Depositional Environments and Diagenesis of a section of the Herbert River Limestone Member, Windsor Group, Upper Pleasant Valley, Nova Scotia

by Richard Horne

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ABSTRACT

A stratigraphic section of the Herbert River Limestone Member, Windsor Group, exposed on Pleasant Brook, Upper Pleasant Valley, N.S., consists of ten carbonate lithologies. From base to top of section (with their respective depositional environment), these are: (1) Calcareous siltstone (lagoonal); (2) algal bindstone (intertidal); (3) wackestone - packstone (shallow sub-littoral); (4) Palaeocrisidia priscilia - organic (algal?) filament bindstone (shallow sub-littoral); (5) brecciated dolomitic wackestone (?); (6) bryozoan bafflestone*; (7) bioclastic packstone*; (8) mudstone - wackestone*(*deep sub-littoral); (9) stromatolites (intertidal); (10) crystalline carbonate (supratidal).

These ten lithologies have been placed into three stratigraphic zones on the bases of lateral distribution, gross terrigenous silt content and distinct changes in the lithologic nature of the rock.

The succession of interpreted environments indicates a transgressive stage followed by a regressive stage of sedimentation. Using the assumed depositional extent of the basin (after Moore, 1967) and the interpreted environments of deposition, geographic and stratigraphic relationships of the environments of deposition have been proposed (fig. 14).

Diagenesis has altered the limestone - dolostone unit during eight major events. In chronological order these are: (1) primary pyrite formation (2) neomorphism (3) dolomitization and associated leaching (4) ?iron oxide introduction (5) stylolitization (6) second stage leaching (7) quartz introduction (8) calcite spar and ?chalcopyrite introduction. Dolomitization occurred by the mixing of fresh and sea waters (Badiozamani 1973).

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CHAPTER I

INTRODUCTION

Purpose

The intention of this thesis was to evaluate a carbonate buildup of the Herbert River Limestone Member, of the Green Oaks Formation, Upper Windsor Group (Fig. 1) with respect to its depositional enviroment, diagenesis and mode of origin. This was achieved through detailed description of the collected samples via polished slabs, this section and other specific laboratory analysis (see laboratory methods).

The possible environments of deposition are evaluated in light of palaeoecological inferences, sedimentary structures and textures, and the association of one rock type with another.

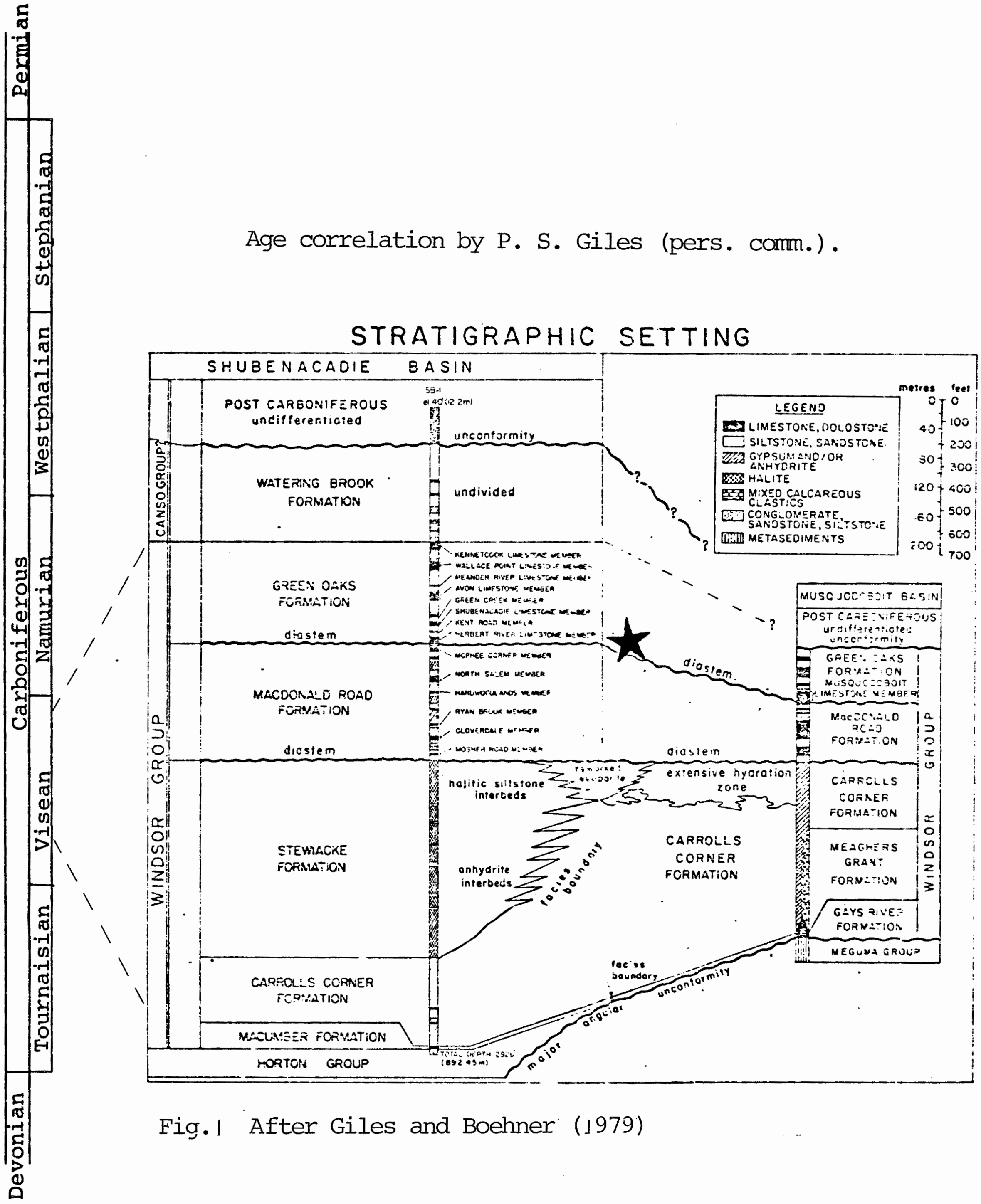
Location and Access

The study area is located on Pleasant Brook, Upper Pleasant Valley, Nova Scotia (Fig. 2). Upper Pleasant Valley is situated approximately twelve kms southwest of Truro. The outcrop of interest has been designated as point "A" on Fig. 2, and has longitude and latitude coordinates of 63°21' and 45°15' respectively.

A well-developed system of highways and secondary roads allows for easy access to the study area. From highway 102, take the Brookfield exit (12) and proceed west towards Pleasant Valley (see Fig. 2). Direct access to the outcrop can be attained by following Pleasant Brook from its intersection with either of the secondary roads (Fig. 2) or by walking the road once used for the removal of limestone by the Canada Cement Lafarge Limited (indicated on Fig. 2).

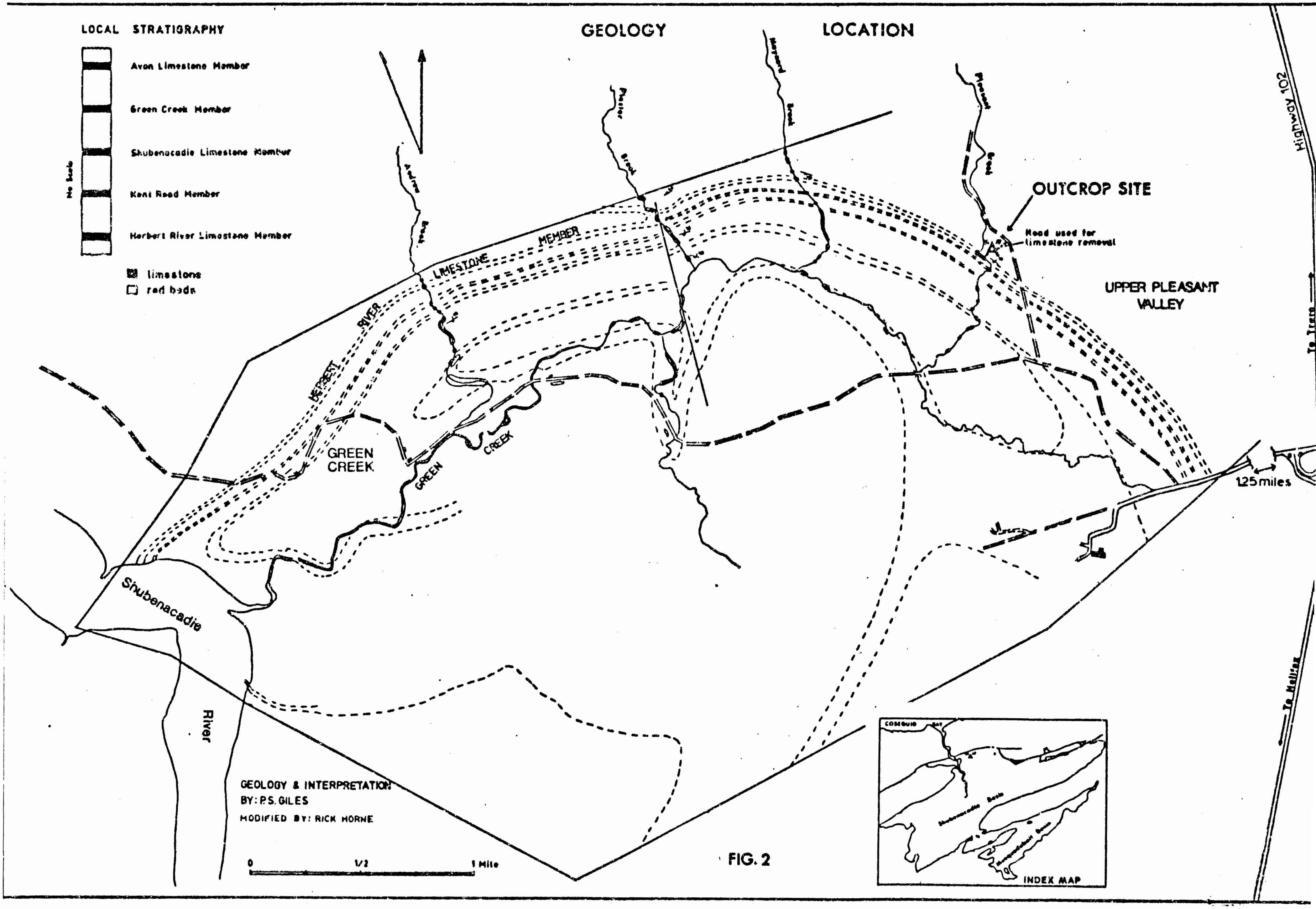
Geologic Setting

The Windsor Group is one of four major lithostratigraphic units within the Carboniferous of Nova Scotia (Schenk 1969). It was deposited in a series of narrow, linear troughs formed through the fragmentation and tilting of the basement rock during this time (Howie and Cummings 1963). The Windsor is characterized by the presence of cyclic marine carbonate units (Bell 1929).



Age correlation by P. S. Giles (pers. comm.).

Fig. 1 After Giles and Boehner (1979)



GEOLOGY LOCATION

GEOLOGY & INTERPRETATION BY: P.S. GILES

MODIFIED BY: RICK HORNE

FIG. 2

Sedimentation was mainly non-marine, resulting from the erosion of the uplifted blocks and subsequent deposition in the resultant basins. Thick clastic units prograded and fined toward the basin (Schenk 1969). The cyclic marine deposits of the Windsor Group reflect repeated interruption of the clastic deposition by marine transgressions, probably related to fluctuations in the sediment input in a subsiding basin (Schenk 1969).

The Windsor Group has been subdivided into six formations (Fig. 1) (Giles and Boehner 1979). This has been done on the basis of distinct changes in the lithologic nature of the limestone units and the presence or absence of certain lithologies (such as evaporites) (P. S. Giles, pers. comm.).

The Herbert River Limestone Member represents the base of Green Oaks Formation (Fig. 1), which is equivalent to the base of the Upper Windsor or subzone C of Bell (1929) and Moore (1967). The division was made first by Bell (1929) based on faunal content. Moore (1967) lists seven reasons for placing the Herbert River Limestone Member at the base of subzone C (Green Oaks Formation) and the reader is referred to his paper for an account of his reasoning.

The section of the Herbert River Limestone Member dealt with here is located in the northern part of the Shubenacadie Basin (Fig. 2) and is situated at the base of the Green Oaks Formation. The Formation in this area is shown geographically and stratigraphically in Figure 2.

Structurally the Green Oaks Formation in the study area (Fig. 2) is in the form of a syncline. The outcrop of interest is situated on the northern limb of the fold. The beds here are striking 125 degrees and dip 75-80 degrees towards the north. That the outcrop is overturned, as previously interpreted by P.S. Giles (Fig. 2), is confirmed by the shapes of algal stromatolites, the general shape and position of the carbonate buildup unit and geopetal structures.

The stratigraphy of the Green Oaks Formation in the study area consists of five limestone members interbedded in red siltstones (Fig. 2). These have been correlated throughout the Green Oaks area (Fig. 2) as well as in the Shubenacadie and Musquodoboit Basins (Giles and Boehner 1979).

In the studied section (on Pleasant Brook) three major lithologic units can be recognized in the field: (1) red siltstones (2) dark, silty, bedded limestone and, (3) light coloured, fossiliferous, vuggy, massive, micritic limestone. Red beds are located at the base and top of the section. The silty limestone unit is medium (3 cm) to thickly (+ 1 m) bedded and appears to be laterally continuous. This is the unit which Giles (1979, Fig. 2) and Moore (1967) have correlated as the Herbert River Limestone Member. The light coloured, massive unit has only a local distribution, seen only on Pleasant and Maynard Brooks (Fig. 2) (P. Giles, pers. comm.). This has been confirmed by the author.

Figure 3 exhibits the apparent extent of the micritic unit at Pleasant Brook. However due to the lack of outcrop, the exact extent is unknown, and the possibility exists that this unit forms a carbonate sheet between Pleasant and Maynard Brooks (Fig. 2). That this micritic unit (buildup) did not extend throughout the entire Herbert River Limestone Member is indicated by the gradational contact between the top of the Herbert River Limestone and the overlying red beds in areas where the micritic unit is not present (P. S. Giles, pers. comm.). Thus the definition of a carbonate buildup (Heckel 1974) is applicable to the upper micritic unit of the Herbert River Limestone Member.

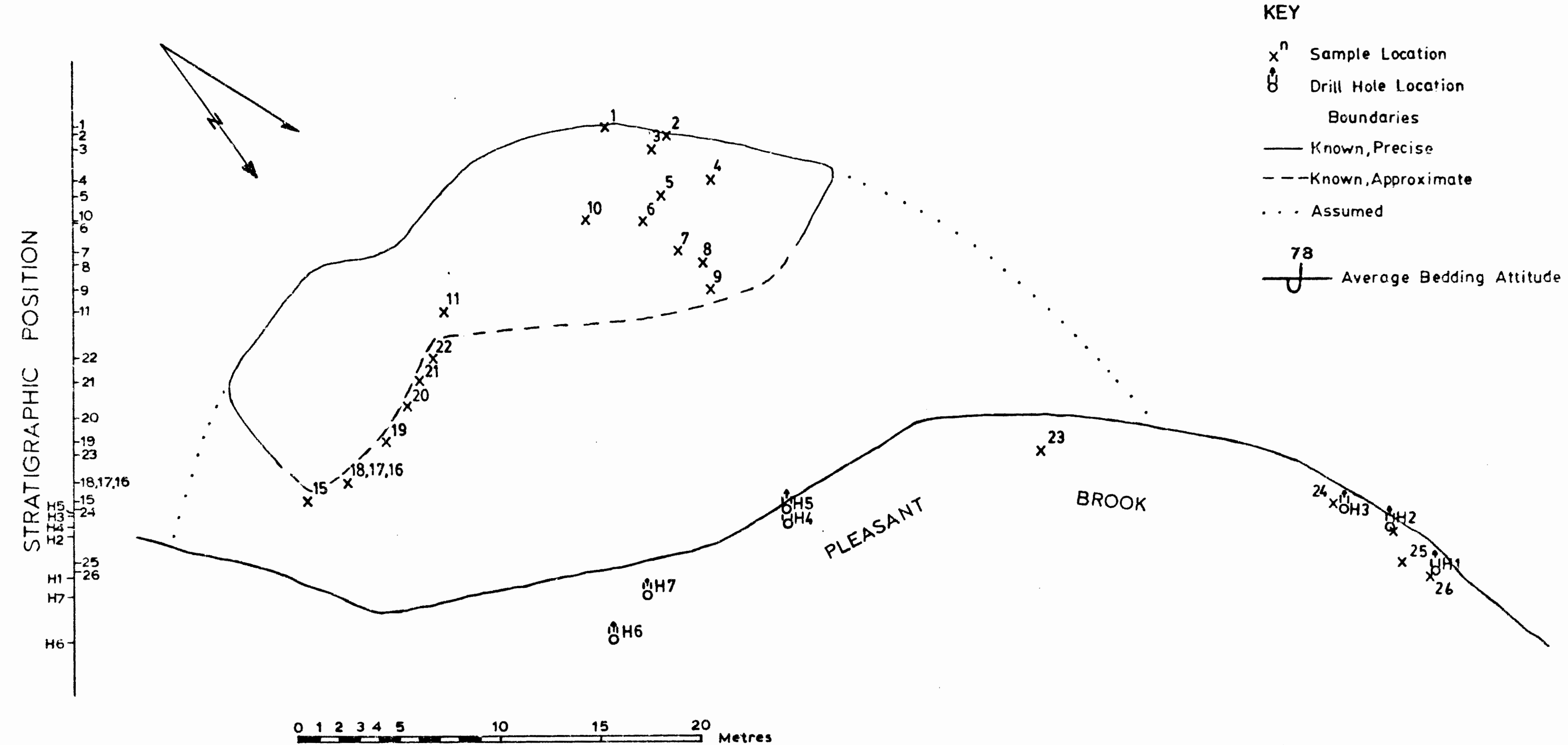
As previously mentioned, the precise extent of the micritic unit (buildup) on Pleasant Brook is not known. However, two factors which may help in better understanding the geometry of the buildup are: (1) the buildup unit is generally more resistant to erosion and thus the outline displayed on Pleasant Brook may be close to the actual shape of the buildup (Fig. 3) (the outcrop pattern of the buildup unit, best seen in Fig. 6, represents an erosional topographic high with respect to the lower units); (2) the geometry of other similar carbonate buildups of Mississippian age are characteristically mound shaped (Lees 1961, 1964; Pray 1958; Giles *et al.* 1979). It is suggested here that the buildup unit had a height to width ratio of greater than .15.

Field Methods

Both Pleasant and Maynard Brooks (Fig. 2) were traversed and known localities of the Herbert River Limestone Member in the Green Oaks area (Fig. 2) were visited. This was done to study lateral variability within the unit.

Sampling of the outcrop under study was done with the objective of sampling each lithology occurring within a stratigraphically vertical section. Because of the attitude of the beds, erosion by stream action has presented a complete cross-section through the vertical stratigraphy making this possible. The difficulty or impossibility of sampling much of the section, due to the presence of overburden and talus, has resulted in the seemingly random positioning of sample locations as shown in Fig. 3. A

MAP OF OUTCROP–POINT A OF FIG. 2



Plane Tabled By:
Rick Horne
Peter Thomas

FIG. 3

minimum sampling interval was established at one metre and maintained when possible. Sampling was done more often when lithologic changes occurred, to ensure sampling of all lithologies.

Seven 4.5 cm diameter cores were drilled, with a JKS 10 GSS sample drill, in the area of the transition between the basal "Typical" Herbert River Limestone Member and the upper carbonate buildup, "Atypical" Herbert River Limestone Member (see Chapter II). This was done to determine the nature of the boundary between these two units as well as to sample an unseen (due to overburden) section. The cores ranged in length from .2 m to .95 m and were drilled perpendicular to stratification.

The outcrop was then mapped using a plane-table, by the author and Peter Thomas, at a scale of 1:200. Outcrop boundaries, both known and inferred, sample locations, drill hole locations, and major lithologic boundaries were plotted at this time (see Fig. 3).

Laboratory Methods

Polishing - Collected hand samples were cut on a rock slabbing saw and polished with silicon carbide grit. Vaseline was used in some cases to highlight detail.

Etching - All samples, including the cores, were etched on one side with a dilute (8%) hydrochloric acid solution. This proved to be helpful in determining the amount and form of dolomite present and the relationships between secondary dolomite and the calcium carbonate host rock.

Thin sections - Thin sections were made from representatives of each lithology. Twenty-nine were produced in total, thus covering variations within each lithology. Thin section descriptions enhanced polished and etched slab descriptions and thus aided in interpreting depositional environments. Thin sections were also helpful in unravelling the diagenetic history.

Cathodoluminescence - A luminoscope ELM-2A was used to determine the relationship between diagenetic dolomite and the host calcium carbonate. As the comparison of plates 10 and 10(a) shows, the use of cathodoluminescence for distinguishing between dolomite and calcite is excellent.

X-Ray Diffraction - X-ray diffraction was used to determine the composition of the non-carbonate fraction of two units. These are: (1) calcareous siltstone, A-0 and (2) wackestone-packstone, A-2. The calcium carbonate fraction was removed by immersing the sample in a hydrochloric acid solution. The results are shown in the appendix. This procedure also enabled a rough estimation of the percentage of insoluble terrestrial sediment to be made.

Previous Work

Bell (1929) first distinguished the Herbert River Limestone Member as a separate distinct unit. This is Bell's g and h units of section S, subzone C (Bell 1929). He describes it as platy and drab with spongiostromid banding to sandy nodular and fossiliferous.

Moore (1967) designated a new type section for the Herbert River Limestone Member and characterizes it faunally, lithologically and texturally. In his paper (Moore 1967) he mentions the section on Pleasant Brook, studied here, and notes it "contains a significant proportion of micrite (over 20 percent total thickness)".

In 1979 P. S. Giles and R. C. Boehner, Nova Scotia Department of Mines, published a preliminary geological map of the Windsor Group in the Shubenacadie and Musquodoboit Basins. These were accompanied by a series of correlation charts for the units within the basins which give a detailed description of each unit. The

Herbert River Limestone Member was included in these descriptions. P. S. Giles also produced an unpublished detailed geological map of the Green Oaks Formation (Fig. 2) in the Pleasant Valley area. The study area is included within the Herbert River Limestone Member on this map.

Other carbonate buildups similar in nature to the one on Pleasant Brook (Fig. 2), studied here, exist within the Herbert River Limestone Member (Giles _et_ _al._ 1979). The one located on Maynard Brook (Fig. 2) has been visited by the author.

To the writer's knowledge no other relevant work on the area has been presented and this will be the first detailed study on the carbonate buildups within the Herbert River Limestone Member.

Classifications

The two most widely accepted and used classification schemes for the classification of carbonate rocks are those of R. J. Dunham (1962) and R. L. Folk (1959). Dunham's classification emphasizes the depositional texture of the rock, which considers that carbonate sedimentation is often not controlled by the nature of a transporting medium alone, but is also dependent on the biological formation of the sediment. This is an important factor because most carbonates are autochthonous with respect to their depositional basin.

Embry and Klovan (1971) further expanded Dunham's classification by adding a grain size modification and dividing the term boundstone into three more descriptive terms. These three new terms emphasize the way in which the rock is bound.

Because the reconstruction of the depositional environments will consider original depositional textures, especially where binding of the sediment occurs, the amplified version of Dunham's classification, Figure 4, of Embry and Klovan (1971) will be employed when describing the samples.

The carbonate classification system devised by Choquette and Pray (1970) for the porosity of carbonate rocks (Fig. 5) will be applied when referring to porosity.

Allochthonous limestones original components not organically bound during deposition						Autochthonous limestones original components organically bound during deposition		
Less than 10% > 2 mm components				Greater than 10% > 2 mm components		By organisms which act as baffles	By organisms which encrust and bind	By organisms which build a rigid framework
Contains lime mud (< .03 mm)			No lime mud	Matrix supported	> 2 mm component supported			
Mud supported		Grain supported						
Less than 10% grains (> .03 mm < 2 mm)	Greater than 10% grains							
Mudstone	Wackestone	Packstone	Grainstone	Floatstone	Rudstone	Bafflestone	Bindstone	Framestone

Fig. I-6. Amplification of original Dunham (1962) classification of limestones according to depositional texture by Embry and Klovan (1971, Fig. 2), courtesy of Canadian Society of Petroleum Geologists

Fig. 4 After Embry and Klovan (1971), from Wilson 1974

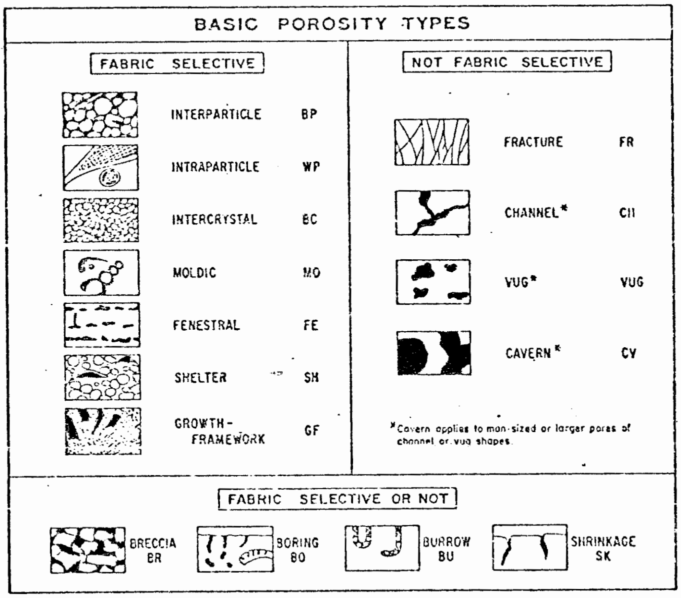


Fig. 5 After Choquette and Pray (1970)

CHAPTER II

LITHOLOGIES (PETROGRAPHY)

Introduction

The section studied on Pleasant Brook consists of a major limestone and dolostone unit contained within red siltstones. Three lithozones have been identified within the carbonate unit.

The basal lithozone consists of dark, silty, bedded bindstone and wackestone. This zone is generally consistent in nature with sections of the Herbert River Limestone Member as described by Bell (1929), Moore (1967) and Giles and Boehner (1979) and will be referred to as zone A or the "Typical" Herbert River Limestone Member.

Between zone A and the underlying red siltstone a calcareous siltstone is present. This unit is not considered as part of the Herbert River Limestone Member proper and is here designated as Sub-lithozone A.

The upper lithozone is characterized by a high percentage of micrite, the presence of fenestellid type bryozoans and lack of bedding. This zone is atypical of the Herbert River Limestone Member and is inconsistent with most described sections of this Member. It will be here denoted as zone C or the Atypical Herbert River Limestone Member. This zone is also equivalent to the carbonate buildup proper.

The middle lithozone represents the transition between zone A, the Typical Herbert River Limestone Member, and zone C, the Atypical Herbert River Limestone Member. It is characterized by the abundance of Palaeocrisidia priscilla and organic (algal?) filaments and a high degree of dolomitization. The dolomite may be brecciated. This lithozone will be denoted as zone B or the transition zone.

Only the contact between zone B and C, which is gradational in nature, has been directly observed. Because of the continuously transgressive nature of the section (see Chapter IV) no major time gaps between the other zones are inferred.

The following chapter describes the lithologies of each zone. Because of the nature of the rock terminology used (Dunham's amplified classification) similar lithologies may occur in different zones.

The rock in this section has undergone various degrees of diagenesis, which at times tends to obscure the original sedimentary textures. This problem comes into play mainly in two situations: (1) the dolomite and calcite crystals which line and/or plug cavities tend to obscure the presence of fenestellid bryozoans; and (2) microdolomite has grown at the expense of micrite. At times it becomes difficult to relate in terms of original depositional textures. This chapter will deal only with description of the units; diagenesis will be covered in a following chapter.

Descriptions

Sub Lithozone A

Calcareous siltstone Unit A-0 (.75 m) Plate 1

This unit is composed almost entirely of terrigenous siltstone cemented by calcium carbonate. Terrigenous components consist predominantly of quartz with a minor amount of muscovite (see appendix). Grain size ranges from medium (0.0156 mm) to coarse (0.0313 mm) silt, and is extremely uniform throughout. Bioclastic material represents less than five percent of the rock volume, although the percentage varies somewhat. Clast types are dominantly crinoid columnals, pelecypods, small brachiopods, and ostracods.

A vague stratification parallel to bedding is produced by the alignment of elongate bioclasts, colour differences and the possible existence of fine organic filaments.

Lithozone A

Algal bindstone Unit A-1 (.75-1.25 m) Plate 2

Algal filaments occur in varying amounts in either a planar or undulatory form. Interstital material ranges from being dominantly pelloidal micrite near the base of the unit to dominantly terrigenous quartz silt at the top. Secondary calcite spar, dolomite and minor sulfide mineralization are common, filling what is interpretated as being fenestral porosity.

Wackestone-packstone Unit A-2 (2.9-3.5m) Plate 3

Clasts of whole and fragmented brachiopods, Rugose corals, and echinoid spines and fragmented crinoid stems, coated grains and micritic intraclasts are abundant within a matrix of predominantly silt-sized quartz and minor muscovite. This relationship between clasts and matrix has resulted in textural inversion.

Laminations exist within the matrix; they are produced by colour variations, (possibly due to algal? filaments) and are parallel with bedding. The alignment of elongate bioclasts within the matrix has also resulted in a linear fabric parallel to bedding.

Lithozone B

Palaeocrisidia priscilia - algal? filament bindstone Unit B-1 (3.5-3.8 m) Plate 4-4(a)

Two components characterize 75 percent of this unit: (1) *Palaeocrisidia priscilia*, a small tubular bryozoan, and (2) organic filaments, which have a probable algal origin. Forams, crinoid columnals, fenestellid type bryozoans, rugose corals, and microcrystalline dolomite are also present. Alternating flat to slightly undulating bands, averaging 1 mm in thickness, of predominantly *Palaeocrisidia priscilla* or algal? filaments parallel bedding (plate 4). This banding is accentuated by the colour difference between the two components.

Brecciated dolomitic wackestone Unit B-2 (3.7-5?) Plate 4

This unit consists predominantly of microcrystalline dolomite with calcium carbonate bioclasts floating in it. The percentage of bioclastic debris is variable, ranging from 10 to 40 percent of the rock volume within the width of the core. At least three types of bryozoans, forams, small brachiopods, and ostracods constitute the bioclastic debris. Bioclasts are often fragmented although large, six or seven branch, portions of fenestellid bryozoans exist. The original matrix (lime mud) accounts for less than 2 percent of the rock.

Pervasive microcrystalline dolomite has replaced the majority of the original lime mud matrix and constitutes from 60 to 100 percent of the sample. Bioclasts tend to resist dolomitization. The degree of dolomitization decreases gradually at both ends of this zone. In areas of intense dolomitization, solution collapse breccia has formed fenestral porosity, within which rotated blocks (.5-3 mm in size) of dolomitized rock exist (see dolomitization Chapter 3).

Calcite spar is common but not abundant relative to the amount of porosity.

Lithozone C

Distribution: The three major lithologies of zone C (C-1, C-2, C-3) are closely related in geometric distribution and in bioclastic composition. No systematic distribution such as bedding exists; variation of lithologic units occurs both vertically and laterally within this zone (see Fig. 7). The contacts between these three lithologies (C-1, C-2, C-3), are gradational, and more than one lithology can occur in a single sample (Plate 5).

The components of each lithology are essentially the same, the difference between the lithologies (C-1, C-2, C-3) being a result of varying the proportions of each component. Varying the proportions of the components results in changes in textures and thus differences in terminology.

Bryozoan Bafflestone Unit C-1 (5-21 m) Plate 5

A varying thickness (1 mm-10 mm) of "bryozoan mesh" envelopes large (1 cm-5 cm) "lumps" of mudstone-wackestone, Plate 5. The bryozoan mesh consists almost entirely of layers of lacy, fenestellid type bryozoan fronds, which are for the most part intact. Brachiopods, gastropods, forams and pelecypods are also present but minor. Fenestellid bryozoans "encrust" the lumps of mudstone-wackestone and/or each other, thus producing layers of bryozoans. The loose arrangement of the bryozoan fronds has produced abundant, continuous shelter porosity.

Dolomite is extensive in the area of the "mesh", occurring as encrusting euhedral crystals and pervasive microdolomite. The presence of dolomite usually obscures the identity of the fenestellid bryozoans.

The mudstone-wackestone portions consist of lime mud with varying proportions of bioclastic debris. Bioclasts are similar in type to those found in the bryozoan mesh. The lime mud is often found as recrystallized neomorphic microspar.

Bioclastic packstone Unit C-2 (5-12.25m) Plate 6

Fragmented clasts of fenestellid bryozoans, brachiopods, gastropods, forams and crinoids float and/or are self supported within micro to macrocrystalline dolomite, Plate 6. Fenestellid bryozoan fronds and punctate brachiopods constitute up to 75 percent of the clasts. The alignment of elongate shells has produced a stratification parallel to the depositional slope.

Crystalline dolomite comprises the bulk of the matrix, up to 60 percent of the rock volume. The crystalline nature of the matrix bestows a large amount of intercrystal porosity to this rock.

Mudstone-wackestone Unit C-3 (15.75-23.5 m) Plate 7

Lime mud is the dominant component, comprising from plus 95 percent to 60 percent of the rock. Bioclasts of bryozoans (both fragmented and partially intact), brachiopods, gastropods and forams constitute the remaining portion of the rock. Silt-sized carbonate grains and peloids are volumetrically important at times as clasts within the mudstone.

Fenestral porosity is common in some areas (Plate 14) and is interpreted as being a result of the formation of collapse breccia. Dolomite is less common than in other lithologies of zone C. Blocky calcite and/or quartz (chalcedony variety) are present in some areas.

Stromatolites Unit C-4 (23.8-24 m) Plate 8

Convex, laminated, hemispheroidal, stromatolitic structures constitute this unit. They have depositional slopes greater than 45 degrees and the laminae are thicker in the tops than on the sides. Laminations are prominent and possess large fenestral porosity concordant with the laminae.

Crystalline carbonate Unit C-5 (23-24 m) Plate 9-9a

In polished slab this rock is characteristically mottled dark to light grey and extremely dense. Bioclastic debris is rare; a few gastropods and possibly forams are present. Fracture, vug, intercrystal and intraparticle porosity is present. Dolomite is absent and druzy calcite spar lines cavities.

Thin section reveals that the rock is predominantly composed of radiating crystals of calcite, constituting up to 75 percent of the rock. These crystals appear to have had two phases of growth (Plate 9a). The origin of the crystals is obscure, however similar crystals in sample 4 (mudstone unit) are perpendicular to the walls of a cavity and represent secondary precipitation. The crystal shape exhibited is characteristic of aragonite (Hurlbut 1971).

Plate 1 : Calcareous siltstone, A-0 - Relatively homogeneous gray carbonate cemented siltstone. A few fossils are present. A vauge stratification exists parallel to bedding. Secondary quartz is common.

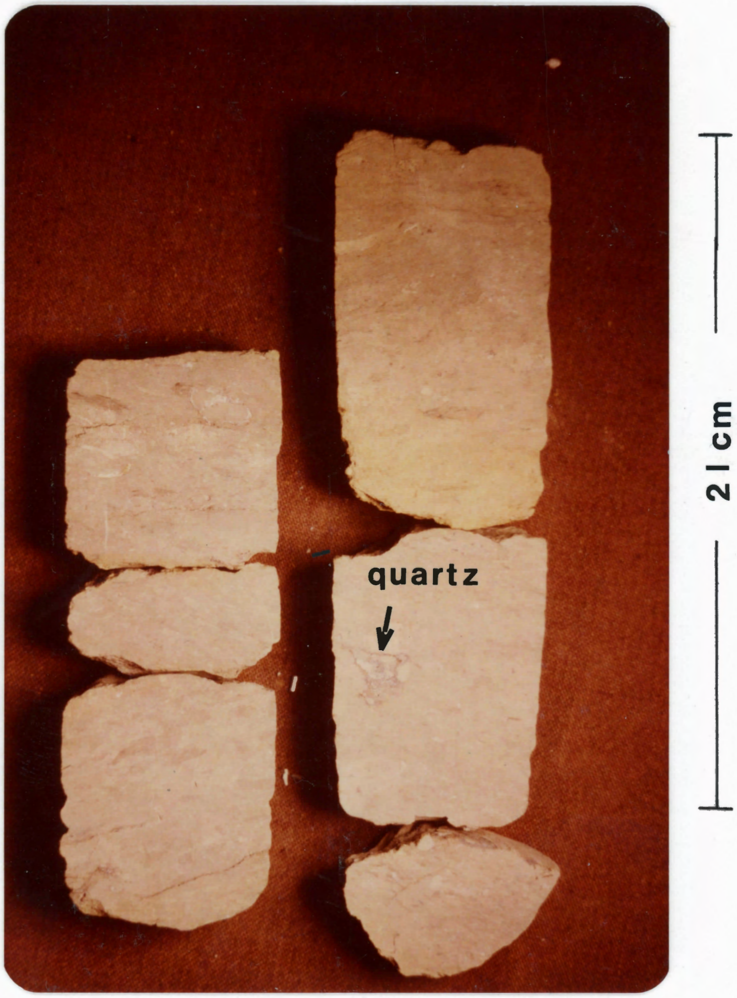


Plate 1

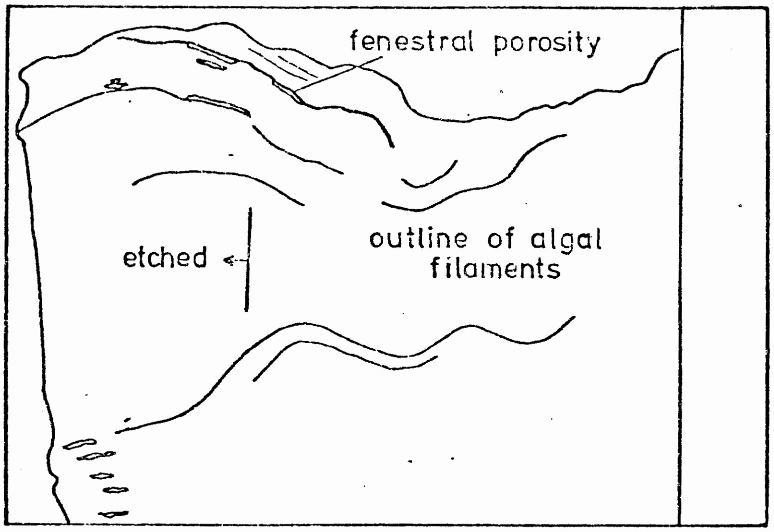
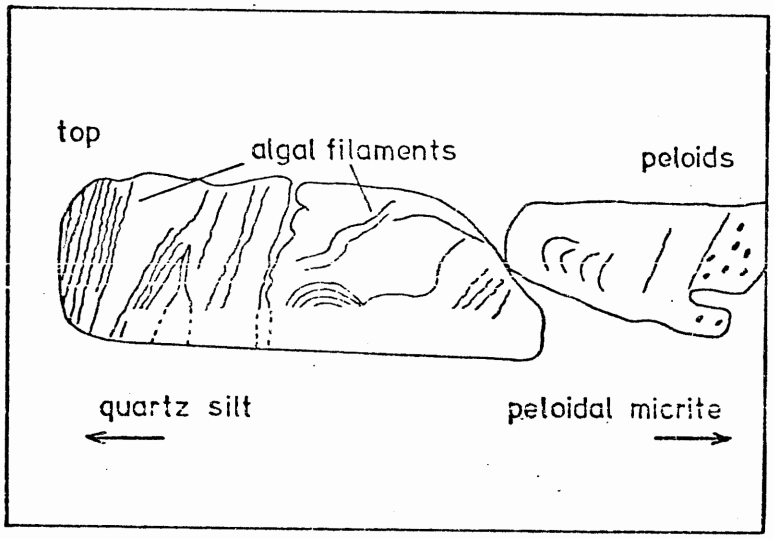


Plate 2 : Algal bindstone A-1 - Undulatory and planar type algal filaments are binding the interstital sediment. Fenestral porosity is present locally. Left half has been etched, showing the high degree of dolomitization (white). Scale is in centimeters.

Plate 2(a): Same unit as plate 2; arrow in photograph is pointing towards the bottom of the unit. The interstital material in the top of the sample is predominantly quartz silt whereas in the bottom of the sample peloidal micrite is more common. Both undulatory and planar type algal filaments are present.



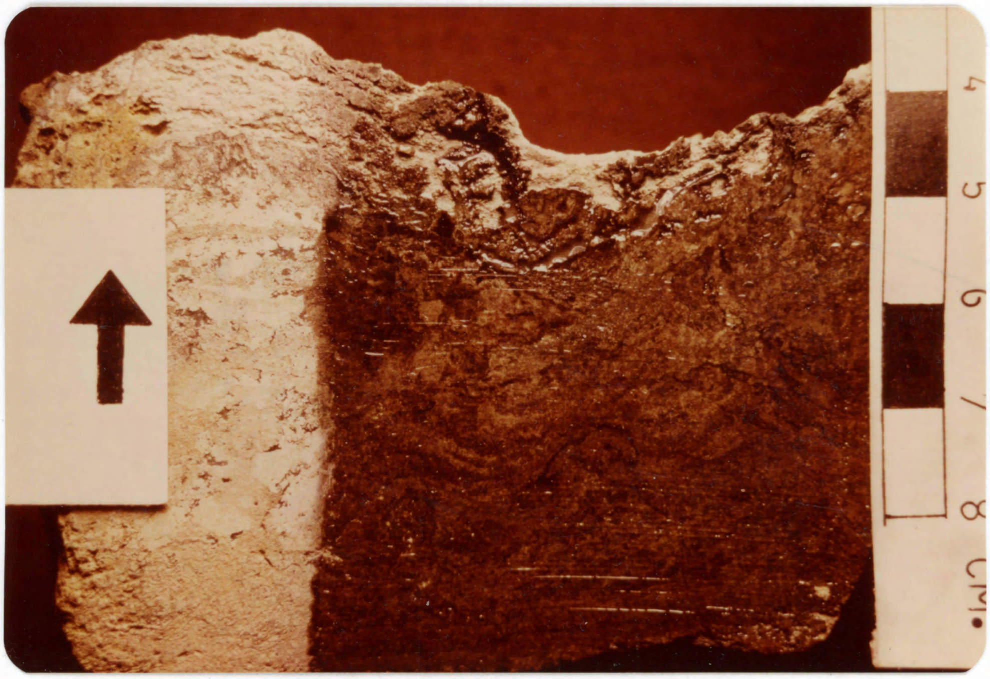


Plate 2

Plate 2(a)

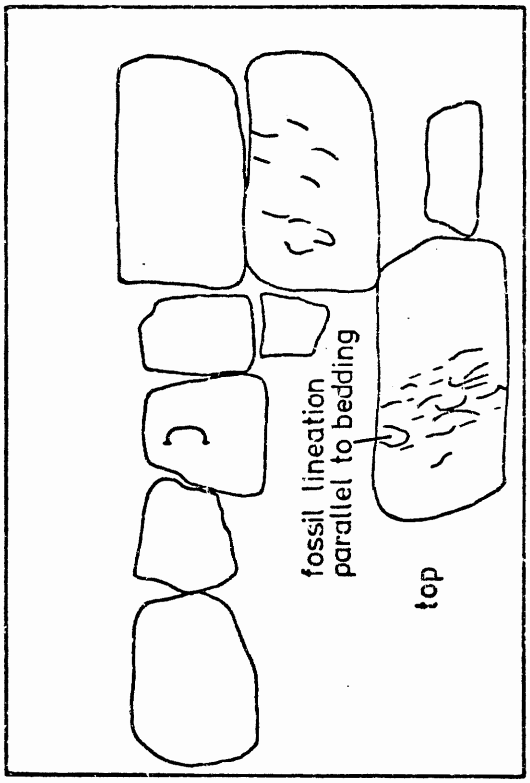


Plate 3 : Wackestone - packstone A2 - Arrow shown in photograph is pointing towards the base of the unit. Variable sized bioclasts and intraclasts in a predominantly quartz silt matrix. A lineation due to the alignment of fossils exists parallel to bedding. Section of core covered by scale is similar in compostion and texture as the uncovered section.

Plate 3

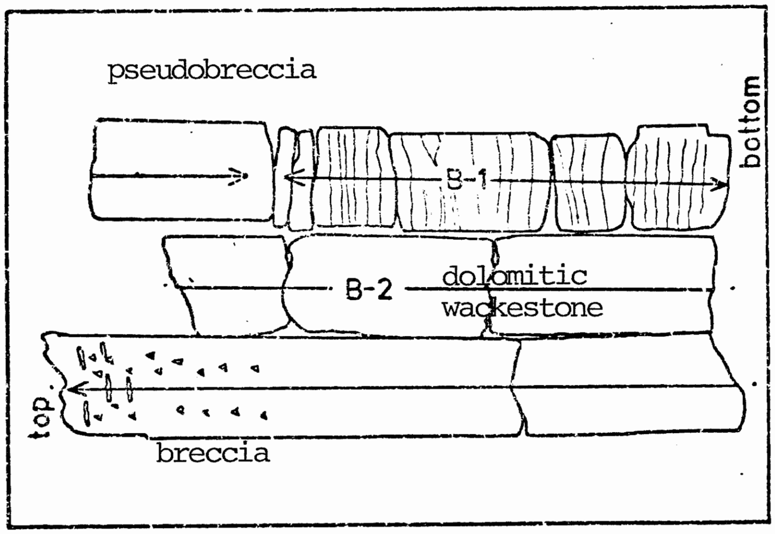


Plate 4 : Photograph is of core 4. The arrow in the photograph is pointing toward base of the core. Two lithologies are represented in this core : (1) <u>Palaeocrisidia priscilla</u> - organic (algal?) filament bindstone which occurs at the base of the core (see trace above) ; (2) brecciated dolomitic wackestone constitutes the upper part of the core. A short zone of pseudobreccia links these two units. Scale is shown in photograph.

Plate 4(a) : <u>Palaeocrisidia</u> <u>priscilla</u> - Organic (algal?) filament bindstone. Photograph is a thin section of the banded unit in plate 2. Dark material is organic filaments and the white material is dolomite. Field of view is 3.7 mm. from left to right (long direction of photograph).

Plate 4

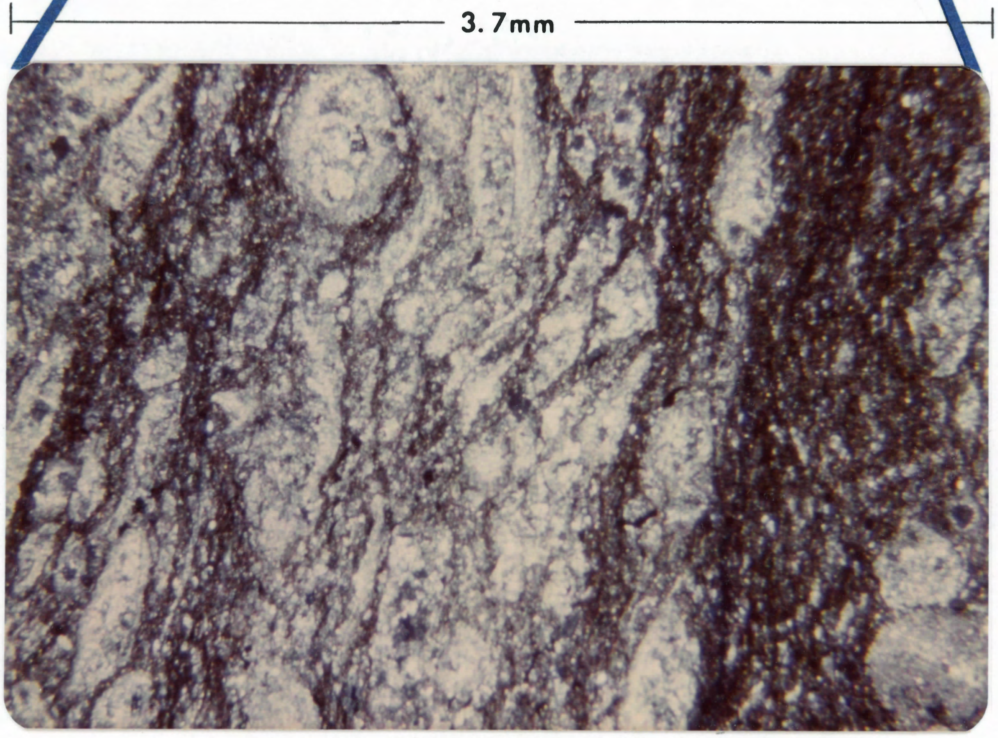


Plate 4(a)

Plate 5 : Bryozoan bafflestone - Up direction is towards the top of the photograph and the scale is indicated on the right side. Patches of lime mudstone - wackestone (brownish areas) are enveloped by a bryozoan mesh (yellowish area). Yellowish areas also correspond to the area of highest dolomitization. Note how the upper part of this sample grades into a bioclastic packstone (Plate 6). The upper right side has been etched.

Plate 6 : Bioclastic grainstone - Scale is in centimeters. Cross - sections of fenestellid bryozoan branches (seen as circles or dots) and fragmented brachiopods are the darker constituents (most are less than 1 mm. in length). The lighter fraction is composed of crystalline dolomite. Elongate clasts are aligned, producing a planar fabric which parallels the depostional slope.

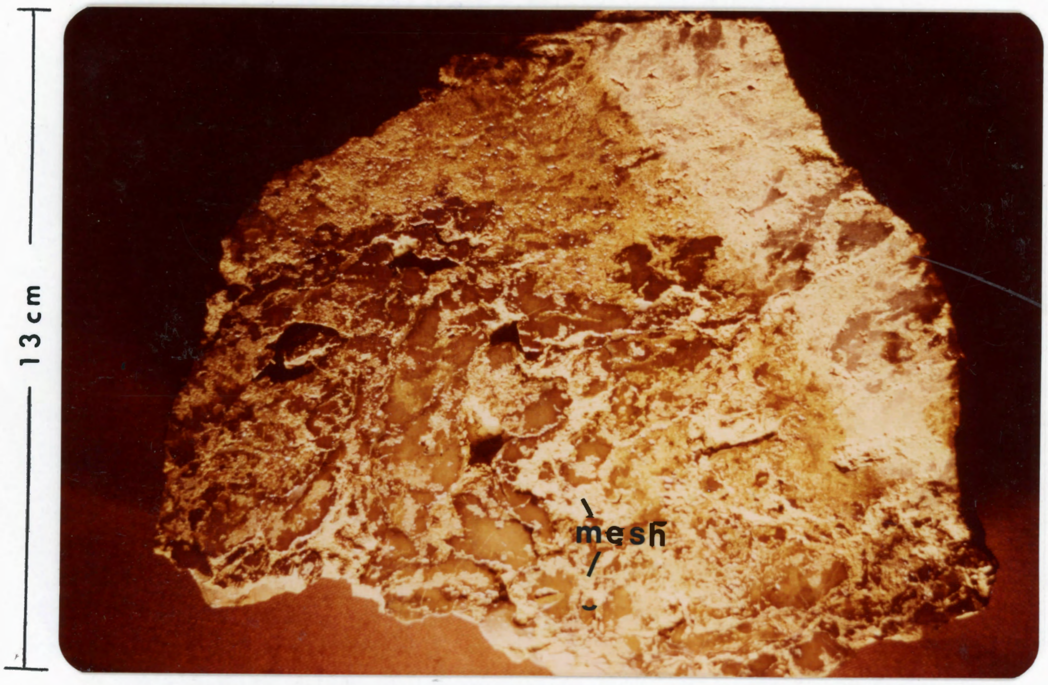
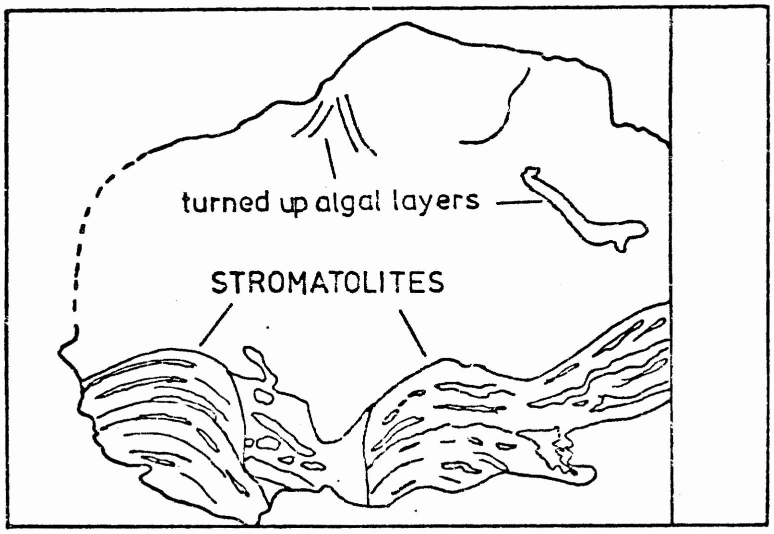


Plate 5

Plate 6

Plate 7 : Mudstone - wackestone (Plate 15 is a closeup of this sample.) - Dark to light brownish areas are calcium carbonate (mudsone - wackestone) and lighter areas are where dolomite is present. Right-hand side has been etched.

Plate 8 : Stromatolites - Convex,laminated,hemispheroidal, stromatolitic structures occur at the base of this sample. Both discrete and linked hemishperoids are present. Concordant fenestral porosity is prevalent within these structures. The upper part of the structure has an increased percentage of lime mud, however turned up algal layers are present.



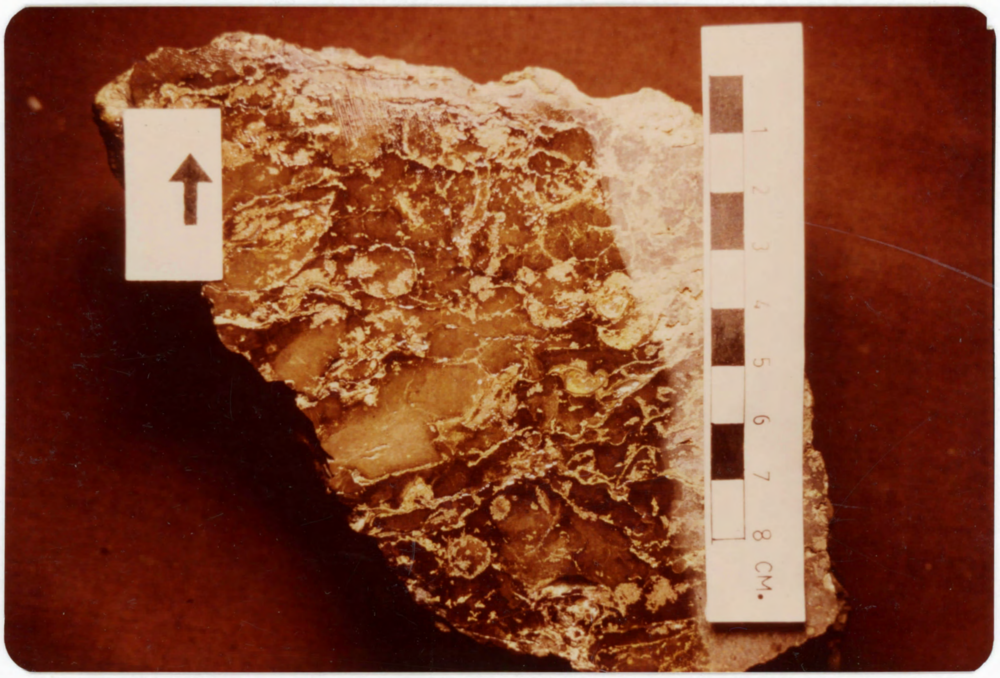


Plate 7

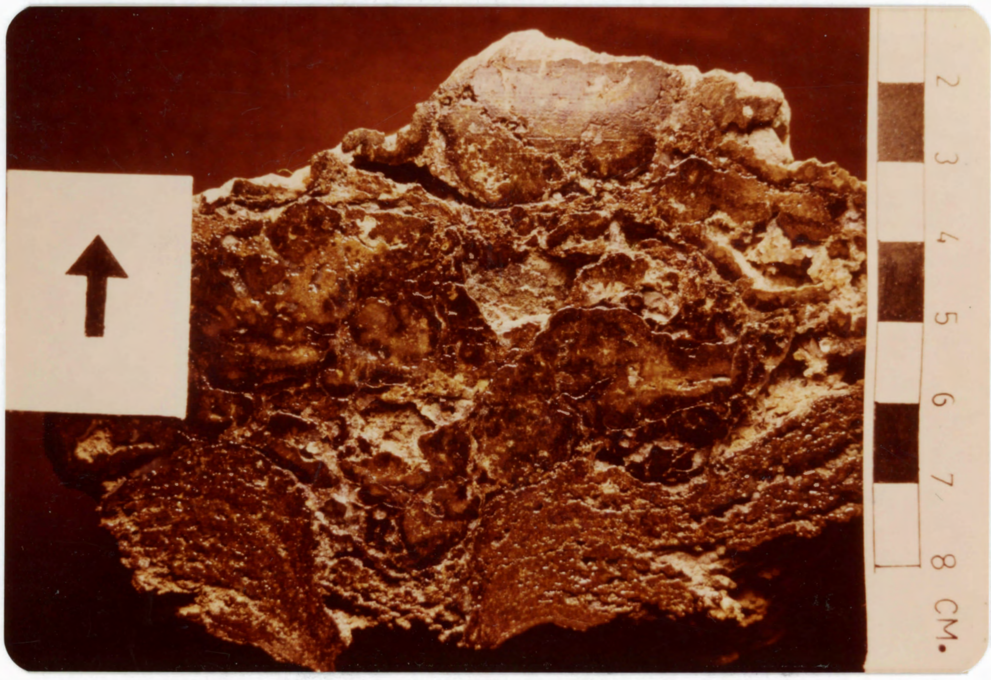


Plate 8

Plate 9 : Crystalline carbonate, C-S- Photograph of polished slab. Dominantly crystalline carbonate. A few fossils (gastropod) and wackestone patches are present. Scale on right side is in centimetres.

Plate 9a : Thin section of above slab. Consists of radiating crystals of calcium carbonate, thought to originally have been aragonite (see text).

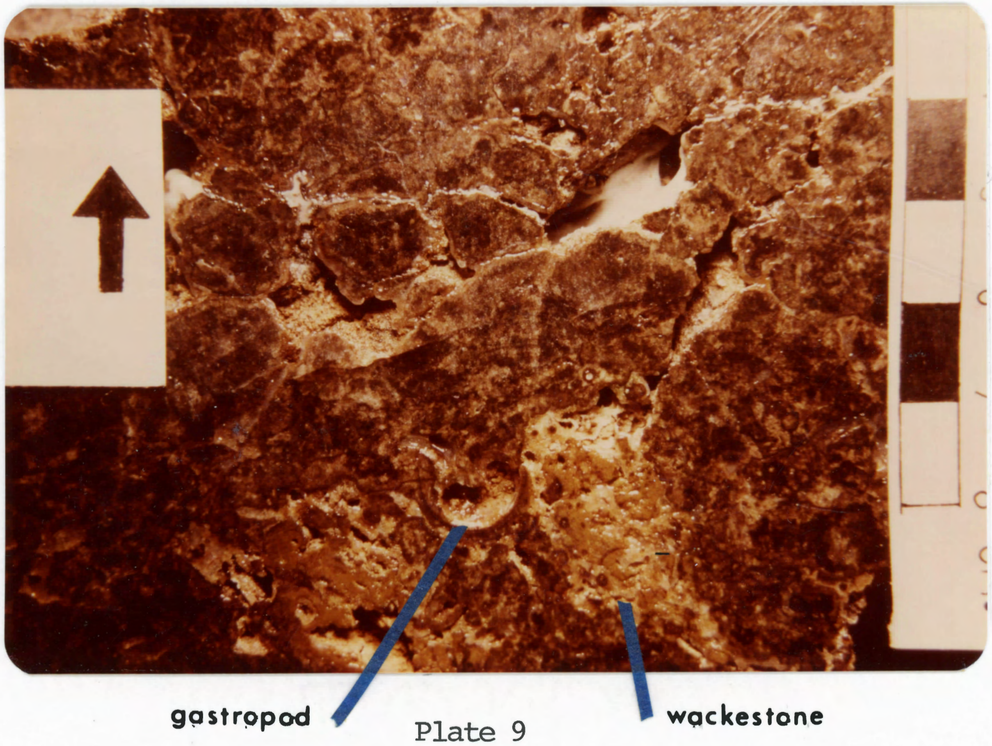


Plate 9

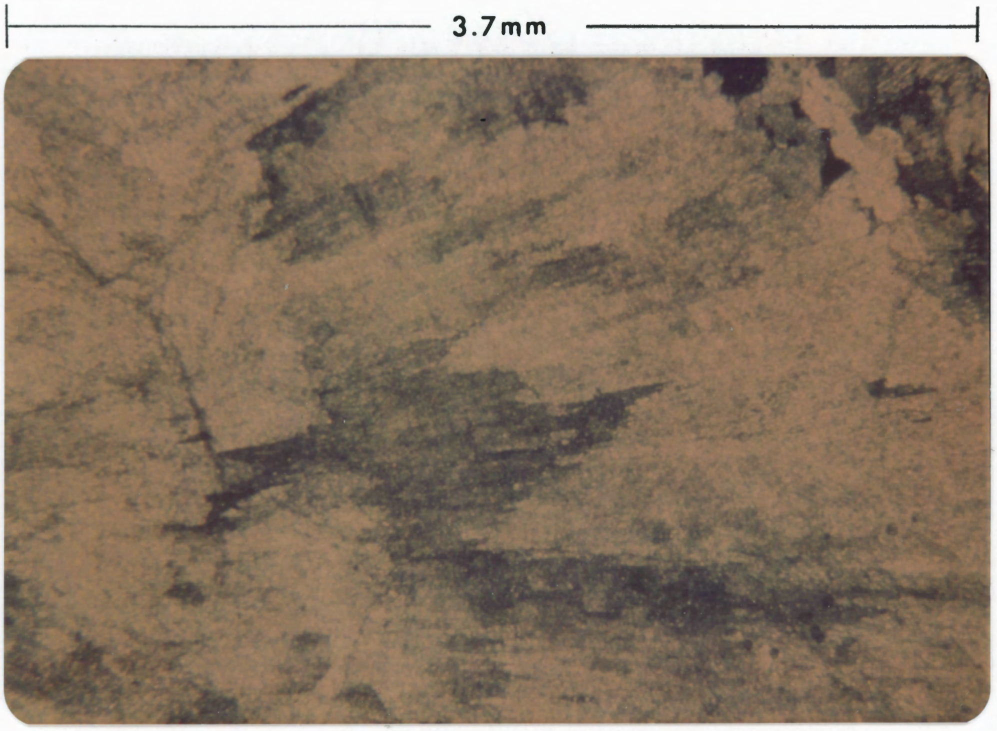


Plate 9(a)

STRATIGRAPHIC COLUMN

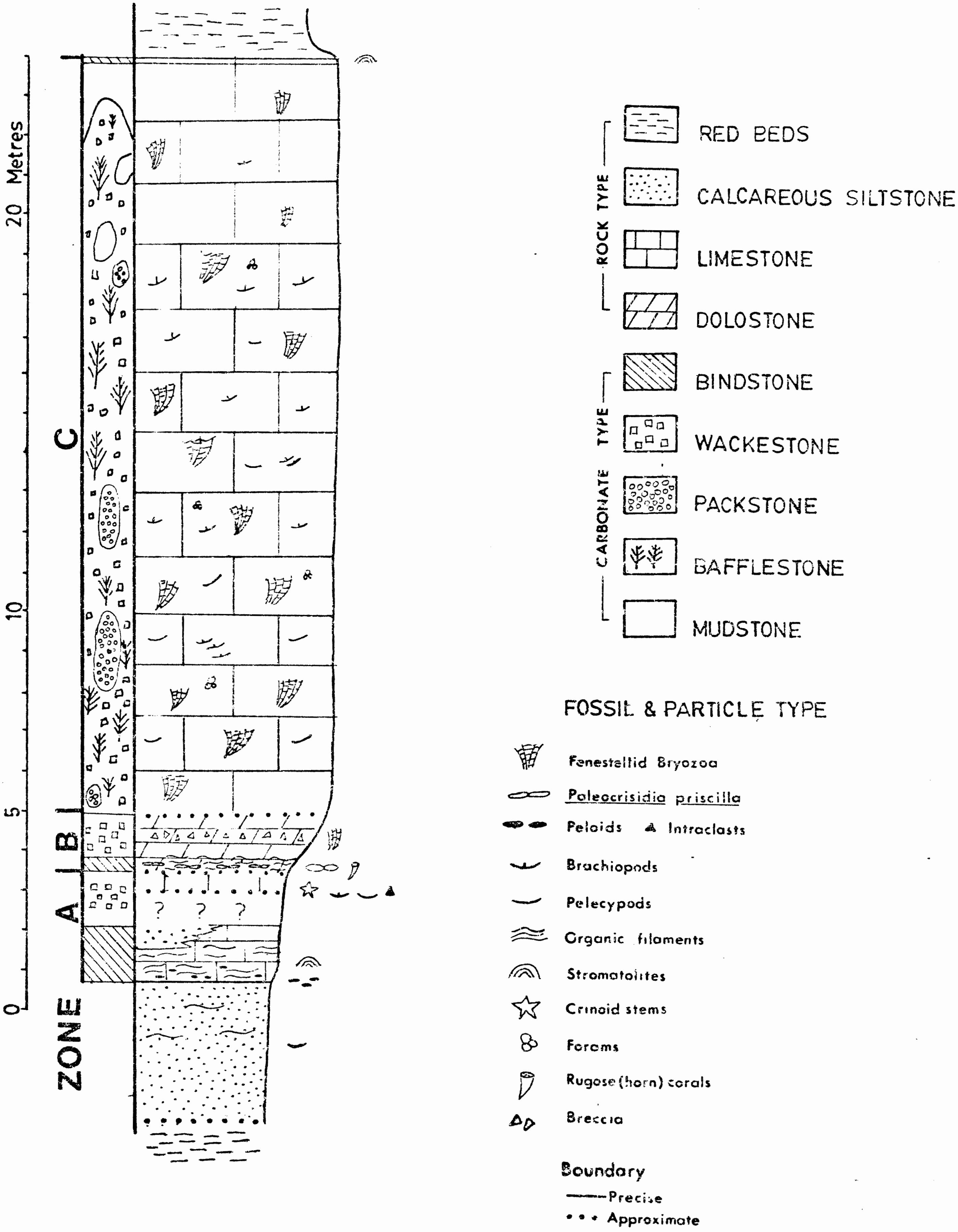


FIG.-6

LITHOLOGIC DISTRIBUTION THROUGH A CROSS-SECTION

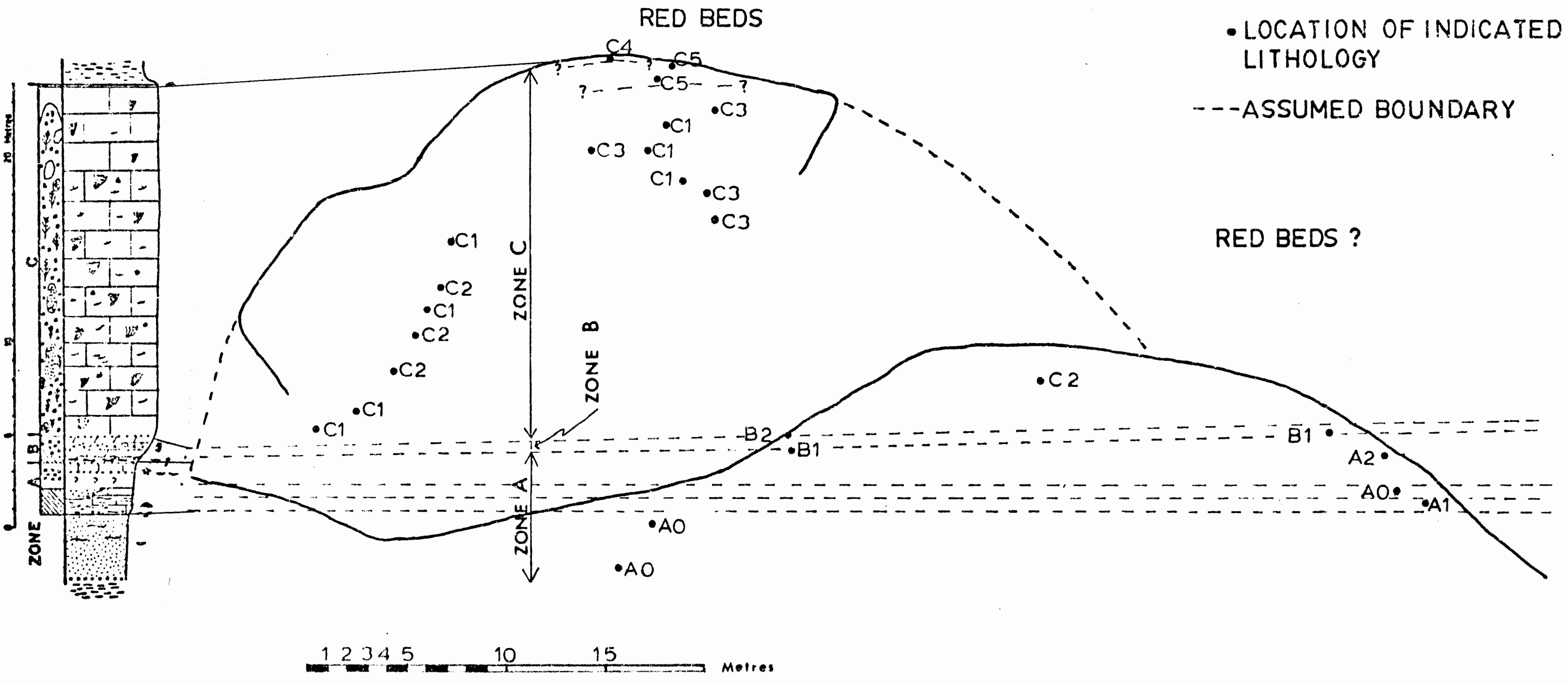


FIG.-7

CHAPTER III

DIAGENESIS

Diagenesis has been an important factor in altering both the composition and texture of the carbonate rock within the studied section. The effect of diagenesis varies both vertically and laterally. In this chapter an outline of the types and effects of the major diagenetic events will be given. A discussion of the observed patterns of the degree (pervasiveness) and extent (distribution) of the diagenetic events and the factors controlling them will also be presented. Finally, the different diagenetic events will be arranged in chronological order. Enviromental implications will be noted in appropriate situations.

Dolomite

Dolomitization has been the most pervasive of all the diagenetic events, with dolomite constituting between 5 and 95 percent of the rock volume. Two forms of dolomite exist : (1) large (.2mm) euhedral crystals and, (2) microcrystalline dolomite. Both forms may be present in any specific area and both are thought to be a result of a single episode of dolomitization. Although dolomitization has occurred in all lithologies, it is best demonstrated in the bryozoan bafflestone, where the dolomite/primary sedimentary textural relationships give good indications of the extent and degree of dolomitization. Thus the bulk of the following discussion will be based on observations from this unit.

The bryozoan bafflestone is characterized by dark, dense, mudstone to wackestone "patches" enveloped by lighter coloured, highly porous micro to macrocrystalline areas (refer to lithologic descriptions). The mudstone-wackestone patches are calcium carbonate in composition whereas the lighter regions are composed of dolomite and/or encrusted bioclastic material. This bioclastic material, for the most part, consists of fenestellid type bryozoan fronds and is referred to as the "bryozoan mesh".

The degree of dolomitization is greatest within the porous region of the bryozoan mesh and decreases in the direction of the dense mudstone-wackestone. This is well illustrated in plates 5 and 11. Clearly the presence of the bryozoan fronds has been the major influence in controlling porosity, which has been the major factor in permitting dolomitizing fluids to penetrate the rock. (ie. the distribution of dolomite is dependant on original fabric porosity provided by the fenestellid bryozoa). It is assumed that, because dolomite is widely distributed throughout the section, permeability was good.

At the microscopic scale, and with the aid of cathodoluminescence, the previously mentioned relationship can be seen to hold true. Blocky euhedral crystals of dolomite are observed within most cavities (Plates 11, 12, 13, and 15). Within many of these cavities bryozoan fronds are present (Plate 11), however, without the aid of cathodoluminescence bioclastic material is difficult to distinguish (compare Plates 11-11(a), and 12-12(a)).

Microdolomite is associated with all porosity, producing penetrative haloes rimming the cavities (see Plates 10-10(a)). Visual comparison of a thin section under crossed nicols and with the quartz plate inserted and the same slide under cathodoluminescence allows the extensive and penetrative characteristics of the dolomite to be studied, (Plates 10-10(a), 11-11(a),12-12(a)).

Usually no major textural change occurs between the microcrystalline neomorphic calcite spar of the host rock (later this chapter) and the penetrative haloes of microdolomite. Where there is a discrepancy, the host rock is coarser grained (Plates 10-10(a),13), a phenomenon which could be due to post-dolomitization aggrading neomorphism of the host rock. This suggests that dolomitization occured early.

The degree of penetration of microdolomite into the calcium carbonate host is variable from one sample to another, even though the rock type and texture may be similar. This strongly suggests that the degree of dolomitization is controlled at least in part by the length of time the conditions for dolomitization persisted. The length of time that dolomitization conditions were present is probably a result of permeability.

Where porosity is high and where the distance between porous areas is short, including porosity produced by bioclasts (inter and intraparticle porosity), penetrative haloes of microdolomite tend to overlap. This produces a rock which is pervasively dolomitized. Such pervasive dolomitization occurs in the bioclastic packstone of Zone E, (Plate 6). Thus, assuming that permeability is good, the degree of dolomitization can be related to the distance between porosity.

A number of conclusions can be made about the dolomitization event:

(1) The extent of dolomitization is controlled by the original interconnected porosity (permeability) ; this is in a large part controlled by bioclastic material, especially fenestellid bryozoas.

(2) Both forms of dolomite are related to one episode of dolomitization.

(3) The degree (pervasiveness) of dolomitization is in part dependant on the distance between porosity and the amount of time dolomitizing conditions were operative. Both of these factors are subject to the control of permeability.

(4) In areas of the section where the dolomite content is high the original permeability can be assumed to have been good.

(5) Dense, non-porous micritic areas show no dolomitization except along the borders with adjacent porosity.

(6) Cathodoluminescence is an excellent method to study the relationships between calcite and secondary dolomite.

Neomorphism

Thin section examination readily reveals that a large portion of the micrite matrix has undergone recrystallization to produce neomorphic spar (Plate 10(a)). Most bioclastic debris also exhibits neomorphic textures (Plate 11,13). The resultant spar averages 3.5 microns in size. As previously mentioned the fact that the calcium carbonate exhibits larger neomorphic microspar crystals than the associated microdolomite demonstrates that the neomorphic process continued within the micrite after dolomitization.

Mineralization

At least three stages of metallic mineralization exist.

(1) Primary pyrite has formed around shells and remnant organic matter within the calcareous siltstone unit. Its prescence is a result of reducing conditions at the time of deposition. This statement is proved and the enviromental implications are discussed in Chapter 4.

(2) Fine powdery and/or crystalline ?? iron oxide (M. Zentilli pers. comm.) is commonly found encrusting dolomite crystals and is often locked between dolomite and calcite crystals (Plate 15). A precise identification of the mineral could not be made because it occurs in extremely low concentrations. The mineral has been found concentrated along microstylolites (Plate 16) suggesting a chronological position between the formation of dolomite and the stylolites.

(3) Secondary sulphide mineralization, ? chalcopyrite, is commonly found associated with late stage blocky calcite spar. It has little volumetric significance.

Stylolites

Microstylolites are present but not common within the section. The formation of the stylolites was post dolomitization and ?iron oxide mineralization. This is suggested by the geometric relationships displayed in (Plate 16) where a stylolite has concentrated both within its boundaries.

Leaching

Two stages of leaching (solution) are apparent: (1) one stage related to the formation of dolomite and (2) related to the formation of calcite spar.

In a few areas of extreme dolomitization (unit B-2) collapse breccia (breccia formed by the dissolution and subsequent collapse of the rock) is present. This is displayed by the presence of rotated blocks of the host rock within fenestral porosity (see top part of core in Plate 4). This event is small-scaled, fenestral porosity averaging 2 mm. in height (Plate 4). Dolomite crystals encrust the rotated blocks showing that the brecciation is related to dolomitization, or had occured earlier.

Irregular cavities cross-cutting fossils, stylolites and pre-existing cavities lined with dolomite indicates a separate episode of leaching which occurred after the formation of these features (Plate 16). The degree of this leaching is variable throughout the section although it is not generally extensive. In most instances it can be seen to be an extension of pre-existing porosity. In such cases it has dissolved pre-existing dolomite (Plate 11,12,16). In some cases (especially in sample 4, Plate 14) this episode of leaching has resulted in the formation of collapse breccia (unrelated to the previously mentioned breccia). Some evidence for this occurs in the bryozoan-bafflestone of the mound proper, but as shown by the unbroken nature of the bryozoans in (see chapter two) collapse breccia is not a major factor in this lithology.

Quartz

Quartz (chalcedony variety) is present but rare and has a patchy distribution (Fig. 10). It is present in the leached (later leaching event) cavities of sample 4 (Plate 14) and within the intraparticle porosity in the calcareous siltstone, unit A-0 (Plate 1). Calcite spar is often encrusting the quartz, indicating that the formation of the quartz was prior to the formation of the calcite spar.

Calcite Spar

Macrocrystalline calcite in the form of dogtooth spar, 1 mm., and large block plugs, 2-3mm., marks the final episode of diagenesis. Both dogtooth spar and the blocky plugs will be referred to as calcite spar in the following discussion.

Distribution and amount of calcite spar is variable both laterally and vertically (Fig. 10). in most cases it is present as fracture filling (Plate 4) or partially plugging previous porosity, which is usually already lined with euhedral crystals of dolomite (Plates 12,15).

CHRONOLOGICAL SEQUENCE OF DIAGENETIC EVENTS

CALCITE SPAR AND ? CHALCOPYRITE

QUARTZ

SECOND STAGE LEACHING

STYLOLITES

? IRON OXIDE

DOLOMITE AND FIRST STAGE LEACHING

NEOMORPHISM

PRIMARY PYRITE

Discussion

A detailed discussion of most of the previously mentioned diagenetic events would be largely irrelevant to an understanding of the depositional enviroments represented within the studied section. Therefore, only the events of syndepositional pyrite and dolomitization will be discussed.

It has been shown that the formation of pyrite is the result of reducing conditions in the prescence of decomposing organic material (Krauskoph 1967). Its formation is restricted to the calcareous siltstone unit, the deposition of which occurred in a restricted region. The above statements will be further discussed in chapter 4.

Of the models available for the dolomitization of limestone, most rely on the prescence of solutions which are many times supersaturated with respect to calcite and dolomite and require an unlimited supply of Mg^{2+} ions (Badiozamani 1973). Many of the common models use evaporation to obtain these conditions.

Although intertidal and supratidal enviroments are preresented in the studied section (Pleasant Brook) and could represent condtions for dolomitization, the carbonate buildup, where dolomite is a major constituent, suggests deposition in the sub-littoral zone in normal marine conditions (see chapter 4). For this reason supratidal dolomitization has been rejected in this case.

An alternative model of dolomitization, which is especially applicable when considering situations involving topographic relief involves the mixing of ground water and seawater. This model is known as the "Dorag" model (Badiozamani 1973) or the "Schizohaline" model (Folk and Land 1975). However the idea is not new and has been suggested by others since Collegno (1834) first considered the possibility of dolomitization by groundwater (Badiozamani 1973).

Badiozamani (1973) shows that the mixing of ground (fresh) water with between 5 and 30 percent seawater results in a brackish water which is less saturated with respect to calcite whereas the dolomite saturation has increased (Fig. 8). Badiozamani (1973) suggests therefore, that dolomitization should occur where fresh water is mixed with between 5 and 30 percent seawater.

In application of this model Badiozamani (1973) has considered the situation of a topographic high, which, when subaerally exposed, forms a fresh water lens within the structure, as displayed in (Fig. 9). It is within the mixing zone that dolomitization occurs. The limestone unit considered by Badiozamani (1973) has been interpreted as representing a sublittoral enviroment.

A direct comparison can be made between the situation considered by Badiozamani (1973) and the situation considered here, in that both carbonate units represent topographic highs and both were deposited and dolomitized in normal marine conditions.

That the top of the buildup is represented by a supratidal enviroment (see chapter 4) would support the Dorag model in that it indicated emergence of the

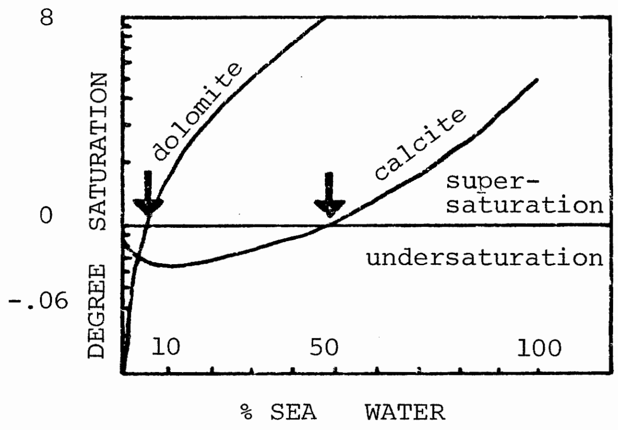


Fig. 8 -The effect of mixing ground water with sea water on saturation degrees of calcite and dolomite.
after Badiozamani (1973)
Dolomitization occurs under conditions between arrows.

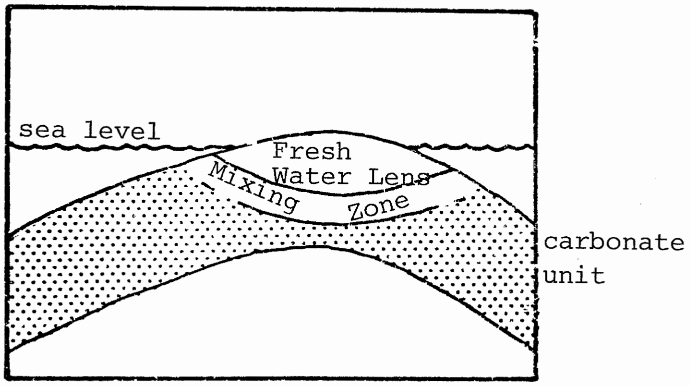


Fig. 9 -Diagrammatic representation of the Dorag dolomitization process of a topographic high.
modified from Badiozamani (1973)

buildup, at which time a fresh water lens would be created within the buildup. Thus, a situation not unlike the one suggested by Badiozamani (1973), Fig. 9, could have present at the time of the emergence of the buildup. Because of the presence of a fresh water lens within the uppermost part of the buildup during the initial emergence, the top section of the buildup would not be expected to contain dolomite. Fig. 10, which shows the relative amount of dolomite through a vertical section shows that the uppermost section of the buildup is void of dolomite. The absence of dolomite in the uppermost part of the buildup (which is characterized by a supratidal environments) supports the idea that dolomitization did not occur as a result of supratidal conditions. One would expect to find the greatest concentration of dolomite in the upper part of the buildup.

The presence of dolomite throughout the remainder of the buildup can be explained by continuous regression which would result in a shift of the mixing zone downward. Thus dolomitization would occur throughout the buildup, excluding the uppermost part.

One implication of this reasoning is that regression can be inferred to have occured at the time of dolomitization. The dorag model also allows for the precise time of dolomitization to be inferred.

RELATIVE AMOUNT OF SELECTED DIAGENETIC EVENTS

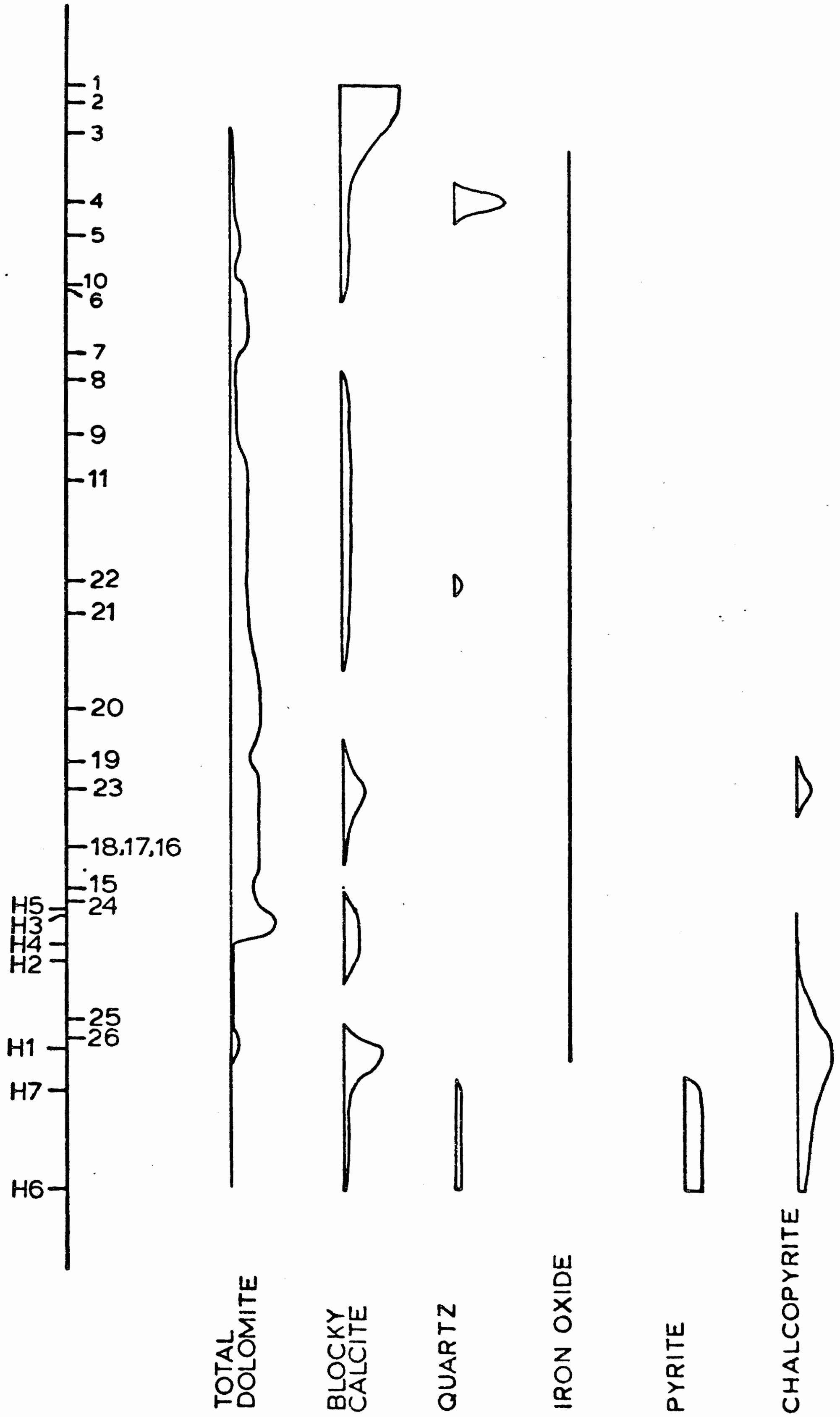


FIG. 10

Plate 10 : Mudstone - wackestone C-3 - Photograph of thin section of the mudstone portion. Scale is indicated above the plate; 3.7 mm. from right to left, the long direction of the photograph. Greenish-blue portions are carbonate rock whereas the purplish area represents porosity. The photograph was taken with the quartz plate and crossed nicols applied.

Plate 10(a) : Same view as Plate 10 with the addiation of cathodoluminescence. The reddish areas represent dolomite, the yellowish areas calcite and the dark areas represent porosity. This photograph demonstrates well the relationship between porosity and dolmitization ; note the dolomite "haloes" surrounding all porosity. Also note the neomorphic state of the calcite with respect to the dolomite.

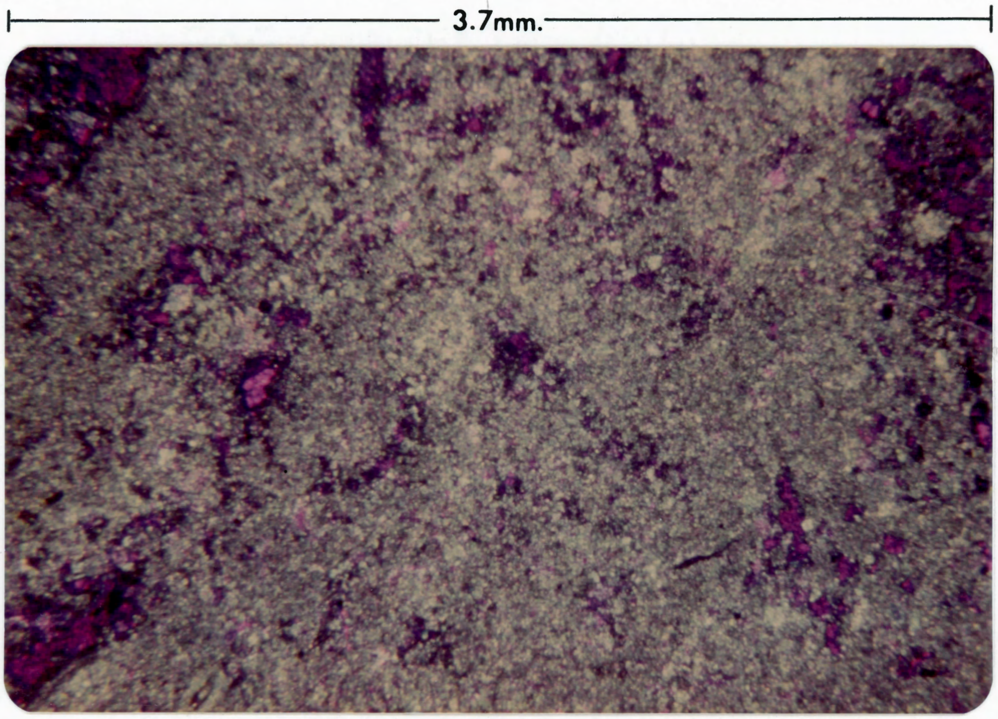


Plate 10

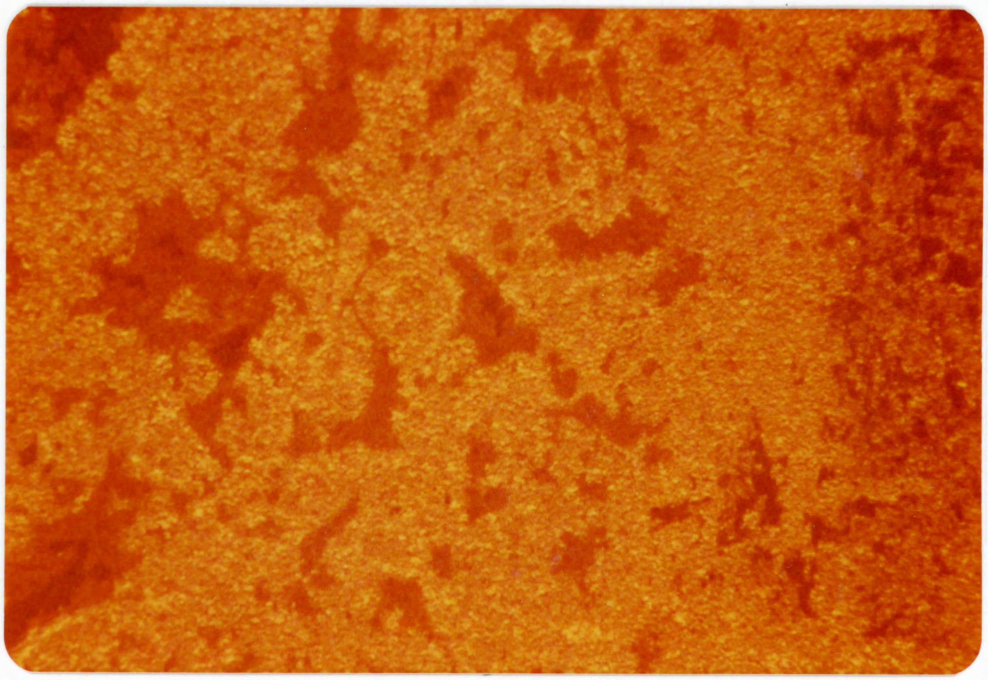


Plate 10(a)

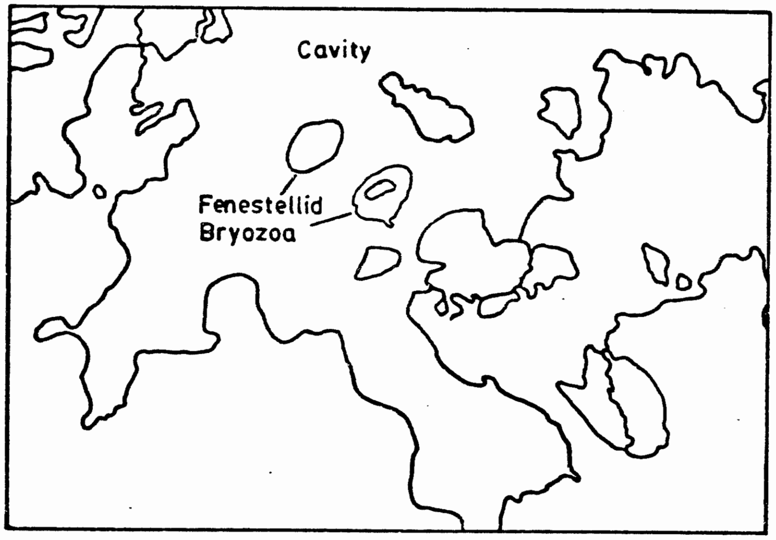


Plate 11 : Yellow=calcite ; Red=dolomite ; darker areas=porosity Field of view is 3.7 mm. from right to left (long direction of photograph). This is a photograph of the bryozoan-bafflestone C-1. Three important features are to be noted here : (1) The presence of fenestellid bryozoans within the cavity (2) The presence of secondary dolomite lining the porous areas (3) The unorthodox distribution of dolomite, which is a result of leaching and partial removal of the dolomite.

Plate 11(a) : Same view as above, except without cathodoluminescence (crossed nicols). Note how difficult it is to distinguish between calcite and dolomite and to determine the presence of bioclasts. Also note the neomorphic texture of the bioclast in the top right corner.

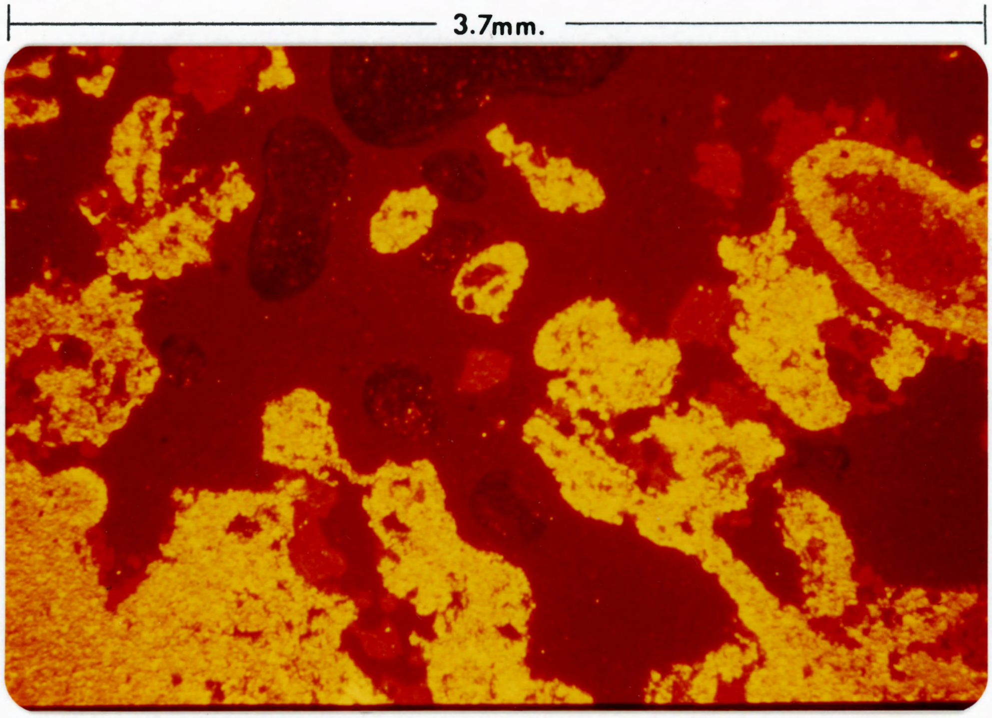


Plate 11

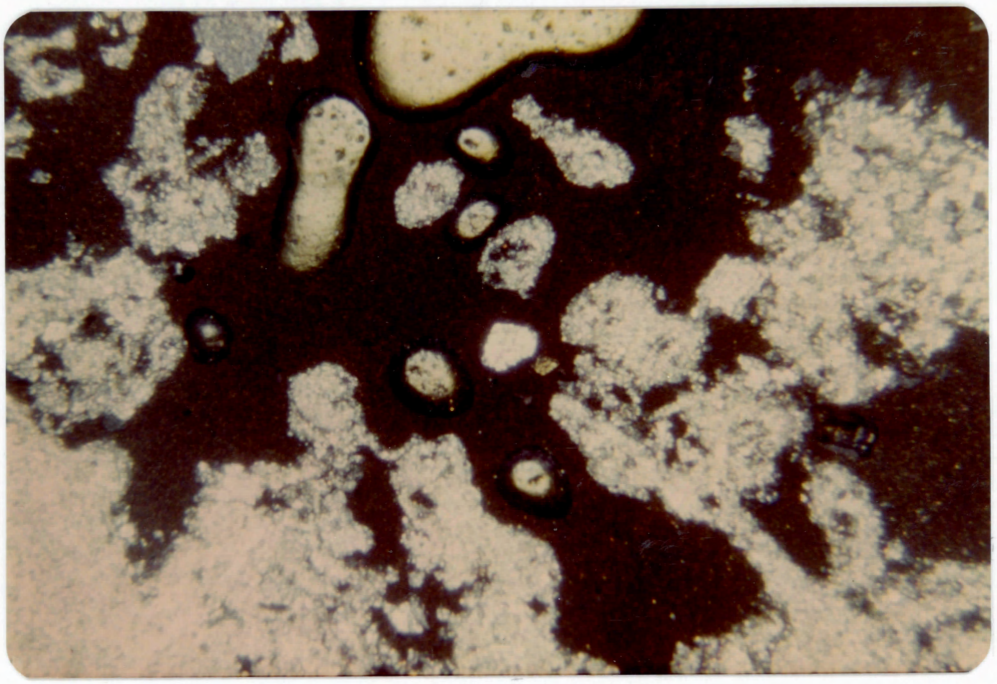


Plate 11(a)

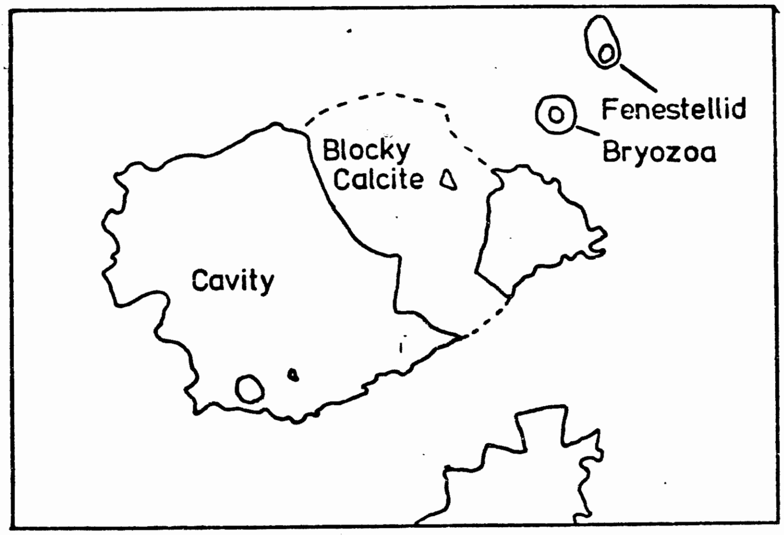


Plate 12 : Color scheme as in plate 11. Photograph is of a cavity which is lined with dolomite crystals, red, and partly plugged with Blocky calcite. Scale is shown above the photograph. Cross-section of branches of bryozoan fronds are present in the top right corner.

Plate 12(a) : Same view as above without the effect of cathodoluminescence and with the addition of crossed nicols and quartz plate. Color scheme as in plate 11.

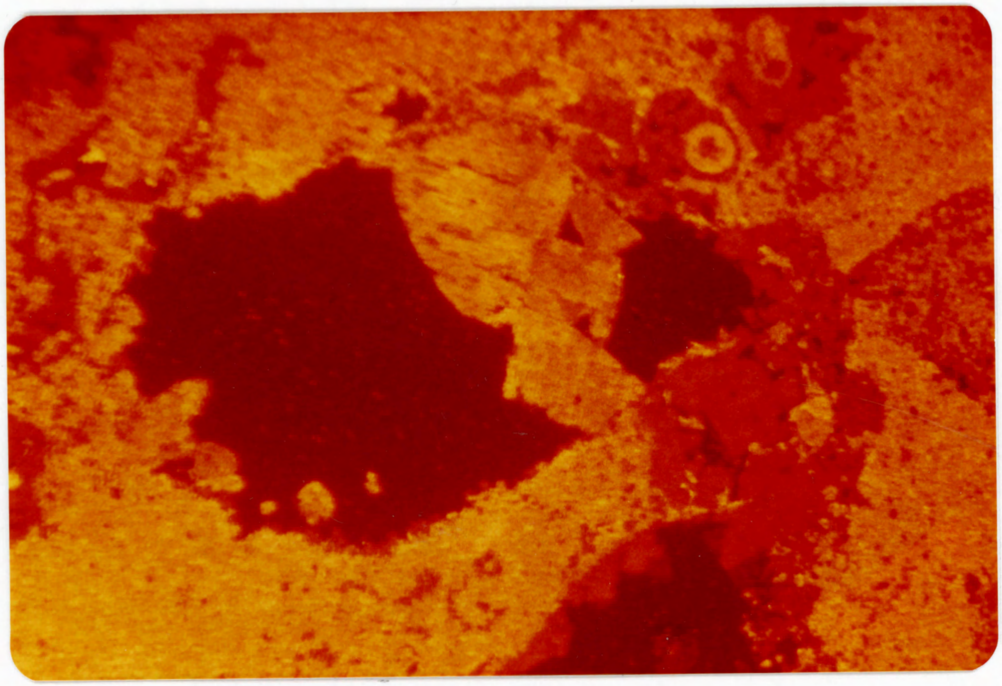


Plate 12

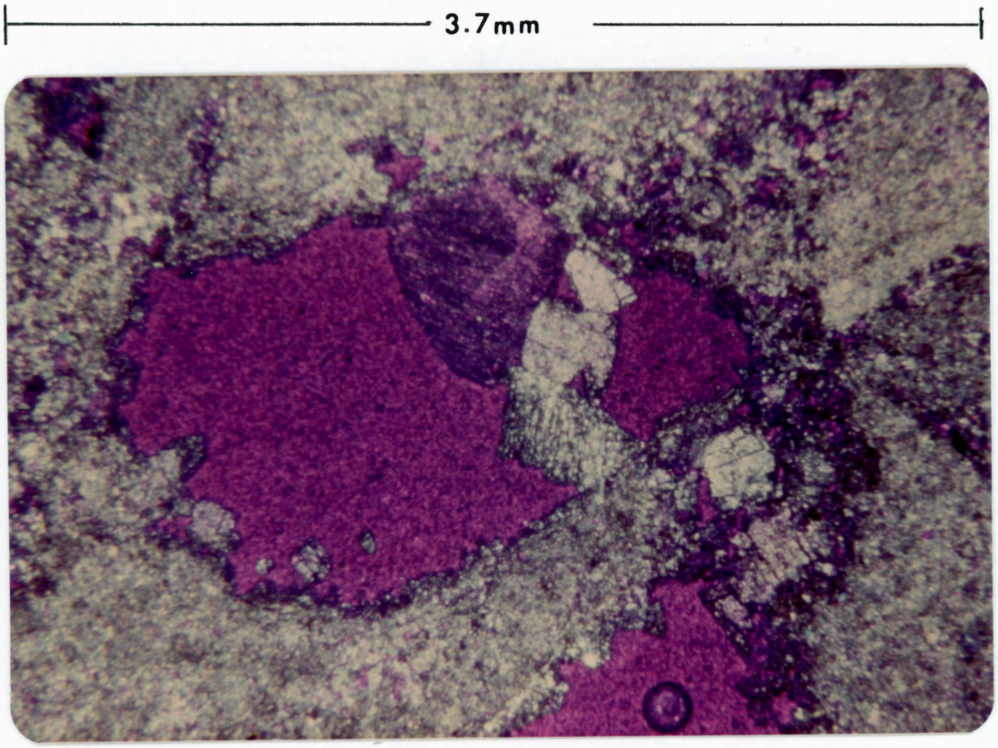


Plate 12(a)

Plate 13 : Photograph of a thin section showing a high degree of dolomitization (dolomite is red). Note how bioclasts resist dolomitization. Calcium carbonate portion (yellow) consists of neomorphic spar.

Plate 14 : Photograph of a polished slab of sample 4. Consists dominantly of collapse breccia with a few large mudstone-wackestone areas (lighter areas). Bioclasts are abundant ; note cross-sections of fenestellid bryozoa. Much of the whitish areas consist of quartz.

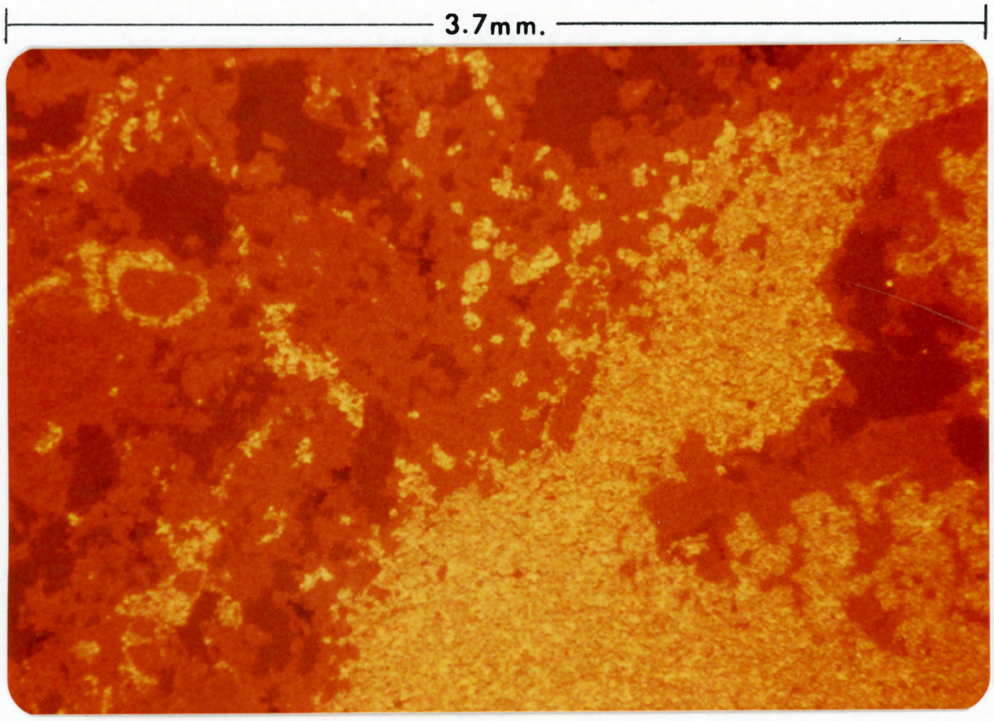


Plate 13

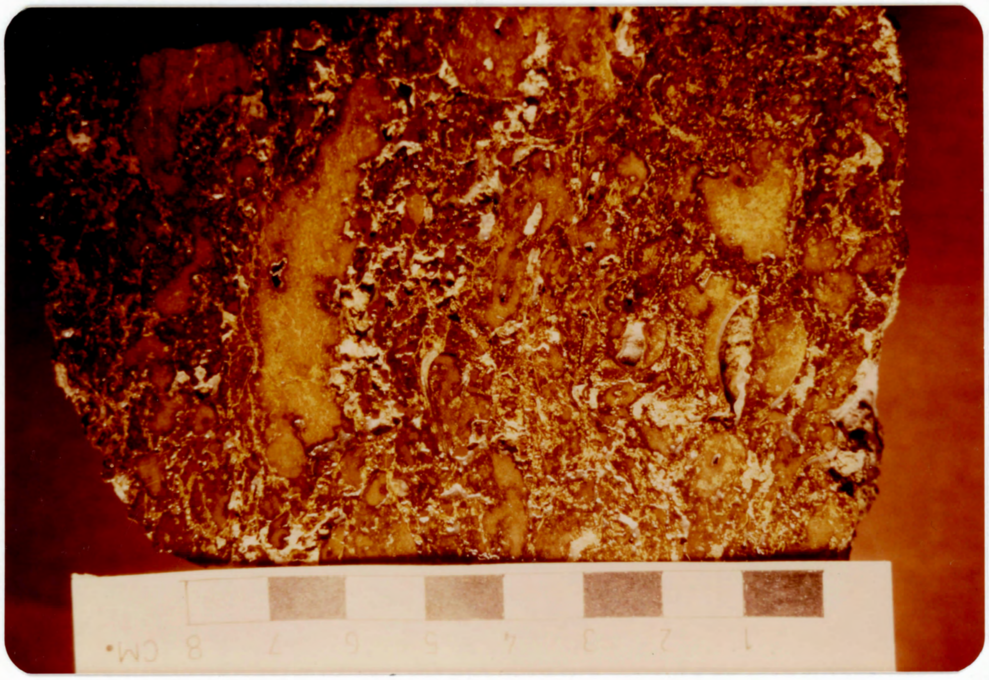


Plate 14

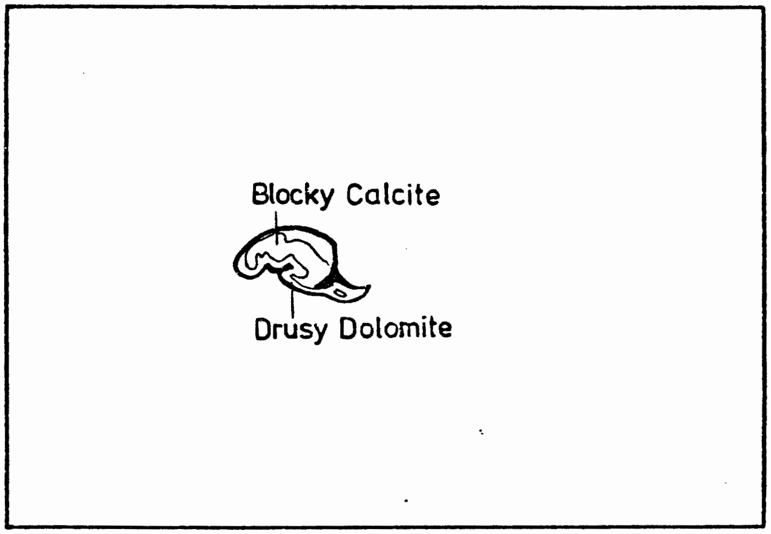


Plate 15 : Photograph of polished slab ; sample 8. The interior of a brachipod has been lined with druzy dolomite crystals which are coated with ? iron oxide. Blocky calcite has later plugged the remaining porosity. Also note here the distribution of dolomite (light yellow areas). The network pattern of the dolomite is often due to the distribution of fenestellid bryozoan fronds.

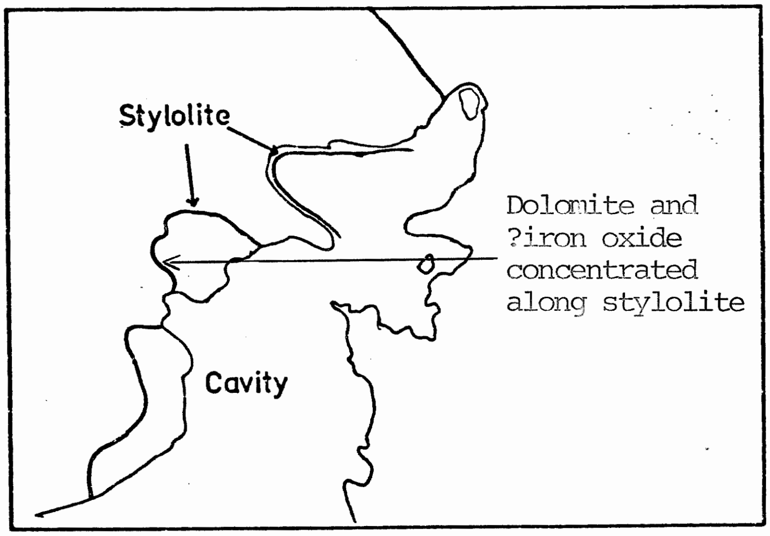


Plate 16 : Photograph of a thin section (under crossed nicols) showing the relationships between microstylolites, solution cavities, dolomite and ? iron oxide. See test for detailed description.

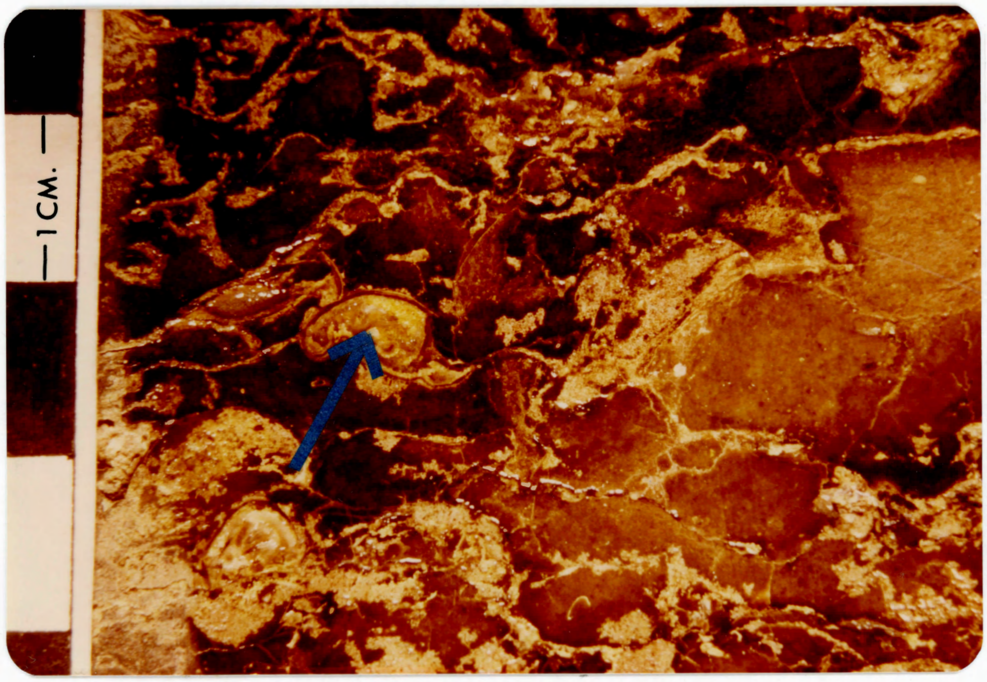


Plate 15

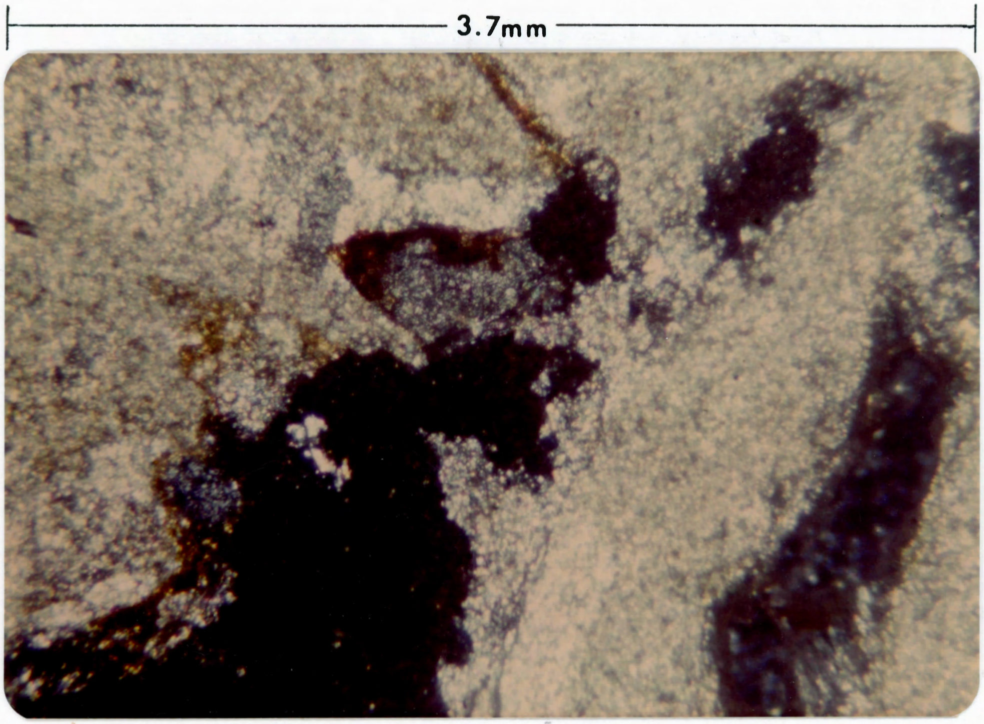


Plate 16

CHAPTER IV

ENVIRONMENTS OF DEPOSITION

Introduction

This following chapter will deal with environments of deposition of the carbonate unit represented on Pleasant Brook. First the depositional environments of each of the lithologic units will be evaluated with respect to a combination of any of the following factors: (1) paleoecological interpretations of in situ fauna, (2) depositional textures, and (3) the association of one lithology with the others. This will be followed by a discussion summarizing the general depositional history as inferred from the sequence of lithologies present in the section. The possible geographic arrangement of the carbonate environments at the time of deposition of the Herbert River Limestone Member will also be considered.

Red Beds

The presence of red beds at the bottom and top of the section suggests non-marine, terrestrial deposition—Schenk (1969) has shown the red colour of the Windsor red beds (Nova Scotia) to be a result of hematite staining of the individual particles. The formation of hematite staining in sedimentary rocks is the result of weathering of iron rich minerals in soils and alluvial deposits (here represented by the Windsor red beds) in warm, humid to arid climates (Walker 1967; van Houten 1968). Smaltz (1968) showed that although moist conditions are necessary in weathering the ferrosilicates, dehydration conditions are needed to preserve the weathered product, hematite. If this hematite is subjected to wet (marine) conditions it becomes reduced and forms limonite, which has a yellow colour (Smaltz 1968). Because of the few rare documented cases of red beds forming in marine condition at the present time, other non-marine indicators are helpful in supporting a terrestrial origin. The lack of marine fossils and evaporites within the red beds supports the hypothesis that the red beds in the study area represent terrestrial deposition.

Calcareous siltstone

Gray carbonate cemented quartz siltstone overlies the basal red siltstones. The contact between these two units has not been observed. The presence of calcareous marine bioclastic debris, calcareous cement, possible organic remains and the lack of hematite staining advocates marine conditions at the time of deposition.

The silt fraction, which constitutes greater than 90 percent of the rock, consists predominantly of very well sorted quartz with minor amounts of muscovite. Fine sub-parallel laminations exist throughout the unit; occasionally there are disturbed by bioturbation. The fauna present shows little diversity, consisting of a few small pelecypods (intact), brachiopods, and a few crinoid stems (which appear to be non-indigenous to the environment). This would suggest unfavourable conditions for life, probably due to brackish or high salinity conditions and the high input of terrigenous sediment. Primary sulfide (pyrite) occurring around organic matter advocates reducing conditions at the time of deposition. (Sulphur from the original protein of organic matter is largely converted to H_2S during decomposition in reducing environments. However some of the sulphur combines with iron to form iron sulphide, pyrite (Krauskopf 1967)).

A recent analogue which has produced similar sediment and sedimentary features as observed in this unit (calcareous siltstone) exists at Rainbow Haven, Cole Harbour, Nova Scotia. Here, near the edge of a barrier lagoon a cross-section through the sediment reveals many of the features seen in the calcareous siltstone unit. Fine, well-sorted quartz silt is finely laminated and extremely uniform throughout. Most of the silt has been transported by wind from a dune system located on the barrier between the beach and the lagoon. Few living organisms were observed; however bioclastic debris has been periodically transported in from the beach during storms. There was a slight reducing environment present, produced by the rotting of organic (algal?) material below the shallow water table. (The water table was a matter of a few centimeters below the surface). A living fauna was present but uncommon as was evidence of bioturbation. Only the top 30 cms was observed. In general the comparison of the two units is remarkably good.

Algal bindstone

Overlying the calcareous siltstone is a planar algal stromatolitic unit. The contact between these two units was not observed. This algal unit has been referred to as planar algal laminations (Giles and Boehner 1979) and stromatolitic limestone (planar type) (Moore 1967). Both authors agree that, when present, this unit represents the base of the Herbert River Limestone Member. Similar observations have been made on Pleasant Brook (this study). P. S. Giles (pers. comm.) has indicated that although the stromatolites are generally planar, "digitate" forms occur in some areas.

Evidence supporting a stromatolitic origin for this unit is:

(1) The algal filaments are generally planar but at times are undulose having slightly over-steepened slopes (Plate 2).

(2) Irregular to laminoid fenestral fabrics are present. The presence of dolomite and calcite plugging the porosity often obscure the presence of this porosity, yet because the dolomite and calcite line the cavities the outline of the fabric can still be observed.

(3) The absence of any substantial amount of bioclastic material. The absence of a diversity of life forms suggests harsh conditions, such as high salinity; a factor which is an important environmental condition in the development of algal structures (Davis 1970). The absence of grazing forms is also an importnat factor in the preservation of algal structures.

Much research has been done on the development of recent algal mats (Logan _et_ _al._ 1974; Brown _et_ _al._ 1974; Davies 1970). Logan _et_ _al._ (1974) have classified algal mats into seven types based on the fabric developed within the mat. It has been convincingly demonstrated that these fabrics are a result of the conditions (environment) to which they are subjected (Logan _et_ _al._ 1974). These conditions are, in a general sense, related to the positioning relative to the shore-water boundary (strand line). The zones corresponding to the different fabrics range between four metres below the prevailing low-water level to two metres above it; or from lower and middle intertidal to supratidal (Logan *et al.* 1974)

The section of algal stromatolites in this unit progressively change vertically from a flat lying "ribbon" form to a more undulose or colloform type. Although this would indicate a transgression from the lower or middle intertidal zone through to the subtidal zone the decrease in terrigenous silt and subsequent increase in micrite could be responsible for this. Logan *et al.* (1974) shows the importance of the type of sediment on the type of fabric which is developed within stromatolites. The transition from silt to micrite in this section is interpreted as the transgression of lagoonal conditions over supratidal silt influenced areas. Similar environments are present at Rainbow Haven, Cole Harbour.

Packstone-wackestone

Overlying the stromatolitic unit is a quartz rich packstone-wackestone. Textural inversion is exhibited throughout the rock where transported brachiopods, rugose corals, crinoid stems, echinoid spines, coated grains and micritic intraclasts are abundant in a matrix of predominantly well-sorted, siltsized quartz. The clasts display poor shape and size sorting. Some fossils such as the brachiopods, corals, crinoids and echinoid spines show evidence of only short transport (low degree of abrasion and fragmentation), where as the intraclasts and coated grains exhibit long distances of travel (transported from other depositional environments). The micritic intraclasts represent deposition in a very low energy environment (lagoon) (Wilson 1975). Coated grains are characteristic of high energy environments (shoal environments in agitated water) (Wilson 1975).

Wilson (1975) attributes textural inversion of this description to the movement of particles indicative of higher energy down local slopes to be deposited in quieter water. The transport of the intraclasts and coated grains may have been initiated by storm action. Clasts which show small distances of transport probably lived close to the area of deposition. Gravity was the transporting agent down the local slopes. Deformation caused by the sudden introduction of the larger clasts displayed throughout this unit supports this idea.

Crinoids, horn corals, and brachiopods are filter feeders and cannot tolerate silty water (Moore, 1967; Duncan, 1957). This supports the fact that they did not live in the environment in which they are found.

Palaeocrisidia priscilla - organic (algal?) filament bindstone

Unfortunately an unsampled section of about one metre exists between the top unit of zone A (packstone-wackestone) and the bottom most portion of zone B (*palaeocrisidia priscilla* - organic filament bindstone). This gap, although short, represents three important changes in the depositional habit of the environment. These are: (1) the underlying "Typical" Herbert River lithologies consist of bindstones and wackestones and indicate deposition in shallow to moderately deep water. The overlying "Atypical" Herbert River Zone, on the other hand, represents a carbonate buildup and thus deposition in deeper water (later this chapter). (2) The amount of terrigenous quartz silt input has drastically declined, from up to 50 percent in the underlying lithologies to virtually 0 percent in the overlying buildup lithologies. (3) The dominance of *Palaeocrisidia priscilla* is characteristic of this zone. The dominating effect of *Palaeocrisidia priscilla* must represent a specific environment in which conditions were suitable for its growth, and possibly unsuitable for other organisms.

The decrease in terrigenous silt, vertically through the section, could be a result of one of two things: (1) the amount of terrigenous silt input into the basin actually declined, or (2) the presence of a topographic high prevented the deposition of silt on top of it. Because the silt content does not decrease vertically through other sections of the Herbert River Limestone Member (where the buildup zone (C) is not present) the later case is preferred.

A paleoecological evaluation of Palaeocrisidia priscilla may help in determining the environment of deposition of this unit. Its presence may also help in determining why the buildup zone originated.

That both the organic (algal?) filaments as well as Palaeocrisidia priscilla are in situ in this unit is shown by the continuous lateral growth of the organic filaments (Plate 2a) and the delicate nature of the test of Palaeocrisidia priscilla. The thin test (5-6 microns thick (Ryan 1975)) would not tolerate much movement. The local accumulation (later this chapter) and encrusting nature of Palaeocrisidia suggests that it probably did not have a planktonic life style.

Little paleoecological information is available on Palaeocrisidia priscilla, and in fact its taxonomic positioning is somewhat obscure. Dawson (1891) first referred to it as the foraminifera *Dentalina priscilla* but later Bell (1929) reclassified it as *Nodosinella priscilla*. Dawson (1891) noted at the time that he was not at all confident of this taxonomic positioning. Moore and Ryan (1976) later relcassified *Nodosenella priscilla*, placing it into the phylum Bryozoa. They did so because of the presence of a secondary chamber and the succession of vesicles that bear stolons. The generic name is due to the close affinity with Palaeocrisidia (Cumming 1966)(Ryan 1977).

Ryan (1977) suggested that *Palaeocrisidia priscilla* was relatively intolerant of muddy water and probably lived in the lower intertidal to higher sublittoral zone where wave action removed the mud fraction. However the possibility of desiccation of the bryozoan in the intertidal zone, the lack of any desiccation features in the algal? filaments and the inconsistency of having a thin shell in a high energy environment would argue against this. (A high energy is necessary to remove the mud fraction;inferred by Ryan (1977)). Dr. P. S. Giles (pers. comm.) has indicated that the presence of *Palaeocrisidia priscilla* appears to be ambiguous with respect to the depositional environment because it is found in most lithologies throughout the Upper Windsor. However the association with algal? material is a common one (Ryan 1975; Mamet 1970; Dawson 1891). *Palaeocrisidia priscilla* is present in the Herbert River

Limestone Member (Moore and Ryan 1976), but high concentrations such as that present here have not been noted in any of the previously described sections. This would suggest that the presence of *Palaeocrisidia priscilla* is dependent on favourable environmental conditions which may be laterally restricted. If the growth rate of *Palaeocrisidia* is high local topographic highs may result.

Here, the depositional environment appears to have been one of low energy, for the reasons given above; probably below wave base. Due to the low percentage of mud present, a lagoonal environment has been excluded (lagoonal environments are characterized by the presence of lime mud (Wilson 1975)). The conditions restricting the distribution of *Palaeocrisidia priscilla* are obscure, however they may be related to the presence of nutrient rich waters; *Palaeocrisidia priscilla* was a filter feeder as are most bryozoans (Duncan 1957).

The units which occur above and below this unit are useful here in interpreting an approximate environment for the deposition of this unit. They indicate water depths below wave base (the unit below, wackestone-packstone has been interpreted as below wave base and the unit above, buildup unit, is interpreted as deeper water still.

Brecciated dolomitic wackestone

Directly overlying the B-1 unit (*Palaeocrisidia priscilla* - algal filament bindstone) is a highly dolomitic wackestone. The lowermost portion of this unit constitutes a pseudobreccia in appearance. However, the breccia pattern is the result of selective dolomitization; the dolomitization is a secondary feature and its extent here is probably a result of porosity, possibly due to borings (algal) in the rock. That this zone does not represent a calcrete breccia (breccia formed during the development of a soil horizon), which is what it looks like on cursory inspection, is shown by: (1) Palaeocrisidia represented on both sides of and within this zone. This suggests continuous sedimentation; (2) dolomitic areas (which are causing the brecciated appearance) have cuspate boundaries with the non-dolomitic areas. There is no textural or compositional changes between these two areas. This indicates that dolomitization was a secondary effect. If this zone represented a true calcrete breccia the blocky (dolomite) areas (Plate 4) should be composed of blocks of the underlying lithology, however this is not the case.

Above the pseudobreccia zone the dolomitic wackestone exhibits collapse brecciation. The distribution of this brecciation is irregular (Plate 4). The formation of the brecciation is related to the dolomitization process and is discussed in Chapter 2. Because of the destructive nature of the dolomite, with regard to the original texture and composition of the rock, an enviromental interpretation has not been attempted.

The extreme top of this unit (the extreme top of core 4, Plate 4) is consistent in texture with the bryozoan bafflestone of zone C. There are fenestellid bryozoans present, which at times create shelter porosity, as in the bryozoan bafflestone. Intense dolomitization however does not allow for confident correlation between the two. However, the stratigraphic positioning of this unit (Fig. 7) and the presence of fenestellid type bryozoa strongly suggest that this zone (top of core 4) is the initiation of the carbonate buildup proper.

Bryozoan bafflestone - Bioclastic packstone - Mudstone - wackestone (Buildup proper)

The environment of depostion of the buildup proper is considered to be below wave base but in an area where minor currents existed. Moore (1967) has made similar conclusions suggesting the buildup represents a deepening of the basin and that minor currents would be needed to carry nutrients to the filter feeders present.

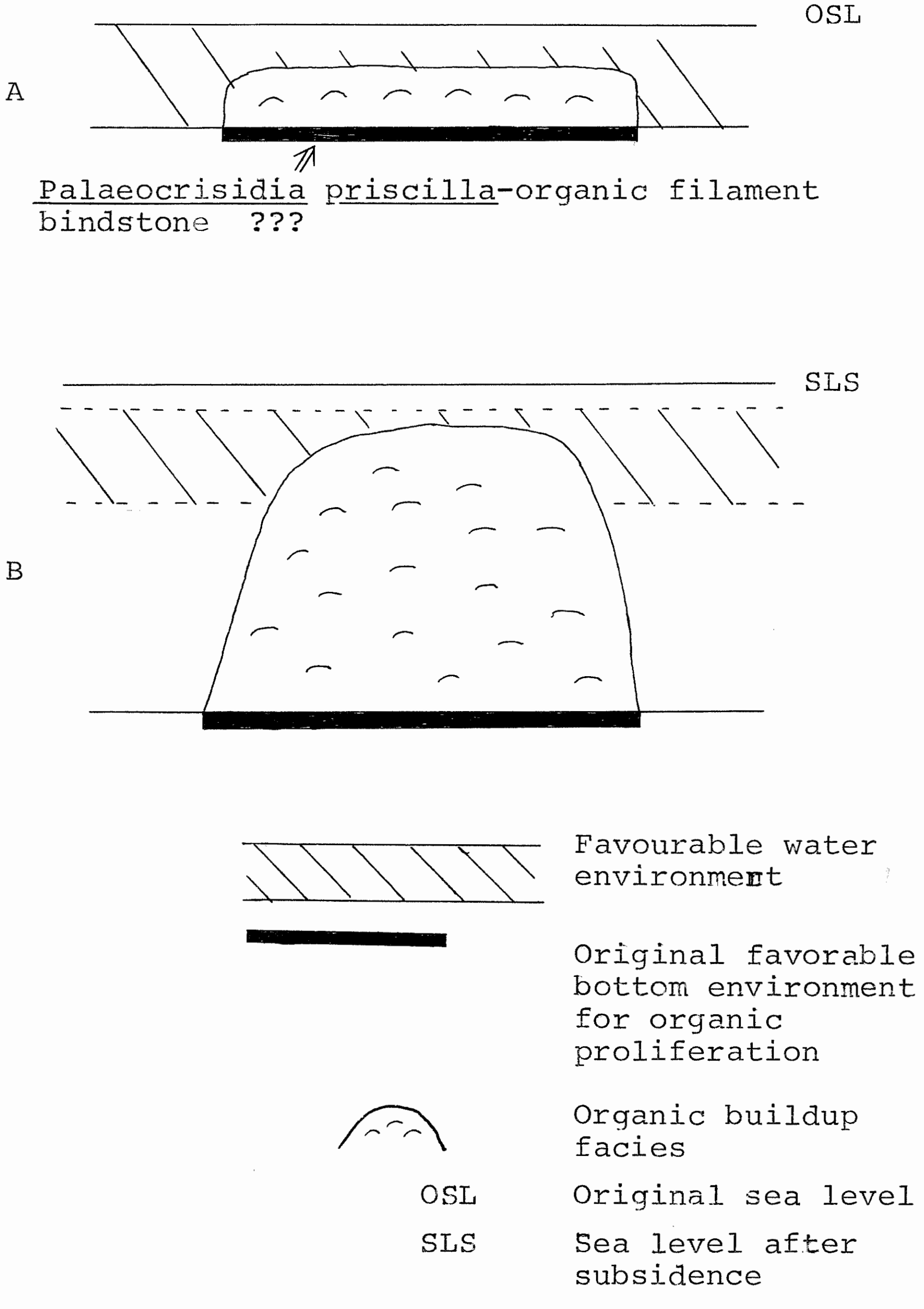
The diversity of fauna present within the buildup advocates normal marine conditions. Nine common fossils are: Fenestrellina lyelli (Bell), Batostomella abrupta (Ulrich), Septopora primativa (Bell), Aviculopecten lyelliformis (Bell), Aviculopecten lyelli (Dawson), Modiola hartti (Bell), Naticopsis howi (Dawson), Naticopsis hartti (Bell), Dietypclostus subfasiculatus (Bell).

The localized distribution of the buildup within the Herbert River Limestone Member is considered to be a consequence of the distribution of the Paleocrisidia priscilla - organic (algal ?) filament bindstone unit, which has a localized distribution pattern. The fenestellid bryozoa and other filter feeders found within the buildup would have found the environmental conditions proposed for the area of deposition of the previously mentioned unit to be suitable for living, whereas the silty environment throughout the rest of the basin would be unfavourable.

The growth of the buildup has been interpreted as being the result of transgression. The buildup would, through increased biological action, grow upward in response to the increasing water depth in order to maintain its position in favourable conditions (Fig. 11)

Figure 11 : The effect of subsidence on an organic buildup. As subsidence occurs the buildup grows upward to maintain its position in favourable ecological conditions. If transgression is too rapid for upward growth to keep up with the buildup will end up below the zone considered as favourable for growth and stop growing. On the other hand if subsidence is slow then the buildup will tend to grow laterally when the upper limit of favourable conditions is reached (Heckel, 1974).

FIG. 11



A Prior to subsidence
B After subsidence

Modified from Heckel (1974)

(favourable with respect to the fauna present). These "conditions" are probably related to factors such as light penetration and/or the nutrient content of the water. Such environmental factors would control the lower limit (maximum water depth) in which the buildup could maintain growth.

The presence of large quantities of lime mud advocates quiet conditions ; in order to prevent winnowing of the fine fraction. Because of the localized extent of the buildup, the absence of micritic facies and diversity of fauna (and large amount of fenestellid bryozoa), which are considered to be indigenous to the buildup, and the topographic relief which the buildup probably represented, the unit is thought to have formed in situ, by organic means. On Rodriquez Bank,Florida, lime mud is produced by Penicillus sp. and other green algae (Turmel and Swanson 1978). Similar organisms would be good candidates as the mud producers of this buildup, as they usually leave no sign of their presence, because they completely disarticulate after dying.

Wave base has been suggested for the upper growth limit of other mud buildups (Wilson 1975 and others). Cotter (1965) however has suggested that "any mechanism that can bind carbonate mud and silt on steep depositional slopes (Waulsortian mud mounds, Lees (1961) (1964), Pray (1958), Cotter (1965) and others) can probably prevent winnowing of fine sediment above wave base." Also, Hagan and Logan (1974) and Ginsburg and Lowenstam (1958) have shown that baffling organism (marine grasses in their examples) can reduce water motion sufficiently to cause fine sediment to settle, or conversely to prevent winnowing. Heckel (1974), Wilson (1975), Pray (1958) and others have suggested that fenestellid type bryozoans may have been effective bafflers, acting much the way marine grasses do today. However extremely agitated water near the surface was probably too strong for fenestellid bryozoa (Duncan 1957, Troell 1962, Moore 1967) and thus restricting the upper growth limit of the buildup to below the zone of highly agitated conditions.

Stromatolites

A thin stromatolitic unit (Plate 8) "caps" the buildup proper. These stromatolites are columnar in growth form, with characteristic oversteepened slopes, thining of laminae along the sides and laminoid fenestral porosity concordant to the laminae. Recent stromatolites with similar geometry develope within the "smooth - mat" of the lower intertidal zone in Shark Bay, Western

Australia (Logan et al. 1974). Smooth mats are characterized by laminations and fine laminoid fenestral fabric (Logan et al. 1974). The columnar structure is a result of the interaction of wave turbulance and/or tidal currents (Logan et al. 1974). Thus the stromatolites in this unit are interpreted as representing an intertidal enviroment.

Stromatolites which are similar in form, compare Plate 8 and Figure 10( ) of Giles et al. (1979), have been observed by Giles et al. (1979) within the Gays River Formation Banks. Giles et al. (1979) suggests the stromatolites are of intertidal origin thus supporting the previous interpretation.

Crystalline Carbonate

This unit is composed almost exclusively of radiating carbonate crystals (see Plate 9a). These crystals have a vertical prismatic longitudinal section and are terminated by a steep sided dipyramid ; a crystal form characteristic of aragonite (Hurlbut 1971). Within sample number 4, representing the mudstone-wackestone lithology just below the crystalline carbonate unit, crystals which have the same crystal form and optical properties line intraparticle porostiy. This indicates that the presence of these radiating crystals is a result of secondary precipitation of aragonite and is not a result of recrystallization of the host rock.

The porosity within the crystalline carbonate which made the precipitation of aragonite possibly is a result of the folding over of algal mat layers and/or the turning up of the edges of shrinkage polygons (Plate 8). Similar structures have been documented by Bathurst (1971) and Davies (1970) as being found in the supratidal regions of Florida Bay and Shark Bay, Western Australia, respectively. A similar environment is suggested for the unit found in this section.

Conclusions Part 1

The Herbert River Limestone - Red bed sequence, present at Pleasant Brook, represents a transgressive - regressive cycle of marine conditions. This is shown by the containment of a marine carbonate unit between terrestrial red beds.

The limestone Member consists of a succession of carbonate lithologies which characterizes a transgressive phase followed by a regressive phase. This succession is summarized in Figure 12. Because the relationship with other sediment deposited at the same time as the buildup is not known (Chapter 1) some confusion exists as to what the water depth was surrounding the buildup. If sedimentation was slow in surrounding areas (with respect to transgression and growth of the buildup) water depth may have reached well below the sub-littoral, possibly in the order of 20 metres (the height of the buildup lithology (Fig. 13)). However if sedimentation in surrounding areas was rapid a situation such as shown in Fig. 13(a) may have been present, with water depth much less than 20 metres.

Prior to the initial depostion of the Member, erosion of uplifted blocks was causing deposition of terrestrial material (red beds) within the basin (see Fig. 14). These are represented by the thick red siltstones indicated in Fig. 2 (stratigraphic column).

Fig 13 and 13 (a) : Graphical representation of two possible relationships between the buildup facies and the off buildup facies. Rate of sedimentation within one facies with respect to the other controls this relationship.

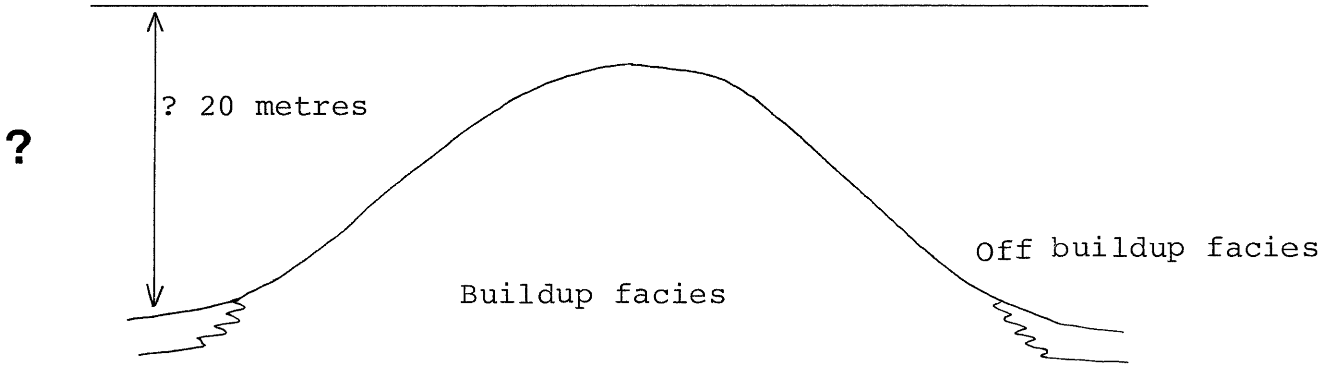


Fig. 13 : Sedimentation rate is slow in the off buildup areas.

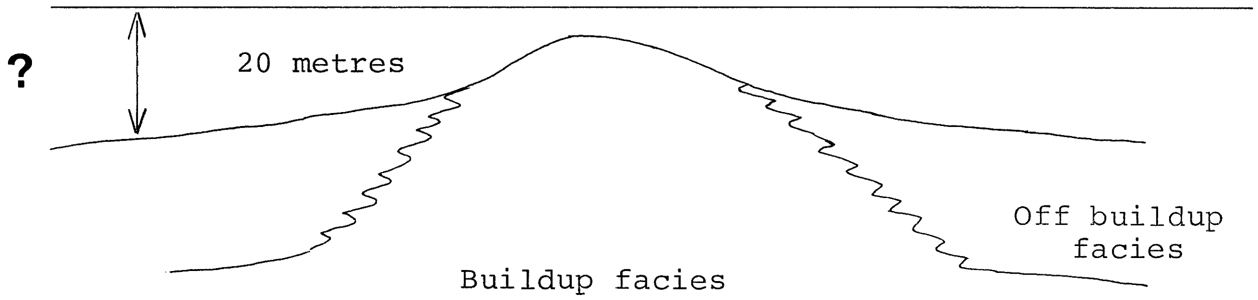


Fig. 13(a) :Sedimentation rate is high in the off buildup areas.

Climatic conditions were warm and humid to arid ; conditions necessary for the formation of red beds (Walker 1967, Van Houten 1968). That terrigenous silt is not present within the buildup to any noticeable degree possibly indicates that arid conditions were not dominant. If climatic conditions were arid, wind blown material would be expected to be common, in which case the terrigenous silt should not be restricted to topographically low areas, as found in this section. A deep but fluctuating ground water table was probably present, allowing for decomposition of ferrosilicates during times of high ground water and preservation of the resultant hematite when the gound water level dropped (Walker 1967).

As the uplifted areas became eroded, sediment input into the basin decreased. With continued subsidence of the basin, marine conditions were induced as flooding of the basin occured. The presence of marine conditions if first recorded by the loss or red pigment (hematite becomes reduced to limonite, a yellow oxide, when subjected to marine conditions (Smaltz 1968)) and the addition of marine fossils, ie. the calcareous siltstone unit.

The transgressive nature of the first part of the section indicates that the strand line was continously shifting landward, allowing for the progradation of deeper water sediments over shallower water sediments. Environments of deposition probably varied laterally within the basin (Fig. 14). This would, in turn, cause variation in the resulting stratigraphic section produced and would explain why Moore (1967), although also interpreting a transgressive succession of lithologies, has described some different lithologies.

The top of the carbonate unit exhibits intertidal and supratidal features, indicating a regressive phase. During this regressive phase, as terrestrial sedimentation increased, terrigenous sediment prograded toward the centre of the basin, eventually covering the buildup. At some time during regression, before sedimentation covered the buildup, the buildup was subaerially exposed, at which time dolomitization occurred and intertidal and supratidal deposits were deposited. The samples of the intertidal and supratidal deposits examined here are considered to represent the crest of the buildup. However these units may be represented on the flanks as well, if the drop in sea level preceeded the deposition of the red beds.

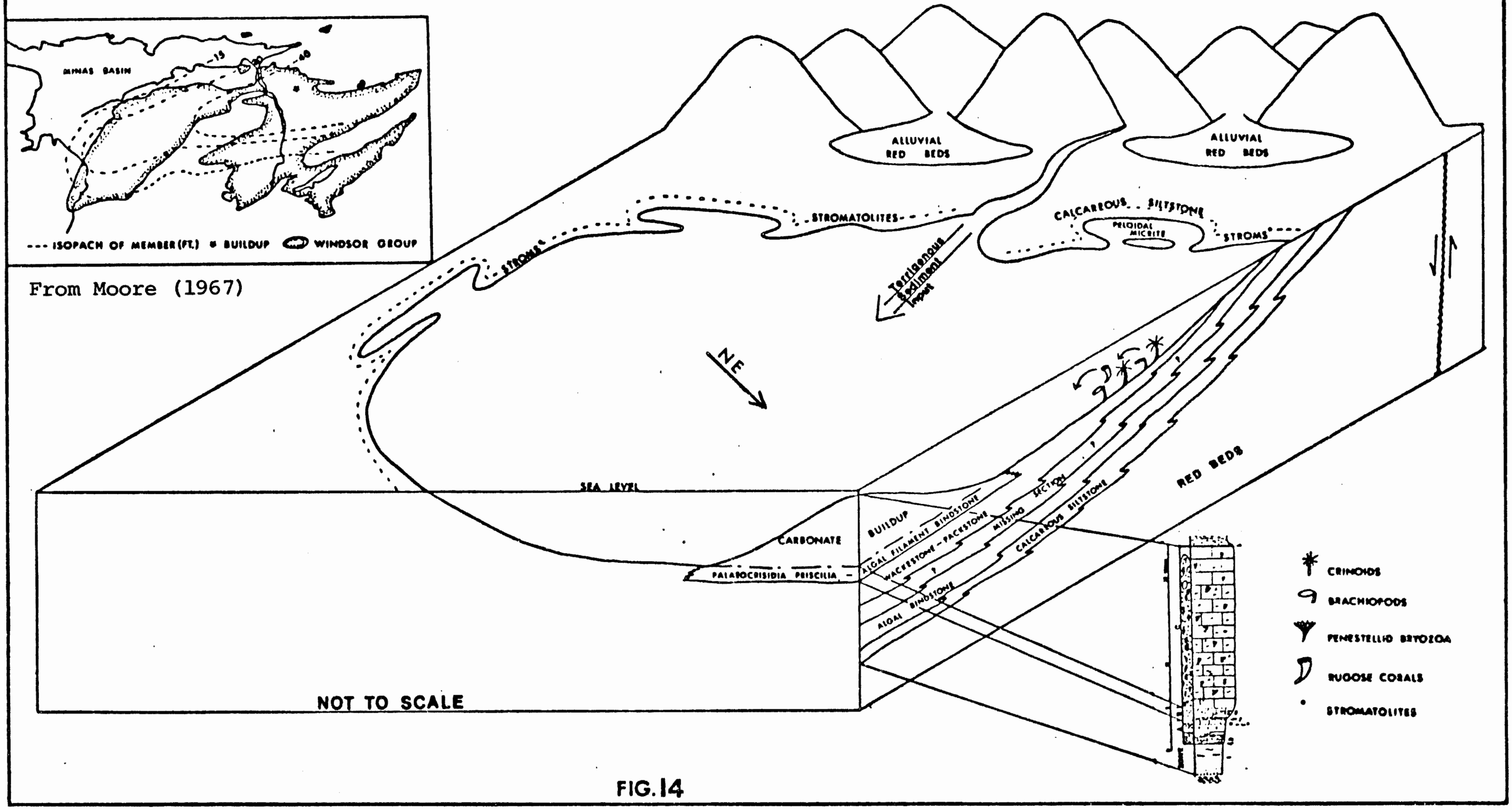
Part II Geographic and Stratigraphic Relationships Between Enviroments of Deposition.

Through the use of isopach lines, Moore (1967) has outlined the "trend" (extent) of the Herbert River Limestone Member within the Shubenacadie and Musquodoboit Basins (Fig. 14). Moore's isopach map is shown in the upper left side of Fig. 14 ; the position of the carbonate buildup studied here has been indicated here as well. Moore (1967) suggest that a "decrease in the thickness of the Member normal to the southwest along the depostional axis, combined with the disappearance of the massive micritic facies (buildup), and a"decrease in maximum coral size and abundance, all in the same direction, suggest that the probable depositional strike of the Herbert River Limestone in the Minas sub-basin (Musquodobit and Shubenacadie Basins) was broadly U-shaped opening to the northeast."

Applying the information on environments of deposition for each of the lithologies, and the stratigraphic sequence of these lithologies,the proposed geographic and stratigraphic relationships of the environments has been schematically represented in Fig. 14. Comparison with the stratigraphic column, lower right corner, shows how the arrangement of environments is consistant with the known succession of environments (lithologies). Only the transgressive phase is represented here (Fig. 14).

Fig. 14 : Geographic and stratigraphic relationships of environments of the Herbert River Limestone Member. This diagram represents only a possible arrangment of environments yet is consistant with the succession of environments (as previously interpreted) and the proposed extent and general environment of the basin in the Herbert River Limestone was deposited (as interpreted by Moore, 1967). Stratigraphic column in lower right is from fig. 6. Isopach map is from Moore (1967).

PROPOSED GEOGRAPHIC AND STRATIGRAPHIC RELATIONSHIPS OF ENVIRONMENTS DURING DEPOSITION OF THE HERBERT RIVER LIMESTONE MEMBER



From Moore (1967)

FIG. 14

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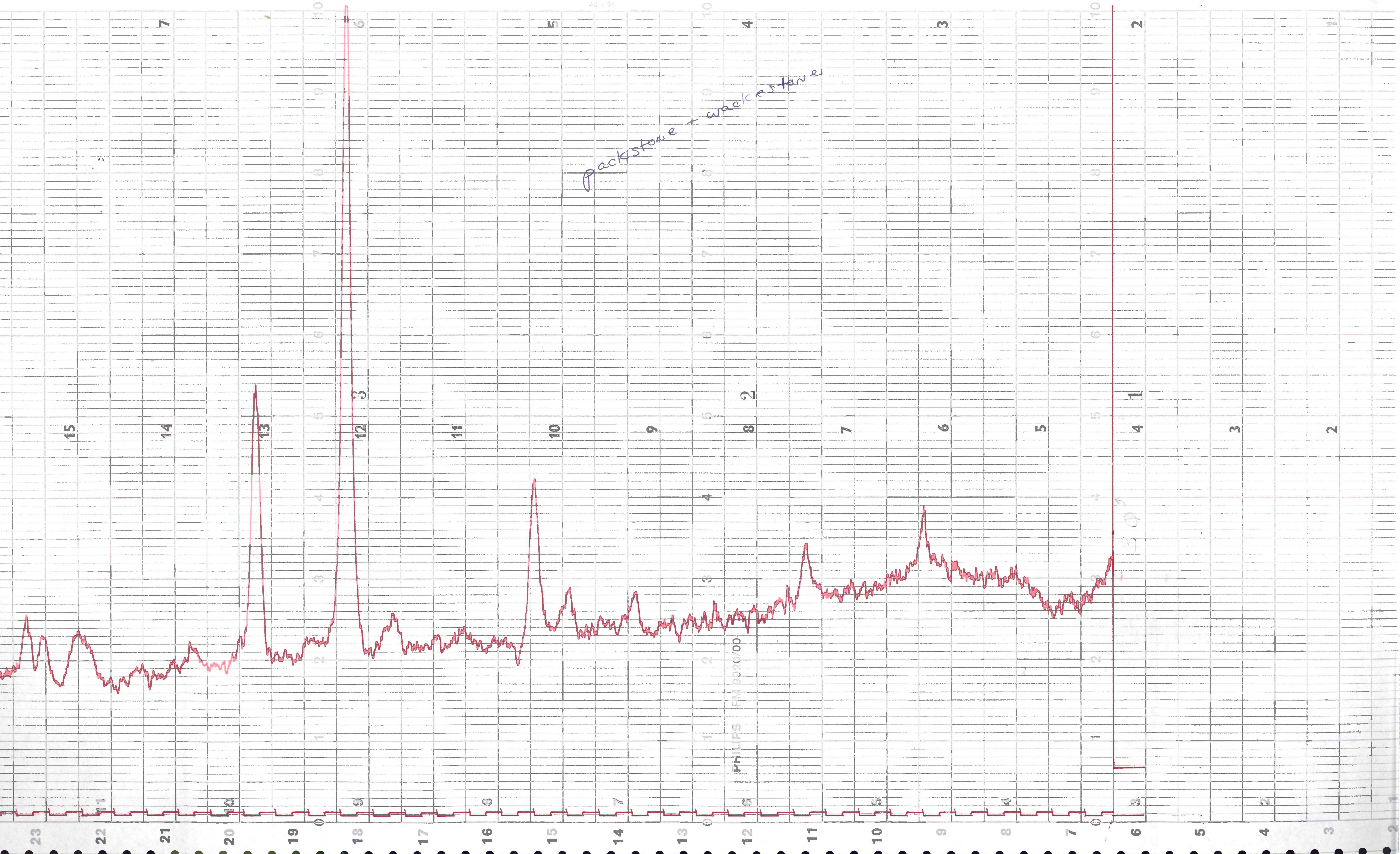
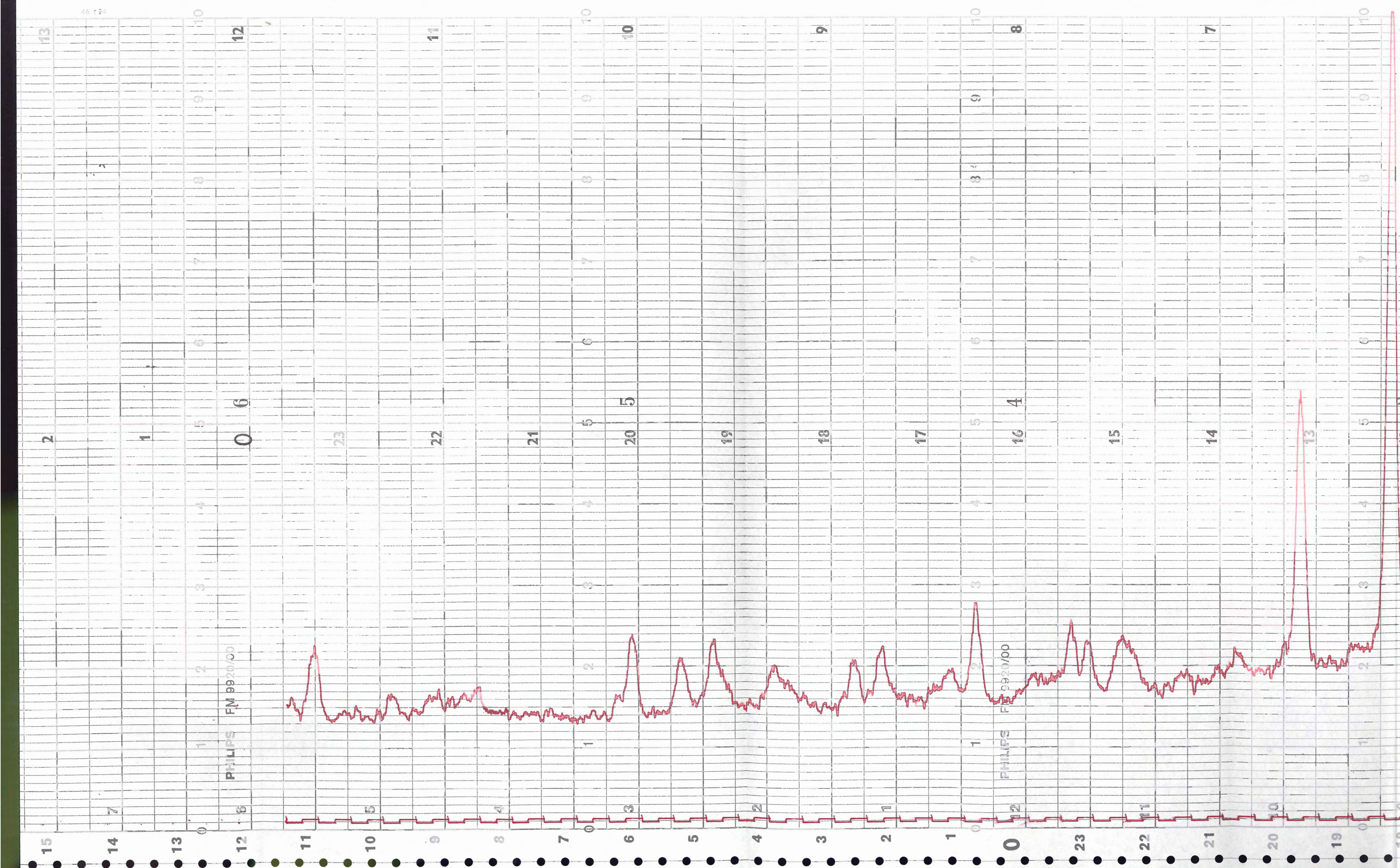
APPENDIX

The non-carbonate portion of the calcareous siltstone and wackestone-packstone units was mineralogically evaluated by X-Ray Diffraction. The results are attached to this page. Both units are basicly composed of quartz and muscovite with quartz being the dominant mineral in both case.

The gross percentage of silt within each of the unit was evaluated at this time, by dissolving the carbonate fraction, this indicated that both units are composed of 50% plus terrigenous silt.



packstone + wackestone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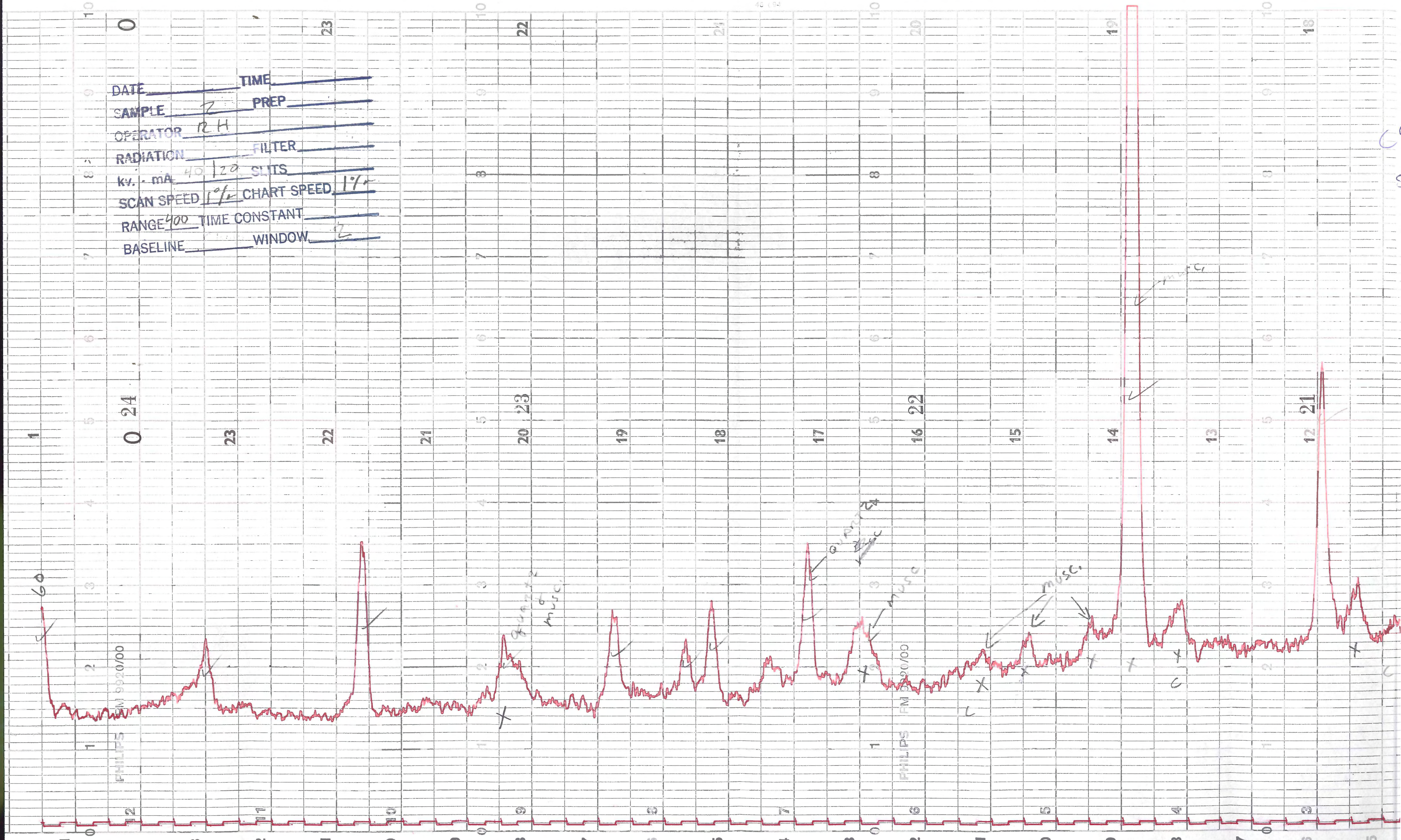

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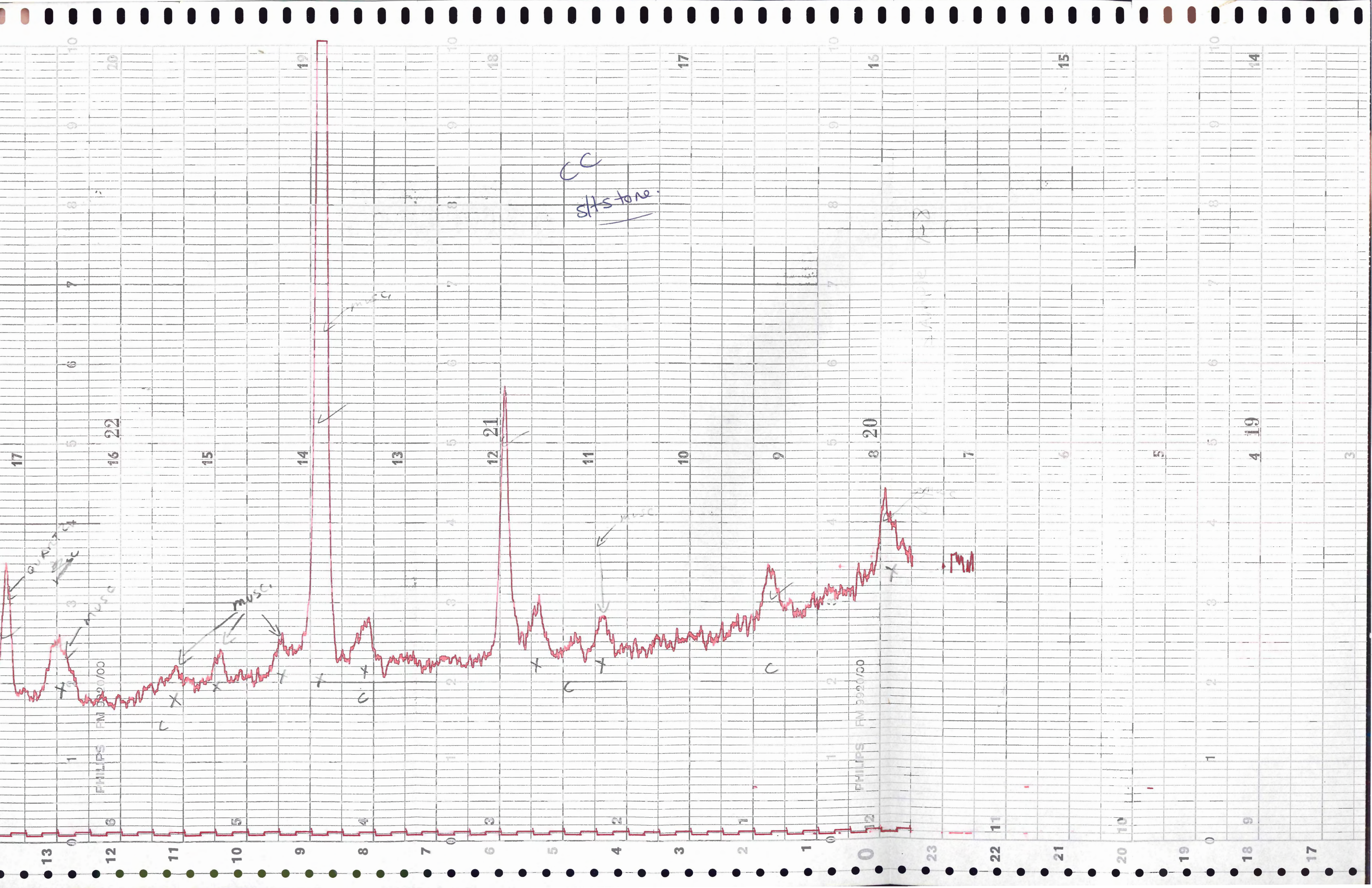
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