Diagenesis in the King's Falls Member of the Trenton Group

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Introduction

The Trenton Group has been widely studied - in the mid-west for its potential as a petroleum resevoir and elsewhere as an example of an ancient carbonate environment. The diagenesis of the Trenton at Ingham Mills in New York's Mohawk River Valley has produced various cement textures. These cements include: non-ferroan calcite, ferroan calcite, ferroan dolomite and quartz as chalcedony. Based on petrographic study, a paragenetic sequence can be constructed with the growth of non-ferroan calcite first, followed by a ferroan phase, in turn followed by dolomitization. The timing of silicic replacement of calcite is ambiguous. The purpose of my research is to resolve such ambiguities using thin-section analysis along with other techniques including cathodoluminescence (CL), stable isotope analysis and Inductively Coupled Argon Plasma Spectrometry (ICP). Using this data a more complete picture of the paragenetic sequence and diagenetic environments evolved.

The King's Falls Member of the Trenton Group

Field Relationships

The King's Falls is primarily composed of alternating grainstones and thin shale layers. Some beds are composed entirely of micrite mud. These tan weathering beds are often nodular in appearance, perhaps due to diagenetic enhancement of burrows during compaction. Fossils are the main sediment constituent and include ostracods, trilobite fragments, brachiopods, bryozoans, gastropods, crinoid columnals, and more rarely coral and straight nautiloids. Many of the grainstone beds have rippled surfaces. Ripples may exhibit crossbedding and imbrication of fossil valves. Other features indicating a periodically high energy environment are mud chips, and limestone clasts, as well as quartzite clasts. Clastic material, including quartz grains, feldspar grains and clays, are found throughout the section.

Some patches of the King's Falls member of the Trenton contain articulated fossils in life assemblages. In one location a build-up of about 40 cm length and 15 cm width is situated on top of a ripple. The build-up is low in relief but was sturdy enough to withstand currents that formed an erosional pit on one side.

The grainstones of the King's Falls are intercalated with thin shaley layers, which become more common in the Sugar River member of the Trenton Group. In the Sugar River Member the grainstone beds are thinner, unrippled and contain a byrozoan, *Prasapera*, which is not present in most of the King's Falls. The transition from King's Falls to Sugar River is a gradual one, the member boundary being an arbitrarily determined layer in a large package of grainstones and shale beds.

Depositional Environment

The King's Falls Member represents a shallow shelf carbonate deposit, perhaps having been deposited as a shoal (Titus,1986; Gardiner-Kuserk,1989). Alternatively it may represent small build-ups surrounded by mobile grainstone belts. Many of the features of the grainstone beds could be acquired during storms. Evidence for tempestites are ripples, pot and gutter casts, and clasts of various types. The Sugar River member of the Trenton represents a transition to a deeper water environment below storm wave base. In the Sugar River, pot and gutter casts, most large clasts and ripples are absent. Grainstones become thinner and shale partings are more frequent.

Diagenesis of the King's Falls Member

Petrography and Cathodoluminescence

Four cements are present in the King's Falls member of the Trenton: non-ferroan calcite, ferroan calcite, dolomite and chalcedony.

Echinoderm overgrowths occupy a sizeable portion of the total pore space, because calcite cements nucleate rapidly on the low-Mg calcite echinoderm plates. Staining reveals non-ferroan cement as the first cement phase in echinoderm overgrowths, followed by ferroan calcite [Figure 1a]. In many places where calcite nucleates on a substrate other than an echinoderm, such as on an originally aragonite shell, the earlier non-ferroan phase just fringes the grain or is not present. More complex zoning exists on overgrowths as revealed by cathodoluminescence (CL). Cathodoluminescence of overgrowth cements reveals that the initial phase is dully luminescent [Figure 1b]. This is followed by two narrow, brightly luminescent bands separated by a narrow dark band. The completion of pore filling is very dully luminescing. The early phase up to, but not including, the bright band, corresponds to the portion of the crystal that stained pink, or non-ferroan. Mauve staining corresponds to the latest stages in crystal growth.

In some pore-filling cements, zones are visible with staining. The earliest calcite phase is non-ferroan, followed by a thin zone of ferroan-calcite, in turn followed by a thin zone of non-ferroan calcite, pore filling is then completed by ferroan calcite. This zoning is found in some solution-fill cavities [Figure 2a]. Under CL the initial non-ferroan phase luminesces dully. The thin band which stained ferroan luminesces brightly. In the second non-ferroan zone the luminescence is slightly brighter than in the first non-ferroan phase [Figure 2b]. Final pore filling is completed by ferroan calcite which, begins with luminescence equivalent to the third zone and decreases to non-luminescence in the pore center.

Ferroan dolomite is present mainly within clay pockets, but it is also present in styolites and more rarely, following calcite or ferroan calcite. Ferroan dolomite is non-luminescent. Dolomite must have occured after the ferroan calcite phase since it is seen replacing ferroan-calcite cement. It also must have occured after styolitization since it is found within the styolites. Ferroan dolomite is closely tied to the prescence of the clay minerals, which are concentrated in mud chips that weather tan and are more resistant than the surrounding limestone.

The timing between ferroan dolomite and chalcedony is ambiguous. The chalcedony is deposited in between ferroan calcite crystals along crystal boundaries. It is most commonly a replacive fabric effecting low-Mg calcite brachiopod valves. Chalcedonic quartz patchily replaces low-Mg calcite leaving islands of shell material in the middle of an area of chalcedony. The quartz retains the original fabric of the shell material. Areas of quartz replacement may contain euhedral ferroan-calcite rhombs near the edges. In other areas the quartz contains inclusions exhibiting rhombic form. These inclusions may represent relict micro-dolomite.

Diagenetic Interpretations

Several factors suggest that cementation began in a freshwater phreatic environment: lack of acicular fringing cements on substrate grains, and solution-fill cavities of mosaic calcite and ferroan calcite. Strontium concentrations of 900 ppm detected by ICP analysis of ferroan calcite support this interpretation.

CL observations indicate that cations other than Mn and Fe are incorporated in calcite cement. In early non-ferroan zones which luminesce dully, either lack of Mn or a quencher other than Fe may cause the dull luminescence. The thin zones which stain mauve normally would not luminesce, but here the luminescence is bright indicating that Mn concentrations must be high and or a sensitizer is present to help overcome the quenching effects of Fe. It should not be assumed that Mn and Fe are the only cations in the system which control luminescence. Activators other than Mn (Pb, Ce) may increase luminescence and quenchers other than Fe (Ni, Co) may be responsible for decreased luminescence (Machel,1987). Use of an electron microprobe would be particularly helpful in determining the composition of individual zones in calcite.

Dolomite formed after most of the pore space had been filled with calcite. The formation of dolomite must have been subject to local conditions since the porosity and permeability of the limestone was greatly reduced (Pingitore,1982). The pore water was not homogeneous throughout the formation during dolomitization. As a result, dolomite formed locally in clay pockets where the conditions for dolomitization were satisfied. Occasionally dolomite rhombs cut across calcite or ferroan calcite near a clay pocket. Mg and Fe needed for the formation of ferroan dolomite may have been derived from the clay minerals (Al-Shaieb and Shelton, 1978) or from seawater mixing (Machel and Mountjoy,1986).

Chalcedony is ambiguous in terms of timing relative to ferroan dolomite. It replaces both non - ferroan and ferroan calcite in solution fill cavities, as well as low-Mg calcite shell material. Rhombohedral inclusions in th e quartz may represent micro-dolomite that formed at a wet film surface before being replaced by quartz. Mg needed for dolomite formation may be derived from solution of shell material containing Mg (Hesse, 1989; Lohmann and Meyers, 1977; Jacka, 1974). Silica may have been derived from several sources: fresh water, mixing zone water, Ordovician sea water, or shale interbeds. Stable isoptope analysis will aid in narrowing the range of possible diagenetic environments.

Conclusions

1) The King's Falls was deposited in a shallow shelf environment, either as a shoal, or as a number of small build-ups surrounded by mobile grianstone belts.
2) Diagenesis began in a freshwater phreatic zone with non-ferroan calcite followed by ferroan calcite. Cements exhibit zoning related to activators and quenchers other than Mn and Fe.
3) Dolomitization occured after the ferroan calcite phase and is related to clay minerals and possibly sea water mixing.
4) Silicification is ambiguous in terms of timing. Silica may have been derived from a number of possible sources: fresh water, mixing zone water, Ordovician sea water, or shale interbeds.

References

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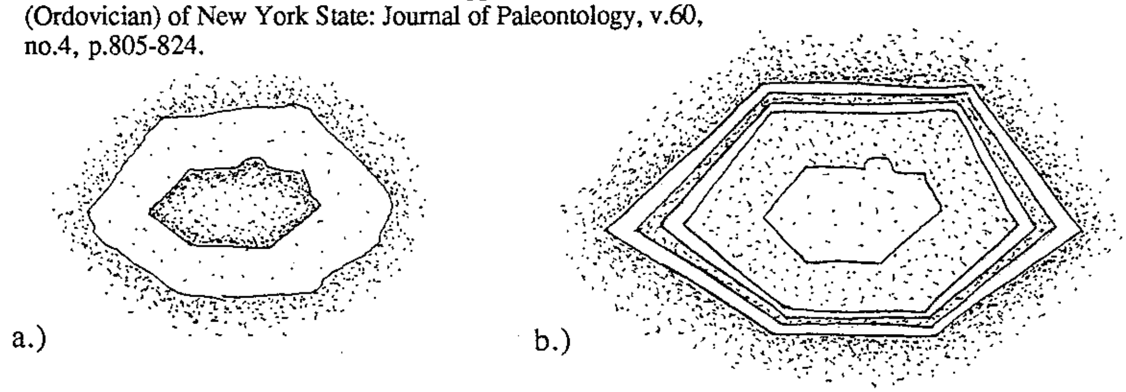

Figure 1: Echinoderm overgrowth. a.) With staining. Stippled areas represent ferroan calcite. Unshaded areas represent non-ferroan calcite. b.) Under CL. Unshaded areas represent bright luminescence.

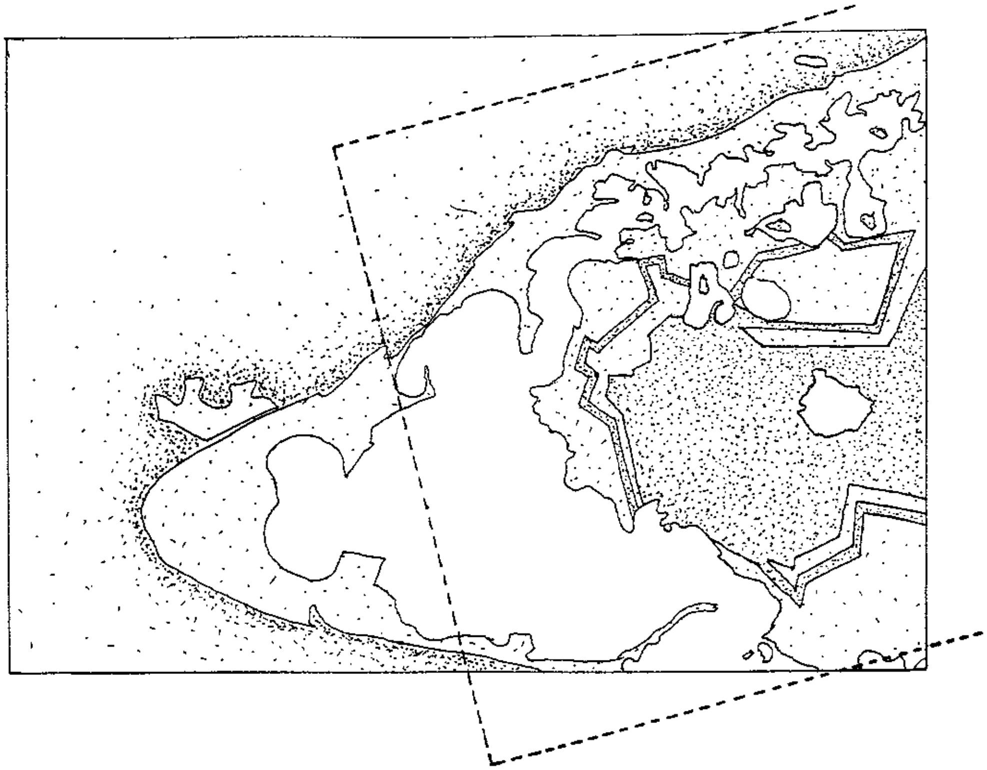

Figure 2a: Stained thin-section. Densely stippled areas represent ferroan calcite, sparsely stippled areas represent non-ferroan calcite, and clear areas are equivalent to chalcedony.

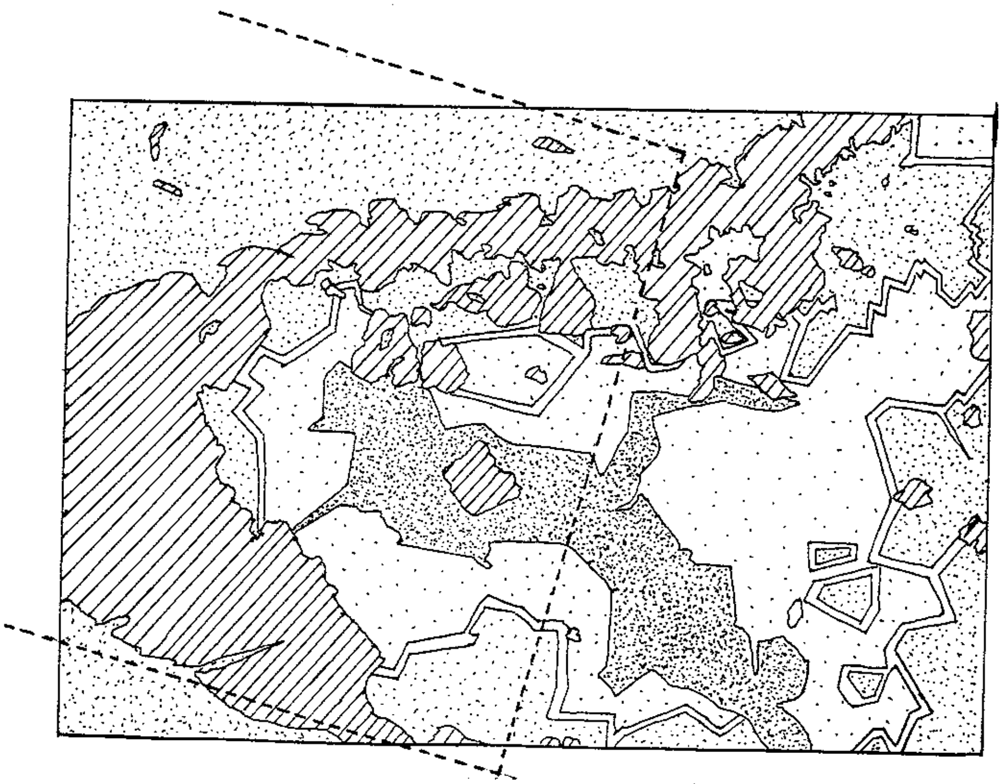

Figure 2b: Cathodoluminescence. Striped pattern is equivalent to non-luminescing chalcedony. Density of stippled patterns approximates luminescence of calcite cements, with the brightest zone being unshaded.