Monterey Formation Overview and Context for New Research

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Abstract

The Miocene Monterey Formation of California provides a potentially unsurpassed archive of Neogene paloeoclimatic and paleoceanographic evolution as its deposition spans the Miocene Climatic Optimum and the Miocene Climatic transition. It is an important reservoir of organic carbon, potentially large enough to have influenced the global transition from greenhouse to icehouse conditions, as well as being the major source rock for petroleum in California. Highly biosiliceous, it is the best-studied of the world's Neogene diatomaceous deposits that developed along oceanic upwelling margins in the Miocene. It accumulated in numerous new and rejuvenated sedimentary basins that developed with the transition from convergent to transform geometry along the Pacific-North American plate margin. The bathymetry of these basins intercepted open-ocean oxygen minimum zones or created restricted, silled basins that helped preserve organic matter and minimized bioturbation and degradation of a detailed sedimentary record. Although the member-scale compositional lithostratigraphic succession is similar between basins – reflecting the climatic/oceanographic stages of the Miocene – local bathymetric gradients and local exposure to deep bottom-scouring currents, created large lateral variation in environment, sediment thickness and composition. These lateral variations are critical controls of reservoir and source-rock properties, and also provide challenges and opportunities for generating quantitative histories of biogeochemical fluxes and paleoceanographic conditions.

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Monterey Formation Overview & Context for New Research

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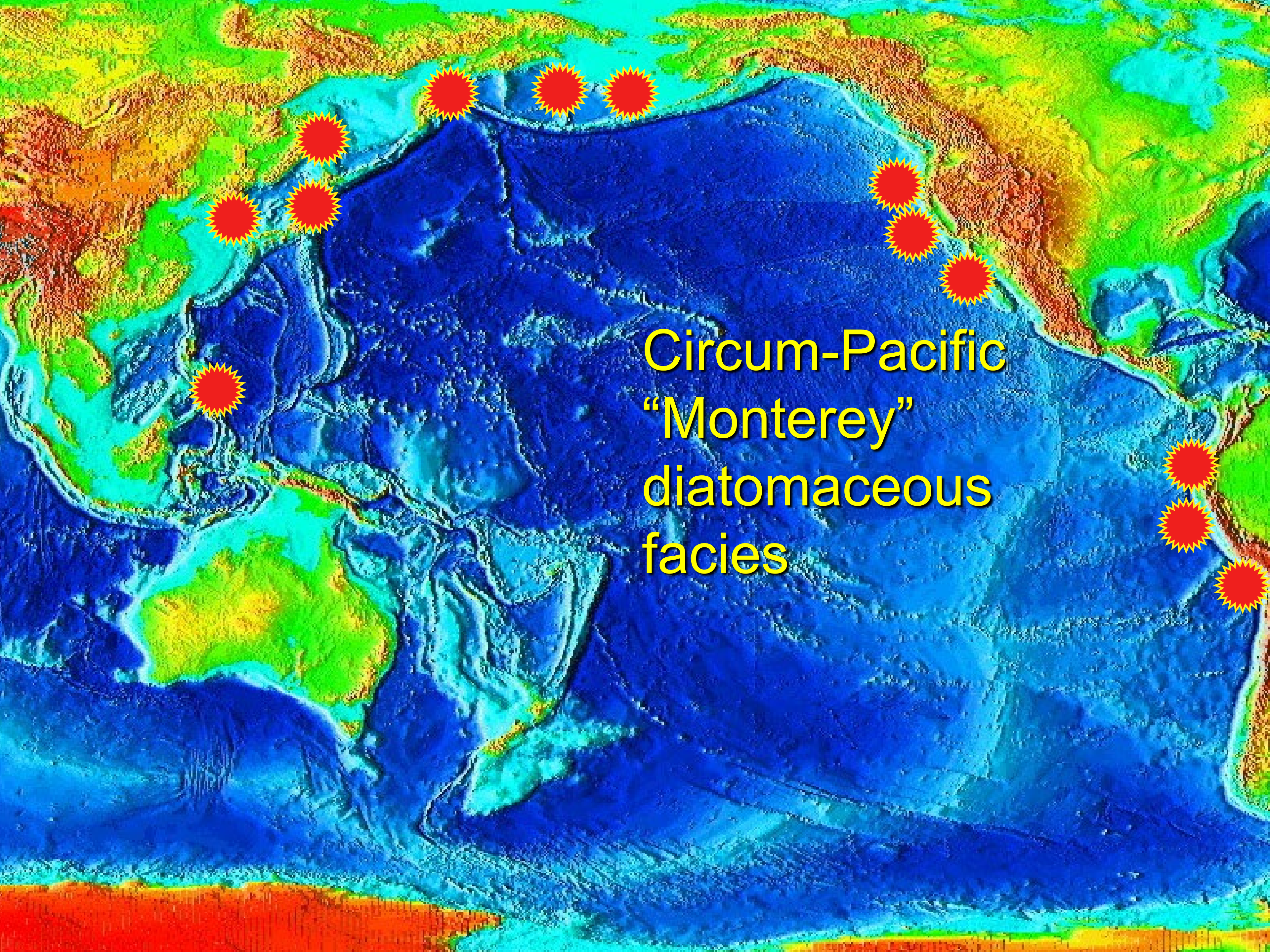
Miocene Monterey Formation

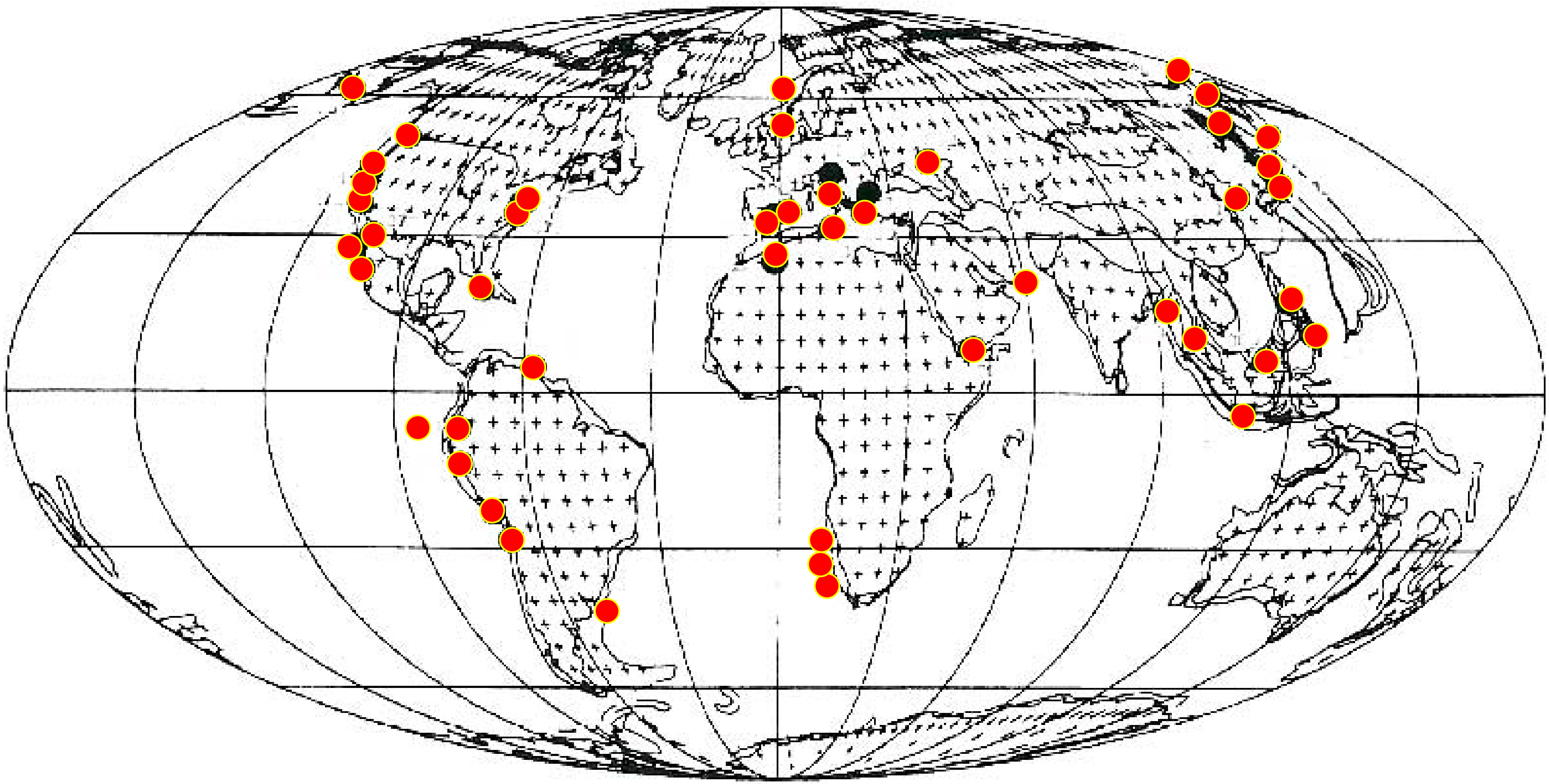
- Important link to past climate change
- Important storehouse of carbon
- Major source & reservoir of oil in California

- Characteristics
    - Fine-grained (mudstone)
    - Siliceous (diatom silica-rich)
    - Organic matter-rich
    - Thin-bedded, laminated

- Age: approximately ~17-6 Ma
- Related deposits span the Pacific Rim

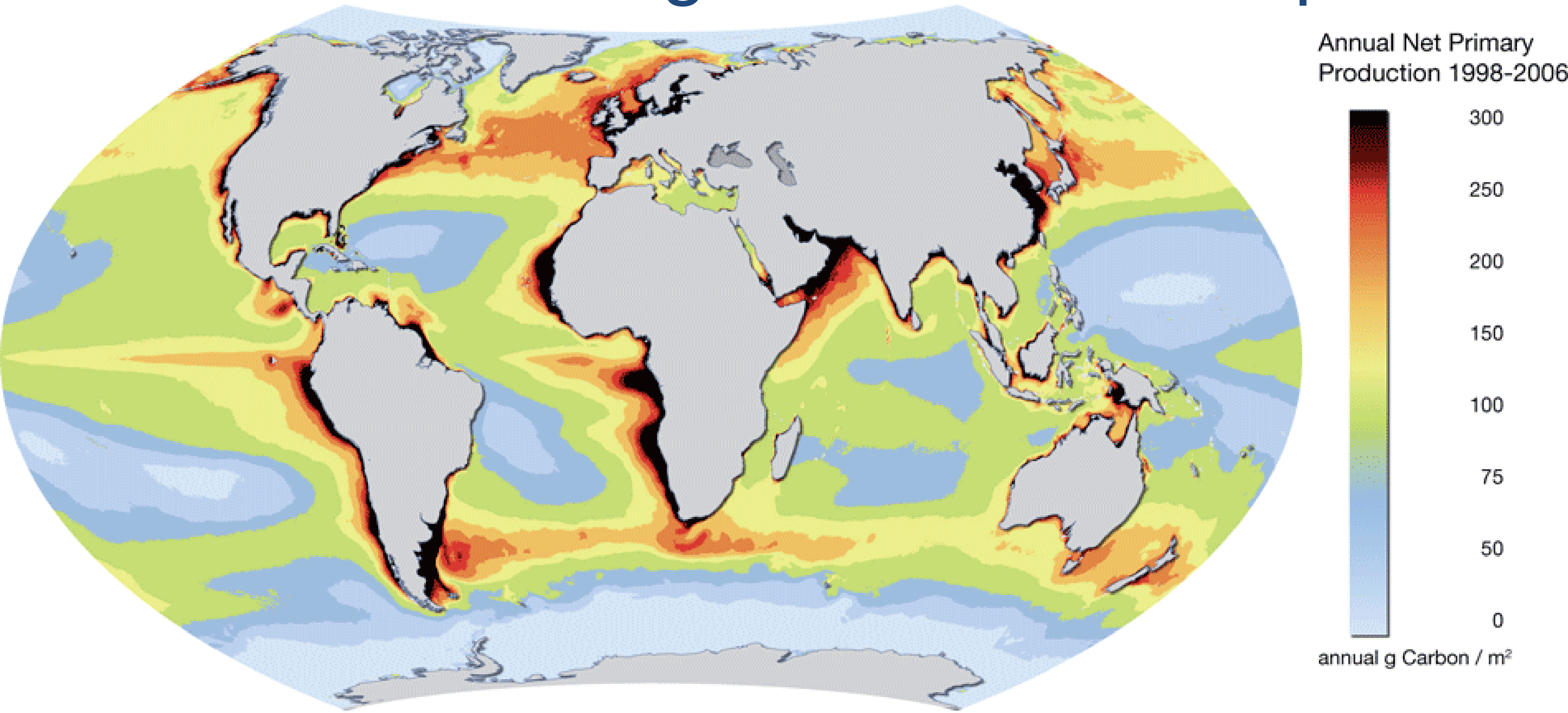

Circum-Pacific
"Monterey"
diatomaceous
facies

Bio-Siliceous Sediments are Common Along Neogene Continental Margins



Modified from Hein & Parrish (1987) and other authors

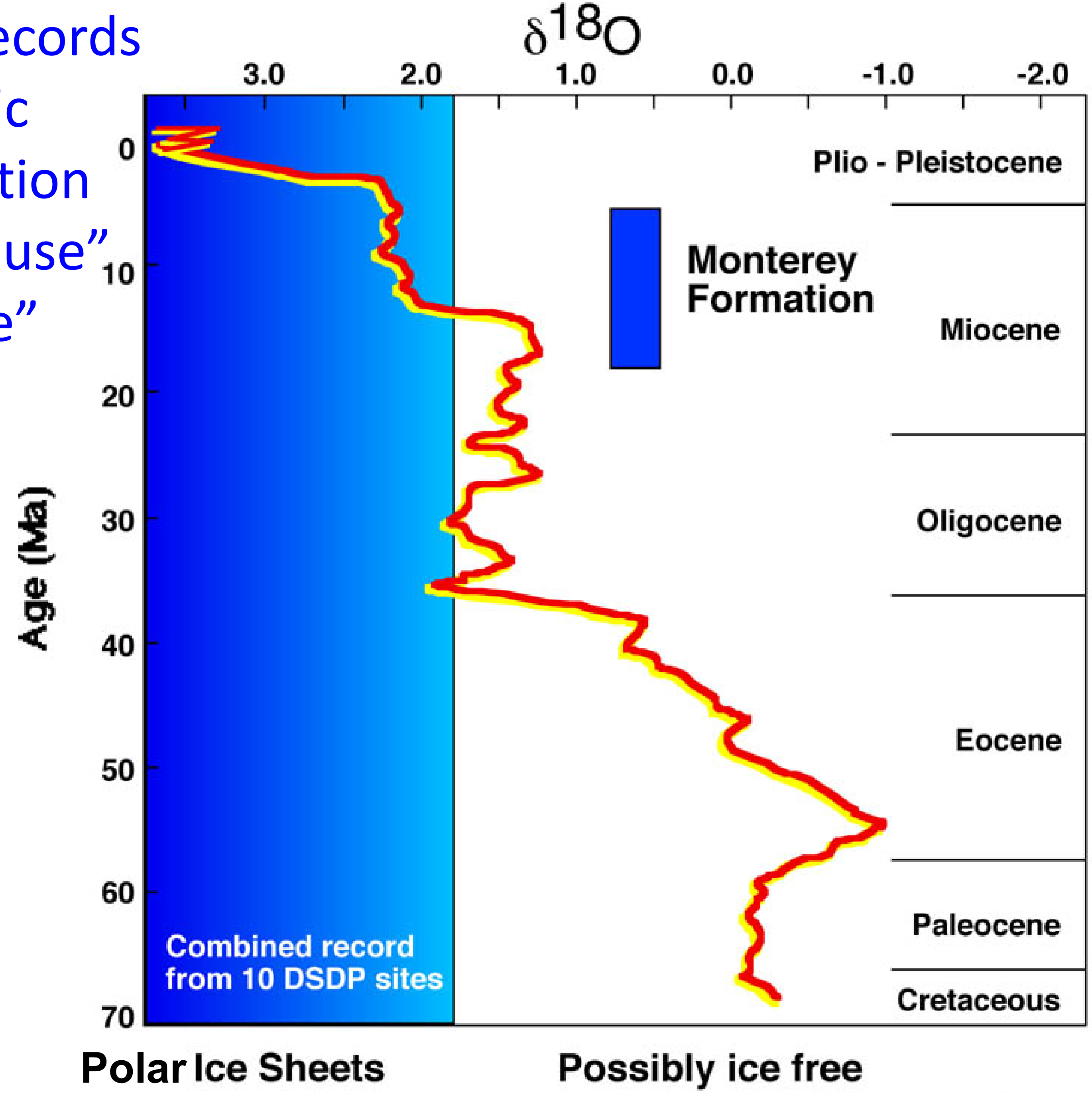
Oceanic Production of Organic Matter by Photosynthesis (mostly diatoms) is similar to the Neogene Siliceous Deposits



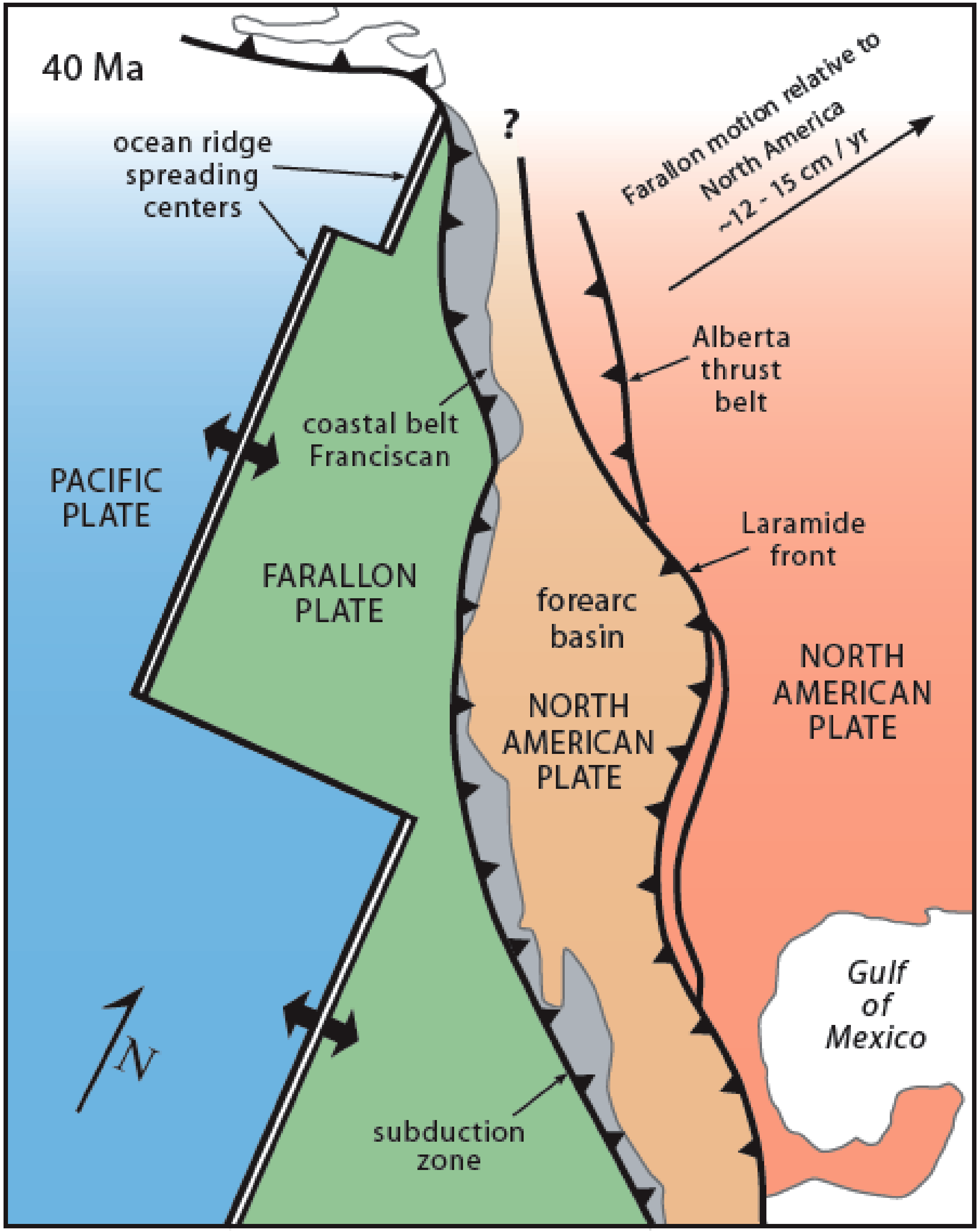
Source: Oregon State University 2007

Production at surface doesn't necessarily mean preservation in the sediment

The Monterey records the Cenozoic Climate Transition from “Greenhouse” to “Icehouse”



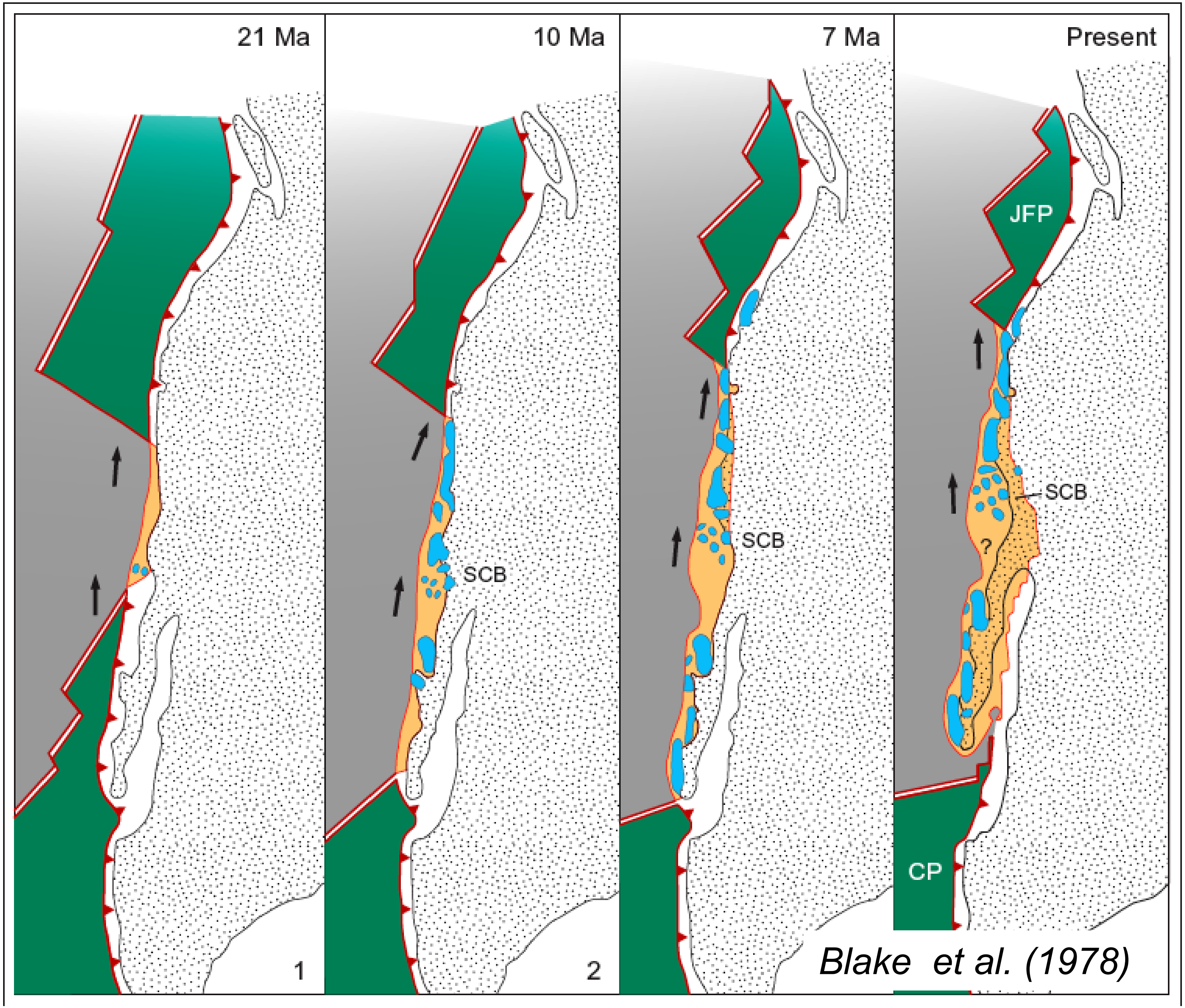
Miller et al. (1987)



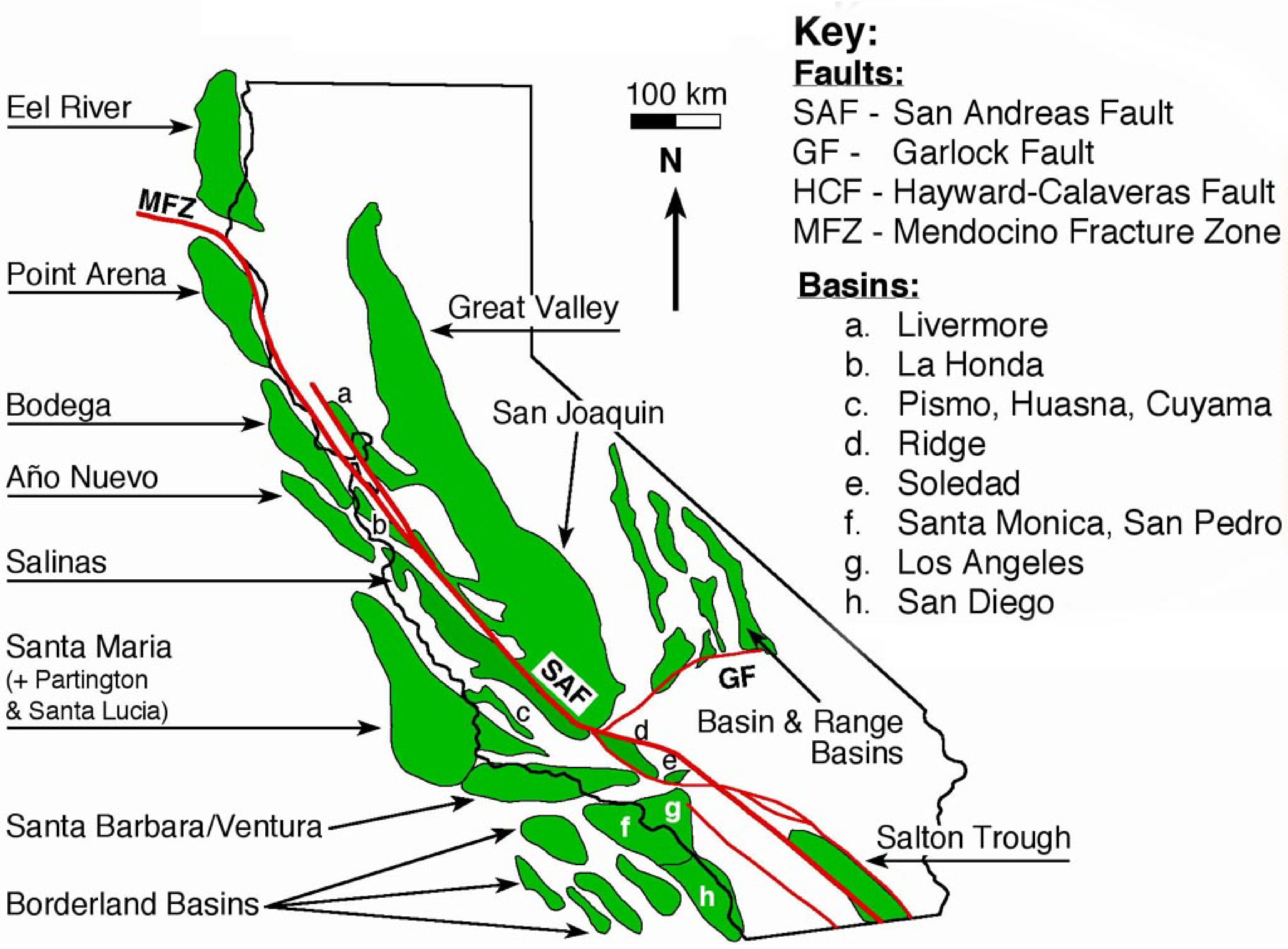
Mid-Miocene tectonic shift from convergent to transform margin formed numerous restricted and silled basins

Dickinson (1979)

Basins formed as the Farallon plate split apart



Blake et al. (1978)

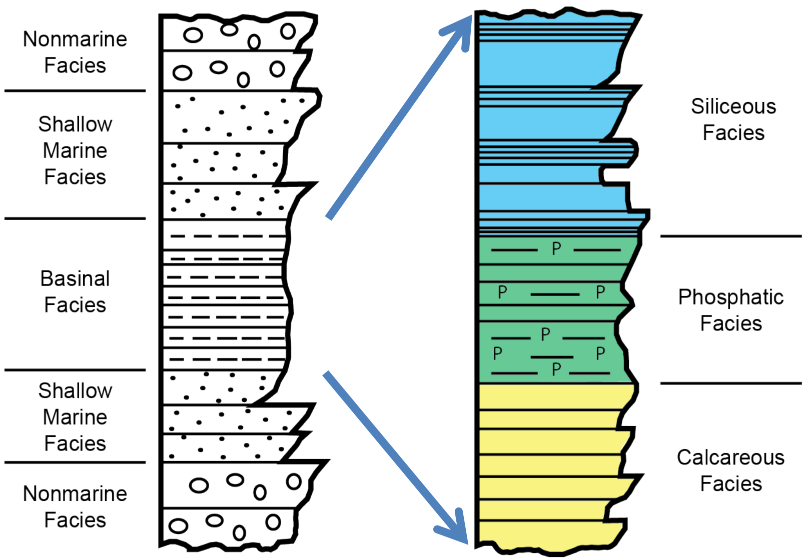

Key:
Faults:
SAF - San Andreas Fault
GF - Garlock Fault
HCF - Hayward-Calaveras Fault
MFZ - Mendocino Fracture Zone
Basins:
a. Livermore
b. La Honda
c. Pismo, Huasna, Cuyama
d. Ridge
e. Soledad
f. Santa Monica, San Pedro
g. Los Angeles
h. San Diego
100 km
N
Eel River
MFZ
Point Arena
Great Valley
Bodega
San Joaquin
Año Nuevo
Salinas
Santa Maria
(+ Partington
& Santa Lucia)
SAF
GF
Basin & Range
Basins
Santa Barbara/Ventura
Salton Trough
Borderland Basins
a
b
c
d
e
f
g
h

Neogene Basinal Stratigraphy

Generalized Basinal Facies of the Monterey Formation

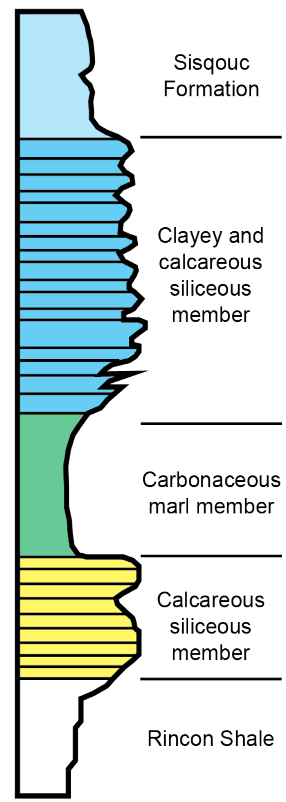
Generalized Upper Tertiary Facies, Coast Ranges, California

Generalized Basinal Facies of the Monterey Formation



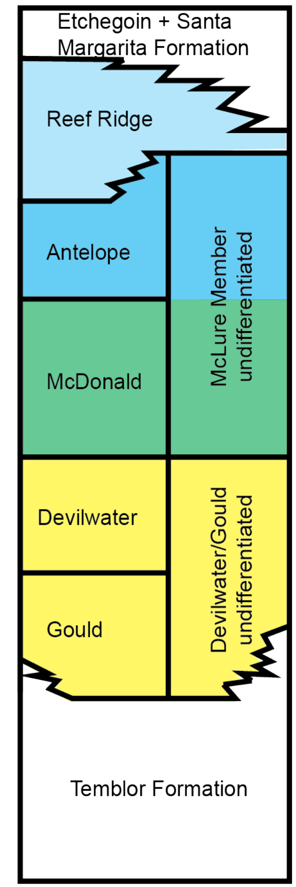
(Pisciotto and Garrison, 1981)

Facies of the Monterey Formation, Santa Barbara, California



(Isaacs, 1983)

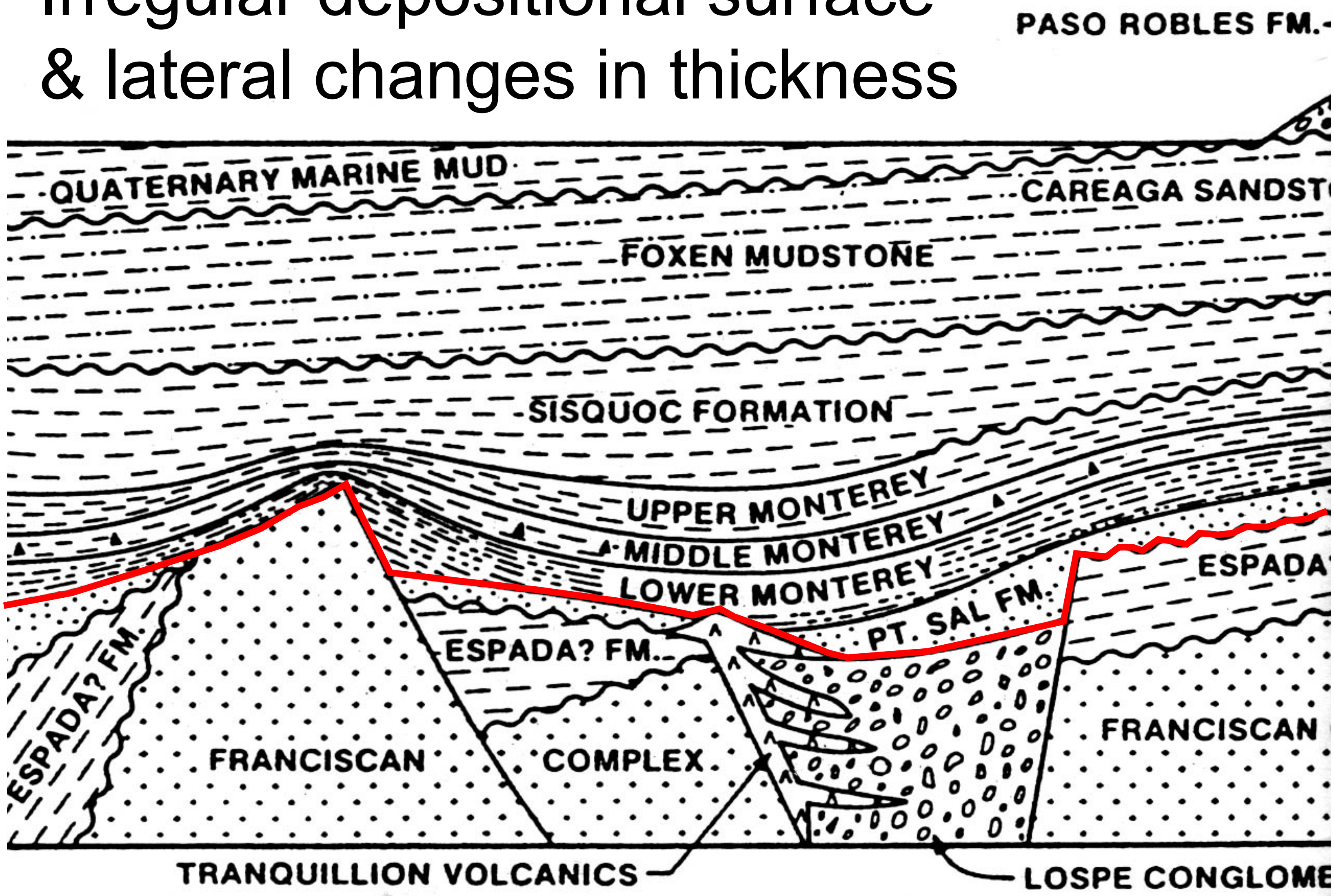
Facies of the Monterey Formation, San Joaquin Basin, California



(Graham and Williams, 1985)


Santa Barbara
Santa Barbara Basin
Ventura Basin
Santa Monica
Basin
Los Angeles
Basin
Santa Cruz
Basin
Patton Escarpment
San Pedro
Basin
Santa Catalina
Basin
Tanner
Basin
San Nicholas
Basin
San Diego Trough
California Continental Borderland

Irregular depositional surface & lateral changes in thickness

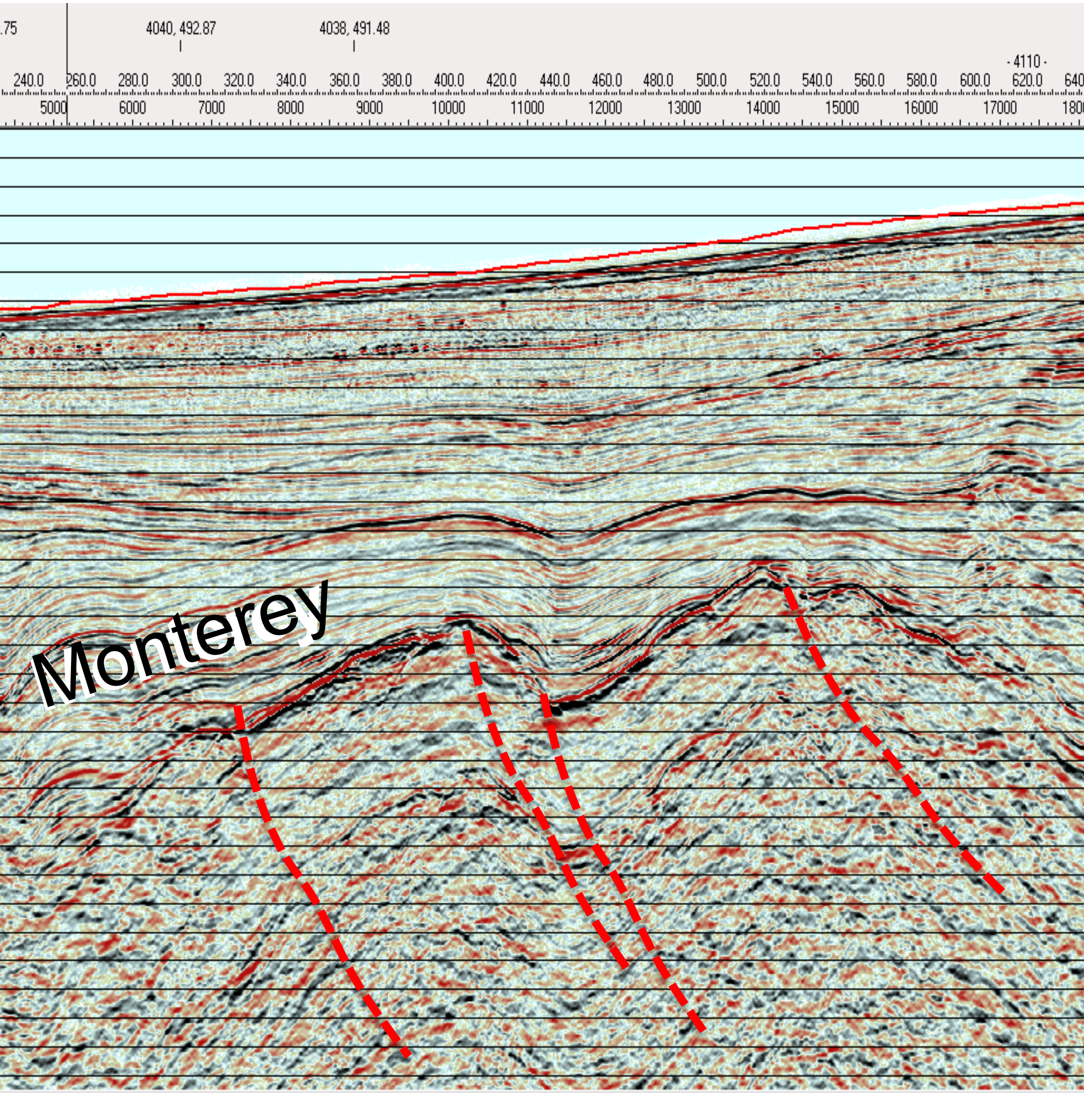


Santa Maria Basin

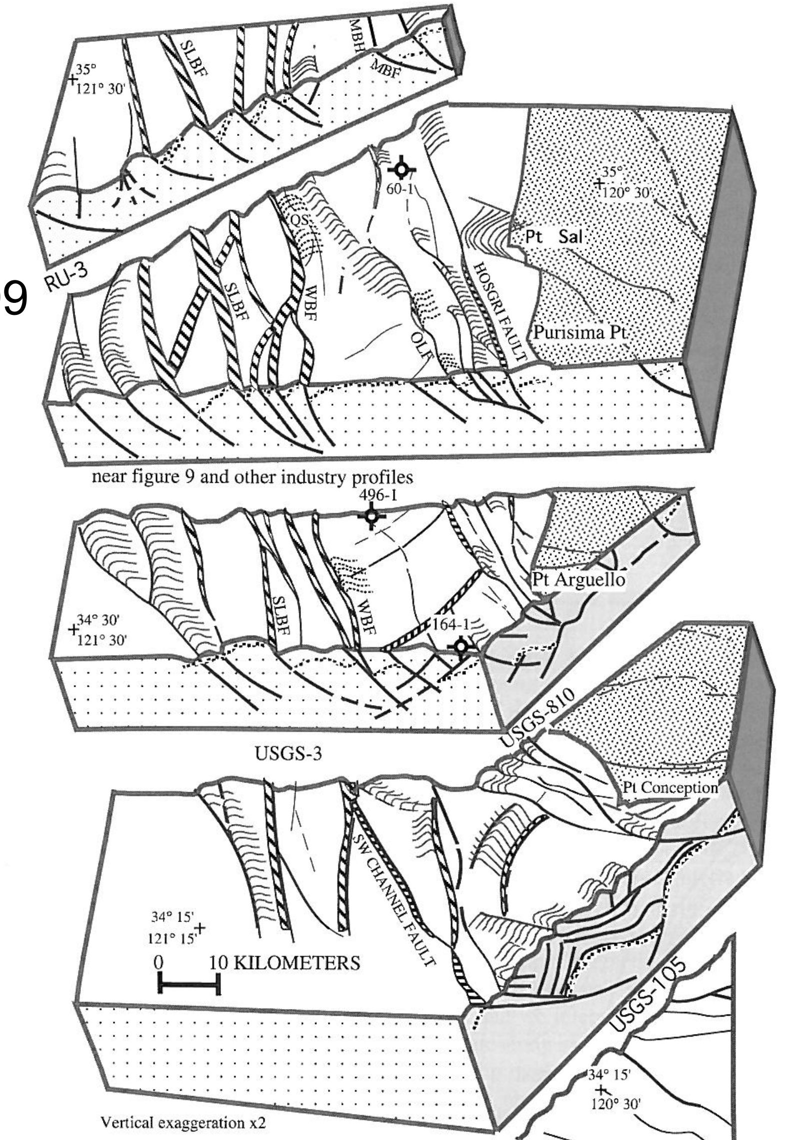
Dunham et al. (1991)

Tilted Fault Blocks of the Offshore Santa Maria Basin

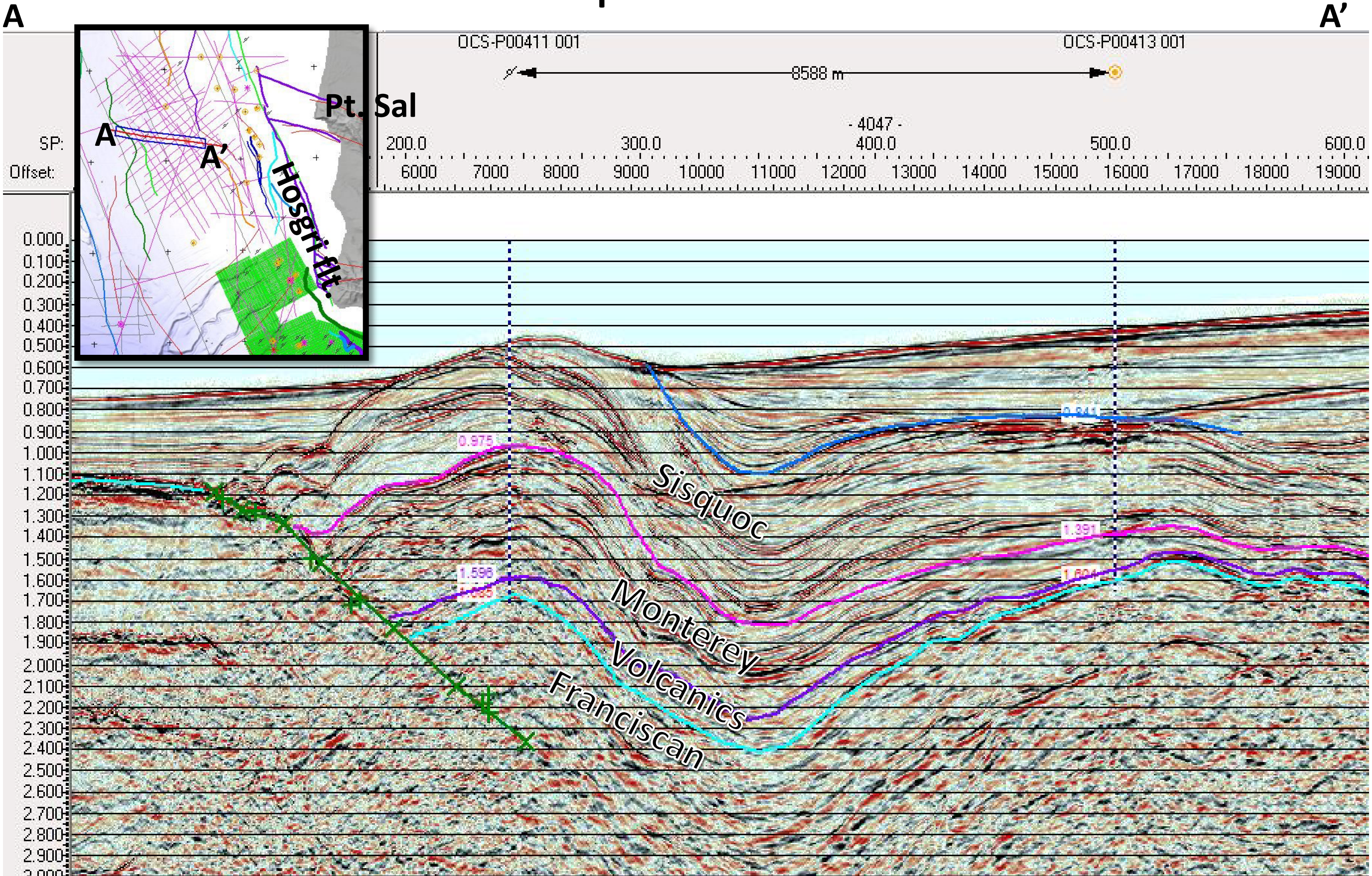
Doris & Behl, 2014



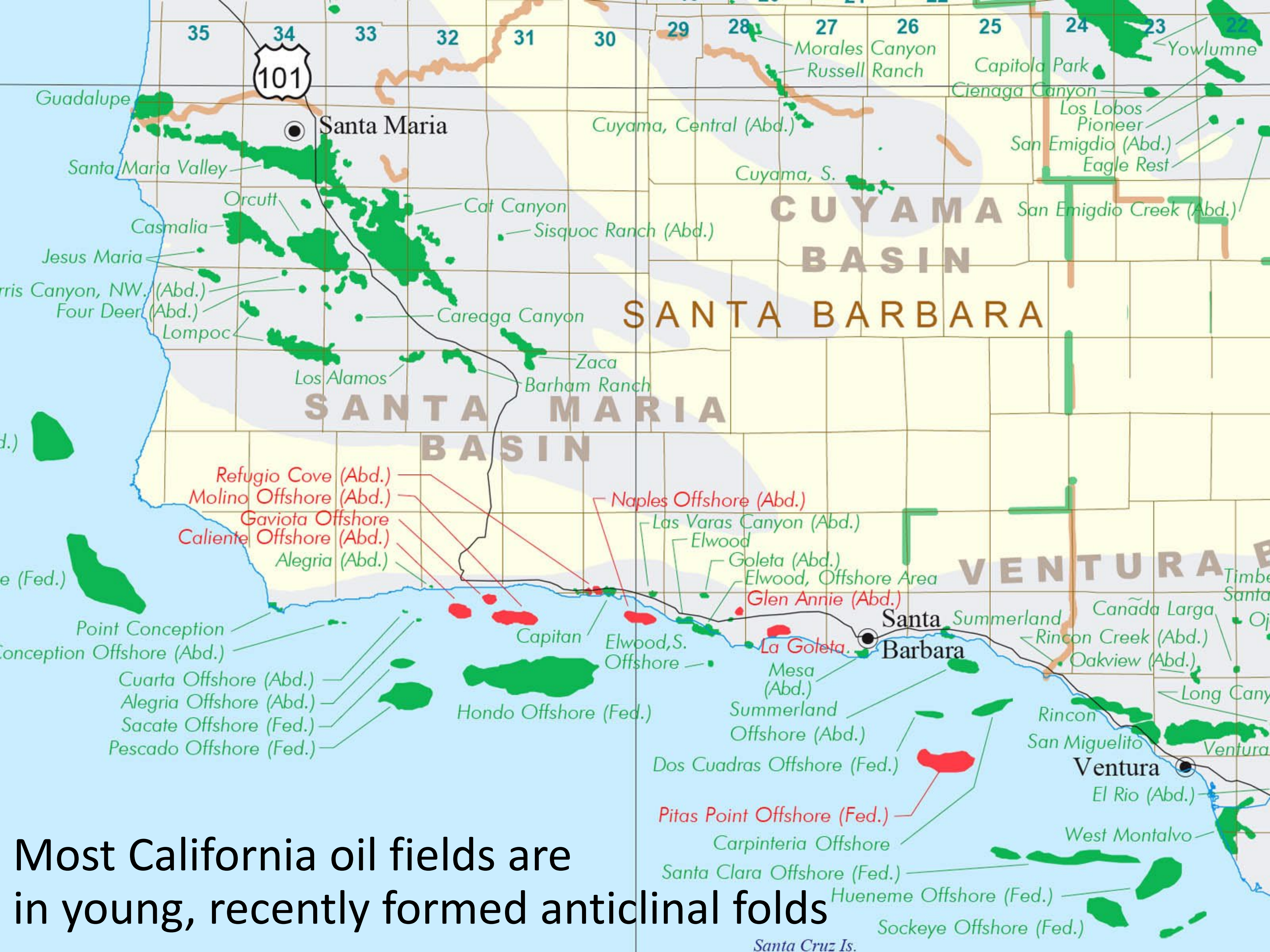
Sorlien et al., 1999



Plio-Pleistocene inversion & deformation of thick Miocene depocenters formed oil fields



Nelson Doris (2013)



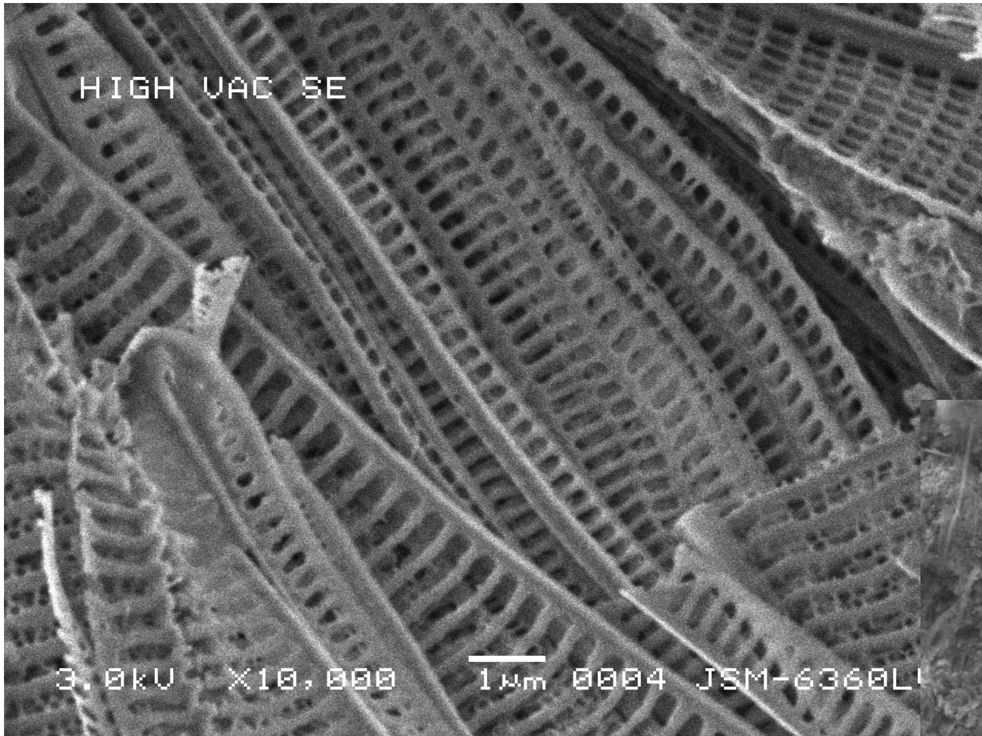
Most California oil fields are
in young, recently formed anticlinal folds

Main Sedimentary Components

- Silica
- Carbonate
- Organic matter
- Phosphate
- Detritus (clay, silt & sand)

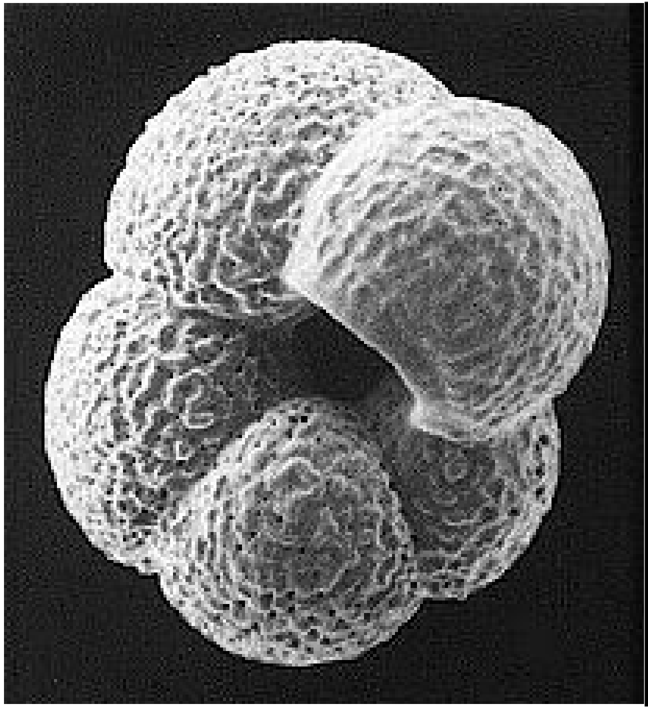
High diagenetic potential of silica, carbonate, phosphate & organic matter

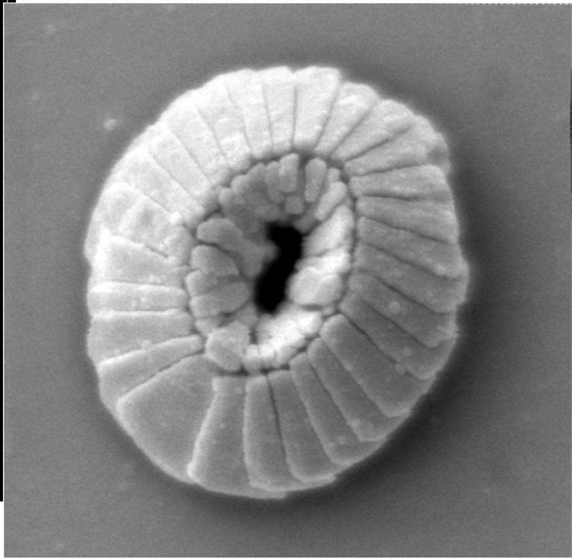
Diatoms


HIGH VAC SE
3.0kV X10,000 1μm 0004 JSM-6360L

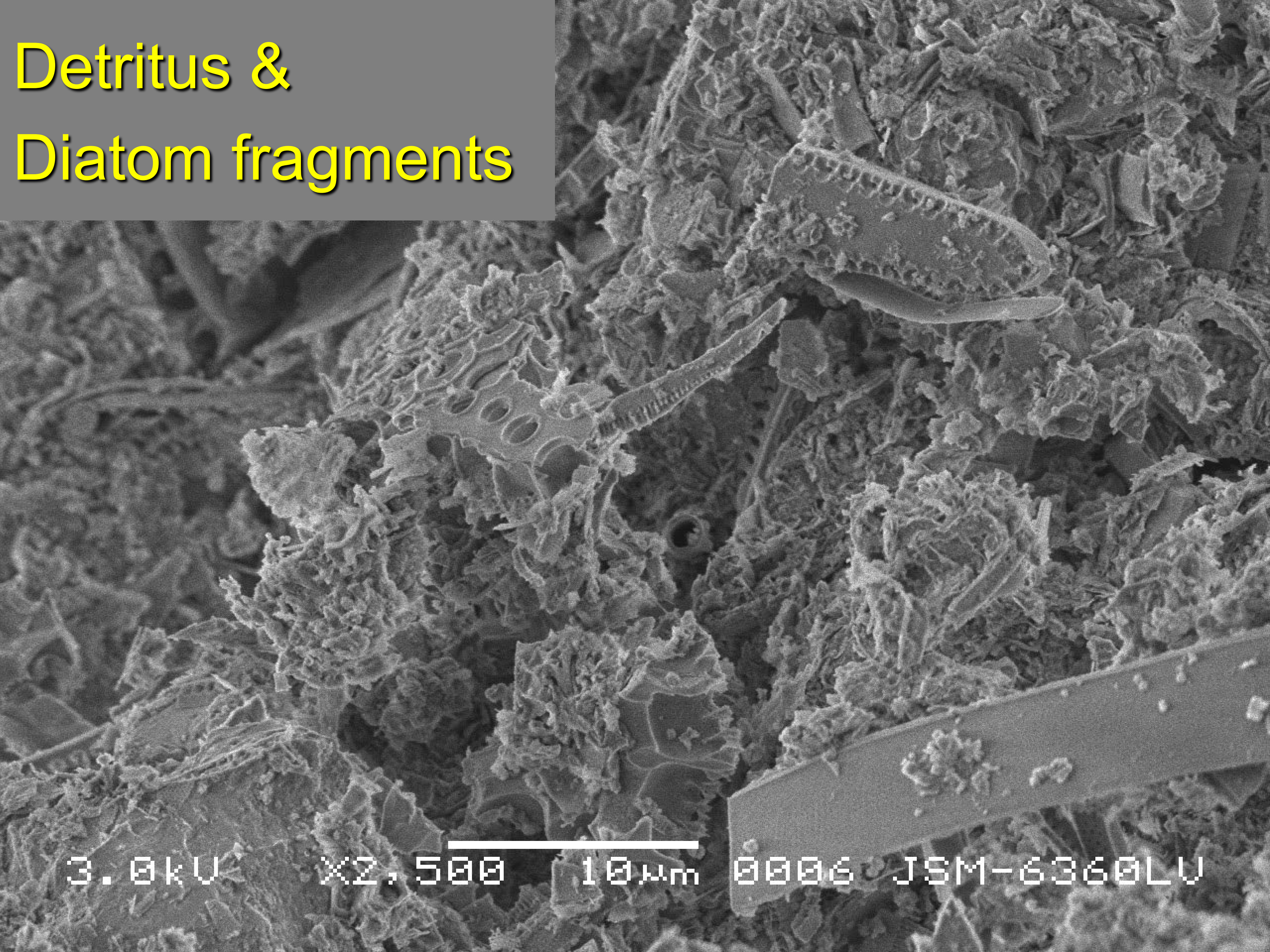

HV
5.0 kV
Spot
3.0
Mag
2344x
Sig
SE
WD
11.11 mm
HFW
0.11 mm
20 μm

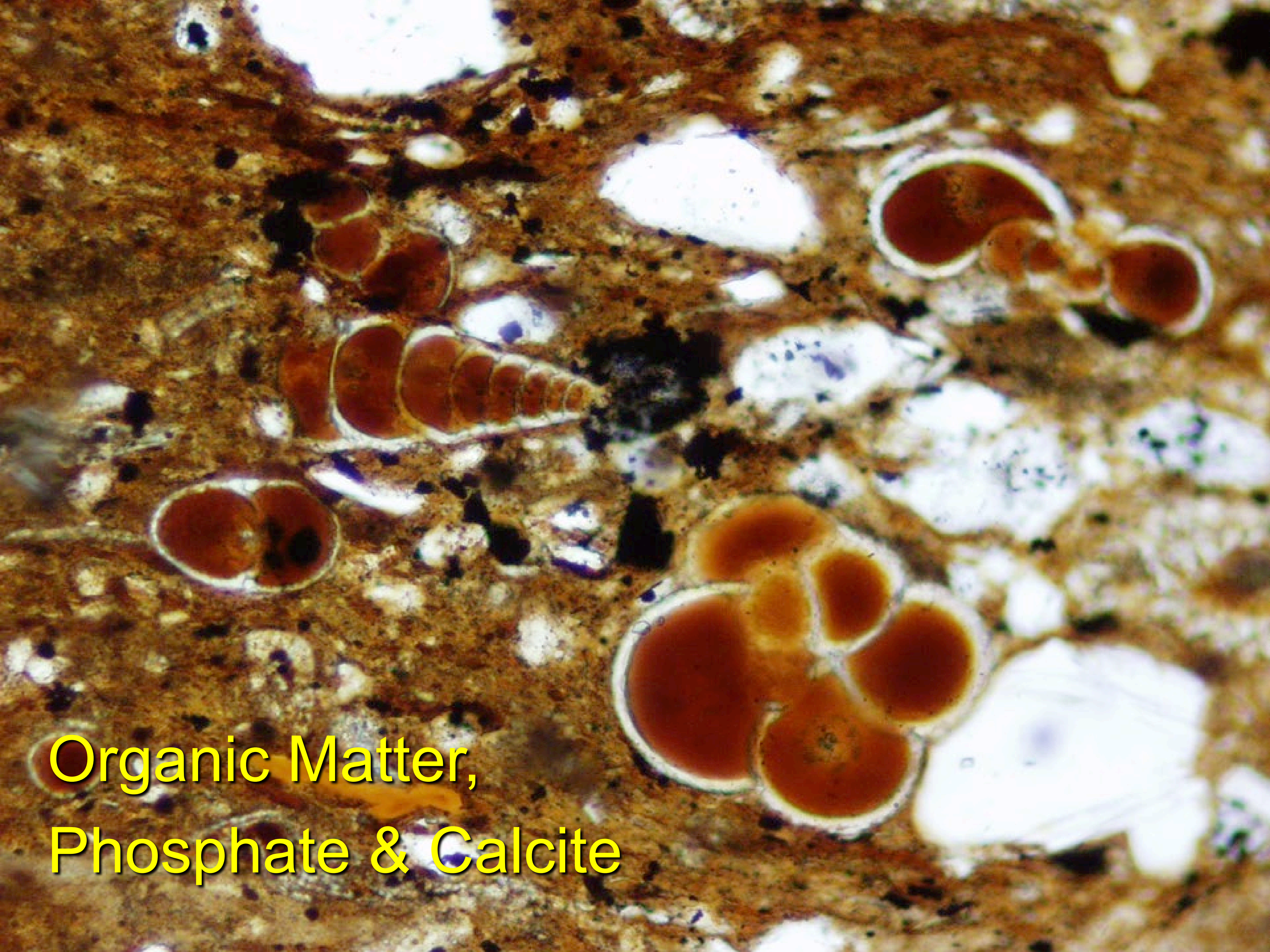
Calcareous Microfossils



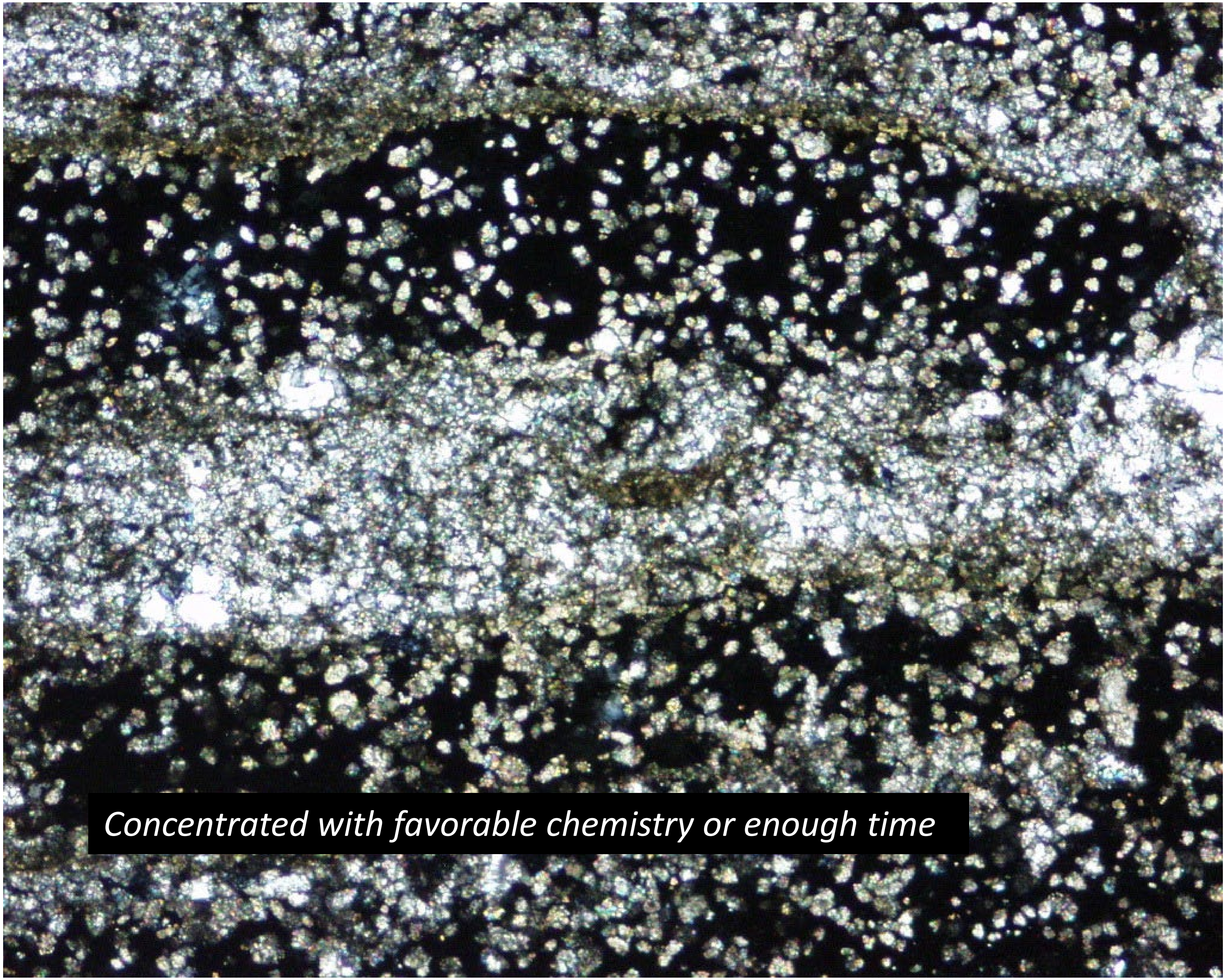


Detritus & Diatom fragments

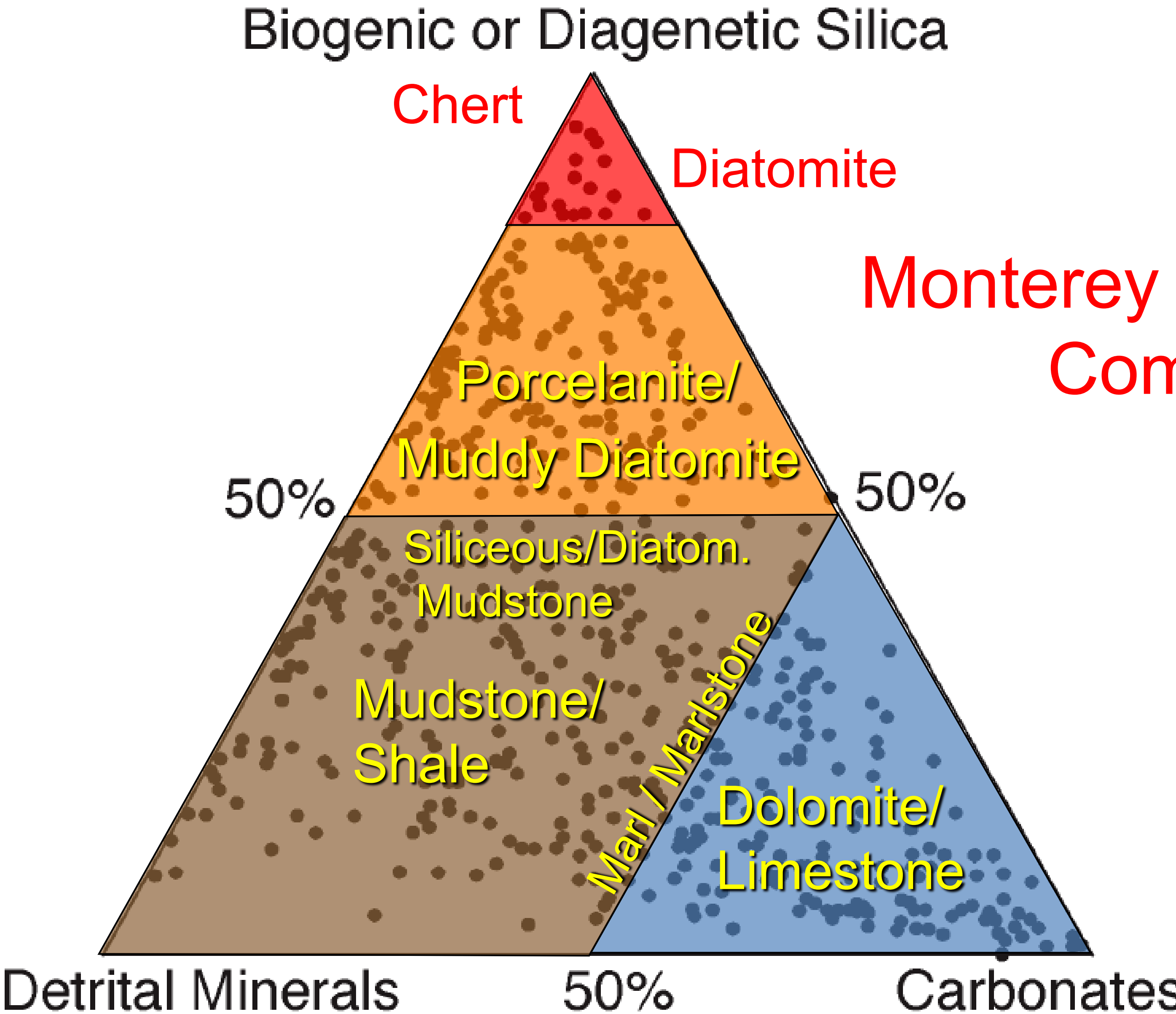



Organic Matter,
Phosphate & Calcite

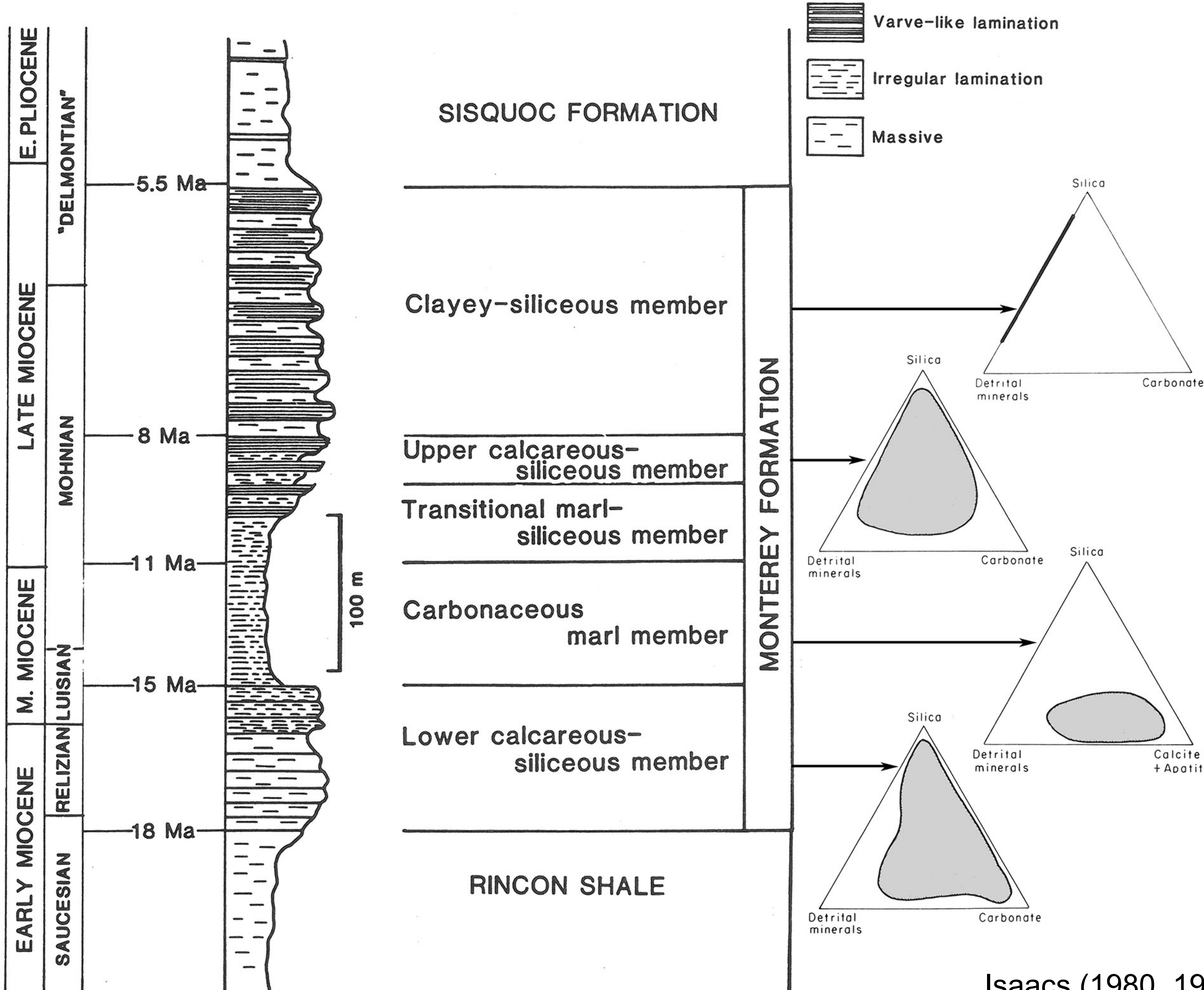
Disseminated Dolomite



Monterey Formation Compositional variability



Compositional data of Isaacs (1985)



Isaacs (1980, 1983)

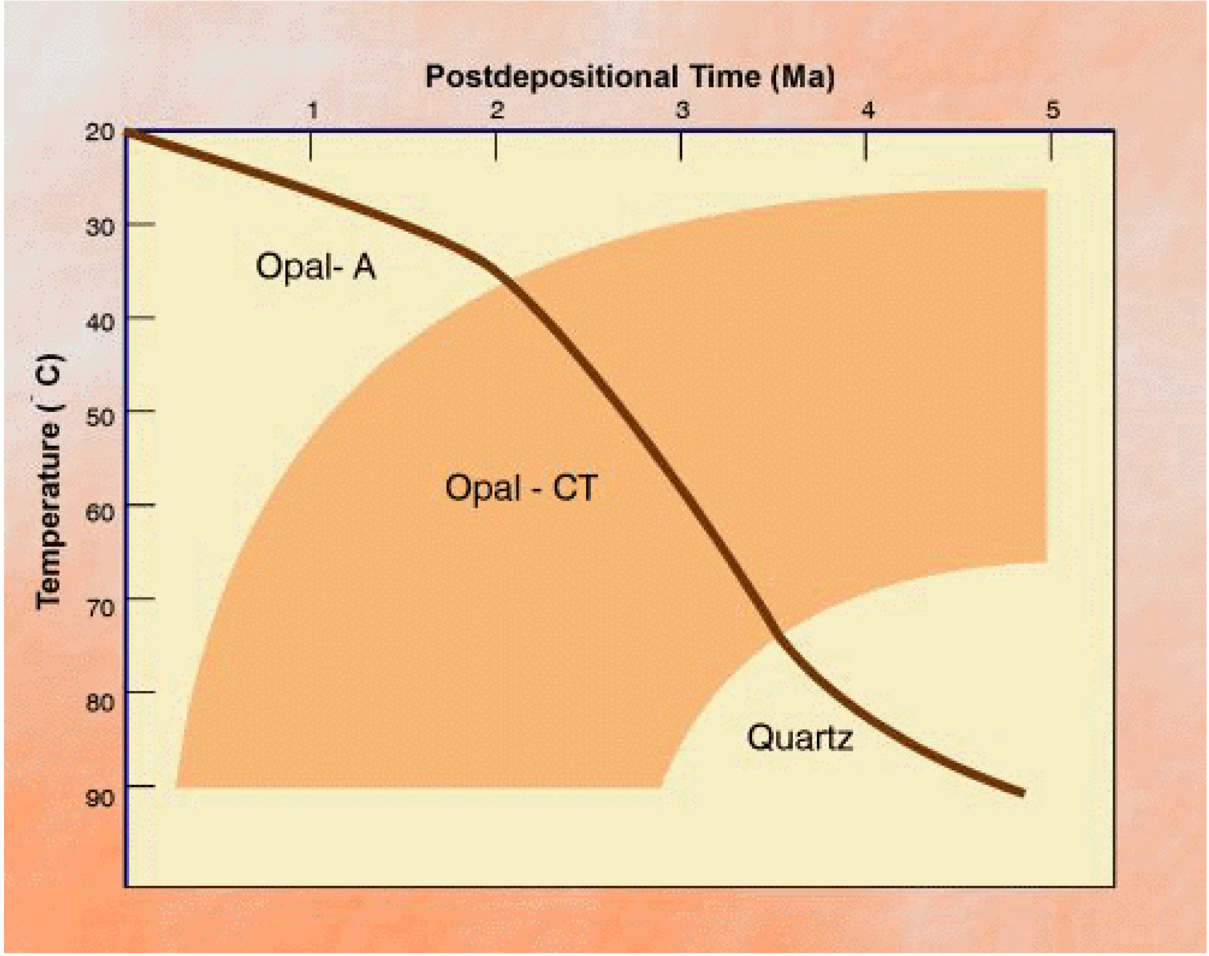
Silica Diagenesis

2-step dissolution/reprecipitation:

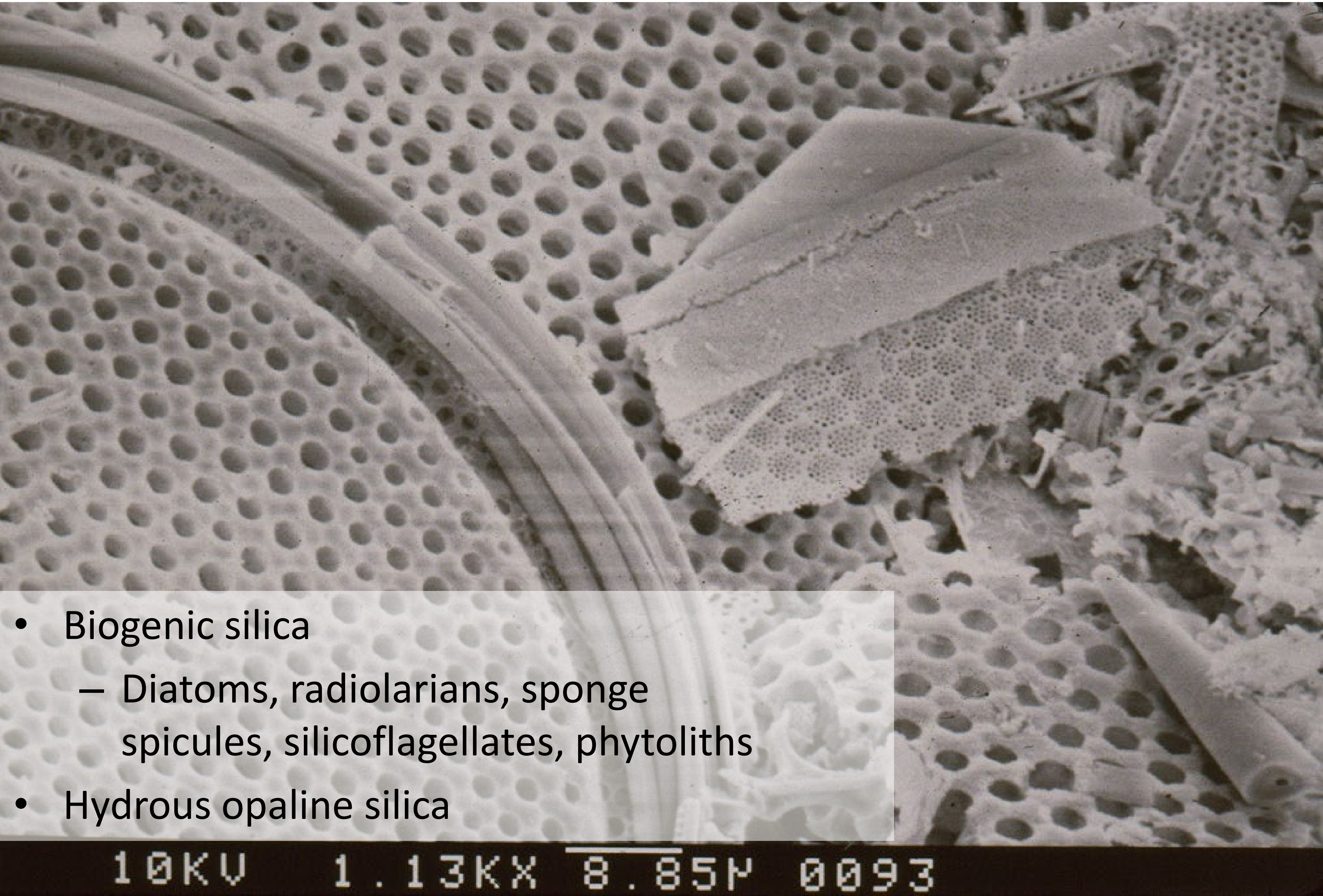
- Opal-A
- Opal-CT
- Quartz

Time +/or Temperature

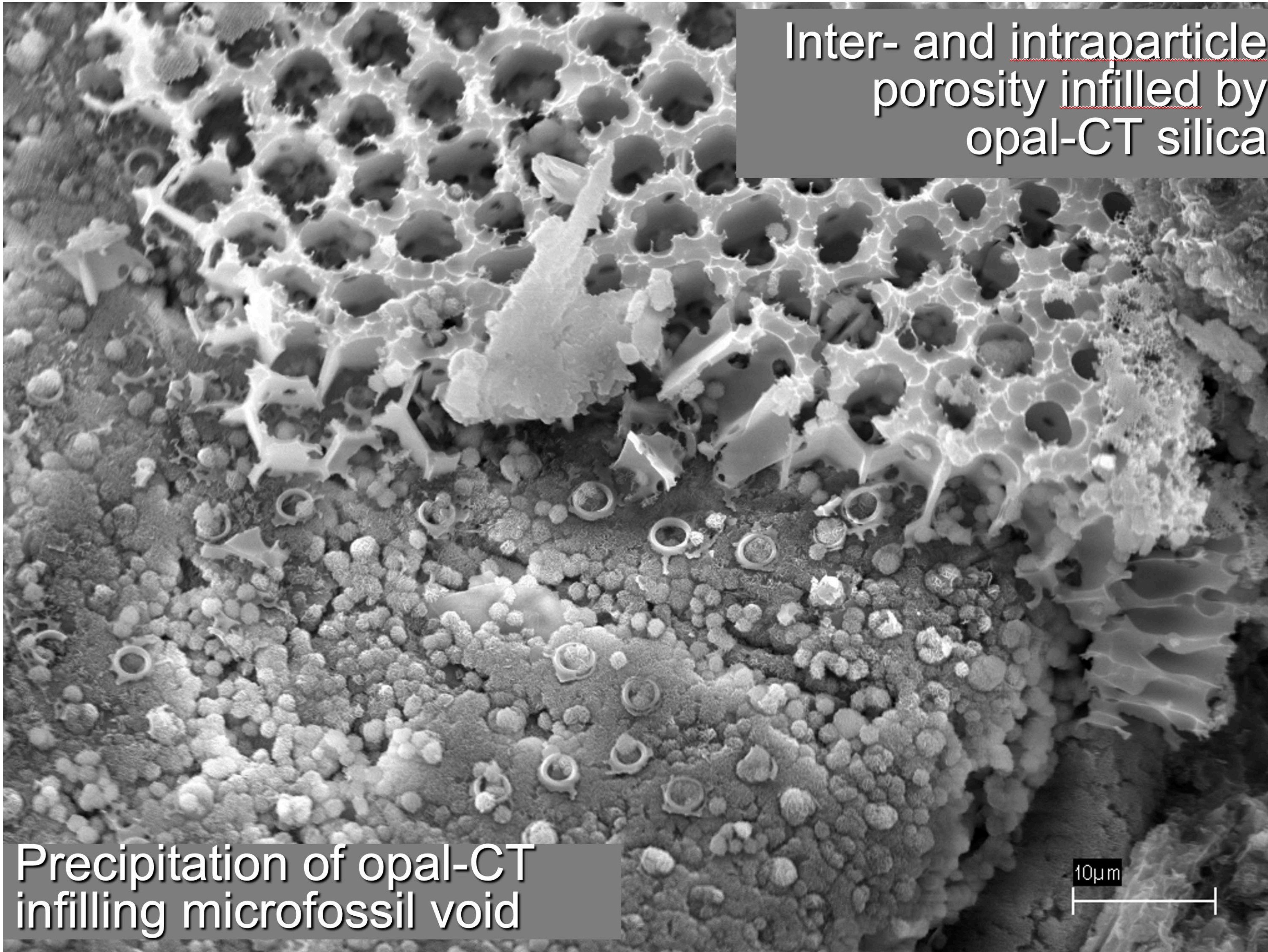
Siever (1983)



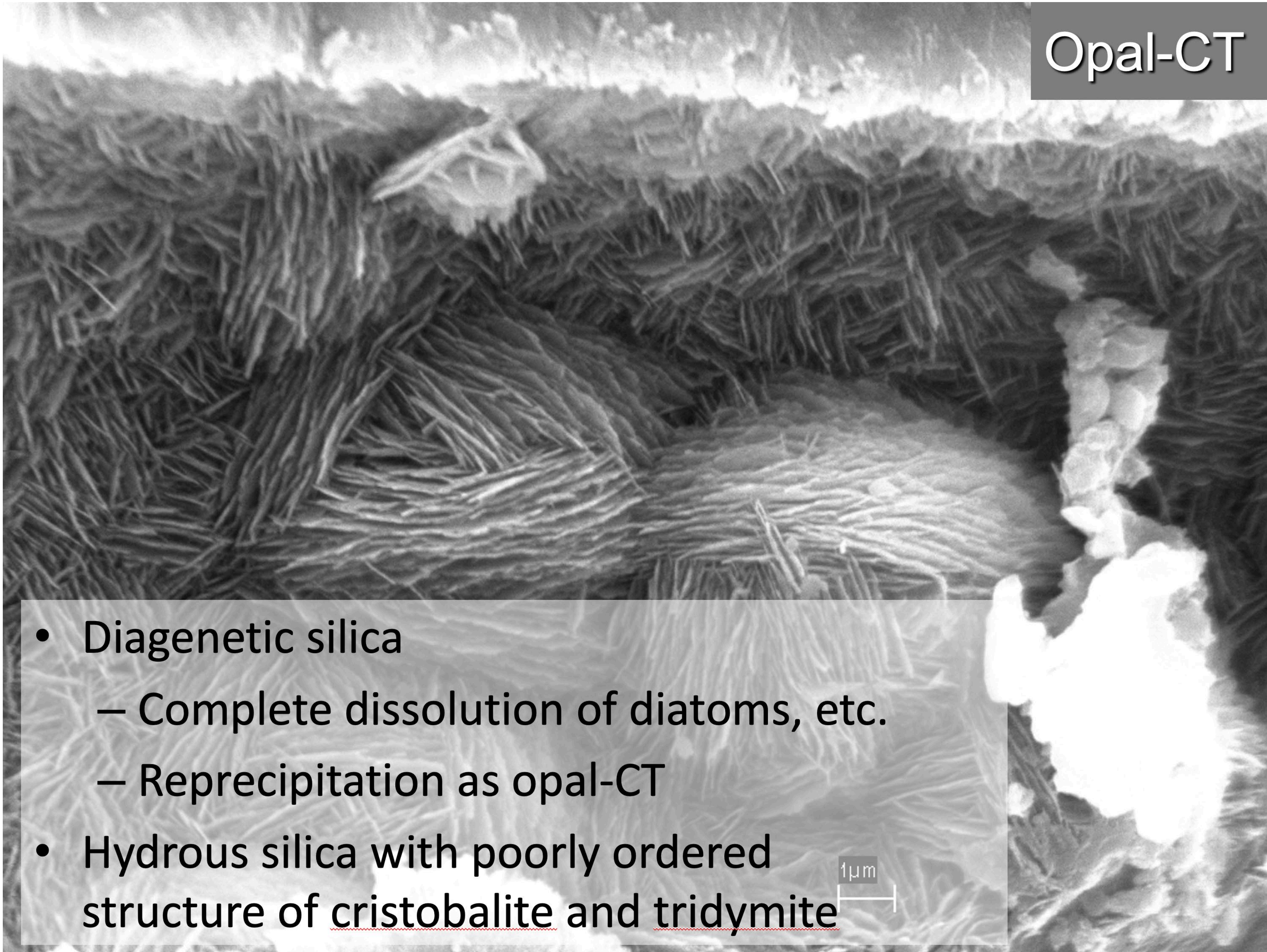
Opal-A



- Biogenic silica
  - Diatoms, radiolarians, sponge spicules, silicoflagellates, phytoliths
- Hydrous opaline silica

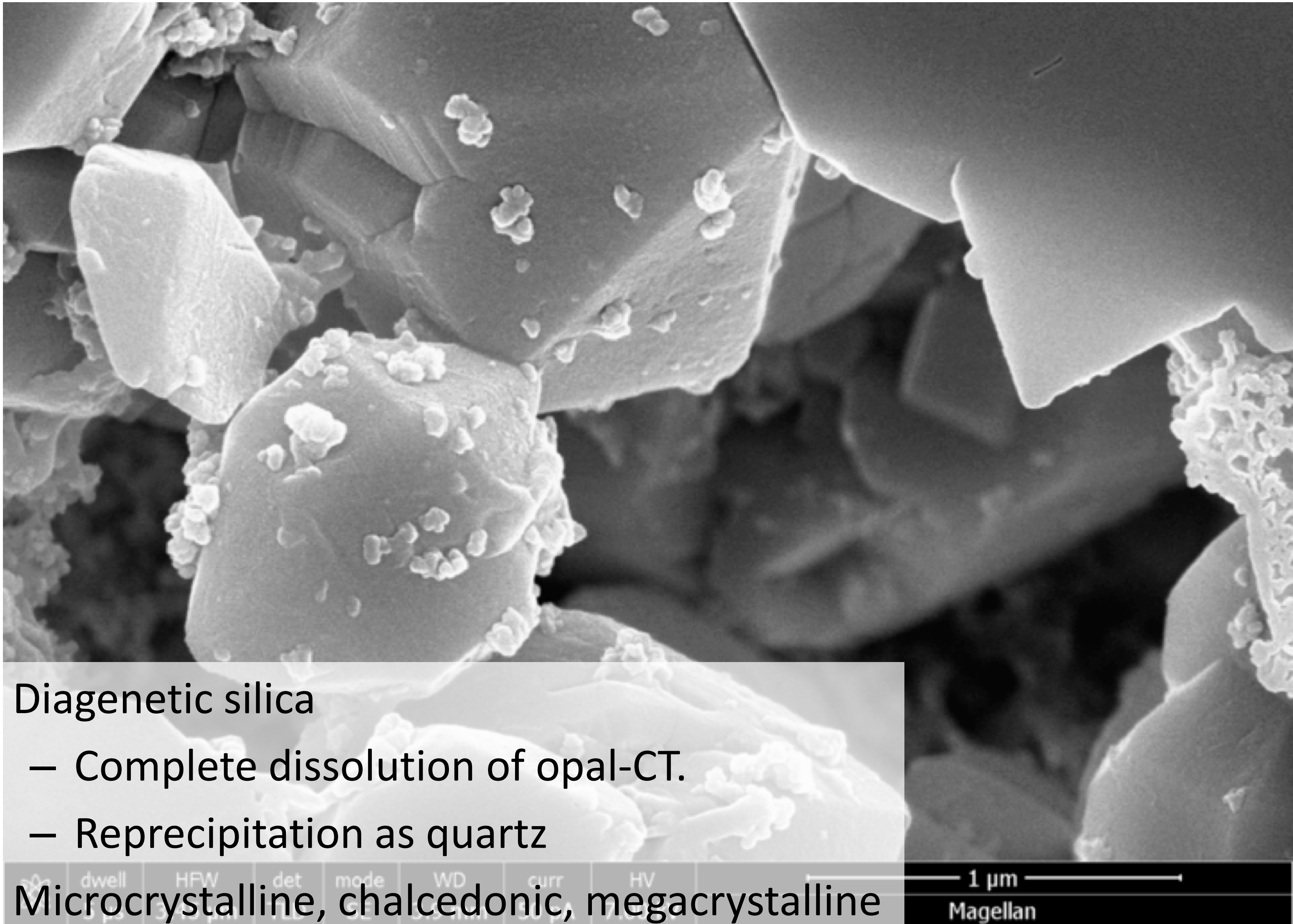

Inter- and intraparticle
porosity infilled by
opal-CT silica
Precipitation of opal-CT
infilling microfossil void
10μm

Opal-CT

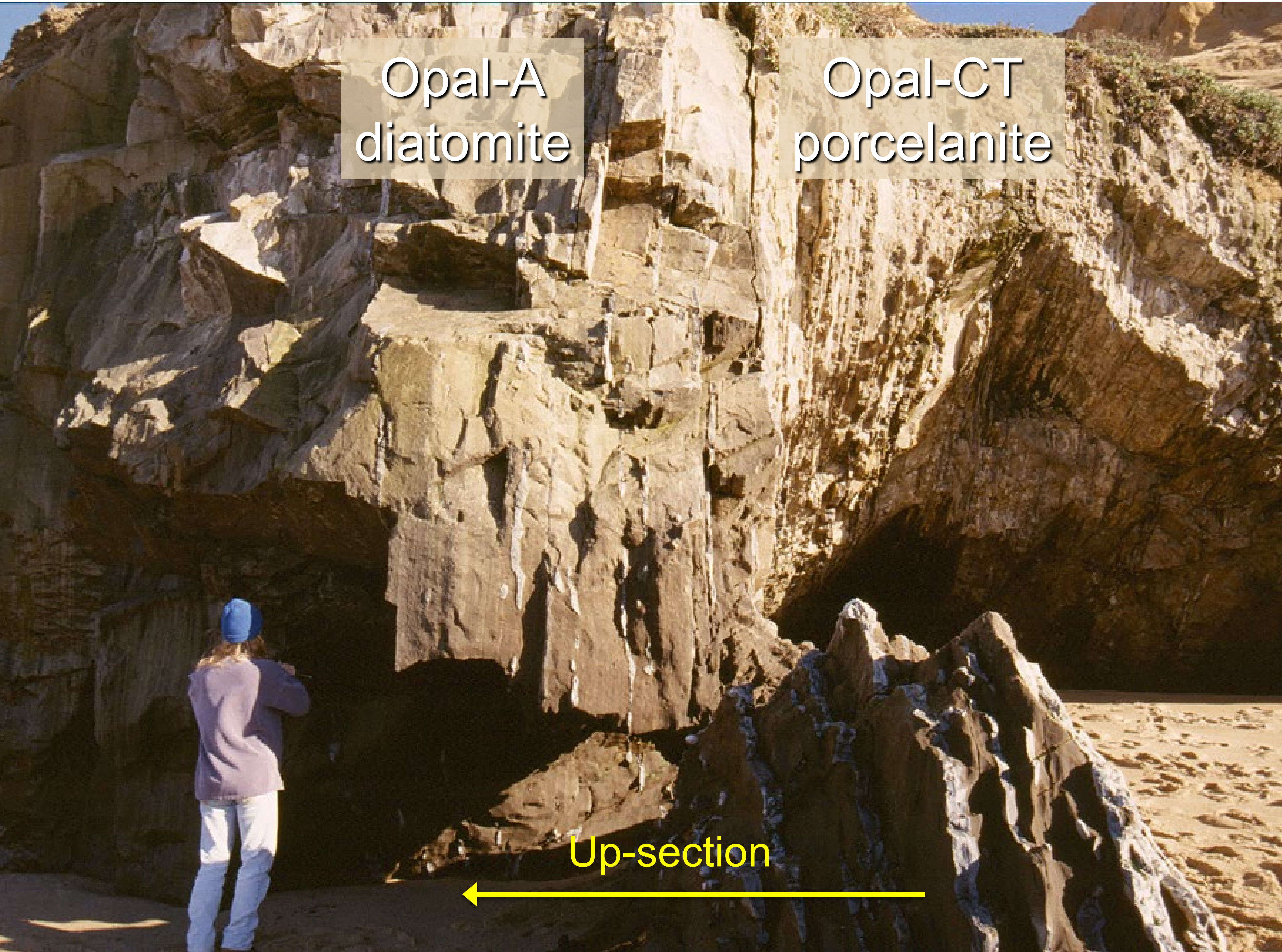


- Diagenetic silica
  - Complete dissolution of diatoms, etc.
  - Reprecipitation as opal-CT
- Hydrous silica with poorly ordered structure of cristobalite and tridymite

Quartz



- Diagenetic silica
  - Complete dissolution of opal-CT.
  - Reprecipitation as quartz
- Microcrystalline, chalcedonic, megacrystalline


Opal-A
diatomite
Opal-CT
porcelanite
Up-section

Sedimentation of Hemipelagic Sediments

Vertical Settling

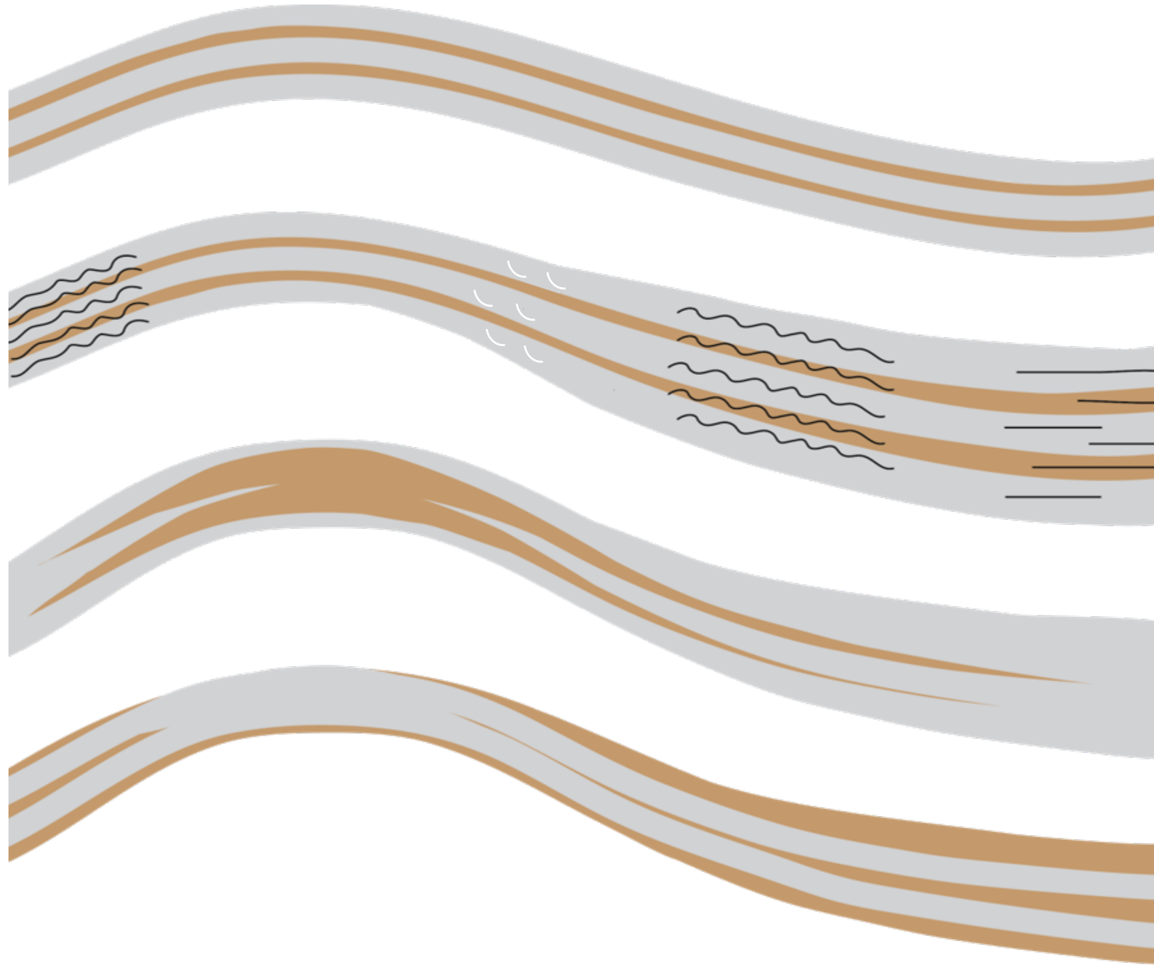
- Flocculation
- Fecal pellets
- Marine snow
- Diatom mats and TEP aggregates

Lateral & downslope transport

- Surface suspension (hypopynal flow)
- Nepheloid plumes (hyperpynal flow)
- Turbidity currents
- Slumps
- Resuspension or reworking by currents

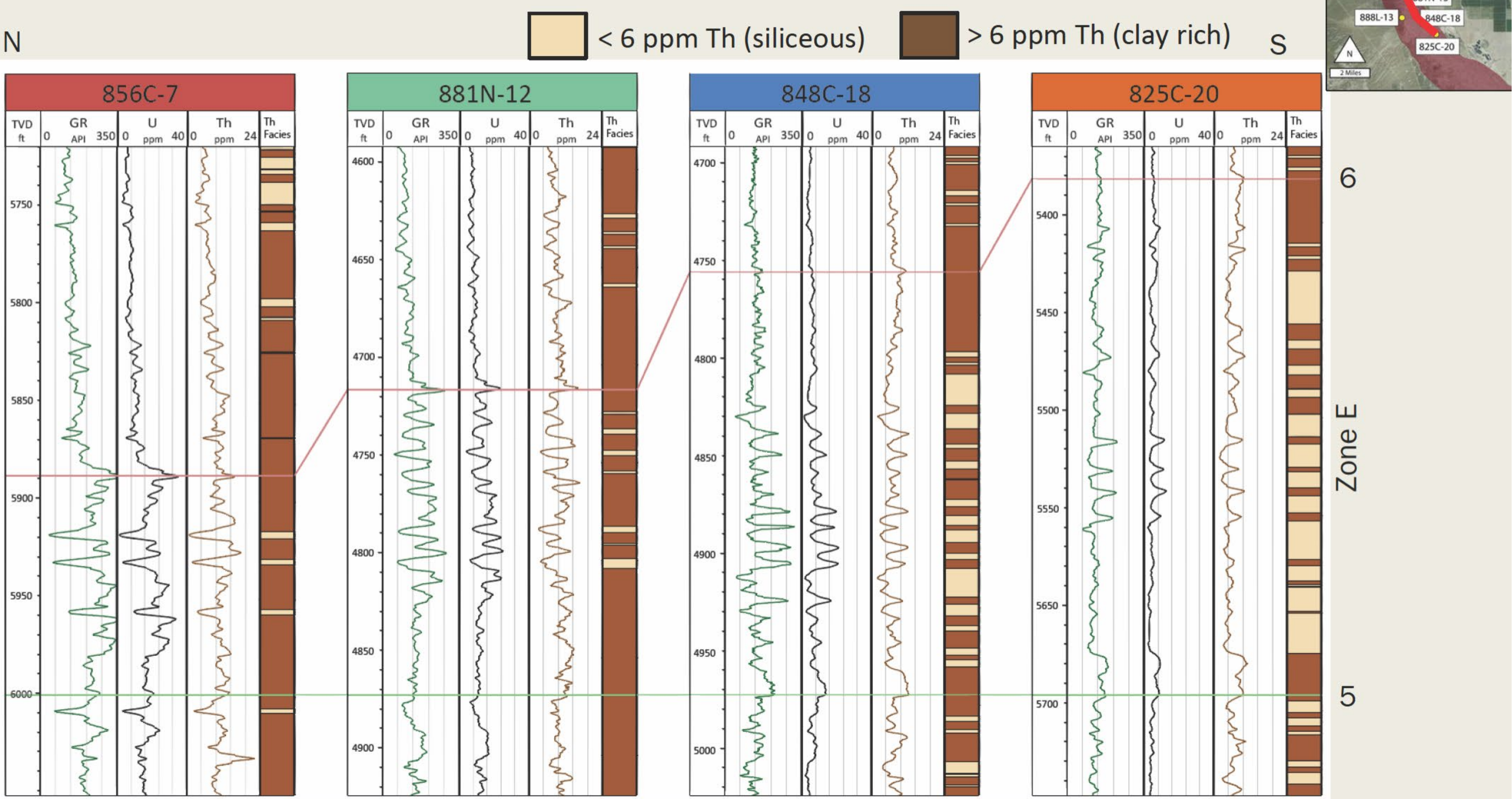
Bathymetric Depositional Patterns

- Uniform thickness/ Uniform composition
- Basinal thickening/ Uniform composition
- Basinal thickening/ Silica-rich basin
- Basinal thickening/ Detrital-rich basin



Erbele and Behl (2015)

Lateral Variation: Zone E



Jack Farrell (2020)

Thicker sections by focusing of siliceous sediment

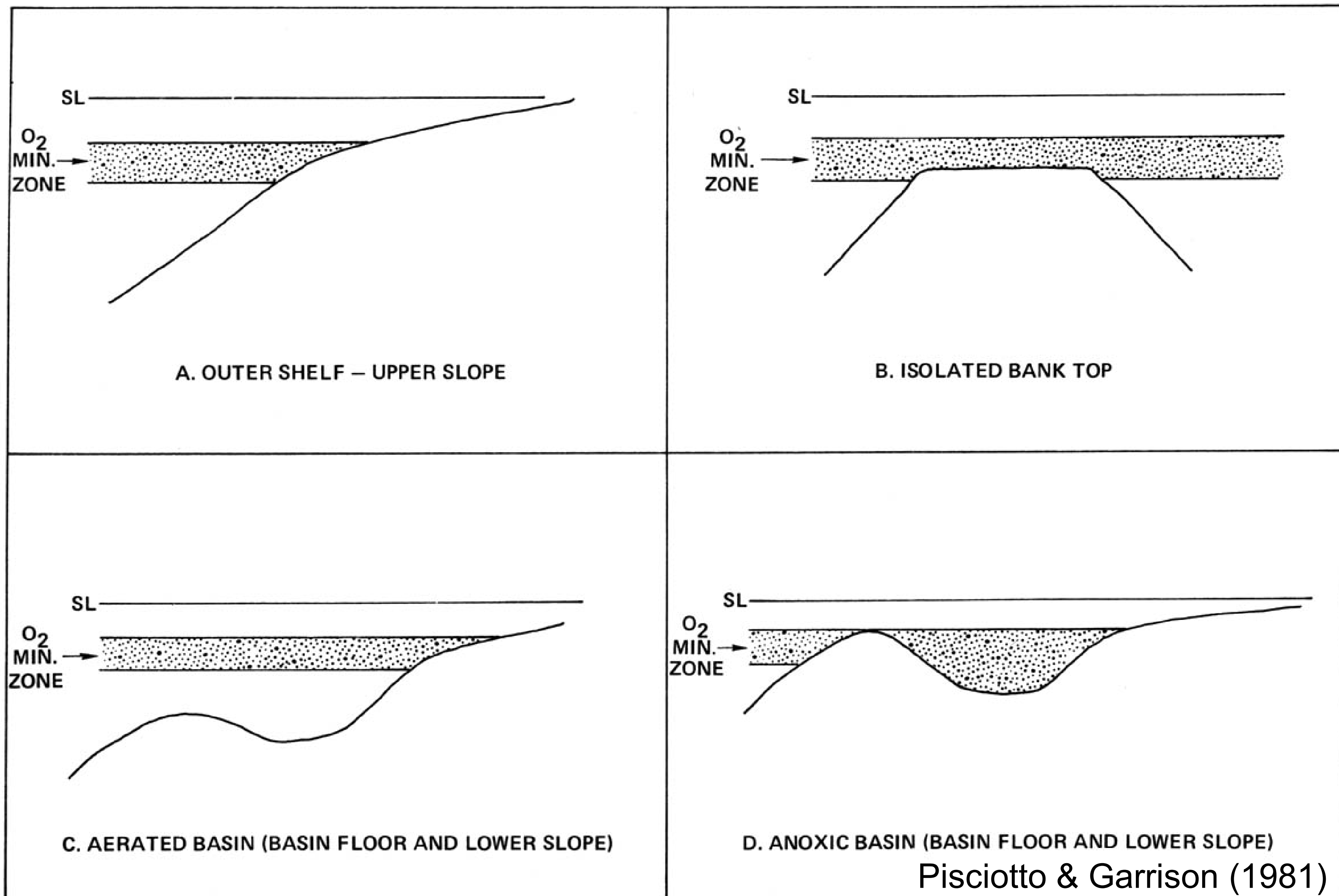
Controls of Sediment Distribution

- Seafloor morphology
  - Basin, slope, banktop/shelf
- Proximal or Distal setting
  - Inner or outer basins
- Arid or Humid climate
  - Riverine or eolian supply, or starved for detritus
- Currents
  - Marginal location and water depth

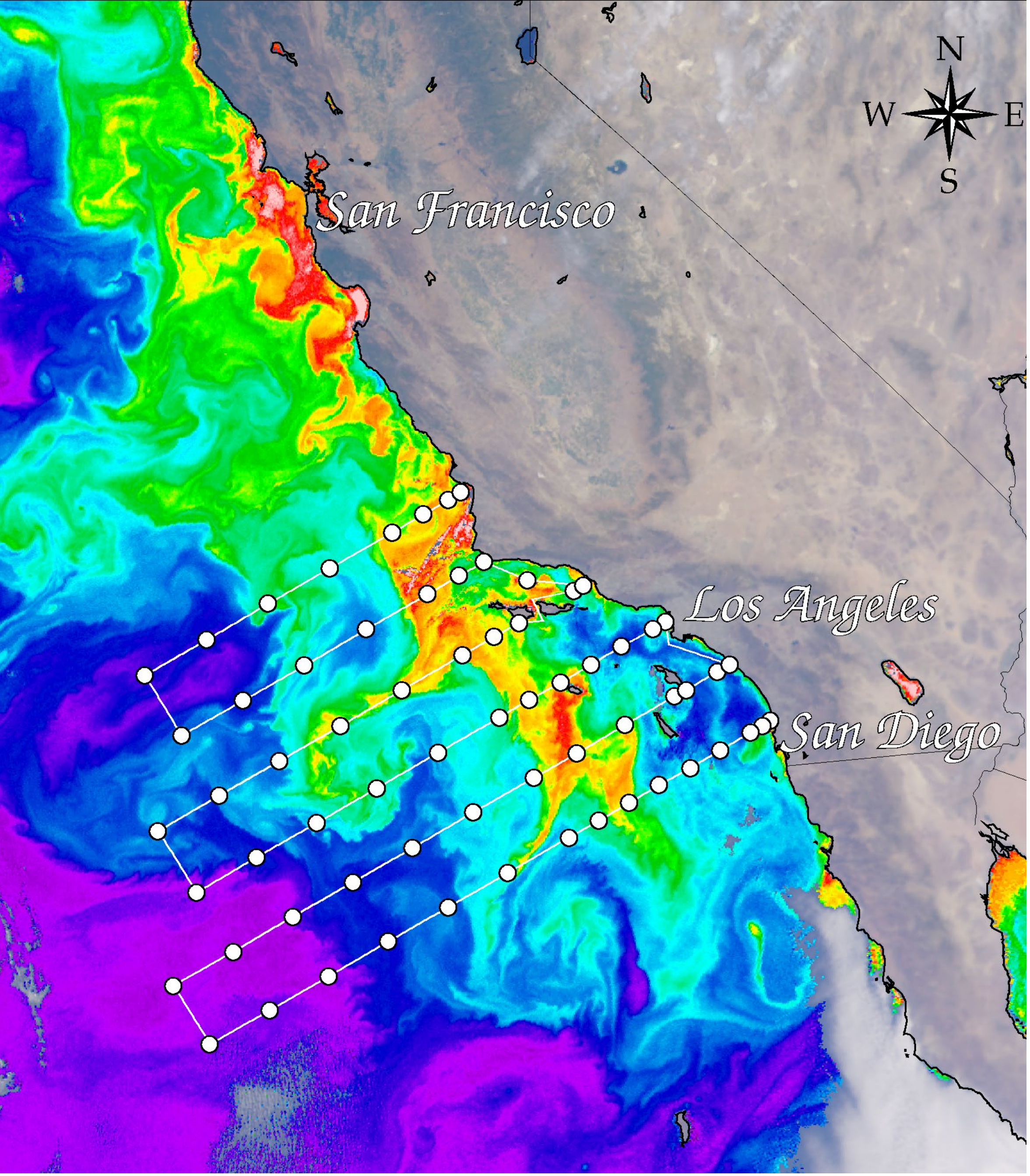
Organic Carbon (TOC)

- Mostly type II kerogen - marine algae
- Mostly between 2% - 6%
- Highest in phosphatic mudstone / carbonaceous marlstone
  - Up to 23% TOC
    (34% organic matter by weight)

Where the Oxygen Minimum Zone (OMZ) hits the seafloor affects organic carbon preservation



Pisciotto & Garrison (1981)

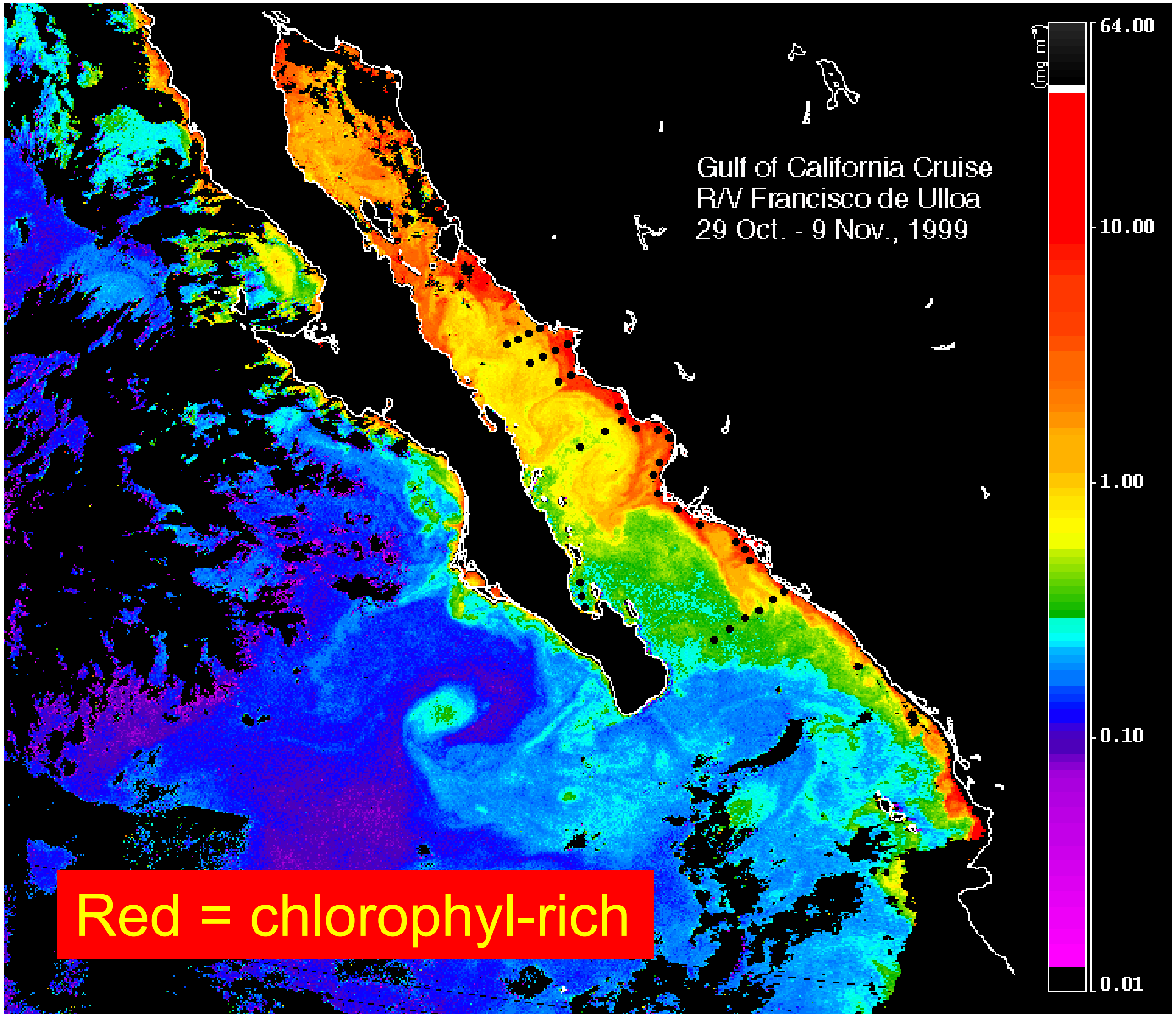


Patchy upwelling leads to uneven distribution of plankton & organic matter

Red = chlorophyl-rich

CalCOFI (2010)

Semi-enclosed basins can have spatially & seasonally complex upwelling patterns



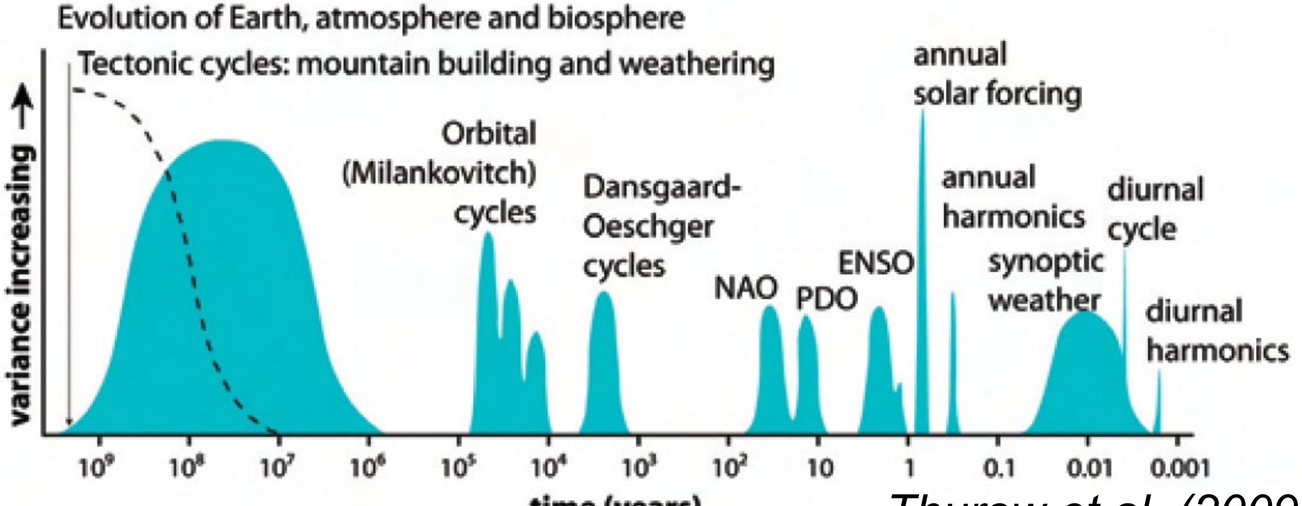
Riverine & Eolian detritus (sand, silt, clay…and iron)

Middle Miocene

Blakey (1997)

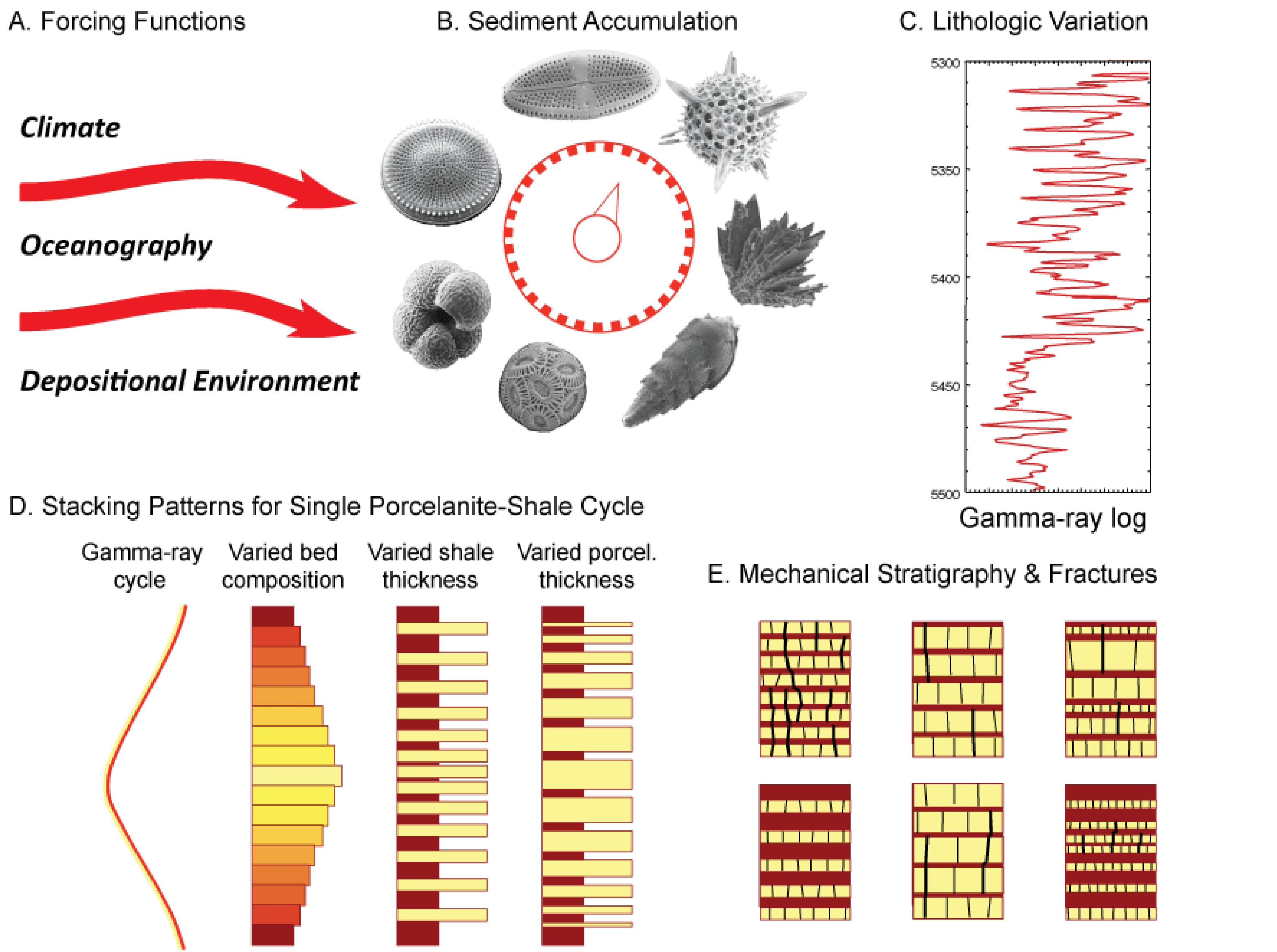
Late Miocene

Climate Cycles & Lithocyclicity



Thurow et al. (2009)

Environment➔Sediment➔Diagenesis➔Rock Properties➔P&P & Def'm Style



Monterey Summary

- Important link to global change & tectonics
- Spans the Pacific Rim
- Organic-rich, highly siliceous, fine-grained
- Vertical and lateral lithofacies variations
  - Global and local controls
- Thin-bedded and cyclic bedding
- High diagenetic potential of silica, carbonate, phosphate & organic matter
- Composition and diagenesis controls physical properties of sediments and mechanical stratigraphy

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