Carbonate Banks of the Gays River Formation in Central Nova Scotia

by P.S. Giles, R.C. Boehner and R.J. Ryan

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CARBONATE BANKS OF THE GAYS RIVER FORMATION IN CENTRAL NOVA SCOTIA

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HALIFAX, NOVA SCOTIA

1979

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ABSTRACT

Carbonate banks which are regionally widespread, but only locally developed, constitute one facies of the Gays River Formation, the basal unit of the Visean Windsor Group in the Musquodoboit Basin and on the southern flanks of the Shubenacadie Basin in southern Nova Scotia. Lithologically, they are characterized by abundant algal bindstone and bafflestone with associated skeletal packstone and wackestone. Their high degree of lithologic and faunal similarity indicates a common sedimentologic history for each of the banks examined. The relative proportions of major constituent faunal groups, the scarcity of plicate and costate brachiopods, the absence of representatives of the phylum Echinodermata, and the presence of newly reported genera of Gastropoda and Bryozoa, are biostratigraphic indicators which may distinguish carbonate banks of the Gays River Formation from similar carbonate banks at higher stratigraphic levels within the Windsor Group.

In the southern part of the Shubenacadie Basin and in the Musquodoboit Basin, carbonate banks have been found only in areas where the Windsor Group oversteps the Horton Group and rests upon rocks of the Meguma Group. They rest with equal frequency on both slate and metagreywacke. Banks overlain by terrigenous rocks on the southeastern margin of the Musquodoboit Basin are distinct in that they contain abundant calcareous algae of the genus *Koninckopora*. Otherwise, they are similar in character to more northwesterly banks which are overlain by thick sulphate evaporites.

Mineralization with sulphides of lead and zinc is most evident in, but not wholly restricted to, the Gays River bank. Sulphides occur mainly as open-space fillings in what has been described as a low temperature, Mississippi Valley type deposit. Migration of metal-bearing fluids through an east-west trending fracture zone is tentatively proposed to explain the localization of these sulphides.

INTRODUCTION

Giles and Boehner (in prep.) define the Gays River Formation as a somewhat heterogeneous assemblage of rock units, which together constitute the basal marine deposits of the Windsor Group of Bell (1929) within the Shubenacadie and Musquodoboit Basins (Fig. 1). One of the principal rock units consists of dolomitic carbonates in locally developed mound-shaped bodies reaching 60 m in thickness, flanked by thin, finely bedded argillaceous and bituminous dolostones. One of these carbonate bodies, here termed the Gays River bank, is mineralized with sulphides of lead and zinc in economic quantities.

The term bank is applied in a general sense to the carbonate buildups of the Gays River Formation, in recognition of the regional distribution of mechanically deposited carbonate rocks within the mounds, in association with rocks accumulated by trapping or baffling of sediments by organisms. Organic banks, as defined by Wilson (1975), seem most similar to the buildups which we studied. However, we acknowledge that some of these buildups can be termed organic framework reefs, as argued by Hatt (1978). In these buildups, wave resistant algal-bound carbonate masses comprise the reef proper, but mechanically accumulated carbonate rocks are volumetrically more important.

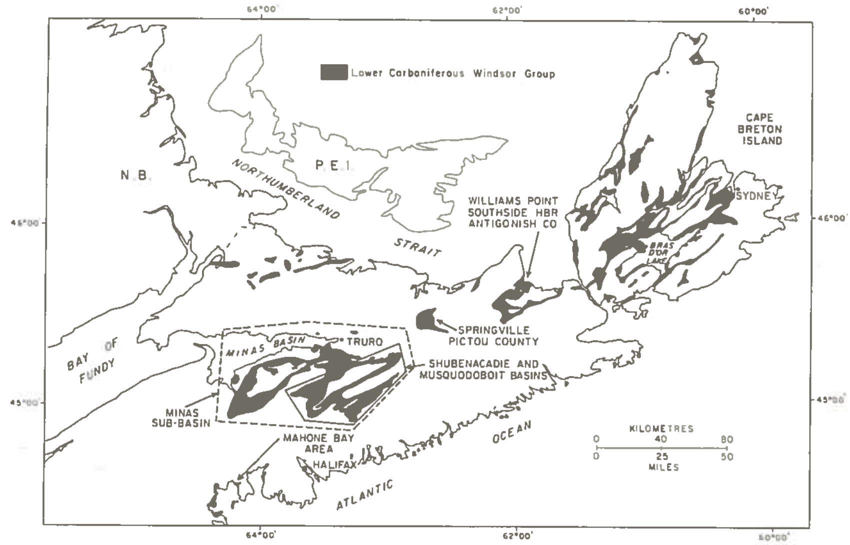

Figure 1: Location map.

Many additional carbonate banks have been documented by extensive diamond-drilling within the Musquodoboit Basin (Boehner, 1977), and in the Shubenacadie Basin (Giles and Boehner, in prep.). We believe that comparison of these carbonate banks (Fig. 2) may offer some insight into regional controls over base metal mineralization. The following report summarizes our observations on the stratigraphy, petrography, paleontology and to a lesser extent, the geochemistry of those banks which are either readily accessible at surface, or in diamond-drill core. Analyses of the fauna was undertaken by Ryan (1978) who expanded this aspect of the study as a M.Sc. thesis at Acadia University, Wolfville, Nova Scotia.

PREVIOUS WORK

MacEachern and Hannon (1974a, 1974b) presented the first published description of reefal carbonates of the Gays River Formation, based on studies of what is here termed the Gays River bank. Since that time, this same bank has been the subject of continuing study by Dr. Paul Schenk and various students of the Department of Geology, Dalhousie

University, Halifax. MacLeod (1975a, 1975b) described the interrelationships of carbonate diagenesis and sulphide mineralization. Hatt and Schenk (1977) and Hatt (1978) completed detailed sedimentological analyses of parts of this bank.

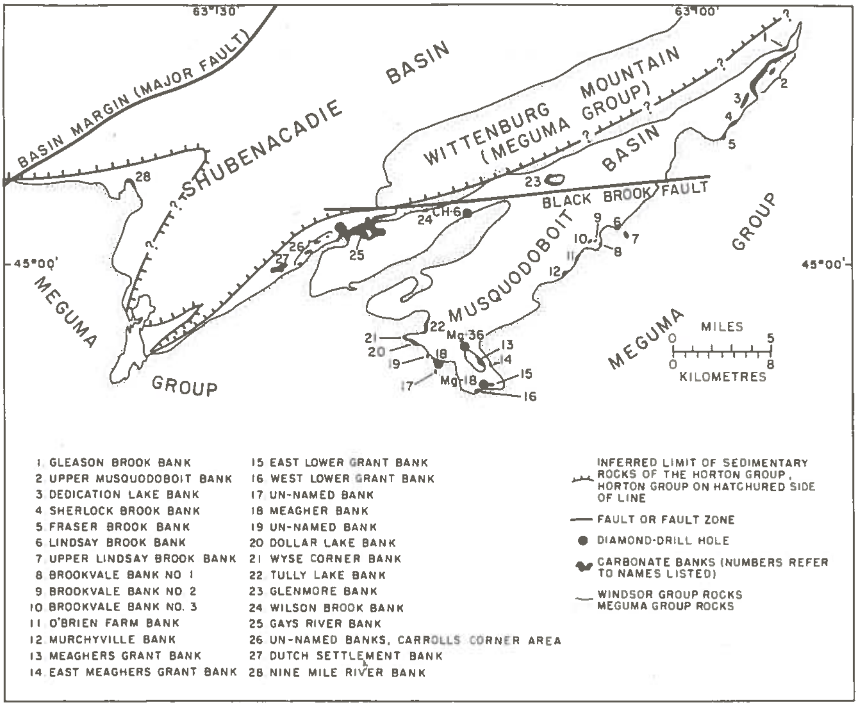

Figure 2: Distribution of carbonate banks of the Gays River Formation, showing their relationship to the limits of the Horton Group.

Boehner (1977) has shown that these banks are relatively widespread in the Musquodoboit Basin and was the first to document their regional distribution and stratigraphic setting. Ryan (1978) studied the faunal and floral elements of numerous carbonate banks of the Gays River Formation and attempted to assess the paleoecology of the various organisms represented.

GEOLOGICAL SETTING

The Gays River Formation represents the deposits of the initial mid-Visean marine transgression into the area of study. The formation comprises the basal unit of the Windsor Group, the stratigraphy of which is summarized in Figure 3, and briefly outlined below.

In its position at the base of the Windsor Group, the Gays River Formation is equivalent to and grades laterally into the Macumber Formation of Weeks (1948). The facies boundary separating the Gays River and Macumber Formations lies within the Subenacadie Basin and coincides closely with the pre-Windsor limits of the underlying Horton Group (Fig. 2). The Gays River Formation thus rests with pronounced angular unconformity upon the pre-Carboniferous Meguma Group, whereas the Macumber Formation lies concordantly upon sandstones, shales and conglomerates of the Lower Carboniferous Horton Group.

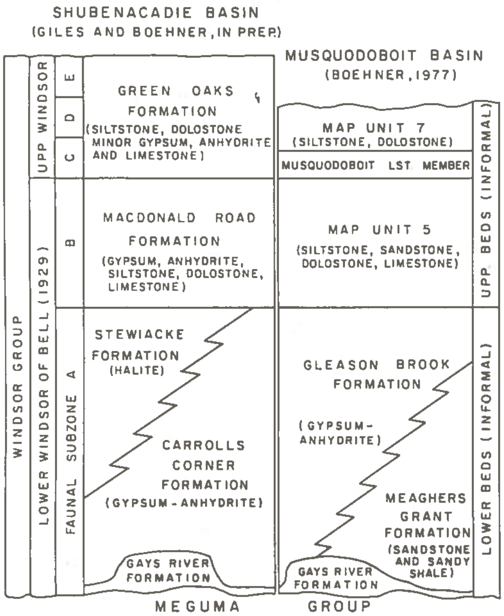

Figure 3: Stratigraphic setting of the Gays River Formation.

Bell (1929, 1958) recognized a disconformity between the Horton Group and the Middle to Late Visean Windsor Group. Palynomorph assembleges from the Horton Group were assigned by Higgs (1975) to the Early Tournaisian NV zone of western Europe. Revised correlation in western Europe (Clayton *et.al.*, 1977) suggests instead a Late Tournaisian age (PC Zone) for assembleges similar to those of the Horton Group. Utting (1978) stated that the base of the Windsor Group was not older than Arundian (Visean lb-2a of George *et.al.*, 1976) and that it might be younger. It thus appears that a significant diastem is present between the Horton and Windsor Groups.

The Gays River Formation is typically overlain by gypsum and/or anhydrite of the Carrolls Corner or Gleason Brook Formations (Fig. 3). However, in the southern parts of the Musquodoboit Basin, sandstone and sandy shale of the Meaghers Grant Formation rest directly on carbonate rocks of the Gays River Formation. The Meaghers Grant Formation is inferred to be a facies equivalent of the Gleason Brook (and Carrolls Corner) Formation. Rock salt up to 300 m in thickness, rests on the Carrolls Corner Formation (Fig. 3), but is not known in the Musquodoboit Basin.

Although rock units within the Windsor Group can be correlated successfully throughout our area of study, important contrasts are present. In the Musquodoboit Basin, evaporites are extremely rare in Map Unit 5 (Fig. 3), although they are both characteristic and abundant in the MacDonald Road Formation in the Shubenacadie Basin. Carbonate members within Map Unit 5 thin dramatically when traced northwards into the MacDonald Road Formation of the Shubenacadie Basin.

Strata of the Green Oaks Formation, which comprise in large part the Upper Windsor of Moore (1967), are broadly similar to the Musquodoboit Limestone and strata of Map Unit 7 of Boehner (1977) in the Musquodoboit Basin, differing mainly in overall thickness which is greater in the Shubenacadie Basin. This change in thickness is apparent for the Windsor Group as a whole, which increases in thickness from 457.5 m in the Musquodoboit Basin to 762.5 m in the Shubenacadie Basin.

FACTORS CONTROLLING BANK DISTRIBUTION

The distribution of known Gays River Formation carbonate banks is shown in Figure 2. Carbonate banks of the Gays River Formation are largely limited to the confines of the Musquodoboit Basin (Fig. 2). The Gays River bank (No. 25, Fig. 2) straddles the boundary between the Musquodoboit Basin and the Shubenacadie Basin to the northwest. Major banks within the Shubenacadie Basin have been documented at Dutch Settlement and Nine Mile River (Fig. 2). Similar banks elsewhere in Nova Scotia occur in the vicinity of Antigonish Harbour in northeastern mainland Nova Scotia, near East River in the Mahone Bay area and in the Springville area of Pictou County (Fig. 1). In all of these locations, pre-Windsor Carboniferous strata are absent beneath the carbonate banks. Thus, the absence of the Horton Group or equivalent strata is of predictive value in defining areas of bank formation, as clearly illustrated in Figure 2.

Within those areas of preferential bank development, the principal factor governing bank formation appears to be paleotopographic. The lithology of the underlying pre-Carboniferous rocks, and the immediately superadjacent Windsor rocks appears to have little control of or relationship to bank development. Evidence for these conclusions is summarized below.

Within the Shubenacadie and Musquodoboit Basins, numerous banks flank or cover paleotopographic highs isolated from the major outcrop areas of pre-Carboniferous rocks (Fig. 2). Others fringe the present structural basins, or occur on promontories and ridges of Meguma basement extending beneath the Visean cover rocks. Figure 4 summarizes the relationships of several of these banks to the underlying Meguma in terms of local relief on the pre-Carboniferous paleotopographic surface, and isopachs of the overlying banks. The coincidence of anomalous isopach highs with areas of high structural contours suggests at least partial control of bank development by paleotogpographic highs.

In the Shubenacadie and Musquodoboit Basins, the Gays River bank rests on metagreywacke of the Meguma Group. Of the remaining banks, approximately 60 per cent rest on metagreywacke, and the others are underlain by slate and/or meta-siltstone, or by thinly intercalated slate and metaquartzite. Thus, although the majority of banks rest upon metagreywacke, the lithologic character of the underlying basement seems to exert minimal control over bank development. Regionally, this same conclusion is suggested by the presence of pre-Carboniferous plutonic rocks beneath the East River and Antigonish Harbour banks (Fig. 1), and fossiliferous Silurian siltstones beneath the Springville bank (Fig. 1).

The Gays River bank is presently flanked and in part overlain by gypsum and anhydrite of the Carrolls Corner and Gleason Brook Formations (Fig. 3). Ten additional banks in the Shubenacadie and Musquodoboit Basins are likewise overlain, or flanked by this thick evaporite unit

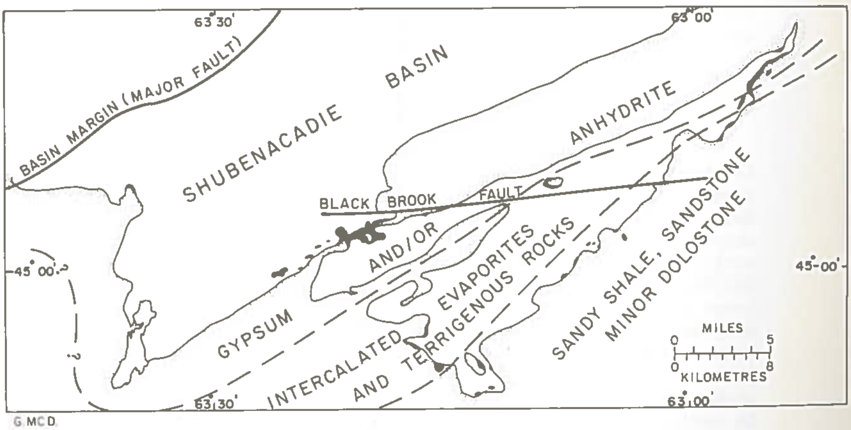

Figure 5: Inferred distribution of the cover rocks to the Gays River Formation.

(Fig. 5), as are the Antigonish Harbour and Springville banks (Fig. 1). The remaining banks are overlain by sandstones and sandy shales of the Meaghers Grant Formation (Fig. 3), or by intercalated terrigenous rocks and evaporites (Fig. 5). It appears, therefore, that the character of the overlying bedrock is of minor importance in predicting bank distribution.

PETROGRAPHY AND ENVIRONMENT OF DEPOSITION

Carbonate banks of the Gays River Formation comprise only one facies of this somewhat variable rock unit. Argillaceous and bituminous dolostones which flank the carbonate banks are regionally more extensive and thus more characteristic of the formation. Because we have emphasized the bank facies in this study, we present only a brief description of this interbank facies in the following pages.

The petrographic description presented here is strictly qualitative, due to limitations imposed by extensive dolomitization. Although this procedure in no way hampers comparitive study, it admittedly limits our conclusions in objectivity. Therefore, we stress only what we consider to be major points of similarity and contrast. In order to minimize lengthy and repetitive description of rock types, we have relied heavily upon the use of photographs for purposes of comparison (Figs. 6 to 18). The scale of the photographs is uniform throughout, and is indicated by a bar 10 mm in length. All are negative prints from petrographic thin sections.

In our examination of these banks, we were impressed with their regional uniformity in lithologic character. This high degree of similarity is apparent in Figures 6 to 18. Contrast between adjacent or widely separated banks is limited mainly to variations in the relative proportions of constituent rock units. Because we note significant variation within single banks, we have emphasized only the major points of contrast between banks.

In subsequent pages, the carbonate rocks are described using the terminology of Dunham (1962), revised by Embry and Klovan (1971). This classification is ideally suited for the dolomitic rocks which dominate the banks, because it is not hindered by inability to identify with certainty all constituent grain types. The terminology is briefly summarized below.

Dunham recognized two broad categories of carbonate rocks which he termed allochthonous and autochthonous. The latter comprised those rocks in which organic binding of grains during sedimentation could be recognized. Allochthonous carbonates, in which sediment binding is unimportant, were divided into the following categories, based on the presence and relative proportion of lime mud as matrix.

Mudstone:	mud supported, less than 10% grains
Wackestone:	mud supported, greater than 10% grains
Packstone:	mud present but grain supported
Grainstone:	no mud present, grain supported

Embry and Klovan (1971) suggested modification of Dunham's autochtohonous category to include the following rock types, collectively termed boundstones.

Bafflestone:	sediments in which baffling by organic components results in grain or mud accumulation
Bindstone:	sediments organically bound by encrusting or agglutinating organisms
Framestone:	sediments comprised mainly of a rigid framework of organisms

In subsequent pages, the carbonate rocks of the Gays River Formation are described using the above terms. Unless otherwise specified the mineralogical composition of the rocks is dolomite.

INTERBANK FACIES

Petrography

The interbank facies typically comprises thinly bedded bituminous dolomitic mudstones and wackestones which are finely crystalline, sparsely fossiliferous, and generally impoverished with respect to carbonate grains or other allochemical constituents. Lamination is not a characteristic feature. Where observed, this feature is produced by fine intercalations of peloidal packstone and dolomitic wackestone (Fig. 6B). The peloidal packstone is very similar to limestones and dolostones of the Macumber Formation, and constitute lithologic evidence for lateral equivalence of the Macumber and Gays River Formations.

The interbank facies extends throughout the Shubenacadie and Musquodoboit Basins, rarely exceeding 3 m in thickness. Topographically

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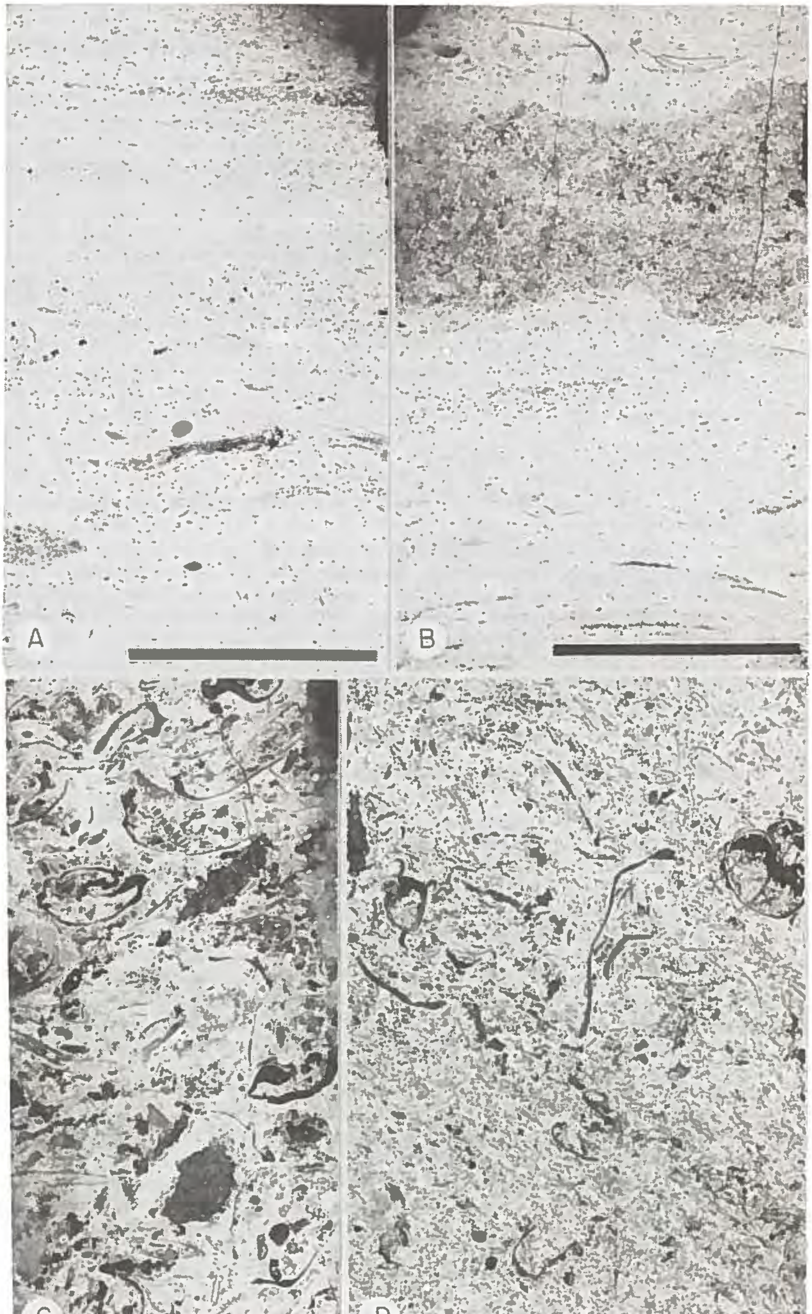
Explanation of Figure 6

Negative prints of thin sections. Bar scale = 10 mm.

Figure 6A, B and C: Profile, in descending order of the typical interbank facies of the Gays River Formation, Hole CH-6, Chaswood area Musquodoboit Basin (Fig. 2); note the thinly bedded, laminated character of the dolostone of A and B, with the presence of scattered thin-shelled molluscan (?) debris; note also the dark argillaceous and bituminous nature of the rock in A and B (lightest areas in prints); scattered small dark spots in A and B represent terrigenous grains, mainly quartz; contrast C with A and B; C represents basal carbonate deposits in which bedding is obscure and faunal elements much more prolific; note relatively large terrigenous rock fragments in lower-centre and upper-right-centre of photograph C; Hole CH-6, A - depth 815.5 feet (248.7 m), B - depth 818.5 feet (249.6 m), C - depth 823.5 feet (251.2 m).

Figure 6D: Dolostone from basal beds of Fraser Brook bank (No. 5, Fig. 2), Musquodoboit Basin illustrating the abundance of terrigenous detritus and the finely comminuted nature of the shell debris, consisting largely of molluscs; this fragmentation is not typical higher in the bank; note the similarity between C and D; Hole FRB-4, depth 64.5 feet (19.7 m).


A
B
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elevated banks pass laterally and down-slope into the interbank facies. However, the interbank facies, in its present distribution, is not restricted to the lowest parts of the structural basins, and in fact is widely distributed at the present Windsor-Meguma contact at surface.

Within the interbank facies faunal elements are usually limited (Fig. 6A and B). In some sections, however, faunal debris may be prolific in thin wackestone beds (Fig. 6C), and may indicate proximity to coeval banks. In these thin beds, the matrix is finely crystalline dolomitic mudstone, and the debris is dominated by pelecypod shells, with lesser gastropods and fragments of bryozoans and calcareous algae. Very similar rock units have been noted near the base of carbonate banks at Nine Mile River and Fraser Brook (Fig. 6D). These rocks differ from skeletal wackstones and packstones typical of well developed, thick banks, in that most of the faunal material is fragmental, and in the common presence of basement rock fragments and/or quartz sand and silt (Fig. 7A and E).

Environment of Deposition

The interbank facies was deposited in the subtidal environment in downslope position relative to the bank facies. Moderate current action is indicated by the local presence of parallel lamination, although currents were not sufficient to winnow the fine mud fraction. Faunal debris, when abundant, appears to have been transported from adjacent banks, although a minor molluscan fauna was probably indigenous to the interbank facies (Ryan, 1978). The common presence of bituminous material in this facies is not considered proof of reducing environments at the time of deposition, because this material is also abundant in highly fossiliferous Gays River Formation carbonate banks.

CARBONATE BANKS - BASAL TERRIGENOUS ROCKS

Petrography

At the base of nearly every carbonate bank, dolomitic sandstones, conglomerates and coarse breccias are irregularly distributed. The composition of these rocks is variable, and is commonly directly related to the composition of the adjacent and underlying basement rocks. Where carbonate banks are well developed, fine-grained terrigenous rocks occur in limited thickness, although in other instances, this detritus may be present throughout the entire vertical succession of the Gays River Formation, and may be justifiably termed a terrigenous facies of the Formation.

The *breccias* are limited in lateral extent and are characterized by the angular and poorly sorted nature of their component blocks. Excellent examples of basal breccias can be seen in the quarries of Mosher Limestone Company Limited in Upper Musquodoboit, and at the base of the Dollar Lake bank (No. 20, Fig. 2). The latter breccia consists of elongate cobbles and blocks of slate. At Upper Musquodoboit, blocks are composed of metagreywacke similar to the underlying Meguma at that locality (No. 2, Fig. 2).

Cobble and boulder conglomerate is, a common locally developed rock unit, at the base of many carbonate banks. These rocks are typically cemented with dolomite. The constituent cobbles are often well rounded and may exhibit a crude imbricate structure when high concentrations of flat or elliptical shapes predominate. Detrital quartz may or may not be abundant in the dolomitic matrix.

Dolomitic sandstones and fine-grained conglomerates may be important constituents of the basal part of some banks. Typical examples are illustrated in Figure 7. Sand and silt-sized material is dominated by quartz with lesser amounts of feldspar, and mica flakes may be locally abundant. Material of this size is typically angular to subangular. Rock fragments in coarser grained rocks are typically oblate and moderately well rounded (Fig. 7C and F). Bedding is often obscure (Fig. 7C), but is usually defined by the parallel alignment of elongate particles (Figs. 7B, D and F). Fragments of mollusc shells constitute the main faunal elements of these terrigenous rocks.

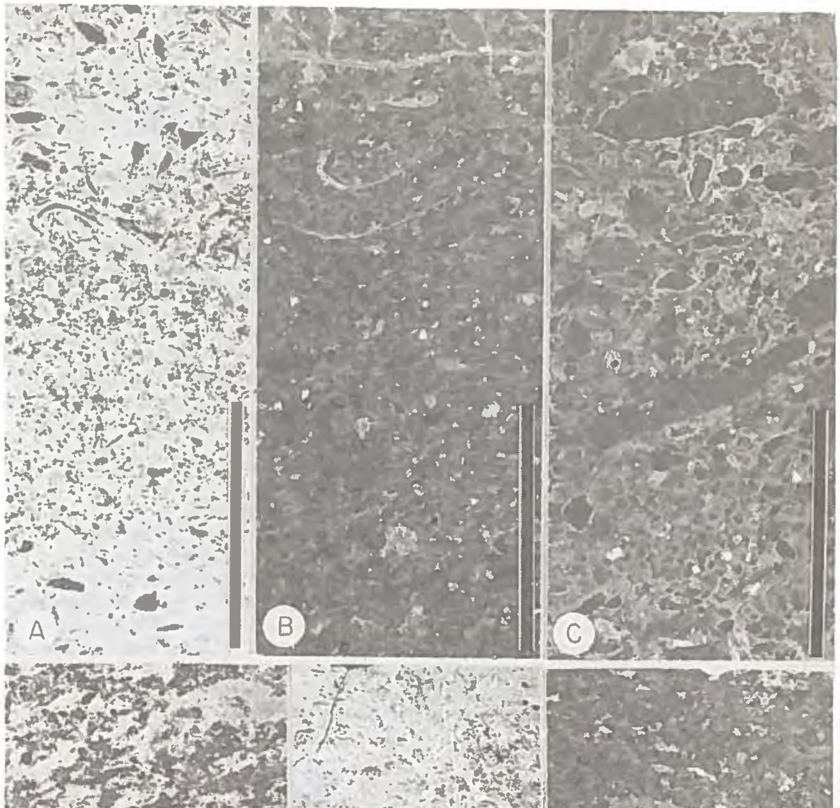
Environment of Deposition

The basal breccias may vary in origin. Within the "lower" quarry at Upper Musquodoboit, a protruding knob of metagreywacke is fringed and capped by dolostone-cemented blocks of the same composition. The size of the blocks may reach several cubic meters, and they appear to rest very near their former position as part of the basement paleo-outcrop. We interpret these as joint-bound blocks, in-filled and cemented in place by carbonate of the superimposed bank deposits. Smaller associated blocks and cobbles are interpreted as talus deposits, also subjected to limited transport and reworking during the marine transgression.

In contrast, in the upper quarries at Upper Musquodoboit, breccias fill local basement irregularities with cobbles and large blocks of metagreywacke and carbonate. The carbonate blocks often exceed one meter in largest dimension and are commonly rich in tabulate corals. Most of the blocks are subangular, and sorting is very poor. The matrix to the boulders consists of dolostone and sandy dolostone. These breccias are overlain typically by medium to thickly bedded shelly dolostone. We suggest that these breccias represent debris slides initiated in the submarine environment early in the bank development, thus explaining the incorporation of bank dolostones.

Boulder and cobble conglomerates are interpreted as the products of marine re-working of talus detritus, probably during the initial marine transgression, and are indicative of shallow-water, high-energy conditions. Imbrication of cobbles is consistent with this interpretation.

Dolomitic sandstones and fine-grained conglomerates were deposited in marine environments, as indicated by their faunal content, under moderate- to high-energy conditions. The erratic distribution of these rock types suggests that the local availability of terrigenous detritus was the main controlling depositional factor.


A
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CARBONATE BANKS - CARBONATE ROCKS

Autochthonous Dolostones

Codiacean Bafflestone

Petrography

Dolomitic Codiacean bafflestone occurs sporadically at the base of several carbonate banks, including the Nine Mile River bank (No. 28, Fig. 2) and the Gays River bank (No. 25, Fig. 2). Its common presence has been noted in the quarry of Calpo Limestone at South Side Harbour, Antigonish County (Fig. 1), a bank that we consider to be stratigraphically equivalent to those of the Gays River Formation. The same bafflestone is present, but less common in a bank in the Mahone Bay area (Fig. 1) studied by one of us (PSG) in considerable detail.

Where Codiacean bafflestones have been observed, they most commonly rest on pre-Carboniferous rocks. Their lateral continuity is presumed to be limited, since closely adjacent drillholes within the Gays River bank only sporadically intersect these rocks.

This type of bafflestone is formed in large part by the remains of calcareous algae assigned to the family *Codiaceae* by Ryan (1978) and Hatt (1978). The rock is massive, and may extend for 3 m or more in diamond-drill core intersections without change in character. Although bedding surfaces are obscure and presumed to be absent, the rock exhibits a very strong sub-vertical linear fabric in slabbed hand specimens and in diamond-drill core. In hole NM-73-3 drilled at Nine Mile River (Fig. 4), this linear fabric is pronounced, and parallels the long axis of the core samples. In other instances, textures within the bafflestone may be limited to mottled patches, some of which show an indistinct radial fabric (Fig. 8A). Well developed radial fabric is typical in surface exposures or

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Explanation of Figure 7

Negative prints of thin sectons. Bar scale = 10 mm.

Basal terrigenous rocks of the Gays River Formation. Carbonate banks rest upon rocks in D and F, whereas the sandstones in A, B, C and E constitute part of the interbank facies in the Nine Mile River and Lower Meaghers Grant areas. All samples cut perpendicular to bedding; tops are located at the respective top of each photograph.

Note the angular to sub-angular nature of the terrigenous detritus in A and E; contrast these with C and F in which the mean grain size is larger. Note also the indistinct bedding in D and E, represented in the other photographs only by a sub-parallel alignment of oblate clasts and/or fossil fragments.

A: Hole NM-9, depth 535 feet, Nine Mile River area (Fig. 4).

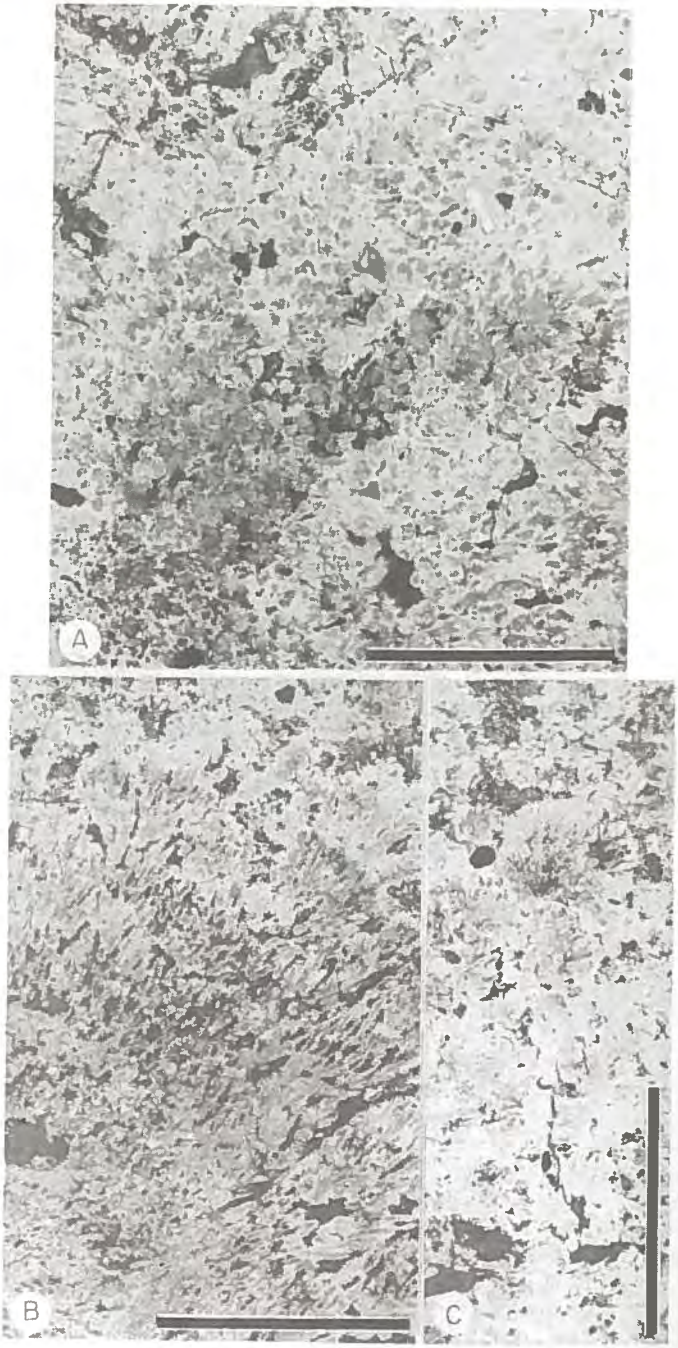
B: Hole NM-29, depth 552 feet, Nine Mile River area (Fig. 4).

C: Hole NM-25, depth 384 feet, Nine Mile River area (Figs. 2 and 4, No. 28)

D: Hole Mg-18, depth 48 feet, West Lower Grant bank (Fig. 2, No. 16)

E: Hole Mg-36, depth 213 feet, Lower Meaghers Grant area (Fig. 2)

F: Hole FRB-4, depth 64.7 feet, Fraser Brook bank (Fig. 2, No. 5)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B
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large hand specimens and may also be observed in diamond-drill core (Fig. 8B). A tuft-like fabric may be associated, and appears to be a variant growth form (Fig. 8C), although this mode of growth could also represent a contrasting growth habit of an associated genus of alga.

The pronounced linear fabric is from the parallel alignment of algal thalli in vertical to sub-vertical growth position. Mottled textures result when these clumps of thalli are cut obliquely or tangentially due to variation in growth orientation.

The matrix of the bafflestone typically comprises vaguely peloidal dolomitic mudstone. In the Gays River bank (No. 25, Fig. 2), Hatt (1978) noted a high proportion of terrigenous grains in this rock type, associated with sand-sized carbonate grains. Hatt also noted geopetal structures within this matrix material in the inter-thalli spaces. Our observations suggest that, on a more regional basis, a carbonate mud matrix is more typical of the Codiacean bafflestone.

Porosity in the bafflestone is low, and limited to sporadically distributed, incompletely filled primary voids, or intra-fossil cavities in associated faunal elements which are limited largely to the tabulate coral *Cladochonus*. Permeability is believed to be low.

Environment of Deposition

Calcareous algae of this type are most prolific in warm, marine waters in depths ranging from the low tide level to several tens of metres (Johnson, 1961). Riding (1975) questioned the use of fossil algae of such uncertain affinities, as indicators of water depth. Nevertheless, intimate association of the Codiacean bafflestones, with coral rich bafflestones, supports the suggestion of Johnson, and indicates that subtidal environments were reached very rapidly during the marine incursion. The presence of sand-sized detritus within the bafflestone matrix at Gays River (Hatt, 1978) indicates that the algal colonies thrived in moderate- to high-energy conditions. The more typical mud matrix which we observed need not indicate a low-energy environment, but may merely reflect the microenvironment in which the sediment was trapped.

Explanation of Figure 8

Negative prints of thin sections. Bar scale = 10 mm.

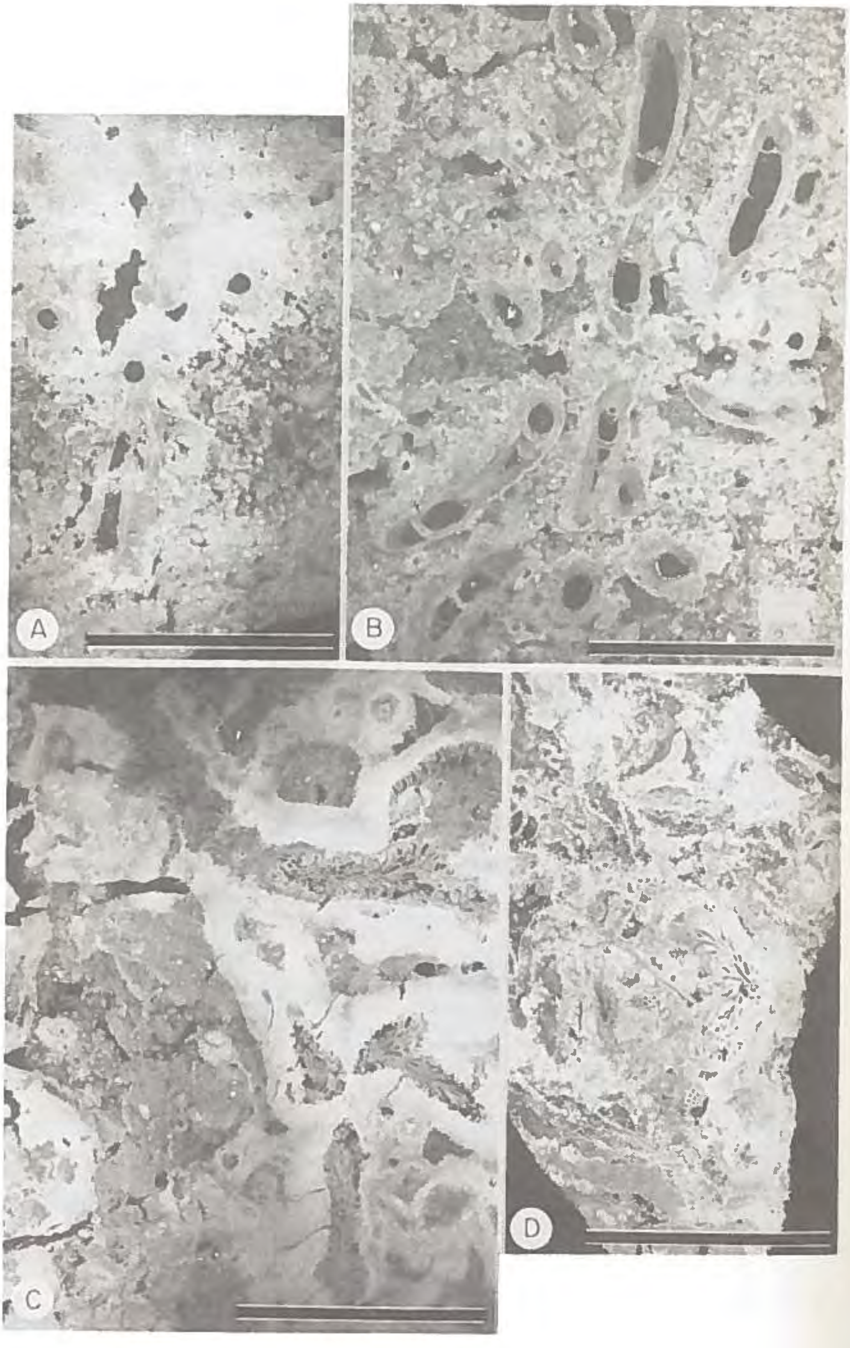
Algal boundstones of the Gays River bank. Note the distinct radiating structure preserved in B, and less pronounced in the upper right parts of A; the mottled texture is typical. Compare the small globular structure in upper centre of photograph C to the larger structure in B; different species of alga may be represented. Small dark spots in lower right of photograph C are quartz grains.

All samples from Hole GR-256 (Fig. 4), Gays River bank (No. 25, Fig. 2).

A: depth 84 feet (25.2 m)

B: depth 157.5 feet (47.2 m)

C: depth 159.0 feet (47.7 m)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The observed variability in matrix type suggests that the Codiacean bafflestone formed in environments ranging from shallow subtidal, to subtidal below effective wave base.

Coral and Bryozoan Bafflestones

Petrography

Tabulate corals of the genus *Cladochonus* and stem-like bryozoans, are commonly present in carbonate banks of the Gays River Formation. Local prolific growth of these organisms resulted in the development of steeply-walled bafflestone masses reaching 5 m in height. These small bioherms are usually flanked by molluscan wackestone and packstone beds described under a subsequent heading. In these bafflestones, either corals *or* bryozoans predominate to the virtual exclusion of all other biota.

Coral and bryozoan bafflestones are best developed in the Gays River (No. 25, Fig. 2) and Nine Mile River banks (No. 28, Fig. 2), but are widespread throughout the Shubenacadie and Musquodoboit Basins (Fig. 1). They are least common in banks in the southern extremities of the Musquodoboit Basin.

Bafflestones, in which tabulate corals or stem-like bryozoans are abundant (Fig. 9), are typically finely crystalline and peloids are the principal allochem. Bedding is usually obscure. In most instances, the corals appear to have been preserved in life position (Fig. 9B). Also a strong preferred sub-vertical orientation in bryozoan-rich dolostones seems to indicate preservation of these stem-like fossils in their growth position. In neither instance is the faunal element believed

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Explanation of Figure 9

Negative prints of thin sections. Bar scale = 10 mm.

Figure 9A and B: Coral-bearing bafflestone containing prolific tabulate corals of the genus *Cladochonus* in a matrix of peloidal and finely intraclastic dolostone. Note the absence of other faunal elements, and the preferred alignment of tubules in B suggesting possible life consistent orientation. This suggestion is consistent with the consistent convexity of tabulae in each of the specimens intersected in B. The thin white rind shown in several tubules in the right half of B is comprised of sphalerite. Sample in A from Hole CB-1, depth 53 feet (16.2 m), eastern extension of Gays River bank (No. 25, Figs. 2 and 4). Sample in B grab sample from Gays River exploration decline, orientation unknown.

Figure 9C and D: Closely spaced erect stem-like bryozoans (C) with early diagenetic cement. Note the excellent preservation of bryozoan structure in spite of complete dolomitization. Also note contrast between cement (?) of C with matrix of C. Photograph D illustrates more complex mottling with no apparent differentiation between cement and matrix as in C. Sample in C from Hole GR-131, depth 171 feet (52.2 m), Gays River bank (Fig. 4). Sample in D from Hole DL-1, depth 32.5 feet (9.9 m), Dollar Lake bank (No. 20, Fig. 2).

capable of building a self-supporting framework, although some of the bryozoan-rich varieties may have approached this state through the addition of cement coatings very early in their diagenetic history (Fig. 9C). The nature of this coating material is uncertain, and an organic (algal or bacterial) origin cannot be discounted. At present, the coatings are composed of micritic dolostone which shows no lamination or algal filaments. It is dissimilar from fibrous or equigranular carbonate crusts which might substantiate its origin as a cementing material.

The matrix in the coral bafflestones ranges from sand and silt-sized carbonate grains in dolomitic mudstone, to peloidal mudstone. Bryozoan bafflestones are typified by a peloidal mudstone matrix in which a few silt-sized grains may be scattered. Geopetal structures are common in the bryozoan bafflestones, but have not been observed in the coral bafflestones.

Porosity is variable in the bafflestones, but is locally very high, consisting mainly of intra-fossil cavities (Fig. 9). The effective permeability is typically low in the coral bafflestone, but may be greater in the bryozoan bafflestone where a higher proportion of interstitial voids are only partly filled with matrix material.

Environment of Deposition

The presence of corals and stem-like bryozoans in life position is clearly indicative of deposition in the subtidal environment. Energy levels were probably low according to the observations of Stach (1936; in Schopf, 1969) who noted that erect, rigid stem-like bryozoans with sub-cylindrical branches are adapted for life in deep or quiet water environments. The fine-grained matrix of the bryozoan bafflestone is consistent with quiet water deposition. However, suitable protected niches within a moderate- to high-energy enivronment might also locally provide the required quiet water environment.

Stromatolitic Bindstones

Petrography

Laminated algal stomatolites occur in many of the carbonate banks, although their distribution is erratic. They have been observed in the Nine Mile River, Dutch Settlement, Gays River and East Lower

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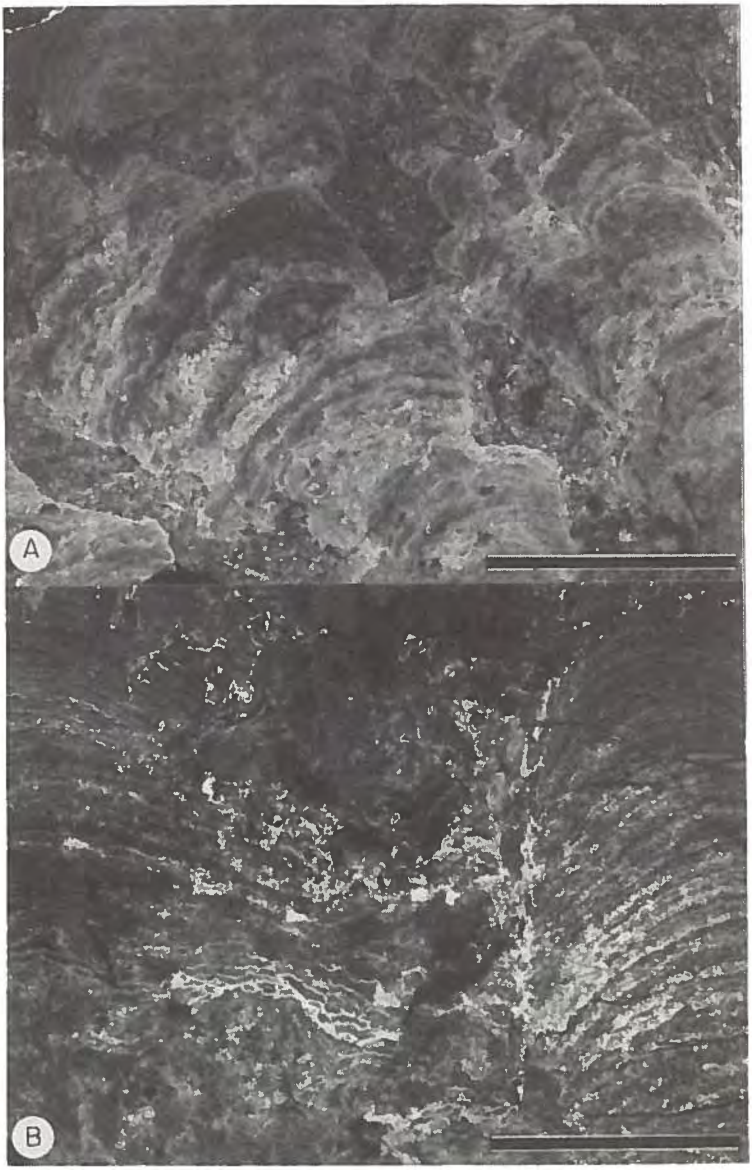
Explanation of Figure 10

Negative prints of thin sections. Bar scale = 10 mm.

Algal stromatolites in dolostones of the Dutch Settlement bank (No. 27, Figs. 2 and 4). Note the apparent digitate habit in A which exhibits irregular external growth and somewhat discontinuous internal lamination. Bifurcation and coalescence of digits can be seen in the centre of the upper photograph. Contrast with B, where the growth habit consists of moderately domed, stacked hemispheroids which produce adjoining digit-like stromatolites with continued upward growth.

A: Hole DS-81, depth 384.8 feet (117.4 m)

B: Hole DS-8, depth 50.2 feet (15.3 m)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Grant banks (Nos. 28, 27, 25 and 15, Fig. 2). They occur near the base or top of the succession in any given bank. In no case were stromatolitic bindstones found resting directly upon Meguma basement rocks.

Typically, the stromatolitic bindstones are less than 0.3 m in thickness. They are finely crystalline and composed entirely of dolomite. They vary in colour from creamy buff to grey-brown. Several growth forms are present. Digitate varieties are common (Fig. 10A and B), and in many instances, appear to originate as individual small growths, rather than through bifurcation upwards from a planar-laminated form. Often, encrusting bryozoans lie at the base of the digitate columns (Fig. 11E) suggesting that initial substrate stabilization was accomplished by the bryozoan and not by the algal colony. Planar laminated forms are typically undulatory in thin section (Fig. 12A) although individual lamina are continuous.

In the lower parts of the banks, the matrix surrounding and capping the digitate stromalolite consists typically of skeletal packstone or skeletal wackestone (Fig. 10A). In the highest parts of the Dutch Settlement bank (No. 27, Fig. 2), stromatolitic bindstone in beds 0.2-0.4 m in thickness, is interstratified with intraclastic packstone in which skeletal material has not been observed.

Environment of Deposition

Algal stromatolites range from supratidal to subtidal environments, although most workers consider them typical of intertidal deposits. Playford and Cockbain (1976) have shown that intertidal forms extend seaward without significant change in morphology, into the subtidal environment. Encrusting bryozoans which occur within stromatolitic bindstones, are typically indicative of high-energy conditions (Schopf, 1969), suggesting a shallow water origin. The position of the stromatolitic

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Explanation of Figure 11

Negative prints of thin sections. Bar scale = 10 mm.

Figure 11A, B and C: Cryptalgal dolostones comprised of thrombolitic growths, compare Johnson (1961, Plate 121-2).

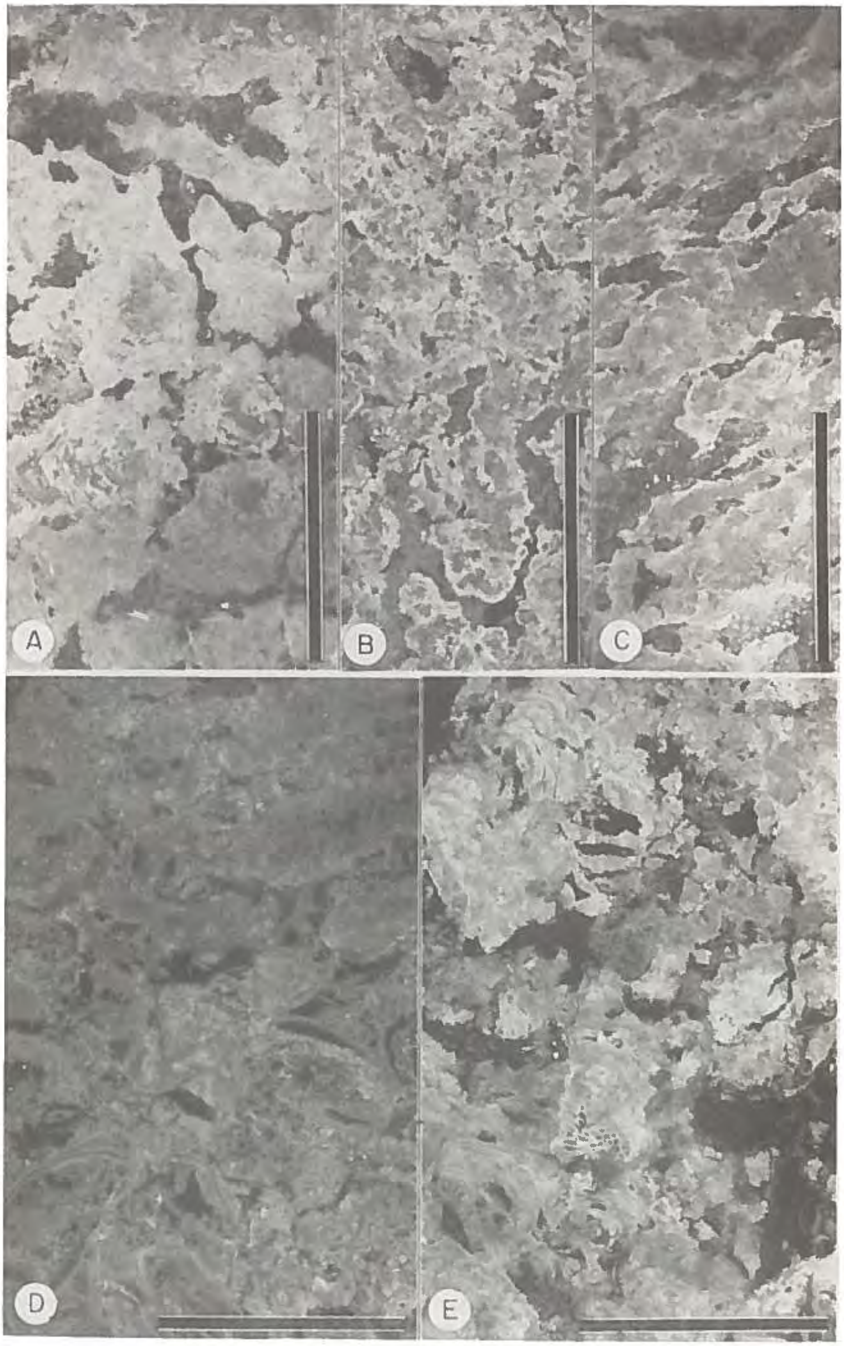
A: Nine Mile River bank (No. 28, Fig. 2), hole NM-6 (Fig. 4), depth 86 feet (25.8 m)

B: Dollar Lake bank (No. 20, Fig. 2), hole DL-1, depth 7.5 feet (2.2 m)

C: Murchyville bank (No. 12, Fig. 2), hole MV-2, depth 22 feet (6.6 m)

Figure 11D: Reworked thrombolites (?) in pelecypod-lump grainstone; Nine Mile River bank, hole NM-8, depth 103.5 feet (31 m) (Figs. 2 and 4).

Figure 11E: Mottled algal bindstone; note encrusting bryozoan overgrown by laminated algal stromatolites; black areas are voids; Gays River bank, grab sample from exploration decline (Fig. 2).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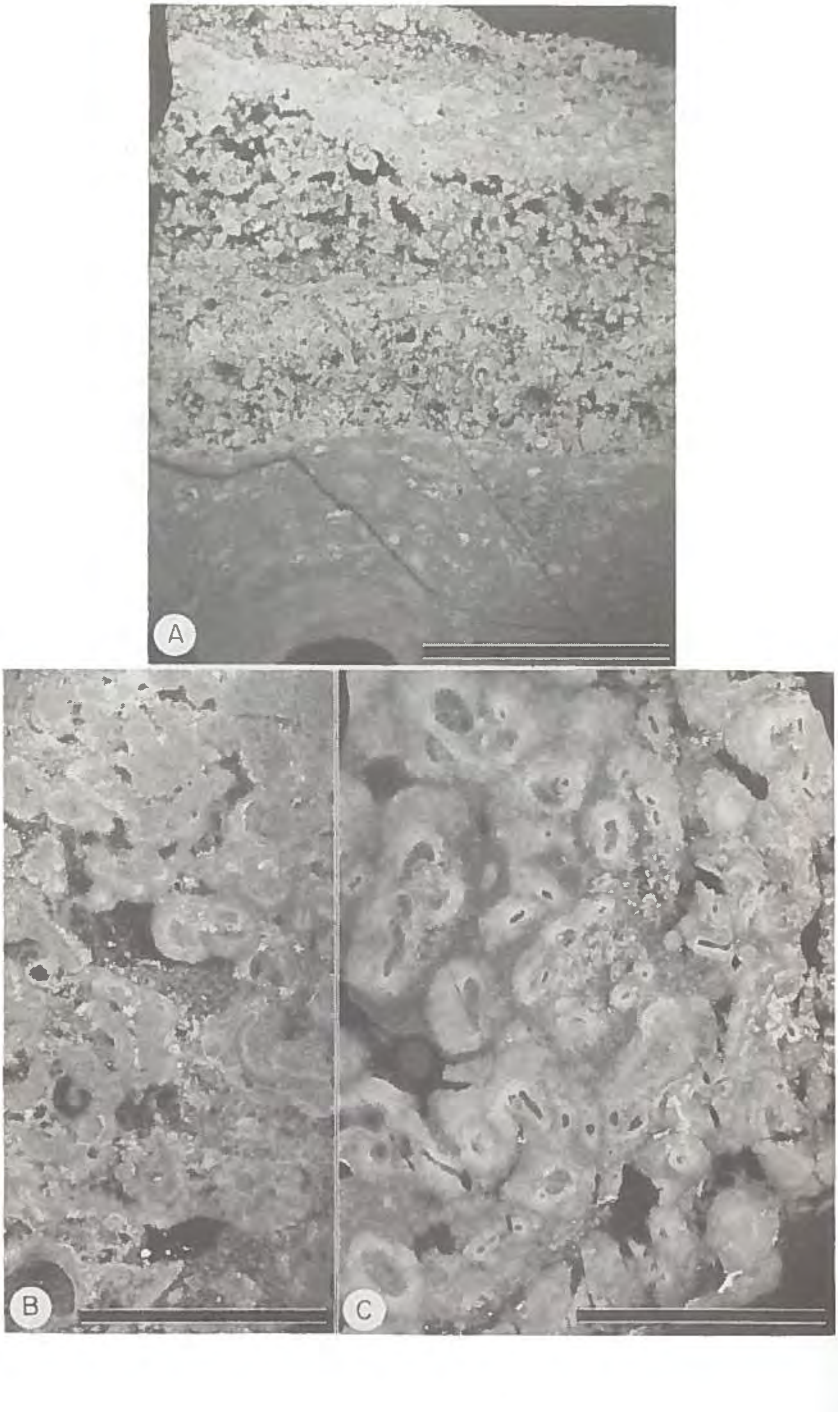
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bindstones low in bank profiles, suggests that they might represent deposits of the initial marine transgression.

Stromatolitic bindstones associated with intraclastic packstones in the upper part of the Dutch Settlement bank appear to represent deposition in a high-energy, ecologically restricted environment. We interpret these associated beds, therefore, as shallow-water, perhaps intertidal deposits. They thus record a period of marine regression late in the history of the bank. The extremely limited fauna could reasonably reflect hypersaline conditions which culminated in the deposition of evaporites of the Carrolls Corner and Stewiacke Formations in the Shubenacadie Basin.

Mottled Algal Bindstones

Petrography

Mottled algal bindstones occur in banks throughout the study area, and have also been noted at Williams Point, Antigonish County (Fig. 1), where they comprise a significant part of that bank (Murray, 1971). These rocks do not appear to be restricted stratigraphically, and in vertical sections, they may extend throughout the bank in which they occur. They represent the lateral equivalent of the more common skeletal packstones and wackestones, and it is notable that they occur in topographically low parts of the Dutch Settlement bank (No. 27, Fig. 2), whereas skeletal dolostones dominate the elevated parts of the same bank.

The algal bindstones are typically mottled grey and light brown, and are composed mainly of clotted, irregular lumps and elongate

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Explanation of Figure 12

Negative prints of thin sections. Bar scale = 10 mm.

Figure 12A illustrates, in its lower part, laminar structure typical of planar laminated algal stromatolites. Note the bulbous convolution evident in left centre of photograph, and the continuity of laminae in the lower part of this bulbous swelling; in the upper parts of this structure, a micro-structure is well developed which disrupts the lateral continuity of laminae; in extreme cases, the microstructure consists of miniature club-shaped forms, each discrete from its adjacent neighbours, and with little, if any, continuity of individual laminae between the forms.

Photographs in B and C illustrate the irregular mottled texture typical of bryozoan-algal association. Encrusting bryozoans appear in B as arcuate cellular objects, encrusted by dolostone of presumed algal origin. In photograph C, the cores of the structures comprise vermiform gastropods, although many encrusting bryozoans are also present. As in B, the algal origin of the dolomitic encrustation is uncertain.

Figure 12A: Hole NM-8, depth 73 feet (22.3 m), Nine Mile River bank (No. 28, Figs. 2 and 4).

Figure 12B: Hole NM-8, depth 98 feet (29.9 m), Nine Mile River bank (No. 28, Figs. 2 and 4).

Figure 12C: Hole MV-2, depth 28.5 feet (8.7 m), Murchyville bank (No. 12, Fig. 2).

masses of dolostone, set in a subordinate matrix of peloidal dolomitic wackestone (Fig. 11A, B and C). Although an obscure laminated character is sometimes apparent (Figs. 11A; 12C), these structures are most typically lacking in laminae, and seem best termed thrombolitic algal structures (Aitken 1967).

Faunal elements are commonly incorporated within the thrombolitic masses and include both stem-like and encrusting bryozoans, molluscs, ostracods and small vermiform gastropods (Fig. 11B, C and E). The algal bindstones are typically massive and exhibit little primary porosity. Only in those rocks where shelly fossils are associated, is significant porosity evident as sheltered areas beneath shells and algal lumps (Fig. 11D). In these rocks, the algal lumps appear to have behaved as large intraclasts, as opposed to the more common type of algal bindstone in which peloidal carbonate silts appear to have been trapped in the irregularities produced by a surface bound by irregular algal growth *in situ* (Fig. 12B).

Environment of Deposition

The incorporation of stem-like bryozoans in thrombolitic masses suggests a quiet subtidal depositional environment, as does the close association of the algal bindstones with Codiacean and tabulate coral bafflestones. In those bindstones, however, where encrusting bryozoans or vermiform gastropods dominate the associated fauna, more restricted environmental conditions are indicated. Encrusting bryozoans are dominant under high-energy conditions (Schopf, 1969) and vermiform gastropods are capable of prolific development in marginal marine environments (Burchette and Riding, 1977). Thus this restricted fauna, and the vertical range of this rock unit from the base to highest parts of the banks, suggests deposition in environments ranging from subtidal below

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Explanation of Figure 13

Negative prints of thin sections. Bar scale = 10 mm.

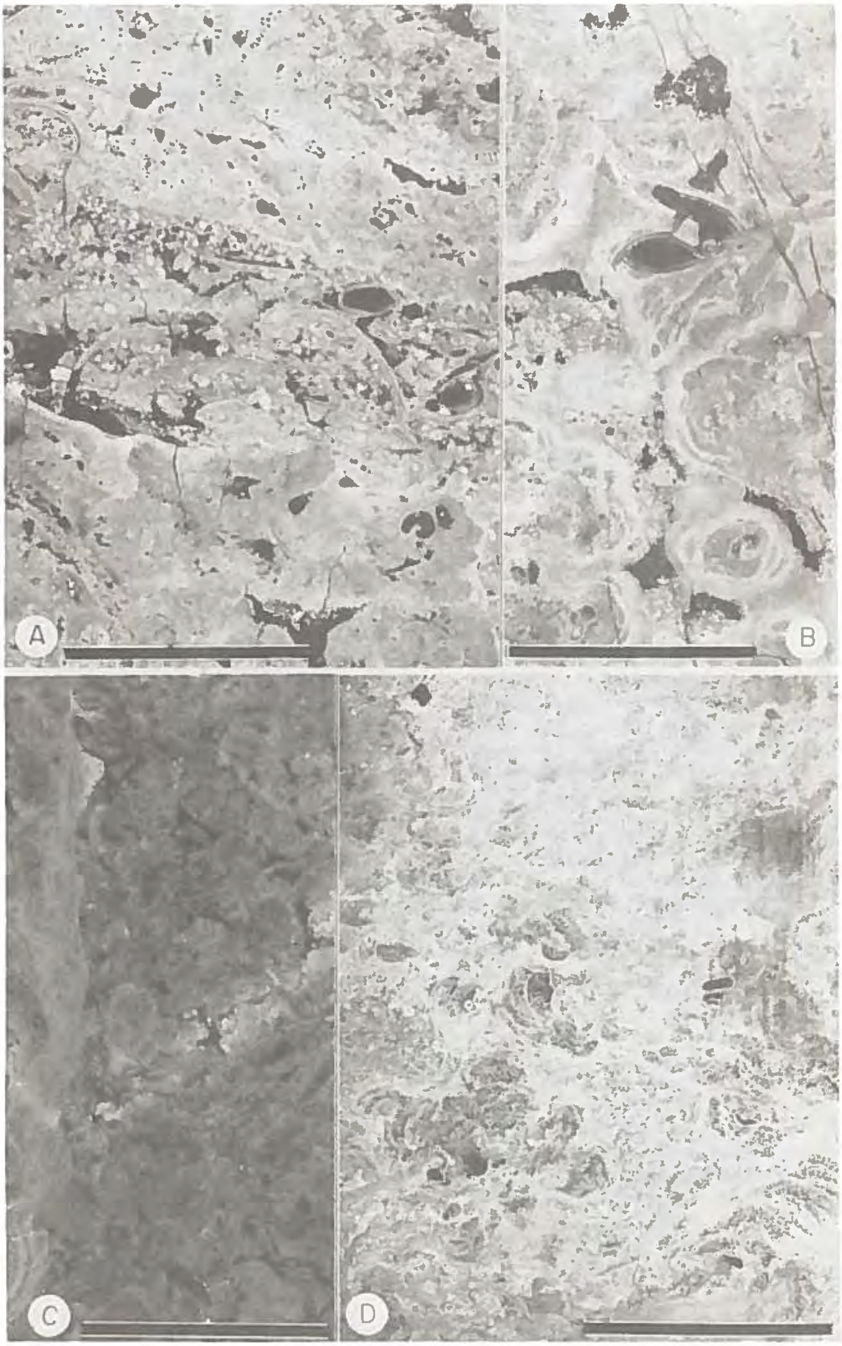
Dolostones in which encrusting bryozoans constitute an important or even dominant biotic element.

Figure 13A: Intercalated bryozoan bindstones with lithic skeletal packstone (centre). Note the sharply defined irregular lower contact of the packstone bed with the underlying bindstone. Also note the truncation of a bryozoan colony in lower centre photograph at the contact; Sample from Hole GR-256, depth 126.0 feet (38.4 m), Gays River bank (Fig. 4).

Figure 13B: Bryozoans with multiple encrustations and associated cement rims; sample from Hole NM-8, depth 73 feet (22.3 m), Nine Mile River bank (Fig. 4).

Figure 13C: Lithic skeletal packstone comprising large rounded intraclasts, shell fragments, and fragments of globular encrusting bryozoan. Visible in left of photograph, is a large single bryozoan colony, genus unknown, which appears to consist of multiple cellular layers, each produced by succeeding encrustations; sample from Hole NM-3, depth 78.5 feet (23.9 m), Nine Mile River bank (Fig. 4); top to right in photograph.

Figure 13D: Prolific encrusting bryozoans with associated small gastropod; sample from Hole DL-1, depth 72.5 feet (22.1 m), Dollar Lake bank (No. 20, Fig. 2).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effective wave base, to shallow subtidal within the zone of wave turbulence. It is possible that the algal bindstones may have been subjected to intermittent exposure in the intertidal environment, although direct evidence for such exposure is lacking.

Bryozoan Bindstones

Petrography

In contrast to bafflestones in which stem-like bryozoans functioned as sediment trapping agents, encrusting bryozoans appear in some instances to have colonized the sediment in an active sediment-binding role. Rocks which are dominated by encrusting bryozoans are thus termed bryozoan bindstones (Fig. 13).

Most typically, the encrusting bryozoans occur in finely crystalline, vaguely mottled dolostone (which itself appears to be of algal origin, Fig. 13A and D), in which the bryozoans appear to colonize the previously stabilized algal-coated surface. In these rocks, sediment-floored interstices are common (Fig. 13A and B, Fig. 12B). The sediment is identical to that which occurs in associated well-bedded skeletal wackestones and packstones. We believe that these interstices were filled or incompletely filled concurrent with the framework formation which consisted of a cavernous algal-bound mass.

Bryozoan bindstones are closely associated with mottled algal bindstones and have a similar distribution within the banks. Skeletal remains and allochthonous carbonate grains are more common in the bryozoan bindstone (Fig. 13A and D).

Environment of Deposition

The bryozoan bindstones were probably deposited in environments ranging from subtidal to low intertidal under moderate- to high-energy conditions. The upward range of these bindstones in vertical profiles, is less than that of the mottled algal bindstones, indicating that deposition was predominantly subtidal.

Allochthonous Carbonate Rocks

Skeletal Wackestones and Packstones

Petrography

These rock types (Figs. 14 and 15) are ubiquitous in carbonate banks of the Gays River Formation throughout the study area. They extend throughout the banks in vertical profiles, with the exception of the uppermost parts of the profiles where skeletal material is usually rare or absent.

Skeletal wackestones and packstones are characterized by the remains of a biota with a limited diversity of recognized species. Pelecypods and gastropods contribute the bulk of the biogenic constituents, with lesser brachiopod and ostracod remains. Preservation of the skeletal material, although variable, is generally good, in spite of extensive dolomitization (Figs. 14D and 15B). Whole brachiopod shells are commonly preserved, although pelecypod shells and ostracod carapaces are often disarticulated, or may be preserved with the valves agape (Fig. 14D). Mechanical attrition is not usually evident. Fenestrate bryozoans are an important fossil component, and may locally be present in abundance. Encrusting bryozoans are present in small quantities, and fragments of stem-like bryozoans have also been noted (Fig. 15A). Encrustation of mollusc shells by bryozoans and algae (Fig. 15B) is common.

Small intraclasts and peloids are the principal grain types associated with the skeletal material (Fig. 14D and 15A). Sand-sized terrigenous grains (Fig. 14c) or quartz silt (Fig. 14b) may be common locally, but are not major contributors to the total grain bulk. Dolomitic mudstone comprises the matrix material in these rocks.

Porosity is usually well developed in the skeletal wackestone and packstone (Figs. 14D; 15A, B and D), and consists largely of inter-fossil and intrafossil vugs, partially in-filled with white to translucent calcite and/or peloidal mudstone. Some of the most porous rocks contain vugs which transect fossil fragments and which appear to be fracture induced. Fenestral pore spaces (Fig. 14D) are locally present.

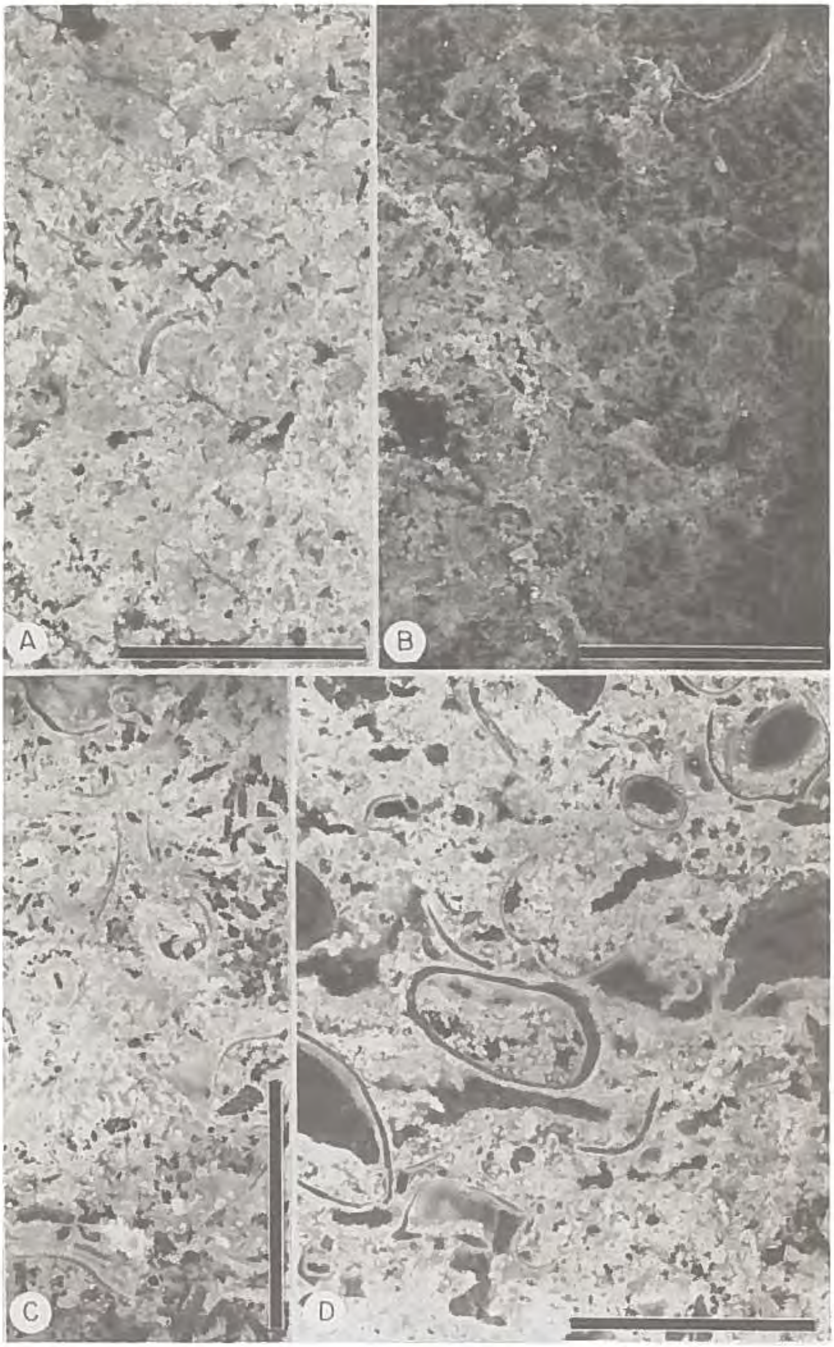
Environment of Deposition

Molluscs, which dominate the fauna in the skeletal wackestones and packstones, are environmentally wide-ranging. Fenestrate bryozoans may withstand stronger currents than rigid stem-like forms (Stach 1936), suggesting that deposition may have occurred in a relatively high-energy environment. However, Schopf (1969) has questioned the ability of highly calcified (rigid) fenestrate growth forms to withstand high energy conditions, and states that they appear to be absent in intertidal environments. It appears that the skeletal packstones and wackestones were thus deposited in the subtidal environment but under moderate energy levels. The presence of a carbonate mud matrix with a high proportion of lithic and skeletal grains is consistent with this interpretation. Also, Hatt (1978) noted that skeletal packstones and wackstones occurred in channels separating coral and Codiacean bafflestone bioherms, thus, supporting a subtidal interpretation.

Koninckopora Wackestones and Packstones

Petrography

One constituent of the shelly wackestones and packstones that is relatively uncommon in banks near the northwestern limits of our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study area, is the calcareous alga *Koninckopora* (de Koninck). In the Fraser Brook and Brookvale banks (Nos. 5 and 10, Fig. 2), *Koninckopora* dominates the biogenic component of the banks over intervals reaching 18 m in thickness. It has been noted in more northwesterly banks mostly as small fragments. At Gays River, an isolated outcrop yielded a hand specimen composed solely of large tubules of *Koninckopora*. The stratigraphic position within the bank could not be determined from this single outcrop.

Petrographically, the *Koninckopora* wackestones and packstones are not distinct from other such rock types dominated by skeletal biogenic material. They are distinguished on the basis of fauna and flora, but otherwise exhibit similar textures and component carbonate grains (see for example Fig. 16B and C).

Koninckopora (Fig. 16B, C and E), is found in abundance in the quarries of Mosher Limestone Company Limited at Upper Musquodoboit, where it is closely associated with abundant shelly fossils in the host beds. Large fragments of this alga, which may exceed 1 cm in diameter and reach 10 cm in length, generally lie in the plane of the bedding in, what appears to be, a haphazard orientation. At this locality, as at most localities, the sub-cylindrical form of the algae is preserved, with the internal portions, which were presumably composed of uncalcified plant tissue, infilled with peloidal mudstones (Fig. 16B). Often the cylindrical form exhibits excellent geopetal structure in cross section, with the upper portions filled with clear calcite and/or dolomite. Most *Koninckopora* retain a sub-circular cross section, indicating that compaction of the fossils was minimal.

At the base of the Fraser Brook bank (Fig. 16D), and at the base of the interbank facies of the Gays River Formation intersected in diamond-drill hole NM-29 (Fig. 16A), a dolomitic mudstone containing a less robust form of *Koninckopora* has been observed. The host rock in each instance is medium to dark grey, as opposed to the buff dolostone

Explanation of Figure 14

Negative prints of thin sections. Bar scale = 10 mm.

Skeletal wackestones and packstones of the Gays River Formation. Molluscs dominate the skeletal component. Note that most of the shells are disarticulated, with the exception of two gaping valves in D. Ostracod carapaces are common constituents in each sample. Note the presence of detrital quartz silt (B) and small rock fragments (C). The matrix in these samples consists of peloidal dolomitic mudstone.

Figure 14A: Sample from Hole NM-3, depth 32.6 feet (9.9 m), Nine Mile River bank (Fig. 4).

Figure 14B: Sample from Hole NM-8, depth 118 feet (35.9 m), Nine Mile River bank (Fig. 4).

Figure 14C: Sample from Hole CB-1, depth 62.5 feet (19.1 m), eastern extremeties of Gays River bank (Fig. 4).

Figure 14D: Sample from Hole GR-256, depth 52 feet (15.9 m), Gays River bank (Fig. 4).

of the typical banks, and the alga is represented by single cell-layer, flat or highly contorted fragments which lie in the plane of the bedding. Associated faunal elements are limited to rare small high-spired gastropods. The insoluble content of this type of dolostone is distinctly higher than in typical bank dolostone, and is evident in the form of detrital quartz grains and small rock fragments.

Environment of Deposition

The family *Dasycladaceae* in which *Koninckopora* is placed, is characteristic of shallow subtidal environments (Johnson 1961, Heckel 1972, Riding 1975). Oolitic carbonates are often closely associated with *Koninckopora*-bearing rocks (Wood, 1930). We accept that the *Koninckopora*-rich banks were probably deposited in the shallow subtidal environment, but we also believe that the increasing abundance of this floral element, reflects increased proximity to the southeastern margin of the Windsor sea during this time.

Dolomitic Wackestones and Packstones

Petrography

In the absence of significant quantities of biogenic elements, peloidal and finely intraclastic dolomitic wackestones and packstones (Fig. 17) are common constituents of Gays River Formation banks. The wackestones and packstones occur in virtually every bank for which petrographic data were available. We have observed no regional preference for development of this rock type.

These rocks are typically massive, and exhibit no primary sedimentary structures. The peloids may be partly of faecal origin, as suggested by MacLeod (1975b) although the indistinct nature of these

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Explanation of Figure 15

Negative prints of thin sections. Bar scale = 10 mm.

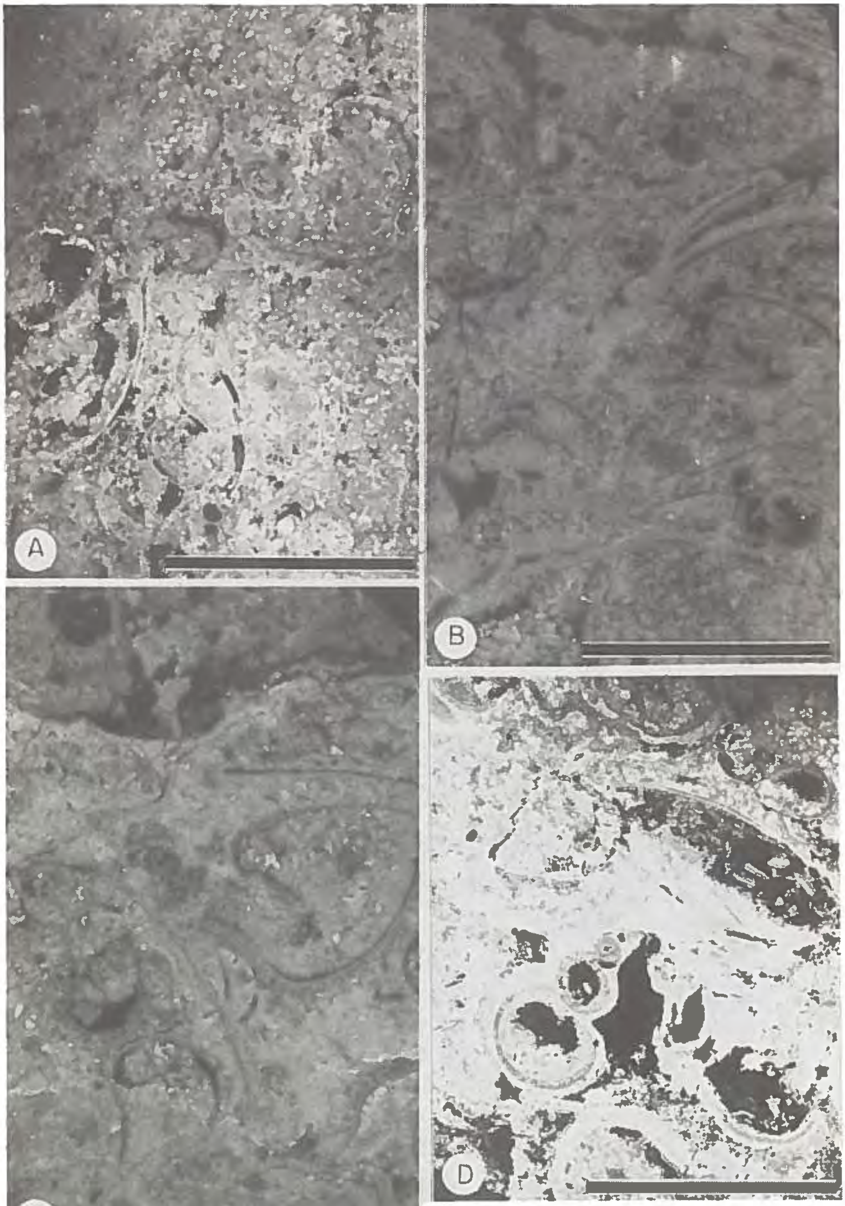
Skeletal wackestones and packstones, illustrating variations in packing, but an overall similarity in texture and porosity. Pelecypods dominate the fragments, with lesser gastropods. Disarticulation of the bivalves is typical, although abrasion and breakage of shells is not common; note the bryozoan-algal encrustations in B.

Figure 15A: Sample GRGB-5, grab sample from the exploration decline, Gays River bank (No. 25, Fig. 2).

Figure 15B: Sample from Hole DL-1, depth 61 feet (18.6 m), Dollar Lake bank (No. 20, Fig. 2).

Figure 15C: Sample from Hole MV-2, depth 56.2 feet (17.1 m), Murchyville bank (No. 12, Fig. 2).

Figure 15D: Sample UM-6; "lower quarry," Upper Musquodoboit bank (No. 2, Fig. 2).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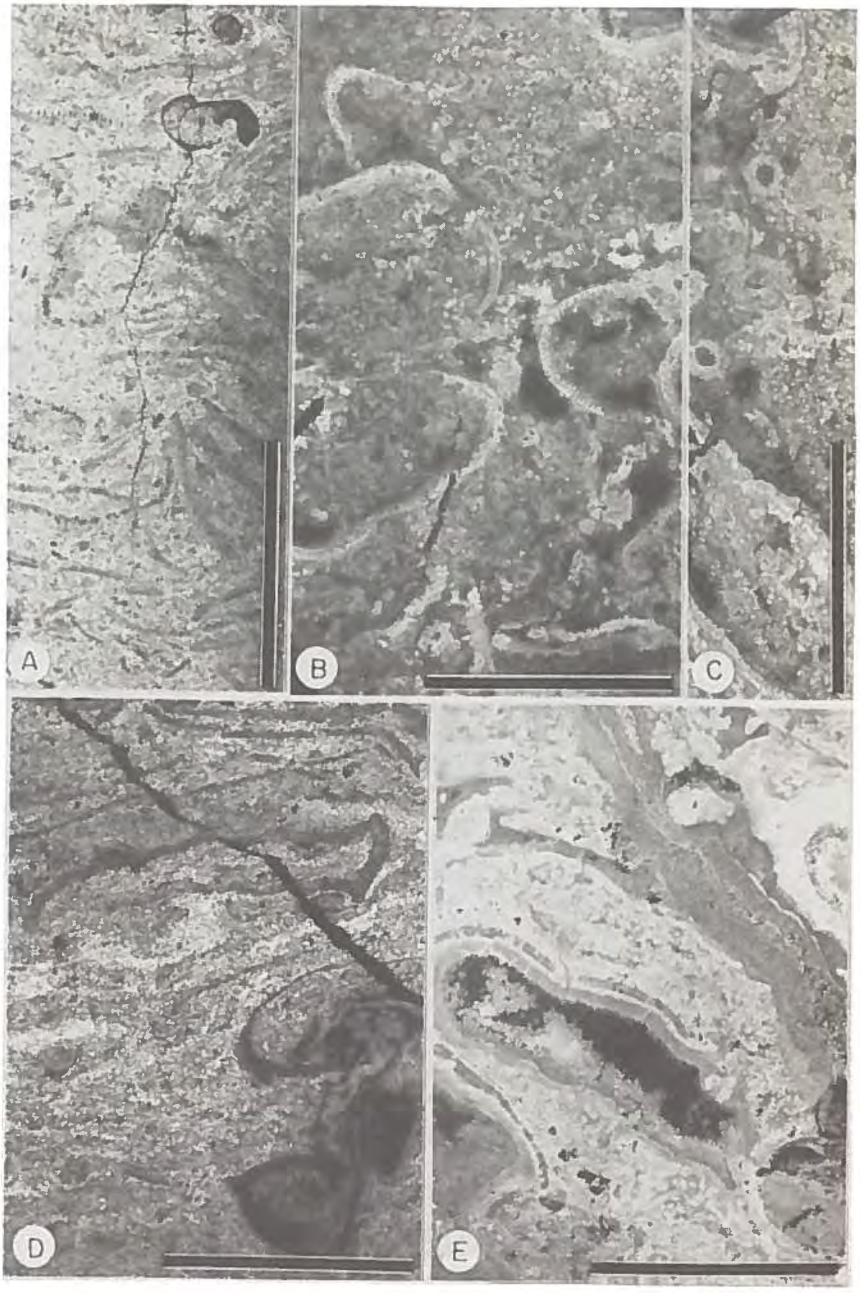
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allochems renders this interpretation highly subjective. Calcareous Foraminifera are common, although like the pellets (peloids), the nature of preservation of these microfossils is inadequate for more specific identification. Lithic carbonate grains are abundant. The matrix typically comprises dolomitic mudstone. Dolomitic wackestones and packstones grade arbitrarily into the more common skeletal wackestones and packstones through the addition of biogenic components, and may also be present as cavity-filling material within the bindstones and bafflestones.

Porosity is highly variable in the peloidal dolostones, as illustrated in Figure 17A, C and D. Generally, these rocks exhibit little macroscopic porosity, and consequently, appear to represent the least potential host for base metal localization. However, the volumetric importance of the peloidal wackestones is small, and thus they exert little control over base metal distribution in the Gays River bank.

Environment of Deposition

The arbitrary separation of the skeletal wackestones and packstones from similar rocks lacking significant biogenic components is convenient for purposes of description, but implies no major differences in environmental setting. Thus we suggest a shallow subtidal depositional environment for the dolomitic wackestones and packstones. We note a preferential concentration of the faunally impoverished rocks in restricted local environments such as the interstices within the mottled algal bindstone.

Intraclastic Lime Packstones

Petrography

Limestone is uncommon in carbonate banks of the Gays River Formation in the Shubenacadie and Musquodoboit Basins. In the uppermost

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Explanation of Figure 16

Negative prints of thin sections. Bar scale = 10 mm.

Dolomitic wackestones and packstones comprised mainly of the calcareous alga *Koninckopora*. Fragments of tubular remains intersected in random orientation in B, C and E. Fragments in A and D occur in silty dolostone, are much less robust, and rarely appear tubular in cross section; these may represent a second species of the genus.

Note the granular nature of the matrix in B, C and E. Small lumps and peloids with scattered calcareous Foraminifera, comprise much of the matrix.

Figure 16A: Sample from Hole NM-29, depth 546 feet (166.5 m), interbank facies, Nine Mile River area (Fig. 4).

Figure 16B: Sample from Hole BV-2, depth 47.5 feet (14.5 m), Brookvale bank No. 2 (Figs. 2 and 4).

Figure 16C: Sample from Hole FRB-4, depth 32.5 feet (9.9 m), Fraser Brook bank (No. 5, Fig. 2 and 4).

Figure 16D: Sample from Hole FRB-4, depth 67.8 feet (20.7 m), Fraser Brook bank (No. 5, Fig. 2 and 4).

Figure 16E: Sample MAMG-1C, grab sample from outcrop, West Lower Grant bank (Fig. 4).

parts of the Gays River and Dutch Settlement banks (Nos. 25 and 27, Fig. 2), limestones have been noted by MacLeod (1975b) and in this study. In the Dutch Settlement bank, depositional textures in the limestone are well preserved. Identical rocks are well exposed in equivalent strata in the Mahone Bay area.

Rod-like grains compose the single allochemical constituent of the lime packstone. These vary in length from 0.2 to 3 mm, and are typically aligned with their long axes parallel to bedding. These grains probably represent faecal or algal pellets, but their size demands classification as intraclasts. The matrix comprises lime mudstone. Intercalated with the intraclastic packstone, are thin stromatolitic bindstones.

Porosity is variable. In part, the lime packstone is cavernous and friable, probably as a result of recent leaching by groundwater, but this porosity decreases in descending profile at Dutch Settlement.

Environment of Deposition

The absence of associated faunal elements suggests deposition in a highly restricted environment. At Dutch Settlement, lime packstones are overlain by gypsum of the Carroll's Corner Formation. Within the Carroll's Corner Formation, similar intraclastic packstones have been noted (Giles and Boehner, in prep.), suggesting that evaporite deposition may have been synchronous with deposition of the lime packstone. The restricted fauna would indicate extreme environmental restriction due to elevated salinities, but cannot show conclusively the depositional setting. We favour an intertidal setting.

Explanation of Figure 17

Negative prints of thin sections. Bar scale = 10 mm.

Peloidal dolostones lacking other abundant allochemical or faunal constituents. Note the uniform texture and limited porosity in D, which is typical of these rocks. The porosity in A is quite exceptional.

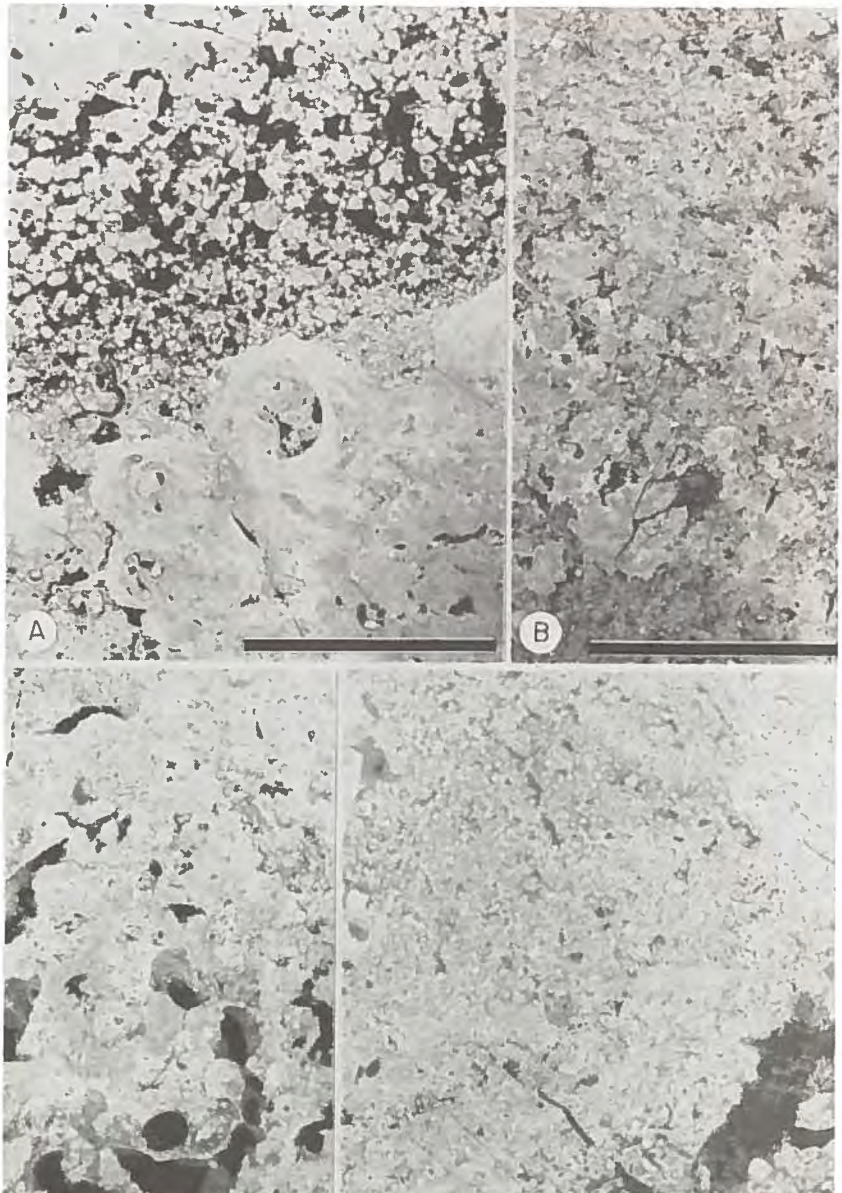
Recrystallization of these rocks may obliterate the peloidal character. Also, where finely crystalline patches occur, such as in B, a mottled texture similar to that of algal boundstone may result. In such cases, the distinction of these rock types may be hindered.

Figure 17A: Sample from Hole GR-256, depth 122 feet (37.2 m), Gays River bank (No. 25, Figs. 2 and 4).

Figure 17B: Sample from Hole CB-1, depth 51.5 feet (15.7 m), eastern extremeties of Gays River bank (No. 25, Figs. 2 and 4).

Figure 17C: Sample from Hole DL-1, depth 52.5 feet (16.0 m), Dollar Lake bank (No. 20, Fig. 2).

Figure 17D: Sample from Hole FRB-4, depth 22 feet (6.7 m), Fraser Brook bank (No. 5, Fig. 2).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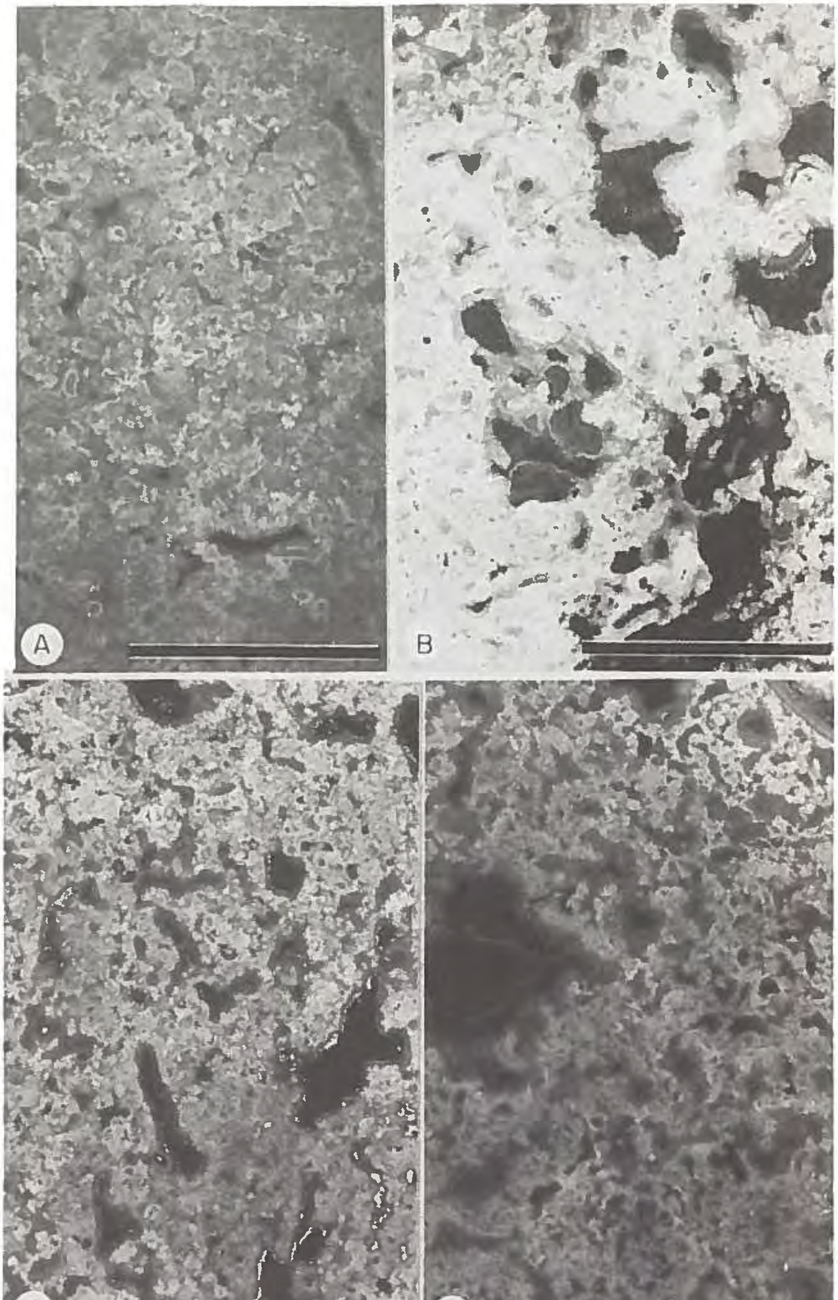
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Carbonates with Uncertain Depositional Texture

Crystalline Dolostone

Petrography

In this category, we place those carbonate rocks in which the original depositional character is obscure, as recommended by Dunham (1962). Typically these dolostones are restricted to the upper portions of their host banks. They are characterized by their mottled appearance in hand specimen, and by their cavernous nature (Fig. 18). Indistinct peloids and rare Foraminifera constitute the only visible allochems and fossils in most samples of this rock type. In a few hand specimens, single mollusc shells were observed. Faunal and floral elements are rare, which contrasts these dolostones with the other rock types observed. No preferential concentration of sulphides of lead and zinc in the crystalline dolostone has been noted.

Porosity is usually high, but may reflect the effect of relatively recent leaching and weathering processes in the position of these rocks near the bank tops. Pores are often elliptical (Fig. 18A and C), but are more typically highly irregular in shape (Fig. 18B and D). Open spaces are rimmed by buff, very finely crystalline dolomite which may be in very sharp contact with the host (Fig. 18D), or which may pass very gradually into the host (Fig. 18B). The host dolostone is typically mottled by what we believe represent small-scale examples of the same rim material which completely fills small voids. In some instances, the mottled appearance is very like that of algal bindstones shown in Figures 11A, B and D.

Environment of Deposition

It seems probable to us, that many of these rocks, which are typified by the photographs of Figure 18, may be in part of algal origin, although no firm evidence of this genetic origin can be presented. Hatt (1978) interpreted these rocks as pustular algal mats and assigned them to the intertidal zone in a restricted shallow lagoonal environment.

Explanation of Figure 18

Negative prints of thin sections. Bar scale = 10 mm.

Crystalline dolostones of uncertain origin. The highly porous nature and the anastomosing mottled texture may be attributed to diagenetic processes, or may reflect an organic (algal ?) origin. The presence of highly irregular voids in random orientation is typical. Very finely crystalline dolomite rims and often totally fills these voids (best shown in D). Sphalerite (white) locally lines and sometimes fills voids, as shown in photograph C. Dolostones of this type occur in the highest parts of the stratigraphic succession in most carbonate banks.

Photograph A: Hole NM-3, depth 42.5 feet (13.9 m), Nine Mile River bank (No. 28, Figs. 2 and 4).

Photograph B: Hole GR-256, depth 55.2 feet (16.8 m), Gays River bank (No. 25, Figs. 2 and 4).

Photograph C: Hole GR-197, depth 70.0 feet (21.4 m), Gays River bank (Fig. 4).

Photograph D: Sample UM-3, "lower quarry," Upper Musquodoboit bank (No. 2, Fig. 2).

BIOSTRATIGRAPHY

GEOLOGICAL SETTING

Schenk (1967) first suggested that the Macumber Formation changed in character basinward, where it was represented by highly fossiliferous, massive limestones which we assign to the Gays River Formation, stating that this relationship existed in the central parts of the Antigonish Basin, and in the Hillsborough area of southeastern New Brunswick. On the other hand, Geldsetzer (1977, 1978a, 1978b) proposed that the Macumber Formation was deposited under hypersaline conditions in shallow water, and was equivalent to shelly carbonate developed preferentially along the (eastern) margins of a hypersaline shallow sea. Geldsetzer believed that salinity was the main controlling factor and that the type Macumber, as described by Schenk (1967), was the basinward equivalent of the shelly facies. Neither of these authors considered the faunal characteristics of the shelly carbonates which they postulated to be lateral equivalents of the sparsely fossiliferous Macumber (Formation) laminites.

Boehner (1977) first presented firm evidence for the equivalence of the Gays River and Macumber Formations. The wide geographic distribution of carbonate banks of the Gays River Formation in the southeastern parts of the Minas Sub-basin (Fig. 1), provides ample scope for study of their constituent faunal elements. The results presented here are of a preliminary nature, but indicate clearly that the A Subzone of Bell (1929), within which the limited Macumber fauna was originally placed, contains locally a reasonably prolific and abundant fauna (cf. Bell, 1929; Moore and Ryan, 1976) in the Gays River Formation. Moore and Ryan (1976) concurred with Bell (1929, 1958), Stacey (1953) and Sage (1954) in believing that the faunal elements of Windsor limestone representative of Bell's subzones B, C, D, and E, are the best means of determining the relative stratigraphic position of such a unit within the Group. Our data suggest that the fauna (and flora) of the carbonate banks of the Gays River Formation contrast in some important aspects with stratigraphically higher faunas.

FAUNA AND FLORA

Table 1 summarizes the fauna and flora which have so far been confirmed in carbonate banks of the Gays River Formation. The regional distribution of these faunal and floral elements may reflect, in part, the preliminary nature of our study, rather than real variations in constituent elements. Comparison of the data of Table 1 with those of Bell (1929, p. 66-67) and Moore and Ryan (1976, p. 22-25) shows clearly that almost all forms present in the Gays River Formation have been previously reported from stratigraphically higher carbonates.

Bryozoans appear to offer the highest potential as biostratigraphic indicators, since possibly newly recognized species or subspecies appear in Gays River banks. In addition, the common presence of encrusting forms such as those illustrated in Figure 13, are typical of these banks, but are uncommon in banks at higher stratigraphic levels in proportion to erect and fenestrate forms. The biostratigraphic significance of the bryozoans must await detailed taxonomic study.

Newly recognized forms include possible new species of *Fenestrellina* and *Cyclopora*, both members of the phylum Ectoprocta. Several genera of calcareous algae appear to be characteristically abundant in carbonate banks of the Gays River Formation. Because calcareous algae in the Windsor Group have received little attention, with the exception of the study of Mamet (1970), we cannot claim that any of the forms which we have observed, are regionally typical of, or restricted to, carbonate banks of the Gays River Formation. Nevertheless, the abundance of one species of Codiacean algae, in our study area at least, seems to be a useful guide to differentiate Gays River banks from those higher in the stratigraphic succession. Regional application of this criterion has not been proven.

In a similar fashion, although tabulate corals are not restricted to banks of the Gays River Formation, they are prolific only in banks of this type, and may be considered rare above this stratigraphic level. They therefore are useful biostratigraphic indicators in our study area.

FAUNA AND FLORA / BANK LOCALITIES	UPPER MUSQUODOBOIT (NO. 2)	DEDICATION LAKE (NO. 3)	FRASER BROOK (NO. 5)	LINDSAY BROOK (NO. 6)	BROOKVALE (NO. 8)	O'BRIEN FARM (NO. 11)	MURCHYVILLE (NO. 12)	EAST LOWER GRANT (NO. 15)	WEST LOWER GRANT (NO. 16)	MEAGHERS GRANT (NO. 13)	MEAGHER (DILLMAN BK.) (NO. 18)	DOLLAR LAKE (NO. 20)	TULLY LAKE (NO. 22)	WILSON BROOK (NO. 24)	COOKS BROOK (NO. 25)	GLENMORE (NO. 23)	GAYS RIVER (NO. 25)	DUTCH SETTLEMENT (NO. 27)	NINE MILE RIVER (NO. 28)	WILLIAMS PT.-ANTIGONISH HARB.	CALPO QUARRY-ANTIGONISH HARB.	EAST RIVER-MAHONE BAY	SPRINGVILLE	OVERALL ABUNDANCE
Aviculopecten sp.	X	X										X				X	X	X						C
Aviculopecten lyelli	X								X								X							R
Aviculopecten lyelliformis	X	X														X	X							R
Batostomella abrupta		X								X	X	X			X	X	X	X	X					RR
Batostomella exilis	X	X			X					X	X	X		X	X	X	X	X	X					C
Beecheria davidsoni	X	X		X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	CC
Cladochonus sp.	X	X					X			X	X	X			X	X	X	X	X			X	X	C
Cyclopora ? sp.		X									X	X	X	X	X	X	X	X	X		X	X		C
Diodoceras avonensis	X																							RR
Fenestrellina sp.	X	X									X	X		X	X	X	X	X	X					C
Koninckopora sp. "A"	X		X	X	X	X	X	X	X			X	X				X		X			X		C
Leptodesma sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	C
Leptodesma acadica	X	X			X		X							X			X	X			X			C
Leptodesma borealis	X																X				X			R
Leptodesma dawsoni	X	X	X											X	X	X	X	X			X			CC
Paraconularia planicostata	X	X					X					X		X		X	X	X						C
Plocezyga ? sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	CC
Pseudozygopleura cf. cara		X															X							RR
Pteronites gayensis	X	X															X							RR
Straparollus minutus	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	CC
Streblopteria debertianum							X																	RR
Unknown Codiaceae											X	X	X				X	X	X	X	X	X	X	R

Data after Ryan (1978)

Table 1: Faunal and floral elements in discrete carbonate banks, Gays River Formation in central Nova Scotia.

Two aspects of the fauna are, however, notable and may prove biostratigraphically significant on a broader regional basis. The first of these is the absence of major groups of organisms which are both common and widespread at higher stratigraphic levels in the Windsor Group. For example, we have noted no representatives of the phylum Echinodermata in the Gays River Formation, within the banks, or within adjacent interbank dolostones. In contrast, crinoidal debris, and to a lesser extent echinoidal debris, is ubiquitous and often prolific throughout the succeeding carbonates of the Windsor Group. Also notably rare, are all plicate and costate brachiopods which appear first in moderate numbers in the lowest carbonate members of the MacDonald Road Formation (Giles and Boehner, in prep.) in our area. Moore (personal communication, 1978) recently reported a single specimen of a small, plicate brachiopod from a Gays River Formation carbonate bank in our study area. Ryan (1978) found no representatives of this type of brachiopod.

The second aspect of the fauna which is notable, is the predominance of molluscs. In contrast, carbonate banks higher in the Windsor Group, are typically dominated by brachiopods. We have attempted to quantify this observation by calculating the proportions of gastropods, pelecypods and brachiopods in equal-area numerical counts of these faunal elements in large hand specimens (Fig. 19). Only relative proportions were thus estimated, since in many instances, we were unable to differentiate disarticulated (single) valves from whole fossils. Also, we made no attempt to differentiate between transported fossils, and those which appeared to be in life position. In essence, we have attempted to objectively describe relative faunal abundance as seen in hand specimen.

The results of this study illustrate a high degree of variability in samples from single carbonate banks, although several, for example the East Lower Meaghers Grant bank (No. 15, Fig. 2), are reasonably consistent in the proportions of these three major groups (Fig. 19A). Considered as a whole, carbonate banks of the Gays River Formation are mollusc-dominated but vary widely in the relative proportion of gastropods and pelecypods. In contrast, the banks which we sampled as representative of limestones of Bell's (1929) subzones B, C and E, are dominated by brachiopods (Fig. 19B and C) and exhibit much less variation in relative proportions of the three groups of faunal elements. The degree of separation evident in Figure 19D suggests that a real distinction can be made between Gays River banks and those of higher carbonate members in the Shubenacadie and Musquodoboit Basins. Variation in paleoenvironmental factors through time seems to us the most reasonable explanation for this distinction.

In an attempt to test our conclusion that the fauna (and flora) of the Gays River banks are biostratigraphically distinctive, we examined carbonate banks in the Antigonish Harbour area (Fig. 1) reported by Schenk (1967) to be Macumber (laminite) equivalent. These banks are located at Williams Point and Southside Harbour and have been previously described by Sage (1954) and Murray (1971, 1975). The reader is referred to these authors for specific locations and regional setting.

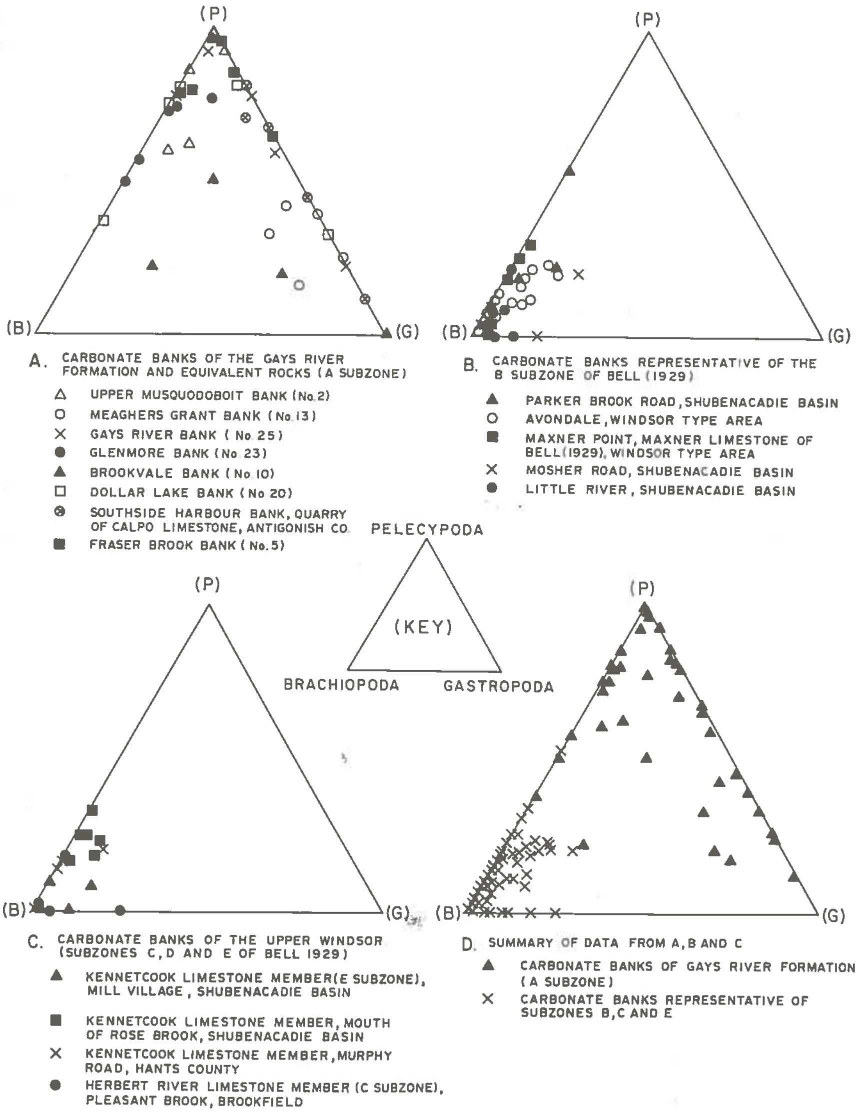


Figure 19: Relative abundance of major faunal groups in selected carbonate banks of the Windsor Group.

Although Sage (1954) considered these banks to contain faunal elements indicative of Bell's (1929) B faunal subzone, he presented data, based on diamond-drill records, which showed that the Southside Harbour bank was overlain by thick anhydrite and salt deposits, similar in general aspect to the Carrolls Corner and Stewiacke Formations of our area, and overlain in turn by a thick succession of siltstone and mudstone (Sage, 1954, p. 44), possibly equivalent to the Tennycape Formation of Weeks (1948). The Southside Harbour bank, therefore, seems a probable correlation of the Gays River type banks, based on lithostratigraphic evidence. Since the Williams Point bank occupies a similar stratigraphic setting (Murray, 1971), it appears to represent an equally likely candidate.

In contrast to the highly dolomitic Gays River banks in our area, the Williams Point and Southside Harbour banks are composed entirely of limestone. The Southside Harbour bank is quarried for high calcium limestone by Calpo Limestone Company Limited, and an analysis of the Williams Point limestone by Murray (1975) shows less than one per cent MgO.

Petrographically and sedimentologically, however, these banks are closely comparable to the Gays River carbonate banks. From the descriptions of Murray (1971), and from personal observation of the diamond-drill core used by Murray in his study, we confirmed in the Southside Harbour bank the common presence of Codiacean bindstone of the type illustrated in Figure 8. Within the more highly fossiliferous limestones at Williams Point, encrusting bryozoans are prolific as in the Gays River banks. Murray's (1971) descriptions of 52 hand specimens collected from the area of exposure of the Williams Point bank, clearly indicate that molluscs dominate the fauna. We have noted no plicate or costate brachiopods in examining diamond-drill core from the Williams Point bank, and Murray (personal communication, 1977) has indicated that this absence is consistent with his own observations. However, Sage (1954) reported the costate *Linoproductus lyelli* from this bank, and its possible presence cannot be refuted.

Examination of the Williams Point bank revealed the common presence of mottled algal bindstone of the type illustrated in Figure 11. This rock type also occurs at the base of the exposure in the quarry of Calpo Limestone. The shelly fauna, at this same locality, is dominated by pelecypods and gastropods (Fig. 19A). Plicate and costate brachiopods were not observed, although we carefully and specifically sought these forms.

Representatives of the phylum Echinodermata do not appear to be represented at either Williams Point or Southside Harbour. Unfortunately the tabulate corals, characteristically abundant in many of the Gays River banks, are also absent at Williams Point and Southside Harbour in the exposures and diamond-drill cores which we examined.

It appears that the correlation of the Williams Point and Southside Harbour banks, with those of the Gays River Formation in our study area, is supported on lithostratigraphic, petrographic and sedimentologic grounds. Biostratigraphic evidence supports this correlation, with the single anomaly of the presence of *Linoproductus lyelli* reported by Sage (1954) but unconfirmed in our study. We believe that the fauna of the Gays River Formation is, in all probability, a useful guide to the identification of its lithostratigraphic correlatives.

VERTICAL AND LATERAL VARIATIONS IN THE BIOTA

Within each carbonate bank of the Gays River Formation, the lateral and vertical distribution of faunal and floral elements is no less complex than the distribution of rock units containing these elements. We have observed only general tendencies based on the most prolific occurrence of major biotic constituents.

Ryan (1978) believed that Codiacean algae, tabulate corals and bryozoans were most prolific in peripheral areas of a bank. Hatt (1978, p. 83) showed that the distribution of his algal bindstone was controlled by the -60 m structure contour constructed on the pre-Carboniferous unconformity. Hatt's bindstone unit was limited in its down-slope extent by this contour, and yet could be traced laterally above this elevation. Hatt noted the association of coral and bryozoan-bearing bafflestones with his algal bindstone. Thus Ryan's suggestion appears to be supported by the work of Hatt.

Within those parts of a bank where faunal elements are most abundant, we note the most prolific tabulate coral and Codiacean alga populations at or near the base of the vertical succession (Fig. 20). Bryozoans tend to be more widely distributed in vertical profiles provided by single drill cores, although fenestrate forms are more prolific in the lower portions of the profiles, than in the upper (Fig. 20).

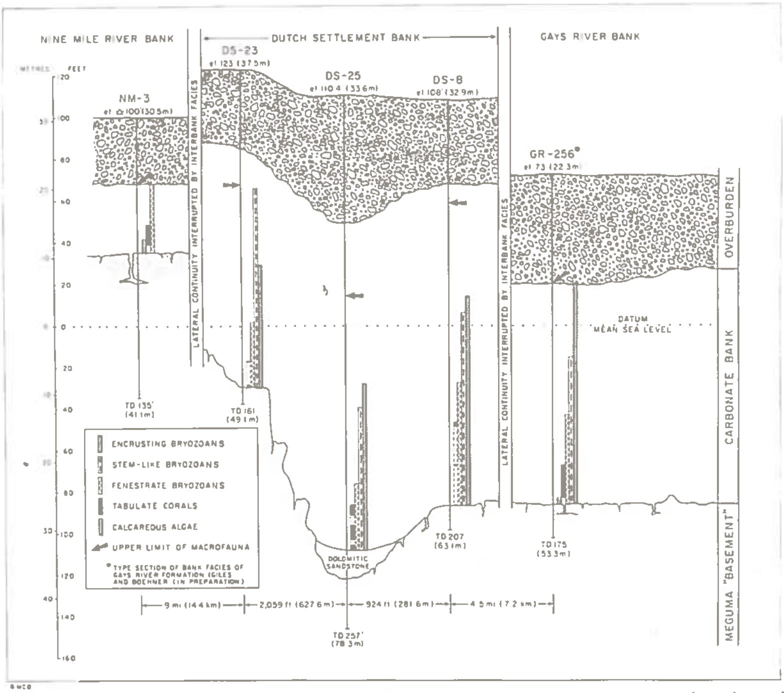


Figure 20: Vertical distribution of faunal and floral elements in the Nine Mile River, Dutch Settlement and Gays River banks.

The Gays River bank provides the single location where rigorous assessment of the lateral and vertical variations in the biota within a single bank can be assessed using closely spaced diamond-drill holes. Cross sections prepared by one of us (RJR) showed no systematic distribution, but were limited to only a small portion of this bank in the vicinity of the mine portal. Thus, ample opportunity exists for more thorough analyses of this aspect of the biota.

Comparison of faunal and floral elements between carbonate banks suggests that regional differences exist. For example, the calcareous alga *Koninckopora* (Fig. 16) is an important floral constituent only in those banks found at or near the southern (present-day) margin of the Musquodoboit Basin (Fig. 21). At Fraser Brook (No. 5, Fig. 2), for example, this genus is the dominant biotic constituent over a stratigraphic interval exceeding 18 m in thickness, in a bank in which corals and bryozoans are rare. It is similarly prolific at Upper Musquodoboit, Brookvale, and Lower Meaghers Grant. Although this alga has been noted in banks further to the north and northwest, it is much more limited in vertical and lateral extent in those banks. Conversely, Codiacean algae of the type illustrated in Figure 8 are prolific only in the most northerly and northwesterly banks (Fig. 21).

With the exception of the Upper Musquodoboit and Dedication Lake banks (Nos. 2 and 3, Fig. 2), the most southeasterly banks are noticeably impoverished with respect to stem-like bryozoans and tabulate corals. Because the depositional slope was towards the north and northwest (Boehner 1977), this broad change from mollusc-*Koninckopora* to mollusc-bryozoan-tabulate coral banks in that direction appears to reflect a basinward change in biofacies (c.f. Mamet, 1970).

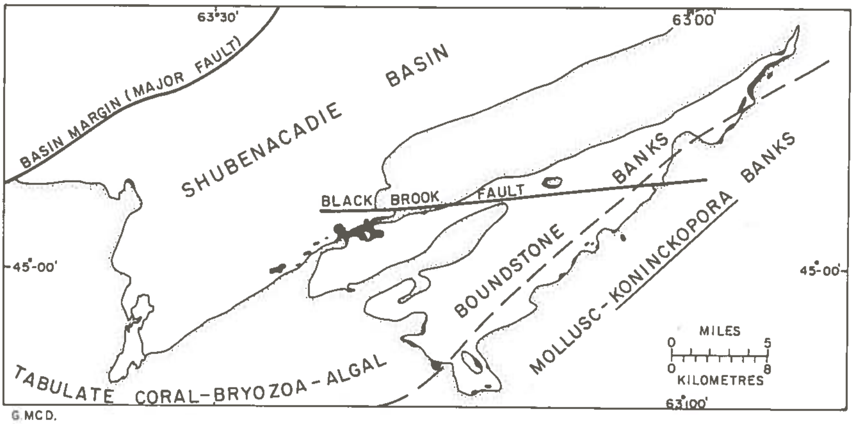


Figure 21: Biofacies variation in carbonate banks of the Gays River Formation.

BASE METALS IN GAYS RIVER FORMATION CARBONATES

Sphalerite and galena, with minor marcasite and chalcopyrite, constitute the dominant metallic mineral assemblage in the Gays River deposit (MacEachern and Hannon, 1974a and b). Mineralization is most commonly limited to open-space filling, although in some instances carbonate rocks may be replaced by both sphalerite and galena. MacLeod (1975a and b) reported the utilization of various types of pore spaces, such as interparticle, sheltered, fenestral (Figs. 18C and 22C), intra-skeletal and moldic, as well as fractures (Fig. 22A and C), by these sulphides during initial metallization. Open pore spaces are commonly partially filled with sulphide minerals (Fig. 22B; Fig. 18C), and significant porosity and permeability remain. MacLeod (1975b) suggested that this might indicate a finite restriction on the quantity of metallic ions available for emplacement.

In many instances, larger pores are floored by finely granular admixtures of dolomite and sphalerite (Fig. 22D). These cavities are also, in most cases, rimmed by a thin rind of sphalerite, and remain unfilled by later calcite or dolomite pore fillings. MacLeod (1975b) considered the sphalerite flooring in these spaces to have formed as a vadose sphalerite silt, derived through weathering of the host carbonate, and redeposited by circulating ground waters. This model was first suggested by Dunham (1969) to explain the formation of detrital carbonate silts as cavity-filling deposits. In the Gays River deposit, significant enrichment of local ore grade is possibly attributable to this process.

In paragenetic sequence, sphaherite predates galena, as indicated by the filling of sphalerite-lined voids by galena. Both sulphides post-date the major period of dolomitization which affected the banks.

Metallization shows no preference for any particular strati-graphic horizon within the bank complex, nor for any particular rock type (MacEachern and Hannon, 1974a and b). Sulphide minerals are most abundant however, on the northwestern (northwesterly dipping) flanks of the Gays River bank (Hannon, 1974, Fig. 11 and 12; MacLeod, 1975b). Galena is a relatively common constituent in the northwestern parts of the mineralized zone, but is increasingly rare to the southeast (Hannon, personal communication in MacLeod, 1975b).

Although it is true that the Gays River bank is the single bank which contains viable economic quantities of zinc and lead, other banks have been reported to contain locally high base metal concentrations. For example, the Lindsay Brook bank (No. 6, Fig. 2), in analyses of cavity filled mineralization in a selected hand specimen, contained 13.7 per cent zinc (assay reported in unpubl. NSDM AFR 27-H-14(17)). This mineralization was reported to occur in highly porous shelly carbonate. In addition, our analyses of diamond-drill core representing the Murchy-ville bank (No. 12, Fig. 2), yielded zinc values up to 4000 ppm over stratigraphic intervals reaching 6 m in thickness.

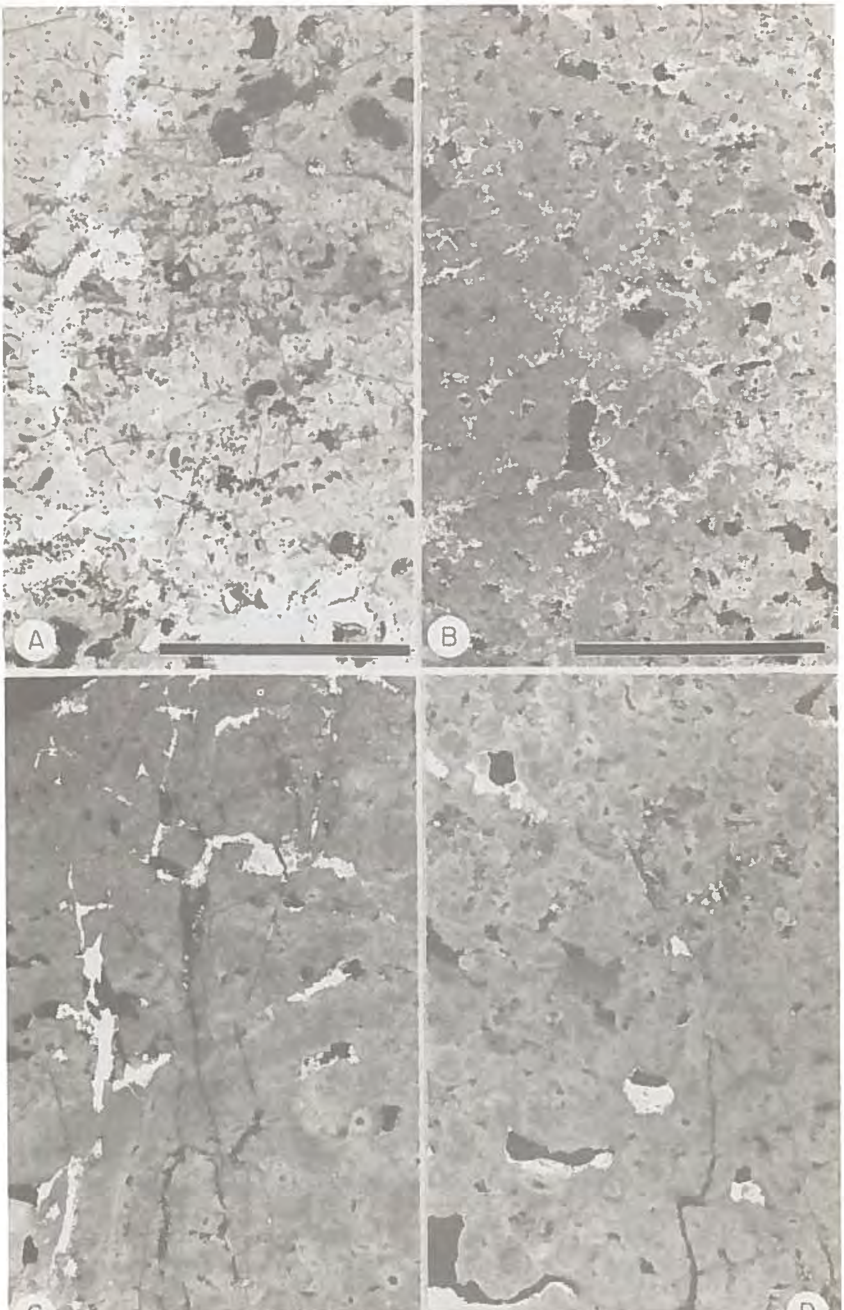
Explanation of Figure 22

Negative prints of thin sections. Bar scale = 10 mm.

Base metals in dolostones of the Gays River bank. All samples from Hole GR-256 (Fig. 4).

Figure 22A and C: Galena (white) filling fracture-related voids. Note that filling is incomplete in C, more complete in A. Sphalerite can be seen in upper right part of A as a thin rind on parts of irregular void. Note that sphalerite is not intimately spatially related to galena in this sample. Sample in A from depth of 76.5 feet (23.3 m). Sample in C from depth of 120 feet (36.6 m).

Figure 22B and D: Sphalerite filling diagenetically induced, irregular voids in dolostone. Note the incomplete filling of larger voids, and the geopetal nature of the filling in D. Sample in B from depth of 116 feet (35.4 m). Sample in D from depth of 151 feet (46.1 m).


A
B
C
D

VARIATIONS IN CHEMICAL COMPOSITION

Partial chemical analyses are presently in progress using approximately 200 samples of carbonate rocks of the Gays River banks. These samples include diamond-drill core, as well as samples selected from surface exposures. With the exception of samples from the Fraser Brook and Dutch Settlement banks (Nos. 5 and 27, Fig. 2), all were originally collected by D. A. Murray as part of an industrial mineral survey of limestone deposits throughout Nova Scotia. Partial analyses of many of the samples which we have considered were first reported in the 1967-1968 Annual Reports of the Nova Scotia Department of Mines.

It is not our intention here to describe in detail the geochemistry of the banks. Analytical results pertaining to the assessment of industrial mineral potential of these carbonate rocks will be fully tabulated in Murray (in prep.). We have selected partial analyses from the diamond-drill cores representing banks in different areas, each of which bears contrasting dominant rock units or biofacies, and which varies in its relationship to the underlying Meguma basement and the superimposed Carboniferous rocks. The analytical results are presented in Tables 2, 3 and 4.

The Gays River bank (No. 25, Fig. 2), in its most northeasterly parts, is represented in Table 2. This bank is dominated by coral and bryozoan bafflestone, with associated molluscan wackestone and thrombolitic algal bindstone. The bank rests on metagreywacke and is overlain and flanked by gypsum and anhydrite approaching 300 m in thickness. The Murchyville bank (No. 12, Fig. 2) is represented by diamond-drill hole MV-2 (Table 3). This bank rests upon slate, and is overlain by approximately 100 m of terrigenous rocks of the Meaghers Grant Formation of Boehner (1977). The Murchyville bank is dominated by *Koninckopora* wackestone and packstone. The third diamond-drill hole (Table 4), represents the Dollar Lake bank (No. 20, Fig. 2), which is similar lithologically and faunally to the Gays River bank. This bank rests upon slate, and contains at its base, a spectacular slate-boulder and cobble conglomerate. The Dollar Lake bank is flanked by a thick succession of intercalated sulphate evaporites and terrigenous rocks, which we believe to lie within the zone of facies transition between the Meaghers Grant and Carrolls Corner Formations (Giles and Boehner, in prep.).

The content of CaO and MgO indicated in Tables 2, 3 and 4, shows clearly a similarity in major element composition of these widely separated carbonate bodies. This similarity is most evident in comparing CaO-MgO ratios, and is apparent in additional analyses not reported in this paper. Because these elements represent mainly the calcite and dolomite fractions of the carbonate rocks, one may conclude that the regional carbonate diagenesis of these banks is remarkably uniform. It is apparent that the Gays River bank, represented in Table 2, is higher in MgO than the Murchyville and Dollar Lake banks. However, mean values indicate that the Murchyville bank is the lowest of these three in MgO content, yet is anomalously high in Zn content as is the Gays River bank in hole CB-2 (Table 2). These data suggest that the Zn content is not necessarily directly related to the proportions of calcite and dolomite present.

Table 2: Partial analyses of diamond-drill hole CB - 2, Gays River bank.

	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Ba(%)	Sr(%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
CB-2-1*	31.57	20.19	1.04	0.19	1.00	0.006	0.052	11	9	2000
CB-2-2	30.38	19.48	2.94	0.45	0.93	0.009	0.065	15	9	1700
CB-2-3	31.91	20.04	0.82	0.19	0.89	0.004	0.077	15	9	1440
CB-2-4	31.29	20.17	2.30	0.23	0.84	0.005	0.081	15	11	1700
CB-2-5	31.10	19.57	2.48	1.61	1.23	0.003	0.059	11	11	1800
CB-2-6	30.47	20.72	1.65	0.21	1.02	0.002	0.053	6	12	1800
CB-2-7	29.69	19.24	3.89	0.06	1.03	0.008	0.050	3	11	1800
CB-2-8	30.45	17.48	7.03	0.93	1.23	0.008	0.059	25	85	180
CB-2-9	29.44	14.95	10.70	1.78	1.23	0.007	0.049	23	110	100
CB-2-10	27.31	14.75	14.40	2.12	1.29	0.012	0.046	21	75	60

*CB-2-1 at top of hole; each sample represents approximately 5 feet (1.5 m) of core.

Table 3: Partial analyses of diamond-drill hole Mv-2, Murchyville bank.

	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Ba(%)	Sr(%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
MV-2-1*	29.40	18.88	1.55	0.55	1.92	0.016	0.044	29	11	16
MV-2-2	29.08	18.64	2.55	0.87	1.90	0.057	0.078	54	11	16
MV-2-3	28.75	18.87	1.75	0.51	1.99	0.005	0.054	40	11	14
MV-2-4	27.66	16.61	6.22	2.36	1.99	0.025	0.045	67	10	18
MV-2-5	27.94	17.84	4.15	1.42	1.89	0.021	0.071	66	9	2480
MV-2-6	29.44	17.58	2.05	0.68	1.99	0.004	0.059	62	11	2000
MV-2-7	28.75	18.06	2.55	1.97	2.02	0.004	0.061	313	11	1600
MV-2-8	26.00	16.34	5.95	1.61	2.24	0.007	0.034	60	11	1600
MV-2-9	27.75	18.12	4.55	1.21	1.84	0.007	0.053	60	11	1600
MV-2-10	28.86	16.81	3.75	0.11	3.70	0.005	0.071	26	110	15

*MV-2-1 at top of hole; each sample represents approximately 5 feet (1.5 m) of core.

Table 4: Partial analyses of diamond-drill hole DL-2, Dollar Lake bank.

	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Ba(%)	Sr(%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
DL-2-1*	31.07	19.26	0.69	0.11	0.84	0.004	0.058	26	100	33
DL-2-2	30.74	17.63	0.61	0.17	0.81	0.003	0.057	30	110	40
DL-2-3	33.67	17.88	0.68	0.17	0.81	0.004	0.050	29	110	15
DL-2-4	31.10	18.84	0.88	0.17	1.02	0.003	0.058	29	110	430
DL-2-5	31.42	18.10	0.88	0.17	1.00	0.034	0.072	30	65	50
DL-2-6	31.84	18.26	0.99	0.26	0.94	0.009	0.065	21	110	20
DL-2-7	29.65	17.60	1.93	1.67	0.81	0.009	0.058	30	110	40
DL-2-8	31.94	15.50	2.60	1.81	1.04	0.010	0.071	26	100	33

*DL-2-1 at top of hole; each sample represents approximately 5 feet (1.5 m) of core.

The content of SiO_2, Al_2O_3 and to a lesser extent, Fe_2O_3, may be assigned primarily to the insoluble (terrigenous) component of these banks. SiO_2 is highest in the Murchyville and Gays River banks which rest upon slate and metagreywacke respectively. The Dollar Lake bank is low in SiO_2 (Table 4), although one might more reasonably expect the analytical results to be comparable for both the Murchyville and Dollar Lake banks. It appears that local contribution of detritus is more significant than basement bedrock character, in governing the abundance of terrigenous detritus within the superadjacent banks.

The content of Ba and Sr appears to vary little between these three banks. It seems reasonable to suggest that no apparent close association of these elements with the metallic elements of Tables 2, 3 and 4 is indicated.

Cu is distinctly more abundant in MV-2-1 (Table 3) than in the banks represented in Tables 2 and 4. Chalcopyrite veins were noted in core in MV-2-1, and seem to explain the higher values of this element. In general, Cu is not abundant within Gays River Formation banks throughout our area of study.

Concentrations of Pb and Zn appear to be inversely proportional, in most instances, at the level of abundance indicated in Tables 2, 3, and 4. This relationship seems to relate readily to differing prerequisite chemical parameters which govern the precipitation of these metallic ions. It is probable that Pb and Zn were contained in the same metal-bearing fluid, rather than fluids of two distinct episodes of metal emplacement. In contrast, high values of both Pb and Zn, such as occur within the ore zone at Gays River, would suggest two episodes of metallization. This, in fact, is supported by the petrographic evidence which indicates that galena was emplaced after sphalerite in paragenetic sequence (MacLeod, 1975b).

FACTORS CONTROLLING MINERALIZATION

Several factors could potentially control the Pb-Zn mineralization known to occur in several of the Gays River Formation carbonate banks. These include the sedimentologic and diagenetic history, the regional paleogeographic setting, and the proximity of the banks to the source of metallic ions.

It is apparent from our study of rock types of the Gays River banks, and from the repeated occurrence of these rocks in widely scattered and discrete localities, that the banks represent deposition under regionally uniform paleoenvironmental conditions. The common sedimentologic history clearly indicated by this uniformity in lithologic character, is corroborated by equally consistent faunal and floral distribution, although the biota seems more indicative of broad differences, than does the overall lithologic character.

The high degree of regional lithologic similarity illustrated in Figures 6 to 18, reflects not only the sedimentologic characteristics of the carbonate rocks, but also indicates a similar diagenetic history, since the latter textures are also apparent in these illustrations.

Dolomitization is pervasive in every known Gays River Formation bank within the area of detailed study. Comparison of the content of CaO and MgO in widely separated carbonate banks, reveals that these elements are present in very similar proportion in every instance, which indicates a relatively uniform regional response to dolomitizing agents. Furthermore, the lateral or vertical proximity of evaporites of the Carrolls Corner (Giles and Boehner, in prep.) or Gleason Brook (Boehner, 1977) Formations, seems unrelated to dolomitization (c.f. MacLeod, 1975b) in that banks overlain and flanked by terrigenous rocks of the Meaghers Grant Formation of Boehner (1977) are as dolomitic as those overlain and flanked by the thick evaporite units. Preliminary data indicate that variation in major element composition among the banks which have been analyzed is minimal. We are not yet able to systematically assess the regional variation in metal ion content, to determine any trends in metal distribution.

We believe that the distribution of Gays River Formation banks can be broadly predicted. For example, in our study area, they occur only in those areas where the Windsor Group overlaps the Horton Group (Fig. 2), and rests directly on pre-Carboniferous rocks. Furthermore, it seems reasonable to speculate that the thickest accumulations of these carbonate rocks should in general be found in close proximity to the point of overlap, since these should represent regionally the most basinward (downslope) occurrences of such deposits. The largest and thickest banks are the most attractive exploration targets by virtue of their ultimate control over the size of associated ore bodies. However, prediction of the distribution of these thick, potential base metal hosts, will be of little avail in mineral exploration, unless some understanding of the control of base metal concentration in these hosts is gained.

We are lead to conclude that the Gays River bank is distinct from other carbonate banks of the Gays River Formation, only in its anomalous content of zinc and lead. Ignoring the physical dimensions of the banks, each seems to have had equal potential as a host for base metal deposits.

Because the character of these carbonate banks, which presently host varying amounts of sulphide minerals, seems to offer no apparent explanation of this control, we believe that other factors must be operative. These factors must include the source of metal ions and the method and direction of transport of these ions to the suitable host. In addition, any explanation proposed should, we feel, explain not only the Gays River deposit, but the other smaller anomalous occurrences as well, in a unified model.

We concur with MacLeod (1975a) in postulating a southeasterly transport direction at Gays River for the metal ions, thereby explaining the preferred concentration of base metals along the northwestern flanks of the Gays River bank. The passive nature of the metal-host relationship illustrated by the cavity-filling metallization process which predominates, seems to afford a reasonable explanation of the restriction of galena to the northwestern flanks of the deposit. The initial sphalerite emplacement would have resulted in a reduction of effective permeability, thus limiting the migration of later fluids towards the southeast. In essence, we envisage the metal emplacement as a self-limiting process through pore reduction.

Too little is known regarding the concentration of lead and zinc in the Lindsay Brook, and Murchyville banks (Nos. 6 and 12, Fig. 2), to assess any possible transport direction for these metal ions. In these banks, however, a general northwesterly dip is evident, as it is on the northwestern flanks of the Gays River deposit.

The source of the metal ions and the nature of their transport remains unproven. MacLeod (1975a) postulated that the metal ions were derived from sedimentary rocks of the Horton Group, and were transported by saline brines produced during deposition of the thick evaporites which overlie the Gays River deposit. These mechanisms fail to explain base metal occurrences at Lindsay Brook and Murchyville in banks which are: a) distant from any Horton rocks which are very sparsely represented in the Musquodoboit Basin (Boehner, 1977), and b) associated, not with thick evaporites, but with sandy shales and sandstones of the Meaghers Grant Formation of Boehner (1977) (Fig. 5). Clearly, if a unified model is the goal, the explanation of MacLeod is not wholly satisfactory.

Boyle (1972) also proposed that the Horton Group provided the necessary base metal ions for metallization of basal Windsor carbonates. However, he presented in his model, the suggestion that metal-bearing fluids were localized in fracture zones, thus explaining the local concentration of base metals. In applying this type of model in the Musquodoboit Basin, the Black Brook Fault (Boehner, 1977) seems to offer a reasonable example of a suitable fracture along which metal-bearing fluids could migrate (Fig. 2). It is notable that each of the mineralized banks dips toward this fault, and lies south of its trace. It thus seems to represent a possible unifying element in a metallogenic model. The source of the metal ions remains uncertain, but could be related to Carboniferous plutonism with the upwards migration of metal-bearing fluids to very shallow depths.

We present this possible explanation of base metal concentration merely as an alternative model which could be considered, and freely admit that supporting data are few. Those who wish to attempt to test this suggested model, should note that the trend of the Black Brook Fault (or fault zone) is east-west, as opposed to the pronounced northeasterly trend of other structures in the area.

CONCLUSIONS

The following conclusions regarding the nature of the Gays River Formation banks, and their control over base metal localization are summarized below:

1) The regionally uniform lithologic character of the carbonate banks justifies their informal designation as a facies member of the Gays River Formation.

2) The relative proportions of constituent faunal elements, the rarity of plicate and costate brachiopods, and the absence of representatives of the phylum Echinodermata, may serve as biostratigraphic indicators to distinguish Gays River banks from others in the Windsor

Group. The bryozoans *Fenestrellina* sp. and *Cyclopora* sp. may be restricted to the Gays River Formation.

3) Carbonate banks of the Gays River Formation do not appear to be developed upon sedimentary rocks of the Horton Group. They appear to rest equally commonly on both slates and metagreywackes of the Meguma Group in southern Nova Scotia, and on a variety of pre-Carboniferous rocks elsewhere.

4) Similarity of rock units and faunal elements indicates a common sedimentologic history for each of the banks examined.

5) Rock textures and preliminary rock chemistry indicate that diagenetic processes have affected each bank in similar fashion, excepting the metallization processes.

6) Mineralization, although most intense at Gays River, is not strictly limited to that bank.

7) A postulated factor which relates all mineralized banks, is proximity to the east-west trending Black Brook Fault. Migration of metal-bearing fluids within and up-dip from this fracture zone is presented as a tentative explanation of base metal distribution.

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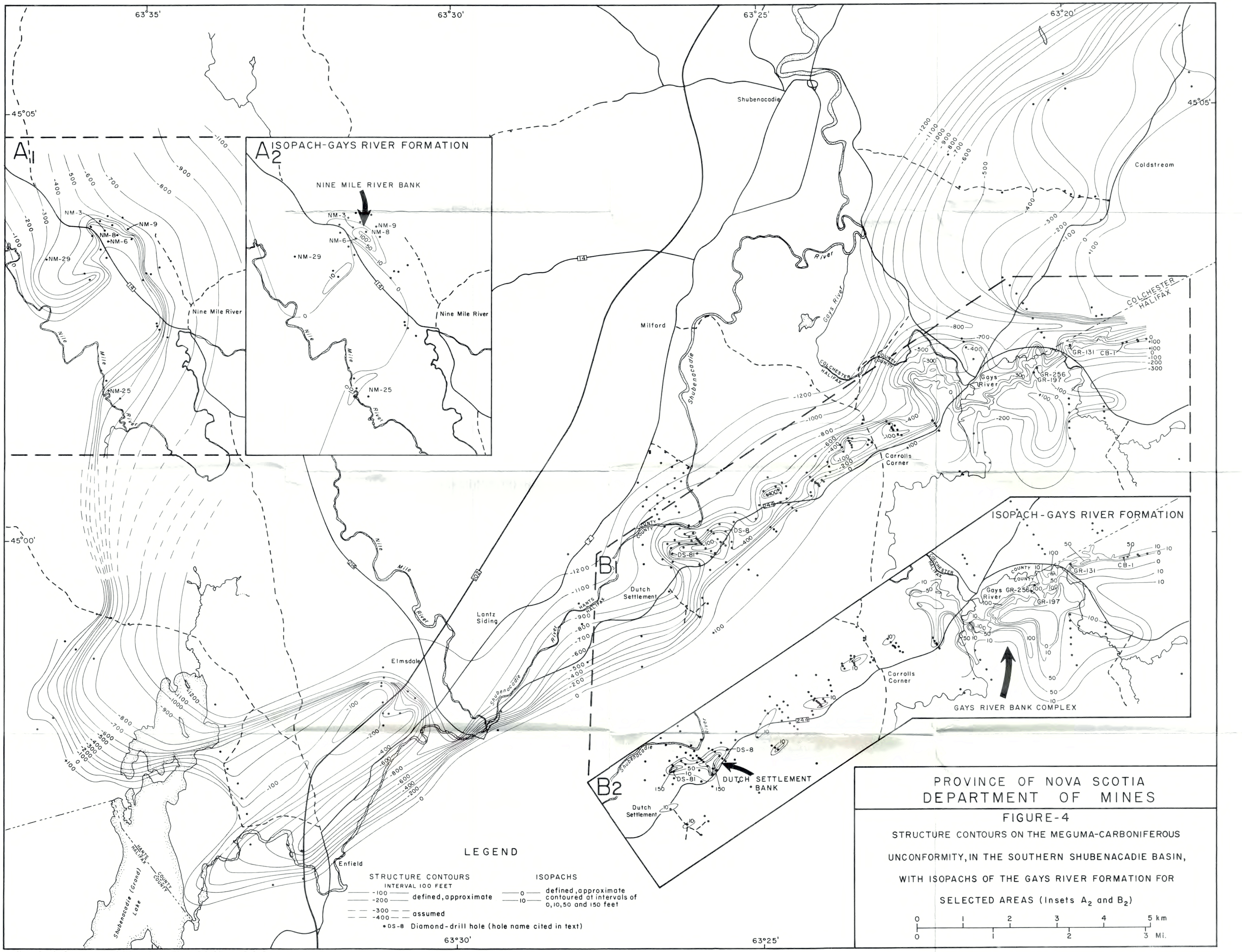

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