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Carbonate Reservoir Mapping, Correlation, and Modeling - Insight from Modern Analogs

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Summary

An interest in modern analogs for carbonate reservoirs is warranted based on the substantial number of carbonate reservoirs, with an emphasis here on those that produce from grainstones and packstones. The guiding premise is that modern analogs can have an important function as conceptual depositional environment (equivalent to facies) models providing an enhanced understanding of outcrop and reservoir stratigraphy and facies analysis. The reservoir aspect includes improved characterization of reservoirs, better addressing interwell heterogeneities, and providing quantitative facies attribute information for input in building reservoir models, e.g., size, shape, complexity, and distribution. Results from several studies on Great Bahama Bank (GBB), the Mecca for investigating all aspects of modern carbonate sands, broaden our perspective of the types of information that can be derived from studies of the modern and in so doing provide key insight to help address many challenging reservoir questions. The perspective offered by studies of the modern, especially those studies that are quantitative in nature, can be invaluable in forming a reservoir analog for mapping, correlation, and modeling.

Theory / Method

Field observations from the main ooid sand bodies on GBB (Fig. 1) show them to be formed of tidal sandbars and channels, but there are important variations to this theme. Cat Cay (small), Schooner Cays (medium) and TOTO (large) show a progressive increase in the size of the sand body and the depositional components therein, whereas variability exists in that Joulter Cays has a muddy component and the Exumas is formed around a backbone of numerous islands.

The depositional features at different scales within and among the various sand bodies illustrate that smaller-scale elements (surface bedforms and sandbar type) shape or create the larger-scale features (sand bodies), whereas the larger-scale features provide boundary conditions constraining the smaller-scale characteristics. The formation of ooids, transport of sediment, and generation of bar forms are limited in the platform interior because elevated tidal current velocities near the platform margin decrease when flood tides impinge farther onto the platform top. But across the platform margin a motif of positive feedback among flow velocity, ooid grain size, tidal sandbar height, channel depth and continuity, sandbar shape, and even the width of the oolitic facies belt (sand body) is a general pattern on GBB (Harris et al., 2019), directly supporting the notion that ooid sands and sand bodies are formed and shaped by hydrodynamic processes and offering a degree of predictability.

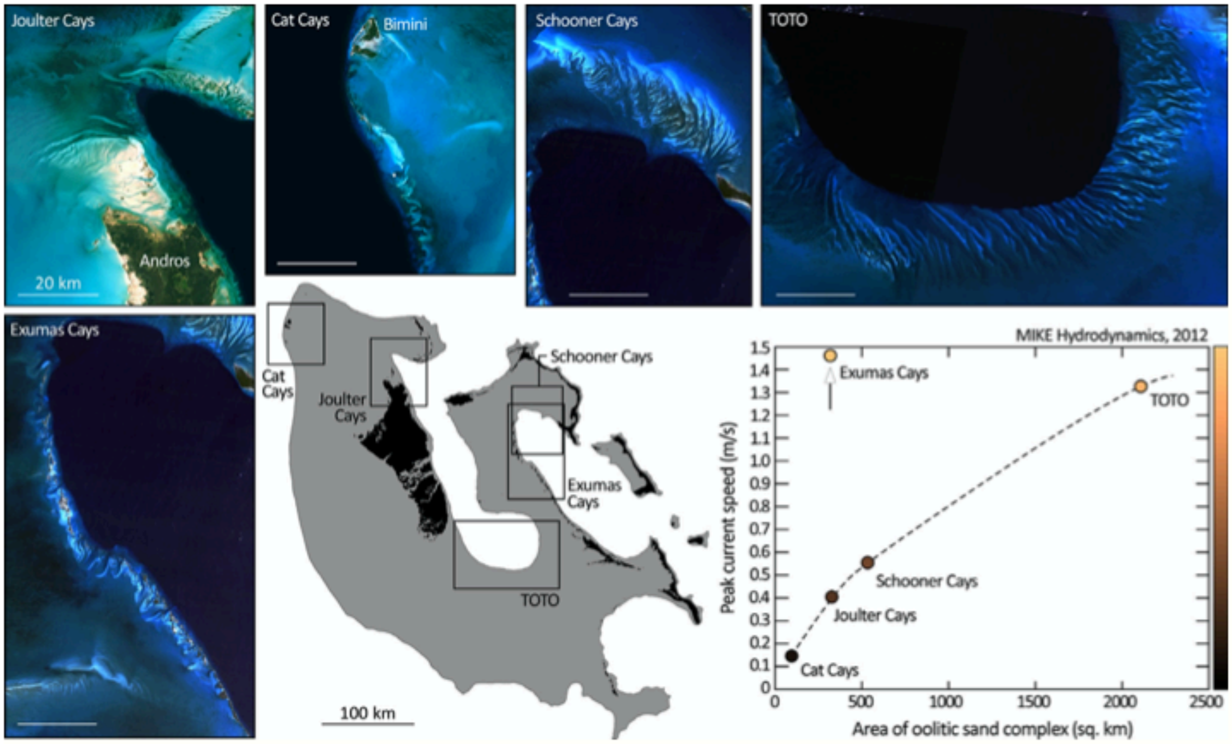


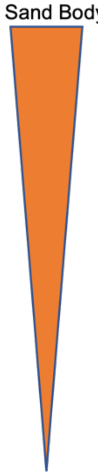
Figure 1: Locations of main ooid-producing areas on GBB – Cat, Joulter, Schooner and Exuma Cays and TOTO - are shown on the map, and their morphology on a Landsat ETM+ scene, all shown at the same scale. Cross plot summarizes size of the ooid sand body versus modeled peak current speeds. (Modified from Purkis et al., 2019)

Hydrodynamic modeling (e.g., Purkis et al., 2017, 2019) reinforces an understanding of the seabed-current patterns along the high-energy platform margins that lead to a significant production of ooid sands and subsequent development of sand bodies with a particular size and configuration. Results suggest there is a predictive relationship between increasing peak current speed and increasing area of a sand body as shown on Figure 1, such that a doubling of peak flow approximately yields a tripling in the area occupied by the sand body. The implication here being that even modest enhancement of hydrodynamic flow can lead to the meaningful increase in the overall dip and strike extent of ooid accumulation, and by extension variations in flow through time might be anticipated to deliver heterogeneity in facies due to expansion and contraction of the sand body.

Interrogation of the size and spatial patterns of the GBB sand bodies as performed by Harris et al. (2011) provides additional insight at development and modeling scales, e.g., 1) the frequency-area relationship of sandbars and bar crests, arising from a population of bodies with a preferred set of areas but randomly delimited in space, is exponential and therefore mathematically predictable; 2) small sandbars tend to be rounded and more closely spaced whereas larger ones (>1 km^2) are elongate and separated by great distance; 3) larger sandbars show more thickness variation than their smaller counterparts; 4) the relative proportion of bar crest well-sorted grainstone with respect to the overall area of less well-sorted sandbars is surprisingly consistent between different sites given differences in morphology and variable distribution of sandbars between them; 5) areas of closely spaced sandbars are evenly positioned along the strike length of the sand body and lie approximately midway within the dip width, and 6) sandbar spacing (= connectivity), or the breadth of tidal channels separating them, varies with level of scrutiny.

Results, Observations, Conclusions

Figure 2 highlights lessons learned from the modern examples that address specific unknowns at the exploration (sand body), development, or modeling (sandbar) scale. Three of the results highlighted in bold (ooid size vs sand body characteristics, sandbar connectedness, and sandbar orientation) are deemed particularly significant and are therefore used as examples to show a link more clearly to reservoir insight.



Exploration scale – Predict potential reservoir volume and characteristics

- Sand body size (strike length, dip width, area)
- Orientation relative to margin
- Sandbars and channels (% of sand body, spacing)
- ***Ooid size vs sand body characteristics***

Development scale - Subsequently direct infill well drilling

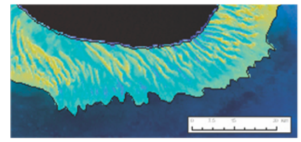
- Sandbar and channel spacing
- ***Connectedness***
- Separation distance
- Density

Modeling scale - Develop a reservoir modeling strategy

- Sandbar size
- Shape
- Complexity
- ***Orientation***
- Topography

Figure 2: Lessons learned from studies of the modern ooid sand bodies of GBB.

Further elaboration on some key findings and the direct impact they potentially have on the understanding of a reservoir is shown on Figure 3. As an example, armed with knowledge of ooid size from analysis of cuttings, one can theorize aspects of the potential sand body and address the challenge of predicting potential reservoir volume and characteristics prior to drilling an appraisal well. Bigger ooids suggest a larger sand body with bigger sandbars and channels, all positive aspects pointing to a substantial reservoir. But, at the same time, the larger and deeper tidal channels are more likely to cut completely through the dip width of the sand body and thus impact the connectivity within the potential reservoir. Models developed from the modern sand bodies of Cat Cay, Schooners Cay and TOTO respectively can help visualize increasing potential reservoir size vs high, medium, and poor connectivity scenarios for a potential reservoir.

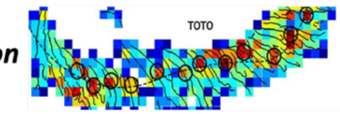


Exploration scale – ***Ooid size vs sand body characteristics***

Bigger ooids suggests larger sand body (width and length), larger bars (longer, wider, thicker), and larger (wider, deeper) and through-going channels =

- Bigger but likely less connected reservoir

Development and modeling scale – ***Connectedness and Orientation***



Anisotropy (in dip direction) due to sandbar and channel orientation; "predictable relationships" [fewer bigger bars but predictable size distribution; bigger are elongated, farther apart and vary more in thickness; patterning to bar spacing; sweet spot (bar crest) is relatively constant percentage of bar size] =

- Depositional bias can be constrained with range of geologic scenarios to lesson uncertainty

Figure 3: Examples of key lessons learned and their direct impact on understanding of a reservoir.

Figure 3 also suggests how connectedness and orientation information from quantitative studies of modern sandbars comes into play at the development drilling and reservoir modeling scales, in that any depositional bias introduced by aspects of the sandbars and channels can be constrained with a range of scenarios to lesson uncertainty in development well placement or modeling guidelines. Of particular importance in this example are the anisotropy created by sandbar and channel orientation in that these features are oriented roughly perpendicular to the strike length of the sand body; as well as a suggestion of predictability from several relationships measured on the modern examples, including size (fewer bigger bars but predictable size distribution), shape and spacing (bigger bars are elongated and farther apart, as well as showing more thickness variation), a patterning to sandbar spacing (density or clustering), and that the sweet spot of the sandbar (well sorted bar crest grainstone) occupies a relatively constant percentage of the sandbar size. Collectively, the varied observations discussed herein add predictability to building sedimentologic-based scenarios for visualizing depositional facies patterns in a reservoir at varied scales, even when confronted with limited core and sample data.

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