Case Study of a Large Conventional Oil Pool Discovery in a Mature Basin: the Upper Mannville of the Western Canada Sedimentary Basin

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Talk Outline

PART 1:

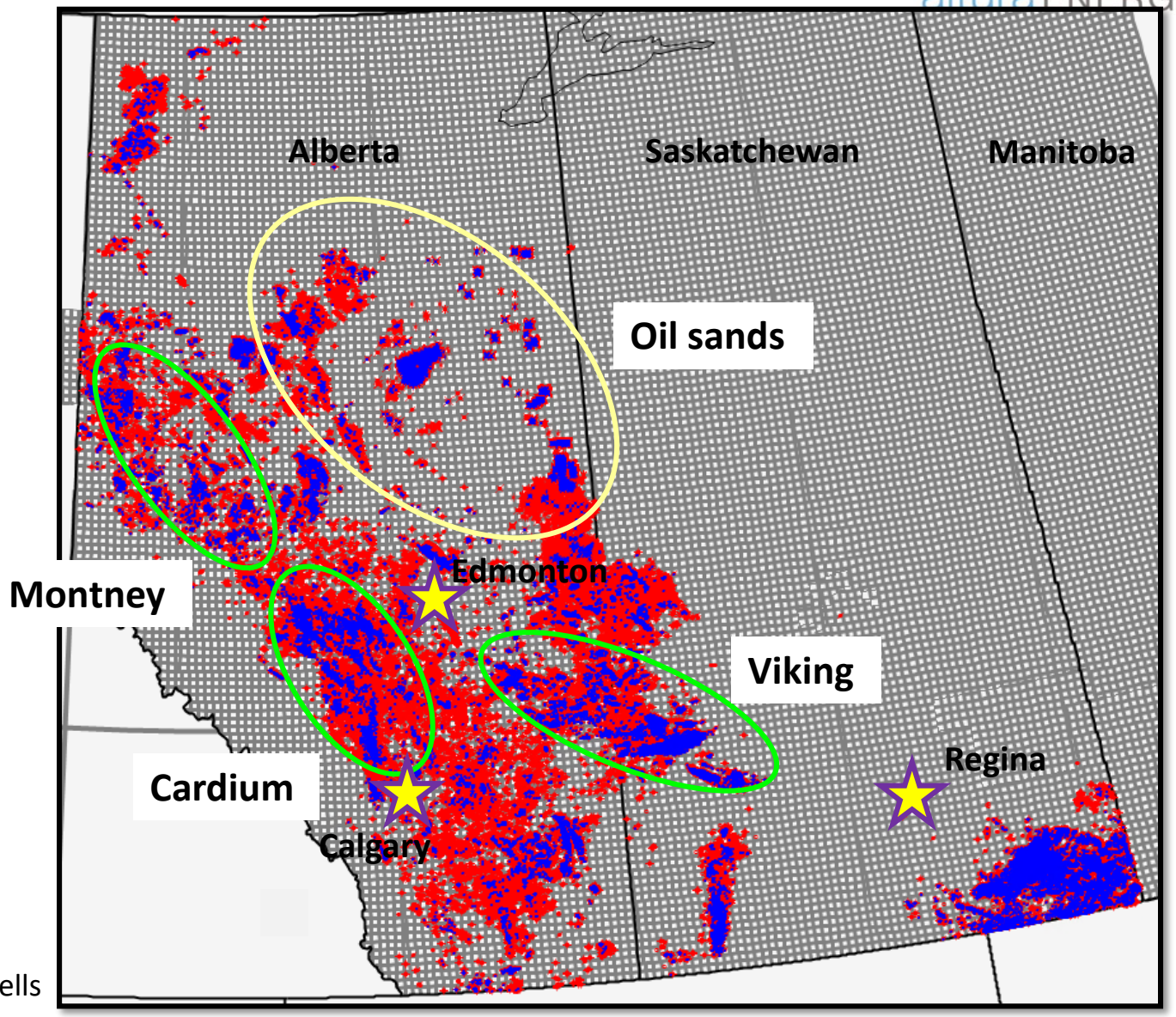
- Upper Mannville regional picture
- Overview of Leduc-Woodbend (LWB) area
- Discuss largest conventional oil pool discoveries in the basin
- Why was this pool undiscovered for so long?

PART 2:

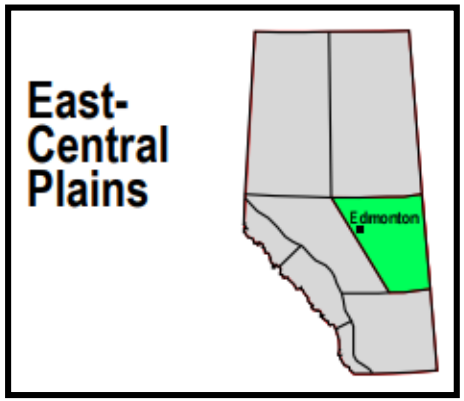
- Pool parameters and key characteristics
- Pool exploitation process
  - Drilling and Completion practices
  - Production results
  - Economics
  - Development plan
- Conclusions

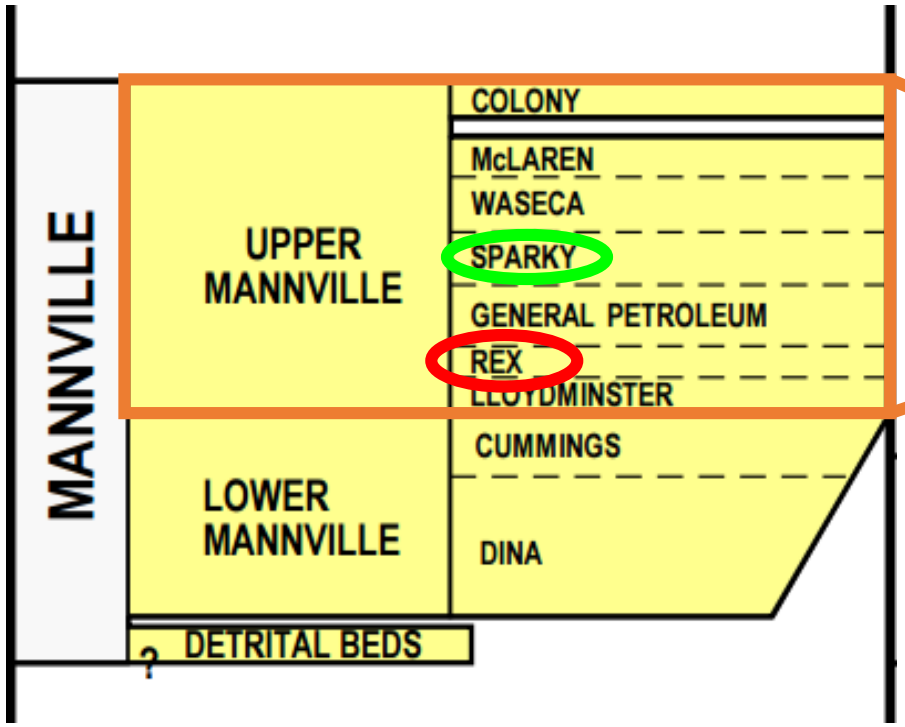
WCSB Distribution of Oil Pools

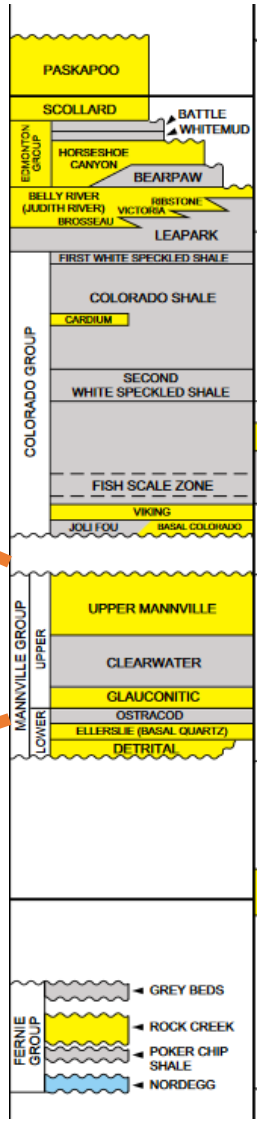
- 172Bn bbls or 10% of world's total proved oil reserves (3rd largest)
- 4.2MM bbls/d production (6th largest)
- Greater than 700k wells

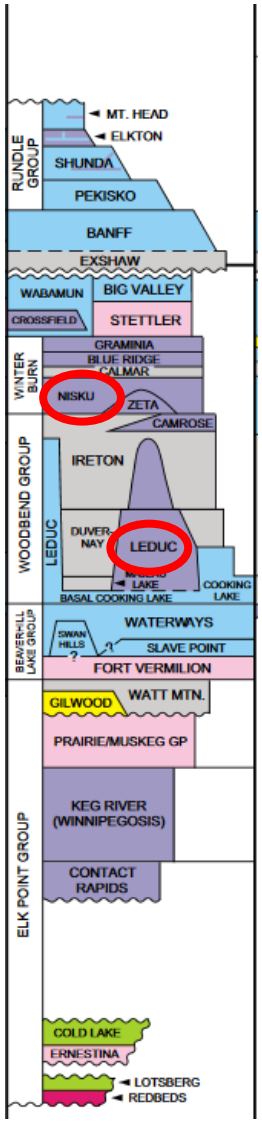


WCSB Stratigraphic Column





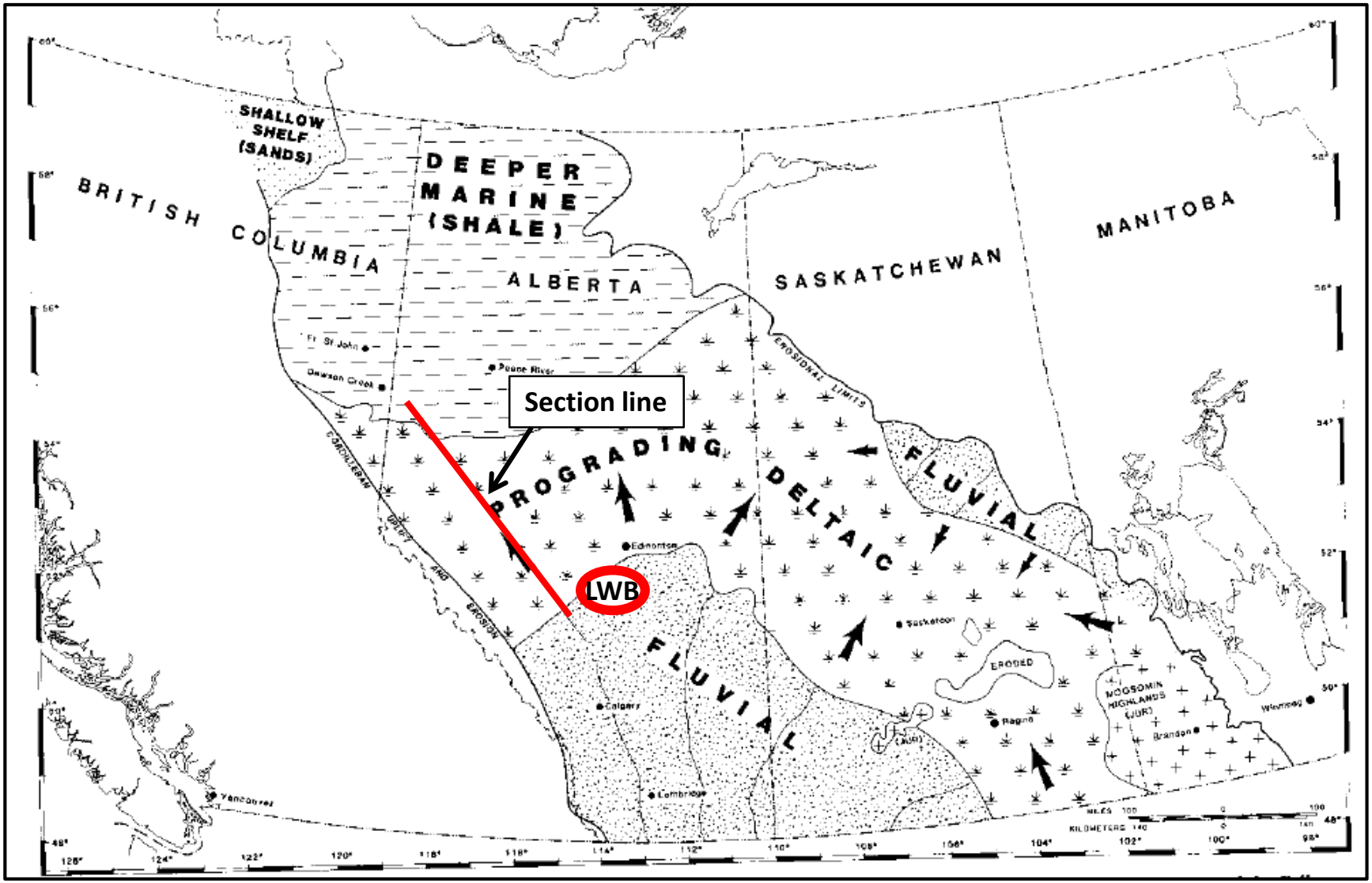




Upper Mannville
Key Characteristics

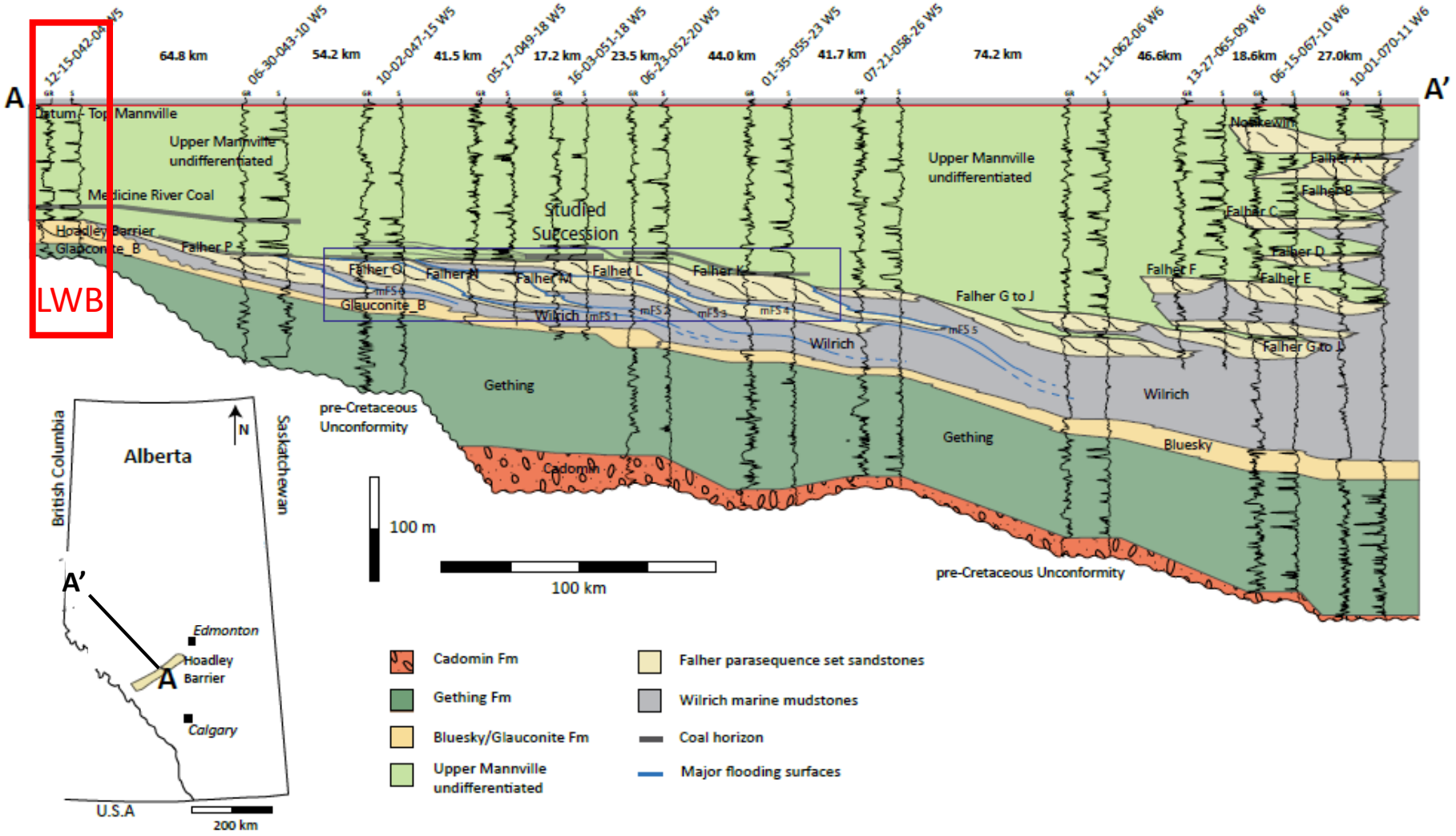
- Full spectrum of depositional environments:
  - Coastal plain to deltaic and marginal marine to fully marine
- Progradation northward across the foreland basin
- Extensive coastal plain deposits in the south to fully marine shales in the north
- Climate was warm and humid with extensive coal deposits to the south
- Sediment load derived from volcanic and tectonic events to the west in the ancestral Canadian and American Rockies
- Sands typically immature and lithic containing volcanic and feldspathic components; complex mineralogy with moderate to abundant amount of clays and cements

Upper Mannville Paleogeography



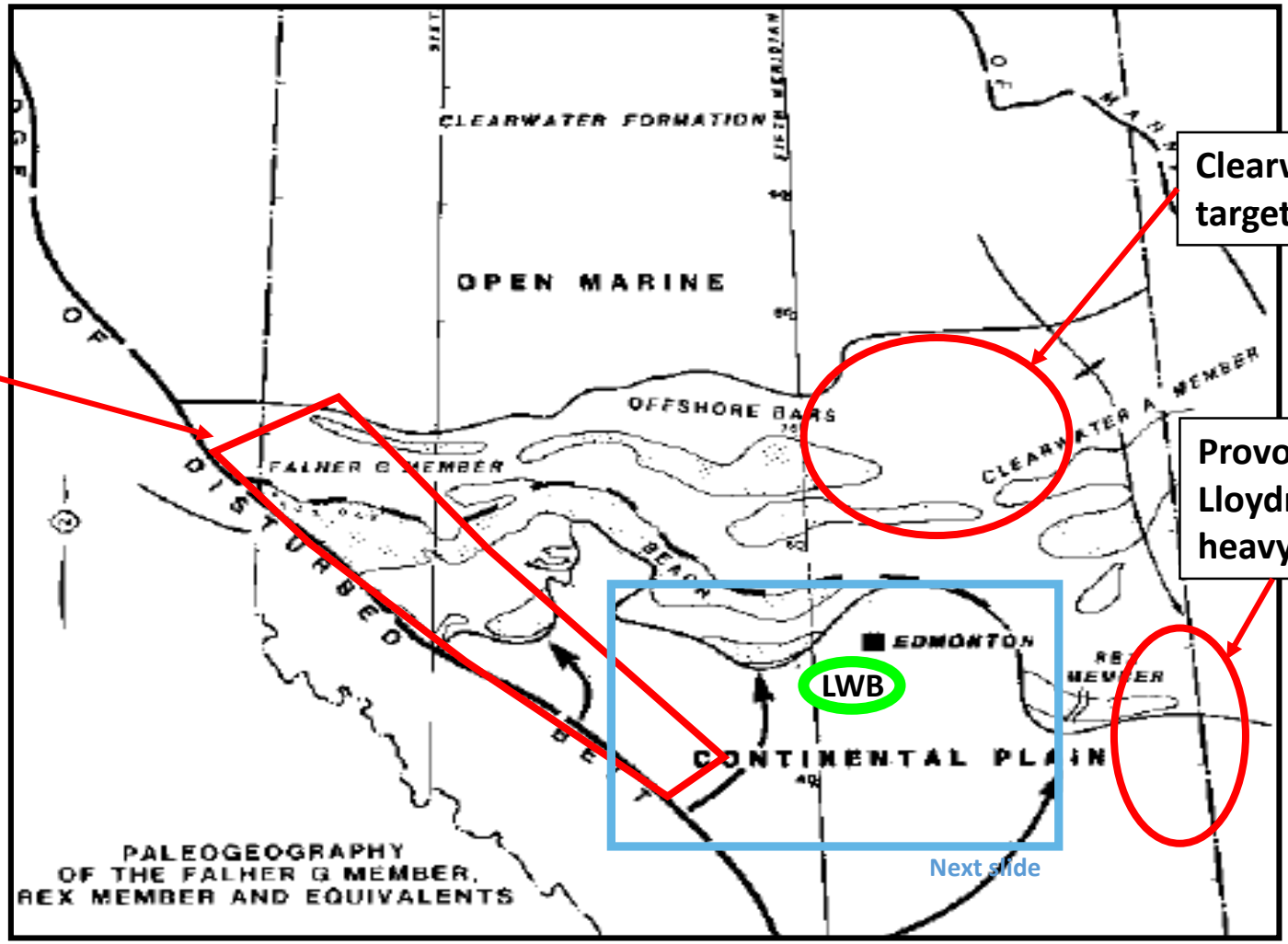
From Leckie and Smith, AAPG Mem 55

Upper Mannville Regional Cross Section



From Newitt 2017

Falher, Rex & Clearwater members Paleogeography



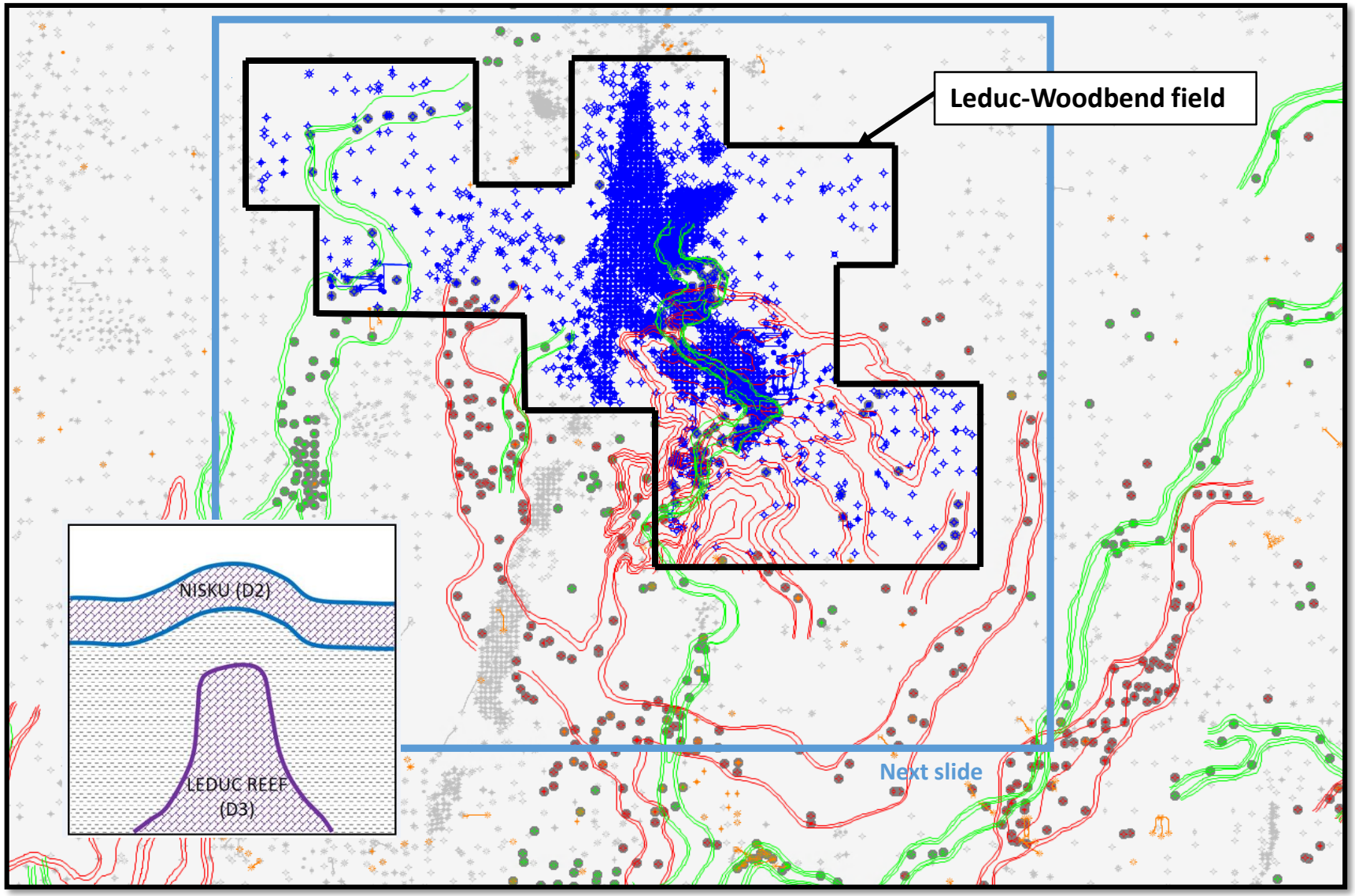
Clearwater oil targets

Spirit River (Falher) deep basin gas fairway

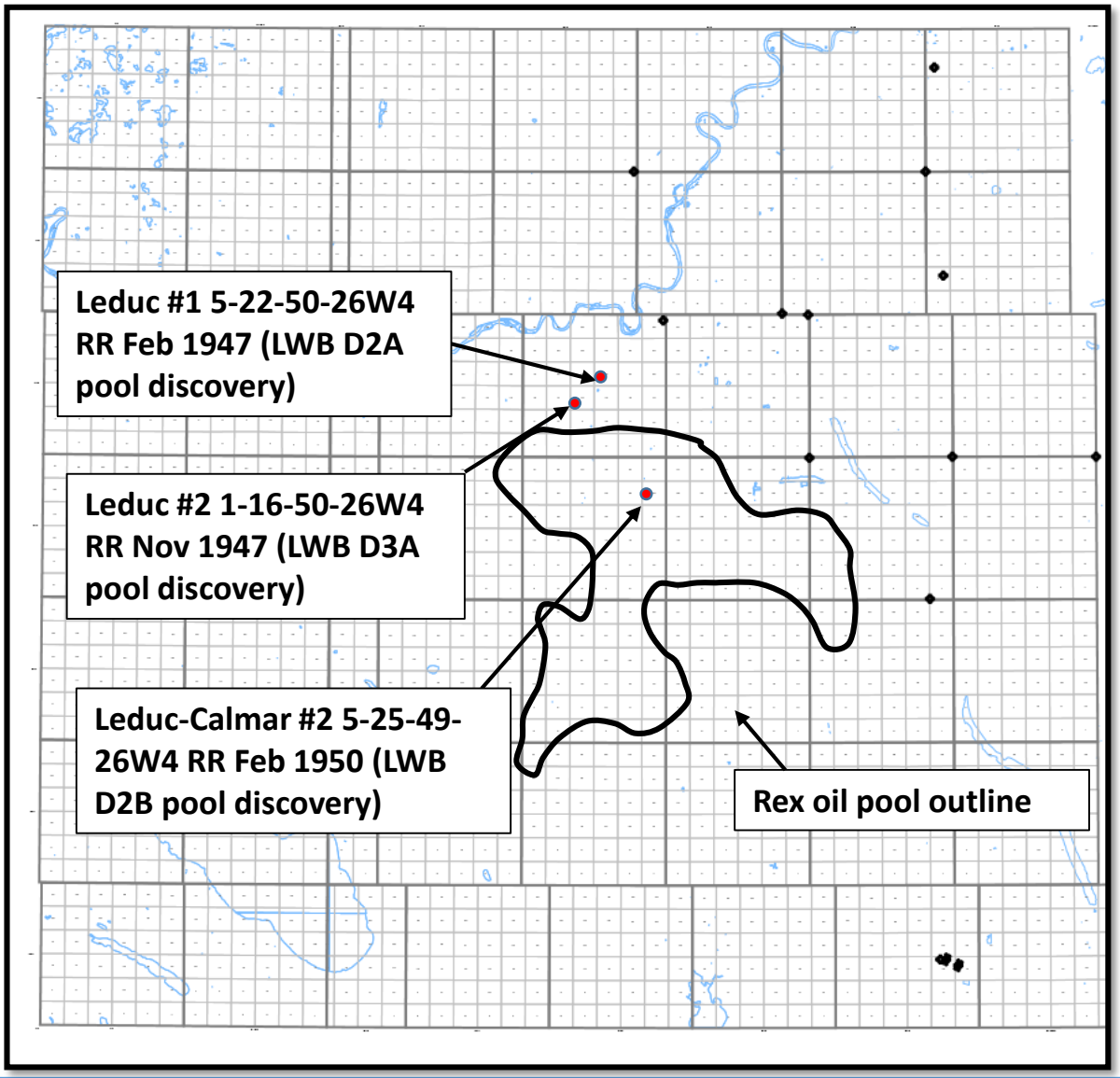
Provost-Lloydminster heavy oil belt

From Masters, AAPG Mem 38

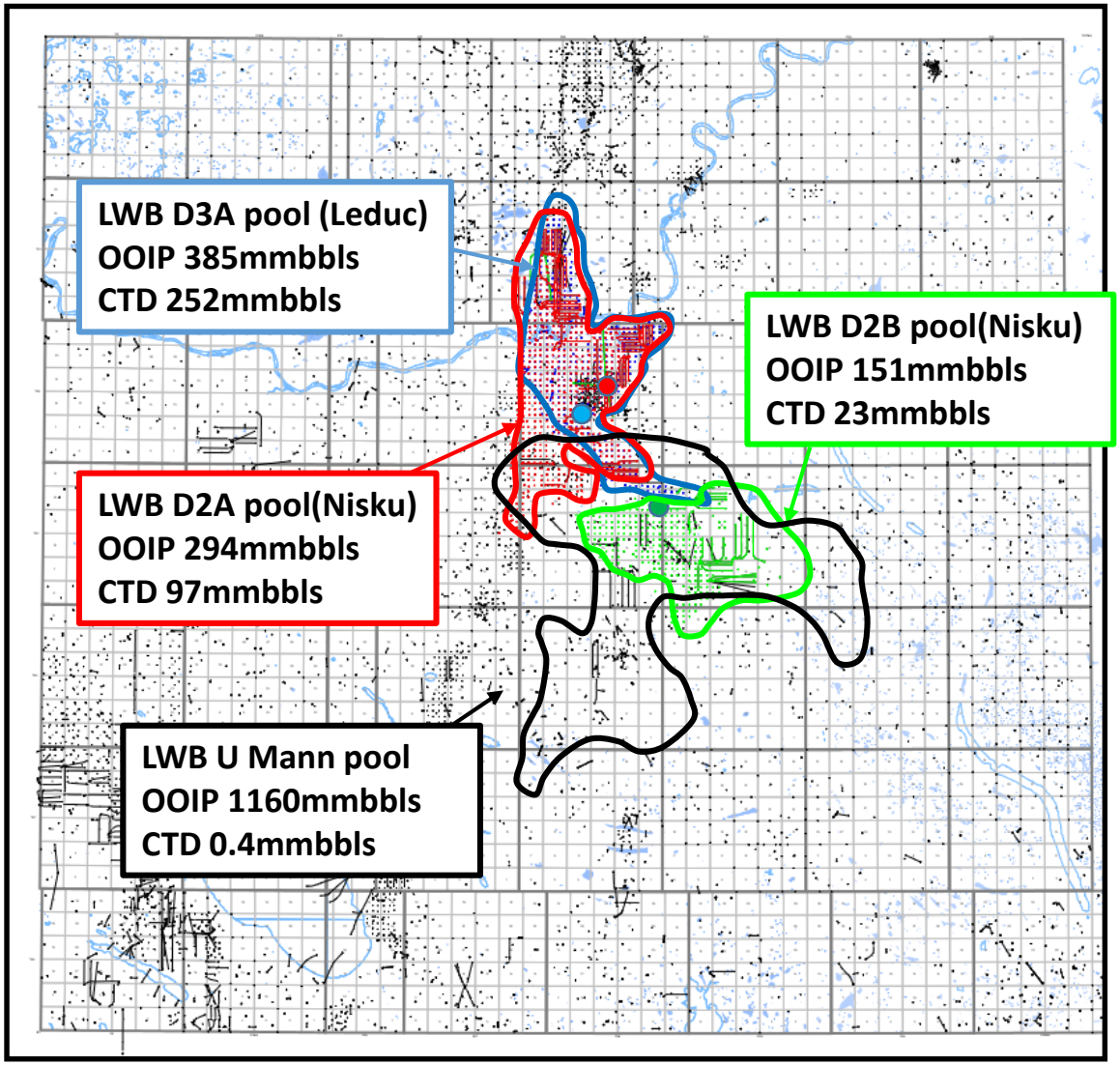
Leduc-Woodbend Field



Well Control prior to 1947



Well Control Today



Top 20 Conventional Oil Pool Discoveries

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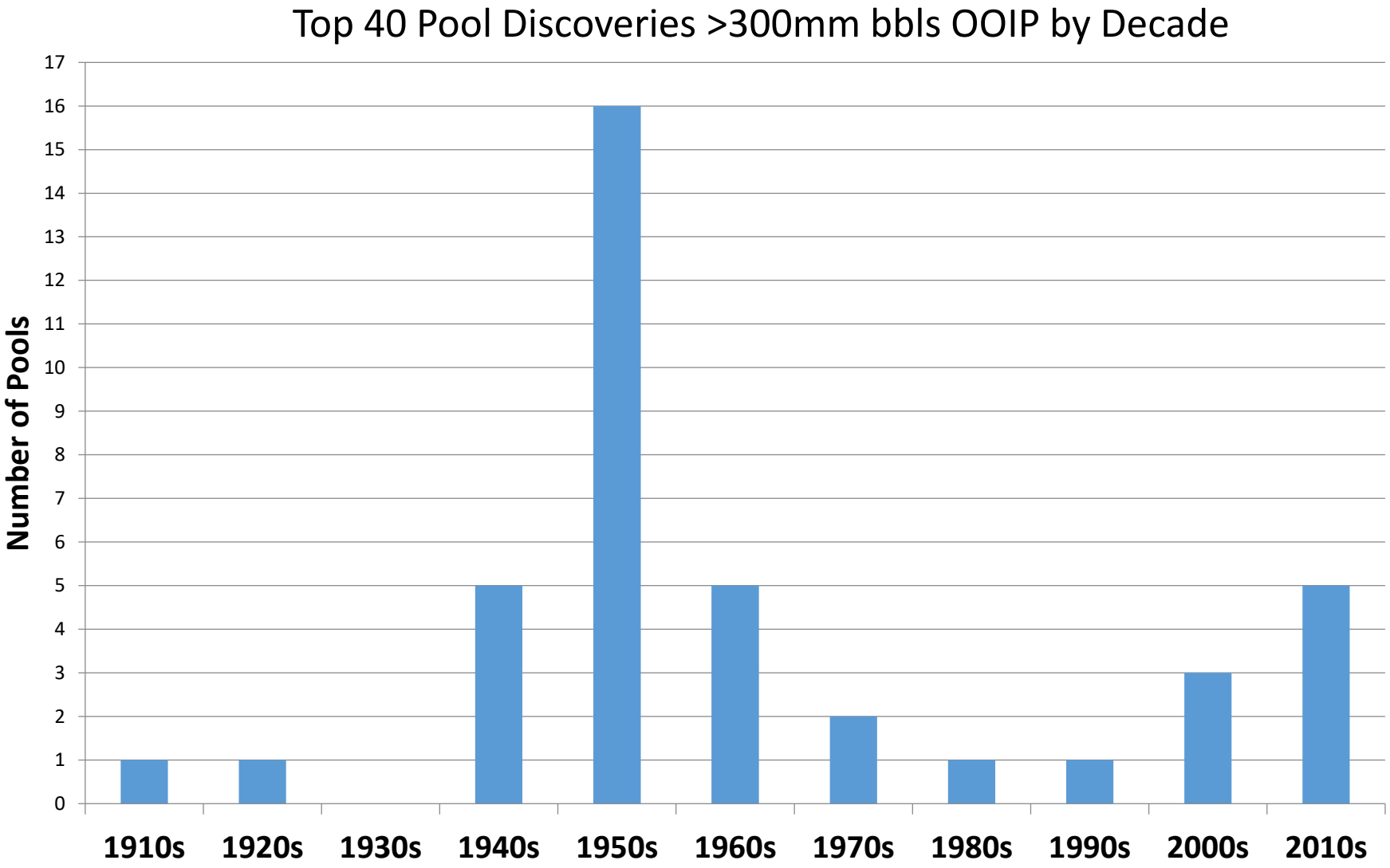
Overall Rank	Area	Pool Name	Twp-Rge	Province	Formation	Disc Date (vt/hz)	OOIP (mmbbls)	notes
1	Pembina	various units	46-50,6-11W5	Alberta	Cardium	1953	7421	halo
2	Viewfield	Viewfield Bakken	6-11,5-11W2	SK	Bakken	1981/2004	4600	technology
3	Marten Hills		73-76,24W4-3W5	Alberta	Clearwater	2009/2011	3000?	technology
4	Swan Hills	BHL A&B	66-70,8-11W5	Alberta	BHL	1957	2895	halo
5	Weyburn/Midale	various units	5-6,10-14W2	SK	Midale	1954	2061	halo
6	Provost	Hamilton Lake units	34-36, 7-12W4	Alberta	Viking	1946	1661	halo
7	Turner Valley	Rundle	18-21,2-3W5	Alberta	TV	1916	1325	
8	Redwater	D-3	56-58,20-22W4	Alberta	Leduc	1948	1302	
9	Sinclair		7-10, 28-30W1	MB	Torquay	?/2004	1300	technology
10	Steelman/Alameda	Steelman/Alameda units	3-5,4-6W2	SK	Midale	1954	1200	
11	Leduc-Woodbend		48-50,24-26W4	Alberta	U Mann	2014/2016	1160	technology
12	Willesden Green	Cardium A	39-44, 4-9W5	Alberta	Cardium	1954	1094	halo
13	Swan Hills South	BHL A&B	65-66,9-11W5	Alberta	BHL	1959	1084	
14	Twining	Rundle A	30-33, 24-25W4	Alberta	Pekisko	1952	935	
15	Nipisi	Gilwood A	78-81,7-9W5	Alberta	Gilwood	1965	909	
16	Mitsue	Gilwood A	69-74, 3-6W5	Alberta	Gilwood	1964	818	
17	Judy Creek	BHL	63-64,10-11W5	Alberta	BHL	1959	817	
18	Morgan	Lloyd A	52-4W4	Alberta	Lloydminster	1962	811	
19	Bonnie Glen	Leduc A	46-47,27-28W4	Alberta	Leduc	1952	787	
20	Cecil/Mulligan		80-83, 8W6	Alberta	U Charlie Lake	1983/2013	700	technology

WCSB Pool Discovery History



Oil pool statistics

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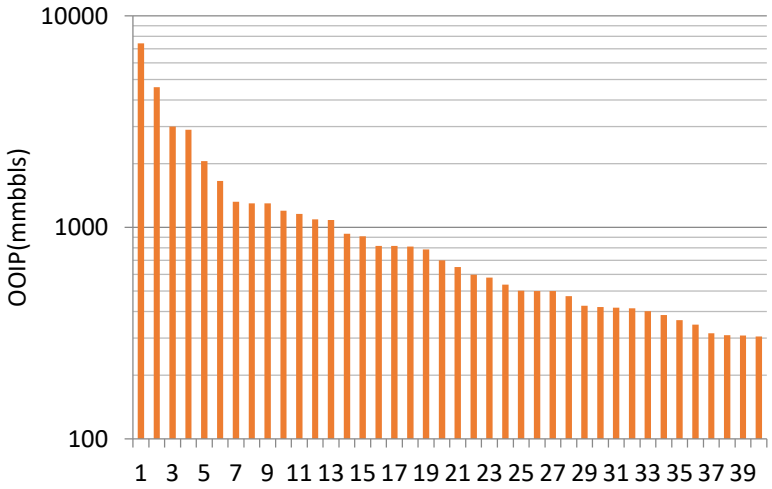
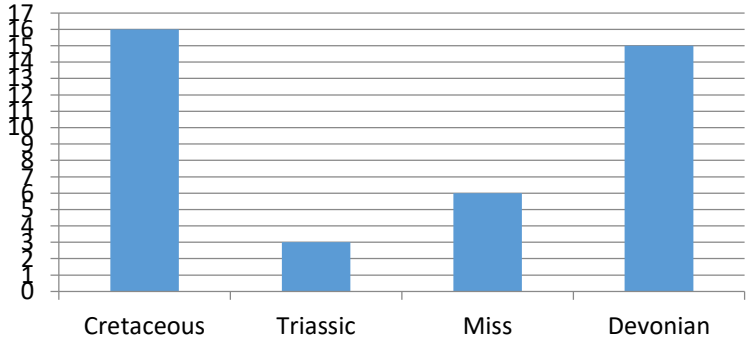
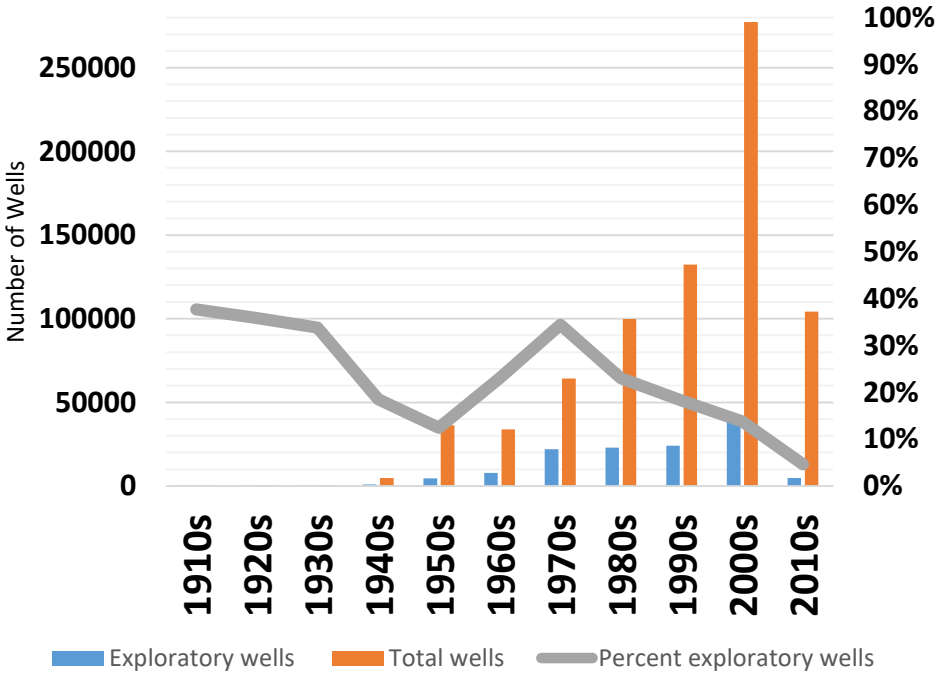
Pool size distribution



Pool by Period



Percent Exploratory wells

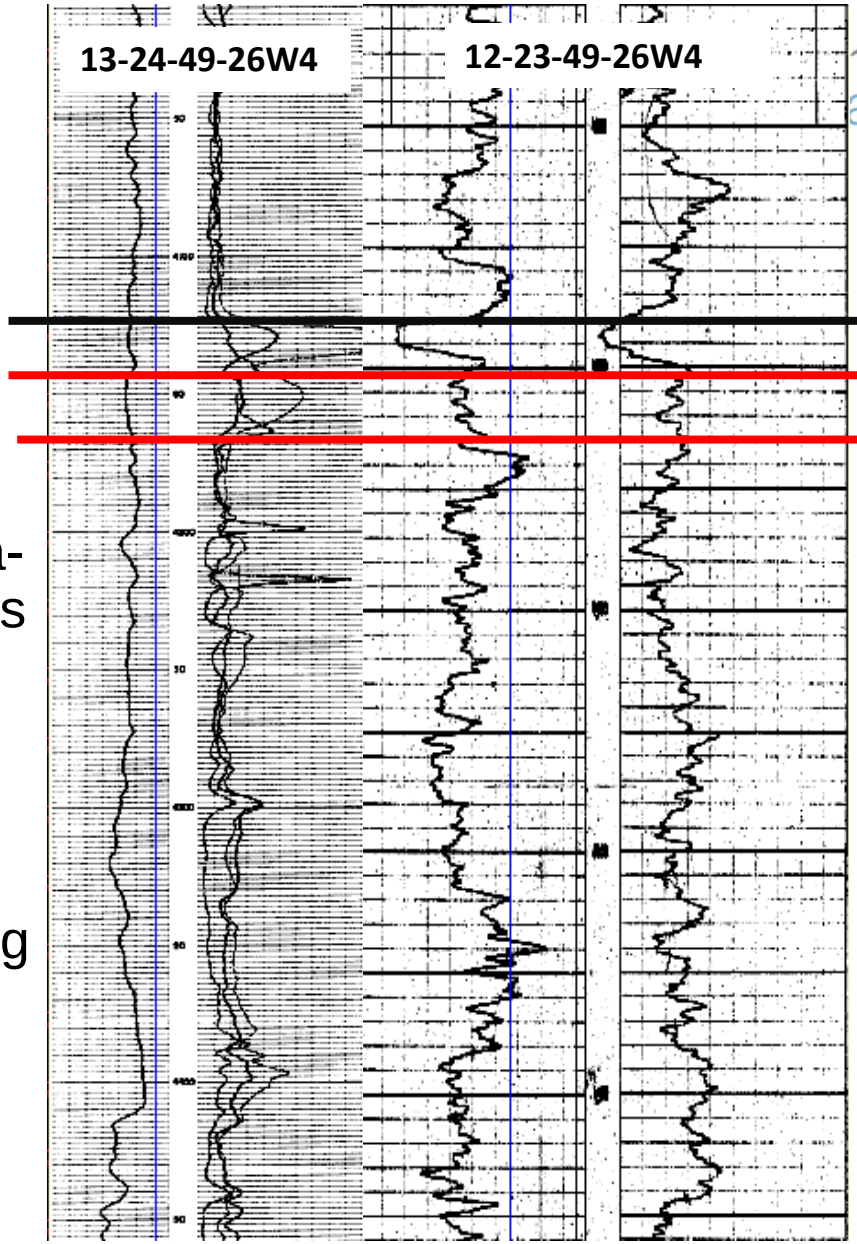


How did the LWB oil pool remain undiscovered for so long?

1. Poor quality logs
   - very little quantitative information available from Electric logs and Gamma-Neutron logs
   - poor logs makes for a relatively quiet area with very few competitors
2. Difficult correlation relationships (coastal plain sequence)
3. Subtle log characteristics
4. Lack of production or drill stem test shows due to tight nature of rock

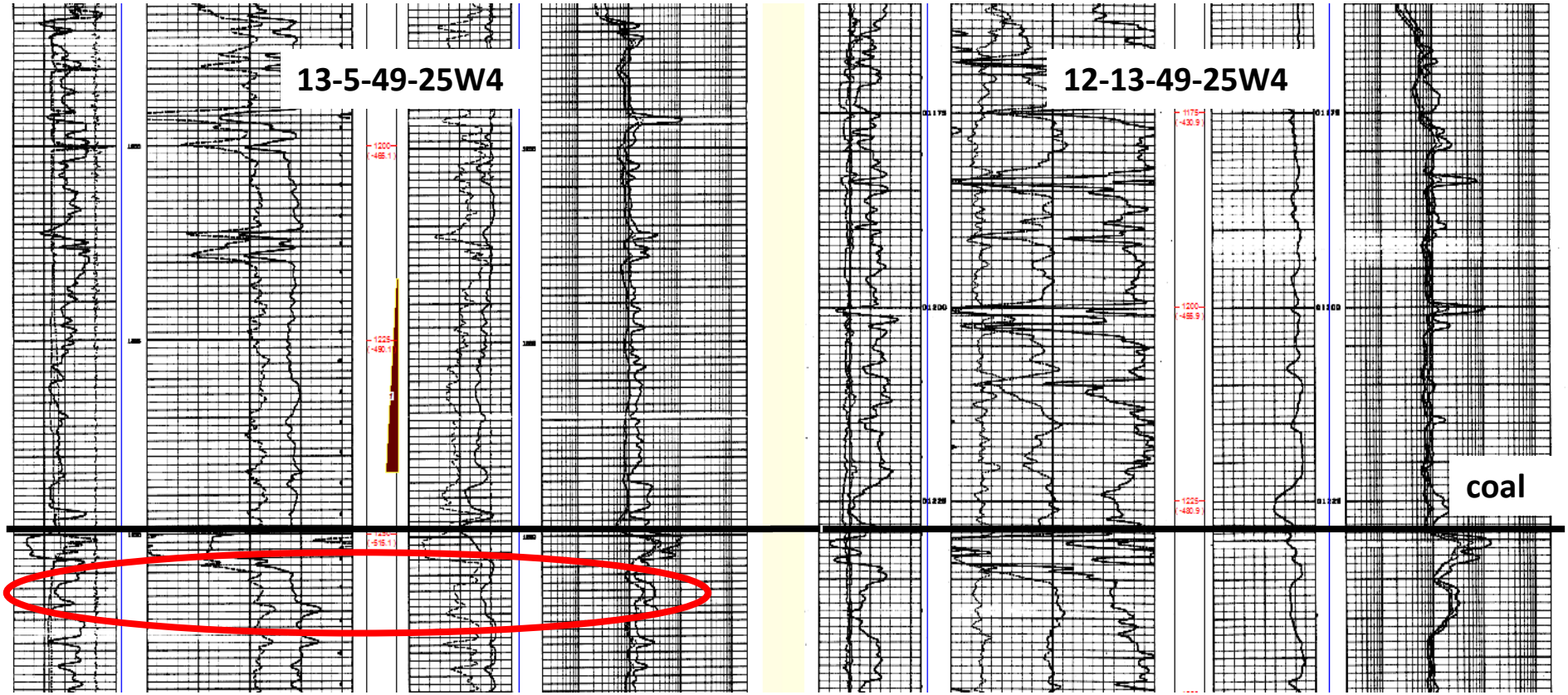
Poor Logs

- Most wells in the area drilled prior to 1960 (eg 13-24 & 12-23)
- Electric logs and Gamma-Neutron logs the only logs run in the 1940s and 1950s
- Many geologists today uncomfortable interpreting or even bother looking at pre 1960s logs



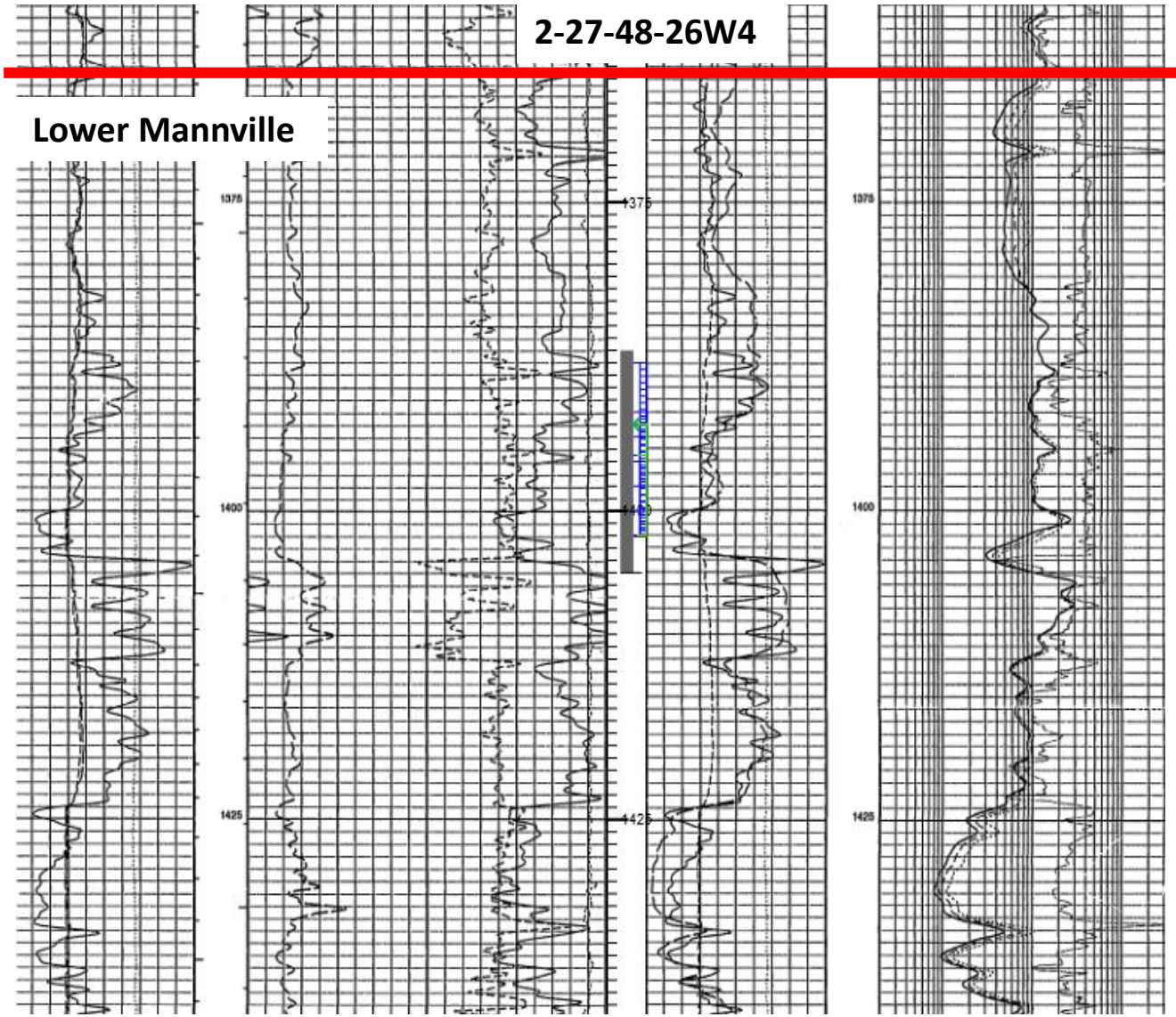
Correlation Challenges

- Being a Coastal Plain environment there are no recognizable shale markers or flooding surfaces
- Thick coals are the only correlatable units but only in limited areas
- Two examples below are six km apart:



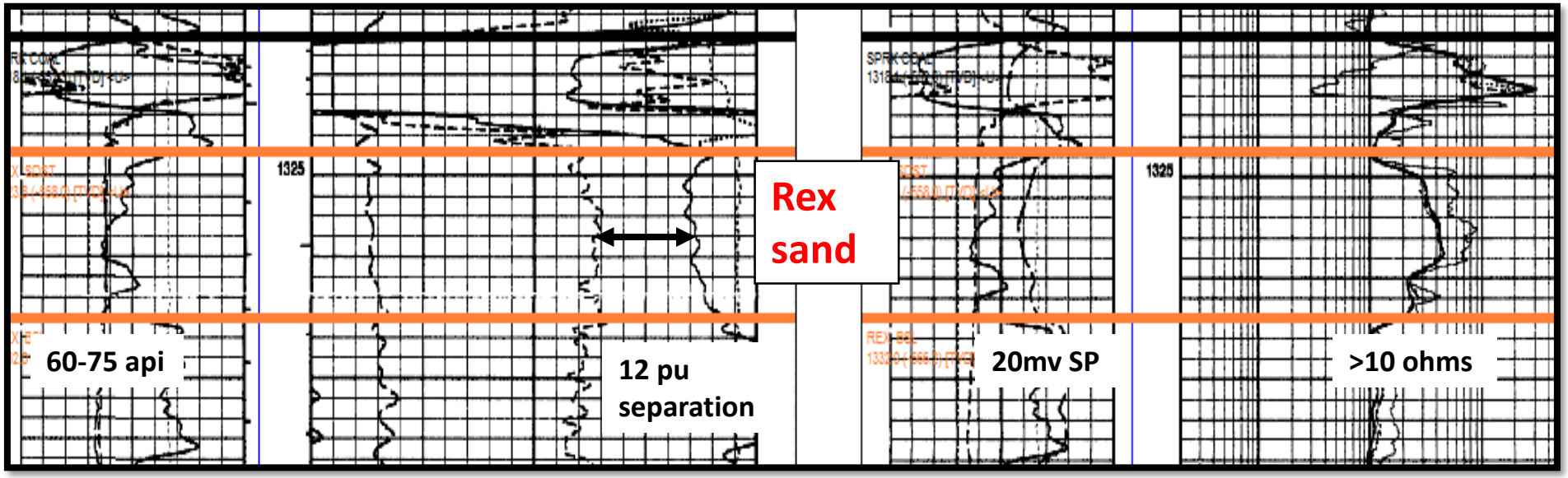
Subtle Log Characteristics

- After initial Devonian targets drilled a second phase of drilling from 1970s to the 2000s
- Clean, high perm Lower Mannville sands were the main target of drilling during second phase
- Lower perm Upper Mannville targets were again ignored because of their subtle log characteristics



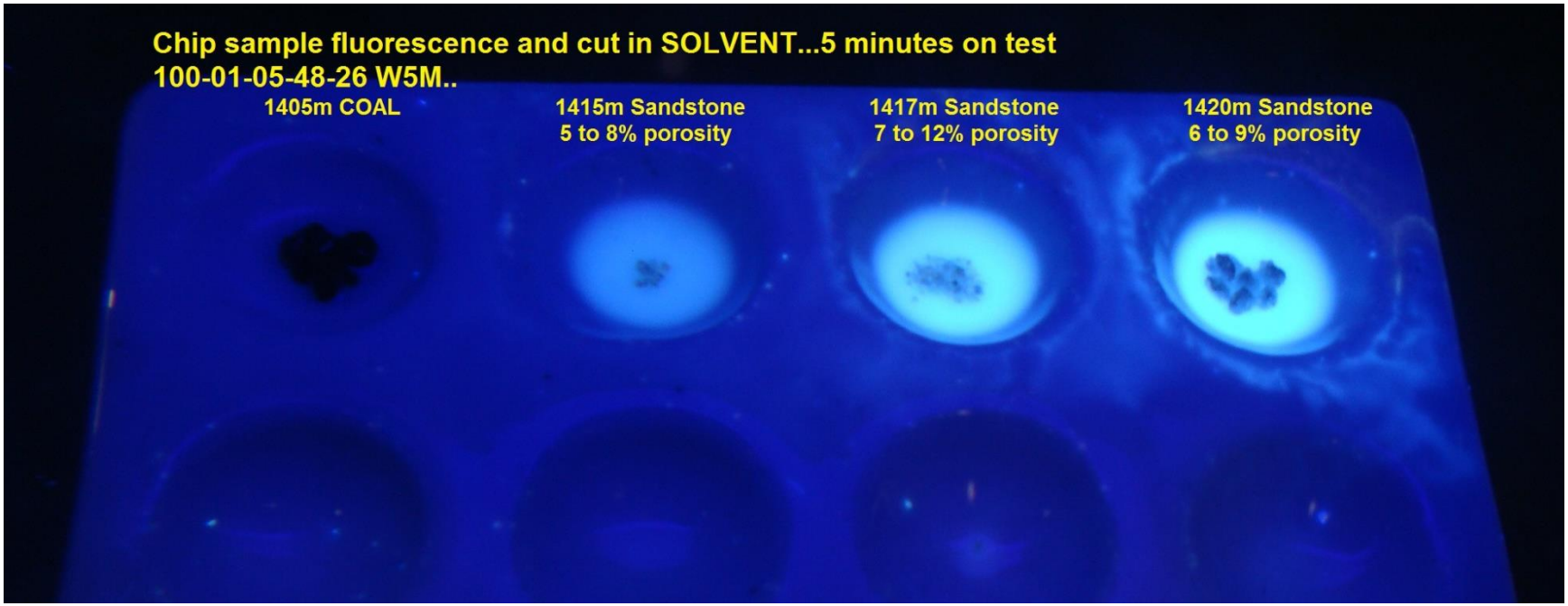
Subtle Log Characteristics

- Neutron-Density separation
- Low to moderate resistivity pay zones
- High gamma readings in sands
- Poor SP development due to low permeability



Lack of Production or Shows

- Prior to 2016, only 3 vertical wells out of almost 900 had production within the pool; 1 gas well and 2 oil wells with all three producing non commercial quantities of hydrocarbons
- All 3 wells originally targeted deeper zones and were recompleted in the Upper Mannville
- The only hint of oil productivity was chip sample analysis with oil staining and fluorescence being key



PART 2:
LWB Rex member oil pool

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POOL PARAMETERS

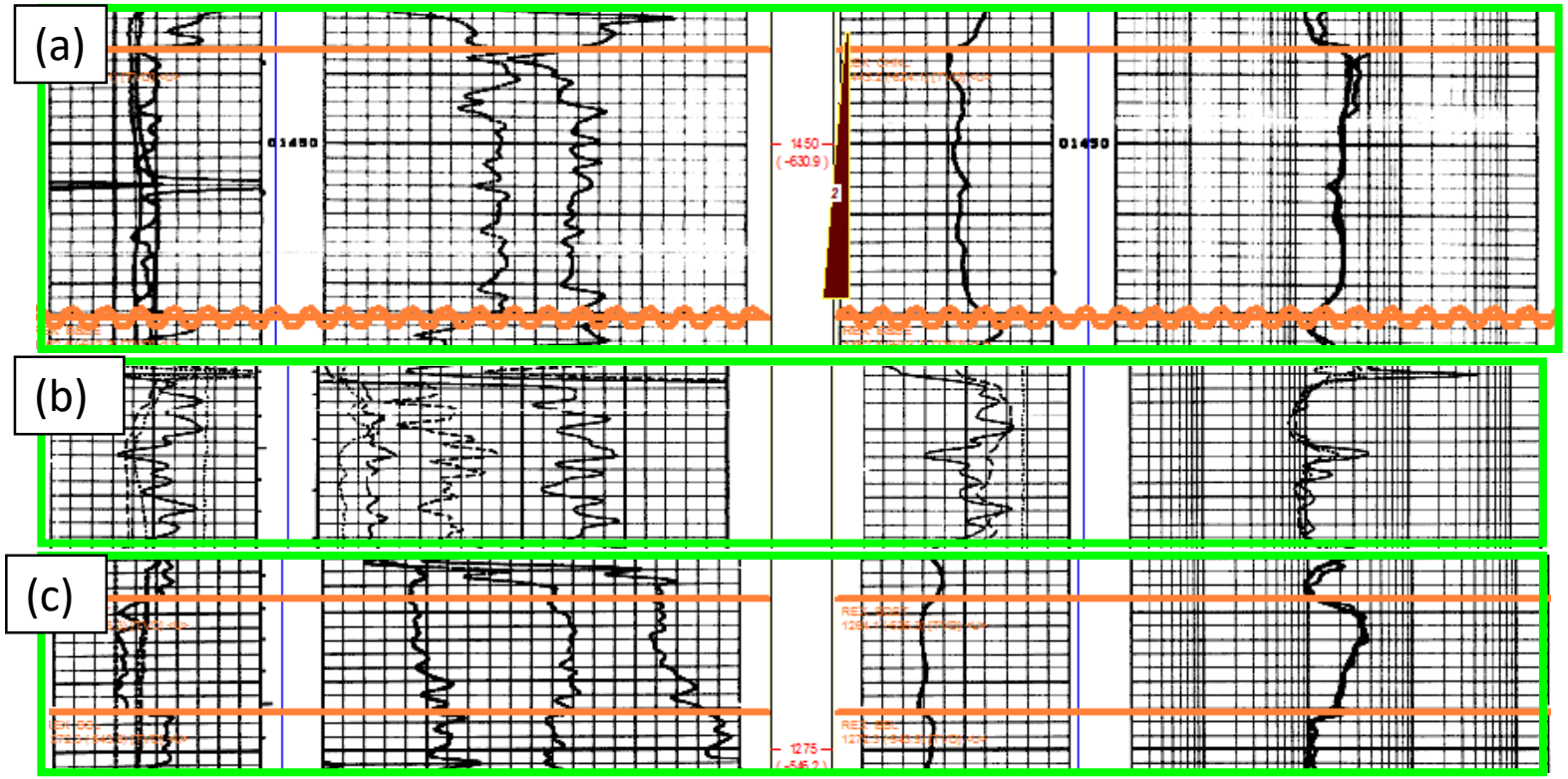
Depth:	1300-1400m
Porosity:	9-15%
Permeability:	unknown but likely 1-10mD (no core in pool)
Areal size:	approximately 200 sections
Average net pay:	6m, range 2-12m
Water saturation:	30-50%
OOIP:	1.0-1.2Bn bbls
Oil quality:	17 API, 100-200cP, 2.8%S
Pressure:	10mPa or about 7.7kPa/m
Oil column:	120m with no known gas cap
GOR:	varies from 200-3000 scf/bbl
Drive:	solution gas
Depositional environment:	delta/distributary channels

Rex member Facies Type Logs

a) **Channel facies**: medium-coarse grained sands, typically 15-25m thick, 1-2km wide; vary from straight to highly sinuous

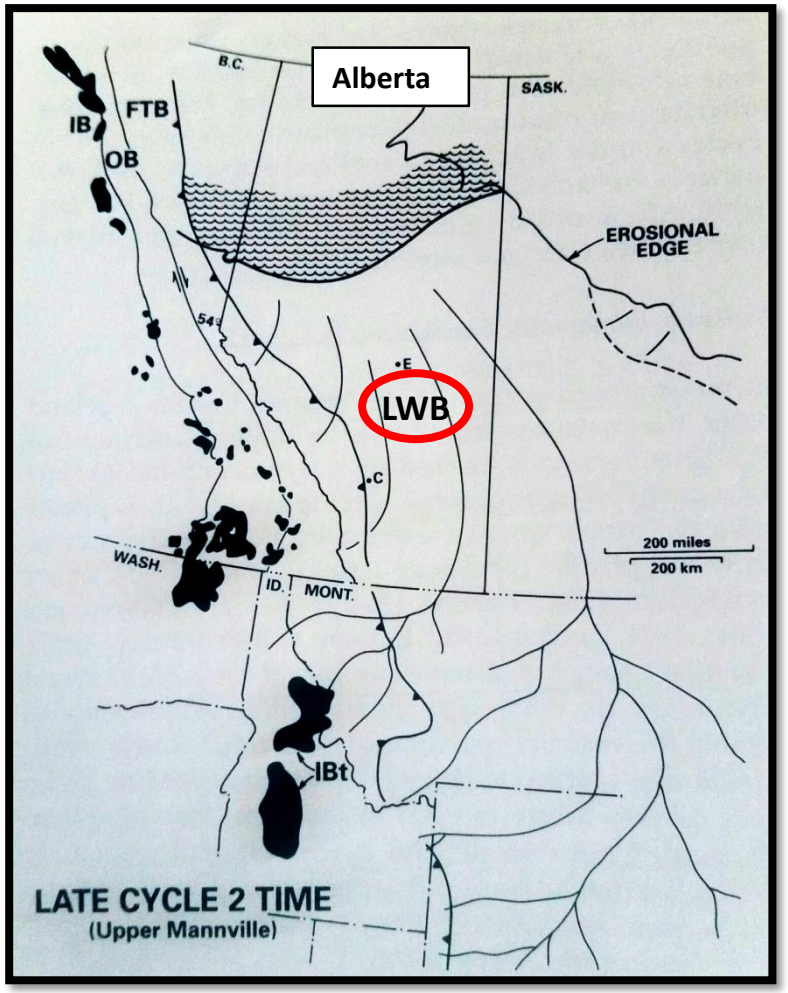
b) **Non channel facies:** silt to fine grained sands interbedded with non-marine shales and thin coals

c) **Delta facies**: fine-medium grained sands; widespread when present



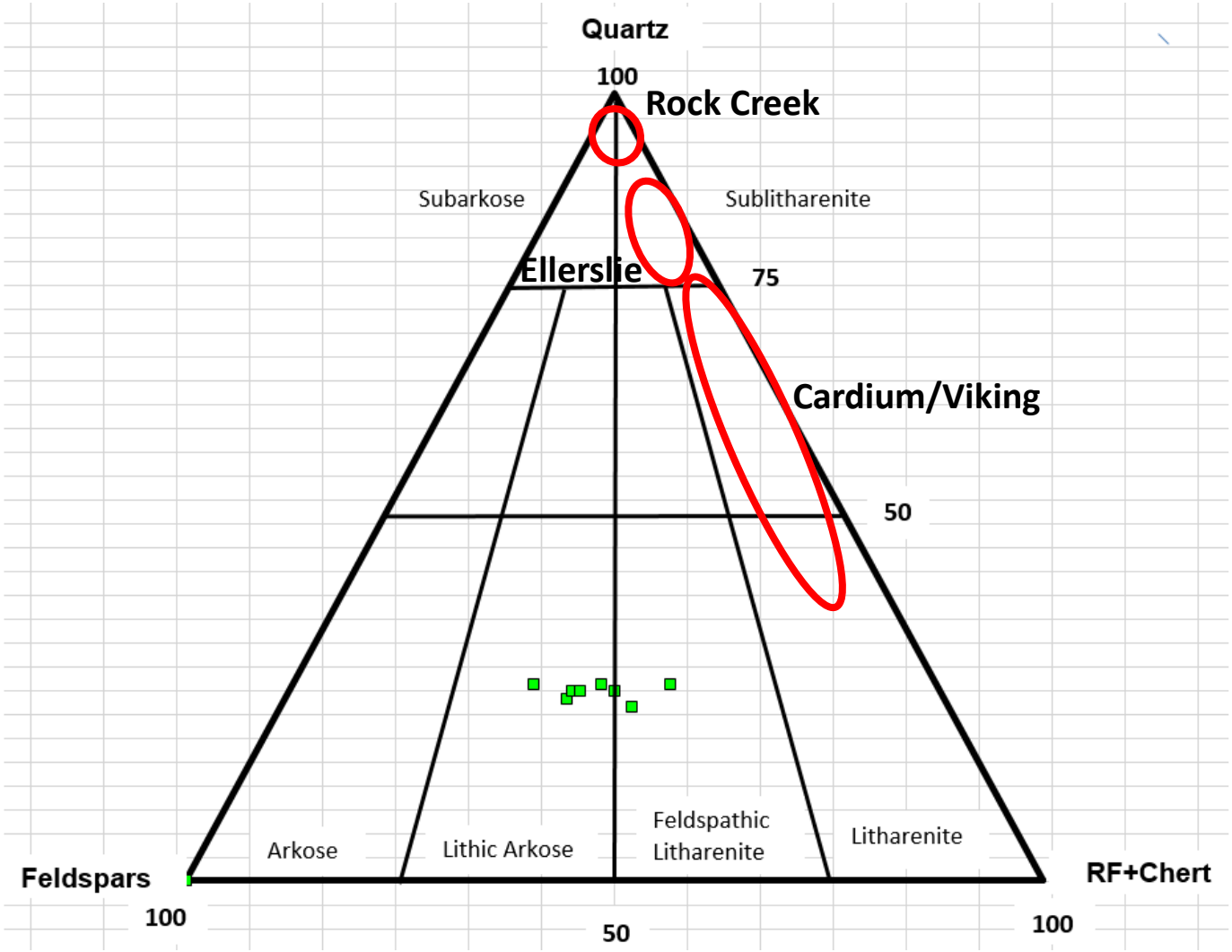
Provenance

- part of the volcano-feldspathic lithofacies within the Upper Mannville
- Texturally immature; likely plutonic or volcanic sources from the south and west; derived from a magmatic arc terrane in Idaho, Washington and BC
- Abundant feldspar and lithic rock fragments; existence of feldspar is important as it controls porosity type
- High percentage of lithic grains severely compacts or alters the framework grains which contributes to poorer permeability



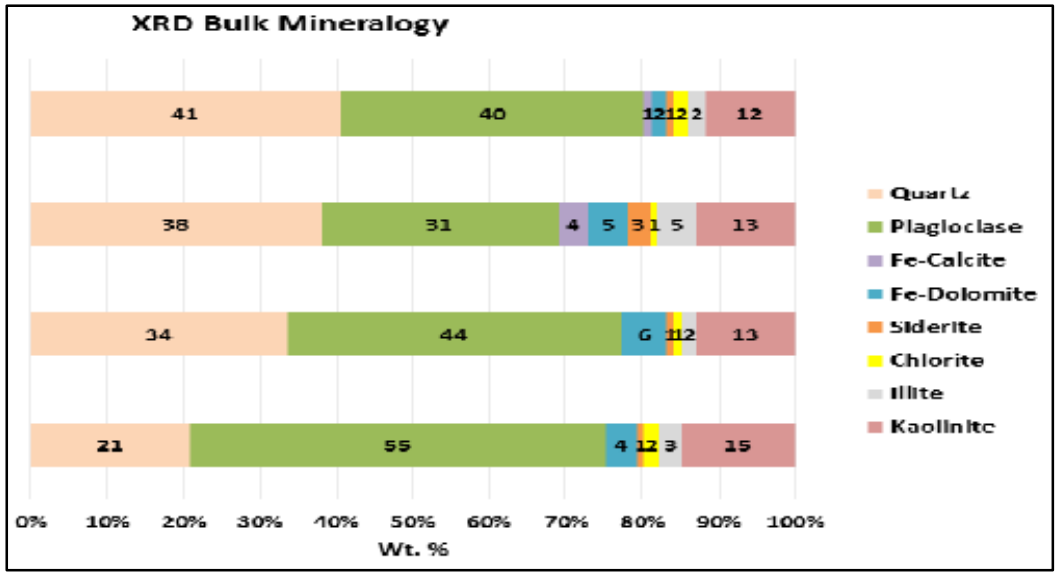
From Potocki and Hutcheon, AAPG Mem 55

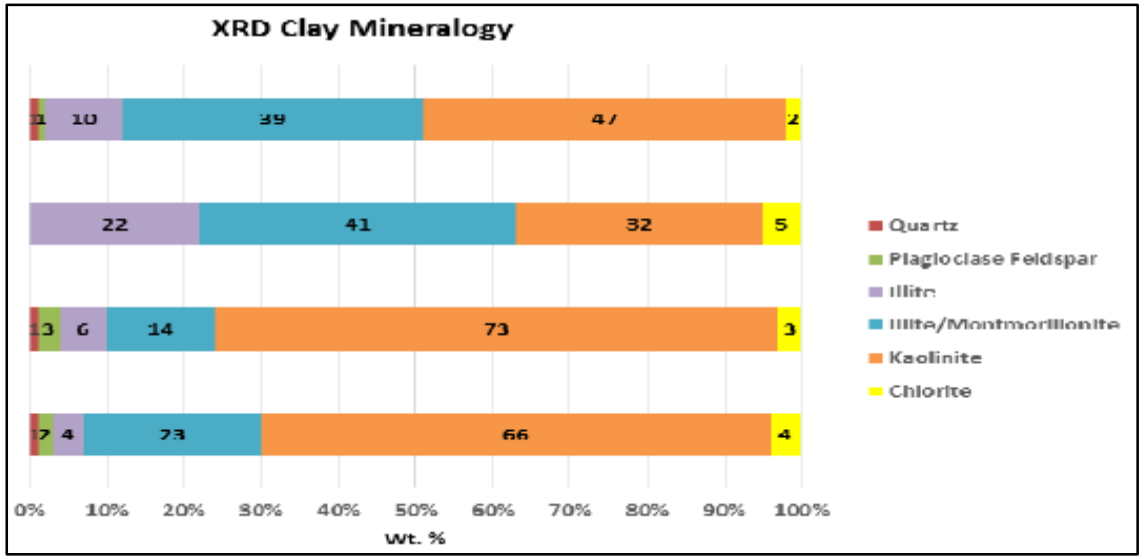
Rock-type Ternary Diagram



Mineralogy data from XRD

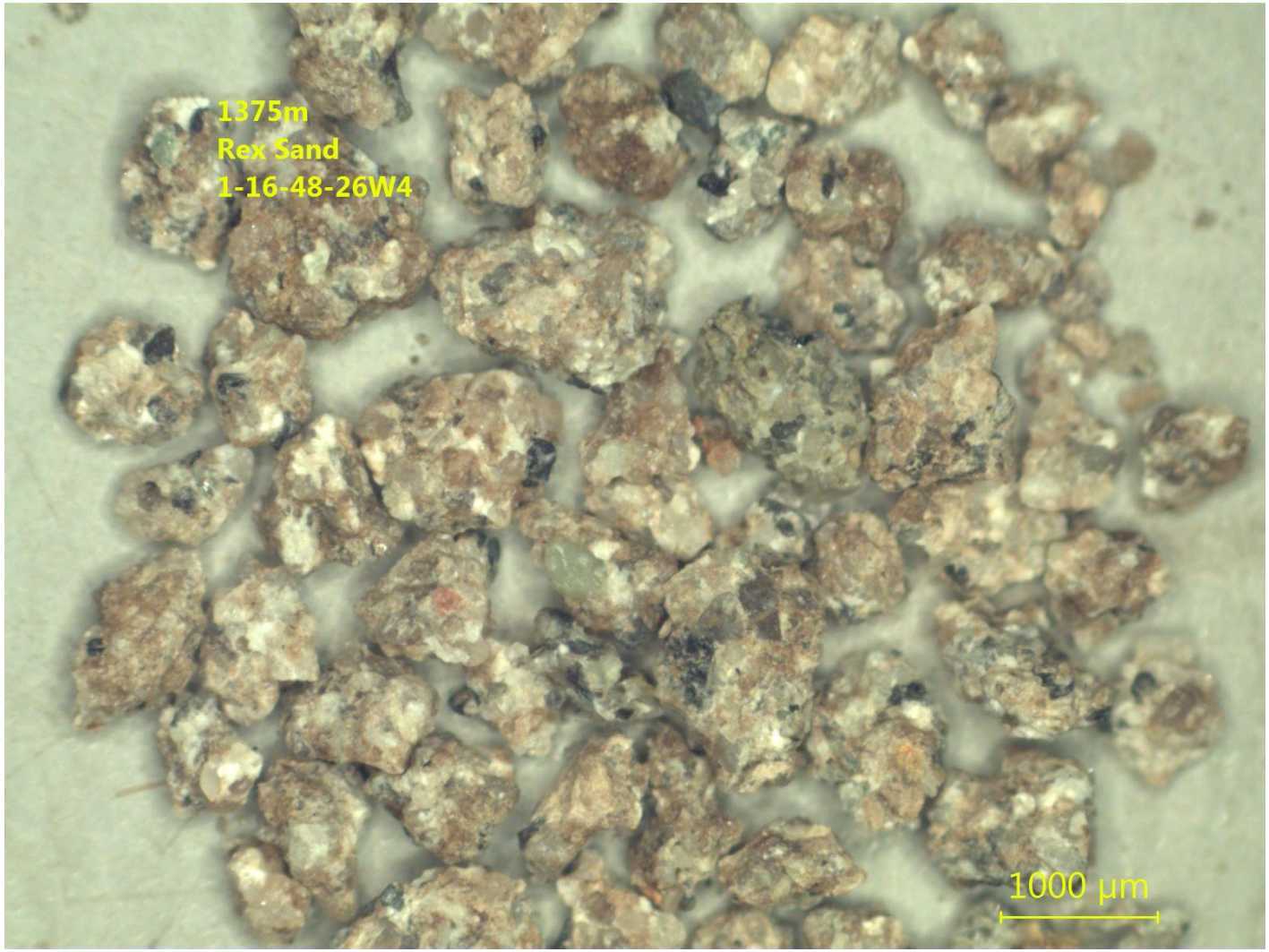
- Bulk mineralogy dominated by plagioclase and quartz
- Clay content varies from 15-40%
- composed mainly of kaolinite, illite and mixed layer illite/ montmorillonite



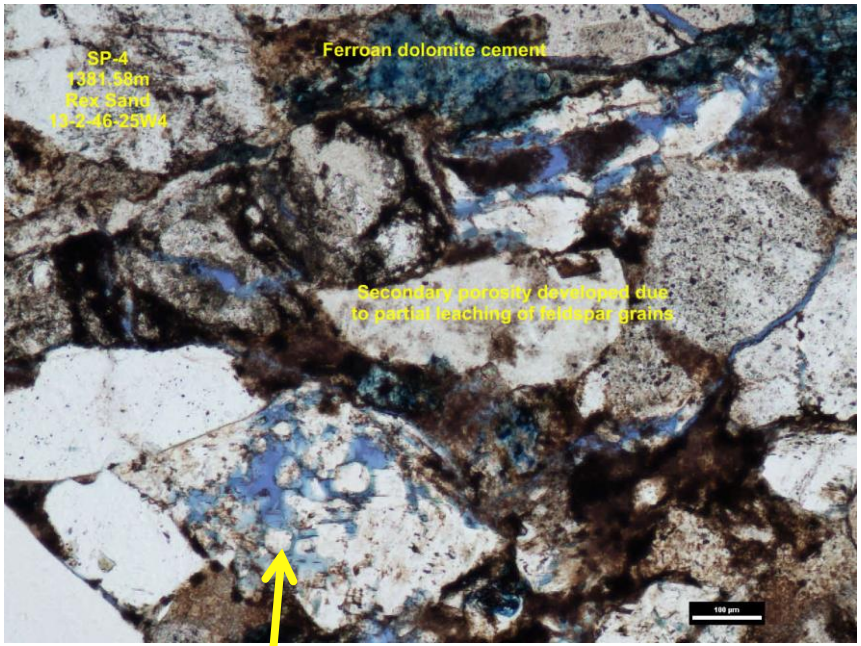


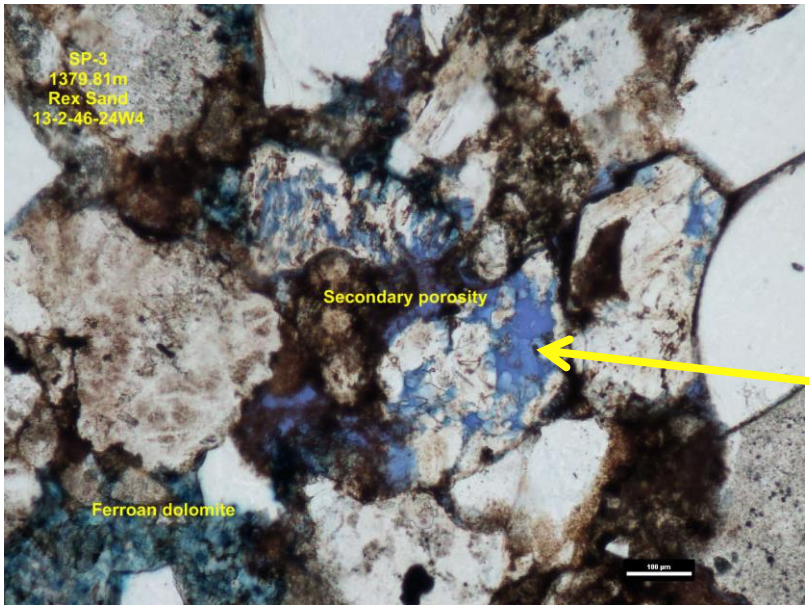
Data from ProGeo Labs

Chip Sample Overview



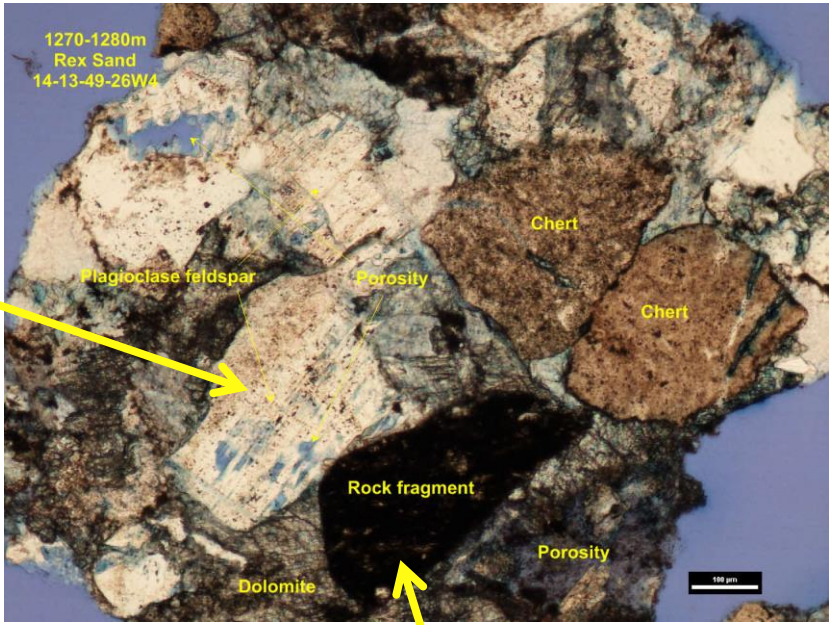
Petrography – porosity examples

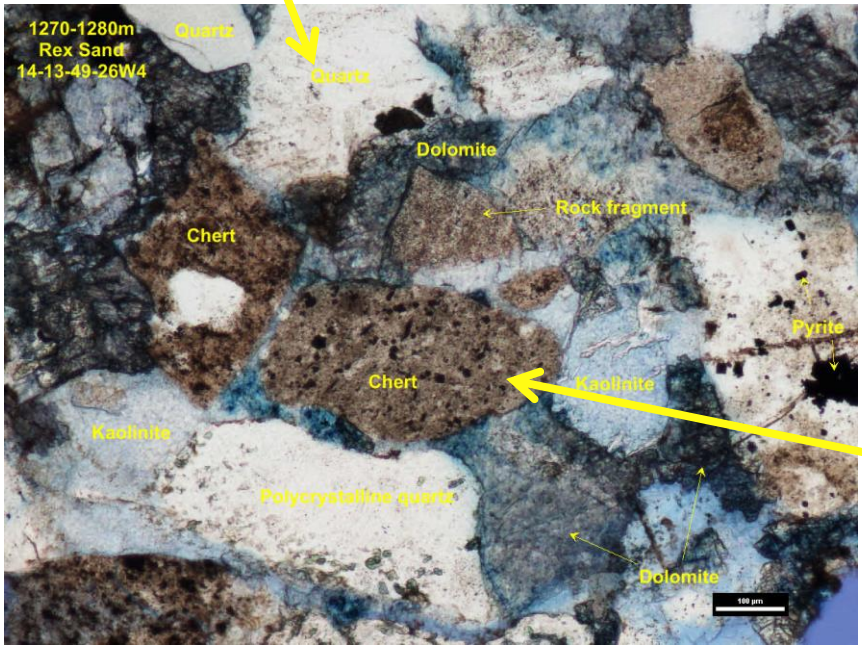




Intragranular porosity

Petrography – grain type examples





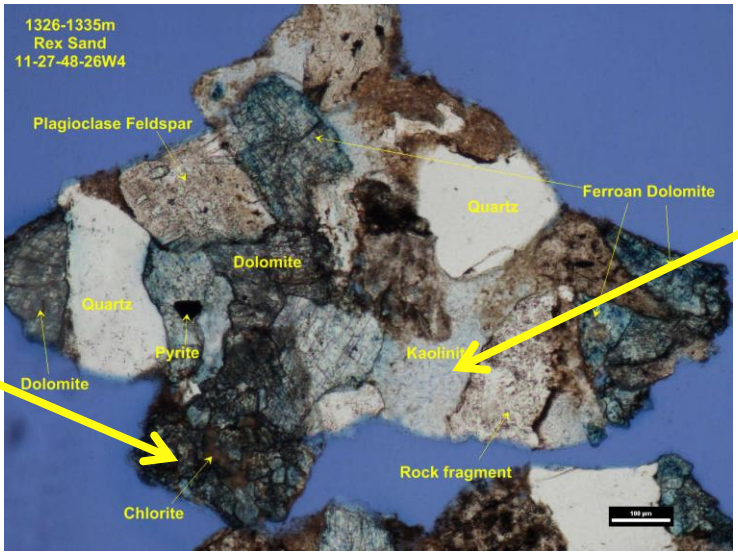
Plagioclase feldspar

Quartz

Rock fragment

Chert

Petrography – cement examples

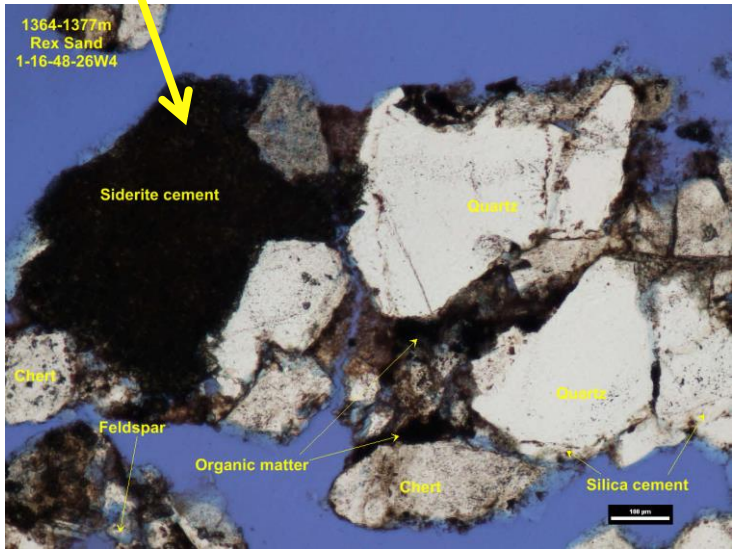


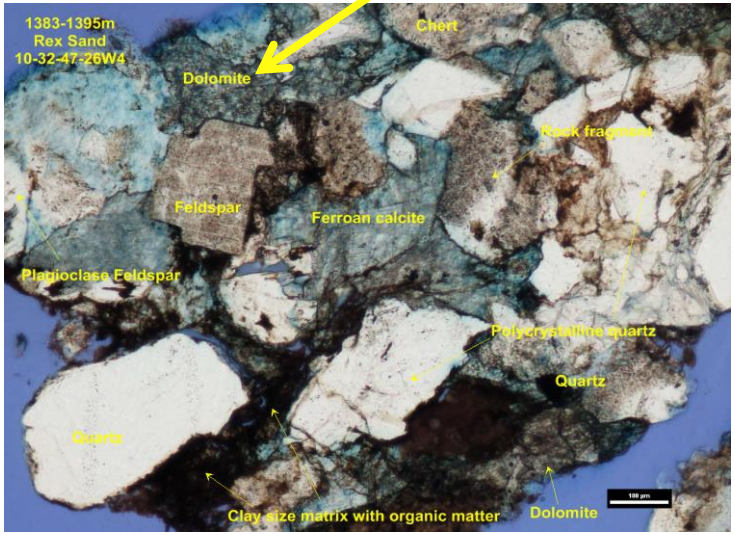
Kaolinite

Chlorite

Siderite

Dolomite

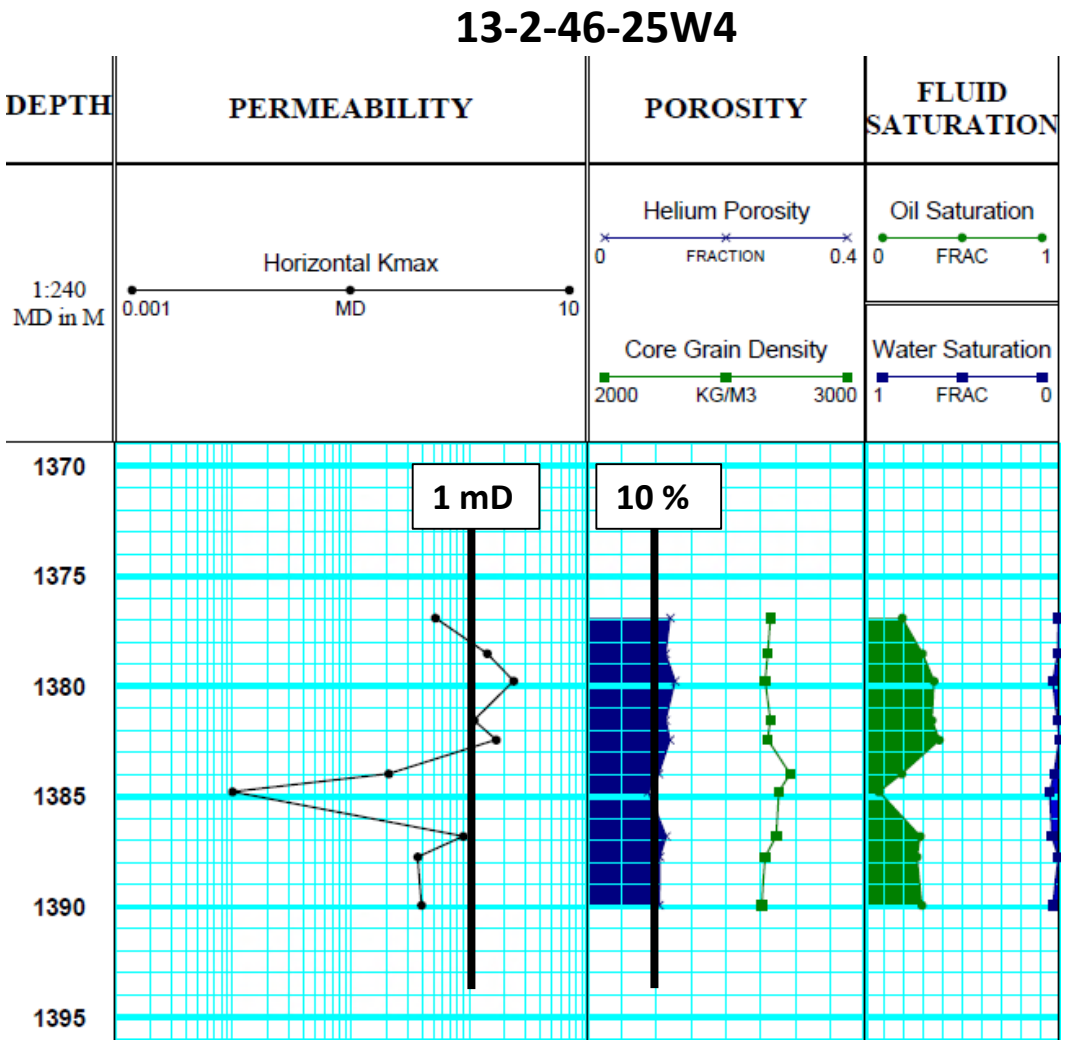




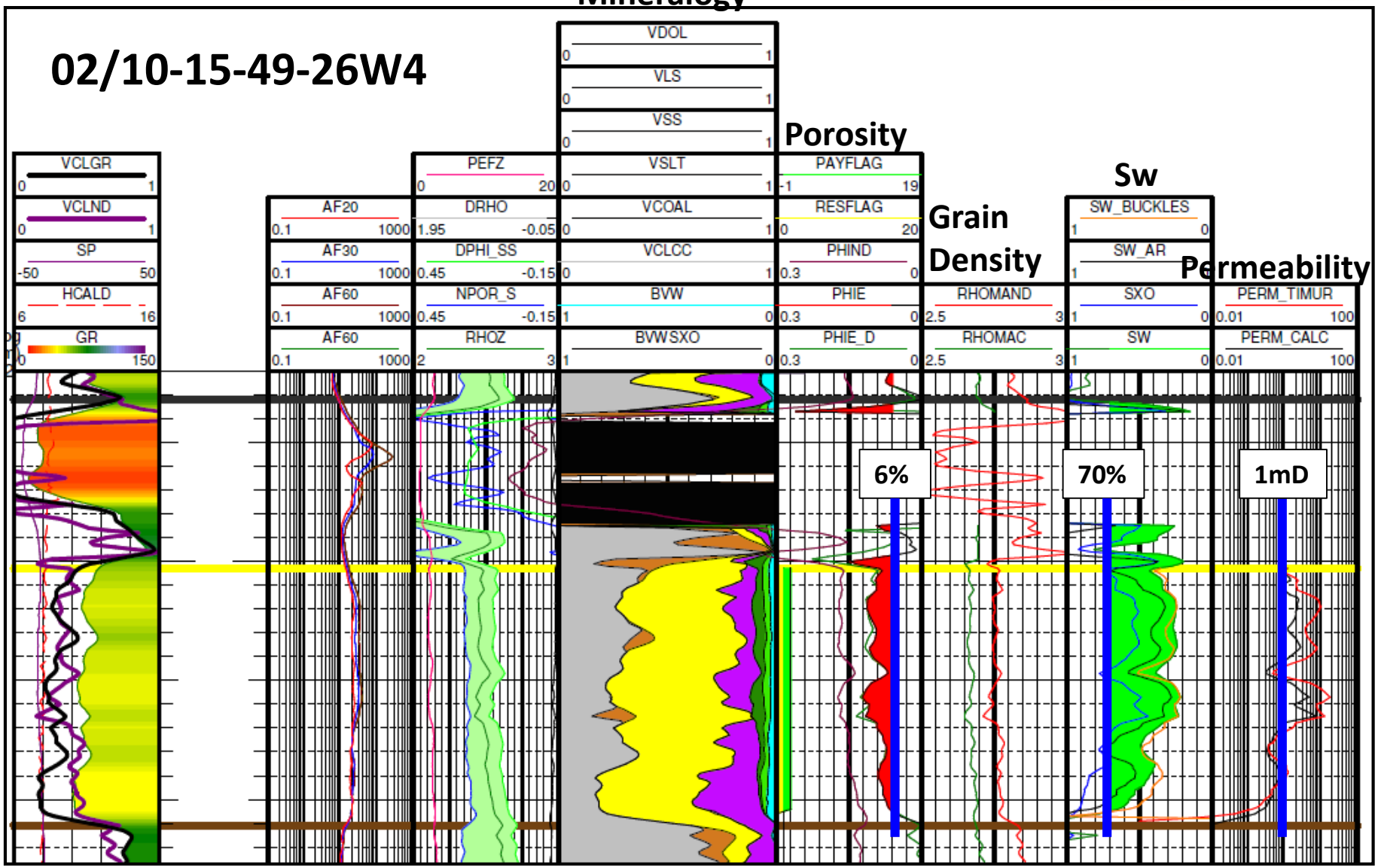
Core Data

- Two cores in the Rex sand nearby, both from distributary channels (13-2-46-25W4 and 13-11-47-27W4)

- Volcano-feldspathic sands quickly decrease in porosity with depth due to lithic material; results in lower permeability in Rex sand vs Lower Mannville sands at LWB



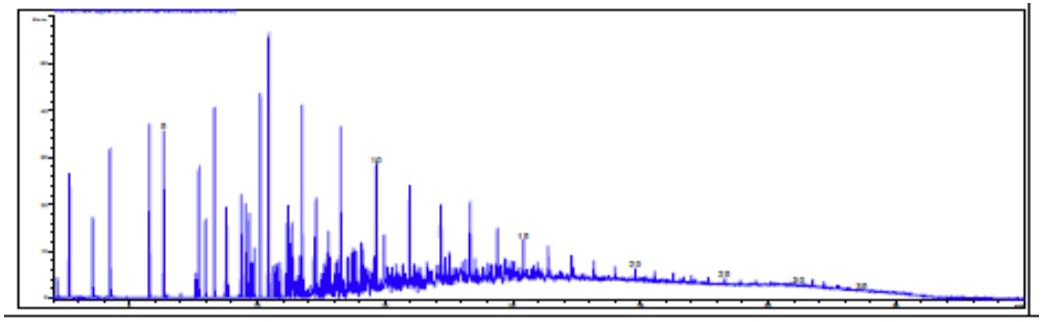
Petrophysical Data

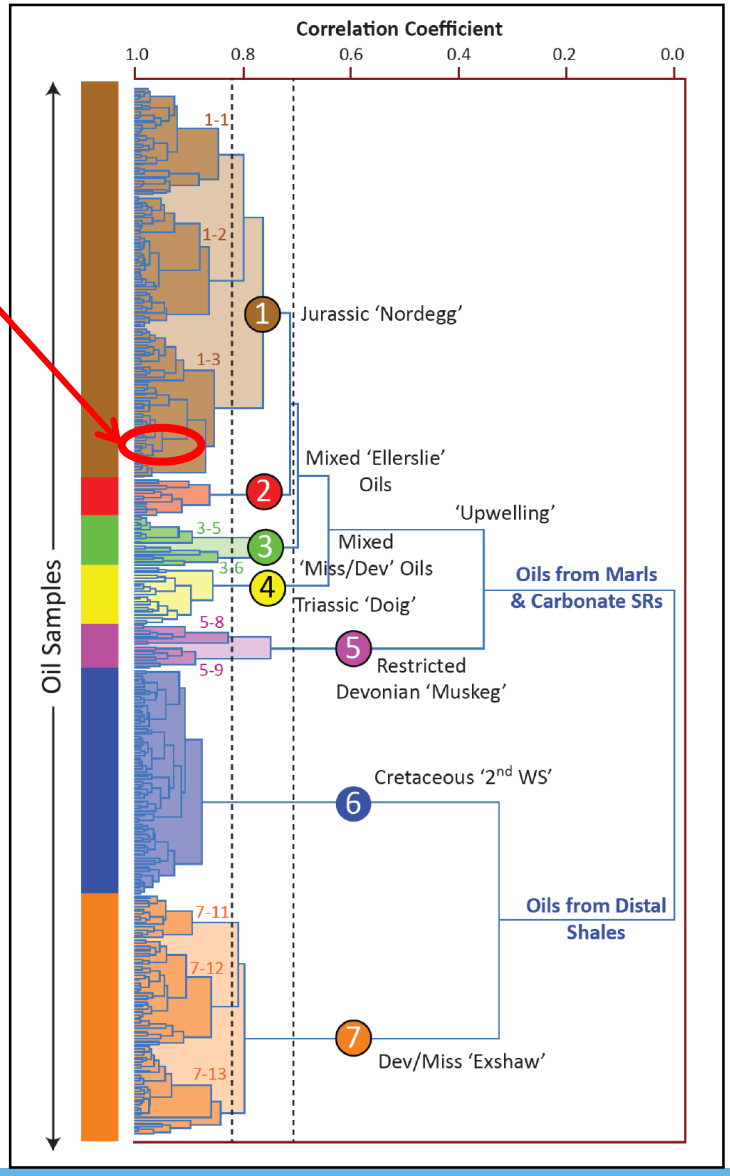


Oil Quality Data

- Moderate degree of biodegration, 16-17 API, 100-200cP, 2.8%sulphur
- Likely from a Nordegg carbonate source as shown by family 1 on plot
- Nordegg oils tend to be low API due to lower thermal maturities near their subcrop edge (approximately 5 Twps to the west) and high sulphur oils due to the sulphur-rich kerogen
- Moderate amounts of light ends which suggests some mixing with other oils; likely from Exshaw

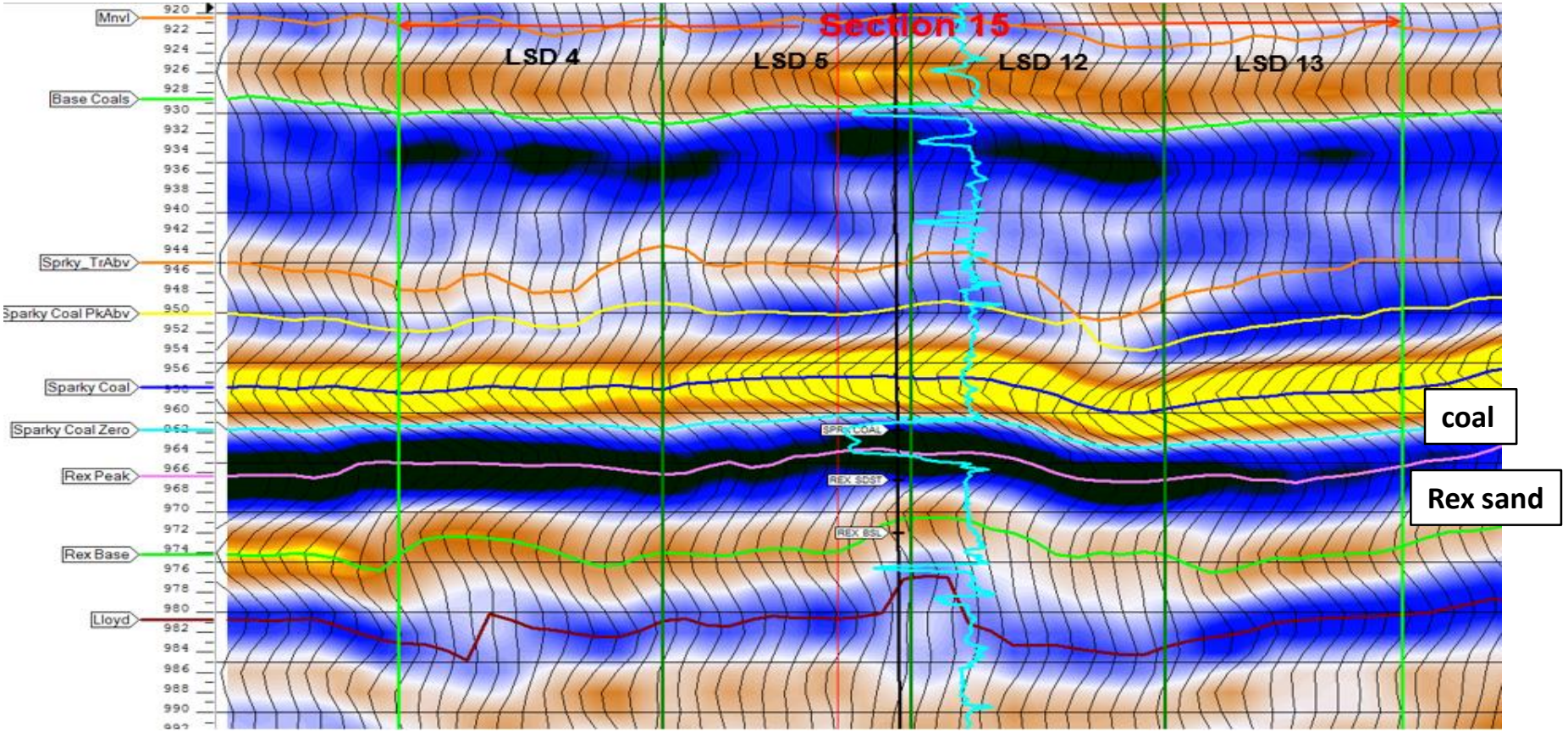
Data from Geomark Research





Seismic Data

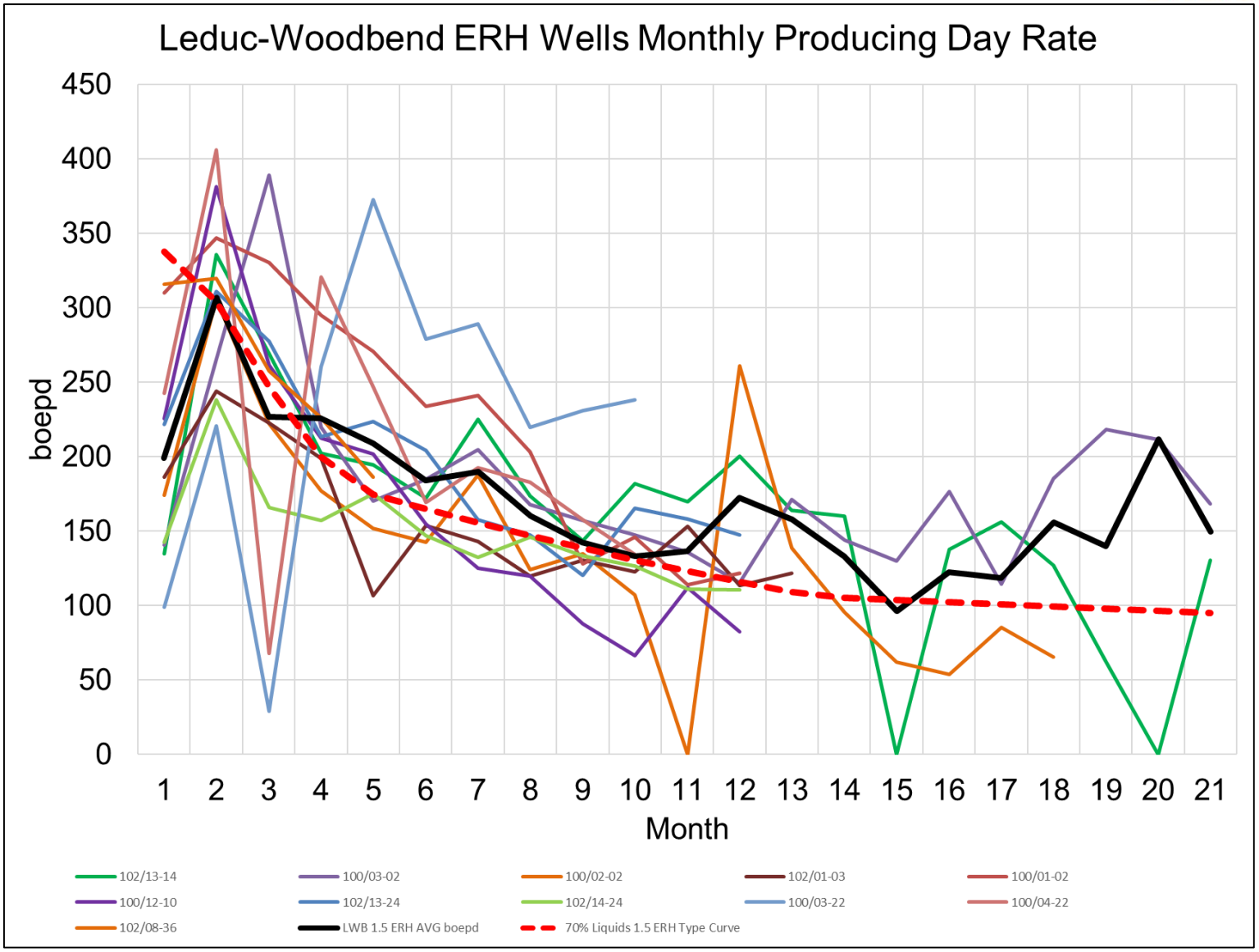
- Reservoir is too thin to be resolved but used for structural control when drilling
- In areas of poor well control have used a Rex isochron to identify thicks



Drilling and Completions

- 1300m vertical depth, 2000-2300m horizontal length
- Horizontal section drills very easily (8 days spud to rig release)
  - Single trip bit runs, no dulling
  - ROPs of >120m/hr when rotating
  - Horizontal section drilled in 2 days
- Intermediate section challenges
  - Poor build rates from KOP to 30° inclination
  - Thick coal section immediately above the Rex sand
- Cemented closeable frac sleeves, all sleeves re-opened after the last frac is complete
- 45m sleeve spacing, have reduced some wells to 30m sleeve spacing
- 15t per interval, 16/30 natural sand
- Fluid system is a crosslinked borate to achieve high proppant concentration at low pump rate

Production Plot



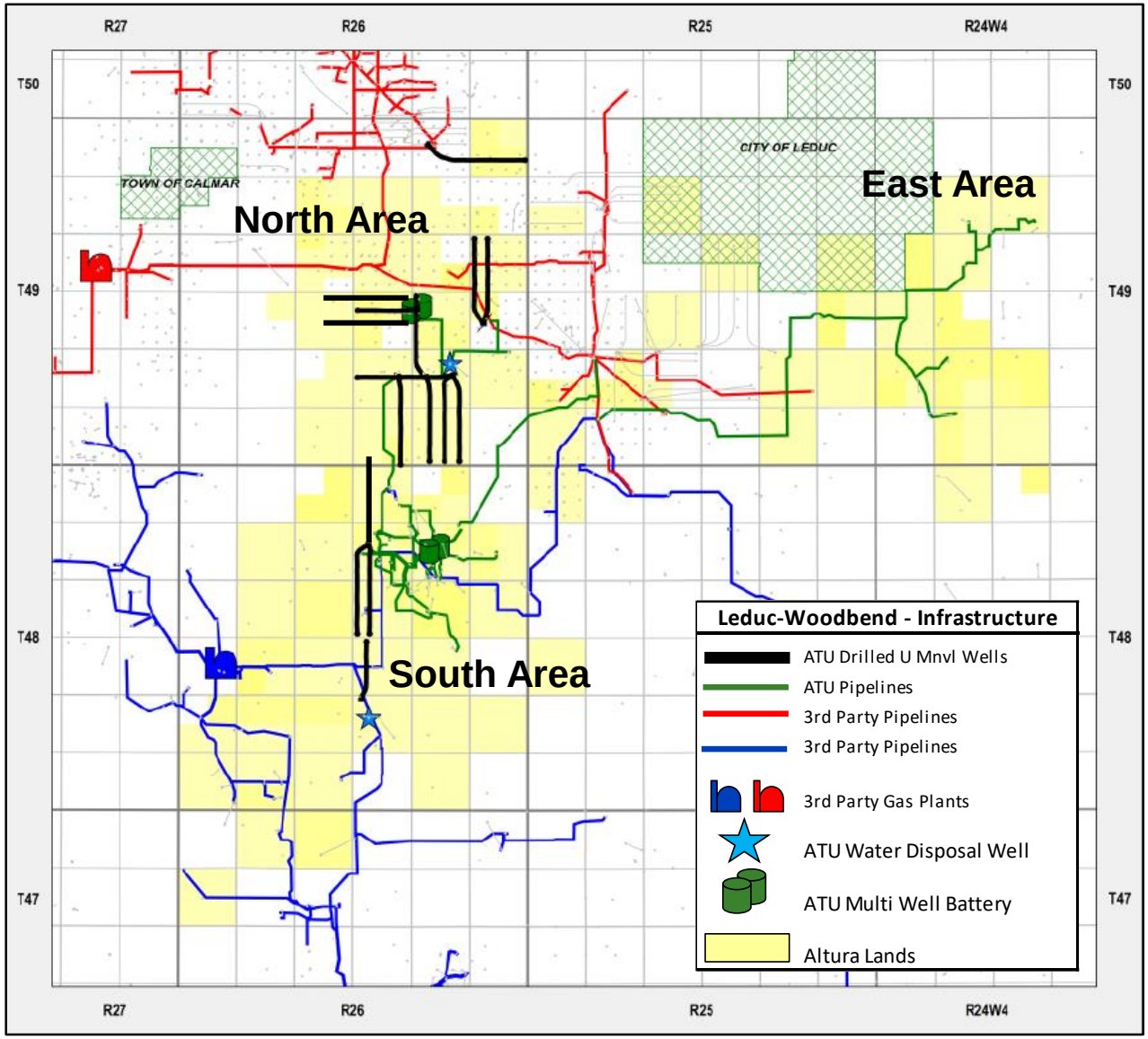
Economics and Inventory of Locations

- Good economics on both freehold and crown lands
- Inventory of over 150 1mile equivalent wells based on 4 wells/section
- Depending on pace of development that translates into 10-15 years of drilling inventory

LWB Type Curve Economics 1.5-Mile Hz MSF (2/3 Crown, 1/3 Freehold) (1)		
Price Forecast	**McDaniel Q3 2019**	**$US55/Bbl WTI Flat**
DCET Capital	$2,300,000	
1st Month IP Rate	330 Boe/d	
1st Year Average Rate	155 Boe/d	
2P EUR (2)	200 Mboe	
NPV10BT	$2.1MM	$0.85MM
Payout (yrs)	**1.4**	**2.0**
IRR	**77%**	**39%**
F&D	$11.50/Boe	
Operating Cost	$11.00/Boe	
Operating Netback	$31.00/Boe	$25.00/Boe
Recycle Ratio	**2.7**	**2.2**
Liquids Weighting	70%	

Pool Development Plan

- Multi-well batteries and water disposal wells in both the north and south areas
- Extensive company owned and third party gas infrastructure
- Well established service base in the area with year round access
- Waterflood pilot project in sec 15 49-26W4



Conclusions

- Upper Mannville a significant hydrocarbon target in the WCSB
  - A common conventional oil and gas producer with multiple pools
  - Contains 9 of the top 40 conventional oil pool discoveries
- A relatively immature, bypassed target
  - Difficult to map and interpret based on subtle log response
  - Poorly understood; limited regional industry trend maps or cross sections available
  - New ideas applied to abundant old data
- Multi-stage frac horizontal wells have allowed economic rates of production from this and other low permeability zones
  - This technology has lead to large oil and gas pool discoveries and extensions
  - In the deep basin producers are realizing massive productivity gains within the gas window
- LWB Rex oil pool in this mature basin is an example of the combination of hard work, skill and luck

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