# "Autocementation": the process which lithified the carbonate hardgrounds in the Carmel Formation (Middle Jurassic) of southwest Utah

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## INTRODUCTION

The Middle Jurassic Carmel Formation of southwestern Utah contains an extensive hardground which was lithified in a lagoon on the landward side of an oolitic shoal. It is only the second Jurassic hardground discovered in North America (Wilson and Palmer, 1994). Nielson (1990) was the first to describe the stratigraphy of the Carmel Formation and he is credited with first identifying the existence of the hardground. Hardgrounds are synsedimentarily-cemented seafloors lithified through dissolution-reprecipitation processes. They are typically formed during "calcite sea" (Mackenzie and Piggot, 1981) intervals when seawater may have had a low Mg/Ca ratio. The seawater chemistry along with algae boring into dead bivalve shells which accumulated on the floor of the lagoon, provide the necessary conditions needed to "autocement" the Carmel Formation hardgrounds.

## CALCITE SEAS

The term "calcite seas" was coined by Milliken and Piggot (1977) when they recognized the cements and fabrics that comprise all shallow marine carbonate rocks have not been consistent throughout geologic history (Wilkinson, 1982). Calcite seas are defined as seas in which low-magnesium calcite is the predominant inorganic carbonate precipitate for non-skeletal grains (Wilson and Palmer, 1994). Such seas were likely undersaturated with respect to aragonite which would explain why aragonitic invertebrate skeletons would have tended to dissolve on the seafloor (Wilson and Palmer, 1992). Aragonite seas would then be seas that favored the precipitation of aragonite. Fluctuations in the seawater chemistry can be tracked through the examination of non skeletal carbonate grains, which provide the best evidence for calcite sea intervals.

The mechanisms responsible for the change in the ocean chemistry are hotly debated. The most likely mechanism may be tectonically-induced changes in both $pCO_2$ and the oceanic Mg/Ca ratio (Sandberg, 1983). Mackenzie and Piggot (1981) hypothesized that high atmospheric $CO_2$ levels and the precipitation of calcite are linked to periods of higher global sea levels (Wilkinson et al., 1982). The high sea level stand was also linked with high spreading rates and increased rates of subduction zone metamorphism (Sandberg, 1983). These cycles overlap with Fischer's (1984) oscillations of climatic episodes known as "greenhouse" and "icehouse" episodes (Sandberg, 1983). The increased subduction would increase volcanism which would raise the $pCO_2$ in the atmosphere. As far as the ocean water chemistry is concerned, Wilkinson (1982) claimed submarine alteration of oceanic crust at mid-ocean ridges via circulation of hydrothermal oceanic water through fractured mafic rocks was a key process. Such a reaction would lead to serpentization which is caused by the mafic rocks extracting magnesium out of the circulating water and releasing calcium-rich water (Wilkinson, 1982). Since the speed of the leaching depends upon the spreading rate, it is likely that submarine weathering actions lowered Mg/Ca ratios during these times of rapid spreading (Wilkinson, 1982).

## MICRITE ENVELOPES

Bathurst (1966) was the first to describe the origin of micritic envelopes while working on the lime sands from the Bimini Lagoon, Bahamas. Various forms of algae typically bore into hard aragonitic shells of marine animals such as molluscs when a stable substrate is unavailable (Bathurst, 1971). The boring action destroyed parts of the outer shell layer and the vacated holes were later filled with micrite and bored again. The process continues until the original aragonitic carbonate grains are centripetally replaced by micrite, a process named "micritization" by Bathurst in 1966. The "micritization" hypothesis went unchallenged until Winland (1968) discovered a relationship between high-Mg calcite and aragonite in the Florida Bay area.

Winland (1968) claimed that since the deposition of high-Mg calcite is common in internal pore spaces in the Florida Bay, algal borings could be filled by high-Mg calcite. His petrographic and chemical analysis showed the primary composition of the envelopes was high-Mg calcite. Lab experiments by Taft (1963) showed that aragonite and calcite remain metastable until a fluid with low Mg concentration enters the system. A solution such as this which is supersaturated with respect to calcite will cause the nucleation and crystal growth of low-Mg calcite on the high-Mg calcite while dissolving aragonite (Winland, 1968). His work sets the stage for the autocementation hypothesis.

## AUTOCEMENTATION HYPOTHESIS

Boring organisms such as algae went to work on the outer layer of dead bivalve shells which had accumulated on the floor of the Carmel lagoon. The algae created a foothold in the valves but eventually they vacated the boring holes. As was the case in the Florida Bay, void spaces and unoccupied boring holes were filled by a micritic high-Mg calcite of an unknown origin. Additional boring occurred and the mechanical destruction of the shells continued. Eventually the low-Mg sea water made its way into the shells.

When the sea water leached into the shells through the damaged portion of the micritic envelopes it begins the dissolution process. Any grain composed of high-Mg calcite will be stabilized to low-Mg calcite by exchanging Ca for Mg in the crystal lattice structure. This process does not dissolve the high-Mg calcite, it just replaces the Mg ions with Ca ions in the already existing lattice (Steinhauff, 1989). In this manner, low-Mg calcite nucleates on the already existing crystal lattice and forms the bladed low-Mg calcite cement which outlines all of the micrite envelopes. This makes sense because a closer microscopic examination of the cement shows that each cement blade is formed of small interlocking crystals. The bladed low-Mg calcite cement was formed in this manner and it was the first cement generated in the hardground (Figure 1). These crystals likely nucleated and continued to grow outward until something halted crystal growth.

Plummer et al. (1976) made a discovery which is key to explaining the process. They discovered that when exposing both aragonite and high-Mg calcite to a low Mg solution, the growth rate of low-Mg calcite proceeded at a faster rate than the dissolution of aragonite. When the aragonite is dissolved, low-Mg calcite spar crystals precipitate to fill the void spaces (Steinhauff, 1989). It makes sense then that the bladed cement formed directly before the blocky spar crystals precipitated in place of the dissolved aragonite. Since the replacement process of the high-Mg calcite on the lattice was faster then the dissolution of aragonite, the blocky spar would precipitate shortly after, effectively halting the growth of the bladed crystals.

Evidence exists which supports the hypothesis that the bladed cement formed before the blocky spar. Some of the micritic envelopes and the associated bladed cements were broken apart by the precipitation of blocky spar crystals (Figure 2). None of the envelopes seem to exhibit an imperfect "break" of the envelope and bladed cement. If the blocky spar did not halt the growth of the bladed calcite, some thin-sections would likely exhibit bladed cements being fractured horizontally or in various other random orientations. The fractures all exhibit a rather perfect fracture along parallel planes.

Point count analysis of five thin-sections indicated the blocky spar crystals were primarily responsible for the lithification of the hardground following carbonate dissolution and reprecipitation. The average thin-section was composed of 28% calcitic grains, 35% aragonitic molds, 9% bladed cements, and 28% blocky spar cements (Figure 3). The amount of originally aragonitic grains is roughly equal to the amount of cement generated, which supports the hypothesis of a dissolution-reprecipitation reaction. The abundance of the blocky spar also indicates it was responsible for the lithification of the hardground (Figure 4).

## CONCLUSIONS

The hardgrounds contained in the Carmel Formation were deposited and lithified in a lagoon on the landward side of an oolitic shoal. During the Middle Jurassic, a calcite sea ocean chemistry was the dominant regime. Algal borings into bivalve shells caused the formation of micrite envelopes which all had a rind of bladed calcite cement surrounding them. The bladed cement precipitated first, but point count analysis shows the precipitation of the blocky low-Mg calcite spar cement formed the hardground.

## REFERENCES CITED

Bathurst, R.G.C., 1966, Boring algae, micrite envelopes and lithification of molluscan biosparites: Geology Journal, v.5, p.15-32.

Bathurst, R.G.C., 1971, Carbonate sediments and their diagenesis: Developments in Sedimentology 12. Elsevier (Amsterdam). p.1-657.

Fischer, A.G., 1984, The two Phanerozoic supercycles, in Berggren, W.A., and Van Couvering, J.A. eds., Catastrophes and Earth history; the new uniformitarianism: Princeton University Press, Princeton, New Jersey, p.129-150

MacKenzie, F.T., and Piggot, J.D., 1981, Tectonic controls of Phanerozoic sedimentary rock cycling: Journal of Geological Society of London, v.138, p.183-196.

Milliken, K.L., and Piggot, J.D., 1977, Variation of oceanic Mg/Ca ratio through time: Geological Society of America Abstracts with Programs, v.9, p.64-65.

Nielson, D.R., 1990, Stratigraphy and sedimentology of the Middle Jurassic Carmel Formation in the Gunlock area, Washington County, Utah: Brigham Young University Geology Studies, v.36, p.153-192.

Plummer, L.N., Vacher, H.L., Mackenzie, F.T., Bricker, O.P., and Land, L.S., 1976, Hydrogeochemistry of Bermuda: a case history of groundwater diagenesis of biocalcarenites: Geological Society of America

Bulletin, v.87, p.1301-1316.

Sandberg, P.A., 1983, An oscillating trend in Phanerozoic non-skeletal carbonate mineralogy: Nature, v.305, p. 19-22.

Steinhauff, D.M., 1989, Marine Cements, in Walker, K.R. ed., The fabric of cements in Paleozoic limestones; a shortcourse/workshop held at the Geological Society of America annual meeting, Studies in Geology (Knoxville), 20, p.37-53.

Taft, W.H., 1963, Cation influence on diagenesis of carbonate sediments: Geological Society of America Abstracts Volume, p.162.

Wilkinson, B.H., Janecke, S.U., and Brett, C.E., 1982, Low-magnesian calcite marine cement in Middle Ordovician hardgrounds from Kirkfield, Ontario: Journal of Sedimentary Petrology, v.52, p.47-57.

Wilkinson, B.H., 1982, Cyclic cratonic carbonates and Phanerozoic calcite seas: Journal of Geological Education, v.30, p.189-203.

Wilson, M.A., and Palmer, T.J., 1992, Hardgrounds and hardground faunas: University of Wales, Aberystwyth, Institute of Earth Studies Publications, v.9, p.1-131.

Wilson, M.A., and Palmer, T.J., 1994, A carbonate hardground in the Carmel Formation (Middle Jurassic, SW Utah, USA) and its associated encrusters, borers and nestlers: Ichnos, v.3, p.79-87.

Winland, H.D., 1968, The role of high Mg calcite in the preservation of micrite envelopes and textural features of aragonite sediments: Journal of Sedimentary Petrology, v.38, p.1320-1325.

**Figure 1.** Bladed low-Mg calcite cement nucleated from micritic envelopes around dissolved aragonitic bioclasts. (Scale = x40)



**Figure 2.** Blocky low-Mag calcite spar with fractured micritic envelopes and bladed low-Mg calcite cements. (Scale = x40)

| Sample #'s | % aragonitic molds | % calcite grains | % blocky calcite spar cement | % bladed calcite cement |
|---|---|---|---|---|
| C/W 141-1005 | 36.1 | 28.4 | 27.0 | 8.5 |
| C/W 141-1006 | 33.2 | 26.8 | 29.8 | 10.2 |
| C/W 143-1004 | 33.6 | 27.2 | 30.0 | 9.2 |
| C/W 143-1005 | 34.9 | 28.4 | 28.0 | 8.7 |
| C/W 160-1002 | 35.7 | 26.1 | 27.8 | 10.4 |

**Figure 3.** The table shows the distribution of the cements and grains as determined by the point count method. The results suggest an aragonite dissolution and calcite precipitation event occurred.
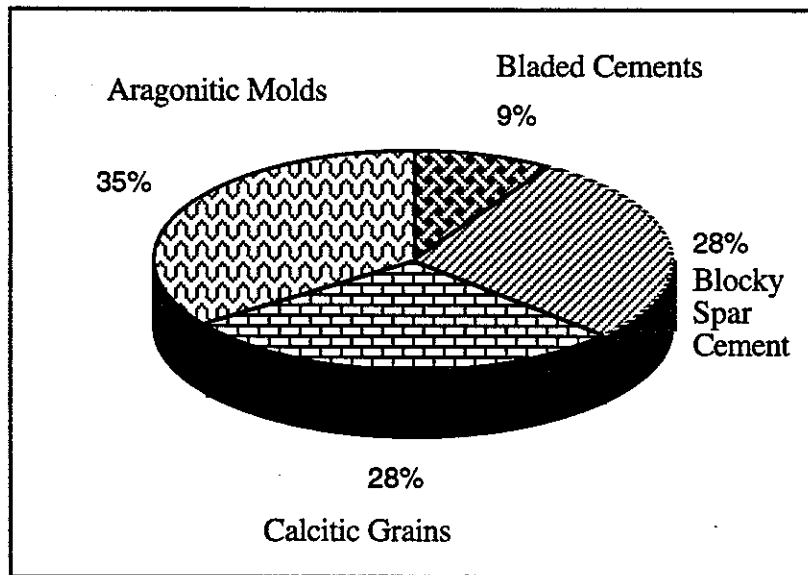


**Figure 4.** The graph represents the distribution of the average grain and cement quantities in the hardgrounds determined by point count analysis. The fact that the blocky spar cement is the dominant cement indicates it was responsible for the lithification of the hardground. The amount of cement generated (37%) is roughly equal to the number of aragonitic molds (35%), which suggests a dissolution and reprecipitation event occurred.