Unbioturbated Marine Mudstones: Environmental Stress or Rapid Deposition? A Worked Example from the Ordovician Beach Formation, Newfoundland, Canada*

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Abstract

Sedimentary successions containing unbioturbated marine mudstones are commonly interpreted as being deposited by particle settling from suspension under oxygen-depleted bottom-water conditions. However, modern research demonstrates that besides suspension settling, combined flows can transport and deposit mud quickly in the aftermath of storm events or during high river discharge. Textural evidence indicating combined flows is difficult to provide for the Phanerozoic rock record, because primary fabrics are usually overprinted by bioturbation. Within this study we have studied Lower Ordovician, storm-dominated, shoreface sediments of Bell Island that exhibit well-bioturbated, interbedded sand- and mudstones with intercalated, unbioturbated mudstones.

We examine the most likely controls on deposition of unbioturbated mudstones through integration of sedimentological and geochemical datasets at a range of different scales. We test the hypothesis that some of the unbioturbated mudstones were deposited as combined flows. Critical features in unbioturbated mudstones include well-developed, low-angle cross stratification and thin (<1 mm), stacked beds with erosional tops and bases. Microscopic bioturbation in the form of very small (mm-sized) Planolites burrows is common in mud- and siltstones previously described as unbioturbated. Mudstones contain 0.5% TOC in average, with peak values of up to 3.4% TOC. Size-frequency distributions of framboidal pyrite reveal a fully-oxygenated water column close to the sediment-water interface during mud deposition. Sedimentary provenance analysis (using Rare Earth Elements) of mudstones reveals that all examined mudstones are either from the same source, or have undergone the same mixing process before deposition. Given: 1) the distal location of the exposure with respect to a potential fluvial source; 2) the fully oxygenated state of the water column; and 3) the evidence for bottom currents, we conclude that at least some of the unbioturbated muds were deposited as wave-enhanced fluid mud flows. A careful, integrated study of other ancient mudstone successions is needed in order to assess the importance of similar sedimentary products originating from advective sediment transport throughout the fine-grained sedimentary record.

Reference

Duke, W.L., R.W.C. Arnott, and R.J. Cheel, 1991,Shelf sandstones and hummocky cross-stratification; New insights on a stormy debate: Geology, v. 19/6, p. 625–628.

Unbioturbated marine mudstones: Environmental stress or rapid deposition?: A worked example from the Early Ordovician Beach Formation

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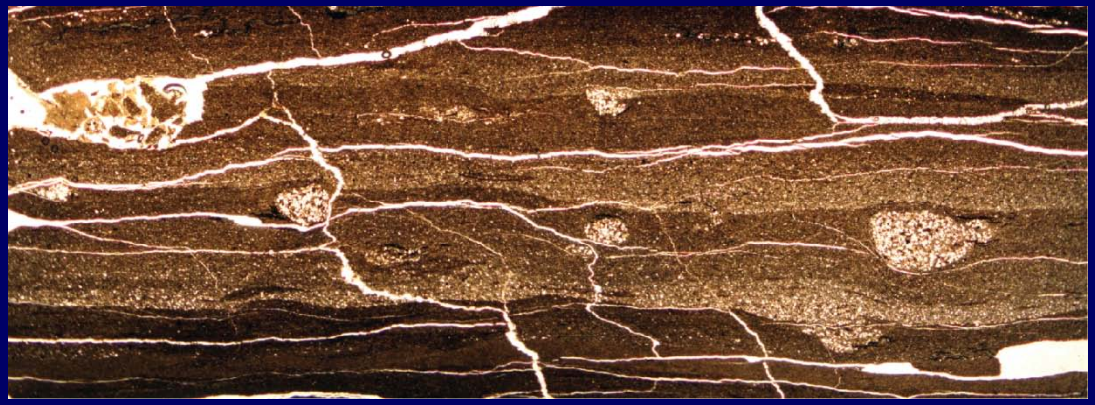

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Introduction

Mud-dominated coastlines process the majority of terrestrial organic material supplied to the world's continental shelves and are the most important storage sites for remineralized organic carbon on the modern earth.

Models typically used in the interpretation of ancient mud-dominated successions are based on modern studies that have mostly been carried out in quiescent depositional environments, such as anoxic basins and carbon-rich estuaries.

The composition of sedimentary organic matter during the early Paleozoic was dominated by bacterial hydrocarbons rather than land-derived particulate organic matter which dominates later in Earth's history.

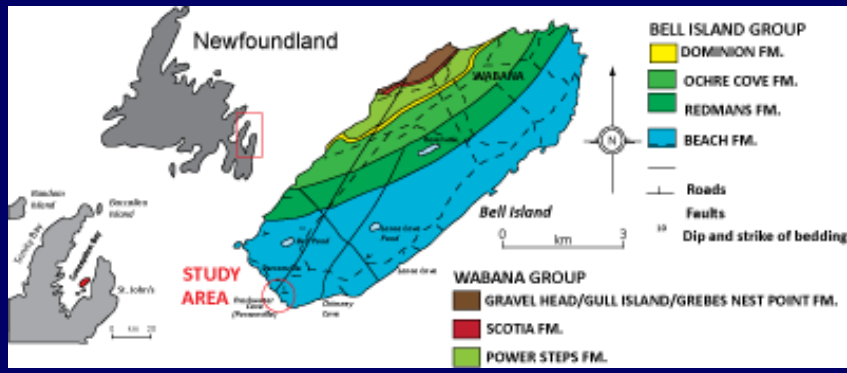
In this Early Paleozoic setting the remineralization efficiencies of organic carbon are predicted to have been relatively high and total residence times of bioavailable organic matter are likely to have been comparatively short.

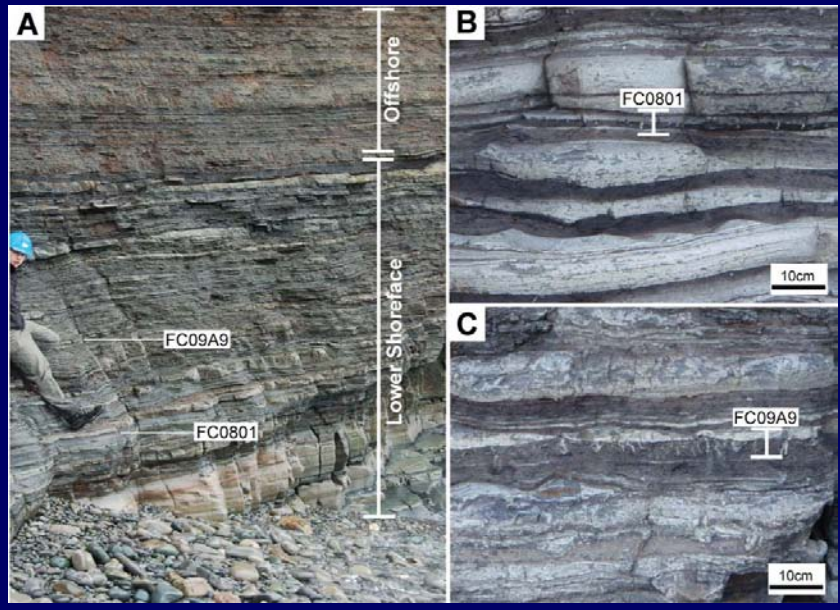
Approach

The Lower Ordovician Beach Formation of Bell Island, Newfoundland represents a strongly wave-dominated, temperate, mud-rich shelf.

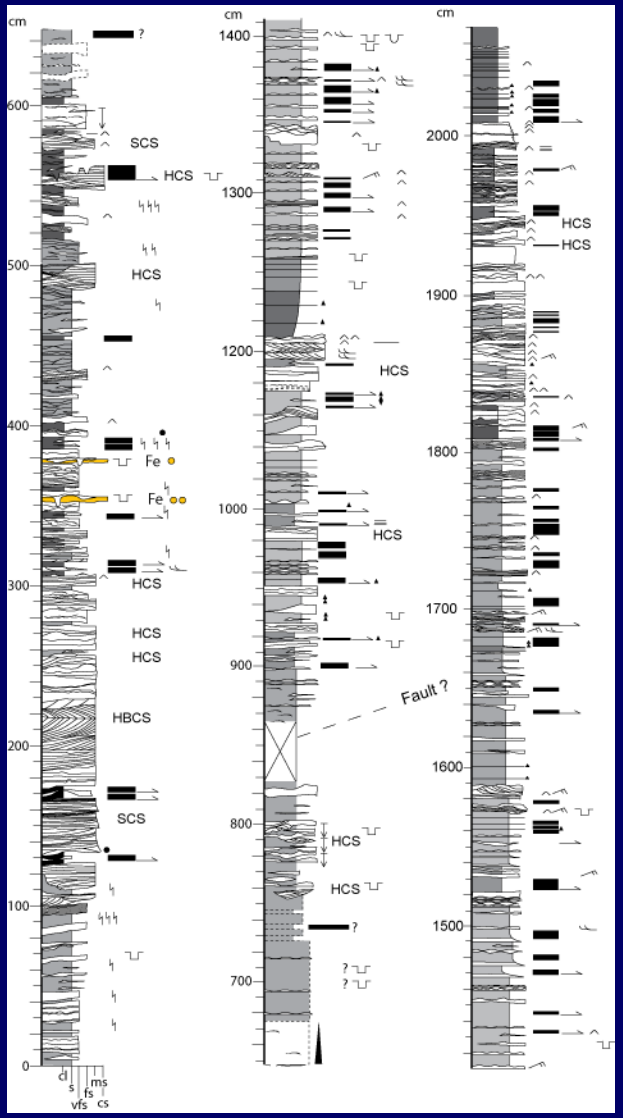
We hypothesize that the distribution and behavior of macrofaunal benthic communities within the Beach Formation are a direct reflection of the bioavailability of organic material and sedimentation timing, rather than an indication of fluctuations in salinity or bottom water oxygenation.

This hypothesis was tested by examining the sedimentological relationships and geochemical composition of sedimentary organic matter, as well as the mineralogical composition of sediment, from selected bioturbated and unbioturbated units within the Beach Formation.





Stratigraphic distribution of unbioturbated muds within the Beach Formation, Newfoundland, Canada



Mudstones and sandstones comprise each c. 50% of the succession.

Represented are storm-dominated shoreface, offshore and fully marine open coastline.

No sedimentary structures that would indicate direct fluvial or tidal influence throughout the Formation.

Unbioturbated mudstones represent mudstones (clay- and silt), and very fine-grained sst, in many cases eroding underlying sandstones.

Unbioturbated siltstones and very fine-grained sands are most likely related to the discharge of a flooding river followed by along-shore dispersal as wave-supported sediment gravity flows (see below, indicated by black bars).

Sampling strategy

Field sedimentary logging and ichnofabric analysis of the Beach Formation, Bell Island, Newfoundland.

Collection of mudstone blocks (rock saw)

Thin sectioning and petrography in order to visualize carbonaceous microlaminae and transport structures.

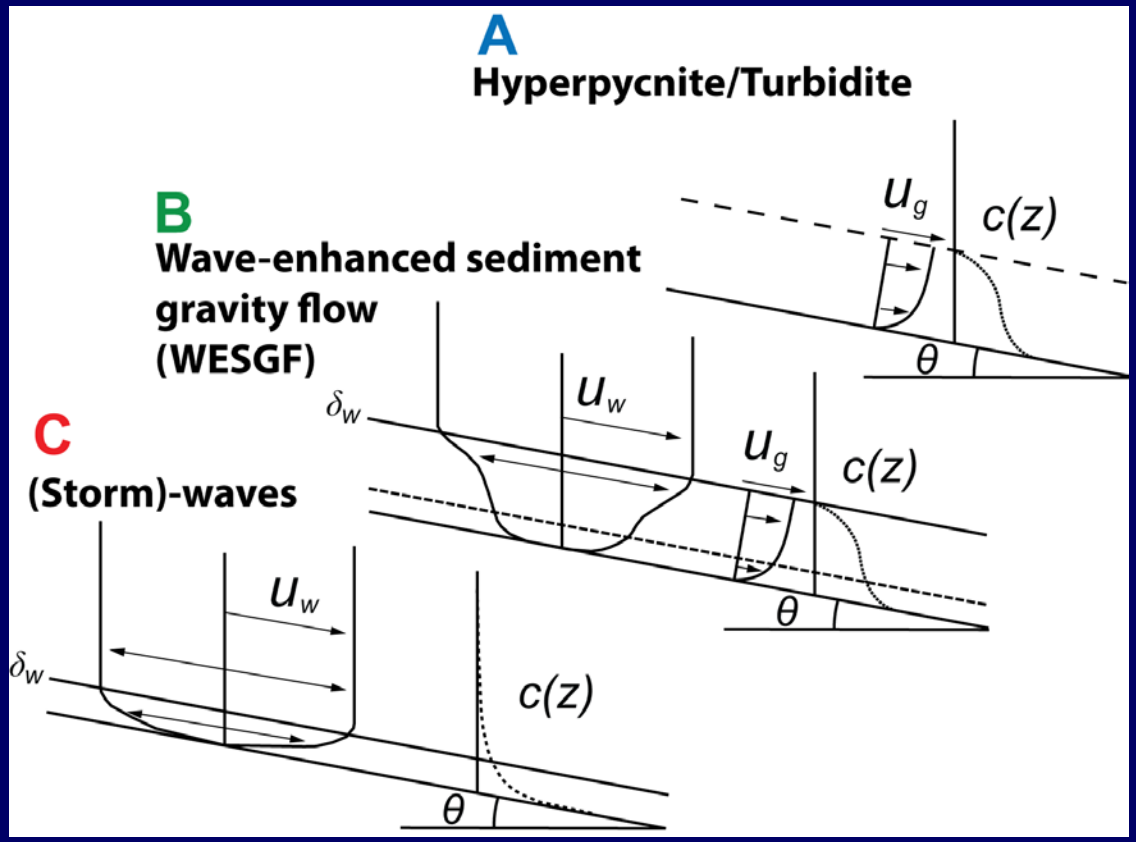
TOC and $\delta^{13}C_{org}$ measurements of kerogen in order to compare bulk geochemical variability across stratal surfaces and variation within single beds.

High-resolution images are then compared with the geochemical profiles of TOC and $\delta^{13}C_{org}$.

Results I – Proposed depositional mechanisms of clay, silt, and very fine sand

Within the Beach Formation, a storm-dominated, muddy coastline three depositional end members were observed (see below):

Discrimination based upon microstratigraphies, bedding contacts, thickness, and geochemical characteristics.

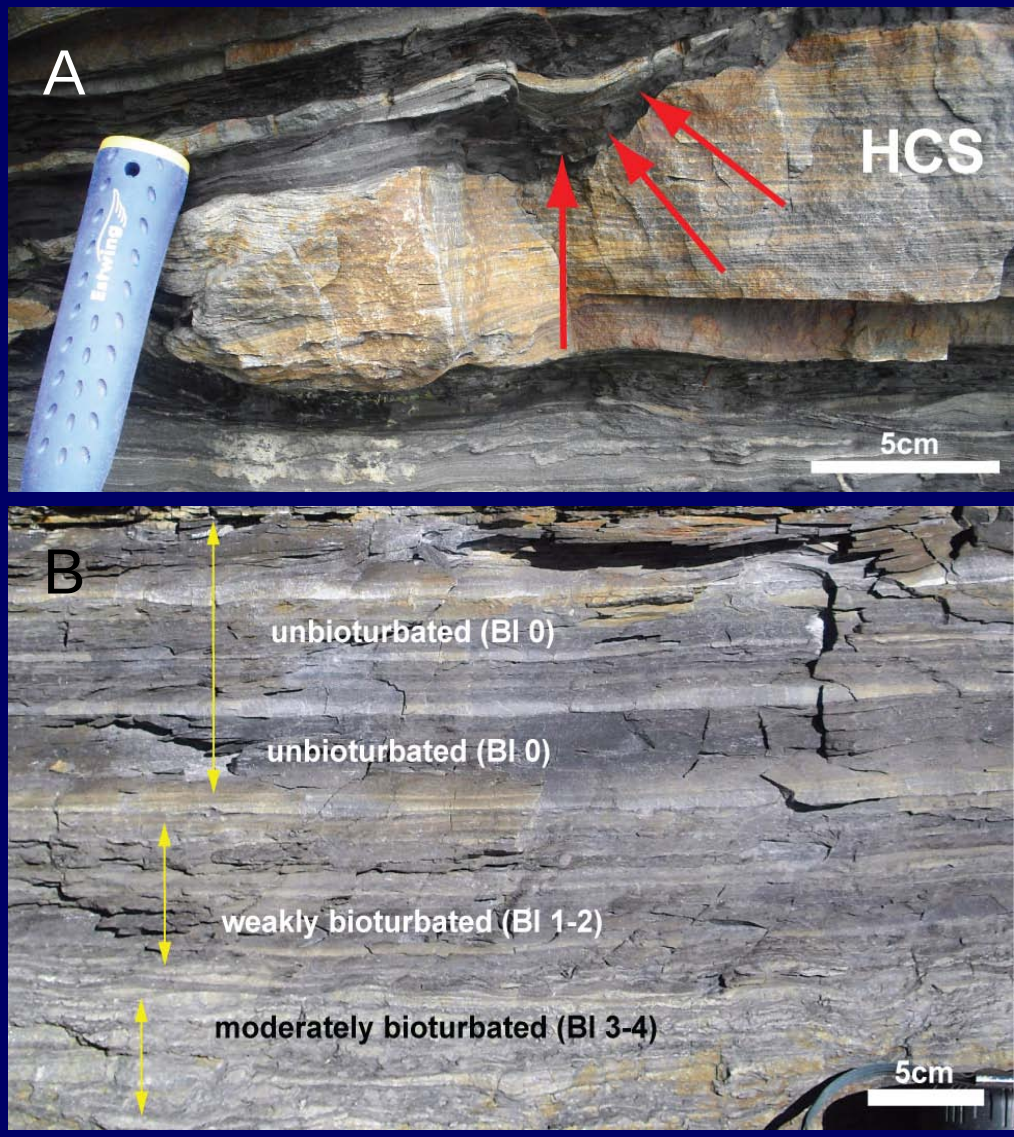


Results II – Mud-turbidites, Hyperpycnites, Wave-enhanced sediment gravity flows (WESGFs)

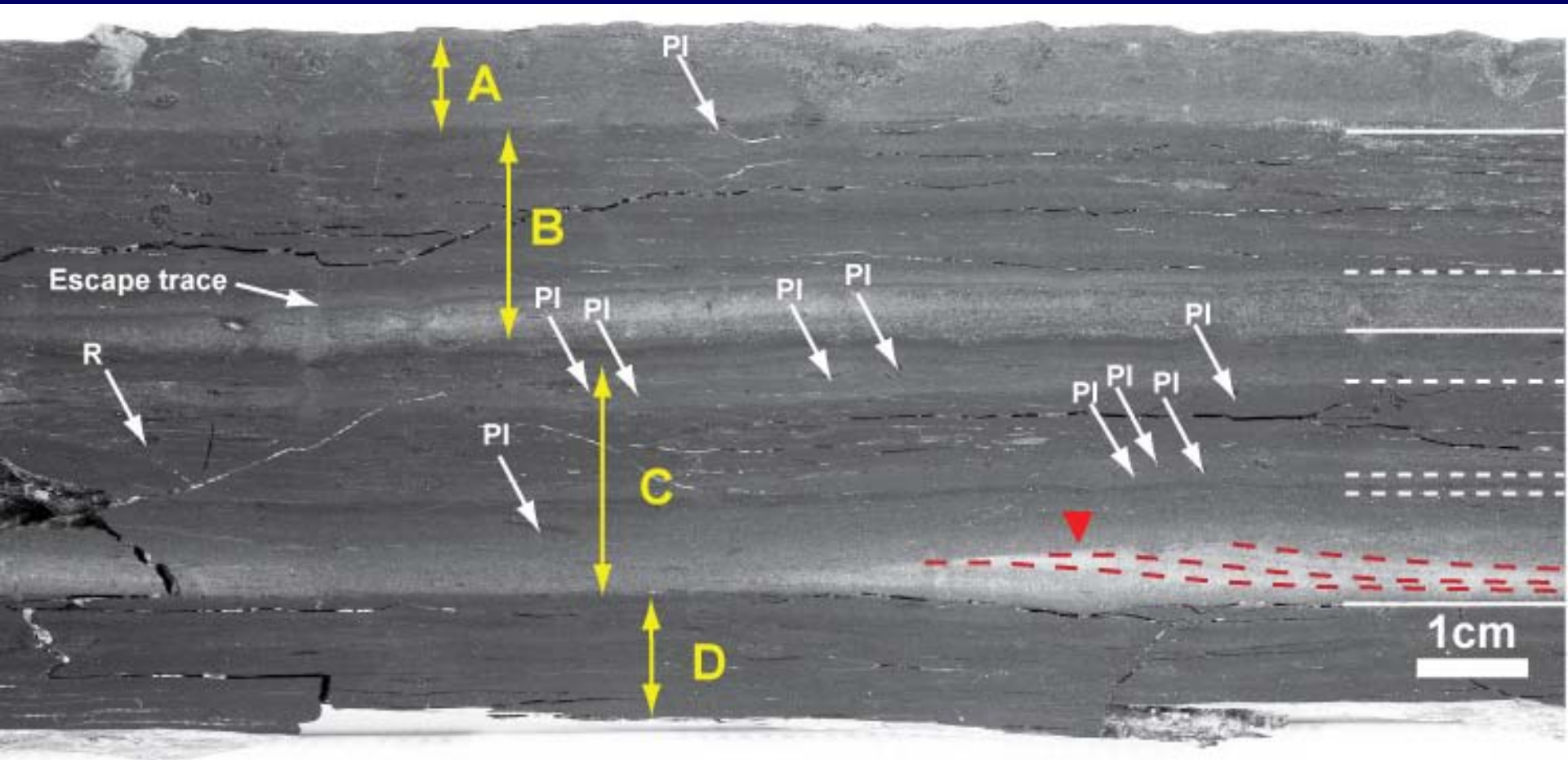
The Beach Formation, a storm-dominated shelf with no significant tidal influence.

Fine to medium sand exclusively deposited by strong oscillatory storm currents (planar beds) in the base, tops show anisotropic HCS (combined flows, arrowed) during waning phase of storm.

Mudstone beds were delivered as river-generated, highly erosive mud turbidites and hyperpycnal currents (A) that propagate across the shelf as wave-supported sediment gravity flows, which are subject to constant reworking (B).

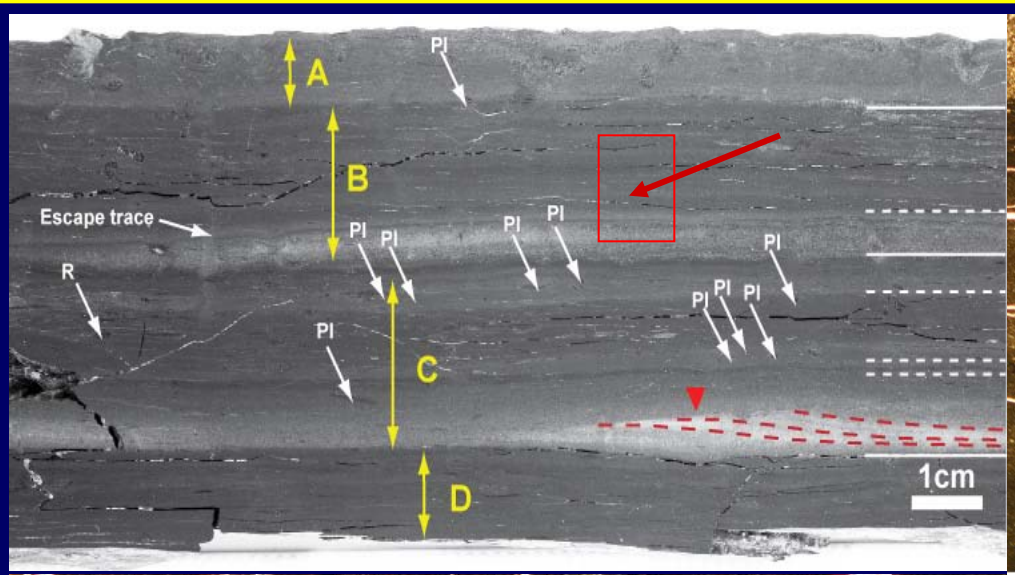


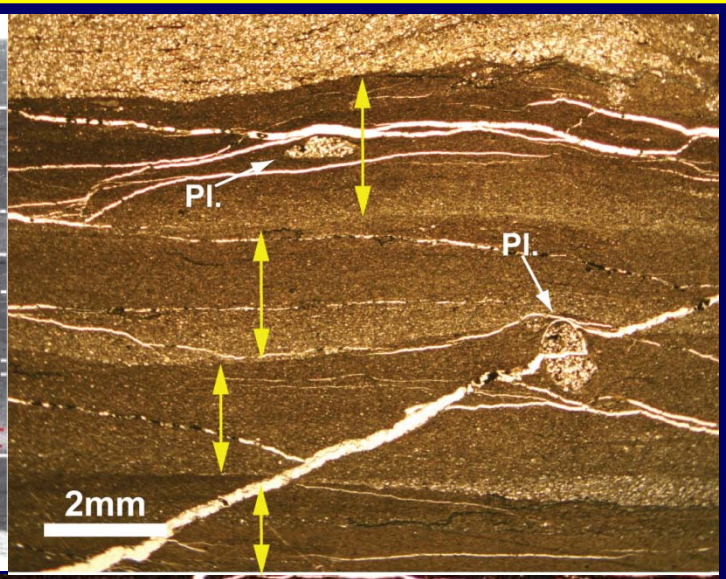
Results III - Wave-enhanced sediment gravity flows

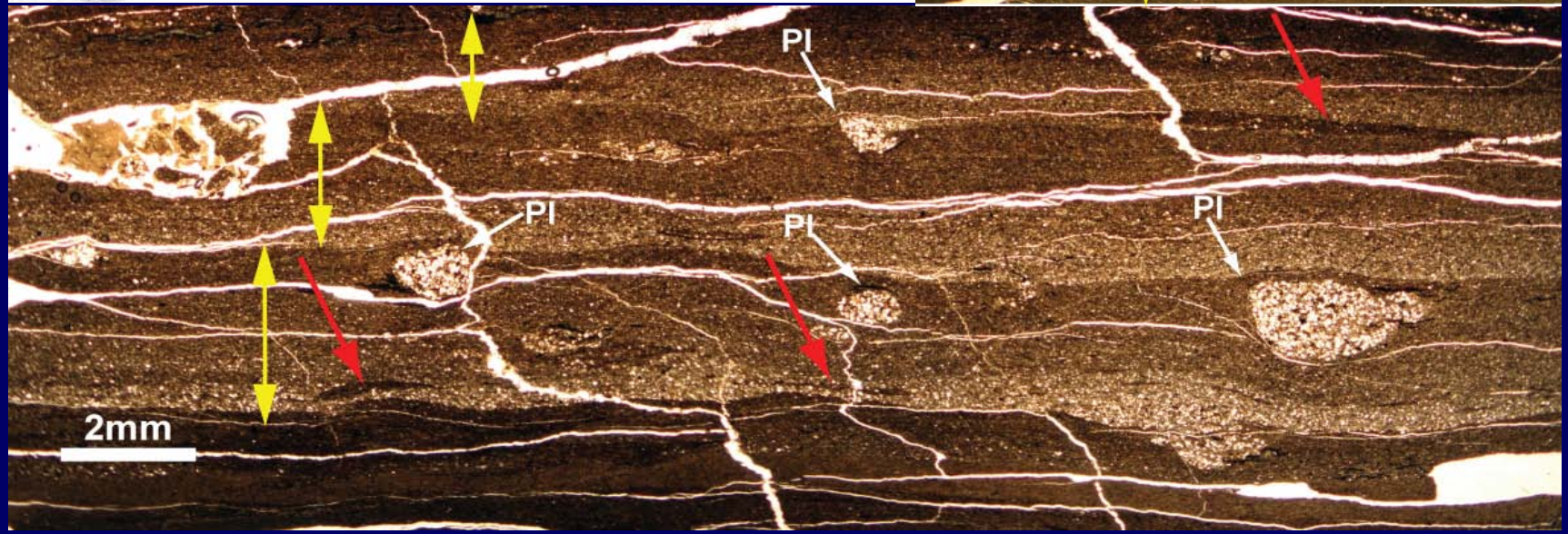


Hand sample containing more than 10 stacked, depositional events.

Results III – Stacking patterns and internal organization of Wave-enhanced sediment gravity flows

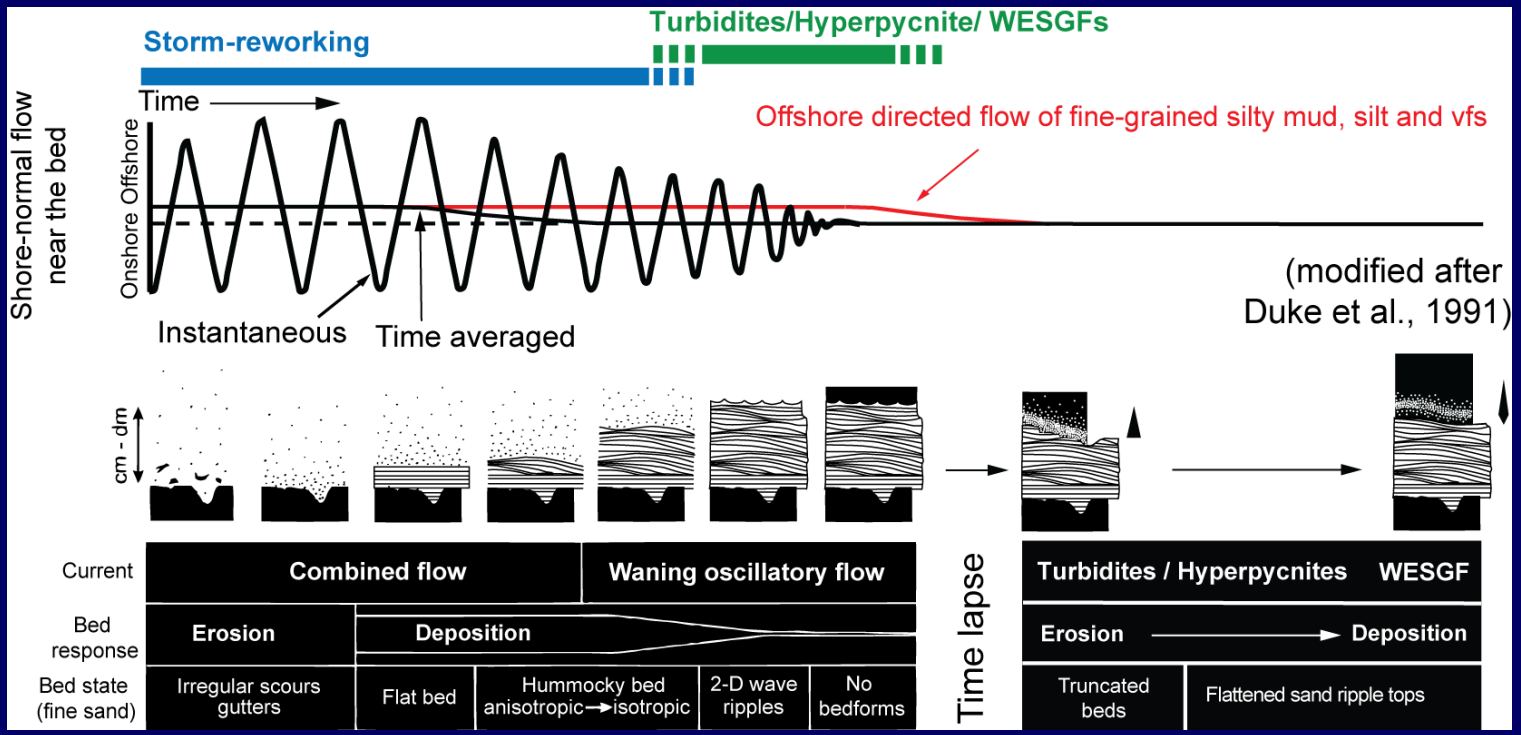






Results III – Suggested depositional timing

Deposition of mud oblique to orientation of sand bedform crests indicates a changing flow direction during the final stage of flow. This relationship supports a scenario where silt and very fine-grained sand were moved by combined flows during the waning stage of the flow probably had an offshore-directed component.

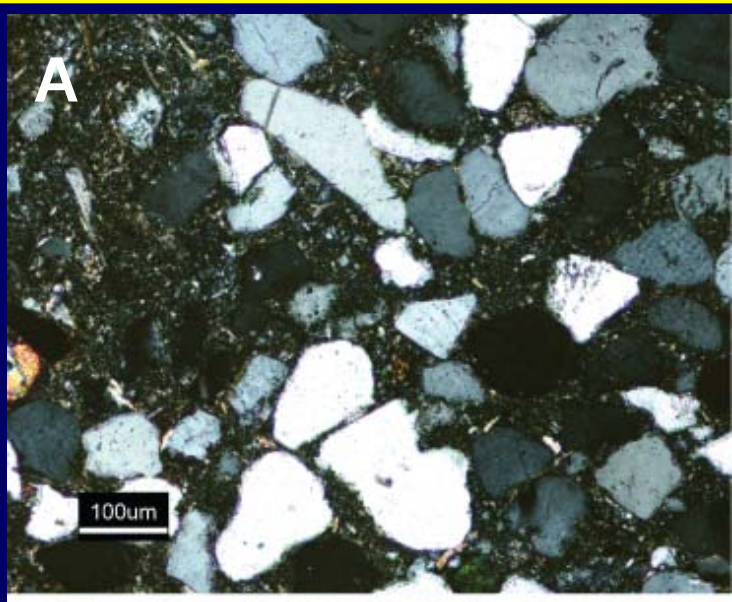


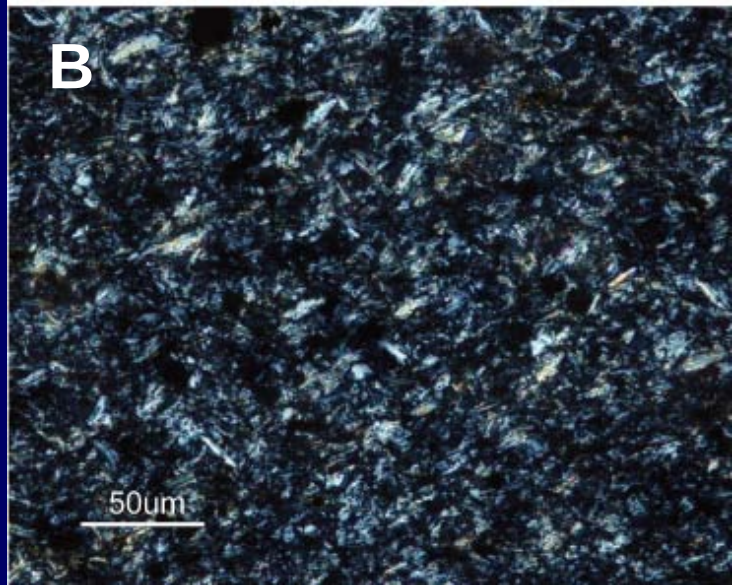
Results IV – Petrographic composition of sediment

Matrix of sandstones (A) contains a very high proportion (up to 30%) of unweathered lithic debris.

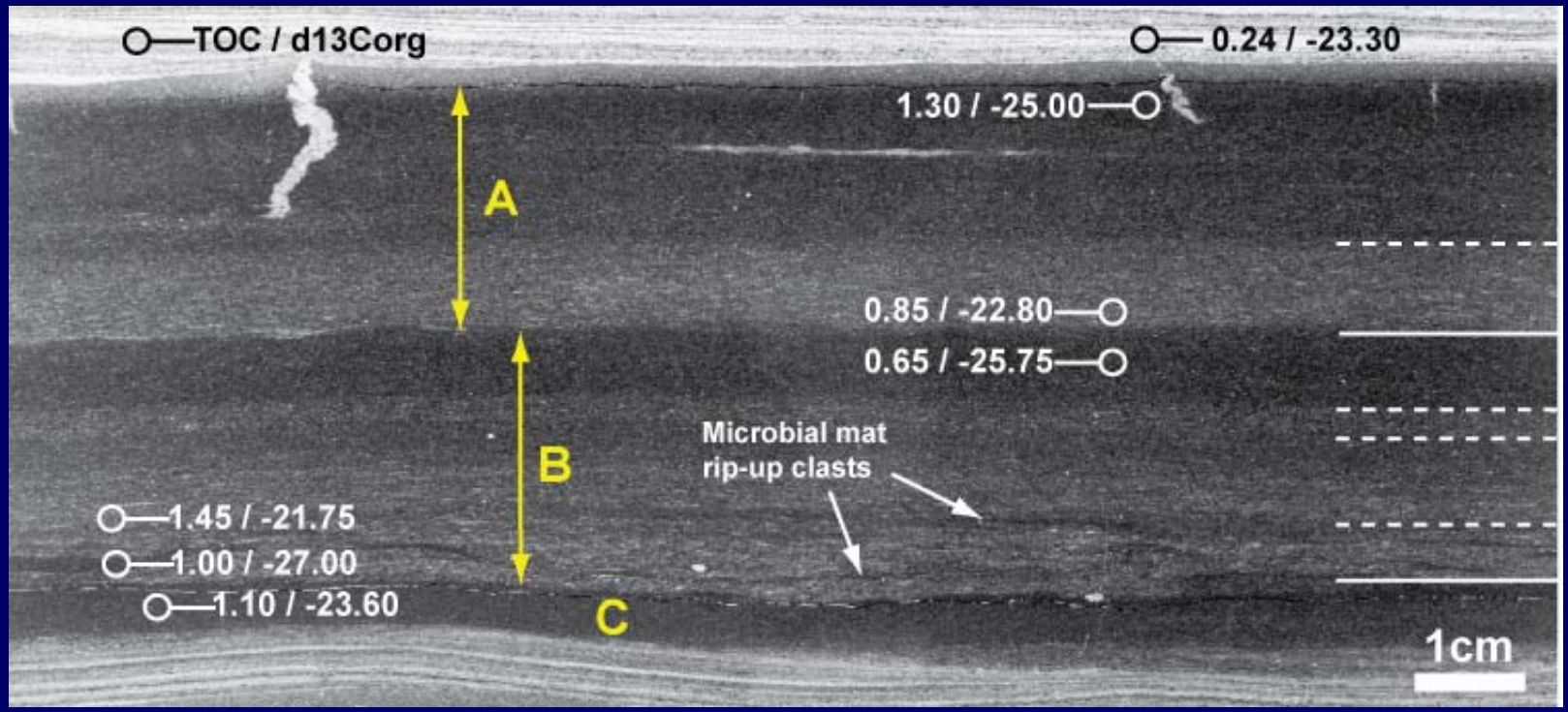
Siltstones and mudstones (B) are composed of more than 40% of clay- and silt-sized quartz, and contain a high proportion of illite and early diagenetic chlorite

The mineralogical composition of the sediment is consistent with previous studies and outlines a non-vegetated hinterland with a high contribution of products derived from mechanical weathering processes.



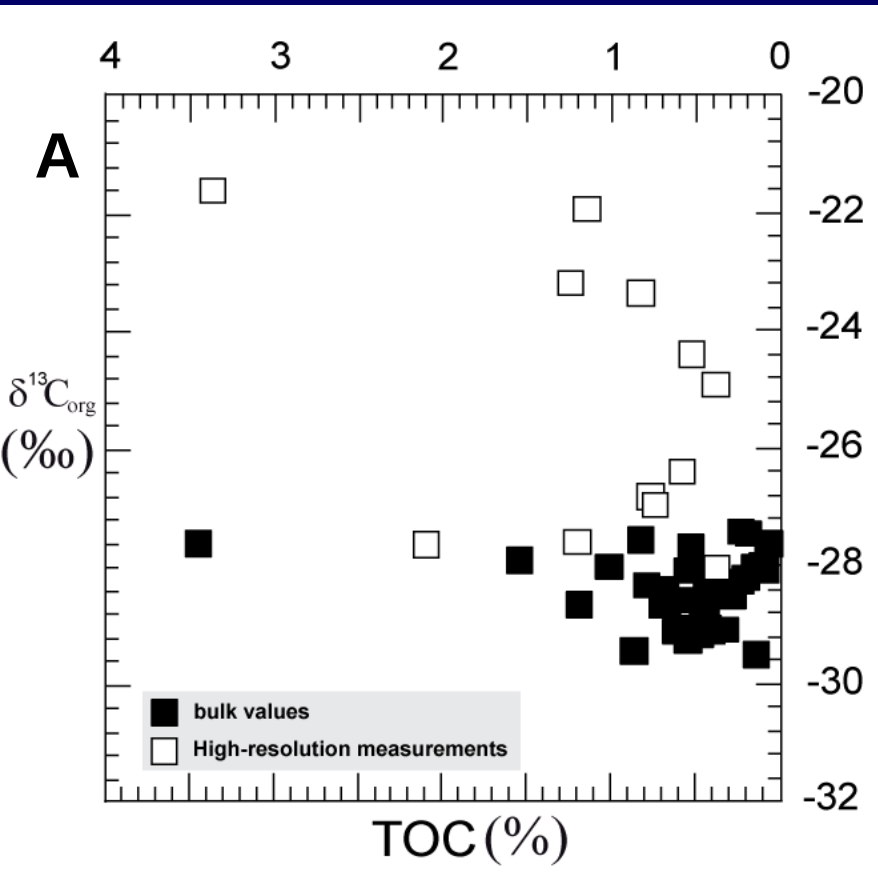


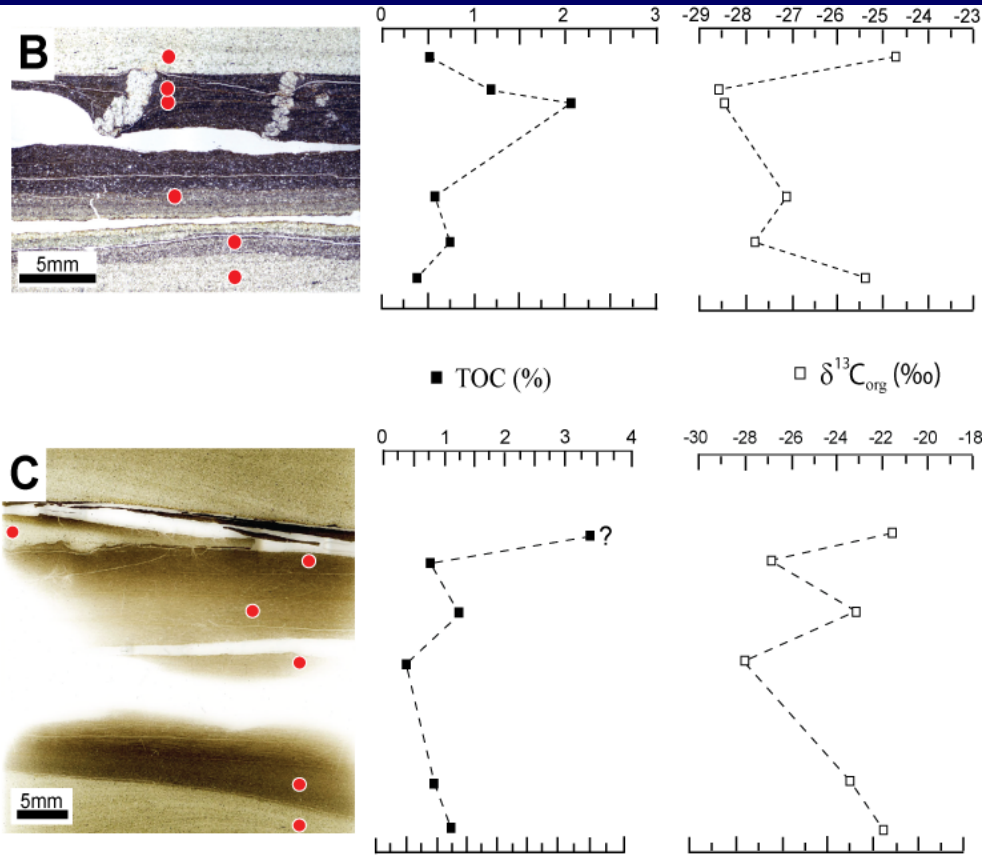
Results V – Kerogen composition of sands and mudstones



C-isotope variations of up to 5‰ within wave-enhanced sediment gravity flows indicate microbial enrichment in discrete layers. The range point towards high microbial activity within units that were deposited rapidly and were subject to periodic reworking.

Results V – Kerogen composition in low and high-resolution





Discussion – Organic matter quality and spatial organization

Microbial organic carbon dominates the composition of sedimentary organic matter throughout the succession. Isotopically light (δ13C = -29.5‰), organic-rich (up to 2.1 % TOC; B) horizons can be observed in association with abundant synaeresis cracks at bedding plane top surfaces.

Fluid mud deposits (hyperpycnites and wave-supported sediment gravity flows) usually show homogeneous values of TOC throughout the depositional event of around 1.0 %. Variability in stable isotopic composition of organic carbon through the succession supports the spatial juxtaposition of many metabolic strategies within mud, and is consistent with periodic reworking of the mud prior to its final deposition (C).

Organic matter is dominated by bacterial organic carbons of varying isotopic composition which is quickly remineralized on a storm-dominated muddy coastline.

The concentration of high-quality bacterial organic matter is consistent with observed colonization strategies that seem to attack the top of the bed.

Conclusion – What controls bioturbation intensities in the Beach Formation?

Anoxic conditions and salinity stress at the sediment-water interface, as proposed in previous publications (e.g., Fillion and Pickerill, 1990), were not found to be the dominant controls on bioturbation intensities within the upper part of the Beach Formation.

Instead, we propose the following environmental parameters as the major controls on bioturbation intensity and style, with their importance expressed in descending order:

Reductant availability > Sedimentation timing and frequency > Oxygenation > Salinity fluctuations

In summary, the Beach Formation represents a storm dominated muddy shoreline, where most likely length of colonization windows and bioavailability of organic material are the most significant controls on bioturbation intensity and style.