AN INTERPRETATION OF THE CARBONATE GEOLOGY EXPOSED IN THE DECLINE AT GAYS RIVER, NOVA SCOTIA

by

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Submitted in partial fulfilment of the requirement for the degree of Master of Science at Dalhousie University, Halifax, Nova Scotia, August 14, 1978.

DALHOUSIE UNIVERSITY

Date **September 25, 1978**

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Title **An Interpretation of the Carbonate Geology Exposed in the Decline at Gays River, Nova Scotia**

Department or School **Geology**

Degree **M.Sc.** Convocation **Fall** Year **1978**

Signature of Author

Abstract

The Windsor Group (Visean) carbonates at Gays River lie unconformably upon a NE trending anticlinal high of Cambro-Ordivician metagreywackes belonging to the Goldenville Formation. The distribution of carbonates sediments is affected by minor relief features found on the anticline which take the form of N-NW trending, 90 meter high spurs with associated re-entrants. These spurs are steep-sloped, and stepped as a result of strongly-developed intersecting joint sets (087/47N, 150/70W).

Physical weathering, prior to carbonate deposition, produced a scree deposit of basement material. The scree has a discontinuous distribution with wedge-shaped accumulations (3m) located at the foot of the spurs, in the re-entrants, and on the basement steps. During initial transgression of the Windsorian sea, the scree was partially reworked and a carbonate matrix was added. The resulting deposit is termed the basal conglomerate.

Carbonate rock types present in the decline can be divided into two lithologic groups. The first group represents a flank deposit derived from the second group of rocks. This flank deposit overlies the basal conglomerate and/or the basement in the re-entrants, The flank deposit consist of a wedge or fan of thinly-bedded lithic skeletal grainstones which are interstratified with thin back carbonaceous laminae. The wedge dips basinward (N-NW) at 25 to 30 degrees. Gypsiferous, peloidal wackestone discontinuously overlies the lithic skeletal grainstones. In turn, the wackestone is overlain by more than 50 meters of anhydrite and gypsum.

Group two rock types consist of algal bindstone and bafflestone, lithic skeletal grainstones and packstones, and algal fenestral wackestone-packstone. In addition, a calcrete profile is present. The rocks of group two are located higher up the basement slope than those of group one. The algal bindstone, algal bafflestones, lithic skeletal grainstones and packstones represent a algal dominated, wave-resistant, organic-framework reef (as defined by Heckel, 1974). The algal fenestral wackestone-packstone records a restricted, shallow-water, lagoonal deposit; which is both adjacent to, and overlying the bindstone and bafflestone rock types. A thin zone of low-middle intertidal sediment is present near the top of wackestone-packstone. This zone exhibits an irregular fenestral fabric. The calcrete profile indicated the presence of an unconformity and subaerial exposure within the depositional history of the carbonates.

Lithologic relations within and among group two rocks are very complex. Lithostratigraphic, let alone chronostratigraphic, correlation of the carbonate units using drill core from adjacent holes (60m spacing) is not possible on the scale used while mapping underground (1cm = 25cm).

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INTRODUCTION

From 1972 through 1977 Imperial Oil Limited and Cuvier Mines Limited conducted exploration on a carbonate-hosted lead and zinc deposit found at Gays River, Nova Scotia. Gays River is located approximately sixty-five kilometers northeast of the city of Halifax, and nine kilometers southeast of the village of Shubenacadie (Fig. 1).

The exploration effort made available a large amount of material for geologic study. The material includes more than forty-five kilometers of diamond drill core taken from over six hundred holes. In addition, an exploration decline(3.5 by 5.5m) driven in 1976 exposed more than six hundred and seventy meters of continuous outcrop for detailed geologic study.

PURPOSE AND SCOPE

This study has a twofold purpose: 1) to define and interpret the carbonate rock types exposed in the decline; 2) to attempt to correlate between drill holes using control from decline mapping.

Excavation of the decline furnished this writer with invaluable familiarity of the geology as it became exposed. This knowledge caused the scope of the present work to restricted to the

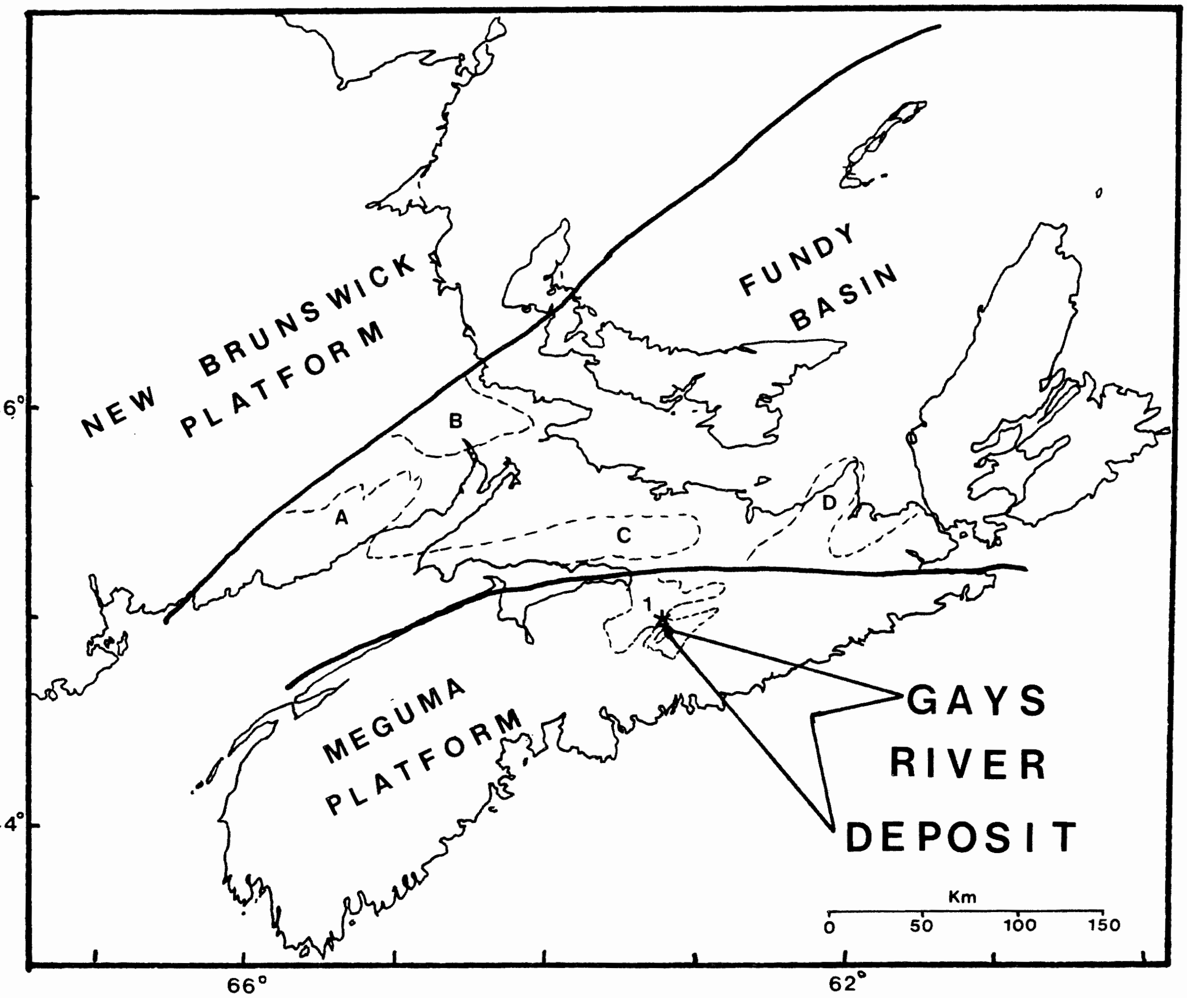


Fig. 1 : Location map showing study area and largest tectonic elements. Small letters indicate horsts, numbers indicate basins.

decline area. Reasons for this restriction were : 1) complex lithologic inter-relationships necessitated a small study area becaues of time limits; 2) the decline offered continuous exposure both vertically and horizontally which is unobtainable from drill core; 3) a facies study based solely on data from drill core would have been hazardous because of errors inherent in core processing and the rapidity of lateral change on lithosomes.

The second aspect of this study-- correlation between drill holes-- had a better chance of legitimate sucess in the decline area. In the decline Imperial drilled a series of vertical ,assessment holes spaced at 15 meter intervals. Core from these closely spaced holes afforded greater control for correlation than that offered by core taken solely from surface-drilled holes. This is because the surface-drilled holes have an average spacing of 60 meters.

The format of this study is set up so that a description of the rock types found at Gays River is first presented. A depositional model is formulated to fit these rock types followed by a depositional history and a brief diagenetic history.

METHODS

From experience gained while mapping underground during the period July to September 1976 while in the employ of Imperial Oil, the present writer chose three map areas within the decline which he believes represent the conspicuous lithologic relations observed in the decline. The areas were mapped at a scale of 1cm= 25cm and in all three map areas , orientated samples were collected from each recognized lithology. More than 130 samples were collected and processed for study.

The samples were first sawn to hand-specimen size and then polished. The polished specimens were used to describe the rock types. Thin sections were used when additional microscopic data were required. Most specimens were etched in dilute (10%) hydrochloric acid and stained with Alizarin Red S solution to determine the distribution of calcite and dolomite.

In map areas one and three, diamond drill holes are located within or near the map confines. Holes UGR5,UGR-51, UGR-52, UGR-53 are in map area one; holes GR-543 and GR-542 are near map area three. Core from these was described. Using data from core samples and the map of the decline side in the respective map area , correlation of the unexposed geology between the drill holes was attempted. The diamond drill cores used are spaced approximately fifteen meters apart and give the best possible control from drilling at Gays River.

CLIMATIC SETTING

On paleomagnetic evidence, Irving (1964, p. 207), and Roy and Robertson (1968) place the Fundy Basin within 10°S latitude and moving northward during the Windsorian Stage. The regional setting was therefore, equatorial and midcontinental. The lack of preserved terrestrial vegetation (Schenk, 1969, p. 1069); and association of algal stromatolites, evaporites and red beds imply that a generally hot and arid climate existed during Windsorian time (Bell, 1929, p. 55; Schenk, 1969, p. 1060; and Howie and Barss, 1975, p. 42). A possible modern setting, analgous to the Windsor might be the hot and arid southeast side of the Persian Gulf.

PREVIOUS WORK

MacEachern and Hannon (1974) concluded that the Gays River lead and zinc deposit was hosted in a dolomitic reefal complex. The authors believed a chain of islands, straddled by the reefal complex separated two Carboniferous sub-basins. To the southeast lay the Musquodoboit sub-basin, to the northwest, the Shubenacadie sub-basin. Low hills formed of Meguma Group metasediments surrounded both basins. Thick accumulations of anhydrite and gypsum border both sides of the reef complex and relations between the carbonate and evaporites are unclear.

Using geometric and paleontologic criteria, MacEachern and Hannon divided the reefal complex into four physiographic zones: forereef, reef crest, reef proper and back reef. Each zone is distinguished by a unique lithology. These zones contain four lithologies: 1) recrystallized micritic dolomite (carbonate grains less than 4 microns across); 2) micritic skeletal dolomite-brachiopod shell horizons; 3) coral bearing dolomite; and 4) algal dolomite originally composed of nodular, calcareous algal mats. The authors suggest that much of the micritic dolomite present may have been originally algal in nature. They believe that dolomitization has erased the original algal fabric.

MacLeod (1975) studied the diagenetic changes in core taken from three surface holes, along a single line and spaced at approximately 60 m intervals. These holes are approximately one kilometre to the southwest of the exploration decline. He divided the diagenetic history into four sections: 1) preburial, 2) very early burial, 3) early burial, and 4) post zinc and lead mineralization.

Diagenetic events recognized by MacLeod within each of the four sections are listed below though no time sequence is implied.

Section	Event
1. Preburial	a) fragmentation of grains
	b) growth of blue-green algae
	c) micritization
	d) algal-foraminifera encrustation.
2. Very early burial	a) early cementation

	b) formation of geopetal structures
	c) pustular algal mat development
	d) lithification of algal bound sediment
	e) desiccation fracturing.
3. Early burial	a) internal sedimentation in lithified layers
	b) dissolution of aragonite
	c) compaction
	d) precipitation of iron sulfide
	e) evaporite related dolomitization
	f) lead and zinc mineralization.
4. Post lead/zinc mineralization	a) phreatic diagenesis
	b) vadose sedimentation which secondarily concentrated economic sulfides
	c) fracturing
	d) styolitization
	e) pore filling by precipitation of allochthonous calcite
	f) dedolomitization.

MacLeod believes that the Gays River carbonates record subtidal to supratidal conditions which resulted from a single marine transgression-regression cycle. He envisages these conditions within a tidal-flat carbonate bank model accompanied by localized, wave-resistant structures.

Hartling (1977), working on core from three holes with the same 60 m spacing and adjacent to MacLeod's, recognized four stratigraphic units within the carbonates. In stratigraphic order the units are from top to bottom:

Cap Unit	- skeletal wackestone
Fenestral Unit	- fenestral-algal boundstone
Algal-Skeletal Unit	- wackestone and boundstone
Basal Siliceous Unit	- reworked talus with more than 15% siliceous material.

Hartling inferred that during transgression, a mudmound buildup, was located within a small, semi-restricted bay. He believes the buildup formed by the coalescence of smaller mud mounds created by baffling organisms. Eventually, the buildup grew into the intertidal zone which resulted in the formation of a tidal flat sequence, complete with supratidal beach ridges.

In the same work area as MacLeod and Hartling, Osborne (1977) examined core from another three, 60 m-spaced surface holes. Osborne identified eight lithologic microfacies and six biofacies assemblage zones. He concurred with MacLeod that the carbonates were deposited during a single transgression. All three workers: MacLeod, Hartling, and Osborne agreed that the carbonates represented deposition in a protected tidal flat environment. As a modern analogue, Osborne proposed the Holocene growth of Rodriquez Bank, a mud bank situated in the Florida reef tract (Turmel and Swanson, 1976).

Boehner (1977) in a study on the Lower Carboniferous stratigraphy in the Musquodoboit Valley describes the Gays River Formation (new name). Boehner ascribed three lithofacies to the Gays River Formation: 1) a thick Bank facies - the carbonates at Gays River comprise one of the largest preserved of ten recognized Bank facies which are peripheral to the Musquodoboit Valley, 2) a thinner Interbank facies, and 3) a basal siliclastic conglomerate which has a carbonate matrix.

Boehner characterizes the Bank facies as a massive to thickly bedded, highly fossiliferous deposit ranging up to 60 metres thick. The author (Boehner) notes lithologic variation within the Bank facies but concludes that this variation is governed by biofacies. Three biofacies are recognized: 1) coral, 2) bryozoan, 3) shelly.

Fauna found in the Bank facies include: several smooth shelled brachiopods, especially Beecheria; the gastropods, Zygopleura and Murchisonia among others; a single tabulate coral Cladochonus; the bryozoa genera Fenestrella and Batostomella; and assorted small pelecypods including Aviculopecten. In addition, Boehner cites the presence of the green dasycladean algae Koninckopora within the Bank facies. In his study, Boehner concludes that the Bank facies implies deeper water, at the time of deposition, than does its stratigraphic equivalent, the Macumber Formation.
Schenk (1967a) interpreted the Macumber lithology as a diachronous, algal carbonate strandline deposit which formed in protected bays. He argued that thick highly fossiliferous carbonates occur

routinely over basement highs where life conditions were better.

ACKNOWLEDGMENTS

I wish to thank the Imperial Oil employees for the opportunity to study the rocks at Gays River,and for the assistance and cooperation given to me. I especially thank Pat Hannon. Also, Dr. Paul Shenk who proposed many helpful and stimulating suggestions and who generously supported this study. Thanks to Dr. Lubomir Jansa and Dr. Peter Giles for critically reading the manuscript. I would also like to thank Dr. Marcos Zentilli for his encouragement and the graduate students of the "penthouse" for thoughtful discussion. Thanks to my wife, RoseMarie, for her patience,understanding and drafting assistance.

CHAPTER II TECTONIC SETTING AND BASEMENT CONFIGURATION

In Eastern Canada, the tectonic activity which followed the Early Devonian, Acadian Orogeny produced a complex horst and graben system termed the Fundy Basin (Bell, 1958; Belt, 1954; Howie and Cumming, 1963; Howie and Barss, 1975; and Schenk, 1967). This "rift" system may have resulted from shearing as North America and Africa collided tangentially, culminating at our latitude in the Late Carboniferous Maritime Disturbance (Schenk, 1975). The system trended northeasterly extending at least from the Gulf of Maine to western Newfoundland, and consisted of very deep basins and intervening horsts. Older, stable platforms bordered both sides of the "rift" system, the New Brunswick Platform lay to the north-east and the Meguma Platform to the south (Fig. 1).

Deposition from Late Devonian through Late Triassic filled the Fundy Basin with locally more than 9100 meters of pre-dominantly continental sediment (Howie and Barss, 1975); as well, relatively thin deposits formed on the platforms. During Mid-Carboniferous at least a dozen inundations of marine water, from a closing midcontinental sea to the south,produced repeated cycles of carbonate, sulfate, and siliclastic redbeds (Bell, 1958). Perhaps during the first of these floodings, the carbonates at Gays River were deposited nonconformibly upon the stable Meguma platform approximately 30 km south of the Fundy Basin-Meguma Platform margin (fig. 1).

Basement Structure

The northwest limb of an anticline, formed in the Goldenville Formation of the Meguma Group, functions as basement for the carbonates examined in this study. This anticline resulted from folding of the Meguma Group into a northeast trending arc by the Devonian Acadian Orogeny (Poole, 1967; Poole et al.,1970). The arc stretches across most of mainland Nova Scotia and within it , folds tend to be tight to open,upright,low plunging and generally persistent features (Fyson, 1966). Individual folds may be 150 km long and 15 km wide. A marked regional cleavage parallels the structural trend.

Within the study area, weathering before carbonate deposition, produced minor relief features on the basement rocks. These features take the form of irregularly spaced spurs which trend north to northwest and project into the Shubenacadie-Stewiacke basin. They are very apparent when one studies the structure contours for the unconformity surface (Fig. 2). The spurs range up to 90 m in height and are a maximun of 250m from crest to crest. Slopes on these spurs are joint controlled and attain as much as 70 degrees over short distances with 40 degree slopes common.

A strongly developed, intersecting joint system cuts the basement rocks (Fig. 3). The sets 087/47 N and 150/70W are most strongly developed; weaker sets are 130/25W and 080/20S. Weathering along these joint, before and during carbonate deposition, produced

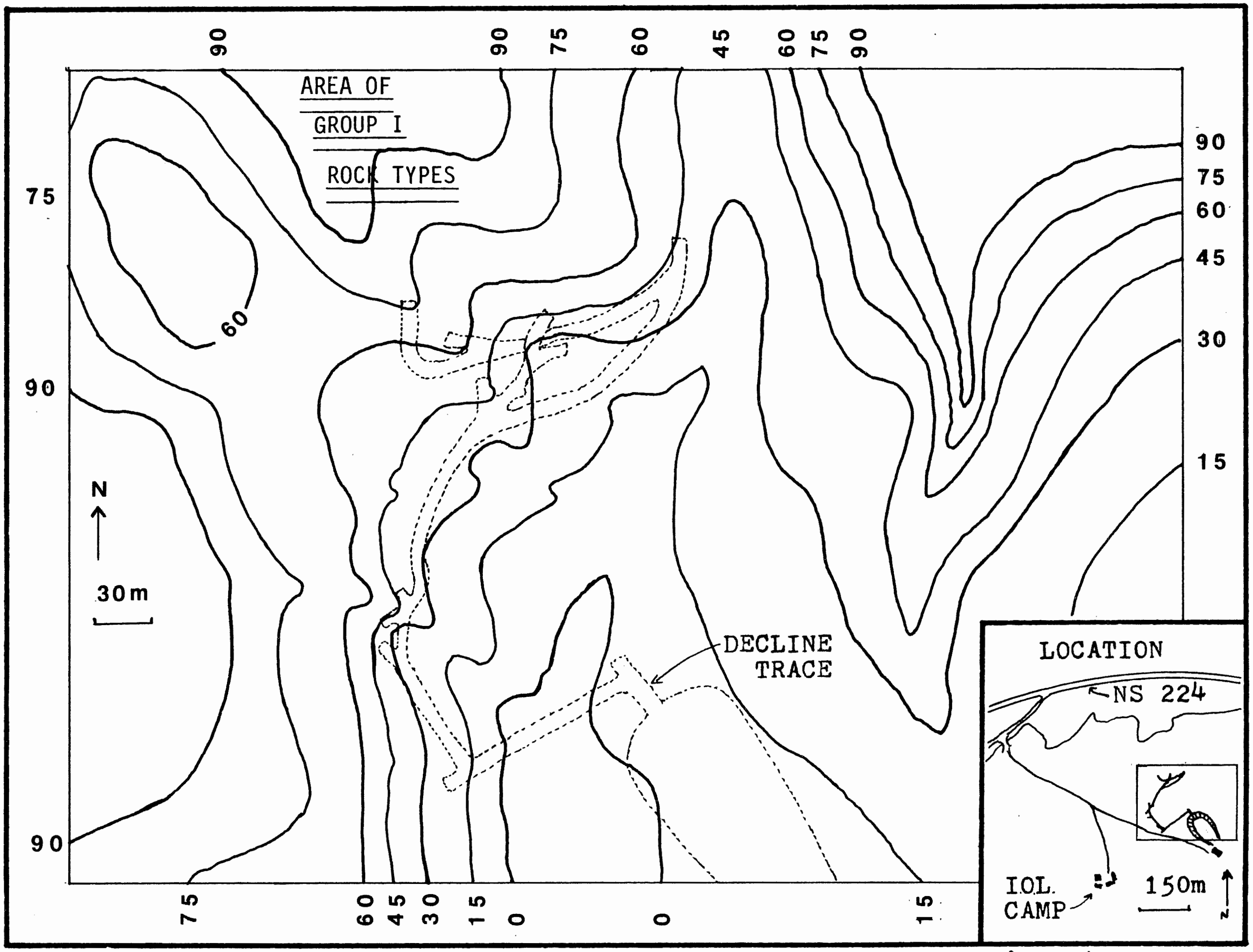


Fig. 2: Structure contour map for top of basement, contours are in metres.

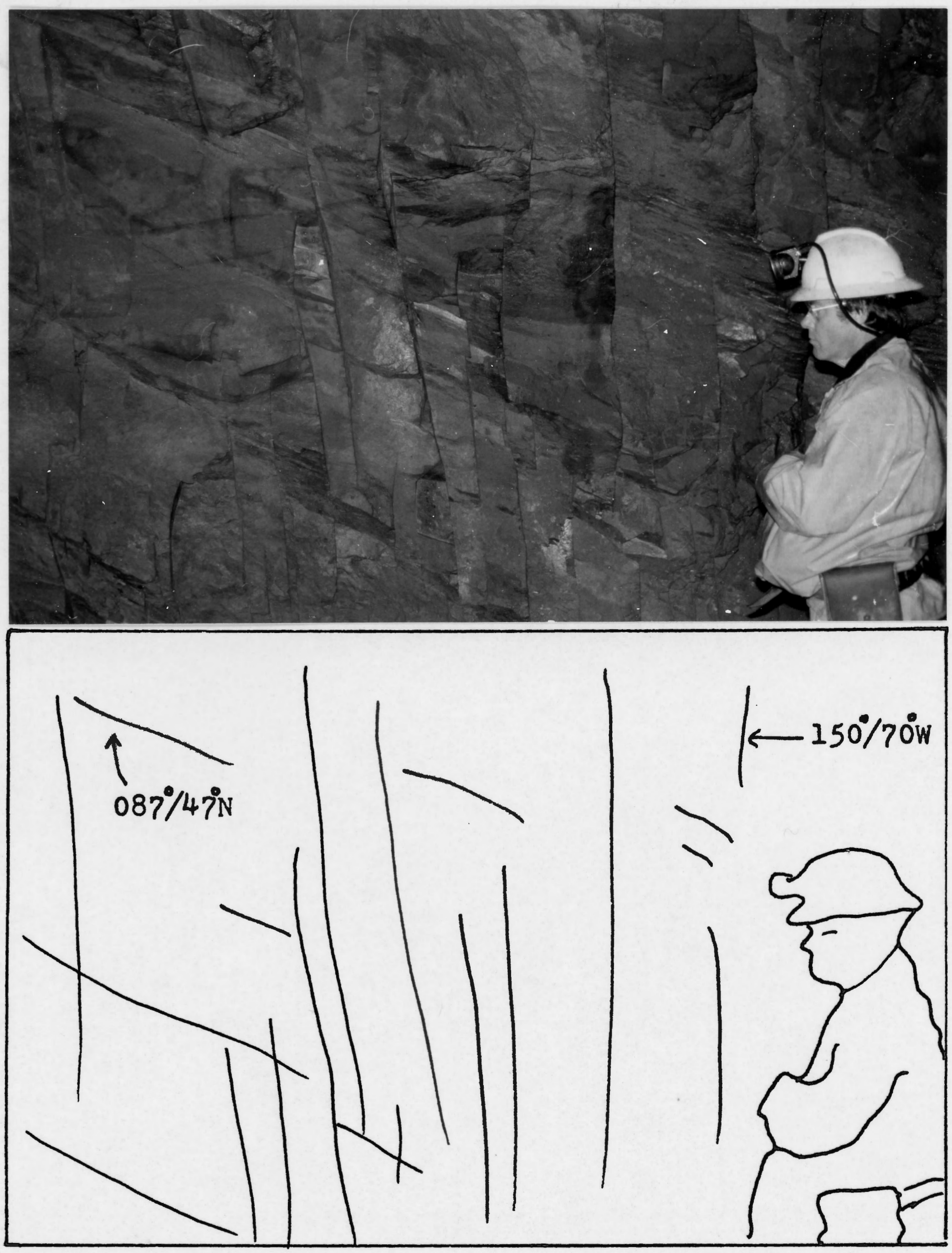


Fig. 3 . Strongly-developed intersecting joint system within basement rock. Blocks of basement rock present in the carbonate lithotypes have shapes which are a function of these intersecting joints.

blocks of basement up to two meters long in outcrop (Fig. 4). Discussion of these clasts is reserved to the section on lithologic description. As a result of the joint system, the slopes on the basement spurs are not uniform but are notched or stepped.

One basement step, exposed in the decline near map area one, is a minimum of six meters high as indicated in core from UGR-53 (Fig. 5). The rising part of this step is very steep (70) because it is formed by the joint plane striking 150 which dips 70W. Eighteen meters to the west, hole 197 penetrates basement 18 meters below the basement elevation in the decline as shown in figure 5. Along the same westward line, 60 meters west of hole 197,hole 367 intersects basement 53 meters deeper still.

In summary, the spurs developed in the basement rocks have slopes which are steep and stepped. The joint set striking 150 and dipping 70 west controls the steepness of slopes formed in an approximate north-south trend; the joint set striking 087 and dipping 47 north controls the steepness of slopes formed in an approximate east-west trend. As a result, north-south trending slopes are steeper.

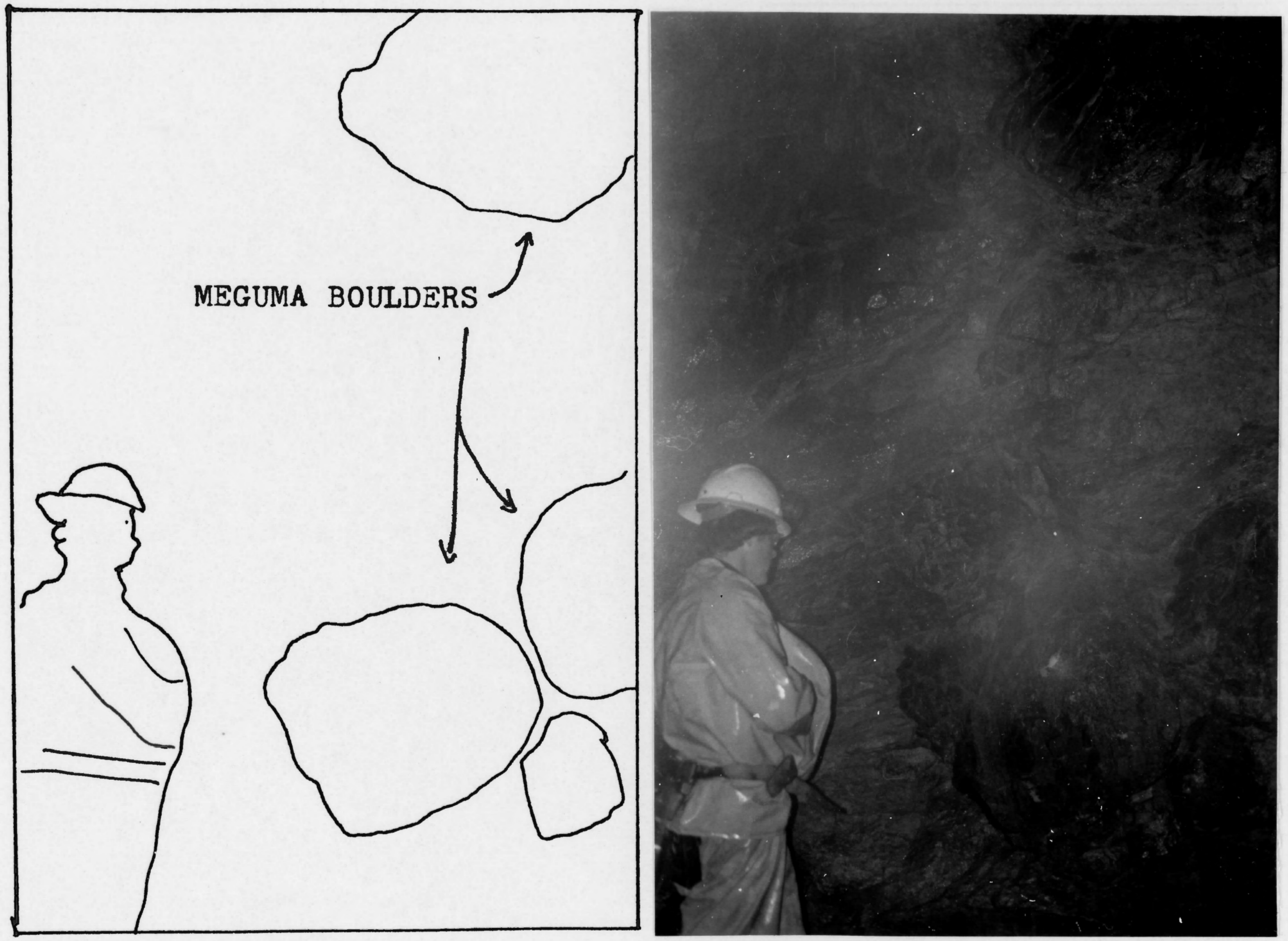


Fig. 4: Boulders of Meguma within a skeletal grainstone.

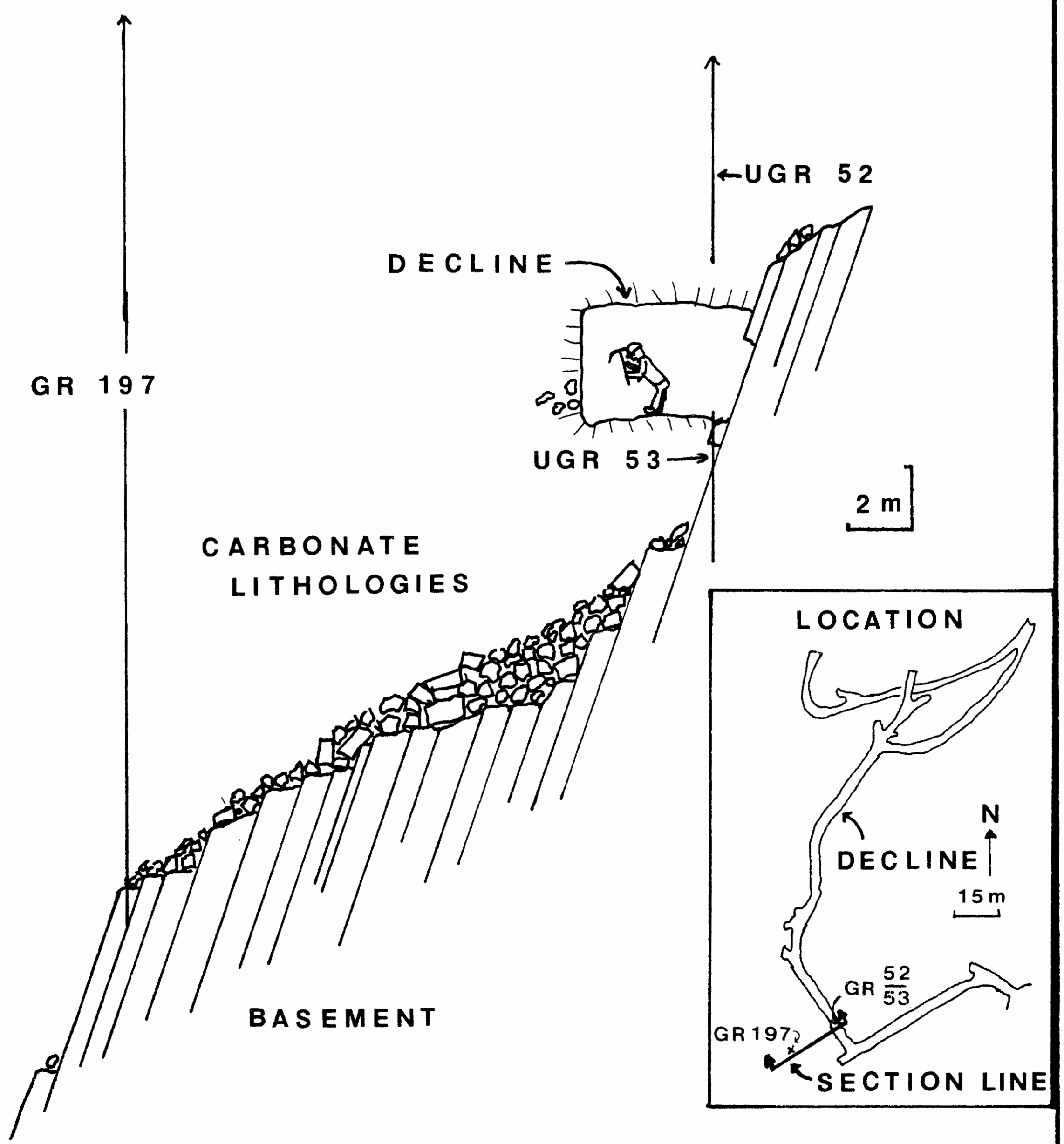


Fig. 5.: Diagram illustrating the slope of the basement rock. Note accumulations of conglomerate.

CHAPTER III STRATIGRAPHIC SETTING OF GAYS RIVER CARBONATES

The Gays River carbonates form part of the Middle Carboniferous Windsor Group. The Windsor Group is described as a succession of cyclic marine carbonates and evaporites within red, non-marine terrigenous deposits (Schenk, 1969). The type section for the Windsor Group described by Bell (1929) is more than 470 metres thick, although Howie and Barss (1975) report thicknesses in excess of 6,000 metres within the Fundy Basin (Fig. 2).

Bell (1929) initially divided the Windsor Group sediments into two faunal zones, and later established five subzones based upon macrofauna observed in the carbonates. These subzones he designated A, B, C, D, E, in ascending stratigraphic order. Later, Bell (1958) recognized a sixth subzone and designated it the F. Bell (1929) assigned a Middle to Late Visean age to the Windsor Group; however, Mamet (1970) working with foraminifera assemblages, proposed a Late Visean to Early Namurian age for the Windsor Group.

Based upon macrofauna present, the carbonates at Gays River should be placed within Bell's B subzone. This is because the carbonates contain such fossils as: the pelecypod *Aviculopectin*, the gastropods *Murchisonia* and *Zygopleura* and the bryozoa *Fenestella lyelli* and *Batostomella*; all of these Bell (1928, p. 66-67) restricted to the B subzone. In contrast, the A subzone is basically unfossiliferous, according to Bell; for he assigned only two fossil forms to the A: The worm *Conularia tenuis* and the pelecypod *Schizodus cheverions*. However, more recently, Giles and Ryan (1976) note that the initial marine Windsor deposits are lithologically variable, consist of limestones and dolostones, are variably fossiliferous and range in thickness from a metre to 60 m. Furthermore, Giles and Ryan observe that the maximum thicknesses are preserved in carbonate banks where the Windsor Group onlaps the Horton Bluff Formation to lie directly upon pre-Carboniferous rocks of the Meguma Group (Cambro-Ordivician). Drilling on the southeast and northwest flanks of the Gays River deposit indicates that the deposit is overlain by several hundred feet of anhydrite and gypsum which Giles and Ryan, and the present author believe to be the thick "basal anhydrite" of the A subzone. Thus, on lithologic grounds the Gays River carbonates belong to the A subzone of Bell and are a facies equivalent of the nearby Macumber or Ribbon Limestone. Stratigraphic relations within the Windsor Group are still unclear and if faunal assemblages are used as a basis for stratigraphic division and correlation then relations may never become clear. Indeed, as Schenk (1969, p. 1039) notes, rapid changes in environments affected the distribution of fauna in the Windsor; and, that the fauna were perhaps, more strongly controlled by environment than by evolution as in the case of modern forms.

The reader is referred to work by: Belt (1964), Boehner and Giles (1976), Giles (1977), Kelley (1967), Schenk (1969), Stacy (1963), and Stevenson (1959) for a more complete discussion of Windsor Group stratigraphy.

CHAPTER IV LITHOLOGY

Nomenclature

Dunham's (1962) textural classification for carbonate rocks, revised by Embry and Klovan (1971) is the standard terminology used to describe rock types throughout this thesis.

Briefly, Dunham based his classification on whether the rocks were autochthonous or allochthonous in nature, and if the sediment was organically bound or not during deposition. If not organically bound, were those clasts larger than 0.03mm in grain support , or were they supported by a mud matrix? A grain supported rock containing no mud is called a grainstone.

A packstone corresponds to the rock type which exhibits original grain support but has a mud matrix. Matrix supported rocks are termed mudstones if there are less than ten percent grains present, and wackestone if there are more than ten percent grains. If evidence of organic binding during deposition is present, Dunham termed the resulting rock a boundstone.

Embry and Klovan (1971) expanded Dunham's original classification in two areas (Fig. 6). First, the authors thought there was a lack of grainsize differentiation in Dunham's classification. Dunham distinguished two grainsize categories-- mud (less than 0.03 mm), and grains (greater than 0.03 mm). Akin to terrigenous clastic classifications,Embry and Klovan proposed three size divisions-- mud (less than 0.03 mm), grains (0.03 to

<table>
<tr><td colspan="4">ALLOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS NOT ORGANICALLY BOUND DURING DEPOSITION</td><td colspan="3">AUTOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS ORGANICALLY BOUND DURING DEPOSITION</td></tr>
<tr><td colspan="4"></td><td rowspan="4">BY ORGANISMS WHICH ACT AS BAFFLES</td><td rowspan="4">BY ORGANISMS WHICH ENCRUST AND BIND</td><td rowspan="4">BY ORGANISMS WHICH BUILD A RIGID FRAMEWORK</td></tr>
<tr><td colspan="3">CONTAINS LIME MUD (<.03 mm)</td><td>NO LIME MUD</td></tr>
<tr><td colspan="2">MUD SUPPORTED</td><td colspan="2" rowspan="2">GRAIN SUPPORTED</td></tr>
<tr><td>LESS THAN 10% GRAINS (>.03mm)</td><td>GREATER THAN 10% GRAINS</td></tr>
<tr><td>MUD-STONE</td><td>WACKE-STONE</td><td>PACK-STONE</td><td>GRAIN-STONE</td><td>BAFFLE-STONE</td><td>BIND-STONE</td><td>FRAME-STONE</td></tr>
</table>

Fig. 6: Classification of carbonate rocks.
(after Dunham, 1962; modified by Embry and Klovan, 1971, and further modified by the present writer.)

2.0 mm), and a new division of grains larger than 2.0 mm. The new division results in two additional rock types: 1) floatstone, a matrix supported rock containing more than ten percent grains which are larger than 2.0 mm; and 2) rudstone, a grain supported rock containing more than ten percent grains greater than two millimeters.

I object to these two new rock types. Most carbonate rocks containing more than ten percent skeletal grains (gastropods, pelecypods, coral,etc.) will generally fall within these two new categories. The result will be a loss of information concerning the depositional environment now implied by the term packstone. A grainsize descriptor can be prefixed to Dunham's four categories making the terms floatstone and rudstone unnecessary.

Embry and Klovan felt it was necessary to convey the nature of binding found within boundstones. There are three fundamental ways to organically bind sediment: 1) construct a rigid framework; 2) encrust and bind the sediment; 3) baffle the sediment (Klement, 1967). Therefore, Embry and Klovan named three rock types -- framestone,bindstone, and bafflestone respectively, to replace Dunham's boundstone class. These three new rock types are used when the nature of sediment binding is evident. The original term, "boundstone " , is retained when the nature of binding is not evident. For example, the nature of binding may be obliterated in rocks which have undergone extensive diagenesis, in such cases, although organic binding is evident its exact nature is not apparent and the rock is therefore termed a boundstone.

Rock Type Descriptions

The carbonate rocks exposed in the decline can be divided into two main groups. The two groups have diverse textures and compositions reflecting different depositional environments.

Group One Rock Types

These rock types were deposited in a re-entrant, between two basement spurs, where the basement slope decreases (Fig. 2). The three carbonate rock types are overlain by a thick evaporite sequrnce (50 m) which is part of the basin filling "basal anhydrite" described by Boehner and Giles (1976). Only the lower two rock types are well exposed in the decline. The third rock type, which overlies the other two, immediately passes into evaporite . The third rock type can be observed only in areas where rock overbreak has formed cavities in the roof of the decline.

The three rock types of the first group are termed: 1) basal conglomerate; 2) carbonaceous, skeletal grainstone; and 3) gypsiferous, peloidal wackestone.

Basal Conglomerate

The term basal conglomerate is used in place of lithic rudstone because of the character of the rock. This rock is an oligomictic orthoconglomerate (Pettijohn, 1958, p. 256) because it contains an intact framework of simple composition and has a mineral cement. The clasts are quartz metawacke from the underlying basement, the matrix is composed of carbonate or silica with minor amounts of lead and zinc sulfides.

The conglomerate rests directly upon the Meguma basement, although clasts of basement material are abundant within the overlying carbonates. The conglomerate is thickest within inter-spur re-entrants and thins up the spur slopes. However, thick wedges (2 m) may be encountered upon the basement steps. The conglomerate attains a maximum thickness of roughly three metres but averages approximately one metre.

The clasts range in size from pebbles to boulders greater than two metres. They tend to be poorly sorted as to size and shape. Shapes range from very round discs to sub-angular blocks, with the blocks dominating. With respect to roundness they grade from subangular to very rounded. Smaller clasts (<20 mm) tend to be more angular than larger clasts. The clasts are block-shaped in outcrop and reflect a joint controlled origin.

Map 3 (Fig. 43) shows that the conglomerate is graded. This grading appears to be a result of reworking during transgression of the Windsorian Sea. The coarser, lower section of conglomerate has a very siliceous matrix. In contrast, the upper section has a carbonate rich matrix and a smaller average clast size. Upper conglomerate matrix consists of sand-sized, fragmented skeletal material, silt to pebble sized siliceous rock fragments, and disseminated sphalerite and galena.

Carbonaceous Skeletal Grainstone

This is the dominant rock type in map area three, and consists of thin beds of skeletal grainstone alternating with carbonaceous laminae. Beds are thin, uniform, and continuous in decline exposure. They range in thickness from 6 mm to 100 mm and dip basinward (NW) at an angle of 25 degrees. Infrequently, the beds exhibit indistinct normal grading as to grainsize (Fig. 7). The grainstones, like the conglomerate, occur within basement re-entrants and are thickest where the basement grade flattens abruptly. The grainstones thin rapidly away from the basement highs in a wedge-like manner and in map area three the grainstone lithology has a maximum thickness of five metres. The grainstones overlie the conglomerate with an irregular to sharp contact (Fig. 43).

Compositionally the grainstones may vary from one bed to the next. Fragments of one skeletal type will dominate a particular bed but may be replaced by a different type in the next bed. In decreasing order of abundance, fragments of: algae, gastropods, bivalves, bryozoa, ostracods, and coral compose the skeletal graintypes present in the grainstones. Blocks of lithified carbonate, peloids, and Meguma fragments are locally abundant. Skeletal fragments are small with blocks of lithified carbonate and Meguma fragments generally very much larger.

All skeletal grains appear to be small-sized and fragmented. Algal fragments occur as small irregular lump-like particles devoid of internal structure. They range up to seven mm long but average close to two mm. Gastropods occur as whole shells and as recognizable fragments. They are, on average, the

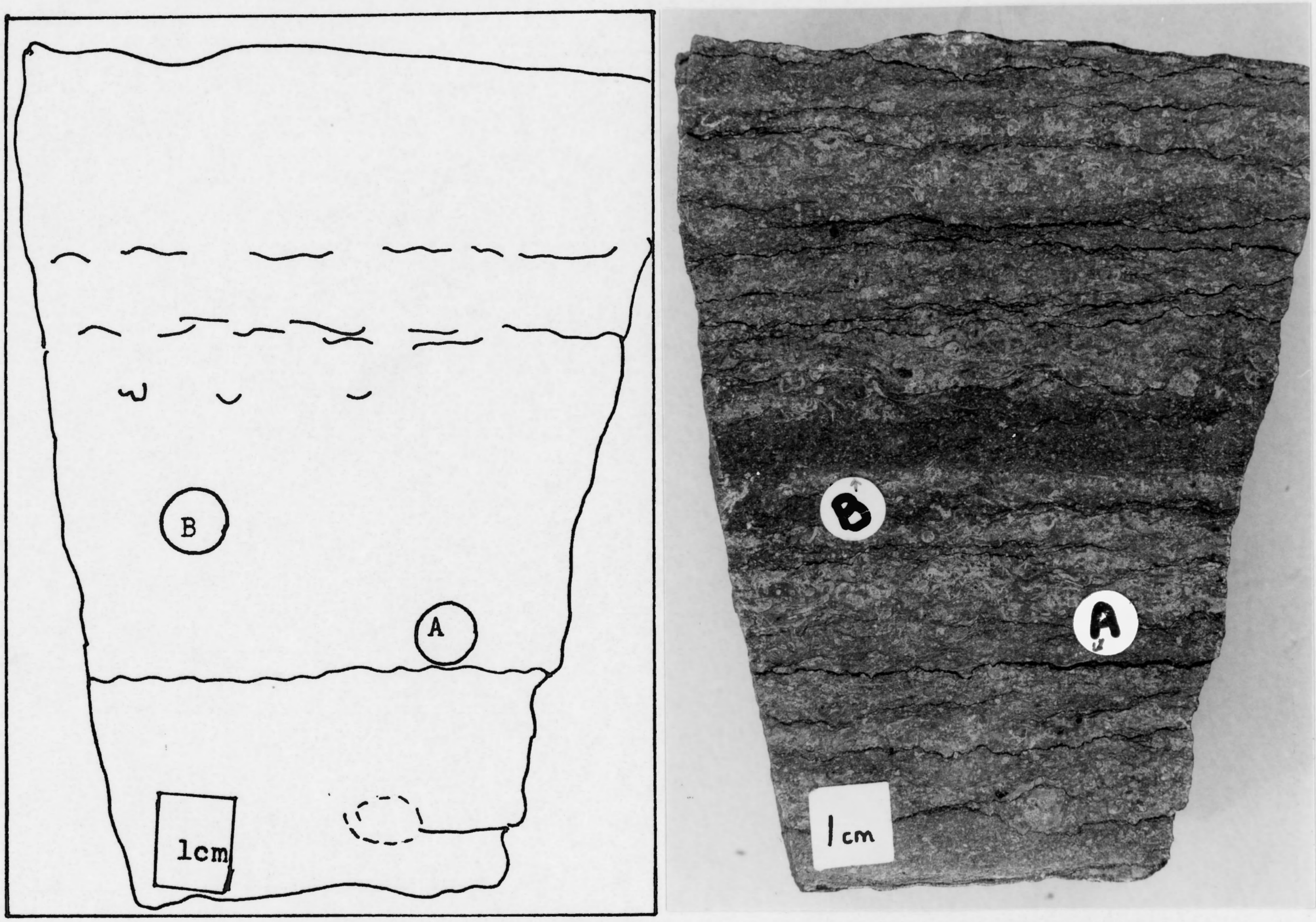


Fig. 7: Carbonaceous skeletal grainstone, note stringers of carbonaceous material (A) and, stratification (B).

largest skeletal grain type present, even though they never exceed five millimeters in cross section. They appear as little round "eyes" filled by sphalerite and galena. Bivalves are represented by small, thin, single-valve fragments. This writer could not determine whether they were brachipods or pelecypods. The valve fragments are less than 0.5 mm thick and are less than a centimeter long. Bryozoa, ostracods and coral are minor constituents. They are always present as small fragments except the ostracods which often occur as whole carapaces. Among bryozoa, ramose forms are most common; fenestrate types are rare. No crinoid fragments are present.

Meguma fragments are quite common (up to 10%). They range from silt to clasts 90 cm in diameter (see Map 3). Their shapes are similar to those found within the underlying conglomerate. The amount of siliceous material incorporated within the grainstones decreases upward through the grainstone section.

Blocks of lithified carbonate material are common in the grainstone. Though normally small in size (centimeters to tens of centimeters across) very large blocks do occur. For example, one block exposed in map area three has minimum dimensions of 8 x 4 x 4 metres (Fig. 43 algal bindstone material). Blocks are predominantly composed of algal skeletal bindstone. Algae dominates the bindstone with ramose bryozoans as the second most abundant grain type. Composition of the blocks is described in more detail under Algal Bindstone.

Black carbonaceous laminations are interbedded with grainstones (Fig. 7). Laminae may vary from 0.1 mm to 3 mm thick. Those thinner than one millimeter are often discontinuous and styolitized, with styolite amplitudes never exceeding five millimeters. Thicker laminae (>1 mm) are normally continuous and uniform. Parting occurs along the thicker laminae. Analysis reveals that the carbon content within laminae is greater than 80 percent by weight (P. Hannon, oral communication). Freshly broken surfaces shine and have a hackly appearance under the hand lens due to small grains of quartz projecting from the fractured surface. Quartz grains constitute 10 to 15 percent of the laminae and are the only grain type observed within laminae. Sphalerite and galena are not concentrated within or near the laminae but have an almost uniform distribution throughout the grainstones.

Fragmentation, compaction, and lead and zinc mineralization obscure much of the depositional texture of the grainstone.

One grainstone bed in map area three is anomalously thick. It varies in thickness from one to three meters. This bed contains many Meguma clasts (up to 90 cm) and large bindstone blocks, including the largest one (8 x 4 x 4 m). The Meguma clasts and bindstone blocks are contained in a gastropod rich matrix (Fig. 8). The lower contact for this unit is sharp and shows deep scouring of the underlying grainstones (see Map 3, Fig. 43). The upper contact is also sharp.

Geopetally filled bivalve shells and columnar stromatolites agrue that the large bindstone block had an allochthonous origin, because they indicate that the block is inverted and therefore not a

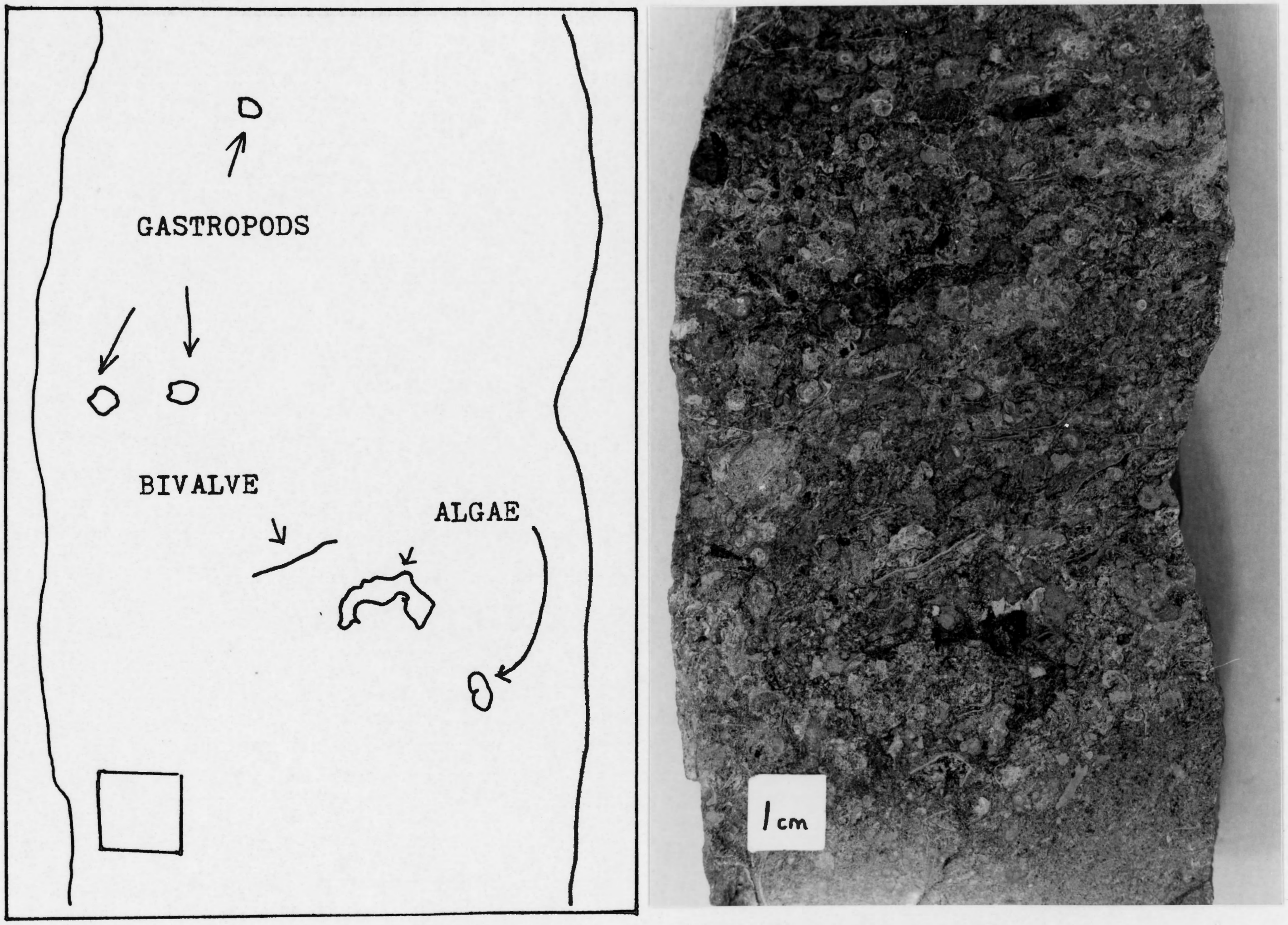


Fig. 8: Gastropod rich grainstone.

small, in place satellite body. Beds deposited after the thick unit drape over and pinch out against the bindstone block; this indicates that the block was lithified prior to deposition of succeeding beds. Association with large Meguma clasts, and soft sediment deformation indicate that the block was lithified prior to deposition because the Meguma clasts indicate high energy conditions at the time the unit was deposited. Such energetic conditions would cause semi-lithified material to break up during transport.

Skeletal grains within the grainstones are composed of a mosaic of anhedral dolomite and calcitic dolomite. Intergranular and intragranular pores within the grainstones are filled with sphalerite, galena, and minor sparry calcite. The sphalerite and galena are fine grained and crystalline. The paucity of pore filling calcite, so abundant in other lithologies at Gays River infers that: 1) compaction closely followed lead and zinc mineralization and predated the majority of secondary calcite precipitation, or 2) sphalerite and galena precipitation nearly completely filled all available pore space before precipitation of calcite began.

Gypsiferous Peloidal Wackestone

This rock type appears to have a very limited distribution. It occurs in only one place in the decline--in a hole in the back (roof) caused by overbreaking of the rocks in this area. The wackestone was not observed in any of the adjacent drill core from holes less than 20 m away.

For this reason both the upper contact with the overlying evaporite, and the lower contact with the underlying grainstones were unobserved.

Peloids and lumps are the only carbonate grain types present within the wackestone; combined they account for approximately 35 percent of the rock volume. Elongate peloids dominate, accounting for 30 of the 35 percent. They range in length from 0.1-2.0 mm and average 0.4 mm. Lumps make up the remaining grain bulk; they are elongate averaging 2.0 mm in length and 0.5 mm in width. Both lumps and peloids are well-sorted with respect to size and shape. They have sharp, uncoated grain boundaries and are dark brown in colour. The majority have their long axis parallel to the plane of stratification.

Neither whole invertebrates nor skeletal fragments were observed in this lithology. The siliceous content is very low (<1%).

The matrix of the wackestone consists of fine-grained, tan coloured dolomite which averages six microns in diameter. The grains are scattered throughout this dolomite matrix. The wackestone matrix is disrupted by porphyroblasts which are composed of a mixture of gypsum, sphalerite and galena (Fig. 9). The porphyroblasts average 5 mm in diameter and are 1-1.5 cm long. They may be angular or subround.

Group Two Rock Types

The carbonate rock types found in group one differ from those of group two as was previously stated. Contrasting the lithologies contained in these groups, makes apparent the dis-

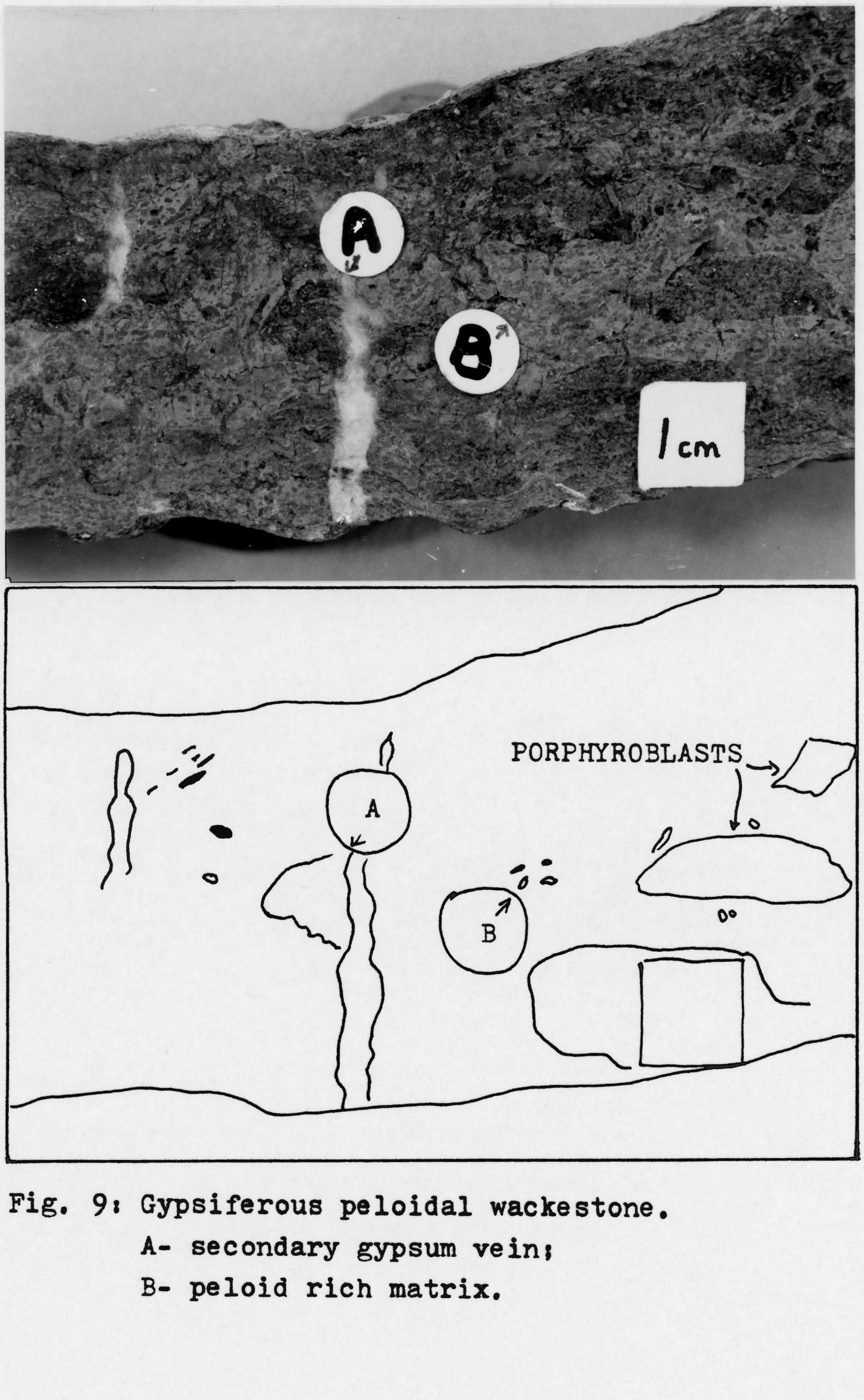


Fig. 9: Gypsiferous peloidal wackestone.
A- secondary gypsum vein;
B- peloid rich matrix.

similarities between them. For example, stratification is prevalent in group one, whereas it is rare in group two. Lithologic relations are clear in group one; relations are complicated in group two. Allochthonous carbonates dominate group one; authochthonous carbonates dominate group two. These disparities indicate the rocks of the respective groups were deposited under different conditions. The major similarity--if not the only one--between the two groups is the fact that both groups contain a basal conglomerate.

Basal Conglomerate

In group two, the basal conglomerate is essentially the same as that found in group one. Similarity exists in clast size, shape and composition, and also in matrix and cement types. However, group two conglomerates tend to contain less siliceous material in the sand size class. Also, skeletal grains comprise 80 percent of the matrix in group two conglomerates; this contrasts the highly siliceous matrix found in the lower part of the group one conglomerates exposed in map area three. Moreover, algal bindstone encrusts many of the Meguma clasts found in the group two conglomerates (Fig. 10), whereas none of the group one clasts exhibited algal encrustations.

The conglomerate in group two has a discontinuous distribution. When excavating the decline, it was necessary in some areas to tunnel through sections of basement, to maintain an acceptable slope. In such areas, the succession, exposed in the decline, passes from carbonate to basement and back to carbonate. If the

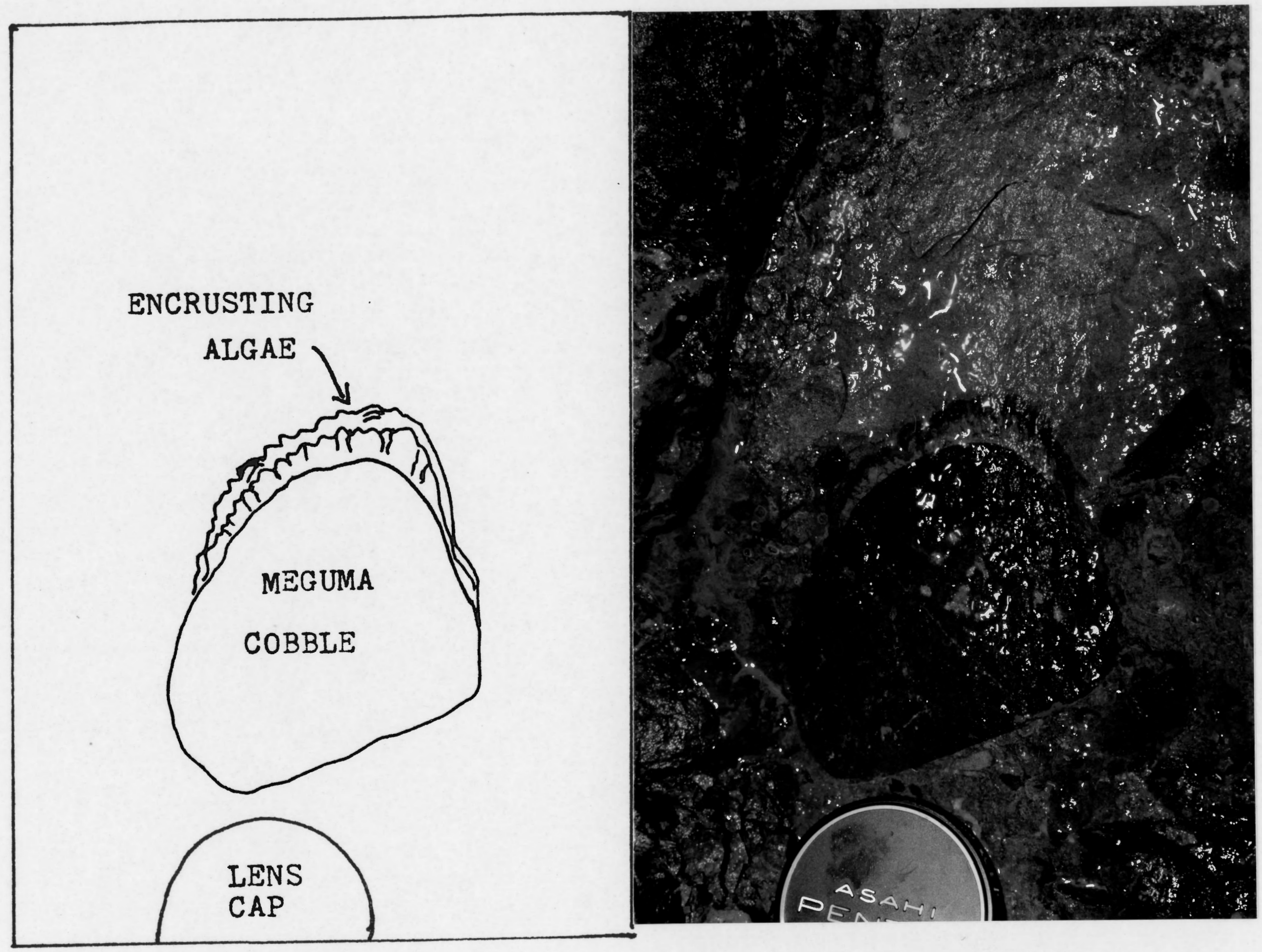


Fig. 10: Meguma cobble with top encrusted by algae. Cobble is surrounded by lithic skeletal grainstone.

slope of the contact between basement and carbonate is greater than 40°, the conglomerate is usually absent. In addition, in some areas, for example near the portal, there is no conglomerate even though the slope of the contact is essentially flat lying. Such areas usually mark the crest of, or, are in the lee of the crests of basement highs. Conglomerate is present on the basement steps, previously described; there the thickest sections (2 m) occur nearest to the steep rising part of the step.

Matrix of group two conglomerates consists of a mixture of skeletal grains, small rock fragments and several cement types. Skeletal types include: algae, gastropods, bivalves and coral. These grains range in size from 0.2 mm to 10 mm and average 4 mm. Sorting of grains is fair with regard to size and poor with respect to shape. Some skeletal grains, especially gastropod and bivalves have their exteriors coated with microcrystalline dolomite. Lithic fragments in the matrix range from 0.1 to 15 mm. Their shape is generally angular and elongate and they are disc to roller in form.

Sparry calcite, sphalerite, and minor galena are the cement types found in the conglomerate. Sparry calcite is the most abundant type and often overlies the sphalerite and galena. The calcite occurs as blocky crystals filling intergranular and intragranular pores. Sphalerite cement is predominantly in intergranular pores where it forms incomplete rims of 0.1 mm sized crystals. The rims may be up to one mm thick but average 0.4 mm. Occasionally galena crystals are present within the sphalerite rims. The blocky calcite spar usually fills the remaining pore space.

Algae, in one form or another, is the most abundant organism exposed in the decline. Though binding forms dominate, baffling types are present. The distinction between binding and baffling forms is important in environment reconstructions (Alberstadt and Walker, 1973; Embry and Klovan, 1971; Wilson, 1975). For this reason the algal lithology has been divided into two rock types--bindstone and bafflestone.

Algal Bindstone

This rock type is an assemblage of encrusting and erect algae, complimented by bryozoa, coral and encrusting forams. An encrusting form of algae dominates this lithology; bryozoa and coral are important accessories which have a patchy distribution within the bindstone. Encrusting foraminifera are a minor component.

Substrates upon which the algae grew include the Meguma basement, conglomerate clasts (Fig. 10) and skeletal fragments. The algae adopt two habits, encrusting and erect. The encrusting habit is most common. Texturally it ranges from homogeneous through laminoid (Monty, 1977) to stromatolitic. Of the three textural varieties, the homogeneous type prevails. Homogeneous encrustations appear as nodular masses, light to dark brown in colour, generally less than 2 cm high and up to 4 cm wide. The nodules, irregular in outline, are often intimately associated with crustose and ramose bryozoa. The resulting texture (Fig. 11) is very similar to that figured by Johnson for an algal limestone found in the St. Genevieve

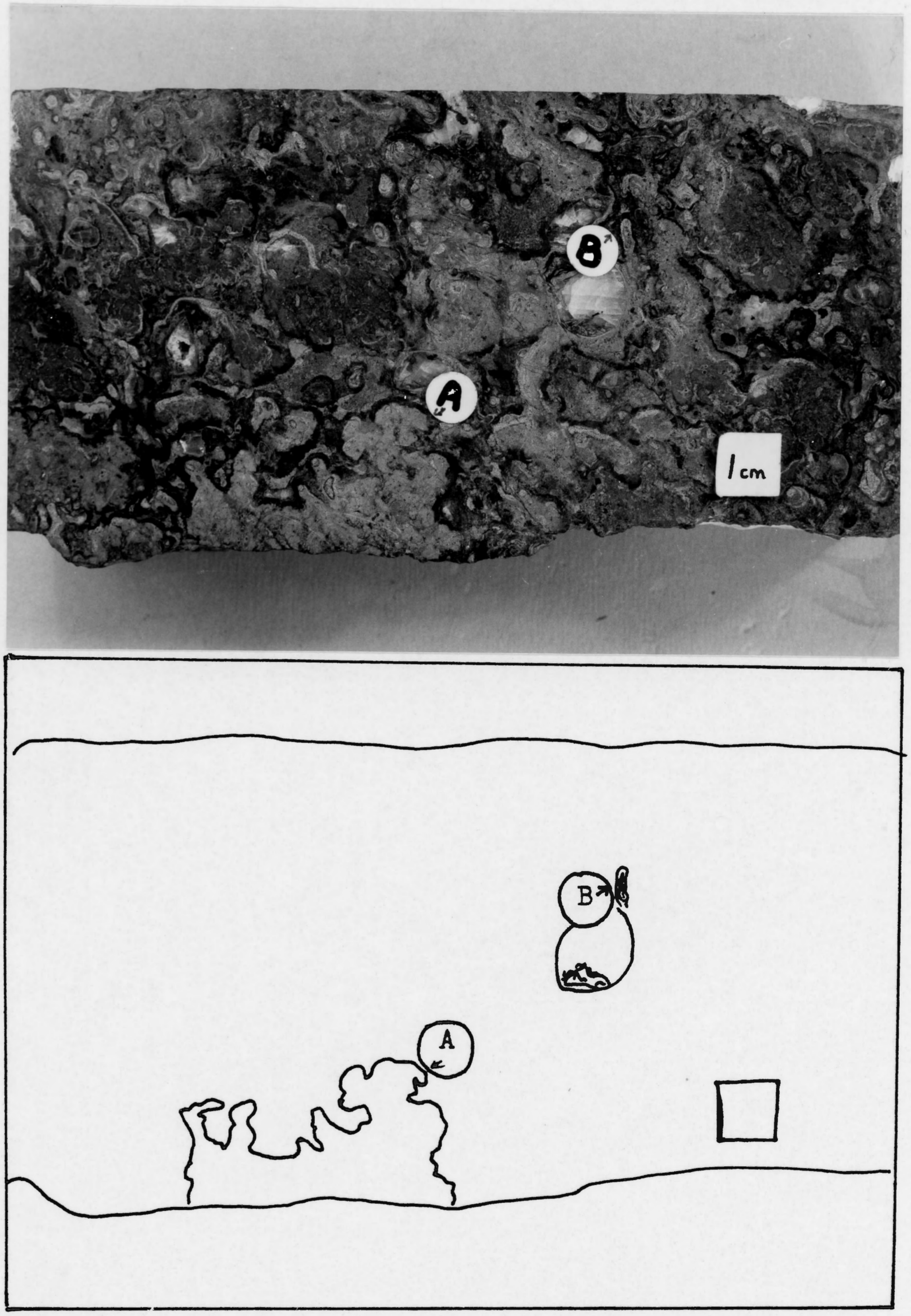


Fig. 11: Algal bindstone. A- algal nodule;
B- ramose bryozoa.

Formation of Mississippian age (Johnson, 1962, pl. 121, fig. 2, p. 265).

Monty (1977, p. 194) defines laminoid fabric as ".... showing no laminae, but the presence of well or poorly aligned structural features which tend to outline an overall layering". At Gays River, the laminoid algal fabric consists of a dark brown layer ranging from 1 mm to 2 mm thick (Fig. 39). The layer is normally continuous and almost isopachous in nature, and internally has faint discontinuous laminae-like features varying from 100 to 200 microns thick. Silt and small foraminifera are the only grain types present in the laminoid fabric. Etching reveals that 4 to 7 micron dolomite grains compose the dark brown layer.

The laminoid structure follows the contour of the underlying substrate and exhibits "lamination" contrary to gravity, which is a criteria for organic binding (Dunham, 1962, p. 117), but is also present in calcrete profiles (Read, 1977). The contact between substrate and the laminoid fabric is sharp.

Small, digitate stromatolites and small thrombolites--bodies similar to stromatolites but lacking laminations (Aitken, 1967)--occur in the bindstone lithology. The stromatolites vary from digitate columnals less than 2 cm high to small nodules up to 8 mm high (Fig. 12). Both columnals and nodules range from 2 to 10 mm wide at their respective bases. Laminations within the stromatolites are distinct and continuous, varying from 1 to 2 mm in height. Substrates for the stromatolites appear to be

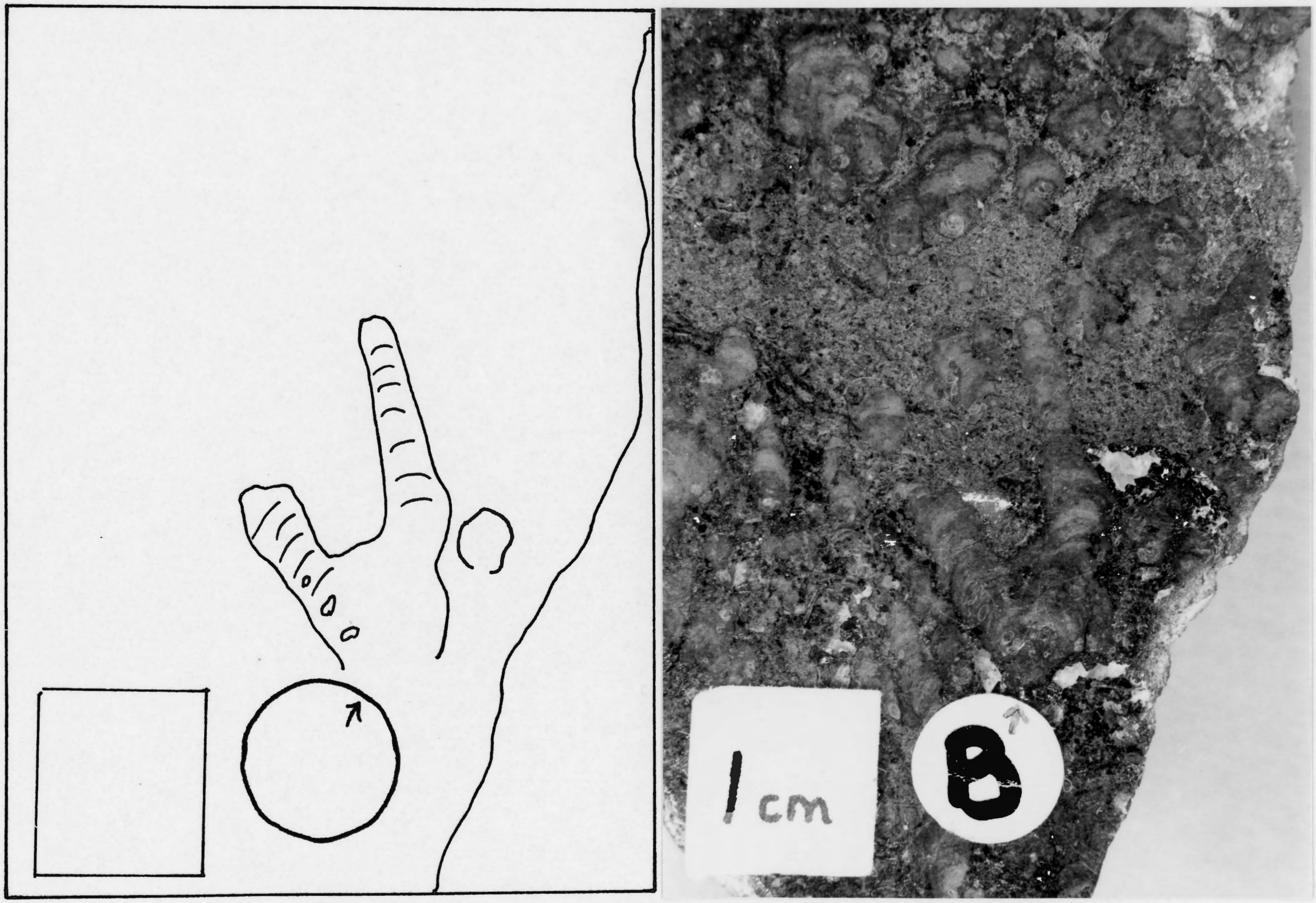


Fig. 12: Algal stromatolites. B- small stromatolite columnals.

the homogeneous algae and small encrusting forams. Intercolumnal material consists of sand sized grainstone. Skeletal fragments, very small rock fragments (Meguma), and cement comprise the grainstone. Recognizable skeletal grains include algae, bivalves and ostracods. Crystalline sphalerite, galena and sparry calcite act as cements.

Thrombolites occur as a minor aspect of the bindstone. They exhibit indistinct laminations and vary in shape from upwardly branching hemispheroids to irregular ellipsoids. In hand specimen, the thrombolites appear as irregular, centimeter-sized clots (Fig. 13). Dolomite grains, 4 to 7 microns in diameter, compose the clots. Fragments of bryozoa and shells are incorporated within the thrombolites. Interstices among the thrombolites are filled with grainstone material very similar to that found between stromatolites; although sparry clacite and galena appear much more abundant within thrombolite interstices.

An erect, sparsely-branched form is the second major habit adopted by the algae in the bindstone rock type. Individual branches are clavate and bulbous in form. Branches are 1 to 2 mm wide, up to 8 mm long and are tan to dark brown in colour. Branches occur in discrete bunches intermixed with encrusting algae. The resulting texture resembles irregular mottled nodules up to 2 cm across and less than 1.5 cm long (Fig. 11). The erect forms often grow upwards from a skeletal grain substrate as Figure 14 illustrates.

No primary algal features on the microscopic scale were

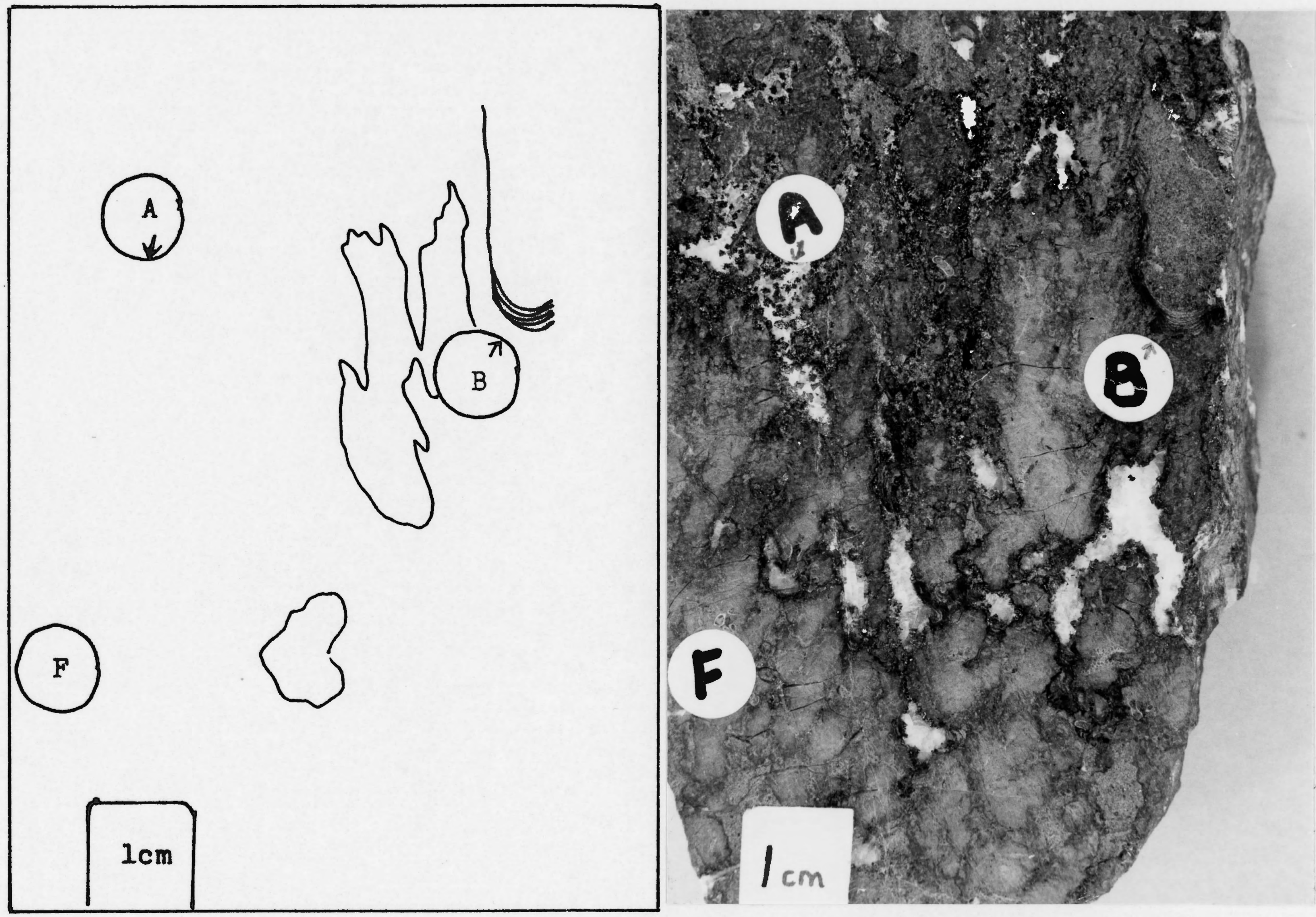


Fig. 13: Thrombolite. A- galena crystals in sparry calcite; B- laminated stromatolite; F- clotted thrombolite texture

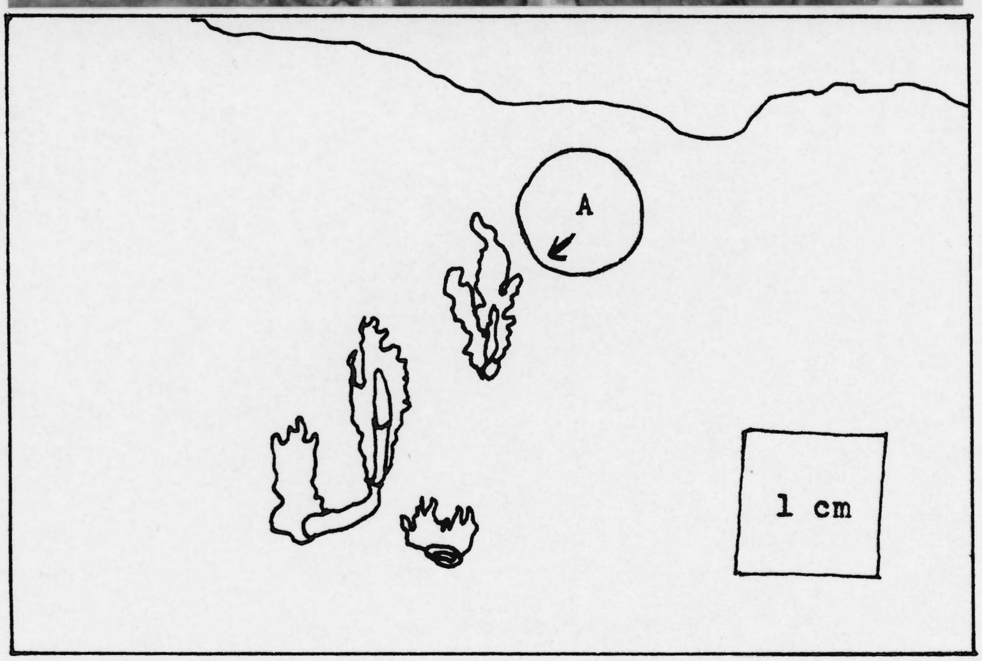


Fig. 14: Algae encrusting coral fragments.

A- digitate algae on a coral substratum.

observed in either branching or encrusting algal forms. In thin section, these rock types appear as a homogeneous mosaic of dolomite. Primary textures observed are on the macroscopic level. However, algal clasts contained in the grainstone (described below) do exhibit microscopic, primary algal textures.

Prominent macrofossils associated with the bindstone are: reticulate bryozoa; erect bryozoa, including Batastomella; fenestrate bryozoa, Fenestrella; the tabulate coral Cladochonus and at least two unidentified pelecypods.

The reticulate bryozoa encrust algae, coral, pelecypods other bryozoa, Meguma rock fragments and also line cavities. The bryozoa consists of thin discontinuous mats which are one zooecia thick (<1 mm). Individual autopores average 200 microns across. The zooecia mats often alternate with encrusting algae to form nodular masses similar to those found in the Miami Limestone Formation described by Multer (1977, p. 255).

Erect or ramose bryozoa are small, averaging less than 1 cm long and slightly over 2 mm wide. They are tiny clubs in which the zooecia are tightly packed. Branching occurs infrequently, with the interbranch angle always acute. Both algae and the reticulate bryozoa encrust the erect bryozoan forms.

Fenestrate bryozoa are a minor component in the bindstone. They are present in the matrix between the nodular masses, generally as broken fronds not in life position. In some areas where the matrix is muddy, fenestrate bryozoans comprise up to 5 percent of the rock volume.

Interstitial material in the bindstone varies from packstone to grainstone. Infrequently, siliclastic grains comprise 50 percent of this material. Normally, however, the amount of siliceous material varies from 5 to 15 percent of the rock volume. Siliclastic grains range from silt to gravel sized particles with sand-sized grains as the norm. Carbonate grains in the interstitial material consist of fragments of algae, bryozoa, bivalves, and coral, along with peloids, and unidentified carbonate grains. There is a direct relation between pore size and the grain size of material filling or partially filling the pore. Small pores (<4 cm long) contain silt to sand-sized material which often exhibits weak stratification due to grain size differences. Large pores contain coarse skeletal grainstones. Cements are of sparry calcite, sphalerite, and galena. Although the porportions of cement types vary, the sparry calcite usually dominates. Pores incompletely filled with sediment are plugged by a cap of sparry calcite (Fig. 15).

The texture of this rock type is predominantly bindstone but areas (pores) do exist which vary from siliceous packstone to siliceous grainstone (Fig. 16). The contacts between bindstone and packstone/grainstone material are always sharp and trace the outline of the bindstone (Fig. 17).

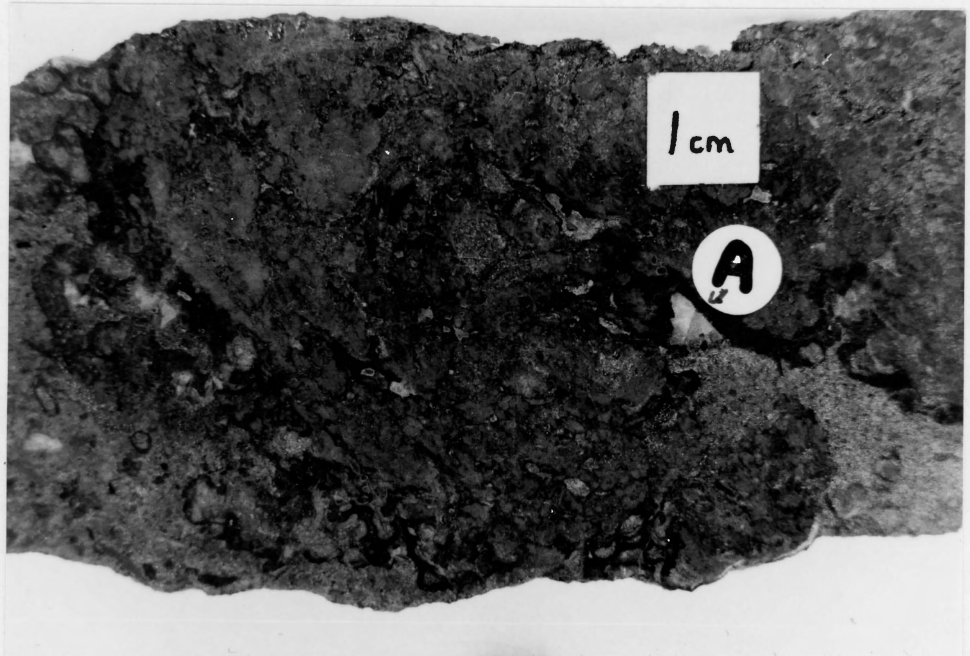
Biologic zonation with the bindstone is very complex. Zonation boundaries are unclear and difficult to trace in the decline. The initial assemblage seems to be algal soon accompanied by bryozoa. It is uncertain as to whether the first bryozoa colonizers were the reticulate or the ramose form. Coral seems to appear after the bryozoa. But again, the relations are not clear. For example, one area will have an in-place algal-coral association without bryozoa but an adjacent area slightly lower stratigraphically, contains all three fossil types in-place. More study would possibly clarify these complex fossil relationships.

Mineralogically, a mosaic of finely-crystalline anhedral dolomite makes up the bindstone. Dolomitization seems to have obliterated all traces of microstructure in this lithology--at least none were present in any samples studied by this writer. According to the porosity classification of Choquette and Pray (1970), bindstone porosity is fabric selective with growth framework and moldic types dominating. The absence of sphalerite and galena within the algal portion of the bindstone indicates that these areas were tight at the time of sulfide precipitation. In contrast, many interstitial areas filled with packstone and grainstone contain abundant intergranular sphalerite and galena.

Circular borings, some encrusted by reticulate bryozoa, indicate that very little compaction occurred within the bindstone.

Algal Bafflestone

This is the second distinct algal rock type. It contrasts markedly with the bindstone in form, distribution and biologic association. Though not as abundant as the bindstone lithology, bafflestone dominates the geology in map area one; is common in other areas of the decline; and is frequently observed in drill



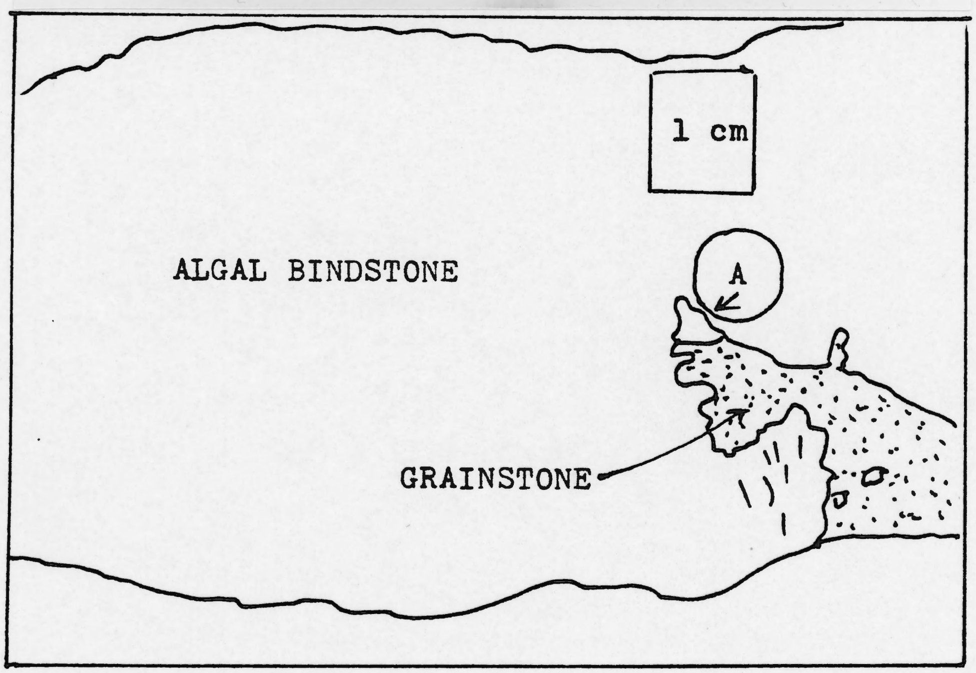


Fig. 15: Algal bindstone with framework pore partially filled with grainstone and closed by sparry calcite (A).

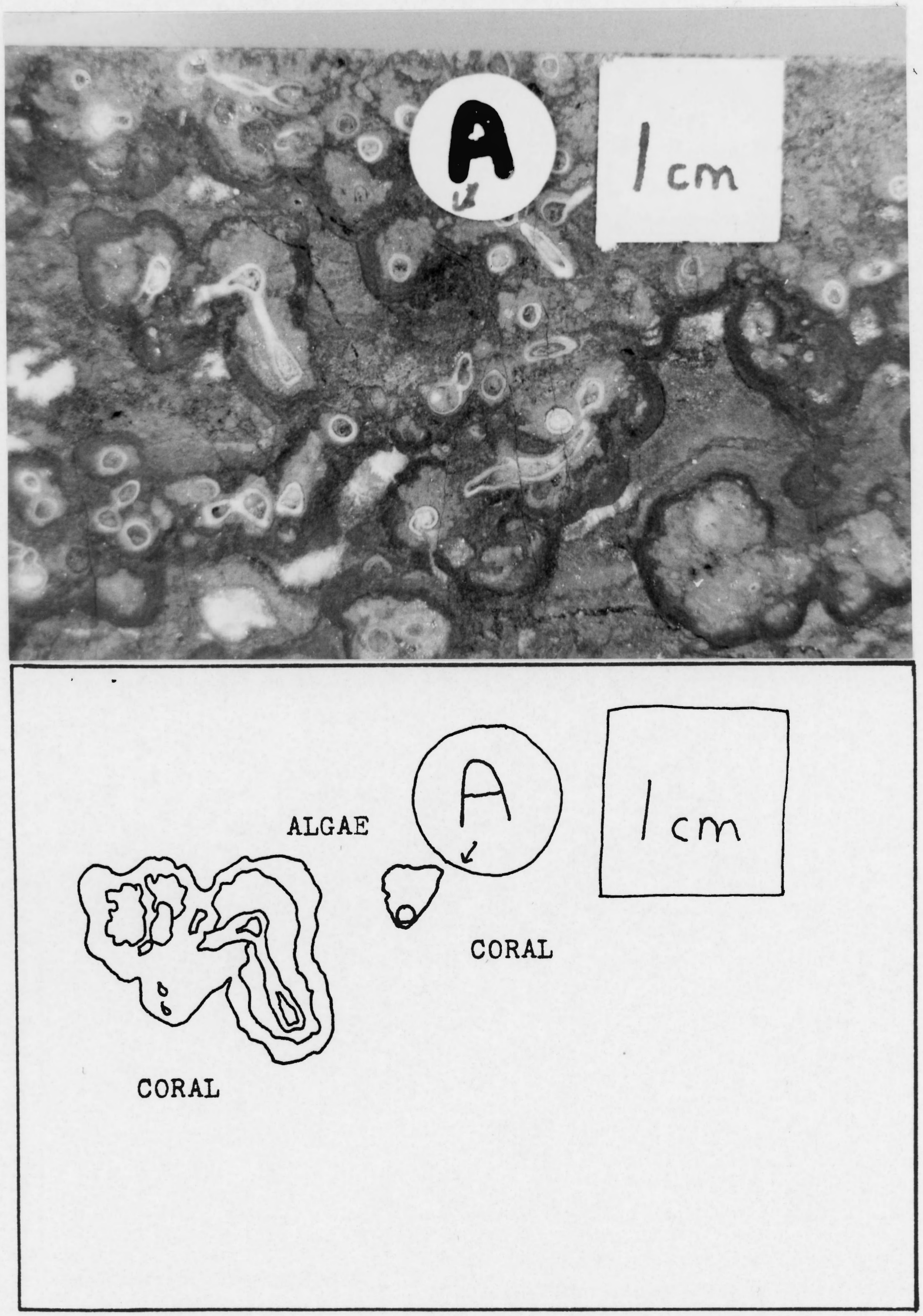
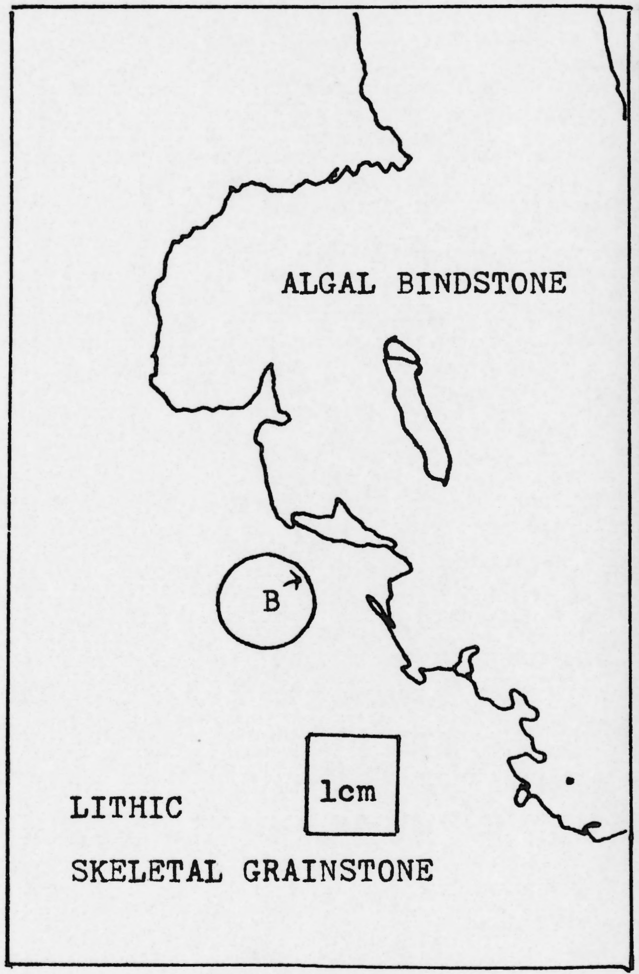


Fig. 16: Bindstone with packstone and grainstone filled pores.
A- branched algae.



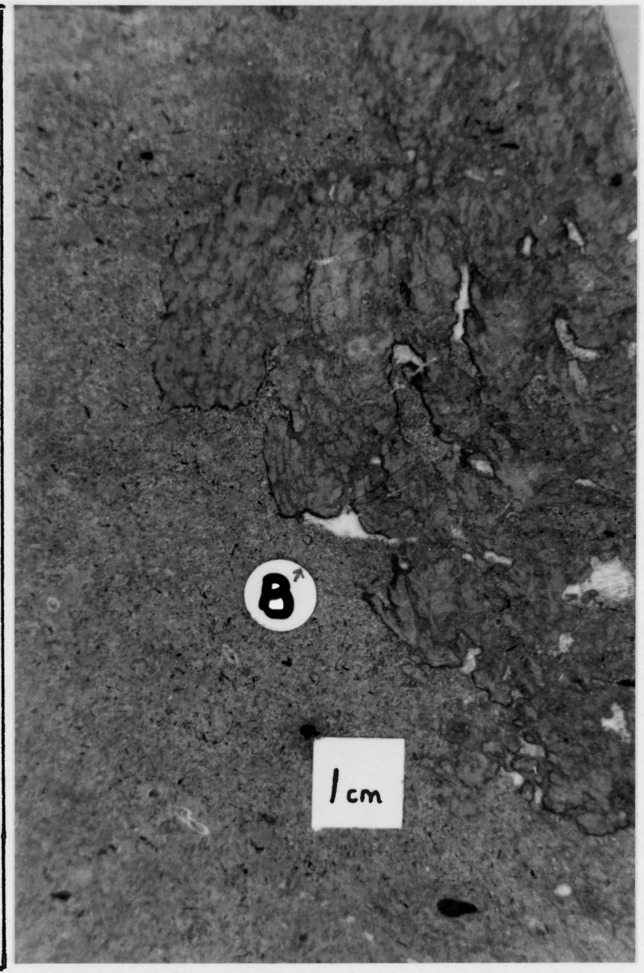


Fig. 17: Contact between bindstone and grainstone.
B- shelter pore filled with sparry calcite.

core.

In map area one (Fig. 45), the bafflestone is exposed on the lee side of a small basement spur. The bafflestone rests directly upon the steeply dipping basement (>45°) and spreads both vertically and laterally. In spite of the steeply dipping substrate the algal thalli are always oriented within 15 degrees of plumb. In some places, the bafflestone overlies the bindstone.

As in the case of the bindstone, pervasive dolomitization appears to have masked completely most primary algal structure on the microscopic level. The only structures within the thalli which could be interpreted as algal filaments were short, bifurcating voids which were uniform throughout their length, and averaged 80 microns in diameter. None the less, even though the present writer did not observe any algal microstructure during microscopic study of his specimens; Paul Brinkle at the Research Centre of Amoco Petroleum Company in Tulsa, Oklahoma, reported ".... radiating bundles of tubes observed in thin section ...." in a sample sent to the Research Centre via Amoco geologists in Calgary. Brinkle (verbal communication, 1977) wrote that the structure was definitely organic and possibly some species belonging to the family Codiaceae in the green algae phylum. In addition, J. Babcock at the University of Tulsa examined the specimen sent to Brinkle. Babcock concurred with Brinkle's comments but added the fabric might represent a colonial coral! J. E. Klovan and A. F. Oldershaw of the University of Calgary found ".... the pecular fabric of the rock is indeed puzzling"; but neither Klovan nor Oldershaw would ".... venture to guess at its probable origin on the basis of the one piece of rock" (J. E. Klovan, verbal communication, 1977). Reasons why the present writer interprets an algal origin for this rock will be put forth in the discussion section of this thesis.

The bafflestone consists of one algal form. As Figure 18 illustrates, the algal thalli are arborescent bodies having short trunks and multiple branches. In longitudinal section, thalli attain an observed maximum length of 25 mm but generally average considerably less, with the normal range being 5 to 15 mm. The size of thalli observed may vary artifically since the direction in which the sample was slabbed may not correspond to the true longitudinal axis of the thalli; any cut taken at an angle to the true longitudinal axis results in a reduction of the length of the thalli.

Branching of the thalli is characteristic. The branches are thin and tapered; they range up to 2 mm wide and 10 mm high. Second and third generation branches are common. Figure 18 shows that the crotch is markedly acute, varying from 15 to 25 degrees. Again, this angle depends upon the orientation of slabbing with respect to the plane of branching of the thalli but angles much greater than 25° are not expected to occur. This near vertical orientation of thalli is uniform throughout the bafflestone. In fact, decline exposures of bafflestone appear to be cut by continuous, closely-spaced, vertical, fine fractures as a direct consequence of thalli orientation; the fractured appearance results from alignment of inter thalli areas filled with sparry

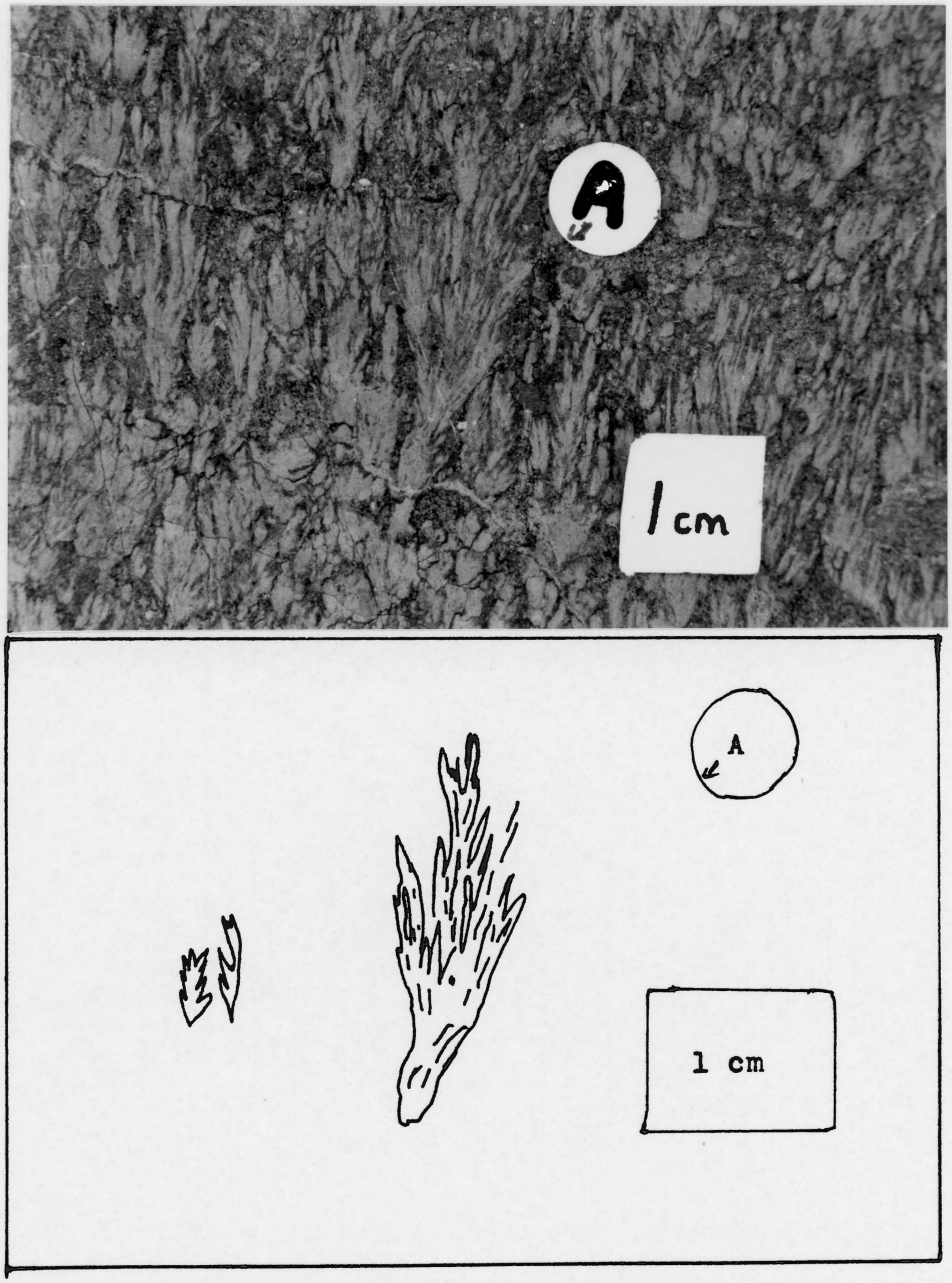
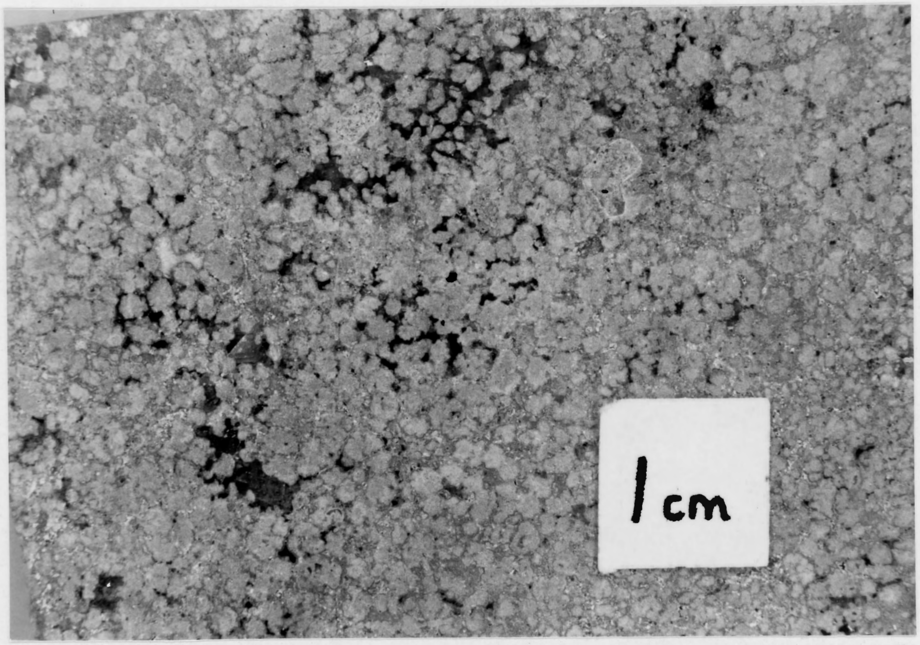


Fig. 18: Algal bafflestone. A- large algal thallus.

calcite and sand sized carbonate and siliclastic grains.

Transverse sections of the bafflestone appear as well sorted "lump" grainstones (Fig. 19). The lump-like appearance is a result of the various diameters of thalli branches cut almost perpendicular to their long axes. Individual lumps have a rounded, jagged form which in many aspects, resembles Beales' (1958) bahamite or the lumps described by Illing (1954). Infrequent nearly horizontal horizons are present where the thalli are bent and broken. No obvious reason for these horizons was observed.

In thin section most thalli have dark, fine-grained exteriors which may represent micritization by boring endolithic algae as described by Bathust (1971) or the micritic cement of James et al. (1976). These exteriors have irregular thicknesses which range usually from 14 to 60 microns, although some thalli consist entirely of fine-grained material. The fine-grained exteriors, composed of grains less than 7 microns, surround a mosaic of coarser grained dolomite, the grainsize of which ranges from 14 to 80 microns and averages 56 microns. Occasionally, the exteriors of the thalli and interstitial grains are isopachously rimmed by long (80 micron), narrow (24 micron) dolomite crystals which exhibit a wavy extinction pattern. These crystals may represent dolomitized bladed spar described by James et al. (1976) or the palisade spar of Schroeder (1972). In addition, overlying the palisade-like crystals and the fine-grained exteriors of the thalli not possessing the palisade crystals, is a continuous lining of dolomite grains which average 24 microns and range from



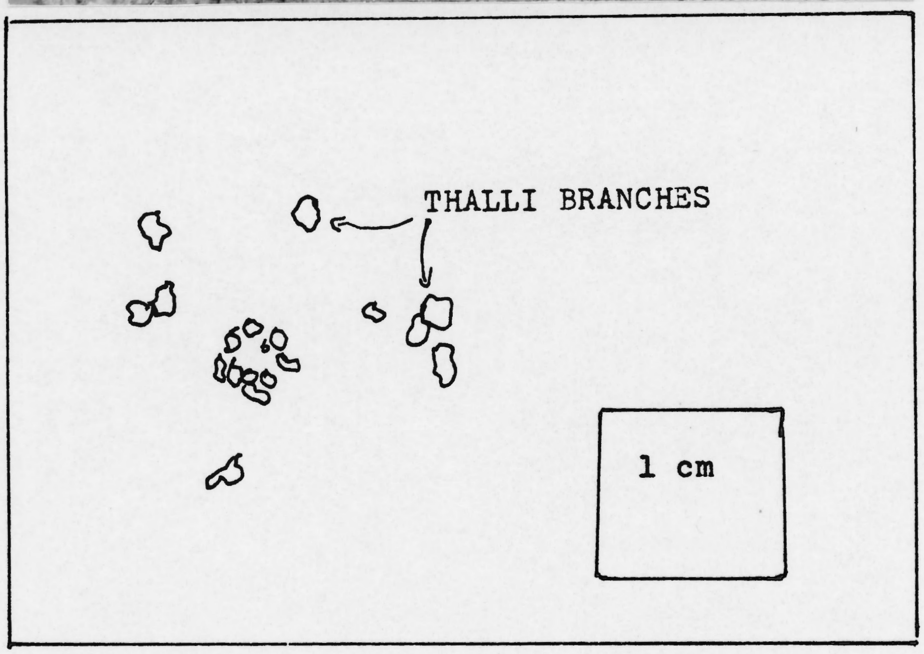


Fig. 19 : Transverse section of algal bafflestone. Thalli branches appear as irregular lumps.

8 to 56 microns. Furthermore, these crystals exhibit euhedral faces on the pore side of the grains. This layer of dolomite ranges from 13 microns to 104 microns and averages 70 microns.

Interstices between thalli and coral are filled with siliceous grainstone. This filling is geopetal in places. The siliceous component consists of silt to sand size quartz, feldspar and rock fragments with a mean grain diameter of 0.2 mm. In some areas, siliclastic grains may account for more than 60 percent of the intersticial material; the remaining bulk composed of small carbonate fragments and ostracods. Occasionally large boulders and cobbles of Meguma are incorporated within the bafflestone. These blocks usually occur individually and do not seem to be associated with channel structures in the bafflestone, or with the underlying conglomerate. Deformation within the bafflestone around and below these boulders appear to be slight. Once deposited, the boulders became substrates for future algal growth. Intermittently high angled cracks incise the bafflestone. These fractures may be 10 to 20 cm wide and up to one meter high. At least two of these cracks join channel structures which cut the bafflestone. Material filling the cracks is similar to that observed in the channels. The fill is a coarse-grained, siliceous grainstone consisting of Meguma clasts and intraclasts imbedded in a skeletal grainstone matrix.

Several variable-sized channel structures cut the bafflestone (Fig. 20). The channel axes trend down toward the basin to the northwest. The largest channel observed measures greater than three metres across and varies from 50 to 80 cm thick. The

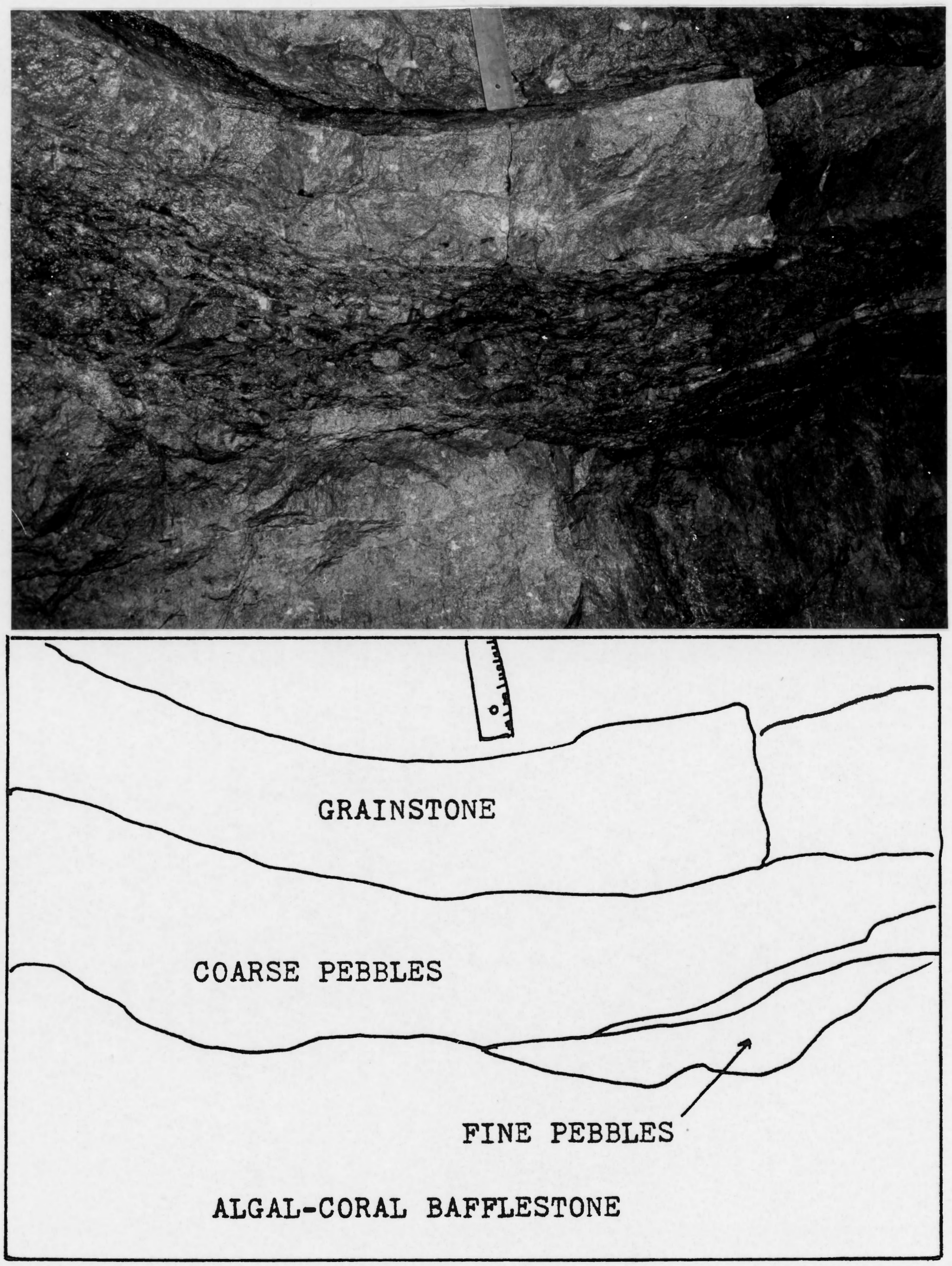


Fig. 20: Channel structure cut in algal-coral bafflestone. Note lag deposits of Meguma pebbles. Scale at the top of the photo is 7.5 cm.

channel-fill is a coarse-grained siliceous grainstone for the most part, which consists of Meguma clasts on lithified carbonate fragments embedded in skeletal grainstone. Some channels have lag deposits composed of Meguma cobbles (Fig. 20). Cross bedding and scour features are common. Channel-fills tend to be made up of descrete lenses of crossbedded grainstone; contacts between lenses are sharp. In addition contacts between channels and bafflestone are very sharp.

The tabulate coral, Cladochonus is the only macrofossil associated with the bafflestone algae. The coral manifest themselves only after the algae become well established. Coralites are short, less than 1 cm long and trumpet shaped. Diameters range from 1 to 1.5 mm. In place corals are erect with coralites growing at a slight angle, one on top of the other, or from the side of the preceeding one (Fig. 21). Cladochonus has a patchy distribution within the bafflestone; it most commonly occurs as little thickets intermixed with the algae. Generally, the algae are more voluminous and are considered the major baffler, but in some areas, corals may constitute 50 percent of the rock volume.

Porosity within the bafflestone is low. Sparry calcite fills the pores, often geopetally. Sphalerite and galena are rare in the bafflestone.

Lithic Skeletal Grainstone

The grainstone rock type in the second rock group is somewhat similar to that described in the first group of rocks. The

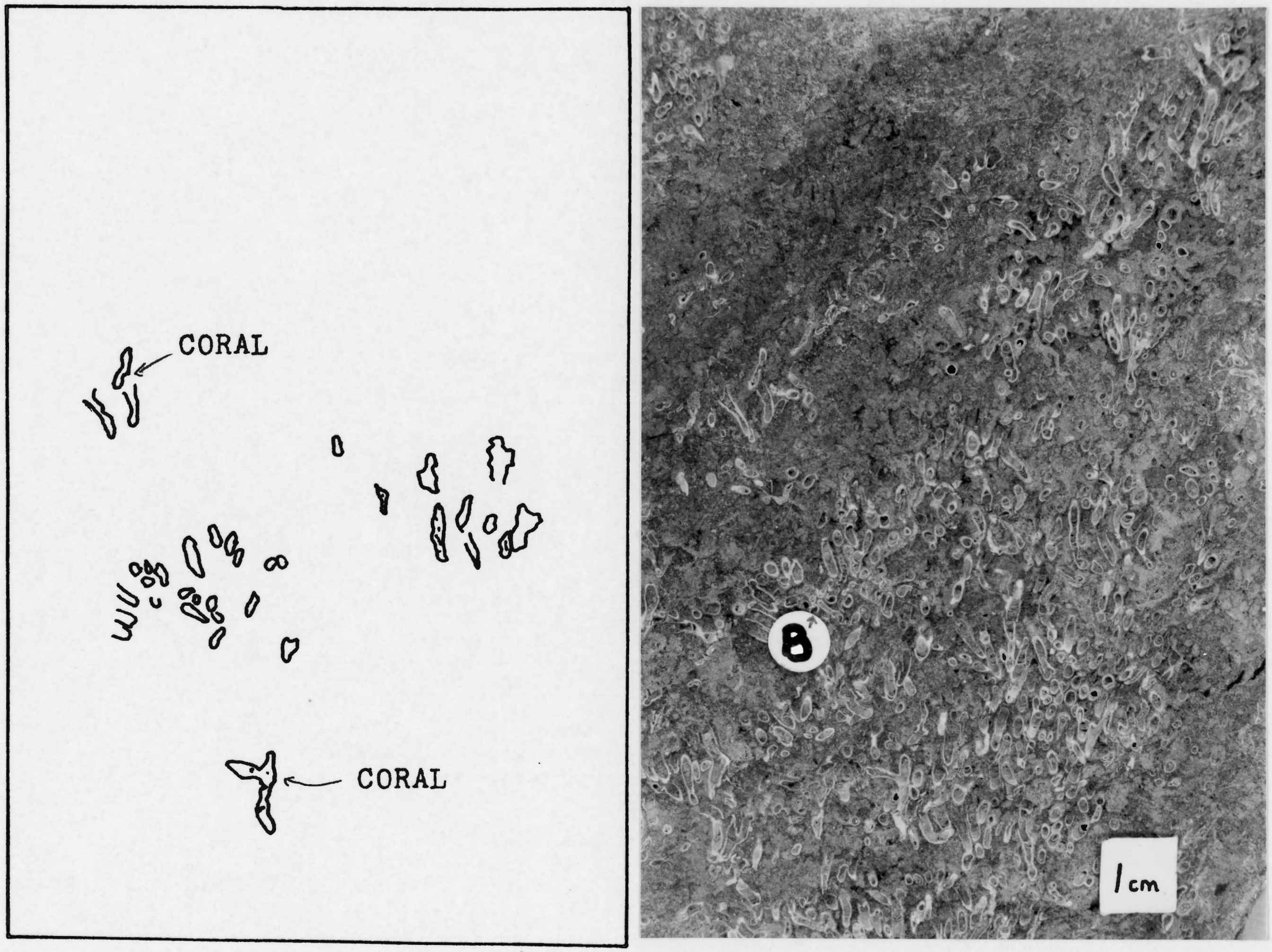


Fig. 21: Algae-coral association, B- section of corallite.

major differences between these two grainstones are:

(1) the amount of packing - the grainstones in group one are more closely packed than those observed in group two;

(2) carbonaceous material is prevalent in the group one grainstones, it is not in those of group two;

(3) the group one grainstones are more fine-grained than the group two grainstones;

(4) group one grainstones are well bedded, the group two grainstones are not;

(5) the group two grainstones have a more complex distribution. They are generally discontinuous; in places, occurring directly above the conglomerate; in places, as channel forms intermixed with the bindstone and bafflestone; and in places, they occur as thinly bedded units intermixed with skeletal packstones.

Grain types consist of: fragmented bivalves, whole and fragmented gastropods, pieces of algal material, fragments of coral and bryozoa, peloids and Meguma rock fragments. Bivalve fragments range up to 1.5 cm long and are less than 0.2 mm thick. Only single valves occur and most valves have their exterior sides coated with microdolomite. Several genera of gastropods are present including *Murchisonia*. Two unidentified gastropod types are also present: one is approximately 7 mm long, is conispiral and has an apical angle close to 30 degrees; the other is also conical in form, less than 5 mm long with an apical angle approximately 60 degrees.

Algal fragments are rounded irregular lumps up to 20 mm long and from 1 to 10 mm high. The genus *Ortonella* is common as irregular nodules. The nodules, showing preserved microstructure, consist of fine ramifying tubes radiating from the center of the nodule. The matrix is mudsized carbonate. The tubes or filaments are straight to undulating, widely separated and circular in cross section (Fig. 22). Filaments have a nearly uniform diameter of 56 microns (Fig. 23). Tubule branching is dichotomous with the interbranch angle approximately 40 degrees. Algal fragments exhibit growth framework pores (Fig. 24). The pores size varies up to 5 mm wide and the fragments may have up to 20 percent porosity, now filled with sparry calcite and sphalerite.

The amount of siliclastic material in the grainstones is not constant. Rock fragments reach a maximum of 15 percent but normally constitute 3 to 5 percent of the rock volume. Fragments range in size from silt to large pebbles up to 2 cm long and they are predominantly elongate in shape. The long axis of fragments is usually parallel to stratification. Shapes are subangular to round.

Peloids, more common in packstones, comprise up to 7 percent of the grainstone. They average 0.4 mm in diameter; have smooth exteriors; are round to elongate; have a sporadic distribution within the grainstones; and are generally more abundant in the finer grained rocks.

Most bioclasts within the grainstones have coated exteriors. Coatings consist of microcrystalline dolomite and are especially common on gastropods and bivalves (Fig. 25). The coating averages 1.5 mm in thickness but up to 4 mm thick coats

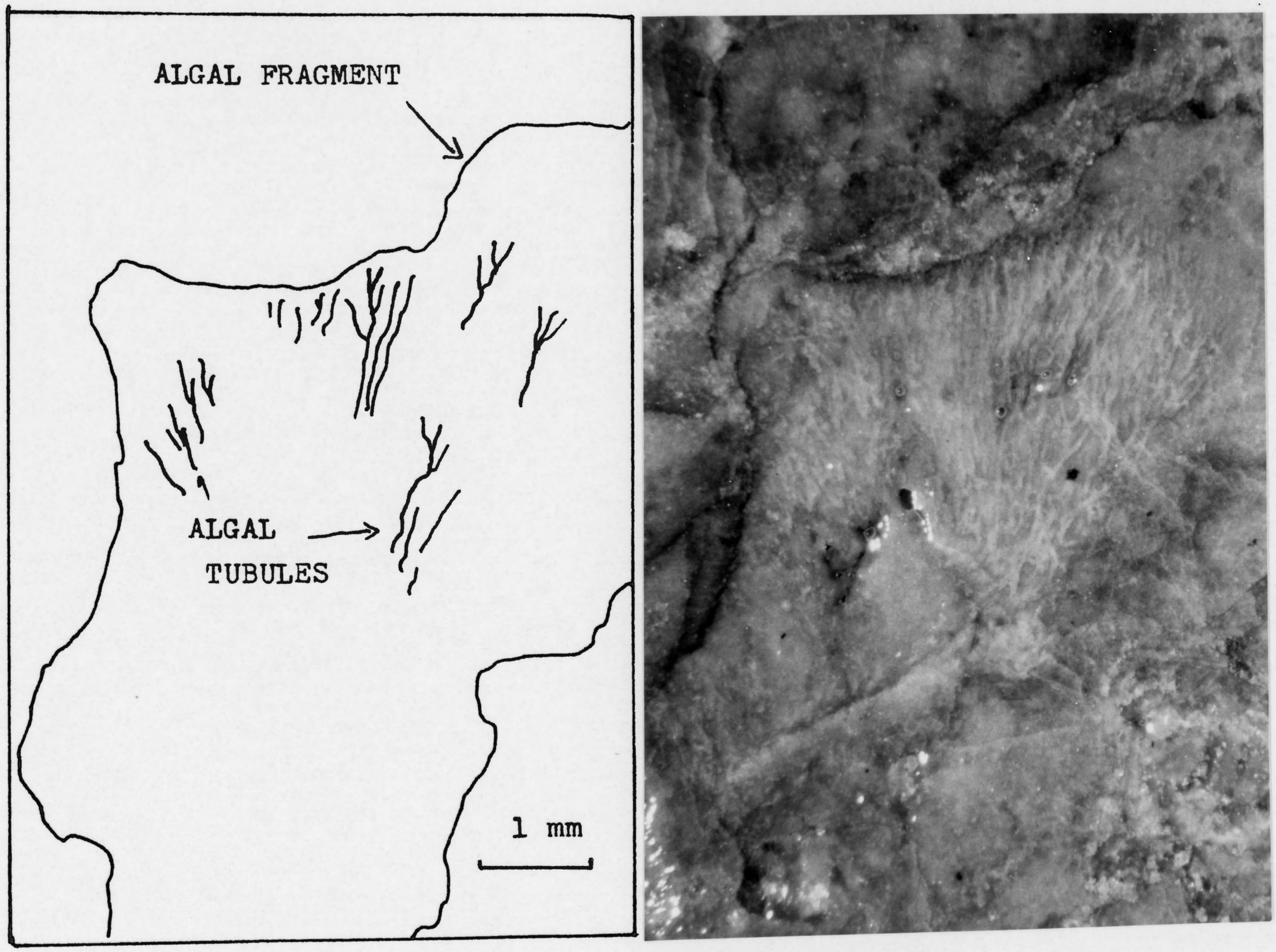


Fig. 22 : Algal fragment with preserved microstructure.

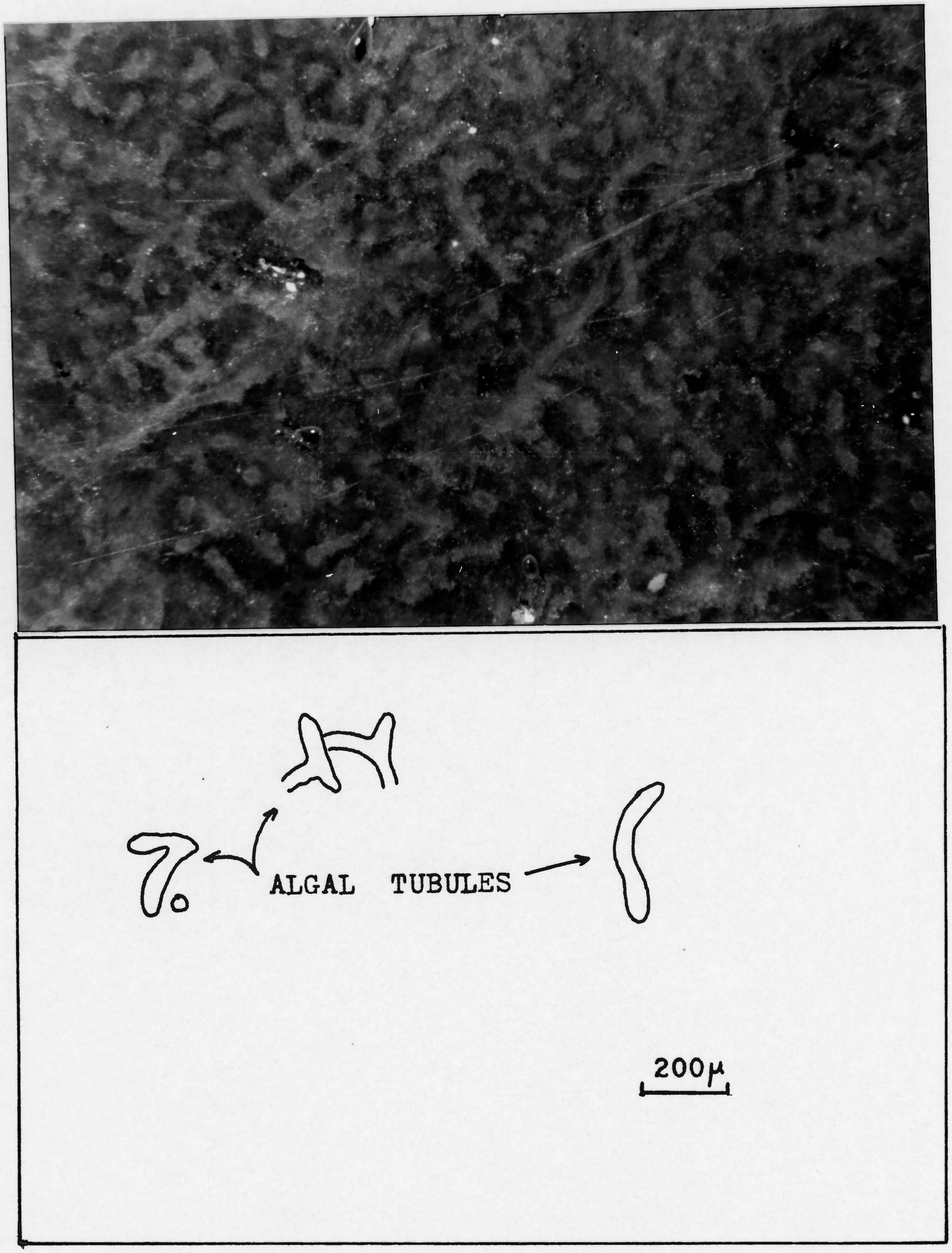


Fig. 23 : Close-up of algal tubules. Tubules average 56 microns in diameter.

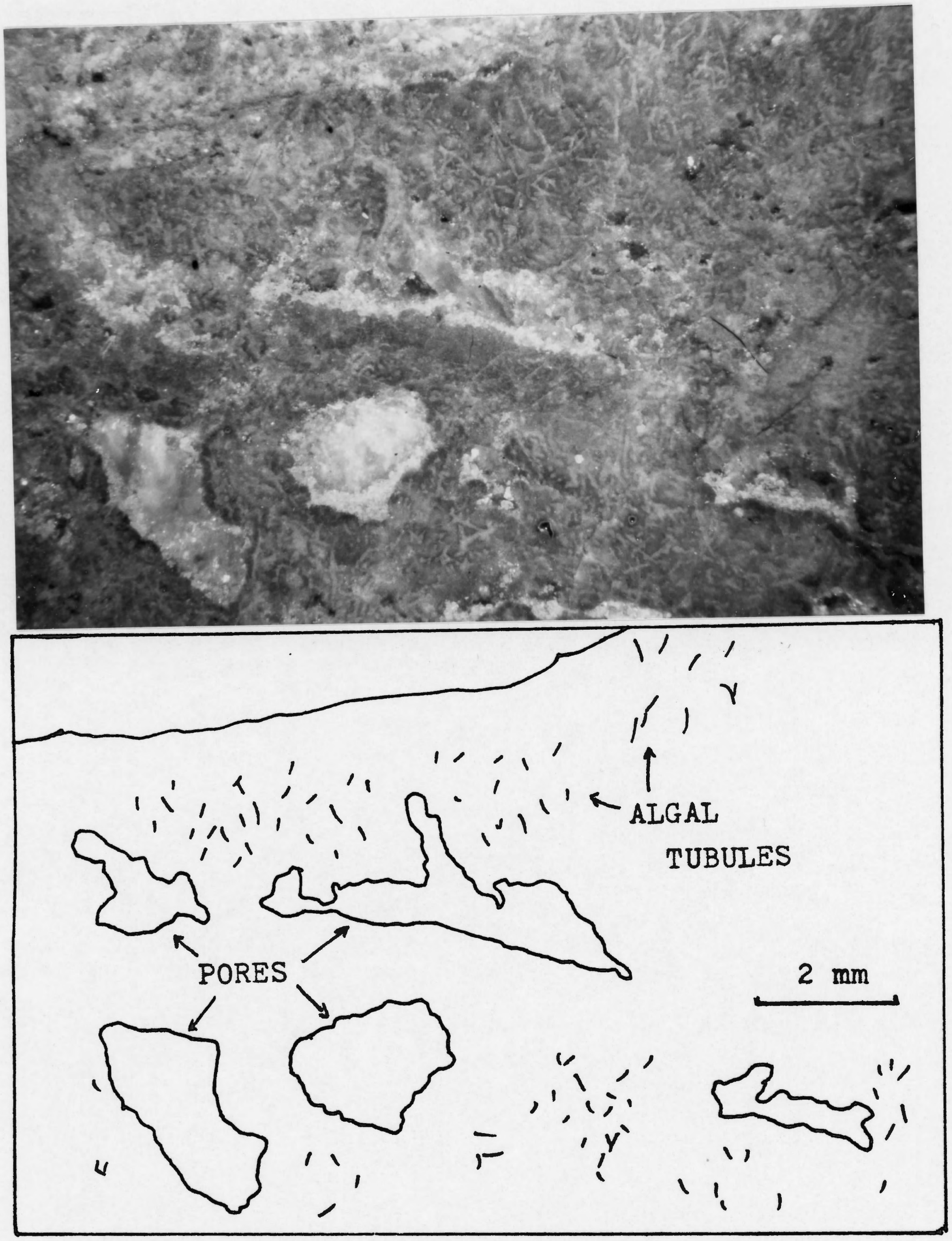


Fig. 24 : Algal fragment with growth-framework pores.

have been observed. In the case of bivalves, because the coatings are restricted to shell exteriors, they probably formed before the shells became disjointed. As Figure 26 shows, the coatings become lobate and branching often takes place, similar to that observed in the bindstone lithology. The morphology of the coatings implies an organic origin. Spongy microtexture, within the coating, is reminescent of partially obliterated algal tubules. This further suggests an organic origin. The delicate branching and lobate forms of the coatings would seem to preclude a micritic envelope origin as described by Bathurst (1971). For in examples cited by Bathurst, none of the envelopes exhibit branching, and very few are lobate on the scale observed on grains at Gays River.

The depositional texture of this rock is lithic skeletal grainstone. Sporadically, the grainstones are interbedded with packstones (Fig. 27) and are frequently associated with bindstones. Stratification when observed is thin ranging from 1 to 10 cm and is distinguished by change in grainsize, change in grain type, or the presence of elongate rock fragments along one horizon. Contacts between beds may be distinct, sharp, and/or scoured. Grainstones are common both above the basal conglomerate and as channel-fill within the bindstone. The most continuous exposures exist between basement highs. Infrequently, in these areas, individual beds can be traced along the decline wall for up to 5 metres. More commonly, however, a particular grainstone statum cannot be traced for any appreciable distance because of the rapidity of lithologic change.

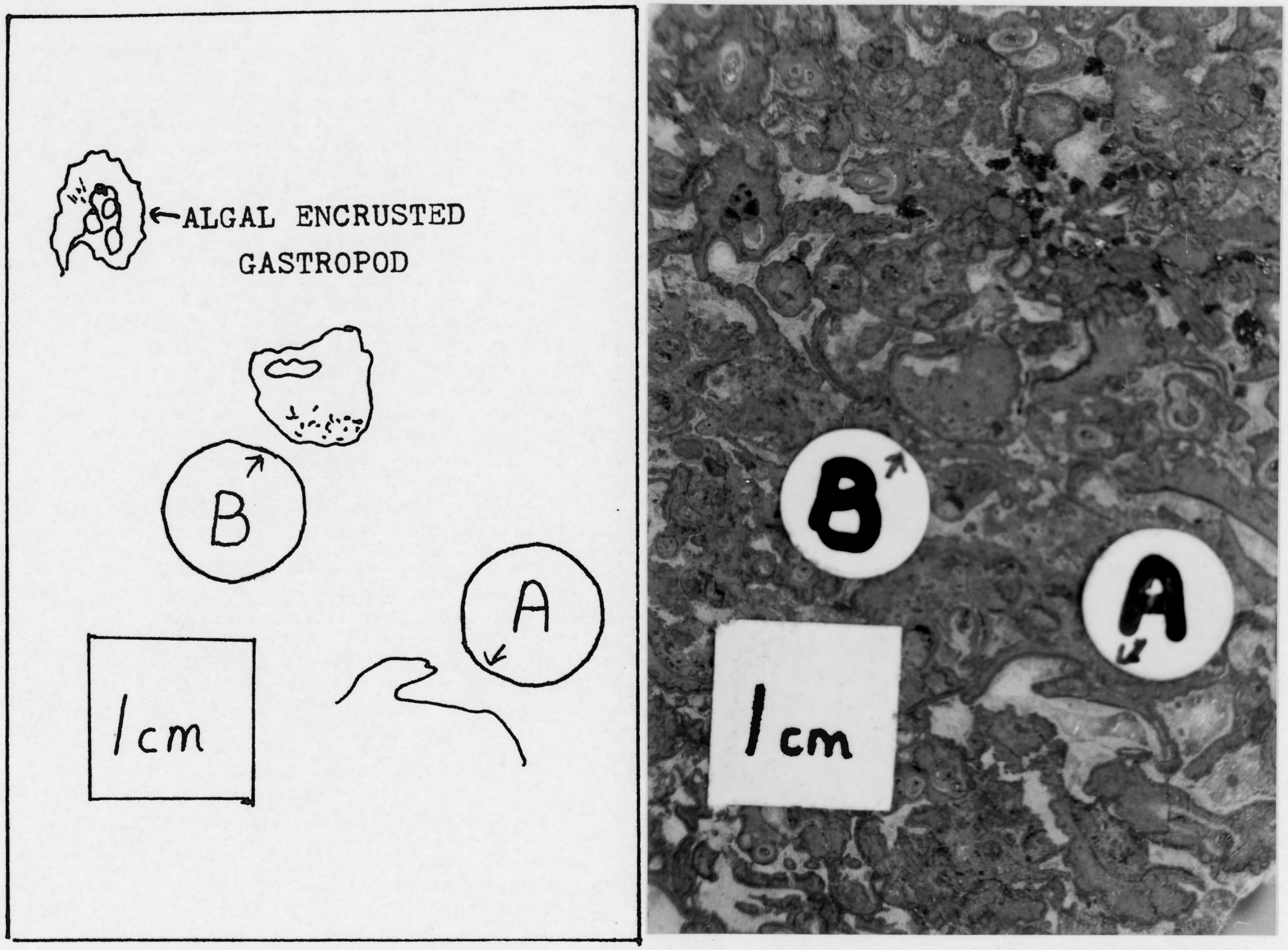


Fig. 25 : Poorly-sorted skeletal grainstone with shelter pores (A), and perched sediment (B).

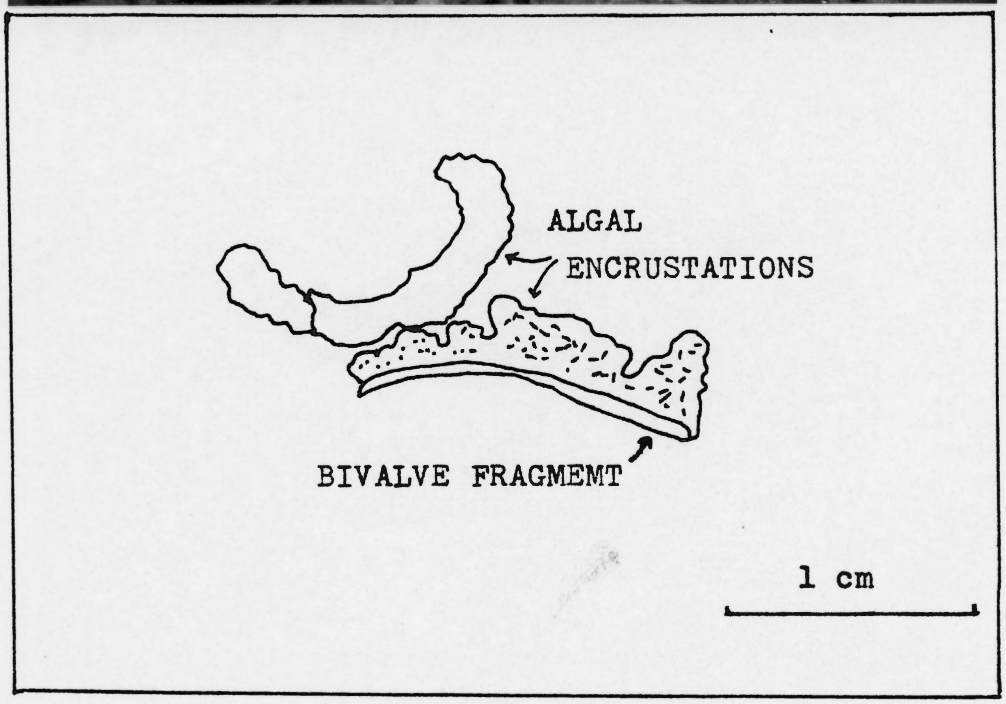


Fig. 26: Algal coatings on skeletal grains. Note lobate forms.

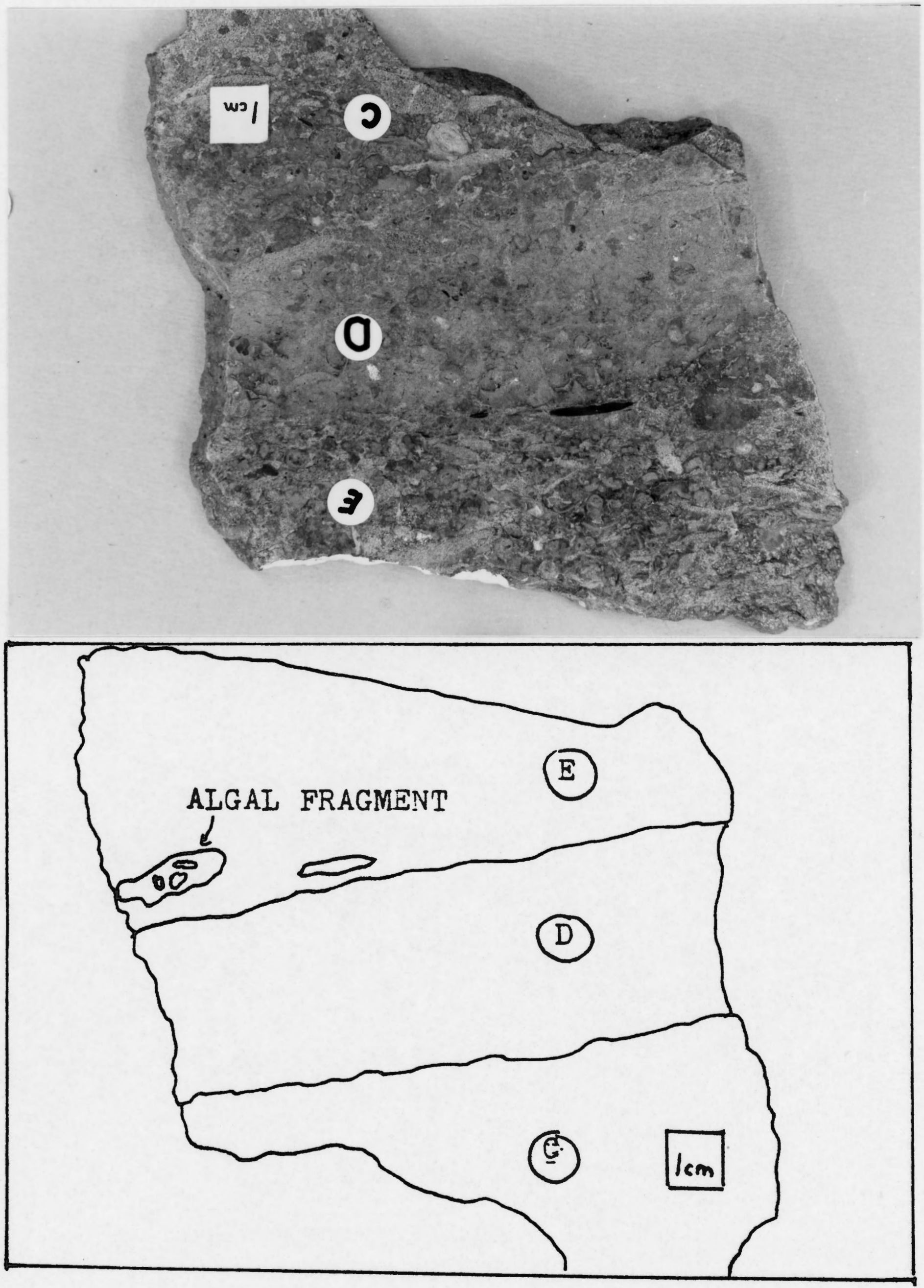


Fig. 27 : Algal packstone (D) interbedded with lithic skeletal grainstones (C),(E).

In both grain size and shape, the grainstones are fair to well sorted for the most part. A direct relationship exists between average clast size and degree of sorting, i.e. the coarser the average grain size the better sorted is the grainstone.

Grainstone porosity consists mainly of two types--intergranular and intragranular. Intragranular porosity is a function of coral and gastropod abundance. Both pore types are filled with varying porportions of sparry calcite, sphalerite and galena. Sparry calcite is the common intragranular cement. As intergranular cement, it overlies both sphalerite and galena if they occur together in the same pore. Coarse grainstones usually have abundant sphalerite as intergranular cement. The sphalerite started as a rim cement which grew outward into the open pore, occasionally completely filling it. The average crystal size of the sphalerite is 0.1 mm. Galena is not as common in the group two grainstones as it is in those of group one. When present the galena forms subhedral crystals 0.9 to 1.5 mm in diameter or occurs as fine veins cutting across the pore spaces.

Lithic Skeletal Packstone

Packstones are uncommon within the decline area. When encountered, they are normally well above the basement, although not always. They are thinly bedded (up to 20 cm), and occasionally interstratified with grainstones. More commonly packstones overlie the grainstones especially in areas situated between basement highs.

Algal fragments, bivalves and peloids are important grain types, with gastropods, ostracods, bryozoa and coral as accessories. Very little siliclastic material is observed and the packstones exhibit fair to poor sorting in shape and size of grains. The packstones contain at least three genera of pelecypods: Aviculopecten sp.; Sanguinolites sp. and the third may be either Steblopteria or Edmondia.

Gastropods noted in the packstones include: Murchisonia, Zygopleura and Straparollus minutus. Minor amounts of fenestrate and ramose bryozoan fragments are also present. As in the grainstones, many of the skeletal fragments have coated exteriors. Moreover, as in the other rock types, dolomitization in the form of anhedral grains ranging from 12 to 20 microns in diameter has blotted out most of the primary microstructure of the bioclasts; exceptions are some algal fragments in which algal tubules are still discernible. Bivalves always occur as single, often fragmented valves, which are commonly nested one on top of the other.

Small round to elongate peloids, unidentified carbonate grains, and seven micron dolomite make up the packstone matrix. Typically, the proportions of these matrix components vary from one area to the next. The matrix may constitute up to 40 percent of the rock volume but averages closer to 15 percent. Shelter effects, floored interstices, and abundant grain contacts observed in the packstones indicate grain support (Dunham, 1962, p. 113). Furthermore, some packstones, especially those dominated by pelecypods appear very similar to the coguina-standard microfacies 12- of Wilson (1975, pl. VIII, p. 427) which he interprets as: "Sediment formed in an environment of constant wave or current action with mud removed by winnowing. .... a common slope or shelf edge sediment." (Wilson, 1975, p. 65).

The packstones contain very minor quantities of sphalerite and galena. Cement consists mainly of microcrystalline dolomite, which was probably calcite or aragonite mud originally. Minor amounts of sparry calcite are also present. Some packstone pores have remained open.

Algal Fenestral Wackestone-Packstone

This rock type forms a thick (7-15 m) continuous cap which occurs in two positions: 1) over the rocks of group two, and 2) over Meguma basement in the portal area where the basement elevation is maximal. This wackestone-packstone thickens northward from the portal area.

Clasts contained in this rock type are: homogeneous lumps, peloids, ostracods, small gastropods, bivalves, fenestrate bryozoa and foraminifera; the most abundant are lumps, peloids and ostracods (Fig. 28). Bivalves and gastropods normally accessory grain types, can be the dominant grain types over short distances (25-100 cm) in the core. Lumps tend to be irregular in outline and vary greatly in size. They range from 0.15 mm up to 20 mm, but the modal value is between three and six millimeters. Lumps have

Fig. 28 : Texture of algal wackestone

elongate shapes and frequently, small algal tubules are preserved within them. There are two forms of tubules: 1) the first form is similar to that found in grains described in the skeletal grainstone lithology--i.e., fine ramifying tubes radiating from the centre of the lumps. The tubes have 56 micron diameters and branch dichotomously with the interbranch angle approximately 40 degrees; 2) the second form is undulating, non-branching, and thick walled, and has a uniform diameter of 40 microns (Fig. 29). This second algal form is possibly Girvanella. Lumps may constitute up to 35 percent of the grains observed in this lithology but the average is 20 percent.

Peloids are abundant within the wackestone. They contribute up to 15 percent of the rock but the average is eight percent. They are round to oval in shape, range in size from 0.08 to 0.22 mm with an average of 0.15 mm and are internally homogeneous. Small algal fragments can be easily mistaken for peloids unless microstructure is preserved or the grain outline is irregular, in which case the grain had an algal origin. Preservation of sharp outline is much better when the peloids occur as internal sediment within bivalve shells. There, individual peloids are easily recognized, whereas within the wackestone matrix peloid outlines are more diffuse.

Ostracods, common within the wackestone have a fairly uniform distribution throughout this rock type. They constitute from three to five percent of the grains. They are white, smooth-shelled forms, flattened in cross-section and measuring from one

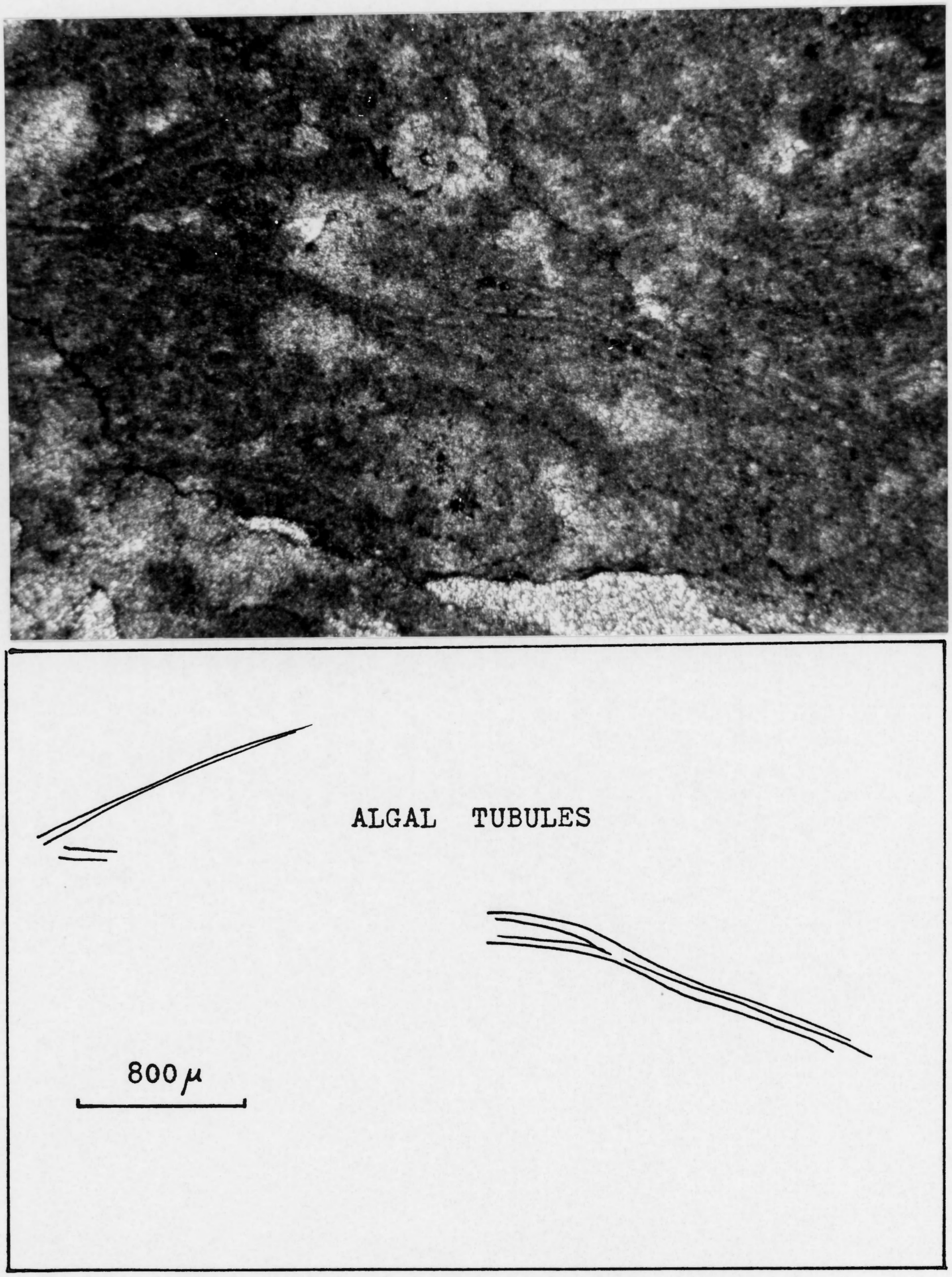


Fig. 29 : Long undulating algal tubules within algal fenestral wackestone-packstone.

to two millimetres long, 0.5 to 1 mm wide. Whole carapaces and single valves occur without any preferred orientation. Ellipsoid-shaped ostracods are not observed with their long axes parallel to the plane of stratification; instead shell orientation appears to be random.

Small gastropods are scattered sparsely throughout the wackestone-packstone, and compose less than two percent of the grains. However, in some sections of core, gastropods may comprise up to 10 percent of the grains present. Only two forms were observed, both are small and both have external coatings. One possibly Stegocoelia compactoidea has an apical angle of approximately 60 degrees; averages five millimeters in length, and is the most common form present. The other form, which is the less common type, has a cuspate exterior and the same average size.

Bivalves are thin (0.5 mm), up to 10 mm in length and have exteriors coated with microcrystalline dolomite. Both whole, articulated shells, and single valves occur with no preferred orientation. The bivalves have a heart-shaped cross section and comprise approximately four percent of the grains.

Bryozoa fragments are rare and when present consist of fragments of fenestrate types which range from two to five millimetres in length.

Foraminifera are also a minor constituent of the wackestone but are more commonly observed in this rock type than in any yet described in this study. Biserial types averaging two millimetres in length are the most common form, with encrusting planispiral forms not as abundant. Both types together constitute less than one percent of the grains.

Coral and siliclastic material are virtually absent in this rock type. An exception is the area near the portal where this rock type immediately overlies basement. In this area, silt and sand-sized siliclastic material may contribute up to 10 percent of the rock. Siliclastic abundance decreases up section in the wackestone.

The depositional texture is a mixture of wackestones and packstones, occasionally intermixed with mudstone. Stratification is not common, and the rock has a mottled appearance, both are possibly a result of bioturbation since packstone-filled, burrow structures are common.

Porosity is variable in this rock type and ranges up to 15 percent. Both fabric selective and non-fabric selective pore types are present. Fabric selective types include: intergranular, intragranular, moldic, fenestral, and shelter. Intergranular pores are the most common type. However, in areas where gastropods and bivalves are common intraparticle and shelter pore are abundant. In core, sections (1-3 m) are seen in which the pores (predominantly intragranular) are filled with white sparry calcite, these sections alternate with sections in which open, moldic pores prevail along with small, secondary, solution vugs. Fenestral pores occur in the uppermost two to four metres of this rock type and range from laminoid to irregular in character (as described by Read (1975) and shown in Fig. 30). The fenestrae are generally flattened and approximately horizontal although, many have an obvious vertical component. Fenestral porosity may be as high as 35 percent. Secondary, non-fabric selective vugs are also present within this lithology. They range from one to 10 mm wide and have irregular outlines usually. Their origin by solution is evident by the presence of partially dissolved bivalve shells (Fig. 31). Solution enlargement of fenestrae is also evident because partially, dissolved bivalve shells are incorporated within the enlarged fenestrae (Fig. 32).

Vugs, fenestrae, and occasionally, skeletal molds are lined with a dark brown rim (Fig. 33). This brown rim is generally isopachous and averages 0.23 mm in thickness. Etching in dilute hydrochloric acid and staining with Alizarin Red S dye indicates that the rims consist of rhombic dolomite (Fig. 34). The dolomite rhombs average 90 microns across their long axes. Only those rhombs which grew outward into the open pore space have euhedral surfaces. Dunham (1972) reports a similar dolomite in the Capitan limestone and he notes that the dolomite is a product of precipitation and not a replacement.

In some pores, the dolomite rim is overlain by crystalline sphalerite. Not all pores contain sphalerite but in those that do the sphalerite occurs as small, euhedral, pale yellow to honey coloured crystals which range from 15 to 140 microns and average 80 microns. Sparry calcite often fills the remaining pore spaces where it overlies both the dolomite rim and when

Fig. 30 : Laminoid to irregular fenestral fabric.

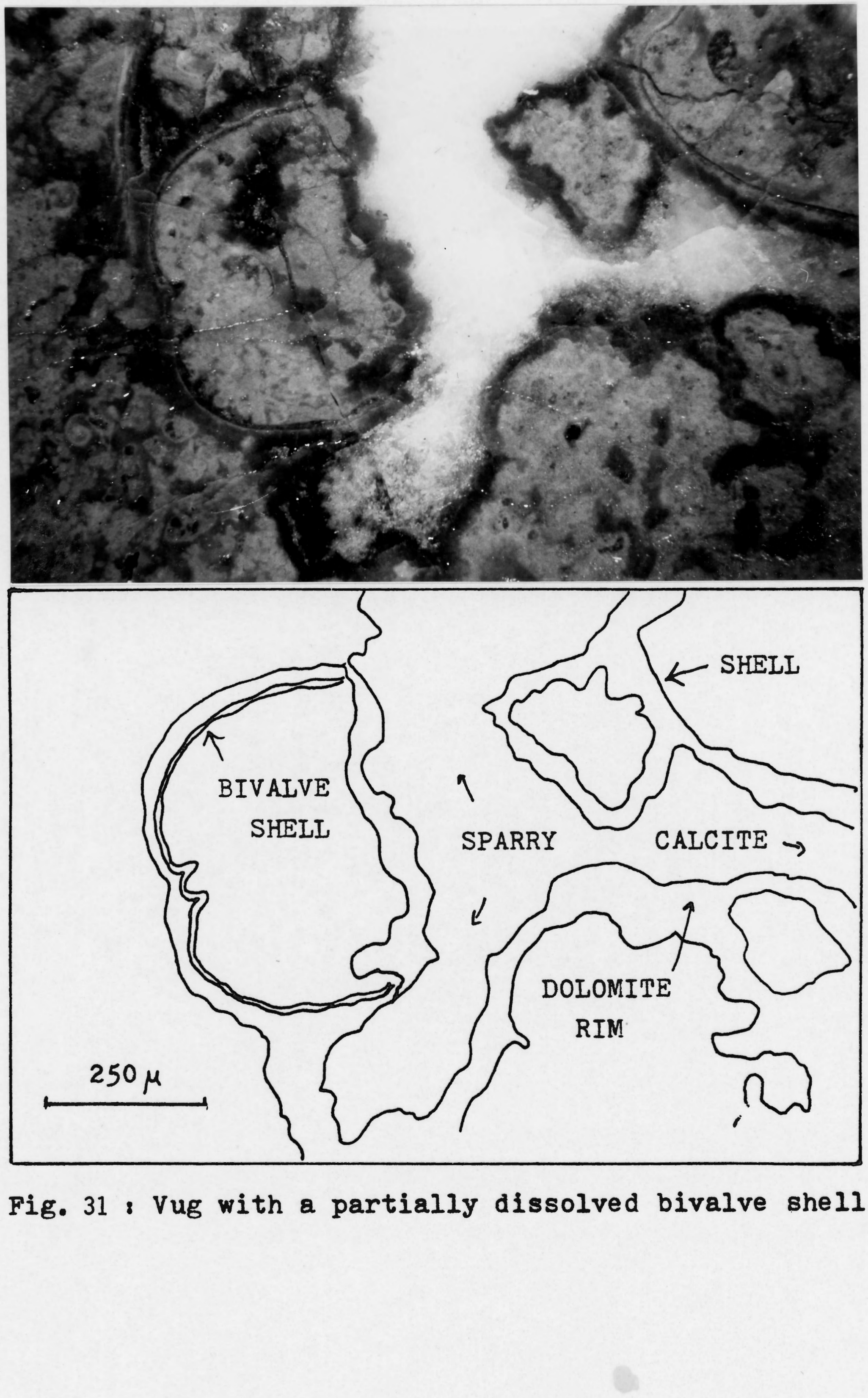


Fig. 31 : Vug with a partially dissolved bivalve shell.

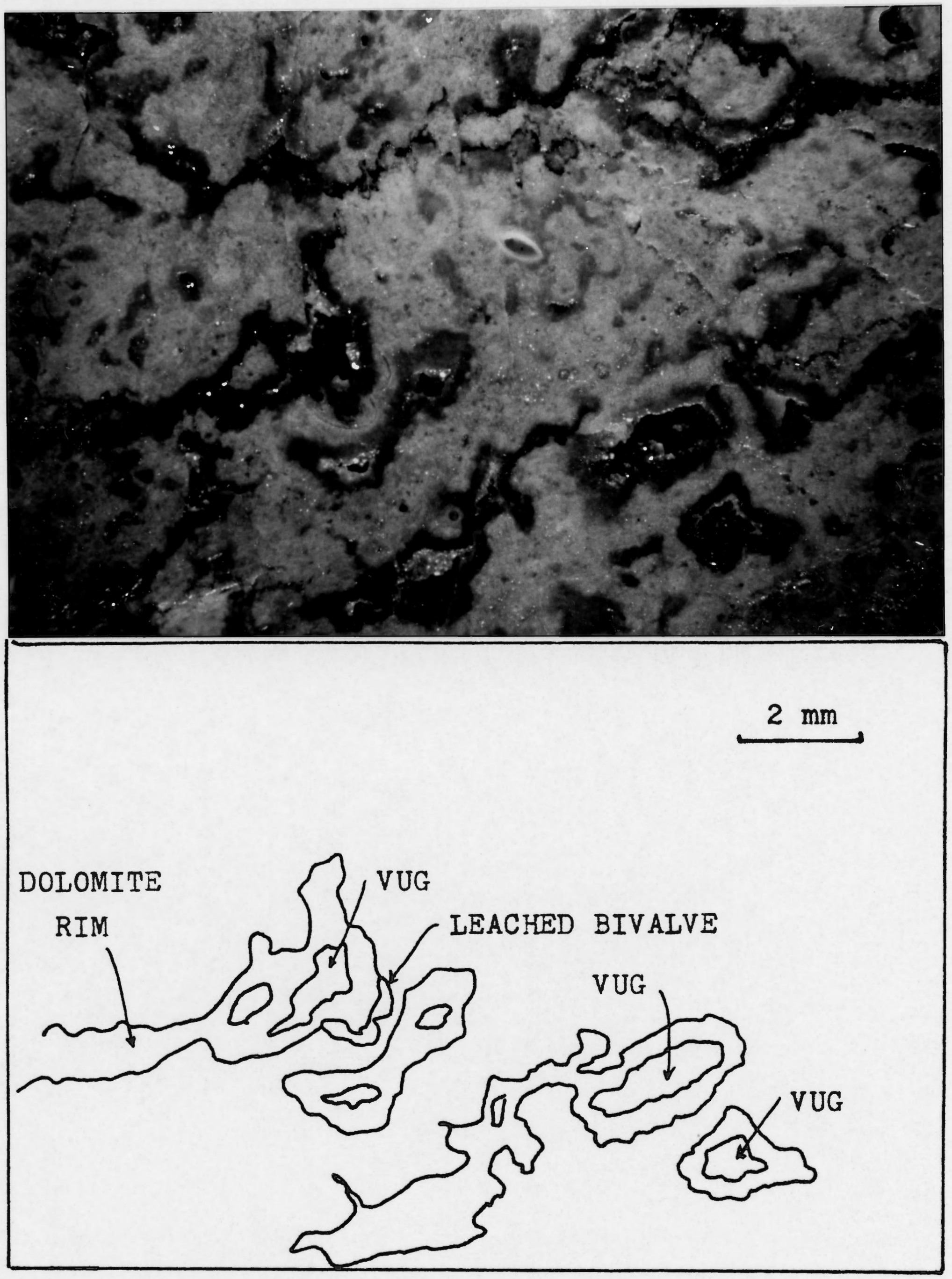


Fig. 32 : Solution enlarged fenestrae

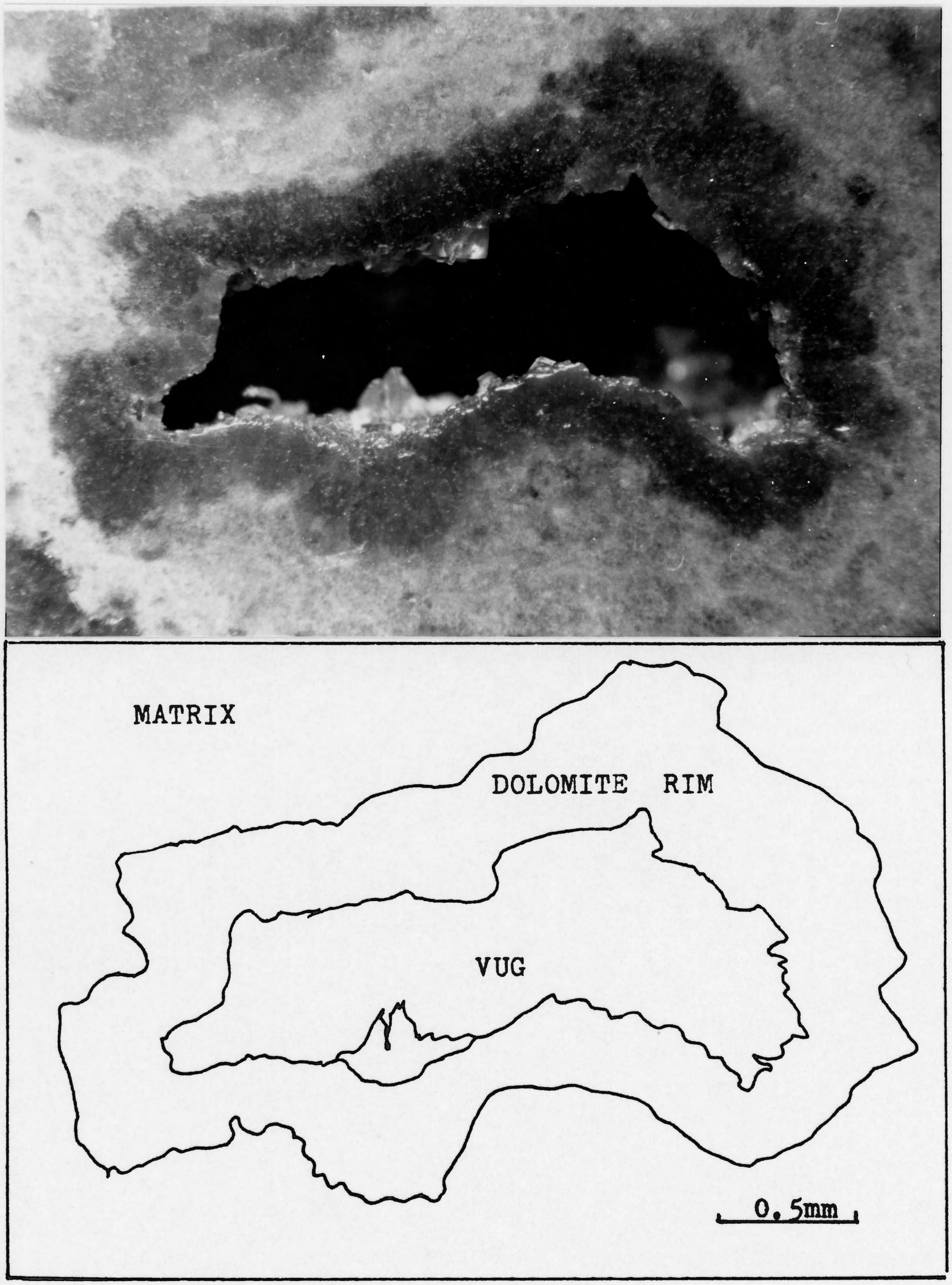


Fig. 33 : Solution pore rimmed by dolomite cement.

present the sphalerite. Figure 34 shows a dolomite rimmed vug which is cut by a fracture. Both the vug and the fracture are filled with optically-continuous, white, sparry calcite. However, only the vug is rimmed by the brown dolomite.

In the portal area, the wackestone-packstone lithology is cut by a widely-spaced (approximately 1 m) joint set. The joints are nearly horizontal, slightly undulating, and almost parallel. They are unique to this lithology. The wackestone-packstone lithology is the only lithology which displays a regular fracture pattern.

Pisolith Ooid Packstone

This lithology has a very limited occurrence. It is found in only one locality in the decline (Fig. 35). The packstone can be traced approximately 1.5 m along the face of the decline in this area but is present on neither the left nor the right side. It is overlain by algal bindstone. Because the packstone occurs at the foot of the face the lithology overlain by the packstone was not exposed.

Figure 36 shows that this lithology consists from bottom to top of: 1) a four centimetre thick section of slightly leached skeletal packstone, 2) a centimetre thick section of very porous, leached oolitic packstone, 3) approximately two centimetres of very porous, pisolitic grainstone in which the pores are filled with sphalerite and galena, 4) 1.5 to 2 cm of fine-grained laminae, in which individual laminations (1 mm) are discontinuous,

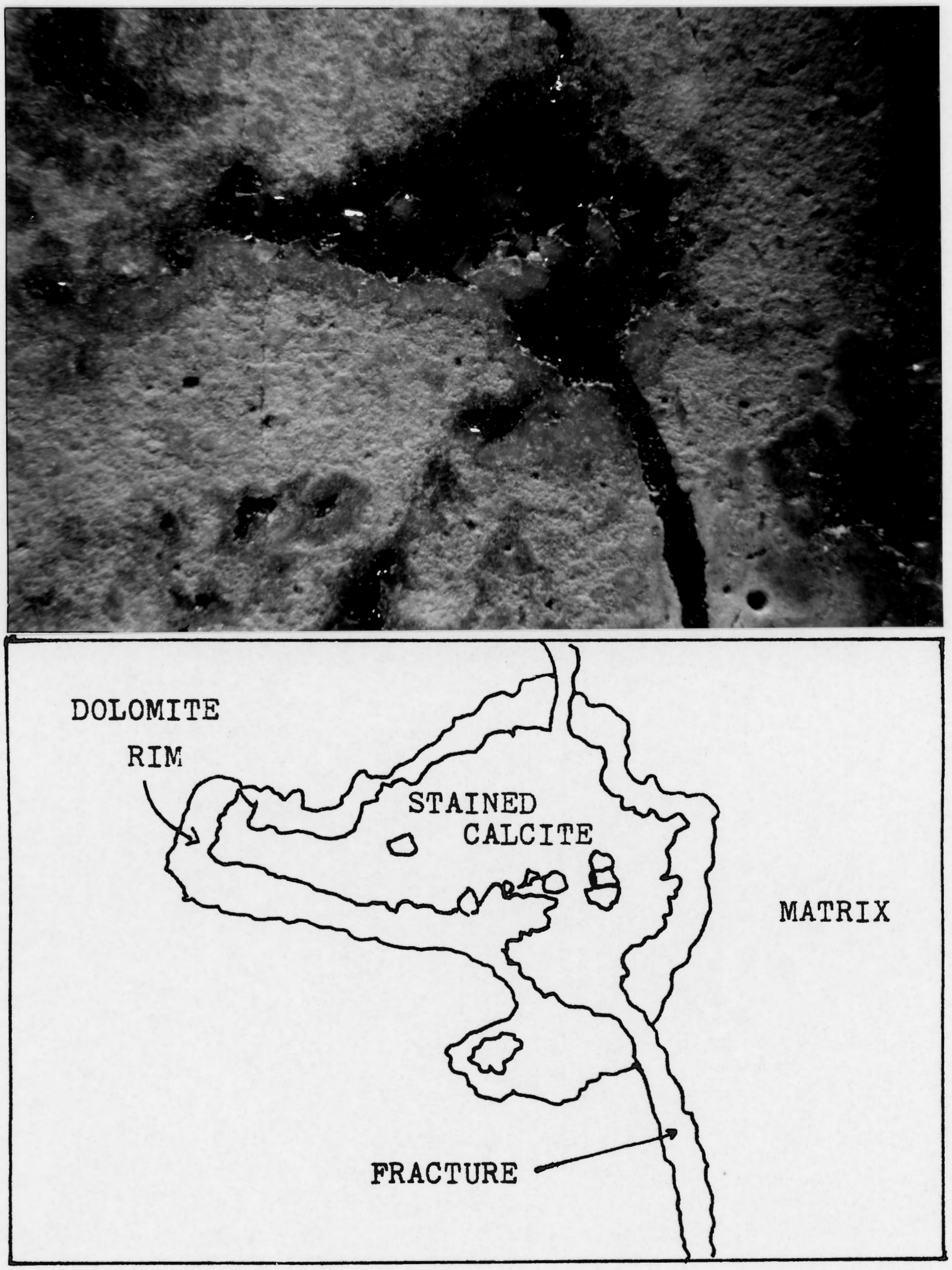


Fig. 34 : Solution vug lined by dark dolomite cement; the vug was fractured, and filled with sparry calcite (stained with Alizarin Red S).

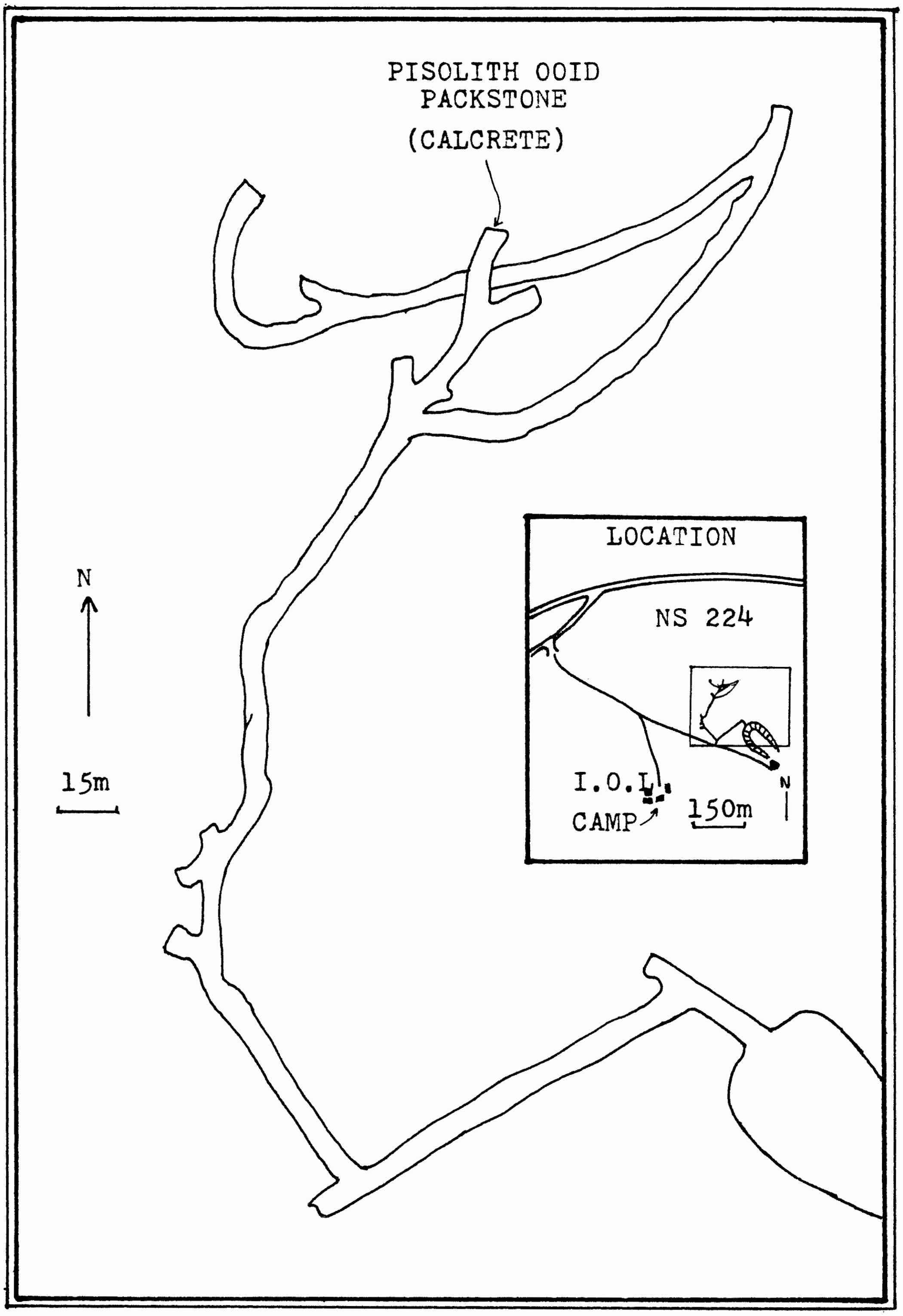


Fig. 35: Decline outline with location of pisolith ooid packstone (calcrete).

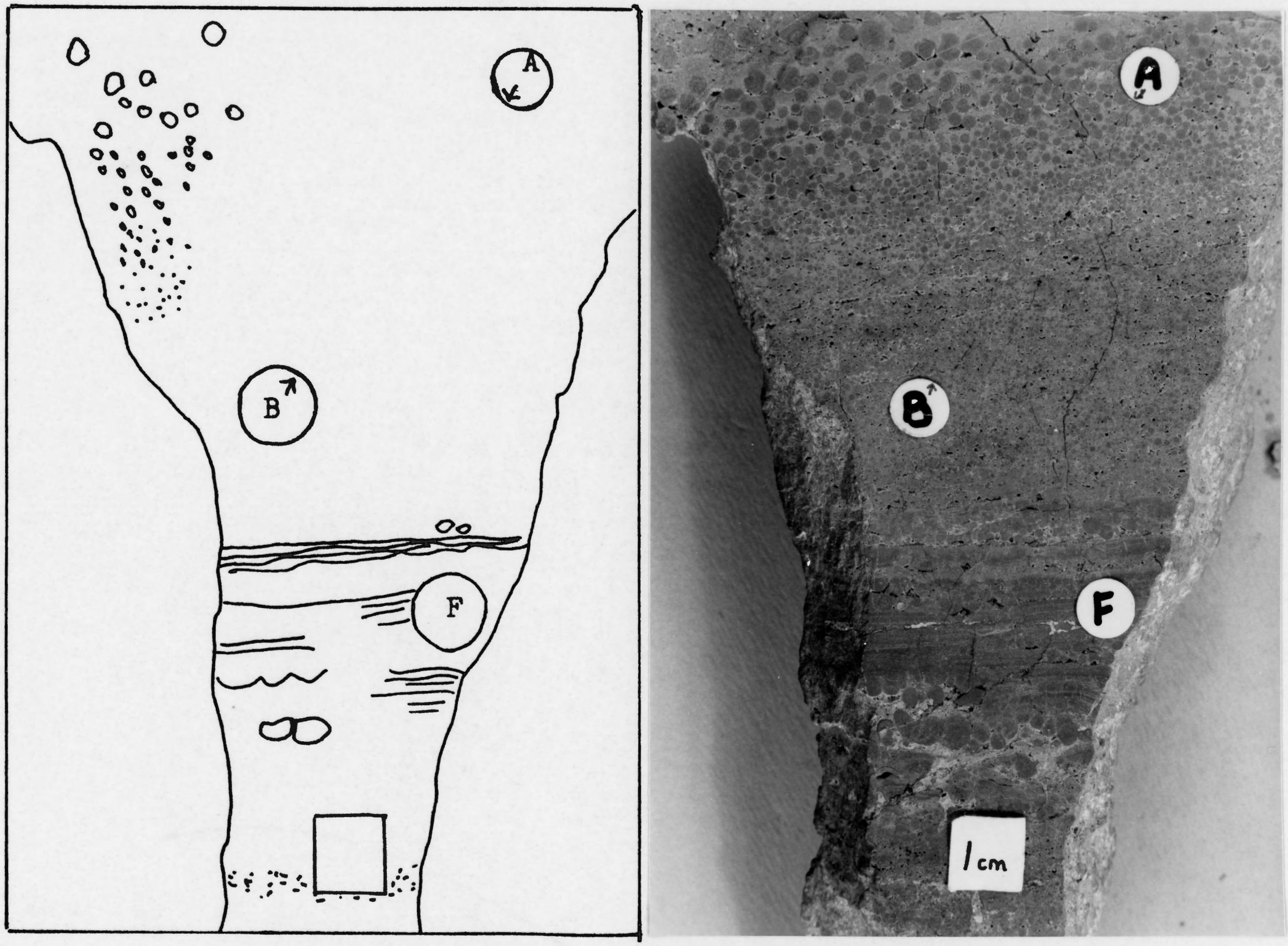


Fig. 36: Pisolith ooid packstone - calcrete profile.
A- reversly graded pisoliths; B- calcrete ooids;
F- laminar calcrete.

slightly undulating, defined by abrupt change in grain size, and consist of round particles which range from 0.04 to 0.13 mm and average 0.075 mm (fine sand), 5) a centimeter thick section of poorly-sorted pisolite and oolite intermixed with weakly-laminated material, 6) a six centimeter section of reversely graded pisolite and oolite. The lower three centimeters consist of ooids imbedded in a microcrystalline (4 microns) dolomite matrix. There is continuous gradation from oolite up into the pisolite. Pisoliths range from two to five millimeters and average three millimeters. They are round to slightly elongate in shape. Although they are normally symmetrical, brecciated and asymmetric pisoliths are present. Distinct nuclei are rare, as both nucleus and cortex are composed of a dolomite mosaic. This mosaic consists of 30 micron crystals. Siliclastic grains are rare. Ooids range from 0.25 to 2 mm and average 0.55 mm. In hand specimen, both ooids and pisoliths occasionally exhibit concentric growth rings. These rings are not apparent in thin section. Usually the number of rings present is small. The maximum number of growth rings observed was six.

Matrix in this rock consists of microcrystalline dolomite (7 microns), and crystalline sphalerite which ranges in size from 16 to 170 microns and averages 90 microns. The matrix is more abundant within the oolite than in the pisolite. In the oolite, although grain-support is generally clearly exhibited, some patches of oolite appear to be in mud-support. Most of (70%) the interparticle porosity within the oolite is filled with microcrystalline dolomite, very little sphalerite (less than 5%) is present. On the other hand, pisolite matrix is less abundant (30%). In the pisolite the matrix often drapes discontinuously over the pisoliths to form descrete layers (Fig. 37).

Shelter pores beneath adjacent pisoliths are usually rimmed and/or filled with sphalerite, although some small pores are open and do not have sphalerite rims.

CHAPTER V DISCUSSION AND INTERPRETATION

DISCUSSION

In this section, I will attempt to:

1) Interpret the rock types in terms of their depositional enviroments;

2) Place the rock types within a depositional model, specifically an organic framework reef as defined by Heckel (1974) Fig. 41;

3) Show that during deposition, subaerial exposure and formation of calcrete occurred in at least one area;

4) Show that correlation, even lithostratigraphic correlation, between adjacent drill core is not possible on the map scale used (1 cm = 25 cm);

5) List a partial, chronologic history of diagenetic events.

Interpretation of Rock Types

The geometry of the two groups of rocks is important in interpreting the depositional environment. As Figure 38 shows

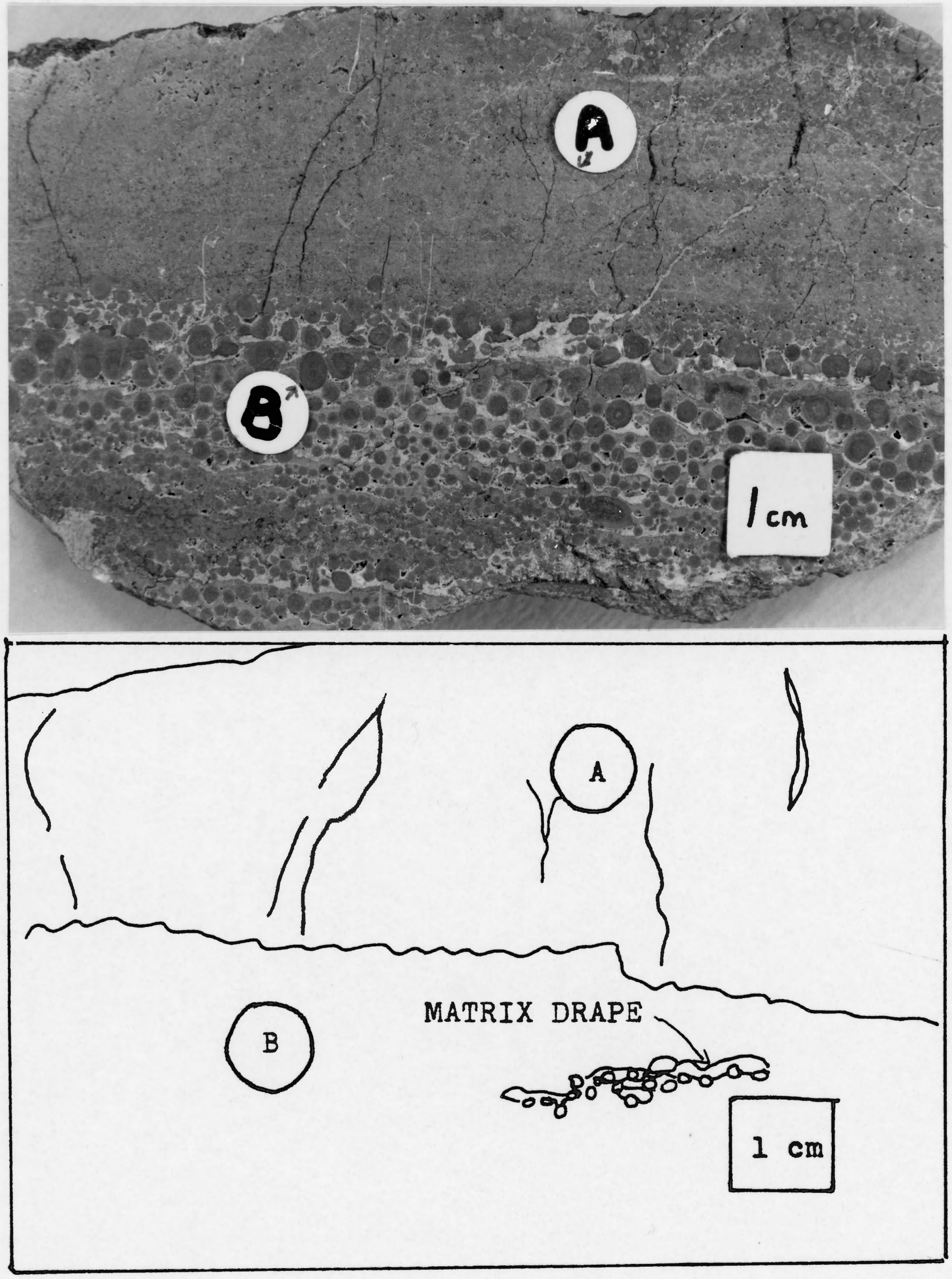


Fig. 37: Pisolith ooid packstone - calcrete.
A- calcrete ooids; B- calcrete pisoliths.

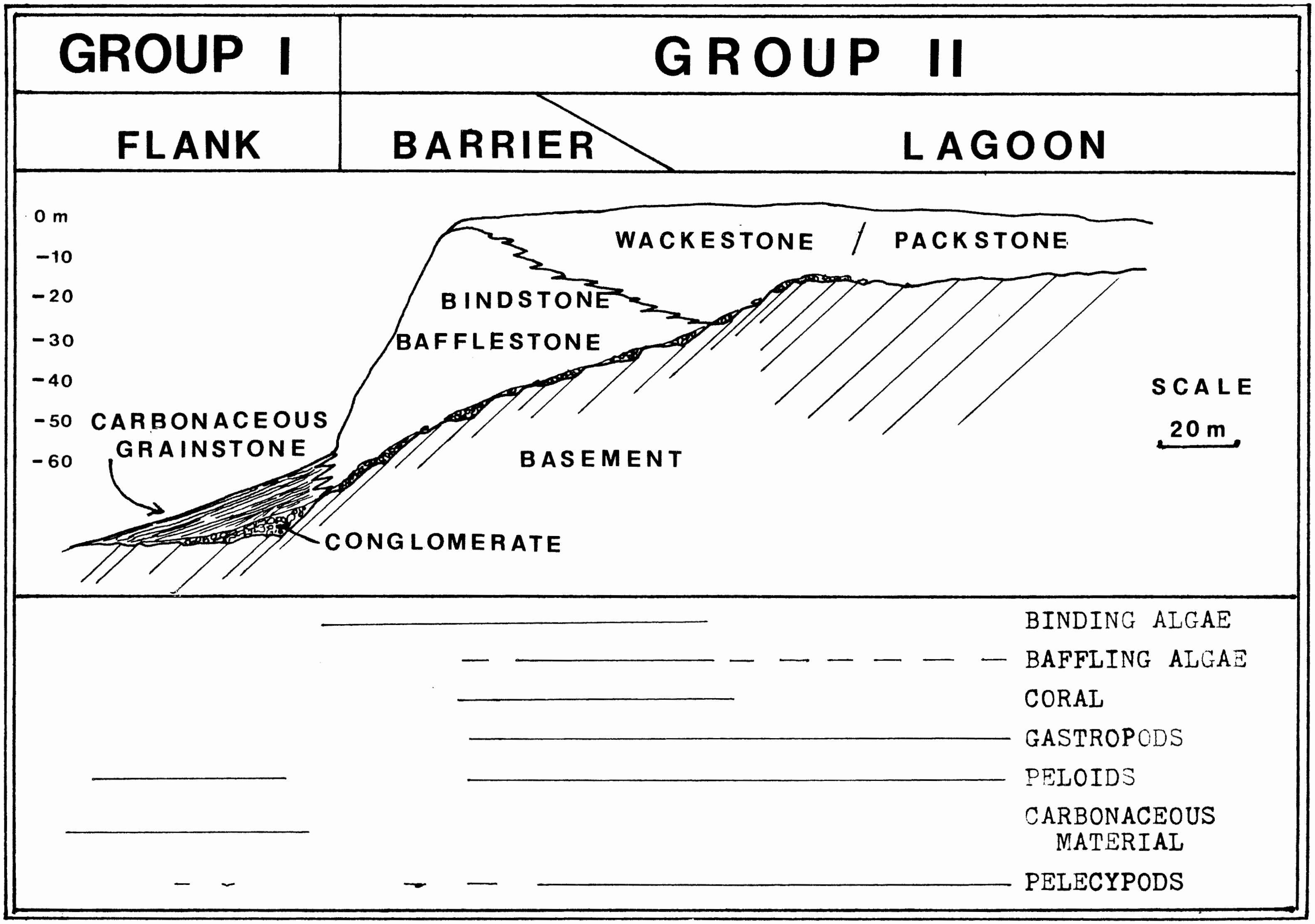


Fig. 38: Depositional model for carbonate-rock types exposed in the decline.

the group one rocks occur at the base of the basement high. The group two rocks were deposited on the basement high.

Basal Conglomerate:

In both rock groups the clasts of this rock type represent a pre-carbonate-deposition deposit. The carbonate matrix was added during transgression. The discontinuous distribution of the conglomerate as thick pods on the basement steps, and the thick accumulations within re-entrants at the foot of the basement high implies a scree origin for the conglomerate clasts. This is supported by the angularity of the clasts. Most of the fines were probably carried downslope by streams and runoff. Some were removed during transgression. Some escaped by filtering down into the talus deposit. This last point is evident from the high content of silt and sand-size material contained in the matrix which occurs in the lower portions of thick accumulations of the conglomerate. In contrast, the upper portions have a matrix rich in skeletal carbonate and these portions exhibit weak grading. During transgression, as the water depth increased the scree material was less intensively reworked. This decrease in the amount of reworking caused the weak grading.

If physical weathering produced the scree material then there would be more coarse material than fines produced because of the hardness of the Meguma metasediments. The contact between carbonates and basement is fresh. Had chemical erosion occurred before carbonate deposition, a zone of alteration would be present in the basement rocks. Such a zone is present in areas where these same basement rocks crop out and are exposed to chemical weathering today. Furthermore, this alteration zone has formed since the last glaciation a maximum of 18,000 years ago. Therefore, it seems probable that mechanical or physical weathering was the dominant agent involved in the production of conglomerate clasts, and so abundant fines may not have been produced.

Most of the carbonate rock types except the algal fenestral wackestone-packstone contain various sizes and amounts of Meguma clasts. This means that there was a continuous but decreasing contribution of basement clasts from the exposed topographic high during carbonate deposition. The amount of Meguma clasts decreased as the basement became covered by carbonates.

Infrequent, very round, discoid boulders of Meguma occur within the conglomerate. These are usually close to the conglomerate basement contact. The discs are scarce and on average are much smaller than most of the large, angular blocks. It is difficult to explain the presence of these texturally, very mature discs which occur in what seems to be an immature partially reworked scree deposit. Very similar clasts are presently formed on shingle beaches located along energetic coastlines.

Group I Rock Types

Carbonaceous Skeletal Grainstones:

This rock type represents a flank deposit found at the foot of the bindstone buildup. The wedge-shape form, basinward dip, and location within basement re-entrants point to a debris flow origin. Other factors such as: the well developed bedding, which is often weakly graded; lack of in situ fauna; presence of large blocks of previously-lithified bindstone material and Meguma clasts; plus the presence of black carbonaceous material; and scoured contacts suggest deposition in deeper anoxic water as discrete, occasionally large-sized, debris flows. The material for these flows originated up slope in the bindstone and grainstones.

Gypsiferous Peloidal Wackestone:

This rock type is very difficult to interpret because of limited data. I believe the mechanism of gypsum formation is critical to the understanding of the depositional environment of the wackestone. It is not yet known how the thick deposits of gypsum which flank both sides of the Gays River carbonates were deposited. The evaporites may be shallow water deposits similar to those described by many writers including Kinsman (1969), Schreiber and Friedman (1976), and specifically Schenk (1969) for the Windsor evaporites. On the other hand, the evaporites may be deep water deposits as Smaltz (1969) has modelled and Evans (1970) evokes for the Windsor Group.

The wackestone is barren of skeletal material. This may mean conditions were adverse and life forms could not adapt to the environment. The wackestone contains porphyroblasts which consist of gypsum, sphalerite and galena. The matrix around these porphyroblasts is fractured and the fractures are filled with gypsum, galena, and sphalerite. Because the matrix is fractured the carbonate must have been lithified at the time of porphyroblast formation. Porphyroblast formation is possibly connected with the start of gypsum formation and therefore, there may be a slight time gap between the last carbonate-peloid wackestone and the first gypsum precipitation.

A second set of gypsum-filled veins cuts across both the wackestone matrix and the prophyroblasts. These latter fractures are oriented vertically and contain only gypsum. Without more information on the formation of the gypsum--deep or shallow--I cannot meaningfully interpret these peloidal wackestones.

Group II Rock Types

Algal Bindstone:

Massive form, presence of grainstone-filled cavities, and the association of both encrusting algae and bryozoa suggest deposition in a shallow, energetic, subtidal environment. The presence of such large, grainstone-filled cavities which are too large to be interstices is one of the criteria Dunham (1962) used to indicate sediment binding. The encrusting algal-bryozoa association built a framework. This framework was rigid enough to resist the water turbulence needed to move the pebbles and cobbles of Meguma found within the grainstones. These cavities represent channels. They cut the bindstone and have a basinward trend (W-NW). Eventually bindstone growth roofed these channels.

Associated with the algae and reticulate bryozoa are ramose bryozoa, coral and bivalves. The ramose bryozoa, coral and bivalves grew in protected pockets formed within the irregular framework of the bindstone.

From drill core data and as indicated in Figure 39 the first in situ bindstone material occurs on the basement at approximately the -60 m contour. Below this contour either carbonaceous grainstones or basal conglomerate lies upon the basement. Evaporites usually overlie these two lithologies below the -60 m contour; but sometimes, especially as one approaches and goes above the -60 m contour the contact between the evaporite and the carbonates has undergone extensive solution. The fact that in situ material (bindstone) does not occur below the -60 m contour means either: 1) the initial transgression was rapid and shallow water organisms could not establish themselves until the rate of transgression slowed; or, 2) during the initial transgression the waters were so turbid with siliclastic material that organisms could not survive. They could not establish themselves until the water cleared. The water cleared as wave base rose, leaving the fines to settle in deeper water. Once the water cleared the algae and bryozoa established themselves on the clean basement and on clasts of basement material (Fig. 40). Once established the bindstone grew vertically and laterally with the rising water level and maintained their position near wave base.

Lithic Skeletal Grainstone:

Figure 41 shows these grainstones are intimately

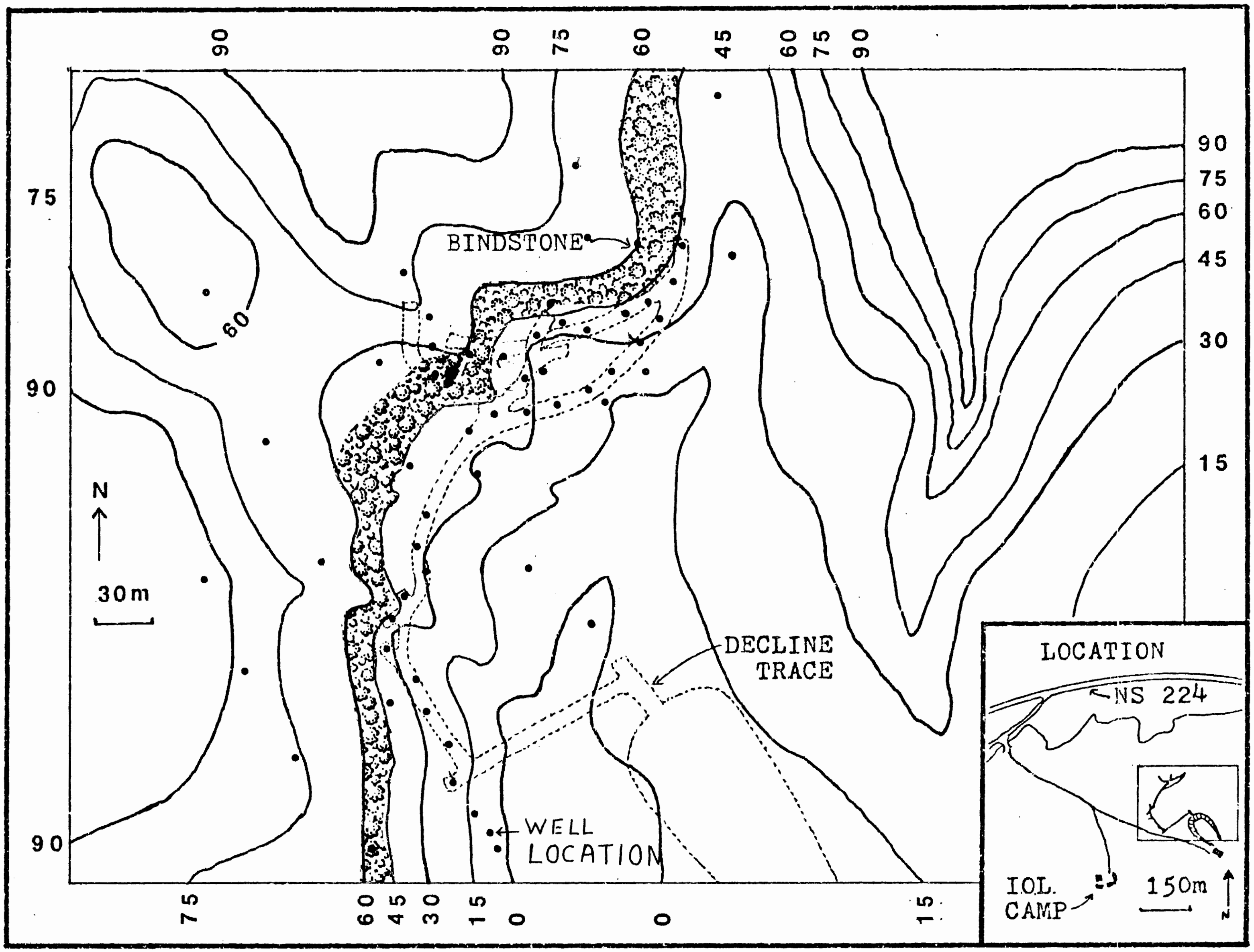


Fig. 39 : Basement contours (metres) with zone of lowest in-situ algal bindstone.

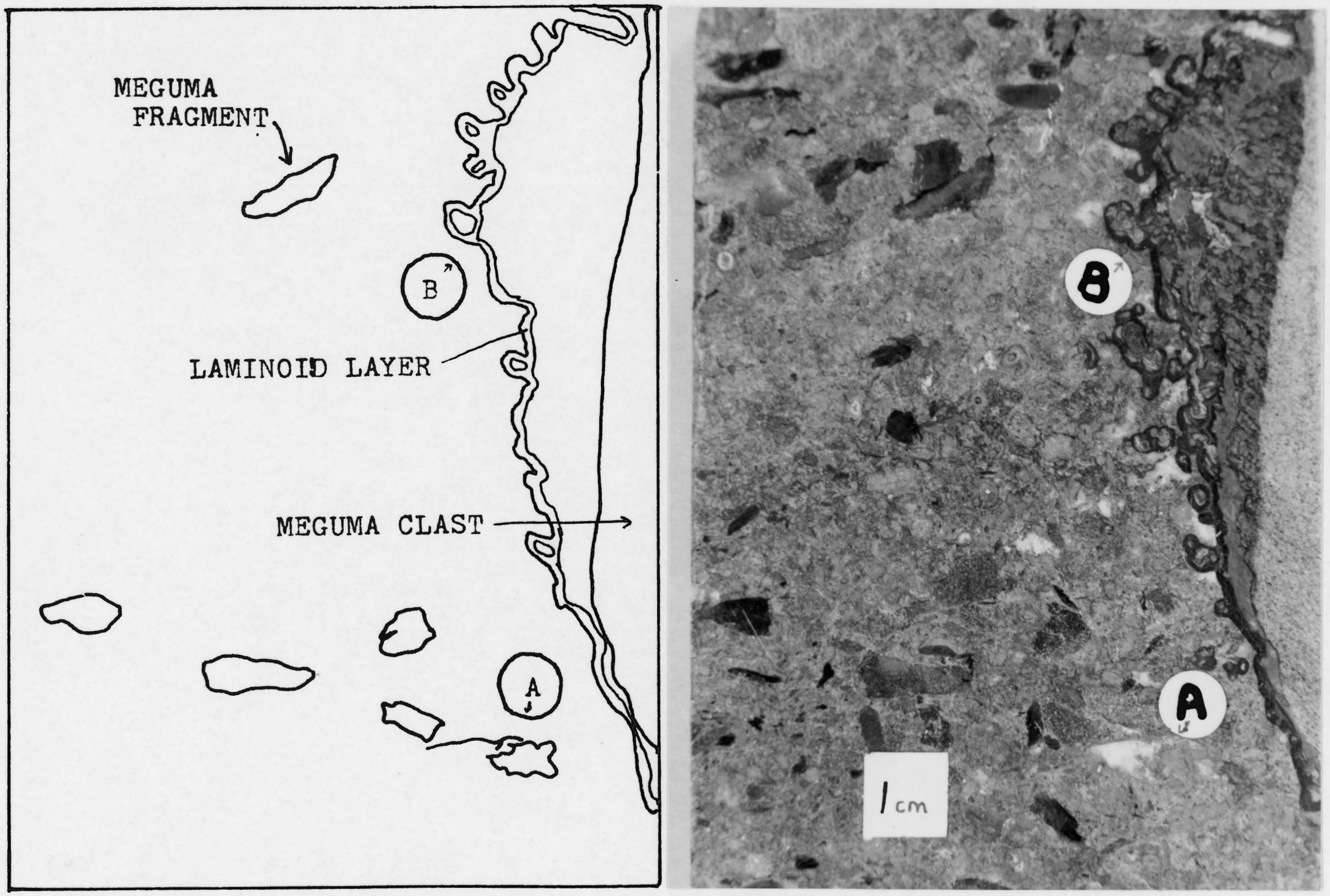


Fig. 40 : Meguma boulder encrusted by algal-bryozoan bindstone.
A- shelter pore; B- bindstone.

associated with the algal bindstone. The grainstones have short cross sectional lengths and appear channel-like in form. They are cross-bedded and often exhibit scoured contacts (Fig.20). Water movement during deposition had to be strong enough to move the many pebbles and small cobbles of Meguma, contained within the grainstones. I believe these grainstones represent channel fill deposited in basin trending channels. The channels under the influence of waves and currents funnelled loose skeletal material, broken pieces of bindstone and Meguma clasts through the bindstone barrier. This process is described by Goreau and Land (1974) for sediment in the Jamaica forereef environment.

In the Jamaican forereef the authors note that areas of active framework growth are clearly separated from areas of unconsolidated sediment. Goreau and Land never found any place where the forereef extends unbroken by sand channels for more than a few hundred metres. Though the channels may be overgrown, the authors observe that some path for sediment drainage must always remain open. Similar overgrown channels occur in the Group two bindstone in which lithic skeletal grainstone is surrounded by algal bindstone (Fig. 42). Goreau and Land observe that although downslope movement of sediment occurs in several ways, slow downslope surface creep of sediment is probably the most effective method. However, after blasting away part of the reef, the authors observed evidence of sedimentation within a basin-trending channel. Sedimentation in this channel was in the form of large, blasted-out reef blocks which had been carried downslope for approximately 40 m.

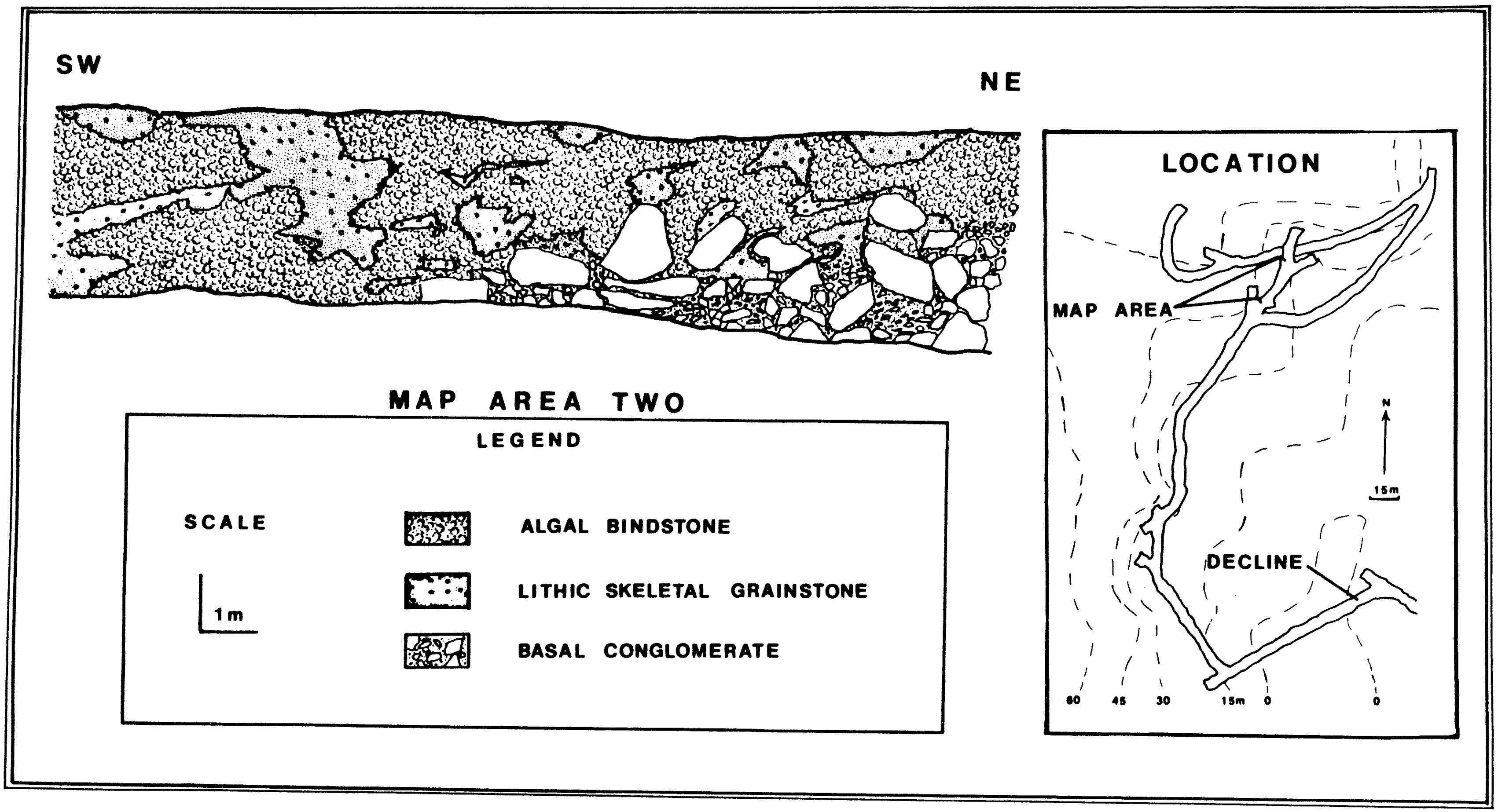


Fig. 41 : Map of area two.

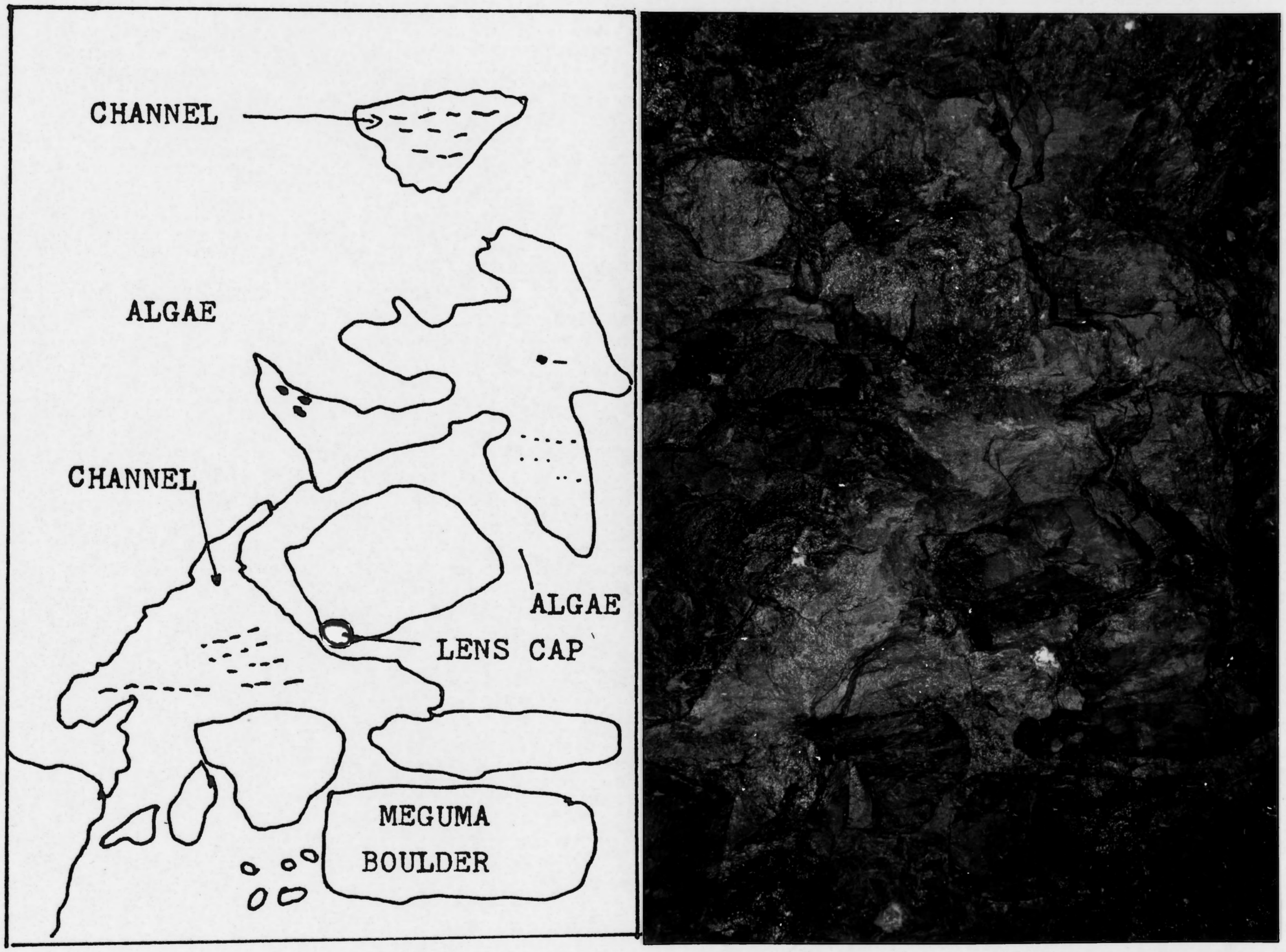


Fig. 42: Channel structures cut in algal bindstone.

The blocks had overridden calcareous algae without tearing them up and were stopped by a six millimetre diameter steel rod which the authors had emplanted in the channel axis to measure erosion. Goreau and Land also noted erosion in the form of small scour marks and exposure of holdfasts of bowled-over, but not uprooted calcareous algae. The authors comment that they do not know whether such an agent of transport analgous to a turbidity current is a common natural phenomenon.

A natural event such as a storm or tsunami might explain the presence of the thick grainstone bed in group one which contains the large blocks of bindstone (Fig. 43).

Lithic Skeletal Packstone:

The packstones by and large are the same as the grainstones. They are different because they contain a matrix. Figure 44 shows that in this area the packstones have much the same distribution as the grainstones and in this area the packstones are considered as deposits within quieter areas, possibly in channels which were no longer active because they were cut off, or blocked by broken bindstone material. In other sections of the decline the packstones are interbedded with grainstones. Sometimes these packstones are dominated by bivalve valves. These valves are commonly nested one on top of the other. Nested valves infer that bioturbation was not extensive in this unit in which they are present. Toots (1961) noted that bioturbation results in objects with preferred orientations becoming reorientated and normally the

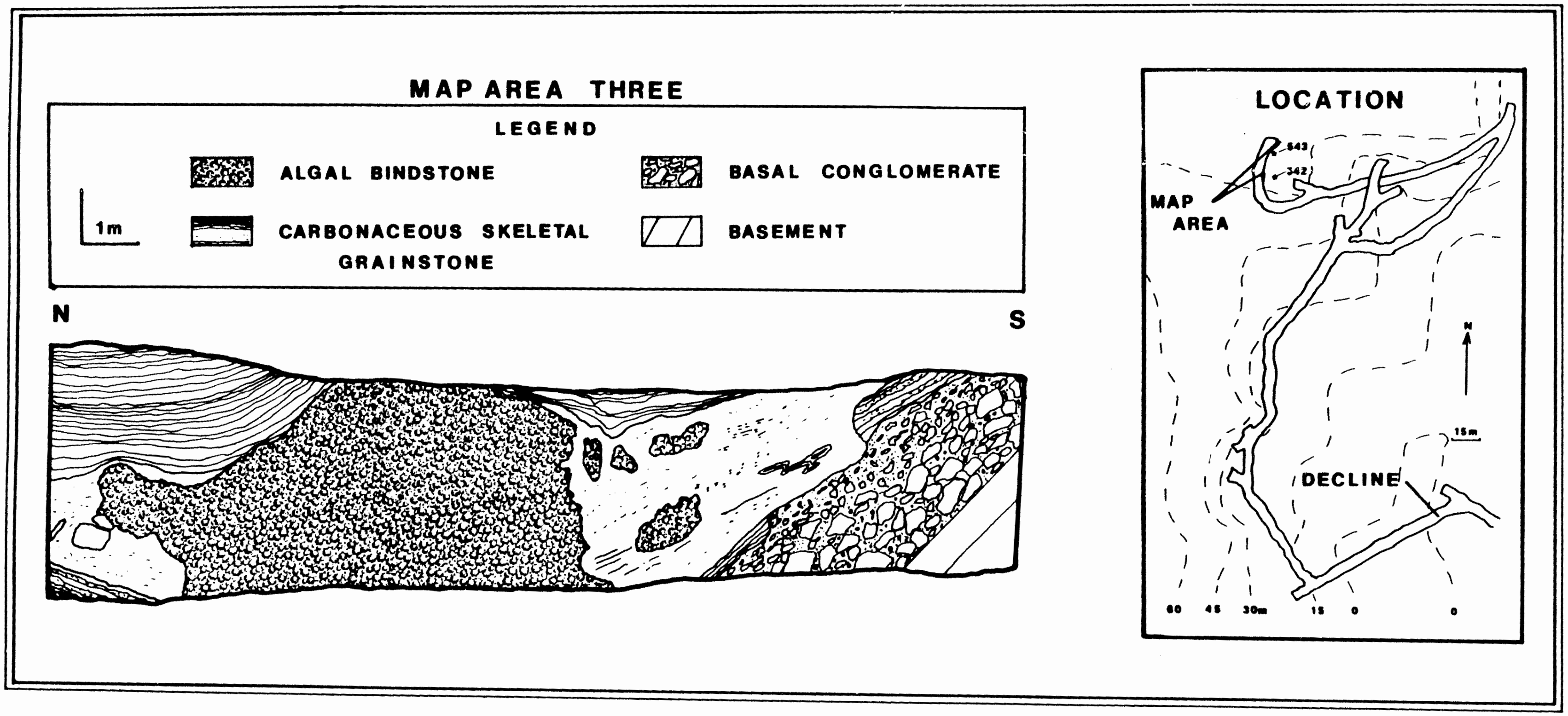


Fig. 43 : Map of area three.

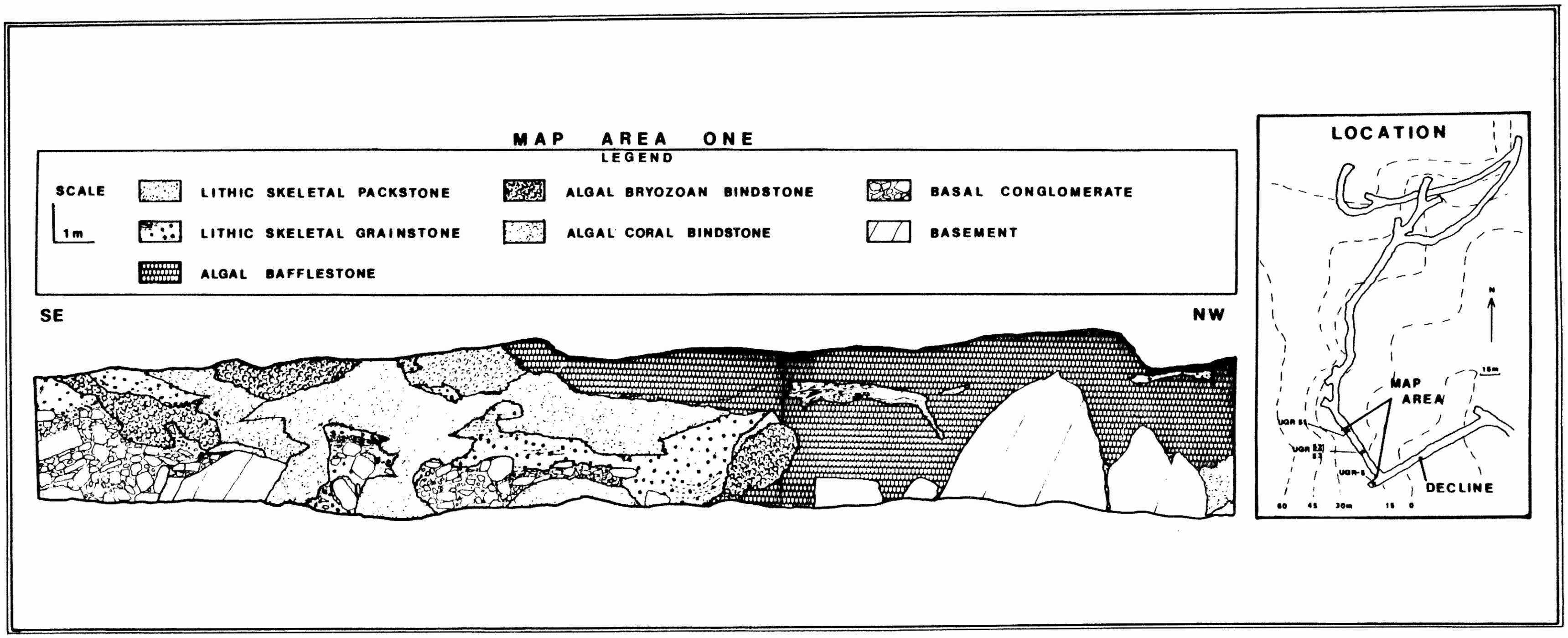


Fig. 44 : Map of area one.

bedding is disrupted. In addition, with respect to valve orientation, there is no preferred position apparent, approximately half the valves are concave up and the rest are oriented concave down. To draw conclusions about the depositional environment for bivalve packstones showing such valve orientation is difficult. In the first place, concave down oriented shells are a normal result of a hydrodynamically active environment (Reineck and Singh, 1975, p. 136; Emery, 1968a). Emery (1968a), and Clifton (1975) observe that the concave up orientation is the dominant orientation in quiet water, bioturbated environments. Both Emery and Clifton note that in such environments concave up is the bioturbational stable position.

Algal Bafflestone:

I interpret this lithology as an algal bafflestone because of the organic-like form of the baffle structure (Fig. 18). They are very delicate. They are associated with the tabulate coral Cladochonus. Meguma clasts are absent except for silt and sand-size material which is present within interstices between the baffle structures. Occasionally, a boulder of Meguma is present in this lithology. In such cases, the baffle structures around and beneath these boulders are only slightly deformed. No ploughing effect is produced by the boulders within the bafflestone. If the boulders slowly slid downslope over the tops of the baffle structures deformation may only be slight. Goreau and Land (1974) noted that after blowing apart a portion of the forereef of Jamaica, calcareous algae were not torn up, even after large blocks of reef material had overridden the algae. Possibly the boulders present in the bafflestone are actually in grain support in three dimensions. They only seem to be embedded within the bafflestone. In three dimensions the boulders may be in grain-support with other boulders which cannot be seen. Algae grew up to and around these boulders and used them as substrates. This would necessitate a very open boulder framework. The framework must allow sufficient light to be absorbed by the algae for photosynthesis. Otherwise, if the boulders blocked out the light, the algae could not have grown beneath them.

The uniform orientation and size of the baffle structures are reminescent of certain green algae, notable the family Codiacae. However, all modern codiacean algae have segmented thalli, which upon death of the organism, disarticulate to form sand and mud sized carbonate sediment (Wray, 1977, p. 80). If the algae which forms the baffle structure in the bafflestone is codiacean, as Brinkle (verbal comm., 1977) suggests, then this species represents a form of Codiacae which did not possess a segmented thalli.

Perhaps the baffle structure belongs to the red algae family. Unsegmented Goniolithon sp. found in the shallowest water of the windward margin of Rodriquez Bank (Turmel and Swanson, 1976) has a somewhat similar branching habit. Turmel and Swanson note that the red algae are restricted to a well defined zone on the windward margin of the bank. In addition the branched growths of Goniolithon entwine to form a dense, forest-like growth that completely covers the bottom. Maybe the baffle structures are a Mississippian analogue of Goniolithon, only slightly smaller and more dense.

Two other possible origins have been suggested for the baffle structure. C. Schrieber (oral comm., 1977) suggested that the fabric may represent an original gypsum fabric replaced by carbonate. Schrieber and Schrieber (1977) report a similar structure formed by precipitation of primary gypsum crusts in the Gessoso-Solifera Formation in Italy. The in situ presence of the tabulate coral Cladochonus intimately associated within the baffle-stone fabric (Fig. 21) refutes an evaporite origin for the baffle structure. L. Jansa (oral comm. 1977) suggested that the fabric may be a dolomite pseudomorph of aragonite crystals. However, the presence of abundant sand-size siliclastic grains within the interstices between the baffle structures implies that the structures were not originally fragile aragonite crystals. Indeed, the very presence of sand-size siliclastic grains necessitates currents strong enough to carry these grains. Such currents would cause the sand grains to abrade the aragonite crystals; on the other hand, the baffle structure branches are not abraded but exhibit finely tapered points. Channels filled with grainstone material incise the bafflestone (Fig. 44). These channels are evidence of strong current activity which fragile aragonite crystals could not have withstood.

Algal Fenestral Wackestone-Packstone:

This rock type contains abundant mud and peloids; and few species of algae, bivalves, gastropods and foraminifera. The lack of stratification, abundant bioturbation features, and absence of crinoidal material suggest deposition in a restricted, shallow lagoonal environment.

Fenestrae (Fig. 30) are common in the upper portion of this lithology. These fenestrae are interpreted as representing deposits in the middle intertidal environment and result from the formation of pustular algal mat (Hagan and Logan, 1974; Logan et al., 1974; Read, 1975). As Figure 30 indicates the fenestrae are unlaminated to poorly laminated and have a slight vertical elongation. According to Logan et al. (1974) the pustular mat grows in well drained middle to upper intertidal areas. The pustular-mat biotope extends through an energy regieme from wave-agitated headlands through semi-protected bights to protected tidal flats. The fabric which results from pustular mat formation is described as irregular fenestral. Logan et al. (1974) and Read (1975) describe this fabric as equidimensional fenestrae, 1-10 mm in diameter, which are irregularly distributed and occupy 40-50 percent of bulk volume; rarely a crude stratification is formed by rough alignment of elongate fenestrae. Normally this fabric is developed in pellet packstone or intraclast pellet grainstone.

Logan et al. write "that the fenestrae form under hollow pustules by detachment of mat-sediment layers from the substrate. The roofing layer hardens and voids are maintained by cementation of the surrounding sediment." (Logan et al., 1974, p. 155). Processes such as growth expansion, shrinkage and swelling with alternate wetting and drying contribute to the distortion of the semi-coherent sediment and create new voids. Pustular mat is rapidly oxidized, and there is little organic material left in the sediment.

Read (1975) figures an example of irregular fenestrae which is very similar to the material found at Gays River and which is shown in Figure 30.

Pisolith Ooid Packstone:

The lithologic profile (Fig. 36) implies formation under subaerial conditions as part of the soil forming process. I believe this is a very good example of a calcrete profile and will develop reasons why I believe this in a later section.

Environmental Model

I believe the carbonate lithologies studies represent an organic framework reef as defined by Heckel (1974). Heckel (1974, p. 96) defines a reef as a carbonate buildup that displays: 1) evidence of a) potential wave resistance, or b) growth in turbulent water which implies wave resistance; and 2) evidence of control over the surrounding environment. Before it is possible to argue that the carbonates at Gays River fulfill Heckel's definition of a reef it must be shown that the lithologies represent a carbonate buildup.

Both Heckel (1974) and Wilson (1975) have defined carbonate buildup. Both definitions are virtually the same. One exception is that Heckel requires that the carbonate mass which is called a buildup is typically thicker than the surrounding equivalent carbonates. Wilson does not have this requirement. Table 1 shows both Heckel's and Wilson's definition of a carbonate buildup in point form. Also listed on Table 1 are the observations made at Gays River which confirm that the carbonates are a buildup.

Gays River as a Reef

We have already seen (Table 1) that the carbonates represent a buildup, but do they exhibit any evidence of potential wave resistance?

Evidence for Wave Resistance:

Wave resistance of a carbonate buildup is a relative term which depends upon such things as: wind, length of fetch, and the surrounding bathymetry (Stanton, 1967). Kornicker and Boyd (1962) write that " .... a community in relatively protected waters may build a wave resistant structure which lacks the rigidity of frame which would characterize a reef maintained in open ocean conditions." This means that organisms building their substrate into the surf zone in an epicontinental sea (such as the Windsorian sea; Howie and Barss, 1975) could be much smaller and less rigidly bound than organisms building into the surf zone in oceanic regiemes (Heckel, 1974). In addition, Boehner (1977) reports that there are at least

TABLE I

COMPARISON OF BUILDUP DEFINITIONS OF HECKEL (1974) AND WILSON (1975) WITH OBSERVATIONS AT GAYS RIVER

DEFINITION OF CARBONATE BUILDUP		GAYS RIVER OBSERVATIONS
HECKEL	WILSON	
1) mass differs from equivalent deposits and surrounding and overlying rocks	1) locally formed laterally restricted	1) carbonates are restricted to the topographic high. They differ from equivalent-Interbank Facies of Boehner (1977) -gypsum flanks both sides
2) typically thicker than equivalent beds	--	2) Boehner (1977) - Interbank Facies rarely exceeds 3 m, whereas, Gays River carbonates average 25 m, never less than 10 m
3) probably stood topographically above surrounding sediment during depositional history	3) possesses topographic relief	3) Gays River carbonates were deposited on a basement high; at culumination of boundstone lithology at least 60 m of water in basin toward NW

10 deposits like Gays River within the Musquodoboit Basin. In all probability, there must be many deposits, similar to those reported by Boehner, in the larger Shubenacadie-Stewiacke Basin. Presently these carbonate deposits are covered by thick sequences of evaporites. However, at the time of carbonate deposition such deposits would further reduce wave energy directed at Gays River by acting as large baffles, possibly, the Florida Reef Tract would be a modern analogue.

Stanton (1967) using data obtained from Bretschneider (1954) figured the interrelations of wind speed, fetch, water depth, and wave height. Stanton's figure is reproduced as Figure 45. Wave height is expressed as the significant wave height--the average height of the highest one-third of the waves measured over a stated time interval. We may apply Figure 45, using some crude assumptions, to get some idea of the type of wave regieme which might have existed during the time of buildup formation. Assume: 1) the depositional areas were sub-linear and contained many deposits of carbonates like Gays River; 2) major climatic depressions causing very energetic wave conditions did not form because of the continental type environment, or if such depressions occurred then the presence of the many carbonate buildups plus the linearity of the depositional basins acted as wave-energy dampers; 3) the Cobequid uplands limited the fetch in a N-S direction of the Windsorian sea to 48 km. The N-S direction is almost perpendicular to the buildup orientation and therefore is the most important fetch direction. A NE-SW fetch was undoubtedly longer but waves from this

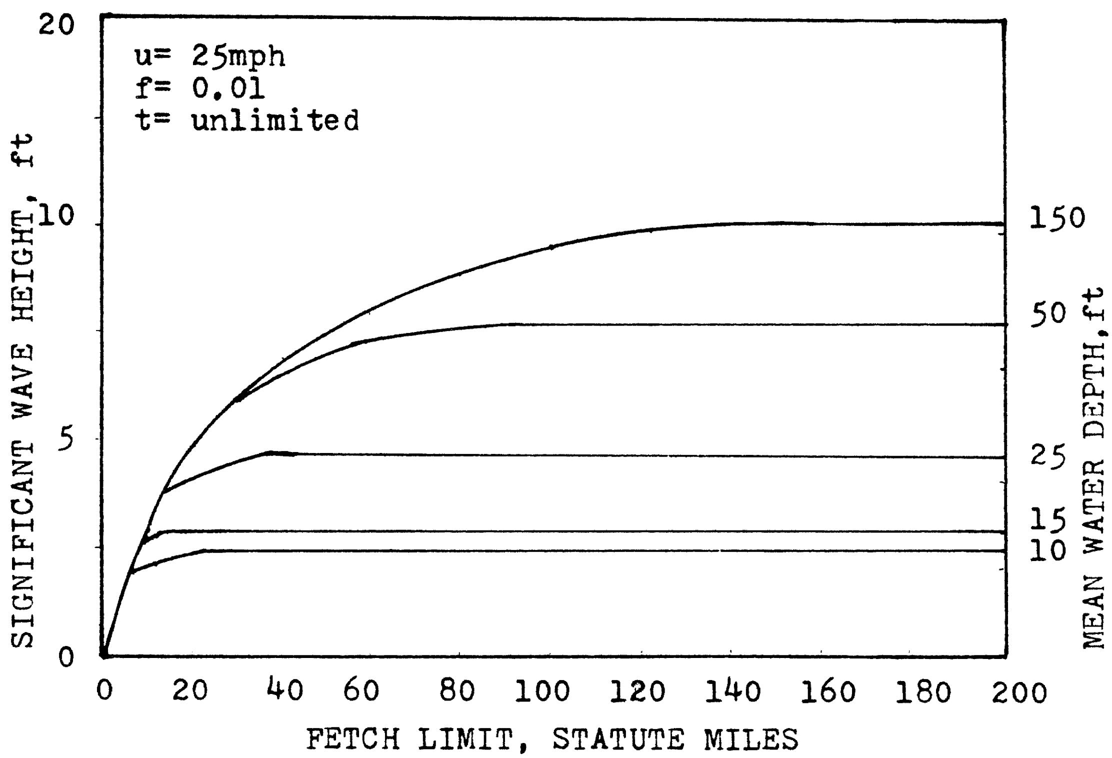


Fig. 45: Wave height of waves generated over bottom of constant depth as a function of water depth, fetch, and wind speed. f, a bottom-friction factor is constant t = wind duration. u = wind speed

(after Stanton, 1967)

direction would be less destructive because of the angle of approach. Then from Figure 45 it can be seen that the significant wave height was just over five feet (1.5 m). Stanton in his calculations assumes a level bathymetry. It seems obvious that this was not so in the case of the basin to the north and northwest of Gays River. The actual significant height would have been much less because of damping of carbonate buildups and bottom friction.

It is also possible that the carbonates in the present study area were deposited on a leeward shore. If Carboniferous reconstructions for plate positions are correct, then as North America and Africa collided in a scissor-like manner, the open seaway lay somewhere to the south and southeast of Gays River. In addition, small deep basins lay to the north and northeast separating North America from Europe. Assuming that the general nature of world wide circulation patterns (large cells) was approximately the same as at present; then at the time of deposition, Gays River, located at 10°S Lat. (Roy and Robertson, 1968), would have been in the path of the Southeast Trade Winds. Constant winds from the southeast would place the study area on a protected leeward shore behind the basement high. Because of the constant southeast wind wave energy from the north and northwest would have been reduced. Heckel (1977) assumes that circulation patterns were the same in the Pennsylvanian as they are now to explain the presence of the phosphatic black shale facies in the Pennsylvanian Cyclothems of Mid-Continent North America. He believes that the Northeast Trade Winds allowed establishment of a large-scale quasi-estuarine circulation in the Mid-Continent epicontinental sea. As a result phosphatic black shales were deposited.

Whatever the case may have been, either dampened wave energy or formation on a leeward shore, large and robust framework organisms were not needed to build a wave resistant structure in the Gays River area during Windsor times.

Dunham (1970) suggests that the key, indicating wave resistance is the nature of binding exhibited in the contemporaneous talus material found in the flank deposits. He postulates that if the talus blocks are organism-encrusted grains of sediment, and large pieces of colonial framework and/or encrusting organisms, then the binding is organic. As noted previously, the large blocks of bindstone contained in the flank beds in the present study area are algal and bryozoan bound (Fig.43). Small algal stromatolites are also associated (Fig.12). Therefore, according to Dunham's hypothesis the buildup is organically bound and consequently this implies wave resistance, given the depositional setting.

Evidence of Growth in Turbulent Water:

If the above fact, organically bound material implying wave resistance is unsatisfactory, then we can return to Heckel's definition and ask: is there evidence of growth in turbulent water which implies wave resistance? Plumley et al. (1962) have listed a set of criteria which they maintain infers a turbulent water environment. If the carbonates at Gays River satisfy these criteria we can assume that Heckel's question concerning water turbulence has an affirmative answer. The criteria of Plumley <u>et al</u>. follow:

Criteria	Gays River Observations
1) Fragmentation of partly indurated sediment or pre-existing rock, ranging in size from silt to boulders of carbonate or other lithology, angular or rounded.	1) Large bindstone blocks and Meguma clasts within the flank deposits (Fig.43).
2) Rounded fragments of fossils that were not originally round.	2) Rounded bivalve and algal fragments (Fig.26).
3) A poorly sorted matrix	3) Fig. 27 shows a packstone with a poorly sorted matrix.
4) Carbonate particles mixed with terrigenous clastics of the same size	4) Fig. 40 shows intermixed terrigenous and carbonate patricles.
5) Mixed faunas and floras, comprising assemblages that are ecologically incompatible.	5) Faunas not identified to genera
6) Presence of oolites	6) --
7) Wave-resistant, colonial organisms in place	7) Algal bindstone with grainstone channels implies wave resistance.
8) Sedimentary structures such as small scale cross-bedding.	8) Fig. 20 shows a channel structure with scoured contacts.

From this listing it is obvious that the carbonates in the study area satisfy most of the criteria and therefore a turbulent environment can be concluded. Because the bindstones grew in turbulent water wave resistance is implied. Therefore part (b) of section one of Heckel's definition of a reef is satisfied.

Evidence of Control over the Surrounding Environment:

The second part of Heckel's definition of a reef concerns whether there is evidence that the buildup exercised control over the surrounding environment.

According to Kornicker and Boyd (1962), influence of the surrounding environment is typically reflected in the formation of flank beds, and often in differentiation of the growing buildup into distinct facies reflecting different effects of various parts of the buildup on waves and currents. These distinct facies have been termed: forereef, backreef and reef-crest by many authors (Heckel, 1974). It has been shown that the carbonaceous grainstones at the base of the buildup represent a flank deposit. This flank deposit was formed as the buildup grew. These grainstones have a wedge-shape geometry which thins basinward. In addition these grainstones dip basinward at approximately 25°.

To test whether or not there has been differentiation into distinct facies reflecting different effects of various parts of the buildup on waves and currents we can apply Walther's Law of Facies. This law states that the vertical succession of lithologies and fauna should mimic the lateral pattern of facies at any particular instant of time if the vertical succession is complete (Walther, 1893). Before applying this law, however, the nature of the lithology relations observed underground must be accented briefly. Further discussion is presented in a following section. Figures 41 and 44 show that lithologic changes both vertically and laterally are complex. On the scale used to map underground (1 cm = 25 cm) it is impossible to make meaningful conclusions about the vertical succession. However, on a gross scale it is possible to conclude from drill core, that the rock types exposed in the decline (Figs. 41, 44) (i.e. bindstones, grainstones, bafflestones and packstones) are overlain by a thick (7-15 m) section of algal fenestral wackestone-packstone. This lithology has been interpreted as a restricted lagoonal deposit which has intertidal material (Fig. 30) in the upper part of the section. Therefore, although within the bindstone-grainstone-bafflestone-packstone assemblage, relations are very unclear and correlation is not possible; a gross overall vertical change in lithology from barrier to lagoonal to intertidal is evident. It is on this gross scale that we can use Walther's Law. Figure 38 shows the result of this application with the addition of the flank deposits. In this figure, we see there is a landward progression from flank beds deposited in the basin, through a bindstone buildup, to a shallow, restricted lagoon, to an intertidal environment. From this we can conclude that the bindstone, acting as a barrier to wave energy, allowed the formation of a lagoon. Therefore, the bindstone exercised control over and influenced the surrounding environment. Now all the requirements of Heckel's definition of a reef are satisfied by the carbonates at Gays River.

Gays River as an Organic Framework Reef

It is possible to refine the term reef, according to Heckel's definition, on the basis of wave resistance (Fig. 46). As

<table>
<tr><td rowspan="2">No evidence of relief. (if high skeletal content, BIOSTROME)</td><td colspan="7">Evidence of positive topographic relief
BUILDUP (if large, broad, PLATFORM, SHELF)</td></tr>
<tr><td>No evidence of type indicated at right</td><td colspan="6">Evidence of potential wave resistance or of turbulent water, implying wave resistance & evidence of some degree of control over surrounding environments.
REEF (if built mainly by organisms, ORGANIC REEF)</td></tr>
<tr><td colspan="2" rowspan="2">BANK</td><td colspan="3">wave-washed talus absent</td><td colspan="3">wave-washed talus present
FRAMEWORK REEF</td></tr>
<tr><td>Organic framework present, but no evidence of water turbulence
POTENTIAL REEF
(in deep or calm water)</td><td>Abraded-grain calcarenites + remains of rooted organisms
ORGANICALLY? BOUND SKELETAL-DEBRIS REEF</td><td>Early rims of drusy spar
SPAR-CEMENTED DEBRIS REEF</td><td>Talus calcilutite: if stromatolitic, STROMATOLITE REEF;
if abraded mud clasts, MUD-FRAMEWORK REEF</td><td>Talus inorganically bound by spar cement
INORGANIC-FRAMEWORK REEF;
SPAR-CEMENTED FRAMEWORK REEF</td><td>Talus organically bound + large skeletal fragments
ORGANIC-FRAMEWORK REEF</td></tr>
</table>

Fig. 46: Classification of carbonate deposits as proposed by Heckel (1974). Terms are in capital letters; criteria are in small letters. Usage is hierarchical, more general terms (above dashed lines) include more specific terms (below dashed lines). This allows refinement of terminology as more evidence becomes available.

has been shown the flank deposit contains blocks of buildup material which imply that the bindstone was a solid lithified framework. The fact that flank beds deposited later than the bed which contains the large blocks of bindstone are truncated, and drape over the large block (Fig. 43) means that the block was lithified prior to the deposition of the truncated, and draping beds. The presence of soft-sediment deformation structures within the unit which contains the blocks indicates that the blocks were lithified before their deposition. From this then, the term reef may now be refined to a framework reef. In addition, the blocks of bindstone material contained in the flank beds exhibit organic-binding and organic encrusting in the form of stromatolites, thrombolites and the algal-bryozoan bindstone. Because of this we can call the buildup, in the study area at least, an organic framework reef.

Evidence of Subaerial Exposure

Figure 47 shows a comparison between the pisolith ooid packstone and the general calcrete profile described by Read (1974). There is almost a one to one correspondence between the two profiles. Read (1974) reports that when fully developed the calcrete profile can be divided into five zones or horizons; in ascending order these are the zones of: 1) unaltered parent material, 2) calcrete mottles, 3) massive calcrete, 4) laminar calcrete, and 5) pisolitic soils. Incomplete profiles may result from insufficient duration of weathering, erosion of the upper

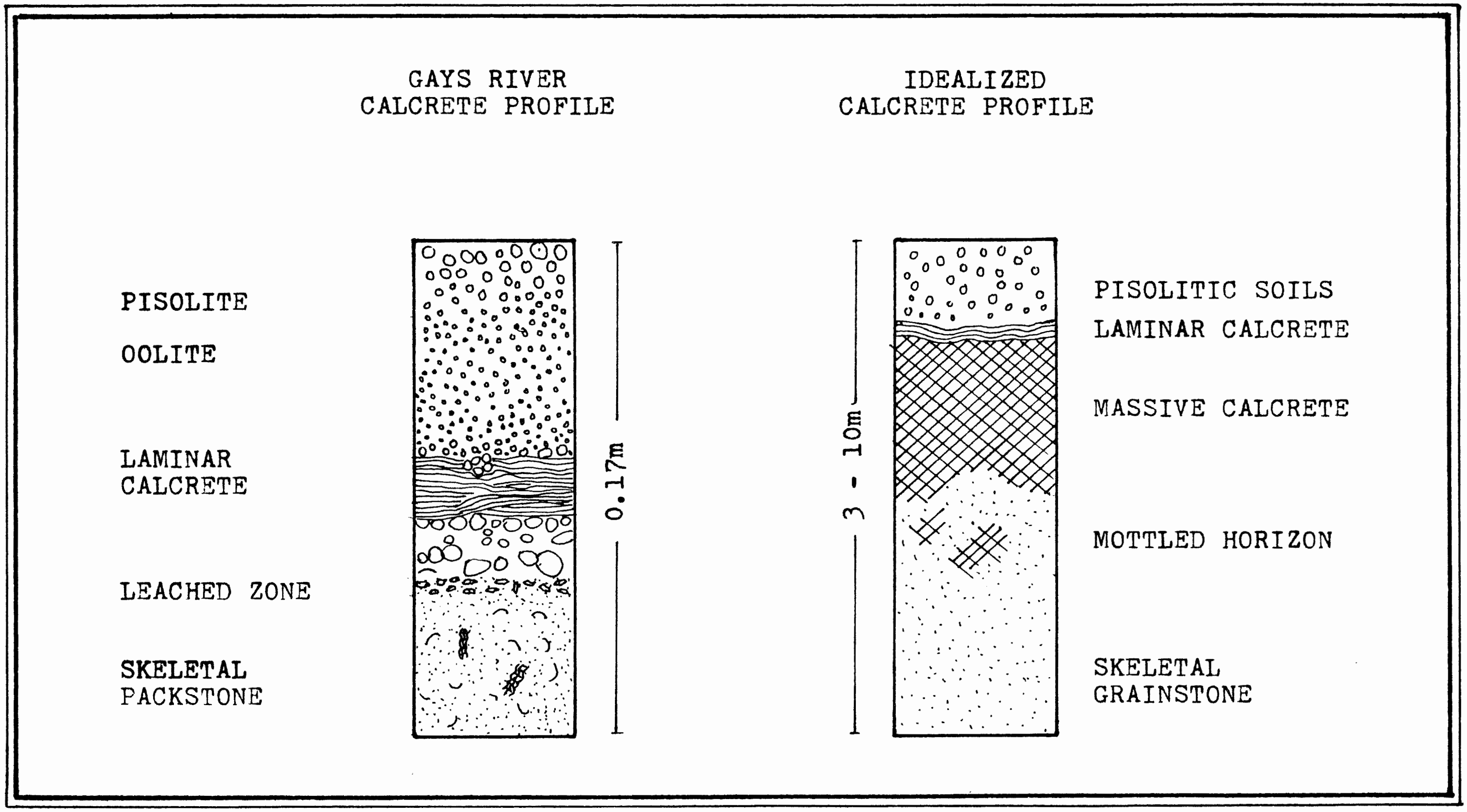


Fig. 48: Comparison of Gays River calcrete profile with Read's (1974) idealized calcrete profile, showing vertical distribution of calcrete zones.

portion of the profile, or ground slope inhibiting profile development. Figure 36 shows that the profile at Gays River does not have a massive calcrete zone, and that the pisoliths are reversely graded. Reverse grading and in situ brecciation both present in the Gays River profile are common in pisolitic soils (Dunham, 1969b; Read, 1974, 1977).

Estaban (1976) noted the microfabrics normally found in calcrete. These microfabrics and observations of the pisolite ooid packstone follow.

Calcrete Microfabric	Gays River Observations
1) Pisoliths, when present are micritic (4), usually with less than five indistinct laminae.	1) Pisoliths are 30 dolomite laminae are diffuse and less than six in number.
2) Micrite and microspar are abundant with clotted peloid texture	2) Micrite is abundant as matrix peloids occur in the laminar section.
3) Sparry cements minor, fibrous cements uncommon.	3) Sphalerite is the only crystalline cement >4 present.
4) Microspar-spar channel system circumgranular cracking.	4) Pisoliths cracked and brecciated.
5) Microspar replacing relic grains and calcrete components.	5) Mud-sized matrix replacing pisoliths.

From the above list it is obvious that the pisolith ooid packstone displays a calcrete microfabric as defined by Estaban (1976).

Calcrete forms as a result of subaerial exposure and soil forming processes, usually in an arid to semi-arid environment (Estaban, 1976; Mutter and Hoffmeister, 1977; Read, 1974, 1977).

They also indicate the presence of a disconformity (Read, 1977). According to Read (1977) the calcrete horizons are characteristic of distinctive stages of calcrete accumulation and reflect increasing disposition of diagenetic carbonate. Carbonate that is leached in upper parts of soil profiles is either reprecipitated in place or is carried down the profile. In the beginning the carbonate precipitates as coatings around grains resulting in calcrete ooids and pisoliths. Lower in the profile, the calcrete coats and replaces grains as well as plugging interparticle pores to form local accumulations of "mud-supported" carbonate. The massive calcrete is formed in the zone of most frequent wetting by undersaturated flow. The massive horizon inhibits percolation and a thin zone of free water accumulates periodically above the horizon. Once this occurs, laminar calcrete forms. Laminar calcrete may be precipitated directly upon bedrock or it may line walls of horizontal to subvertical fissures and irregular cavities.

At Gays River only a single occurrence of calcrete was found (Fig. 35). This restricted occurrence of the calcrete at Gays River is similar to that of the Capitan Reef. There, Dunham (1969b) accounts for the restricted distribution as a result of pisolite formation in an island surrounded by normal marine facies. This may also be the case at Gays River. At Gays River, the algal bindstone lithology overlies the calcrete. This relation indicates submergence of the exposed surface.

Pisoliths can grow by means other than during the formation of calcrete. Shinn (1972) reports the presence of pisoliths and ooids within a vug found in an algal cup reef near Bermuda but notes that the origin of the pisoliths and ooids is unclear. He infers that breaking waves momentarily produce strong reversing currents which gush through certain cavities. In such conditions particles are rolled, tumbled and coated. If the pisoliths at Gays River were formed as Shinn hypothesizes then they are evidence of strongly agitated water conditions. However, considering the whole profile, evidence is strongly in favour of a calcrete origin for the pisolith-ooid packstone. The vertical profile is almost a duplicate of that described by Read (1974). The pisoliths are reversely graded and brecciated in situ characteristics which Dunham (1969b) and Read (1974, 1977) say are common to calcretes. The microfabrics observed in the Gays River profile concur with those described by Estaban (1976). It seems overwhelmingly clear that the pisolith ooid packstone is indeed a calcrete.

Correlation

Figures 41 and 44 show that lithologic changes both vertically and horizontally are rapid and complex. Both of these sections are basically parallel to depositional strike. Even so, all the carbonate geology observed in the decline is complex. This is true whether exposures are parallel or perpendicular to depositional strike. One explanation which may account for this is the fact that the decline stays close to the carbonate-basement contact. In doing this, the decline tends to follow the basin-side contour of the basement slope (Fig.2). As a result, carbonate rock types deposited close to the basement and on this basement slope are the most exposed underground. Bindstones and grainstones are the two rock types which occur most often in this position. The complexity of the relations between rock types reflects their environment of deposition. I have interpreted the bindstones and grainstones as analogues to a modern coral-algal reef, only in a low energy setting. Correlation within these units on the scale mapped (1 cm = 25 cm) is impossible. Just the same as correlation on such a scale would be impossible in a modern coral-algal reef. The environment is too complex. It can be seen from Figures 41 and 44 that even with all the control present in these maps, the lithologic relations are still unclear. It is then easy to understand that correlation between adjacent drill core, even on a 15 m spacing, is not meaningfully possible. Even less meaningful, is attempted correlation between drill core which are from 50 to 60 m apart.

Diagenesis

Although a detailed discussion of the diagenetic history of the Gays River carbonates is not in the scope of this study, certain diagenetic aspects may be concluded.

1) Subsea cementation occurred in the bindstone, which filled intraskeletal pores with microcrystalline and sparry

carbonate. Whether the original material was aragonite or high magnesium calcite is unknown. Pores are now filled by sparry calcite. This cementation is possibly analogous to that described in modern reefs by such writers as Friedman et al. (1974), Friedman (1975), and James et al. (1976). In modern reefs the cementation process takes place near the reef margin (James et al., 1976); and within 60 cm of the reef surface (Friedman et al., 1974). Early subsea cementation is evident in the bindstone blocks which are present in the flank beds at Gays River. These blocks contain geopetal structures in the form of shells, and growth-framework pores. Both are partially filled with silt-sized grains which are overlain by sparry calcite.

2) The bafflestone must have had high porosity at the time of formation. This is evident by the size of the inter-thalli pores. These pores contain silt and sand-sized carbonate the siliclastic material and are plugged by sparry calcite. However, there is very little sphalerite on galena within what appears to have been a very porous and permeable lithology. Therefore, either there was no direct path into the bafflestone lithology for the ore carrying solution; or the calcite which fills the interstices between the thalli predates sphalerite and galena precipitation. The former seems unlikely because of the presence of mineralized grainstones adjacent to the bafflestone. Whether the pore filling calcite is an early subsea cement as is found in the bindstone, or resulted from dissolution of overlying carbonate which was sub-aerially exposed is unknown. Sub-aerial exposure

must have occurred because of the many solution vugs found in the algal fenestral wackestone-packstone (Fig. 31). These vugs indicate solution in the vadose zone. Additional evidence for sub-aerial exposure is the presence of pores (Fig. 48) which are rimmed with sphalerite, and filled by silt-sized siliclastic grains. That the grains filling these pores consist solely of siliclastic material implies solution of overlying carbonate, concentration, and infiltration of the insoluble siliclastic particles within pores. Some of these grains have euhedral outgrowths of quartz. These outgrowths must have occurred after the silt was deposited. Otherwise, the outgrowths would have been broken off during transport. The pores containing these siliclastic grains are filled by sparry calcite.

3) Dolomitization postdated local solution of calcite and aragonite. The brown dolomite rims, shown in Figure 34 , indicate, upon etching, that the rhombic dolomite grew outward into an empty pore. Dunham (1972) reports a similar dolomite in the Capitan Limestone. He notes that the dolomite is a product of precipitation and not replacement. The fact that those sides of dolomite grains which face out into the pore are generally euhedral, whereas, the sides facing in toward the wall are jagged in conformity with the surface on which they grew, is evidence enough for Dunham to conclude a precipitation origin. I believe that a similar mechanism is responsible for these brown rims of dolomite observed at Gays River. The presence of dolomite in the form of cement bears on the composition of the dolomitizing

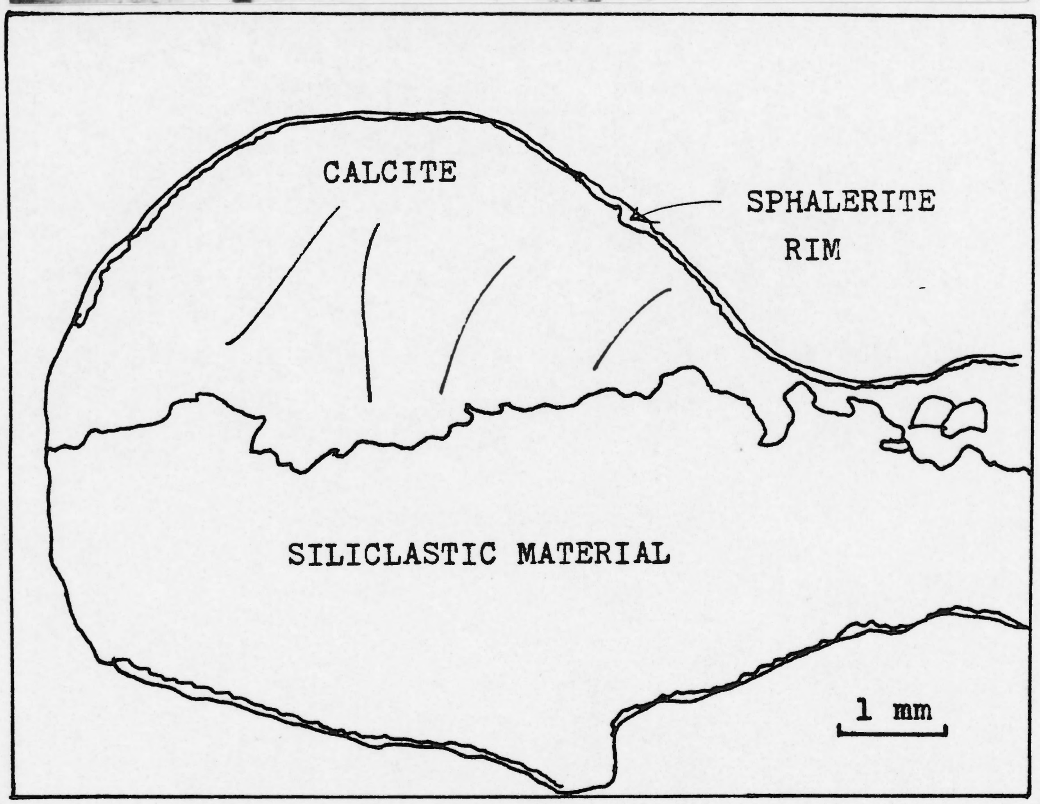


Fig. : Sphalerite lined vug partially filled with siliclastic silt.

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fluid. The composition was such that nucleation could be initiated, and that carbonate ions needed to grow dolomite were available without the local solution of calcite or aragonite (Dunham, 1975). This infers that the dissolution of calcite and aragonite in the buildup carbonates, which resulted in vug formation, must have predated dolomitization. If dissolution was concomitant with dolomitization calcium ions would have inhibited the dolomitization process. Calcium ions exclude magnesium ions from the nucleation sites because of the higher surface binding energy of the calcium ion (Berner, 1971).

4) Because crystalline sphalerite overlies the rhombic dolomite in pores, sphalerite precipitation succeeded dolomitization. I did not observe a single case where sphalerite was overlain by the brown dolomite ion.

5) Sparry calcite, not the same generation as the early subsea one, overlies the sphalerite and generally fills the remaining pore space. This calcite is the last cement phase observed and as Figure 34 indicates the calcite precipitation postdates brittle fracture of the rock.

In summary, a partial chronologic history of diagenetic events may be proposed. From oldest to youngest these events are:

1) First generation of sparry and microcrystalline carbonate cement is precipitated as early subsea cement.

2) First generation of dissolution of carbonate by subaerial exposure, to produce vugs in which dolomite cement would later

grow. Possibly the calcrete formed at this time also.

3) Dolomitization with precipitation of dolomite cement.

4) Sphalerite and galena precipitation.

5) Concentration and infiltration of insoluble silt which was deposited in pores lined by sphalerite.

6) Growth of quartz outgrowths on silt grains.

7) Second generation of sparry calcite is precipitated and it fills most of the remaining pore spaces.

CONCLUSIONS

From this study of the geology exposed in the decline at Gays River the following conclusions are made:

1) The carbonate lithologies in the decline area comprise a wave-resistant organic-framework reef according to the definition of Heckel (1974).

2) At some point during deposition sub-aerial exposure occurred in at least one area. In this area, a calcrete profile was formed.

3) Algae both encrusting and erect in form was the dominant organism during growth of the organic framework reef.

4) Spurs and re-entrants developed in the basement had a controlling effect upon carbonate deposition.

5) The basement spurs were joint controlled and had steeply-stepped slopes.

6) A talus deposit consisting of clasts of basement material

existed prior to carbonate deposition.

7) It is not possible to correlate the geology between drill holes (15 m spacing) using the core from adjacent holes on the scale used for mapping underground (1 cm = 25 cm).

8) A partial time sequence of diagenetic events is obvious. Listed in ascending chronological order these events are:

a) Early subsea precipitation of carbonate in some reef margin pores;

b) Sub-aerial exposure and solution of unstable carbonate to produce vugs, and calcrete;

c) Dolomitization with precipitation of dolomite cement;

d) Precipitation of sphalerite and galena;

e) Infiltering of ground water caused concentration and deposition of insoluble silt in pores lined by sphalerite;

f) Growth of euhedral outgrowths on quartz silt contained in the pores;

g) Precipitation of second generation sparry calcite after brittle fracture of the rock has occurred.

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