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?*

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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


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?

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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
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
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

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

Primary Silica Cement
(Oxidizing Environment)

Secondary Lisegang Banding
(Oxidizing Environment)

Bitumen-saturated Sandstone
(Reducing Environment)

Tertiary Calcite-Kaolinite
Cement at the Diagenetic Front
(Reducing Environment)
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.
Isopach map of net Hardinsburg oil and bitumen-saturated sandstone.
Isopach map of net Caseyville oil and bitumen-saturated sandstone.

Caseyville eroded into Big Clifty

Caseyville eroded into Hardinsburg

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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.
How tar sands reservoirs became undersaturated in water during tectonic uplift

Big Clifty Core
MegaWest CH 102 Clark
Butler County
626.0 - 626.5 ft

Methane Bubbles
In Core Photo

Methane Bubbles

Gas Effect Crossover

Neutron Porosity
Haney Limestone
Density Porosity

Big Clifty Sand

Beech Creek Lime

Upper Paint Creek Limestone

www.norwestcorp.com
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)
Recovered 0.2 – 0.4 BO/Ton
With ~95% efficiency
(Average ~350 Tons/100 BO)

Caseyville Fireflood (1959)
Recovered 3100 BO (~54% of OIP)

Big Clifty Wet-fireflood (1969)
Recovered “>50% of OIP”

Big Clifty Wet-fireflood (1981)
Recovered 6005 BO (~55% of OIP)

CO₂-Steamflood
(Never installed, 1981)

Conventional Steamflood
(Never installed, 2007)

Thermal EOR and bitumen recovery
pilot projects in the tar sands
Case History
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.
- The proposed project would not have been economic
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

Information Circular 33

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

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Report of Investigations 35

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

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Heavy Oil and Bitumen Resources of the Western Kentucky Tar Sands

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