The Role of Variable Paleotopography and Upwelling on Deposition of Oligocene Mixed Heterozoan-Large Benthic Foraminifera-Coral Sequences, Jamaica*

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Abstract

Late Oligocene-Miocene carbonate exposures along a 70 km transect from the south to north coast of Jamaica illustrate the importance of paleotopography and regional upwelling on the nature and distribution of facies and sequence stratigraphic architecture. In contrast to previous studies interpreting a broad S-N dipping ramp, paleotopographic reconstruction indicates the Cretaceous to Eocene substrate had variable paleotopography and that the Late Oligocene-Miocene carbonates were deposited on the flanks of substrate highs and dip up to a documented 8° in various directions away from highs. Facies are dominated by heterozoan (molluscs, echinoderm, bryozoans) and large benthic foraminifera (LBF) packstones and grainstones. Coral boundstones are locally present, occurring as isolated corals, small mounds and thickets. The only photozoan components in this tropical setting are corals, dominantly those tolerant of turbid- and cooler-water conditions (e.g. *Porites* sp., *Montastraea* sp.) and LBFs, many of which tolerate mesotrophic and cooler water conditions (e.g. *Lepidocyclina*, *Sorites*). The facies composition and stratigraphic architecture reflect adverse photic zone conditions, likely due to the well-documented upwelling in the Caribbean during this time. The grainy nature of the facies and variable paleotopography made the systems susceptible to reworking and transport. In general, substrate slopes >5° promoted bypass of sediments as sedimentary gravity flows. Substrate slopes <5° generally preserve in-place facies, consisting of heterozoan-LBF packstones grainstones and local in-place corals. Presence of abraded and non-abraded bioclasts, trough crossbedding, in-place *Kuphus* sp. and local corals and stromatolites indicate shallow subtidal environments with intermittent energy. These types of atypical tropical carbonate systems occur throughout the rock record and form significant reservoirs (e.g. Cenozoic reservoirs in the Caribbean and Indo-Pacific). In addition to forming ramps, it is increasingly being recognized that the systems can be composed of transported deposits in relation to paleotopography. This study provides insight and quantitative data on substrate slope gradients that promote in-place preservation of shallow-water facies, or bypass to deeper water. The results provide some predictive capability for understanding the nature of facies, facies distribution, and reservoir character in similar subsurface systems with variable paleotopography.
This map shows the paleogeography during the early-middle Oligocene (red & yellow is the land areas, light blue is shallow water and dark blue is deeper water). The Caribbean was in a tropical setting during the Oligocene and connected with the Pacific Ocean. Many studies have shown that this connection resulted in regional upwelling in the Caribbean during the Oligocene-Miocene, which affected shallow-water marine environments.

REGIONAL SETTING

STUDY AREA LOCATION

This study focuses on Oligocene carbonate strata of the White Limestone Group in Jamaica, which are well-exposed (100-200 m laterally, 40-60 m vertically at localities) along 50 km of “Jamaica North-South Highway” (JNSH) and in adjacent quarries on the eastern and central part of Clarendon Block.

The light blue color represents the Oligocene-Miocene limestone deposits known as the White Limestone Group, the focus of this study.

Simplified geologic map of Jamaica (modified from Mitchell, 2016) (dark blue & red colors represent Cretaceous volcanics and yellow are Eocene carbonates, which represent the substrate paleotopography. Reconstruction indicates those where substrate highs during the Oligocene.

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PURPOSE

• To develop sequence stratigraphic and sedimentologic models and determine controls on deposition of Oligocene mixed Heterozoan-Large Benthic Foraminifera-Coral Sequences.

• To demonstrate that relative sea level and variable substrate paleotopography were dominant controls on stratal geometries and facies distributions.

• To evaluate if relative sea level rises and falls resulted in distinct heterozoan-photozoan compositional patterns.

• To evaluate other potential controls on facies compositions and distributions, including paleo-oceanographic conditions, such as documented upwelling in the Caribbean region during that time.

SIGNIFICANCE & IMPLICATIONS

• Atypical tropical shallow-water carbonate systems composed of heterozoans but just some photozoan components (only those that tolerate adverse photic zone conditions) are more important than commonly thought and form significant petroleum reservoirs.

• In addition to forming ramps, systems can be composed of transported deposits in relation to steep paleotopography, and form deep water reservoirs similar to silicilastic deep water systems.

• This study provides insight and quantitative data on substrate slope gradients that promote in-place preservation of shallow-water facies, or bypass to deeper water. Many of the facies in the system show favorable reservoir characteristics.

• Understanding the sea-level history in relation to paleotopography provides a predictive capability for facies types, distributions, stratal geometries, and reservoir character in similar subsurface systems with variable paleotopography.
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GEOLOGIC SETTING

Fault depositional sequences (DS1, DS2, DS3 & DS4) that dip / g19/g16/g219/g3/g68/g90/g68/g92/g3/g73/g85/g82/g80/g3/g83/g68/g79/g72/g82/g75/g76/g74/g75/g86/g17, bivalves; LBF Cretaceous DS3 paleotopographic / g20/g16/g21/g219/g3/g71/g76/g83 scale. The reconstruction indicates that the Cretaceous-Eocene substrate had variable paleotopography and that the Oligocene Carbonates were deposited on the flanks of substrate highs, showing proximal-distal lateral facies changes in different directions, away from the highs. Outcrops show various patterns of heterozoans and photozoans in abundance. Photozoans consist of corals tolerant of turbid- and large-benthic-foraminifera (e.g. Lepidocyclina, Miliolidae, Poritiidae and Amphisteginidae). BH AREA

DS1 & DS2 are locally exposed in FP area only. DS1 consists entirely of LBF-rich packstone & grainstone with in-place Kuphus sp. in situ Lucinid bivalve in situ Kuphus sp. in situ Kuphus. DS2 consists entirely of Lepidocyclina-rich rudstone-packstone facies. Facies in DS1 & DS2 show intense bioturbation, mixtures of abraded and non-abraded bioclasts and local in-place Kuphus open-marine, subtidal environment.

FP & PXP AREAS

Tectonic and depositional control led to fining upward cycles composed of mollusk, red algae (i.e. rhodoliths) LBF rudstone-packstone with localized in-place Kuphus. Facies are intensely bioturbated and bioclastic. Mixing LBF is suggested to be due to intermittent energy, likely 10 m water depth. DS4 deposits in FP area consist of interbedded LBF-rich packstone & grainstone with localized in-place Kuphus. Facies are intensely bioturbated and bioclastic. Mixing LBF is suggested to be due to intermittent energy, likely 10 m water depth.

FACIES DESCRIPTIONS & PRELIMINARY INTERPRETATIONS

LBF-rich Packstone-Grainstone

Leptocyclina (C), Miliolidae (C), Amphoragnosta (C), mollusks (e.g. Kuphus), red algae (R), Echinoids (C), Bryozoa (R), Coral (frag.) (R), mixtures of abraded and non-abraded bioclasts; EOD: In-situ, low-medium energy, subtidal environment likely <10 meters water depth.

Miliolidae-rich Packstone

Leptocyclina (C), Miliolidae (C), Amphoragnosta (C), mollusks (e.g. Kuphus), red algae (R), Echinoids (C), Bryozoa (R), Coral (frag.) (R), mixtures of abraded and non-abraded bioclasts; EOD: In-situ, medium energy, shallow-open marine, subtidal environment likely >10 meters water depth.

Red Algae Packstone

Red algae (A), Leptocyclina (C), Miliolidae (R), Amphoragnosta (R), mollusks (e.g. Striolaria), Echinoids (C), Bryozoa (R), Coral (frag.) (R), mixtures of abraded and non-abraded bioclasts; EOD: In-situ, high energy, shallow-open marine, subtidal environment likely <10 meters water depth.

Coral-rich Boundstone-Packstone

Coral (frag.) (A), Porites sp., Metridiidae (A), Leptocyclina (C), Miliolidae (R), Amphoragnosta (R), mollusks (e.g. Kuphus), red algae (R), Echinoids (C), Bryozoa (R), mixtures of abraded and non-abraded bioclasts; EOD: In-situ, low-medium energy, shallow-open marine, subtidal environment, above FWMB likely >20m water depth.

Mollusk Washout-Packstone

Leptocyclina (C), Porites sp., Leptocyclina (A), Spondylus (R), Miliolidae (C), Amphoragnosta (R), Kuphus sp. in situ Kuphus, Lucinid bivalve in situ Kuphus; Matrix supported, very fine grain size; EOD: Sediment gravity flows (calciturbidites and debrites).

Lepidocyclina-rich Packstone-Rudstone

Coral frag.) (R), Lepidocyclina (C), Miliolidae (R), Amphoragnosta (R), mollusks (e.g. Strombus), Echinoids (C), Bryozoa (R), Coral (frag.) (R), mixtures of abraded and non-abraded bioclasts; EOD: In-situ, high-medium energy, shallow-open marine, subtidal environment likely <20 meters water depth.

Calciturbidite

Coral (frag.) (A), Lepidocyclina (C), Miliolidae (R), Amphoragnosta (R), mollusks (e.g. Strombus), Echinoids (C), Bryozoa (R), Coral (frag.) (R), mixtures of abraded and non-abraded bioclasts; EOD: In-situ, low-medium energy, shallow-open marine, subtidal environment likely <20 meters water depth.

Fine-grained Packstone-Grainstone

Coral frag.) (R), Lepidocyclina (C), Miliolidae (R), Amphoragnosta (R), mollusks (e.g. Strombus), Echinoids (C), Bryozoa (R), Matrix supported, very fine grain size; EOD: Sediment gravity flows (calciturbidites and debrites).

Coral Rudstone-Floatstone

Coral frag.) (A), Lepidocyclina (C), Miliolidae (R), Amphoragnosta (R), mollusks (e.g. Strombus), Echinoids (C), Bryozoa (R), mixtures of abraded and non-abraded bioclasts; EOD: In-situ, low-medium energy, shallow-open marine, subtidal environment, above FWMB likely >20m water depth.
SUMMARY OF RESULTS

Road cut and quarry exposures of the White Limestone Group in a 1,500 km² area of Jamaica were studied to develop a sequence stratigraphic framework and understand the roles of sea level, paleotopography, and paleoceanographic on deposition.

Recently acquired Sr isotope data for age dating identify four 3rd-order Oligocene carbonate sequences that developed on the flanks of substrate paleohighs. Previous studies interpreted a broad, regional dipping S-N ramp, the results of this study indicate a different setting with variable substrate paleotopography that influenced stratal geometries, facies composition, and facies distribution in the carbonate systems.

Although the setting was in the tropics, the sequences are dominated by grainy shallow-water carbonates composed of LBF’s and heterozoans, and some corals that form localized buildups. These characteristics and lack of other components (green algae, submarine cement, ooids, abundant mud) typically associated with tropical shallow-water systems suggest non-optimal photic zone conditions, likely associated with regional upwelling in the Caribbean.

Sea level interacting with variable substrate paleotopography exerted a strong control on preservation of shallow water facies, or bypass of shallow-water facies to deeper water environments.

When sea level intersected gentle substrate slopes (0-5'), in-place shallow-water facies and lateral facies transitions were preserved. These include sea-grass environments (1-10 m deep) characterized by in situ Clypeaster sp., Strombus sp.; coral buildup environments (1-20 m deep) characterized by Porites sp., Montastraea sp., high energy environments (1-20 m deep) characterized by x-beds, highly abraded bioglast; low-intermittent energy environments characterized by abundant bioturbation and mixtures of abraded and non-abraded bioclasts.

When sea-level intersected steep substrate slopes (e.g. 20'), shallow water facies were bypassed downslope as sediment gravity flows (turbidites, debrirates) and deposited in deeper water environments where they are interbedded with fine-grained packstone-grainstone facies.

Alternations of in-place shallow water facies and sedimentary gravity flows in an area likely reflect sea level variably intersecting gentle and steep substrate slopes during relative rises and falls. Areas where sea level continues to intersect gently dipping substrates during the relative rises and falls appear to record those fluctuations with lateral shifts and alternations of in-place shallow and deeper subtidal deposits.

PRELIMINARY INTERPRETATION AND DISCUSSION

Near the PxP area, sea level may have variously intersected gentle and steeper substrate slopes during rises and falls. Steeper substrate slopes promote bypass of shallow-water material downslope. In-place facies could reflect lower positions of sea level and intersection of gentle substrate slopes.

Substrate paleo high near FP area shows approx. 5-6’ slope and substrate paleo high near PxP area has 1-2’ slope that changes abruptly to the west to 20’ slope.

DS3 at FP and PxP preserve in-place shallow-water depositional environments. This suggests that during DS3 time sea level near FP and PxP was intersecting gentle substrate slopes allowing preservation of in-place facies.

Basal DS4 at FP and PxP areas preserve in-place shallow-water depositional environments. This suggests that during this time sea level near FP and PxP loc. was intersecting gentle substrate slope allowing preservation of in-place facies.

Upper DS4 at FP area preserve in-place shallow-water depositional environments. Upper DS4 at PxP area shows in-place facies interbedded with sedimentary gravity flows deposits. This relationship could reflect sea-level rises/falls intersecting variable substrate slopes.

In this scenario, during Upper DS4 time sea level was intersecting gentle substrate slopes near FP during both rises and falls allowing preservation of in-place facies.

Near the PxP area, sea level may have variously intersected gentle and steeper substrate slopes during rises and falls. Steeper substrate slopes promote bypass of shallow-water material downslope. In-place facies could reflect lower positions of sea level and intersection of gentle substrate slopes.