A LITHOLOGIC STUDY OF THE STONY MOUNTAIN AND STONEWALL FORMATIONS IN SOUTHERN MANITOBA

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by
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ABSTRACT

The outcrop section of the Upper Ordovician Stony Mountain formation and the Lower Silurian (?) Stonewall formation shows a mid-cratonic carbonate succession, into which terrigenous sediment was introduced in widely varying amounts.

The bioclastic limestones of the lowest member were formed in an open sea, in which the sedentary fauna was scattered over the bottom and into which there were periodic introductions of abundant, fine terrigenous sediment. The overlying carbonate unit was deposited in slightly deeper waters and received a more continuous supply of this sediment. The third member was deposited in a locally semi-evaporitic, inter-shoal area which gradually changed to more open sea conditions, allowing the growth of biostromal coralline reefs. These conditions were terminated by an abundant and continuous influx of coarse and fine terrigenous sediment. The unit containing this sediment is herein named the Williams member of the Stony Mountain formation.

The overlying Stonewall formation was entirely formed in a reef environment. Infrequent additions of abundant, fine terrigenous sediment killed the reef organisms and caused changes in reef locations.

The change from solitary coralline colonies to full, though small, biohermal coralline reefs is due to the first appearance of encrusting, layered calcareous algae.

The terrigenous sediment was supplied from three sources. One was a group of islands of Precambrian rock located just to the north, one the landmass to the south-east that also supplied the Maquoketa and Queenston formations, and one, a landmass to the east which produced the Lower Silurian (?) sandstones of the James Bay subsurface.

CHAPTER ONE

INTRODUCTION

The results of a detailed lithologic study of the Stony Mountain and Stonewall formations, as found in a belt of quarries and outcrops immediately north of the city of Winnipeg, are presented in this thesis. The thesis deals primarily with petrographic and sedimentational questions but also includes discussions on the purely lithologic aspects of stratigraphic correlation and interpretation.

Much paleontologic information has been published concerning these formations, especially at their surface exposures, but only a small amount of lithologic description and interpretation is available and this deals almost entirely with the subsurface.

The present work was undertaken to help achieve a better balance. It is believed that the information set forth will give a much better understanding of the paleoecology of the Stony Mountain fauna and of the other faunas and faunal variations occurring in the two formations. Without such ecologic reconstruction the fine paleontologic work cannot lead to entirely accurate correlations. It is also hoped that the information presented will be of value in making correlations between the outcrop and subsurface sections, especially as the surface terminology, albeit modified, is used throughout. This latter purpose is aided by the examination given to those lithologic characteristics which can be studied from well cores and even by examination of well cuttings. Throughout the work attempts are made to shed light on some of the various aspects of carbonate deposition and diagenesis. In this, the terrigenous sediment is of much use, especially in the predominant dolomites, aside from the information it gives regarding land masses of the time.

Following a review of previous investigations at the end of this chapter, the second chapter gives information on the sources of the basic material used, the experimental procedures followed and the various ways in which the resulting data were analyzed.

The next five chapters deal in a detailed manner with the Gunn, Penitentiary and Gunton members, and a new member - the Williams member, Stony Mountain formation and with the Stonewall formation respectively.

The eighth chapter, entitled, "Sources of Terrigenous Sediment", is an attempt to uncover the factors which lead to the differences in amount, size and composition which were found in the insoluble residues of the five aforementioned units.

The ninth and final chapter contains a brief summary of the whole with those conclusions that had not been previously stated.

The writer wishes to thank his advisor, Professor E. I. Leith, for his assistance and advice in every phase of the work of this thesis. He also wishes to thank the Shell Oil Company of Canada, Ltd. for their financial assistance toward the field work, and the Winnipeg Supply and Fuel Company, Ltd. for making well cores available. To his wife, Glorian, he extends thanks for her assistance and encouragement.

DEVELOPMENT OF THE NOMENCLATURE

Although several workers reported on these rocks in the nineteenth century, among them Panton (1884 in G. M. Dawson, 1886, p.89), Dawson (1886, p.89) and Tyrrell (1892, p.204E), it was not until Dowling's work that the present nomenclature began to develop, as shown in Figure 1. In 1900 Dowling proposed the name Stony Mountain formation for those rocks at Stony Mountain that occurred below the "Silurian" and above the "Trenton" (the present Red River formation). The first measured sections of this formation and of the "Silurian" at Stonewall were given by MacLean (1913, pp.71-74) in 1913. The next year Kindle (1914, p.249) named the rocks at Stonewall, as well as all the rocks to the west below the Devonian, the Stonewall limestone.

In 1943 Okulitch (1943, p.60) carried out a detailed paleontologic study of the Stony Mountain formation in the belt of quarries and outcrops near Winnipeg and subdivided the formation into four members. In ascending order they were the Stony Mountain Shale member, the Penitentiary member, the Gunton member and the Birse member. Mainly on paleontologic grounds Okulitch placed the lower five and one-half feet of Kindle's type section at Stonewall in the Birse member. In 1951 Baillie (1951, p.15) redefined the Stonewall formation as only the lowest unit of his new Interlake group, and extended the formation down to include the red arenaceous and argillaceous dolomites underlying Kindle's original unit. However, in 1952 after a core had been cut at Stonewall down to the Penitentiary member, Baillie (1952, p. 21) redefined the Stonewall-Stony Mountain contact and placed it at a thin, yellow, arenaceous band at the top of the red argillaceous beds. This is exactly the same position used in the present study. Baillie (1952, p.21) also altered the subdivisions of the Stony Mountain formation and included the type Birse member of Okulitch in the Gunton member apparently on grounds of lithologic similarity. This will be discussed in Chapter 5.

The Silurian-Ordovician boundary was moved to the top of Baillie's Stonewall formation by Stearn (1956, p.1478) in 1953. On purely paleontologic grounds, he also removed

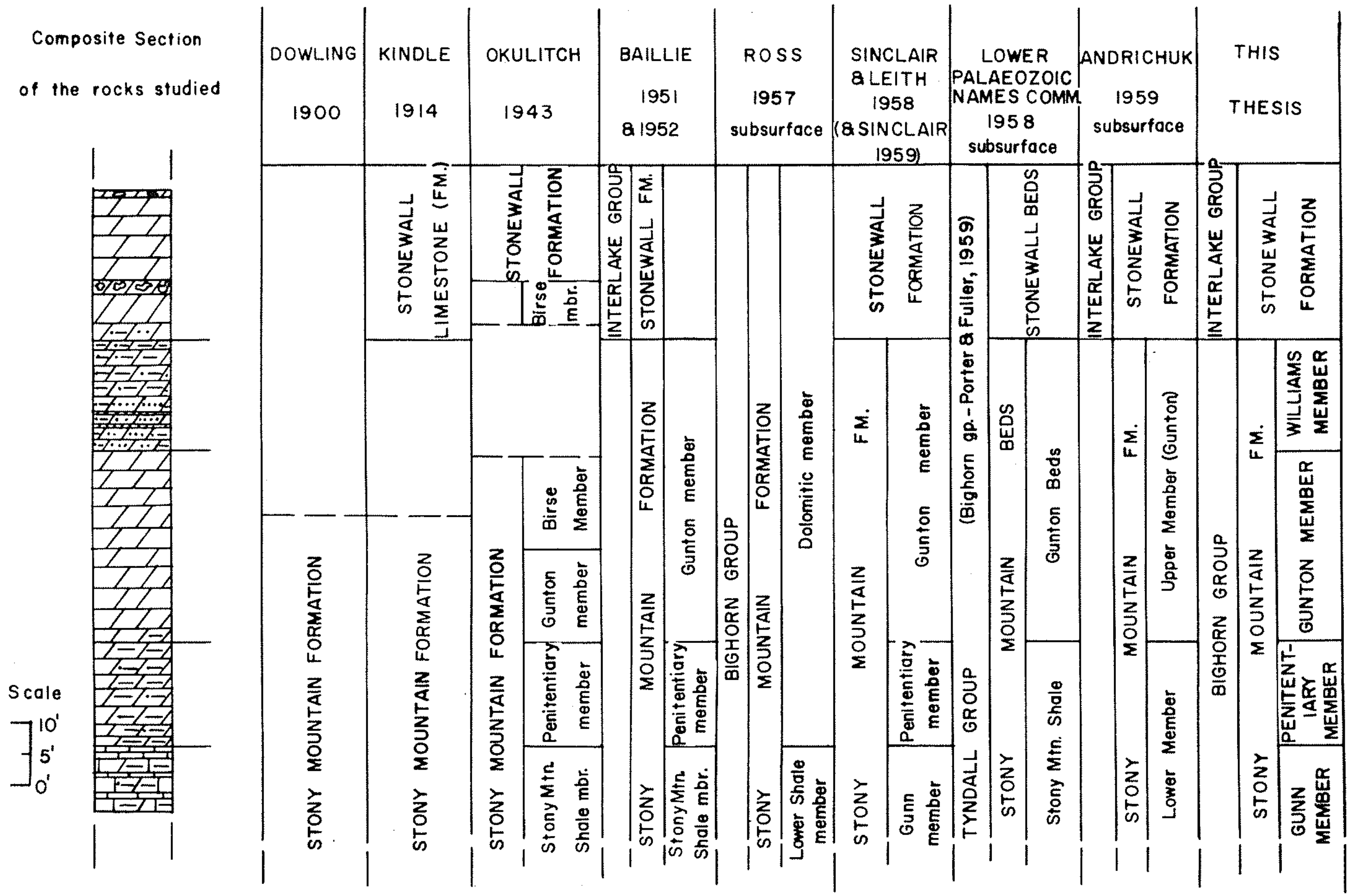


FIGURE I

DEVELOPMENT OF THE NOMENCLATURE

the Stonewall formation from the Interlake group.

Sinclair and Leith (1958, p.244), in order to avoid the confusion of having the same name for both the formation and a member of it, proposed that the Stony Mountain Shale member of Okulitch be called the Gunn member.

The first important work in print dealing with the subsurface nomenclature of these rocks was published by Ross (1957, p.447M) in 1957. As he was dealing primarily with the paleontology he did not differentiate between the two formations but regarded the Stonewall as a portion of the "dolomitic member" of the Stony Mountain along with the Gunton and Penitentiary members. He then grouped this expanded Stony Mountain formation with the Red River formation to form the new Bighorn group.

In 1959 Porter and Fuller (1959, p.130), also dealing with the subsurface, while keeping the original Bighorn group, reinstated the Stonewall formation and divided the Stony Mountain formation at the base of the Gunton member, extending the name Stony Mountain Shale to include both the Penitentiary and Stony Mountain Shale members of Okulitch. The Lower Palaeozoic Names and Correlations Committee of the Saskatchewan Geological Society followed the nomenclature of Porter and Fuller, with the exception of substituting "Tyndall group" for the Bighorn group of Ross.

Andrichuk (1959, p.2371) avoided redefinitions by dividing the Stony Mountain formation into a Lower Member and an Upper Member (Gunton). He also reinstated the Stonewall formation as the lowest division of the Interlake group, for, "on a lithological basis, the main sedimentary break in the subsurface occurs at the base of the Stonewall formation",(Andrichuk, 1959, p.2371).

In this thesis the name Bighorn group is used but is restricted so as not to apply to the Stonewall formation. Also, the name "Gunton member" is restricted to only the lower part of Baillie's Gunton member. The upper part is named the Williams member. The reasons for introducing this new unit are discussed in Chapter 6.

CHAPTER TWO

SOURCES OF BASIC MATERIAL

The localities which supplied the basic materials for this thesis are found in a long, narrow area stretching north from the western suburbs of the city of Winnipeg almost to the town of Teulon, in the province of Manitoba. The measured sections, detailed macroscopic field descriptions and specimens of the rocks for analysis and reference were obtained from quarries and gravel pits, from a very few natural outcrops, from constructional excavations in the western suburbs of the city of Winnipeg and from cores cut by the Winnipeg Supply & Fuel Co. Ltd. at their Stonewall quarries.

METHODS OF LITHOLOGIC ANALYSIS

The samples taken were each designated according to the collecting locality, the lithologic unit from which they came and their position above the base of the section at that locality. The List of Localities is given at the beginning of Appendix A, with the southernmost locality numbered 1. The name of the unit from which the sample came is shown by one of the following abbreviations: Gu. for the Gunn member, P. for the Penitentiary member, Gt. for the Gunton member, W. for the Williams member and S. for the Stonewall formation.

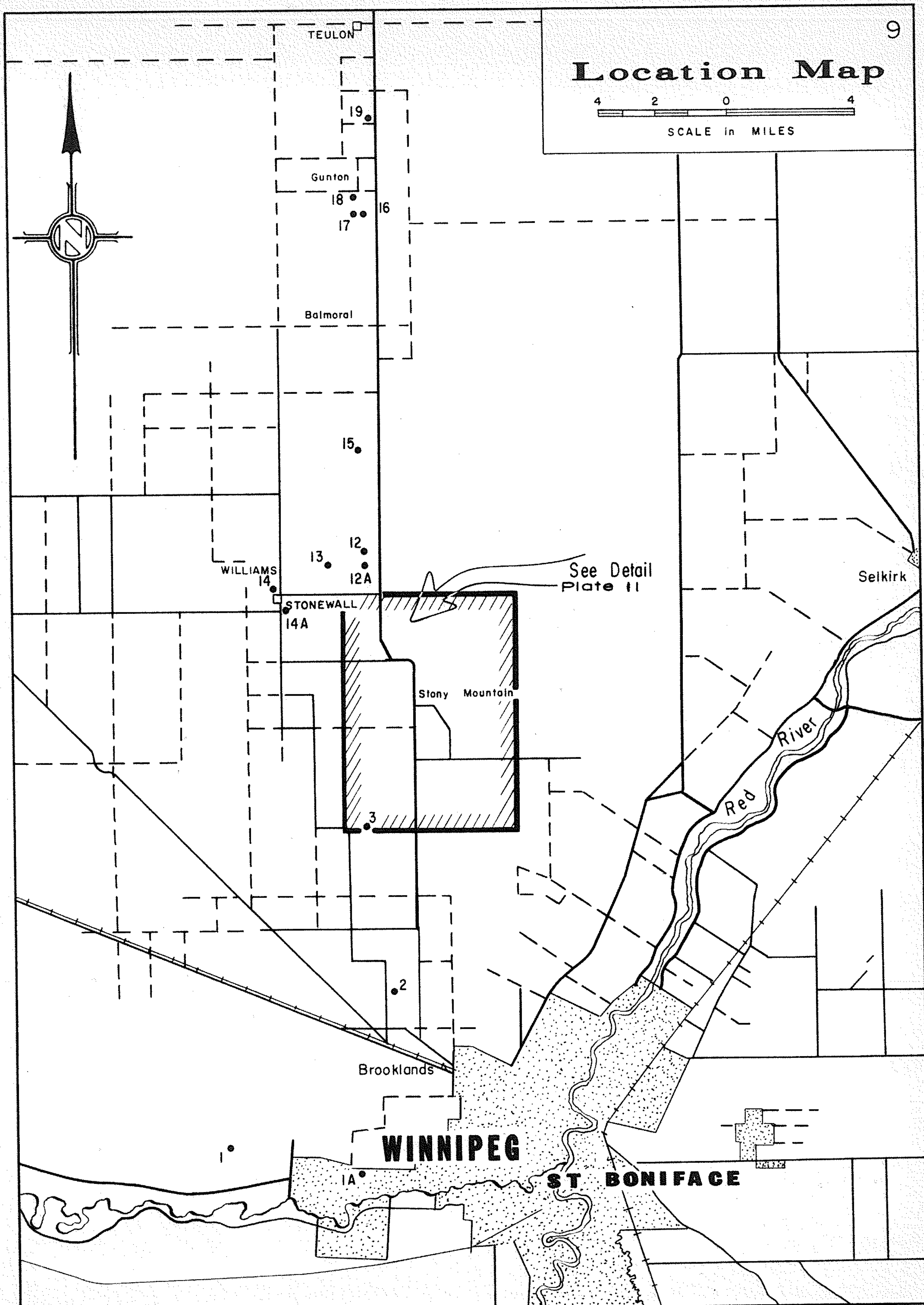

Location Map
4 2 0 4
SCALE in MILES
TEULON
19
Gunton
18
17
16
Balmoral
15
12
13
12A
WILLIAMS
14
STONEWALL
14A
See Detail
Plate II
Selkirk
Stony Mountain
Red River
3
2
Brooklands
WINNIPEG
1
1A
ST BONIFACE

PLATE I

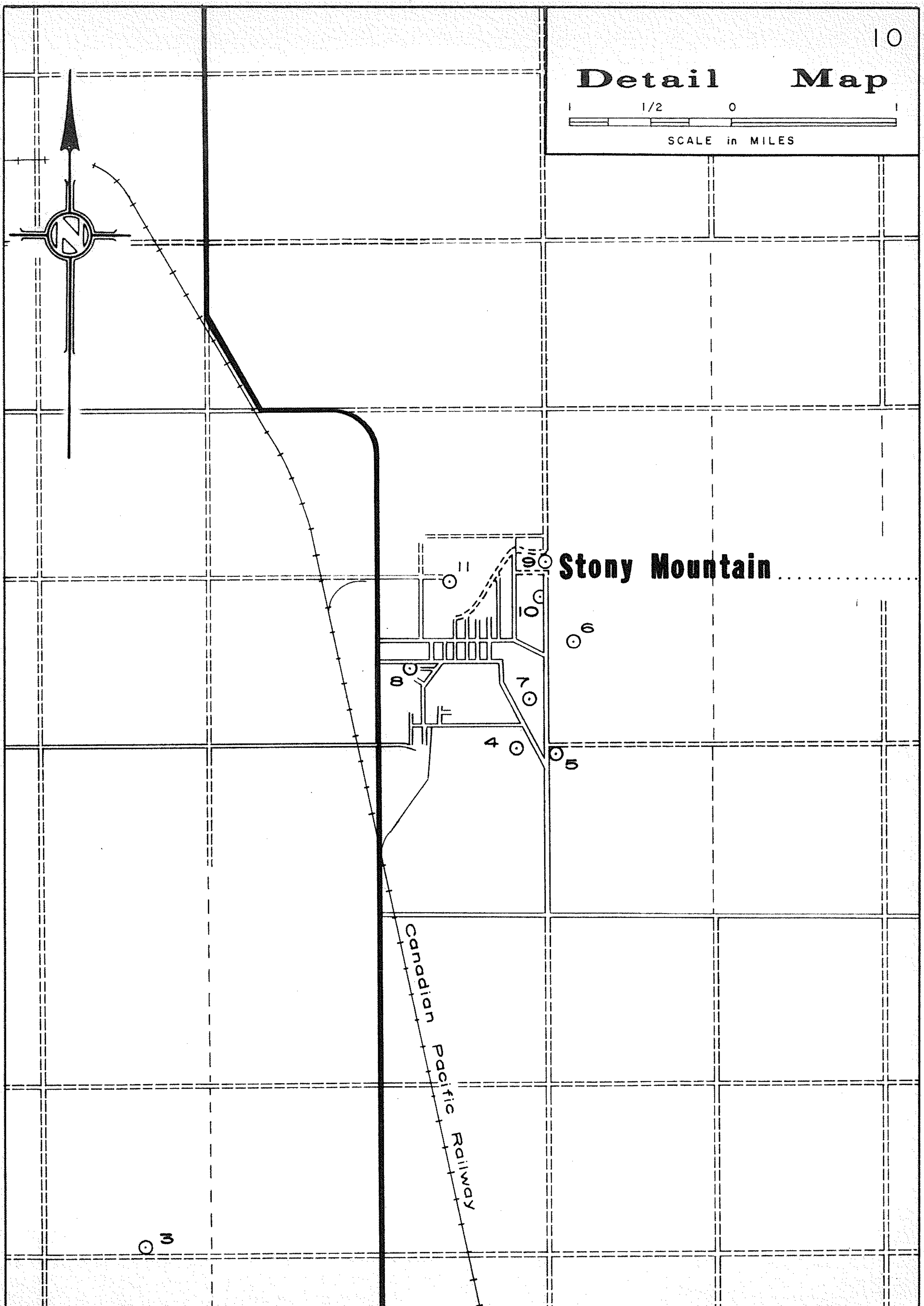

10
Detail Map
1/2 0
SCALE in MILES
N
Stony Mountain
Canadian Pacific Railway
3
4
5
6
7
8
9
10
11

PLATE 11

The second number signifies the position above the base of the section at that locality. For example, 16P.10 signifies that the sample came from the Penitentiary member at the East Gunton Quarry and is the tenth sample from the base of that section.

Every one of the collected samples was divided as follows: one piece each, for insoluble residue analysis, for making polished and etched sections, for reference and in a few cases for making a thin section.

INSOLUBLE RESIDUE TECHNIQUE

Fragments of rock, weighing a total of from 20 to 140 grams, were chosen for each locality from every bed or group of beds that showed visible lithologic differences with the next bed or beds above or below it in the section. These fragments were gently washed and thoroughly dried before weighing, and afterwards, were placed in glass containers and covered with water. Then a solution of hydrochloric acid (muriatic acid) was slowly added so as to avoid loss of material or excessive destruction of the more delicate residue textures. When addition of acid caused no further effervescence, the residue was allowed to settle and the solution of calcium and magnesium salts was decanted. Next, water was added, the residue settled and the solution again decanted in in order to wash the remaining salts from the residue. As the salts tended to flocculate the finer particles, no separation was possible until they were removed.

Once the clay sized particles remained suspended, progressive decanting of these particles was performed using at least three glass containers. The purpose of this was to trap in the second container any silt sized particles which might have been accidentally decanted from the initial container. The particle size was checked at intervals by looking at a sample of the suspended material under a microscope. Later microscopic examination of the silt sized residue showed that although the method was time consuming it was also accurate.

After clay sized and silt-sand sized particles had been separated, the two residues were dried and weighed and the clay sized fraction was discarded.

The silt-sand sized fraction for the samples from the Gunn, Penitentiary and Gunton members and the Stonewall formation were examined with a microscope using a fine micrometer eyepiece to determine the proportions in the various silt and sand size divisions. The silt-sand sized fraction for the samples from the Williams member and from the lowermost two beds of the Stonewall formation were wet seived through a standard screen to separate off the silt sized portion. This portion was then examined under a microscope as before. The sand sized portion was dried and separated into its size components by the use of standard screens shaken in a Ro-Tap machine for a period of ten minutes.

Throughout the analysis of the insoluble residues for this thesis the size divisions used are those of Wentworth Grade Scale, (K. Wentworth, 1922, p.381).

ETCHED SECTION TECHNIQUE

Slabs of all the samples collected were etched with hydrochloric acid, following the suggestions of Lamar (1950,p.2). These slabs were cut with the two largest sides parallel. One of these sides was polished with 400 size grinding powder and was washed clean. A glass tray was used, deep enough to allow covering of the slabs to a depth of not more than one-half inch. Greater depths allowed a furrowing of the edges of the slabs during etching. The slabs were placed in the tray in a solution of eight percent hydrochloric acid and allowed to remain for periods of time which had to be adjusted to each individual type of rock. They were next gently agitated to remove loose residue particles, immersed in water in order to dissolve the salts and then allowed to dry.

THIN SECTIONS

Thin sections were made of eighteen units in order to supply information on various questions of composition and texture. As many of these rocks are soft or crumbly, small sections were cut and were then indurated by boiling them in a solution of Canada balsam and Xylene. Although this method did not a allow a true thin section to be made, the fragments could be ground thin enough to show most features desired.

In discussing the textures of the carbonate rocks, especially as determined from thin and etched sections, the grade scale used is that of Wentworth, as modified by Payne (1942, p.1706) for crystalline sedimentary rocks.

TABLE I

WENTWORTH GRADE SCALE

Mean Size (mm)	For Insoluble Residues	For Carbonate Minerals
4-2	Granule	Granular crystalline
2-1	Very coarse sand	Very coarse crystalline
1-1/2	Coarse sand	Coarse crystalline
1/2-1/4	Medium sand	Medium crystalline
1/4-1/8	Fine sand	Fine crystalline
1/8-1/16	Very fine sand	Very fine crystalline
1/16-1/32	Coarse silt	Sublithographic
1/32-1/64	Medium silt	Sublithographic
1/64-1/128	Fine silt	Sublithographic
1/128-1256	Very fine silt	Sublithographic
Less than 1/256	Clay	Lithographic

TREATMENT OF THE DATA

Using the field measured sections and the insoluble residue data all the localities were correlated and the results were drawn on one structural and two stratigraphic cross-sections. The former was drawn structurally so as to show the present relationship between the Williams member and the rocks below, and between the Birse Quarry section and the Stonewall formation. Data collected in the field were added to that contained in Johnston (1934, p.63-71) and a geologic map of the sub-Pleistocene surface was drawn.

The data collected from the decantation and microscopic examination of the insoluble residues were utilized in drawing histograms which show distributions that are typical for the Gunn, Penitentiary and Gunton members and for the Stonewall formation. These histograms are inaccurate to the extent that all of the clay sized residue is shown in the 1/256 to 1/512 mm. range, although it is probable that some of this material is finer in size. Therefore, this size range will show a much larger peak than exists in the residue.

An expanded graph was drawn showing the cumulative frequency distributions for all the Williams member samples analyzed. Photographs are included of the grains of the various sand sizes of two seived samples, one from the Williams member and one from lower beds of the Stonewall formation. Logs of the total insoluble residue were drawn for three sections of the Gunton member and two of the Penitentiary member in a study of possible methods of correlation.

The etched sections were used for evidence regarding structure, such as nodules and cross-bedding, the distribution of insoluble residue and carbonate grains and particles, and the distribution of dolomite crystals, especially in the Gunn member. Photographs of etched sections showing these features are included.

The thin sections were used for measuring textural sizes, for obtaining evidence about dolomitization and, especially in the Gunn member, for noting a variety of petrographic and sedimentational features. A few photographs showing important features are used.

CHAPTER III

STONY MOUNTAIN FORMATION

The name - Stony Mountain formation - as used herein, follows the original definition of Dowling (1900, p.47F), with the exact definition of its upper boundary after Baillie (1952, p.21) as that boundary was not exposed in Dowling's time. Therefore, the Stony Mountain formation is defined as the rocks in the upper part of the Bighorn group of the Upper Ordovician, that are underlain by the Red River formation, also in the Bighorn group, and are overlain by the Stonewall formation, the lower unit of the Interlake group.

The subdivisions of the formation used herein are, in ascending order, the Gunn, Penitentiary, Gunton and Williams members. The Gunn member was defined by Sinclair and Leith (1958, p.244) and the Penitentiary member, by Okulitch (1943, p.60). The Gunton member was named by Okulitch (1943, p.60), was redefined by Baillie (1952, p.21) and is further redefined in Chapter V of this thesis. The Williams member is named and defined in Chapter VI. As each of these units is lithologically distinct from the Gunn member and from one another they will be treated in separate chapters.

GUNN MEMBER

TERMINOLOGY AND STRATIGRAPHIC RELATIONS

The Gunn Member of the Stony Mountain formation was originally defined by Okulitch (1943, p.60) as the Stony Mountain Shale member, but was given its present name by Sinclair and Leith (1958, p.244) in order to avoid nomenclatural confusions. Also, even the most argillaceous beds in the unit can only be described as argillaceous limestones; both compositionally - at the City of Winnipeg Quarry, Stony Mountain the upper nine feet of the member consisted of an average of 82% carbonate, with the lowest percentage found in any of the Gunn member samples at 75.5% - and texturally - even the most argillaceous beds are rarely finer than coarse sublithographic in the carbonate portion. Also, Porter and Fuller (1959, p. 155) report that the uppermost beds of the member in the subsurface are the most argillaceous.

It is the lowest member of the formation, but its lower contact is not exposed and it is only slightly understood from cutting and cores. It rests on the Red River formation, the uppermost beds of which underlie the Winnipeg Airport and are cream to pink massive dolomite. The lower eighty percent of the member is little known in Winnipeg area but is similar to the upper part rather than to the Red River formation in the subsurface (J. M. Andrichuk, 1959, p.2373).

The upper contact with the Penitentiary member is well exposed at several localities and is gradational over an interval of from three to five inches. Sections of the uppermost part of the Gunn member measuring from a few inches to ten feet thick are exposed at several localities in the vicinity of Stony Mountain. It is therefore to the uppermost part that this chapter is confined.

DETAILED PETROLOGY

The methods used to obtain petrologic information from the top ten feet of the Gunn member are generally the same as for the rest of the units but there is a different emphasis due to the much greater preservation of original petrologic detail in these rocks. Therefore, etched sections and thin sections were most important.

BIOCLASTIC* LIMESTONES

Although all the rocks in the Gunn member appear to be primarily bioclastic limestones, that name will only be

* When used in this thesis with reference to the rocks of the Gunn member, the term "bioclastic" is used simultaneously in both the more recent and the original sense. Herein, therefore, a "bioclastic " rock is one that is both composed of fossil fragments (Andrichuk, 1959) and is the result of the work of organisms (Grabau, 1904).

used for those limestones containing very small amounts of insoluble residue. A study of the first part of Appendix B will show that there are two distinct groupings with reference to amounts of insoluble residue.

Using this definition, bioclastic limestone makes up slightly less than twenty percent of the whole section (Location 11), even though it represents the local norm into which the terrestrial sediment was added.

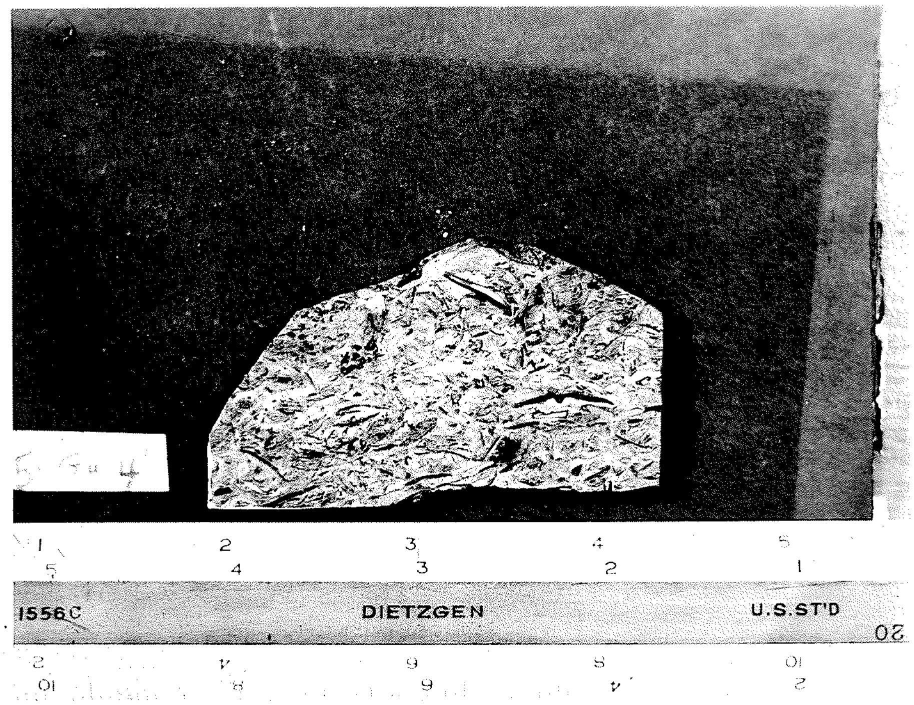
These bioclastic limestones can be separated into two main groups: the variety containing coarse bioclastic material and the much less frequent variety composed only of fine sediment

COARSE BIOCLASTIC LIMESTONE

This rock type is composed almost entirely of the broken or more or less comminuted skeletal remains of brachiopods, bryozoans, solitary and colonial corals, cephalopods, gastropods, trilobites and minor amounts of pelecypods, crinoids and indeterminate (echinoderm?) spines and tests. Abundant conodonts were also found by Ethington and Furnish (1960, p.265). These fragments are enclosed or suspended in a matrix composed either of sub-lithographic to lithographic calcite or medium to coarse crystalline, clear sparry calcite. The fossil fragments have an extremely large size range from sublithographic (or perhaps smaller) to at least a cobble sized diameter for the largest colonial corals. There can be a marked variation in the mean size of fossil fragments within an inch vertically in a bed. The sparry calcite was found to have an extreme size variation from fine crystalline to granular crystalline either in the rock matrix or in large fossil fragments. Some of the shell fragments retain a fibrous calcite structure. Plate III A shows an etched section of a coarse bioclastic limestone.

In these coarse bioclastic limestones the distribution of the two types of matrix is complex. Some portions have mainly a sublithographic calcite matrix with only small scattered areas of sparry calcite, Plate IV A, and others almost entirely a sparry calcite matrix in which, in the two dimensional view, the fossil fragments seem to be suspended, Plate IV B. Rocks in which sparry calcite is the chief matrix usually have fewer, more widely spaced fossil fragments, although they are still abundant, than rocks with sublithographic matrix, where the fragments are closely packed. Even in those rocks with abundant sparry calcite matrix, there is a certain amount of sublithographic calcite in the interiors of shells, between the septa of horn corals and in other such confined spaces.

One other relationship between these two types of calcite was found. In two examples, single brachiopod



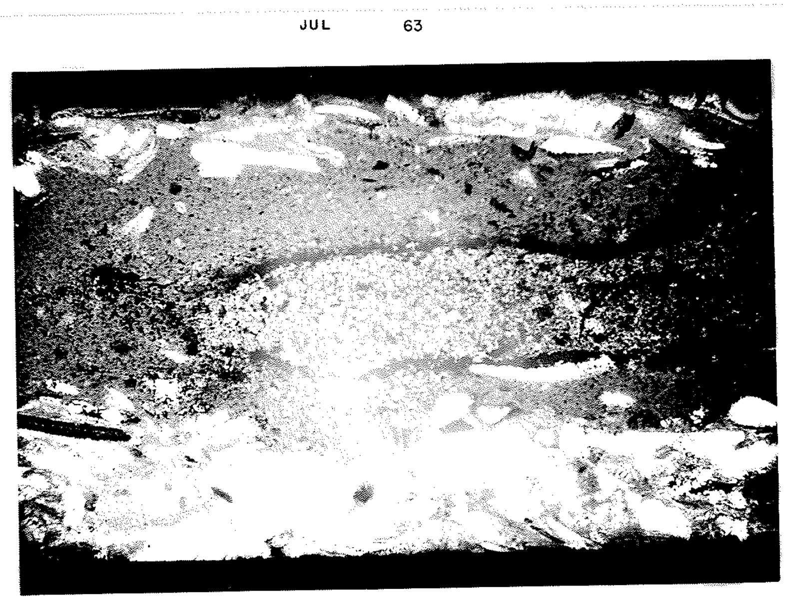


PLATE III

A. Etched section of coarse bioclastic limestone, cut perpendicular to the bedding. (5Gu.4).

B. Thin section of a burrow, with hematite outline and surrounding dolomitized area. (20X). (11Gu.1).

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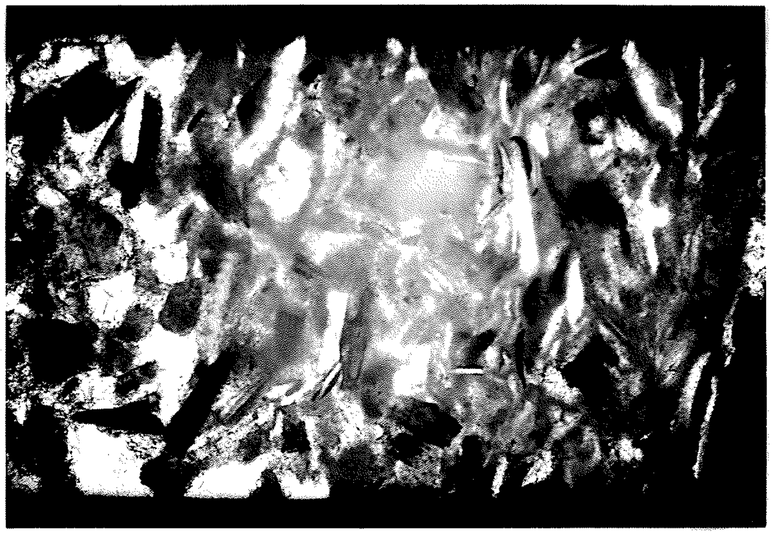

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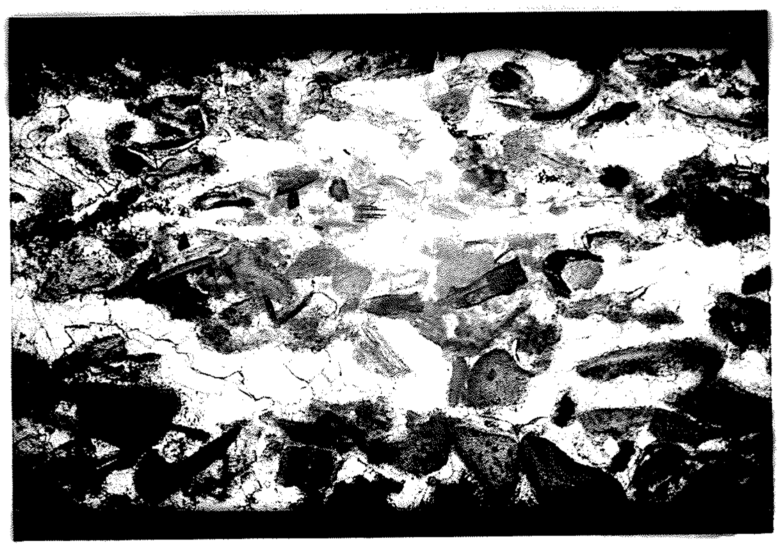


PLATE IV

A. Thin section of coarse bioclastic limestone with predominantly sublithographic calcite matrix. (20X) (11Gu.1).

B. Thin section showing predominantly sparry calcite matrix. (20X) (11Gu.1).

valves, which are resting convex upward, "cover" a thin flat layer of sublithographic calcite which does not extend beyond the valve into the surrounding coarse bioclastic limestone. Above this fine calcite, and filling the remainder of the contained area, is sparry calcite. A coiled gastropod shell contains a small elongate mass of sublithographic calcite against one wall, the remainder of the area within the shell being filled with sparry calcite.

Common in this type of limestone, as in the other limestones of the member, are the many, randomly spaced, tube-like features of round or oval cross-section - as shown in Plate III B, p.22 and in Plate V, p. 25 - which suggest burrows. Most of these features are filled with dolomite and minor hematite, but the remainder are filled with a coarse sublithographic calcite composed of a fairly homogeneous mass of fossil fragments. These fragments are coarser than the usual sublithographic matrix but considerably finer than the fossil fragments surrounding the "burrow".

The insoluble residue, composed of quartz and minor varying proportions of hematite, is only a very small part of the rock - from 1.01 to 1.63 percent. There is a notable gap between the clay sized particles and the much less abundant coarse silt and various sand sized grains, as shown by the histograms for 4Gu.2 and 11Gu.4 in Figure 2, p. 26.

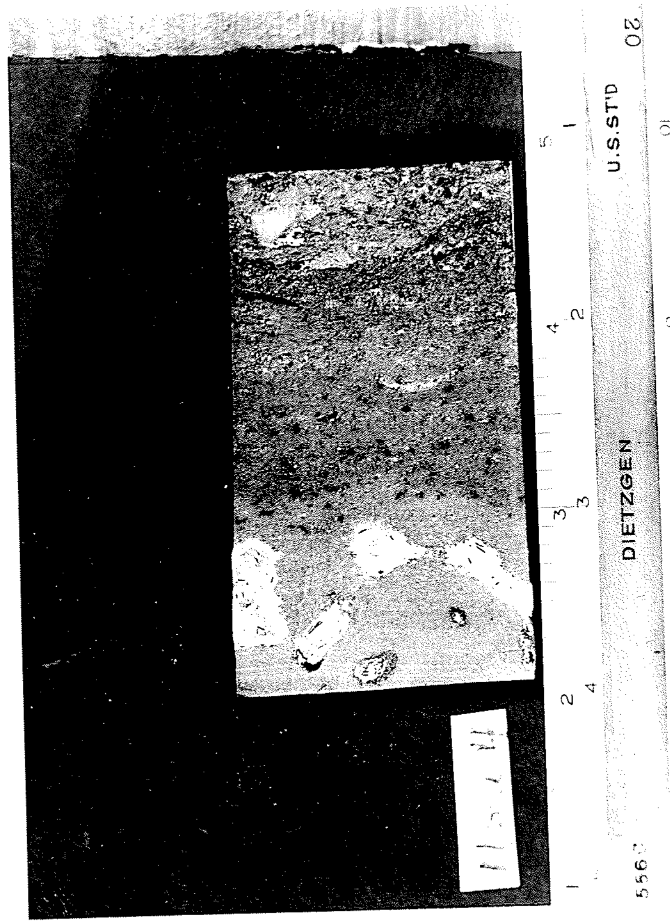


PLATE V

Etched section of bioclastic limestone grading upward from fine to coarse, showing burrows. (11Gu.4).

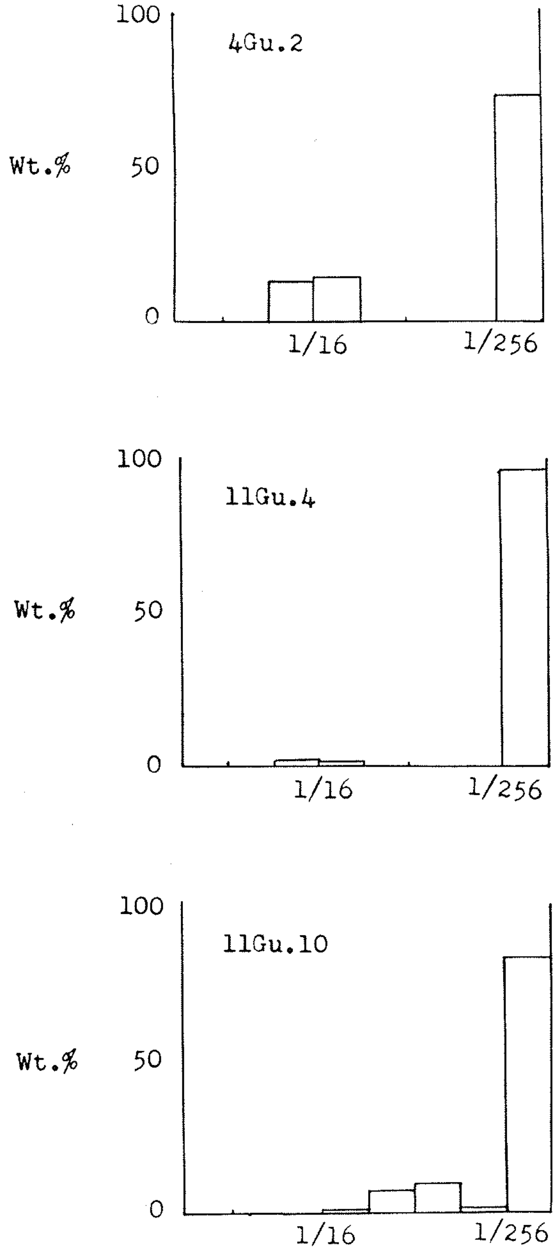


FIGURE 2

CHARACTERISTIC DISTRIBUTIONS OF INSOLUBLE RESIDUE PARTICLES FROM THE GUNN MEMBER

About thirty percent of the sub-angular to sub-rounded silt and sand sized quartz grains show regeneration (H.A. Ireland et. al., 1947, p.1489), which varies from poor to complete. The etched sections show these grains to be very scattered in the rock.

Hematite, which occurs in these coarse bioclastic rocks is separable into three types. First, there is that which replaces calcite in fossil fragments. Here, the internal and external structure of the fragment are replaced before the whole is filled into a solid mass of hematite. Second, it is disseminated as minute particles in the sub-lithographic calcite matrix, often as flat slivers approximately one-twenty-fifth of a millimeter thick. Some of these splinters glitter as if crystalline. Sparry calcite has little or none of this hematite. Third and most important quantitatively, it occurs in concentration mainly around but also in the oval or round, tubular "burrows." Regardless of its occurrence, the hematite in these limestones almost invariably has a porous and "lacy" appearance in the residue.

In one residue sample, two or three percent of crystalline aggregates of pyrite were also found.

Another mineral present in minor and varying amounts is dolomite. It is present as sublithographic to very fine crystalline rhombic euhedra or subhedra. These are found scattered through the finely sublithographic calcite matrix or, much less frequently, in the sparry calcite areas. Where sparry calcite is present as a shell filling there are no dolomite crystals present, although the sublithographic calcite in the same shell may be more heavily dolomitized than that outside.

In the "burrows", the sublithographic to very fine crystalline rhombs and subhedra are much more abundant and often fill the area. In some places, as in Plate III B, p. 22, the dolomite crystals also fill the area surrounding the "burrow". Two other occurrences of more abundant dolomite were found. In one area, undolomitized fossil fragments are scattered abundantly in a completely dolomitized matrix. Although the area is irregular in shape the fragments are smaller than in the surrounding bioclastic limestone. The other type is one of dolomitized areas in which the matrix and the finest fragments are replaced and the coarse fragments are scattered about unaltered. The boundary between the dolomitized and undolomitized areas is fairly sharp. Also, in one bed, some coarse shell fragments have been thoroughly dolomitized.

Macroscopically, the coarse bioclastic limestones show these additional characteristics.

They are light tan-grey to light brownish-grey and rarely light grey, often with a reddish to pale purple tint from included hematite. Scattered small rust-red and greenish, circular or oval "burrows" are present. In the transition zone between the Gunn and Penitentiary members, ocherous yellow dolomite is intermingled with coarse bioclastic limestone.

The fossil fragments, if large and of unequal dimensions, are generally oriented parallel to the bedding but otherwise show a random orientation. Colonial corals unless very small always appear in the growth position.

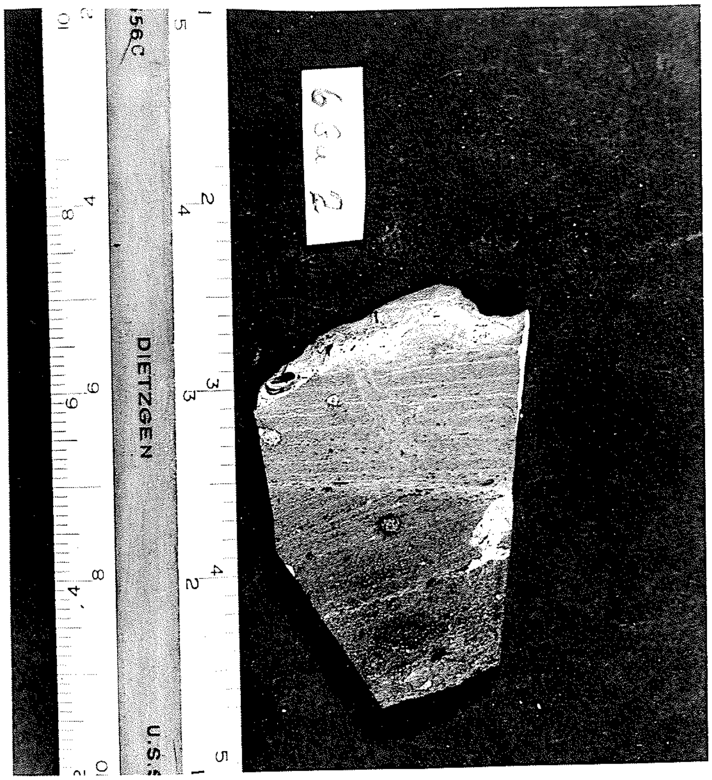
The beds of this limestone average from one to three inches in thickness but were measured from less than one inch up to eight. The bedding planes are irregular with an intermittent lensing being common, some beds lensing out completely into reworked argillaceous limestone. Certain beds are only slightly reworked by scattered "burrowing", some with "burrows" throughout (thinner beds) or only at the top and the base (thicker beds). These "burrows" always extend into the argillaceous bioclastic limestone beds.

Contained in one bed of coarse bioclastic limestone is an elongate flat-lying fragment of a light grey laminated, sublithographic limestone, which is only very slightly rounded at the corners.

FINE BIOCLASTIC LIMESTONE

This rock type makes up only a very few percent of the uppermost Gunn member but it is significantly different from the rest. It is composed of fine to coarse sublithographic calcite, through which abundant fine crystalline to coarse sublithographic comminuted fossil fragments are scattered. A scattered number of dolomite euhedra and subhedra are present ranging in size from sublithographic to fine crystalline, but averaging very fine crystalline. Hematite, if present, is disseminated in the rock and the very small amount of quartz is scattered throughout. The insoluble residue amounts and size distributions are the same as for the coarse bioclastic limestones.

Macroscopically, the rock is light grey often with a reddish tint. It occurs in irregular beds, from one-half to over one inch thick, which exhibit fine internal bedding and cross-bedding as shown in Plate VI, p.31. This fine limestone usually grades upward more or less abruptly into medium to coarse bioclastic limestone, as in Plate V, p.25. The rock has scattered, reddish to yellowish-grey, dolomitized "burrows", with hematite concentrated usually around the circumference, again shown in Plates V and VI A. These plates also exhibit a few "burrows" which have disturbed the laminations but which do not consist of dolomite and hematite.



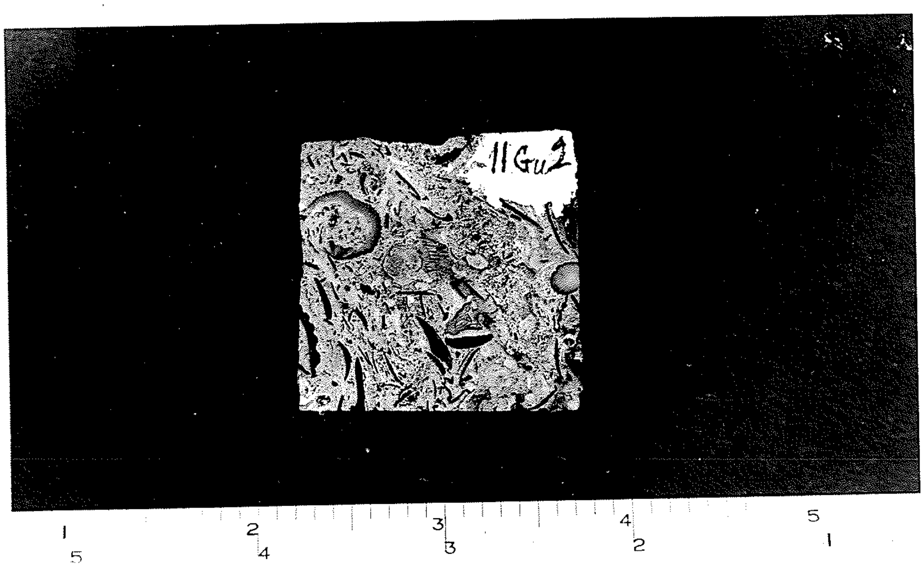


PLATE VI

A. Etched section of fine bioclastic limestone, with cross-bedding and burrows. (6Gu.2).

B. Etched section of an argillaceous bioclastic limestone, cut parallel to the bedding. (11Gu.2).

One of the beds contains included sub-rounded to spherical pellets of very fine sublithographic calcite, which have diameters of from one and one-half to three millimeters with the average up to one and three-quarter millimeters. The limestone containing these pellets has two or three times as much clay sized insoluble residue as comparable beds.

ARGILLACEOUS BIOCLASTIC LIMESTONE

This rock type makes up slightly more than eighty percent of the exposed Gunn member but due to organic mixing and dolomitization it affords the least sedimentational information of the three types.

The colour is usually red to maroon with minor amounts of greenish-grey but these colours are often faded due to leaching through weathering, with the green altering to limonite yellow. It is a mixed rock with abundant "blebs" and small lenses of medium to coarse crystalline bioclastic limestone incorporated into the argillaceous portion. These masses of bioclastic limestone have mean diameters from three to six millimeters but are also much larger and much smaller. The bedding is thin and irregular.

It is in these rocks that large numbers of entire or nearly entire fossils are found as in Plate VI B. These are especially plentiful on the very top of coarse bioclastic limestone beds, where some brachiopod valves are still articulated although filled with argillaceous sediment.

In addition to such fossils there is an even greater amount of fossil fragments from pebble size down.

Strictly speaking, this rock should be called a dolomitic, argillaceous, bioclastic limestone as most of the rock other than the fossil fragments and the bioclastic limestone "blebs" and lenses is composed of sublithographic euhedra and minor subhedra and anhedra of dolomite.

The insoluble residue in these rocks has a different distribution than that of the other two types, as shown by the histogram for sample 11Gu. 10 in Figure 2, p. 26. Also the amount of residue is very much greater, the mean total residue being 22.0 percent and the mean clay sized residue being 18.3 percent of the rock.

The hematite in this rock type ranges from about five to slightly over twenty percent of the insoluble residue (11Gu. 10 has just over ten percent). This is distributed between fine clay sized hematite disseminated in the argillaceous portion of the rock and fine to very fine silt sized hematite concentrated around the circumferences of the "burrows". A small amount of coarser hematite is also scattered randomly throughout some of the coarse bioclastic limestone beds.

SEDIMENTATION OF THE GUNN MEMBER

The seas of this time were open, unrestricted and clear enough to allow a very flourishing animal life. The preserved skeletal remains show that those animals represented seem to have lived separately either on or moving over the bottom. The secondary evidence of the burrows suggests that some animals also moved in the bottom sediment. The largest preserved remains, belonging to the colonial corals, show a low, hump-like form which sat on the bottom.

At death the skeletal remains became particles of sediment and were more or less broken and comminuted, some of it as finely as coarse sublithographic and some probably as fine as lithographic, although the finest calcite particles would probably have aggregated or been dissolved, thus making their existence almost impossible to prove. The coarse and fine bioclastic limestones were formed entirely of this former skeletal material. The very small amounts of insoluble residue that were introduced from outside the area were of no importance - sedimentationally - to these two types of rock.

That the sea was not too shallow is suggested by the following. The skeletal fragments show an extremely wide range of size and shape with little orientation; thereby showing a lack of sorting, as in Plate III A, p.22.

For this reason, it appears that intense biological activity, probably entirely by bottom-surface and burrowing scavengers, is responsible for the comminution of the sediment. The effect of wave and swell energy was restricted to breakage of the larger shells and minor redistribution of the top layer of sediment during and following storms. In one bed of coarse bioclastic limestone, a single brachiopod valve lies convex upward with the lowermost portion of the enclosed space occupied by a thin, flat layer of sublithographic calcite. This sediment was either washed in by wave energy or an equivalent layer "outside" the value was removed, probably by the same storm waves which initially deposited the valve in such a position that it could not be moved again by the available wave energy. In another bed, a gastropod shell is only partially filled with sublithographic calcite along the side upon which it rested against the bottom. This sediment must have been washed into the shell by wave energy which was not sufficient to move the shell.

One exception to this general rule is shown by the elongate, flat-lying fragment of a laminated, sublithographic limestone, with only very slightly rounded corners, in a coarse bioclastic limestone bed. A violent storm probably tore up the entire bed of fine bioclastic limestone and scattered it in fragments.

There was almost continuous alteration in the rates of sedimentation of coarse bioclastic limestone presuming that the rate of scavenger comminution remained approximately the same. There is often a marked size change in the fossil fragments in every vertical inch of a bed, with a tendency to be coarser upward suggesting an accelerating rate of sedimentation.

An exception to this is the thin beds or basal portions of beds composed of fine bioclastic limestone. These few units represent relative standstills during which the fossil fragments were comminuted to a size no larger than coarse sublithographic or, less frequently, fine crystalline. That this is not due to a sorting out of fine sediment by storm waves is suggested by the fact that some of these beds show a coarsening upward, as in Plate V, p. 25, the opposite to the graded bedding that would result from post-storm settling. However, currents were effective in moving this fine sediment once it has been produced, as fine cross-bedding and vague laminations are present, as shown in Plate VI A, p. 31.

A return to a more rapid rate of deposition above these thin beds of fine bioclastic limestone is signalled, more or less abruptly, by a gradation to coarse bioclastic limestone.

One bed of fine bioclastic limestone contains subrounded to spherical pellets of very fine sublithographic calcite. These pellets etched out more rapidly than did the remainder of the beds. Their origin is obsure, but may be connected to the occurrence in this bed of two to three times as much clay sized residue as in comparable beds. Possibly they are cohesive masses of clay sized residue and sublithographic calcite brought together either by their hydraulic similarity or by some organic adhesive supplied by a bottom scavenger. Their shape is probably due to mild rolling by bottom currents.

The preceding paragraphs have outlined the sedimentation of those rock types from the Gunn member which represent carbonate formation and deposition in approximately the same area. The argillaceous bioclastic limestones owe their present aspect largely to the intermittent addition of significant amounts of terrigenous sediment from well outside the area.

This terrigenous sediment was composed of clay sized particles, with only a very small silt sized component, suggesting that it was brought into the area in suspension. It would have very considerably increased the clay sized component of the sediment, especially increasing the amount of finer clay sizes by several times.

Each period of introduction and deposition of this sediment occurred after a bed of coarse bioclastic limestone had become progressively coarser toward the top indicating an increased rate of deposition and perhaps also of subsidence. Lying on the top of most of these beds is a large collection of entire or nearly entire fossils that are well-preserved and often still articulated. They represent a mass death brought about by the introduction of the terrigenous sediment.

This killing is thought to have been caused by a relatively slow increase in the amount of suspended material in the water, particularly in the finest sizes, rather than by the sudden introduction of muddy water conditions by storms and/or the very rapid introduction of terrigenous sediment. The periodic occurrence of storms which suspended large quantities of fine sediments in the water is not doubted. However, these animals would have been able to survive these conditions by closing up for one or two days until the sediment was thoroughly flocculated by the sea water. They seem to have been able to survive similar conditions in which the fine sediment was exclusively calcareous and would not have flocculated as rapidly as clay particles. However, a more continous introduction of suspended terrestrial sediment would have slowly clogged up the vital organs of these animals and thus caused death.

In this regard, the colonial corals are interesting indicators of environment. One colony shows the typical, slightly flattened, convex shape, except for one side against which bioclastic sediment has been piled by sea currents. This side had been unable to grow and is relatively flat vertically. However, in common with all other colonies, but one, the entire colony had died together due to the introduction of terrigenous sediments. The one exception is the only example noted of a colonial coral that may have been killed by bioclastic calcareous sediment. This large colony grew and died by sudden changes which gives the colony a double tiered appearance, with its first and last stages the smallest. Perhaps intermittent decreases in the rate of bioclastic sedimentation allowed it to expand and intermittent increases in the rate caused it to die back due to partial burial.

Following deposition of the terrigenous sediment and probably due to a large amount of organic material trapped therein, an intense amount of burrowing and perhaps surface feeding was done by scavengers. Some of the burrowing may have been done by animals capable of living in bottom sediment although feeding from the overlying water. The end effect was a very thorough mixing of the sediment. Not only was the terrigenous sediment and any small bioclastic debris churned together thoroughly but any beds of fine and coarse bioclastic limestone that had been deposited during lulls in the influx of terrigeneous sediment were also included. Because these beds tended to be much less than an inch thick, the thinnest ones and most of the others disappeared into the whole mass to become the "blebs" and small lenses that are so abundant in this argillaceous, bioclastic limestone. Only occasional thin, flat, plate-shaped lenses of coarse bioclastic limestone testify to the former presence of some beds, while larger portions of others have survived. Not surprisingly, the bedding of the argillaceous limestones is thin and very irregular.

The thicker beds of coarse and fine bioclastic limestone, which represent the periods when abundant terrigenous sediment was not being supplied, also were burrowed into at the same time, some extensively. The thinner beds have burrows passing through them into the argillaceous limestone above and below and the thicker beds have burrows in both the upper and lower portions of the beds, suggesting that they too were burrowed through, unless these lower burrows are the last work of scavengers from below. An example is shown in Plate V, p.25. The intermittent lensing that is common to these beds is also due to the burrowing which sometimes has removed whole portions of both the upper and lower parts of these thicker beds and incorporated them into the argillaceous limestone. The upper portion of the fine bioclastic limestone bed in Plate VI A, p.31, shows evidence of this removal.

Another feature of this mixing by burrowing is the occurrence in the argillaceous bioclastic limestone of abundant entire or nearly entire fossils seemingly floating in the rock, as in Plate VI B, p.31. These undoubtedly represented the sudden death groupings from the tops of coarse bioclastic limestone beds, which beds have been completely incorporated into the rock. The fossils, which were too large to be ingested by the scavengers, have remained.

Although the aspect of mixing has been emphasized, these burrowing organisms also acted to reduce the size of the fossil and rock fragments in the argillaceous limestone by their chewing and/or digestive processes. Those few burrows not dolomitized show a fairly homogeneous mixture, in which the fossil fragments are coarser than the surrounding sublithographic matrix but finer than the fragments in the surrounding rock.

These burrowing organisms did not produce such definite evidence of their existense during the deposition of the coarse bioclastic limestones, and were only slightly active during periods of deposition of fine bioclastic limestones, as is illustrated in Plate VI A, p.31 and Plate V, p.25.

DIAGENESIS

After the last burrowing scavengers had finished their work and the sediment was no longer disturbed certain changes occurred. The clear sparry calcite began to form, some of the iron oxide migrated to form pyrite (and hematite?) aggregates and small crystals of dolomite began to grow. The oval shape of some of the burrow cross-sections, as in Plate III B, p.22, suggests that some compaction may also have occurred.

The medium to coarse crystalline, clear sparry calcite seems to have been due to three processes. By far the most important was the recrystallization of areas of sublithographic to lithographic calcite matrix, but minor roles were played by the crystallization of fossil shell fragments and the precipitation of sparry calcite in shell chambers.

In the coarse bioclastic limestones today, there is a mixture of sparry calcite and sublithographic calcite matrix, as in Plate IV, p.23. Although the former type greatly predominates, the scattered occurrence of small areas of sublithographic to lithographic matrix within areas of medium to coarse crystalline sparry calcite matrix, with sharp boundaries and with no difference in the size of included fossil fragments, suggests that the finer matrix is only a remnant of the original matrix of the rock. It was also noted that sublithographic calcite occurs as the filling of shell interiors and the spaces between the septa of horn corals, while outside, sparry calcite alone is present between the fossil fragments, further suggesting remnants of a once universally fine matrix. Further evidence is presented in some coarse bioclastic limestones by the distribution of sparry calcite matrix in those portions of the rock having fewer, more widely spaced fossil fragments while sublithographic matrix surrounds more closely packed fragments, although no difference in the range of fragment size was seen. This suggests a greater ease of crystallixation where matrix was more abundant. Also, some clear sparry calcite shows smaller crystals with different optical orientations surrounding some fossil fragments suggesting growth into a matrix after deposition. If the area had been a void, large calcite crystals would be expected. No compaction features, such as broken, but only slightly parted fossil fragments or solution contacts between fragments, were seen, suggesting lack of large pore spaces. (It will be remembered that the sparry calcite matrix was often most abundant in those rocks containing fewer, more widely spaced fragments.)

Lastly, the thin sections showed that the sparry calcite matrix contains "floating" dolomite rhombs and quartz grains. The rhombs do not seem to have formed along with precipitated calcite, (see the next paragraph), and it is impossible for the angular quartz grains to be anything but an indication of a former finer matrix.

The last type of sparry calcite in this member is found filling former voids within gastropod shells and under brachiopod valves. Smaller amounts of sublithographic calcite are also present, but the are confined to the "down" side and have a sharp flat boundary with the sparry calcite, suggesting a former void. No dolomite rhombs were seen in this sparry calcite.

Authigenic dolomite is common in some of the rocks of the Gunn member and is present in all. It is very extensive in the burrowed sediment; that is, it consists of most of the rock other than fossil fragments and coarse bioclastic limestone "blebs" and lenses in the argillaceous bioclastic limestone and it is very abundant in the burrows in the fine and coarse bioclastic limestones. In fact, the first rock type might more accurately be called a dolomitic, argillaceous, bioclastic limestone.

Dolomite is also present in much smaller amounts scattered or very scattered in the fine and coarse bioclastic limestones, in the areas of sublithographic to lithographic calcite and less abundantly in the sparry calcite. In some few areas of sublithographic calcite, it is very abundant in shell fragments, especially brachiopods and gastropods.

This type of dolomitization was not seen in areas of sparry calcite matrix. Dolomite is also present in rare, irregularly shaped areas in the coarse bioclastic limestones. These are usually expansions of the burrow dolomitization into the surrounding rock, as can be deduced from noting the undolomitized fragments in the center and the area and the hematite outline to the burrow, as in Plate III B, p.22, but there are rarer areas which do not afford any clues as to their origin, although they may be of the same type. The finest visible fossil fragments are dolomitized in these areas and leave the coarser fragments scattered and unaltered. The boundaries between the dolomitized and undolomitized portions are fairly sharp.

In the argillaceous bioclastic limestones, and in the other burrows, the dolomite occurs as sublithographic euhedra and minor subhedra and anhedra. In the fine and coarse bioclastic limestones, it occurs as scattered sublithographic to very fine crystalline euhedra and subhedra, with rarer fine crystalline sizes in the fine bioclastic rock.

As the most intensive dolomitization seems always to be connected with burrows it appears that either the burrowing was effective in producing a higher porosity than in the surrounding rocks, thereby allowing magnesium bearing solutions readier access, or the digestive processes of the burrowing animals concentrated the amount of magnesium present, or both. As dolomitized burrows always extend into argillaceous, bioclastic limestones, the clay minerals of the terrigenous sediment may have been important sources of magnesium and agents for its concentration.

In the coarse bioclastic limestones the sublithographic matrix is more dolomitized than the sparry calcite areas. It is suggested that during recrystallization of the sublithographic type to sparry calcite the magnesium contained in the entrapped sea water was expelled due to loss of porosity and was concentrated in those areas of finer matrix that remained.

This process was intensified in the case of shells which had not been filled with sediment. Here it appears that the magnesium was concentrated in the water contained within or under the shell and when sparry calcite precipitation began, the sublithographic calcite in or under the shell was more heavily dolomitized.

The iron in the argillaceous bioclastic limestone of the Gunn member in the subsurface is present in the ferrous state, giving the rock a green-grey (J.M. Andrichuk, 1959, p. 2373) or dark green (R. J. Ross, Jr., 1957, p.447M) colour. At the surface, the iron is present almost entirely as masses of fine to very fine, silt sized, crystalline hematite or as finely disseminated, clay sized hematite .

Therefore the present red colour at the surface appears to be entirely a weathering phenomenon.

In the fine and coarse bioclastic limestones of the subsurface the iron is in both the ferric and ferrous states (J. M. Andrichuk, 1959, p. 2373). At the surface, the very small amount of iron present is ferric iron. The surface colour in these limestones, therefore, seems to be only partially a result of weathering, perhaps due to a much lower porosity.

It is suggested that the hematite of the argillaceous bioclastic limestones, which makes up from five to just over twenty percent of the entire insoluble residue, may have come into the area as ferrous iron. It would have been reduced during its journey, if it originally was ferric sediment, by organic means. It cannot be known how much of the abundant organic matter present in these rocks survived the thorough scavenging that occurred, but it is suggested that it was probably too little to reduce that amount of ferric iron once it had been deposited.

The lacy, porous, crystalline masses of hematite occur in various ways. They are scattered in the coarse bioclastic limestone lenses but more often are found about the edges. They occur semi-concentrically within the oval and round burrows and they are more rarely found as a replacement for calcite in fossil fragments. These modes of occurrence, when considered along with the presence in one bed of fine crystalline pyrite masses, suggests that following deposition of the rock much of the iron migrated, especially along the burrows, and formed pyrite aggregates.

It was seen that in the burrows and other dolomitized areas the "hematite" masses were formed of crystals, suggesting that the dolomite had formed first. As has been explained previously, it is thought that the sparry calcite and dolomite formed at about the same time, with the crystallization of sparry calcite seeming to assist dolomite formation.

Within the fine and coarse bioclastic limestones thirty percent of the quartz in the coarse silt and very fine sand sizes of the insoluble residue shows poor to complete regeneration of euhedral crystals.

CHAPTER IV

PENITENTIARY MEMBER

TERMINOLOGY AND STRATIGRAPHIC RELATIONS

The Penitentiary member of the Stony Mountain formation was named by Okulitch (1943, p.60) and described from the City of Winnipeg Quarry, Stony Mountain. This thesis follows that original definition.

The Penitentiary member is underlain by the Gunn member and overlain by the Gunton member of the Stony Mountain formation. The basal contact is gradational over three to four inches and the upper contact usually over a slightly greater vertical span.

The thickness of the member at the type section, Location 11, is sixteen feet, eight inches, a figure slightly in excess of that given by Okulitch. At only two other localities, both in the vicinity of Stony Mountain, can the full section be measured.

However, a marked difference in thickness occurs at the Watchtower Quarry, Location 4, where the section is only twelve feet, six inches thick. The other locality, which is closer to Location 4 than to the type section, has a thickness of at least fifteen feet with the upper contact covered. Any placing of the Gunn-Penitentiary contact at a higher level than at the type would have affected both these sections equally, so another explanation is needed.

At the upper Penitentiary contact at Location 4 there is a two inch thick bed containing not only very weathered and leached Penitentiary dolomite but also abundant quartz silt and sand, clay, roots and traces of igneous rock fragments. In short, a soil zone containing a mixture of Ordovician, Pleistocene and present-day material. The overlying seven feet of dolomite of the Gunton member is an erosional remnant of the larger mass of these rocks capping Stony Mountain.

In earlier reports (A. MacLean, 1913, p.70), reference is made to a slight southeastward dip to these beds, which is at variance with the southwestward dip to the west of Stony Mountain. Also, the glaciers that passed over these rocks deposited material only on the southward and eastward sides of the Gunton remnant leaving the other two sides scraped clean. If the upper most beds of the Penitentiary member had been well weathered and thereby weakened during pre-glacial and/or intraglacial times, the weight and movement of the ice could have crushed these beds and differentially depressed the Gunton remnant.

DETAILED PETROLOGY

The methods used to obtain petrologic information from the rocks of the Penitentiary member were: examination of insoluble residues and thin sections and, to a lesser extent, etched sections. Original carbonate sediment features are not well preserved due to almost complete dolomitization.

This member is composed entirely of one rock type showing only minor textural, compositional and structural variations. It is a dolomite, composed of a sublithographic mosaic of dolomite crystals which are rarely euhedral even in those places where traces of very fine crystalline dolomite are present. In several thin sections these areas of slightly coarser dolomite are found scattered in the finer mosaic. However, in two instances, the coarser dolomite is situated in contact with and slightly scattered in the fine to very coarse crystalline sparry calcite of recrystallized fossil shells, as in Plate VII A, p.52.

In some beds, thin sections and etched sections showed irregularly shaped, semi-nodular areas consisting of a mosaic of sublithographic dolomite crystals, with minor to rare euhedral forms, partially mixed into a sublithographic to very fine crystalline dolomite crystal mosaic, in which the largest crystals are mainly euhedral and which shows faint irregular laminations in part. The boundary between these areas is always sharp, and is shown in Plate VII B, p.52.

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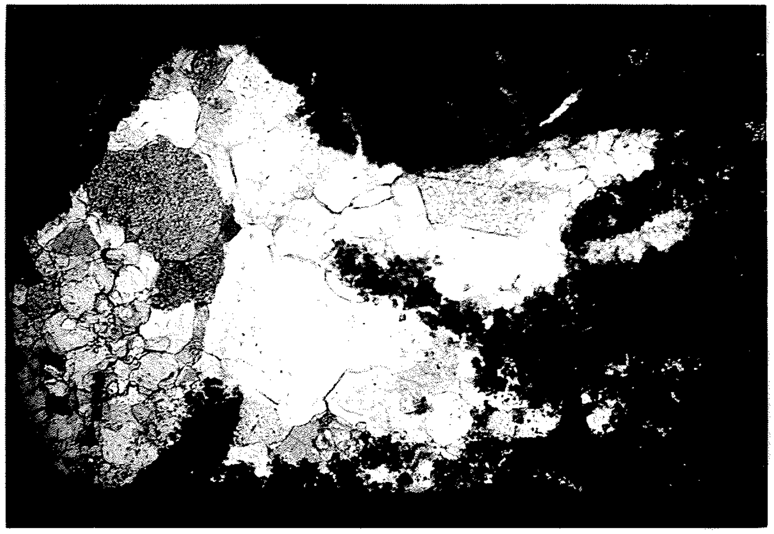

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PLATE VII

A. Thin section of a partially dolomitized sparry calcite shell remnant (crossed Nicols). (20X)(6P.4).

B. Thin section of the boundary between a semi-nodular area partially mixed into the surrounding coarser dolomite. (20X). (11P.12).

The insoluble residue in the Penitentiary member, consisting of quartz and iron oxides, is an important constituent. The total residue makes up from 8.4 to 25.0 percent of the whole rock, with a clay-sized fraction, from 0.3 to 7.0 percent of the whole. The means are nearly centered between each set of extremes.

The three histograms for 3P.1, 11P.21 and 16P.3 given in Figure 3, p.54, show the different size relationships present within the member proper. The histogram for 11P.12, also in Figure 3, shows the transitional nature of the Penitentiary-Gunn contact as expressed in a bimodal tendency akin to that found in the residues of the fine and coarse bioclastic limestones of the Gunn.

The quartz in these residues is present as silt and clay sized, non-regenerated grains. On some of the etched sections aggregates of clay and finer silt sized quartz particles are present, ranging up to the very coarse sand grade in size. As it was not possible to distinguish the particles from these aggregates from the finer single quartz grains, they were all placed together in the insoluble residue statistics. In one bed near the top of the member, a nodule of one-eighth inch diameter, composed of grey and red chalcedony, was noted.

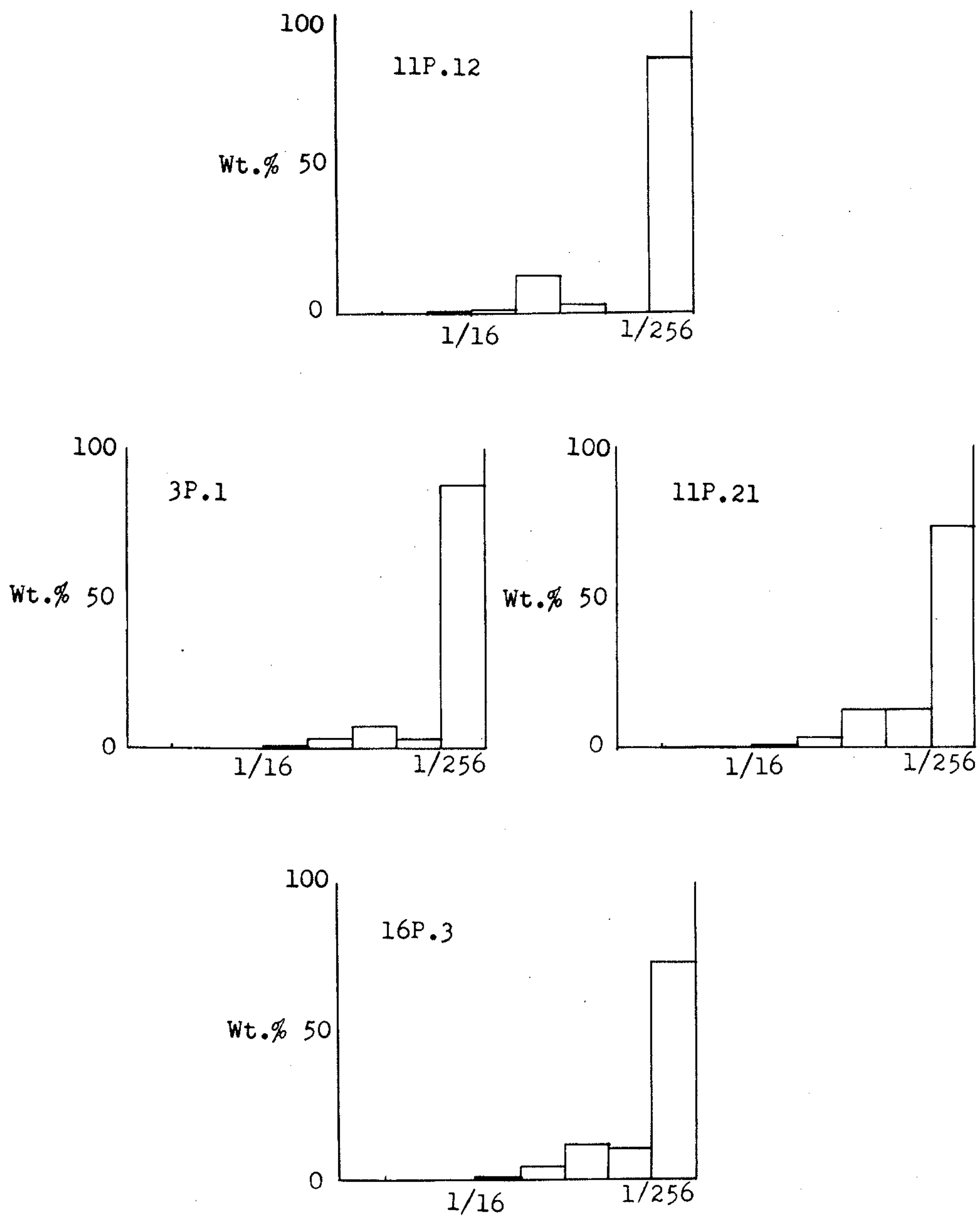

FIGURE 3

CHARACTERISTIC DISTRIBUTION OF INSOLUBLE RESIDUE PARTICLES FROM THE PENITENTIARY MEMBER

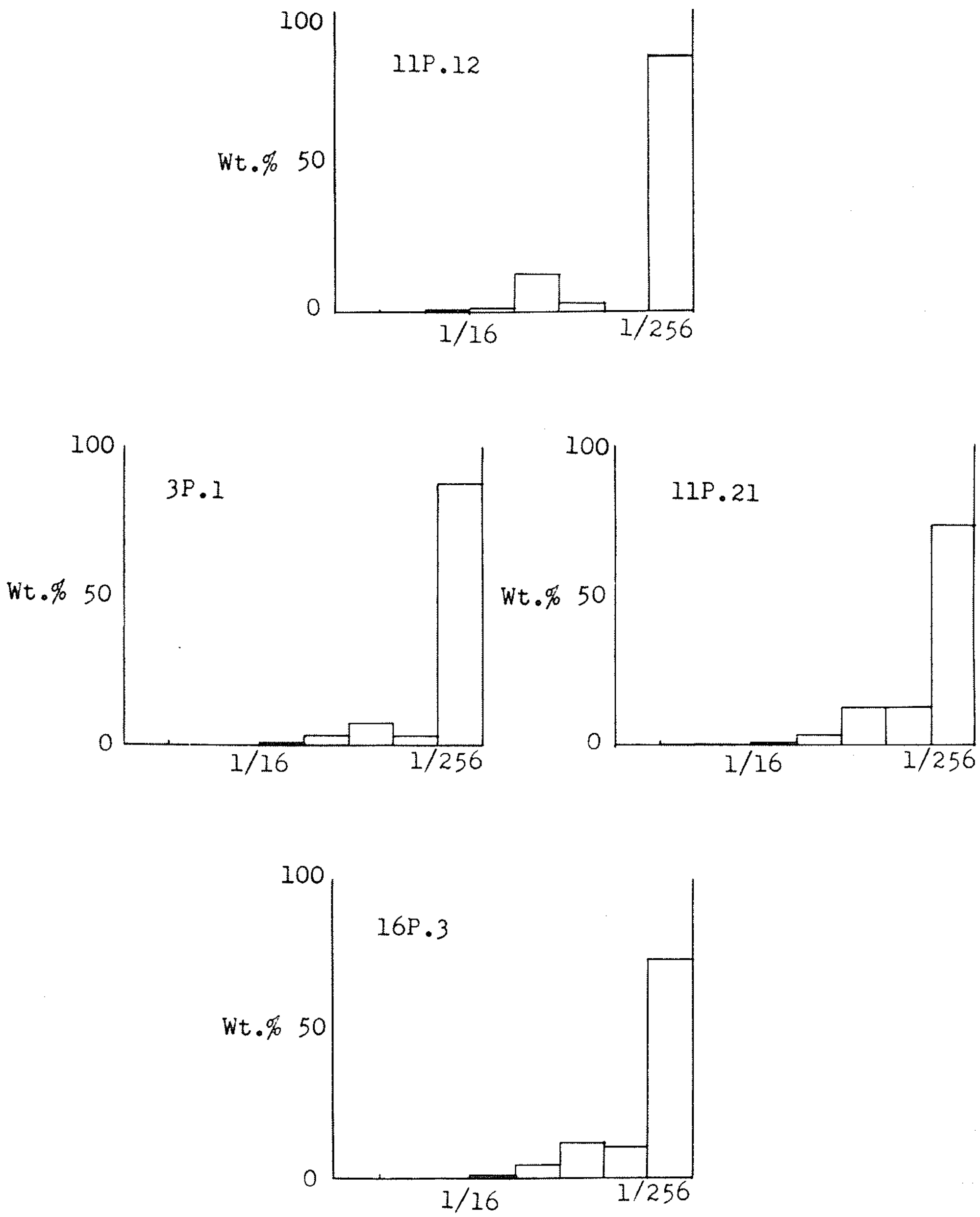

FIGURE 3

CHARACTERISTIC DISTRIBUTION OF INSOLUBLE RESIDUE PARTICLES FROM THE PENITENTIARY MEMBER

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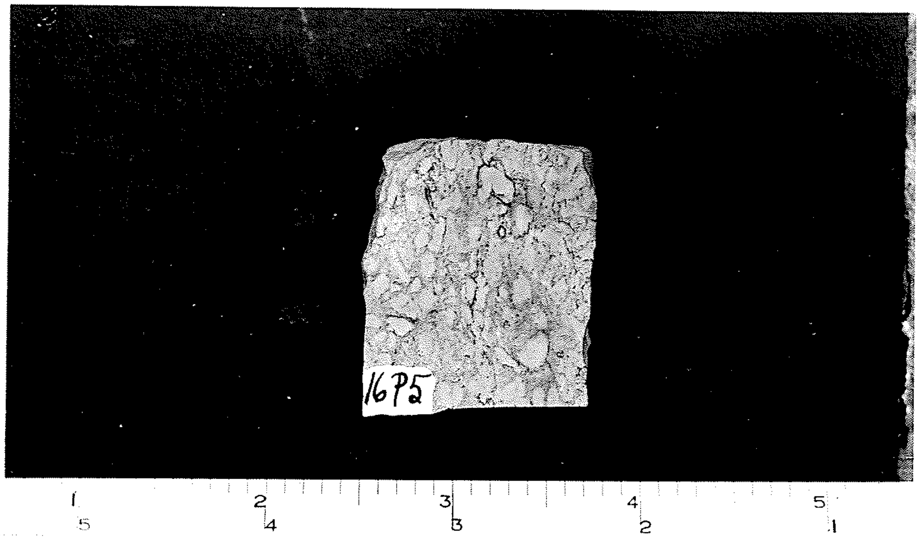
PLATE VIII

A. and B. Thin sections exhibiting the occurrence of hematite-limonite as fossil fragment replacements and local infilling or fracture filling. (20X). (16P.11).



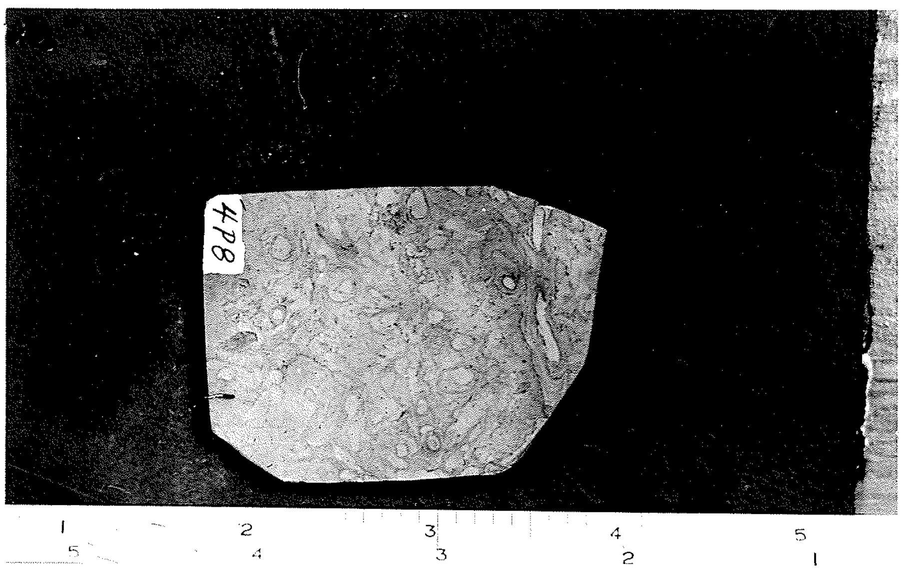


PLATE IX

A. Etched section of a yellowish-green, maroon and light purple dolomite which exhibits mottling due to burrowing. (16P.5).

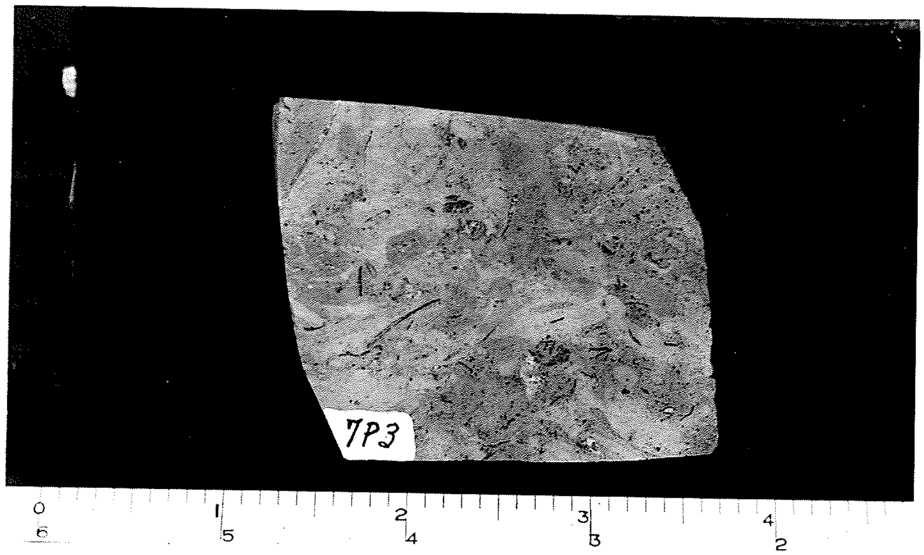
B. Etched section of an ocherous yellow dolomite which exhibits mottling due to burrowing. (4P.8).

usually extending in from the bedding planes, to flecks and patches of deep rust-red and orange scattered within the rock.

The rocks are almost all visibly fossiliferous to some extent, despite dolomitization. The lower third, just above the Gunn member, is most abundantly so, with the upper third in the northern part of the area showing only traces. The remains occur as clear sparry calcite masses after calcareous shells, as in Plate X A, p.59, or as internal and external molds when the calcite has been dissolved. The most common types are those of brachiopods. These brachiopod shells are almost invariably unbroken and are often articulated. When articulated, they are filled with the same sediment as that surrounding them.

The beds of the Penitentiary member range from one inch to twelve inches in thickness, with most from three to eight inches. In the lower two-thirds of the unit, the beds are massive with slightly irregular or nodular bedding planes. In the upper one-third, the bedding is very irregular due to slight to extreme nodularity. This is especially noticeable in the uppermost beds at Location 16, the East Gunton Quarry, as illustrated by Plate X B, p.59.

Some solution "porosity", not due in the main to fossil calcite solution, is found in cavernous, rotted and



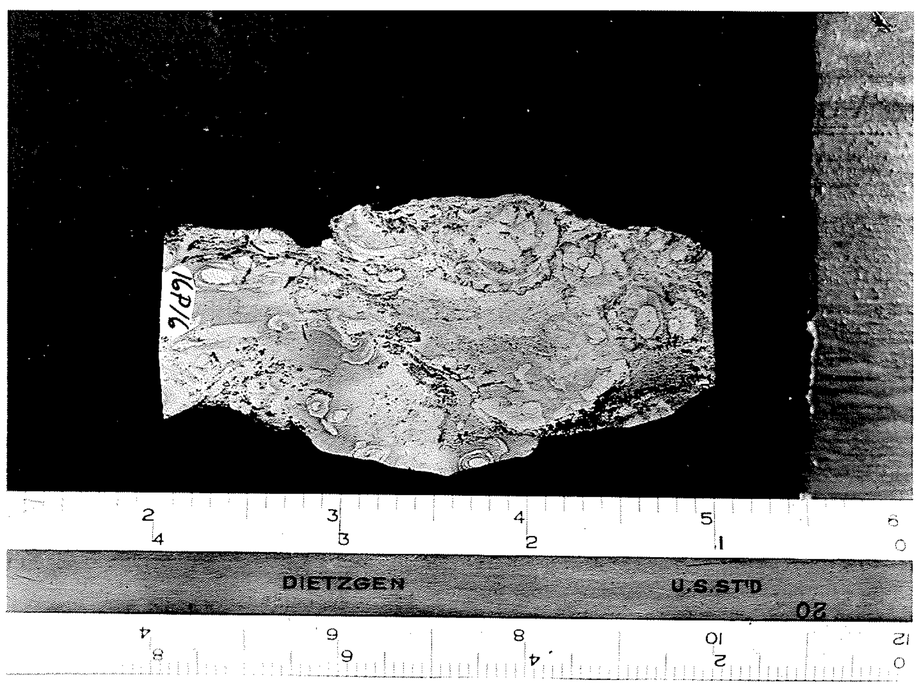


PLATE X

A. Etched section of a light grey-green and ocherous yellow, argillaceous dolomite containing sparry calcite fossil remains. (7P.3).

B. Etched section of a light purple, very argillaceous, nodular dolomite. (16P.16).

very weathered portions of beds, which are brightly coloured by varying amounts of the iron oxides.

SEDIMENTATION

Although dolomitization in the Penitentiary member has destroyed most of the indicators of depositional environment, enough has survived to give a good general picture of conditions at that time. The types, sizes and positions of fossil remains, the size-range and distribution of the insoluble residues, the fineness and completeness of dolomitization, the more or less massive character of the beds with only fine nodular variations and the irregular but smooth sided shapes of these nodules give a picture of an environment of deposition situated in the open sea and being supplied with finer size material, yet just far enough below average wave base that only the heaviest storm waves could substantially disturb the sediment.

The size of the fossil shells, and their being filled, when articulated, with the same sediment that surrounds them, shows life and deposition in an open sea and deep water, fine sediment environment. Although the disarticulation of some shells could be due to wave energy, it seems more likely to be the work of scavengers, abundant evidence of whose burrowings can be seen in the upper portion of the member due to hematite mottling. That this burrowing is not seen except in beds containing abundant hematite suggests only that sufficient iron oxide to outline them is not present elsewhere in the member.

The relative lack of fossil remains in the uppermost beds of the Penitentiary member in the northern part of the area seems to be due to a greater amount of burrowing and the formation of more abundant and smaller nodules than in the southern part of the area. This type of greater energy environment would not be as favourable either to life or to preservation of fossil remains.

The ubiquitous insoluble residue suggests a continuous supply of terrigenous sediment into an open sea area and, by its thorough mixture with the calcareous sediment, that both sediment types were approximately the same size range. If the calcareous sediment was coarser, then the same environment that produced it would not allow a large component of clay-sized terrigenous sediment to remain. The fineness and near completeness of dolomitization also argue for a finely divided sediment whose much larger surface area facilitated the change both as to access and time, especially as dolomitization tends to coarsen the grain size when starting from a finer calcareous sediment (A. V. Carozzi, 1960, p. 269). In addition, some of the beds, especially near the top of the member, are composed of irregularly shaped, but smooth sided nodules which suggest finer original sediment, namely lime muds and terrigenous fine silt and clay sized particles.*

The few, small, semi-nodular structures also suggest fine sediment. In the case of 11 P .12, the transition from Gunn to Penitentiary members is evident in the sublithographic to very fine crystalline dolomite, probably derived from a sediment similar to that of the coarse bioclastic limestones, and in the sublithographic dolomite of the slightly elongate semi-nodules, identical to that in much of the Penitentiary member. The presence of faint, irregular laminations in the coarser portion suggests intrastratal movement, perhaps due to unequal compaction of a thin Penitentiary-type bed overlain and underlain by the last examples of Gunn sedimentation.

The aggregates of clay and finer silt sized particles of quartz, which are scattered on some etched sections of the Penitentiary member, could have been formed from floating masses of wind blown quartz, if allogenic, and would then

* As conditions were such, during deposition of the overlying Gunton member as to leave distinctive evidence of the pattern and causes of the nodularity often found in that member, and, as the nodularity of the Penitentiary member, although less distinct, is considered of like type and therefore of like genesis, the detailed discussion of that feature is left to the next chapter.

suggest a very quiet environment of deposition; but if authigenic, they have no sedimentational significance. As the origin of these aggregates could not be determined with any certainty, the question remains open.

DIAGENESIS

Following sedimentation, certain changes occurred within the unit which produced the rock now found in the outcrop. Some of these took place almost at once and some not until the late cenozoic.

One of the first changes was the recrystallizing of calcareous shells to fine to coarse crystalline, clear sparry calcite.

The most important change to occur, however, was the almost total dolomitization of the whole unit. This process resulted in a sublithographic mosaic texture of dolomite crystals which obliterated all earlier features of the calcareous sediment from which it formed. It has been suggested that most of this calcareous sediment was a lime mud, which would therefore contain a large percentage of entrapped sea water. The fine particle size and the nearness of the necessary solutions would have allowed a relatively rapid and complete development of a fine euhedral and subhedral dolomite mosaic. Evidence from thin sections shows that even after this alteration of the lime mud, sufficient magnesium was present in the proper form to continue the dolomitization process, this time attacking or continuing to attack the coarser fossil fragments, as illustrated by Plate VII A, p.52, As many of these had already altered to sparry calcite, and all had a larger size, the process was slowed and many euhedral and subhedral crystals were formed with a range of size up to very fine crystalline.

Perhaps those areas which show only partial dolomitization of sparry calcite fossil fragments record the depletion of all available magnesium. Whether any of the finer calcareous sediment had crystallized first to sparry calcite cannot now be determined, but the overall fineness of the mosaic contrasted with areas of known sparry calcite dolomitization suggests not.

Evidence from the subsurface shows that the bright and even brilliant colours so noticeable in this unit at the outcrop are of relatively recent origin. In Ross (1947, p.447M) and Andrichuk (1959, p. 2373) reference is made to the"dark green", "green" and "green-gray" colours seen in the subsurface wherever rocks equivalent to the Penitentiary member were found. This suggests that from the time of deposition, the iron of the insoluble residues has been present in the ferrous state, very finely disseminated throughout the rock.

The most abundant surface colour is an ocherous yellow, which would represent the oxidation of the disseminated iron to still disseminated and diffused limonitic compounds. However the upper part of the unit shows an abundance of colour variations on red, suggesting a greater abundance of iron in the rock and oxidation only to hematite, even though cavernous weathering is occasionally seen.

Some of this hematite may have been originally pyrite, especially that now seen as aggregates. This is suggested by the outlining of the extensive burrowing by the red colours while the interiors are usually greenish, perhaps due to some entrapped organic matter, and especially by the ghost hematite outlines of fossil fragments now completely enclosed in the dolomite mosaic, as in Plate VIII, p. 56.

CHAPTER V

GUNTON MEMBER

TERMINOLOGY AND STRATIGRAPHIC RELATIONS

The Gunton member was named by Okulitch (1943, p.60), who placed the type sections at the City of Winnipeg Quarry - Stony Mountain, at the Little Stony Mountain Quarry, (Location 2 of this thesis), and at the Gunton quarries.

Overlying the fifteen to nineteen foot Gunton member Okulitch placed a Birse member (1943, p.63), whose type sections are - the Birse Quarry section, (Location 12 of this thesis), the upper portion of the sections at the Gunton quarries and a five foot section of porous dolomite at the Stonewall Quarry, below a red, nodular bed. Stearn (1956, p.11), on the other hand suggested a correlation between the Birse Quarry units and the main quarry beds at Stonewall above the red, nodular bed. Baillie (1952, p.20) considered that the principal Birse member type section is equivalent to a part of the Gunton member, and included it and the upper Gunton Quarry beds in his redefined Gunton member. Aided by a bore-hole at Stonewall, Baillie indirectly suggested that no correlation exists between the Birse section and any of the Stonewall Quarry beds.

The writer is in agreement with this part of Baillie's redefinition for the following reasons. The lithologic and structural variations cited by Okulitch are entirely local within the middle part of the Baillie's Gunton member and are not found at those other localities where the upper Gunton is present. The extent of these variations in an eastward direction is not known, due to erosion, but they may originally have been much more widespread.

The other reason for the differentiation of an upper Birse and lower Gunton members was the overall faunal variations, especially in numbers and types of Beatricea and in the existence of cephalopod remains. During the present study, cephalopod remains and a large Beatricea nodulosa (S. J. Nelson, 1959, pp.60-61) were found well down in Okulitch's Gunton member, and many Beatriceas were found in early quarrying at the City of Winnipeg Quarry, Location 11, where only the lower part of the Gunton is present, (E. I. Leith, personal communication), thus considerably blurring this difference. The relative abundance is undoubtedly less in the lower portion of Baillie's Gunton member, but this is due to adverse ecologic conditions, (see 'Sedimentation', p.60).

Other evidence supporting the redefinition was uncovered during the study of the insoluble residues for the unit. Except for the continued effect of Penitentiary sedimentation in the lowermost beds, the variations in the sand size, silt sized, clay sized and total residue amounts do not show any distinct change, either locally or over the whole area, within Okulitch's Gunton-Birse interval.

Baillie's redefinition, however, went further than an integration of the two members into one. From the Stonewall bore-hole (A. D. Baillie, 1952, p.20) he described a section of "arenaceous and argillaceous" beds which overlies Okulitch's Gunton-Birse section. As the contact between the two sections appeared to be gradational he grouped them together into his Gunton member.

In this thesis, however, the Gunton member is restricted to those beds below the "arenaceous and argillaceous" beds and above the Penitentiary member. The "arenaceous and argillaceous" beds are named the Williams member, because of their lithologic distinctness and the abrupt lithologic change that does occur at their base. This matter is given a more detailed discussion in Chapter 6, where the Williams member is defined.

The upper contact of the redefined Gunton member is abrupt, although sedimentation was continuous, and the lower contact is gradational, sometimes over an interval of one foot. The thickness of the member as measured from two cores cut at Stonewall is thirty feet, four inches.

DETAILED PETROLOGY

Examinations of etched sections and thin sections were used, along with the insoluble residue data, to obtain petrologic information about this member. Field study of the quarry and outcrop sections gave information on the various structures found within and between the beds.

The Gunton member is composed almost entirely of one rock type with the principal variations within the unit being mainly due to the different structures. This predominant rock type is a sublithographic and minor very fine crystalline dolomite. It is composed of a mosaic of dolomite crystals of which only a trace to a very minor part are euhedral and only slightly more are subhedral. The only exception found occurred in four thin beds within two feet of the middle of the member at Locations 11 and 17, where the crystals of the mosaic are sublithographic and very fine crystalline in size, with traces of the fine crystalline size. There are very minor euhedral but abundant subhedral crystals. An illustration is given in Plate XI, p.70.

In some of the thin sections, scattered areas are found which are most often of medium crystalline size, but range up to very coarse crystalline. These carbonate areas show optical continuity by exhibiting equal extinction over the whole area. They characteristically contain abundant, scattered, irregularly shaped inclusions of single dolomite crystals and small areas of several crystals. Plate XII, p. 71, shows one of these areas.

The insoluble residues of the Gunton member compose only a small proportion of the rock ranging from 0.5 percent

Up.

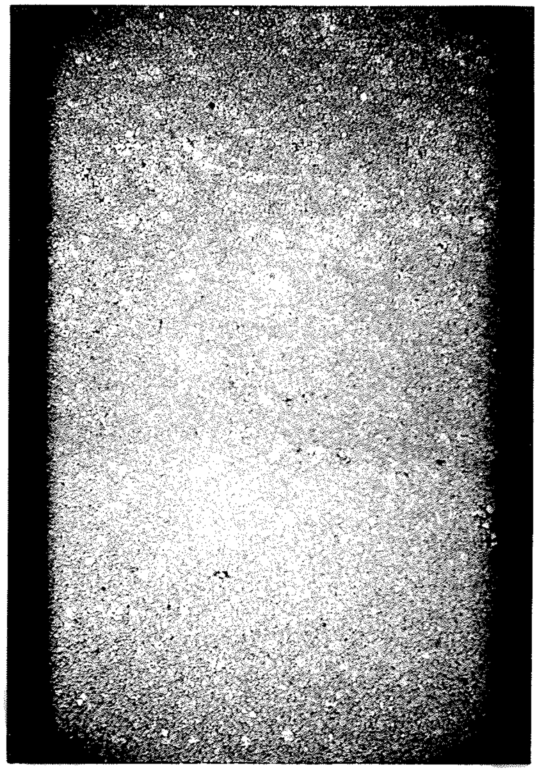


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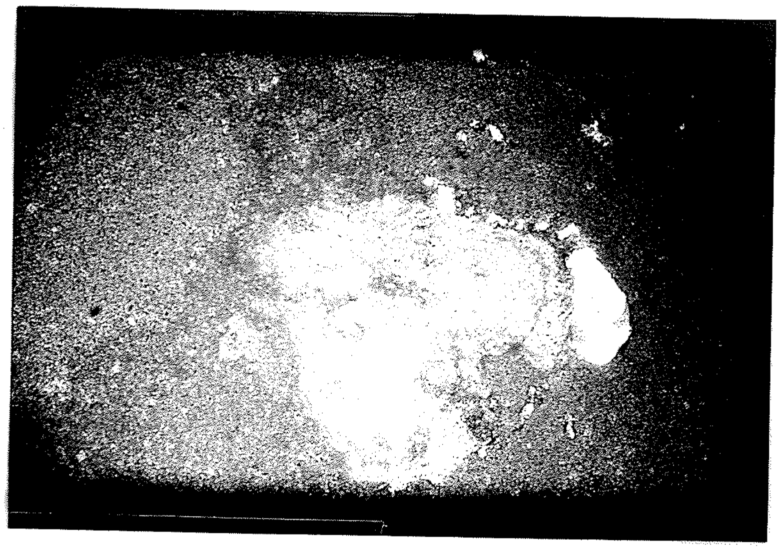
PLATE XI

Thin section of the contact between dolomite crystal mosaics of different average sizes and shapes. (20X). (11Gt.45).



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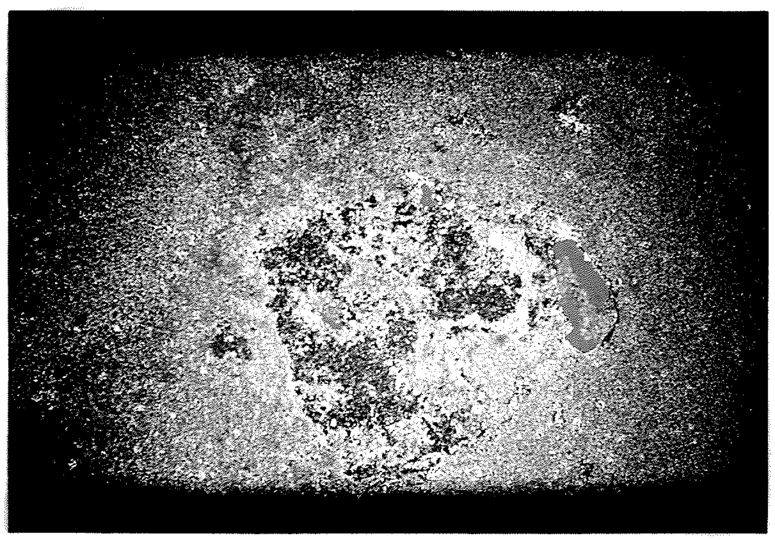

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PLATE XII

A. Thin section of a carbonate area containing abundant, irregularly shaped inclusions of single or grouped dolomite crystals. (18X). (9Gt.6B).

B. The same area under crossed Nicols showing optical continuity. (18X).

to 5.6 percent throughout all but the lowermost portion of the unit. The clay sized range for the same rocks is from 0.3 percent to 3.7 percent of the whole rock, the silt sized, from less than 0.1 percent to 3.4 percent and the sand sized, from 0.0 percent to 0.2 percent. In the lowermost beds, the effect of Penitentiary sedimentation lingered, giving a total residue range of from 7.0 to 11.5 percent.

The histogram for 3Gt. 3, given in Figure 4, p.73, exhibits this "Penitentiary effect", while the other eight given in Figures 4,and 5, p.74, are representative of the various distributions found in the remainder of the member.

Quartz is by far the most common residue mineral, usually forming all of it. It is present almost entirely as silt and clay size grains and a minor to very minor part of these are regenerated. In several units, the regeneration has produced silt sized, well-formed, prismatic quartz crystals which may make up one to two percent of the residue. The larger grains in several samples show a ragged outline, some due to uneven regeneration. Several perfectly regenerated sand sized grains show "frosting" and pitting. Another stubby, fully regenerated, sand sized quartz grain has its entire central portion missing, with the edges around the cavity being very ragged. The hole is elongated with the grain.

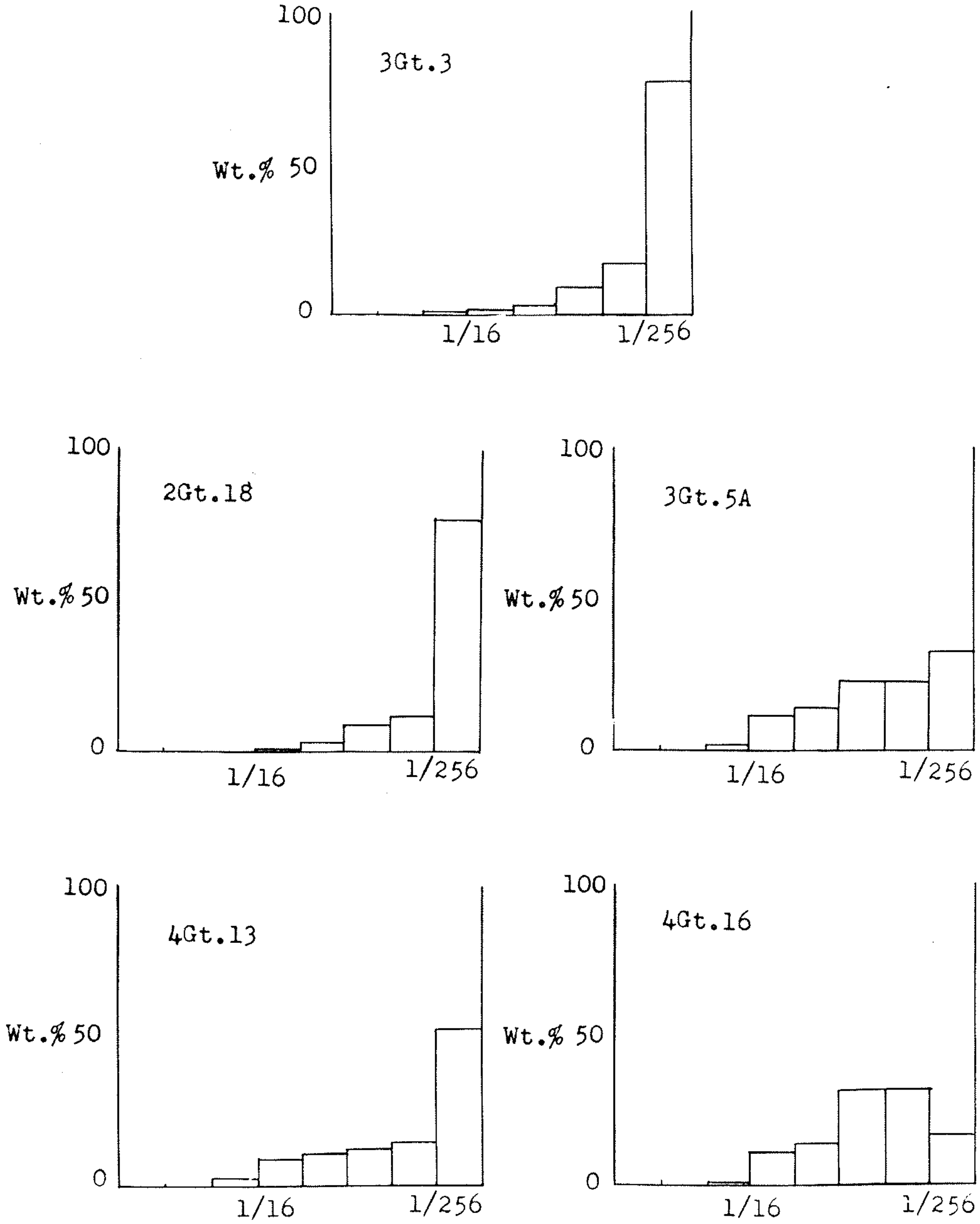


FIGURE 4

CHARACTERISTIC DISTRIBUTION OF INSOLUBLE RESIDUE PARTICLES FROM THE GUNTON MEMBER-PART I

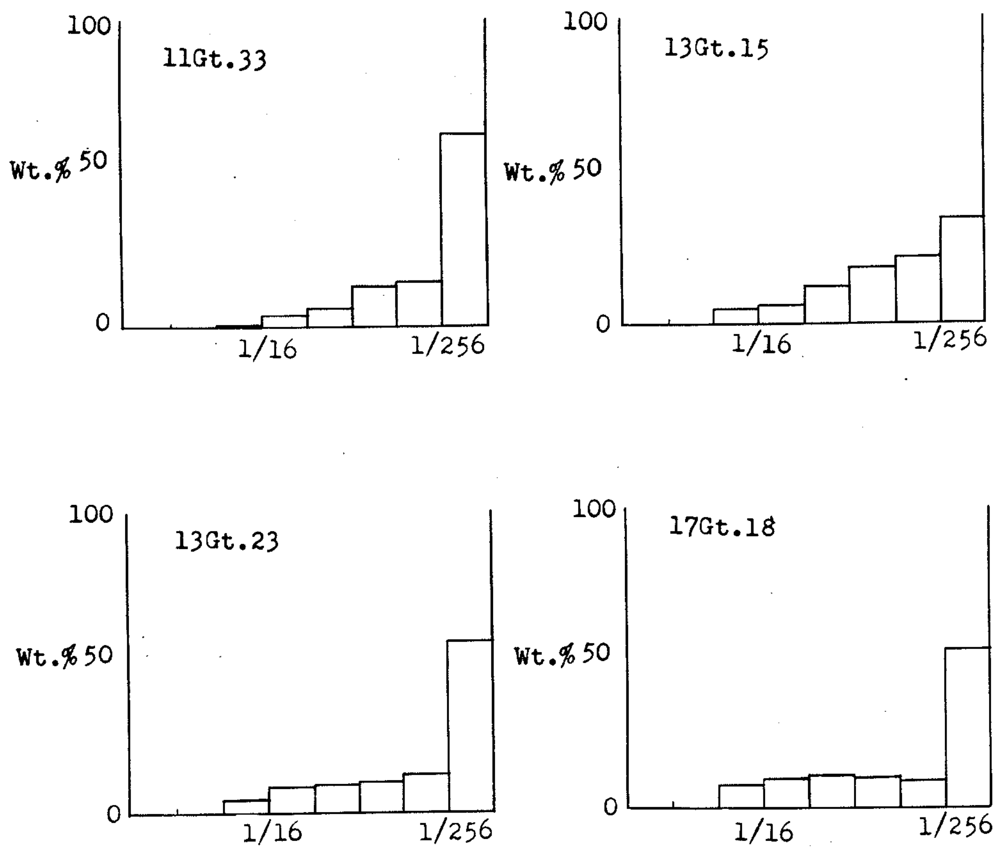


FIGURE 5

CHARACTERISTIC DISTRIBUTION OF INSOLUBLE RESIDUE PARTICLES FROM THE GUNTON MEMBER-PART II

The iron oxides are present as hematite and limonite with pyrite. The hematite occurs either as lacy aggregates up to coarse sand size or it is diffused through the rock giving it a red colour. In most beds there is no hematite, but if present, it occurs in amounts ranging from traces to, in one case, five percent of the residue. The limonite, when present, is suffused through the rock giving it a yellowish tone.

The pyrite occurs as single disseminated crystals or aggregates. These aggregates have nearly the same lacy pattern as some of those formed of hematite. Pyrite occurs less often than hematite, but ranges, when present, from traces to thirty percent, (13Gt.1), of the residue.

The finer clay sized residue is usually pale grey-green, probably due to ferrous iron.

Etched sections and thin sections show hematite, and rarely pyrite, to be disseminated through some beds, with hematite concentrated along some nodular contacts.

Additional facts about the Gunton member were obtained by macroscopic study and are now given. The colours within the unit are many but in general they are variations on light tan, brown and yellowish-grey or light greyish and yellowish-brown, with a lesser appearance of light greenish-grey. More rarely, and in the lower two-third of the unit only, light rose-red occurs. It is characteristic of the very nodular units at the Gunton quarries. Light to medium grey was found in a few beds in the New Stonewall Quarry, (the Lily Pit), associated with much disseminated pyrite. Purple and maroon weathering colours are rare, occurring as streaks in the rocks; and the ocherous yellow and lesser orange colours, characteristic of weathering in the Penitentiary member, are confined to the gradational beds at the base of the member. Approximately one-third of the beds in the Gunton are mottled or slightly mottled, with the mottles usually being a slightly darker and browner shade than the surrounding material, as in Plate XIII A, p.77.

The thickness of the bedding in this member varies, ranging usually from one inch to ten inches, but with a very few beds ranging from nine to eighteen inches. There is also a twenty-one inch bed and a thirty-eight inch bed present in the lower part of the section at Location 11. The Gunton beds are approximately one-half of a massive nature and one-half of a nodular nature. The nodules range in diameter from approximately one-quarter inch to two inches in the lower two thirds of the member and from approximately three-quarters of an inch to two and one-half inches in the upper third, as illustrated by Plate XIII B, p.77. Due to the almost equal number of massive and nodular beds, the bedding planes of the Gunton range from irregular to slightly nodular to nodular.

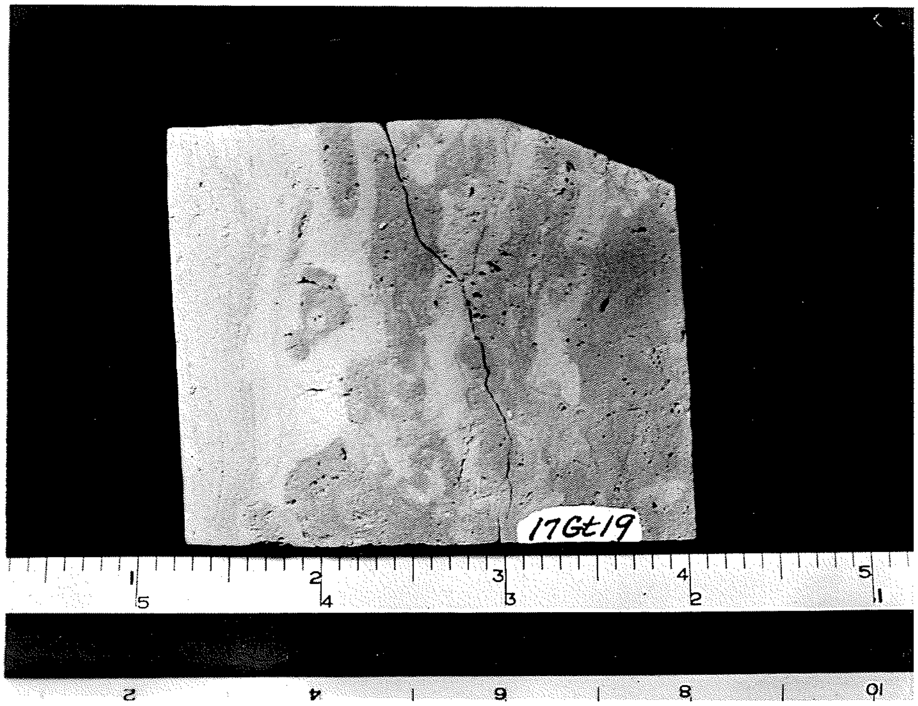


PLATE XIII

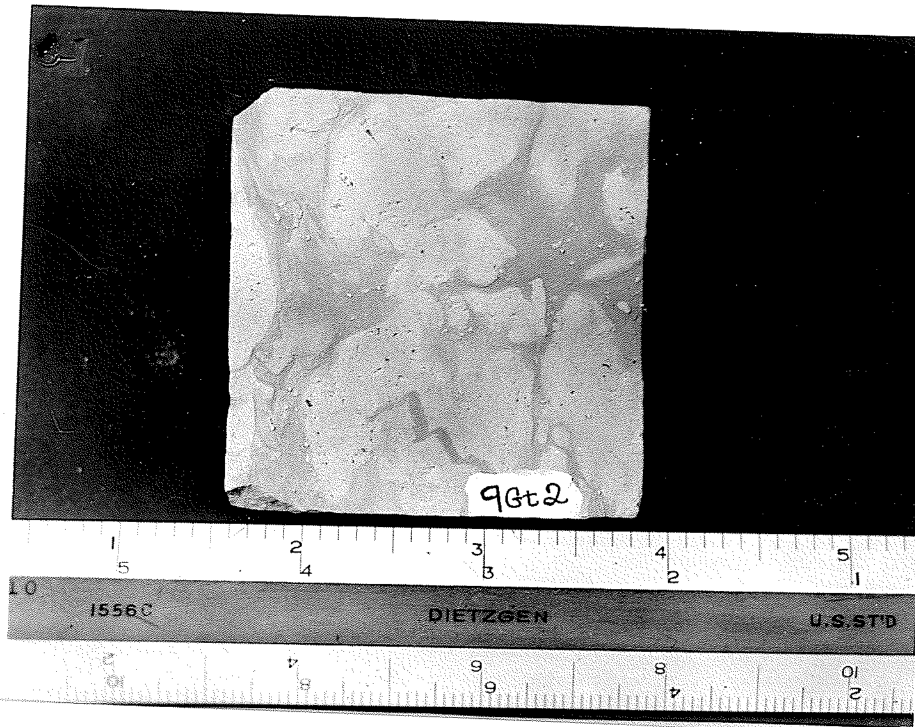
A. Etched section of a mottled dolomite with darker and browner mottles. (17Gt.19).

B. Etched section of a nodular dolomite with abundant green shaly partings. (13Gt.22).

In the lower one-quarter of the member, in the southern half of the area, there are a few beds which exhibit a faintly to very brecciated appearance. As shown by Plate XIV, p.79, the "fragments" have a lighter colour than the matrix. With these beds there are considerably fewer nodular beds than in the equivalent portion of the section at the Gunton quarries to the north and there are the same number of beds in the southern area as those with a brecciated appearance that can be called hard and even brittle. These "hard", homogeneously sublithographic beds are not present in the northern quarries. In the middle portion of the member there are no brecciated beds but the ratio of nodular to massive structures is still greater in the northern portion of the area. These several variations are discussed in more detail in the "Sedimentation" section.

The porosity in the outcrop and quarry sections of the Gunton member shows a marked variation going upward in the section. The lower third of the unit is generally tight and shows only scattered fine porosity, with the exception of vugs and cavities due to solution of anhydrite (?) and salt. The salt solution pores take the form of well to poorly formed hopper molds, which are present only in the lower three feet at Location 4.

The middle portion of the member has more scattered to abundant solution vugs and pores due to the solution of



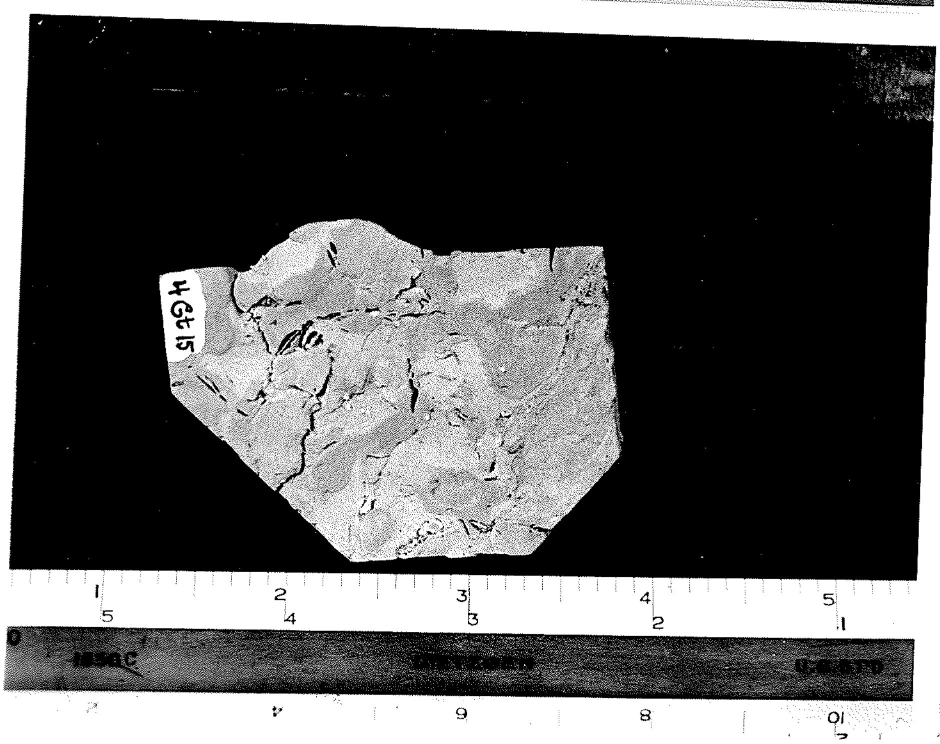


PLATE XIV

Etched sections of light greenish and yellowish-grey dolomites with a brecciated appearance.

A. - 9Gt.2.

B. - 4Gt.15.

fossil remains. In the upper portion, over two-thirds of the beds have some noticeable porosity, with the uppermost beds being vuggy due in large part to solution of the abundant fossils.

In the lower portion of the unit only very scattered fossil remains are found but these increase in abundance going upward. Between nineteen and twenty feet from the base there is an especially fossiliferous bed in the middle of which, at Locations 12, 12A and 13, numerous Aulacera undulata (S.J. Nelson, 1959, pp.58-61) were found. At the very top of the member there are several beds containing abundant fossils, especially corals.

Other macroscopic features and materials present in lesser amounts will now be outlined. On most nodular surfaces there is a thin film or parting of grey-green clay and fine silty sediment as in Plate XIII B, p.77. It can be irregular as to distribution and thickness or can cover the entire surface evenly. If the thickness is uneven, the green sediment is thinnest on the high areas of the uneven nodular surface and thickest in the depressions, even to the point of forming tiny "blebs" if the sediment is abundant. The greatest abundance was found in the upper third of the member.

Pyrite is present on the joints, cracks and bedding and nodular planes in some parts of the unit, as single disseminated crystals or as crystal aggregates. It is most abundant in the lower third of the unit occurring only as traces in the remainder, with very rare exceptions. It is especially abundant in the lower beds at Location 13.

Small chert nodules are sparingly present especially in the middle of the unit and at Locations 12, 12A and 13. The abundant remains of Aulacera, cited above, are silicified with chalcedony and now have a white, powdery, devitrified coating.

In the lower and middle portions of the unit, a very few two to two and one-half millimeter crystals of clear anhydrite or selenite were found. In the middle and upper parts are very sparsely distributed square pores ranging in size from one to six millimeters across. They show no signs of iron staining.

SEDIMENTATION

The contact between the Penitentiary and Gunton members is marked by a gradual change from an abundance of terrigenous sediment to relatively very little and from sedimentation in deeper marine waters to shallower and more restricted conditions of deposition. Whether it is a coincidence that both occurred at the same time, or whether the building of shoals near the thesis area (J. M. Andrichuk, 1959, p. 2380) and the large decrease in the availability of terrigenous sediment are related, is not known. Possibly the marked decrease in amount of terrigenous sediment allowed the production of organic carbonate sediment, which built the shoals or near-shoals and supplied much, if not all, the finer carbonate muds, by allowing more abundant life to thrive.

In any case, by the time the last effects of Penitentiary sediment had ended shoal areas had become established and were producing restricted conditions in certain of the inter-shoal areas. The entire thesis area was in one of these inter-shoal areas, except perhaps at the very end of Gunton time, and exhibits the effects of fine sediment production in not very deep marine waters at the northern end and restricted, locally semi-evaporitic conditions at the southern end.

In the lower six feet of the Gunton beds, at Locations 2, 3, 4, 8, and 11, there is evidence of semi-evaporitic deposition. Between approximately two and three feet and again between four and six feet from the base of the member there are dolomite beds exhibiting a slightly to very brecciated appearance. The beds are not very porous, unless they are at the pre-quarry erosion surface. Almost all the other beds in these five sections exhibit either abundant fine porosity or scattered to abundant solution pores and cavities although most beds in the lower Gunton of the thesis area are tight. Most important of these porous beds are those between two and three feet at Location 4, which show abundant well to poorly formed salt hopper molds, and the lower twenty inches at Location 4 and 8, which show scattered, poorly formed hopper molds. A scattered trace of one and one-half to two and one-half millimeter anhydrite-selenite(?) clear crystals was found from four to five feet in the sections of Locations 4 and 13, but these crystals may be authigenic.

As the south and north ends of this semi-evaporitic area, at Locations 2 and 13, there are two groups of hard, sublithographic dense beds of dolomite, some of which break with a near conchoidal fracture. These occur at the same position, respectively, as the lower hopper mold and brecciated beds and the upper brecciated beds of Location 3 to 11. These dense beds are probably due to the deposition of sublithographic, primary dolomite crystals, as later dolomitization would have produced coarser crystal sizes (A. V. Carozzi, 1960, p.269).

Above the Penitentiary-Gunton transition beds at Location 11 are the two thickest beds in the Gunton member. They are twenty-two and thirty-eight inches thick and are brecciated or very porous. It is probable that this lack of bedding is not a primary feature but came about due to the collapse of the beds during evaporite solution. It also appears that the porous beds are not brecciated because they contained a smaller amount of evaporites and had sufficient strength not to collapse during and following solution. As the deposition of evaporites during lower Gunton time was of a local and sporadic nature, and as succeeding deposition shows almost no signs of evaporitic conditions, and especially as the beds next above any brecciated bed do not show any collapse features and the brecciated beds themselves suggest that some of the sediment involved was still relatively unconsolidated, the solution of these evaporites and the resultant brecciation occurred entirely within lower Gunton time before the deposition of the next succeeding bed.

While evaporitic conditions existed in the south-central portion of the thesis area, the northern area was receiving very fine carbonate sediment only. This sediment was deposited in alternating bands of massive and nodular beds, as shown in the lower right hand portion of Plate XV A, p.85, which indicate conditions of deposition just below and just above, respectively, the depth to which storm waves could reach in this inter-shoal area. Very little eustatic change or a very small decrease or increase in the rate of production of sediment would have been sufficient to change the bedding structure from nodular to massive and back again.

The nodules themselves are amorphous, fitting between one another in such a way that they must have been composed

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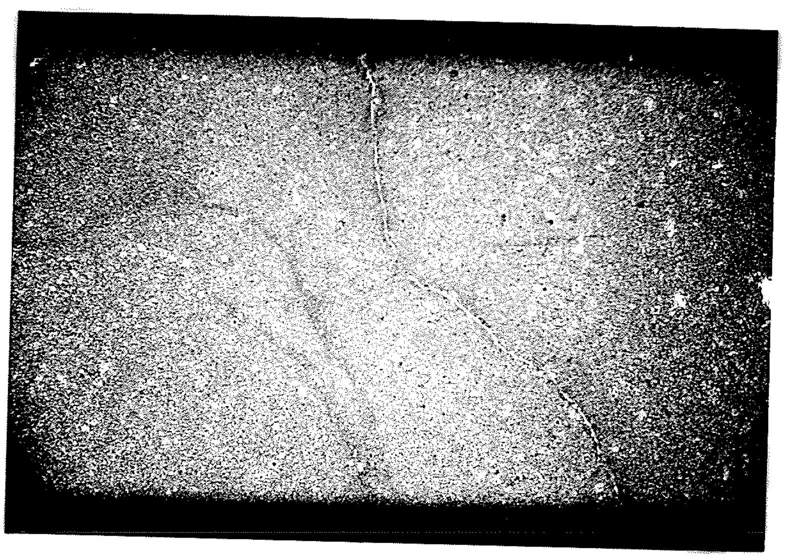


PLATE XV

A. The Gunton member section at Location 16, the East Gunton Quarry.

B. Thin section across nodular boundaries, with no variation in average crystal sizes. (Approx. 20X).

of only slightly adhering sediment when they were deposited, yet sediment that adhered sufficiently to give the characteristic nodular surface. Such "blobs" also must have been composed of very fine calcareous sediment, a conclusion which is supported by the occurrence of whole, coiled gastropod shells and by the sublithographic texture of the present dolomitized rock. As illustrated in Plate XV B, p.85, the average dolomite crystal sizes do not vary across nodular boundaries.

The nodules are separately distinquishable today as there is usually a thin coating or film of light greyish-green clay and fine silt sized particles between them. In some cases the green sediment forms an evenly distributed film, but often it is found to have been removed from the higher knobs of the nodular surface and to be collected in the lower hollows. This seems to indicate that the storm waves that scooped up the nodular "blobs" from a layer of fine sediment and then deposited them, also took the finer insoluble residue clay and silt sized particles into suspension or introduced them from outside the area. After the storm's passing, the finer sediment would slowly flocculate onto the newly formed nodular surface producing the coating. If sufficient gentle wave energy remained, this material was washed off the higher portions of the surface and accumulated in the hollows.

It is possible that the presence of a green coating, once established, would aid storm waves in scooping up nodular "blobs" from a fine sediment layer deposited since the last effective storm, by inhibiting adhesion between the nodular carbonate sediment and the new carbonate sediment.

An indication of the storm energy associated with the nodules is given by the occurrence of a large Beatricea nodulosa lying on its side, yet of sufficient diameter to fill an entire bed otherwise composed of small nodules. This would represent a whole history of storms, the first of which toppled the Beatricea from its base on a massive bed and may have rolled it.

As Gunton sedimentation continued the ratio of nodular to massive bedding declined, until the upper third of the member there was more massive bedding produced than nodular. Also, the general distinction between nodular and massive bedding became less noticeable, with the average size of individual nodules now larger. At the same time, the strong eustatic sea level changes became less numerous but more definite, so that, as well illustrated on the left side of Plate XV A, p.85, noticeable breaks in the sedimentation occurred. These interruptions mark a comparatively sudden, relative lowering in sea level which allowed the wave energy to produce a zone of small nodules with abundant green coatings. During this period very little fine carbonate sediment was able to accumulate. Then followed a gradual return to the preceding, relative sea level marked by the formation of progressively thicker and less finely nodular beds with thinner green coatings. Before the next lowering of sea level, massive beds were usually being formed. From this it can be deduced that the smaller the nodules are, the farther above storm-wave base was the depositional surface.

A different and much less common depositional situation is represented by the four thin beds at the middle of the member at Locations 11 and 17. Although only three inches thick or less, these beds are composed of a very homogeneous mosaic of dolomite crystals, shown in Plate XI, p. 70, which are the coarsest in the member in spite of averaging only fine crystalline in size. The dolomite also has a much greater abundance of subhedral and rarer euhedral shapes.

Underlying one such bed, as illustrated by Plate XVI, p.89, is a surface whose even undulation strongly suggest ripple marks. At the center of the "troughs" of these "ripples" are wedge-shaped cracks extending downward into the finer sediment below, and filled with coarser crystalline dolomite like that in the bed above. It is suggested that these cracks represent mudcracks that were developed, probably subaerially, during the rare times when at least portions of the area were exposed. This must

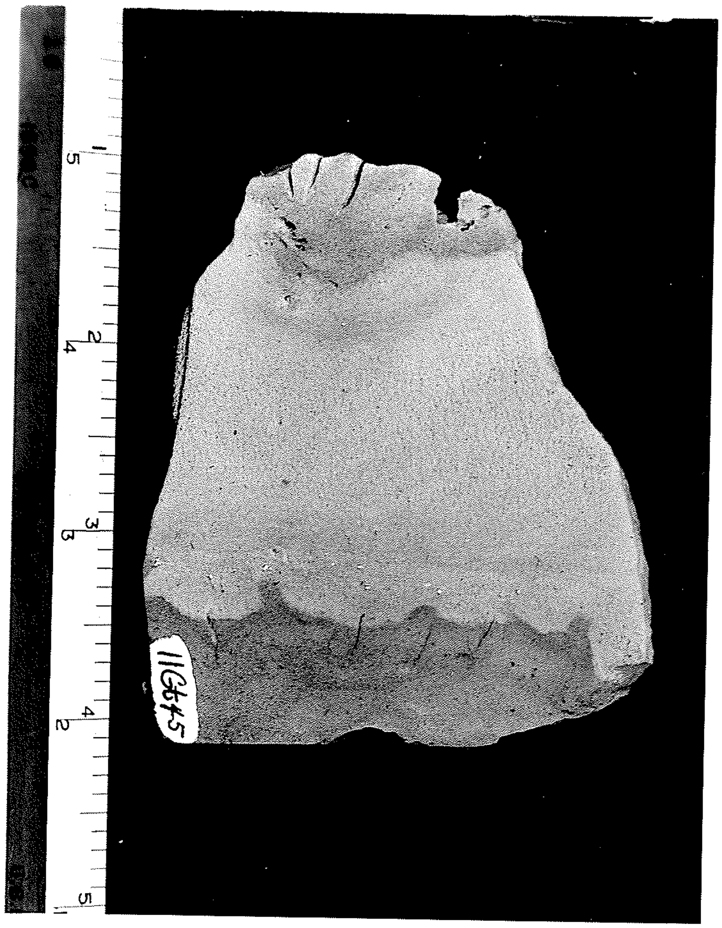


PLATE XVI

Etched section of a bed of coarser dolomite underlain by a "ripple" marked surface. (11Gt.45).

have occurred relatively suddenly, or in a very sheltered location, as the finer sediment was not removed before exposure, but merely ripple-marked. The very noticeable breaks in sedimentation in the upper portion of the section at location 16, illustrated in Plate XV A, p.85, suggest circumstances leading to a more or less complete removal of the finer, loose sediment before any possible exposure occurred.

The sediment which forms the thin beds overlying these surfaces was probably derived from the erosion of the shoal areas during these periods of shallower water. This erosion could have been caused by subaerial solution and wave action, and the beds in question would be the result of the distribution of this debris during the return to deeper waters.

Although most of the Gunton member is characterized by a relative lack of fossil remains, there are certain beds which are extremely fossiliferous. At the South Birse and New Stonewall quarries, at a level two-thirds up from the base of the member, an abundance of *Aulacera undulata* testifies to conditions that must have been very favourable for that animal during at least a short period. Whether it was so for other faunal types cannot be as easily determined, as the *Aulacera* are silicified but the remainder of the rock is dolomitized. However this bed, and those just above and below, contain abundant vugs and cavities suggesting solution of fossil remains.

The return of less favourable ecologic circumstances is shown by the finely nodular bed, containing abundant green clayey partings, which overlies the aforementioned beds.

Conditions that were very favourable for abundant life also occurred during the deposition of the uppermost three feet of the member. As exposed at the New Stonewall, Birse and East Gunton quarries these beds have abundant to very abundant solution vugs and cavities. At the South Birse Quarry the equivalent beds also contain an abundance of the skeletons of colonial corals, not yet dissolved. These beds may represent an extension of the shoal conditions into this area.

This abundant life was brought to a sudden end by the influx of large quantities of terrigenous sediment.

Although these examples of organic abundance are the most conspicuous, there are other more scattered remains. The gastropods, cephalopods and stromatoporoids are of this type, as are the circular, hollow tubules of probable organic (crinoidal?), origin that are found in parts of the section and are shown in Plate XVII, p.92.

Also found in the middle and lower portions of the member are burrows. These burrows occur in a few, thin, argillaceous beds, but are most abundant as circular or oval light grey-green mottles in more massive rock. The greenish colour is probably due to a more complete organic

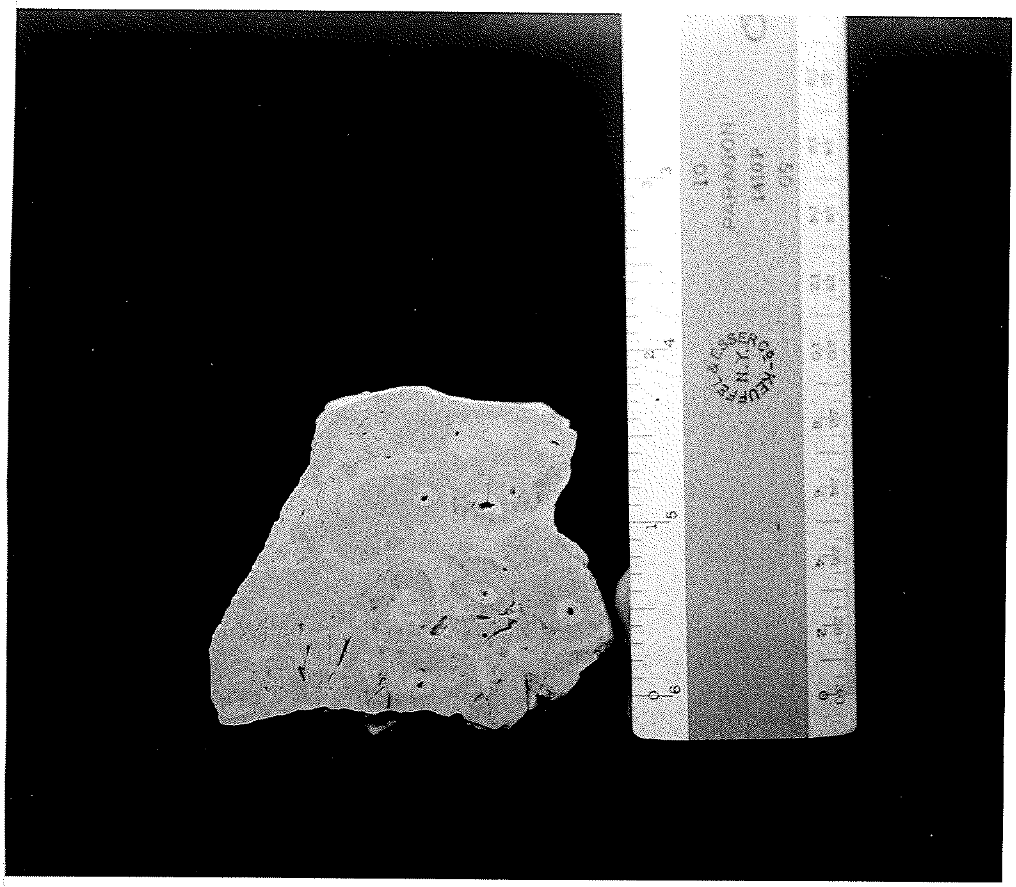


PLATE XVII

Polished section of dolomite containing hollow tubules of probable organic (crinoidal?) origin.

reduction of the iron present. They have been measured at diameters up to five-sixteenths of an inch, and are similar in appearance and size to those in the argillaceous bioclastic limestone of the Gunn member. However, in the Gunton member in contrast, these burrowing organisms were much less abundant and had almost no effect on the structures of the sediment in which they lived. This is undoubtedly another indication of the restricted marine conditions of Gunton time which were usually less favourable to abundant life.

The insoluble residues in this member are present in such small amounts that they are completely incidental to the sedimentation.

DIAGENESIS

By far the most significant diagenetic alteration that occurred in the Gunton member was the nearly complete dolomitization of the unit. The process produced rocks with a very consistent dolomite mosaic size of sublithographic with minor amounts of very fine crystalline. The only exceptions to this, regardless of the structures involved, are the four thin beds that are interpreted as dolomitized shoal debris following a period of emergence or near emergence. This slightly coarser mosaic, with the abundant subhedral crystals, seems to have been produced by a secondary dolomitization, probably aided by a greater than average permeability.

The hard, dense dolomites and the darker portions of the brecciated and porous dolomites associated with the semi-evaporitic deposition in the lower part of the member are possibly of primary origin. However, most of the one-third of the dolomites which exhibit mottling and those containing abundant fossil remains are certainly of secondary origin. Birse (1928, p.220) has shown that the darker mottles contain a much higher percentage of magnesium than the surrounding lighter portions, and Clarke and Wheeler (1922, p.7-13,40) show no present corals or gastropods which contain more than a fraction of the amount of magnesium present in the Gunton fossils of these types. A few beds show decisive evidence of secondary dolomitization with the mottling pattern being closely related to the bedding planes.

For secondary dolomitization to occur, it is important to have the avenues for supplying sufficient magnesium for the reaction and removing the calcium that has been replaced. As the burrows in the Gunn member proved to be important agents of dolomitization, it is probable that the light grey-green burrows in the Gunton were also. The hollow tubules that are sometimes present seem to have acted as channels for magnesium-bearing solutions as they are now found in the midst of the darker more dolomitized mottles, as illustrated by Plate XVII, p.92.

Although the darker portions of the brecciated, mottled beds are possibly of primary dolomite the lighter portions may be secondary. If so, they were dolomitized either penecontemporaneously, during the period of solution of the evaporites or during a reorganization of calcite and magnesite, if original conditions had favoured the deposition of these minerals.

In all these cases of the mottling of dolomites in the Gunton member, it appears that the process of dolomitization was not completed. It is therefore agreed that the mottling of these dolomites is "merely an incipient stage in the process of dolomitization" (F. M. Van Tuyl, 1916, p.345). Probably the unmottled dolomites of the Gunton member represent a stage much closer to completion.

Whether mottled or unmottled, these rocks usually present in thin section the rather homogeneous aspect of a very fine dolomite crystal mosaic. However, in a few sections there are areas of a carbonate mineral, each of which shows equal extinction and is therefore composed of a single crystal. An example is given in Plate XII, p.71. These crystals range in size from medium to very coarse crystalline and in turn contain abundant, irregularly shaped inclusions of single crystals and groups of crystals, each of which has the same general crystal size and shape as in the surrounding dolomite mosaic. One has even maintained a vaguely rhombic shape, although the remainder tend to be ragged in outline. The large single crystal areas are clearer than the surrounding dolomite and, although the inclusions precluded exact optical identification, are thought to be calcite. If so, they would represent an incipient calcification of the rock.

The diagenetic changes so far discussed involved only the carbonate minerals. The usually very small amounts of insoluble residue have also undergone changes since they were deposited. This is especially true of the silica in the member, as there has been quartz grain regeneration and crystal growth, chert nodule formation and the remarkably selective silicification of <u>Aulacera</u> remains.

In many samples, some of the quartz grains showed a usually complete regeneration, especially of the larger detrital grains. This regeneration produced stubby, euhedral quartz crystals. Also present in some of the residues, in amounts up to two percent, are rod-like, euhedral quartz crystals of much smaller size than the stubby variety. Almost all of these crystals, especially the rod-like ones, have well formed pyramid terminations.

Because of the size-shape difference between these two types, they appear to have begun differently. The stubby, larger variety are due to additions of silica to rounded, detrital, quartz grains of the coarser silt or finer sand size. The rod-like, smaller variety seem to be due to silica additions to much smaller detrital quartz grains. The elongate character of these crystals shows that the detrital grain has acted more as a "seed" or precipitation center for silica and is only a very small part of the final crystal.

Following the formation of these quartz euhedra, there was replacement of silica by carbonate minerals. Many of the regenerated, stubby crystals, in particular, show a "frosting" and pitting on their surfaces, although the raggedness in a few instances prove to be due to incomplete regeneration. One case of advanced replacement is shown by a stubby quartz crystal which had lost its entire central portion, leaving a ragged edged, oval pore, elongated with the crystal length. In contrast, the exterior crystal faces are quite smooth.

A very few, scattered, small, greyish-tan chert nodules were seen in the Gunton member at Locations 12A and 1e. Their exterior surface consists of white silica powder from devitrifaction.

A very selective silicification of large fossils is seen in the horizon containing abundant Aulacera undulata. All the remains of this columnar stromatoporoid are completely replaced by chalcedony, the outer portion of which has since been devitrifed. This phenomenon does not occur elsewhere in the member, nor are other stromatoporoids silicified in other parts of the section.

Also present in some of the residues from the Gunton member are aggregates of hematite and pyrite, as well as very fine hematite and limonite as a colouring agent. The fine ferric oxides probably came from the relatively recent oxidation of the green and brown iron minerals present in much of the rock. The hematite and pyrite aggregates are very similar to those in the Gunn member, the hematite variety coming from the oxidation of the pyrite variety.

The pyrite aggregates are more usually found along nodular contacts and bedding planes, but the smaller aggregates are also disseminated throughout some beds. The larger type are probably formed by precipitation of iron that has been leached from the green sediments of the internodular films. The disseminated, smaller type of aggregates are perhaps due to reducing conditions that could have been produced just beneath the sea water-sediment surface in the very fine original sediment.

CHAPTER VI

WILLIAMS MEMBER

TERMINOLOGY AND STRATIGRAPHIC RELATIONS

The rocks of this proposed member were first described by Baillie (1951, p.11) from a pit in the Stonewall Quarry and were placed by him in the Stonewall formation (A. D. Baillie, 1951, p.11). However, a bore-hole, cut at Stonewall by the Winnipeg Supply and Fuel Co., Ltd., showed an apparent gradational contact with the underlying rocks. Therefore, Baillie (1952, p.21) raised the lower contact of the Stonewall formation and placed the rocks, herein put in the Williams member, in the upper part of his redefined Gunton member of the Stony Mountain formation. The contact between the Stonewall and Stony Mountain formations was placed at the top of " a thin band of yellowish-grey arenaceous dolostone" (A.D. Baillie, 1952, p.21), the definition that is followed in this thesis, (See Appendix A, Location 14).

However, it is not agreed that the lower contact of these beds is gradational. Although sedimentation was continuous, the introduction of large amounts of coarser terrigenuous sediment began quite suddenly, (see Table II,p.100).

Not only does the lower contact of these beds exhibit an abrupt lithologic change, but the abundant terrigenous sediment gives a very different and distinctive character to the rocks. The most noticeable example of the latter is the contrast between the beds on both sides of the abrupt lower contact. The beds below contain abundant coral remains, those above have a massive, silty nature.

TABLE II

CHANGE IN INSOLUBLE RESIDUE PERCENTAGES ACROSS THE GUNTON-WILLIAMS CONTACT

Sample Number	Percentage of Total Insoluble Residue As				Total Insoluble Residue Percentage (Appendix B)
	Coarse Silt	Very Fine Sand	Fine Sand	Medium Sand	
13 Gt. 25	6.33	2.71	0.0	0.0	1.15
13 Gt. 27	1.20	0.24	0.0	0.0	0.57
13 Gt. 28	1.24	0.10	0.0	0.0	1.45
14 W. 0	48.09	13.04	0.0	0.0	5.68
14 W. 1	14.98	41.79	17.40	0.46	23.46

In addition to possessing distinctive lithologies and sharp contacts, this unit is developed over a wide area and is especially useful in subsurface correlations. It was found by Kupsch (1952, p.31) in east-central Saskatchewan in thicknesses up to ten feet and was the best marker unit in this part of the section. Andrichuk (1959, p.2371) found these rocks throughout south and southwestern Manitoba, although the unit thins and becomes finer grained toward the west. He used the top of the beds as the upper boundary of the Stony Mountain formation. Porter and Fuller (1959, p.156) recognized the sandy and silty facies of this unit in southeastern Saskatchewan and traced an equivalent, thinner, shale facies into eastern Montana. To the west, the unit is not present due to non-deposition.

Therefore, these rocks are placed in a new member of the Stony Mountain formation, named the Williams member, which is defined as those beds between the redefined Gunton member and the Stonewall formation. This member is retained in the Stony Mountain formation as the lower contact shows continuous sedimentation, but the upper contact represents at least a diastem of short duration.

The new member is named the Williams member after a station located just north of the Stonewall quarries on the Winnipeg-Arborg line of the Canadian Pacific Railway. The type section of the Williams member is found in a pit in the north-west portion of the Stonewall quarries, about midway between the two groups of lime kilns, and is located in the southeast quarter of Section 36, Township 13, Range 1, East of the Principal Meridian. The lower three feet of the member are not exposed in the pit but were studied from two cores cut by the Winnipeg Supply and Fuel Co., Ltd. nearby. From these cores, the thickness of the Williams member was found to be seventeen feet, three inches, plus or minus two inches.

In summary, then, the Williams member consists of those beds in the Stony Mountain formation that are underlain by the beds of the redefined Gunton member and overlain by the beds of the Stonewall formation.

DETAILED PETROLOGY

As the insoluble residues are such an important part of the rocks of this member and as the remainder is dolomitized, the information on this member came from a study of the insoluble residues and the various macroscopic features found in hand specimens and on polished and etched sections.

Macroscopically, the member can be divided into two almost equal parts, the lower being only six inches thicker than the upper. The lower portion is characterized not only by a much greater variation in textures and structures but also by a greater abundance of the coarser insoluble residue grains. The upper portion is characterized by the abundance of finer insoluble residue particles and a red colour. Although they have many features in common, the two parts of the Williams member will be described more or less separately.

Lower Part of the Williams Member

The lower one hundred and six inches of the Williams member is composed predominantly of light yellowish-grey dolomite. The other two lithologic types described below are only a few inches thick in aggregate. The yellowish-grey colour is replaced in a few beds by a light grey, a light greenish-grey or, in the uppermost beds, by a pale rose-red tint.

The dolomite in these grey beds is sublithographic in texture with only a small amount being very fine crystalline. The insoluble residues, however, show a much wider range in sizes and amounts. Not including the lowermost bed, which is slightly transitional, the total residue ranges from 16.23 to 37.21 percent of the whole rock, the clay sized residue ranges from 2.09 to 6.13 percent, the silt sized residue, from 1.09 to 12.11 percent and the sand sized portion, from 3.34 to 32.30 percent.

Another type of dolomite, found only in the lower one-quarter of the member, forms beds which together total less than six inches in thickness. It is a light yellowish-tan to light tan-yellow rock of a sublithographic to lithographic texture. The total insoluble residue in these beds ranges from 2.21 to 9.59 percent, with the clay sized portion from 0.99 to 3.74 percent, the silt sized, from 4.04 to 5.61 percent and the sand sized, from 0.04 to 1.03 percent of the rock.

The third rock type in this lower half of the member occurs only as films and thin, usually irregular laminations and beds. It is a pale-green, dolomitic shale, usually composed of fine silt and green clay particles, but rarely it is also sandy.

The insoluble residues in these three lithologies vary only in relative amounts, they are of the same type throughout. The sand and silt sized fractions are composed entirely of quartz grains and the clay sized fraction is a mixture of quartz and clay particles, the clay particles being a light green, ferrous iron colour. Heavy mineral grains are extremely rare.

The photomicrographs of the sand sized grains from the residue of 14W. 19 given in Plate XVIII, p.105, are typical of those in the member. The coarse sand-sized grains are well-rounded, usually show a high degree of sphericity and are etched and pitted. Also in this size class are many aggregates formed of very fine to medium sand grains. There is a steady change in properties with diminution in size, so that, in the very fine sand size sample, the grains are sub-rounded to sub-angular, with traces of both rounded and angular grains, and have low to medium sphericity, with traces of high sphericity. These grains are only finely pitted. Throughout, the angularity of the grains is due to breaking or large-scale pitting.

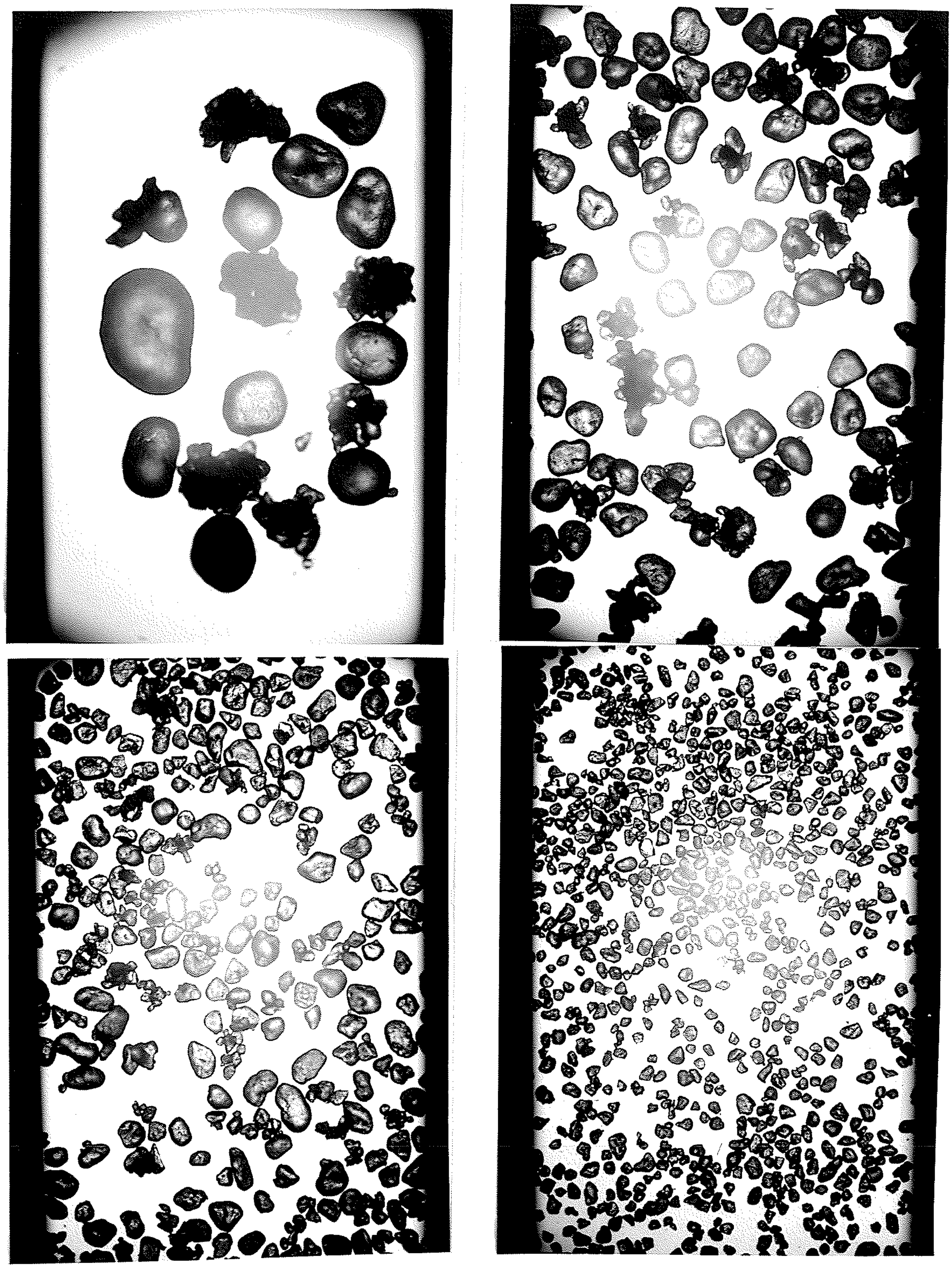


PLATE XVIII

Photomicrographs of the sand sized grains from the insoluble residue of 14W.19. (20x).

A. Coarse sand sized.

B. Medium sand sized.

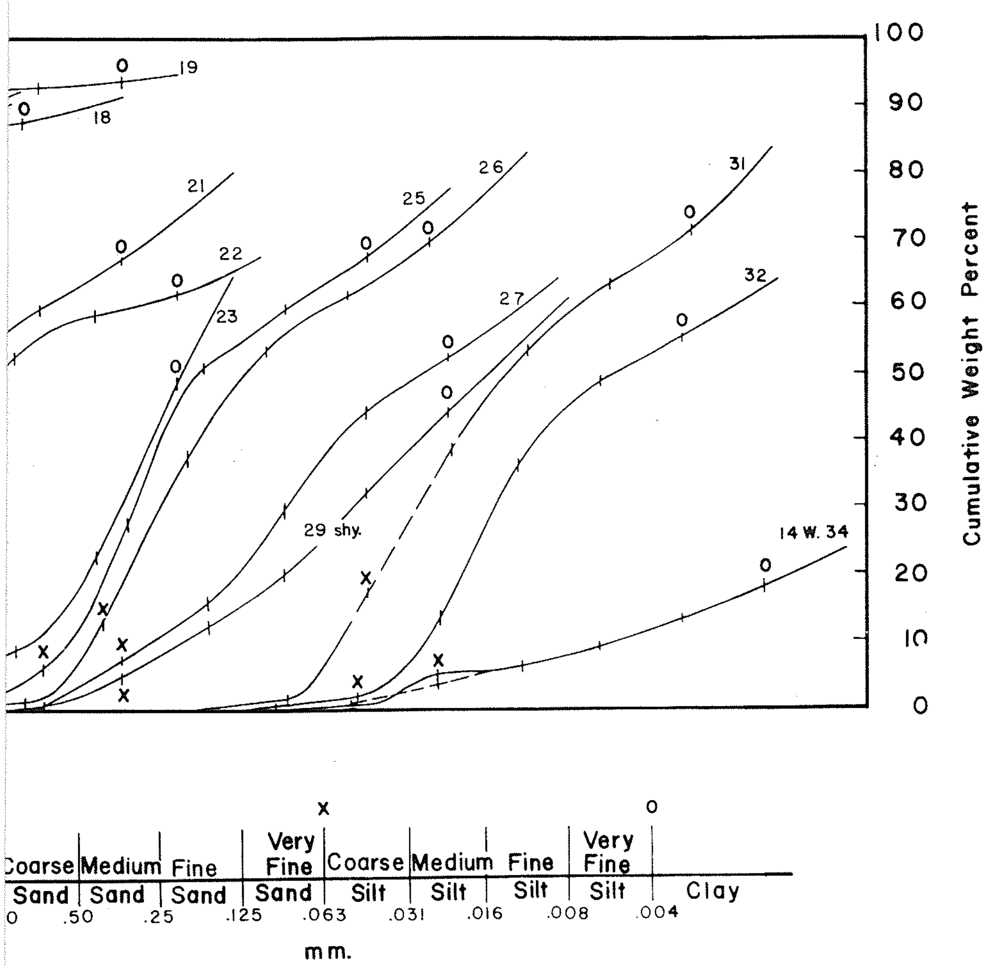
C. Fine sand sized.

D. Very fine sand sized.

The size distributions of all the insoluble residues taken from the Williams member are given in Figure 6, p.107. These curves are interpreted reconstructions of the original residue percentages, for the sizes of the individual grains in the aggregates were determined and added to their respective categories. The curves marked 14W.0 to 14W. 19, inclusive, represent those residues from the lower half of the unit. The curve, 13Gt.28, represents the distribution of the residues in the upper part of the top bed of the Gunton member and 14W.0 that of the lowermost bed of the Williams member.

The typical distribution for the lower part of the member shows a concentration of more than fifty percent of the whole residue in the fine sand and very fine sand size categories, with a few examples in the very fine sand and coarse silt categories. The few curves which seem atypical, those for 14W.5 lith., 14W.11 lith. and 14W.14 lith., are actually the distributions of the residues from the yellow sublithographic to lithographic beds. The curve for 14W.4 represents a rock with laminations and "blebs" of pale green shale.

In general, the bedding of the light yellowish-grey dolomites is massive with flat bedding planes, although the bed thickness is average only from one to three inches, with a range from just less than one inch to six inches. However,



19
18
21
22
23
25
26
27
29 shy.
31
32
14 W. 34
100
90
80
70
60
50
40
30
20
10
0
Cumulative Weight Percent
Coarse Sand
Medium Sand
Fine Sand
Very Fine Sand
Coarse Silt
Medium Silt
Fine Silt
Very Fine Silt
Clay
.50
.25
.125
.063
.031
.016
.008
.004
mm.

some beds show faint to strong laminations or fine banding, and one bed showed distinct cross-bedding especially on an etched surface. This banding and lamination is due to the concentration of insoluble residue material on planes in the rock, as illustrated by Plate XIX, p.109. In some examples the material is green, fine silt and clay sized material, which gives a more distinct break; but usually it is the coarser silt and sand sized grains that were concentrated, leading to banding and especially to faint laminations.

The yellow lithographic beds also show fine laminations due to relative concentrations of finer insoluble residue material on some planes. These yellow beds, which range in thickness from one-quarter inch to one and one-half inches, most commonly have a flat lower bedding plane with an irregular, undulating upper surface. They therefore appear more lensing in character. Another feature which is common to all these beds is a conchoidal to sub-conchoidal fracture. Two such beds are illustrated in Plate XX, p.110.

The pale grey-green, dolomitic shale occurs as films and partings and as irregular, "bleby" laminations of one-eighth inch thickness or less.

Both the yellow-lithographic and the pale grey-green types are also found as included fragments in come of the yellowish-grey dolomite. The green inclusions are found as scattered to abundant "blebs" of various shapes, as in Plate XIX B, p.109. The yellow fragments are less common

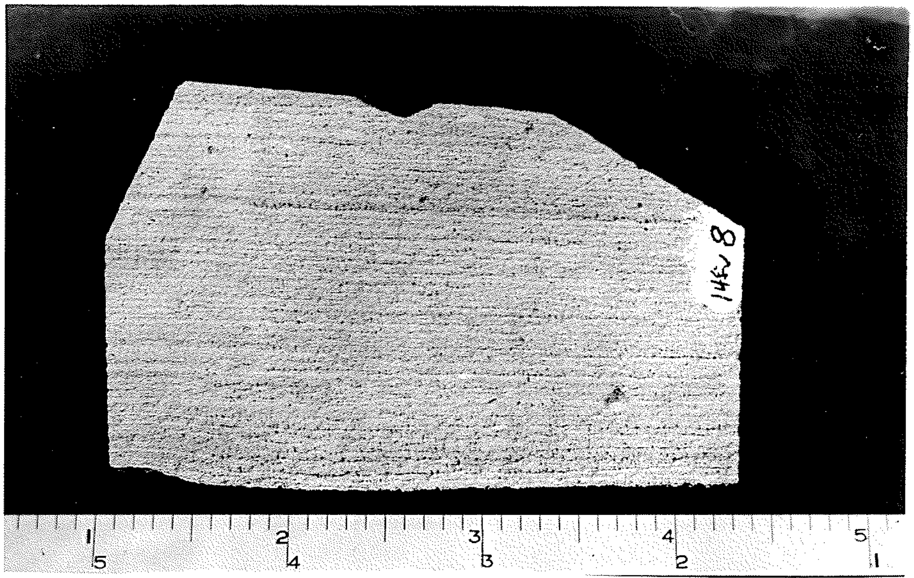
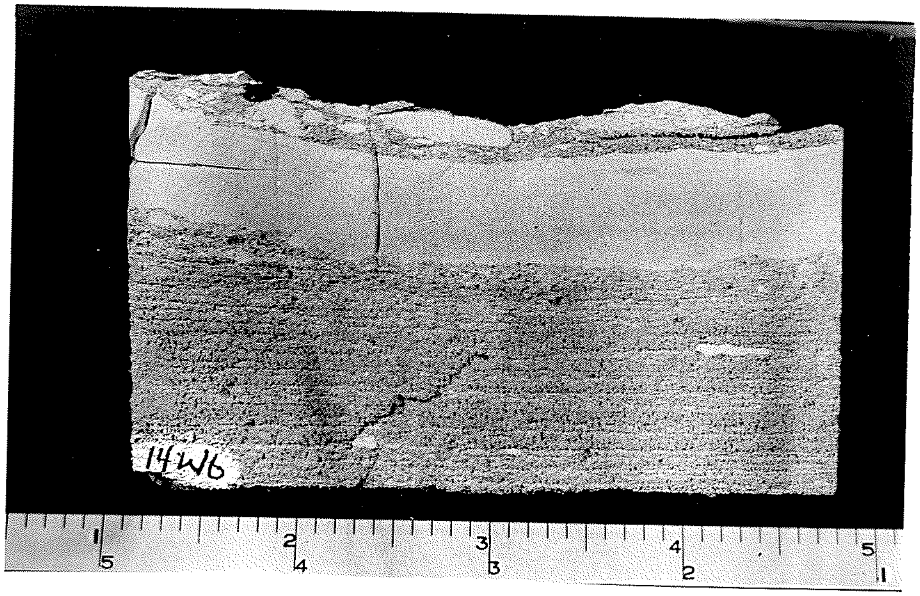


PLATE XIX

A. Etched section of a light yellowish-grey dolomite, with laminations due to concentration of coarser insoluble residue grains. (14W.8).

B. Etched section of a light yellowish-grey dolomite, with laminations below and intermixed pale grey-green shaly "blebs" and partings above. (14W.4).



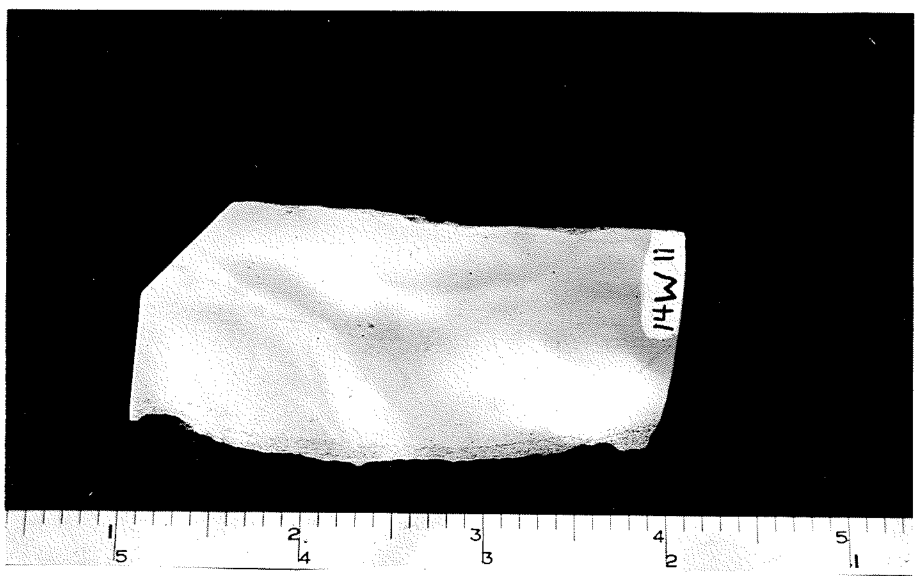


PLATE XX

A. Etched section of a bed of bright tan-yellow, finely sublithographic dolomite, underlain by laminated, very sandy dolomite and overlain by very sandy dolomite containing pebbles and grains derived from the bed.
(14W.6 lith.)
(14W.6 sdy.)

B. Etched section of a bed of light greenish-grey, finely sublithographic dolomite with a flat lower bedding plane.
(14W.11 lith.)

but are abundant when present. They occur as rounded pebbles and grains or as "blebs" and tiny lenses parallel to the bedding. In one example, illustrated by Plate XX A, p.110, they appear in the yellowish-grey dolomite bed overlying a yellow, sublithographic to lithographic bed with a very uneven upper surface.

Porosity is almost completely absent from this member, only traces having been found in one bed. However, from eighty to ninety-two inches from the base of the unit, there are several occurrences of scattered to abundant cubic pores, probably caused by the solution of salt crystals.

Upper Part of the Williams Member

The upper one hundred inches of the Williams member is generally more homogeneous than the lower half. It is composed entirely of dolomite, which varies in colour from rose-red to light reddish-grey with rare maroon and dark purple streaks. In one bed, there are round, pale greenish-grey spots and the upper most eighteen inches is partly pale greenish-grey. This dolomite is mainly sublithographic to very fine crystalline, but the uppermost beds may be as fine as coarse lithographic in part.

If fissility were the only characteristic needed to define a shale, then two thin units in this part of the section could be so defined. However, they are referred to as very argillaceous and silty dolomites in Appendix A, as they contain much more than fifty percent dolomite.

The insoluble residues of the upper half of the member are similar in type to those in the lower half, except that here the iron is in the ferric state. On a whole, this hematite varies, when present, from less than one percent of the whole residue to just over six. The mineral is still mainly in the clay sized residue, but in some samples it has become partly aggregated and now occurs in the silt and sand sized portions. In residues 14W.26, 14W.27 and 14W.31 it has noticeably increased the sand sized percentage, due to the type of aggregation shown in Plate XXI, p. 113. This appears to be the result of solution of hematite in the more permeable layers and aggregation along the boundaries with less permeable rock.

The amounts in the various residue categories were found to be: in the total insoluble residue, from 18.67 to 33.76 percent of the whole rock, in the clay sized residue, from 6.09 to 30.87 percent, in the silt sized residue, from 1.01 to 15.41 percent and in the sand sized residue from 0.29 to 6.25 percent.

The percentage distribution of these residues is also given in Figure 6, p.107, with the curves from 14W.21 to 14W.34, inclusive, representing the residues from the upper

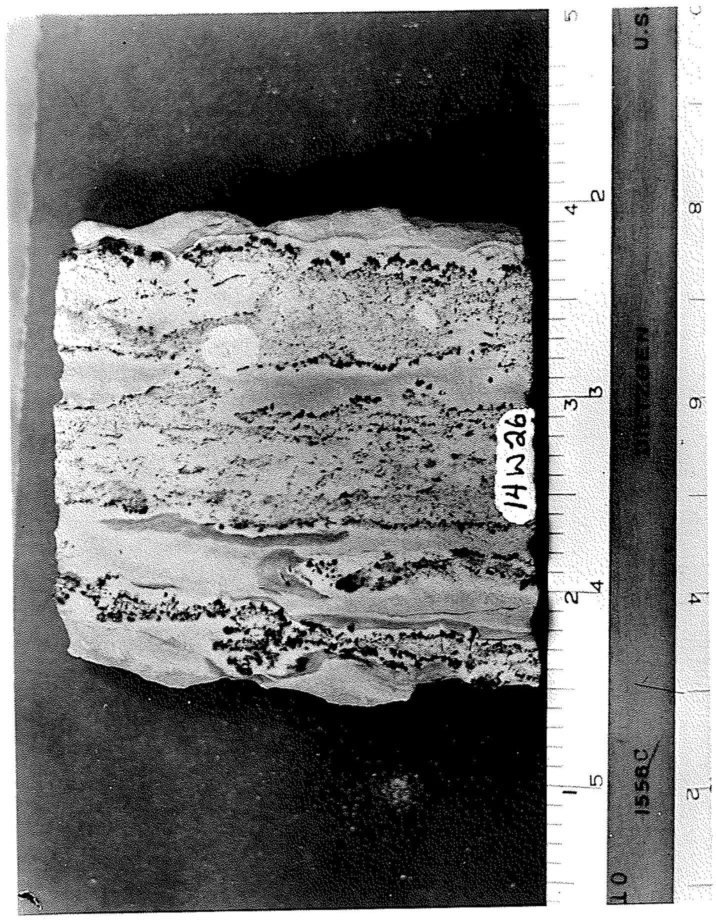


PLATE XXI

Etched section of a light reddish-grey and minor rose-red, very silty dolomite, containing abundant hematite aggregations along permeability barriers. (14W.26) half of the member. The curves show much less grouping of large parts of each residue in one, two or three size categories as is characteristic in the lower unit, and a few show almost equal distribution. The curves for 14W.23 and 14W.29 shy. show a different distribution, especially the former, and these are the beds that exhibit fissility and contain the highest percentages of clay sized particles in the member, with the exception of 14W.34, the topmost bed.

The bedding in this part of the member is generally massive, but a few beds show fine laminations. Both types are illustrated by Plate XXII, p.115. The bedding planes are usually indistinct, and some are slightly irregular. The bed thicknesses range from one inch to three inches, and the laminations, in one bed, range from one and one-half to four millimeters, i.e. from one sixteenth to nearly three sixteenth of an inch, in thickness.

In this latter bed, the base and top are very irregular and the laminations parallel this irregularity.

SEDIMENTATION

The sedimentation of the Williams member began with a sudden influx of large amounts of terrigenous sediment. This smothered the abundant coralline fauna that had been

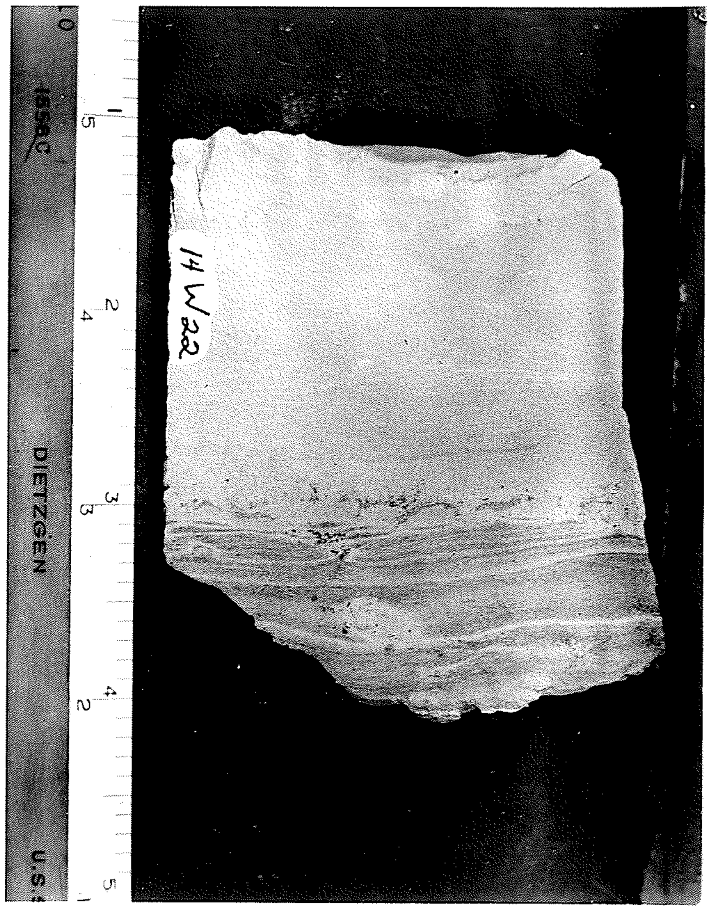


PLATE XXII

Etched section of a light rose-red, massive dolomite underlain by a rose-red, laminated dolomite, showing truncation of the upper laminations. (14W.22).

forming the sediment of the uppermost Gunton beds and set the depositional pattern for the rest of the member.

Throughout the unit the carbonate material and the terrigenous sediment are more or less thorughly intermixed, giving a so-called floating appearance to the quartz grains. As calcite and quartz have very nearly the same specific gravity, it was assumed, during the analysis of the insoluble residues, that the carbonate sediments and terrigenous sediments in any one bed had originally possessed the same size distribution; the calcite grain outlines being later destroyed by dolomite crystal growth. Even if some of the original carbonate detritus was aragonitic, the specific gravity difference would not have appreciably altered this picture. Therefore, it is assumed that the cumulative frequency curves in Figure 6, p.107, represent not only the reconstructed size distribution of the terrigenous sediment but also that of the carbonate detritus and, therefore, of the entire original sediment as well.

With only a few exceptions, the curves for the lower half of the member show notable concentration of residue in two or three size ranges. This is taken to indicate an environment of deposition which sorted the terrigenous sediment that was introduced at this location, and concentrated the coarser grains. Such an environment must have been characterized by very shallow, very active water. Several lines of evidence to support this view are given in the following pages.

Cumulative frequency curves for beach sands show a great similarity to the curves representing the more sorted sediment (W. C. Krumbein and F. J. Pettijoh, 1938, p.216). The Williams member sediment differs only in the much larger amount of finer silt and clay sized particles that remain, indicating that the sorting was not quite as thorough as that on a beach, but still was accomplished in almost as active an environment.

One bed in the lower part of the member showed definite cross-bedding, which is overlain by flat lying, slightly laminated bedding. This shows the depositional action, if short-lived, of a fairly strong current moving abundant loose and mainly coarse sediment.

During laboratory separation of the clay sized portions of the residues from the lower half of the member, it was noted that following thorough suspension of the whole residue, the much more rapid settling of the sand and coarser silt grains left a light green clay and fine silt sized suspension which slowly settled to form a thin, light green layer on top of the coarser grains. Similar layers, now more consolidated, are common in the lower half of the member, where they form partings and laminations between and within the yellow-grey, sandy and silty dolomites. It is suggested that they were formed in a similar way to those in the laboratory. After a storm had stirred the calcareous and terrigenous sediment, the coarser grains would have settled and some or all of the finer particles would have remained in suspension. These would slowly flocculate and form one of the pale grey-green layers.

If this interpretation is correct, it would suggest that the terrigenous sediment was relatively unsorted until it reached this area, then was partially separated by active waters, and finally was redepositied practically in the same place. This is probably the case for the coarser sediment but it seems likely that it does not entirely apply to the finer portion, for some of the pale grey-green partings and laminations could have been formed by the settling of sediment that had originally been suspended much closer to the ultimate source of the terrigenous sediment.

There are laminations and bandings in this part of the section which are the result of relative concentrations of the coarser residue grains and, by inference, the coarser original carbonate detritus, along planes and in thin beds. Andrichuk (1959, p.2380) found that this concentration of coarser material was most effective in those areas which had formed shoals during Gunton time. These shoals presumably were still areas of relatively shallower and therefore more active waters.

This implies, that, if the original terrigenous sediment contained a finer fraction, it has been removed and transported elsewhere. Porter and Fuller's report (1959, p.156) on the distribution of equivalent beds to the westward is of interest here, for they found that the sand grains are present only into eastern Saskatchewan, while the finest terrigenous sediment was deposited much further to the west. This definitely shows substantial sorting and bypassing of finer sediments during the deposition of the Williams member.

The discussion so far has centered on the distribution and redistribution of loose sediment. However, in such an active environment there was also the rearrangement of sediment that had been deposited in relatively less active periods and had become somewhat cohesive. The light grey-green thin beds and partings are usually irregular and "bleb-like" in thickness, and some yellowish-grey, sandy dolomite contains small "blebs" of this material mixed into the beds. For example, the difference between the curves for 14W.3 and 14W.4 is probably entirely due to the grey-green "blebs" included in the 14W.4 bed. See Plate XIX B, p.109. This again illustrates the shallowness of water and the unsheltered aspect of deposition in the lower half of the member, in which wind and storm variations could easily make themselves felt.

In addition to this circumstance, a few beds are found in this lower portion that suggest not only a noticeable shallowness of water but even a cutting-off of some of the area from the open sea and the formation of lagoons and some dry land.

The light tan-yellow, sublithographic to lithographic dolomite, that makes beds of no more than one and one-half inches in thickness, is also characterized by its denseness and its resulting conchoidal to sub-conchoidal fracture. This description is remarkably similar to Hadding's (1958, pp.22-25) description of lithographic limestone from the Jurassic of England and the Silurian of Gotland. He stated that this type of rock is a lagoonal sediment and is formed partly in the littoral zone.

However, the lithographic rocks of the Williams member are not limestones, but dolomites, and their fineness of size suggests the possibility of a primary or near primary origin for the dolomite grains.

These beds also possess distinctive insoluble residue distributions. The curves for 14W.5 lith. and 14W.11 lith. show very little sorting and that for 14W.14 lith., none at all, even though these residues encompass the entire size range present in the terrigenous sediment. This lack of sorting is particularly striking when compared to the considerable sorting that occurred during the deposition of most of the sediment. These lithographic beds also contain a considerably smaller quantity of insoluble residue than do the others, and 14W.14 lith., the least sorted of all, is found in a part of the section in which some beds contain abundant salt molds.

This evidence indicates that the yellow, lithographic dolomites were deposited in very shallow water lagoons that were cut off from the sea. Not only were these lagoonal areas separated from a source of terrigenous sediment, but evaporitic conditions were sometimes able to develop. The very poor or non-existent sorting of the sediment formed in these lagoons is due to the inability of the very shallow water to separate the materials rather than simply keeping them mixed.

In the one instance when concentration of coarser quartz grains within a lithographic bed formed laminations, the closed body of water could not bypass the finer sediment and the curve for the whole bed thereby suggests poor sorting. It is also possible that some of these coarse grains are the result of wind action on the temporarily emergent nearby sediment, with the finer material being sorted out by the wind, while the coarser grains were deposited in the adjacent lagoon. This finer sediment could later have been added by the settling of dust, to maintain the overall unsorted character.

A present day example of the formation of very fine dolomite sediment is described by Alderman and Skinner (1957, pp. 561-567), from localities in southeastern South Australia, and this sediment very closely resembles that of the lithographic beds of the Williams member. It is formed in lagoons and intermittent, saline lakes recently cut off from the sea. It has a larger component of insoluble residue than the lithographic beds of the Williams member, because quartz is the dominant loose sediment in the surrounding areas, with only a small amount of carbonate being present, the opposite to the situation in the Ordovician.

Alderman and Skinner (1957,p.562) also found that the carbonate sediment forms a hard surface during its exposure to the air, and Dunbar and Rodgers (1957, p.180) state that carbonates, when exposed to air, are mudcracked and tend to harden. In the beds just above the lithographic beds of this member there are usually abundant rounded pebbles and grains, or "blebs" and lenses, of yellow, lithographic dolomite, as in Plate XX A, p.110. The underlying lithographic bed has an uneven upper surface suggesting erosion. It seems very likely that the pebbles and grains were formed when the active, deeper sea water returned to this location and tore up the cracked and harden upper portion of the bed, rounded the fragments and incorporated them into the normal, very sandy and well sorted sediment of the open, though shallow sea. The yellow lithographic "blebs" and lenses would then represent a relatively shorter exposure to the air and the incorporation of more plastic grains in the overlying bed.

The sediment of the upper one hundred inches of the Williams member is marked by fewer, less distinct variations than in the lower half and the distribution curves of the insoluble residues in Figure 6, p.107 show the markedly less sorted character of the sediment. These facts point to a considerable deepening of the water leading to a much less active environment of deposition.

Although this environment remained typical of the upper half of the unit it began somewhat abruptly as shown by a comparison of the curves for 14W.19 and 14W.21. Yet the coarsest residue grains found in the member, i.e. coarse sand sized, first appear in 14W.18 and become more abundant in 14W.21, continuing intermittently until 14W.27. When added to the fact that abundant terrigenous sediment continued to be deposited, these facts show that sheltering of the area was not a factor in the new residue distributions, for this would have prevented the continued and increased introduction of the coarsest grains and would have sharply reduced the total amount of the residue in the sediment.

While most of the curves in this part of the section are considered to be representative of relatively unsorted terrigenous sediment, akin to that from which the coarser residues of the lower half were derived by considerable sorting, the curves for 14W.23, 14W.27, 14W.29 shy. and 14W.34 all show an apparent excess of clay and very fine silt sized particles. In the first case the resulting sediment is finely laminated suggesting especially quiet water. These laminations are wavy and irregular, showing movement of the water-laden sediment, probably due to loading or storm wave action. In the first three cases, the amount of fine hematite that was deposited reached peak amounts of approximately three to six percent of the residue, and completely overwhelmed the already ineffective reducing ability of the deeper water environment.

The bed represented by the 14W.34 curve has an especially large amount of clay sized residue, amounting to 82.2 percent of the terrigenous sediment. The carbonate in this bed is also very fine, ranging from lithographic to fine sublithographic. This suggests the deposition of primary or near primary dolomite in an environment into which large quantities of bypassed, finer terrigenous sediment were being dumped, as areas progressively nearer the thesis area were raised above the depositional base level. This process continued until deposition also ceased at this locality. The nature of the lithologic break above this bed suggests that erosion of an unknown amount of sediment occurred, with reduction of the hematite, before the sedimentation of the Stonewall formation began.

DIAGENESIS

The most important diagenetic change that occurred in the rocks of the Williams member was the dolomitization of the calcite detritus. Because of the present fineness of the dolomite and residue grain sizes in parts of the unit and because the original sediment grain sizes are thought to have been equally fine it is probable that these beds represent primary or near primary dolomite, as dolomitization of fine grained calcite tends to notably increase the grain size, (Carozzi, 1960, p.270). However, the other beds have very much coarser quartz grains than dolomite crystals at the present, and strongly suggest original coarser calcite sediment, since dolomitized. As even this dolomite is generally only very fine crystalline to sublithographic in size, its formation was probably relatively rapid and therefore occurred shortly after deposition when magnesium solutions were still able to reach the sediment easily.

The quartz grains, especially the larger sizes, underwent fine etching and pitting after deposition, as can be seen in Plate XVIII, p.105. This was caused by a process of replacement of silica by the carbonate minerals.

Some of the quartz grains in the residue, which are in contact or in near contact in the rock, were aggregated into clusters of various sized by a process of deposition of small quantities of silica, again as in Plate XVIII, p.105. Whether this silica was made available by replacement during etching and pitting is not certain, but the most aggregated grains are those of the most abundant size grades, suggesting that chance grouping determined the formation of the aggregates.

The iron in the Williams member is found entirely as ferrous iron in the lower half of the member and almost entirely as ferric iron in the upper half. As Porter and Fuller (1959, p.156) found the red colour in equivalent rocks over a large area in the subsurface, and as Andrichuk (1959, p.2374) found both red and green colours, also in the subsurface, it is considered that the present surface colours are generally those of the original sediments and do not reflect basic colour changes due to recent weathering.

There has, however, been a certain amount of rearrangement of the hematitic iron of the upper half, especially near those beds that are richest in it, as shown in Plate XXI, p.113. Irregular concentration patterns and aggregates have been formed in those portions of the beds which are between the more argillaceous, less permeable rocks with abundant hematite, and the silty, more permeable, now less hematitic rocks. This seems to signify a deposition of hematite at the boundary of hematite-impermeable rock. Within the very argillaceous and hematite-rich beds there are dark red, apparent laminations, which may be an original concentration of hematite at laminar boundaries, but suggests a recent diffusion and precipitation of hematite in accord with the Liesegang phenomenon (J. D. Carl and G. C. Amstutz, 1958, pp. 1467-8).

CHAPTER VII

STONEWALL FORMATION

TERMINOLOGY AND STRATIGRAPHIC RELATIONS

When Kindle (1914, p.249) named the "Stonewall limestone" in 1914 he included under the term all the beds above the Ordovician and under the Devonian in the Interlake region. The type section was taken at the Stonewall Quarry, although it exposed only the lower portion of the "limestone". The term "Stonewall formation" was also used.

Okulitch (1943, p.67) extended his Birse member of the Stony Mountain formation to include the lower six feet of Kindle's unit; four feet, eight inches of this, by actual measurement and a hidden one foot, four inches by inference.

In his earlier work on these rocks, Baille (1951, p.6) redefined the "Stonewall limestone" as the Interlake group and restricted, (1951, p.6) the name "Stonewall formation" to those rocks between the Stony Mountain formation below and his "Unit B" of the Interlake group above. The section at the Stonewall Quarry is incomplete, as it does not include the upper beds of Baillie's formation.

In this 1951 work, the beds now placed in the Williams member of the Stony Mountain formation were included by

Baillie, (p.15), in the Stonewall formation. However, in 1952, (p.21), he included these beds in the Stony Mountain formation and placed the lower contact of the Stonewall formation (and the Interlake group) at the "abrupt lithologic change" at the top of uppermost silty and very argillaceous bed.

This thesis uses the latter definition for the lower contact, and defines the Stonewall formation as those beds at the base of the Interlake group which are underlain by the Williams member of the Stony Mountain formation and are overlain by units of the Interlake group not present at the Stonewall Quarry.

The thickness of this lower portion of the Stonewall formation is twenty-three feet, three inches at the northwest Stonewall Quarry. This quarry is located north of the school at the town of Stonewall.

During subsurface work, in areas beyond the occurrence of the Williams member, Ross (1957, p.450M) found that the lithologic character of the Stonewall and the upper part of the Stony Mountain formations were so similar that he could not define the boundary between them with any certainty. He (1957, p.445M) therefore included the Stonewall beds in the Stony Mountain formation, and made this the upper part of his Bighorn group.

The Lower Palaeozoic Names and Correlations Committee of the Saskatchewan Geological Society (The Lower Palaeozoic Names and Correlations Committee, 1958, p.10) reinstated the Stonewall unit as separate from the Stony Mountain "beds", and this was followed by Porter and Fuller, (1959, p.141) although they kept it in the Bighorn group.

Also working in the subsurface, however, Andrichuk (1959, p.2381) returned the Stonewall formation to the Interlake group, as he found the Stonewall-Stony Mountain contact to be the "main sedimentary break", as it is in the outcrop.

DETAILED PETROLOGY

The information detailed below was derived from a megascopic study of etched sections and outcrop sections and from a microscopic study of insoluble residues and a few thin sections.

The Stonewall formation begins with a two to three millimeter thick "bed" of bright yellow, sandy, powdery dolomite. The insoluble residue herein amounted to 5.66 percent of the whole and its size distribution is shown by the histogram, 14S.34A, in Figure 7, p.131. Limonite makes up much of the clay sized fraction.

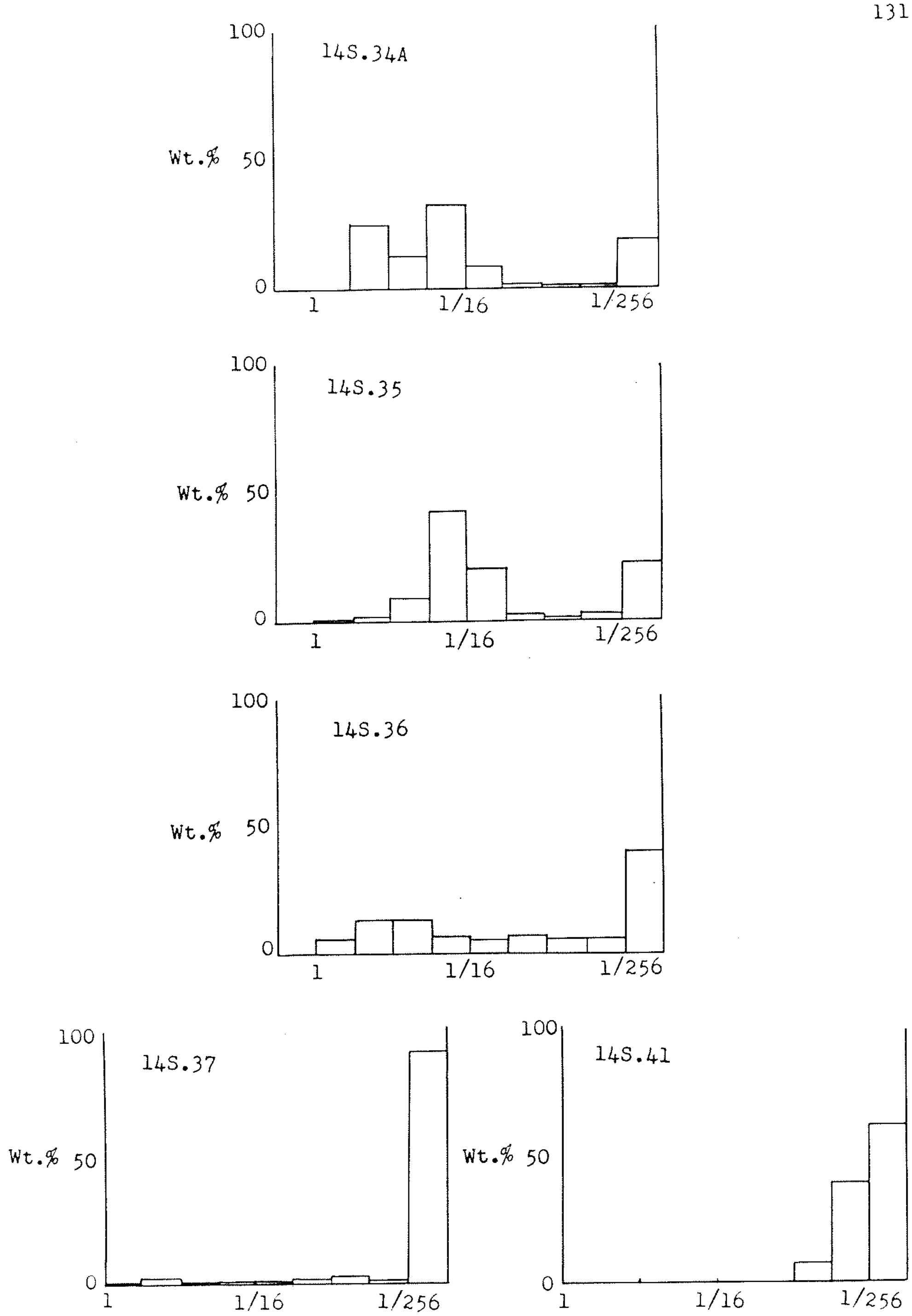


FIGURE 7

CHARACTERISTIC DISTRIBUTIONS OF INSOLUBLE RESIDUE PARTICLES FROM THE STONEWALL FORMATION

Overlying this "bed" are three beds of six, three and six inches thickness, repectively. These beds are composed of light tan-grey to light brownish-grey, slightly calcareous dolomite, of very fine to fine crystalline size. The lowest bed also contains some medium crystalline dolomite. All these beds are massive, but the lowest also has poorly defined cross-bedding. Plate XXIII, p.133, shows an etched section of the middle bed.

There are fine to medium pores in the lower beds, which become more abundant upward, as in Plate XXIII. In the upper bed, there are abundant fine to coarse sized pores and vugs.

The insoluble residue included in these three beds vary in amount from 7.31 percent to 2.30 percent of the whole rock, with the sand sized grains varying from 3.98 percent to 0.04 percent, the silt sized, from 1.85 percent to 0.62 percent and the clay sized from 1.48 percent to 1.64 percent. The total residue and sand and silt sized amounts decrease absolutely going upward, while the clay sized portion increases, from a combination of absolute and relative factors. However, in all three beds, as can be seen in the histograms for 14S.35, 14S.36 and 14S.37 in Figure 7, p.131, there is a range in the residue from clay sized to coarse sand sized grains. The coarser grains are unevenly distributed in part; for example, being

Up

PLATE XXIII

Etched section of one bed of light tan-grey dolomite, with abundant fine to medium porosity. (14S.36).

concentrated in the central portion of one bed, thus giving an erratic aspect to the variations, upward in the beds, of the sand sized grades.

As in the Williams member, the aggregated quartz grains were visually separated and placed in their respective size ranges to give a reconstructed original distribution.

The terrigenous sediment in these beds is composed almost entirely of quartz, with traces of hematite. Unlike the Williams member, there are also traces of heavy minerals in the residue. Wallace and McCartney (1928, p.214) detailed these as abundant tourmaline and zircon, common magnetite, minor pyrite and traces of garnet. In the residues, some of the hematite grains are cubic in form.

Photomicrographs of the individual sand sized residues of 14S.35 are presented in Plate XXIV, p.135, and these show a variation from well-rounded, coarse sand sized grains, with a high sphericity, to sub-rounded to sub-angular, very fine sand sized grains, with low to medium sphericity. The degree of etching and pitting of the grains also decreases with grain size. Any angular grains were due to pitting or fracturing. The aggregates were formed mainly of very fine and fine sand sized grains, and themselves reached only fine and medium sand sizes.

In the residue for 14S.36, which has the most abundant fine, medium and coarse sand sized grains, comparatively, of

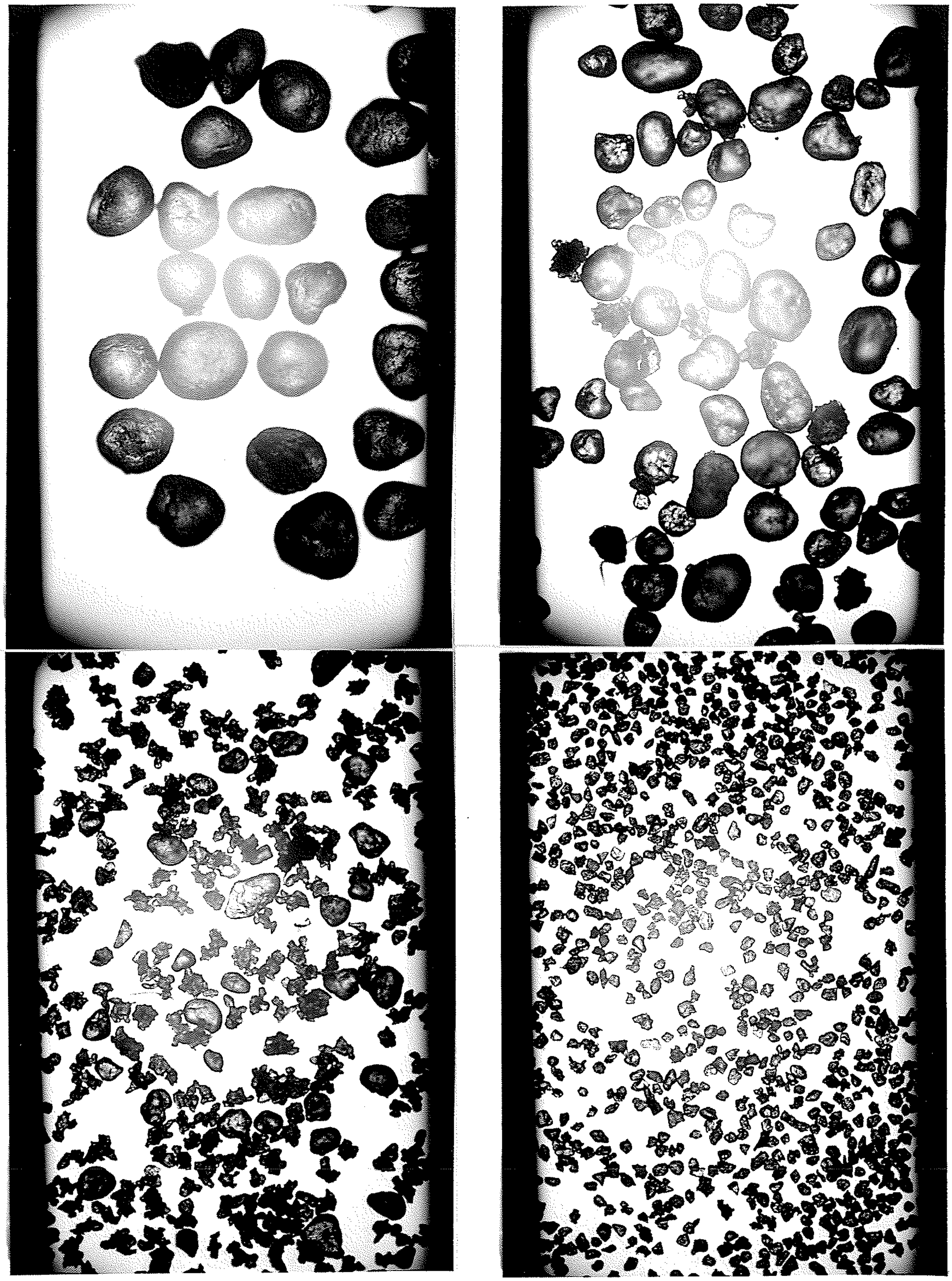


PLATE XXIV

Photomicrographs of the sand sized residue grains from 14S.35. (20X).

A. Coarse sand sized. B. Medium sand sized.

C. Fine sand sized D. Very fine sand sized the three beds, these grains are very pitted and irregular in outline, even to the point of being ragged, as shown by Plate XXV, p.137. There are flat surfaces on some of the quartz grains that do not appear due to regeneration, although some regeneration is present, and there are some rhombohedral indentations.

Above these three beds, which total fifteen inches in thickness, is a fifty-eight inch interval of light tan to brownish-grey or light greyish-brown, slightly calcareous dolomite. The mosaic crystals are very fine crystalline to sublithographic in size, with traces of fine euhedra. There is a coarse crystalline area of equal extinction, containing abundant, scattered anhedral crystals, which is very similar to such areas in Gunton dolomites.

The lower portion of the unit contains two, massive, nine inch thick beds, separated by faint bedding planes, but the upper forty inches consists of one massive bed. There is scattered, fine porosity in the lower beds, and abundant medium to vuggy porosity and scattered, fine, infilled areas in the upper bed. This upper bed is slightly mottled with yellowish-grey tones, and there are brown dolomitization patterns, mainly parallel to the bedding, which give part of the unit a slightly banded appearance. The upper bed also contains abundant colonial corals, which are up to six inches in diameter and more abundant in the upper part.

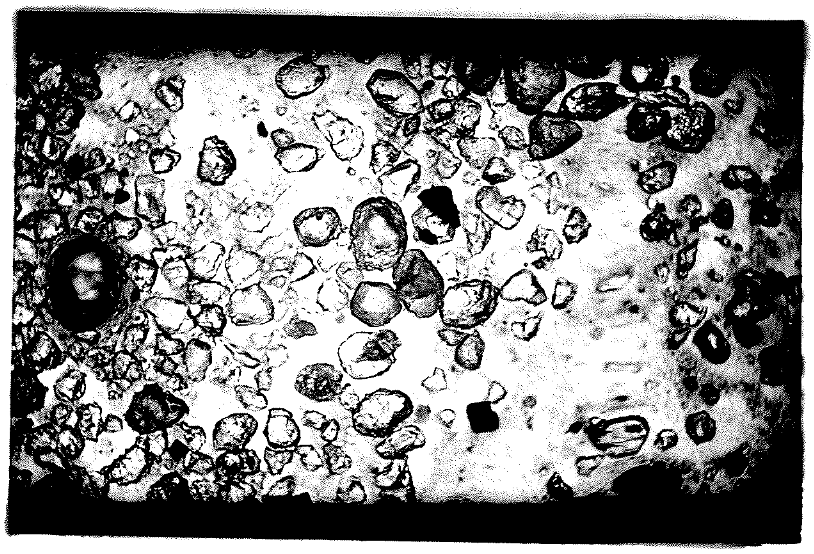


PLATE XXV

Photomicrograph of the unseived, sand sized, insoluble residue of 14S.36. (20X).

This unit contains from 0.38 to 0.60 percent total insoluble residue, with just under sixty percent of this as clay sized particles. There is approximately forty percent very fine silt sized particles present, with less than five percent in the fine silt category. There is nothing coarser than silt in the residue.

The terrigenous sediment is entirely of quartz, but there is also a very small amount of pale brown "iron scum" in the residue.

Overlying the massive, coralline bed is a fourteen inch thick, nodular unit of two, six inch beds overlain by a two inch layer. The rock is a fine sublithographic dolomite, which is light brownish-grey in the lower bed and maroon, with purple streaks and spots, in the middle bed. The upper two inches change laterally from one colour to the other. The lower bed contains green and greenish-grey partings, and the entire unit is extremely nodular. An etched section from the middle bed is shown in Plate XXVI, p.139.

The insoluble residue for this nodular interval is principally composed of quartz, but also contains up to four percent very finely disseminated hematite. The total residue amounts to 6.75 percent of the rock, with 3.68 percent clay.

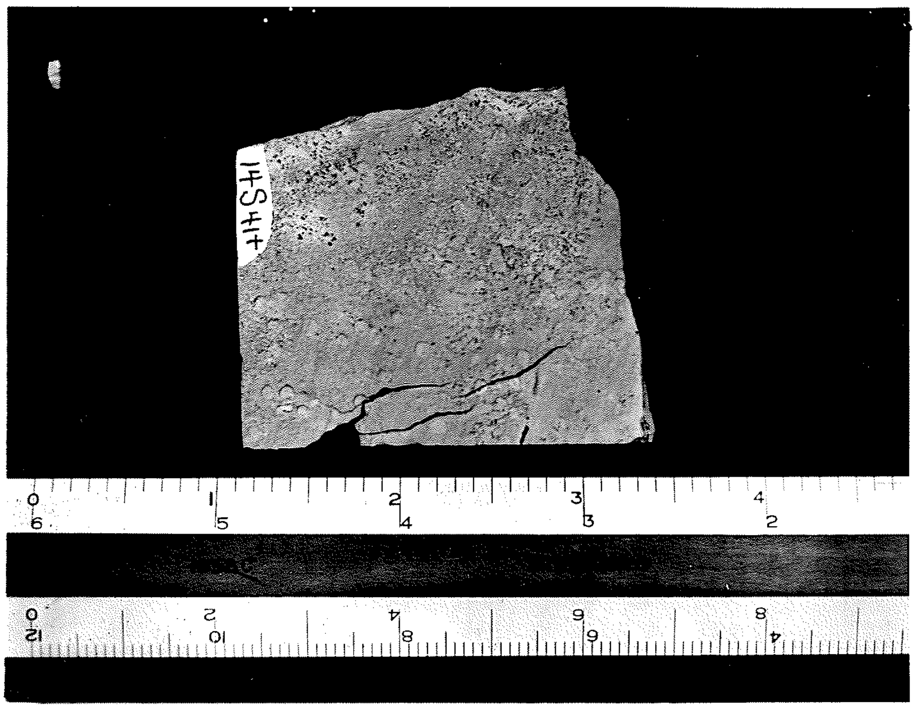


PLATE XXVI

Etched section of a very nodular, maroon dolomite, with purple streaks and pale rose-red spots. (14S.41+).

sized and 3.07 percent silt sized particles. The distribution of this residue, as shown in the histogram 14S.41 in Figure 7, p.131, is nearly identical to those of the underlying and overlying beds, with the exception of the lowermost three beds of the member, although it contains proportionately more fine silt than the beds above. These nodular beds simply contain much more residue.

Above the nodular beds is a forty-two inch unit of light tan-grey, sublithographic to very fine crystalline, slightly calcareous dolomite. It is composed of massive, two to six inch thick beds. The rock is hard and slightly splintery and contains some fine porosity.

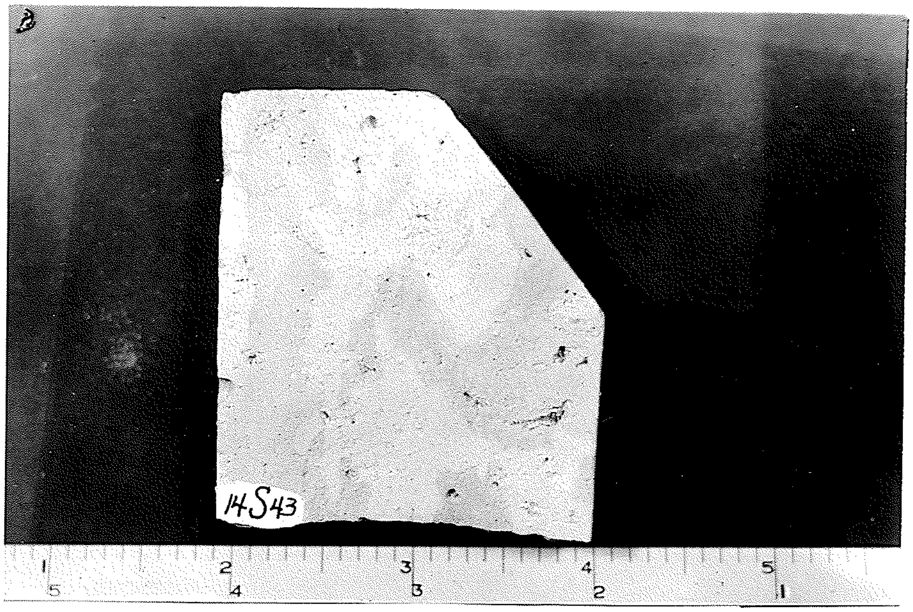
The content of total insoluble residue varies from 1.01 to 1.27 percent, with the clay sized fraction constituting approximately two-thirds of the whole, with only traces of fine silt and nothing coarser. There is again a very small proportion of light brown "iron" material in addition to the quartz.

The next overlying portion of the Stonewall formation is one hundred inches thick and is composed of light tan-grey and light cream-grey, slightly calcareous dolomite. The mosaic is of very fine crystalline size, with a minor fine crystalline component. The rock is faintly mottled in part, and occurs in massive beds from six to seventeen inches thick, with slightly irregular bedding planes. The unit is extremely fossiliferous for the most part, containing abundant colonial corals as well as gastropods, brachiopods and cephalopods. It also has much fine to coarse porosity as illustrated in Plate XXVII A, p.142. Generally speaking, this one hundred inch unit is very similar to the fity-eight inch, coralline and massive unit lower in the formation.

The insoluble residues are only 0.52 to 0.50 percent of the rock with the clay sized component at 0.32 percent and the very fine silt sized component ranging from 0.17 to 0.20 percent. There are only traces of fine silt and nothing coarser. This residue is composed of quartz and a slightly larger amount of light brown, clay sized, "iron scum".

Overlying this fossiliferous interval is a thirty-six inch, pale tan-grey, slightly calcareous dolomite, composed of a sublithographic to very fine crystalline mosaic with no porosity. The unit begins with a three inch, slightly nodular bed, which is overlain by massive beds from one to four inches thick. The rock is hard, has a subconchoidal fracture and is slightly splintery. Plate XXVII B, p.142, shows an etched section of this dense rock.

The residue forms 1.56 percnet of the rock, with 1.09 percent in the clay sized range and 0.47 percent in the silt sized range. Again, there are only traces of fine silt and nothing coarser. The composition is the same as that in the beds below.



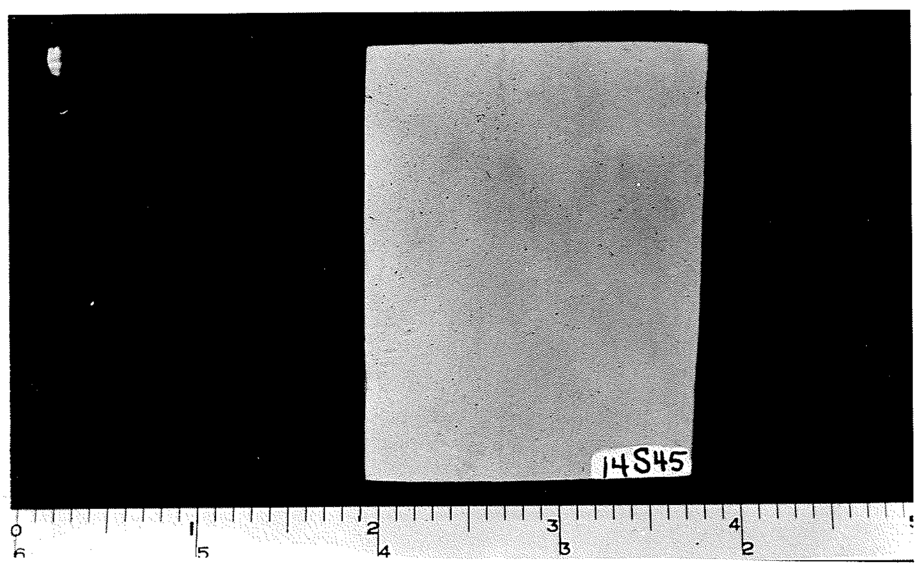


PLATE XXVII

A. Etched section of a light tan and cream-grey dolomite, with fine to coarse porosity probably from fossil solution. (14S.43).

B. Etched section of a pale tan-grey, hard, dense dolomite. (14S.45).

The uppermost fourteen inches of the Stonewall formation, as exposed at the Stonewall Quarry, is in one bed. The lower portion of this bed consists of a light brownish-grey, very fine crystalline, massive dolomite, with abundant fine to coarse porosity. This dolomite grades upward into a dolomite conglomerate, a polished section of which is shown in Plate XXXVIII A, p. 144.

The groundmass of this conglomerate, which forms only a very small and variable part of the rock, is light brownish-grey, with a sublithographic texture in the dolomite mosaic. It is illustrated in Plate XXVIII B, p.144.

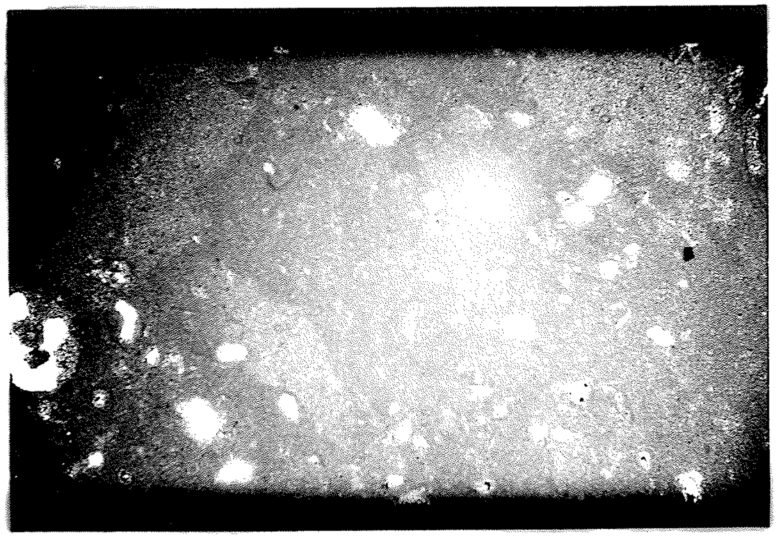
The fragments and pebbles are light grey to light cream-grey and consist of dolomite with a sublithographic to lithographic mosaic texture. They range in diameter from the silt sizes to a maximum of six inches. In shape they are extremely varied, ranging from well rounded to rare fragments that are angular and show only a very poor to fair development of sphericity. On the whole, these fragments and pebbles are still plainly visible, even to the smallest sizes, as can be seen in Plate XXVIII.

The larger pebbles are of various types. One variety has an abundance of many sized and shaped pores, in thin section, which are either filled or partially filled with clear carbonate, as shown by Plate XXIX, p.145. The mosaic is finely sublithographic but details are still visible.

PLATE XXVIII

A. Polished section of dolomite conglomerate, showing a variety of pebble types including reef debris and included pebbles. (14S.47).

B. Thin section of a finer portion of the conglomerate, showing the lithographic dolomite groundmass. (20X). (14S.47).



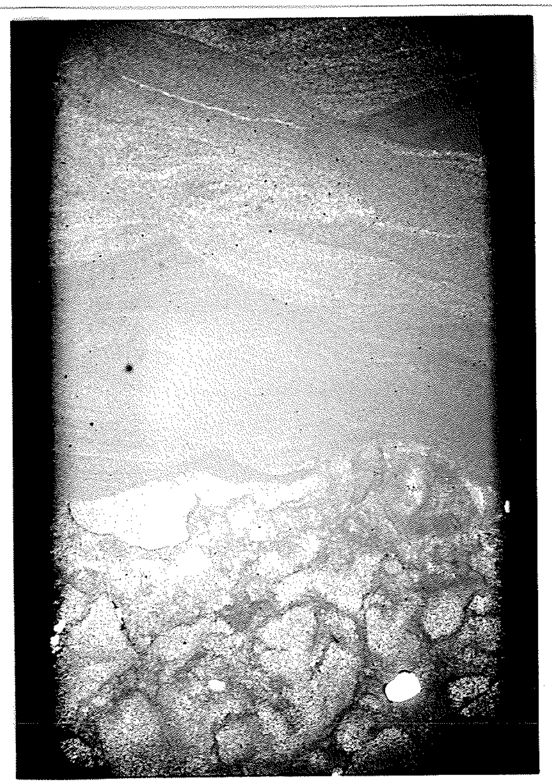


PLATE XXIX

A. Thin section of a fragment of coral or coralline algae(?) adjacent to finer dolomite conglomerate. (20X). (14S.47).

B. Thin section of a fragment of layered, "calcareous" algae, overlying reef debris. (20X). (14S.47).

This variety suggests a fragment of coral or coralline algae.

Another type consists of fine sublithographic dolomite showing fine sub-parallel, wavy laminations, which include minute fossil fragments in a few cases. This type strongly suggests the depositional action of layered, "calcareous" algae, as in Plate XXIX B, p.145, and Plate XXX, p.147.

Elongate but rounded pebbles occur, which are finely fragmental in part, with a finely sublithographic dolomite crystal mosaic and fine scattered "pores", now almost all infilled. One such pebble, shown in the lower portion of plate XXXI, p.148, has a thin, layered coating along the upper side, deposited by "calcareous" algae.

Another elongate pebble is faintly laminated parallel to its elongation and has a subconchoidal fracture.

The rock as a whole contains microscopic cracks, which are now filled with calcite.

The insoluble residues vary from a total of 0.40 percent in the lower, massive portion of the bed to 1.36 percent in the conglomerate. The clay sized portion varies from 0.32 to 0.95 percent and the very fine silt sized portion, from 0.08 to 0.41 percent. There is nothing coarser than very fine silt. The brown "iron scum" is most abundant in this bed, but is still present in only a very small amount.

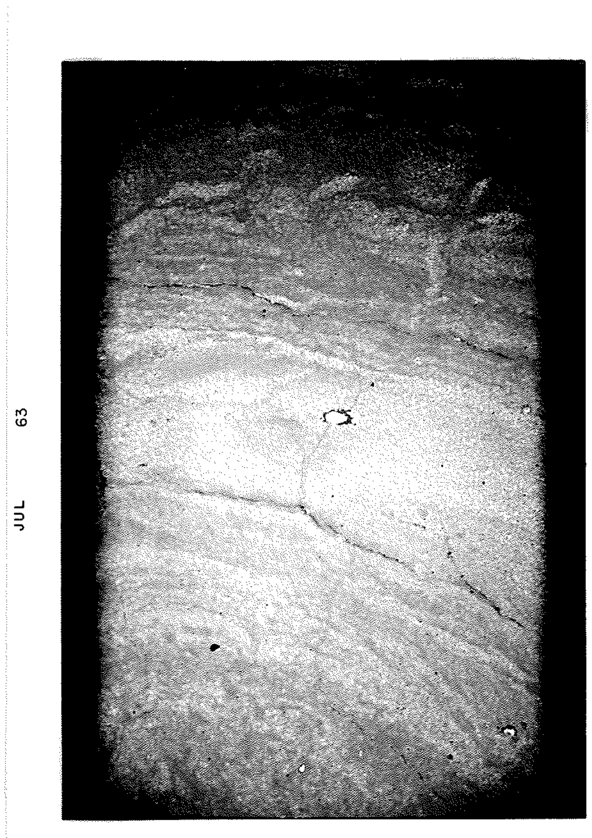


PLATE XXX

Thin section of a fragment of more coarsely laminated "calcareous" algae, with included fossil fragments near the the top. (20X). (14S.47).

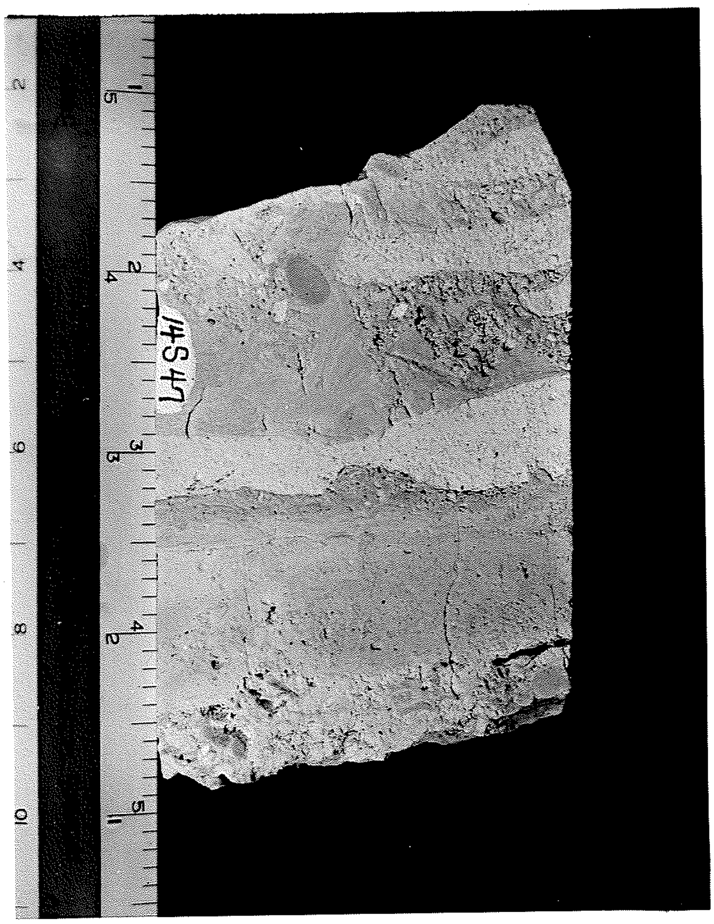


PLATE XXXI

Etched section of dolomite conglomerate, showing portions of several elongate pebbles and a fragment of layered, "calcareous" algae. (14S.47).

SEDIMENTATION

The very fossiliferous, coralline units, the dense, hard units, the cross-bedded unit and the conglomeratic unit add up to an environment of deposition which bears much resemblance to the type of reef-inter-reef deposition described by Hadding (1956, pp. 99-116) from the Silurian of Gotland.

The first bed of the Stonewall formation above the yellow, thin, residual bed shows one set of cross-beds, which fill the entire six inches. At first, it would seem that this bed is also residual in the sense that it is formed of debris eroded from the uppermost beds of the Williams member. However, comparison of the very argillaceous, lithographic Williams beds with this very fine to medium crystalline, porous, very slightly sandy bed shows that it could not have been derived therefrom. In particular, the presence of an important heavy mineral suite shows that the sediment of this bed came from different sources, with the terrigenous sediment from a less mature situation than that which supplied the Williams member, and the carbonate sediment from a nearby shoal environment. The coarser dolomite crystal sizes point to secondary dolomitization of calcite detritus, and the cross-bedding, to a shallow water current moving abundant sediment once and leaving it undisturbed.

The next two beds, taken together, become more porous upward, but are only slightly smaller in dolomite crystal size. They suggest dolomitization of calcite (or aragonite) detritus derived from nearby incipient-reef growth. The more usual, finer, shoal sediment would not develop both the very fine to fine crystalline dolomite and the abundant porosity, and an environment that could concentrate coarse and medium sand sized quartz grains along planes in the middle of a bed would not allow it to remain.

The steady diminution upward in the amount of terrigenous sediment, with a continuation of the wide range in particle size, shows a continuous retreat of the shoreline farther from this area, while the sea remained shallow and was able to transport the coarser grains.

Above these three beds is a massive unit, which marks the return of coralline reefs at this locality. Although the lower"beds" are not as distinctly reefoid, they posses many large vugs which suggest solution of fossil remains. The upper forty inches, however, is distinctly a reef mass as it is a single unit containing abundant colonial coral remains and equally abundant vugs which were formed by solution of fossils, in some case, demonstrably, of corals. Also suggesting a reef mass are the irregular undulations on the floor of the quarry above this unit.

The growth of this reef was suddenly stopped, as was the coralline growth at the top of the Gunton member, by a strong influx of terrigenous sediment. These finer silt and clay sized particles mixed with the more abundant fine carbonate sediment to form nodules, some with green shaly partings as in the Gunton member.

These conditions continued long enough to deposit fourteen inches of nodules, and then ceased. But its effects had been widespread, as it is found well into the subsurface, (Porter and Fuller, 1959, p.134) so that on the return of reef deposition the positions of the reefs were different.

At this location the rock overlying the nodular unit is a hard, splintery dolomite. It was deposited in a "back-reef", protected environment, and, judging from its dense fineness, the waters were sufficiently restricted either to deposit the carbonate sediment as dolomite or to very soon dolomitize it, and then to allow it to remain.

Conditions for reef growth continued to be favourable, and the next one hundred inches to be deposited show at least a partial return of reef growth to this locality. The bedding is not quite as massive as in the unit below the nodular beds, but the great abundance of not only colonial corals, but also of gastropods, brachiopods, and cephalopods, show an open, shallow sea environment. It is possible that a slightly more massive reef was developed in the vicinity and that these rocks represented a nearby "fore-reef" environment of deposition.

A temporary return to the deposition of nodules, this time with much less terrigenous sediment, again ended reef growth. These nodules form only a three inch thick deposit and are overlain by three feet of hard, slightly splintery dolomite with a sub-conchoidal fracture. This rock represents, again, the deposition of carbonate sediment in a protected, retricted, "back-reef" environment, where the sediment was either primary dolomite or was dolomitized very soon after deposition.

That there were reefs growing "nearby" is proven by the fourteen inch bed at the top of the section at the Stonewall Quarry. Above the hard, splintery dolomite, the lower part of the bed is a very fine crystalline, porous dolomite, probably composed of coarser original sediment than the underlying beds. Upward, the sediment increases in size until the upper part of the bed has become a dolomite conglomerate. A study of the fragments and pebbles shows that many are the remains of reef forming organisms, such as corals, coralline algae (?) and layered "calcareous" algae.

This conglomerate represents a relative lowering of sea level rather than progressively nearer reef growth, for there are also pebbles of sublithographic dolomite which contain fine fragments or fine laminations and represent original deposition in a protected, "back-reef" environment. The relative lowering of sea level was sufficiently great to allow the tearing up of already consolidated sediment as well as the breaking up of at least part of the reef mass.

This process must have been somewhat intermittent as one of the sublithographic sediment pebbles is coated with fine layers deposited by algae.

The terrigenous sediment in the rocks above the fourteen inch nodular bed are a very minor part of the rock. The total amount varies from 1.56 percent to 0.40 percent, and the clay sized residue increases upward, relatively, until it is approximately eighty percent of the whole. Fine silt sized grains do not appear in the uppermost beds.

The most abundant residue occurs in the hard, dense beds and in the dolomite conglomerate. This is probably due to a slower rate of deposition in the former beds and the inclusion of pebbles of dense sediment in the latter.

Although the terrigenous sediment in the lowest beds of the member was probably transported by the action of marine water, the very small amount and fine size of the residue in the remaining beds suggests that it was wind blown dust.

DIAGENESIS

The most important diagenetic change in the Stonewall formation is the dolomitization of the rocks. With the probable exception of the hard, dense, splintery dolomites, all the rocks of the Stonewall formation have undergone secondary dolomitization. This is suggested by the dolomite crystal sizes and the slightly calcareous nature of the rocks, and is strongly shown by the contained fossil remains, and by the dolomitization patterns which follow the bedding.

Much of the fine porosity in the rocks of the member has been infilled by clear carbonate, probably dolomite. On the other hand, there has been much solution of fossils, especially colonial corals, mainly due to surface or near-surface weathering.

In the lowermost beds of the Stonewall formation, the insoluble residues have undergone minor alterations. The quartz grains have been slightly to finely etched and pitted by carbonate replacement. This is most noticeable on the coarser grains generally, but also on the coarser grains of 14W.36 in particular, as in Plate XXV, p.137. In the latter case, the grains are very pitted and irregular, which may be due in small part to regeneration, but many of the flat faces are not quartz crystal faces and one of the pits is rhombic in shape, showing dolomite crystal replacement.

Probably due to this replacement of quartz, lightly cemented aggregates of quartz grains have formed. These are most commonly of very fine sand and coarse silt sized grains in 14S.35, and do not contain more than a few grains. As these sizes are the most common in the sample, it appears that aggregation is a purely random process and occurs when any residue grains are close enough together.

Also in these lower beds, hematite pseudomorphs have formed from oxidation of pyrite.

CHAPTER EIGHT

SOURCES OF TERRIGENOUS SEDIMENT

The information gained from the terrigenous sediment in the rocks of the Stony Mountain and Stonewall formations has been used to arrive at an understanding of the processes of sedimentation. In addition certain features of these residues supplied information regarding their source.

In the fine and coarse bioclastic limestones of the Gunn member, there is a very distinct bi-modal distribution to the small amount of terrigenous sediment, as shown by the histograms for 4 Gu. 2 and 11Gu.4 in Figure 2, p.26. The coarse silt and very fine sand sized quartz grains show a noticeable to very noticeable undulatory extinction. When the residue is more abundant, as in the argillaceous bioclastic limestones, these coarser grains are nearly lost in the finer sediment, and the medium and coarse silt sized quartz shows much less undulatory extinction.

The residues in the Penitentiary member are very similar in distribution and amount to those in the argillaceous bioclastic limestones, and therefore contain only a very little coarse silt and no very fine sand, as in Figure 3, p.54.

In the Gunton member there is much less terrigenous sediment. The very fine sand again appears, even in 3Gt.3 the transition beds above the Penitentiary member, and a much larger proportion of the residue is made up of silt sized grains, as is shown by Figure 4, p.73, and 5, p.74. The coarser grains become more abundant toward the north end of the thesis area, and have a pronounced undulatory extinction.

A very much larger amount and proportion of sand and coarser silt sized quartz grains are present in the Williams member, as illustrated by Figure 6, p. 107. They show either a very slight to slight undulatory extinction or none at all. This is considerably less than that shown by the coarser quartz grains in the Gunton member and is even less than that of the coarser silts in the argillaceous bioclastic limestones of the Gunn member.

The lower four beds of the Stonewall formation, as shown in Figure 7, p. 131, also contain much sand and coarser silt sized quartz grains, showing very slight or no undulatory extinction, although the remainder of the formation has no terrigenous sediment coarser than fine silt size.

This evidence suggests at least two distinct sources for the terrigenous sediment of the two formations. The one supplied the coarser, undulose quartz grains in the Gunn and Gunton members, along with a probable and similarly small proportion of the finer sediment. It probably supplied the same type of sediment to the Penitentiary member also, but it was evidently hidden by a process of massive dilution. The other source or sources supplied almost all the finer sediment in the Gunn and Gunton members, all that was seen in the Penitentiary member, and all the coarse and fine sediment in the Williams member and the Stonewall formation. These sources probably supplied the heavy minerals to the lower Stonewall beds during a period of slightly more rapid erosion; and produced the larger amounts of hematite in the argillaceous, bioclastic limestones of the Gunn member, in the upper beds of the Penitentiary member, in the upper Williams member and in the nodular bed of the Stonewall formation, during times of lower land masses and/or more thorough chemical weathering.

Hunter (1951, pp.1ff.) has described the igneous rocks of the Precambrian inlier situated on the northeast shore of Lake St. Martin. He found that the quartz in these rocks exhibited pronounced undulatory extinction.

This inlier is one hundred miles north-northwest of Teulon, which is at the north end of the thirty-four mile long, north-south trending thesis area. From its present position within the Ordovician outcrop belt, in a region of only the very gentlest structures, it appears that the inlier was an island in the Ordovician sea, a drowned Precambrian monadnock. The map which accompanies Baillie's report (1952, Map 51-6) shows a much smaller Precambrian inlier situated only seventy-five miles north of Teulon; and others may be present.

These "islands" supplied the coarser terrigenous sediment found in the Gunn and Gunton members, and probably also thatin the Penitentiary member.

This conclusion is supported not only by the undulatory extinction of the coarser quartz grains, but also by a comparison of the positions of these inliers with the northward increases in abundance of the coarser residue grains in the Gunton member, as presented in Table III, p.160.

In his paper on Ordovician correlations in North America, Patterson (1961, p.1372) illustrates the former continuity of the lower Stony Mountain and Maquoketa formations. Such continuity probably also existed in an easterly and southeasterly direction from the Manitoba outcrop belt. As the sandy Williams and argillaceous Gunn and Penitentiary units in the Stony Mountain formation decrease in thickness and grain size in a westward (J. W. Porter and J. C. G. M. Fuller, 1959, p.156) or northwestward (pp.150-151) direction, respectively, the source must be sought in an eastward or southeastward direction. On the grounds that Patterson and the above assumption are correct, the source of the more abundant terrigenous sediment will be to the eastward or southeastward beyond the Precambrian "exposure" on the Sioux arch.

The finer residues in the Gunn, Penitentiary and Gunton members have very similar size distributions, for example, 11Gu.10, 11P.21 and 11Gt.33. The intermittent introduction during Gunn time of terrigenous sediment with

TABLE III

COMPARISON OF MEAN PERCENTAGES OUT OF

TOTAL INSOLUBLE RESIDUE

FROM THE GUNTON MEMBER

	0"-180"*1		180"-220"		220"-340		340"-364"	
AT LOCATION	Coarse Silt	Very Fine Sand	Coarse Silt	Very Fine Sand	Coarse Silt	Very Fine Sand	Coarse Silt	Very Fine Sand
2	1.05	0.16						
11	3.09	0.69	1.82	0.45				
12					5.35	0.73*3		
13	*2		7.41	4.44	4.39	2.07	1.22	0.17
17	5.47	0.86	11.58	6.70	5.98	1.43		
			Maximum "island" effect		Covered or nearly so		Covered (or reef effect)	

*1 Distances from the base of the member.

*2 Not representative due to pyrite aggregates.

*3 These large percentages are relative in part, as total residue is decreasing more rapidly then the coarser fractions.

slightly smaller grain sizes suggests less active erosion, or a more distant, less stable source, than during Penitentiary time. The Gunton residue amounts and distributions seem to indicate the return of less active erosion on an apparently slightly nearer source. However, the shoaling during Gunton time may have led to local sorting and coarsening of some of these residues.

This general similarity of terrigenous sediment coupled with a source direction to the southeast indicates a single source for the finer residues of the Gunn, Penitentiary and Gunton members. In well data (M. Y. Williams, 1919, Figure 3)(J. F. Caley, 1943, pp.9-10)(R. B. Newcombe, 1932, pp.139-140)(R. R. Shrock, 1939, p.534)(J. E. Brown and J. W. Whitlow, 1960, pp.31-44)from Ontario, Michigan, Wisconsin, Illinois and Iowa, it appears that this source is the same landmass that produced the terrigenous sediment in the Maquoketa, Queenston and Juniata formations of the Upper Ordovician.

However, on investigating these and other well data in an effort to discover the source of the terrigenous sediment in the Williams member, it was found that no equivalent beds existed in the units which overly the above mentioned formations. The Iowa, Illinois and Wisconsin wells showed only carbonate and the Michigan and Ontario wells, only some shale. The Williams member sediment must therefore have come from a different source than the finer grains in the lower three members of the formation.

It was previously concluded, from well data to the west of the Manitoba outcrop belt, that the source for the Williams member was to the eastward of the thesis area. Thus, a well drilled on the southwestern shore of James Bay (N. Hogg, J. Satterly and A. E. Wilson, 1952, pp. 133-137), which is slightly north of due east from the outcrop area, should provide a suitable test. This well encountered a two hundred and seventy foot section, below known Silurian rocks, that contains a total of ninety-eight feet of sand stone, mainly at the base.

The terrigenous sediment in the lower four beds of the Stonewall formation is without doubt from this same source to the east. The traces of heavy minerals suggest a less mature sediment, perhaps from a different source rock than the quartz. The remainder of the formation contains nothing but very small amounts of very fine terrigenous sediment, probably entirely wind-blown. This came from an apparently lower and more distant land to the east, but the growth of reef bodies at this time may have been responsible for some of this apparent distance by restricting the distribution of the coarser grains.

CHAPTER NINE

CONCLUSIONS

This chapter summarizes the findings of the preceding chapters and contains those more general conclusions that have not been stated previously.

It was found that the coarse and the fine bioclastic limestones of the Gunn member were formed from the organic comminution of organic detritus, with only a very small amount of wave energy involved. It is concluded that the factors which controlled the size of the organic detritus were:

1. Original size.
2. Original shape.
3. Structural strength of the shell, spine, corallum, etc.
4. Amount of bottom scavenging.
5. Amount of burrow scavenging.
6. Wave energy above the site of deposition.
7. Amount of dissolved carbon dioxide.
8. Rate of deposition-subsidence, (i.e. the effect of time).

The argillaceous bioclastic limestones of this member are due to the intermittent influx of abundant terrigenous sediment, followed by intense organic activity and, finally, by dolomitization. The terrigenous sediment in the upper most part of the Gunn member, if there had been no organic mixing, would have produced slightly calcareous shale beds comprising at least eighteen percent of the section.

It is considered that the clear, sparry calcite in this member was formed in three ways:

1. By recrystallization of the original, sublithographic calcite matrix.
2. By recrystallization of probably aragonitic shells.
3. By the infilling of spaces under and within shells.

The first process produced considerably more sparry calcite than the other two combined.

The sediment which formed the Penitentiary member was deposited in a quiet, probably deeper water environment, which became slightly shallower and more active toward the end of Penitentiary time. This sediment was predominantly of fine carbonate grains but also contained continuously abundant, equally fine, terrigenous sediment.

The basal portion of the Gunton member in the southern part of the thesis area contains beds which indicate locally semi-evaporitic conditions in a restricted energy environment. The brecciated and porous beds are due to evaporite solution and the hard, dense dolomites to probable primary dolomite deposition. The associated nodular and massive beds in the northern part of the area indicate production and accumulation of fine carbonate sediment just above and just below the effective storm wave base, respectively.

The various types of mottling in the dolomites of the Gunton member point to differential and incomplete dolomitization due to a lack of adequate permeability in some of the fine sediment.

The uppermost beds of the member show the beginnings of reef development in the thesis area. This growth was suddenly stopped by the introduction of abundant, partly coarse, terrigenous sediment.

As the beds containing this sediment are lithologically distinct from those below and show an abrupt lithologic change at their base, a new member was named for these upper beds of the Stony Mountain formation --the Williams member.

The lower half of this member generally exhibits much sorting, probably in a near-littoral environment. It also contains thin, yellow, lithographic beds with little terrigenous sediment, which suggest dolomite deposition in temporary lagoons cut off from the open sea and the source of terrigenous sediment. Another type of deposit is the many thin, green shale laminations caused by the slower settling of the finer terrigenous particles following storms.

The upper half of the member consists of much less sorted sediment, but it also contains the coarsest grains in the member. This points to deeper, open waters which could not sort the material while still allowing the influx of the coarser terrigenous sediment.

The uppermost beds of the member contain the finest sediment and represent the influx of large amounts of clay sized particles from an emerging area approaching from the east. This emergence reached the thesis area and caused an unknown, but probably small amount of erosion.

The Stonewall formation began above the hiatus with beds that contain the last appearance of coarse terrigenous sediment in the area. This sediment showed a lesser maturity by containing traces of heavy minerals, including garnet and magnetite. Above these beds nothing coarser than fine silt sized, probably wind bore grains reached the area.

The entire formation was deposited during a period of intensive reef growth, either in the Stonewall area or nearby. Therefore, the beds either were formed as reefs or were deposited in the back-reef or fore-reef environments. Individual reefs remained small in size because sudden changes in the environment, due mainly to the influx of various amounts of very fine terrigenous sediment. The uppermost bed exposed is a conglomerate, formed of both reef and back-reef sediment fragments and is due, therefore, to a lowering of sea level.

It was found that the occurrence of the colonial corals changed during Stony Mountain and Stonewall time. Initially the colonies had a separate existence (Gunn), but later they became incorporated, first into biostromal reefs (Gunton) and then into biohermal reefs (Stonewall). As the encrusting layered "calcareous" algae do not seem to have been present as such during Gunn time but have left abundant remains in some beds of the Stonewall formation, they appear to be entirely responsible for this change.

Several general conclusions can also be drawn from the study of the insoluble residues. Figure 8, p.168, shows a comparison between the total weight percent of the residue in various sections of the Penitentiary and Gunton members. It is seen that this parameter cannot be used to correlate specific portions of a member within a small area, whether the total amounts of residue be large or small, as lateral variations are not sufficiently great or are too erratic in such small portions of the section. At the same time, this method is very useful in correlating entire members over much larger areas, for the more general variations in the amount of total residue have great lateral persistence.

In contrast, Table III, in Chapter 8, p.160, illustrates that the coarser residue fractions are useful for correlation even in areas as small as that of the thesis, provided there are relatively local sources of sediment.

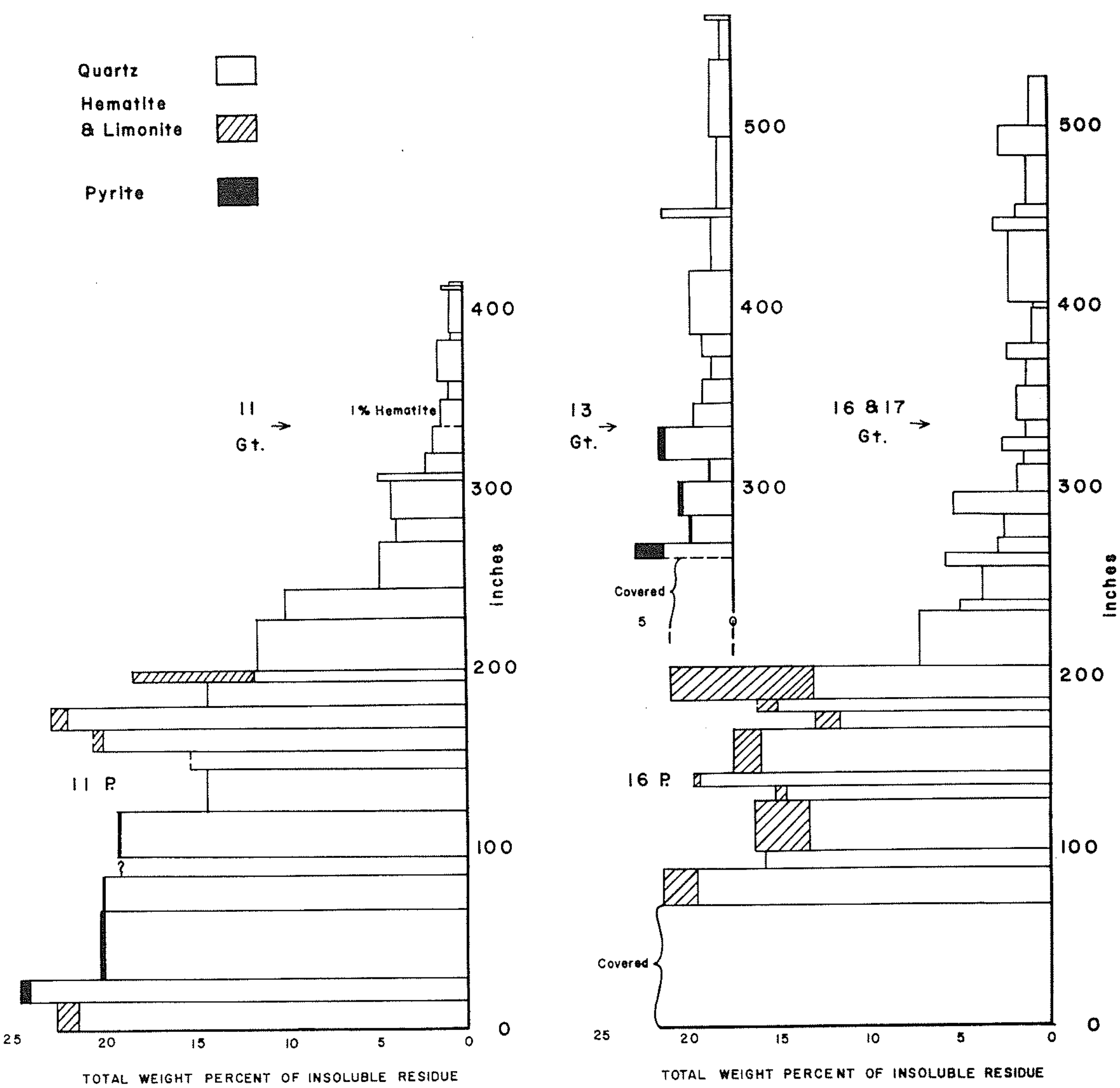


FIGURE 8

COMPARISON OF TOTAL WEIGHT PERCENT

OF INSOLUBLE RESIDUE

IN THE PENITENTIARY AND GUNTON MEMBERS

In the Gunn, Penitentiary and Gunton members, the amounts and size distributions of the terrigenous sediment were found to be independent of conditions at the site of deposition. In the lower half of the Williams member, in contrast, the amounts and especially the size distributions were very dependent on local conditions; although the residues in the upper half were much less so. The lower four beds of the Stonewall formation show only a general independence, but in the remainder of the unit the amounts and sizes of residue particles were almost entirely unaffected by local conditions.

However, throughout the two formations, those local structures which are related to organic skeletal growth were very sensitive to the amount of terrigenous sediment being supplied to the site of deposition, especially if introduced relatively rapidly.

The mobility of some of the silica and iron oxides in these carbonate rocks have raised questions concerning the conditions, whether ancient or recent, under which these minerals were moved and added as secondary "growths", or were formed into aggregates in various parts of the rock. No answers were found in this study to these problems.

Stratigraphic Section No. 2, (Figure 10, in pocket), drawn from the Stonewall to the Birse quarries shows that the physiography of the Stonewall area is controlled by two cuestas formed from the Gunton member and the Stonewall formation, now partially covered by Pleistocene sediment. These cuestas are caused by the relative erosional weakness of the Gunn-Penitentiary and Williams units, respectively.

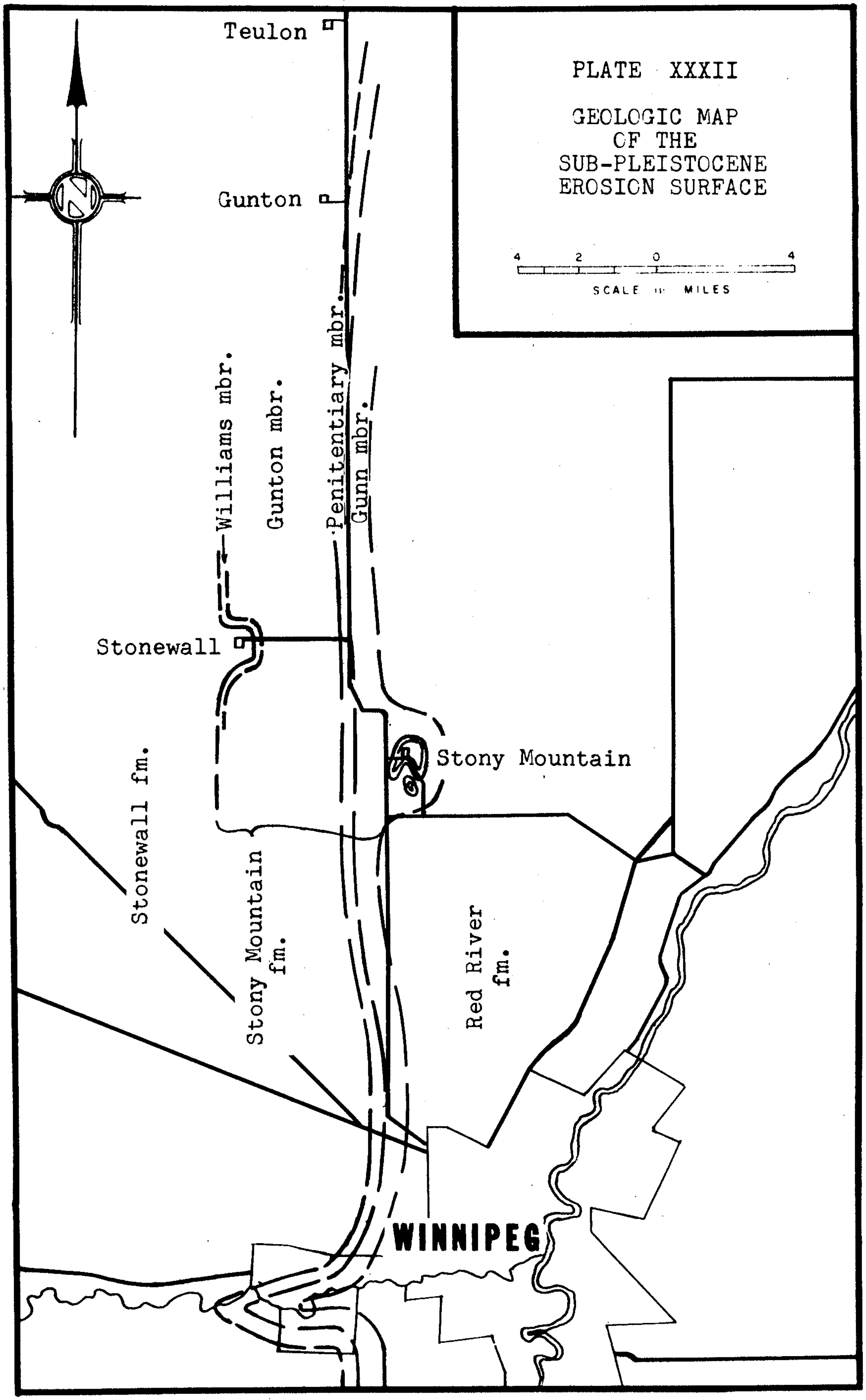


PLATE XXXII
GEOLOGIC MAP
OF THE
SUB-PLEISTOCENE
EROSION SURFACE
4 2 0 4
SCALE IN MILES
Teulon
Gunton
Williams mbr.
Gunton mbr.
Penitentiary mbr.
Gunn mbr.
Stonewall
Stony Mountain
Stonewall fm.
Stony Mountain fm.
Red River fm.
WINNIPEG

BIBLIOGRAPHY

A SELECTED BIBLIOGRAPHY

Alderman, A. R. and Skinner, H. C. W.(1957) Dolomite sedimentation in south-east of South Australia: Am. Jour. Sci., vol. 255, pp. 561-567.

American Commission on Stratigraphic Nomenclature (1961) Code of Stratigraphic Nomenclature: Am. Assoc. Petroleum Geologists Bull., vol. 45, pp. 645-665.

Andrichuk, J. M.(1959) Ordovician and Silurian stratigraphy and sedimentation in southern Manitoba, Canada: Am. Assoc. Petroleum Geologists Bull., vol. 43, pp. 2333 - 2398.

Baillie, A. D.(1951) Silurian geology of the Interlake area, Manitoba: Manitoba Dept Mines and Nat. Res., Mines Branch Publ. 50-1.

_______(1952) Ordovician geology of Lake Winnipeg and adjacent area, Manitoba: Manitoba Dept. Mines and Nat. Res., Mines Branch Publ. 51-6.

Beales, F. W.(1953) Dolomitic mottling in Palliser(Devonian) limestone, Banff and Jasper National Parks, Alberta: American Association Petroleum Geologists Bull., vol.37, pp. 2281-2293.

Birse, D. J.(1928) Dolomitization processes in the Palaeozoic horizons of Manitoba: Trans. Roy. Soc. Canada, 3rd Sev., vol. 22, sec. IV, pp. 215-221.

Brown, C. E. and Whitlow, J. W. (1960) Geology of the Dubuque South Quadrangle, Iowa-Illinois: U. S. Geol. Survey, Bull. 1123A.

Caley, J. F.(1943) Palaeozoic geology of the London area, Ontario: Geol. Survey Canada, Mem. 237.

Carl, J. D. and Amstutz, G. C.(1958) Three-dimensional Liesegang rings by diffusion in a colloidal matrix, and their significance for the interpretation of geological phenomenon: Geol. Soc. America Bull., vol. 69, pp. 1467-1468

Carozzi, A. V.(1960) Microscopic sedimentary petrography: John Wiley and Sons, Inc., New York.

Clarke, F. W. and Wheeler, W. C.(1922) The inorganic constitnents of marine invertebrates: U. S. Geol. Survey Prof. Paper 124.

Cumming A. D., et al.(1958) Report of the Lower Palaeozoic Names and Correlations Committee: Sask. Geol. Society.

Dawson, G. M.(1886) On certain borings in Manitoba and the Northwest Territory: Trans. Roy. Soc. Canada, vol. 4, pp. 85-99.

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

Dunbar, C. O. and Rodger , J.(1957) Principles of stratigraphy: John Wiley and Sons, Inc., New York.

Ethington, R. L. and Furnish, W. M. (1960) Upper Ordovician conodonts from southern Manitoba: Jour. Paleontology, vol. 34, pp. 265-274.

Galloway, J. J.(1922) Red limestones and their geologic significance (abstract): Geol. Soc. America Bull., vol. 33, pp. 105-106.

Grabau, A. W.(1904) On the classification of sedimentary rocks: American Geologist, vol. 33, pp. 228-247.

Hadding, A.(1956) The lithological character of marine shallow water limestones: Proc. Roy. Physiographic Society at Lund, vol. 26, pp. 99-116.

_______(1958) Origin of the lithographic limestones: Proc. Roy. Physiographic Society at Lund, vol. 28, pp. 21-23.

Hogg, N., Satterly, J. and Wilson, A. E.(1952) Drilling in the James Bay Lowland, Part 1: Ont. Dept. Mines, Ann. Rept., vol. 61, pt. 6, pp.115-140.

Hunter, H. E. (1951) Igneous rocks in the Lake St. Martin area, Manitoba: Manitoba Dept. Mines and Nat. Res., Mines Branch Publ. 50-10.

Ireland, H. A. et al.(1947) Terminology for insoluble residues: Amer. Assoc. Petroleum Geologists Bull., vol. 31, pp. 1479-1490.

Johnston, W. A.(1934) Surface deposits and ground-water supply in Winnipeg map-area, Manitoba: Geol. Survey Canada, Mem. 174.

Kindle, E. M.(1914) The Silurian and Devonian section of western Manitoba: Geol. Survey Canada, Summ. Rept. 1912, pp.247-261.

Krumbein, W. C. and Pettijohn, F. J.(1938) Manual of sedimentary petrography: Appleton-Century-Crofts, Inc., New York.

Krumbein, W. C. and Sloss, L. L. (1951) Stratigraphy and sedimentation: W. H. Freeman and Co., San Francisco.

Kupsch, W. O. (1952) Ordovician and Silurian stratigraphy of east central Saskatchewan: Sask. Geol. Survey, Rpt.10.

Lamar, J. E.(1950) Acid etching in the study of limestones and dolomites: Illinois State Geol. Survey, Circular 156.

MacLean, A.(1913) Ordovician and Silurian of Stony Mountain and Stonewall, Manitoba: Geol. Survey Canada, Transcontinental Excursion C1, Guidebook 8, pp. 69-77.

Milner, H. B.(1952) Sedimentary petrography: Thos. Murby and Co., London.

Nelson, S. J.(1959) Guide fossils of the Red River and Stony Mountain equivalents (Ordovician): Alberta Soc. Petroleum Geologists Jour., vol. 7, pp. 51-61.

Newcombe, R. B. (1932) Oil and gas fields of Michigan, Part II: Mich. Geol. Surv., Publ. 38, Geol. Ser. 32.

Okulitch, V. J.(1943) The Stony Mountain formation of Manitoba: Trans Roy. Soc. Canada, 3rd Ser., Vol. 37, sec. IV, pp. 59-74.

Panton, J. H.(1884), in Dawson (1886), p. 89.

Patterson, J. R.(1961) Ordovician stratigraphy and correlations in North America: Amer. Assoc. Petroleum Geologists Bull., vol. 45, pp. 1364-1377.

Payne, T. G. (1942) Stratigraphical analysis and environmental reconstruction: Amer. Assoc. Petroleum Geologists Bull., vol. 26, pp. 1697-1770.

Pettijohn, F. J.(1949) Sedimentary rocks: Harper and Brothers, New York.

Porter, J. W. and Fuller, J.G.C.M.(1959) Lower Paleozoic rocks of northern Williston Basin and adjacent area: Amer. Assoc. Petroleum Geologists Bull., vol. 43, pp. 124-189.

Ross, R. J., Jr.(1957) Ordovician fossils from wells in the Williston Basin, eastern Montana: U. S. Geol. Survey Bull. 1021-M, pp. 439-510.

Shrock, R. R.(1939) Silurian formations and contiguous strata in eastern Wisconsin: Geol. Soc. America Bull., vol. 50, pp. 529-562.

Sinclair, G. W.(1959) Succession of Ordovician rocks in southern Manitoba: Geol. Surv. Canada, Paper 59-5.

_______ and Leith, E. I.(1958) New name for an Ordovician shale in Manitoba: Jour. Paleontology, vol.32, pp. 243-244.

Stearn, C. W.(1956) Stratigraphy and palaeontology of the Interlake group and Stonewall formation of southern Manitoba: Geol. Surv. Canada, Mem. 281.

Tyrrell, J. B.(1892) Report on north-western Manitoba: Geol. Surv. Canada, Ann. Rept. k890-1891, pt.E.

Van Tuyl, F. M.(1916) The origin of dolomite: Iowa Geol. Survey, Ann. Rept. 1914, (vol.25), pp. 251-422.

Wallace, R. C. (1913) Pseudobrecciation in Ordovician limestones in Manitoba: Jour. Geol., vol. 21, pp. 402-421.

_______ and McCartney, G.C.(1928) Heavy minerals in sand horizons in Manitoba and eastern Saskatchewan: Trans. Roy. Soc. Canada, 3rd Der., vol. 22, sec. IV, pp. 199-214.

Wentworth, C. K. (1922) A scale of grade and class terms for clastic sediments: Jour. Geol., vol. 30, pp. 377-392.

Williams, M. Y. (1919) The Silurian geology and faunas of Ontario Peninsula, and Manitoulin and adjacent islands: Geol. Survey Canada, Mem. 111.

APPENDIX

APPENDIX A

LIST OF LOCALITIES

1	Assiniboine Race Track	Gt.
1A	Thompson Drive	Gt.
2	Little Stony Mountain Quarry	P.-Gt.
3	Lilyfield Quarry	P.-Gt.
4	Watchtower Quarry	Gu.-P.-Gt.
5	South Roadside Outcrop	Gu.
6	Major's Gravel Pit	Gu.-P.
7	East of Penitentiary Outcrop	Gu.-P.-Gt.
8	North of Penitentiary Outcrop	P.-Gt.
9	Northeast Stony Mountain Outcrop and Road Cut	Gt.
10	North Roadside Outcrop	Gt.
11	City of Winnipeg Quarry - Stony Mountain	Gu.-P.-Gt.
12	Birse Quarry	Gt.
12A	South Birse Quarry	Gt.
13	New Stonewall Quarry - "Lily Pit"	Gt.
14	Stonewall Quarry	W.-S.
15	Northeast Stonewall Gravel Pit	Gt.
16	East Gunton Quarry	P.-Gt.
17	West Gunton Quarry	Gt.
18	North Gunton Quarry	P.-Gt.
19	Teulon Outcrop.	Gt.

Stony Mountain Formation
Gunn member - Gu.
Penitentiary member - P.
Gunton Member - Gt.
Williams member - W.
Stonewall Formation - S.

KEY TO THE INSOLUBEL RESIDUE TERMINOLOGY USED IN APPENDIX A

5 - 10%	Clay sized residue (in the entire rock)	=	slightly argillaceous
10 - 15%	Clay sized residue	=	argillaceous
15 - 30%	Clay sized residue	=	very argillaceous
30% +	Clay sized residue	=	extremely argillaceous
5 - 10%	Silt sized residue	=	slightly silty
10 - 15%	Silt sized residue	=	silty
15 - 30%	Silt sized residue	=	very silty
30% +	Silt sized residue	=	extremely silty
5 - 10%	Sand sized residue	=	slightly sandy
10 - 15%	Sand sized residue	=	sandy
15 - 30%	Sand sized residue	=	very sandy
30% +	Sand sized residue	=	extremely sandy

APPENDIX A

DESCRIPTION OF MEASURES SECTIONS

ASSINIBOINE RACE TRACK
(Location 1)

Gunton Member

3"+ Dolomite, light tan-brown and tan, mottled, massive, sublithographic to minor very fine crystalline. (1Gt.1)

THOMPSON DRIVE
(Location 1A)
(

Penitentiary Member

6"+ Dolomite, light yellowish-green, light maroon and light purple, mottled, massive, fossiliferous. (1AP.1)

LITTLE STONY MOUNTAIN QUARRY
(Location 2)

Gunton Member

2' 0"+ Dolomite, light grey-brown and light yellowish-brown, mottled with some, (up to 5/16" diam.) light greenish grey oval and circular areas, very fine crystalline to sublithographic, slightly nodular with pale green shaly films, very scattered fine porosity. (2Gt.20)

Dolomite, light brown and light yellowish-brown mottled, slightly nodular, very fine crystalline, scattered fine porosity. (2Gt.19)

Dolomite, light brownish-grey and light brownish-yellow mottled, sublithographic to very fine crystalline, very scattered fine porosity. (2Gt.18)

\- in two 12" or 24" bed.

Location 2 (continued)

10"	Dolomite, Light brown, light brownish-grey and light yellowish-brown, mottled, faintly nodular in part, (1" diameter), with traces of green shaly partings, hard, sublithographic to very fine crystalline, scattered fine porosity, one bed. (2Gt.17)
1' 3"	Dolomite, light greyish-brown, light yellowish and greenish-grey, mottled and banded, sublithographic to very fine crystalline, very scattered fine porosity, one bed. (2Gt.16)
1' 0"	Dolomite, light greyish-brown and greyish-yellow, mottled, as above, one bed. (2Gt.15)
1' 6"	Dolomite, light greyish and yellowish-brown, mottled, very fine crystalline, hard, scattered solution vugs (up to 1"), from fossils, one bed. (2Gt.14)
1' 3"	Dolomite, light yellowish-brown, sublithographic to very fine crystalline, hard, one bed. (2Gt.13)
1' 4"	Dolomite, light yellowish-brown and minor pale rose-brown, mottled, coarsely nodular with green shaly partings, 3" to 5" beds. (2Gt.12)
1"	Dolomite, light yellowish-brown, extremely and finely nodular, abundant green shaly parings. (2Gt.11)
1' 4"	Dolomite, light yellowish-brown, greenish tints, faintly nodular becoming nodular downward (11/2" diam.), green partings, slightly fossiliferous, 3" to 4" beds. (2Gt.10 & 9)
1' 4"	Dolomite, light brown to light yellowish-brown, mottled, very fine to fine crystalline, faintly broken appearance, fossiliferous (hollow columns and large solution cavities), 4" to 6" beds. (2Gt.8)
3' 0"	Dolomite, light yellow-grey and minor light grey-brown, very faintly mottled, sublithographic to minor very fine crystalline, hard, brittle with a sub-conchoidal fracture. (2Gt.7)

Location 2 (continued)

Dolomite, light yellowish-grey to light tan-grey with a green tint in part, scattered fine Porosity. (2Gt.6)

Dolomite, light grey-green and light greyish-yellow, mottled, very fine crystalline, slightly argillaceous. (2Gt.5)

- in 4" to 6" beds.

Penitentiary Member

1' 2" Dolomite, light yellowish-green mottled with much orcherous yellow to light orange, slightly nodular, sublithographic with traces very fine crystalline, fossiliferous argillaceous, in 7" beds. (2P.4)

8" Dolomite, light yellowish-green, light maroon and light purple, mottled in part, fossiliferous, argillaceous, one bed. (2P.3)

1' 2" Dolomite, light greenish-yellow, slightly nodular, sublithographic, very slightly fossiliferous, very argillaceous, in 1" to 4" beds. (2P.2)

1'10"+ Dolomite, light greenish-yellow, with mottles of medium brownish yellow and pale purple, sublithographic, slightly fossiliferous, very argillaceous, in 1" to 7" very irregular beds. (2P.1)

LILYFIELD QUARRY
(Location 3)

Gunton Member

1' 3" + Dolomite, pale rose and light greenish and tan-grey, mottled, very fine crystalline to sublithographic, with some green shaly blebs and partings, in 3" to 5" beds. (3Gt.8)

4" Dolomite, light brown, pale greenish and tan-grey, very faintly mottled, fossiliferous. (3Gt.7)

Location 3 (continued)

1' 6" Dolomite, light tan-grey, faintly nodular at the top, very fine crystalline, abundant solution vugs. (3Gt.6)

Dolomite, light greyish-tan to light-grey-brown, mottled, hard, brittle, very fine crystalline to sublithographic, numerous solution vugs. (3Gt.5A)

Dolomite, light grey-brown and light greenish and tan-grey, very fine crystalline to sublithographic, hard, brittle in darker parts, very brecciated appearance, scattered fine porosity. (3Gt.5)

- in 3" to 5" beds.

2' 0" Dolomite, light grey and pale greenish-grey, mottled, sublithographic, scattered solution porosity. (3Gt.4)

Dolomite, light greenish-grey and light ocherous yellow, mottled, sublithographic to very fine crystalline, slightly argillaceous. (3Gt.3)

Penitentiary Member

2' 8"+ Dolomite, light greyish-green with ocherous yellow streaks, light maroon mottles in lower portion, sublithographic, slightly fossiliferous to fossiliferous (as molds), slightly argillaceous to argillaceous downward. (3P.2&1)

WATCHTOWER QUARRY
(Location 4)

Gunton Member

1' 2"+ Dolomite, light yellowish-grey and light grey-green to light brown, mottled, with a faint brecciated appearance, sublithographic, abundant solution vugs. (4Gt.18)

Location 4 (continued)

10"	Dolomite, light brownish-grey and pale greenish-grey, mottled, sublithographic, with a brecciated appearance and scattered very fine porosity in the upper half, and fine to large solution vugs and a trace of coarse dolomite crystals (up to 1 1/2 mm. long) in the lower half of one bed. (4Gt.17 &16)
1' 1"	Dolomite, pale yellowish-grey, mottled and banded, very fine crystalline to sublithographic, slightly brecciated appearance, traces fine porosity, in 3" beds. (4Gt.15)
10"	Dolomite, light yellowish and greenish-brown, very fine crystalline,slightly nodular traces of pyrite, finely mottled, in 1/2" - 3" beds. (4Gt.14)
1' 2"	Dolomite, light greenish and greyish-brown, sublithographic, with very abundant, well to poorly formed, salt hopper molds and with a brecciated appearance in the lower part, one bed. (4Gt.13)
1' 8"	Dolomite, pale yellow and minor light greenish-grey, mottled, with traces of poorly formed hopper molds, in 2" to 4" beds. (4Gt.12)

<u>Penitentiary Member</u>

2"	"Soil zone", pale greyish-yellow, very calcareous, with abundant clay, quartz silt, minor quartz sand, traces igneous pebbles and roots. (4P.11A)
8"	Dolomite, light yellow to light orange, sublithographic, argillaceous, slightly fossiliferous, one bed. (4P.11)
1' 0"	Dolomite, light greenish yellow to light maroon, argillaceous, one bed. (4P.10)
10"	Dolomite, light yellowish-green and minor orcherous yellow, argillaceous, slightly fossiliferous bed. (4P.9)
1' 7"	Dolomite, orcherous yellow mottled with maroon along solution channels, very argillaceous, one bed. (4P.8)

Location 4 (continued)

1' 3"+ Dolomite, orcherous yellow pale orange and light yellowish-green, mottled, sublithographic to minor very fine crystalline, argillaceous, very slightly fossiliferous. (4P.7 & 6)

5' 4" Covered

1' 8"+ Dolomite, ocherous yellow and light grey-green, mottled, argillaceous, slightly fossiliferous. (4P.5)

<u>Gunn Member</u>

4' 4" Limestone, light grey-green and light maroon with scattered orcherous yellow blebs in the upper part, coarse crystalline to sublithographic bioclastic fragments, extremely fossiliferous, with minor "worm" burrows, in lensing beds up to 2" in thickness with one 4 1/2" bed. (4Gu.4)

thoroughly interbedded and intermixed with

Limestone, pale maroon and minor pale green, very argillaceous, slightly silty, very mixed, very to extremely fossiliferous in very irregular beds. (4Gu.3)

2" Limestone, light grey-green as above.

1' 8" Limestone, pale maroon and light-greenish-grey, very argillaceous, very fossiliferous.

3" Limestone, light brownish-grey, some faint reddish tints, bioclastic, lower 1" is fine to sublithographic, the remainder is coarse crystalline to sublithographic, burrows in the top and bottom, in one bed which lenses to 1" thick. (4Gu. 2)

2' 1" Limestone, light marron and light greenish-grey, very argillaceous, very mixed with "blebs" of coarse crystalline limestone and minor 1/2" to 1" beds of this Limestone. (4Gu.1)

4" Limestone, light brownish-grey, mainly medium to coarse crystalline, extremely fossiliferous, greenish-grey, very argillaceous Limestone, in two 2" beds. (4Gu.1)

APPENDIX B

PERCENTAGES BY WEIGHT OF INSOLUBLE RESIDUE

Sample Number	Total Percentage	Percentage Clay Size*	Percentage Silt Size*	Percentage Sand Size*
4 Gu. 2	2.25	1.63	0.33	0.29
4 Gu. 3	20.98	14.95	6.03	.00
5 Gu. 1	3.77	3.74	.01	.02
6 Gu. 2	1.56	1.55	.01	.01
7 Gu. 1	1.42	1.40	.01	.01
11 Gu. 1	1.27	1.27	.01	.00
11 Gu. 2	23.10	19.74	3.36	.00
11 Gu. 4	1.44	1.39	.02	.03
11 Gu.10	24.51	20.24	4.27	.00
11 Gu.11	2.04	1.01	.82	.21
1A P. 1	17.81	14.93	2.88	.00
2 P. 1	18.03	16.27	1.76	.00
2 P. 3	14.73	10.46	4.27	.00
2 P. 4	13.50	13.20	.30	.00
3 P. 1	12.03	10.51	1.51	.00
3 P. 2	8.39	7.90	.48	.00
4 P. 6	16.75	13.60	3.15	.00
4 P. 7	18.13	13.78	4.35	.00
4 P. 8	20.65	16.97	3.68	.00
4 P. 10	14.24	11.69	2.55	.00
4 P. 11	13.39	11.95	1.44	.00
6 P. 4	18.15	14.33	3.82	.00
7 P. 3	17.22	13.21	4.01	.00
7 P. 5	15.50	12.62	2.88	.00
8 P. 1	13.37	12.04	1.33	.00
11 P. 12	22.67	19.20	3.45	.02
11 P. 13	24.97	17.98	6.99	.00
11 P. 14	20.29	16.37	3.92	.00
11 P. 18	20.09	14.51	5.55	.03
11 P. 21	19.20	13.97	5.22	.00
11 P. 24	14.30	12.09	2.20	.00
11 P. 27	22.98	17.08	5.90	.00
11 P. 29	14.28	10.61	3.67	.00
11 P. 30	18.33	17.30	1.03	.00
16 P. 1	21.46	15.22	6.24	.00
16 P. 3	15.66	11.38	4.28	0.00

* The above sizes correspond to those of the Wenworth Grade Scale.

Location 4 (continued)

1' 0"+ Limestone, very argillaceous and Limestone,"clean"-
interbedded.

SOUTH ROADSIDE OUTCROP
(Location 5)

Gunn Member

2' 4"+ Limestone, reddish grey and marron, very mixed, very argillaceous, very fossiliferous, very interbedded (5Gu.5)

with

Limestone, light tan-grey, reddish in part, coarse crystalline to sublithographic, extremly fossiliferous, in 3/4" to 1 1/2" beds. (5Gu.4)

Limestone, very argillaceous, as above (5Gu.3)

Limestone, light tan-grey, pale reddish tint, coarse crystalline or finer, slightly reworked, in 1" to 3/4" beds. (5Gu.2)

1' 6" Covered

4"+ Limestone, very argillaceous, extremely fossiliferous, irregularly bedded (5Gu.1)
- and -
Limestone, light reddish-grey, very fine crystalline, in 1/2" irregular beds.

MAJOR'S GRAVEL PIT
(Location 6)

Penitentiary Member

8"+ Dolomite, light green-grey and minor orcherous yellow, sublithographic, argillaceous, very fossiliferous (as molds, clear sparry calcite shells and corals). (6P.4)

Location 6 (continued)

Gunn Member

4" Limestone, light grey, medium yellowish-brown on the outer portions, medium crystalline or less, extremely fossiliferous, with fossil fragments lying parallel to the bedding. (6Gu.3)

4" Limestone, light brownish-grey, in the upper portion - numerous ocherous yellow patches, extremly fossiliferous, coarse crystalline or less; in the lower portion-light to medim grey, reddish tint, fine crystalline and less burrowed. (6Gu.2)

2"+ Limestone, light maroon and pale greyish-yellow, very argillaceous, extremely fossiliferous, very mixed and incorporating small fragments of medium to coarse crystalline (or less), "clean" Limestone. (6Gu.1)

EAST OF PENITENTIARY OUTCROP
(Location 7)

Gunton Member

1' 4"+ Dolomite, light grey-brown and light tan-grey, faintly mottled and pale greyish-rose and light grey, mottled, sublithographic to minor very fine crystalline. (7Gt.7)

Dolomite, light greenish-grey to light greenish-tan, traces fossiliferous. (7Gt.6)

- in 2" to 3" beds.

Penitentiary Member

2' 5" covered

6"+ Dolomite, maroon, light purple and ocherous yellow, mottled, sublithographic argillaceous, traces fossiliferous. (7P.5)

Location 7 (continued)

3' 3" Covered

6"+ Dolomite, pale grey-green with ocherous-yellow flecks, sublithographic, argillaceous, slightly fossiliferous. (7P.4)

6' 5" Covered

6"+ Dolomite, light grey-green and ocherous yellow, mottled, sublithographic, argillaceous, with abundant sparry calcite fossil remains. (7P.3)

1' 5" Covered

<u>Gunn Member</u>

4' 3"+ Limestone, light red, light maroon and minor light greenish-grey, argillaceous, slightly fossiliferous, very mixed
- interbedded with
Limestone, light tan-grey, faintly red, medium to coarse crystalline or less, very fossiliferous, in beds of 2" or less. (7Gu.2)

8" Limestone, light brownish-grey and scattered red burrows, coarse crystalline or less, extremely fossiliferous, with valves convex up, down and sideways, one bed. (7Gu.1)

4"+ Limestone, argillaceous, as above.

NORTH OF PENITENTIARY OUTCROP
(Location 8)

<u>Gunton Member</u>

10"+ Dolomite, light orange and light brownish-grey, mottled, very fine crystalline to sublithographic, with a faint brecciated appearance, abundant solution vugs, in 3" to 6" beds. (8Gt.5)

Location 8 (continued)

1' 7" Dolomite, light brownish-grey and pale yellowish grey, mottled, very fine crystalline to sublithographic, with a brecciated appearance in part, traces pyrite in 2 1/2" to 5" beds. (8Gt.4)

2' 0" Dolomite, light tan-grey and pale yellowish-grey, mottled, sublithographic, abundant fine porosity in part, in 3" to 5" beds. (8Gt.3)

1' 6" Dolomite, pale grey-green, with tan and rose streaks, sublithographic, slightly argillaceous, scattered poorly formed salt hopper molds in 3" to 5" beds. (8Gt.2)

Penitentiary Member

1' 2"+ Dolomite, light grey-green and ocherous yellow, mottled, sublithographic, very fossiliferous (molds), argillaceous, in 3" to 5" beds. (8P.1)

NORTHEAST STONY MOUNTAIN OUTCROP AND ROAD CUT
(Location 9)

Gunton Member

4' 7"+ Dolomite, light tan-grey and light brown, mottled, sublithographic to minor very fine crystalline, scattered fine to very fine porosity, in 2" to 5" beds. (9Gt.6A and 6B)

11" Dolomite, pale greenish and yellowish grey, sublithographic to minor very fine crystalline, slightly to very nodular bedding, scattered fine porosity. (9Gt.5 and 5A)

Dolomite, pale green, pale maroon and purple, light orange, slightly nodular, sublithographic to very fine crystalline, scattered small to medium solution pores. (9Gt.4)

1' 2" Dolomite, light greyish brown, pale maroon and pale greenish grey, mottled in part, slightly to very nodular, sublithographic to minor very fine crystalline. (9Gt.4A and 3)

Location 9 (continued)

4' 8"+ Dolomite, light greenish and yellowish-grey, sublithographic to very fine crystalline, one 4" bed with abundant solution cavities, (fossils?) (9Gt.2)

Dolomite, light, yellowish-grey and light brown-grey faintly mottled in part, very fine crystalline, scattered (9Gt.1)

- in 1" to 5" beds, mainly 4" to 5".

NORTH ROADSIDE OUTCROP
(Location 10)

Gunton Member

1' 0"+ Dolomite, pale greyish-brown and light tan-grey with scattered pale green "blebs", mottled, very fine crystalline, some fine porosity. (10Gt.1)

CITY OF WINNIPEG QUARRY, STONY MOUNTAIN
(Location 11)

Gunton Member

1' 3"+ Dolomite, light greyish-brown and light yellowish-grey, mottled, very fine crystalline to minor sublithographic scattered solution cavities. (11Gt.48)

- and 1' from the base,

Dolomite, light greyish-yellow, sublithographic to very fine crystalline, with very minor fine crystalline, grandular appearance, only 3/4" bed. (11Gt.47)

1' 1" Dolomite, light greyish-brown and pale grey-white, mottled and banded, sublithographic to very fine crystalline, scattered fine to medium solution porosity one 4 1/2mm. square pore. (11Gt.46)

Location 11 (continued)

2½" Dolomite, light greyish-yellow, sublithographic to very fine crystalline and very minor fine crystalline, grandular appearance scattered fine porosity. (11Gt.45)

1' 1" Dolomite, light grey-brown and minor pale yellowish-grey, lightly mottled, sublithographic to very fine crystalline. (11Gt.44)

1' 10" Dolomite, light yellowish-brown, very fine crystalline to sublithographic. (11Gt.43)

Dolomite, light rose and light brownish-grey, finely nodular, sublithographic to very fine crystalline, scattered fine porosity, with a 1/2" granular dolomite bed. (11Gt.42)

\- in 2" to 6" beds

11" Dolomite, light grey-green and light greyish brown, pink tints, mottled, sublithographic, nodular to very nodular at the base. (11Gt.41)

2' 9" Dolomite, light brownish and tan-grey, light yellowish to greenish-grey, lightly mottled, very fine crystalline, to minor sublithographic, scattered fine porosity in the upper half, one 3 mm square pore, in four beds separated by thin semi-nodular contact intervals, lower beds is 4" thick. (11Gt.37-40)

1' 10" Dolomite, light brownish-grey and light greenish-grey, lightly mottled, sublithographic to minor very fine crystalline, abundant solution cavities in small part, one bed. (11Gt.36)

3' 2" Dolomite, light brownish and greenish-grey, very fine crystalline, to minor. Sublithographic. (11Gt.35)

Dolomite, light grey-brown, very fine crystalline, finely nodular with green shaly partings in part, with medium to large solution cavities. (11Gt.34)

Location 11 (continued)

Dolomite, light greenish, orange and brownish-grey, mottled, sublithographic to minor very fine crystalline, with a brecciated appearance, scattered small to medium solution pores. (11Gt.33)
- in one bed, the lower 1' 8" of which has a brecciated appearance.

1' 5" Dolomite, light grey and green mottled with pale orange, sublithographic to very fine crystalline, faintly nodular in part, slightly argillaceous, very scattered porosity, in one bed. (11Gt.32)

2' 4" Dolomite, light greenish and yellowish-grey with orange streaks, sublithographic to minor very fine crystalline, slightly silty, slightly argillaceous, scattered solution porsity, in 4" to 12" beds. (11Gt.31)

Penitentiary Member

1' 1" Dolomite, light green and light yellowish-green with maroon and light purple, finely mottled ("burrows"), sublithographic, with a 1" "roiled" portion in one bed, argillaceous to very argillaceous, abundant solution porosity, in 3"-7" beds. (11P.29&30)

1' 1" Dolomite, light green and light yellowish-green, faintly mottled, sublithographic, very argillaceous scattered fossil remains. (11P.28)

Dolomite, light green and rose, mottled with maroon ("burrows"), very argillaceous, slightly silty. (11P.27)

- in 3" to 7" beds.

2' 4" Dolomite, light green and light brownish-yellow, mottled with very irregular light maroon and purple patches (mainly in from the bedding planes), sublithographic, slightly finely fossilferous, argillaceous. (11P.26)

Dolomite, light green with brownish-yellow tints in part, hard, argillaceous, with rotted and cavernous porosity. (11P.25)

- in 2" to 5" beds.

Location 11 (continued)

2' 2" Dolomite, light yellowish-green with brown tints, sublithographic, argillaceous, slightly fossiliferous, scattered solution porosity, in 3" to 8" beds. (11P.23 & 24)

1' 1" Dolomite, light green and ocherous yellow, mottled sublithographic argillaceous, slightly silty, slightly fossiliferous, in 5" to 8" beds. (11P.21 & 22)

1' 9" Dolomite, light yellowish-green, light brownish-yellow and pale ocherous yellow, mottled, sublithographic, argillaceous, slightly silty, slightly fossiliferous, in 3" to 8" beds. (11P.19 & 20)

1' 6" Dolomite, light green, sublithographic, argillaceous, slightly silty, very fossiliferous, abundant solution porosity, in 3" to 8" beds.(11P.17 & 18)

2' 7" Dolomite, light greenish and ocherous-yellow, sublithographic, very argillaceous, abundantly fossiliferous, (as molds) abundant fossil-solution porosity, in 5" to 7" beds.(11P. 15 & 16)

2' 0" Dolomite, light greenish-yellow, sublithographic, very argillaceous, slightly silty in lower part, abundant sparry calcite fossil shells and fragments, in 2" to 4" beds. (11P.13 & 14)

1' 2" Dolomite, light yellowish-green, traces light brown streaks, sublithographic, very argillaceous (slightly more than above), in 2" to 4" beds. (11P.12)

<u>Gunn Member</u>

2' 3" Limestone, pale grey and medium yellowish-brown, fine to coarse crystalline or less, very fossiliferous with many fragments lying in the plane of the bedding, containing dusky yellow "blebs", in an entirely lensing and thickening bed of 3" max. thickness. (11Gu.11)

Location 11 (continued)

Limestone, pale red and maroon with minor light greenish-grey patches, very mixed, very argillaceous, dolomitic, fossiliferous, (11Gu.9)
with one 1/2" clean Limestone bed near the top. (11Gu.10)

Limestone, light tan-grey, mottled in part by pale greenish-grey and rust-red, medium to coarse crystalline or less, very fossiliferous, in an 1 1/2" bed of uneven thickness. (11Gu.8)
Limestone, very argillaceous as above.

Limestone, light grey (tan tint) with minor red mottling, medium to coarse crystalline or less, very fossiliferous, in one 2" bed. (11Gu.7)

Limestone, light grey, medium to coarse crystalline or less, extremely fossiliferous, containing 1/4" shaly "blebs" elongated parallel to the bedding from which a red stain spreads into the grey portion, in one 1 1/2" to 2" bed. (11Gu.6) Upper

1' 6" Limestone, pale red and maroon with minor light greenish-grey to light greenish-yellow, very argillaceous, dolomitic, very fossiliferous, very mixed and containing about 1/8" "blebs" of light grey limestone in the lower portion. (11Gu.5 & 6)

3" Limestone, light grey (tan tint), becoming light reddish-grey toward the top, fine crystalline at the base becoming coarse crystalline or less upward, very fossiliferous, reddish and yellowish "burrows" in the lower part, in one slightly lensing bed. (11Gu.4)

2' 5" Limestone, pale red and maroon, light yellowish and greenish-grey, very argillaceous, dolomitic, very fossiliferous, very mixed, containing 1/4" to 1/8" "blebs" of light tan grey limestone. (11Gu.2 & 3)

3" Limestone, medium tan-grey, reddish tint, medium to coarse crystalline or less, very fossiliferous, in one bed (11Gu.1)

Location 11 (continued)

1' 10"+ Limestone, very argillaceous, as above, but extremely fossiliferous in part, and Limestone medium tan-grey, as thin beds and included "blebs". (11Gu.1)

BIRSE QUARRY
(Location 12)

Gunton Member

1' 5"+ Dolomite, light grey-brown and light tan-grey, mottled, sublithographic to very fine crystalline, very abundant large solution cavities, in one 3" bed(upper) and one 14" bed. (12 Gt.17 & 18)

10" Dolomite, pale brownish-grey and light tan-grey, faintly mottled, sublithographic to minor very fine crystalline, nodular, scattered fine porosity, scattered solution pores in the upper half. (12Gt.16)

1' 7" Dolomite, light tan and brownish-grey, sublithographic to minor very fine crystalline, very nodular with much green shaly coatings in the lower 1', slightly nodular with 1" to 3" bedding and scattered pyrite in the remainder. (12Gt.14 & 15)

4' 9" Dolomite, light brownish-grey and light tan-grey, faintly mottled, sublithographic to very fine crystalline, coarsely nodular with green shaly films, 2 1/2 to 6mm. square pores. (12Gt.13)

Dolomite, light tan-grey and minor light brownish-grey, faintly mottled, sublithographic to very fine crystalline, scattered fine porosity, scattered fine pyrite on the fractures. (12Gt.12)

Dolomite, light tan-grey and light brownish-grey, faintly mottled, sublithographic to minor very fine crystalline, slightly nodular, scattered fine porosity. (12Gt.11)

Location 12 (continued)

Dolomite, light tan-grey sublithographic to very fine crystalline, very slightly nodular (upper) to coarsely nodular (lower) with green shaly films between the nodules. (12Gt.9 & 10)

Dolomite, light brownish-grey, very finely nodular (up to 3/4" nodule diameter), abundant shaly films, - a 4" interval. (12Gt.9a)
\- in 1" to 3 1/2" beds.

2' 5" Dolomite, light greyish-brown, light greenish-grey and minor light yellowish-grey, mottled, very fine crystalline to sublithographic, faintly and coarsely nodular, scattered fine porosity. (12Gt.8)

Dolomite, light brownish-grey and light tan-grey, mottled, sublithographic to minor very fine crystalline, scattered irregularly shaped nodules in the matrix and traces of green partings, a numerous solution cavities, scattered disseminated pyrite. (12Gt.7)

Dolomite, light tan-grey, sublithographic to minor very fine crystalline, minor fine to medium porosity and solution cavities. (12Gt.6)

1' 0" Dolomite, light brownish-grey, sublithographic to minor very fine crystalline, scattered fine pyrite, with lighter edges along the bedding planes in 1" to 2" beds. (12Gt.5)

8" Dolomite, light tan-grey, slightly mottled, sublithographic to very fine crystalline, nodular with green shaly partings irregularly covering the nodular surfaces, scattered fine pyrite, scattered fine porosity in 2 1/2" to 4" beds. (12Gt.3 & 4)

1' 7" Dolomite, tan and light tan-grey, faintly mottled, very fine crystalline, in 2 1/2" to 4" beds. (12Gt.2)

2"- Dolomite, pale rose-red and light brownish-grey, sublithographic to very fine crystalline, nodular. (12Gt.1)

SOUTH BIRSE QUARRY
(Location 12A)

Gunton Member

(Beds equivalent to 12Gt.17 and 18 have abundant solution porosity and contain very abundant corals).

10" Dolomite, light borwn, light tan-grey, finely mottled, sublithographic to minor very fine crystalline, scattered solution cavities, containing silicified remains of Aulacera undulata, equivalent of 12Gt.7.

4' 0" (Beds equivalent to 12Gt.2 to 6 inclusive).

3' 11" Dolomite, light greyish-brown and pale brownish-grey, mottled, sublithographic to very fine crystalline, scattered fine pyrite. (12AGt.1)

Dolomite, light yellowish-brown and light grey-brown, mottled, sublithographic to very fine crystalline. (12AGt.0)

1"+ Dolomite, as above, slightly nodular. (12AGt.1-)

NEW STONEWALL QUARRY
(Location 13)

Gunton Member

1' 1"+ Dolomite, light greyish-brown and minor pale yellowish-tan, slightly mottled, very fine crystalline to sublithographic, with very abundant solution cavities, one bed. (12Gt.27 & 28)

1' 1" Dolomite, light greyish-brown and pale yellowish-tan, mottled, sublithographic to very fine crystalline, abundant solution cavities, two beds. (13Gt.26)

1' 4" Dolomite, light greyish-brown and pale yellowish-tan, mottled, sublithographic to minor very fine crystalline, slightly nodular with green shaly partings in part, scattered fine to medium porosity, one bed. (13Gt.25)

Location 13 (continued)

2' 5" Dolomite, light greyish-brown and light tan-grey, mottled, sublithographic to minor very fine crystalline, abundant very fine Pyrite, nodular in part, from 1" beds at the top to a 10" bed at the base. (13Gt.24)

3' 2" Dolomite, light tan-grey and pale yellowish-grey, faintly mottled, sublithographic to minor very fine crystalline, slightly nodular becoming very nodular in the lower 3", green partings in part, in 3" to 10" beds. (13Gt.23)

5" Dolomite, light tan-grey and pale greyish-brown, sublithographic to minor very fine crystalline, nodular to very nodular with abundant green shaly partings. (13Gt.22)

2' 5" Dolomite, light greyish-brown mottled with light tan and greenish-grey, sublithographic to minor very fine crystalline, numberous small solution cavities. (13Gt.21)

Dolomite, light brownish and light greenish-grey, mottled, sublithographic to minor very fine crystalline, abundant solution cavities, containing silicified remains of *Aulacera undulata*. (13Gt.20)

Dolomite, light greyish-brown finely mottled with light tan-grey, sublithographic to minor very fine crystalline, numerous solution cavities. (13Gt.19)

- in 6" and 7" poorly defined beds.

5" Dolomite, light yellowish-brown, sublithographic to minor very fine crystalline, scattered fine porosity, in two beds. (13Gt.18)

1' 3" Dolomite, light tan-grey and light greyish-brown, very fine crystalline, scattered fine pyrite. (13Gt. 16 & 17)

1' 4" Dolomite, light tan-grey, faintly mottled, sublithographic to very fine crystalline, coarsely nodular (up to 1 3/4" diam.) with non-continuous green shaly partings in poorly defined 6" beds. (13Gt.15)

Location 13 (continued)

2' 10" Dolomite, light grey and pale tan-grey, slightly mottled varying laterally to light brownish-grey and light brown mottled with pale tan-grey, sublithographic to minor very fine crystalline, slightly nodular in part of the light brown portion, minor solution cavities mainly near the middle, in very poorly defined 6" beds. (13Gt.14)

4" Dolomite, light greyish-tan, faintly nodular in part, sublithographic to minor very fine crystalline. (13Gt.13)

1' 2" Dolomite, light tan-grey and pale grey-brown mottled with light greyish-green, sublithographic to very fine crystalline, one 5mm. square pore seen, one bed. (13Gt.11 & 12)

5" Dolomite, light greyish-brown and light tan-grey, mottled, nodular in the lower part with thicker than usual green shaly partings, scattered fine porosity, one bed. (13Gt.10)

8" Dolomite, light grey-(greenish tint), faintly nodular, sublithographic, very hard. (13Gt.9)

4" Dolomite, light yellowish-grey, sublithographic to minor very fine crystalline, slightly nodular in part, abundant Pyrite on some nodular surfaces. (13Gt.8)

1' 0" Dolomite, light yellowish-brown mottled with light brown with light greenish-grey centers, sublithographic to minor very fine crystalline. (13Gt.7)

9" Dolomite, light brownish-grey and light grey, faintly mottled, sublithographic to very fine crystalline, hard, abundant pyrite on the nodular planes, in two 4 1/2" beds. (13Gt.6)

2" Dolomite, light to medium grey, sublithographic, coarsely nodular (from 3/4" to 2") abundant pyrite on joints and nodular surfaces. (12Gt.5)

Location 13 (continued)

6" Dolomite, light tan-grey (greenish tints), very faintly mottled, sublithographic to minor very fine crystalline, abundant fine pyrite in part. (13Gt.4)

2' 2"+ Dolomite, medium grey and light brownish-grey, mottled, sublithographic, hard, abundant pyrite on the bedding planes, one 2mm. crystal (Selenite?) (13Gt.3)

Dolomite, light tan-grey and pale brownish-grey, faintly mottled, sublithographic, hard, faintly nodular, one 2.5mm. crystal (Selenite?) (13Gt.2)

Dolomite, light grey and light tan-grey, sublithographic, hard, abundant Pyrite grains and aggregates on joints and bedding planes. (13Gt.1)

STONEWALL QUARRY
(Location 14)

Stonewall formation

(South Wall, Northwest Quarry)

1' 2"+ Dolomite Conglomerate, the finer fragments are light brownish-grey, sublithographic; the coarser fragments are light grey or light cream-grey, sublithographic to finely sublightographic. The pebbles are well rounded to rarely sub-angular and have very poor to fair sphericity. The largest pebble diameter seen is 5" (14S.47)

- grading downward to:

Dolomite, light brownish-grey, sublithographic, fairly abundant fine to coarse solution porosity. (14S.46)

3' 0" Dolomite, pale tan-grey, sublithographic to minor very fine crystalline, hard with a subconchoidal fracture in part, in 1" to 4" beds, slightly nodular in the lower 3". (14S.45)

Location 14 (continued)

8' 4" Dolomite, light tan-grey and light cream-grey, faintly mottled, sublithographic to very fine crystalline, with fine to coarse solution porosity. (14S.44)

Dolomite, light tan-grey and light cream-grey, sublithographic to minor very fine crystalline, with fine to carse solution porosity. (14S.43)
- in 6" to 17" beds.

3' 6" Dolomite, light tan-grey, sublithographic to very fine crystalline, slightly splintery, abundant fine porosity. (14S.42)

(Pit Section, Northwest Quarry)

7" Dolomite, maroon with purple streaks and pale rose-red spots, fine sublithographic, very slightly argillaceous, very slightly silty, very nodular; overlain by 2" of light grey, slightly argillaceous and slightly silty, finely nodular Dolomite. (14S.41+)

7" Dolomite, light brownish-grey with pale tan-grey spots and grey-green shaly parting, fine sub-lithographic very slightly argillaceous and silty very nodular. (14S.41-)

3' 4" Dolomite, light brownish-grey and pale tan and yellowish-grey, mottled, sublithographic to very fine crystalline with traces of fine crystalline, dolomitization pattersn mainly parallel to the "bedding", abundant medium to coarse solution cavities. The upper portion especially has abundant large colonial corals up to 6" in diameter. (14S.40)

9" Dolomite, light tan and brownish-grey, sublitho-graphic to very fine crystalline, scattered fine porosity, one bed. (14S.39)

9" Dolomite, light greyish-brown, sublithographic to very fine crystalline, scattered fine porosity, one bed. (14S.38)

(the base of this bed = 14S.38-)

Location 14 (continued)

6" Dolomite, light brownish-grey, very fine crystalline to minor sublithographic and fine crystalline, abundant fine to coarse porosity and solution cavities, one bed. (14S.37)

3" Dolomite, light tan-grey, very fine to minor fine crystalline, abundant fine to medium porosity, one bed. (14S.36)

6" Dolomite, light tan-grey, very fine to minor fine crystalline at the top and fine to minor very fine and medium crystalline at the base, very slightly sandy, faintly cross-bedded, hard, scattered fine porosity, one bed. (14S.35)

2-3mm. Bright yellow weathering residue bed, very slightly sandy, dolomite. (14S.34A)

STONY MOUNTAIN FORMATION

Williams Member

3" Dolomite, pale greenish-grey, sublithographic, extremely argillaceous, hard. (14W.34)

7" Dolomite, rose-red and light reddish-grey, fine sublithographic, silty, argillaceous. (14W.33)

8" Dolomite, light grey(faint greenish tint), sublithographic, very silty, argillaceous. (14W.32)

1' 0" Dolomite, light reddish-grey and rose-red with purple patches and streaks, sublithographic, slightly sandy, silty and slightly argillaceous, in indistinct 1" to 3" beds. (14W.30 & 31)

1' 6" Covered

4' 4" Dolomite, light rose-red, sublithographic to minor very fine crystalline, silty and argillaceous (14W.29 slty.)
and Dolomite, medium rose-red, silty and very argillaceous fissile. (14W.29 shy.)

Location 14 (continued)

Dolomite, light reddish-grey, sublithographic to very fine crystalline, silty and argillaceous, 1" to 1 1/4" thick with very irregular upper and lower bedding planes. (14W.28)

Dolomite, light reddish-grey and minor rose-red, sublithographic to minor very fine crystalline, silty and argillaceous. (14W.27)

Dolomite, mainly in 14W.27, with round pale greenish-grey spots, very silty and slightly argillaceous. (14W.26)

Dolomite, light reddish-grey, very fine crystalline to sublithographic, silty and slightly argillaceous; with Dolomite, rose-red, very argillaceous, laminated in part. (14W.25)

Dolomite, rose-red to light reddish-grey, sublithographic silty and argillaceous. (14W.24)

Dolomite, rose-red to maroom with purple patches, sublithographic, very silty and very argillaceous, fissile, of 1.5 to 4mm. thick, both light and dark, laminations, (3"). (14W.23)

Dolomite, light rose-red, very fine crystalline to sublithographic, silty and slightly argillaceous, with the lower 1" of slightly irregular laminations and rose-red colour, (4"). (14W.22)
\- in 1" to 3" indistinct beds.

5" Dolomite, light grey (tan tint) and minor rose-red to light purple, sublithographic, silty and slightly argillaceous, hard, with irregular green shaly partings. (14W.21)

Dolomite, pale tan-grey, sublithographic, silty and slightly argillaceous, hard. (14W.20)

10" Dolomite, light yellowish-brown (reddish tint), sublithographic extremely sandy, with flat bedding planes. (14W.19)

Location 14 (continued)

Dolomite, light yellowish-grey, sublithographic, very sandy, scattered fine to medium porosity, a few green shaly films. (14W.18)

11" Dolomite, light yellowish-grey (reddish tint), very fine crystalline to sublithographic, silty, slightly sandy. (14W.17)

Dolomite, light yellowish-grey, sublithographic, very sandy. (14W.16)

Dolomite, light yellowish-grey, very fine crystalline to sublithographic, silty, slightly sandy, faintly laminated in part. (14W.15)

Dolomite, light grey (greenish tint), sublithographic extremely sandy. (14W.14 Main)

Dolomite, light yellowish-grey, sublithographic, in a 1/4" to 1/2" thick bed. (14W.14 lith.)

Shale, pale green, very dolomitic, silty, slightly irregular to "bleby", up to 3/8" thick. (14W.14 lower)

Dolomite, light yellowish and greenish-grey, sublithographic to minor very fine crystalline, very sandy. (14W.13)
- abundant salt molds are present in most beds.
- in 1/4" to 6" beds.

3" Dolomite, light greenish and yellowish-grey, sublithographic, extremely sandy, (14W.12) interbed with bed of pale grey-green Shale, very "bleby" and irregular and up to 1/8" thick.

1" Dolomite, light grey (pale green tint), fine sublithographic, with a flat lower bedding plane and an undulating upper plane, from 3/4" to 1 1/2" thick. (14W.11 lith)
-with a lamination of green-grey, very sand, very argillaceous Dolomite on the base.

2" Dolomite, light brownish and yellowish-grey, very fine crystalline to sublithographic, silty, faintly laminated. (14W.10)

8" Dolomite, light brownish and yellowish-grey, sublithographic silty, faintly laminated, with a 1/4mm. pale green Shale lamination and several slightly more yellow laminations within 1/2" of the green one. (14W.9)

Dolomite, light yellowish-grey, sublithographic, very sandy. (14W.8)
- in 1" to 3" beds with flat bedding planes.

10" Dolomite, light yellowish-grey, sublithographic, very sandy, faintly laminated. (14W.7)

Dolomite, light greenish-yellow, sublithographic, very sandy, with abundant rounded pebbles and grains from 14W.6 lith. (14W.6 Upper)

Dolomite, bright tan-yellow, fine sublithographic, from 1/4 to 3/4" thick, lensing. (14W.6 lith.)

Dolomite, light yellowish-grey, sublithographic, very sandy, faintly laminated. (14W.6 sdy.)

- in 1" to 3" beds

10" Dolomite, pale yellowish-grey, fine sublithographic, hard, slightly silty, in 1/8" to 1" beds totalling a maximum 1 3/8" in thickness. Top shows evident erosion before next deposition.(14W.5lith.) finely interbedded with sandy Dolomite and with and extremely sandy 1/3" Dolomite bed at the base

Dolomite, light yellowish-grey, sublithographic, alternately slightly sandy and sandy, faintly laminated, containing light grey-green and light grey very dolomitic shale "blebs" and partings; with a 1/4" bed of extremely sandy Dolomite at the base. (14W.5-)

Dolomite, light yellowish and greenish-grey, sublithographic to minor very fine crystalline, slightly argillaceous, slightly sandy.
- with pale grey-green, very dolomitic Shale "blebs" and partings intermixed into the upper part and becoming laminated at the base. (14W.4)

- in 1" to 3" beds.

Location 14 (continued)

2" Dolomite, light yellowish-grey, sublithographic, slightly silty, very sandy, with abundant pale grey-green, very dolomitic Shale "blebs" over a 1/2" interval. (14W.3)

5" Dolomite, light grey, sublithographic, slightly silty, very sandy. (14W.2)

4" Dolomite, light yellowish-grey, sublithographic, slightly silty, sandy, banded in part; with scattered pale grey-green Shale blebs and rare irregular green Shale partings. (14W.1)

- the floor of the smallest pit.

2' 6" Dolomite, light yellowish-grey, sublithographic, slightly silty, sandy.
- from cores.

6" Dolomite, light yellowish-grey, sublithographic, very slightly silty. (14W.0)

- base of the member.

SOUTH STONEWALL QUARRY
(Location 14A)

Stonewall formation

5' 1" + Dolomite, light brownish-grey and light tan-grey, faintly mottled, sublithographic to minor very fine crystalline, extremely fossiliferous (with abundant colonial corals), abundant fine porosity, abundant medium to coarse solution cavities, (equivalent to 14S.43) (14A.S.43)

2' 9"+ Dolomite, light tan-grey, sublithographic to minor very fine crystalline, hard, scattered fine porosity, (equivalent to 14S.42). (14A.S.42)

NORTHEAST STONEWALL GRAVEL PIT
(Location 15)

Gunton Member

2"+ Dolomite, pale brown and light tan-grey, faintly mottled with elongate "blebs" of pale greenish-grey, very fine crystalline to sublithographic with traces of pale green shaly partings. (15Gt.1)

EAST GUNTON QUARRY
(Location 16)

Gunton Member

2' 3"+ Dolomite, light tan-grey and light brown, mottled, sublithographic to minor very fine crystalline, scattered fine porosity and medium to coarse solution cavities. (16Gt.27)

Dolomite, light tan to yellowish-grey and light brownish-grey, mottled, sublithographic to minor very fine crystalline, slightly nodular in part, a few green shaly parings abundant solution cavities. (16Gt.26)
- in 4" to 6" beds.

1' 4" Dolomite, light tan-grey and light brownish-grey, mottled, sublithographic to minor very fine crystalline, very slightly nodular to nodular (up to 3" diameter) (16Gt.25)

23'6" As in 17Gt.1 to 17Gt.24 inclusive.

Penitentiary Member

1' 5" Dolomite, maroon and light brownish-yellow, mottled, sublithographic, argillaceous, slightly nodular. (16P.18)

Dolomite, medium brownish-yellow, faintly mottled, sublithographic, very argillaceous, slightly nodular, with a 1/8" blue-grey and red Chalcedony nodule. (16P.17)

Location 16 (continued)

Dolomite, light purple, banded and faintly mottled, sublithographic, very argillaceous, slightly nodular. (16P.16)

- in 1" to 2 1/2" beds.

3' 6" Dolomite, light greenish-yellow, light purple and maroon, slightly mottled and banded, sublithographic, argillaceous, slightly nodular. (16P.13, 14 & 15)

Dolomite, light green (rose tint in part), light maroon and purple mottled, sublithographic, argillaceous, traces to minor fossil-solution porosity. (16P.11, & 12)

- in 1" to 3 1/2" beds, (mainly 1 1/2" to 2 1/2")

1' 3" Dolomite, light green with maroon, red and orange flecks, mottles and bands, sublithographic, slightly silty, argillaceous, traces of fossil-solution porosity. (16P. 9 & 10)

Dolomite, light greenish and brownish-yellow, faintly mottled, sublithographic, argillaceous, traces of brachiopod molds and sparry calcite remains. (16P.8)

Dolomite, light yellowish-green with rust-red and light purple flecks and bands, sublithographic, argillaceous. (16P.7)

- in 1 1/2" to 3 1/2" beds.

4' 10"- Dolomite, light yellowish-green, very faintly mottled, sublithographic, argillaceous, with a bright orange-red, 1/16" weathered bed at the top. (16P.6)

Dolomite, pale yellowish-green, maroon and light pruple, mottled, sublithographic, slightly silty, slightly argillaceous,-mottling due to burrows up to 3/8" in diameter with a faint rose tint at their centers. (16P.5)

Location 16 (continued)

Dolomite, pale yellowish-green, marron and light purple, mottled, sublithographic with traces of very fine crystalline, slightly silty, slightly argillaceous,
- mottling due to burrows up to 3/8" in diam. with a faint rose tint at their centers. (16P.4)

Dolomite, pale green with scattered orange flecks in the fossil solution cavities, sublithographic, argillaceous, in one 12" bed. (16P.3)

Dolomite, pale green and maroon, mottled, with the green mainly in burrow centers, sublithographic, slightly silty, very argillaceous, traces of fossil-solution porosity. (16P.1 & 2)

WEST GUNTON QUARRY
(Location 17)

Gunton Member

1' 4"+ Dolomite, light tan to yellowish-grey and light greyish-brown, mottled, sublithographic to minor very fine crystalline. (17Gt.24)

11" Dolomite, light greyish-brown and light tan and yellowish-grey, faintly mottled, sublithographic to very fine crystalline, with scattered solution cavities. (17Gt.23)

8" Dolomite, light greyish-brown and light an, mottled, sublithographic to minor very fine crystalline, scattered fine porosity. (17Gt.22)

3" Dolomite, light tan-grey and light greyish-green sublithographic to minor very fine crystalline, very nodular (small) to nodular (large) with abundant green shaly partings and "blebs". (17Gt.21)

Location 17 (continued)

8" Dolomite, light tan-grey, pink, slightly mottled, sublithographic to minor very fine crystalline, slightly nodular with green shaly partings and blebs, minor solution cavities, in 2" to 3" beds. (17Gt.20)

3' 0" Dolomite, light brownish-grey and light tan to yellowish-grey, mottled, sublithographic to very fine crystalline, in 2 1/2" to 4" beds. (17Gt. 18 & 19)

3" Dolomite, light yellowish and greyish-brown, sublithographic to very fine crystalline with traces fine crystalline, granular texture, relatively very flat bedding. (17Gt.17)

1' 2" Dolomite, light brownish-grey and light tan grey, mottled, sublithographic to minor very fine crystalline, lower 3" are nodular. (17Gt.16)

8" Dolomite, light tan-grey, light greyish-green and light rose-red, sublithographic, finely nodular. (17Gt.15)

7" Dolomite, pale greyish-brown and light greenish-grey, faintly mottled, sublithographic to minor very fine crystalline, nodular to slightly nodular with abundant green shaly partings, in 1" to 2" beds. (17Gt.14)

11" Dolomite, light greyish-brown and light greenish and tan-grey, mottled, sublithographic to minor very fine crystalline, slightly nodular with irregular and discontinuous green shaly partings, scattered fine solution porosity. (17Gt.13)

1' 8" Dolomite, light greyish-brown and light tan-yellow, sublithographic to minor very fine crystalline, finely nodular with many green shaly partings, fine to coarse solution cavities, especially in the upper half. (17Gt.12)

1' 0" Dolomite, light brownish-grey and light tan-grey, sublithographic to minor very fine crystalline, nodular to faintly nodular with some green shaly partings, one 1.5 mm. crystal of Selenite (?) seen. (17Gt.11)

Location 17 (continued)

8" Dolomite, light tan and brownish-grey, sublithographic to minor very fine crystalline, coarsely nodular with some green shaly partings, containing at least one large Beatricea nodulosa in irregular 2" to 3" beds. (17Gt.10)

7" Dolomite, light brownish-grey and light tan and yellowish-grey, mottled, sublithographic to minor very fine crystalline. (17Gt.9)

1' 4" Dolomite, light yellowish-brown, sublithographic to minor very fine crystalline in 4" and 6" beds. (17Gt.8)

1' 0" Dolomite, light yellowish and greyish-brown, sublithographic, coarsely nodular with some irregular green shaly partings, in vague 1" to 4" beds. (17Gt.7)

1' 1" Dolomite, light greyish-brown and light greenish-brown, slightly mottled, sublithographic to very fine crystalline, faintly nodular with green partings in the lower 2", one bed. (17Gt.6)

9" Dolomite, light tan-grey and minor rose-red, maroon and tan-yellow, sublithographic, upper 1" is finely nodular, remainder is massive to nodular (with 1 1/2" or less diameter). (17Gt.5)

7" Dolomite, light greyish-tan, sublithographic, upper 1" has 1/4" to 1/2" nodules, remainder is very coarsely nodular. (17Gt.4)

1' 6" Dolomite, light greyish and yellowish-brown, mottled, sublithographic in 3" to 6" beds. (17Gt.3)

6" Dolomite, light yellowish-brown, rose-red and light yellow, sublithographic, nodular. (17Gt.2)

2' 7" Dolomite, light yellowish-brown and minor rose-red with yellowish streaks, sublithographic, in 2" to 4" beds with a 3" nodular bed' 1" from top and a 6" nodular unit at the base, one 2mm. Selenite(?) crystal seen. (17Gt.1)

Penitentiary member

NORTH GUNTON QUARRY
(Location 18)

Gunton Member

1' 8"+ Dolomite, pale brownish and tan-grey, mottled, sublithographic to minor very fine crystalline in 3" to 5" beds. (18Gt.20)

1' 2" Dolomite, pale brownish-grey and light tan-grey, lightly mottled, sublithographic and very fine crystalline, scattered fine porosity, in 4" to 6" beds. (18Gt.19)

1' 3" Dolomite, light rose-red, light greenish-grey and very minor light yellowish-brown, mottled, sublithographic to minor very fine crystalline, extremely nodular with small to large nodules up to 1 1/2" diameter and very abundant green shaly "blebs" and partings. (18Gt.18)

1' 2" Dolomite, light brownish and yellowish-grey, slightly mottled, sublithographic to very fine crystalline, slightly nodular (very nodular at the top), abundant green shaly partings, in 2" to 4" beds. (18Gt.17)

1' 8" Dolomite, light brownish-grey and light tan to yellowish-grey, mottled, sublithographic to minor very fine crystalline, faintly nodular, scattered solution cavities especially in the upper part, in 2 1/2" to 4" irregular beds. (18Gt.16)

6" Dolomite, pale brownish-grey, sublithographic to minor very fine crystalline, scattered green shaly partings, scattered solution cavities, in 2 1/2" to 3 1/2" irregular beds. (18Gt.15)

1' 3" Dolomite, pale brownish to light tan-grey, sublithographic to minor very fine crystalline, coarsely nodular (up to 1 1/2" diameter) with green shaly partings, in 1" to 3" beds. (18Gt.14)

Location 18 (continued)

2' 0"	Dolomite, light grey-brown and light tan to yellowish grey, sublithographic to minor very fine crystalline, faintly nodular in the upper 10", in 3" to 6" beds. (18Gt.13)
7"	Dolomite, pale brownish-grey, minor light yellowish-brown and rose-red, sublithographic, very finely nodular in the upper 2" with green partings. (18Gt.12)
1' 4"	Dolomite, light brownish and light tan to greenish-grey, mottled, sublithographic, hard, nodular in the lower 1", in 2" to 5" beds. (18Gt.11)
6"	Dolomite, light tan to greenish-grey and minor rose-red to yellowish-brown, sublithographic, slightly nodular, hard. (18Gt.10)
5"	Dolomite, light yellowish to minor reddish-brown and light greenish-grey, sublithographic to minor very fine crystalline, slightly nodular in part. (18Gt.9)
10"	Dolomite, light rose-red to yellowish-brown and light greenish-grey, sublithographic to minor very fine crystalline, nodular, in 2" and 4" beds. (18Gt.8)
6½"	Dolomite, light yellowish to tan-grey and pale brownish-grey, slightly mottled, sublithographic to very fine crystalline. (18Gt.7)
6"	Dolomite, pale brownish to tan-grey, sublithographic to minor very fine crystalline. (18Gt.6)
7"	Dolomite, light rose-red and minor yellowish-brown, with the red colour spreading into the overlying bed in one place, sublithographic to minor very fine crystalline, in a 3" and a 4" bed. (18Gt.5)
4"	Dolomite, pale tan to brownish-grey, sublithographic to minor very fine crystalline, slightly coarsely nodular, one bed. (18Gt.4)

Location 18 (continued)

9" Dolomite, light brownish-grey with minor light yellowish and greenish-grey, slightly mottled, sublithographic to minor very fine crystalline, coarsely nodular with some green shaly partings, scattered fine porosity, in one 3" and one 6" bed. (18Gt.3)

10" Dolomite, pale tan to brownish-grey, sublithographic to very fine crystalline, with very fine nodules and green shaly partings on the bedding planes. (18Gt.2)

Penitentiary member

1' 0"+ Dolomite, light rose-red and yellowish-brown intermingled, sublithographic, nodular, hard. (18P.1)

TEULON OUTCROP
(Location 19)

Gunton Member

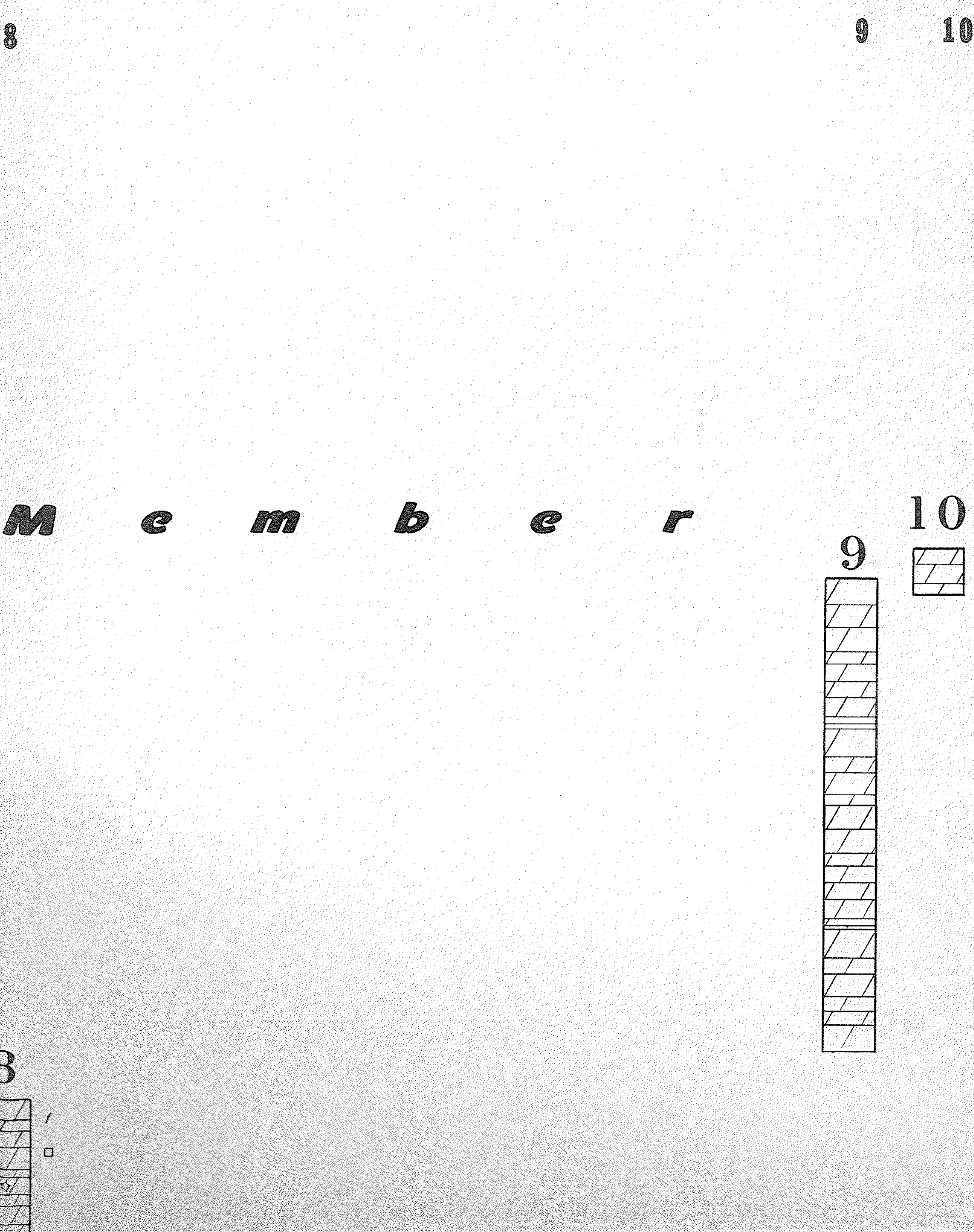
6"+ Dolomite, light tan and minor brownish-grey, sublithographic to very fine crystalline, hard with a semi-conchoidal fracture in part. (19Gt.1)

Sample Number	Total Percentage	Percentage Clay Size*	Percentage Silt Size	Percentage Sand Size*
16 P. 5	16.33	9.43	6.90	0.00
16 P. 7	15.06	12.21	2.85	.00
16 P. 10	19.57	13.33	6.23	.00
16 P. 12	17.53	13.12	4.41	.00
16 P. 14	12.91	10.15	2.76	.00
16 P. 16	20.94	17.08	3.86	.00
18 P. 1	9.13	6.53	2.60	.00
1 Gt. 1	1.30	.82	.48	.00
2 Gt. 5	9.15	6.55	2.60	.00
2 Gt. 6	3.85	2.72	1.13	.01
2 Gt. 8	2.24	1.20	1.02	.02
2 Gt.10	3.37	2.80	.57	.01
2 Gt.12	1.17	1.11	.06	.00
2 Gt.15	.69	.59	.10	.00
2 Gt.18	.46	.35	.11	.00
2 Gt.19	.63	.48	.15	.00
2 Gt.20	1.05	.91	.14	.00
3 Gt. 3	10.98	8.40	2.58	.00
3 Gt.5A	1.90	.58	1.29	.03
3 Gt. 6	4.67	3.43	1.23	.01
3 Gt. 8	4.19	2.28	1.91	.00
4 Gt.12	7.02	2.11	4.90	.01
4 Gt.13	1.58	.82	.71	.04
4 Gt.14	1.98	.78	1.19	.01
4 Gt.16	6.89	1.19	5.65	.05
7 Gt. 7	4.59	3.83	.76	.01
8 Gt. 2	10.02	5.17	4.85	.00
8 Gt. 4	1.99	1.16	.82	.01
9 Gt. 2	4.47	3.15	1.31	.01
9 Gt.5A	2.42	1.42	1.00	.01
9 Gt.6A	1.26	.68	.57	.01
11 Gt.31	11.48	5.20	6.28	.00
11 Gt.32	9.89	6.87	3.02	.00
11 Gt.33	4.64	2.91	1.73	.00
11 Gt.35	3.73	2.53	1.20	.00
11 Gt.37	4.74	2.31	2.43	.00
11 Gt.39	1.64	.59	1.00	.05
11 Gt.42	.80	.53	.27	.01
11 Gt.43	1.46	1.05	.38	.03

Sample Number		Total Percentage	Percentage Clay Size*	Percentage Silt Size*	Percentage Sand Size*
11 Gt.45		.65	.48	.17	0.01
11 Gt.46		.59	.42	.17	.01
11 Gt.47		1.12	.85	.27	.00
12AGt.1-		2.82	1.63	1.18	.01
12AGt. 0		5.02	4.08	0.94	.00
12 Gt. 2		1.96	.72	1.17	.07
12 Gt. 6		1.09	.62	.46	.01
12 Gt. 8		1.81	1.23	.58	.00
12 Gt.10		1.31	.64	.66	.01
12 Gt.12		1.00	.46	.52	.02
12 Gt.15		2.96	1.88	1.08	.01
12 Gt.16		3.01	1.72	1.28	.01
12 Gt.17		.91	.60	.29	.02
13 Gt. 1		5.33	2.48	2.85	.00
13 Gt. 3		2.23	.85	1.30	.08
13 Gt. 4		2.93	1.45	1.47	.01
13 Gt. 7		1.26	.39	.81	.06
13 Gt. 9		4.91	2.75	2.15	.00
13 Gt.11		2.15	.53	1.54	.08
13 Gt.14	(Lt.)	1.58	.70	.84	.04
13 Gt.14	(Dk.)	1.14	.46	.65	.03
13 Gt.15		2.34	.76	1.48	.10
13 Gt.19		1.11	.76	.32	.02
13 Gt.22		3.95	2.75	1.19	.01
13 Gt.23		.76	.43	.30	.03
13 Gt.25		1.15	.66	.46	.03
13 Gt.27		.57	.30	.27	.00
13 Gt.28		1.45	1.15	.30	.01
15 Gt. 1		.64	.34	.30	.00
16 Gt.25		2.63	1.64	.97	.02
16 Gt.27		1.00	.53	.44	.03
17 Gt. 1		7.08	2.90	4.17	.01
17 Gt. 3		3.58	1.67	1.91	.00
17 Gt. 4		5.62	2.26	3.36	.00
17 Gt. 6		2.48	1.34	1.13	.01
17 Gt. 7		5.23	3.67	1.56	.00
17 Gt. 9		1.34	.68	.66	.03
17 Gt.11		1.20	.32	.87	.01
17 Gt.14		2.25	,52	1.56	.02
17 Gt.16		.92	.31	.55	0.06

Sample Number	Total Percentage	Percentage Clay Size*	Percentage Silt Size*	Percentage Sand Size*
17 Gt.17	.76	.47	.24	0.05
17 Gt.18	2.12	1.10	.87	.15
17 Gt.22	1.75	.98	.72	.04
17 Gt.24	1.18	.80	.37	.01
18 Gt. 2	2.88	.89	1.98	.01
18 Gt. 3	1.52	.36	1.14	.02
18 Gt. 5	4.22	2.45	1.78	.00
18 Gt. 6	3.04	1.13	1.91	.00
18 Gt. 7	2.81	1.17	1.64	.00
18 Gt. 9	6.21	3.42	2.79	.01
18 Gt.11	4.23	1.28	2.93	.02
18 Gt.13	1.20	.78	.42	.01
18 Gt.16½	1.72	1.04	.60	.08
18 Gt.18	3.41	1.72	1.67	.02
18 Gt.19	.84?	.34?	.43	.07
19 Gt. 1	2.45	1.23	1.22	.00
14 W. 0	5.68	1.06	3.92	.70
14 W. 1	23.46	3.39	6.07	14.00
14 W. 3	33.07	3.98	6.67	22.41
14 W. 4	17.61	6.13	4.20	7.28
14 W. 5	(lith.)9.59	3.74	5.61	.24
14 W. 6	(Sdy.)32.91	2.36	2.56	27.99
14 W. 6	(lith.)2.21	1.55	- -0.66 -	-
14 W. 8	24.41	2.09	2.47	19.85
14 W. 10	16.23	2.27	10.62	3.34
14 W. 11	(lith.) ?	?	4.65	.04
14 W. 12	37.21	3.19	1.72	32.30
14 W. 14	(lith.)6.06	.99	4.04	1.03
14 W. 16	26.48	3.39	1.09	22.00
14 W. 17	21.12	2.87	12.11	6.14
14 W. 18	25.77	3.19	4.67	17.91
14 W. 19	36.95	2.39	3.29	31.27
14 W. 21	20.63	6.80	12.46	1.37
14 W. 22	18.67	7.17	10.28	1.22
14 W. 23	31.22	15.95	14.98	.29
14 W. 25	18.85	6.09	11.61	1.15
14 W. 26	27.24	8.34	15.41	3.49
14 W. 27	27.58	13.07	12.43	2.08

Sample Number	Total Percentage	Percentage Clay Size*	Percentage Silt Size*	Percentage Sand Size*
14 W. 29(Shy.)	33.76	18.83	13.32	1.61
14 W. 31	29.09	8.34	14.50	6.25
14 W. 32	27.55	12.01	15.04	.50
14 W. 34	33.75	30.87	1.01	1.88
14 S. 34A	5.66	1.04	.66	3.96
14 S. 35	7.31	1.48	1.85	3.98
14 S. 36	4.65	1.83	1.12	1.70
14 S. 37	2.30	1.64	.62	.04
14 S. 38-	.38	.21	.17	.00
14 S. 39	.55	.30	.25	.00
14 S. 40	.60	.36	.24	.00
14 S. 41	6.75	3.68	3.07	.00
14 S. 42	1.01	.71	.30	.00
14 S.42A	1.27	0.83	.44	.00
14 S. 43	.52	.32	.20	.00
14 S. 44	.50	.33	.17	.00
14 S. 45	1.56	1.09	.47	.00
14 S. 46	.40	.32	.08	.00
14 S. 47	1.36	.95	.41	.00
14AS. 42	.85	.51	.34	.00
14AS. 43	0.64	0.38	0.26	0.00



EXPLANATION

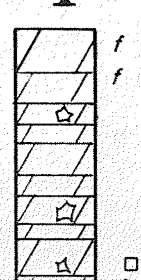
- DOLOMITE
- DOLOMITE, Argillaceous
- DOLOMITE, Silty
- LIMESTONE
- LIMESTONE, Argillaceous
- LIMESTONE, Silty
- COVERED

- *f* Fossiliferous
- Nodular
- Pyrite
- Fragmental appearance
- Salt hopper molds

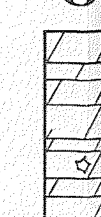
4 5 6 7 8

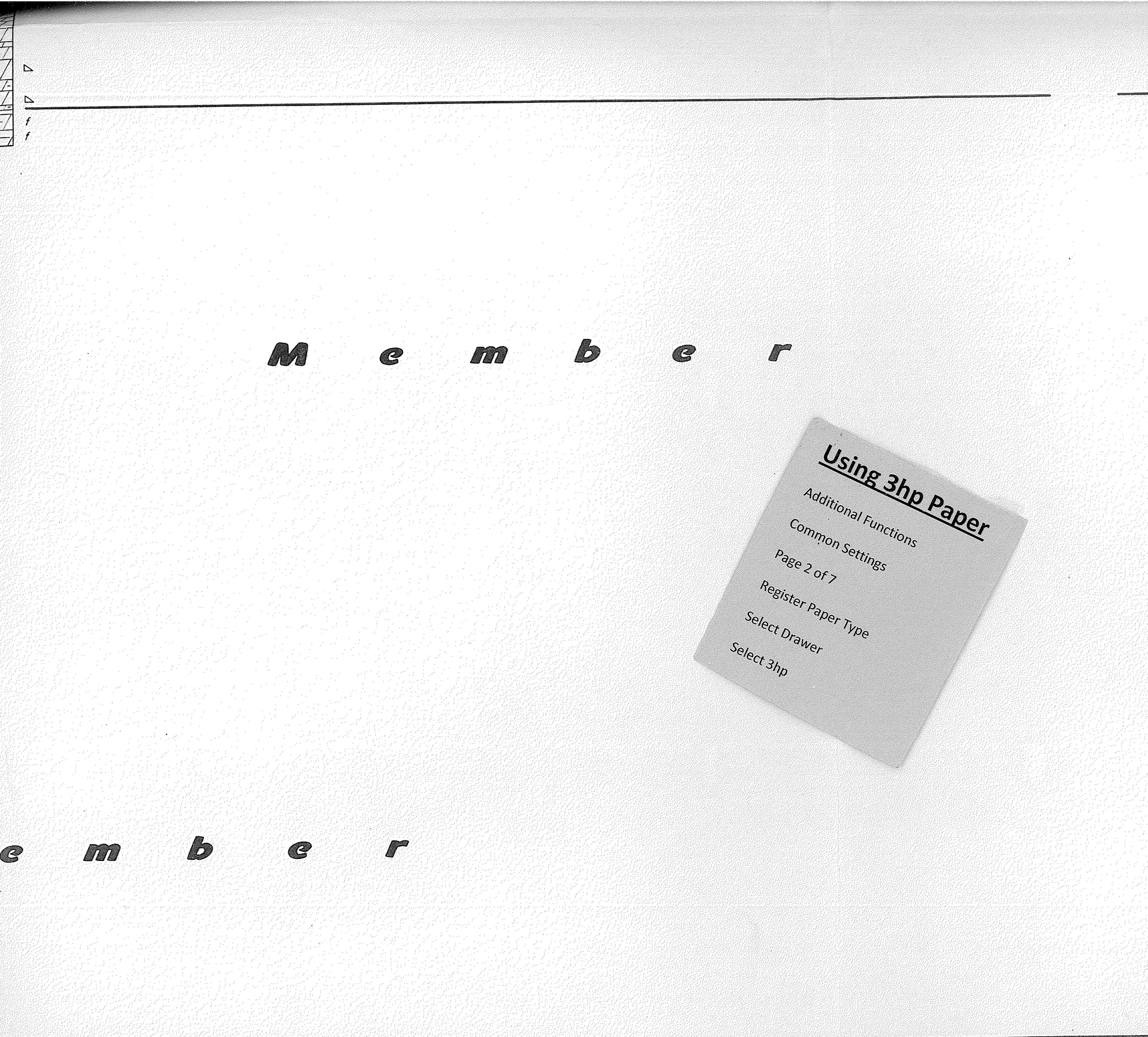
G u n t o n M

4



8





Vertical Scale 1 in = 30 ft
Horizontal Scale 1 in = 800 ft

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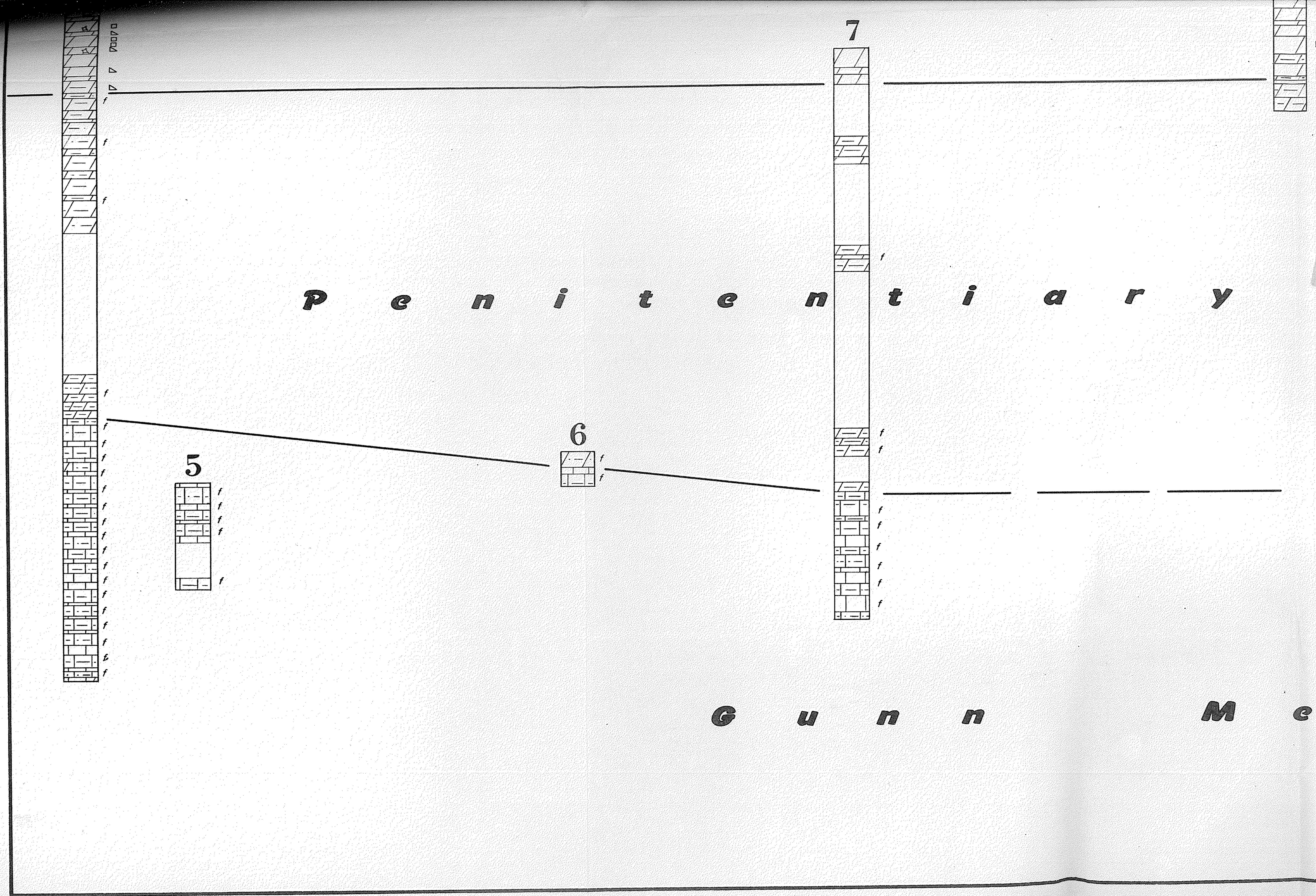
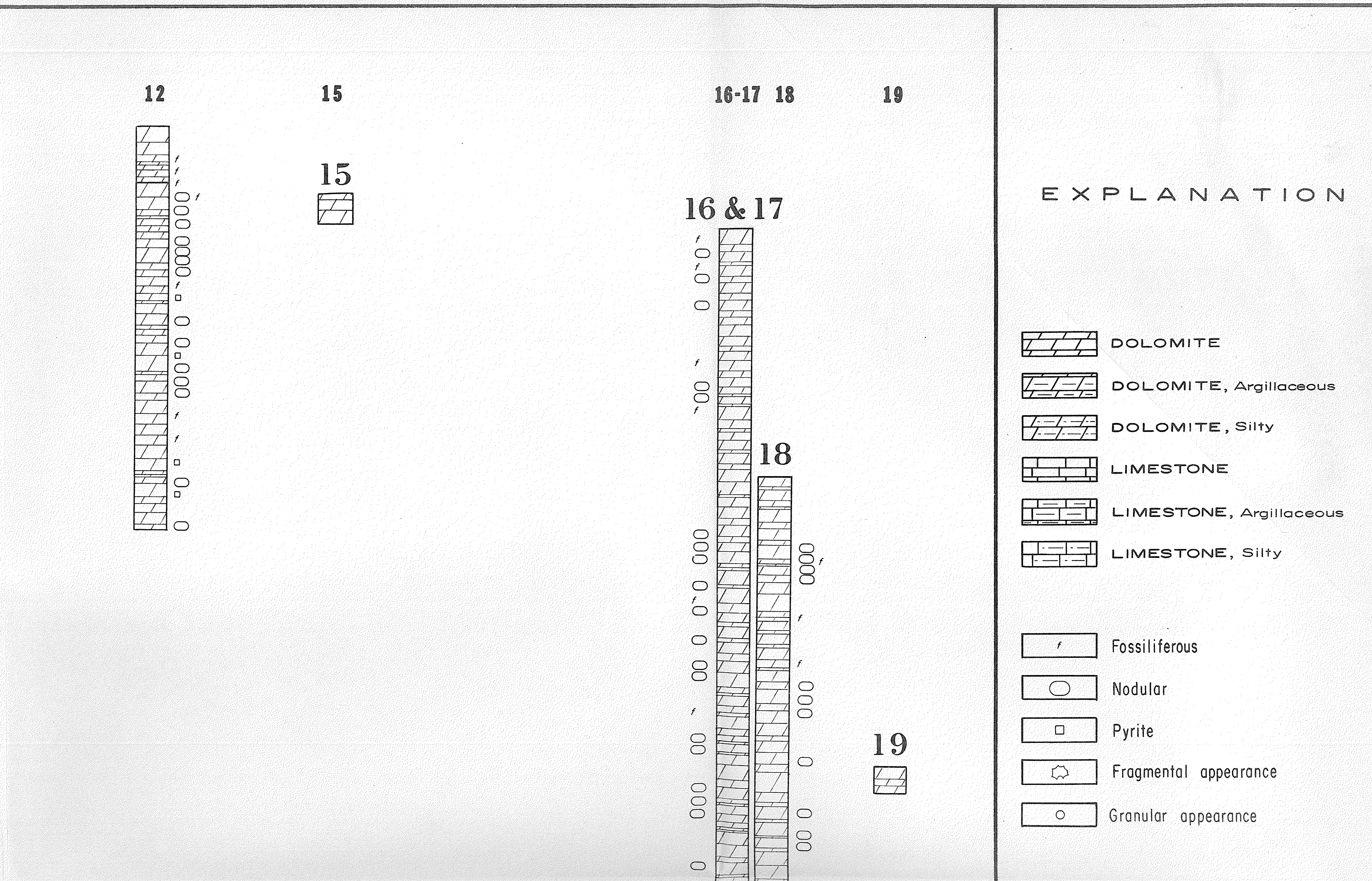
DEPARTMENT of GEOLOGY and MINERALOGY

STRATIGRAPHIC SECTION No. 3

Winnipeg, Manitoba

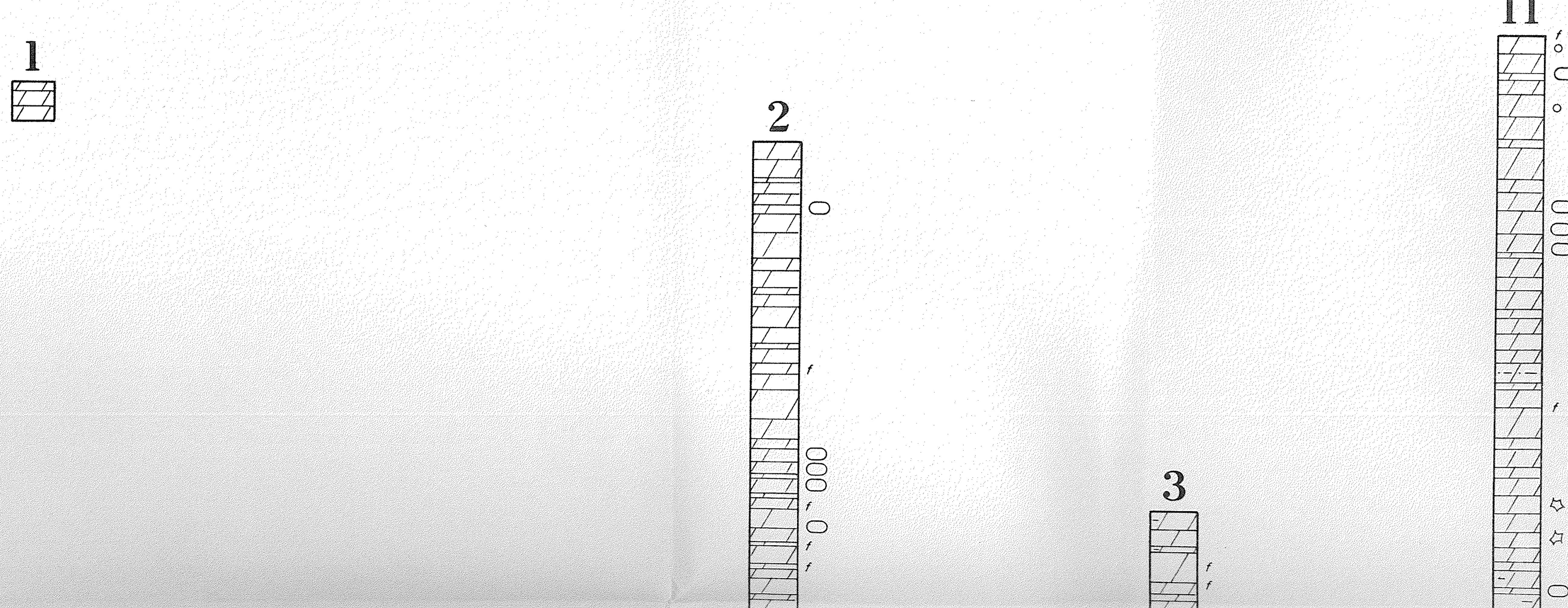
Drawn by		Figure 11
Approved by		
Date		
Traced by		

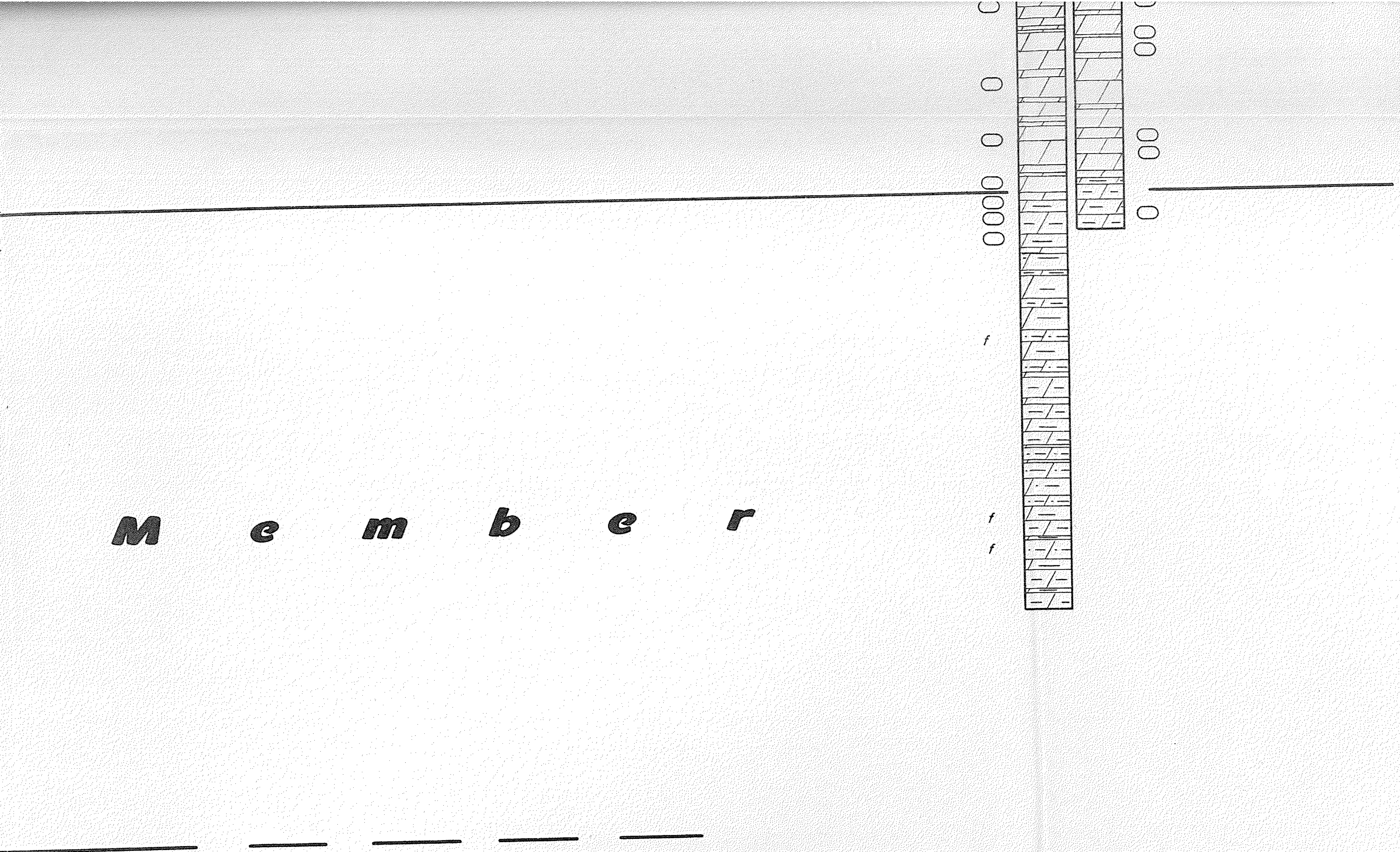

7
Penitentiary
6
5
Gunn Me


12
15
16-17
18
19
15
16 & 17
18
19
EXPLANATION
DOLOMITE
DOLOMITE, Argillaceous
DOLOMITE, Silty
LIMESTONE
LIMESTONE, Argillaceous
LIMESTONE, Silty
Fossiliferous
Nodular
Pyrite
Fragmental appearance
Granular appearance

1 1A 2 3 11

G u n t o n M e m b e r





Vertical Scale 1 in = 30 ft
Horizontal Scale 1 in = 8,000 ft

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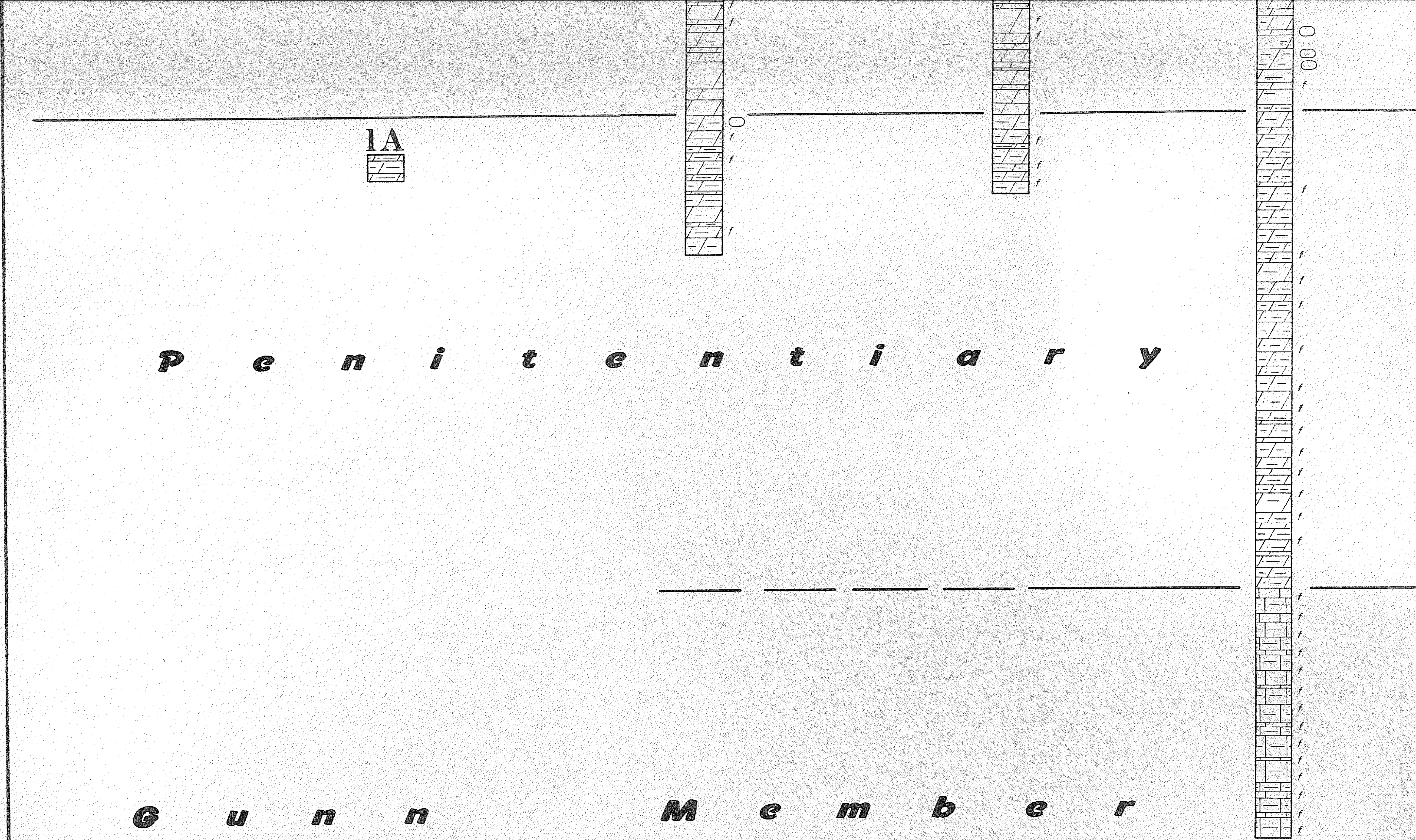
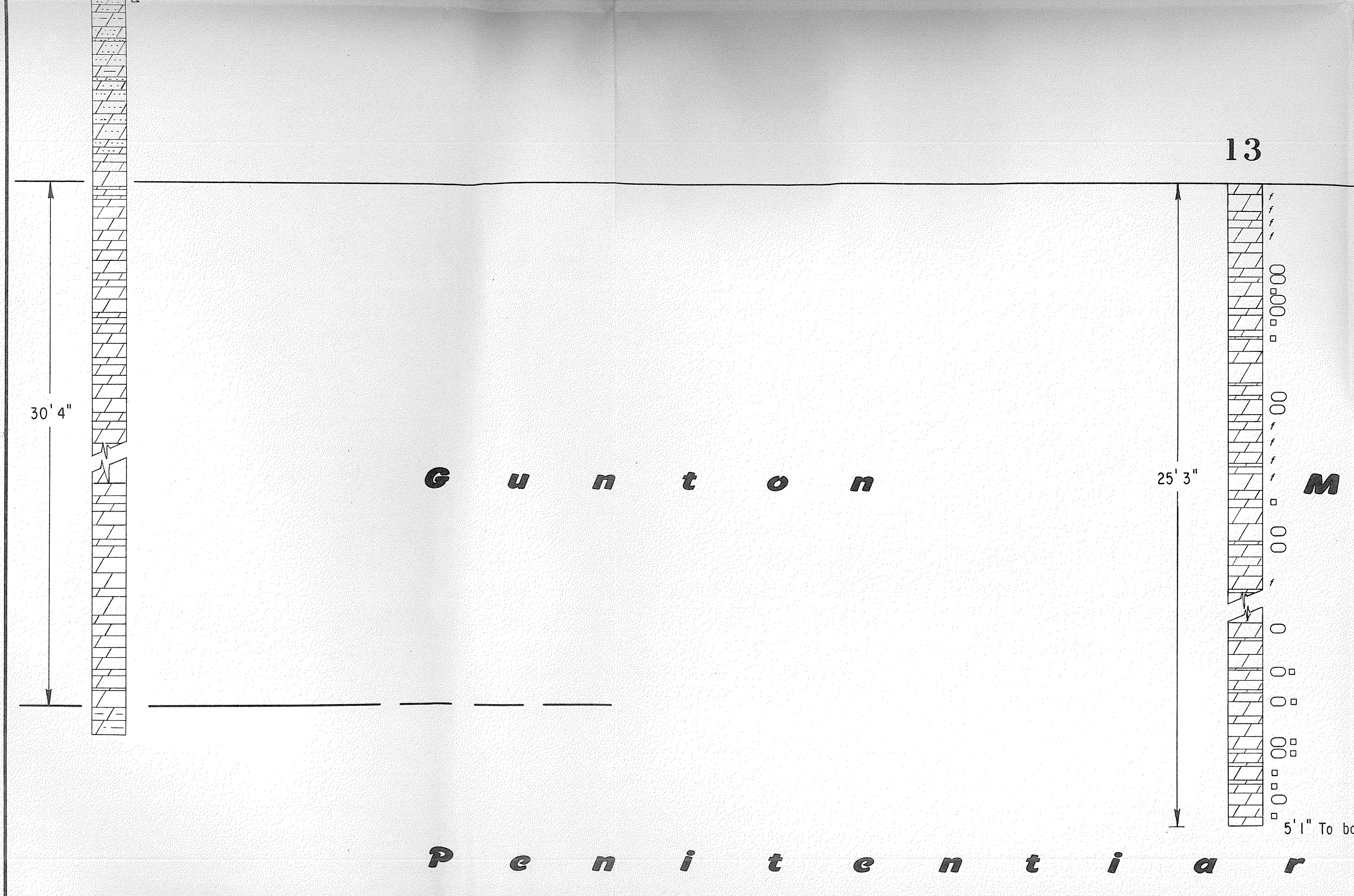
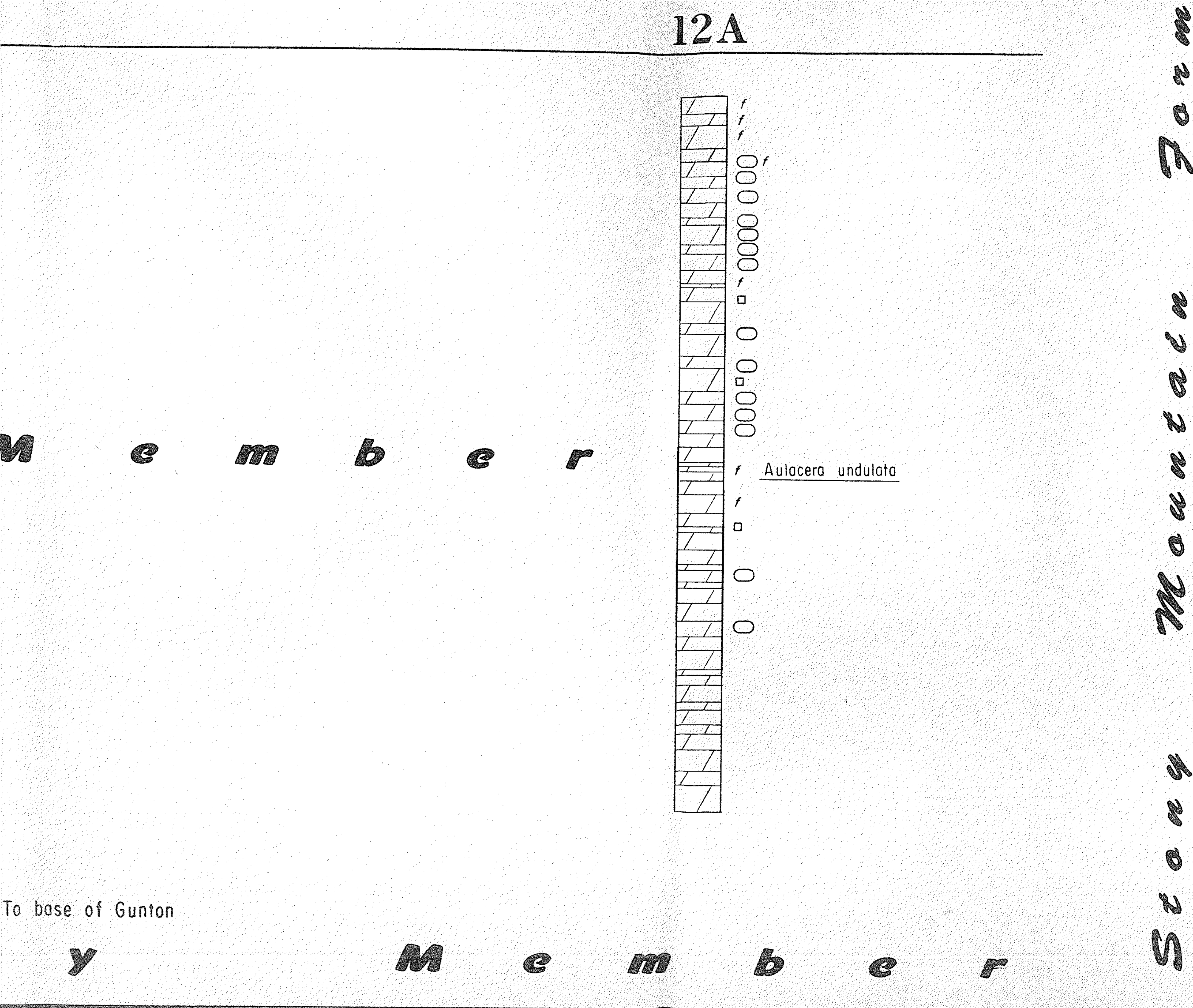
STRATIGRAPHIC SECTION No. 1

Winnipeg, Manitoba

Drawn by		Figure 9
Approved by		


1A
Penitentiary
Gunn Member


13
30' 4"
25' 3"
Gunton
M
5' 1" To bo
Penitentiar



Vertical Scale 1 in = 30 ft
Horizontal Scale 1 in = 1,000 ft

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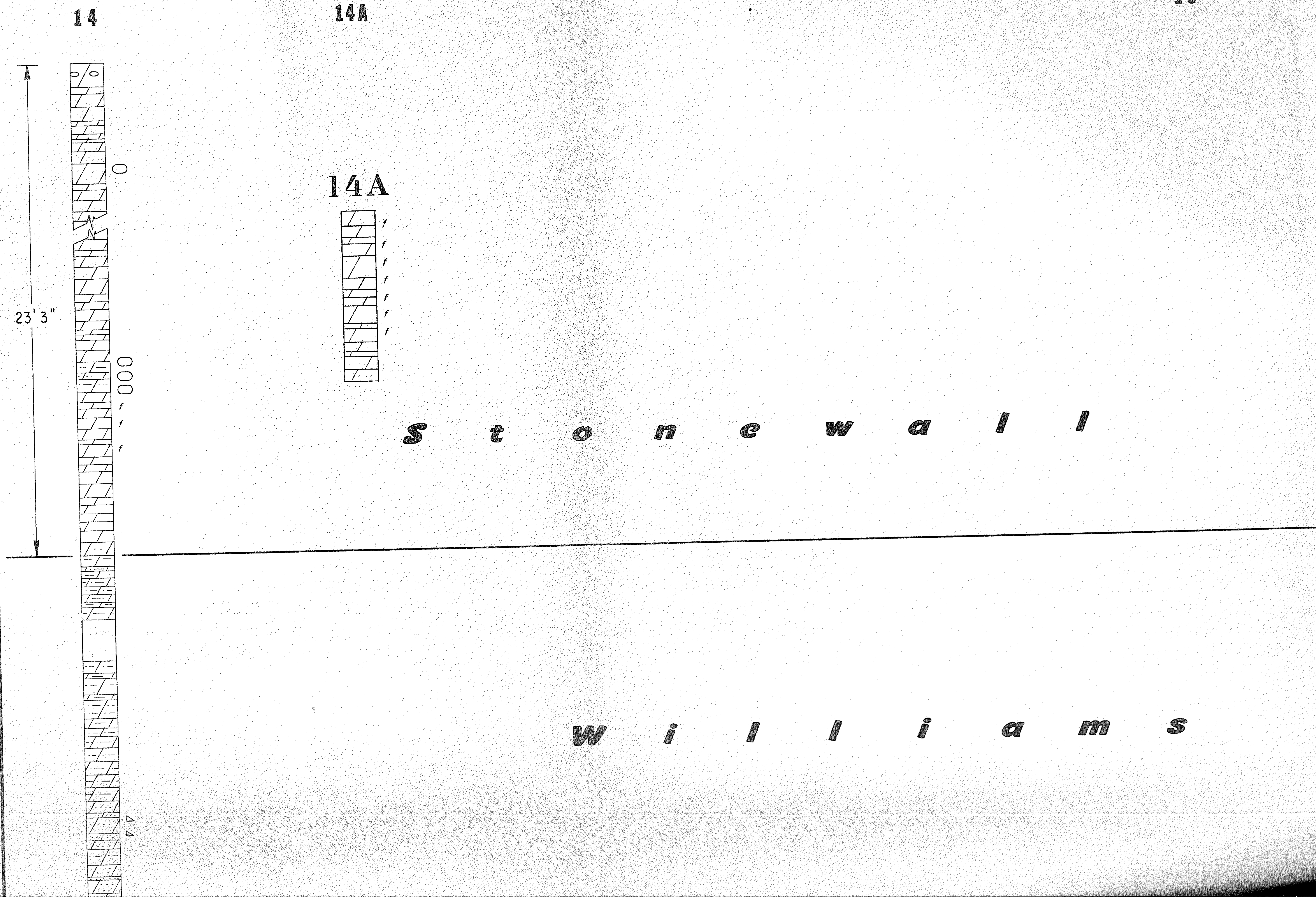
STRATIGRAPHIC SECTION No. **2**

Winnipeg, Manitoba

Drawn by		Figure 10
Approved by		
Date		
Traced by		


14
14A
14A
23'3"
Stonewall
Williams

Formation

Member

EXPLANATION

- DOLOMITE
- DOLOMITE, Argillaceous
- DOLOMITE, Silty
- DOLOMITE, Sandy
- DOLOMITE, Conglomerate

- Fossiliferous
- Nodular
- Pyrite
- Salt molds