# Middle Miocene Organic Carbon Accumulation Rates in the Monterey Formation in the Santa Barbara and Santa Maria Basins, California

**Scott Hornafius**

Search and Discovery Article #51696 (2022)**
Posted November 30, 2022

*Adapted from extended abstract based on oral presentation given at 2022 CGS & PSAAPG Monterey Formation Research Conference 2022, Nov. 4-5, Ventura, CA
 DOI:10.1306/51696Hornafius2022

## Abstract

Middle Miocene post-compaction sedimentation rates in the Monterey Formation vary rapidly both laterally and vertically due to tectonically induced changes in depositional setting and changes in phytoplankton productivity rates, detrital input, and sediment redistribution by bottom currents. Extremely condensed intervals in the Lower Mohnian Stage (10-13 Ma) are found in the stratigraphic sections exposed along the Santa Barbara coastline between Naples Beach and Gaviota Beach, where sedimentation rates average 4 to 9 m/my over this 3-my interval. In contrast, expanded intervals are found in the middle Miocene basin center in the Santa Barbara-Santa Maria basin where sedimentation rates up to 100 m/my are found. The condensed sections in the coastal outcrops west of Santa Barbara are comprised of phosphatic marls with average TOC values of 10-12.5% in the Lower Mohnian. These condensed sections were deposited in a bank top environment where diatomaceous sediments were swept by currents into the adjacent basin, resulting in silica-poor intervals. The Lower Mohnian Stage in the adjacent depocenter is silica-rich with average TOC values in the range of 2-4%. Calculated organic carbon accumulation rates (OCAR) are only 0.1 $mg/cm^2/yr$ for the bank top deposits, but up to four times higher in the centers of the adjacent basins. In the underlying Luisian Stage (13-15.5 Ma) the sedimentation rates are as low as 25 m/my in coastal exposures west of Santa Barbara, but two to four times higher in the adjacent basin, where the OCAR averages as much as 1.0 $mg/cm^2/yr$.

## References

Barnette, C., 2015, Re-Os geochronology of the Monterey Formation, Union Leroy 51- 18 well, Santa Maria Basin, California: M.S. thesis, University of Houston, Texas, 66p.

Echols, R.J., 1994, Biostratigraphy of the Luisian and Mohnian Stages between Santa Barbara and Gaviota, California, in Field Guide to the Monterey Formation between Santa Barbara and Gaviota, California; Pacific Section AAPG, v. GB72, p. 1-16.

Follmi, K.B., et al., 2005, Phosphogenesis and organic-carbon preservation in the Miocene Monterey Formation at Naples Beach, California – The Monterey hypothesis revisited; Geological Society of America Bulletin, v. 117, p. 589-619.

Hancock, L.G., 2018, Proxy applications for reconstructing carbon and sulfur cycling in ancient marine environments: Ph.D. dissertation, University of California, Riverside, 228 p.

Hornafius, J.S., 1991, Facies analysis of the Monterey Formation in the northern Santa Barbara Channel; AAPG Bulletin, v.75, p.894-909.

Hornafius, J.S., 1994a, Overview of the stratigraphy of the Monterey Formation along the coastline between Santa Barbara and Gaviota, California, in Field Guide to the Monterey Formation between Santa Barbara and Gaviota, California; Pacific Section AAPG, v. GB72, p. 1-16.

Hornafius, J.S., 1994b, Correlation of volcanic ashes in the Monterey Formation between Naples Beach and Gaviota Beach, California, in Field Guide to the Monterey Formation between Santa Barbara and Gaviota, California; Pacific Section AAPG, v. GB72, p. 45-58.

Isaacs, C.M., 2001, Depositional Framework of the Monterey Formation, California, in Isaacs, C.M. and Rullkotter, J., eds.; The Monterey Formation – From Rocks to Molecules, Columbia University Press, New York, NY, p.1-30.

John, C.M., et al., 2002, Carbonaceous and phosphate-rich sediments of the Miocene Monterey Formation at El Capitan State Beach, California, U.S.A.; Journal of Sedimentary Research., v. 72, no. 2, p. 252-267.

Knott, J.R., et al., 2022, Tephrochronology of the Miocene Monterey and Modelo Formations, California; Geological Society of America Special Paper 556, p. 187-214.

Schwalbach, J.R., and Bohacs, K.M., 1995, Stratigraphic sections and gamma-ray spectrometry from five outcrops of the Monterey Formation in southwestern California: Naples Beach, Point Pedernales, Lion’s Head, Shell Beach, and Point Buchon: United States Geological Survey Bulletin 1995-Q, Q1-39.

Schwalbach, J.R., and Bohacs, K.M., 2020, The Monterey Formation at Shell Beach, California, in Outcrops that change the way we practice petroleum geology; Pacific Section AAPG Guidebook #81.

# Middle Miocene Organic Carbon Accumulation Rates in the Monterey Formation in the Santa Barbara and Santa Maria Basins, California

**Author: Scott Hornafius**

*Contributors: John Barron*
*Richard Behl*
*Gregg Blake*
*Jeff Knott*
*Jon Schwalbach*

November 4, 2022

# Test of the "Monterey Hypothesis"

***The "Monterey Hypothesis" proposes that the decrease in global temperatures that started ~15 Ma was due to extraction of $CO_2$ from the ocean-atmosphere system caused by the rapid accumulation of the organic carbon in the Monterey Formation and other organic-rich units around the Pacific rim.***

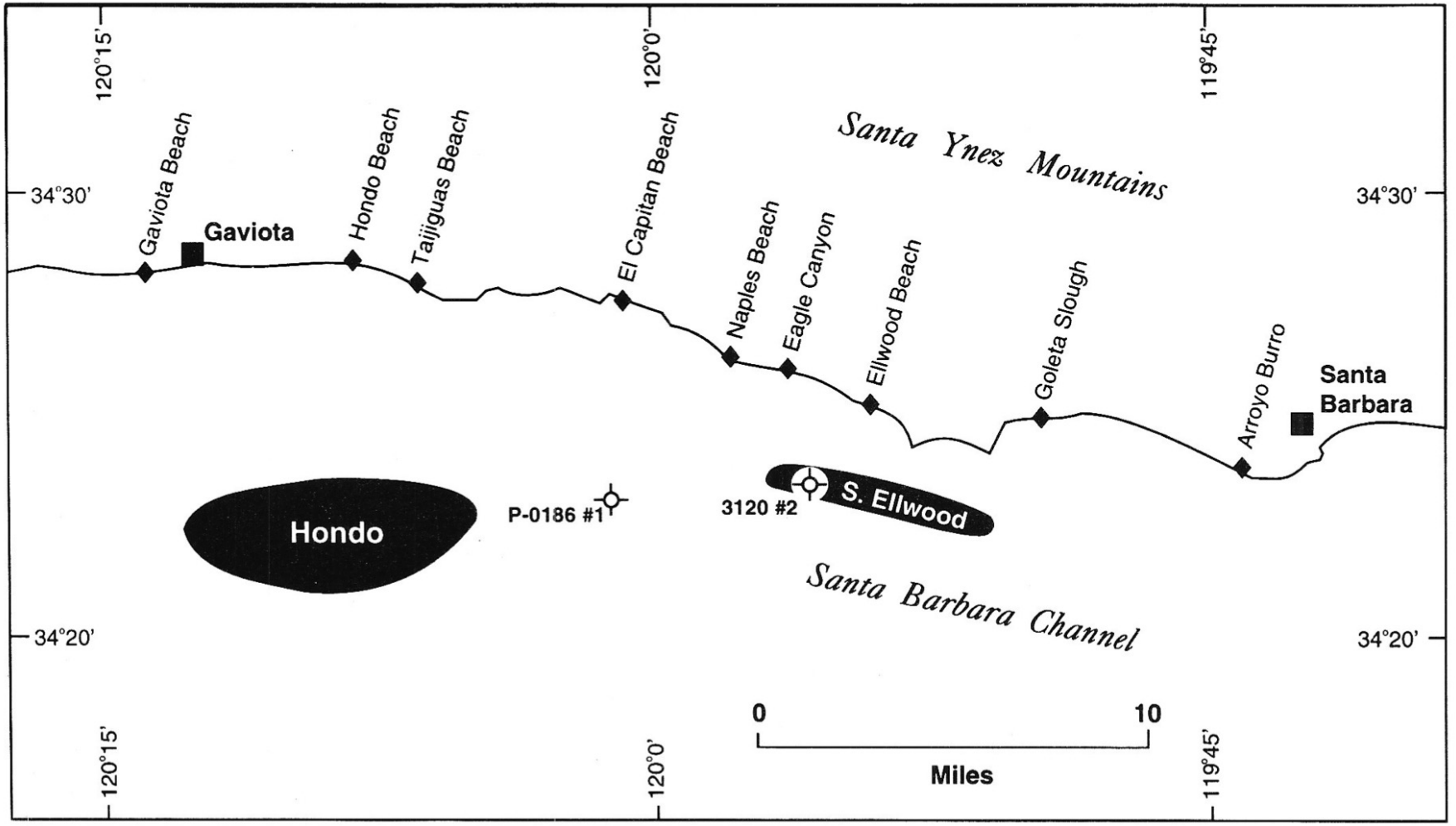
***Studies of the organic carbon accumulation rate (OCAR) in the Monterey Formation along the Santa Barbara coastline by Follmi et al. (2005) and John et al. (2002) concluded that the OCAR in the Monterey Formation during the middle Miocene was not sufficient to have affected the $CO_2$ content of the ocean-atmosphere system due to the extremely low sedimentation rates in those stratigraphic sections.***

***The highly condensed intervals in the middle Miocene along the Santa Barbara coastline were deposited on a submarine bank top where the organic-rich sediments were winnowed by bottom currents and redeposited as expanded Monterey intervals in the adjacent basin.***

***This presentation evaluates the possibility that the expanded middle Miocene intervals in the Monterey Formation in the Santa Barbara and Santa Maria Basins had sufficiently high organic carbon accumulation rates (OCAR) to make the Monterey Hypothesis viable if these basin deposits are representative of the middle Miocene OCAR in the circum-Pacific region.***

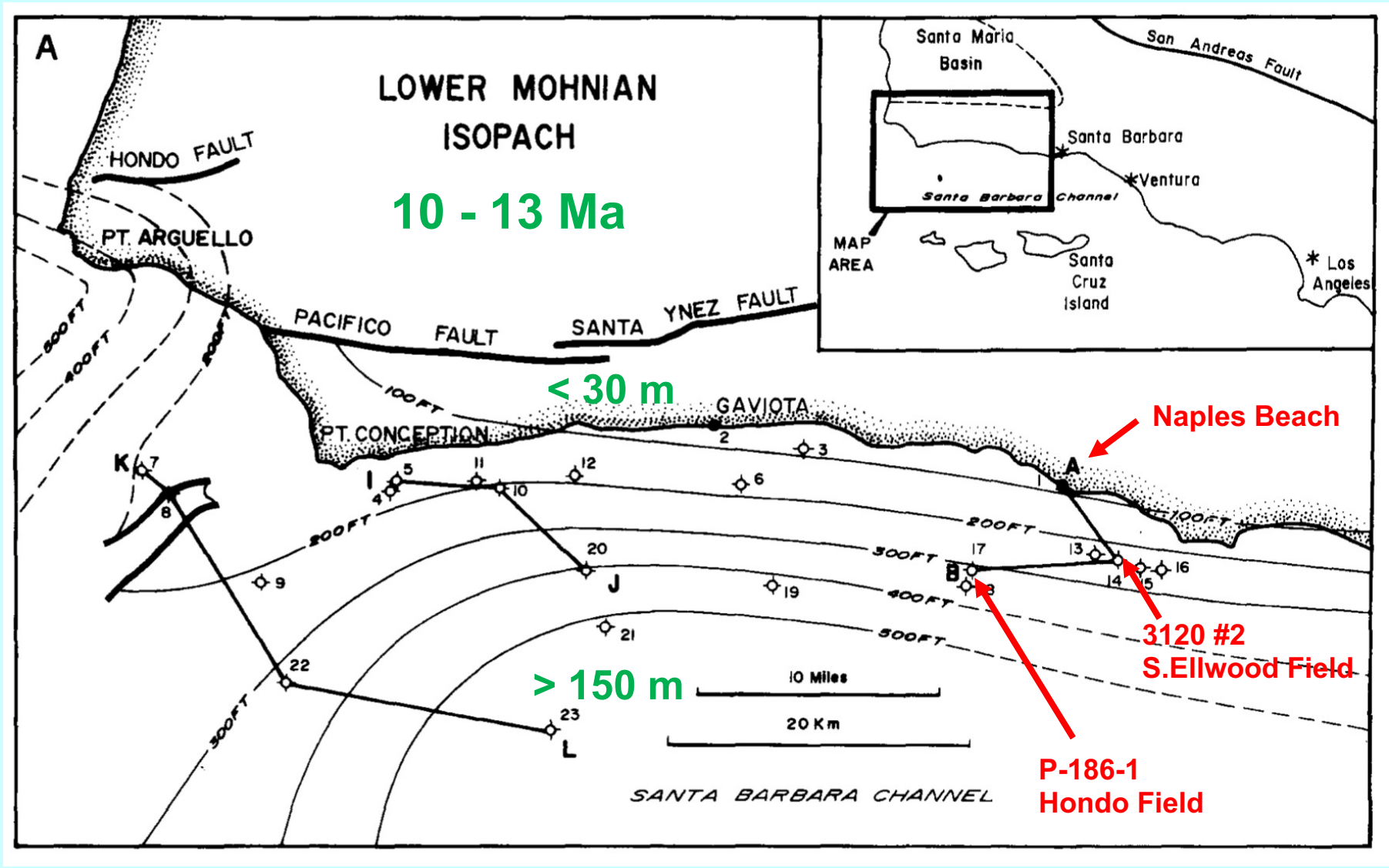
# Monterey Formation Stratigraphic Sections

***Santa Barbara Coastal Exposures and Offshore Oil Fields***




Hornafius (1994a)

# Key Wells in the Northern Santa Barbara Basin

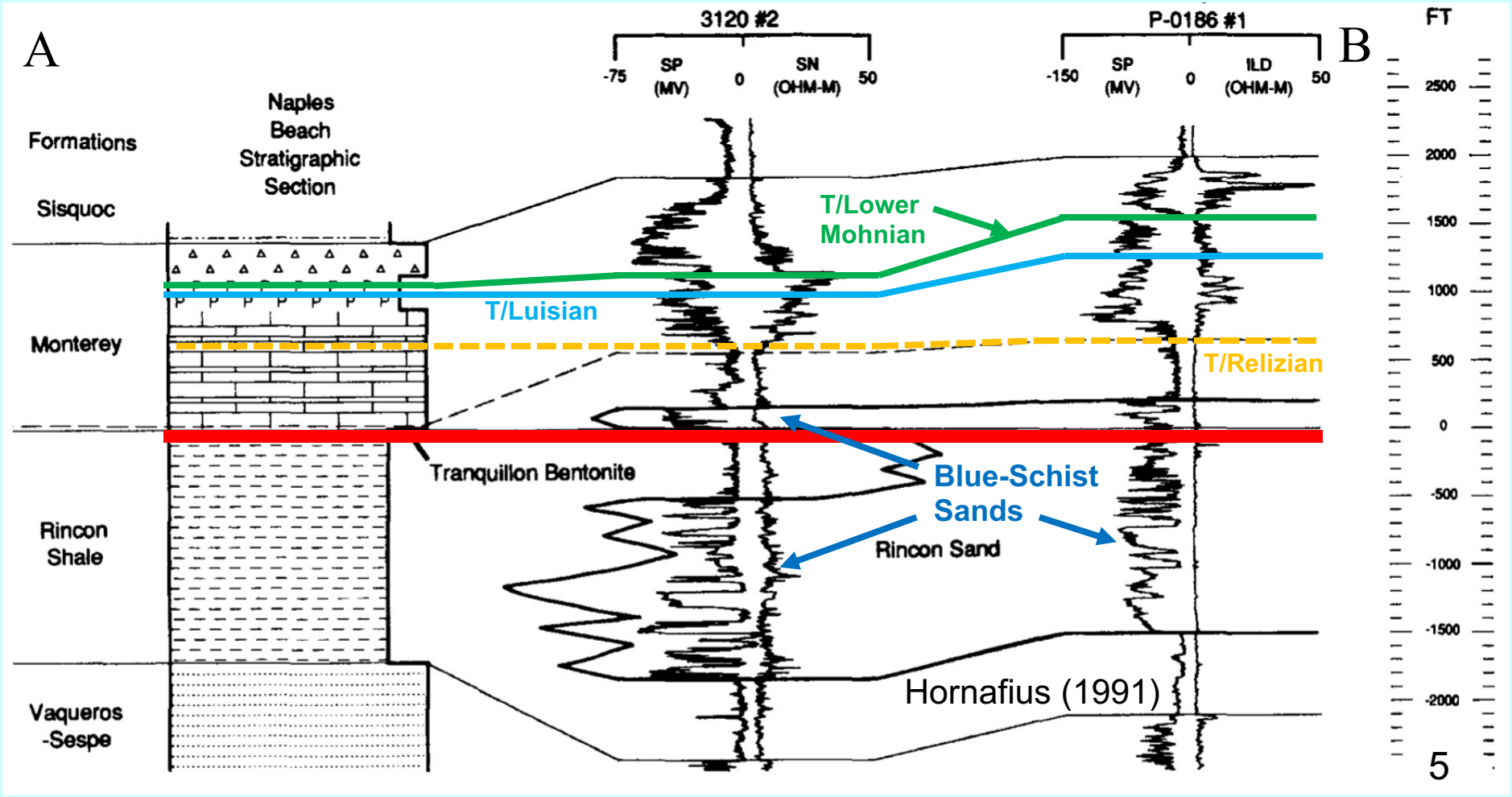



Hornafius (1991)

# Stratigraphic Changes – Northern Santa Barbara Basin

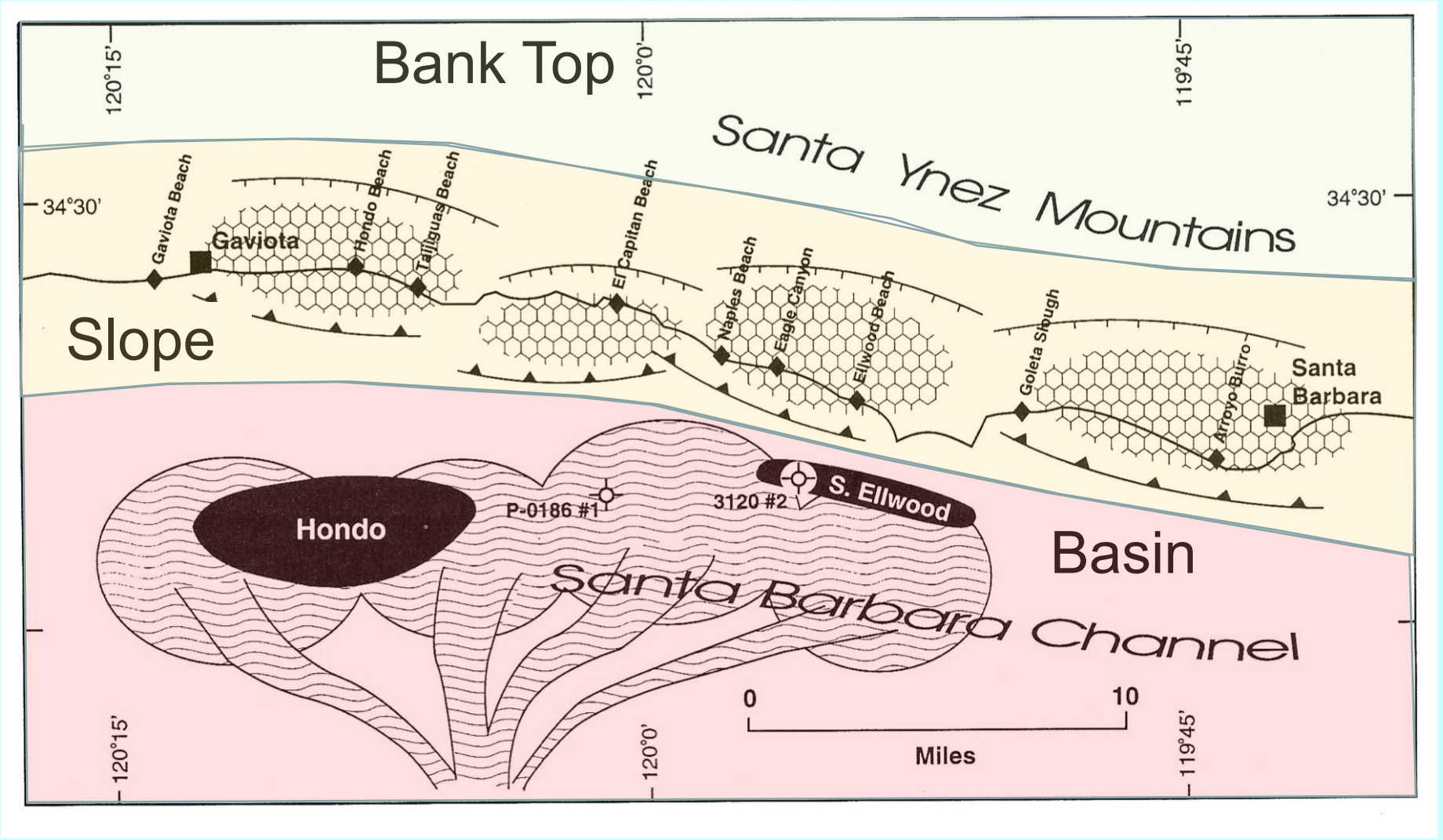
***Monterey Shale with high silica and calcite content above the Tranquillon Bentonite indicates environment isolated from clastic sources to the south and east***

***Rincon Shale contains thick blueschist-bearing turbidite sands in offshore wells that indicates basin axis is 3 miles south of Naples Beach in the Early Miocene***



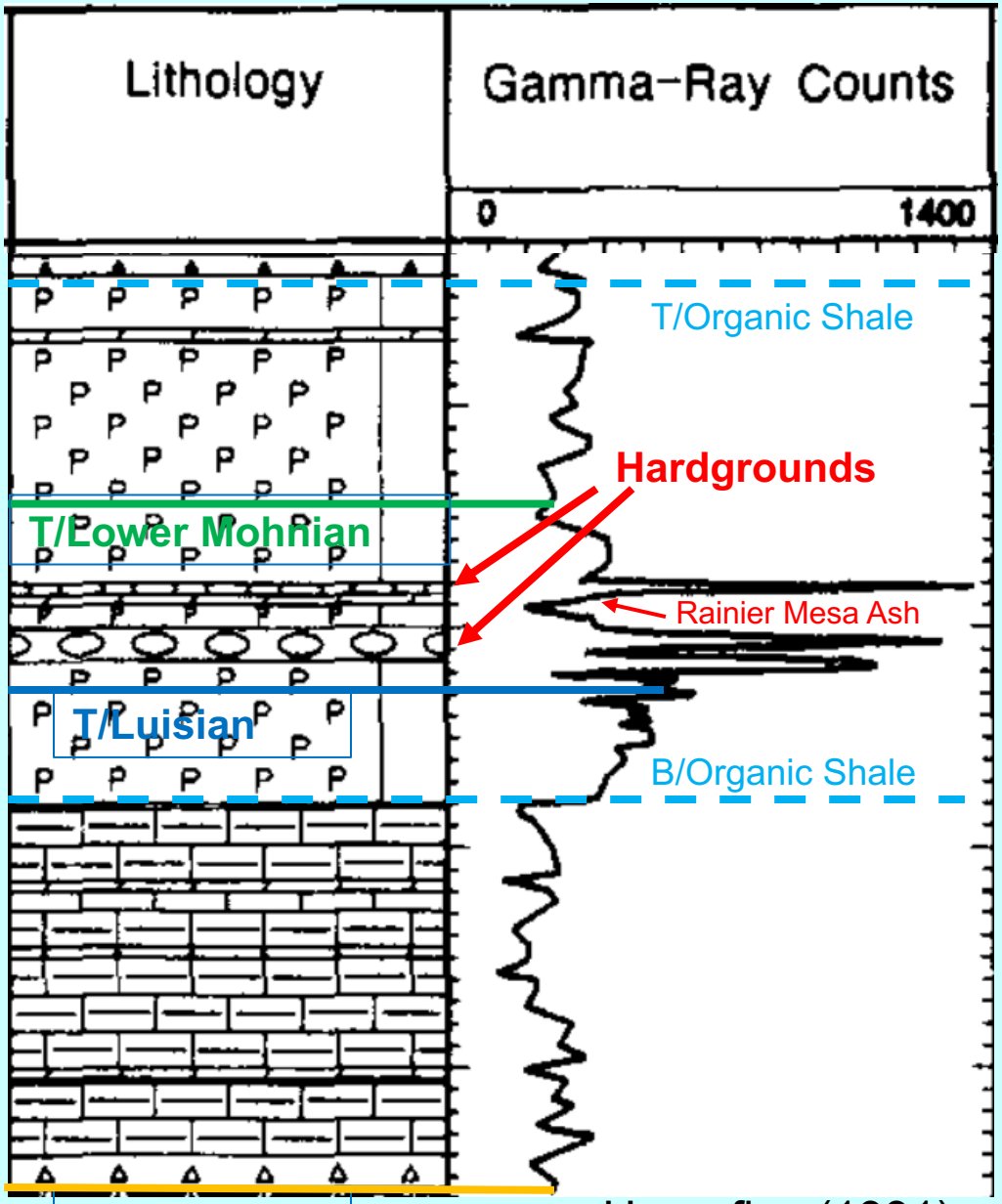
# Northern Santa Barbara Basin Paleogeography

***Late Saucesian ( ~18 Ma)***



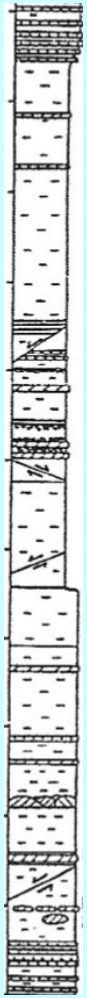

Hornafius (1994a)

# Naples Beach - Gamma–Ray vs Uranium (ppm)

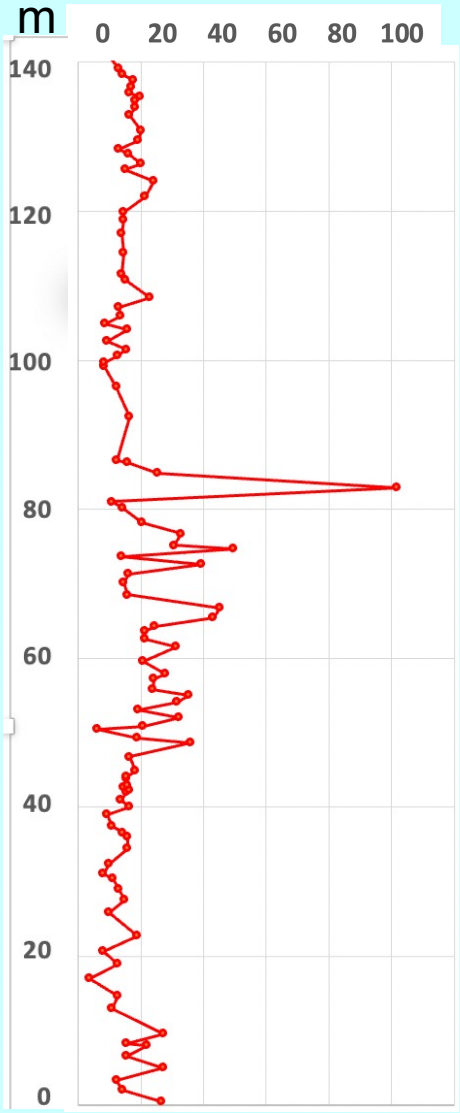



Hornafius (1991)

Section East of Dos Pueblos Creek



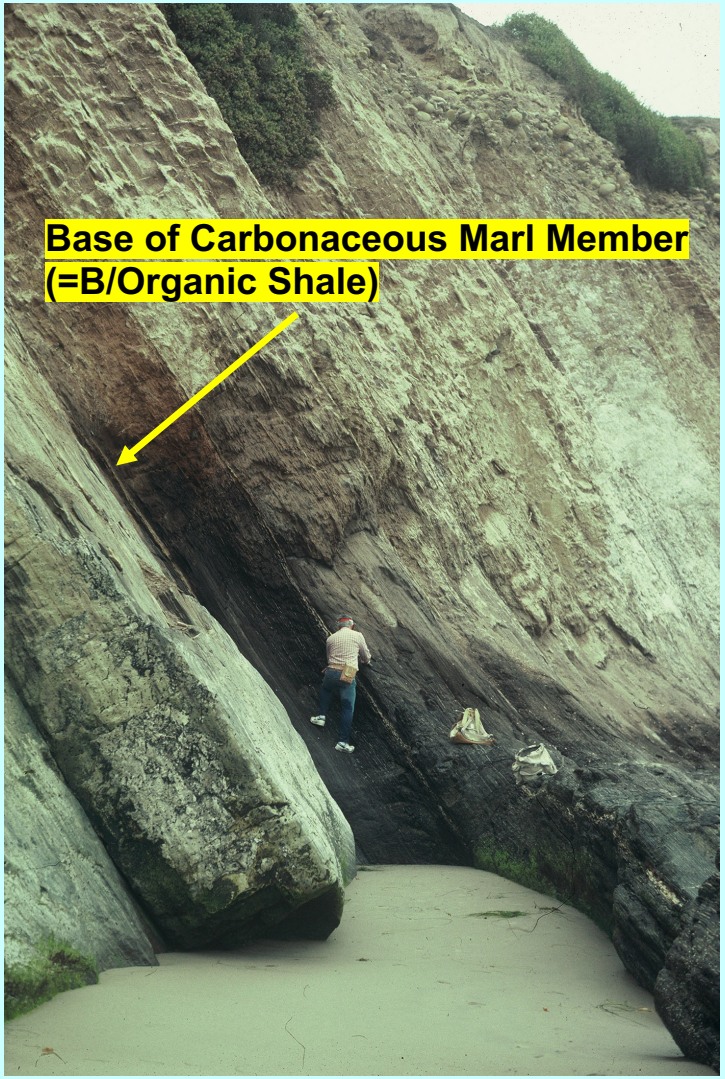
Lab U (ppm)




Hancock (2018)

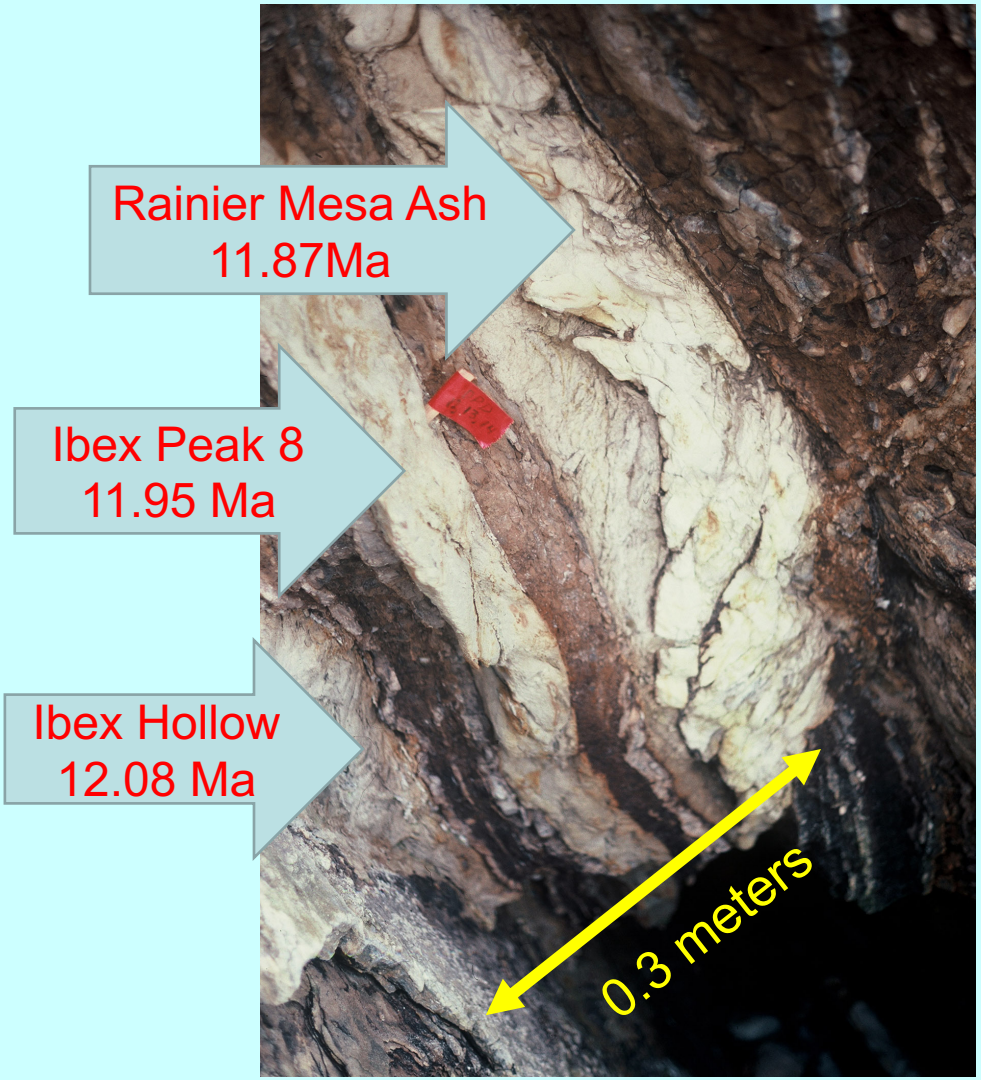
# Naples Beach – Carbonaceous Marl Member

Base of Carbonaceous Marl



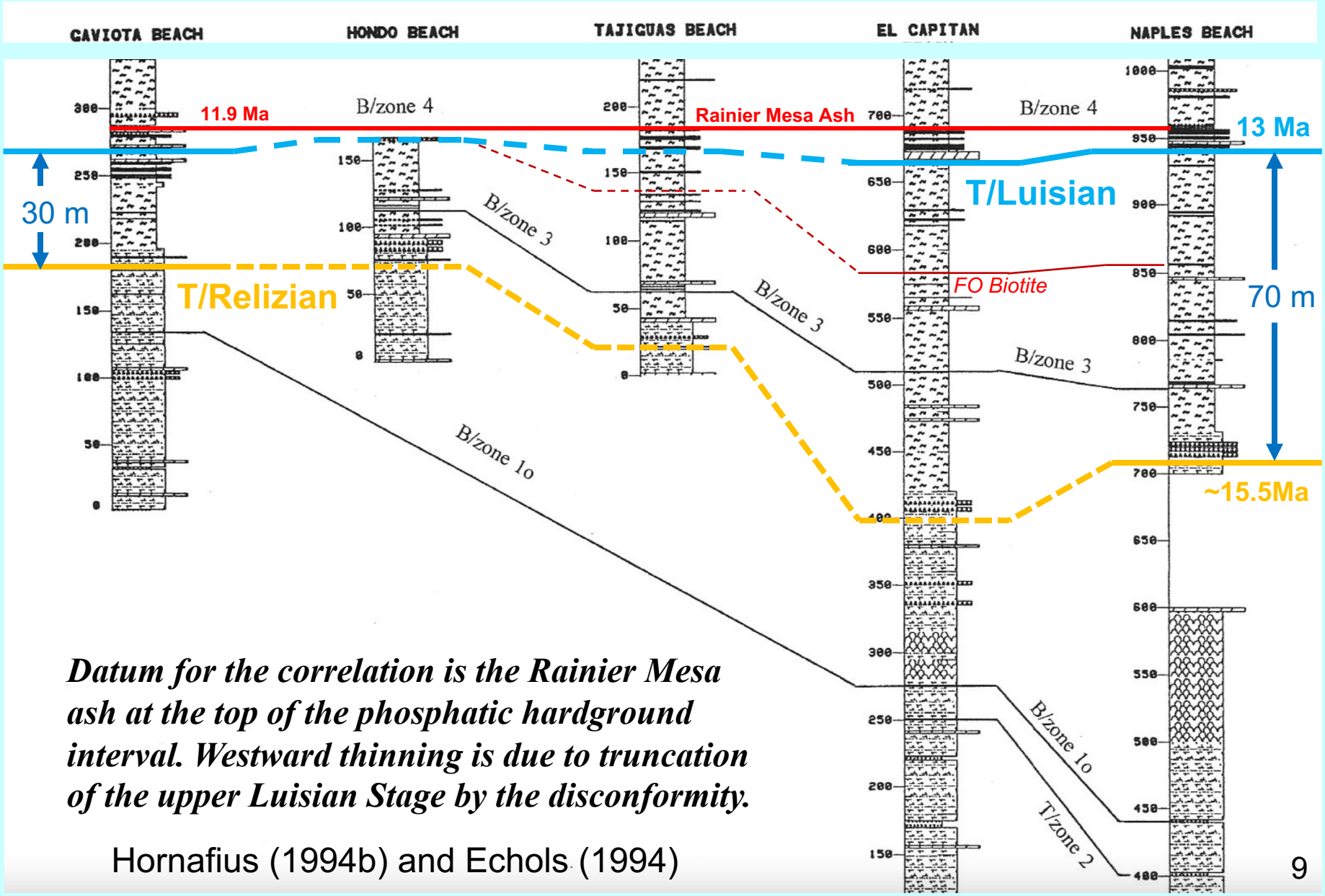

Sarna-Wojcicki (1989)

Middle of Carbonaceous Marl




Knott (2022)

# Correlations between Santa Barbara Sections




***Datum for the correlation is the Rainier Mesa ash at the top of the phosphatic hardground interval. Westward thinning is due to truncation of the upper Luisian Stage by the disconformity.***

Hornafius (1994b) and Echols (1994)

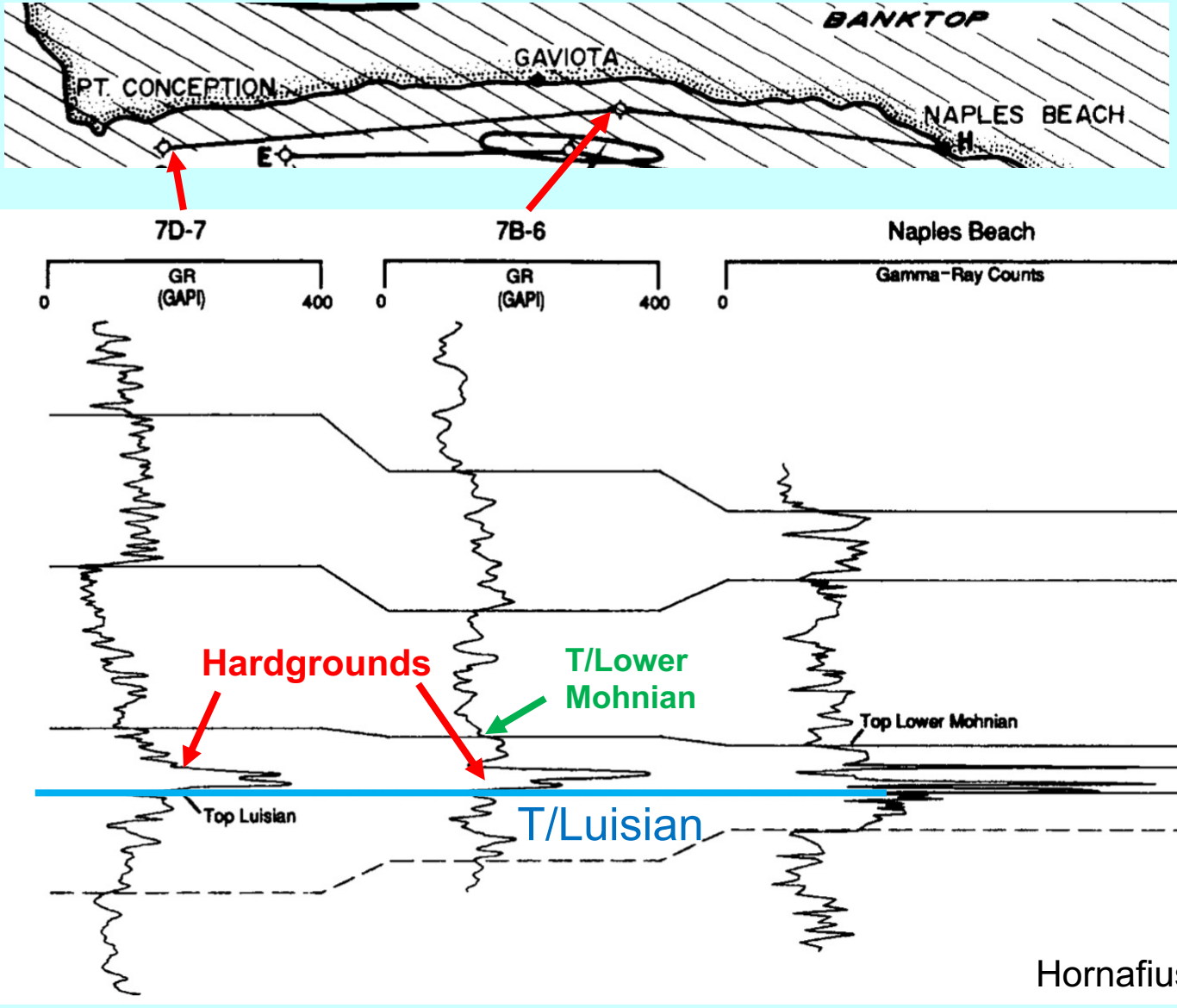
# Monterey Phosphatic Hardground Creation

***Phosphatic nodules and lenses form in organic-rich sediments at shallow burial depths. The sediments are then winnowed by bottom currents, leaving only the dense phosphate nodules as a pebble conglomerate.***

***A phosphate conglomerate "hardground" remains on the seafloor for up to 0.5 my, continuing to be scoured by bottom currents and absorbing uranium from the seawater, resulting in highly radioactive phosphatic crusts evident on gamma-ray logs.***

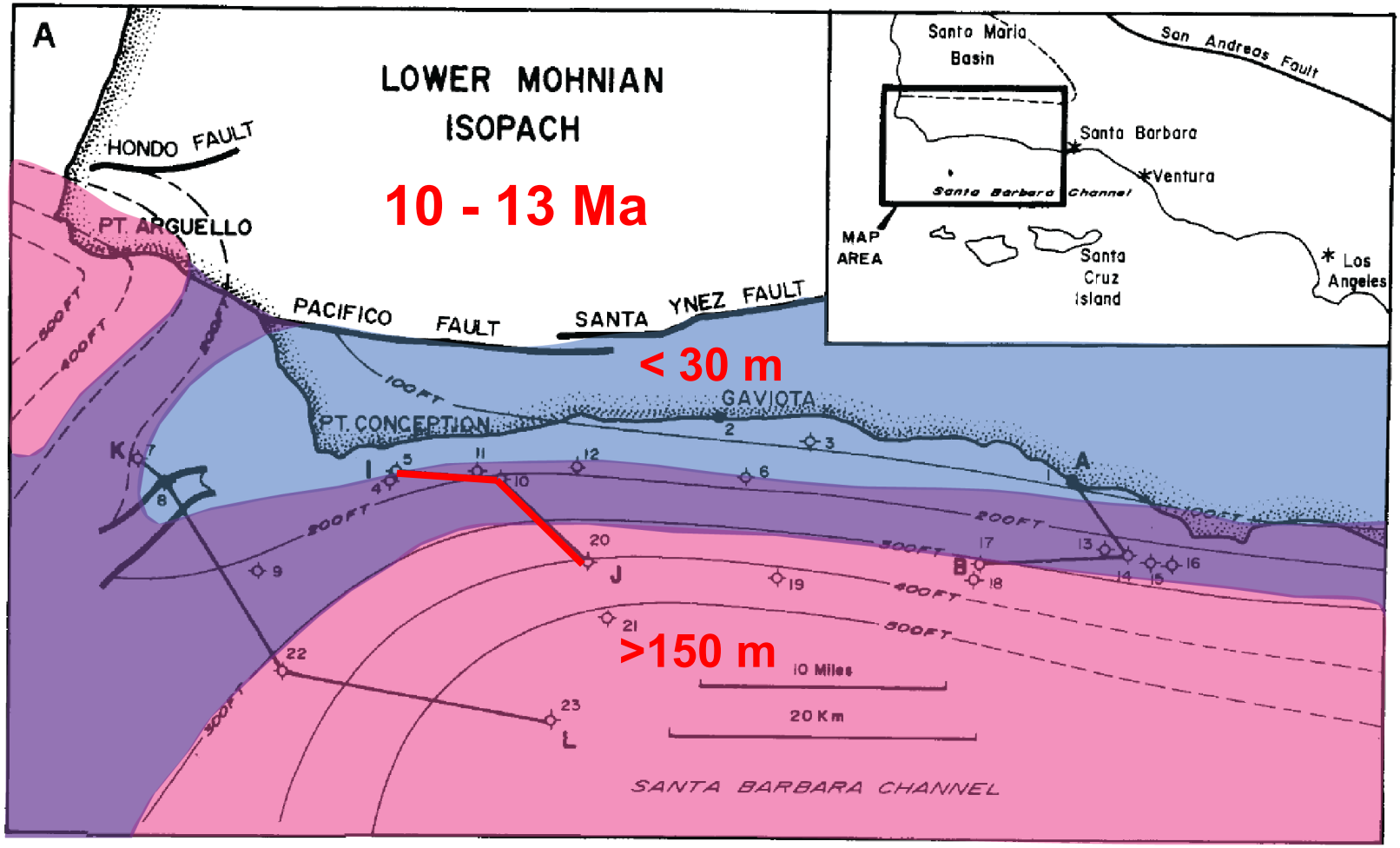
# Monterey Phosphatic Hardground Interval

Nearshore Core Holes in Northern Santa Barbara Channel



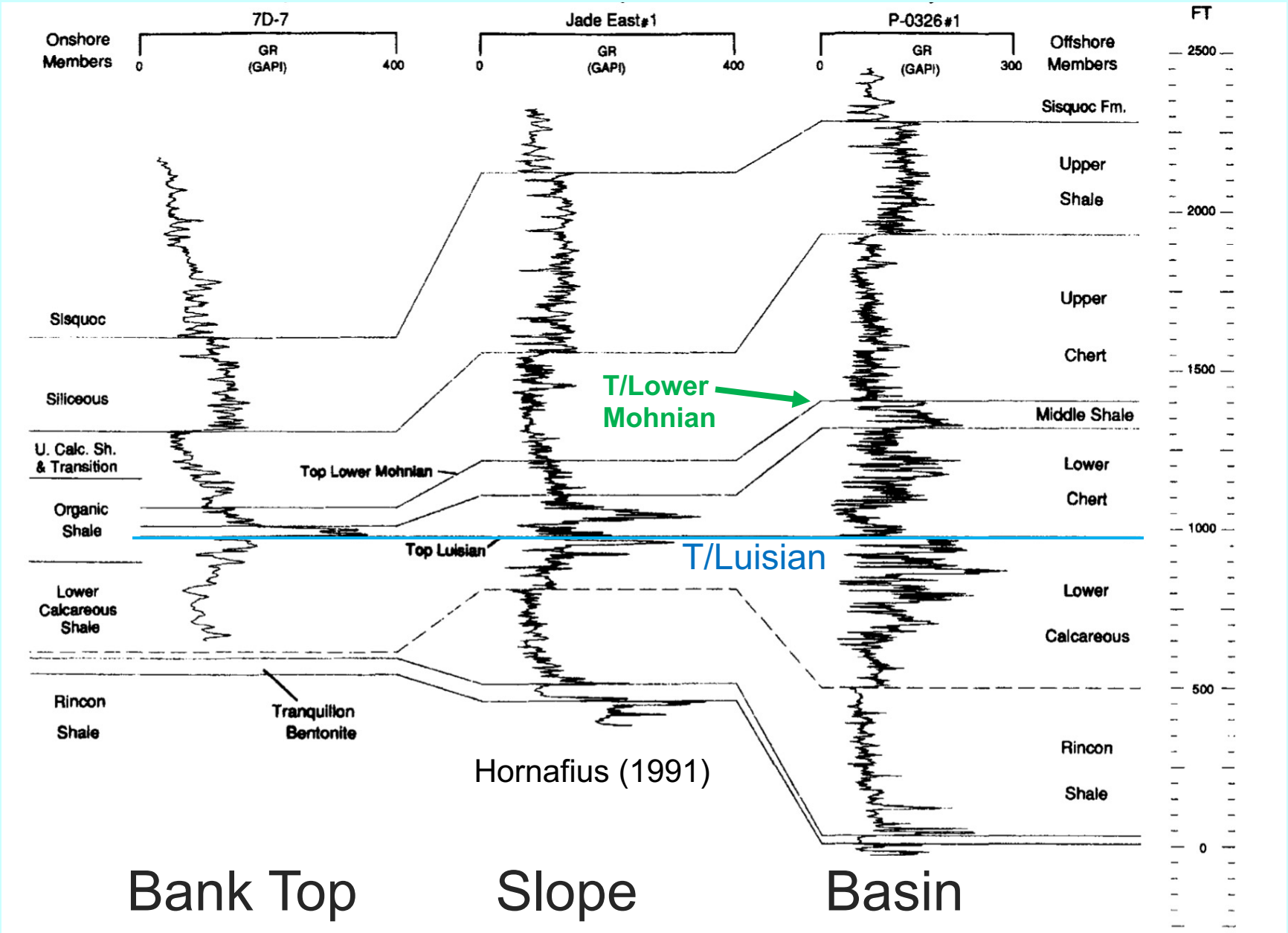

Hornafius (1991)

# Monterey Depositional Environments



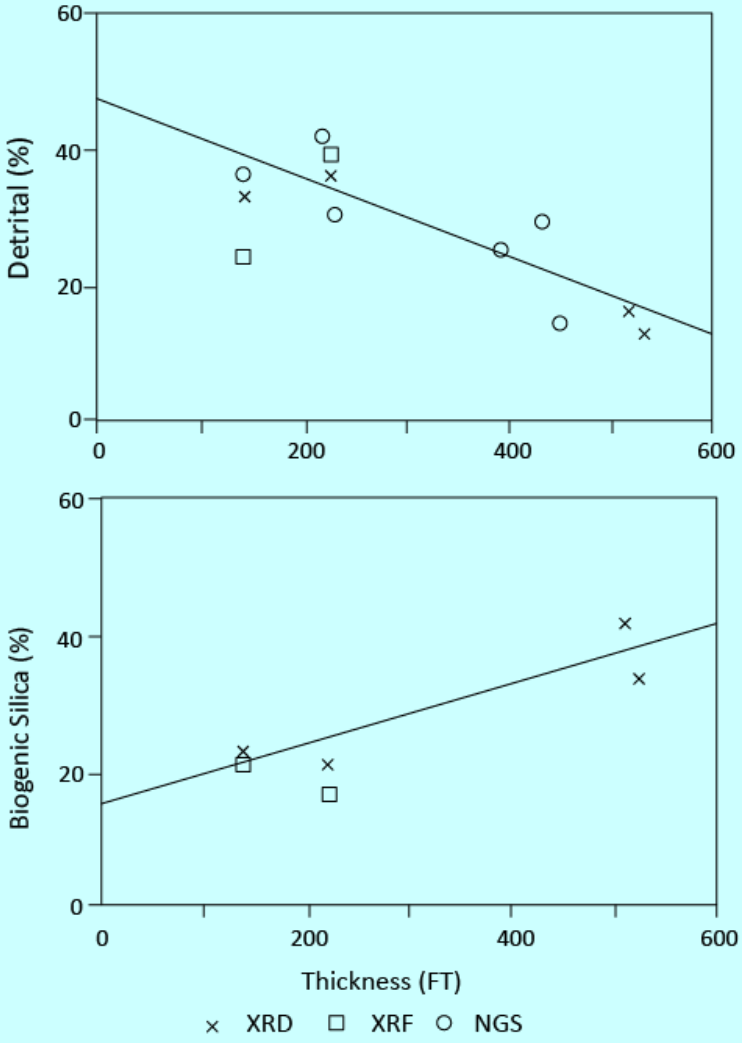

Hornafius (1991)

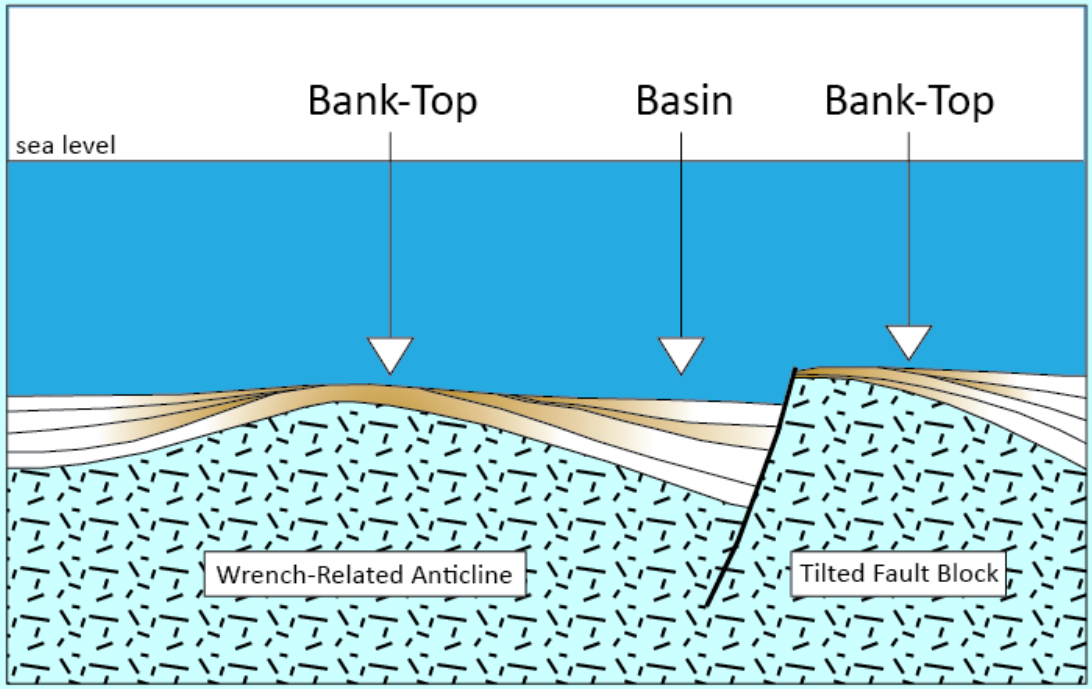
# Monterey Thickness Changes



# Monterey Compositional Changes

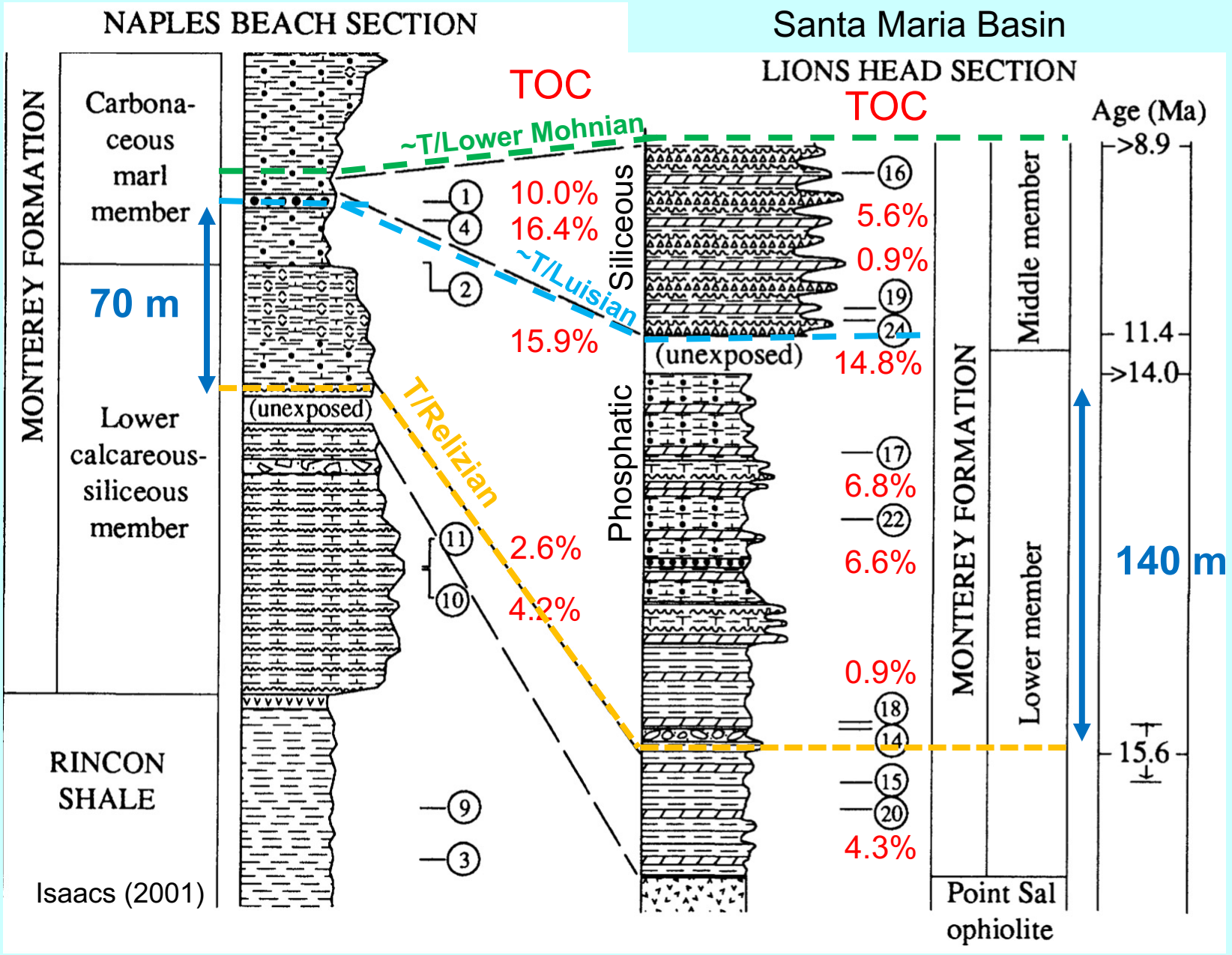
***Lower Mohnian Stage - Northern Santa Barbara Basin***



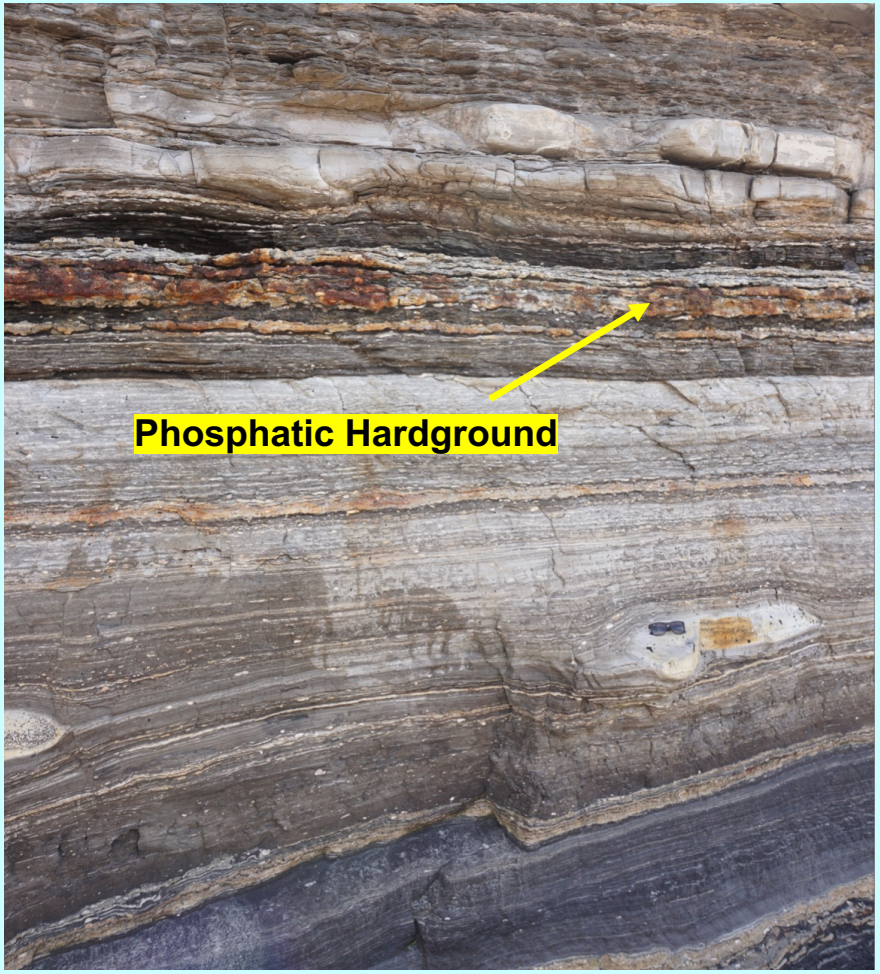

Hornafius (1991)

# Bank Top to Basin Lithologic Changes



# Middle Miocene - Monterey Lithostratigraphic Changes

**Tajiguas Beach Carbonaceous Marl**

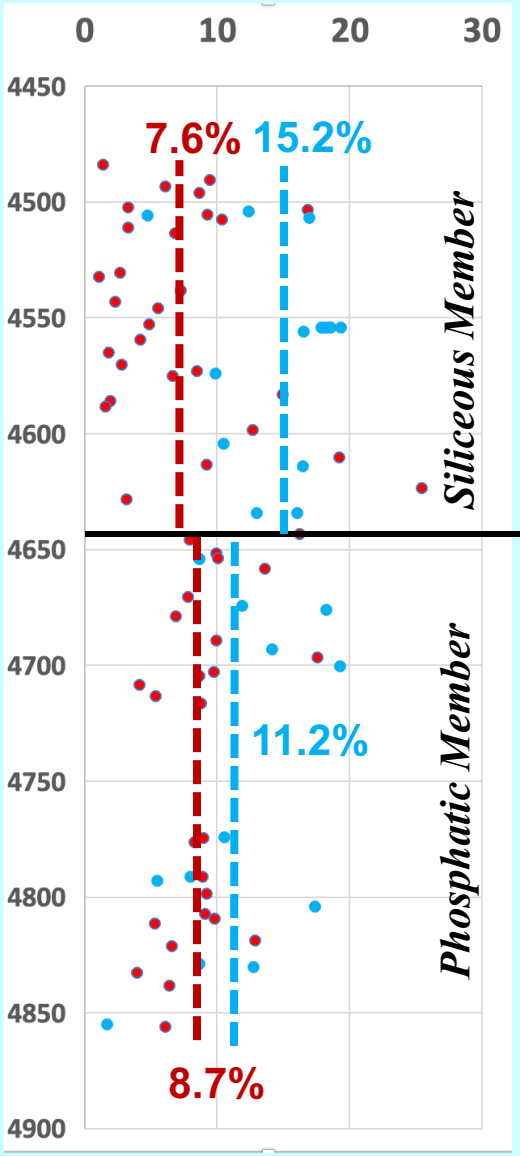



*Lower Mohnian Bank Top Deposit*

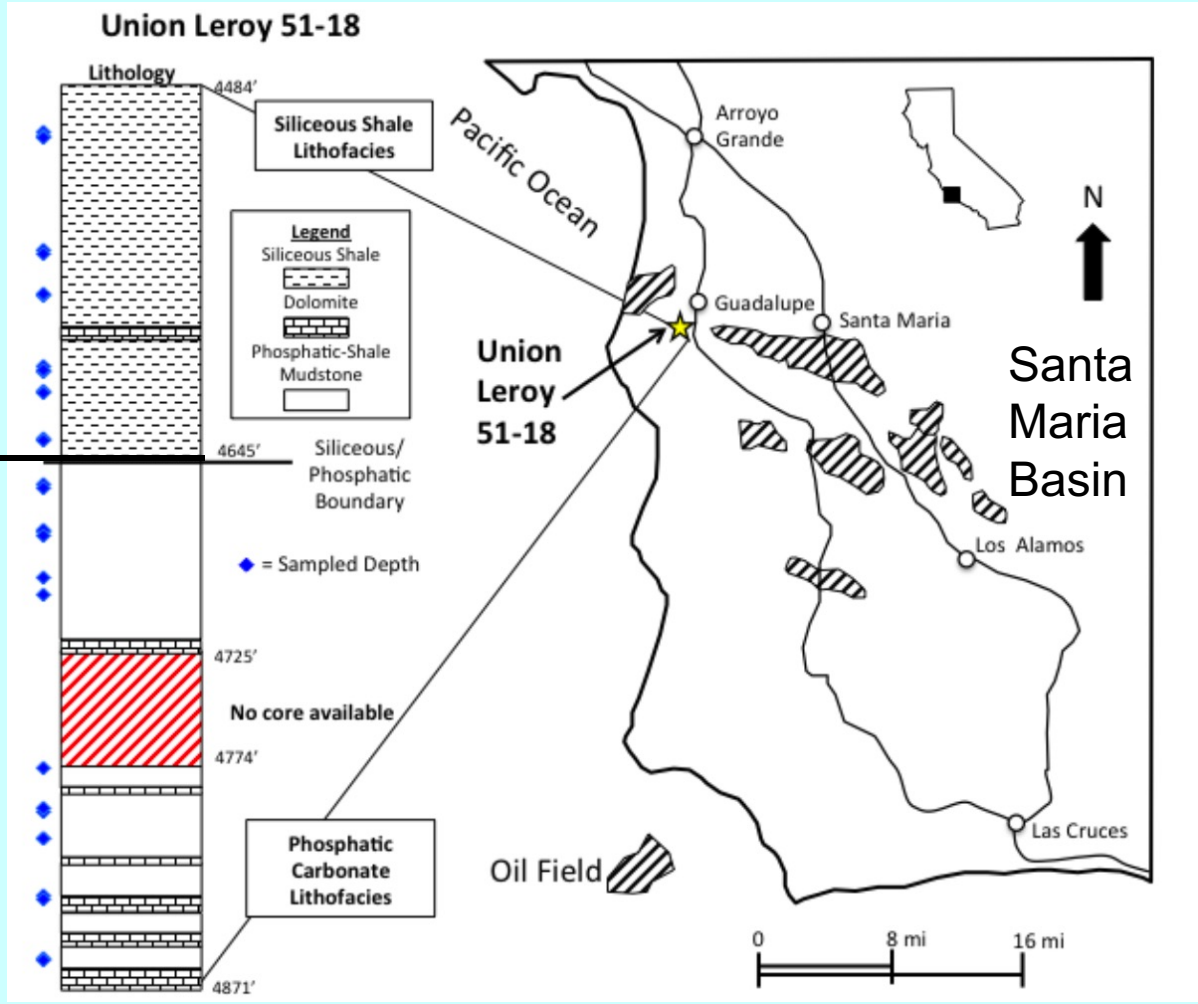
**Lion's Head Folded Black Glassy Chert**

*Lower Mohnian Basin Deposit*

# Union Leroy 51-18 Core – TOC (%)




Union Leroy core straddles phosphatic/siliceous contact

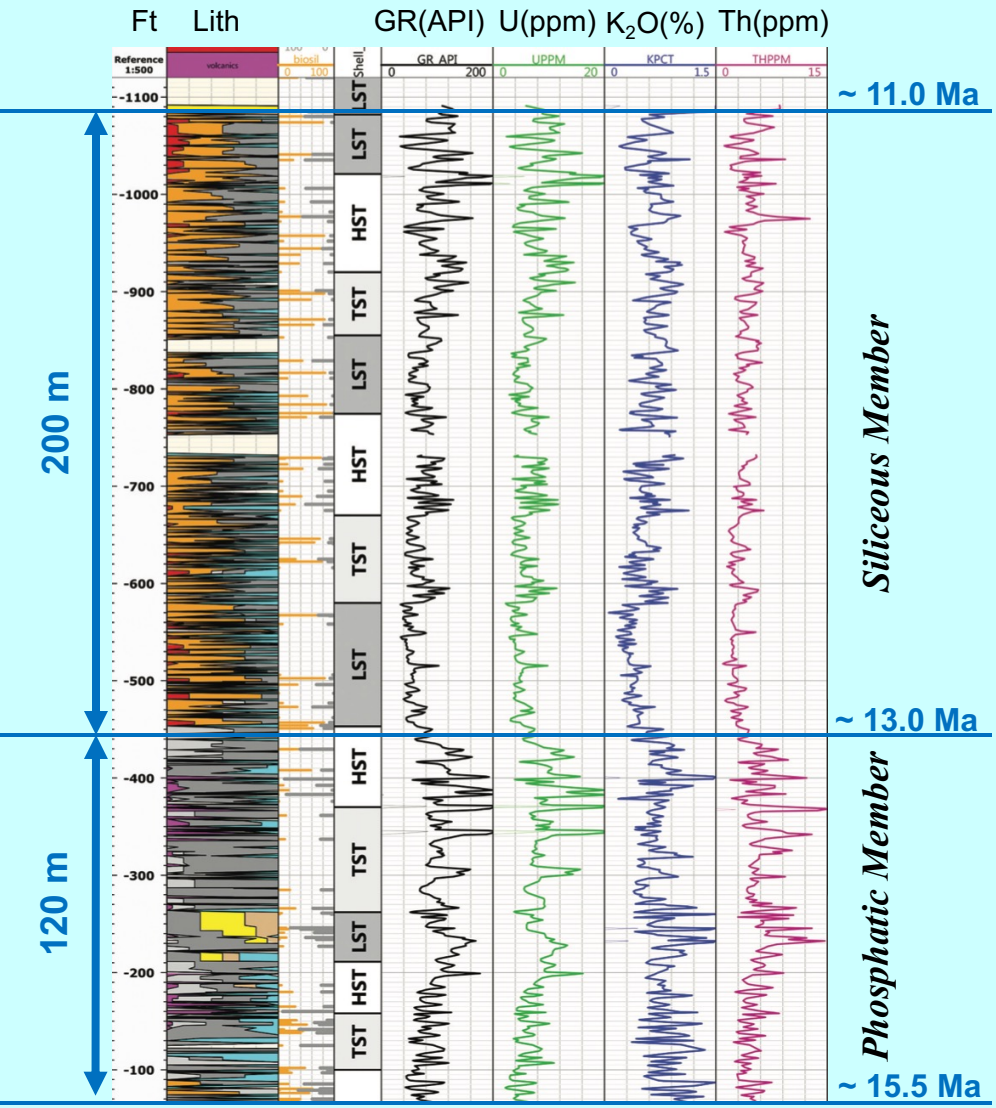



Barnette (2015) TOC values and averages in blue

Hancock (2018) TOC values and averages shown in red

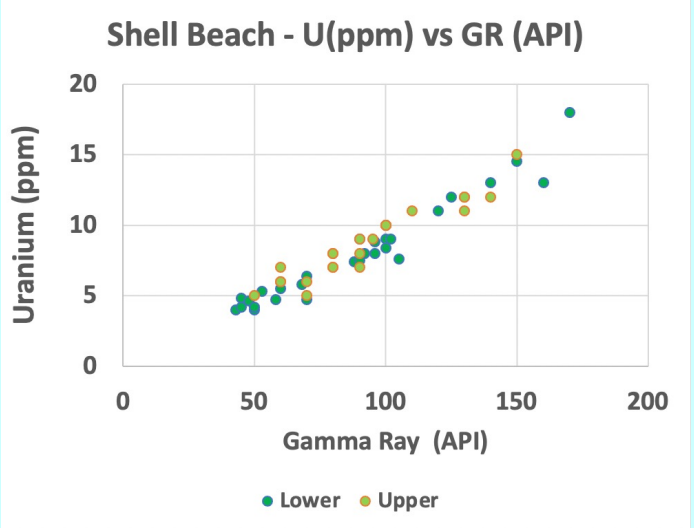
# Shell Beach – Gamma Ray Spectra-Log

$$GR(API) = 8*U(ppm) + 16*K_2O(\%) + 4*Th\ (ppm)$$

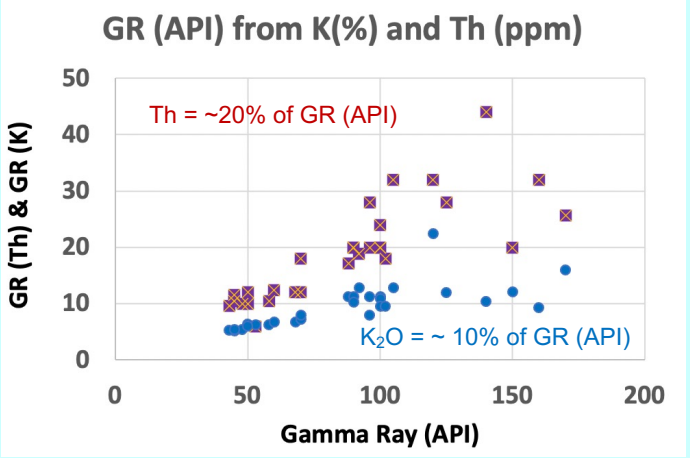



Schwalbach and Bohacs (2020)

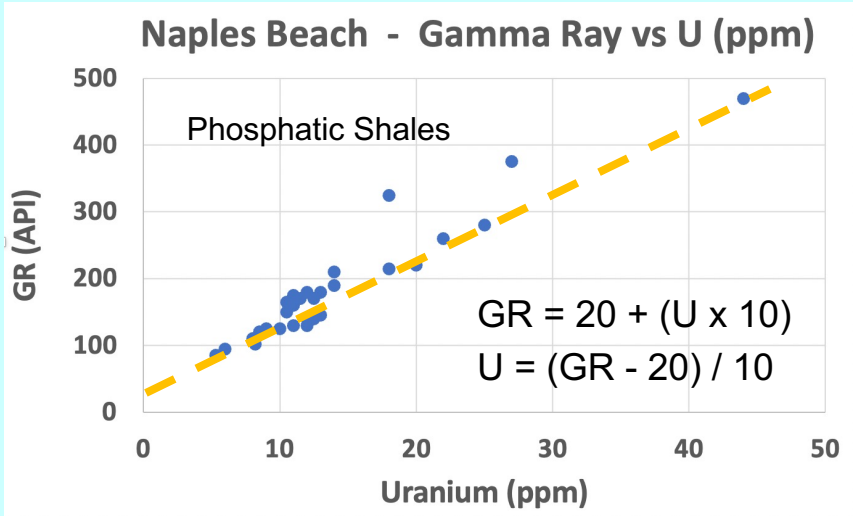
U (ppm) highly correlated to total GR (API)



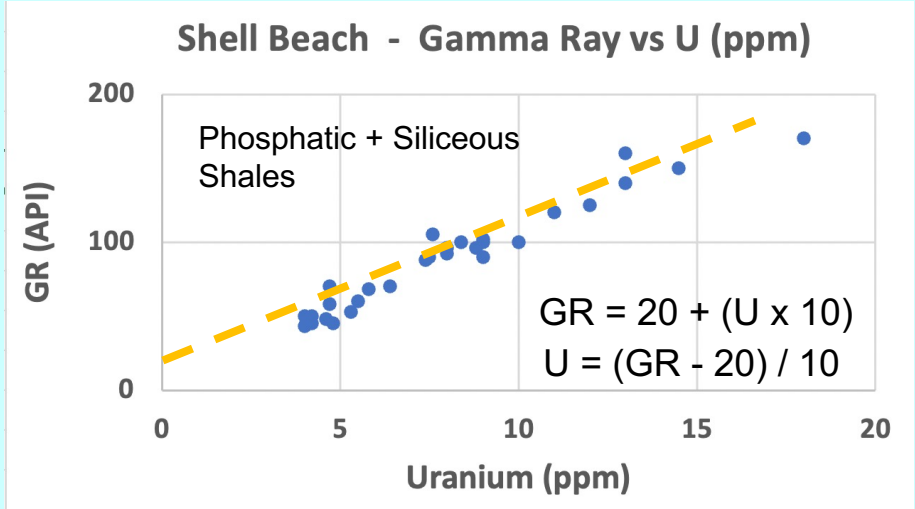

Th + $K_2O$ contribute ~30% to total GR (API)



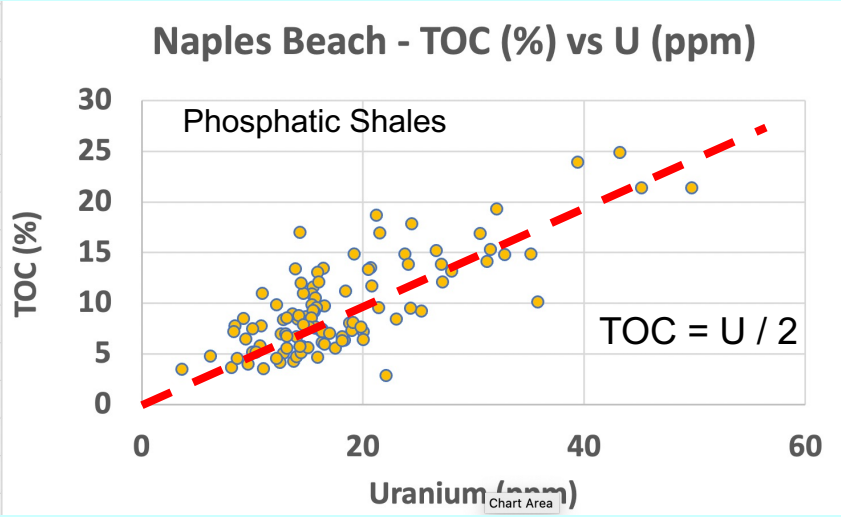
# Calculation of TOC from Gamma–Ray Logs



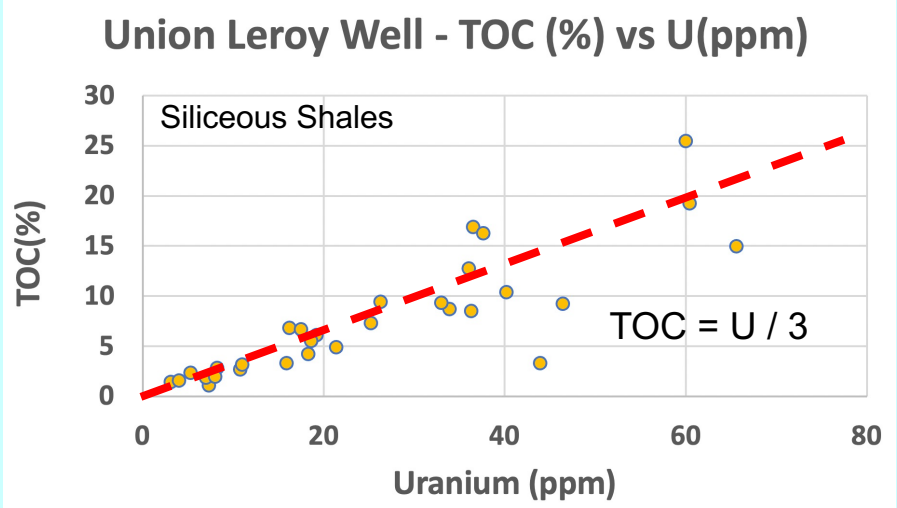

Schwalbach and Bohacs (1995)




Schwalbach and Bohacs (1995)




Hancock (2018)




Hancock (2018)

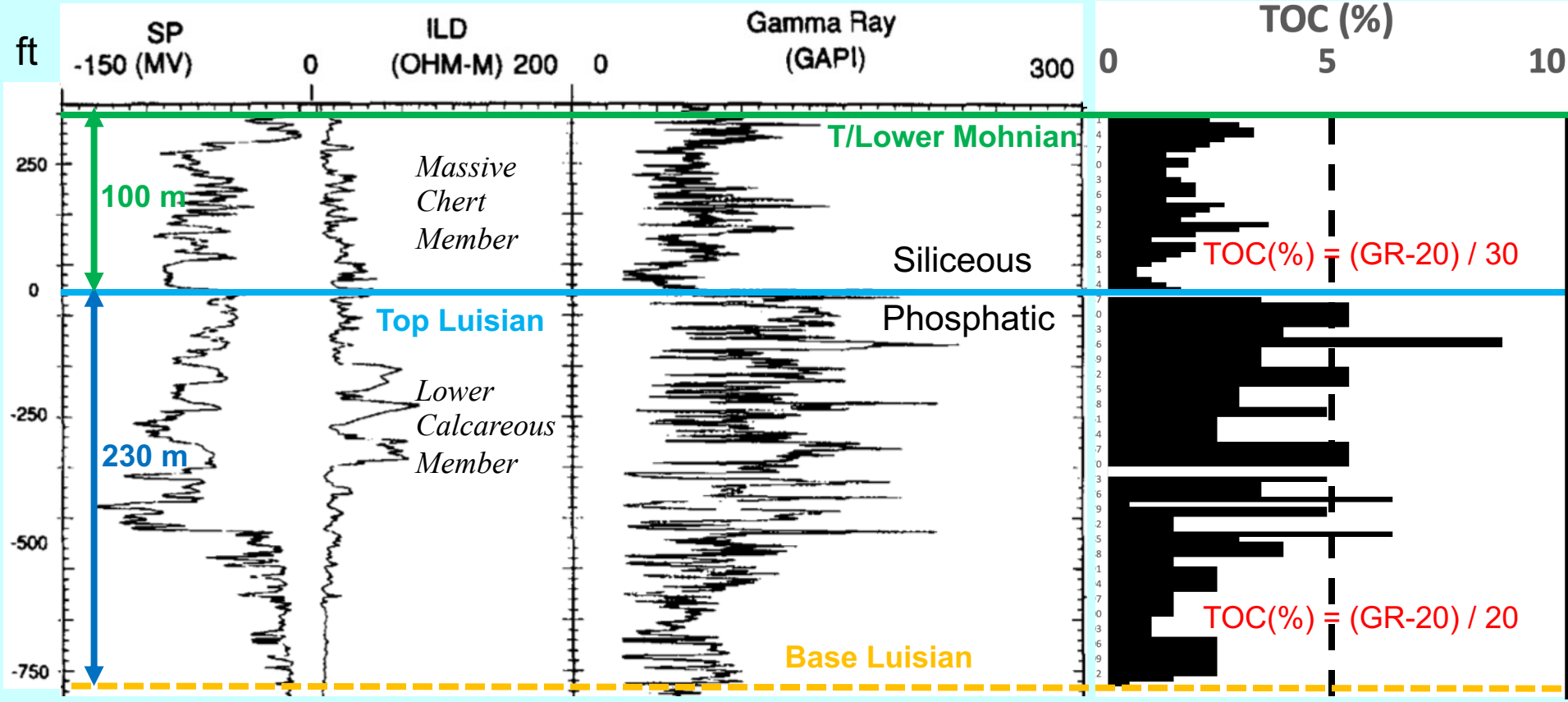
**TOC(%) = (GR-20) / 20**

**TOC(%) = (GR-20) / 30**

# Calculation of TOC from Gamma–Ray Logs

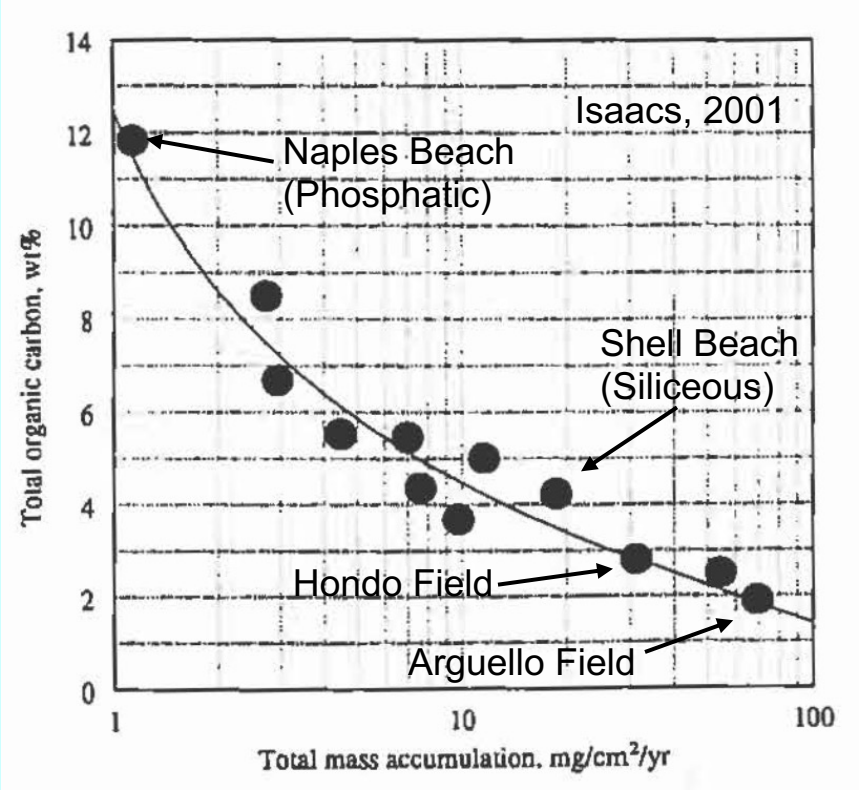
## *P-186-1 Well near the Hondo Field*

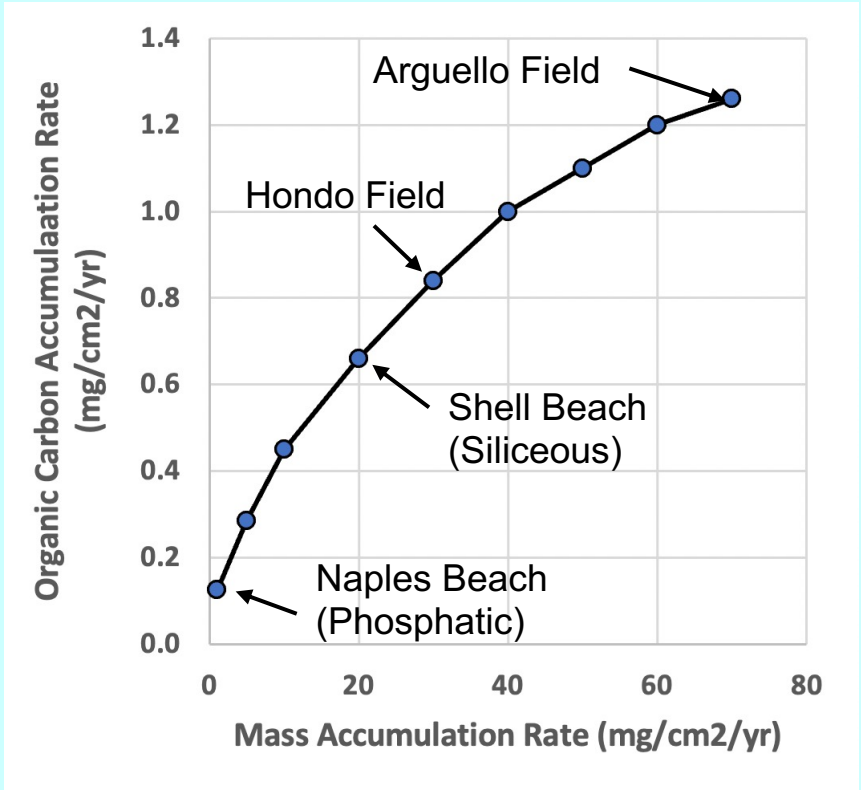
Estimated TOC Content




Hornafius (1991)

# Organic Carbon Accumulation Rate (OCAR)



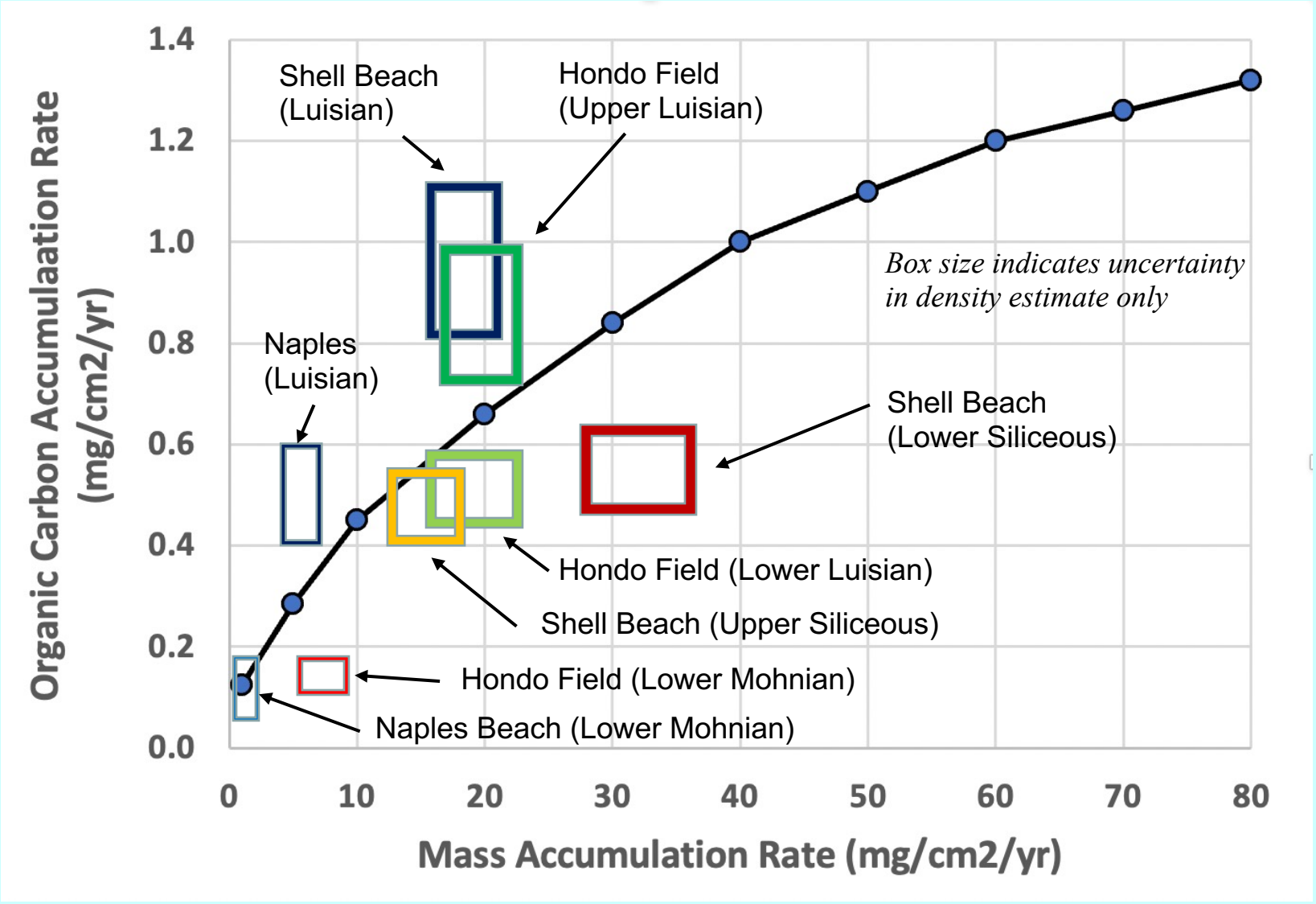

***Isaacs showed that TOC decreases with increasing mass accumulation rate (MAR)***

***Rate of decrease in TOC is slower than rate of increase in MAR (note log scale)***

***Redrawing the Isaacs plot as OCAR vs MAR shows effect of sedimentation rate***

***Areas with higher sedimentation rates have higher OCAR (=MAR x TOC)***

# Organic Carbon Accumulation Rate (OCAR)




*OCAR vs MAR curve in blue is redrawn from Isaacs (2001) using OCAR = MAR x TOC*

# Monterey Hypothesis Revisited

***Middle Miocene sedimentation rates in the deepest parts of the Santa Barbara and Santa Maria Basins were much higher than on the bank top exposures along the Santa Barbara coastline. Post-compaction sedimentation rates in the Luisian Stage (13-15.5 Ma) increase from ~30 m/m.y. at Naples Beach to ~60 m/m.y. at Lions Head and Shell Beach to ~90 m/m.y. near the Hondo Field. In the Lower Mohnian Stage (10-13 Ma) post-compaction sedimentation rates increase from <10 m/m.y. at Naples Beach to ~30 m/m.y. near the Hondo Field and to ~100 m/m.y. at Shell Beach.***

***Although the TOC content of the Monterey decreases with increasing sedimentation rate, the rate of decrease is less than the rate of increase in mass accumulation rate. As a result, the organic carbon accumulation rate (OCAR) increases with increasing mass accumulation rate (MAR). In the Luisian Stage the OCAR increases from ~0.5 mg/cm$^2$/yr at Naples Beach to twice that rate near the Hondo Field and at Shell Beach. In the Lower Mohnian Stage at Naples Beach the OCAR increases from ~0.15 mg/cm$^2$/yr to up to four times that rate at Shell Beach.***

***In order to adequately test the Monterey Hypothesis, areas where high sedimentation rates occurred in the inboard basins of California need to be studied to see if the trend towards higher OCAR with increasing MAR continues at higher sedimentation rates (e.g., in the San Joaquin Basin, the Salinas Basin, and the Los Angeles Basin).***

*References*

Barnette, C., 2015, Re-Os geochronology of the Monterey Formation, Union Leroy 51-18 well, Santa Maria Basin, California: M.S. thesis, University of Houston, Texas, 66p.

Echols, R.J., 1994, Biostratigraphy of the Luisian and Mohnian Stages between Santa Barbara and Gaviota, California, in Field Guide to the Monterey Formation between Santa Barbara and Gaviota, California; Pacific Section AAPG, v. GB72, p. 1-16.

Follmi, K.B., et al., 2005, Phosphogenesis and organic-carbon preservation in the Miocene Monterey Formation at Naples Beach, California – The Monterey hypothesis revisited; Geological Society of America Bulletin, v. 117, p. 589-619.

Hancock, L.G., 2018, Proxy applications for reconstructing carbon and sulfur cycling in ancient marine environments: Ph.D. dissertation, University of California, Riverside, 228 p.

Hornafius, J.S., 1991, Facies analysis of the Monterey Formation in the northern Santa Barbara Channel; AAPG Bulletin, v.75, p.894-909.

Hornafius, J.S., 1994a, Overview of the stratigraphy of the Monterey Formation along the coastline between Santa Barbara and Gaviota, California, in Field Guide to the Monterey Formation between Santa Barbara and Gaviota, California; Pacific Section AAPG, v. GB72, p. 1-16.

Hornafius, J.S., 1994b, Correlation of volcanic ashes in the Monterey Formation between Naples Beach and Gaviota Beach, California, in Field Guide to the Monterey Formation between Santa Barbara and Gaviota, California; Pacific Section AAPG, v. GB72, p. 45-58.

Isaacs, C.M., 2001, Depositional Framework of the Monterey Formation, California, in Isaacs, C.M. and Rullkotter, J., eds.; The Monterey Formation – From Rocks to Molecules, Columbia University Press, New York, NY, p.1-30.

John, C.M., et al., 2002, Carbonaceous and phosphate-rich sediments of the Miocene Monterey Formation at El Capitan State Beach, California, U.S.A.; Journal of Sedimentary Research., v. 72, no. 2, p. 252-267.

Knott, J.R., et al., 2022, Tephrochronology of the Miocene Monterey and Modelo Formations, California; Geological Society of America Special Paper 556, p. 187-214.

Schwalbach, J.R., and Bohacs, K.M., 1995, Stratigraphic sections and gamma-ray spectrometry from five outcrops of the Monterey Formation in southwestern California: Naples Beach, Point Pedernales, Lion's Head, Shell Beach, and Point Buchon: United States Geological Survey Bulletin 1995-Q, Q1-39.

Schwalbach, J.R., and Bohacs, K.M., 2020, The Monterey Formation at Shell Beach, California, in Outcrops that change the way we practice petroleum geology; Pacific Section AAPG Guidebook #81.