Canada's Oil Sands

Maurice Dusseault
The Largest Sedimentary Basins

1. Western Canada Sedimentary Basin (our primary oil source)
2. Hudson Bay Basin
3. Mackenzie & Banks Basins
4. Canadian Arctic Basin
5. Baffin Bay
6. Labrador Sea Shelves
7. Scotian Shelf
8. Grand Banks
9. Anticosti
10. Maritimes Basins
GeoEngineering and the WCSB
Oil and Gas Traps

- First, you need an organic source rock
- Then, it has to be buried >3000 m deep
- Oil must flow to suitable porous traps
  - Stratigraphic traps
  - Fault-controlled traps
  - Folds
  - Salt domes or salt sheets
- The trapping mechanisms for oil and gas...
  - Impermeable barriers (shale, salt)
  - Capillary barriers (fine-grained strata...
Geological Disposition, Canada

Conventional production

Alberta Cross-Section
What is the Oil Sands' Past?

- How did the sediments get placed where they are? Where did they come from?
- Burial of the oil sands
- Where on earth did all that oil come from?
- What has happened to the oil sands in the last 50 million years?
- In the last million years? Ice Ages...
- In the last 10,000 years? Exposure at the surface
- In the last 100 years?
Stratigraphy

- Lithostratigraphy: lithological sequence of the strata and depositional environments

The strata containing oil sands are clastics—gravels—sands—silts—shales.

Underlying strata are organic (carbonates—limestones & dolomites), evaporites (salt—anhydrite—some carbonates) some minor sands and shales, and about 1 km below the oil sands, granites & gneisses.
Up to 80 MYBP

- Igneous rock - stable Canadian Shield
- Subsidence - Pre-Cambrian sandstones, then sands, shales, carbonates, salt (and potash), more shale, more carbonates...
- Then - gentle westward tilting, + uplift, erosion, dissolution of salt, etc.
- 115 MYBP, Cretaceous, a new shallow sea invaded as the basin subsided again
- From the bottom up: residual soils and mud in lakes, coarse river seds, deltas, bars, shallow marine sediments (Mannville Group)
A long period of erosion of the carbonates left a river valley gently rolling landscape

Karstic features

Then subsidence started ~120 MYBP

And, the landscape was covered with a new sequence of clastics:

The Mannville Group
Fluvio-Deltaic Complexity!

Complexity makes geo-engineering more challenging.
Modern analogue

Chesapeake Bay
Block diagram portraying a later stage of McMurray sedimentation, during initial transgression of the Boreal Sea.

Courtesy Neil Edmunds
Exactly how are you going to scale up to the reservoir level?
Then, from 80 MYBP - 1.5 MYBP

- Burial to depth, diagenesis reduced porosity, compacted clays into shale, etc.
- Oil invaded about 80 MYBP
- Gradual uplift as basin rose above sea level
- Removal of 500-1000 m of overlying strata
- Dissolving of salt at depth generated collapse structures and some structure
- Some pre-glacial gravels and river valleys
- Then the glacial era began
  - Glacial loading, erosion, depositing of glacial and post-glacial sediments...
Cementation, Diagenesis

- Stresses:
  - Initial state, \( \phi = 35\% \)
  - Porosity reduction

- Time, temperature, chemistry:
  - Cementation, \( \phi = 25-32\% \)

- Pressure solution:
  - \( \phi = 25-32\% \)
X-Section across BC and Alta

- This is a Cross-Section from SW of Vancouver Island going through Ft McMurray to the NE

- Former volcanic arc, now belt of batholiths
- Rockies Thrust belt
- Foreland basin
- Oilsands
- Distal foreland basin
- Continental crust
- Juan de Fuca subduction zone
- Vancouver Island, Coast Ranges, Mt Baker
- Rocky Mtn Trench
- Craton

Scale: 0 100 200 km

Legend:
- PACIFIC
- BC
- ALBERTA
- SASK
Oil Invasion

- Oil comes from cooking the organic matter in shales (depth + T) > 3000 m deep
- This happened in the Alberta Syncline area
- Oil moved up-dip to the north east
- Trapped in reefs, sands...
- And - exposed to bacteria which ate the small molecules to make their cell walls
- Releasing CH₄, making oil highly viscous...
- And, the oil stopped moving, giving us the heavy oil and oil sands that we exploit now
Vast Heavy Oil Deposits Model

Source: Head Jones & Larter 2003, Nature
Alberta X-Section

- Late Upper Cretaceous / Tertiary
- Colorado Gp
- 2nd White Specks
- Upper Mannville
- Base Of Fish Scales
- Grosmont
- Beaverhill Lake
- Prairie Evaporite
- Winnipegosis
- Leduc reefs
- Swan Hills reefs
- Oil sands

- McMurray Formation
- Glacial deposits

- ProCambrian
- Granite Wash
- Winterburn
- Iretan
- Wabamun
- Upper Mannville
- Lower Mannville
- Leduc Formation

- SW
- NE

- 600 km
- 500 km
- 400 km
- 300 km
- 200 km
- 100 km
- 0 km
Quaternary Unconformity

<10,000 yr old

115,000,000 yr old
70 m of Athabasca Oilsands, North of Fort McMurray, Alta
Some Numbers for Context

- World Oil Production: 87 MMbod
- USA Consumption: 21 MMbod
- Canada Consumption: 2.2 MMbod
- Per capita - World (lower than in 1971): ~4.8 b/person
- Per capita - USA: ~24 b/person
- Per Capita - Canada: ~25 b/person
- Per Capita - China: ~2.0 b/person

Canada produces about 38 b/p. We are a net exporter of oil.
How Much is 25 Barrels?

1.59 m

1.59 m

1.59 m

1.81 m
>80% of the world’s primary energy comes from fossil fuel: oil, gas, coal
~75% of oil consumption is transportation – cars, trucks, trains, ships, planes
How Much is Left? - A

- Originally 13.5-14.5 Tb liquid HC (not counting gas, shale oil, CH₄ hydrates...)
  - ~4.6 Tb conventional oil low viscosity

The 1.1 Tb of oil consumed to date (174 cubic kilometers) was 97% conventional oil, <3% heavy oil. To a large extent, this is the "easy" oil. The next 1 Tb will be less easy, another 0.5 Tb very challenging.

- ~0.5-0.6 Tb from application of known new recovery technology, not "booked"
How Much is Left? - B

- ~9.4 Tb heavy oil (~67-68% of total)
  - ~7-7.5 Tb in sandstones
  - ~2-2.3 Tb in carbonates (usually fractured)

The 2-3 Tb of heavy oil that can be recovered (technically), will be challenging. Anything we can do to reduce CO$_2$ emissions, increase energy efficiency, etc., will help.

- ...4-5 Tb ultimately recoverable, in total
So... Canada's Position...

- ~2 Tb Heavy oil
  - ~1.6 Tb in sandstones, high $\phi$, uncedemented
  - ~0.4 Tb in carbonates, highly fractured, karstic, dolomitized, high viscosity $10^6$ cP

- ~15% of the World’s liquid petroleum, not including natural gas, shale oil...

- Canada: 0.5% of the World’s population...

- The world wants our oil...

- What are we going to do?
**World Reserves: Today's View**

These are not “sanctioned” by any agency

Sources: Oil and Gas Journal – Dec 2002, AEUB
World Reserves: A Better View

Venezuela ~513 Bb reserves
Canada ~350 Bb reserves

Highly conservative estimates
Heavy Oil - Global View

- Arctic conditions
- Steam flood
- Offshore challenge
- Cold production

Cradle of new technologies: Mining, SAGD, VAPEX, THAI™…

Source: JPT, IEA, Schlumberger OFS Marketing

Barrels OOIP
- ~1 billion
- ~10 billion
- ~100 billion
- >1 trillion
USA's Position...

- Imports account for 65% of oil consumption
- Barack Obama, Arnold the Terminator, Al Gore... Increasingly green, CO$_2$ concern...
- Will there be a Carbon Trading System in the USA, or a Carbon Tax?
- Increasing concern over Canadian heavy oil and its large "carbon footprint" as well as the environmental issues in open pit mining
- Are we going to do nothing and let the USA set our agenda?
- What about the Keystone Project?
Alberta – Oil, Gas
BC – Hydro
Sask – Oil
Manitoba – Hydro
Quebec – Hydro
NS – Gas
NFLD – Oil
NB – Hydro

(Ontario & PEI – Nothing!)

Source: EIA Annual Energy Outlook 2008
Geological Issues in Oil Sands

- Disposition of the strata (volume, t, Z...)
  - River channels, beaches, offshore bars, blanket sands, deltaic sands...
- Porosity and permeability of the rocks
- Lithology - sands, shale, silt, ironstones
- Oil, water, and gas saturations - $S_o$, $S_w$, $S_g$
- Nature of the shales as cap rocks
- *In situ* stresses, pressures, temperatures
- Mechanical properties of the rocks

**GEOLOGY IS FUNDAMENTAL TO ALL GEOENGINEERING!**
Canadian Viscous Oil - >2.0 MMbod

Open Pit Mining
Surface Mining

Athabasca Deposit
McMurray Formation

Only the shaded area is amenable to surface mining.
Mining Environmental Issues

- Water requirements for processing
- Atmospheric emissions
- Tailings dikes and stability
- Non-consolidating sludge disposal
- Long-term fate of ponds
- Landscape revamping and land reclamation
- Water seepage into the Athabasca River
- Sulphur and coke... What to do?
- H₂ requirements for upgrading
- Accidental spills, etc...
70 m of Athabasca Oilsands, North of Fort McMurray, Alta
Looking North to the Mine Area
Suncor Tailings and Water Ponds
Suncor, Syncrude (distant)
Seepage from Tailings Dykes

- Pond seepage through foundation = 2 L/s
- Seepage of dyke construction water = 65 L/s

5 olympic-size swimming pools per day! or <0.01% of average flow
Reclamation will be Done...!

...but it must be mandated, with clear targets...
Mining Environmental Issues

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In Situ Environmental Concerns

- Water requirements for steam
- Sand disposal
- Stable emulsions, sludges, oily water...
- High energy needs for steam generation
- Well integrity and GW protection
- Sulphur and Coke: What to do?
- $H_2$ requirements for upgrading
- Accidental spills, etc...
David Dodge
Pembina Institute
150 km South of Ft McMurray

SAGD - Steam-Assisted Gravity Drainage: the primary EOR development in 40 years

Glacial Gravel and Till
Colorado Group
Mannville
Cleary
McMurray Oil Sands
Paleozoic Limestone

Ground Age
10,000 yrs
80 million yrs
100 million yrs
115 million yrs
350 million yrs
Preserving our Wildlife

Saskatchewan

Oil Sands

Saskatchewanian
Material from waste pits being dumped into a concrete holding tub for injection
Cleaning Sludge from Tanks
Tank Bottom Sludges

50% H₂O
30% oil
20% minerals
30 m³ Vacuum Truck
Oily Sand Wastes
In Situ Environmental Concerns

- Water requirements for steam
- Sand disposal
- Stable emulsions, sludges, oily water...
- High energy needs for steam generation means large use of methane
- Well integrity and GW protection
- Sulphur and Coke: What to do?
- H₂ requirements for upgrading
- Accidental spills, etc...
Figure 3
Well-to-wheels Greenhouse Gas Emissions for Oil Sands and Other Crudes

Source: IHS CERA
Results of a meta-analysis of 13 publicly available life-cycle studies.
Assumptions:
* Assumes 55 percent of exports to the United States are dilbit blends and 45 percent are SCO (source: NEB 2009 oil sands exports).
** Steam injection is used for production.
*** Assumes SOR of 3.35.
12 percent loss of volume upgrading bitumen to SCO.
All SAGD crude production cases assume an SOR of 3.
All oil sands cases marked "Dilbit" assume that the diluent is consumed in the refinery, with no recycle of diluents back to Alberta, and only 70 percent of the barrel is from oil sands.
All oil sands cases marked "Bitumen" assume that the diluent is recycled back to Alberta, and all of the barrel processed at the refinery is from oil sands.

Source: CERA Report
Solid & liquid wastes can be placed deep in sedimentary basins with very low risk levels.
Coke & Sulphur at Syncrude
CPI Injection Site – Duri

Waste disposal: a regulatory issue!
No regulations – no clean-up...!
Some Predictions...

- Things will change; they always do...
- ...but your grandchildren will be driving cars powered in part by fossil fuels...
- Resisting technological change is futile...
- ...but companies (people) do it all the time...
- Canada will become “greener”...
- ...based more and more on green technologies, not huge de-industrialization
- Solutions currently exist for all major oil sands environmental problems
- Will is needed for implementation
Oilsands is not a sunset industry, not in your lifetimes! But, we have to learn to do it cleaner, wiser, etc… Soon!

The cleaner we do it, the more the World will be impressed, and the better off everyone will be