Sedimentologic and Paleoceanographic Controls of Anoxia in the Holocene Cariaco Basin (Venezuela): Implications for Control of Deposition of Cretaceous (Eagle Ford) and Jurassic (Haynesville) Source Rocks in Texas*

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Search and Discovery Article #51340 (2016)**
Posted December 26, 2016

*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016
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Abstract

The recent worldwide unconventional shale oil and gas boom raises questions about controls on the deposition of organic-rich, fine-grained rocks. Environmental and depositional factors such as upwelling, nutrient supply, preservation, and paleo-oxygenation ultimately contribute to the organic richness and hydrocarbon potential of the source rock. In fine-grained rocks such as mudstones, geochemical investigations have proved useful in identifying productive source intervals for unconventional plays. Most studies on Paleozoic and Mesozoic producing source rocks compare redox-sensitive metals and major elements, TOC, isotopes, and mineralogy to identify sweet spots and probable producing zones. Geochemical and sedimentological studies of modern anoxic basins offer analogues for ancient basins and have the potential to elucidate answers to long-standing questions. However, a direct comparison of a Quaternary anoxic basin (e.g., the Cariaco Basin, offshore Venezuela) to Mesozoic source rocks, such as the Upper Jurassic Haynesville and Upper Cretaceous Eagle Ford Formations of Texas, has not been conducted to date. For this study, we selected three complete slabbed cores from the ODP Site 1002 - Cariaco Basin - and described them for sedimentological structures, facies types, pore types, permeability, grain size, fauna, mineralogy, and ichnofacies. Geochemical analyses in addition to present analyses include major and minor elements indicative for anoxic and euxinic conditions, TOC, and isotopes. The Cariaco Basin and the Eagle Ford and Haynesville cores exhibit similar features, such as alternating layers of organic-rich, laminated marls and planktonic-foram-rich limestones. These alternating deposits exhibit distinct geochemical and sedimentologic signatures probably related to sea-level fluctuations, upwelling, and detrital sediment supply. Characterizing recent mudrocks with detailed controls of water and sediment geochemistry, oceanographic changes, age, and nutrient and sediment flux provide in-depth information for controls on Mesozoic source rocks.

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Sedimentologic and paleoceanographic controls of anoxia in the Holocene Cariaco Basin (Venezuela): implications for control of deposition of Cretaceous (Eagle Ford) and Jurassic (Haynesville) source rocks in Texas

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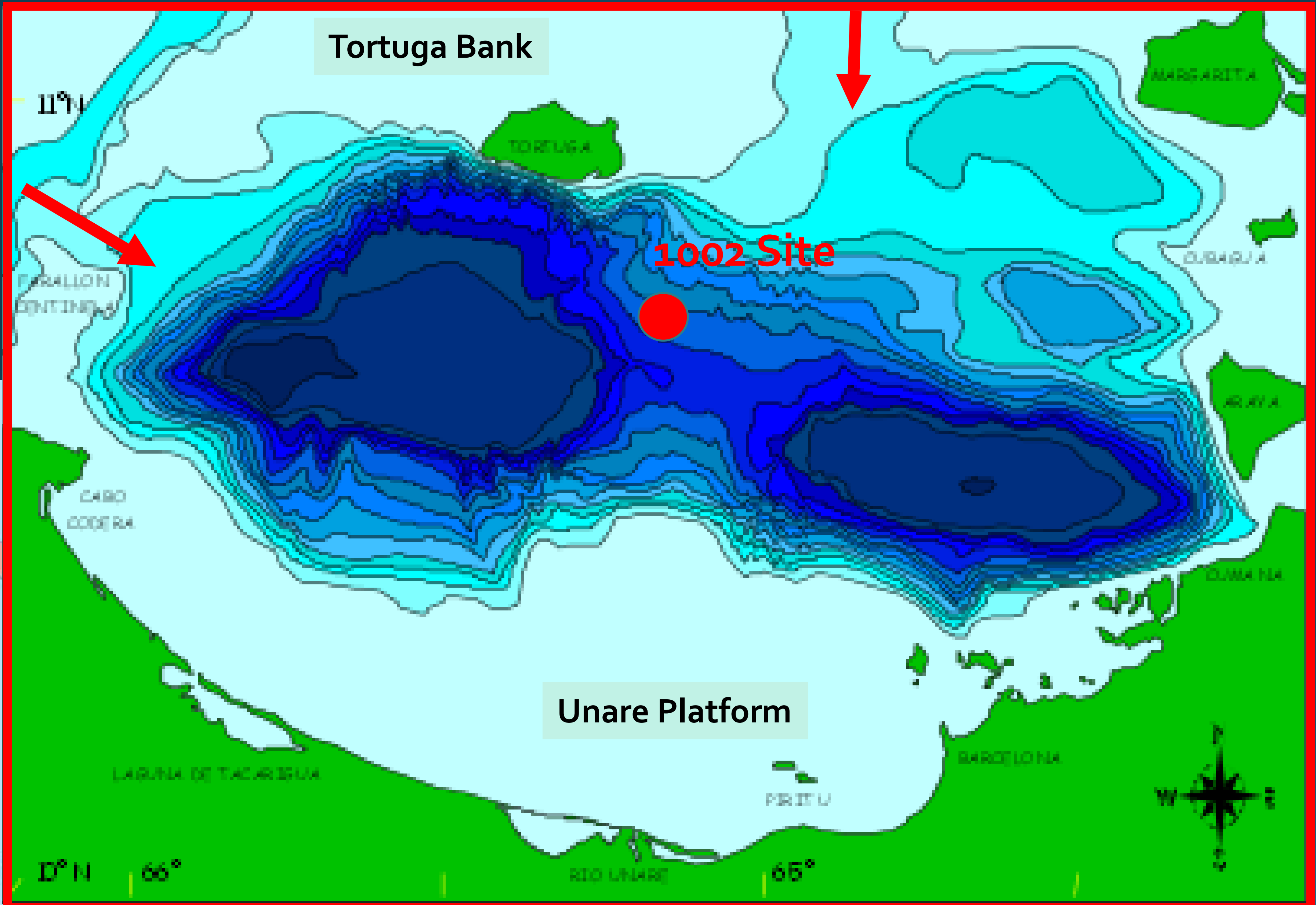
Objectives

- Modern analog to Texas shale basins
- What are controls of geochemical and mineralogical variations, organic matter accumulation, sedimentation rates, bioturbation, sedimentary structures?
- Evolution of pore types and permeability, organic matter, and diagenetic features?

Geologic Setting

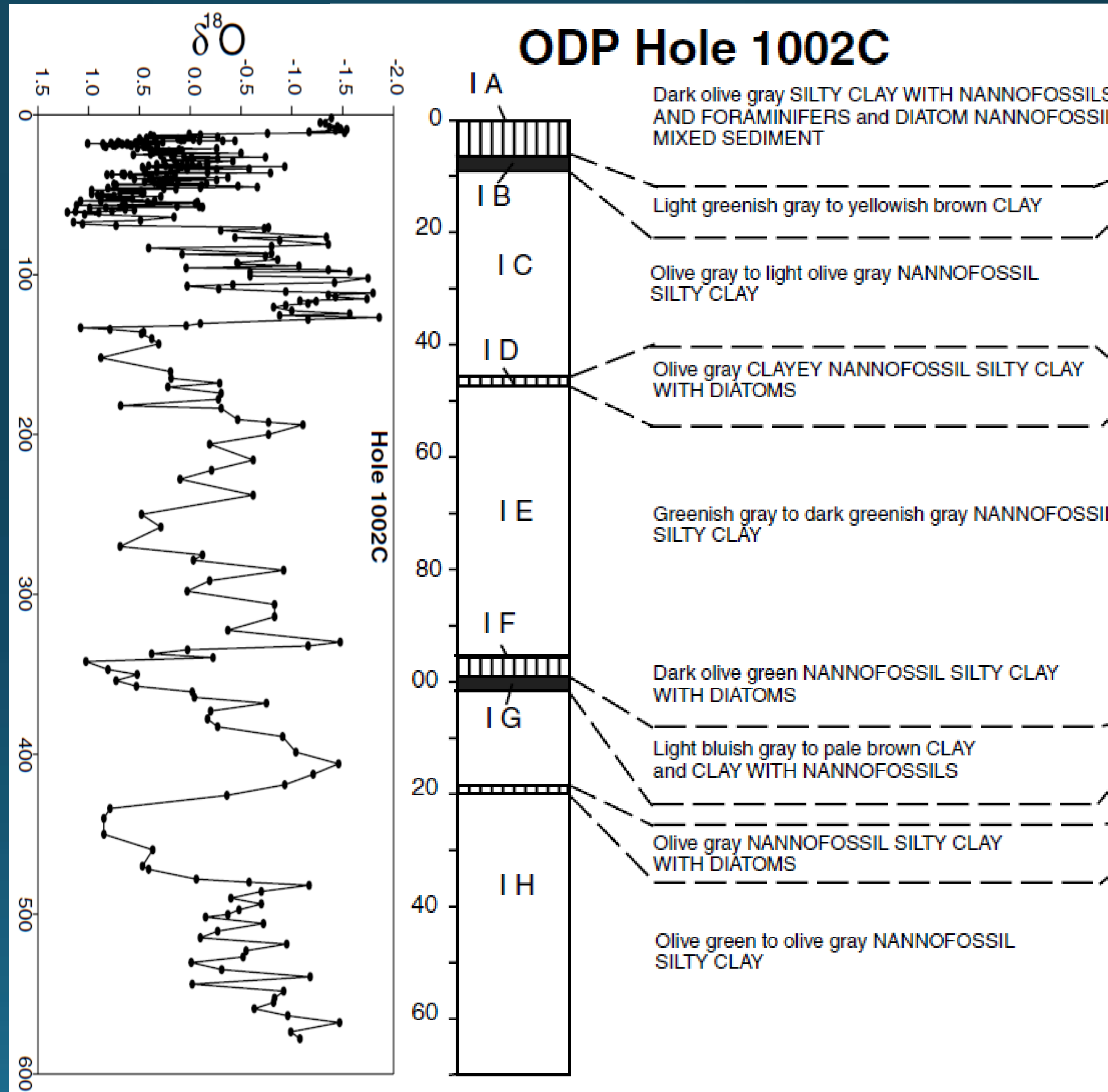
- Off-shore Venezuela
- Quaternary pull-apart basin
- Silled, anoxic basin

Geologic Setting



Stratigraphy

- Quaternary Basin
- Core spans 0 – 540,000 years (0-170 m)



From Peterson et al. (2000)

Why Cariaco basin?

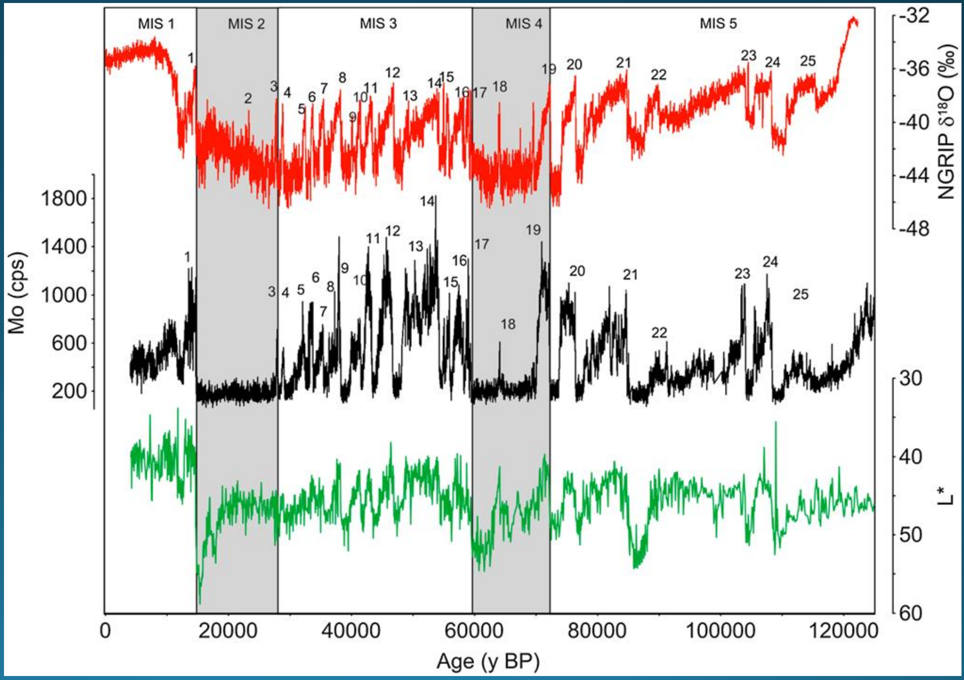
- 2nd- largest anoxic basin in the world
- Anoxia >250 meter water depth
- Varved sediments
- High-resolution paleoceanographic reconstructions
- Core have not been examined using modern techniques examining shale resource plays

Controls on alternating laminated/bioturbated sediments?

Data

- 5 cores from drill site 1002
- Vast geochemical, paleogeographic and paleontologic records
  - Minor, major elements
  - Isotope analyses
  - TOC
  - Age dating
  - Interpretation and documentation of sea-level fluctuation
  - Ecosystems
  - Upwelling history

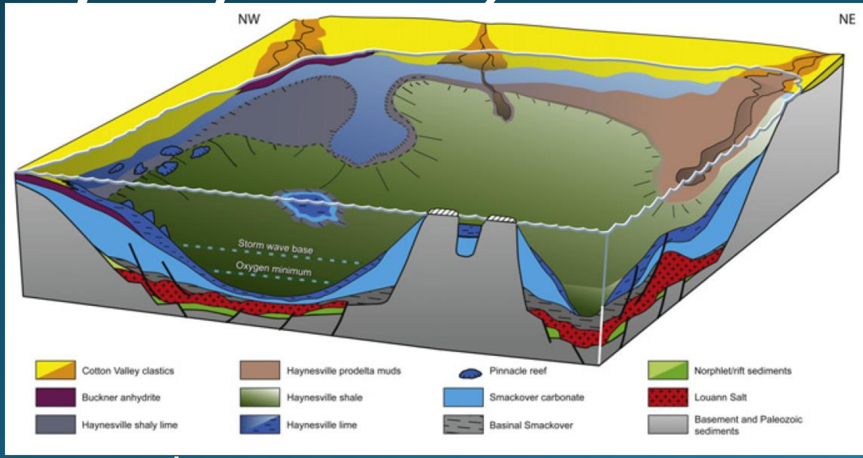
e.g., Gibson and Peterson (2014)

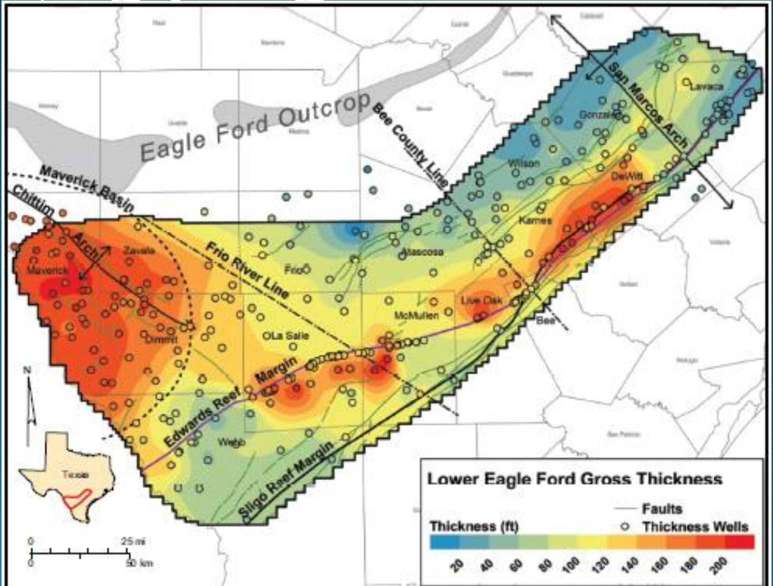


ANALOG TO SHALE-GAS/OIL BASINS

This study:

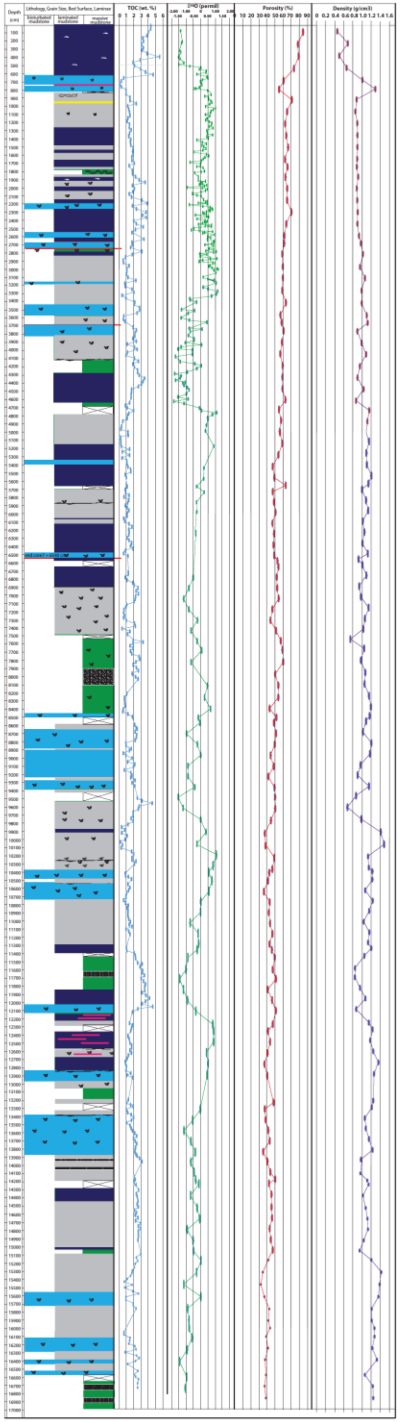
- Detailed sedimentologic and facies core descriptions
- Ar-ion milled SEM samples of porosity, diagenesis, mineralogy, facies types, and biochemical constituents
- Analog to shale basins in Texas (e.g., Eagle Ford, Haynesville)





(Hammes et al., 2011, 2016)

Core IODP Leg 165, Site 1002C: 0-170m



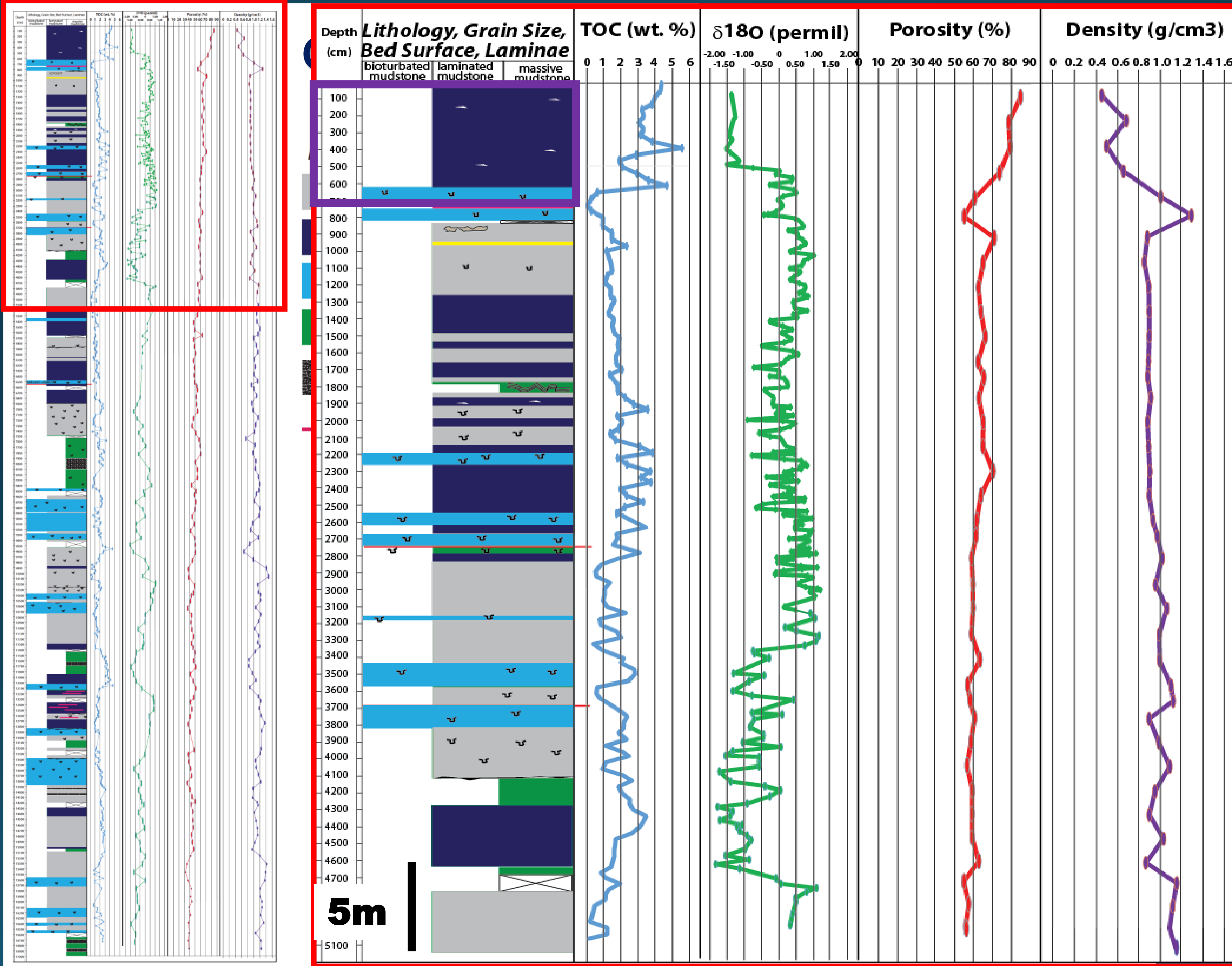
LEGEND

FACIES:

- weakly laminated mudstone (nano-fossil ooze)
- thinly (mm) laminated mudstone (organic-rich)
- bioturbated mudstone
- massive mudstone (nano-fossil ooze)
- massive, drilling disturbed core
  slight laminations and white cements
- turbidite (clay or fine-grained sand/silt)
- missing core

SEDIMENTARY STRUCTURES, FOSSILS:

- burrows
- burrow filled with sand (?turbidite?)
- pteropods and shells
- pyrite
- wood fragments
- cross bedding
- slump feature
- sharp surface



Depth (cm)
Lithology, Grain Size, Bed Surface, Laminae
bioturbated mudstone
laminated mudstone
massive mudstone
TOC (wt. %)
δ18O (permil)
Porosity (%)
Density (g/cm3)
0 1 2 3 4 5 6
-2.00 -1.00 0 1.00 2.00
-1.50 -0.50 0.50 1.50
0 10 20 30 40 50 60 70 80 90
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
100
200
300
400
500
600
800
900
1000
1100
1200
1300
1400
1500
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1700
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3200
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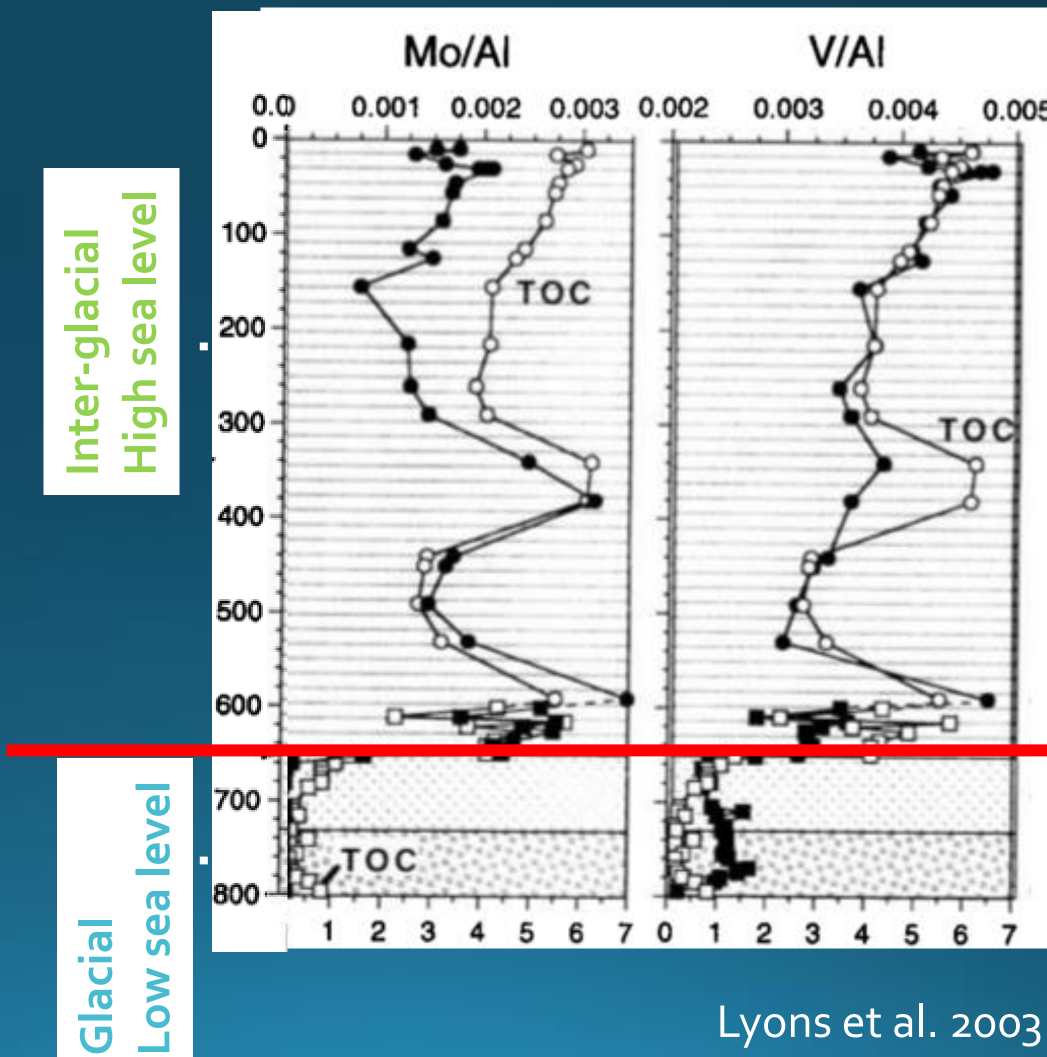
3400
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700
5100
5m

Anoxic Sediments

First 8 meters of sediment below sea bottom:
- anoxic (dark) – oxic (light)

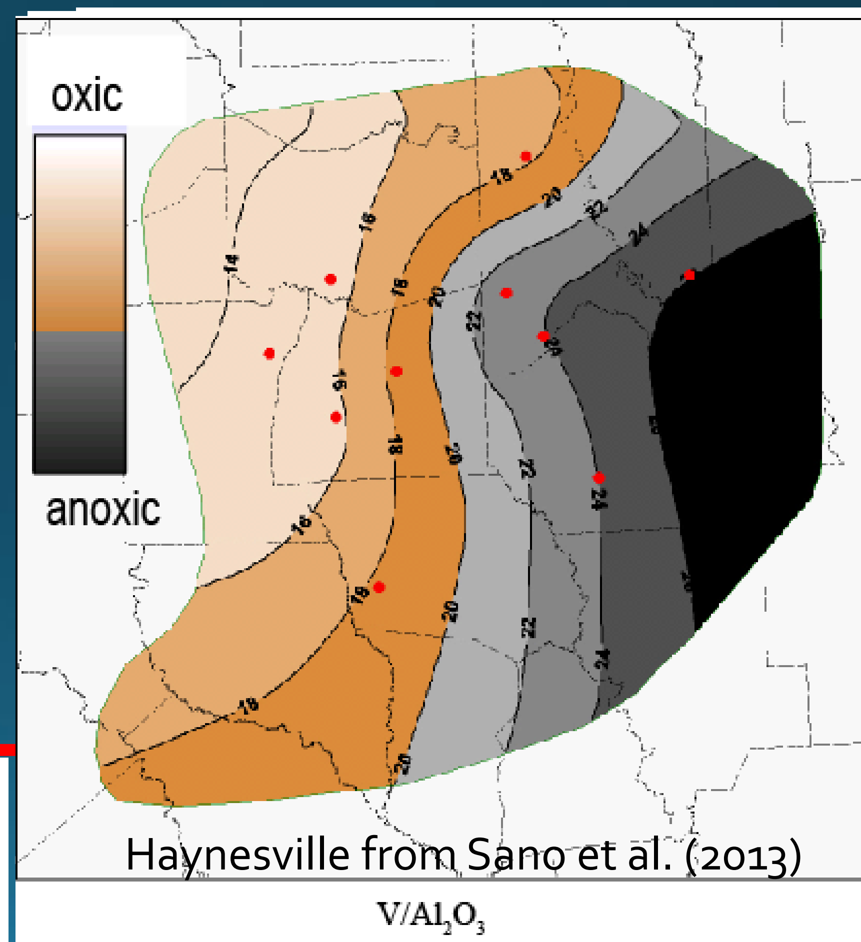


Lyons et al. 2003

Anoxic Sediments

First 8 meters of sediment below sea bottom:
- anoxic (dark) – oxic (light)

Inter-glacial
High sea level

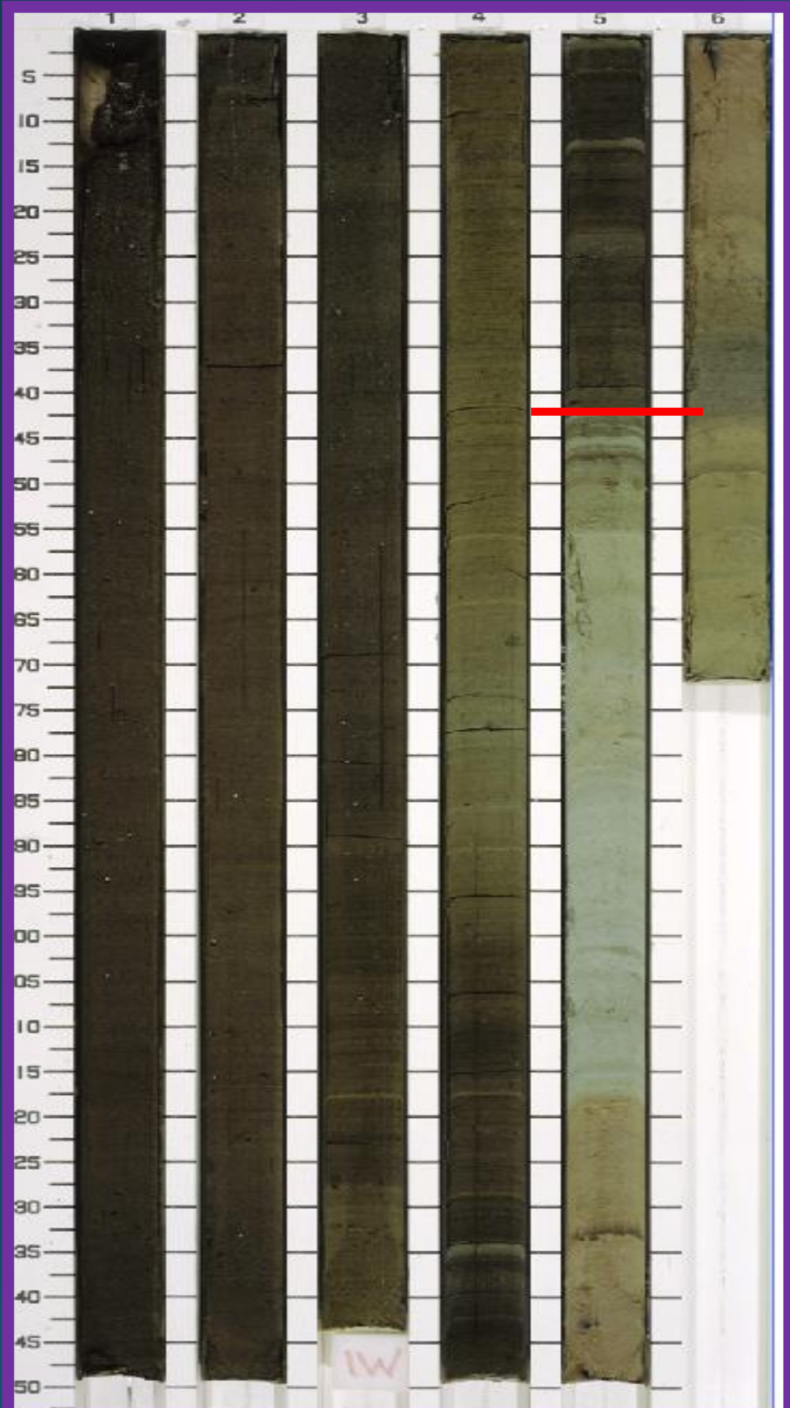


Glacial
Low sea level

Lyons et al. 2003

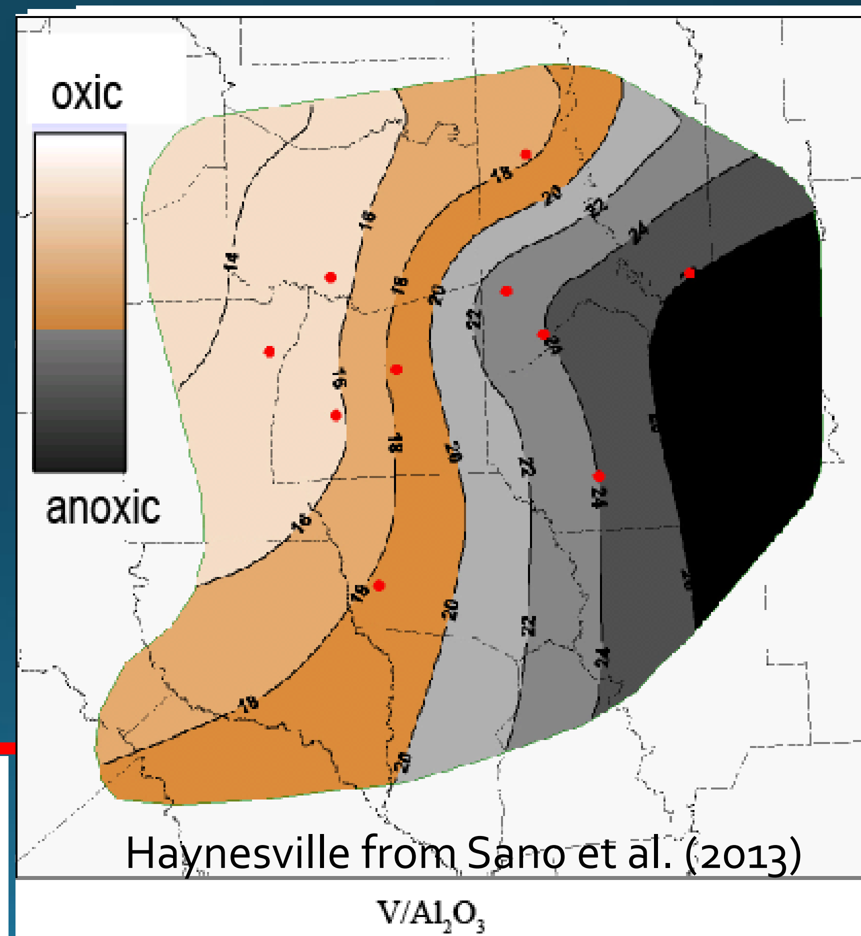
Anoxic Sediments

First 8 meters of sediment below sea bottom:
- anoxic (dark) – oxic (light)

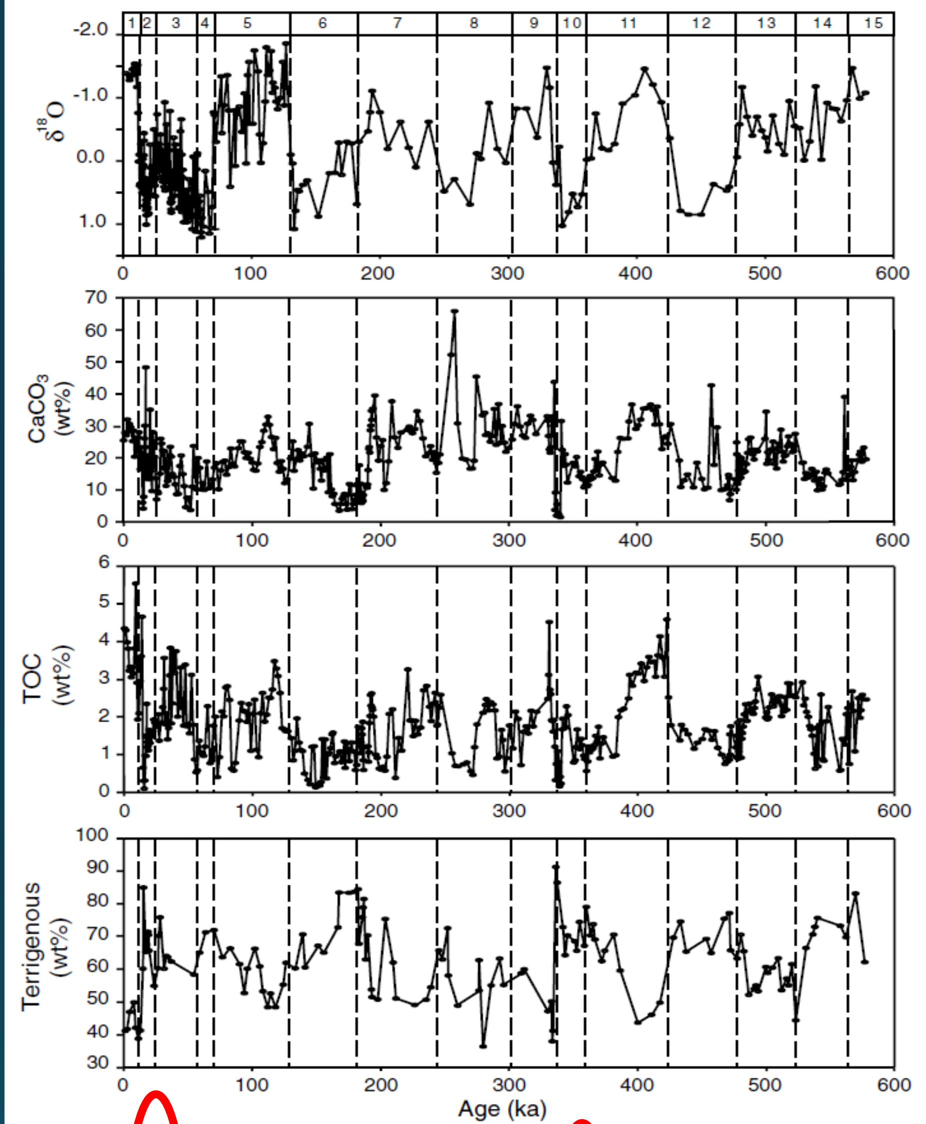


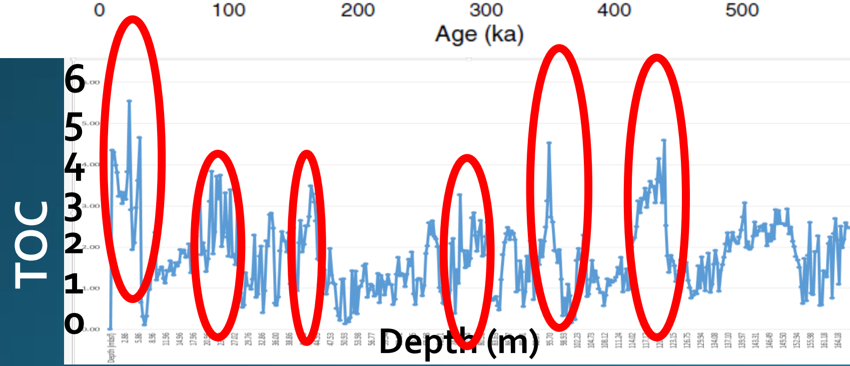
Inter-glacial
High sea level

Glacial
Low sea level



Lyons et al. 2003





Climate proxies

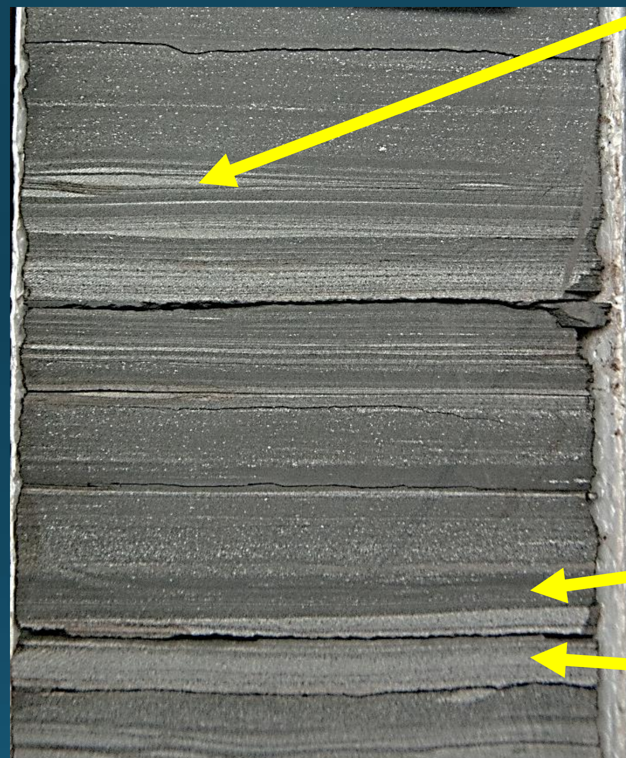
- Geochemical profiles of
  - δ18O variations
  - carbonate,
  - TOC,
  - terrigenous fraction,
  - (from Peterson et al., 2000)
- by age and
- TOC by depth

Sedimentology + Facies

- Laminae
- Layering
- Cross bedding
- Bioturbation
- Turbidites

- Finely laminated organic-rich mudstone
- Weakly laminated mudstone (organic poor)
- Bioturbated mudstone (organic-poor)
- Planktic tests wacke-/packstones
- Massive mudstone
- Turbidites

Laminations and bioturbation (e.g., Eagle Ford)



What are the causes of these layers?

- Light laminae contain planktonic forams (diatoms)
- Indicator of productivity during winter-spring upwelling season

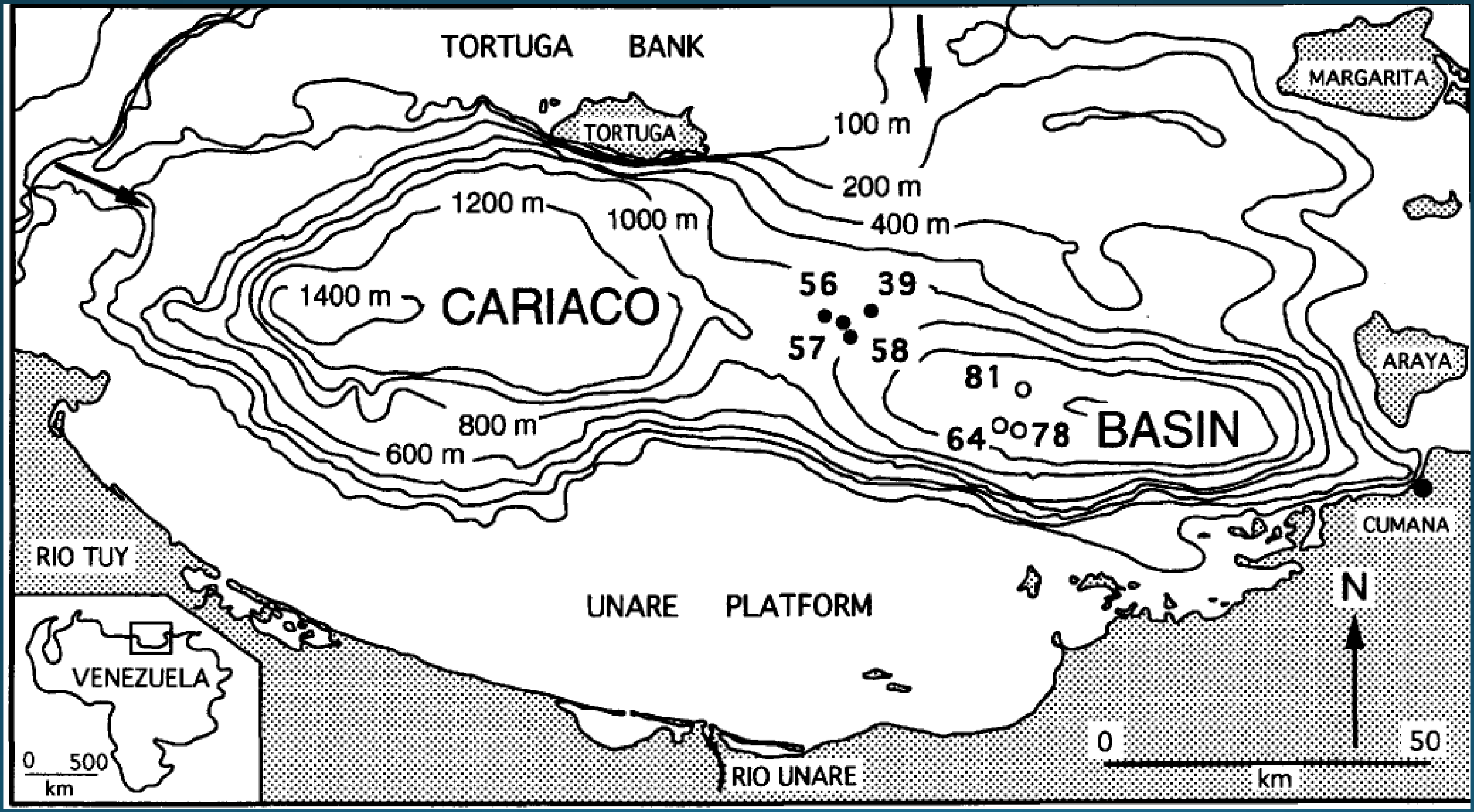
- Dark laminae contain terrigenous mineral grains indicating runoff from northern South America during late summer-fall rainy season

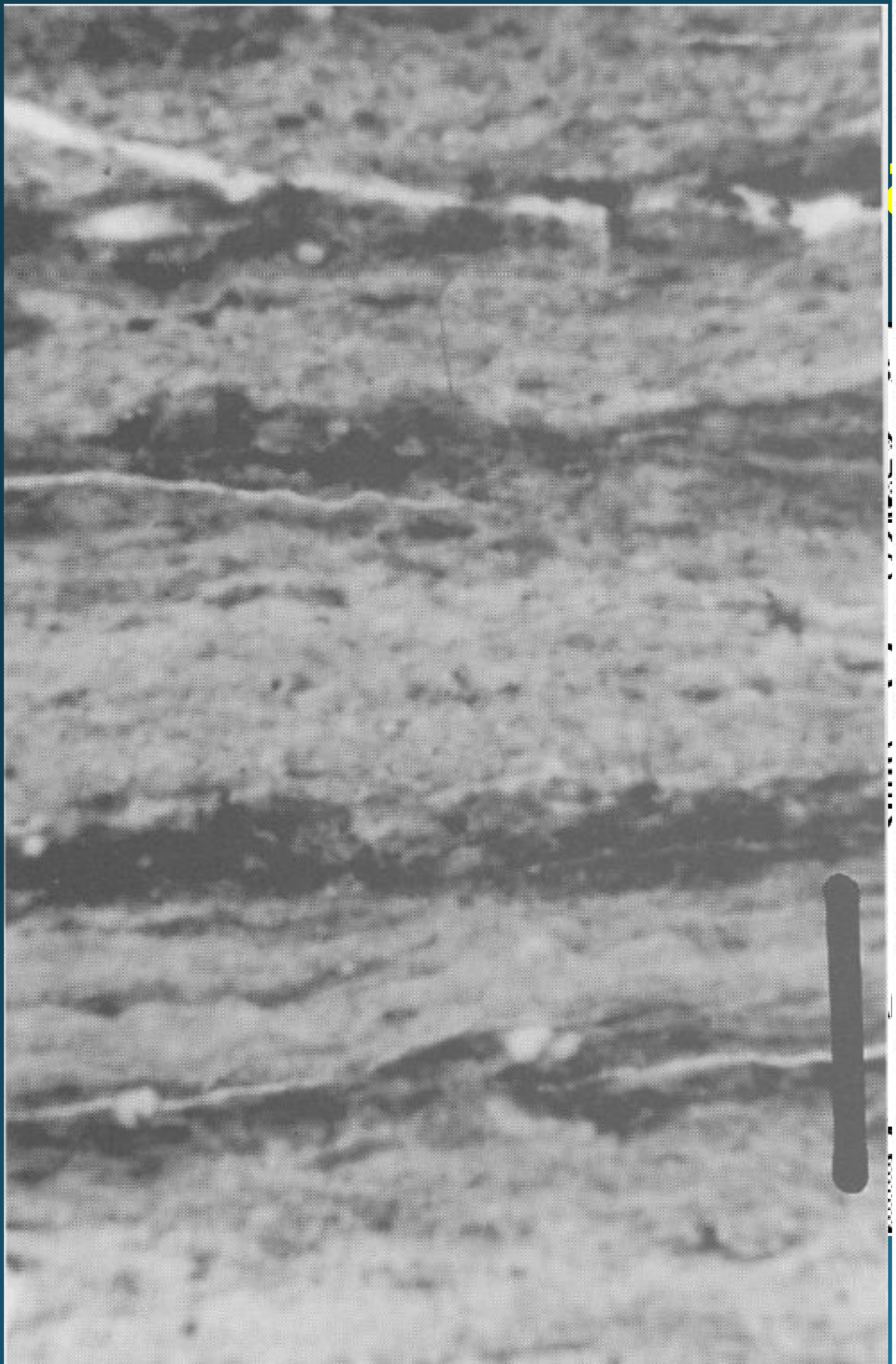
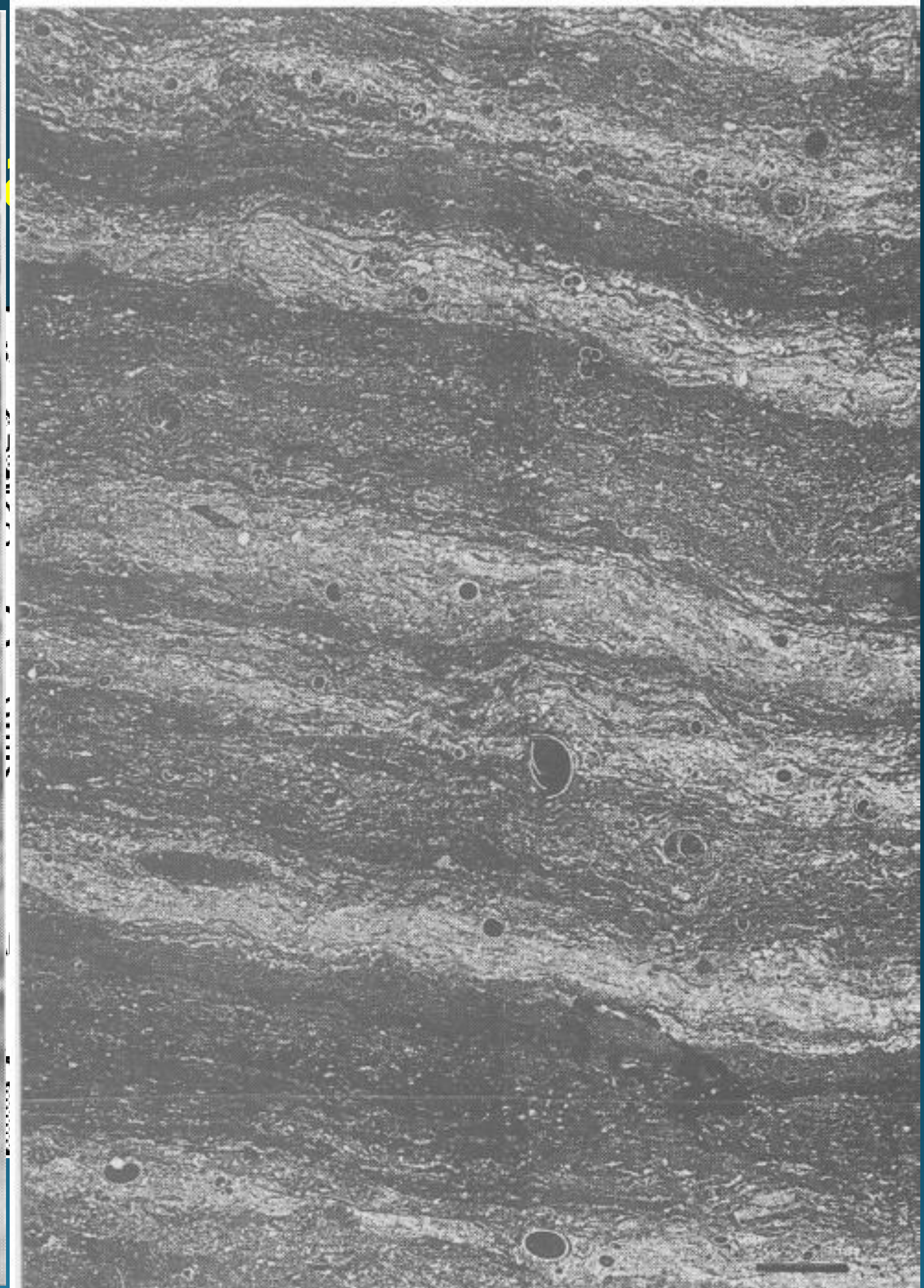
Source: Hughen et al., 1996

Origin of laminations

- Varve-like laminations due to interannual to millennial-scale climatic changes (e.g., Hughen et al., 1996)

Origin of laminations

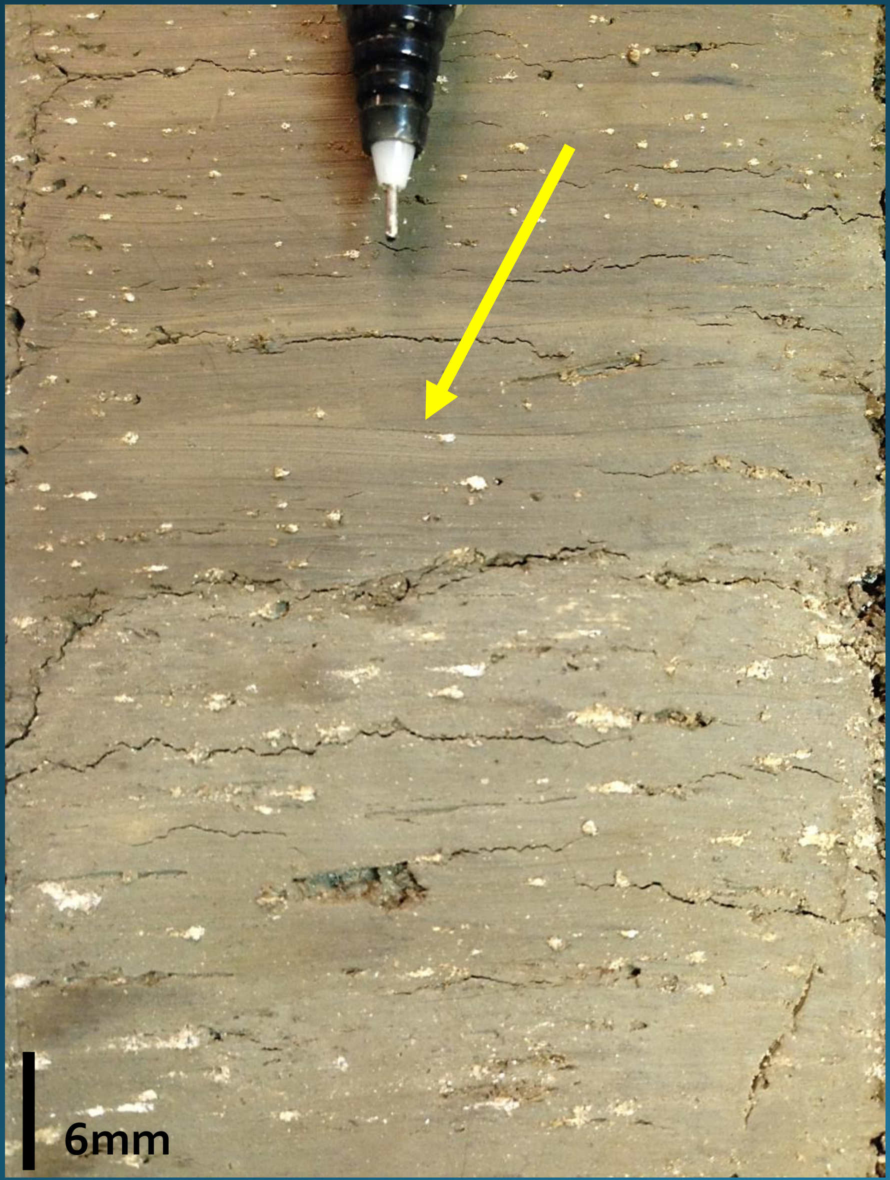


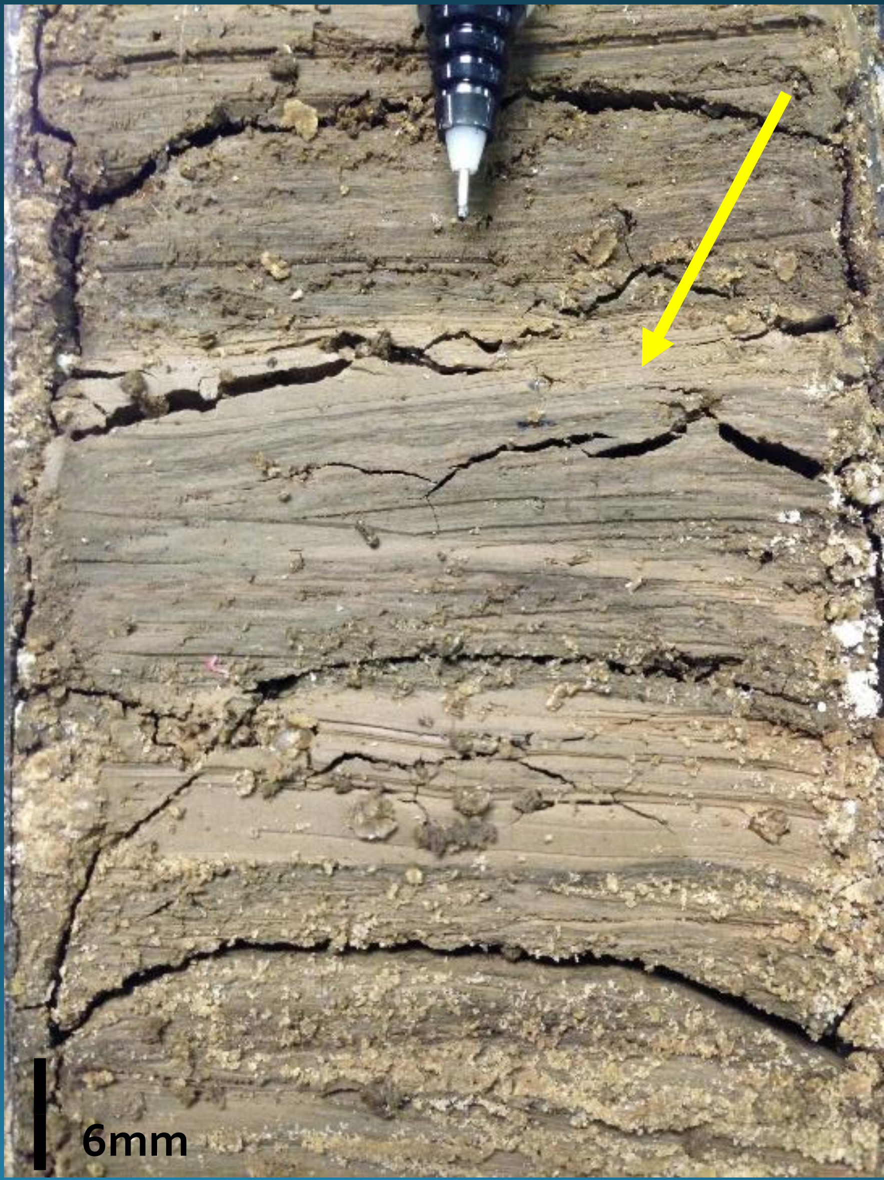



Click to view video

Compaction… 90%

Cross bedding





Origin of cross bedding and ripples

- Bottom currents
- Contourites
- During glacial periods where lower sea level produces stronger circulation (e.g., Robinson et al., 2007)

Bioturbation

Origin of bioturbation

- Bioturbation under oxic conditions during glacial times
- Low total organic carbon
- e.g., Haug et al. (1998)

Turbidites

clay

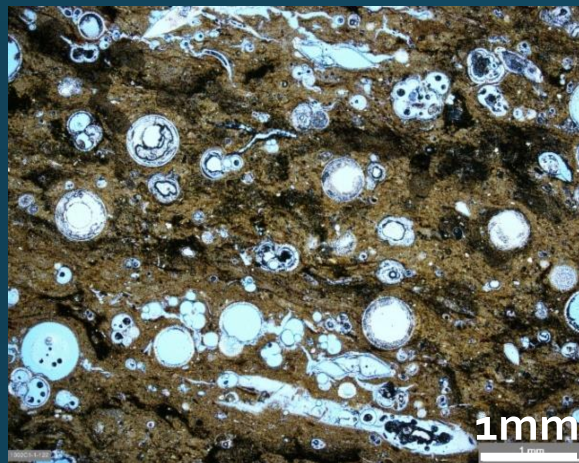
organic-rich layer

clay

Facies

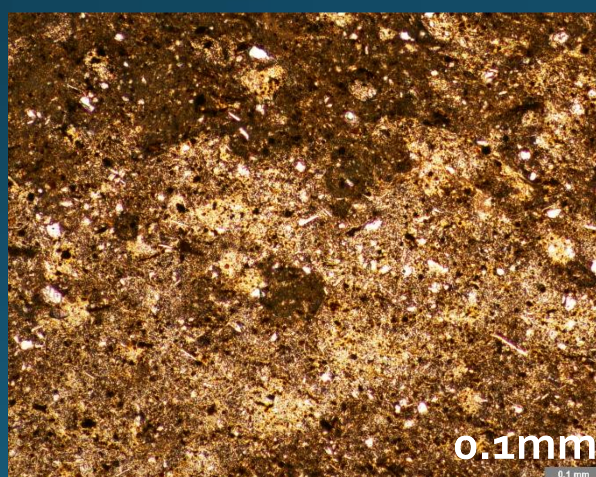
Cariaco Basin | Mesozoic Shale Basin

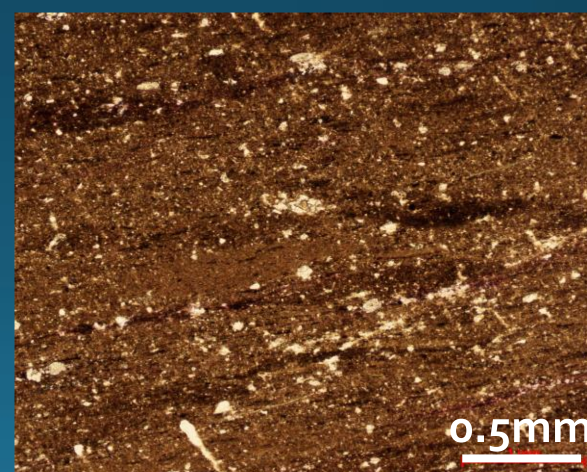
Planktonic foram packstone



Eagle Ford, Denne et al. (2014)

Bioturbated mudstone



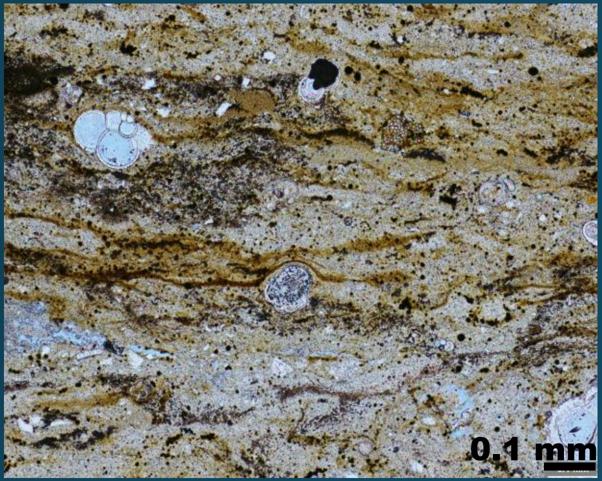


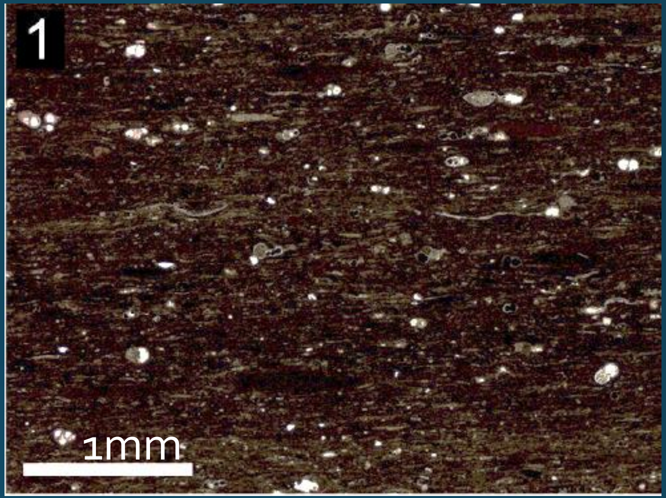
Haynesville, Hammes et al. (2011)

Facies

Cariaco Basin — Mesozoic Shale Basin

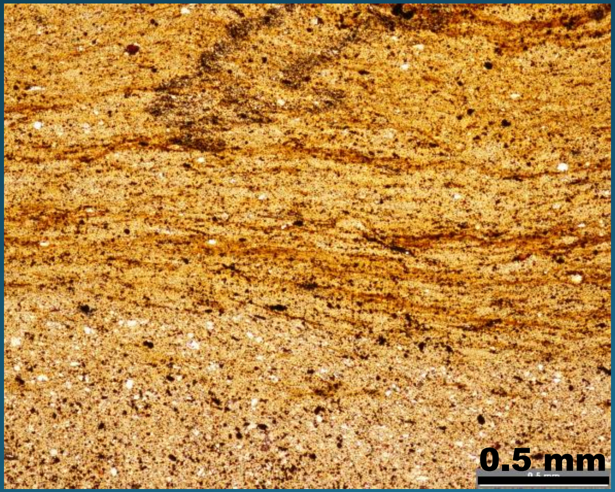
Planktonic foram mudstone

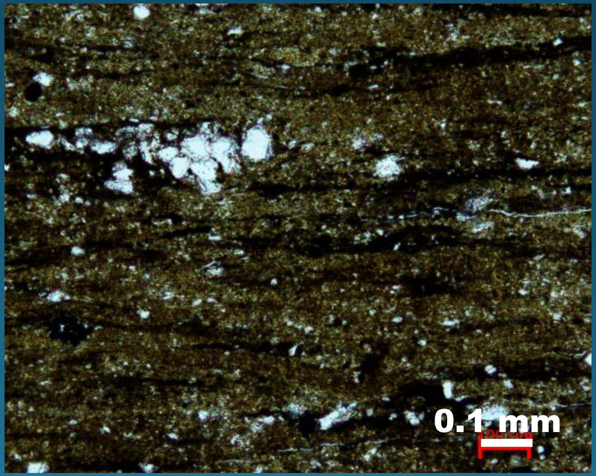




Eagle Ford, Denne et al. (2014)

Laminated mudstone



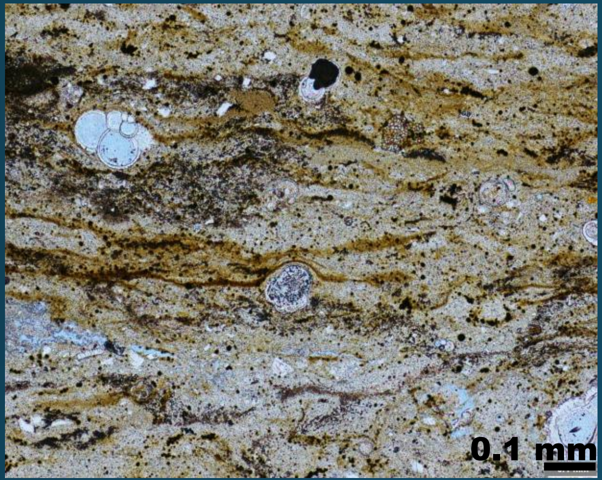


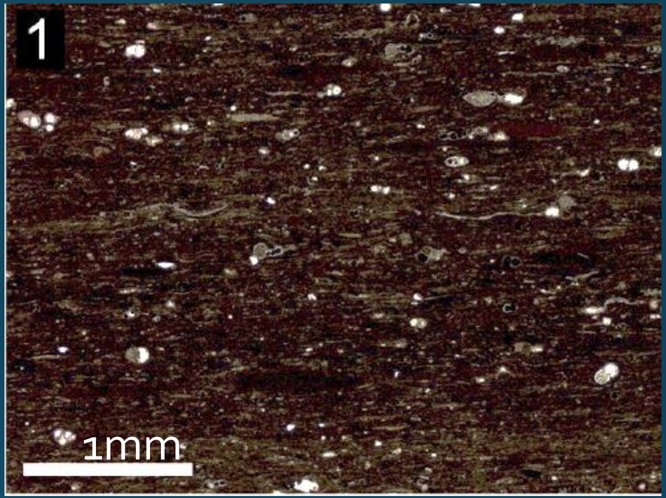
Haynesville, Hammes et al. (2011)

Facies

Cariaco Basin | Mesozoic Shale Basin

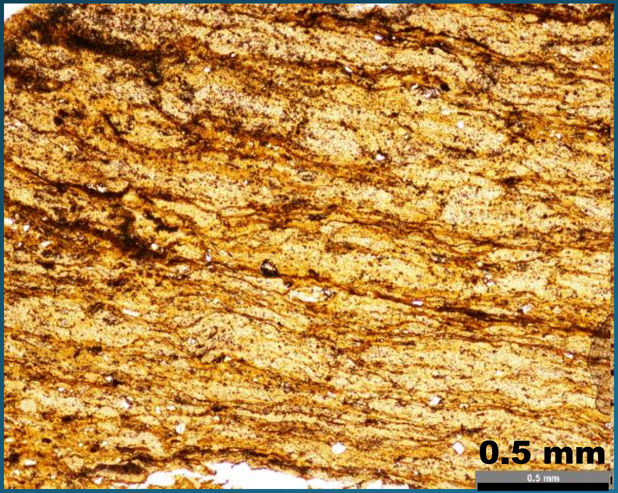
Planktonic foram mudstone

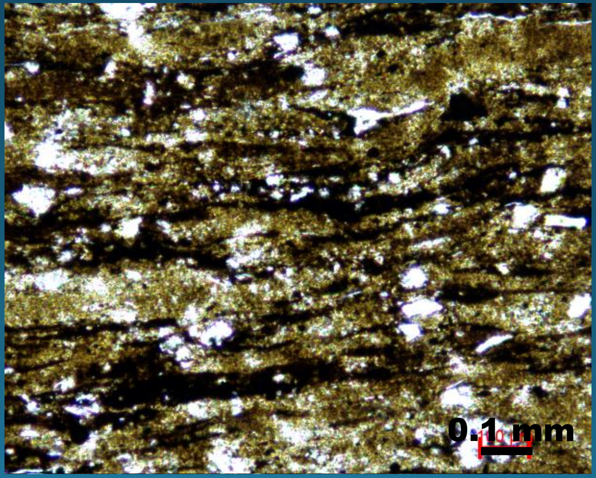




Eagle Ford, Denne et al. (2014)

Laminated mudstone



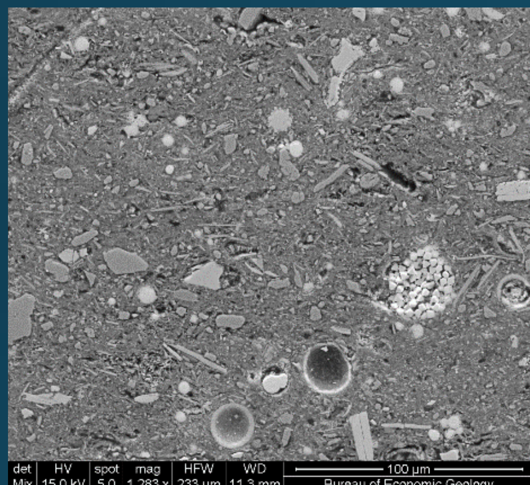


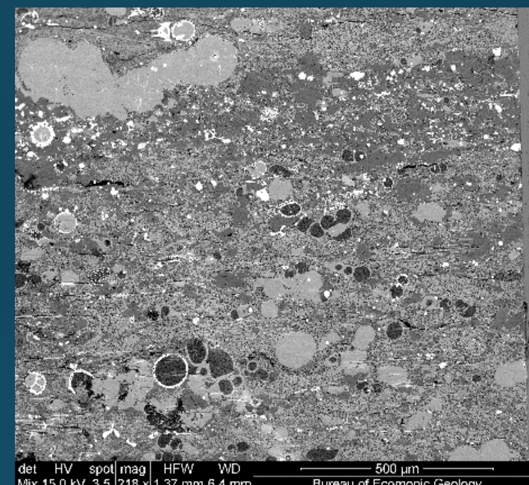
Haynesville, Hammes et al. (2011)

Ar-ion milled SEM - Porosity, mineralogy, organic matter

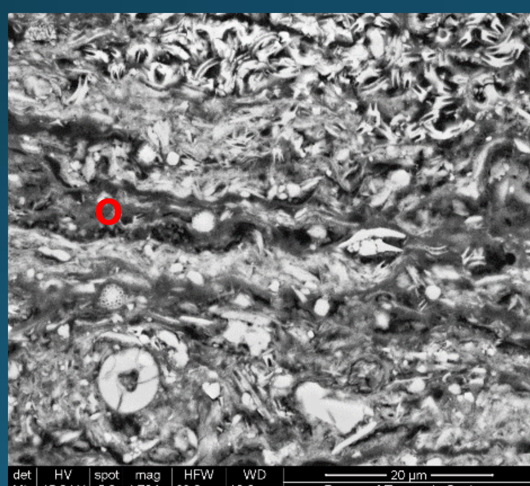
Cariaco Basin | Eagle Ford Basin

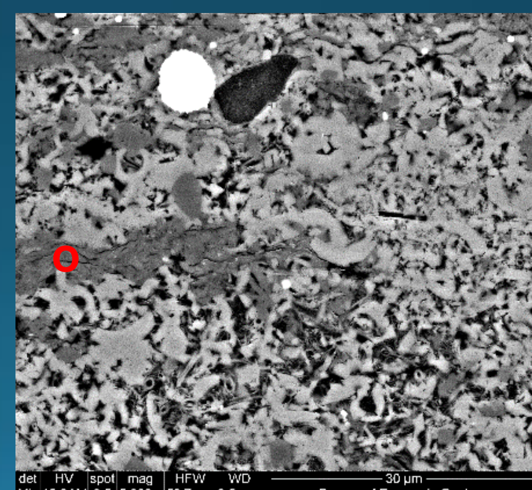
Globigerinid, skeletal wackestone





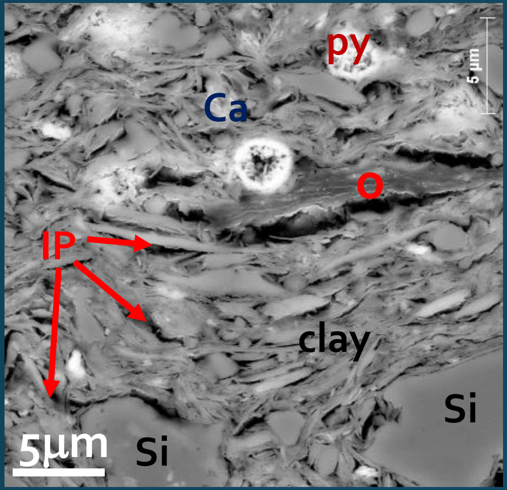
Laminated, skeletal packstone with organics and interparticle porosity

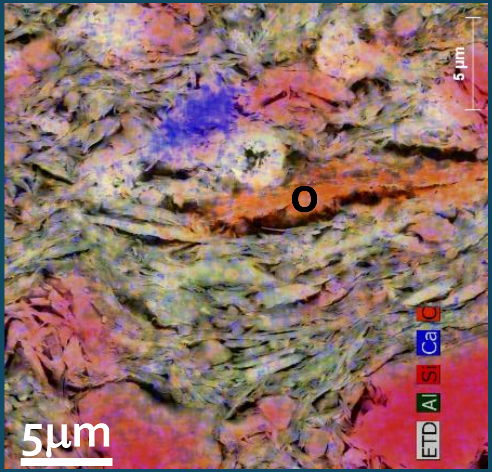


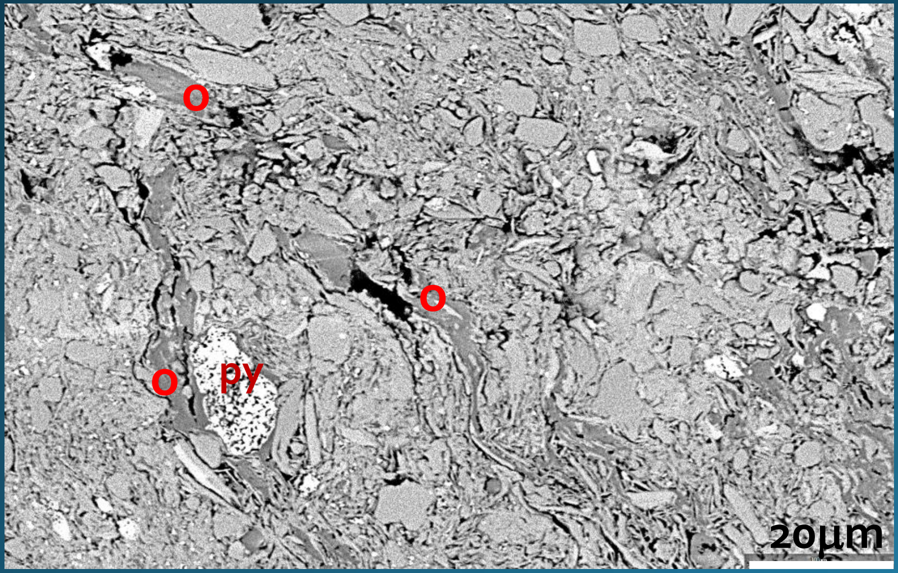


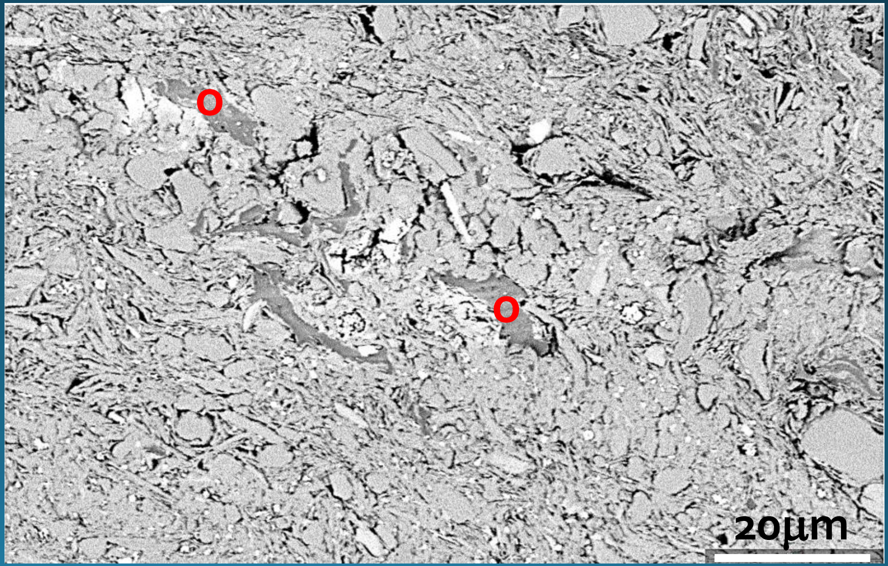
SEM - Cariaco Basin mineralogy, organic matter:

Organic matter within matrix dominated by Si, clay, pyrite, and carbonate





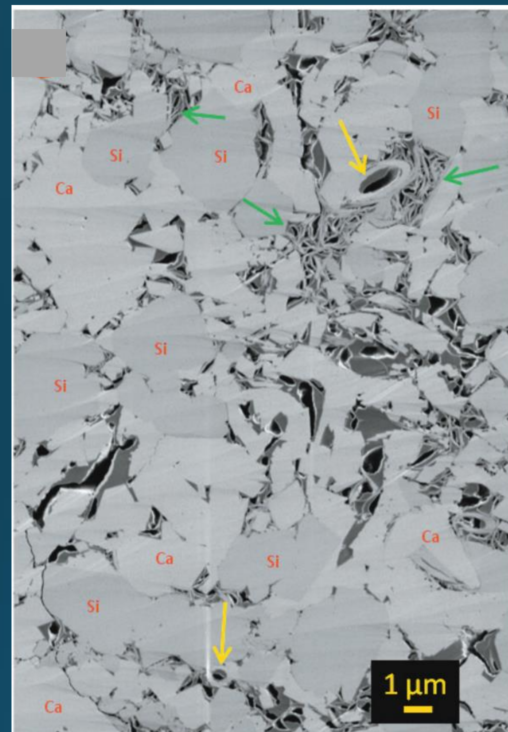


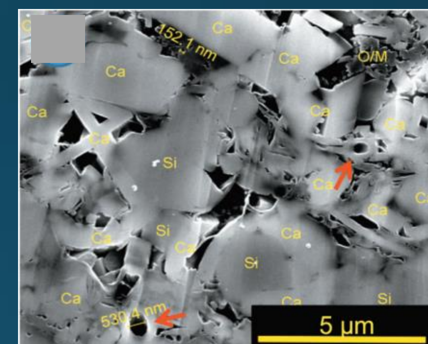


SEM overview BSE images courtesy of FEI

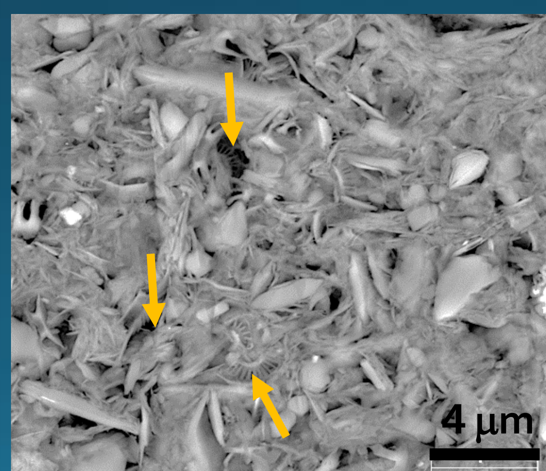
SEM - Porosity and cements

Eagle Ford (from Driskill et al. (2013)



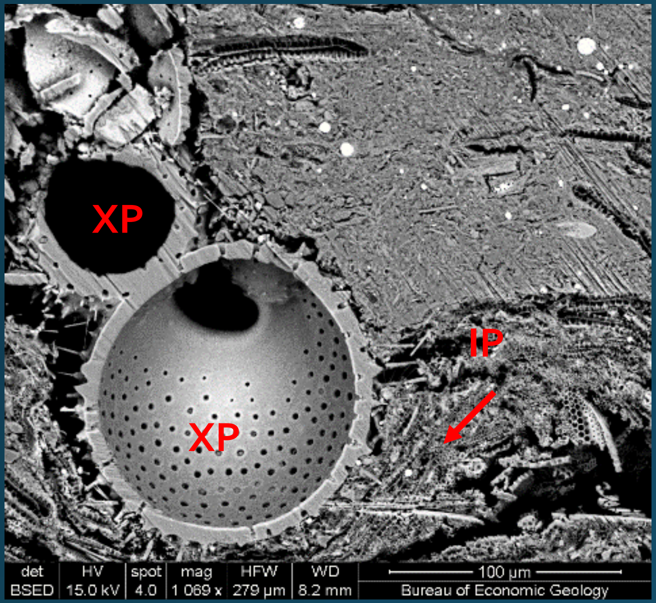


Cariaco Basin

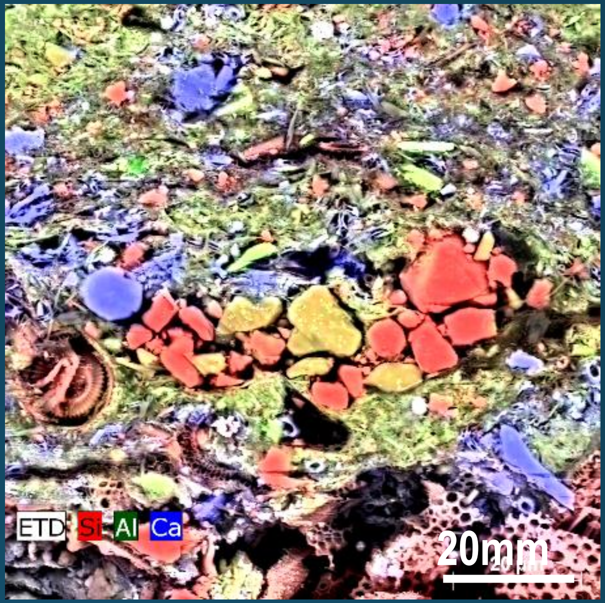


SEM – porosity, cementation, foraminifers

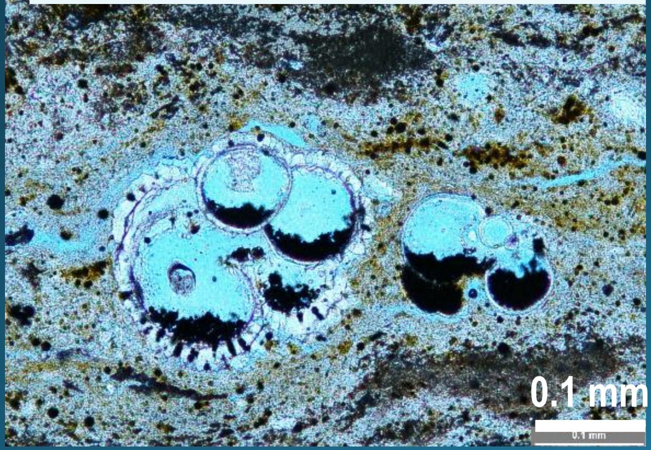
Cariaco Globigerinids



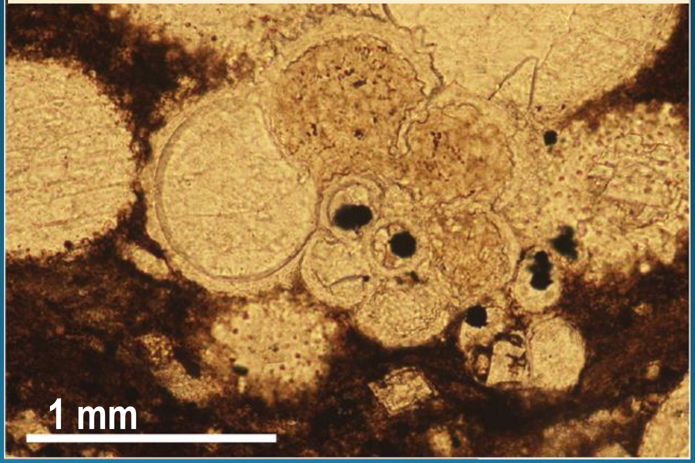
Cariaco agglutinated foram



Cariaco Globigerinid forams



Eagle Ford Hedbergella delrioensis



From Denne et al. (2014)

Conclusions

- Analog to Eagle Ford and Haynesville shales in Texas.
- Laminated, organic-rich layers related to high sea level and upwelling.
- Bioturbated organic-poor layers deposited during lower relative sea level and increased terrigeneous input.
- Laminae couplets are annually deposited varves (Hughen et al., 1998).

Conclusions cont'd

- Sedimentary structures include laminations, cross-bedding, bioturbation, claystone turbidites.
- Porosity is reduced by 50% within the first 170 meters.
  - inter- and intra-particle pores.
- Organic matter is immature, squeezed between clay, calcite and silty material in laminated facies.

Future Work

- Establish predictive model for pore, pore-throat, pore-scale fluid flow, and maturation of organic matter using immature sediments
- Evaluate genesis, physico-chemical reactions, porosity magnitude and tortuosity, and pore-network relationship
- Investigate controls on deposition, preservation, and favorable lithology for fracking