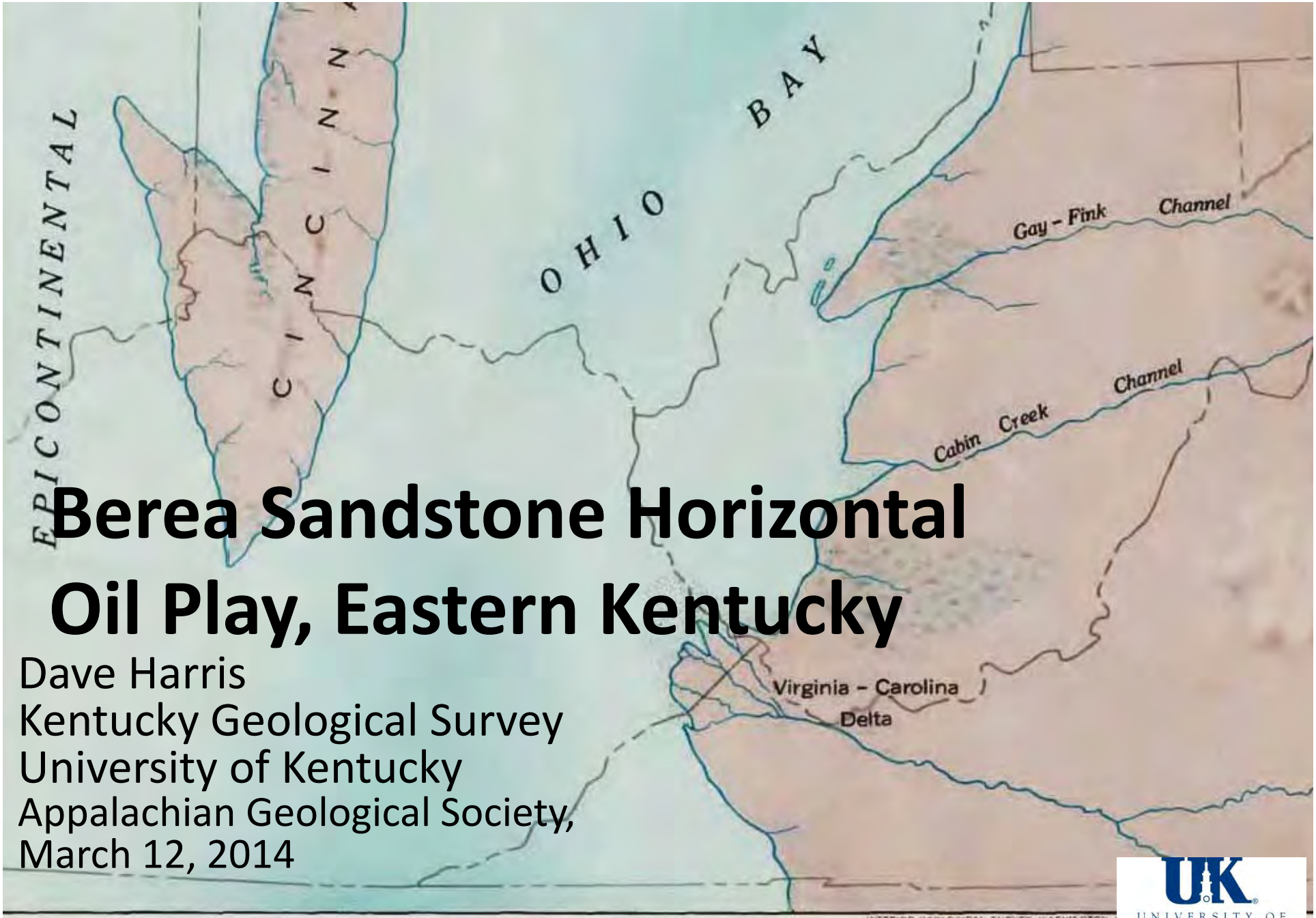
# Berea Sandstone Horizontal Oil Play, Eastern Kentucky

Dave Harris
Kentucky Geological Survey
University of Kentucky

Appalachian Geological Society,
March 12, 2014




(Pepper and other, 1954) PALEOGEOGRAPHIC MAP OF MIDDLE BEREA TIME

UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

# Outline

- Why consider horizontal wells in the Berea?
- Berea stratigraphy and depositional history
- Production trends
- Devonian thermal maturity
- Reservoir quality
- Greenup and Lawrence County activity
- Summary and recommendations
- Berea Sandstone Consortium

UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

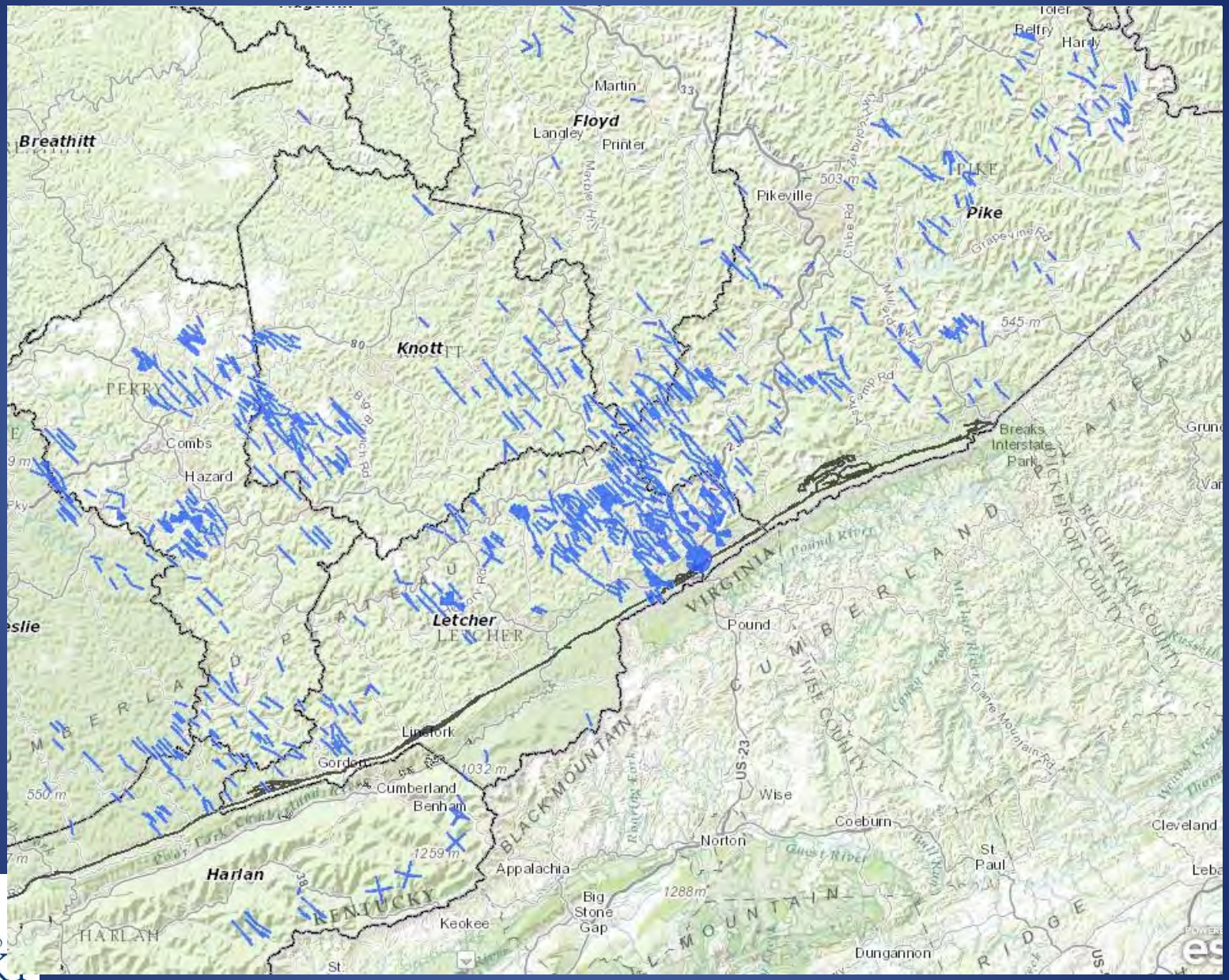
# Why Horizontal Drilling?

- Horizontal wells can improve production in many non-shale reservoirs:
  - Naturally fractured reservoirs: increased fracture contact
  - Reservoirs with isolated compartments/perm barriers
  - High permeability reservoirs with water coning problems
  - **Low permeability reservoirs: increases permeability-feet (Kh)**
- Berea is a classic low-permeability reservoir
  - FERC tight formation status (Lawrence/Pike Counties in early 1980's)
  - Very fine-grained (siltstone dominated in E. Ky.)
  - EQT drilled ~75 horizontal Berea gas wells in Pike County

(M. McLear, KOGA presentation, June 2010; PDF on Core Minerals web site)

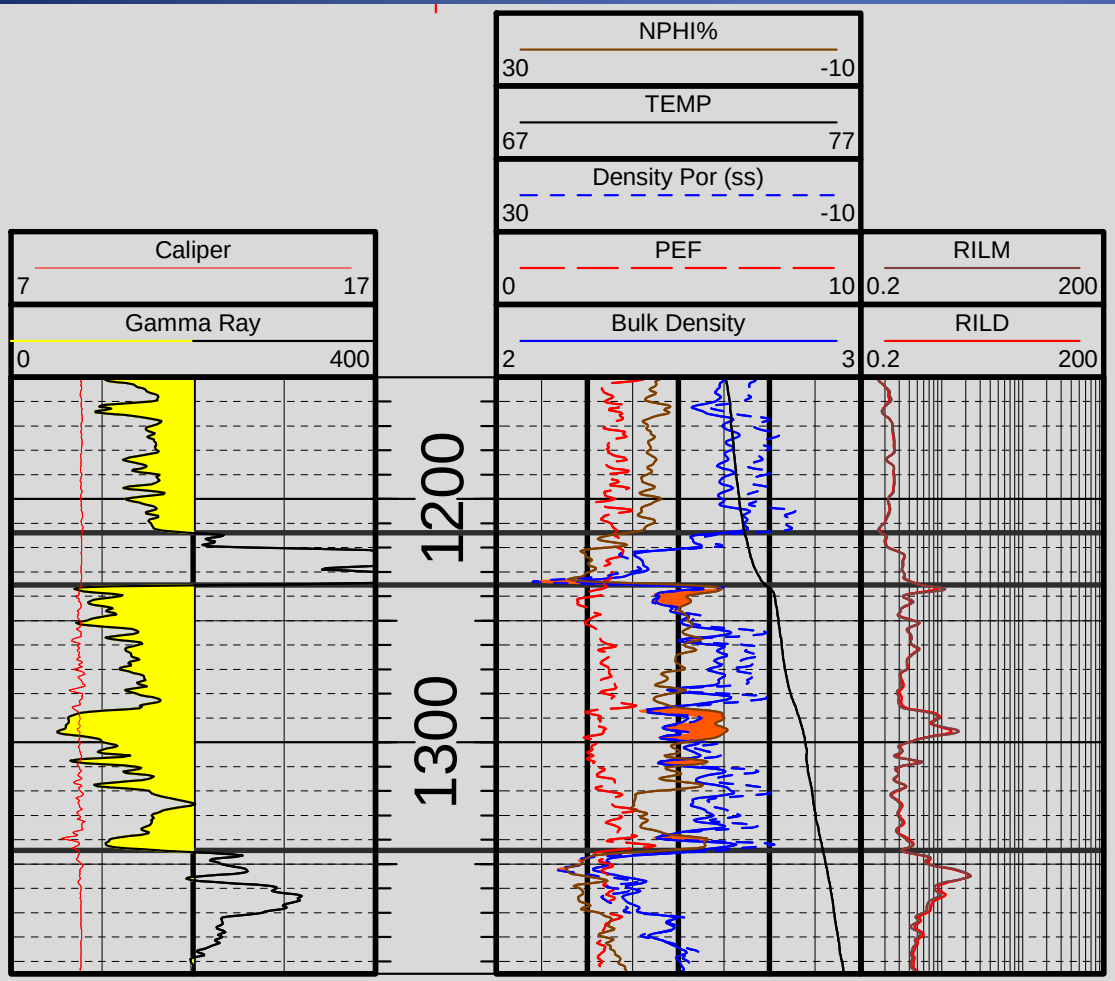
UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

# Devonian Shale Horizontal Play, Southeast Kentucky




University of Kentucky
Kentucky Geological Survey

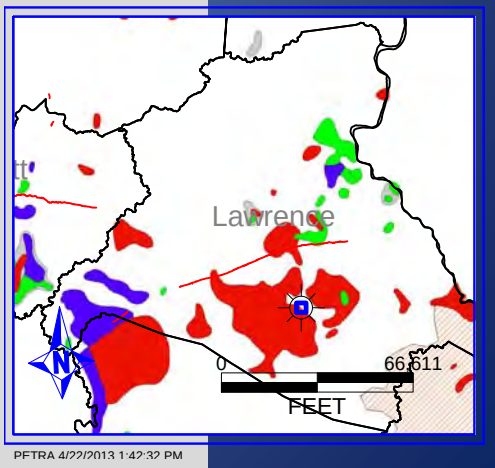
# Berea “Sandstone” Type Log, Lawrence County




Sunbury Sh
Berea Ss/Bedford Sh

Ohio Sh

137383
APP ENERGY 1 MOORE, C
Lawrence
KY

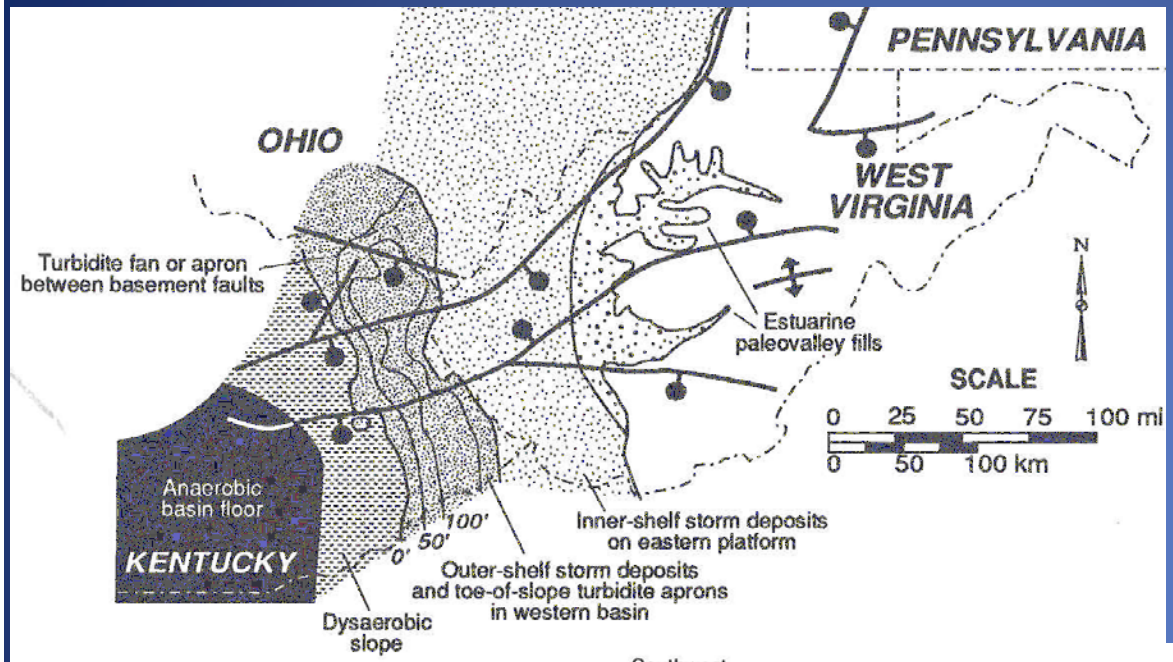


# Berea Depositional Setting

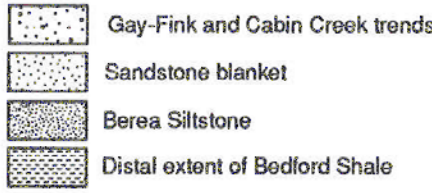
- Key references:
  - Pepper, de Witt, and Demarest, 1954, USGS Prof Paper 259
  - Pashin and Ettensohn, 1995, GSA Special Paper 298; also PhD thesis by Pashin at UK
  - Elam, 1981, MS thesis at UK
  - Frantz and Lancaster, 1993, GRI Topical Report 94/0258: Reservoir Engineering & Treatment Design Technology, Research Results of Ashland Ford Motor Co. 80 (COOP 2), Pike Co., KY
- Regressive sequence deposited in Acadian foreland basin with sources to the east and north
- In E. Ky. Berea siltstones deposited on a storm-dominated marine slope and outer shelf, (common hummocky cross-bedding, wave ripple lamination, turbidite sequences)
- KGS Berea Play Web Page: www.uky.edu/KGS/emsweb/berea_ss/Upper_Devonian_Berea_SS.htm

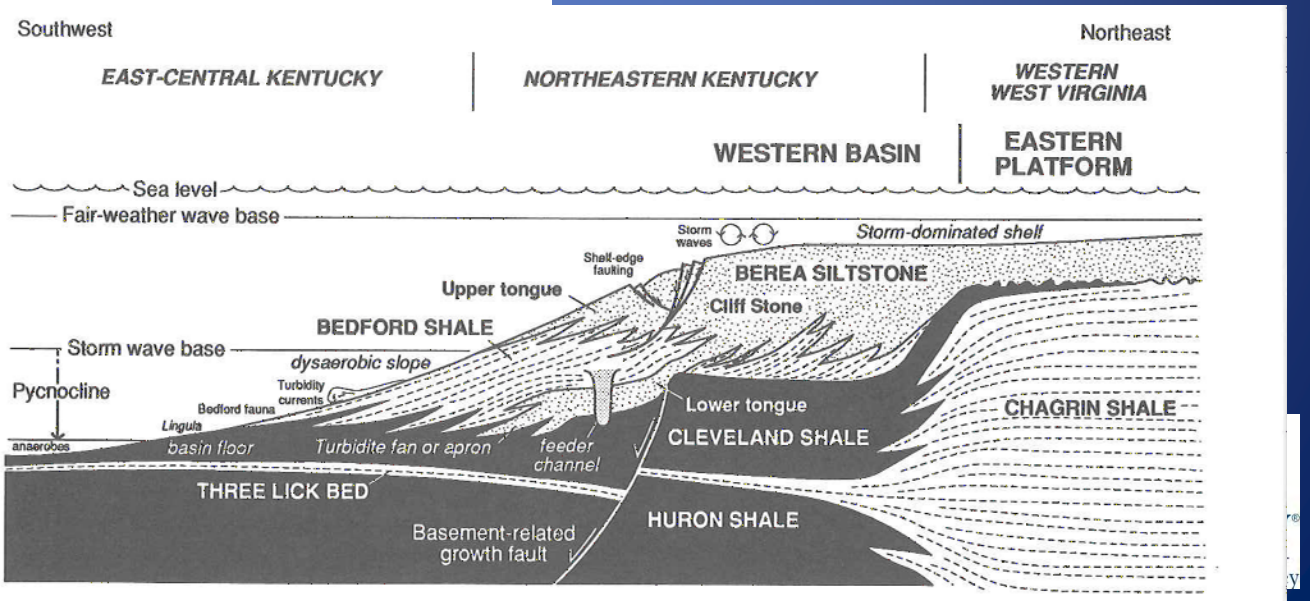
UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

# Berea Paleogeography




(Pashin & Ettensohn, 1995)

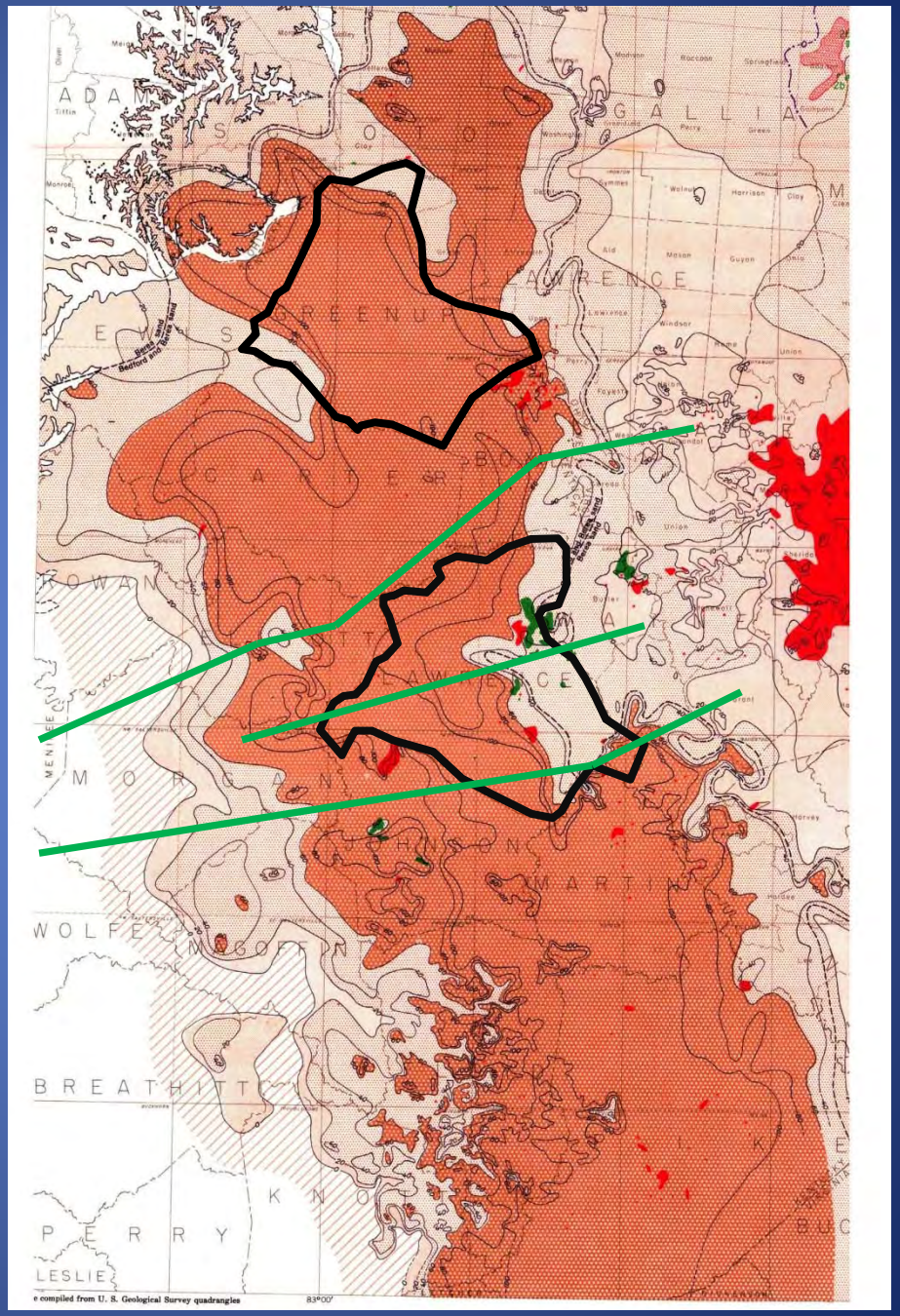


# Berea Siltstone Thickness

- North-south trending thick, dark red = Berea “sand” > 60 feet
- Greenup and Lawrence Counties, Ky. highlighted
- Possible fault influence on Berea thickness (Pashin and Ettensohn, 1995)

(from Pepper and others, 1954)



# Berea Depositional Trends

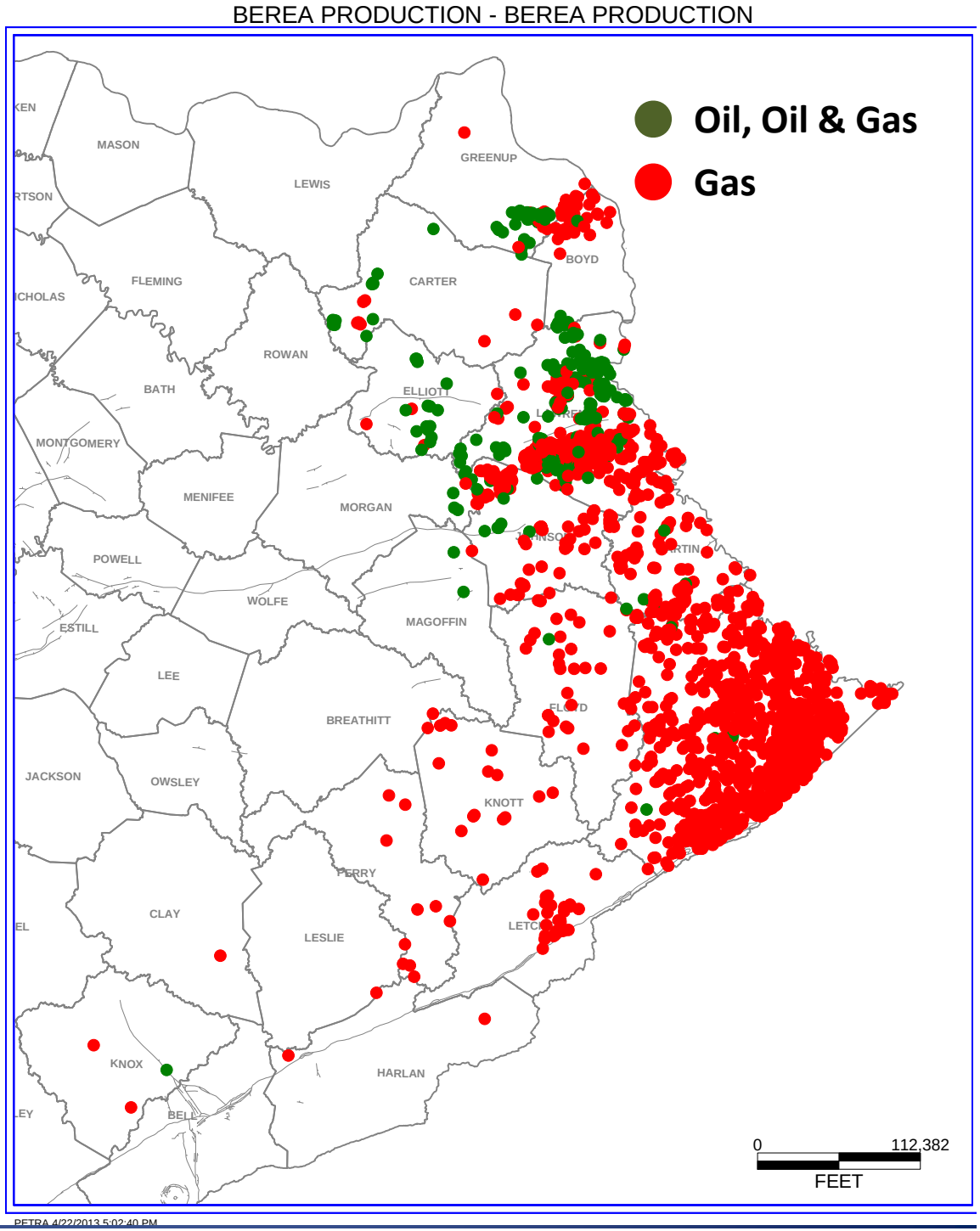
- Reservoir continuity complex on local scale: lenticular sheet silts and very fine sands deposited by storms and turbidity currents

- Thick Berea trend thins and pinches out to west in central Kentucky, and onto shallower eastern platform in W. Va.

# Berea Hydrocarbon Distribution

Oil production limited to shallower, northeastern part of basin

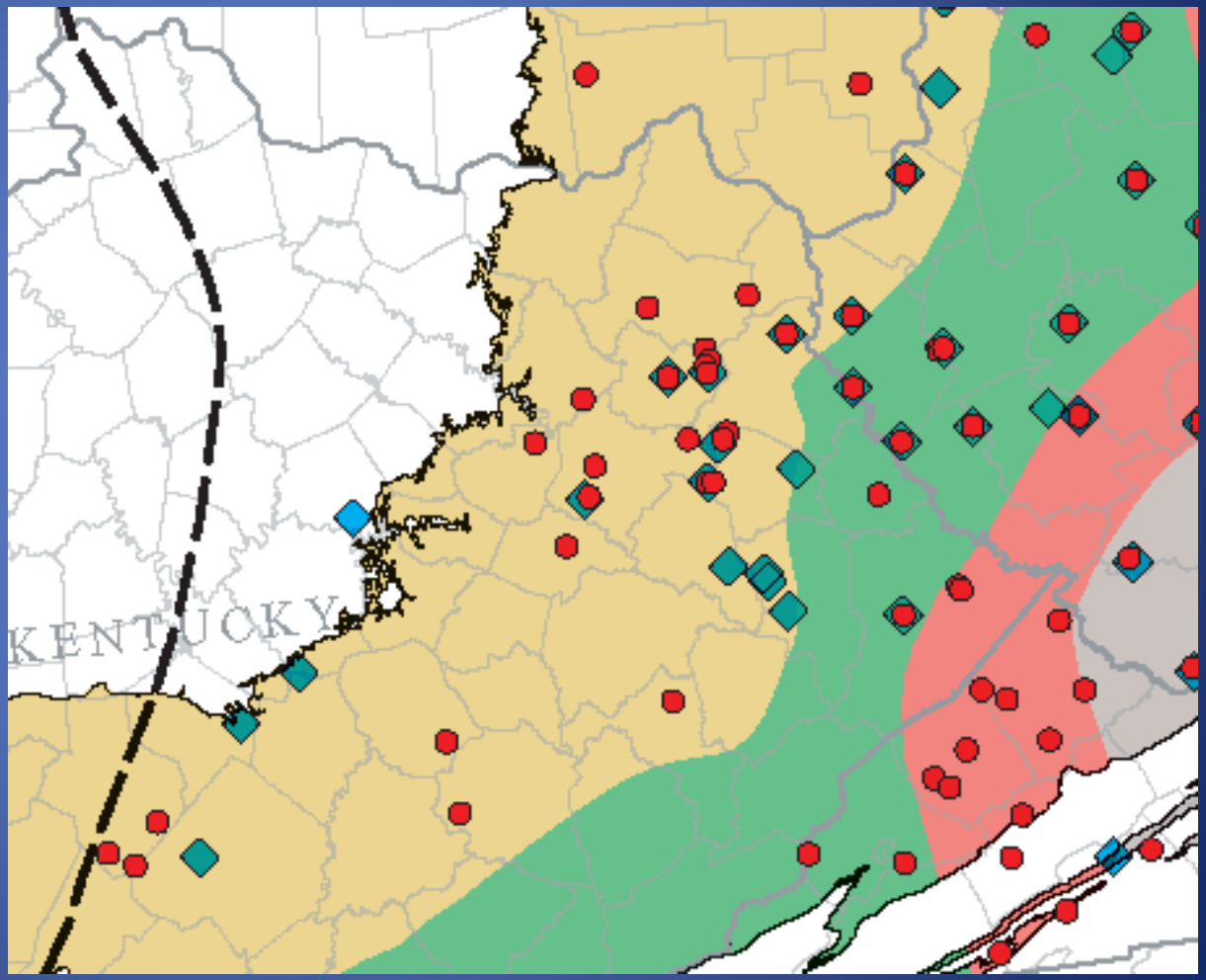
1,898 Berea completions from KGS database



## Berea hydrocarbon distribution reflects Devonian shale thermal maturity

- Devonian shale shown as immature in much of eastern Kentucky
- Does Berea production reflect lateral migration or is vitrinite reflectance ($R_o$) suppressed in the Ohio Shale?

2012 USGS Thermal Maturity Map
(East and others, SIM 3214, 2012)



# Thermal maturity (cont.)

Other workers place the oil window farther north, and note similarity of $R_o$ in Penn. coals to deeper Devonian shale (Rimmer and Cantrell, 1988). Devonian $R_o$ data may be suppressed.

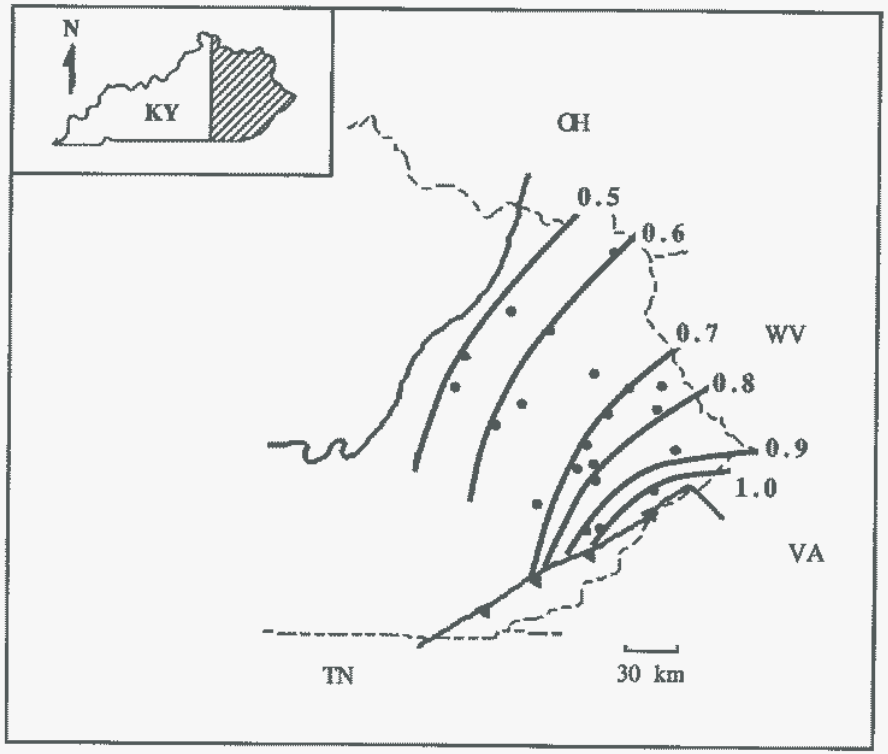



Figure 2. Mean random vitrinite reflectance (%$R_o$, in oil) for the Cleveland Shale.

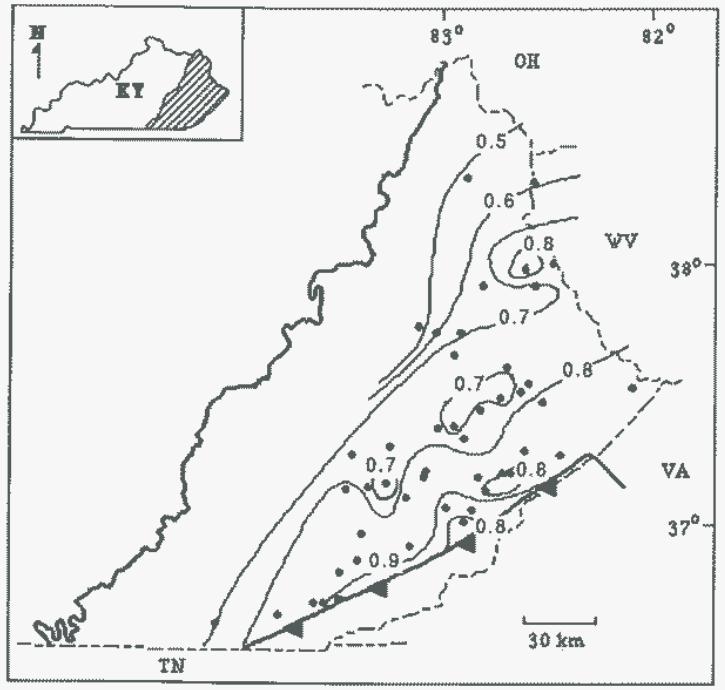
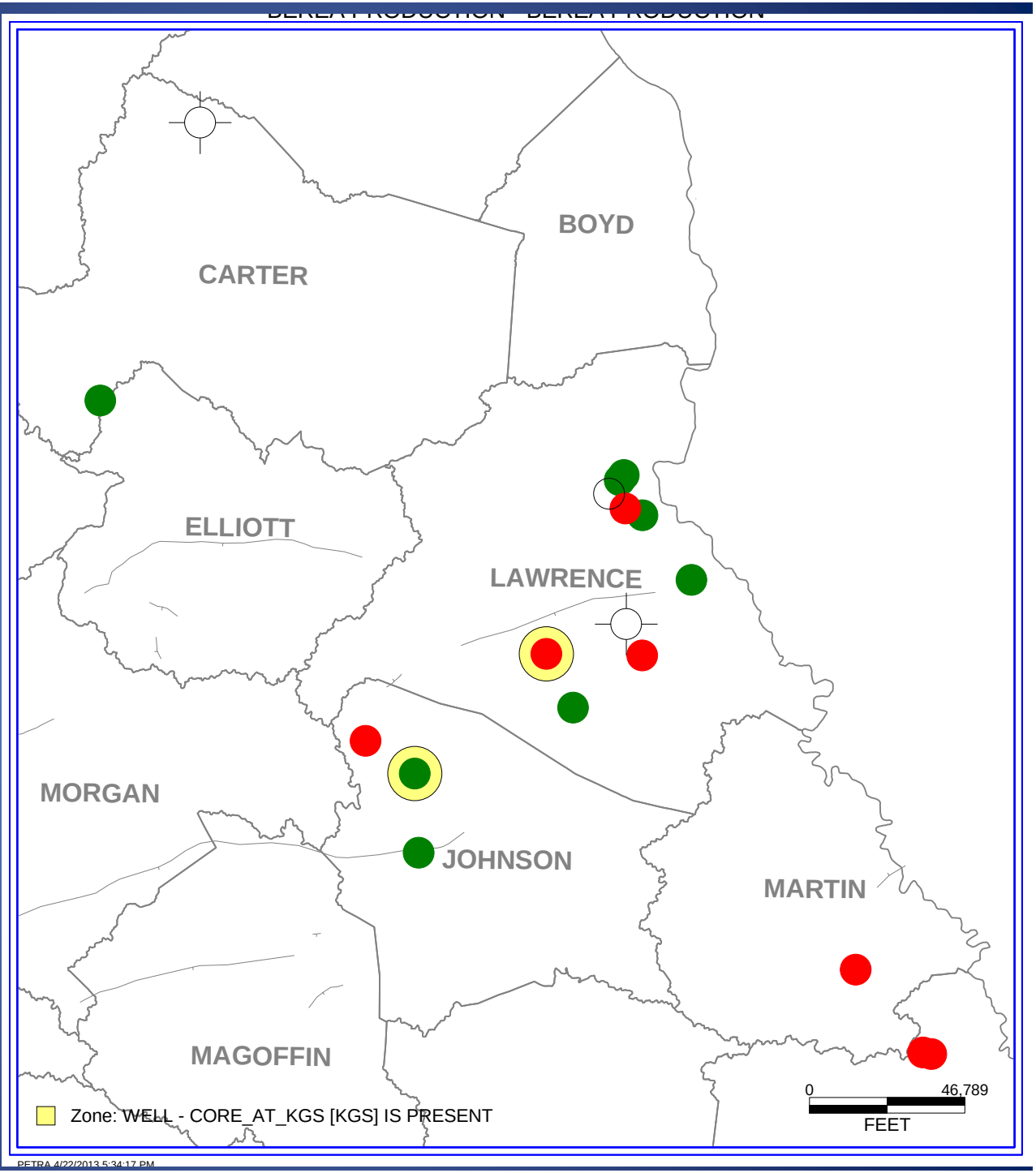


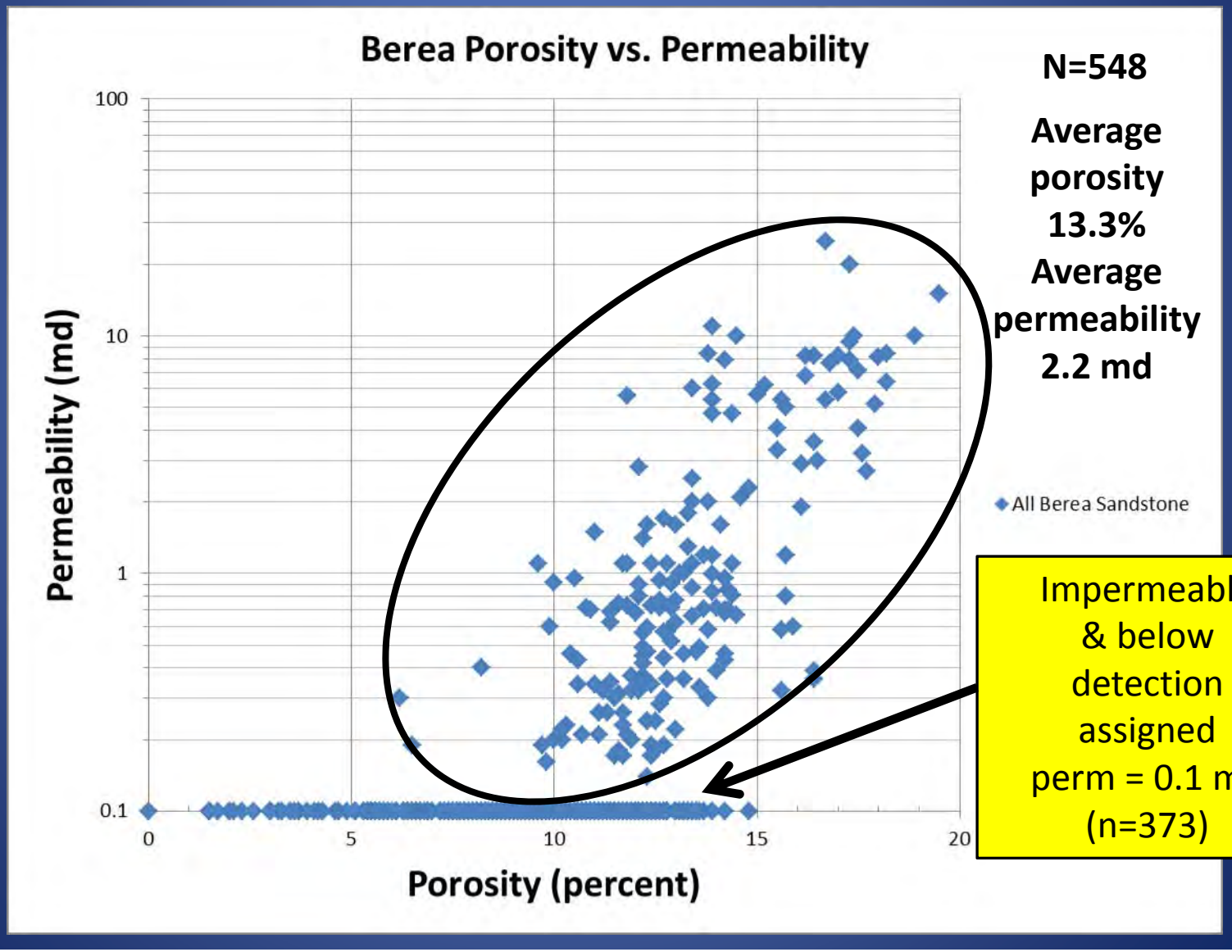

Figure 3. Mean maximum vitrinite reflectance (%$R_{max}$, in oil) for the Fire Clay coal bed (after Hower and Rimmer[2]).

# Berea Reservoir Quality

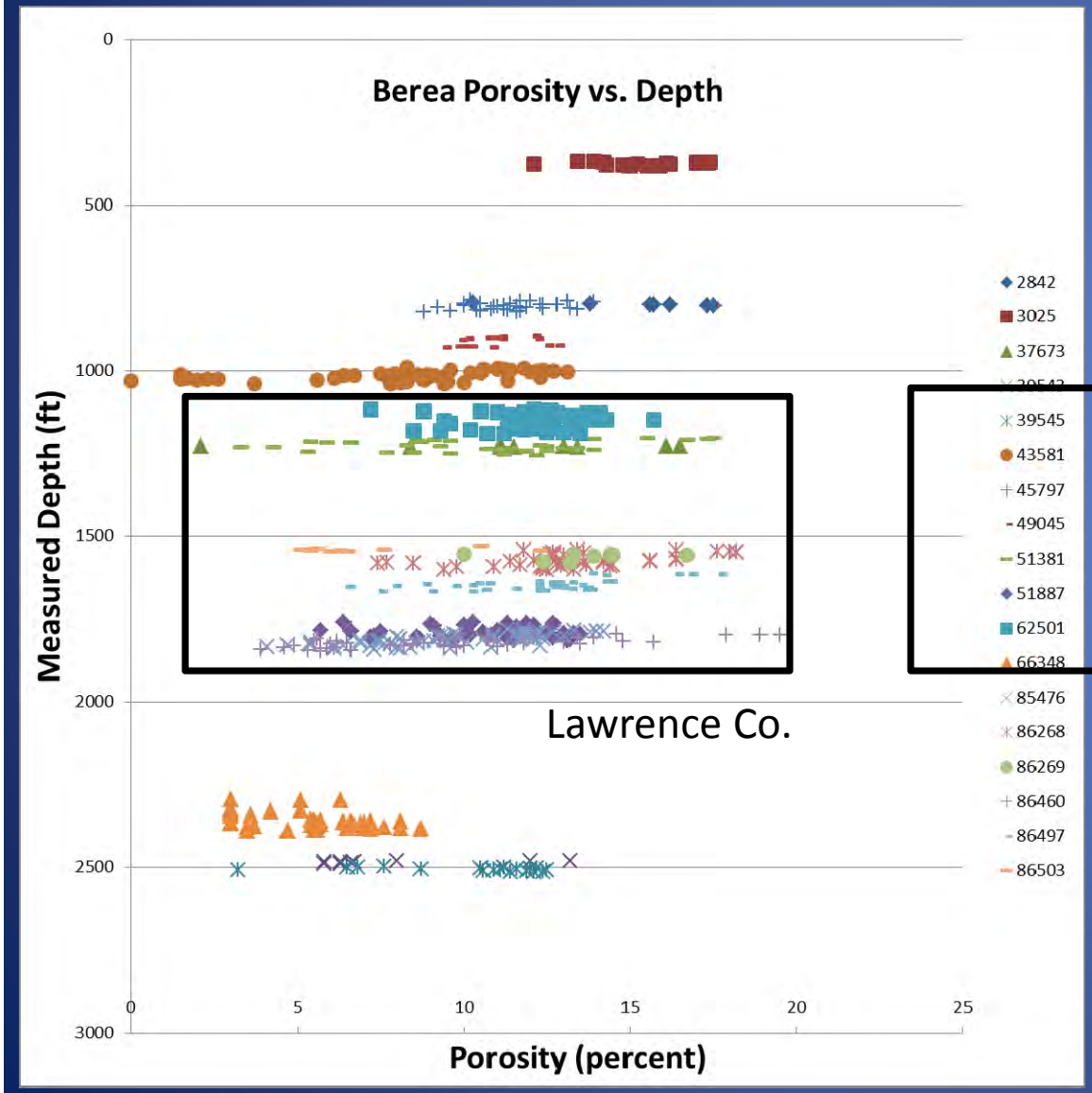
- FERC tight gas formation status established in early 1980's (Lawrence and Pike Counties)
- Core analyses for 18 Berea cores compiled and available at KGS



# Berea Core Data, E. Kentucky



# Reservoir Quality vs. Depth



# Reservoir Quality Summary

- For permeable samples, average core porosity is 13.3% and permeability is 2.2 md.
- Berea in E. Ky. dominated by very low permeability siltstones
- Reservoir quality is variable within the Berea, no significant depth control on porosity observed, perm does appears to decrease with depth
- Other controls need further work

UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

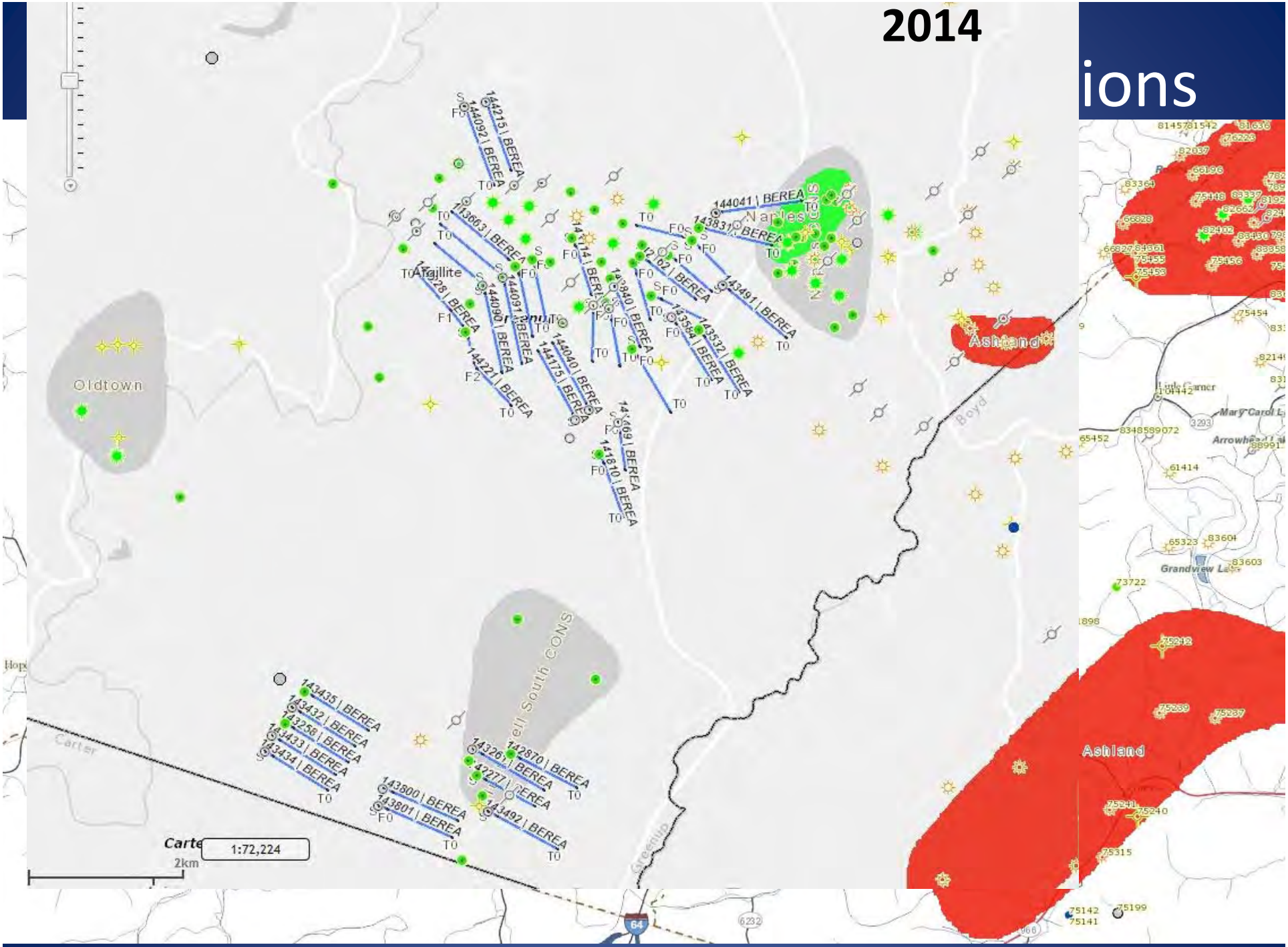
# Berea Horizontal Activity

- Greenup County
  - Operator is Nytis Exploration, first well completed in March 2011
  - 43 horizontal wells permitted; completion data submitted for 28 wells
  - Infill/stepout drilling in older shallow (1,100 ft) Berea oil fields (Hunnewell, Naples)
  - Structure is regional dip to SE; stratigraphic traps
  - Average lateral is 2,500 ft., oriented SE-NW (downdip)
  - Multistage hydraulic fracture stimulation
    - 5-12 stages in open hole, ave. of 4,700 bbl total fluid, with 230,000 lbs. sand
  - Significant water production reported

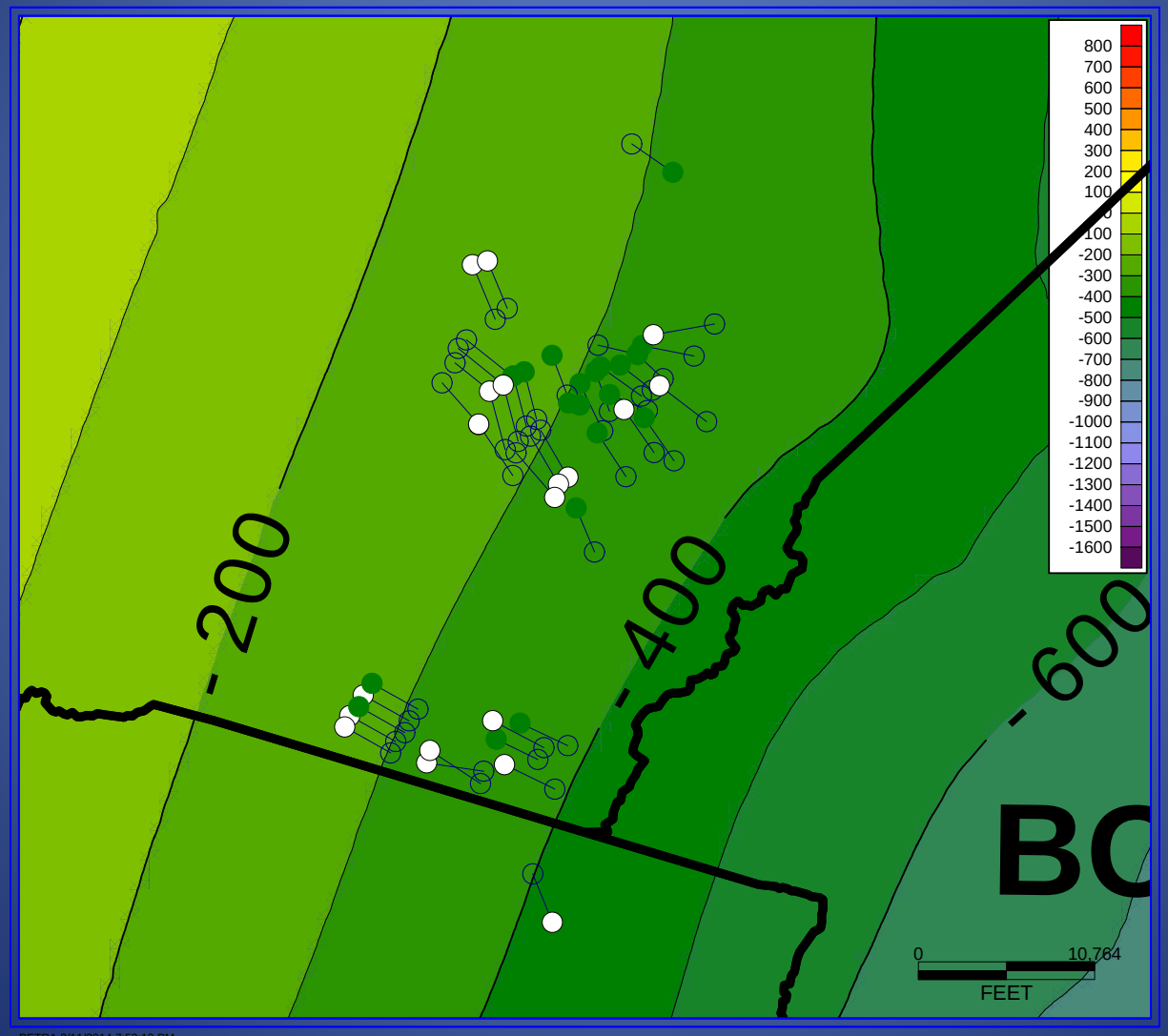
UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

# 2014

# ions

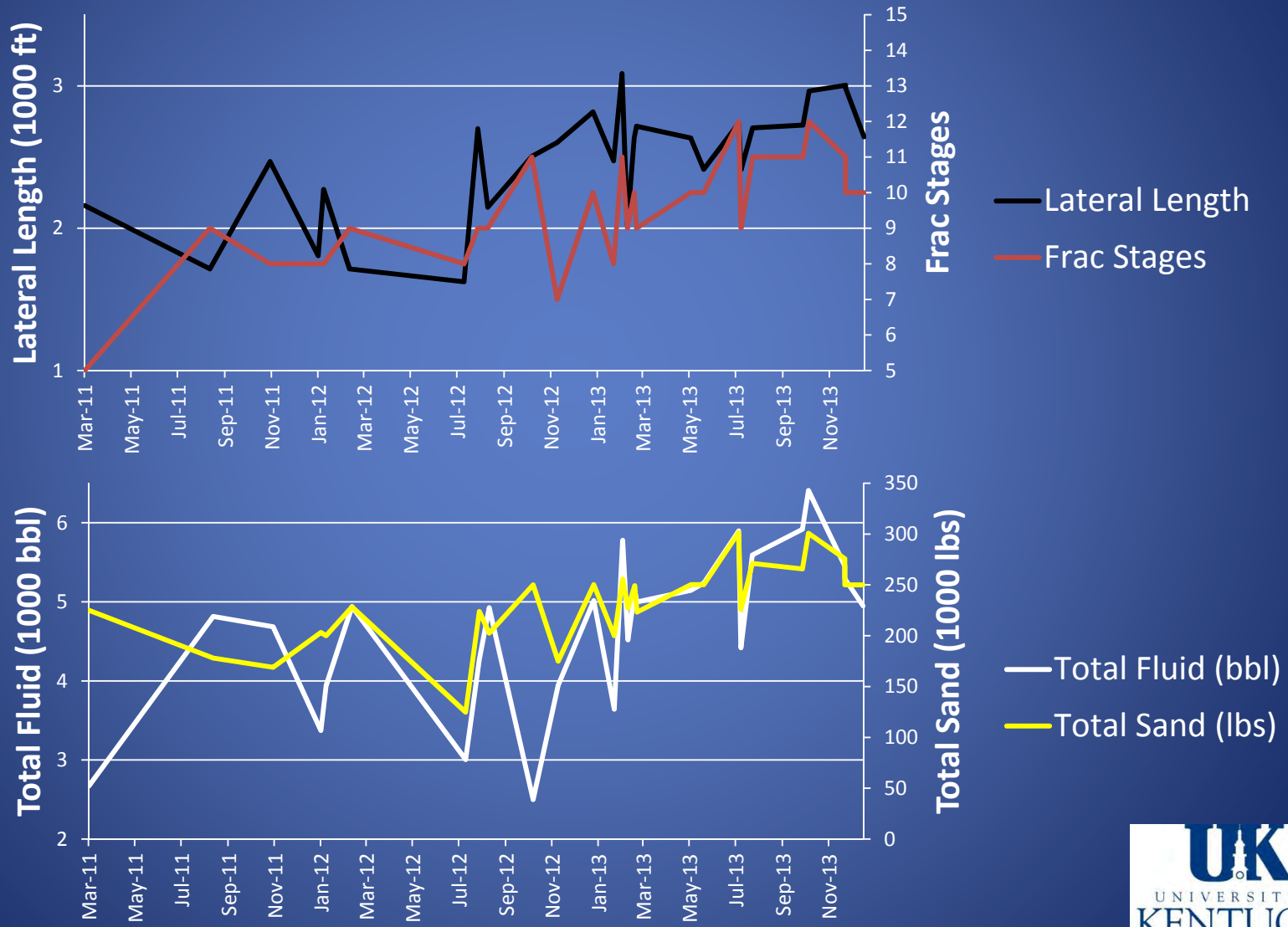

Oldtown
Argillite
Naples
Ashland
Ashland
Carter
Boyd
Grandview
Little Garner
Mary Carol
Arrowhead
1:72,224
2km
64
144041 | BEREA
143831 | BEREA
144215 | BEREA
144092 | BEREA
113863 | BEREA
144091 | BEREA
144090 | BEREA
144221 | BEREA
144040 | BEREA
144175 | BEREA
143840 | BEREA
143491 | BEREA
143564 | BEREA
143532 | BEREA
144469 | BEREA
141810 | BEREA
143435 | BEREA
143432 | BEREA
143258 | BEREA
143433 | BEREA
143434 | BEREA
143800 | BEREA
143801 | BEREA
143261 | BEREA
142870 | BEREA
143492 | BEREA

# Greenup County Top Berea Structure with Nytis Horizontals (as permitted)




UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

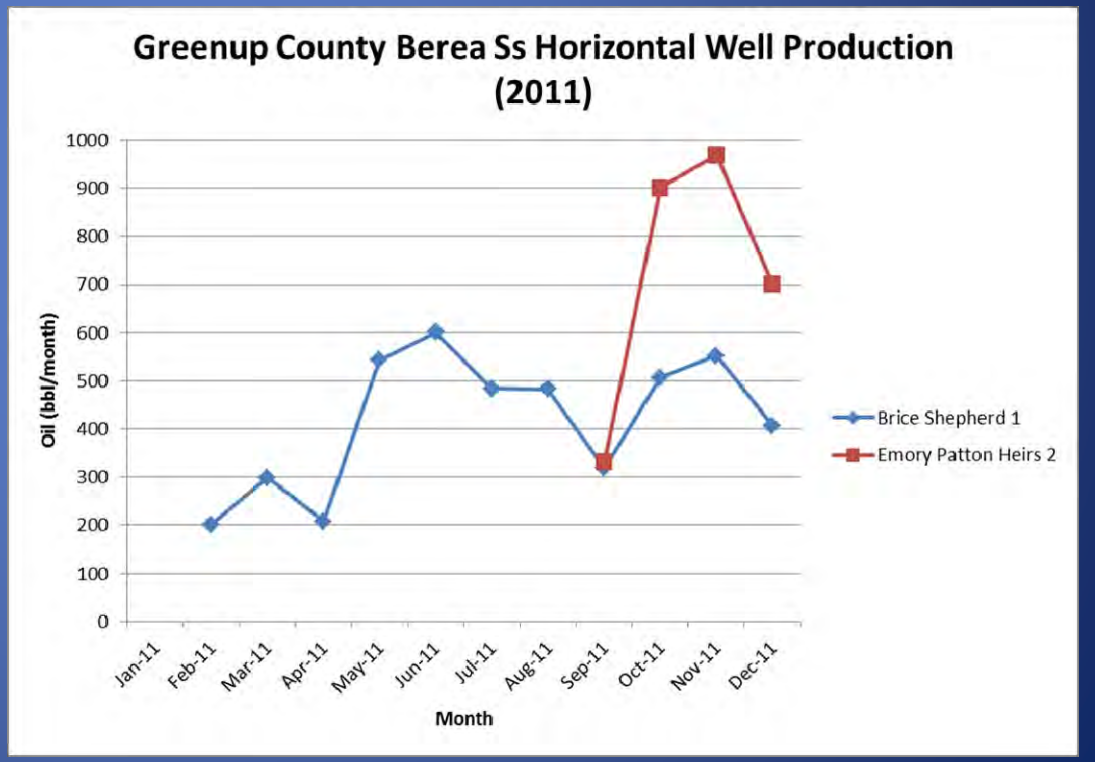
# Greenup County Berea Horizontals




UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

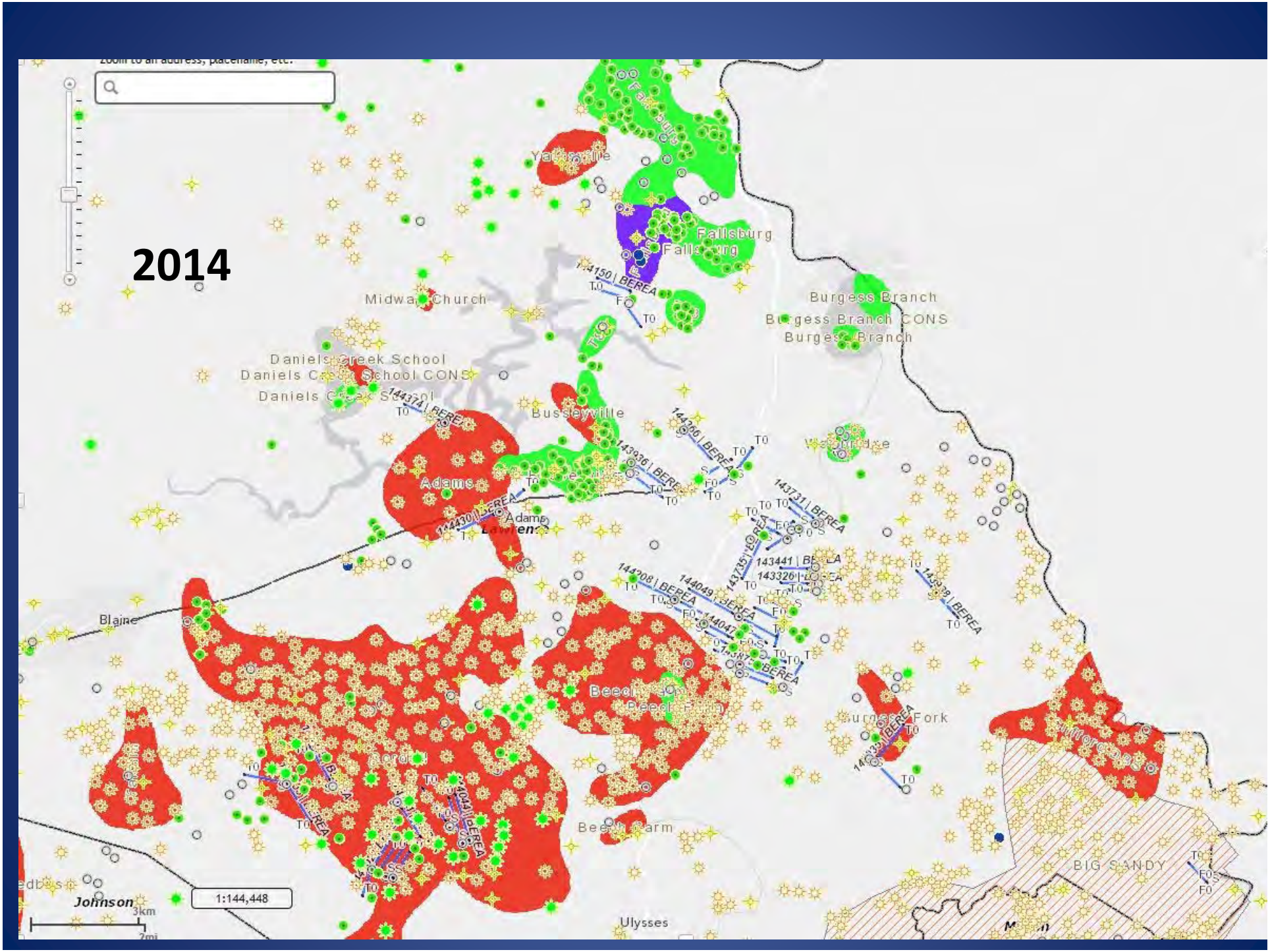
# Greenup County Horizontal Completions (17 wells with IP as of March 2014)

- Reported oil IP's: 12–70 BOPD; 7–37 MCFGD
- Water IP: 15–114 bbl/day
- WOR: 1.3–6, ave=3
- 2011 production data released for 2 wells: average 572 bbl/well/month



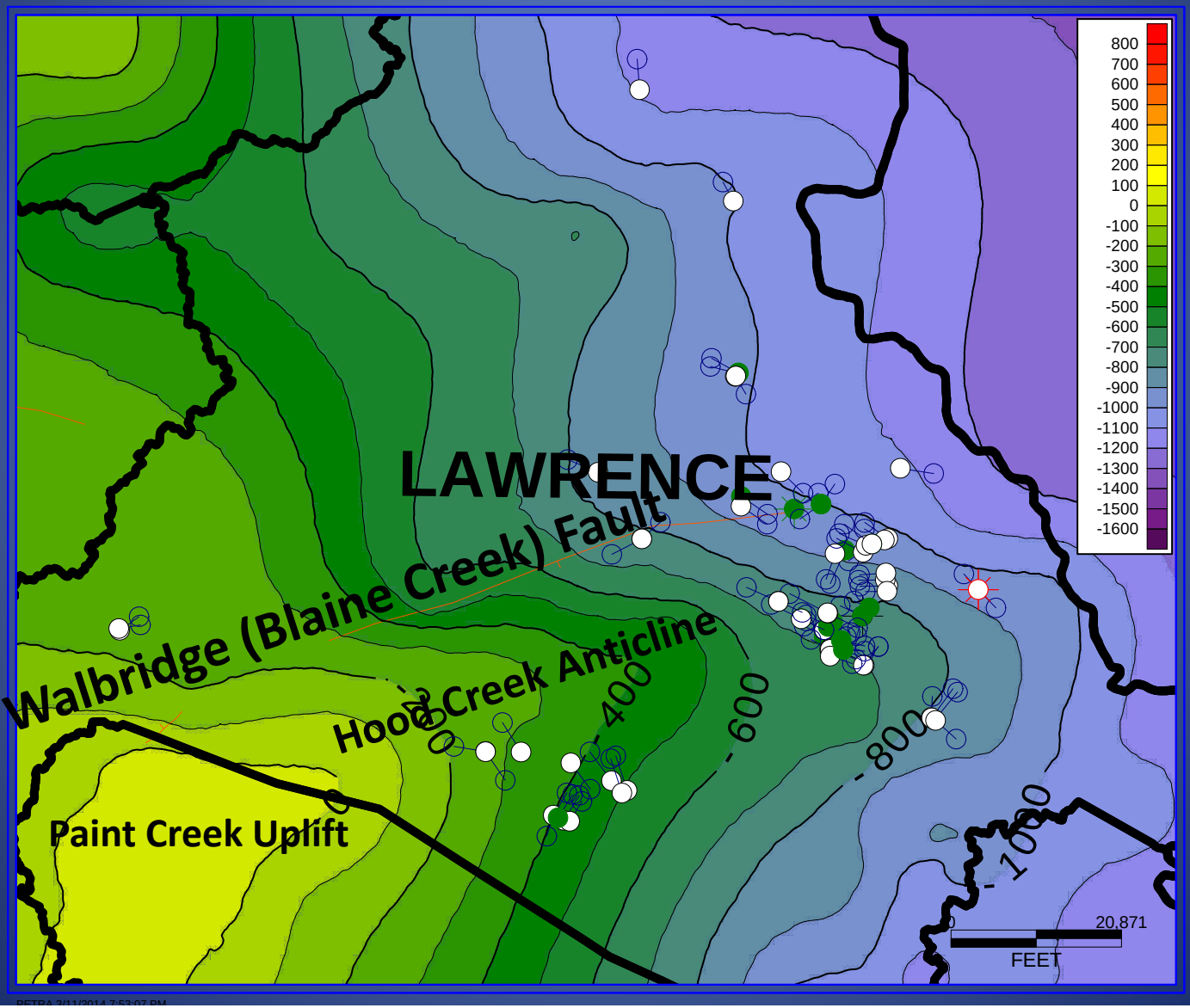
# Lawrence County Horizontal Activity

- 74 horizontal wells permitted, first completion in October 2012
  - Operators: Eagle & others (27), Nytis (14), Hay Expl. (12), App (8)
- Completion reports available for 27 wells, no public production data yet
- Reported oil IP rates (25 wells) range from 8-44 bopd, ave=25 bopd. Gas average= 12mcfd
- Water rate reported for 1 well: WOR=.33
  - Much less water production than Greenup County

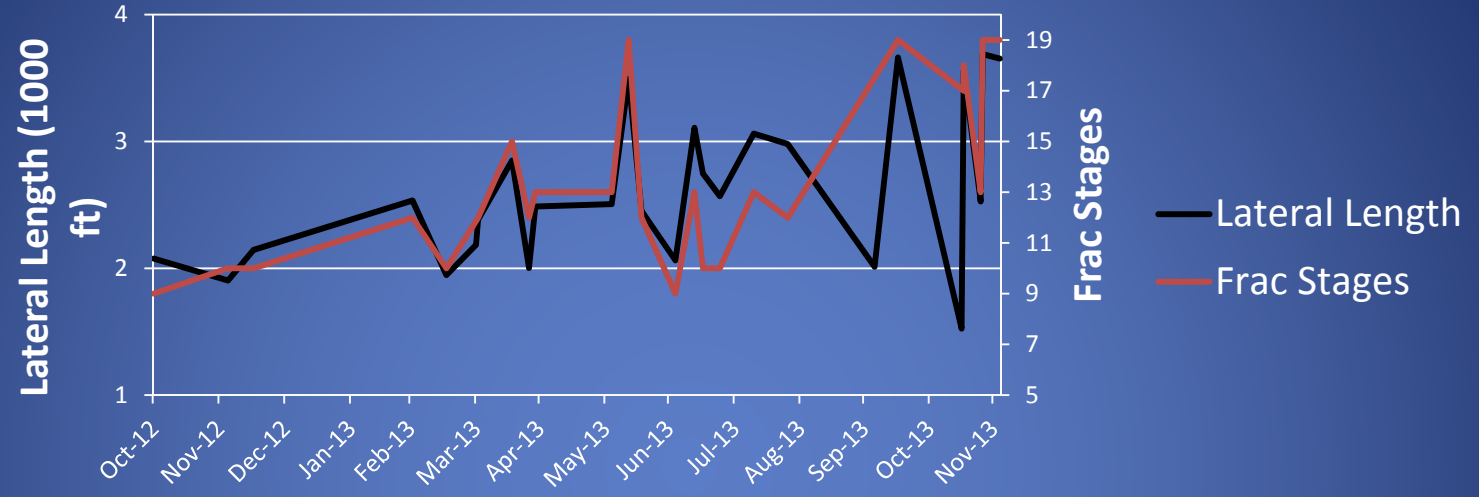

2014
Midway Church
Daniels Creek School
Daniels Creek School CONS
Bussleyville
Adams
Blaine
Johnson
Ulysses
Fallsburg
Burgess Branch
Burgess Branch CONS
1:144,448

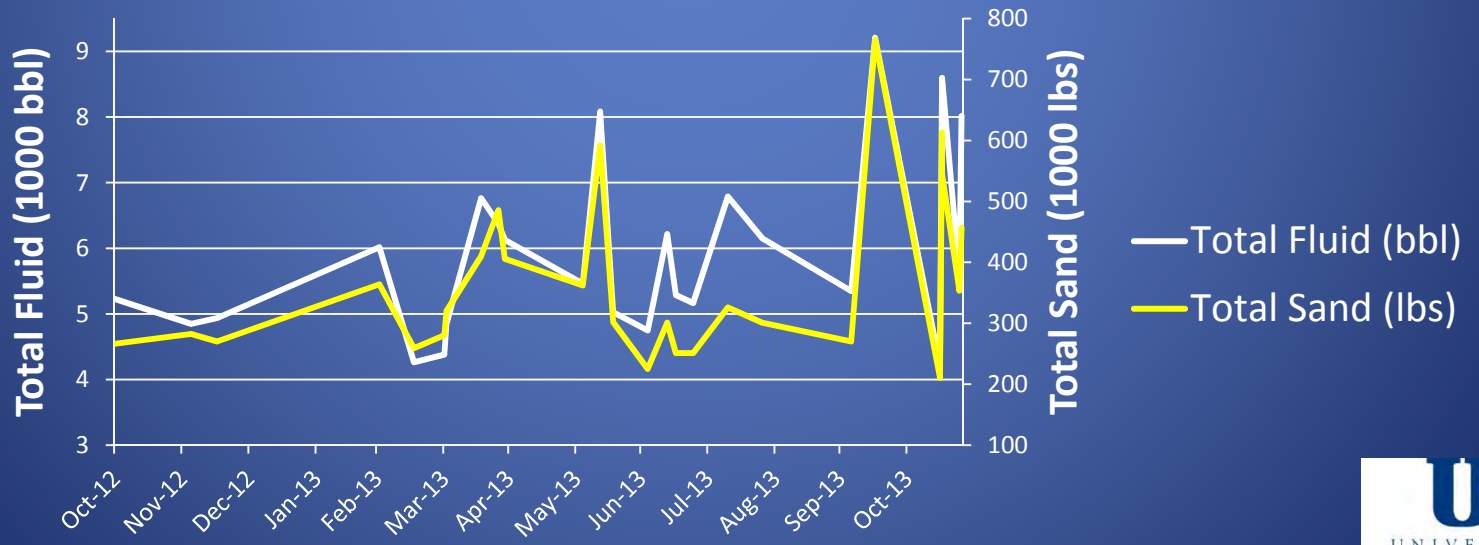
# Lawrence County Top Berea Structure

(Faults not contoured)



# Lawrence County Berea Horizontals



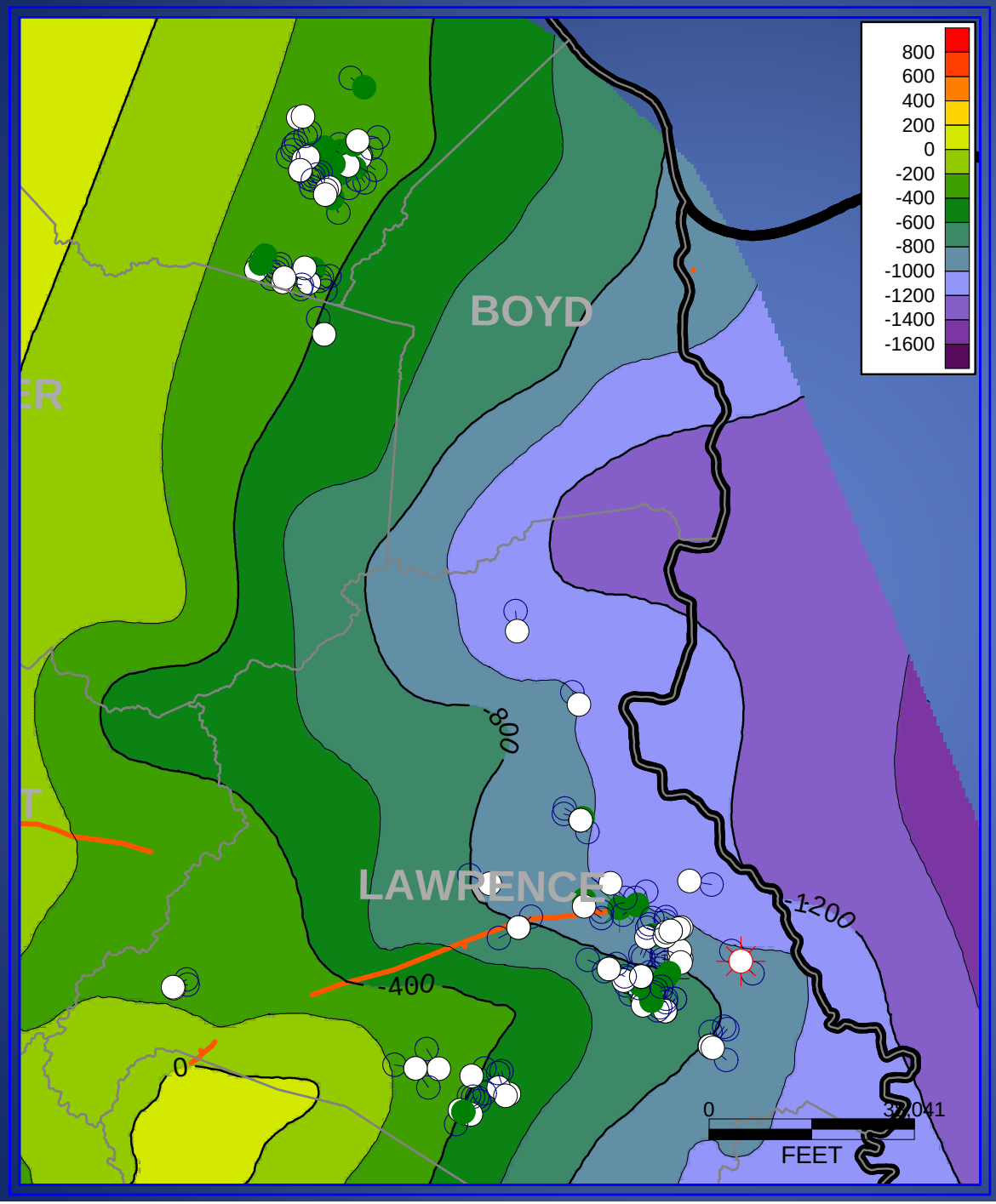




UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

# Summary and Recommendations

- Horizontal drilling is a technical success in Berea siltstone oil reservoirs
- Evaluating economic success will require longer term production data, but look promising
- Berea oil play defined by:
  - Regional hydrocarbon phase and thermal maturity
  - Lateral extent of thick siltstone reservoir
  - Stratigraphic trapping, but local structural control may influence oil/gas/water saturations (needs additional work)
  - Porosity and permeability suitable at depths < 2,000’

UNIVERSITY OF KENTUCKY
Kentucky Geological Survey




# Regional Structure Top Berea

# Berea horizontal permits shown

200 ft contour interval

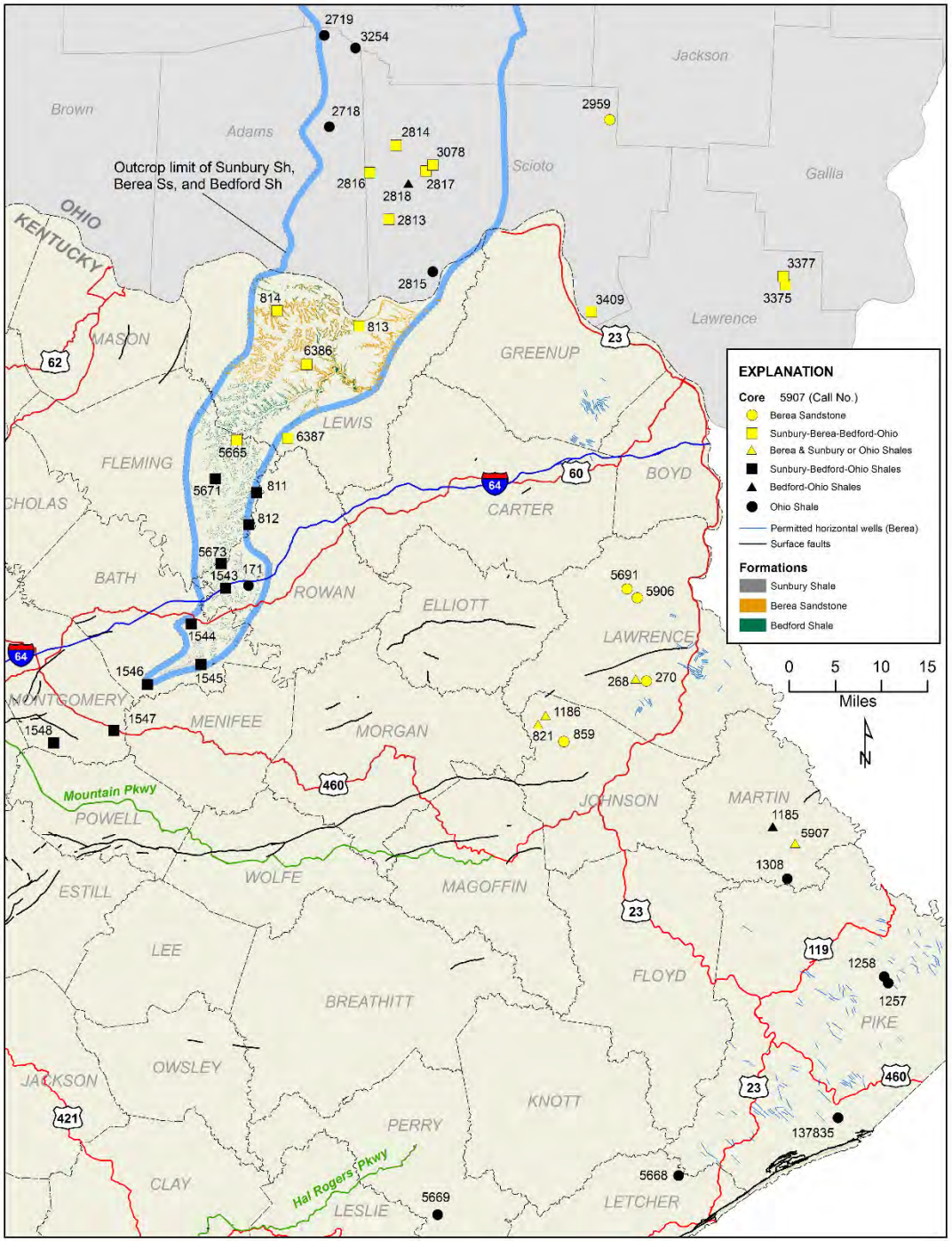
UNIVERSITY OF KENTUCKY
Kentucky Geological Survey

# Summary and Recommendations (cont.)

- Greenup County reservoirs have higher water saturations than Lawrence County-
  - One possible explanation: Lawrence County closer to mature source rock and received direct HC charge; Greenup Co. oil may have migrated laterally
- Porosity zones are 10 to 30 ft thick
  - Need good geologic model (stratigraphic and structural) to keep laterals in pay zone

# Berea Sandstone Consortium

- New Berea research project starting at KGS
- Goals:
  - Improved thermal maturity estimates and maps: why does the Berea produce where it does?
  - Geochemically tie Berea hydrocarbons to their source and help to define the limits of the source generation kitchen: local vs. long-distance migration
  - Interpret the detailed stratigraphy and structure of the Berea using numerous cores, logs and outcrops to characterize the Berea reservoir
- Industry funded, 18-month study
  - Collaborating with USGS and Ohio Geological Survey




# Core Location Map

Yellow symbols = Berea cores
Black symbols = shale cores