Outcrop/Behind Outcrop (Quarry), Multiscale Characterization of the Woodford Gas Shale, Oklahoma*

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*Adapted from oral presentation at AAPG International Conference and Exhibition, Calgary, Alberta, Canada, September 12-15, 2010. Please see closely related articles, "Characterization and Origin of Fracture Patterns in a Woodford Shale Quarry in Southeastern Oklahoma for Application to Exploration and Development", S&D article #50352, and "Stratigraphy of the Woodford Shale from Behind-Outcrop Drilling, Logging, and Coring", S&D article #50147.

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Abstract

An outcrop-behind outcrop study was conducted in and adjacent to a 250x175x40m quarry of the gas-producing Woodford Shale to structurally/stratigraphically characterize it from the pore- to subregional scales using a variety of techniques. Strata around quarry walls were described and correlated to a 70m long continuous core drilled 150m back from the quarry wall and down to the Woodford-Hunton unconformity. Well logs obtained include Element Capture Spectroscopy (ECS), Neutron Porosity (NPHI), Density Porosity (DPHI), Combination Magnetic Resonance (CMR), Formation Micro Imager (FMI), and Sonic Scanner (MSIP), all trademarks of Schlumberger.

Strata around the quarry are horizontally bedded. ECS, FMI and porosity logs provided a basic two-fold subdivision into an upper, relatively porous, quartzose lithofacies and a lower, more-clay rich, and less porous lithofacies, but detailed core description, coupled with FMI and quarry wall correlations revealed several types of finely-laminated lithofacies. Organic geochemistry and biomarkers are closely tied to lithofacies, and reveal cyclic variations in oxic-anoxic depositional environments.

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FMI and core analysis indicated fracture density is much greater in the upper quartzose lithofacies, than in the lower, more clay-rich lithofacies. A LiDAR survey around the quarry walls identified two near-vertical fracture trends in the quartzose lithofacies: one striking N85E with spacings of 1.2m, and the other striking N45E corresponding to the present stress field. FMI analysis only displayed the latter fracture set.

Based upon log-derived geomechanical properties, Young's Modulus and Poisson's Ratio are lower for the quartzose interval, probably due to its higher porosity. However, at a finer scale, some clay rich zones exhibit a relatively low Young's Modulus and high Poisson's Ratio while other zones of similar composition exhibit the opposite trend, indicating factors besides porosity play a role in geomechanical properties. SEM analysis of core samples indicated that, in addition to porosity, mineral composition and crystal structure, lithofacies type, and micro-fractures/-porosity all affect geomechanical properties to varying degrees.

This integrated study has provided improved insight into the causal relations among properties at a variety of scales, which can be valuable for improved targeted drilling and production in the Woodford, and perhaps other gas shales.

Selected References

Portas, A.R.M., 2009, Characterization and origin of fracture patterns in the Woodford Shale in eastern Oklahoma for applications to exploration and development: Unpublished M.S. thesis, The University of Oklahoma, Norman, Oklahoma, 110 p.

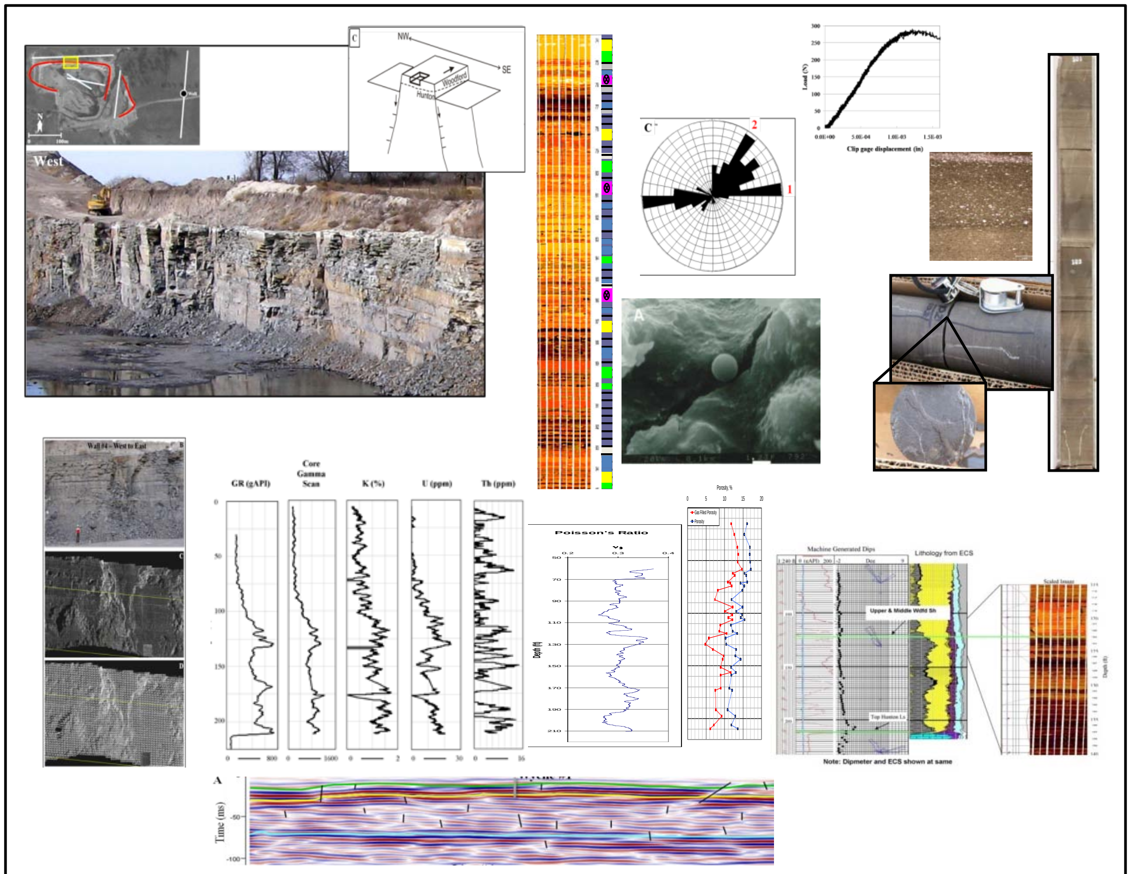
Rodriguez, N.D. and R.P. Philp, 2010, Geochemical characterization of gases from the Mississippian Barnett Shale, For worth Basin, Texas: AAPG Bulletin, v. 94/11, p. 1641-1656.

Schieber, J. and J.B. Southard, 2009, Bedload transport of mud by floccules ripples; direct observation of ripple migration processes and their implications: Geology Boulder, v. 37/6, p. 483-486.

Sierra, R, M.H. Tran, Y.N. Abousleiman, and R.M. Slatt, 2010, Woodford Shale mechanical properties and impacts of lithofacies, 44th U.S. Rock Mechanics Sumposium and 5th U.S.-Canada Rock Mechanics Symposium, Salt Lake City, ARMA10-461.

Outcrop/behind outcrop (quarry), multiscale characterization of the Woodford Shale, Oklahoma

Dr. Roger M. Slatt (presented by Katie Hulsey)



Advantages of outcrop/ behind outcrop studies

Vertical and Lateral Characterization of properties

Advantage 1: Core/log data to compare to outcrop data

Stratigraphic Characterization

Advantage 2a: Detailed stratigraphy and stratification

Advantage 2b: Geochemistry for paleoenvironments

Advantage 2c: Sequence stratigraphy for correlation and mapping

Structural Characterization

Advantage 3a: Quantification of outcrop fractures

Advantage 3b: Comparison of outcrop, core, and log observed fractures

Advantage 3c: Extending outcrop fractures into the subsurface

Petrophysical and Geomechanical properties

Advantage 4a: Geomechanical characterization

Advantage 4b: Effect of depositional processes on geomechanical properties

Integration of Multidisciplinary properties observed

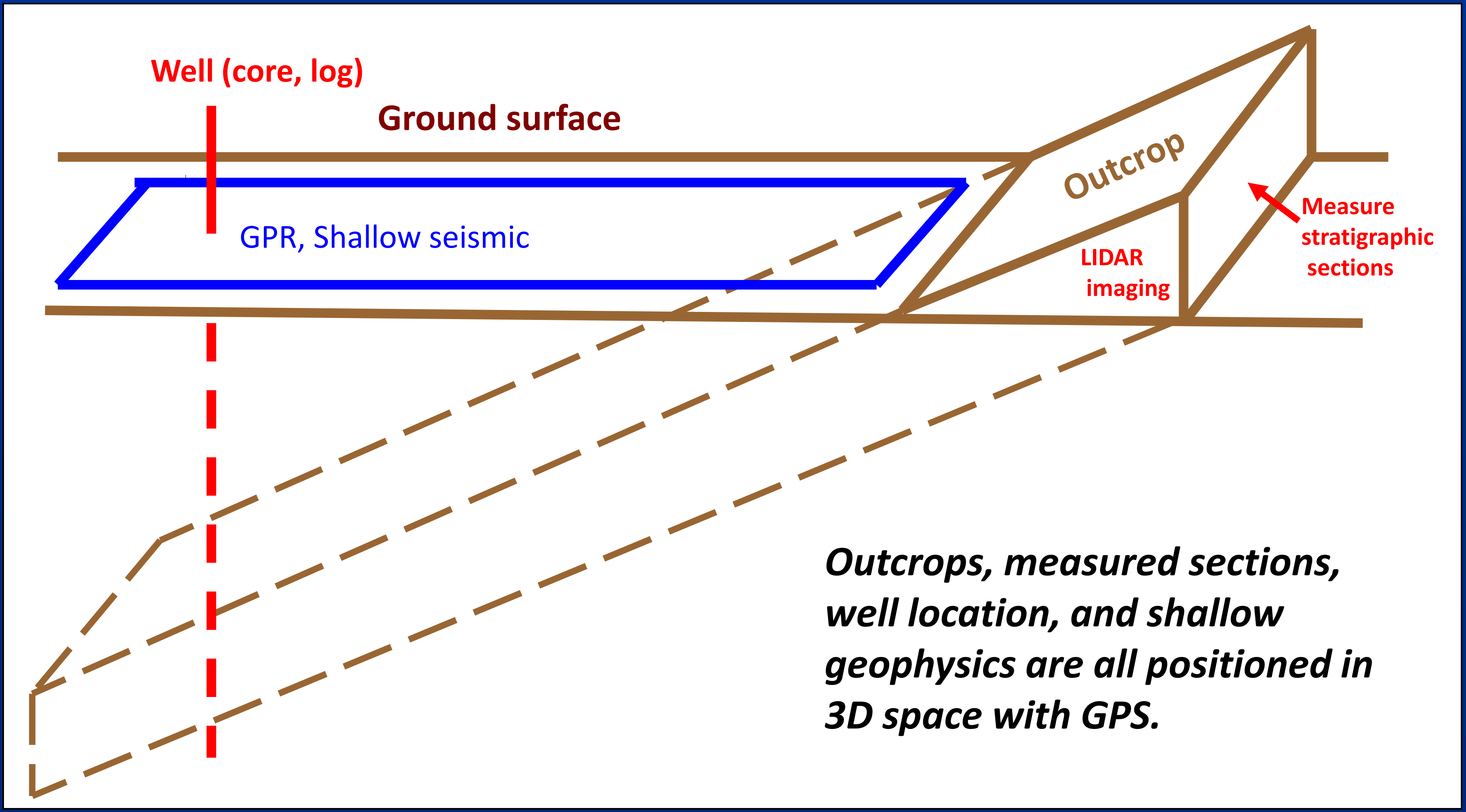
Advantage 5: Effect of depositional properties on hydrocarbon migration pathways: Direct observation and testing

Disadvantage 1: Cost of procuring Core for subsurface

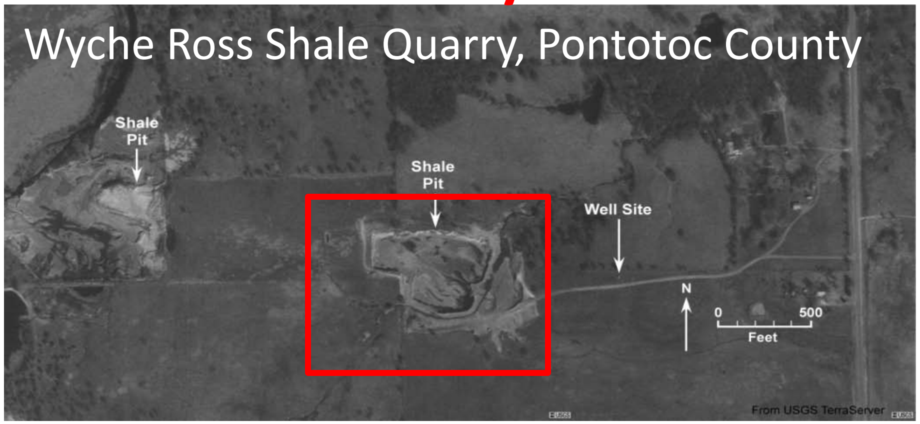
Disadvantage 2: Finding suitable outcrop

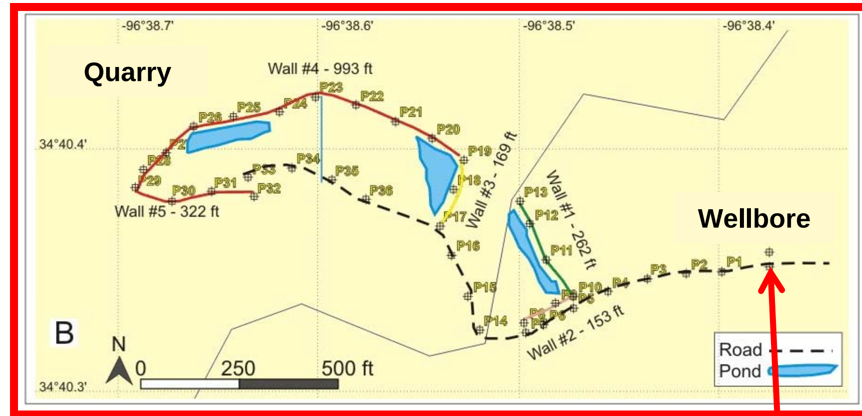
Integrated outcrop/behind outcrop characterization studies

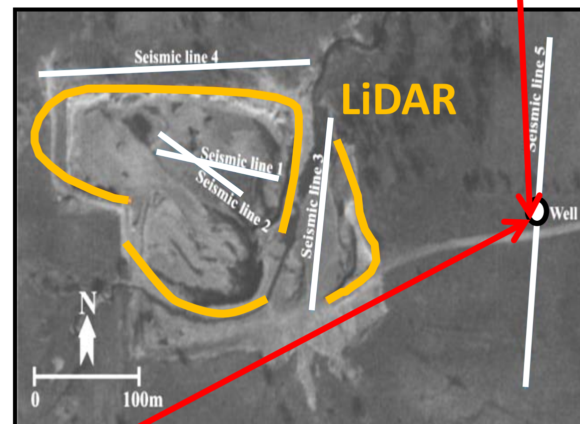
- *Mt. Messenger*, New Zealand (Browne and Slatt, 2002)
- *Lewis Shale*, Wyoming (Witton et al., 2000; Slatt et al., 2009
- *Jackfork*, Arkansas, (Rothfolk, 2006; Slatt and Davis, 2010)
- *Woodford Shale*, Oklahoma, (Slatt et al., in press)



Study Area


Wyche Ross Shale Quarry, Pontotoc County
Shale Pit
Shale Pit
Well Site
N
0
500
Feet
From USGS TerraServer

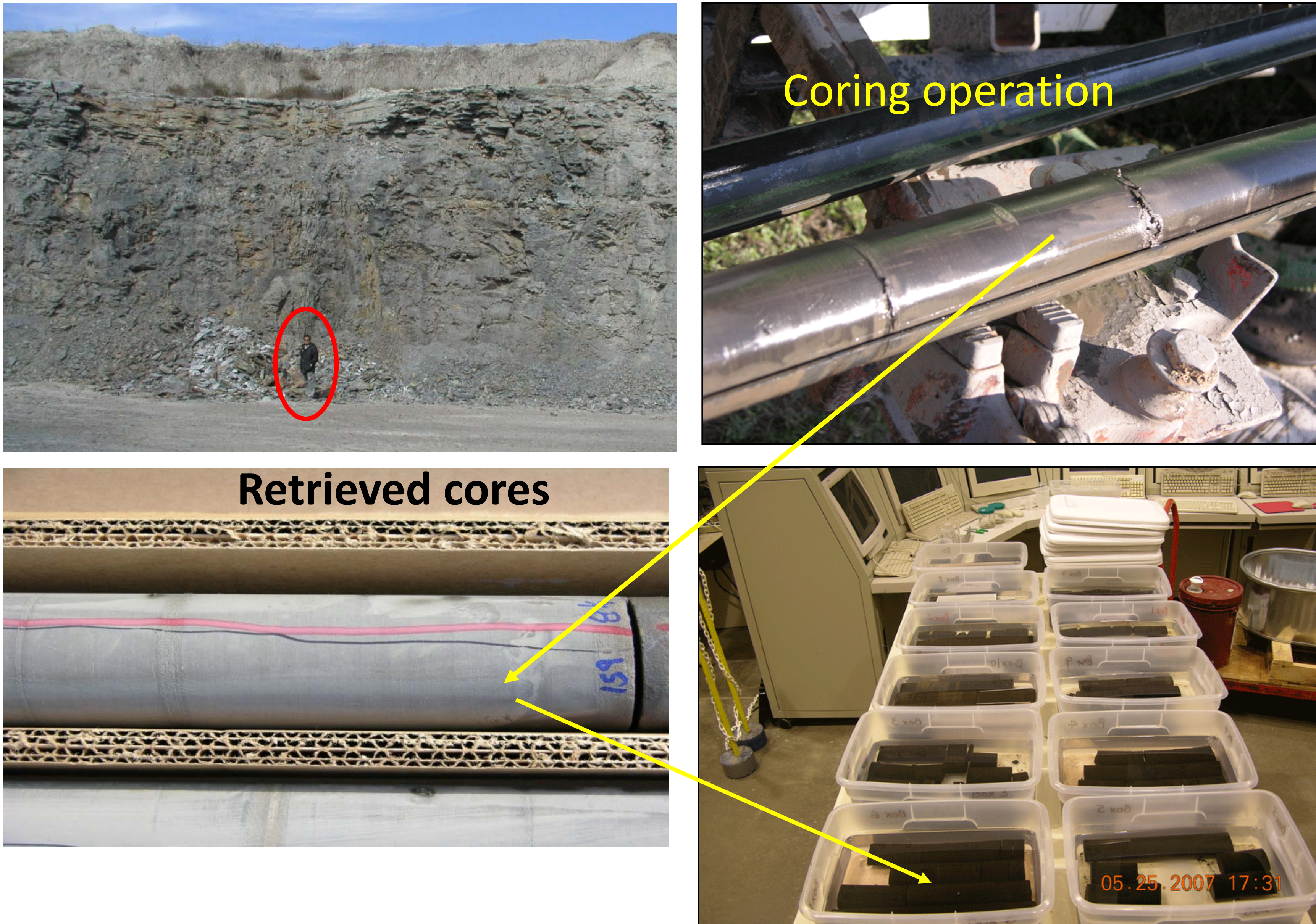

-96°38.7'
-96°38.6'
-96°38.5'
-96°38.4'
Quarry
Wall #4 - 993 ft
34°40.4'
Wall #5 - 322 ft
Wall #3 - 169 ft
Wall #1 - 262 ft
Wall #2 - 153 ft
Wellbore
B
N
0
250
500 ft
34°40.3'
Road
Pond


Seismic line 4
LiDAR
Seismic line 1
Seismic line 2
Seismic line 3
Seismic line 5
Well
N
0
100m


West
Panoramic view of Quarry


East

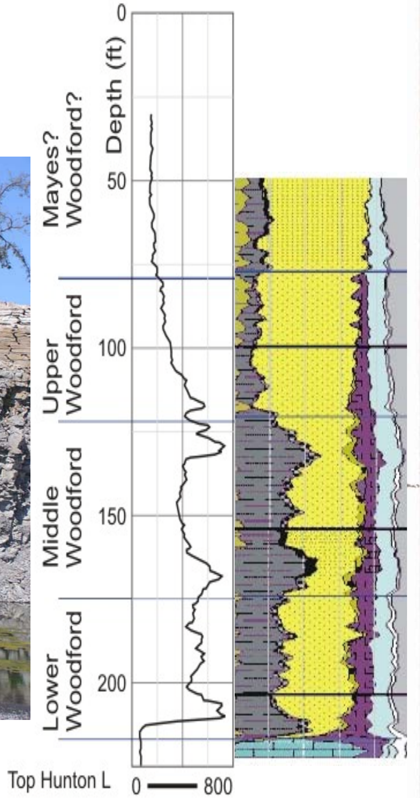
Advantage 1: Fresh core to compare to outcrop and to preserve



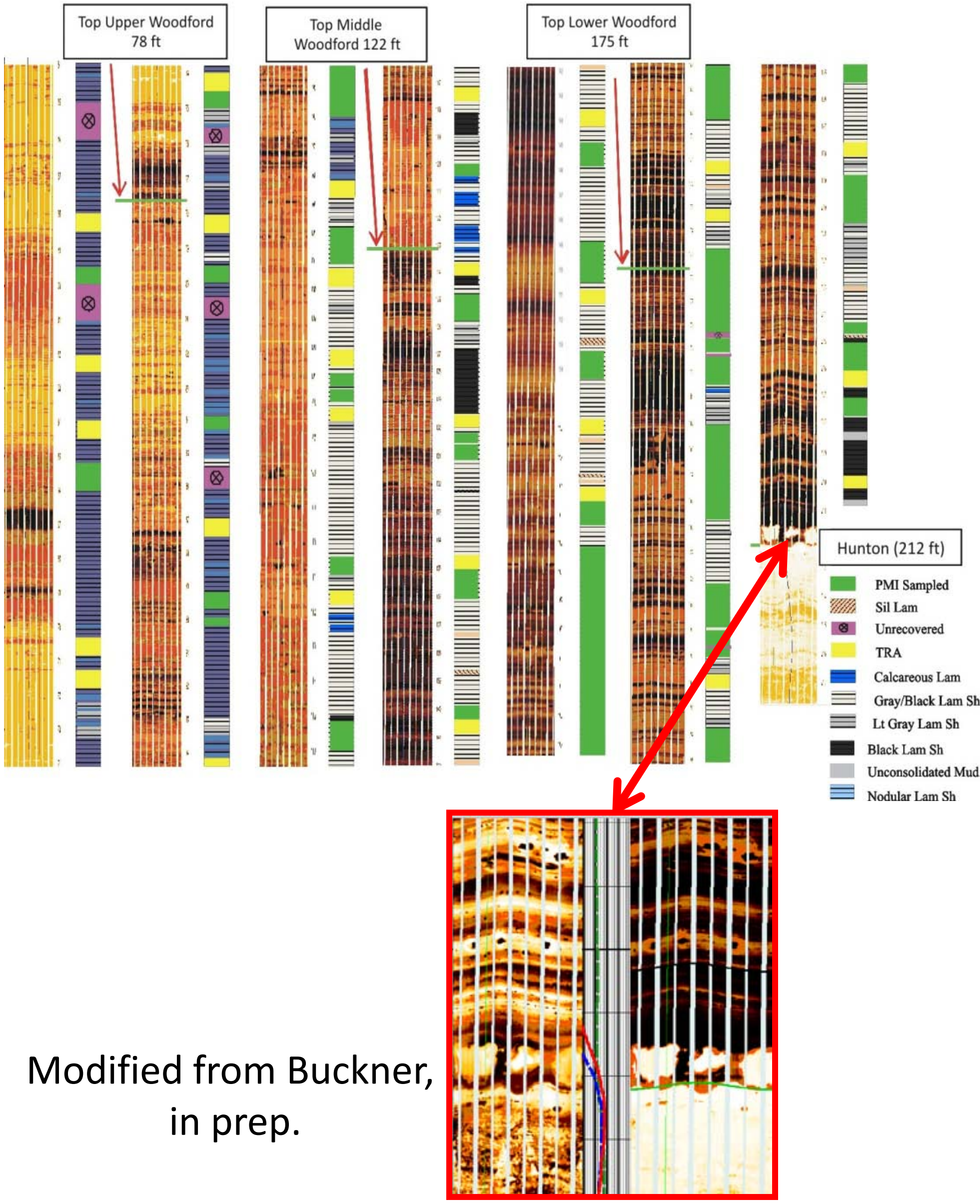
Core samples immersed in minercal oil

Advantage 2a: Detailed stratigraphy and stratification

Outrcop **GR and ECS logs** **Core** **FMI and core-described lithofacies (colors)**

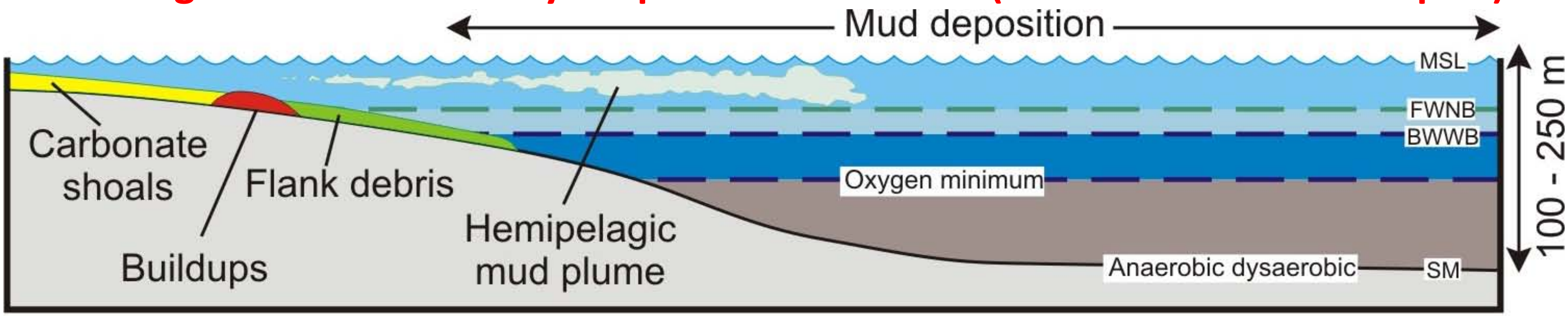


Quartz is yellow
Clay is gray

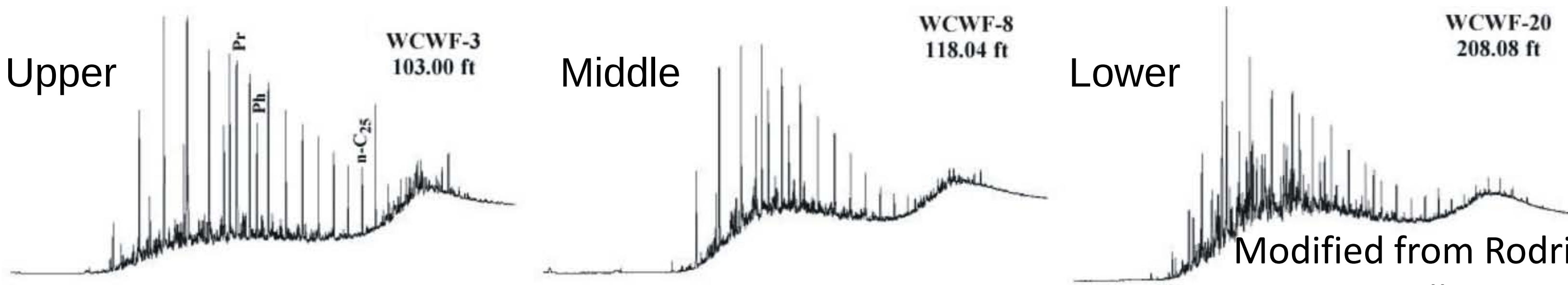


Modified from Buckner, in prep.

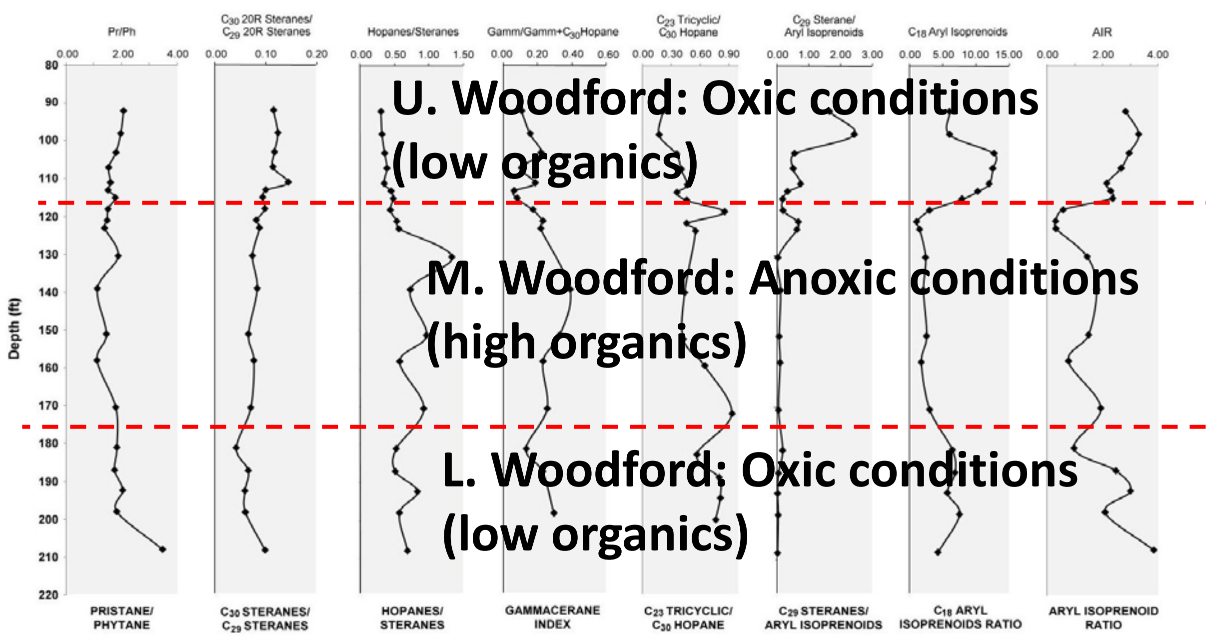
Advantage 2b: Geochemistry for paleoenvironment (non-oil immersed samples)



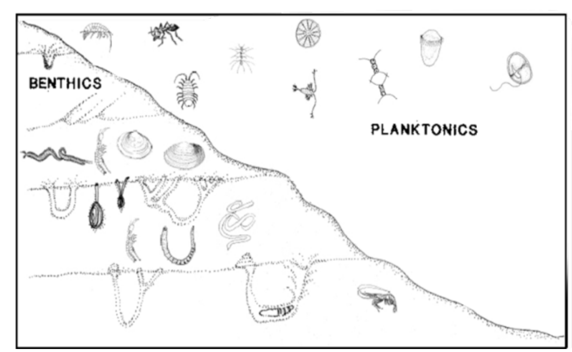
Modified from Loucksand Ruppel, 2007



Modified from Rodriguez, 2009; Micelli, 2010

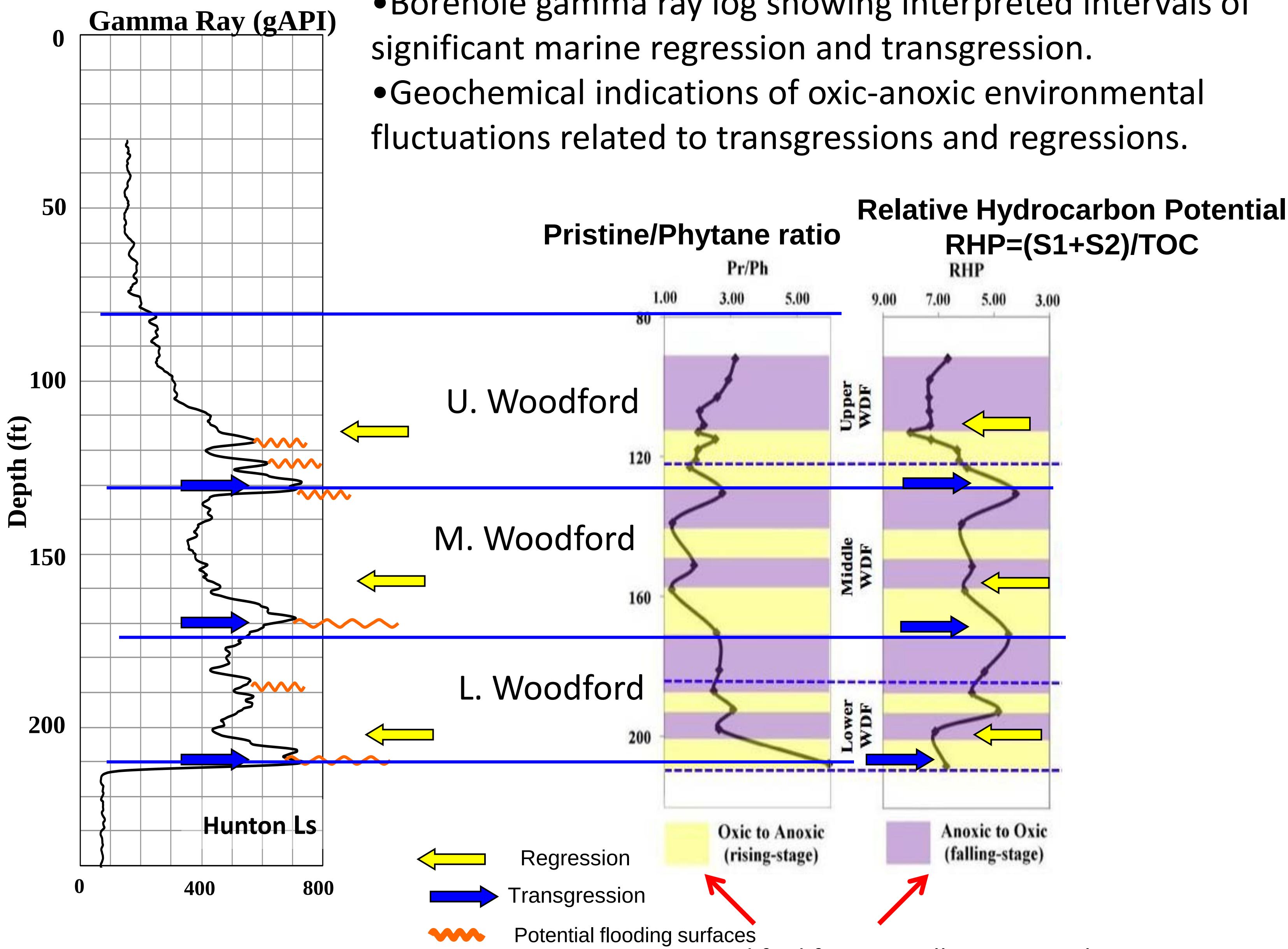


Gas chromatograms of saturate fractions from bitumen extracts of the well (Pr = pristane; Ph = phytane, n-C_{25}= C_{25} normal alkane).



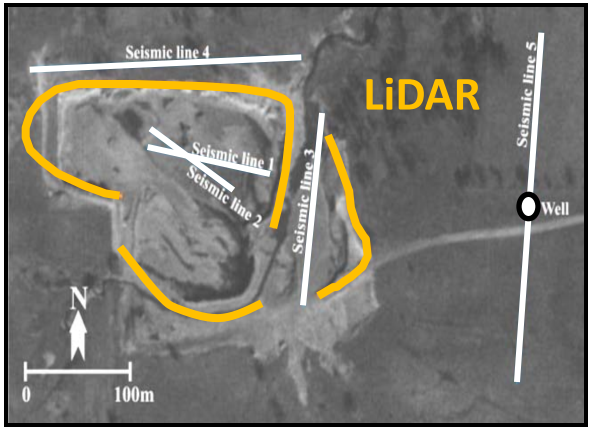
Advantage 2c: Sequence stratigraphy for correlation and mapping

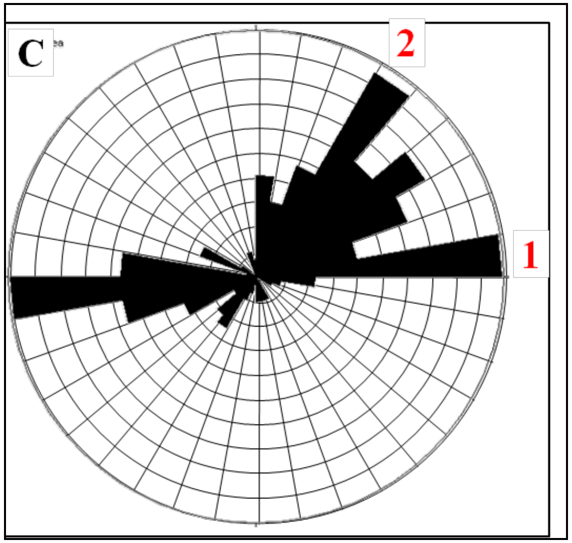
- Borehole gamma ray log showing interpreted intervals of significant marine regression and transgression.
- Geochemical indications of oxic-anoxic environmental fluctuations related to transgressions and regressions.

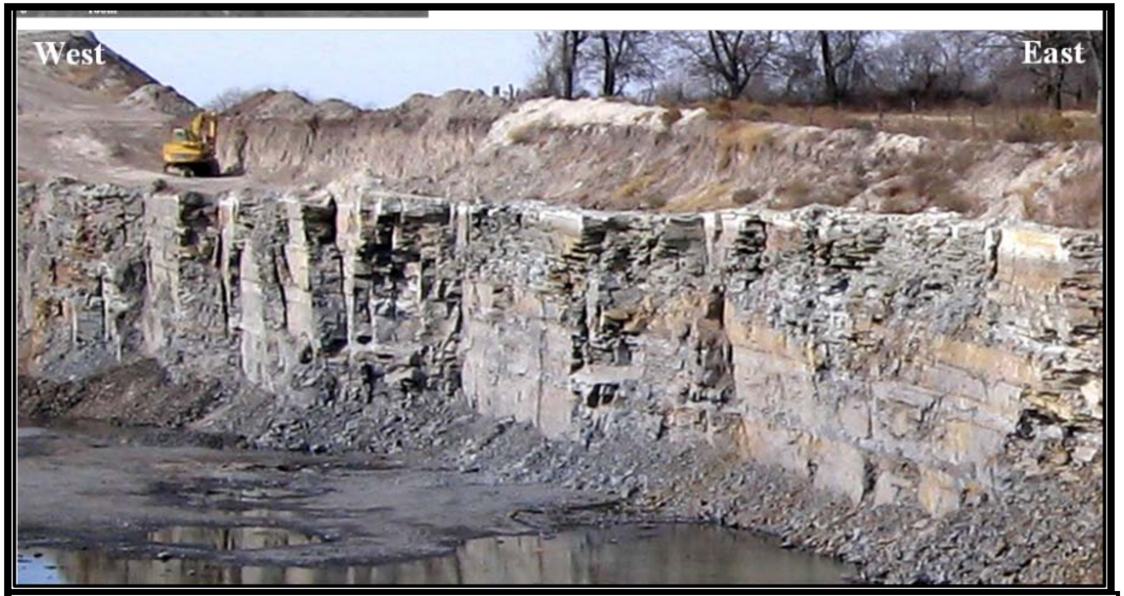


Modified from Micelli, 2010; Buckner, in prep.

Advantage 3a: Quantification of fractures



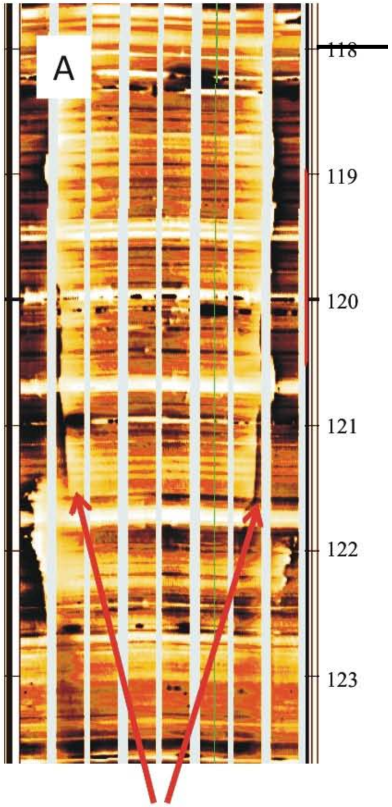


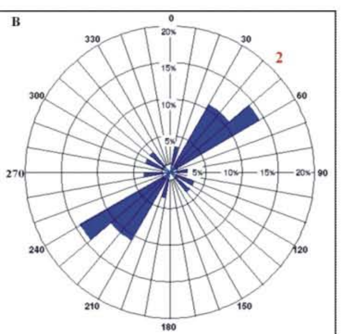


-280 fractures determined from LIDAR survey;
-Two trends (1 and 2)
-1.2m (4ft) spacing

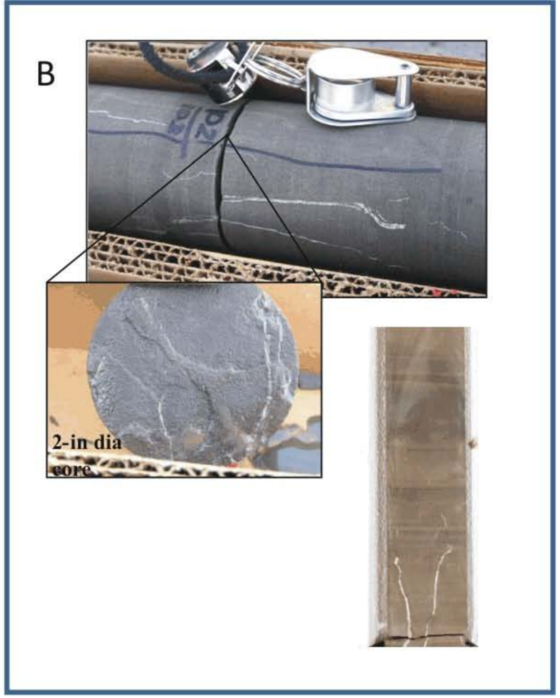
Modified from Portas, 2009

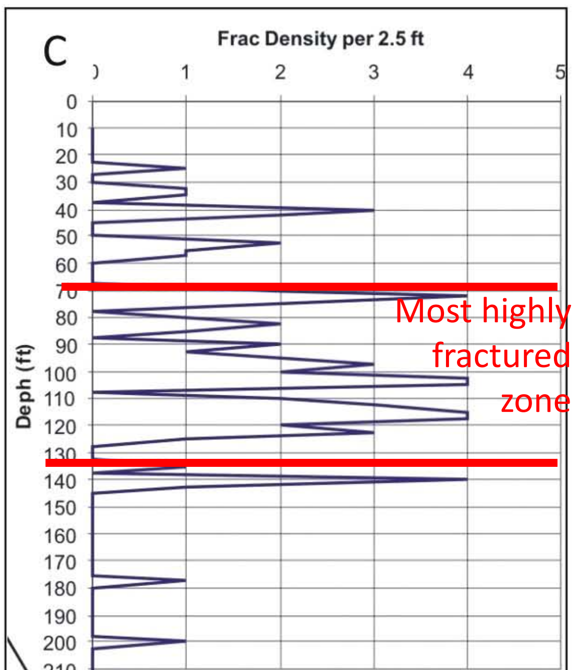
Advantage 3b: Comparison of fractures with core and log fractures

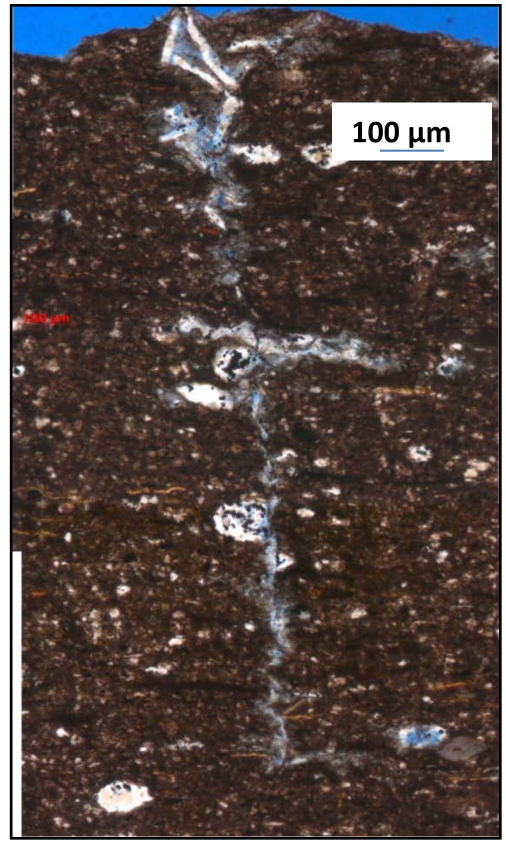




Modified from Buckner, in prep.



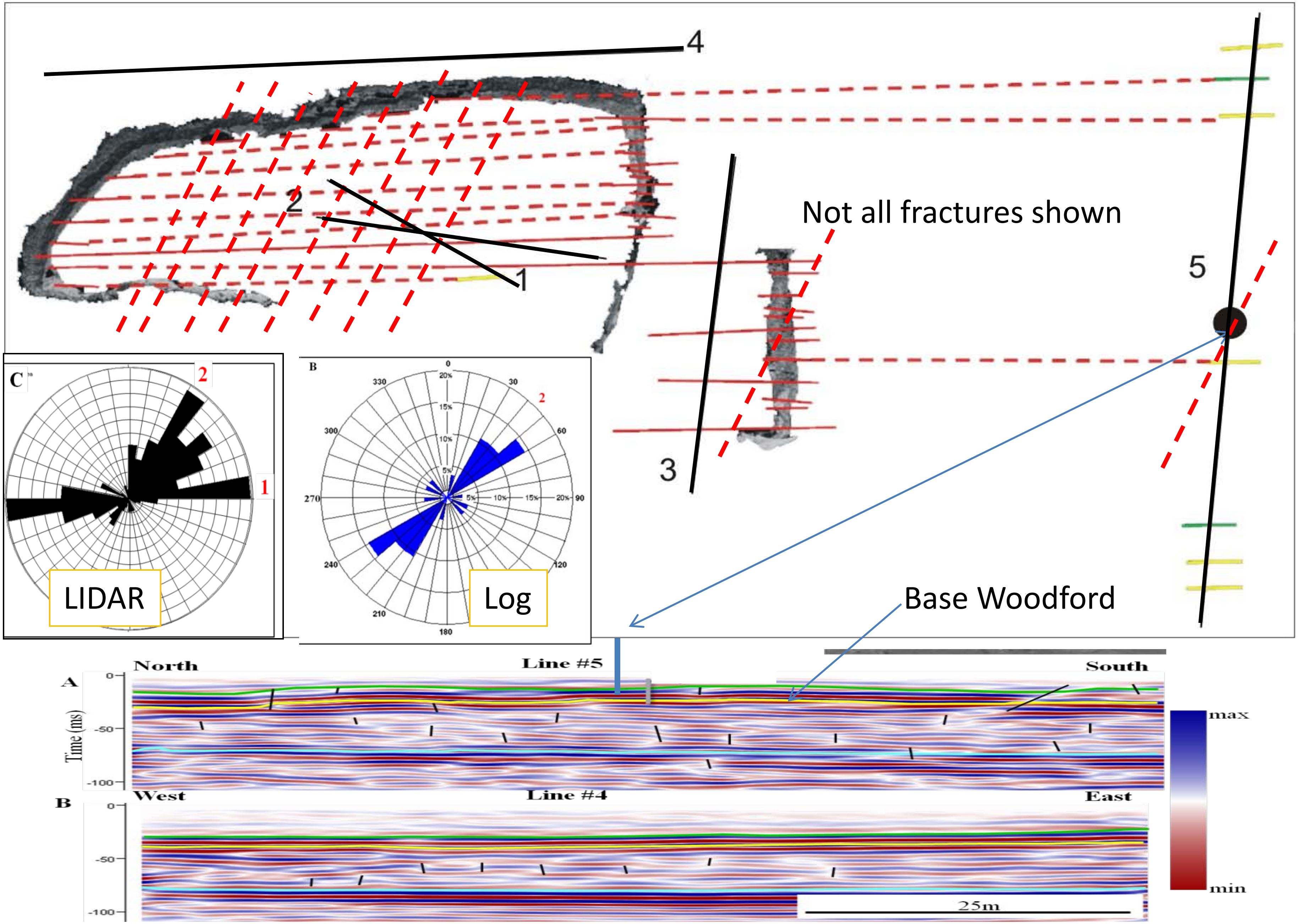




Thin section showing fracture microporosity (blue).

- -14 fractures detected on image log (all group 2);
- -Main fracture trend (group 1) not detected on log.
- -69 (mostly small) fractures Identified in core.

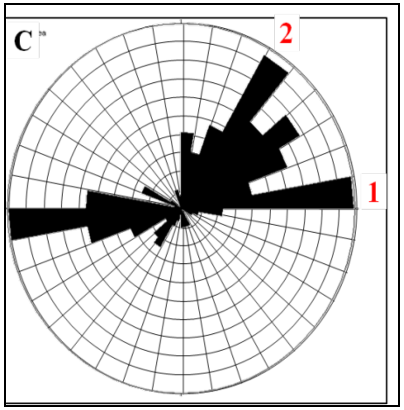
Advantage 3b': Comparison of fractures with core and log fractures



Modified from Portas, 2009

Advantage 3c: Extending outcrop fractures into the subsurface

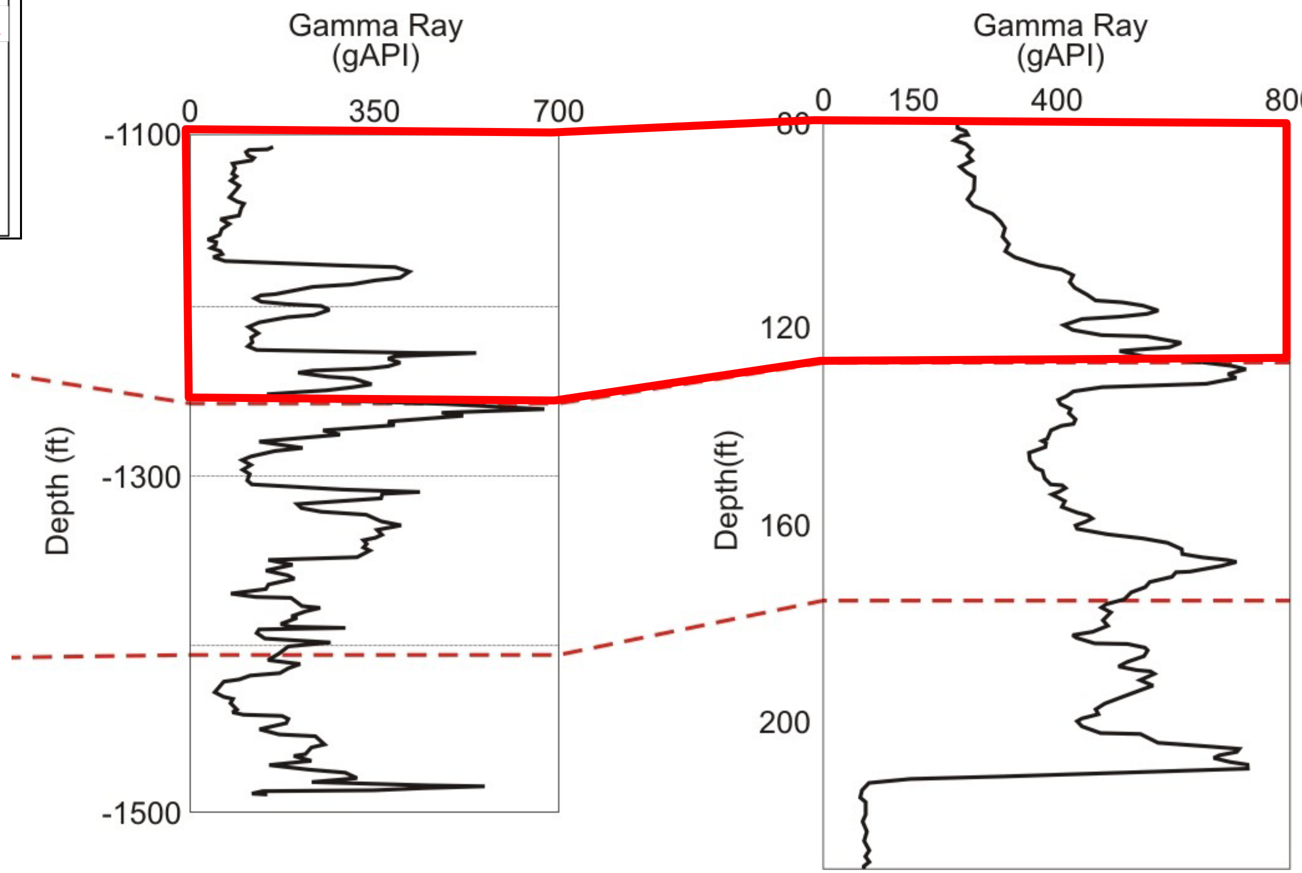
Most fractured and brittle interval:
1.5fractures/ft. vertical;
1 fracture/4ft. horizontal.



Upper Woodford

Middle Woodford

Lower Woodford

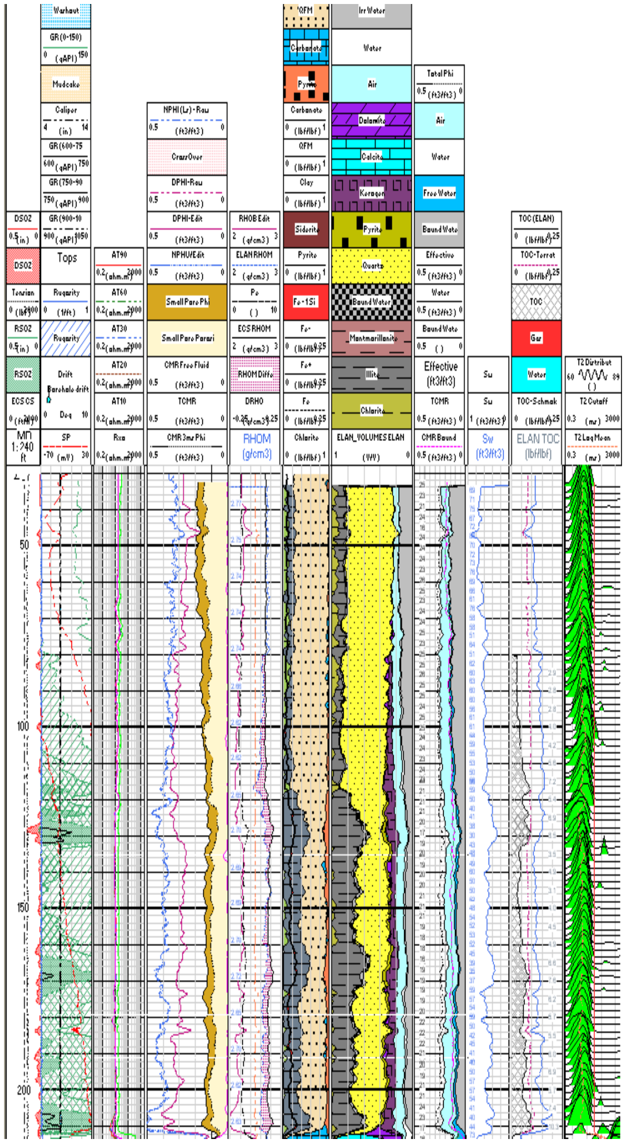


Subsurface well near-by

Quarry well from this study

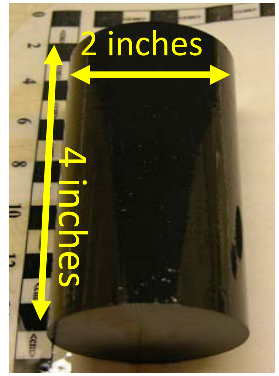
Advantage 4a: Geomechanical characterization of fresh (non desiccated) rock

Field Scale Log Data



Geomechanical lab measurements

Tri-axial from retrieved core



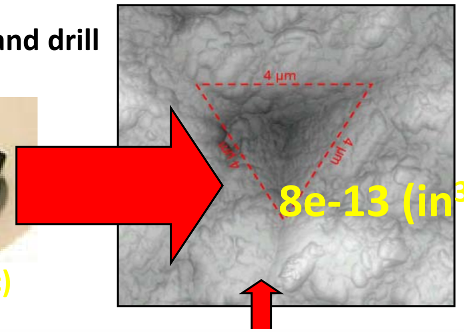
Volume = 206 (cc)

IDSTD™ from cavings and drill cuttings

Volume = 6.1 (cc)

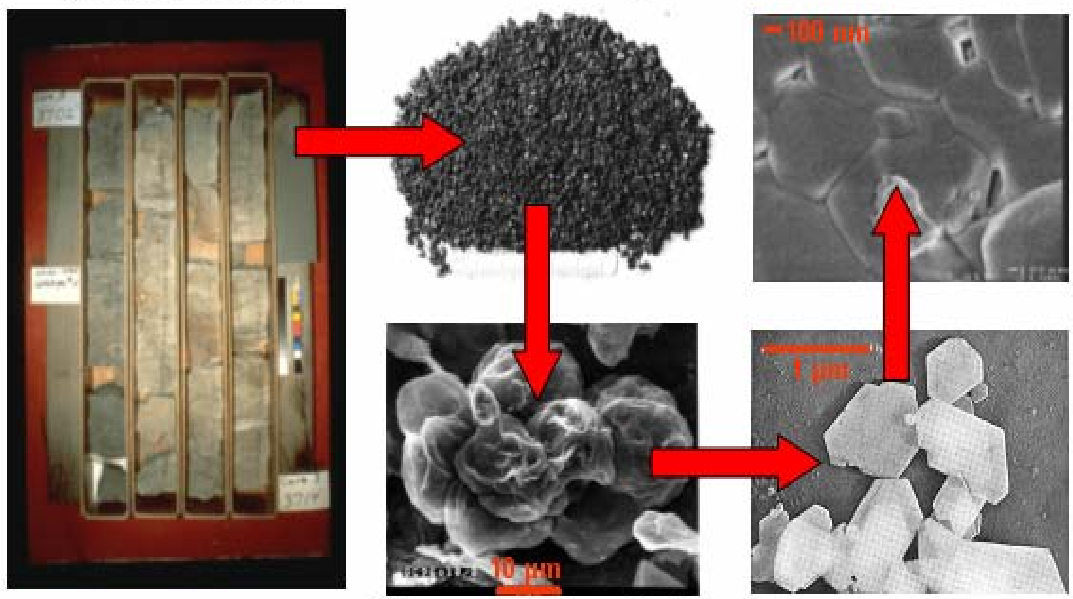
8 X 8 micrometers

NANO-Indenter



Macro-scale

Drill Cuttings

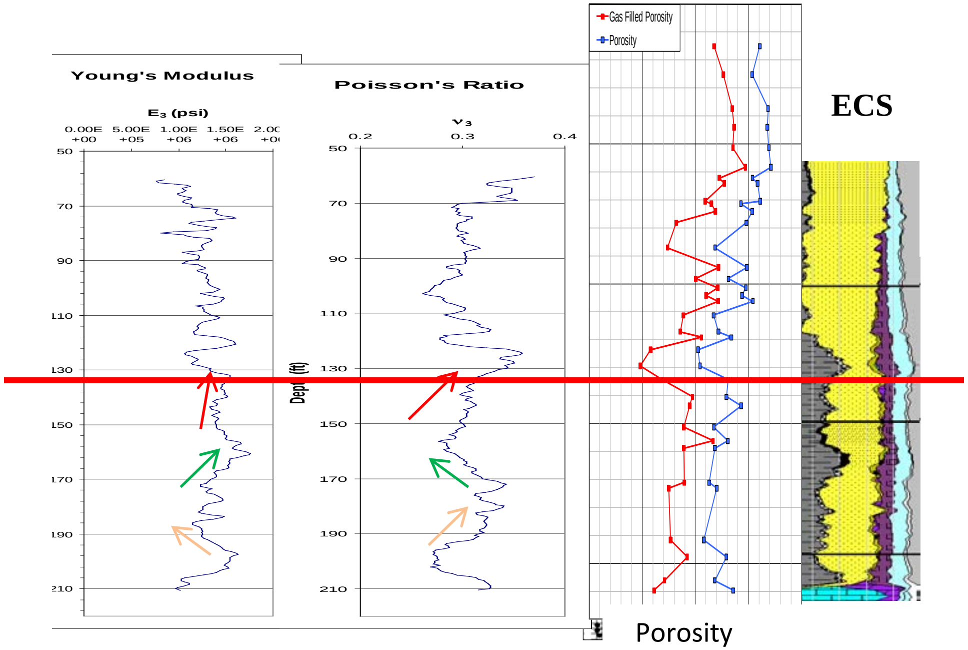


Micro-scale: SEM

Nano-scale: ESME

SPE 110120

Advantage 4a’: Geomechanical characterization of fresh (non desiccated) rock



Formation	Depth meters (ft)	Max. Load (N)	Frac. Toughness (MPavm)
Upper Woodford	33.81 (110.93)	489.00	1.17
	36.85 (120.90)	133.00	1.15
Middle Woodford	41.36 (135.70)	83.00	0.65
	44.28 (145.28)	89.00	0.74
Lower Woodford	50.59 (165.98)	89.00	0.74

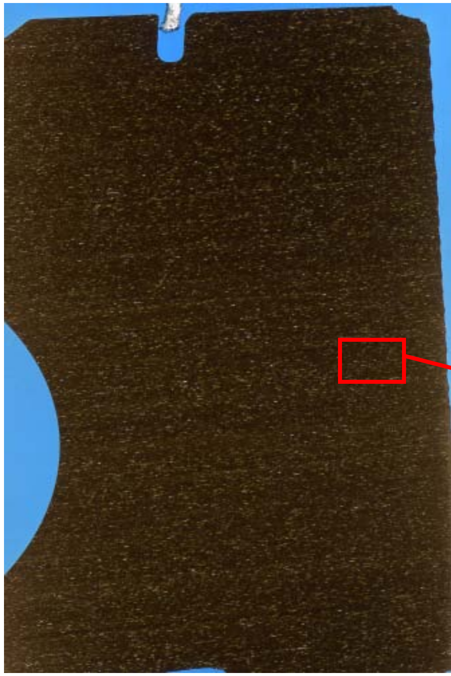
Tougher = harder to propagate fracture once originated.

Lower TOC, higher quartz

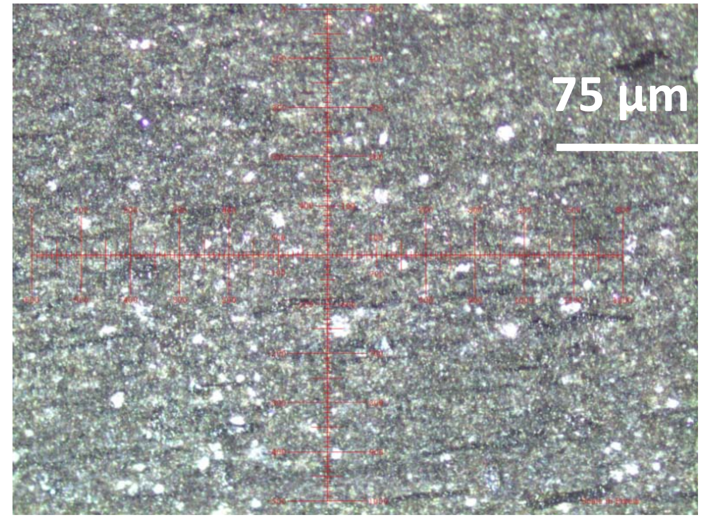
Higher TOC, higher clay

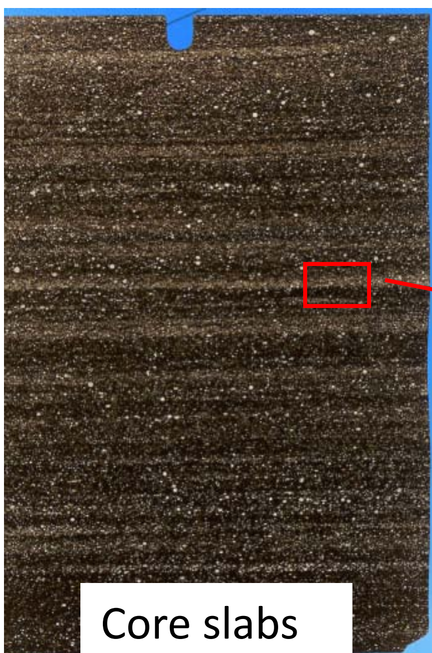
Modified from Sierra, 2010

Advantage 4b: Effect of depositional processes on geomechanical properties

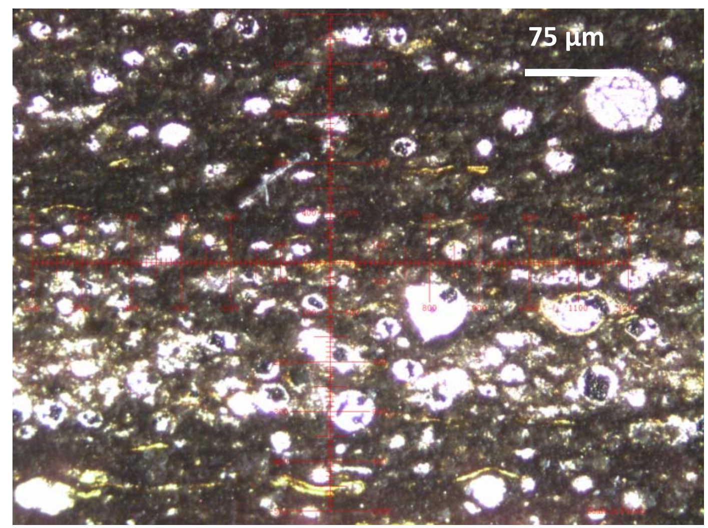


weakly laminated (layered) shale





Strongly laminated (layered) shale

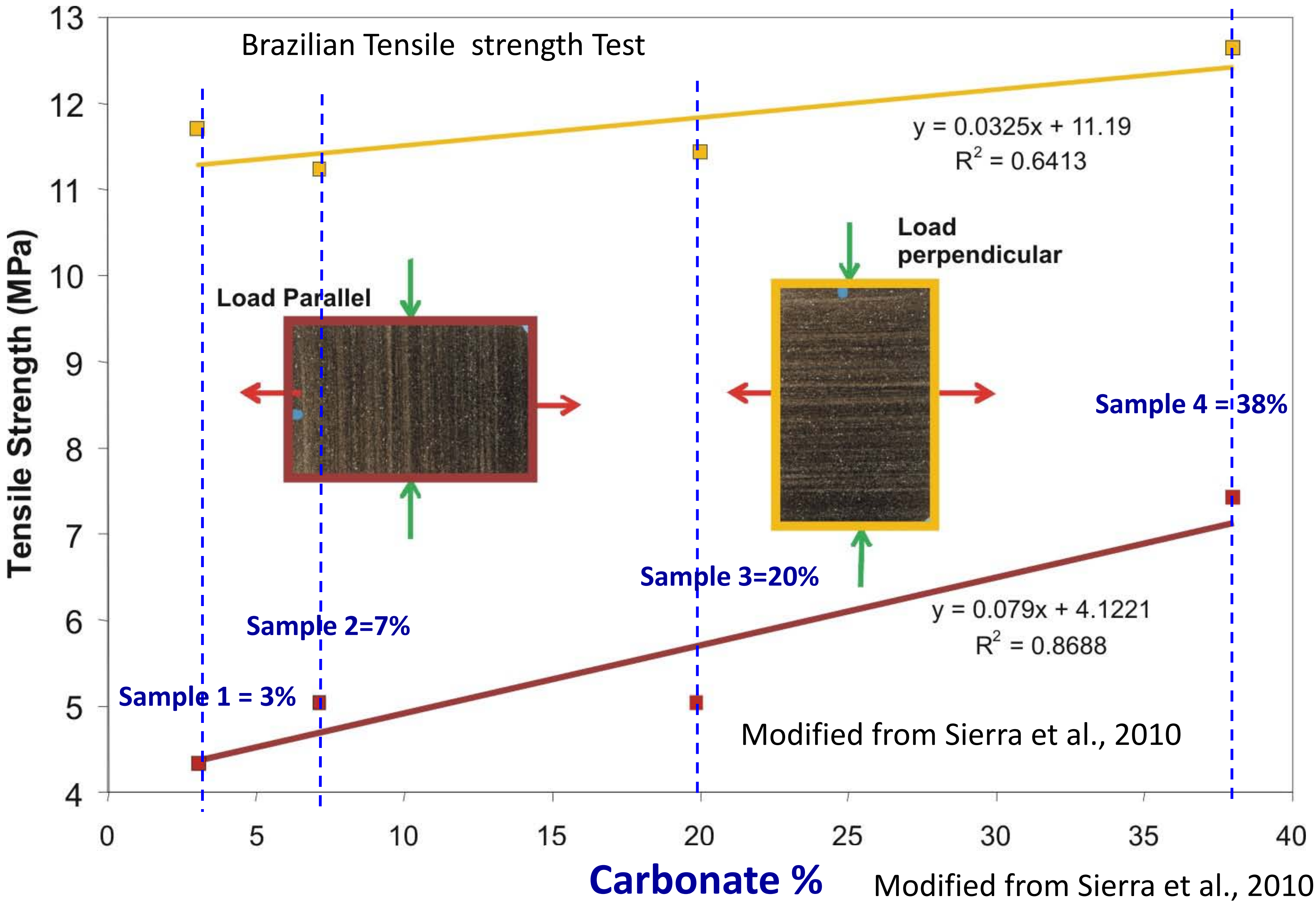


Core slabs

Modified from Sierra et al., 2010

Thin sections

Advantage 4b: Effect of depositional processes on geomechanical properties

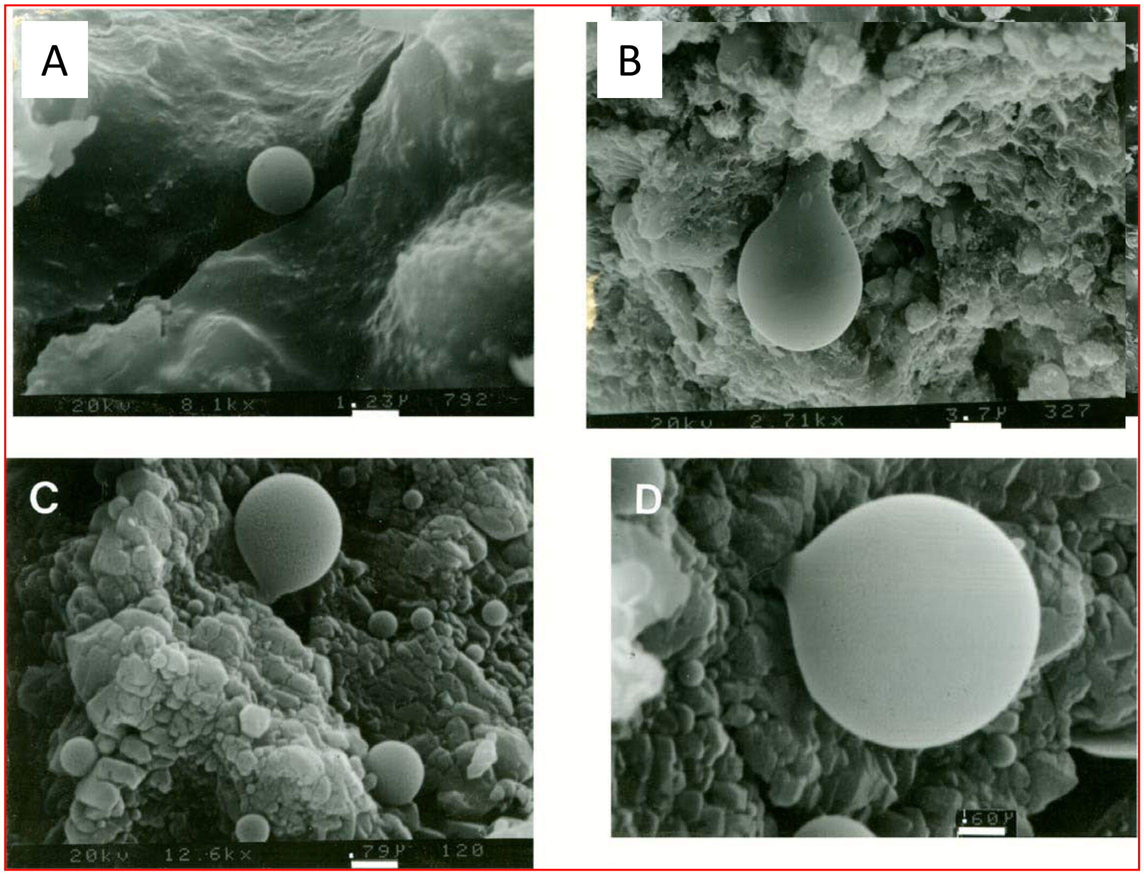


Modified from Sierra et al., 2010

Advantage 5a: Effect of depositional and geomechanic properties on hydrocarbon migration pathways: Direct observation

SEM micrographs of the Woodford Shale (I-35-B) during hydrous pyrolysis experiment – heating to 350ºC for 5 days.

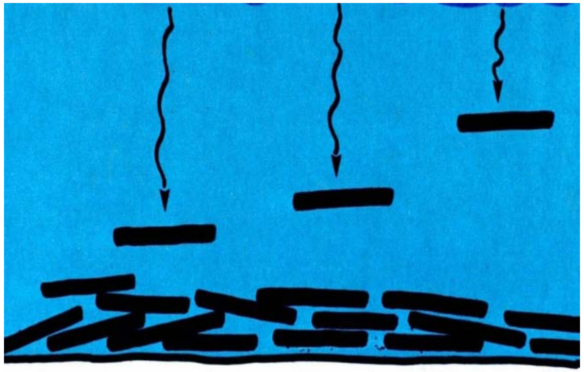
A) Oil droplet in micro- fracture
B-D) Oil droplets oozing from rock matrix into open micro-fractures.



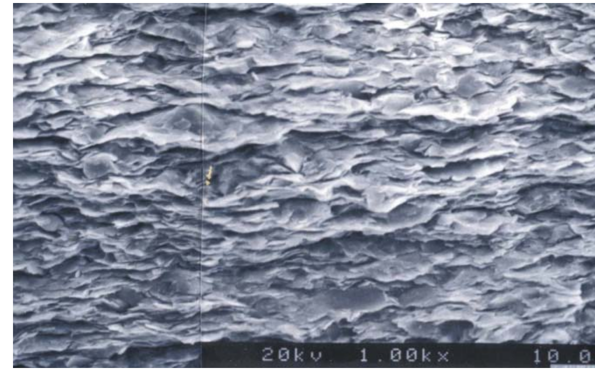
Furnace and sample holder (arrow) used in hydrous pyrolysis experiments for 5 days.

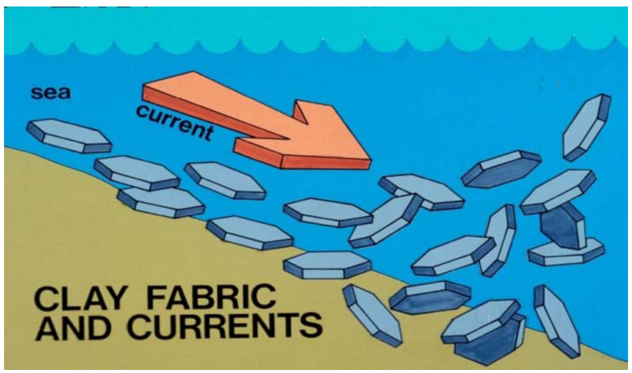
HC flow through matrix/fracture pores

Advantage 5a’: Effect of depositional properties on hydrocarbon migration pathways



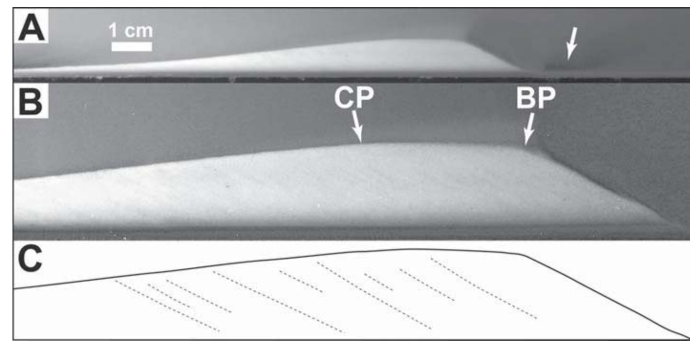
Hemipelagic **settling from sea water column**

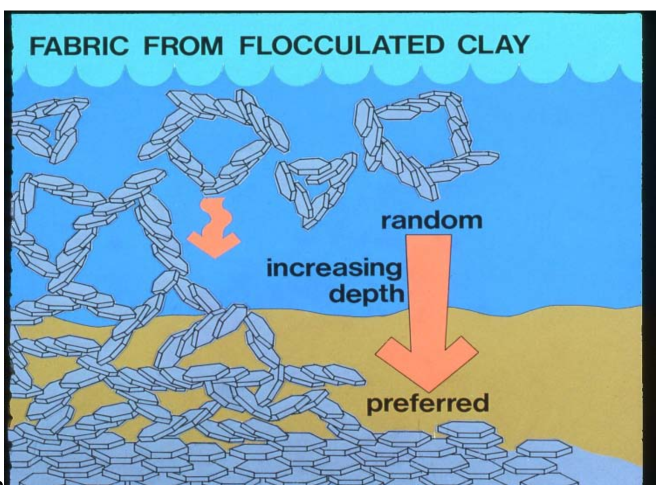




Hyperpycnal/turbidity current transport

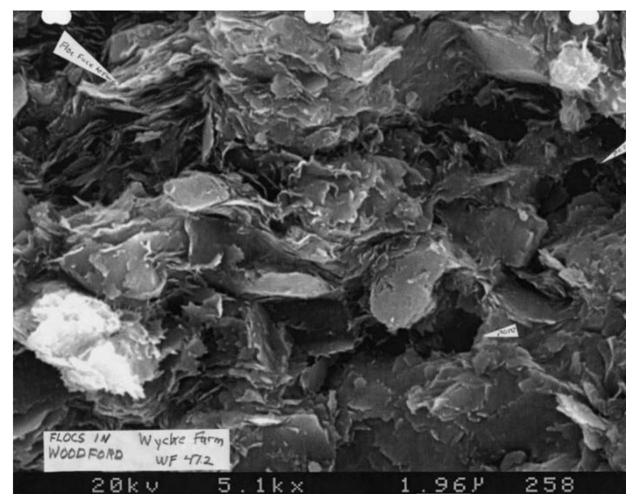
Floccule ripple from flume tank. Schieber and Southard, 2009





Clay flocculation

Floccules provide open framework (O’Brian and Slatt, 1991



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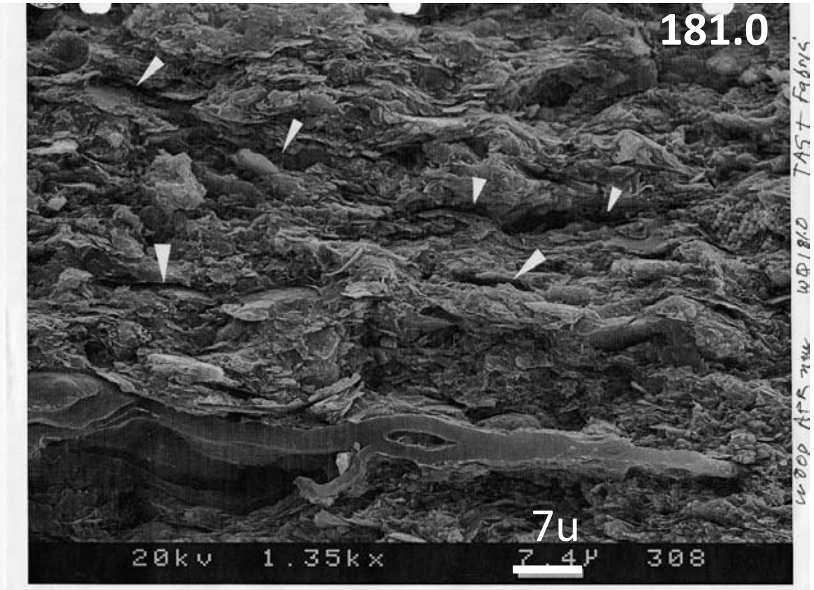
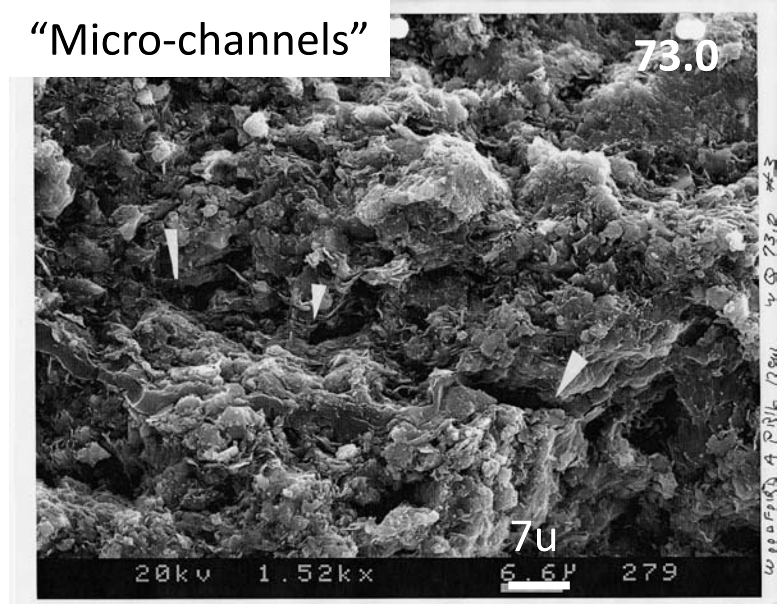
Advantage 5b: Effect of depositional properties on hydrocarbon migration pathways

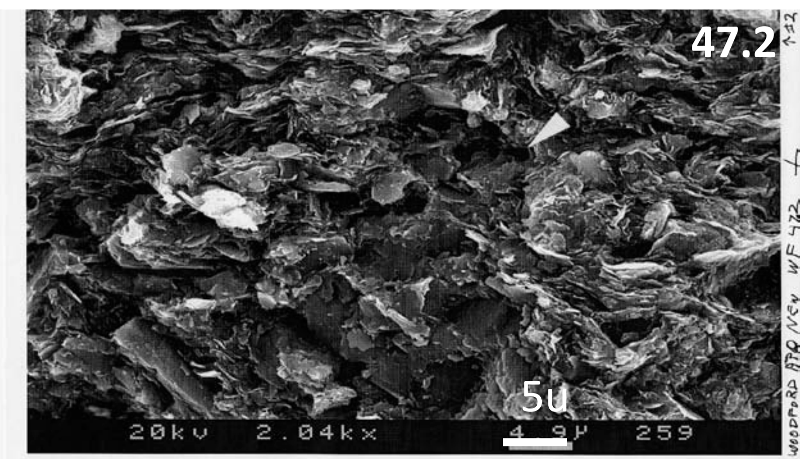
"Micro-channels". Note collapsed spore



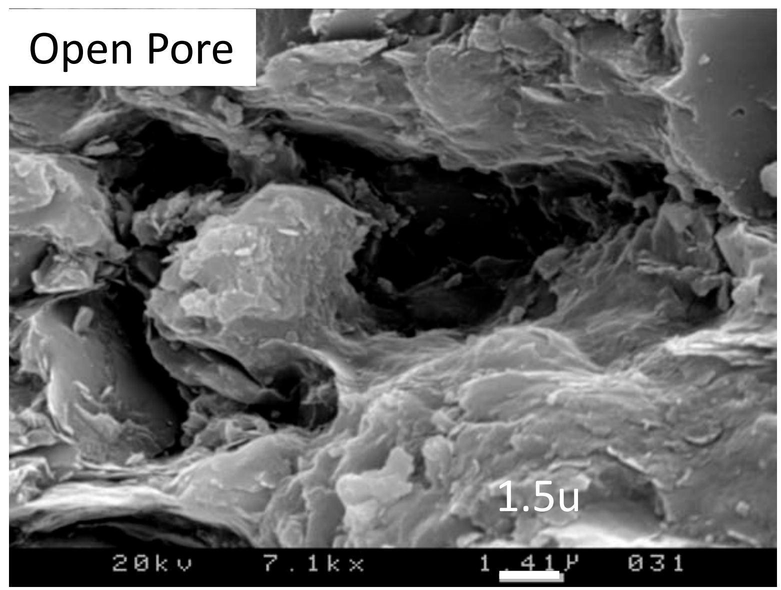
"Micro-channels"



Open pore network due to floccule domains (clumps).



Open Pore



Outcrop/ behind outcrop Woodford Study

Vertical and Lateral Characterization of properties

Subsurface data was directly compared to outcrop data

Stratigraphic Characterization

Strata is horizontally bedded and highly stratified.

Upper Woodford: high quartz content, low TOC, high porosity

Middle Woodford: high clay content, high TOC, lower porosity

Lower Woodford: intermediate quartz/clay content

Systematic variations in geochemical parameters and lithofacies patterns relate to relative sea level.

Structural Characterization

Outcrop revealed two sets of near-vertical fractures.

Wellbore data indicated that the Upper Woodford was more brittle and contain higher fracture density.

Petrophysical and Geomechanical properties

Geological Mineral composition, porosity, and rock fabric were found to affect rock strength and fracture potential.

Integration of Multidisciplinary properties observed

Depositional processes, such as preservation of floccule domain, can provide a more open framework and micro-channels for hydrocarbon migration pathways.