Ooids as Archives of Past Conditions*

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Search and Discovery Article #51578 (2019)**
Posted July 8, 2019

*Adapted from oral presentation given at 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/51578Harris2019

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Abstract

Ooids are concentrically coated, sand-size carbonate grains that are a key environmental indicator of high-energy depositional conditions and are significant to the evolution of carbonate platforms, shelves and reservoirs from around the world.

How do ooids form? - Latest studies support the stance that ooid cortex formation is driven mainly by a microbially mediated organomineralization process: (*a*) a biologically induced mechanism, whereby by-products of metabolic activities can change the physicochemical conditions of the microenvironments, inducing an increase in alkalinity and deposition of mineral particles, and (*b*) a biologically influenced mechanism, whereby an organic material, such as microbial extracellular polymeric substance (EPS) exudates, serve as a template for carbonate mineralization through the adsorption of ions and mineral nucleation.

Where do ooids form? - Ooid sand bodies generally develop in platform-margin sites with water depths between 0 and 8 m and where tidal velocities are intensified. Hydrodynamic modeling reveals a predictive relationship in that doubling the peak current velocity increases the area of a sand body by a factor of three, and there are distinct sedimentological trends observed in the field that parallel the decrease in current speed across a sand body in a platform-ward direction. Positive feedback among flow velocity, ooid grain size, tidal bar height, channel depth, bar shape and orientation, and even the width of the sand body is a general pattern that supports the notion that ooid dispersal and accumulation are controlled by hydrodynamic processes.

Ooids as archives of past conditions - Besides the microbial involvement in precipitation that leads to ooid formation, microbes can induce textural and geochemical transformations through a cascade of microscale biological processes in tandem with geochemical conditions. This provides cautionary implications for the use of ooids as archives for paleo-environmental reconstructions. However, grain size, sand body size and morphology seemingly have a direct relationship to the current strength, suggesting that ooid sand bodies can be exploited to discern hydrodynamics that existed in the past and aspects of sand body morphology are predictable. Thus an important consequence of the dual

influence of ooid formation and accumulation is extracting the paleophysical energy record from oolitic deposits is potentially more viable than extracting the paleochemical record.

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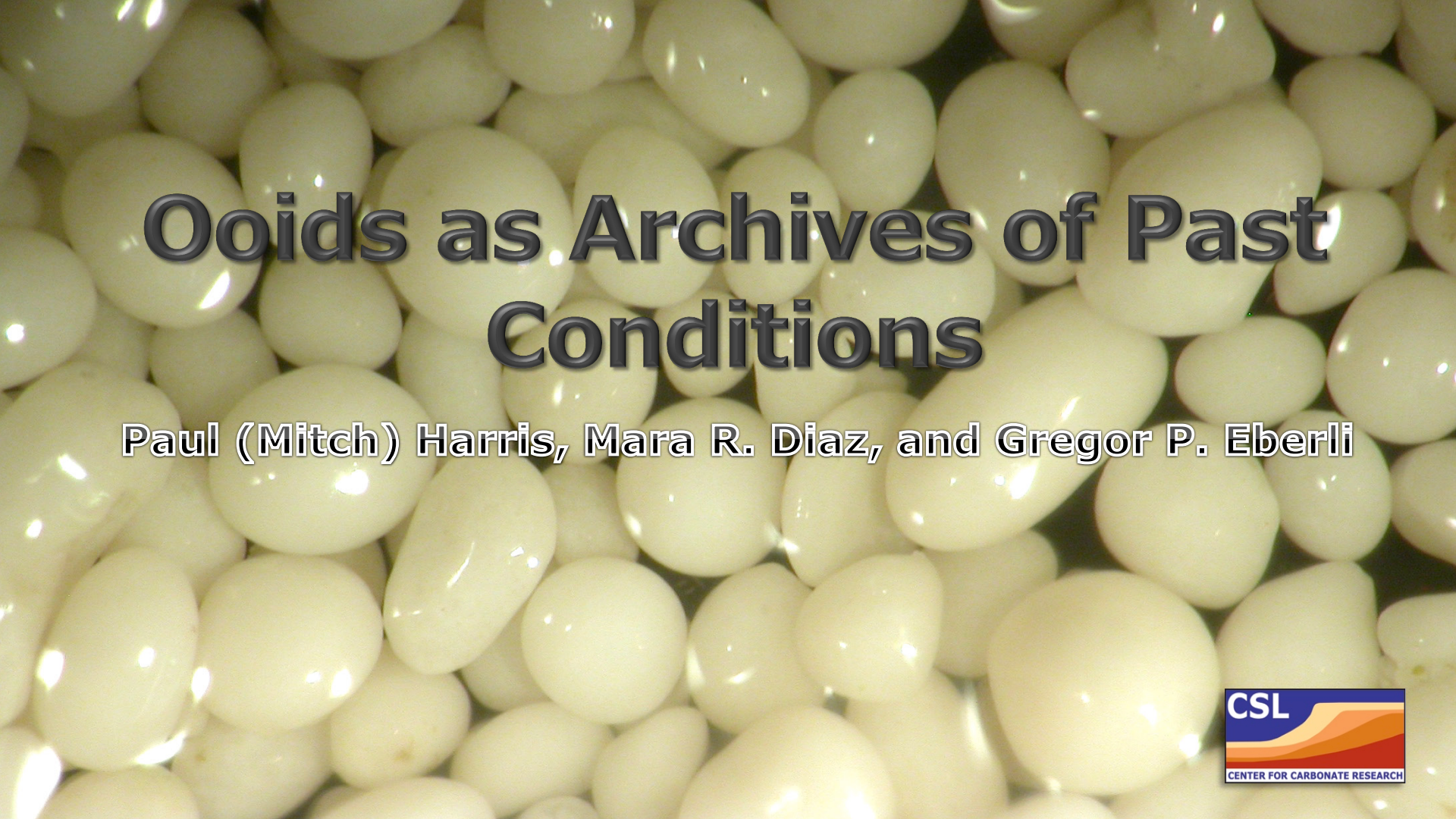

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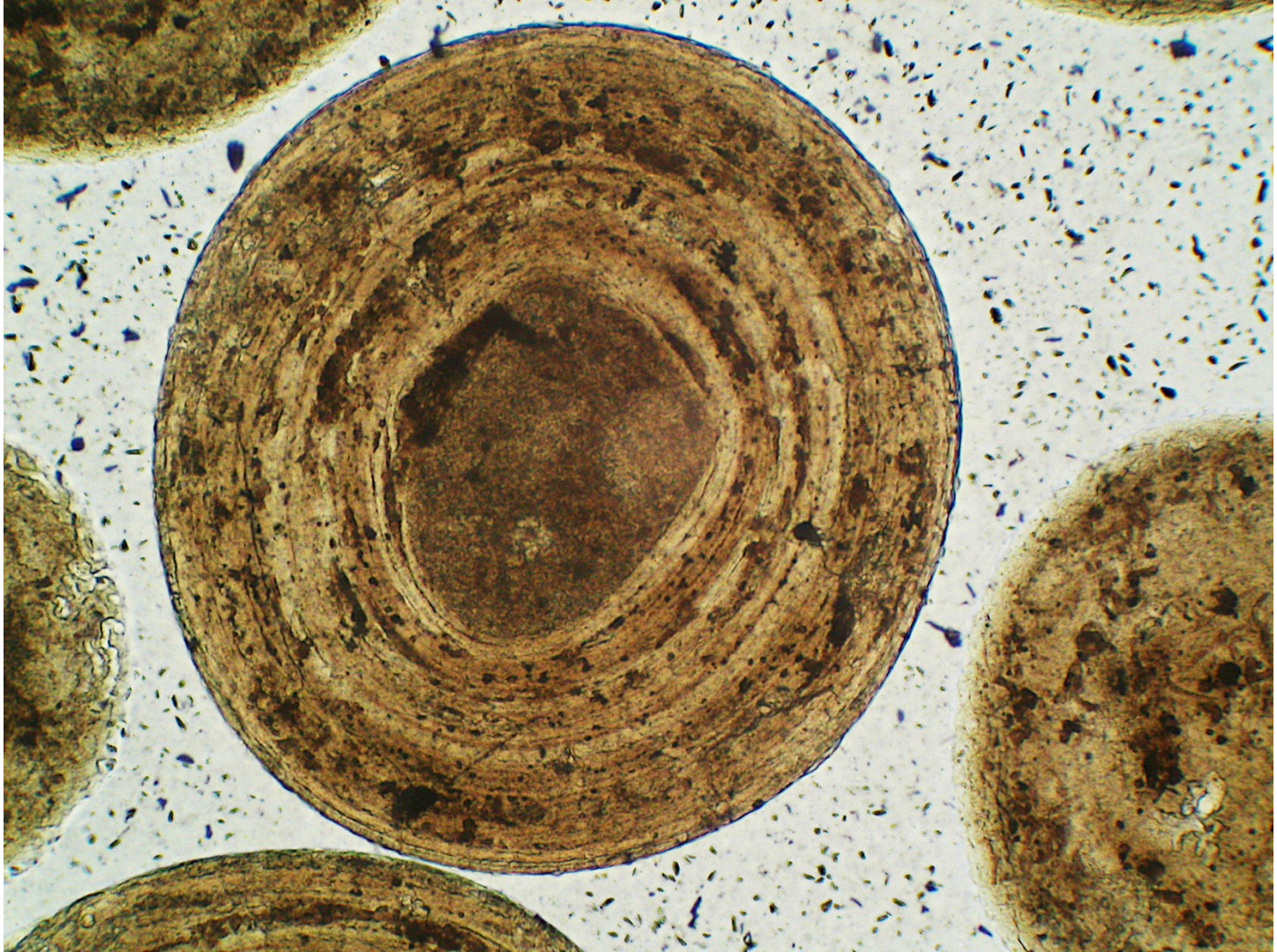
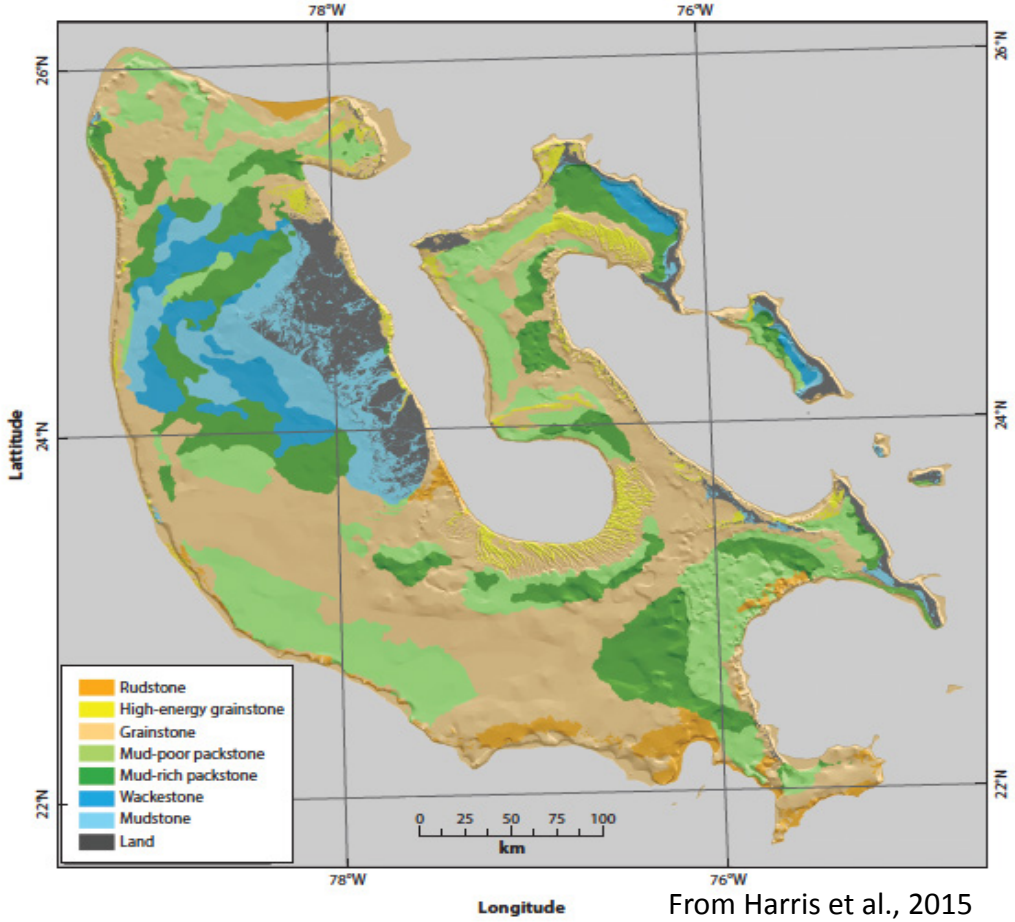


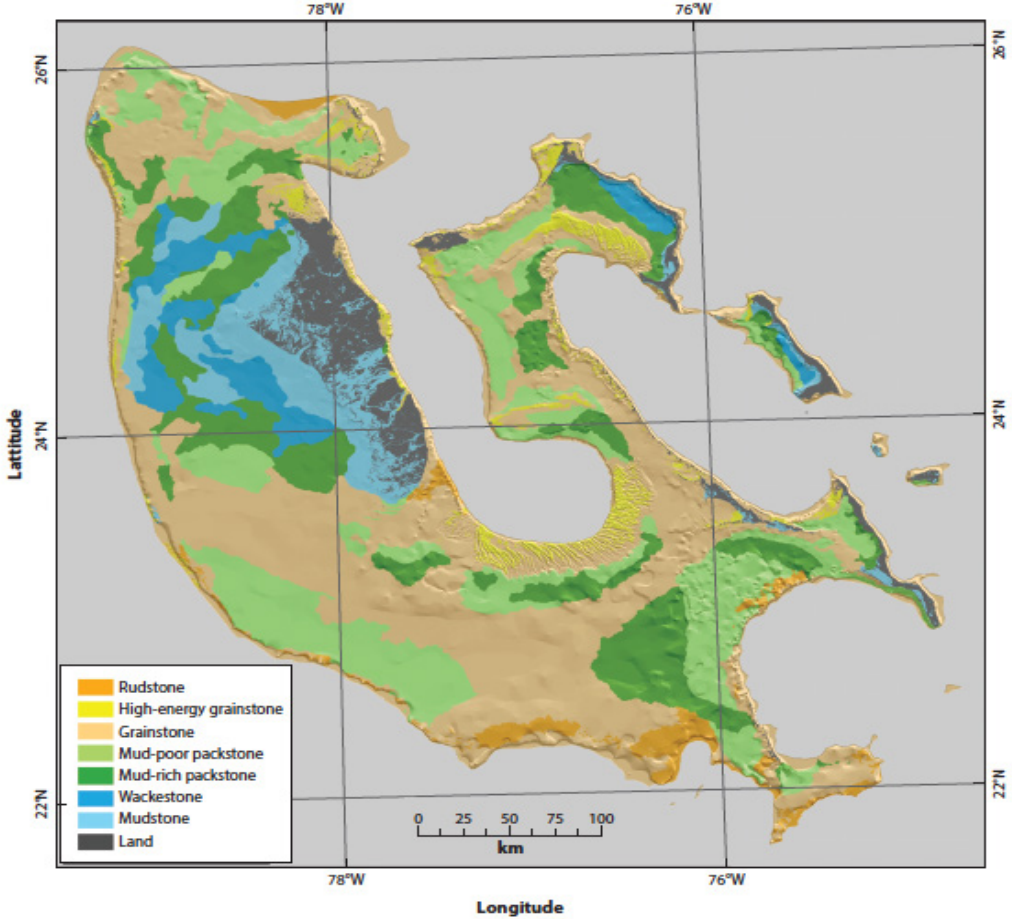
OOIDS – **SO WHAT**



From Harris et al., 2015

- Ooids are significant to the evolution of carbonate shelves, platforms and reservoirs of all ages
- Ooids are a key environmental indicator of high-energy depositional conditions
- Trends in ooid composition and size are considered to record changes in seawater chemistry, paleoclimate, and paleoceanography

Ooids – **So What**



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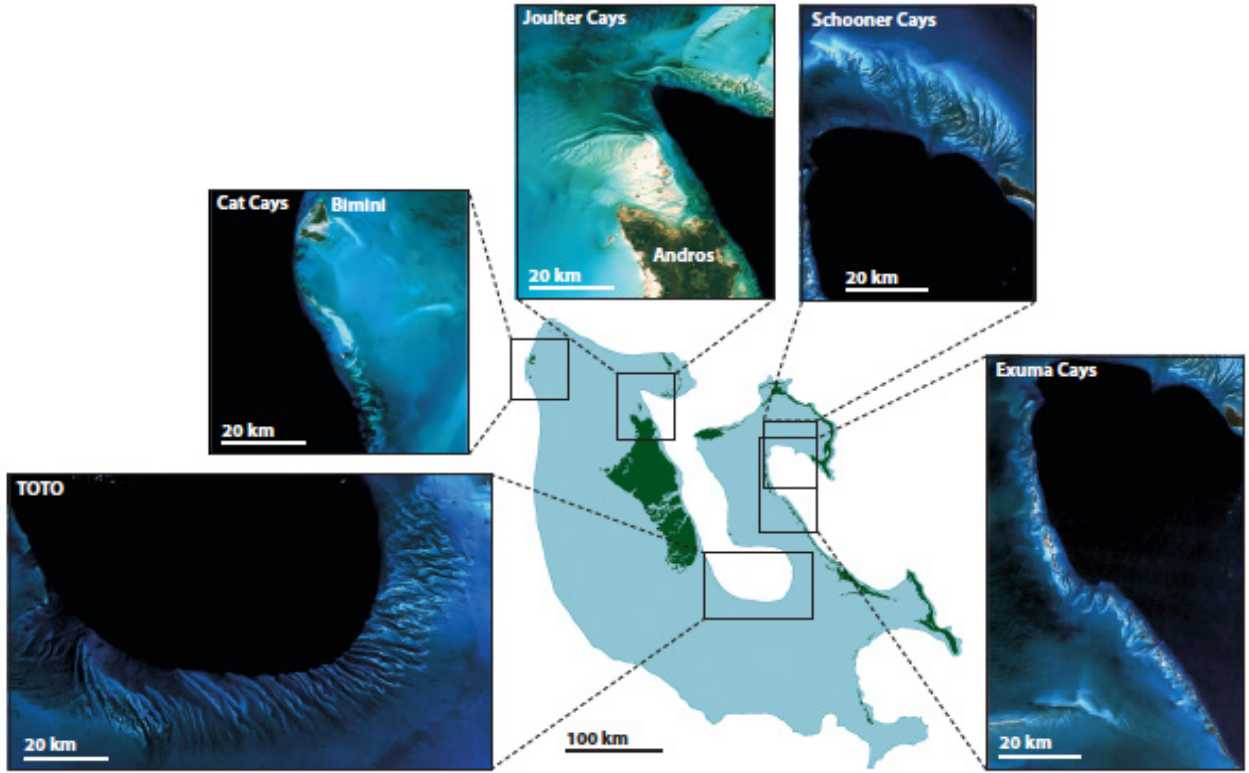
Ooids = High-Energy Depositional Environment



Modified from
Purkis and Harris, 2017

Vast majority of GBB ooids form within high-energy sand bodies consisting of shallow-water tidal bars alternating with channels

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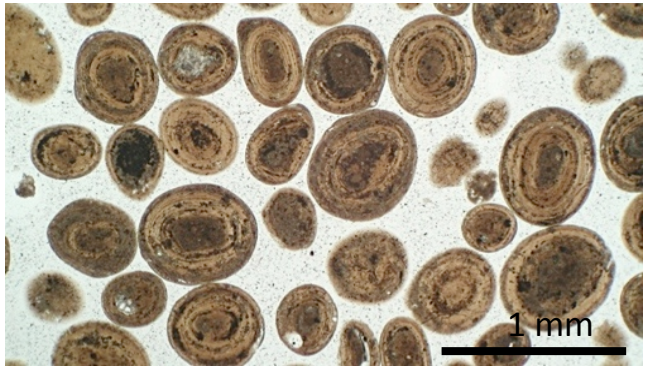
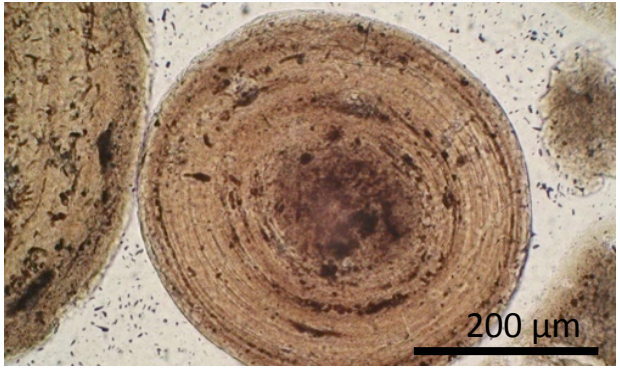


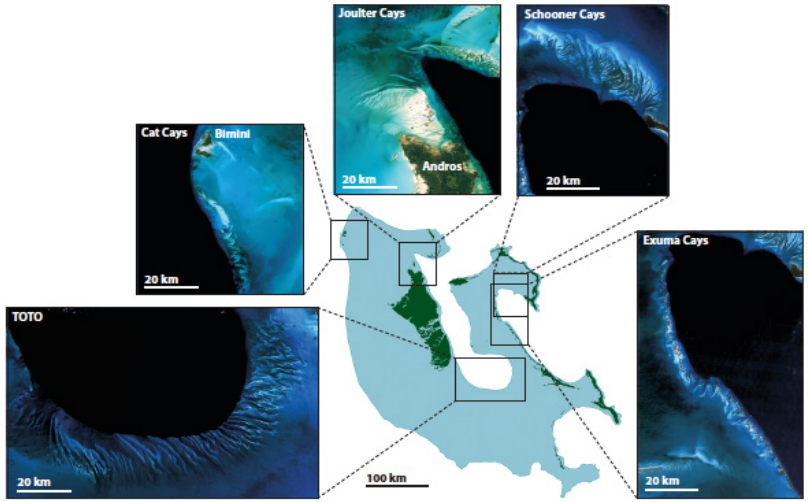


Well-formed, well-sorted, cross-bedded ooids indicate high-energy depositional conditions

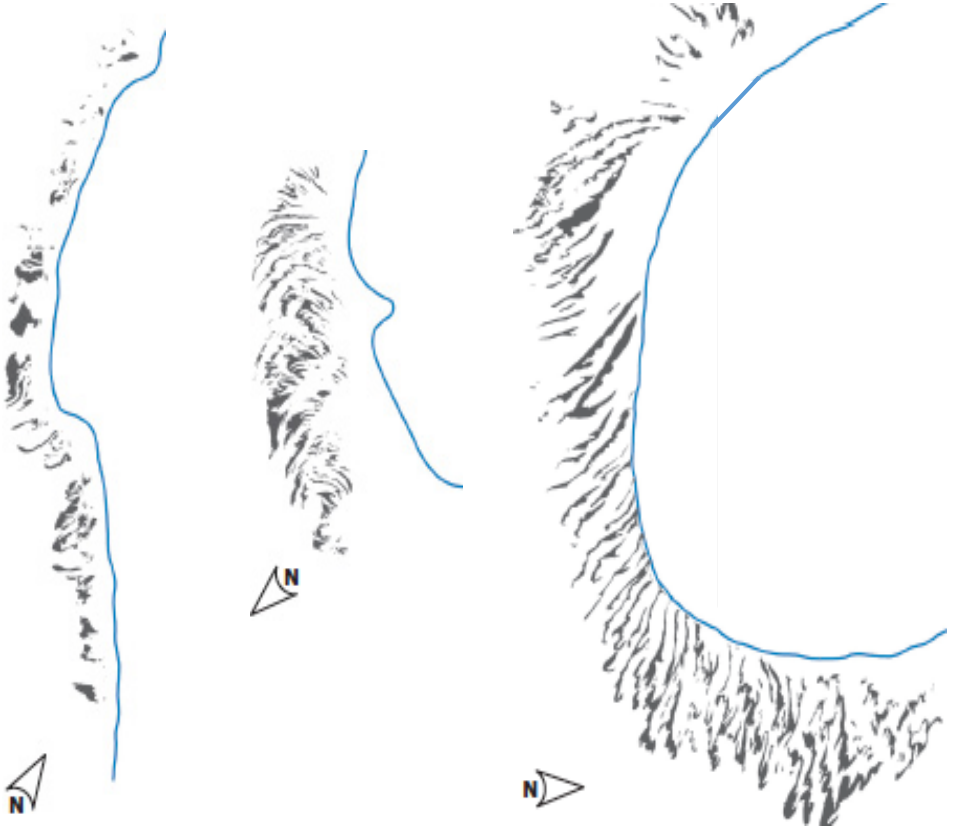
Ooids as Archives of Past Conditions

- Ooids **are a key environmental indicator** of high-energy depositional conditions ✔

Morphology of Ooid Sand Bodies



Change in sand body size and sandbar geometry suggests a relation to current changes



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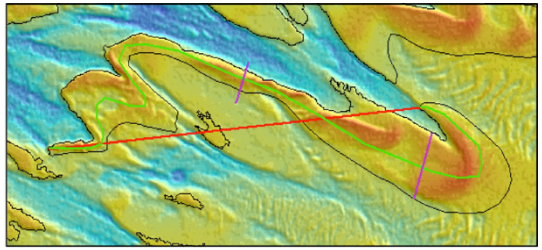
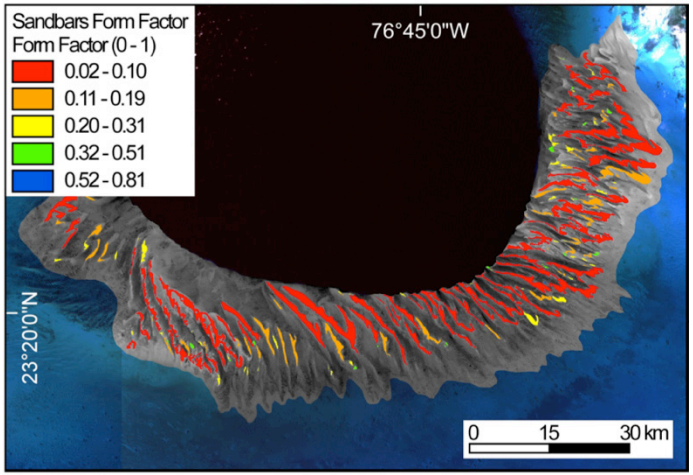
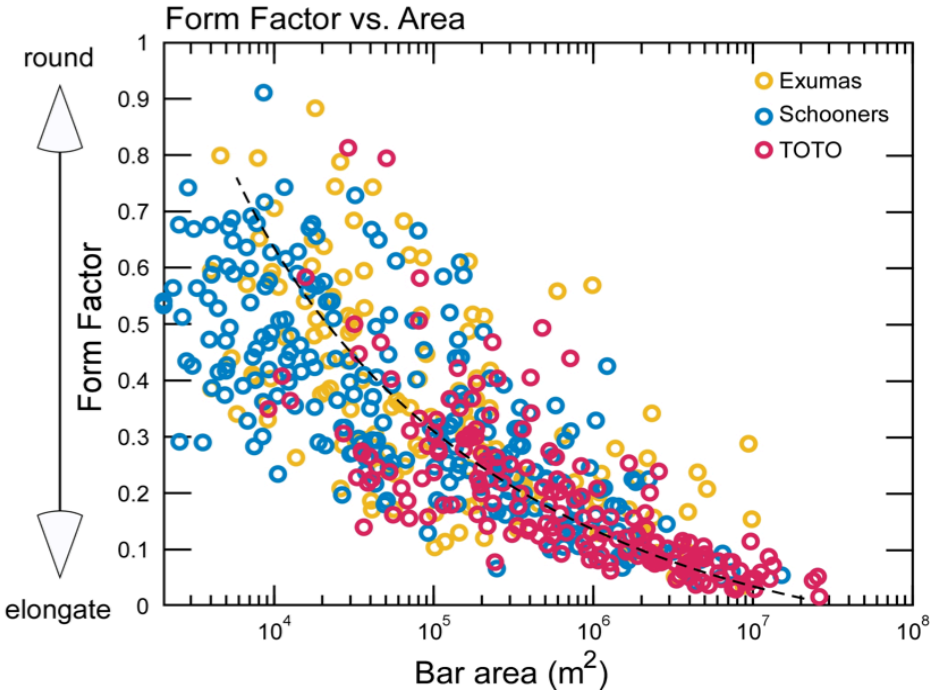
Morphology of Ooid Sand Bodies



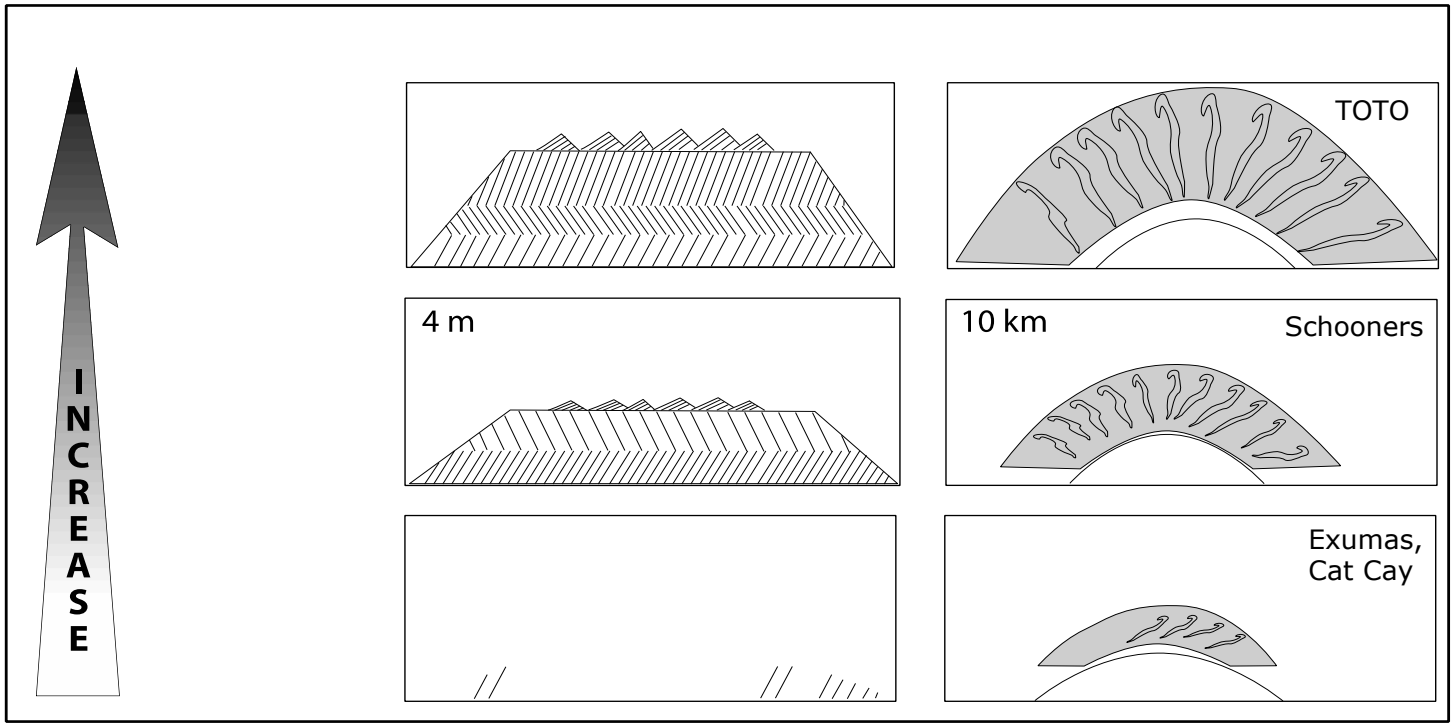




Modified from Harris et al., 2011

Change in sandbar geometry across many sand bodies suggests a relation to current changes

Ooid, Sand Bar and Sand Body Size

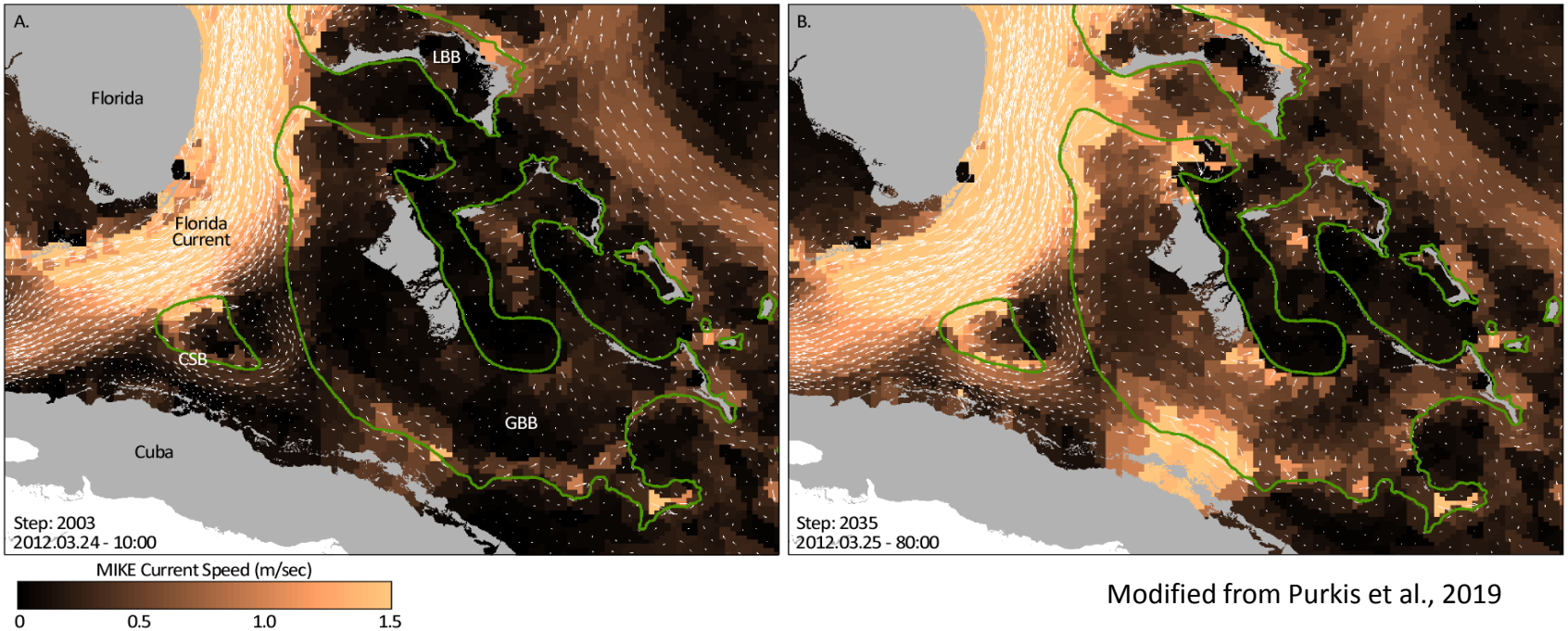


Modified from Harris et al., 2019

Coarser ooids, larger sandbars and broader ooid facies belts relate to stronger currents

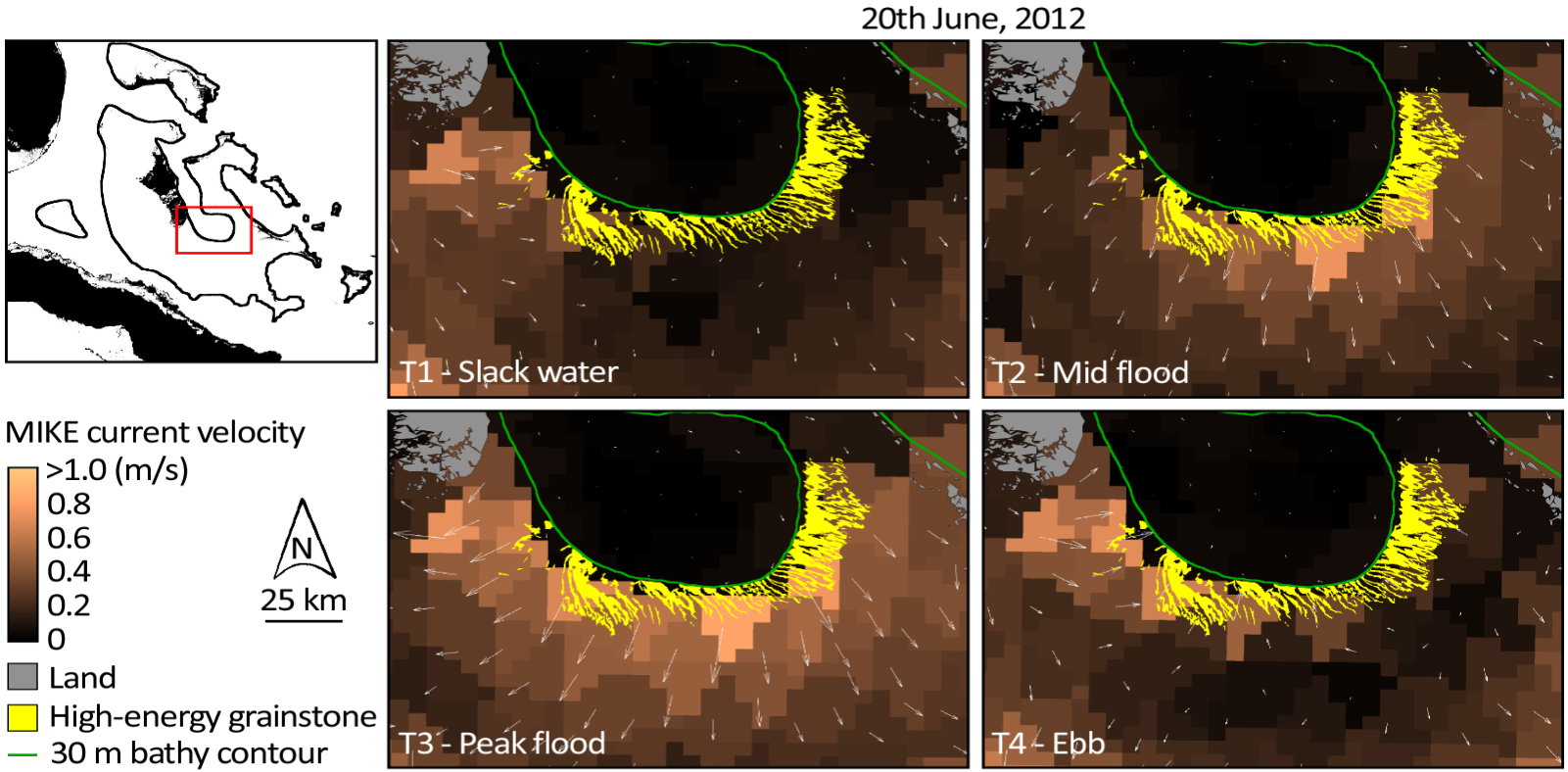
MIKE 3 – Hydrodynamic Model

- Run for 1 Jan 2012 to 1 Jan 2013 with a time-step of 1 min
- Forced by prevailing ocean hydrodynamics surrounding the platform captured at a resolution of 0.08 × 0.08°
- Tides, winds and atmospheric pressure captured at a resolution of 0.25 × 0.25°
- Wind data computed as 1-hour average of the effective wind at an altitude of 10 m



Modified from Purkis et al., 2019

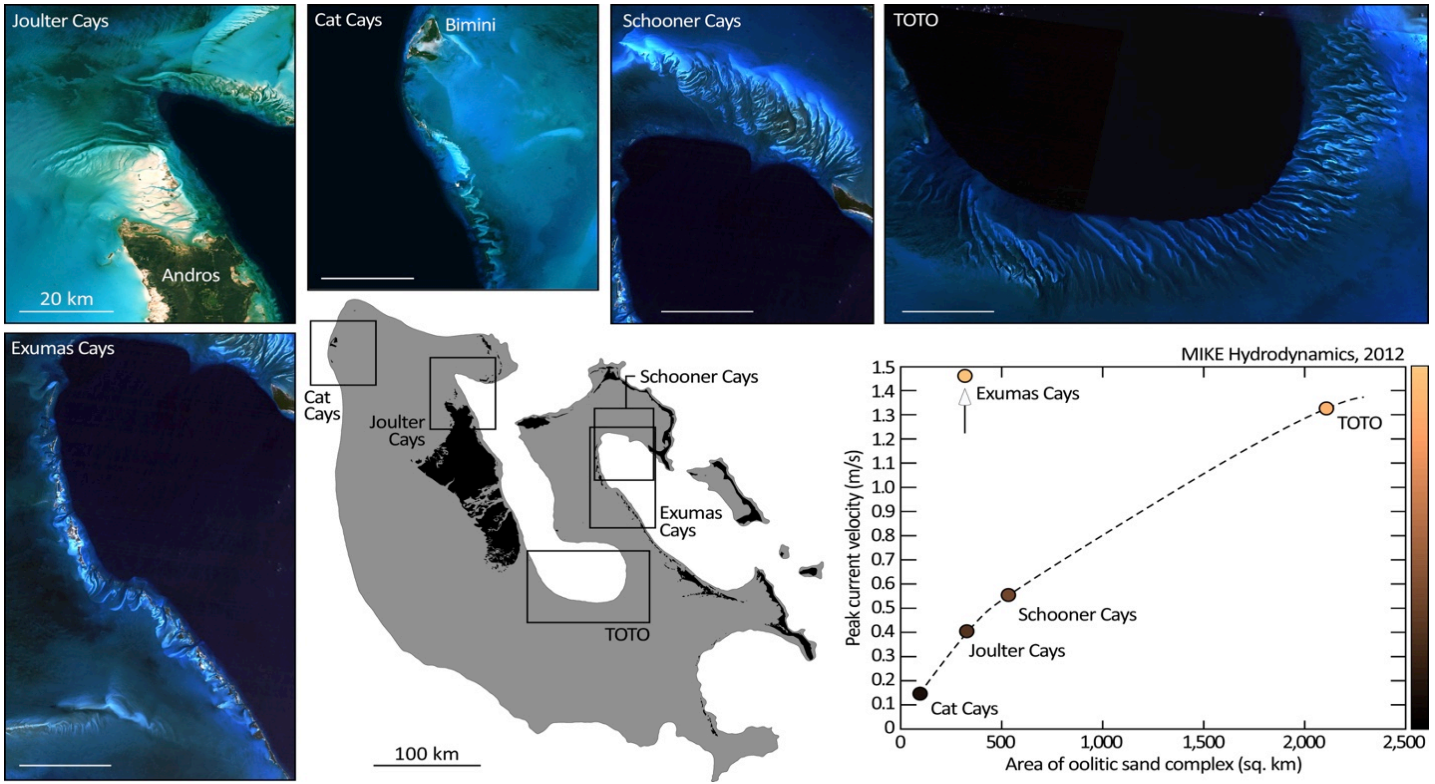
Hydrodynamic Flow and Ooid Sand Bodies



Modified from Purkis et al., 2019

Current intensity and direction from hydrodynamic models suggests nature of currents that sculpt sand body and sand bar patterns

Ooid Sand Body Size vs Current Velocity



Modified from Purkis et al., 2019

Predictive relationship from modeling in that doubling the peak current velocity increases the area of the sand body by a factor of three

Ooids as Archives of Past Conditions

- Ooids **are a key environmental indicator** of high-energy depositional conditions ✔

- Ooid grain size, sand body size and morphology **relate to current strength** - extracting the paleophysical energy record is possible and aspects of sand body morphology (bar height, shape and orientation; channel depth and orientation; sand body width) are predictable ✔

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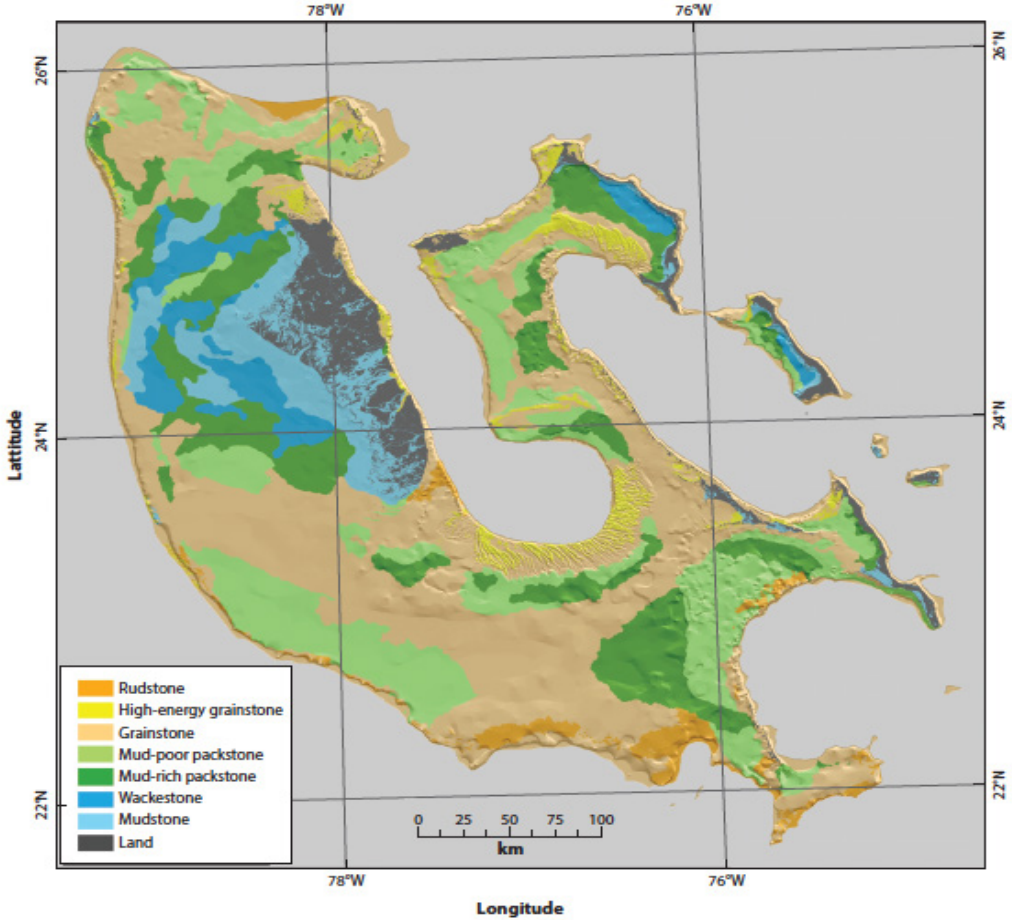

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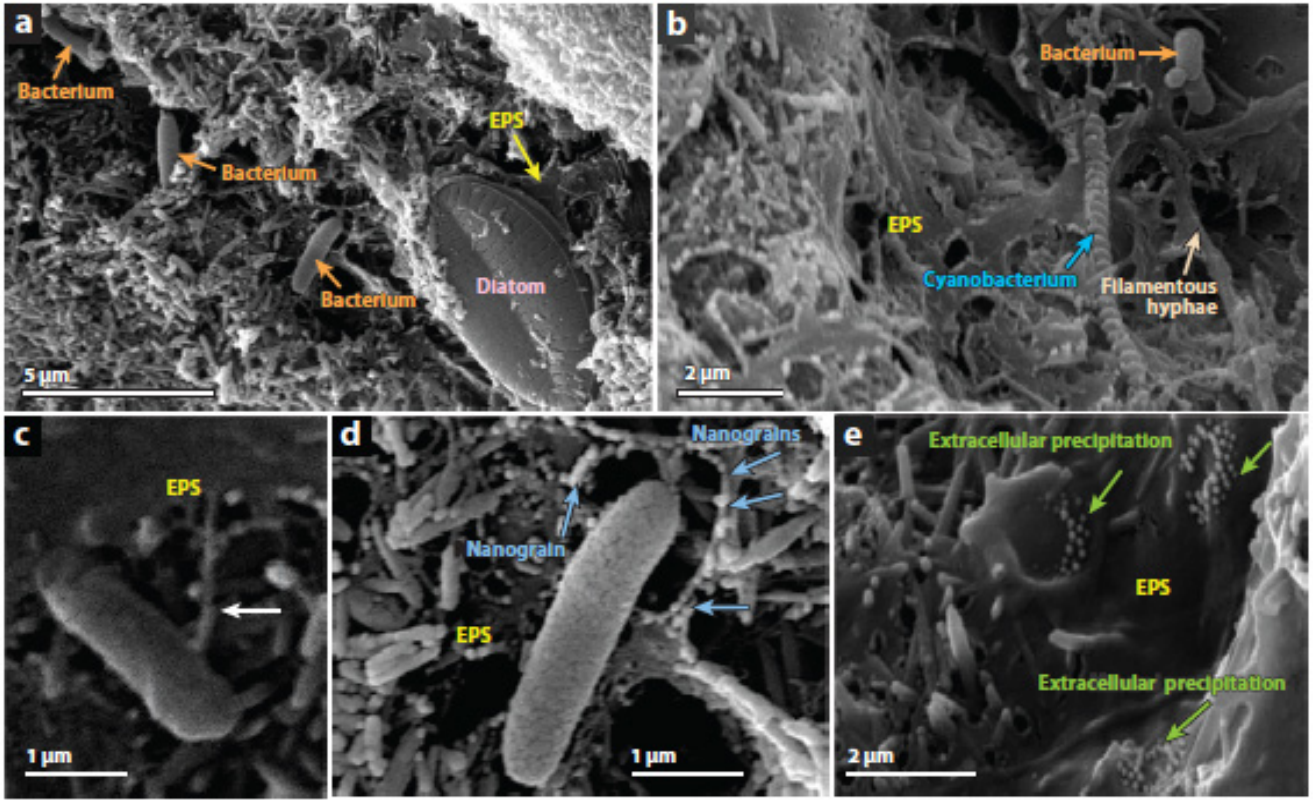
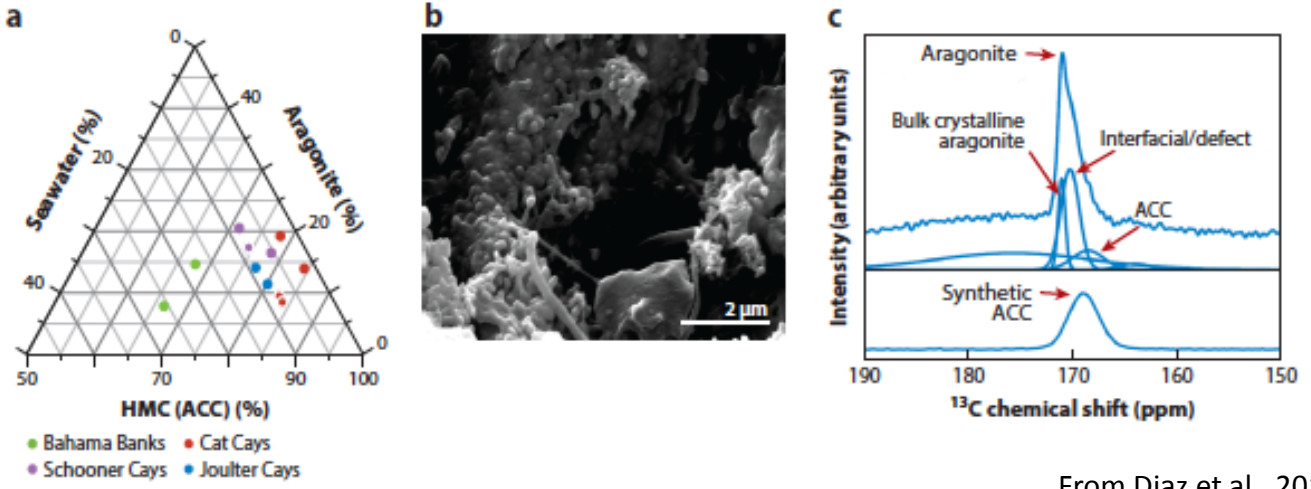
Microbial Communities in Ooids



From Diaz et al., 2017

Diverse and well preserved viable microbial assemblages with evidence of biogenic signatures intrinsically related to organomineralization

Geochemical Signature, Nanograin Structures, and NMR Spectrum of Ooids

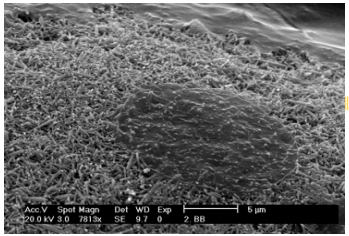


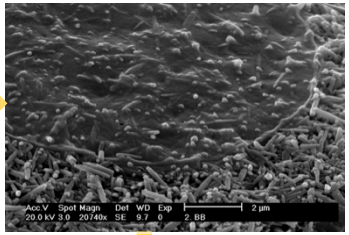
From Diaz et al., 2015, 2017

Leached geochemical signature, SEM, and nuclear NMR spectrum of ooids provides evidence for ACC in ooids and association with organic matter.

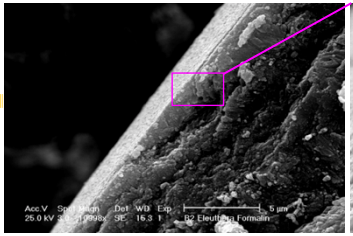
Conceptual Model for Ooid Formation

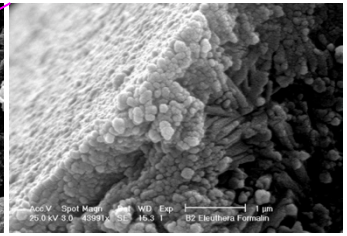
1. EPS colonization in outer cortex



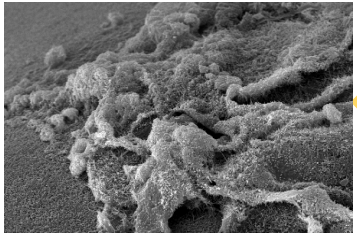


2. ACC development within EPS matrix

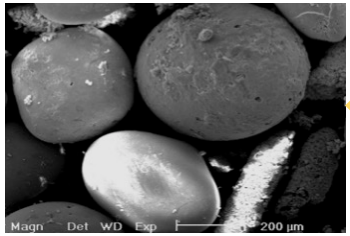




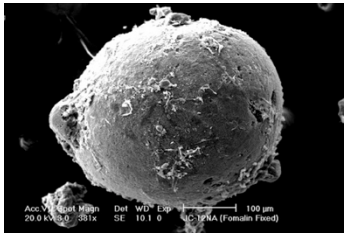
3. ACC forming a thin layer in outer cortex

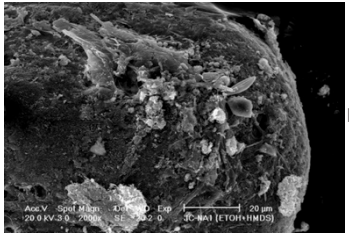


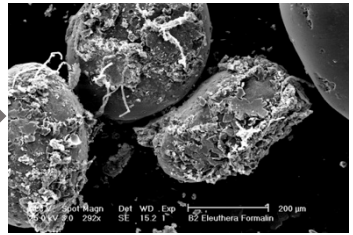
4. ACC crystallization to aragonite leading to formation of a new cortical layer



5. Abrasion/polishing of new $CaCO_3$ precipitates by turbulence







6. Microbial infestation leading to cementation and micritization

Growth Phase
Active Shoals

Biofilm EPS in ooid outer cortices promotes the first stages of CaCO3 precipitation by providing nucleation sites for the formation of a thin layer of ACC nanograins that eventually transitions into aragonite crystal layers

Deterioration Phase
Inactive Sites

From Diaz et al., 2017

Geochemical Imprints in Leachates as Indicators of Ooids Precipitating in Disequilibrium

- **Alkalinity Values** (ca.6.5 to 9.6 mM) higher than theoretical levels (0.2mM)
- Heavy imprints on **$\delta^{13}C$ DIC** (-1.7‰) – recalibration of ACC metastable phase or microbial respiration of photoautotrophic biomass
- **$\delta^{34}S$** of the leachates that are more negative (+17.1 ‰) than $\delta^{34}S$ of CAS (+19.4‰) – imprint of chemolithotrophic oxidation of H_2S
- **Sulfate levels** (1 to 3mM) exceeding theoretical levels (0.001mM) – stoichiometric dissolution of CO_3^-
- Fractionation pattern of **$\delta^{15}N$ and $\delta^{18}O$ of NO_3^-** deviating from external sources of NO_3 – imprint of denitrification and/or ammonium oxidation
- **Nitrogen levels** (0.44 to 0.62 µM) surpassing those of ambient waters (0.03 to 0.1µM)
- Ratios of **S/Ca** (21 to 53 mol mol-1) surpassing those of ambient seawater (ca. 9 mol mol-1)

From Diaz et al., 2015

Other Supporting Data

$\delta^{13}C$ isotopic imprints on ooids that are at variance with the theoretical values for inorganic carbonate precipitation (Andres et al, 2016, Trienekens, 2007)

Sr^{2+} concentrations (5510 ppm) that are below those of Holocene ooids (8,000 to 10,000ppm) (Kahle, 1965)

$\delta^{11}B$ (21.2 to 22.2‰) and **Boron-pH** estimates surpassing modern mean-annual seawater values of the Bahamas (Zhang et al., 2017)

Offsets in the isotopic imprints of $\delta^{18}O$ and $\delta^{13}C$ on unaltered ooid cortices (Duguid et al., 2010)

Ooids are constantly reshaped by biotic and abiotic factors that occur during and after growth, suggesting **cautionary implications for the use of ooids as archives for paleo-environmental** reconstructions

Ooids as Archives of Past Conditions

- Ooids **are a key environmental indicator** of high-energy depositional conditions ✔
- Ooid grain size, sand body size and morphology **relate to current strength** - extracting the paleophysical energy record is possible and aspects of sand body morphology (bar height, shape and orientation; channel depth and orientation; sand body width) are predictable ✔
- Geochemical signature of ooids is not in equilibrium with the seawater in which they form – **caution when interpreting paleochemical record** ?

Key Findings

- Ooids, a key environmental indicator of high-energy depositional conditions, are significant to the evolution of carbonate platforms, shelves and reservoirs of all ages.

- The controlling factor of ooid grain size as well as ooid sand bar and sand body distribution, size, and morphology is the physical energy.

- Biological mechanisms (microbially mediated organomineralization) are very important in the formation of ooids, and one consequence of this is the geochemical signature of ooids is not in equilibrium with the seawater in which they form.

- An important consequence of the dual influence of ooid formation and distribution is that extracting the paleophysical energy record from oolitic deposits is potentially more accurate than doing so for the paleochemical record.

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