Diagenetic alteration of Early Jurassic carbonate rocks and their impact on the rock texture, Bay of Fundy, Canada

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Abstract

The rocks of Scots Bay Formation occur only along the south shore of the Bay of Fundy where they are exposed in small coves from east of Baxters Harbour to west of Scots Bay, Nova Scotia. Lithologically, the Scots Bay Formation is dominated by clastic sediments, including sandstone, silty sandstone, conglomertic sandstorm, and shale. Carbonate and silicified carbonate rocks include calcareous sandstone, packstone, mudstone, wackcstone, and stromrtolitic limestone. Jasperoid chert nodules and bedded cherts are common throughout much of the formation .

The intense shallow burial diagenesis resulted in extensive cementation, recrystallization and authigenic silica mineralization which cause low values of porosity/permeability throughout the carbonate section of Scots Bay Formation.

Phreatic and vadose meteoric cements make up most of the cements of Scots Bay lirnestones. Three types of calcite cement occur in the Scots Bay Formation : drusy mosaic, blocky, and minscus cement. The chert is principally diagenetic in origin and consists of chalcedony and mirocrystalline quartz that formed as pore filling cement and replacements of carbonate sediments and calcareous fossils. The source of the silica was hot-spring fluids associated with the underlying basaltic volcanic flows.

key words:Scots Bay, Baxters Harbour , Clasticsediments , Rocks

Introduction

The carbonate section of the Scots Bay Formation in the Fundy Basin has invariably been considered to be deposited lacustrine nearshore environment . These rocks consist of calcareous sandstones, packstone, wackestones, and mudstone - wackestones. The limestones are thin to thick -bedded and thinly laminated, white and greenish gray, peloidal, stromatolitic, and often replaced by chert. Chert bands and jasperoid nodules are common. Understanding of diagenesis and its processes is a crucial pre-requisite to interpretation of lithofacies characteristics and depositional environments. Diagenetic processes affect both pre- and post-lithification sediment characteristics, as they produce changes in textures, structures, and mineral composition. With time, as carbonates are deposited, precipitated, buried, eroded, exposed and reburied, they interact with surficial and interstitial fluids, each of which affects the sediments or rocks in a special way and leaves a unique diagenetic signature [15].

Freshwater diagenesis is characterized by rapid and extensive changes in (a) CO_2 concentration and isotope composition, (b) degree of $CaCO_3$ supersaturation, and (c) flow rates and intermixing of waters [8].

As work on ancient lacustrine rocks is scarce, the study and interpretation of the diagenetic history of Scots Bay rocks is not an easy task. Prior to this study, diagenesis of the Scots Bay rocks has not been dealt with in meaningful detail. [3] studied the petrology of Scots Bay as part of a Masters thesis, whereas a few other studies tended to concentrate on paleontology and sedimentology. This paper will present the results of a petrographic and diagenetic study of the carbonate rocks of the early Jurassic Scots bay Formation that exposed along the south shore of Bay of Fundy (Fig. 1).

The laboratory work took place at Acadia University that included descriptions and identifications of rocks in hand specimen and 75 thin section. Low power photomicrography was done to study rock texture and describing the diagenetic framework of Scots Bay carbonate rocks. Oracet Blue 2R was used in thin section preparations and point counts made to determine porosity, Alizarin Red S solution was used for the dolomite identification, and Feigl's solution was used for distinguishing aragonite from calcite. Acetate peels of selected samples were examined with a binocular microscope. The faunal content was studied from acid insoluble residues by using different types of microscopes (binocular, petrographic and SEM).

DIAGENETIC FRAMEWORK

In general, carbonate diagenetic processes encompass dissolution, compaction, cementation, replacement, and recrystallization. Most of these processes have been active in the

Scots Bay Formation in addition to some post-lithification processes such as calcite fracture filling. Compositionally, the carbonate-siliciclastic rocks of the Scots Bay Formation consist of a mixture of carbonates and siliciclastic material. The carbonates consist of bioclastics, peloids, and stromatolites, whereas the siliciclastic material consists mostly of quartz, feldspar and chert.

The most common lithologic unit in the Scots Bay Formation is a bioclastic silty sandy limestone. One rock sample from this unit at West Broad Cove (e.g., WCS3C) shows a framework of quartz, micaceous feldspar, chert, rock-fragments (some of which are volcanic), and clay clasts.

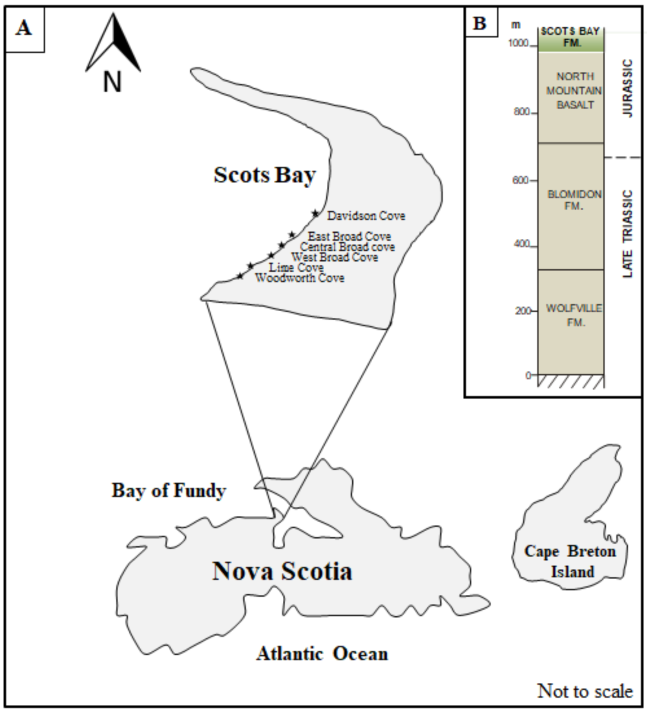

Figure 1. Location map of the study area. A, the Bay of Fundy in northern Nova Scotia and the main outcrops of Scots Bay Formation in the Scots Bay area. B, Stratigraphic section of the study area.

The matrix/pseudomatrix is made up of partially chloritized clay. In other samples, there is a local occurrence of patchy, sparry diagenetic cement. In the Scots Bay Formation, the most abundant fossils are ostracodes whose shells are commonly thin and silicified. Drusy quartz infills the articulated valves (Fig. 2). In most cases, the matrix between allochems is generally a mixture of both micrite and recrystallized microspar.

The Scots Bay rocks shows a number of diagenetic phases and events such as cementation, recrystallization, replacement and formation of porosity that have altered the original depositional fabric of the rock and influenced its rock textures.

The second most common unit within the formation is composed of bioclastic calcareous sandstone that locally grades into sandy peloidal limestone. In this unit, in which chert and partly silicified stromatolitic limestone are the most distinctive features, minor ostracodes and algal stems are locally present. Recrystallization from micrite to microspar is evident in sample LCS1C from Lime Cove (Fig. 3). The presence of patches of peloid-like grains that are nearly filled by recrystallized micrite suggests that some peloids have been recrystallized. It is difficult, however, to distinguish a sparry cement, which is present as void filling, from recrystallized calcite. Both, however, will be discussed in the next section. Folk [9] suggested that peloids showing indistinct boundaries might appear so partly as an optical effect due to the small size of the near-spherical pellets and minuscule thickness of the petrographic thin section. In other rocks, however, recrystallization of pellets, matrix or both produce microspar that blurs their boundaries. The presence of uncrushed peloids indicates early lithification, as this is a common process in recent pellets [18].

Figure 2. Photomicrograph of silty sandy limestone at East Broad Cove showing ostracode shell filled with drusy quartz cement. (sample ESS1C). Crossed polars; width of view is 2.5 mm.

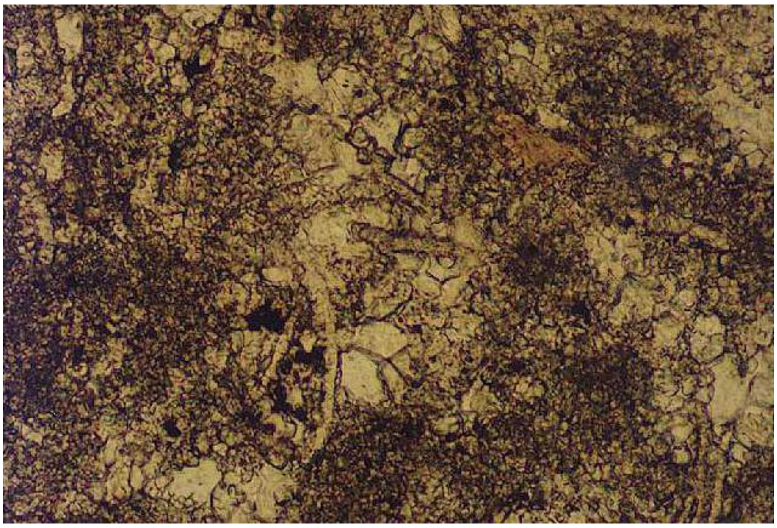

Figure 3. Photomicrograph of wackestone-packestone from Lime Cove (sample LCS1E) showing an inter-allochems matrix made up of a mixture of micrite (dark brown) and recrystallized micrite (light). Uncrossed polars; width of view is 4 mm.

Cementation

Cementation of limestone requires an enormous input of $CaCO_3$ and an efficient fluid flow mechanism for complete lithification [18]. Sparry and microsparry cement can be clearly distinguished from micrite by coarser grain size (more than 10 microns) [8-9] Cementation plays a very significant part in rock forming by joining and holding the grains together.

Cements in the Scots Bay Formation include calcite, silica, iron oxide, and chlorophaeite. Three types of calcitic cement are found. These are: (1) drusy mosaic cement (sparry and microsparry cement), (2) blocky cement and (3) meniscus cement. The original carbonate was probably low-Mg calcite. This is indicated by microprobe analysis showing only 0.23 wt% Mg^{2+} Dolomite is not known to occur in the Scots Bay Formation [4].

Silica cement fabrics consist of three types: (1) chalcedonic quartz (spherulites), (2) microcrystalline quartz, and (3) drusy quartz. These types will be discussed in more detail in the next chapter which is devoted to cherts. Iron oxide and chlorophaeite occur locally as rim cements. Hematite-stained chalcedonic quartz and shreds of goethite are locally present.

Interlocking of quartz grains is common in the Scots Bay rocks. The degree of grain interlocking is low, indicating a low compaction pressure process. Quartz cementation was probably an early diagenetic event, as indicated by well-preserved wood fossils in the core of chert nodules.

Drusy and blocky calcite cements are the most common cements in the Scots Bay Formation and are clearly distinguishable from recrystallized micrite as they occur along fractures or in cavities formed after dissolved fossils. Drusy calcite is usually found as pore-filling in which crystal size increases progressively towards the pore center (Fig. 4). In cavity filling, crystal size of drusy mosaic cement increases away from cavity wall, forming one of the fabric criteria for cement [1].

Drusy mosaic and blocky calcite is relatively coarsely crystalline (0.1 to 0.8 mm) due to slow growth. Their formation indicates that, at times, the pores and fractures must have been filled with water; thus pointing to a phreatic zone environment. Differentiating meteoric phreatic cements from burial cements is difficult if not impossible without thermometry from fluid inclusions or oxygen isotopes [17]. In contrast to neomorphic spars, sparry cements have a high frequency of plane intercrystalline boundaries [2]. Calcite cement crystals in the Scots Bay Formation, particularly within spherical voids, show this tendency (Birney, 1985). The blocky cement is usually found as fracture filling (Fig. 5). The blocky calcite crystals often exhibit some well- developed cleavage where the boundaries between the sparry crystals are made up of plane interfaces (Fig. 6).

Some microspar occurs locally in fractures, dissolved shells and cavities and, as such, it is post micrite, but not a recrystallized product of it. The boundary between micrite and this micro-sparry cement is sharp (Fig. 2).

Meniscus cement is of minor, sporadic occurrence in the Scots Bay Formation. Meniscus and pendant cements are excellent indicators of the vadose environment, but if cementation is prolonged and the pores were to be filled, their characteristic shapes would usually be lost [15].

Croystals of meniscus cement are usually finely crystalline.

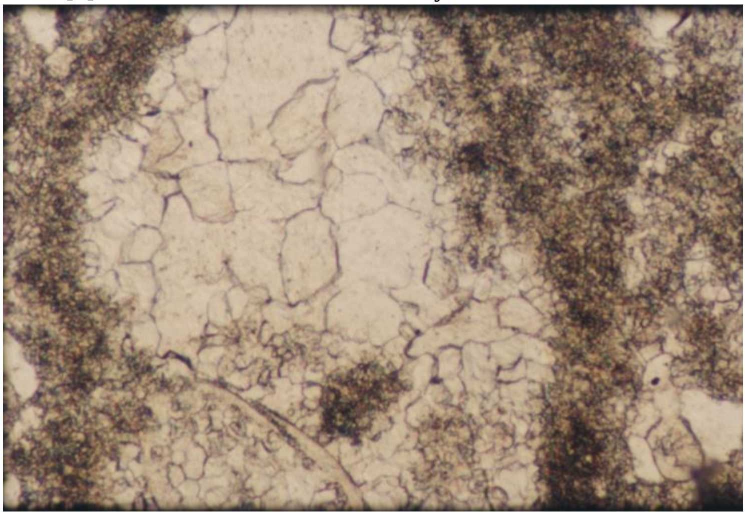

Figure 4. Photomicrograph of peloidal limestone showing plane interface boundaries between crystals of the drusy mosaic cement. It also shows crystal size increasing away from the cavity wall. East Broad Cove (sample ESS1V). Crossed polars; width of view is 2.5 mm.

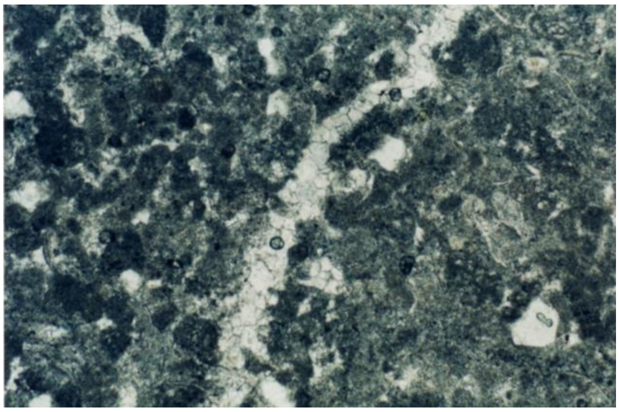

Figure 5. Photomicrograph of wackestone-packestone showing the blocky calcite (cement) as fracture filling (sample LCS1E). Crosse polars, width of view is 4 mm.

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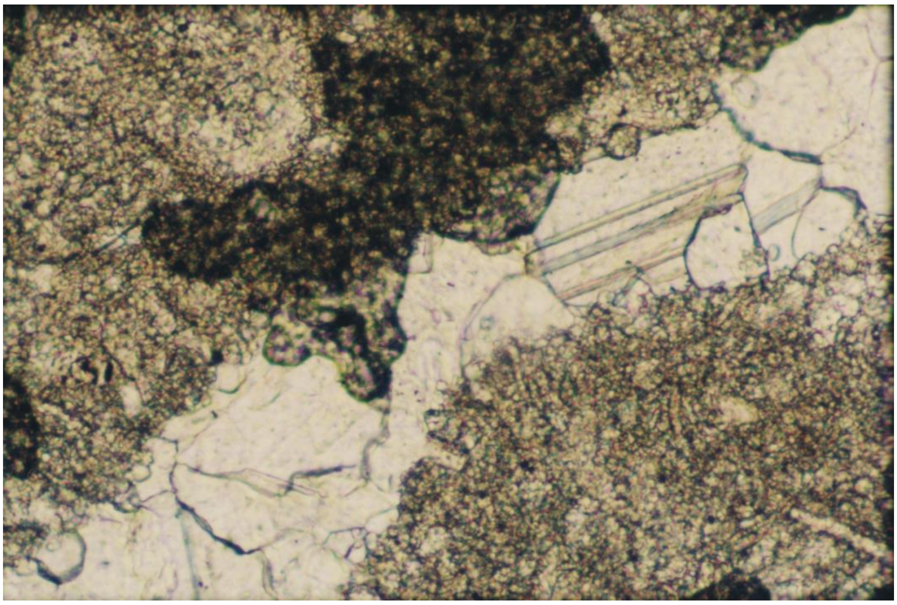

Figure 6. Photomicrograph of wackestone-packestone showing sharp boundary between micrite and blocky calcite (Fracture filling), note some crystals exhibit well developed cleavage where the boundaries between the sparry crystals are made up of plane interfaces(sample LCS1E). Crossed polars; width of view is 2.5 mm.

Replacement

Silicification or silica replacement is the most extensive diagenetic phenomenon observed in the Scots Bay Formation. Dolomite, which is the most common replacement mineral in carbonate rocks, was not found in the Scots Bay Formation. Silicification occurs in many forms, as chert nodules, chert beds and as silicified fossils. In some rock samples of the Scots Bay Formation microcrystalline quartz replaces calcite. On the other hand, chalcedonic spherulites and drusy quartz occur as cement in cavity fillings. The latter shows increasing crystal size away from the cavity wall (Fig. 7). In sample ESS1S from East Broad Cove, silica replaces spar within micronodules prior to any replacement of the framework's microspar and micrite (Fig. 8). Silica replacement is discussed in the next section.

Dissolution is facilitated when limestones are exposed to fresh water. It is more effective near the air/rock interface because it is controlled by the flux of CO_2 in meteoric water [15]. Good solution porosity occurs at Woodworth Cove where it is locally lined with calcite (Fig. 9). The interparticle porosity that is probably produced by dissolution of parts of the matrix negates significant compaction and suggests that such dissolution may have occurred in vadoze or phreatic zones preceding deep burial. The types of cement, whether drusy to blocky (phreatic) or meniscus (vadose), described in the previous section, also indicate near-surface meteoric diagenesis.

Meteoric water first encountering carbonate sediments is normally undersaturated with respect to $CaCO_3$ dissolution takes place and yields a vuggy porosity which is the most important petrographic evidence for dissolution. Porosity in the Scots Bay Formation is considerably low, the maximum porosity estimates range between 15 and 20%

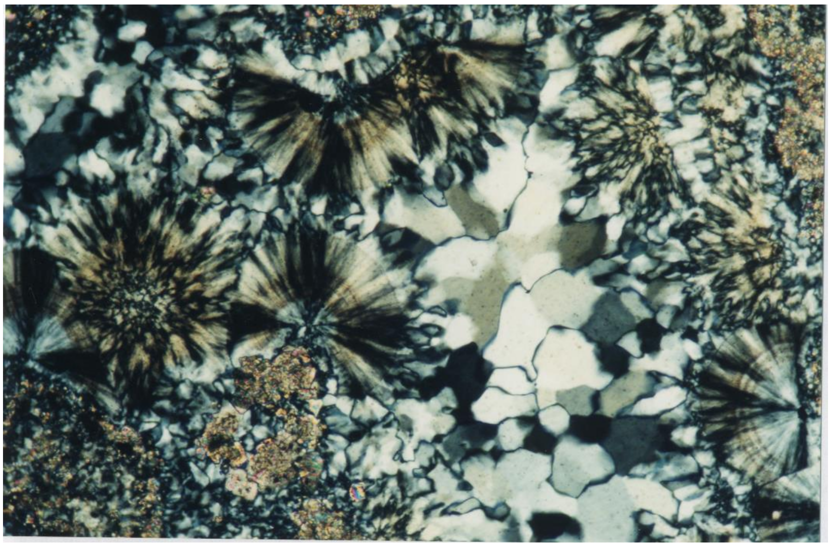

Figure 7. Photomicrograph of chertified limestone showing chalcedonic spherulites and drusy cement as cavity filling. The latter shows crystal size increasing away from the cavity wall. East Broad Cove (sample ESS1R). Crossed polars; width of view is 2.5 mm.

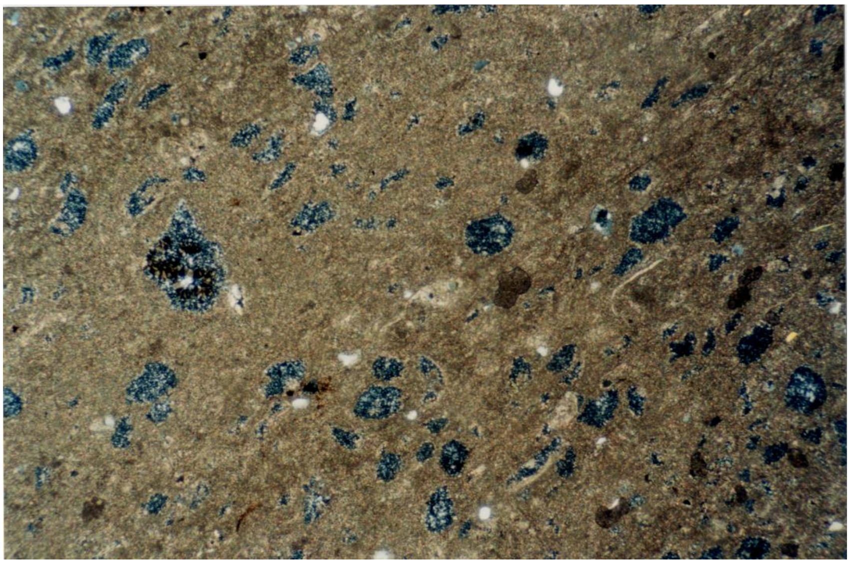

Figure 8. Photomicrograph of peloidal wackestone showing silica replacing spar within micronodules prior to any replacement of the framework's microspar and micrite. East Broad Cove (sample ESS1S). Crossed polars; width of view is 4 mm.

in fossiliferous limestone at Central Broad Cove. The average total porosity in Scots Bay Formation is 2 to 3 %. However, it appears to have been reduced by precipitation of sparry calcite cement and early diagenetic silica such as chalcedony and drusy quartz. In some samples porosity reduction may be as high as 20%.

Dissolution and Porosity

Primary porosity has not been observed in the Scots Bay Formation.

Although moldic porosity is not common, it has been observed in fossiliferous limestones at Central Broad Cove. It occurs as a result of leaching out of fossils.

The development of open fracture porosity in some samples suggests a tectonic origin. Fractures are mainly filled with blocky and drusy calcite cement (Figs. 5 and 6). In general, it is doubtful that the total porosity contribution from open fractures exceeds 1%, as also noted by [16].

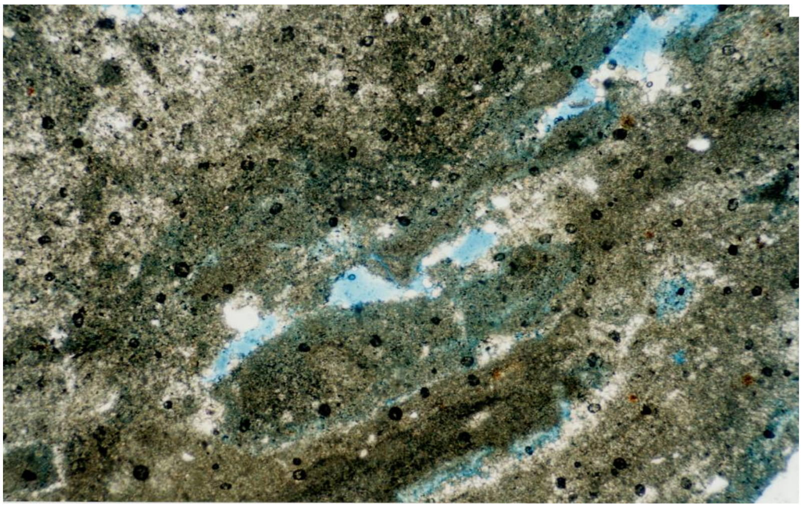

Figure 9. Photomicrograph of wackestone showing solution porosity that is locally lined with neomorphic and sparry calcite cement (upper left). (Woodworth Cove, sample WCS1B). Uncrossed polars, width of field is 4 mm.

Recrystallization

Recrystallization embraces any change in the fabric of a mineral or monomineralic sediments. Fine-grained microcrystalline matrix can be partly recrystallized to coarse-grained calcite spar, as can be found in the Scots Bay Formation. The term grain-growth was introduced into carbonate petrology by Bathurst [1] to describe the familiar alteration of micritic calcite to sparry calcite.

Recrystallized calcite can be seen in figure 10, which shows patches of the original micrite with fuzzy boundaries that have not undergone recrystallization yet. This textural aspect helps to differentiate neomorphic sparry calcite from sparry void-filling cement. When sharp boundaries can be seen between sparry cement and original matrix, cavity filling cementation is clearly the dominant process. In some samples, the lack of allochems and presence of microspar indicate that the latter did not form as a cement, but rather as a recrystallized micrite. Another way of identifying recrystallized micrite is to find some terrigenous grains suspended in microspar, such as those in samples LCCS1D and CCS1C2 from Lime Cove and Central Broad Cove.

In some specimens, such as in East Broad Cove sample ESS1S, clusters of clots of microcrystalline matrix are surrounded by a recrystallized material with fuzzy boundaries (Fig. 10). This pattern is called grumose structure. Grumeleuse structure appears as many little clots of an extremely finely crystalline, dark gray calcite standing out in a matrix of colorless granular calcite [1-5].

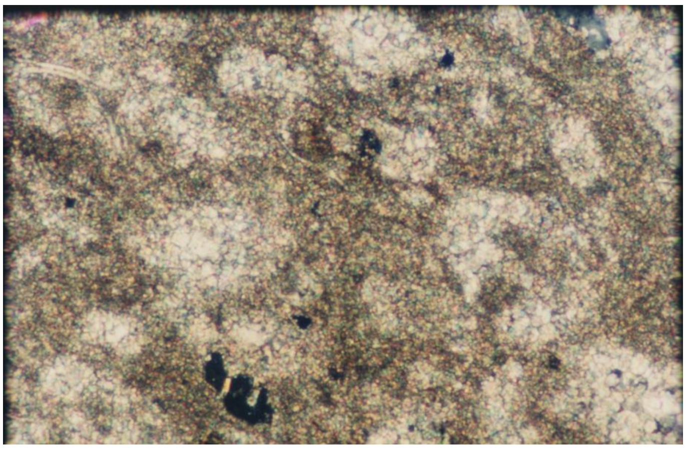

Figure 10. Photomicrograph of peloidal limestone showing fine-grained microcrystalline matrix that has been partly recrystallized to microspar. It shows grumose structure (patches of micrite standing out as dark gray in a matrix of colorless mocrospar). East Broad Cove (sample ESS1S). Crossed polars; width of view is 4 mm.

Paragenetic sequence

Lithification processes probably began during early diagenesis, as indicated by the presence of uncrushed peloids and the lack of other compaction phenomena. Dissolution of calcareous unstable minerals (e.g., aragonitic shells), possibly in vadose and phreatic zones, appears to have occurred prior to the first cementation phase (Table 1). Cavities and dissolved fossils formed due to dissolution under conditions prevalent in the meteoric environment. Once cavities became filled with $CaCO_3$-saturated water, cementation processes ensued. Recrystallized microspar and meniscus cement may have formed prior to the drusy and blocky cement. The latter did not evolve until after the development of micro-fractures. Drusy and blocky calcite cements are probably the manifestation of the last cementation events

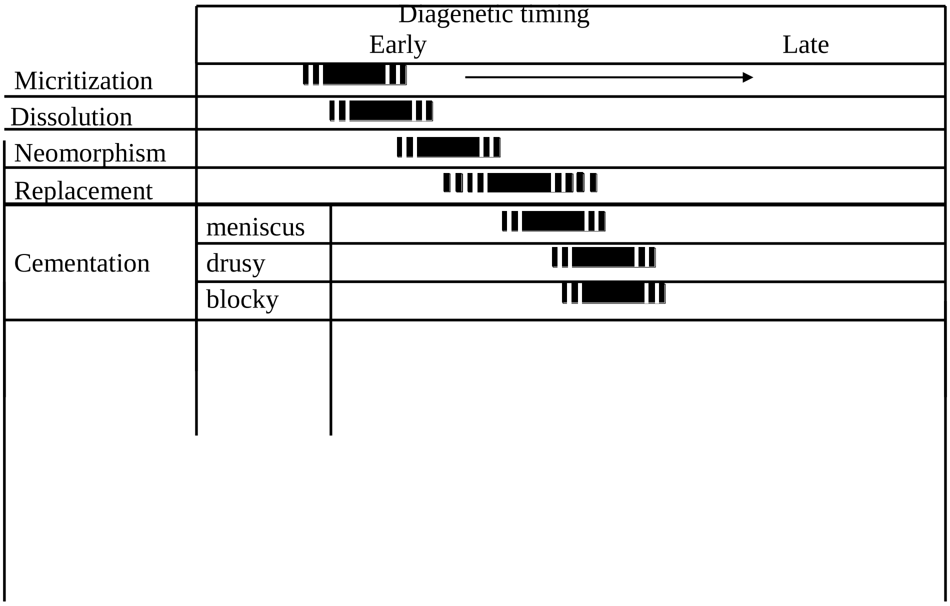

Table 1. Paragenetic sequence showing progression of the main diagenetic process that affected the Scots Bay Formation in relative time.

Conclusions

During early diagenesis, some calcite dissolution took place in shallow burial environments or near the surface before cementation. Three types of calcite cements occur in the Scots Bay Formation: drusy mosaic, blocky, and minscus cement. Phreatic and vadose meteoric cements make up most of the cements of Scots Bay limestones. On the other hand, meniscus cement probably formed very early during lithification and prior to formation of the drusy and blocky sparry cements, a process which clearly appears to have been initiated by dissolution. Porosity in the Scots Bay Formation averages about 3-4%, is mainly secondary, and appears to have been generated by solution.

Evidence of recrystallization of micrite into microspar are: 1) fuzzy contacts between the recrystallized microspar and relict micrite, 2) micrite inclusions within the microspar, and 3) replacement of some micritic allochems (pellets) by microspar.

Silica occurrence in the Scots Bay Formation is exhibited mainly by the occurrence of nodular and bedded chert, both being replacement products. Detrital quartz and pore-filling silica cement are subordinate.

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