# Geology of the Monterey Formation of California

With comments on recent oil field developments

By Thomas MacKinnon
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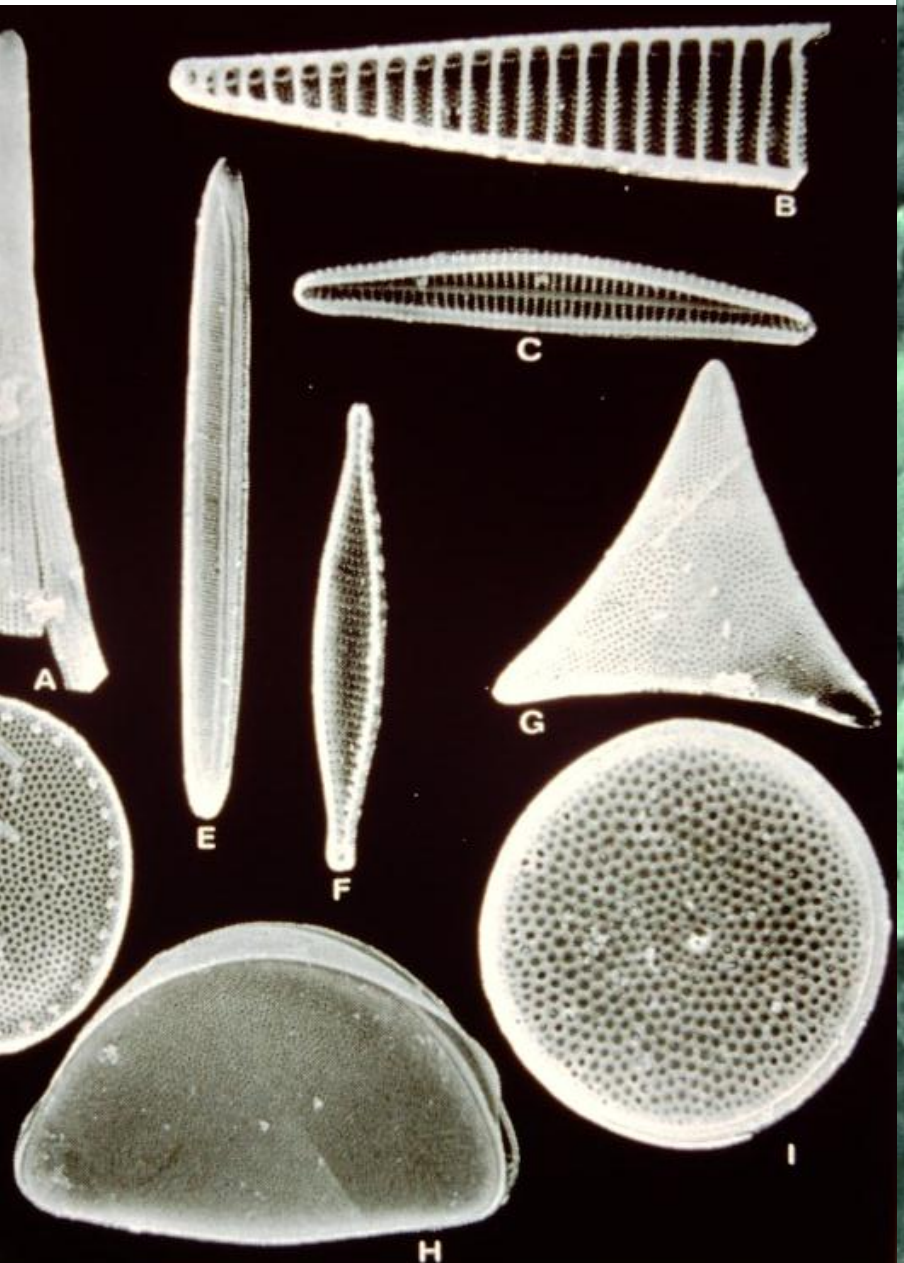
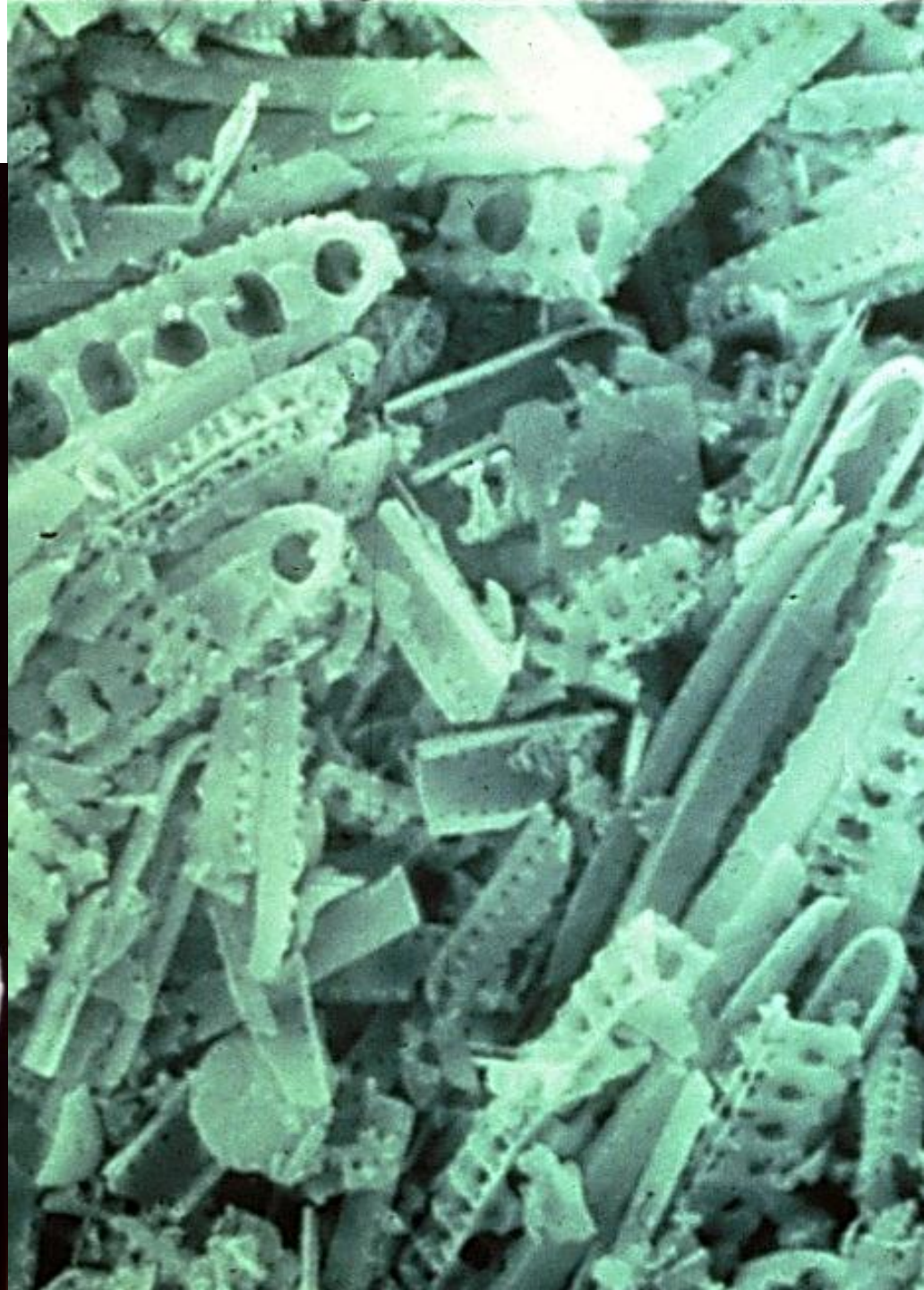
Famous for silica (diatoms)
Chert and Porcelanite

Widespread in California
Typically 300 to 1000 m (up to 3000 m)

**Diatoms:** planktonic plants with siliceous shells



# Fresh Diatomite “Hemipelagic”

**Laminated**

**Bioturbated**

**Chert**
**Porcelanite,**
**Siliceous mudstone**
**Calcareous mudstone**
**Dolostone**

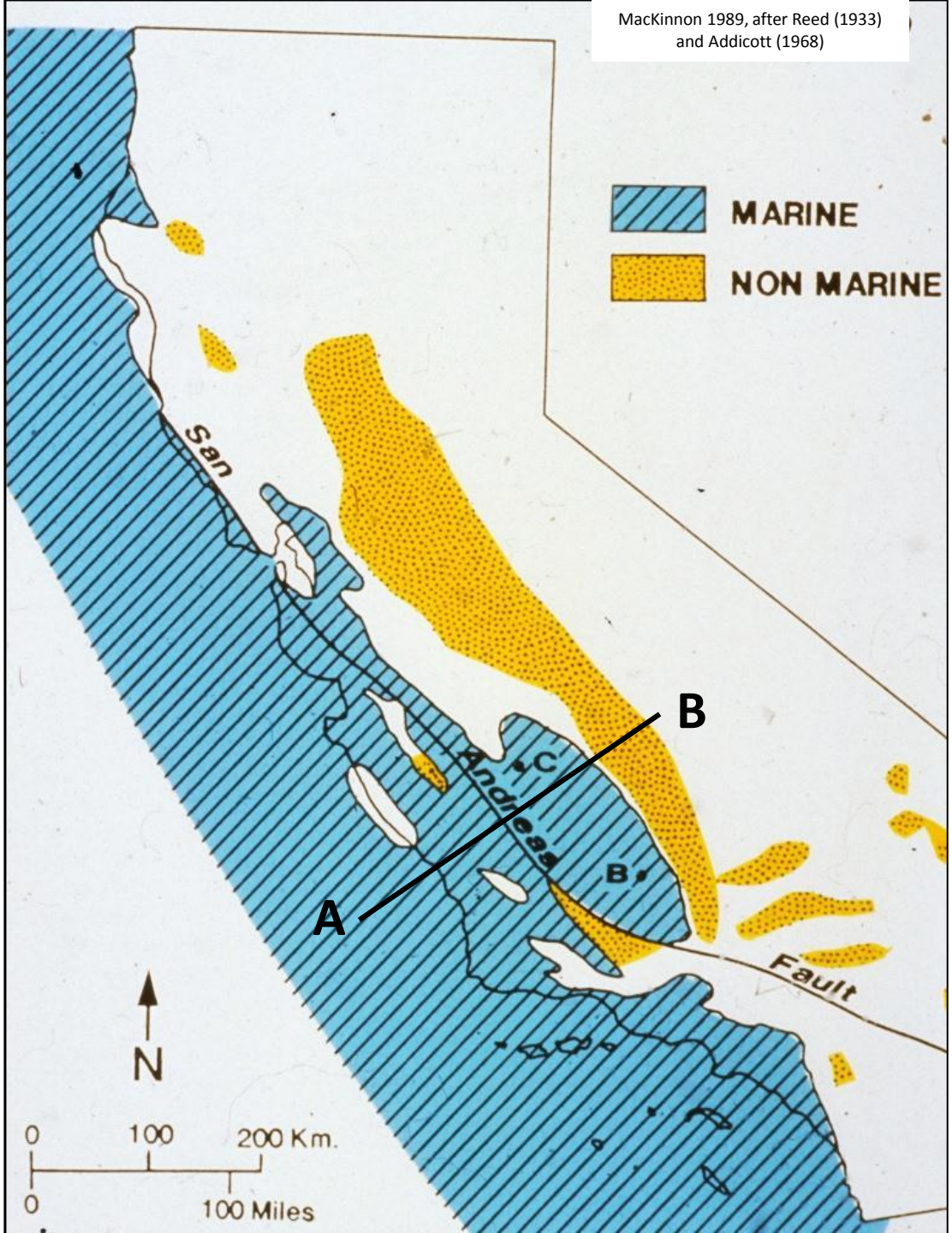
**silica, carbonate, and organic matter**

**Terrigenous**

**Planktonic**
Diatoms
Radiolaria
Coccoliths
Unshelled algae
Bacteria

**Benthic**
Foraminifera (predominately)
Unshelled algae
Bacteria

Quartz
Feldspar
Clays
Other minerals

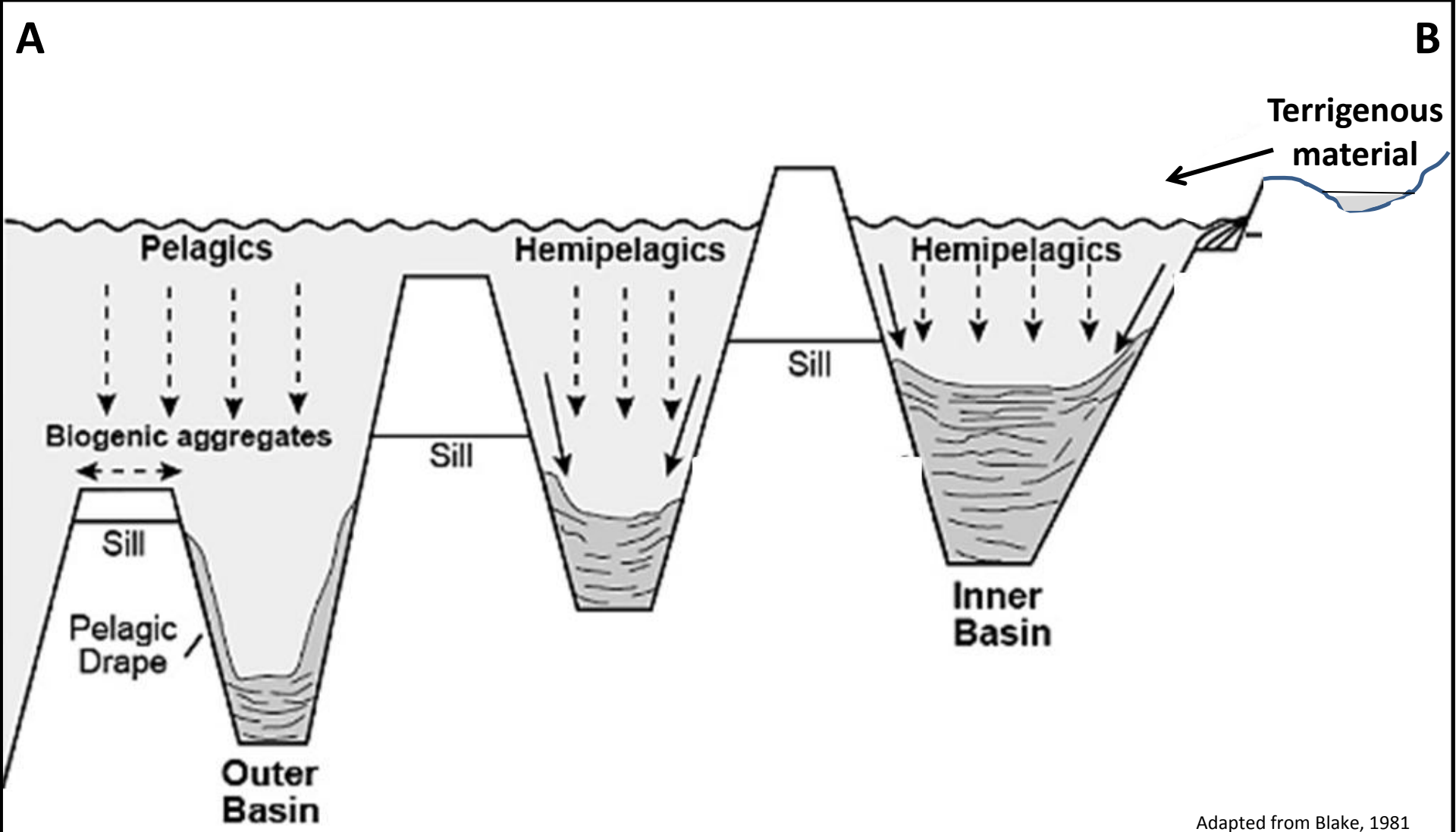



# Mid to Late Miocene

- A trans-tensional continental margin
- Terrigenous material trapped on land or in nearshore basins
- High diatom productivity

# Mid to Late Miocene:

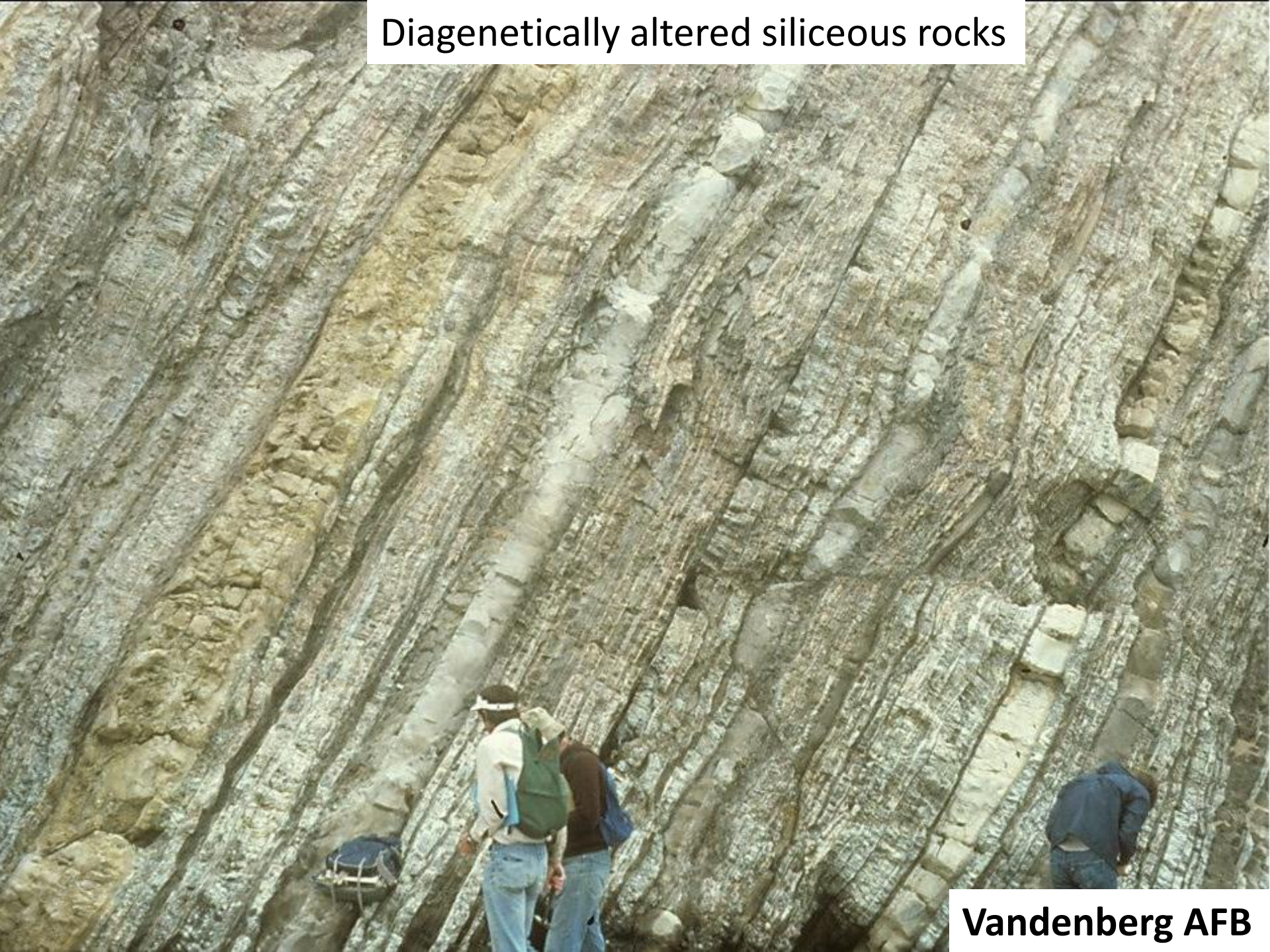
- basins were isolated from terrigenous input
- Intense upwelling and biologic productivity




Adapted from Blake, 1981

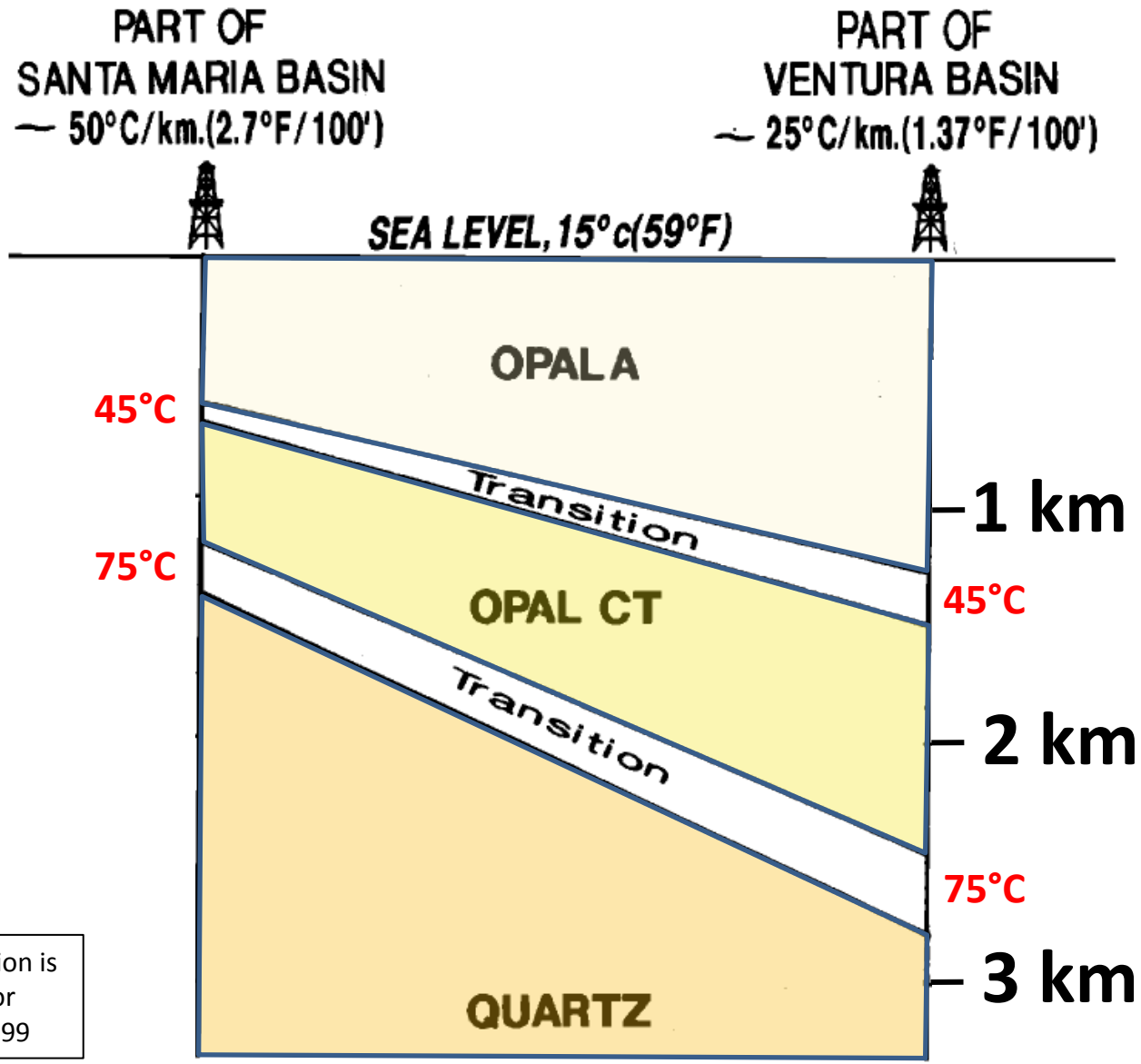

Weathered Diatomite
Lompoc

# Diagenetically altered siliceous rocks



**Vandenberg AFB**

- **Imagine its all diatomaceous and at maximum burial depth**




bulk composition is also a factor
See Behl, 1999

| | |
|---|---|
| Chert: | glassy, won't scratch, conchoidal fracture |
| Porcelanite: | unglazed porcelain, will scratch, conchoidal to splintery fracture |

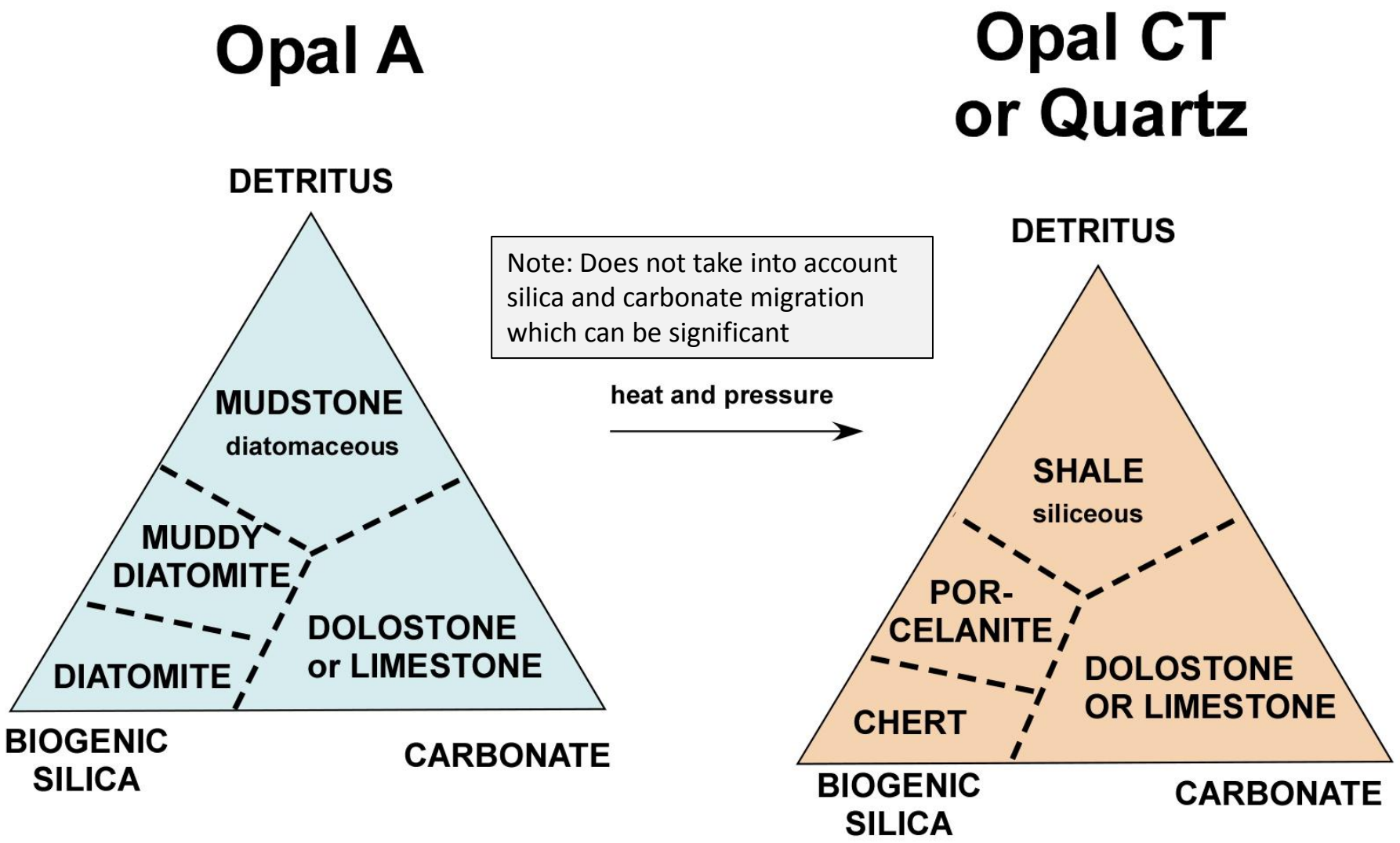
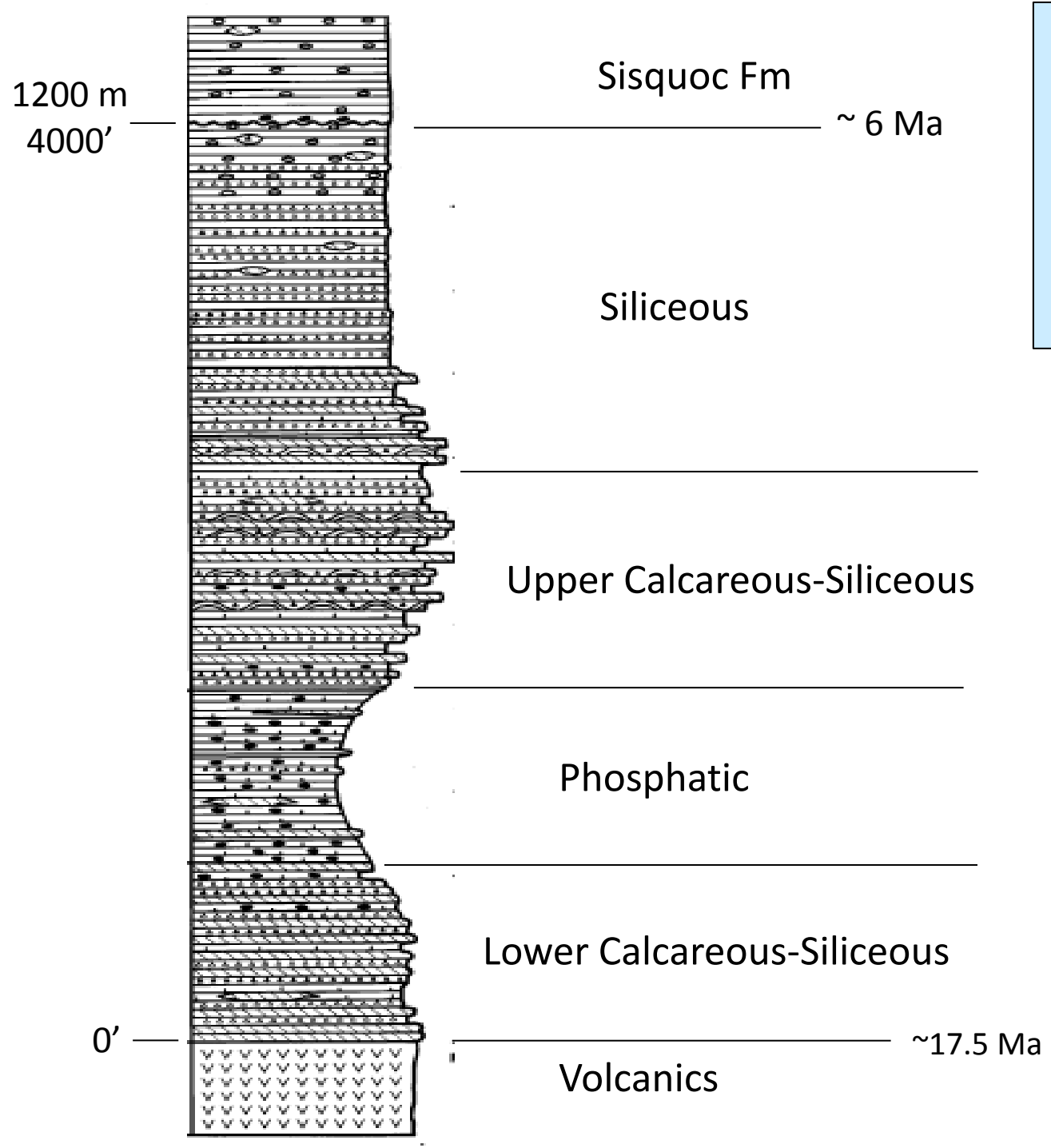


Photo By Rick Behl

## Bedding origin

1. Compositional differences
2. Silica migration
3. Carbonate migration
4. Turbidites




**The Monterey can be subdivided stratigraphically**

**Pt Arguello & Pt Conception Area**

MacKinnon, 1989

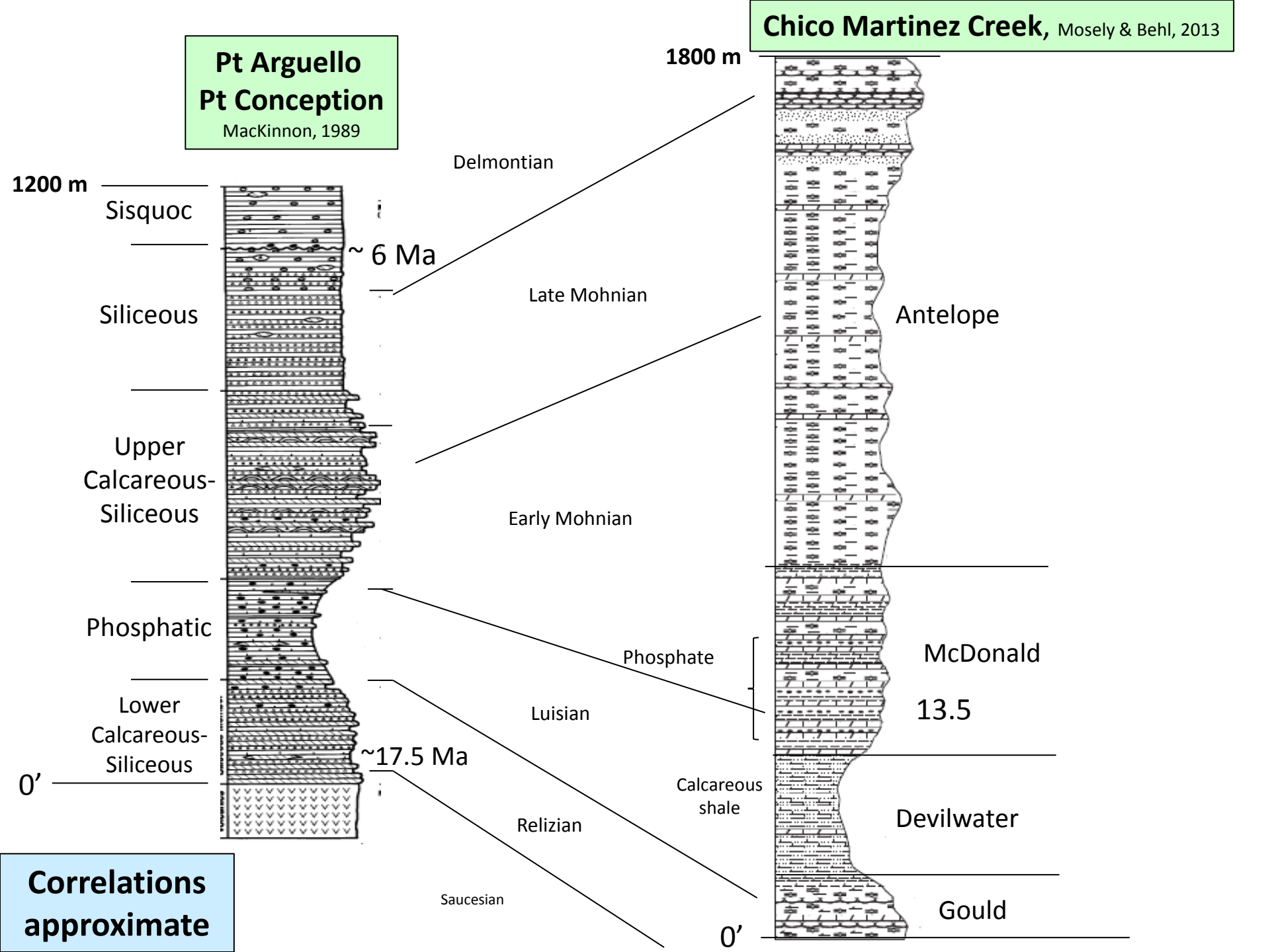

Monterey Fm
Rincon Fm
Santa Barbara

# Lower Calcareous-Siliceous member


Phosphatic Member

# Upper calcareous-siliceous member


Clayey-siliceous member


Pt Arguello
Pt Conception
MacKinnon, 1989
Chico Martinez Creek, Mosely & Behl, 2013
1800 m
1200 m
Sisquoc
~ 6 Ma
Siliceous
Upper
Calcareous-
Siliceous
Phosphatic
Lower
Calcareous-
Siliceous
0'
~17.5 Ma
Delmontian
Late Mohnian
Early Mohnian
Luisian
Relizian
Saucesian
Antelope
Phosphate
McDonald
13.5
Calcareous
shale
Devilwater
Gould
0'
Correlations
approximate


Santa Maria Coast


West side, San Joaquin Valley,
mainly porcelanite
Photo By Rick Behl

# Newport Back Bay

Photo By Rick Behl

Santa Cruz Island
Porcelanite and chert

# Phosphatic member

# Central Coast

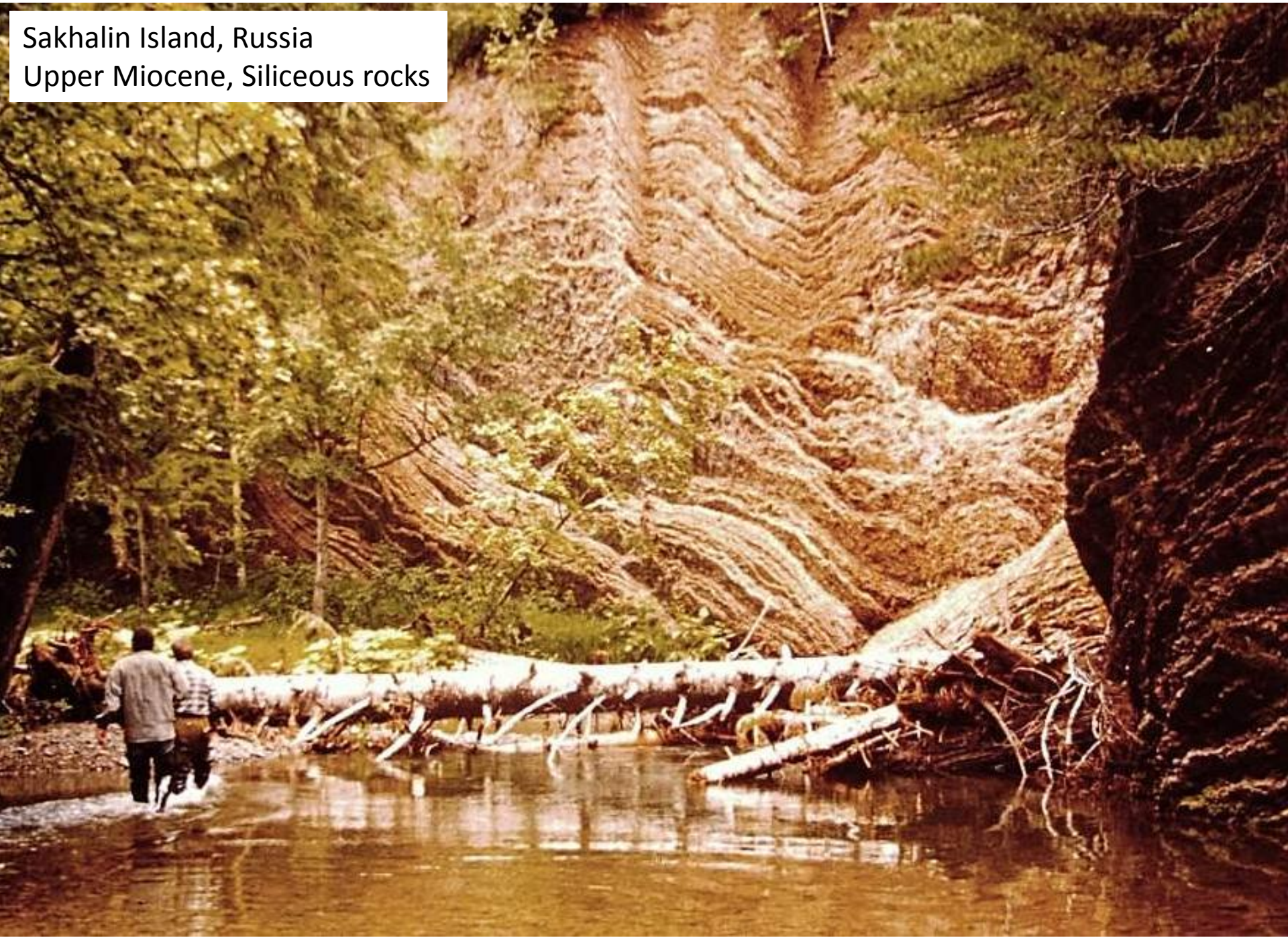
Photo from Andrew Alden website


Pt Reyes


Pt Arena

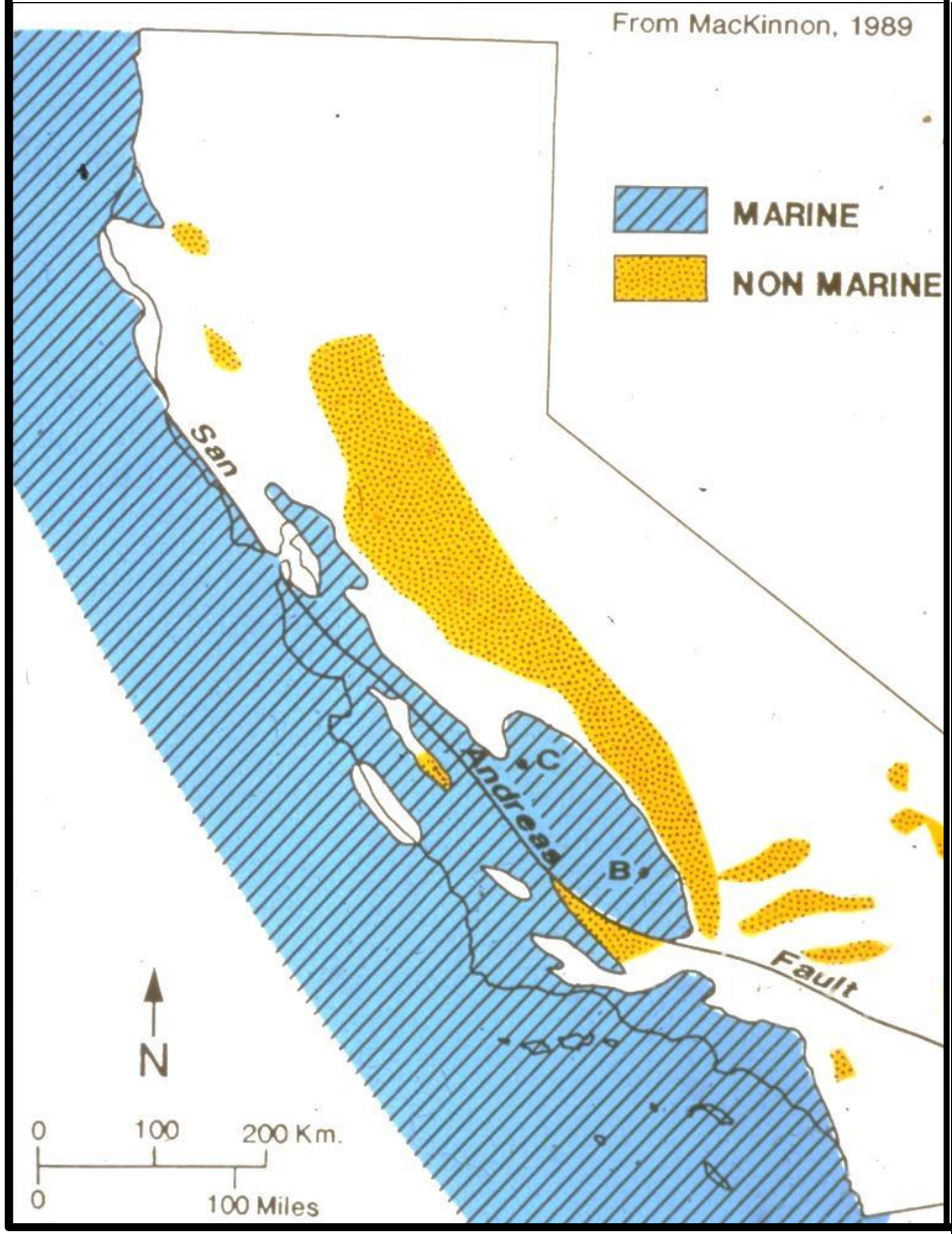

Pt Arena

| | |
|---|---|
| ~29 to 18 m.y.a. | Shift from subduction to transform.<br>California margin subsided due to transtension |
| ~18 m.y.a | **Monterey deposition begins**<br>Abrupt decrease in terrigenous material to offshore<br>Increased upwelling; high productivity<br>transform faulting, extension, volcanism, rotation. |
| ~15 m.y.a. | Polar cooling, even more upwelling.<br>High productivity continues |
| ~6 m.y.a. | **End of Monterey deposition**<br>Shift to transpression,<br>Coast Ranges begin to form;<br>Terrigenous deposition increases. |

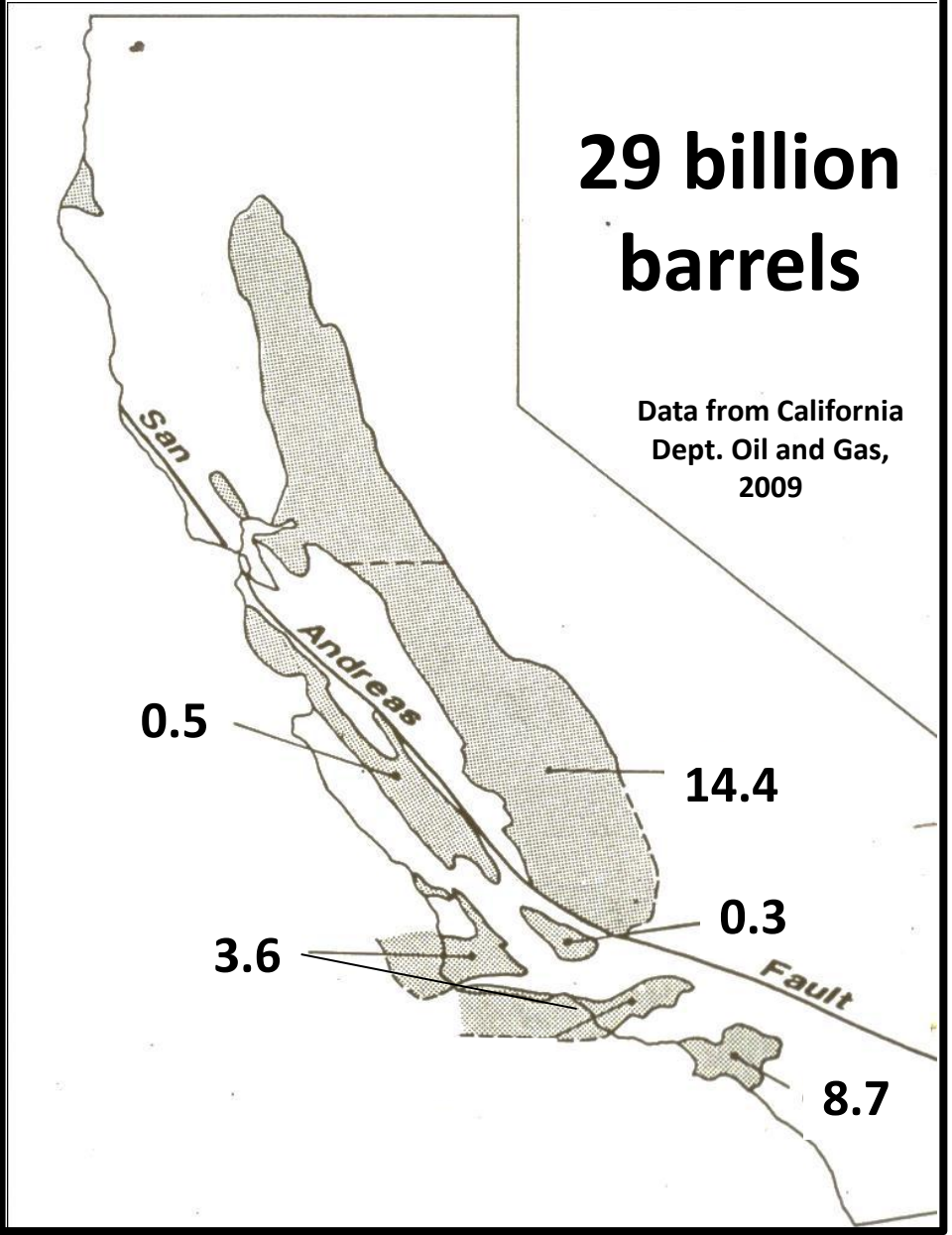

Sakhalin Island, Russia
Upper Miocene, Siliceous rocks

**~90% of oil produced in California was sourced from the Monterey.**

# Paleogeography




# Billions of barrels Produced



## Source

Kerogen type II
diatoms, foraminifera, coccolithophores, dinoflagellates, and bacterial mats

## Total organic carbon (TOC)

typically 3-5% by weight, 2.5% is good

## Generating depths ???

5000 to 17000’

# Reservoir Rocks

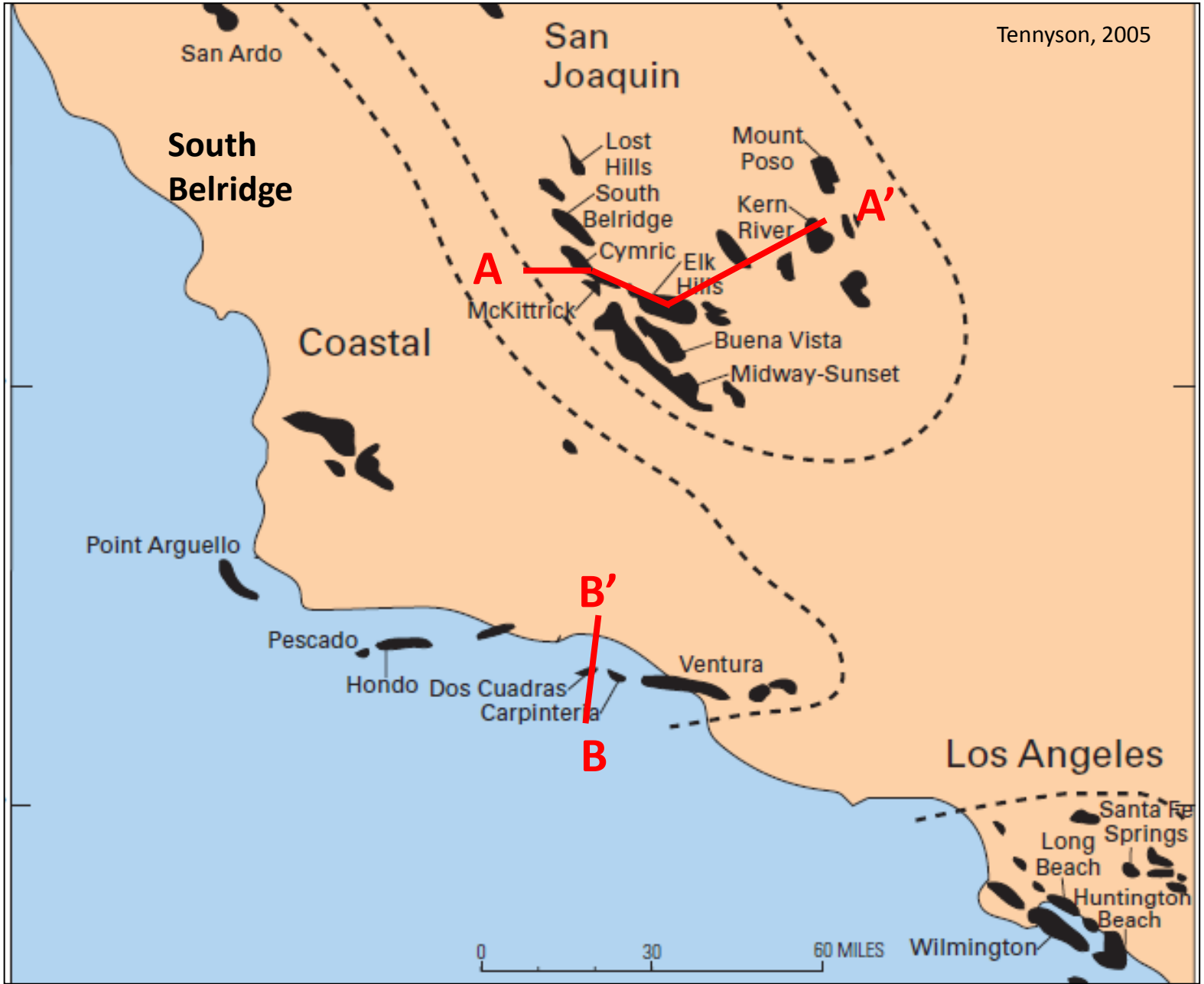
**29 billion barrels**

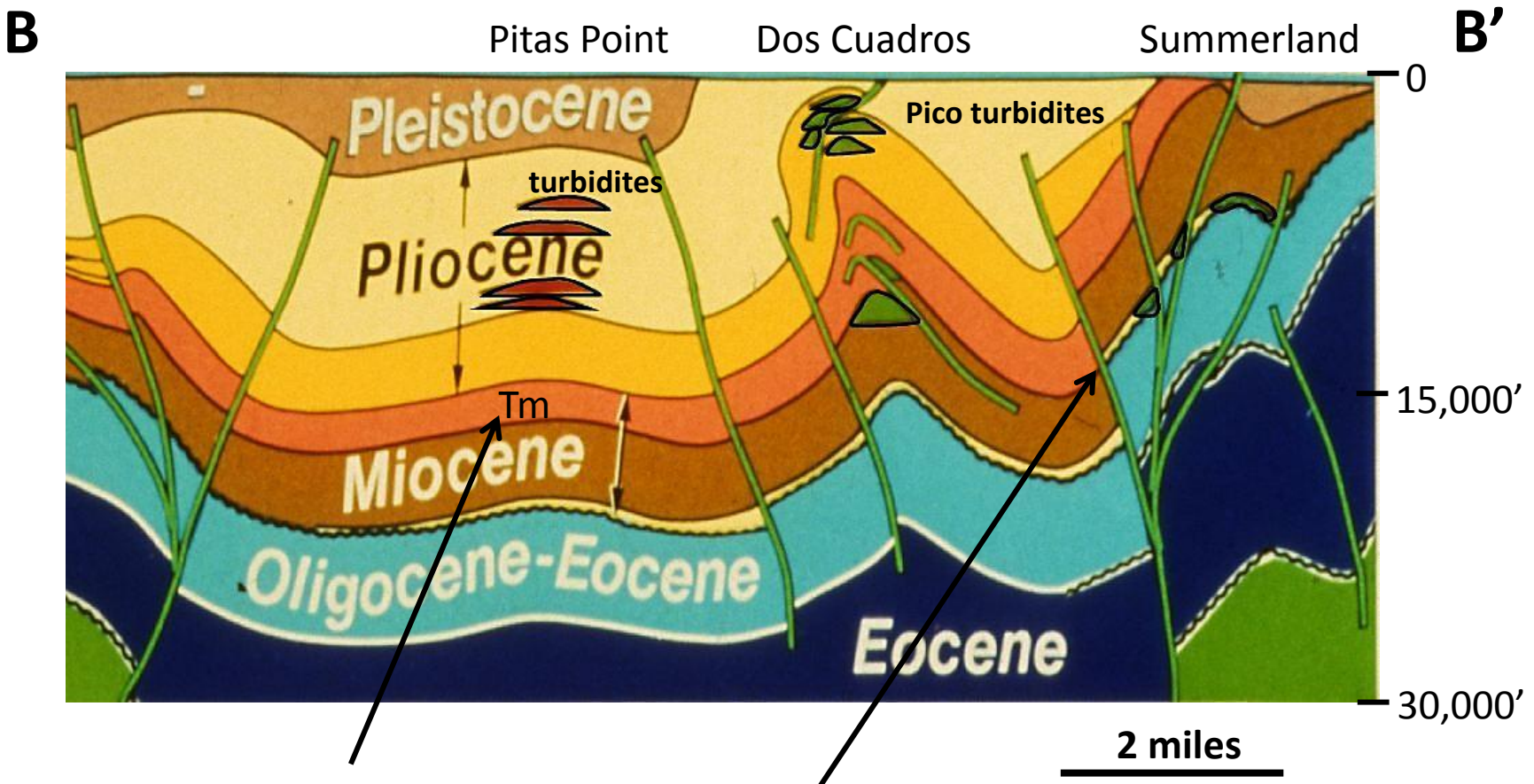
**~10% produced from Monterey rocks**

**~90% produced from sandstones**

**above, adjacent and within the Monterey**

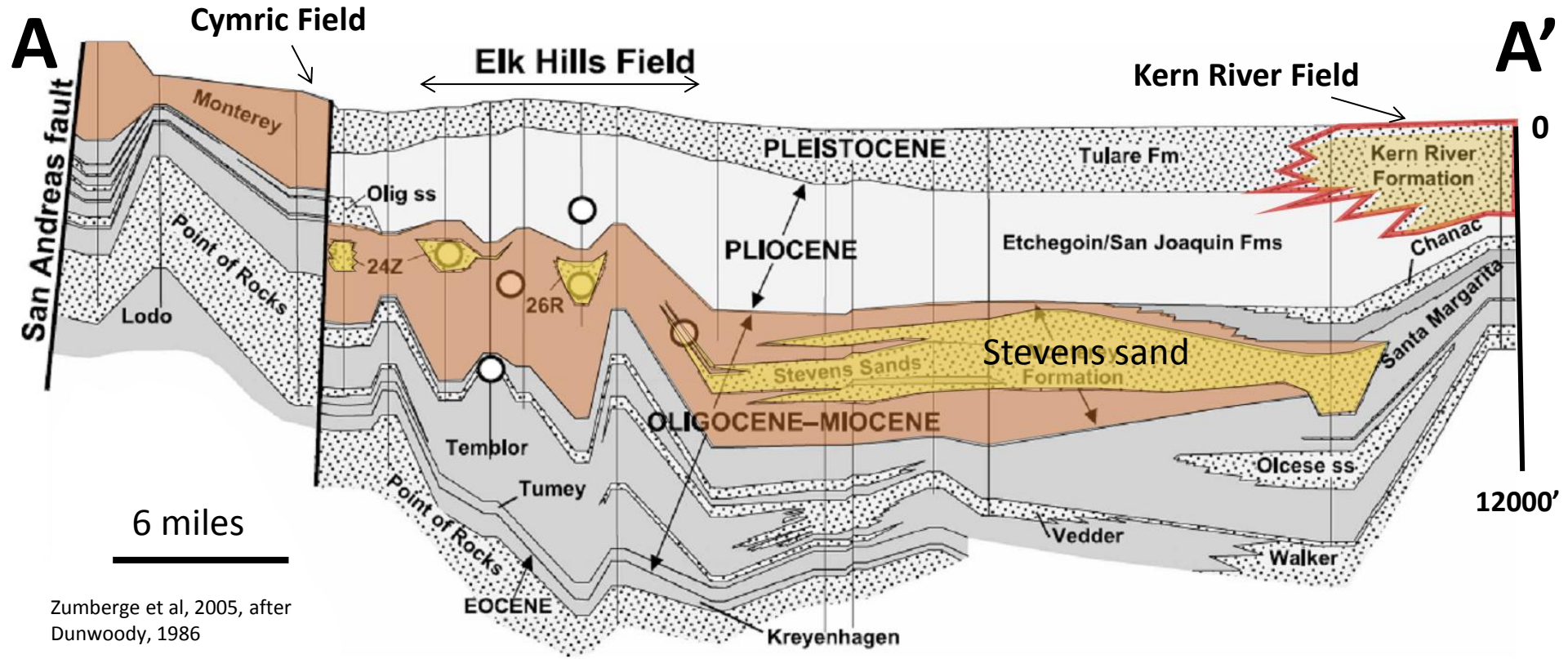
# Only 10% of total oil produced is from Monterey reservoirs






**Overlying turbidite sands are dominant play type here and in LA Basin**

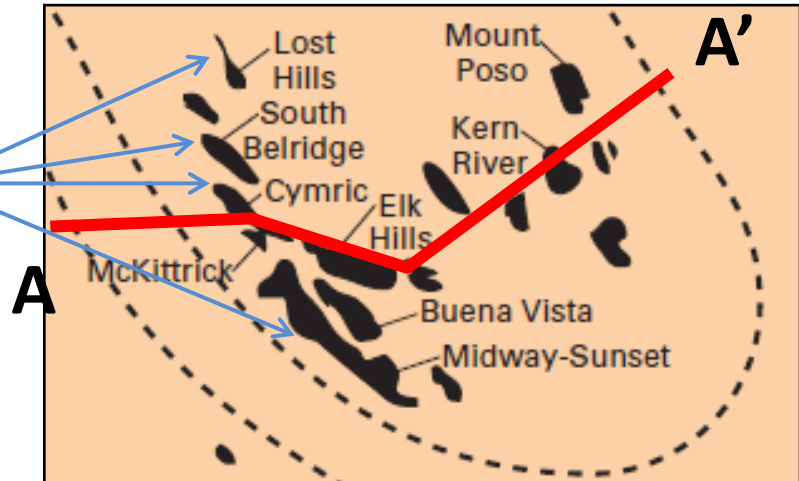
# Bulk of production is from Stevens turbidite sands and overlying Plio/Pleistocene clastics




Zumberge et al, 2005, after Dunwoody, 1986

Monterey Fm

Diatomite fields



# What about the 10% of oil that comes from Monterey Formation Reservoirs?

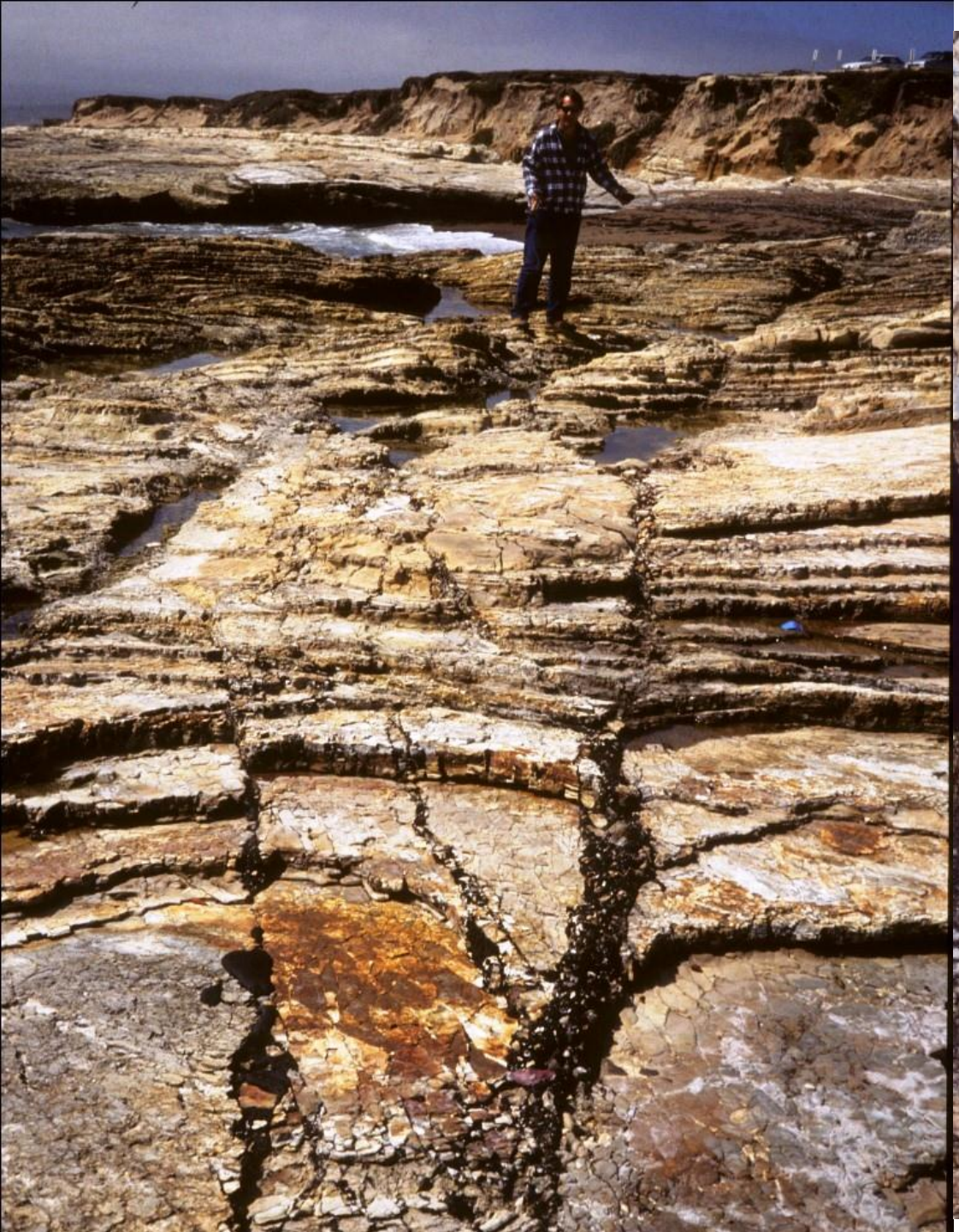
| | |
|---|---|
| Opal CT and quartz | ~2-35% porosity |
| Diatomite | ~ 35-70% porosity |
| All rock types | < 1 md permeability |

| | |
|---|---|
| Sand | ~1000 md |
| Sandst. | ~100's md |

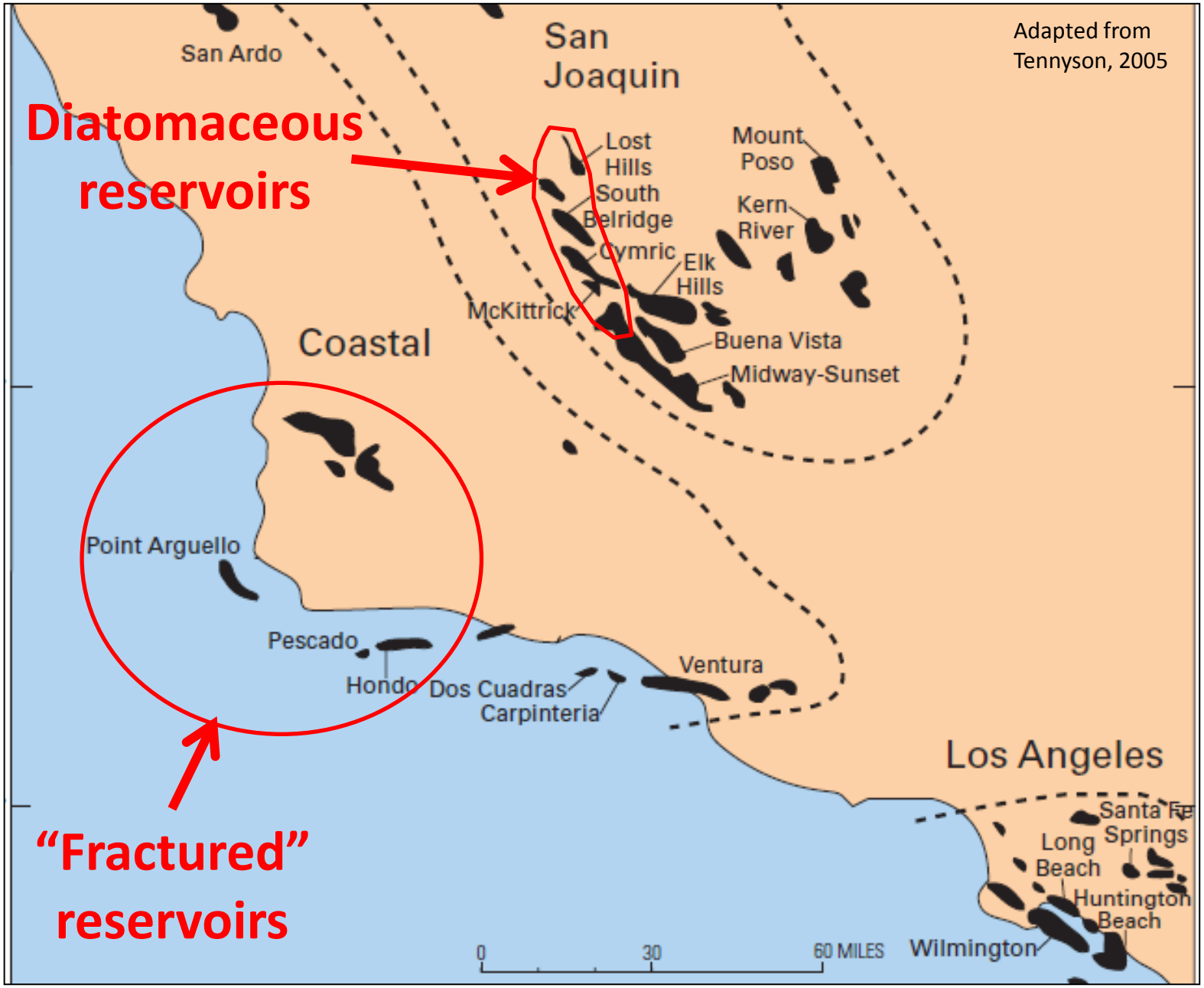
**Oil stored in Matrix**
**Produced from Natural or induced fractures**

# Fractured Reservoirs





# Diatomite reservoir….few fractures


Adapted from
Tennyson, 2005
Diatomaceous
reservoirs
San Ardo
San
Joaquin
Lost
Hills
South
Belridge
Cymric
McKittrick
Elk
Hills
Mount
Poso
Kern
River
Buena Vista
Midway-Sunset
Coastal
Point Arguello
Pescado
Hondo
Dos Cuadras
Carpinteria
Ventura
Los Angeles
Santa Fe
Springs
Long
Beach
Huntington
Beach
Wilmington
0
30
60 MILES
"Fractured"
reservoirs

©Sara Leen, National Geographic



**Diatomite reservoir**
**South Belridge field**

**“Fractured” reservoir**
**Pt Arguello field**

## Pt Arguello, Chert & Porcelanite

**Primary, water flood; no fracking**

**Deviated wells drilled to intersect fractures**

**Selective perfing of highly fractured intervals**

**Acid jobs to clean up wellbore**

**3600 acres**

**High initial production, fast decline**

**Fluids move rapidly through natural fractures**

**Recovery factor 6-8%??**

**56 wells**

***2008***

**2,500 BOPD**

**177,000,000 cum**

**reserves ~ 36 million**

Data from CA DOG &
Plains Exploration

## Belridge field, Diatomite

**Propped frac stimulation and waterflood (since 1977)**

**Steam flood in selected areas**

**3500 acres**

**Low initial production, slow decline**

**Fluids move 0.3 to 1 meter per year**

**Recovery factor 10%??**

**4129 producers, 1343 injectors, 380 steam**

***2009***

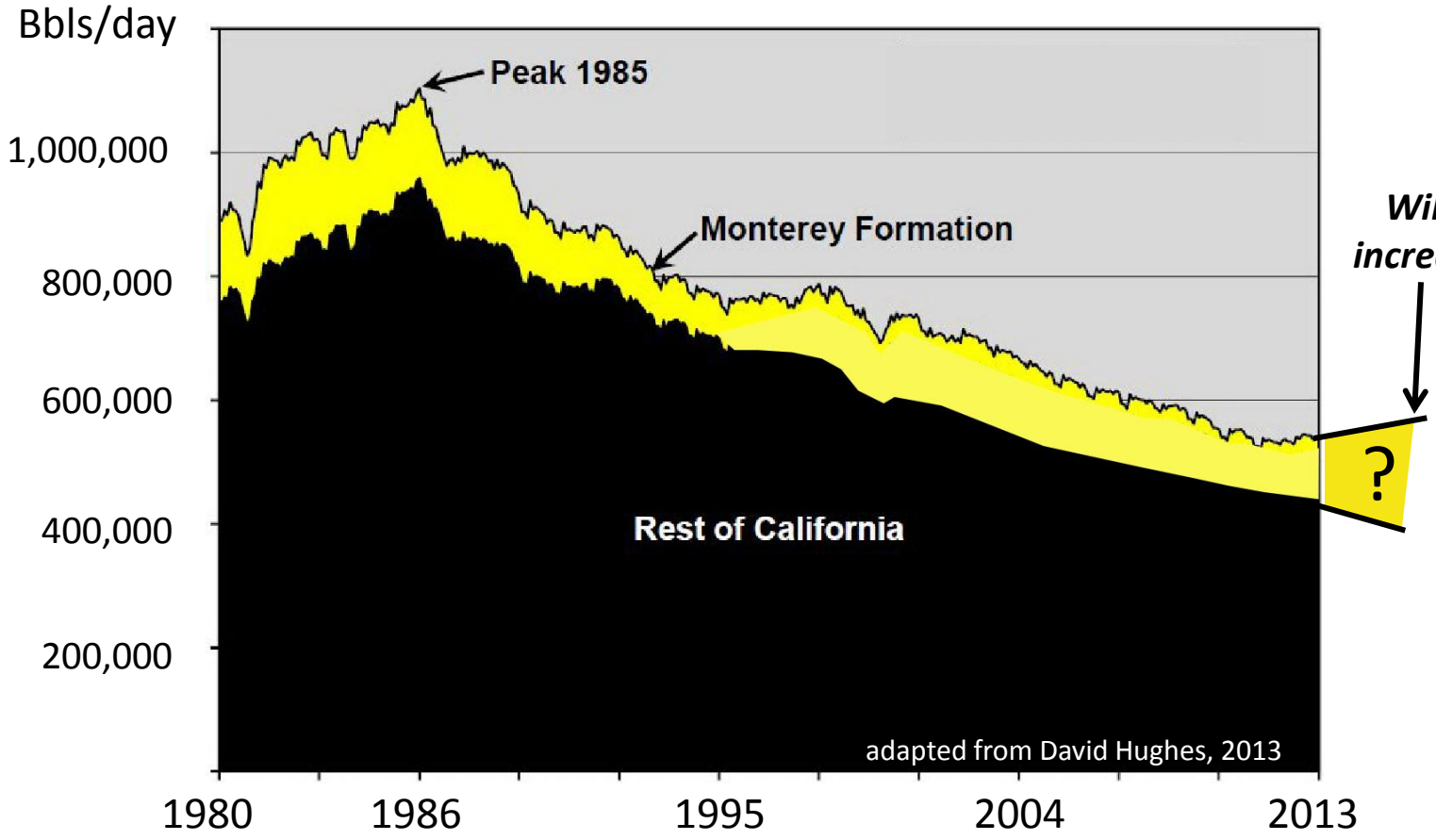
**40,000 BOE per day**

**270,000,000 cum**

**reserves ~ 300 million**

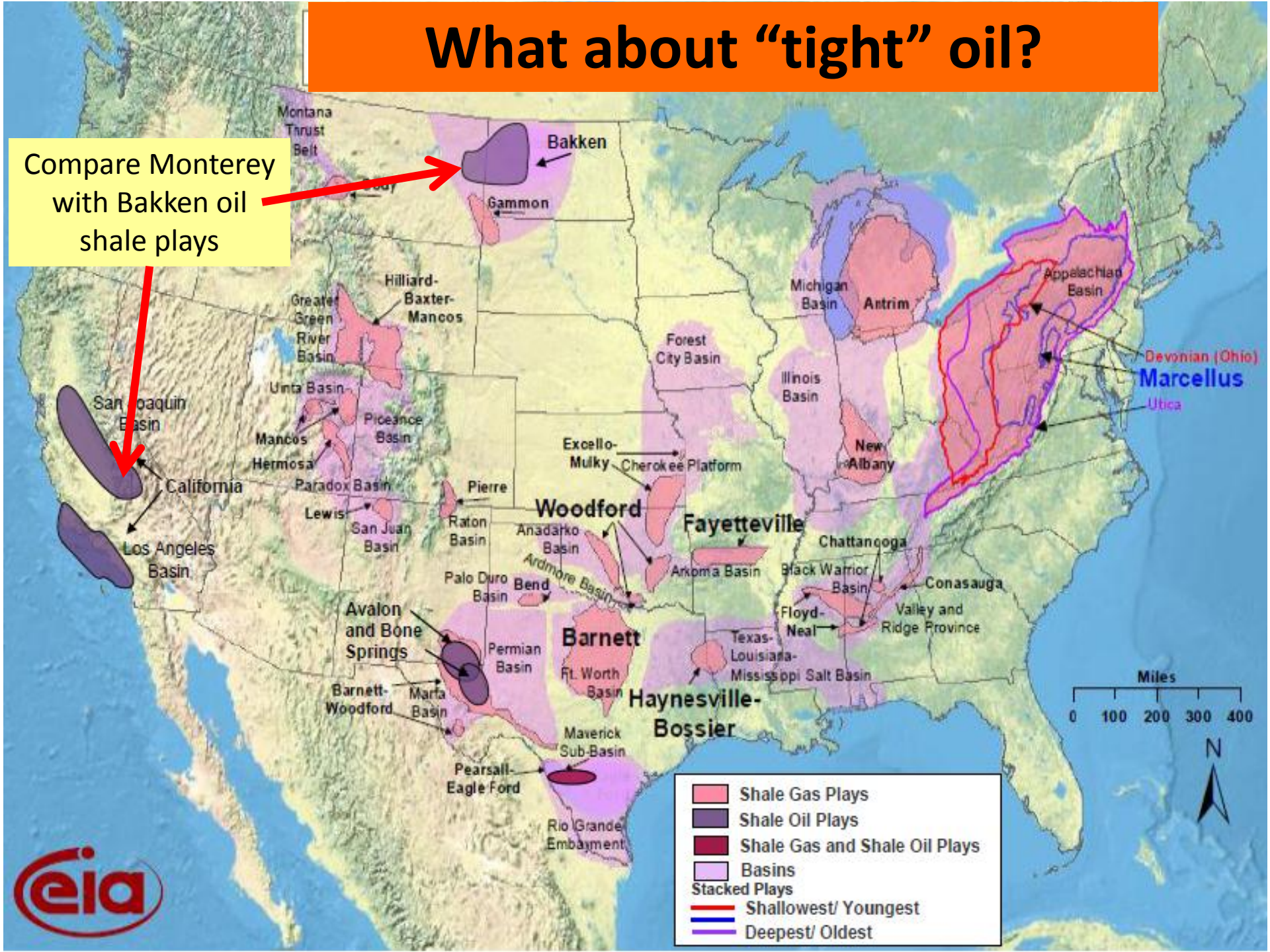
Data from Allan and Lalicata, 2012

# California Production




- **Diatomite reservoirs holding fairly steady or increasing**
- **chert and porcelanite production has declined.**
- **New fields are not being discovered**
- **Remaining reserves with existing technologies = ~ 10 billion barrels (USGS)**

# What about “tight” oil?



**“Vast Oil Reserve May Now Be Within Reach, and Battle Heats Up”**

New York Times, Feb 2013

**“Fixing California: Will fracking bonanza be allowed?**

**The States new law on fracking could clear the path for enormous economic growth”**

San Diego U-T, September 2013

# OR

**“The Monterey Shale: Big Deal or Big Bust?”**

AAPG Explorer, November 2012

# How misinformation started

"In 2011, the U.S. Energy Information Administration (EIA) published a report by INTEK Inc. which stated that the Monterey Formation contains **15.4 billion barrels*** of technically recoverable tight oil "

Using this estimate, a "University of Southern California (USC) economic analysis...projected as much as a $24.6 billion per year increase in tax revenue and 2.8 million additional jobs by 2020."

From Hughes, J.D., 2013, Drilling California, a reality check on the Monterey Shale

***15.4 billion barrels estimate is for unconventional "tight oil" similar to Bakken shale play; no trap is required**

**INTEK's Assumptions Are mind-boggeling**

**Non-field lease holdings in the San Joaquin Valley total 1,121,500 net acres = 1,752 square miles**

**550,000 B/O per well**

| | Active |
|---|---|
| Depth (ft) | 11,250 |
| Thickness (ft) | 1,875 |
| Porosity (%) | 11 |
| Total Organic Content (% wt) | 6.5 |

| | Active |
|---|---|
| Area (sq. miles) | 1,752 |
| EUR (MBO/ well) | 550 |
| Well Spacing (wells/ sq. mile) | 16 |
| TRR (BBO) | 15.42 |

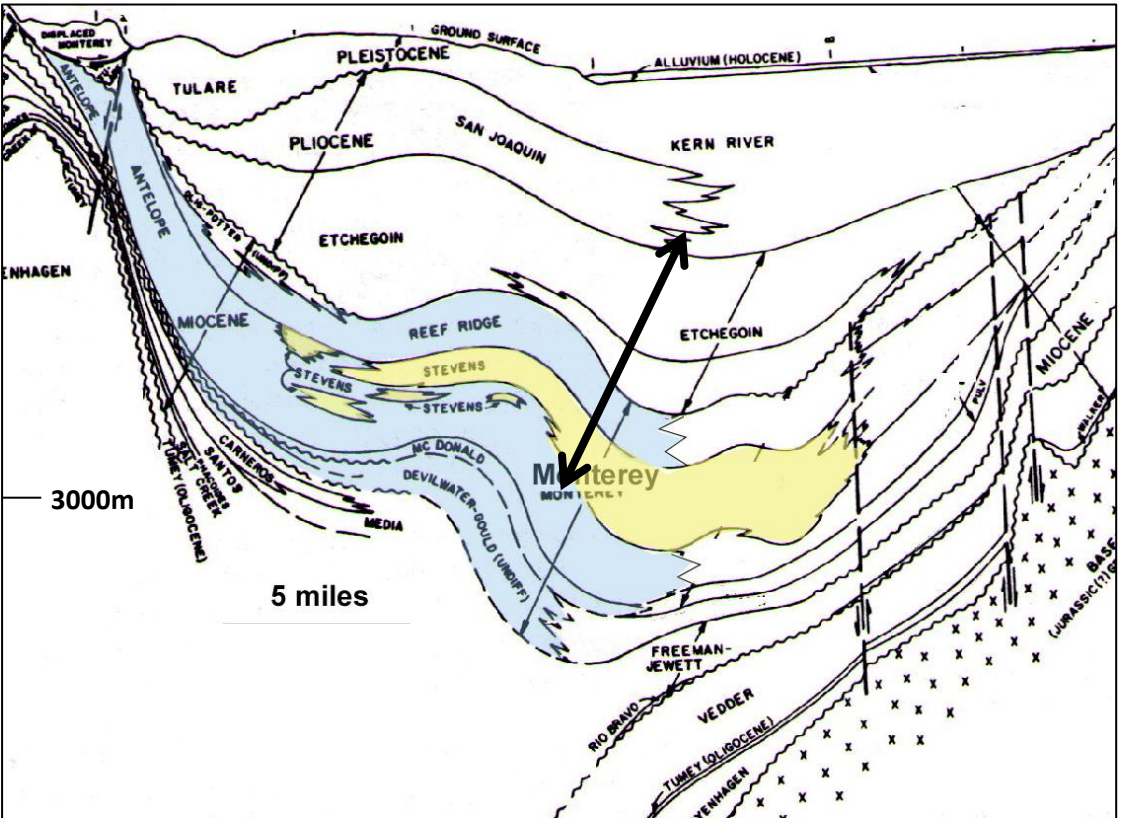
16 wells per sq. mile x 1752 sq. miles= 28,000 wells

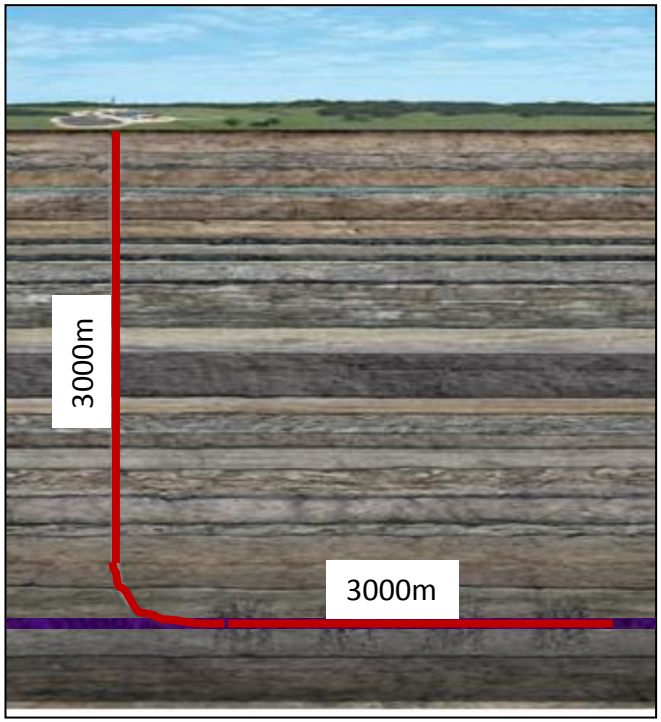
28,000 wells x 550,000 BOPW = 15.4 billion barrels

Note: our taxes paid a contractor for this report.
USGS would have done it right

# Monterey versus Bakken “oil shales”

| | Bakken | Monterey |
|---|---|---|
| TOC | High | High |
| Porosity | 2-15 | 2-25* |
| Permeability | <1md | <1md |
| Thickness | 100-250’ | 6000+ |
| Structure | simple | complex |



# Development


**Bakken oil and gas**


**Monterey oil**

# Other key differences

- **Oil in the Monterey can migrate out as it is generated, leaving oil that is relatively immovable.**
- **In the Bakken, oil is generated but cannot get out without human intervention.**
- **Bakken oil is lighter (API gravity) and is overpressured**
- **Pore structure apparently is different**

## What happened to The "Bonanza"?

**Recent drilling in non-structural traps has been unsuccessful**

**New estimate is 600 million, down from 15.4 Billion**

revised in Spring 2014

## What about the remaining "conventional" Monterey oil?

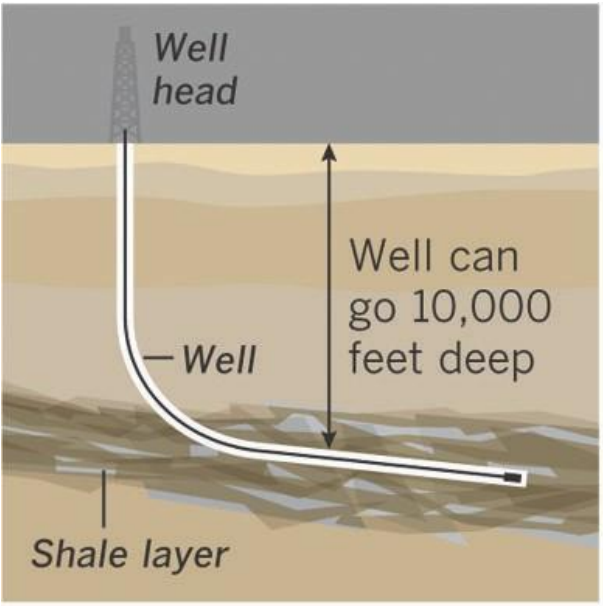
- **Current Recovery factor: <10%**
- **Billions of barrels remain in already discovered fields,** Tennyson et al, 2012, USGS

# Fracking

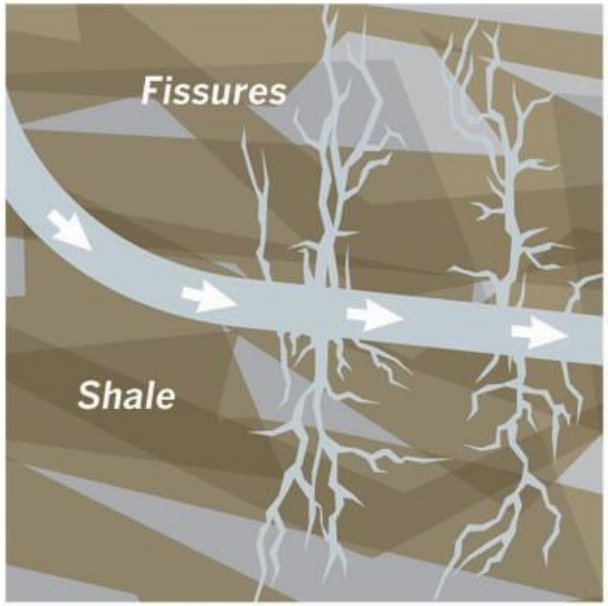
- The first commercially successful applications  by 1950.
- As of 2012, ~2.5 million hydraulic fracturing jobs performed worldwide
- more than one million of them in the United States.
- Used in vertical, deviated and horizontal wells

King, 2012, SPE

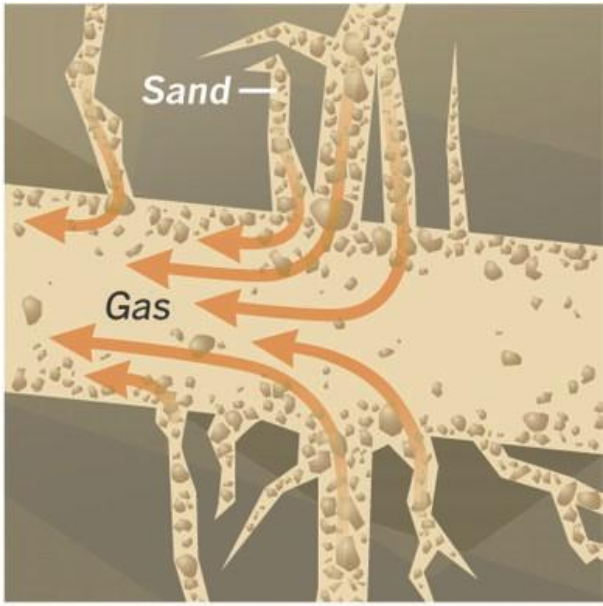
Drill




frac




Propents keep fracs open




Graphic: Doug Stevens, 2012, LA Times

Mix of water, chemicals and propent “forcefully” injected into formation

**Fracking itself is not the problem, it's the associated activities**

1. Potential Contamination of Aquifers (casing failure)
2. Air pollution near wellsite
3. Utilization of Scarce Water Supplies
4. Earthquakes caused by Injection of Flow-back Water
5. **Methane Leakage From Wells & pipelines**

# Government oversight is required

## New Fracking law passed:

- Fracking procedure more tightly controlled
- Chemicals now revealed.
- If you live near a fracking site, you will receive notice
- You can request a baseline water test

## Has fracking increased in California?

- Current rates about the same as “pre-recession”
- records not kept in past, will be in future
- ~1500 wells per year

Calif. Council Science and tech report, 2014

# Gas versus coal

- **Smog – gas clearly better than coal**
  - No particulates (e.g. sulfur (acid rain), mercury, and ash)
  - Millions of people will live longer and be healthier
- **Greenhouse Gases**
  - Replacing gas with coal will reduce greenhouse gas emissions as long as methane leakage is controlled
- **Long term**
  - Replacing all coal with gas will not solve our climate problems

From Cypress coast surfboards website