Stratigraphy of the Woodford Shale from Behind-Outcrop Drilling, Logging, and Coring*

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Abstract

Outcrop studies used in conjunction with coring and logging of reservoir rocks are widely used to characterize complex stratigraphic variability while minimizing cost compared with obtaining these data from exploratory wells. To increase knowledge base in the Woodford Shale in the western portion of the Arkoma Basin of southeastern Oklahoma, an OU-Devon-Schlumberger project cored 200 ft. of Woodford section behind an active quarry and ran an extensive logging suite to its basal contact with the Hunton Limestone. Preliminary results indicate that numerous macroscopic features visible in whole core - such as phosphate and pyrite nodules, near-vertical healed fractures, and pulses of silica-rich layers - appear in image log data, and where present in sufficient proportions and thicknesses, these can also be resolved on conventional logs. This is especially true when distinguishing between the stratigraphic sections of Middle and Lower Woodford believed to be present in the cored interval. Microscopic analysis of thin-sections show areas of microporosity development associated with chert-filled burrows and surrounding authigenic pyrite grains. Increased microporosity is also present within chert-filled liptinite macerals observed in silica-rich layers, while the opposite is true in compacted liptinite macerals associated with argillaceous layers. Large-scale features such as layers rich in phospahtic nodules and lenses are correlative over a distance of at least 600 ft. along the quarry walls. Characteristics identified in this project will be used for application in Woodford wells which may not have as extensive a dataset in hopes of assisting in decisions regarding lateral target zones and completion practices.

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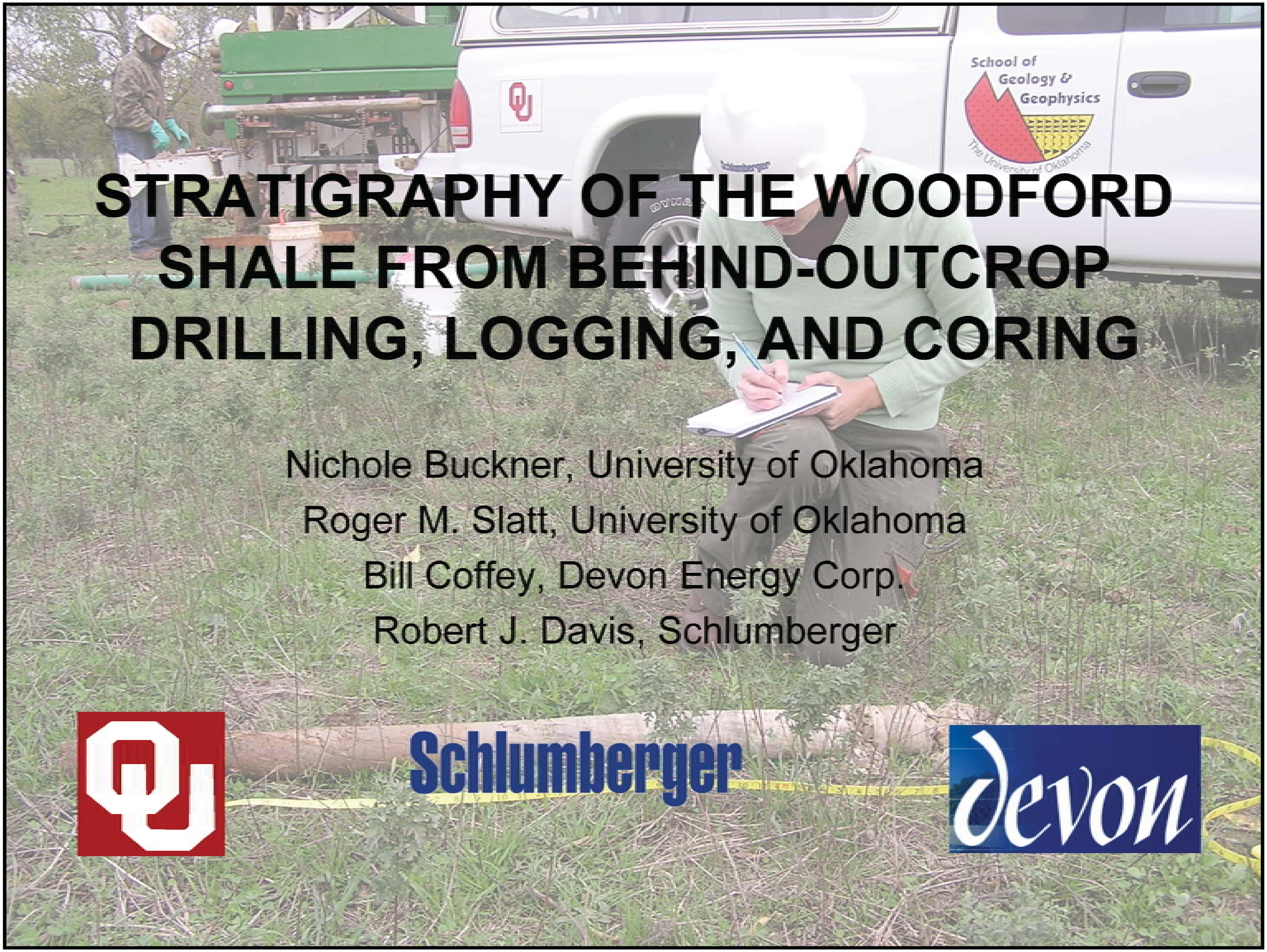
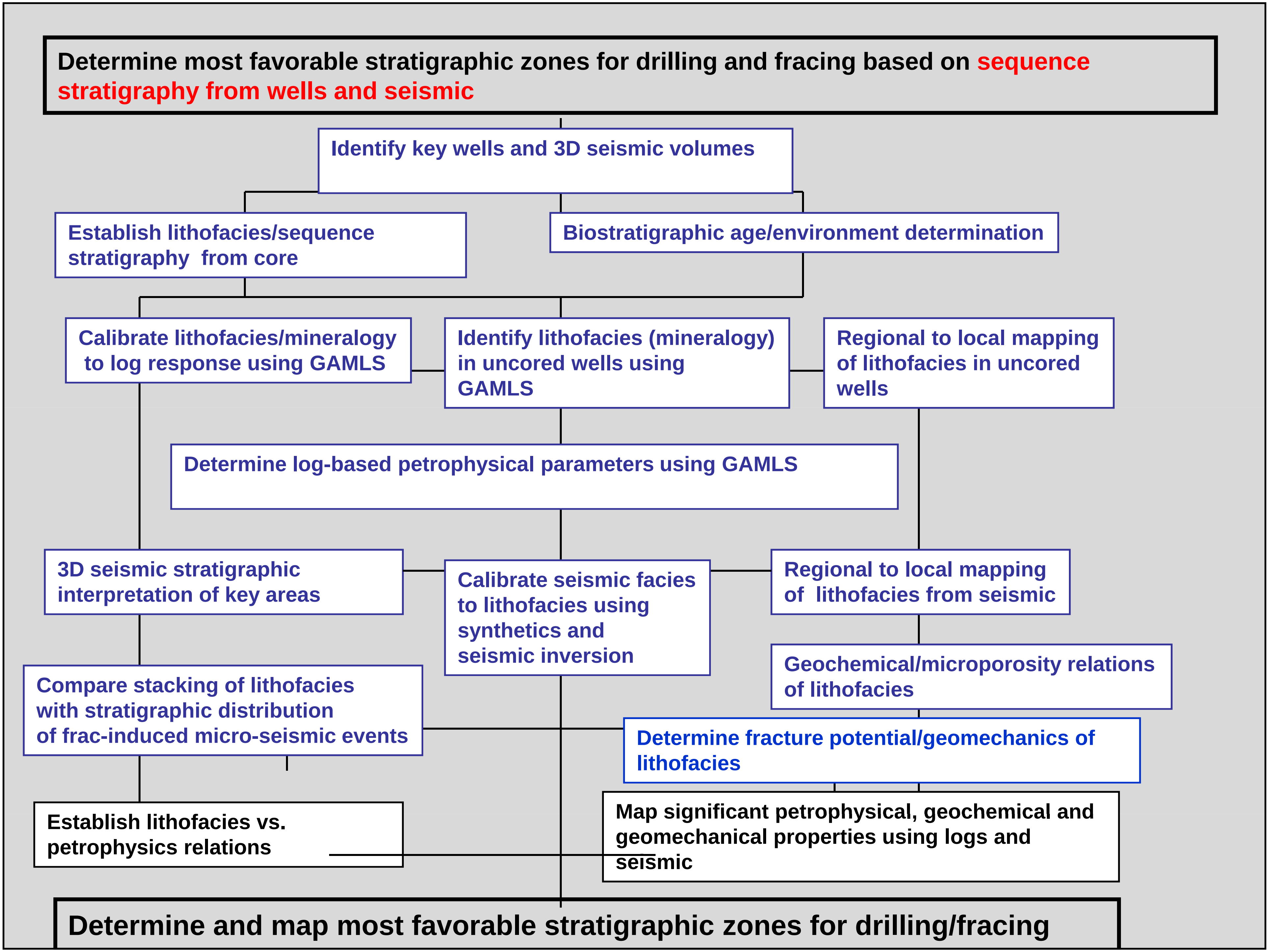


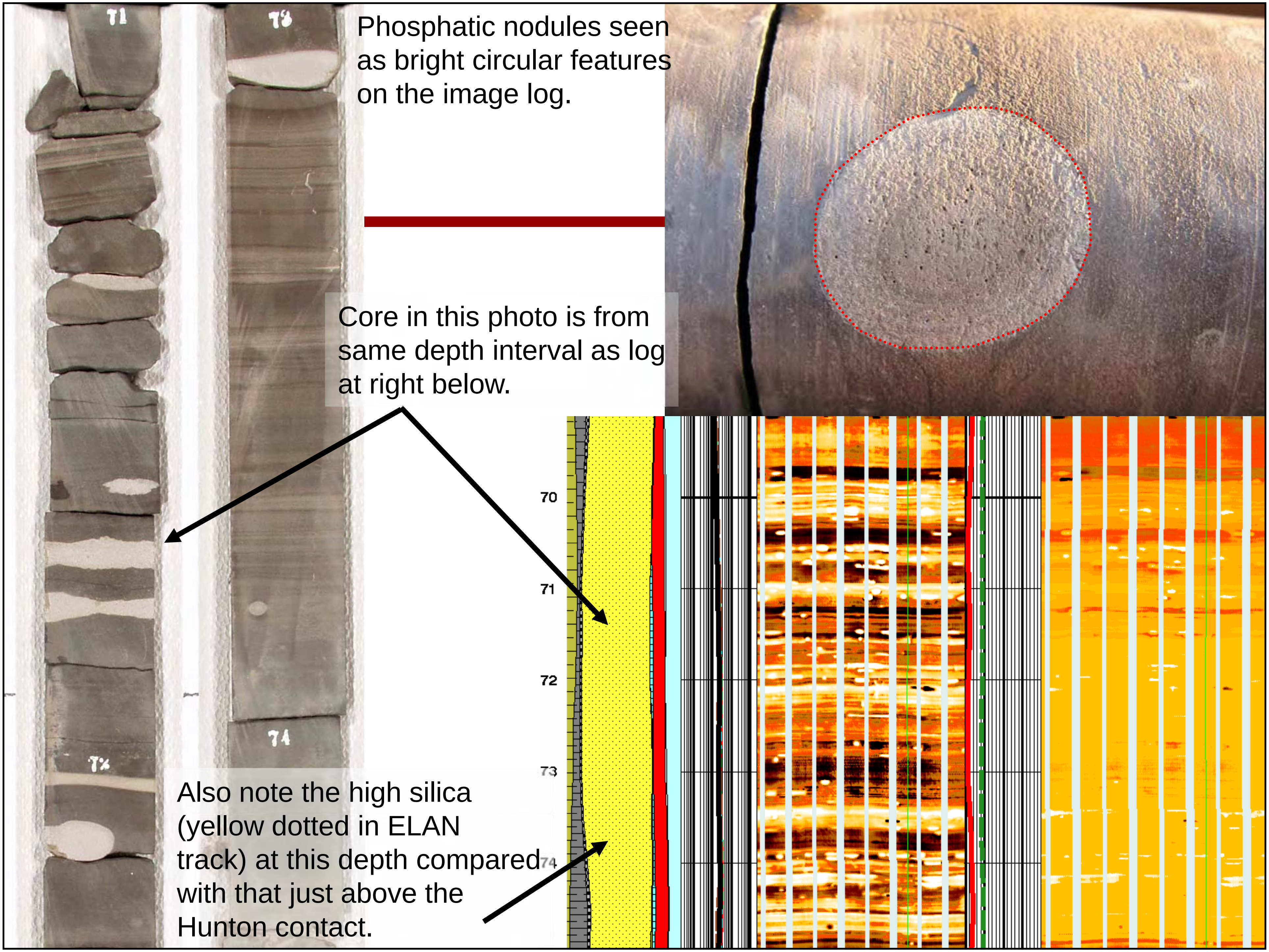

Determine most favorable stratigraphic zones for drilling and fracing based on sequence stratigraphy from wells and seismic
Identify key wells and 3D seismic volumes
Establish lithofacies/sequence stratigraphy from core
Biostratigraphic age/environment determination
Calibrate lithofacies/mineralogy to log response using GAMLS
Identify lithofacies (mineralogy) in uncored wells using GAMLS
Regional to local mapping of lithofacies in uncored wells
Determine log-based petrophysical parameters using GAMLS
3D seismic stratigraphic interpretation of key areas
Calibrate seismic facies to lithofacies using synthetics and seismic inversion
Regional to local mapping of lithofacies from seismic
Geochemical/microporosity relations of lithofacies
Compare stacking of lithofacies with stratigraphic distribution of frac-induced micro-seismic events
Determine fracture potential/geomechanics of lithofacies
Establish lithofacies vs. petrophysics relations
Map significant petrophysical, geochemical and geomechanical properties using logs and seismic
Determine and map most favorable stratigraphic zones for drilling/fracing

Recent Behind-Outcrop Studies: to relate rock and well log properties at and laterally beyond the wellbore

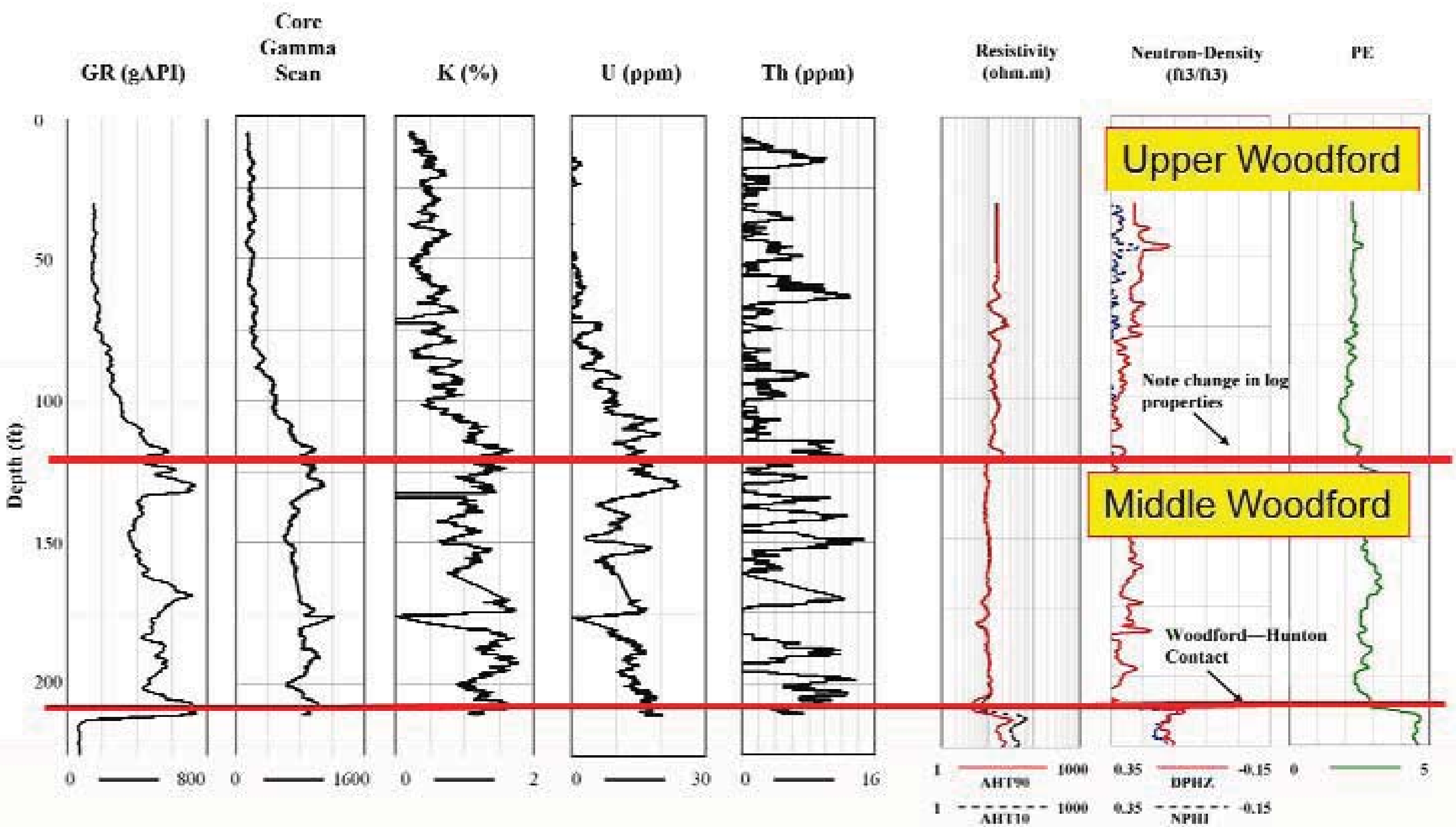
- Behind-outcrop drilling, logging (*including borehole image logs*), coring, and shallow seismic:
  - *Mt. Messenger Fm.*, New Zealand, 1994 (Browne and Slatt, 2002)
  - *Lewis Shale*, Wyoming, 1998 (Witton et al., 2000; Slatt et al., 2008)
  - *Jackfork Group*, Arkansas, 2006 (Rothfolk, 2006; Slatt and Davis, in press)
  - ***Woodford Shale*, Oklahoma (Buckner, M.S. thesis, in prep.)**

Note proximity to two Woodford exposures. Explosives shed seen in picture and aerial photo.

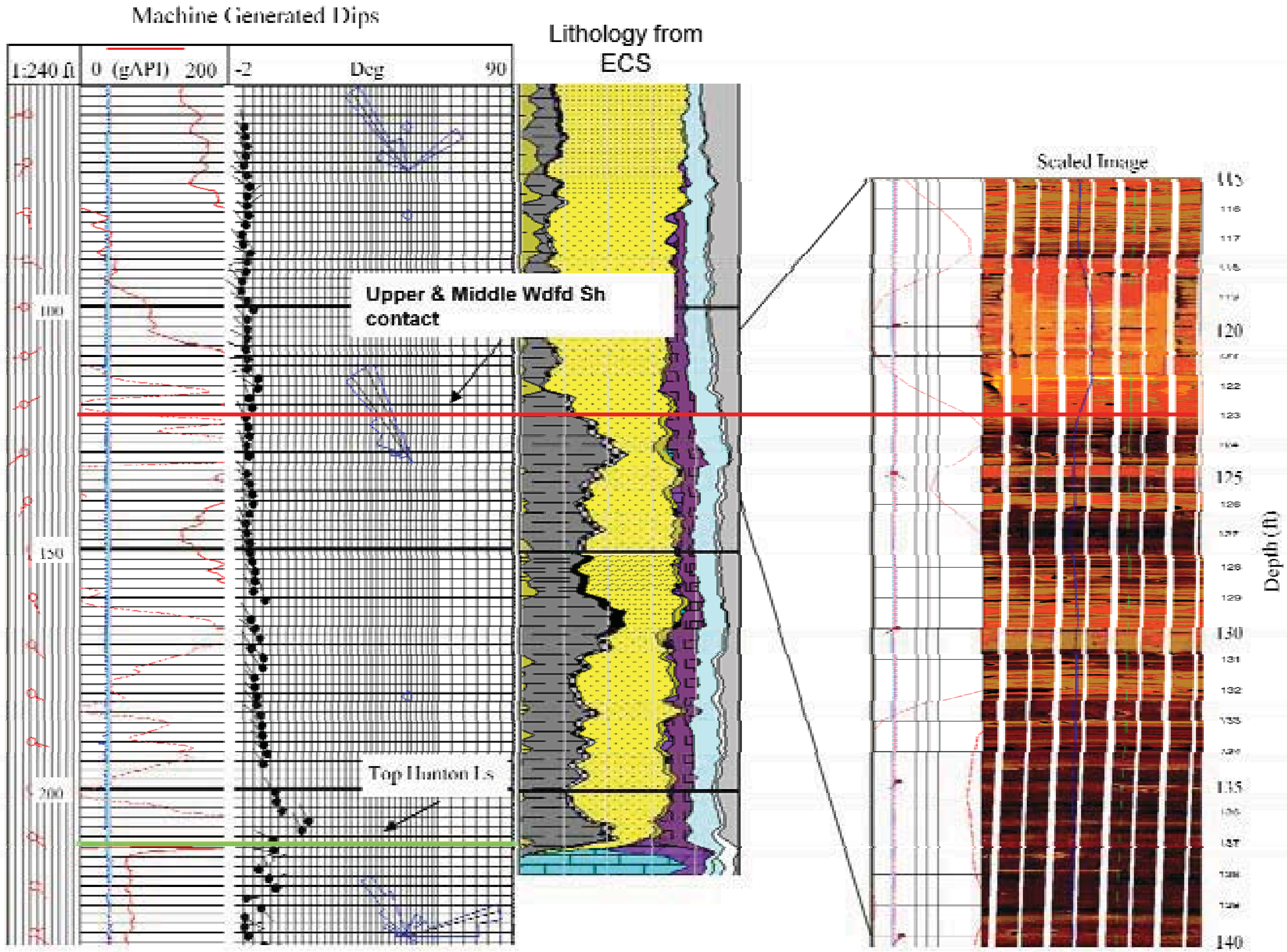

Horizontal beds
Drillsite location at east quarry wall


Phosphatic nodules seen as bright circular features on the image log.
Core in this photo is from same depth interval as log at right below.
Also note the high silica (yellow dotted in ELAN track) at this depth compared with that just above the Hunton contact.
70
71
72
73
74

Relate well log properties to rock properties

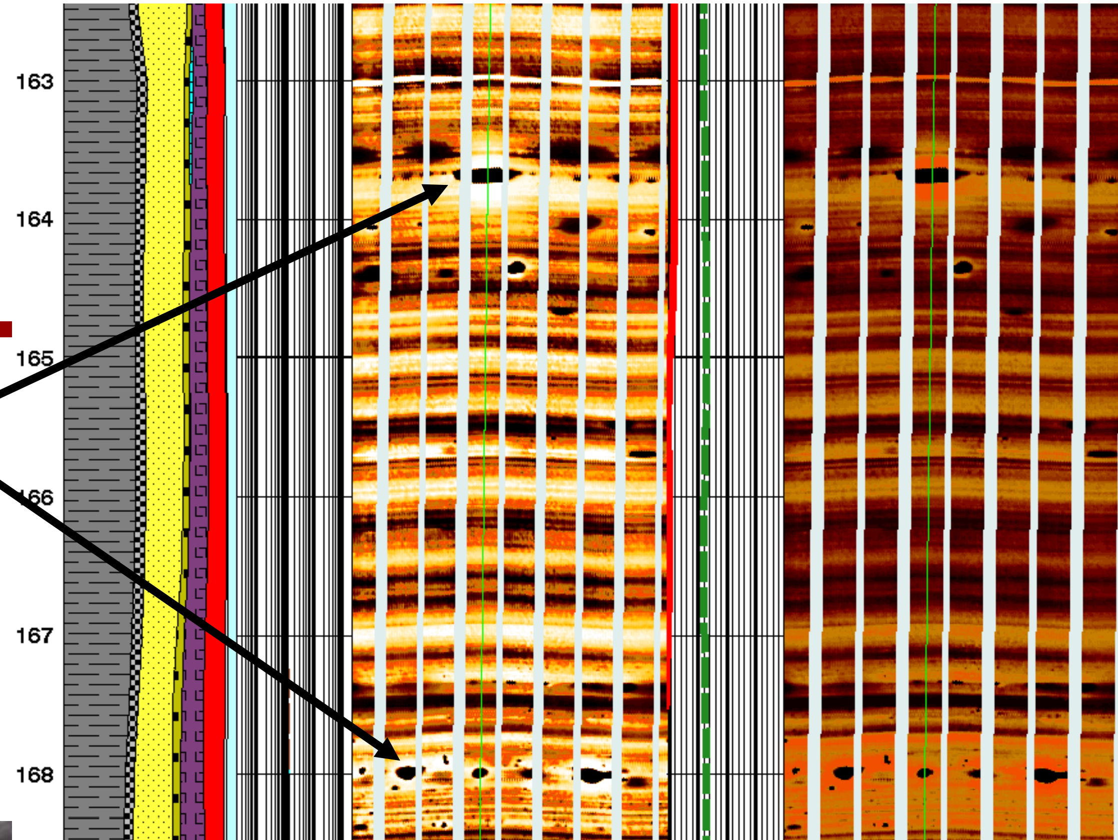


Gamma ray dependence on U in Woodford → use GR as transgressive-regressive cycle indicator

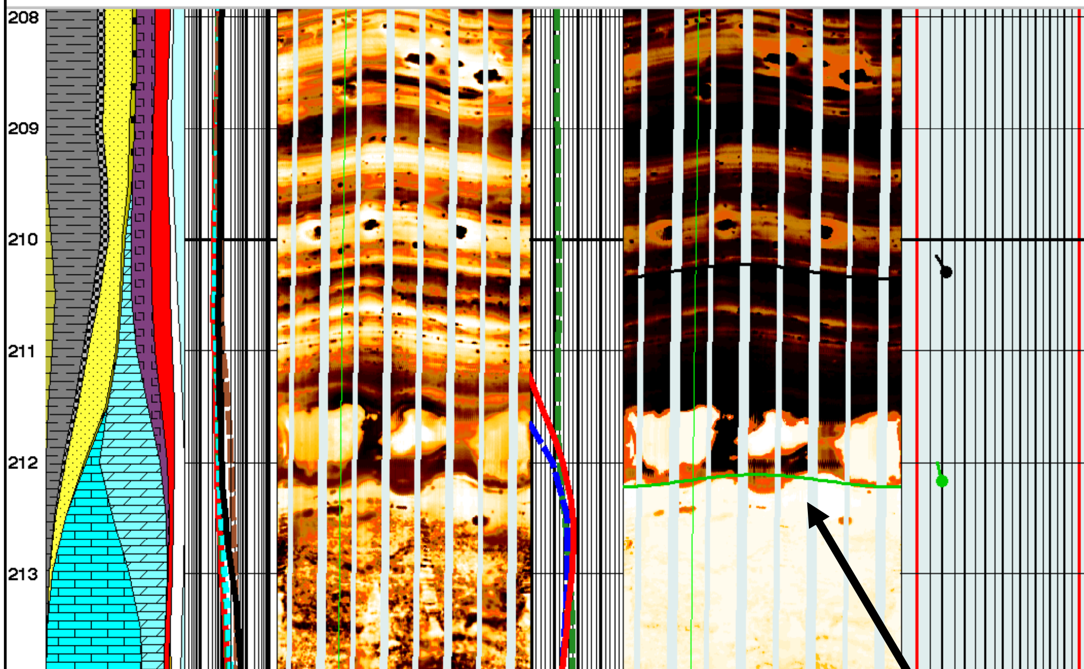


Note slight increase in dip above the interpreted U. Woodford and M. Woodford members.

Pyrite is seen as dark circular features with bright colored halos on image log.



Basal Contact



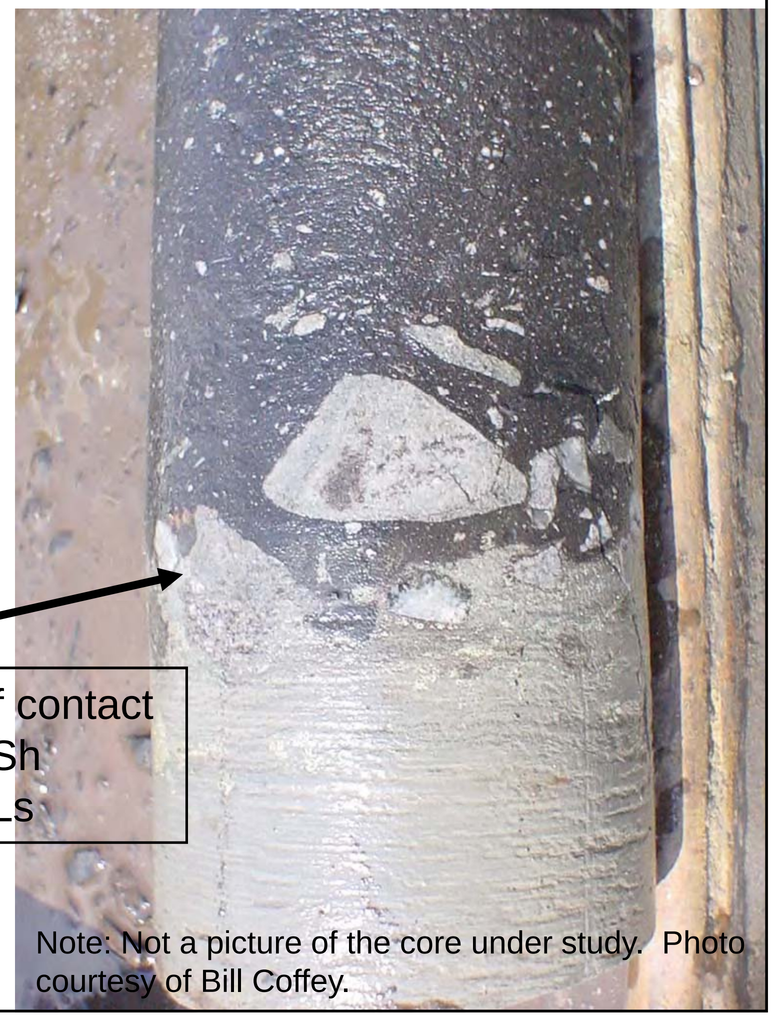
FMI & ELAN shown above.

Directly above Hunton:
9º at 329º azi (315 is due NW)

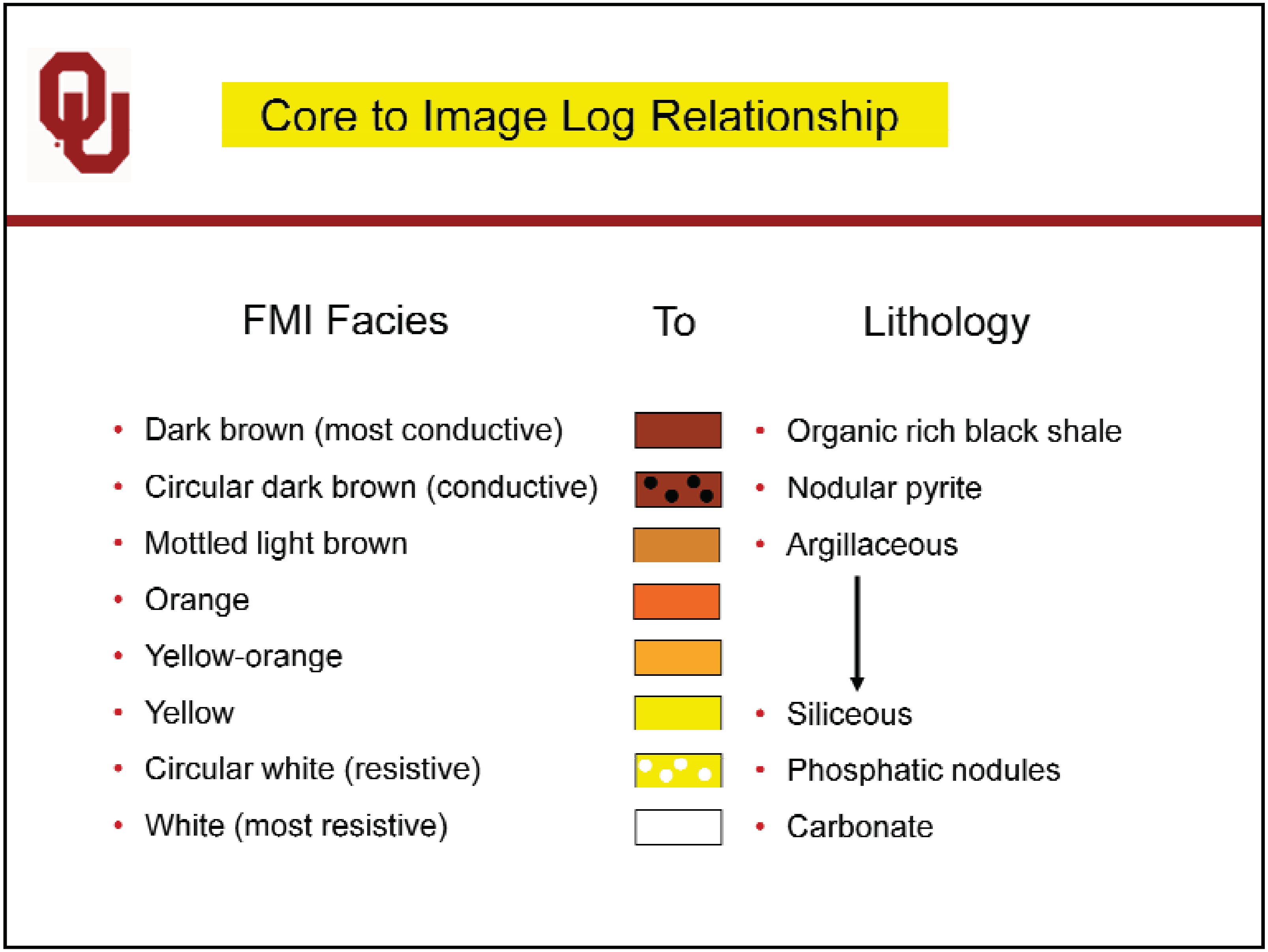
Uphole:
3º at 316º az

Effects of localized post-Woodford depositional structure (Lawrence Uplift)

Note erosional nature of contact between the Woodford Sh and underlying Hunton Ls

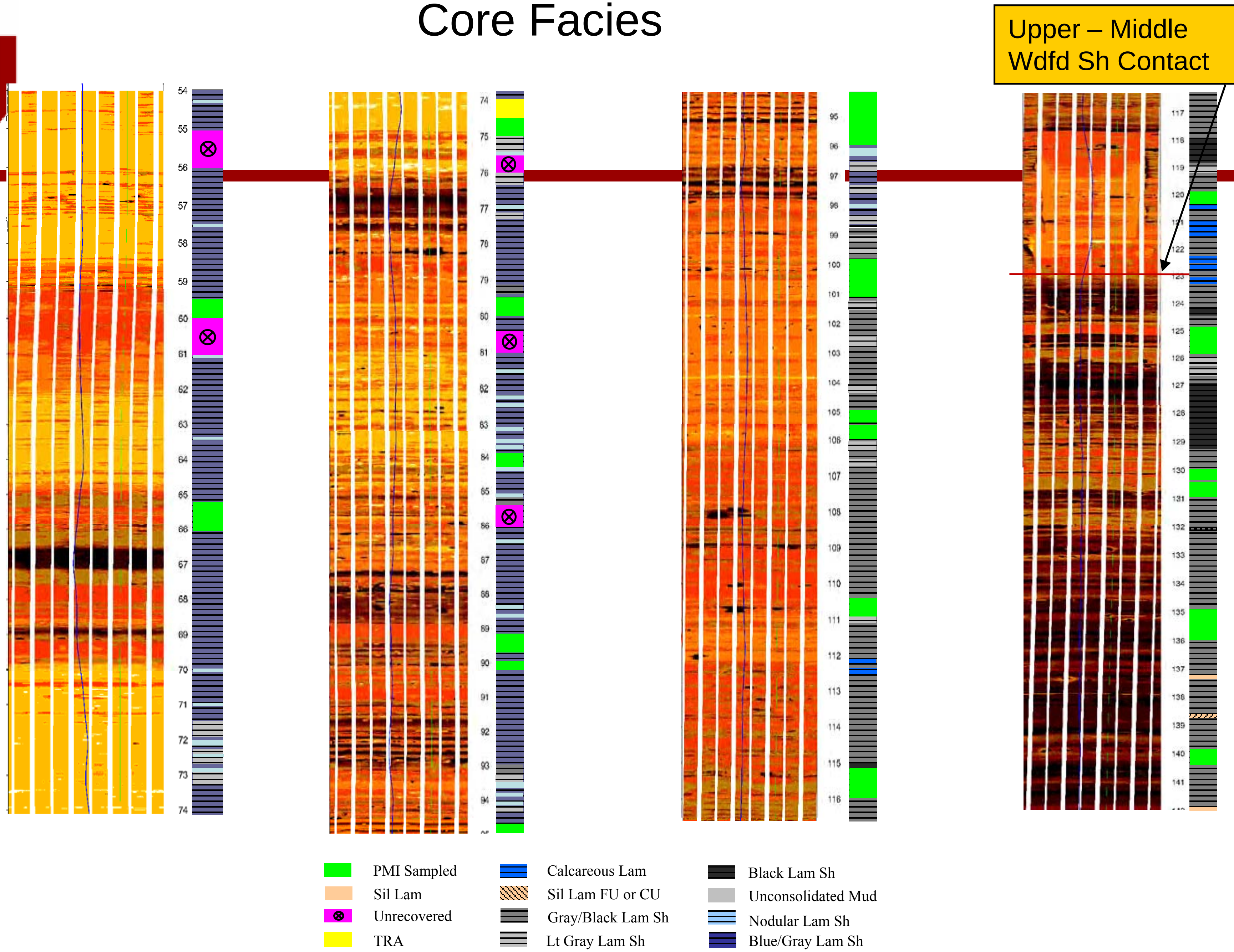


Note: Not a picture of the core under study. Photo courtesy of Bill Coffey.



Keep in mind that these color variations are based on variations in the scaled image. This image is affected by the total range of resistivity found within the footage of log being processed. Therefore, a wider variation in resistivity values will yield a more subtle change in color and its interpreted lithology.

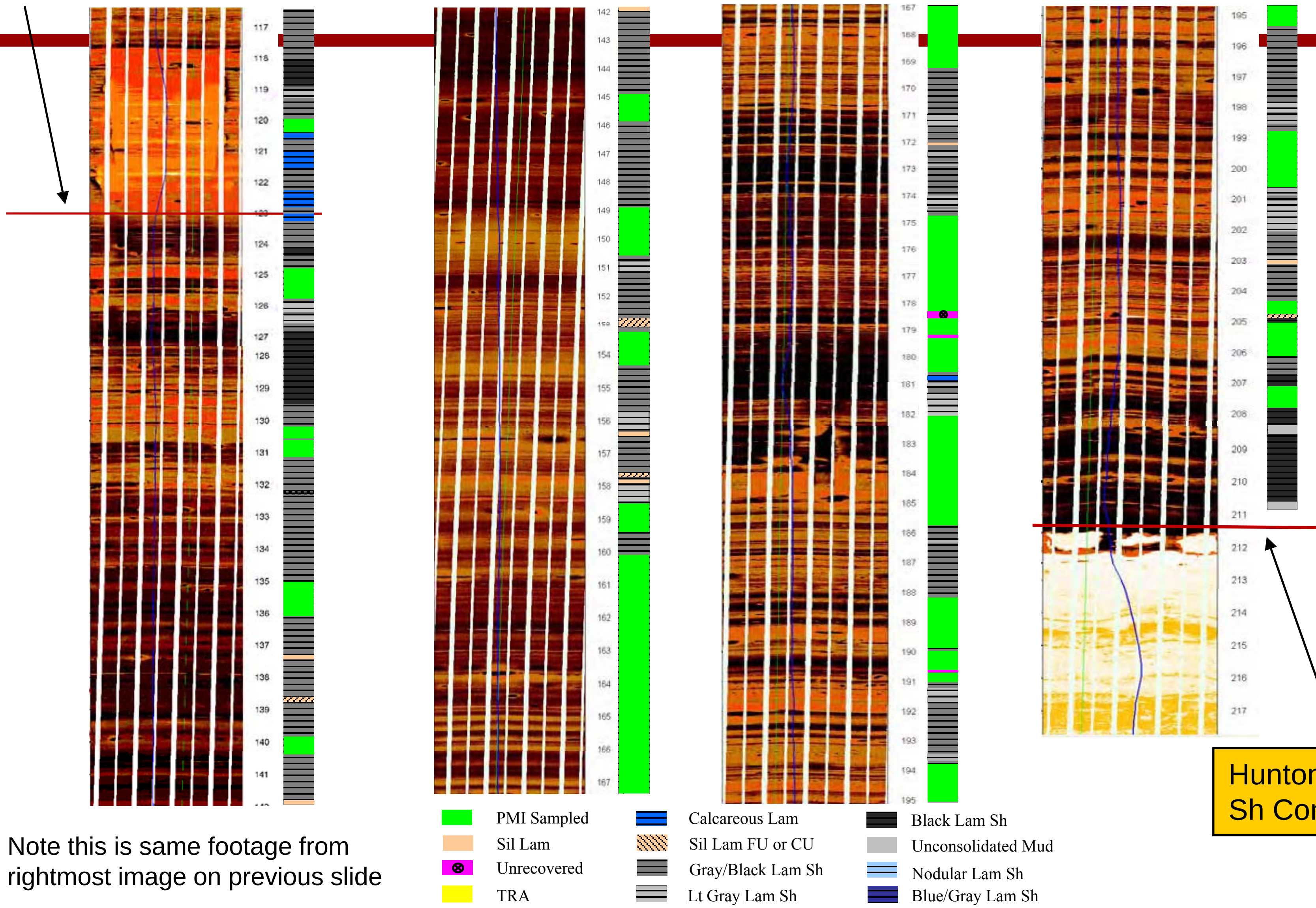
Core Facies



Upper – Middle Wdfd Sh Contact
PMI Sampled
Sil Lam
Unrecovered
TRA
Calcareous Lam
Sil Lam FU or CU
Gray/Black Lam Sh
Lt Gray Lam Sh
Black Lam Sh
Unconsolidated Mud
Nodular Lam Sh
Blue/Gray Lam Sh

Core Facies

Upper – Middle
Wdfd Sh Contact

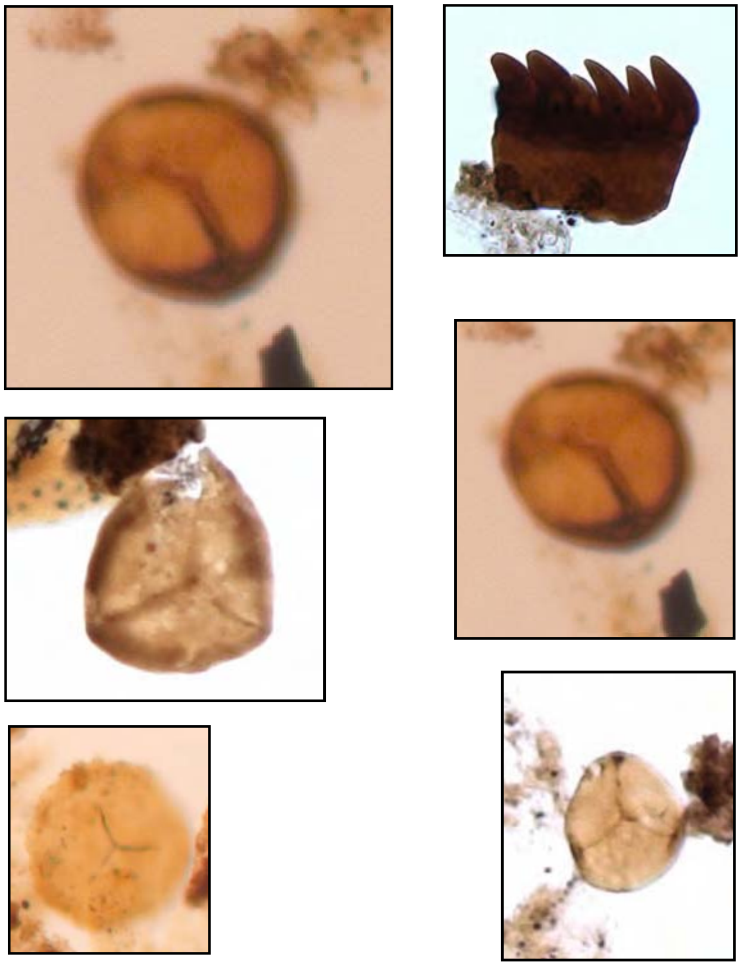


Hunton - Wdfd
Sh Contact

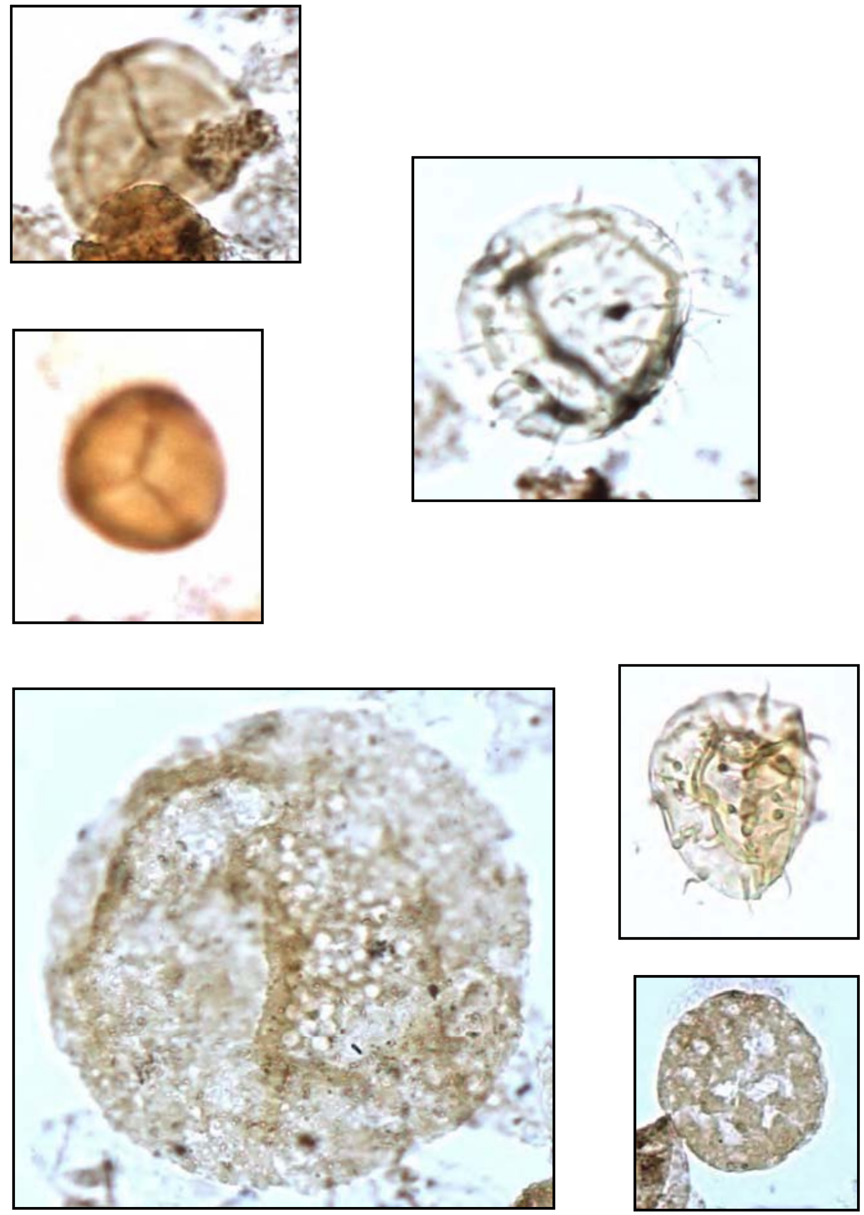
Note this is same footage from
rightmost image on previous slide

Microflora-fauna

PS2 Core Depth 38.9’



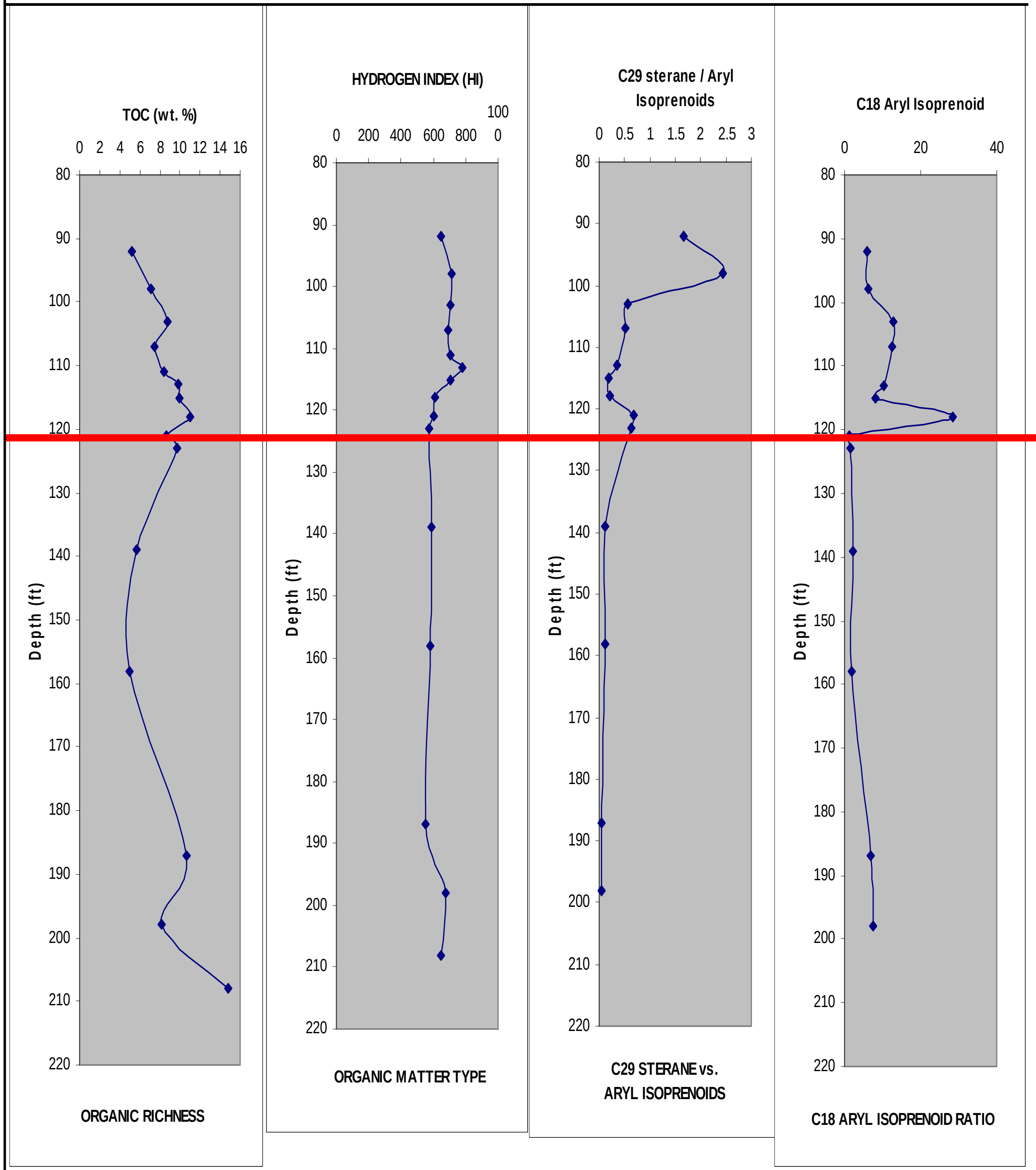
PS3 Core depth 54.2’



All samples shown at same magnification

50 µm

Organic geochemistry



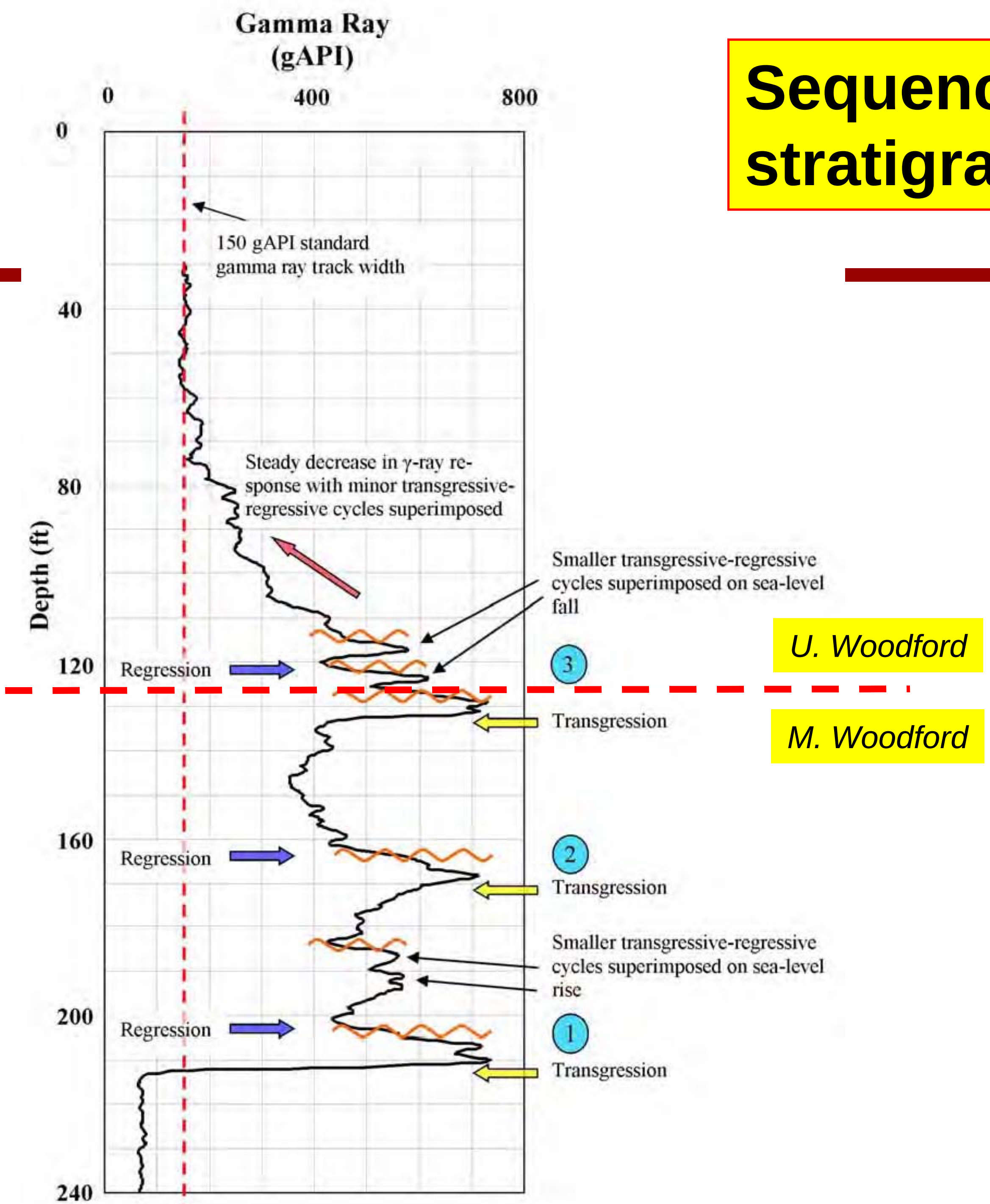
Higher concentrations of eukaryotic biomarkers-C29 steranes indicating more oxic conditions

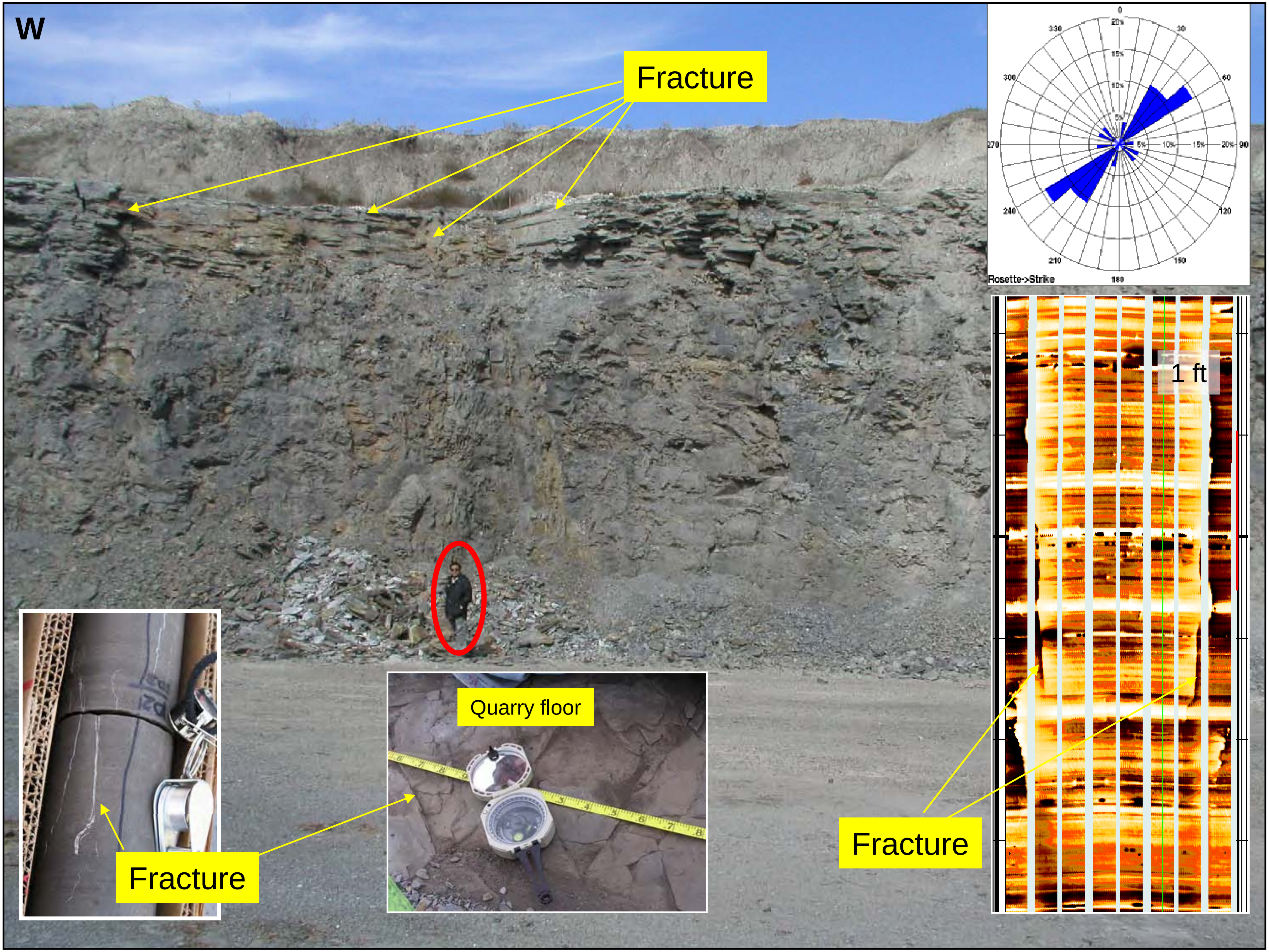
U. Woodford

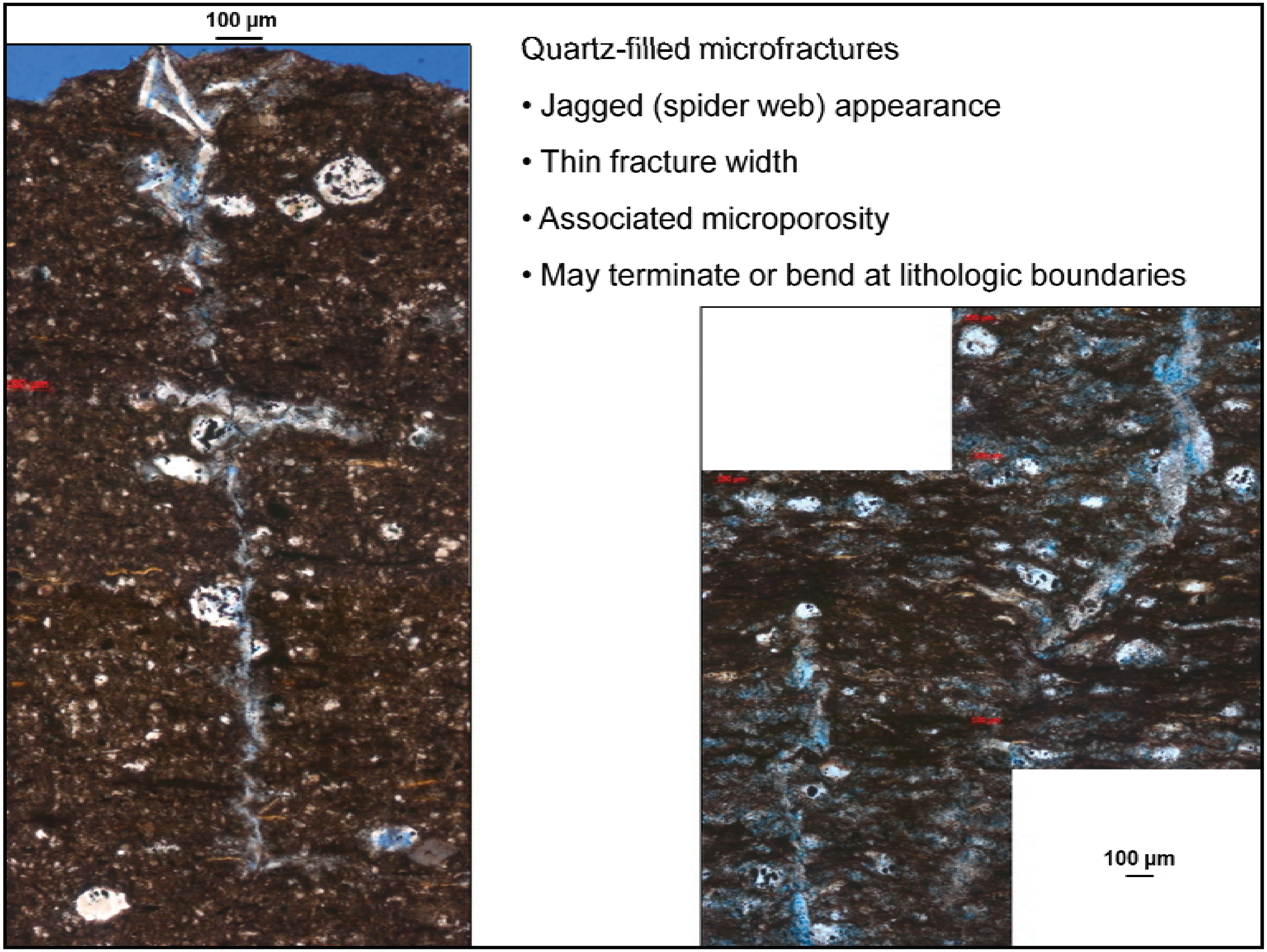
M. Woodford

Higher Concentrations of Chlorobiaceae-indicating euxinic conditions (anoxic;H2S rich conditions)-probably stratified water column

Sequence stratigraphy

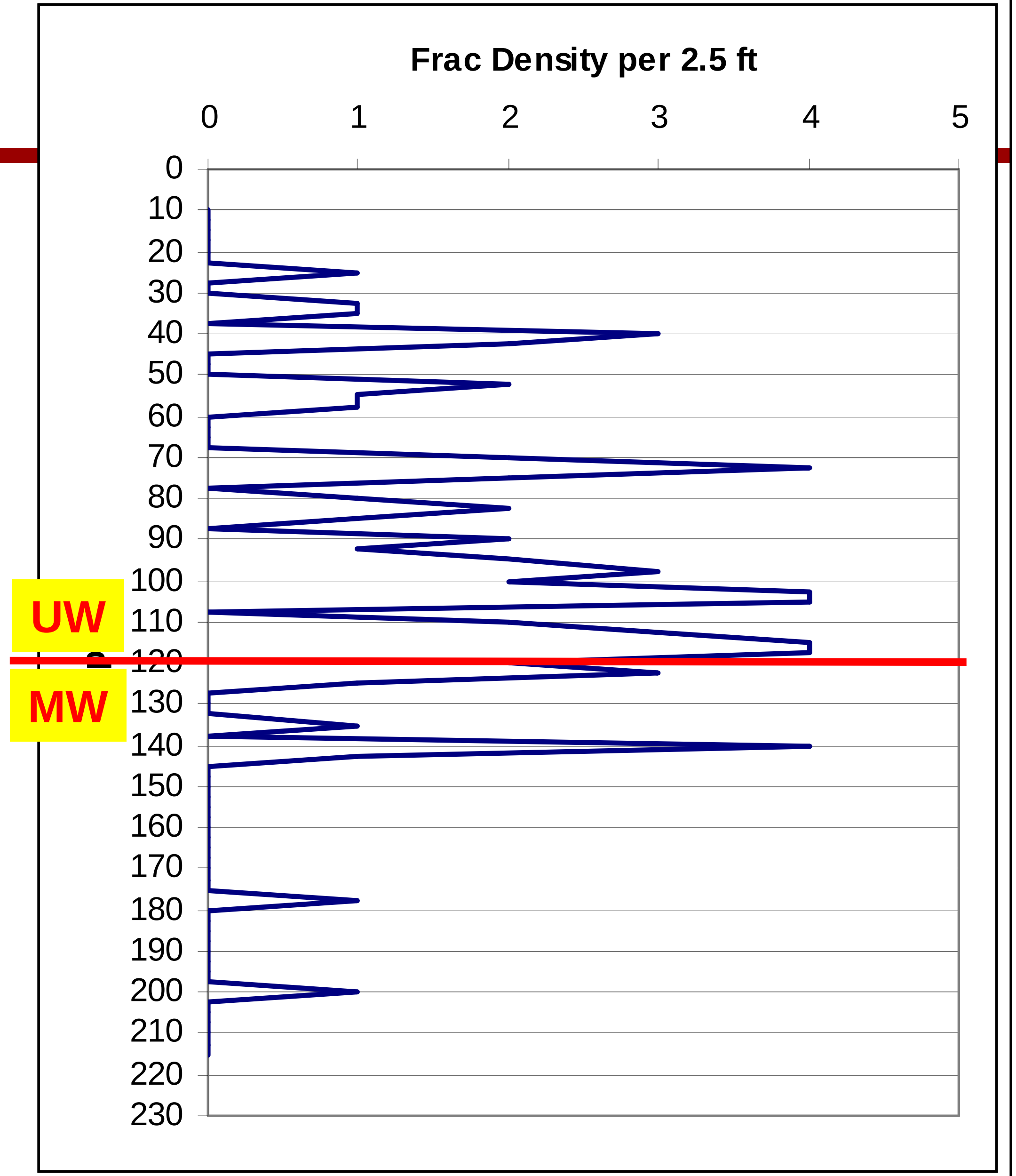



W
Fracture
0
30
60
90
120
150
180
210
240
270
300
330
5%
10%
15%
20%
Rosette->Strike
1 ft
Quarry floor
Fracture
Fracture



Note difference in character between fractures healed with predominantly quartz (two at left which appear to follow a much more jagged path) and predominantly calcite (right which has a much smoother edge). This calcite-filled fracture is also wider in aperture.

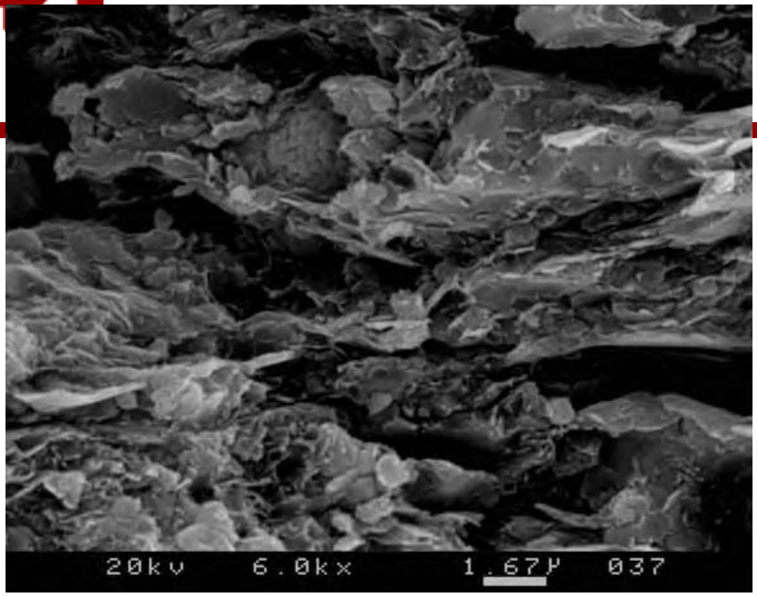
Core Fractures

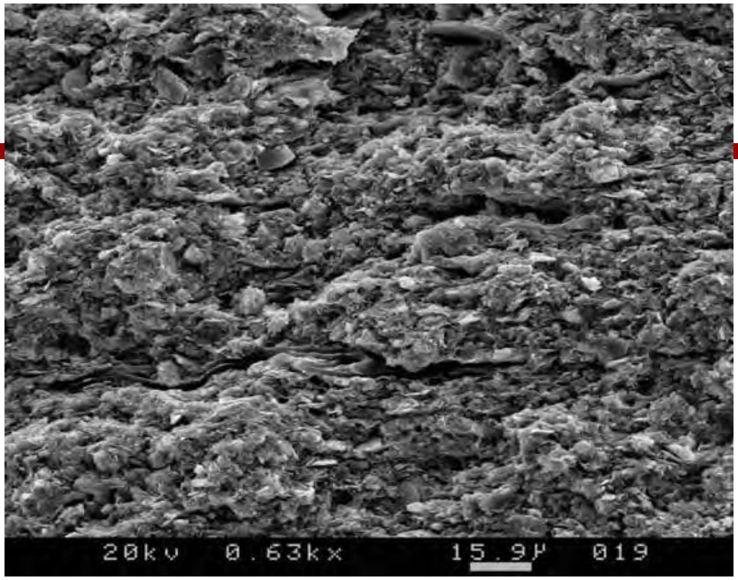


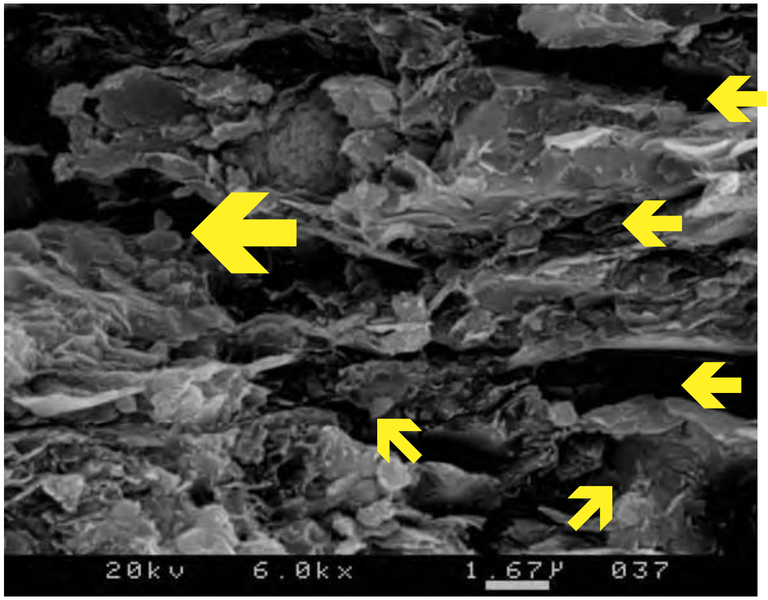
FMI Fractures

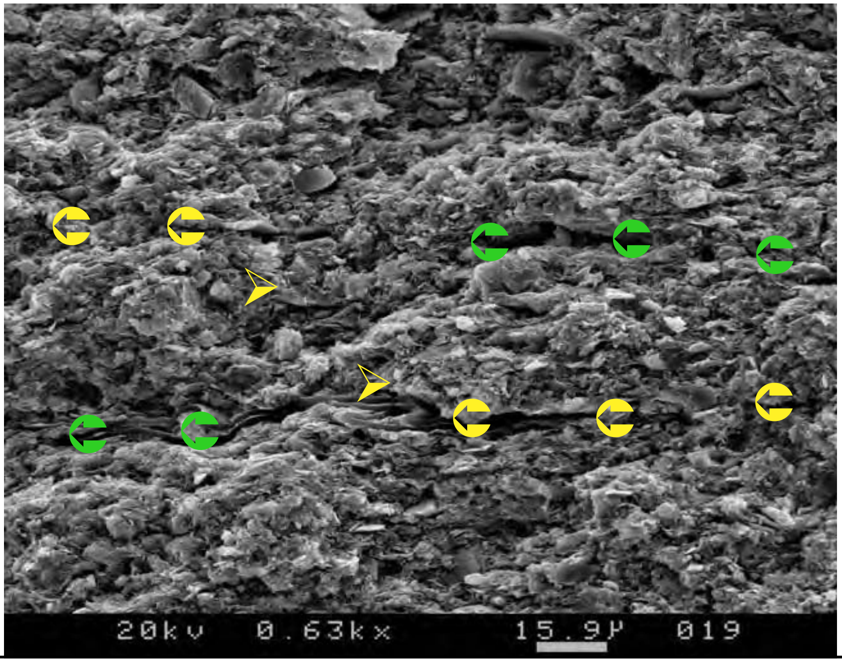
Bottom Depth (ft)	Vertical Extent (ft)	Type
184.5	2.5	Healed
122.75	5	Healed
116.9	0.4	Healed
116.8	0.2	Healed
115.1	0.2	Healed
114.2/113.0	0.2/0.2	Healed
113.5	0.6	Healed
112.6	0.3	Healed
110.1	0.2	Healed
102.3	0.2	Healed
101.0	0.6	Healed
98.3	0.2	Healed
93.9	0.1	Healed
82.0	0.1	Healed

Microporosity: Migration routes? Planes of weakness?

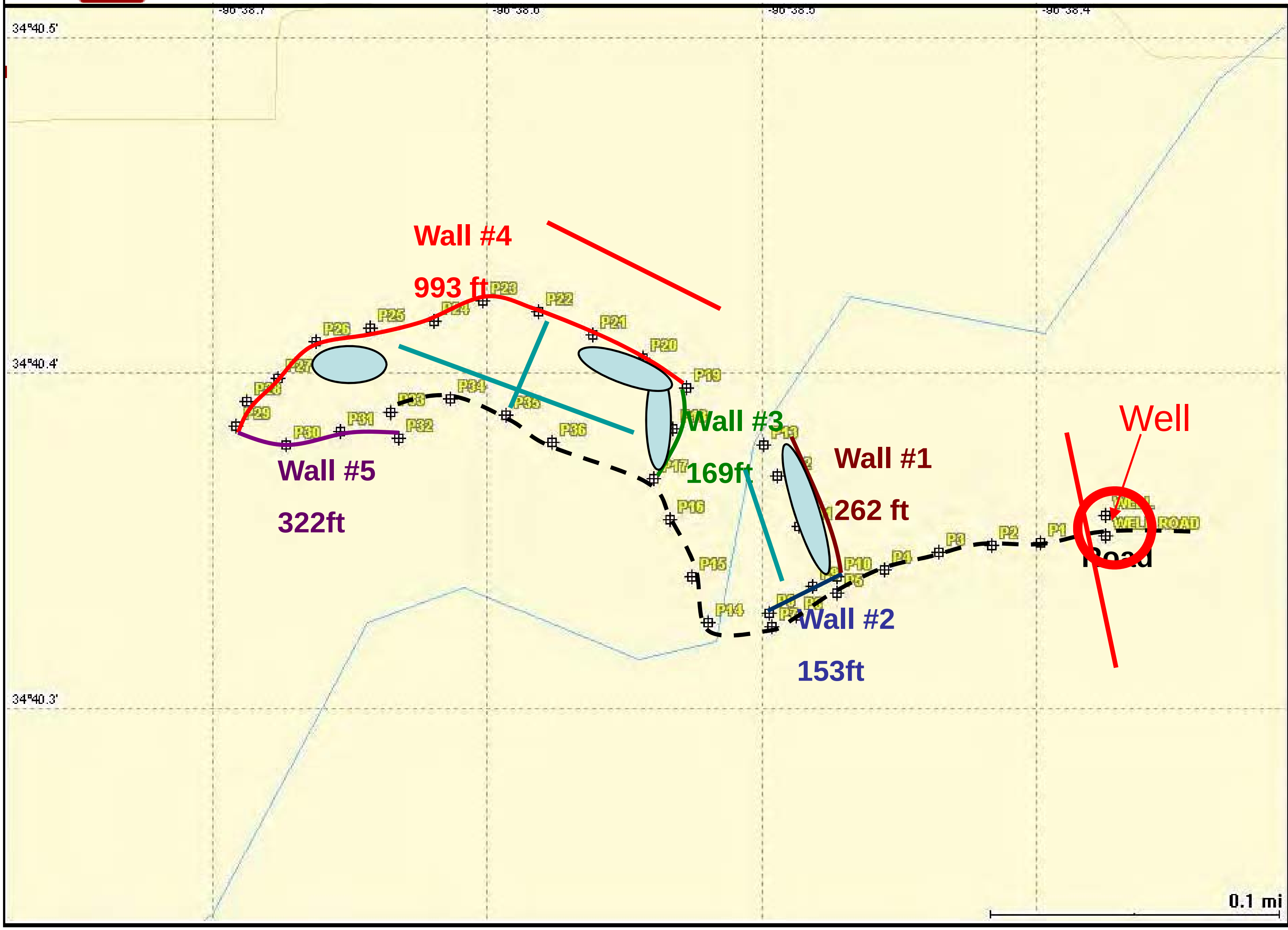


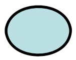






Seismic and LiDAR shoots to relate fractures, lithology, and unconformity





Conclusions, Applications, & Future Work

- Highly variable lithology within Woodford Shale members; upper and middle Woodford differ;
- Log and rock properties are correlative;
- Middle Woodford TST; Upper Woodford HST;
- Strata are laterally continuous the length of the quarry (and undoubtedly farther away);
- Fracture variability as a result of quartz content;
- Fractures have microporosity;
- LiDAR Fracture Analysis & Shallow Seismic study underway to interrelate geological variables
- Biostrat and organic geochemical analyses are important.

Selected References

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Soyinka, O.A., and R.M. Slatt, 2009, Identification and micro-stratigraphy of hyperpycnites and turbidites in Cretaceous Lewis Shale, Wyoming: Sedimentology, v. 55/5, p. 1117-1133.

Witton-Barnes, E M; N.F. Hurley; R.M. Slatt, 2002, Outcrop and subsurface criteria for differentiation of sheet and channel-fill strata; example from the Cretaceous Lewis Shale, Wyoming, *in* Deep-water reservoirs of the world; Gulf Coast Section Society of Economic Paleontologists and Mineralogists Foundation, 20th annual Bob F. Perkins research conference, v. 20; p. 1087-1105.