Linking Diagenesis with Depositional Environments as It Bears on Pore Types and Hydrocarbon Storage—An Example from the Cretaceous Eagle Ford* Formation, South Texas

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Search and Discovery Article #80443 (2015)**
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*Adapted from presentation at Tulsa Geological Society Dinner Meeting, January 6, 2015.
Editorial note: Closely related article on the Eagle Ford by the author and co-workers is "Development of Organic and Inorganic Porosity in the Cretaceous Eagle Ford Formation, South Texas," Search and Discovery Article #50928 (2014).

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Abstract

Integration of sequence stratigraphy, diagenesis, and geochemistry provides a comprehensive understanding of the nature, distribution, and connectivity of pores in the hydrocarbon-productive Cretaceous Eagle Ford Formation, South Texas. For this study, samples were gathered from two wells that contain 1) foraminiferal mudstones with high (up to 8 wt%) total organic carbon (TOC) contents, deposited in the transgressive system tract (TST) or near the maximum flooding surface (MFS), and 2) limestones with relatively low TOC (<1 to 2 wt%) contents, deposited during highstands (HST). The Eagle Ford differs in thermal maturity between the wells, with the formation at *'low'* maturity (Ro ~0.7%) in one and at higher maturity (Ro ~1.2%) in the other.

Early diagenesis in TST/MFS mudstones resulted in precipitation of euhedral pyrite, quartz, and kaolinite, which filled foraminifera tests (intraparticle pores) and partially filled interparticle pores between detrital grains. In HST limestones, euhedral microsparry calcite precipitated from recrystallization of abundant foraminifera and coccoliths; interparticle pores remained between calcite crystals. In both lithologies, bitumen coats all precipitated minerals. Bitumen occludes pores in mudstones, whereas it lines pores and only locally occludes them in limestones. Subsequent porosity development in the bitumen (limited connectivity) was observed only in the high-maturity well and principally in mudstones. Based on laboratory measurements and inferred from focused-ion-beam scanning electron microscopy, good connectivity exists between interparticle pores in limestones, which is consistent with higher hydrocarbon yield (S1 peak in RockEval analyses) from limestones relative to mudstones, and indicates that hydrocarbon storage is significant in limestones.

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Hunt, J.M., 1996, Petroleum Geochemistry and Geology, 2nd edition: W.H. Freeman, New York, 743p.

Jarvie, D.M., and M.H. Tobey, 1999, TOC, Rock-Evaluation and SR Analyzer Interpretive Guidelines: Humble Instruments and Services, Inc., Geochemical Services Division, Humble, Texas, Application Note 99-4, p. 1-16.

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Linking diagenesis with depositional environments as it bears on pore types and hydrocarbon storage—an example from the Cretaceous Eagle Ford Formation, South Texas

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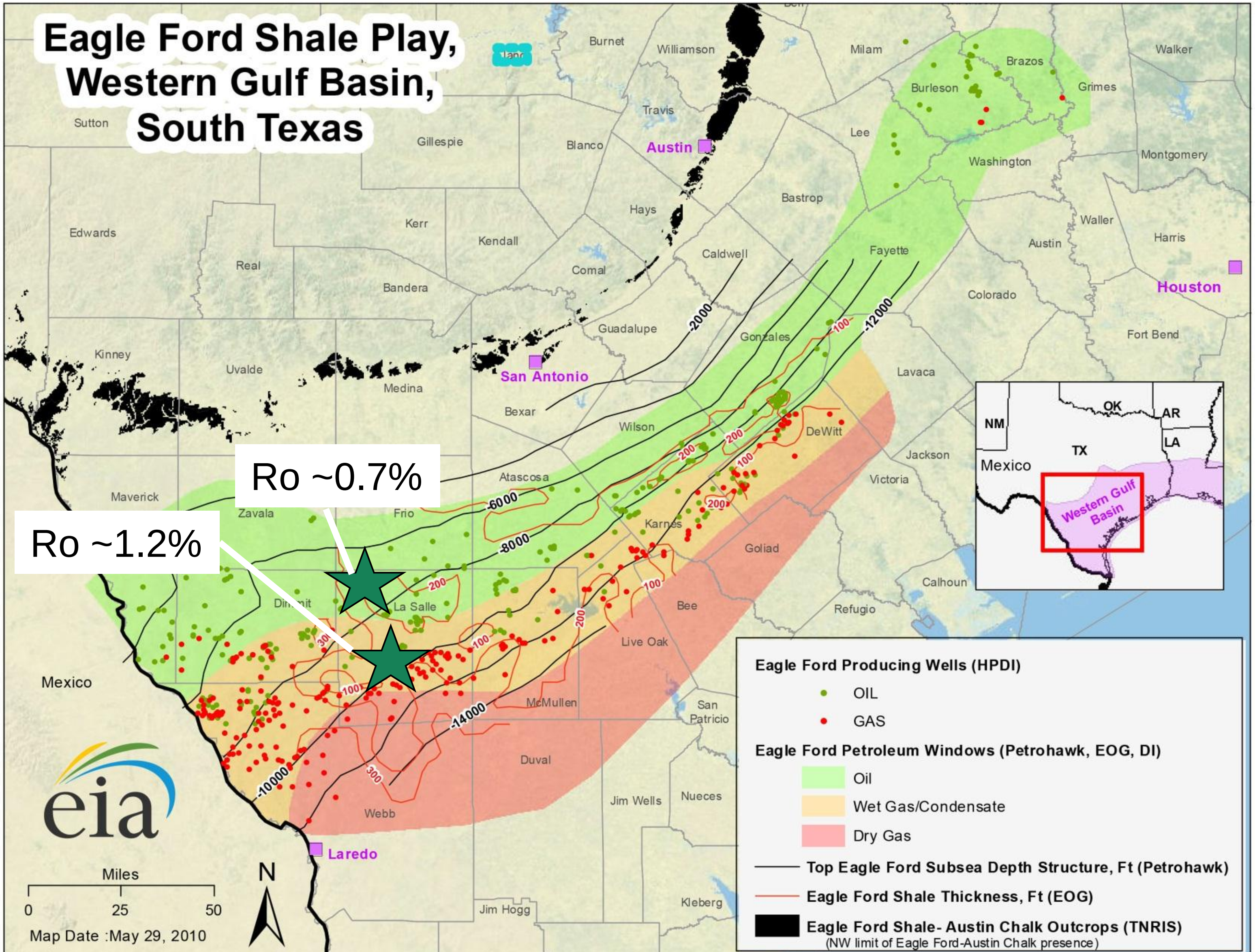
January 6, 2015

Tulsa Geological Society

Paleogeographic setting, Eagle Ford

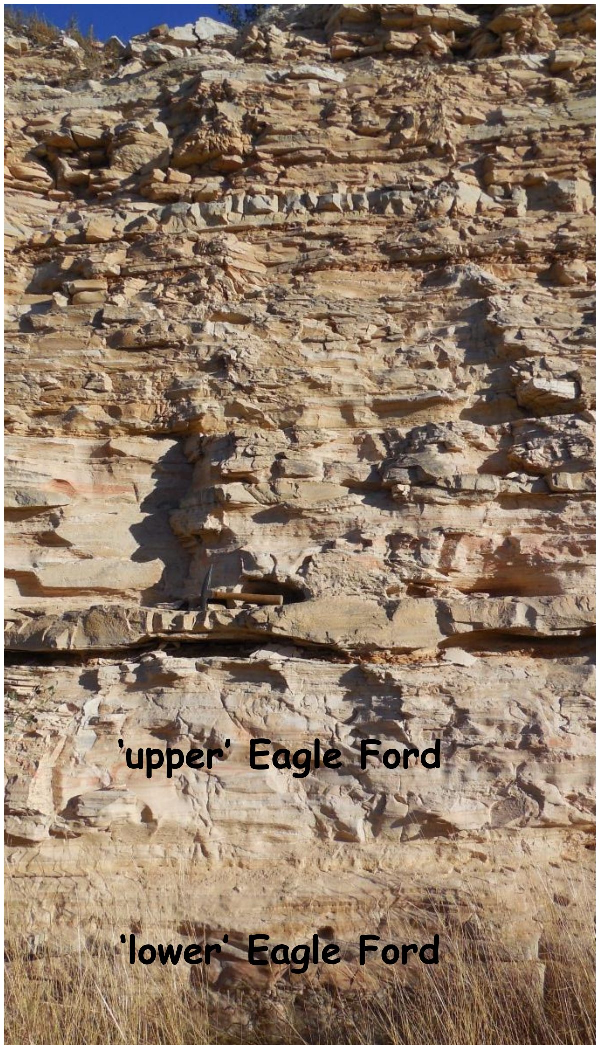
From R. Blakey, http://jan.ucc.nau.edu/~rcb7/nam.html

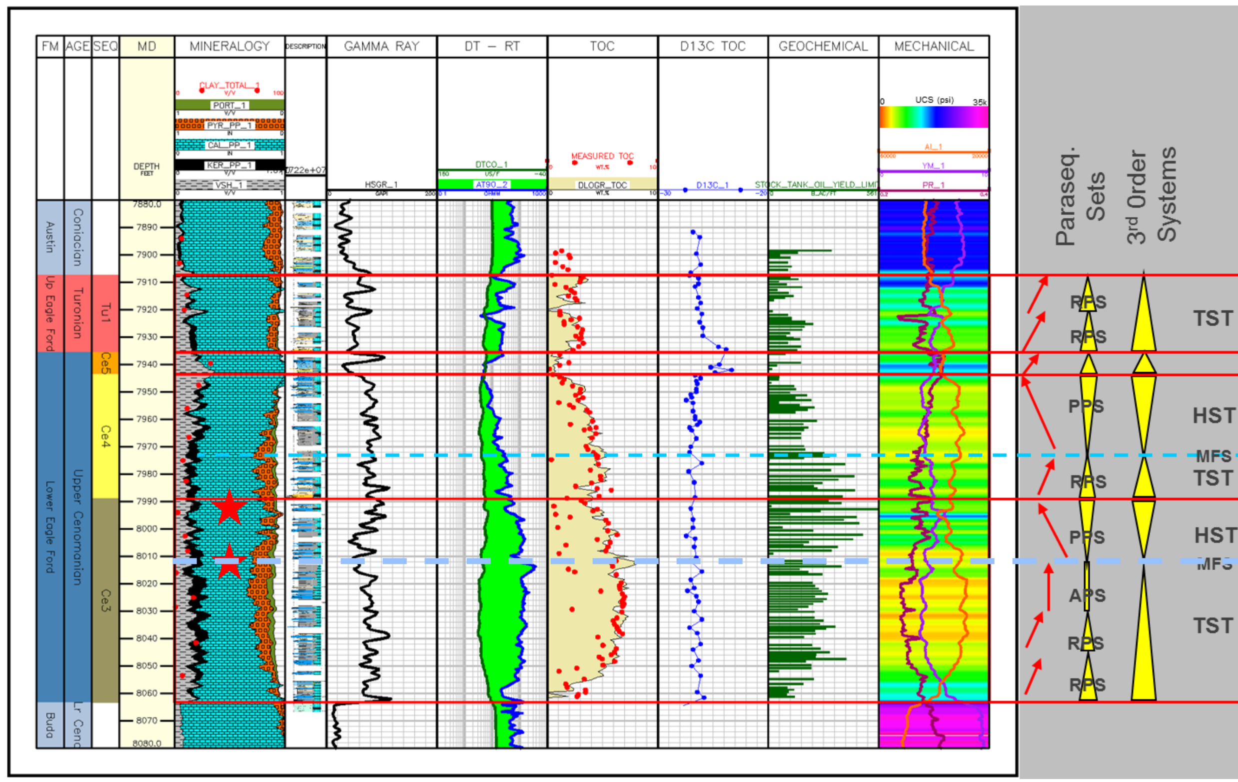
Study well locations



Sequence stratigraphic framework

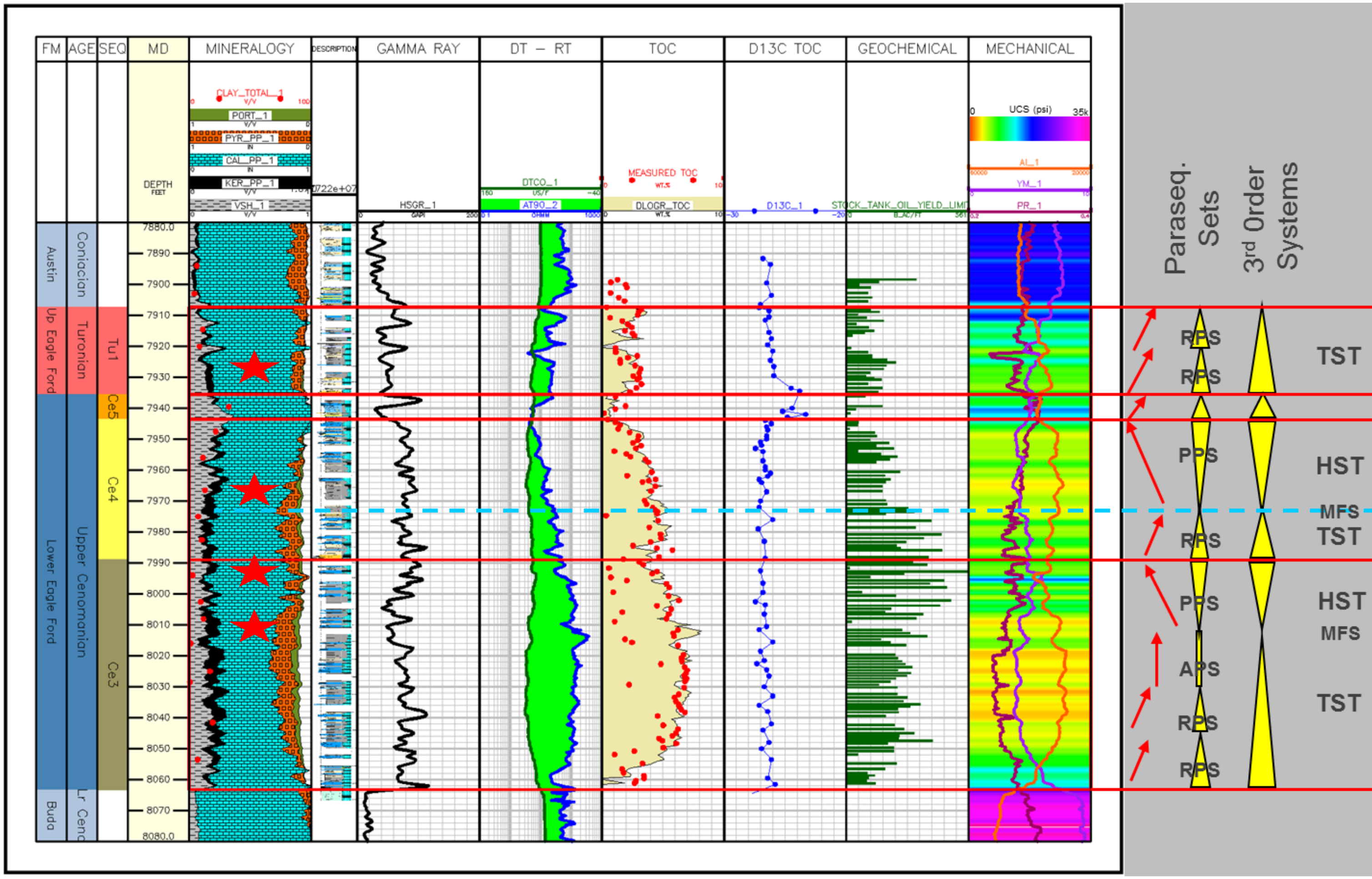
Eagle Ford, near Del Rio, TX

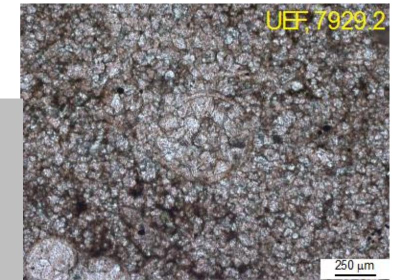


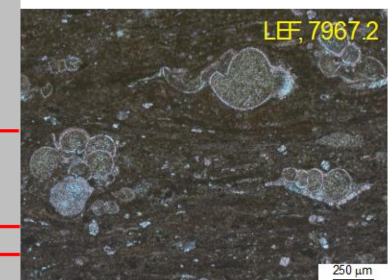


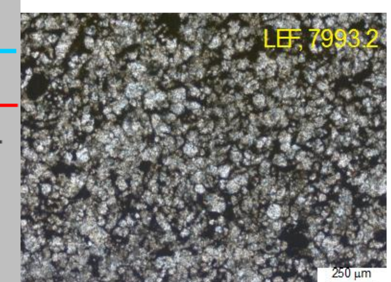
Broadly, two lithologies of interest

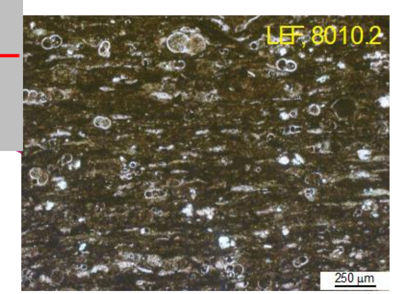
Org-rich mudst, TST-MFS, up to 8% TOC, Φ = 8-9%, k_{eff} = 50 nD





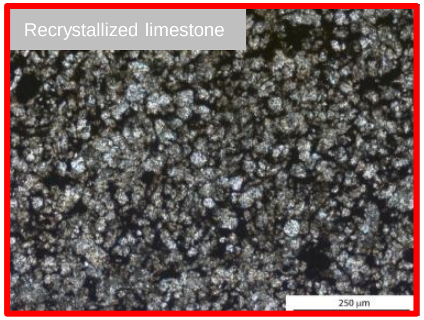




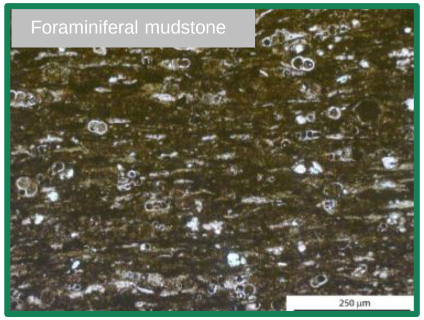


Limestones, HST, <1 locally up to 3% TOC, Φ = 6-7%, k_{eff} = 300 nD

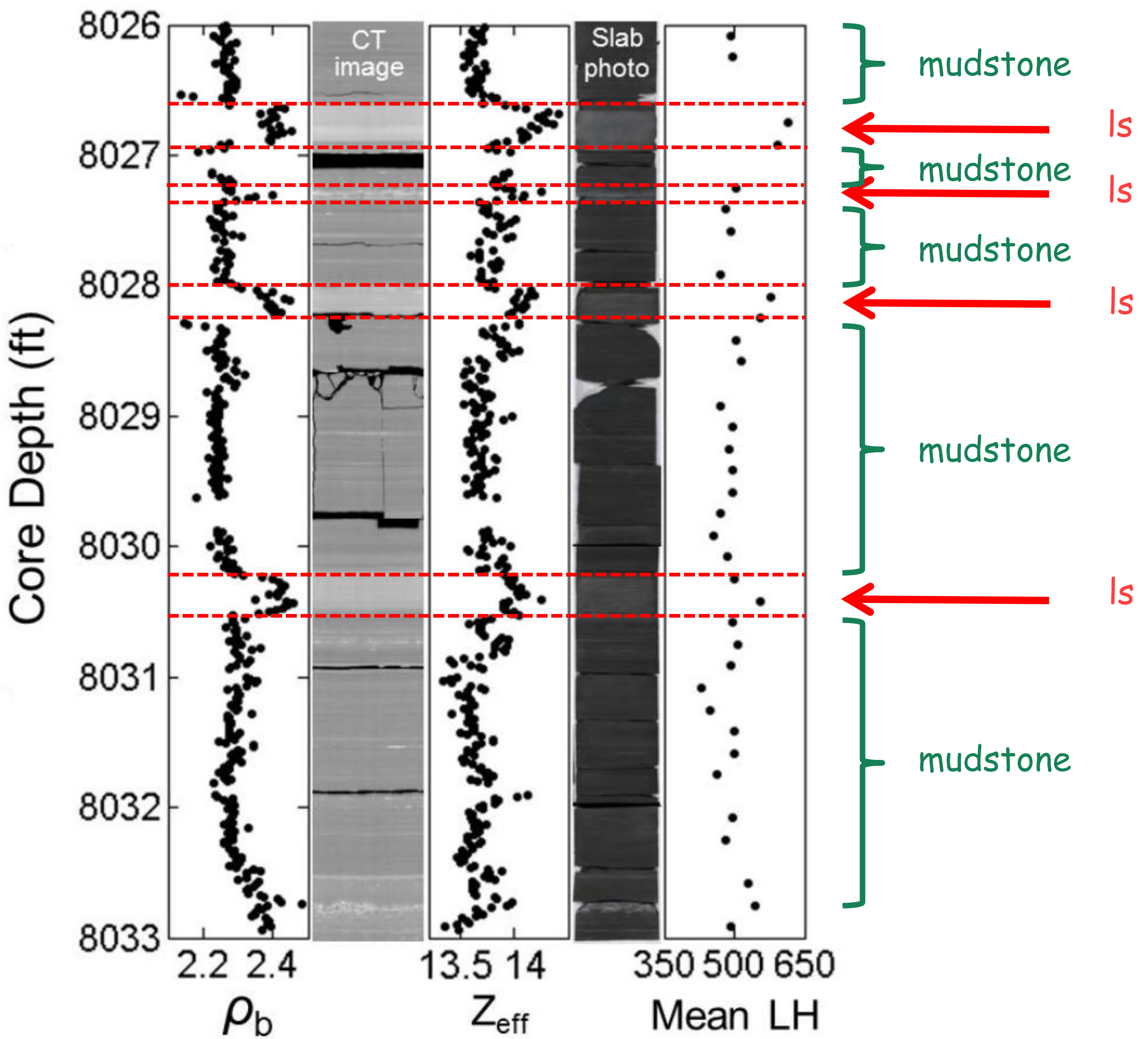
Broadly two lithologies of interest



organic lean
(<2 wt% TOC)



organic rich
(up to 8 wt% TOC)



From Ritz et al., 2014

Petrologic goals for porosity studies

Place inorganic & organic porosity development within a temporal and thermal framework for lithologies of interest (org-rich mudst & ls)

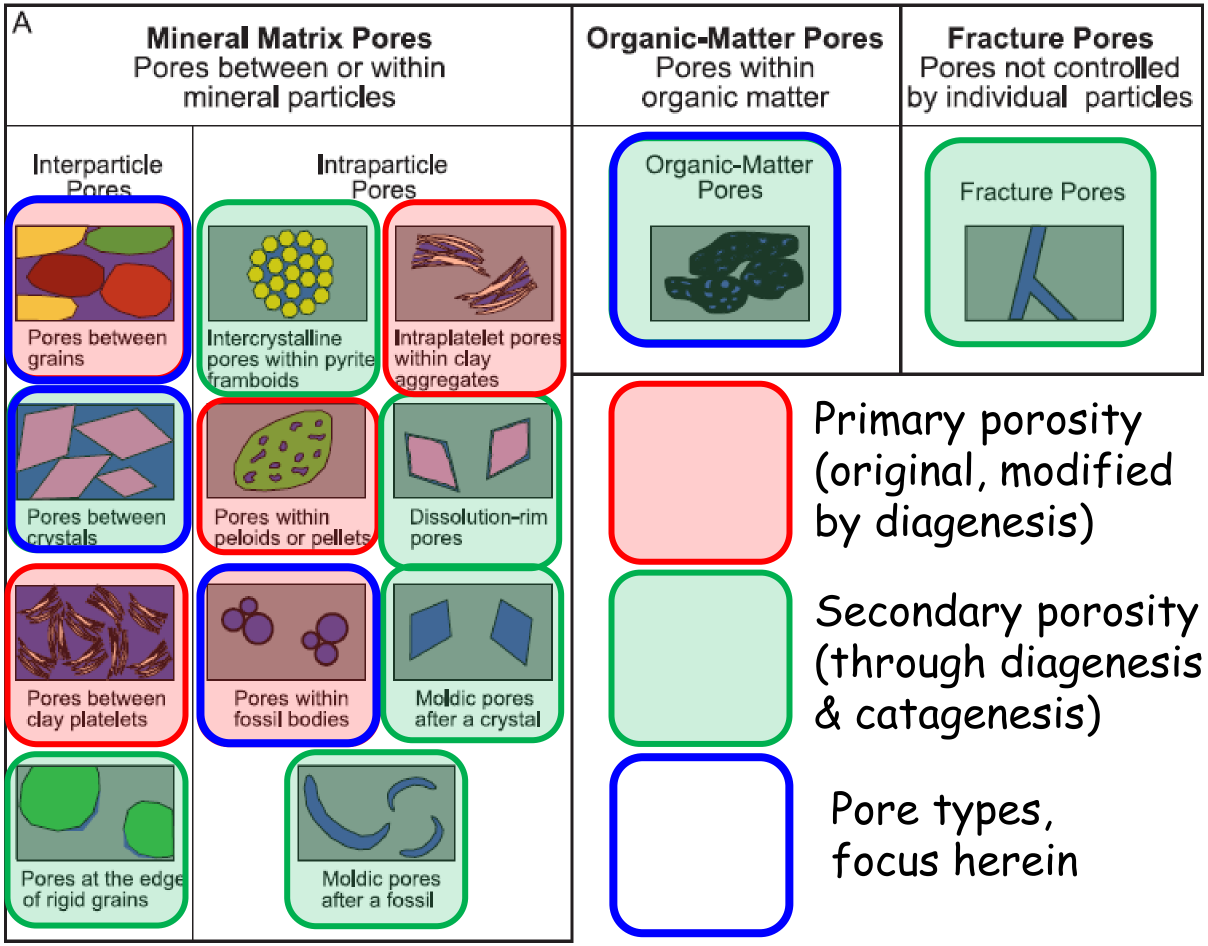
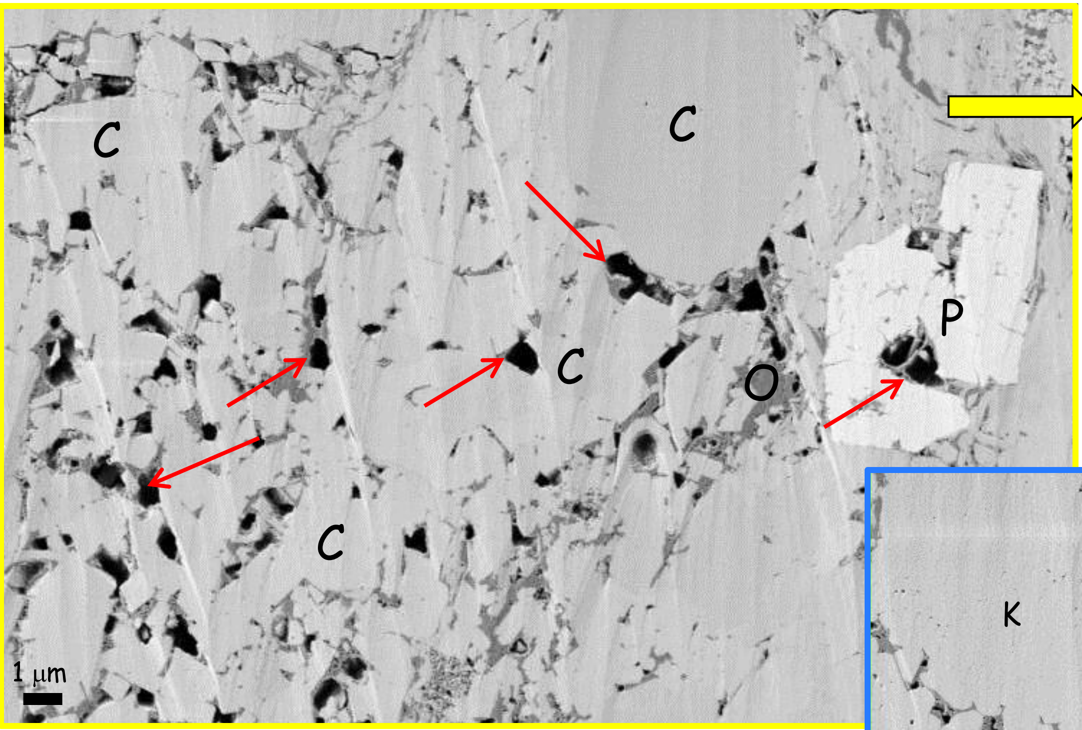


Figure modified from Loucks et al., 2012; AAPG Bulletin

Nature of pores, mudstone & limestone

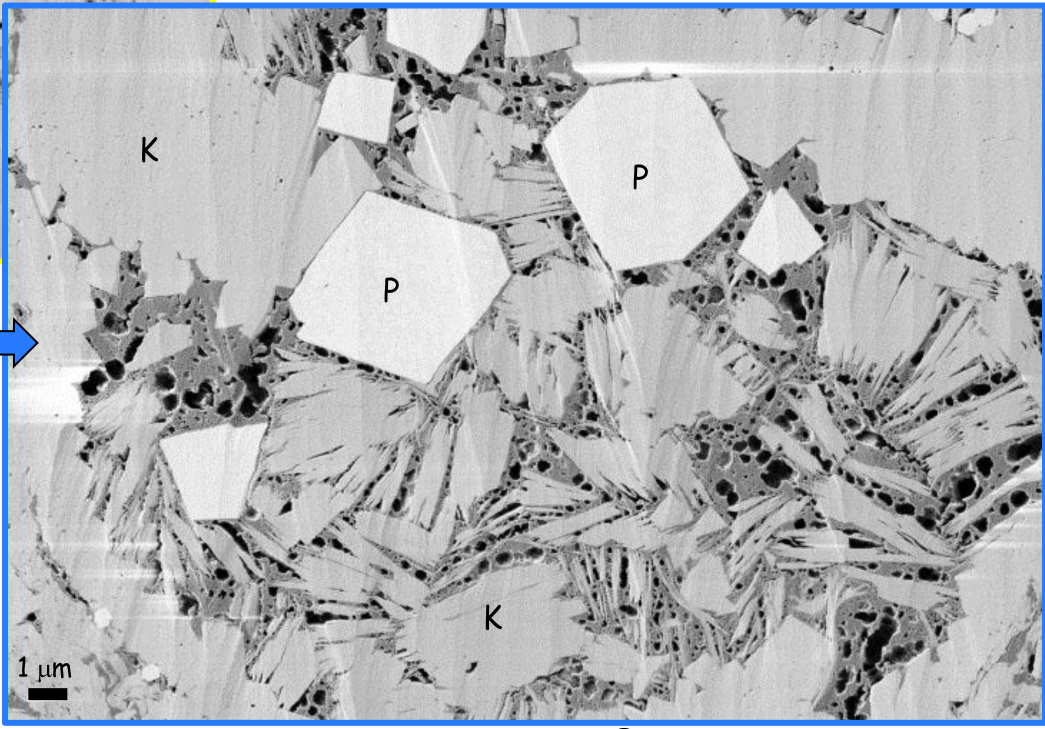


LIMESTONE:

- Most pores are interparticle between authigenic calcite (C) or pyrite (P)
- Fractures filled with calcite and/or organic material
- Organic pores observed, in some samples

MUDSTONE:

- Both intra- & interparticle pores
- Organic pores abundant, in some samples
- Fractures filled with calcite and/or organic material



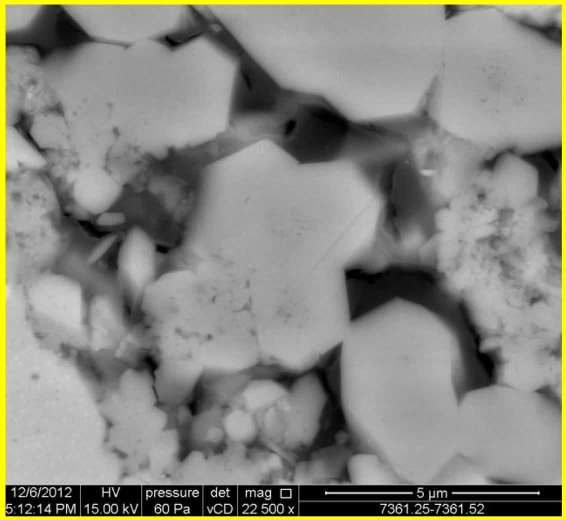
Organic porosity in some samples…

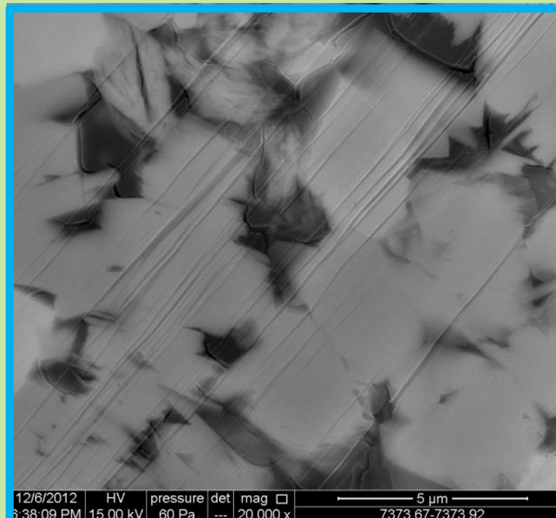
Organic porosity, function of thermal maturity

HST limestones | TST/MFS organic mudstones

Eagle Ford Ro ~0.7%:

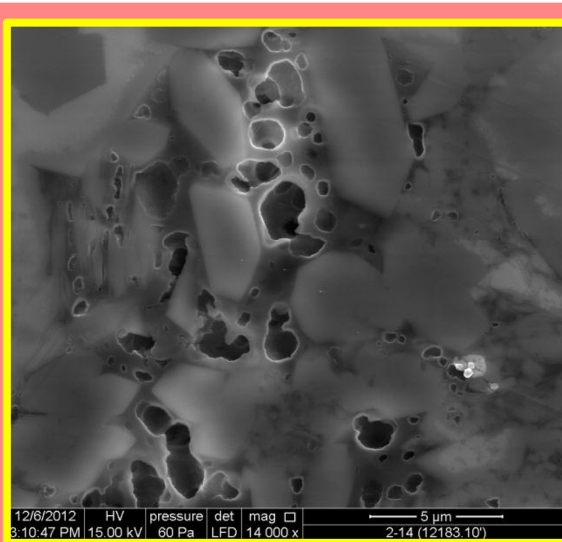
Organic pores minimal or lacking entirely

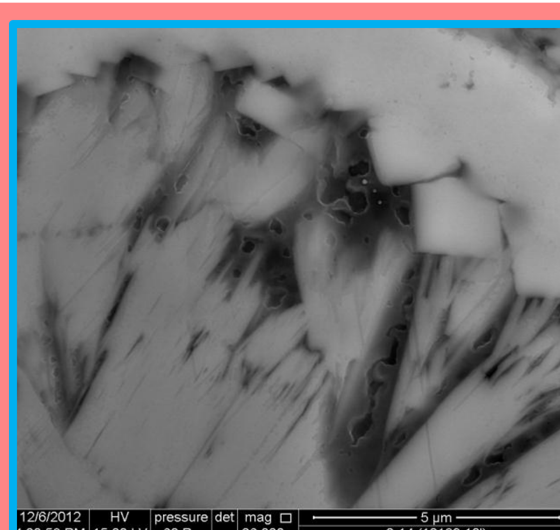




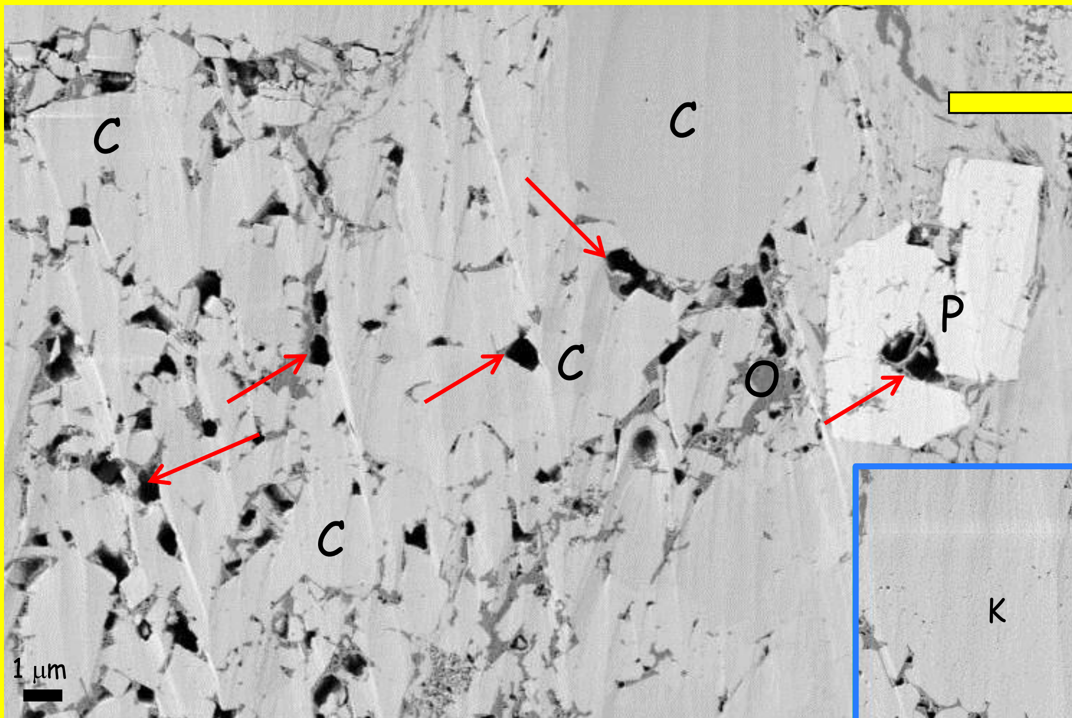
Eagle Ford Ro ~1.2%:

Organic pores very well developed



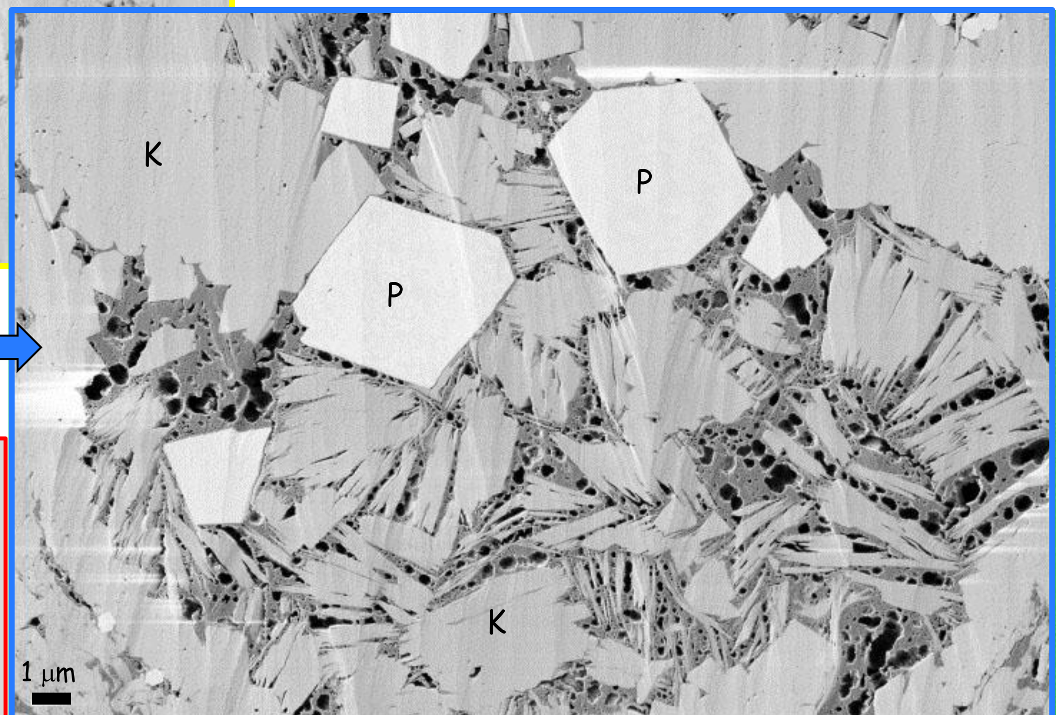


Nature of the pore-filling organic material



Organic material in limestones:
- Coats early diagenetic minerals
- Locally occludes remaining pores
- Can line interparticle pores

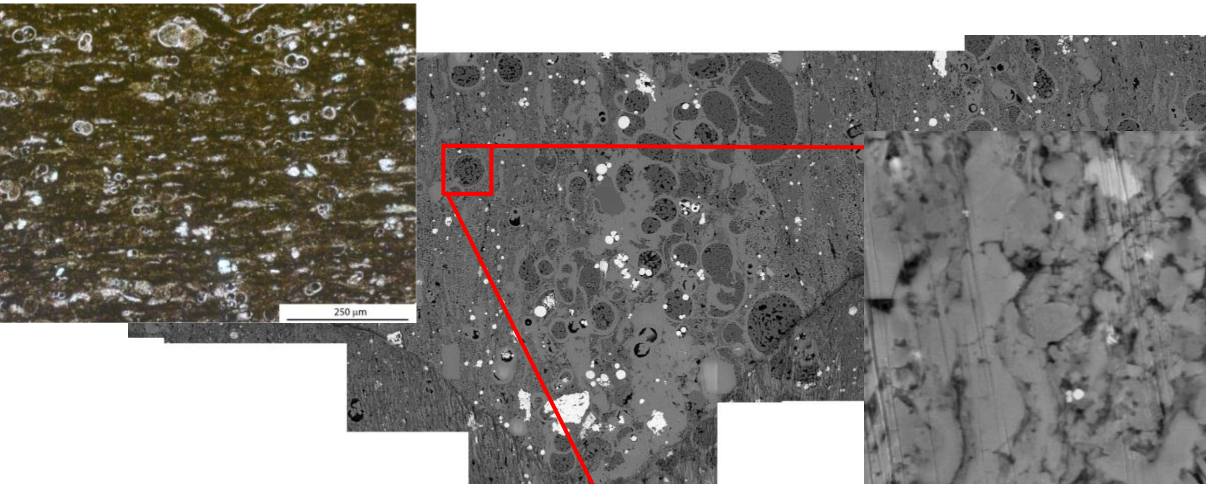
Organic material in mudstones:
- Coats early diagenetic minerals
- Occludes pore (intra- & interxtalline)

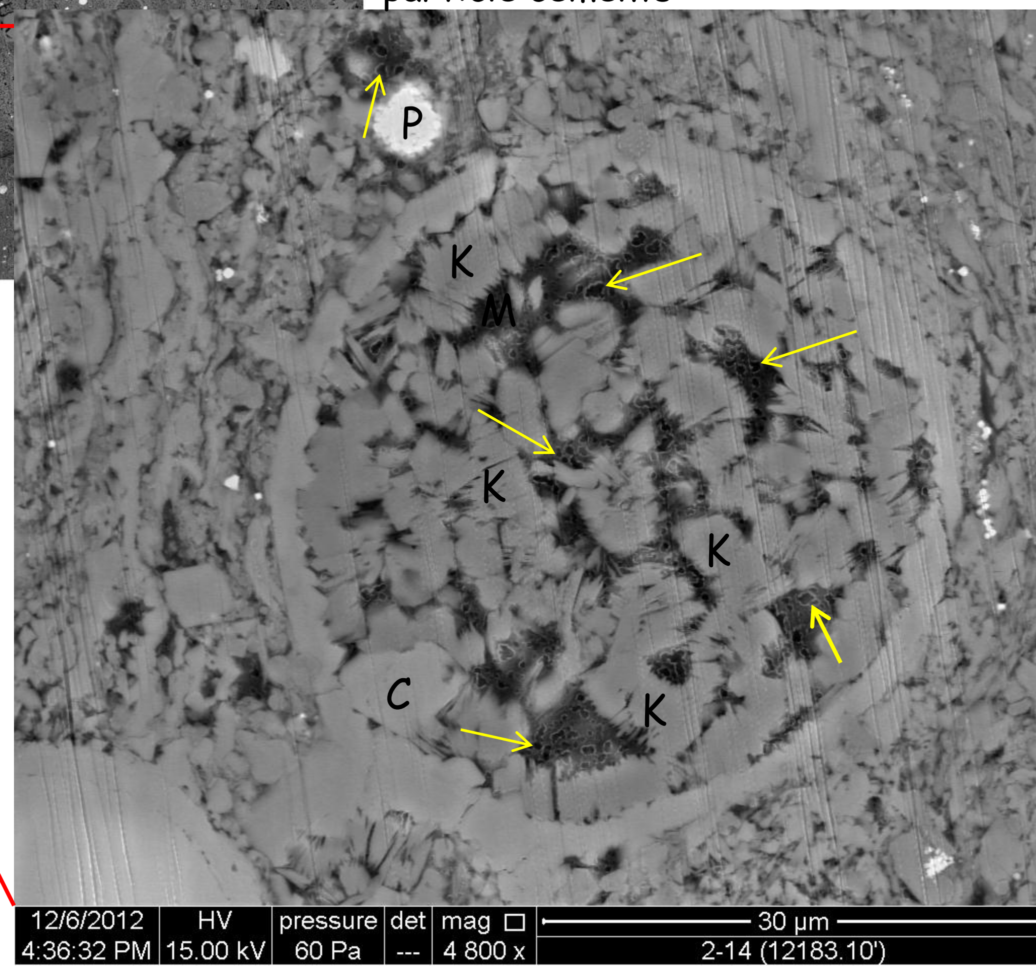


Organic material post-dates early, diagenetic minerals, was mobile (fills pores), & abundant in mudstones but less so in limestones = *migrated bitumen, now, in part, 'pyrobitumen'*

Timing of events, org-rich TST/MFS mudstones

Kaolinite (K), pyrite (P), calcite (C), & **abundant** 'bitumen' as intra/inter-particle cements

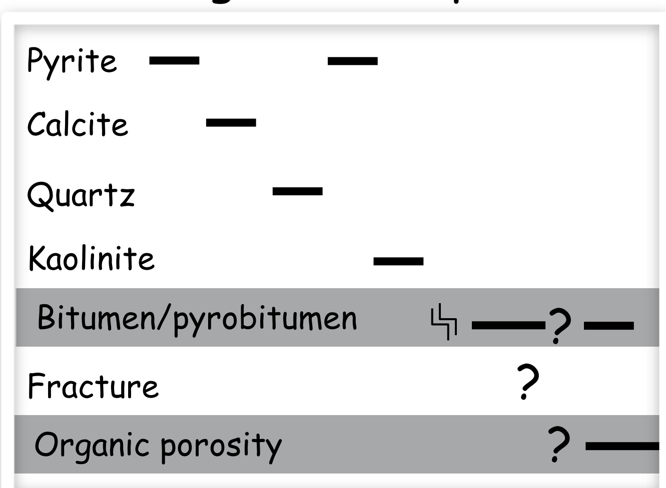




Minimal compaction of forams prior to authigenic mineral ppt —authigenic minerals early

Similar diagenetic history in both cores

Paragenetic sequence

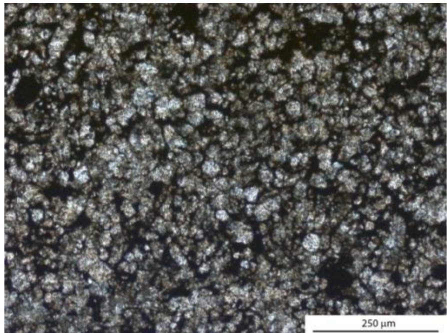


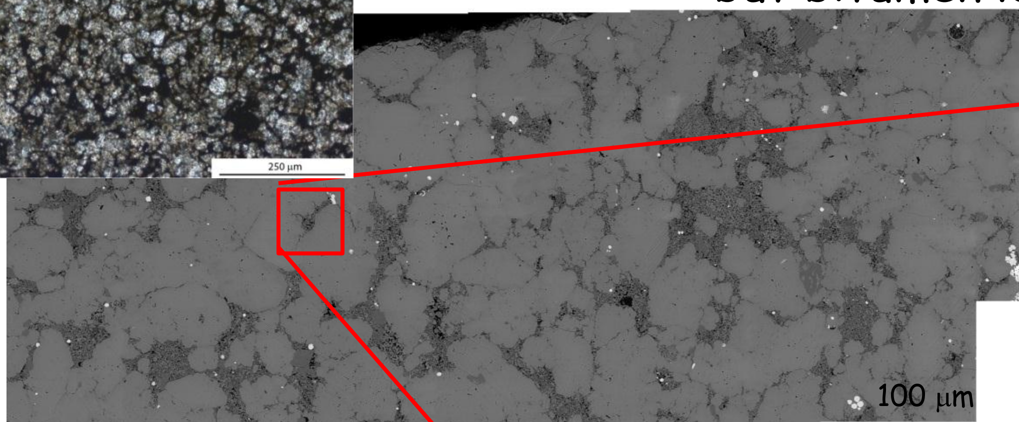
'Bitumen/pyrobitumen' filled remaining interparticle pores

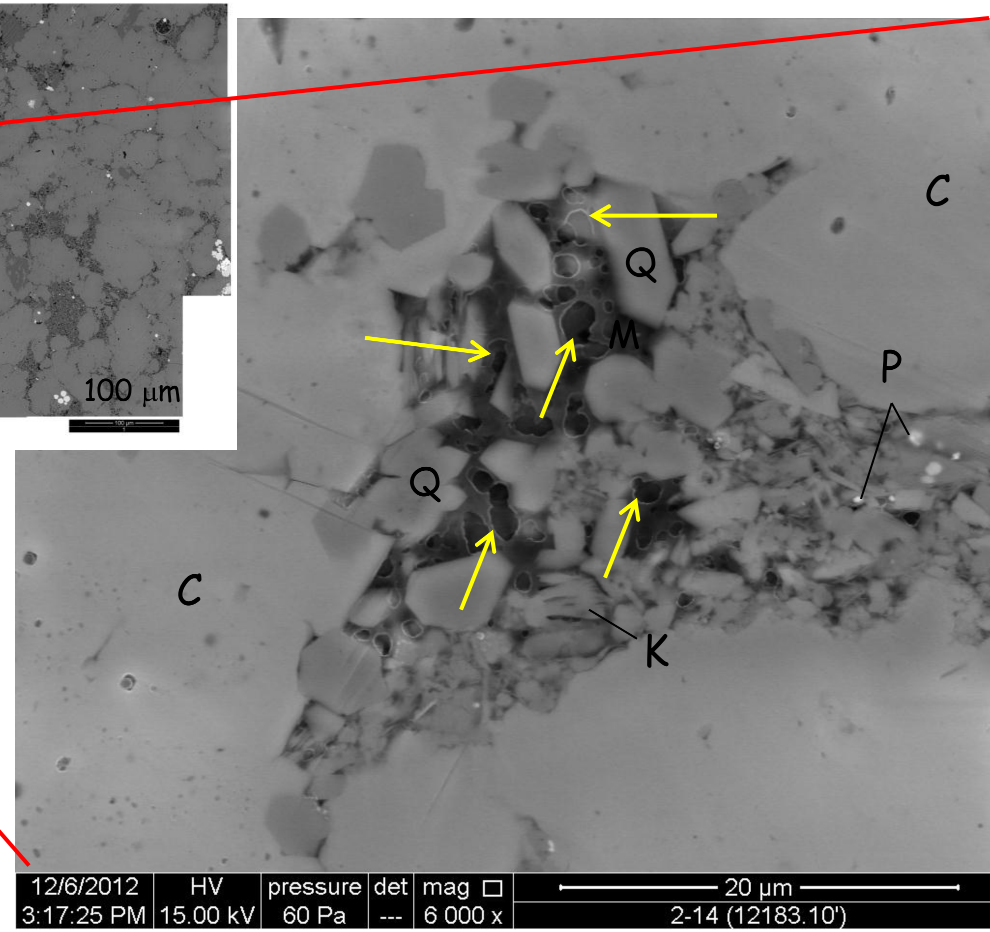
Organic pores, 'late' diagenesis (secondary ϕ), EF high maturity

Timing of events, HST recrystallized limestones

Authigenic pyrite (P), quartz (Q), calcite (C), Kaolinite (K), & '**bitumen**'—interparticle cements but bitumen less common in ls than mudst

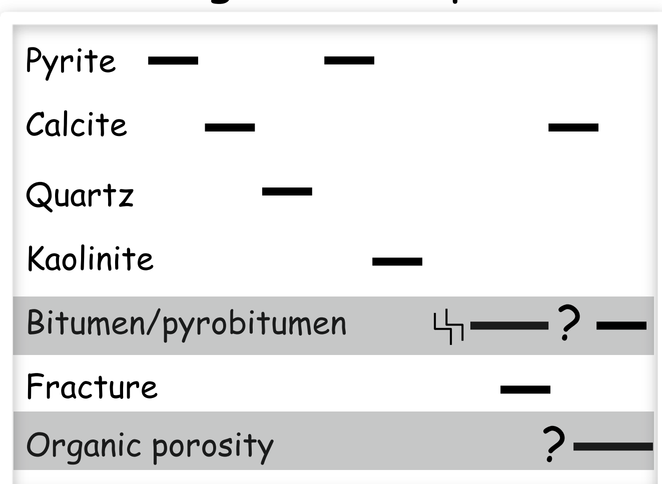






Calcite recrystallized from biological components

Paragenetic sequence



'Bitumen/pyrobitumen' filled remaining interparticle pores

Organic pores, 'late' diagenesis (secondary ϕ), EF high maturity

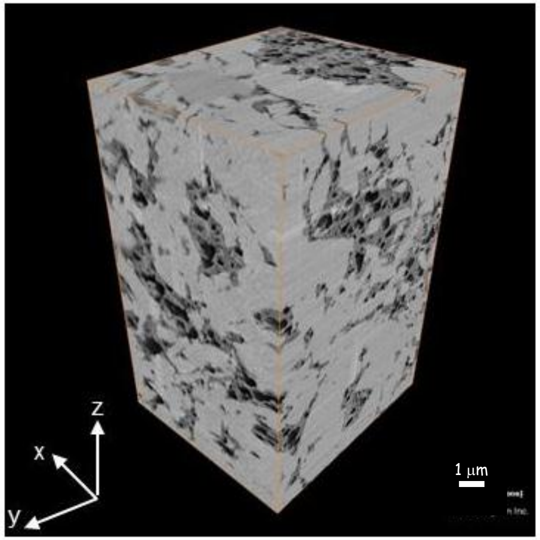
Eagle Ford diagenesis summary

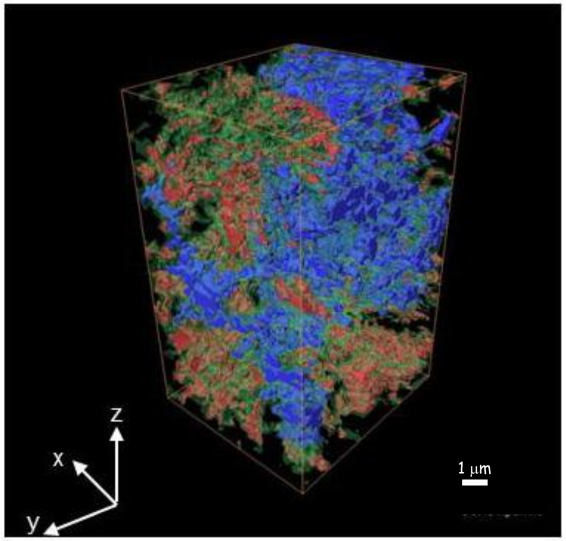
- Early diagenesis similar in TST/MFS organic-rich mudstones, both cores
- Early diagenesis similar in HST limestones, both core
- 'Bitumen/pyrobitumen' present in limestones and mudstones—abundant in mudstones
- Organic porosity development minimal or absent in low maturity (0.7% Ro) but abundant in high maturity (1.2% Ro)
- Organic porosity (secondary ϕ) developed in 'bitumen' (now largely pyrobitumen) that fills pores remaining after ppt of early-formed minerals (e.g., kaolinite, calcite, pyrite, etc.)
- Organic-rich mudstones = organic porosity & associated storage best developed and dominates pore types (minor intercrystalline porosity)
- Recystallized limestones = intercrystalline porosity & associated storage best developed and dominates pore types (minor organic porosity)

Pore type & connectivity a function of lithology

Organic-rich mudstones

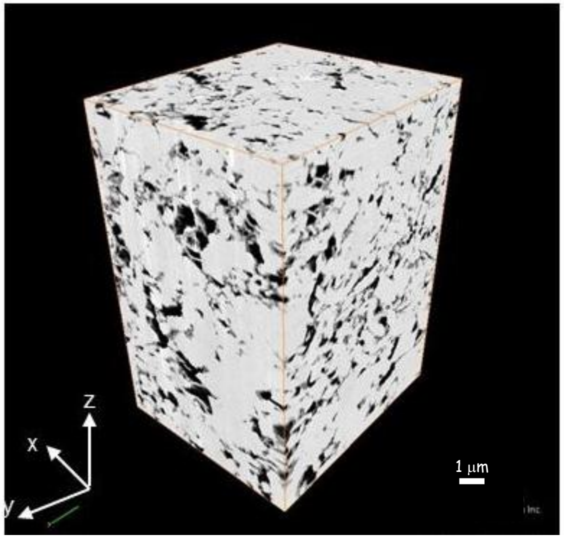
TST/MFS organic-rich mdst, has some pore connectivity, largely <u>organic porosity/storage</u>: a function of thermal maturity. Lower calcite contents result In more ductile framework.
(50 nD)

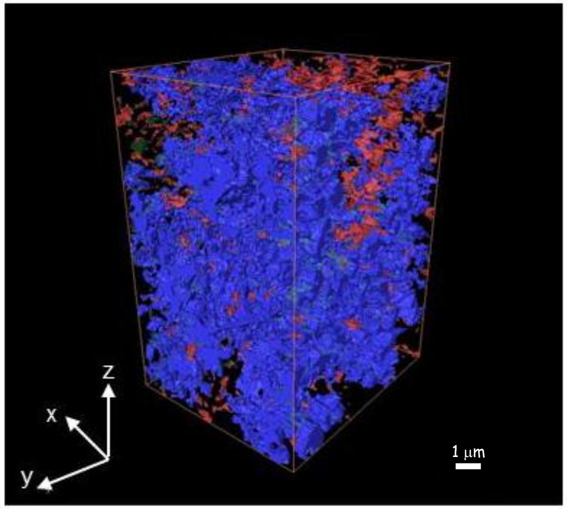




Organic-lean limestones

HST limestone has good pore connectivity, largely <u>interparticle porosity/storage</u>: not as dependent on thermal maturity. Rigid framework due to diagenetic calcite.
(300 nD)



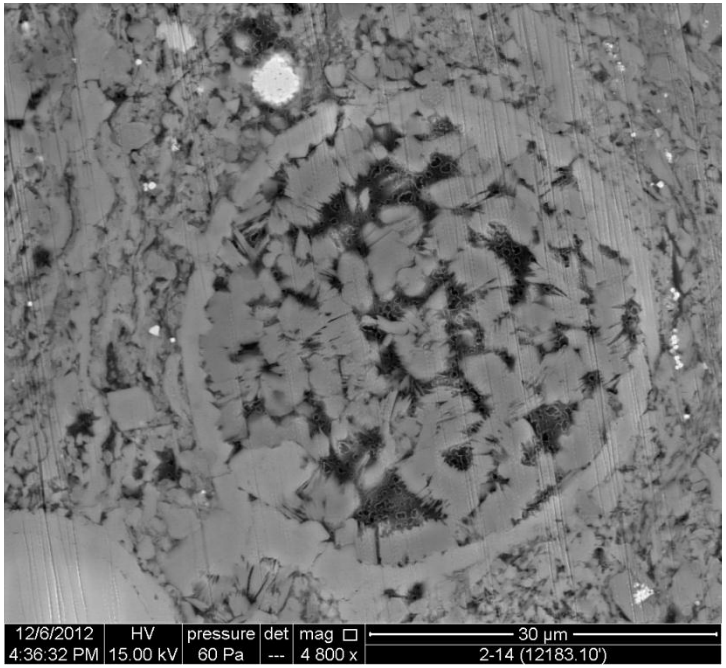


<u>EXPLANATION</u>
Green = organic material
Blue = interconnected porosity
Red = unconnected porosity

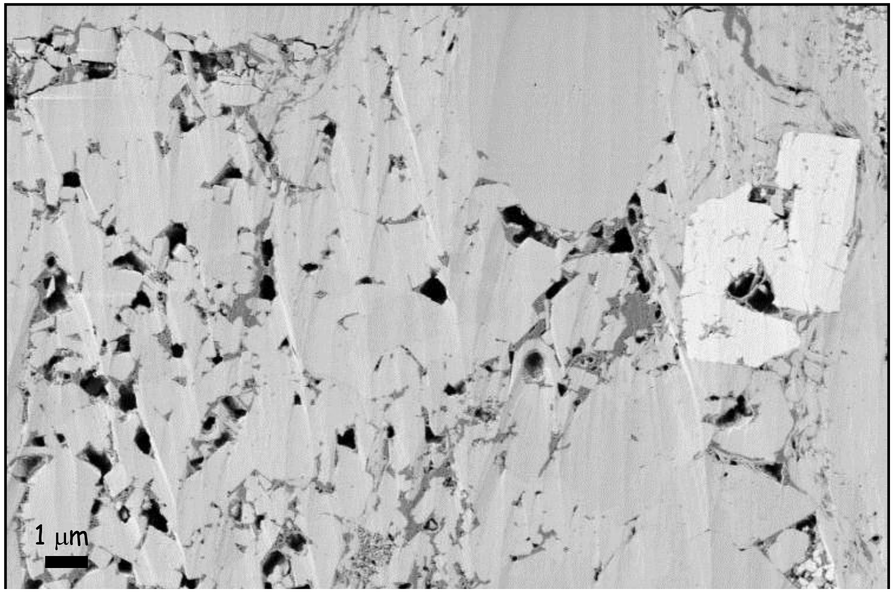
Eagle Ford, summary of pore types by lithology

- Pore types varies by lithology
  - OM pores dominate in org-rich mudstones, higher maturities
  - Interparticle pores largely in limestones
- Interparticle pores provide best connected porosity/storage

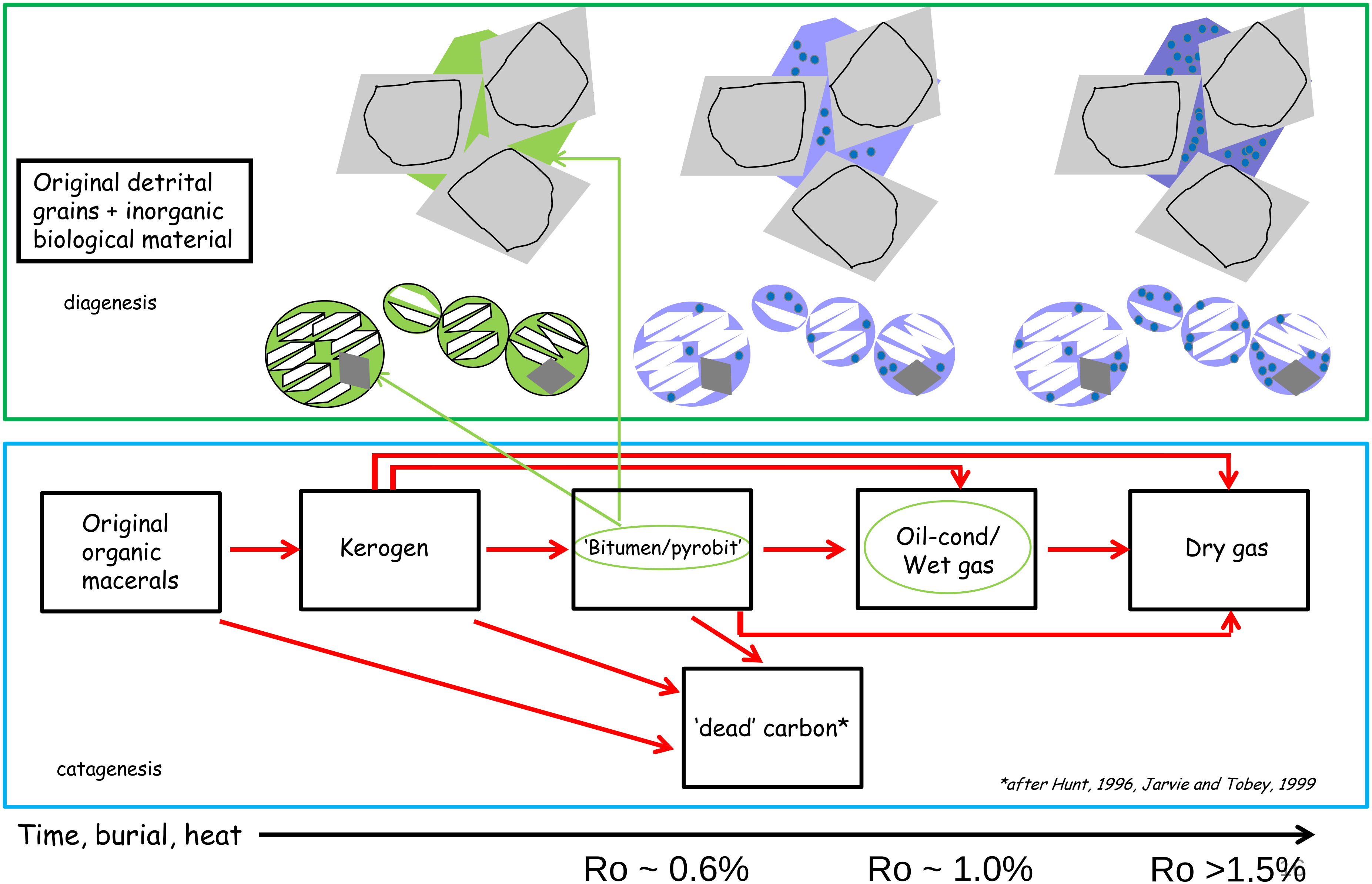
Organic-rich mudstone



Recrystallized limestone

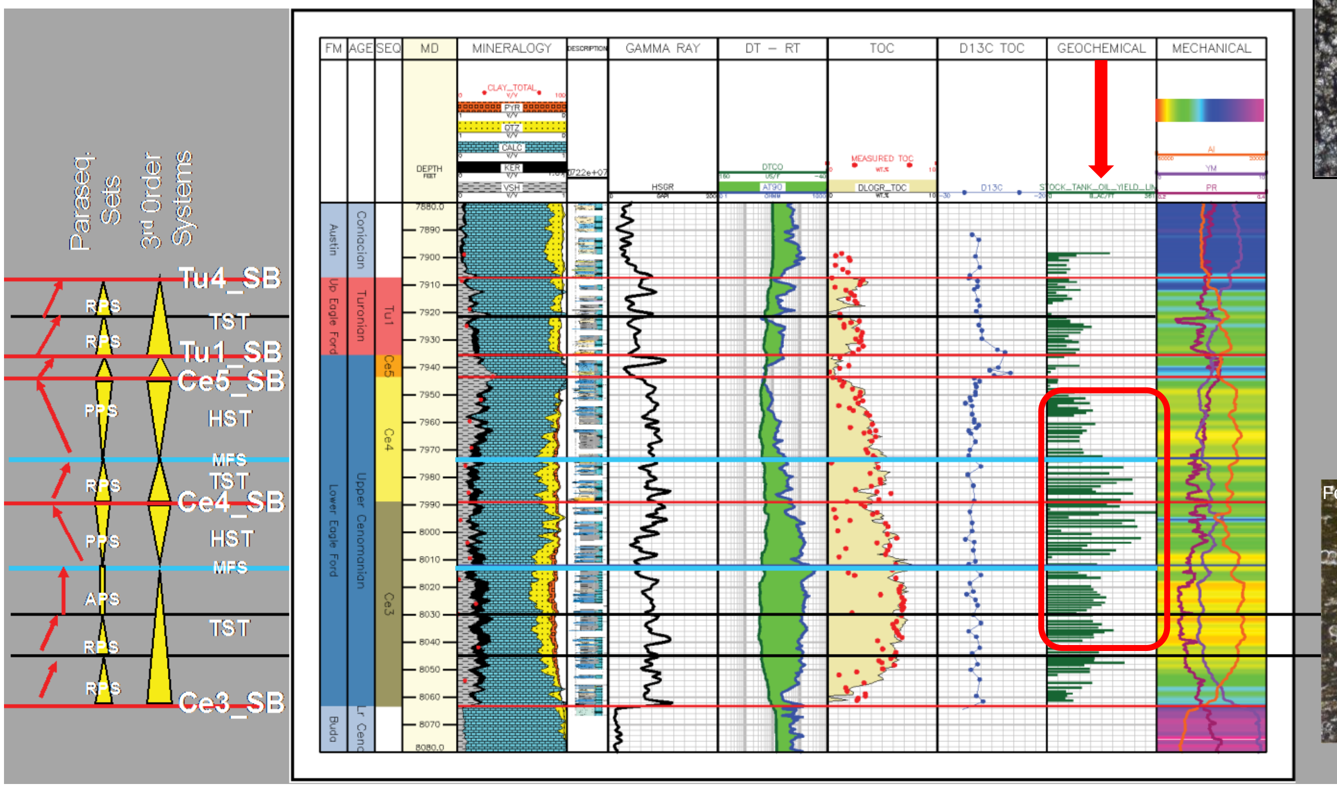


Pairing diagenesis with catagenesis

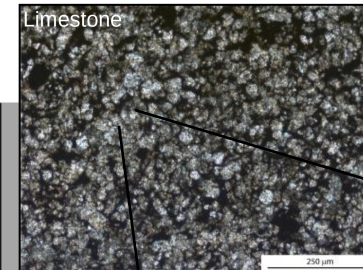


Porosity & storage related to sequence strat

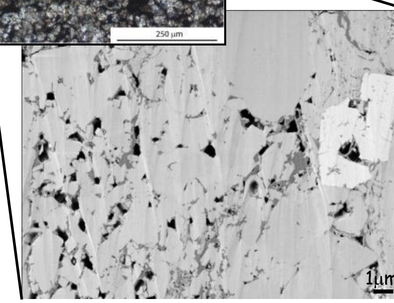
Lithologic (sequence strat) controls on pore types
Interparticle in limestones vs organic in mudstones

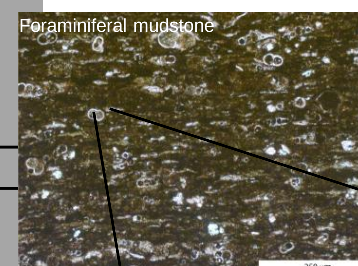


From John Guthrie and Randy Mitchell

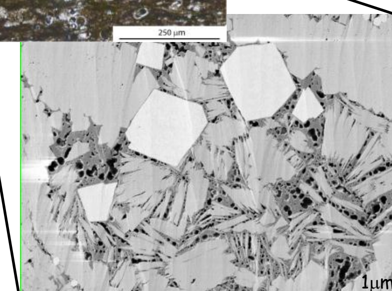


TOC = <2%
Φ = 6-7%
S_w = 40-50%
k_{eff} = 300 nD
Interparticle pores
Minor org pores
Zone of moveable oil



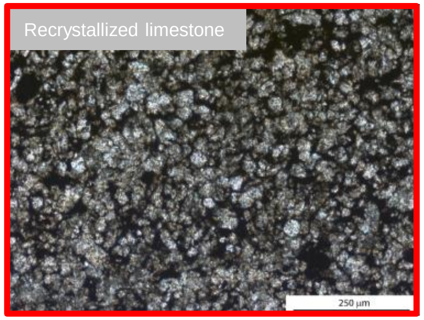


TOC = 5-8%
Φ = 8-9%
S_w = 20%
k_{eff} = 50 nD
Abundant org porosity
Lower moveable oil

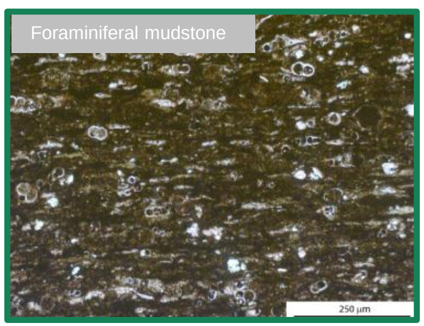


Storage (geochem) then linked to both sequence strat & diagenesis

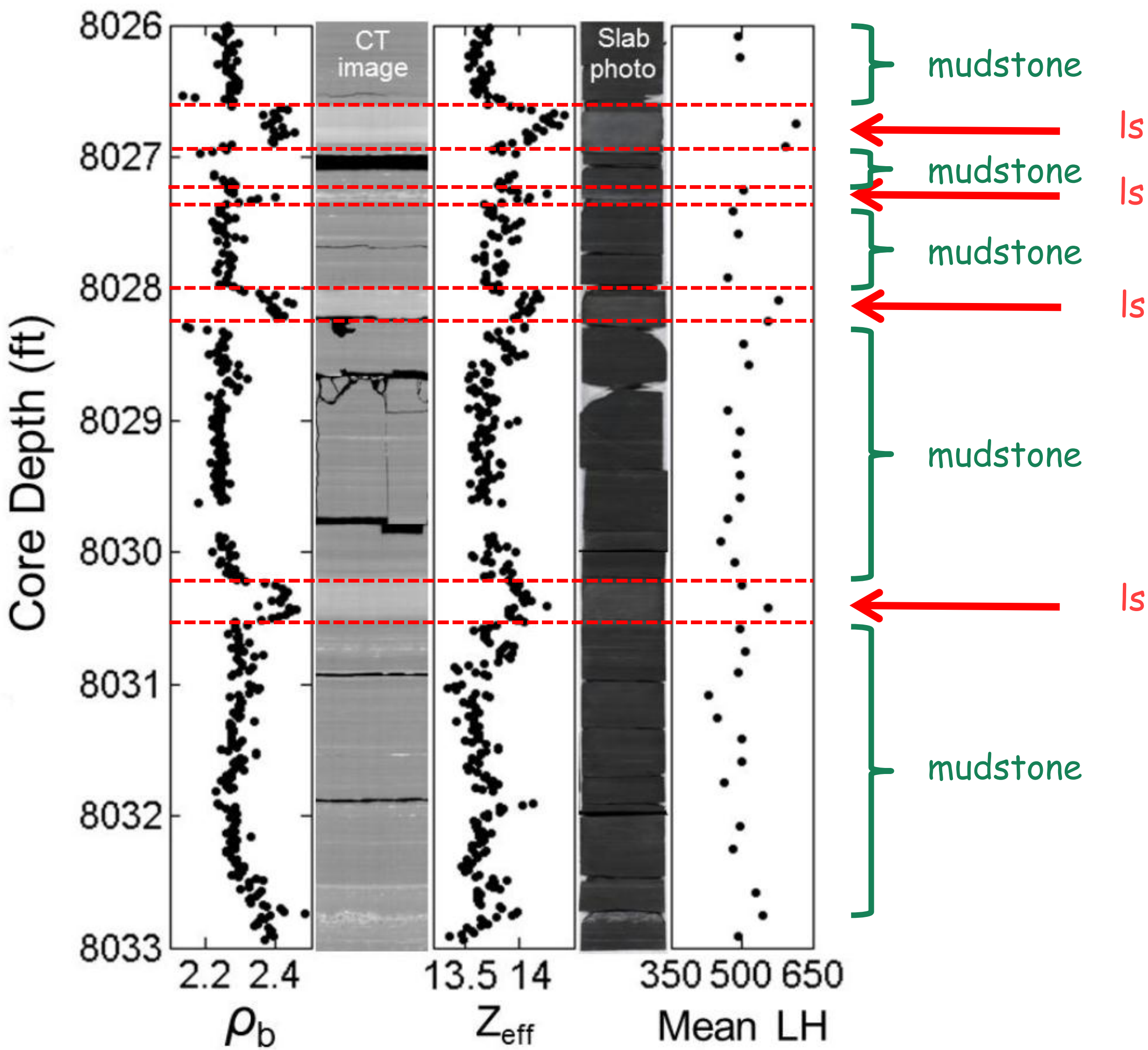
Broadly two lithologies of interest



organic lean



organic rich

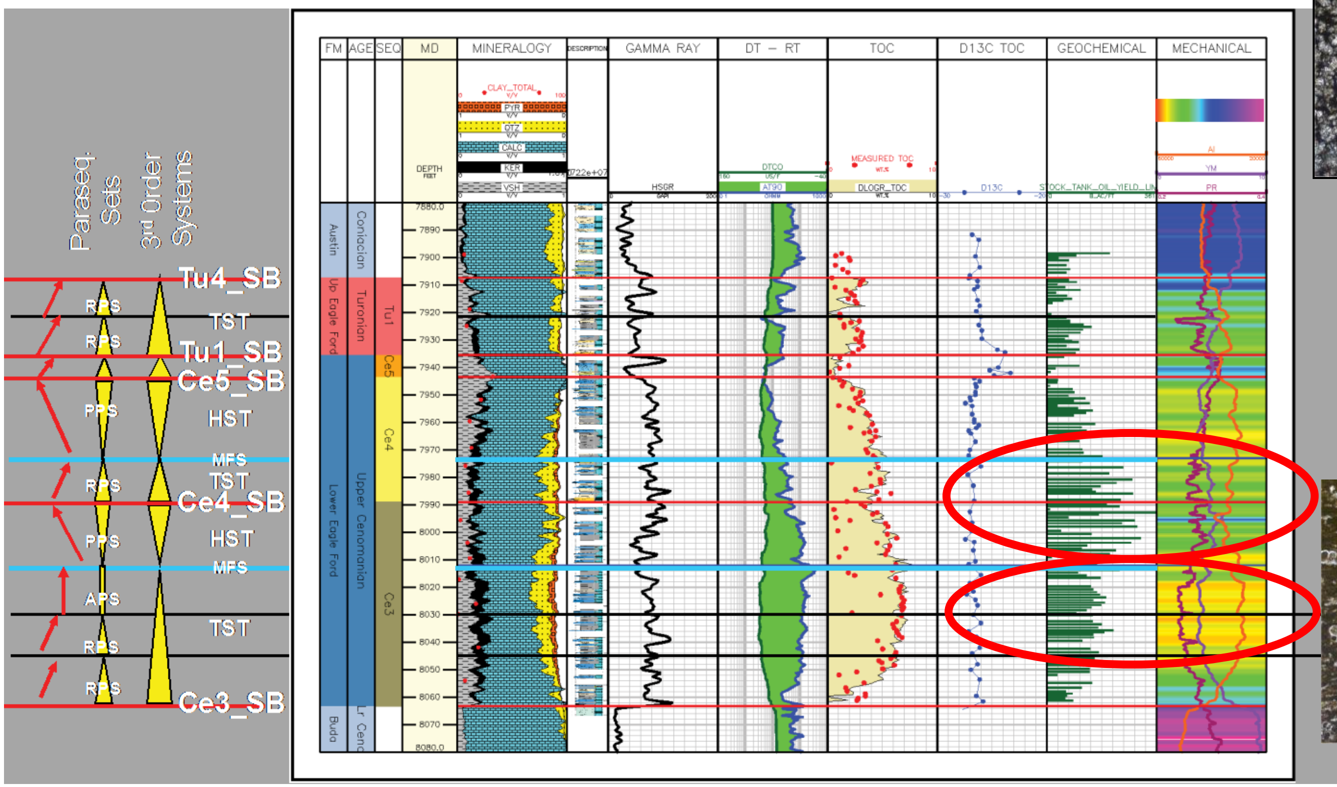


Ritz et al., 2014

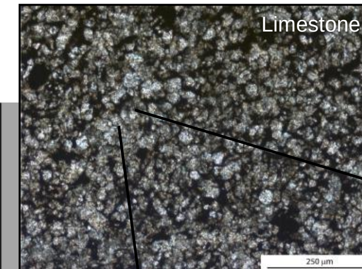
Hardness linked sequence strat (diagenesis)

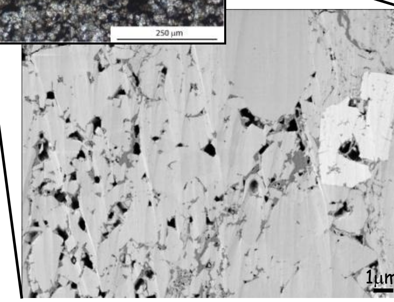
Influence of lithology on 'brittleness' & production

Lithologic (sequence strat) controls on TOC & mineralogy
Limestones harder, mudstones more ductile

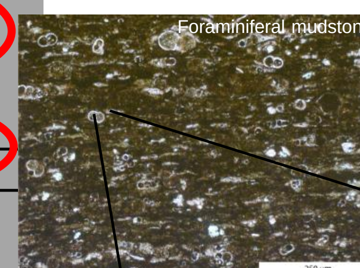


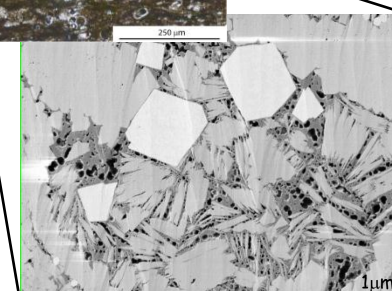
From John Guthrie and Randy Mitchell





TOC = <2%
Φ = 6-7%
S_w = 40-50%
k_{eff} = 300 nD
Interparticle pores; more calcite = more rigid. Zone of fracability & moveable HC





TOC = 5-8%
Φ = 8-9%
S_w = 20%
k_{eff} = 50 nD
Less calcite, more ductile
Zone of moveable oil

Limestones more 'fracable' & provide HC storage

Conclusions

- Porosity development—diagenesis (inorganic) & catagenesis (organic)
  - both important for HC storage & production
- Pore types related to original lithology, function of depo environment
- Inorganic (interparticle) pores in HST (interbedded) limestones
  - Early diagenesis (calcite recrystallization) led to interparticle porosity
  - Overall 'higher' perm in ls due to diagenesis
- Organic pores in organic-rich TST/MFS mudstones, thermally mature
  - Early diagenesis resulted in authigenic mineral precipitation
  - Early catagenesis resulted in occlusion of remaining pores with bitumen
- Organic pores developed the pore-filling bitumen (now pyrobitumen)
  - Organic porosity (secondary ϕ) probably began at >Ro ~1.0%
- Moveable HC in both mudstones & limestones
  - Both lithologies contribute to production
- Reservoir characterization, function of diagenesis & sequence strat

Acknowledgments

- John Guthrie (geochem), Matt Honarpour (reservoir engineering), Randy Mitchell (petrophysics), Robert Handford (sequence strat), Libby Ritz (hardness)
- Hess Corp. for support of this work and permission to present results
- Sanchez Energy Corp. for permission to present results