Alberta Oil Sands – Faja Orinoco … Bitumen Reservoir Comparison
The World's Two Biggest 'Conventional' Oil Accumulations

Canadian provinces of Alberta, Saskatchewan; *Western Canadian Sedimentary Basin*

- **1.7 Tbbl** in 3 areas – Athabasca, Cold Lake, Peace River (140,000 km^2)
- **9 mines**, **~25 tEOR* projects**, **~5 cEOR* projects**, **dozens of heavy primary projects**
- 10% of volume surface minable, where overburden <50m
- First mine 1967, UTF field laboratory, first commercial steamflood 1980s
- Exports oil as upgraded SCO, dilbit/WCS via pipeline to USA and Vancouver
- Undeveloped carbonate subcrop in Athabasca region
- **Currently producing ~3.6 MMbbl/d, ~30 Bbbl cumoil**

Venezuelan states of Guarico, Anzoategui, Monagas; *Eastern Venezuelan Basin*

- **1.4 Tbbl** in 4 adjacent areas – Boyacá, Junín, Ayacucho, Carabobo (55,000 km^2)
- **5 heavy primary projects**, limited EOR pilots
- 0% of volume surface minable, overburden too thick
- First production late 1990s, after early 1990s *Apertura* policy directive
- Exports oil as Merey-16 diluted bitumen, from Puerto La Cruz port
- Peak >0.75 MMbbl/d, **currently producing 0.5 MMbbl/d, ~4.5Bbbl cumoil**

*tEOR = thermal enhanced oil recovery (aka 'steam flood'); cEOR = chemical enhanced oil recovery

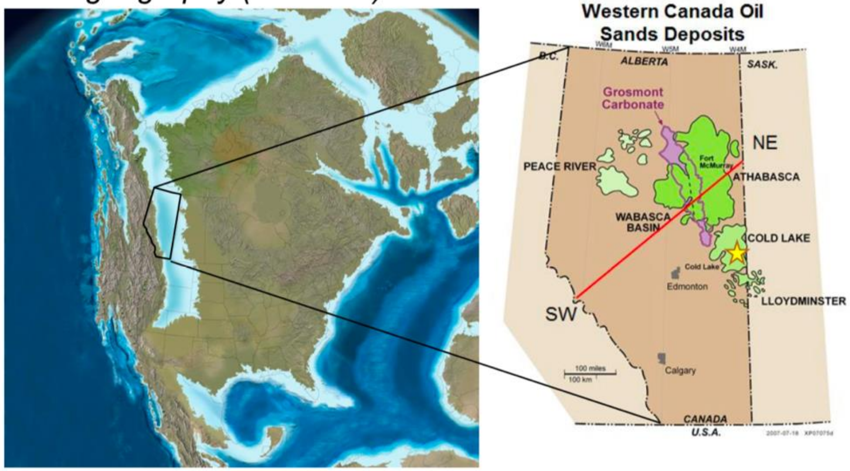
Alberta Oil Sands are not a perfect subsurface analog for Faja, but very useful

OBJECTIVES

- ✓ **Use Alberta Oil Sands as development template for Faja Orinoco**; Alberta tEOR projects well-documented in annual D54 reports to regulator AER
- ✓ Map Faja reservoirs and fluid types to Canadian analogs; screen acreage, design and refine development concepts

Alberta Oil Sands Geology

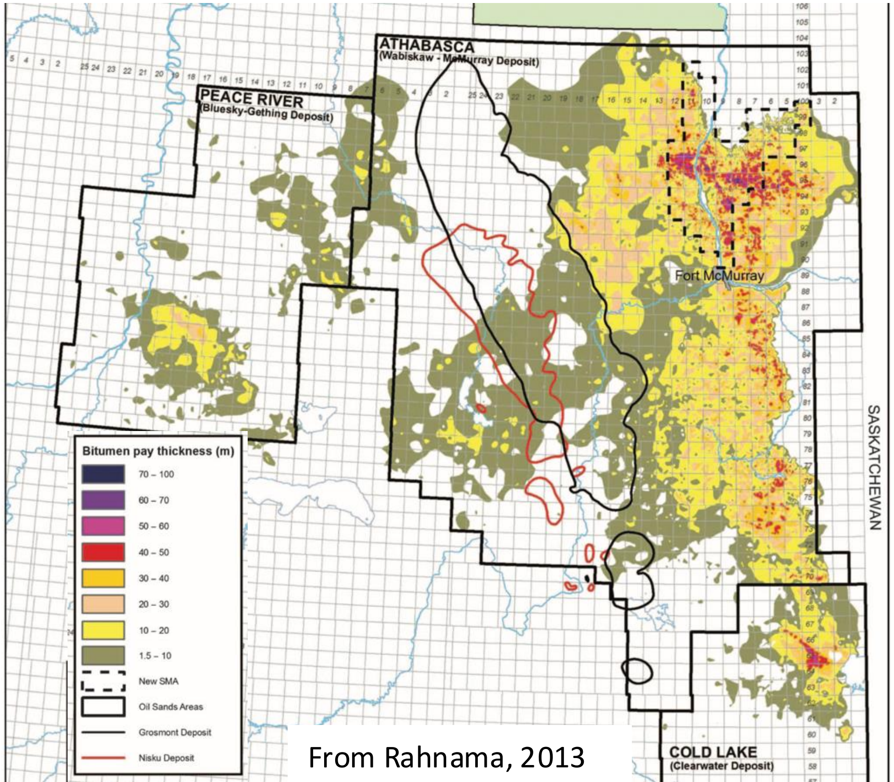
Paleogeography (~100 Ma)



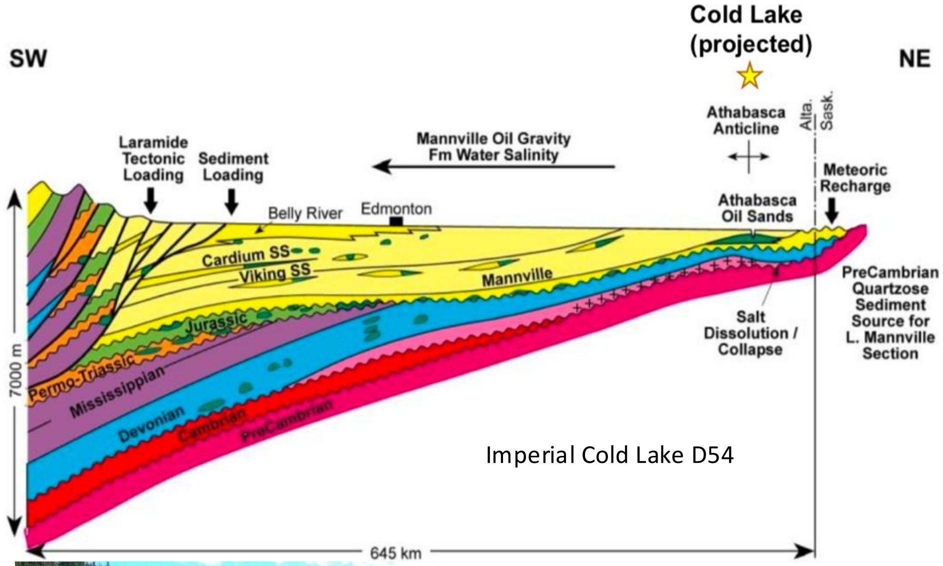
Cretaceous Lower Mannville Group reservoirs

- **McMurray Formation** Athabasca
- **Clearwater Formation** Cold Lake
- **Bluesky Formation** Peace River

- Poorly-consolidated sand deposited during sea level transgression (rise), opening of Western Cretaceous seaway
- Bitumen reservoirs 5-40m thickness
- Basal fluvial channels, top estuarine/marine; big $$$ in inclined heterolith strata (IHS) … point bars
- Undeveloped carbonate subcrop (Devonian Grosmont)



From Rahnama, 2013



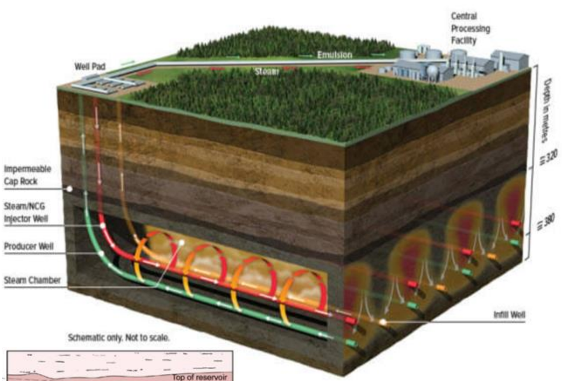
Imperial Cold Lake D54

Famous Steepbank River outcrop IHS atop Devonian carbonate, between oil sands mines

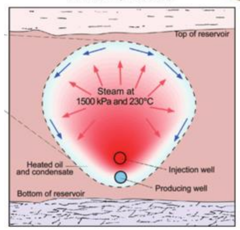
Heavy Oil Production Styles, Alberta Oil Sands

Mining – 1.6 MMbbl in areas with overburden 40m or less (90% RF) … N/A in Venezuela

Thermal EOR (SAG-D, CSS) 1.6 MMbbl in areas with high hydrocarbon density (NtG*por*So)



MEG Energy website



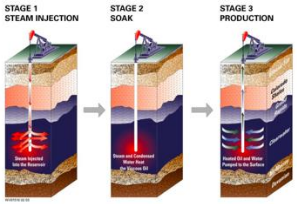
X-sec SAG D pair
Invented by Roger Butler

SAG-D, "Best solution for the best reservoir" … **60+% RF**

- 1D effective KV over 20+ m
- Adjacent steam chambers
- Producer 5m below injector, 1 km laterals
- Reservoir to sufficient temp, then gas injection
- CVE ChristinaLake/FosterCreek, SU Firebag
- 85% of tEOR

CSS … 35-55% RF

- Effective in heterogeneous reservoirs, low KV
- Does not rely on interwell communication
- Vertical, deviated, horizontal configurations
- IMO Cold Lake, CNRL Primrose
- 15% of tEOR



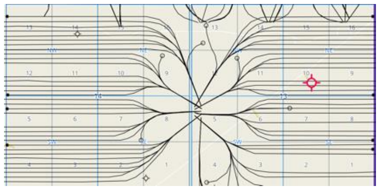
8-16 cycles
Increasing in length

Imperial Oil D54 filing

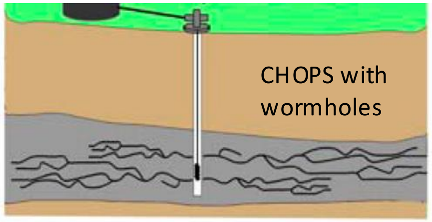
Key metric for steam floods is SOR (steam:oil ratio)
Operators using less steam, more solvent after 'steam chest' established

Heavy Primary Production 0.3 MMbbl/d, lower viscosity oil (5,000-10,000 cP)

- Artificial lift for heavy oil, Progressing Cavity Pumps (PCP) … **5-15% RF**
- Long laterals in moderately-consolidated sand (Clearwater), sand control
- Initial innovation CHOPS (Cold Heavy Oil Production With Sand)
  - No sand control; high-permeability 'wormholes'
  - Typically vertical wells, produced fluid/solid treated onsite

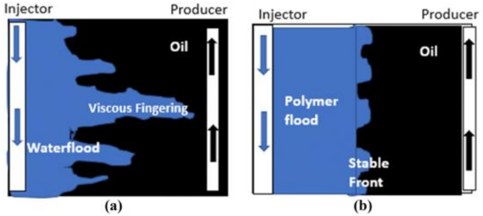


Baytex multilaterals near Peace River

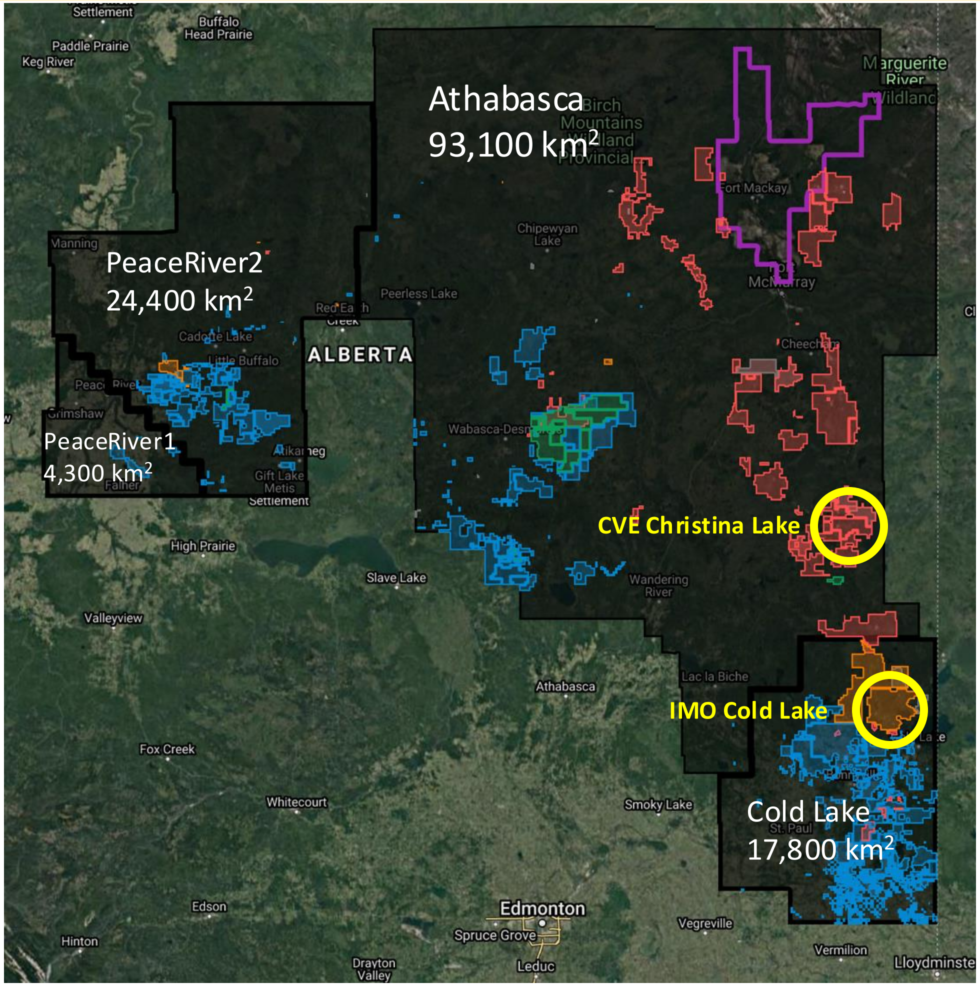


cEOR (Polymer Flood) <0.1 MMbbl/d in laminated reservoirs, lower viscosity

- Increase viscosity of injectant with polymer to improve mobility ratio
- Mobility ratio improves sweep, reduces viscous fingering
- case study CNRL Pelican Lake Project (SPE 165234), 5 m thick, **RF 20-30%?**
- Polymer injection in horizontal wells
- **Balance injectivity with improved mobility**



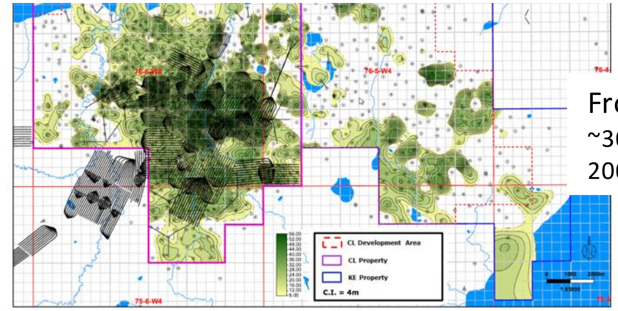
Development Map



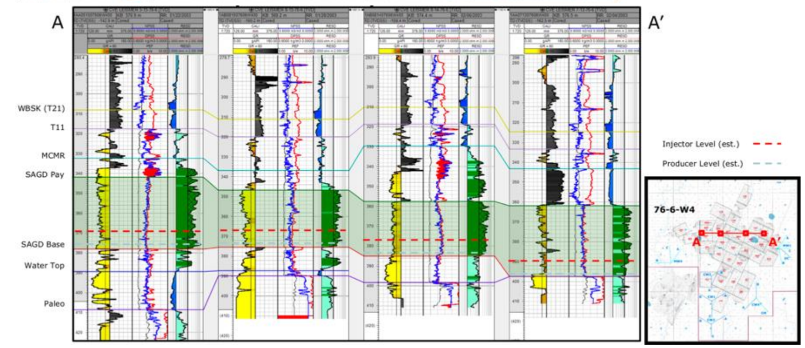
Development schemes (140,000 km²)

- Surface minable area, 4880 km²
- Thermal EOR, SAG-D (Steam-Assisted Gravity Drainage)
- Thermal EOR, CSS (Cyclic Steam Stimulation)
- Chemical EOR (Polymer Flood)
- Heavy Primary (Artificial Lift)

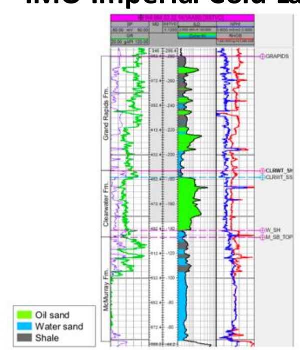
CVE Christina Lake SAG-D 240,000 bbl/d (#1 tEOR in world)

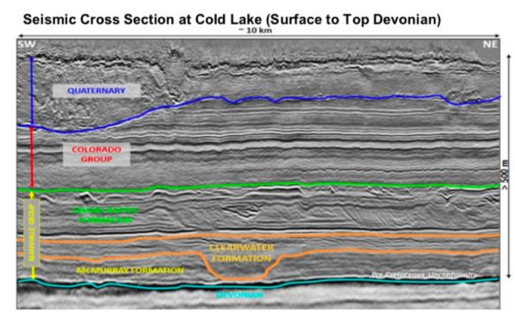


From 2019 D54
~30 pads
200+ SAG-D pairs

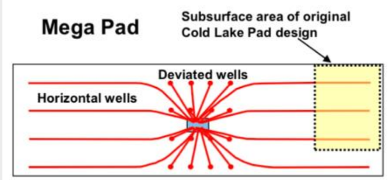


IMO Imperial Cold Lake CSS 150,000 bbl/d (first tEOR in AB)



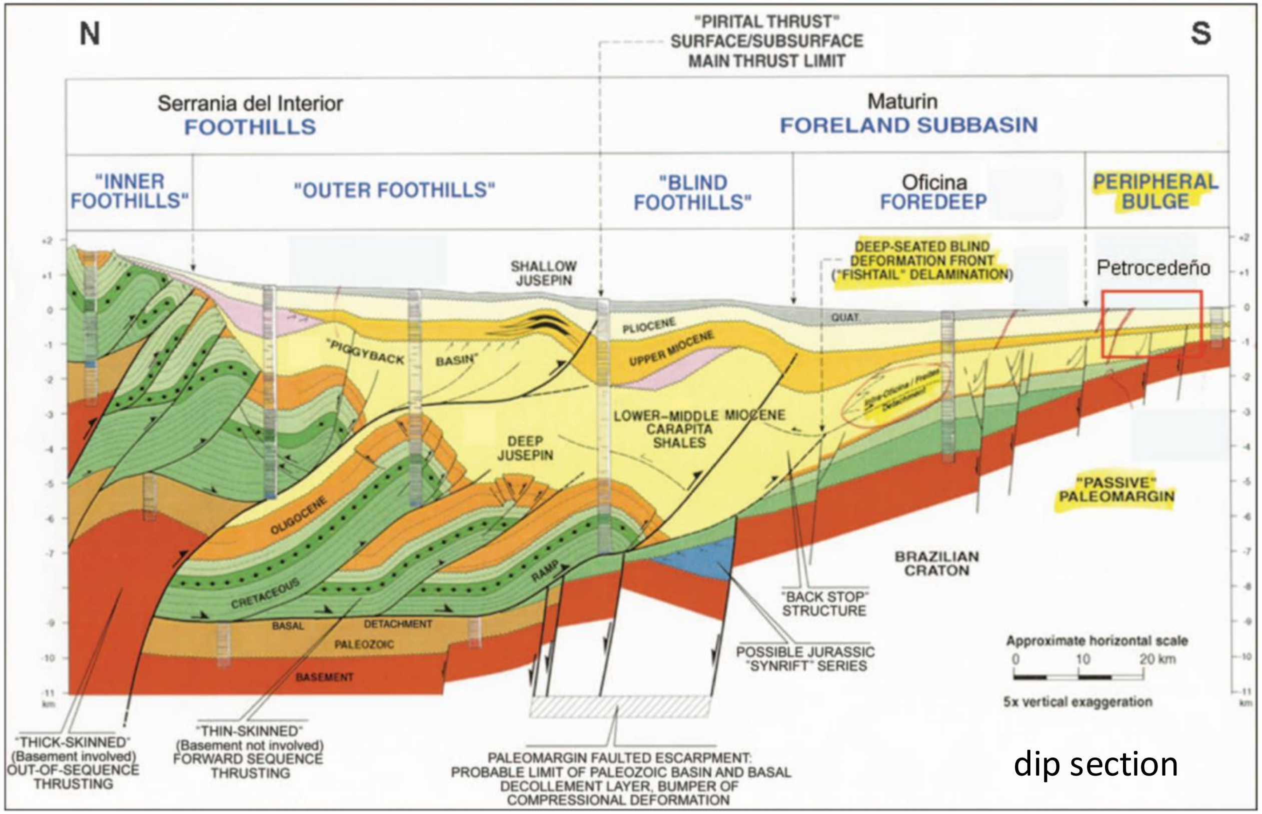


> Up to 35 wells on 4 or 8 acre spacing
> Mix of deviated and horizontal wells



From 2019 D54
~200 pads
1000+ wells; P/I, I

Faja Orinoco Geology, Eastern Venezuelan Basin morphology

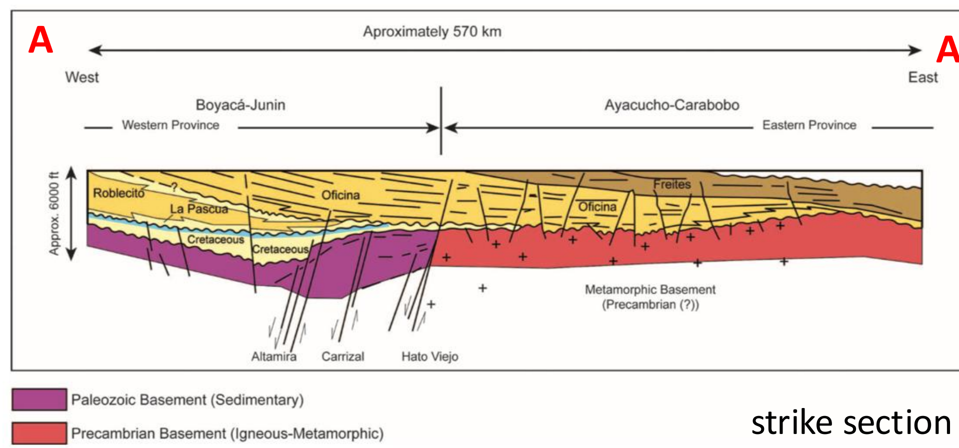


dip section

Maturin foreland sub-basin

Faja Orinoco is bitumen-saturated Miocene Oficina pinchout atop Guyana Shield, 175 km N-S

- Lower Miocene Oficina Reservoir
- Cretaceous Querecual source, 'kitchen' in foreland depocenter south of Serrania del Interior
- Numerous conventional traps to north – Jusepin, El Furrial Fields

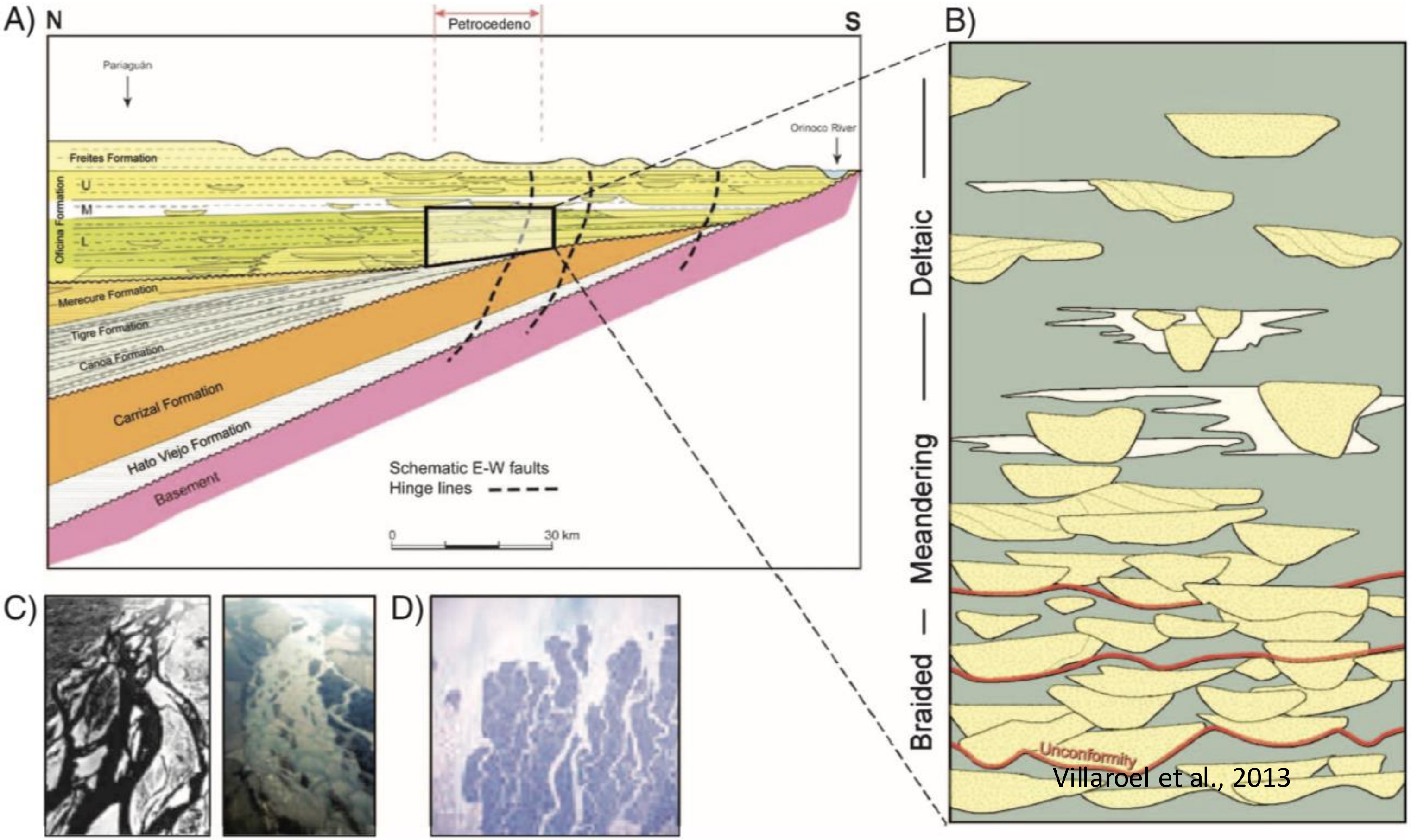


strike section

Faja Orinoco Geology, Sedimentology

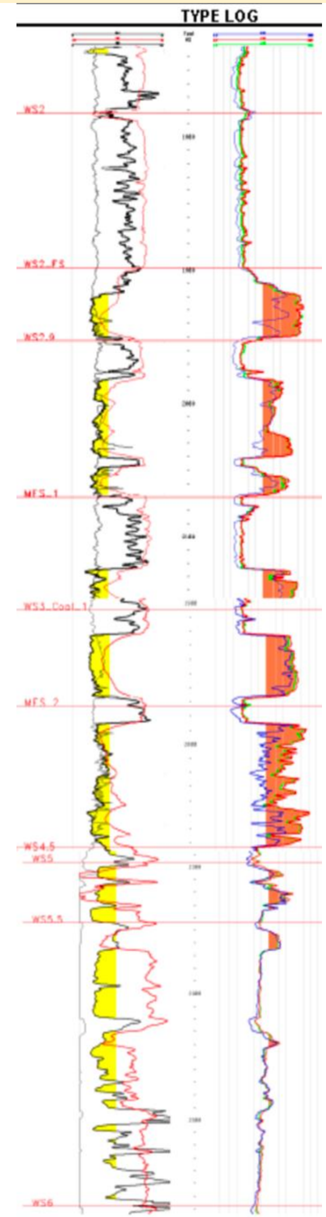
Cross-section across Faja Orinoco Junín Block

Thicker gross interval, and more complex reservoir architecture than Alberta



Braided fluvial channels

Meandering deltaic distributary channels



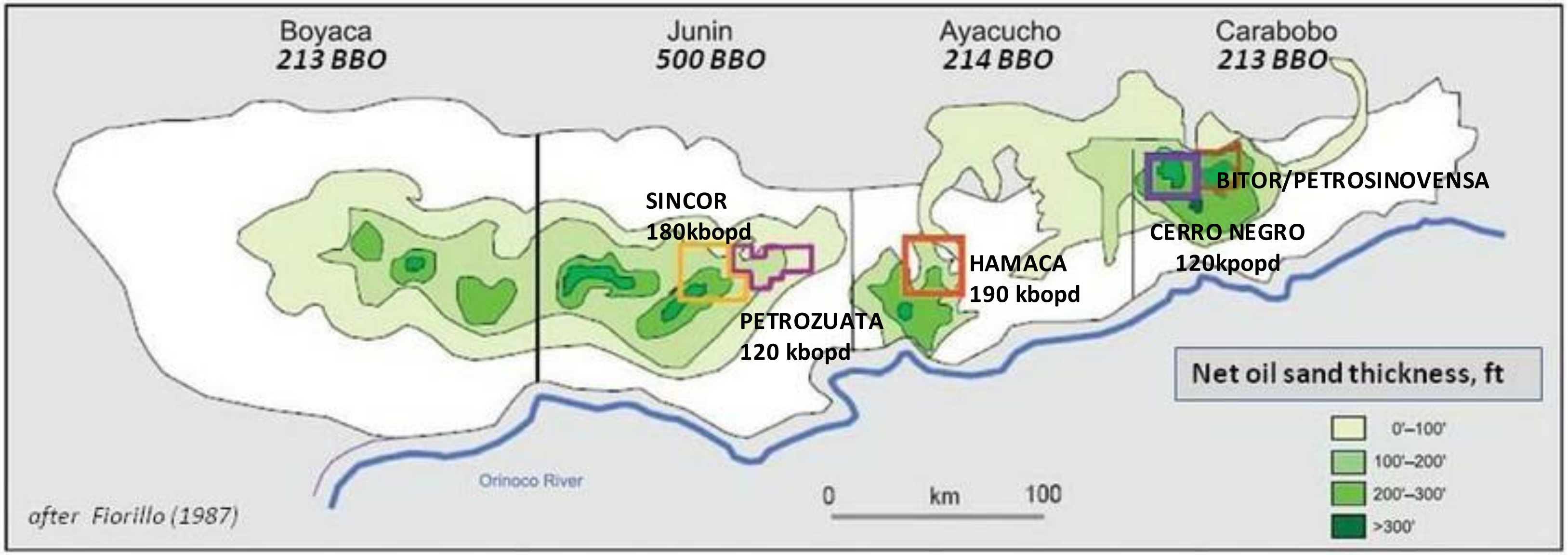
Petrozuata type log
Kopper et al., 2001

Isolated reservoirs must be developed in isolation

- Miocene Lower Oficina stacked braided channel sands, updip transition to meandering and isolated channel/crevasse-splay complexes. Uppermost Oligocene Merecure Formation also reservoir-prone in places.
- Seal – Middle Oficina shales, mudstones

Development Map, Faja Orinoco

PetroMonagas – Russian-operated, originally XOM *Cerro Negro*
Petro San Felix (PetroAnzoategui) – PDVSA-operated, originally COP *Petrozuata* (1st project on-stream)
PetroCedeño – PDVSA-operated, originally Statoil/Total *SINCOR*
PetroPiar – Chevron-operated, originally Texaco/COP Hamaca
PetroSinovensa – CNPC-operated, originally PDVSA *BITOR*, blending project with no associated upgrader

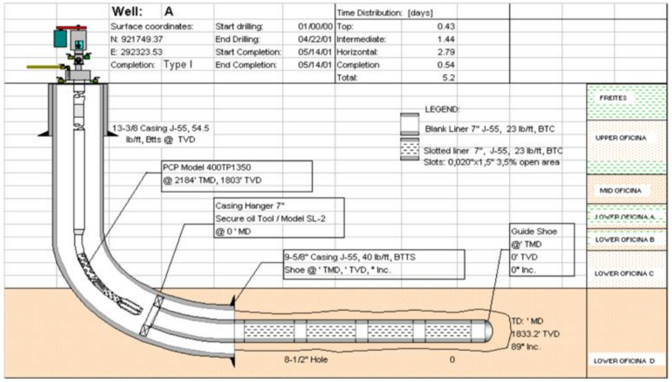


• Depth range	1600–4000 ft	•Initial res. pres	800–1000 psi
• Temperature range	115–130°F ~50C	•In-situ viscosity	1000–5000 cp
• Gross thickness	200'–500'	•Porosity range	28–34%
• Net thickness	50'–300'	•Permeability	1–20 + d
• API gravity	7.5–9.5	•Water Saturation	8–30%
• Initial gas-oil ratio	60–70 scf/Bo	•Rec. factor (cold)	9–12.5%

Case Study, Sincor (originally PDVSA/Total/Statoil)

Now PetroCedeño after 2021 departure of Total/Equinor

- 200 kbopd in 2004, 180 kbopd upgrading capacity
- Unconsolidated sand, 1800’ depth, 8° API
- 4600’ extended reach wells with PCP AL
- Diluent injection 47° API naphtha at toe or PCP; API to 16°
- 335 horizontal wells early, later multilaterals; 8.5” horizontal, 7” slotted liner; 900+ wells by 2013
- 200 km pipeline to coast
- Final products 32° API Zuata sweet, sulfur/coke



Well schematic diagram from Ramirez et al., 2004

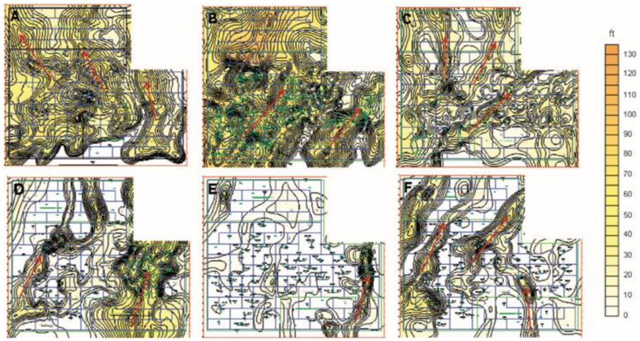
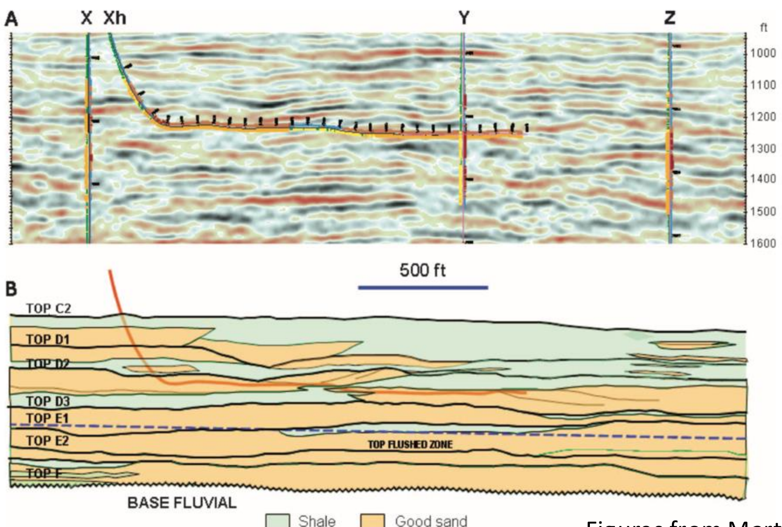
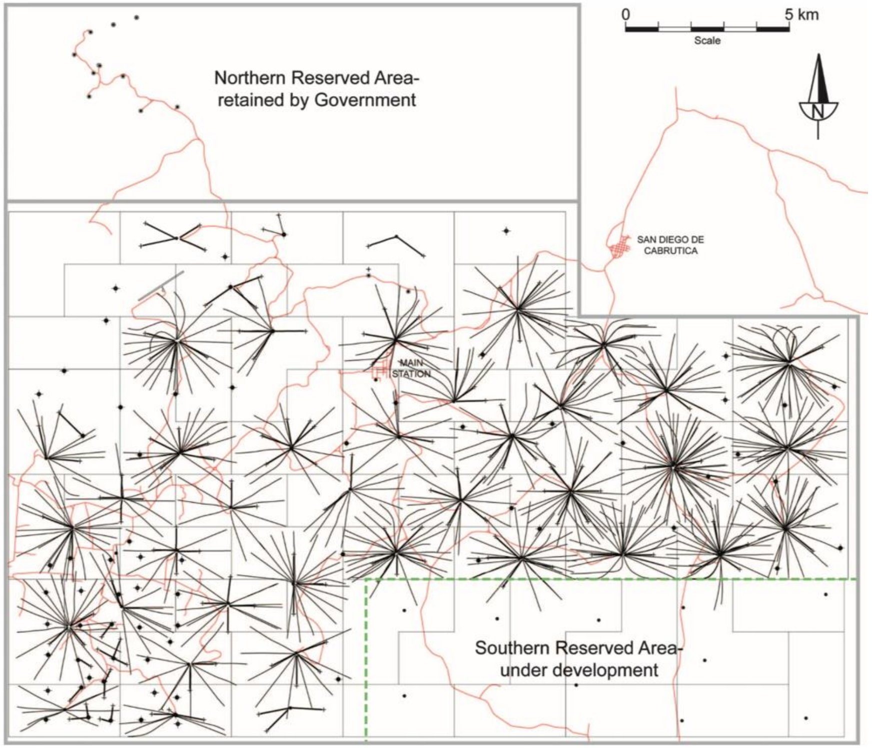


Figure 15. Net sand maps of successive sequences. (A) Sequence 3 (unit E1); (B) sequence 5 (unit D1/D2); (C) lower part of sequence 6 (unit C2); (D) sequence 8 (unit B2); (E) sequence 9 (unit B1); (F) sequence 10 (unit A2). 10 ft (3 m).



Figures from Martinius et al., 2013

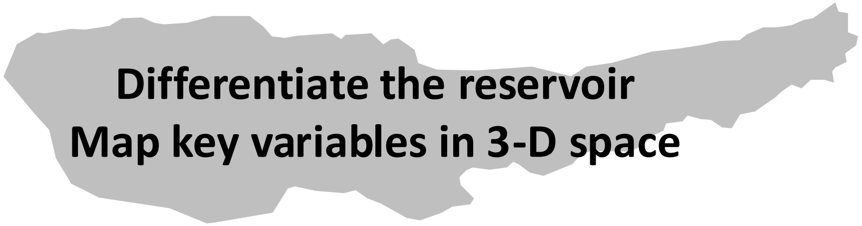


Sincor development scheme, radial horizontal wells

What next? More detailed reservoir characterization.

Objectives

- Use Alberta Oil Sands as development template for Faja Orinoco
- Map Faja reservoirs and fluid types to Canadian analogs

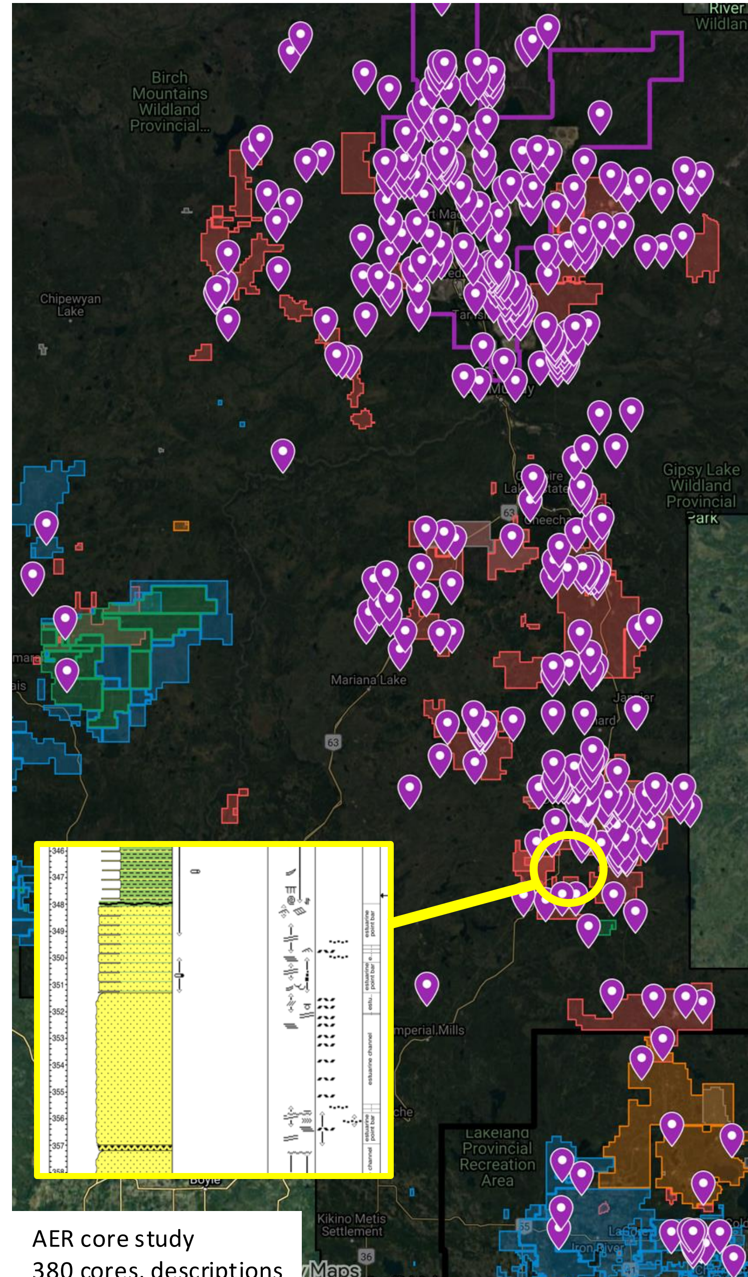


Differentiate the reservoir
Map key variables in 3-D space

- **Net thickness**
- Number of flow units
- Depth to top reservoir
- **Hydrocarbon density** (NtG*por*S_o) by flow unit
- Dykstra/Parsons permeability variation, at well scale
- **Effective KV** over flow units
- Base water thickness where OWC present
- Fluid properties – **viscosity**/API, lateral/vertical variation in multi-phase fluid saturation (oil, water, gas)

Near-term deliverable

- ✓ GIS project with shapefiles…
- ✓ Map of ALL well penetrations, not just development areas
- ✓ 100 type logs, maybe 50 described cores, core photos
- ✓ Top structure map (hi-res)
- ✓ Net thickness map (hi-res)
- ✓ Vertical permeability map by flow unit
- ✓ Map of lease boundaries



AER core study
380 cores, descriptions