Preservation Potential of Primary Depositional Fabric in Event-Dominated Muddy Shelf Settings: A Semi-quantitative Facies Model*

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Abstract

Muddy shelf deposits derived from river discharge account for much of the sediment accumulating in modern oceans. Such deposits preserved in ancient successions are also volumetrically significant. Hydrodynamic observations and models produced over the past decade have elucidated depositional controls on such deposits, particularly regarding newly recognized classes of gravity-driven sediment flows that are partially supported by turbulence from a combination of waves and currents. Complementary studies have described modification of such deposits by post-depositional processes such as bioturbation and consolidation, with respect to the character of preserved sedimentary fabric. To date, the effects of these interacting processes have not been integrated to provide an overall facies perspective on preserved deposits.

The goal of this study is to combine and explore these two lines of inquiry, muddy shelf sediment dynamics and post-depositional modification, to create a semi-quantitative facies model for preserved sedimentary fabric in these event-dominated sedimentary systems. This is accomplished by integrating the results of an analytical model for wave-enhanced sediment-gravity flows (developed by Carl Friedrichs and Don Wright), with a numerical model for interacting event sedimentation and bioturbation. Three cases of wave/gravity-driven sediment flux are considered: moderate (Eel Shelf, N. California), high (East Cape, North Island New Zealand), and very high flux (Gulf of Papua, and Amazon Shelf). Rates of bioturbation and event-driven sedimentation are derived from process studies over event to seasonal timescales, and modeled long-term deposition rates are integrated and tuned to match known sediment accumulation over centennial timescales (measured by radioisotope geochronology).

Results show that extensive primary depositional fabric is preserved only under the highest deposition rates averaged over near-annual timescales. For moderate and high flux settings, primary depositional fabric is thus best preserved near the mid-shelf maximum in deposition rate (for example, on shelf clinoform foresets or near the center of a mid-shelf mud belt). However, for the highest fluxes, fluidized bed conditions in both topset and foreset zones of clinoforms are hostile to macrofauna, resulting in reduced bioturbation rates and increased primary fabric preservation compared to lower flux cases.

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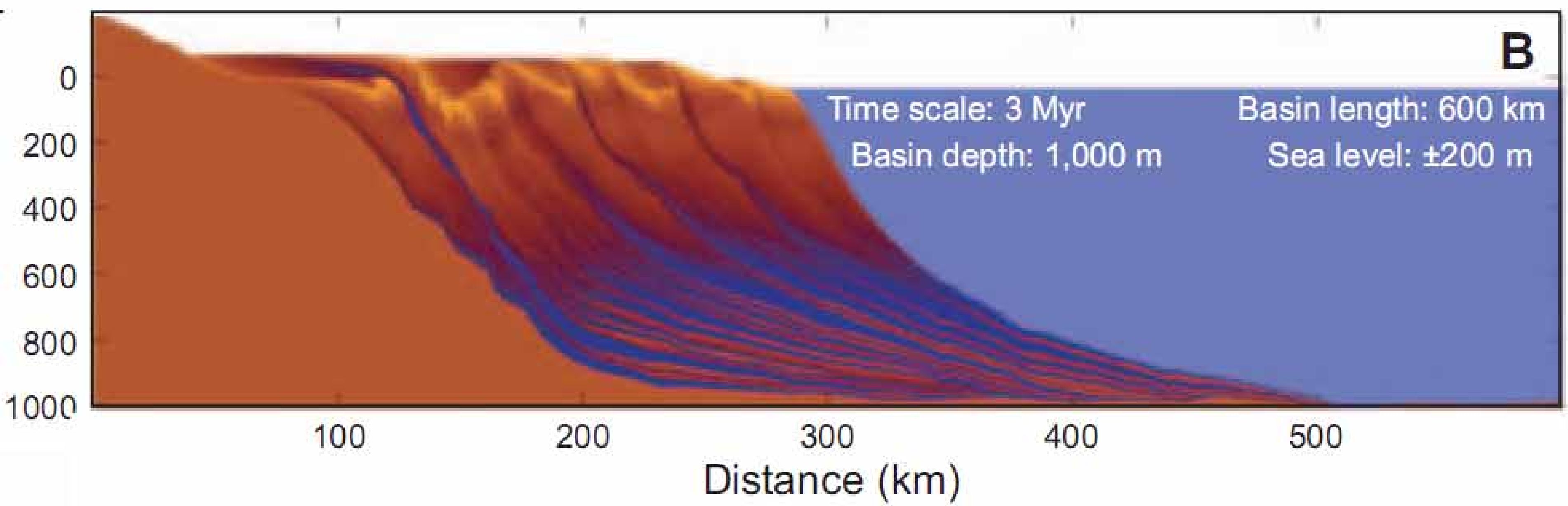
Motivation:

As marine sedimentologists and oceanographers, we have studied depositional processes and products for decades.

•Powerful observational tools (currents, waves, sediment deposition)

•Increasingly sophisticated predictive models that capture physical processes with impressive fidelity   (example from Syvitski et al., 2007)

But: What do we see at the outcrop scale?



Overprinting from Bioturbation

Most models omit bioturbation

•Major fabric element in most rocks
•Important control on physical properties, fluid flow

Goal Here:
Integrate basic predictive models of SEDIMENTATION and BIOTURBATION

Evaluate our ability to quantitatively predict resultant facies relationships.

Specific Case with Three Examples

Sedimentation Model:

Muddy shelf deposits created by high-concentration suspensions, advected under combined influence of gravity, waves, and currents:

Wave-Current Enhanced Sediment Gravity Flows (model of Friedrichs and Wright 2004, for waves only = WESGF)

→ ***Increasing Sediment Flux*** →

Mid-shelf mud patch ↔ *Muddy Shelf Clinoform*

Eel Shelf, California | *Waiapu Shelf, NZ* | *Gulf of Papua Clinoform*

Sommerfield et al., 1999
Bentley and Nittrouer, 2003
Wheatcroft et al., 2007

Ma et al. 2008
Kniskern et al. 2010

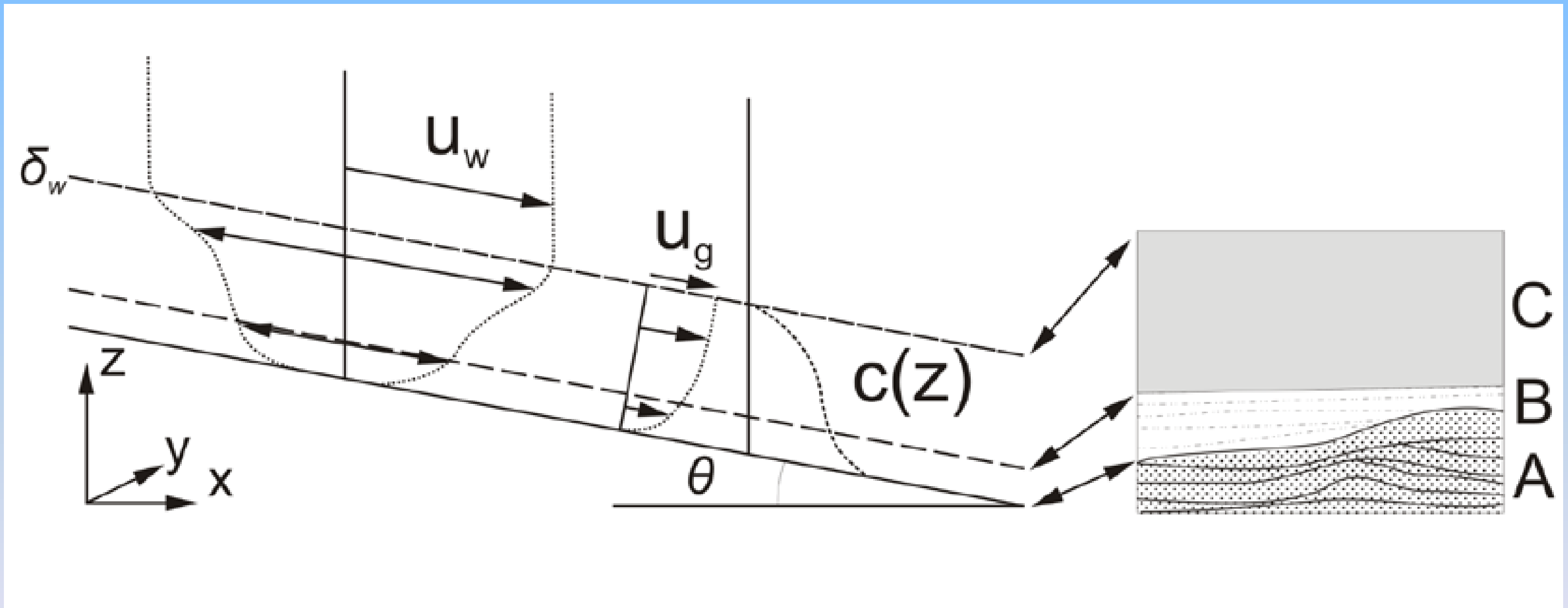
Walsh et al., 2004
Martin et al., 2008

Bioturbation/Preservation model of Bentley et al., 2006

Analytical model for WESGF's: Friedrichs and Wright 2004

Transport/deposition controlled by:
strong wave resuspension (U_w), high sediment flux, BBL density stratification C(z), and slope θ

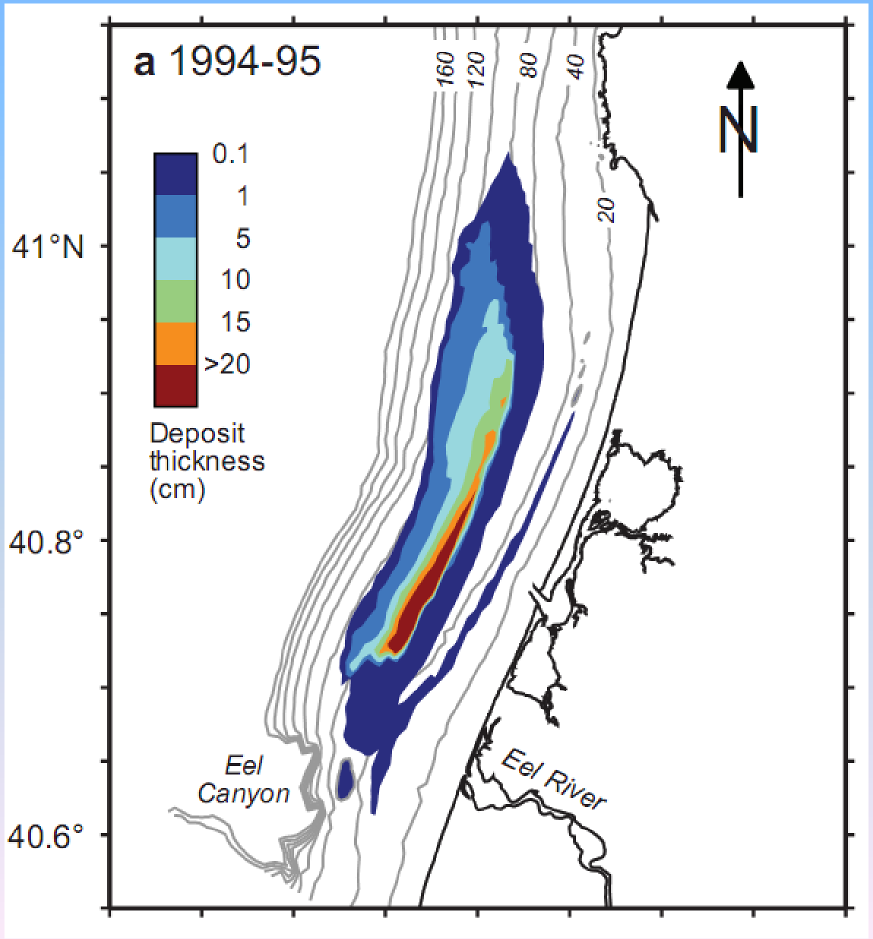
Produces beds characteristic of many energetic, high sediment-flux shelves
Consistent with equilibrium clinoform morphology

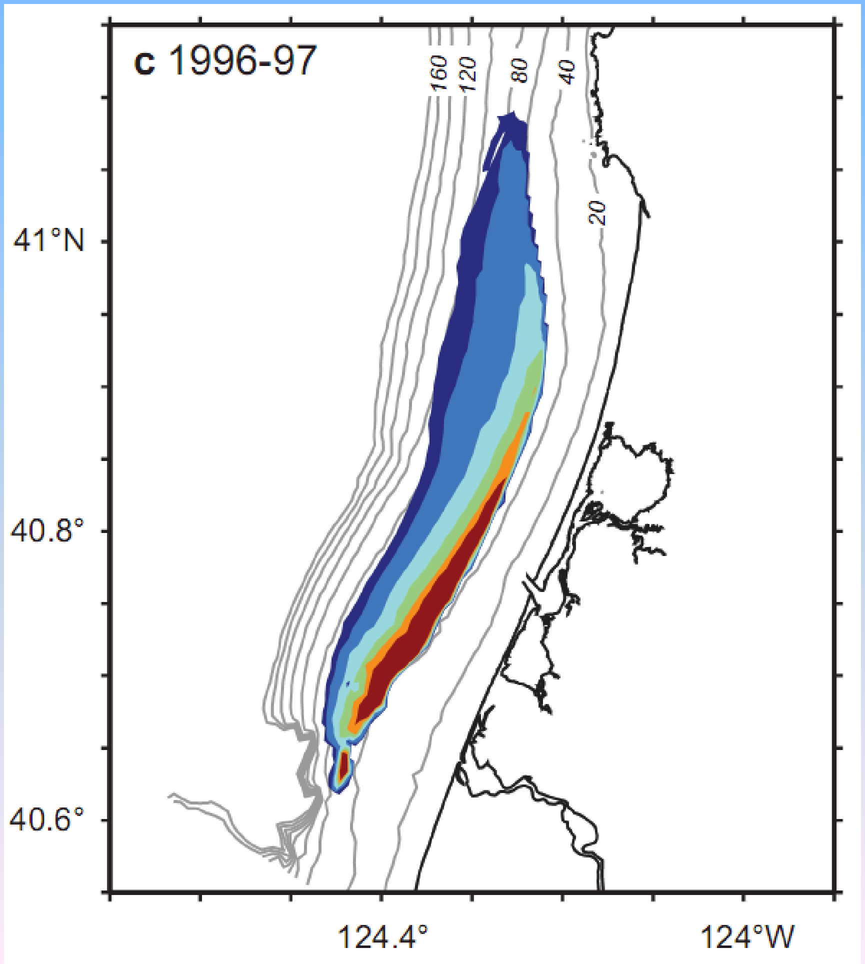


Dynamics of Friedrichs and Wright 2004 yields stratigraphy described by Macquaker, Bentley, and Bohacs 2010.

Model application on Eel Shelf, California

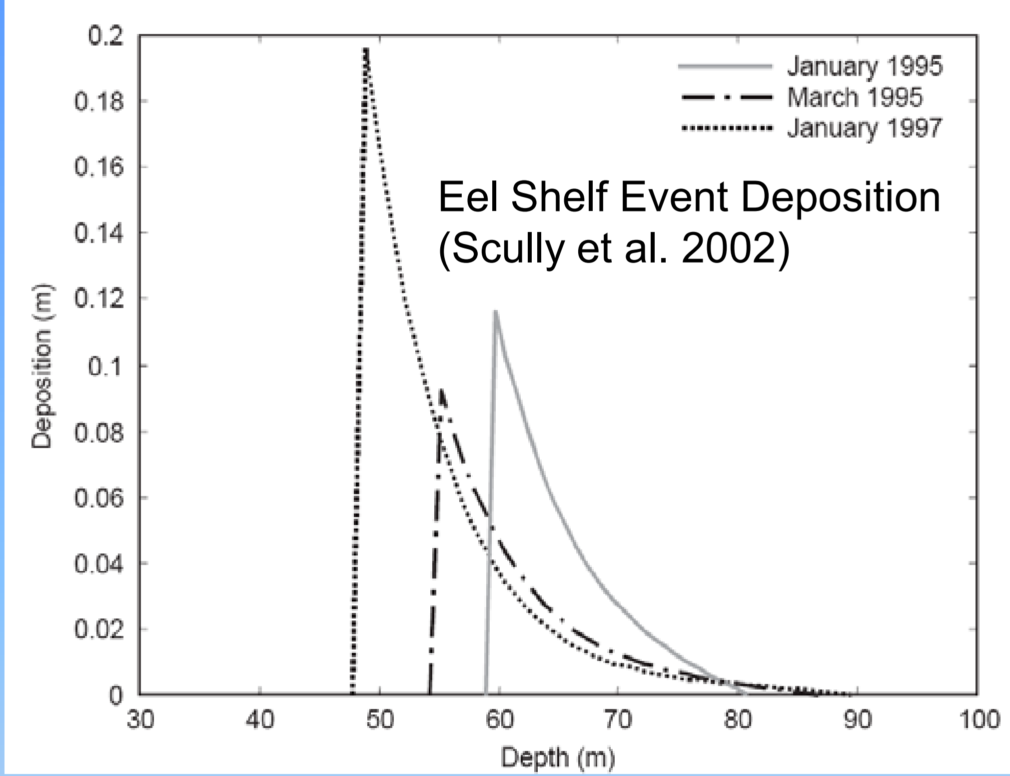
Annual WESGF thickness produced by Eel River floods confidently modeled by Scully et al. 2003





Model Implementation

WESGF Event Model:
•WESGF cross-shelf deposition rate per event
•Input: seabed slope, wave conditions
•Assume: monochromatic waves, sufficient sediment supply from inshore to feed WESGF



Sediment accumulation 10-100y:
•Assume negligible erosion
•Determine reasonable return periods for events
•Randomize return period and event intensity ***to create stacked event layers***
•Postulate background sedimentation rate from low-intensity events
•Check against ^{210}Pb accumulation rates

Limitations:
•No erosion (reasonable simplification for these settings over short timescales)
•No feedback between sedimentation and seabed slope

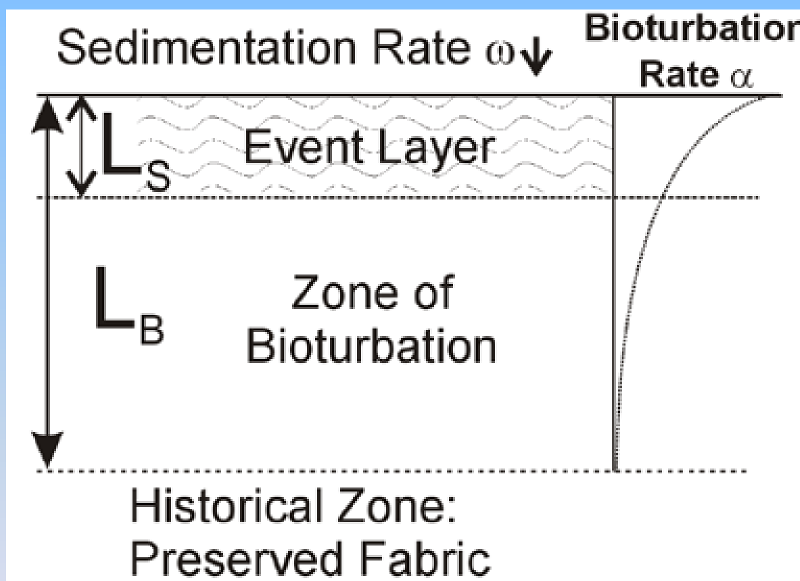
Bioturbation Model: Bentley et al., 2006

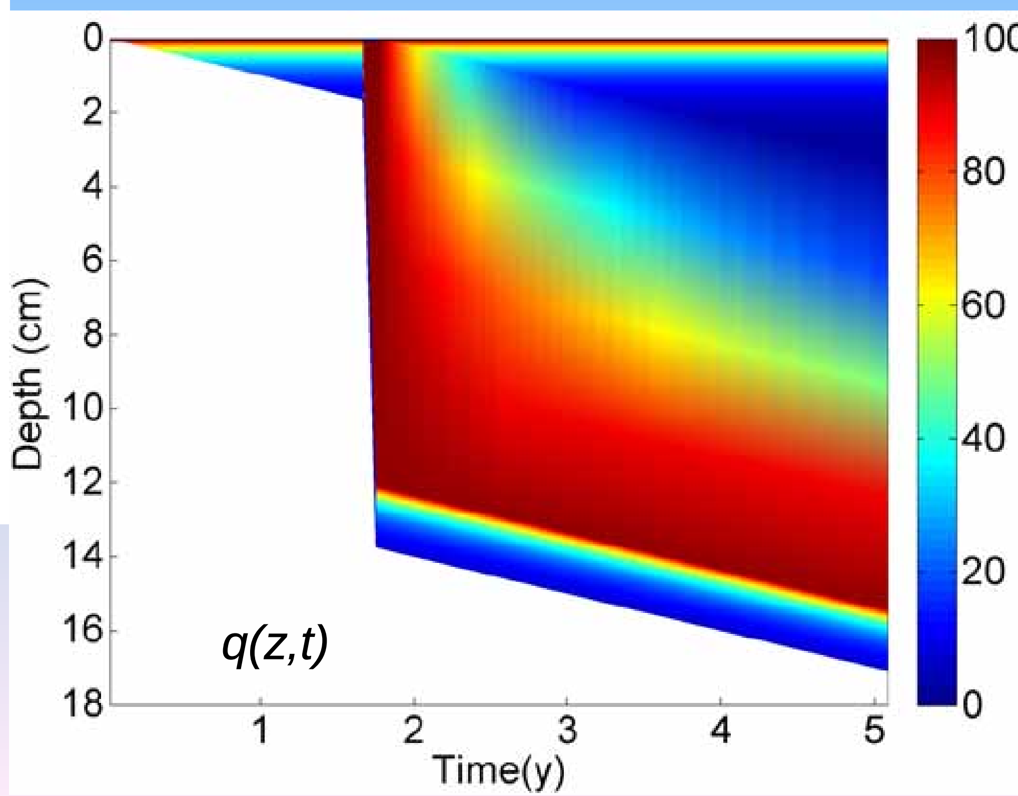
Preservation quotient q (opposite of bioturbation index)

Function of :

$$q_{z,t} = q_0 \exp\left(- \int_0^z \frac{\alpha(z)}{\omega(t)} dz \right)$$

- Bioturbation rate α(z)
- Burial rate ω(t), events + background





q=100% for physical fabric

q=0 for biogenic fabric

Implementation

Bioturbation rate α(z), :

derived from field measurements of bioturbation depth, intensity (D_b, L_b) using methods of Bentley et al. (2006)

Sedimentation Rate ω(t):

Given by WESGF/event model at specific locations across shelf

•40-100y time span

•<monthly timesteps

Multiple one-d simulations gridded or combined for cross-shelf profile of preservation quotient q

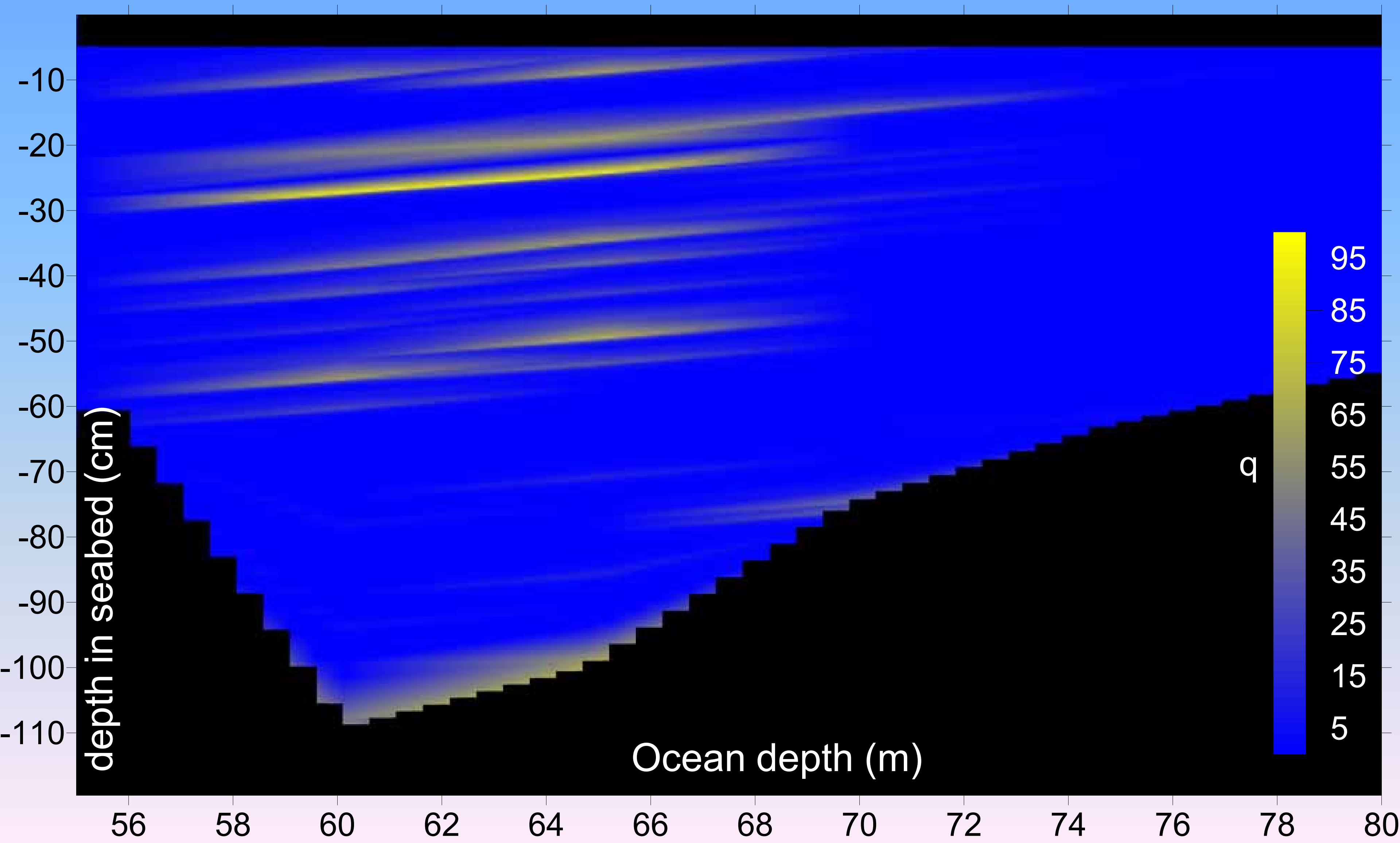
Compared to bed preservation and bioturbation in X-radiographs of study area cores

Eel Shelf 100y

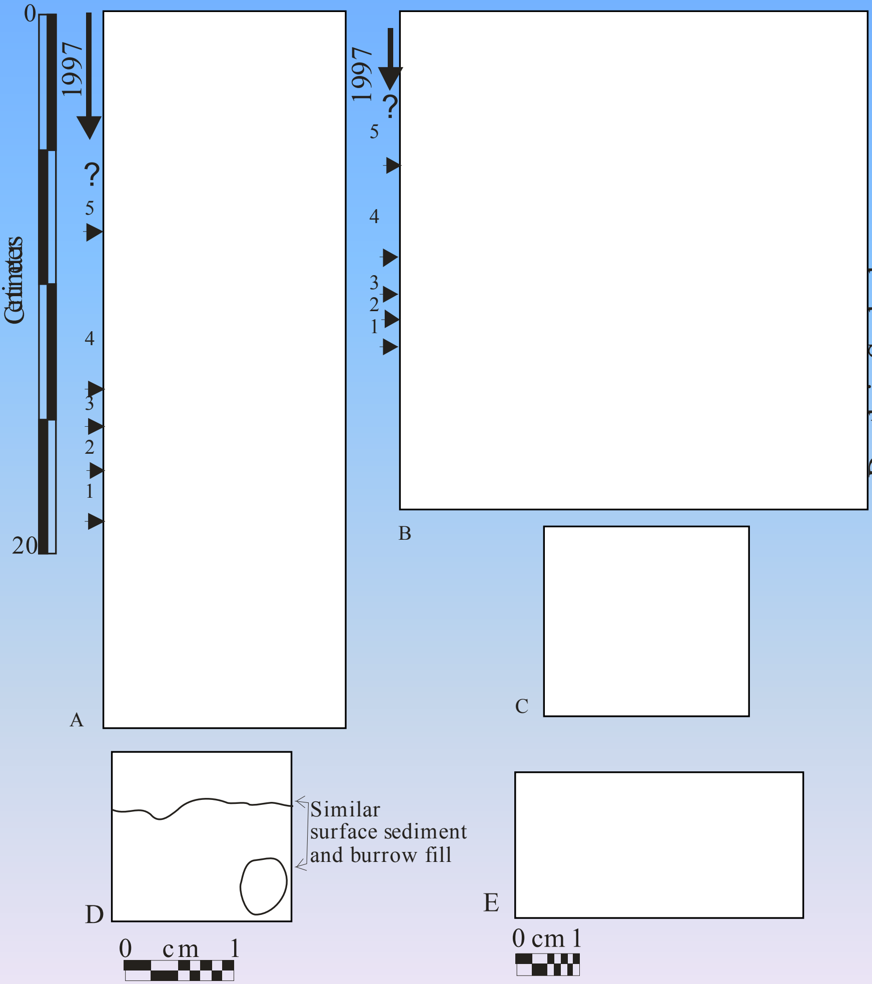
Inner edge
Thin beds, bypassing
Low q

Muddy mid-shelf
Depocentre
Highest q

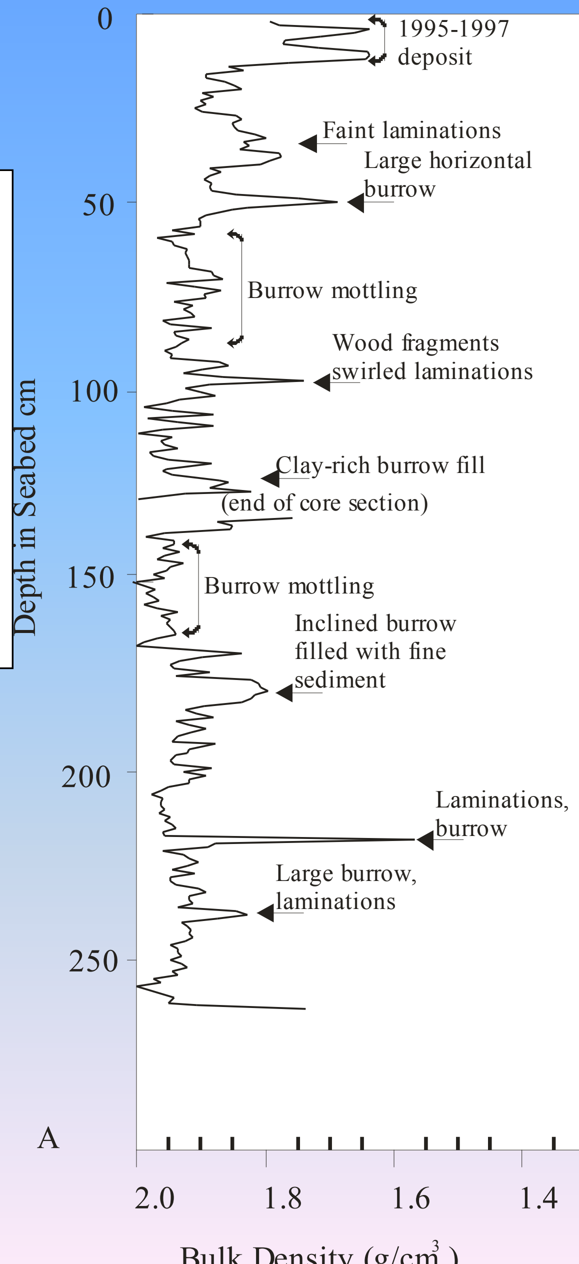
Muddy outer shelf
Thin beds, low supply
Low q



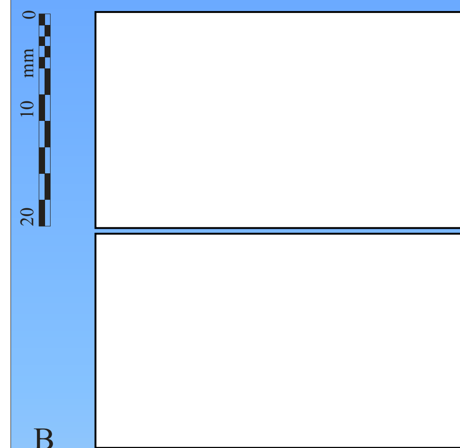
Eel Shelf Sedimentary Fabrics



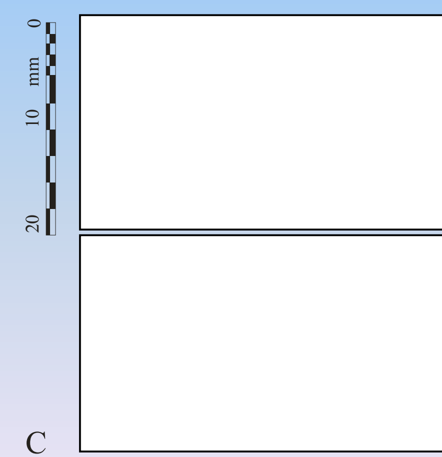
M9707 S60PC
Sediment Bulk Density



W9606 S60PC
26-30.5 cm

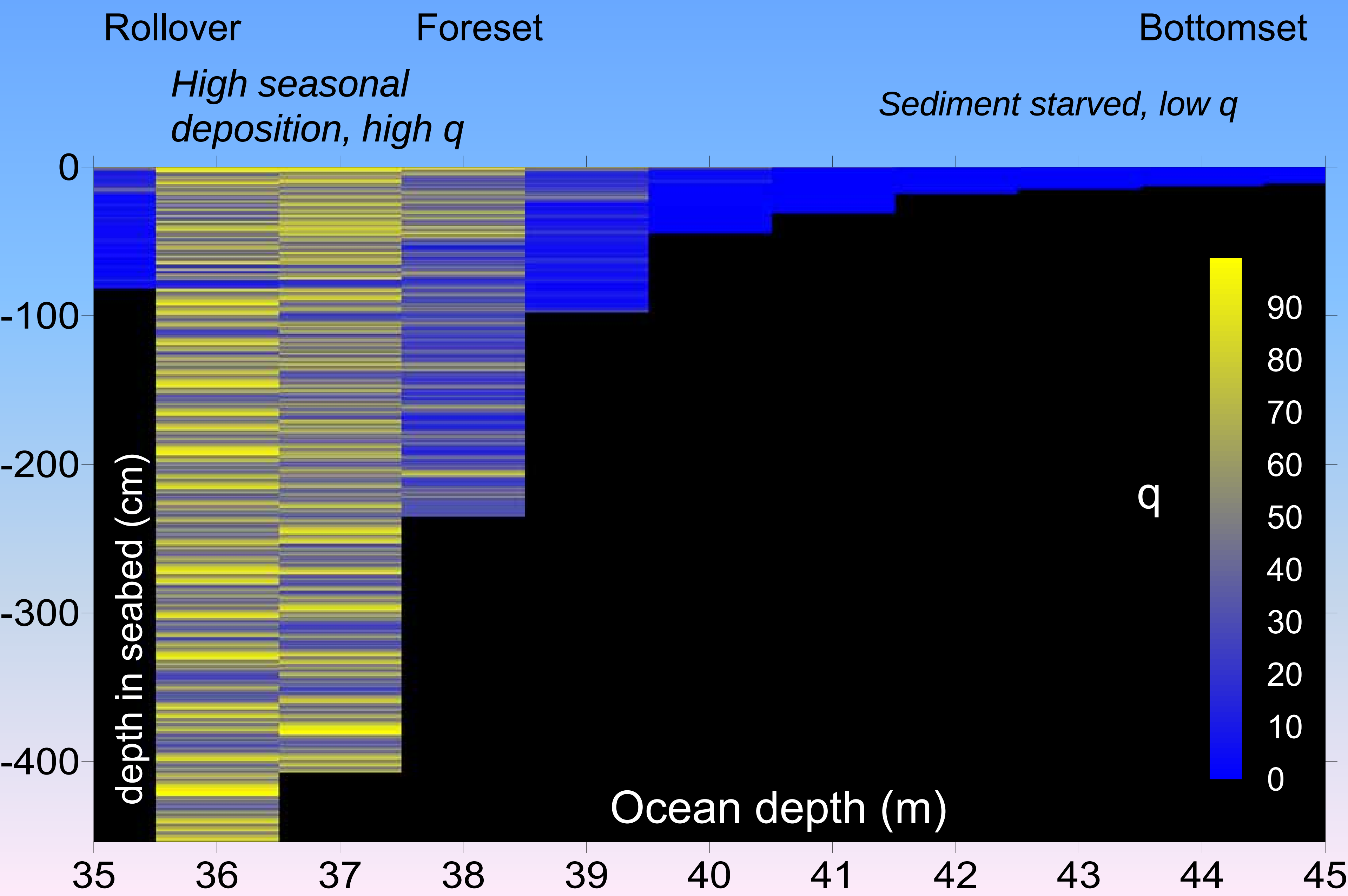


W9606 S60PC
293.5-295.75 cm

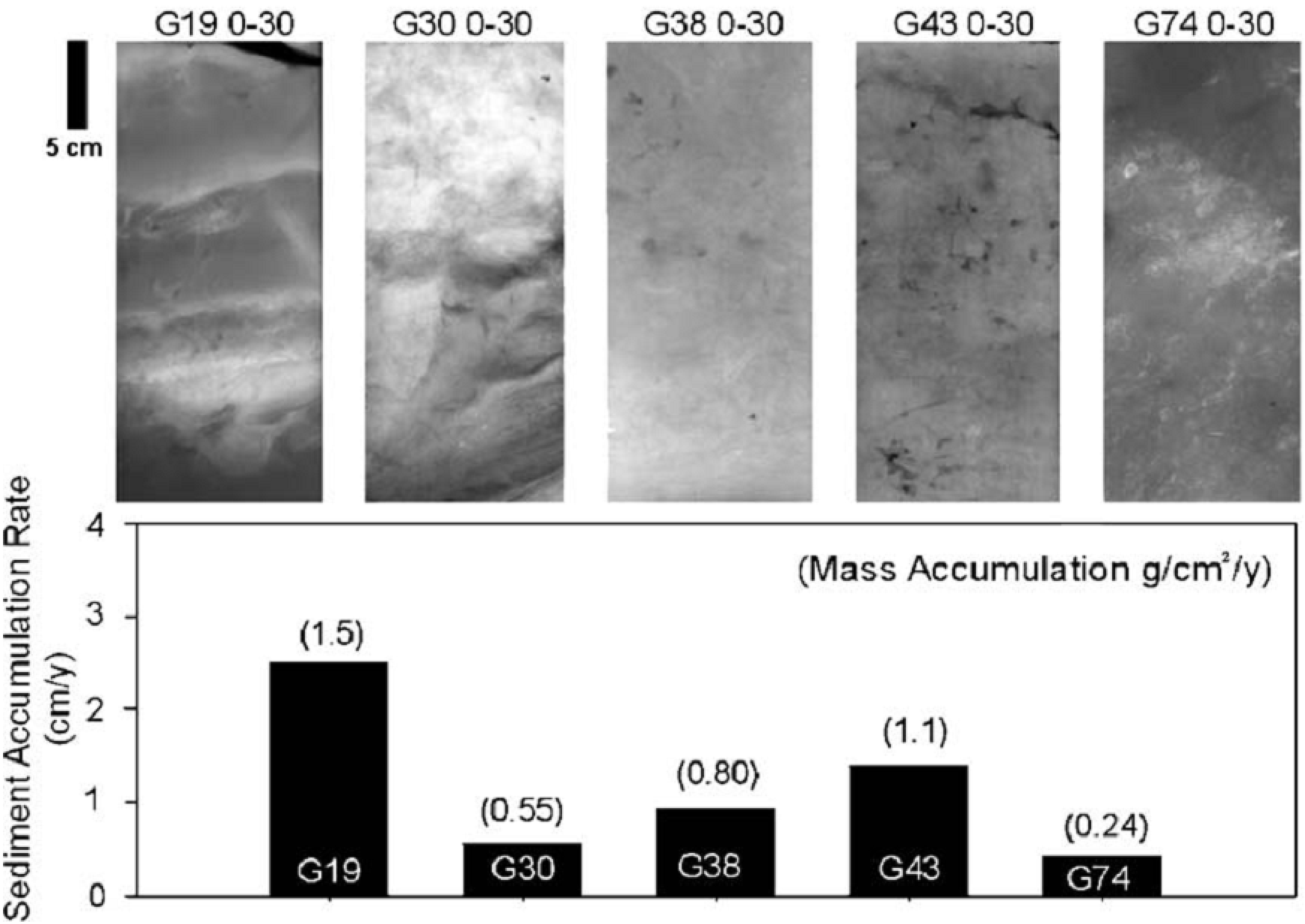


(various Wheatcroft, Bentley papers)

GoP Clinoform 100y, monsoon/trade forcing



Cross-shelf transect, Walsh et al. 2004



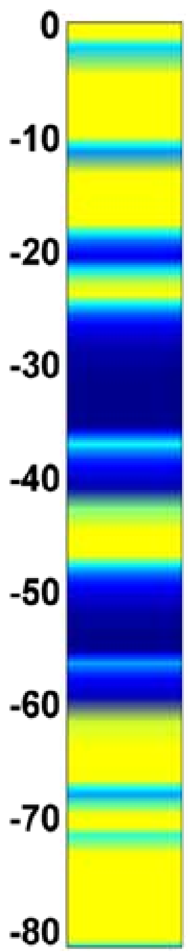
Waiapu Simulations, Observations

Ma et al. 2008: strong currents support gravity flows to >100m

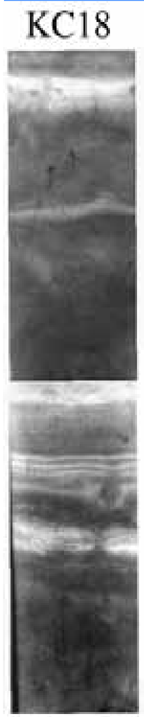
Analytical WESGF model cannot capture complexity

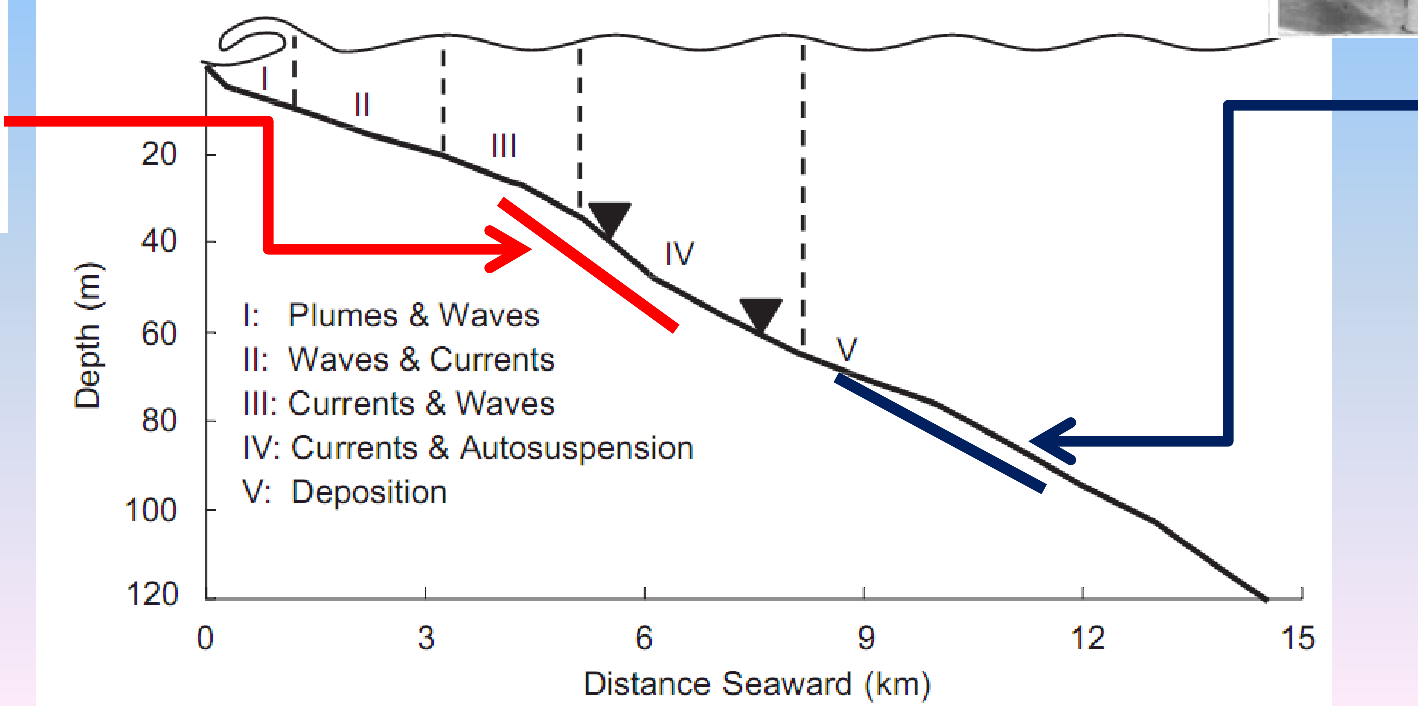
BUT

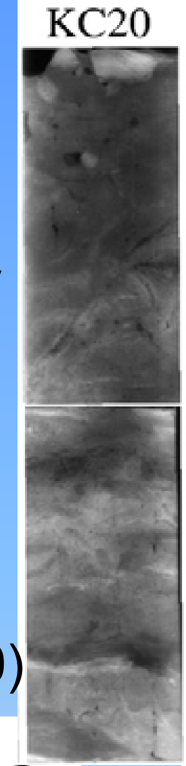
q model tuned to Pb-210 sed. rates replicates fabric observed by Kniskern et al. (2010)

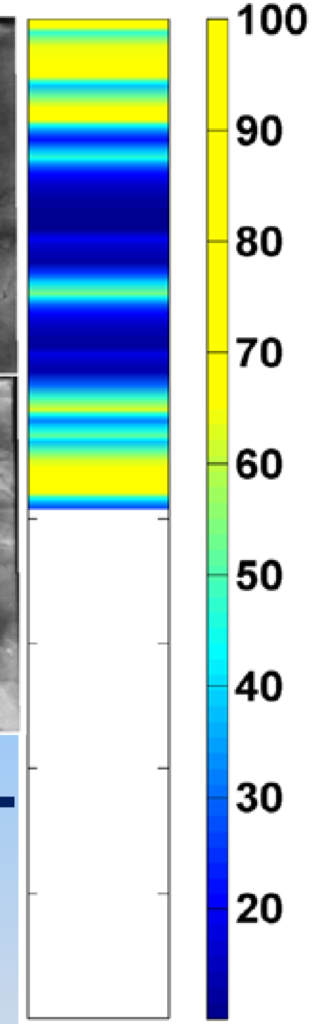


(core depth cm)









q

So what does this tell us?

Predicted fabric distributions look like we think they should.
Models employing oceanographic process measurements can faithfully capture important geological properties.

Bioturbation overprints primary fabric for all but highest burial rates
(Perhaps no surprise to some of us but . . . .)

We can now simulate these bed properties using simple models over outcrop/core scales, in multiple dimensions

Needs more work.
These models are a good start and are computationally efficient,
But also overly simplistic
(i.e., bioturbation functions, *d(slope)/d(t),* wave and current complexity and influence, gridding artifacts, high short-term deposition rates)

And finally,

<u>A way forward . . . .</u>

As we learn more about how bioturbation changes fluid flow, organic content, and physical properties in mudstones, we can begin to:

•***consider a wider range of hypothetical processes, conditions***

•***more reliably predict resultant facies/property distributions***.

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