[PS]The Hartselle Sandstone, Alabama's Oil Sands Resource*

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Abstract

The Mississippian age Hartselle Sandstone of northwestern Alabama has been estimated to contain approximately 7.5 billion barrels of bitumen, with roughly 350 million barrels within 15 meters (50 feet) of the surface. No commercial development of these oil sands has occurred as of yet. With the increased desire for North American energy independence, the Alabama Oil Sands Program (AOSP) was established to provide a comprehensive, up-to-date geological and engineering assessment of oil sands resources in Alabama, as well as a thorough evaluation of legal and regulatory issues surrounding development. The AOSP serves as a focus for oil sands activities and initiatives in the state to conduct complete geological, geochemical, geophysical, and engineering analyses. After a comprehensive review of the legacy data available at the Geological Survey of Alabama and the State Oil and Gas Board, a “fill in the gaps” approach is being used for the AOSP. Previously sampled and tested outcrops have been revisited in order to implement modern testing methods to provide updated information about the hydrocarbons and physical properties of the Hartselle Sandstone. Additional sites have been identified and are being sampled and analyzed. A ground penetrating radar (GPR) survey has been conducted in the area of interest, in order to better define the vertical structure and possible hydrocarbon saturation down to an estimated depth of 200 m within the Hartselle Sandstone. Additional analyses of newly acquired cores and subsequent chemical analyses of the rock and bitumen will help ground truth the GRP survey. With the acquisition of this new data, current reservoir models and reserve estimates can then be recalculated using up to date methodologies. Newer near-surface and in situ extraction technologies are being investigated for their applicability to small- to medium-sized deposits such as the Hartselle in Alabama. Thus, the AOSP will provide a comprehensive assessment of the potential for development of the Hartselle Oil Sands of Alabama.

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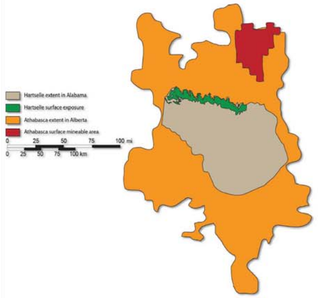
After a comprehensive review of the legacy data available at the Geological Survey of Alabama and the State Oil and Gas Board, a "fill in the gaps" approach is being used for the AOSP. Previously sampled and tested outcrops have been revisited in order to implement modern testing methods to provide updated information about the hydrocarbons and physical properties of the Hartselle Sandstone. Additional sites have been identified and are being sampled and analyzed. A ground penetrating radar (GPR) survey has been conducted in the area of interest, in order to better define the vertical structure and possible hydrocarbon saturation down to an estimated depth of 200 m within the Hartselle Sandstone. Additional analyses of newly acquired cores and subsequent chemical analyses of the rock and bitumen will help ground truth the GRP survey. With the acquisition of this new data, current reservoir models and reserve estimates can then be recalculated using up to date methodologies. Newer near-surface and in situ extraction technologies are being investigated for their applicability to small- to medium-sized deposits such as the Hartselle in Alabama. Thus, the AOSP will provide a comprehensive assessment of the potential for development of the Hartselle Oil Sands of Alabama.

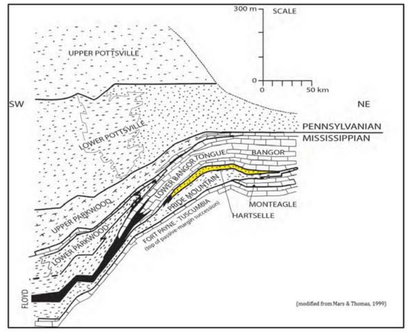
ATHABASCA, ALBERTA VS. HARTSELLE SANDSTONE OF ALABAMA



(from Hills et al., 2016)

- Alberta's oil sands contain about 174 billion barrels of bitumen (Hein, 2006).
- Reserve estimates of oil sands in Alabama are only 7.5 billion barrels of bitumen, with approximately 350 million barrels estimated in the near surface (Wilson, 1987).
- The areal extent of the Wabiskaw-McMurray deposit is approximately 58,000 km² (22,400 mi²) (AER, 2014) with the surface mineable area being approximately 3,700 km² (about 1,430 mi²) (Hein and Cotterill, 2006)
- The surface exposure of the Hartselle is less than 1,230 km² (475 mi²) (Wilson, 1987).

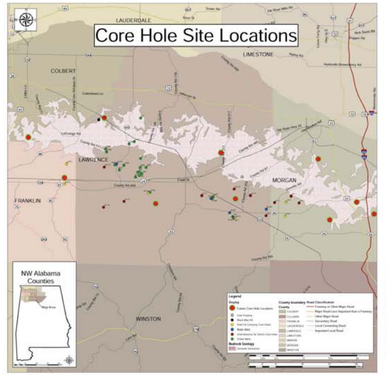
ORIGIN OF HYDROCARBONS IN THE HARTSELLE SANDSTONE



- The Hartselle Sandstone is richly impregnated with bitumen and is porous and permeable thus supporting a conclusion that the bitumen migrated to its present position (Wilson 1987).
- The probable source formations for this bitumen in the Hartselle Sandstone are the dark-colored shales of the Pride Mountain and Floyd Shale Formations, which are stratigraphically lower in the section (Hooks, 2015).
- Many potential sources of bitumen surrounding the Hartselle Sandstone, migration of the petroleum seems more likely than an in situ origin in this situation (Hills et al, 2016).

Outcrop of Hartselle Sandstone

CORE HOLE DRILLING PROGRAM



- For this study a number of rock cores will provide fresh, unweathered samples for analysis and testing, as well as information on thickness, morphology, and physical properties of the oil sands.
- In some cores, geophysical logs to measure parameters such as porosity, rock densities, and acoustic properties, will be collected.

Core Drilling site

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- Alberta Energy Regulator, 2014, Alberta's Energy Reserves 2013 and Supply/Demand Outlook 2014-2023: ST98-2014, 289 pp.
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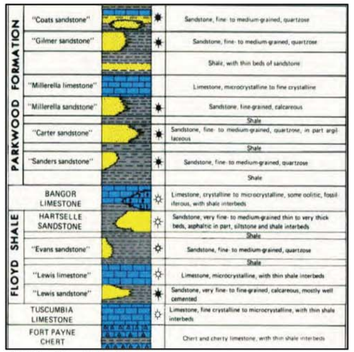
LOCATION MAP

(modified from Wilson, 1987)

Hartselle Sandstone: (saturatied with bitumen)

- Hartselle Sandstone variously saturated with bitumen at the surface in north-central Alabama at various locations dispersed throughout a 112 km (70 mile) long east-west belt that extends from central Morgan County to Colbert County (Hills et al., 2016).
- The outcrop belt (surface exposures) of the Hartselle is generally less than 8 km (5 mi) wide, north to south (Wilson, 1987).
- Hartselle Sandstone dips to the south into the subsurface and underlies other rock units at increasing depths. In Walker and western Jefferson Counties, for example, the Hartselle is encountered in wells at depths of approximately 600 m (approximately 2000 ft) (Hills et al., 2016).

GENERALIZED STRATIGRAPHY of NORTHWESTERN ALABAMA



(Modified from Pashin and Gastaldo, 2009)

- Most significant bitumen deposits for Alabama occur within the Hartselle Sandstone (Wilson, 1987).
- The Hartselle Sandstone is the thickest and most persistent quartzose sandstone in the Mississippian sequence in Alabama (Thomas, 1972).
- It is generally a light colored fine grained, well-sorted, quartzose sandstone that is locally cross-bedded, is partly calcareous thick-bedded to massive, and contains interbeds of clay shale (Thomas, 1972).
- Thickness of the formation range from 0 to a maximum of more than 150 feet (Thomas, 1972).

Hartselle Sandstone: (saturatied with bitumen after heating)

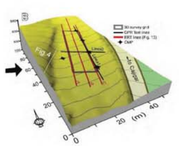
GROUND PENETRATING RADAR (GPR)

TECHNIQUE

Courtesy of Terravision

- Radio waves are emitted at surface to record the dielectric permittivity of the subsurface
- Acquisition systems consist of a transmitter, receiver and recording system
- Records response to frequencies ranging from 1-4500 (MHz)
- Depth of penetration 0-100 m + (subject to acquisition system)
- Vertical resolution cms to meters: depending on frequencies used. (McMechan,1997)
- Lateral resolution subject to special sampling in acquisition (2D or 3D)

RECENT TECHNOLOGICAL ADVANCES



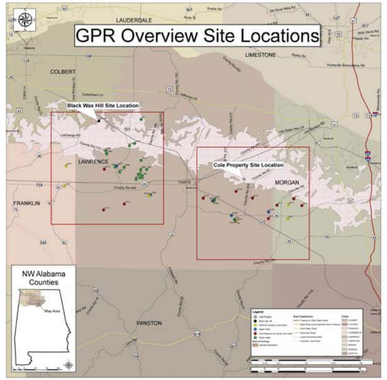
- Soviet developed system originally used for Mars exploration re-developed for mining and oil and gas applications
- Power of transmitter 100,000x historical transmission systems used in GPR
- Results in greater depth of penetration, up to 200 m.
- Recent applications of GPR in conjunction with Electrical Resistivity Tomography (ERT) technology for use in near surface detailed mapping

Petrel Roberts

- A new feature added to this study will be the use of ground penetrating radar (GPR). In conjunction with Electrical Resistivity Tomography (ERT), recent advances in GPR technology can provide detailed results at greater penetration than previous systems. GPR with provide a detailed, continuous image that can be ground-truthed with cores (e.g. top image - Interpreted GPR results plotted with core and permeability profiles (Hills et al, 2016).
- Some studies have projected that imageable depths may be up to about 200 m (650 ft), with recent advances in technology, depending on material type and conditions (Petrel Robertson Consulting Ltd., personal communication, 2014).

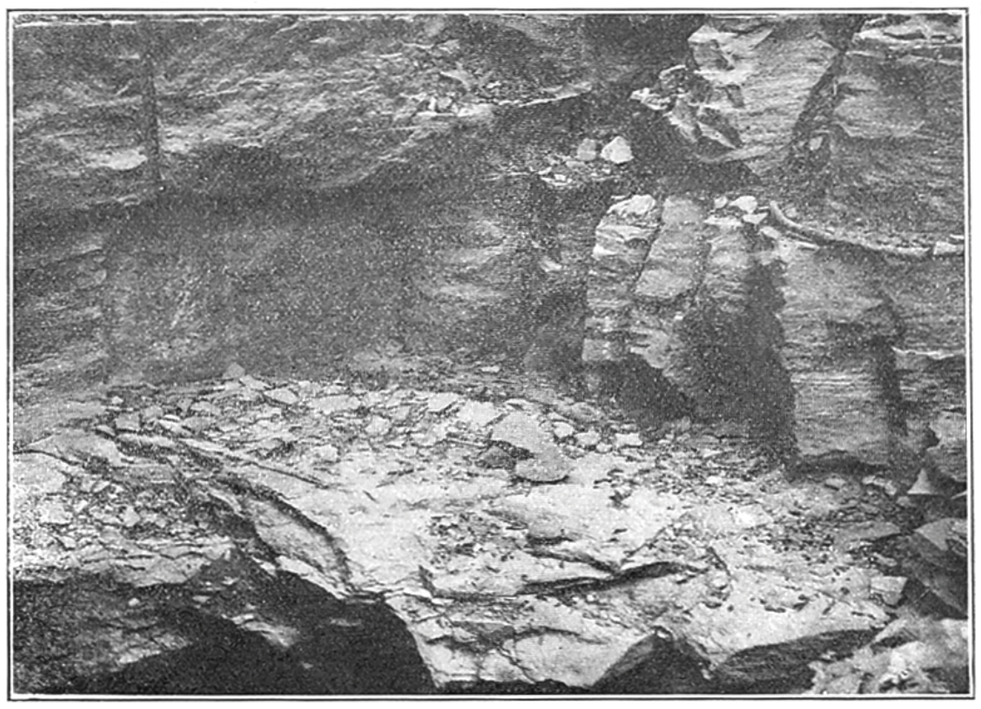
Outcrop of Hartselle Sandstone

ALABAMA OILS SANDS FIELD WORK

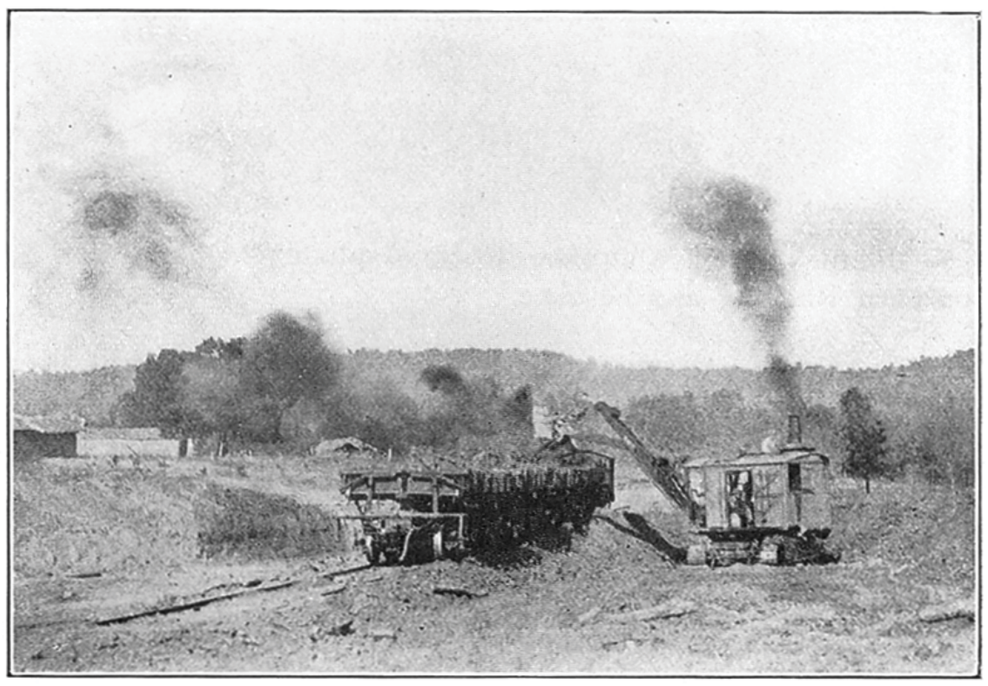


- For this study we have two GPR location sites.
- Both located atop Hartselle Sandstone outcrop.
- One source has visible outcrop bitumen saturation the other does not.
- There is sporadic sub-surface data available in the area for correlation.

HISTORICAL PHOTOS OF OIL SANDS IN ALABAMA



A

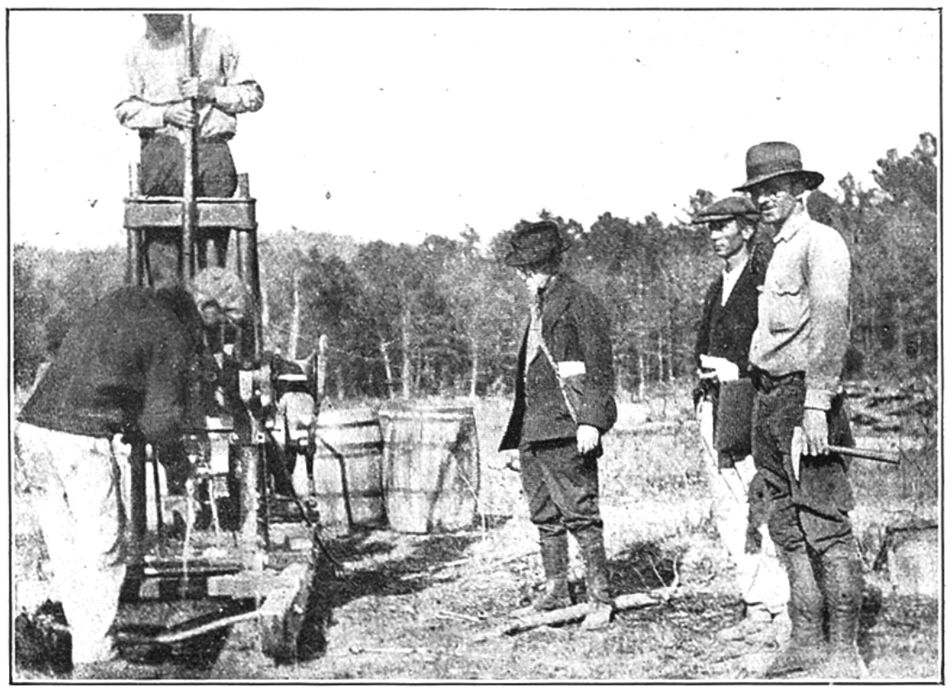


B

B
PLATE 6

- A – Cherokee Rock Asphalt Company, AL Quarry face showing stratification of asphaltic sandstone.

- B – View of the active Cherokee Quarry, showing stripping operation in progress. The steam shovel is standing on the top of the asphaltic strata.



A

B

B
PLATE 7

- A – Diamond drill testing in the Cherokee Quarry.

- B – Plant of the Cherokee Rock Asphalt Company on the Southern Railway at Cherokee.

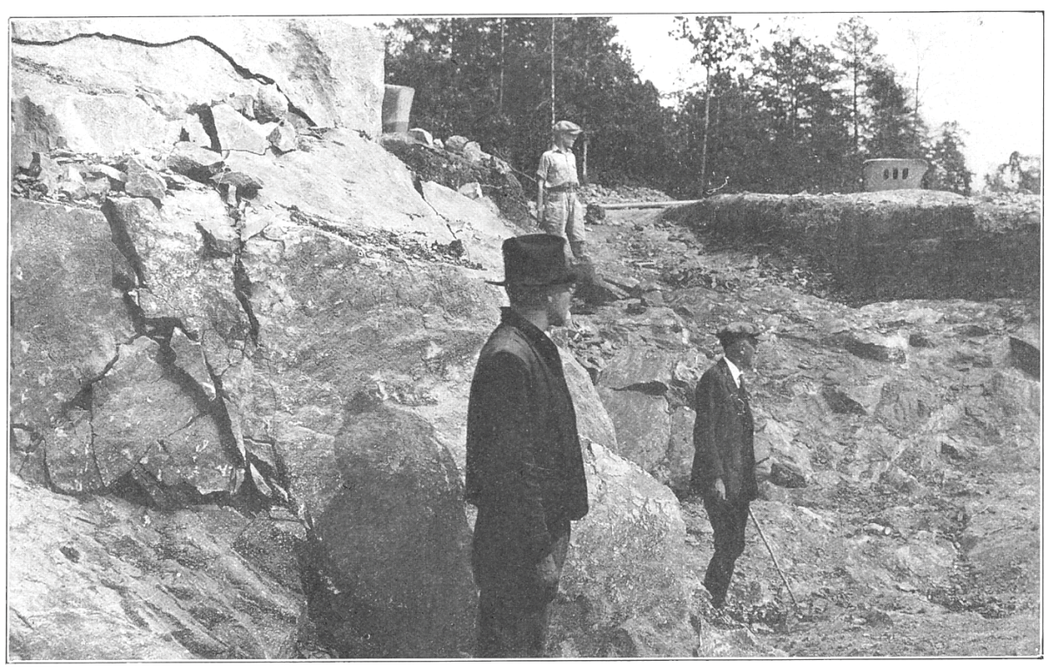


PLATE 13

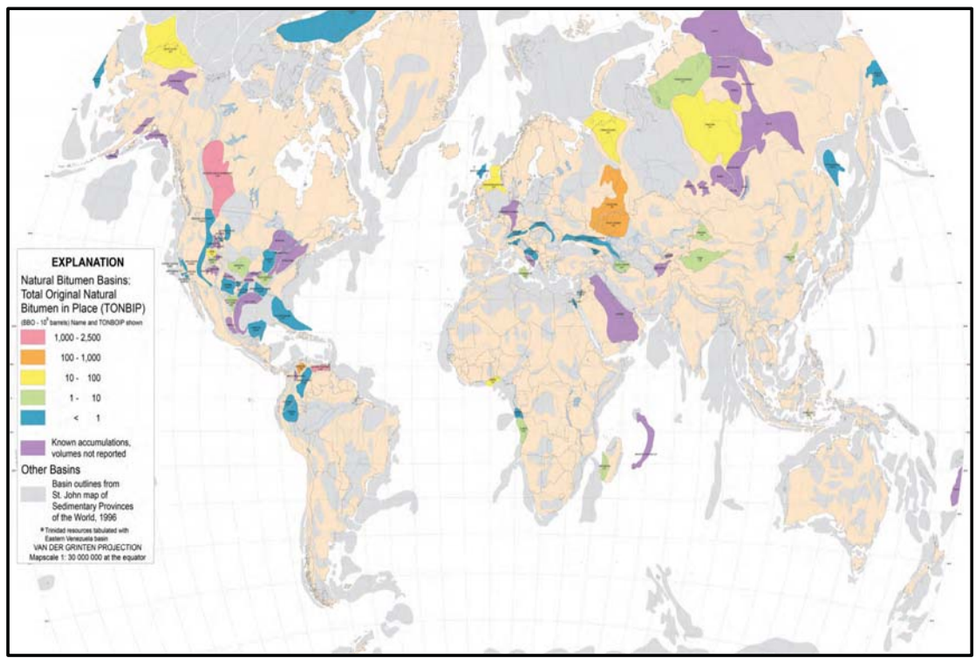
- Margerum Quarry of the Alabama Rock Asphalt Company.

PLATE 11

- Margerum Quarry of the Alabama Rock Asphalt Company. Showing the quarry face and physical character of the deposit.

Pictured here are photos published in **Geological Survey of Alabama Special Report 13** in 1925**.** By George Clark.

OIL SANDS AROUND THE WORLD



Meyers et al., 2007, USGS OFR 2007-1084

- Natural bitumen is reported in 598 deposits in 23 countries.
- World resources of bitumen are estimated to be over 2.6 trillion barrels (Attanasi and Meyer, 2010), compared with the remaining conventional crude oil reserves of 1.02 trillion barrels (e.g., Hein, 2006).
- The majority (almost 2.5 trillion barrels) of natural bitumen is found in North America, with the largest oil sands deposits in Alberta, Canada.
- The only commercially developed deposits as sources of synthetic crude oil, the Athabasca, Peace River, and Cold Lake oil sands areas, are in Alberta, and represent

CANADIAN OIL SANDS VS. ALABAMA OIL SANDS

COMPOSITION

- The Hartselle Sandstone in Alabama is primarily a fine-grained, quartzose sandstone that is generally light colored except where impregnated with bitumen.
- Average composition of bitumen in Alabama's oil sands of the Hartselle is: carbon, 81.4%, hydrogen, 10.2%, oxygen, 2.5%, nitrogen, 0.8%, sulfur, 1.7% (Wilson, 1987).

	Hartselle (Alabama)	Athabasca (Alberta)
C %	81.4	83.1
H %	10.2	10.6
C/H ratio	8.0	7.8
Ni %	0.8	0.4
S %	1.7	4.8
O %	2.5	2.1

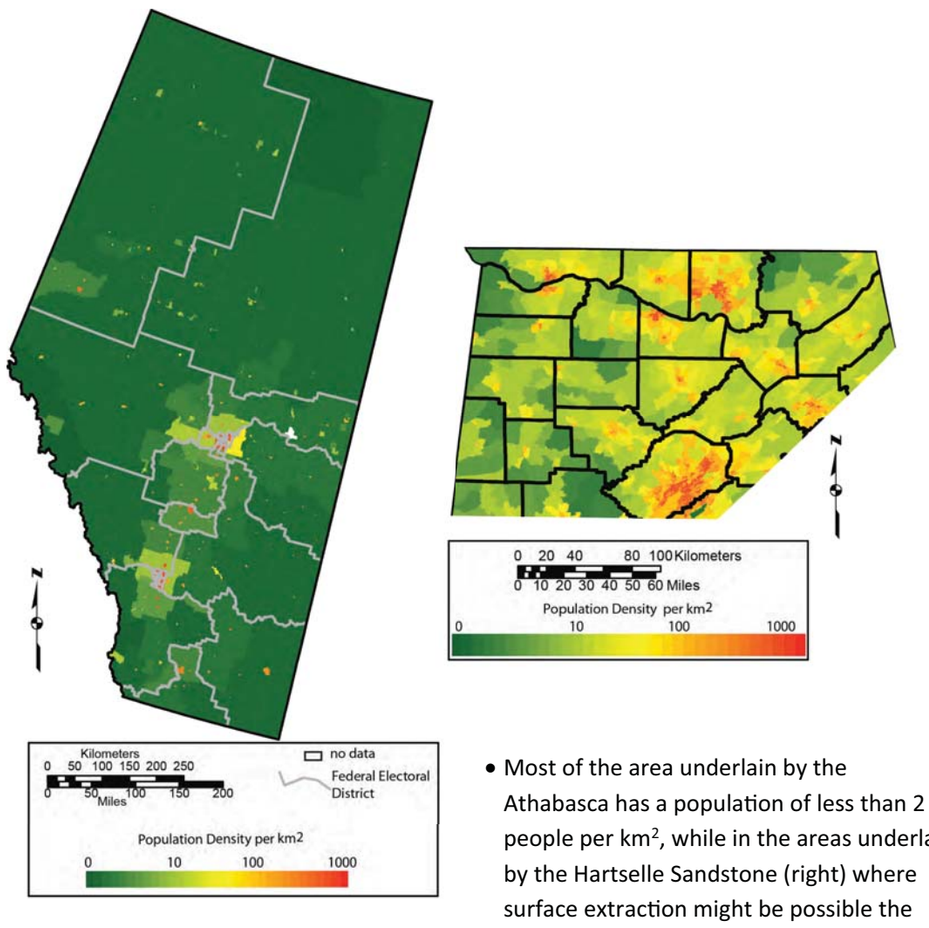
- The sand grains of Canadian oil sands are composed of quartz with traces of mica, rutile, zircon, tourmaline, titanium, nickel, iron, vanadium, and pyrite (e.g., Kaminsky et al., 2008).
- Alberta's oil sands consist of approximately 55-80 wt% sands (primarily quartz), 4-18 wt% bitumen, 5-34 wt% fine solids, and 2-15 wt% water (Bichard, 1987; Kasperski, 2001).
- The composition of bitumen in Canada's oil sands is: carbon, 83.2%, hydrogen, 10.4%, oxygen, 0.94%, nitrogen, 0.36%, sulfur, 4.8%, although individual deposits show some variability (e.g., Starr et al., 1981).

WATER WET AND OIL WET

(from Anderson, W.G. 1987)

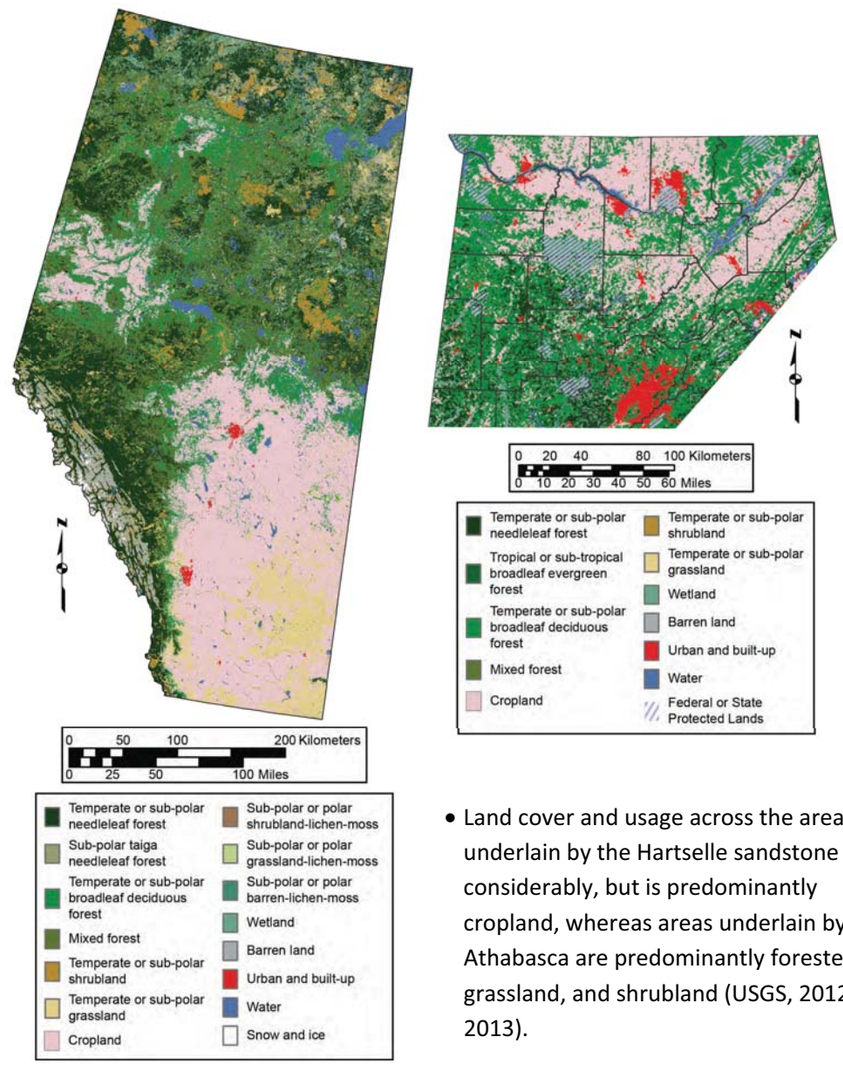
- In water-wet formations a thin film of water coats the surface of the grains in the matrix. In oil-wet formations, oil adheres directly to the solids.
- Wettability determines the distribution of the commingled fluids within reservoir rocks and can directly affect oil recovery.
- Water-wet conditions are more favorable to efficient oil production.
- Changes in wettability have been shown to alter recovery (e.g., Sparks et al., 2003; Dehghan et al., 2009), with recovery decreasing in oil-wet media.
- Techniques that are well established for the water-wet oil sands in Alberta may not provide good return on investment in the oil-wet deposits of Alabama.

POPULATION DENSITY



- Most of the area underlain by the Athabasca has a population of less than 2 people per km^2, while in the areas underlain by the Hartselle Sandstone (right) where surface extraction might be possible the population density ranges from 2 to more than 1,000 people per km^2.

LAND USE



(from Hills et al., 2016)

- Land cover and usage across the area underlain by the Hartselle sandstone varies considerably, but is predominantly cropland, whereas areas underlain by the Athabasca are predominantly forested, grassland, and shrubland (USGS, 2012; CEC, 2013).