Monterey Formation Lithofacies: Linking a Complex Story of Deposition and Diagenesis to Help Unravel Stratigraphic Relationships*

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Abstract

The Monterey Formation is well known as a heterogeneous fine-grained rock of significant economic interest. Its role as a reservoir, source rock, and seal has been documented in many studies. Much less work has been done, however, trying to understand and use individual lithofacies associations for the purpose of stratigraphic evaluation, and ultimately predicting lithofacies distributions.

Casual workers often assume a relatively simplistic process of pelagic settling of biogenic material as the primary depositional process. The Monterey, however, contains a significant component of fine-grained terrigenous clastics. Mud and mudstone studies over the past few decades revealed a range of transport processes, from hypo- and hyperpycnal flows to dilute gravity flows, that distribute fine-grained sediments far into the basin. Both the fine-grained clastics and biogenic components are stripped from the water column and delivered to the seafloor by flocculation, organic aggregation, and biogenic pelleting. Muds on the sea floor are subject to reworking by a variety of bottom currents. The Monterey contains evidence of all these processes.

After deposition, diagenesis takes over within the first meter of burial. Diagenetic reactions are a function of sediment composition as well as rate of burial and pore water chemistry. Precipitation from pore waters can account for greater than 50 percent of the rock volume for some bedsets.

The resultant lithofacies and lithofacies associations are diagnostic of depositional environment. The lithofacies associations, including stratal stacking patterns, change laterally moving from one basinal environment to another. We can improve our predictions of source, reservoir, and seal by looking more closely at basic rock data and using proxies such as well logs and seismic data to map lithofacies distributions relative to specific depositional environments.

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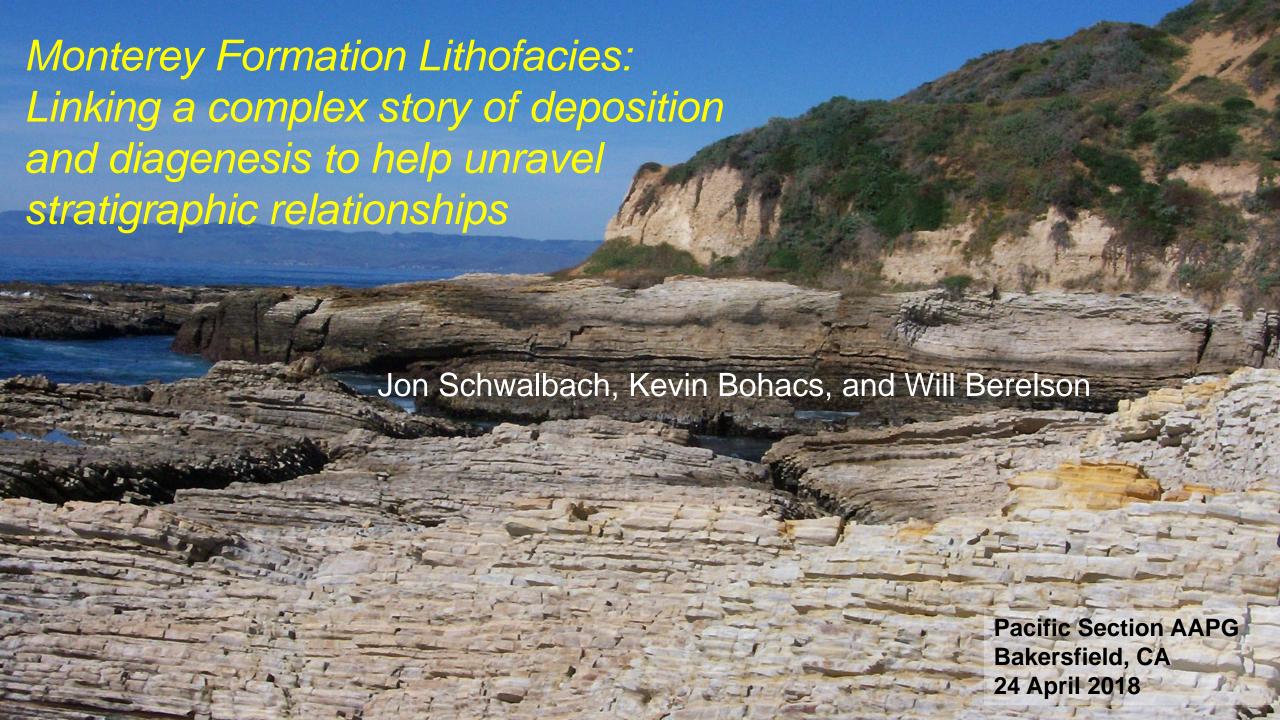
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Pelagic Rain?









The Road Map

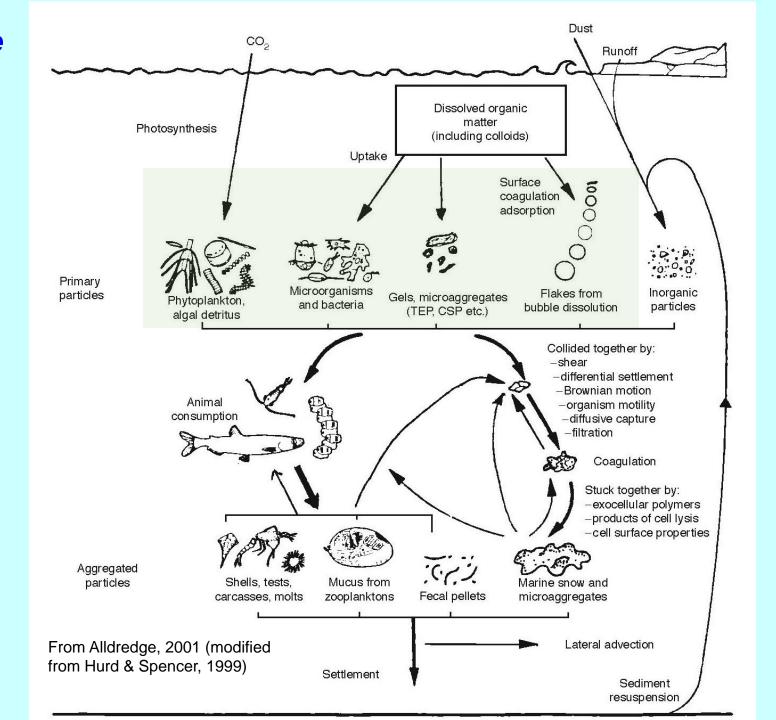
- Depositional Processes
 - Organic and Inorganic Components
 - Distribution Mechanisms, Patterns
- Diagenesis
 - Burial and Silica Phase Changes Obscure Dep'l Fabric
 - Early-formed Cements (Phosphate, Dolomite) Provide Clues About Dep'l Processes
- Stratigraphic Applications (Correlation)
- Map Patterns Related to Depositional Environment

Fine-grained sediment gets to the seafloor through a series of complex mechanisms

Most nonliving organic matter traveling from the surface to the deep sea sinks not as individual particles, but in the form of large fecal pellets & large aggregates of organic detritus

- Primary particles can be transformed biologically into fecal pellets, molts, and mucus feeding webs through the feeding activities of zooplankton
- Particles collide with each other and stick together to form progressively larger aggregates through the physical process of coagulation

(Slide modified from M. Keller, pers. comm.)



Fine-grained sediment gets to the seafloor through a series of complex mechanisms

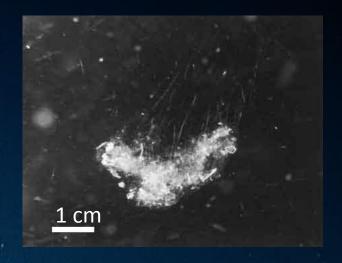
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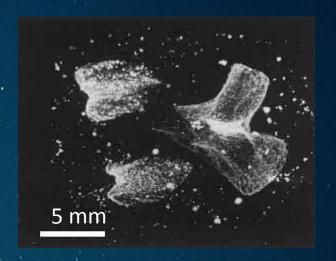
- Primary particles can be transformed biologically into fecal pellets, molts, and mucus feeding webs through the feeding activities of zooplankton
- Particles collide with each other and stick together to form progressively larger aggregates through the physical process of coagulation

CO Runoff Dissolved organic matter Photosynthesis (including colloids) Uptake Surface coagulation adsorption Primary Flakes from Inorganic particles Gels, microaggregates and bacteria bubble dissolution particles (TEP, CSP etc.) algal detritus Collided together by: -differential settlement Brownian motion organism motility consumption -diffusive capture filtration Coagulation Stuck together by: exocellular polymers products of cell lysis -cell surface properties Aggregated Mucus from particles Marine snow and zooplanktons Fecal pellets microaggregates From Alldredge, 2001 (modified Lateral advection from Hurd & Spencer, 1999) Settlement Sediment resuspension

(Slide modified from M. Keller, pers. comm.)

Marine Snow example, GOM





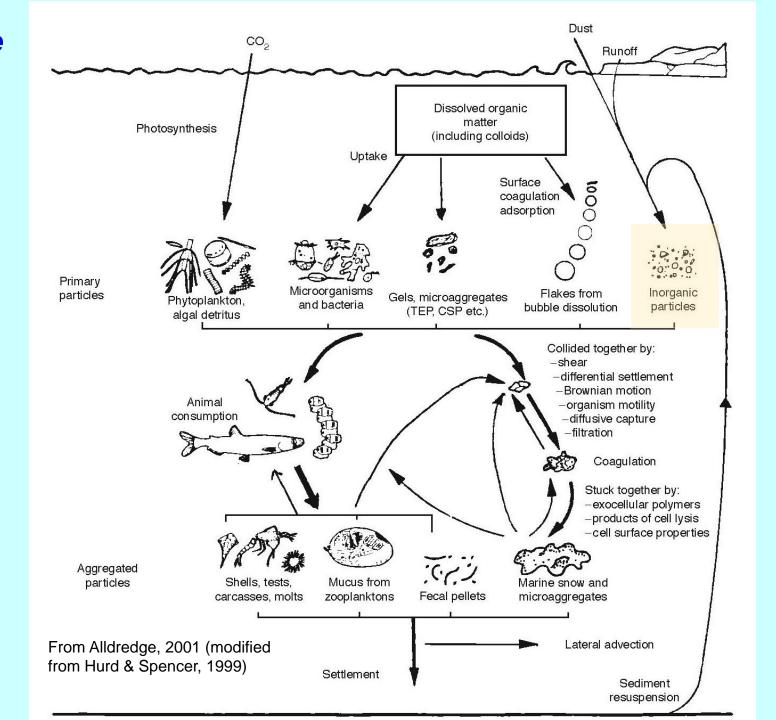
Inserts from Alldredge, 2001

Fine-grained sediment gets to the seafloor through a series of complex mechanisms

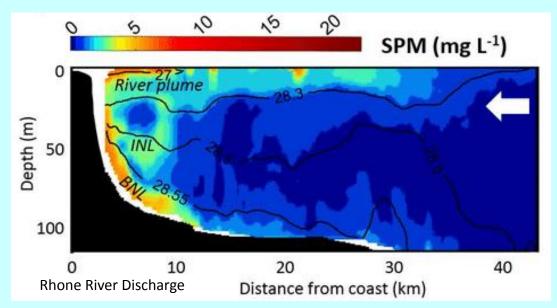
Most nonliving organic matter traveling from the surface to the deep sea sinks not as individual particles, but in the form of large fecal pellets & large aggregates of organic detritus

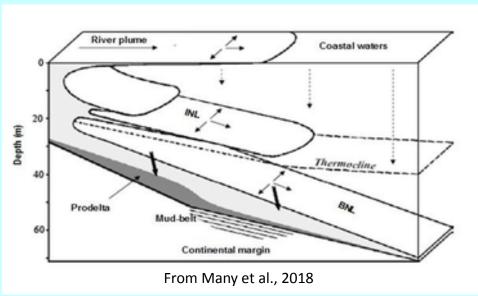
- Primary particles can be transformed biologically into fecal pellets, molts, and mucus feeding webs through the feeding activities of zooplankton
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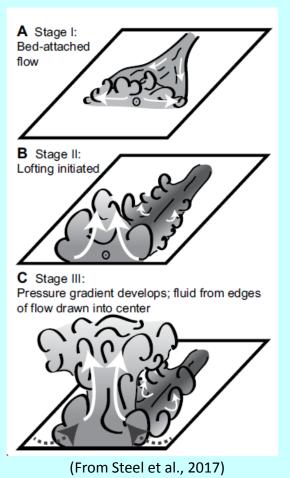
(Slide modified from M. Keller, pers. comm.)



Inorganic Particles Are Typically Transported by Hypo and Hyperpycnal Plumes







Lofting from Buoyancy Reversal of Turbidites

Plumes can persist for 100's of kms from sediment source

Aeolian contributions can also be important locally

Fine-grained sediment gets to the seafloor through a series of complex mechanisms

Most nonliving organic matter traveling from the surface to the deep sea sinks not as individual particles, but in the form of large fecal pellets & large aggregates of organic detritus

- Primary particles can be transformed biologically into fecal pellets, molts,
- Particles collide with each other and stick together to form progressively larger aggregates through the

Primary Flakes from Inorganic particles Gels, microaggregates and bacteria bubble dissolution particles (TEP, CSP etc.) algal detritus Collided together by: -differential settlement Brownian motion and mucus feeding webs through the organism motility consumption diffusive capture feeding activities of zooplankton filtration Coagulation Stuck together by: exocellular polymers products of cell lysis -cell surface properties physical process of coagulation Aggregated Mucus from particles Marine snow and Fecal pellets zooplanktons microaggregates From Alldredge, 2001 (modified Lateral advection from Hurd & Spencer, 1999) Intermediate and bottom currents (Slide modified from M. Keller, pers. comm.) Settlement

CO

Photosynthesis

Runoff

Dissolved organic matter

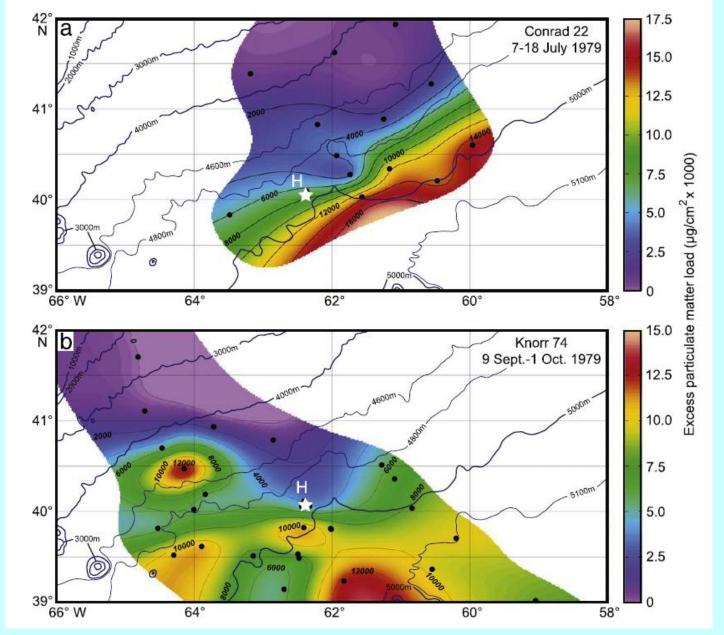
(including colloids)

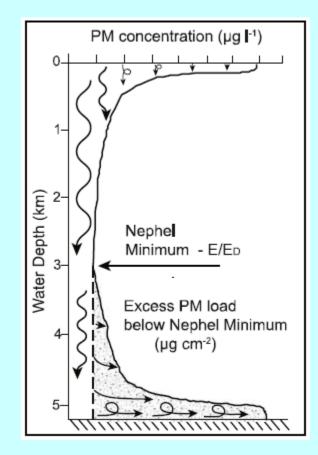
Surface

coagulation adsorption

Uptake

Western North Atlantic Benthic Nepheloid Layer PM Distribution



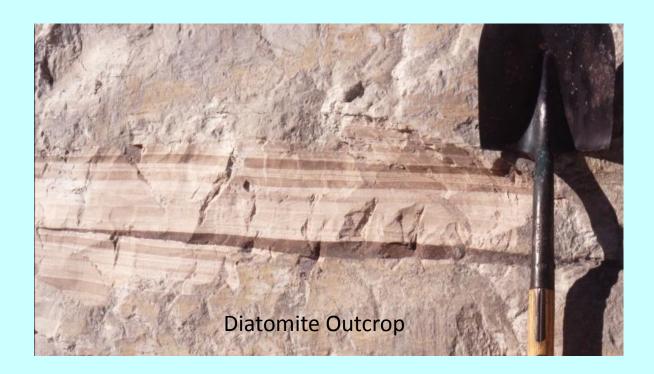


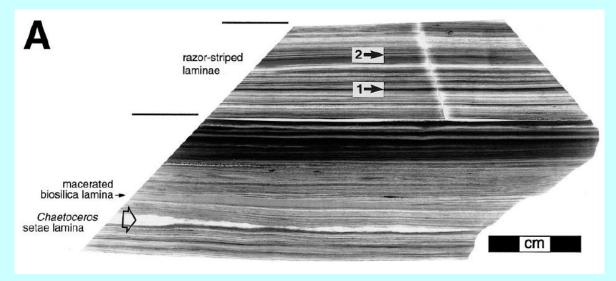
- General Downslope Increase in Concentration
- Implication: highest depositional rates in the center of small basins and sub-basins like the Miocene California margin

From Gardner et al., 2017

Burial and Silica Diagenesis

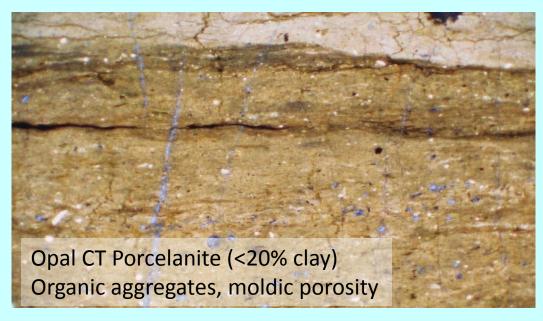
- Burial compaction and silica phase transitions obscure initial depositional fabric and geometry.
- Diatomite outcrops are least impacted, and serve as good analogs for altered sediments.
- Chang, Grimm, White and others worked with diatomite samples to document initial lamina composition and depositional textures.



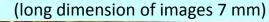


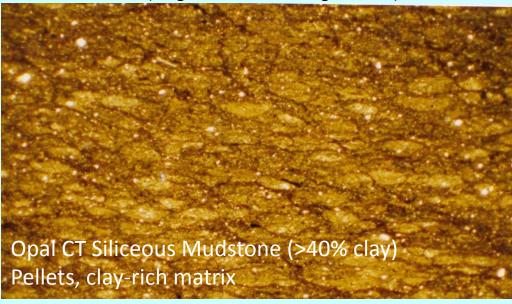
X-radiograph of diatomite slab from Chang, Grimm, and White, 1998

Thin Sections of Opal CT and Quartz Phase Monterey Lithofacies











Early Cement/Nodules Provide Clues to Depositional Conditions

Development of Cement/Nodules

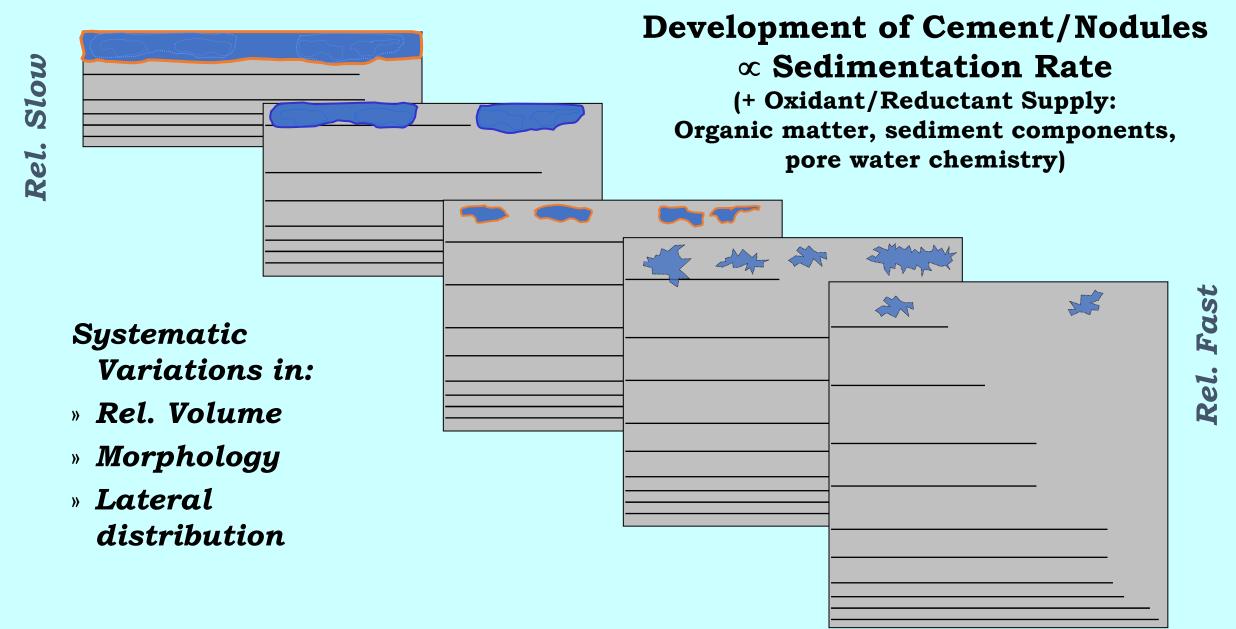
∞ Sedimentation Rate

Systematic Variations in:

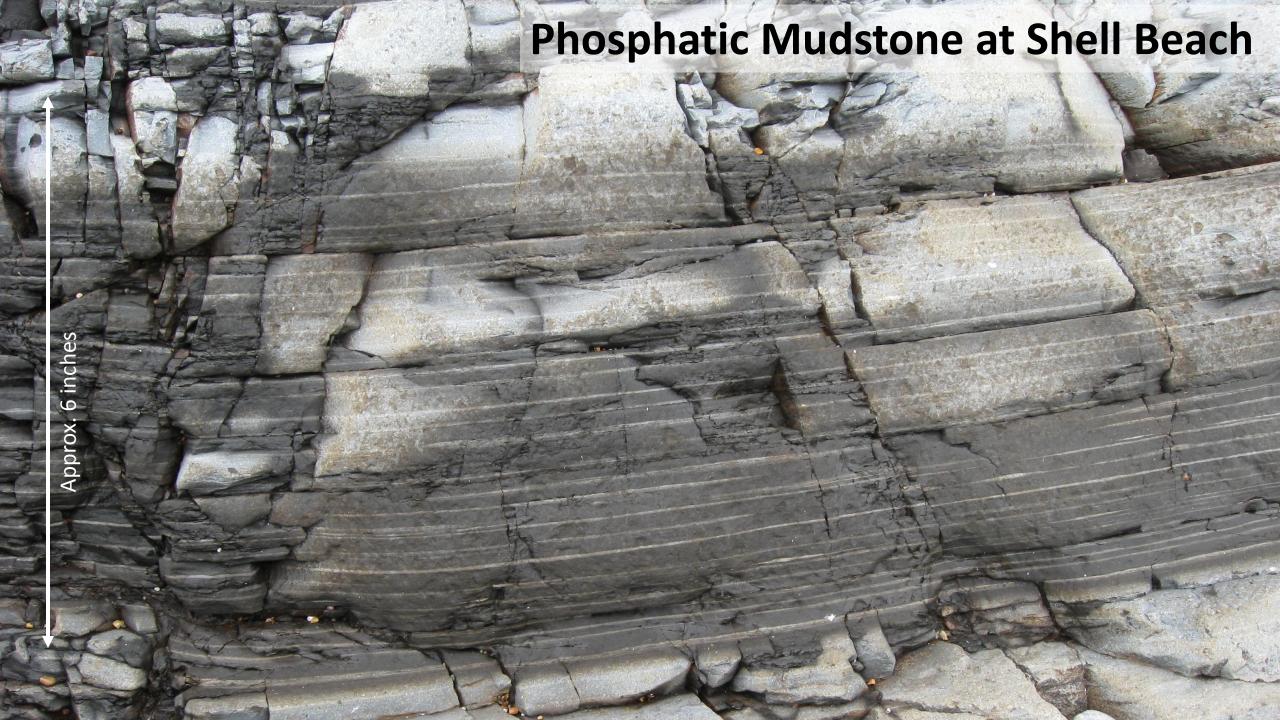
- » Rel. Volume
- » Morphology
- » Lateral distribution

Generally Phosphate and Dolomite in the Monterey Formation

Development of Early Cement/Nodules



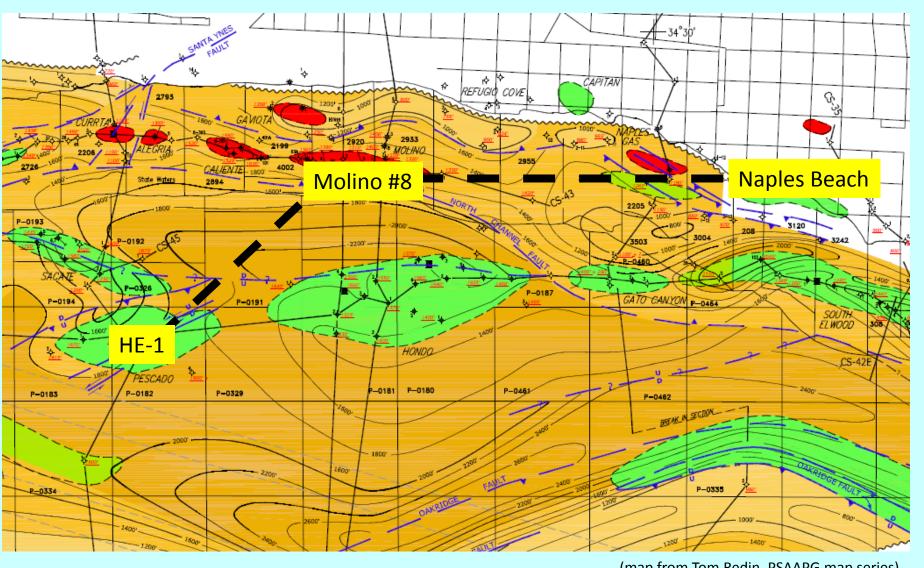








Stratigraphic Correlation: Santa Barbara Channel



Monterey Isopach Map

Gas Fields



Oil Fields



Contour Interval 200'

Line of Section

3 miles



Schematic Stratigraphic Section: Santa Barbara Channel

Monterey sediments

Period of pop-deposit

Period of non-deposition or erosion

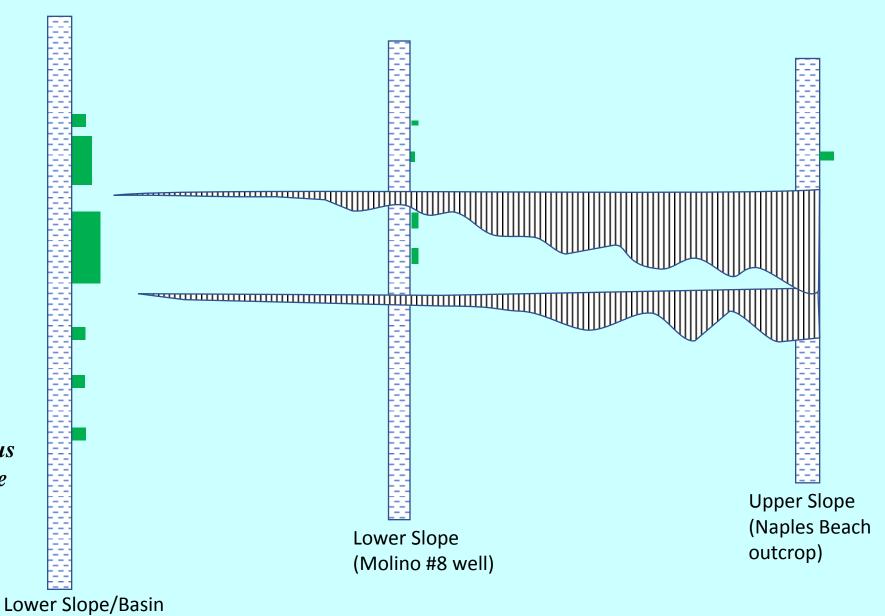
Chert

Upper Slope – thinnest, condensed intervals and erosional surfaces, phosphatic and siliceous mudstone, slump/debris flows

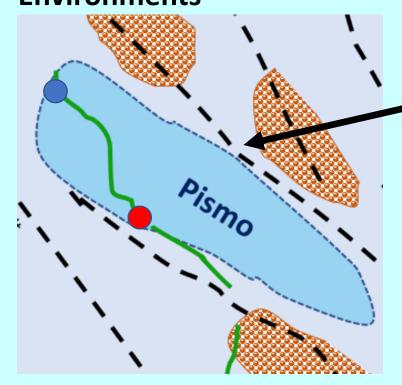
Lower Slope – expanded section, phosphatic and siliceous mudstone, dolomite, porcelanite

Basin Depocenters - thickest section, biosiliceous, chert, porcelanite

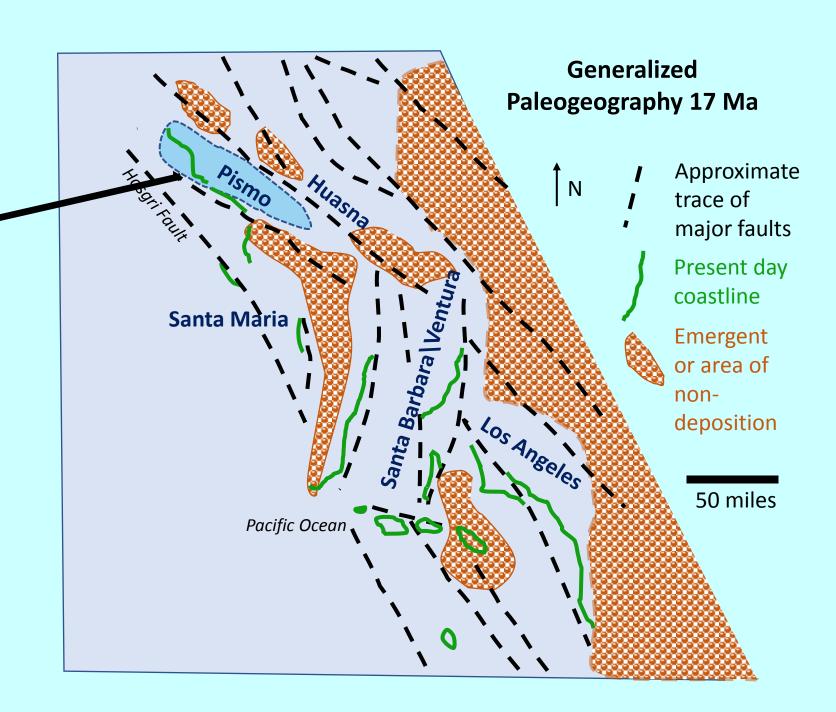
(He-1 well)

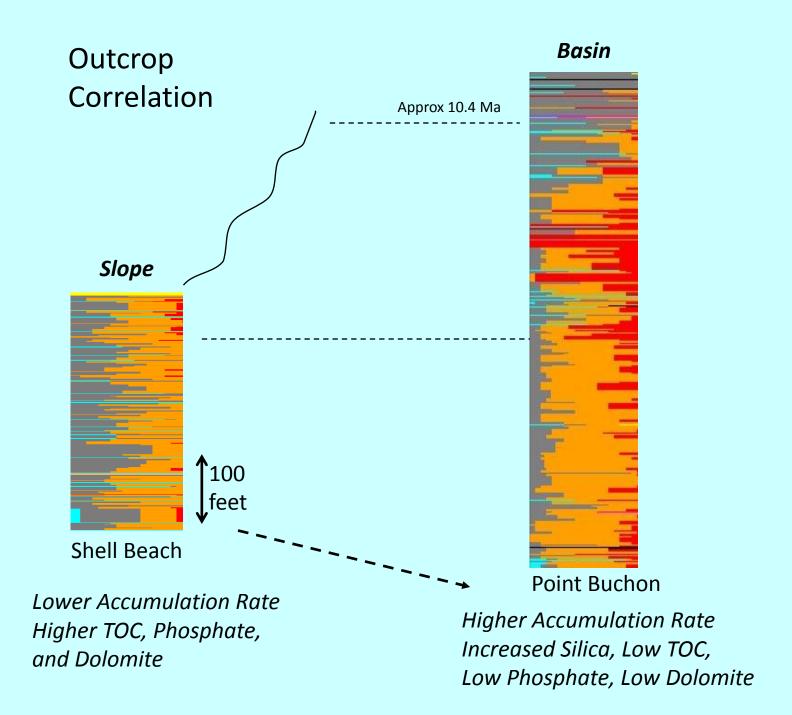


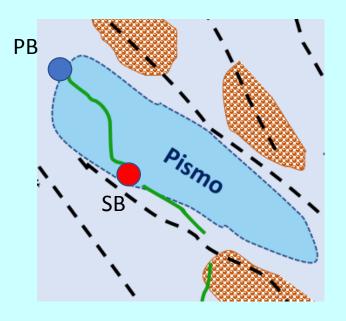
Compare Lithofacies from Different Depositional Environments

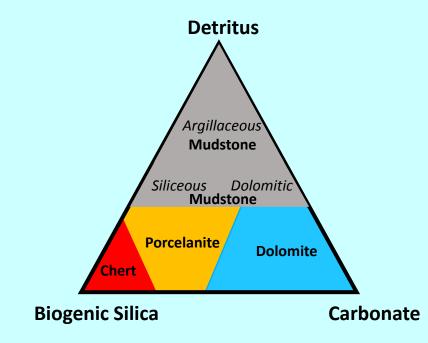


- Shell Beach, Slope
- Point Buchon, Basinal



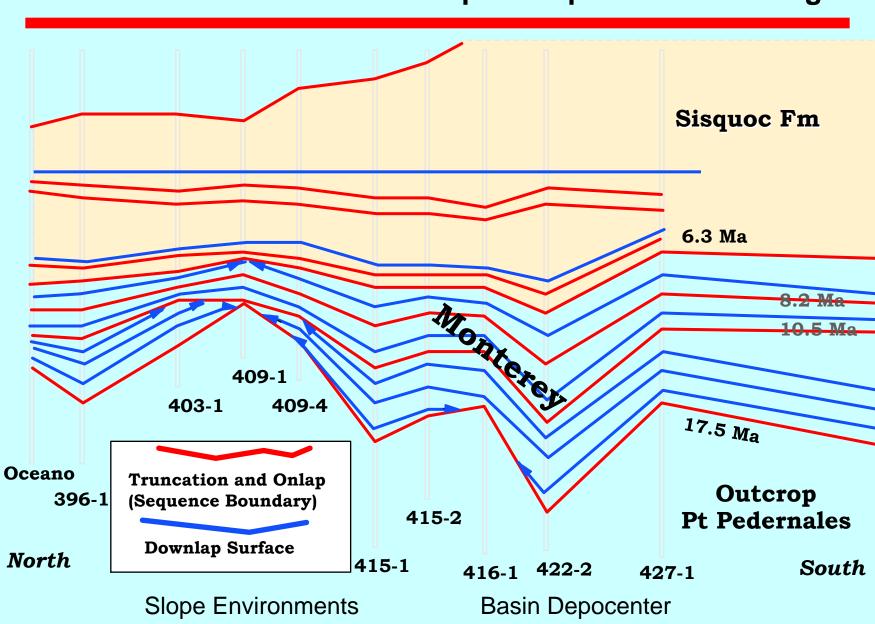




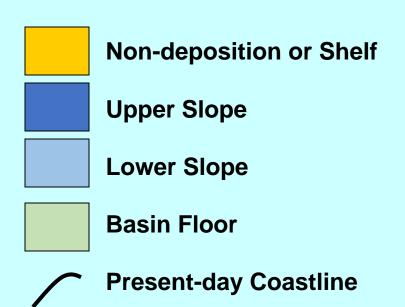


Well-log Cross Section Santa Maria Basin Example: Slope – Basin Setting

- Comparison and ID of Facies Trends Requires Comparing Time-Equivalent Strata
- We Use a Sequence
 Stratigraphic
 Approach to Map
 Equivalent Intervals
 from Different
 Depositional
 Environments
- (Come to the SEPM
 Garrison Research
 Conference in Santa
 Cruz in a couple
 weeks to hear more
 about this!)



Map of Upper Monterey Paleogeography and Depositional Environments

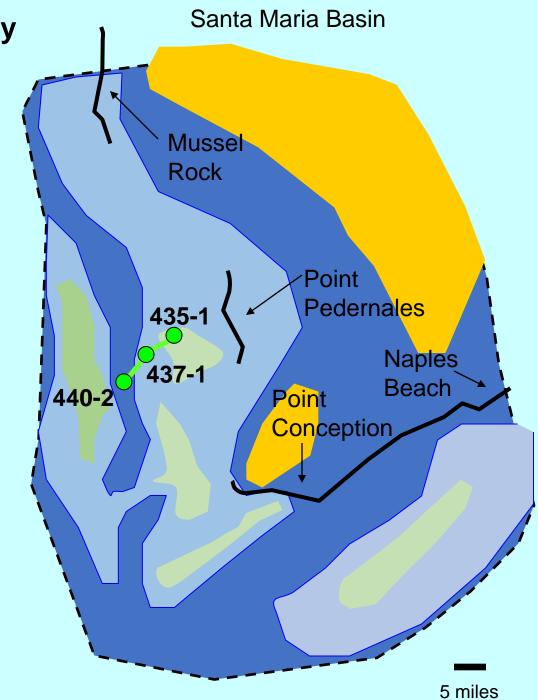




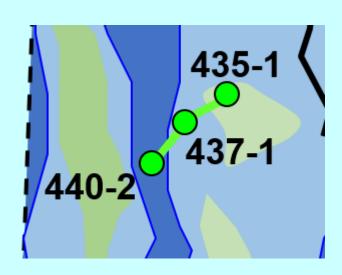
Upper Slope – *440-2*

Lower Slope – *437-1*

Basin Depocenter – 435-1

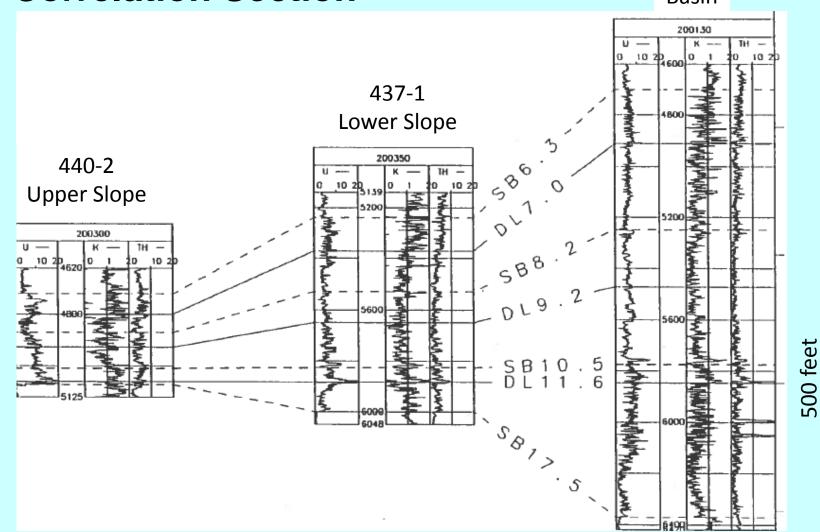


435-1 Basin



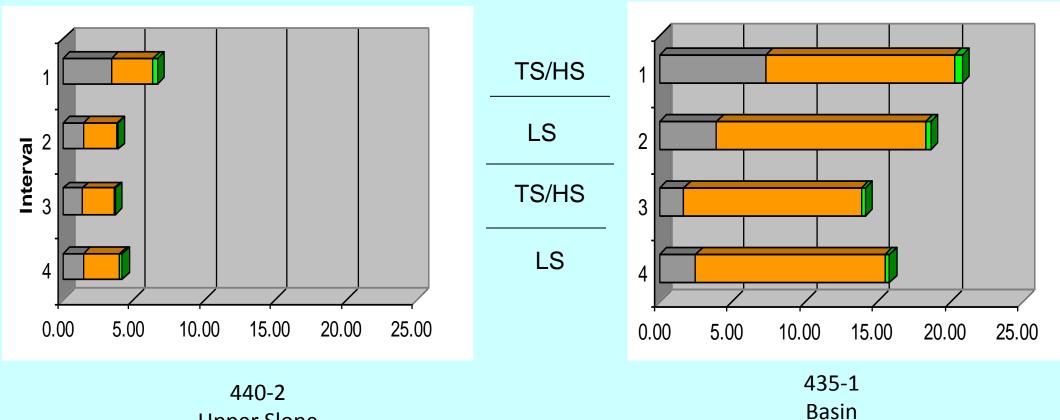
Simplified Log Model Uses Gamma-Ray and Bulk Density Logs to Estimate Sediment Components (Ignores Carbonates)

- U → TOC
- K → Detritus



Assume Remainder is Biogenic Silica

Well-Log Calculated Sediment Accumulation Rates (mg/cm²/yr) by Systems Tract and Depositional Environment



Upper Slope

Detritus Bio Silica TOC

Highest Accumulation Rates in Basin Driven by Biogenic Silica

The Message

- Spending a little time to review the fundamentals, in this case depositional processes and diagenesis, can help guide correlation and lithofacies predictions.
- Lithofacies vary in predictable patterns that can be related to depositional environment.
- A key step to lithofacies prediction is to subdivide the strata into chronostratigraphic sequences.
- The resultant maps and associated products are useful for reservoir- and source-rock-quality prediction.
- Lithofacies packages determine reservoir properties and should guide decisions to optimize drilling and completion decisions.

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