DIAGENESIS OF THE ROCKLAND, KINGS FALLS AND SUGAR RIVER FORMATIONS,TRENTON GROUP, MIDDLE ORDOVICIAN; CENTRAL NEW YORK

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Introduction

The purpose of this study is to understand the diagenesis of the Rockland, Kings Falls and Sugar River Formations of the Trenton Group limestones by means of petrographic analysis. The Trenton Group was studied as early as June, 1836, by Conrad, and has been extensively examined since. Most notable of the geologists who have worked on the Trenton is Marshall Kay, who studied these limestones for over three decades (Kay, 1937, 1968). However, no recent petrographic study of the Trenton Group, as it is exposed at Inghams Mills, has been done using modern techniques.

By combining thin section and acetate peel analysis with recorded stratigraphic positions of samples within the outcrop, a chronology of events can be established to describe the diagenetic processes of the Trenton Group.

Field and Laboratory Methods

The information for this study was gathered through fieldwork and laboratory examination of the Rockland, Kings Falls and Sugar River Formations of the Trenton Group at one continuous section at Inghams Mills, Fulton County, New York. A detailed stratigraphic section was developed by establishing a baseline (0.00 m) and measuring upsection to noted horizons. These horizons were designated by observing distinct changes in lithology and faunal content. To aid our sampling process, a portable coring drill, property of Smith College, was used to sample units where a vertical cross-section was necessary and otherwise difficult to collect.

Laboratory work at Smith College provided the opportunity for immediate processing of thin sections and acetate peels. The peels were made following the techniques described by Wilson and Palmer (1989) and are useful because of their short preparation time, low cost and accurate representation of the etched surface of a carbonate sample. After completion of the field study, additional thin sections were professionally prepared by Pioneer Thin Sections, Inc. The thin section blanks were then repolished and acetate peels were made corresponding to the thin sections. The study of the initial thin sections and acetate peels under Nikon Labophot-Pol petrographic microscope led to the preparation of more thin sections using the equipment available at the College of Wooster. After attaining the proper thickness of the second set of thin sections through examination of the birefringence of quartz, some were stained with potassium ferricyanide for the detection of ferroan cement and with alizarin red-S to check for the presence of dolomite.

Results and Discussion

The pre-lithification conditions of the Trentonian sediments are well understood through both field and laboratory study (Barton, 1992; Titus, 1989). The depositional environment was one of significant biological and physical activity. Burrows and large ripples are present at the outcrop, as are fossils of organisms capable of disturbing sediments (trilobites), indicating some of the pre-diagenetic processes at work on the sea-floor. As this redistribution of sediments was taking place, some units were cemented with low-magnesium calcite while either still exposed to the marine waters, or while just below the sediment-water interface. Given the high fossil content and the types of organisms known to have been present, the dissolution of aragonite shells, such as gastropods, could have provided at least part of this early cement. Aragonite has been found to be more soluble than calcite under some marine conditions, and is often reprecipitated into calcite (Walter, 1985); this has been previously noted in carbonate rocks of the Ordovician (Palmer et al., 1988). Some of the rippled and burrowed units did not undergo immediate cementation. Continued deposition preserved these sedimentary features until cementation in the burial diagenetic environment.

Iron was also a component of the depositional and diagenetic environment. Several iron-based minerals (siderite, hematite and pyrite) were identified in the thin sections.

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Early Cementation:

Appearing in less than half of the examined units, early cements were generally confined to the shallower facies of the Trenton Group. This corresponds to the environment of gastropods as shallow-water dwellers (gastropods being the most likely source of aragonite and commonly noted in the field and lab studies). The early cemented units contained radial-fibrous, turbid equant, turbid syntaxial rim overgrowth and micrite cement types.

> *Radial-fibrous cements* -- The single unit containing radial-fibrous cements is gastropod-rich; this isopachous cement is actually situated within a gastropod internal mold in one example. This unit is also surprisingly free of echinoderm remains. Echinoderm debris, appearing as a host for syntaxial rim overgrowths, is common in most of the units.
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> *Turbid equant cements* -- These cements are common through the lower units of the studied section. Upsection, the strata represent deeper water facies and the turbid crystals seen below take on a clear, inclusion-free appearance. This, plus potassium ferricyanide stain analysis, implies that these clear crystals formed in the burial diagenetic environment (Potassium ferricyanide reacts with ferroan iron by coloring the ferroan region of material light blue, Dickson (1966) states that the zoned pattern resulting from the staining is evidence of successive periods of cementation.). The turbid equant cement crystals tend to be relatively large, commonly more than 1.5 mm along a long axis and occasionally reaching 3.5 mm.
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> *Turbid syntaxial rim overgrowths* -- The marine variety of syntaxial overgrowth cements appears as a turbid, inclusion-rich, calcite rim, commonly hosted by echinoderm grains. These overgrowths share both crystallographic orientation and extinction with the host grain. As is the case with the other marine cements in this study, the frequency of turbid overgrowths decreases rapidly upsection in the sampled section.
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> *Micrite cements* -- Micrite cement shows the widest range of appearance in the units studied. It takes on several forms, including massive, pelleted and as internal molds of fossil organisms, particularly the zooecia of bryozoans. These micrite cements share the characteristics of the other early cements, such as being free of high ferroan iron content, but petrographic characters of micrite cement are few and difficult to study due to the size of the cement crystals (4-30 microns) (Jernigan & Walker, 1989).

The units which were cemented in the marine realm were often subject to erosional processes following cementation. If the unit was lithified while still at the sediment-water interface, continual movement of sediment by wave action and biologic activity may have eroded and altered the surface topography. Some units, however, were cemented while in the marine diagenetic environment, but below the depth to which physical alteration was likely. Due to the energy change (low to moderate) in the environment of deposition, it is difficult to determine whether ripples and burrows are not present in certain layers due to depositional conditions or observed soft-sediment deformation following deposition and prior to lithification.

Following the early cementation and possible post-depositional physical alteration of some units, silicification took place in restricted areas within some of the early cemented units. Silicification is a poorly understood process by which free silica partially or entirely replaces fossils, allochems or cement crystals. The importance of noting the partial silicification of certain units in this study is that all such units contain evidence of early cementation. The importance of this relationship is not understood, but it may be the result of silica having been trapped by the early lithification of the sediment surrounding it, whereas in later cemented units the silica was unconfined and allowed to move out of the unit due to the increased lithostatic pressure of continued sedimentation. The source of the silica is not known, but quartz grains are common in the units sampled, indicating that there is some source for the occurrence of this mineral.

Burial Cementation:

Once the sediments passed through the marine phreatic zone into the burial diagenetic environment (Fig. 1), the precipitation of burial cements occurred in all units not entirely cemented already. Burial cements are common throughout the studied units, particularly upsection, but also in many of the units in which early cements are found. These cements are characterized by inclusion-free morphs, typically containing a high Fe^{2+} content as revealed by staining. Two types of burial cements are present in the Trenton Group rocks of this study: equant and syntaxial rim overgrowths.

Equant cements -- Equant cements appeared as an inclusion-free variety of the turbid equant cements seen commonly in many of the early-cemented units. As described in the previous section dealing with turbid equant cements, these clear equant crystals are easily distinguished by their inclusion-free nature and blue color following staining with potassium ferricyanide.

Syntaxial rim overgrowths -- Clear syntaxial rim overgrowths are the most common cement morphology, early or late, found in these rocks. The typical overgrowth appears as a rim on an echinoderm fragment with which it will share crystallographic orientation. These crystals are typically clear and are, as other burial cements, stained blue with potassium ferricyanide.

The results of using potassium ferricyanide stain on thin sections of these rocks has been informative. Not only was the distinction between questionable marine versus burial cement made, but the degrees to which a crystal reacted to the stain revealed the chronologic relationship in the crystals within a pore. Growth zones of calcite crystals are seen to react increasingly with the potassium ferricyanide toward the pore center. This implies that the pore water chemistry became more ferroan as the burial depth below the marine environment increased with time.

Post Cementation:

The final event of the diagenetic processes of the Trenton Group of central New York was a period of calcite venation. Though only seen rarely in thin section, veins of clear equant calcite crystals cross-cut previously precipitated micrite and clear equant cements. The veins are noted in hand samples and in the field. The only information to be gleaned from these features is that they were likely formed on joint surfaces which followed complete lithification.

Conclusions

From this information, a flow-chart was constructed depicting the sequence of events from sedimentation through diagenesis (Fig. 2). Soon after the deposition of the sediments which now compose the Trenton Group limestones, two distinct diagenetic pathways developed. Both are within the framework of Longman's (1980) pathway B of diagenetic sedimentation (Fig. 1). The distinction between these two pathways is based on whether or not early cements are present in a particular unit. One of the pathways involves sediments which were lithified to some extent while on the sea-floor or immediately below (the marine phreatic zone). The other pathway involves sediments which were not cemented until continued sedimentation significantly changed local pore-water chemistry, inducing burial cementation conditions. The units which experienced early cementation to any degree were subjected to a different sequence of events than were the units which underwent no cementation until within the burial diagenetic environment.

The limestones of the Rockland, Kings Falls and Sugar River Formations were lithified from fossiliferous calcium carbonate sediments in a shoaling then deepening depositional environment. These sediments were cemented in either, or both, the marine phreatic zone or the burial diagenetic environment as evidenced by the calcite cements present in the studied units.

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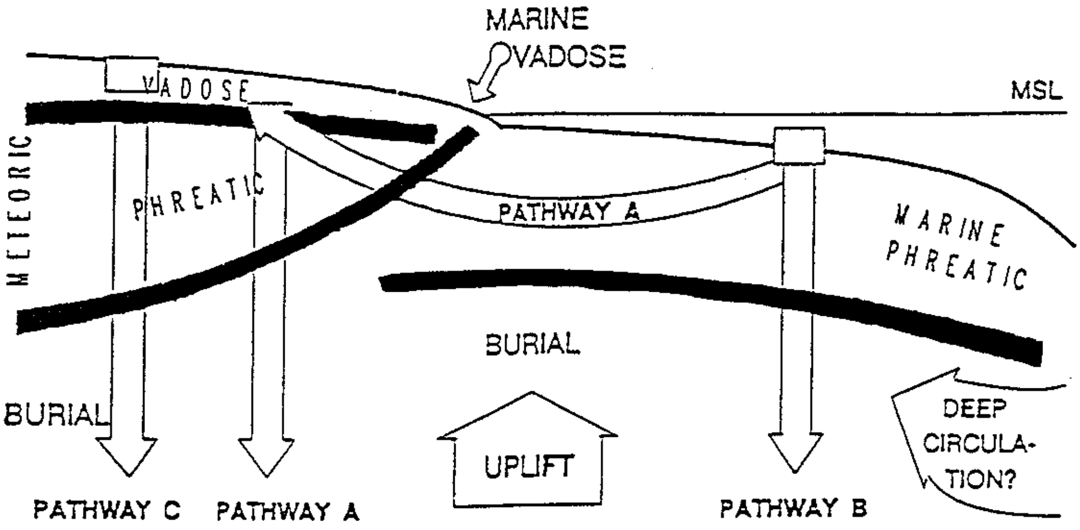

Figure 1. Common diagenetic environmental pathways followed by carbonate sediments. Modified after Longman, 1980.

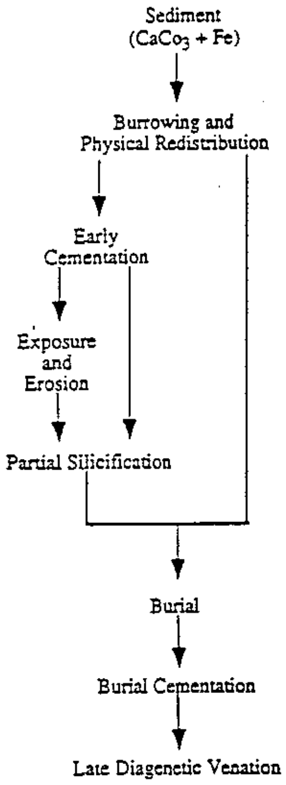

Figure 2. Flow chart of diagenetic events.