[PS]Depositional and Reservoir Character of Mixed Heterozoan-Large Benthic Foraminifera-Siliciclastic Sequences, Middle Miocene, Dominican Republic*

Elson E. Core[1,2], and Evan K. Franseen[1,2]

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Abstract

Five middle Miocene 4th- to 3rd-order mixed heterozoan-large benthic foraminifera (LBF)-siliciclastic sequences (DS) developed in response to relative sea-level fluctuations interacting with variable substrate paleotopography. Each sequence is capped by evidence of subaerial exposure (SB), including local paleosols, that evidence relative sea-level falls. The sequences (0–11 m thick) are dominated by shallow marine (1–40 m water depth) carbonate packstone-grainstone facies consisting of LBF, molluscs, echinoderms, and bryozoans. This composition reflects the influence of well-documented upwelling in the Caribbean region during this time, which prevented development of photozoan reefs typically formed in tropics. The basal portions of DS1 and DS3 consist of volcaniclastic-carbonate conglomerates and breccias near flanks of volcanic substrate highs that were deposited as debris and grain flows during transgressions. DS2 consist entirely of LBF-bivalve packstone-grainstone. These deposits transition to massive and burrowed LBF packstone-grainstones in lows, away from substrate highs and are in turn overlain by massive and burrowed LBF-bivalve packstones and grainstones. These facies become cross-bedded and contain in-place *Kuphus sp.* bivalves evidencing shallowing upward to the SB that caps each sequence. DS4 and DS5 consist entirely of massive and burrowed LBF-bivalve packstones and grainstones that contain in-place *Kuphus sp.* bivalves in the upper portions (shallowing upward) throughout their lateral extent.

The absence of gravity flows, the horizontal to gently dipping bedding, and lateral facies consistency suggest most of the original paleotopography had been filled by the time of DS4 and DS5 deposition. The facies characteristics and variable substrate paleotopographic setting in this study are similar to Cenozoic systems forming significant reservoirs in the Caribbean and Indo-Pacific region. Results from this study indicate that sea-level interacting with variable volcanic substrate paleotopography were major controls on sequence stratigraphic architecture and facies distribution. Erosion associated with subaerial exposure resulted in significant lateral thickness variability of sequences. Ongoing petrographic study and analysis of porosity and permeability data from samples in the study area is focused on quantifying reservoir character of facies, determining controls on reservoir character, and developing a static reservoir model for the system.

Reference Cited

Ortega-Ariza, D., E.K. Franseen, H. Santos, R.W. Ramírez, and E.E. Core, 2015, Strontium-Isotope Stratigraphy for Oligocene-Miocene Carbonate Systems in Puerto Rico and the Dominican Republic: Implications for Caribbean Processes Affecting Depositional History: The Journal of Geology, v. 123, p. 539-560.

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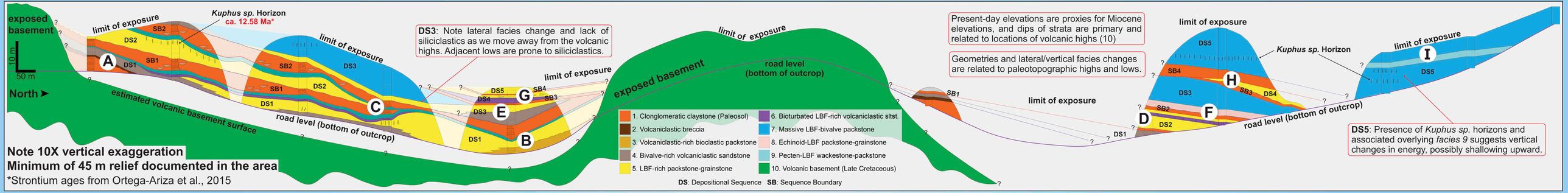


PURPOSE

- To develop a sequence stratigraphic framework and determine controls on deposition of a middle Miocene mixed heterozoan-large benthic foraminifera-siliciclastic system during a time when regional upwelling in the Caribbean affected shallow-water areas.
- To demonstrate that sea-level fluctuations and variable substrate paleotopography were dominant controls on facies distribution, sequence character, and stratal geometries.
- To present initial results on reservoir character of the system, including porosity and permeability data.
- To provide a useful outcrop analog that can be used to improve conceptual models for deposition and reservoir character that can be applied to similar reservoir systems in the Caribbean, Indo-Pacific, and elsewhere around the world.

IMPLICATIONS

- Atypical tropical shallow-water carbonate systems composed of heterozoans and only some photozoan components (only those that tolerate adverse photic zone conditions) are more important than commonly thought, and form important petroleum reservoirs.
- Typical tropic shallow-water carbonate depositional and reservoir models don't apply because these atypical systems are predominantly composed of loose grains and form non-rimmed platforms, ramps, and deep-water deposits composed of sediment gravity flows.
- Models for atypical tropical systems must include additional controls on carbonate production and physical processes that cause reworking and transport; sea-level changes, water energy, and substrate slope angles are important.
- Industry will be able to use outcrop analogs of understudied atypical tropical systems to aid in model development and prediction for similar systems that form reservoirs.

GEOLOGIC SETTING

The Caribbean region during the Miocene was affected by upwelling, which had a major effect on development of shallow-water carbonate systems in this tropical setting.

Adverse photic zone conditions prevented the development of typical photozoan reef systems, and instead, shallow-water ramp systems with complex mixtures of heterozoans and certain photozoans developed.

Predominant photozoan biota are those that tolerate higher nutrients, reduced temperatures, and turbid water. Abundant framework-building organisms, submarine cement and mud are typically lacking.

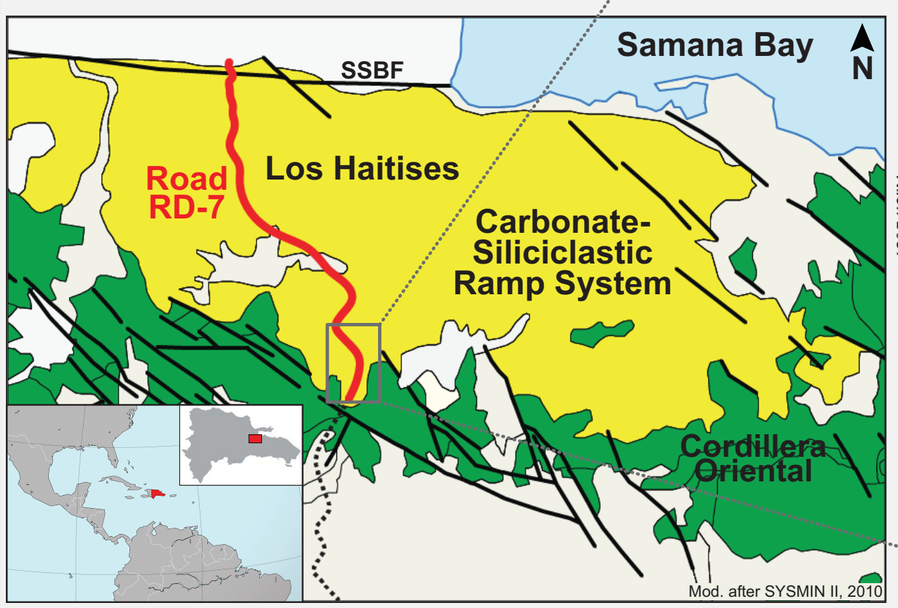
The systems are composed predominantly of loose grains and form ramps and deeper-water systems composed of sediment gravity flows.

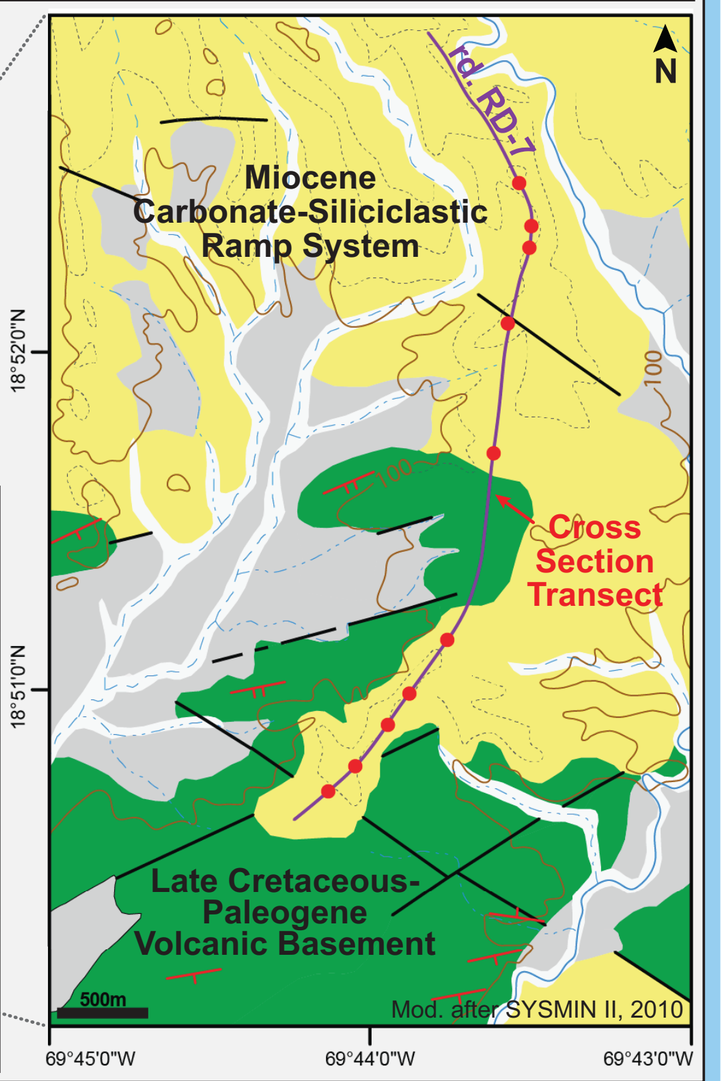
STUDY AREA LOCATION

The study area is located along road RD-7 in the vicinity of Los Haitises, NE Dominican Republic.

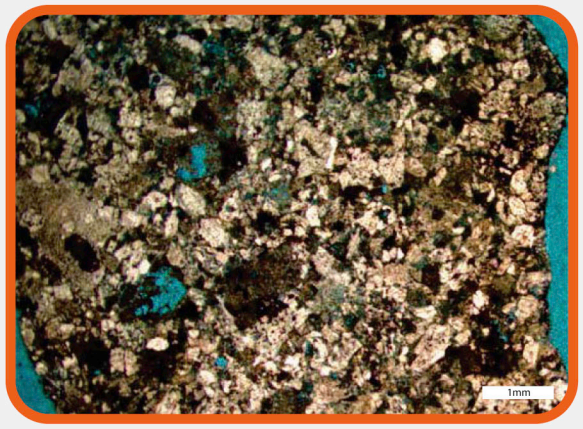
Late Cretaceous volcanic basement (green) forms the substrate upon which the mixed carbonate-siliciclastic strata of this study were deposited.

Subaerial exposure and erosion on the volcanic substrate created variable paleotopography with highs and lows; paleotopography is mostly preserved.

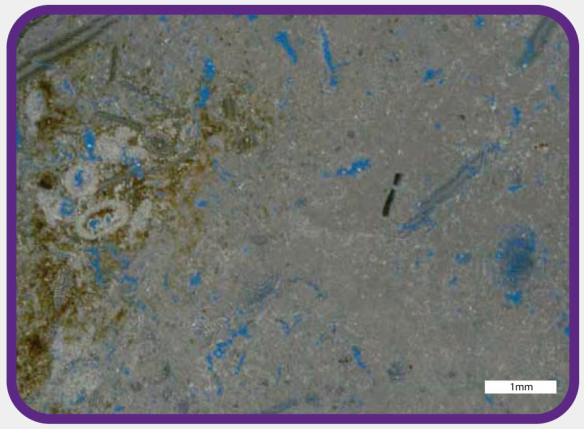




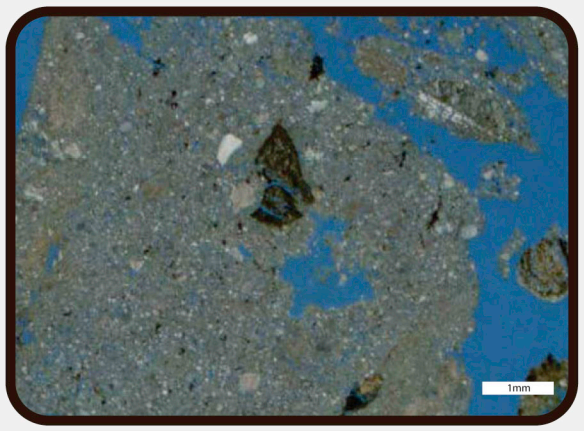
FACIES



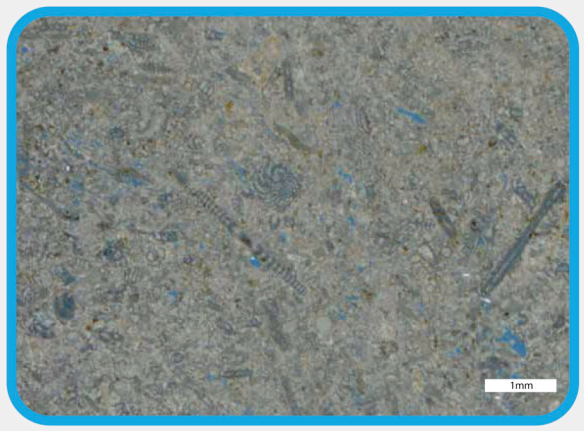
Clonglomeratic claystone (Paleosol)



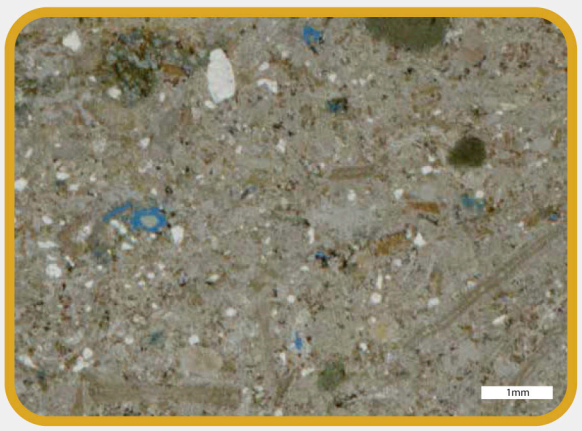
Bioturbated LBF-bivalve-rich volcaniclastic siltstone



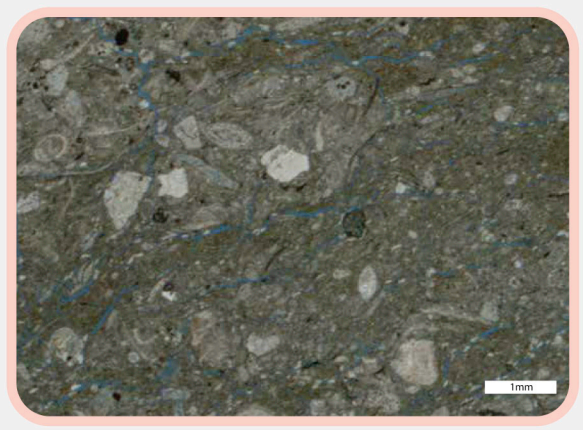
Volcaniclastic breccia (Debris Flow)



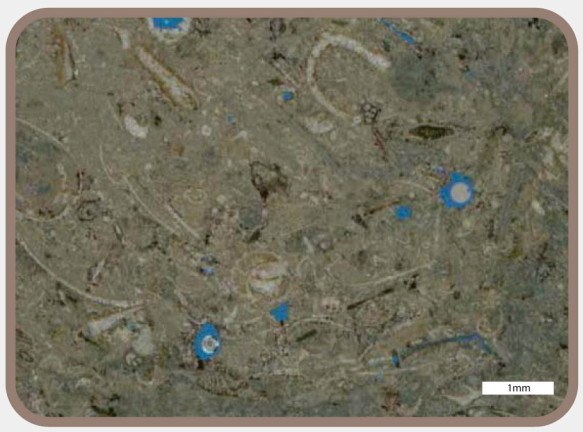
Massive LBF-bivalve packstone



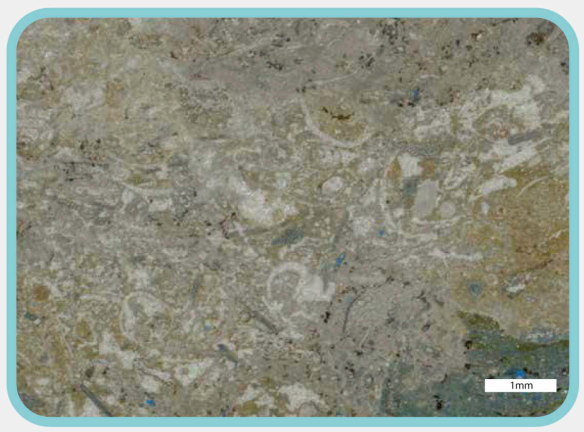
Volcaniclastic-rich bioclastic packstone (Debris Flow)



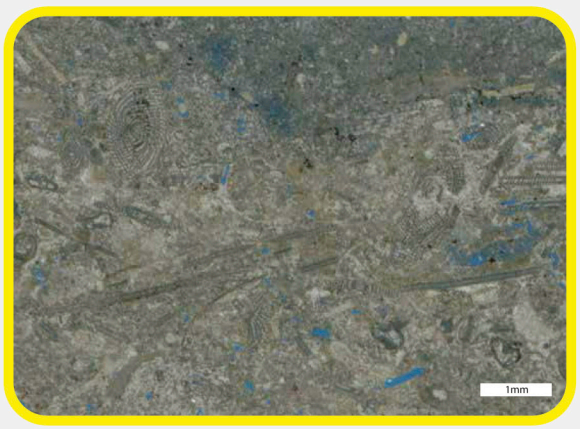
Echinoid-LBF packstone-grainstone



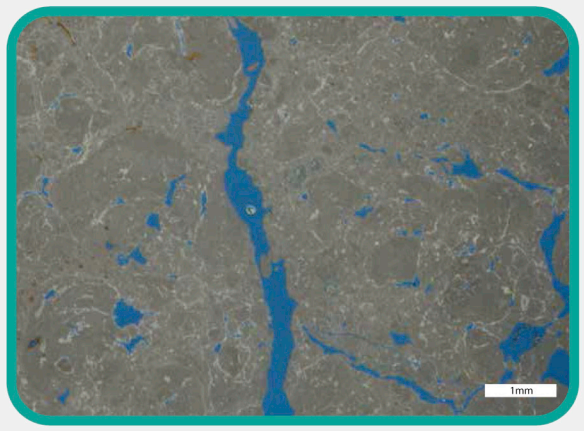
Bivalve-rich volcaniclastic sandstone (Grain Flow)



Pecten-LBF wackestone-packstone

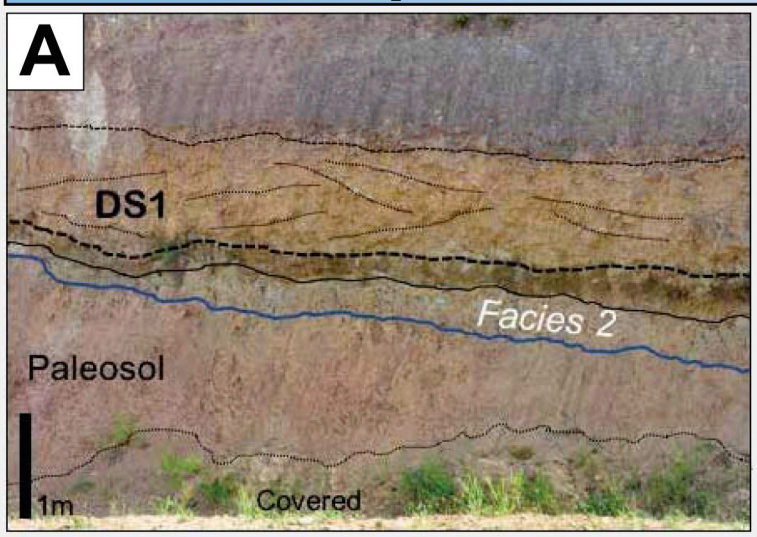


LBF-rich packstone-grainstone

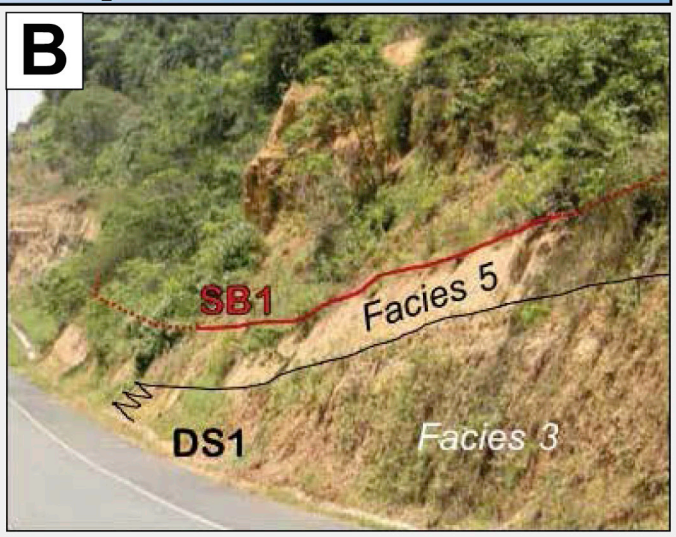


Pedogenic altered facies (Mollisol)

Depositional Sequence 1



Outcrop photo showing sediement gravity flow (facies 2) developed on the flank of southern volcanic high.



Outcrop photo showing sediment gravity flow (facies 3) developed on the flanks of volcanics.

Basal **DS1** strata consist of sediment gravity flow (*facies 2,3, & 4*) on the flanks of volcanic highs and in adjacent lows, also steeply dipping strata are documented on the flanks of volcanic highs (**A** & **B**).

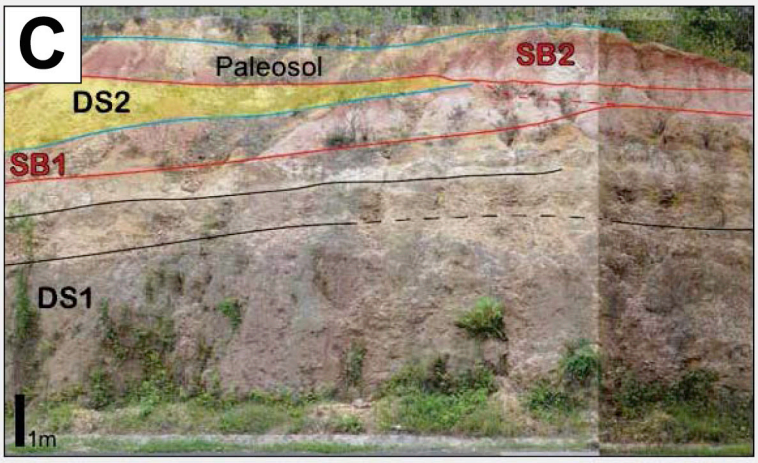
Sediments are transported downslope into lower-slope low-lying areas. Elsewhere basal deposits consist of LBF-bivalve packstone-grainstone (*facies 5*).

The upper portion of DS1 consists predominantly of LBF-bivalve packstone-grainstone with in-place *Kuphus sp.* (*facies 5*). Cross stratification and ***Kuphus sp.*** [1] in growth position at the top may suggest shallowing upward of the sequence.

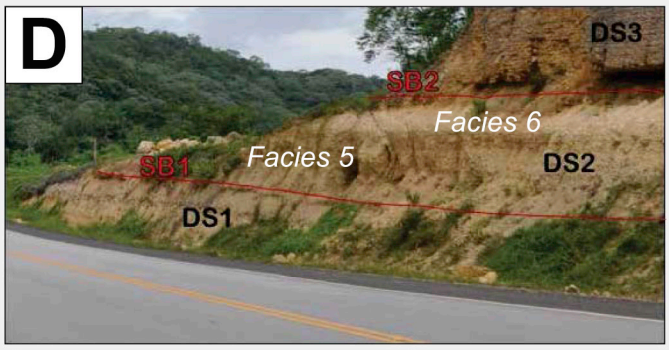
The sequence is capped by subaerial exposure surface and paleosol (*facies 1*) (**SB1**). Erosion associated with subaerial exposure resulted in variable sequence thickness.

[1] Ortega-Ariza 2016 indicated ***Kuphus incrassatus*** represents water depths of max 40 m when found alone. However, *Kuphus sp.* in association with other diagnostic criteria (e.g. cross stratification) may indicate very shallow water environments. Sequences are dominated by in-place normal marine facies deposited in ~1-40 m water depth.

Depositional Sequence 2



Outcrop photo: note upper subaerial exposure (SB2) completely eroded away DS2 locally.

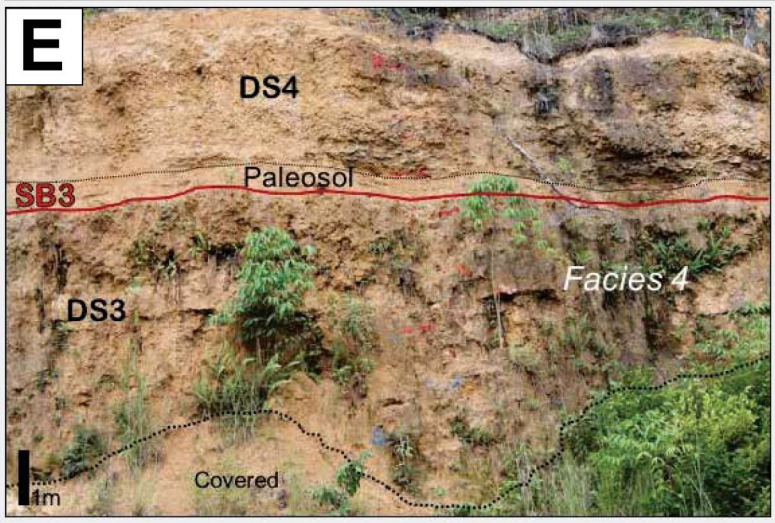


Outcrop photo: Note vertical facies change from LBF-bivalve packstone-grainstone (facies 5) to bioturbated LBF-rich volcaniclastic packstone (facies 6).

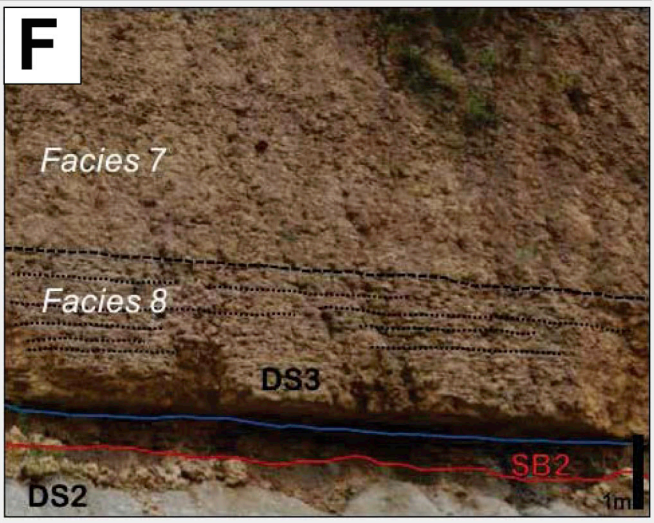
DS2 consists predominantly of LBF-bivalve packstone-grainstone (*facies 5*) with in-place *Kuphus sp.* bivalves. Locally DS2 shows some vertical facies variation of LBF-rich packstone-grainstone (*facies 5*) to a bioturbated LBF-rich volcaniclastic siltstone (facies 6) with faint cross bedding (**D**).

The sequence is capped by a subaerial exposure surface and paleosol (*facies 1*) (**SB2**); associated erosion completely eroded away DS2 locally (**C**).

Depositional Sequence 3



Note bivalve-rich volcaniclastic sandstone laterally changes into a massive LBF-bivalve packstone.

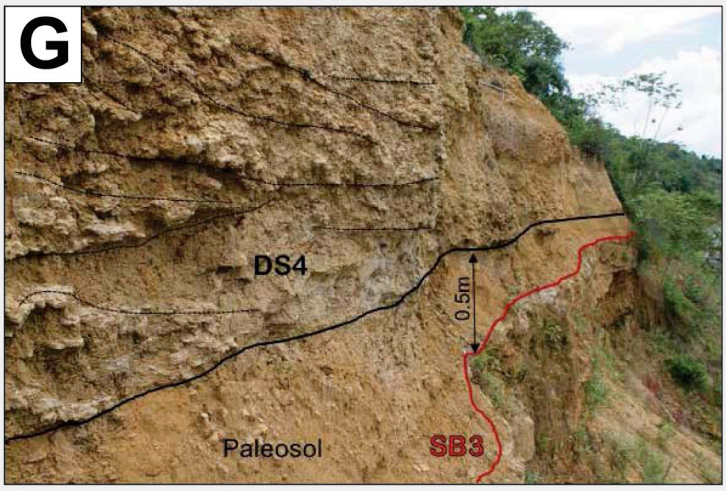


Outcrop photo showing vertical facies change from facies 8 to facies 7.

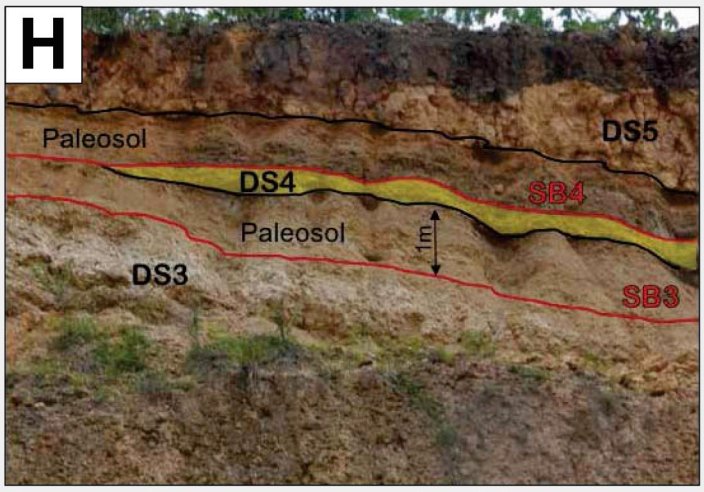
Basal **DS3** consists of sedimentary gravity flows (*facies 4*) developed on the flanks of volcanic highs and in adjacent lows that change laterally to a massive LBF-bivalve packstone (*facies 7*) with in-place *Kuphus sp.* The sequence is capped by a subaerial exposure surface and paleosol (facies 1) (**SB3**).

DS3 contains last significant siliciclastic deposits. Suggest sources farther away and local volcanic highs getting covered.

Depositional Sequence 4



Outcrop photo showing facies 5 with crossbedding overlying subaerial exposure and paleosol (SB3).



Outcrop photo: note upper subaerial exposure (SB4) completely eroded away DS4 locally.

DS4 is locally preserved near the southern flank of a volcanic high (**G**). Sequence consists entirely of LBF-bivalve packstone-grainstone facies (*facies 5*) with in-place *Kuphus sp.* bivalves. Where preserved, there's no significant vertical or lateral facies changes observed. The sequence is capped by erosional surface and paleosol (*facies 1*) (**SB4**).

Lack of siliciclastics may indicate initial filling of topography.

Depositional Sequence 5

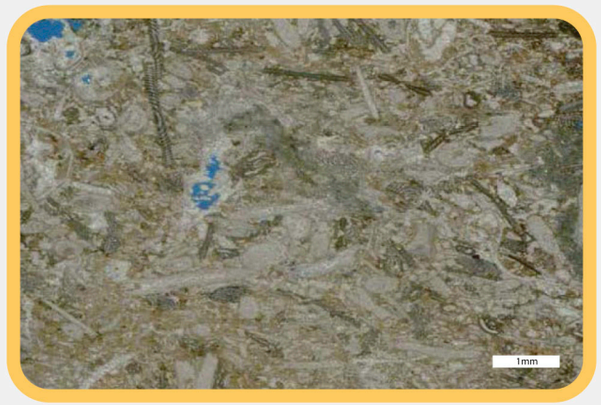
Location of DS5 outcrops showing massive LBF-bivalve packstone (facies 7) with *Kuphus sp.* horizons overlain by Pecten-LBF Wackestone-Packstone (facies 9).

Basal **DS5** strata consist of LBF-bivalve packstone-grainstone (*facies 5*), overlain by massive LBF-bivalve packstone (*facies 7*) with in-place *Kuphus sp.* and pecten-LBF wackestone-packstone (*facies 9*) indicating shallowing up.

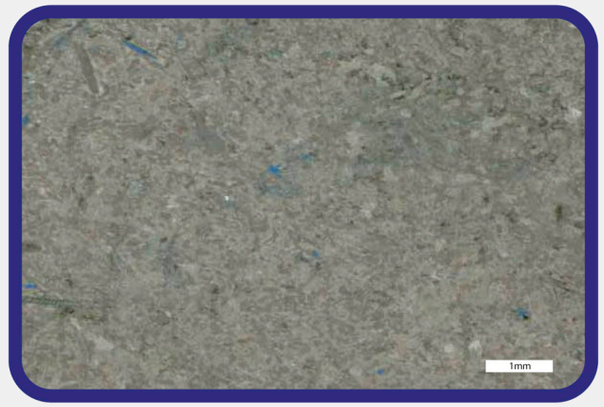
The absence of sediment gravity flows, the low dip angles, and lateral consistency of facies in **DS4** and **DS5** suggest most of the original paleotopography had been filled by the time of their deposition.

PRELIMINARY POROSITY AND PERMEABILITY ANALYSIS

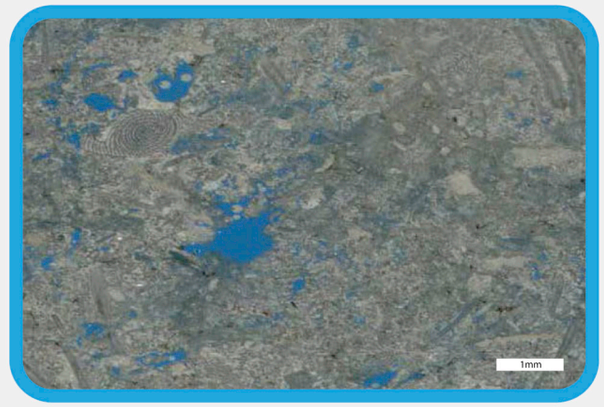
Well sorted,
fine sand size
LBF-rich packstone-grainstone
Ave He Φ: 23%
Ave K_{air}: 6.6md



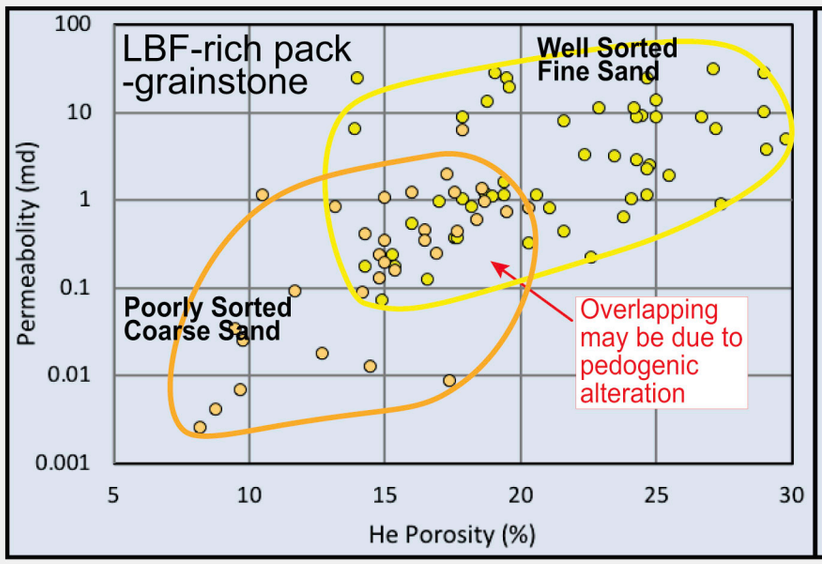
Poorly sorted,
coarse sand size
LBF-rich packstone-grainstone
Ave He Φ: 15%
Ave K_{air}: 0.59md

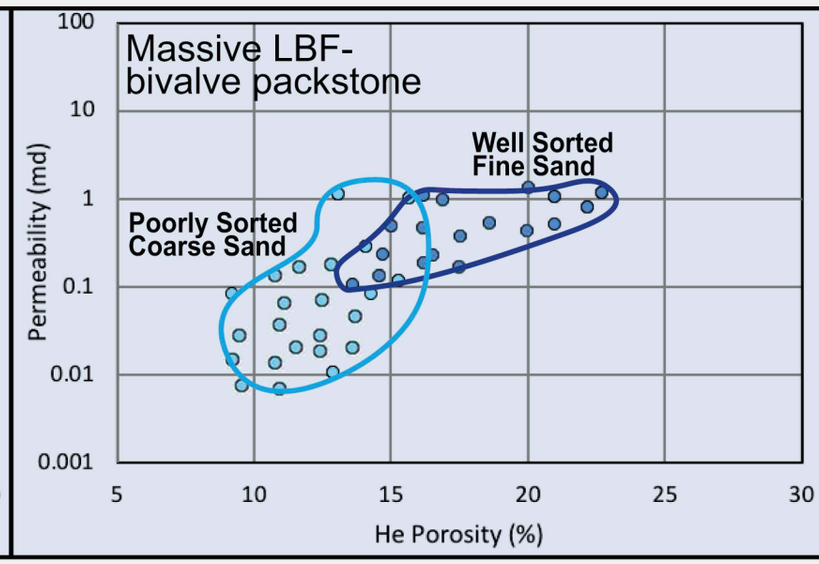


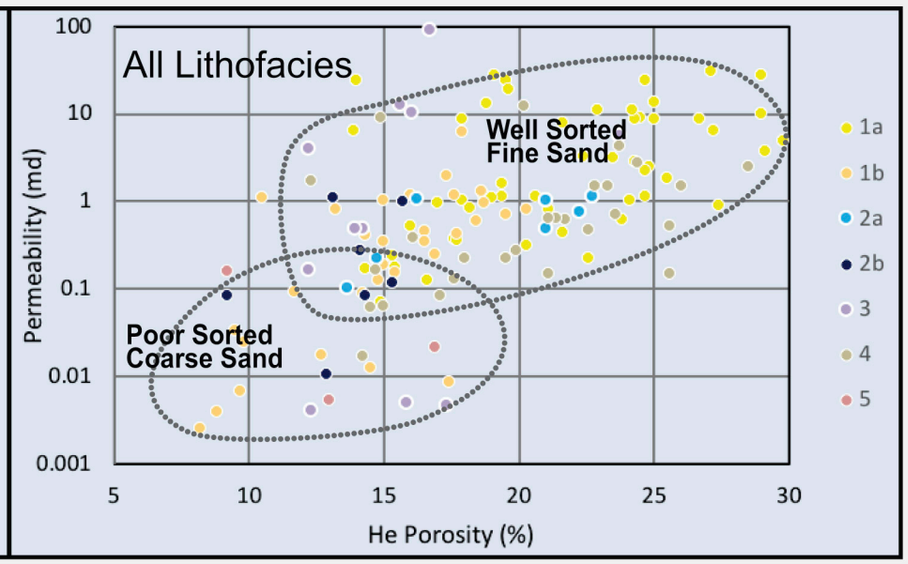
Well sorted,
fine sand size
Massive LBF-bivalve packstone
Ave He Φ: 20%
Ave K_{air}: 3.7md



Poorly sorted,
coarse sand size
Massive LBF-bivalve packstone
Ave He Φ: 14%
Ave K_{air}: 0.43md







Porosity and permeability values in the study area appear to be mostly controlled by a combination of grain size, sorting and diagenesis associated with subaerial exposure surfaces that cap sequences (e.g., pedogenic alteration).

Well-sorted fine-sand facies contain average porosity of 23% and average permeability of 5.1md; and the poorly-sorted coarse-sand facies contain average porosity values of 14% and average permeability of 0.50md.

Paleosol development and pedogenic alteration appear to locally reduce porosity and permeability at the top of sequences. Pedogenically altered well-sorted fine sand LBF-rich packstone-grainstone facies shows ave porosity values of 12% and ave permeability values of 0.03md.

POROSITY, PERMEABILITY, GRAIN SIZE & SORTING

Stratigraphic sections showing vertical porosity and permeability curves, grain size and sorting classifications

- Clonglomeratic claystone
- Volcaniclastic breccia
- Volcaniclastic-rich bioclastic packstone
- Bivalve-rich volcaniclastic sandstone
- LBF-rich packstone-grainstone
- Bioturbated LBF-rich volcaniclastic sltst.
- Massive LBF-bivalve packstone
- Pedogenic altered facies (Mollisol)

Cross section showing location of stratigraphic columns

CONCLUSIONS

- Five middle Miocene 4th- to 3rd-order mixed heterozoan-large benthic foraminifera-siliciclastic sequences capped by subaerial exposure developed in response to relative sea-level fluctuations (10's of meters) interacting with variable substrate paleotopography.
- Sea level and variable volcanic substrate paleotopography were major controls on sequence stratigraphic architecture and facies distribution of sequences. Erosion associated with subaerial exposure also resulted in variable sequence thickness laterally.
- Sequences show primary dips of 1-10 degrees, dipping away from substrate highs. Facies deposited near steep substrate slopes (5-10˚) are dominated by sediment gravity flows, and facies deposited on gentle substrate slopes (1-5˚) reflect original depositional environments.
- Sequences consist mostly of normal marine facies that appear to represent original environments of deposition, reflecting ~1-40 m water depth. Gravity flow facies (carbonate and volcaniclastic) occur in basal portions of DS1 and DS3 on the flanks of volcanic highs and in adjacent lows.
- The absence of sedimentary gravity flows, the low dip angles, and lateral consistency of facies in DS4 and DS5 suggest most of the original paleotopography had been filled and adjacent volcanic basement had been covered by the time of their deposition.
- Initial analysis of data from 180 core plugs indicate the facies with the best porosity and permeability are well-sorted fine-sand sized LBF-rich packstone-grainstones (23%, 6.63md) and well-sorted fine-sand sized massive LBF-bivalve packstone (20%, 3.71md). Partial pedogenic alteration is locally present, and reduces porosity and permeability at the top of sequences.
- In general sediment gravity flow facies located at toes-of-slopes show low porosity and permeability values; basal parts of sequences show well-sorted fine-sand sized facies followed by poorly-sorted coarse-sand sized facies near the top generating an upward decrease in p&p.