Predicting Diagenetic Alteration in Carbonate Reservoirs from Sea-level History and Modeling

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SUBSURFACE APPLICATION: Important for all carbonate reservoirs that have experienced subaerial exposure such as Tengiz, Arbuckle/Ellenburger/Tarim, Pennsylvanian/Permian of Permian Basin and Midcontinent, Mississippian Midcontinent, Shuaiba, Lisburne Group of Alaska, Shuaiba
STATUS: Long-term project in progress
TIMING: Significant results to be reported – Results currently available to membership
FUNDING: Partial

Purpose
Given popular models of low-temperature diagenetic alteration, it would be helpful if diagenetic alteration could be accurately predicted from knowing the history of sea-level change and modeling hydrogeologic data, known rates from extant systems, or chemical equilibria. This is an important direction, and well worth continuing its pursuit (see Whitaker and Smart, 2007; Jones et al., 2003), but still, there remains much to learn about the variables that control diagenesis in such low-temperature systems for effective predictive modeling

Most researchers focus on freshwater vadose, freshwater phreatic, mixing zone, and marine diagenesis at low temperature (Figure 1). Views of these systems have commonly held that if you get one of these salinity realms, then you get a particular diagenetic product in the rock - whether it is dissolution, cementation, or replacement. The idea that predictable salinity realms should lead to a predictable diagenetic record has been pervasive, but the rock record and modern systems tell another story that should lead us to rethink this model. The purpose of this project is to systematically study the rock record as ground truth in refining conceptual and quantitative models for predicting diagenetic alteration in carbonate reservoirs, given a history of sea-level rise and fall.

Project Description
Given a cycle of sea level fall and rise, one should be able to predict the diagenetic record at a given point in the rock because of the predictable fluids that pass any given point in the rock (Figure 2). Known sea-level history can result in a predictable pattern of cementation (Figure 3). This fluid history would be predicted to form a diagenetic salinity cycle associated with each cycle of sea level change (Csoma et al., 2004). If diagenetic systems are predictable, with each salinity realm leading to a predictable diagenetic product, then each diagenetic salinity cycle should be somewhat symmetrical in terms of diagenetic product, and successive diagenetic salinity cycles should yield repetition in diagenetic products.

In a study of diagenesis associated with a single paleokarst surface, Csoma et al. (2004) recognized a complex paragenesis consisting of no less than 22 paragenetic events, which led to the designation of four diagenetic salinity cycles. The diagenetic products of each
were not symmetrical and each of the four resulted in different products. Thus, simple
diagenetic models relating to groundwater salinity realms do not seem to predict diagenetic
product faithfully. This research asks the question: why not?

The answer may lie in our understanding of processes in the meteoric realm. Most analyses
of early meteoric carbonate diagenesis interpret dissolution, low-Mg calcite cementation, or
mineral stabilization as the dominant processes. Few deal with all, and questions remain as
to which will dominate in any given ancient system. Even in very young or extant meteoric
systems, researchers continue to debate the relative importance of rate of fluid flow, CO₂
degassing near the water table, mixing at the water table, microbiolally controlled chemistry,
and rates related to alteration of unstable minerals (e.g., Budd and Land, 1990; Budd, 1994;
1998; McClain et al., 1992). Some groups focus on dissolution in such systems because of
observations in some modern aquifers (Whitaker and Smart, 2007). On the other hand,
numerous researchers dealing with reservoir rocks and outcrop analogs have shown a
complex record of low-Mg calcite cementation, the distribution of which is related to
aquifer configuration, climate, and duration of subaerial exposure (e.g., Goldstein, 1988;
Saller et al., 1994; Carlson et al., 2003; and Buijs and Goldstein, 2006).

This project will focus on quantifying the diagenetic processes and products of known sea-
level change to refine predictive models of early diagenetic alteration associated with events
of subaerial exposure in the stratigraphic record. It will systematically evaluate the
formation and reduction of porosity associated with subaerial unconformities on marine
carbonates. Techniques include cathodoluminescence cement stratigraphy, fluid inclusion
geothermometry and stable isotope geochemistry.

**Deliverables**
The work will provide quantitative models of porosity evolution given various systems of
subaerial exposure in carbonate reservoir systems. The long-term goal is collaboration with
others to produce refined models for quantitatively predicting porosity distribution in
ancient systems.

**References**
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Figure 1. Traditional hydrozone approach to carbonate diagenesis.
Figure 2. Diagenetic salinity cycle predicted from an event of sea level fall and rise (after Csoma et al., 2004). Yellow spot is fixed point in a carbonate reservoir rock experiencing cycle of different diagenetic environments.

Figure 3. Hydrogeological model for calcite cement precipitation in two cemented zones. (A) Precipitation of calcite in the upper cemented zone along a paleo-water table. (B) After formation of the upper cemented zone, water table dropped from the combined effect of eustatic sea-level fall, tectonic uplift and landscape incision. After the water table fell, the locus of cementation shifted downward, and formed the lower cemented zone. (see Li dissertation for details)