Reevaluation of the Heavy Oil and Bitumen Resources of the Western Kentucky Tar Sands: What Did We Learn about the Tar Sands That Is New?*

J. Richard Bowersox[1]

Search and Discovery Article #80568 (2016)**
Posted December 19, 2016

*Adapted from oral presentation given at 2016 AAPG Eastern Section Meeting, Lexington, Kentucky, September 25-27, 2016

[1]Kentucky Geological Survey, University of Kentucky, Lexington, KY (j.r.bowersox@uky.edu) 40506

Abstract

Upper Mississippian Big Clifty and Hardinsburg sandstones and overlying Lower Pennsylvanian Caseyville Formation host heavy oil and bitumen in a belt extending from Logan County north to Breckinridge County in Kentucky. After more than 100 years of study, however, the tar sands' source rock, heavy oil and bitumen origins, reservoir partitioning observed in outcrops and in the subsurface, and resources volume have remained controversial. This study addresses and answers these questions. Trace-metal geochemical evidence demonstrates that tar-sand oil was sourced from the New Albany Shale and are geochemically indistinguishable from other Mississippian oils in the Southern Illinois Basin. Early Triassic primary migration from the New Albany was vertically along fault planes into Big Clifty and Hardinsburg reservoirs developed in downthrown fault blocks, with secondary migration into the Caseyville where erosion at its base breached underlying reservoirs. Reservoir compartmentalization observed in outcrops and cores was associated with oil migration, when the oil was a geochemically-reducing fluid reacting with pore water and the surrounding matrix to precipitate a distinctive diagenetic mineral suite. Migrating oil was biodegraded to heavy oil and bitumen during oil emplacement by microbes sequestered in the reservoirs during burial. During biodegradation of the oil, immobile bitumen was deposited on the pore walls causing the tar-sand reservoirs to be oil-wet, leaving only about 40% of the total oil in place as mobile and potentially producible. One characteristic of the tar sands is that total-fluid saturations in cores are much less than 100%. Reservoir porosity expansion during rapid pre-Middle Cretaceous tectonic uplift, reservoir fluids cooling, and lack of an active aquifer connection led to the tar-sand reservoirs becoming undersaturated in water. Additional pore space filled with low-pressure methane evolved from the water, evidenced by methane bubbling from cores and isolated gas caps developed over heavy oil in the Big Clifty. Estimated oil in place in the

tar sands is 3.36 MMMBO; however, the only commercial process for developing these resources was mining rock asphalt for road surfaces from 1889 to 1957. No EOR or bitumen extraction process has been developed since that time beyond technically successful, but uneconomic, projects.

Selected References

Ball, M.W., 1951, The synthetic liquid fuel potential of Kentucky: Oil impregnated strippable deposits: New York, New York, Ford, Davis and Bacon, Inc., 347p.

Ball and Associates, Ltd., 1965, Surface and shallow oil-impregnated rocks and shallow oil fields in the United States: U.S. Bureau of Mines, Monograph 12, 375p.

Bowersox, J.R., 2016a, Rocks to Roads to Ruin: A Brief History of Western Kentucky's Rock Asphalt Industry, 1888–1957: Kentucky Geological Survey, Series XII, Information Circular 33, 45p.

Bowersox, J.R., 2016b, Heavy Oil and Bitumen Resources of the Big Clifty Sandstone, Northeast Grayson County and Adjacent Hardin County, Kentucky: Kentucky Geological Survey, Series XII, Report of Investigation 35, 21p.

Bowersox, J.R., 2016c, Heavy Oil and Bitumen Resources of the Western Kentucky Tar Sands: Kentucky Geological Survey, Series XII, Report of Investigation 36, 39 p.

Hoffman, M.E., 2008, Sub-capillary pressure equilibrium reservoirs: Their formation and effect on oil and gas production: The Mountain Geologist, v. 45, p. 107-119.

Hoffman, M.E., 2013, Reservoirs that are not in capillary pressure equilibrium: Unconventional Resources Technology Conference, Denver, Colorado, USA, 12–14 August 2013, SPE-168888-MS, 10p.

Lewin and Associates Inc., 1984, Kentucky, *in* V.A. Kuuskraa, and E.C. Hammershaimb, editors, Major Tar Sand and Heavy Oil Deposits of the United States: Oklahoma City, Oklahoma, Interstate Oil Compact Commission, p. 85-116.

McGrain, P., 1976, Tar sands (rock asphalt) of Kentucky — a review: Kentucky Geological Survey, Series 10, Report of Investigations 19, 16p.

Nehring, R., R. Hess, and M. Kamionski, 1983, The Heavy Oil Resources of the United States: Santa Monica, California, Rand Corporation, United States Department of Energy Contract Report R-2946-DOE, 143p.

Noger, M.C., 1984, Tar-sand resources of western Kentucky: Lexington, Kentucky, Institute for Mining and Minerals research, University of Kentucky, Proceedings, 1984 Eastern Oil Shale Symposium, p. 151-178.

Potter, P.E., E. Nosow, N.M. Smith, D.H. Swann, and F.H. Walker, 1958, Chester cross-bedding and sandstone trends in Illinois Basin: AAPG Bulletin, v. 42, p. 1013-1046.

Potter, P.E., and R. Sevier, 1956, Sources of basal Pennsylvanian sediments in the Eastern Interior Basin: 1. Cross bedding: Journal of Geology, v. 64, p. 225-244.

Rowe, J., and S.D. Burley, 1997, Faulting and porosity modification in the Sherwood Sandstone at Alderley Edge, northeastern Cheshire: An exhumed example of fault-related diagenesis, *in* N.S. Meadows, S.P. Trueblood, M. Hardman, and G. Cowan, editors, Petroleum Geology of the Irish Sea and Adjacent Areas: Geological Society, London, Special Publications, v. 124, p. 325-352.

Schumacher, D., 1996, Hydrocarbon-induced alteration of soils and sediments, *in* D. Schumacher and M. A. Abrams, editors, Hydrocarbon Migration and Its Near-surface Expression: AAPG Memoir 66, p. 71-89.

Williams, D.A., M.C. Noger, and P.J. Gooding, 1982, Investigation of Subsurface Tar-sand Deposits in Western Kentucky: A Preliminary Study of the Big Clifty Sandstone Member of the Golconda Formation (Mississippian) in Butler County and parts of Edmonson, Grayson, Logan, and Warren Counties: Kentucky Geological Survey, Series 11, Information Circular 7, 25 p.

Reevaluation of the Heavy Oil and Bitumen Resources of the Western Kentucky Tar Sands: What Did We Learn about the Tar Sands That Is New?

J. RICHARD BOWERSOX, PHD, PG, CPG

KENTUCKY GEOLOGICAL SURVEY

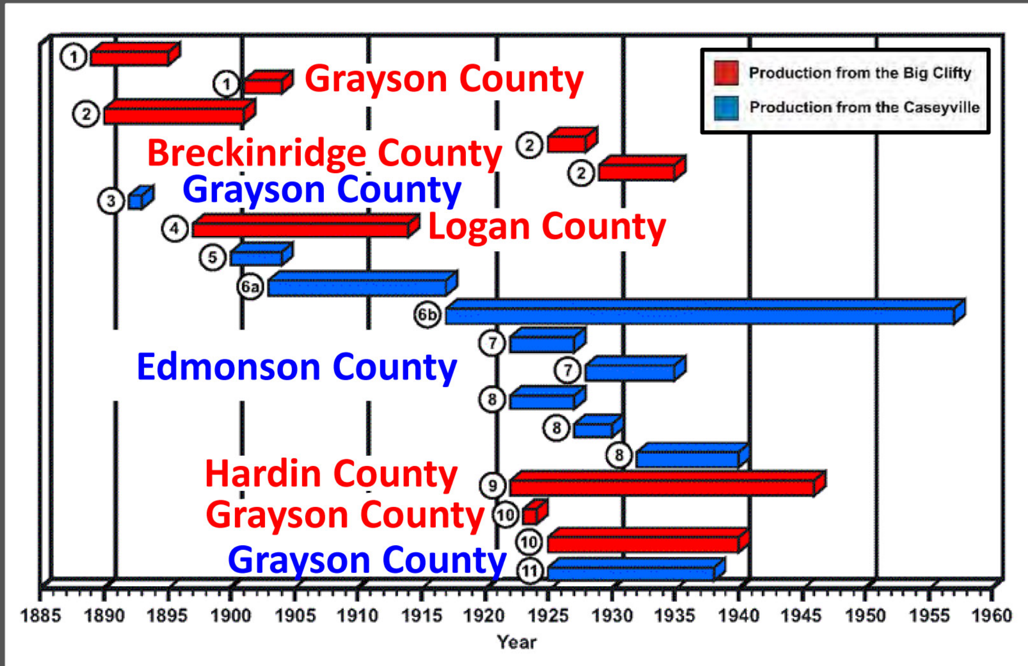
UNIVERSITY OF KENTUCKY

LEXINGTON, KENTUCKY

Presentation Outline

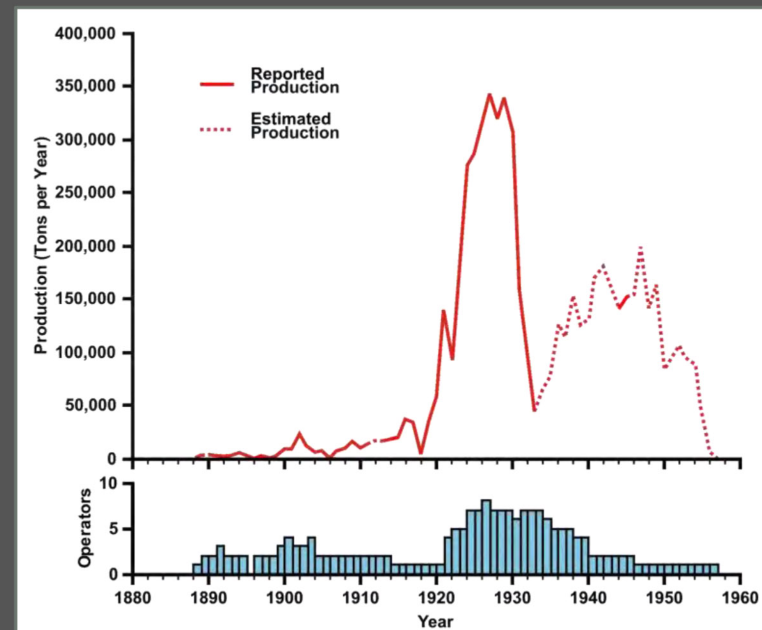
- Background History and Previous Work
- Data Sources
- Stratigraphy, Depositional System, and Structure
- Migration and Trapping
- Origin of the Tar Sands Reservoirs
- Oil in Place
- Thermal EOR Tests and Case History Example
- Conclusions

Rocks to Roads to Ruin: Western Kentucky's Rock Asphalt Industry



There are 11 documented occurrences of rock asphalt production.

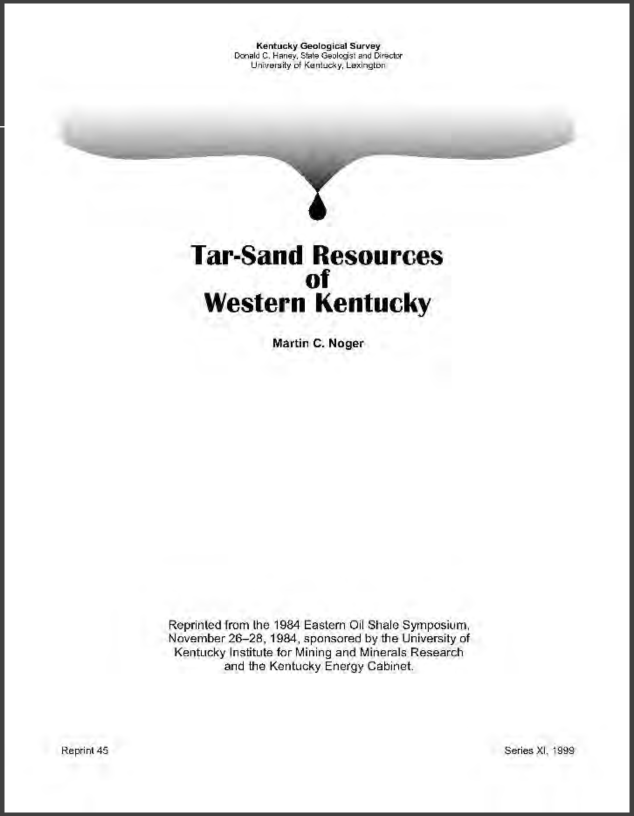
Natural rock asphalt was quarried for road surfacing from about 1888 until 1957; however, no subsequent development of the western Kentucky tar sands has proven commercial.



Estimated rock asphalt production was 6 million tons containing about 2.3 million barrels of bitumen.

Previous Work

- Mining
  - Jillson (1917 – 1929) surface deposits
- Bitumen extraction and thermal EOR
  - Ball and Associates (1951) surface deposits
  - IOCC (1965) surface to 500 ft
  - McGrain (1976) surface deposits
  - Williams, Noger, and Gooding (1982) all depths
  - IOCC (1982) all depths
  - Rand Corporation for DOE (1983) all depths
  - Noger (1984) all depths


Kentucky Geological Survey
Donald C. Haney, State Geologist and Director
University of Kentucky, Lexington

Tar-Sand Resources of Western Kentucky

Martin C. Noger

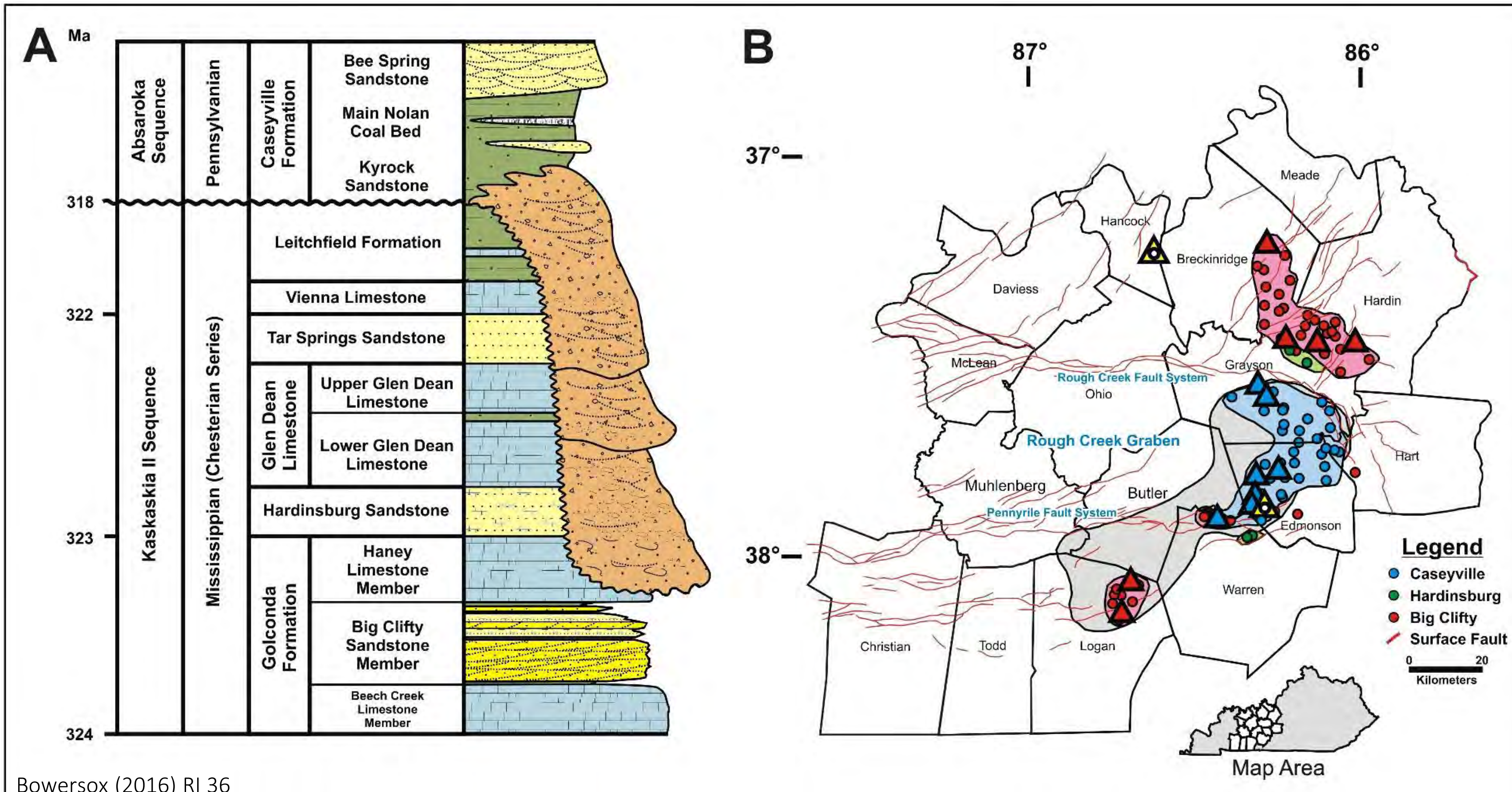
Reprinted from the 1984 Eastern Oil Shale Symposium, November 26–28, 1984, sponsored by the University of Kentucky Institute for Mining and Minerals Research and the Kentucky Energy Cabinet.

Reprint 45 | Series XI, 1999

Data Sources

- 1500 well records
  - 977 wells with electric logs
  - 753 wells with drillers' logs
- Reservoir data
  - 138 cores (4053 sample analyses)
  - 200 wells/surface samples/quarry samples where SoØ was calculated from weight-percent bitumen
    - 61 analyses from wells
    - 125 surface samples
    - 14 quarry samples

Stratigraphy and Distribution of the Western Kentucky Tar Sands

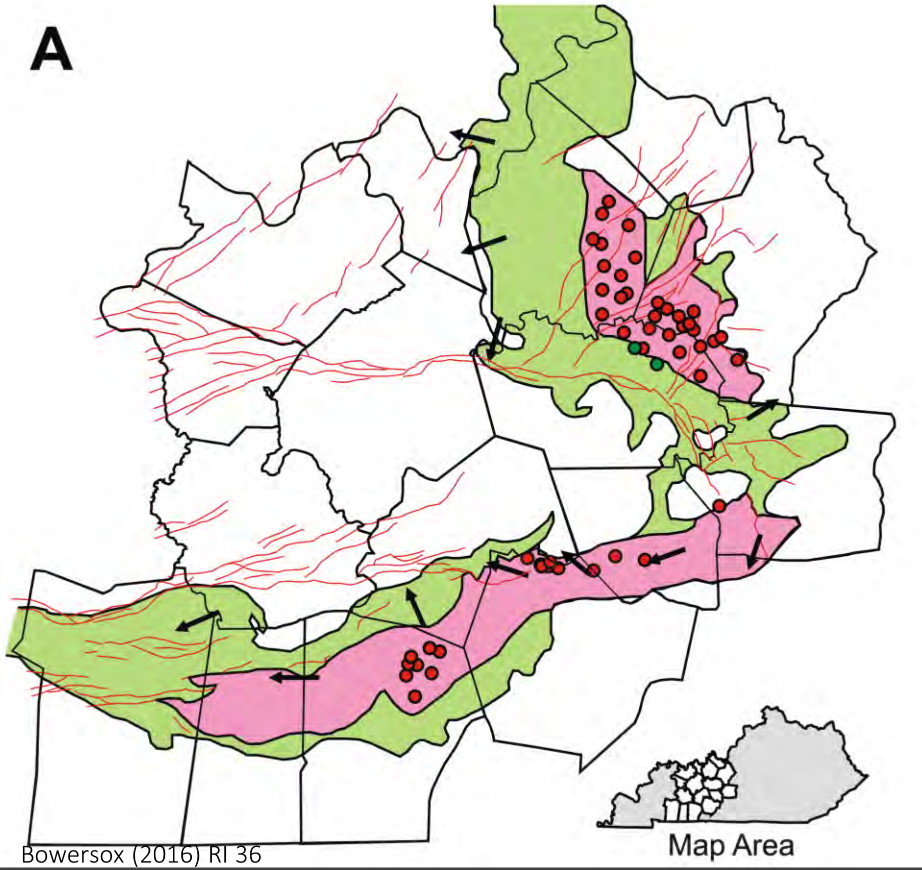


Bowersox (2016) RI 36

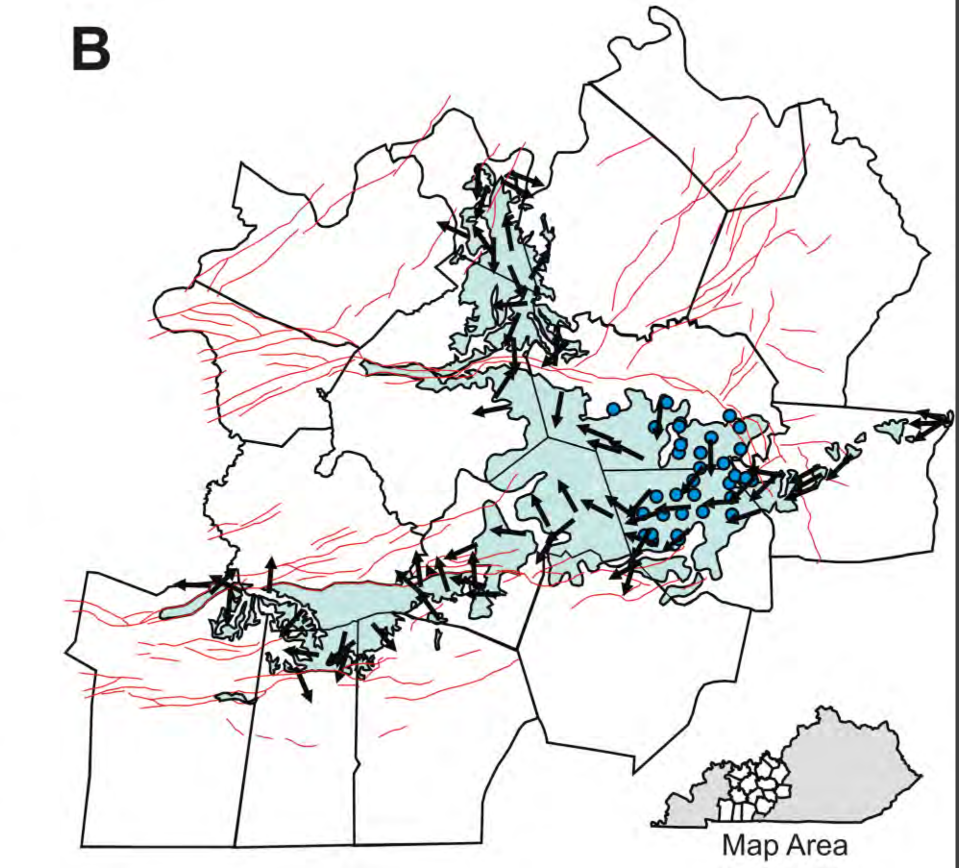
Exposure of bitumen-saturated Big Clifty Sandstone in a roadcut on the Western Kentucky Parkway, Grayson County.

KGS photo by Brandon Nuttall

Generalized Tar Sands Outcrops and Depositional Trends

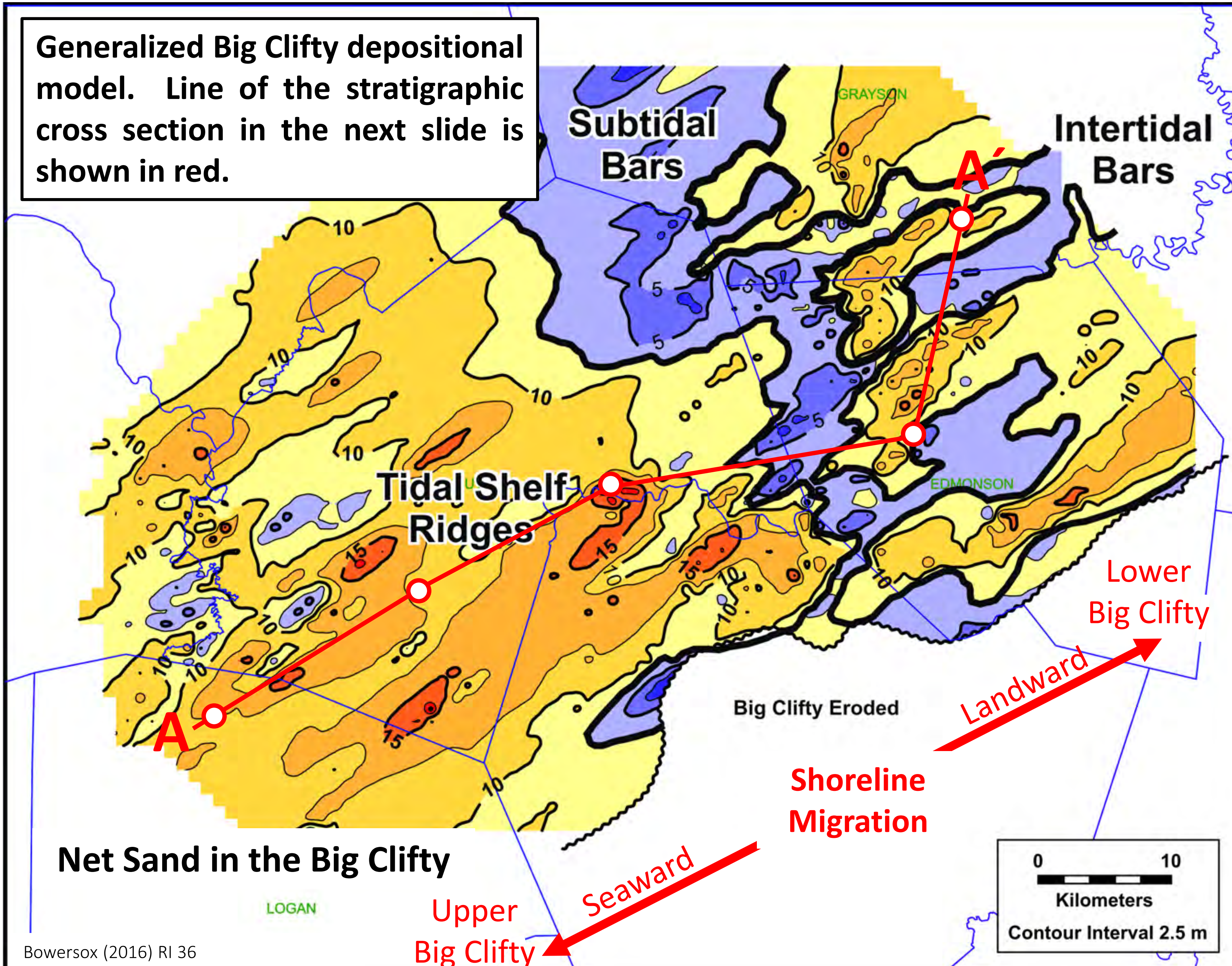


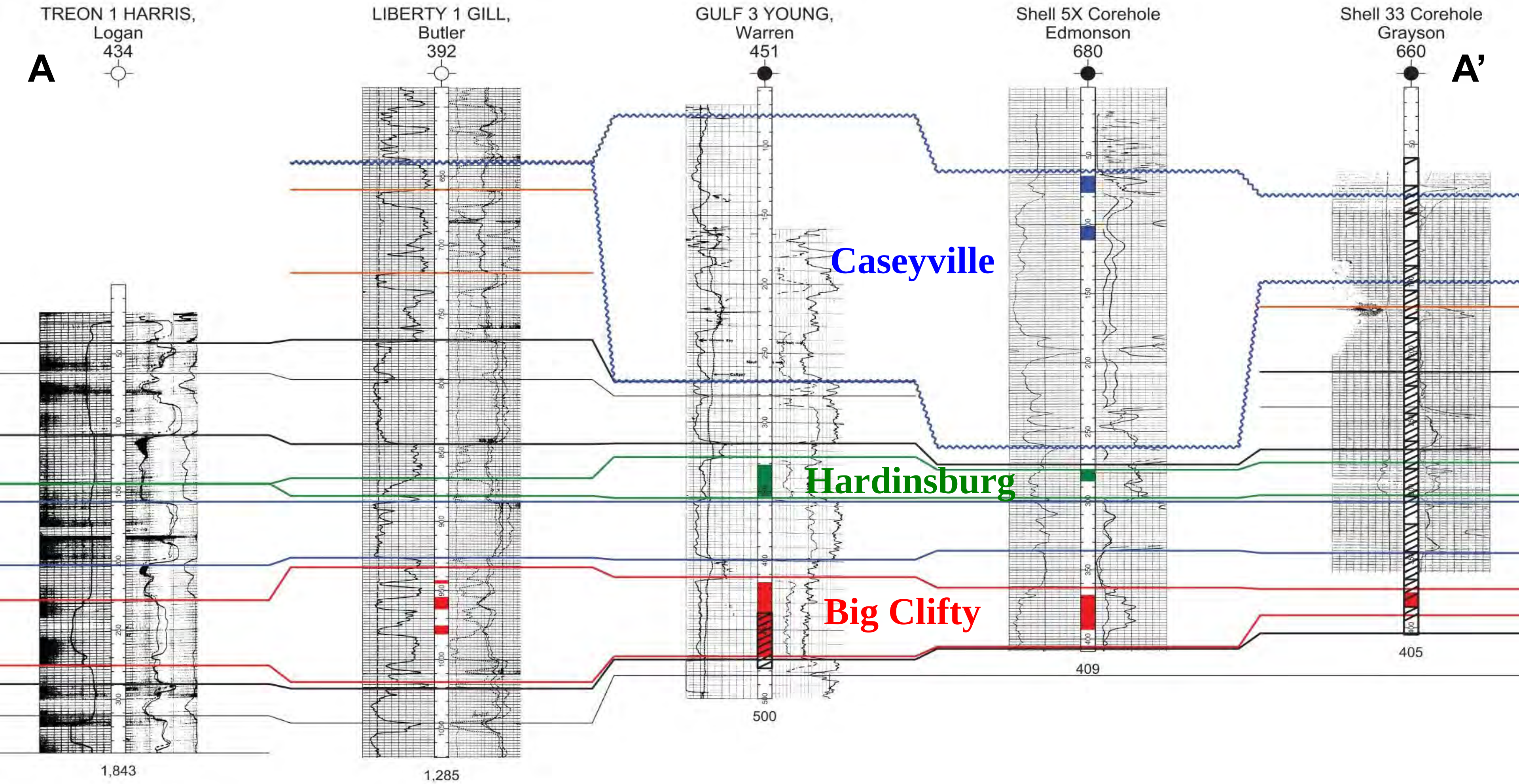
Chesterian depositional trend (after Potter et al., 1958)



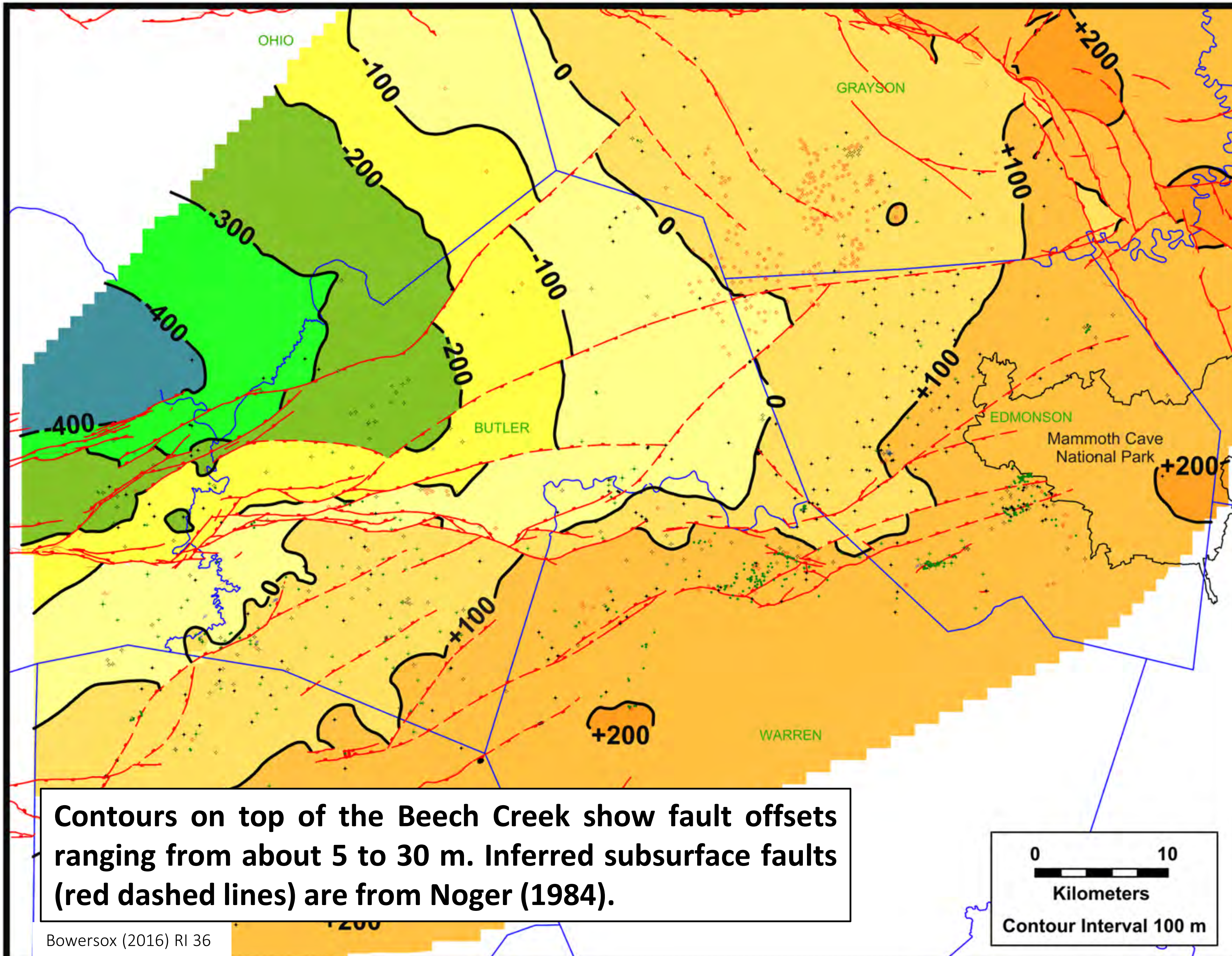
Caseyville depositional trend (after Potter and Sevier, 1956)

Generalized Big Clifty depositional model. Line of the stratigraphic cross section in the next slide is shown in red.



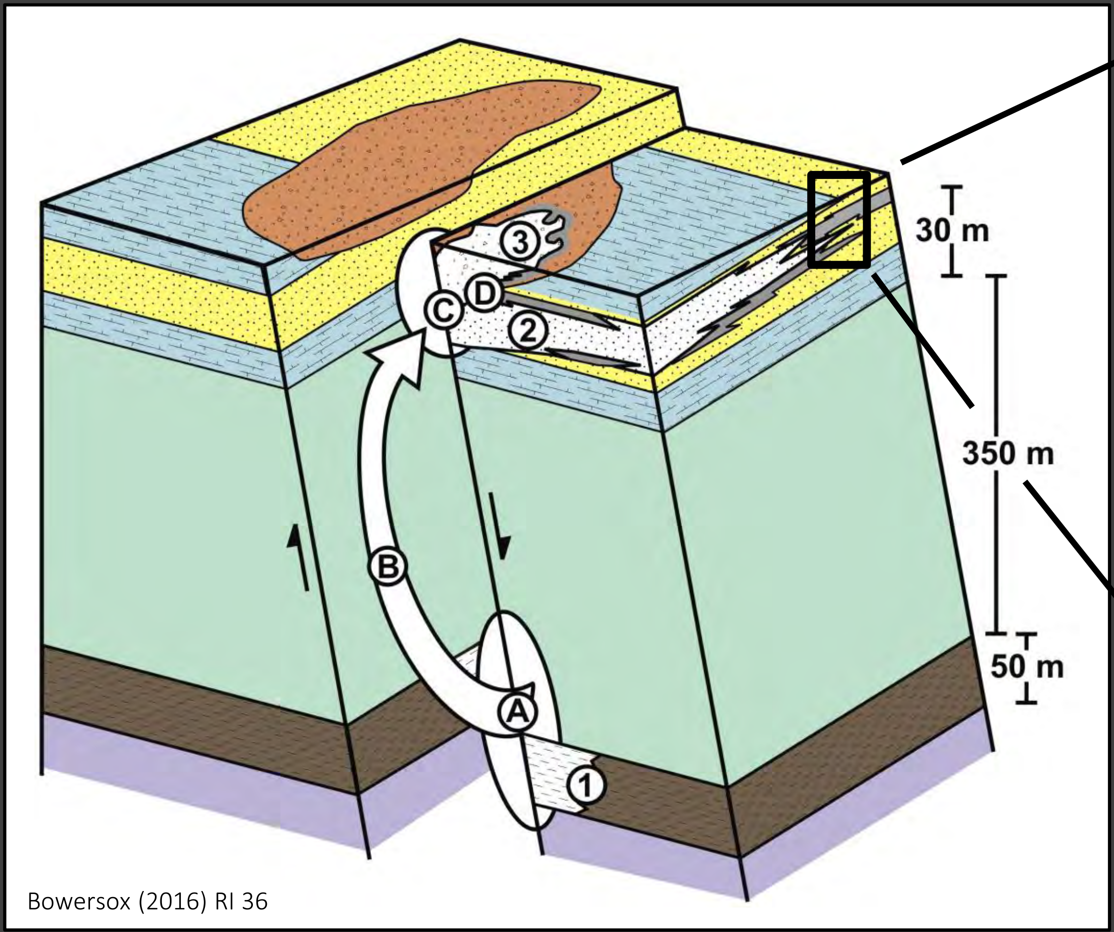


Stratigraphic cross section from Logan to Grayson County (datum is the top of the Haney Limestone). Incision by paleo-river channels into underlying Chesterian reservoirs allowed oil migration from the Hardinsburg and Big Clifty into the Caseyville.



Contours on top of the Beech Creek show fault offsets ranging from about 5 to 30 m. Inferred subsurface faults (red dashed lines) are from Noger (1984).

Bowersox (2016) RI 36

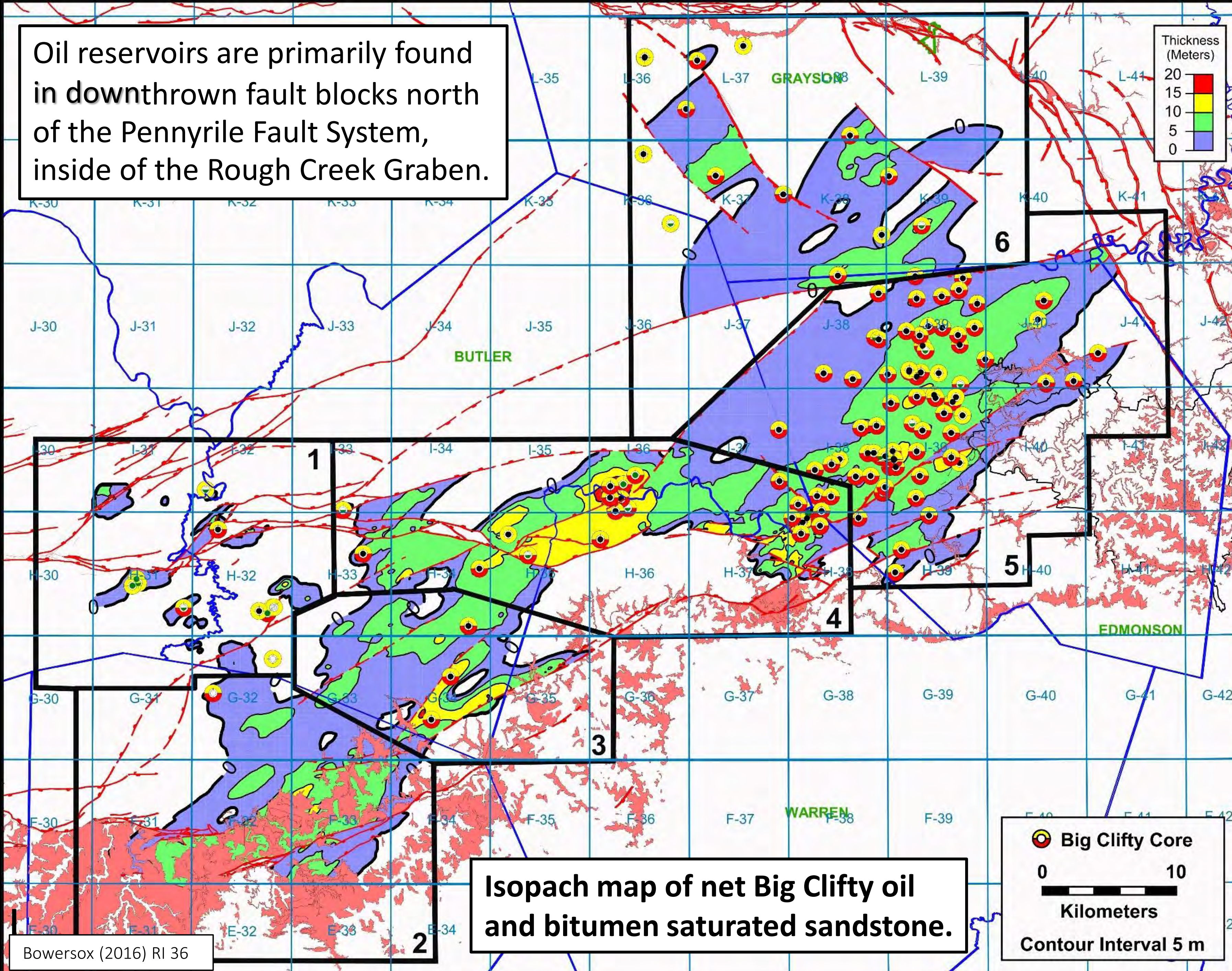


Megawest CH 102 Clark
Warren County
Big Clifty Sandstone
520.0 – 520.7 ft

More than ample geochemical evidence demonstrates that the New Albany Shale is the source of the tar sands oil. Oil migrated from the New Albany along fault planes (A-B-C-D) from (1), then into the tar sands (2-3) (modified after Rowe and Burley, 1997). Reservoir diagenetic partitioning (white bands in the core photo) is characteristically associated with oil migration where the oil is the geochemically-reducing diagenetic fluid in the petroleum reservoir (Schumacher, 1996).

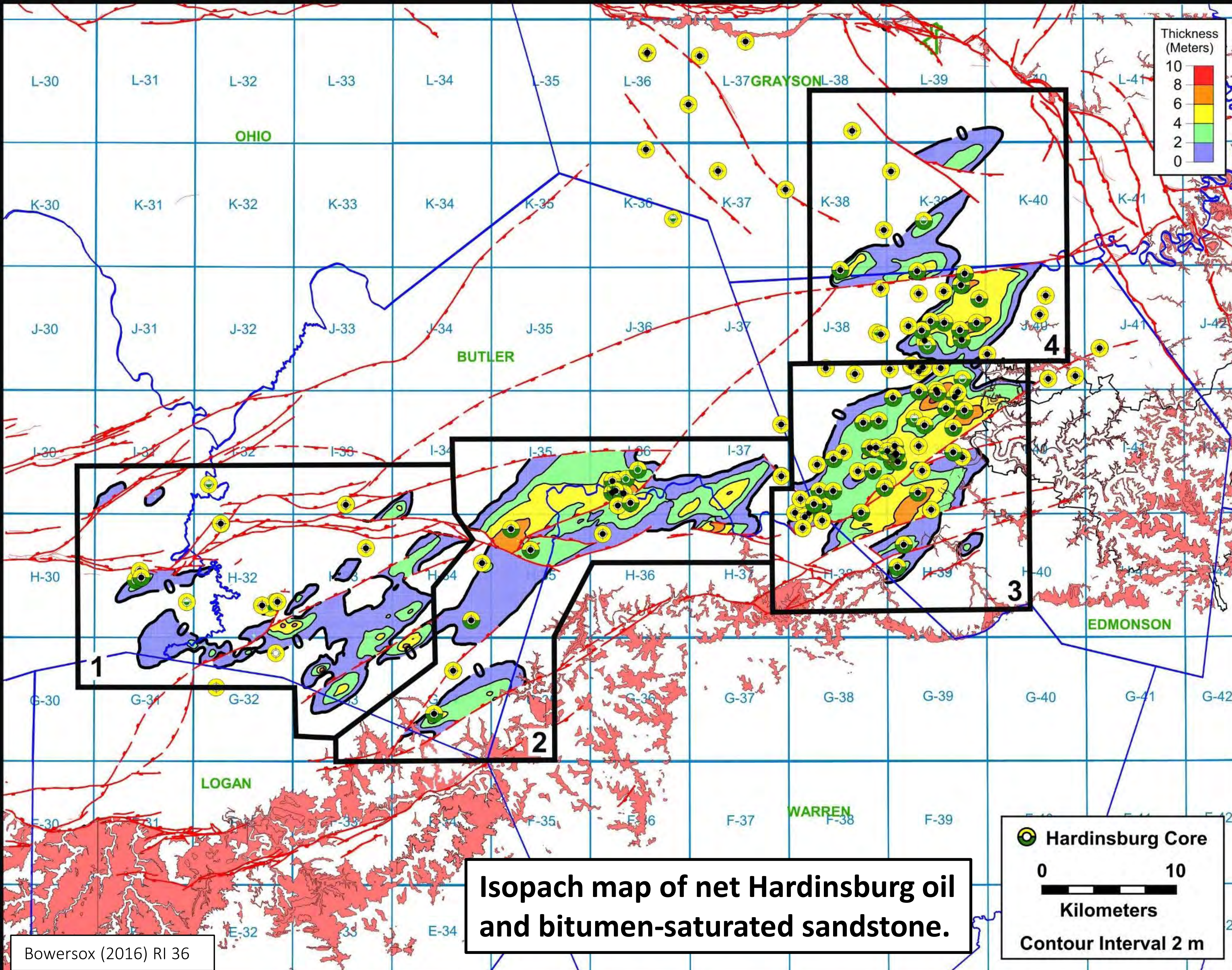
Diagenetic Facies in the Caseyville Sandstone
Indian Creek Quarry, Edmonson County

Oil reservoirs are primarily found in downthrown fault blocks north of the Pennyrile Fault System, inside of the Rough Creek Graben.



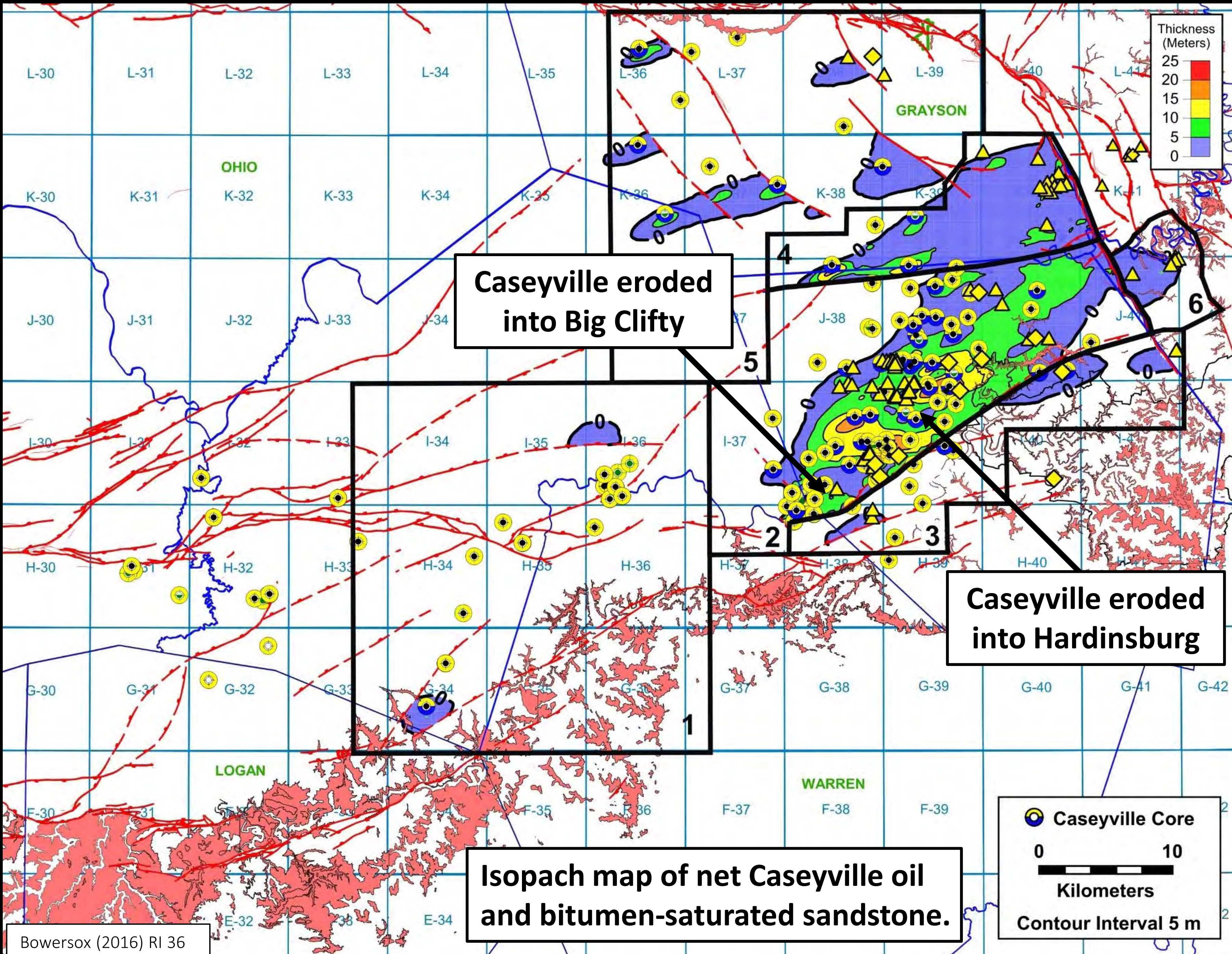
Isopach map of net Big Clifty oil and bitumen saturated sandstone.

Bowersox (2016) RI 36



Isopach map of net Hardinsburg oil and bitumen-saturated sandstone.

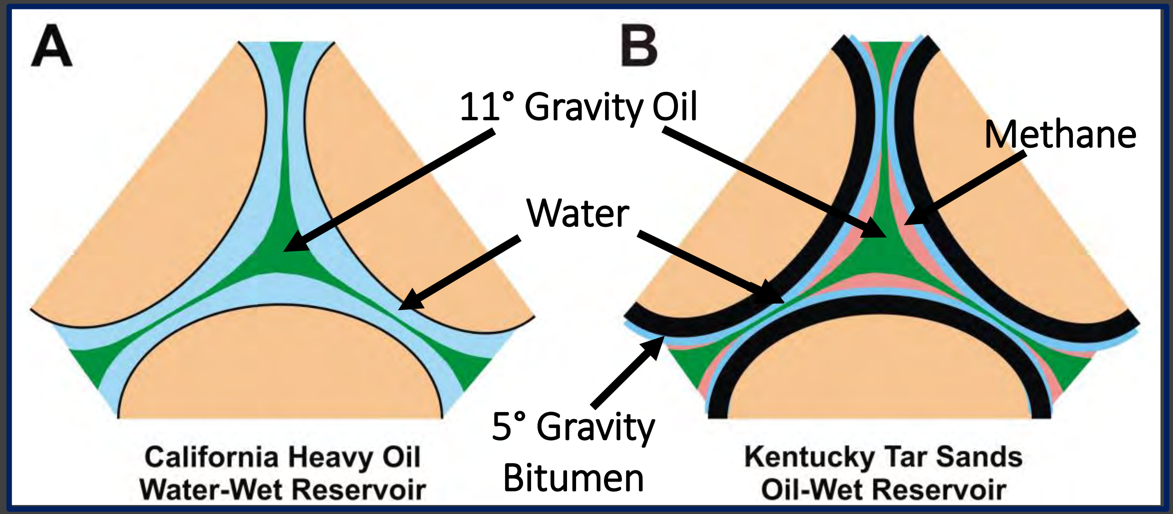
Bowersox (2016) RI 36



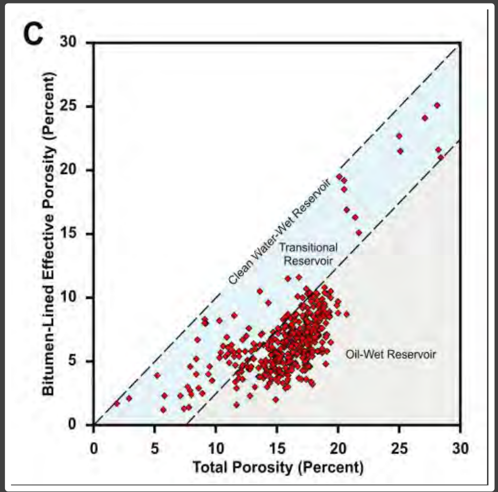
Isopach map of net Caseyville oil and bitumen-saturated sandstone.

Bowersox (2016) RI 36

Water-Wet versus Oil-Wet Reservoirs



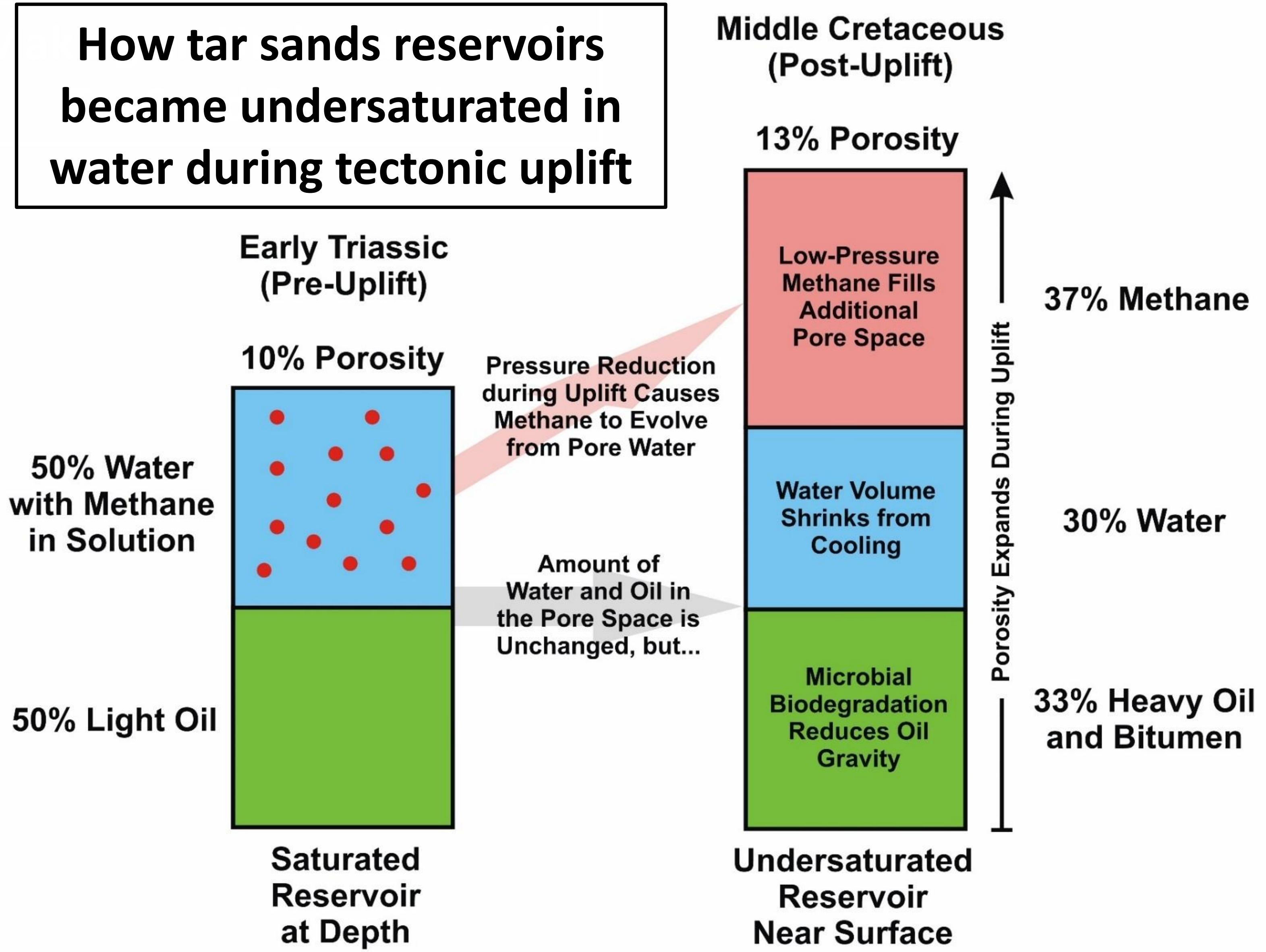
Biodegradation of the oil during migration and trapping formed an immobile bitumen lining of the pore space.



Core analysis from the Big Clifty shows the effect of pore-lining bitumen on reservoir porosity.

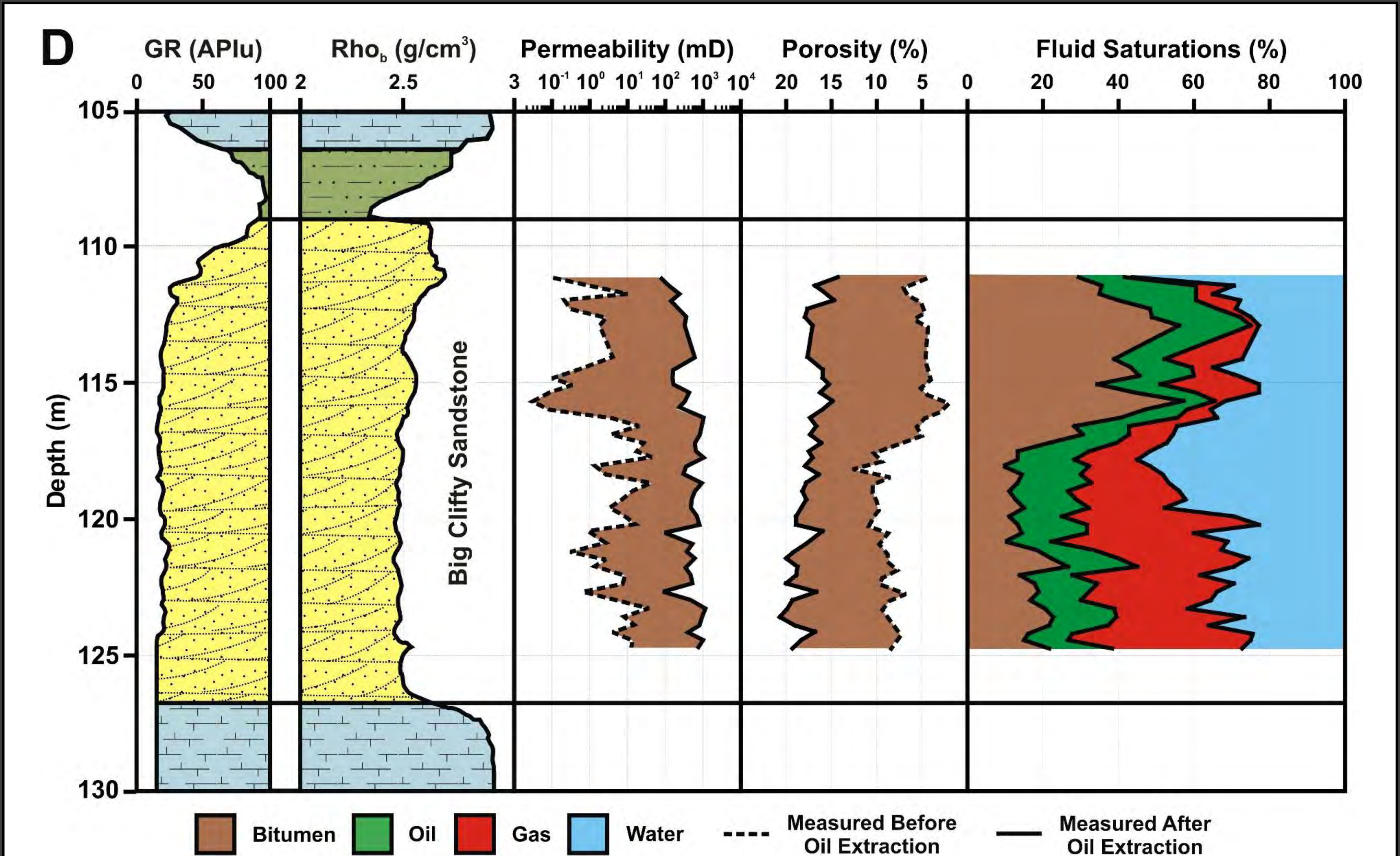
Figures A – C from Bowersox (2016) RI 36

How tar sands reservoirs became undersaturated in water during tectonic uplift



See the discussion in Hoffman (2008, 2013).


MegaWest 102 Clark
550
Neutron
Porosity
Haney Limestone
Density
Porosity
600
Gas Effect
Crossover
Methane Bubbles
In Core Photo
Big Clifty Sand
650
Beech Creek Lime
Upper Paint Creek
Limestone
700
Methane
Bubbles
Big Clifty Core
MegaWest CH 102 Clark
Butler County
626.0 - 626.5 ft
www.norwestcorp.com



Bowersox (2016) RI 36

Interpretation of core analysis from the Westken 18 Vincent well, Edmonson County, showing the effects of microbial degradation of the oil and reservoir undersaturation. **On average, only about 40% of the total oil in place is mobile and potentially producible.**

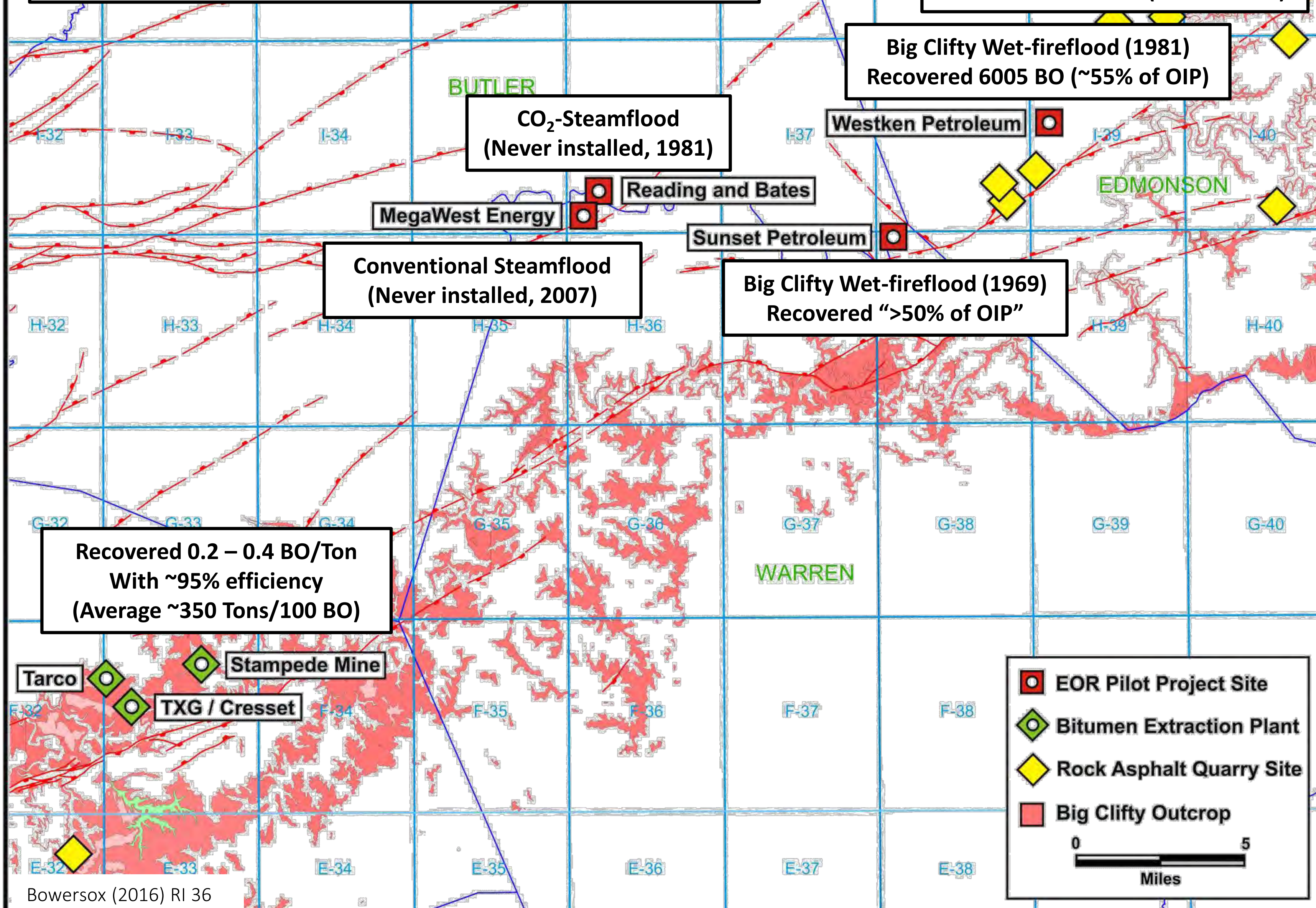
Western Kentucky Tar Sands Resources

Estimated Oil in Place is 3.36 Billion Barrels

- **Caseyville Formation: 117,200 acres, 740 MMBO**
  - Contingent: 111,000 acres, 700 MMBO = 6,300 BO/acre
  - Prospective: 6,200 acres, 40 MMBO
- **Hardinsburg Sandstone : 125,500 acres, 357 MMBO**
  - Contingent : 121,100 acres, 345 MMBO = 2,850 BO/acre
  - Prospective : 4,400 acres, 12 MMBO
- **Big Clifty Sandstone: 364,000 acres, 2,260 MMBO**
  - Contingent : 333,600 acres, 2,100 MMBO = 6,300 BO/acre
  - Prospective : 30,400 acres, 160 MMBO

Total Oil in Place is about 9% more than the previous evaluation of Noger (1984)

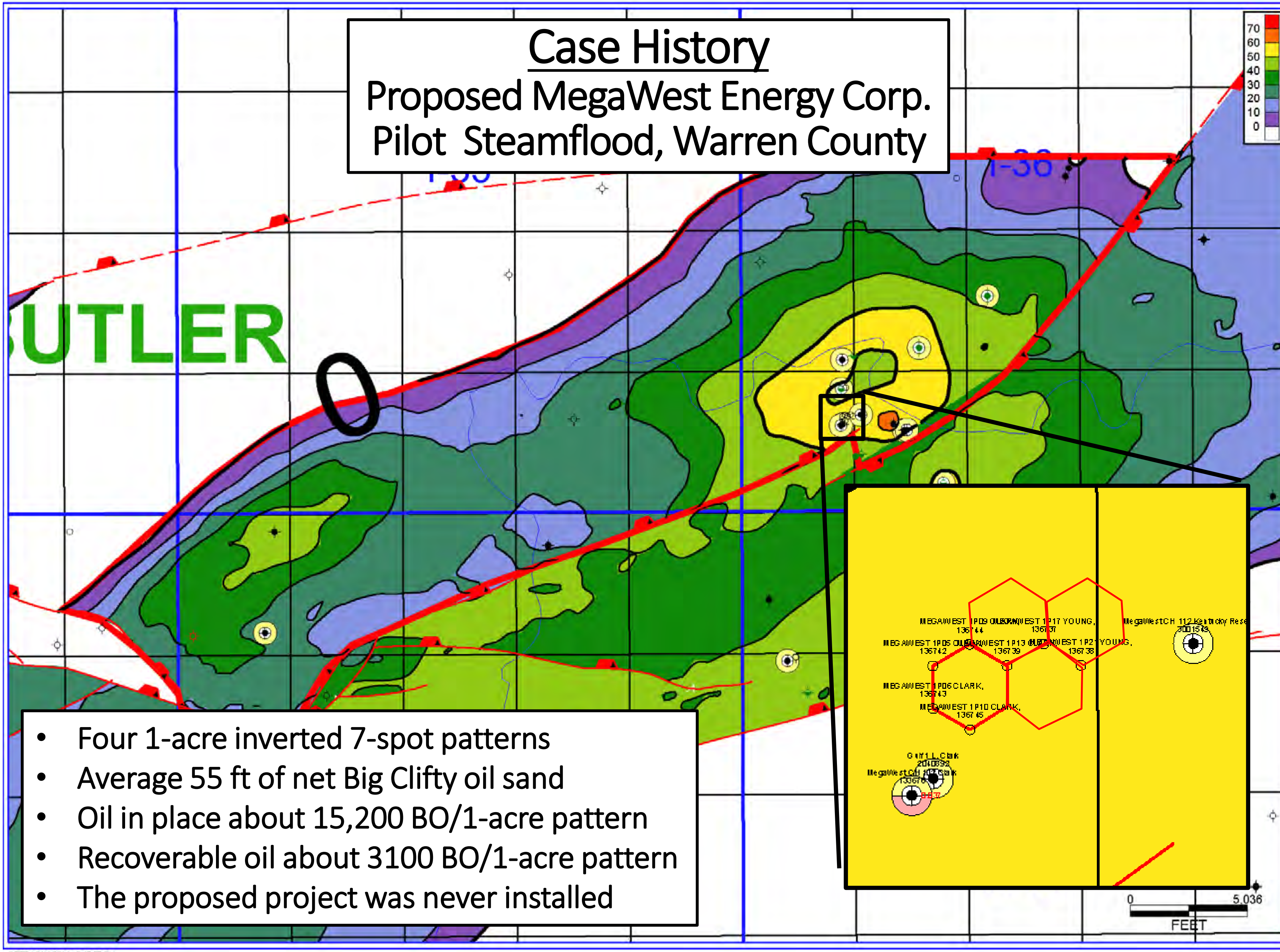
Thermal EOR and bitumen recovery pilot projects in the tar sands



Bowersox (2016) RI 36

<u>Case History</u>

Proposed MegaWest Energy Corp. Pilot Steamflood, Warren County



- Four 1-acre inverted 7-spot patterns
- Average 55 ft of net Big Clifty oil sand
- Oil in place about 15,200 BO/1-acre pattern
- Recoverable oil about 3100 BO/1-acre pattern
- The proposed project was never installed

Case History: MegaWest Energy Pilot Steamflood Project

Assumptions:

- Average OOIP = 15,200 BO/1-acre pattern
- Recoverable OIP = 7,600 BO/1-acre pattern at 50% recovery efficiency
- At an oil price of $100/BO (in 2007) the gross revenues would be $760,000 per pattern, a commercial project.

Reality:

- Movable oil in the Big Clifty is ~40% of OIP, or 3,100 BO/1-acre pattern.
- Revenues would be about $310,000 at $100/BO, less operating costs, trucking, and overhead ($25/BO), royalties (20%), taxes (5% of sales), and capital investment recovery (~$200,000) = $355,000 per pattern, about 15% more than revenues.
- <u>The proposed project would not have been economic</u>

So, what did we learn about the tar sands during this evaluation that is new?

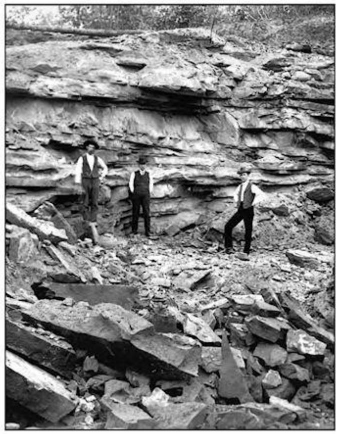
1. Geochemical evidence demonstrates that oil in the tar sands were sourced from the New Albany Shale.
2. Diagenetic partitioning of the tar sands reservoirs was in a geochemically reducing environment associated the migration of the oil.
3. Oil in the tar sands reservoirs was microbially biodegraded to heavy oil and bitumen before Middle Cretaceous exposure at the surface.
4. Tar sand reservoirs are oil-wet, a consequence of the microbial biodegradation of the oil depositing bitumen on the reservoir pore walls.
5. Tar sand reservoirs are undersaturated in water, and underpressured because of rapid tectonic uplift and the lack of connection to an active aquifer.

Recent KGS Publications

Kentucky Geological Survey
University of Kentucky, Lexington

Rocks to Roads to Ruin:
A Brief History of Western Kentucky's Rock-Asphalt Industry, 1888–1957

J. Richard Bowersox



Information Circular 33 | Series XII, 2016

Information Circular 33

Kentucky Geological Survey
University of Kentucky, Lexington

Heavy-Oil and Bitumen Resources of the Big Clifty Sandstone, Northeastern Grayson County and Adjacent Hardin County, Kentucky

J. Richard Bowersox

Report of Investigations 35 | Series XII, 2016

Report of Investigations 35

Kentucky Geological Survey
University of Kentucky, Lexington

Heavy Oil and Bitumen Resources of the Western Kentucky Tar Sands

J. Richard Bowersox

Report of Investigations 36 | Series XII, 2016

Report of Investigations 36

All publications are available for free from the KGS Publications catalog

http://kgs.uky.edu/kgsweb/pubs/pubsearch.asp

Kentucky Geological Survey