Storm-dominated diatomite: transport and deposition from micro-texture

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Abstract

Diatomite acts as a locally important reservoir rock, resource for biostratigraphy, and in Pisco Basin, Peru is often associated with the burial of fossil marine vertebrates. Unusually thick accumulations of diatomite occur throughout the Mio-Pliocene around the Pacific margin, and models accounting for their deposition focus on high diatom productivity sufficient to overcome siliciclastic dilution. However, the diatomite and diatomaceous mudstone deposits of the Pisco Basin show longitudinally bedded hummocky and swaley cross-stratification interpreted to reflect a dominance of storm deposition. Other notable facies include laminated swale drapings, sometimes associated with fossil cetacean burial, and faintly laminated to structureless diatomite. In addition to diatoms, these deposits are primarily composed of silt, smaller quartz and feldspars, and volcanic ash.

This study focused on formation and interpretation of storm-generated microtextures from a variety of diatomaceous mudstones of the Pisco Basin using data collected from oriented thin sections, SEMs of fractured rock surfaces, and in three dimensions using micro-CT (5 μm resolution). Low-angle and sometimes truncated micro-couplet laminae and lenses were observed within hummocky and swaley, and swale draping deposits. These contain a basal, normally graded siliciclastic silt component capped in diatomite. Large diatom fragments, complete valves, and broken-up diatom mats occur within a micromatrix (<30 μm) of highly fragmented diatomaceous debris. Micro-couplets often show reverse grading in pore size with greatest porosity in the intraskeletal pores of diatomaceous caps. Faintly laminated to structureless diatomite shows a greater quantity of complete valves, supporting sparse grains of floating, siliciclastic silt. These are interpreted as diatomaceous tempestites and a model is proposed for diatomite and diatomaceous mudstone deposition above storm wave-base under waning storm surge.

Geologic Setting

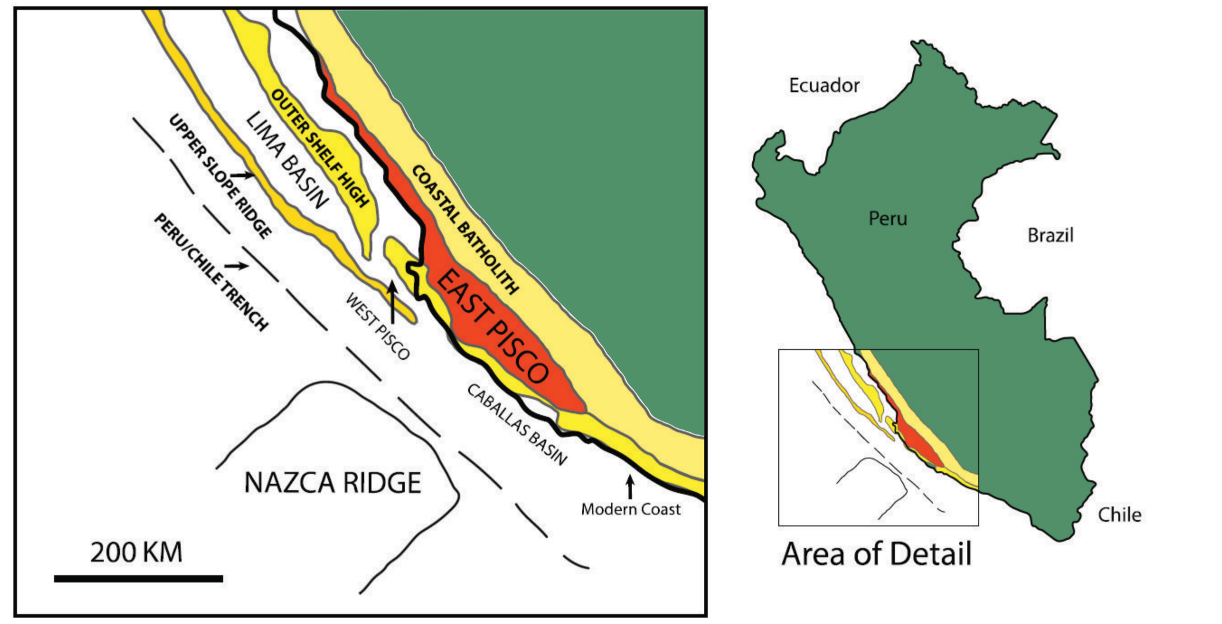


Figure 1. Overview of study area, the East Pisco (orange), and associated structural features. During the Mio-Pliocene, the East Pisco formed a shallow embayment protected by the Outer Shelf High, sandwhiched between it and the Andean Coastal Batholith.

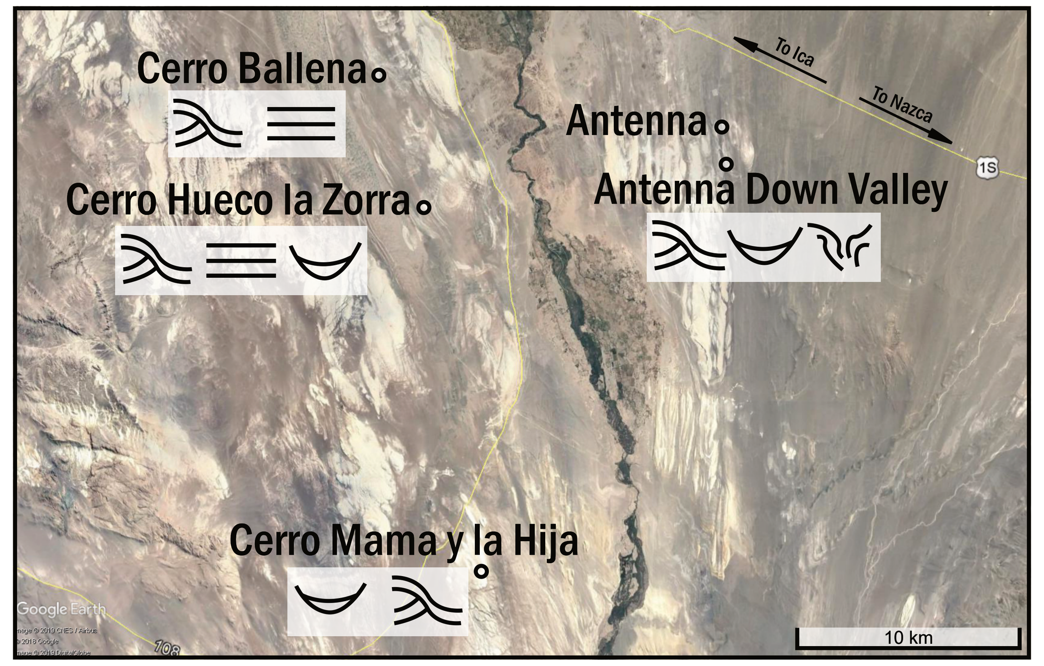


Figure 2. Satellite image of East Pisco, locations visited, and facies observed at each. Strong ocean upwelling and high productivity have been invoked in the past to explain the thick accumulations of diatomaceous sediments within the basin (Brand 2004).

Cerro Ballena / Cerro Hueco la Zorra

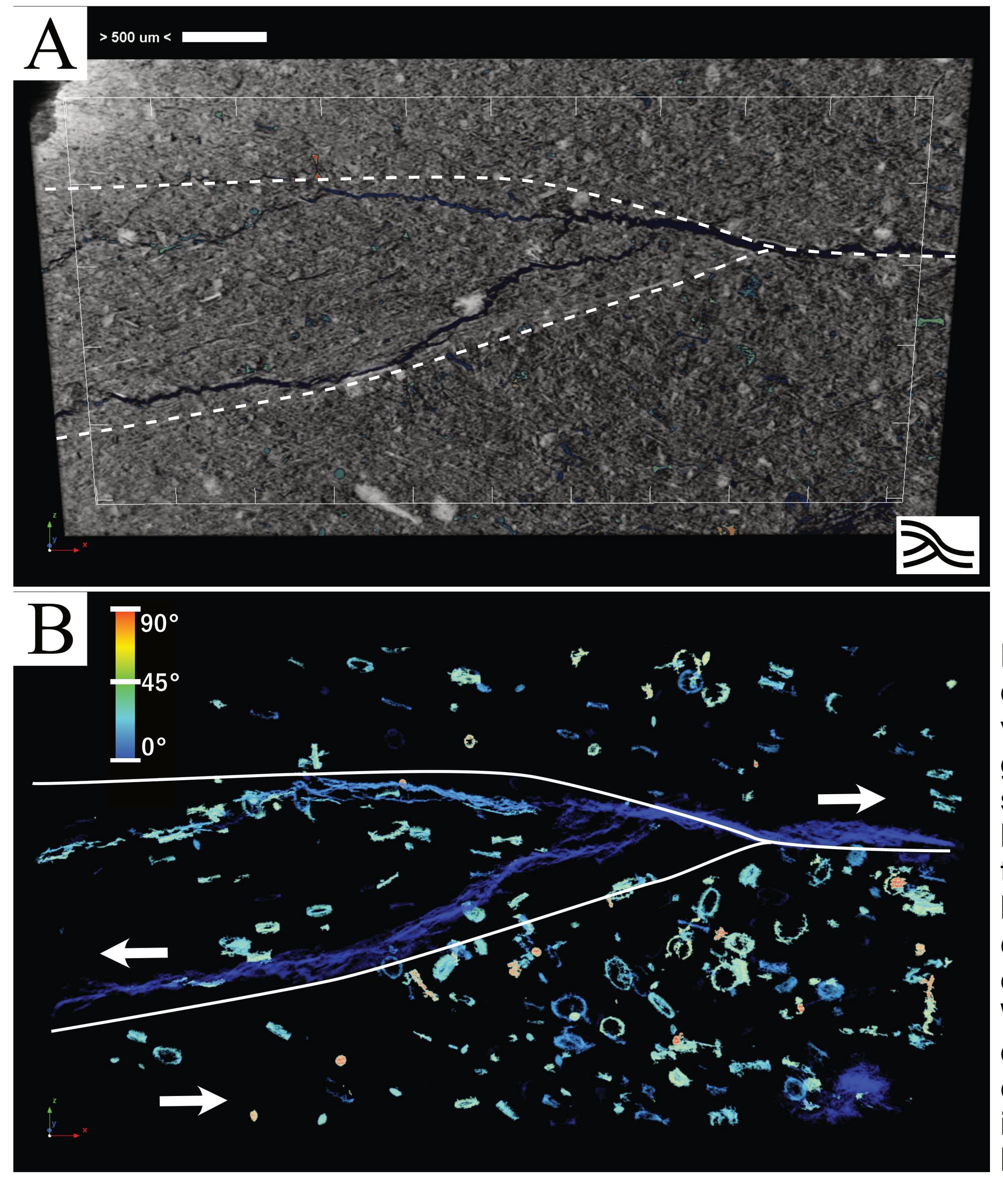
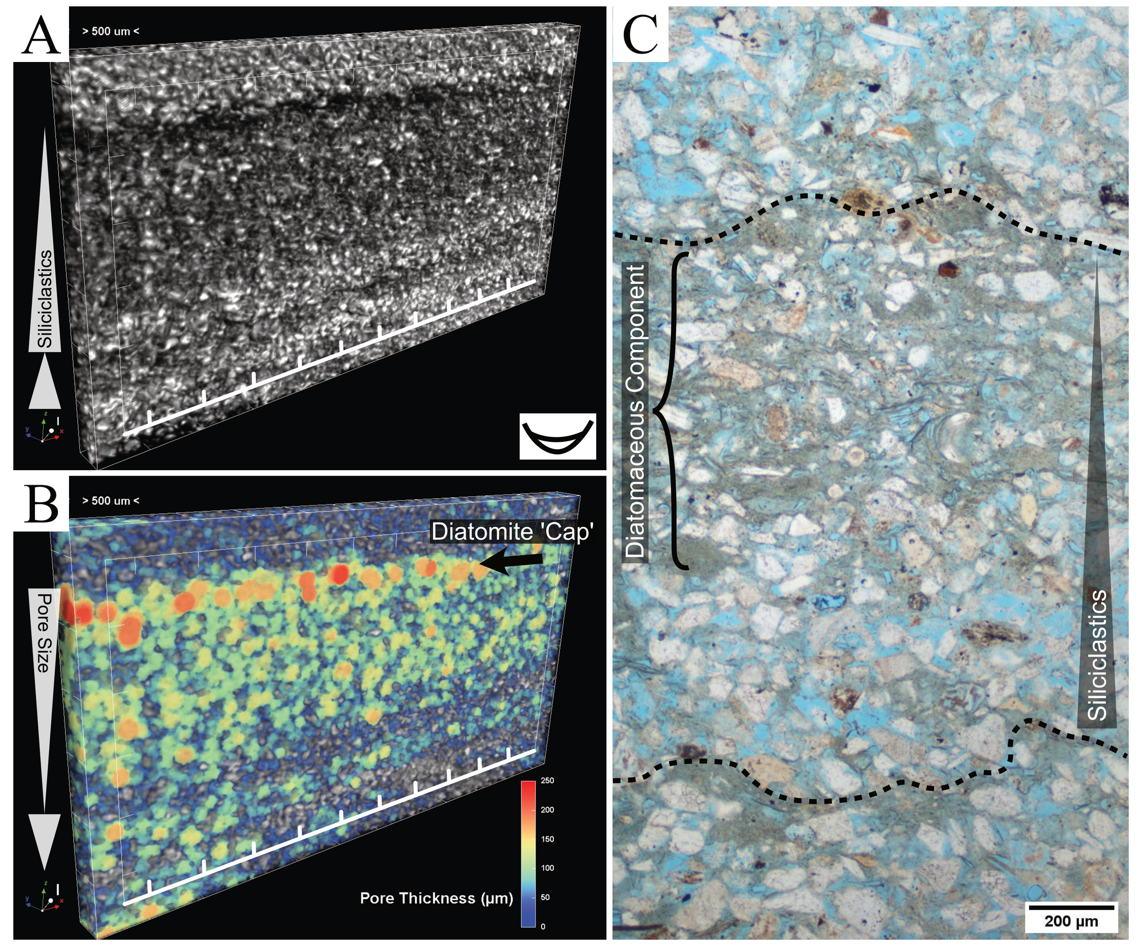


Figure 3.1 Outcrop view of faintly laminated diatomite from Cerro Ballena, originally interpreted as planar laminated but later revised to low angle HCS/SCS (note arrow). Signs of truncation are often subtle in the Pisco diatomite, but prevenlant under careful inspection nonetheless.

Figure 3.2 Micro-CT scan of low-angle HCS/SCS diatomite from Cerro Hueco la Zorra showing surface view of block with three domains of oriented platy grains, outlined by dashed lines (A). Lower image shows a 3D model with the matrix subtracted, highlighted to isolate large, uncompacted centrics by the 'rings of porosity' created by their resistant girdle bands (B). Model is about 500 μm thick. Rings are color coded for orientation to visualize lamina geometry (blue elements are near horizontal, red are near vertical). White arrows indicate bulk dip direction for their given domain (toward the left or right). An image of a similar centric diatom can be seen in Figure 5.3, with individuals about 200 μm across. Cracks are artificial but trend along truncation surfaces.

Cerro Mama y la Hija



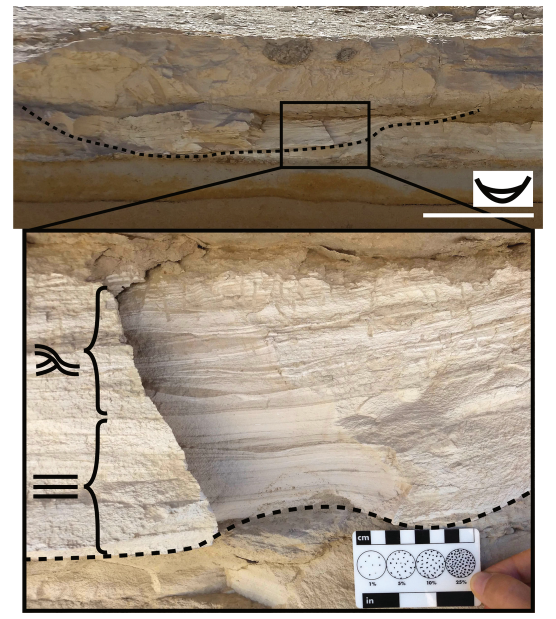


Figure 4.1 Outcrop view of interlaminated siltstone-diatomite swale draping. Basal swale swour is followed upward by largely planar lamination, capped with small-scale HCS/SCS. Top is truncated and bioturbation is present. White scale bar is 1 meter (top image).

Figure 4.2 Micro-CT scan showing internal arcitecture of interlaminated channel drapes of Cerro Mama y la Hija, revealing graded micro-couplets of basal silt fining upward into finer silt-diatomite (A). A 'heatmap' of pore size can be seen in (B), used to illustrate reverse graded pore size within couplets, with greastest porosity within the diatomite 'caps'. A thin section from the same sample showing but different couplet can be seen in (C). Silt sequestrations oberserved here mimic experimental textures created by Yawar and Schieber (2017) in unidirectional flume experiments illustrating the generation of silt lamina in mudstones. This may suggest that the unidirectional component of combined flow most influences texture while combined flow influences macroscopic architecture.

Antenna / Antenna Down Valley

Overview: Characteristic lithology for both locations consists of diatomite intermixed with ash. Amalgamated HCS/SCS accompanied by extensive soft-sediment deformation is common. Exaggerated swales and gutter casts are common as well, somtimes bearing sand-pebble lags and whales at thier bases.

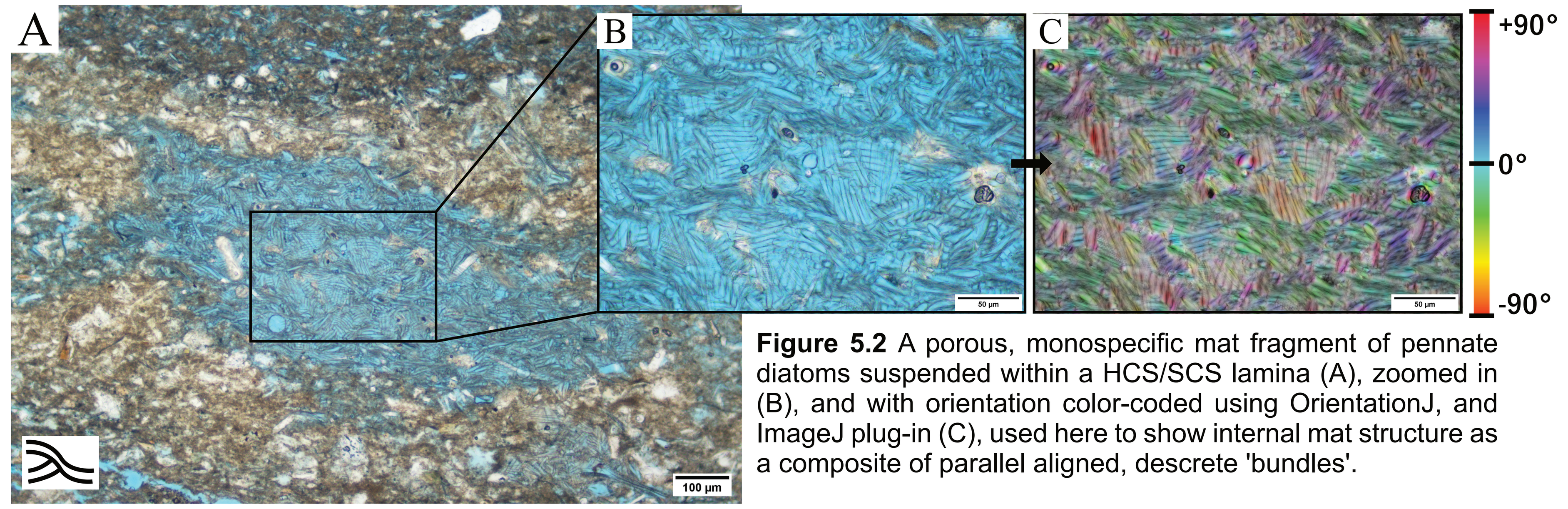


Figure 5.2 A porous, monospecific mat fragment of pennate diatoms suspended within a HCS/SCS lamina (A), zoomed in (B), and with orientation color-coded using OrientationJ, and ImageJ plug-in (C), used here to show internal mat structure as a composite of parallel aligned, descrete 'bundles'.

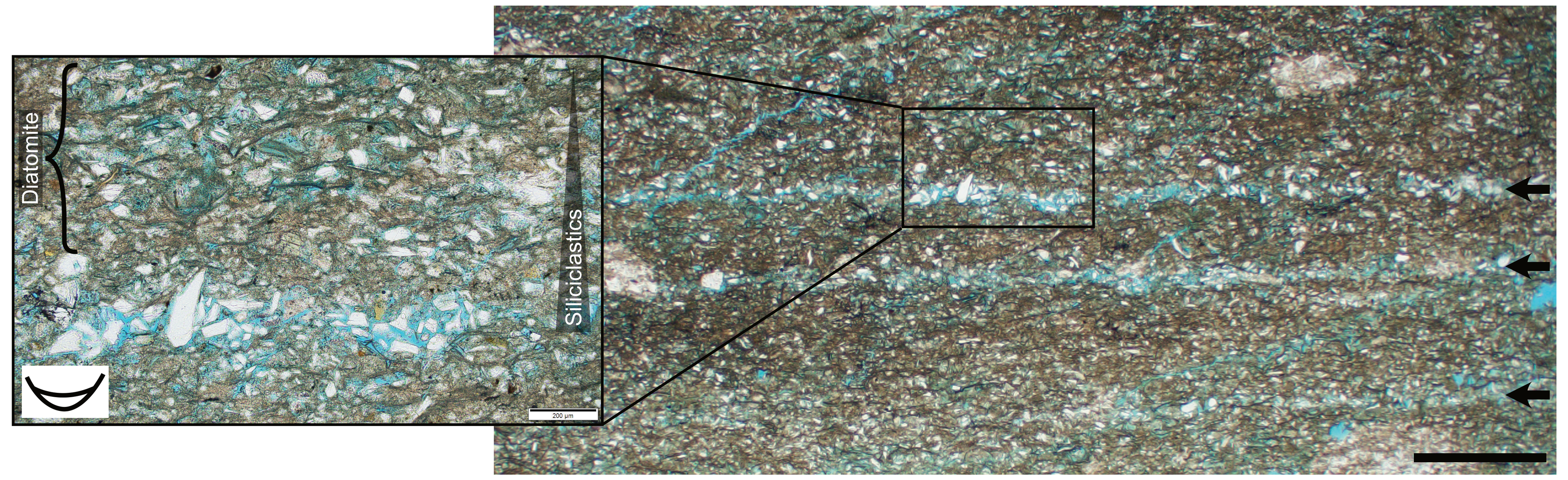


Figure 5.1 Sequestrations of coarser silt into lamina (arrows) within a channel draping. Note similarity to Figure 4.2, but more diatomaceous. In Pisco diatomite, it is relatively difficult to find samples that do not exhibit sequestrations of coarse silt into lamina or lenses at a textural level, even in macroscopically massive samples. Scale bar is 1 mm.

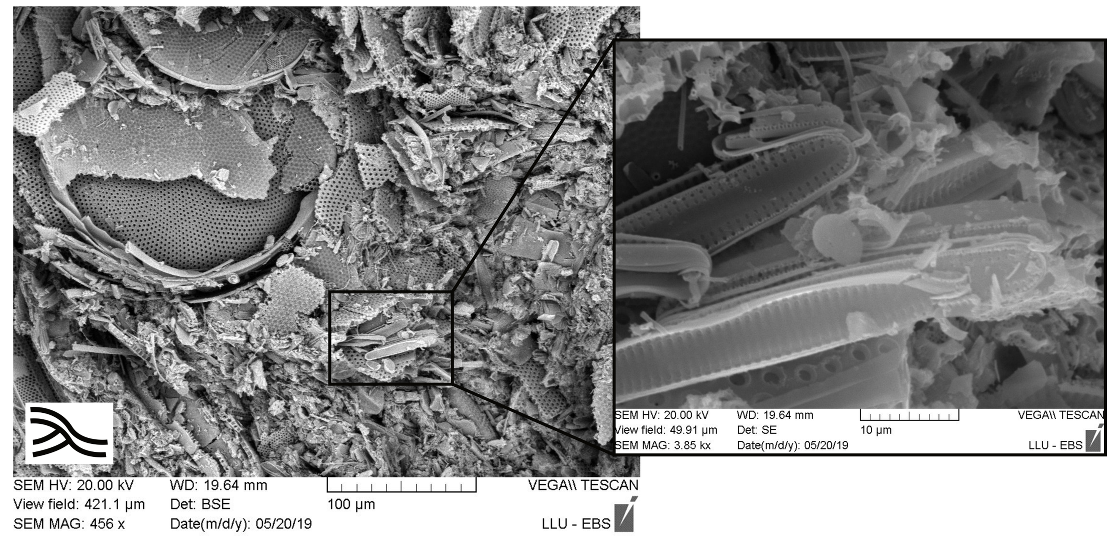


Figure 5.3 SEMs showing HCS/SCS matrix, diatomaceous debris with few in-tact individuals (left). Zoomed in (right), isolated mat fragments as parallel aligned 'bundles' were found in many samples, suggesting widespread mat break-up.

East Pisco's Offshore Transition Zone Under Storm Conditions and Combined Flow

or

"Ye Olde Diatoms in Unreasonable Abundance"

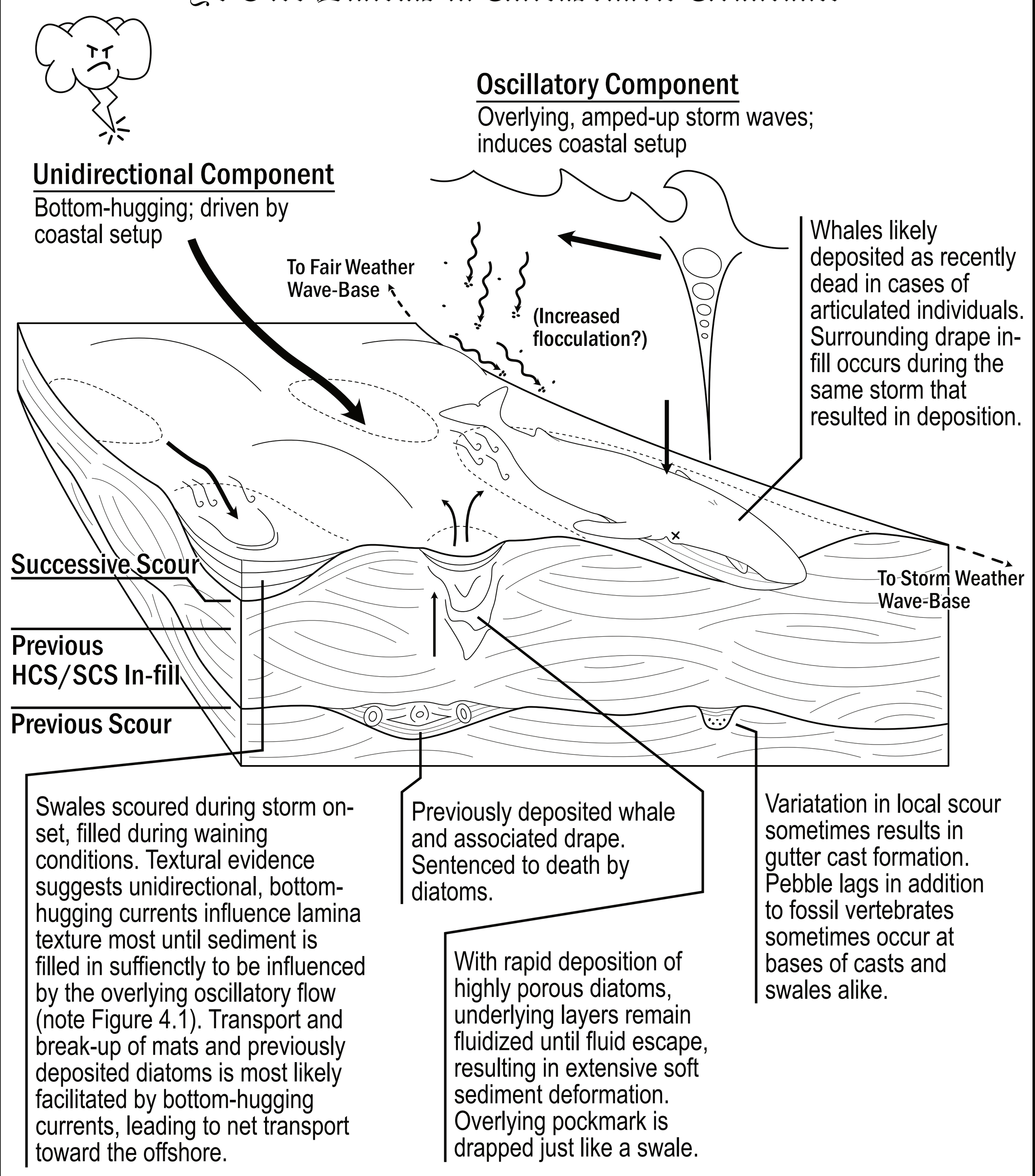


*Diagram based on Antenna / Antenna Down Valley

Closing remarks: SCS tends to dominate over HCS, suggesting a prevalance of scour over deposition overall. This may also be an indicator that diaotmite can deposit toward the shoreward end of the offshore transition zone, closer to fair weather wave-base, where SCS is thought to be more prevalent over HCS (Dumas 2006).

On the generation of silt lamina, with regard to texture, Yawar and Schieber (2017) proposed that courser silt drops out of clay floccules as they migrate and collide during bedload transport, leaving a courser silt 'lag' overlain by clay and finer silt. While texturally similar, obvious signs of diatom flocculation (apart from mat fragments) remain unapparent in Pisco diatomite, likely overwritten by compaction and other post-depositional processes. Thus, the precise mechanism that would allow such a fine-grained and porous medium to deposit under inclement conditions remains a mystery.

Symbol Legend

- Swale Drapes
- Hummocky-Swaley Cross Stratification (HCS/SCS)
- Planar Lamination
- Soft Sediment Deformation

References

Brand, L. R., et al. (2004). Fossil whale preservation implies high diatom accumulation rate in the Miocene–Pliocene Pisco Formation of Peru. Geology, 32(2), 165-168.

Dumas, S., & Arnott, R. W. C. (2006). Origin of hummocky and swaley cross-stratification—The controlling influence of unidirectional current strength and aggradation rate. Geology, 34(12), 1073-1076.

Yawar, Z., & Schieber, J. (2017). On the origin of silt laminae in laminated shales. Sedimentary geology, 360, 22-34.