Carbonate Cementation in Meteoric Phreatic Systems:  
Morphology, Distribution, and Rates  

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**STATUS**: Long-term project in progress  
**TIMING**: Significant results to be reported – Results currently available to membership  
**FUNDING**: Currently none, earlier work funded by Shell.

**Purpose**
This project simulates precipitation of carbonates (i.e., cementation) under phreatic conditions and seeks to:
- Quantify rates of carbonate of cement precipitation  
- Quantify the impact of microorganism on carbonate cementation  
- Quantify the relative role of flow rates vs. saturation (e.g. fluid chemistry) on cementation  
- Quantify the impact of diminishing permeability as cementation progresses.  
- Establish petrographic and geochemical diagnostic criteria for the identification of inorganic vs. microbially mediated cementation  

To date, very little experimentation has been conducted to simulate and quantify carbonate cementation processes in shallow or deep phreatic systems. Yet, such data is crucial to the modeling of porosity/permeability evolution in carbonate and other systems in which carbonate cements play key roles. The lack of such data limits the accuracy and utility of predictive models for cementation and is imperative that rate laws and appropriate algorithm for cement distribution be integrated with reactive transport and porosity evolution models.

**Project Description**
During much of the second half of the 20th century carbonate geologists embarked in extensive documentation of carbonate diagenetic features in modern and ancient systems while geochemist conducted numerous experiments aimed at determining the physicochemistry of carbonate precipitation. While much progress was made in the understanding of carbonate dissolution processes, many uncertainties regarding carbonate precipitation remain. Surprisingly, empirical data have rarely been integrated in experimental design, and few experimental designs have actually simulated natural systems. Our recent work (DeChoudens-Sanchez, 2007; DeChoudens-Sanchez and González, 2009) on the simulation of speleothem precipitation has shown that experimental design integrating empirical observations is key to replication of mineralogy and textures in natural systems. Furthermore, few studies have systematically carried out comparative experiments of inorganic and microbially mediated or assisted precipitation.

Our team has applied the lessons learned from simulation of vadose carbonate precipitation to create a flow-cell design that simulates phreatic cementation. After extensive troubleshooting of the experimental apparatus the system is ready for intensive simulations of
cementation in phreatic systems. Initial experiments have produced cementation fabrics that are nearly identical to those observed in nature (Figure 1).

Two surprising findings in the early stages of experimentation are: 1) the formation of putative meniscus cements (Figure 2), and 2) the observation that cementation rates appear to be greater under slower flow conditions. If reproducible, the former observation questions the validity of the paradigm of meniscus cements as indicators of vadose environments. The latter is counterintuitive as other experimental and empirical work suggested that increased reactant delivery rates, as controlled by increased fluid flow, would result in faster carbonate cementation. Our experimental simulations of vadose system have also shown that inorganic processes can produce many textures and fabrics that have been utilized as diagnostic of microbially mediated precipitation (DeChouden-Sanchez et al., 2007).

Our current and future work focuses on simulation on carbonate cementation under a range of flow rates, fluid chemistry, and temperature in which parallel simulations of inorganic and microbially influenced systems are run. Both the impact of living and dead microbial biomass is being explored. Whereas spheres and ooids are the substrate of choice in early experimentation, the experiments can utilize a variety of carbonate substrates (sands) from modern environments or reservoirs. The experiments are designed to allow quantification of cementation rates, distribution of cements, and temporal and spatial evolution of cements and their impact on permeability. Long-term experimentation (i.e.- running experiments for over a year) is expected to allow study of replacement processes and resulting fabrics.

**Deliverables**

The outcome of these simulations will be kinetic rate laws that can be integrated into predictive models and simulation. These will: 1) include fluid chemistry dependence; 2) quantify impact of biomass on cement mineralogy, morphology, and fabrics; and 3) describe models, equations, or algorithms of the temporal evolution and spatial distribution of cements and their impact on permeability.

**References**

DeChouden-Sánchez, V., 2007, Calcium carbonate polymorphism: new insights into the role of solution saturation state and composition (Mg/Ca) on calcium carbonate mineralogy, morphology, and fabrics: [unpublished Ph.D. dissertation], University of Kansas, 203 p.


Figure 1. High-Mg calcite cemented silica spheres (0.5 mm diameter). Isopachous fibrous calcite with binding of spheres along grain-to-grain contacts has produced aggregates that resemble grapestone. Fluid Mg/Ca 1:1.

Figure 2. Apparent high-Mg calcite meniscus cement (?) developed along silica sphere contacts.