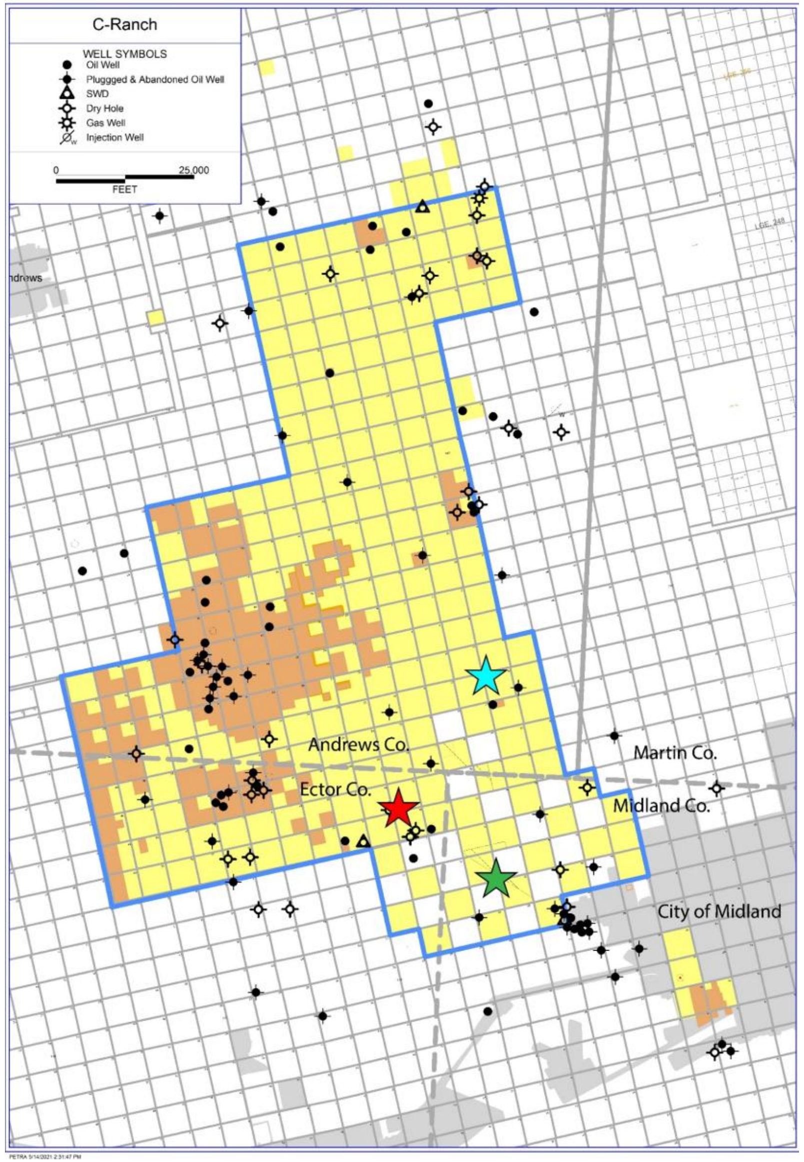
Characterization of lower Barnett unconventional source rocks Midland Basin, Texas

Dan Olive

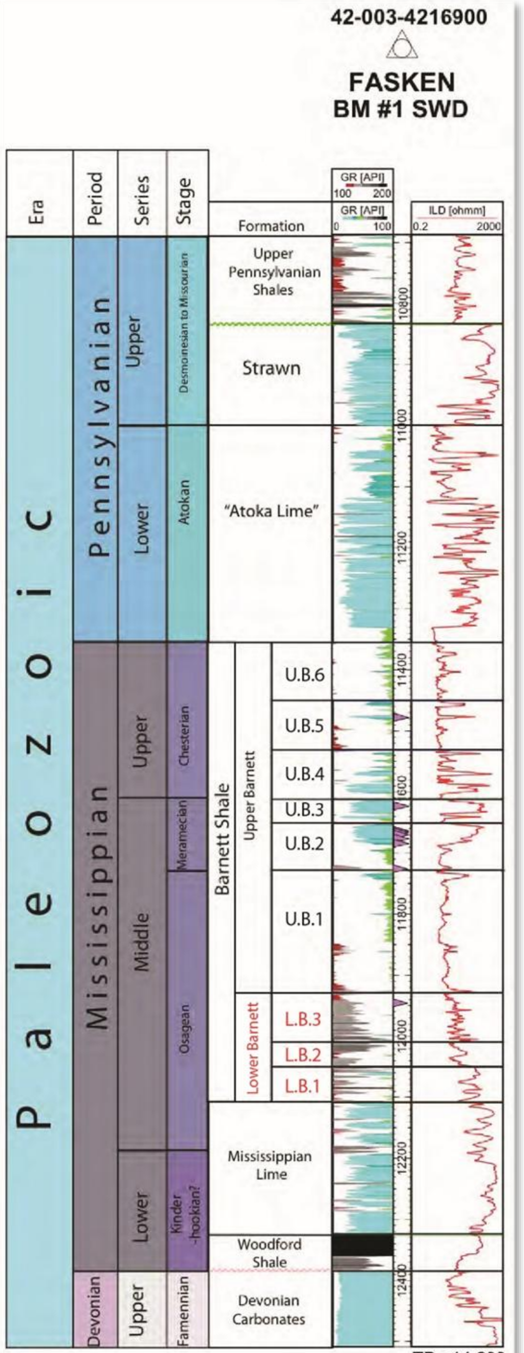
Study area

- The study area (C-Ranch) is located at the intersections of Andrews, Martin, Ector, and Midland counties.
- Red star shows Fasken Fee BK 1514 core location



Purpose

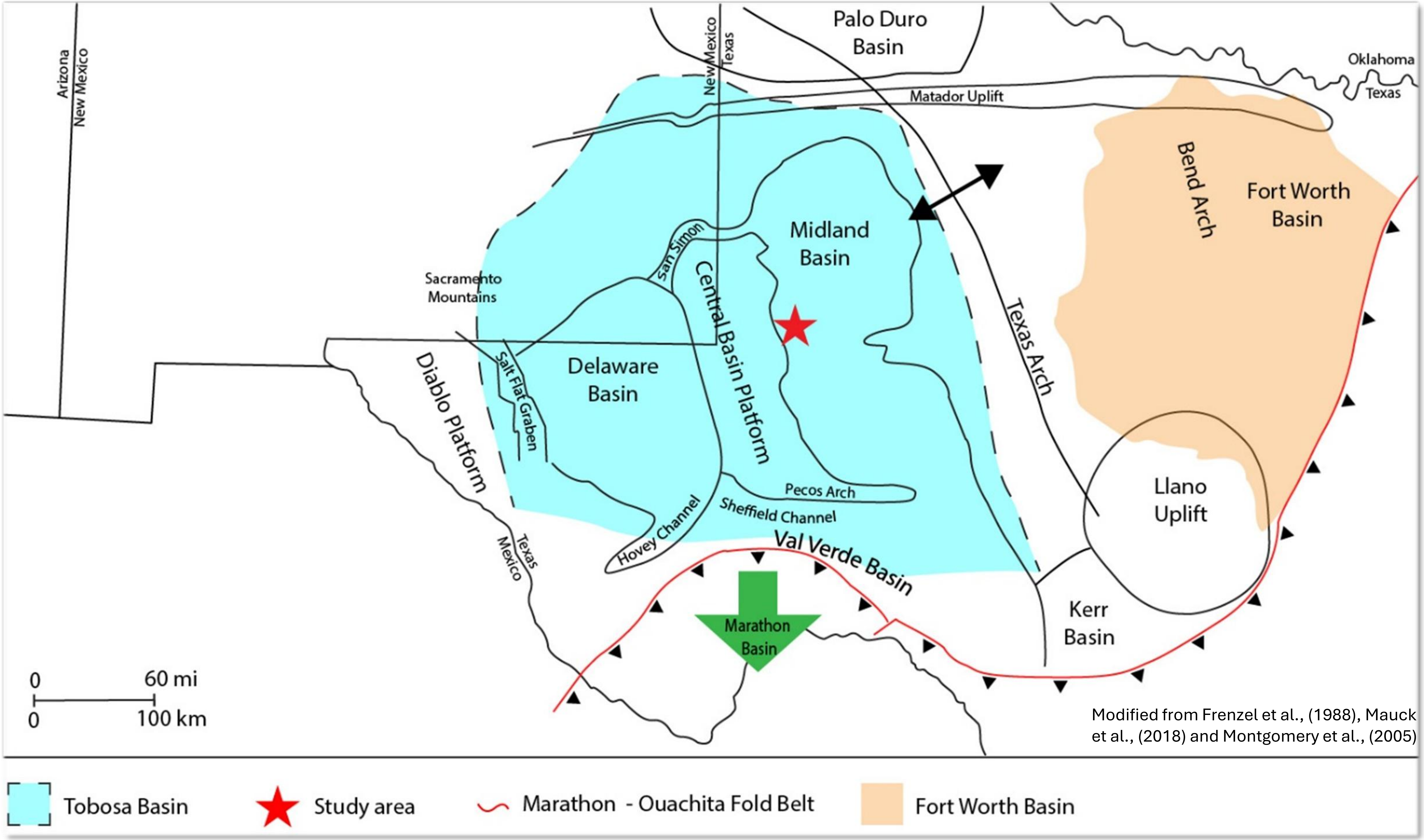
- Describe the lower Barnett on the C-Ranch
  - Define Lithofacies
  - Develop stratigraphic framework
  - Determine depositional environment
- Evaluate source rock and reservoir potential
  - Geochemical analysis of organic matter
  - Petrophysical analysis of reservoir facies
  - Provide recommendations for exploration

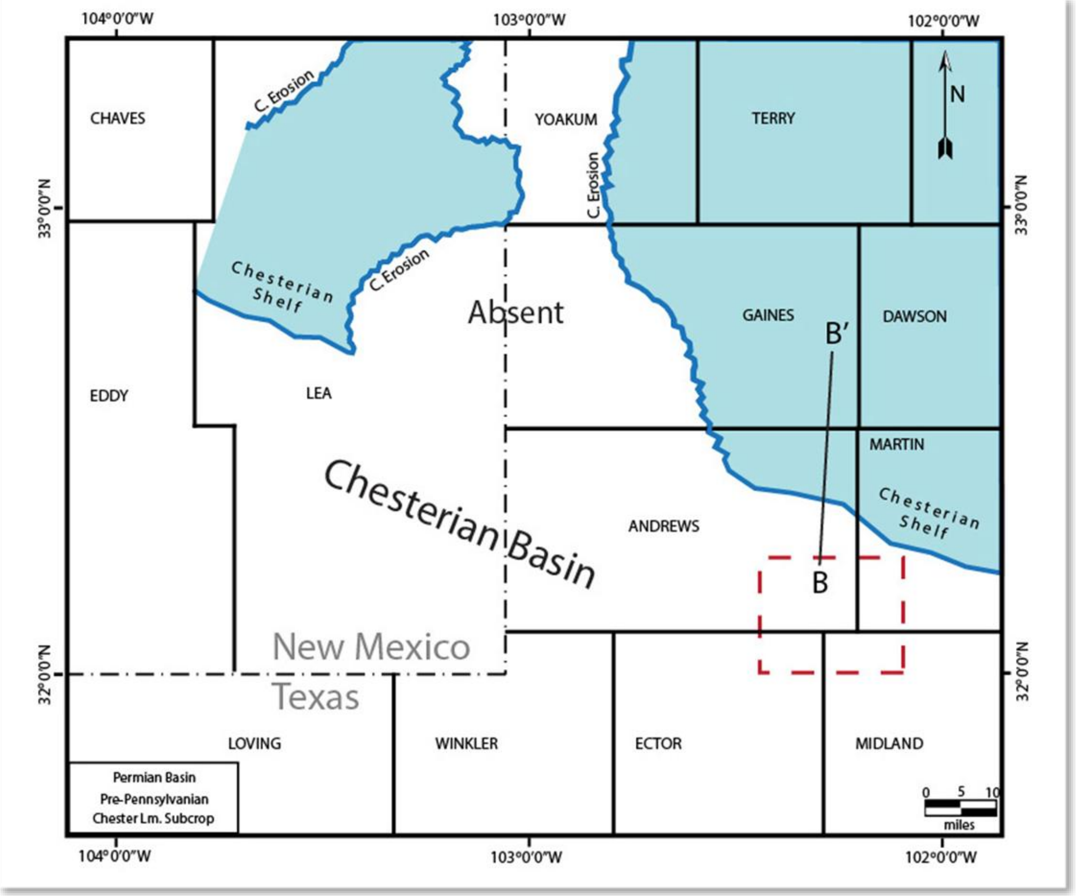


Modified from Osterlund (2012)

TD : 14,200
ELEV_KB : 3,009

Osterlund (2012) Usage in this paper	
Pennsylvanian	
Upper Barnett	U.B.6
	U.B.5
	U.B.4
	U.B.3
	U.B.2
	U.B.1
Lower Barnett	L.B.3
	L.B.2
	L.B.1
Mississippian Lime	
Woodford Shale	


Arizona
New Mexico
New Mexico
Texas
Palo Duro
Basin
Oklahoma
Texas
Matador Uplift
Bend Arch
Fort Worth
Basin
Midland
Basin
San Simon
Sacramento
Mountains
Central Basin Platform
Texas Arch
Delaware
Basin
Salt Flat Graben
Diablo Platform
Pecos Arch
Sheffield Channel
Hovey Channel
Val Verde Basin
Llano
Uplift
Texas
Mexico
Marathon
Basin
Kerr
Basin
0 60 mi
0 100 km
Modified from Frenzel et al., (1988), Mauck et al., (2018) and Montgomery et al., (2005)
Tobosa Basin
Study area
Marathon - Ouachita Fold Belt
Fort Worth Basin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32°0'0"N
CHAVES
YOAKUM
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EDDY
LEA
GAINES
DAWSON
MARTIN
ANDREWS
LOVING
WINKLER
ECTOR
MIDLAND
C. Erosion
Chesterian Shelf
Absent
Chesterian Basin
New Mexico
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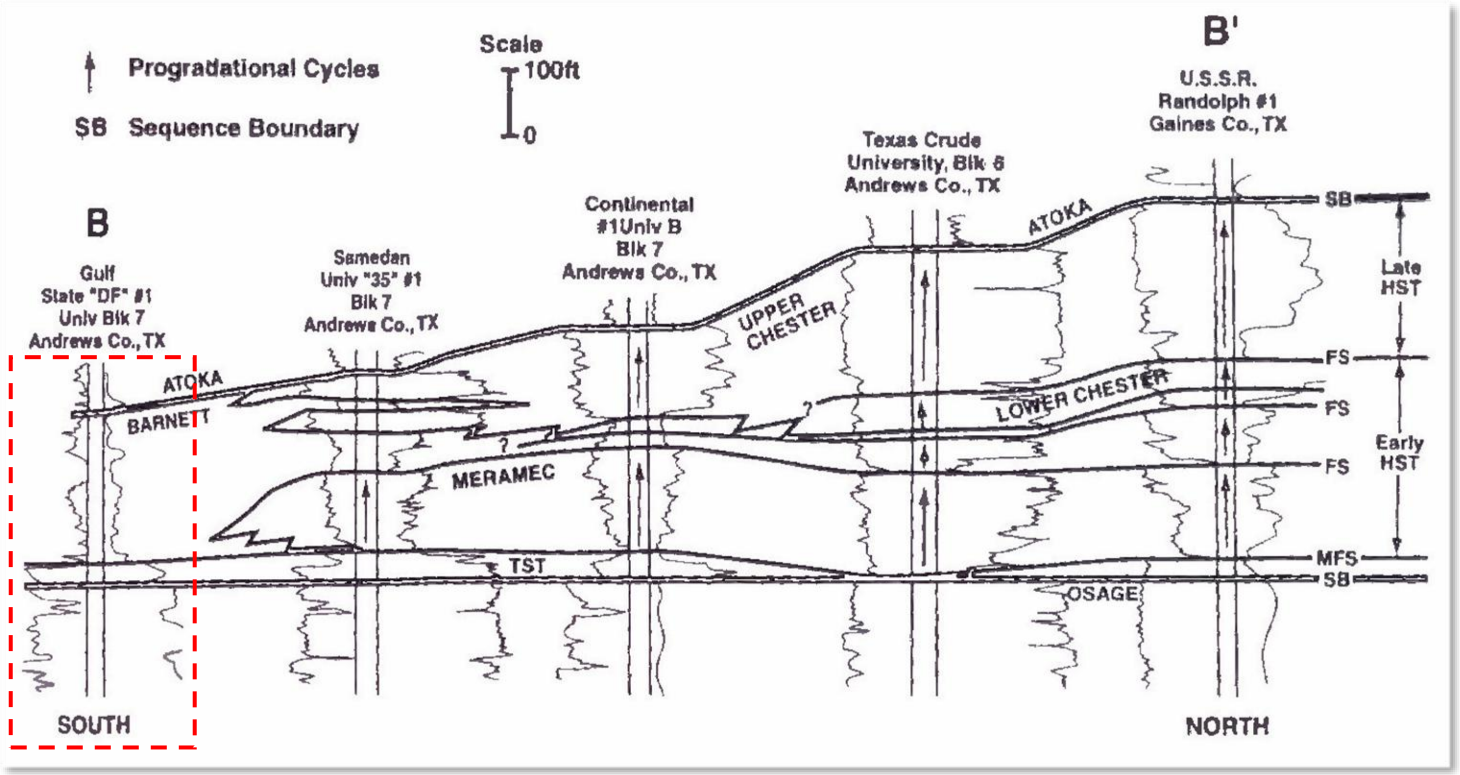
miles
Permian Basin
Pre-Pennsylvanian
Chester Lm. Subcrop


Progradational Cycles
SB Sequence Boundary
Scale
100ft
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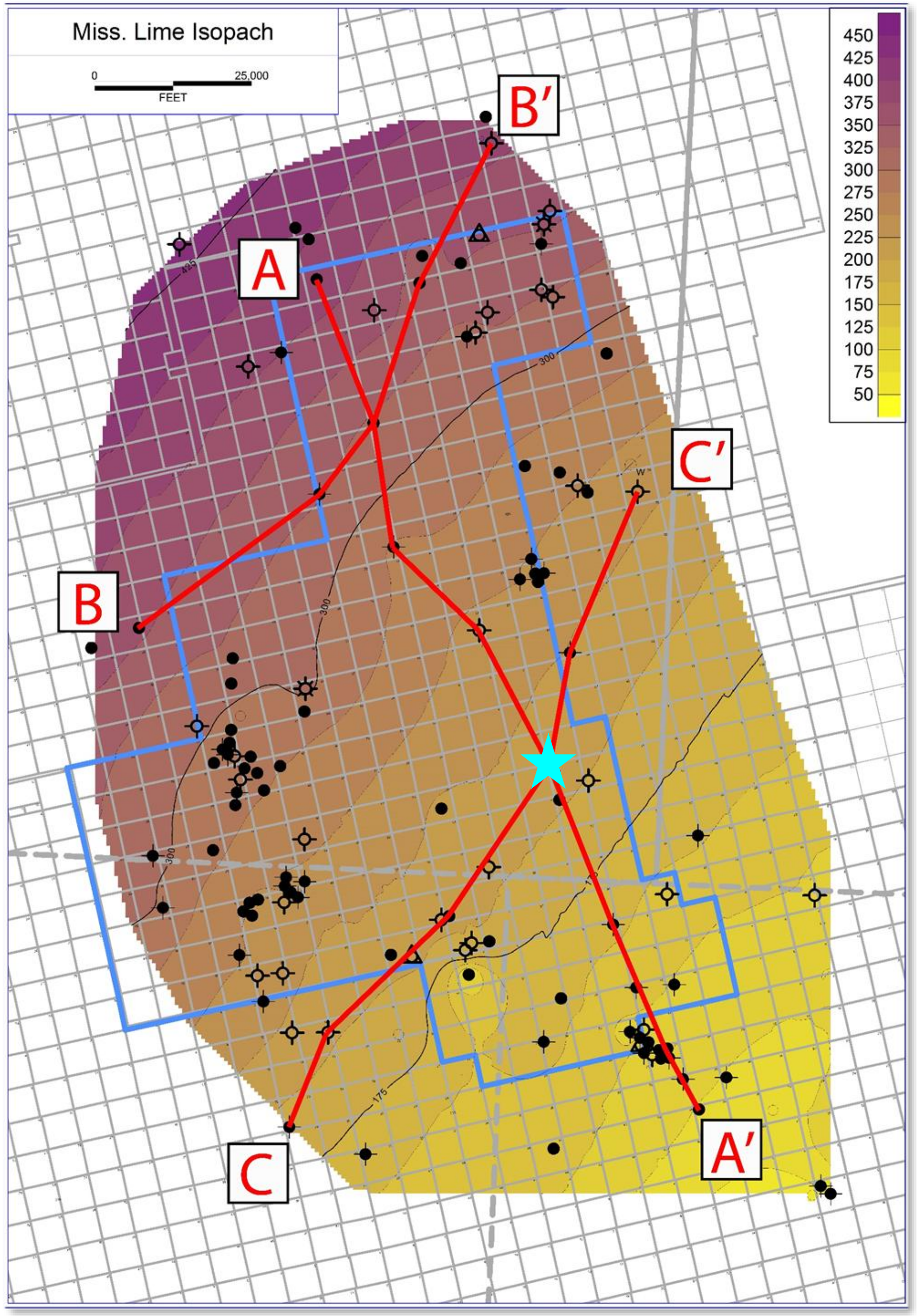
State "DF" #1
Univ Blk 7
Andrews Co., TX
Samedan
Univ "35" #1
Blk 7
Andrews Co., TX
Continental
#1Univ B
Blk 7
Andrews Co., TX
Texas Crude
University, Blk 6
Andrews Co., TX
U.S.S.R.
Randolph #1
Gaines Co., TX
ATOKA
BARNETT
UPPER CHESTER
LOWER CHESTER
MERAMEC
TST
OSAGE
SB
FS
MFS
Late HST
Early HST
SOUTH
NORTH

Stratigraphy and Structure



Miss. Lime Isopach
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200
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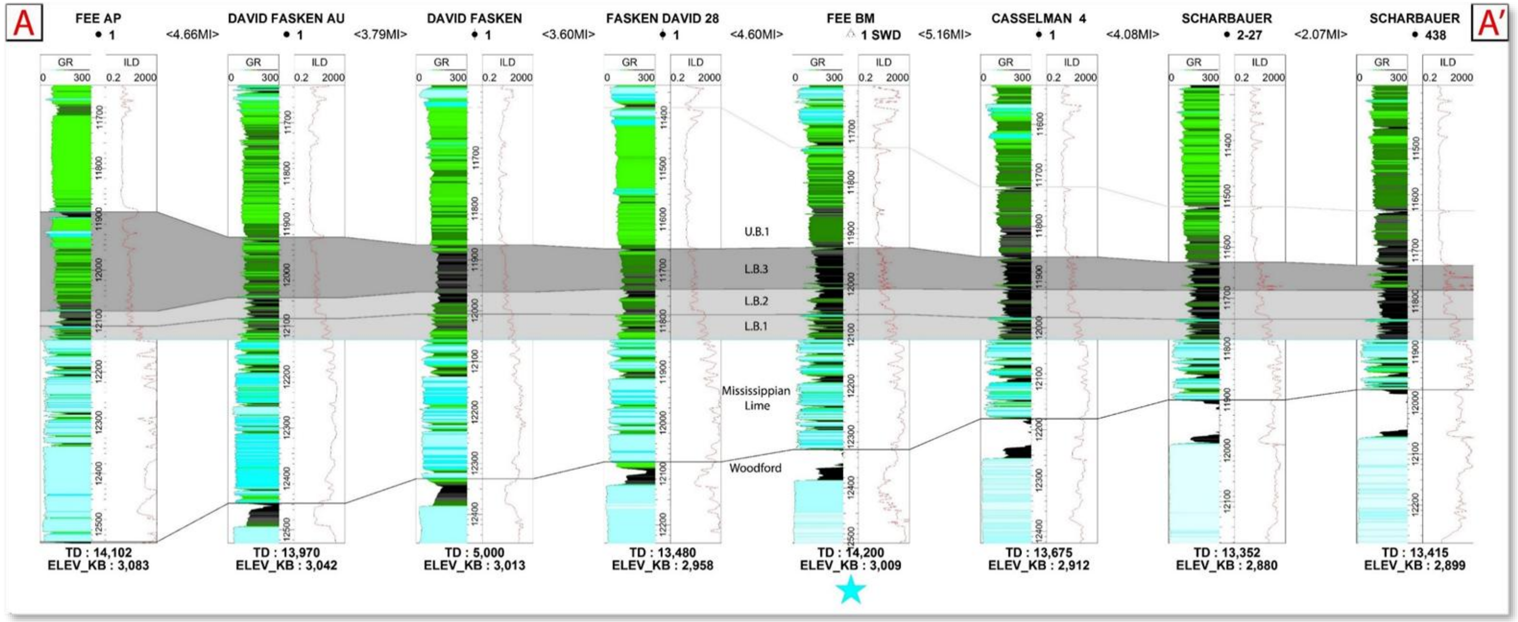
B
C
A'
300
175



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CASSELMAN 4 1
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SCHARBAUER 2-27
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SCHARBAUER 438
A'
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ILD
0 300
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U.B.1
L.B.3
L.B.2
L.B.1
Mississippian Lime
Woodford
TD : 14,102
ELEV_KB : 3,083
TD : 13,970
ELEV_KB : 3,042
TD : 5,000
ELEV_KB : 3,013
TD : 13,480
ELEV_KB : 2,958
TD : 14,200
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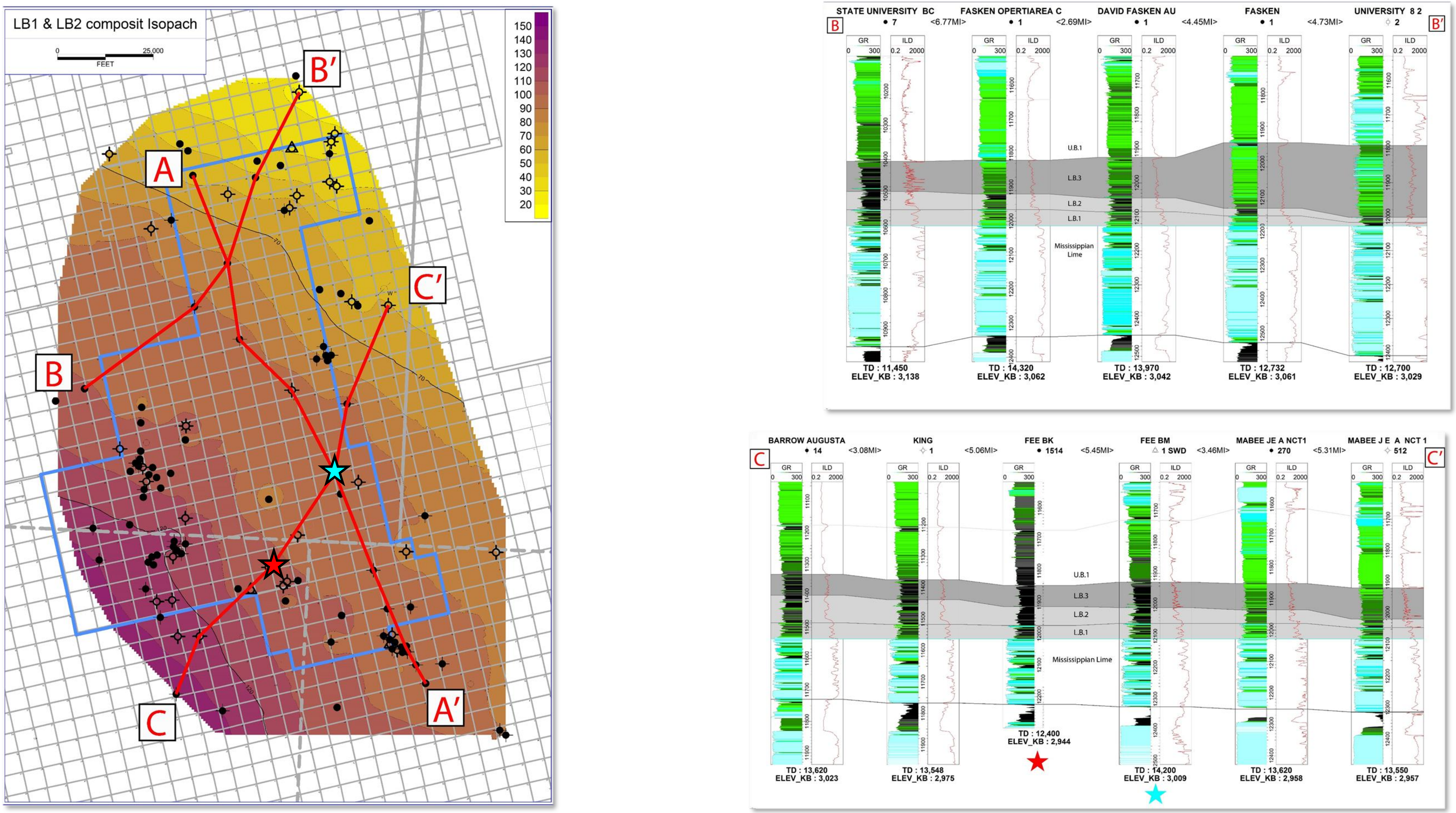
LB1 & LB2 composit Isopach
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C′
STATE UNIVERSITY BC
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FASKEN OPERTIAREA C
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DAVID FASKEN AU
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FASKEN
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UNIVERSITY 8 2
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GR
ILD
U.B.1
L.B.3
L.B.2
L.B.1
Mississippian Lime
TD : 11,450
ELEV_KB : 3,138
TD : 14,320
ELEV_KB : 3,062
TD : 13,970
ELEV_KB : 3,042
TD : 12,732
ELEV_KB : 3,061
TD : 12,700
ELEV_KB : 3,029
BARROW AUGUSTA
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KING
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FEE BK
1514
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FEE BM
1 SWD
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MABEE JE A NCT1
270
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MABEE J E A NCT 1
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TD : 13,620
ELEV_KB : 3,023
TD : 13,548
ELEV_KB : 2,975
TD : 12,400
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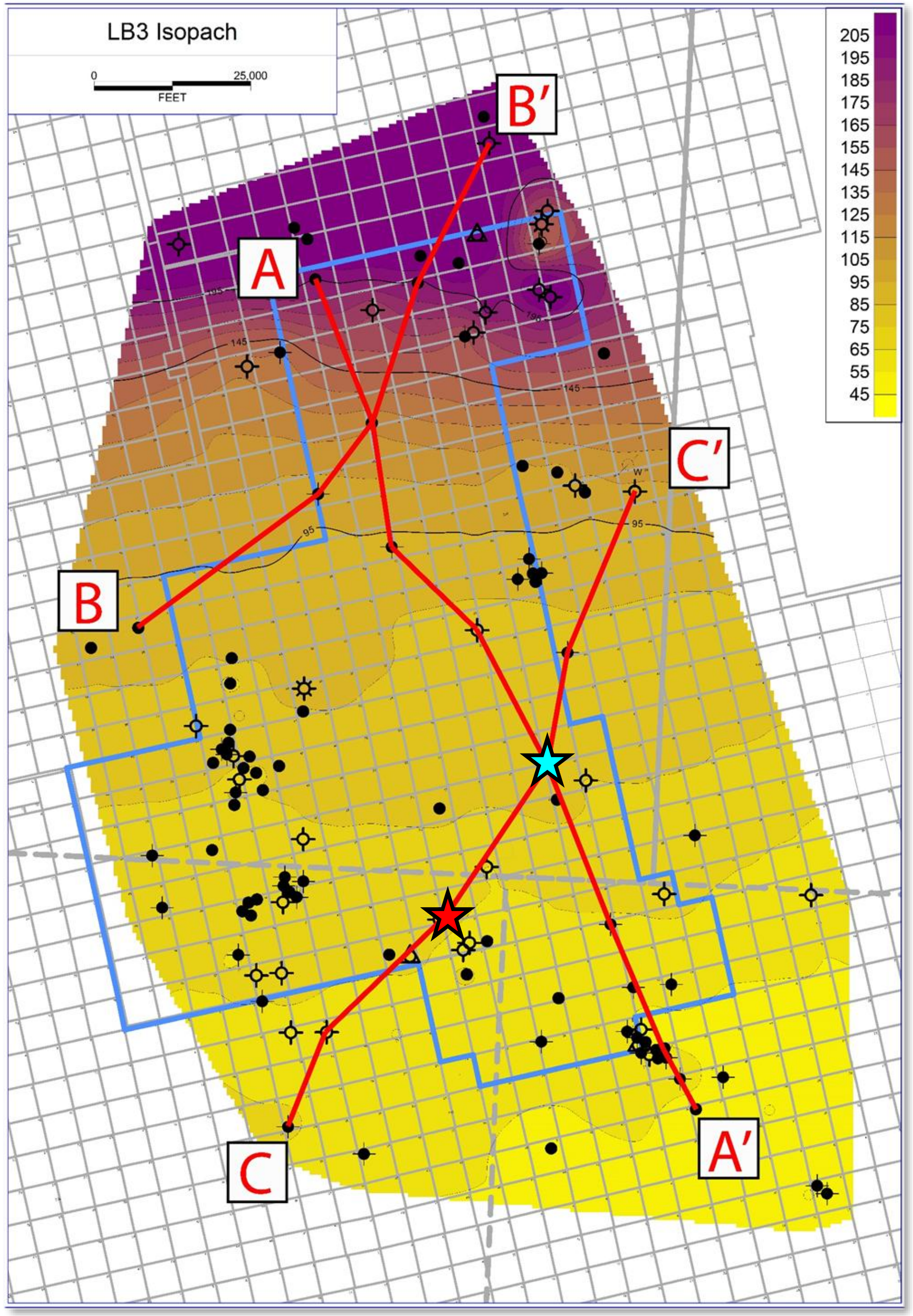
ELEV_KB : 3,009
TD : 13,620
ELEV_KB : 2,958
TD : 13,550
ELEV_KB : 2,957


LB3 Isopach
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FEET
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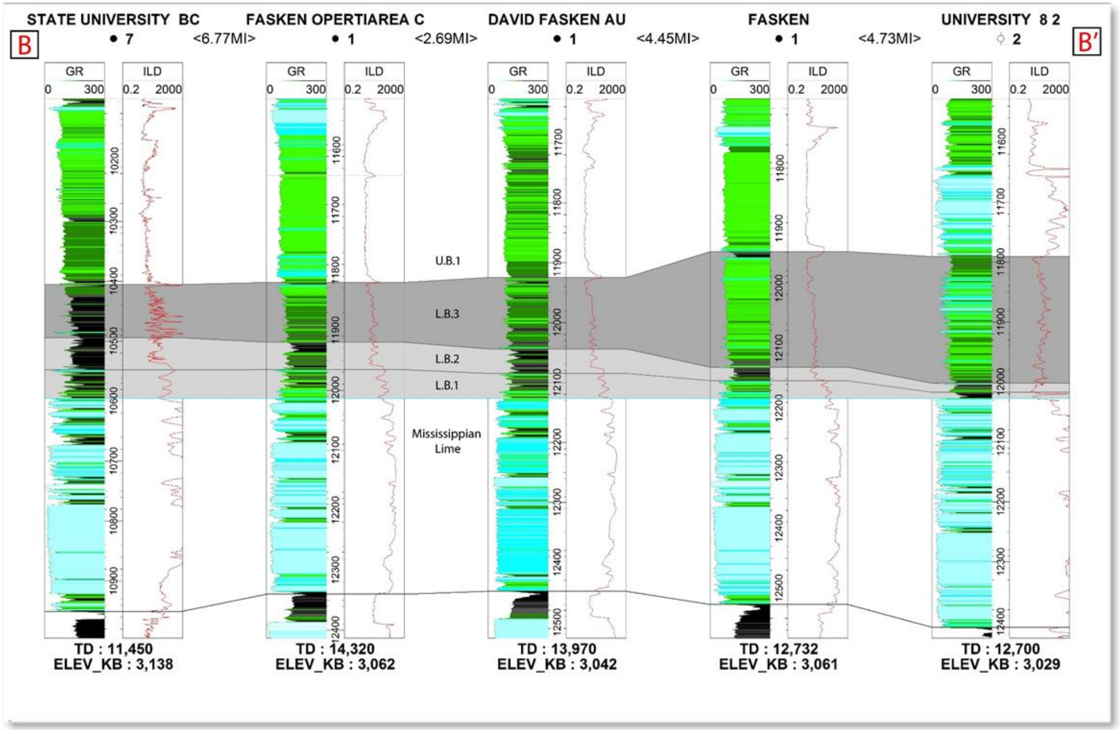
A′
B
B′
C
C′
145
95


B
B′
STATE UNIVERSITY BC 7
<6.77MI>
FASKEN OPERTIAREA C 1
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DAVID FASKEN AU 1
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FASKEN 1
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UNIVERSITY 8 2 2
GR
ILD
0 300
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U.B.1
L.B.3
L.B.2
L.B.1
Mississippian Lime
TD : 11,450
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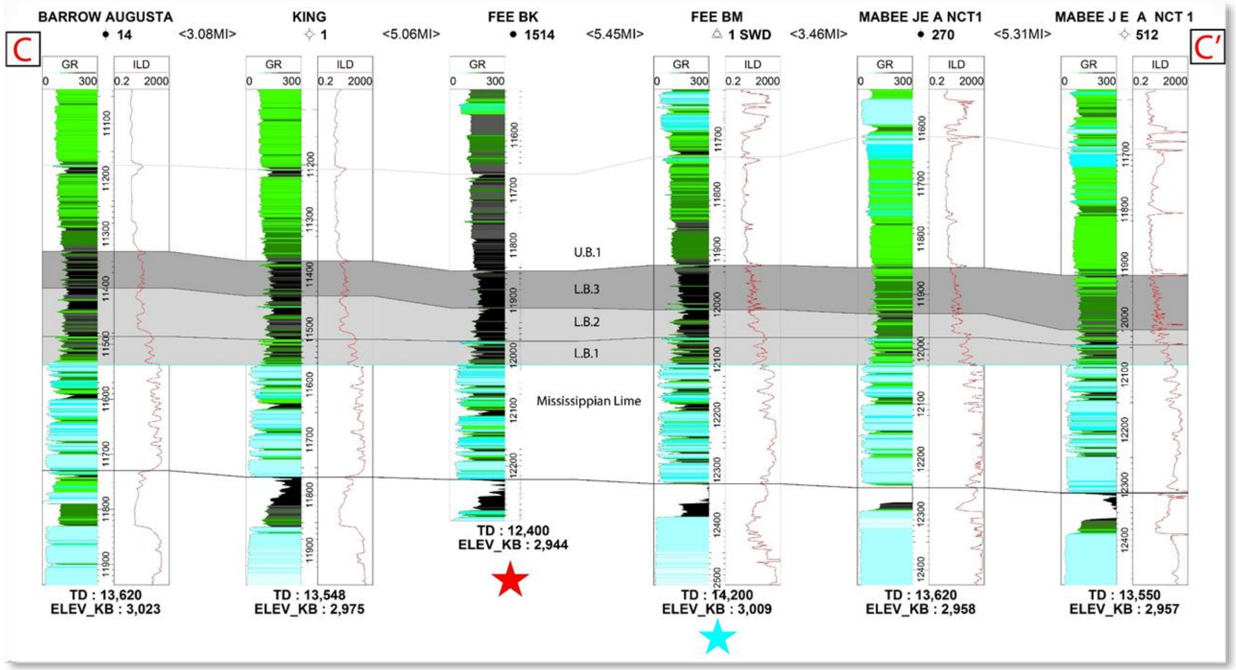
TD : 12,732
ELEV_KB : 3,061
TD : 12,700
ELEV_KB : 3,029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C′
BARROW AUGUSTA 14
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KING 1
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FEE BK 1514
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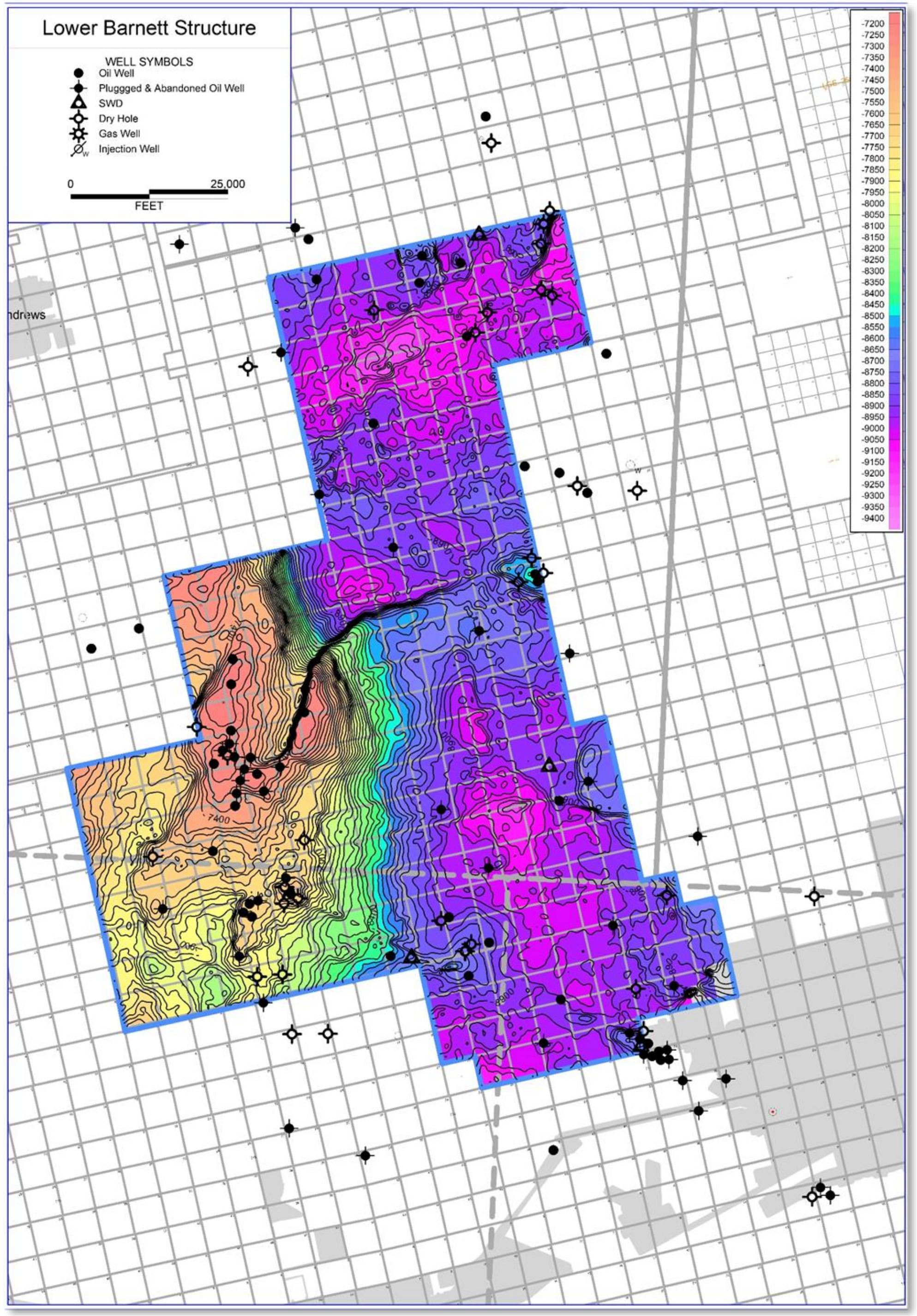
FEE BM 1 SWD
<3.46MI>
MABEE JE A NCT1 270
<5.31MI>
MABEE J E A NCT 1 512
GR
ILD
0 300
0.2 2000
U.B.1
L.B.3
L.B.2
L.B.1
Mississippian Lime
TD : 13,620
ELEV_KB : 3,023
TD : 13,548
ELEV_KB : 2,975
TD : 12,400
ELEV_KB : 2,944
TD : 14,200
ELEV_KB : 3,009
TD : 13,620
ELEV_KB : 2,958
TD : 13,550
ELEV_KB : 2,957

Structure

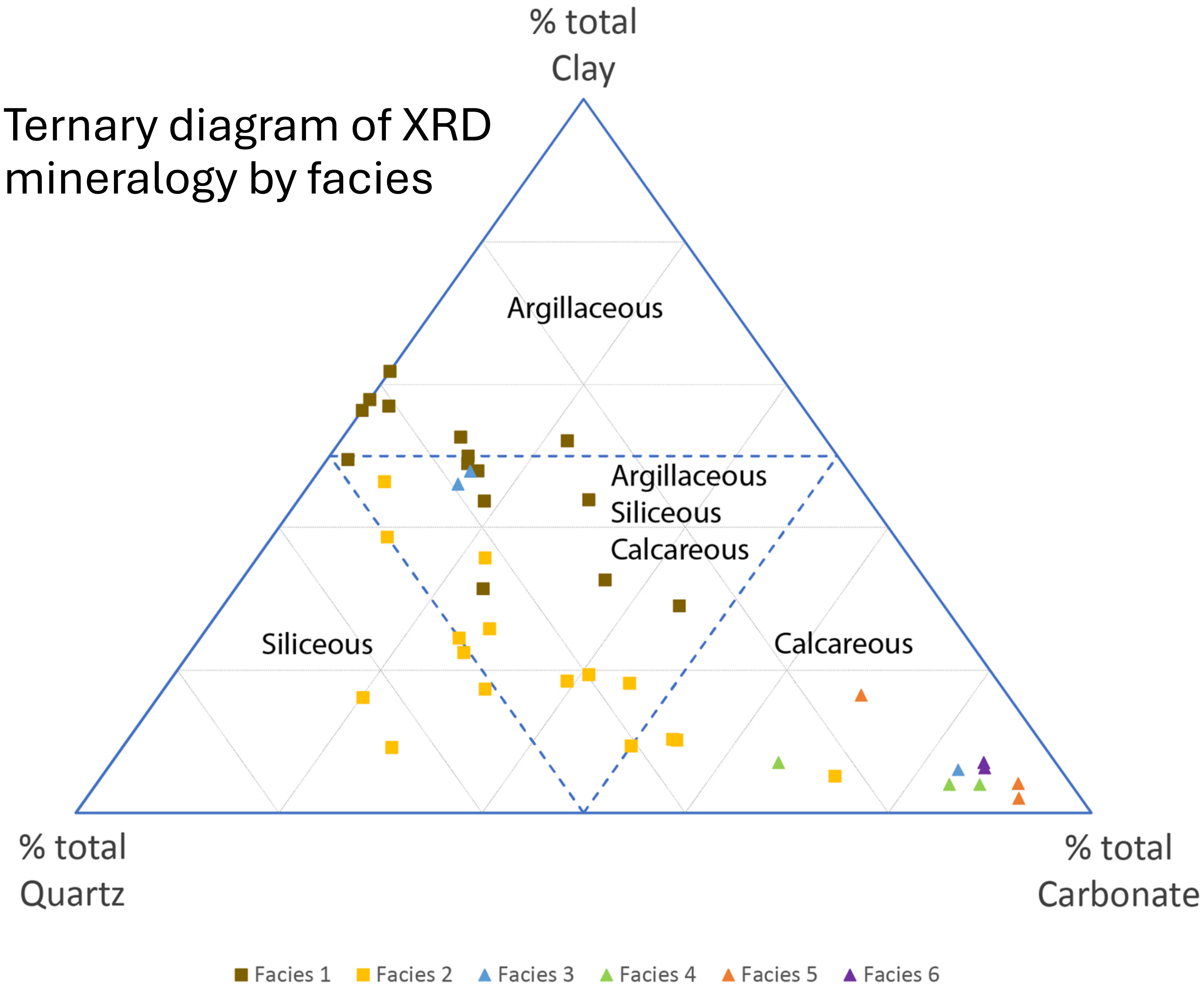
- Structure contour of the top of the lower Barnett generated from 3D seismic and well control
- Depth to the top of the lower Barnett from sea level ranges from -7000 feet in the west to -9400 feet in the east

Upper Barnett	U.B.6
	U.B.5
	U.B.4
	U.B.3
	U.B.2
	U.B.1
Lower Barnett	L.B.3
	L.B.2
	L.B.1

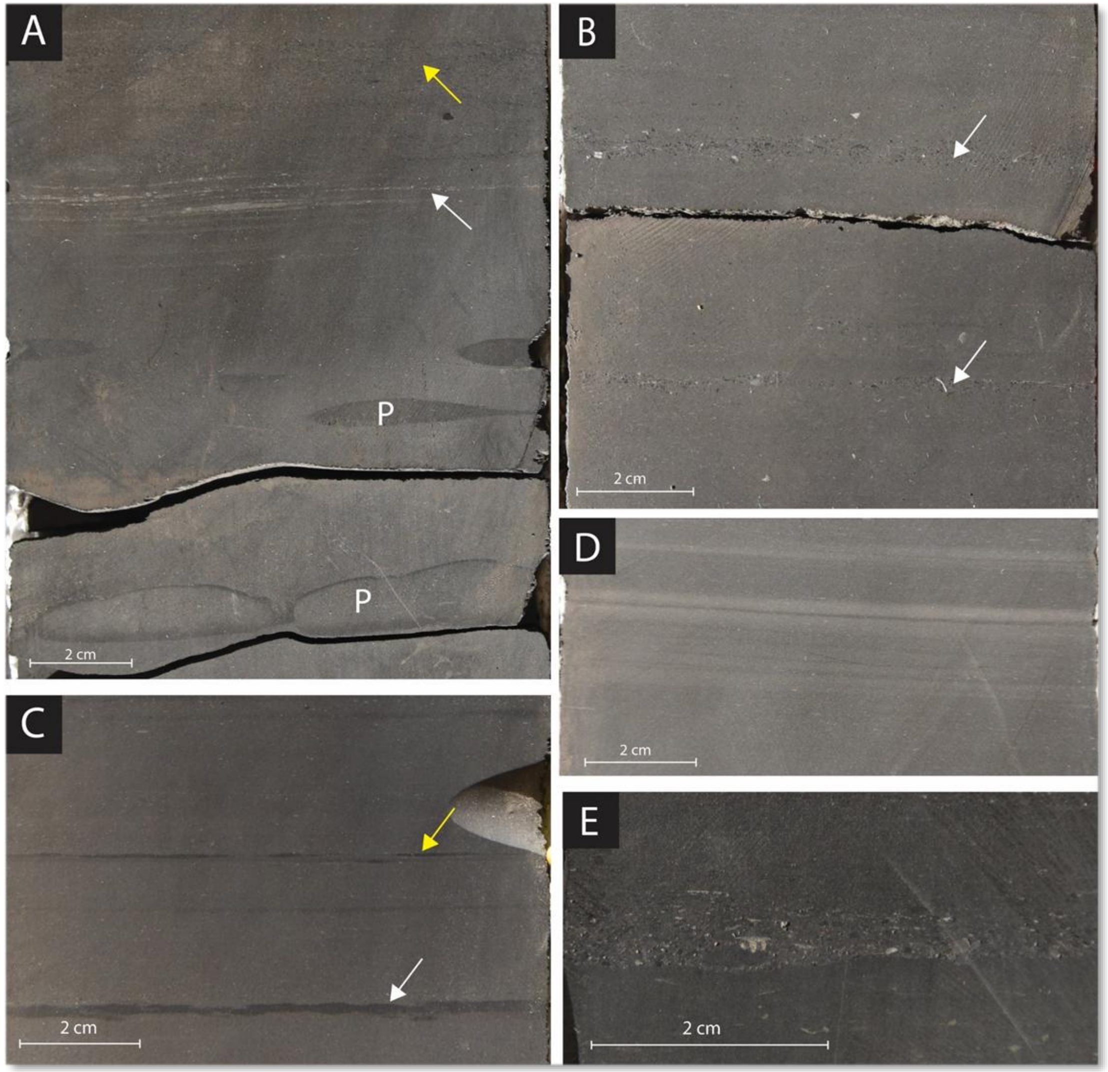


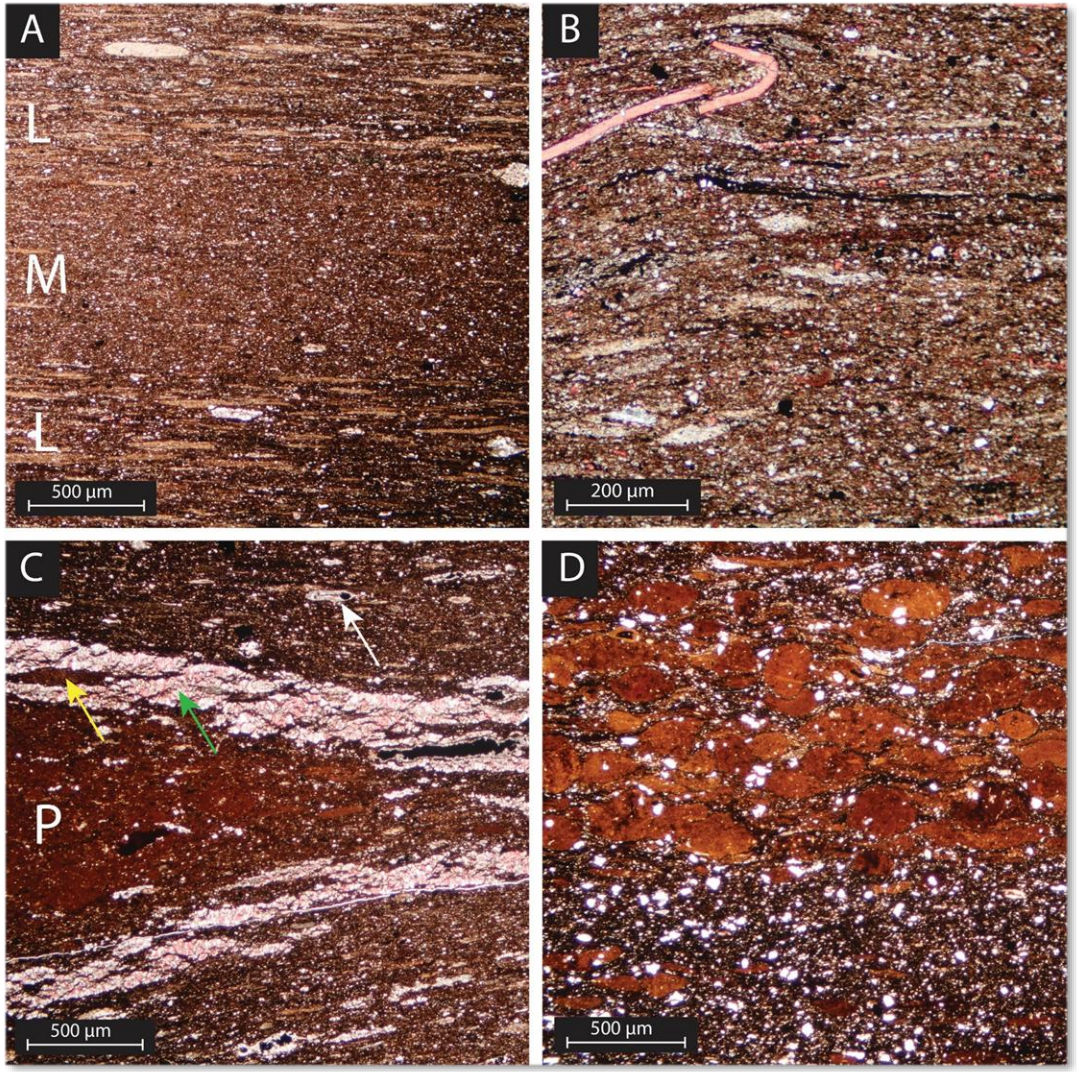
Lithofacies

Ternary diagram of XRD mineralogy by facies



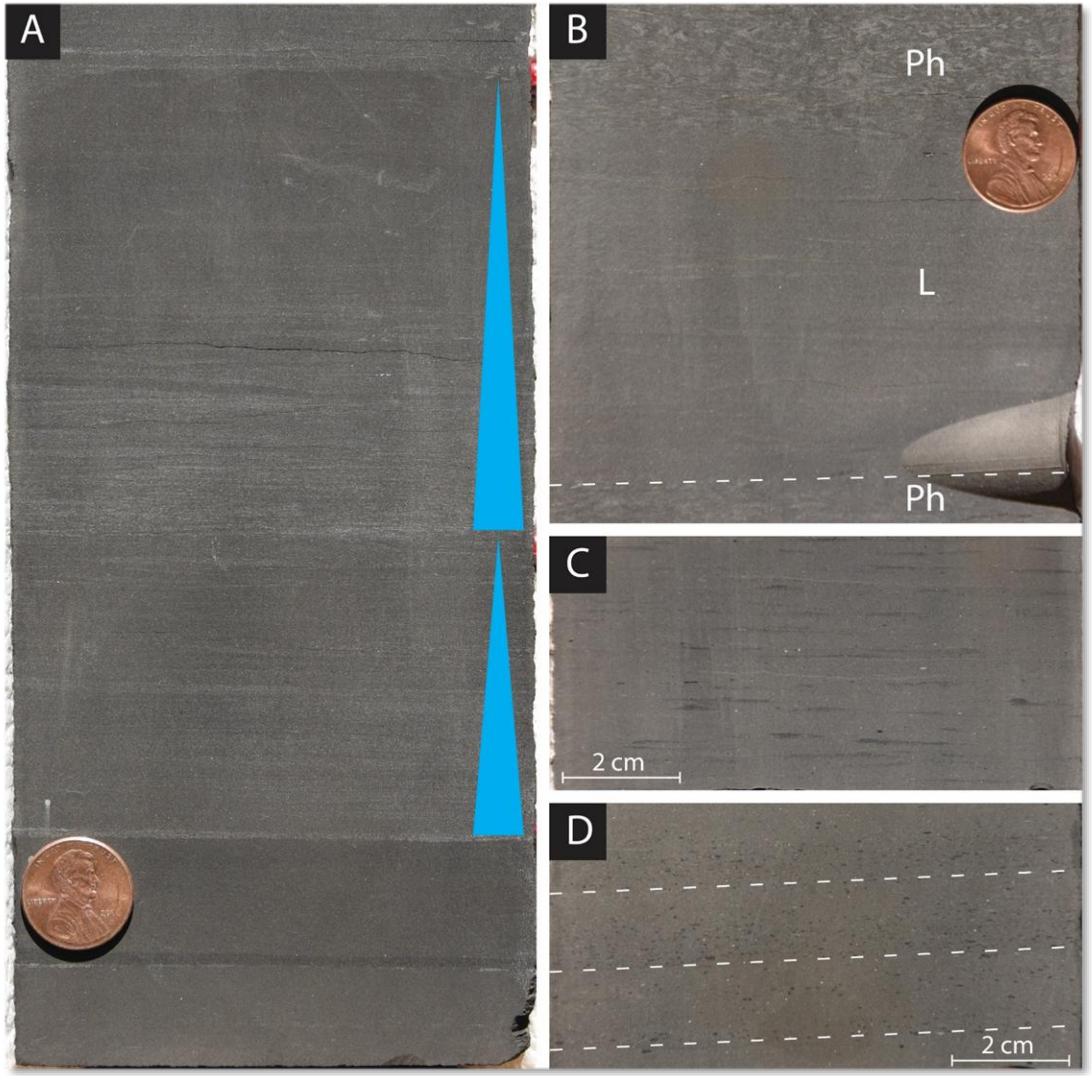
Facies 1. Fine to medium argillaceous siliceous mudstone; Pyritic, nodular, lenticular, laminated to massive

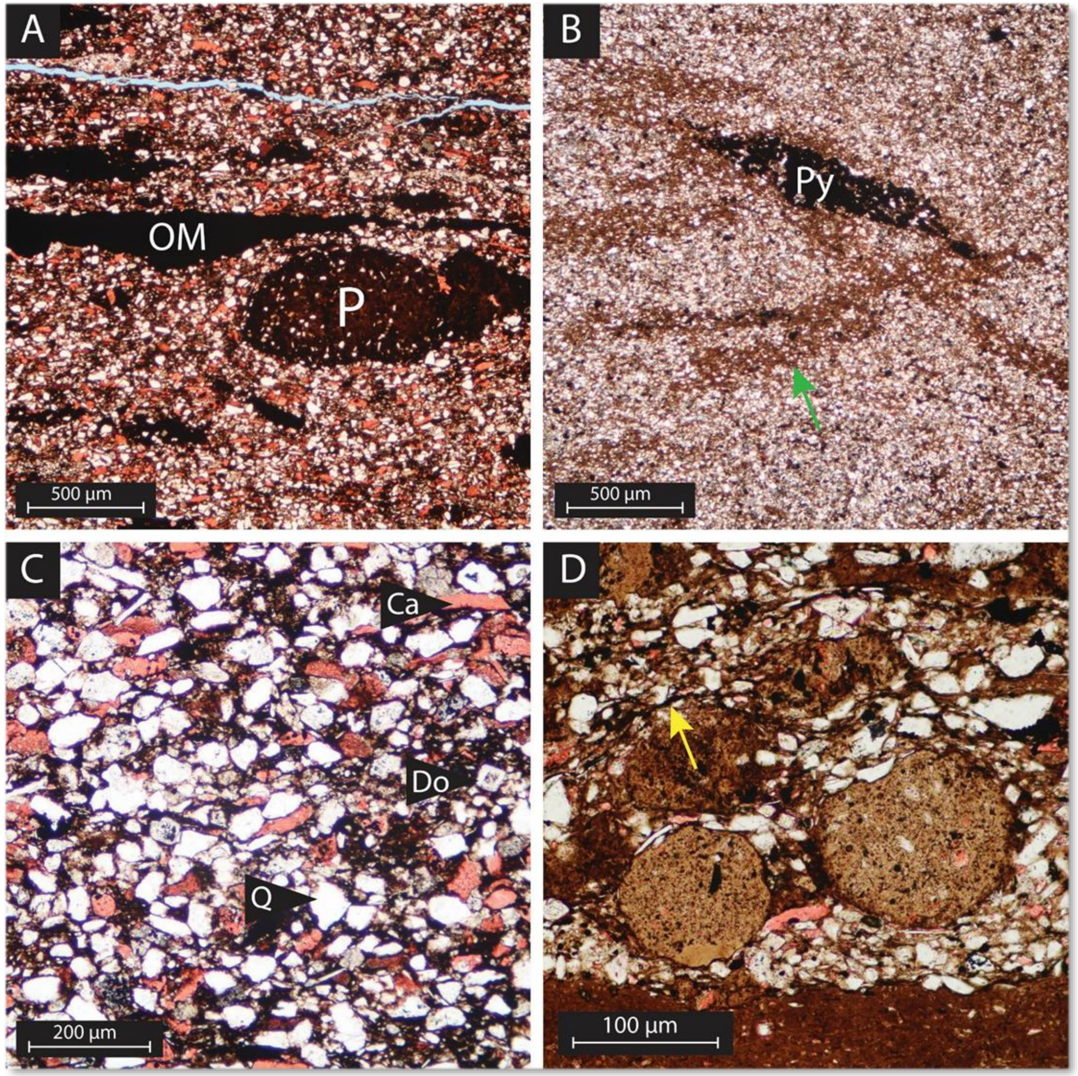




Average porosity = 1.08%   Average permeability = 0.0001mD

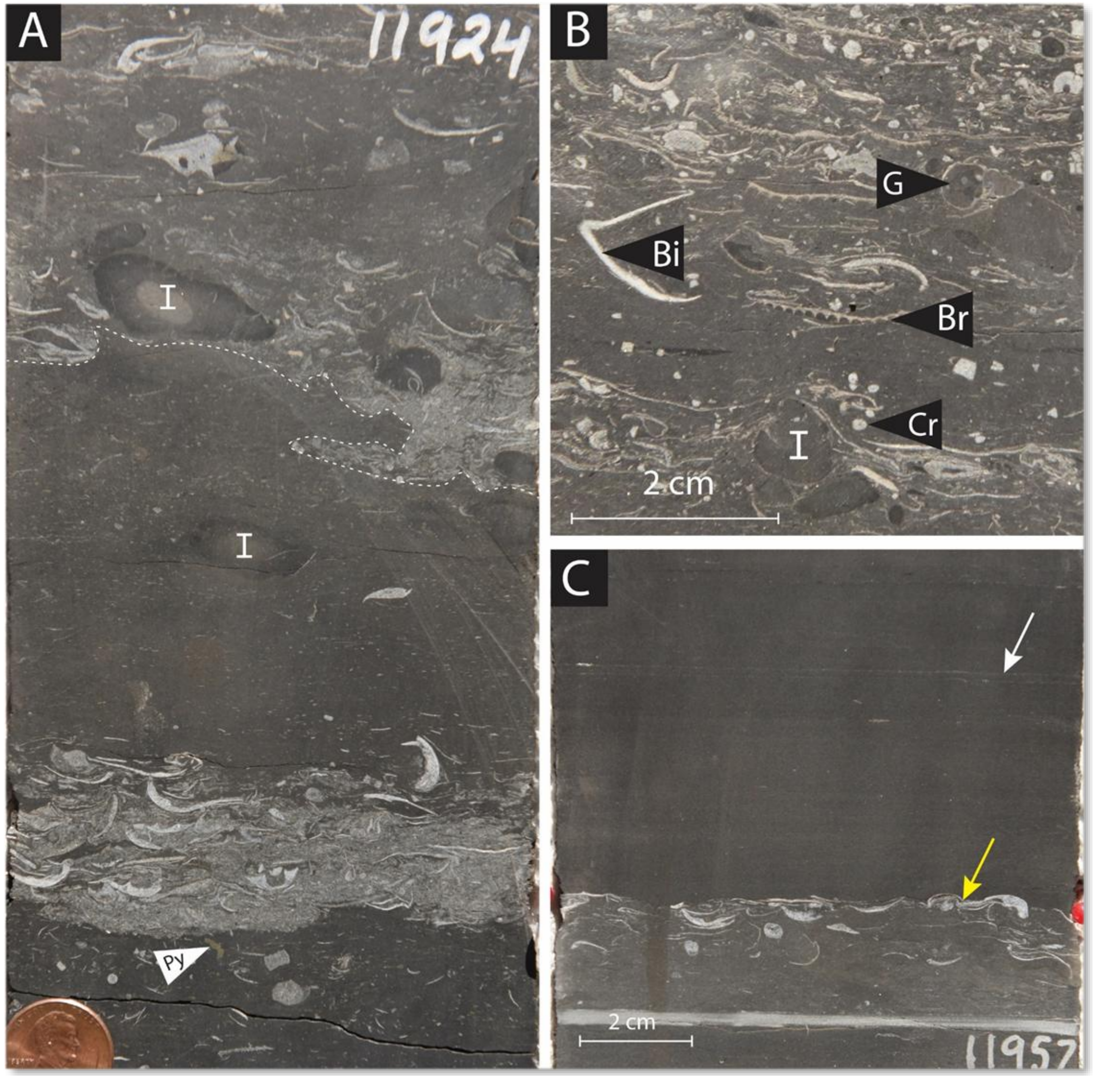
Facies 2. Medium to coarse siliceous calcareous to siliceous argillaceous mudstone; Laminated to burrowed

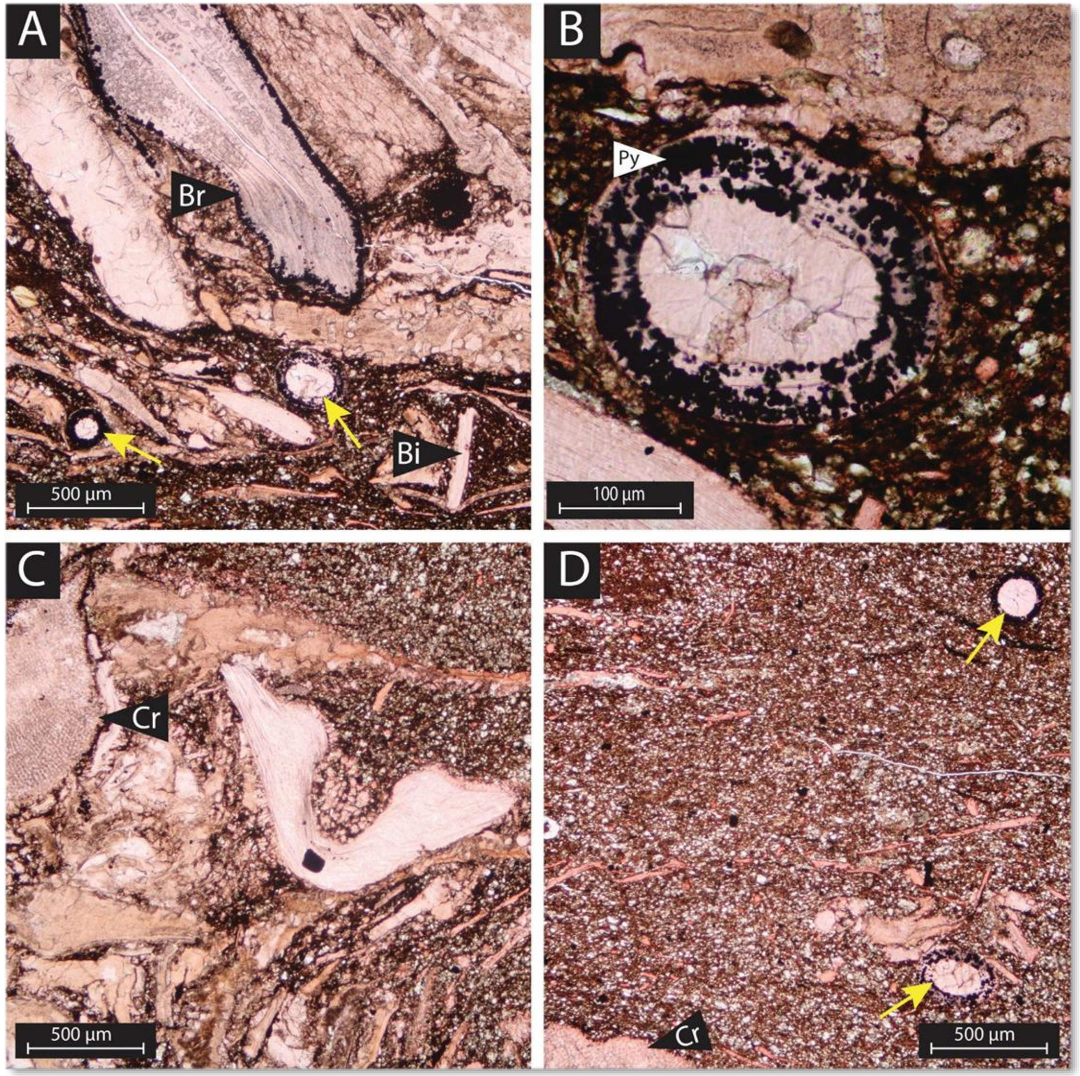




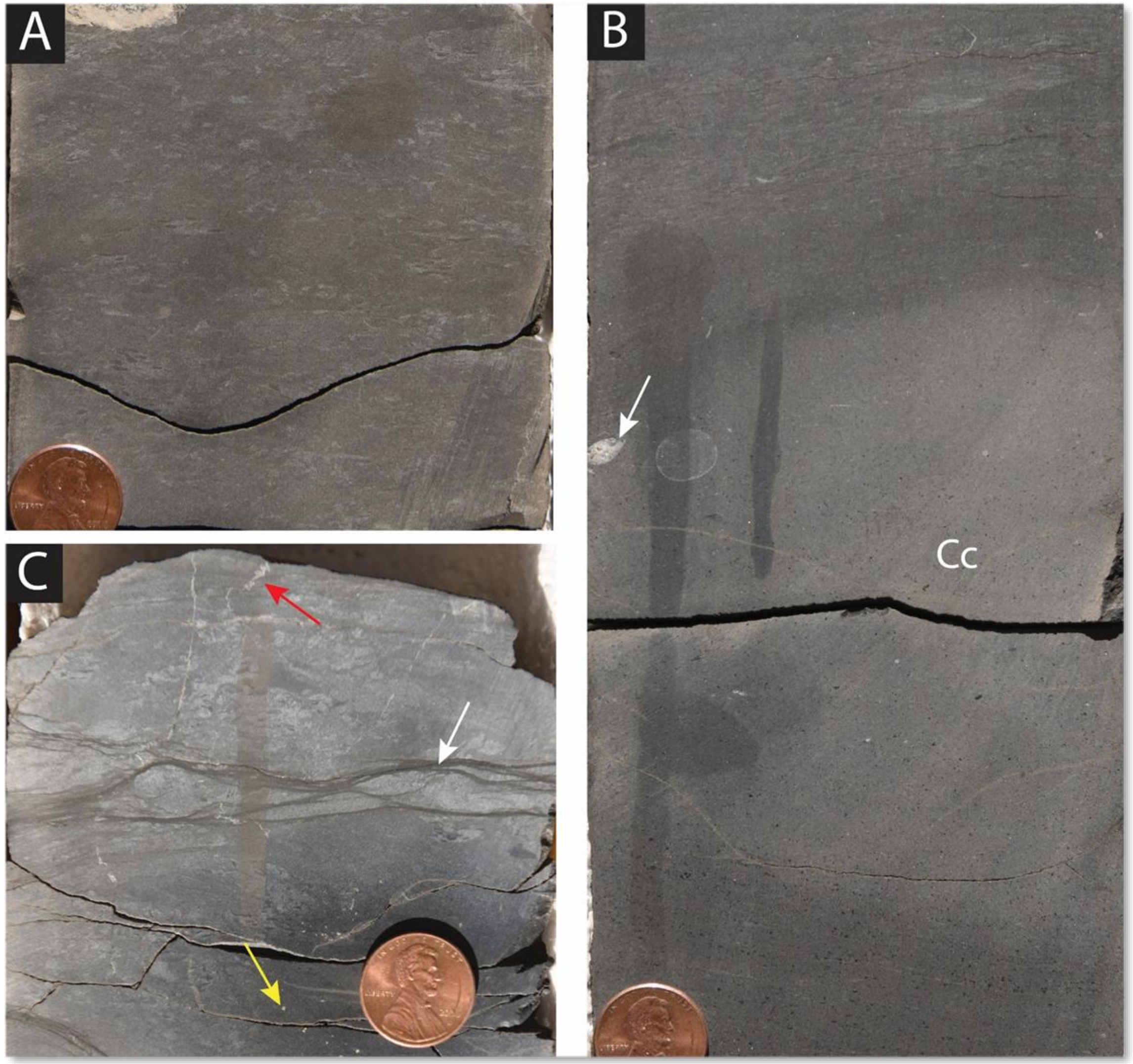
Average porosity = 1.52%   Average permeability = 0.02mD

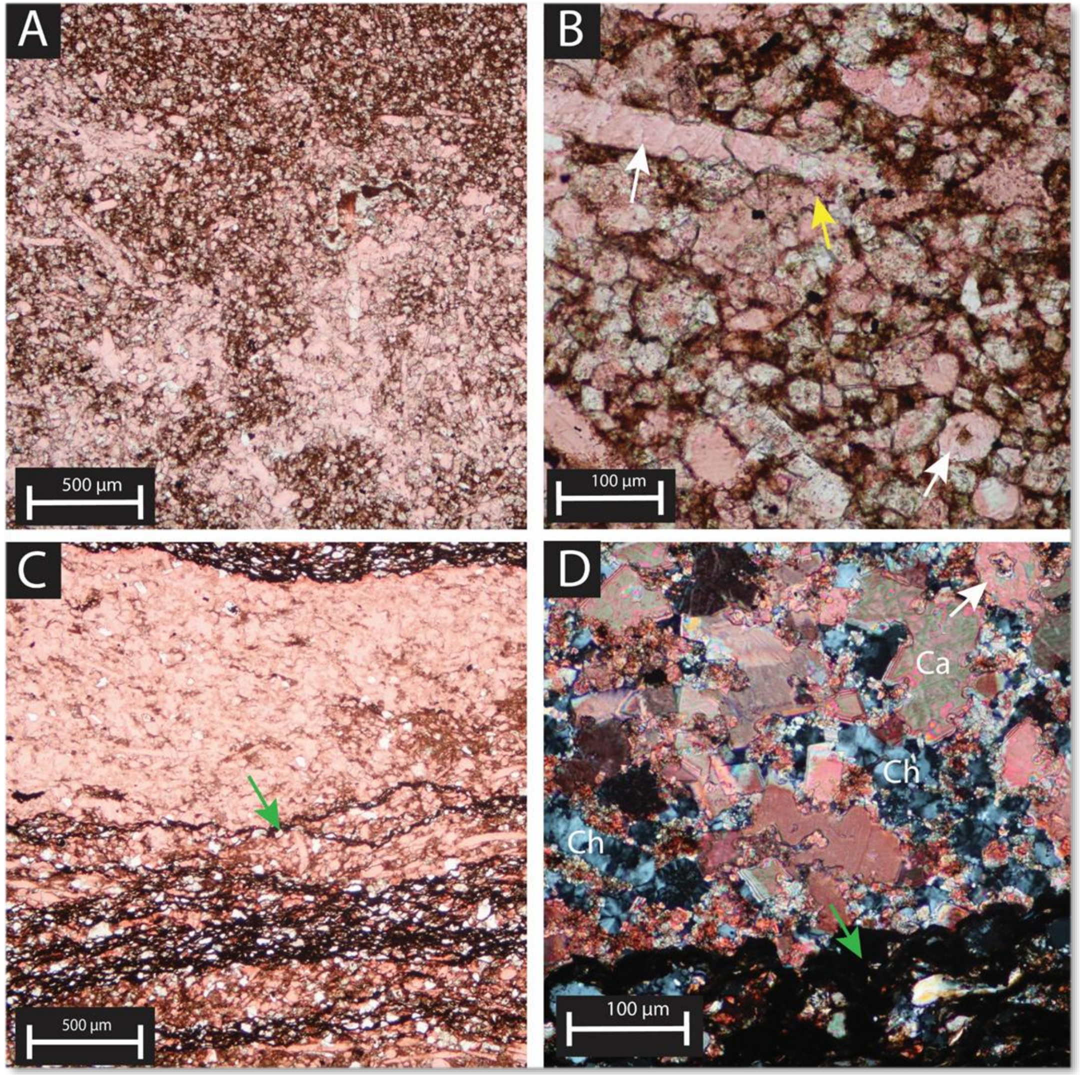
Facies 3. Skeletal wackestone-packstone to rudstone





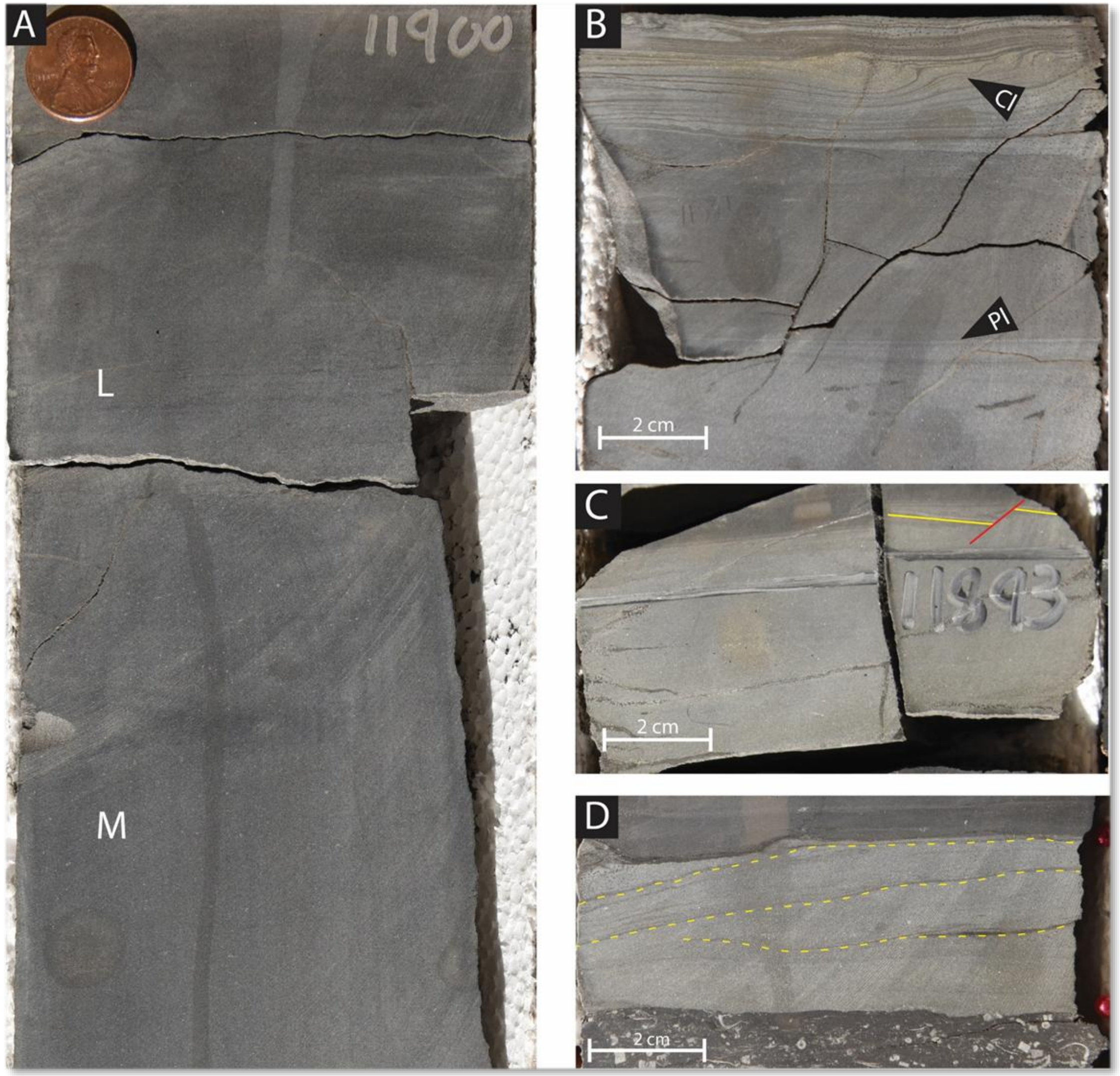
Facies 4. bioclastic packstone-wackestone; Massive to burrowed

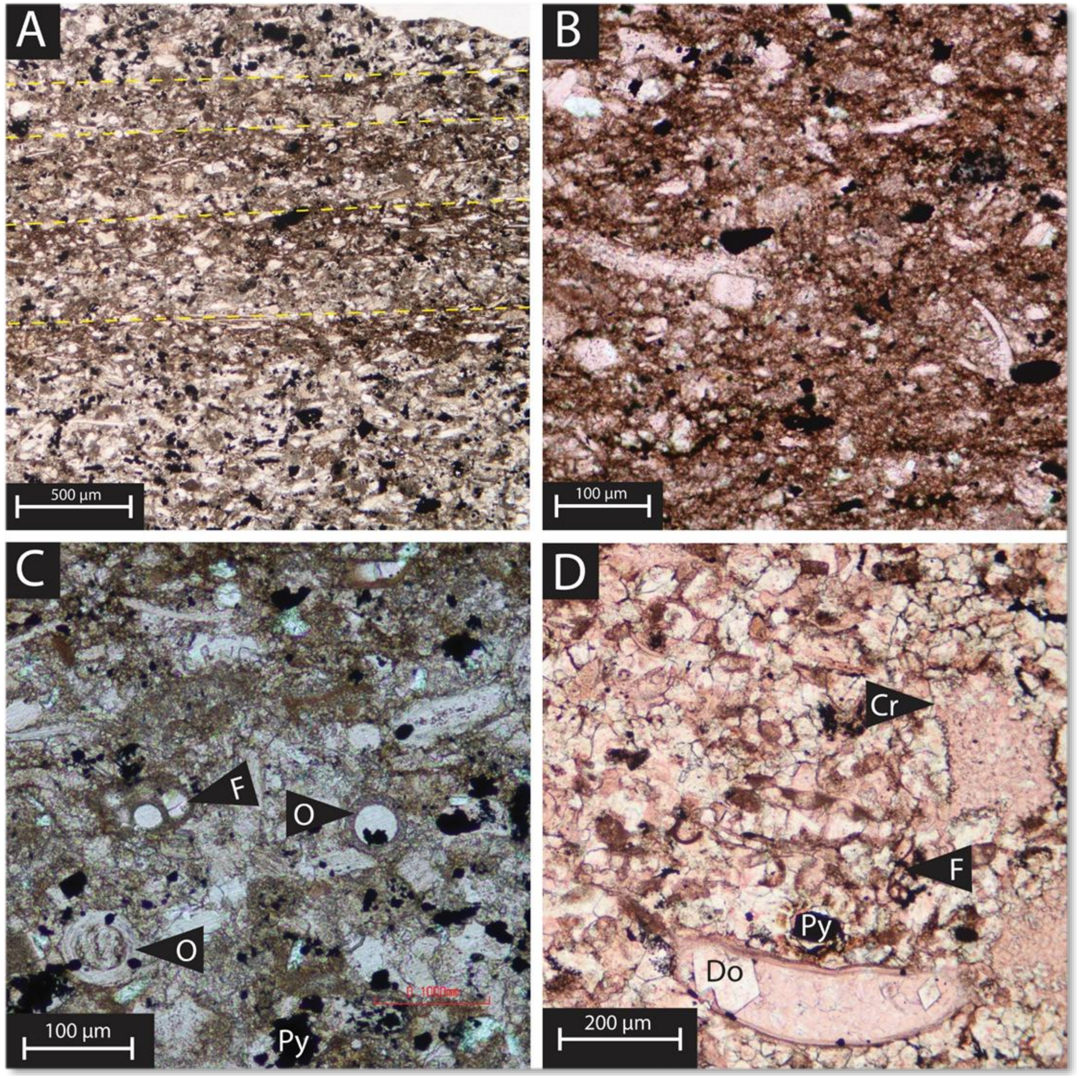




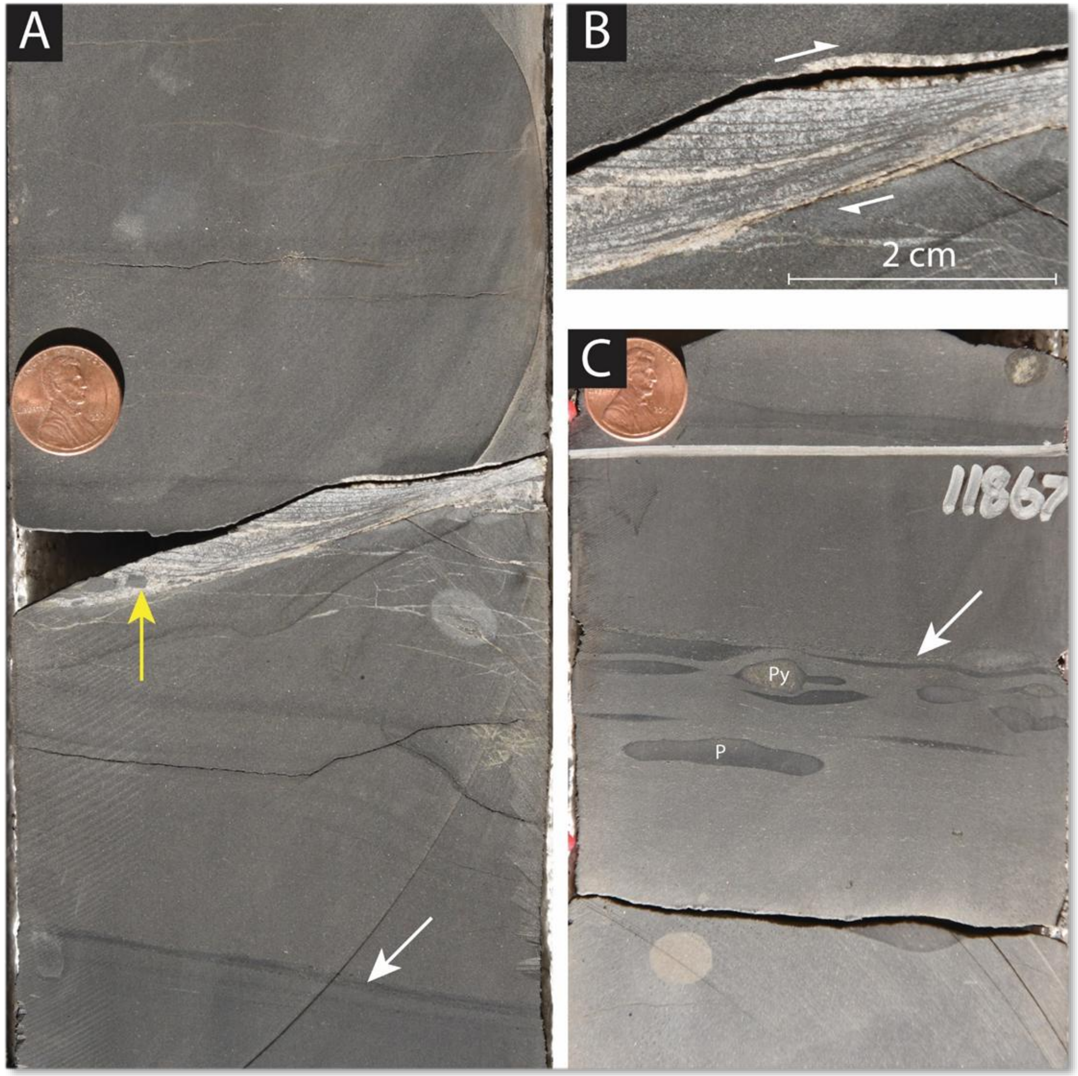
Average porosity = 1.77%   Average permeability = 0.05mD

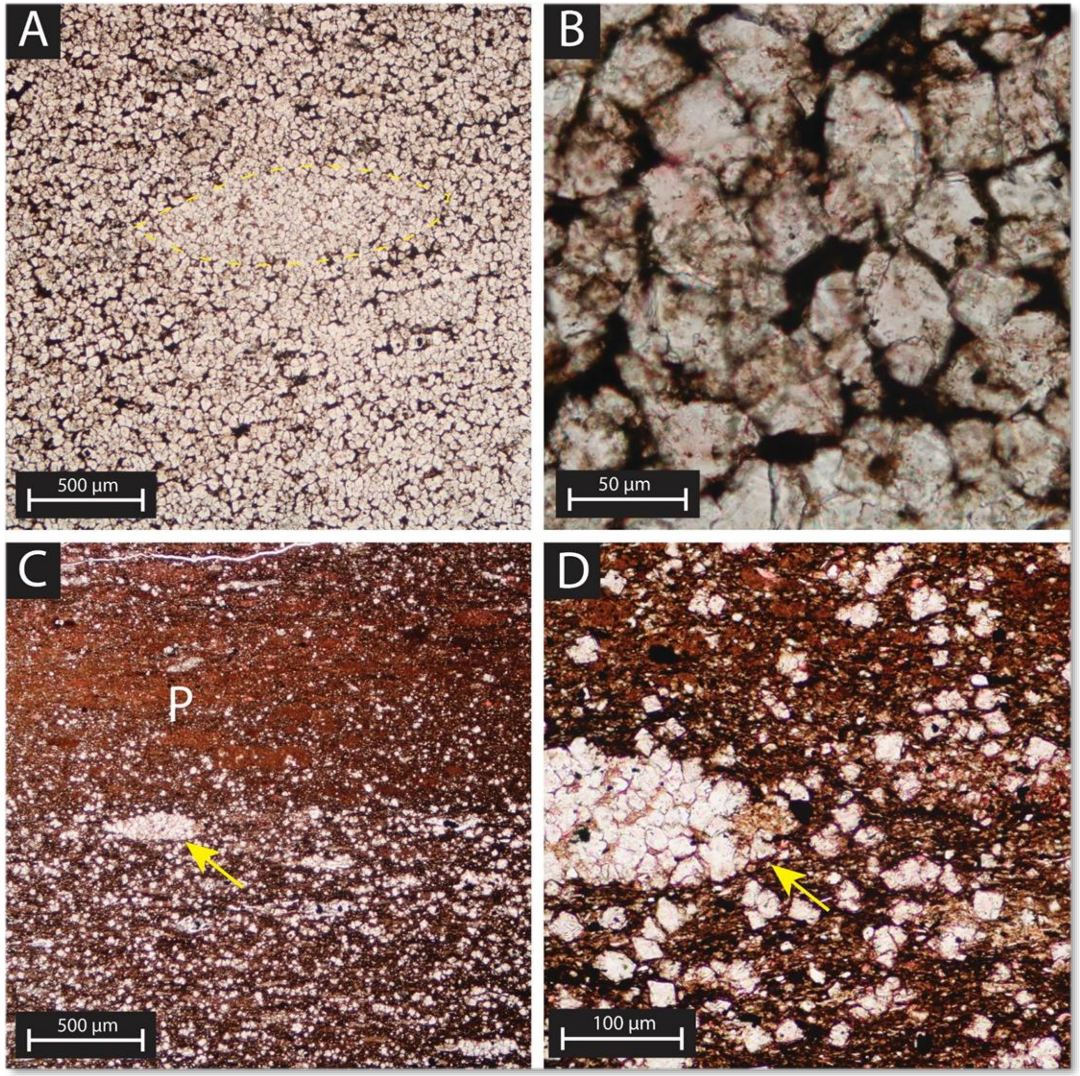
Facies 5. Laminated bioclastic packstone to grainstone





Facies 6. Dolomite packstone





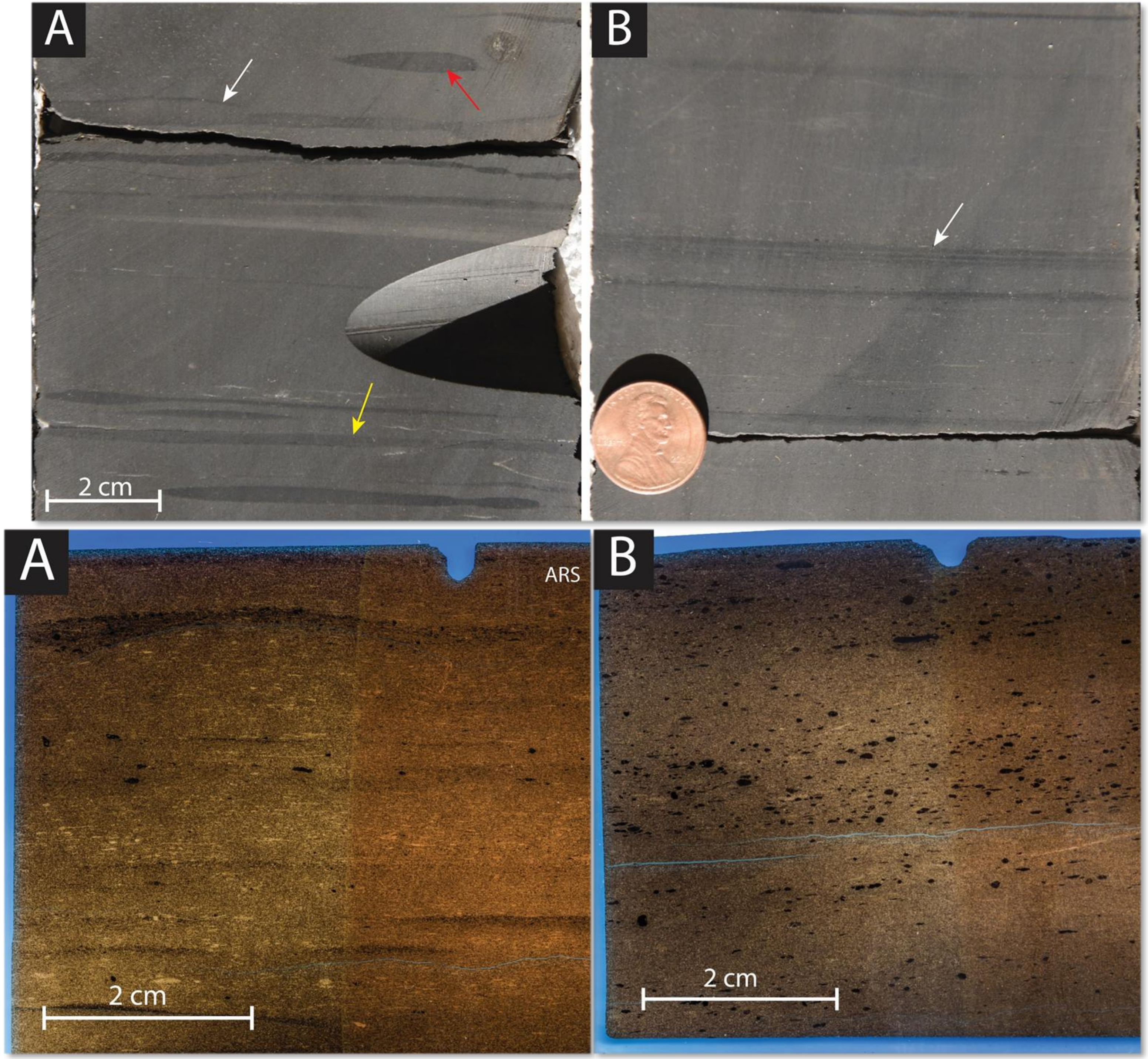
Average porosity = 0.93%   Average permeability = 0.0001mD

Depositional Processes

- Facies 1, 2, and 4 are dominant facies in core
- Accumulation by:
  - Downslope processes
    - Density flows
    - Turbidites
  - Suspension settling
- These beds often show signs of reworking suggesting bottom currents were prevalent
  - Scours
  - Mudclasts
  - Phosphatic peloids
- Beds of facies 3 and 5 appear to record uncommon events
  - Facies 3 beds record debris flows
  - Facies 5 beds record possible grain flows derived from shallow water
- Facies 6 is problematic but comprises a very small portion of the core

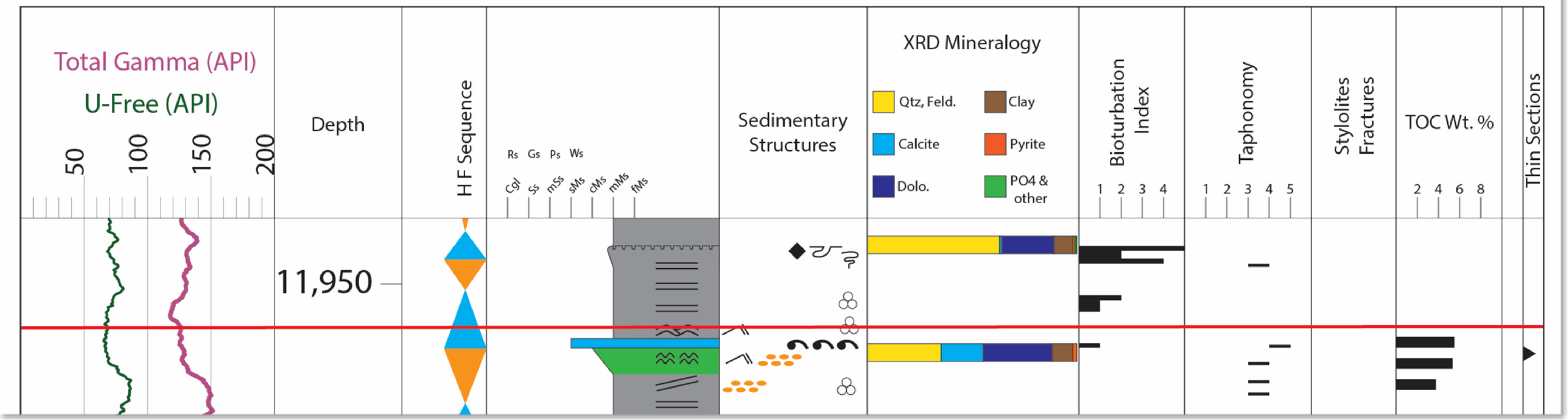
Phosphate

- *"In Situ"*
  - Pristine
- Reworked
  - Condensed
  - Allochthonous



Lithofacies Distribution in lower Barnett

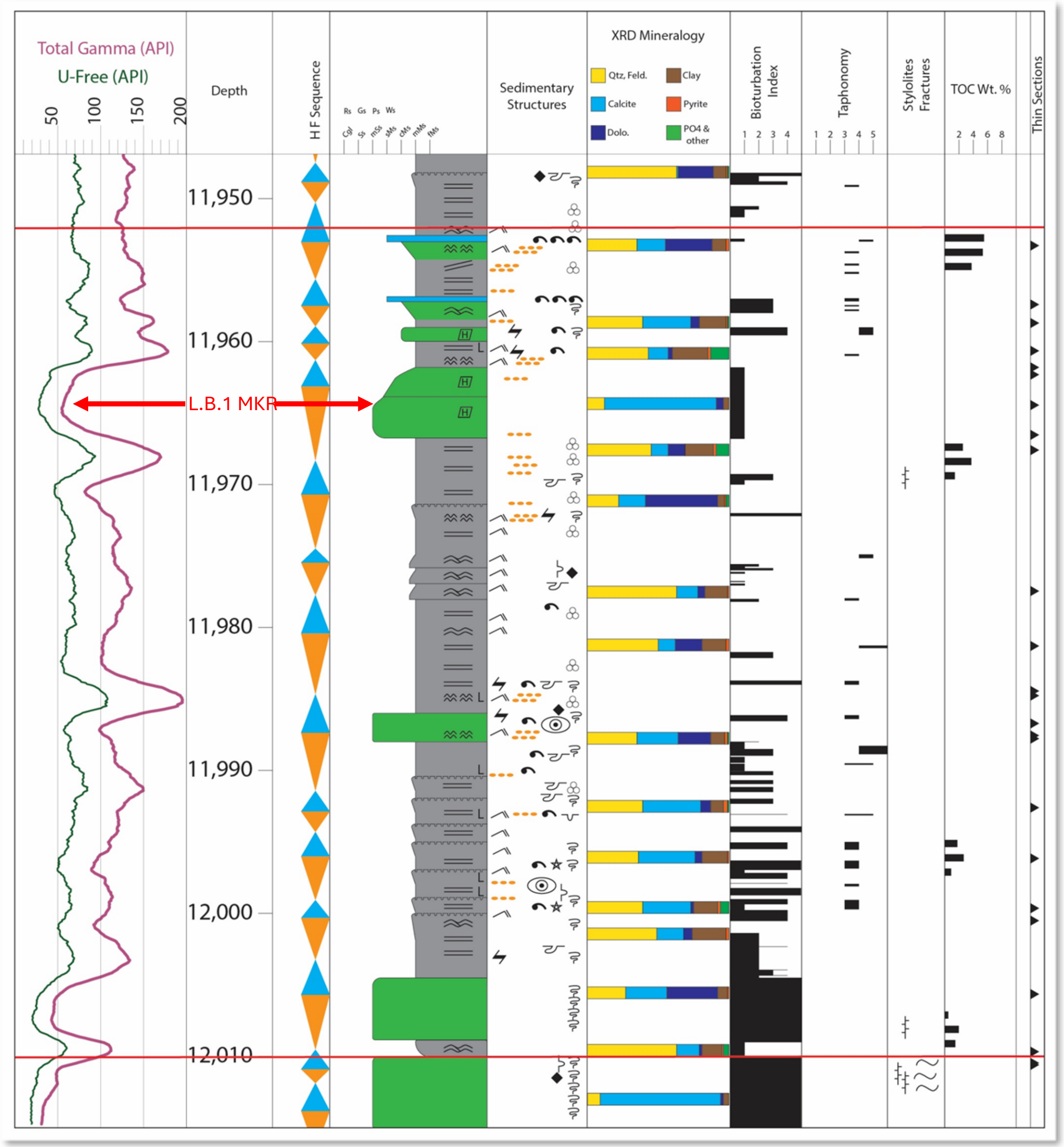
Core description legend



L.B.1

- Approximately 56 feet thick
- Mixed carbonate-siliciclastic system
- Dominated by facies 2 (light gray)
- Interbeded facies 4 (green)
- Thin beds of skeletal rich facies 3 near top (blue)
- Bioturbation (distal *Cruziana* ichnofacies) decreases upwards through L.B.1
- TOC increases upwards

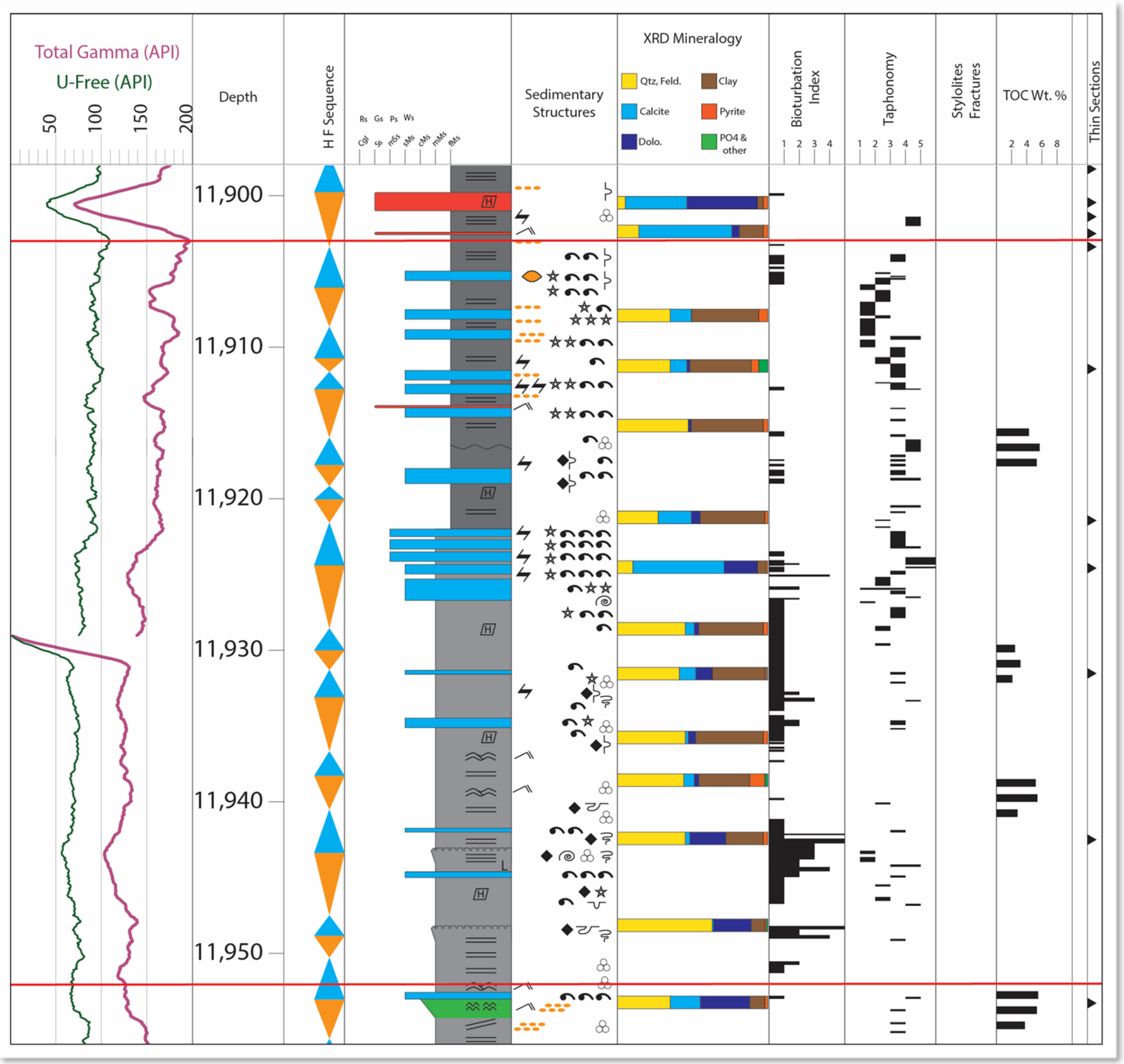
Lower Barnett	L.B.3
	L.B.2
	L.B.1



L.B.2

- Approximately 50 feet thick
- Dominated by facies 2 (light gray) and facies 1 (dark gray)
- Interbedded facies 3 (blue)
- Increased bioturbation at base which diminishes upward
- Upward transition from distal *Cruziana* to *Zoophycos* (becoming less oxygenated and has a less cohesive substrate)
- Becomes more argillaceous towards top in facies 1

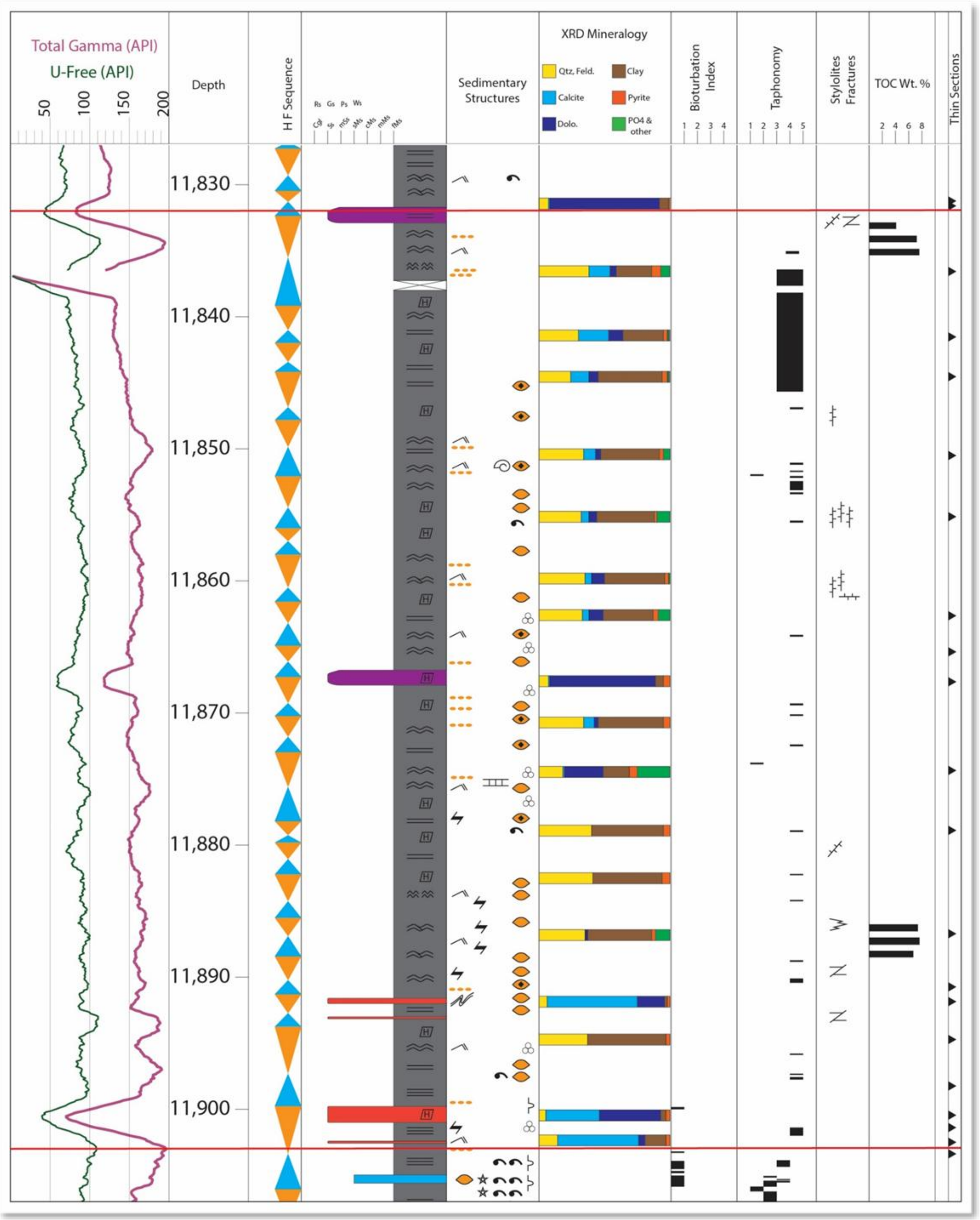
Lower Barnett	L.B.3
	L.B.2
	L.B.1

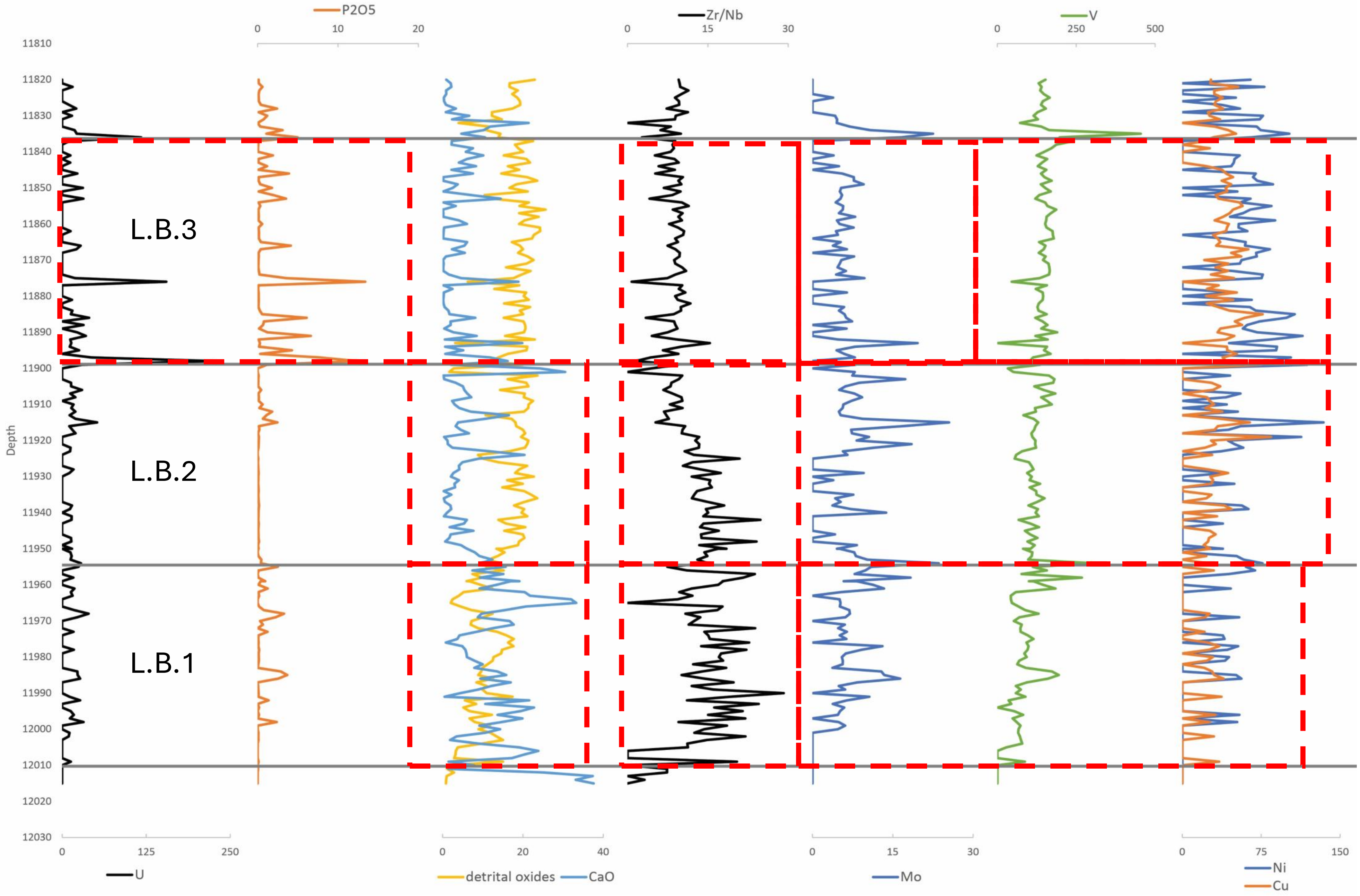


L.B.3

- Approximately 72 feet thick
- Dominated by facies 1 (dark gray)
- Facies 5 beds are near the base (red)
- Facies 6 beds (purple)
- Most argillaceous and TOC rich subunit
- Contains abundant phosphate nodules and laminae
- Only one bed contained burrows near the base of the subunit

Lower Barnett	L.B.3
	L.B.2
	L.B.1

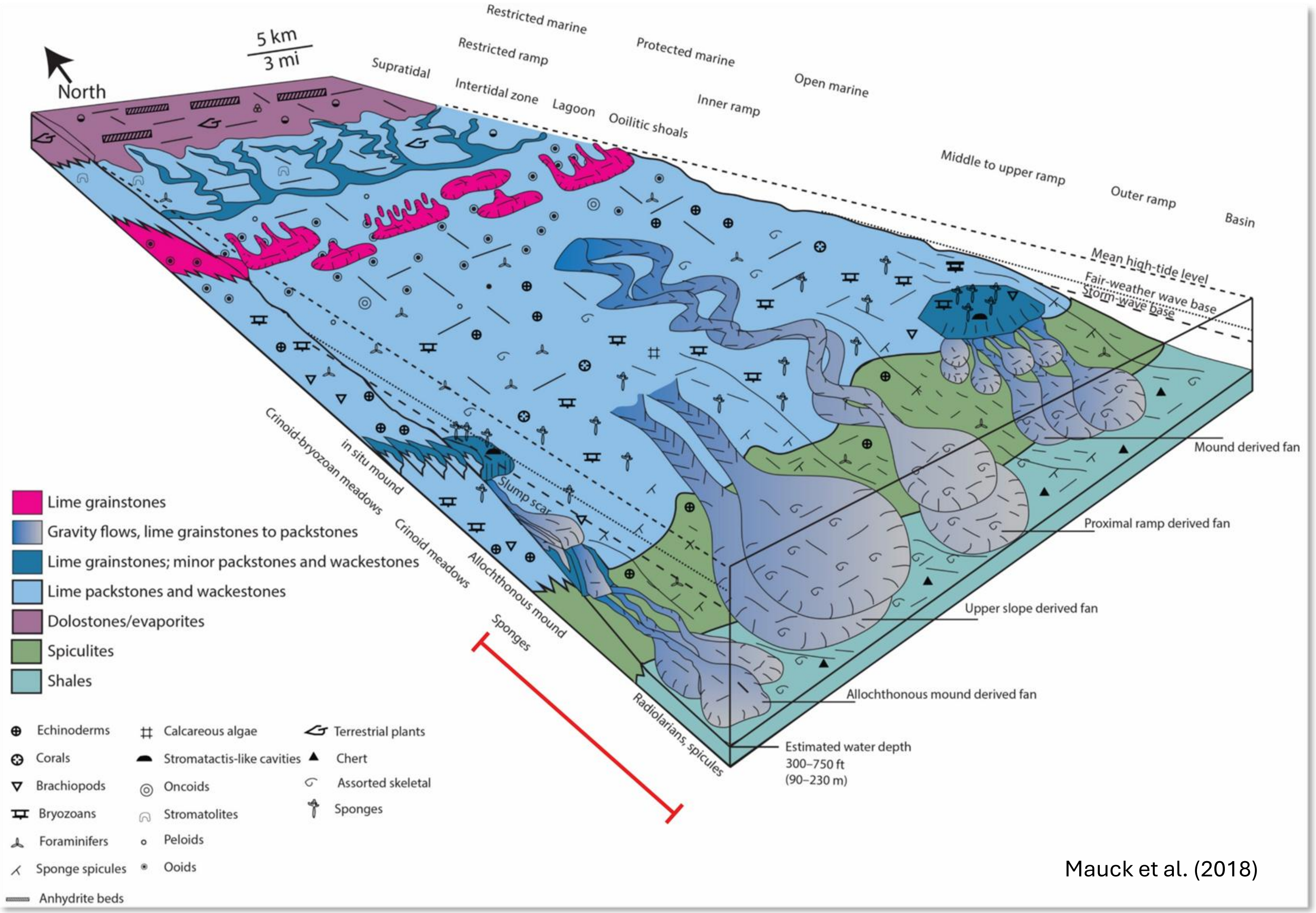




P2O5
Zr/Nb
V
Depth
L.B.3
L.B.2
L.B.1
U
detrital oxides
CaO
Mo
Ni
Cu

Depositional conditions

- Outer ramp to basin
- Facies 2 and 4 record more proximal deposition likely sourced from mid ramp
- Facies 1 records more distal deposition dominated by dilute turbidites and suspension settling
- Lower Barnet strata record an overall deepening



Mauck et al. (2018)

Organic Matter

Geochemical requirements for organic matter in effective source rocks

- Quantity measured as total organic carbon (TOC)

- Quality or type of organic matter (OM)
  - Kerogen type:
    - I – Lacustrine (oil prone)
    - II – marine algal (oil and gas prone)
    - III – terrestrial plant material (gas prone)
    - IV – inert (heavily oxidized or recycled organic matter)

- Thermal maturity

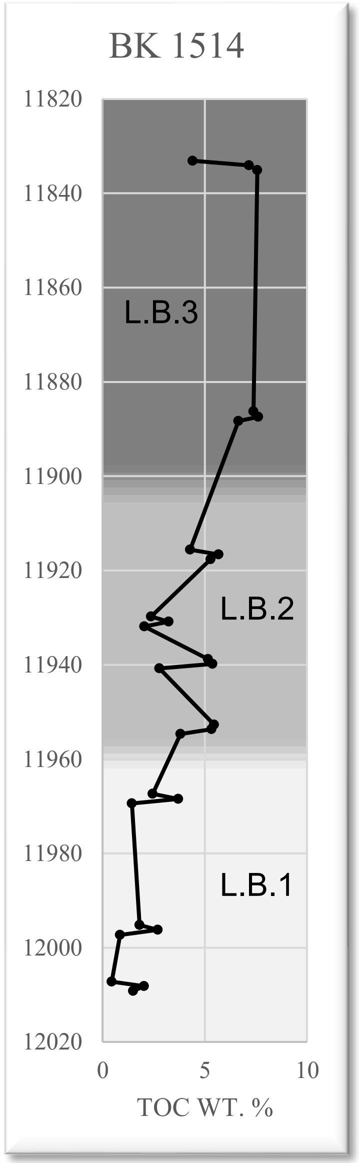
Quantity

- Fasken Fee BK 1514 samples contain up to 7.62% TOC with an average of 4.02% TOC
- TOC values increase upwards through the core

Geochemical parameters describing petroleum potential of an immature source rock

Petroleum Potential	Organic Matter: TOC (wt. %)	Rock-Eval Pyrolysis: S_1[a]	Rock-Eval Pyrolysis: S_2[b]
Poor	0–0.5	0–0.5	0–2.5
Fair	0.5–1	0.5–1	2.5–5
Good	1–2	1–2	5–10
Very Good	2–4	2–4	10–20
Excellent	>4	>4	>20

Peters and Cassa (1994)



Quality

- Hydrogen index plots near 100 for the BK 1514 and BE 724 wells
- This figure would suggest mostly type III kerogens
- S_2/TOC graphs are less reliable kerogen type predictors at maturities over 1.0% R_o

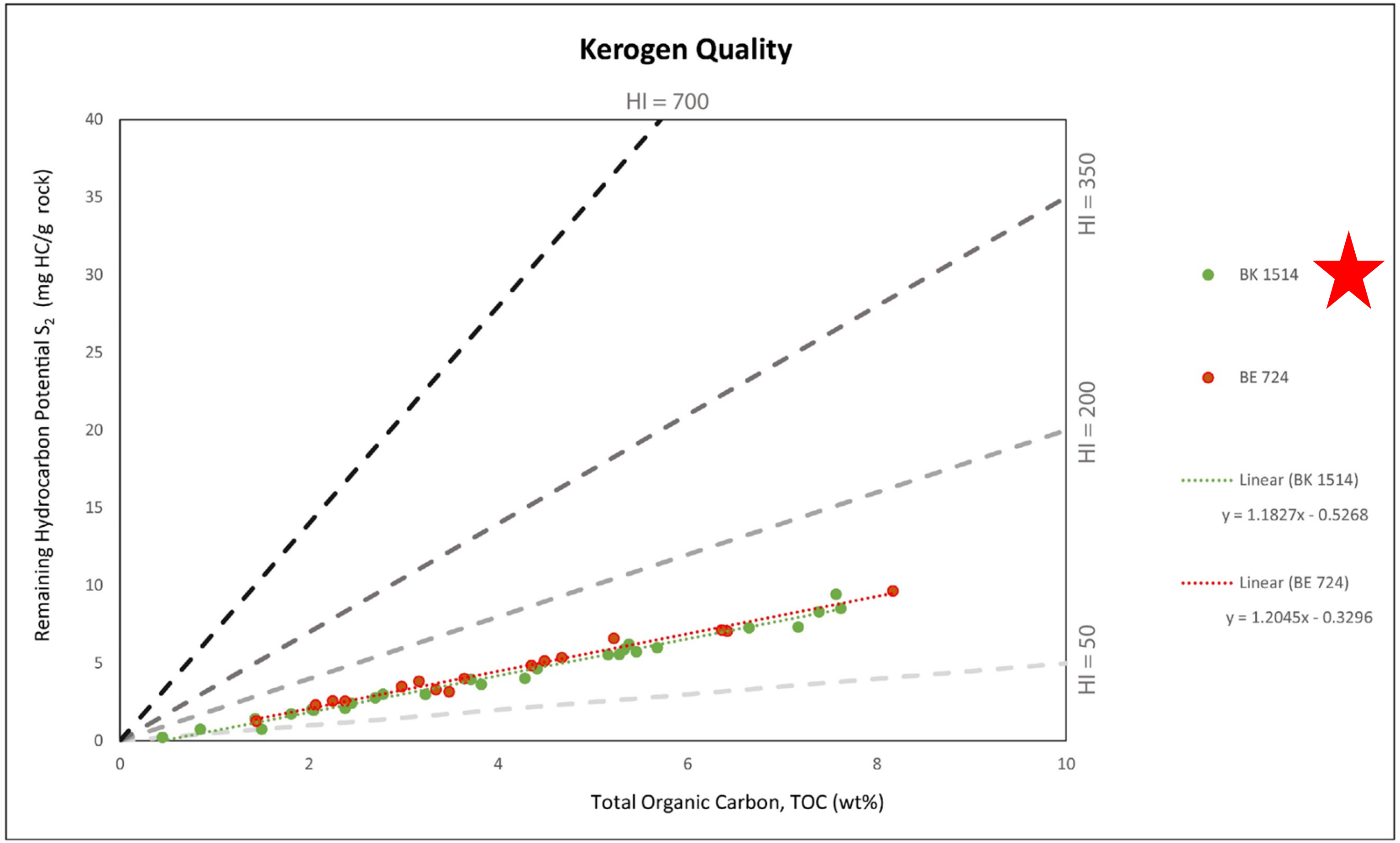


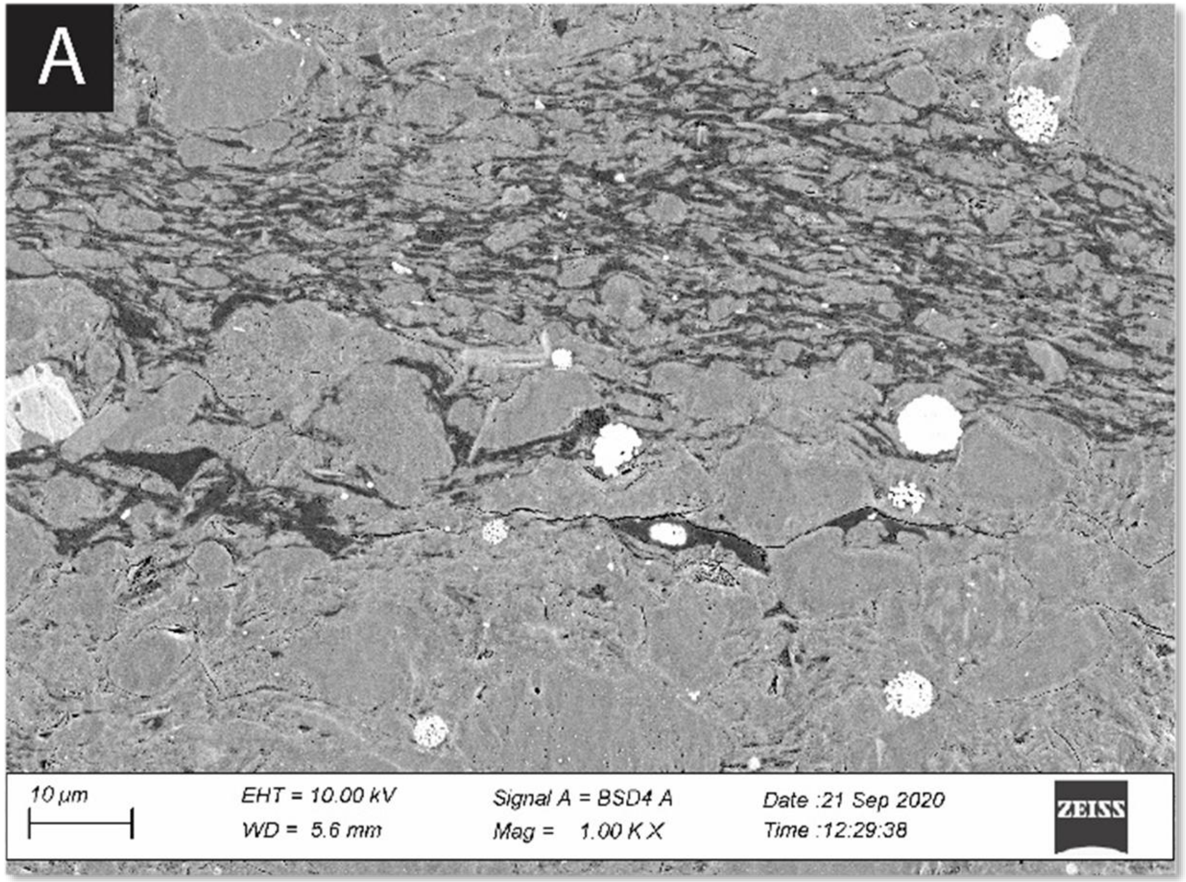
Table 5.2. Geochemical Parameters Describing Kerogen Type (Quality) and the Character of Expelled Products[a]

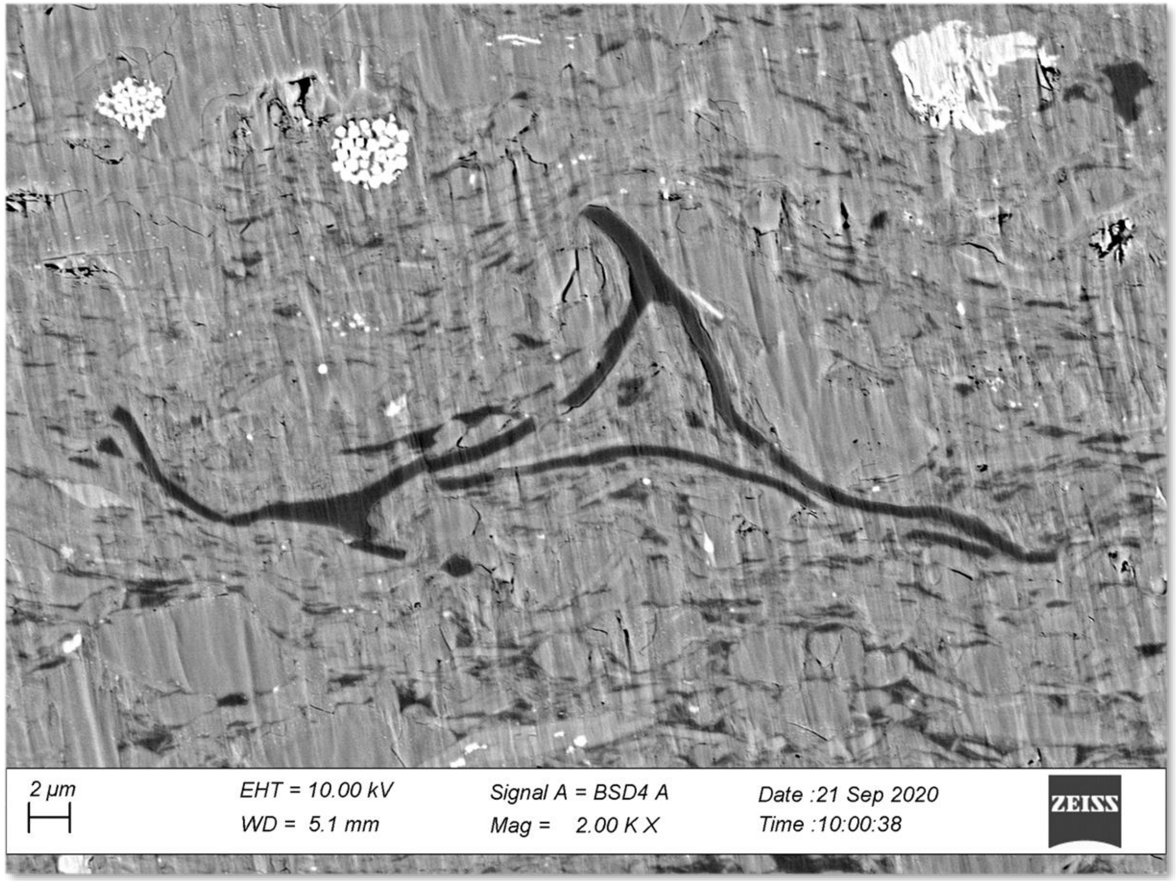
Kerogen Type	HI (mg HC/g TOC)	S_2/S_3	Atomic H/C	Main Expelled Product at Peak Maturity
I	>600	>15	>1.5	Oil
II	300–600	10–15	1.2–1.5	Oil
II/III[b]	200–300	5–10	1.0–1.2	Mixed oil and gas
III	50–200	1–5	0.7–1.0	Gas
IV	<50	<1	<0.7	None

[a]Based on a thermally immature source rock. Ranges are approximate.

[b]Type II/III designates kerogens with compositions between type II and III pathways (e.g., Figure 5.1) that show intermediate HI (see Figures 5.4–5.11).

SEM imaging of lower Barnett samples confirmed primarily amorphous organic matter



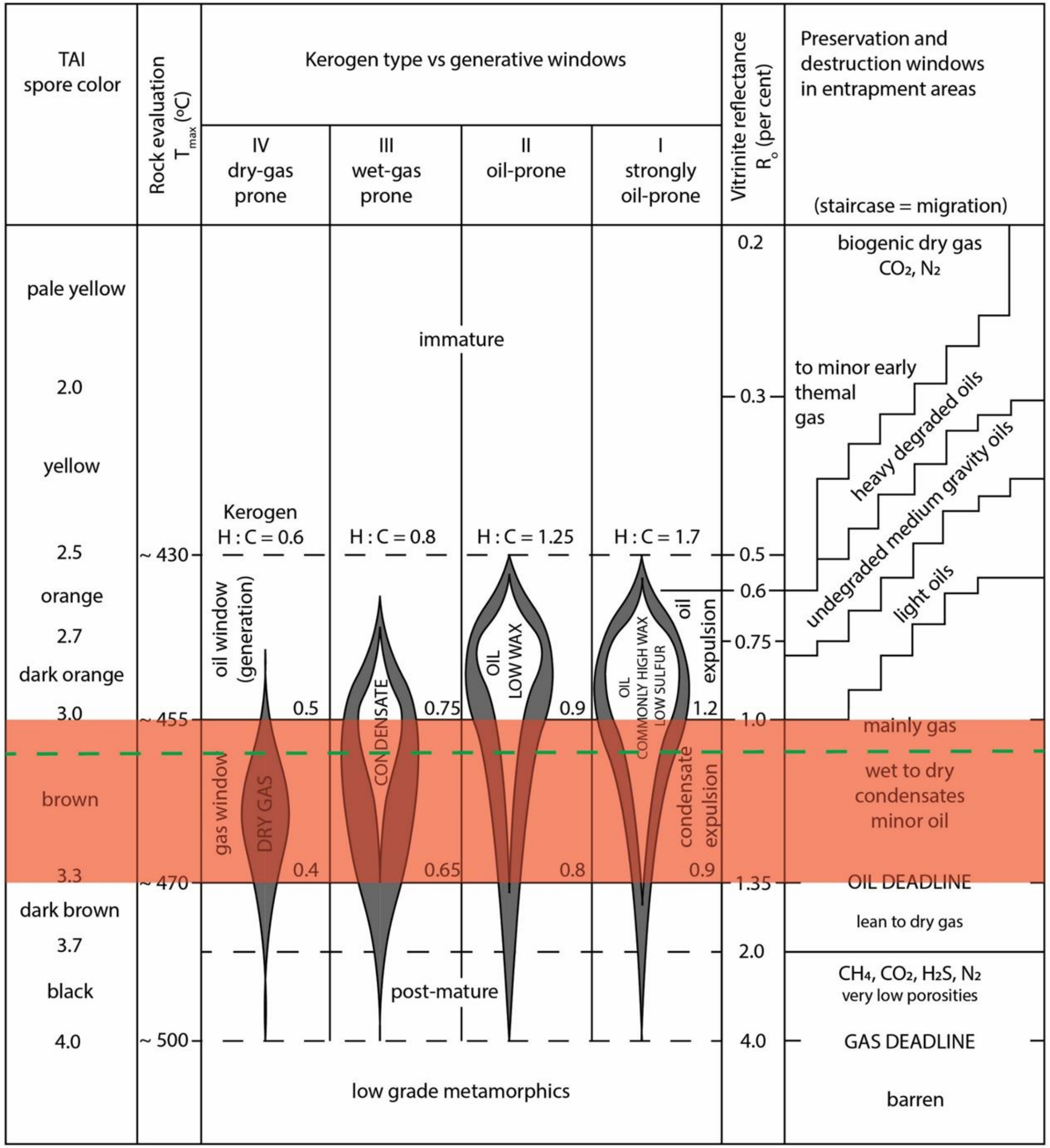


- Compacted amorphous OM (most common)
  - Type II kerogen

- Structured OM grain (less common)
  - Type III kerogen

Thermal maturity

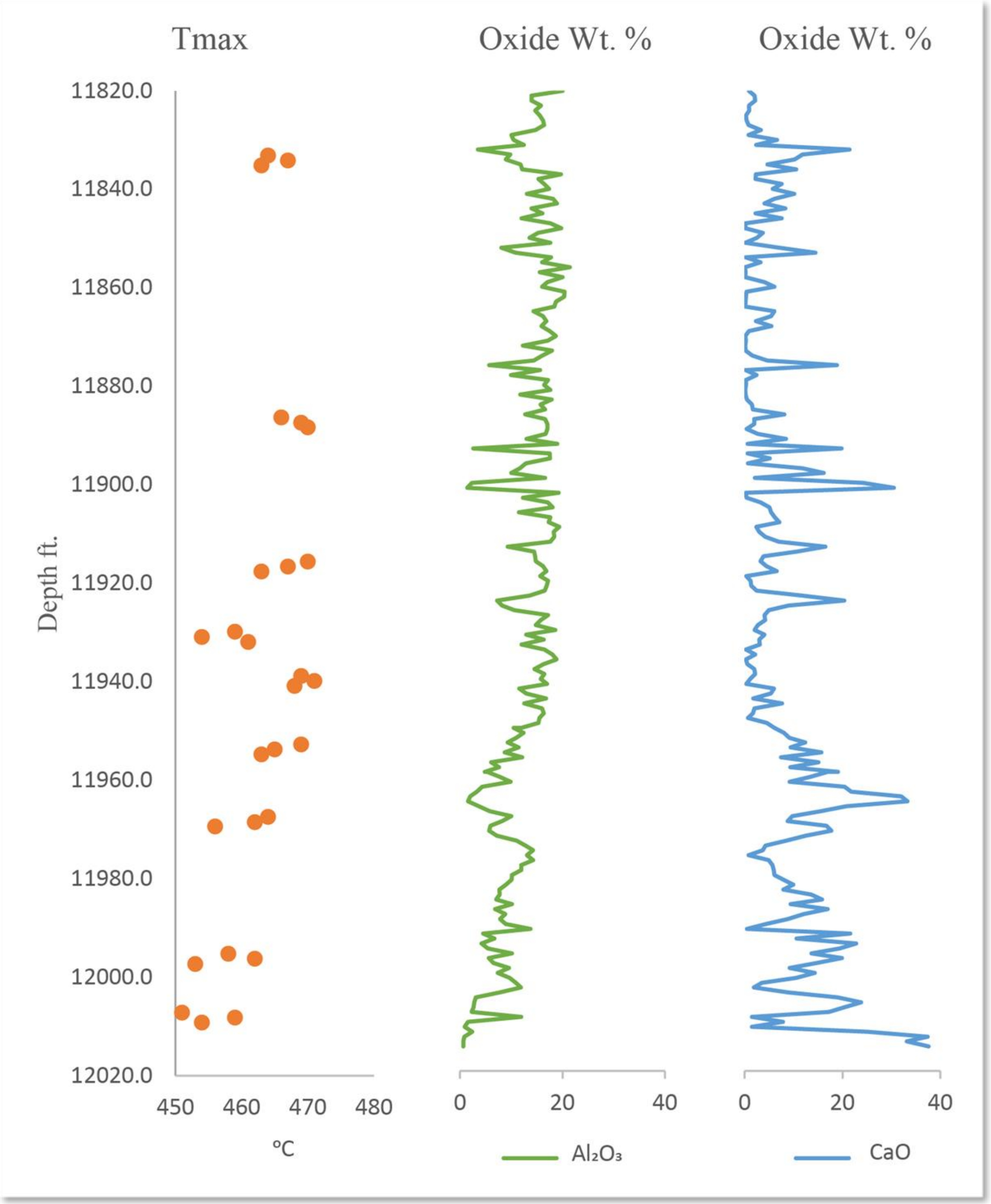
- Multiple datasets
  - Estimated R_o% from TAI for lower Barnett samples are 0.6% to 0.8%
  - Alginite fluorescence: orange color indicates early oil window
  - Two vitrinite reflectance samples averaged 1.07 R_o%
  - Tmax from pyrolysis averaged 463 °C or between 1.0% and 1.3% equivalent R_o



TAI spore color
Rock evaluation T_{max} (°C)
Kerogen type vs generative windows
IV dry-gas prone
III wet-gas prone
II oil-prone
I strongly oil-prone
Vitrinite reflectance R_o (per cent)
Preservation and destruction windows in entrapment areas
(staircase = migration)
pale yellow
2.0
yellow
2.5
orange
2.7
dark orange
3.0
brown
3.3
dark brown
3.7
black
4.0
~ 430
~ 455
~ 470
~ 500
immature
Kerogen H : C = 0.6
H : C = 0.8
H : C = 1.25
H : C = 1.7
oil window (generation)
gas window
DRY GAS
CONDENSATE
OIL LOW WAX
OIL COMMONLY HIGH WAX LOW SULFUR
oil expulsion
condensate expulsion
0.5
0.75
0.9
1.2
0.4
0.65
0.8
0.9
post-mature
low grade metamorphics
0.2
0.3
0.5
0.6
0.75
1.0
1.35
2.0
4.0
biogenic dry gas CO_2, N_2
to minor early themal gas
heavy degraded oils
undegraded medium gravity oils
light oils
mainly gas
wet to dry condensates minor oil
OIL DEADLINE
lean to dry gas
CH_4, CO_2, H_2S, N_2
very low porosities
GAS DEADLINE
barren

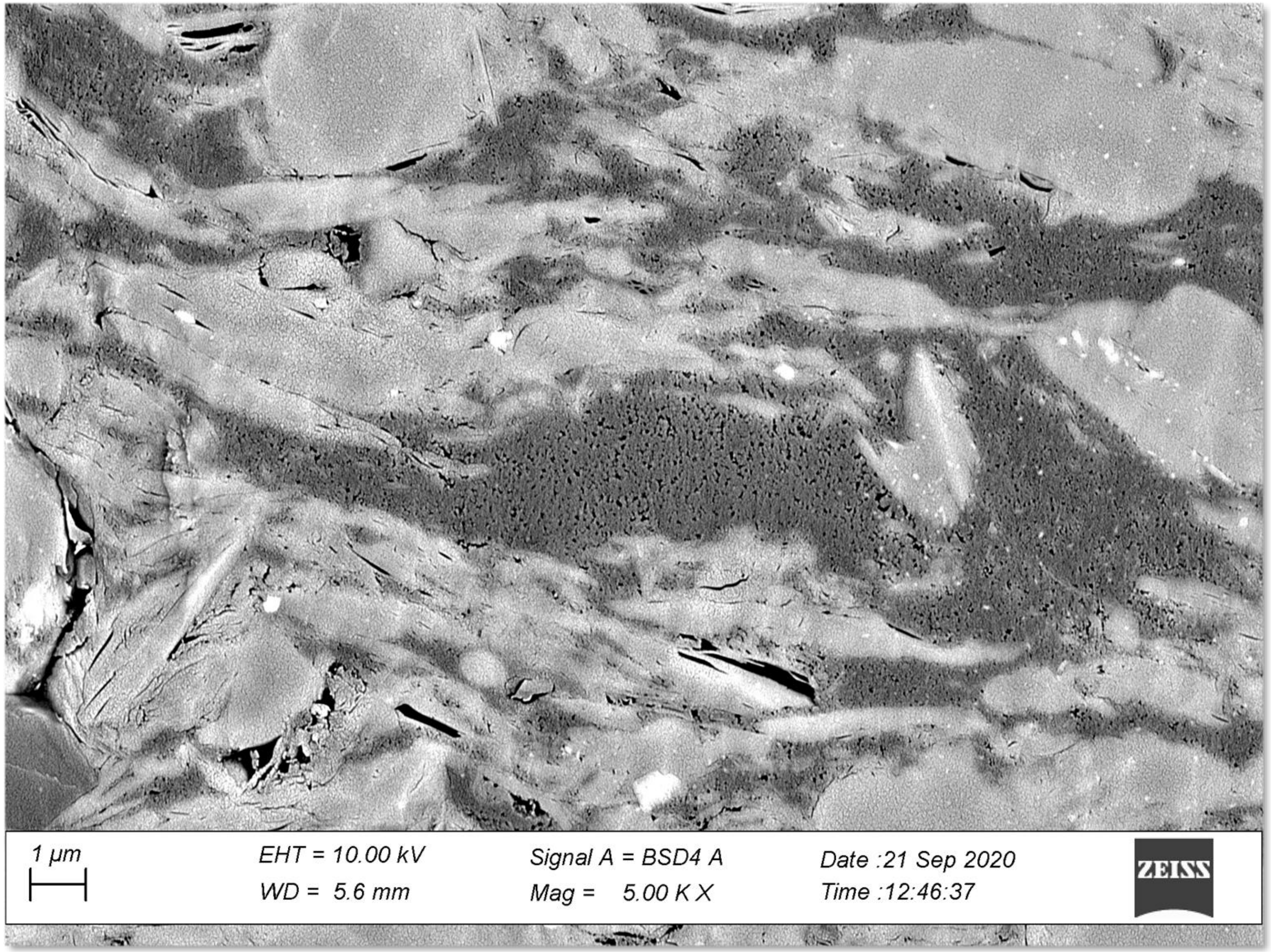
Mineralogy and T_{max}

- T_{max} values range from 451 °C to 471 °C
- T_{max} values increase with increased clay (Al_2O_3) and decreased carbonate (CaO)
- T_{max} was likely influenced by mineral matrix
- Shifts in T_{max} cannot be explained by geothermal gradient

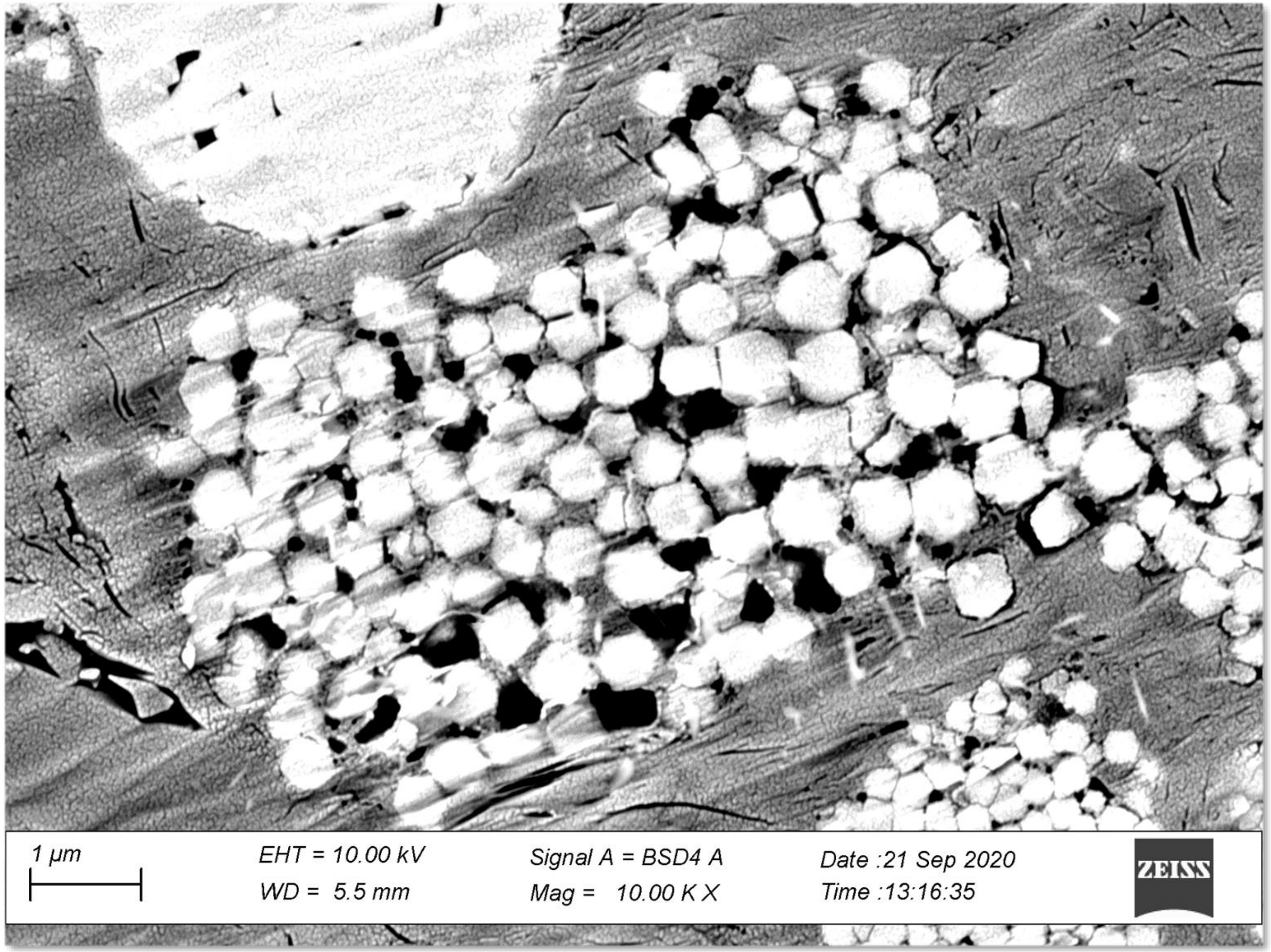


Organopores

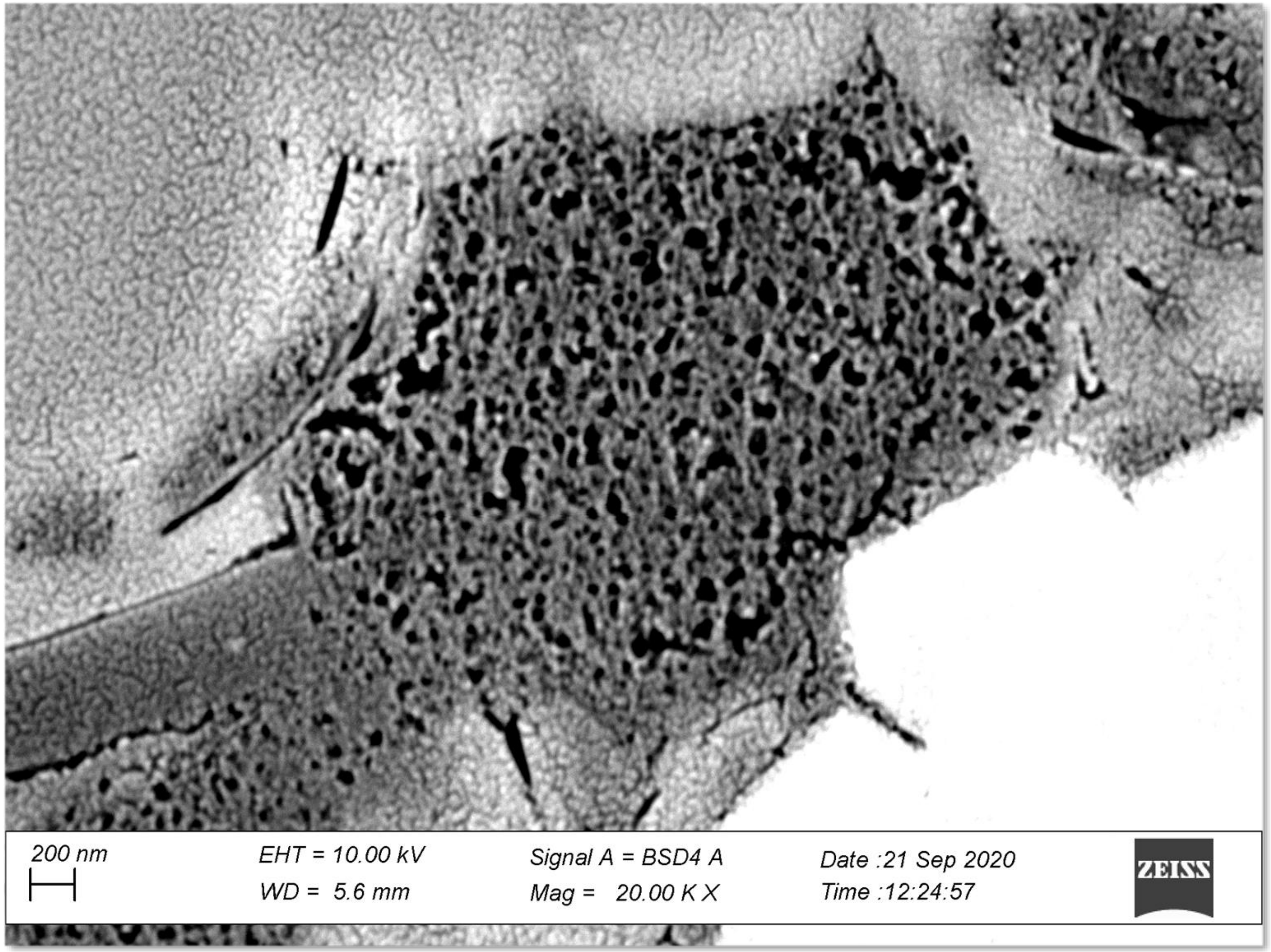
- Primary pore types in the L.B.3 subunit:
  - Interparticle organopores in OM grains



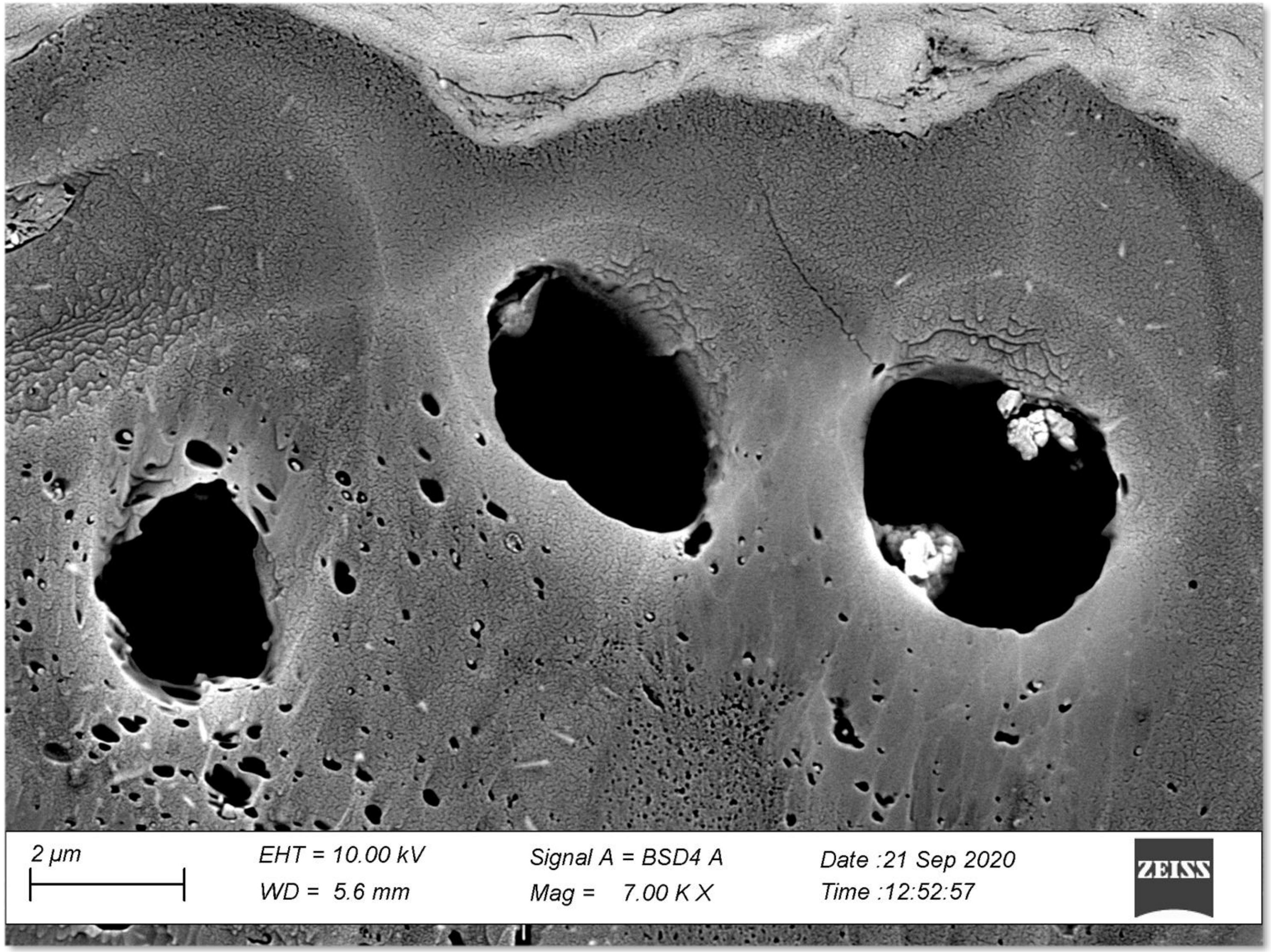
- Primary pore types in the L.B.3 subunit:
    - Interparticle organopores in OM grains
    - Intracrystaline pores in pyrite framboids



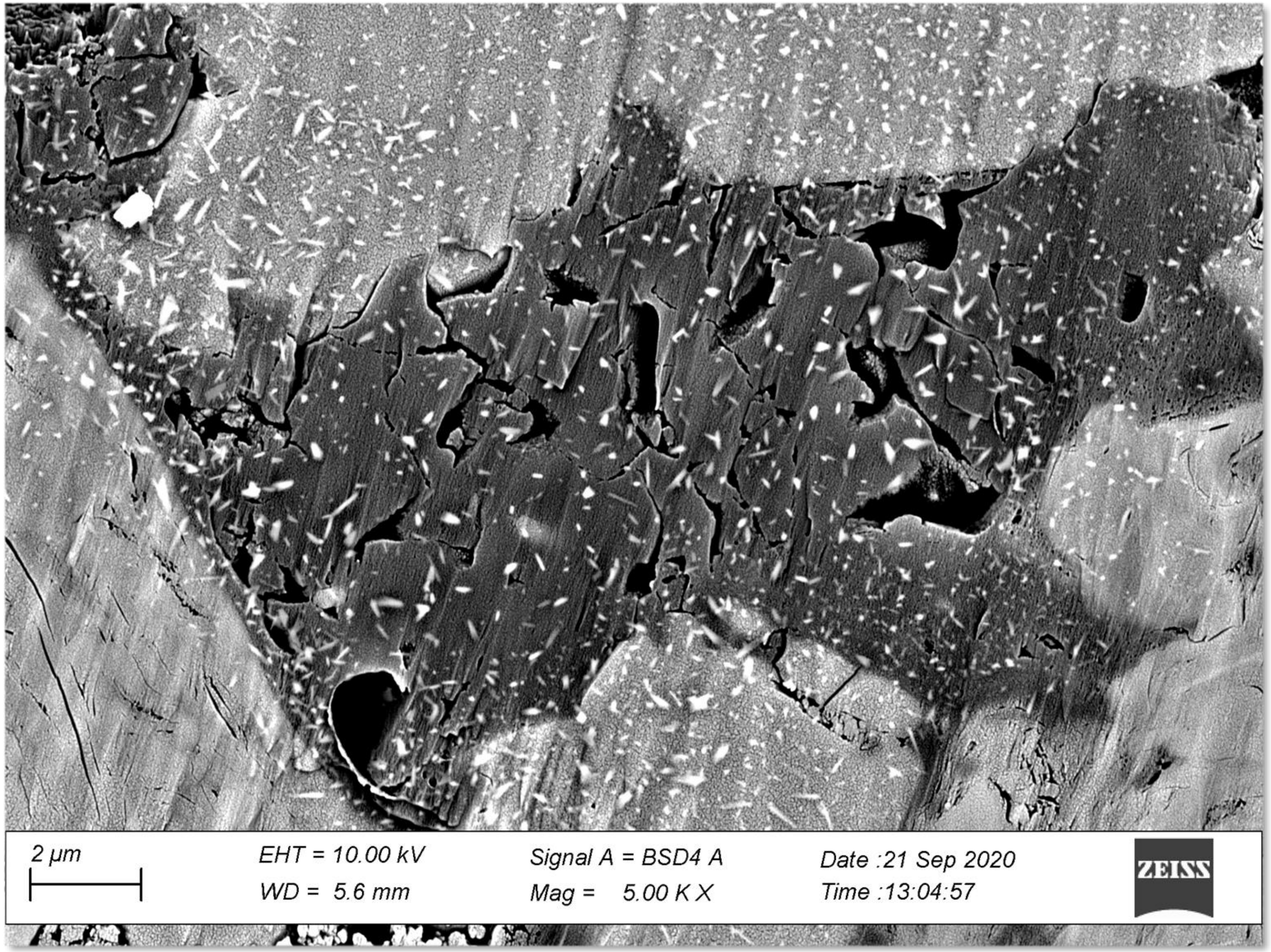
- Primary pore types in the L.B.3 subunit:
  - Interparticle organopores in OM grains
  - Intracrystaline pores in pyrite framboids
- Organopore morphology:
  - Spongy irregular connected nanopores (common)

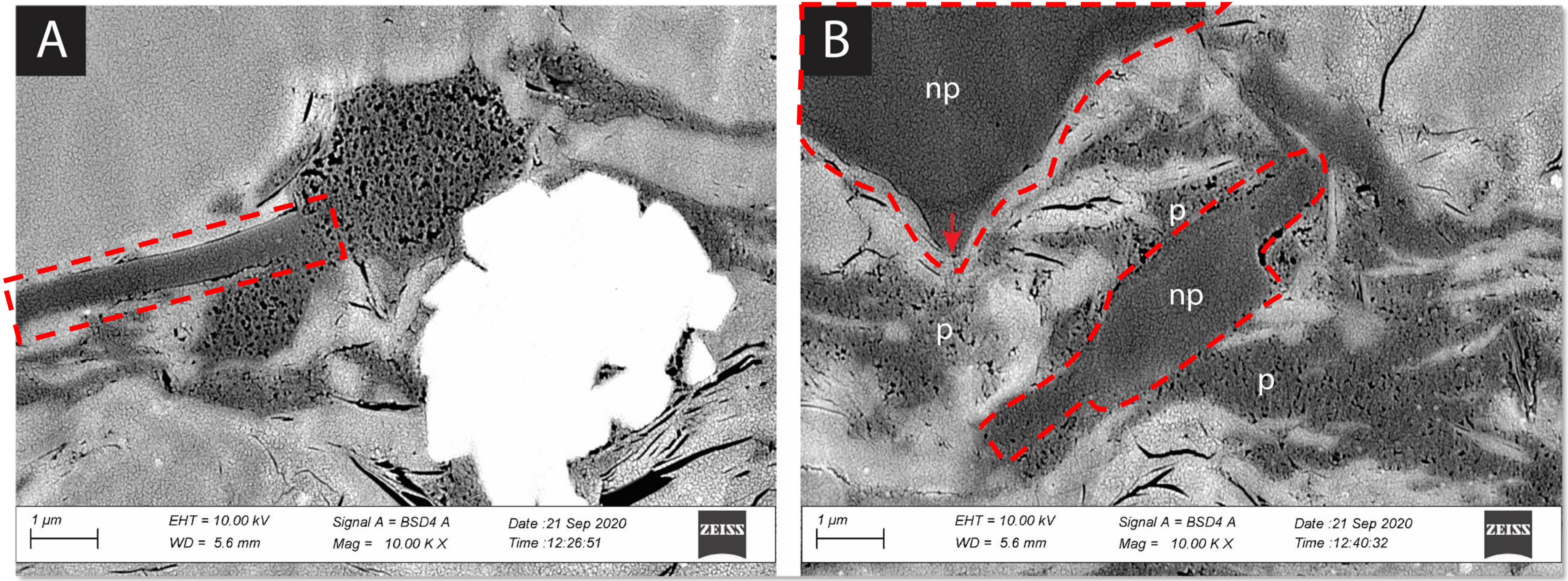


- Primary pore types in the L.B.3 subunit:
  - Interparticle organopores in OM grains
  - Intracrystaline pores in pyrite framboids
- Organopore morphology:
  - Spongy irregular connected nanopores (common)
  - Round to oval micropores (rare)

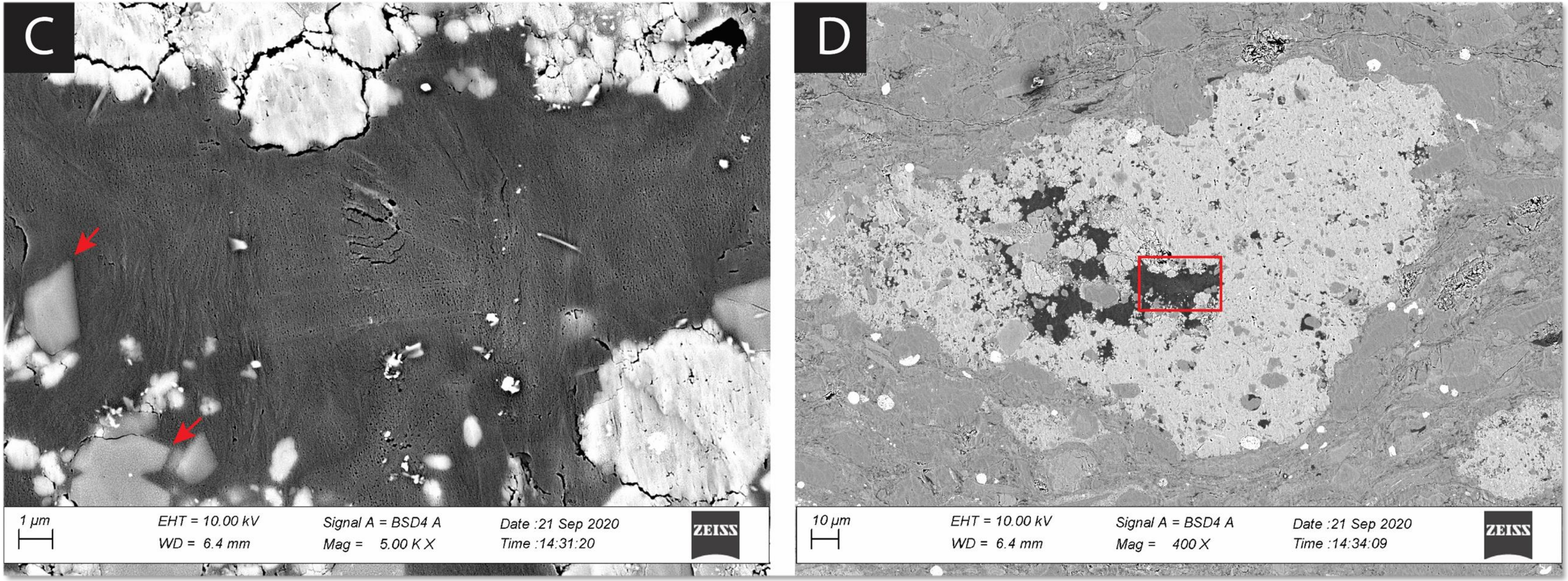


- Primary pore types in the L.B.3 subunit:
  - Interparticle organopores in OM grains
  - Intracrystaline pores in pyrite framboids
- Organopore morphology:
  - Spongy irregular connected nanopores (common)
  - Round to oval micropores (rare)
  - Angular micropores (rare)



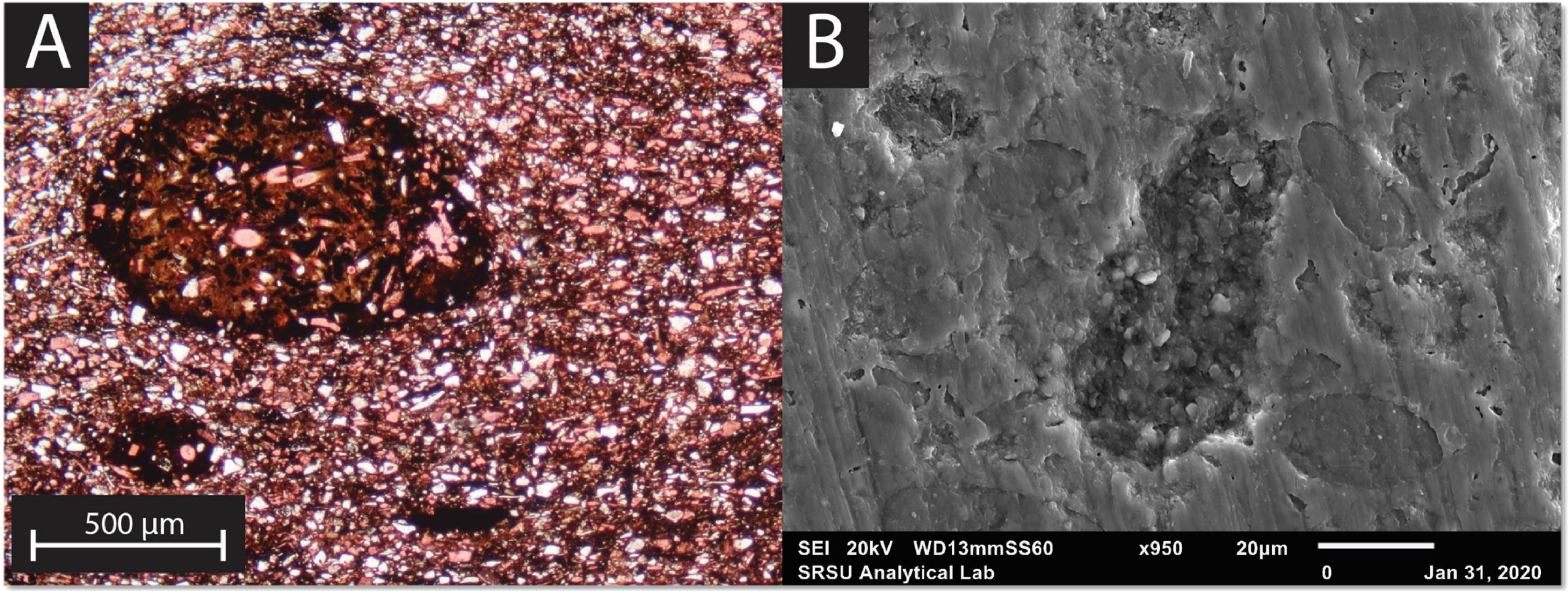


- Angular, compaction resistant OM grains interpreted to be plant material (type III kerogen) lack pore development



- Organic matter within phosphatic peloid
- Euhedral cement at margins of grain
- Interpreted to be migrated HC that filled interparticle pore during initial HC generation.
- Organopores developed during later stages of maturation

- SEI image of pore within phosphatic peloid
- Euhedral cement lining pore walls
- It is likely that phosphatic peloids preserved interparticle porosity during compaction of the host rock
- Therefore presence of phosphatic peloids may enhance reservoir properties where abundant



Conclusions & Recommendations

Conclusions

- The lower Barnett was deposited in an outer ramp to basinal setting below storm wave base
- Deposition occurred as downslope transport by density flows and debris flows and a common reworking mechanism prevailed
- Overall, lower Barnett records a rise in sea level
  - Decrease in grainsize, bed thickness upwards
  - Decrease in bioturbation upwards and shift from more proximal to more distal ichnofacies
  - Increase in clay deposition and OM preservation upwards
  - Increase in redox sensitive trace elements upwards
- OM analysis suggest sufficient OM content, quality and maturity to have generated hydrocarbons

Recommendations

- Hydrocarbons produced in the study area will likely be a combination of gas and condensates
- The OXY MF 185H produced 340,690 barrels of condensate and 2,176,198 MCFG between March 11, 2019 and April 30, 2021.
- High clay composition in the TOC rich L.B.3 subunit could present challenges to drilling
- Reservoir properties of the L.B.1 and lower L.B.2 are more ideal
  - Highest porosity and permeability
  - Silt and calcite rich facies are more ideal for fracture propagation
- Sheet like deposits of facies 4 such as the L.B.1 marker are a favorable target for geosteering efforts

Acknowledgements

- Fasken Oil and Ranch Ltd.
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Questions?