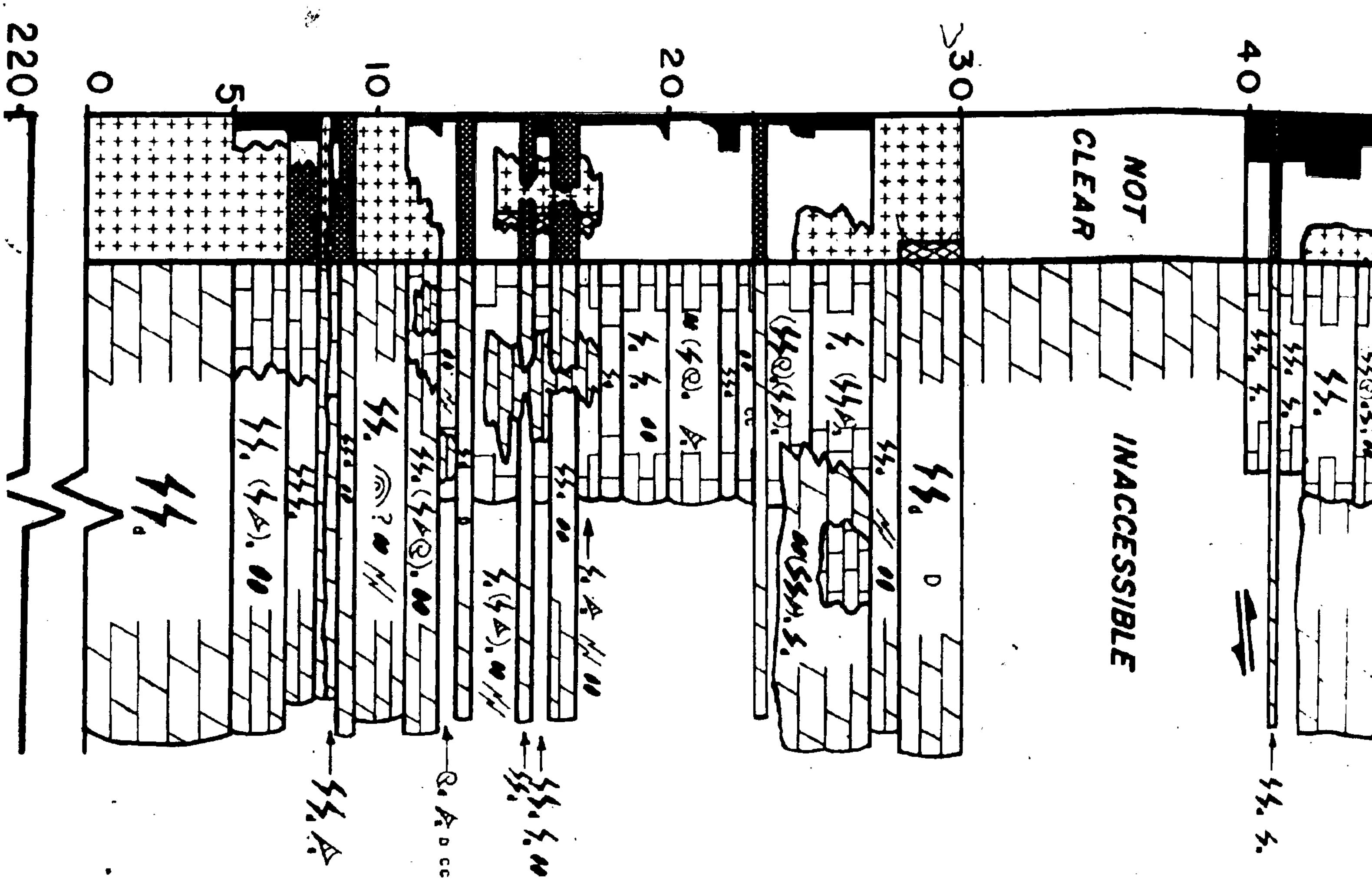
220
poorly exposed
to covered

CATOCHE FORMATION



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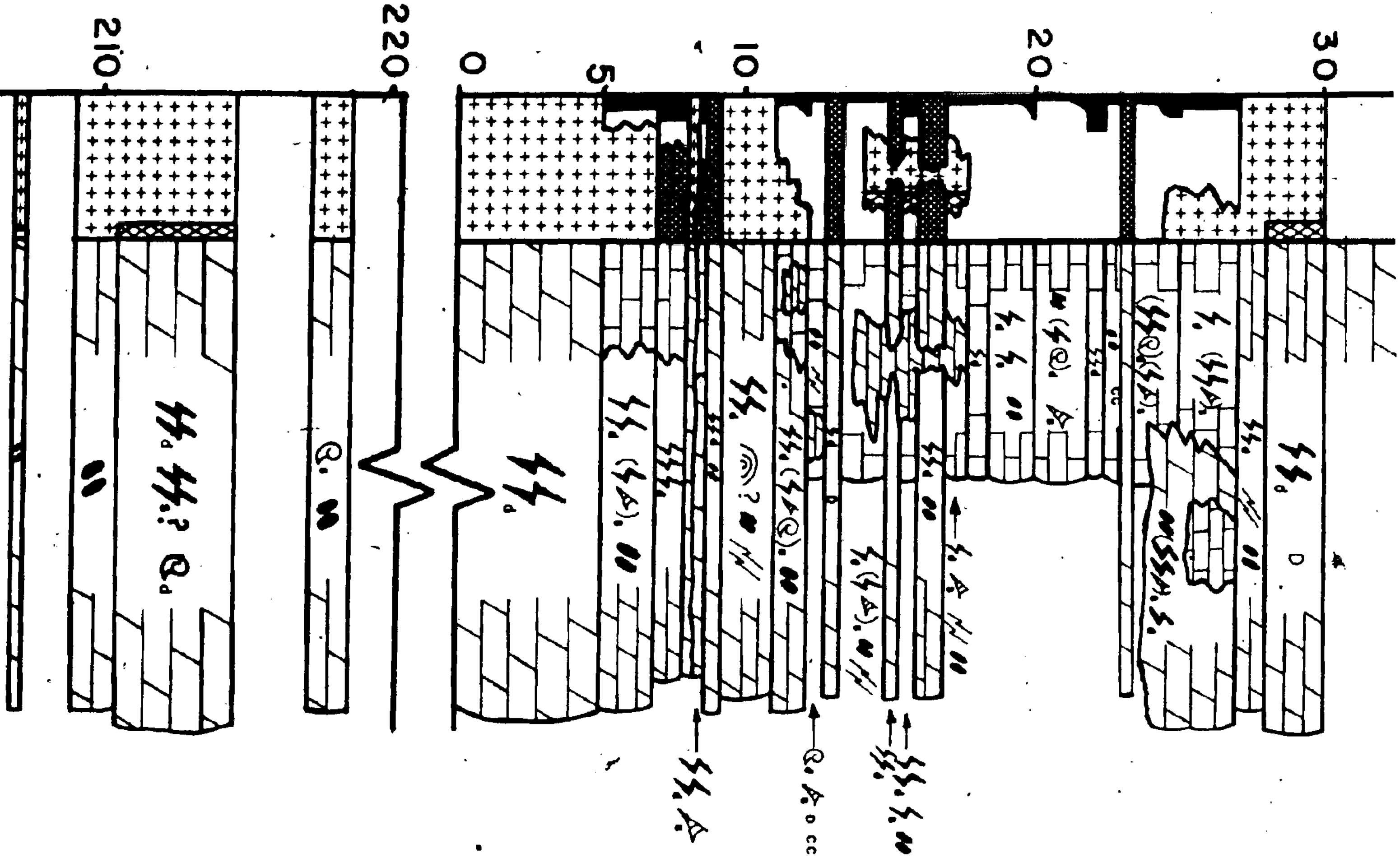
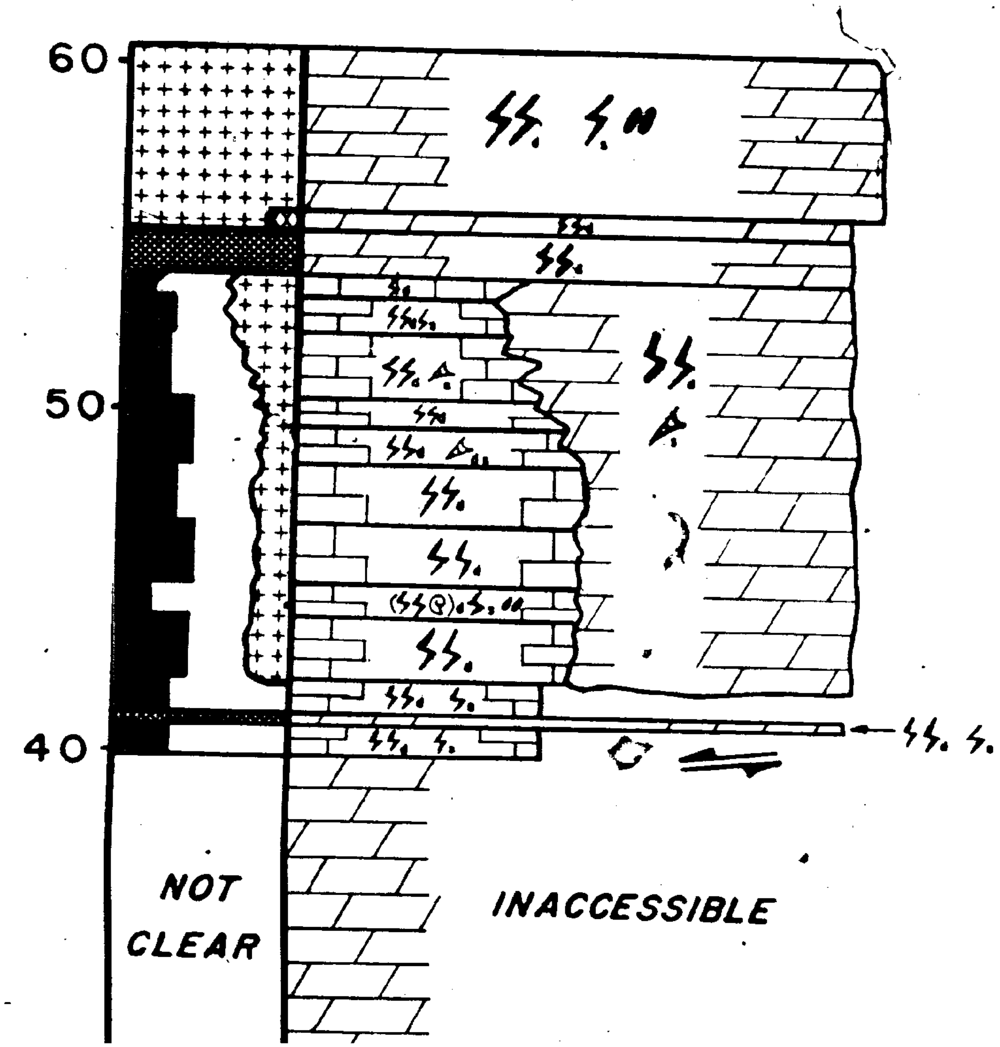


CAPE NORMAN
(GREAT NORTHERN PENINSULA)



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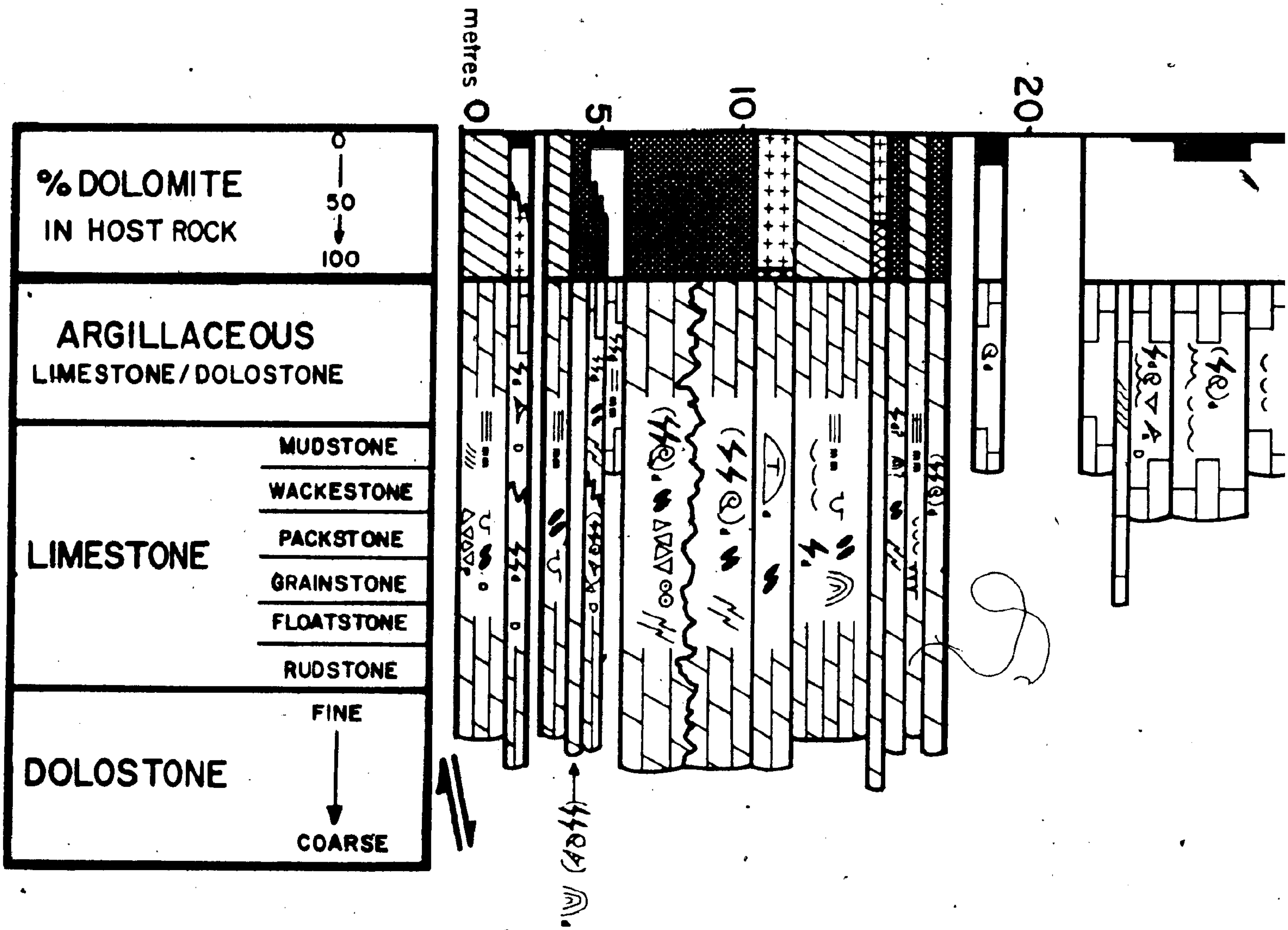

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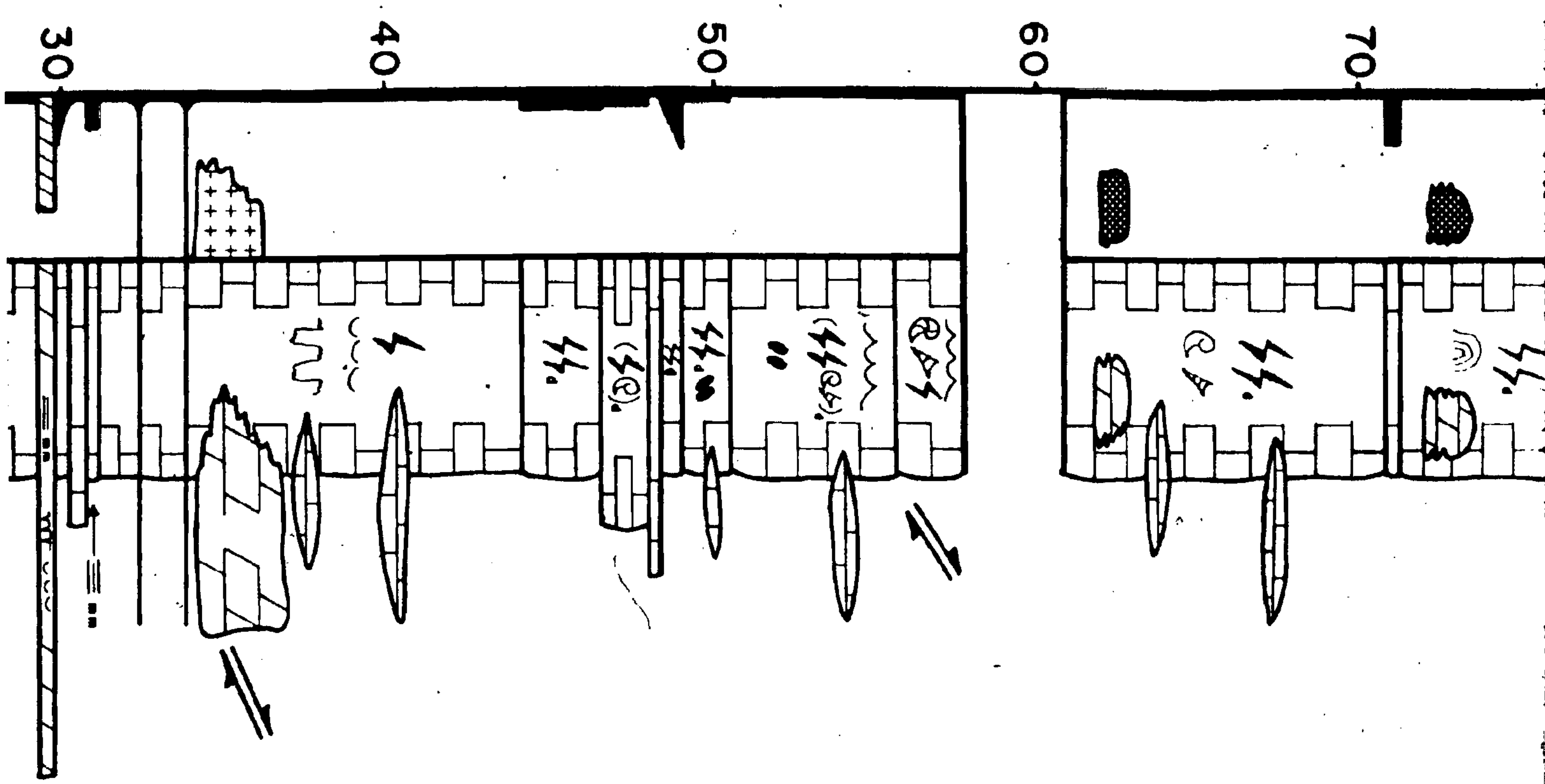
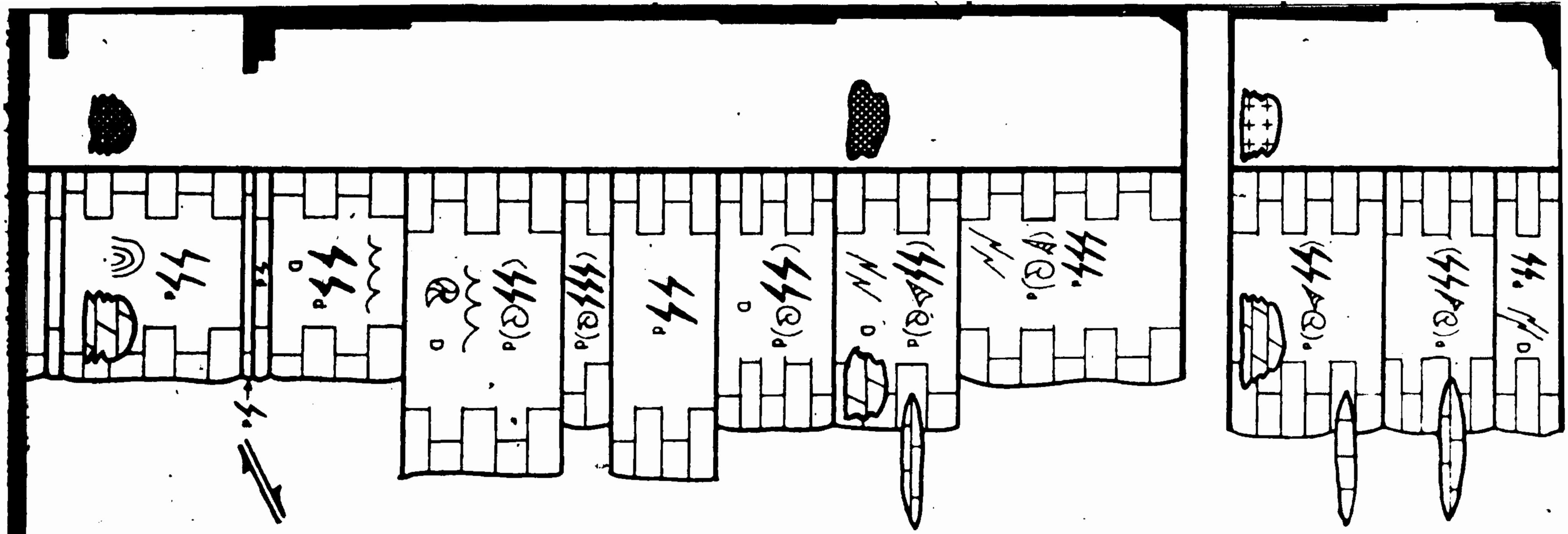
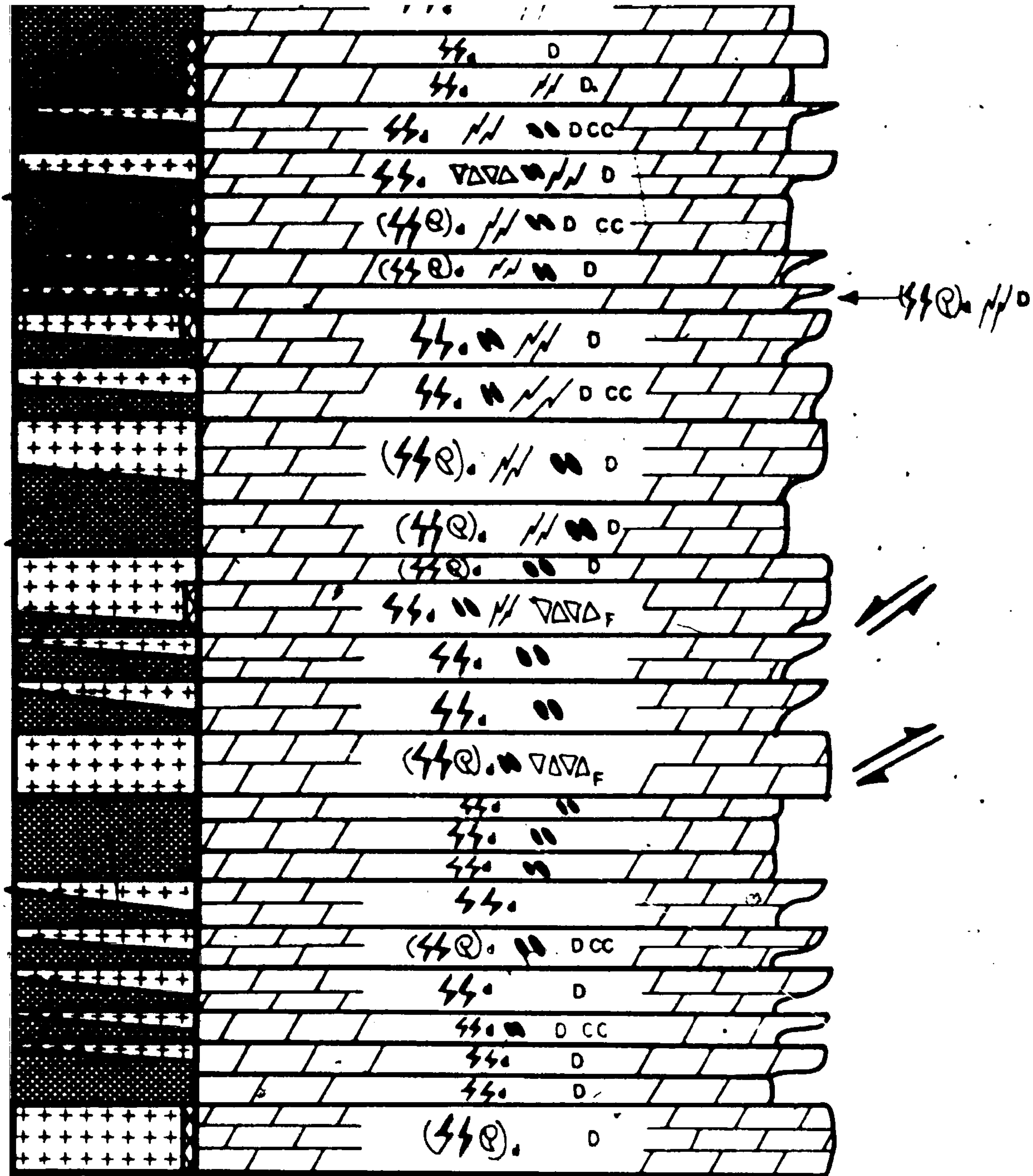




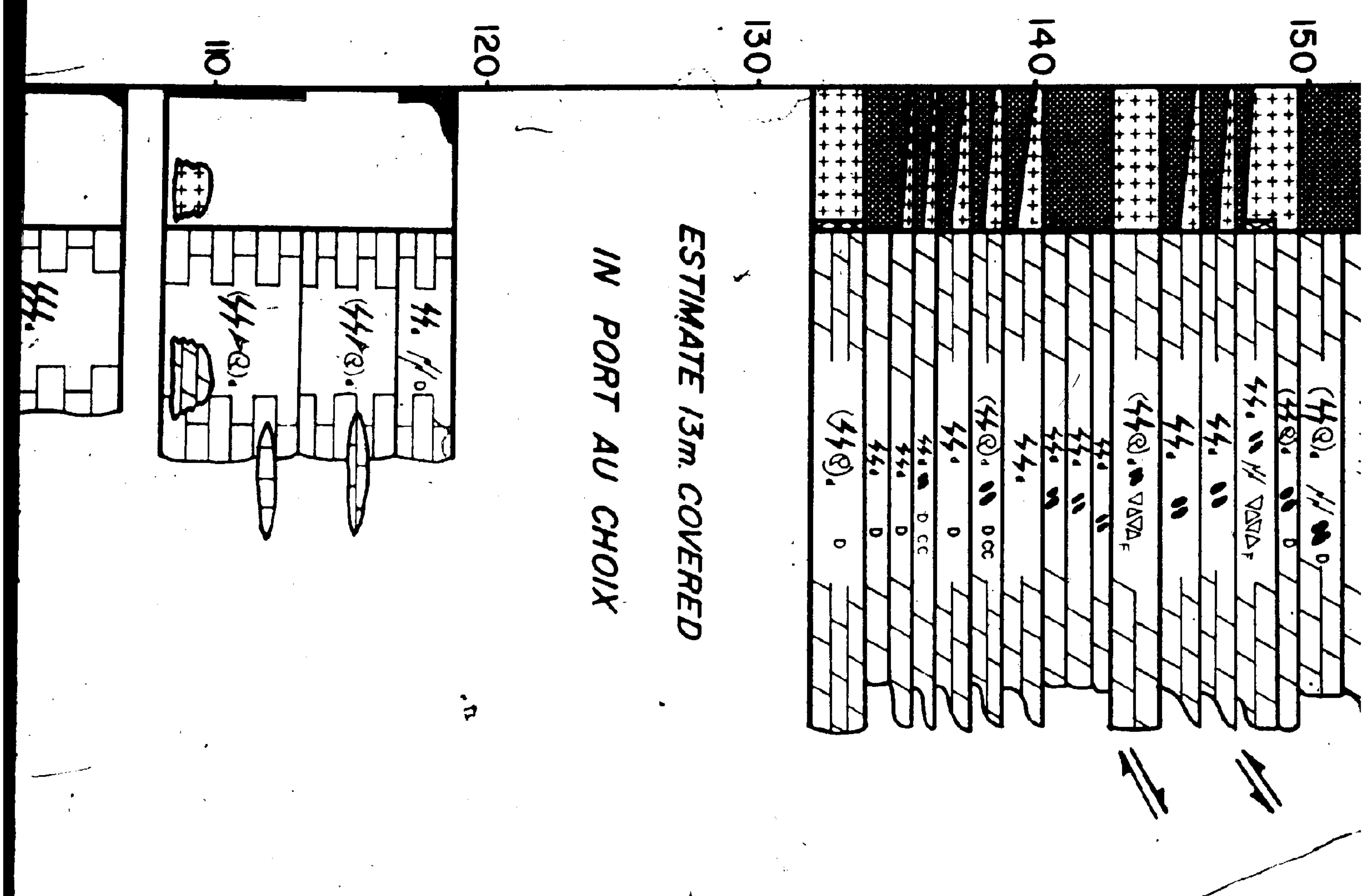


ESTIMATE 13m. COVERED

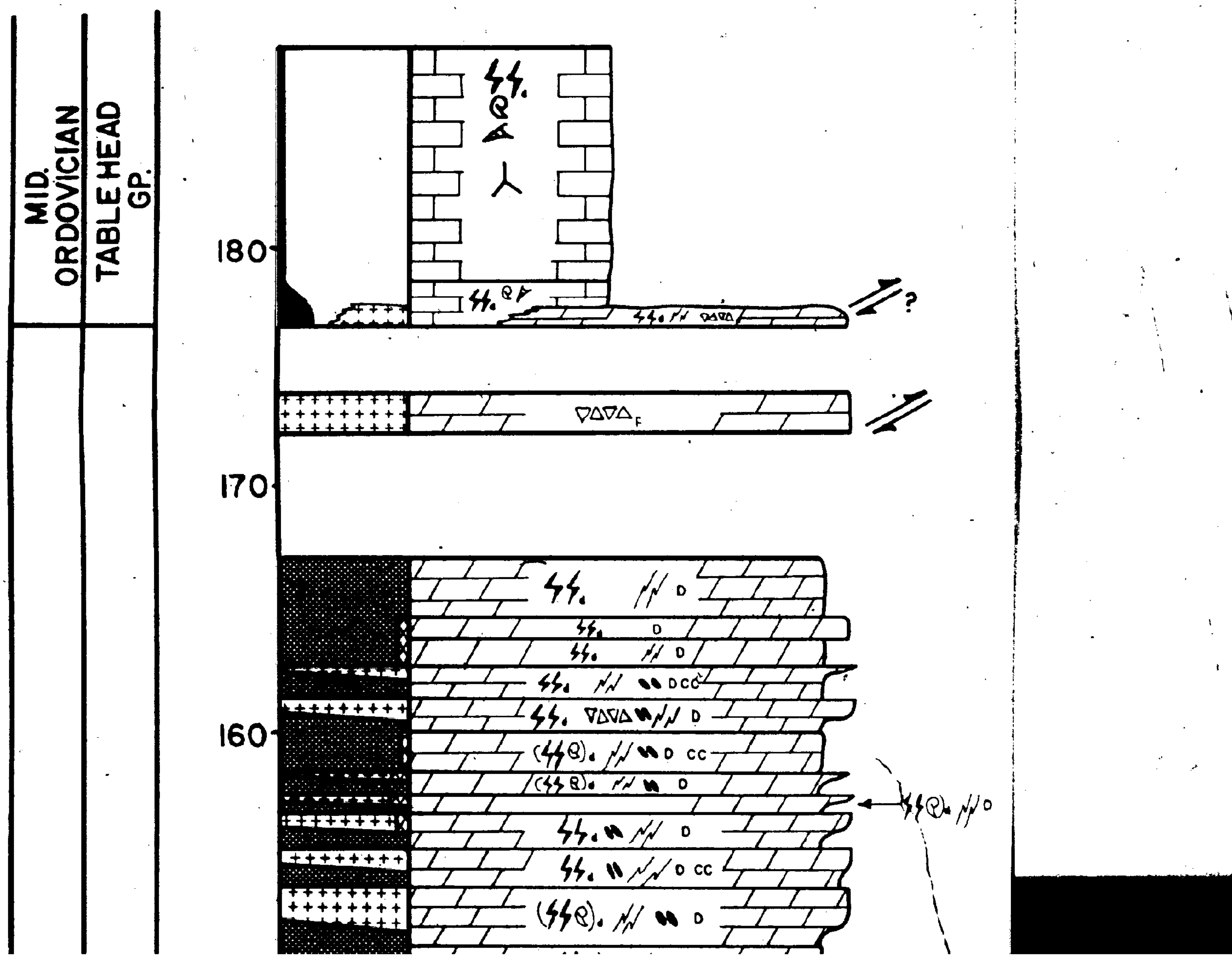
IN PORT AU CHOIX

GROUP

FORMATION



PORT AU CHOIX
(GREAT NORTHERN PENINSULA)



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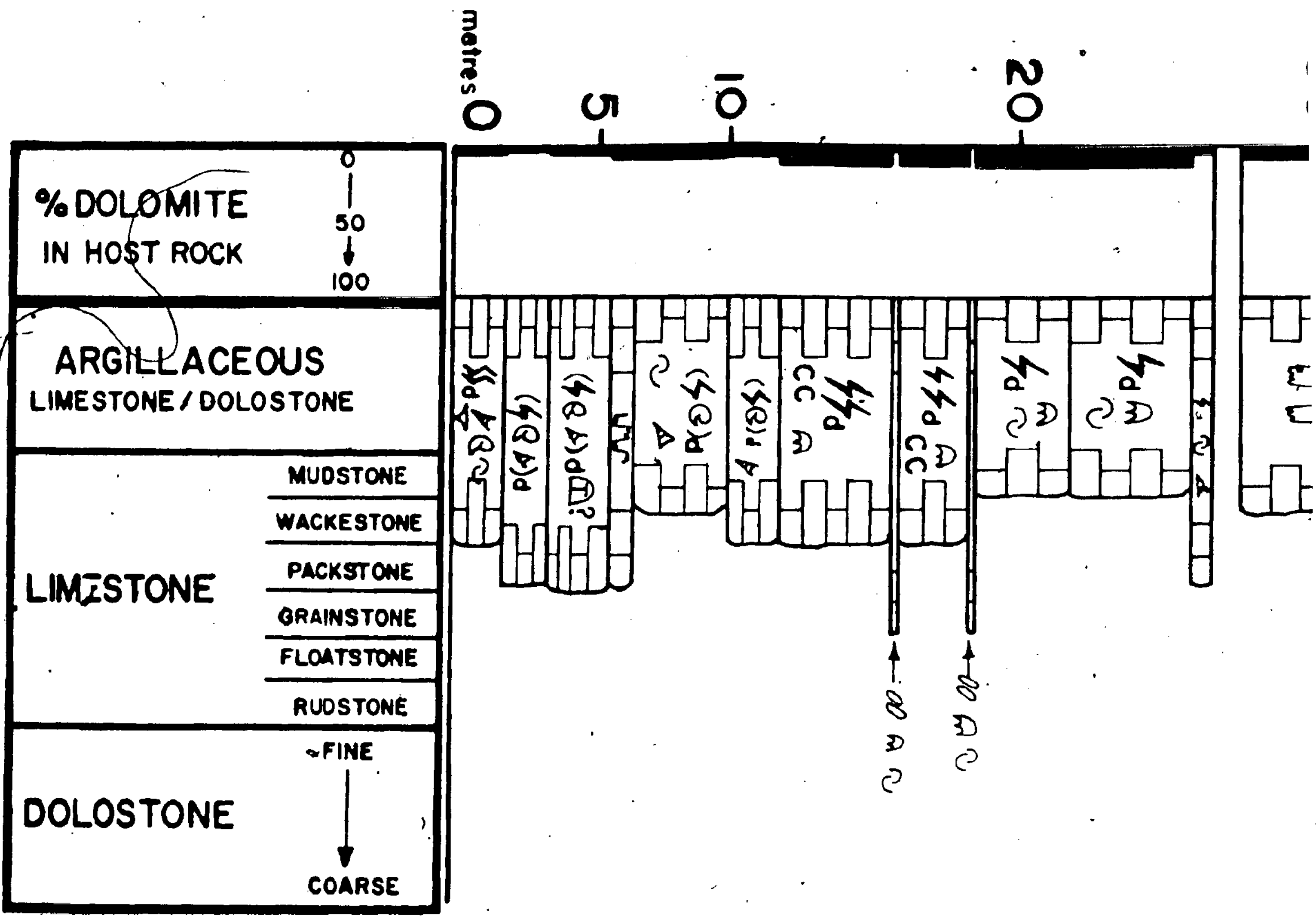
metres
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% DOLOMITE IN HOST ROCK
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ARGILLACEOUS LIMESTONE / DOLOSTONE
LIMESTONE
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
FLOATSTONE
RUDSTONE
DOLOSTONE
FINE
COARSE

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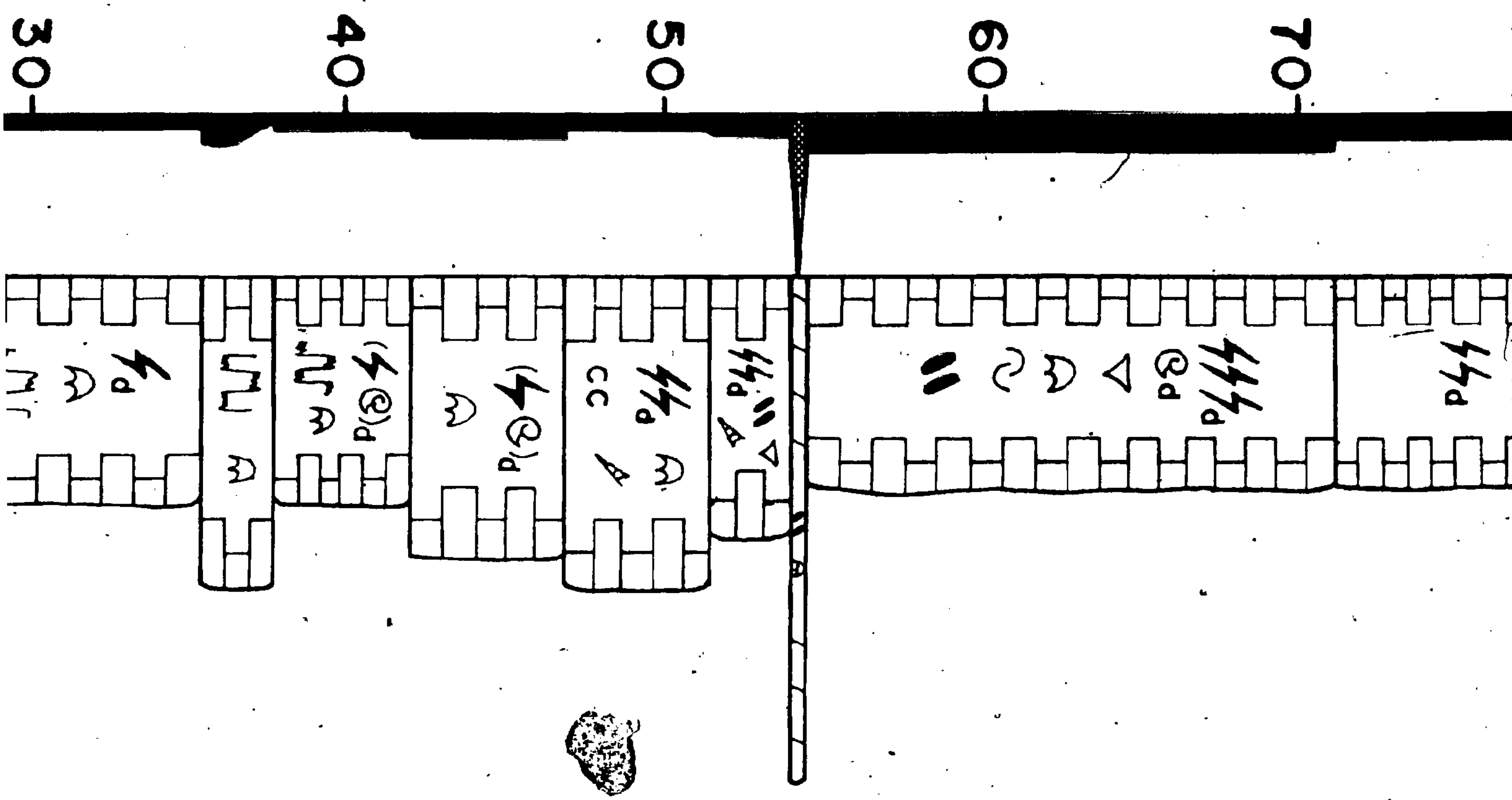
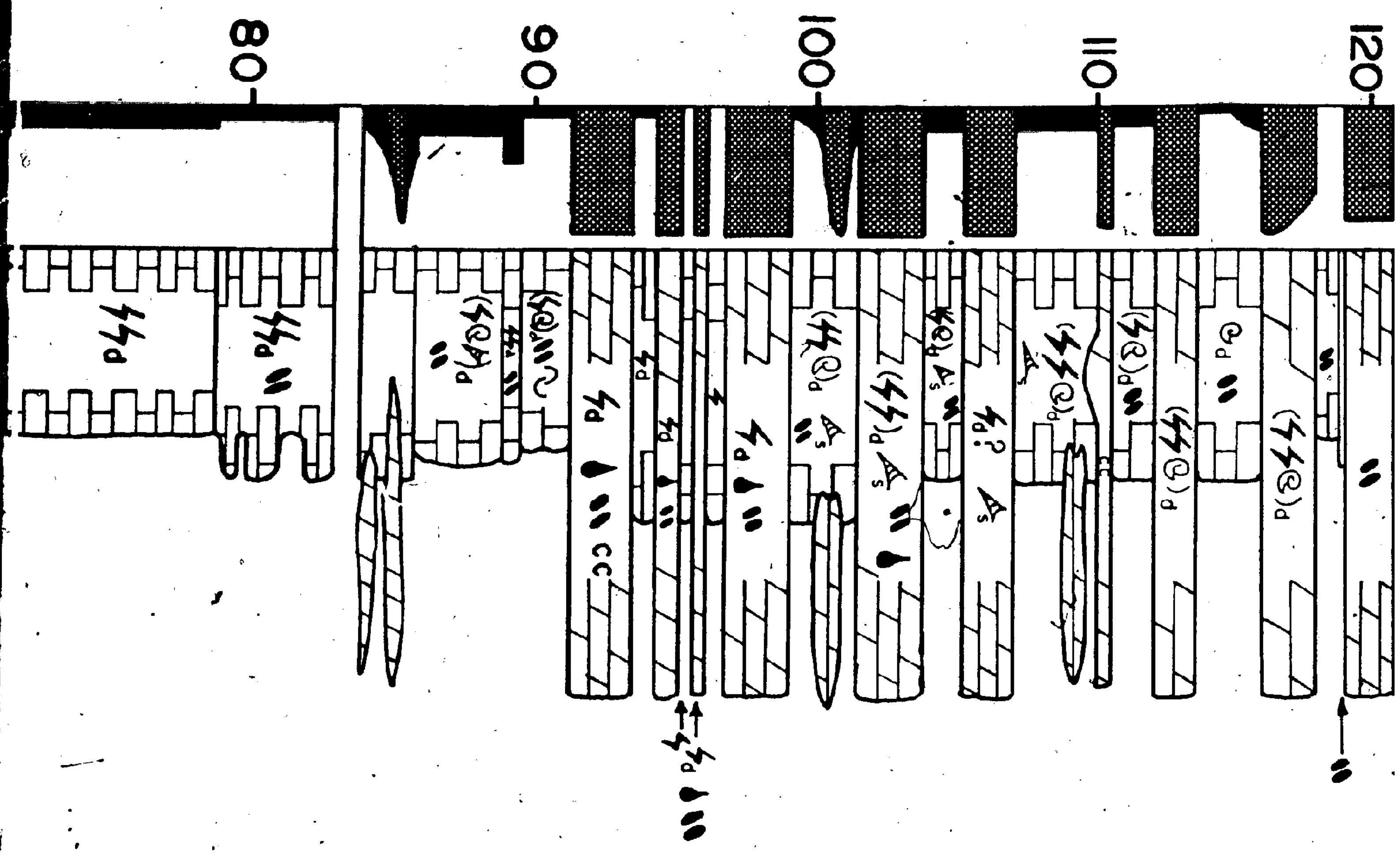
LOWER O

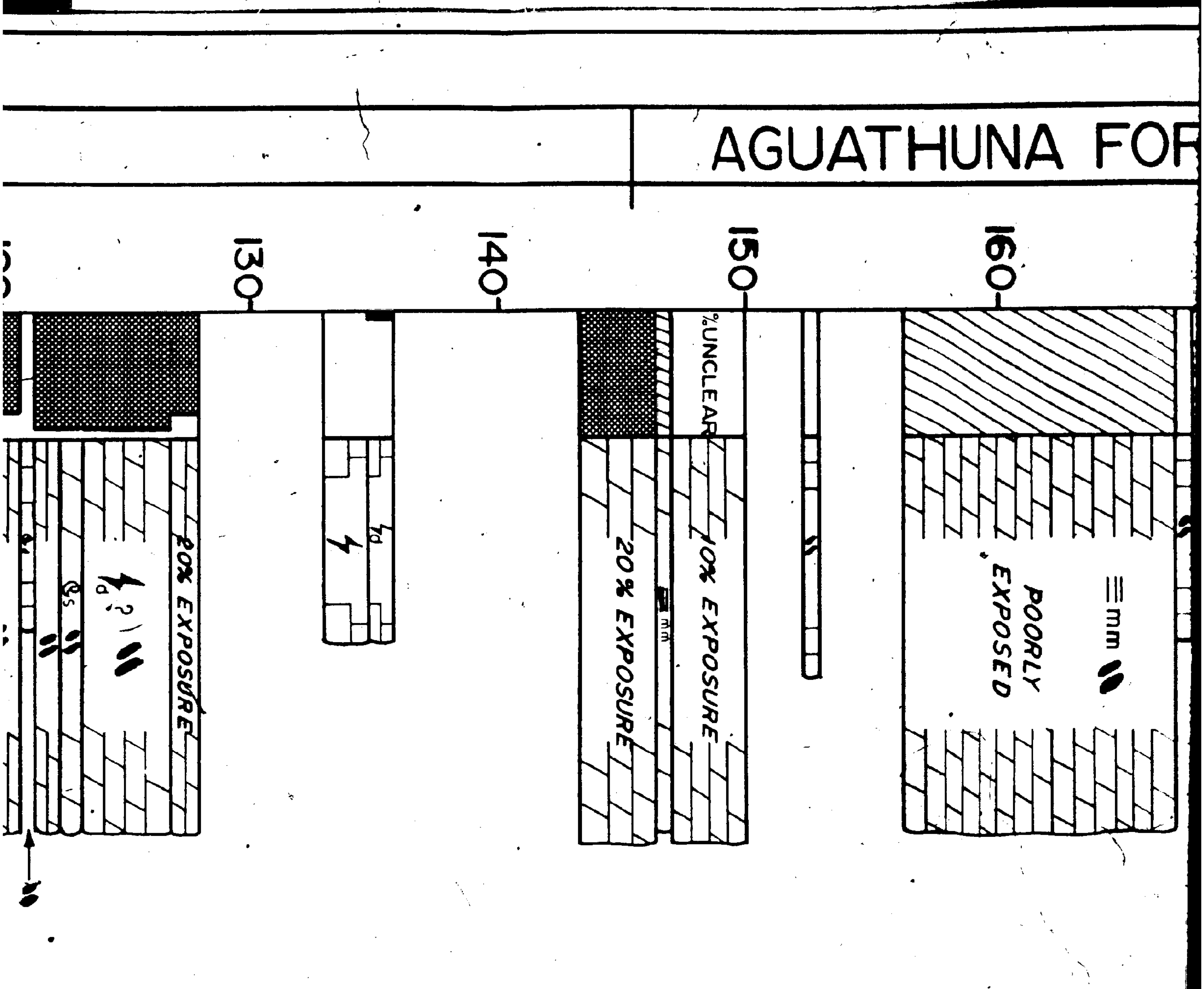
CATOCHE FOR



R ORDOVICIAN ST. GEORGE GROUP

FORMATION




AGUATHUNA FOR
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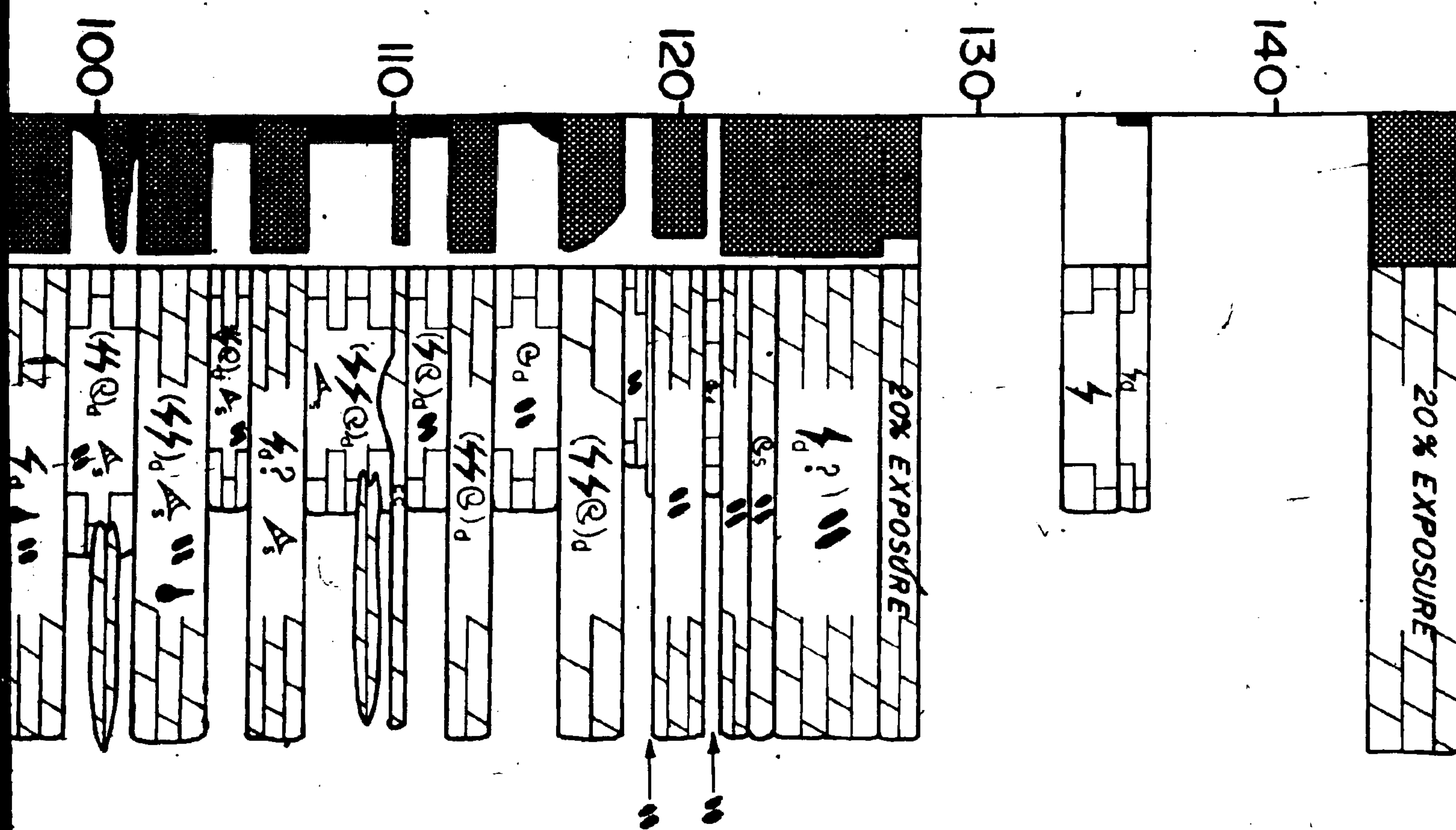
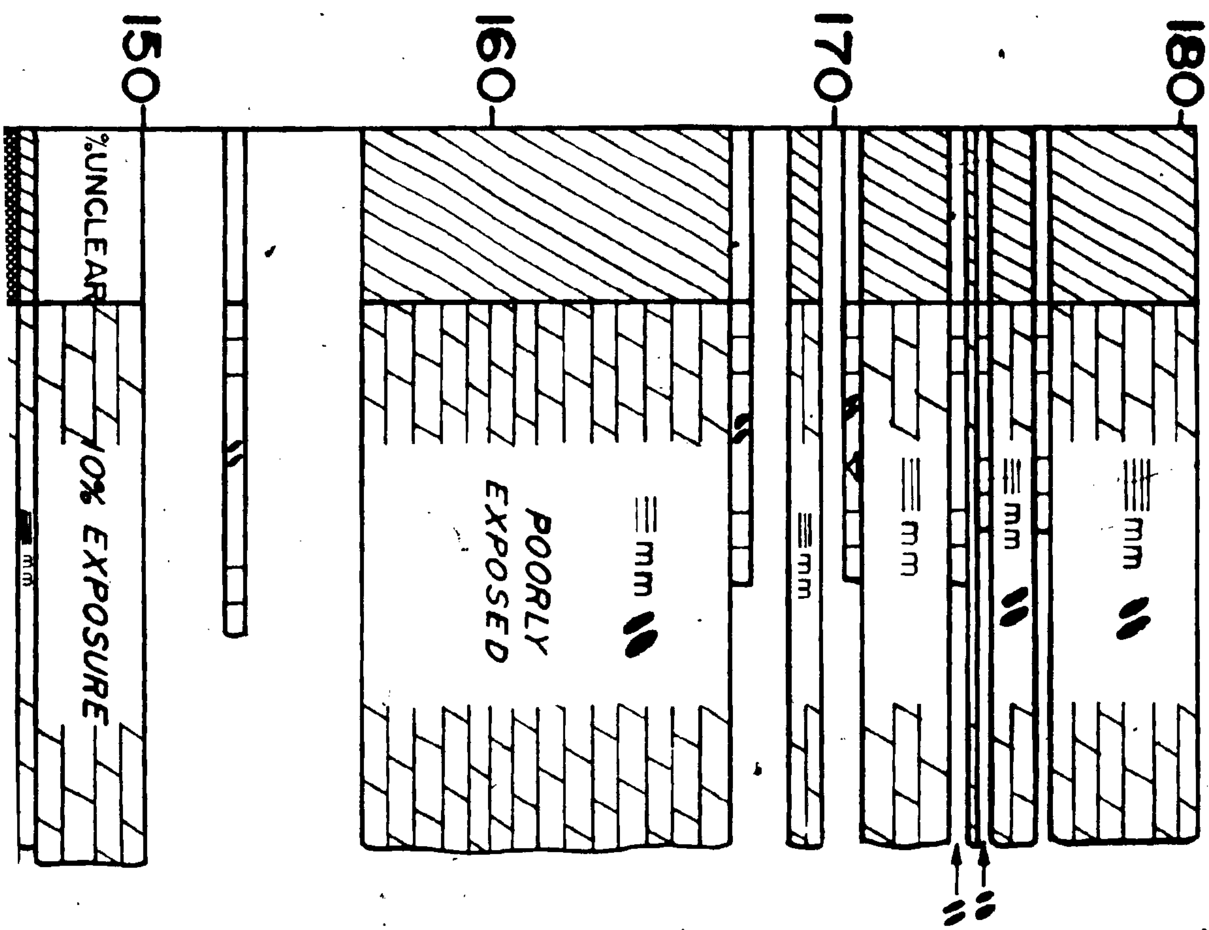
20% EXPOSURE
20% EXPOSURE
%UNCLEAR
10% EXPOSURE
POORLY EXPOSED

EORGE GROUP



SMELT CANYON

AGUATHUNA FORMATION



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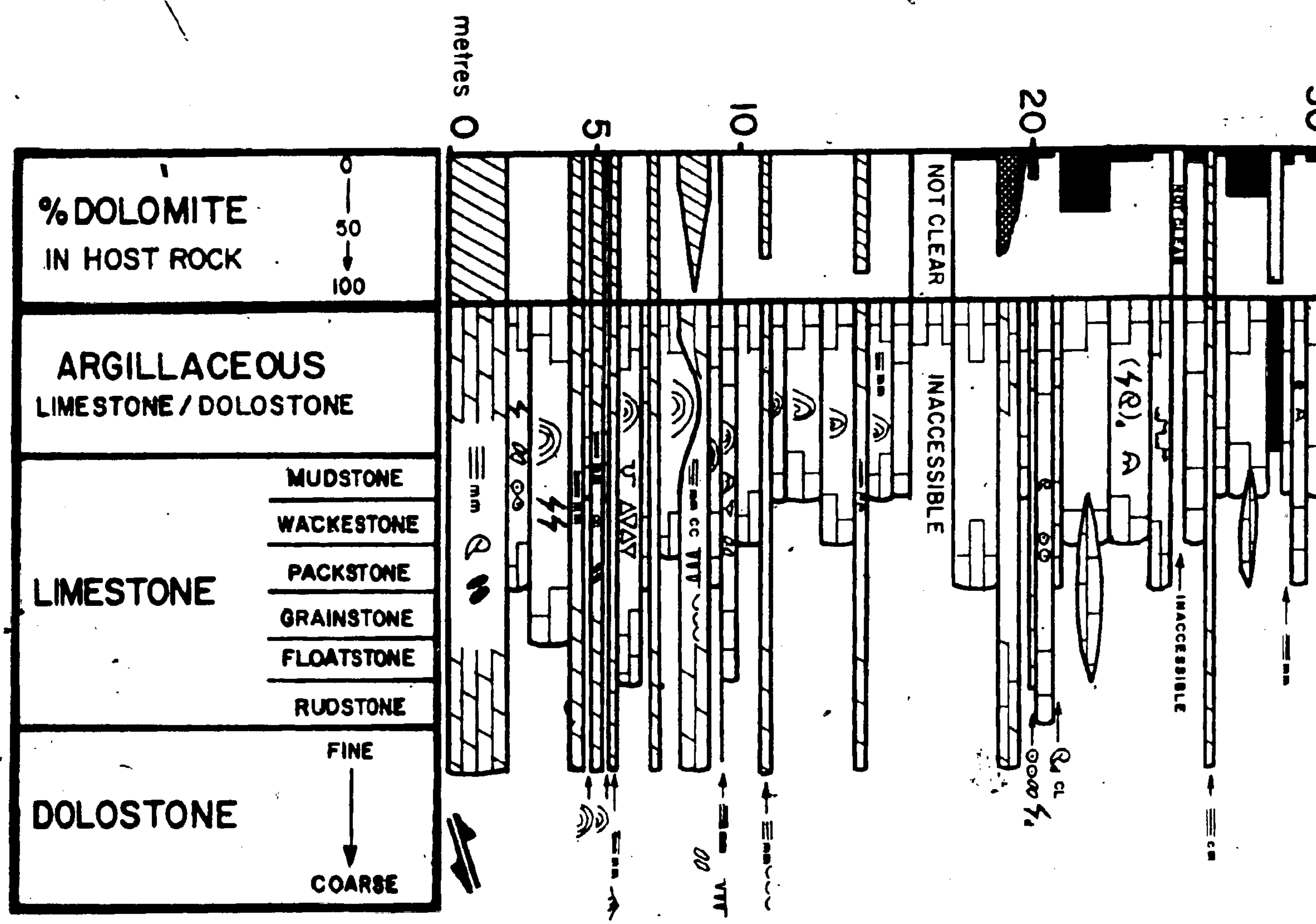
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% DOLOMITE IN HOST ROCK
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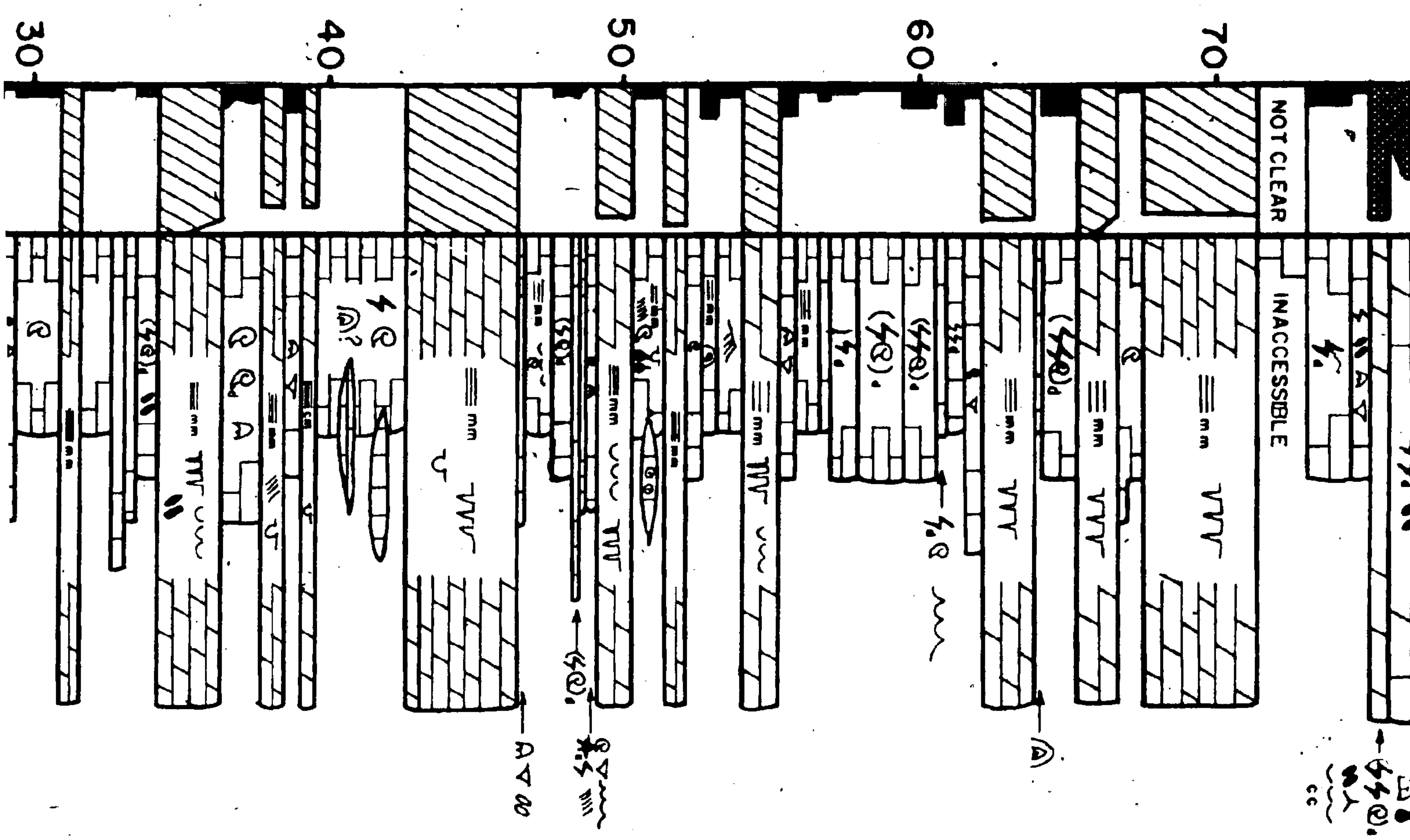
ARGILLACEOUS LIMESTONE / DOLOSTONE
LIMESTONE
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
FLOATSTONE
RUDSTONE
DOLOSTONE
FINE
COARSE
NOT CLEAR
INACCESSIBLE
INACCESSIBLE

1 OF/DE

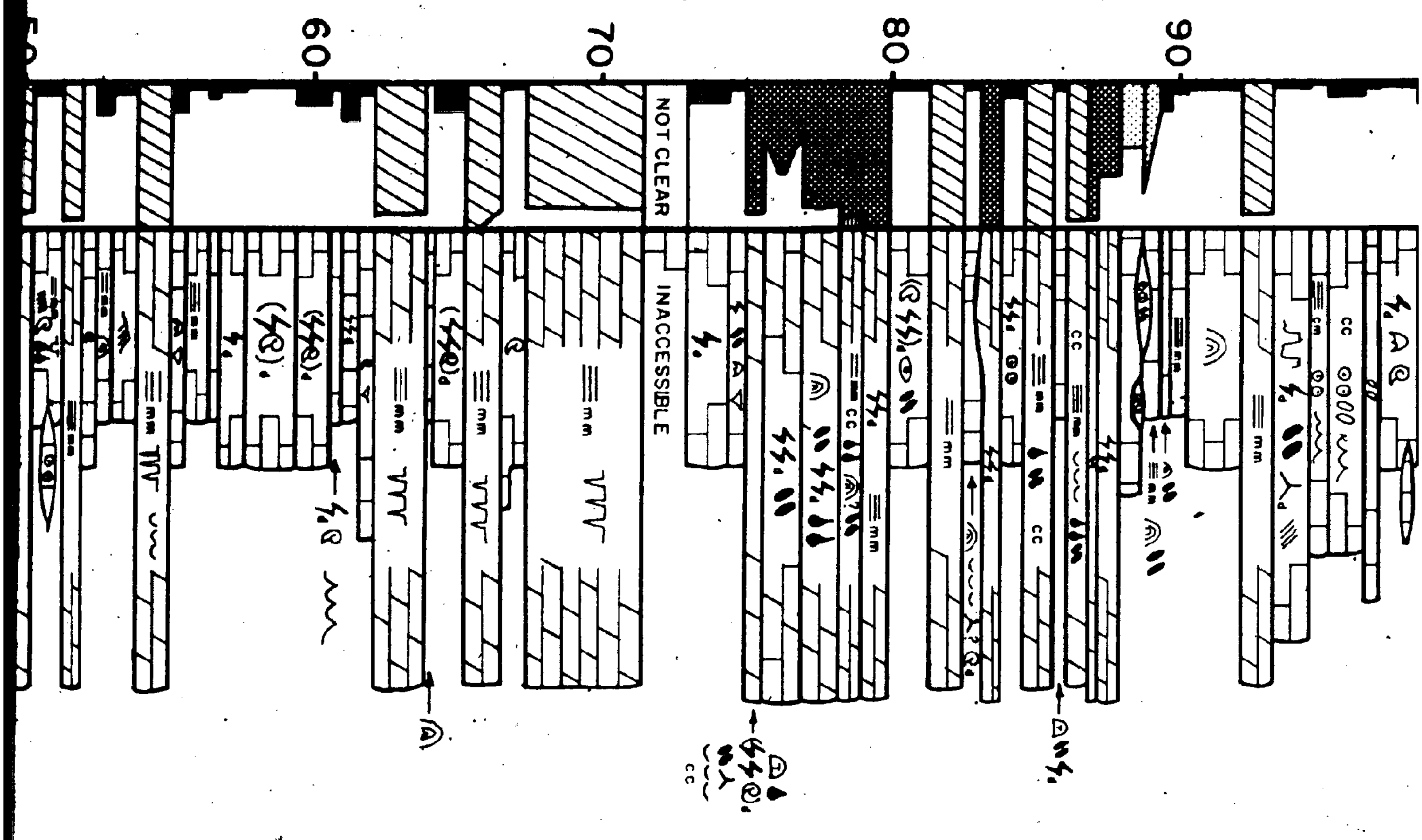
LOWER ORDOVICIAN ST. GEOR

BOAT HARBOUR FORMATION

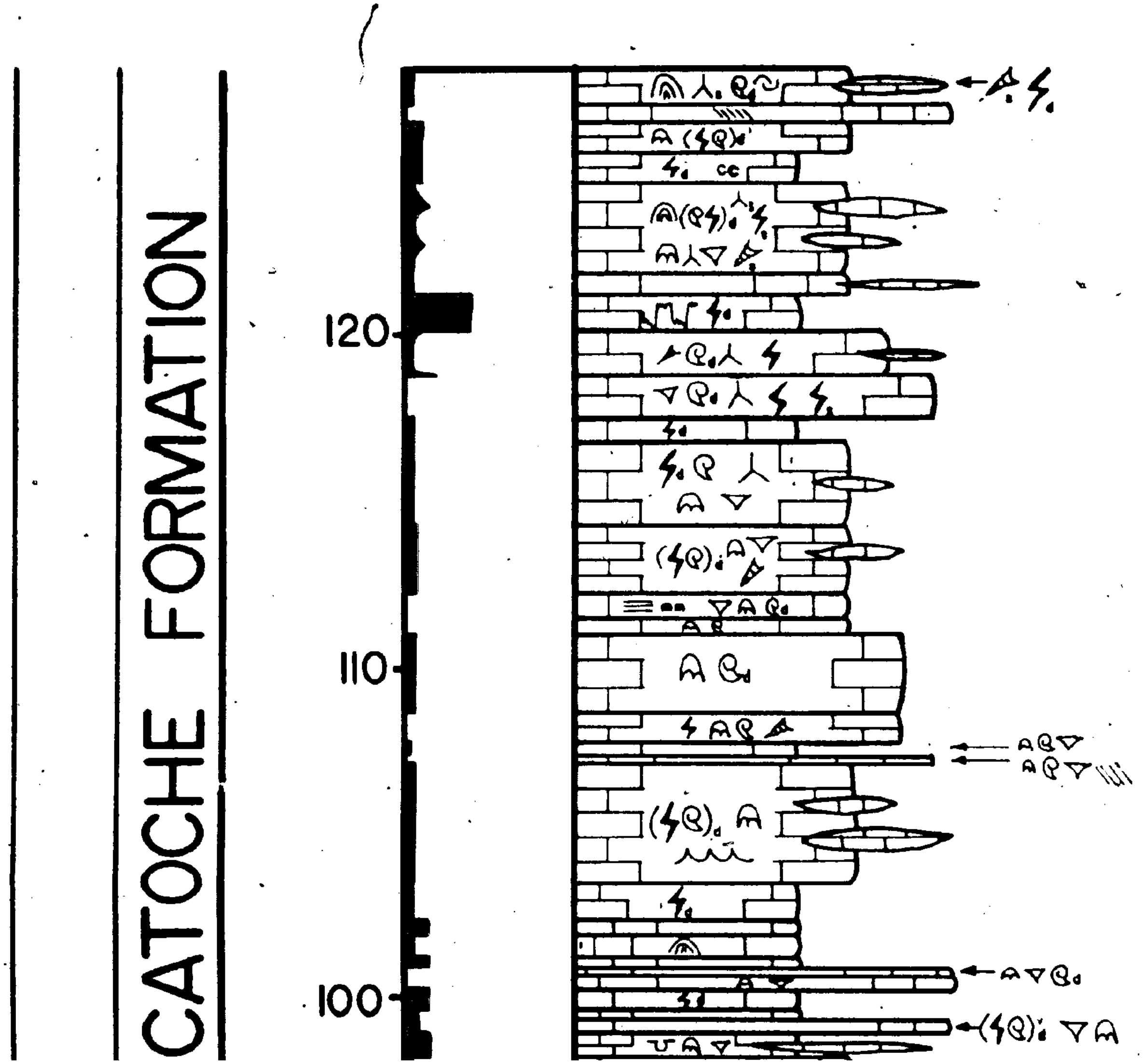


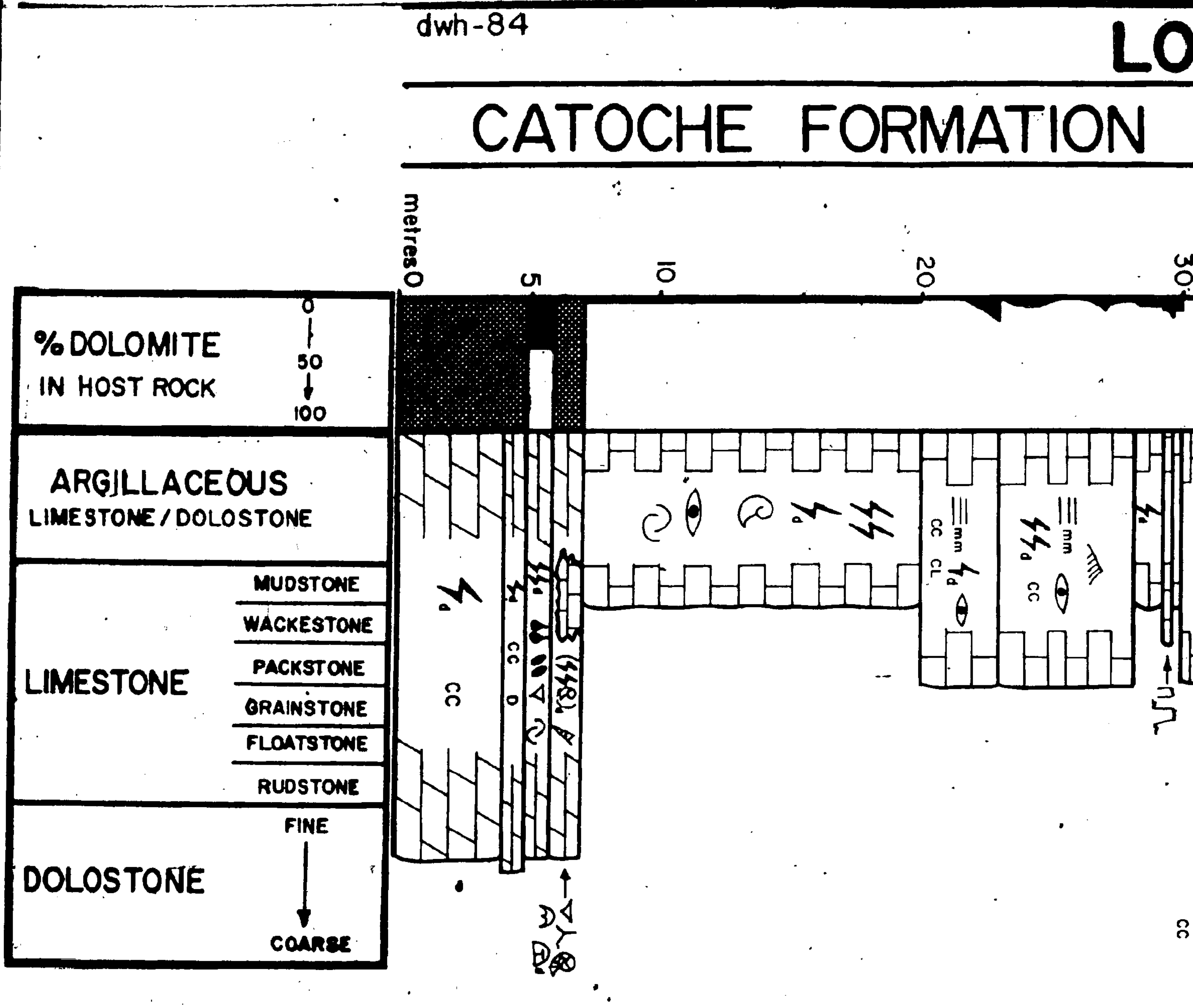
ORDOVICIAN ST. GEORGE GROUP

FORMATION



LOWER COVE
(PORT AU PORT PENINSULA)




dwh-84
LO
CATOCHE FORMATION
metres
0
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30
% DOLOMITE IN HOST ROCK
0
50
100
ARGILLACEOUS LIMESTONE / DOLOSTONE
LIMESTONE
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
FLOATSTONE
RUDSTONE
DOLOSTONE
FINE
COARSE
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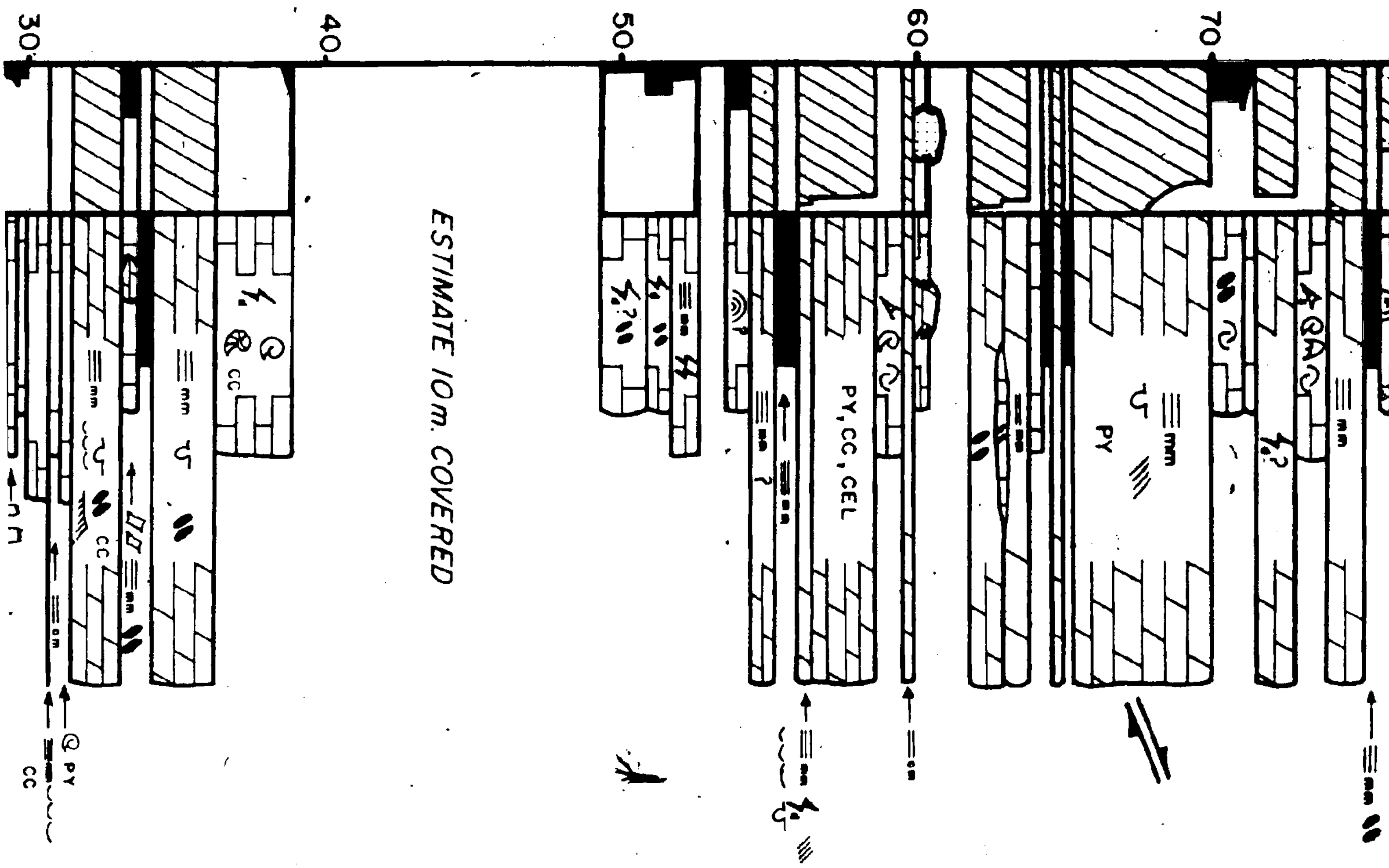
1 OF/DE

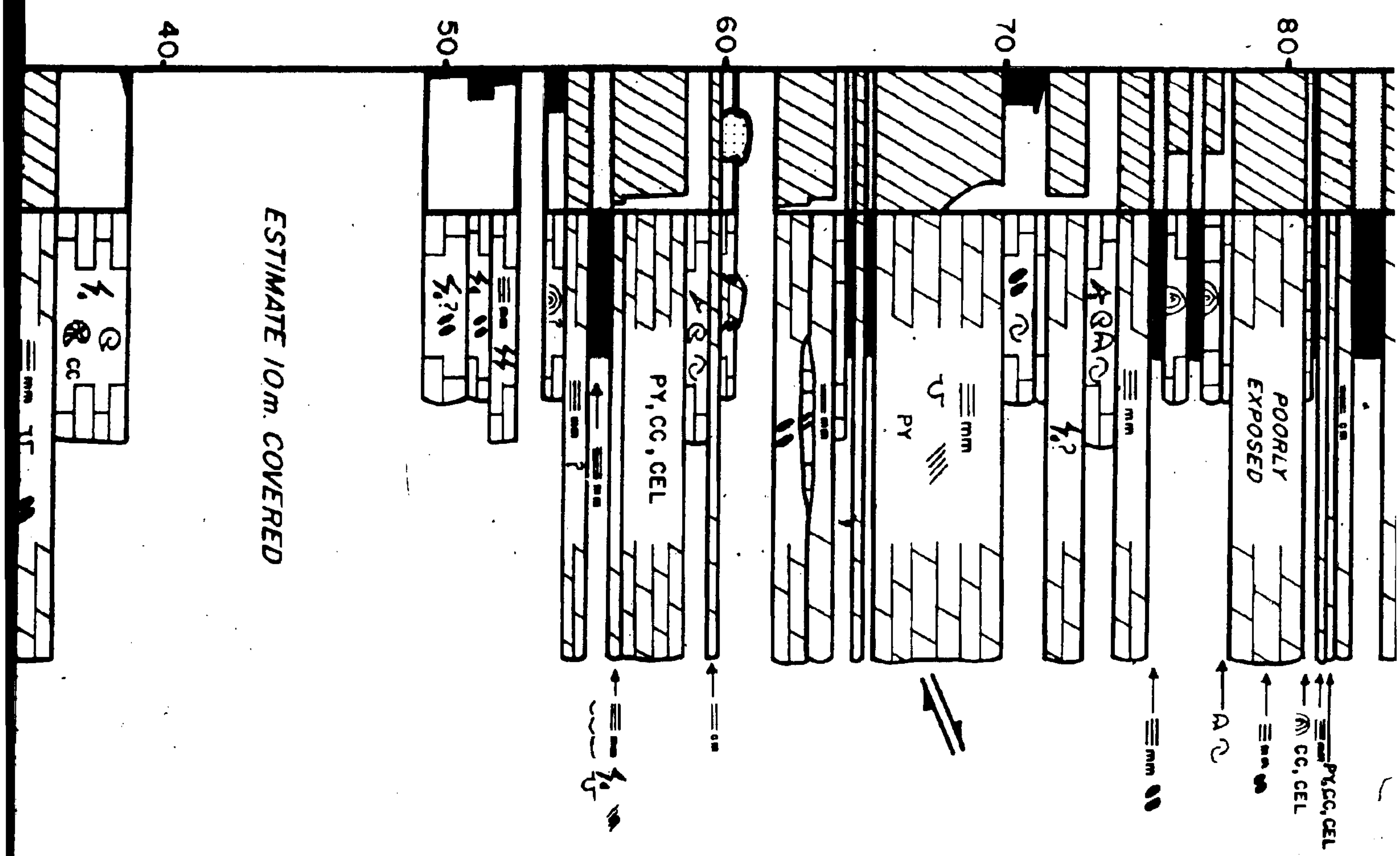
OWER ORDOVICIAN ST. GEORGE GROUP

AGUATHUNA FORMA



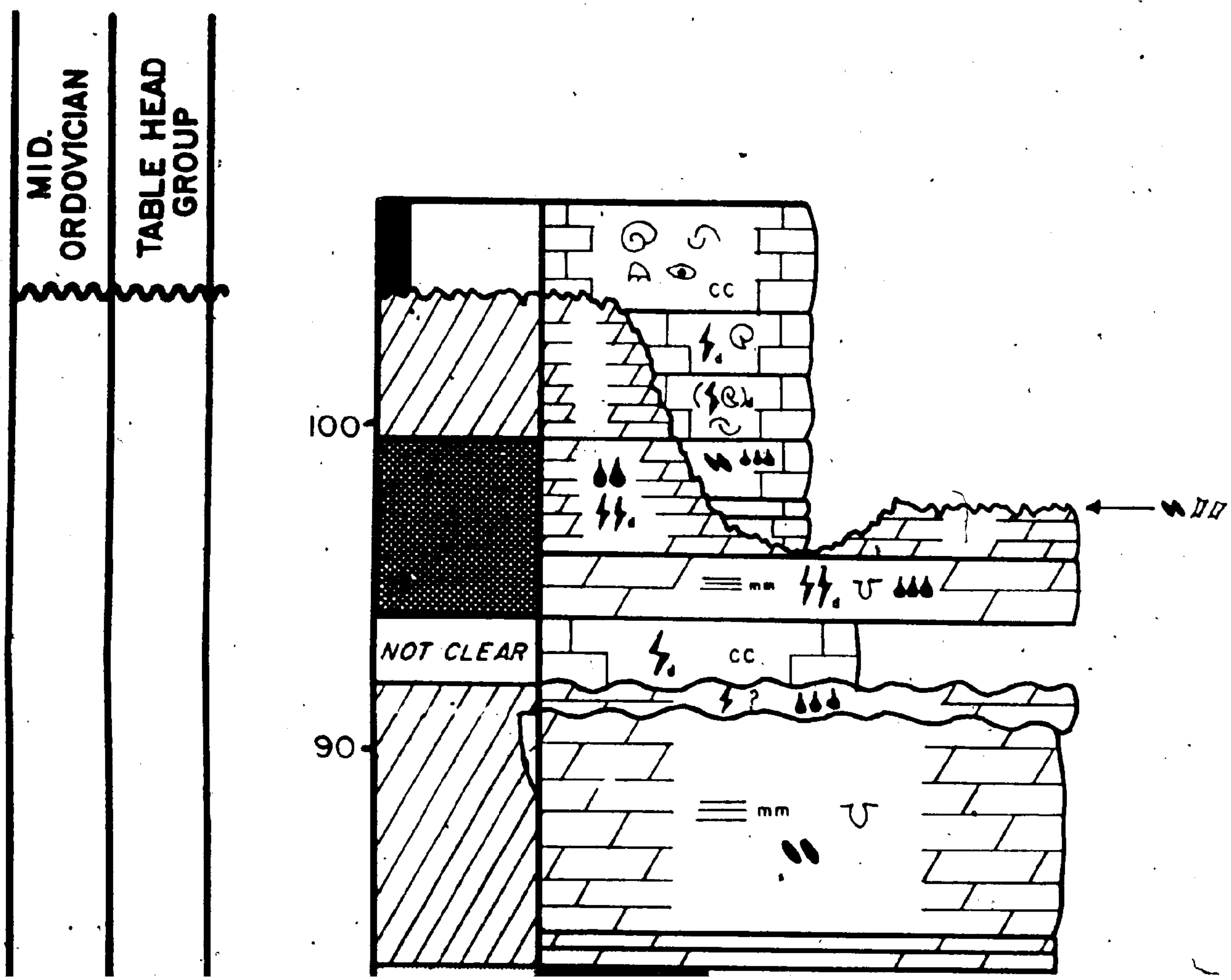
R ORDOVICIAN ST. GEORGE GROUP

AGUATHUNA FORMATION



AGUATHUNA QUARRY

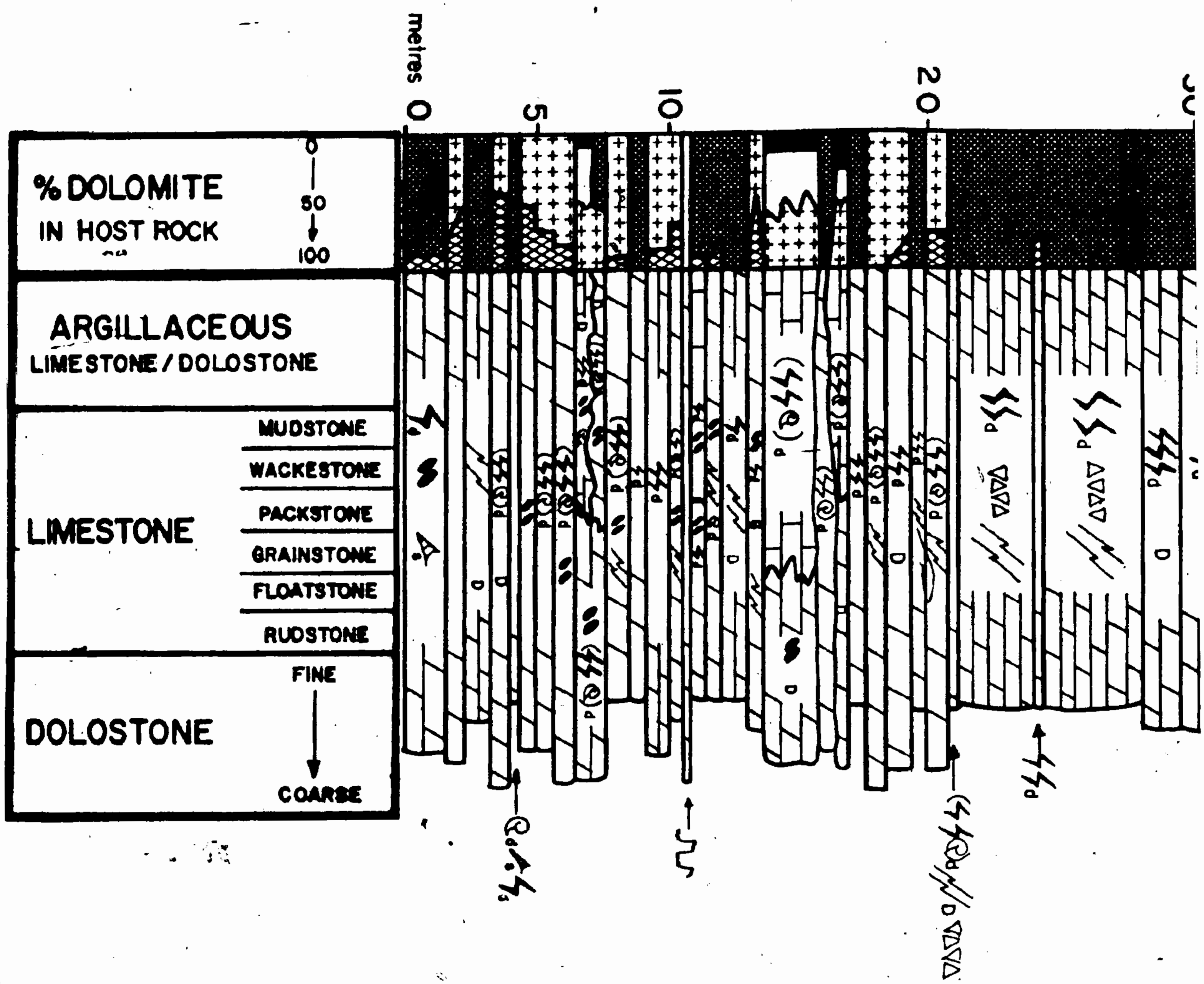
(PORT AU PORT PENINSULA)



dwh-84

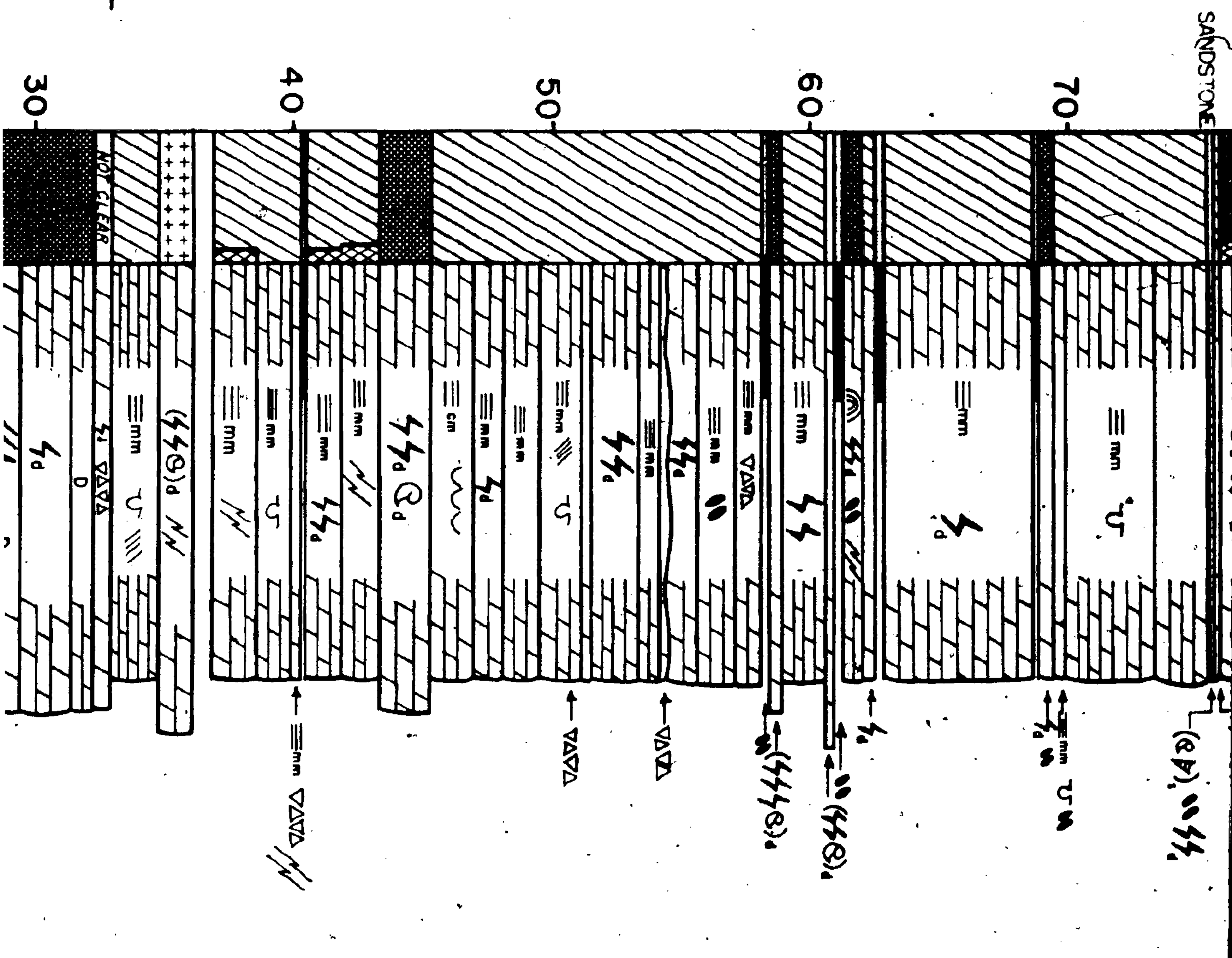
LOWE

CATOCHE FORMATION



ER ORDOVICIAN ST. GEORGE GROUP

N | AGUATHUNA FORMATIO



OWER ORDOVICIAN ST. GEORGE GROUP

TION | AGUATHUNA FORMA

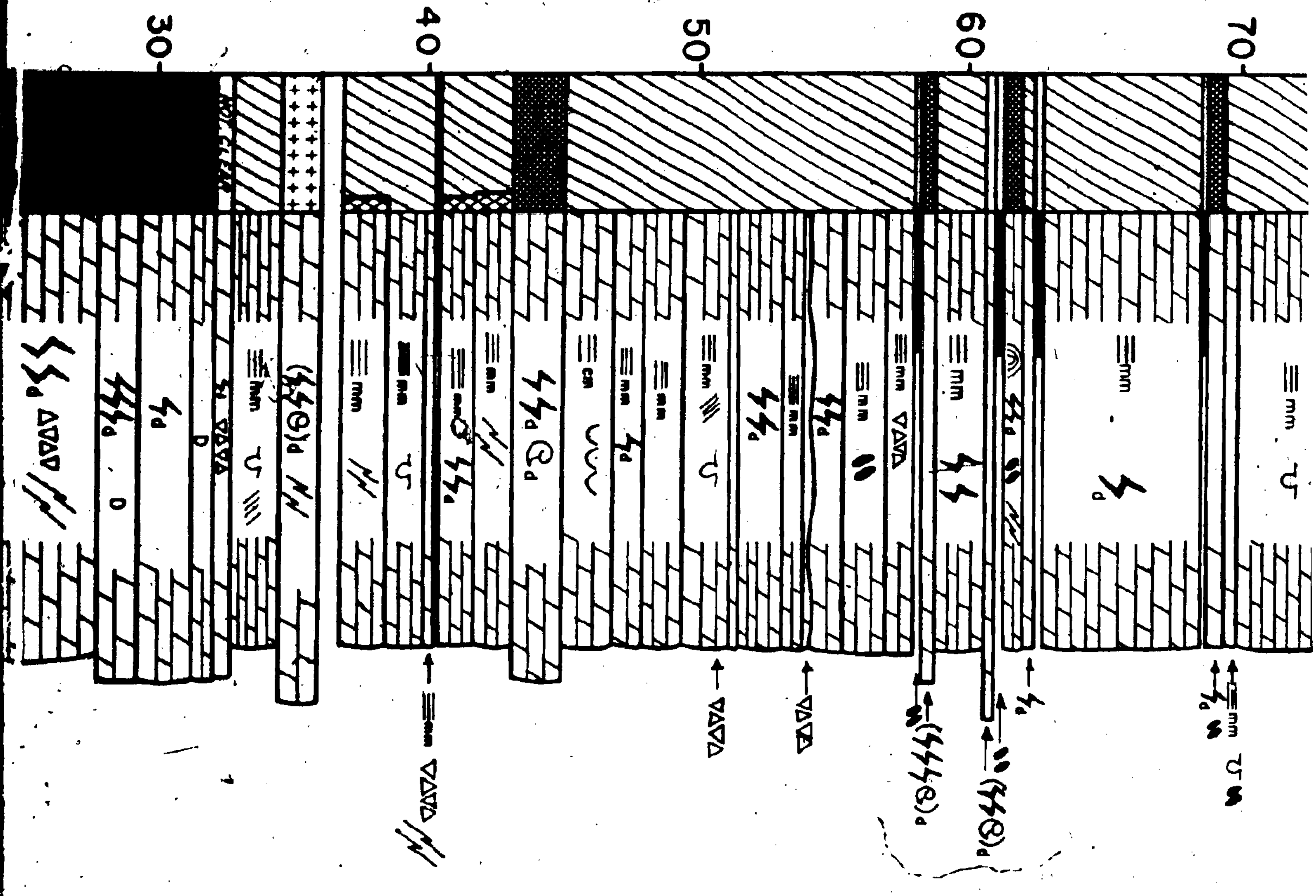
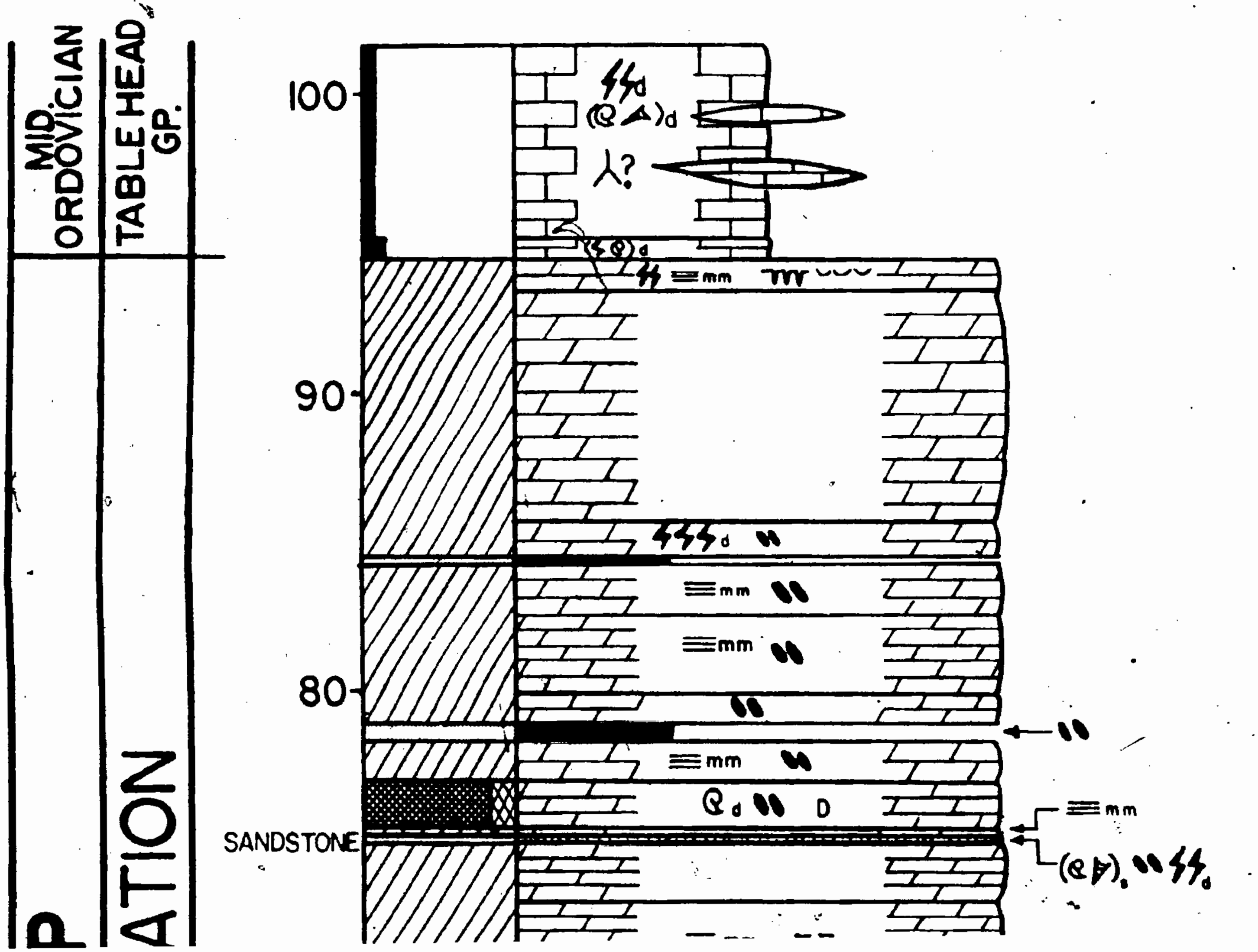


TABLE POINT

(GREAT NORTHERN PENINSULA)



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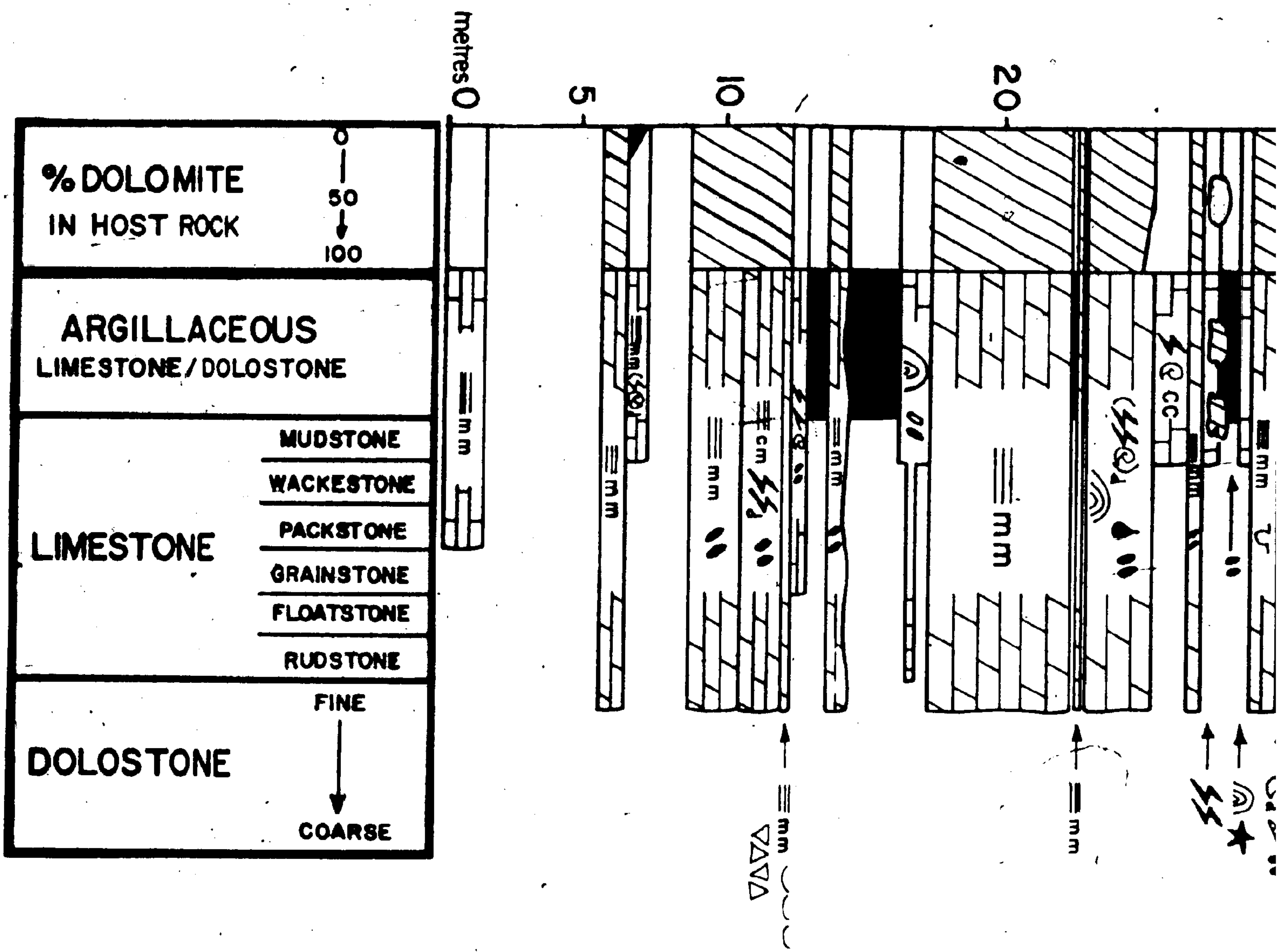
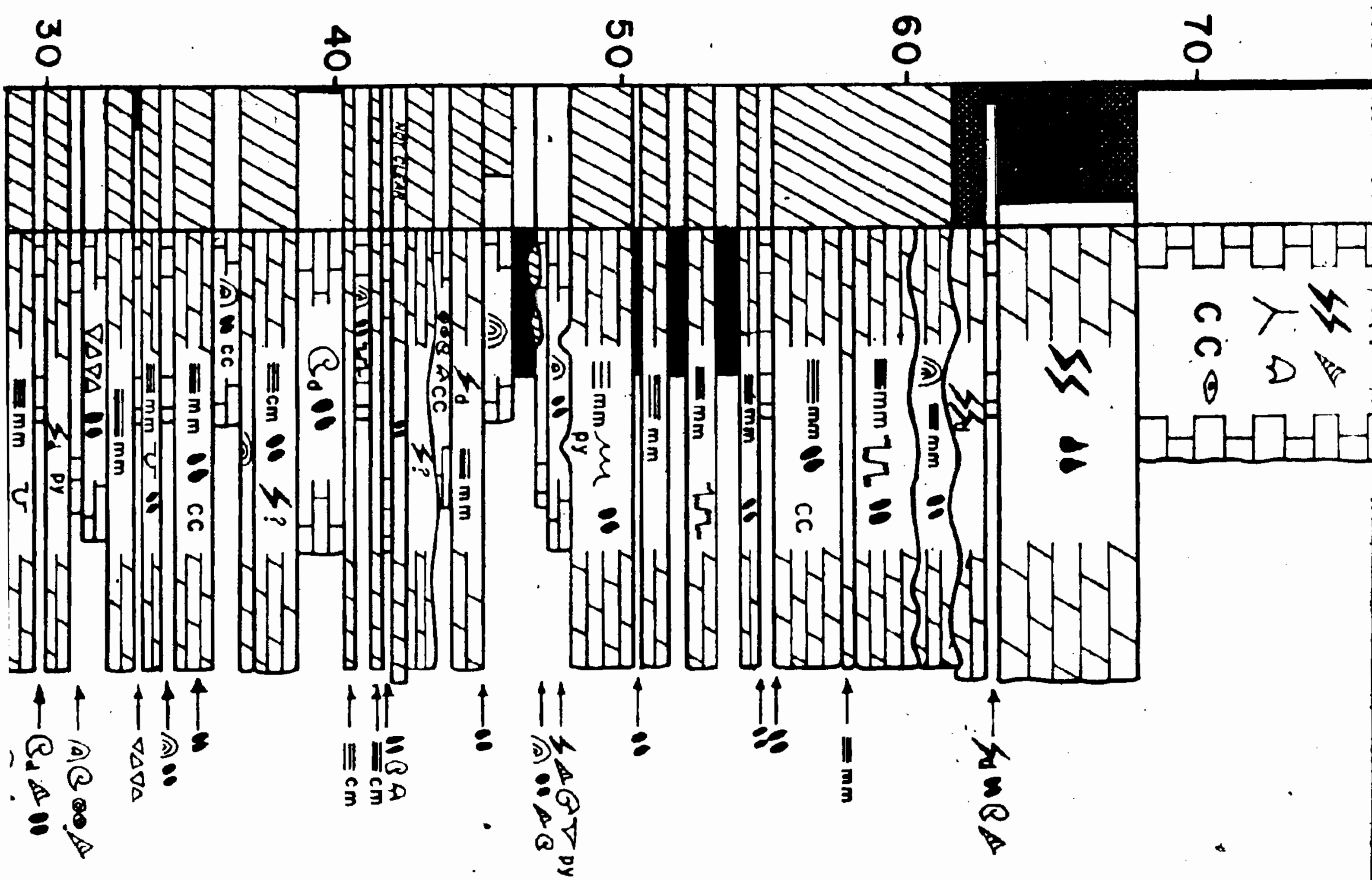
LOWER ORDOVIC

AGUATHU



1 OF/DE

CIAN ST. GEORGE GROUP	MID. ORDOVICIAN
IUNA FORMATION	TABLE HEAD GP.



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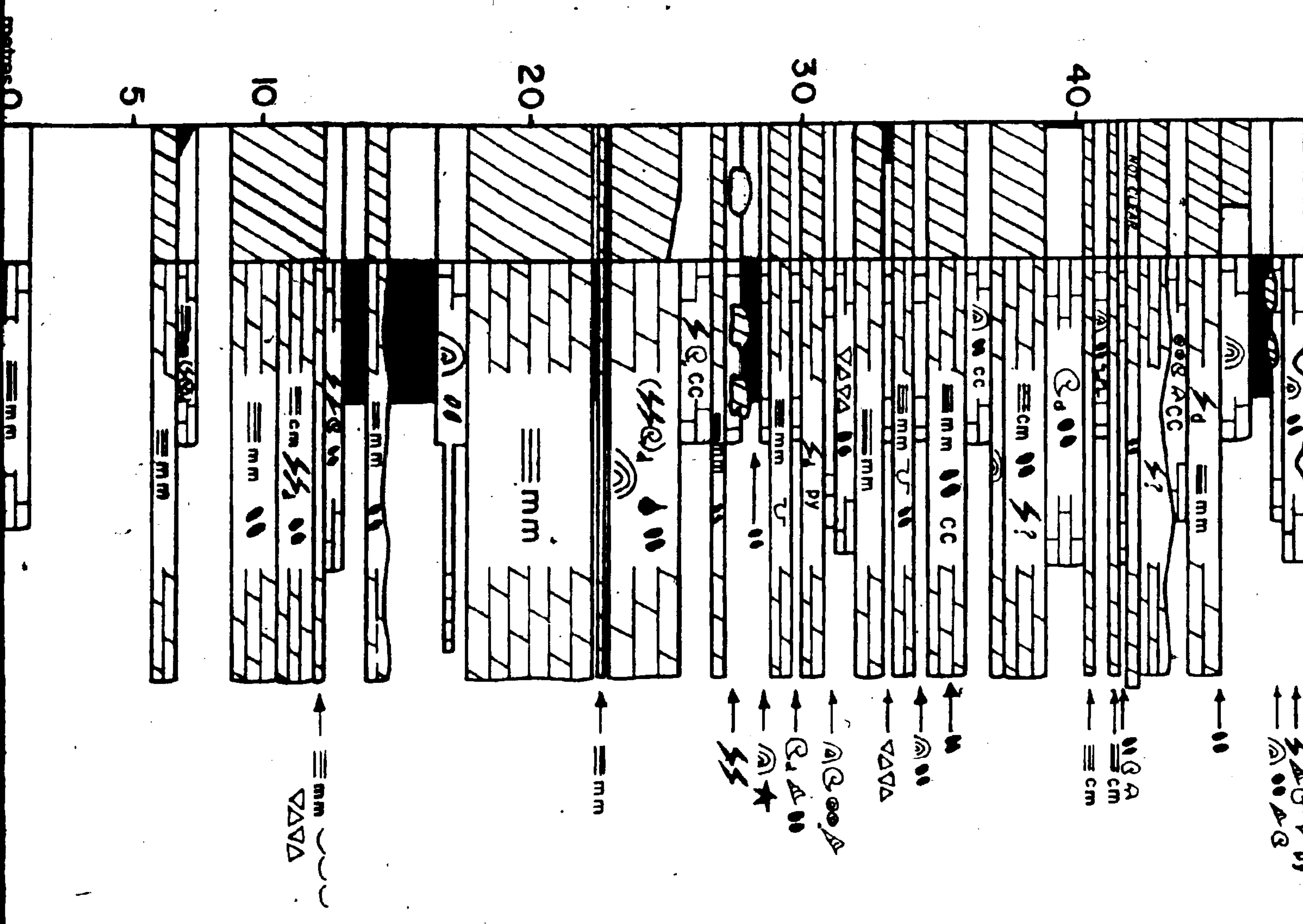
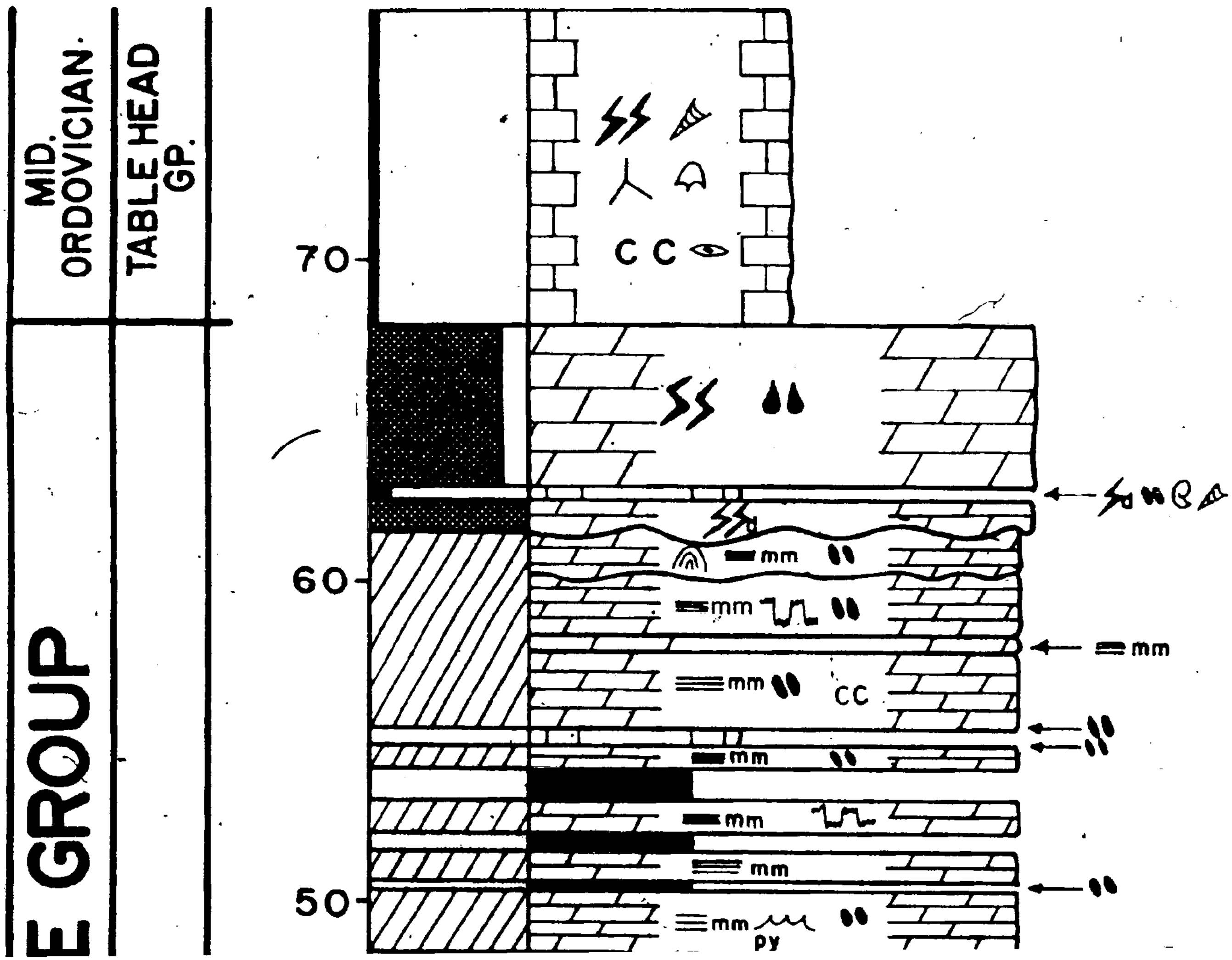
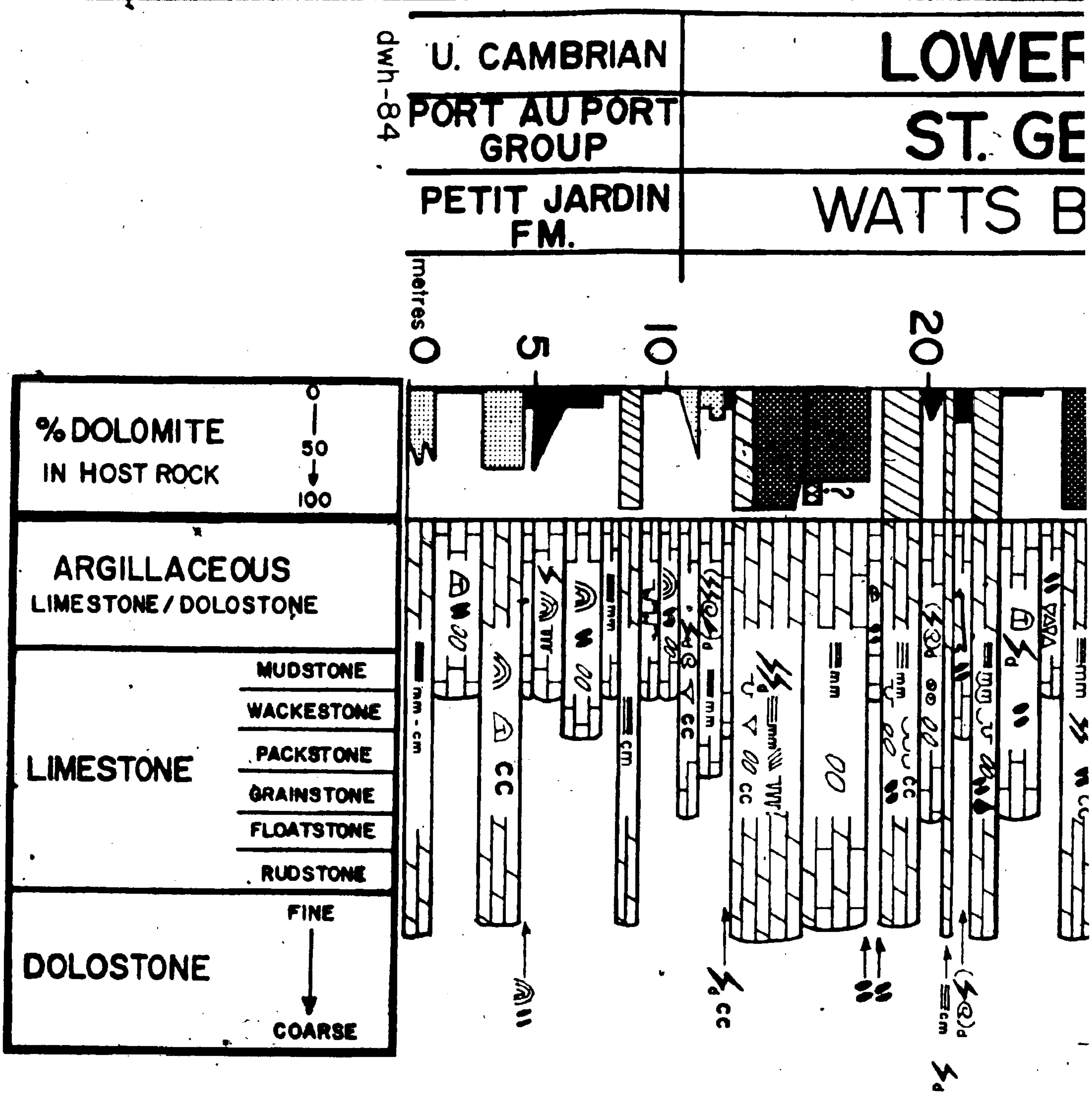
LOWER ORDOVICIAN ST. GEORGI

AGUATHUNA FORMATION



N.W. GRAVELS
(PORT AU PORT PENINSULA)

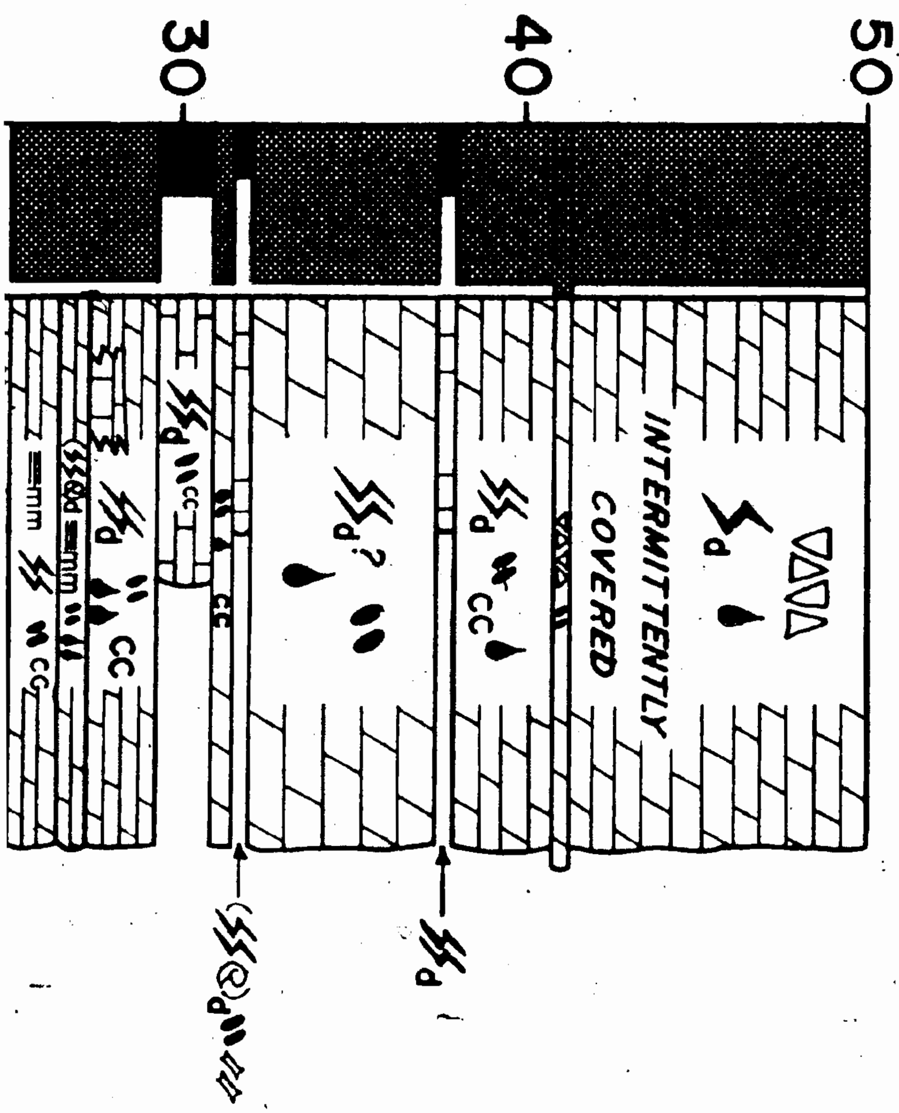



dwh-84
U. CAMBRIAN
LOWEF
PORT AU PORT GROUP
ST. GE
PETIT JARDIN FM.
WATTS B
metres 0
5
10
20
% DOLOMITE IN HOST ROCK
0
50
100
ARGILLACEOUS LIMESTONE / DOLOSTONE
LIMESTONE
MUDSTONE
WACKESTONE
PACKSTONE
GRAINSTONE
FLOATSTONE
RUDSTONE
DOLOSTONE
FINE
COARSE

R ORDOVICIAN

EORGE GROUP

BIGHT FORMATION



BERRY HEAD