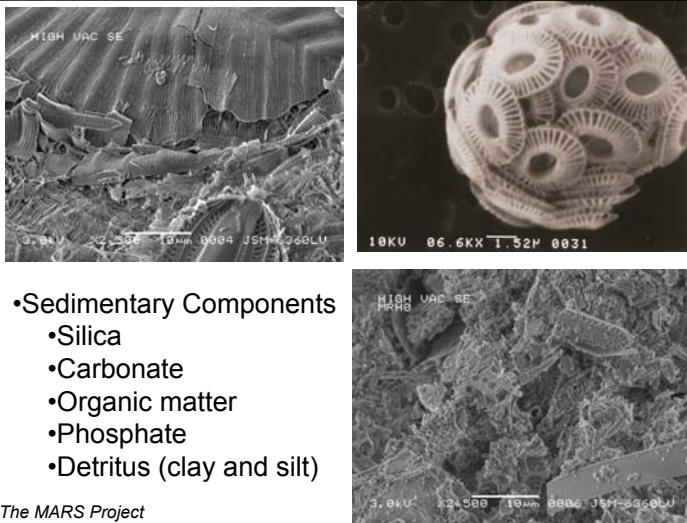


Miocene Monterey Formation: Lithology & Diagenesis

Richard J. Behl
California State University
Long Beach, CA

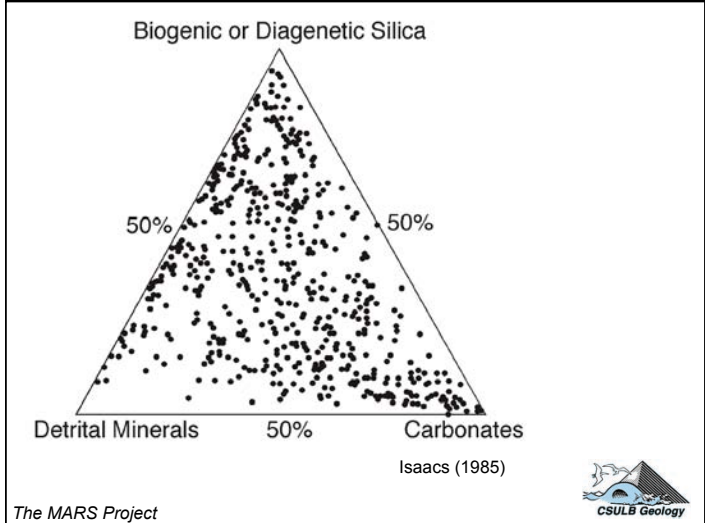
The MARS Project: Monterey And Related Sediments




•Sedimentary Components

- Silica
- Carbonate
- Organic matter
- Phosphate
- Detritus (clay and silt)

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Diatoms - Chrysophyta

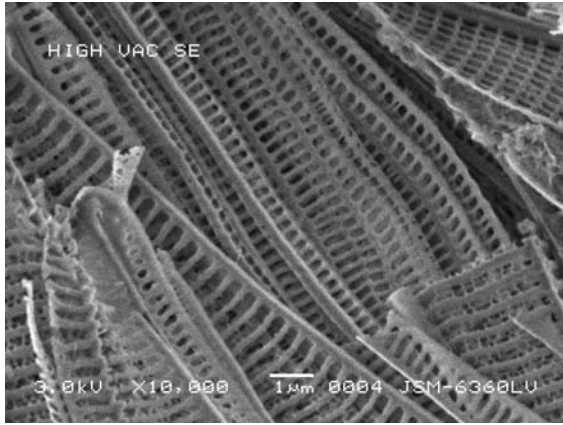


Algal Microfossils

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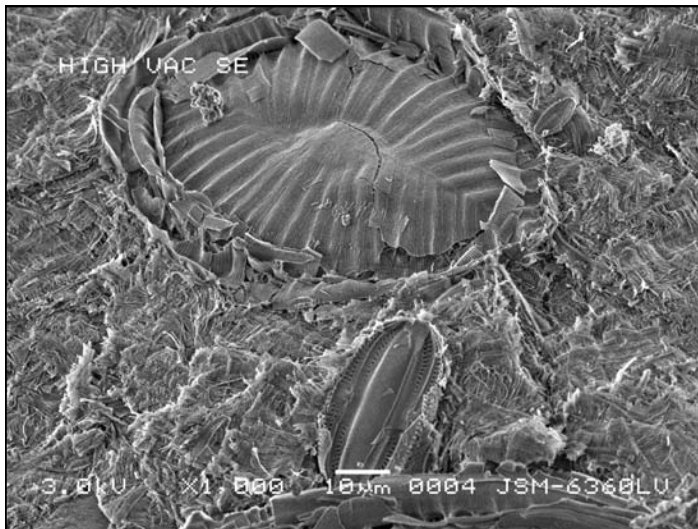
Pennate Diatoms in Diatomite



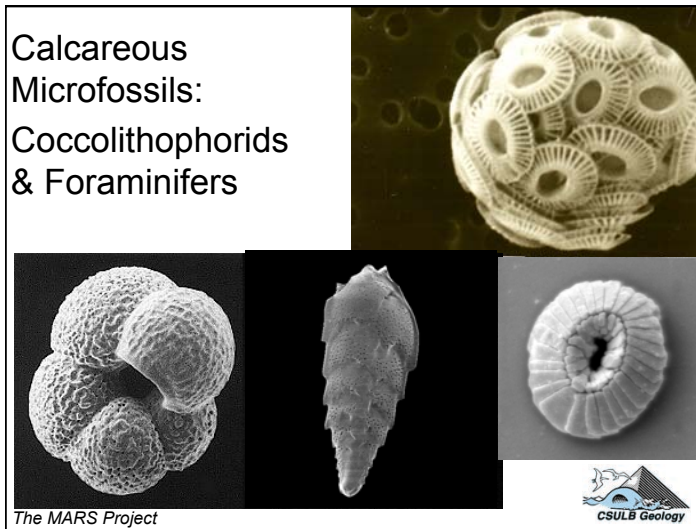
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Large Centric Diatom in Diatomite

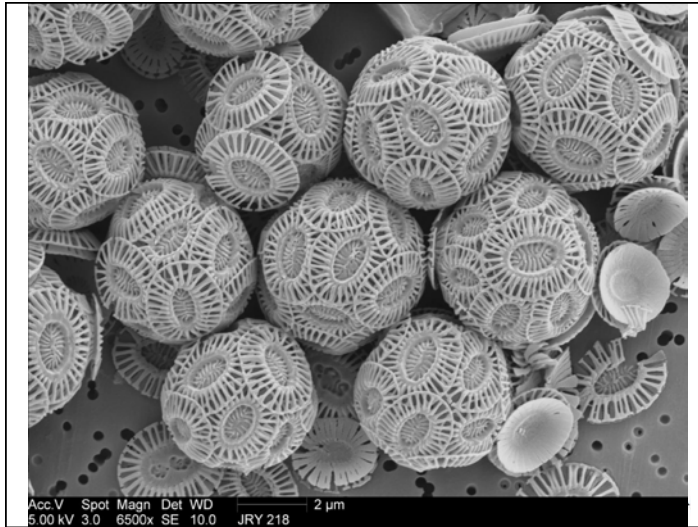


Calcareous Microfossils: Coccolithophorids & Foraminifers

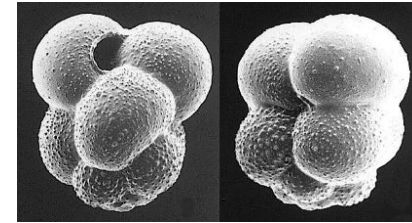
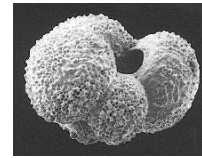


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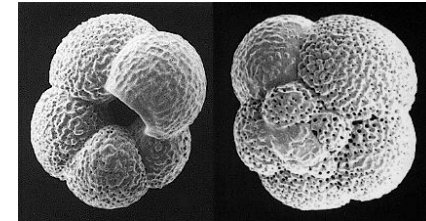




Foraminifera

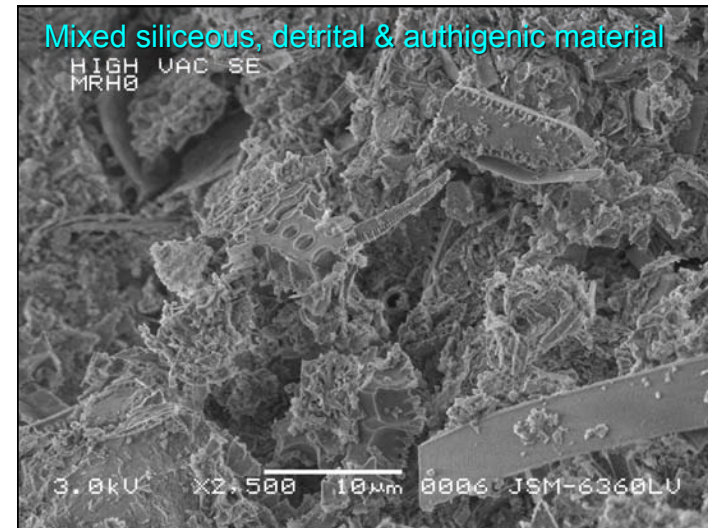
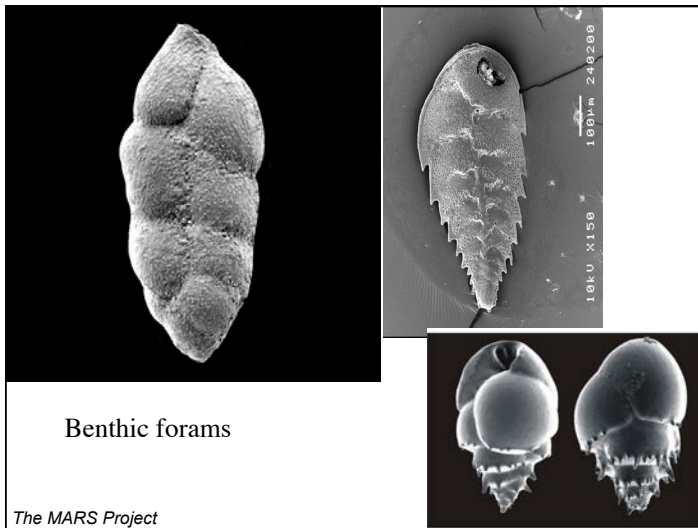


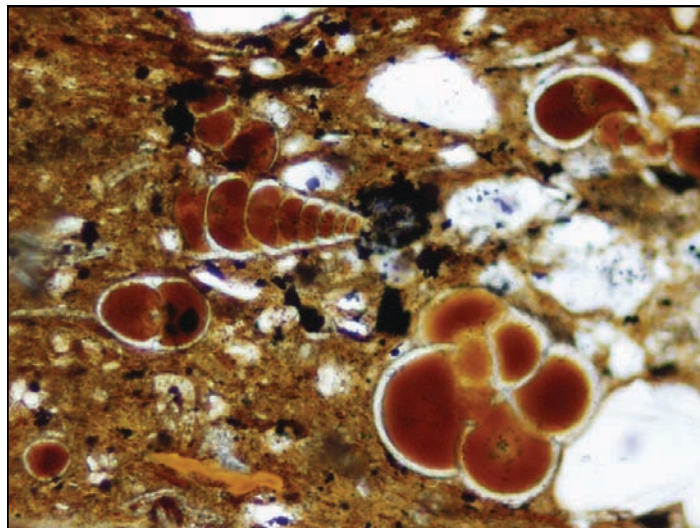
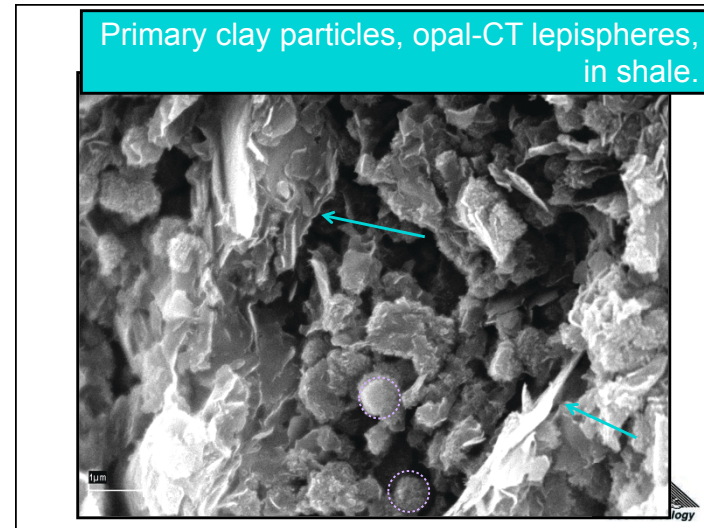
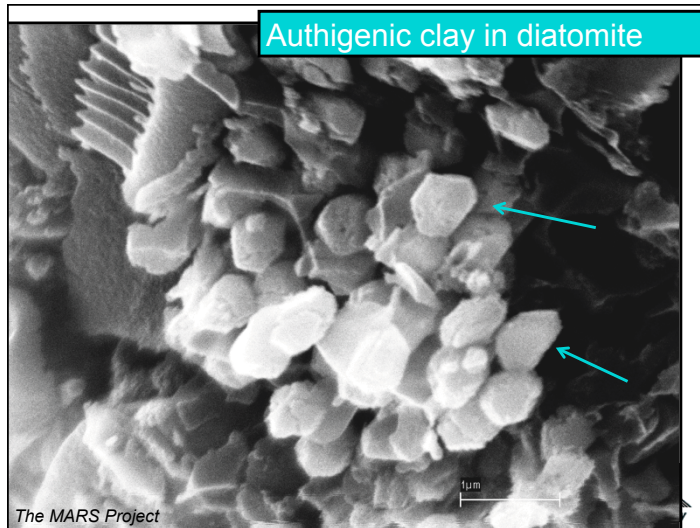
Planktic forams



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CSULB Geology






Physical Characteristics of Monterey Lithologies

- Factors that control physical rock properties
 - ◆ Silica Phase
 - ◆ Detrital Content
 - ◆ Carbonate Content
 - ◆ Organic Matter
 - ◆ Porosity


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Rock Types

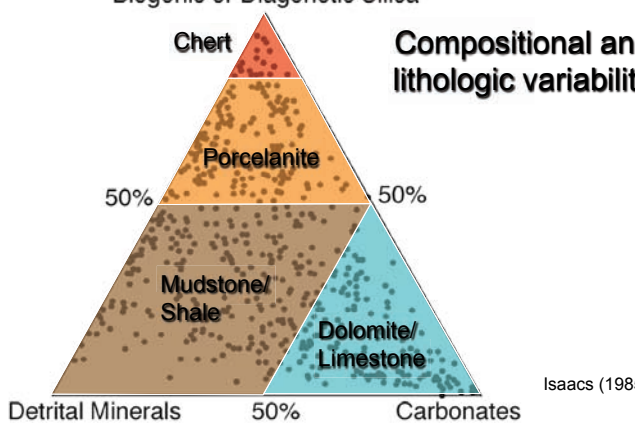
↑ Silica

- Chert
- Porcelanite
- Siliceous Shale/Mudstone
- Clay Shale/Mudstone
 - ◆ (Also: Calcareous and Diatomaceous Shale)
- Diatomite
- Dolostone/Limestone/Marlstone
- Phosphatic Shale
- Sandstone




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Compositional and lithologic variability



Isaacs (1985)



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	SILICA MINERALOGY	XRD PATTERN OF DOMINANT SILICA MINERAL	LITHOLOGY
INCREASING DIAGENETIC GRADE ↓	OPAL-A		Diatomite Muddy Diatomite Diatomaceous Mudrocks
	OPAL-CT		Chert and porcelanite Porcelanite and porcellaneous mudrocks Siliceous mudrocks
	QUARTZ		Chert and porcelanite Porcelanite and porcellaneous mudrocks Siliceous mudrocks

DECREASING SILICA CONTENT →

DEGREES 2θ

Pisciotta & Garrison, 1981

•Silica phase ≠ lithology!





The MARS Project

Lithologies of the Monterey

Diatomaceous rocks

- Biogenic Silica
 - ◆ Opal-A (mostly diatoms, + silicoflagellates, radiolarians, and sponge spicules)
- Composition
 - ◆ Up to 90% biogenic silica
- Physical Properties
 - ◆ Very soft < 2
 - ◆ Highly porous (60-85%)
 - ◆ Firm (diatomites fracture!)
 - ◆ Can be calcareous, phosphatic, etc.
 - ◆ Density increases with detrital content
 - ◆ Brown in subsurface, white if weathered





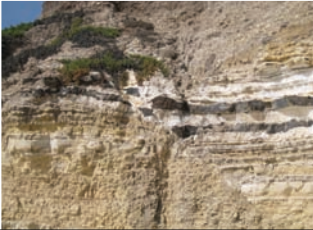
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Lithologies of the Monterey

Characteristics of chert

- Diagenetic Silica
 - ◆ Opal-CT or Quartz
- Composition
 - ◆ 90% diagenetic silica (not considering carbonate)
 - ◆ dolomite, calcite, organic and clay laminations
- Physical Properties
 - ◆ Hardness Index ≥ 5 (>steel probe)
 - ◆ Luster – vitreous to resinous
 - ◆ Fracture – conchoidal, smooth
 - ◆ Brittle,
 - ◆ Low porosity



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Chert & Siliceous Shale

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Lithologies of the Monterey

Characteristics of porcelanite

- Diagenetic Phase
 - ◆ Opal-CT +/-or Quartz
- Composition
 - ◆ 50-85% diagenetic silica
 - ◆ Detrital minerals, dolomite, calcite
- Physical properties
 - ◆ Hardness Index ≤ 3
 - ◆ Luster – matte (lacks vitreous luster)
 - ◆ Blocky, hackly fracture
 - ◆ Typically laminated
 - ◆ Mod high porosity
 - ◆ Low to moderate permeability



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Effects of Silica Phase

Table 1.--Effects of silica phase on field characteristics.

Characteristic	Biogenous opal-A	Diagenetic opal-CT	Diagenetic quartz
Gross hardness	<2	>2	>2
Cohesiveness and resistance to erosion	Low	Moderate to high	
Surface texture, where fresh	Flaky	Vitreous, waxy, matte, or grainy	
Diatom frustules	Visible where >20%	Absent	
Dry bulk density	0.8-1.4 g/cm ³	1.4-2.1 g/cm ³	1.8-2.5 g/cm ³

	Typical Porosity (%)	Grain Density (g/cc)	Permeability (air, md)	Pore-throat diameter (microns)	Oil Saturation (%)
Opal CT	25-40	2.25-2.35	0.01 - 0.1's	0.01 - 0.1	0 - 30
Quartz	15-30	2.55-2.85	0.1 - 1.0's	0.1 - 1.0	30 - 60

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CSULB Geology

Lithologies of the Monterey

- Diagenetic Phase
 - ◆ Opal CT or Quartz
- Composition
 - ◆ 30-50% diagenetic silica
 - ◆ Mostly detritus
- Physical properties
 - ◆ Surface luster - Dull, matte
 - ◆ Fracture/fault – Closed
 - ◆ Some degree of fissility
 - ◆ Harder than nonsiliceous rocks owing to the silica content
 - ◆ Non-reservoir



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Lithologies of the Monterey

■ Phosphatic Shales/Marlstone

- ◆ Pure nodules and disseminated impure layers
- ◆ White cream or rose-colored blebs are generally more resistant than surrounding shale.
- ◆ Frequently calcareous and usually organic rich

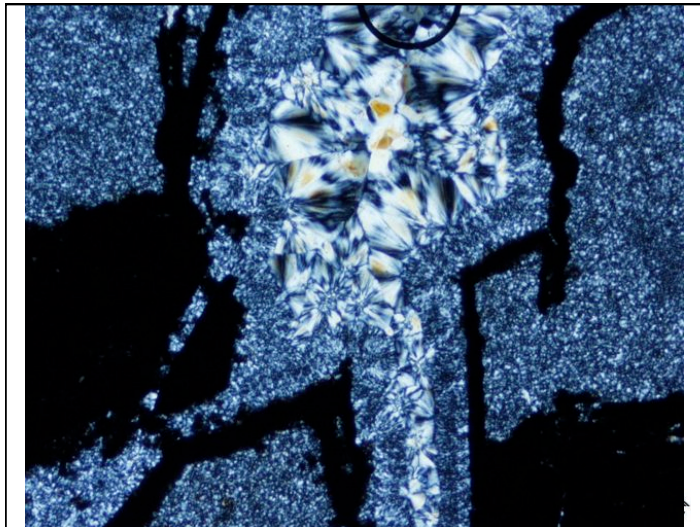


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Interbedded chert & dolomite

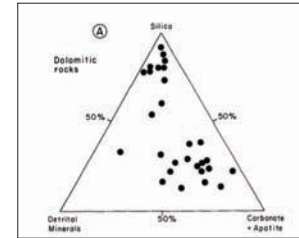
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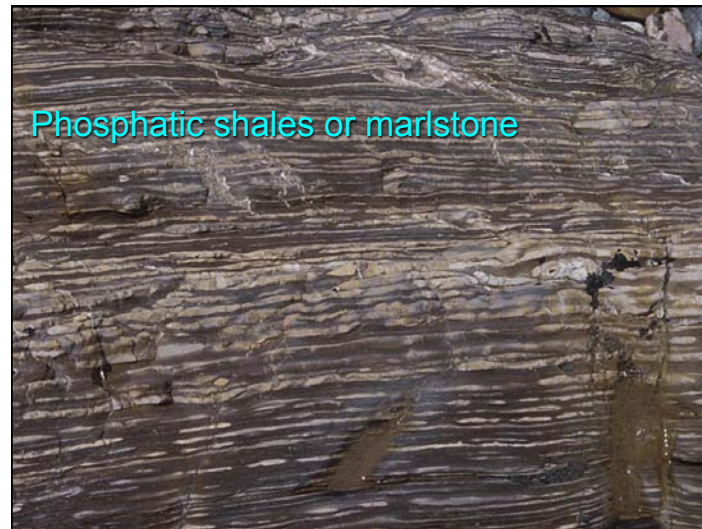


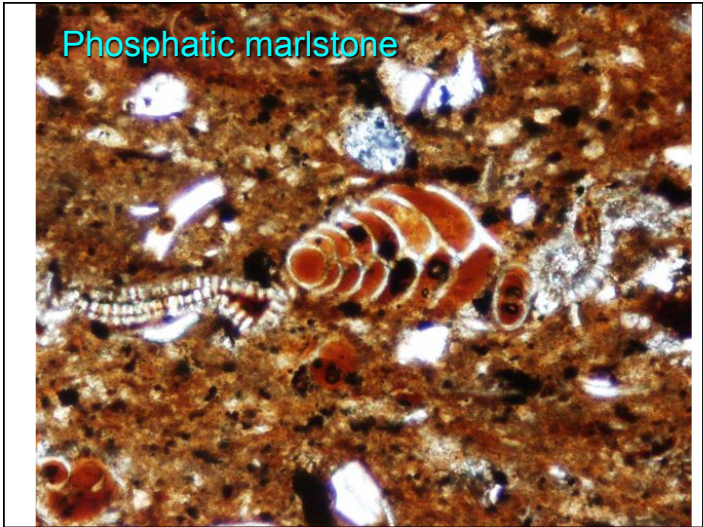
Lithologies of the Monterey

■ Dolomite/Dolostone

- ◆ Nodular, bedded, laminations, or disseminated
- ◆ Authigenic, diagenetic
- ◆ Brittle beds, extensive fractures and breccias
- ◆ Locally porous

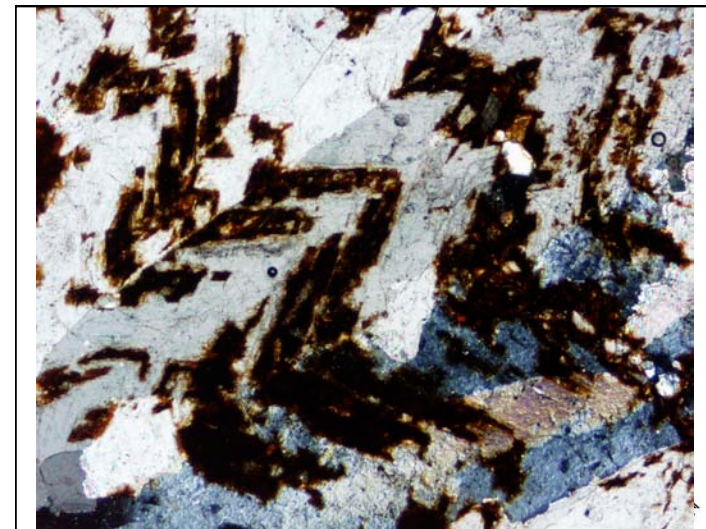
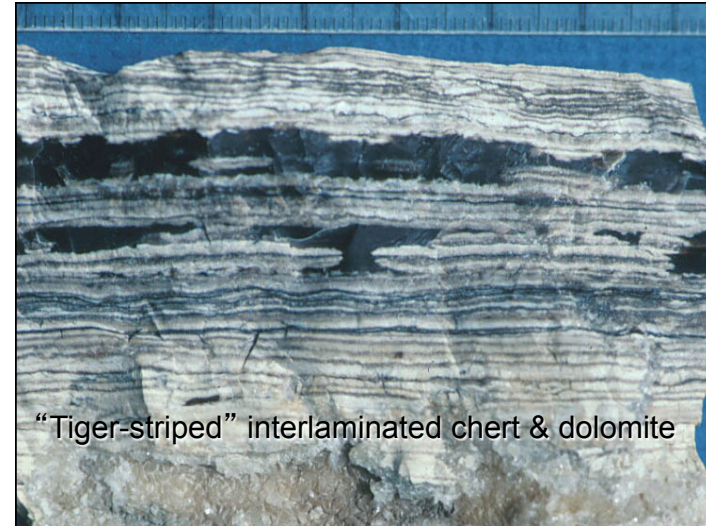
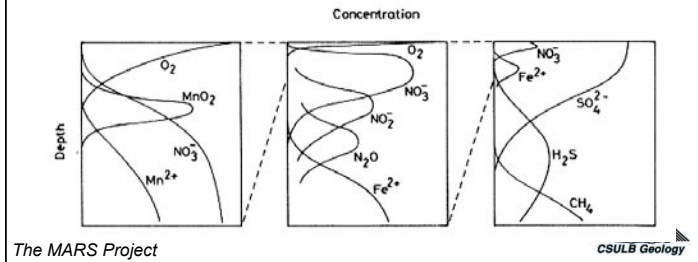


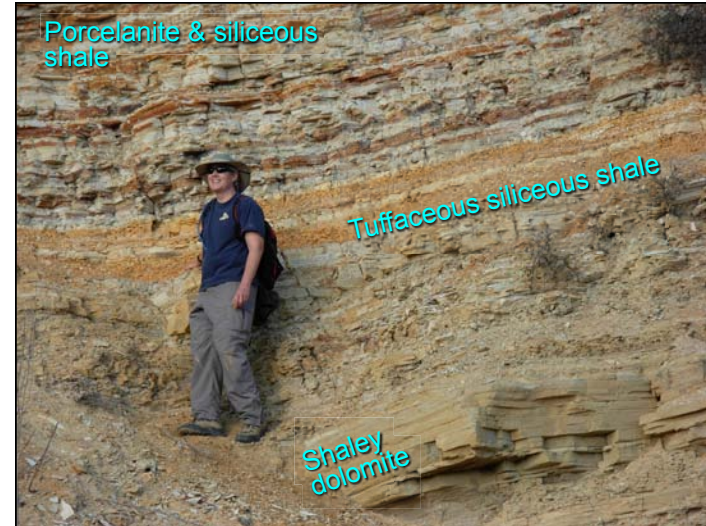
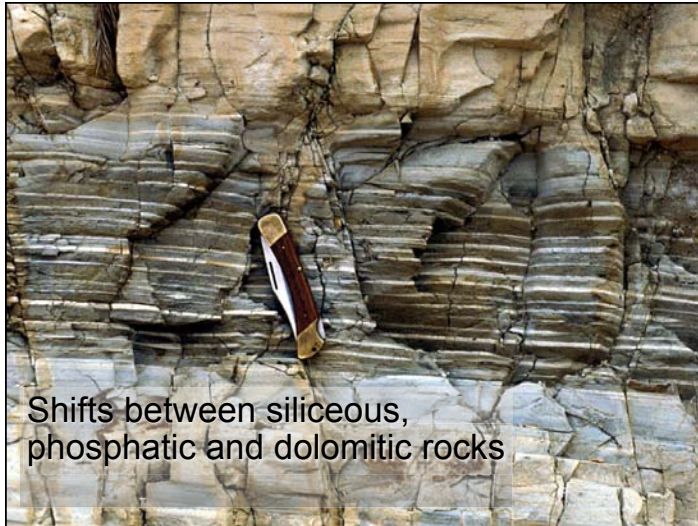




Carbonate diagenesis


- Recrystallization of calcite (CaCO_3)
- Conversion to dolomite $\text{CaMg}(\text{CO}_3)_2$
- Authigenic precipitation of dolomite
- Dissolution and precipitation in veins






- Main Sedimentary Components
 - Silica
 - Carbonate
 - Organic matter
 - Phosphate
 - Detritus (clay and silt)

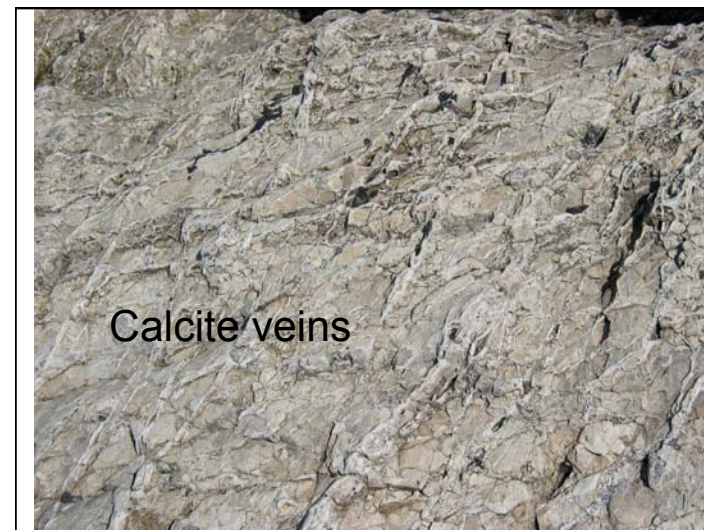
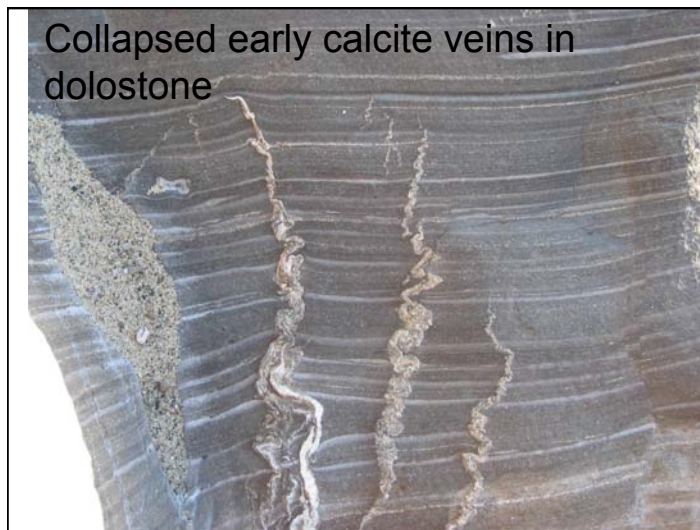
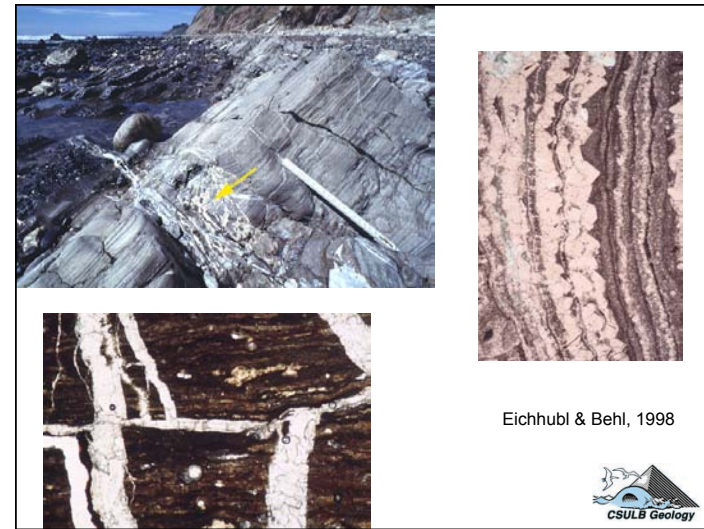
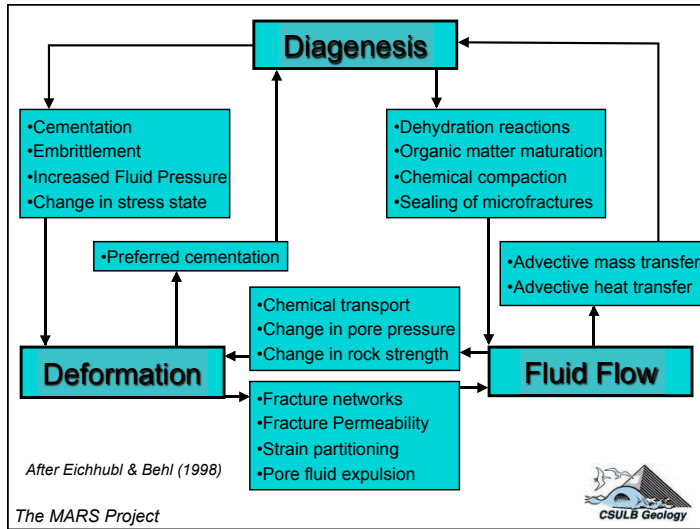
High diagenetic potential of silica, carbonate, phosphate & organic matter

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Diagenetic Pathways of Constituents in the Monterey Formation

- Siliceous Sediments
 - ◆ Opal-A ← 45-50°C
 - ◆ Opal-CT ← 65-80°C
 - ◆ Diagenetic quartz
- Calcareous Sediments
 - ◆ Early forming "Proto"-dolomite
 - ◆ Higher order stoichiometric dolomite
- Clay Sediments
 - ◆ Mixed-layer smectite-illite ← 80-115°C
 - ◆ Increased illite component
- Organic Matter ← As low as 60°C

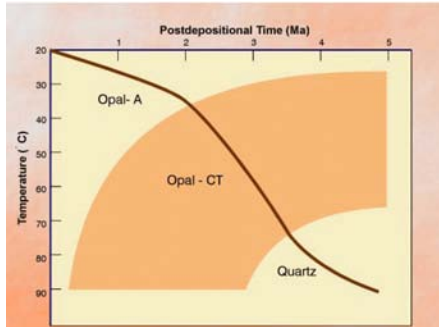
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Silica Diagenesis

2-step dissolution/reprecipitation:

- Opal-A
- Opal-CT
- Quartz



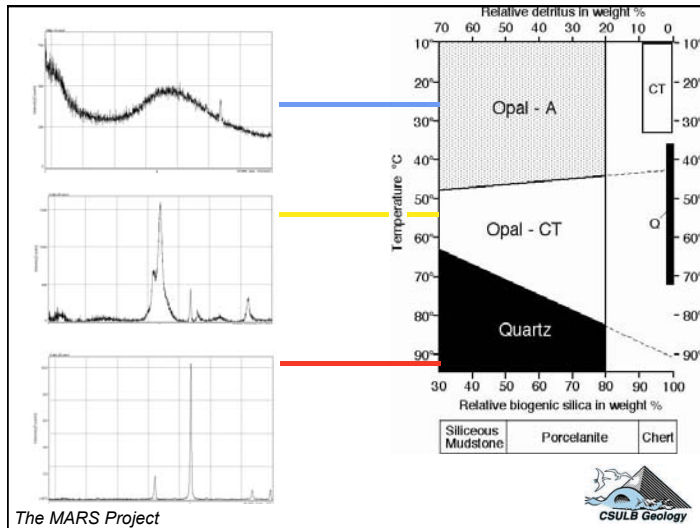
Siever (1983)

The MARS Project

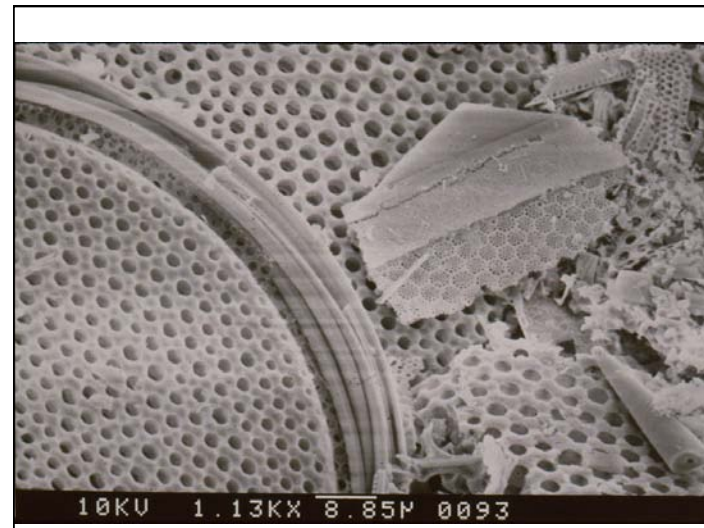
Opal-A → Opal-CT → Quartz

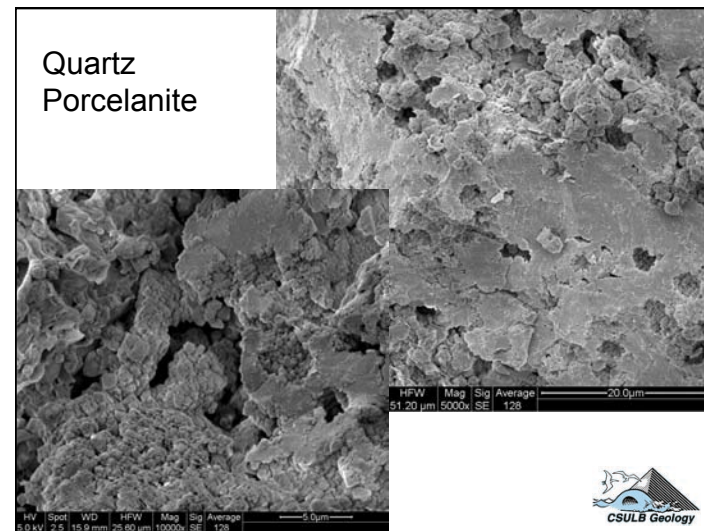
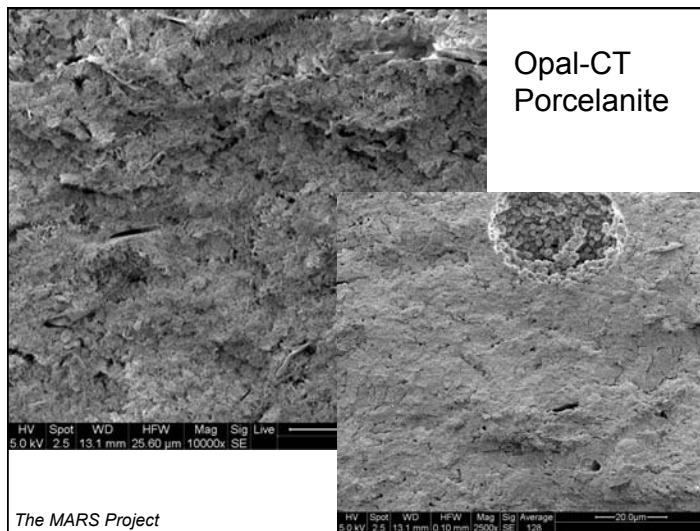
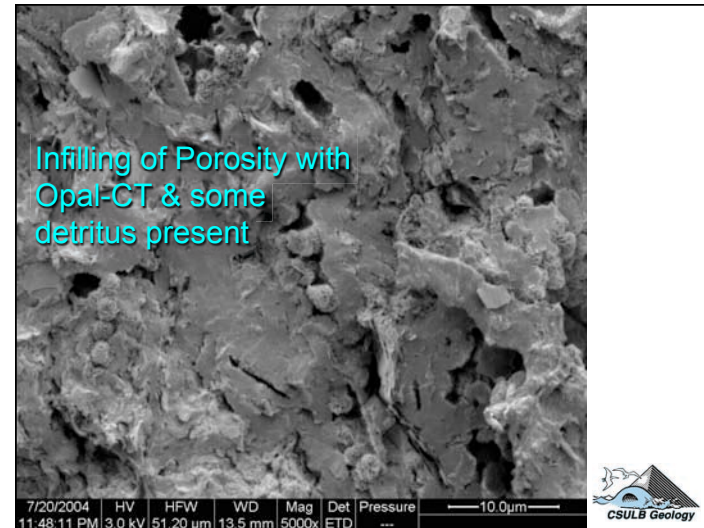
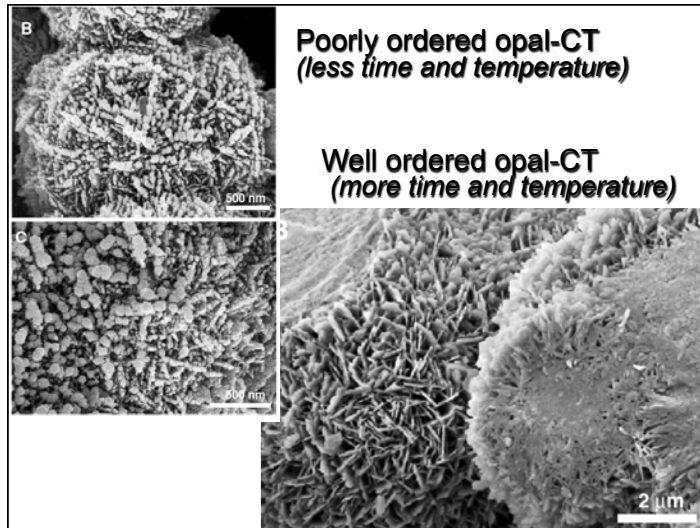
Time	████████████████████
Temperature	████████████████████
Silica Solubility	████████████████████
pH	████████████████████
crystallite size	████████████████████
particle surface area	████████████████████
Pore water chemistry	████████████████████
[SiO ₂]	████████████████████
[Mg ²⁺]	████████████████████ ????????
[OH ⁻]	████████████████████
Sediment composition	████████████████████
smectite clays	████████████████████ ● ● ● ● ● ● ● ●
organic matter	████████████████████ ● ● ● ● ● ● ● ●
Permeability	████████████████████

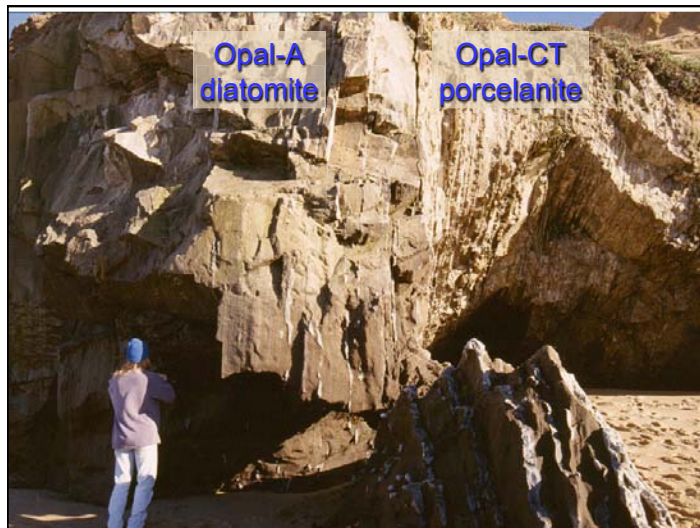
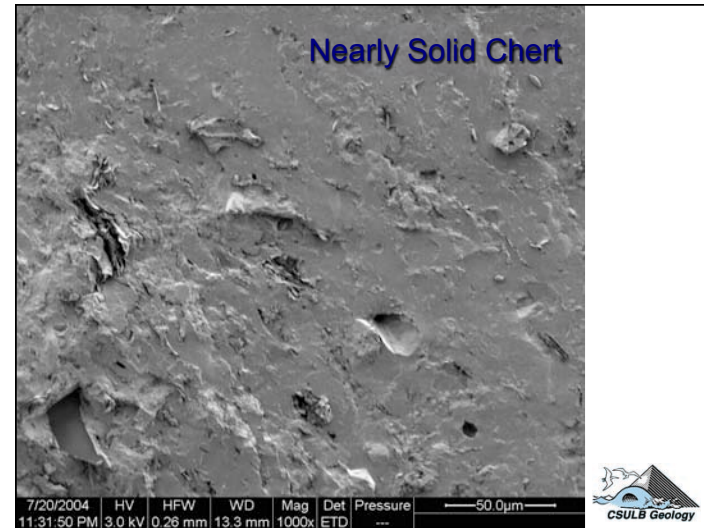
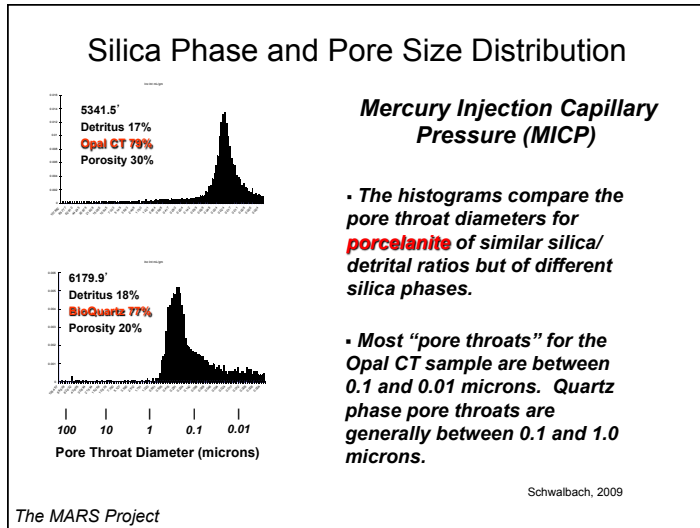
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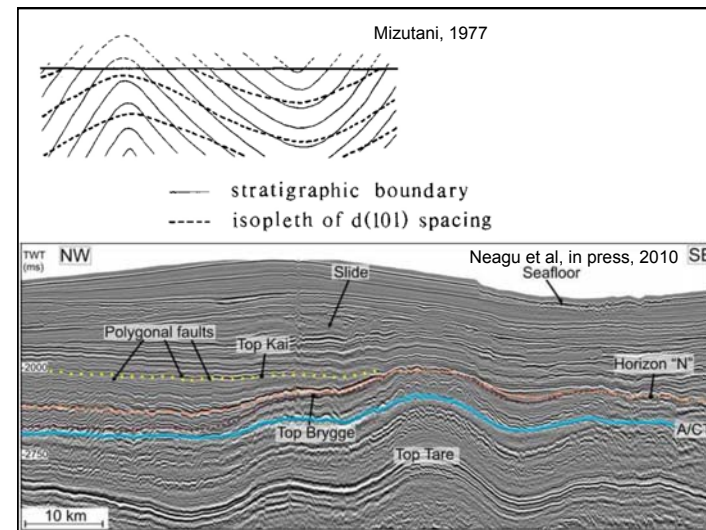
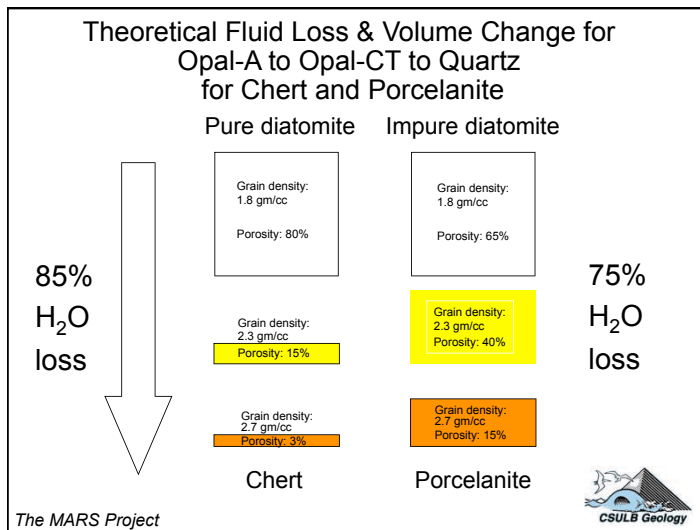
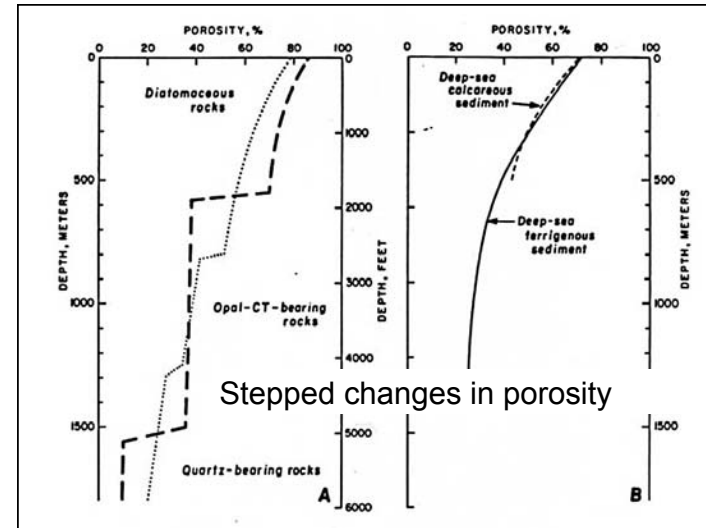


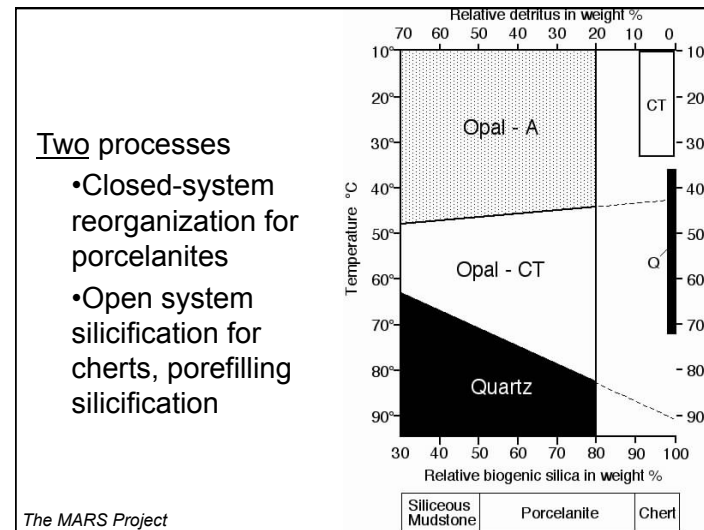
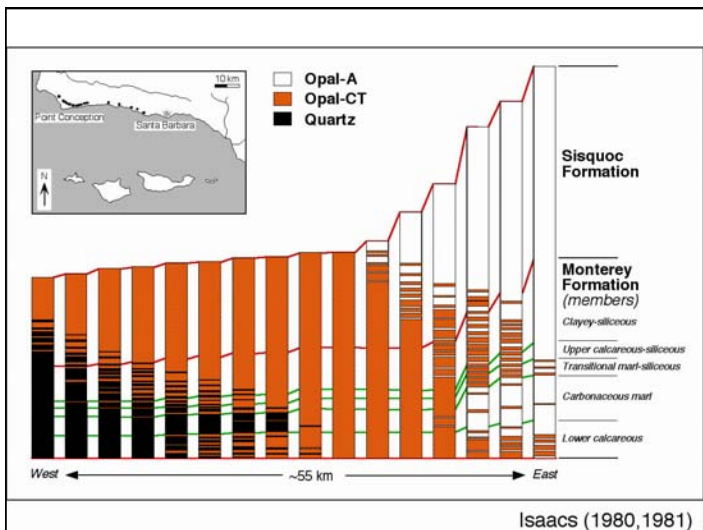
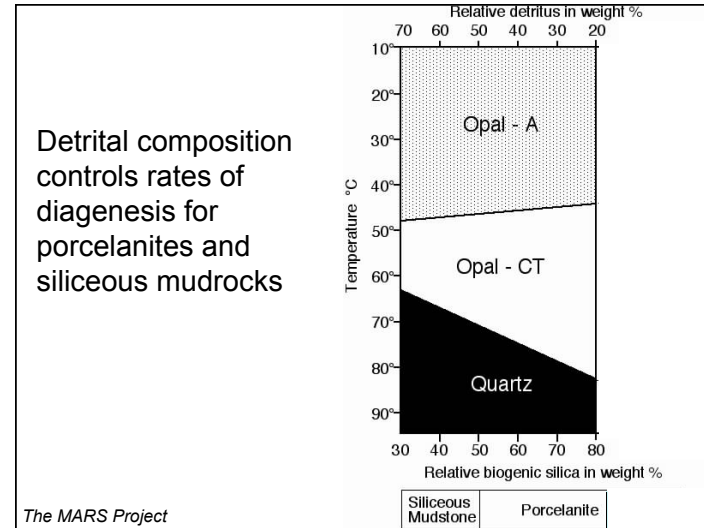
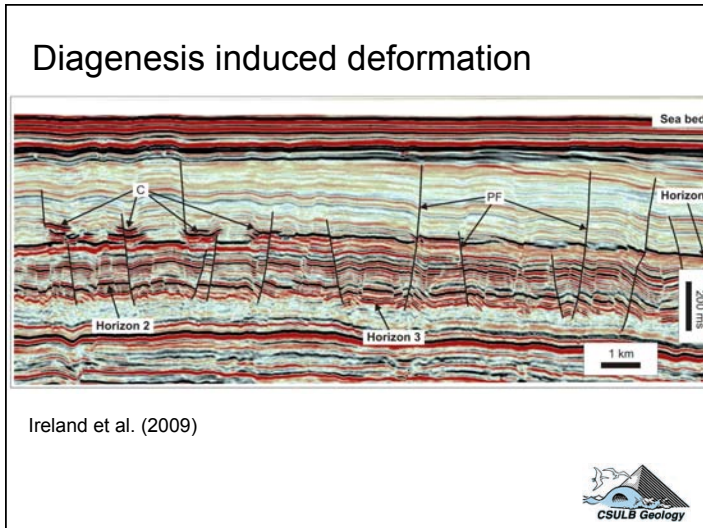
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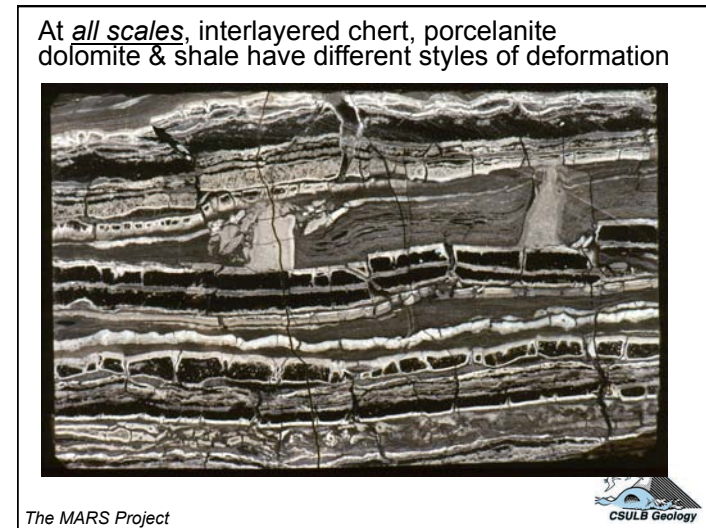
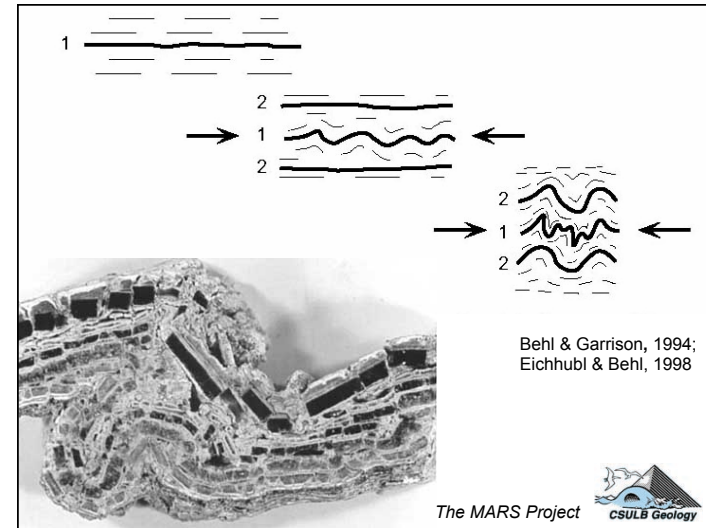
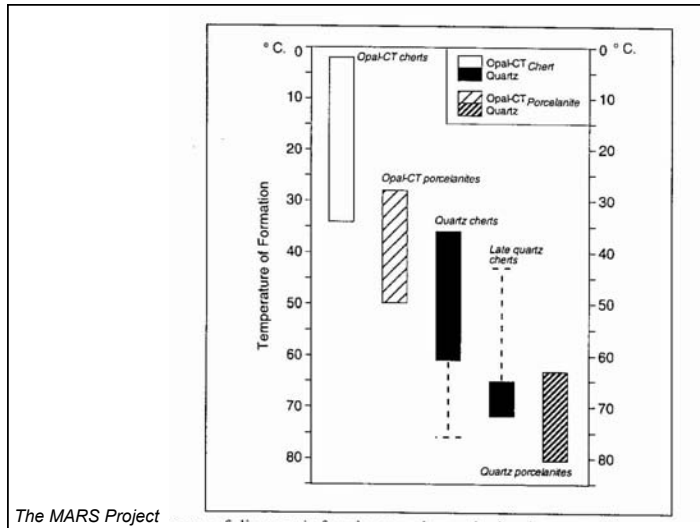
















Monterey Lithology Summary

- Heterogeneous composition
 - ◆ Silica
 - ◆ Carbonate
 - ◆ Detritus (silt and clay)
 - ◆ Organic matter and phosphate
- Lithology determined by primary composition + diagenesis
- Compositional variability controls timing & type of diagenesis
- Sedimentary and diagenetic variability leads to mechanical stratigraphy and heterogeneous styles of deformation

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