Geology of the Berea Horizontal Oil Play, Eastern Kentucky

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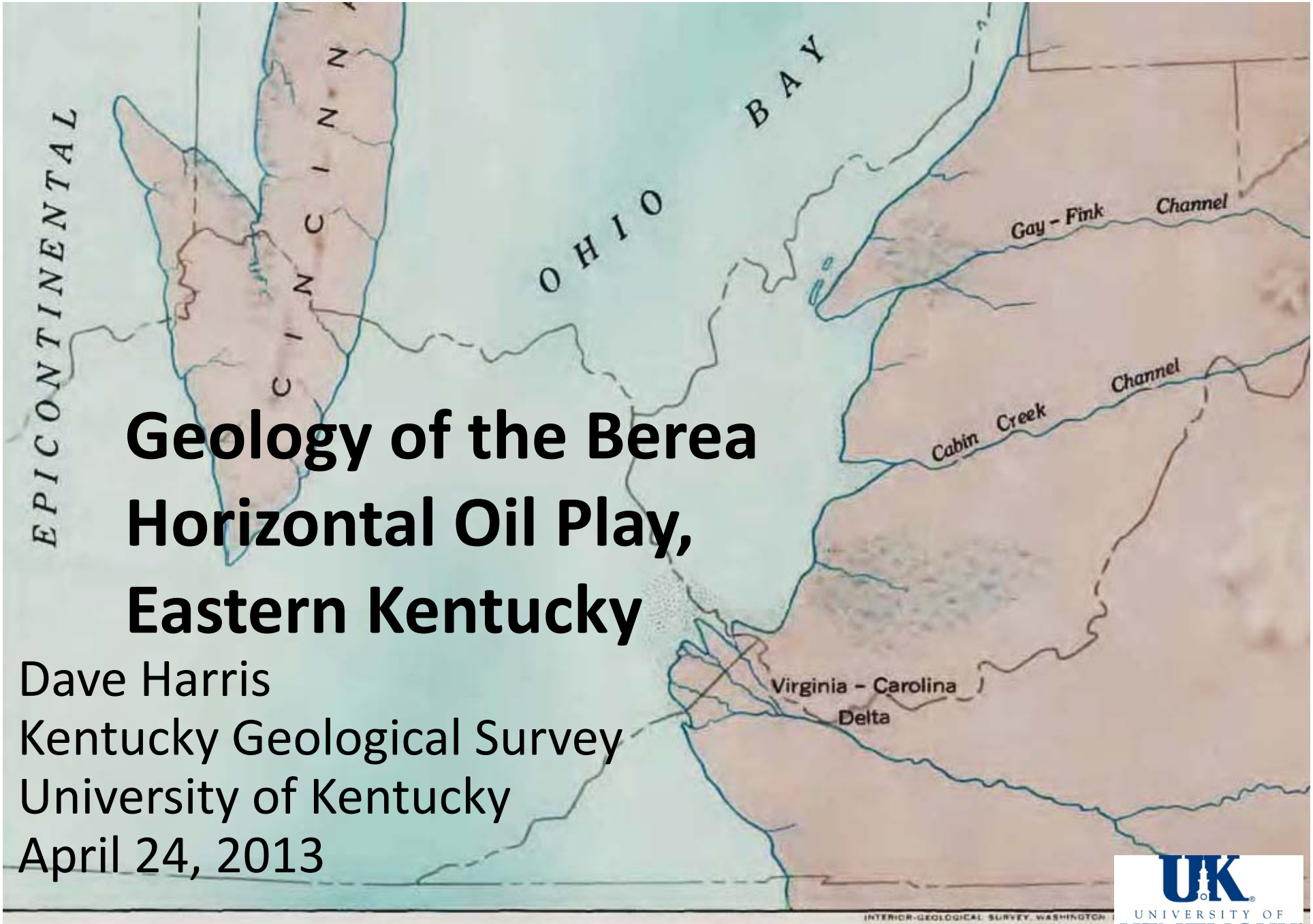
April 24, 2013



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

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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

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Acknowledgements

- Discussions with Steve Ferris (Nytis), Monte Hay (Hay Exploration), Cimarex staff

- Tom Sparks (KGS) for top Berea structure map

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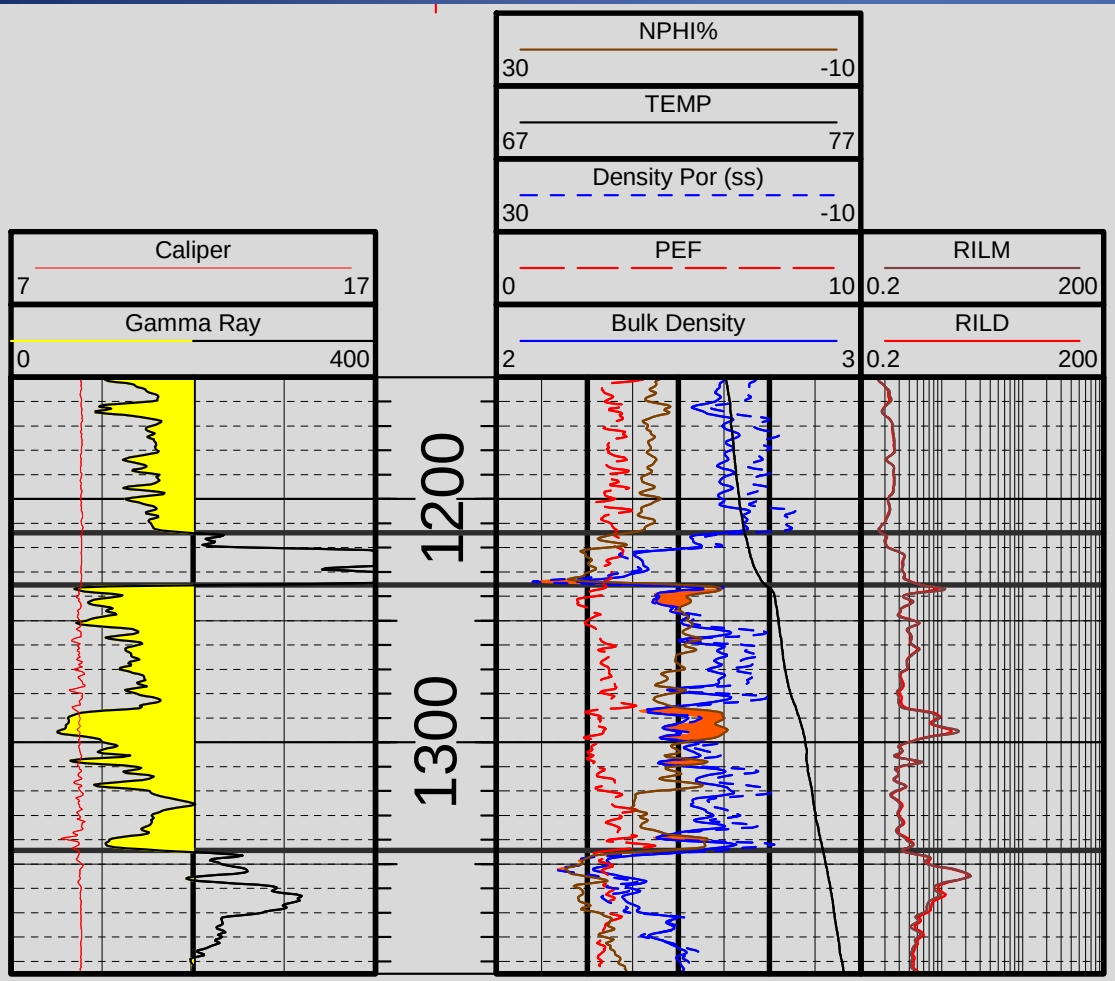
Why Horizontal Drilling?

- 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 29 horizontal Berea gas wells in Pike County

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

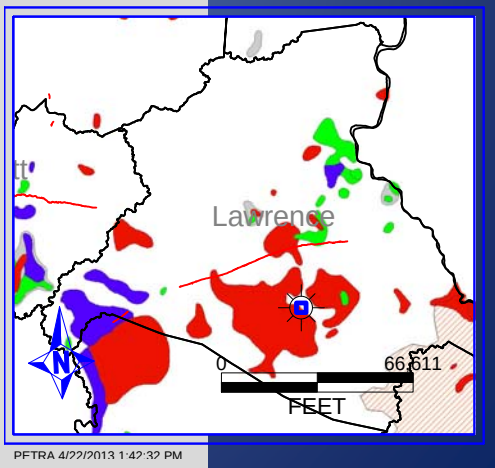
Berea “Sandstone” Type Log, Lawrence County



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)

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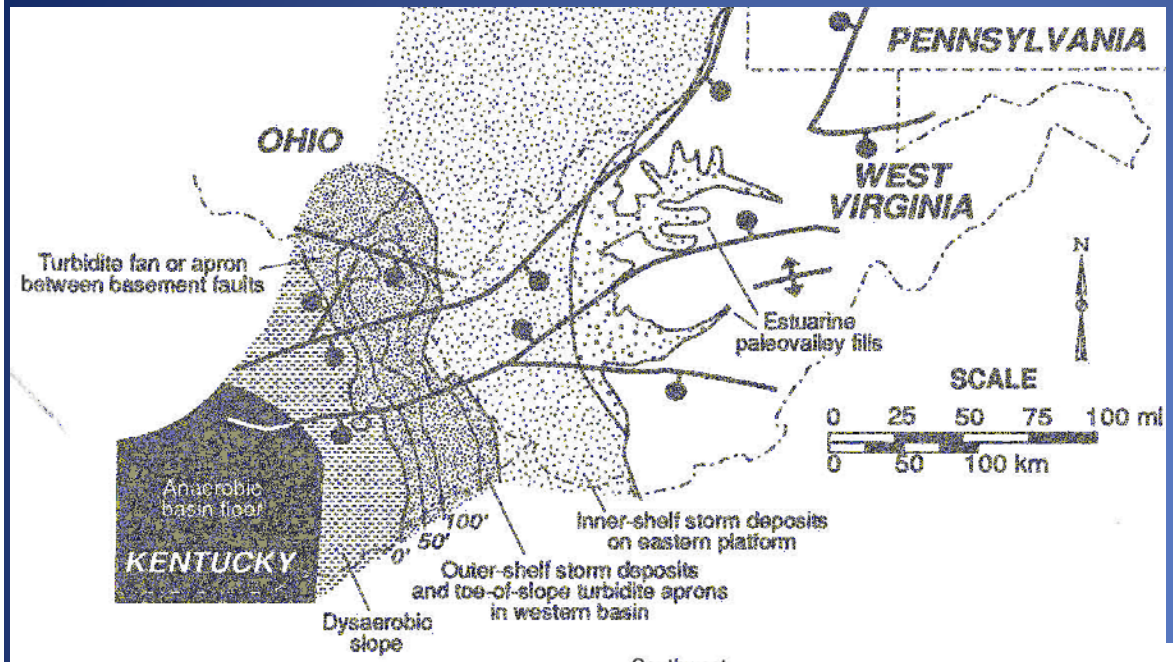
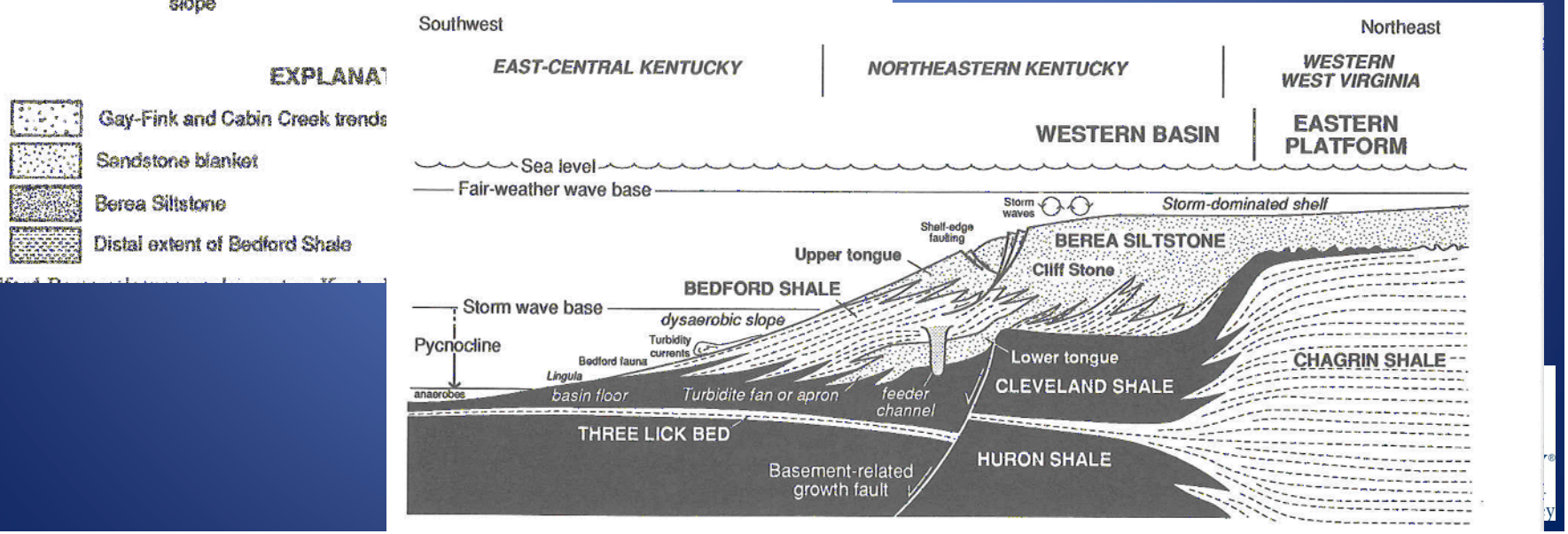
Berea Paleogeography



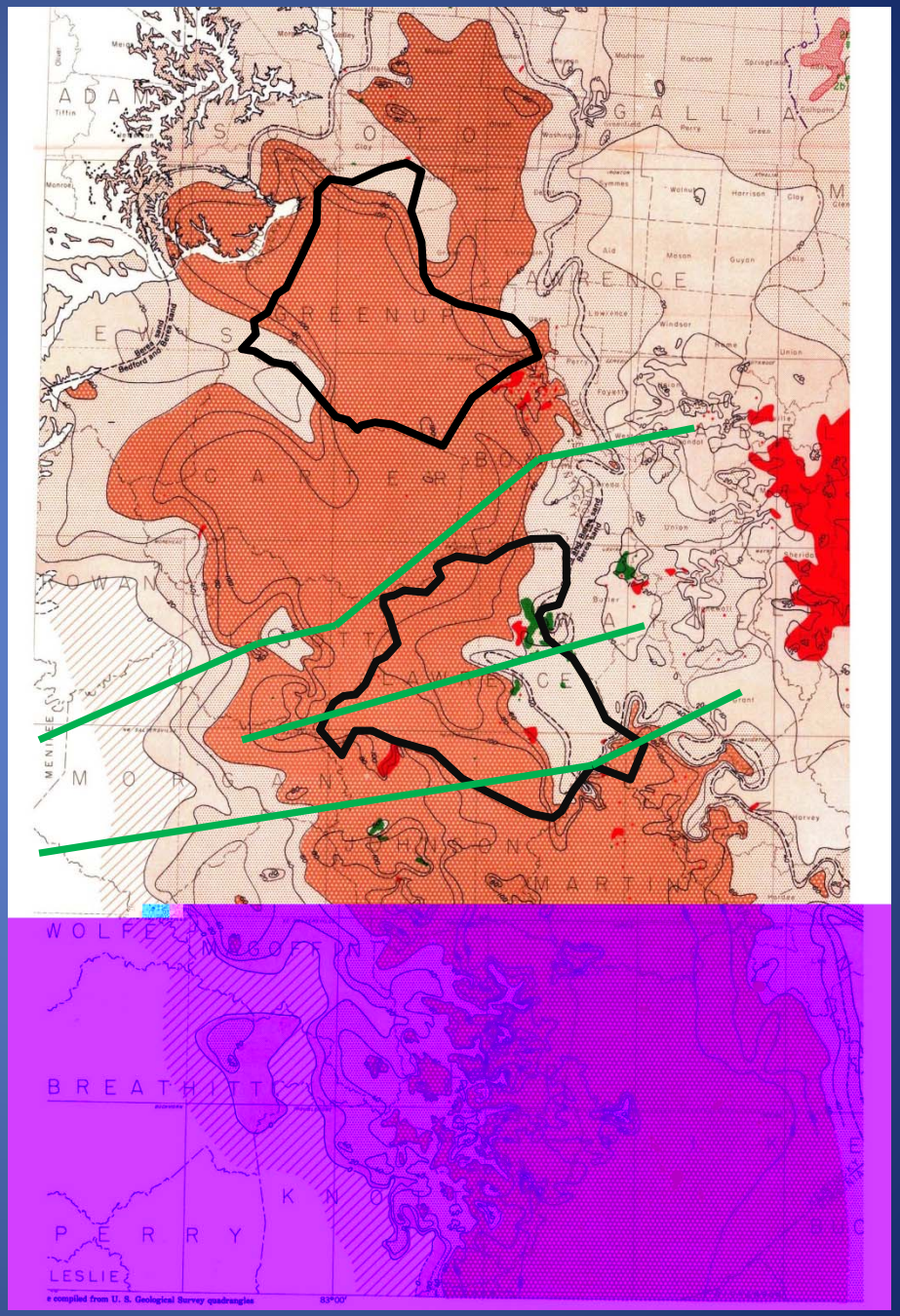
(Pashin & Ettensohn, 1995)



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

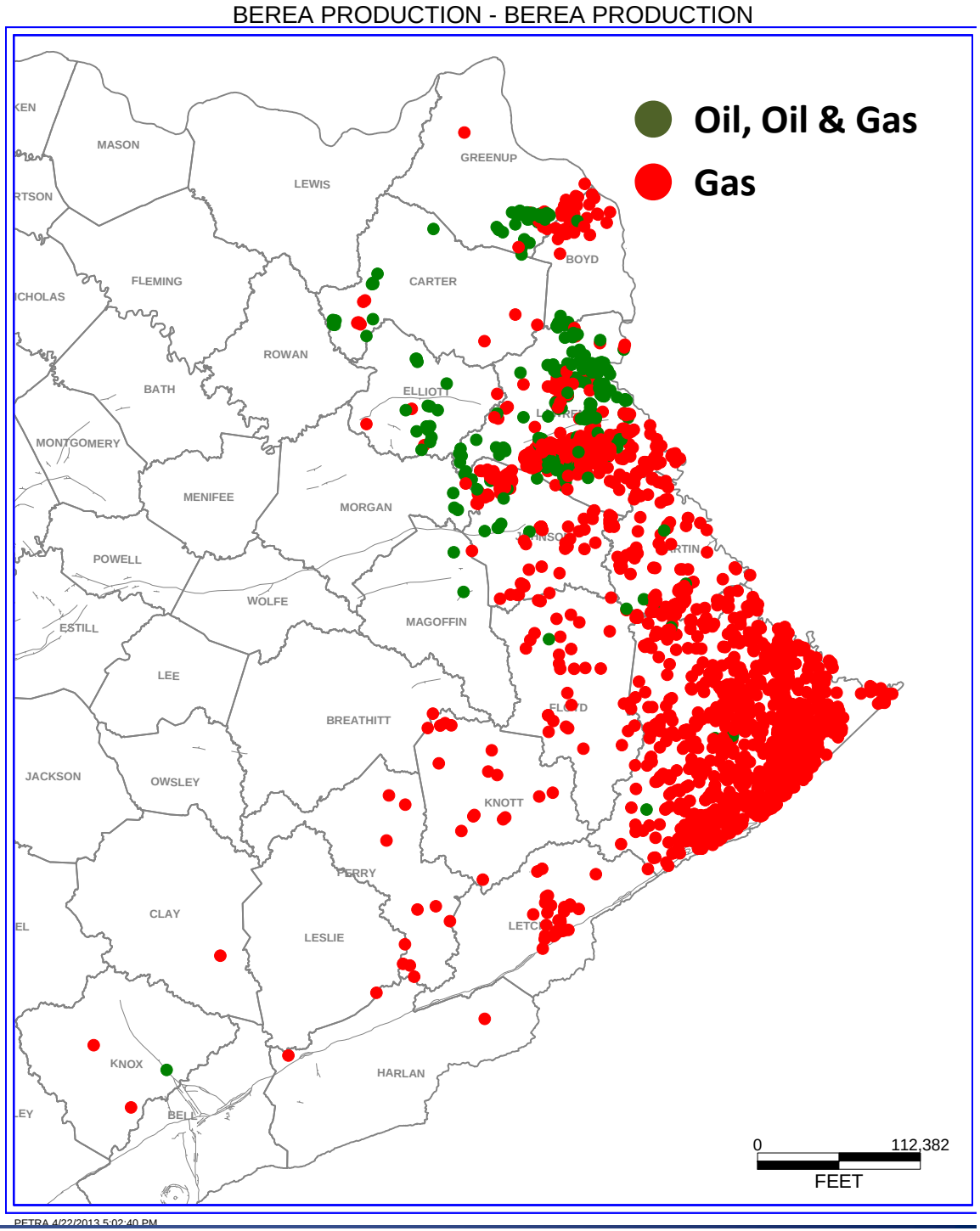
- Reservoir continuity complex on local scale: lenticular sheet silts and very fine sands deposited by storms and turbidity currents

- 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

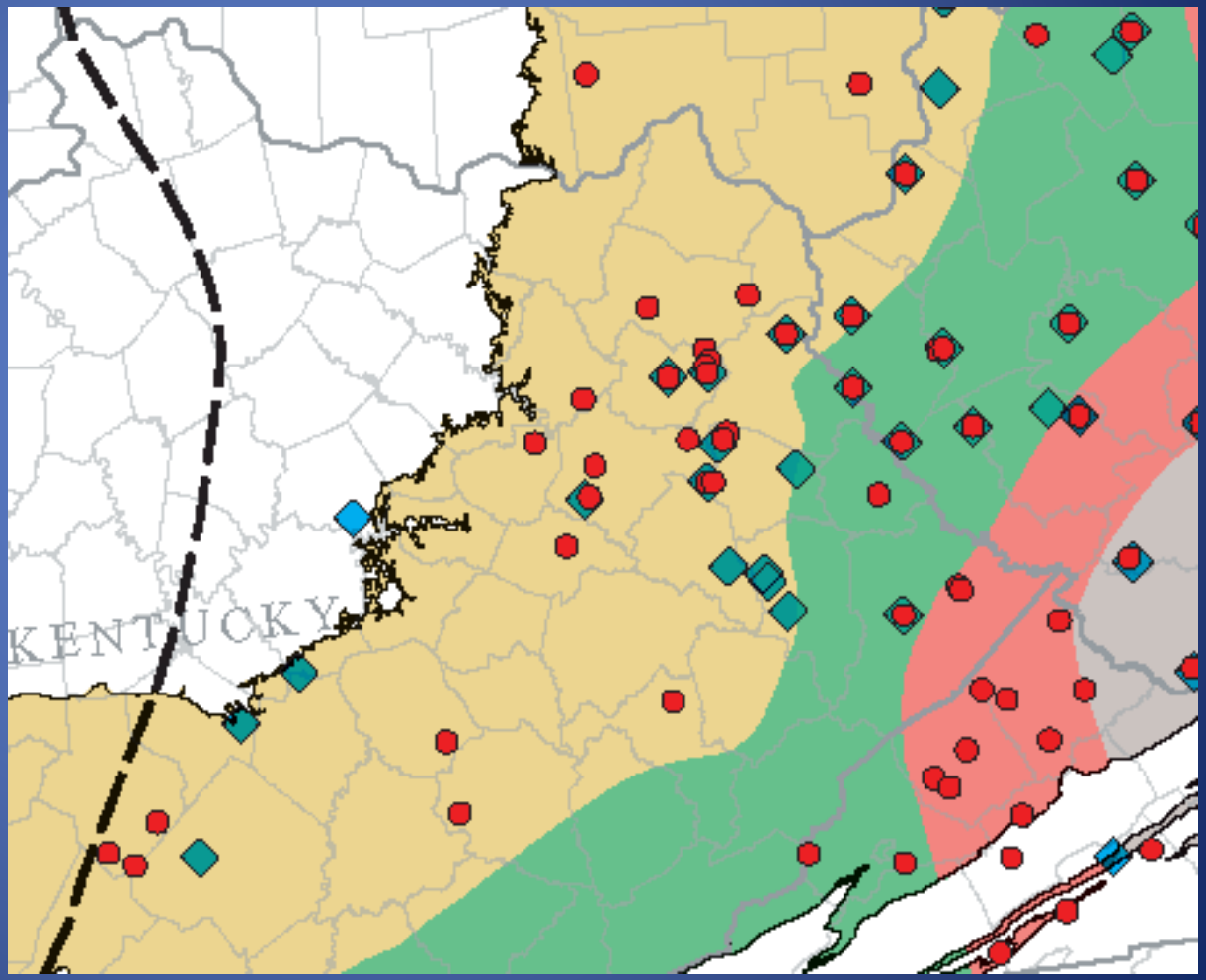
1,898 Berea completions from KGS database



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.

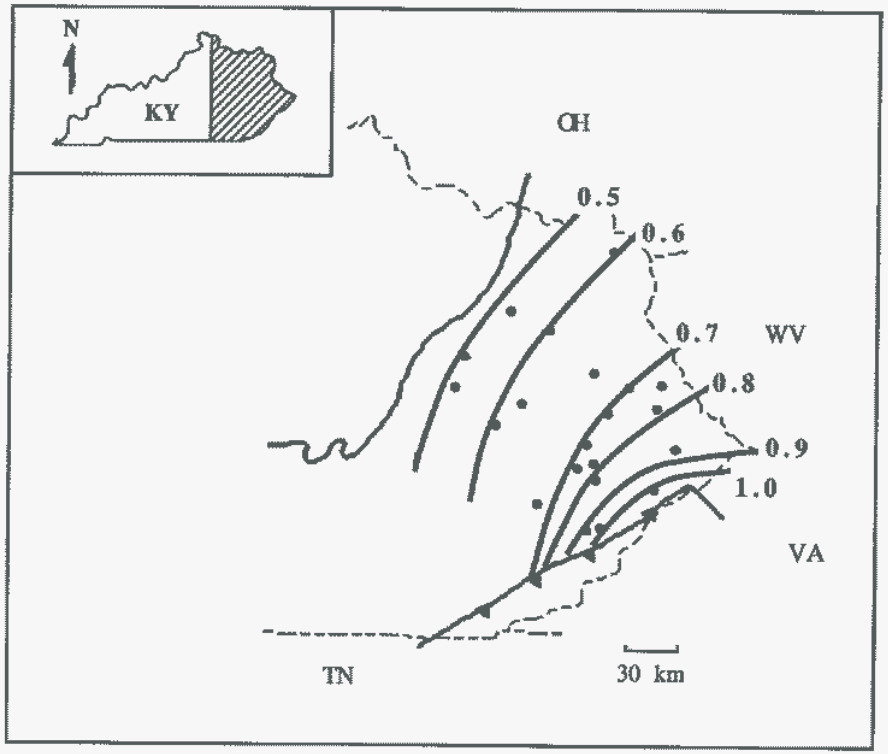


Figure 2. Mean random vitrinite reflectance (%R_o, in oil) for the Cleveland Shale.

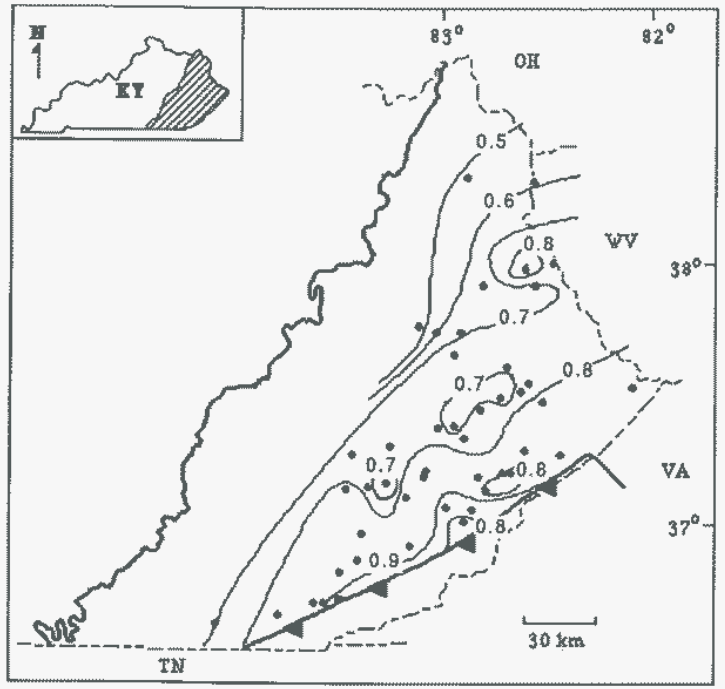
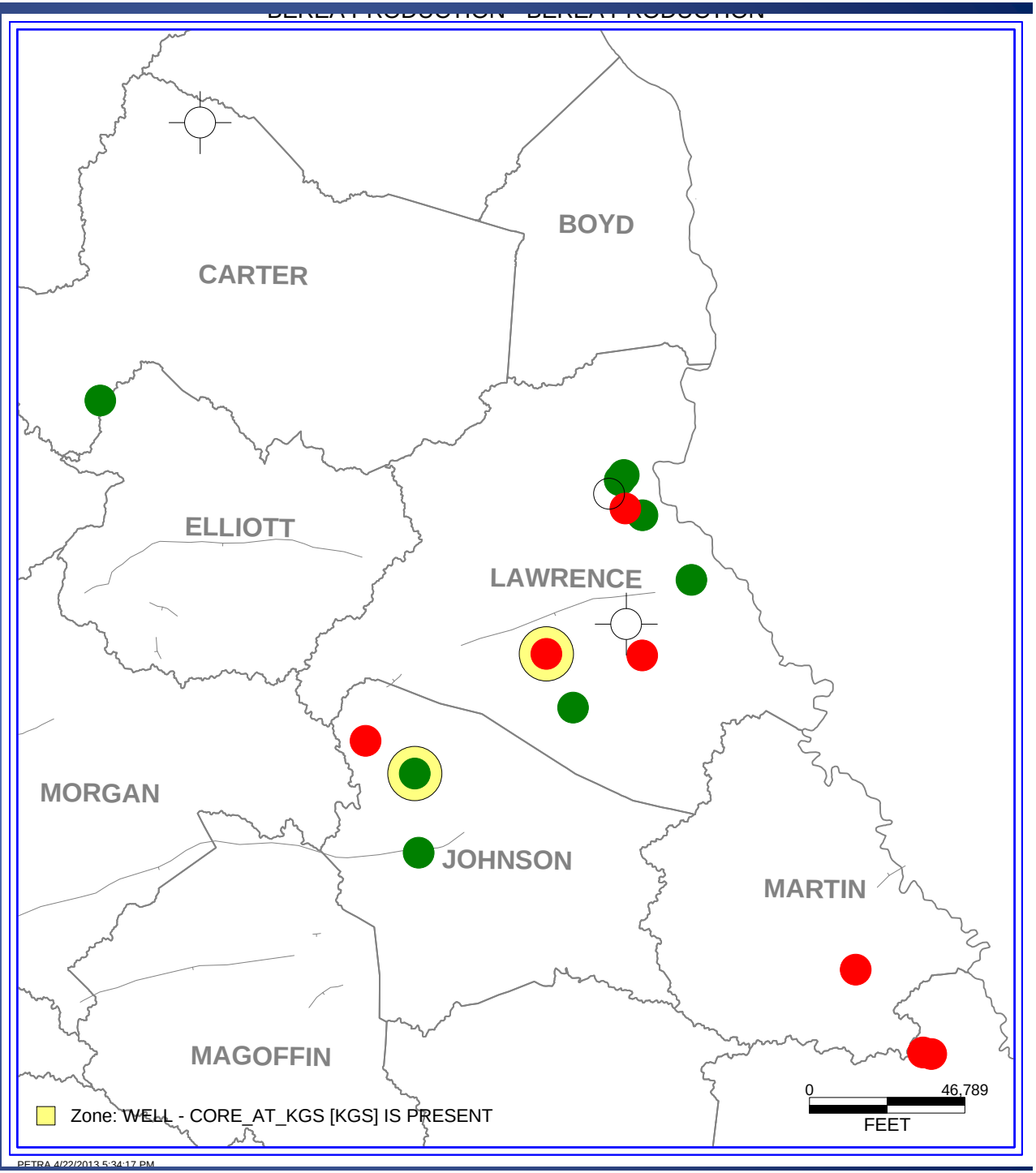


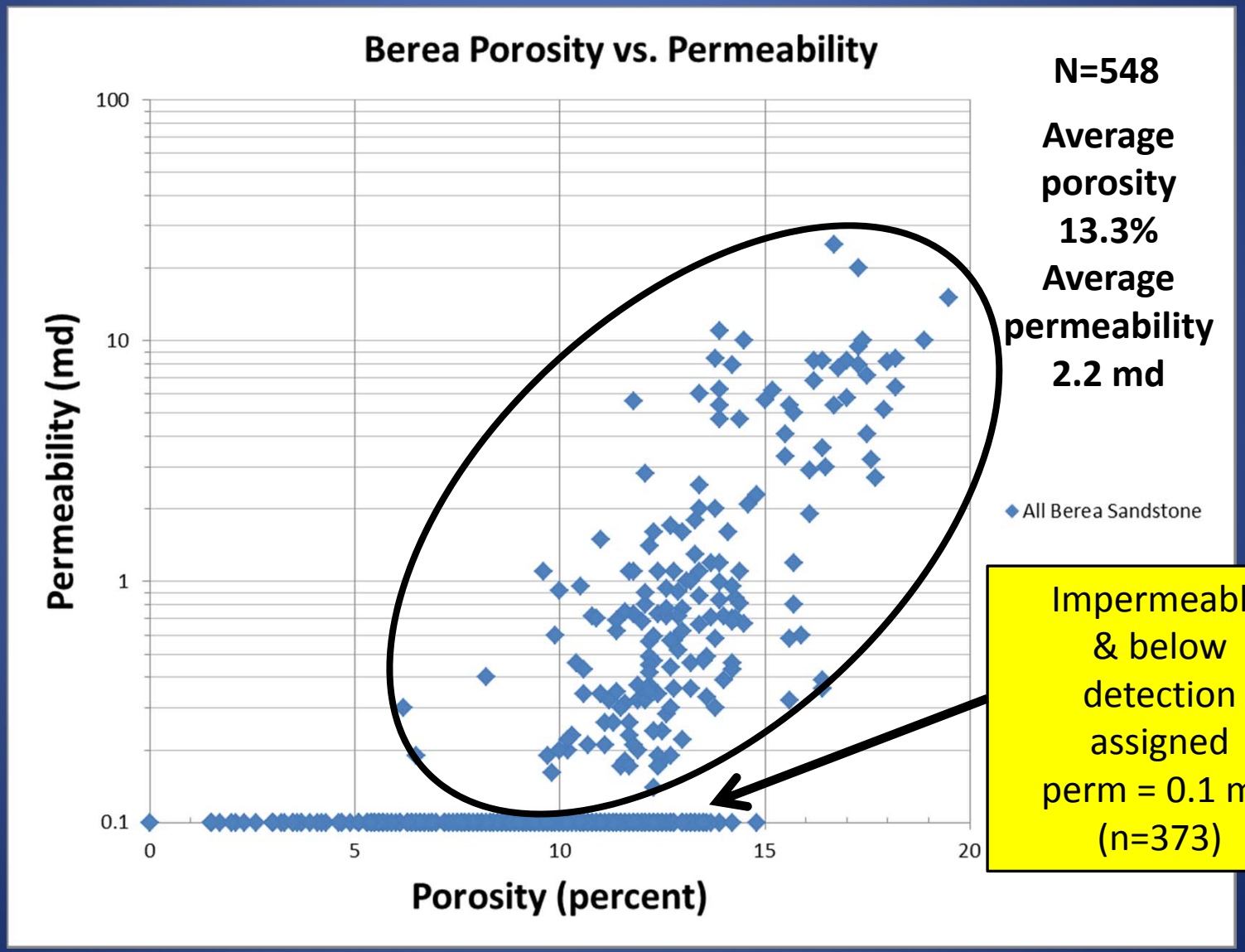
Figure 3. Mean maximum vitrinite reflectance (%R_{max}, in oil) for the Fire Clay coal bed (after Hower and Rimmer[2]).

Berea Reservoir Quality

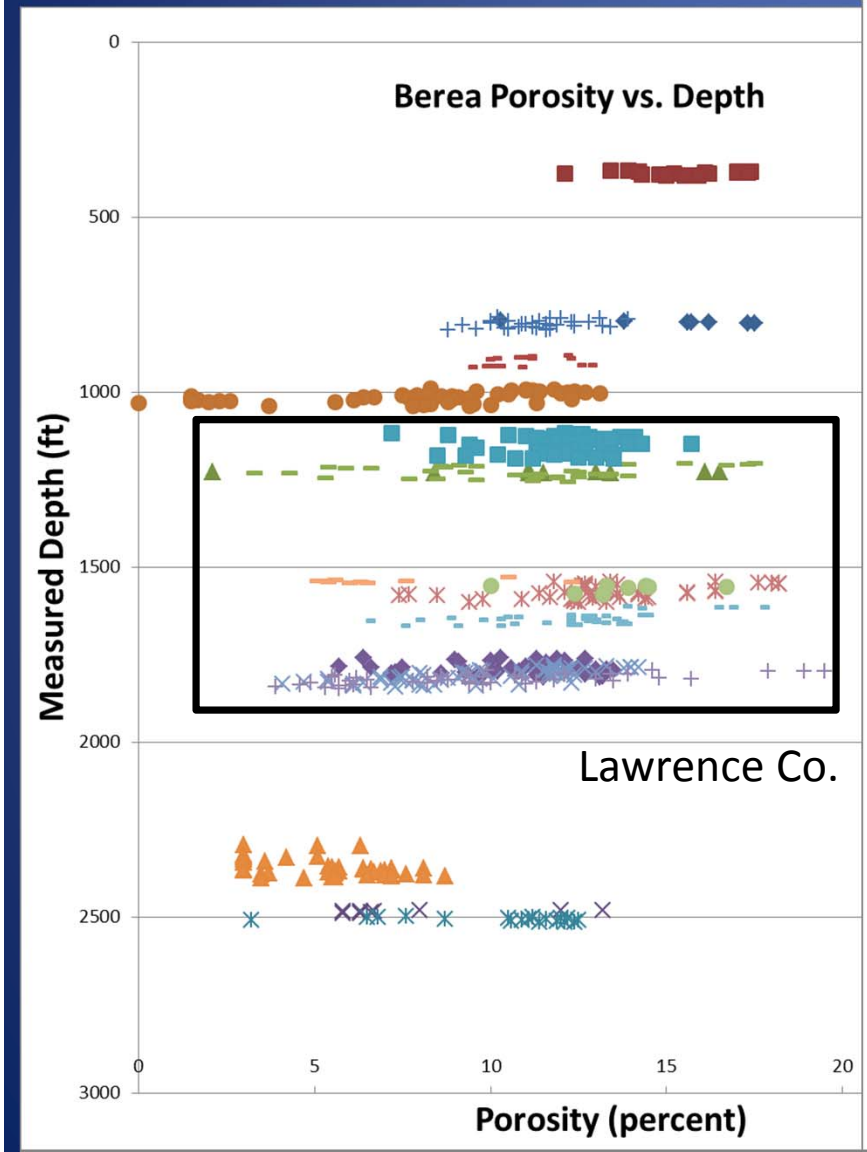
- FERC tight gas formation status established in early 1980's (Lawrence and Pike Counties)
- Core analyses for 18 Berea cores compiled and available at KGS

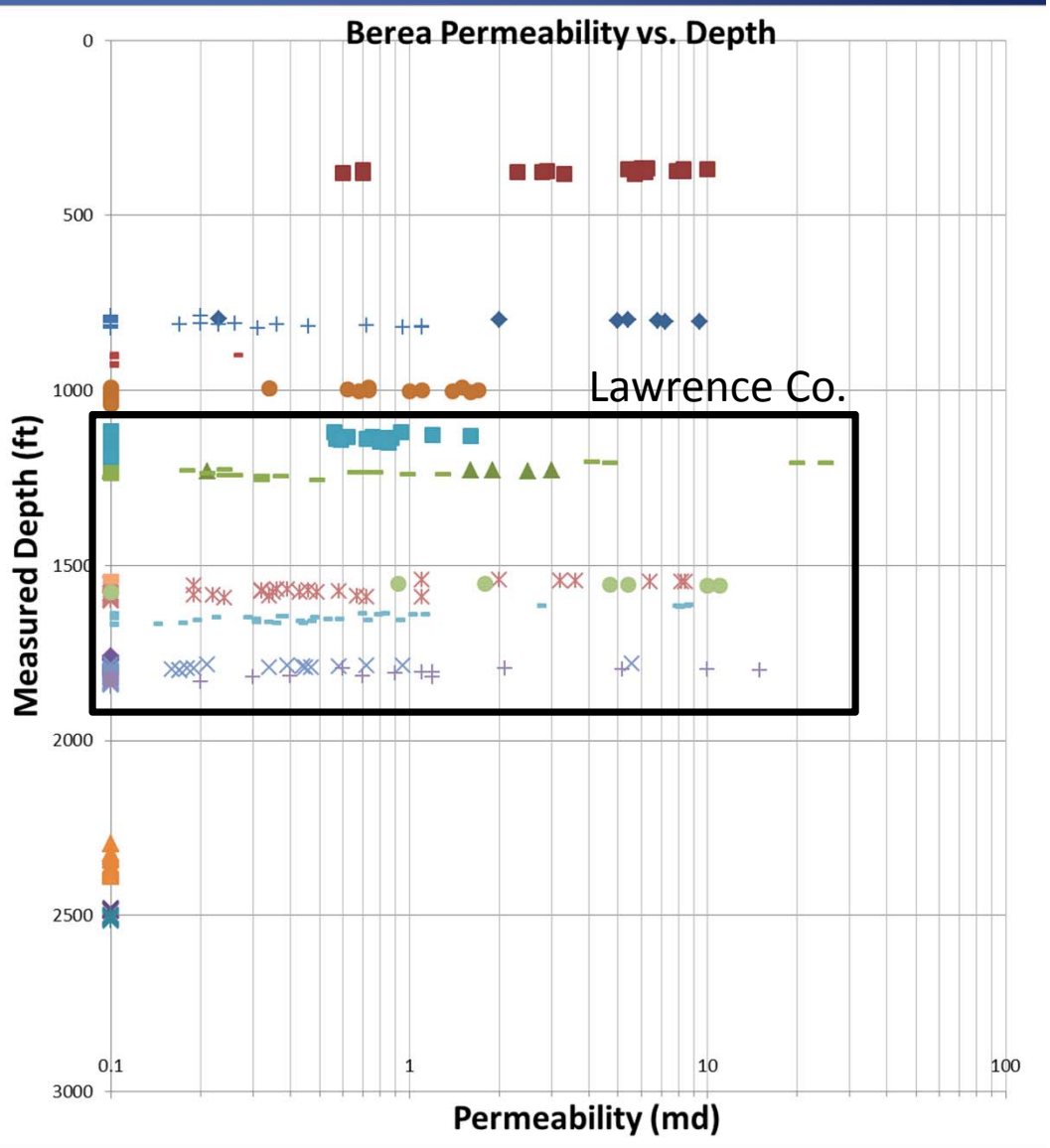


Berea Core Data, E. Kentucky



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

Berea Horizontal Activity

- Greenup County
  - Operator is Nytis Exploration, first well completed in March 2011
  - 22 horizontal wells permitted; completion data submitted for 11 wells
  - Infill/stepout drilling in older shallow (1,000 ft) Berea pools (Hunnewell, Naples)
  - Structure is regional dip to SE, with apparent stratigraphic traps
  - Typical lateral is 2,000 ft., oriented SE-NW (downdip)
  - Multistage hydraulic fracture stimulation
    - 5-11 stages in open hole, 2,500 to 4,900 bbl total fluid, with 200,000 lbs. sand
  - Significant water production reported

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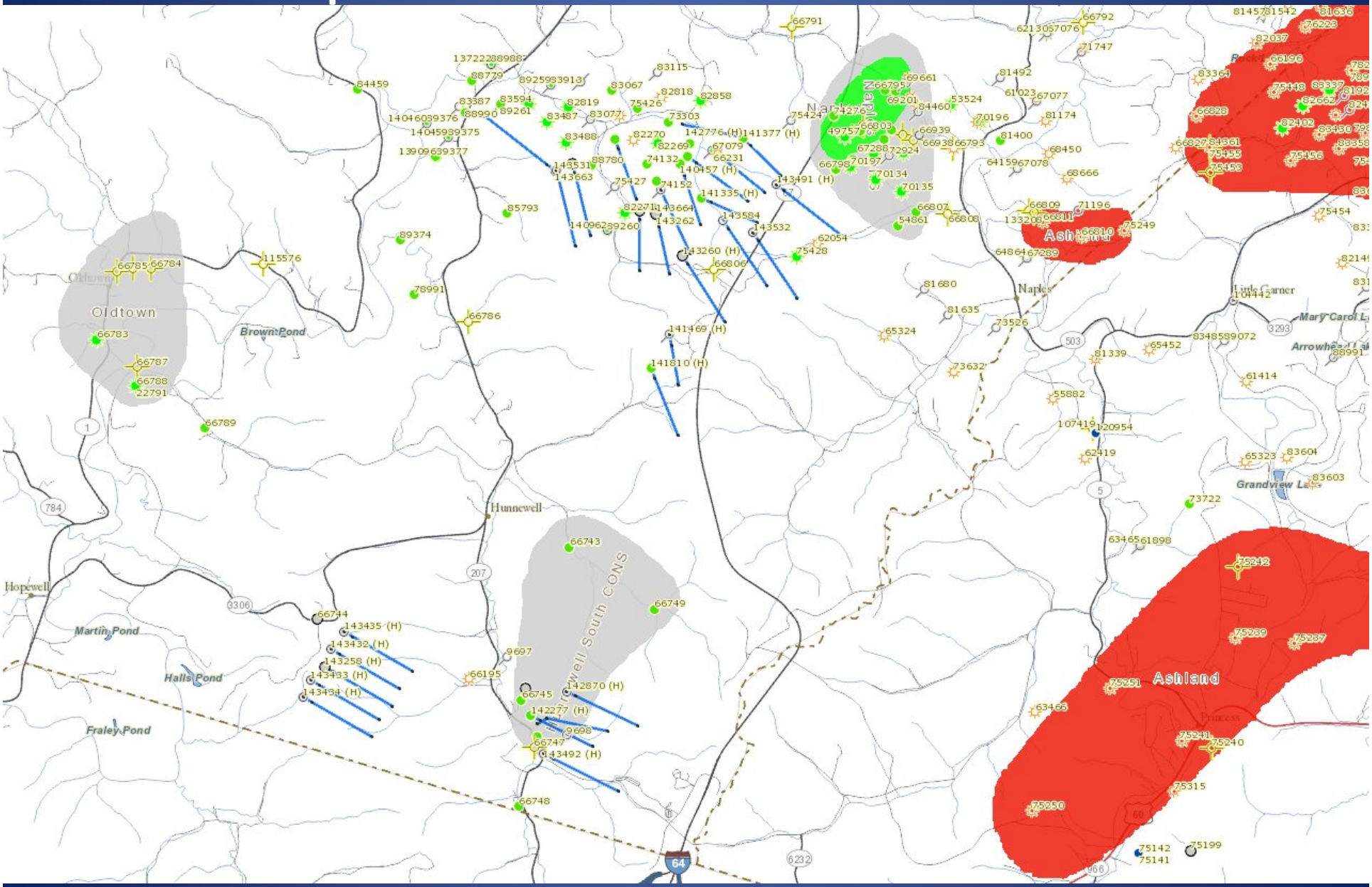
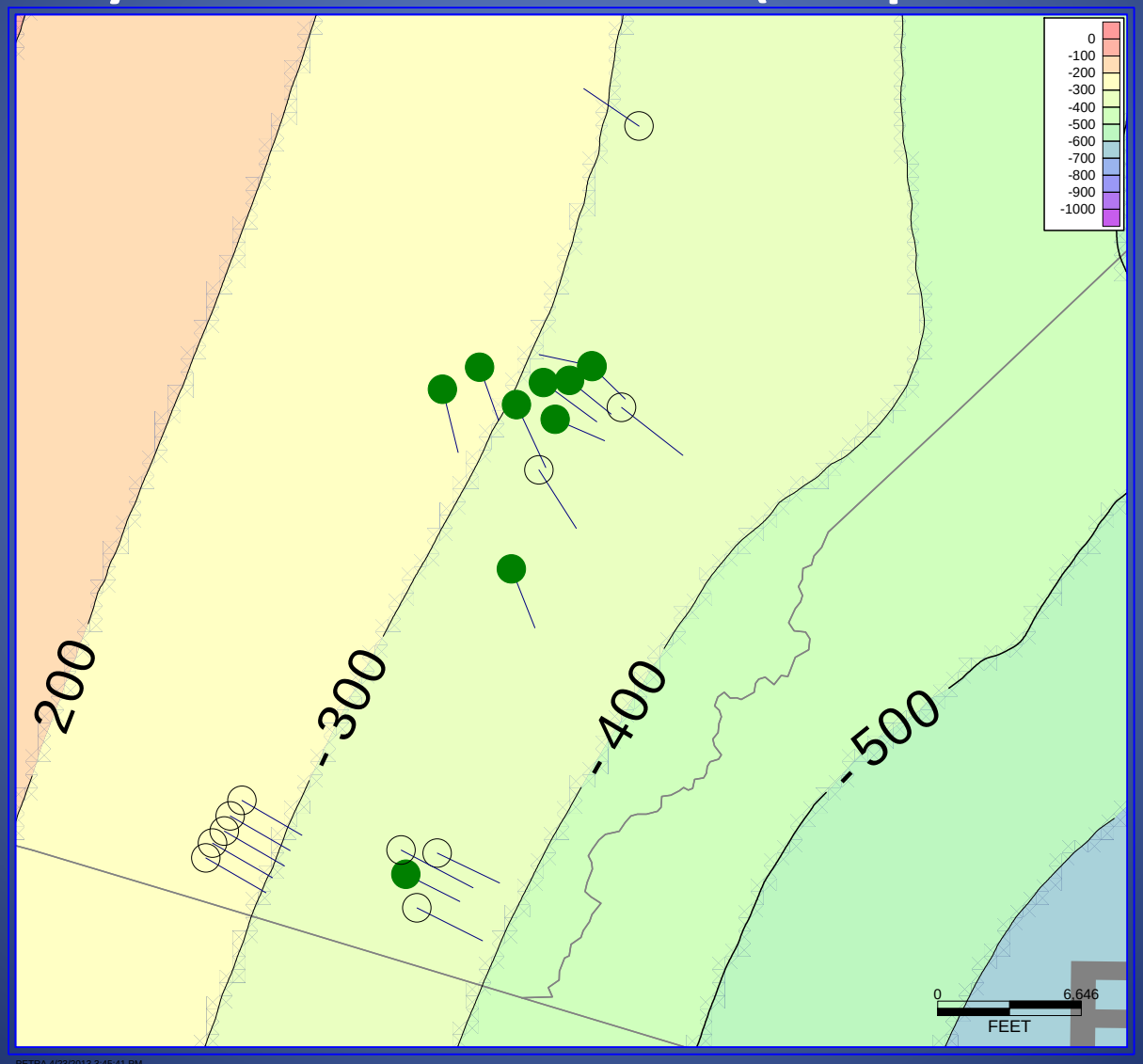
Greenup Co. Horizontal Well Locations



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



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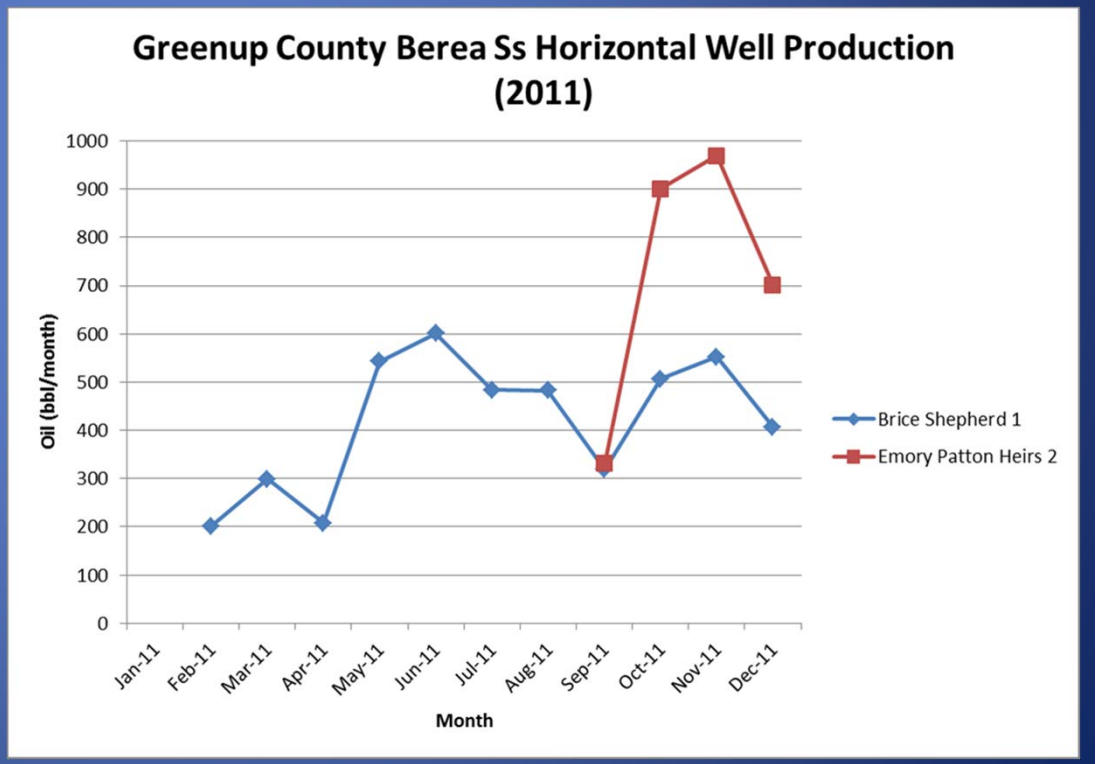
Greenup County Horizontal Completions (5 wells)

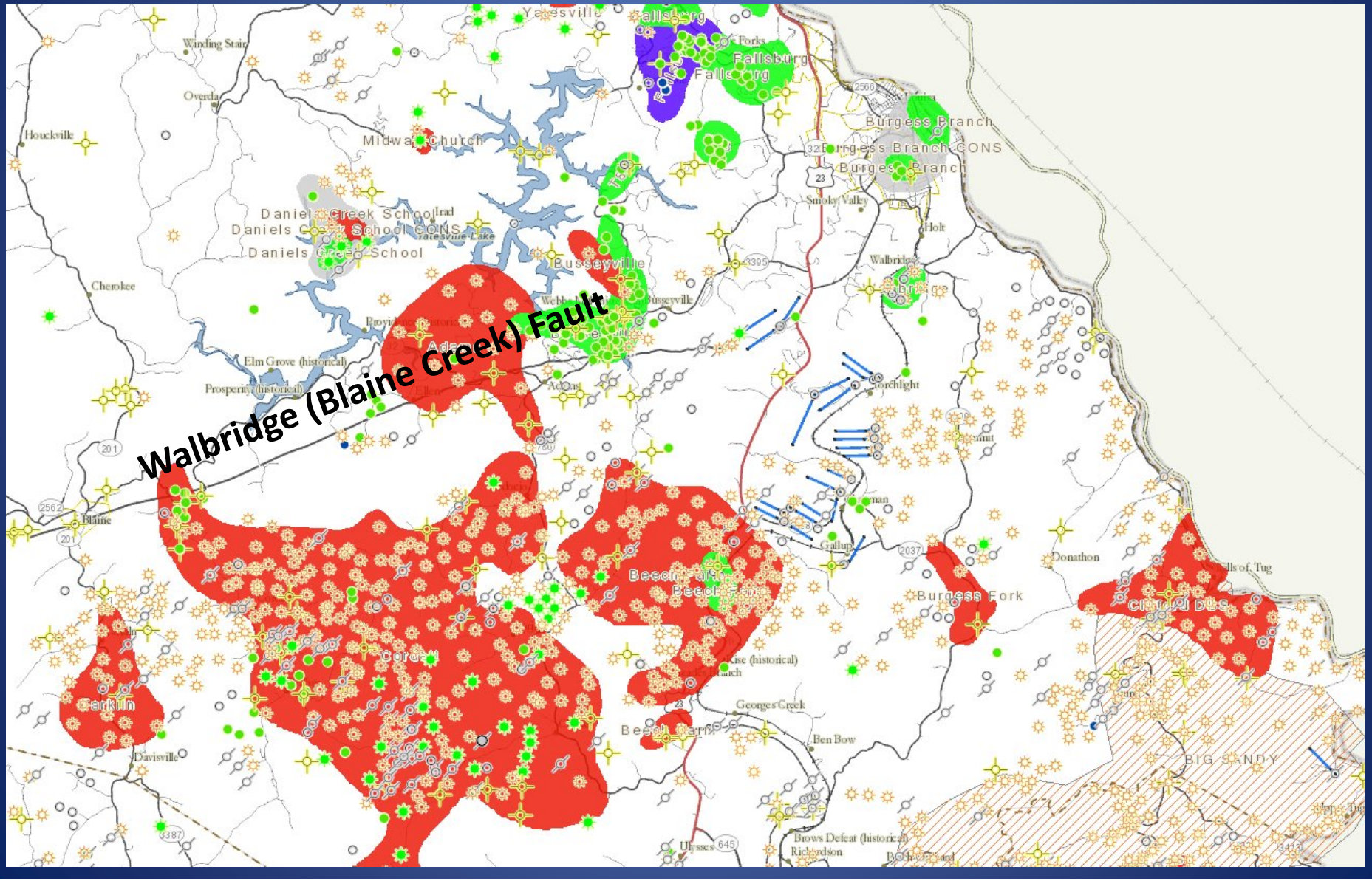
- Reported oil IP's: 16–32 BOPD; 7–37 MCFGD
- Water IP: 28–114 bbl/day
- WOR: 1.5–6, ave= 2.8
- 2011 production data released for 2 wells: average 572 bbl/well/month



Lawrence County Horizontal Activity

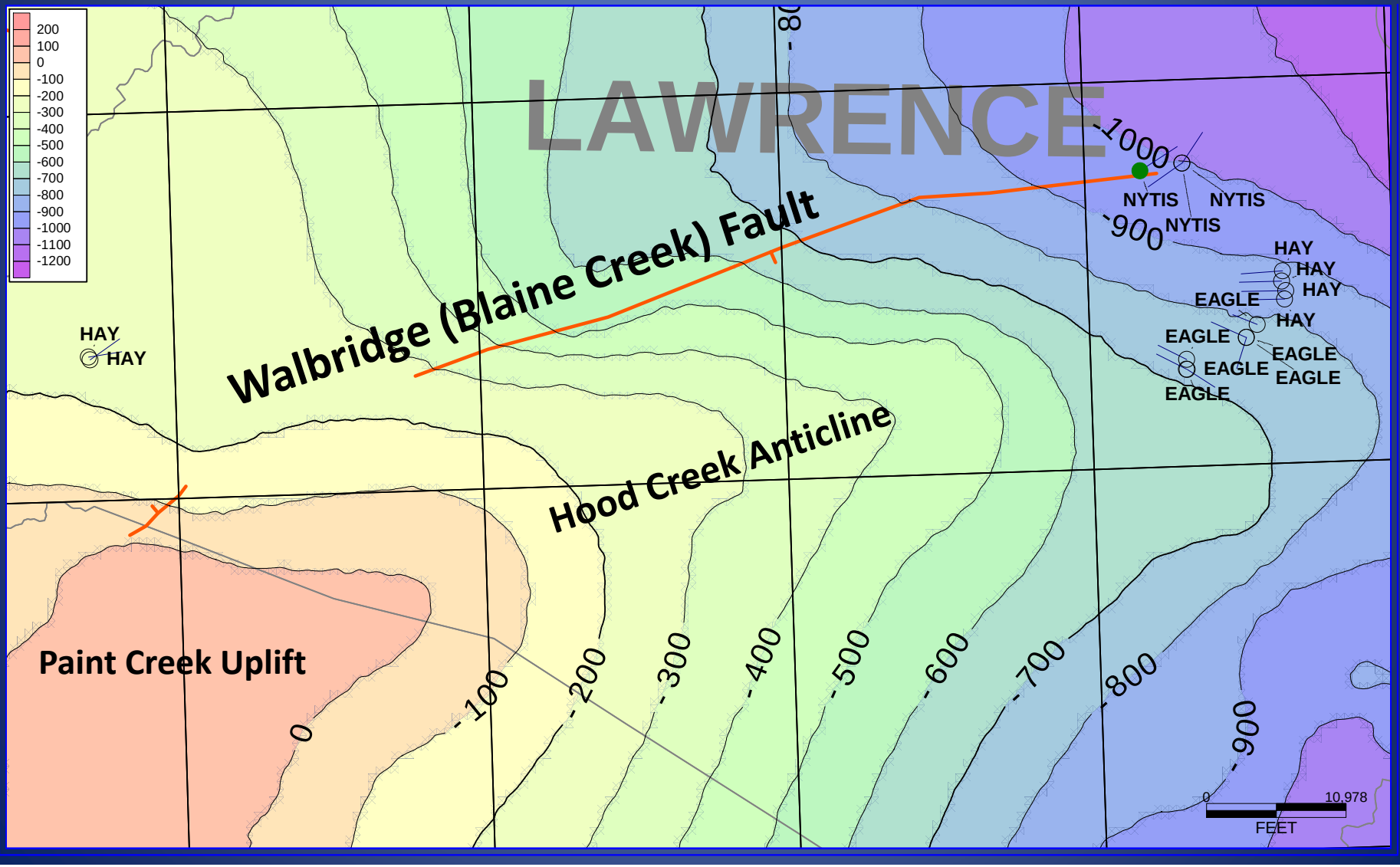
- 15 horizontal wells permitted, first completion in October 2012
  - Operators: Eagle Well Services (6), Hay Exploration (6), Nytis (3)
- Current drilling is near the Walbridge (Blaine Creek) Fault, downdip of gas production in Cordell and Beech Farm fields
- Completion data available for one well, no public production data
- Nytis Torchlight Trust Unit #4 (P109494) (north of Walbridge Fault)
  - MD=4,445 ft; TVD=1,807 ft (2,100 ft lateral)
  - 9-stage frac with 5,227 bbl total fluid, 266,000 lbs sand
  - Reported IP: 30 BOPD oil with 10 bbl water, 26 MCFGD (WOR=0.3)
- Production from other wells rumored to be water-free.
- Lawrence County reservoirs may be solution gas drive, in contrast to Greenup County (water drive?).

Lawrence Co. Horizontal Well Locations

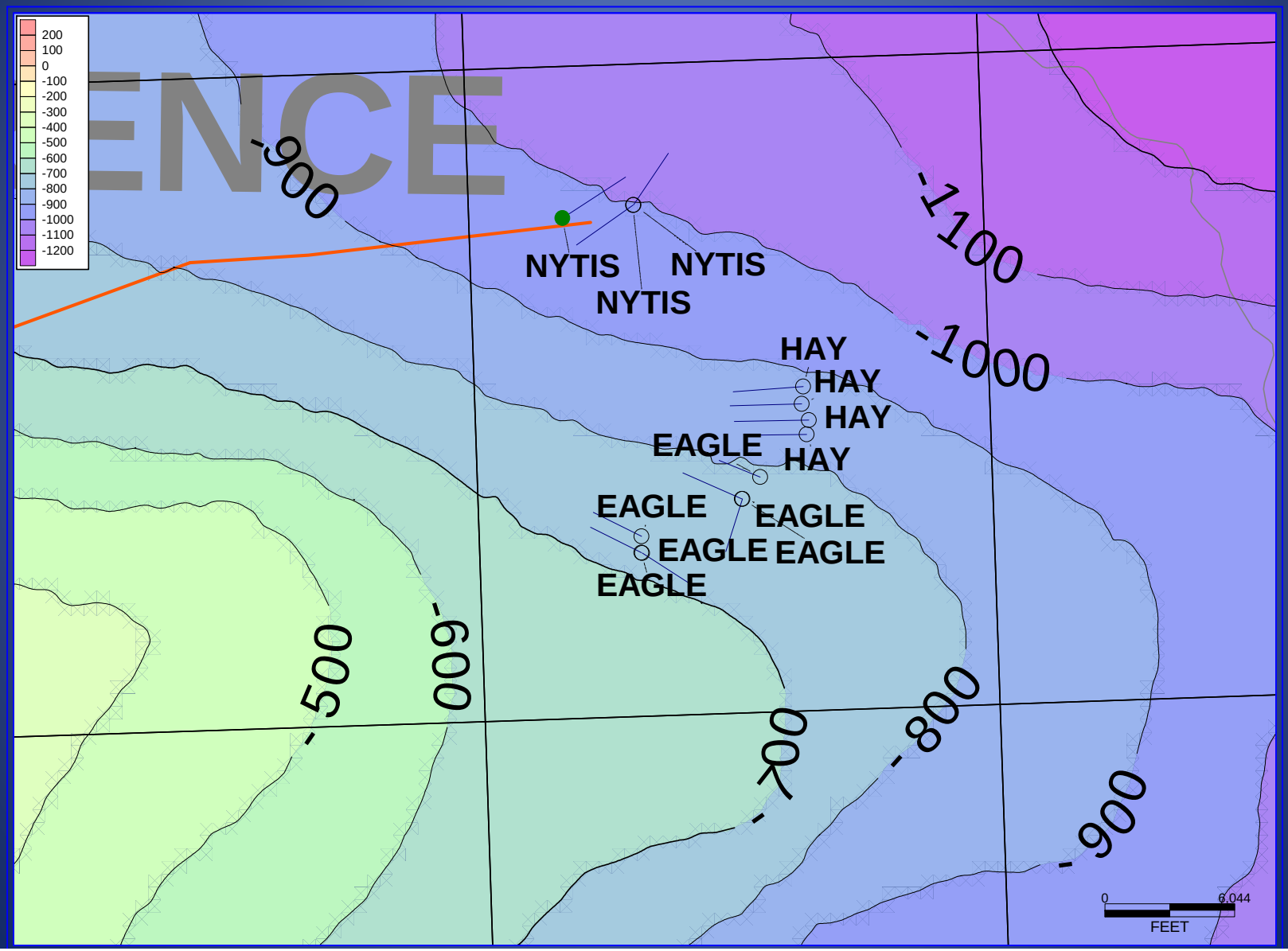


Lawrence County Top Berea Structure

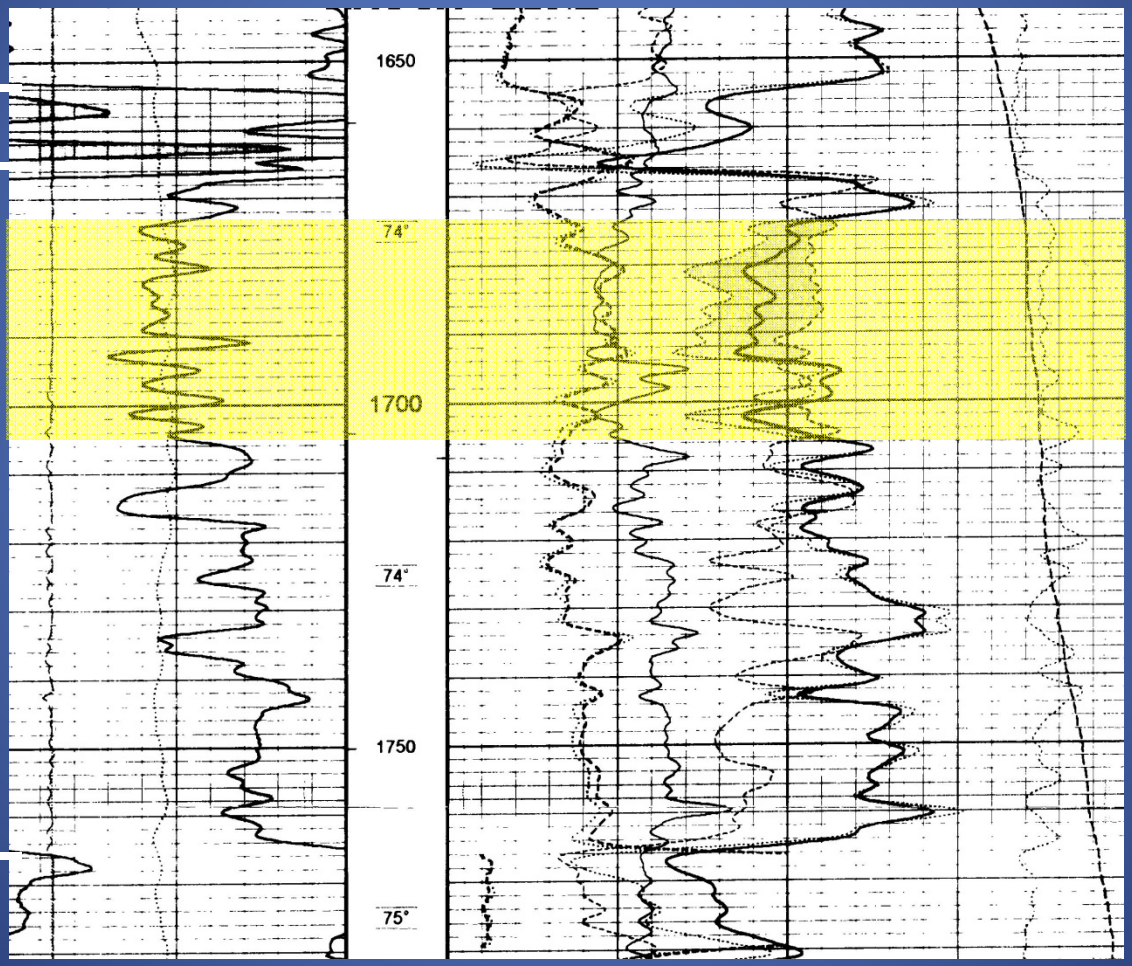
(Faults not contoured)



Significant structure across producing area



Hay Exploration #6 Walbridge Holding, Permit 99084, 12-S-83 Vertical hole 275 ft from Berea horizontal (P109747)



Sunbury Shale

Berea/Bedford

Ohio Shale

Berea gas completion 31 ft gross interval

IP 60 MCFGD commingled with Dev. shale

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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’

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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