

# **PS 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.

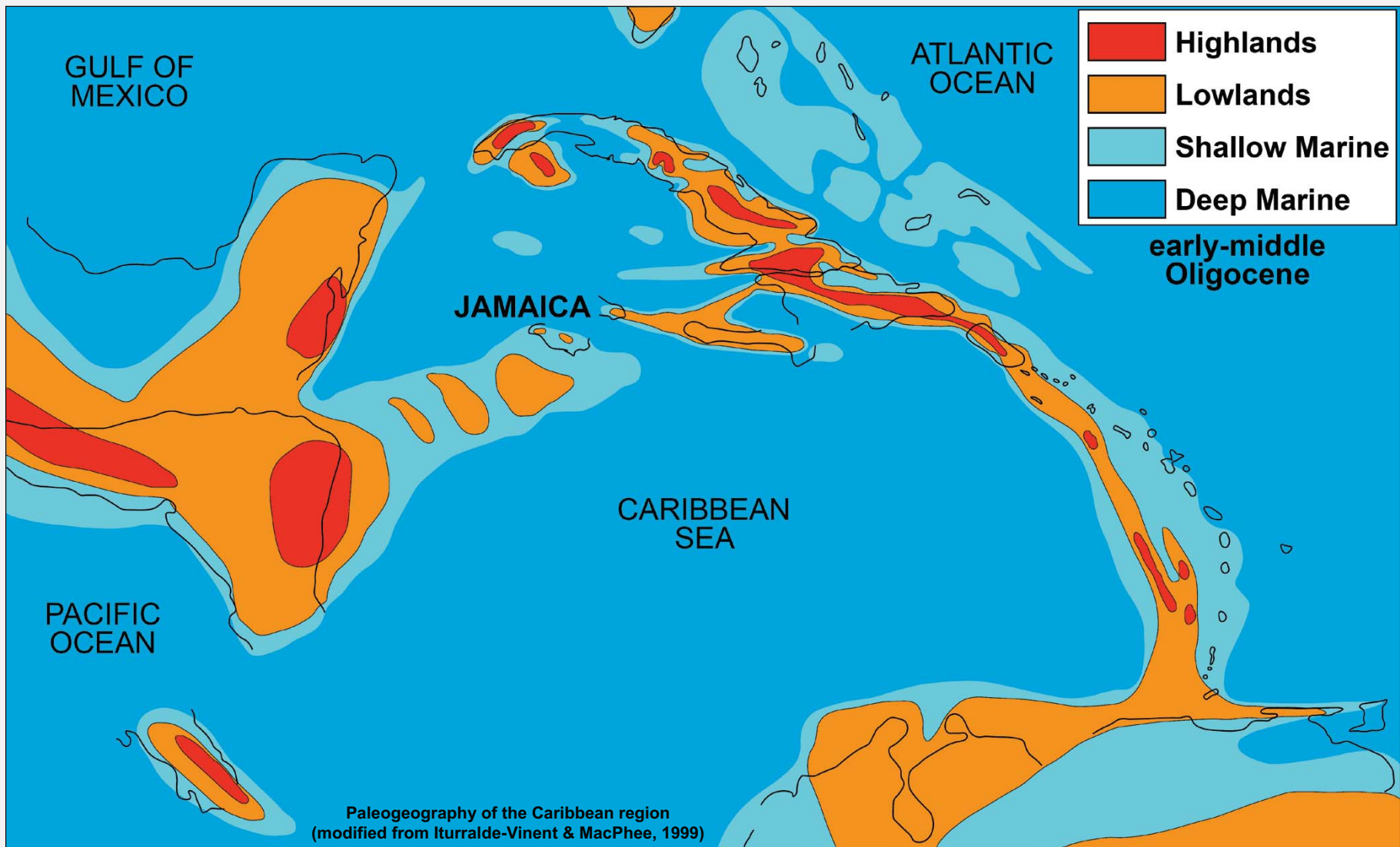
## PURPOSE

- 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 siliciclastic 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.

## REGIONAL SETTING

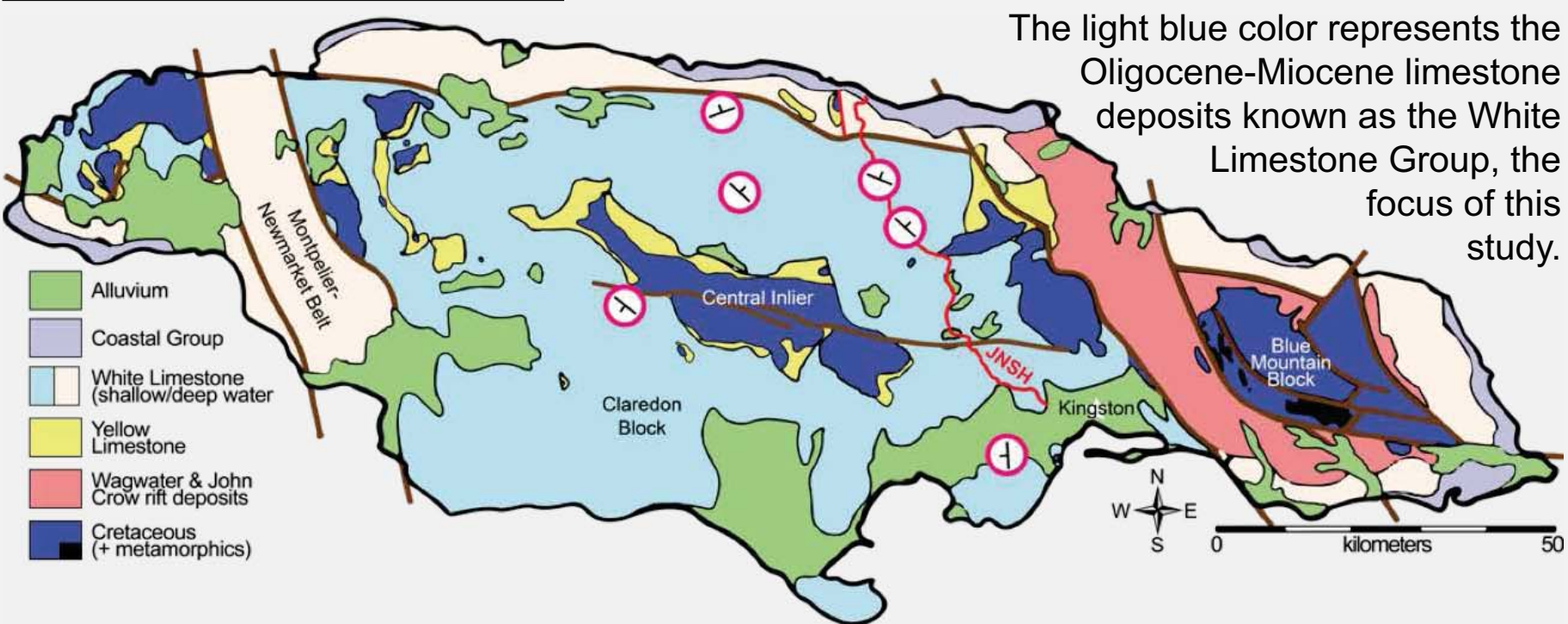


This map shows the paleogeography during the early-middle Oligocene (red & yellow is the land areas, light blue is shallow water and dark blue is deeper water). The Caribbean was in a tropical setting during the Oligocene and connected with the Pacific Ocean. Many studies have shown that this connection resulted in regional upwelling in the Caribbean during the Oligocene-Miocene, which affected shallow-water marine environments.

## 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.



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.

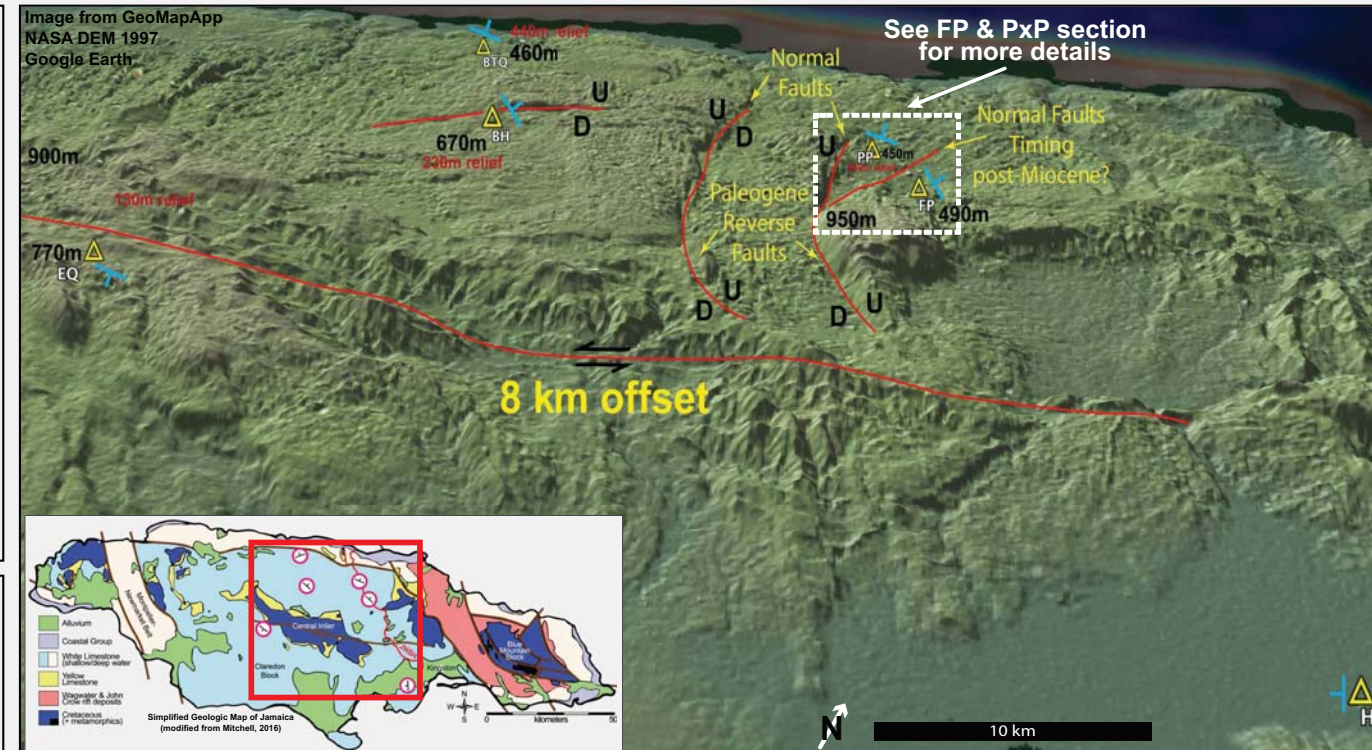
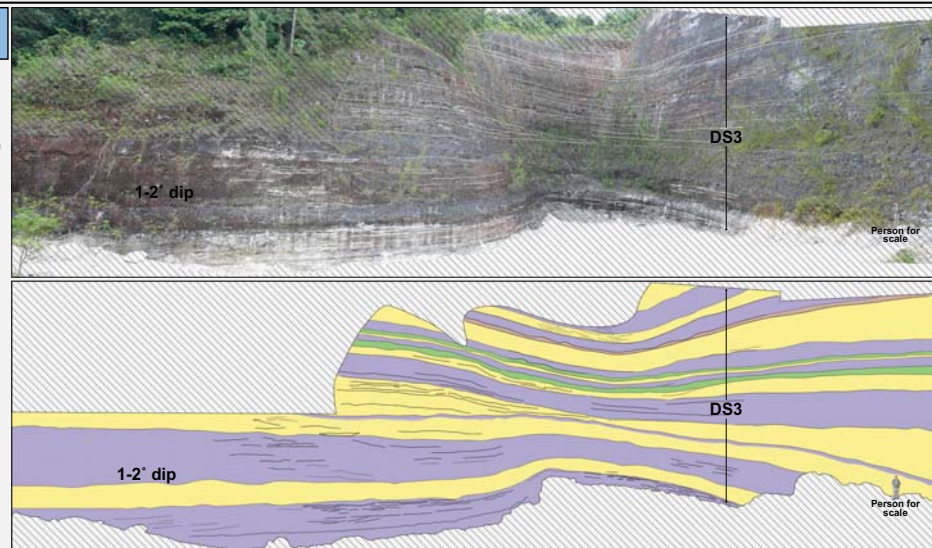
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## BTQ AREA

The Browns Town quarry area consists of a 44-meter thick partial sequence (DS3 - ca. 31.42-30.92 Ma) that dips approximately 1-2° away from paleohighs. This sequence is composed of mollusk, whole echinoids (i.e. *Clypeaster* sp.) and LBF packstone-grainstone alternating with wackestone- packstone facies. The presence of unabraded to slightly abraded skeletal grains and low-angle trough cross bedding suggest low intermittent energy, shallow open-marine, possibly sea-grass environment indicated by the well-preserved echinoids.



## GEOLOGIC SETTING

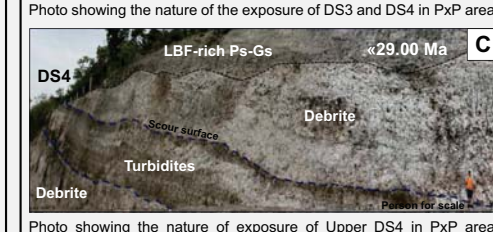
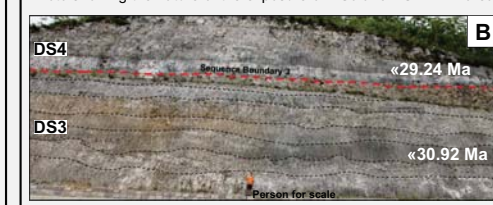
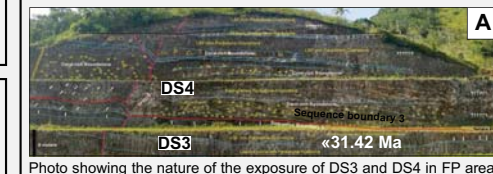
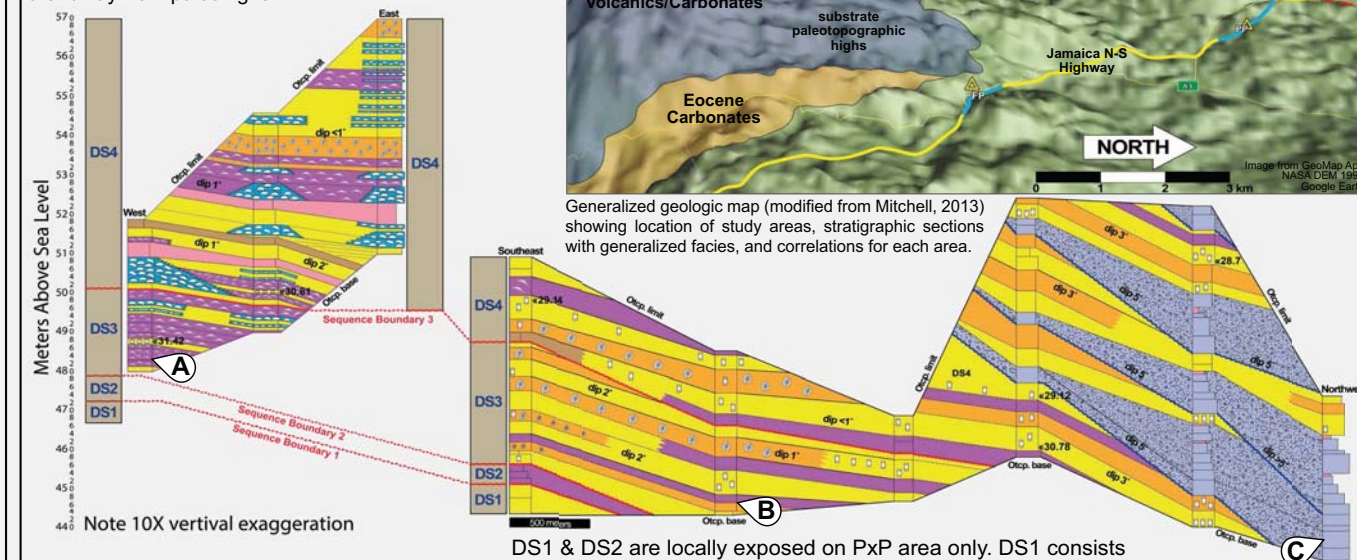
Post-depositional meter-scale faults occur throughout the field area. A variety of diagnostic way-up indicators (e.g. *Kuphus* sp. bivalves; *Montastrea* sp. corals in growth position; and gravity geopotals), and other useful way-up indicators (e.g. whole echinoderms oriented along surfaces) occur throughout the study area and allow reconstruction of paleotopography.

The reconstruction indicates that the Cretaceous-Eocene substrate had variable paleotopography and that the Oligocene heterozoan-LBF-coral sequences, dipping 0-8°, were deposited on the flanks of substrate highs, and show 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 cool-water conditions (e.g. *Porites* sp., *Montastrea* sp. and *Solenastrea* sp.) and large-benthic-foraminifera (e.g. *Lepidocylinids*, *Miliolids*, *Peneroplid* and *Amphisorites*).

## FP & PxP AREAS

The Faiths Pen & Phoenix Park areas show four major depositional sequences (DS1, DS2, DS3 & DS4) that dip 0-5° away from paleohighs.



DS1 & DS2 are locally exposed on PxP area only. DS1 consists entirely of LBF-rich packstone & grainstone with in-place *Kuphus*. DS2 consists entirely of *Lepidocyclus*-rich rudstone-packstone facies. Facies in DS1 & DS2 show intense bioturbation, mixtures of abraded and non-abraded bioclasts and local in-place *Kuphus*. This indicates a low to medium energy, below fair-weather wave base environment, 20-40 m w.d. The sequences are capped by a sharp, erosional subaerial exposure surface reflecting a relative fall in sea level.

DS3 in FP area consists of LBF-rich rudstone, packstone and grainstone with in-place *Kuphus* interbedded with coral-rich boundstone that occur as isolated coral thickets. Coarse-grained bioclasts with high to moderate abrasion, in-place *Porites* coral buildups and abundant in-place *Kuphus* support a very shallow-water environment, 1-10 m w.d. DS3 is capped by an erosional subaerial exposure surface reflecting a relative fall in sea level. DS3 deposits in PxP area consist of interbedded LBF-rich packstone-grainstones with localized in-place *Kuphus*. Facies are intensely bioturbated and bioclasts are moderately abraded suggesting a low to intermittent energy, below FWWB, 20-40 m w.d.

DS4 deposits in FP area consist of interbedded in-place grainy facies with *Kuphus* and abundant coral-rich boundstones forming isolated buildups. Facies with isolated coral buildups, high-medium abraded bioclast indicate a very shallow-water, high to moderate energy environment, 1-10 m w.d. DS4 deposits in PxP area consist of interbedded in-place LBF-rich packstone & grainstone with localized *Kuphus*. Low to intermittent energy environment below FWWB is suggested by intense bioturbation and abundant whole mollusks and LBF. At four intervals, these facies are erosionally truncated and overlain by coral rudstone-floatstone interpreted as SGF's.

## FACIES DESCRIPTIONS & PRELIMINARY INTERPRETATIONS

### LBF-rich Packstone-Grainstone

*Lepidocyclus* (C), *Miliolid* (C), *Amphistegina* (C), mollusks (e.g. *Kuphus*) (C), red algae (R), Echinoids (C), Bryozoans (R), Coral (frag.) (R); mixtures of abraded and non-abraded bioclasts; massive locally bedded; EOD: In-situ, low-medium energy, subtidal environment likely <10 meters water depth.

### Miliolid-rich Packstone

*Lepidocyclus* (C), *Miliolid* (A), *Amphistegina* (R) mollusks (*Kuphus*) (C), red algae (R), Echinoids (C), Bryozoans (R) Coral (frag.) (R); mixtures of abraded and non-abraded bioclasts; EOD: In situ, Intermittent energy, shallow open-marine, subtidal environment likely <10 m water depth.

### Red Algae Packstone

Red algae (A), *Lepidocyclus* (C), *Miliolid* (R), *Amphistegina* (R) mollusks (e.g. *Strombus*) (R), Echinoids (C), Bryozoans (R), Coral (frag.) (R); mixtures of abraded and non-abraded bioclasts; EOD: In situ, Intermittent energy, shallow open-marine, subtidal environment likely <10 m water depth.

### Coral-rich Boundstone-Packstone

Coral (*In situ*) (*Porites* sp., *Montastrea* sp.,) (A), *Lepidocyclus* (C), *Miliolid* (R), *Amphistegina* (R), mollusks (C), red algae (R), Echinoids (C), Bryozoans (R); mixtures of abraded and non-abraded bioclasts; EOD: In-situ, med-high energy, subtidal environment, above FWWB likely <20 m water depth.

### Mollusk Wackestone-Packstone

Mollusks (Gastropods; e.g. *Strombus*) (A), *Lepidocyclus* (C), *Miliolid* (R), *Amphistegina* (R), Red algae (R), Echinoids (e.g. *Clypeaster*) (C), Bryozoans (R), Coral (frag.) (R); EOD: In situ, low energy, subtidal environments likely associated with seagrass (<20 m w.d.).

### Lepidocyclus-rich Packstone-Rudstone

*Lepidocyclus* (A), *Miliolid* (C), *Amphistegina* (A), mollusks (e.g. *Kuphus*) (C), red algae (R), Echinoids (C), Bryozoans (R), Coral (frag.) (R); mixtures of abraded and non-abraded bioclasts; massive locally bedded; EOD: In-situ, low-medium energy, subtidal environment likely <10 meters water depth.

### Fine-grained Packstone-Grainstone

Coral (frag.) (R), *Lepidocyclus* (C), *Miliolid* (R), *Amphistegina* (R), mollusks (C), Red algae (R), Echinoids (R), Bryozoans (R); Matrix supported, very fine grain size; EOD: Sediment gravity flows (calciturbidites and debrites).

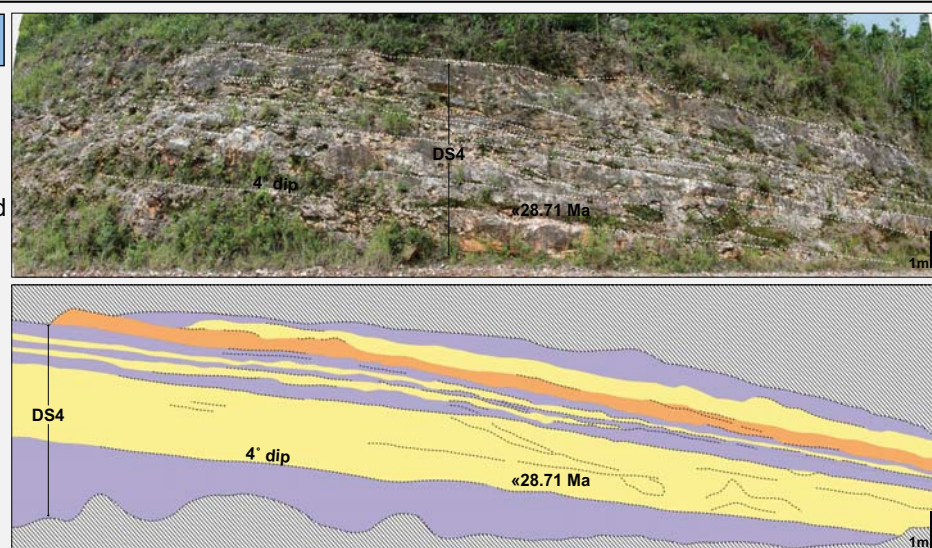
### Coral Rudstone-Floatstone

Coral (frag.) (A), *Lepidocyclus* (C), *Miliolid* (R), *Amphistegina* (R), mollusks (C), Red algae (C), Echinoids (C), Bryozoans (R); Matrix supported with clasts up to 10's of cm size; EOD: Sediment gravity flows (calciturbidites and debrites).

Key: (A) abundant, (C) common, (R) rare

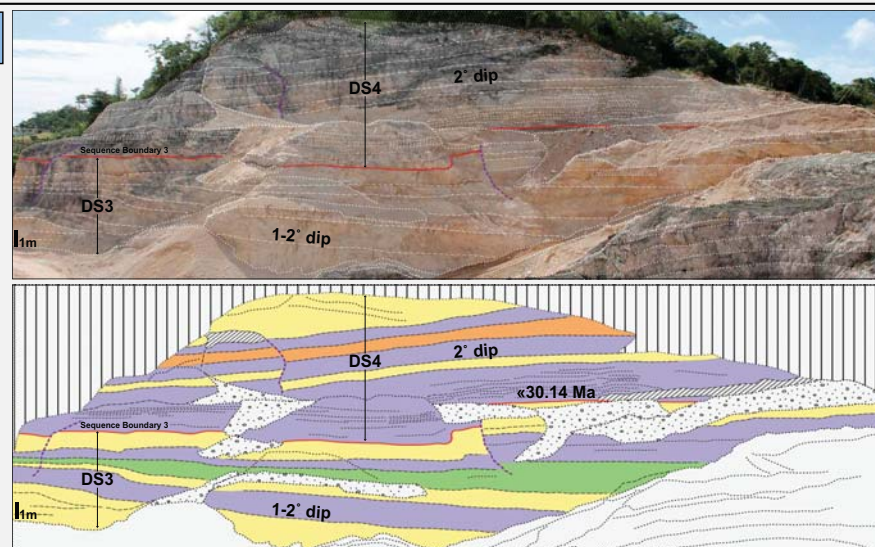
## BH AREA

The Bauxite Hole area shows a 26-meter thick partial sequence (DS4 - ca. 28.71 Ma) dipping 4-5° away from paleohighs. This sequence is composed of mollusk and LBF- dominated packstone-grainstone with bioturbation and local crossbedding, and in-place *Kuphus* sp. bivalves indicating a shallow open-marine, subtidal environment.



## EQ AREA

The Evans quarry area shows two major depositional sequences (DS3 and DS4 - ca. 30.14 Ma) that dip 0-1° away from paleohighs. DS4 consists of mollusk, red algae and LBF packstone-grainstone facies interpreted as shallow open-marine, subtidal deposits and is capped by a sharp, erosional subaerial exposure surface (SB). DS4 consists of mollusk, red algae and LBF packstone-grainstone facies. The presence of moderately abraded skeletal grains and low-angle trough cross bedding suggest a low-medium energy, shallow open-marine, subtidal deposits. The upper contact of DS4 is not exposed.



## HQ AREA



The Hellshire quarry area shows a 31-meter thick partial sequence (DS? - not yet dated) dipping 6 degrees to the west. The sequence consists of five fining upward cycles composed of mollusk, red algae (i.e. rhodoliths) LBF rudstone- packstone and fine-grained packstone-grainstone facies. Soft sediment deformation, normally graded beds and scoured surfaces indicate that these are sedimentary gravity flow deposits.

## PRELIMINARY INTERPRETATION AND DISCUSSION

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.

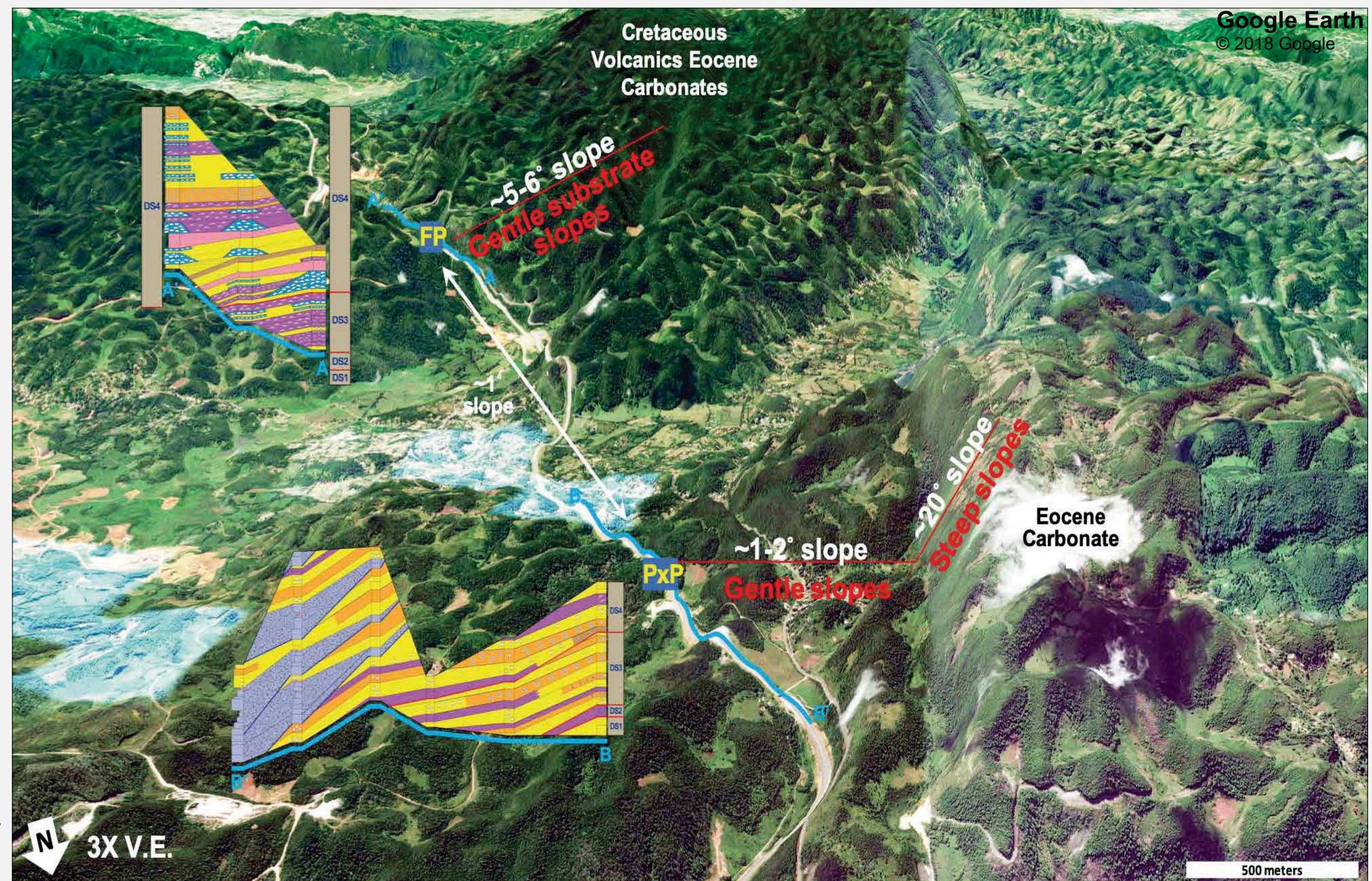
Basal DS4 at FP and PxP areas preserve in-place shallow-water depositional environments.

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.



## SUMMARY OF RESULTS

Road cut and quarry exposures of the White Limestone Group in a 1,500 km<sup>2</sup> 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 3<sup>rd</sup>-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, debrites) 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.