The Monterey Formation of California: New Research Directions*

Richard J. Behl[1]

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[1]Geological Sciences, California State University, Long Beach, CA (behl@csulb.edu)

Abstract

The Miocene Monterey Formation is an exceedingly heterogeneous, biogenic-rich (siliceous, calcareous and carbonaceous) deposit and only a minor fraction of its volume would be considered a true “shale”. It is California’s primary petroleum source rock and an important “conventional” reservoir in many areas, primarily exploiting naturally fractured rocks. Recently, due to its great thickness, broad areal extent and organic-richness, the Monterey was recently estimated to hold more than half of all the recoverable shale oil resources in the lower 48 states. This significance raises the following fundamental and applied research questions: How much of the Monterey’s varied lithostratigraphy reflects global vs. local environmental conditions? How do facies in the formation vary laterally? How does porosity and permeability vary with diagenetic setting and timing - not just silica phase and composition? How does diagenesis and deformation vary with depositional environment, primary composition and structural setting?

As part of the CSU Long Beach Monterey and Related Sedimentary rocks (MARS) Project, we are investigating stratigraphic, geochemical, diagenetic, and structural aspects of this important formation with the following goals: Refine the chronostratigraphy lithostratigraphy for the Monterey Formation of the San Joaquin Basin, applying chemostratigraphic, cyclostratigraphic and tephrochonologic methods. Investigate compositional variability in facies of the "Nodular Shale" or "Black Shale" of the Los Angeles Basin. Characterize Monterey lithologies and microfacies petrographically, including unusually porous diagenetic siliceous rocks. Investigate variability in genus-level composition of diatomite related to depositional environments and the influence of diatom assemblage on physical properties and diagenetic potential. Study mechanical stratigraphy in different lithologies and stratal architectures and their influence on fracture development in the Monterey Formation. Develop a genetic model of lithologic composition and cyclicity that can be predictive of mechanical stratigraphy and fracturability in different lithofacies. Hopefully, with

success in these endeavors, the Monterey Formation, with its varied composition and stratigraphic character, can serve as a valuable analog for other “shale” and non-conventional resource plays.

References

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Website

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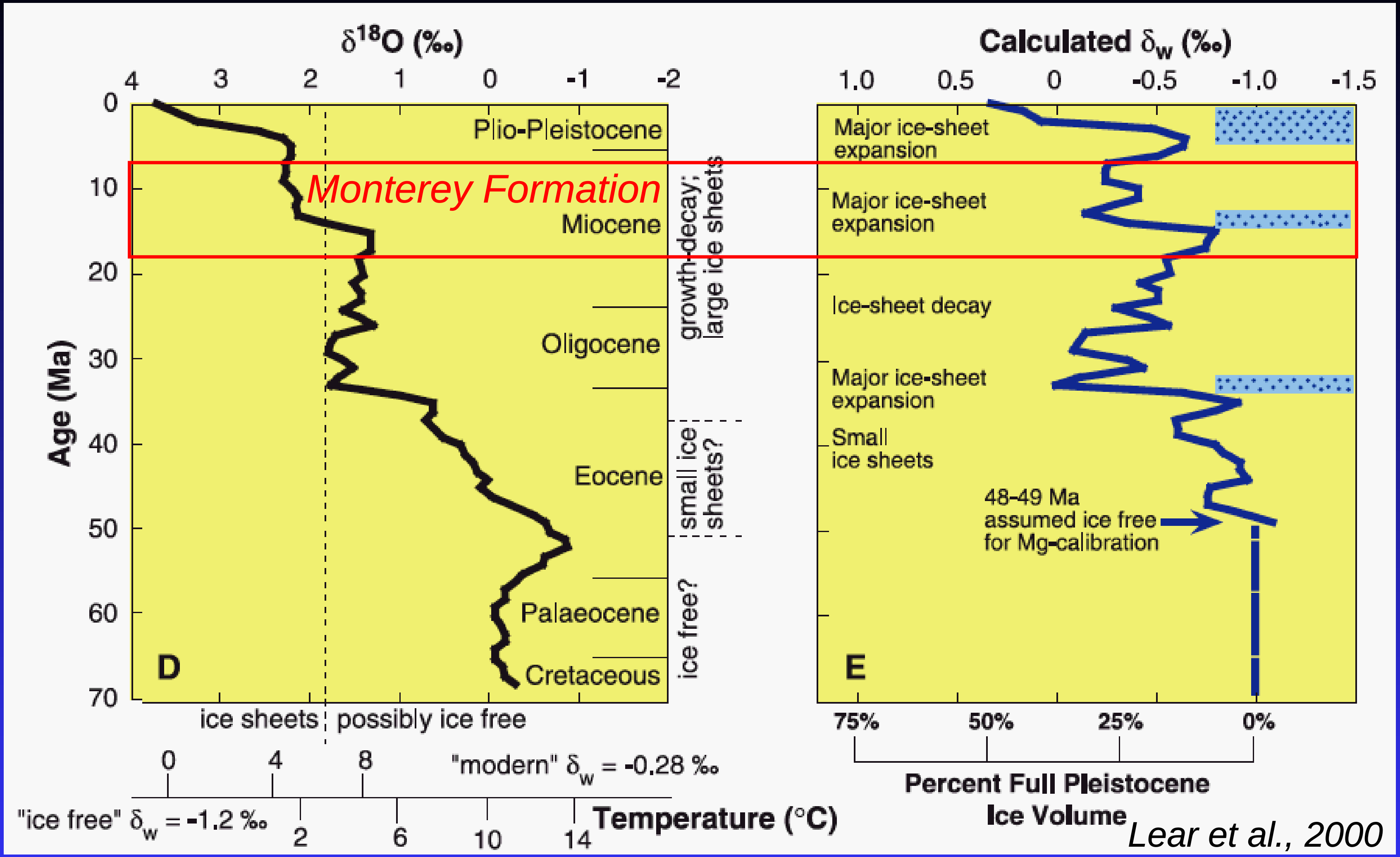
The Monterey Formation of California: New Research Directions
(some in old places..)

Richard J. Behl
California State University
Long Beach, CA

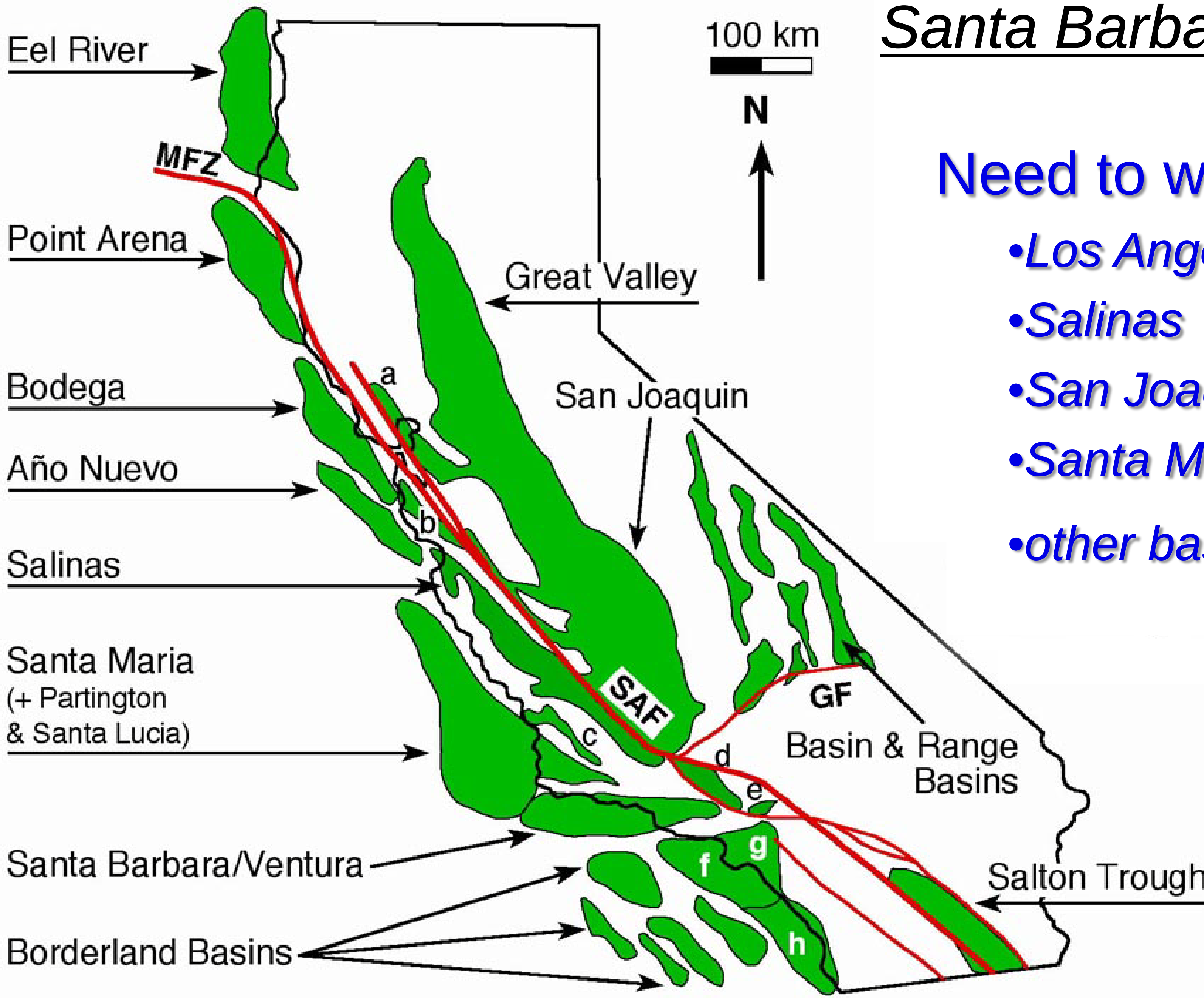
Monterey Research Directions

1. Understanding global vs. local control of lithology & stratigraphy
2. How can we better date & correlate the Monterey?
3. What really happens at the silica phase transitions?
4. Unifying genetic sedimentology with mechanical stratigraphy.



Tectonic subsidence from ~17 or 18 Ma
Global sea level rise to ~14 Ma
Ice sheet expansion ~14-12 Ma

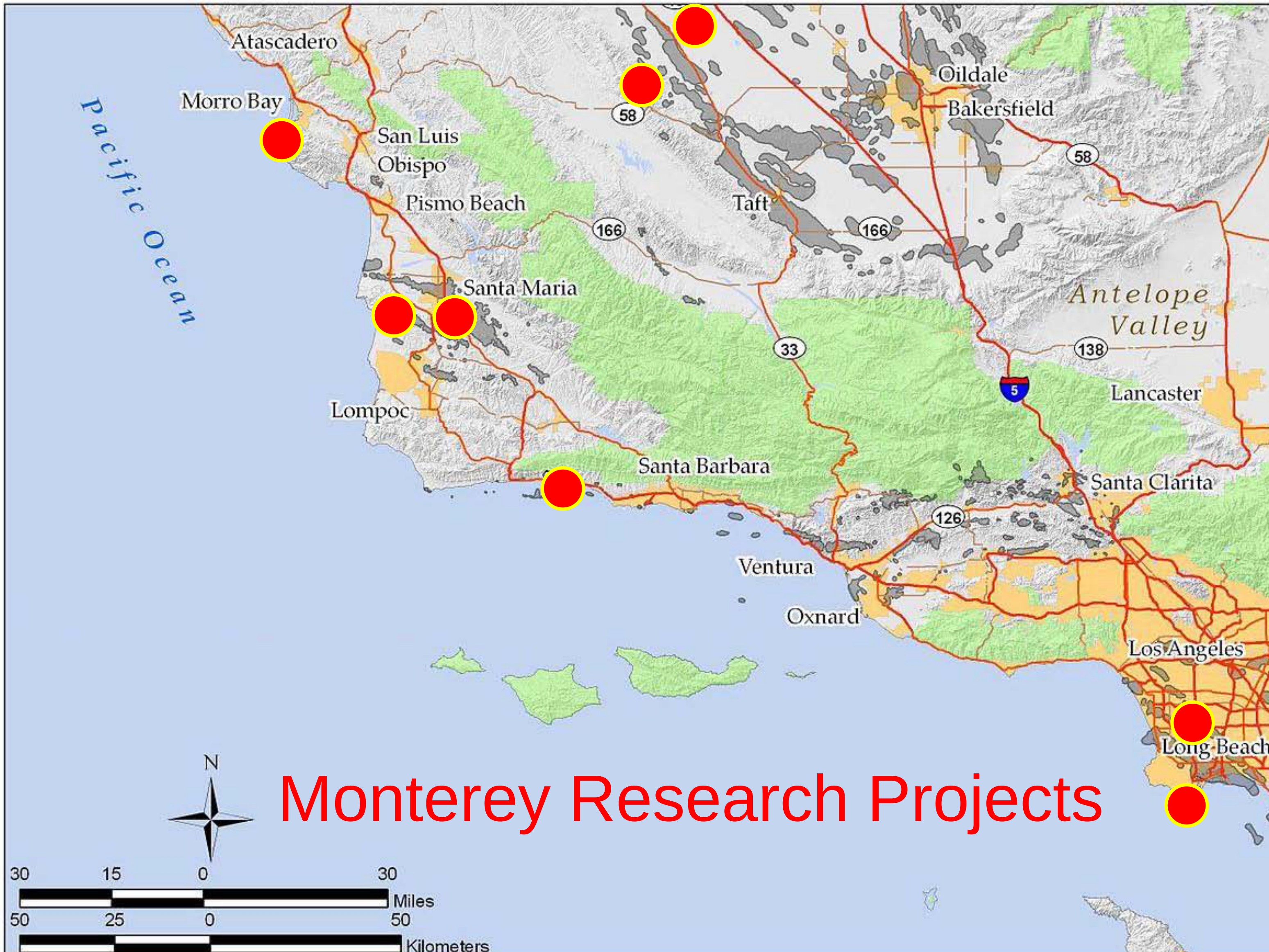
Much learned, *but too much focus on Santa Barbara Basin*



Need to work in:

- *Los Angeles*
- *Salinas*
- *San Joaquin*
- *Santa Maria*
- *other basins*

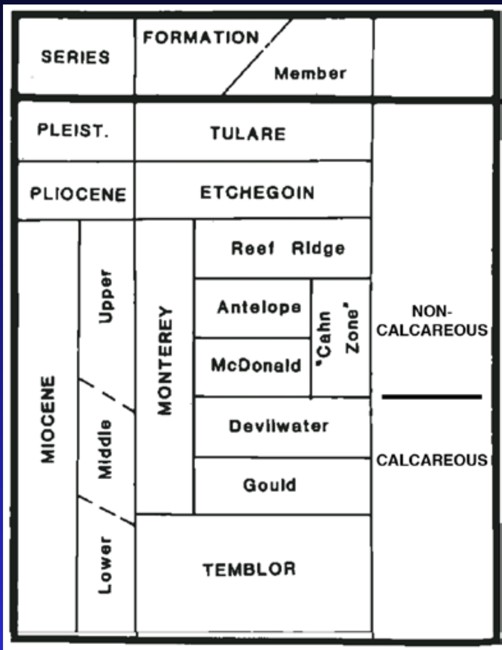
The Long Beach MARS Project
(Monterey And Related Sedimentary rocks)

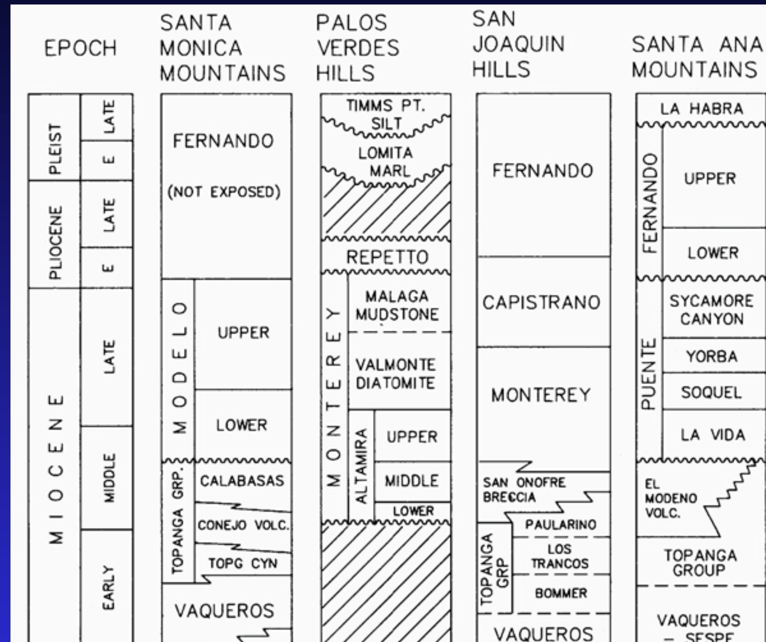


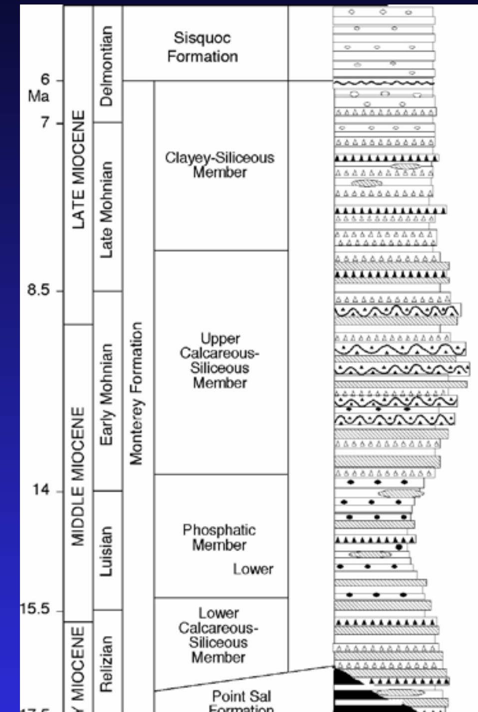
Monterey Research Directions

1. Understanding global vs. local control of lithology & stratigraphy
    - *Expand geochemical characterization of members to unstudied basins*
    - *Detailed characterization of good sections in outcrop and subsurface*
    - *Tie oceanographic & bathymetric setting to sediment character*

San Joaquin Basin | Los Angeles Basin | Santa Maria Basin





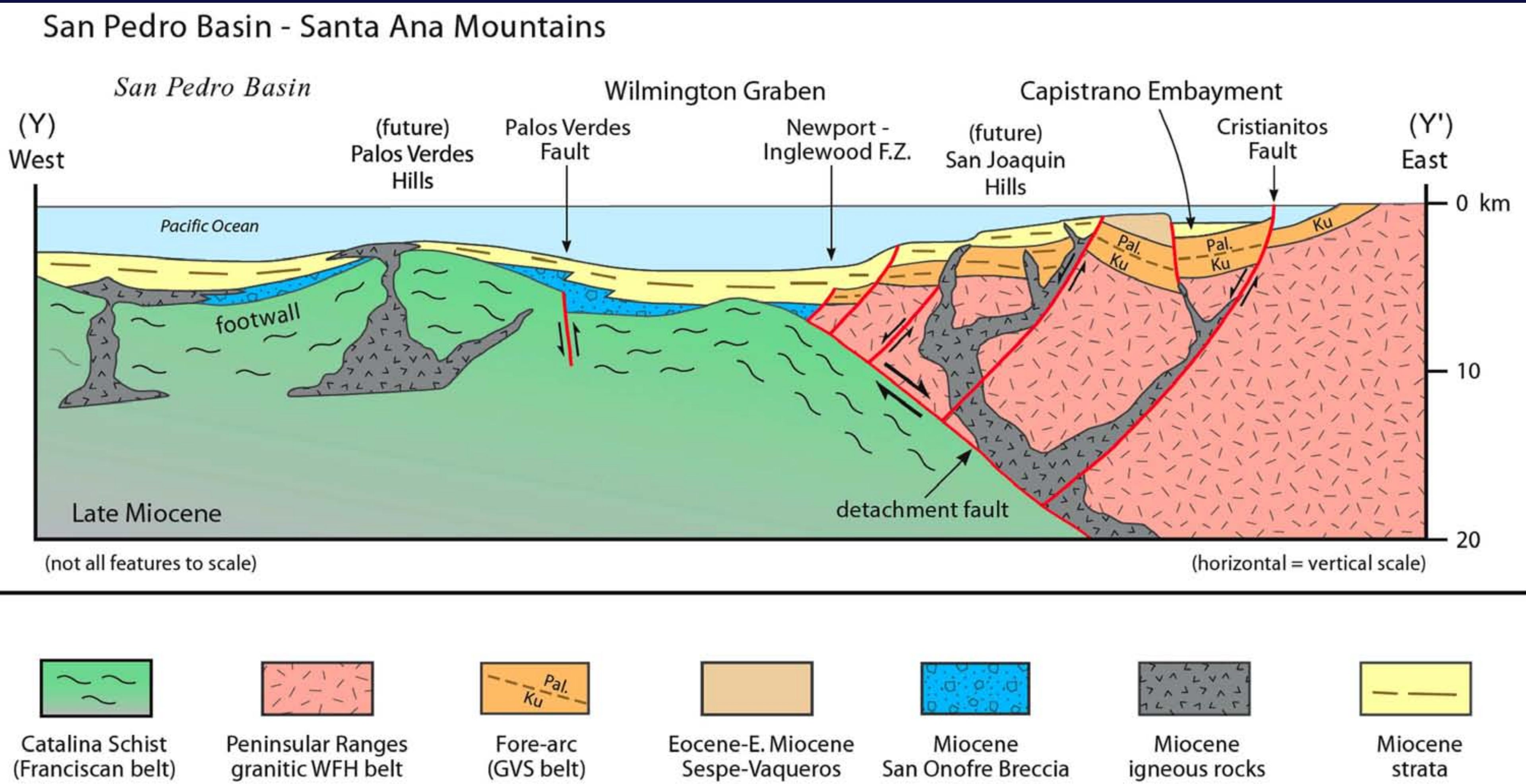


How similar is Monterey stratigraphy in:

- Inboard and outboard basins?
- North to south?
- Across individual basins?

Long Beach MARS Project: Monterey and Related Sedimentary rocks

Influence of bathymetry and basin setting?



Crouch & Suppe (1993)

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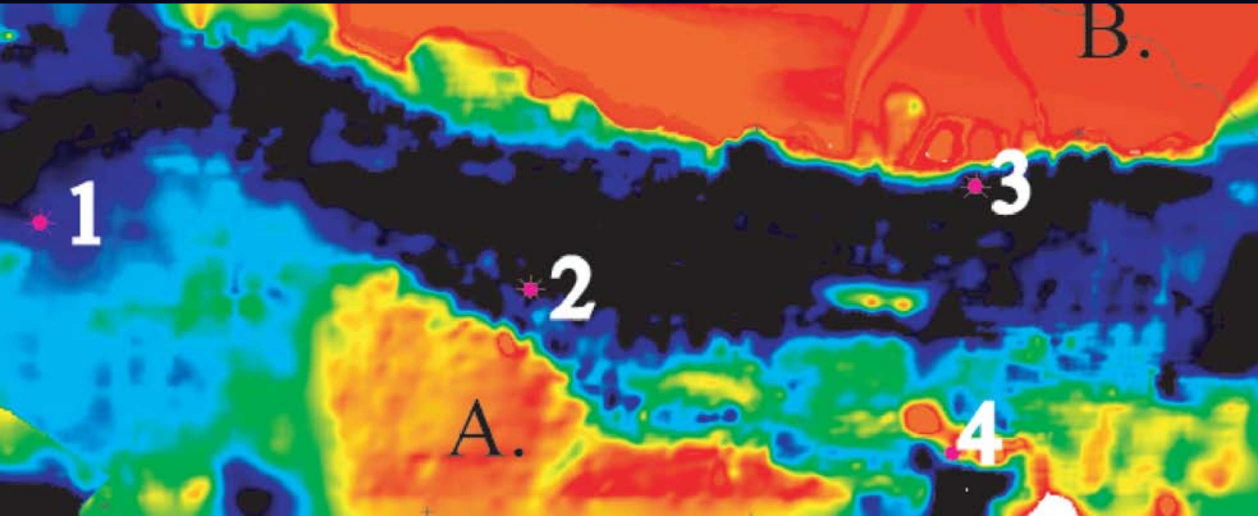
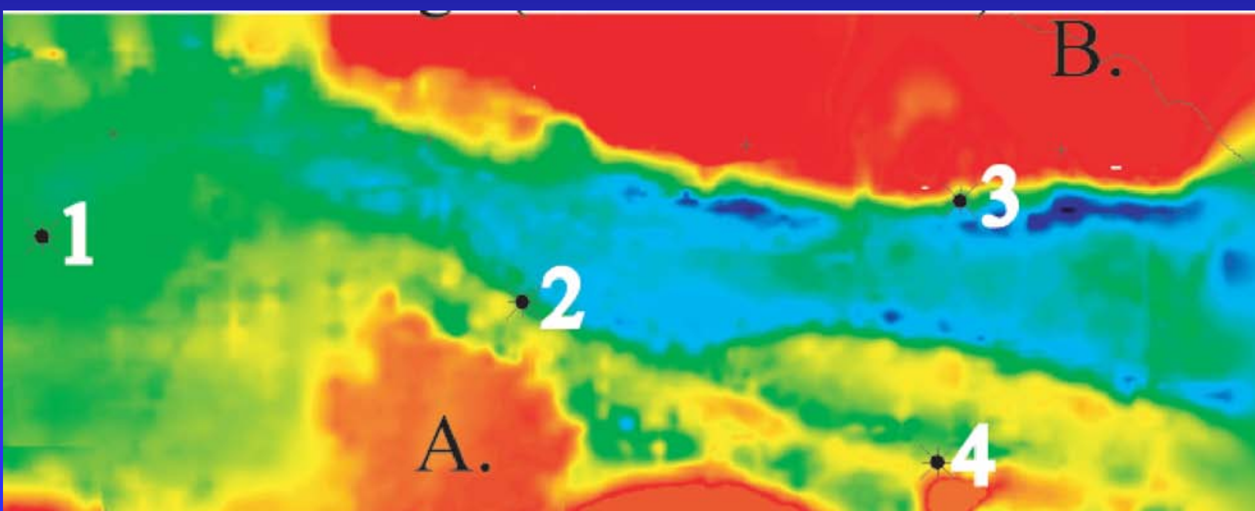
CSULB Geology

Rapid change in muddy sediment accumulation in modern analogs



Santa Barbara Channel



Dramatic changes in sedimentation
in just 0.1-0.2 Myr

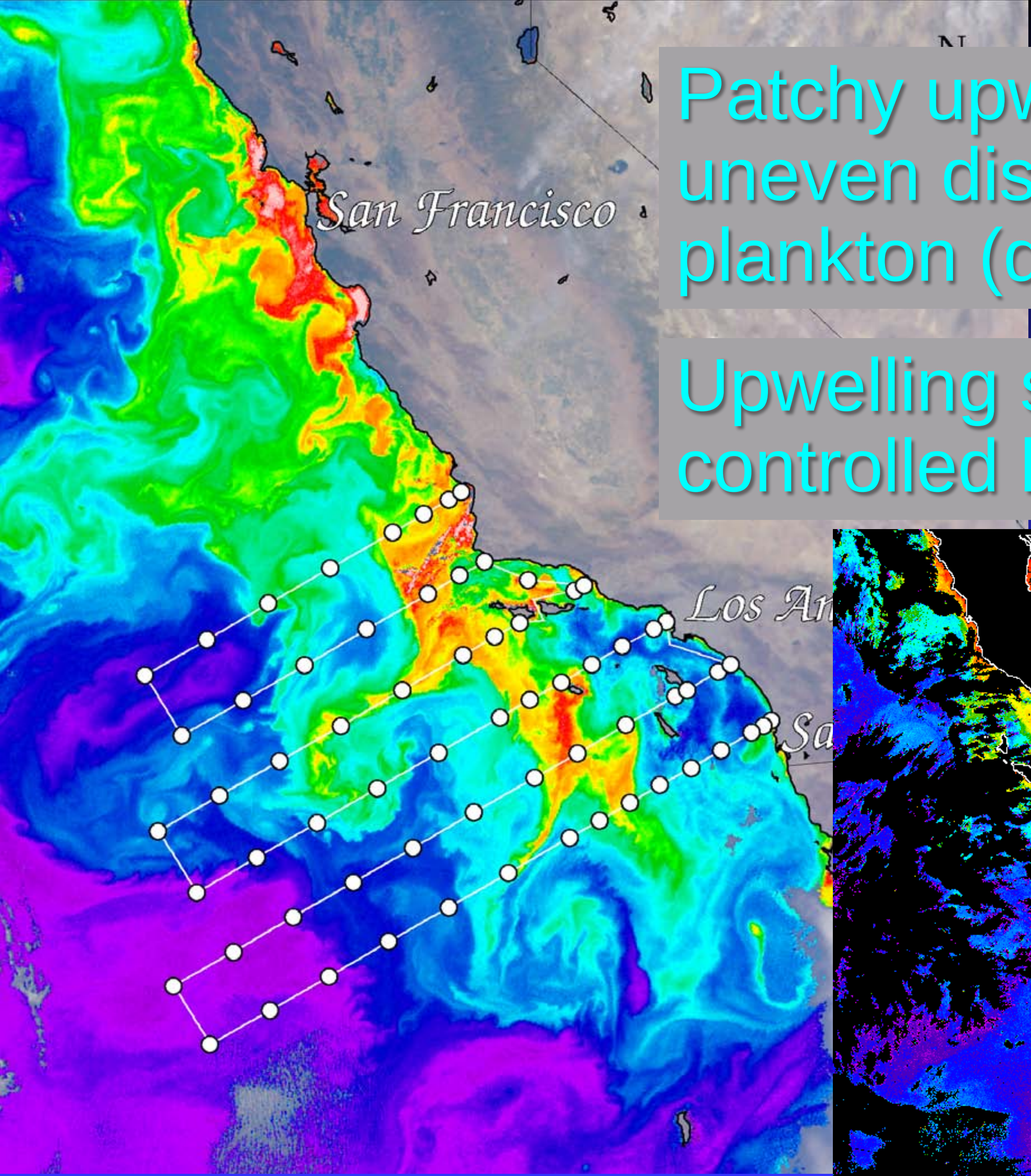
Next talk!

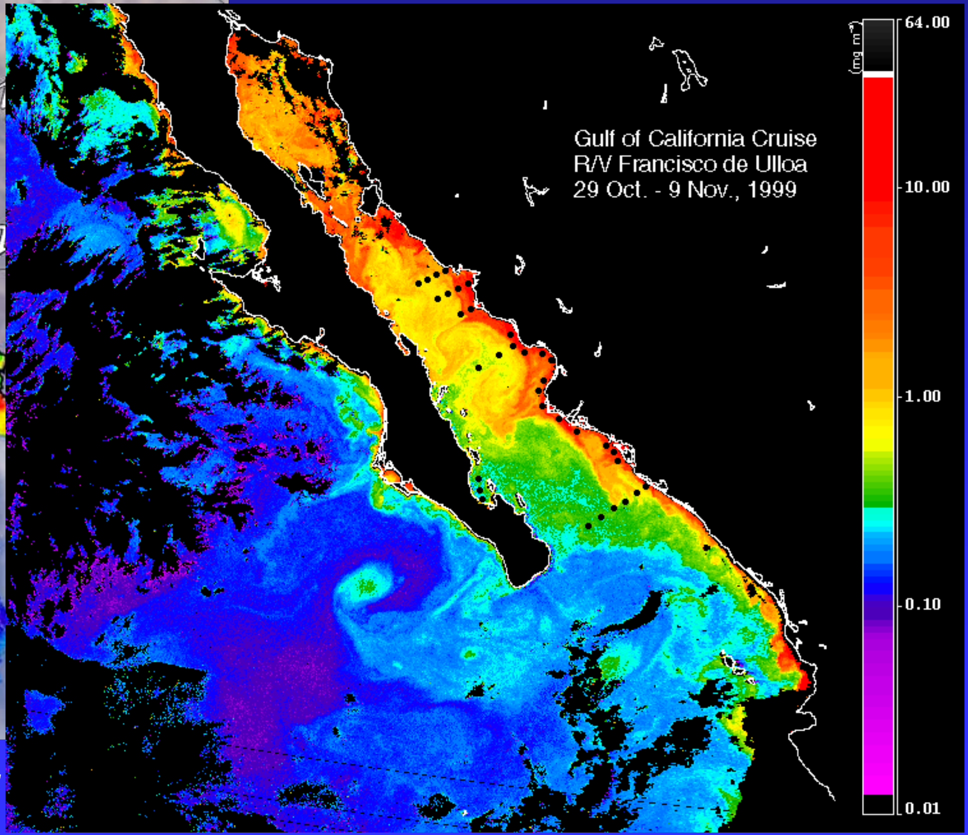
Marshall, 2012

m/kyr

Patchy upwelling leads to uneven distribution of plankton (diatoms, etc.)

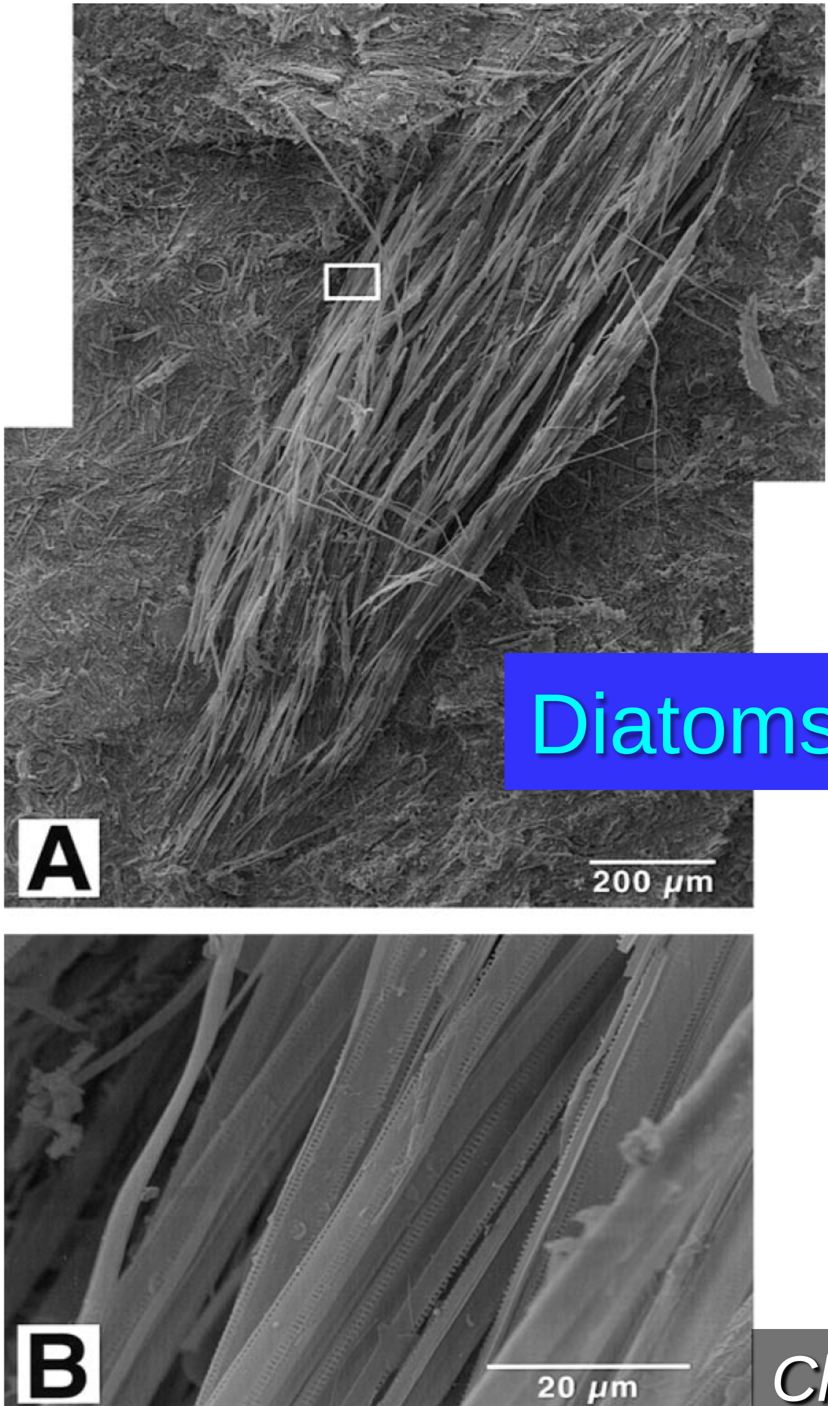
Upwelling strongly controlled by margin shape

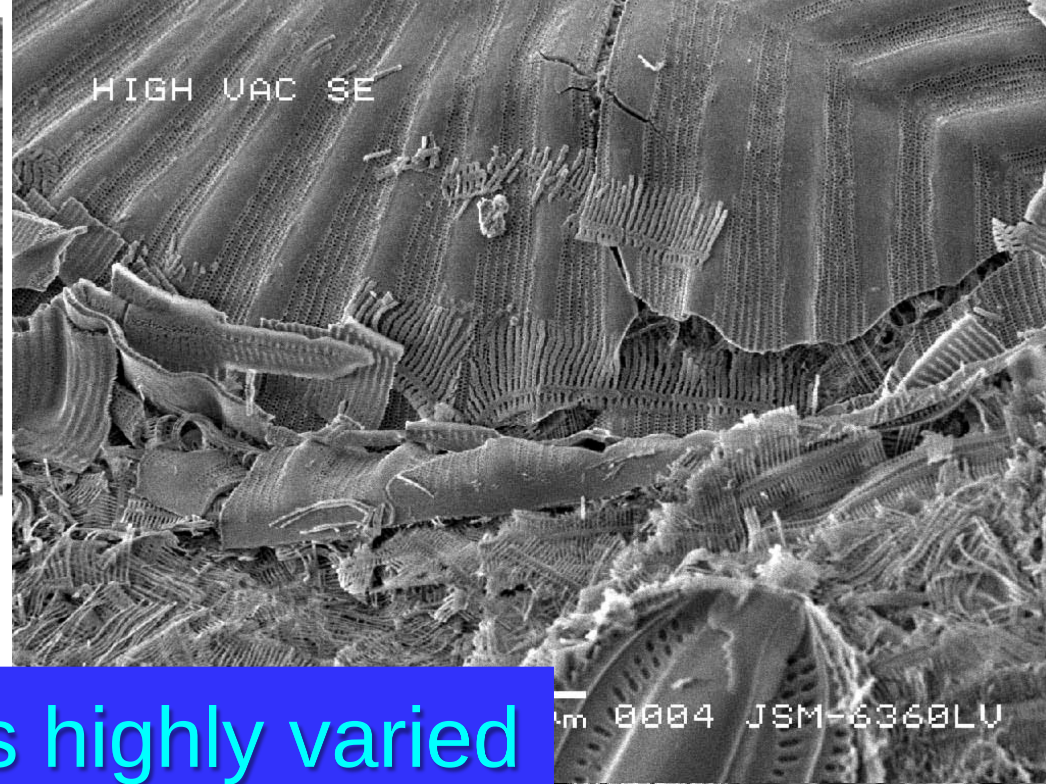




Long Beach MARS Project: *Monterey and*

Diatoms highly varied





Chang et al. and Pike & Kemp studies

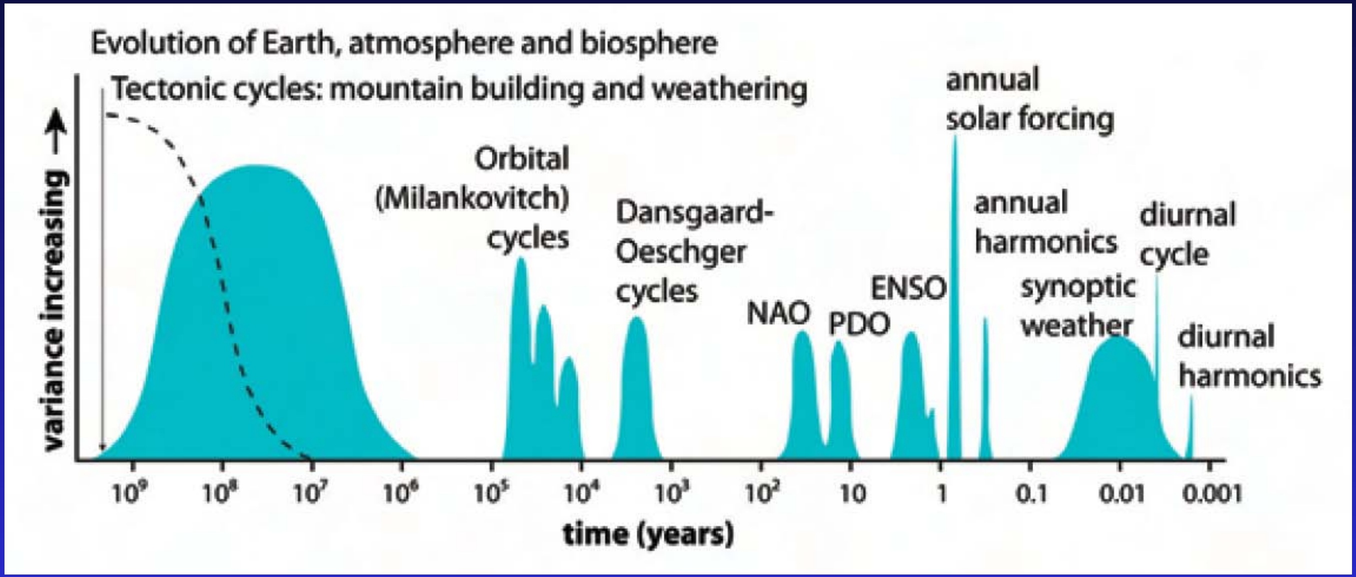
Early-Mid Miocene — Blakey (1997) — Late Miocene

Monterey Research Directions

Time-transgressive benthic biostratigraphy

2. How can we better date & correlate it?
    - Planned approaches:
        - *Isotope stratigraphy*
        - *Chemostratigraphy*
        - *Tephrochronololgy*
        - *Sequence stratigraphy*
        - *Cyclostratigraphy*

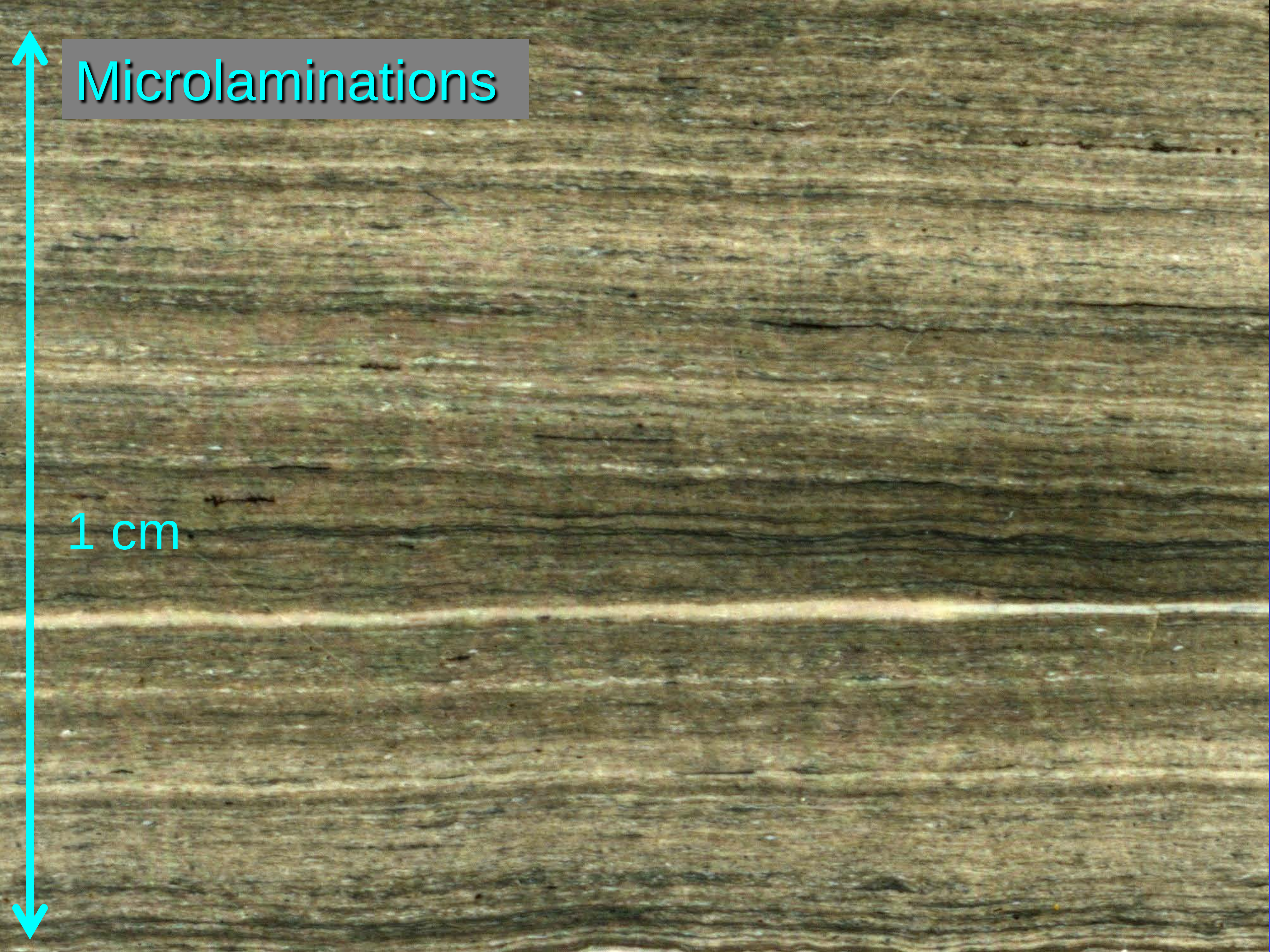
Climate Cycles & Litho-cyclicity



Lithologic Cyclicity & Climate

Shown at all scales:

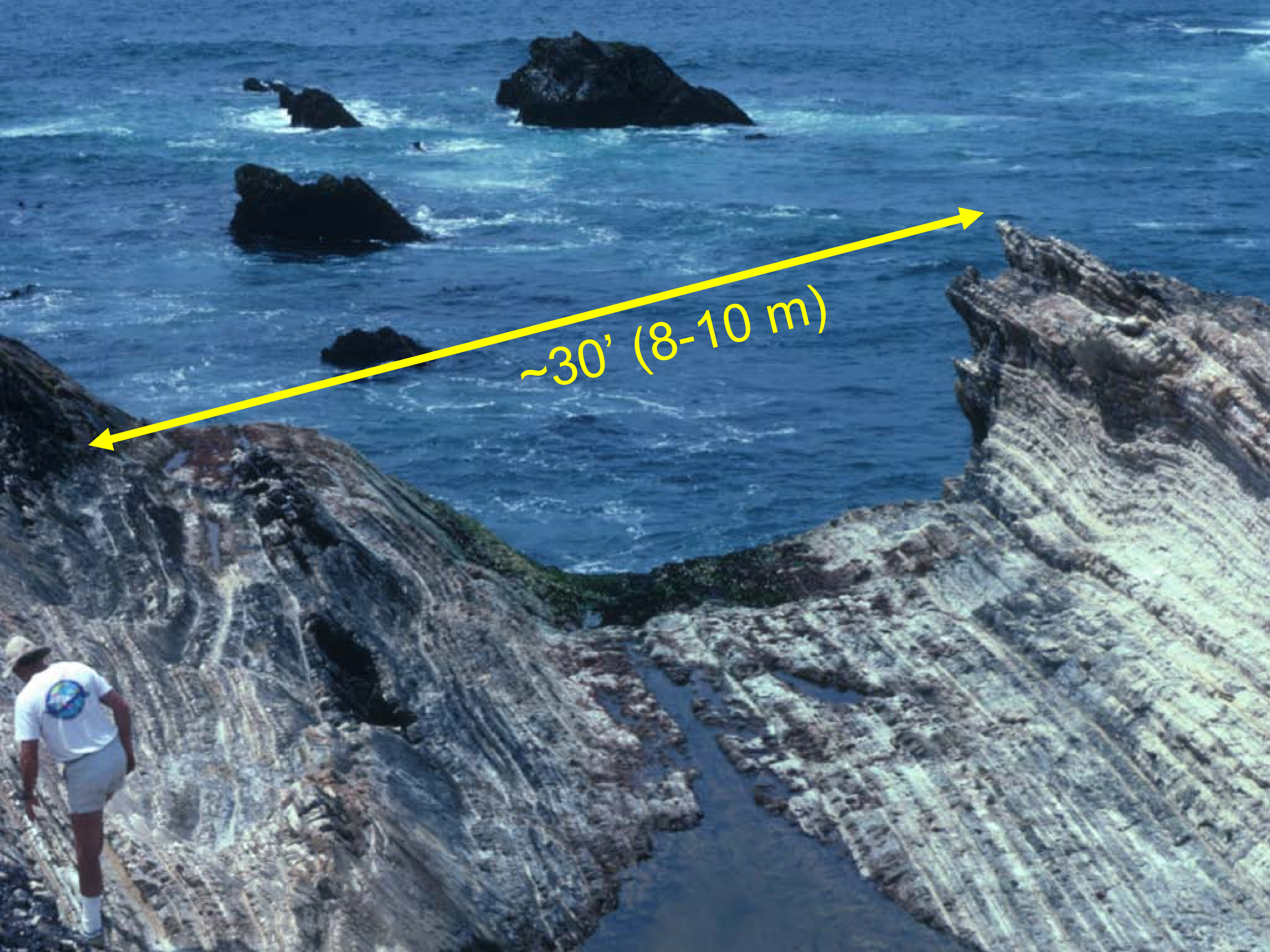
- Composition
  - *$CaCO_3$, silica, clay, organic carbon*
- Sedimentary fabric
  - *Bedding thickness and ratios*
  - *Laminations, bioturbation*


Microlaminations
1 cm


Thick laminations & bundles
15 cm

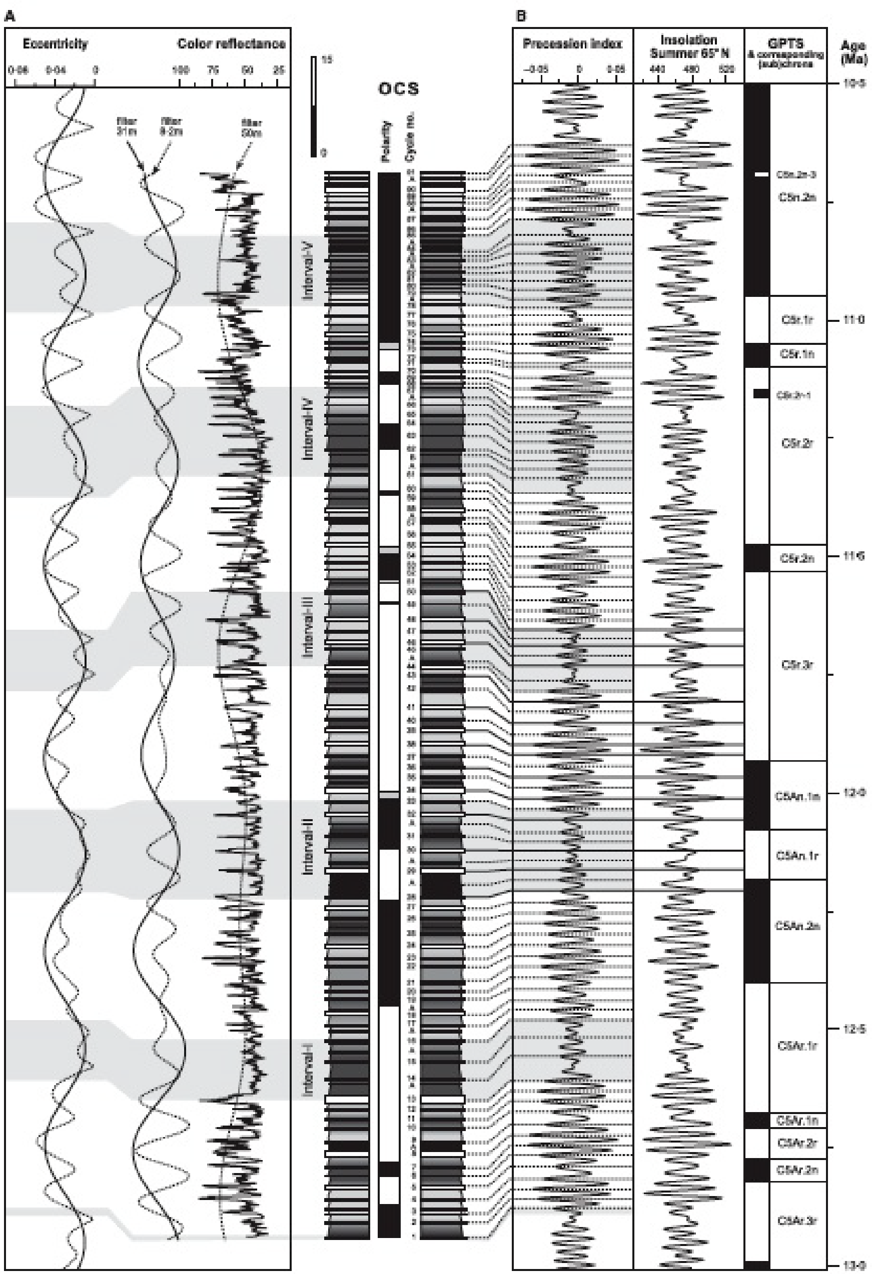

Thin beds
1 m


Meter-scale (2-4')
beds or bed sets
1 m


~30’ (8-10 m)

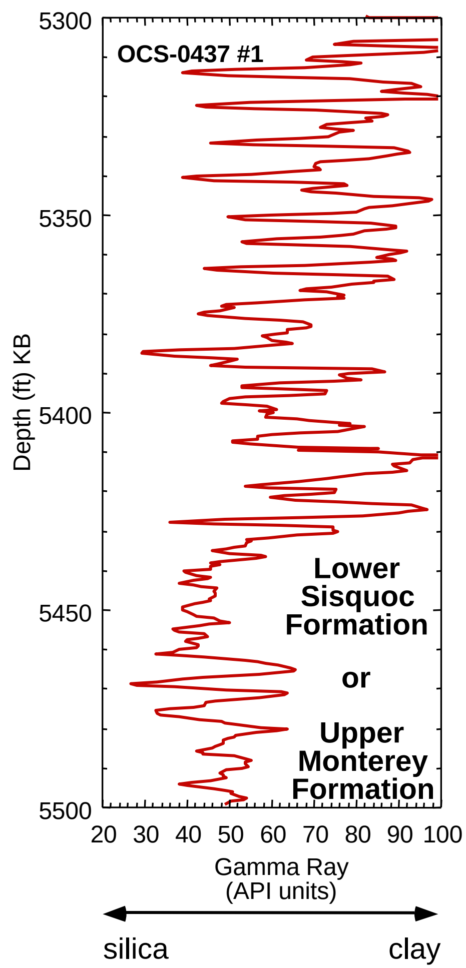
Mid-Miocene, Orera, Spain

Milankovitch cycles drive climate and sedimentation

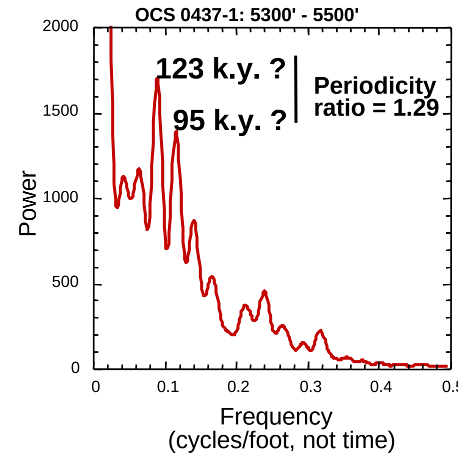


Aziz et al. (2004)

Point Pedernales Field,
Offshore Santa Maria Basin



10’ cycles

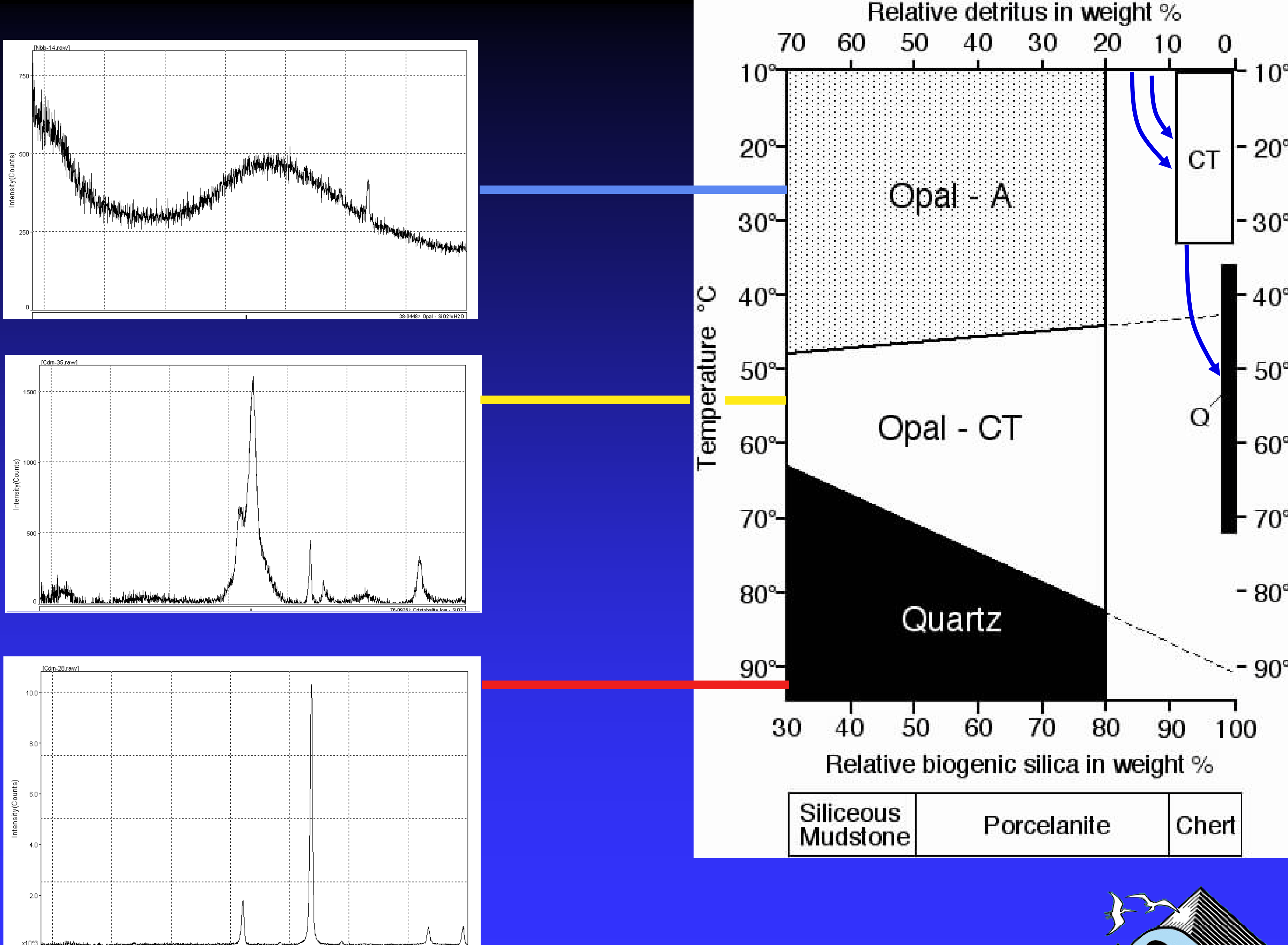


Estimated sed. rate = 100 ft/m.y. (2.77 cm/k.y.)

Pam Hill, MS research

Monterey Research Directions

3. What really happens at the silica phase transitions?
   - *Geochemical rearrangement*
   - *Fluid expulsion*
   - *Formation of pressure compartments*
   - *Diagenesis-related deformation*



Long Beach MARS Project: Monterey and Related Sedimentary rocks

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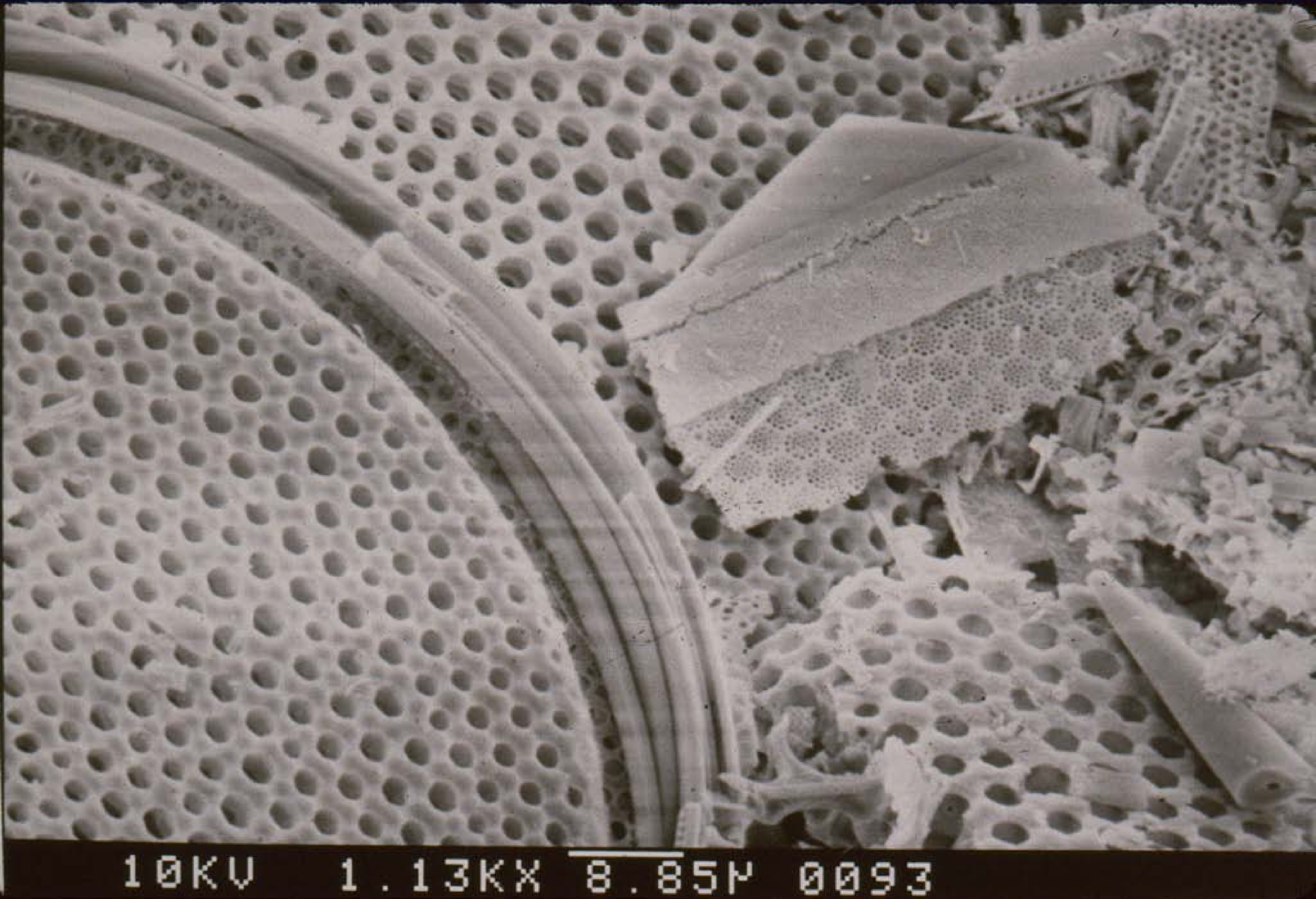
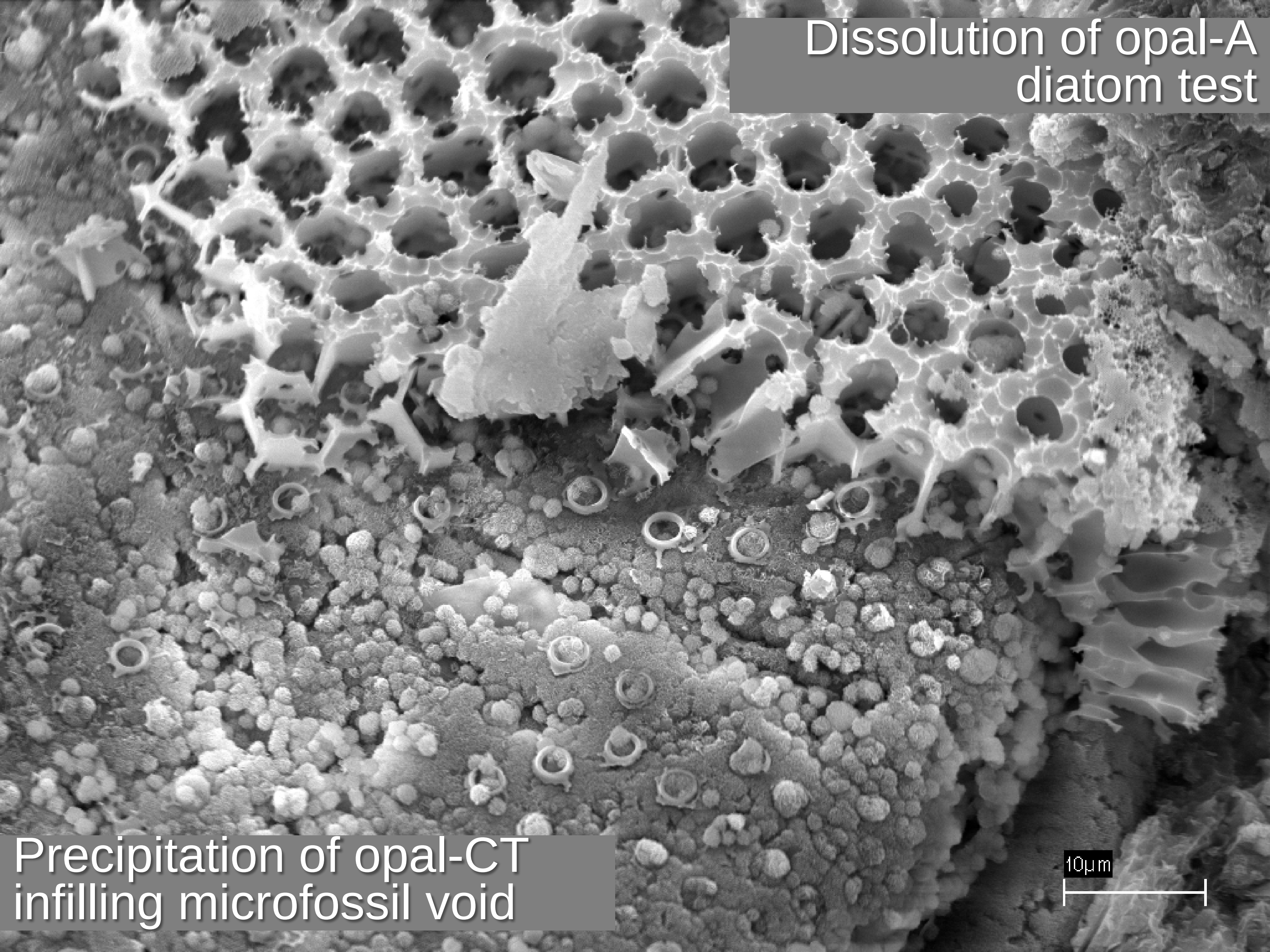
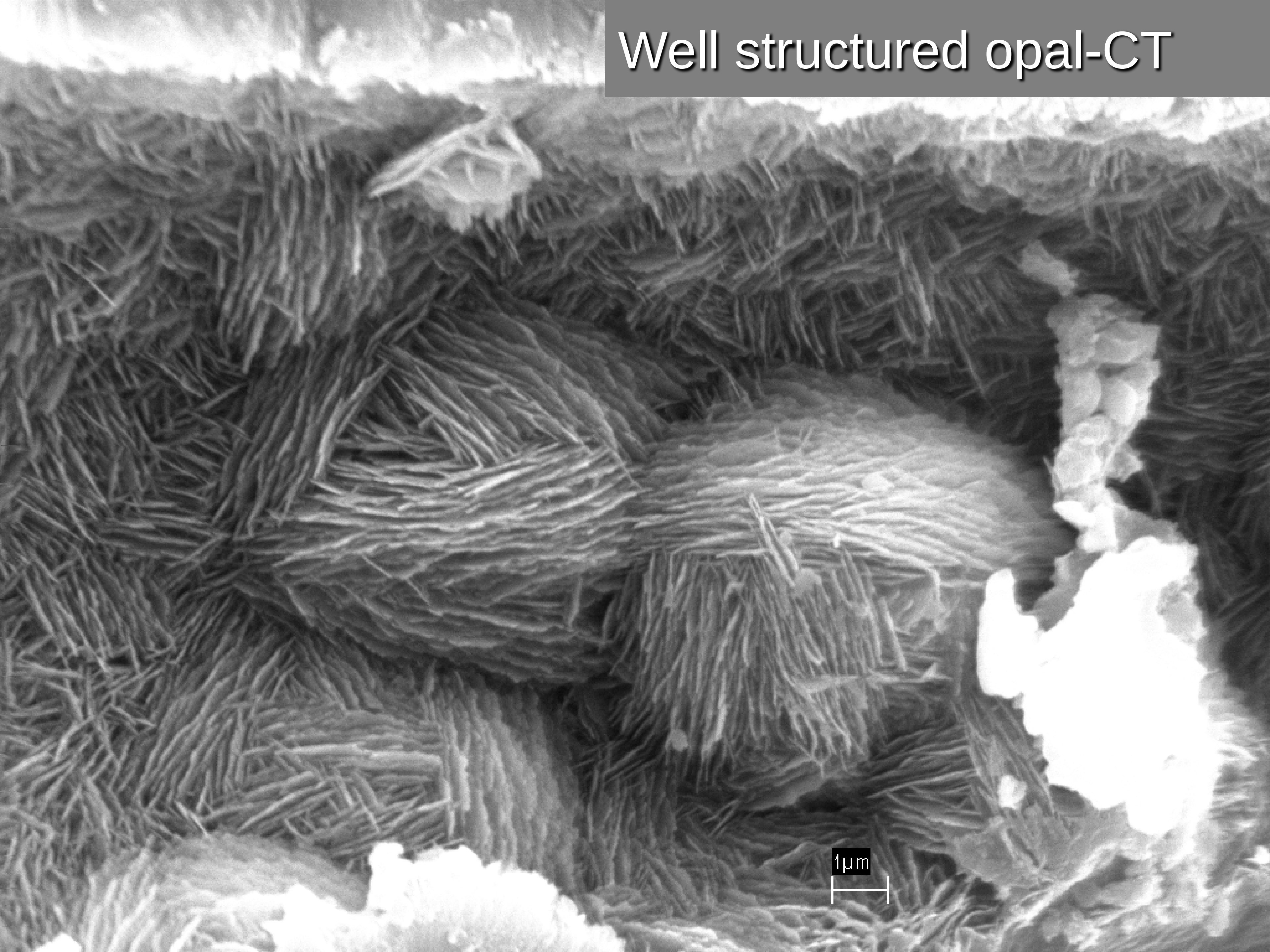
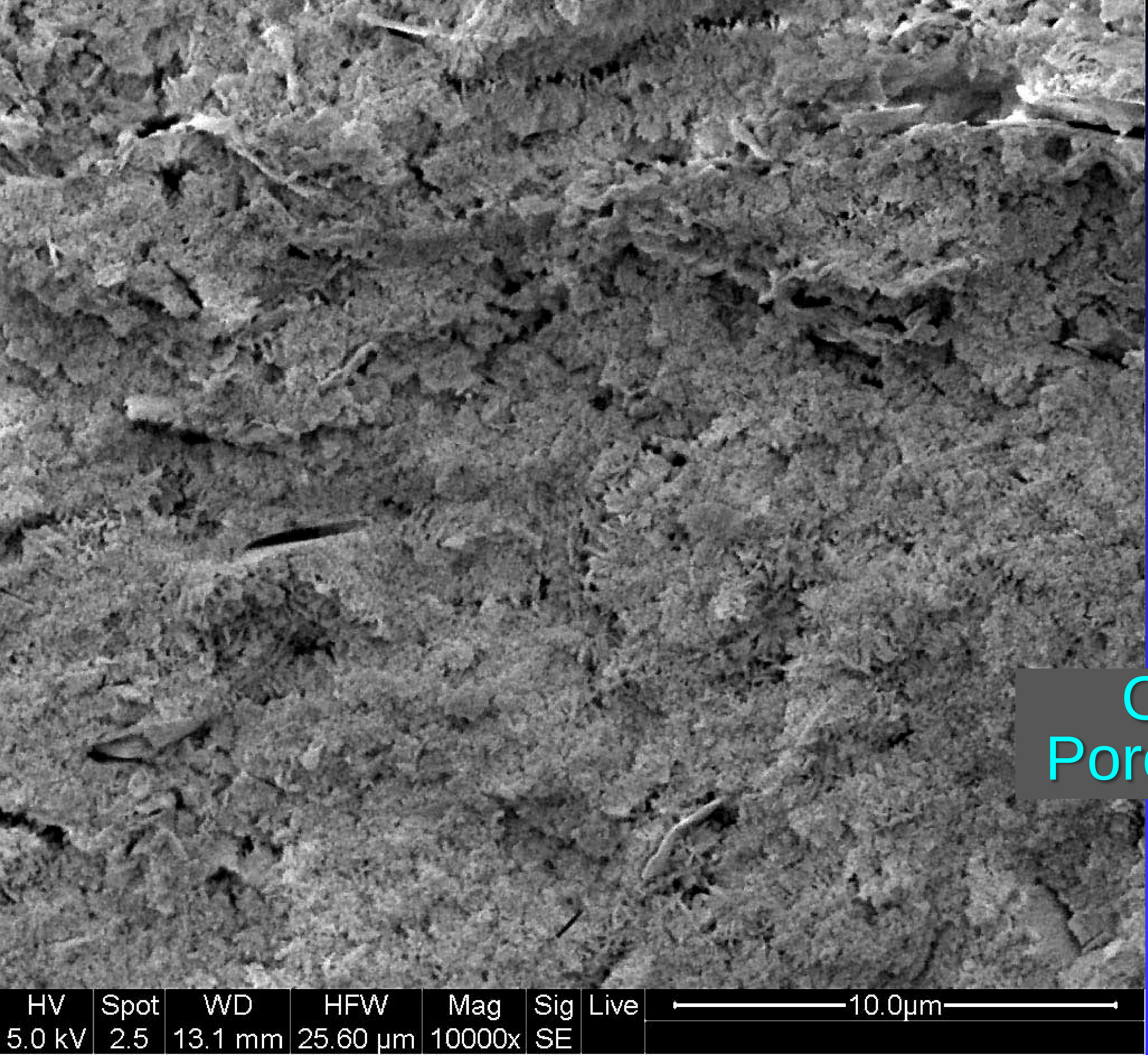

10KV 1.13KX 8.85P 0093


Dissolution of opal-A diatom test
Precipitation of opal-CT infilling microfossil void
10µm

Well structured opal-CT





Opal-CT Porcelanite

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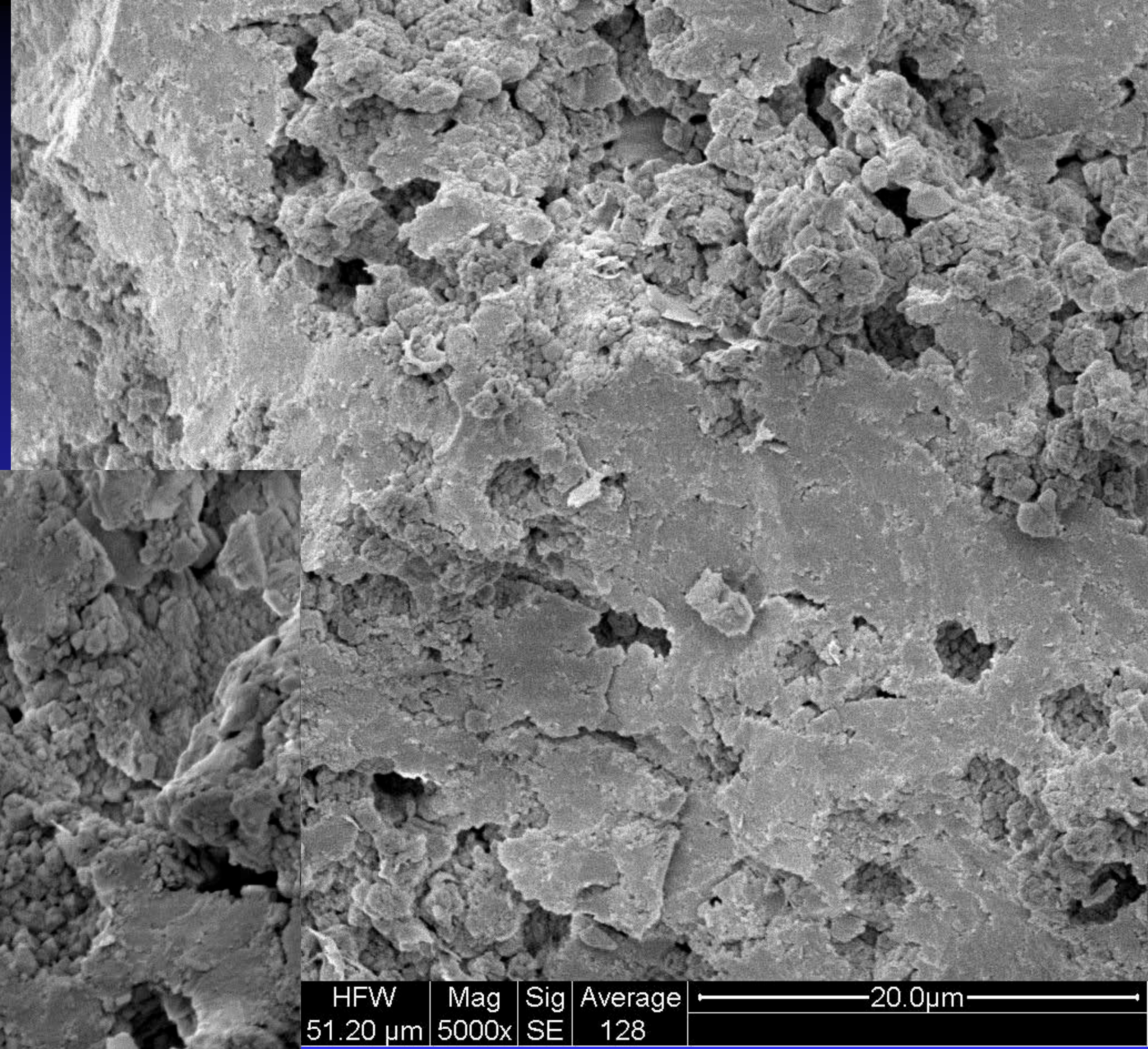
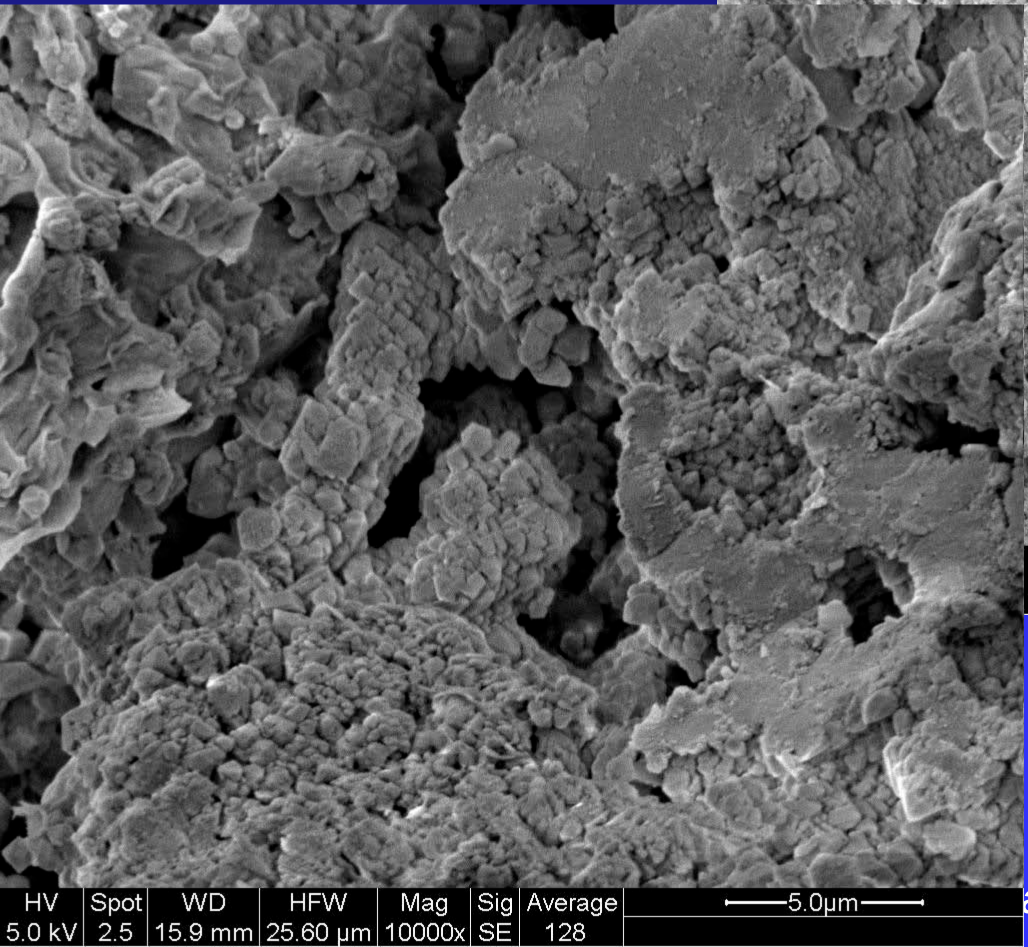
Quartz Porcelanite





ated Sedimentary rocks

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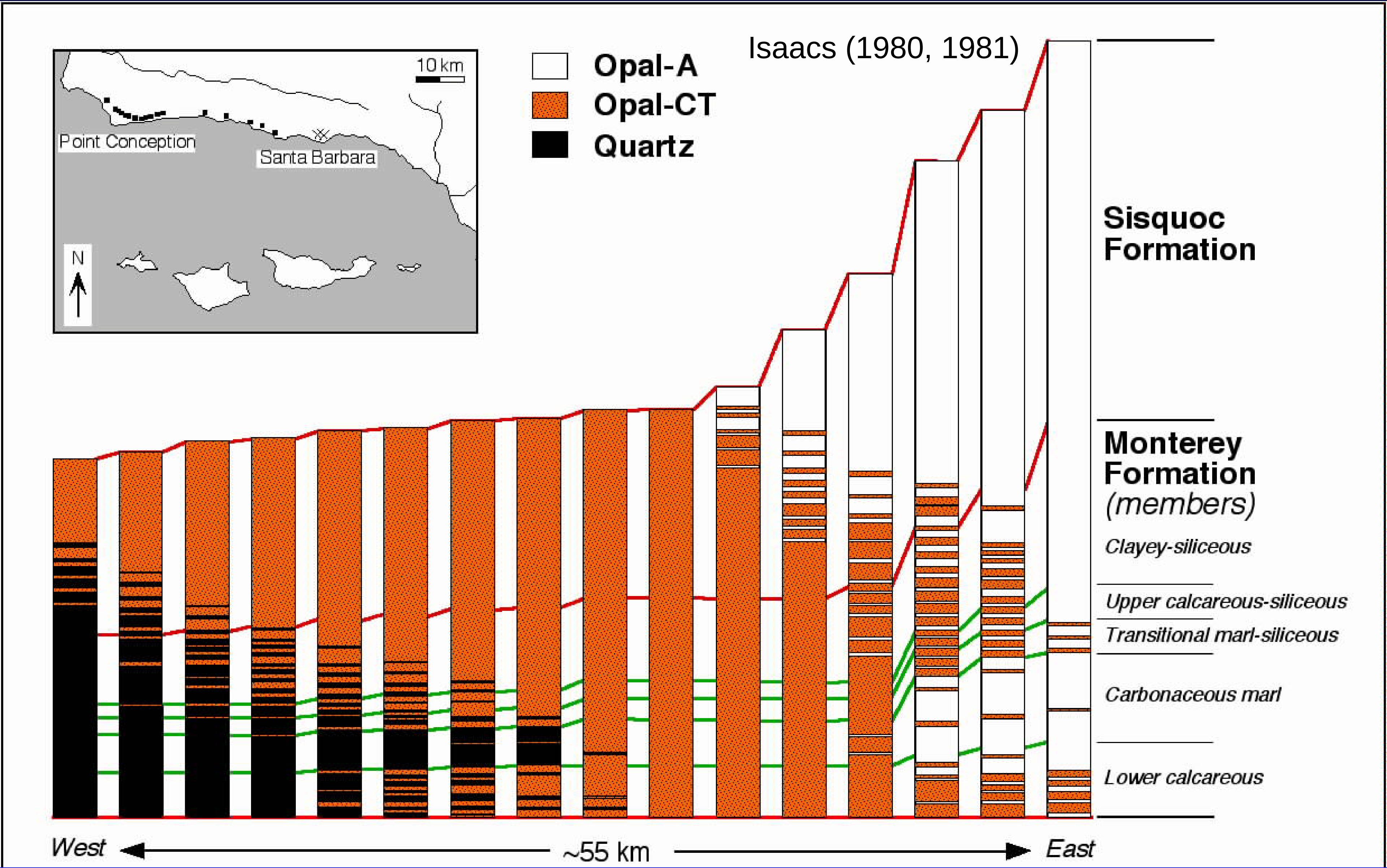
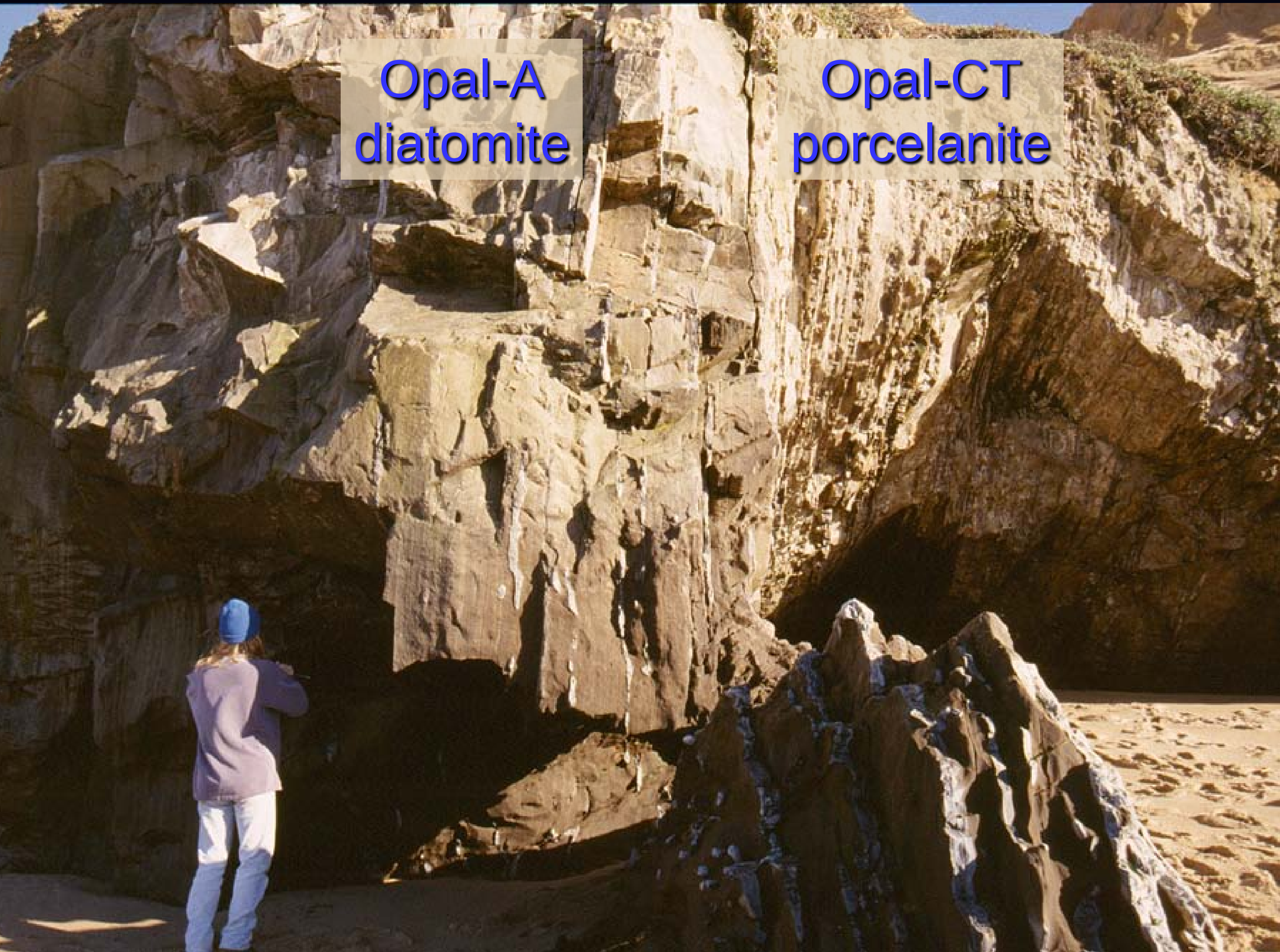
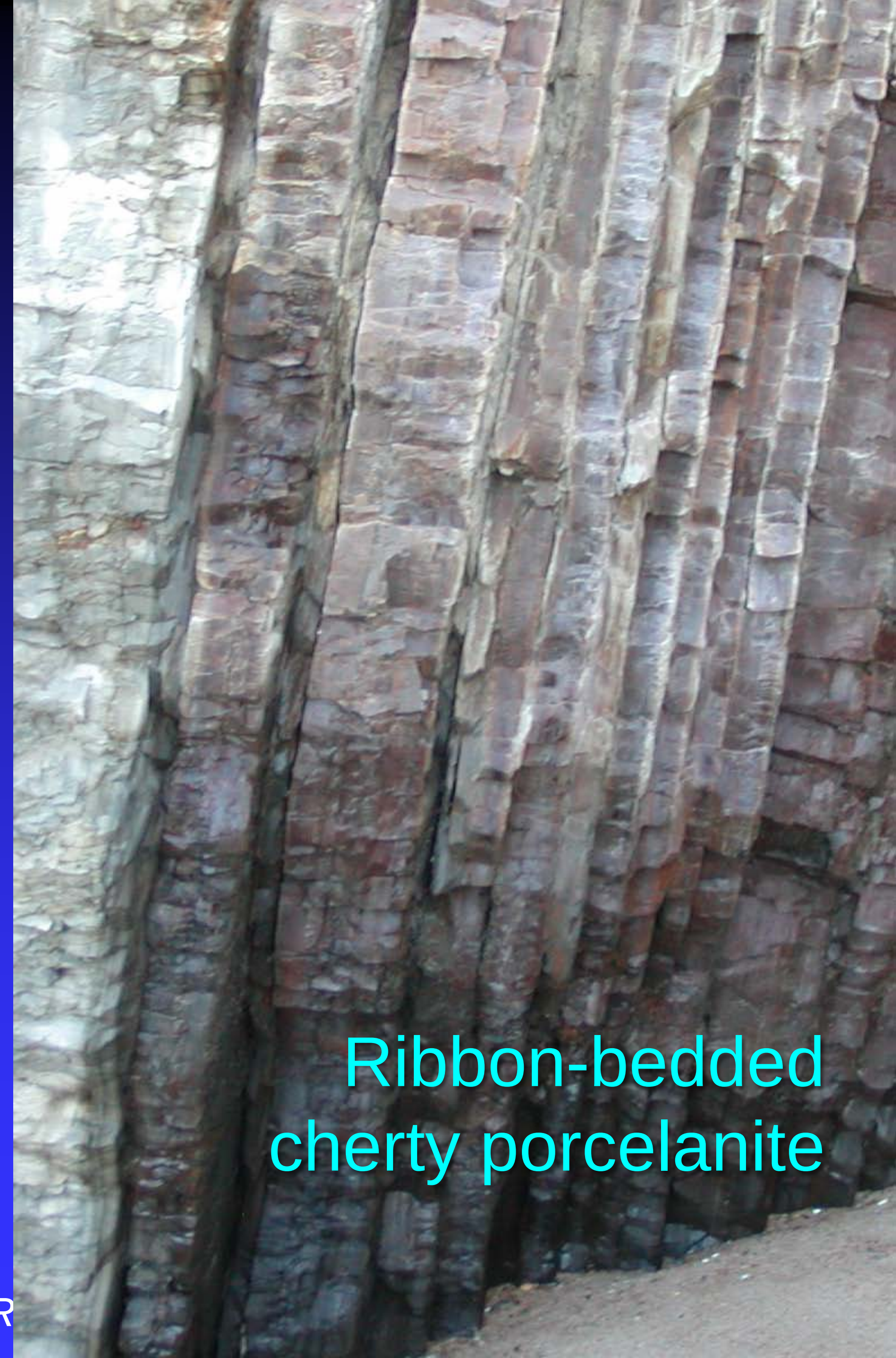
Silica phase transition zones are not simple




Opal-A
diatomite
Opal-CT
porcelanite

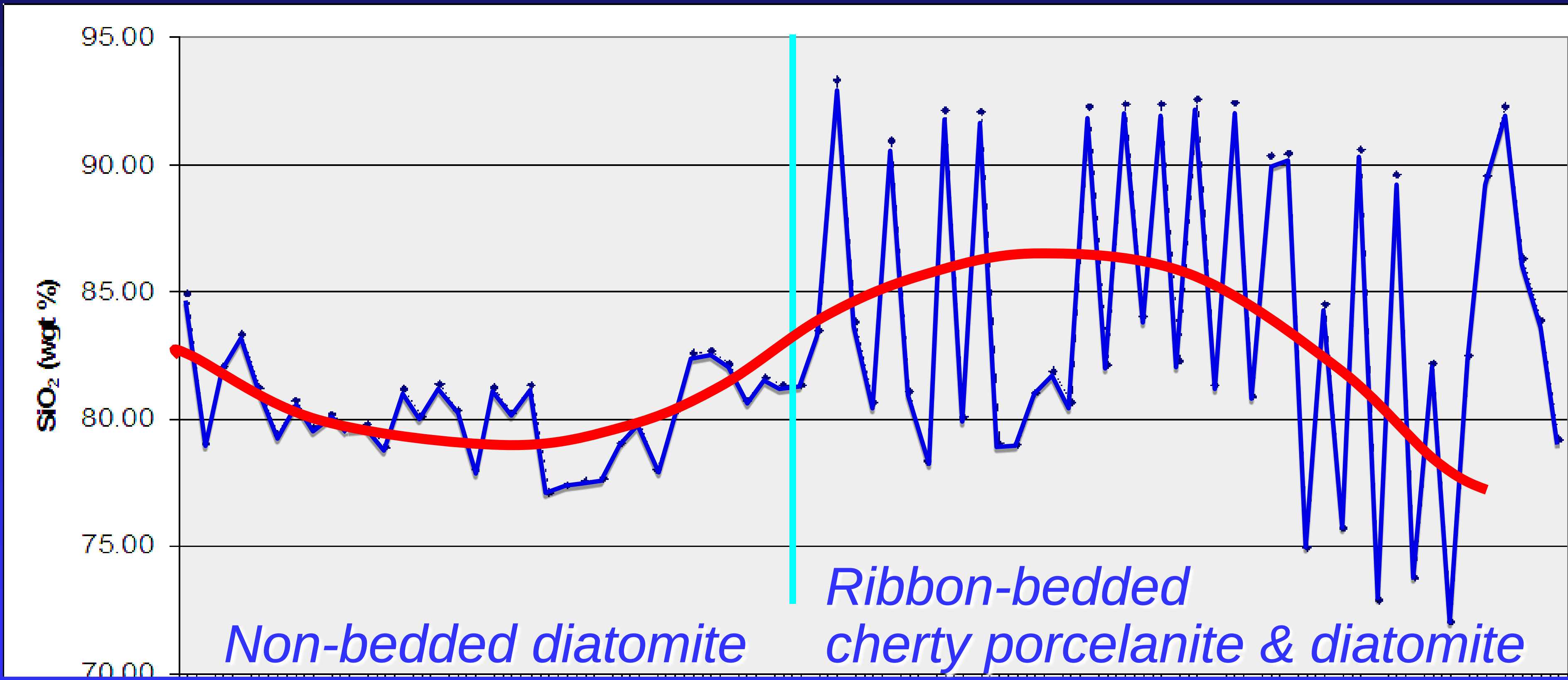

Laminated, but
massive-bedded diatomite


Ribbon-bedded
cherty porcelanite

R

Bed-to-Bed Diagenetic Segregation of Silica at Mussel Rock

Opal-A *Opal-A + Opal-CT*



Charlotte Deason, MS research

Long Beach MARS Project: Monterey and Related Sedimentary rocks

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Theoretical Fluid Loss & Volume Change for Opal-A to Opal-CT to Quartz for Chert and Porcelanite

	Pure diatomite	Impure diatomite	
85% H_2O loss	Grain density: 1.8 gm/cc Porosity: 80%	Grain density: 1.8 gm/cc Porosity: 65%	75% H_2O loss
	Grain density: 2.3 gm/cc Porosity: 15%	Grain density: 2.3 gm/cc Porosity: 40%	
	Grain density: 2.7 gm/cc Porosity: 3%	Grain density: 2.7 gm/cc Porosity: 15%	
	Chert	Porcelanite	

Long Beach MARS Project: Monterey and Related Sedimentary rocks

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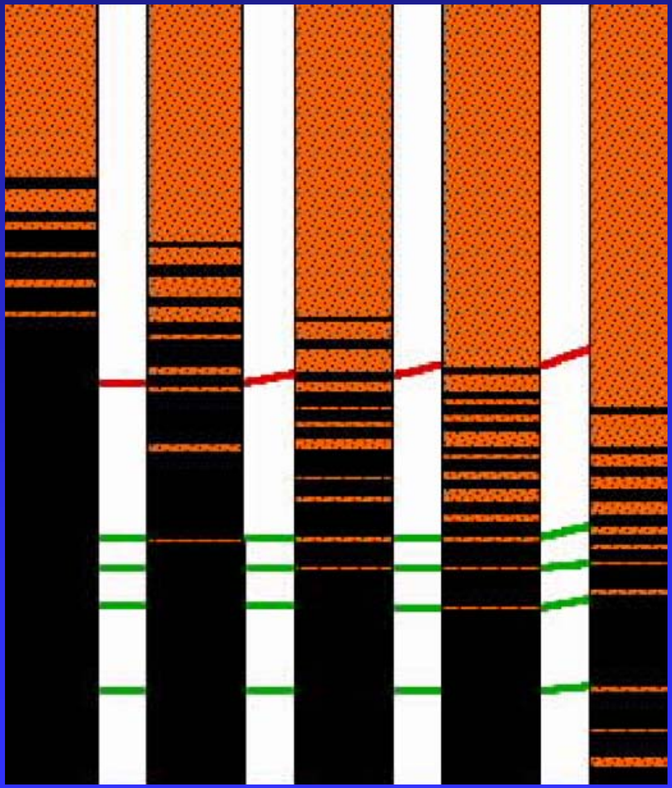
Do geochemical and pressure compartments form at the phase boundaries?

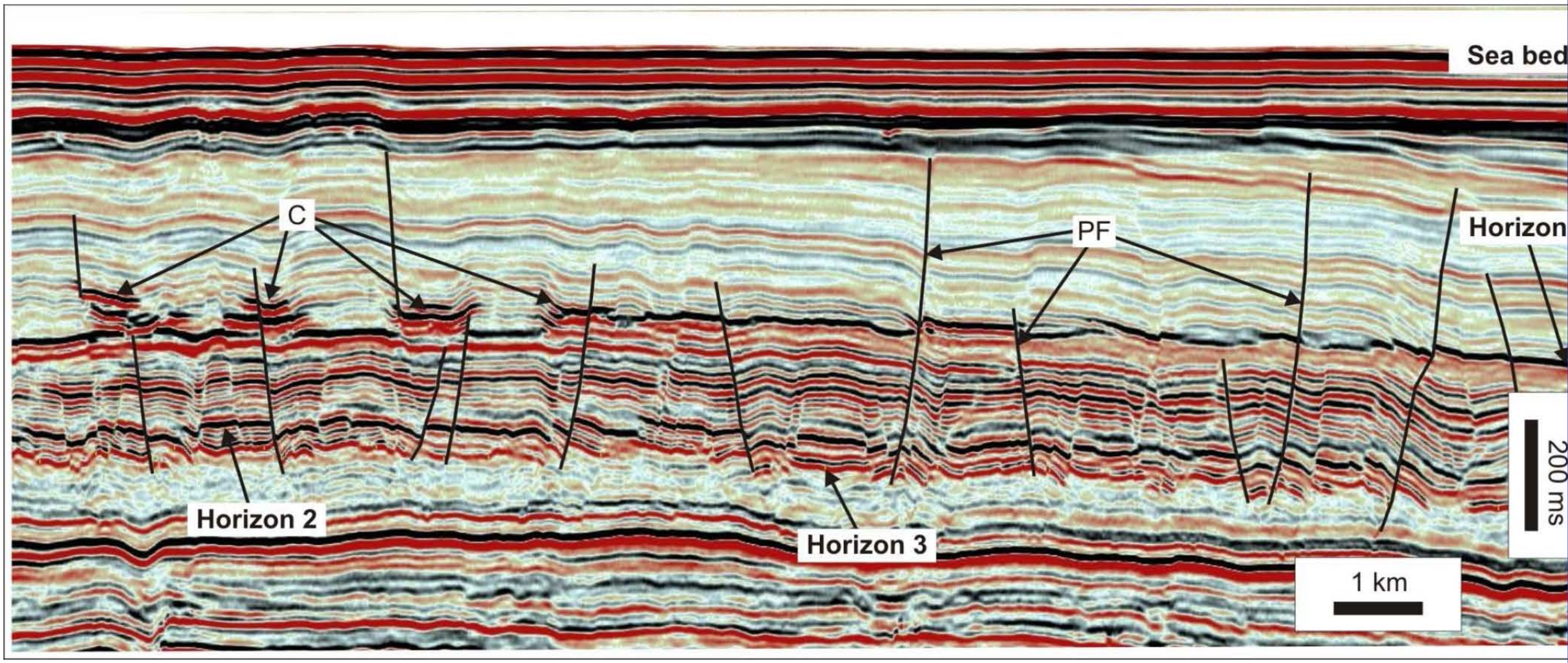


Could these help explain:

- *localized diagenesis?*
- *localized fractures and faults?*
- *unusually porous rocks?*
- *Would they differ at the A/CT and CT/Quartz transitions?*

What are the controls of the geometry of silica phase boundaries?

Diagenesis induced deformation



Ireland et al. (2009)

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CSULB Geology

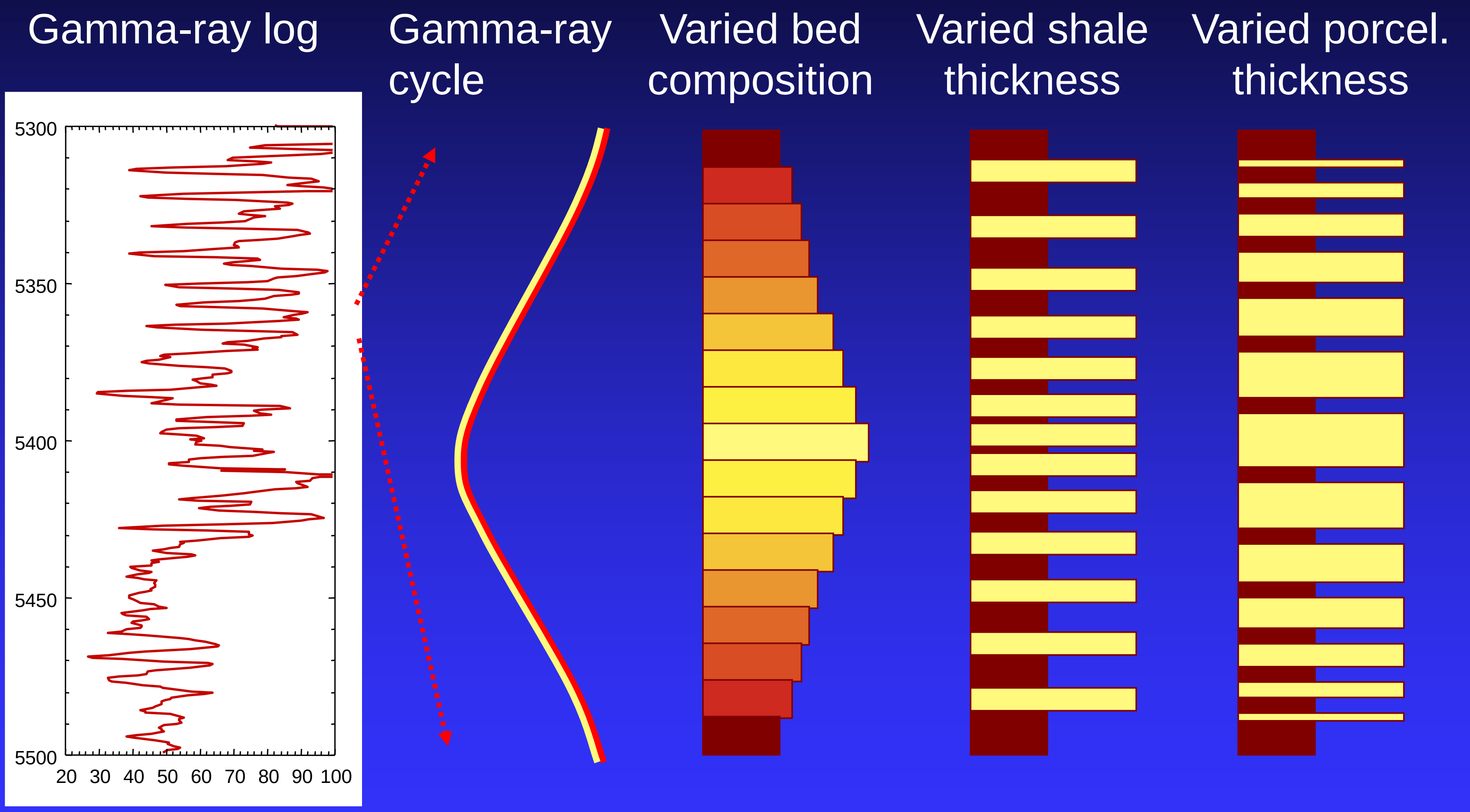
Monterey Research Directions

4. Linking genetic stratigraphy with mechanical stratigraphy

- If climatic cyclicity and depositional setting control lithologic composition and stacking pattern, then mechanical stratigraphy should follow.

Can we predict where and when lithologic type and bedding ratios would be optimal for maximum fracture development?

Stacking Patterns for Silica-Clay cycle



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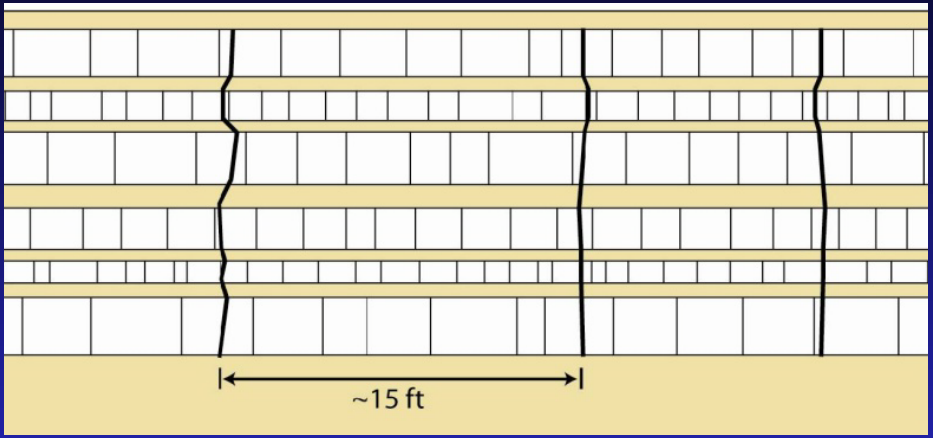
Fracture density depends on lithology and layer thickness



Michael Gross

So,where in the basin and where in the cycle is the sweet spot for maximum fracture development?

The Long Beach MARS Project
(Monterey And Related Sedimentary rocks)

1. Development of a focused center of excellence for research into Monterey Formation geology
2. Provide sustainable support for ongoing research into the Monterey Formation for graduate student & post-doctoral scholars
3. Develop well-trained graduate students, ready for entry into the petroleum industry
4. Encourage fruitful intellectual interaction between industry and academia on real problems

Acknowledgements –thank you!

2011-2012 MARS Project Founding Members

- *Occidental Petroleum*
- *ExxonMobil*
- *Aera Energy*
- *Venoco, Inc.*
- *BreitBurn Energy Partners*
- *PXP - Plains Exploration & Production*
- *Signal Hill Petroleum*
- *Bayswater Exploration & Production*