DEPOSITION AND DIAGENESIS OF THE UPPER RED RIVER FORMATION (UPPER FORT GARRY MEMBER) AND STONY MOUNTAIN FORMATION (UPPER ORDOVICIAN) NORTH AND WEST OF WINNIPEG, MANITOBA

A Thesis
Submitted to
The Faculty of Graduate Studies
The University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

---

by
Garnet Cecil Grant Wallace

DEPOSITION AND DIAGENESIS OF THE UPPER RED RIVER FORMATION (UPPER FORT GARRY MEMBER) AND STONY MOUNTAIN FORMATION (UPPER ORDOVICIAN) NORTH AND WEST OF WINNIPEG, MANITOBA

BY

GARNET CECIL GRANT WALLACE

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

The upper Ordovician (Richmondian) upper Red River and Stony Mountain Formations were studied in detail from drill core and quarry exposures at Headingley, Stonewall and Stony Mountain, Manitoba. The stratigraphy, depositional history and diagenetic alterations were documented for the upper portion of the Fort Garry Member (Red River Formation) and the Gunn, Penitentiary, Gunton and Williams Member (Stony Mountain Formation).

The upper Fort Garry was deposited in a low to high energy tidal flat setting characterized by clean carbonate sedimentation. Following a period of subaerial exposure at the end of Fort Garry time the Gunn Member was deposited. Sedimentation during Gunn time took place in a shallow marine environment characterized by low energy conditions, an influx of terrigenous material and the development of low-relief mud banks. The lower Penitentiary (deposited conformably upon the Gunn Member) represents shallow but open marine conditions while the upper Penitentiary was deposited in a constantly shallowing lagoonal setting which eventually became subaerially exposed. Sedimentation took place predominantly under low energy conditions with a constant influx of terrigenous material. The Gunton Member at Stony Mountain and Stonewall, Manitoba was deposited in an evaporitic tidal flat setting and a laterally equivalent marine setting respectively. Sedimentation took place in both low and high energy settings in a clean carbonate environment. Following a period of emergence which occurred at the end of Gunton time the Williams Member was deposited. Sedimentation during Williams time took place in a shallow marine setting in which slightly emergent mounds developed. The lower

Williams represents a high energy beach setting and the upper Williams represents a low energy intermound setting which eventually became emergent.

Diagenetic processes such as; borings, burrowing, the development of Phase I cements, some secondary porosity, early (primary) dolomite, authigenic feldspar, length slow chalcedony and some pyrite occurred relatively early in the diagenetic history of the sediments in the eogenetic to shallow mesogenetic environments. The development of chert, some pyrite and hematite, Phase II cement, neomorphic spar, secondary dolomite, and some secondary stylolites occurred later in the diagenetic history of the sediments in the mesogenetic environment. The development of Phase III cement, some secondary porosity and some hematite occurred in the telogenetic environment and represent the last diagenetic processes to occur.

TABLE OF CONTENTS

PAGE

Chapter

PAGE

Chapter

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Chapter 1 INTRODUCTION

Location of Study Area

The study area is located in south central Manitoba north and west of the city of Winnipeg (Figure 1). The majority of data was collected from the City of Winnipeg Quarry located at Stony Mountain, Manitoba. Five sections were measured at this locality. One section was obtained from core hold M-2-69, drilled by the Manitoba Department of Mines, Resources and Environmental Management, while the remaining four sections were obtained from quarry exposures (Plate 1).

Additional sections were obtained from core hole M-1-69, drilled at Stonewall, Manitoba, and core recovered from drill hole M-3-74 taken from a locality approximately 5.6 km north of Headingley, Manitoba.

Small outcrops in the Stony Mountain area along with the Standard Limestone Products Quarry located 1.6 km north of the Stonewall junction on Hwy. 7 also were studied.

Stratigraphic Framework

The Stony Mountain Formation, named by Dowling (1900) is Upper Ordovician in age. Based on paleontological studies by Whiteaves (1895, 1897), Twenhofel (1925), Okulitch (1943), and Nelson (1959 a,b), the Stony Mountain Formation is Richmondian in age (Table 1).

Unconformably overlying the Red River Formation is the Stony Mountain Formation. The Stony Mountain Formation is in turn unconformably overlain by the Stonewall Formation. Though the exact position of the Silurian contact has been located in different parts of the Stonewall

Figure 1: Location of the quarries and drill holes used in this study and the approximate subsurface geological boundaries in the Winnipeg area (Modified from Bannatyne, 1975).

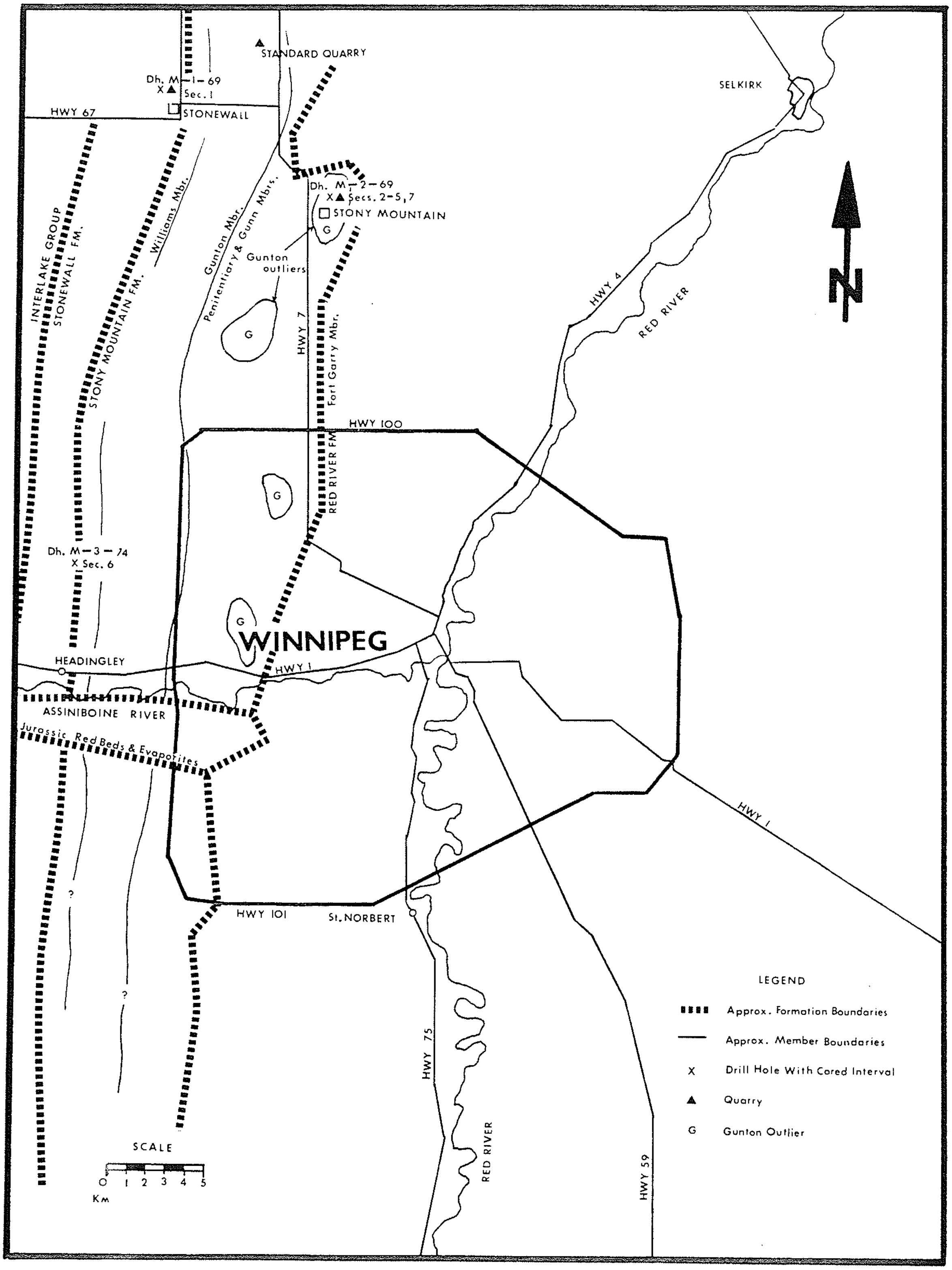

STANDARD QUARRY
Dh. M-1-69
Sec. 1
HWY 67
STONEWALL
SELKIRK
Dh. M-2-69
Secs. 2-5, 7
STONY MOUNTAIN
Gunton outliers
INTERLAKE GROUP
STONEWALL FM.
STONY MOUNTAIN FM.
Williams Mbr.
Gunton Mbr.
Penitentiary & Gunn Mbr.
HWY 7
Fort Garry Mbr.
RED RIVER FM.
HWY 4
RED RIVER
N
HWY 100
Dh. M-3-74
Sec. 6
WINNIPEG
HEADINGLEY
HWY 1
ASSINIBOINE RIVER
Jurassic Red Beds & Evaporites
HWY 101
St. NORBERT
HWY 75
HWY 59
LEGEND
Approx. Formation Boundaries
Approx. Member Boundaries
Drill Hole With Cored Interval
Quarry
Gunton Outlier
SCALE
0 1 2 3 4 5
Km

Table 1: Stratigraphic table of formations encompassing the upper Red River, Stony Mountain, Stonewall and Interlake strata of southwestern Manitoba.

Time Rock Units	Okulitch 1943	Baillie 1952	Porter & Fuller 1959	Smith 1963	Cowan 1971	This Study 1978
Systems / Series / Stages						
Silurian		Interlake Group	Interlake Group		Interlake Group	
	Stonewall Formation	Stonewall Formation	Stonewall Formation	Stonewall Formation	S/O Stonewall Formation	Stonewall Formation
	S/O	S/O	S/O	S/O		S/O
Upper Ordovician / Cincinnatian / Richmondian	Stony Mountain Formation: Birse Member	Stony Mountain Formation: Gunton Member	Stony Mountain Formation: Gunton Member	Stony Mountain Formation: Williams Member	Stony Mountain Formation: Williams Member	Stony Mountain Formation: Williams Member
	Gunton Member			Gunton Member	Gunton Member	Gunton Member
	Penitentiary Member	Penitentiary Member	Stony Mountain Shale Member	Penitentiary Member	Penitentiary Member	Penitentiary Member
	Stony Mountain Shale Member	Stony Mountain Shale Member		Gunn Member	Gunn Member	Gunn Member
		Red River Form. / Selkirk Member	Red River Form. / Upper		Red River Form. / Fort Garry Member	Red River Form. / Fort Garry Member

S/O Silurian/Ordovician contact proposed by the authors.

section by various authors (Table 1), it has been placed at the base of a conglomeratic unit located at the top of the Williams Member. For the purpose of this study the lower Stonewall conglomerate is considered Silurian in age.

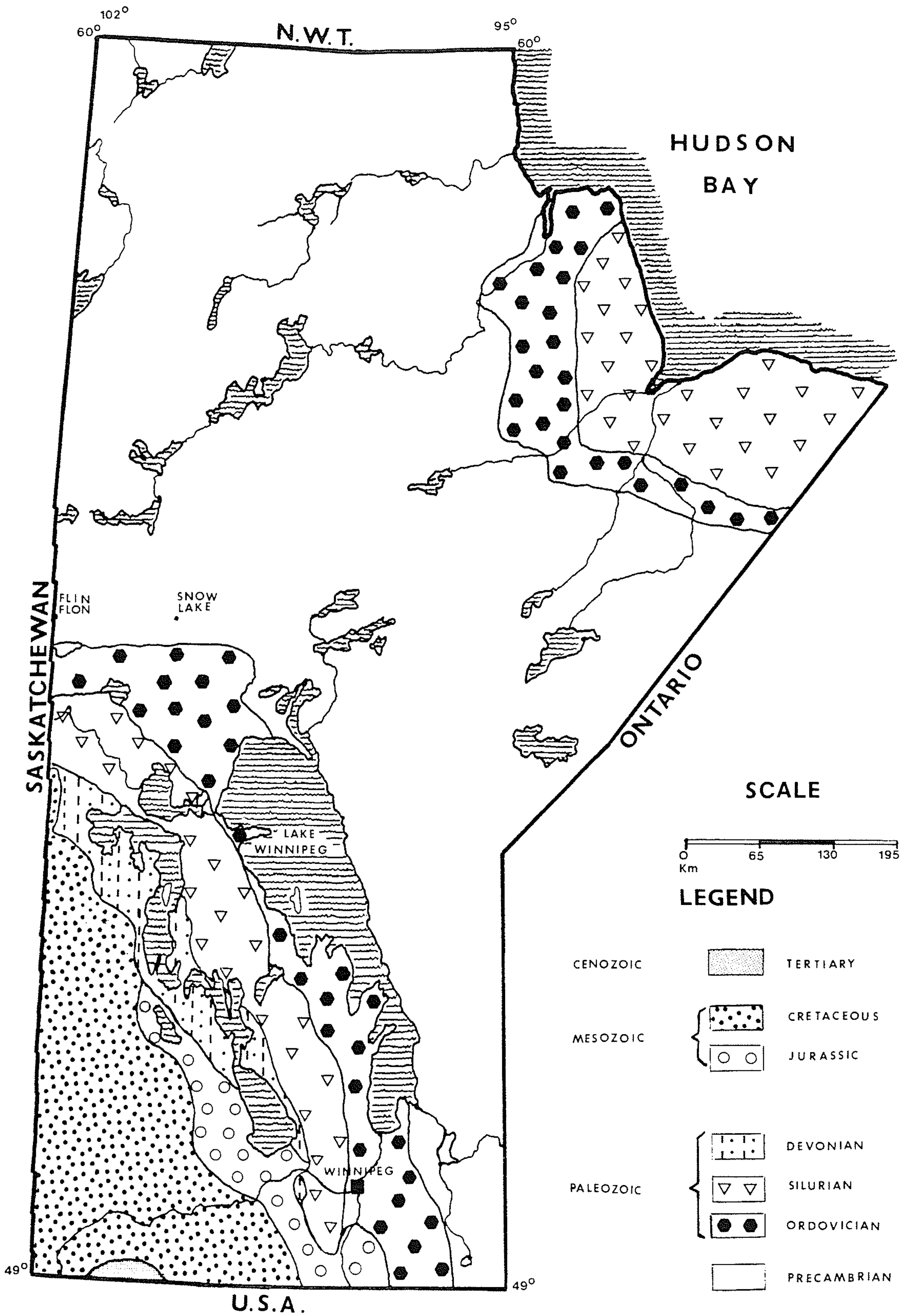
Regional Geology

The Paleozoic strata which outcrops in the northeastern and southwestern corners of the province (Figure 2) unconformably overlies the Precambrian surface.

In the northeastern corner of the province, south-southeast of Churchill, the Paleozoic strata are Ordovician, Silurian and Devonian in age. These rocks are remnants of the sediments deposited within the Hudson Bay Platform during the Paleozoic era. Cumming (1971) noted that these rocks are essentially carbonates and that the Ordovician Churchill River Group is equivalent to the Stony Mountain Formation of southwestern Manitoba.

In the southwestern corner of Manitoba (the ancestorial north-eastern flank of the Williston Basin) Paleozoic, Mesozoic, and Cenozoic strata were originally deposited. However, as a result of many periods of emergence and erosion many portions of the section are absent. The Paleozoic section in this area of the province consist of Ordovician, Silurian, Devonian and Mississippian strata. All but the Mississippian strata are exposed in southwestern Manitoba; this age of strata is present only in the subsurface of the extreme southwestern corner of Manitoba. The remaining portion of the Paleozoic strata have been removed during the pre-Jurassic erosional period.

Figure 2: Geological map of Manitoba (Modified after Manitoba Mines Branch Publication, Map 65-1).


102°
60°
N.W.T.
95°
60°
HUDSON
BAY
FLIN
FLON
SNOW
LAKE
SASKATCHEWAN
ONTARIO
LAKE
WINNIPEG
WINNIPEG
49°
49°
U.S.A.
SCALE
0
65
130
195
Km
LEGEND
CENOZOIC
TERTIARY
MESOZOIC
CRETACEOUS
JURASSIC
PALEOZOIC
DEVONIAN
SILURIAN
ORDOVICIAN
PRECAMBRIAN

The Ordovician outcrop in southwestern Manitoba is exposed in a north-south direction stretching from the United States border along the west shore of Lake Winnipeg. Seventy kilometers north of Lake Winnipeg the outcrop belt changes direction and trends in an east-west direction approximately 30-40 km south of Snow Lake and Flin Flon, Manitoba.

The Ordovician Winnipeg Formation, which overlies the Precambrian erosional unconformity in southwestern Manitoba, is composed of sandstone and interbedded shales. The basal portion is predominantly a sandstone sequence and the upper portion is predominantly shale. The total thickness of this formation is highly variable, ranging from zero to 66 m (McCabe, 1971, p. 171).

Conformably overlying this formation is the early Upper Ordovician Red River Formation. McCabe and Bannatyne (1970) subdivided this carbonate unit into four Members, in ascending order these are; the Dog Head, Cat Head, Selkirk and Fort Garry. The Red River Formation varies in thickness throughout the province from 52.5 to 150 m (McCabe, 1971, p. 171).

Unconformably overlying the Red River Formation is the Upper Ordovician Stony Mountain Formation. Smith (1963) subdivided the Stony Mountain Formation into four Members, in ascending order these are; the Gunn, Penitentiary, Gunton and Williams (Table 1). The Ordovician Silurian contact in this study has been placed at the top of the Williams Member. The Gunn and Penitentiary Members are composed of very argillaceous (up to 35 weight percent illite) and argillaceous (up to 25 weight percent illite) dolomite respectively. The Gunton is the cleanest carbonate member in which the basal 1.5 meters contain 12 weight percent clay and the remaining portion less than 2 weight percent. The Williams Member is a dolomite unit with up to 37 weight percent of arenaceous and argillaceous material. The thickness of the Stony Mountain Formation throughout the province ranges from 33 to 49 m (McCabe, 1971, p. 171).

Unconformably overlying the Stony Mountain Formation is the Stonewall Formation. The Stonewall Formation is predominantly dolomite but contains thin argillaceous beds in the middle and upper portion of the formation. The Stonewall Formation ranges in thickness from 9 to 21 m (McCabe, 1971, p. 171).

Objectives

The main purpose of this study is to provide a detailed examination of the uppermost portion of the Fort Garry Member of the Red River Formation and the Stony Mountain Formation in the Winnipeg area, emphasizing sedimentation and diagenesis. The objectives were to:

(1) provide a detailed petrographic description of these units,

(2) interpret their depositional history, and

(3) document their diagenetic history.

Previous Work

Following the initial study by Dowling (1900) on the Ordovician strata of Manitoba many similar studies have followed. Cowan (1971, Table 1, p. 237) described the evolution of stratigraphic nomenclature for the Ordovician and Silurian in southern Manitoba over the last 77 years. Regional stratigraphic mapping of the Paleozoic by the Geological Survey of Canada and the Manitoba Mines Branch has been documented by McCabe (1971).

Descriptions of the fauna of the Stony Mountain type section, of Richmondian age, are found in Nelson (1975, p. 464-476) and Baillie (1952, p. 32-36).

Local study of the outcropping portion of the Stony Mountain and Stonewall Formations by Smith (1963) indicated that this carbonate succession was subjected to periodic influxes of terrigenous material. The high argillaceous Gunn and Penitentiary Members are thought to represent open marine deposits which gave way to shallower and somewhat hypersaline conditions by middle Gunton time. During deposition of the Williams Member beach mounds developed in which quartz and argillaceous material were deposited. Following a short break in sedimentation a deepening of the waters occurred during Stonewall time allowing the development of small reefs to take place (Smith, 1963).

A regional study of the Ordovician and Silurian Formations around the Cedar Creek Anticline of southeastern Montana led Roehl (1967) to conclude that the environment of deposition of these Formations could be compared to the Recent low-energy marine and subaerial carbonate environments in the Bahamas.

Kendall (1976) studied the Ordovician carbonate succession in southern Saskatchewan and felt that emphemeral tidal flats developed along the marginal periphery of the Williston Basin. Evaporitic brines formed on these tidal flats and migrated basinward during withdrawal of the seas. This resulted in the formation of anhydrite beds which marked the end of a cyclic depositional period in the subtidal environment.

Methods of Study

The field work consisted of describing four quarry sections and one drill core (M-2-69) at Stony Mountain, Manitoba and drill core at Stonewall (M-1-69) and Headingley (M-3-74), Manitoba. From the total 153 m of measured sections 225 samples were collected.

Two hundred and twenty-five polished slabs were prepared and etched in mild hydrochloric acid from which 175 slabs were selected for thin section study and 50 slabs for acetate peel preparation. All thin sections were stained with potassium ferricyanide and alizarian red S (Dickson, 1965) to identify ferroan and non ferroan calcite and dolomite. Five hundred to six hundred point counts per thin section were used for modal analysis of selected slides.

X-ray diffraction analysis was used to identify carbonate and terrigenous minerals. X-ray diffraction analysis was also used to provide semi-quantitative measurements of the weight percent calcite in dolomite according to Royse et al. (1971).

Acknowledgements

The author wishes to acknowledge the advice and aid given to him by his advisors; Dr. R. S. Harrison, Dr. P. Laznicka, Dr. H. McCabe in the preparation of this manuscript. Financial support was supplied by Dr. R. S. Harrison of the University of Manitoba for the preparation of the photographic plates.

The author is indebted to Dr. H. McCabe and the Manitoba Mines Branch for permission to work in the government core storage facilities at the University of Manitoba and for supplying the three drill cores that penetrated Stony Mountain Formation.

Field assistants: Messrs. G. Gerelus, G. Webster and J. Pedora provided valuable aid during various trips to the field.

Technical aid was supplied by the support staff at the Dept. of Earth Sciences at the University of Manitoba. R. Pryhitko provided valuable photographic assistance. K. Mysyk provided instruction and assistance on the use of the x-ray diffractometer.

The author especially wishes to acknowledge the constructive comments and discussions which occurred while at the University of Manitoba among his fellow colleagues in the Carbonate Research Group.

Special thanks must be given to the author's wife, Patricia Wallace, who typed the initial manuscript and for her understanding nature throughout the preparation of this manuscript.

Lastly, the author wishes to acknowledge John Pedora for his constructive comments leading to the preparation of the final manuscript and Susan Pedora for typing the final draft.

Chapter 2 STRATIGRAPHY AND DEPOSITIONAL HISTORY

Introduction

The upper Red River Formation and Stony Mountain Formation are carbonate units with varying amounts of terrigenous material. Figure 3 demonstrates that the insoluble residue content ranges from less than 1 to 35 weight percent in the sections measured. This chapter will discuss the lithological variations of the carbonate rock types characteristic of each formation and document their environmental interpretation.

Red River Formation

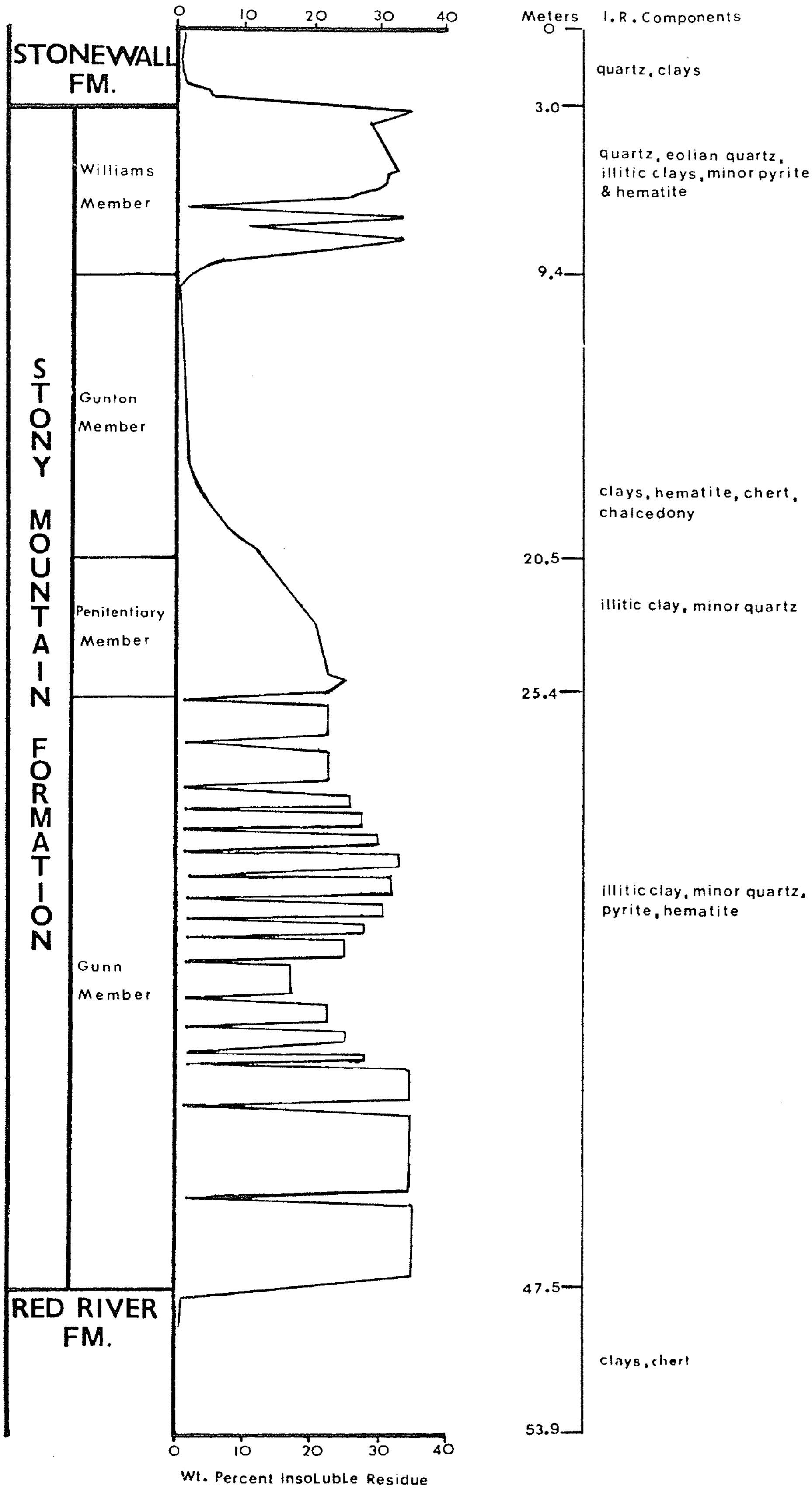
Fort Garry Member

Introduction

The upper Fort Garry Member of the Red River Formation near Winnipeg can be divided informally into an upper dolomite and an overlying upper limestone unit (McCabe, personal communication, 1976). Drill core of the upper Fort Garry Member was taken at Section 6 and 7. As shown in Figure 4 (back pocket) the deepest drill core of the Fort Garry Member was obtained at Section 6 measuring 6.3 m while the core hole at Section 7 recovered approximately 3.9 m. The upper limestone unit varies from 1.3 to 3.0 m respectively as shown in Figure 4 (back pocket).

The upper contact of the Fort Garry Member in the study area is a sharp well defined surface. The variations in thickness of the upper limestone unit, the nature of the contact and the sharp lithologic change (see Figure 3) in the overlying Gunn Member of the Stony Mountain

Figure 3: Insoluble residue (in weight percent) in the interval between the top of the Red River Formation and the lower portion of the Stonewall Formation.


0 10 20 30 40
Meters
I.R. Components
STONEWALL FM.
quartz, clays
3.0
Williams Member
quartz, eolian quartz, illitic clays, minor pyrite & hematite
9.4
STONY MOUNTAIN FORMATION
Gunton Member
clays, hematite, chert, chalcedony
20.5
Penitentiary Member
illitic clay, minor quartz
25.4
illitic clay, minor quartz, pyrite, hematite
Gunn Member
47.5
RED RIVER FM.
clays, chert
53.9
Wt. Percent Insoluble Residue

suggest that the upper contact is an erosional surface.

Stratigraphy

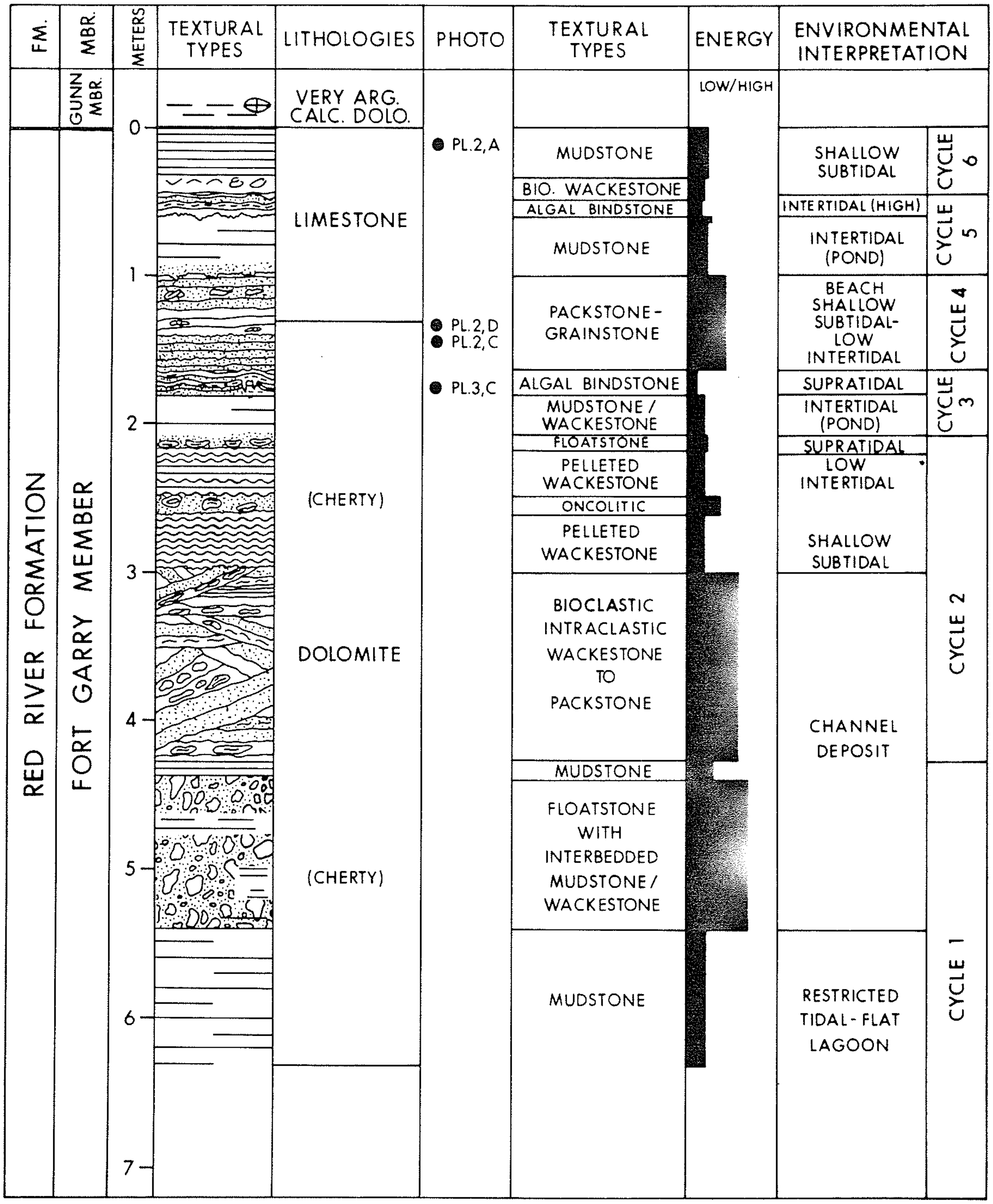
Figure 3 shows that the upper Fort Garry Member is a clean carbonate. Insoluble residue analysis of the upper limestone unit reveals that less than 1 weight percent insoluble residue is present. Clay is the insoluble residue in the upper limestone unit whereas clay and chert characterize the underlying dolomite unit.

The diagrammatic stratigraphic section presented in Figure 5 displays the textural types of carbonate rocks which are present in the drill core of the Fort Garry interval of Section 6 (M-2-69). Lithologies, textural types (based on Embry and Klovan's (1971) classification system for carbonate rocks), energy conditions and environmental interpretations are discussed.

The basal 0.90 m of the Fort Garry Member is composed of a thickly bedded uniformly dense carbonate mudstone similar to the mudstone displayed in Plate 2, Figure A. White chert nodules (up to 3 cm in size) are found along the bedding planes of this interval. Bivalve remnants, crinoid ossicles, unknown skeletal debris and scatter pellets comprise less than 5 percent of the interval.

Overlying the mudstone interval is a 1 m thick unit composed of a crudely bedded, dark grey, intraclastic floatstone with minor interbedded pale yellow mudstone to wackestone. Scattered throughout the interval are white chert nodules similar to those in the underlying mudstone. The intraclasts are randomly oriented, range from 0.3 to greater than 2.5 cm in size, are rectangular to equant in shape, angular to subangular and form the main component in beds which range from 15 to

Figure 5: A diagrammatic stratigraphic section of the Fort Garry interval measured from Section 6. (Headingley, Manitoba)


FM.
MBR.
METERS
TEXTURAL TYPES
LITHOLOGIES
PHOTO
TEXTURAL TYPES
ENERGY
ENVIRONMENTAL INTERPRETATION
GUNN MBR.
VERY ARG. CALC. DOLO.
LOW/HIGH
RED RIVER FORMATION
FORT GARRY MEMBER
0
1
2
3
4
5
6
7
LIMESTONE
(CHERTY)
DOLOMITE
(CHERTY)
PL.2,A
PL.2,D
PL.2,C
PL.3,C
MUDSTONE
BIO. WACKESTONE
ALGAL BINDSTONE
MUDSTONE
PACKSTONE-GRAINSTONE
ALGAL BINDSTONE
MUDSTONE / WACKESTONE
FLOATSTONE
PELLETED WACKESTONE
ONCOLITIC
PELLETED WACKESTONE
BIOCLASTIC INTRACLASTIC WACKESTONE TO PACKSTONE
MUDSTONE
FLOATSTONE WITH INTERBEDDED MUDSTONE / WACKESTONE
MUDSTONE
SHALLOW SUBTIDAL
INTERTIDAL (HIGH)
INTERTIDAL (POND)
BEACH SHALLOW SUBTIDAL-LOW INTERTIDAL
SUPRATIDAL
INTERTIDAL (POND)
SUPRATIDAL
LOW INTERTIDAL
SHALLOW SUBTIDAL
CHANNEL DEPOSIT
RESTRICTED TIDAL-FLAT LAGOON
CYCLE 6
CYCLE 5
CYCLE 4
CYCLE 3
CYCLE 2
CYCLE 1

20 cm in thickness.

Unidentified fossil debris, crinoid ossicles and bivalve remains comprise less than 5 percent of the interval and occur in both intraclasts and matrix. Thin horizontal shale partings are present in minor amounts throughout this interval.

The contact between the floatstone and underlying mudstone interval is not exposed in the drill core, however, the rather sudden change in component size over such a short interval suggests that the contact is a scoured surface.

Gradationally overlying the floatstone is a thin bedded mudstone interval, 13 cm thick, containing 2 cm thick white chert nodules along the bedding planes and a distinct absence of fossil remains.

Succeeding this is a 1.31 m thick interval of bioclastic-intraclastic wackestone to packstone. This unit is characterized by moderate to high angle cross bedding (20^{o} to 30^{o}), scoured surfaces, slumping fabrics and undulating bedding surfaces. The skeletal components consist of unknown debris, highly comminuted bivalve remains, crinoid ossicles, gastropods and algal mat fragments. The intraclasts vary in size and shape, are characteristically tabular in form, and are predominantly carbonate, although some are composed of very argillaceous carbonate. Scattered throughout the allochems are pellets of unknown origin.

Overlying the upper scoured surface of the bioclastic-intraclastic wackestone to packstone interval is a 0.76 m thick interval of pelleted wackestone. This interval is characterized by thin bedding and small scale ripples. Interbedded within this interval (see Figure 5) is a thin bed of concentric laminated oncolitic structures less than 0.5 cm in size. White chert nodules developed parallel to bedding are present in the lower 40 cm of this interval.

Faunal allochems are mainly unknown debris, bivalve remains and to a lesser extent, small low spired gastropods and crinoid remains. Pellets may have originally been more abundant in this interval but have been obscured by dolomitization.

Overlying the pelleted wackestone to mudstone is a 3 cm thick floatstone interval composed of finely laminated mudstone with desiccated intraclasts up to 2 cm in length and 0.6 cm in thickness.

Immediately above the floatstone is a uniformly dense carbonate mudstone interval 0.33 m thick. The mudstone is characterized by a homogenous but somewhat mottled appearance, a very minor biological component and moderately thick horizontal bedding.

The succeeding 14 cm interval is composed of a very finely laminated algal bindstone. As seen in Plate 3, Figure 3, the algal bindstone is characterized by desiccation features, birdseye structures and the development of fenestral porosity. Between some laminae very minor micro-intraclastic and bioclastic debris has accumulated.

Figure 5 shows that the overlying 0.70 m thick interval is a thinly bedded packstone to grainstone. The interval is characterized by thin low angle cross bedding, small scale graded bedding, scoured surfaces and a parallel alignment of intraclasts to bedding plane surfaces. The interval is dominated by the presence of peloids, intraclasts and well developed moldic porosity after peloids (Pl. 2, Figs. C and D; Pl. 10, Fig. D respectively). Some of the peloids which have not been highly altered during diagenesis have an internal microstructure which indicates they were originally oolites.

The intraclasts are extremely variable in size, shape and composition; however, the majority are composed of dolomite. The intraclasts may be finely laminated or composed of dense dolomite mud. A unique intraclast found only in this interval is composed of argillaceous dolomite and contains finer, subangular to angular intraclasts of the same material (Pl. 2, Fig. D).

The skeletal components are comprised of unknown debris, bivalve remains, and to a lesser extent, gastropods and crinoid pieces. In all cases the biological components are highly comminuted.

Succeeding the packstone to grainstone interval is a 0.56 m interval of limestone mudstone and algal bindstone. The 0.40 m interval immediately overlying the packstone to grainstone interval is comprised of a uniformly dense, thickly bedded, non-fossiliferous mudstone. This mudstone is similar to the overlying mudstone shown in Plate 2, Figure A except that the bedding is thicker. Immediately overlying the mudstone is a 16 cm interval comprised of a poorly preserved algal bindstone. This interval is characterized by burrowing, ripped up algal mat intraclasts and poorly preserved fenestral porosity.

Overlying the algal bindstone is a 15 cm thick bioclastic wackestone. This interval contains disarticulated and articulated thin-shelled bivalves, gastropods and large quantities of pellets floating in a mudstone matrix.

Succeeding the bioclastic wackestone and forming the uppermost bed of the upper Fort Garry Member is a 29 cm interval of thinly bedded non-fossiliferous carbonate mudstone. As shown in Plate 2, Figure A the mudstone has a very dense uniform appearance and lacks sedimentary structures.

The upper contact is a sharp surface which separates the very clean limestone of the Fort Garry Member of the Red River Formation from the very argillaceous calcareous dolomite of the overlying Gunn Member of the Stony Mountain Formation.

Environmental Interpretation

The upper Fort Garry Member has been interpreted to have been deposited in a clean carbonate tidal flat setting. Textural rock types and their stratigraphic sequences compare favorably with Recent tidal-flat sequences in the Bahamas (Roehl, 1967; Shinn et al., 1969; Gebelein, 1974) and Persian Gulf (Loreau and Purser, 1973). As shown in Figure 5 the upper Fort Garry may be interpreted in two ways. Firstly, this portion of the Fort Garry may represent a prograding tidal flat complex which kept pace with minor transgressive fluctuations. By the end of Fort Garry time the seas had withdrawn leaving much of the surrounding area exposed. Alternatively, this portion of the Fort Garry may represent six cycles of regressive sedimentation. Each cycle being initiated in the shallow subtidal or restricted lagoonal environment and ending in the intertidal to supratidal zone during a period of emergence.

The first hypothesis, left column, as shown in Figure 5 would envisage the basal 0.90 m of the section to represent a low energy environment. The absence of fossil remains, burrows and the predominance of the mud component suggests a restricted tidal-flat lagoon or subtidal setting.

The overlying 2.45 m interval has been interpreted to represent a high energy tidal flat channel deposit. As is the case with Bahamian channels (Roehl, 1967), this interval is characterized by a fining upward sequence, cross bedding in the upper portion of the channel along with scoured surfaces, slump structures and varied grain constituents.

Deposited on the channel strata is a 0.76 m thick pelleted wackestone interval. Interbedded within the central portion of this unit is a 10 cm thick oncolite pelleted wackestone. The predominance of pellets, the gentle rippled nature of the strata and the stratigraphic position of this interval suggest that this interval was deposited in a shallow subtidal to intertidal environment during a minor transgressive event. Energy conditions were generally low except during the time the oncolitic pelleted wackestone interval was deposited. Bathurst (1971) noted that the development of oncolites takes place in the intertidal to shallow subtidal environment under moderately high energy conditions.

The overlying 3 cm thick floatstone interval has been interpreted as a supratidal lag deposit that developed under low energy conditions during a short period of emergence. The intraclasts are thin wafer-like clasts with upturned edges. Similar clasts have been documented in the supratidal environments of tidal-flat complexes in the Persian Gulf (Purser, 1973) and the Bahamas (Shinn et al., 1969; Gebelein, 1974).

The remaining 2.1 m of the upper Fort Garry Member represents a repetitive sequence of short lived inundations followed by even shorter periods of emergence as shown in Figure 5. The final period of emergence which is interpreted to have occurred at the end of Fort Garry time is not preserved in the record due to the erosional nature of the transgressive sea which initiated sedimentation during Gunn time.

The second hypothesis concerning the environmental interpretation of the upper Fort Garry Member calls for deposition to occur in a series of regressive cycles identified as cycles 1 through 6. Each cycle is initiated in the subtidal environment following a period of extreme shallowing or emergence. The termination of each cycle is reached when the cycle reaches an emergent phase.

The second hypothesis differs from the first in the interpretation of the lower 3.35 m of the Fort Garry Member. The first cycle would include the basal mudstone, overlying floatstone and the overlying mudstone. This hypothesis discounts the existence of a tidal flat channel deposit; instead, the basal mudstone would be interpreted as a subtidal deposit which was overlain by a shallow subtidal to intertidal floatstone deposit. This deposit would then be overlain by a restricted lagoonal mudstone deposit which would mark the end of the first cycle.

The second cycle would then include the bioclastic-intraclastic wackestone to packstone, the pelleted wackestone and the overlying floatstone. In this interpretation the bioclastic-intraclastic wackestone to packstone unit would be interpreted to represent a high energy subtidal to shallow subtidal deposit which was overlain by a low energy intertidal pelleted wackestone. The end of the second cycle would be marked by the deposition of the overlying floatstone unit.

The environmental interpretation of cycles 3 through 5 match the proposed interpretation of the first environmental hypothesis. Cycle 6 marks the last regressive sequence of the upper Fort Garry Member. Following emergence of unknown duration at the end of the Fort Garry time the seas inundated the Winnipeg area during Gunn time.

Stony Mountain Formation

Gunn Member

Introduction

Overlying the Fort Garry Member of the Red River Formation is the Gunn Member of the Stony Mountain Formation. The sharpness of the contact and the sudden lithological change (representing a subtidal deposit over a tidal-flat setting of the Fort Garry Member) suggests that the upper contact of the Fort Garry Member is an erosional surface.

Though each outcrop section provided data on the upper 0.5 to 4.0 m of the Gunn Member, the complete Gunn interval was obtained from drill cores taken from Section 6 and 7. Analysis of the drill core indicate that the Gunn Member in the study area is approximately 22 m thick.

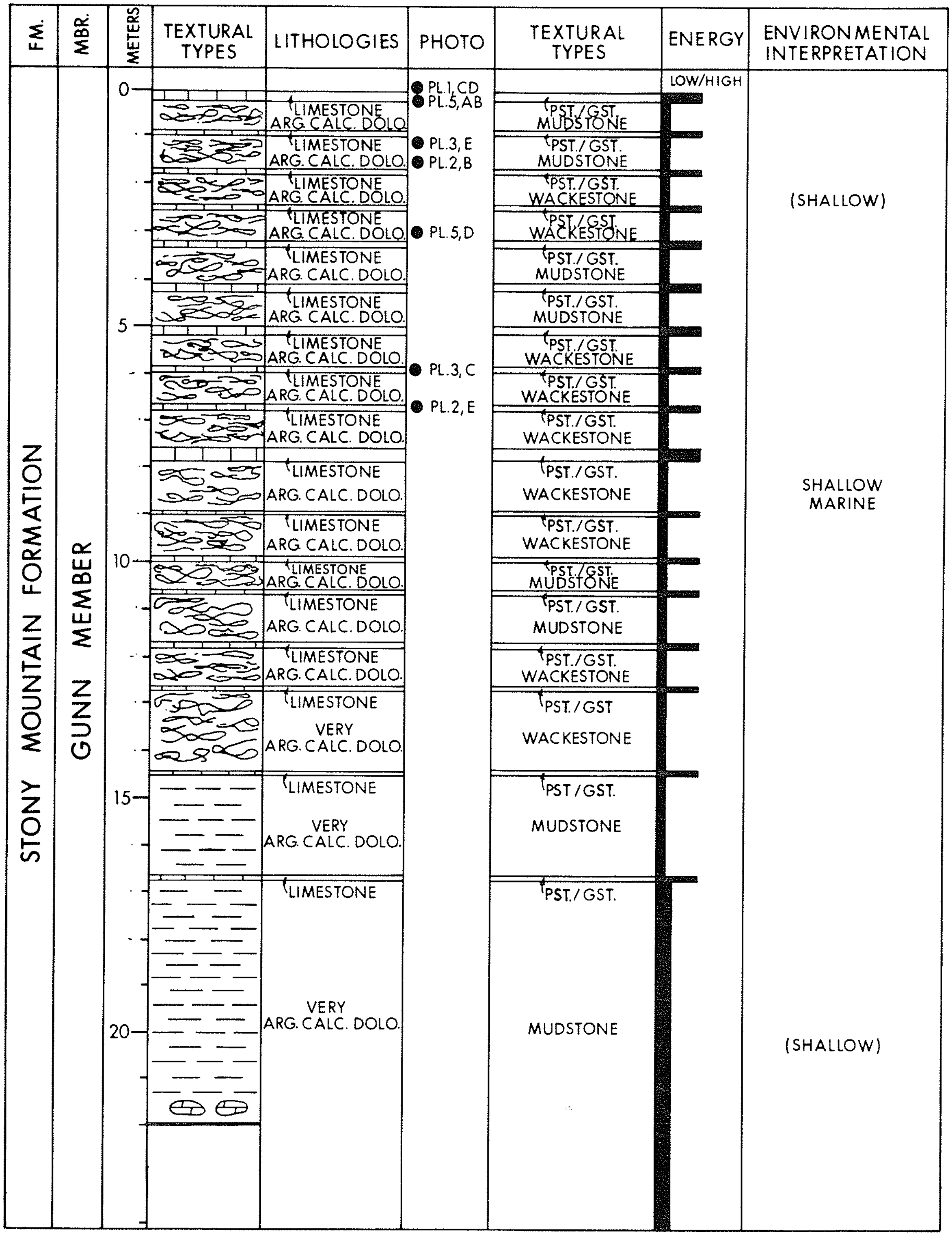
Stratigraphy

As can be seen in Figure 3 the rapid transgressive event of the Gunn time was accompanied by the influx of large amounts of terrigenous material. The terrigenous component consists mainly of illitic clays, iron oxide and minor quartz (Smith, 1963; Roehl, 1967; Booth and Osborne, 1971). These components comprise 17 to 35 weight percent of the Member and some intervals have as low as 1 to 3 weight percent insoluble residue. The influx of terrigenous material begun at Gunn time and continued to the end of the Penitentiary time.

From the diagrammatic stratigraphic section of the Gunn Member (Figure 6) it can be seen that two lithological units are present. An argillaceous calcareous dolomite forms the predominant lithological type while the remaining portion of the Gunn is made up of extremely clean limestone to calcareous dolomite.

The argillaceous calcareous dolomite contains 17 to 35 weight percent insoluble residue. X-ray analysis of this portion of the

Figure 6: A diagrammatic stratigraphic section of the Gunn Member measured from Section 7. (Stony Mountain, Manitoba). PST/GST, Packstone/ Grainstone textural rock types.



F.M.
MBR.
METERS
TEXTURAL TYPES
LITHOLOGIES
PHOTO
TEXTURAL TYPES
ENERGY
ENVIRONMENTAL INTERPRETATION
LOW/HIGH
STONY MOUNTAIN FORMATION
GUNN MEMBER
0
5
10
15
20
LIMESTONE
ARG. CALC. DOLO.
VERY
ARG. CALC. DOLO.
PL.1, CD
PL.5, AB
PL.3, E
PL.2, B
PL.5, D
PL.3, C
PL.2, E
PST./GST.
MUDSTONE
WACKESTONE
(SHALLOW)
SHALLOW
MARINE
(SHALLOW)

Gunn Member indicates that dolomite comprises 65 to 80 weight percent of the carbonate fraction and calcite constitutes the remaining 20 to 35 weight percent. This lithological variety comprises 85 percent of the Gunn Member as carbonate mudstones or wackestone.

The thin limestone to calcareous dolomite intervals contain 1 to 3 weight percent insoluble residue. This portion of the Gunn Member occurs in a fine grained bioclastic packstone to grainstone and a medium to coarse grained bioclastic packstone to grainstone unit. X-ray analysis indicates that the fine grained variety contains 55 to 60 weight percent dolomite and 40 to 45 weight percent calcite. The coarse grained packstone to grainstone is composed of 98 to 99 weight percent calcite and 1 to 2 weight percent dolomite. This lithological variety comprises approximately 15 percent of the Gunn section.

The Gunn section is composed predominantly of wackestone (50 percent), mudstone (35 percent) and minor (15 percent) interbedded packstone to grainstone beds (Figure 6).

Mudstones contain less than 5 to 10 percent fossil remains which are well preserved (disarticulate and articulate). Brachiopods (both phosphatic and calcitic remains) pelecypod shells, crinoid pieces, horn corals, broken colonial corals, bryozoans and minor amounts of gastropods are the main faunal allochems. Rare cephalopods (Pl. 6, Figs. A and B) and Paleofavosites colonies are present also in the mudstone portion of the Gunn.

The mudstone is pale purple to maroon or dusky red on weathered outcrop surfaces and is reddish brown in the subsurface. Burrows (Pl. 2, Fig. B) are common throughout all mudstone portions of the member except the lower 3 to 4 m where thin horizontal bedding is present. The burrows are 0.1 to 0.2 cm in diameter, rimmed with hematite, contain pyrite and are characterized by ellipsoidal to subspherical cross sections and a pale greenish grey colour.

Wackestone differs from mudstone portions of the Gunn mainly in the proportion of faunal allochems. Wackestones may have up to 50 percent faunal components (Pl. 2, Fig. E). Bioturbation is demonstrated by disoriented faunal remains. Where bivalves are disarticulated the bivalve is oriented convex up, giving rise to a shelter pore space and the development of a geopetal fabric (Pl. 8, Figs. A to D).

The packstone to grainstone textural type is the least abundant of the three rock types found in the Gunn Member. Figure 6 displays the 17 thickest packstone to grainstone intervals in the Gunn Member. This portion of the Gunn is medium to light grey in colour and very resistant to weathering. The basal contact of the unit is a sharp, flat, scoured surface (Pl. 1, Figs. C and D). The upper contact is also sharp but is undulating and somewhat rippled (Pl. 1, Fig. D). These units range in thickness from 3 to 12 cm and are characterized by thin horizontal to inclined bedding, ripples, low angle cross bedding, microscoured surfaces, small scale graded bedding and in some cases climbing ripples (Pl. 3, Figs. C to E). The thin sheet-like bedform of the packstone to grainstone units vary in lateral extent to as large as 150 by 70 m in the quarries at Stony Mountain, Manitoba. Also characteristic of these intervals are the epilithic and endolithic lebenspurren (Seilacher, 1964)(Pl. 5, Fig. A to C) which occur on and within the packstone to grainstone beds.

The biological components of this unit are varied and display a high degree of comminution (Pl. 5, Fig. D; Pl. 7, Figs. C to F), unlike the mudstone or wackestone. Modal analysis (Appendix C) indicates that the allochems comprise 44 to 59 percent, matrix 10 to 37 percent, and cement 16 to 45 percent. Within the thicker packstone beds (greater than 6 cm), thin grainstone beds composed of allochems and cement are present (Pl. 6, Fig. D; Pl. 7, Figs. C to F). Allochems are composed of highly comminuted bioclastic debris: disarticulate bivalve shells which are not as highly comminuted but have been subjected to algal boring, brachiopod shells, (Pl. 5, Fig. D) some of which are micritized, crinoid pieces, whole solitary corals, rare broken colonial corals, bryozoans and complete high spired gastropods (Pl. 3, Fig. C).

Environmental Interpretation

The Gunn Member of the Stony Mountain Formation has been interpreted to represent a low energy shallow marine deposit characterized by the influx of relatively large amounts of terrigenous material. These conditions developed as a result of the marine transgression which followed a period of emergence at the end of Fort Garry time.

As noted above, the Gunn Member is made up of three textural rock types; wackestones, mudstones and packstones to grainstones. The wackestone (Pl. 2, Fig. E) represents the most dominant textural type (Figure 4 (back pocket); Figure 6) and has been interpreted to represent a relatively normal subtidal marine environment. Energy conditions were relatively low but water circulation was sufficient to allow the development of a large and diversified faunal community.

The mudstone (Pl. 2, Fig. B) represents the second most dominant textural type (Figure 4 (back pocket); Figure 6) and has been interpreted to represent two depositional environments. As shown in Figure 6 the lower 3 to 4 m of the Gunn Member is characterized a mudstone with well developed thin bedding. This interval has been interpreted to represent a shallow subtidal marine environment characterized by a relatively fast sedimentation rate and a large terrigenous component. These two factors inhibited to development of any large faunal community during the lower Gunn time. Where the mudstones are highly burrowed they have been interpreted to represent a somewhat restricted lower energy subtidal marine environment characterized by a slow sedimentation rate (Howard, 1975).

The packstone to grainstone (Pl. 1, Figs. C and D; Pl. 3, Figs. C and D; Pl. 5, Figs. A and B) intervals are the least dominant textural type present in the Gunn Member. These units have generally been interpreted as storm lags deposited under high energy conditions over short periods of time (Smith, 1963; Kendall, 1976; Leith, personal communication, 1976) in the subtidal environment. However, the presence of climbing ripples and the other prominant sedimentary structures in some packstone to grainstone intervals does not fully support the above interpretation. Similar packstone to grainstone deposits have been noted in the Florida Keys where very low relief mud banks are rimmed with such deposits (Harrison, personal communications, 1978). The action of waves encroaching upon the slightly submergent mud banks is interpreted to have deposited the carbonate grains as sheets or aprons around the banks. This wave action would also be sufficient to place the clay constituents in suspension and winnow out the carbonate mud in many cases.

The inferred shallowness of this last interpretation cannot be categorically proven, however, the presence of scattered colonial corals (Paleofavosites) and algal borings in many bivalve remains suggests that water depths may have been somewhat shallower than previously interpreted during the depositional history of the Gunn Member

Penitentiary Member

Introduction

Conformably overlying the Gunn Member of the Stony Mountain Formation is the Penitentiary Member. The complete Penitentiary Member was measured at four different locations (Figure 4, back pocket) and was found to vary between 4.3 to 4.9 meters in thickness throughout the study area.

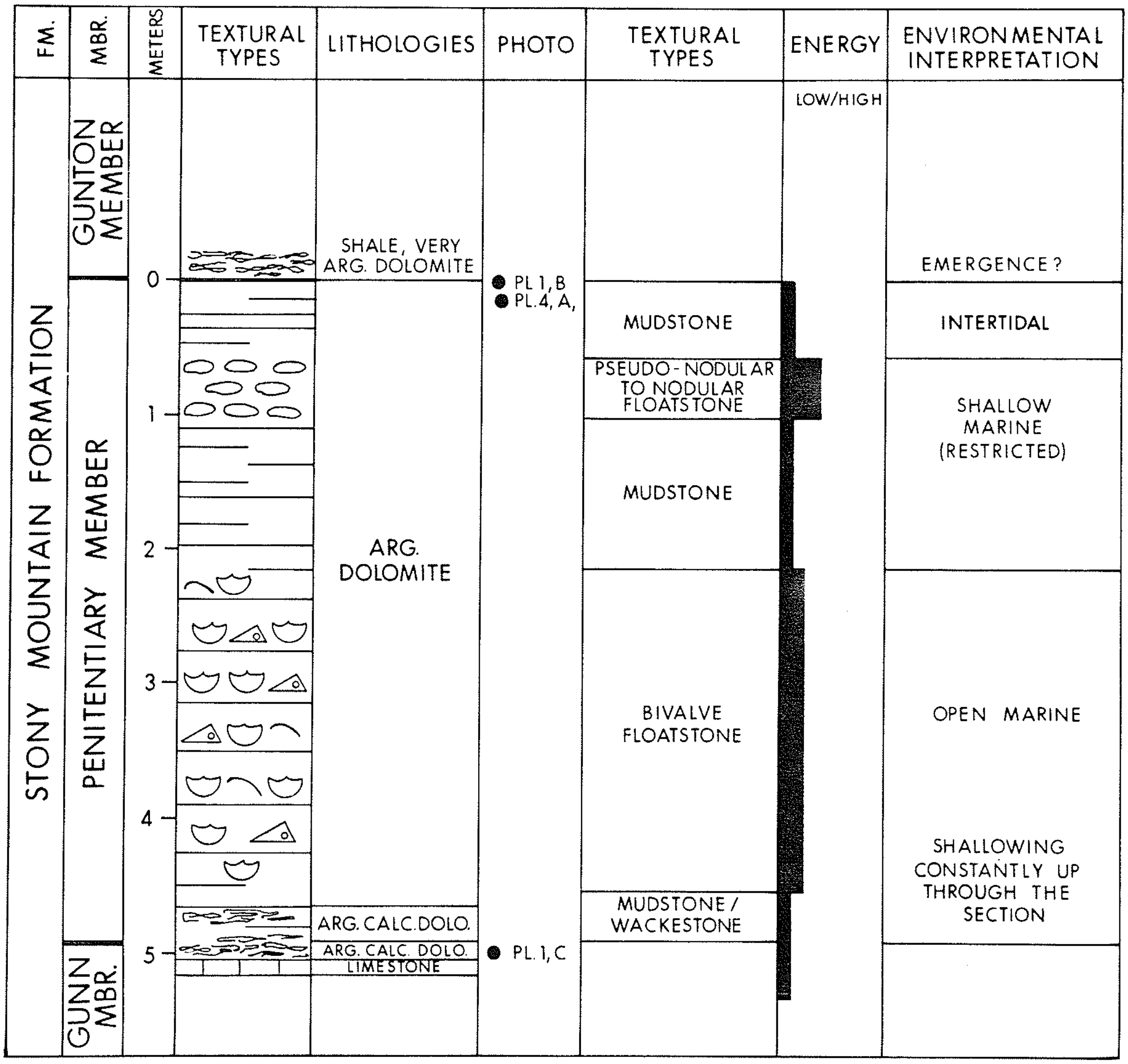
Stratigraphy

Figure 3 shows that Penitentiary time was characterized by a sizeable influx of terrigenous material. The insoluble residue ranged from 12 to 25 weight percent and is composed of illitic clay and quartz. As can be seen in Figure 3 the terrigenous content in the Penitentiary Member steadily declined throughout Penitentiary time.

In this study the basal contact between the Penitentiary Member and the underlying Gunn Member has been placed at the top of the last packstone to grainstone bed in the Gunn Member (Pl. 1, Fig. C). As shown in Figure 7 the contact between the two Members is separated by a transitional zone that is composed of an argillaceous calcareous dolomite. In the study area this zone ranges between 20 to 70 cm in thickness and varies from a mudstone to wackestone. This interval is highly burrowed, dusky red to pale maroon in colour and contains disoriented recrystallized calcite bivalve fragments and other bioclastic debris.

Overlying the transition zone is a bivalve floatstone interval (Figure 7) composed of argillaceous dolomite. In the Stony Mountain -

Figure 7: A diagrammatic stratigraphic section of the Penitentiary Member measured from Section 3. (Stony Mountain, Manitoba)


FM.
MBR.
METERS
TEXTURAL TYPES
LITHOLOGIES
PHOTO
TEXTURAL TYPES
ENERGY
ENVIRONMENTAL INTERPRETATION
LOW/HIGH
STONY MOUNTAIN FORMATION
GUNTON MEMBER
PENITENTIARY MEMBER
GUNN MBR.
0
1
2
3
4
5
SHALE, VERY ARG. DOLOMITE
ARG. DOLOMITE
ARG. CALC. DOLO.
ARG. CALC. DOLO.
LIMESTONE
PL 1, B
PL. 4, A,
PL. 1, C
MUDSTONE
PSEUDO-NODULAR TO NODULAR FLOATSTONE
MUDSTONE
BIVALVE FLOATSTONE
MUDSTONE / WACKESTONE
EMERGENCE ?
INTERTIDAL
SHALLOW MARINE (RESTRICTED)
OPEN MARINE
SHALLOWING CONSTANTLY UP THROUGH THE SECTION

Stonewall area this textural type comprises the lower half of the Penitentiary Member but at Headingley, Manitoba the bivalve floatstone comprises much less, as shown in Figure 4 (back pocket). This interval is characterized by thick planar bedding (up to 25 cm in thickness), coarse (2 to 6 cm) moldic porosity (predominantly after bivalves), a pale greenish grey to beige colour and an ocher weathering colour.

In all cases the shells of the faunal constituents have been removed by selective dissolution leaving molds, casts, and steinkerns. Throughout the bivalve floatstone intervals the individual beds contain 15 to 45 percent fossil remains. Bivalves and brachiopods form the predominant fossil type with minor amounts of horn corals, bryozoan stems, low spired gastropods and rare stromatoporoids (Aulacera), crinoid stems and tabulate corals comprising the other fossil types present in the interval.

The fossil remains in many cases are floating in a lime mud matrix which possesses poor to fair intercrystalline porosity. In many areas the matrix appears to have been pelleted but the outlines have been somewhat obscured by later dolomitization.

Succeeding the bivalve floatstone is a 1.2 m thick mudstone interval (Figure 7). Throughout the study area this unit comprises 40 to 60 percent of the upper half of the Penitentiary Member (Figure 4, back pocket). This interval is characterized by a moderate to thickly bedded nature, the predominance of lime mud over any other carbonate constituents, and trace amounts of bivalves, gastropods and pellets.

This mudstone interval is overlain by a pseudo-nodular to nodular floatstone approximately 40 cm thick (Figure 7). These structures are rounded loaf-shaped bodies up to 5 cm in length and 2 cm in thickness.

This interval grades laterally into a nodular mudstone unit where colour mottling accentuates the nodules (Pl. 3, Fig. F) along with recessive weathering of the matrix. As in the underlying interval only trace amounts of skeletal debris are present.

The overlying and uppermost interval of the Penitentiary Member is composed of an argillaceous dolomitic mudstone (Pl. 4, Fig. A). This interval is characterized by a dense homogenous appearance, thin bedding, flaggy weathering, some burrowing and a mottled grey-white and orange-beige appearance.

Environmental Interpretation

The Penitentiary Member has been interpreted to represent a continuation of the marine conditions which were initiated in Gunn time. The steady decline in the amount of terrigenous material during Penitentiary time suggests that circulation patterns in this portion of the Williston Basin may have changed or that the source areas of the terrigenous material were depleted.

The lower Penitentiary Member, and in particular the bivalve floatstone textural type, have been interpreted to represent a relatively deeper open marine environment than was present in Gunn time. Energy conditions were relatively stronger than in Gunn time.

The upper Penitentiary in general has been interpreted to represent a period of continuous shallowing of the marine environment until emergent conditions were finally attained at the end of Penitentiary time, i.e. a regressive depositional cycle. The mudstone and overlying pseudo-nodular to nodular floatstone of the upper Penitentiary Member have been interpreted to represent shallow and possibly somewhat restricted subtidal marine conditions similar to those in the Bahamas (Gebelein, 1974) and the Persian Gulf (Purser, 1973). The succeeding mudstone deposit that forms the uppermost interval of the Penitentiary Member has been interpreted to represent an intertidal deposit. Following this an emergent period of unknown duration occurred prior to Gunton time.

Gunton Member

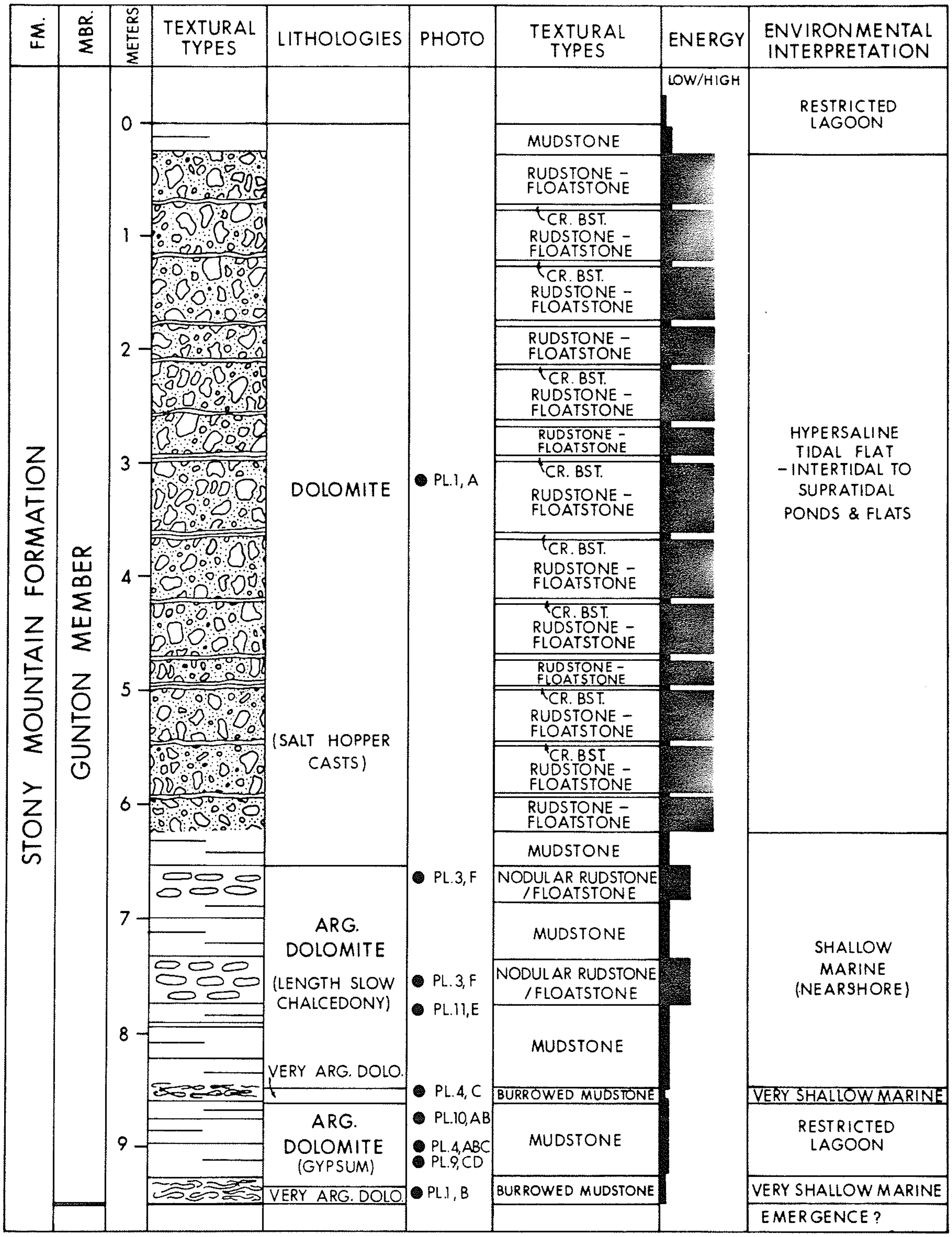
Introduction

Overlying the Penitentiary Member is the Gunton Member of the Stony Mountain Formation. The contact between these two Members has been interpreted to represent a diachronous surface. The complete Gunton Member (Section 1) measures approximately 11 m in thickness at Stonewall, Manitoba. At Stony Mountain, Manitoba a composite thickness measuring 9.5 m was preserved in outcrop (Figure 8).

Stratigraphy

The erosional surface that separates the Gunton Member from the underlying Penitentiary Member forms a distinctive marker throughout the study area. At Headingley, Manitoba the base of the Gunton Member is marked by a 20 cm thick red shale zone (Pl. 4, Figs. A and B). This interval is characterized by steeply dipping (40 to 45 degrees), finely laminated, penecontemporaneously-faulted bedding. At Stonewall, Manitoba the contact, though somewhat less distinct, is at the base of a reddish to purplish burrowed mudstone zone (see Figure 4, back pocket) approximately 1 m thick. The contact at Stony Mountain, Manitobe is well exposed (Pl. 1, Fig. B) and has been placed at the base of a 50 to 70 cm

Figure 8: A composite diagrammatic stratigraphic section of the Gunton Member measured from Sections 3 and 5. (Stony Mountain, Manitoba). CR. BST., cryptalgal bindstone textural rock type.


FM.
MBR.
METERS
TEXTURAL TYPES
LITHOLOGIES
PHOTO
TEXTURAL TYPES
ENERGY
ENVIRONMENTAL INTERPRETATION
LOW/HIGH
STONY MOUNTAIN FORMATION
GUNTON MEMBER
0
1
2
3
4
5
6
7
8
9
DOLOMITE
(SALT HOPPER CASTS)
ARG. DOLOMITE
(LENGTH SLOW CHALCEDONY)
VERY ARG. DOLO.
ARG. DOLOMITE (GYPSUM)
VERY ARG. DOLO.
PL.1, A
PL.3, F
PL.3, F
PL.11, E
PL.4, C
PL.10, AB
PL.4, ABC
PL.9, CD
PL.1, B
MUDSTONE
RUDSTONE - FLOATSTONE
CR. BST.
RUDSTONE - FLOATSTONE
CR. BST.
RUDSTONE - FLOATSTONE
RUDSTONE - FLOATSTONE
CR. BST.
RUDSTONE - FLOATSTONE
RUDSTONE - FLOATSTONE
CR. BST.
RUDSTONE - FLOATSTONE
CR. BST.
RUDSTONE - FLOATSTONE
CR. BST.
RUDSTONE - FLOATSTONE
RUDSTONE - FLOATSTONE
CR. BST.
RUDSTONE - FLOATSTONE
CR. BST
RUDSTONE - FLOATSTONE
RUDSTONE - FLOATSTONE
MUDSTONE
NODULAR RUDSTONE / FLOATSTONE
MUDSTONE
NODULAR RUDSTONE / FLOATSTONE
MUDSTONE
BURROWED MUDSTONE
MUDSTONE
BURROWED MUDSTONE
RESTRICTED LAGOON
HYPERSALINE TIDAL FLAT - INTERTIDAL TO SUPRATIDAL PONDS & FLATS
SHALLOW MARINE (NEARSHORE)
VERY SHALLOW MARINE
RESTRICTED LAGOON
VERY SHALLOW MARINE
EMERGENCE ?

thick purple burrowed horizon in the southeastern pit. At the stratigraphically equivalent position in the northwest pit the basal contact has been placed at the base of the first purple horizon (Figure 5, back pocket; Figure 8).

As shown in Figure 3 the lower third of the Gunton contains 3 to 12 weight percent insoluble residue in the Stony Mountain area. The remaining two-thirds of the Member is composed of a clean dolomite with less than 2 weight percent insoluble residue (mainly illitic clay). In the Headingley area the basal red shale is extremely pure containing less than 5 weight percent carbonate material.

As shown in Figure 8 the basal 15 cm of the Gunton Member in the northwest pit at the Stony Mountain quarry is a burrowed mudstone. This interval is purple in colour and characterized by the development of horizontal burrows. The burrows are circular in cross section and seldom exceed 5 mm in diameter.

Overlying the purple burrowed horizon is a well bedded 70 cm thick mudstone interval (Figure 8) with a sharp upper contact. No skeletal debris is present. However, there are four porous bedding zones. Three of the four porous bedding zones are displayed in Plate 4, Figure C. Petrographic analysis of this interval revealed that these porous zones were formed by the dissolution of gypsum. Plate 10, Figure A is a photomicrograph of twinned gypsum crystals which are present in this interval and Plate 10, Figure B shows the moldic pore development after the dissolution of the gypsum.

At the stratigraphically equivalent levels in Section 4 porous zones have been enlarged during dissolution resulting in the development of small channels. The floors of the channel are often littered with very fine to fine grained dolomite clasts which are cemented together by isopachous cement (Pl. 9, Figs. C and D).

Overlying the well-bedded mudstone interval and resting on a well defined surface is a second purple burrowed horizon 12 cm thick (Pl. 4, Fig. C). Like the first burrowed horizon this interval is composed of a very argillaceous, hematitic dolomite and is characterized by its purplish colour and horizontal burrowing which seldom exceeds 5 mm in cross sectional diameter.

A 2.2 m thick argillaceous dolomite interval composed of thin to medium bedded mudstone with two 20 and 30 cm thick nodular floatstone to rudstone interbeds overlies the second purple burrowed horizon. The nodular floatstone to rudstone intervals are composed of rounded, loaf-shaped, mudstone intraclasts (Pl. 3, Fig. F). The intraclasts are composed of non-fossiliferous carbonate mudstone, and are highly variable in size ranging from 2 to 6 cm in length and 1 to 2 cm in thickness. Skeletal debris comprises less than 2 percent of this interval. However, length slow chalcedony spherulites (Pl. 11, Fig. E) are scattered throughout this interval. These microscopic structures are oval in shape and generally less than 0.4 mm in size.

The succeeding 6 m interval is composed of clean dolomite containing less than 2 weight percent insoluble residue (Figure 3). Figure 8 shows that this interval is composed predominantly of rudstone to floatstone textural types with a mudstone matrix and thin interbedded cryptalgal laminae. The rudstone to floatstone beds range from 12 to 35 cm in thickness while the cryptalgal laminae vary from 1 to 3 cm in thickness.

The intraclasts may comprise as much as 95 percent of the individual rudstone to floatstone beds throughout this 6 m interval. The fragments are angular to rounded, tabular in shape, up to 12 cm in length, are commonly oriented parallel or slightly inclined to the bedding surface; however, they are sometimes perpendicular to the bedding surface. Within the lower 2 m of this interval salt hopper casts up to 2.5 cm in size have been found in some intraclasts.

The mudstone component within the rudstone to floatstone beds may comprise as much as 30 percent of any individual bed. The mudstone component weathers more easily than the intraclasts giving the outcrop a coarse pitted appearance.

The cryptalgal units comprise approximately 5 to 10 percent of the 6 m interval (Figure 8). These units are 1 to 3 cm thick, can be finely laminated or appear as dense dolomite with no readily apparent laminations. The lower surface forms a sharp contact which drapes over irregularities in the underlying strata. In the lower 2 to 3 m of this interval the upper surface of these horizons commonly shows evidence of desiccation.

Overlying the 6 m interval of floatstones to rudstones with interbedded cryptalgal laminae is a 20 to 40 cm thick dolomite mudstone unit (Figure 8). This interval is moderately bedded, composed mostly of mottled carbonate mudstone with minor intraclasts. Skeletal debris comprises approximately 5 percent of the interval and consists of molds and casts of brachiopods, gastropods bioclastic debris and rare colonial corals.

The upper 1.5 m of the Gunton Member has been eroded at Stony Mountain, Manitoba, however, it is present at Stonewall, Manitoba and consists of thickly bedded mudstones overlain by thinly bedded finely laminated mudstones (Figure 4, back pocket). No skeletal debris was found in either the thick or thinly bedded mudstone intervals. However, the thinly bedded and finely laminated mudstone contains moldic pores after gypsum (Pl. 4, Fig. E; Pl. 10, Fig. C).

Environmental Interpretation

The basal contact of the Gunton Member has been interpreted to represent an erosional surface which resulted when the seas withdrew at the end of Penitentiary time. The development of red shale at the base of the Gunton Member in the Headingley area (Pl. 4, Figs. A and B) is strikingly similar to the erosional sinkhole surfaces described by Multer (1975) in Florida and the Bahamas. The development of purple burrowed horizons at equivalent stratigraphic positions at Stonewall and Stony Mountain, Manitoba (Figure 4, back pocket; Pl. 1, Fig. B) are interpreted to represent restricted lagoonal to shallow subtidal environments developed in slight depressions on the Penitentiary surface during earliest Gunton time. The oxidized residuum is interpreted to have been derived from surrounding exposed surfaces and washed into the depressions during the initial transgressive phase of Gunton time.

Gunton time was characterized by shallow subtidal sedimentation in which prograding tidal flats developed (Stony Mountain, Manitoba) along with laterally equivalent subtidal marine deposits (Stonewall, Manitoba) similar to those described by Roehl (1967) and Shinn et al. (1969). The stratigraphic Gunton section described above (from Stony Mountain, Manitoba) and displayed in Figure 8 has been interpreted to represent a shallow subtidal marine environment in which restricted lagoonal and tidal flat sedimentation took place.

The lower 2.5 to 3.0 m of the Gunton Member at Stony Mountain, Manitoba was deposited in a restricted lagoonal to shallow marine environment adjacent to an emergent tidal flat mound. Restricted conditions are evidenced by the predominance of mud-sized carbonate material, the lack of skeletal debris, the presence of thinly bedded gypsum and the occurrence of length slow chacedony spherulites (Pl. 11, Fig. E) which according to Folk and Pittman (1971) are indicators of evaporitic conditions.

Low energy conditions prevailed for the most part during the deposition of this interval. However, as shown in Figure 8, periods of higher energy conditions are interpreted to have occurred during the deposition of the nodular rudstone to floatstone intervals (Pl. 3, Fig. F). These intervals are interpreted as intraclastic lags (derived from a nearby tidal flat) that were deposited during somewhat stormy conditions in the restricted lagoonal to shallow marine environment.

The overlying 6 m Gunton section has been interpreted as a prograding hypersaline tidal flat sequence that developed in a shallow subtidal environment at a rate equal to the subsidence rate. The hypersaline tidal flat is characterized by the development of intertidal to supratidal deposits. The rudstone to floatstone intervals have been interpreted as high energy intraclastic lags derived from the high intertidal or low supratidal environment and deposited in the low intertidal to shallow subtidal environment. This interpretation is evidenced by the presence of salt hopper casts in some of the larger intraclasts. Purser (1973) has described similar features in the Persian Gulf. The cryptalgal laminae have been interpreted to represent algal bindstone and/or primary dolomite crusts similar to those formed in the intertidal to lowest supratidal environment in the Bahamas (Roehl, 1967). Emergence is evidenced by the development of desiccation features on the upper surface of the cryptalgal bindstone intervals.

Overlying the 6 m of prograding tidal flat section is the 1.5 m mudstone interval that has been interpreted as a low energy evaporitic lagoonal deposit which eventually became emergent at the end of Gunton time. This hypothesis is evidenced by the development of thinly bedded gypsum intervals in the upper portion of the mudstone (Pl. 10, Fig. C), the lack of any skeletal debris and the presence of an upper scoured surface overlain by an intraclastic nodular rudstone (Pl. 4, Fig. E).

Williams Member

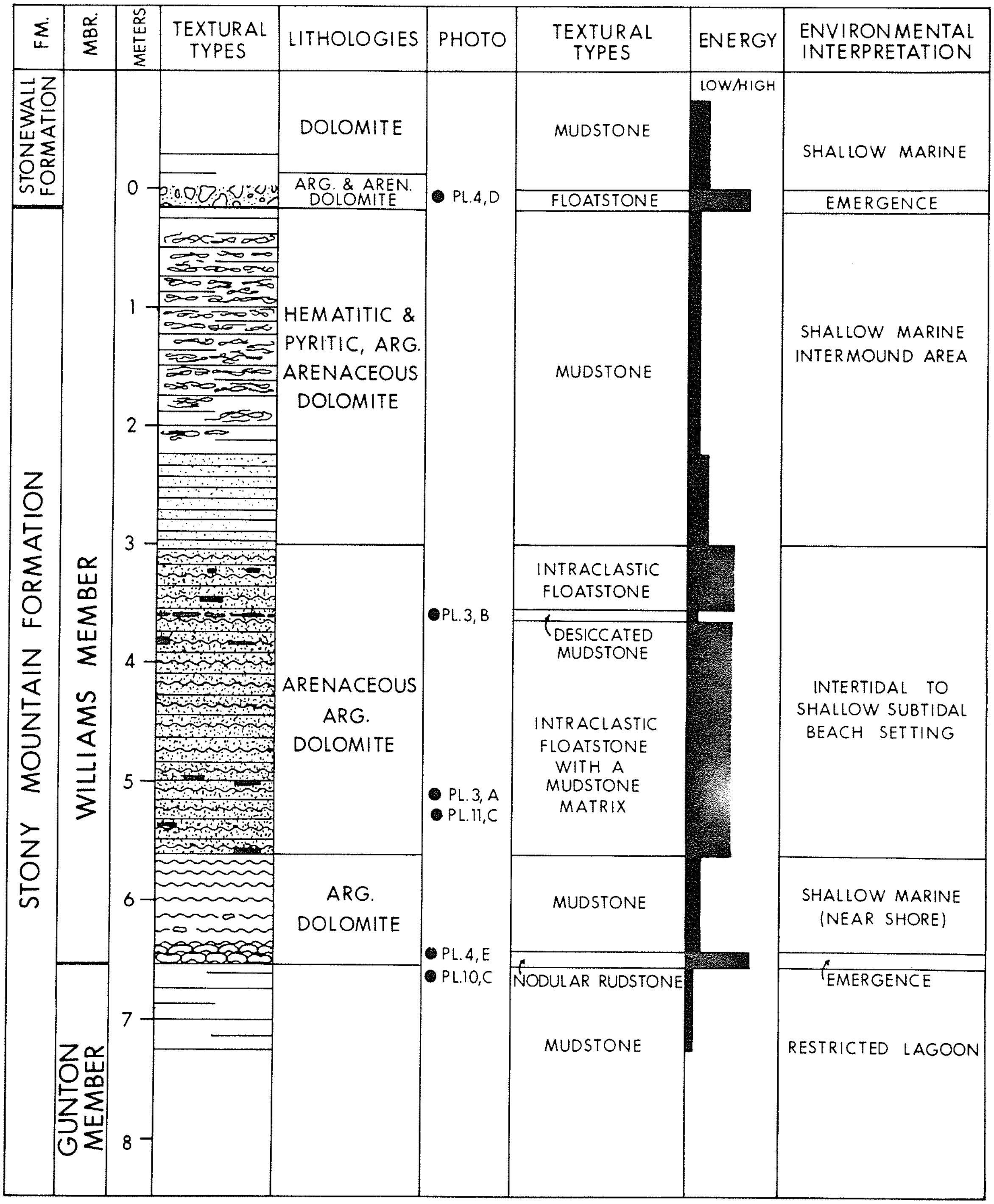
Introduction

Succeeding the Gunton Member is the Williams Member of the Stony Mountain Formation. As shown in Figure 4 (back pocket) this uppermost member of the Stony Mountain Formation was encountered in the drill core obtained in Section 1 only. The Williams Member is approximately 6.4 m thick at this location and is bounded by erosional surfaces.

Stratigraphy

As shown in Figure 3, Williams time was marked by a sudden influx of a large amount of terrigenous material, 30 to 33 weight percent. In the lower meter of the Williams Member the terrigenous component was composed exclusively of illitic clays. The overlying 2.5 m contained slightly more clayey terrigenous material than arenaceous material and the upper 2.9 m contained slightly more arenaceous terrigenous material than clayey material (Figure 9). Modal analysis of the Williams Member

Figure 9: A diagrammatic stratigraphic section of the Williams Member measured from Section 1. (Stonewall, Manitoba)


FM.
MBR.
METERS
TEXTURAL TYPES
LITHOLOGIES
PHOTO
TEXTURAL TYPES
ENERGY
ENVIRONMENTAL INTERPRETATION
LOW/HIGH
STONEWALL FORMATION
STONY MOUNTAIN FORMATION
WILLIAMS MEMBER
GUNTON MEMBER
0
1
2
3
4
5
6
7
8
DOLOMITE
ARG. & AREN. DOLOMITE
HEMATITIC & PYRITIC, ARG. ARENACEOUS DOLOMITE
ARENACEOUS ARG. DOLOMITE
ARG. DOLOMITE
PL.4,D
PL.3,B
PL.3,A
PL.11,C
PL.4,E
PL.10,C
MUDSTONE
FLOATSTONE
MUDSTONE
INTRACLASTIC FLOATSTONE
DESICCATED MUDSTONE
INTRACLASTIC FLOATSTONE WITH A MUDSTONE MATRIX
MUDSTONE
NODULAR RUDSTONE
MUDSTONE
SHALLOW MARINE
EMERGENCE
SHALLOW MARINE INTERMOUND AREA
INTERTIDAL TO SHALLOW SUBTIDAL BEACH SETTING
SHALLOW MARINE (NEAR SHORE)
EMERGENCE
RESTRICTED LAGOON

revealed that the sand-size terrigenous fraction was comprised predominantly of quartz with minor K-feldspar grains (Appendix C). The K-feldspar is mainly present in the upper 5.4 m of the member and in most cases has a unique K-feldspar overgrowth around the detrital grains.

As shown in Figure 9 the lower meter of the Williams Member is an argillaceous dolomite composed of a 10 cm nodular rudstone interval overlain by a 90 cm mudstone interval pale greenish white in colour. The rudstone interval (Pl. 4, Fig. E) is composed of well-rounded mudstone intraclasts which average 0.2 to 8.0 mm in diameter. Though not well exposed, this interval appears to be coarsening upwards. The overlying 90 cm interval is composed of thinly bedded, gently rippled, alternating light and dark mudstones. The lower 20 cm of the interval is characterized by steeply dipping bedding (20^{o}) while the upper 70 cm is horizontally bedded. The thin beds in some cases appear to contain thin wafer-like intraclasts.

No skeletal debris was found in the lower meter and only trace amounts of sand-sized terrigenous material were noted. The terrigenous material was composed of very fine grained quartz.

The succeeding 2.5 m interval is a pale creamy white arenaceous argillaceous dolomite which is made up of an intraclastic floatstone (wackestone) with a mudstone matrix (Figure 9). The entire interval is characterized by intraclastic lags composed of dense micritic dolomite (Pl. 3, Fig. A), a thin bedded mudstone matrix, slightly inclined bedding, gentle ripples, scoured surfaces, a large sand sized terrigenous component which commonly shows graded bedding, minor and thin cross bedding (Pl. 3, Fig. B) and a complete absence of skeletal debris.

The intraclasts range from 0.5 to 25 mm in size (Pl. 3, Fig. A), are finely laminated, vaguely pelleted to pelleted (Pl. 2, Fig. F; Pl. 3, Fig. B; Pl. 11, Fig. C) are composed of dense micritic dolomite (10 to 20 microns in size) with only minor traces of very fine grained sand sized terrigenous material (eolian quartz?). The intraclasts less than 5 mm in size have rounded edges and are generally oval to lenticular in shape while the larger clasts are subrounded to subangular and tabular in shape. The finer intraclasts are commonly oriented parallel to bedding and are concentrated in ripple troughs while the larger intraclasts are oriented en echelon to the bedding surface (Pl. 3, Fig. A).

The mudstone matrix is composed of a much coarser grained dolomite than the intraclasts and in many cases may show multiple zoning. The mudstone matrix also contains a much larger terrigenous constituent (up to 30 weight percent) than the intraclasts. The terrigenous component consists predominantly of very fine to medium grained detrital sand-sized material and illitic clays. The sand-sized constituents are mainly rounded to well rounded, strained and unstrained single quartz crystals and minor elongate and subrounded K-feldspar grains. The detrital constituents accentuate the sedimentary structures (Pl. 3, Fig. B) and show good sorting and well developed graded bedding. In many cases skeletal debris is completely lacking within the mudstone portion of this interval.

The upper 2.9 m of the Williams Member consists of a 1 m thick pale greenish white to yellowish white mudstone overlain by a 1.7 m thick pale purplish to brownish maroon mudstone and an uppermost 0.2 m thick pale greenish grey mudstone. The lower meter (Figure 9) gradationally overlies the underlying intraclastic floatstone interval. This interval is characterized by a large terrigenous constituent (30 to 33 weight percent, see Figure 3 and Appendix C), thin horizontal to slightly inclined bedding and a noticeable absence of intraclastic and skeletal debris.

Gradationally overlying this interval is a 1.7 m thick mudstone. This unit is characterized by a pale purplish to brownish maroon colour, a roiled appearance, a large terrigenous component (30-35 weight percent, see Figure 3 and Appendix C), minor hematite and pyrite, and some burrows. No sedimentary structures, intraclasts or skeletal debris were observed in this interval.

The uppermost 0.2 m of the Williams Member has a gradational basal contact and an erosional upper contact which is overlain by a floatstone (a basal polymictic conglomerate of the overlying Stonewall Formation), see Figure 9. The uppermost 0.2 m thick interval is characterized by a uniform appearance, moderately thick bedding and a large terrigenous component (30 to 33 weight percent, see Figure 3 and Appendix C).

Environmental Interpretation

The Williams Member of the Stony Mountain Formation has been interpreted as a shallow marine carbonate deposit bounded by erosional surfaces. Sedimentation throughout Williams time was characterized by a constant influx of large amounts of terrigenous material (clay and sand sized constituents which inhibited faunal development) and two distinctly different depositional environments.

As was noted earlier the end of Gunton time was marked by shallowing of marine waters and emergence of the sediments. The presence of a thinly bedded gypsum sequence a few centimeters below the sharp upper contact of the Gunton, the overlying nodular rudstone (basal conglomerate) of the Williams Member and the sudden introduction of the large terrigenous component at the beginning of Williams time (Figure 3) suggests that the Gunton and Williams Members were separated by a period of subaerial exposure and erosion.

Following the period of emergence at the end of Gunton time the seas returned to the Winnipeg area and it is postulated that deposition in the lower Williams took place in a moderately high energy beach environment characterized by shallow subtidal to low intertidal deposits (Figure 9). The dense micritic dolomite intraclasts so common to this portion of the Williams Member are strikingly similar to the primary dolomite crusts found in the high intertidal to low supratidal zone of the Bahamas (Shinn et al. 1965; Roehl, 1967) and the Persian Gulf (Purser, 1973) and have been classified as such. The intraclasts have been interpreted to have formed within emergent intertidal to supratidal ponds where brines were concentrated. The fact that the intraclasts contain only minor amounts of terrigenous material (in particular clay) indicates that the environment in which they were formed was removed some distance from that environment in which they were deposited. Also, the presence of very minor amounts of very fine grained well-rounded quartz in the intraclasts (Pl. 11, Fig. C) may be the eolian quartz noted by Smith (1963) to be present in the Williams Member. If this is the case then this would be further evidence supporting a subaerial environment of formation for the intraclasts.

The hypothesis that the lower Williams is a moderately high energy beach environment is evidenced by the presence of numerous sedimentary structures: good sorting and graded bedding (displayed in the terrigenous material), ripples, cross bedding, scoured surfaces, en echelon lag deposits, primary dolomite crust and desiccation features.

The upper Williams gradationally overlies the lower Williams and has been interpreted as a low energy shallow marine intermound environment. The lack of any prominent sedimentary structures, such as those present in the lower Williams, and the presence of a large burrowed interval (Figure 9) indicate that the depositional environment was removed from the beach zone where the sedimentation rate was relatively fast. This represents an environment characterized by a slow sedimentation and low energy conditions.

The uppermost 0.2 m interval of the Williams Member has been interpreted as being deposited in a low energy shallow marine intermound environment also. However, the absence of burrowing indicates that the sedimentation rate was somewhat faster than the underlying 1.7 m.

As mentioned above the upper surface of the Williams Member has been interpreted as an erosional surface. This hypothesis is supported by the sharp nature of the contact, the sudden lithological change which occurs across the contact (Figure 3) and the nature of the overlying floatstone which has been interpreted as a basal conglomerate of the overlying Stonewall Formation.

The dominant grains within the 20 cm floatstone interval (Pl. 4, Fig. D) are intraclasts, pellets, oolites and peloids (Appendix C). The intraclasts comprise 27.8 percent of the floatstone and are highly variable in composition, size and shape. They are formed of dense sublithographic dolomite mudstone, finely laminated arenaceous dolomite and minor thin shale chips. The dense mudstone intraclasts are the largest intraclasts, very irregular in shape, well rounded and vuggy.

The finely laminated arenaceous intraclasts are tabular in shape, well rounded and display a cross bedded fabric.

The pellets comprise 12.7 percent of the interval and are generally less than 150 microns in size. The oolites and peloids comprise 6.7 percent of the interval, are rounded to somewhat elongate and range from 300 to 700 microns in diameter.

The highly variable nature of the constituent grains, the different environments which they represent, their absence in the underlying strata and nature of the basal contact that separates them from the underlying Williams Member suggest that this interval is an erosional lag (a basal conglomerate) formed during the early transgressive event of the Stonewall time.

Summary of Depositional History

The upper Fort Garry Member of the Red River Formation and the Stony Mountain Formation in the Winnipeg area were deposited by shallow epeiric seas (Heckel, 1972) that inundated the northeastern flank of the Williston Basins numerous times. During Upper Ordovician time the epeiric seas advanced and retreated many times depositing carbonates which were periodically ladened with illitic clays and quartzofeldspathic material (Baillie, 1952; Moore, 1958; McGrossan and Glaister, 1964; Nelson, 1959a, 1975; Lochman and Balk, 1970).

During upper Fort Garry time carbonate sedimentation took place in a shallow marine environment almost completely devoid of any terrigenous material (Figure 3). Tidal flat depositional environments similar to those found in the Bahamian (Roehl, 1967; Shinn et al, 1969) and Persian Gulf (Purser, 1973) areas have been postulated to have occurred (Figure 5). Overlying a channel deposit are a series of shallow subtidal to low intertidal deposits capped by supratidal deposits in the upper 3 m of the Fort Garry Member. These cycles have been interpreted as periods of regressive sedimentation developed in a constantly shallowing marine environment. Alternatively, the cycles may be interpreted as periods of progradational tidal flat buildups following periods of shallow submergence. By the end of Fort Garry time the seas withdrew leaving the sediments subaerially exposed.

When the epeiric sea transgressed the landmass during Gunn time it was ladened with a large terrigenous component (up to 35 weight percent) that characterized Gunn sedimentation. Unlike the underlying Fort Garry Member of the Red River Formation the Gunn Member of the Stony Mountain Formation has been interpreted as being deposited in shallow marine environments. The Gunn was characterized by low energy conditions, a diversified faunal community and a slow sedimentation rate for the most part. The presence of the thin packstone to grainstone bed has led some researchers to interpret these beds as storm sheets that were deposited rapidly and free of terrigenous clays. Alternately, if the Gunn Member is interpreted as a somewhat shallower marine environment (similar to the Florida Keys) with low relief mud banks, the packstone to grainstone beds could be compared favourably with the sheets or aprons that surround the mud banks. The constant action of wave energy as it moved onto the mud banks would account for the numerous sedimentary structures present in these beds along with the low terrigenous clay content.

The shallow marine conditions prevalent during Gunn time continued on unabated until upper Penitentiary time when the seas began to withdraw. Carbonate sedimentation during this period was characterized by a constant supply of terrigenous clays that were steadily declining throughout Penitentiary time. The lower Penitentiary time has been interpreted to represent a relatively open marine environment characterized by moderate energy conditions (Figure 7) and a well developed and diversified faunal community. The upper Penitentiary time has been interpreted as representing a period of restricted marine conditions. Continuous withdrawal of the epeiric seas basinward resulted in the subaerial exposure and weathering of the majority of Penitentiary sediments. However, slight topographic depressions in the upper surface are interpreted to have escaped the effects of intense weathering.

The Gunton Member was deposited unconformably over the Penitentiary Member as the epeiric seas slowly transgressed the Winnipeg area. The lower 3 m of the Gunton Member has been interpreted as being deposited in shallow marine to restricted lagoonal environments (Figure 8) characterized by minor amounts of terrigenous clays (Figure 3) and evaporites. The upper 6.5 m of the Gunton Member has been interpreted as being deposited in evaporitic tidal flats and laterally equivalent marine environments (Figure 4, back pocket; Figure 8) similar to those presently found in the Bahamas (Roehl, 1967; Shinn, 1969). This period of the Gunton time was characterized by clean carbonate sedimentation (Figure 3) and evaporitic pond development. For the most part the subsidence rate was slow enough to allow the tidal flats to be slightly emergent throughout this period. The uppermost 1.5 m of the Gunton was deposited in an extremely shallow evaporitic lagoonal setting which was subaerially exposed at the end of Gunton time. Sedimentation during this period of Gunton history was characterized by clean carbonates (Figure 3) and thinly bedded gypsum deposits.

The final transgressive event of the epeiric seas during Stony Mountain time was initiated with the deposition of the Williams Member.

This final phase of sedimentation of carbonate material was marked by a sudden influx of large amounts (30 to 33 weight percent, Figure 3) of terrigenous clays and sand sized constituents. In general the overall depositional environment has been interpreted as a shallow marine environment in which slightly emergent mounds developed (Figure 9). The lower Williams has been interpreted to represent a high energy beach environment situated nearby an emergent mound. The sedimentation rate was relatively rapid and the deposits were characterized by intertidal to shallow subtidal sediments with numerous sedimentary structures. The upper Williams has been interpreted as a shallow marine environment situated between emergent mounds. The energy condition and sedimentation rates were low during this period of time and the deposits were characterized by poorly bedded and burrowed marine sediments.

The end of Williams time and Stony Mountain history was marked by the withdrawal of the epeiric seas basinward for the final time. When the epeiric sea returned during lower Stonewall time it was characterized by extremely clean carbonate sedimentation in a low energy marine environment.

Chapter 3 DIAGENESIS

In this study diagenesis is defined as all biological, physical and chemical changes which alter the original sediment during and after deposition but prior to the temperatures and pressures associated with metamorphism (Blatt et al., 1972).

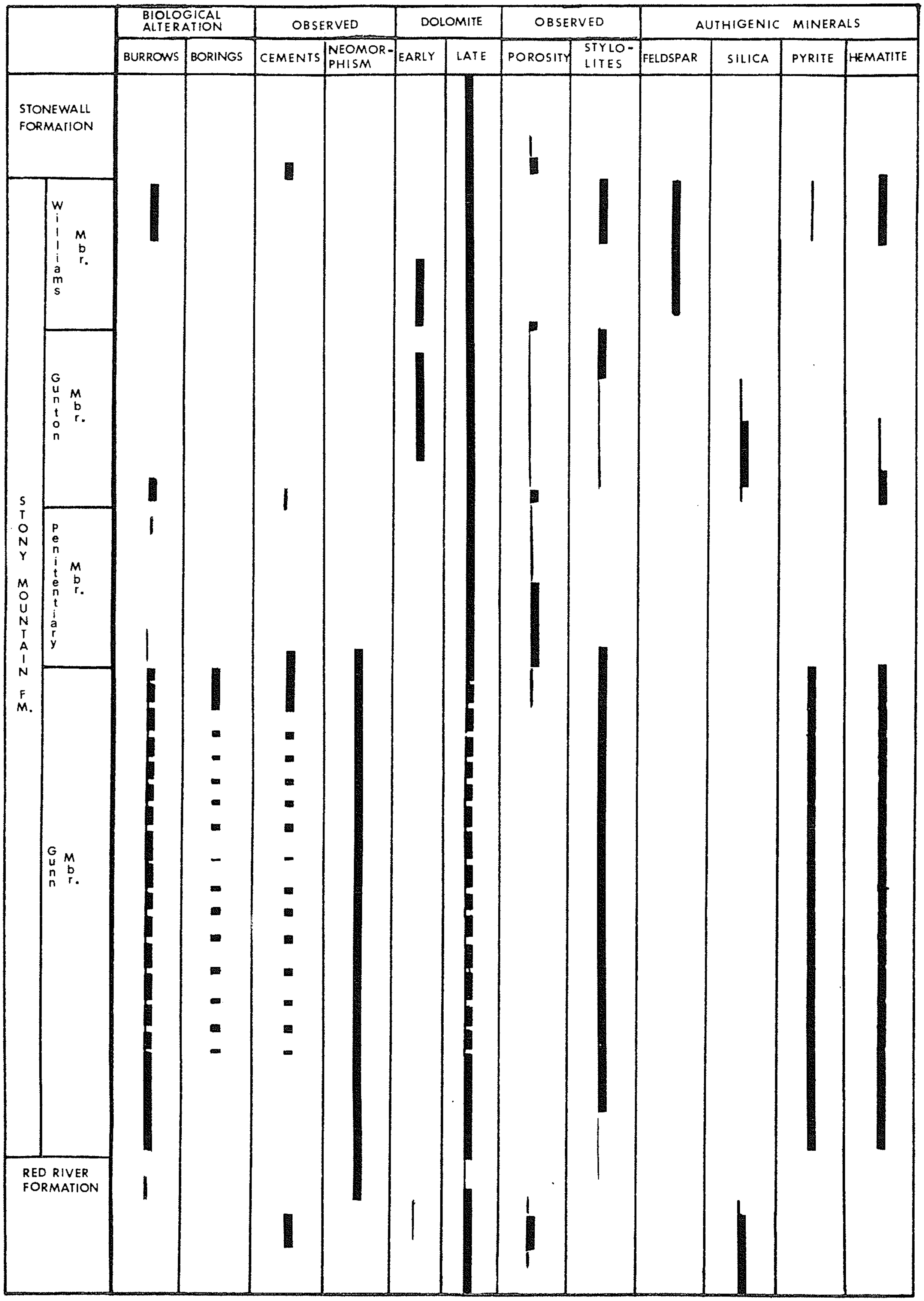
Biological Diagenesis

The process of biological diagenesis is defined by this author as an early phenomenon resulting from benthonic scavengers searching for food and/or seeking a protected environment. This activity (burrowing and boring) homogenizes the sediment and releases bacteria important for other diagenetic changes and provides passageways for migration of diagenetic fluids.

Burrowing

As shown in Figure 10 evidence of burrowing is most commonly observed in the Gunn and to a lesser extent in the lower Gunton and upper Williams Member. The intense biological activity in the Gunn developed two distinct sedimentary fabrics. The mudstone portion of the Gunn is characterized by the development of long, thin, generally horizontal burrows (Pl. 2, Fig. B). The wackestone portion of the Gunn is characterized, in many cases, by a churned appearance (Pl. 2, Fig. E). The destruction of bedding and disorientation of faunal allochems characterize these intervals. However, in the packstone to grainstone intervals burrows are considerably larger in size but are restricted to the upper surface of the interval in a horizontal or vertical fashion (Pl. 5, Figs. A, B and C)

Figure 10: Diagenetic processes and the observed locations in the section. Thick lines indicate a prominent diagenetic change while thin lines indicate limited diagenetic alteration.


BIOLOGICAL ALTERATION
OBSERVED
DOLOMITE
OBSERVED
AUTHIGENIC MINERALS
BURROWS
BORINGS
CEMENTS
NEOMOR-PHISM
EARLY
LATE
POROSITY
STYLO-LITES
FELDSPAR
SILICA
PYRITE
HEMATITE
STONEWALL FORMATION
STONY MOUNTAIN FM.
Williams Mbr.
Gunton Mbr.
Penitentiary Mbr.
Gunn Mbr.
RED RIVER FORMATION

and generally leave the bedding and sedimentary structures in tact.

The burrows in the mudstone are 1 to 4 mm in diameter, generally circular to oval in cross section, 2 to 3 cm in length (minimum) and inclined 10 to 15 degrees from the horizontal. In most cases the sediment within the burrow is of a much lighter colour than the enclosing sediments. The burrows are rimmed with one and sometimes two layers of hematite and commonly have noticeable pyrite growths within the burrow. These burrows most likely represent the morphological genus Fodichnia (Seilacher, 1964).

The burrows in the packstone to grainstone intervals of the Gunn can be classified as epilithic (burrows developed on the upper surface of a lithological unit) feeding trails and endolithic (burrows developed within a lithological unit) dwelling burrows, Pasichnia and Domichnia respectively (Seilacher, 1964).

The Pasichnia can be divided into two distinct morphological groups as shown in Plate 5, Figures A and B. The smallest is a dendritic variety 2 to 3 mm wide with a 3 to 5 mm wide central canal. This variety displays termination at the dendroid branches, may be up to 30 cm in length, and commonly has a marginal ridge 1 to 2 mm high.

The largest variety of trails is 1.5 to 3.0 cm wide, up to 2 cm deep, and U-shaped in cross section. These trails are characterized by an axial ridge 2 mm high and 3 to 5 mm wide. No marginal ridges were observed beside the trails. Unlike the small dendroid trails these markings do not branch from a central canal. They commonly cross one another (Pl. 5, Fig. B) and in some cases are cut by the smaller variety of Pasichnia.

The endolithic trace fossil, Domichnia, is restricted to the fine bioclastic packstone unit. The observed vertical burrows have a 2 to 3 cm rampart built on the upper surface of the bed and completely penetrate the fine bioclastic packstone (3 to 5 cm). The point of entry of these burrows measures 8 to 12 mm, while the terminal point commonly tapers down to 2 to 3 mm (Pl. 5, Fig. C). In many cases the vertical burrows are surrounded by oxidation halos indicating that they acted as solution passageways for later diagenetic fluids.

Borings

The biological process of boring into hard substrate was observed on a microscopic and megascopic scale in the Gunn Member only (Figure 10). In particular, the packstone to grainstone portion of the member proved to be favourable sites for micro and macroborings. Fossil remains of a cephalopod in the upper 1 to 2 m of the member were riddled with macroborings.

Microborings

The development of microscopic borings on a hard substrate, hardgrounds or skeletal remains has been documented by innumerable workers, for example, see Lindstrom (1963), Bathurst (1966) and Kobluk (1976; 1977a). These microscopic tubular cavities developed as a result of algal activity along the periphery of the substrate. Taylor and Illing (1969) noted that the algal boring process rarely resulted in the tubular cavity penetrating more than 200 microns into the substrate. Bathurst (1966) suggested that the rinds which developed on bored surfaces of an allochem were formed after the death and decay of the algal material within the tubular borings. However, recent work by Kobluk (1976;

1977a) has shown that "the coalescence of dense populations of exposed calcified filaments could produce a micrite envelope about a grain, without the destruction or alteration of the grain periphery associated with the classical mechanisms of micrite envelope formation". Such constructive envelopes are the result of only very limited penetration of the grain periphery by filamentous algae. The filamentous algae actually colonize the outer surface of the grain protected by a carbonate sheath which is secreted by the algae.

The micritized grains that are present in the Gunn Member are usually bored on just one side; however, as seen in Plate 7, Figure A the complete periphery of some allochems are micritized. In most cases the micritic carbonate has been recrystallized to equant microspar. Iron oxide has been deposited within some vacated tubules.

Bathurst (1971) and Evamy and Shearman (1965) noted that the development of micrite envelopes on echinoderm fragments inhibits the development of later cements. This phenomenon occurs on bivalve grains in the Gunn Member.

The process of micritization is active in the supratidal and intertidal environments (Bathurst, 1971) as well as in the subtidal environment (Kobluk, 1976; Swinchatt, 1969). The limiting factor in subtidal environment is the presence of sunlight. Swinchatt (1969) has noted that the lower limit at which micritization can occur is equivalent to the lower limits of the photic zone.

Macroborings

Like microborings, the macroborings occur on a hard substrate. In the Stony Mountain Formation this phenomenon has been observed in the upper 1 to 2 m of the Gunn Member only. At Section 2 macroborings were observed on the remains of an Armenoceras cephalopod. These borings are similar to those found in the Lower Cambrian of Labrador which belong to the morphogenus Trypanites and may have been formed by polychaete worms, cirripeds or sipunculids (James et al., 1977).

The cephalopod measured 420 mm in length and was bored predominantly on the upper surface and to a much lesser extent on the bottom surface. The upper surface contains 190 borings ranging in size from 0.1 to 2.0 mm (Pl. 6, Figs. A and B). The lower surface contains 26 borings which are the same size range as above. As shown in Plate 6, Figure B the longest observed length of any one boring is approximately 15 mm.

Borings into the packstone to grainstone intervals of the Gunn Member occurred also. As shown in Plate 6, Figures C and D nearly circular passageways were developed. The borings measure 0.2 to 2 mm in diameter, are circular in cross section and always filled with pyritic, hematitic, argillaceous dolomite from the overlying interval. The presence of these constituents within the packstone to grainstone intervals and the fact that they are restricted to the borings indicate that the borings acted as important fluid migration pathways.

The borings have been interpreted as early diagenetic features that developed in the eogenetic zone within a submarine hardground after Phase I cementation.

Chemical Diagenesis

Chemical changes are by far the most numerous diagenetic processes which occurred in the Stony Mountain Formation. The development of cements, neomorphic spar, dolomite, porosity, stylolites and authigenic minerals was brought about by solutions migrating through the pore systems.

Friedman (1964) noted that Holocene carbonates are predominantly aragonite and high-Mg calcite. If these minerals remained in their original marine environment then they would not undergo any mineralogical changes. However, if the sediments are placed in contact with waters or solutions which are chemically different, mineralogical and textural changes will occur leaving low-Mg calcite and possible development of voids.

Cementation

The development of cement in carbonate rocks has been the subject of much geological research in the last decade. Friedman (1964), Taylor and Illing (1969), Bathurst (1971), Bricker (1971), Kendall (1971), Steinen and Matthews (1973), Lindholm (1974), Meyers (1974), Harrison (1975), Badiozamani et al. (1977), and Macintyre (1977) deduced the physical environments and chemical conditions that were present at the time of formation of certain cements. From their investigations a number of generalizations on the formation of cement can be made:

1) Cementation is currently taking place in the fresh water vadose and phreatic environments and in the submarine environments.
2) Fresh water cements are low magnesium calcite which often form clear coarse spar.
3) Submarine cements are high magnesium calcite or aragonite which form dense submicrocrystalline to microcrystalline cement or balded to fibrous crystals.
4) High magnesium and aragonite components when subjected to fresh water

undergo mineralogical stabilization to low magnesium calcite or undergo dissolution. Resultant voids may be filled with low magnesium cement.

5) The magnesium content of the crystalline solutions controls the morphology of the calcite cement.

Cements are observed only in the fine grained and coarser carbonate rocks. As shown in Figure 10 the process of cementation has been documented in the upper Fort Garry Member, the Gunn Member, in particular the packstone to grainstone intervals, the lower Gunton Member and in the basal conglomerate of the Stonewall Formation. Detailed petrographic analysis revealed the presence of three distinct phases of cement development in the upper Red River and Stony Mountain Formations. These phases of cement (Phase I, II and III) are summarized in Table 2.

Phase I Cements

This phase is characterized by the development of equant druse, bladed druse, syntaxial, and equant blocky cement morphologies. All varieties are non-ferroan calcite cements which are interpreted to have been developed in the eogenetic to shallow mesogenetic environment of Choquette and Pray (1970).

Petrographic analysis of the various primary pore settings (interparticle, intraparticle, and sheltered) in the packstone to grainstone portion reveals that a definite cement stratification exists. Where druse, syntaxial, and blocky cement morphologies are present druse and syntaxial cement development appears to have been contemporaneous followed by the development of blocky cements. Where only the druse and

Table 2: Details of Phase I, II and III cements.

Morphological Cement types	Pore Setting	Relationship to pore	Crystal Size (microns)	Chemical Composition of Calcite	Interpreted Diagenetic Environment	Location in the Section
Phase I						
Equant Druse	Interparticle	isopachous	12-15	Non-Ferroan	Eogenetic	Fort Garry Mbr-Grainstone
	Intraparticle	microstalactitic	20-60	Non-Ferroan	Shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
Bladed Druse	Interparticle	isopachous	5-18	Non-Ferroan	Eogenetic to shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
	Intraparticle	isopachous	10-25	Non-Ferroan	Eogenetic to shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
	Sheltered	microstalactitic	7.5-60	Non-Ferroan	Eogenetic to shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
Syntaxial Echinoderm Rim	Interparticle	pore filling	up to 1000	Non-Ferroan	Eogenetic to shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
	Sheltered	pore filling	up to 1000	Non-Ferroan	Eogenetic to shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
Equant Blocky	Interparticle	pore filling	20-30	Non-Ferroan	Eogenetic to shallow mesogenetic	Fort Garry Mbr & Gunn Mbr
	Intraparticle	pore filling	20	Non-Ferroan	Eogenetic to shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
	Sheltered	geopetal and pore filling	up to 1.100	Non-Ferroan	Eogenetic to shallow mesogenetic	Gunn Mbr-Packstone/Grainstone
Phase II						
Equant Blocky	Fracture	fracture filling	50-200	Ferroan	Mesogenetic	Gunn Mbr-Packstone/Grainstone
	Intraparticle	pore filling	1000	Ferroan	Mesogenetic	Gunn Mbr-Packstone/Grainstone
Phase III						
Bladed Druse	Channel	isopachous colloform	10-80	Non-Ferroan	Telogenetic	Lower Gunton Mbr

blocky habit exists the initial cement development is druse overlain by blocky.

(I) Drusy Cement

The drusy cements are present in either an equant or bladed variety (Pl. 5, Fig. D; Pl. 7; Pl. 8, Fig. A; Pl 10, Fig. D). Druse may form either isopachous rims (Pl. 5, Fig. D; Pl. 7, Fig. C; Pl. 10, Fig. D) in interparticle pore settings and intraparticle pores (Pl. 7, Fig. B) or microstalactitic druse (Pl. 8, Fig. A) in a sheltered pore. As noted in Table 2 the equant druse and bladed druse vary from 12 to 60 microns and 5 to 60 microns respectively depending on the nature of the pore in which they develop. Both varieties of druse are composed of non-ferroan calcite and form clear crystals. As shown in Plate 7, Figure B and Plate 8, Figure A, fine thin bladed druse evolves into a squatter sawtooth form with considerably fewer terminations.

(II) Syntaxial Cement

Syntaxial rim cement is restricted to echinoderm grain fragments in the packstone to grainstone intervals of the Gunn Member. These fragments are single crystals of calcite which readily act as points of nucleation. Evamy and Shearman (1965) pointed out that the overgrowth from an echinoderm forms a single crystal which is in optical continuity with the grain.

The syntaxial echinoderm rim cements found in the packstone to grainstone units form optically continuous crystals up to 1 mm in size (Pl. 5, Fig. D). The intrabiotic pores are filled with micritic material and appear as dusty areas in the thin section under crossed nicols (Pl. 7, Fig. A). In one unique case three generations of echinoderm rim cement are present (Pl. 7, Fig. C). Evamy and Shearman (op. cit.) noted such an occurrence; however, unlike theirs no chemical changes were noted in the cement composition. All three overgrowth stages are non-ferroan.

(III) Blocky Cement

This cement variety represents the last cement developed in the remaining primary pores of the packstone to grainstone portion of the Gunn. It overlies the drusy and syntaxial cements and is found also in pore spaces of the upper Fort Garry packstone to grainstone beds (Pl. 10, Fig. D). The cement crystals range from 1 micron to greater than 1.1 mm in diameter, are clear to dusty, non-ferroan, and are found in sheltered, interparticle, and intraparticle pores of the packstone to grainstone portion of the Gunn (Pl. 5, Fig. D; Pl. 6, Fig. C; Pl. 7, Figs B, C and F; Pl. 8, Fig. A).

Origin

The three types of Phase I cements have been interpreted as being formed early in the diagenetic history of the packstone to grainstone units in primary pore settings. Phase I cements have been interpreted as being formed in the eogenetic to very shallow mesogenetic marine environment. This suggests that the packstone to grainstone units of the Gunn Member represent marine hardgrounds.

The hypothesis of the early development of Phase I cements and the resulting development of marine hardgrounds is evidenced by the presence of borings in the packstone to grainstone units. The borings (described above) truncate the Phase I blocky cement type (Pl. 6, Figs. C and D; Pl. 11, Fig. A). As was noted in the above discussion, the development of blocky cement represents the last variety of Phase I cements to be developed in the eogenetic environment.

Phase II Cements

As shown in Table 2 the Phase II cement is found in fractures and intraparticle cavities. This volumetrically minor generation of cement forms equant blocky crystals which are 50 microns to 1 mm in size and is composed of ferroan calcite.

The cement developed in the packstone to grainstone intervals of the Gunn Member are located in thin hairline fractures and in solution enlarged cavities beside the fractures (Pl. 6, Fig. D; Pl. 11, Figs. A and B). As shown in Plate 11, Figure A the cement developed in fractured bivalve grains commonly has an occluded solution enlarged cavity surrounded by a ferroan neomorphic halo.

As noted above the cement is found also in intrabiotic pores, such as Paleofavosites corals and high spired, thin walled gastropods. Plate 9, Figures A and B show the development of Phase II cement in the corallite chamber. The initial cement within the corallite chamber is non-ferroan and is light coloured in the photomicrograph; the ferroan cement phase is the darker material (F).

Origin

Phase II cements formed after the development of Phase I cements and borings. The cements is interpreted to have developed in the mesogenetic environment as a result of subsurface waters enriched in iron migrating through the sediment. This interpretation is supported by:

1) Hairline fractures that cut through the packstone to grainstone intervals are filled with ferroan cement which truncates the Phase I

cement.

2) Plate 11, Figure A shows a fracture cutting nearly vertically through the boring (on the left side) and the bivalve shell. The coarse grained spar (C) found in the solution enlarged cavity is composed of Phase II ferroan cement.

Phase III Cement

This generation of cement is found only in the lower few meters of the Gunton Member (Figure 10 and Table 2). It is developed only in solution-enlarged channels which commonly contain clasts of dolomite (Pl. 9, Figs. C and D) clustered in the lowest points of the channel floor. The cement is characterized by the development of three distinct non-ferroan calcite phases.

The initial phase forms an isopachous bladed druse which is clear and is composed of bladed crystals 30 to 50 microns in length. The second phase of cement forms a dirty micritic isopachous rim 10 to 15 microns thick around the grains. The third and final cement phase is a bladed isopachous druse composed of crystals which are clear and 60 to 80 microns thick (Pl. 9, Figs. C and D).

Origin

The Phase III cements have been interpreted as the last stage of cement development and possibly one of the latest diagenetic processes. The cement was formed by non-ferroan solution migration through the telogenetic environment. The fact that the Phase III cement lines the cavities and encloses the lime mud intraclasts in a colloform fashion indicates that the original sediment had been dolomitized prior to the development of this variety of cement.

Neomorphism

The term neomorphism was introduced by Folk (1965) to embrace the following processes: inversion, recrystallization and strain recrystallization of a mineral. The process actually results from *in situ* wet phase polymorphic transformation of the original component. The *in situ* removal of one component and the precipitation of another component takes place on a molecular level without the formation of a void stage. Such ultra-fine transformations may in many cases leave the microstructure of the grain unaltered.

Folk's inversion process encompasses the transformation of one mineral to its polymorph. The change of aragonite mud or skeletal debris to calcite is one such process and has been documented by Folk (1965) and James (1974).

The recrystallization process involves the change of the original lime mud to an equant calcite mosaic. The process of crystal enlargement, whereby finely crystalline carbonate (i.e. lime mud) is replaced by a mosaic of coarser spar has been called aggrading neomorphism by Folk (1965). Depending on the size of the spar developed it can be classified as microspar (grains 5 to 31 microns) or pseudospar (grains larger than 31 microns).

As shown in Figure 10 neomorphic fabrics are observed only in the upper portion of the Fort Garry Member, the complete Gunn Member (in particular the packstone to grainstone intervals), and the lower transition zone of the Penitentiary Member. In the lower transition zone of the Penitentiary Member aggrading neomorphism of the matrix and neomorphic recrystallization of the grains has occurred.

Matrix Neomorphism

The matrix found within the packstone to grainstone intervals of the Gunn Member is composed of low magnesium calcite. The crystals are 4 to 24 microns in size and are equant-shaped.

If Folk's (1965) suggestion that ancient equant microspar represents recrystallized equivalents of Recent lime muds is correct then the microspar found in the packstone to grainstone intervals is recrystallized mud. Furthermore, the fact that the mud (now microspar) is low magnesium calcite and that Recent muds are composed of high magnesium calcite and aragonite (Stehli and Hower (1961); Stockman et al. (1967); Matthews (1966); Land et al. (1967)) suggests that the mud has gone through an inversion process also.

Origin

It is interpreted that the aggrading recrystallization and inversion processes of neomorphism took place in the eogenetic to shallow mesogenetic environment. This alteration has been interpreted to have occurred relatively early in the diagenetic history of the sediment. Matrix neomorphism is believed to have been initiated at the same time as Phase II cementation but ceased to be an active process prior to the end of Phase II cementation.

Grain Neomorphism

This type of neomorphism is observed in the coarse bioclastic packstone to grainstone intervals of the Gunn Member, in particular the brachiopod shells and rarely in broyozoan fragments (Pl. 11, Figs. A and B; Pl. 6, Fig. D). In Plate 11, Figure A the recrystallized neomorphic fabric forms an aureole around the ferroan Phase II cement. The neomorphic spar (N) is restricted to the boundaries of the bivalve, is ferroan, ranges from 10 to 70 microns in size and displays some of the original microstructure.

In Plate 11, Figure B the right half of the bivalve (solid black arrow) has also undergone grain neomorphism without affecting the Phase I drusy cement developed along the bottom of the grain. The original microstructure is just barely discernable in the photomicrograph.

Origin

As with matrix neomorphism grain neomorphism has been interpreted as a relatively early diagenetic process which took place in the shallow mesogenetic environment. The fact that it is closely associated with the development of ferroan Phase II cement indicates that the timing and environmental conditions were similar for the development of both products.

Dolomitization

The large quantities of dolomite in the ancient record and the lack of any Recent equivalents has been a perplexing problem to many geologists in the last 25 years (Zenger, 1972). The development of thin dolomite crusts has been noted in the Persian Gulf (Illing et al., 1965), the Bahamas (Shinn et al., 1965), Florida (Shinn, 1968 and Multer, 1975), Jamaica (Land and Epstein, 1970; Land, 1973) and Bonaire (Deffeyes et al., 1965; Murray, 1969) but no examples of thick dolomite successions comparable to the ancient have been noted.

Hypotheses of the Origin of Dolomite

(I) Dolomitization by Seepage Refluxion

Adams and Rhodes (1960) developed this hypothesis as a result of their study of the Permian dolomites of Texas. Deffeyes et al. (1965) noted that the island of Bonaire provided a Recent example of the seepage reflux hypothesis developed by Adams and Rhodes.

This process of dolomitization calls for restricted circulation in which dense hypersaline brines formed. Due to density differences the hypersaline magnesium brines move down through the primary pore system displacing the connate waters and dolomitizing the sediment.

Theoretically this process could dolomitize vast amounts of sediments. The main controlling factors would be the recharge rate of the restricted lagoonal area and the permeability of the underlying sediments.

(II) Dolomitization by Evaporitic Pumping

Illing et al. (1965) and Shinn et al. (1965) proposed this method of dolomitization as a result of their research in the Persian Gulf and the Bahamas respectively. This hypothesis calls for the upward movement of water through the sediments of the intertidal and supratidal zones by capillary action due to evaporitic conditions. As the waters are drawn upward and evaporated, the water table below becomes hypersaline. With the aid of high temperatures aragonite and calcite are replaced by dolomite.

This process results in the development of thin dolomite crusts composed of dolomite crystals less than 5 microns in size. These crusts are generally found a few centimeters above the high intertidal zone. Land et al. (1975) noted that this process could not account for thick successions of dolomite because the formation of the crust is a terminal process. Once the crust is formed the evaporative pumping mechanism is sealed from porous sediment by this impermeable layer.

(III) Dolomitization by Mixing

Since the work by Hanshaw et al. (1971) on the intrusion of Florida groundwater lenses into the off-shore marine sediments much attention has been focused on dolomitization by mixing of two different water types by numerous workers: Badiozamani (1973), Land (1973), Folk and Land (1975) and Land et al. (1975).

Essential to this mechanism is the development of a fresh water phreatic lens extending into sediments which normally contain connate marine waters.

Folk and Land (1975) presented a theoretical consideration of the effects of the Mg:Ca ratio and the salinity on the formation of the dolomite in various environments. They concluded that high Mg:Ca ratios and high salinites were not necessary for the formation of dolomite as long as the crystallization rate was not rapid. The zone of mixing is such an environment. The salinity is decreased along with the foreign ion concentration, the Mg:Ca ratio is constant, and the nucleation rate is slow. All these factors favour the formation of "limpid" dolomites which the above authors feel is a characteristic product of such mixing zone dolomitization.

Land et al. (1975) and Folk and Land (1975) consider the mixing zone dolomitization process to be volumetrically the dominant diagenetic process by which early carbonate sediments become dolomitized.

Dolomitization of the Stony Mountain Formation

As shown in Figure 10 the development of late dolomite is common throughout the upper Fort Garry Member (except in the upper limestone unit), in the Gunn Member (except where packstone to grainstone intervals are found) and in the Penitentiary, Gunton and Williams Member. Early or primary dolomite development has been recognized in the upper Fort Garry, the upper Gunton, and the lower Williams Member.

(I) Early Diagenetic Dolomites

Early diagenetic dolomite in the Gunton Member is preserved in the section as 1 cm to 2.5 cm thick beds interbedded with conglomerate rudstones (see Chapter 2). These beds appear very dense and in some cases display a very fine scale lamination. The very finely laminated beds in some cases show desiccation features and contain intraclastic debris.

In the Williams Member the early diagenetic dolomite forms intraclasts (Pl. 3, Figs. A and B; Pl. 2, Fig. F) up to 2 cm long and 0.75 cm thick as well as thin beds. The intraclasts and beds are composed of dense dolomite (Pl. 2, Fig. F) which is commonly laminated. The intraclasts are "floating" in a very coarsely crystalline arenaceous dolomite. The intraclasts themselves contain less than 1 percent arenaceous material whereas the surrounding host rock contains up to 35 weight percent insoluble residue. As seen in Plate 3, Figure B, the dolomite crusts are somewhat desiccated.

Microscopic examination indicated that the intraclasts and thin beds are composed of non-ferroan dolomite crystals which range in size from 4 to 10 microns. The intraclasts are commonly pelleted

(Pl. 11, Fig. C) and often finely laminated (Pl. 3, Fig. B). As shown in Plate 11, Figure C the intraclasts are composed predominantly of dirty micritic dolomite and minor eolian quartz (e).

The dense lithographic and sublithographic beds and intraclasts of the Gunton and Williams Member are interpreted to have been formed in the eogenetic intertidal to supratidal environment. Their relationship to the underlying and overlying strata, the presences of desiccation fabrics, and the finely laminated and pelleted nature are strikingly similar to the dolomite crust found today in the Persian Gulf (Illing et al., 1965) and the Bahamas (Shinn et al., 1965). The early diagenetic dolomite (primary dolomite) may have formed by the process of evaporitive pumping as described by the above authors.

(II) Secondary Dolomitization

Development of secondary dolomite is common throughout the majority of the Gunn Member. X-ray analysis reveals that the wackestone and mudstone portions of the Gunn are made up to 65 to 75 weight percent dolomite whereas the coarse bioclastic packstone to grainstone intervals are composed of only 1 to 3 weight percent dolomite.

The secondary dolomite developed in the Gunn Member may be zoned or non-zoned. Both types are ferroan and usually form euhedral crystals which range in size from 20 to 200 microns when zoned and 20 to 40 microns when not zoned (Pl. 11, Fig. D). Up to six stages of zoning have been observed in one coarsely crystalline dolomite rhomb. The central portions of many of these crystals appear to have a dark nuclei and each successive growth stage is clearer that its predecessor (Pl. 11, Fig. C).

The development of dolomite in the Gunn Member was initiated relatively early after the development of Phase I cement and most likely during the development of Phase II ferroan cement.

This interpretation is supported by:

1) The absence of dolomite from the coarse bioclastic packstone to grainstone beds (less than 3 weight percent) where Phase I cements are developed.

2) The presence of dolomite in the boring passageways which penetrate the packstone to grainstone intervals.

3) The association of dolomite with Phase II cements in the intra pores (corallites) of the Paleofavosites specimens.

The zoned dolomite developed over a period of time in the shallow mesogenetic environment as a result of the mixing of iron enriched meteoric and marine waters.

The clarity of the dolomite crystals developed from the mixing of marine and fresh waters has received much attention from Folk and Land (1975) and Land et al. (1975). The presence of large "limpid" (clear) crystals has been suggested as a possible criterion for identifying dolomite developed as a result of mixing.

As mentioned earlier each successive zone of dolomite developed in a multizoned crystal show an increase in clarity until the final zone(s) are extremely clear. Furthermore, "limpid" crystals 20 microns to 40 microns in size and euhedral in shape are common in the Gunn Member. The presence of limpid crystals suggest that the Gunn Member was dolomitized as a result of mixing of marine and fresh waters in the mesogenetic environment.

Development Porosity

The development of porosity takes place when a solubility contrast occurs. Work by Steinen (1974) and Steinen and Matthews (1974) indicates that dissolution of unstable minerals and stabilization of the sediment occurs in the fresh water phreatic and vadose zone. However, such processes will occur whenever carbonates are exposed to waters of other than marine composition. The timing and environment of porosity development is highly variable. Porosity may develop early at shallow depths in the eogenetic zone, somewhat later in a deeper burial situation in the mesogenetic zone or at a much later geological time after the rock has been elevated and subjected to subaerial erosion in the telogenetic environment (Choquette and Pray, 1970).

In the study area the development of porosity has been noted in the upper Fort Garry Member of the Red River Formation, the lower Penitentiary, the Gunton and the lower conglomeratic bed of the Stonewall Formation, see Figure 10.

The development of porosity in the Fort Garry Member is restricted to the packstone to grainstone interval (Figure 5). In this portion of the member moldic porosity after peloids has developed. As shown in Plate 10, Figure D, vugs up to 1.5 mm exist. In many cases almost the complete peloid has been dissolved away leaving only a thin rind. Interparticle porosity is also present in this interval but contributes very little to the overall porosity grade. These pores are generally angular and range from 50 to 100 microns in size.

The porosity grade is estimated to be very good, i.e. approximately 15 percent. Moldic porosity comprises 90 to 95 percent of the pore type with interparticle porosity comprising 5 to 10 percent.

In the lower Penitentiary, well-developed moldic porosity after bivalves, gastropods, bryozoan and colonial corals forms the predominant pore type (Fig. 7). The vug size is limited only by the shell size of the faunal component, generally 30 cm. Intercrystalline porosity, microns in size, is present in the matrix of the bivalve floatstone interval of the lower Penitentiary.

The porosity grade is estimated to be good to very good, i.e. 10 to 15 percent. Moldic porosity comprises 75 to 80 percent of the pore type with intercrystalline comprising 20 to 25 percent.

Porosity development in the Gunton is restricted to the development of moldic pores in the lower and upper portions of the member (Fig. 10). As shown in Plate 4, Figure C, the development of porosity is restricted to the bedding horizons marked (E) in the photograph Closer examination of these bedded porosity zones indicates that gypsum once occupied the moldic pores (Pl. 10, Figs. A and B). The moldic pores that developed in many cases have been enlarged further with large vugs measuring 5 cm being developed. Pore communication appears to be very good along these horizons.

Also associated with this portion of the Gunton is the development of porosity after salt hoppers. This porosity type is very minor volumetrically but extremely important environmentally. Pore size may be as large as 3.5 cm.

Development of porosity in the upper Gunton is restricted to the development of moldic pores after gypsum (Pl. 10, Fig. C). As shown in Plate 4, Figure E, this moldic porosity is developed below the Gunton-Williams contact in finely laminated dolomite.

The total porosity development in the Gunton Member appears to be restricted to the development of moldic pores after the evaporitic minerals, gypsum and halite. This suggests that fresh water dissolution played an important role in the development of porosity. The porosity is interpreted to have formed in the eogenetic and telogenetic environments.

As noted earlier the development of porosity is interpreted to have occurred throughout the history of the rock. In the case of the porosity developed in the Fort Garry and the upper portion of the Gunton its association with nearby unconformities suggests that these hiatus played an important part in the development of porosity at a relatively early time. The development of porosity in the lower Penitentiary has been interpreted as a somewhat later diagenetic phenomenon which took place in the shallow mesogenetic environment.

Stylolite Development

The development of stylolites is common in the section studied (Figure 10). Stylolites both macroscopic and microscopic in size have been observed in the upper Fort Garry, Gunn, lower Penitentiary, Gunton and upper Williams. The stylolites in the upper Fort Garry are best observed in polished and etched slabs. The stylolites rarely exceed 2 mm in height.

Stylolites developed in the Gunn Member are easily recognizable in outcrop and drill core. The packstone to grainstone intervals display the best development of both macroscopic and microscopic stylolites. These units are commonly bounded by stylolites and contain numerous internal stylolites. Up to seven internal stylolites have been observed in a single packstone to grainstone interval only 8 to 10 cm thick. The stylolites rarely exceed 5 mm in length and may have an insoluble residue seam less than 0.05 mm in thickness associated with it. The maximum amount of removed section due to stylolitization in the packstone to grainstone interval was observed to be approximately 25 percent. The development of internal stylolites resulted in the truncation of Phase I cements in all cases. In many cases where the stylolites represent a boundary between two different types of packstone to grainstone units very thin argillaceous seams occur. In some cases these seams have euhedral ferroan dolomite crystals developed within them.

The stylolites found in the upper three members of the Stony Mountain Formation commonly form major surfaces parallel to bedding. These surfaces attain amplitudes over 1.5 cm in height.

As Bathurst (1971) pointed out stylolites are the result of pressure-solution along grain to grain contacts. Weyl (1959) proposed that the vast amounts of carbonate material that was removed due to this process was removed by a wet solution film. This implies that the development of stylolites would have to occur prior to the complete occlusion of all pore space by cement.

The development of stylolites has been interpreted to have been initiated in the shallow mesogenetic environment and continued to have been an active diagenetic process well into the mesogenetic environment. The fact that Phase I cements are truncated by stylolites and that the insoluble residue seams have become sites of dolomite nucleation indicates that the stylolites developed after the period of Phase I cementation and before at least a portion of late dolomitization.

Development of Authigenic Minerals

A total of four authigenic minerals have been observed in the Fort Garry Member of the Red River Formation and the Stony Mountain Formation (Figure 10). Authigenic feldspar is present in the Williams Member, chert in the upper dolomite unit of the Fort Garry Member, length slow chalcedony in the lower portion of the Gunton Member, pyrite in the Gunn Member and to a lesser extent in the upper Williams and hematite in the Gunn, lower Gunton and upper Williams.

Authigenic Feldspar

The development of authigenic feldspar is indicated by the development of feldspar overgrowth on a detrital feldspar grain (Pl. 11, Fig. F). Petrographic analysis on the universal stage by J. Macek indicate that the detrital grains were composed of K-feldspar (mainly microcline). The overgrowths were identified as being composed of K-feldspar also.

Basal and longitudinal sections parallel with the C-axis were commonly observed in this section revealing a wide variety of overgrowth development. As shown in Plate 11, Figure C, some overgrowth increase the detrital grain size by only 5 percent while in other cases the total grain size has been increased as much as 30 percent by the overgrowth.

The occurrence of authigenic feldspar as shown in Figure 10 is restricted to the Williams Member of the Stony Mountain Formation. To the best of the author's knowledge the development of authigenic feldspar has never been documented in the Ordovician strata of Manitoba. Modal analysis of the Williams Member (Appendix C) indicates that the authigenic feldspar comprise up to 4 percent of the Williams Member.

Origin

Hypotheses concerning the development of authigenic feldspar have been numerous, as shown in Table 3. It can be seen that essentially three principal schools of thought exist on the genesis of authigenic K-feldspar.

The first hypothesis suggests that formation of K-feldspar could have occurred at the sediment-water interface from seawater if the $K^+/(K^+ + Na^+)$ ratio was at the right concentration (Weaver, 1967). This may be the case where sporadic occurrences of authigenic feldspar exist.

The second hypothesis suggests that illite clays would serve as the source of the potassium, aluminum and silicon ions. This process would occur in the transitional zone between the eogenetic and mesogenetic environment and would be triggered by the beginning of dolomitization (Bower, 1966; Swett, 1968).

The third hypothesis postulates that the alteration of volcanic glass could account for the development of K-feldspar overgrowths (Buyce and Friedman, 1975; Honess and Jeffries, 1940; Deffeyes, 1959; Sheppard and Gude, 1973). This process may take place in the eogenetic environment and represents a two stage alteration process whereby the volcanic glass is altered to a zeolite then to authigenic K-feldspar.

The presence of K-feldspar overgrowths in a highly alkaline, hypersaline, supratidal environment (Buyce and Friedman, 1975) indicates that a fourth mechanism of authigenic feldspar formation possibly exists.

The development of authigenic K-feldspar in the Williams Member is interpreted to have occurred just prior to/or contemporaneous with the initiation of secondary dolomitization in the eogenetic to

Table 3: Summary of hypotheses on the formation of authigenic K-feldspar.

Author	Hypotheses on the formation of authigenic K-feldspar
Bowie et al. (1966)	Feldspar will develop in a marine environment which contains clays and volcanic glass. The release of potassium from the clays along with the formation of amorphous silica from the volcanic glass will promote the development of K-feldspar overgrowths at lower K^+/H^+ ratios.
Buyce & Friedman (1975)	Feldspar will form from tephra following the development of an intermediate zeolite stage at low temperature ($100^{\circ}C$) and pressure.
Deffeyes (1959)	Feldspar will form by the diagenetic alteration of rhyolite glass from a vitric ash fall in an alkaline environment.
Honess & Jeffries (1940)	Feldspar will develop from the alteration of acidic volcanic glass.
Kastner (1971)	Feldspar will form from the dissolution of detrital feldspar and concurrent precipitation on other feldspar grains.
Merino (1975)	Feldspar will form by the alteration of mafic minerals, plagioclase, quartz and dacitic volcanic glass at $100^{\circ}C$ and at depths in excess of 1000 m.
Orville (1964)	Feldspar may form by crystallization from normal sea water with the K^+/H^+ concentration equal to 10^6 if it is saturated with the more soluble amphorous silica.
Sheppard & Gude (1973)	Feldspar will form from volcanic glass as a second stage alteration product, i.e. the alteration of the volcanic glass to a zeolite stage and then the zeolite stage altering to an authigenic feldspar.
Swett (1968)	Feldspar may form from illitic bearing carbonates during the dolomitization process.
Weaver (1967)	Concluded that the weathering conditions in the lower Paleozoic prior to the rapid development of plant life that later caused soil acidity, resulting in much less Na^+ supplied to the seas than at present. The result was seawater with a $K^+/(K^+ + Na^+)$ ratio that permitted the formation of at least some authigenic illite and K-feldspar on the sea floor.

shallow mesogenetic environment. Supportive evidence for this interpretation is displayed in Plate 11, Figure F where the K-feldspar overgrowth is in direct contact with the detrital quartz grains.

Silicification

Silicification took place in the upper dolomite unit of the Fort Garry Member, the upper portion of the Penitentiary Member and the lower portion of the Gunton Member (Figure 10). The Fort Garry and upper Penitentiary are sites of chert development while length slow chalcedony spherulites developed in the lower Gunton.

(I) Chert

The chert nodules vary considerably in size and shape. The chert found throughout the upper dolomite unit of the Fort Garry Member is: white, lobate loaf-shaped (as large as 4 cm in length by 1.5 cm in width), developed parallel to bedding surfaces and are commonly surrounded by an aureole. The chert in the upper Penitentiary Member is found only at the Standard Quarry where it forms spherical nodules up to 8 cm in diameter. The outer surface commonly has a black crusty coat while the inner surface is white.

Origin

The development of chert nodules is interpreted to be the result of replacement of carbonate material by silica. The lobate loaf-shaped nodules are commonly surrounded by silicified carbonate aureoles. These aureoles may be 5 mm in thickness and commonly have skeletal debris and carbonate inclusions.

The silica may have been derived from the remains of siliceous sponges as suggested by Berner (1971), from the detrital quartz in shallow saline bodies of water with a high pH (Peterson and von der Borch, 1965), or from the weathering of montmorillonite to kaolinite which liberates silica, as suggested by Altschuler et al. (1963).

The fact that the silica aureoles contain inclusion of minute fossil fragments and dolomite crystals indicates that this process occurred near the end if not after the development of secondary dolomite.

(II) Length Slow Chalcedony

This variety of microquartz is found only in the lower Gunton. The length slow chalcedony forms spherulitic structures (Pl. 11, Fig. E) which are commonly less than 400 microns in diameter and possess a length slow, radial fibrous fabric. These structures are located in the matrix of the nodular rudstone to floatstone interval of the lower Gunton. At nearby stratigraphically equivalent beds gypsum molds and salt hopper casts are present.

Origin

Recent studies on length show chalcedony spherulites by Folk and Pittman (1971), Pittman and Folk (1970), Pittman (1971) and Siedlecka (1972) indicate that this variety of chalcedony formed relatively early in the diagenetic history of sediments and is a replacement of evaporitic minerals under high pH conditions. As seen in Plate 11, Figure E the spherulites have partially corroded edges. The author feels this is supportive evidence to the fact that spherulite developed relatively early in the eogenetic to shallow mesogenetic environment.

Pyrite

As shown in Figure 10, pyrite is found mainly in the Gunn

Member. The pyrite is found disseminated throughout the heavily burrowed mudstone and wackestone portions of the Gunn and concentrated in borings, burrows and stylolitic surfaces associated with the packstone to grainstone units. The former pyrite commonly forms cubic crystal and framboidal masses within the burrows and borings. These pyritic bodies are generally less than 2 mm in size. The pyrite developed along the stylolites is considerably larger than the above-mentioned pyrite. Well-developed cubic crystals (up to 8 mm in size) with striation typify this later period of pyrite development.

Origin

The pyrite has been interpreted to have formed in the eogenetic and mesogenetic environments. The pyrite found disseminated throughout the Gunn Member and concentrated in the burrows and borings of this Member has been interpreted as an early diagenetic product formed in the eogenetic environment. The pyrite found along the stylolitic surfaces has been interpreted as a later diagenetic product formed in the mesogenetic environment due to the migration of iron enriched solutions during and/or after the development of stylolites.

As noted by Berner (1971), Pettijohn (1975), Reineck and Singh (1975) and Kobluk and Risk (1977b) biological reworking (burrowing and boring) would result in the release of bacteria. The bacteria would take part in the decomposition of organic matter and the reduction of sulfur which would result in the precipitation of pyrite around bacterium or algal cell nuclei.

Hematite

Hematite is closely associated with the development of pyrite as can be seen in Figure 10. As shown in this figure it is developed in the Gunn, lower Gunton and upper Williams. The hematite in these intervals occurs as: lacy aggregates (Smith, 1963), halos around pyrite grains, rims around burrows and generally disseminated throughout the section.

Origin

The hematite probably developed as a result of alteration of pyrite in the presence of oxygenated waters as suggested by Deer et al. (1972). The formation of hematite most likely took place in the mesogenetic and telogenetic environments.

Summary

The upper Fort Garry Member of the Red River Formation and the Stony Mountain Formation have been subjected to numerous diagenetic changes as shown in Figure 10. Biological and chemical diagenetic processes such as; burrowing and boring, cementation, neomorphism, dolomitization, authigenic mineral development and the development of secondary porosity and stylolites have been interpreted as processes that have occurred in either the subaerial or submarine eogenetic environment or the mesogenetic or telogenetic environment.

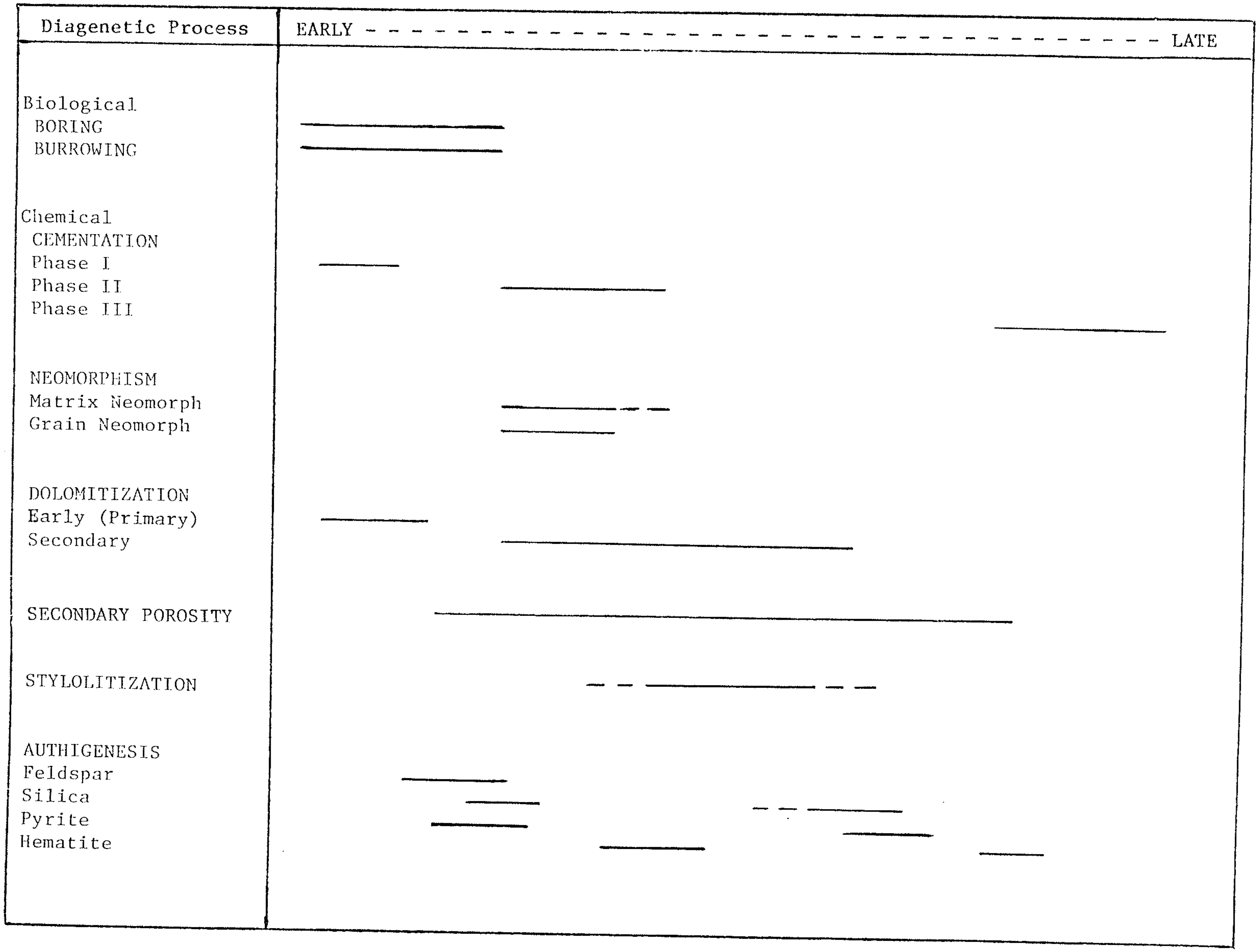
The relative timing of the diagenetic processes is shown in Figure 11. The biological processes (burrowing and boring) have been interpreted as early diagenetic processes which took place in the marine eogenetic environment. Chemical alteration such as the development of Phase I cements and early (primary) dolomite have also been interpreted as early diagenetic processes which occurred in the marine and subaerial eogenetic environment respectively. The presence of micritized skeletal debris in the packstone to grainstone intervals indicate that the microboring process (micritization) took place prior to Phase I cementation. However, the macroboring process has been interpreted as occurring after Phase I cementation but still relatively early in the diagenetic history of the sediment. This interpretation is supported by the fact that Phase I cements in the packstone to grainstone intervals have been truncated by macroborings.

The presence of Phase II ferroan cement in fractures which truncate Phase I cements and borings indicates that the Phase II cement type postdates the development of Phase I cements and borings. Phase II cements have been interpreted as a somewhat later diagenetic product that formed in the mesogenetic environment as a result of subsurface waters enriched in iron migrating through the sediment.

Phase III cements have been interpreted as late a diagenetic product that developed in the telogenetic environment. The fact that this non-ferroan cement encloses dolomite clasts on the floors of solution-enlarged channels indicates that this process postdates secondary dolomitization and most other diagenetic processes (Figure 11).

As shown in Figure 11 the process of neomorphism (both matrix and grain neomorphism) has been interpreted as a relatively early and short lived diagenetic process. Both matrix neomorphism and grain neomorphism have been interpreted as processes that were active in the eogenetic to shallow mesogenetic environment. The close association noted between the development of Phase II ferroan cements and grain neomorphism is believed to indicate the time span in which the latter process was active. However, the process of matrix neomorphism is believed to have been active somewhat longer than grain neomorphism.

Figure 11: Relative timing of diagenetic processes.


Diagenetic Process
EARLY - LATE
Biological
BORING
BURROWING
Chemical
CEMENTATION
Phase I
Phase II
Phase III
NEOMORPHISM
Matrix Neomorph
Grain Neomorph
DOLOMITIZATION
Early (Primary)
Secondary
SECONDARY POROSITY
STYLOLITIZATION
AUTHIGENESIS
Feldspar
Silica
Pyrite
Hematite

The development of dolomite has been interpreted as occurring throughout a long time span (Figure 11). The development of early or primary dolomite has been interpreted to have occurred very early in the subaerial eogenetic environment. However, the development of secondary dolomite has been interpreted to have occurred sometime later in the shallow mesogenetic to deeper mesogenetic environment as a result of mixing of marine and fresh waters.

The development of porosity has been interpreted to have occurred from a relatively early to an extremely late time period in the diagenetic history of the sediments (Figure 11). The development of porosity occurred in the eogenetic, mesogenetic and telogenetic environments as a result of burrowing, boring, solution migration and weathering.

The development of stylolites has been interpreted as a relatively later diagenetic process (Figure 11) which took place in the mesogenetic environment. This process is a result of pressure-solution and the movement of solution through the sediment therefore is closely related to secondary dolomitization and the development of secondary porosity.

The development of authigenic minerals (in particular feldspar, silica, pyrite and hematite) has been interpreted to have occurred at various times in the diagenetic history of the sediment. The development of authigenic feldspar overgrowths has been interpreted as a relatively early process that was active in the eogenetic to shallow mesogenetic environment. It is postulated that the illitic clays provided the necessary elements and that the process was triggered by the initiation of dolomitization.

Silification has resulted in the development length slow chalcedony spherulites and chert nodules. The development of length slow chalcedony has been interpreted to have occurred in the eogenetic to shallow mesogenetic environment as a replacement of evaporitic minerals under high pH conditions. The fact that the spherulites have been slightly corroded by dolomite indicates that these structures developed prior to secondary dolomitization. The development of chert has been interpreted as a later diagenetic process (Figure 11). The original carbonate material has been interpreted to have been replaced by silica under high pH conditions.

The development of pyrite has been interpreted to have taken place early in the eogenetic environment and at a much later time in the mesogenetic environment. The former occurrence is believed related biological activity while the latter is believed related to migration of iron enriched subsurface solutions developed during and/or after the stylolitization process.

The close association of hematite with pyrite and postulated erosional surfaces has led to the interpretation that hematite was produced in two different environments and time periods. The hematite associated with pyrite is interpreted to have been formed in the mesogenetic environment in the presence of oxygenated waters. The hematite associated with the erosional surfaces have been interpreted as weathering products developed in the subaerial environment.

SUMMARY

Red River Formation

Fort Garry Member

The upper Fort Garry has been interpreted as being deposited in a shallow marine environment that was characterized by clean carbonate sedimentation and the development of emergent tidal flat complexes similar to those found in the present day Bahamian and Persian Gulf areas. A complex interfingering of textural rock types and sedimentary structures indicates that sedimentation took place predominantly in the extremely shallow subtidal to supratidal environments and was subjected to periods of non deposition and subaerial exposure (Figure 5). By the end of Fort Garry time the shallow epeiric sea had withdrawn basinward leaving the sediments completely exposed for an unknown duration of time.

Seven diagenetic processes have been documented within the upper Fort Garry Member (Figure 10). Burrowing, interparticle Phase I cementation, early (primary) dolomitization and porosity development took place early in the diagenetic history of the sediment in the eogenetic to shallow mesogenetic environment. Neomorphism, the development of secondary dolomite and chert nodules represent later diagenetic processes which occurred in the mesogenetic environment (Figure 11).

Stony Mountain Formation

Gunn Member

Following the period of emergence that occurred at the end of Fort Garry time a shallow epeiric sea transgressed the Winnipeg region depositing the basal member of the Stony Mountain Formation unconformably upon the Red River Formation. The presence of numerous textural rock types and sedimentary structures (Figure 6) indicates that the Gunn Member was deposited in a shallow marine environment quite different than that of the underlying Fort Garry Member of the Red River Formation. Gunn time was characterized by a large and constant influx of terrigenous material (Figure 3), low energy conditions for the most part, a diversified benthonic faunal assemblage and the development of mud banks (similar to those found in the Florida Keys) around which bioclastic packstone to grainstone aprons or sheets were deposited.

As shown in Figure 10 eight diagenetic processes have been documented in the Gunn Member. The development of burrows, borings (both macroborings and microborings), Phase I cements and pyrite in the burrows and borings took place very early in the diagenetic history of the sediment in the eogenetic to very shallow mesogenetic environment. The development of hematite, neomorphism of the sediments, secondary dolomite and stylolites took place at later diagenetic periods in the shallow mesogenetic to deep mesogenetic environment (Figure 11).

Penitentiary Member

The Penitentiary Member was deposited conformably upon the Gunn Member as shallow marine conditions continued into Penitentiary time. The lower Penitentiary was deposited in a shallow but open marine setting where a diversified faunal community could develop. Like the Gunn Member energy conditions were relatively low and the terrigenous influx was constant. The upper Penitentiary was deposited in a constantly shallowing and restricted marine environment. During this time period the energy condition varied from low to relatively high (Figure 7) and the terrigenous material showed a constant and steady decline (Figure 3). By the end of Penitentiary time the seas have been interpreted to have withdrawn basinward leaving all but topographic depressions in the top of the Penitentiary Member subaerially exposed.

The development of secondary dolomite throughout the Penitentiary Member has eliminated the recognition of other diagenetic processes except those developed in the transition zone (Figure 10) between the Gunn and Penitentiary Member. The presence of burrows in the transition zone and the vaguely pelleted areas of the bivalve floatstone interval suggests that burrowing of the lower Penitentiary sediments occurred early in their diagenetic history in the eogenetic environment (Figure 11). The occurrence of blocky cement under sheltered pores and neomorphically recrystallized shell remains have been interpreted as somewhat later diagenetic processes which occurred in the shallow mesogenetic environment. The development of secondary dolomite, secondary porosity and stylolites took place in the mesogenetic environment and represent later diagenetic alterations (Figure 11).

Gunton Member

As the epeiric sea slowly transgressed the Winnipeg region, the Gunton Member was unconformably deposited upon the Penitentiary Member. The textural rock types and numerous sedimentary structures present in this member indicate that it was deposited in a shallow marine environment in which evaporitic tidal flats (similar to those found in the Bahamas and Persian Gulf) developed (Figure 8). The evaporitic tidal flat and laterally equivalent marine textural rock types were deposited in a clean carbonate environment (Figure 3) in which the tidal flat build-ups kept pace with the subsidence rate. By the end of Gunton time the epeiric sea had begun to withdraw basinward leaving restricted evaporitic lagoons behind and finally emergent sediments.

As shown in Figure 10 a total of seven diagenetic processes have been documented in the Gunton Member. The development of burrows, early (primary) dolomite crusts and length slow chalcedony spherulites took place in the eogenetic environment early in the diagenetic history of the sediments. The development of secondary dolomite and stylolites are later diagenetic processes along with the development of some porosity. These processes were active in the mesogenetic environment. Telogenetic hematite formed as a residuum during a period of exposure at the end of Penitentiary time. The development of Phase III cement is a much later diagenetic process which took place in the telogenetic environment (Figure 11).

Williams Member

The uppermost member of the Stony Mountain Formation (the Williams Member) was deposited unconformably upon the Gunton Member. Sedimentation took place in a shallow marine environment which was ladened with large quantities of terrigenous clays and quartzofeldspathic material (Figure 3, Appendix C). Textural rock types and sedimentary structures indicate that the lower Williams was deposited in a shallow subtidal to intertidal beach setting adjacent to an emergent mound while the upper Williams was deposited in a shallow marine environment between emergent mounds or basinward of an emergent mound (Figure 9). Deposition of the lower Williams took place in a high energy environment with a fast sedimentation rate while the upper Williams was deposited under low energy conditions and a slow sedimentation rate. The end of Williams time and the Stony Mountain period saw the withdrawal of the marine waters basinward and the emergence of the sediments.

A total of seven diagenetic processes have been documented in the Williams Member (Figure 10). The burrowing of the sediments, development of early (primary) dolomite crusts, authigenic feldspar overgrowths and pyrite occurred early in the diagenetic history of the Williams Member in the eogenetic to shallow mesogenetic environment. The development of secondary dolomite, hematite and stylolites occurred in the shallow and deep mesogenetic environments during later periods of diagenesis.

REFERENCES

Adams, J. E. and Rhodes, M. L., 1960, Dolomitization by seepage refluxion: Am. Assoc. Petroleum Geologist Bull., v. 44, p. 1912-1920.

Altschulter, Z. S., Dwornik, E. J., and Kramer, H., 1963, Transformation or montmorillonite to kaolinite during weathering: Science, v. 141, p. 148-152.

Baillie, A. D., 1952, Ordovician geology of Lake Winnipeg and adjacent areas, Manitoba: Manitoba Mines Branch Publ. 51-6.

Badiozamani, K., 1973, Dorag dolomitization model, Ordovician, Wisconsin: Jour. Sed. Petrology, v. 43, p. 965-984.

_______________, MacKenzie, F. T., and Thorstenson, D. C., 1977, Experimental carbonate cementation: salinity, temperature and vadose-phreatic effects: Jour. Sed. Petrology, v. 47, p. 529-542.

Bannatyne, B. B., 1975, High-calcium limestone deposits of Manitoba: Manitoba Mines Branch Publ. 75-1.

Bathurst, R. G. C., 1966, Boring algae, micrite envelopes and lithification of molluscan biosparite: Geol. Jour., v. 5, p. 15-32.

__________________, 1971, Carbonate sediments and their diagenesis: Elsevier Publishing Company, New York, 620 p.

Blatt, H., Middleton, G., and Murray, R., 1972, Origin of sedimentary rocks: Prentice-Hall Incorporated, New Jersey, 634 p.

Berner, R. A., 1971, Principles of chemical sedimentology, McGraw-Hill Book Company, Montreal, 240 p.

Bricker, O. P., 1971, Carbonate cement: The Johns Hopkins Press, Baltimore, 376 p.

Booth, J. S. and Osborne, R. H., 1971, The American Upper Ordovician standard, XV clay mineralogy of insoluble residue from Cincinnatian limestones, Hamilton County, Ohio: Jour. Sed. Petrology, v. 41, p. 840-843.

Bowie, S. H. U., Dawson, J., Gallagher, M. J., Ostle, D., Lambert, R. St. J. and Lawson, R. I., 1966, Potassium rich sediments in the Cambrian of northwest Scotland: Inst. Mining and Metallurgy Bull., v. 714, p. 125-145.

Buyce, M. R. and Friedman, G. M., 1975, Significance of authigenic K-feldspar in Cambrian-Ordovician carbonate rocks of the Proto-Atlantic shelf in North America: Jour. Sed. Petrology, v. 45, p. 808-821.

Choquette, P. W. and Pray, L. C., 1970, Geological nomenclature and classification of porosity in sedimentary carbonates: Am. Assoc. Petroleum Geologist Bull., v. 54, p. 207-250.

Cowan, J., 1971, Ordovician and Silurian stratigraphy of the Interlake area, Manitoba: in A. C. Turnock ed., Geoscience Studies in Manitoba, Geol. Assoc. of Canada, Spec. Paper #9, p. 235-241.

Cumming, L. M., 1971, Ordovician strata of the Hudson Bay Lowlands in northern Manitoba: in A. C. Turnock ed., Geoscience Studies in Manitoba, Geol. Assoc. of Canada, Spec. Paper #9, p. 189-197.

Deer, W. A., Howie, R. A., and Zussman, J., 1972, An introduction to the rock forming minerals: Longman Group Ltd., London, 528 p.

Deffeyes, K. S., 1959, Zeolites in sedimentary rocks: Jour. Sed. Petrology, v. 29, p. 602-609.

_______________, Lucia, F. J., and Weyl, P. K., 1965, Dolomitization of Recent and Plio-Pliestocene sediments by marine evaporite waters on Bonaire, Netherland Antilles: in L. C. Pray and R. C. Murray, ed., Dolomitization and Limestone Diagenesis a symposium, Soc. Econ. Paleont, Min., Spec. Publ. #13, p. 71-88.

Dickson, J. A. D., 1965, A modified staining technique for carbonate in thin section: Nature, v. 205, p. 587.

Dowling, D. B., 1900, Report on the geology of the west shore and islands of Lake Winnipeg: Geol. Survey of Canada, Ann. Rept. 1898, v. 11, pt. F.

Embry III, A. F. and Klovan, J. E., 1971, A late Devonian reef tract on northeastern Banks Island, N.W.T.: Bull. Can. Petroleum Geology, v. 19, p. 730-781.

Evamy, B. D. and Shearman, D. J., 1965, The development of overgrowths from echinoderm fragments: Sedimentology, v. 5, p. 211-234.

Folk, R. L., 1965, Some aspects of recrystallization in ancient limestones: in L. C. Pray and R. C. Murray ed., Dolomitization and Limestone Diagenesis a symposium, Soc. Econ. Paleont. Min., Spec. Publ. #13, p. 14-48.

___________ and Land, L. S., 1975, Mg/Ca ratio and salinity: two controls over crystallization of dolomite: Am. Assoc. Petroleum Geologist Bull., v. 59, p. 60-68.

___________ and Pittman, J. S., 1971, Length - slow chalcedony: a new testament for vanished evaporite minerals: Jour. Sed. Petrology v. 41, p. 1045-1058.

Friedman, G. M., 1964, Early daigenesis and lithification in carbonate sediments: Jour. Sed. Petrology, v. 34, p. 777-813.

Frost, J. G., 1974, Subtidal algal stromatolites from the Florida back-reef environment: Jour. Sed. Petrology, v. 44, p. 532-537.

Gebelein, C. D., 1974, Guidebook for: modern Bahamian Platform environments: Geol. Soc. Amer., 93 p.

Hanshaw, B. B., Back, W., and Deike, R. G., 1971, A geochemical hypothesis for dolomitization by groundwater: Econ. Geology, p. 710-724.

Harrison, R. S., 1975, Porosity in Pleistocene grainstones from Barbados: some preliminary observations: Bull. Can. Petroleum Geology, v. 23, p. 383-392.

Honess, A. P. and Jeffries, C. D., 1940, Authigenic albite from the Lowville Limestone at Bellefonte, Pennsylvania: Jour. Sed. Petrology, v. 10, p. 12-18.

Howard, J. A., 1975, The sedimentological significance of trace fossils: in R. W. Frey, ed., The study of trace fossils, Springer-Verlag, New York, p. 131-146.

Illing, L. V., Wells, A. J., and Taylor, J. C. M., 1965, Penecontemporary dolomite in the Persian Gulf: in L. C. Pray and R. C. Murray ed., Dolomitization and Limestone Diagenesis a symposium, Soc. Econ. Paleont. Min., Spec. Publ. #13, p. 89-111.

James, N. P., 1974, Diagenesis of scleracterian corals in the subaerial vadose environment: Jour. Paleontology, v. 48, p. 785-799.

____________, Kobluk, D. R., and Pemberton, S. G., 1977, The oldest macroborers: Lower Cambrian of Labrador: Science, v. 197, p. 980-983.

Kastner, M., 1971, Authigenic feldspar in carbonate rocks: Amer. Min., v. 56, p. 1403-1442.

Kendall, A. C., 1971, Intertidal sediments as a criterion of void filling cement: in O. P. Bricker ed., Carbonate Cements, Johns Hopkins University Press, Baltimore, p. 303-307.

______________, 1976, The Ordovician carbonate succession (Bighorn Group) of southeastern Saskatchewan: Report #180, Dept. Min. Res., Saskatchewan Geological Survey, 186 p.

Kobluk, D. R., 1976, Micrite envelope formation, grain binding, and porosity modification by endolithic (boring) algae in modern and ancient reef environments: Abst., p. 78, Geol. Assoc. of Canada (29th) annual meeting.

_____________ and Risk, M. J., 1977a, Calcification of exposed filaments of endolithic algae, micrite envelope formation and sediment production: Jour. Sed. Petrology, v. 47, p. 517-528.

_____________, 1977b, Algal borings and framboidal pyrite in Upper Ordovician brachiopods: Lethaia, v. 10, p. 135-143.

Land, L. S., 1973, Holocene meteoric dolomitization of Pleistocene limestone, north Jamaica: Sedimentology, v. 20, p. 411-424.

__________, 1973, Contemporaneous dolomitization of middle Pleistocene reefs by meteoric water, north Jamaica: Marine Sci. Bull., v. 23, p. 64-92.

__________ and Epstein, S., 1970, Late Pleistocene diagenesis and dolomitization, north Jamaica: Sedimentology, v. 14, p. 187-200.

__________, Mackenzie, F. T. and Gould, S. J., 1967, Pleistocene history of Bermuda: Geol. Soc. Amer. Bull., v. 78, p. 993-1006.

__________, Salem, M. R. J., and Morrow D. W., 1975, Paleohydrology of ancient dolomites: geochemical evidence, Am. Assoc. Petroleum Geologist Bull., v. 59, p. 1602-1625.

Lindholm, R. C., 1974, Fabric and chemistry of pore filling calcite in septarian veins: models for limestone cementation: Jour. Sed. Petrology, v. 44, p. 428-440.

Lindstrom, M. 1963, Sedimentary folds and the development of limestone in an Early Ordovician sea: Sedimentology, v. 2, p. 243-275.

Lochman-Balk, C., 1970, Upper Cambrian faunal patterns on the craton: Geol. Soc. Amer. Bull., v. 81, p. 3197-3224.

Loreau, J. P. and Purser, B. H., 1973, Distribution and ultrastructure of Holocene ooids in the Persian Gulf: in B. H. Purser ed., The Persian Gulf, Springer-Verlag, New York, p. 279-328.

Macintyre, I. G., 1977, Distribution of submarine cements in a modern Caribbean fringing reef, Galeta Point, Panama: Jour. Sed. Petrology, v. 47, p. 503-516.

Matthews, R. K., 1966, Genesis of Recent lime mud, in southern British Honduras: Jour. Sed. Petrology, v. 36, p. 428-454.

Merino, E. 1975, Diagenesis in Tertiary sandstones from Kettleman North Dome, California. I. diagentic mineralogy: Jour. Sed. Petrology, v. 45, p. 320-336.

Meyers, W. J., 1974, Carbonate cement stratigraphy of the Lake Valley Formation (Mississippian) Sacramento Mountains, New Mexico: Jour. Sed. Petrology, v. 44, p. 837-861.

McCabe, H. R., 1971, Stratigraphy of Manitoba, an introduction and review: in A. C. Turnock ed., Geoscience studies in Manitoba, Geol. Soc. of Canada Spec. Paper #9, p. 167-187.

__________ and Bannatyne, B. B., 1970, Lake St. Martin crypto-explosion crater and geology of the surrounding area: Manitoba Mines Branch, Geol. Paper 3/70.

McCrossan, R. G. and Glaister, R. P., 1964, Geological history of western Canada: Alberta Soc. Petrol. Geologist, Calgary, Canada, 233 p.

Moore, R. C., 1958, Introduction to historical geology: McGraw-Hill Book Company Incorporated, Toronto, 656 p.

Multer, H. G., 1975, Carbonate rock environments: 2nd ed., Fairleigh Dickinson University Press, New Jersey, 175 p.

Murray, R. C., 1969, Hydrology of south Bonaire, N. A. - a rock selective dolomitization model: Jour. Sed. Petrology, v. 39, p. 1007-1013.

Nelson, S. J., 1959a, Arctic Ordovician fauna: an equatorial assemblage ?: Alberta Soc. Petrol. Geologist, v. 7, p. 45-47, 53.

______________, 1959b, Guide fossils of the Red River and Stony Mountain equivalents (Ordovician): Alberta Soc. Petrol. Geologist, v. 7, p. 51-61.

______________, 1975, Paleontological field guides: northern Canada and Alaska: Bull. Canadian Petrol. Geology, v. 23, p. 481-683.

Okulitch, V. J., 1943, The Stony Mountain Formation of Manitoba: Trans. Roy. Soc., Canada, 3rd. ser., v. 37, sec. 4, p. 59-74.

Orville, P. M., 1964, Is K-feldspar stable in a near surface sedimentary environment? (abstract): Geol. Soc. Amer. Bull., Spec. Paper 76, p. 126.

Peterson, M. N. A. and von der Borch, C. C., 1965, Chert: modern inorganic deposition in a carbonate-precipitating locality, Science, v. 149, p. 1501-1503.

Pettijohn, E. J., 1975, Sedimentary rocks: 3rd ed., Harper and Row Publishers, Incorporated, New York, 628 p.

Pittman, J. S., 1971, The geological significance of length-slow chalcedony: a replacement of evaporite minerals: Ms submitted to the Geol. Soc. Amer. Bull.

______________ and Folk, R. L., 1970, Length-slow chalcedony: a new testament for vanished evaporite minerals (abstract): Geol. Soc. Amer., Ann. Meeting (Milwaukee) program, p. 654-655.

Porter, J. W. and Fuller, J. G. C. M., 1959, Lower Paleozoic rocks of the Williston Basin: Am. Assoc. Petroleum Geologist Bull., v. 43, p. 124-189.

Purser, B. A., ed., 1973, The Persian Gulf: Springer-Verlag, New York, 471 p.

Reineck, H. E. and Singh, I. B., 1975, Depositional sedimentary environment, Springer-Verlag, New York, 439 p.

Roehl, P. O., 1967, Stony Mountain (Ordovician) and Interlake (Silurian) facies analogs of Recent low-energy marine and subaerial carbonates, Bahamas: Am. Assoc. Petroleum Geologist Bull., v. 51, p. 1979-2032.

Royse Jr., C. F., Wadell, J. S., and Peterson, L. E., 1971, X-ray determination of calcite-dolomite: an evaluation: Jour. Sed. Petrology, v. 41, p. 483-488.

Seilacher, A., 1964, Biogenic sedimentary structures: in J. Imbrie and N. D. Newell, eds., Approaches to Paleoecology, John Wiley and Sons, Incorporated, New York, p. 296-315.

Sheppard, R. A. and Gude, A. J., 1973, Zeolites and associated authigenic silicate minerals in tuffaceous rocks of the Big Sandy Formation, Mohave County, Arizona, U. S. Geol. Survey Prof. Paper 830, 36 p.

Shinn, E. A., 1968, Selective dolomitization of Recent sedimentary structures: Jour. Sed. Petrology, v. 38, p. 612-616.

____________, Ginsburg, R. N., and Lloyd, R. M., 1965, Recent supratidal dolomite from Andros Island, Bahamas: in L. C. Pray and R. C. Murray eds., Dolomitization and Limestone Diagenesis a symposium, Soc. Econ. Paleont. Min., Spec. Publ. #13, p. 112-123.

____________, Lloyd, R. M. and Ginburg, R. N., 1969, Anatomy of a modern carbonate tidal-flat, Andros Island, Bahamas, Jour. Sed. Petrology, v. 39, p. 1202-1228.

Siedlecka, A., 1972, Length-slow chalcedony and relicts of sulphates-evidence of evaporitic environments in the Upper Carboniferous and Permian beds of Bear Island, Svalbard: Jour. Sed. Petrology, v. 42, p. 812-816.

Smith, D. L., 1963, A lithologic study of the Stony Mountain and Stonewall Formations in southern Manitoba: unpublished M.Sc. thesis, University of Manitoba, 219 p.

Stehli, F. G. and Hower, J., 1961, Mineralogy and early diagenesis of carbonate sediments: Jour. Sed. Petrology, v. 31, p. 358-371.

Steinen, P. P., 1974, Phreatic and vadose diagenetic modification of Pleistocene limestone: petrographic observations from subsurface of Barbados, West Indies: Am. Assoc. Petroleum Geologist Bull., v. 58, p. 1008-1024.

______________ and Matthews, R. K., 1973, Phreatic vs vadose diagenesis. Stratigraphy and mineralogy of a cored bore-hole on Barbados, West Indies: Jour. Sed. Petrology, v. 43, p. 1012-1020.

Stockman, K. W., Ginsburg, R. N., and Shinn, E. A., 1967, The production of lime mud by algae in south Florida: Jour. Sed. Petrology, v. 37, p. 633-648.

Swett, K., 1968, Authigenic feldspar and cherts resulting from dolomitization of illitic limestones: a hypothesis: Jour. Sed. Petrology, v. 38, p. 128-135.

Swinchatt, J. P., 1969, Algal boring: a possible depth indicator in carbonate rocks and sediments: Geol. Soc. Amer. Bull., v. 80, p. 1391-1396.

Taylor, J. M. C. and Illing, L. V., 1969, Holocene intertidal calcium carbonate cementation, Qatar, Persian Gulf: Sedimentology, v. 12, p. 69-107.

Twenhofel, W. H., 1924, Geology of Anticosti Island: Geol. Survey of Canada, Mem. 154.

Weaver, C. E., 1967, Potassium, illite and the ocean: Geochim. Cosmochim. Acta, v. 31, p. 2181-2196.

Weyl, P. K., 1959, Pressure-solution and the force of crystallization - a phenomenological theory: Jour. Geophys. Research, v. 64, p. 2001-2025.

Whiteaves, J. F., 1895, Systematic list, with references, of the fossils of the Hudson River or Cincinnati Formation at Stony Mountain, Manitoba: Geol. Survey of Canada, Paleozoic Fossils, v. 3, pt. 2, p. 111-128.

________________, 1897, The fossils of the Galena-Trenton and Black River Formation of Lake Winnipeg and its vicinity: Geol. Survey of Canada. Paleozoic Fossils, v. 3, pt. 3, p. 129-242.

Zenger, D. H., 1972, Dolomitization and uniformitarianism: Jour. Geol. Education, v. 20, CEGS Short Review #19.

PLATES

PLATE 1 - FIELD PHOTOS

A. Stony Mountain Formation. NW quarry at the City of Winnipeg Quarry at Stony Mountain Manitoba. The upper portion of the Gunn Member (G) is the darker grey unit exposed below the first arrow. The contact with the overlying Penitentiary Member (P) is gradational over 70 cm but at this quarry has been placed at the quarry floor in the fore ground. The basal contact of the Gunton (GT) is placed at the position of the first purple burrowed horizon, which is less than 10 cm thick in this pit. Penitentiary Member is approximately 4.5 m thick.

B. Stony Mountain Formation. SE quarry at the City of Winnipeg Quarry at Stony Mountain Manitoba. The Penitentiary Member (P) is overlain by the snow draped Gunton Member (GT). The black arrow indicates the base of the Gunton Member and the base of the first purple burrowed horizon. The purple burrowed horizon is approximately 50 cm thick.

C. Stony Mountain Formation. View of the Gunn (G) Penitentiary (P) contact. The interbedded nature of the bioclastic packstones and slightly fossiliferous mudstones of the Gunn Member is well displayed. The Gunn Member in the NW pit is a deep purple to maroon with pale red to grey bioclastic beds 5 cm thick. The overlying Penitentiary is a rich orange-beige colour and is very recessive. Approximately 1.5 m of the Gunn Member are displayed in this photograph.

D. Stony Mountain Formation. SE quarry at the City of Winnipeg Quarry at Stony Mountain Manitoba. View of the heavily burrowed, slightly fossiliferous mudstone (M) and packstone to grainstone (P) textural rock types found in the Gunn Member. The upper surface of the pack-stone to grainstone intervals commonly have large U-shaped burrows (black arrow) developed on it. Scale in cm.

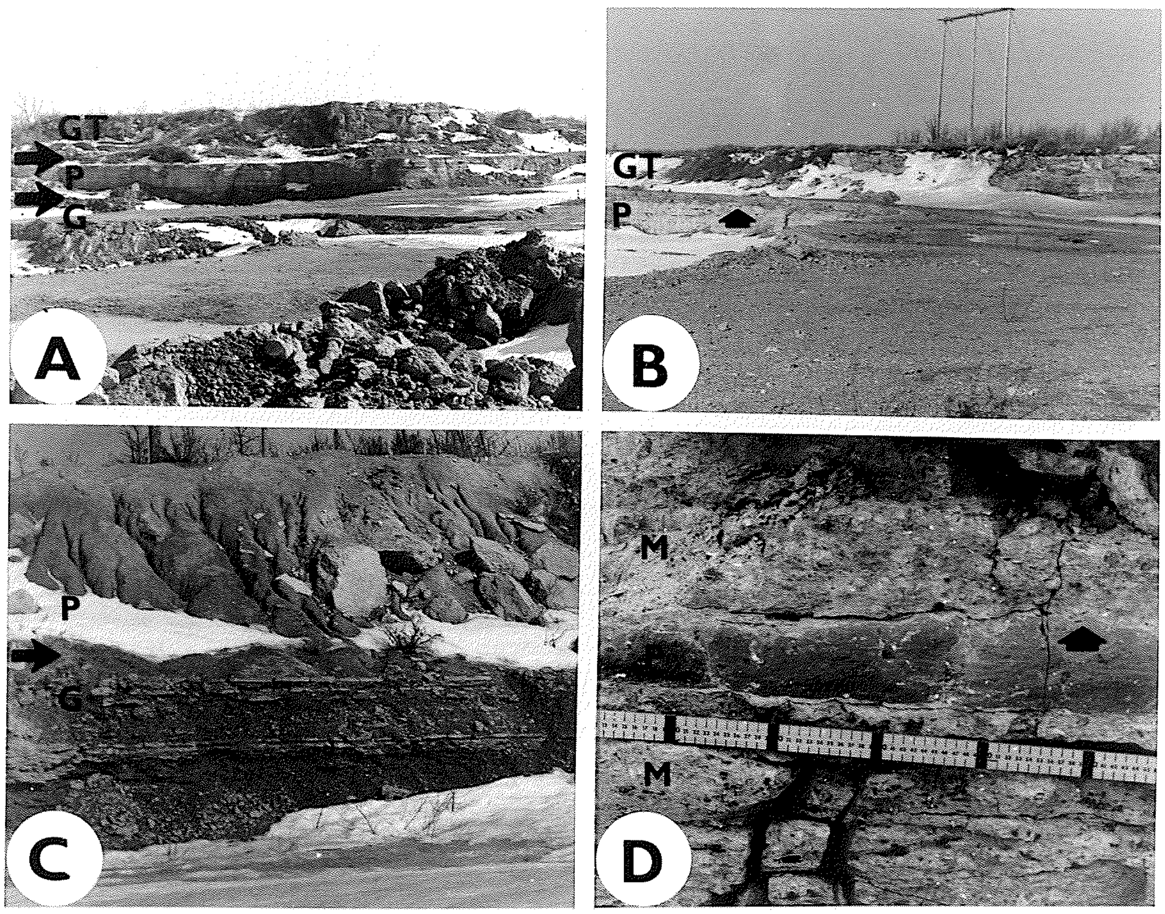

GT
P
G
A
GT
P
B
P
G
C
M
M
D

PLATE 2 - TEXTURAL ROCK TYPES

A. Red River Formation - upper part of the Fort Garry Member. A thinly bedded lithographic mudstone unit overlies a flat pebble conglomeratic rudstone unit. Both facies are cut by later fractures. The clasts (C) of the rudstone unit are commonly laminated and are variable in size. Sample 7-F-6, negative print of peel, bar-5 mm.

B. Stony Mountain Formation - Gunn Member. Mudstone textural rock type. As can be seen in the photograph this rock type is characterized by numerous horizontal burrows which are rimmed with hematite. Large calcite crystal growths (G) are rare in the mudstone. Hand sample from Section 4 viewed perpendicular to bedding, bar-1 cm.

C. Red River Formation - upper part of the Fort Garry Member. Intraclastic packstone to grainstone textural rock type. In this example pellets, pelletoids, and fine clasts (speckled portion of the photograph) are much more abundant than coarse clasts (C). The small dark areas are moldic pores. The black arrow marks an erosional break above which a finely laminated dolomite has been deposited. Sample 6-F-29-2, negative print of thin section, bar-1 mm.

D. Red River Formation - upper part of the Fort Garry Member. Close up view of a unique clast type found above the finely laminated dolomite of Pl. 2, Fig. C. The coarse clast is well rounded and composed of very fine argillaceous dolomite clasts (C). These clasts are angular to subangular and surrounded by an isopachous equant druse. The voids (V) represent moldic pores. Sample 6-F-28, thin section, bar-500 microns.

E. Stony Mountain Formation - Gunn Member. Fossiliferous wackestone (floatstone) textural rock type. Bioclastic debris, bivalves (B), solitary corals (CR), and bryozoans (BY) are some of the fossil remains preserved in the sample. Sample 6-F-11, hand sample slabbed perpendicular to bedding surface, bar-5 mm.

F. Stony Mountain Formation - Williams Member. Intraclastic floatstone textural rock type. Clast (C) are composed of finely laminated, vaguely pelleted, dolomite with crystals microns in size. The matrix (QF) is composed mainly of quartz, feldspar, and coarsely crystalline zoned dolomite (60 to 220 microns in size). Sample 1-W-13, negative print of peel, bar-5 mm.

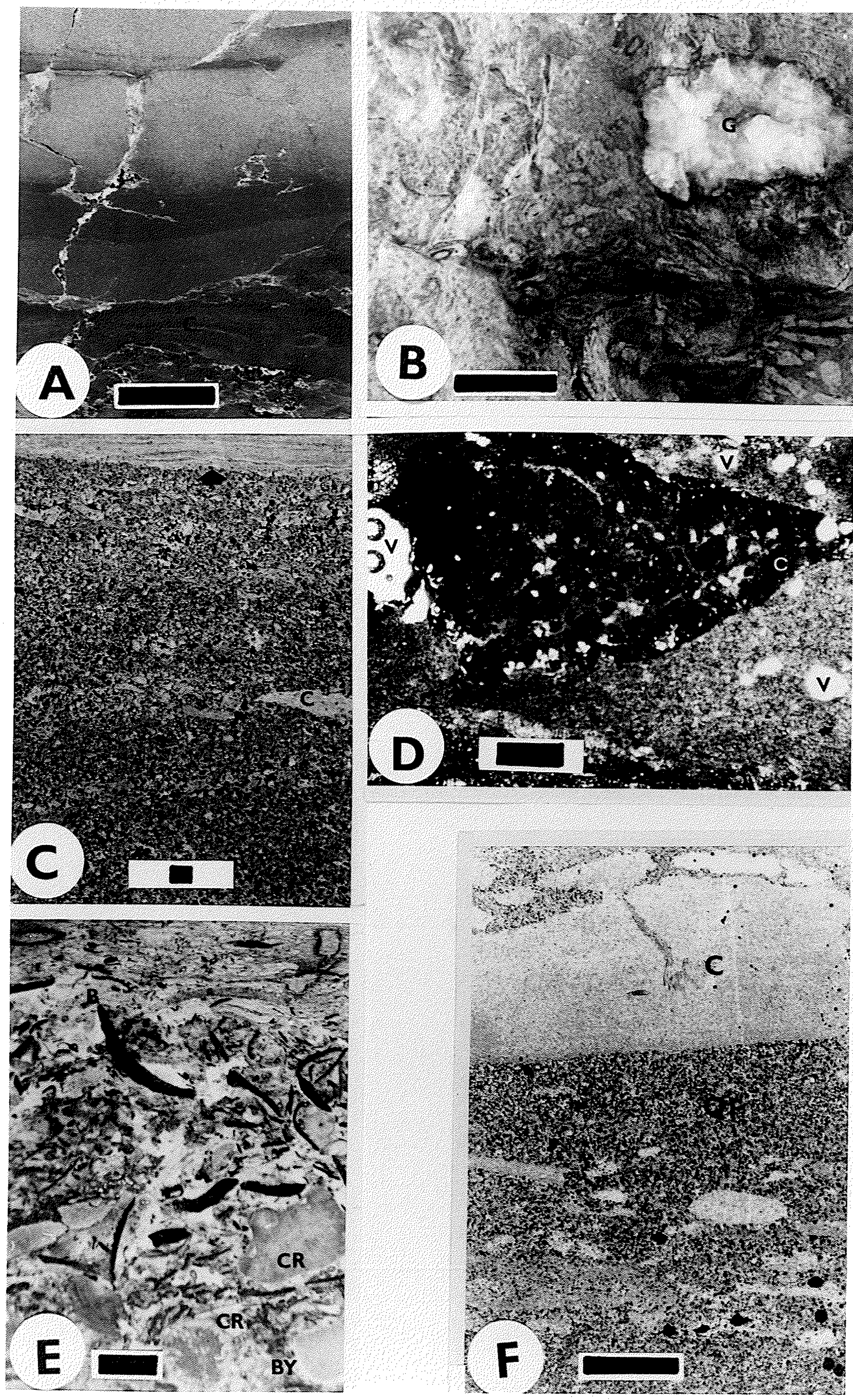

A
C
B
G
C
D
V
V
C
V
E
B
CR
CR
BY
F
C

PLATE 3 - TEXTURAL ROCK TYPES

A. Stony Mountain Formation - Williams Member. This photograph characterizes the intraclastic floatstone textural rock type found in the lower half of the Williams Member. The intraclasts (C) are interpreted as early diagenetic crusts developed in the intertidal-supratidal zone and deposited in a beach environment. Sample 1-W-13, hand sample, bar-1 cm.

B. Stony Mountain Formation - Williams Member. Finely laminated, pelleted, microcrystalline dolomite crust (DC) overlies a cross bedded, quartzofeldspathic, pelletted, and somewhat intraclastic wackestone. The upper surface of the dolomite crust contains vertical fractures which may represent desiccation features. Sample 1-W-10, negative print of thin section, bar-5 mm.

C. Stony Mountain Formation - Gunn Member. Coarse bioclastic packstone to grainstone textural rock type. The well developed horizontal bedding, large gastropods (G) and the presence of numerous stylolites (arrows) typify this textural rock type. Sample 4-G-10, hand sample, bar-1 cm.

D. Stony Mountain Formation - Gunn Member. Gradational contact between the coarse bioclastic packstone to grainstone (lower quarter of the photograph) and the overlying fine bioclastic packstone to grainstone textural rock type. Low angle climbing ripple laminations are present in the fine bioclastic packstone to grainstone interval. Sample 2-6-X-3, hand sample, bar-1 cm.

E. Stony Mountain Formation - Gunn Member. Fine bioclastic packstone overlain by a coarse bioclastic unit which is in turn overlain by a fine bioclastic packstone unit. The arrow points to the stylolitic nature of the contact between the lower fine and coarse bioclastic units. Sample 3-G-X, hand sample, bar-1 cm.

F. Stony Mountain Formation - Gunton Member. Nodular rudstone to floatstone textural rock type. The dolomite crystals in the intraclasts are somewhat clearer and smaller in size than the matrix. The matrix is darker than the intraclasts and the recessive nature in the field would indicate that it is somewhat more argillaceous. Sample 4-GT-36, negative print of peel, bar-5 mm.

G. Red River Formation - upper part of the Fort Garry Member. Algal bindstone textural rock type. Very fine birdseye porosity (black ovoid voids) and desiccation cracks confined to certain beds indicate that the unit was exposed for at least short periods of time. Sample 6-F-29-3, negative print of thin section, bar-5 mm.

PLATE 3 - TEXTURAL ROCK TYPES

A. Stony Mountain Formation - Williams Member. This photograph characterizes the intraclastic floatstone textural rock type found in the lower half of the Williams Member. The intraclasts (C) are interpreted as early diagenetic crusts developed in the intertidal-supratidal zone and deposited in a beach environment. Sample 1-W-13, hand sample, bar-1 cm.

B. Stony Mountain Formation - Williams Member. Finely laminated, pelleted, microcrystalline dolomite crust (DC) overlies a cross bedded, quartzo-feldspathic, pelletted, and somewhat intraclastic wackestone. The upper surface of the dolomite crust contains vertical fractures which may represent desiccation features. Sample 1-W-10, negative print of thin section, bar-5 mm.

C. Stony Mountain Formation - Gunn Member. Coarse bioclastic packstone to grainstone textural rock type. The well developed horizontal bedding, large gastropods (G) and the presence of numerous stylolites (arrows) typify this textural rock type. Sample 4-G-10, hand sample, bar-1 cm.

D. Stony Mountain Formation - Gunn Member. Gradational contact between the coarse bioclastic packstone to grainstone (lower quarter of the photograph) and the overlying fine bioclastic packstone to grainstone textural rock type. Low angle climbing ripple laminations are present in the fine bioclastic packstone to grainstone interval. Sample 2-6-X-3, hand sample, bar-1 cm.

E. Stony Mountain Formation - Gunn Member. Fine bioclastic packstone overlain by a coarse bioclastic unit which is in turn overlain by a fine bioclastic packstone unit. The arrow points to the stylolitic nature of the contact between the lower fine and coarse bioclastic units. Sample 3-G-X, hand sample, bar-1 cm.

F. Stony Mountain Formation - Gunton Member. Nodular rudstone to floatstone textural rock type. The dolomite crystals in the intraclasts are somewhat clearer and smaller in size than the matrix. The matrix is darker than the intraclasts and the recessive nature in the field would indicate that it is somewhat more argillaceous. Sample 4-GT-36, negative print of peel, bar-5 mm.

G. Red River Formation - upper part of the Fort Garry Member. Algal bindstone textural rock type. Very fine birdseye porosity (black ovoid voids) and desiccation cracks confined to certain beds indicate that the unit was exposed for at least short periods of time. Sample 6-F-29-3, negative print of thin section, bar-5 mm.

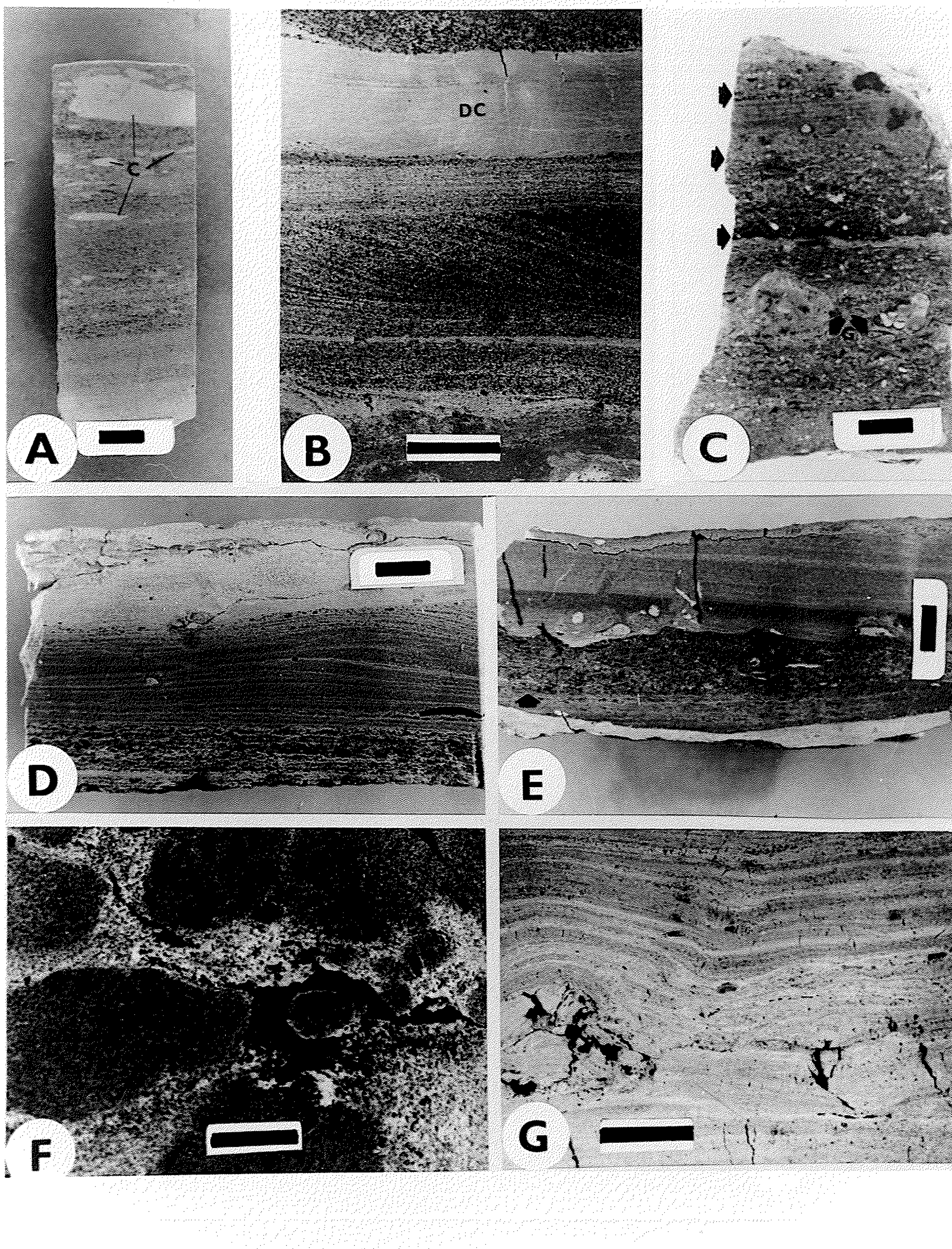

C
A
DC
B
C
D
E
F
G

PLATE 4 - EROSIONAL UNCONFORMITIES

A. Stony Mountain Formation - Penitentiary Member. The "terra rosa" bed which separates the Penitentiary Member (P) from the Gunton Member (GT) at Headingley Manitoba is indicated by the solid black arrows. Section 6, M-3-74 drill core, scale on the left in cm.

B. Stony Mountain Formation - "Terra Rosa". Close up view of the lower 13 cm of the "terra rosa" bed. The lower 6 to 7 cm of the unit is composed of brecciated dolomite (Bx) inclined at a 15-20^{O} angle to the core axis. The intraclasts are imbedded in a red shale matrix which is finely laminated. Overlying the brecciated interval is the steeply dipping, very finely laminated shale bed (arrows). Section 6, M-3-74 drill core, bar-1 cm.

C. Stony Mountain Formation - NW quarry at the City of Winnipeg Quarry at Stony Mountain Manitoba. Field view of the evaporitic bearing mudstones found in the lower portion of the Gunton Member. The three horizontal porosity zone (E) represent voids formed by the dissolution of gypsum. The second purple burrowed horizon overlying the evaporitic mudstone (arrows) is composed of very argillaceous hematitic dolomite. The basal contact is extremely sharp and has been interpreted as a subaerial exposure surface. Geological pick 30 cm in length.

D. Stony Mountain Formation - Stonewall Formation. Basal floatstone rock type interpreted as a conglomerate of the Stonewall Formation unconformably overlying the Williams Member. The bed is composed of argillaceous quartzofeldspathic dolomite. Intraclasts (C) and oolites, pellets, and peloids (O) make up the vast majority of the grains. The black specks represent moldic pores. Sample 1-W-1, negative print of thin section, bar-1 mm.

E. Stony Mountain Formation - Gunton Member. Erosional surface at the top of the Gunton. The portion of the sample below the hollow arrow is a finely laminated evaporitic bearing mudstone. The large solid black arrow indicates porosity zone which developed as a result of the dissolution of gypsum. The zone above the hollow arrow is the erosional rudstone deposit which marks the top of the Gunton Member. The intraclasts (C) are well rounded and contain good interparticle porosity. Sample 1-GT-1, hand sample, bar-1 cm.

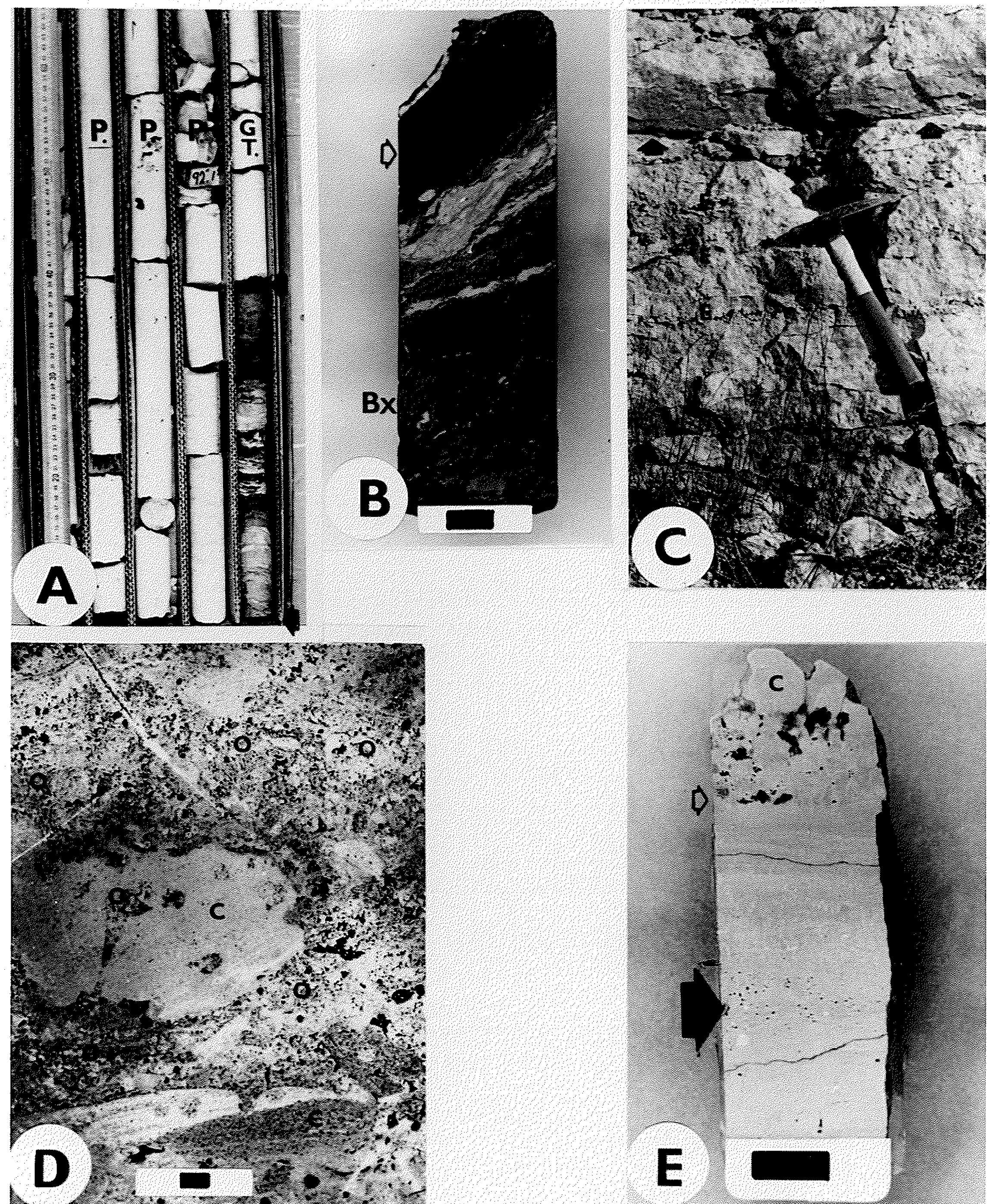

A
P.
P.
P.
G
T.
B
Bx
C
D
c
E
c

PLATE 5 - BIOLOGICAL DIAGENESIS

A. Stony Mountain Formation - Gunn Member. Fine epilithic burrows on the surface of a bioclastic packstone bed. The fine burrows (solid arrow) consist mainly of a central canal from which a root-like system of smaller canals branch off. The main canal system has a marginal ridge which rises 1 to 1.5 mm above the surface of the bioclastic packstone unit. Sample 2-G-1, bedding plane surface, scale in cm.

B. Stony Mountain Formation - Gunn Member. Large epilithic burrows on the surface of a bioclastic packstone unit. The burrows are filled with a very fine grained, argillaceous limestone light greenish grey to light blue grey in colour. Sample 2-G-1, bedding surface, scale in cm.

C. Stony Mountain Formation - Gunn Member. Vertical endolithic burrow. The point of entry of the burrows on the surface of the fine bioclastic packstone is commonly 5 mm or more in diameter. The burrow diameter narrows considerably as the depth of penetration increases. The bedding surface shows the development of a mound or rampart (R) which is commonly 5 mm high. The burrows are filled with argillaceous ferroan dolomite. Sample 2-G-1, negative print of peel, bar-5 mm.

D. Stony Mountain Formation - Gunn Member. Borings. The upper surface of the brachiopod (B) has been subjected to algal borings. The development of tubules (hollow arrow) and later filling of the boring by micrite result in the development of micrite envelopes. Syntaxial rim cement (S) has developed very early in this shelter pore space around the enclosed echinoderm grain (E). Most of the other grains are cemented by an equant isopach druse (Phase I cement). Sample 5-G-8, thin section, bar-500 microns.

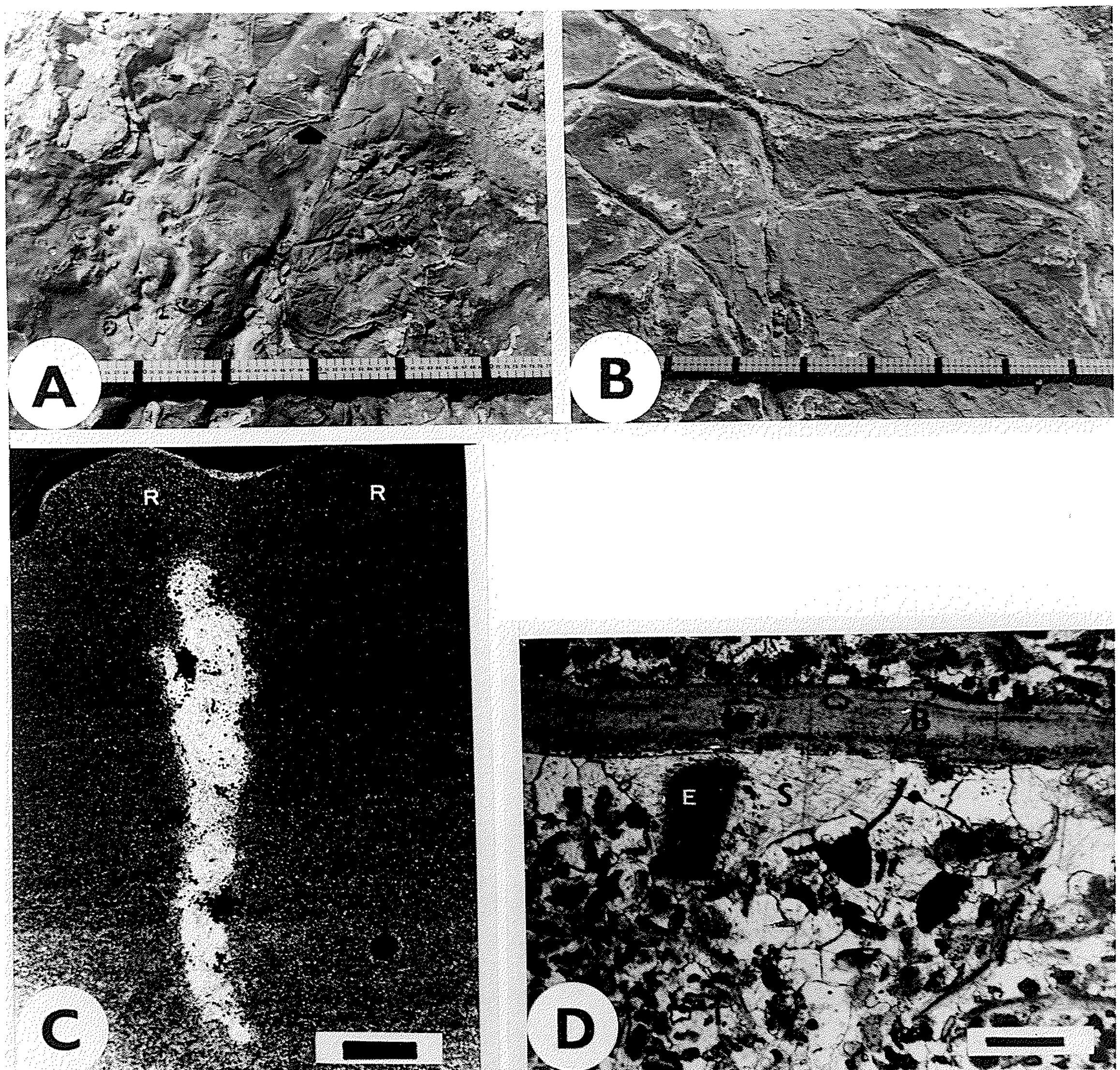

A
B
R
R
C
E
S
B
D

PLATE 6 - BIOLOGICAL DIAGENESIS

A. Stony Mountain Formation - Gunn Member. Macroborings on the surface of an Armenoceras cephalopod. The morphological genus Trypanites formed from spinoid polycheate or sipunculid worms. Section 4, scale in cm.

B. Stony Mountain Formation - Gunn Member. Close up cross sectional view of the Armenoceras displaying the diameter of the Trypanites borings (B) and the depth of penetration. Section 4, view cut at the 32.5 cm mark, bar-1 cm.

C. Stony Mountain Formation - Gunn Member. Borings in the shell of a punctate brachiopod (B). The borings are filled with hematitic argillaceous and sometimes pyritic carbonate material from the overlying beds. Sample 2-G-X-3, thin section, bar-500 microns.

D. Stony Mountain Formation - Gunn Member. The boring in the lower portion of the photo truncates the early blocky cement (arrow) which formed beneath the brachiopod shell. The central portion of the brachiopod shell has been dissolved away and filled with later Phase II ferroan blocky cement (C) which is greyish white in the photograph. Neomorphic recrystallization of the shell has resulted in the development of equant ferroan microspar (N). Sample 2-G-X-3, thin section, bar-500 microns.

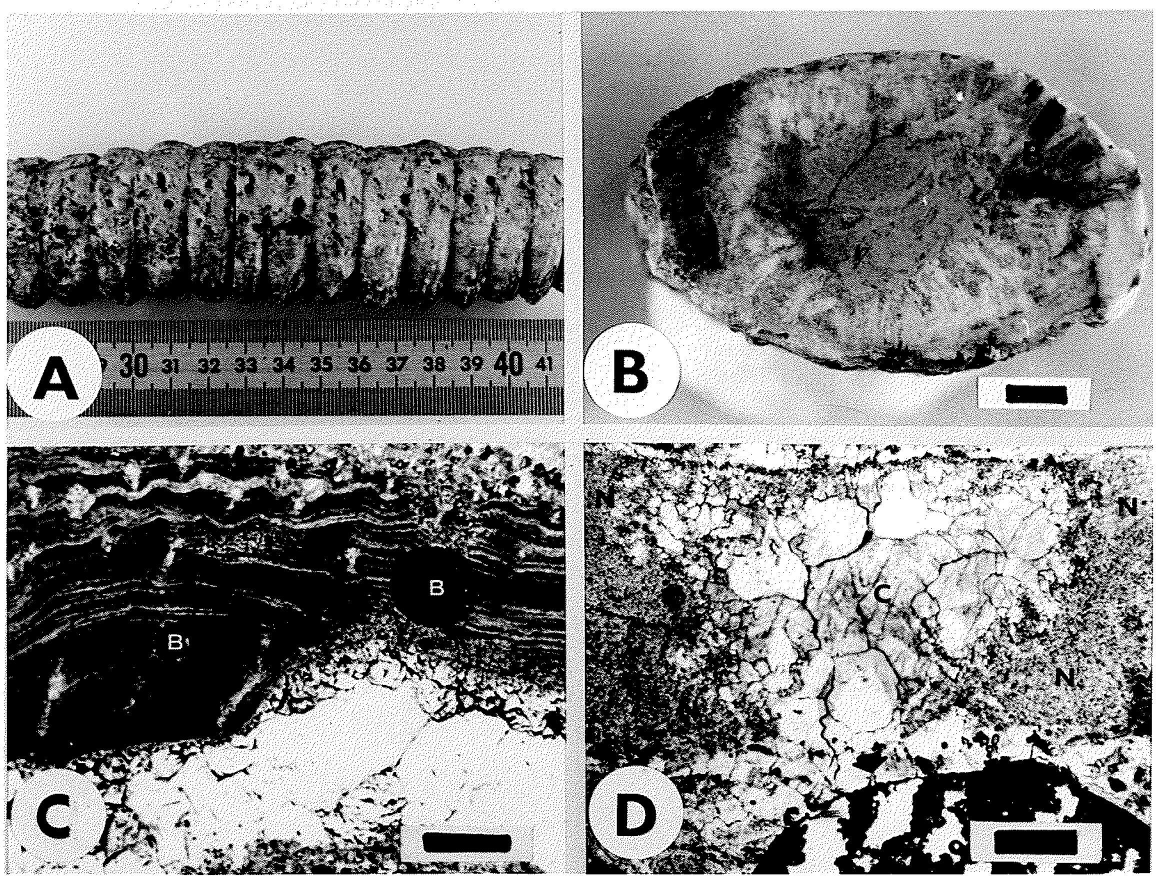

A
B
C
D
30 31 32 33 34 35 36 37 38 39 40 41
B
B
N
N
N
C

PLATE 7 - PHASE I CEMENTS

A. Stony Mountain Formation - Gunn Member. Phase I cements. The micritic envelope (black arrows) has developed completely around the periphery of the bivalve. Developed on the micrite envelope is an equant druse cement which is in turn overlain by echinoderm rim cement (S). Where the echinoderm rim cement is present it is overlain by an equant blocky variety of cement (B). Where just the equant druse cement type is present it is overlain by the equant blocky cement (B). Sample 5-G-10, thin section, cross nicols, bar-100 microns.

B. Stony Mountain Formation - Gunn Member. Phase I cements. The intraparticle pore developed by the brachiopod shells has been totally occluded by a bladed druse (D) and an equant blocky cement (B). The initial cement was an isopachous bladed druse which evolved from 30 to 60 micron crystals to bladed crystals 100 microns or more in size. Overlying the initial bladed druse and occluding the remaining pore space is the equant blocky cement (B). Sample 6-G-18-3, thin section, bar-100 microns.

C. Stony Mountain Formation - Gunn Member. Phase I cements. Echinoderm grain (E) with three stages (arrows) of optically continuous bladed cements. Coral grain (CR) is surrounded by an isopachous rim of equant druse. Occluding the remaining pore space and overlying the other two cement types is the Phase I Blocky cement (B). Sample 2-G-3, thin section, bar-100 microns.

D. Stony Mountain Formation - Gunn Member. Phase I cements. Echinoderm grain (E) has developed a rim cement which has poikilotopicly enclosed an overlying bivalve grain. The development of an equant druse on the upper surface of the bivalve only indicates that the original pore space between the two grains was filled by an earlier forming echinoderm rim cement. Sample 5-G-6, crossed nicols, bar-500 microns

E. Stony Mountain Formation - Gunn Member. Bioclastic packstone with microspar matrix, micritized grains, hairline vertical fractures (arrow) and clear Phase I cement. Sample 2-G-X-3, thin section light, bar-1 mm.

F. Stony Mountain Formation - Gunn Member. Phase I Blocky cement (B) forming in sheltered pore. Sample 4-G-13, thin section, bar-500 microns.

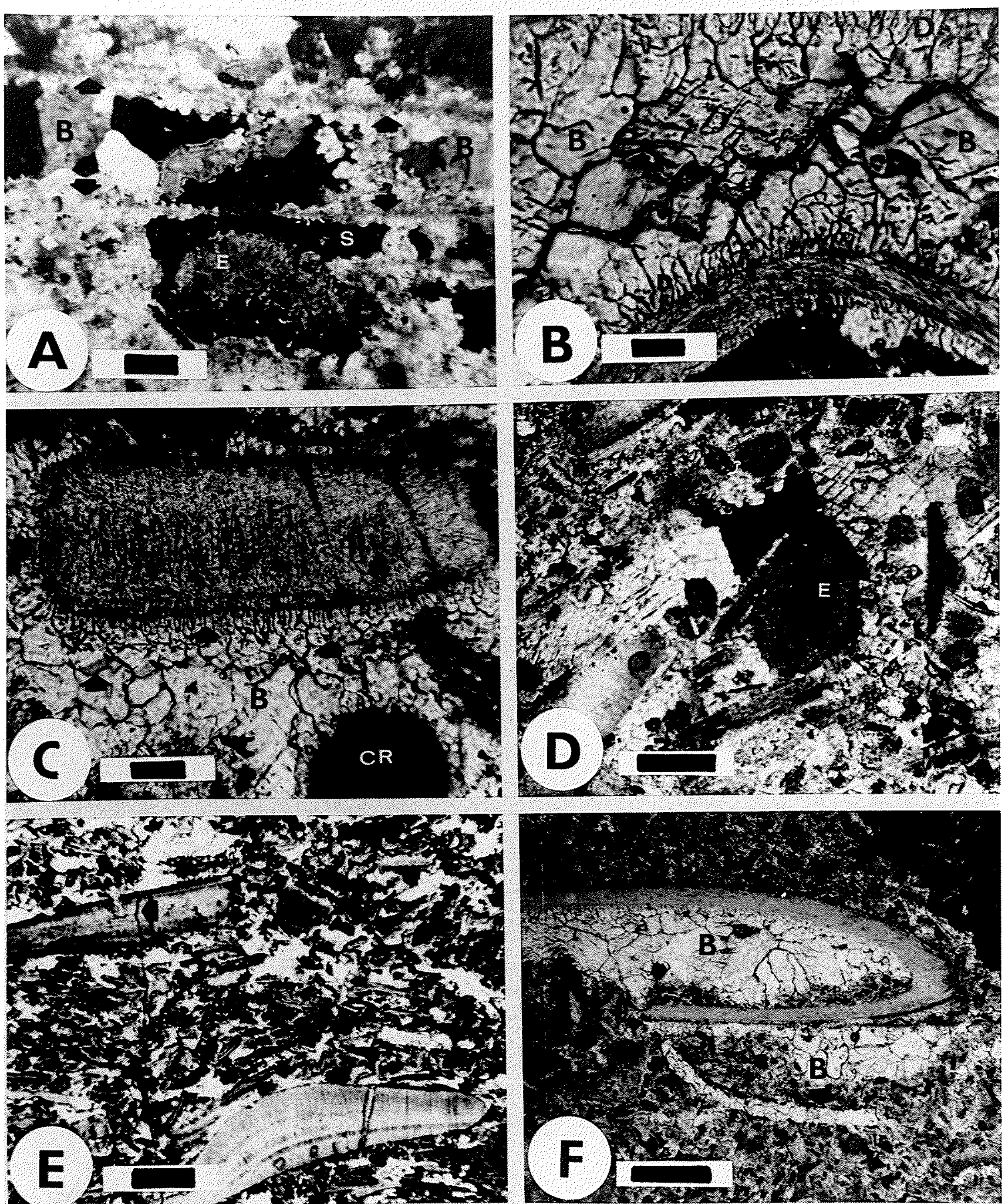

A
B
B
E
S
B
D
B
B
C
B
CR
D
E
E
F
B
B

PLATE 8 - PHASE I CEMENTS

A. Stony Mountain Formation - Gunn Member. Close up view of Pl. 7, Fig. F. Bladed druse (D) is formed on the lower surface of the brachiopod and around the grains on the floor of the sheltered pore. Overlying the druse is the Phase I blocky cement (B) which occludes the remainder of the sheltered pore. Sample 4-G-13, thin section, bar-100 microns.

B. Stony Mountain Formation - Gunn Member. Geopetal fabric developed beneath a brachiopod valve. The cement (central white area) overlies a finely laminated silt which in turn overlies the mudstone matrix. Sample 6-G-3, thin section, bar-1 mm.

C. Close up view of the left of Pl. 8, Fig. B. The silt was deposited upon what appears to be a scoured surface (SC) of the underlying sediment. A thin layer of equant druse has developed on the ceiling of the sheltered pore (arrow) and on the top of the vaguely bedded crystal silt. The remaining pore space occluded by an equant blocky cement. Sample 6-G-3, thin section, crossed nicols, bar-500 microns.

D. Close up view of the right side of Pl. 8, Fig. B. The druse developed in a microstalactitic fashion on the ceiling of the sheltered pore (D) underlies the silt that fills the lower portion of the cavity. Occluding the remainder of the pore is equant blocky cement (B). Sample 6-G-3, thin section, bar-100 microns.

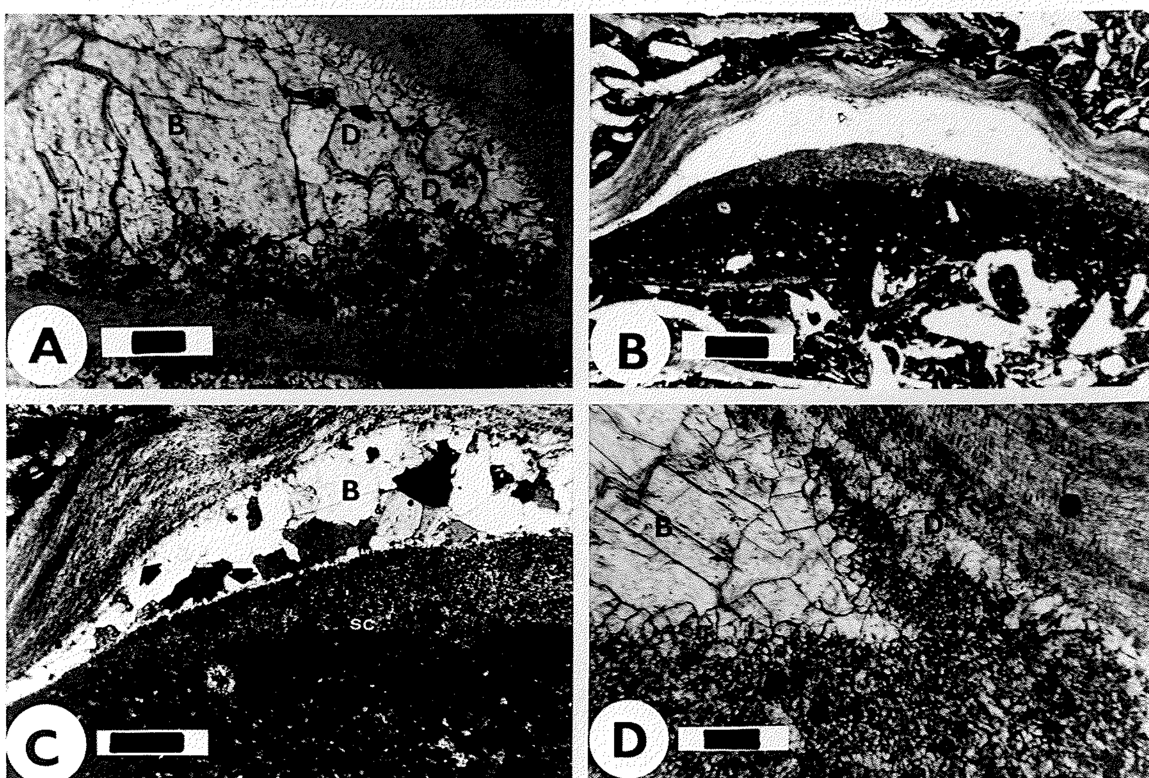

A
B
D
D
B
B
B
sc
C
D
B
D

PLATE 9 - PHASE II & III CEMENTS

A. Stony Mountain Formation - Gunn Member. Phase II ferroan cements (F) appears greyish while the initial non-ferroan cement (B) appears white. In this corallite chamber no initial druse stage is present. However, dolomitized internal lime mud (D) is commonly found on the floors of the corallite chambers. Section 2, Paleofavosites, thin section, bar-500 microns.

B. Stony Mountain Formation - Gunn Member. Corallite chamber with an initial non-ferroan bladed druse (D). Overlying this is the Phase II ferroan cement (F) which is in turn overlain by a clear non-ferroan blocky cement (B). Sample 2-G-X-1, thin section, bar-500 microns.

C. Stony Mountain Formation - Gunton Member. Phase III non-ferroan cement found lining channels and forming a colloform like cement fabric around dolomite clasts in the bottom of the channel. Sample 4-P-32, thin section, crossed nicols, bar-500 microns.

D. Close up view of Pl. 9, Fig. C. The initial isopachous bladed druse which forms around the grains is overlain by a dark micritic layer of cement up to 15 microns thick. This layer is in turn overlain by another clear isopachous bladed druse layer. The dolomite intraclasts (P) appear to be vaguely pelleted. Sample 4-P-32, thin section, crossed nicols, bar-100 microns.

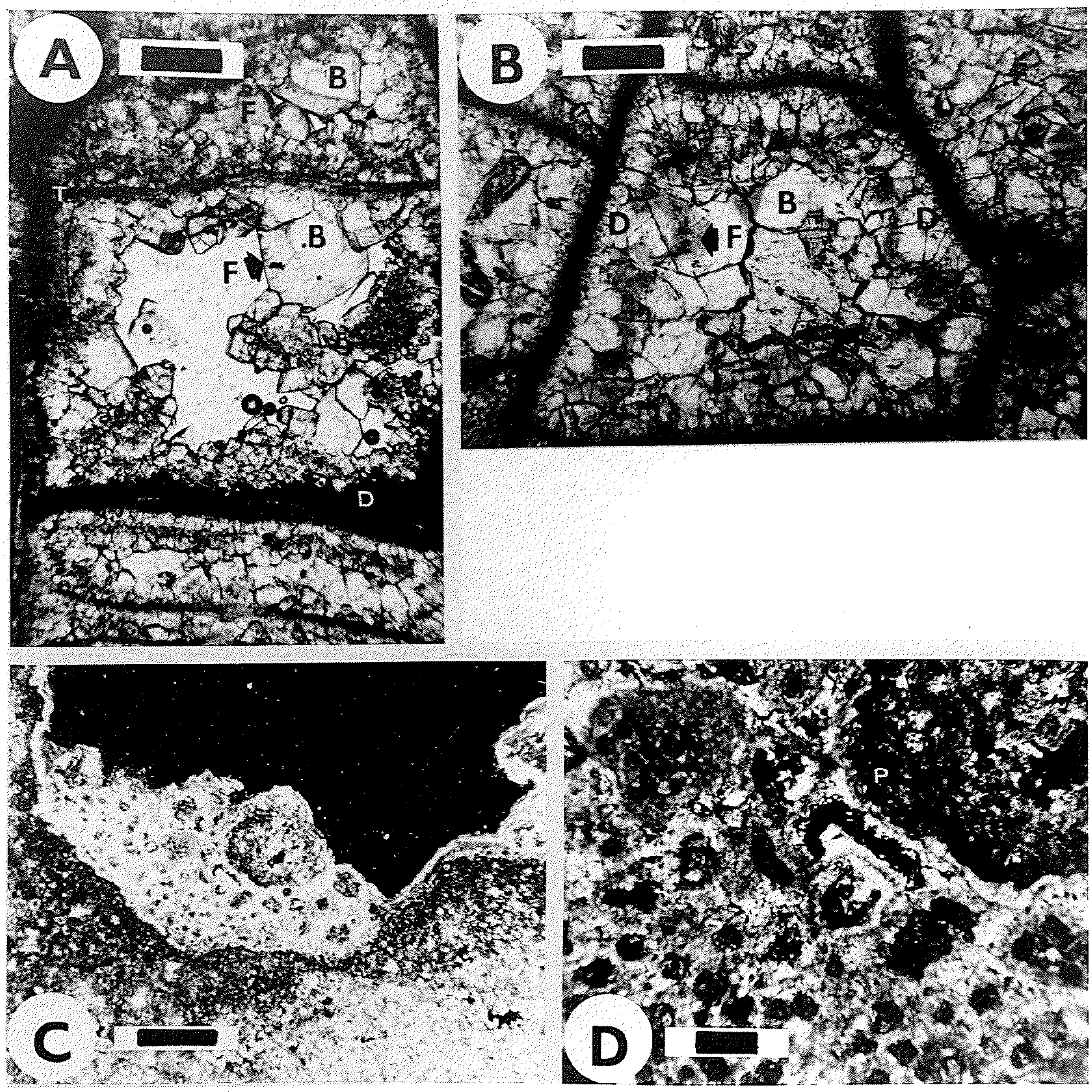

A
B
F
T
.B
F
D
B
D
F
B
D
C
D
P

PLATE 10 - SECONDARY POROSITY

A. Stony Mountain Formation - lower Gunton Member. Gypsum crystals (Se) in an argillaceous dolomite. The dolomite crystals form a subhedral interlocking mosaic with poor intercryalline porosity. Dolomite crystals seldom exceed 30 microns in size. Sample 5-P-X, thin section, crossed nicols, bar-100 microns.

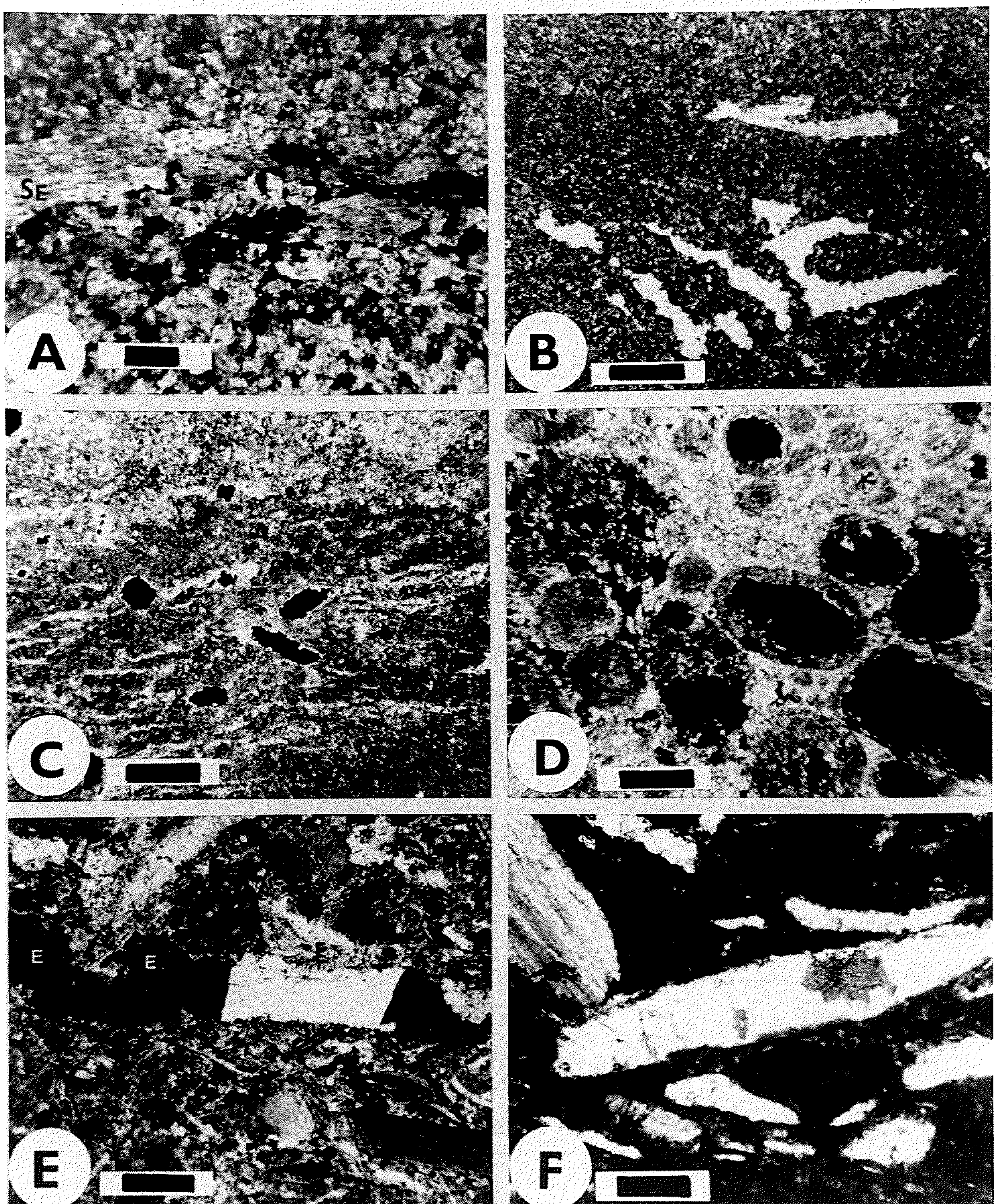
B. Stony Mountain Formation - lower Gunton. Argillaceous dolomite with moldic porosity developed after gypsum. Sample 3-P-X, thin section, bar-500 microns.

C. Stony Mountain Formation - upper Gunton Member. Moldic porosity is interpreted to be after gypsum developed in finely crystalline dolomite. Sample 1-GT-1, thin section, crossed nicols, bar-500 microns.

D. Red River Formation - upper part of the Fort Garry Member. Moldic porosity developed in the intraclastic pelletoidal packstone to grainstone texture rock type by selective dissolution of the grains. Sample 6-F-29-2, thin section, crossed nicols, bar-500 microns.

E. Stony Mountain Formation - Gunn Member. Former moldic void (?) of a bivalve occluded with echinoderm syntaxial cement from four surrounding grains (E). Sample 6-G-24-2, thin section, crossed nicols, bar-500 microns.

F. Stony Mountain Formation - Gunn Member, wackestone textural rock type. Apparent moldic voids (?) occluded by blocky cement. These grains may actually represent recrystallized fragment which have been altered to pseudospar. Sample 6-G-7-A, thin section, crossed nicols, bar-500 microns.


SE
A
B
C
D
E
E
E
F

PHATE 11 - NEOMORPHISM, DOLOMITIZATION, AND AUTHIGENESIS

A. Stony Mountain Formation - Gunn Member. Grain neomorphism. The microstructure of the central portion of the brachiopod shell has been replaced by equant, ferroan calcite, neomorphic microspar (N). Separating two neomorphic zones is an area of Phase II ferroan cement (C). The dark oval area under the brachiopod shell is a macroboring within the bioclastic packstone. Sample 2-G-X-3, thin section, bar-500 microns.

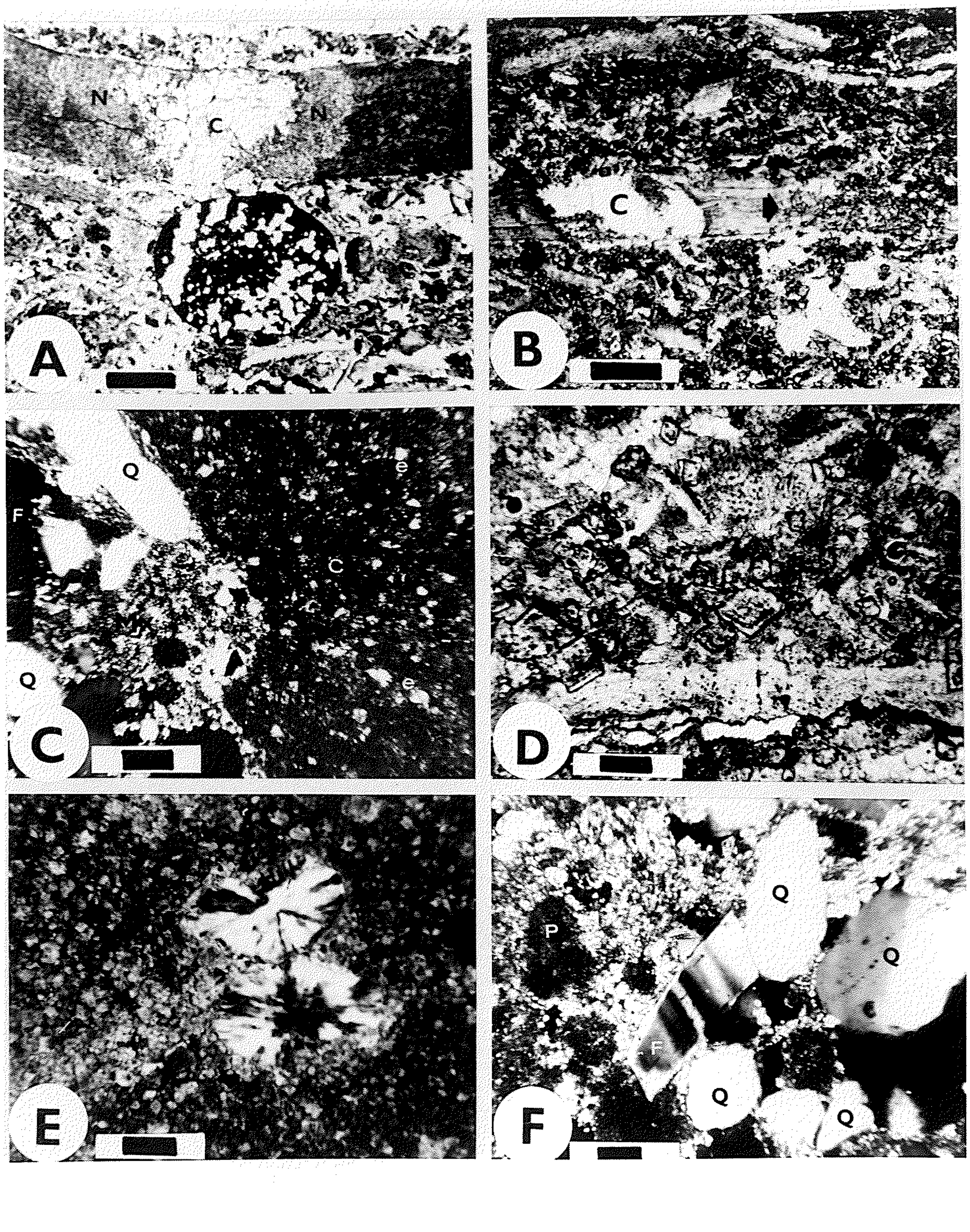
B. Stony Mountain Formation - Gunn Member. Grain neomorphism. The right portion of the brachiopod (arrow) has been replaced by ferroan calcite microspar. The microstructure is totally obliterated but the gross shape remains intact. The thin layer of equant druse which is found on the bottom of the shell has been unaffected by the neomorphic process. The left portion of the brachiopod has also undergone grain neomorphish but has been altered to clear pseudospar. Sample 2-G-1, thin section, bar-500 microns.

C. Stony Mountain Formation - Williams Member. Early diagenetic (primary) dolomitization. The dark pelleted intraclasts (C) is composed of dark micritic dolomite and minor coarser dolomite rhombs. Within the intraclasts (C) are rare, well rounded, and extremely fine eolian quartz grains (e). Larger quartz grains (Q) and feldspar grains (F) float in a much coarser crystalline argillaceous dolomite. Sample 1-W-13c, thin section, crossed nicols, bar-100 microns.

D. Stony Mountain Formation - Gunn Member. Secondary dolomitization. Multi-zoned euhedral dolomites selectively replace the mud component of the bioclastic packstone unit. Sample 2-G-1, thin section, bar-100 microns.

E. Stony Mountain Formation - Gunton Member. Silicification. Length slow chalcedony spherulites developed in an argillaceous dolomite mudstone. Sample 4-GT-36, thin section, crossed nicols, bar-100 microns.

F. Stony Mountain Formation - Williams Member. Authigenic K-feldspar developed on a detrital feldspar (microcline) core (F). Strained and unstrained quartz (Q), pellets (P) and feldspar grains (F) are inbedded in an argillaceous dolomite matrix. Sample 1-W-13f, thin section, crossed nicols, bar-50 microns.


N
C
N
A
C
B
Q
e
F
C
Q
e
C
D
E
Q
P
Q
F
Q
Q
F

APPENDIX A Section Descriptions

Sec. 1. Drill hole M-1-69 - Stonewall, Manitoba

Sec. 2. City of Winnipeg Quarry - southeast pit - Stony Mountain, Manitoba

Sec. 3. City of Winnipeg Quarry - northwest pit - Stony Mountain, Manitoba

Sec. 4. City of Winnipeg Quarry - southeast pit - Stony Mountain, Manitoba

Sec. 5. City of Winnipeg Quarry - northwest pit - Stony Mountain, Manitoba

Sec. 6. Drill hole M-2-69 - northwest pit - Stony Mountain, Manitoba

Sec. 7. Drill hole M-3-74 - 5.6 km north of Headingley, Manitoba

Section 1 Drill hole M-1-69 - complete section logged - STONEWALL, MANITOBA. Section measured from the surface to depth, i.e. 0 meters to 27.24 meters.

STONEWALL FORMATION

0-28 cm. - Dolomite - mottled pale cream grey and greenish-grey (5 YR 8/1, 5 Y 6/1) - very fine grained to crystalline dolomite. Very fine grained pinhead porosity (vugs less than .5 mm.) - porosity less than 2% (trace).

28-76 cm. - Dolomite - pale cream grey to whitish - very fine grained to crystalline dolomite - dense. Decrease in porosity to less than .5%.

76-96 cm. - Dolomite - mottled creamy white to grey (N7 to N8). Vuggy porosity possibly after moldic - arcuate shape to some vugs - fractured appearance delineated by tortuous porosity patterns - .5 to 1 cm. - less than 5% (poor).

96-125 cm. - Argillaceous dolomite - pale maroon and beige beds - pale maroon bed has hairline vertical fracture filled with pyrite and hematite - spackles throughout the pale beige units - ? - possible worm burrows up to 3 mm. in diameter present.
- lower 6.5 cm is brecciated to nodular in appearance.

125-141 cm. - Dolomite - pale creamy grey - vague mottling - very fine grained to crystalline dolomite. Porosity - nil.

141-254 cm. - Dolomite - mottled (5 YR 8/1, 5 Y 6/1) greenish cream grey and beige - very fine grained - pseudobrecciated appearance. Vuggy porosity up to 2 cm. - not connected - 5-10% (good) - cavities have drusy lining. 1-STW-1 (200 cm.) 1-STW-2 (240 cm.).

254-273 cm. - Arenaceous dolomite - white (N9), beige. Trace amounts of calcite - intraclastic, subangular to subrounded, 1-2 cm. in size and less. Large scale bedding features present. Small vug porisity less than 2%.
1-W-1

273-277 cm. - Arenaceous dolomite - overall cream grey clast with dark grey laminated clasts - undulating contact with underlying beds. Clasts; ovoid to tabular subrounded to angular.
1-W-2

STONY MOUNTAIN FORMATION - WILLIAMS MEMBER

277-289 cm. - Argillaceous arenaceous dolomite - pale greenish grey - homogenous. Low pinhead porosity - wavy gradational contact with underlying beds.

289-318 cm. - Very argillaceous arenaceous dolomite - pale purplish to brownish maroon with minor greenish beige areas - roiled appearance - hematitic and pyritic - pyrite surrounds alteration zones which are pale greenish grey.

318-336 cm. - Argillaceous dolomite - pinkish purple with a roiled appearance - small speckles a lighter beige color - hematitic, no pyrite.

336-427 cm. - Arenaceous argillaceous dolomite - pale red to purple (10 R 6/2, 5 R 8/2) with pale greenish grey roiled appearance - Pyrite along stylolite seams and lining burrow cavities - bedding planes lined with pyrite 1-3 cm. thick beds in places - slightly inclined 1-W-3 (415 cm.)

427-548 cm. - Argillaceous arenaceous dolomite - pinkish beige to pale greenish grey - horizontally bedded, finely laminated unit, with pyrite rich horizons 5 mm. thick. 1-W-4 (445 cm.) 1-W-5 (470 cm.)

548-560 cm. - Argillaceous dolomite - pale pink to pale greenish grey - faintly bedded to mildly bioturbated near the contact which is sharp but uneven. Vertical hairline fractures lined with pyrite and hematite.

560-618 cm. - Arenaceous dolomite - pale greenish white to creamy white, white (5 YR 8/1, N9, N8) with pale reddish areas (5 R 8/2) intraclastic (1-2 cm.) - subrounded to angular - thinly bedded, very finely laminated, graded bedding - (amount and size of quartz grains), uneven scour contact with underlying bed. Large scale bedding and dense desiccated dolomites 1-W-10.
1-W-6 (565 cm.), 1-W-7 (575 cm.), 1-W-8 (590 cm.) 1-W-9 (618 cm.), 1-W-10 (608 cm.)

618-629 cm. - Arenaceous Argillaceous dolomite - pale greenish cream white to white - very intraclastic - arenaceous - 5 cm. thick beds - cross bedding - clasts up to 1 cm.

629-648 cm. - Arenaceous dolomite - greenish creamy white to white - fine to very fine grained dolomite - medium to fine grained guartz - cross bedded - thinly laminated beds with a faint trace of possible clastic horizon 5-8 mm. thick.

648-741 cm. - Argillaceous arenaceous dolomite - pale greenish white to creamy white (5 YR 8/1, N7, N8) overall with thin pinkish purple horizons (5 RP 6/2) - hematite and pyrite present - two thin horizons overlying a rippled surface - thinly laminated - intraclastic horizons - clasts 2-2.5 cm. x 1-1.5 cm.
1-W-11 (680 cm.), 1-W-12 (690 cm.)

741-805 cm. - <u>Arenaceous argillaceous dolomite</u> - overall color is pale greenish cream white (5 GY 8/1) while the clast are white (N9) - 3 major beds containing flat tabular clasts up to 2.5 cm. x .7 cm. and ovoid clasts 3-5 mm. - arenaceous content increase downward along with quartz grain size - graded bedding - bottom portion of the section has thin beds of dolomite overlying an undulating surface.
1-W-13 (770 cm.), 1-W-14 (780 cm.)

805-910 cm. - <u>Dolomite</u> - creamy pale white to pale greenish white - very fine grained to crystalline dolomite - slightly argillaceous in places. Flat wafer shaped clasts with upturned edges occur within chalky white dolomite beds (desiccation?) - two other fine grained clastic zones are present. - 20^{o} inclination to bedding may indicate part of a slump structure or ripple of large scale or a scour. End of the Williams Member sharp contact with underlying Gunton Member.
1-W-15 (890 cm.)

- GUNTON MEMBER -

910-966 cm. - <u>Dolomite</u> - white (N8) - crystalline dolomite - horizontal bedding - thin laminae up to 1 cm. - poor porosity - pinhead and moldic (after gypsum) - pale yellowish brown staining around moldic pores, giving a somewhat local mottled appearance.
1-GT-1 (910 cm.)

966-1274 cm.- <u>Dolomite</u> - somewhat mottled pale greenish white (cream white) and greyish white (5 YR 8/1, N7). Upper portion of the bed has a brecciated to pseudobrecciated appearance. Near the 9.70 meter mark the unit becomes spotted - dark cored ellipsoids with lighter rims - fractured surfaces curved and covered with iron staining (yellowish brown). Porosity approximately 3-5% (poor) - mainly vuggy - surrounded by a lighter colored halo.
1-GT-2 (970 cm.), 1-GT-3 (1220 cm.)

1274-1317 cm.-<u>Dolomite</u> - mottled cream white and white - very fine grained to crystalline - pseudobreccia to breccia as above. Porosity mainly pinhead and minor vuggy - less than 2% (trace).

1317-1343 cm.-<u>Dolomite</u> - mottled appearance - white to cream white - very fine grained to crystalline - definitely brecciated.
1-GT-4 (1330 cm.)

1343-1386 cm.-<u>Dolomite</u> - pale greenish grey to greyish white - erosional contact-burrowed areas white - tubular shaped - near base of the section burrows are rimmed by hematite.

1386-1426 cm.-<u>Dolomite</u> - white (N9) - very fine grained dolomite to crystalline dolomite - chalky appearance.
1-GT-5 (1400 cm.)

1426-1515 cm.-Dolomite - somewhat mottled cream white to white - crystalline dolomite - undulating bedding surfaces - moldic to vuggy porosity lined with drusy calcite? (1-2 cm.) - 2-4% (poor).
1-GT-t (1460 cm.)

1515-1637 cm.-Dolomite - mottled cream white and grey white - crystalline dolomite - burrowed in places. Large vuggy porosity - after moldic? - 1.3 cm. in some cases - irregular shape.
1-GT-7 (1520 cm.)

1637-1716 cm.-Dolomite - greyish white (N7) and cream white - crystalline dolomite burrowed. Trace vuggy porosity.
1-GT-8 (1700 cm.)

1716-1839 cm.-Dolomite - pale greenish white and cream white - very fine grained to crystalline - pseudobrecciated to brecciated appearance - lighter fragments - subangular and appear to float in a matrix of greenish grey dolomite - in places burrowed - no bedding traces - some burrows appear to be rimmed with hematite. Porosity, pinhead, moldic, and vuggy after moldic brachiopods. 1.5-2.0 cm.
1-GT-9 (1800 cm.), 1-GT-10 (1820 cm.)

1839-1939 cm.-Argillaceous dolomite - mottled pinkish red and beige (10 R 6/2, 5 R 8/2) - very fine grained to crystalline dolomite - pseudobrecciated to brecciated appearance - burrowed in places - very irregular habit - rimmed with hematite - the base of this bed is scoured with some intraclasts - brachiopod and other bioclastic debris is present - stylolites present. Lower portion of the interval is characterized by purple burrows.

1-P-1 (1930 cm.)

1939-2023 cm.-Argillaceous dolomite - pinkish red to somewhat purple with blotches of beige (5 R 5/4) - burrows beige color - in some cases rimmed with hematite. Purple Burrowed Horizon
1-P-2 (1980 cm.)

- PENITENTIARY MEMBER -

2023-2098 cm.-Argillaceous dolomite - light brown dry color - purplish wet color - very fine grained - mottled appearance - horizontal nature to mottling - beige color in purplish matrix. Gradational contact between the two members.

2098-2125 cm.-Argillaceous dolomite - pale greenish white to creamy white - blebs of pyrite present.

2125-2240 cm.-Fossiliferous argillaceous dolomite - pinkish purple with horizontal blebs and burrows (10 R 6/2, 5 R 8/2, 10 R 7/2) burrows rimmed with hematite - roiled appearance - nodular. Fossiliferous; gastropods and brachiopods. Undulating contacts.
1-P-3 (2220 cm.)

2240-2405 cm.-Fossiliferous argillaceous dolomite - pale pinkish to pale cream white and pale greenish yellow (5 R 7/4, 10 Y 8/2) burrows coated with hematite or pyrite - thin shale beds appear to be filling cavities. Fossiliferous; brachiopods, horn corals, bryozoans and others - mainly casts. Porosity mainly moldic (up to 2.0 cm. across) and minor pinhead.
1-P-5 (2320 cm.), 1-P-6 (2350 cm.) and 1-P-7 (2380 cm.)

2405-2580 cm.-Fossiliferous Argillaceous dolomite - vaguely mottled - pale greenish white to grey white - reddish tint to churned up areas - roiled appearance - fossiliferous - brachiopods, bryozoans, horn corals. Porosity - mainly moldic - approximately 5% (poor).
1-P-8 (2550 cm.)

- GUNN MEMBER -

2580-2743 cm.-Very argillaceous limestone - pale pinkish red to purple or maroon - very fine to fine grained components - hematite and pyrite - hematite lined burrows - roiled appearance - Porosity mainly interparticle. The contact between the Penitentiary Member and Gunn Member gradational over .3-.5 meters.

Section 2 City of Winnipeg Quarry (Southeast Pit)

- GUNN MEMBER -

Quarry Floor - Very argillaceous limestone - greenish grey to blue grey (N7) - 1.5 to 3.0 cm. thick - finely laminated - forms a crust or upper layer on the underlying bed - Very fossiliferous; brachiopods, cephalopods (Selkirkoceras) bivalves and gastropods.

2-G-1 - Very argillaceous limestome - Fossils

Photos - Burrows - fossils

- Bioclastic limestone - purplish grey to grey - 7.5 to 10 cm. thick - fine bioclastic limestone - laminated - 5-10° inclinations to laminations - upper surface marked by burrows and trail excavations covering entire surface - 1-3 cm. wide x 1.5 - 2.0 cm. deep - lower surface fossiliferous, pyritic and hematitic bearing - pyrite very abundant, 4-5 mm. cubes, found in burrow canals - stylolitic lower contact - stylolites throughout. - Very flat lower contact, undulating upper surface.

2-G-1 - Burrows - Fossils

Trench section measured from the lower part of the trench up to quarry floor.

0-41 cm. - Fossiliferous argillaceous limestone - purple to maroon, dusky red (5 RP 6/2 to 5 RP 4/2) with pale greenish grey burrow areas (5 YR 8/1) - roiled appearance - burrowed - nearly horizontal appearance - beds up to 11.5 cm. thick, average 5 to 6 cm. thick, bedding surface uneven to undulating.

2-G-2

41-47 cm. - Bioclastic limestone - grey - 6.4 - 7.0 cm. thick - displays graded bedding - coarse bioclastic overlain by fine bioclastic limestone - shell debris randomly oriented - no apparent laminations. Lensing nature of bed, thickness varies from 6 - 10 cm.; flat lower contact undulating upper contact, bed at least 10 meters long.

2-G-3

47-96 cm. - Fossiliferous argillaceous limestone - bluish purple to dusky red (5 RP 6/2 to 5 RP 4/2) with areas of heavy hematitic staining (deep red) - roiled appearance (bioturbated), beds 5 - 10 cm. thick.

2-G-4

96-109 cm. - Bioclastic limestone - grey - 12.7 cm. thick - coarse bioclastic overlain by fine bioclastic - graded bedding separated in places by a thin argillaceous limestone bed, beige to light purple. Fine Bioclastic limestone - sharp somewhat ripple - like upper contact, the central part of the bed is burrowed and stained with hematite. This unit forms a very distinctive unit throughout the east quarry trench section. Upper 8 cm. dense, aphanitic, - lower 2 cm. - 3 cm., coarses then above -faintly laminated.
2-G-5
Photos - rippled contact
- general appearance

109-170 cm. - Fossiliferous argillaceous limestone - purplish to maroon - 61.3 cm. - blotchy hematite concentrations - slightly fossiliferous - burrows lined with hematite - horizontal habit to burrows. Beds 3.8 - 5.1 cm. thick, uneven to irregular undulating surface. Upper surface of the underlying surface has large burrows on the surface (similar to quarry floor).
2-G-6

Section 3 City of Winnipeg Quarry (Northwest Pit)

Section measured from the base of quarry floor through the upper part of the Gunn, the Penitentiary and the lower Gunton.

- GUNN MEMBER -

0-33 cm. - Fossiliferous argillaceous limestone - purple to maroon with blotchy red areas, due to hematite in the burrows - very bioturbated appearance. Fossils; brachiopod and bivalve debris along with large solitary horn corals up to 2 - 3 cm.
3-G-1

33-43 cm. - Bioclastic limestone - grey (N7) - Three 1.3 cm. beds of fine grained bioclastic limestone - these beds are contained in a 10 cm. thickness and are discontinuous throughout the quarry wall - lower contact of beds is undulating - very small scale scour surfaces are present within beds.
3-G-2

43-53 cm. - Fossiliferous argillaceous limestone - 10.2 cm. thick - gradational contact between Gunn and Penitentiary heavily burrowed (bioturbated) - hematitic. Very fossiliferous; brachiopods and shell debris - up to 1.5 - 2.0 cm. long.
3-G-3

- PENITENTIARY MEMBER -

53-76 cm. - Argillaceous dolomite - creamy grey with a light purple central portion. 5 cm. thick beds - as with 3-G-3 the reddish purple zone contains course white clacite nodules rimmed with hematite. The central red shale portion has a blotchy appearance - no fossils seen on quarry wall.
3-P-4

76-99 cm. - Argillaceous dolomite - creamy white to greenish grey (5 GY 8/1) - 23 cm. thick - very fine grained dolomite - no fossils - nodular appearance - lower contact is irregular and somewhat indistinct in places - upper contact forms a distinctive break in the quarry section, perfectly horizontal.
3-P-5

99-173 cm. - Fossiliferous argillaceous dolomite - creamy white to greenish grey (5 GY 8/1) and beige (5 Y 8/4) - distinctly different from the underlying bed. Extremely fossiliferous (in places 25 - 30%) - brachiopods, bivalves, bryozoans and corals (in order of abundance) - found mainly as molds and casts. Good porosity 10-15% - moldic and vuggy - up to 5.0 cm. in size.
3-P-6

173-203 cm. - Fossiliferous argillaceous dolomite - grey to beige (N7, 5 Y 8/4), 31.9 cm. thick. - similar to underlying bed but only 20% fossils. In places the bed has a dense, fine to very fine grained dolomite habit. The zone around the porous areas has an orangy beige coloration (limonite) - due to the solution effect of weathering (weathering halos).
3-P-7

203-218 cm. - Fossiliferous argillaceous dolomite - same as underlying bed.
3-P-8

218-239 cm. - Fossiliferous argillaceous dolomite - mottled yellowish orange and pale greyish green (10 YR 8/6, 5 G 8/1)- similar to underlying bed but more bryozoans present - bedding surfaces irregular but distinct. The mottling follows horizontal bedding planes and porous areas.
3-P-9

239-312 cm. - Fossiliferous argillaceous dolomite - mottled yellowish orange and pale greenish grey weathered surface - greyish white fresh surface - beds 16 to 30 cm. thick - porous areas deeply weathered (limonite) halo very friable - Porosity the same as underlying beds.
3-P-10 (250 cm.), 3-P-11 (270 cm.), 3-P-12 (300 cm.)

312-414 cm. - Fossiliferous argillaceous dolomite - similar mottled appearance - beds 2 - 22 cm. thick - decrease in the total fossil content. Moldic and vuggy porosity down to 5 - 10% (fair)
3-P-13

414-445 cm. - Dolomite - tan to yellowish grey - crystalline to very fine grained - dense - slightly argillaceous dolomite.

445-460 cm. - Dolomite - similar color - nodular (2 x 3 cm.) - differential weathering of the matrix - irregular lower and upper contacts.

460-491 cm. - Dolomite - beige to yellow (5 Y 8/4) - very fine grained to crystalline - slightly argillaceous. Flaggy weathered appearance.
3-P-14

- GUNTON MEMBER -

491-504 cm. - Argillaceous dolomite - purple to maroon (5 RP 6/2) - highly burrowed - horizontal and flat - 2 - 4 mm. diameter circular cross section. FIRST PURPLE BURROWED HORIZON - hematitic
3-P-15

504-519 cm. - Dolomite - beige to yellow - very fine grained to crystalline - dense - very slightly argillaceous - few traces of fossil molds. Moldic porosity (3 - 4%) (poor) upper contact very uneven - solutions marked.

Change quarry wall - start mapping from FIRST PURPLE BURROWED HORIZON MARKER.

491-504 cm. - FIRST PURPLE BURROWED HORIZON

504-588 cm. - Argillaceous dolomite - mottled grey white (N8) and orangy beige (10 YR 8/4) - Flaggy appearance - uneven bedding surfaces - nodular beds- beds 5-10 cm. thick. Four porosity zones with a horizontal habit occur within this zone - solution enlarged moldic - fenestral and vug - 1 - 3 cm. - throughout this quarry face.
3-P-16 Photo - horizontal porosity.

588-600 cm. - Argillaceous dolomite - brownish purple to maroon (5 RP 6/2) with pale (5 YR 8/2) burrowed areas - very sharp lower contact (very distinct bedding contact) "an erosional break?" with a very diffuse upper contact - SECOND PURPLE BURROWED HORIZON - hematitic
3-P-17 Photo - S.P.B.H.

600-721 cm. - Dolomite - beige to yellowish tan - very slightly argillaceous - locally the beds are vaguely laminated- very minor red tinge to the beds in some areas.

Section 4 City of Winnipeg Quarry (Southeast Pit)

This section is measured from the base of quarry walls up through the upper few meters of Gunn, Penitentiary and Gunton Members.

Part 1

- GUNN MEMBER -

0-35 cm. - Fossiliferous argillaceous limestone - mottled purple and maroon with greenish grey circular burrows with hematite rims - burrows horizontal - bedding 1-8 cm. thick - undulating surfaces - thin discontinuous bioclastic limestone lenses - fossiliferous.

35-40 cm. - Bioclastic limestone - grey to somewhat purplish grey - very dense crystalline - beds 4 - 10 cm. thick - coarse to fine fossil fragments - bed is rimmed in places with limonite - 1 cm. thick alteration zone - 6 m. long bed - sharp horizontal lower surface - upper surface is undulating. Fossils oriented horizontally - vaguely laminated - some burrows rimmed.
4-G-1

40-94 cm. - Fossiliferous argillaceous limestone - mottled purple and maroon with pale greenish grey areas - hematitic - horizontal burrows 1 mm. diameter - 30 mm. long - rimmed with hematite - minor vertical burrows much larger - thin discontinuous lenses of fine bioclastic limestone - nodular habit to beds on weathered surface.

94-101 cm. - Bioclastic limestone - pale red to light grey (10 R 6/2, N7) - this bed is continuous for at least 12 m. - samples 4-G-2 to 4-G-14 were taken along this bed at 1 m. spacings. Lower contact is sharp and flat while the upper contact is sharp but wavy - minor vertical burrows found in up 1 - 2 cm. of bed.

4-G-2 - 0 m. 1.8 - 2.0 cm. thick - sharp undulating contact vague laminae
4-G-3 - 1 m. 4 cm. thick - pyrite and hematite present
4-G-4 - 2 m. 6 cm. thick - fine bioclastic - decrease in fossil content
4-G-5 - 3 m. 6.5 cm. thick
4-G-6 - 4 m. 6.5 cm. thick - 1 layer only
4-G-7 - 5 m. 8.0 cm. thick - 3 bioclastic layers separated by 1 cm. of shale - graded bedding
4-G-8 - 6 m. 6.0 cm. thick - underlying bed 4.5 cm. thick
4-G-9 - 7 m. 7.5 cm. thick
4-G-10 - 8 m. 9.0 cm. thick
4-G-11 - 9 m. 6.0 cm. thick - overlying bed 4 cm. thick, contains .5 cm. shale interbed
4-G-12 - 10 m. 4.0 cm. thick - sharp, flat lower contact, undulating upper
4-G-13 - 11 m. 4.0 cm. thick
4-G-14 - 12 m. 6.0 cm. thick - both contacts sharp and flat.

101-158 cm. - Fossiliferous argillaceous limestone - purple to maroon or moderate red (5 RP 6/2, 5 R 4/6) - minor bioclastic lens within the first 15 cm. - very fossiliferous.

158-163 cm. - Bioclastic limestone - pale red to grey (10 R 6/2, N7) fine bioclastic - lower contact sharp but undulating 6 m. long.
4-G-15

163-243 cm. - Fossiliferous argillaceous limestone - similar colors - burrows have no set direction - roiled or turbid appearance.

243-255 cm. - Bioclastic limestone - grey (N7) - coarse bioclastic - undulating contacts.
4-G-16

255-320 cm. - Fossiliferous argillaceous limestone - similar appearance with 2 minor bioclastic lens layers - 2 - 4 cm. thick.

320-324 cm. - Bioclastic limestone - greyish - coarse bioclastic lens shaped layer 25 - 40 cm. long - minor channel deposit?

324-354 cm. - Fossiliferous argillaceous limestone - similar color and appearance - moderate red, churned up - with discontinuous and minor bioclastic lenses.

Part 2

0-42 cm. - Fossiliferous argillaceous limestone - similar appearance, very fossiliferous - brachiopods - bivalves and unknowns.

42-46 cm. - Bioclastic limestones - grey - coarse - with large moldic cavities (3 x 1 cm.) filled with calcite.
4-G-17

46-154 cm. - Fossiliferous argillaceous limestone - similar color - burrows very unoriented - approximately 30% fossils.

154-163 cm. - Bioclastic limestones - grey - fine grained - laminated - cross bedding - rippled upper surface - flat lower surface - this layer is surrounded by a rust orange alteration zone 1 cm. thick - 50 x 15 m.
4-G-18, 4-G-19 Photos - 5

163-243 cm. - Fossiliferous argillaceous limestone - moderate red - horizontal burrows -very hematitic - with two bioclastic limestone layers;
185-190 Bioclastic limestone - fine bioclastic - laminated - 4-G-20
235-243 Bioclastic limestone - greenish grey - fine - laminated with a possible scoured lower contact with the overlying beds 4-G-21

This marks the end of the Gunn Member - The contact is very sharp but somewhat undulating. Scoured in places.

- PENITENTIARY MEMBER -

243-254 cm. - Argillaceous dolomite - pinkish beige - sharp but wavy bedding surface - nodular.

254-304 cm. - Argillaceous dolomite - cream yellow (10 Y 8/2) - upper 10 cm. display flaggy weathering - very few fossils less than 10% slight rose red tinge to the beds in places. 4-P-21, 4-P-22

Part 3

0-57 cm. - Fossiliferous argillaceous to somewhat arenaceous dolomite light greenish grey (5 GY 8/2 to 5 G 8/1) - very fine grained to crystalline dolomite - massive nature to bed - vaguely laminated in place - becoming nodular (clastic) near the top, fossils 15-20%. Porosity - moldic (brachiopods horn corals and fragments) - 5% (poor). 4-P-25

57-78 cm. - Argillaceous dolomite - mottled greyish yellow and pale greenish yellow (5 Y 8/2, 10 Y 8/2) - very nodular habit (5 x 3 cm.) rounded loaf shaped. Porosity - vug after moldic, less than 5% (poor). 4-P-26

78-185 cm. - Fossiliferous argillaceous dolomite - overall color is pale greenish yellow (10 Y 8/2) with ocherous yellow (10 YR 8/4 - 10 YR 8/6) associated with fracture zones and porosity areas. Very fine grained dolomite - beds 3.5 - 5 cm. thick - trace of laminae in the upper 1/3 portion of bed - sharp undulating contact with hematite along bedding contact. Porosity - moldic and vuggy after moldic with 3.5 x 3 cm. voids - 5 - 10% (fair). 4-P-27

185-187 cm. - Very argillaceous dolomite - mottled orcherous yellow and pale greenish yellow (10 YR 8/6, 10 YR 6/6) with (10 Y 8/2) - brecciated to nodular - very recessive 4-P-28

187-197 cm. - Dolomite - pale yellowish green - very dense crystalline dolomite. Porosity - nil. 4-P-24

197-308 cm. - Argillaceous fossiliferous dolomite - greenish grey fresh surface - weather surface mottled ocherous yellow or rusty orange and beige - (10 YR 8/6, 5 Y 8/4) - lower 20 cm. nodular. Moldic and vuggy porosity decrease from bottom to top (fair to poor)

308-342 cm. - Very argillaceous dolomite - very recessive along quarry face - covered by nodular rubble - originally a muddy horizon?

- GUNTON MEMBER -

342-427 cm. - Argillaceous dolomite - yellowish beige and reddish brown (5Y 8/3, 5 YR 6/4) - prominant over entire quarry wall - brownish maroon areas (5 R 4/6) - massive dolomite with undulating bedding surfaces - Possibly 5 - 10%. Upper 15 - 20 cm. heavily burrowed - deeper purple color
FIRST PURPLE BURROWED HORIZON 4-P-29

427-458 cm. - Argillaceous dolomite - mottled (10 YR 7/4, 5 RP 6/2) - beige to pale yellowish beige and brownish purple - flaggy weathering bedding 2 - 4 cm. - irregular or uneven upper and lower contacts.
4-P-30A, 4-P-30B overlying red unit becoming nodular - hematitic

458-466 cm. - Argillaceous dolomite - reddish brown - hematitic - very undulating upper surface - fairly continuous - nodular. Porosity - nil.

Part 4

- GUNTON MEMBER -

0-42 cm. - Argillaceous dolomite - maroon to brownish purple with greenish grey burrows with a horizontal habit 2 - 4 mm. diameter - overlain by rusty light brown beds - purplish beds have a rippled appearance.
4-P-31 Photos - 2
FIRST PURPLE BURROWED HORIZON (Gunton basal contact)

42-59 cm. - Argillaceous dolomite - yellow to purple and light rusty brown layers (10 YR 8/6, 10 YR 7/4, 5 RP 6/2, 5 RP 4/2) - the RP unit is filled with horizontal burrows concentrically zoned - the 10 YR 7/4 zone is porous. The porosity is along a horizontal bed - irregular solution enlarged fenestral - cavities lined with drusy calcite.
4-P-32

59-149 cm. - Dolomite to argillaceous dolomite - beige to pale yellow and pale purple brown (10 YR 7/4), (5 YR 7/2) - very fine grained to crystalline - distinctly bedded - 2 - 5.5 cm. thick. Porosity - vuggy with a somewhat fenestral arrangement.
4-P-33

149-164 cm. - Argillaecous to very argillaceous dolomite - mottled appearance - overall color brownish purple to maroon (5 RP 5/2, 5 RP 6/2) and greyish orange (10 YR 8/2, 5 YR 7/2) - burrowed with a horizontal habit - very distinct - nodular in places - no fossils.
SECOND PURPLE BURROWED HORIZON

164-363 cm. - Dolomite - a range of color from yellowish grey (5 Y 9/1, very pale greenish grey (5 GY 9/1) and pale yellow to cream white colors (5 Y 7/2, 5 Y 8/4) - lower portion of bed slightly argillaceous - flaggy weathering prominant throughout nodular and brecciated beds. This bed represents a channel deposit.

4-GT-35 92 cm. above second purple burrowed horizon (nodular to brecciated)
4-GT-36 135 cm. (nodular) 1 cm. x 3 cm.
4-GT-37 172 cm.

0-50 cm. - Flaggy dolomite - very fine grained.

50-135 cm. - Nodular to brecciated dolomite with a slight flaggy appearance - chert nodules present (up to 8 cm. Standard Quarry) - concentrically laminated nodules up to 2 cm. present
-upper 35 cm. of nodular beds display some fenestral porosity
-nodules definitely a lighter color than the surrounding matrix
-upper contact nodular
-brecciated beds within the nodular - distinct units

135-200 cm.- Flaggy dolomite

The basal contact of the Gunton Member is located at the base of the first purple burrowed horizon. This unit is very distinctive throughout the quarries in this area and the Standard Quarry.

Section 5 City of Winnipeg Quarry (Northwest Pit)

Section measured from the bottom of the quarry floor up through the Gunn, Penitentiary and Gunton Members.

Part 1

- GUNN MEMBER -

0-44 cm. - Fossiliferous argillaceous limestone - maroon to brownish purple with pale greenish grey burrows with a horizontal habit - in places roiled appearance predominates - nodular - minor lenses of bioclastic limestone beds.

28-30 cm. - Bioclastic limestone - grey - not very continuous - sharp upper and lower contacts - upper contact flat, lower contact arched convex up. 5-G-1 hematitic

44-49 cm. - Bioclastic limestone - pale reddish grey (5 YR 7/2) - coarse bioclastic - vague laminations - burrowed in places (filled with argillaceous and hematitic material) - flat, sharp, lower contact undulating and sharp upper contact.
5-G-2 1st continuous bioclastic layer.

49-77 cm. - Fossiliferous argillaceous limestone - similar in appearance to underlying beds with a lens layer of bioclastic limestone - cavity 1.5 - 2.0 cm., almost completely filled with calcite - very fossiliferous - brachiopods - horn corals and fragments.

77-86 cm. - Bioclastic limestone - similar appearance - fine bioclastic bed overlain by coarse bioclastic beds - fine beds very well laminated on a mm. scale while the coarse is burrowed and somewhat laminated - shell debris horizontal
5-G-3 (1 & 2) 2nd continuous layer.

86-137 cm. - Fossiliferous argillaceous limestone - similar to underlying beds - nodular weathered appearance - horizontal habit to hematite rimmed burrows - very fossiliferous - brachiopods, shell debris, horn corals (rare) and gastropods - few bioclastic limestone lens layers present.

137-144 cm. - Bioclastic limestone - light grey to light brownish grey (N7, 5 YR 6/1) - coarse bioclastic bed overlain by fine very well laminated bioclastic limestone. - lamination gently undulating.
5-G-4 3rd continuous layer.

144-190 cm. - Cover

190-252 cm. - Fossiliferous argillaceous limestone - similar to underlying beds - very fossiliferous; brachiopods, shell debris, bivalves, and echinoid pieces.
5-G-5

252-260 cm. - Bioclastic limestone - similar - fine bioclastic - well laminated, very flat, sharp, lower contact.
5-G-6 4th continuous layer.

260-320 cm. - Fossiliferous argillaceous limestone - similar with minor bioclastic limestone lens layer.

320-326 cm. - Bioclastic limestone - similar appearance - coarse bioclastic bed overlain by fine bioclastic limestone bed - sheltered vugs - brachiopod shells convex up - sheltered pore filled by clear spar, geopetal fabric.
5-G-7 5th continuous layer.

326-333 cm. - Fossiliferous argillaceous limestone - similar appearance - very friable and recessive.

333-342 cm. - Bioclastic limestone - similar as underlying beds - fine bioclastic with burrowed upper surface - U shaped feeding trail present - hematitic and pyritic - stylolitic - flat lower contact with an undulating upper contact.
5-G-8 6th continuous layer.

342-374 cm. - Fossiliferous argillaceous limestone - same color and burrowed nature - burrows; areas of hematite and pyrite concentrations - Brachiopods and shell debris content considerably reduced.
5-G-9

374-382 cm. - Bioclastic limestone - same color as previous beds - coarse bioclastic with well developed horizontal habit - lower contact sharp or in many cases looks like it is overlying a rippled argillaceous limestone upper surface.
5-G-10 7th continuous layer.

382-407 cm. - Fossiliferous argillaceous limestone - maroon with uneven areas of cream yellow beds - minor discontinuous bioclastic limestone bed 404 - 407 cm. - overlain by a very thin limonitic yellow alteration halo - stylolitic - fine bioclastic laminated - cross bedded.
5-G-11

- PENITENTIARY MEMBER -

407-412 cm. - Argillaceous dolomite - beige to yellow with grey lenses of bioclastic limestone
5-G-12

412-448 cm. - Argillaceous dolomite - somewhat calcitic - beige to cream yellow actual preservations of shells present - nodular beds.

448-522 cm. _ Argillaceous dolomite - calcareous - purple - burrowed areas hematitic-actual preservations of calcite fossil fragments.
5-G-13

522-543 cm. - Argillaceous dolomite - beige to yellow - limonitic - nodular to brecciated.
5-P-14

Page 3

250-300 cm. - are covered with vegetation and rubble - this zone covers the Gunton/Penitentiary Member.

- GUNTON MEMBER -

0-50 cm. - Dolomite - mottled (N9 to N8) with minor areas of (10 YR 7/4), brecciated to nodular - uniform well rounded clastic beds overlain by finely laminated (cryptalgal laminae) - intraclasts up to 2 cm. Porosity vuggy - in area 28 - 30 cm. above basal contact.
5-GT-15

53-105 cm. - Dolomite - mottled appearance - matrix (5 Y 6/1) and clasts (5 Y 8/1) yellowish grey - brecciated to nodular with concentrically laminated structures - rounded clasts - vague bedding 12 cm. - sharp but undulating contact.
5-GT-16

105-150 cm. - Dolomite - same colors of mottled appearance - upper surface has a nodular appearance. Upper surface - cryptalgal laminae bed 5 mm. thick - (5-GT-17-2). These cryptalgal laminae are present throughout the quarry wall. Porosity is vuggy and is related to the differential weathering of the matrix - 2 x 3 cm. and up to 6 x 2 cm. (moldic?) - some cavities rimmed with carbonate minerals. Porosity zone 125-145 cm.
5-GT-17-1, 2

150-231 cm. - Dolomite - mottled appearance; clasts (10 YR 7/6) and matrix (10 YR 8/2) - crystalline grain size of dolomite - brecciated to nodular - vague bedding or laminated zone midway up this portion (cryptalgal laminae). Differential weathering of matrix gives the rock a very vuggy porous appearance. Intraclasts are tabular to equant in shape and are 6-8 cm. in size. Poor moldic porosity after brecciated and tumbled skeletal debris exists throughout the interval.
5-GT-18-1, 2

231-256 cm. - Dolomite - crystalline dolomite with flaggy weathering - overlying a thin soil horizon - possibly Pleistocene clays and soils (1 - 2 cm. thick).
Vertical joints penetrate the section throughout the quarry. These joints served as avenues through which the water and clay could percolate to the horizontal bedding planes. Major bedding break is a large stylolite.

256-362 cm. - Dolomite - beige to cream white (10 YR 6/6); clasts and matrix (10 YR 6/6) - crystalline dolomite - flaggy appearance in places - sharp bedding surfaces - bedding thicknesses 5 - 15 cm. Differential weathering of matrix - upper contact covered by 5 mm. thick soil horizon.
5-GT-19

362-499 cm. - Dolomite - mottled tan to beige with ocherous to brownish yellow - brecciated with beds 5 - 13.5 cm. thick with 1 - 2 cm. thick dense cryptalgal laminae beds (ocherous to brownish yellow) -1- flat upper and lower - upper surface of the cryptalgal laminite is desiccated along the axial ridge of minor 1 - 2 cm. mound surfaces which undulate - large salt hopper casts 1 - 2 cm. are preserved in the material between the cryptalgal laminae - 12 such dense cryptalgal laminite surfaces are preserved in this section.
-2- brecciated fragments in some beds show a reverse grading effect - 5 mm. - 6 cm. size - rounded edges - some flat pebble shaped.
-3- Porosity is a result of mainly differential weathering of matrix and in some cases moldic after tumbled fragments of colonial tabulate corals (8 x 10 cm.). Porosity up to 2 cm. - 10 - 15% (very good) but not interconnected.
5-GT-20-1 - cryptalgal laminae and breccia beds   Photos 8

499-544 cm. - Dolomite - similar mottled colors and weathering appearance
-1- cryptalgal laminae horizons 1.5 cm. thick separating a 6 cm. thick brecciated zone - four such cryptalgal laminae horizons
-2- Porosity - similar - 2 - 3 cm. vugs
5-GT-21

544-594 cm. - Dolomite - similar appearance - nodular - nodular bedding surfaces - with 1 - 3 cm. relief which may represent surfaces of dissolution (stylolites) - thin soil profile between the next major overlying unit.

594-644 cm. - Dolomite - mottled - overall color (10 YR 7/4) and clasts and or burrows (10 YR 8/2) - nodular to brecciated - very crystalline dolomite - flaggy appearance to weathered surface - beds 2 - 6 cm. thick - contacts stylolitic. Cavernous porosity 12 x 5 cm. voids possible after tumbled fossil debris.
5-GT-22

644-706 cm. - Dolomite - mottled appearance - dense dolomite beds orange brown (10 YR 6/6), clast and matrix (10 YR 7/4, 10 YR 8/2, N8) - first appearance of noticeable fossil remains - approximately 5% - brachiopods, gastropods and rare (1) colonial coral - 7 x 1 cm. - major bedding surfaces are stylolitic - very nodular. Vuggy to cavernous porosity. Four dense cryptalgal laminae beds present.
5-GT-23

Section 6 Drill hole M-2-69 - complete section logged - STONY MOUNTAIN, MANITOBA. Section measured from surface to depth i.e. 0 meters to 30.32 meters.

- PENITENTIARY MEMBER -

0-3.04 m. - Fossiliferous argillaceous dolomite - mottled medium yellowish orange and light greyish yellow green (10 YR 7/6, 5 GY 8/2) - (10 YR 7/6) is associated with the moldic and vuggy zones - no primary bedding structures - slightly calcareous. Porosity is mainly moldic; after brachiopods - horn corals - bryozoan and minor vug. Porosity 10 - 15% (very good) not interconnected - Fossils - molds of interior and cast mainly - 15 - 20% unoriented.
6-P-1

Gradational contact between the Penitentiary Member and the underlying Gunn Member over a distance of 10 - 20 cm.

- GUNN MEMBER -

3.04-3.96 m. - Fossiliferous argillaceous limestone - mottled appearance - overall color pale red (5 R 6/2) with burrows greyish orange pink to dusky red (5 YR 7/2), (5 R 3/4) - fossil debris (5 R 8/2). Fossils - disarticulated and articulated - some shell convex up - generally unoriented - brachiopods and horn corals (1.5 - 2.0 cm.) - coarse bioclastic lenses are present - generally less than 2 cm. - stylolitic contacts.
6-G-1-1 (3.5 m.), 6-G-1-2 (3.26 m.)

3.96-4.16 m. - Bioclastic limestone - light brownish grey (5 YR 6/1) - coarse bioclastic - two layers separated by a 4 cm. unit of fossiliferous argillaceous limestone.
1st bed - dusky red burrows which are horizontal - large solitary horn corals - 1 cm. - lying horizontal - brachiopod shells convex down - horizontal habit - sharp but wavy lower contact.
2nd bed - similar color - horizontal habit to debris - flat sharp lower contact - uneven undulating upper contact - 6 cm. thick
6-G-2 (4.06 m.)
Argillaceous limestone - floatstone with brachiopods in vertical growth positions (1 x 1.5 cm.) - debris 30%

4.16-4.33 m. - Fossiliferous argillaceous limestone - similar color - fossils brachiopod shells (whole and pieces) and horn corals - 20 - 30% fossiliferous material - Floatstone with mudstone matrix.

4.33-4.50 m. - Bioclastic limestone - coarse - shell debris horizontally oriented - horizontal burrows filled with hematite - shell fragments convex up - uneven stylolitic upper surface
Two internal stylolites (2 mm.)
6-G-3 (4.45 m.)

4.50-4.70 m. - Fossiliferous argillaceous limestone - with bioclastic limestone lenses and other clasts - horizontal burrows rimmed with hematite and pale greenish grey interior - vertical burrows - fossiliferous debris horizon - floatstone with wackestone matrix - gastropod conchs and shell debris - lithoclastic limestone horizon - 3 stylolites
6-G-4 (4.55 m.)

4.70-4.77 m. - Bioclastic limestone - fine grained - well laminated - horizontal burrows with some vertical burrows - rimmed with hematite - dusky red (5 R 3/4) - stylolitic upper and lower contacts

4.77-5.86 m. - Fossiliferous argillaceous limestone - pale red to pale reddish brown (5 R 6/2, 10 R 5/4) with dusky red (5 R 3/4) burrow areas - fine horizontal burrows (5 YR 7/2) are rimmed with hematite - hematite bearing unit (as with the above beds) two bioclastic limestone beds - 2 cm. thick - two stylolites. Fossil debris 15 - 20% - floatstone with mudstone to wackestone matrix
6-G-5 (5.70 m.)

5.86-5.91 m. - Bioclastic limestone - light grey (N7) - horizontal debris - no burrowing - internal and contact stylolites

5.91-6.00 m. - Fossiliferous argillaceous limestone - similar colors - burrows horizontal - 2 - 4 mm. diameter - fossiliferous wackestone

6.00-6.06 m. - Bioclastic limestone - similar color - fine to medium debris - stylolitic - roiled appearance to burrowed areas - burrows horizontal

6.06-6.35 m. - Fossiliferous argillaceous limestone - pale reddish brown - stylolitic - central portion of bed heavily burrowed - dusky red - horizontal - contains one bioclastic layer 1.5 cm. thick

6.35-6.55 m. - Bioclastic limestone - coarse - bedded - horizontal debris - stylolitic upper and lower contact
6-G-6 (6.40 m.)

6.55-6.91 m. - Fossiliferous argillaceous limestone - horizontal fabric to debris - light colored hematitic burrows - 3 mm. in diameter- same overall color - slightly fossiliferous wackestone

6.91-7.76 m. - Bioclastic limestone - with 28 cm. of fossiliferous argillaceous limestone. Bioclastic limestone - coarse - horizontal debris - convex up - scour channels - upper and lower contacts stylolitic internal stylolites - light grey color (N7).

Argillaceous limestone - pale red to greyish orange pink (5 R 6/2, 5 YR 7/2) - stylolitic bedding contacts - fossiliferous wackestone.
6-G-7 (6.93 m.), 6-G-8 (7.59 m.)

7.76-8.11 m. - Fossiliferous argillaceous limestone - hematitic - pale reddish purple with blotchy areas of greyish red purple (5 RP 6/2, 5 RP 4/2) - highly comminuted fossil debris - very bioturbated - lower and upper contact stylolitic - fossiliferous wackestone
6-G-9 (7.93 m.)

8.11-8.71 m. - Bioclastic limestone - beds with intercalation of light green shale - light olive grey (5 Y 6/1)
6-G-10 (8.65 m.)

8.71-8.78 m. - Fossiliferous argillaceous limestone - light olive grey (5 Y 6/1) with dusky red rimmed burrows (hematite) - mudstone

8.78-8.81 m. - Bioclastic limestone - medium grained - horizontally oriented debris - flat lower contact - undulating to irregular upper contact packstone

8.81-9.10 m. - Fossiliferous argillaceous limestone - pale red purple to greyish red purple (5 RP 6/2, 5 RP 4/2) with blotches of greyish pink (5 R 8/2) - fossil debris (5 YR 7/1), (N 3), and (5 YR 6/1) - highly comminuted debris - bioturbated - dendroid bryozoans and corals - horn corals - brachiopod/bivalve - crinoid pieces and debris - fossils 30% - up to 2 cm. pieces - floatstone with wackestone matrix
6-G-11 (8.95 m.)

9.10-9.35 m. - Bioclastic limestone with thin intercalations of argillaceous limestone - fine bioclastic with some coarse debris - horizontal - solitary coral (1.8 x 1 cm.)

9.35-9.78 m. - Fossiliferous argillaceous limestone - pale red purple to greyish red purple (5 RP 6/2, 5 RP 4/2) - burrows (5 YR 7/2) horizontal - stained with hematite - very stylolitic - fossiliferous wackestone

9.78-9.83 m. - Bioclastic limestone - coarse with horn corals up to 1 cm. long - packstone

9.83-9.92 m. - Fossiliferous argillaceous limestone - similar - floatstone with wackestone matrix

9.92-10.06 m.- Bioclastic limestone - grey to light grey (N6, N7) - medium to coarse grained - debris horizontal - lower 6 cm. medium to fine bioclastic - stylolitic contacts

10.06-10.30 m.- <u>Fossiliferous argillaceous limestone</u> - reddish purple - horizontal burrows lighter color - fossiliferous wackestone

10.30-10.39 m.- <u>Bioclastic limestone</u> - grey (N7) - medium to coarse debris, horizontally bedded

10.39-10.71 m.- <u>Fossiliferous argillaceous limestone</u> - similar colors - with minor horizontal burrows - two lenses of bioclastic limestone

10.71-10.85 m.- <u>Bioclastic limestone</u> - grey to pale grey - medium to coarse grained debris - horizontal habit to debris - flat sharp lower contact stylolitic upper contact
6-G-12 (10.71 m.)

10.85-11.26 m.- <u>Fossiliferous argillaceous limestone</u> - shell debris in fairly large pieces - horizontal - in places imbricated

11.26-11.30 m.- <u>Bioclastic limestone</u> - grey - coarse - convex up debris - packstone

11.30-12.77 m.- <u>Fossiliferous argillaceous limestone</u> - similar colors - abundant bivalve debris and crinoids - floatstone with a wackestone matrix. Bioclastic limestone - minor beds - a total of 20 cm. thickness
6-G-13-1, 2 (11.80 m.), 6-G-14 (12.30 m.)

12.77-12.84 m.- <u>Bioclastic limestone</u> - greyish to pinkish grey - coarse debris horizontal - stylolitic contact

12.84-13.14 m.- <u>Fossiliferous argillaceous limestone</u> - horizontal fabric to debris - mainly bivalve and crinoids - floatstone with wackestone matrix

13.14-13.20 m.- <u>Bioclastic limestone</u> - coarse bioclastic overlain by fine bioclastic with thin intercalations of argillaceous limestone - graded bedding - fine laminations

13.20-14.17 m.- <u>Fossiliferous argillaceous limestone</u> with two five cm. thick bioclastic beds

Fossiliferous argillaceous limestone - pale red purple - fine burrows 2 - 3 mm. - rimmed with hematite - in places no burrows. Fossils - mainly brachiopod and crinoid (40% in places) with vague horizontal bedding - mudstone to floatstone with wackestone matrix

13.26-13.31 m. - Bioclastic limestone - fine to medium grained - horizontal

13.40-13.46 m. - Bioclastic limestone - medium to coarse - bedded - stylolites common throughout

6-G-15 (13.50 m.)

14.17-14.37 m.- Bioclastic limestone - two bioclastic limestone beds separated by 5 cm. of argillaceous limestone (as above beds) - well developed horizontal bedding - 1 cm. brachiopod shells present - a great deal of dissolution has taken place - seven stylolites present

14.37-15.10 m.- Fossiliferous argillaceous limestone - red purple to greyish red purple. Fossils - 35 - 45% - up to 2 cm. long in size - bryozoan and gastropods (complete remains) plus brachiopod and bivalve shell debris with rare solitary cup corals. Floatstone with wackestone matrix
6-G-17 (15.08 m.)

15.10-15.27 m.- Bioclastic limestone - two beds - coarse grained, horizontal fabric mainly brachiopod debris with 2 - 5 mm. pyrite cubes - lower stylolite contact - separated by 3 cm. argillaceous limestone bed which has been burrowed horizontally - rimmed with hematite

15.27-15.74 m.- Fossiliferous argillaceous limestone - with a 5 cm. bioclastic limestone bed - no burrowing - red purple to greyish red purple - vague horizontal bedding - mainly whole brachiopod remains in vertical orientation present - in situ deposit.
15.60-15.64 m. - Bioclastic limestone - fine to medium grained debris - horizontal fabric
6-G-18 (15.51 m.)

15.74-15.85 m.- Bioclastic limestone - grey to pinkish grey - coarse grained bioclastic overlain by fine bioclastic - fine bioclastic finely laminated - graded bedding - strong current control.
6-G-19 (15.81 m.)

15.85-16.35 m.- Fossiliferous argillaceous limestone - with one bioclastic bed 2 cm. thick - overlying bioclastic limestone beds are bryozoan stems 2 cm. long and horizontally oriented brachiopod shell debris and whole remains
6-G-20 (16.16 m.), 6-G-21 (16.35 m.)

16.35-19.95 m.- Some core lost due to the compaction of core (60 cm. lost). Bioclastic limestone comprises approximately 17% while the remainder is made up of fossiliferous argillaceous limestone.

The majority of this section is made up of argillaceous fossiliferous limestone. Fossil content varies from bed to bed - 10 - 30% mainly brachiopods, bryozoans, crinoids and debris. Bedding ranges from 3 - 5 cm. Floatstones with wackestone matrix - mudstones - fossiliferous wackestones. Very stylolitic. Color ranges from pale yellowish brown, moderate yellowish brown to dark yellowish brown. (10 YR 6/2, 10 YR 5/2, 10 YR 4/2)

Bioclastic limestone -

16.65-16.83 m. - upper 10 cm. consists of intercalations of bioclastic limestone and pale green grey argillaceous limestone - bits and pieces of the brachiopods are up to 1.5 cm. long - crinoid ossicle, and solitary corals. Packstone.

-lower 8 cm. consists mainly of fine grained calcarenite sand with some coarse shell debris - oriented horizontally - stylolitic
6-G-22

17.15-17.22 m. - fine grained underlain by coarse grained debris (2/5) crinoids and brachiopods. Packstone.
6-G-23

17.34-17.40 m. - coarse bioclastic overlain by fine bioclastic - graded bedding, inclined to vertical burrows at the surface (to 2cm. depth) - stylolitic shell debris horizontal - convex down - hematitic seam between the bioclastic beds
6-G-24

17.95-18.20 m. - two beds - 2 and 5 cm. thick - separated by intercalations of fossiliferous argillaceous limestone - brachiopods 50 - 50%, bryozoans 20%, crinoids 5 - 10%, and unknown debris 25% (Fossils make up 35 - 45% of the bed). Very prolific faunal growth.

18.47-18.51 m. - coarse bioclastic limestone - horizontal and vertical shell orientation

19.95-25.31 m.- The only sign of poor core recovery-in this box 4.27 metres only.

19.95-24.00 m.- Fossiliferous argillaceous limestone - with minor bioclastic limestone layers - horizontal brachiopod debris - poorly sorted - convex down.
Fossiliferous argillaceous limestone - debris mainly broken brachiopods (up to 2 cm. long) and crinoids.
The last 100 cm. takes on a very mottled appearance - dusky yellow and moderate grey purple (5 Y 6/4, 5 P 5/2) - this unit is lumpy to nodular in appearance.
The debris is poorly sorted - less than 15% - inclined - roiled appearance.
Note - this portion of the unit looks like it may have been a turbid flow scouring the underlying limestone beds. Very sharp contact between the Gunn Member and Fort Garry Member of the Red River Formantion may represent some sort of erosion break - paraconformity.

RED RIVER FORMATION - FORT GARRY MEMBER -

24.00-25.32 m.- Good core recovery
Limestone with minor dolomitic limestone - pale yellowish orange, very pale orange to yellowish grey (10 YR 8/6, 10 YR 8/2, 5 Y 8/1)
70 cm. - lithographic to sublithographic - finely laminated - algal layer? - desiccated mudstone
30 cm. - debris beds - articulate brachiopod - birdseye structures, some filled with calcite cement - debris bed 1 cm. thick separated by 2.5 mm. mudstone - definite graded bedding - moderate sorting. Wackestone.
Porosity - coarse fenestral, vuggy, birdseye - 15% (excellent)
Well developed birdseye structures 25.20-25.32 m. between finely laminated mudstone - pelletoidal algal bindstone
6-F-26 (24.40 m.)
6-F-27 (24.55 m.) Subaerial exposure
6-F-28, 1, 2 (25.00, 25.10, 25.25 m.) There may be algal bindstone present in this sample - 5 mm. of debris and oncolite like structure overlain by finely laminated dolomitic limestone which display birdseye structures.

25.32-30.32 m.- Good core recovery.
Dolomite - white, pale yellowish orange, very pale orange and yellowish grey (N8, 10 YR 8/6, 10 YR 8/2, 5 Y 8/1)

25.32-25.84 m.- Dolomite - finely laminated algal bindstone - millimetre laminae-grey-separated by zones of pale yellow. Some sublithographic dolomite laminae have a clastic appearance and measures at least 1.5 x .30 cm. - desiccated clasts are present - very flat clasts 4 x 1 mm.are also present. Porosity is almost completely occluded; birdseye structures and some fenestral porosity is present. 5 - 10% (fair)
6-F-29 (25.39 m.), 6-F-29-1 (25.43 m.), 6-F-29-2 (25.60 m.)
6-F-29-3 (25.64 m.)

25.84-26.02 m.- Dolomite - pale yellow color - somewhat mottled - sublithographic - many fine vugs filled with a much finer material - yellow in color. Porosity - vuggy - less than 5% (poor). Mudstone

26.02-26.17 m.- Dolomite - pale yellowish brown (10 YR 6/2) - 5 mm. separated by pale yellowish orange (10 YR 8/6). Porosity - very fine - vuggy. Mudstone.

26.17-26.38 m.- Dolomite - yellowish grey (5 Y 8/1) - distinctly different from the overlying dolomite - the upper surface contains a suncracked dolomite crust which are vaguely laminated. The lower 15 cm. is comprised of dense non-descript dolomite (5 Y 8/1) mudstone and churned up debris beds 1 cm. thick. Porosity - fine to medium vug - less than 5% (poor)
6-F-30

26.38-26.96 m.- Dolomite - finely laminated - fine clastic beds with oncolites 4 x 1 mm. Dense dolomite beds with very irregular surfaces - ? ripple marked with wave length equal to 5 cm. - Beds 3 - 4 cm. thick with chert nodules with a surrounding alteration halo - 5 mm. wide - Gastropods up to 1 cm. x 3 mm. crinoids. Porosity very fine vug and moldic with minor birdseye - less than 5% (poor)
6-F-30-1 (26.73 m.), 6-F-30-2 (26.83 m.)

26.96-28.27 m.- Dolomite - grey laminations generally overlain by greyish orange (10 YR 7/4) dense dolomite which in turn may be overlain by a clastic bed - algal bindstone - the main component of these beds may be fossil debris or ripped up algal mats. One very porous zone approximately 10 cm. thick - selective dissolution of algal mat chips. 2 cm. of nodular chert at 27.64 m. 1 cm. of nodular chert beds at 27.80 m. Large scale cross bedding (20-30^{o}) and scours are present. Porosity is moldic and vug - 10 - 15% (good)
6-F-31 (26.96 m.), 6-F-32 (27.10 m.), 6-F-33 (27.35-28.00 m.)

28.27-28.40 m.- Dolomite with chert nodules - 2 cm. thick bed of chert nodules. The chert occupies the pale yellow orange mottled areas while the remainder of the unit is greyish orange. Mudstone.
6-F-34 (28.38 m.)

28.40-29.40 m.- Dolomite with chert nodules - mottled - overall color (10 YR 6/2) with mottles (10 YR 7/4 - 10 YR 8/6). Ten thin chert nodule beds are present in this interval composed of brecciated dolomite. Clasts are angular to subangular, less than .3 to greater than 2.5 cm. in size. Fine vuggy to moldic porosity - less than 5% (poor). Floatstone.
6-F-35

29.40-30.32 m.- Dolomite - with chert nodules - overall color as above (10 YR 6/2). Moderately thick, well developed horizontal bedding. Trace of moldic bioclastic debris. Poor porosity, less than 5%. Mudstone.
6-F-36

Section 7 Drill hole M-3-74 - partial section logged - HEADINGLEY, MANITOBA. Section measured includes the lower Gunton, Penitentiary, Gunn and the Upper Fort Garry Members (27.43 meters to 58.84 meters).

- GUNTON MEMBER -

27.42-27.70 m.- Dolomite - white (N9) - slightly argillaceous - intraclastic to pseudobrecciated appearance. Floatstone with mudstone matrix.

27.70-28.08 m.- Shale - dolomitic to calcareous - moderate reddish brown to light brown (10 R 4/6, 5 YR 5/6) - this shale bed is laminated - slightly inclined to steeply inclined to core axis - it is underlain by a clastic dolomite bed. Clasts - rounded, 3 mm. to 32 mm. in size. *TERRA ROSSA - this unit forms a distinctive break in sedimentation. Represents a removal of section and an unconformity, i.e. soil horizon.

- PENITENTIARY MEMBER -

28.08-28.21 m.- Dolomite - clastic (the above mentioned beds), light greenish grey (5 GY 8/1) with matrix greenish yellow grey (5 GY 7/2)

28.21-29.71 m.- Dolomite - mottled - overall color; moderate orange pink to light orange pink (5 YR 8/4, 5 YR 8/3), with clasts? (5 R 8/2) - nodular - pseudobrecciated - slightly argillaceous and fossiliferous. Thin hairline fractures steeply inclined, filled with hematite. Matrix in some areas contains greenish grey argillaceous material (5 GY 8/1) giving the matrix a darker appearance than the clasts. Porosity - very coarse vug and solution enlarged moldic after solitary horn corals and brachiopods, 5 - 10% (fair). Floatstone with mudstone matrix.

29.71-31.11 m.- Argillaceous dolomite - mottled appearance - pale red matrix (10 R 6/2) and light greenish grey to pale red (5 GY 8/1, 5 R 6/2) pseudonodular to pseudobrecciated accented by mottling - clasts? - up to 3.2 cm. - rounded. Porosity, very minor fine vuggy - (trace).

31.11-32.64 m.- Fossiliferous Argillaceous dolomite - slightly calcareous - pale red (10 R 6/2) 31 cm. zone with the remainder a light greenish grey to pale greenish yellow (5 GY 8/1, 10 Y 8/2). Porosity mainly moldic after brachiopods, bryozoan (coarse) and fine to coarse vuggy - 10% (good). Fossiliferous wackestone.

32.64-33.04 m.- Argillaceous dolomite - greyish orange pink to light brown (5 YR 7/2, 5 YR 6/4) - vague horizontal bedding. Porosity - fine to medium vuggy - 5 - 10% (fair). Mudstone.

Gradational contact with Gunn Member becomes very shaly beyond this point.

- GUNN MEMBER -

33.04-35.08 m.- Fossiliferous argillaceous limestone - pale red to greyish orange pink (5 R 6/2, 5 YR 7/2) with minor areas of light brown (5 YR 5/6) with clasts of bioclastic limestone in two horizons. Clasts - coarse and fine bioclastic - light brownish grey (5 YR 6/1) - stylolitic

Fossils - 5 - 20% disarticulated brachiopods, crinoids with rare bryozoan and cup corals. Where concentrated the debris makes the unit a brachiopod wackestone - debris horizontal in many places.
Heavily bioturbated and in many places the burrows are rimmed with hematite. The burrows are always a lighter greyish pink - horizontal habit. Porosity - high - very fine intercrystalline porosity and minor vuggy porosity.

35.08-35.13 m.- Bioclastic limestone - light brownish grey (5 YR 6/1) with blotches of yellowish grey and dusky red (5 Y 8/1, 5 R 3/4) - coarse bioclastic - brachiopod, bivalve debris, crinoids and unknown debris. Stylolitic - clastic upper contact - sharp flat lower contact. Grainstone to packstone.

35.13-35.69 m.- Fossiliferous argillaceous limestone - same color - very hematitic heavily burrowed - very bioturbated - rimmed burrowed areas - with 2 cm. thick bed of fossiliferous limestone - with upper and lower stylolitic contacts. Beds 2 - 8 cm. thick - articulate and disarticulate debris of brachiopods - bivalves and horn corals. Bivalve horn coral wackestone.

35.69-35.86 m.- Bioclastic limestone - 5 - 6.5 cm. beds separated by argillaceous limestone, dusky red - coarse and fine bioclastic - finely laminated - graded bedding - gentle low amplitude ripples inclined laminations - upper portion burrowed and filled with yellowish grey (5 Y 8/1) argillaceous material - shells convex down 7-G-1.

35.86-36.60 m.- Fossiliferous argillaceous limestone - reddish brown to pale red (10 R 4/6, 10 R 6/2) with lighter hematite rimmed burrows. Brachiopods, large solitary corals, and bivalve debris. Mudstone to fossiliferous wackestone.

36.60-36.75 m.- Bioclastic limestone - light grey (N8) with pale red (10 R 6/2) areas surrounding gastropods and clastic zones. Large gastropods, horn corals, brachiopods, crinoids, unoriented. Packstone - grainstone.

36.75-37.93 m.- Fossiliferous argillaceous limestone - similar appearance with lenses of bioclastic limestone making up one-half of the bed.
37.03-37.06 m. - minor bioclastic limestone - fine grained - laminated

37.93-38.17 m.- Fossiliferous argillaceous limestone - pale yellowish brown (10 YR 6/2) and very light grey (N8) bioclastic lenses. Bryozoan rich brachiopod bearing wackestone.

38.17-38.71 m.- Argillaceous limestone - pale red (10 YR 6/2) - fine grained. Hematitic slightly fossiliferous (bivavles). Mudstone.

38.71-38.94 m.- Bioclastic limestone - 3 beds - medium to fine grained - fine grained well laminated and distinctly bedded 10 cm. bed - overlain by a coarse grained horizontally bedded limestone.

38.94-39.42 m.- Argillaceous limestone with one bioclastic limestone bed (39.07-39.12 m.). Minor brachiopods and cup corals, less than 5%. Mudstone with thin packstone - grainstone bed.

39.42-40.24 m.- Bioclastic limestone - 80% with 20% argillaceous limestone. Alternating coarse and fine grainstone sequences with minor mudstone sequences.

40.24-40.37 m.- Argillaceous limestone - bedding inclined 20 - 30^{o} to core axis with lenses of bioclastic limestone - slump structures. Mudstone.

40.37-42.67 m.- Argillaceous limestone - light brownish grey to light grey (5 YR 6/1 - N7) with minor beds of bioclastic limestone - light grey (N8) argillaceous limestone comprises 80% of this section and bioclastic limestone comprises 20%. (10 beds less than 2.5 cm. thick).

42.67-42.90 m.- Bioclastic limestone - medium to coarse grained - well bedded - slight inclination to bedding - overlain by 5 cm. of fine bioclastic limestone with minor clay partings.

42.90-45.39 m.- Fossiliferous argillaceous arenaceous limestone - with minor bioclastic limestone

Fossiliferous argillaceous arenaceous limestone - various fossil sizes and wide variety - brachiopods, crinoids, bryozoans, cup corals and bioclastic debris - pale yellowish brown with local areas of dark yellowish orange (10 YR 6/2, 10 YR 6/6). Bioclastic limestone - light grey (N8) and light brownish grey (5 YR 6/1).

45.39-45.52 m.- Bioclastic limestone - three beds - fine - coarse - fine with brachiopod shells convex down, 2.5 - 3 cm. disarticulated - finely laminated.

45.52-46.89 m.- Fossiliferous argillaceous limestone with minor (less than 5%) bioclastic limestone. Argillaceous limestone - in places arenaceous - pale red (10 R 6/2) with hematite rimmed burrows - moderate red (5 R 4/6) - coarse debris (5%) bivalve, bryozoans, crinoids - fine debris (95%) - horizontally bedded - concentrated along some planes.

Bioclastic limestone - very thin stylolitic controlled beds - somewhat burrowed.

46.89-46.95 m.- Bioclastic limestone - coarse debris - horizontally bedded - upper - lower contacts stylolitic - internal stylolites - non-burrowed - brachiopods, bivalves, crinoid, and debris. Grainstone - packstone
7-G-2 (46.66 m.)

46.95-47.48 m.- Fossiliferous argillaceous limestone - generally horizontally bedded - brachiopods, bryozoans, crinoids, and debris - bivalves, convex down and up. Minor bioclastic limestone.

47.48-47.63 m.- Bioclastic limestone - fine debris with minor coarse debris - well laminated - bedded.

47.63-49.31 m.- Fossiliferous argillaceous limestone - in places horizontally bedded - fossils mainly brachiopods - crinoids and cup corals and rare gastropods. Beds range from 3 to 15 cm. thick and compositionally from unfossil-ferous mudstone to brachiopod, horn coral, gastropod floatstone (35% fossils) with mudstone matrix. The shells present in the floatstones are well preserved. Current and biological destruction was minimal, life prolific, and sedimentation rates normal. The mudstone beds which are devoid of fossil life and horizontally bedded may represent periods of slightly quicker sedimentation rate and somewhat higher current activity - conditions unsuitable for life.
7-G-3 (49.20 m.)

49.31-49.55 m.- Bioclastic limestone - very coarse overlain by medium to fine bioclastic. Well laminated fine bioclastic bed. Coarse debris convex up with shelter voids filled.

49.55-51.74 m.- Fossiliferous argillaceous limestone - color varies from pale yellowish brown (10 YR 6/2) to dusty red (5 R 3/4) and burrowed areas moderate red (5 R 5/4). Fossils include brachiopods and bryozoans with periodic horn coral occurrences. Beds vary from 5 - 13 cm. in thick-ness and form mudstones to floatstones (20% debris) with mudstone to wackestone matrix.

51.74-51.77 m.- Bioclastic limestone - coarse debris - articulate and inarticulate brachiopod remains. Last bioclastic limestone bed.
7-G-4

51.77-54.95 m.- Argillaceous limestone to somewhat fossiliferous argillaceous limestone - (10 YR 6/2 to 5 R 5/4) - burrows present - beds 5 - 12 cm. thick. Beds from 54.44 - 54.95 m. are a greyish yellow green color (5 GY 7/2) and somewhat arenaceous but extremely argillaceous. Finely laminated and nodular - clast are up to 4 cm. - rounded and composed of limestone (light grey) - Basal conglomerate??
7-G-5 (54.90 m.)

Very sharp abrupt contact with the underlying Fort Garry Member of the Red River Formation represents an unconformity i.e. paraconformity.

RED RIVER FORMATION - FORT GARRY MEMBER -

54.95-57.84 m.- First limestone marker beds - overall pale orange (10 YR 8/2)

54.95-55.41 m.- Limestone - dense - lithographic - very finely laminated. Mudstone.

55.41-55.46 m.- Limestone - variously colored - very pale orange (10 YR 8/2) and yellowish grey (5 Y 7/2) - dense - lithographic - well bedded unit 1.5 cm. thick overlying clastic sparry cemented bed 2.0 cm. thick - possibly some algal clasts. Porosity - coarse vuggy - 5 - 10% (fair).
7-F-6

55.46-56.42 m.- Limestone - pinkish grey and yellowish grey (5 YR 8/1, 5 Y 8/1) dense - lithographic - very finely laminated millimeter laminae

56.42-56.47 m.- Intraclastic limestone - very pale orange (10 YR 8/2). Possible torn up algal clasts.

56.47-56.58 m.- Limestone - finely bedded - inclined 20^{o} to the core axis, cryptalgal laminae. Porosity - vuggy, partially filled with blocky spar cement. Some portions of the cryptalgal laminae destroyed by burrowing. Bindstone.
7-F-7

56.58-57.85 m.- Limestone - very pale orange to buff white (10 YR 8/2, N9) lithographic - very finely laminated. Mudstone.

57.85-58.87 m.- Slightly calcareous dolomite

57.85-57.96 m.- Dolomite - dense - crystalline - vaguely burrowed. Mudstone.

57.96-58.18 m.- Brecciated dolomite - clasts - very light olive grey (5 Y 6/1) in a yellowish grey dolomite matrix (5 Y 8/1) - very coarse subangular to angular - flat - clasts. Float breccia. Floatstone in a mudstone matrix - clasts 60 - 70%.
7-F-8

58.18-58.24 m.- Dolomite - lithographic. Dense mudstone.

58.24-58.37 m.- Slightly calcareous and argillaceous dolomite - yellowish grey (5 Y 8/1) and light grey (N7). Algal bindstone - very good example with fenestral and birdseye porosity.
7-F-9

58.37-58.56 m.- Slightly argillaceous dolomite - finely laminated and clastic beds - flat chip conglomerate, possible somewhat burrowed.

58.56-58.87 m.- Dolomite - buff white to yellowish grey (N9, 5 GY 8/1) - alternating finely laminated beds with birdseye porosity and clastic beds with medium sized clasts. Bedding inclined at a 10 - 15° angle to the core axis. Porosity - medium vug - birdseye and interparticle - vugs partially filled with sparry calcite, 10% (good).
7-F-10

Appendix B Insoluble Residue Analysis

Sample	Beaker Weight	Beaker and sample wt.	Filter and sample wt.	I.R. wt.	% of I.R.
6-G-9	94.51	118.10 gm	10.05 gm	7.80 gm	33.06
6-G-14	98.82	115.76	5.22	2.97	17.54
6-G-20	100.3	111.43	6.12	3.87	34.77
6-G-25	74.92	89.43	7.34	5.09	35.08
7-F-6	100.1	127.42	2.49	0.24	00.87
7-F-7	91.57	97.12	2.29	0.04	00.72

X-ray Analysis*

* X-ray analysis carried out on a Phillips diffractometer with; copper radiation, nickel filter, 400-1000 counts per second, and a scanning speed of 1°2θ. Dolomite: Calcite ratios calculated according to the method purposed by Royse et al. (1971). The average of five runs per sample were used to calculate the averages.

Sample			Dolomite	Calcite	Quartz
G-1	6-F-36	chert nodules	-	-	X
G-2	6-F0	upper limestone	12%	88%	-
G-3	1-W-11		100	00	X
G-4	1-W-13	matrix	100	00	X
G-5	1-W-13	clasts	95	05	X
G-6	4-P-28		79-80	20-21	-
G-7	4-Gt-36-2		100	-	-
G-8	4-Gt-36-4		100	-	X
G-9	5-P-X-2		100	-	X
G-10	5-P-14	argil, dolomite	X	X	X
G-11			X	X	-
G-12	2-G-2	fossil, floatstone	69	31	X
G-13-1	2-G-X-3	fine bioclastic	58	42	-
-2	2-G-X-3	coarse bio.	1-2	99-98	-
G-14	6-F-27-1	no results			
G-15	5-G-9	fossil, floatstone	67-76	24-33	-

X mineral present
- mineral not present

Appendix C   Modal Analysis Data

i Williams Member

Sample	Qtz.	AuF.	Mx.	Int.	Ool.	Pel.	Z-dolo.	Por.	Total
1-W-1	23	5	138	171	41	78	107	52	615
1-W-2	100	25	142	165	2	0	165	25	624
1-W-3	75	7	327	0	0	0	224	43	676
1-W-4	61	11	396	0	0	0	59	0	527
1-W-5									
1-W-6	62	11	389	2	0	0	101	37	602
1-W-7$_{u}$	124	17	378	0	0	4	31	17	571
1-W-7$_{l}$	14	7	286	10	0	49	64	11	441
1-W-8	150	25	324	0	0	0	101	19	619
1-W-9$_{A}$	116	35	290	22	0	0	118	37	618
1-W-9$_{B}$	35	21	377	22	0	0	144	10	609
1-W-10	30	11	203	0	0	166	31	1	442
1-W-11	59	11	392	2	0	0	138	12	614
1-W-12$_{i}$	129	29	248	124	0	24	39	31	624
1-W-12$_{ii}$	76	10	239	117	0	21	120	22	605
1-W-13$_{c}$	215	20	201	141	0	0	11	26	614
1-W-13$_{f}$	173	32	274	87	0	11	25	15	617
1-W-14	2	4	354	133	0	0	115	2	610
1-W-15	0	4	515	5	0	0	54	25	603

i Percentage equivalents

Sample	%	%	%	%	%	%	%	%
1-W-1	3.7	0.8	22.4	27.8	6.7	12.7	17.4	8.5
1-W-2	16.3	4.0	22.8	26.4	0.3	0.0	26.4	4.0
1-W-3	11.1	1.0	48.3	0.0	0.0	0.0	33.1	6.4
1-W-4	4.6	2.1	75.1	0.0	0.0	0.0	11.2	0.0
1-W-5								
1-W-6	10.3	1.8	64.6	0.3	0.0	0.0	16.8	6.2
1-W-7$_{u}$	21.7	3.0	66.2	0.0	0.0	0.1	5.4	3.0
1-W-7$_{l}$	3.1	1.6	64.0	3.6	0.0	11.0	14.3	2.5
1-W-8	24.2	4.0	52.3	0.0	0.0	0.0	16.3	3.1
1-W-9$_{A}$	18.8	5.7	46.9	3.6	0.0	0.0	19.1	6.0
1-W-9$_{B}$	5.8	3.5	61.9	3.6	0.0	0.0	23.7	1.6
1-W-10	6.8	2.5	45.9	0.0	0.0	37.6	7.0	0.2
1-W-11	9.6	1.8	63.8	0.3	0.0	0.0	22.5	2.0
1-W-12$_{i}$	20.7	4.7	39.7	19.9	0.0	3.9	19.9	5.0
1-W-12$_{ii}$	12.6	1.7	39.5	19.3	0.0	3.5	19.3	3.6
1-W-13$_{c}$	35.0	3.3	32.8	23.0	0.0	0.0	1.8	4.2
1-W-13$_{f}$	28.0	5.2	44.4	14.1	0.0	1.8	4.1	2.4
1-W-14	0.3	0.7	58.0	21.8	0.0	0.0	18.9	0.3
1-W-15	0.0	0.7	85.4	0.8	0.0	0.0	9.0	4.2

Appendix C Modal Analysis Data

ii Gunn Member

Sample		Gn.	Mx.	Ct.	(∩)	(⩌)	(ʊ)	(⊙)	(ɸ)	(YΔ)	Total
5-G-9	Msl	41	446	40	33	6	0	2	0	0	527
2-G-2	Wsl	62	438	2	37	15	3	5	2	0	502
2-G-6	Wsl	158	858	23	54	30	28	14	32	0	1,039
5-G-x(6)	Wsl	118	480	12	64	30	7	17	0	0	610
6-G-1(2)	Wsl	152	558	16	52	10	22	21	47	2	726
2-G-3	Psl	135	58	109	57	55	0	21	1	1	302
4-G-4	Psl	219	84	130	x	x	x	x			433
4-G-5	Psl	331	141	92	x	x	x	x	x		564
4-G-6	Psl	141	31	136	x	x	x	x			308
4-G-7	Psl	286	130	134	x	x	x	x	x	x	550
4-G-8	Psl	77	38	44	x	x	x	x			159
4-G-10	Psl	275	72	153	x	x	x	x	x	x	500
4-G-13	Psl	263	206	102	x	x	x	x	x	x	571
4-G-14	Psl	311	213	134	x	x	x	x	x	x	658

ii Percentage equivalents

Sample	%	%	%	%	%	%	%	%	%	%
5-G-9	7.8	84.6	7.6	6.3	1.1	0.0	0.4	0.0	0.0	100
2-G-2	12.4	87.3	0.3	7.4	3.0	0.6	1.0	0.4	0.0	100
2-G-6	15.2	82.6	2.2	5.2	2.9	2.7	1.3	3.1	0.0	100
5-G-x-6	19.2	78.7	2.0	10.5	4.9	1.1	2.8	0.0	0.0	100
6-G-1-2	20.9	76.9	2.2	7.2	1.4	3.0	2.9	6.4	0.0	100
2-G-3	44.7	19.2	36.1	18.9	18.2	0.0	7.0	0.3	0.3	100
4-G-4	50.6	19.4	30.0	x	x	x	x			100
4-G-5	58.7	25.0	16.3	x	x	x	x	x		100
4-G-6	45.7	10.1	44.2	x	x	x	x			100
4-G-7	52.0	23.6	24.4	x	x	x	x	x	x	100
4-G-8	48.4	23.8	27.8	x	x	x	x			100
4-G-10	55.0	14.4	30.6	x	x	x	x	x	x	100
4-G-13	46.0	36.1	17.9	x	x	x	x	x	x	100
4-G-14	47.2	32.3	20.5	x	x	x	x	x	x	100

* These samples represent selected samples from the three facies which characterize the Gunn Member.

* Bioclastic debris (∩), bivalves (⩌), brachiopods (ʊ), crinoids (⊙), coral debris (ɸ), bryozoans and gastropods (YΔ).

* x indicates that the various grains were present.

STONEWALL FORMATION

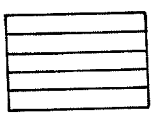
LEGEND

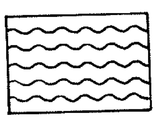
DEPOSITIONAL TEXTURE

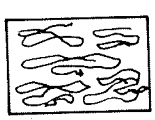
Mst MUDSTONE
Pst PACKSTONE
Flst FLOATSTONE
Bst BINDSTONE
Wst WACKESTONE
Gst GRAINSTONE
Rst RUDSTONE

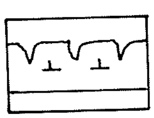
e EVAPORITE BEARING
In INTRACLASTIC
PN PSEUDONODULAR
c CRYPTALGAL
N NODULAR

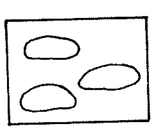
SEDIMENTARY STRUCTURE

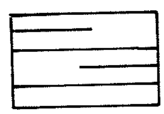

THIN BEDDING

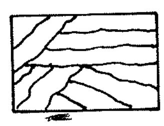

RIPPLES

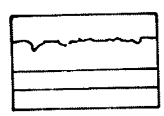

BURROWING

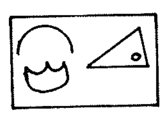

DESICCATED SURFACE


INTRACLASTS

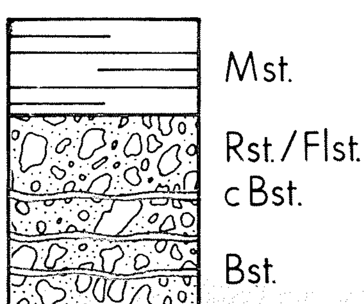

THICK BEDDING


CROSS BEDDING

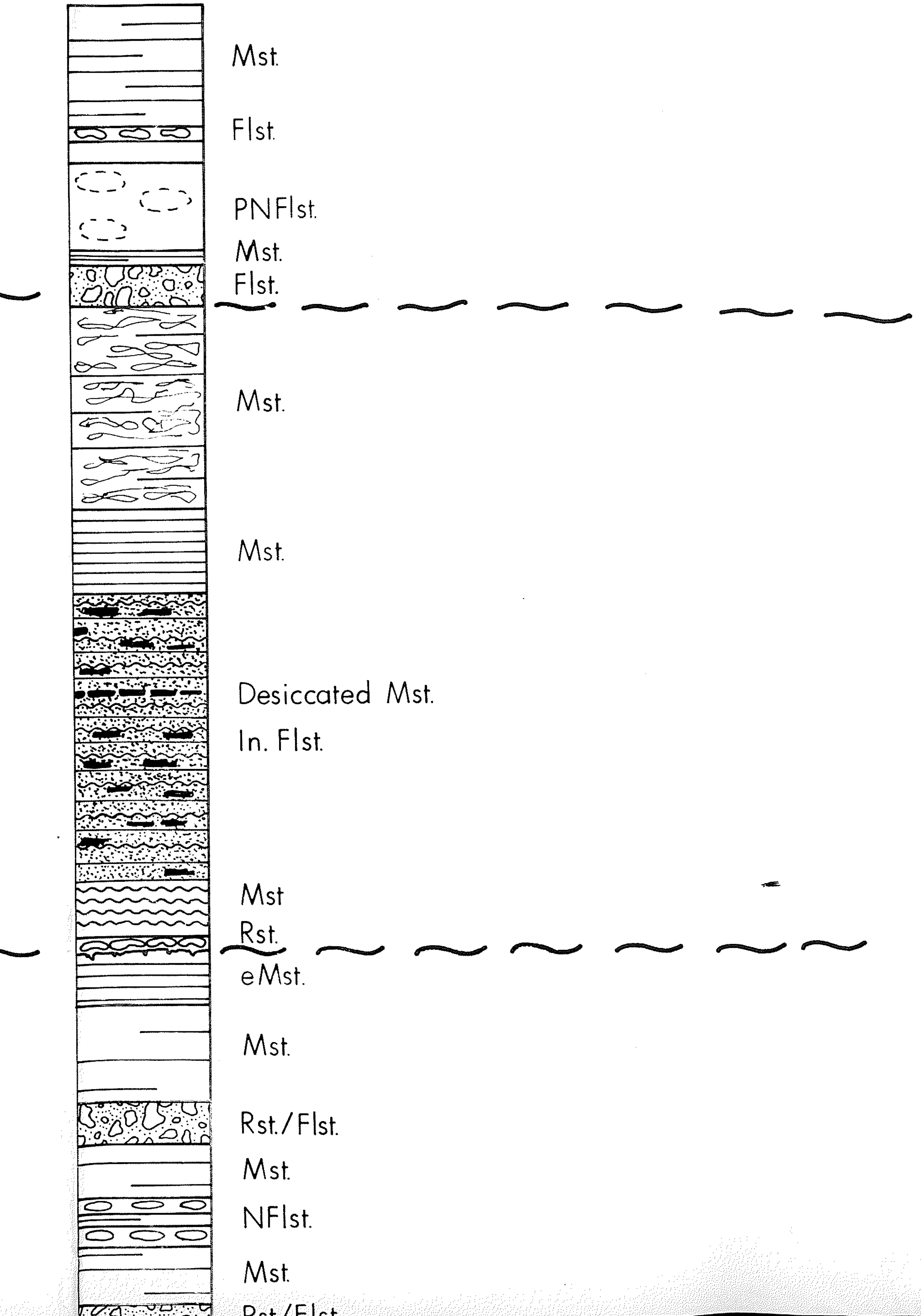

SCOURED SURFACE


FOSSIL REMAINS

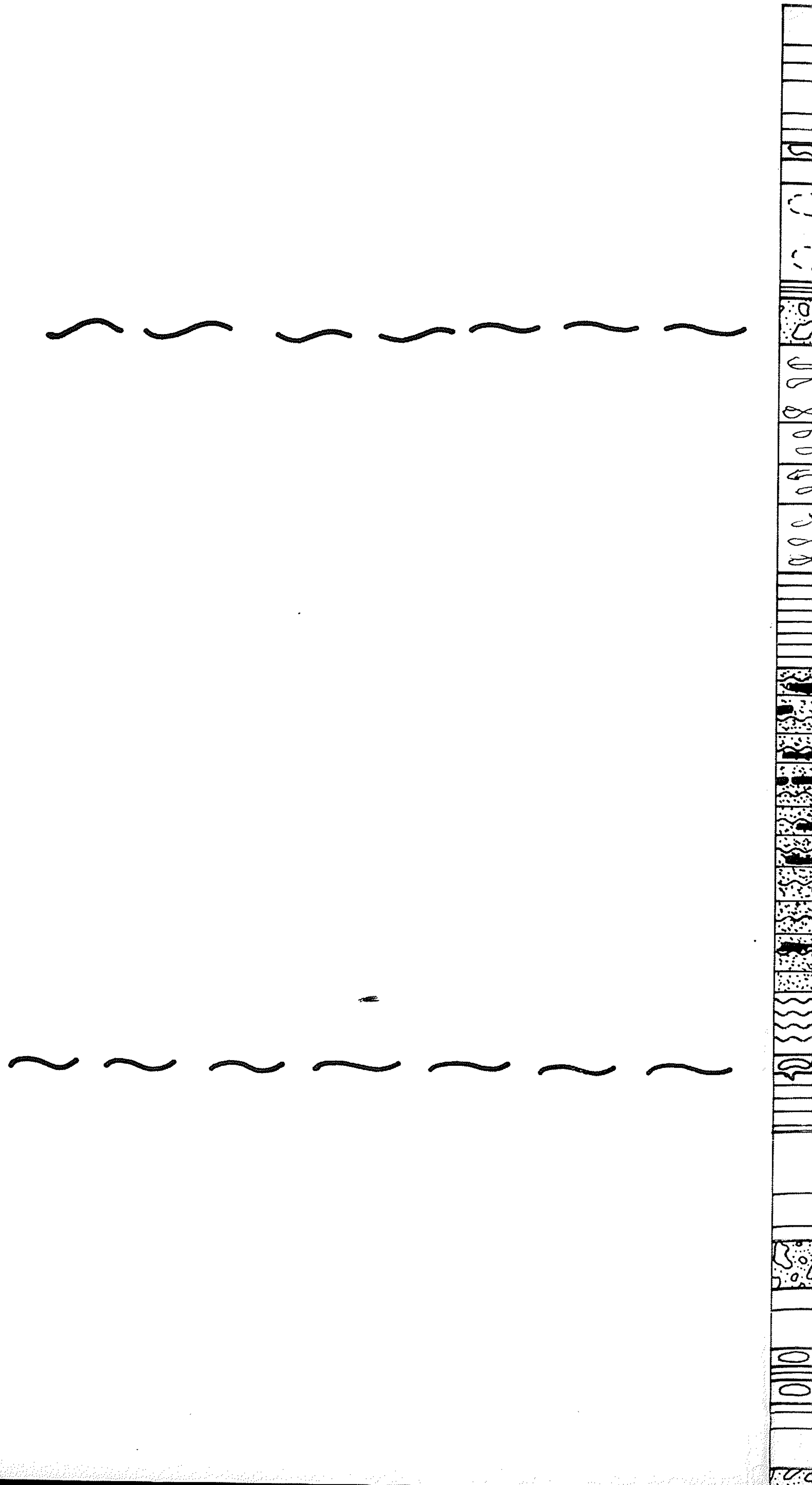
WILLIAMS MEMBER



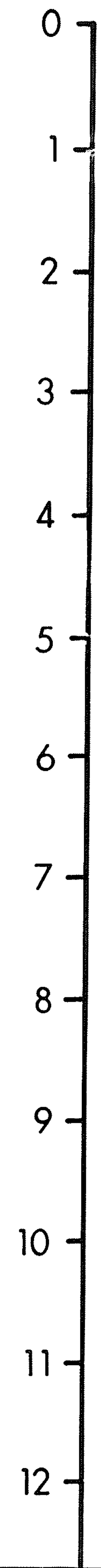
NY MOUNTAIN FORMATIONS



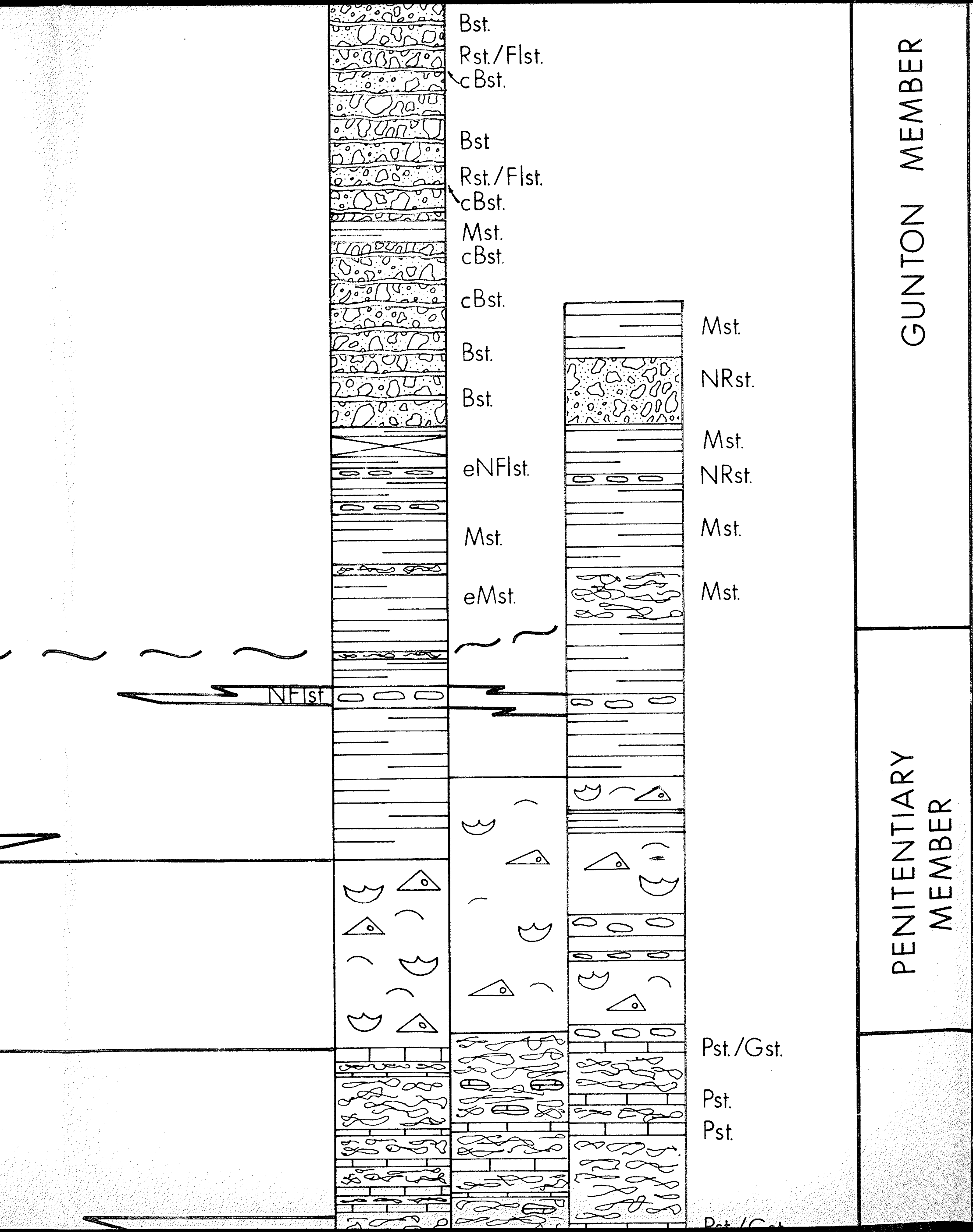
SS SECTION OF THE UPPER RED RIVER AND STONY M

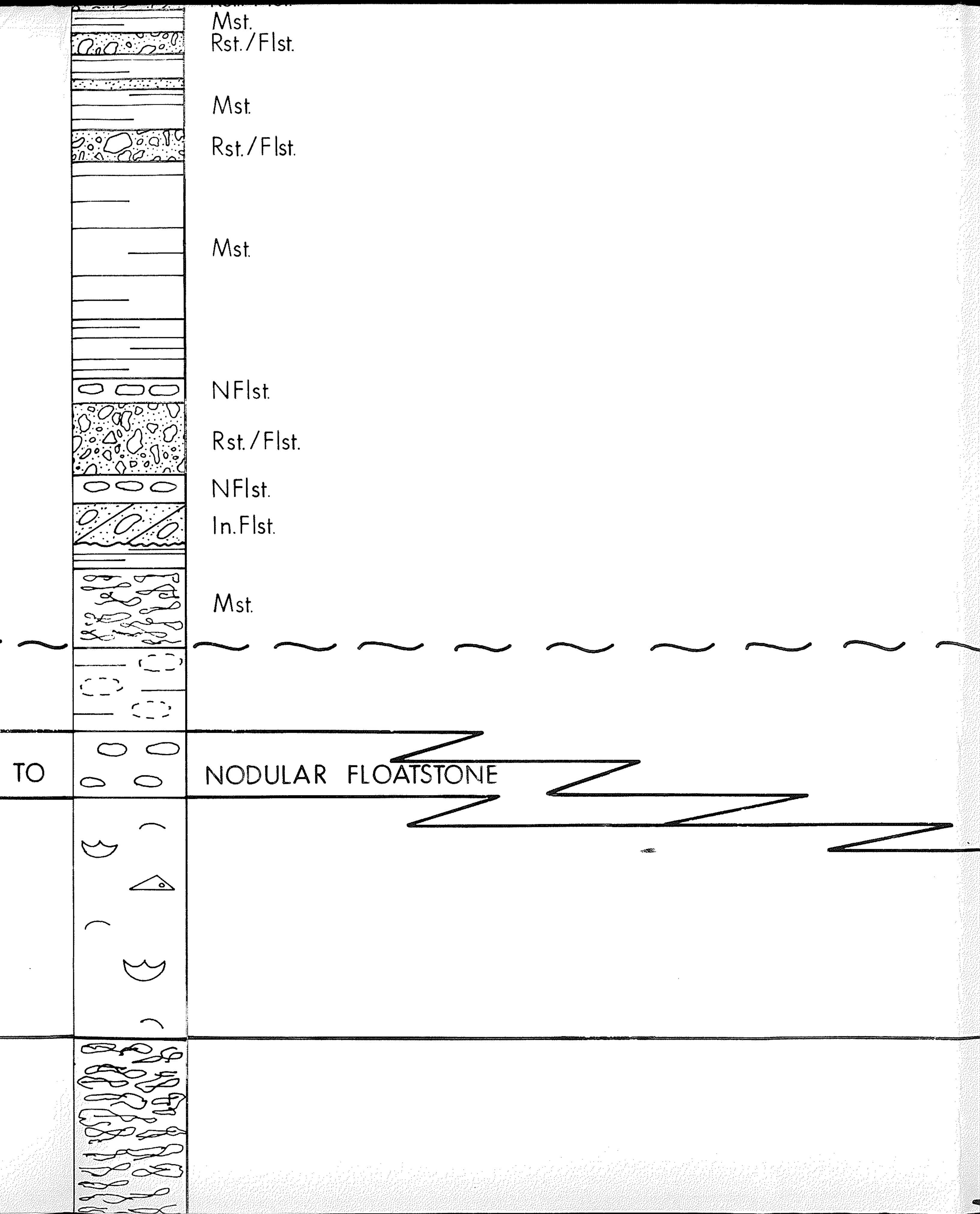


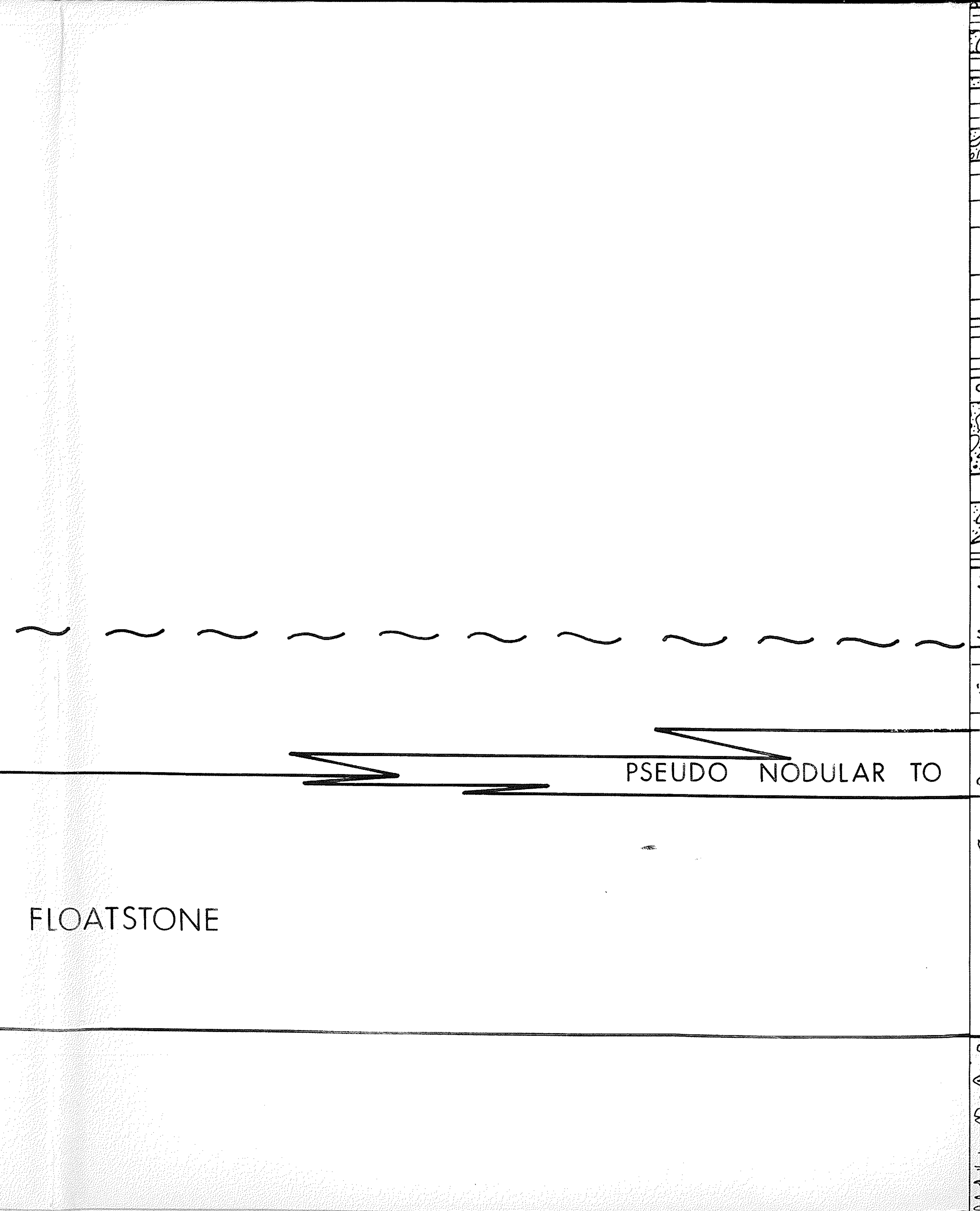
DIAGRAMMATIC CROSS

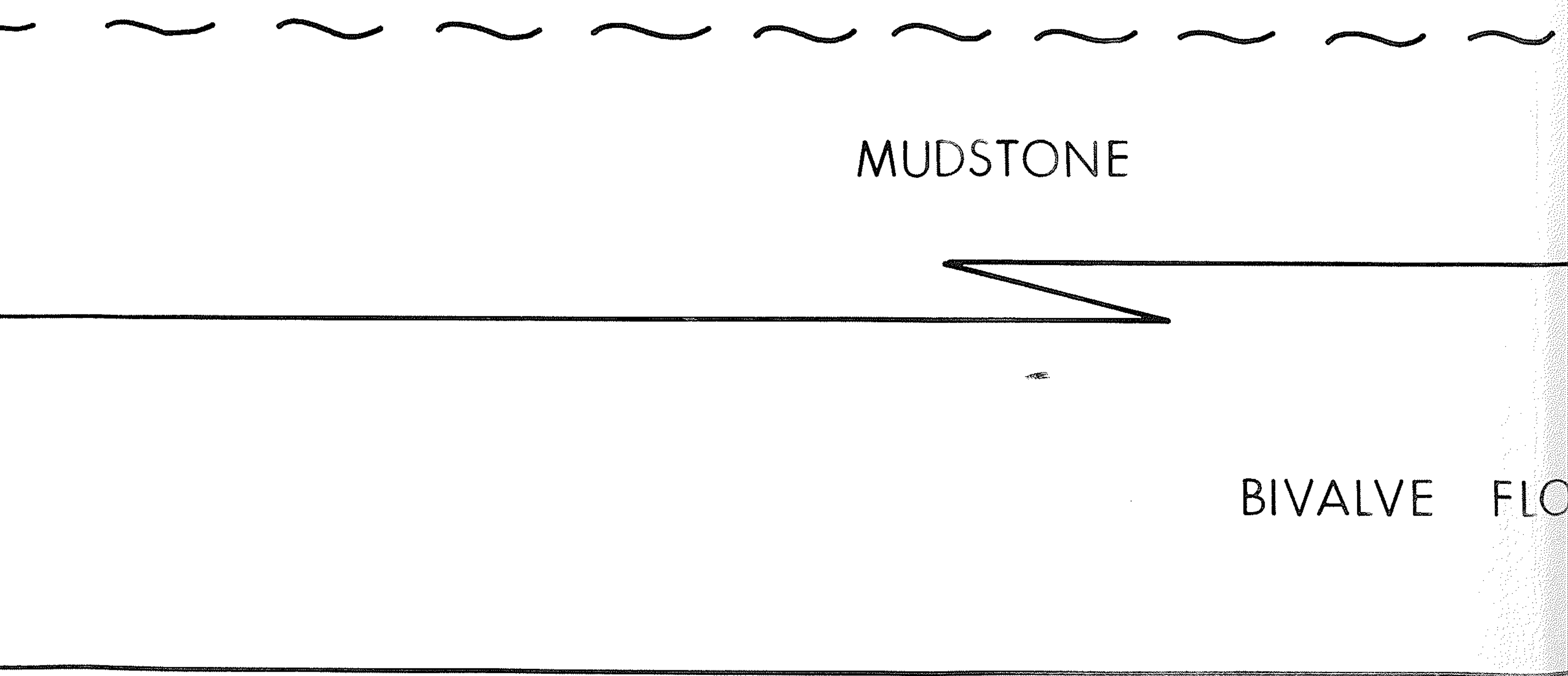

0
1
2
3
4
5
6
7
8
9
10
11
12

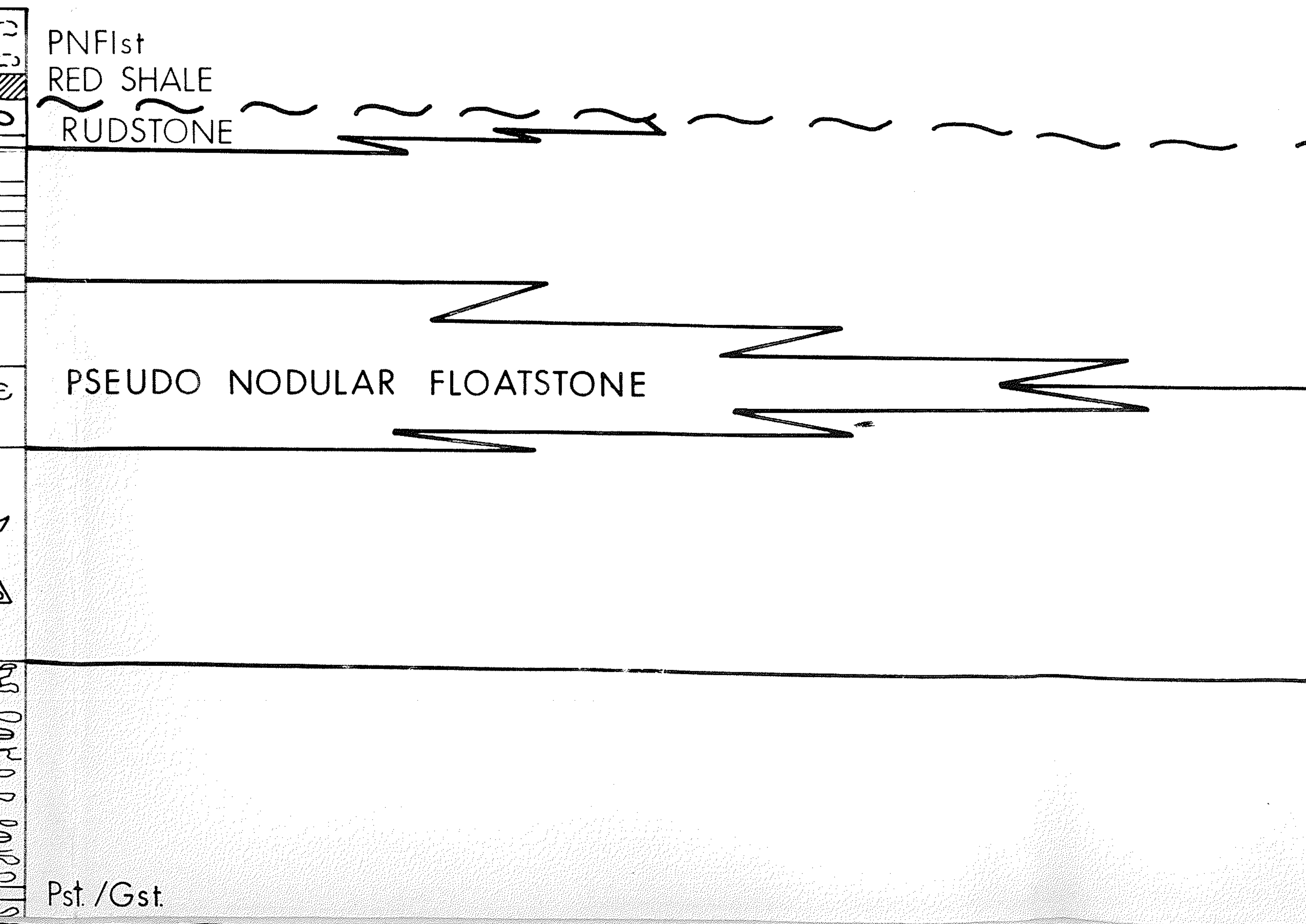
	PENITENTIARY MEMBER	GUNTON MEMBER
NTAIN FORMATION		

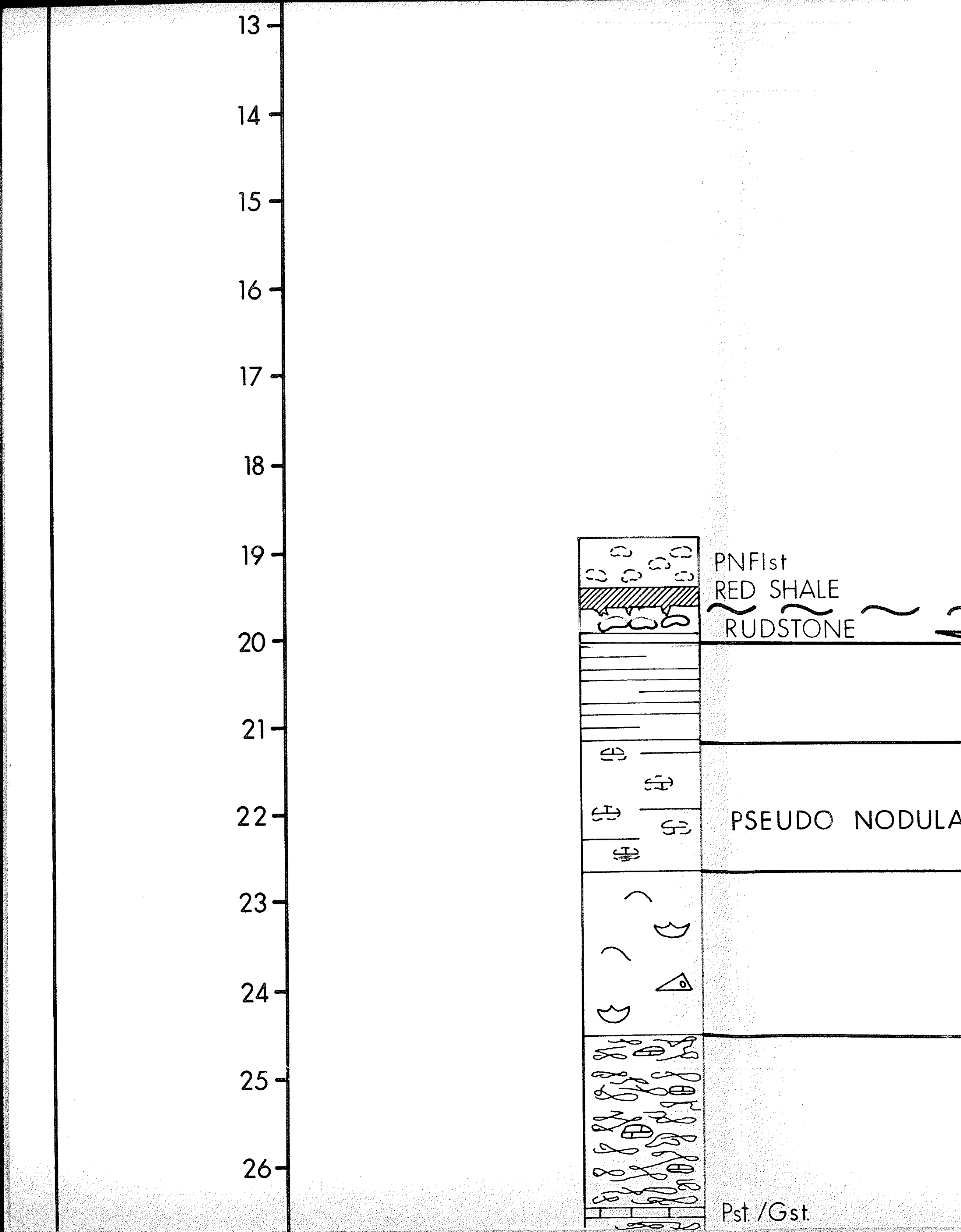

Bst.
Rst./Flst.
cBst.
Bst
Rst./Flst.
cBst.
Mst.
cBst.
cBst.
Bst.
Bst.
eNFlst.
Mst.
eMst.
NFlst
Mst.
NRst.
Mst.
NRst.
Mst.
Mst.
Pst./Gst.
Pst.
Pst.
GUNTON MEMBER
PENITENTIARY MEMBER


Mst.
Rst./Flst.
Mst.
Rst./Flst.
Mst.
NFlst.
Rst./Flst.
NFlst.
In.Flst.
Mst.
TO
NODULAR FLOATSTONE


PSEUDO NODULAR TO
FLOATSTONE


MUDSTONE
BIVALVE FLO

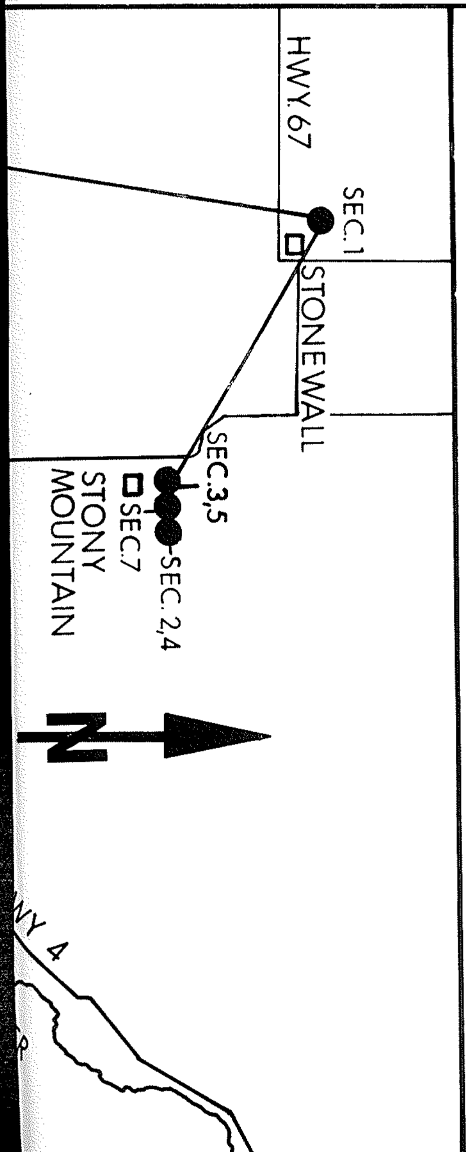

PNFlst
RED SHALE
RUDSTONE
PSEUDO NODULAR FLOATSTONE
Pst. /Gst.

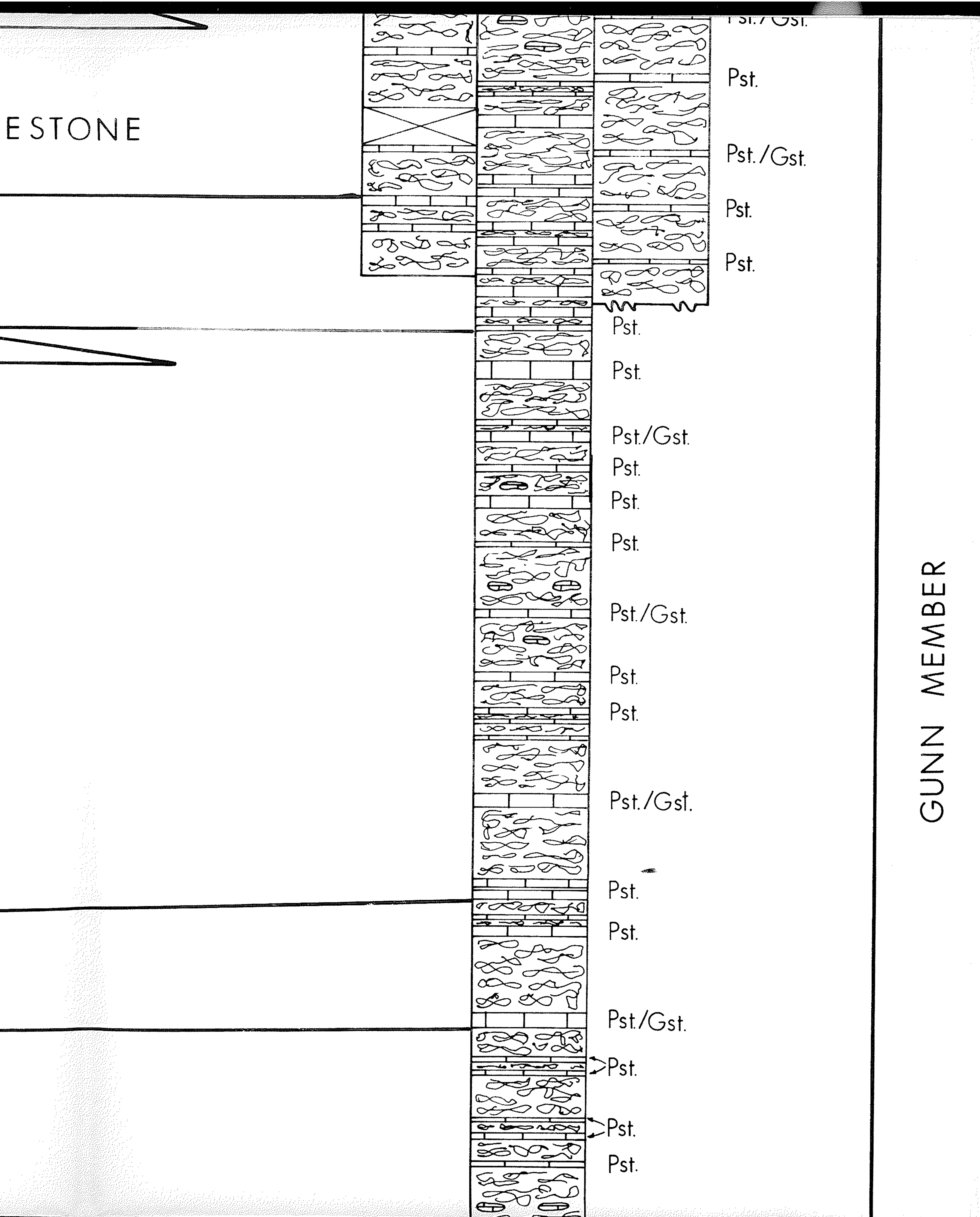


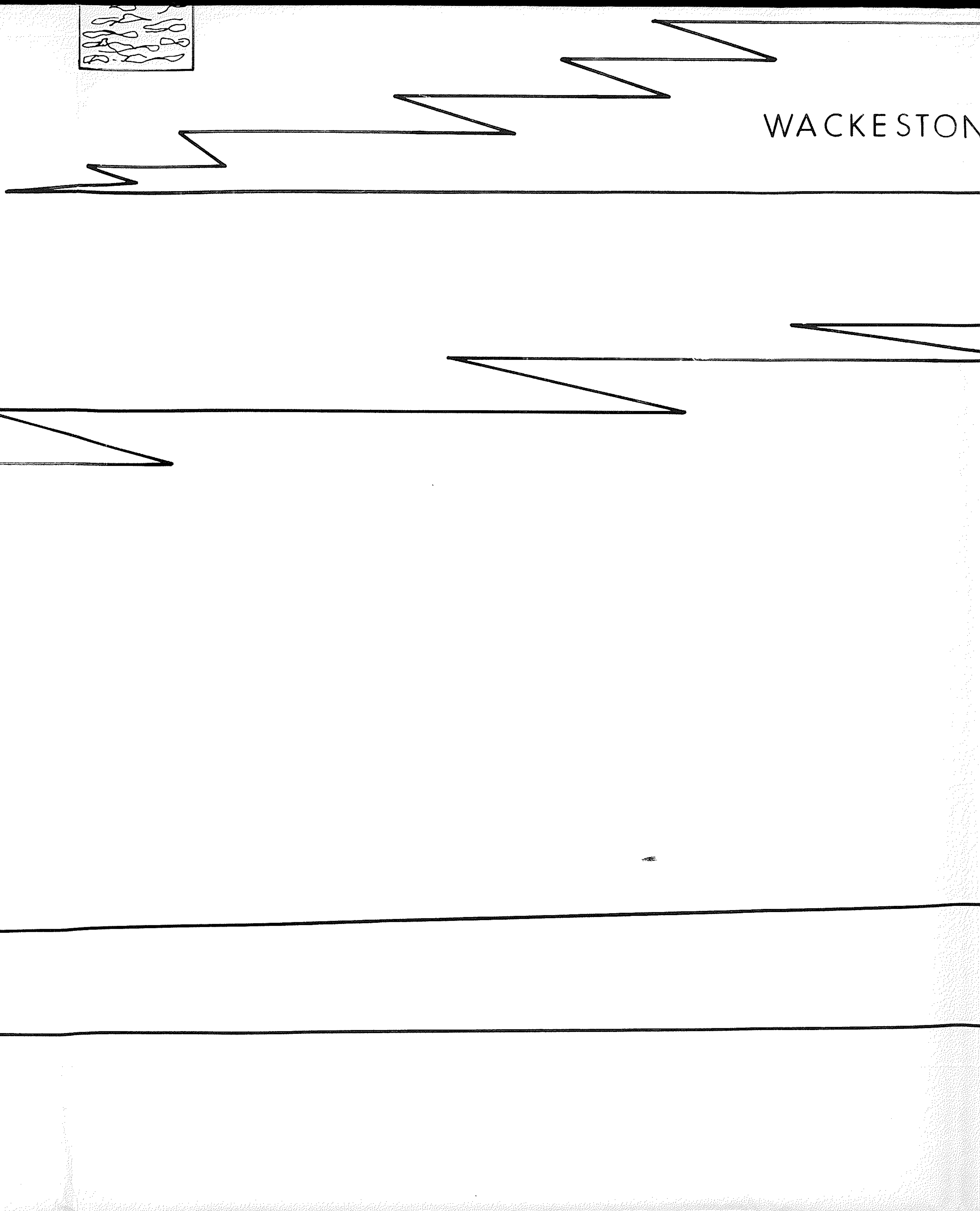
13
14
15
16
17
18
19
20
21
22
23
24
25
26
PNFlst
RED SHALE
RUDSTONE
PSEUDO NODULA
Pst. /Gst.

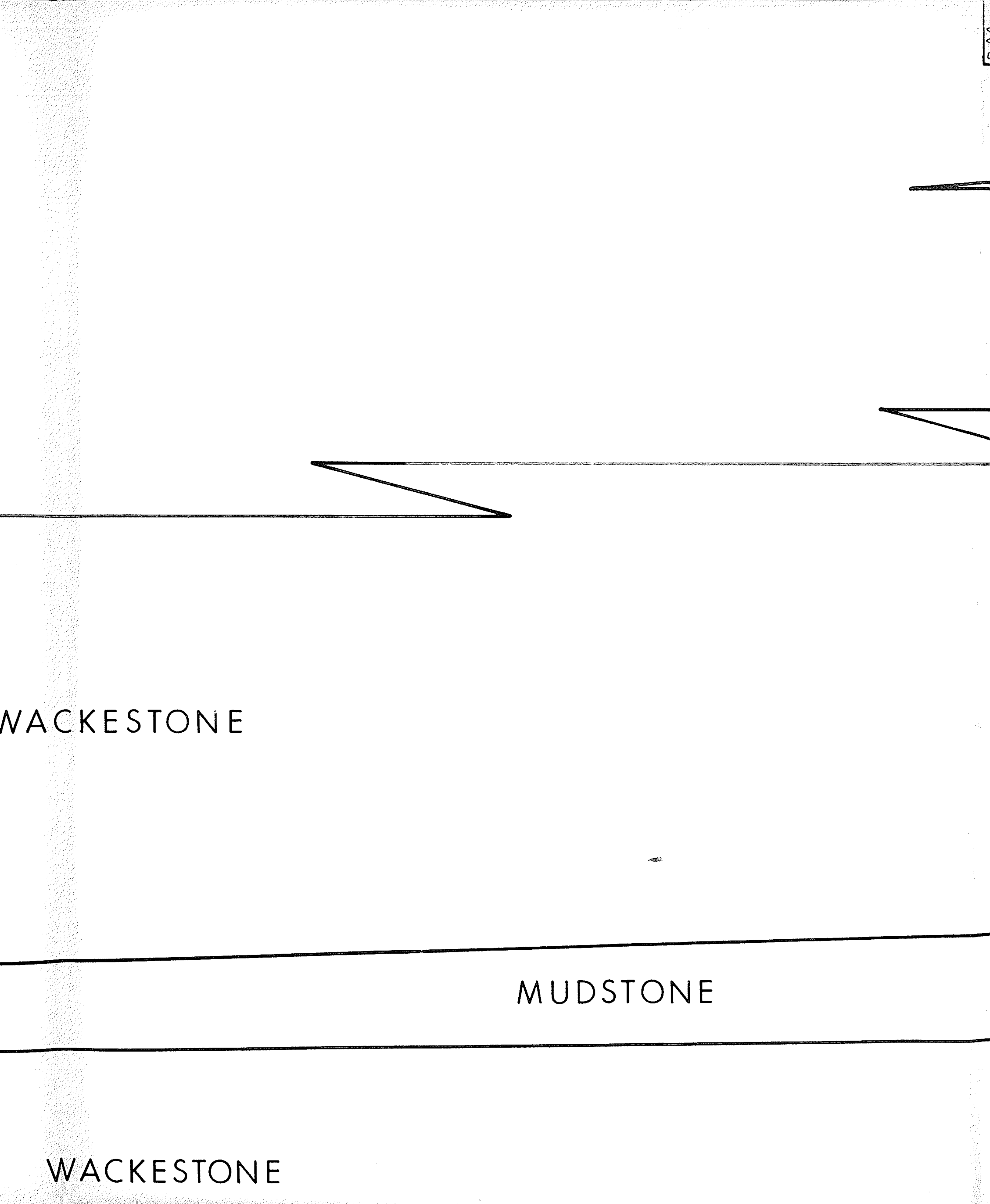
GUNN MEMBER

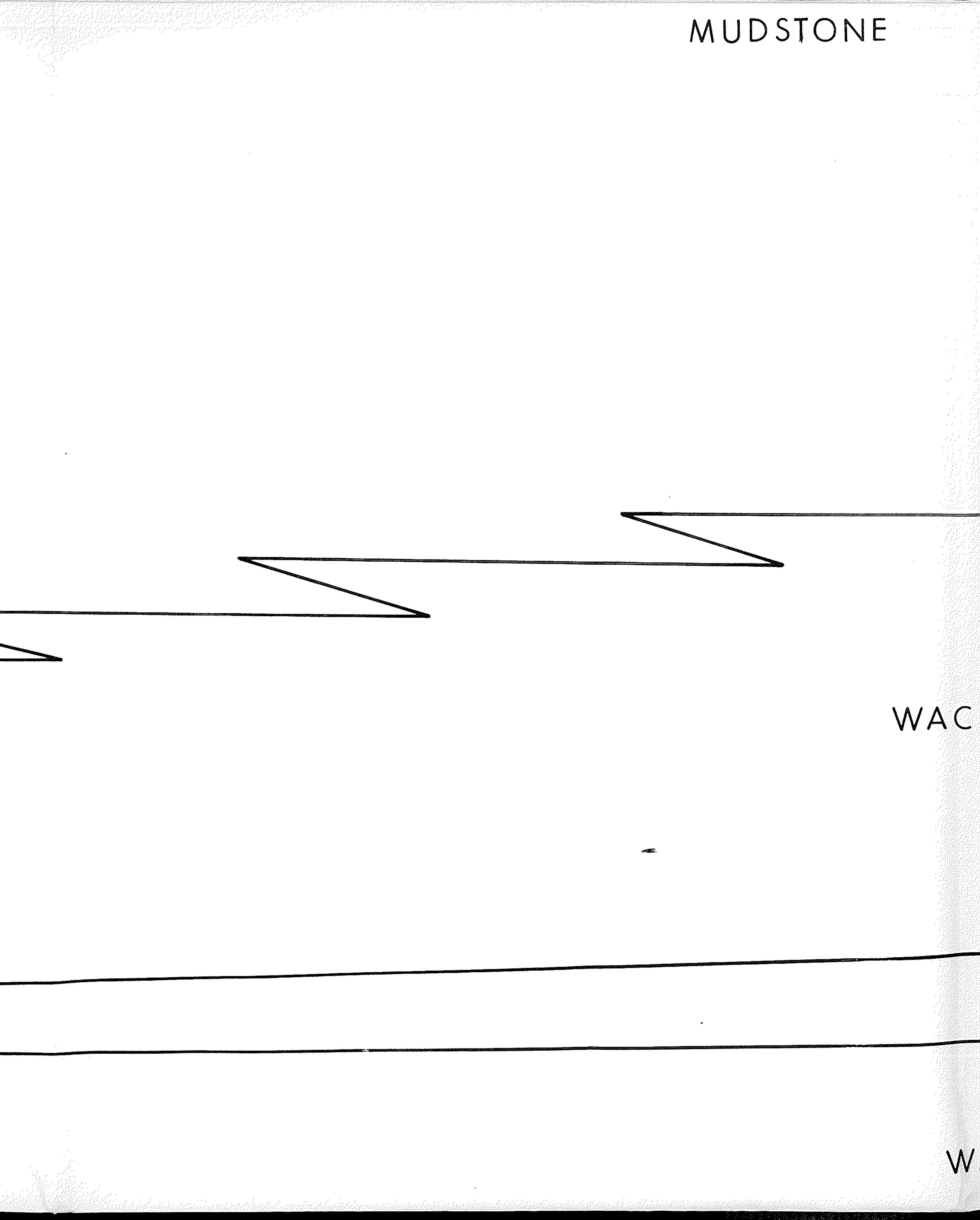
STONY MOUN




ESTONE
Pst.
Pst./Gst.
Pst.
Pst.
Pst.
Pst.
Pst./Gst.
Pst.
Pst.
Pst.
Pst./Gst.
Pst.
Pst.
Pst./Gst.
Pst.
Pst.
Pst./Gst.
Pst.
Pst.
Pst.
GUNN MEMBER


WACKESTON


WACKESTONE
MUDSTONE
WACKESTONE


MUDSTONE
WAC

Pst.

Pst.
Pst.

Pst./Gst.

Pst.
Pst.

Pst.
Pst.

Pst. /Gst.

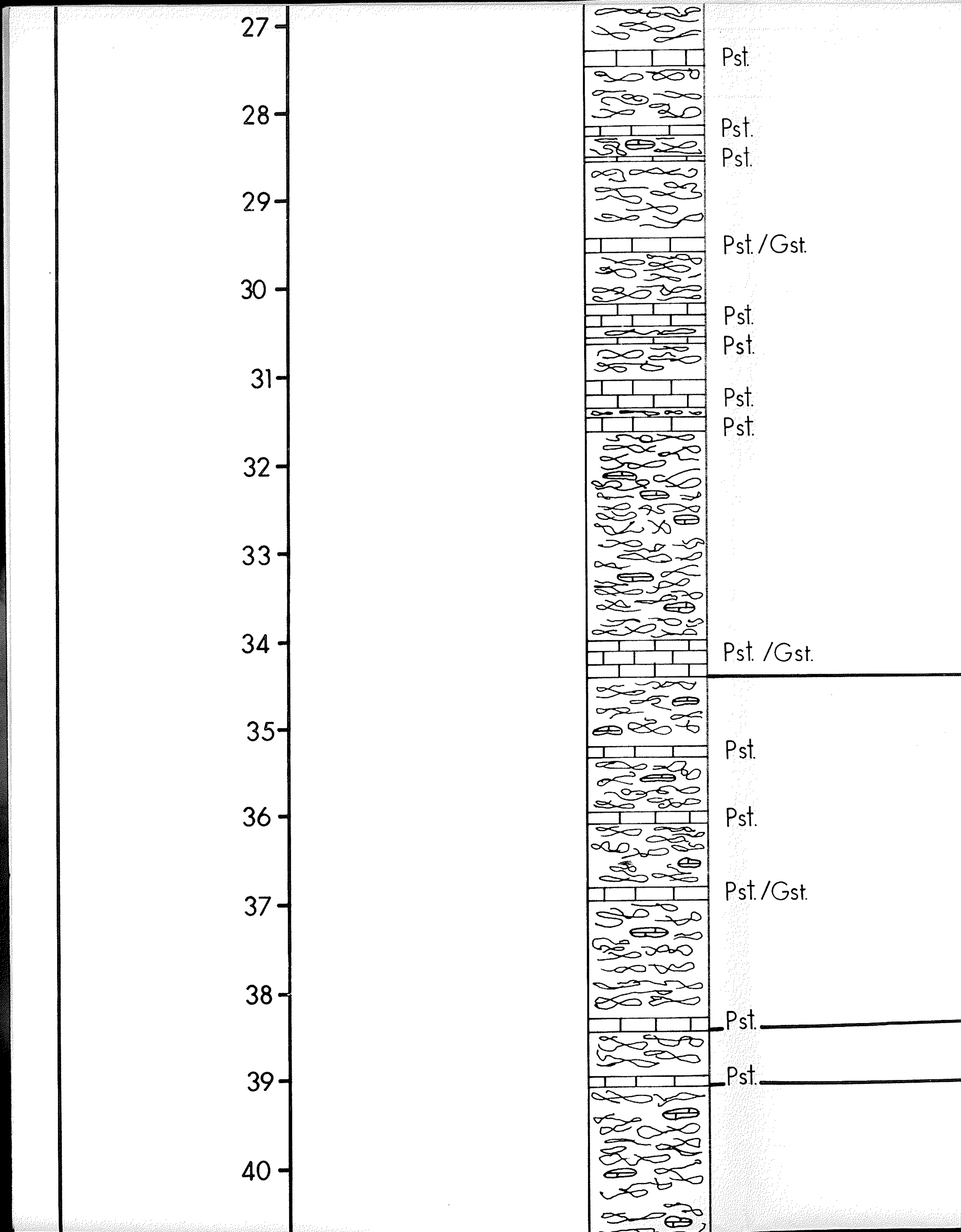
Pst.

Pst.

Pst./Gst.

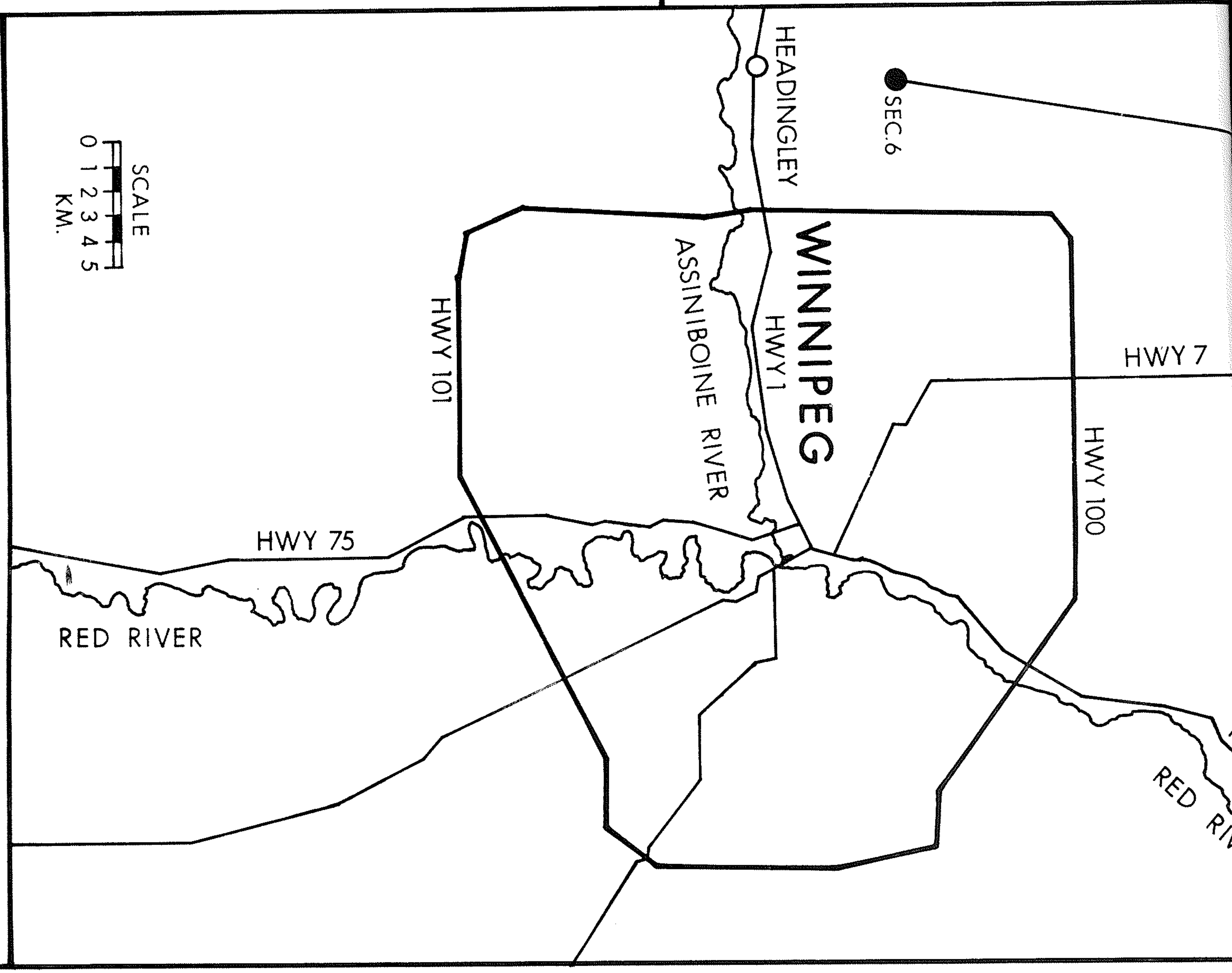
Pst.

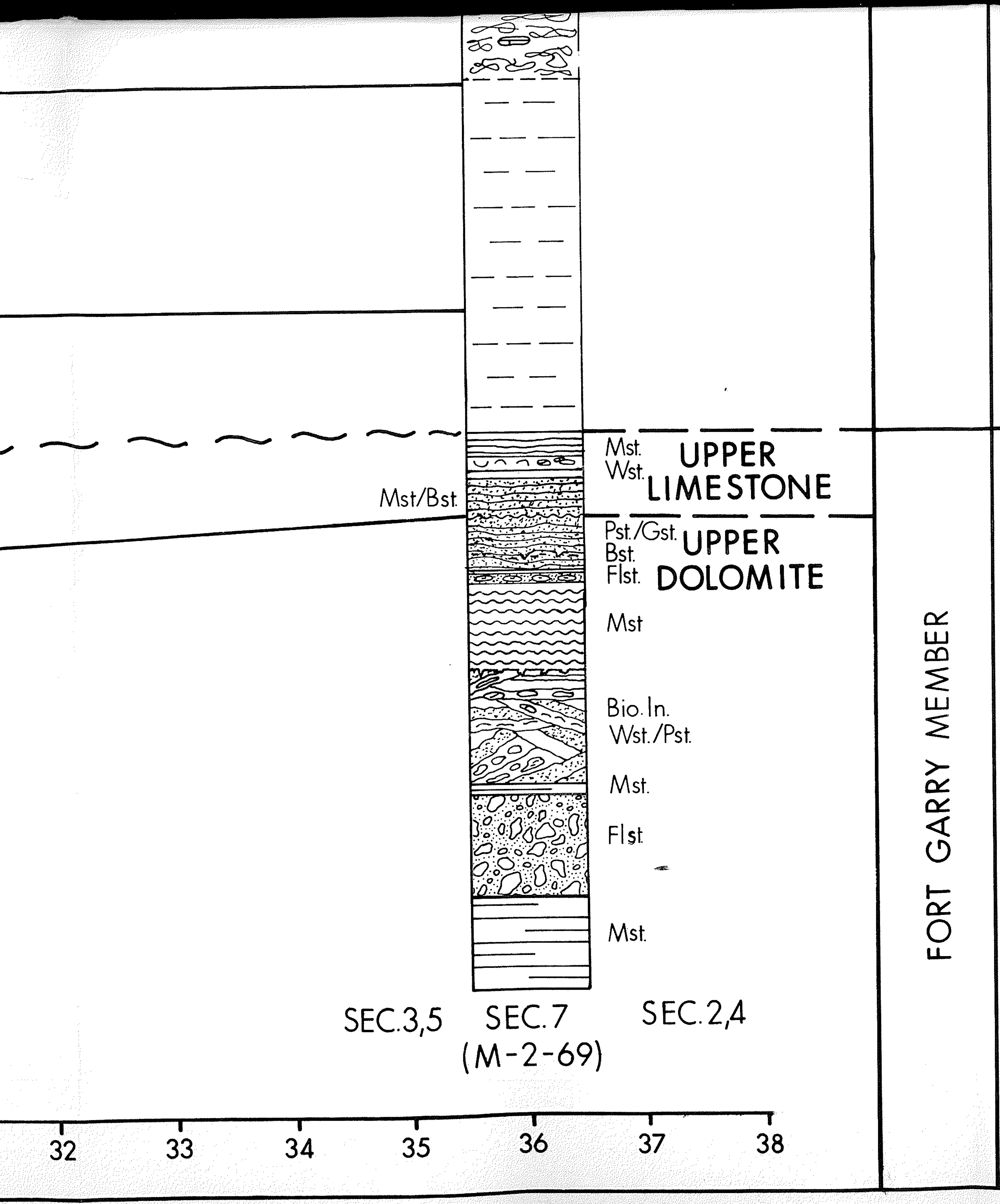
Pst.


27
Pst.
28
Pst.
Pst.
29
Pst. /Gst.
30
Pst.
Pst.
31
Pst.
Pst.
32
33
34
Pst. /Gst.
35
Pst.
36
Pst.
Pst. /Gst.
37
38
Pst.
39
Pst.
40

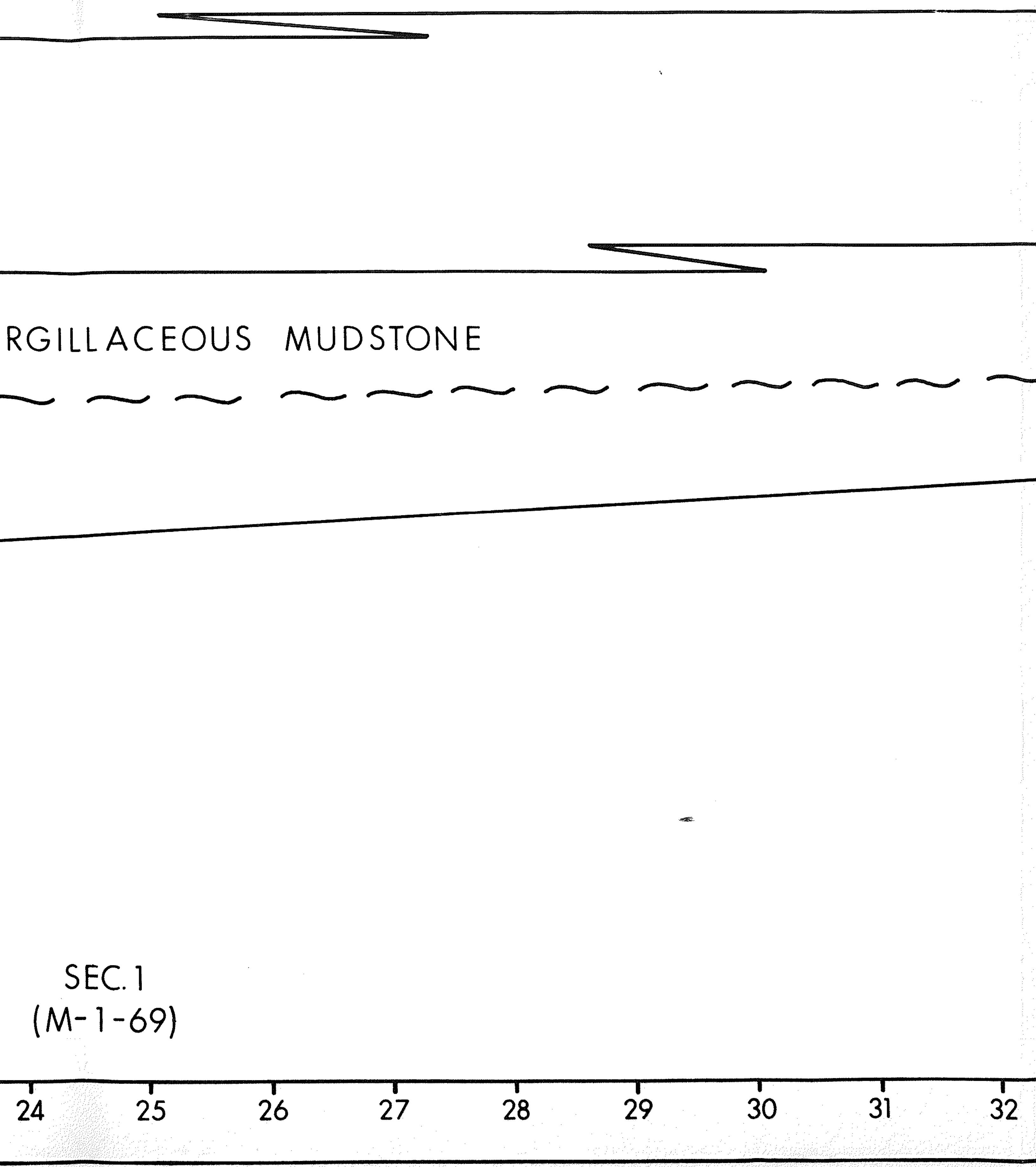
FORT GARRY MEMBER

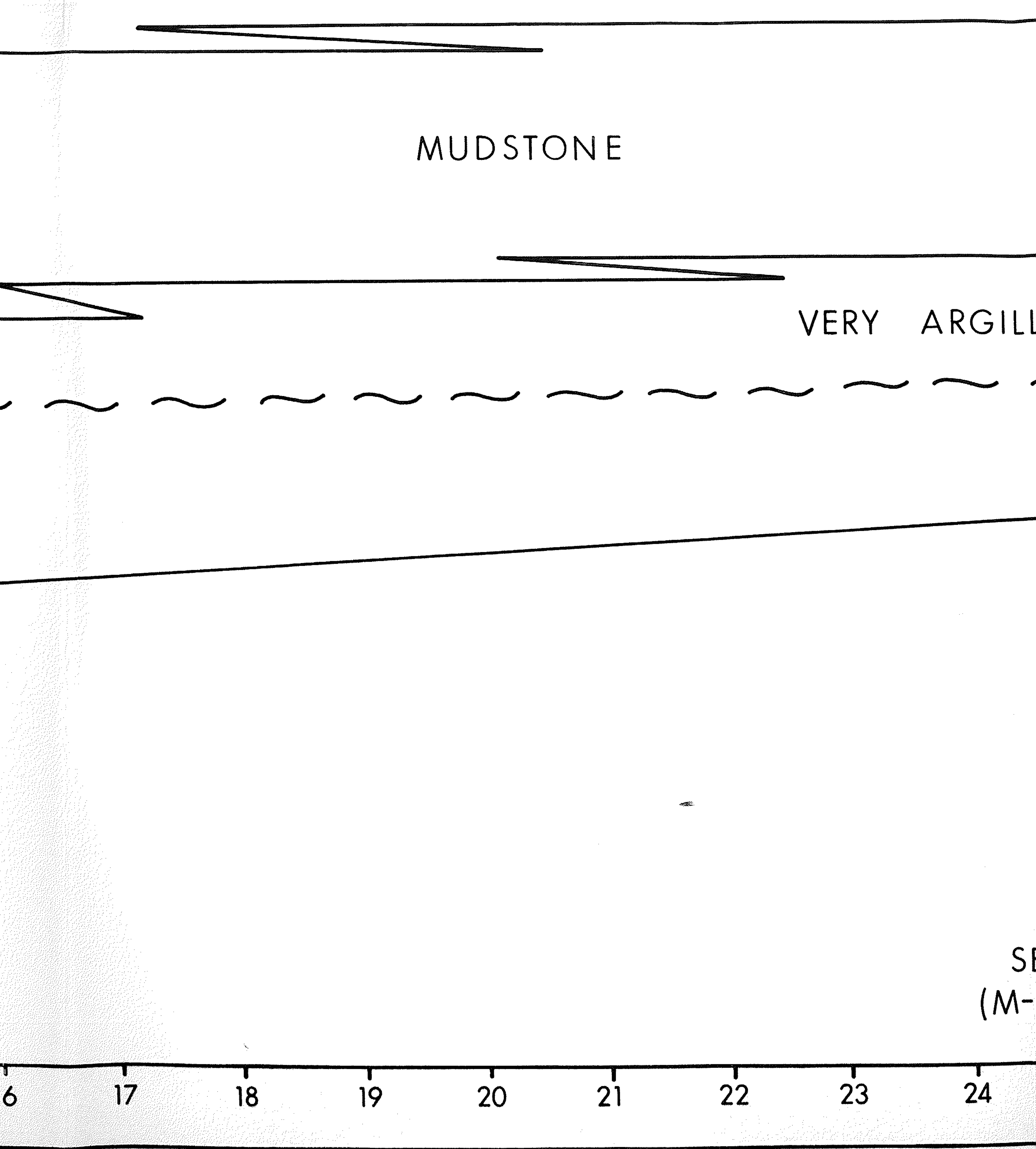
RED RIVER FORMATION

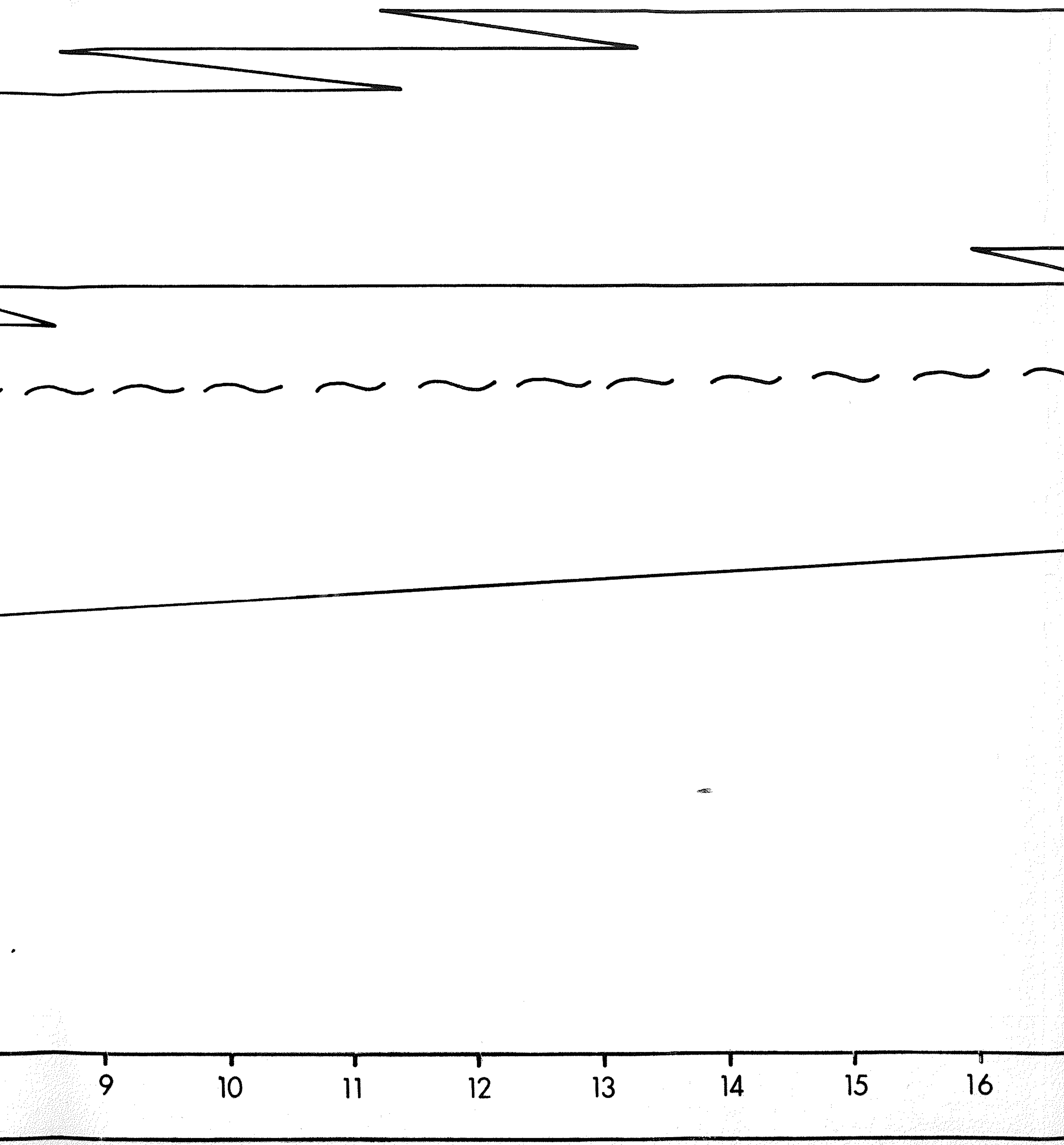


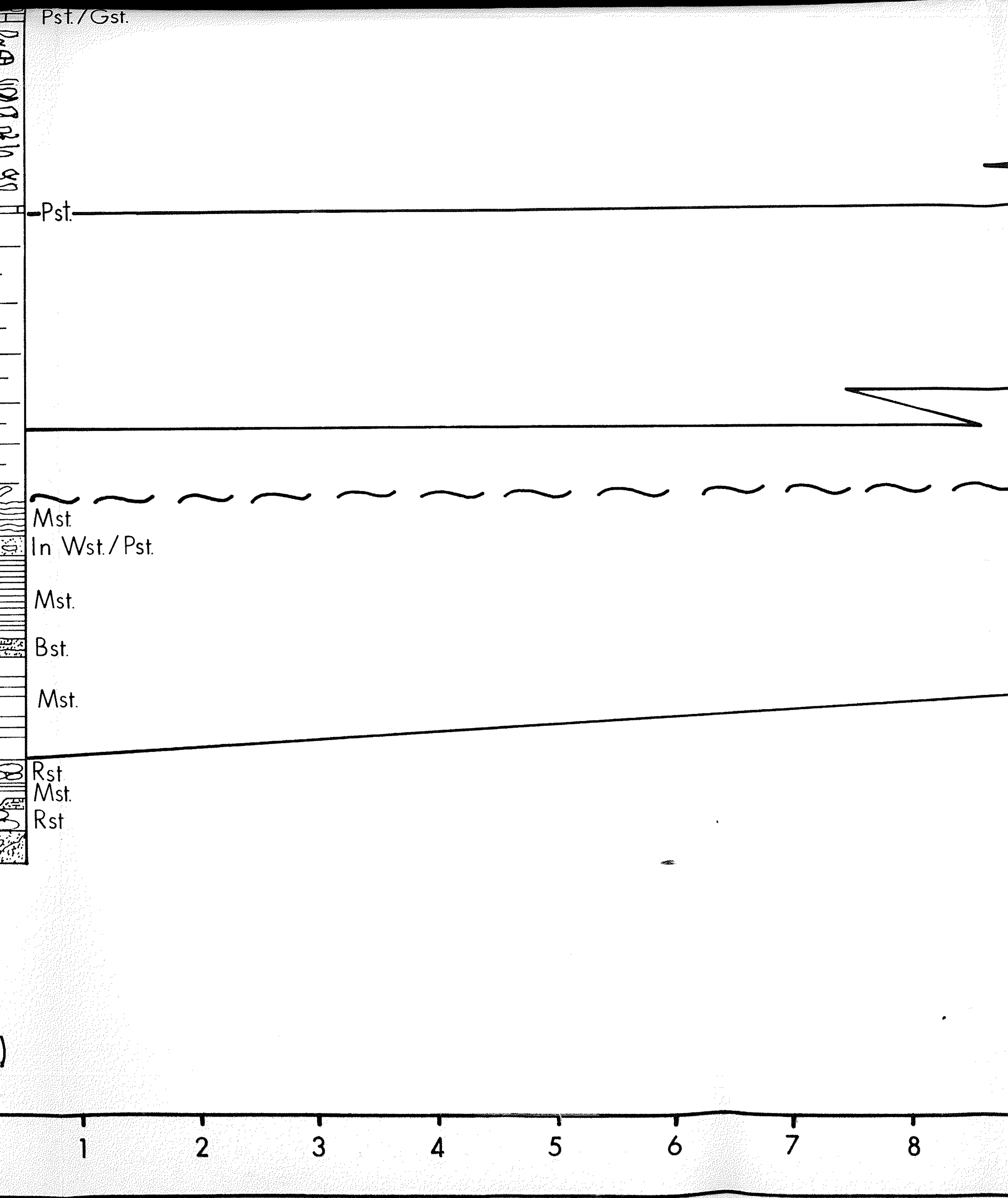


Mst.
Wst.
UPPER LIMESTONE
Mst/Bst.
Pst./Gst.
Bst.
Flst.
UPPER DOLOMITE
Mst
Bio. In.
Wst./Pst.
Mst.
Flst.
Mst.
SEC.3,5
SEC.7 (M-2-69)
SEC.2,4
32
33
34
35
36
37
38
FORT GARRY MEMBER

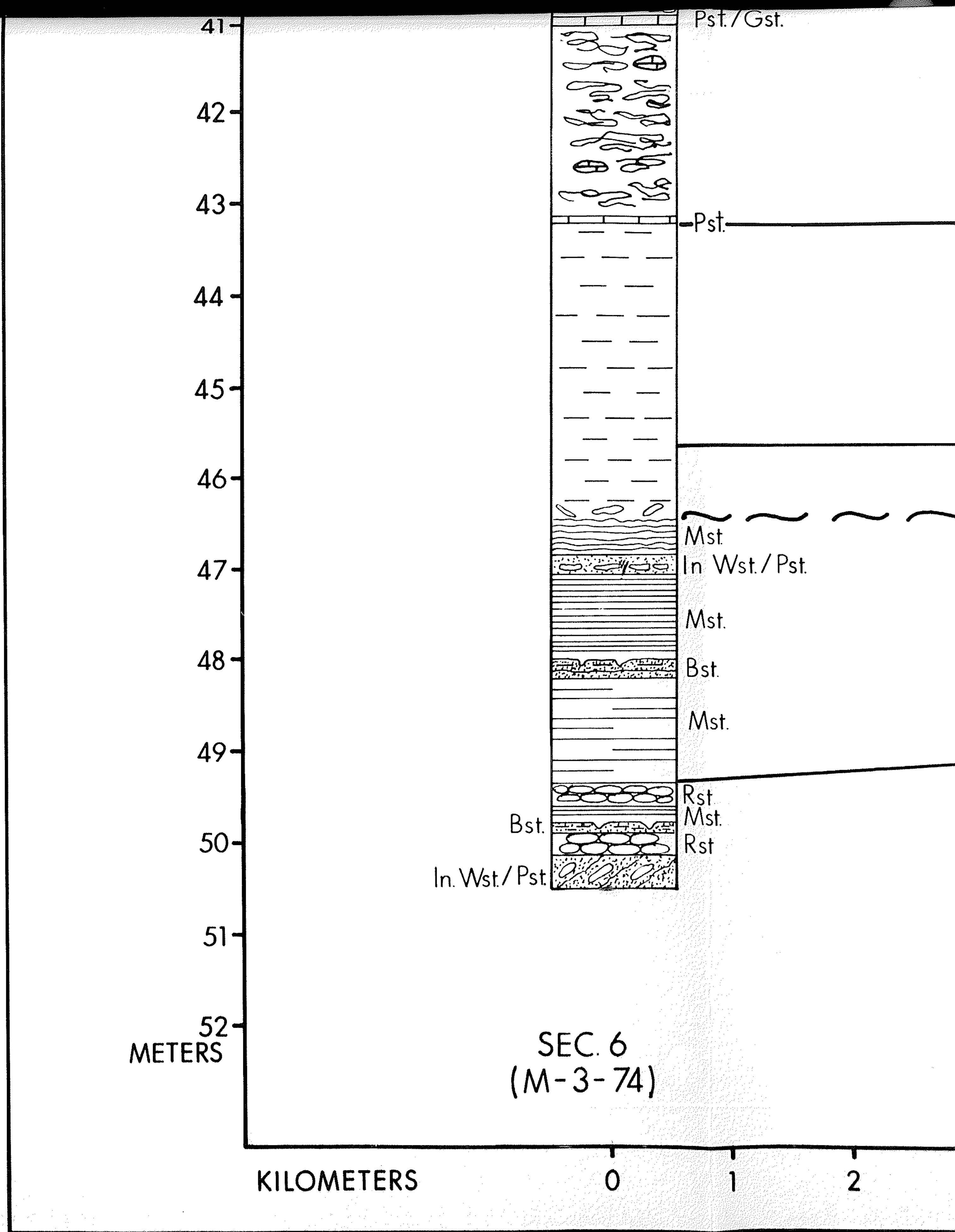

RGILLACEOUS MUDSTONE
SEC. 1
(M-1-69)
24
25
26
27
28
29
30
31
32


MUDSTONE
VERY ARGILL
6
17
18
19
20
21
22
23
24


9
10
11
12
13
14
15
16



Pst./Gst.
Pst.
Mst.
In Wst./Pst.
Mst.
Bst.
Mst.
Rst
Mst.
Rst
1
2
3
4
5
6
7
8



41
42
43
44
45
46
47
48
49
50
51
52
METERS
Pst./Gst.
Pst.
Mst.
In Wst./Pst.
Mst.
Bst.
Mst.
Rst.
Mst.
Rst
Bst.
In. Wst./Pst.
SEC. 6
(M-3-74)
KILOMETERS
0
1
2