Analysis of the Upper Devonian to Lower Carboniferous (Frasnian-Tournaisian) Woodford Shale in the KGS-OGS Current #1, Southwestern Arkoma Basin*

W. Lynn Watney[1], Darwin R. Boardman[2], Jim O. Puckette[2], John R. Victorine[1], John H. Doveton[1], and Anna Cruse[3], and Neil Suneson[4]

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[1]Kansas Geological Society, Lawrence, KS (lwatney@kgs.ku.edu)
[2]Oklahoma State University, Stillwater, OK
[3]Samson Resources, Tulsa, OK
[4]Oklahoma Geological Survey, Norman OK

Abstract

A continuous 540-ft-long wireline slim hole core of Upper Devonian to Lower Carboniferous shale was acquired in the OGS-KGS Current #1 borehole in 2008. Site is located in the southwestern portion of the Arkoma Basin on a well defined structural block called the Lawrence Uplift in south-central Oklahoma. The corehole encountered 230 ft of Upper Devonian - Lower Carboniferous Woodford Shale, 20 ft of OsageanWeldon Limestone and Kinderhookian pre-Weldon Shale, and 290 ft of Meramecian and Chesterian Caney Shale. The succession consists of basinal shales, siltstone, and minor limestones. The relatively shallow depth of the coring location has minimized diagenesis and the Woodford Shale lacks extensive silificification. The corehole was taken to serve as a regional reference section to be tied to global stratotypes, using chronostratigraphic methods to develop a robust, process-based understanding of the strata.

Biostratigraphic, petrophysical, geochemical, and sequence-stratigraphic information was derived from the core and borehole wireline logs to infer controls on deposition. Primary lithofacies were described from slabbed core supplemented by SEM and thin-section petrography. High resolution (0.1-ft sampling) slim hole logging tools, including spectral gamma, neutron-density porosity, and resistivity logs were used with the core description to develop a provisional sequence stratigraphy.

Meter- to decimeter-scale depositional sequences and parasequences are defined comprising oxic (high Th/U ratio) to euxinic conditions (low Th/U ratio). Sequence boundaries are sharply defined by scoured surfaces with basal beds including phosphate nodule lags and lenticular and often cross-laminated, detrital siltstone with abrupt lower contacts. Without lateral context, the distinction of forced regression or simply scouring by bottom currents is often unclear. Sediment condensation is characterized by organic- and uranium-rich, phosphatic and pyritic hard, dark-gray shales with pelagic fauna dominated by radiolarians. Condensed intervals are associated low resistivity and lower density. The

condensed section is overlain by less organic-rich green or gray claystone or silty claystone containing benthic fauna, trace fossils, pellets, and minor glauconite. The regressive lithofacies is characterized by high Th/U ratios, attributed to more alumina-rich, terrestrial clays. Oxic claystones in the Chesterian Caney Shale are notably soft and bioturbated. Siltier clays in the Woodford are hard and exhibit discontinuous microfractures. Abrupt contacts between condensed and regressive lithofacies in a rhythmic succession comprise the upper Chesterian Caney Shale, clearly suggesting forced regression. Wavelet analysis of the Woodford Shale, using the natural gamma log, indicates four bundles of ~100-ft-scale cycles comprised of shorter wavelength (~12 ft) cycles. This is contrasted with distinct 6 to 12-ft-long cycles of the Chesterian interval. These cycles in general reflect alternating current energy, fluctuating levels of oxygen and biotic activity and changing bottom- and pore-water chemistry. It has yet to be determined what the broader significance is of the apparent cyclicity in the Woodford Shale.

Selected References

Averbuch, O., N. Tribovillard, X. Devleeschouwer, L. Riquier, B. Mistiaen, and B. Van Viet-Lanoe, 2005, Mountain building-enhanced continental weathering and organic carbon burial as major causes for climatic cooling at the Frasnian-Famennian boundary (c. 376 Ma)?: Terra Nova, v. 17, p. 25-34.

Comer, J.B., 1992, Organic geochemistry and paleogeography of Upper Devonian formations in Oklahoma and northwestern Arkansas, *in* K.S. Johnson, and B.J. Cardott, (eds.), Source Rocks in the Southern Midcontinent, 1990 Symposium: Oklahoma Geological Survey, Circular 93, p. 70-93.

Hall, M., 2005, Composite colour display of spectral gamma ray logs: Canadian Well Logging Society, *InSite*, v. 24/4, p. 21-24

Royer, D.L., R.A. Berner, I.P. Montanez, N.H. Tabor, and D.J. Beerling, 2004, CO_2 as a primary driver of Phanerozoic climate: GSA Today, v. 14/3, p. 4-10.

Turgeon, T.C., R.A. Creaser, and T.J. Algeo, 2007, ReOs depositional ages and seawater Os estimates for the Frasnian-Famennian boundary: Implications for weathering rates, land plant evolution, and extinction mechanisms: Earth and Planetary Science Letters, v. 261, p. 649-661.

Selected Websites

Blakey, R, 2013, Mississippian Paleogeography: Colorado Plateau Geosystems, Inc. Website accessed May 8, 2013. (http://www2.nau.edu/rcb7/namM345.jpg; http://cpgeosystems.com/340moll.jpg)

Indiana University-Geoscience, Shale Research Lab., An Invitation to explore shale geology: Website accessed July 17, 2013. www.shale-mudstone-research-schieber.indiana.edu

Kansas Geological Society Core Library, Colorlith: KGS, Lawrence, Kansas. Website accessed July 17 2013. http://www.kgs.ku.edu/stratigraphic/KIMELEON/

Kansas Geological Society Core Library, Oil and Gas Core Images, Main Well page-35-123-23588: KGS, Lawrence, Kansas. Website accessed July 17, 2013.
http://chasm.kgs.ku.edu/apex/qualified.cimg2.CoreImages?f_well=1038225872

ANALYSIS OF THE UPPER DEVONIAN TO LOWER CARBONIFEROUS (FRASNIAN-TOURNAISIAN) WOODFORD SHALE IN THE KGS-OGS CURRENT #1, SOUTHWESTERN ARKOMA BASIN

W. Lynn WATNEY[1], Darwin R. BOARDMAN[2], Jim O. PUCKETTE[2], John R. VICTORINE[1], John H. DOVETON[1], Anna CRUSE[3], and Neil SUNESON[4]

Oklahoma Geological Survey

KANSAS GEOLOGICAL SURVEY
The University of Kansas

[1]Kansas Geological Survey, The University of Kansas, 1930 Constant Avenue, Lawrence, KS 66047

[2]Boone Pickens School of Geology, Oklahoma State University, Stillwater, OK 74078

[3]Samson Resources, Tulsa, OK 74103

[4]Oklahoma Geological Survey, University of Oklahoma, Norman OK 73019

AAPG Woodford Shale Forum

BOONE PICKENS SCHOOL OF GEOLOGY

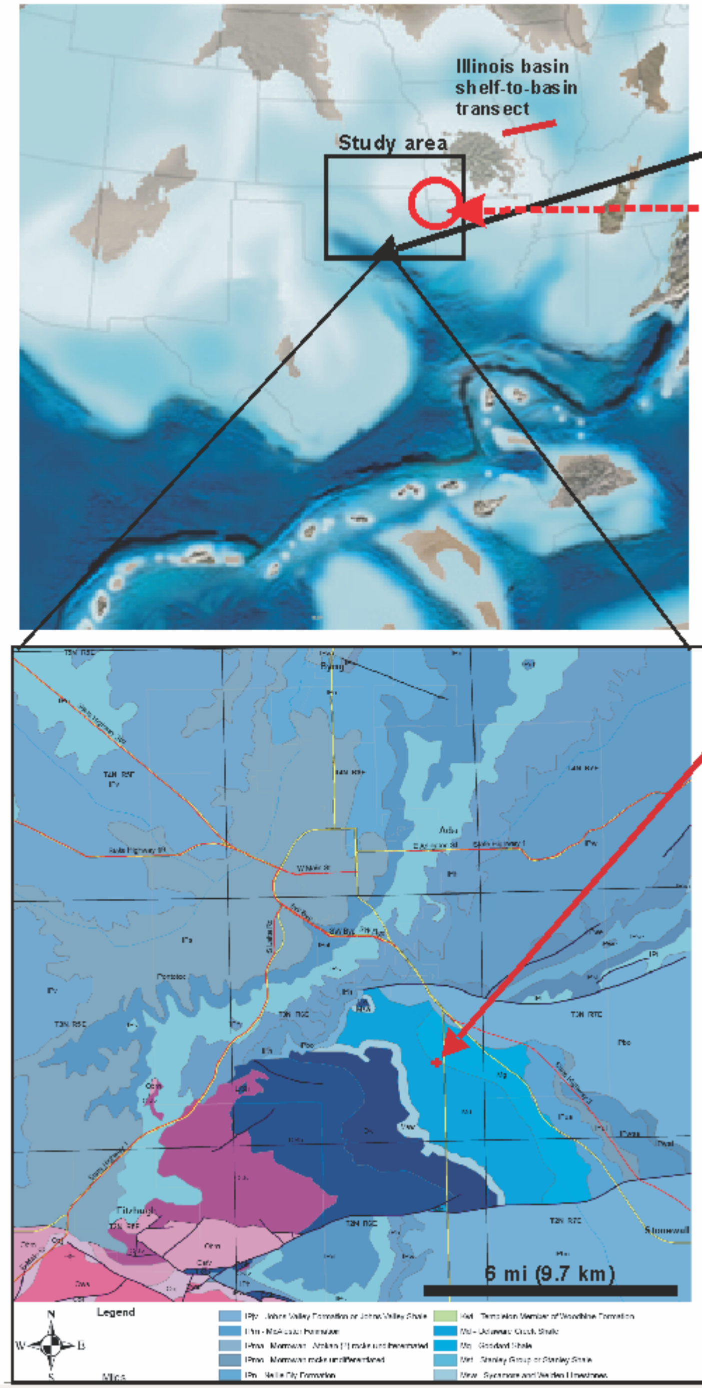
Outline

1. Objectives
2. Geologic Setting
3. Characterization of Provisional Depositional Sequences
4. Comparison of Woodford and Chattanooga shales – from OGS-KGS Current #1 Corehole to surface localities in NE OK, NW Ark, SE Mo.
5. Summary

Acknowledgement: Robert Walton, Cicaco, Camarillo, CA for funding well logging

2. Geologic Setting -- Arkoma foreland basin and adjoining shelf margin along upper Midcontinent

- Prolonged, notable subsidence along Arkoma Basin foredeep, proto-Anadarko Basin, and sag basin near the Arbuckle aulacogen
- Prevailing basin anoxia in foreland due to deep water, high subsidence, low sedimentation rate
- Restricted water circulation in shallower locations along narrow seaway
  - tropical setting, possible thermocline with apparent elevated nutrient supply
  - possible upwelling and runoff from surrounding landmass supporting productivity
- Prominent, active basement faults including wrench and related regional fault systems that extend unto adjoining craton and influenced sediment accommodation and distribution
- Later elevated thermal events related to burial with fluid flow along fault systems; localized magmatic activity



Paleogeographic reconstruction of early Mississippian for North America by Blakey (http://www2.nau.edu/rcb7/namM345.jpg)

Location of core representative of the basinal Conditions during the Mississippian Subsystem is shown.

Shelfward surface exposures of Chattanooga Shale Are being sampled for carbon, metals, and conodonts

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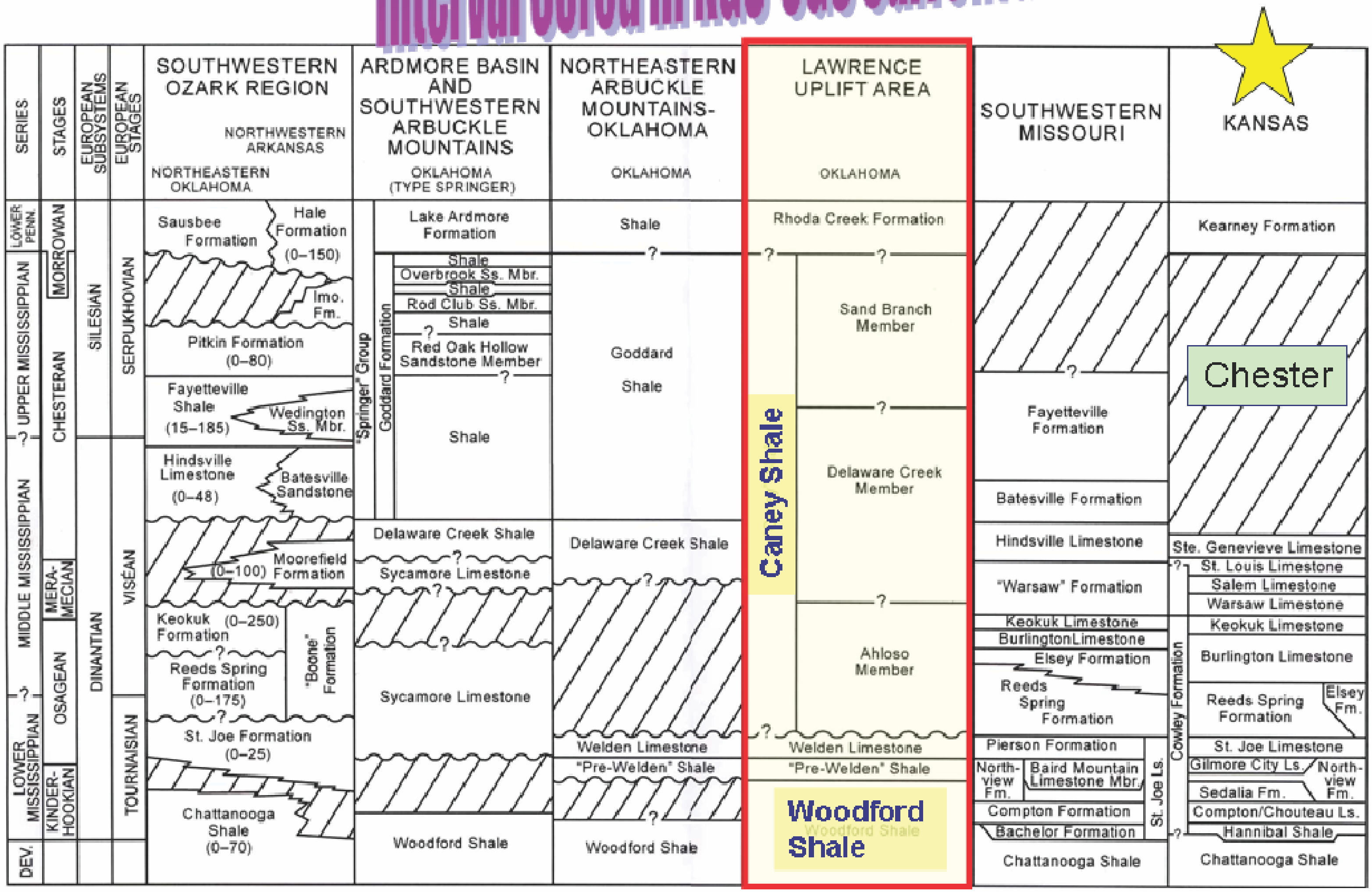
COREHOLE LOCATION NEAR ADA, OK WITHIN LAWRENCE UPLIFT

Basinal shale core

KGS-OGS

Current #1

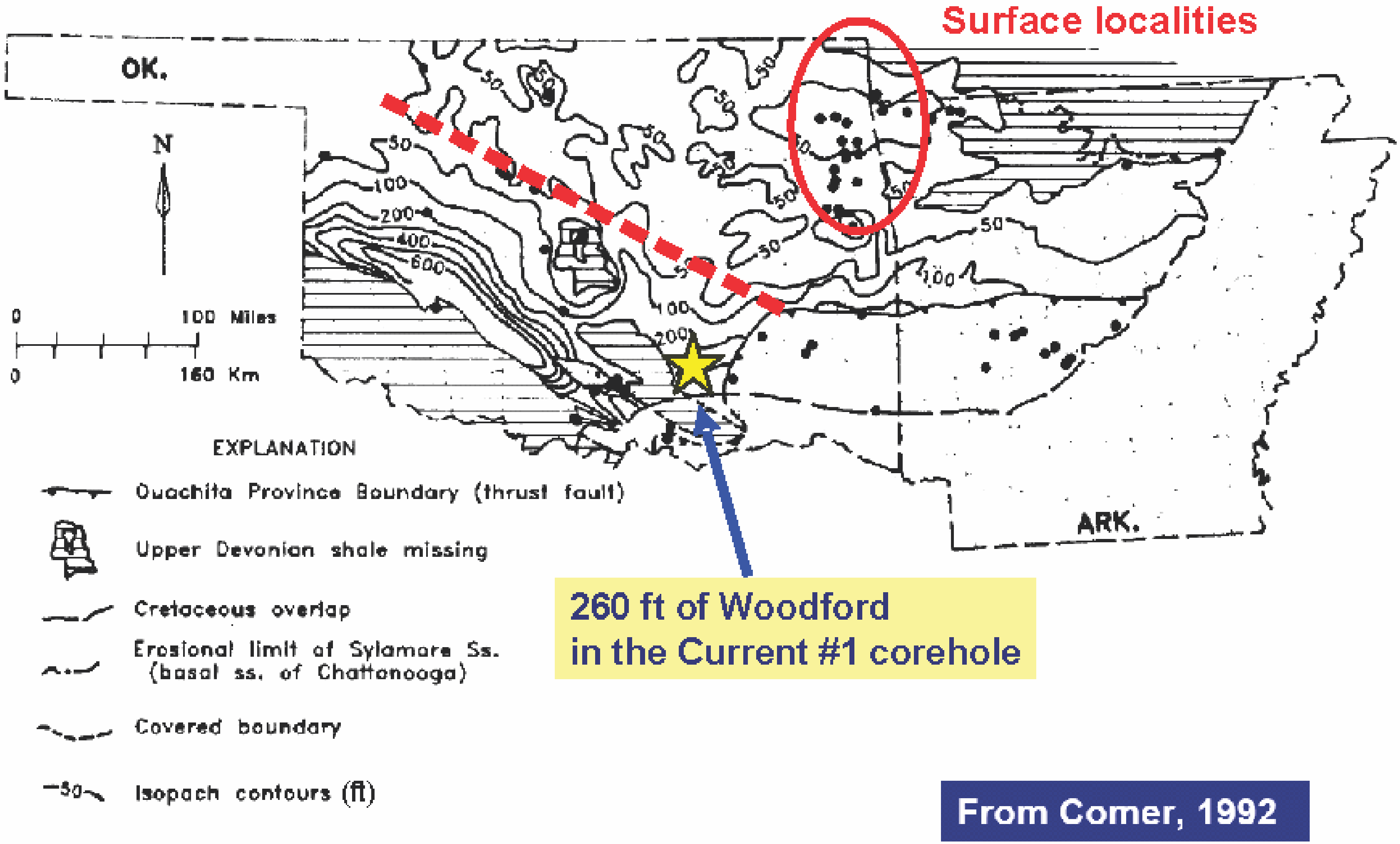
Interval Cored in KGS-OGS Current #1



Chaplin, OGS (2007)

600 ft. interval cored in KGS-OGS Current #1 is 99.2% shale

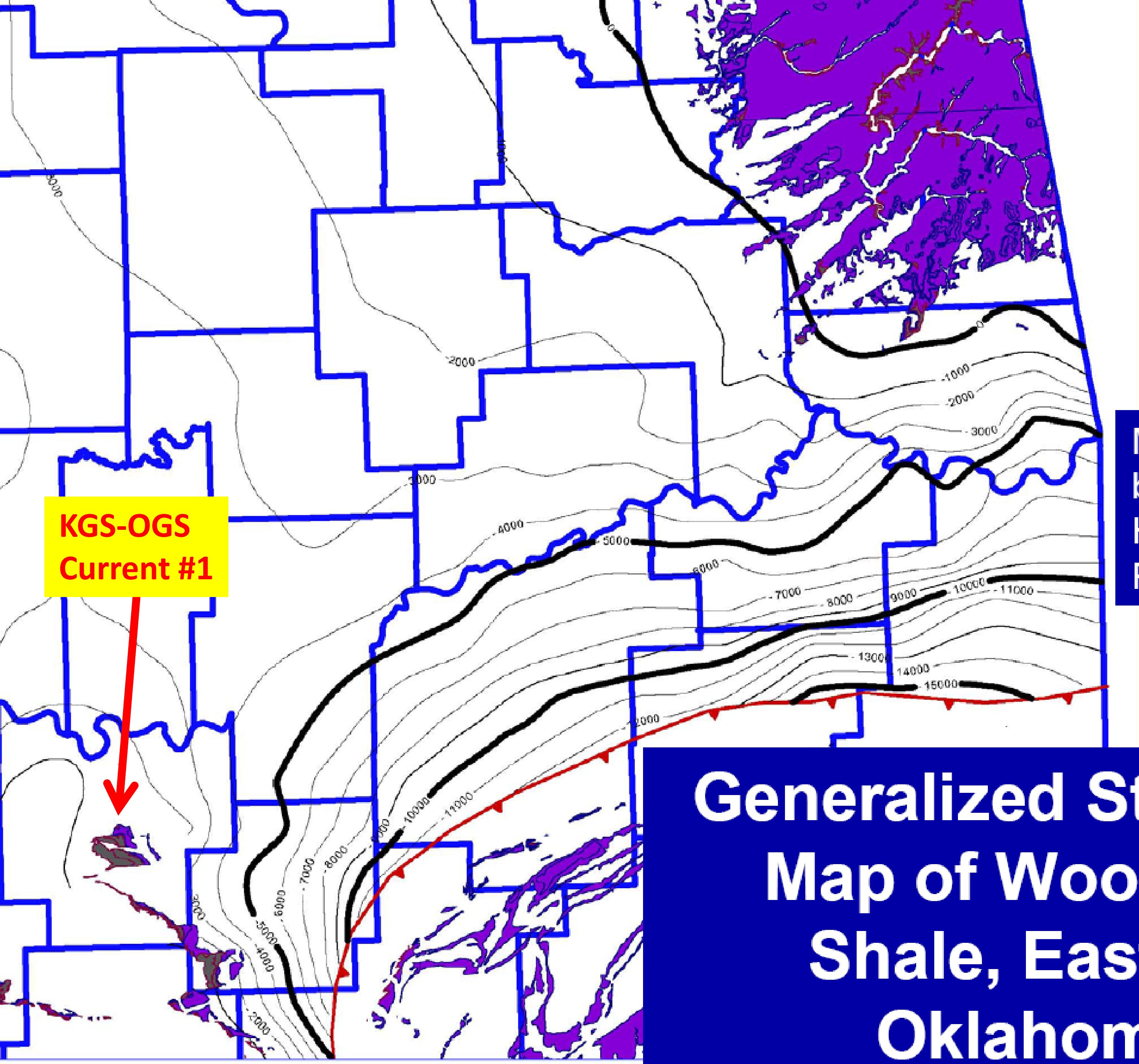
Isopach Map of Woodford Shale



From Comer, 1992

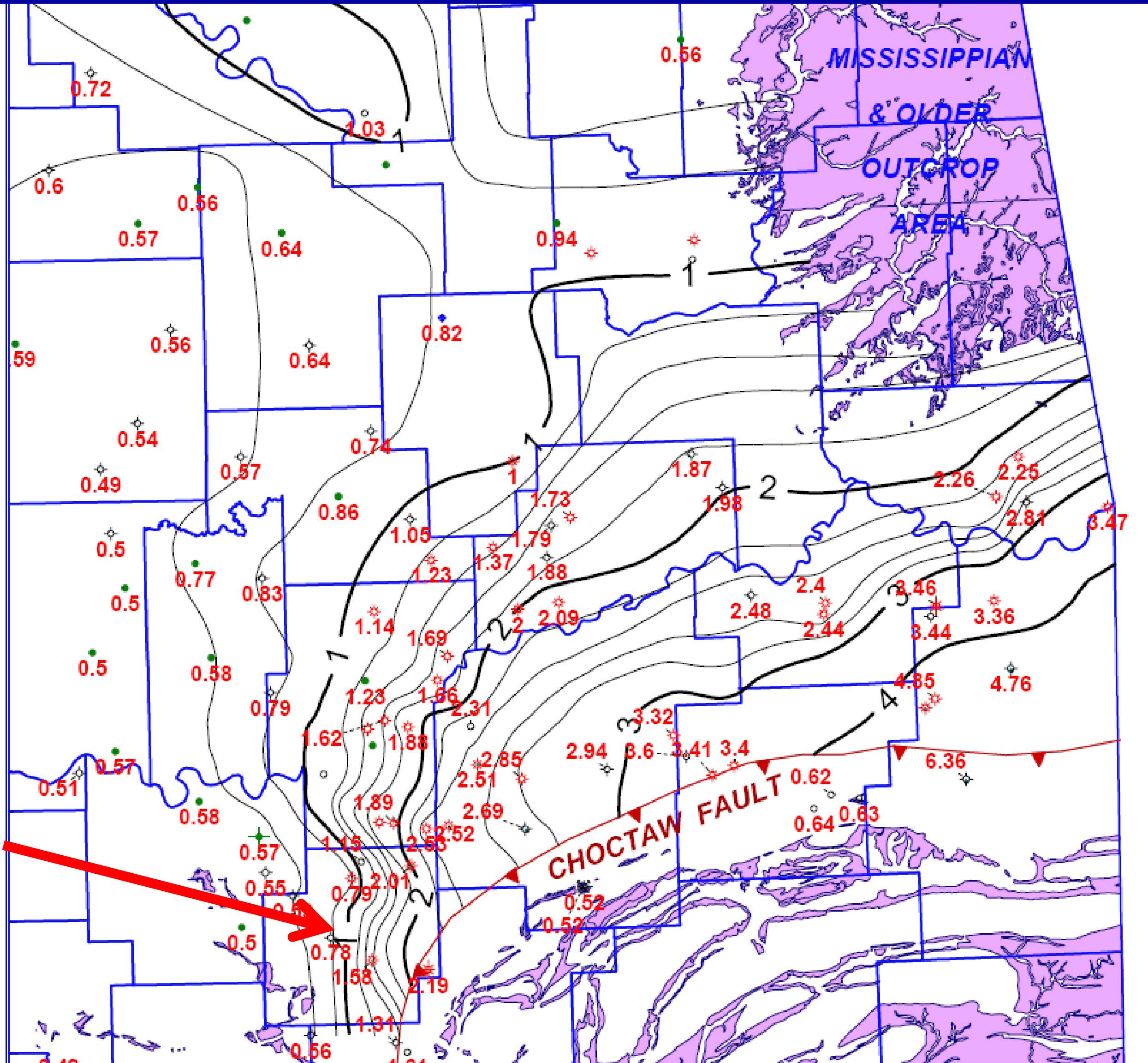
http://www.ogs.ou.edu/pdf/woodfordcardotttsop.pdf

Generalized Structure Map of Woodford Shale, Eastern Oklahoma



Map prepared by R. Vance Hall using Petra

Isoreflectance Map of the Woodford Shale in Eastern Oklahoma



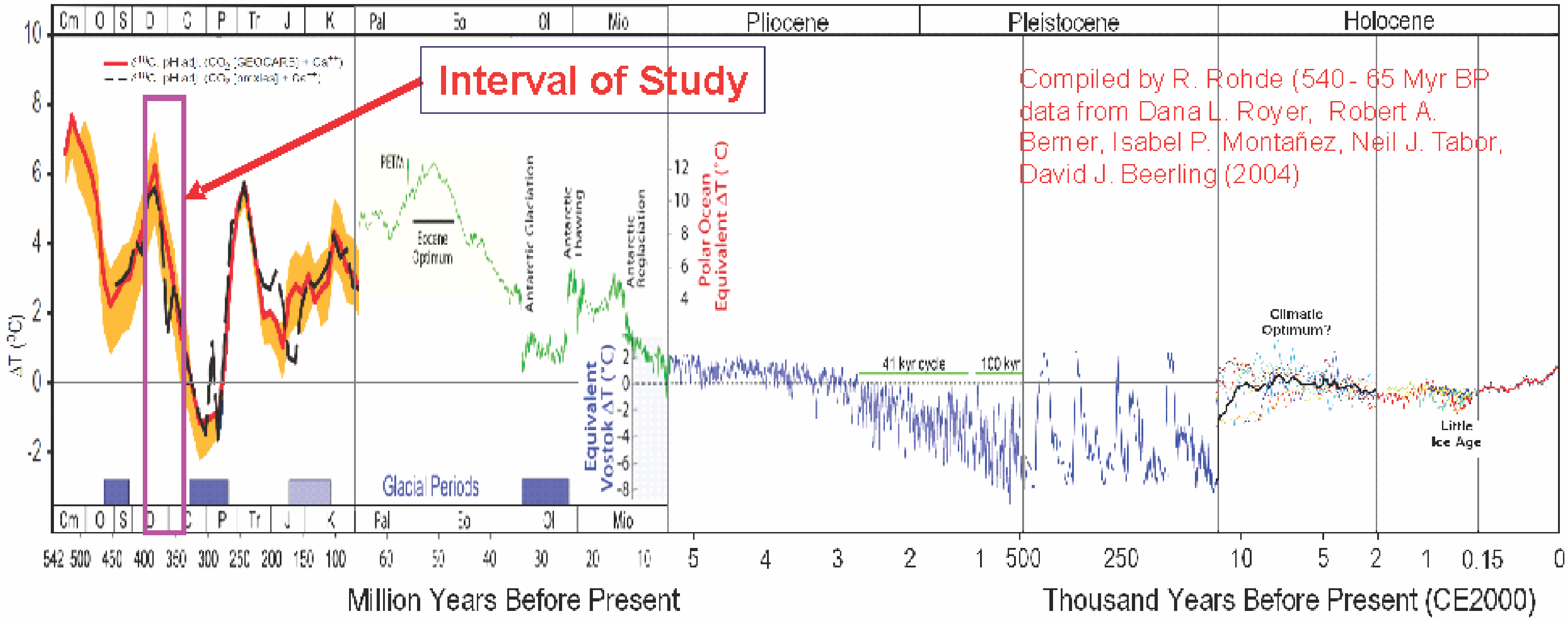
KGS-OGS Current #1

Map prepared by R. Vance Hall using Petra

Cardott, in preparation

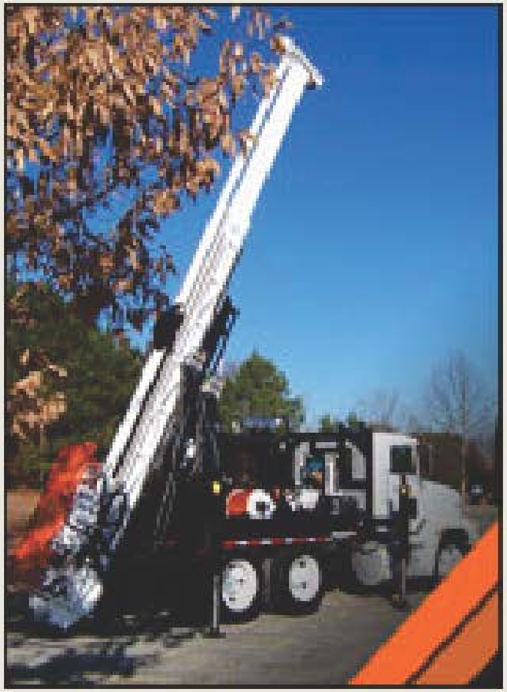
Climate Extremes

Temperature of Planet Earth



- Intense orogenic and drastic climate variations including onset of Gondwanian glaciation in Late Devonian
- *Frasnian-Famennian* boundary in Late Devonian –
  - *loss of biodiversity (mass extinction, 14% marine fauna)*
  - *demise reefal carbonate platforms*
  - *extensive organic-rich strata*
  - *long-term global cooling (Averbuch et al., 2005)*
  - *short-term global warming "Kellwasser events"* *(Buggisch 1991)*
  - *dramatic change in weathering rates*
  - *recent geochemical study negates bolide impact and volcanism (Turgeon, Creaser, Algeo, 2007)*

KGS Core Rig

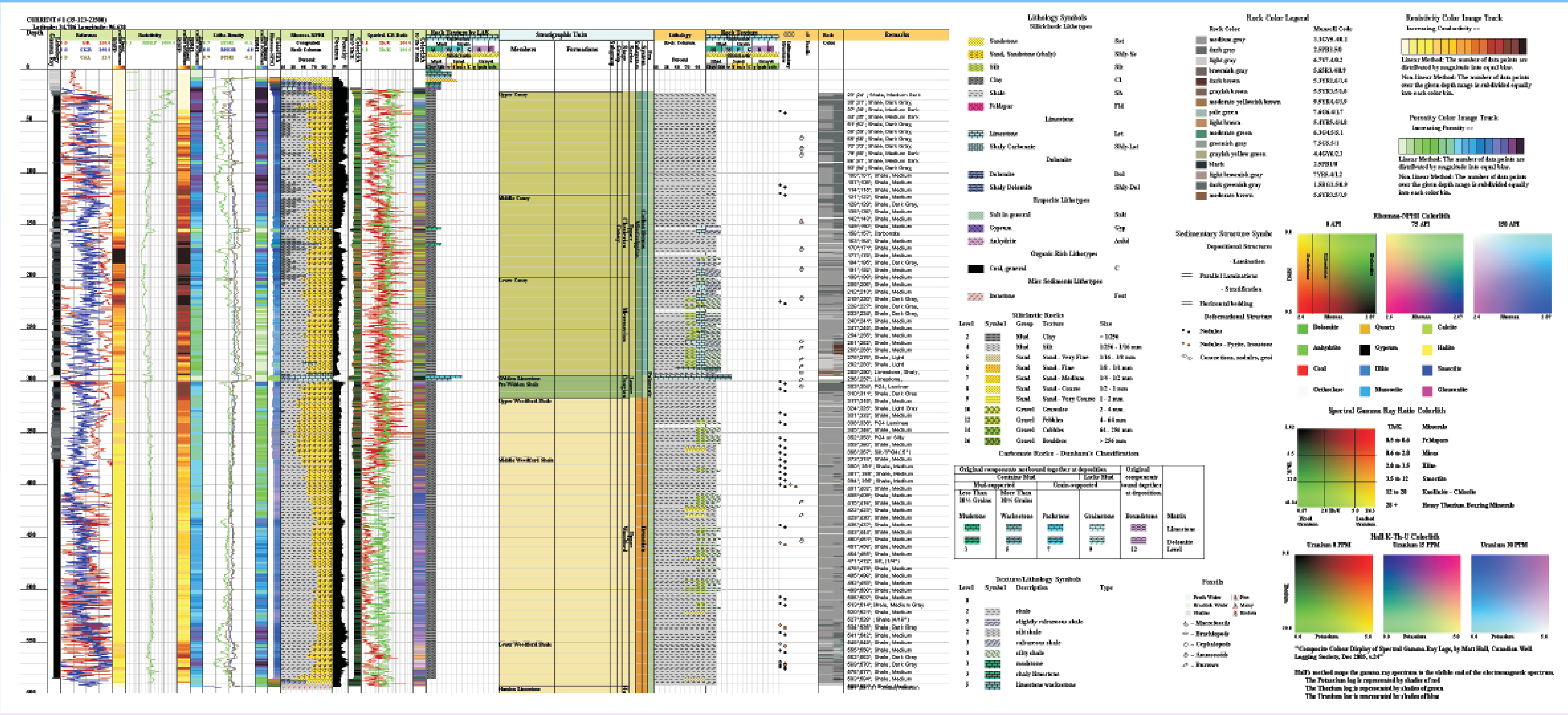


New Core Rig for KGS

– **Longyear-LF90D Hydraulic Diamond Core Drill**

- Depth capacity of 900 m (2950 ft) NQ/NRQHP
- Hydraulic rod making and breaking
- Independent dual hydraulic mast raising cylinders
- Hydraulic mast dumping capability up to 2340 mm (92 in)
- Hydraulic, telescopic, 6 m (20 ft) pull mast for ease of setup with 16,000 lb capacity mainline hoist

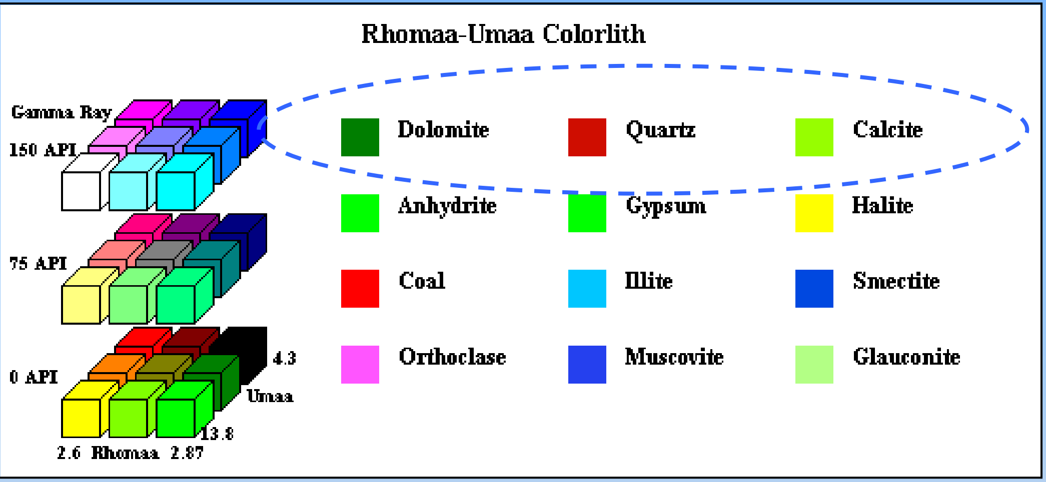
Mississippian (Osagean) Weldon Limestone through Woodford Shale interval in core <u>on display at this meeting</u>

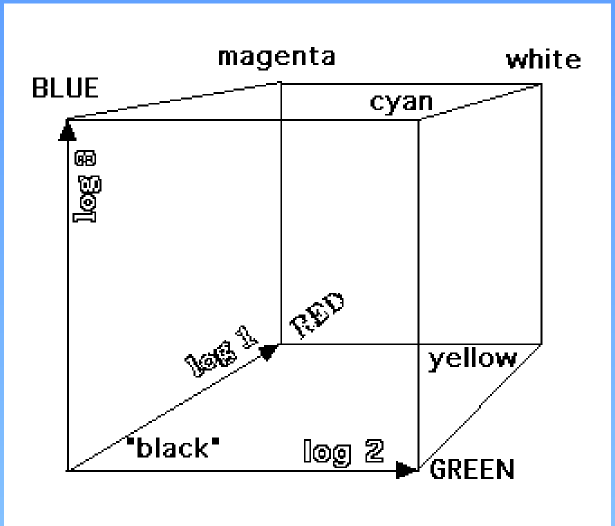


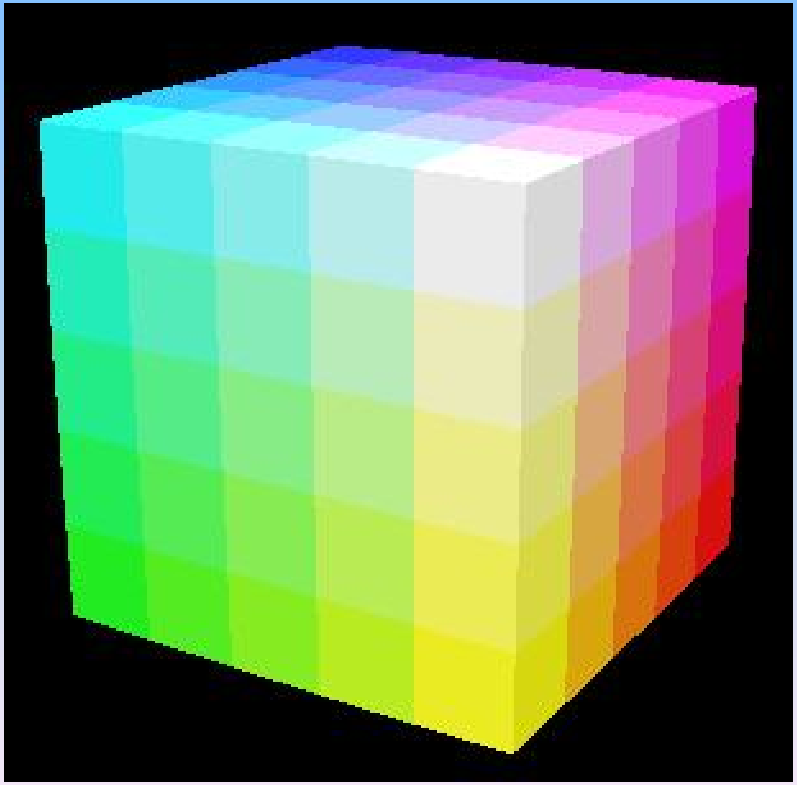
Core Analysis

- Slimhole (3 1/2 inch) wireline corehole
- Slimhole logs ran -- spectral gamma ray, neutron, density, sonic, resistivity
- Cores were slabbed, photographed, and described to determine lithofacies, texture, color, and characteristics of bedding contacts, and establish preliminary sequence stratigraphy.
  - On line photos -- http://chasm.kgs.ku.edu/apex/qualified.cimg2.CoreImages?f_well=1038225872
- Cores were sampled every half-ft to 1 ft for paleo and geochemical analysis. Additional samples were taken for SEM and thin-section study.
- Half of core is archived to preserve record and for sampling at later time.

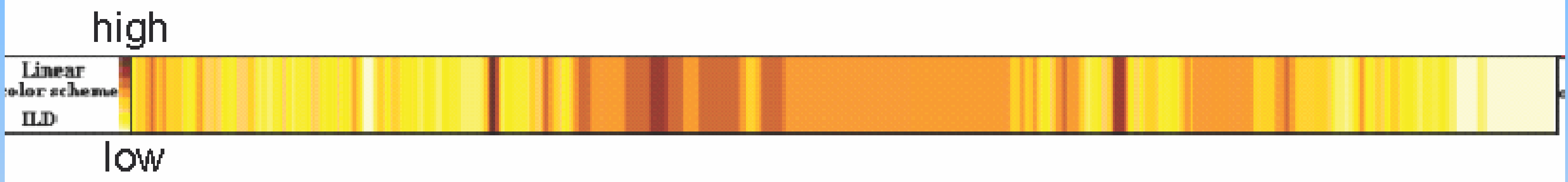
Plotting lithology on the three-dimensional color cube







Resistivity and Porosity Log Imaging



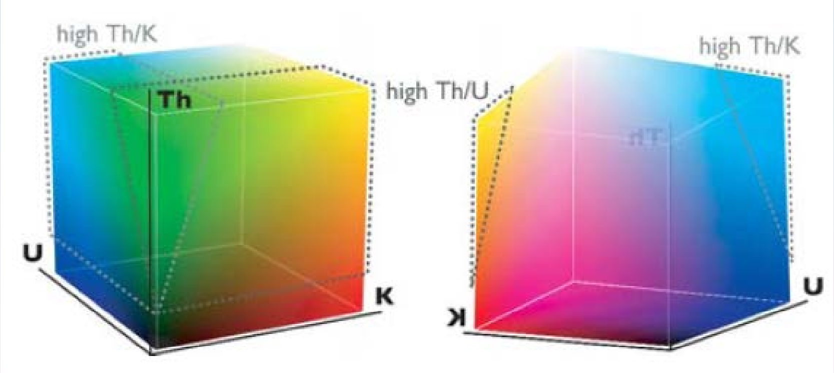
Resistivity and porosity (density) log imaging using quantization – data distributed by magnitude into equal bins and assigned color.

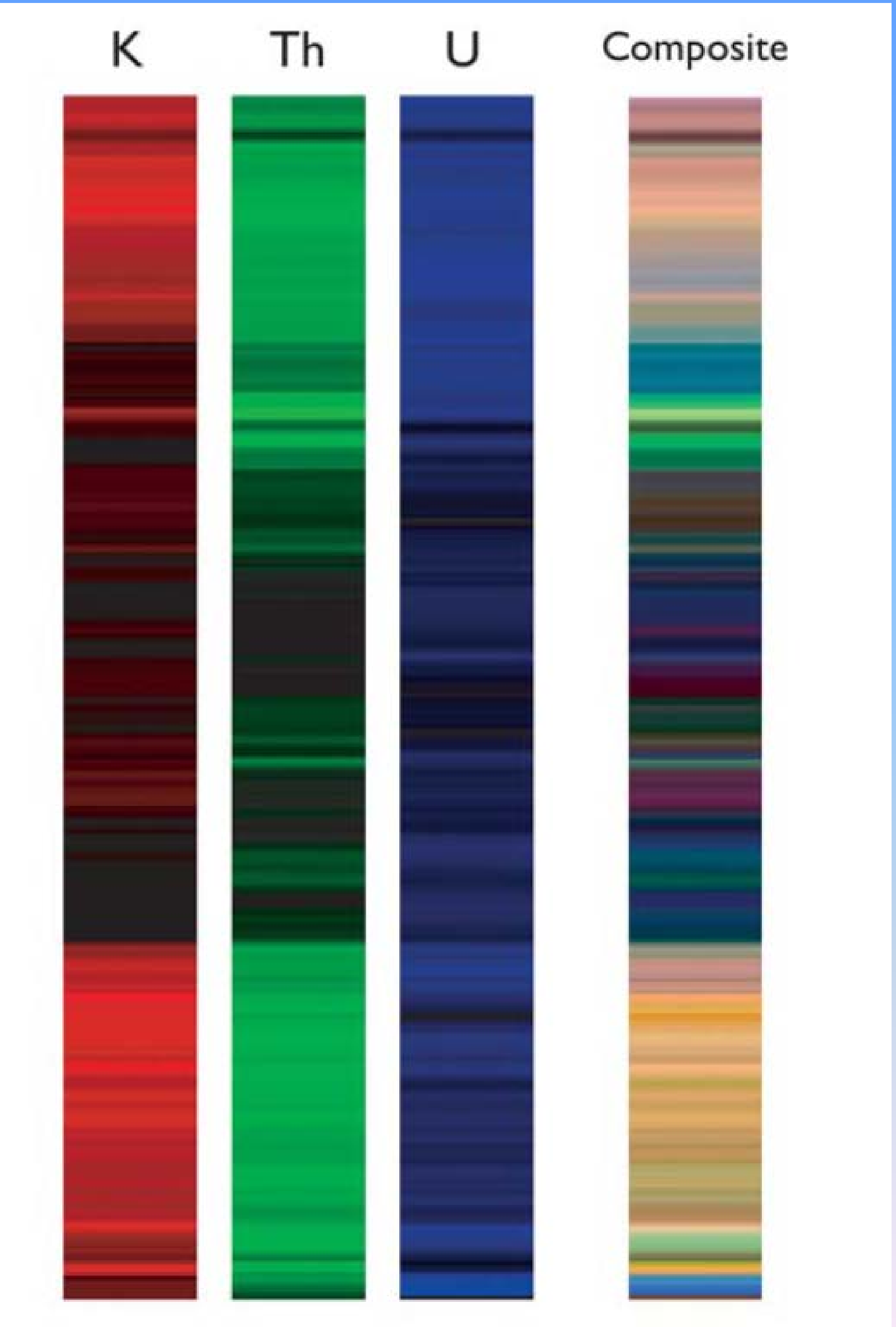
Transformation of K, Th, U logs into color-cube space image logs – migration of the invisible gamma-ray spectrum into the visible spectrum

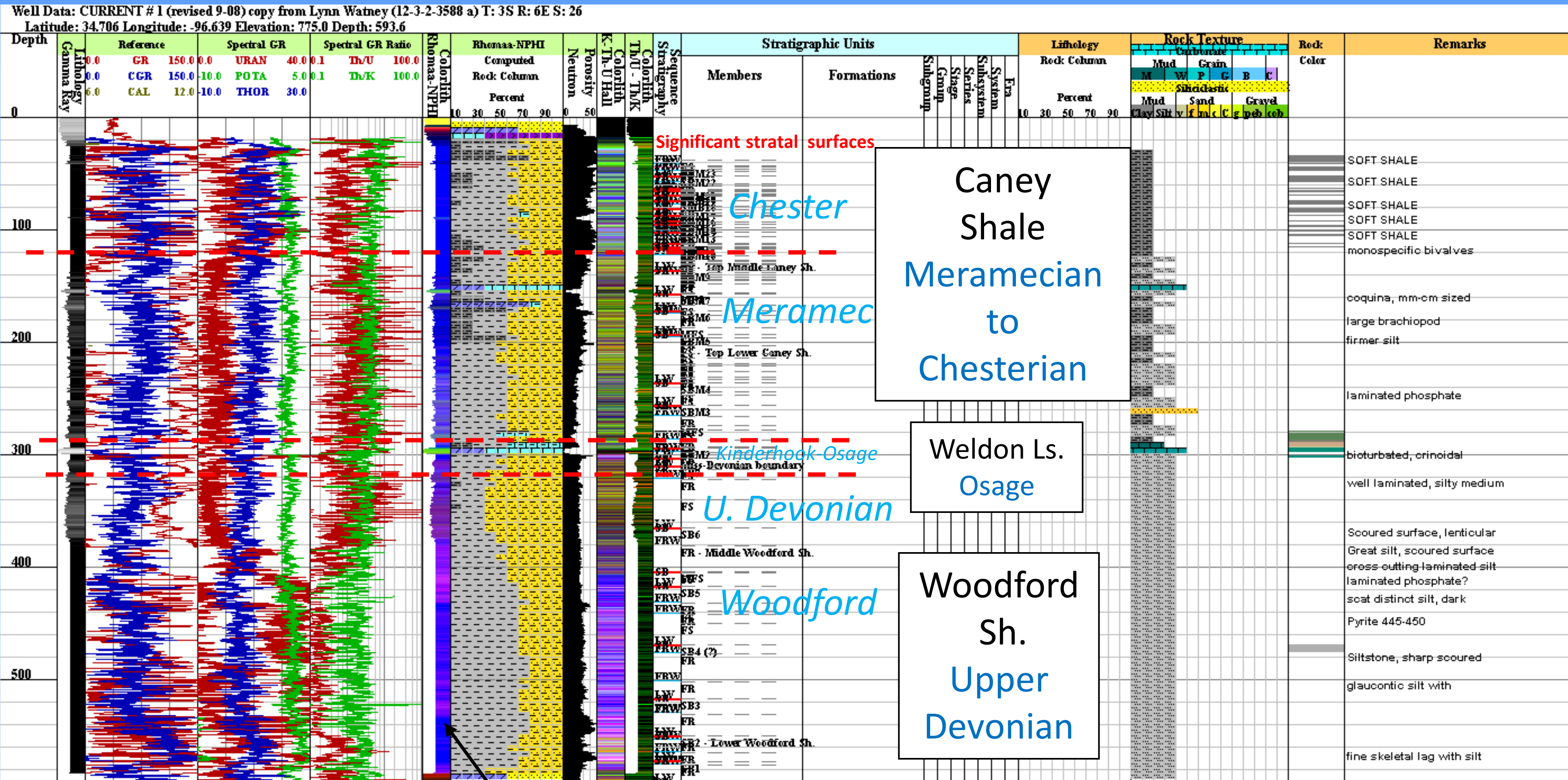
(from Hall, 2005)

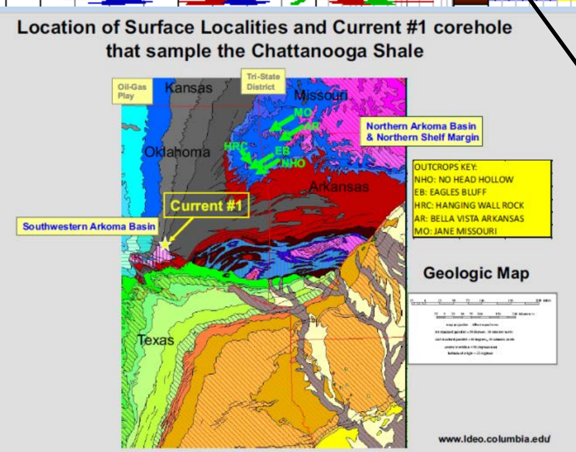
Hall Plot

http://www.kgs.ku.edu/stratigraphic/KIMELEON/
Doveton & Victorine, KGS







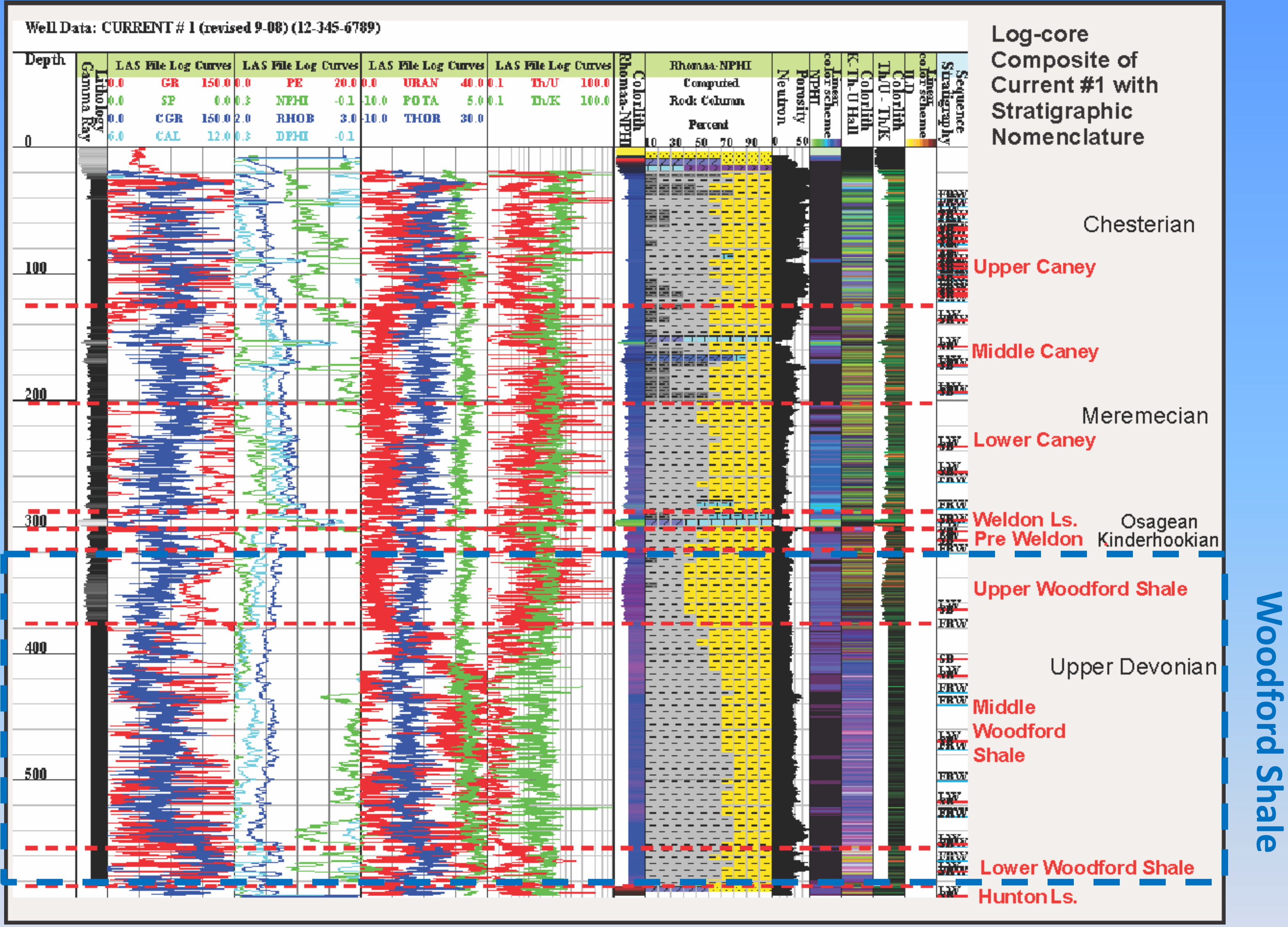


Key

Colorlith Th/U-Th/K – most reduced (low Th, high U) = black

K-Th-U **Hall plot** – uranium rich = violet

Rhoma-Neutron Colorlith



- Distal shelf and slope equivalents of Woodford Shale typically include abundant interbeds of radiolarian cherts and black fissile shales with locally abundant non-skeletal phosphate.
- The phosphate-rich interval is generally restricted to a relatively short stratigraphic interval in the upper Famennian part of the Woodford Shale or near the Devonian-Mississippian (Famennian-Tournaisian) boundary (paraphrased from Jim Puckette, OSU)

Depositional sequence boundaries defined in Eastern Devonian Chattanooga Shale

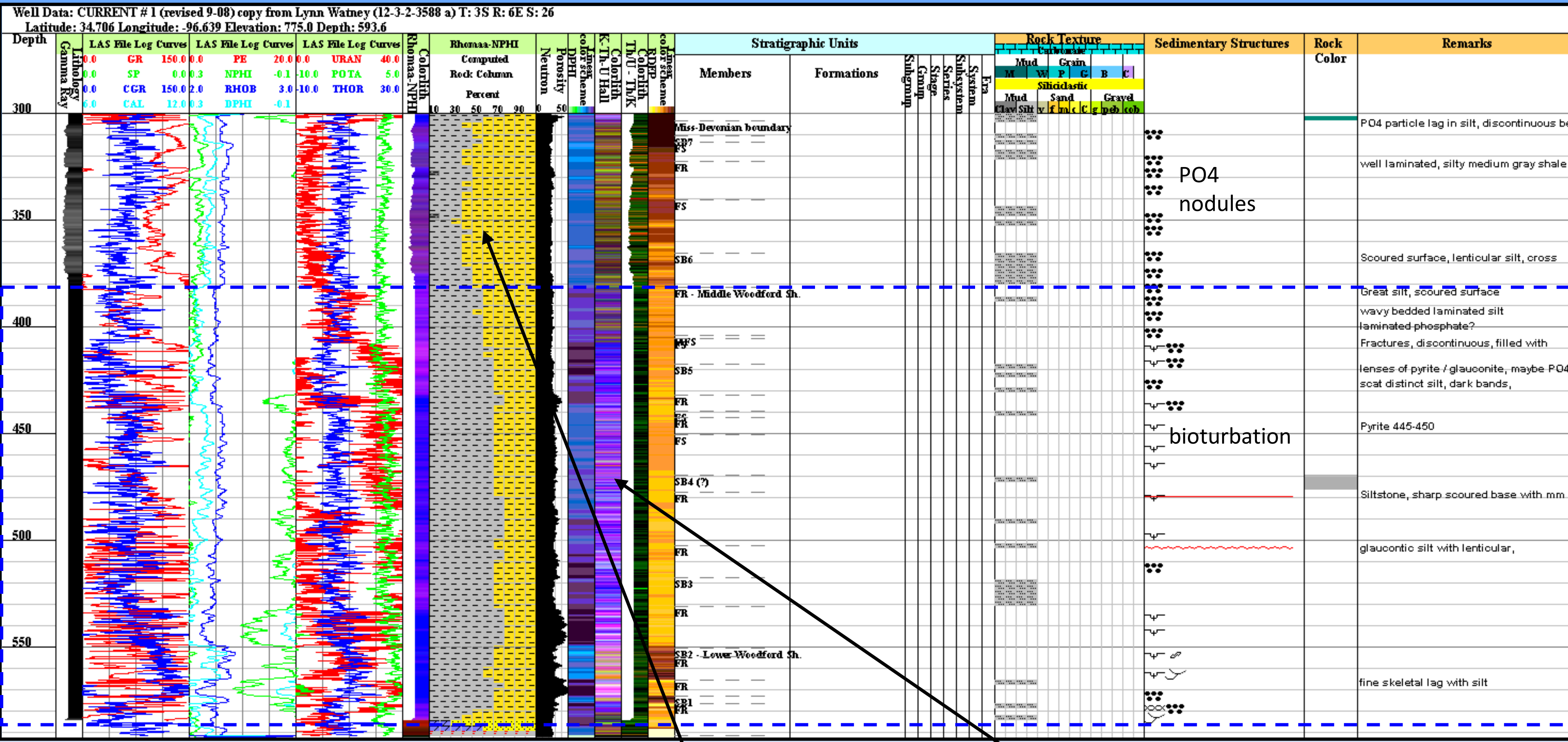
1. sandy, silty, or pyritic lag deposits of up to several cm thickness;
2. sharp-based shale beds;
3. low-angle truncation of shale beds;
4. scoured surfaces; and
5. soft-sediment deformation in underlying shales.

Tracing erosion surfaces from outcrop to outcrop is based on a combination of: 1)petrographic matching of lag deposits; 2) the petrography and microfabrics of individual shale packages; 3) conodont data; and 4) gamma ray surveys.

Shale Research Lab – Indiana U. – Jürgen Schieber
www.shale-mudstone-research-schieber.indiana.edu

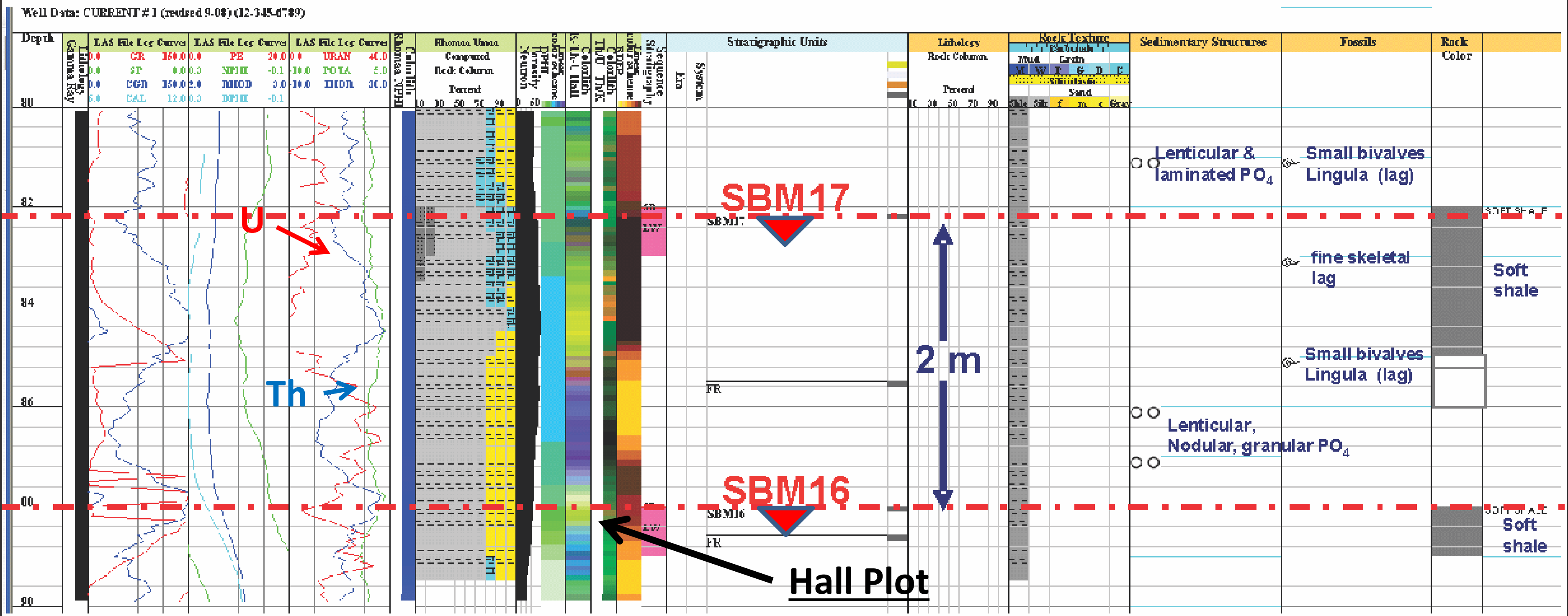
---> PRECEDENT FOR DELINEATING DEVONIAN DEPOSITIONAL SEQUENCES

Woodford Shale interval of Current #1 corehole



- Middle and Lower Woodford Shale have considerably higher uranium (**Hall Plot**) and darker color (more organic-rich) than upper Woodford Shale
- Upper Woodford Shale has twice as much quartz silt with many intervals exhibiting scoured surfaces and cross stratification
- Abbreviations -- FR (forced regression) **n=10**, SB (sequence boundary) **n=7**, FS (flooding surface) **many**

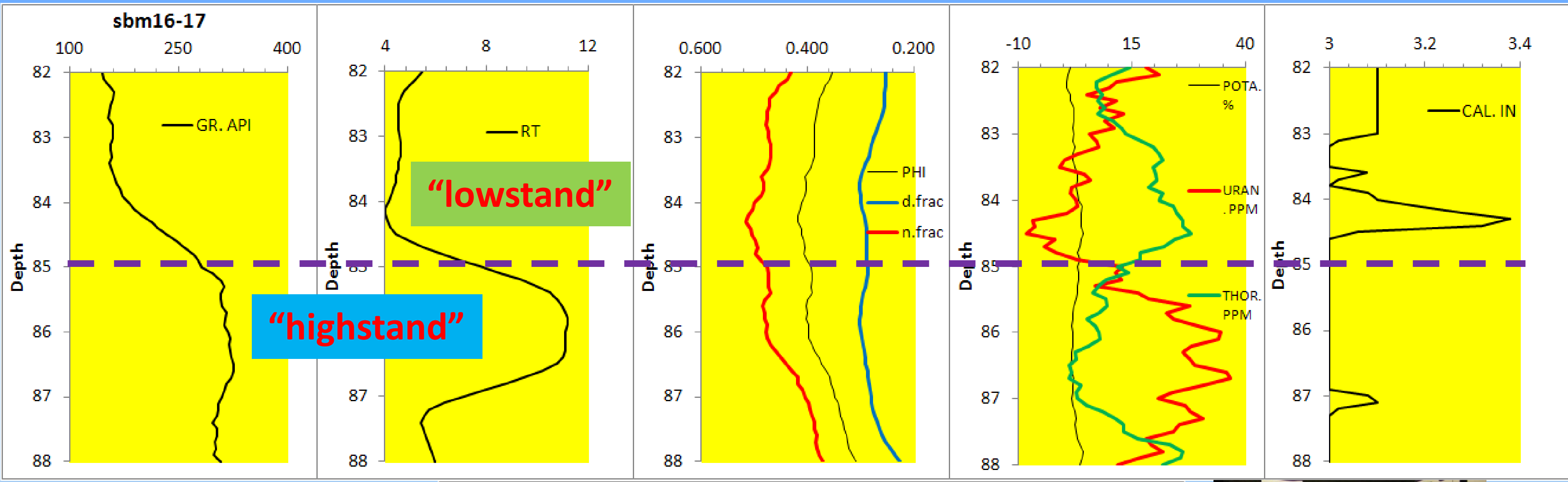
Proposed Depositional Sequence for Upper Caney (Chesterian)

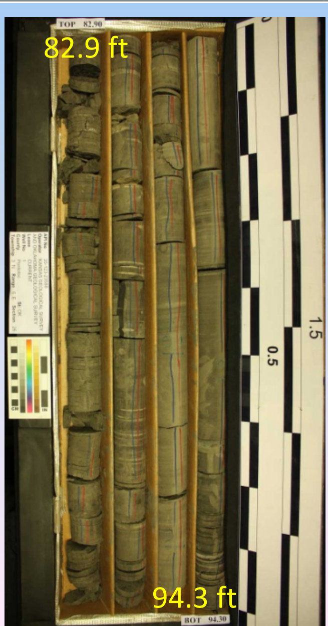


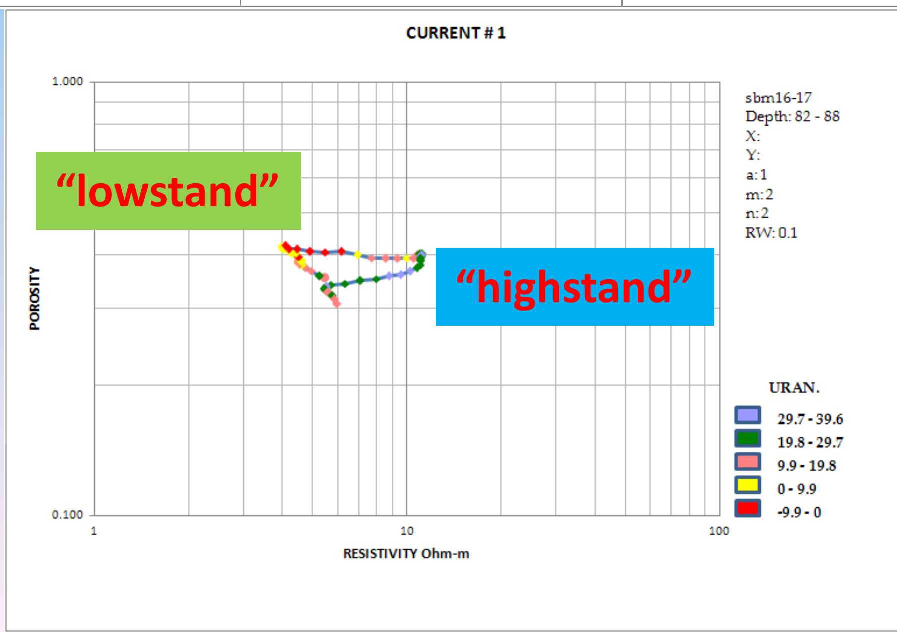
SB = sequence boundary -- abrupt upper surface overlying silty, bioturbated shale, or soft blocky mudstone, or green shales, some Th enriched; boundary is overlain by laminated, dark gray to black, often uranium-rich, phosphatic hard shale.

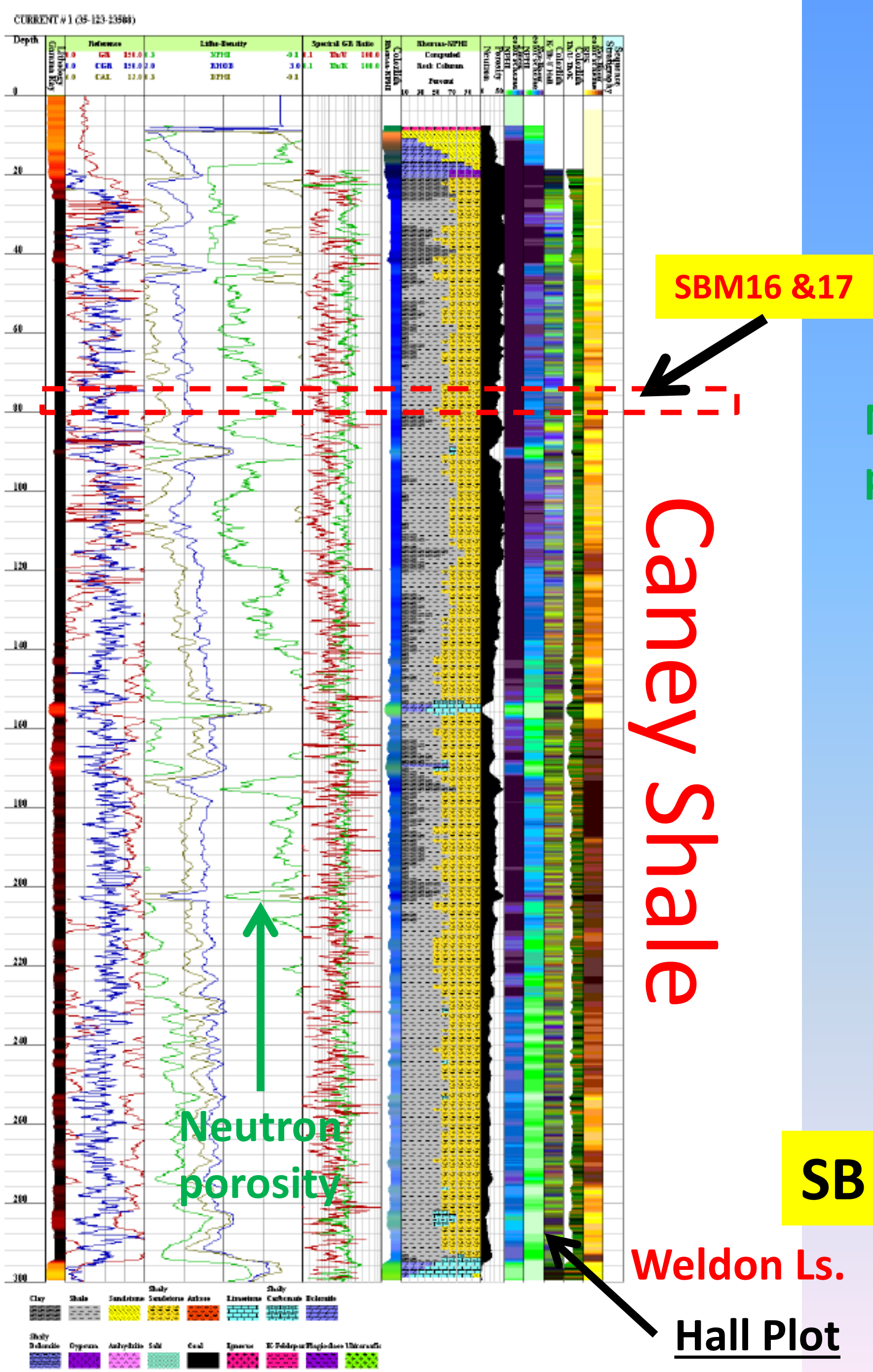
FR = forced regression -- surface of abrupt shift in lithofacies; often silty shales overlying uranium-rich, commonly PO_4 or pyritic, laminated shales.

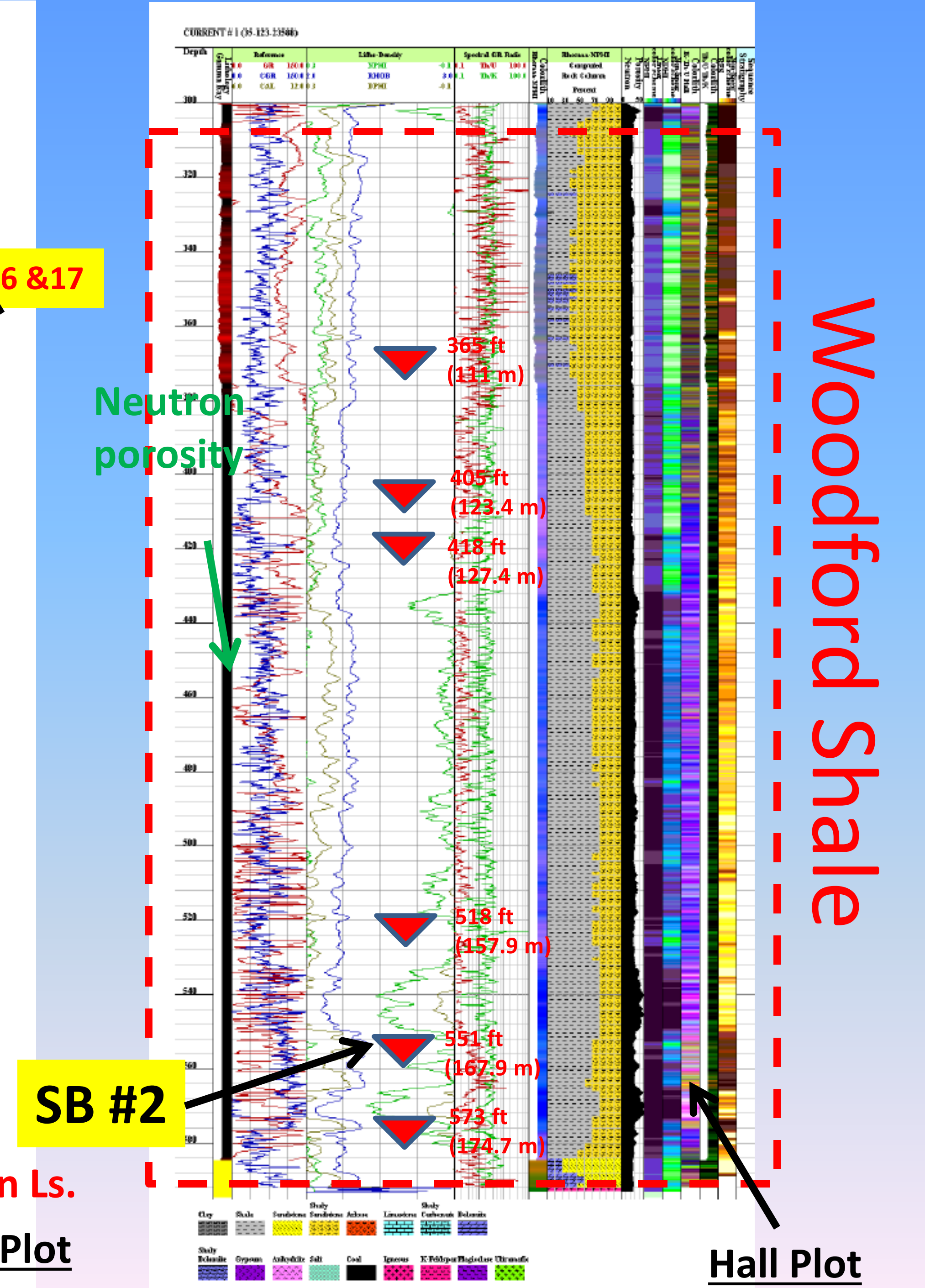
Petrophysical View of a Chesterian Depositional Sequence between Boundaries 16 & 17



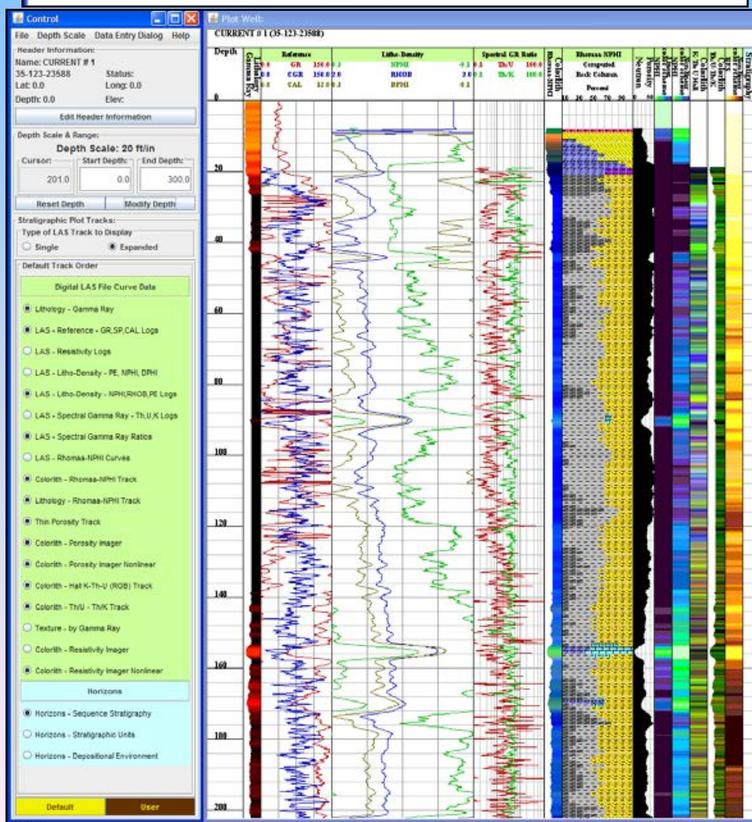


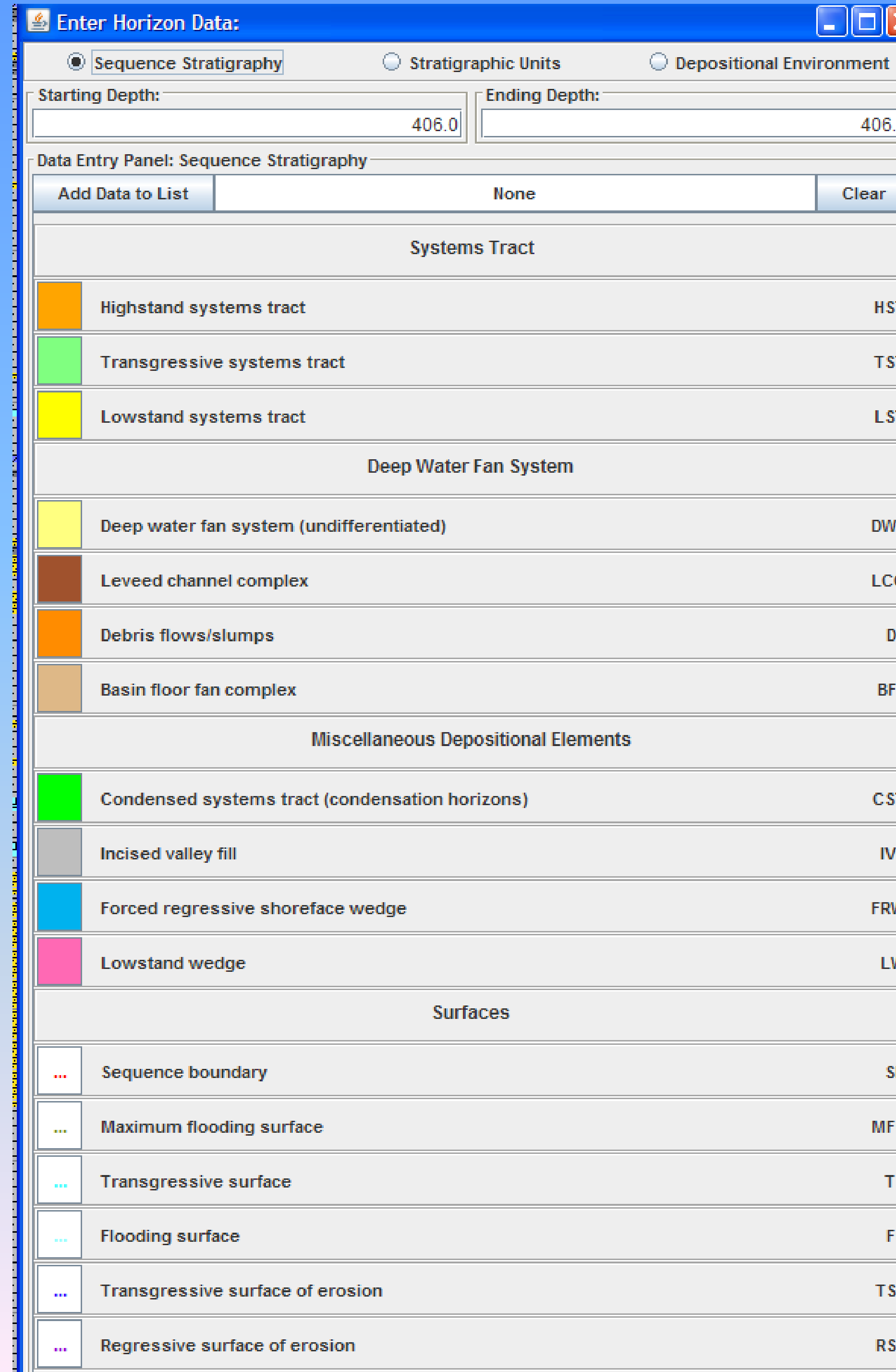



CURRENT # 1 (35-123-23560)
SBM16 &17
Caney Shale
Neutron porosity
Weldon Ls.
Hall Plot

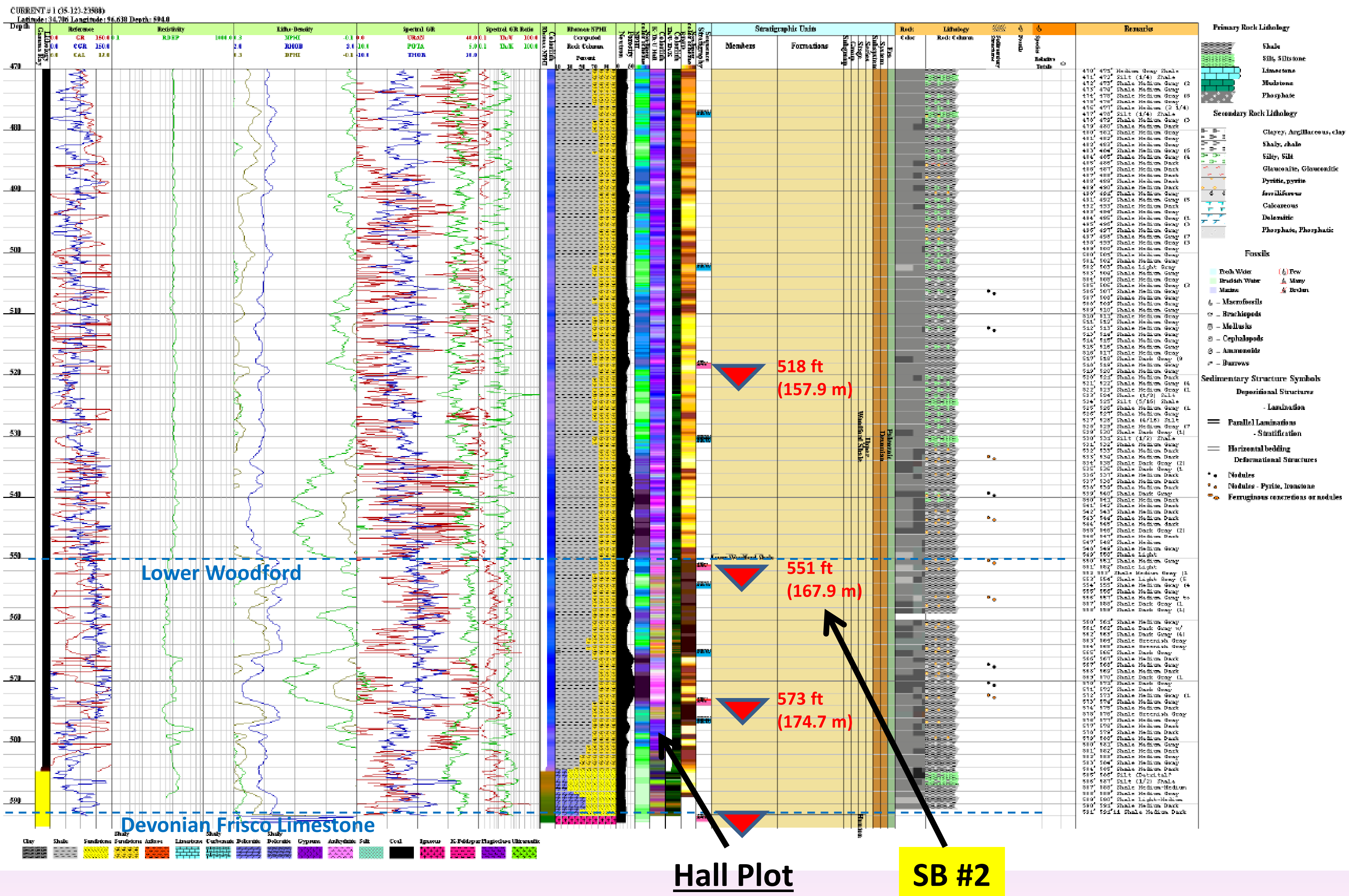

CURRENT # 1 (35-123-23560)
Woodford Shale
Neutron porosity
365 ft
(111 m)
405 ft
(123.4 m)
418 ft
(127.4 m)
518 ft
(157.9 m)
551 ft
(167.9 m)
573 ft
(174.7 m)
SB #2
Hall Plot

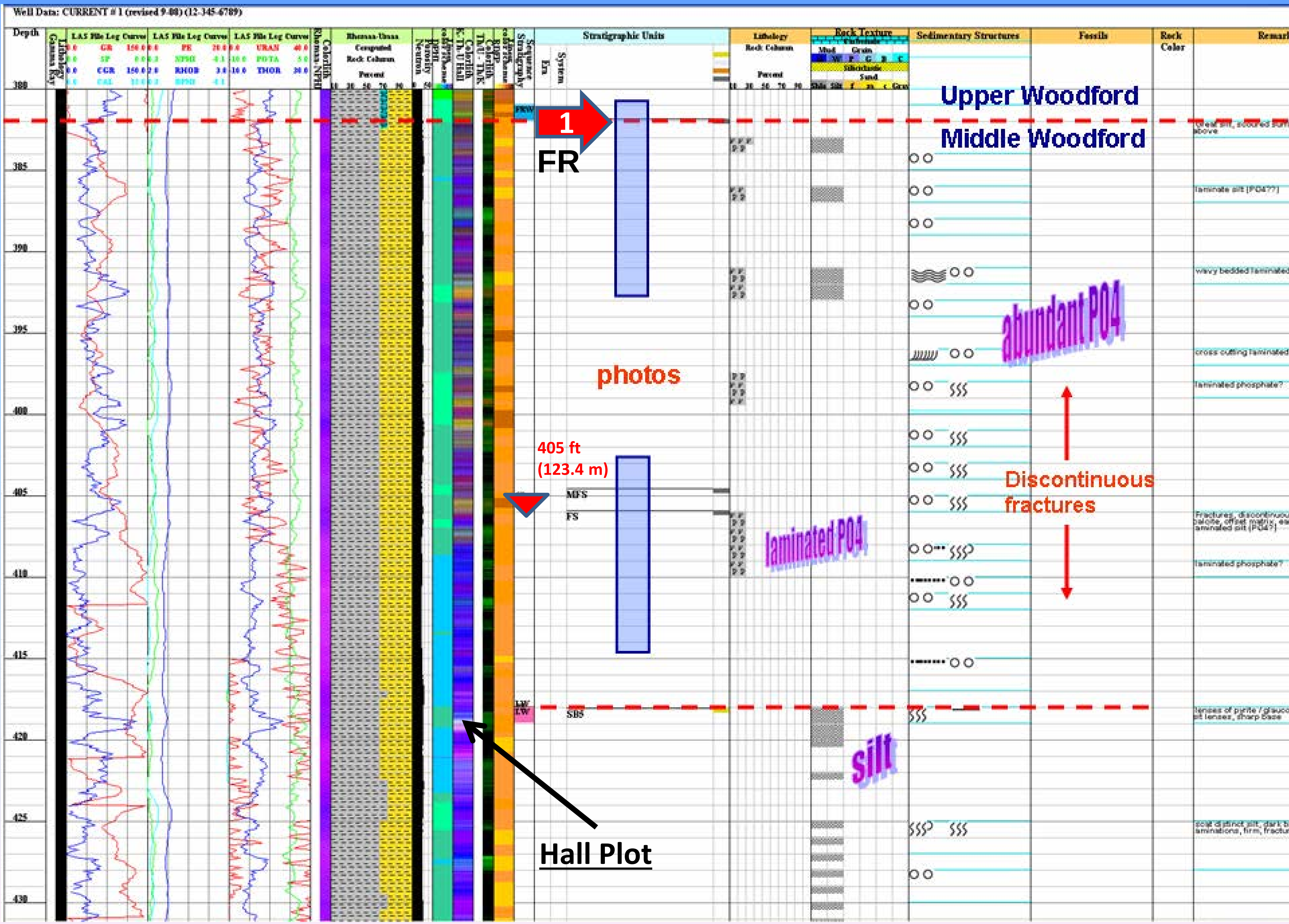
http://www.kgs.ku.edu/stratigraphic/PROFILE/





Woodford Shale – Current #1





Well Data: CURRENT # 1 (revised 9-08) (12-345-6789)
Depth
Stratigraphic Units
Lithology
Rock Texture
Sedimentary Structures
Fossils
Rock Color
Remarks
Upper Woodford
Middle Woodford
1
FR
photos
abundant PO4
laminated PO4
405 ft
(123.4 m)
MFS
FS
SBS
Discontinuous fractures
silt
Hall Plot
380
385
390
395
400
405
410
415
420
425
430

380.9-392.6 ft – Photo of slabbed core at and below contact of upper and middle Woodford Shale. Boxes are 3 ft long. Top of middle Woodford Shale is finely laminated, dark gray, and organic-rich containing abundant large cm-sized nodules, lenses, and laminated phosphate. Occasional phosphate with fine pyrite centers. Wavy bedded, mm-laminated, more silty interval at bottom. Contact at upper & middle Woodford Shale contains shale clasts in siltstone and large phosphate nodules at contact appearing as if winnowed by currents. Upper Woodford Shale has abrupt decrease in uranium from 20 ppm below to 5 ppm above the contact.

Contact between ***upper and middle Woodford Sh.***

= nodular and lenticular PO4 "lag"

Upper = laminated PO4 and few nodules and lenses

Silt layers = biogenic and detrital?

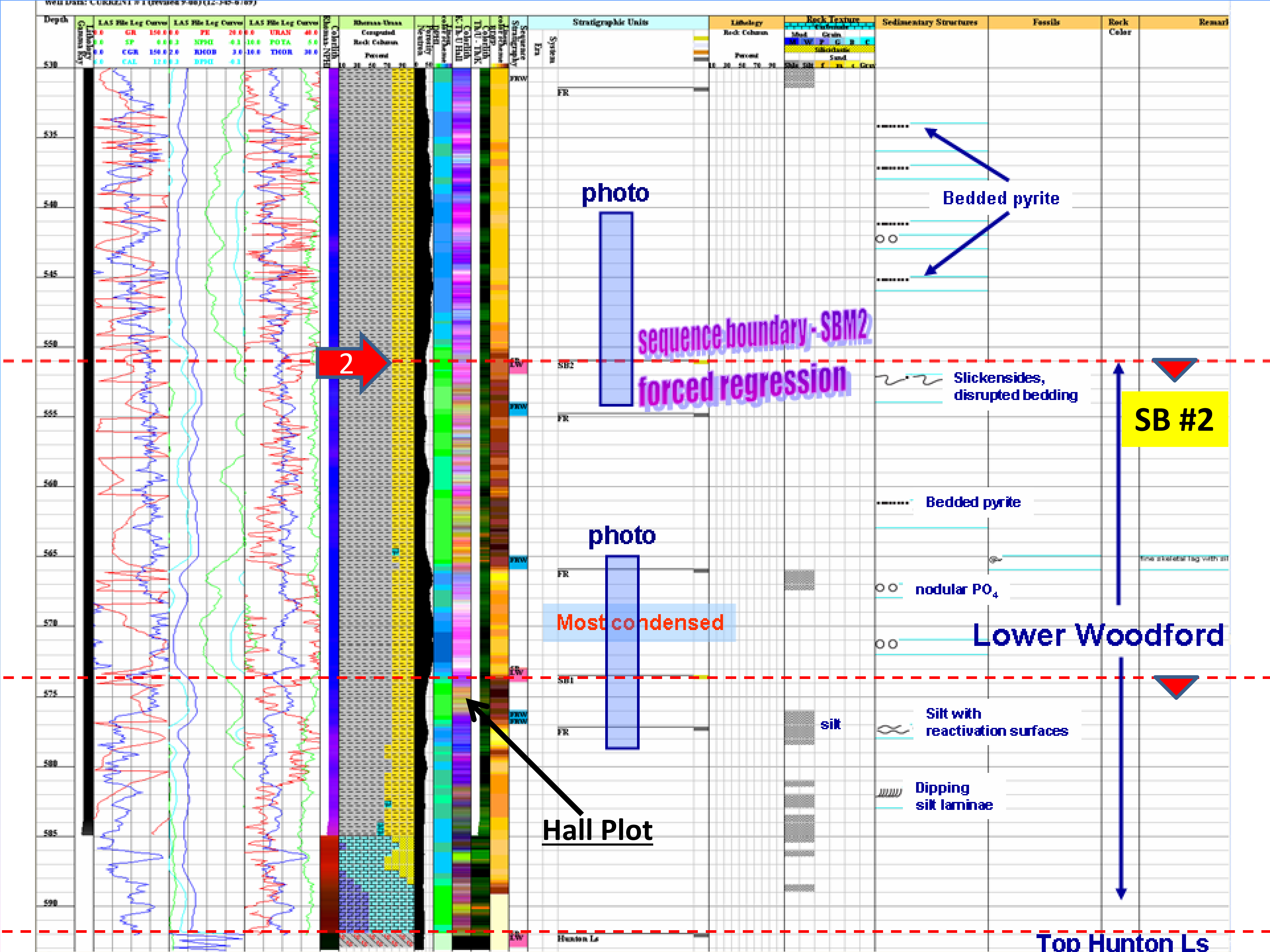
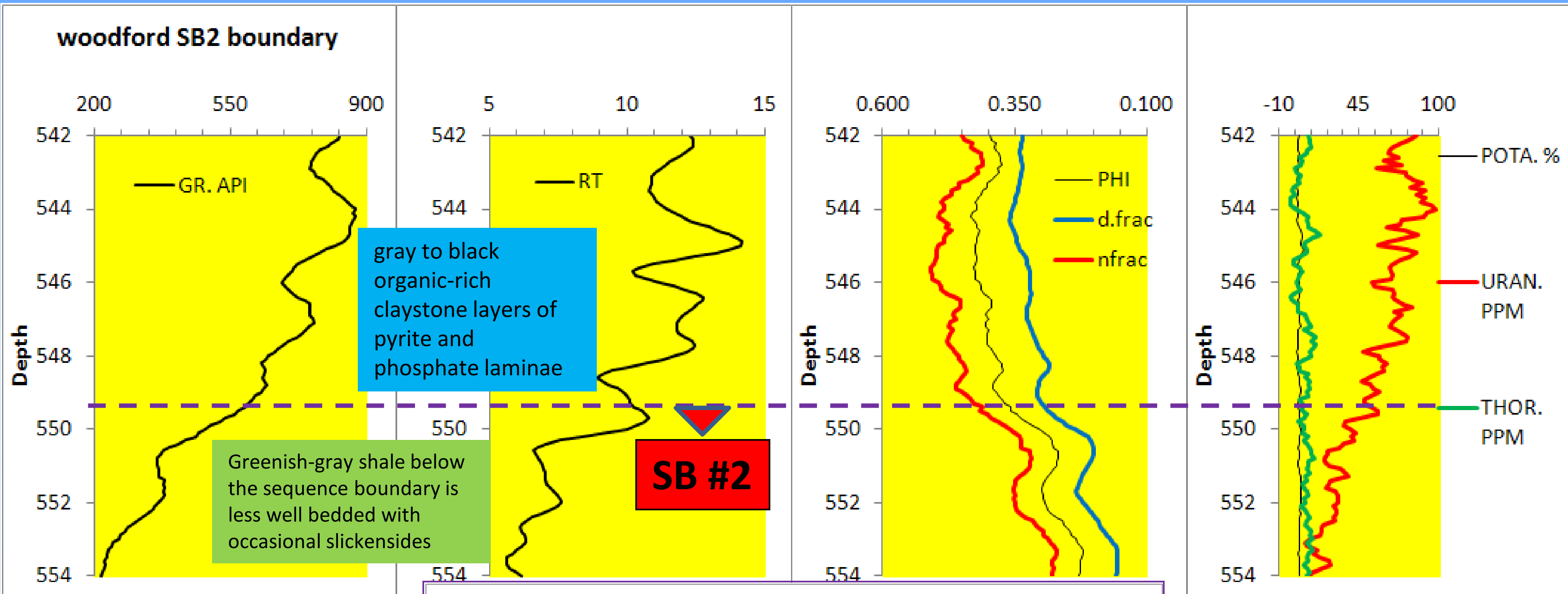


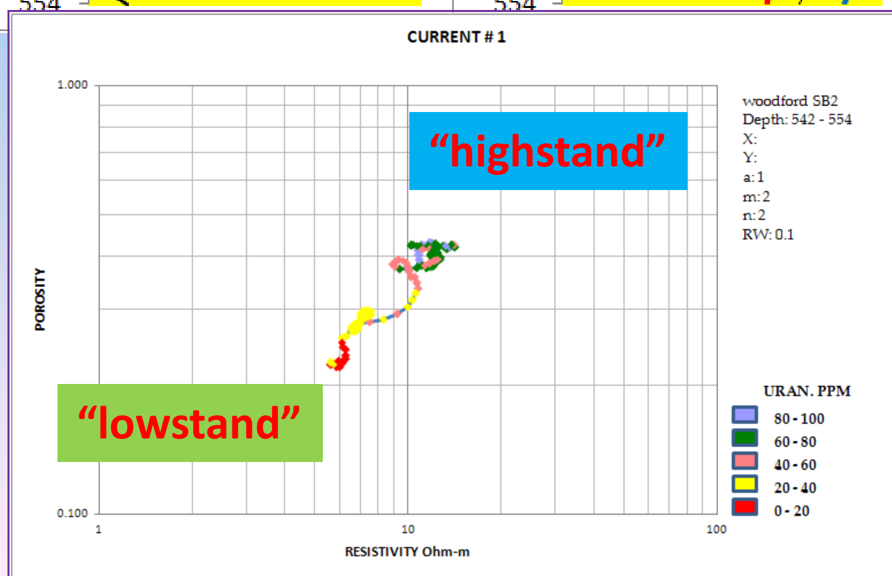
photo
Bedded pyrite
sequence boundary - SBM2
forced regression
2
Slickensides,
disrupted bedding
SB #2
Bedded pyrite
photo
nodular PO_4
Most condensed
Lower Woodford
silt
Silt with
reactivation surfaces
Dipping
silt laminae
Hall Plot
Top Hunton Ls

Contact between middle and lower Woodford Shale – ***sequence boundary #2, possibly near Frasnian-Famennian boundary***

Core photograph from 542.4 ft to 553.9 ft. – Sequence boundary (SB#2) separating the middle from the lower Woodford Shale. Greenish-gray shale below the sequence boundary is less well bedded with occasional slickensides. Above the sequence boundary is gray to black organic-rich claystone layers of pyrite and phosphate laminae. Uranium concentration in this shale climbs to 70 ppm, while shale below the sequence boundary has uranium concentrations from 10 to 30 ppm.

Petrophysical view of provisional **sequence boundary #2** between lower and Middle Woodford





Thorium is unchanging in contrast to the Chester sequence example.
Also higher apparent porosity for "highstand" in contrast to Chester.

http://www.kgs.ku.edu/stratigraphic/KIMELEON/index.html

KIMELEON Web Site

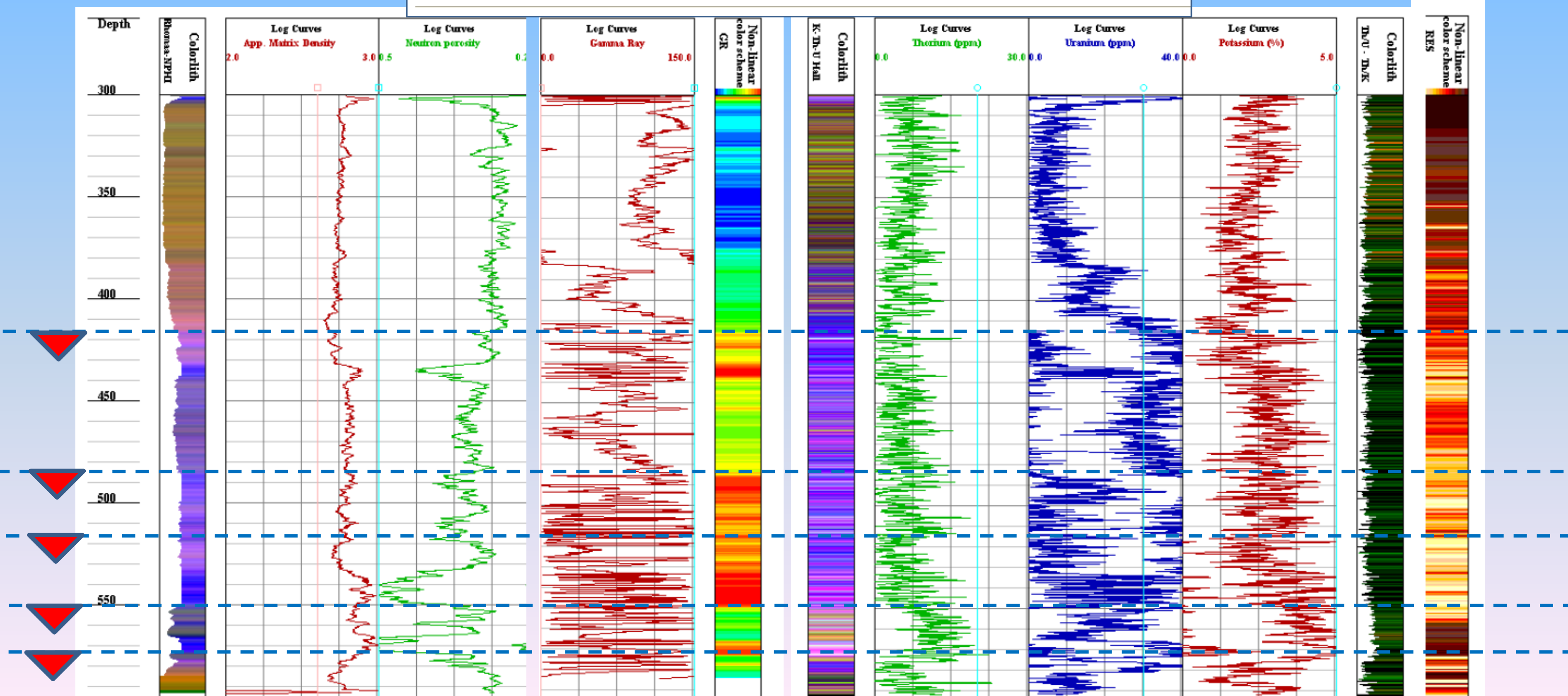
Main Page | History | Applet | Web Start | Help | Copyright & Disclaimer |

KIMELEON is an interactive colorlith plot applet, which was created to allow the user the ability to interact with the digital LAS data from purely a visual sense. This web tool was created to assist the geologist in analyzing regions of the subsurface to better understand the geology. The digital LAS Log curves are combined in different means to produce color image tracks, by changing the magnitude ranges of the colorlith tracks the geologist can bring out more subtle variances in the data and hence a better understanding of the region of interest. The user can create Portable Network Graphics (PNG) images of the displayed plots.

Sections:

Main Page	(this page)
History	Brief history of "COLORLITH", which uses the mix of primary color intensities to create a color log of well data by depth.
Applet	Java Application accessible from the browser.
Web Start	Java Application initially downloaded using the browser, but can be run outside of the browser.
Help	Help on Kimeleon.

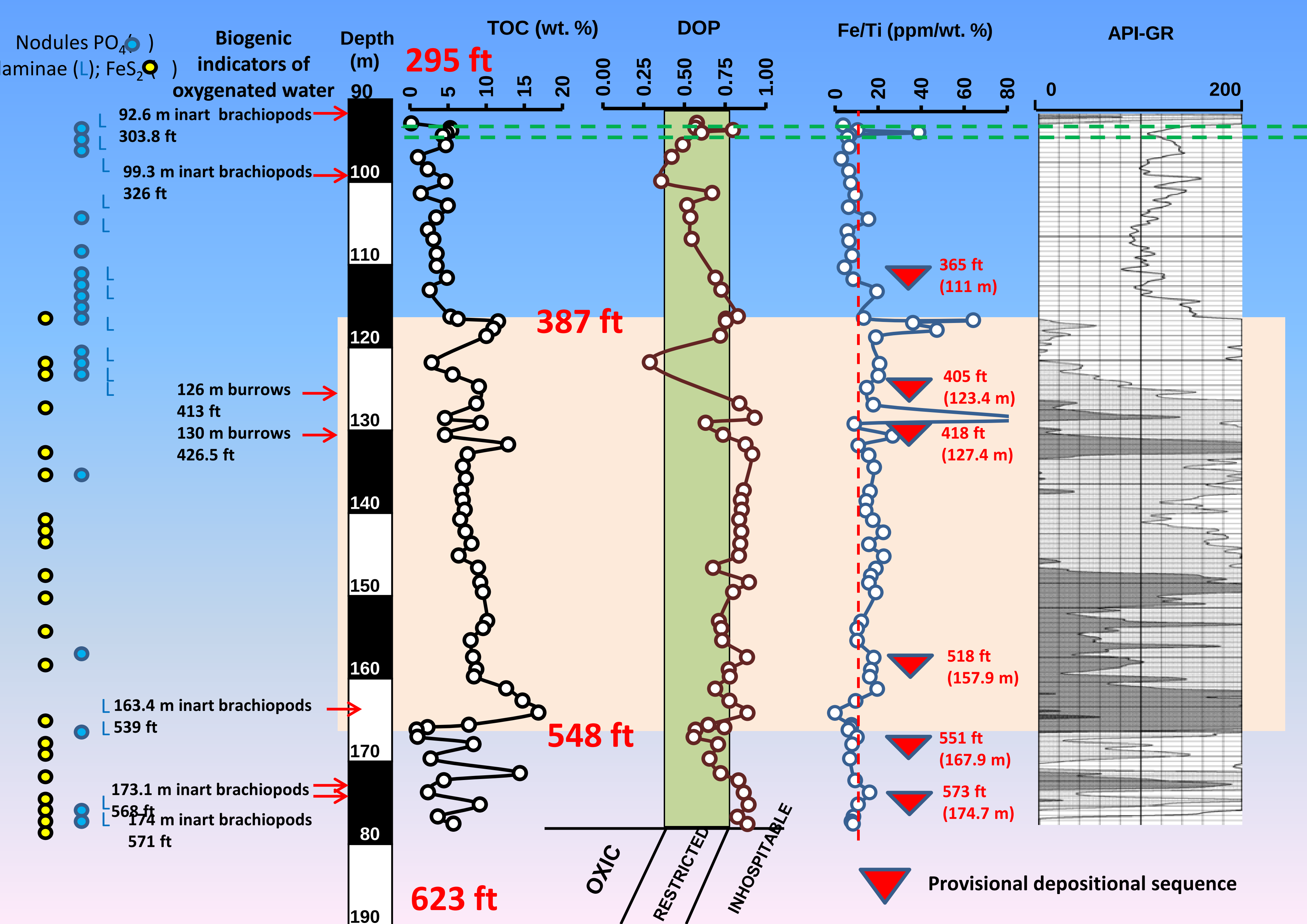
The Woodford Shale interval as "seen" using Kimeleon software (free KGS software tool)



Fluctuating bottom water conditions

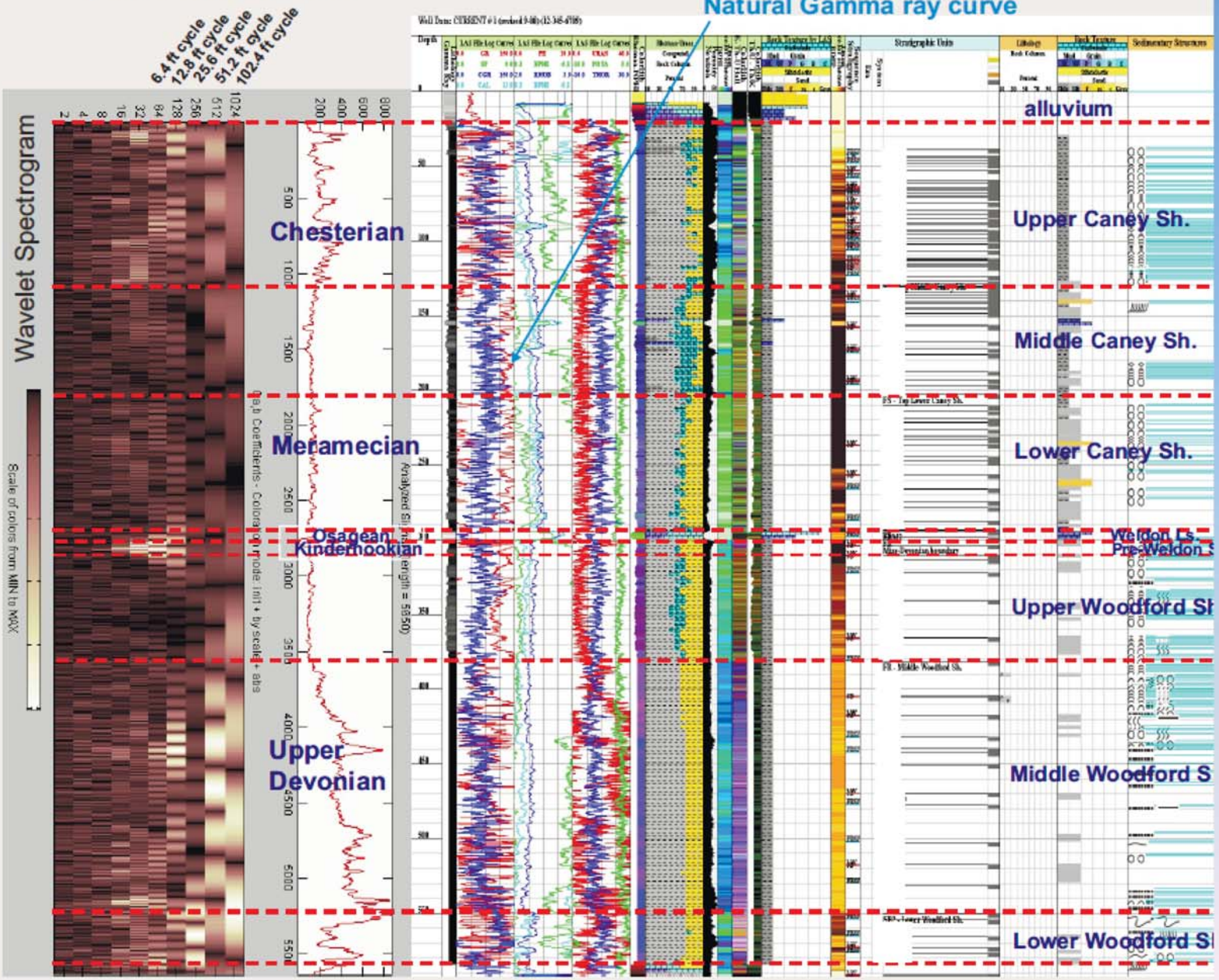
- In general, intervals containing evidence of euxinic bottom water during deposition have increased Mo, TOC, DOP, low Th/U ratios
- In contrast, intervals with evidence of bottom water oxygenation such as inarticulate brachiopods and burrowing have lower values of TOC, Mo, DOP, and higher Th/U ratios and represent disruption of the water stratification that was prevalent during Woodford time.

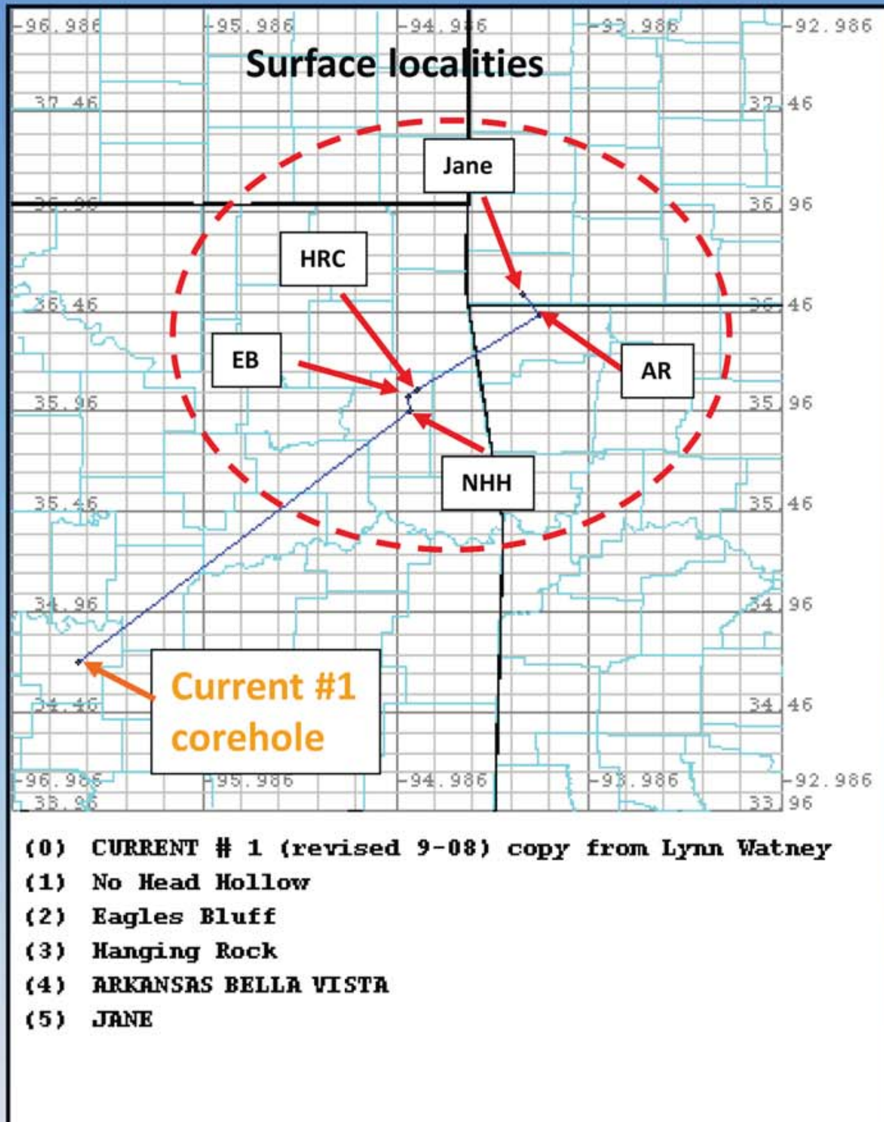
Woodford Interval



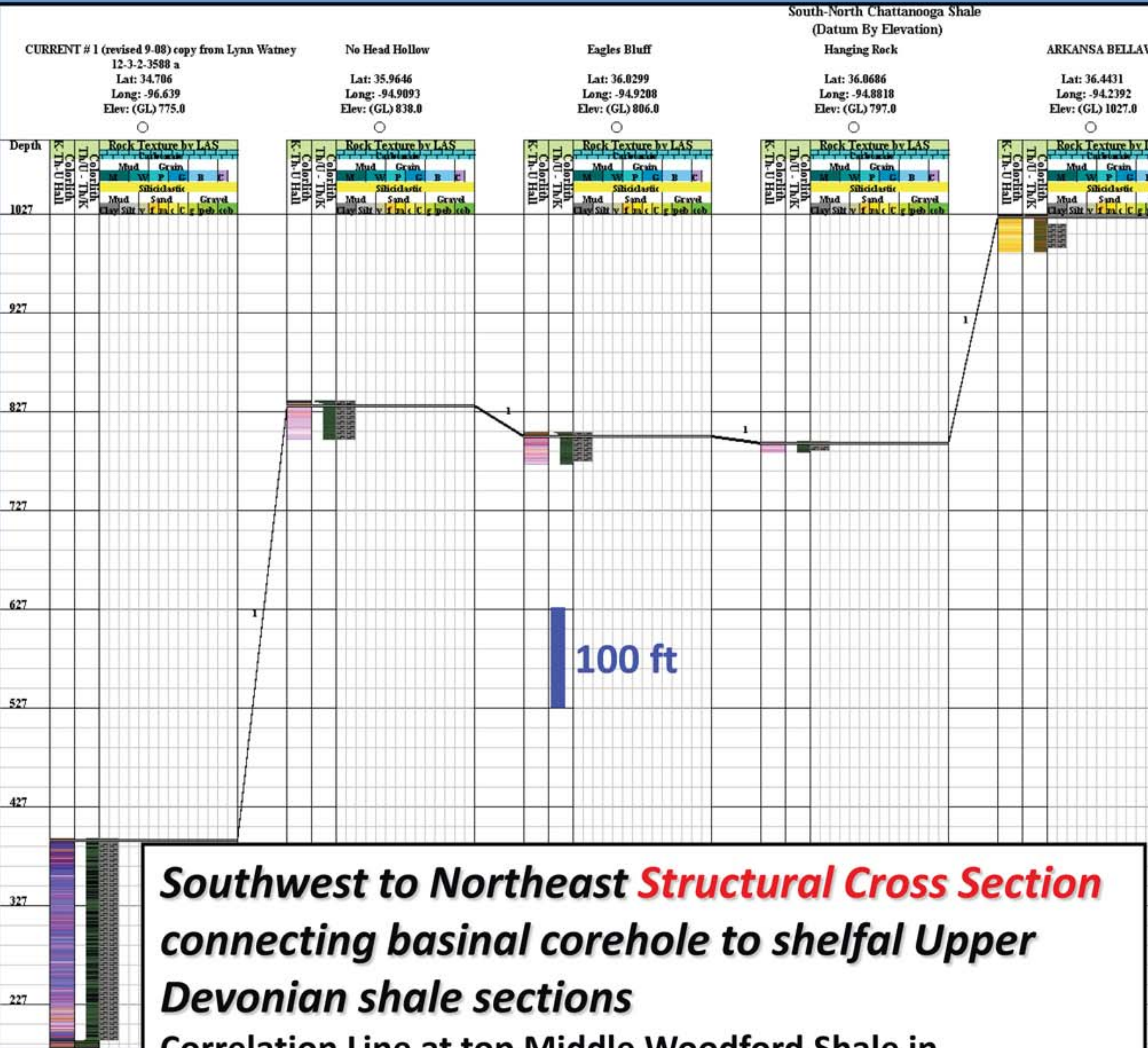
Morelet Wavelet Transform of natural gamma ray (1 unit depth = 0.1 ft)

KGS-OGS Current #1 Well log & Core description





The high shelfal expression of the Chattanooga Shale is typified by black fissile shale with minor silt but generally lacking in non-skeletal phosphate and bedded cherts.

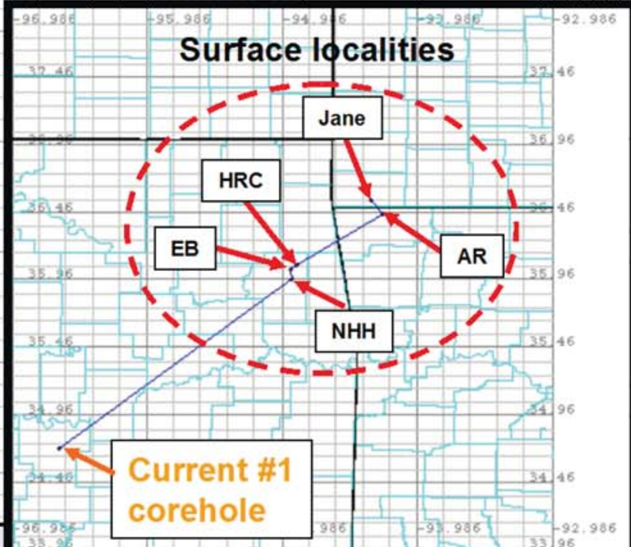


Color columns:

left – Hall Plot, K-Th-U

middle – Th/U – Th/K ratio

right – General lithology



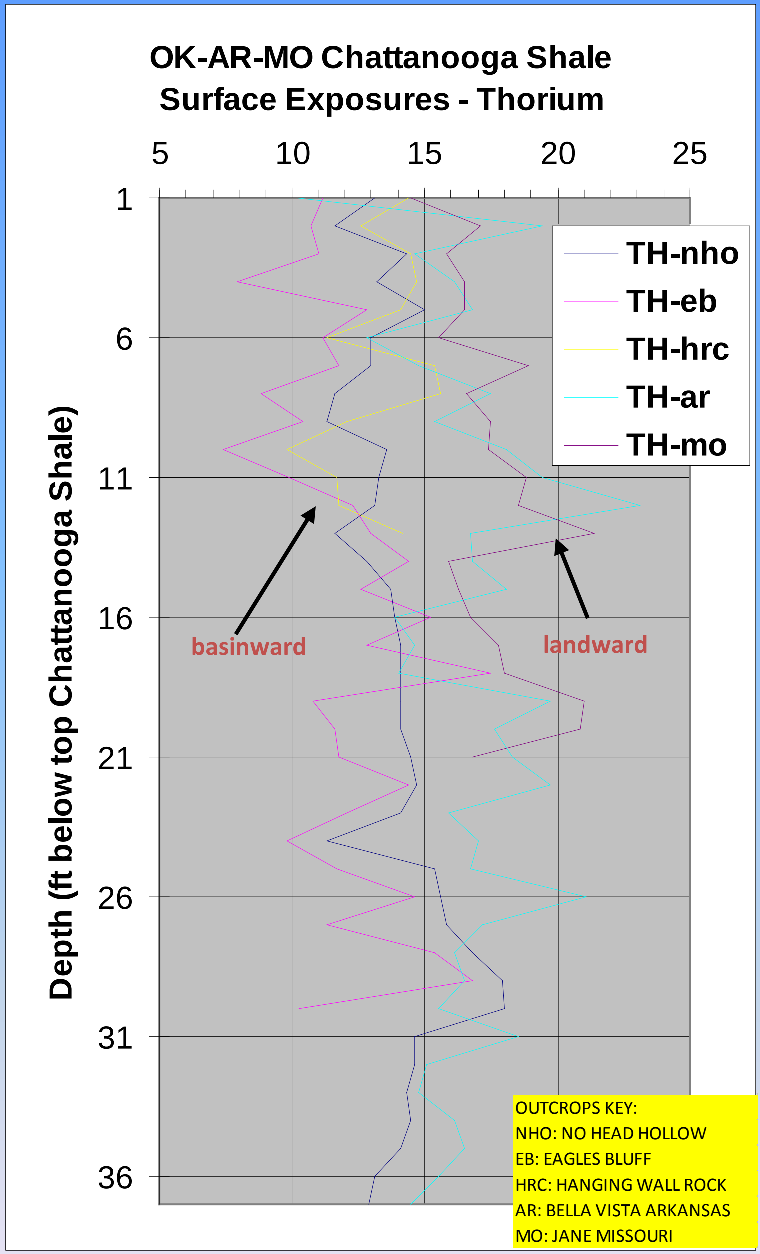
(0) CURRENT # 1 (revised 9-08) copy from Lynn Watney
(1) No Head Hollow
(2) Eagles Bluff
(3) Hanging Rock
(4) ARKANSAS BELLA VISTA
(5) JANE

Southwest to Northeast Structural Cross Section connecting basinal corehole to shelfal Upper Devonian shale sections

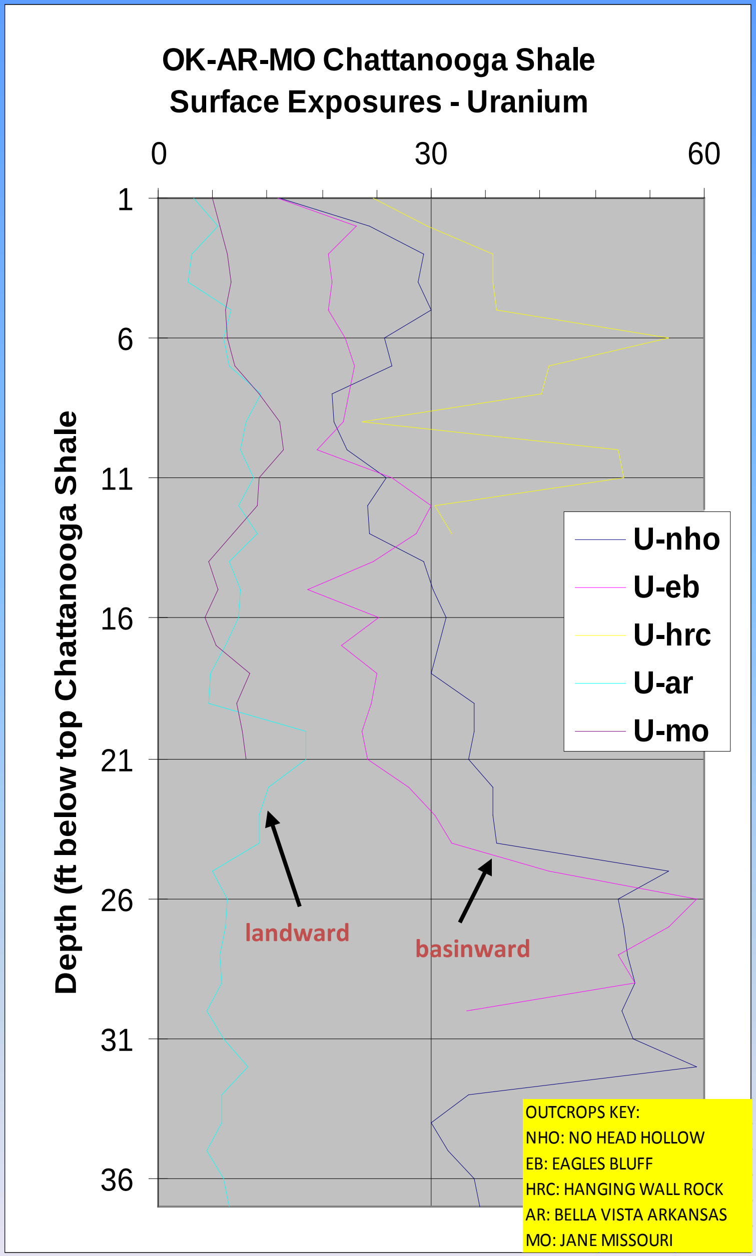
Correlation Line at top Middle Woodford Shale in southernmost corehole & top Chattanooga Shale

No horizontal scale –

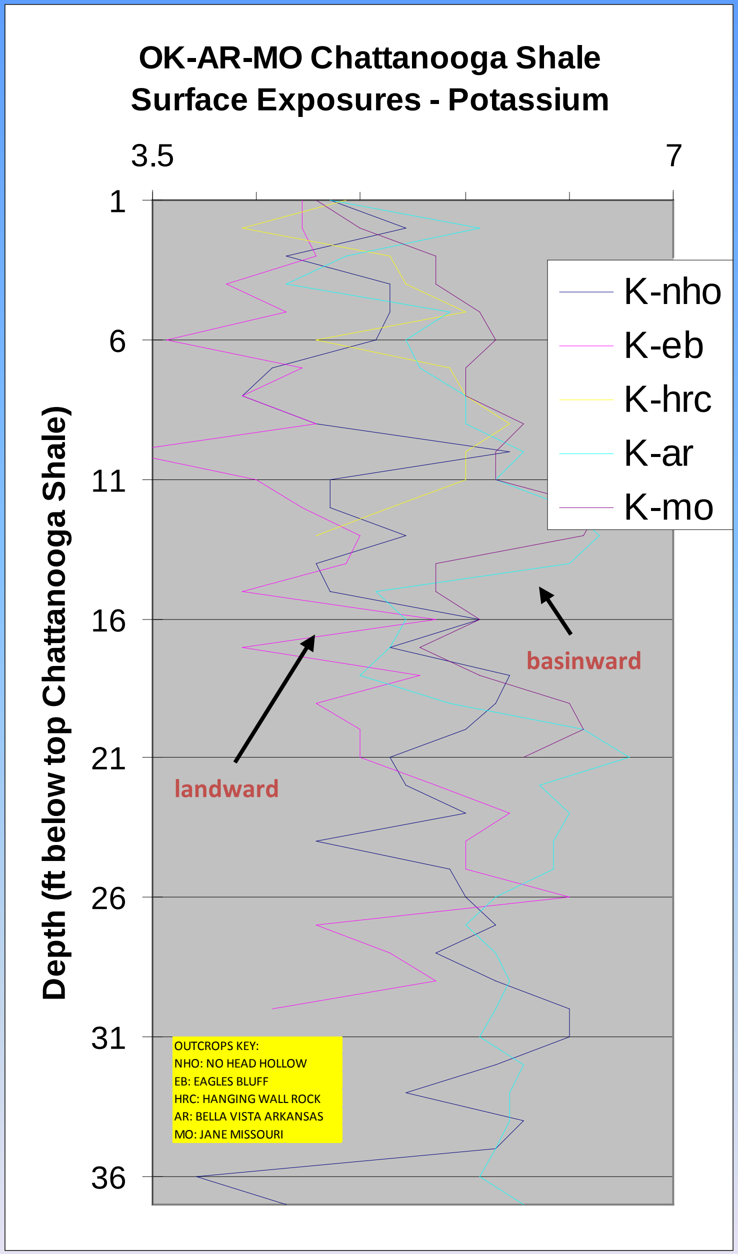
Total distance = 180 mi (289 km)

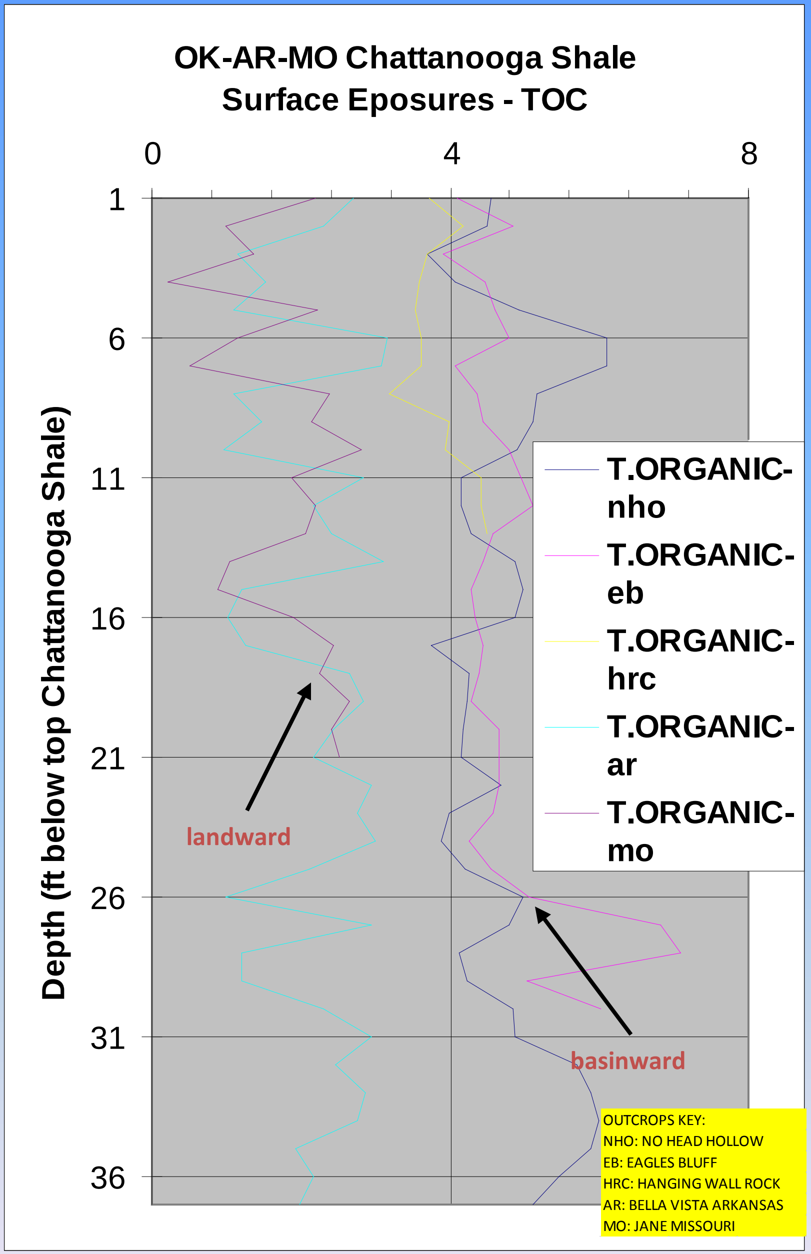


- Thorium is highest in northern shelfward sections
- Gradual increase with Th with depth



- Uranium increase with depth, markedly increasing at base
- Uranium highest in southern basinward locatities – nho & eb
- Parallels changes in TOC, higher at depth and in basin





- **Potassium increase with depth**
- **Potassium generally higher in northern shelfward locations**

- **TOC notably higher in southern basinward sections**
- **Generally TOC correlates to uranium concentration**

Summary

- Clearly defined intervals of reduced oxygen to anoxic to euxinic shales reflected in geochemistry, mineralogy, TOC, fauna, and petrophysical properties
- Thorium is higher in “lowstand” shales of Chesterian and is unchanging in example of the Woodford.
- Extensive mapping needed to substantiate depositional sequences and understand sediment accommodation and sediment preservation/erosion.
- Consistent shelf-to-basin in Woodford to Chattanooga Shale – Th increases landward and K, U, and TOC increase basinward (toward Current #1)

Oklahoma Geological Survey

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