Souring of Kaybob Duvernay Wells: Investigation of Hydraulic Fracture Barrier Effectiveness, Completions Design and Pre-Duvernay Structural Features*

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Abstract

The Devonian Duvernay Formation is an organic-rich mudrock that is a prolific self-sourcing light oil to condensate-rich gas reservoir in the Kaybob region of Central Alberta. Well tests show initial rates up to 3900 boe/d with EUR values less than 1.6 MMBOE. As the Duvernay play appraisal progressed since 2010, more wells are testing or producing sour hydrocarbons (0.5-8000 ppm) from a sweet hydrocarbon play. A need to understand and model the processes that sour Duvernay wells is crucial as souring impacts the economics, health and safety of operations. Both the underlying Beaverhill Lake Group and the Duvernay laterally equivalent Leduc Formation contain conventional oil and gas pools that are sour (< 45%). These sour pools are the most probable source of the H_2S seen in ~10% of drilled wells (June, 2015) within the Kaybob Duvernay play. The possible reasons for souring include artificial and natural fracture conduits, proximal Leduc reef facies changes, communication between existing sour Duvernay and Beaverhill Lake wells or in-situ thermal sulfate reduction processes. The most likely cause of this souring is artificial fracturing and the increase in sour wells over time is due to, in part, the increase in hydraulic fracture fluid volumes from 5-10 m^3/m to 25-35 m^3/m (2012-2015).

Companies have increased in hydraulic fracture volume designs based on observation that the EUR increases with increasing hydraulic fracture fluid volumes (including proppant loading). Cross plotting the hydraulic fracture fluid volume (m^3/m) and the basal fracture barrier thickness indicates that as the basal fracture barrier thins (< 18 m) the barrier becomes less effective and the risk of souring increases. The basal fracture barrier consists of the Duvernay middle carbonate, Majeau Lake and Waterways

formations. Increasing the hydraulic fracture fluid volume (i.e. from 15m^3/m to 30m^3/m) will reduce the effectiveness of the basal fracture barrier and also increase the risk of souring Duvernay wells in areas where the fracture barrier is greater than 18 m thick. Sour risking map has been created for the Kaybob Duvernay play based the basal fracture barrier thickness and mapping of Beaverhill Lake pools and Leduc reefs.

References Cited

Krouse, H.R., C.A. Viau, L.S. Eliuk, A. Ueda, and S. Halas, 1988, Chemical and isotopic evidence of thermochemical sulphate reduction by light hydrocarbon gases in deep carbonate reservoirs: Nature, v. 333, p. 415-419.

Oldale, H., and R. Munday, 1994, Devonian Beaverhill Lake Group of the Western Canada Sedimentary Basin, *in* G. Mossop and I. Shetsen, eds., Geological Atlas of the Western Canada Sedimentary Basin: Canadian Society of Petroleum Geologists and Alberta Research Council Special Report, Edmonton, AB, Canada; p. 149-163.

SOURING OF KAYBOB DUVERNAY WELLS: INVESTIGATION OF FRAC BARRIER EFFECTIVENESS, COMPLETIONS DESIGN AND PRE-DUVERNAY STRUCTURAL FEATURES

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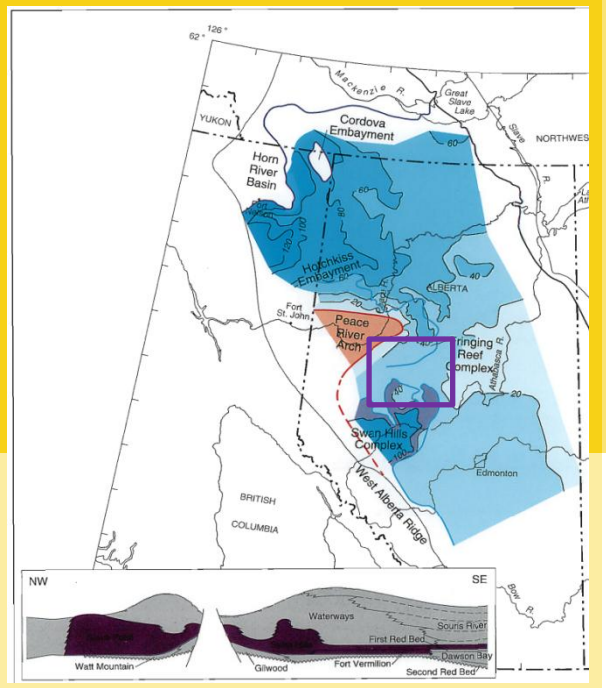

■ Modified from Oldale and Munday 1994 (WCSB Atlas)

June 2016

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Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.
Organic: Our use of the term Organic includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.
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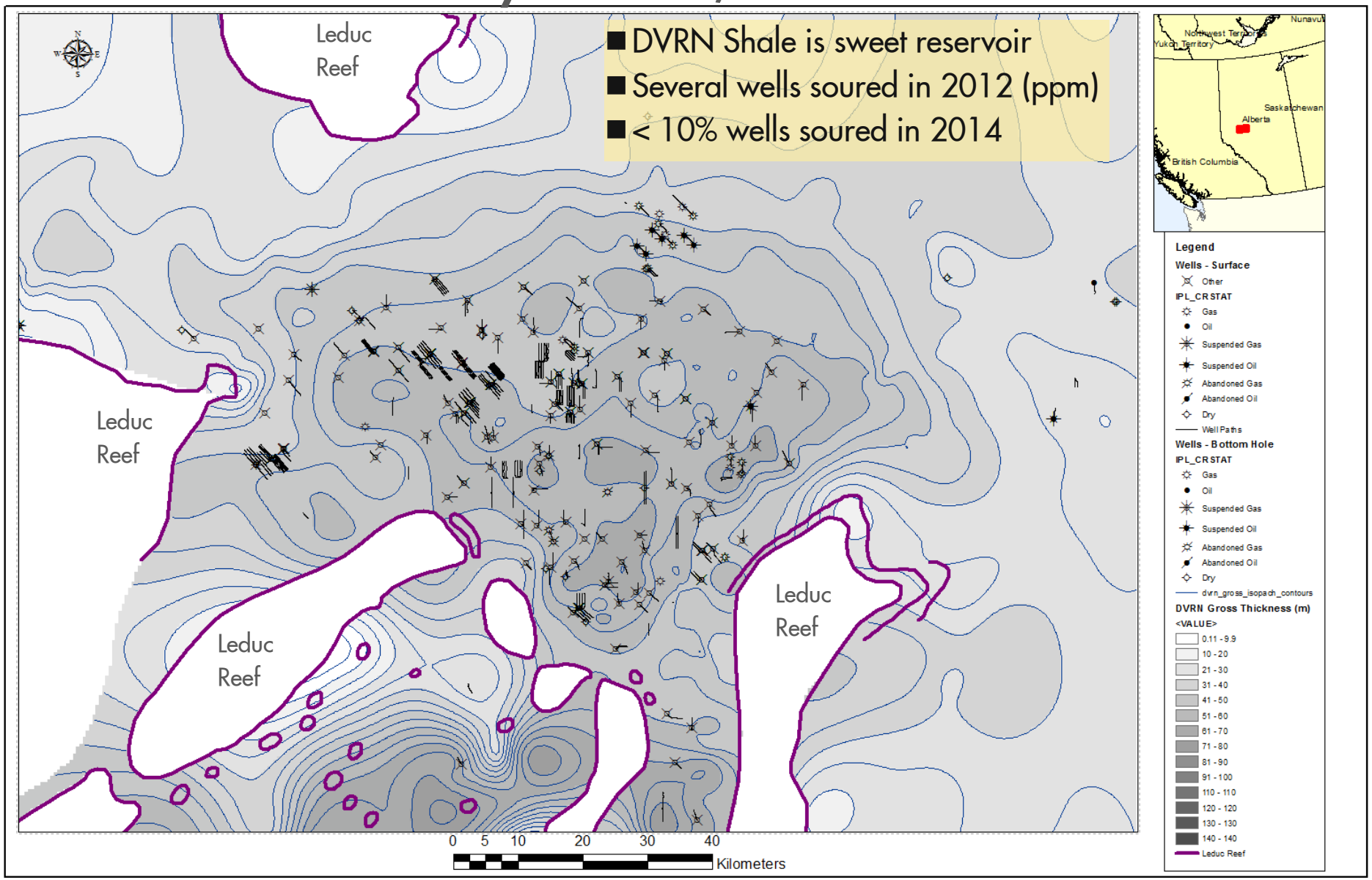
HSE RISKS – H2S EXPOSURE

Exposure Conc. (ppm)	Possible Health Effects
< 1	Smell it
< 10	No known adverse effects; need respiratory protection
20-50	Eye, nose, throat, lung irritation
100-150	Severe respiratory irritation, loss of smell sense, > 8hrs can be fatal
200-300	Headaches, drowsiness, several hrs lungs fill with fluid
300-500	1 to 4 hrs = unconsciousness and death
500-700	1 hr knockdown and possibly fatal
> 700	Immediate knockdown – may be fatal

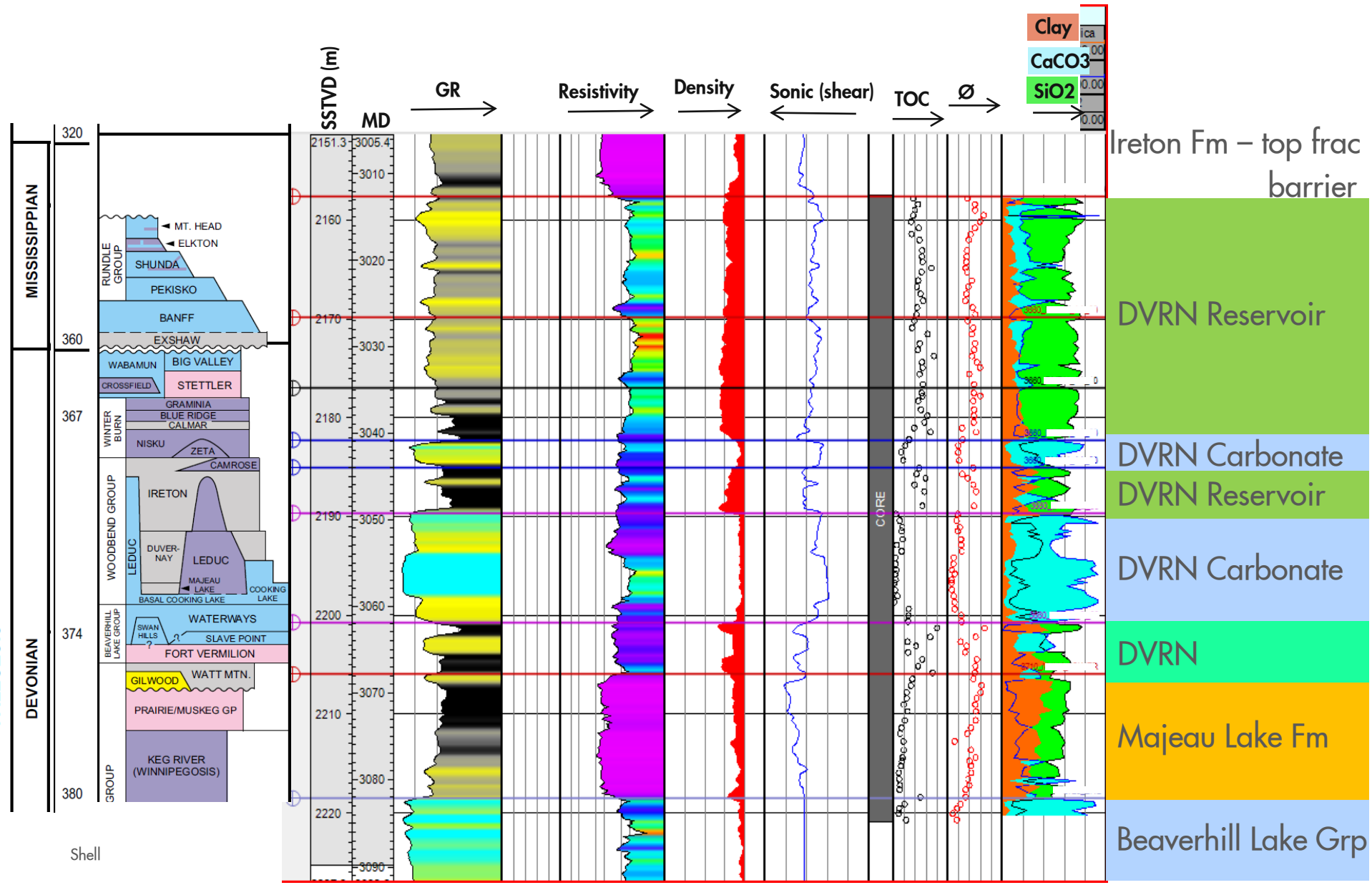
■ From Enform H2S Alive, hydrogen sulphide training

STUDY AREA - DVRN GROSS THICKNESS & DRILLED WELLS

Kaybob Area, Central Alberta



TYPE LOG – DVRN WELL IN KAYBOB



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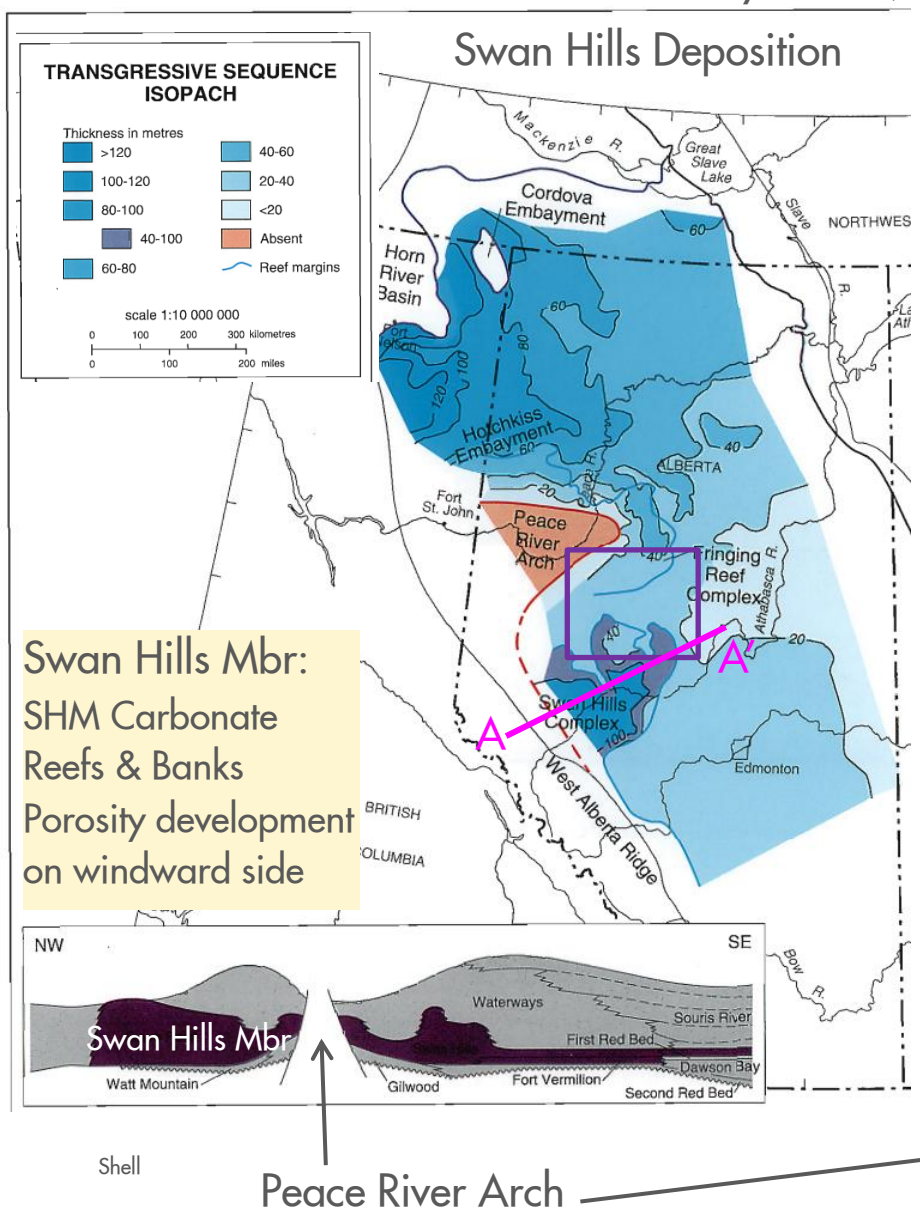
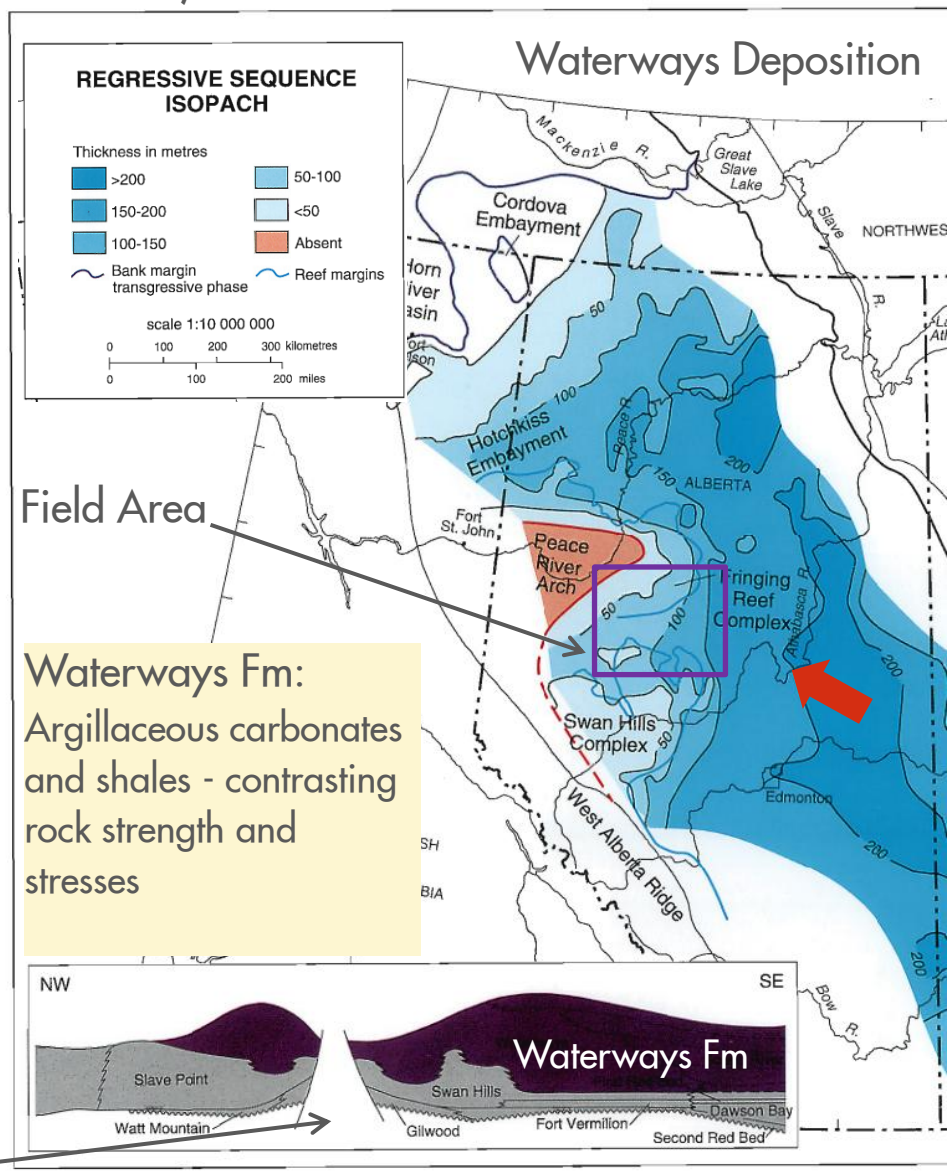
DEVONIAN BEAVERHILL LAKE GROUP - PALAEOENVIRONMENTS

- Modified from Oldale and Munday 1994 (WCSB Atlas)



Swan Hills Mbr:
SHM Carbonate Reefs & Banks
Porosity development on windward side



Field Area

Waterways Fm:
Argillaceous carbonates and shales - contrasting rock strength and stresses

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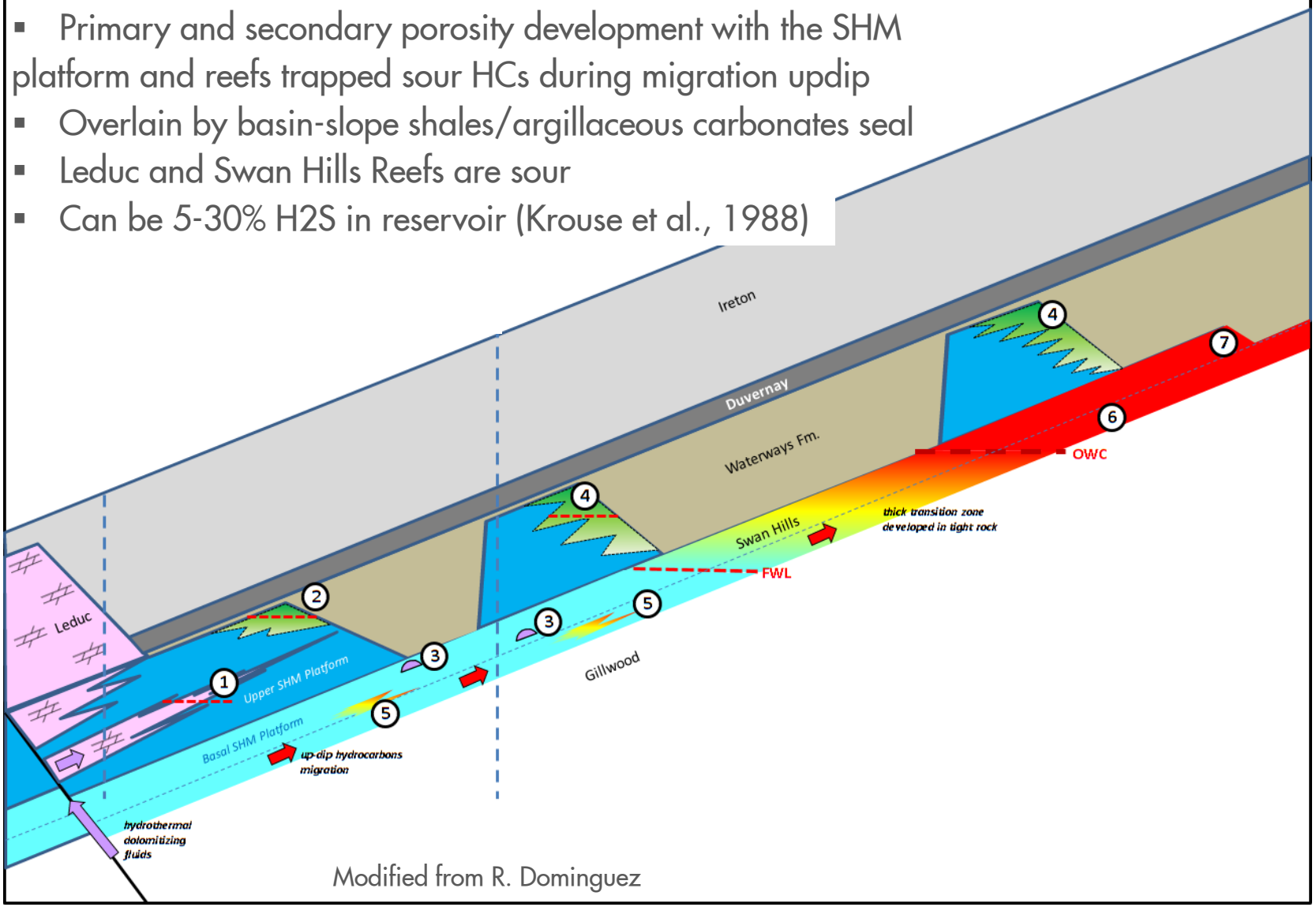
Peace River Arch

FLUID MIGRATION MODEL BHL GROUP

A A`

SSW NNE

- Primary and secondary porosity development with the SHM platform and reefs trapped sour HCs during migration updip
- Overlain by basin-slope shales/argillaceous carbonates seal
- Leduc and Swan Hills Reefs are sour
- Can be 5-30% H2S in reservoir (Krouse et al., 1988)

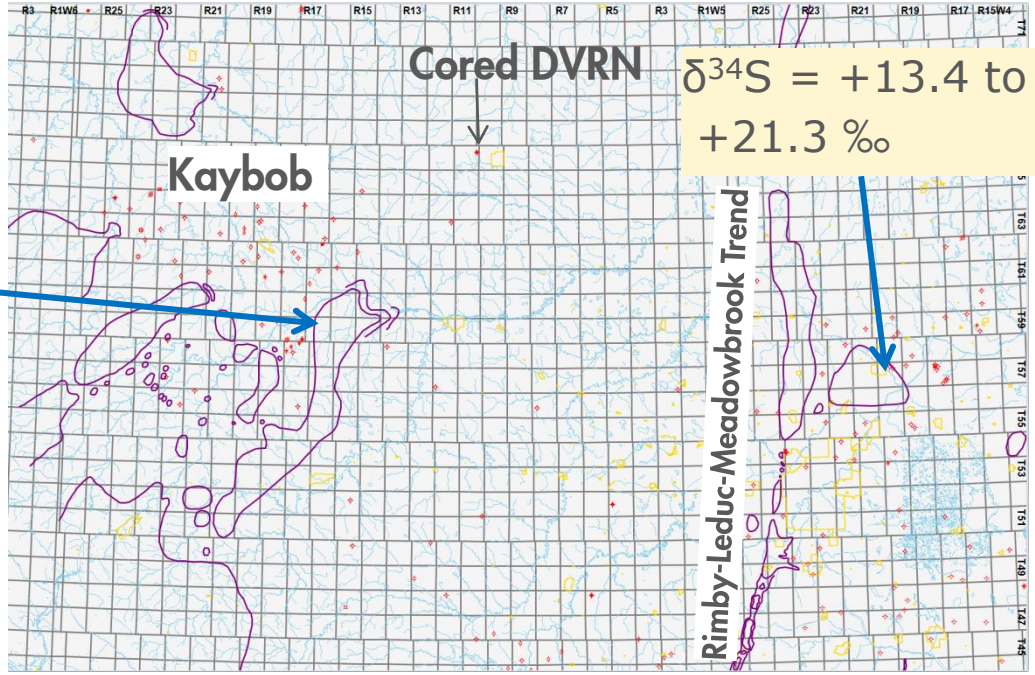


Modified from R. Dominguez

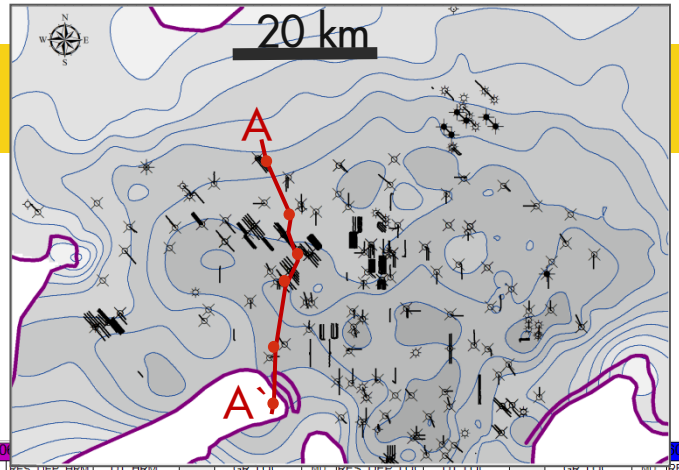
H2S SOURCES IN BHL AND LEDUC CARBONATES

- H2S in WCSB carbonate reservoirs
  - From either bacterial sulphate reduction (BSR) or thermochemical sulphate reduction (TSR)
  - Organic matter or light hydrocarbons are the catalyst
  - Abiogenic (TSR; > 90 C) and biogenic reactions (< 90 C)
- Sulphur isotopes - biogenic reaction fewer positive values
  - TSR more positive and similar to evaporite values (sulphate sourced from anhydrite)
  - Sulphur isotope samples from Leduc is +13.4 to +21.3 ‰ (Krouse)
  - Kaybob samples show a range between +20.3 to +22.8 ‰

$\delta^{34}S$ = +20.3 to +22.8 ‰



NORTH-SOUTH X-SECTION, KAYBOB



GR RES DT

A A`

100113006421W500 [MD] | 100112806321W500 [MD] | 100100906321W500 [MD] | 100063106 | 100022W500 [MD]

GR_LQC | GR_HRM | RES_DEP_LQC | RES_DEP_HRM | DT_LQC | DT_HRM

Datum: Top of Ireton Fm

Duvernay Carbonate

Waterways Fm

Duvernay Fm

Ireton Fm

Leduc/SHM Reef Build-ups

Swan Hills Mbr

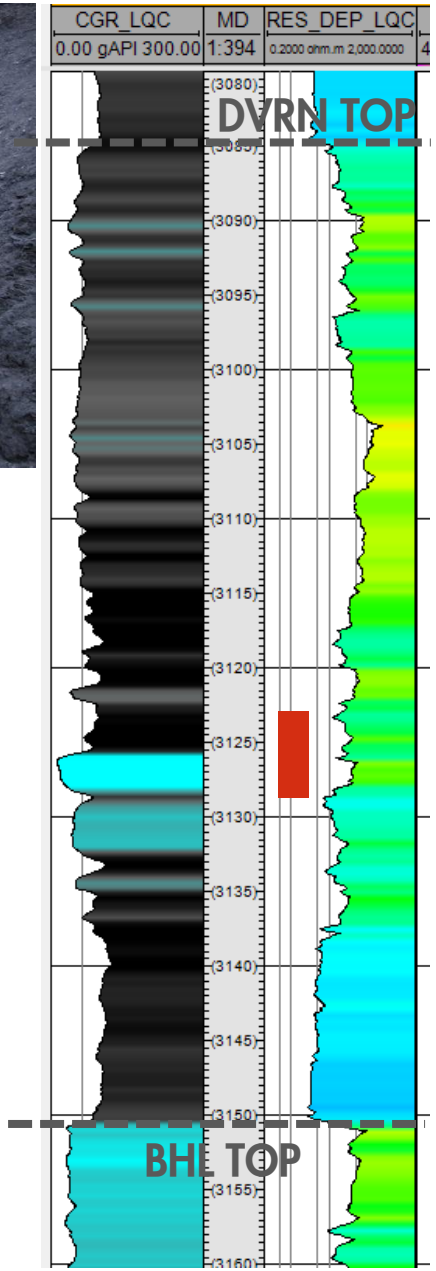
Lower Sour Risk | Mod to High Sour Risk | High Sour Risk

DUVERNAY MIDDLE CARBONATE

Perdrix (Duvernay) Outcrop, Roche Miette

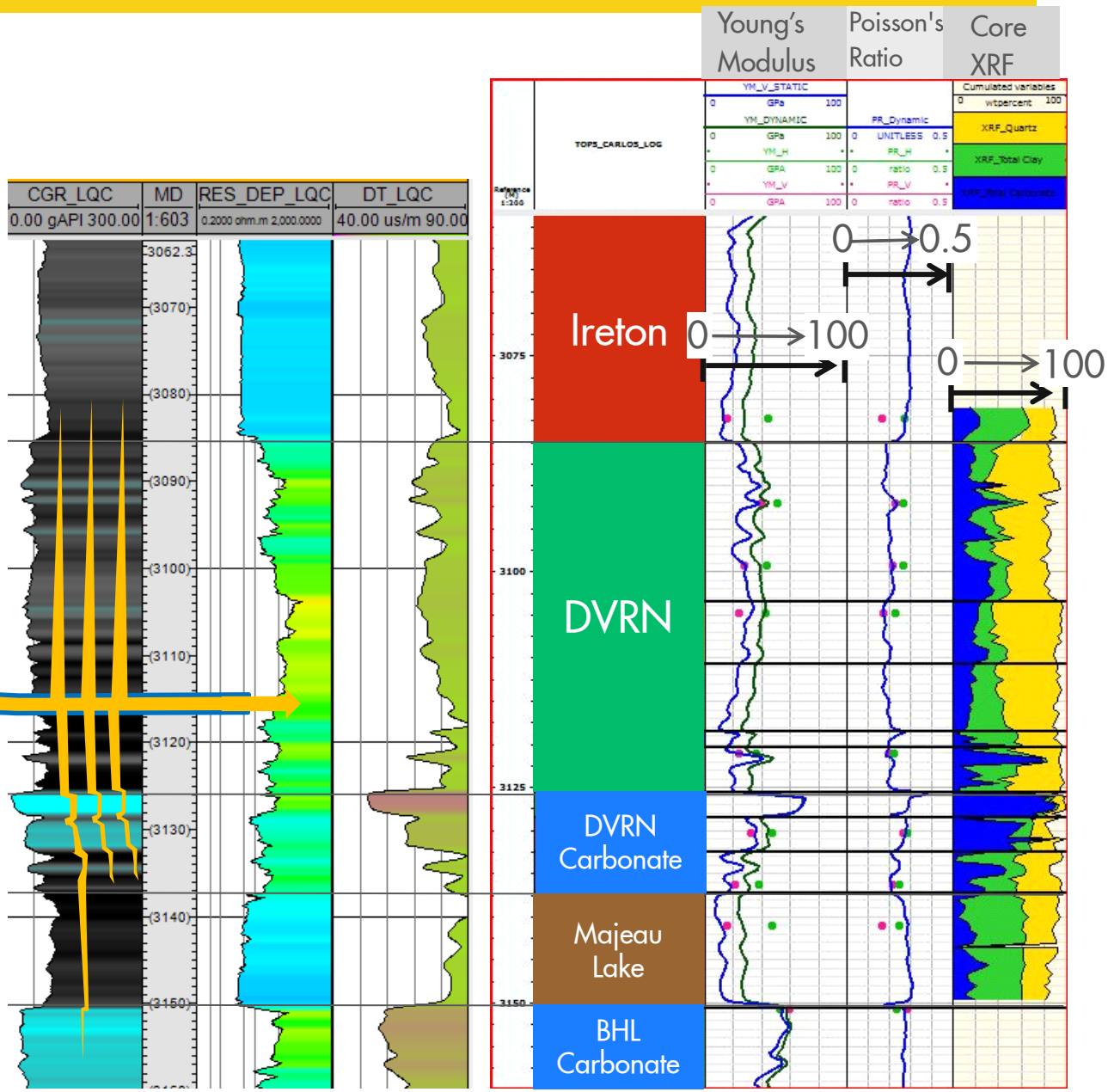
Middle Duvernay Carbonate:

Alternating carbonate and shale package

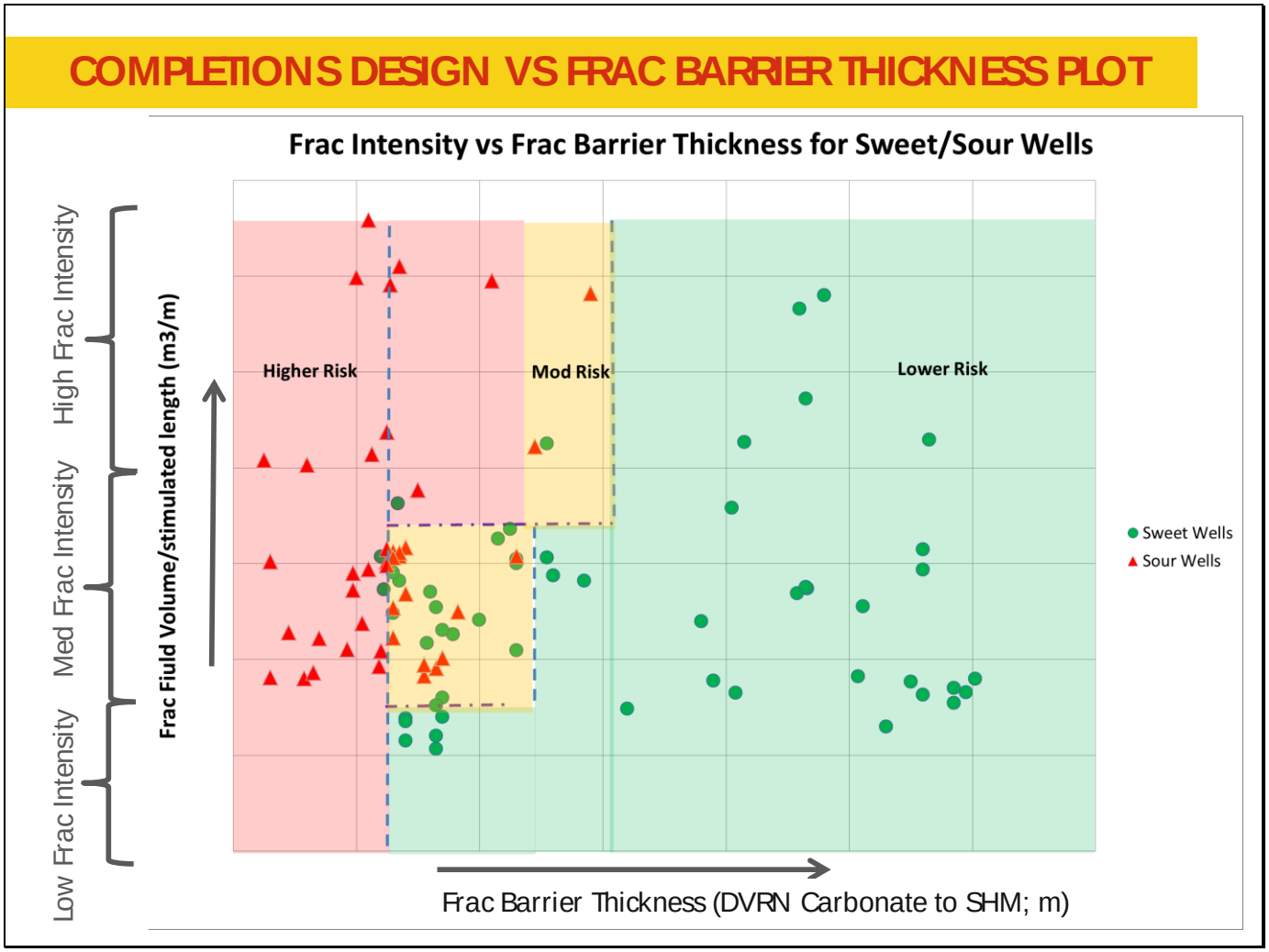


Geomechanical stratigraphy in DVRN

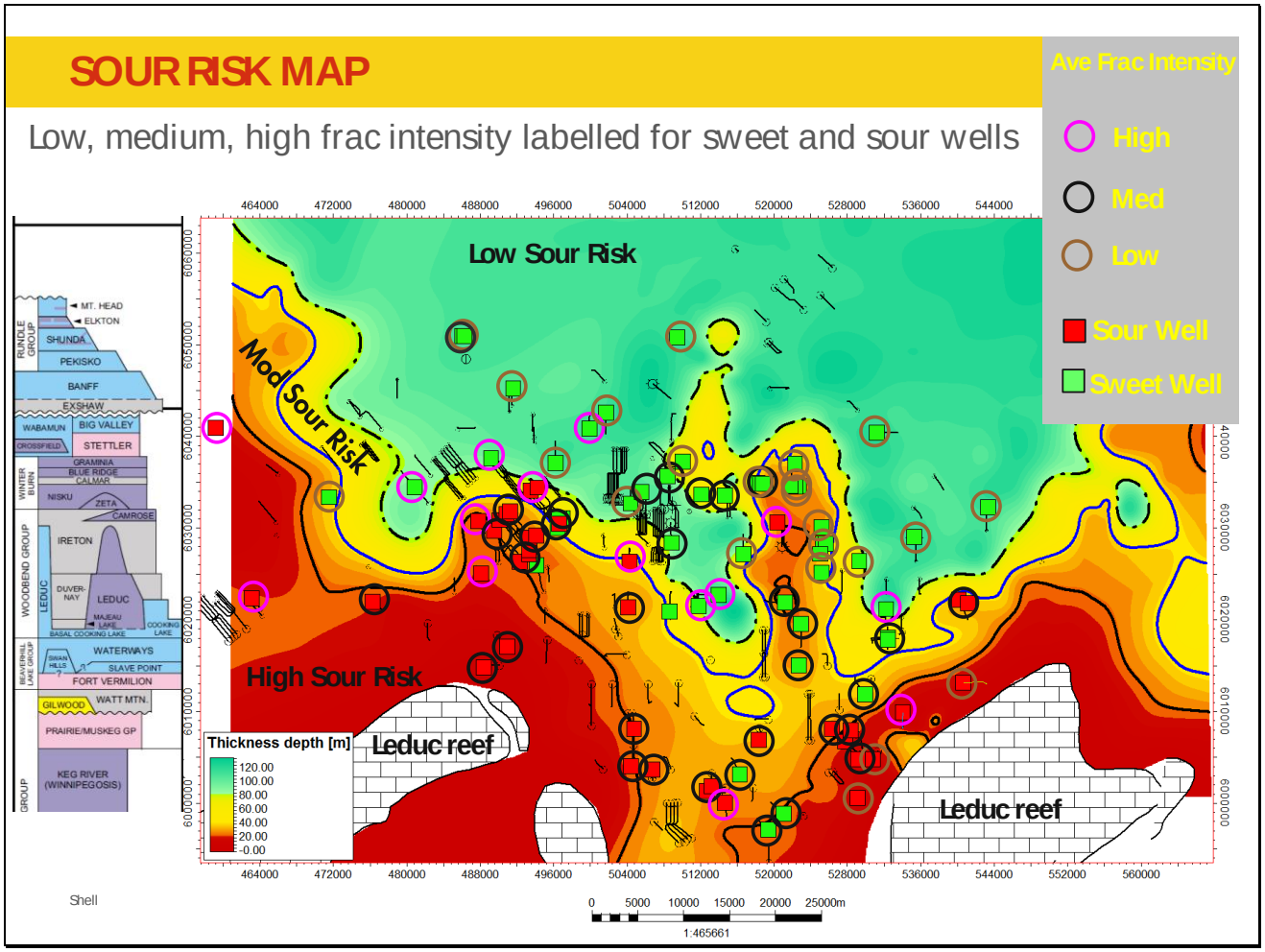
- lithological changes related to depositional/accommodation changes
  - DVRN Carbonate
  - Waterways Fm (BHL Gp)
- Increasing heterogeneity will increase contrasting rock strengths and internal rock stresses
  - reduce fracture effectiveness
- Ineffective fracs still grow into underlying strata – low proppant placement, increased tortuosity = poor communication



COMPLETIONS DESIGN VS FRAC BARRIER THICKNESS PLOT



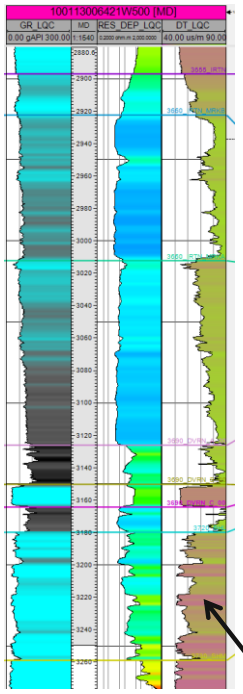
Presenter's notes: Combination of frac intensity (frac fluid per metre, as well as proppant tonnage per metre) and the basal frac barrier thickness (DVRN Carbonate + Majaeu Lake + Waterways) will influence whether a DVRN well will sour or not. Porosity needs to develop within the Swan Hills member (reef or platform) in order for DVRN well to sour. When the barrier is thin, like adjacent to the Leduc Reef, no frac design mitigation will stop the well from souring (i.e., both low and high intensity fracs will sour the well).

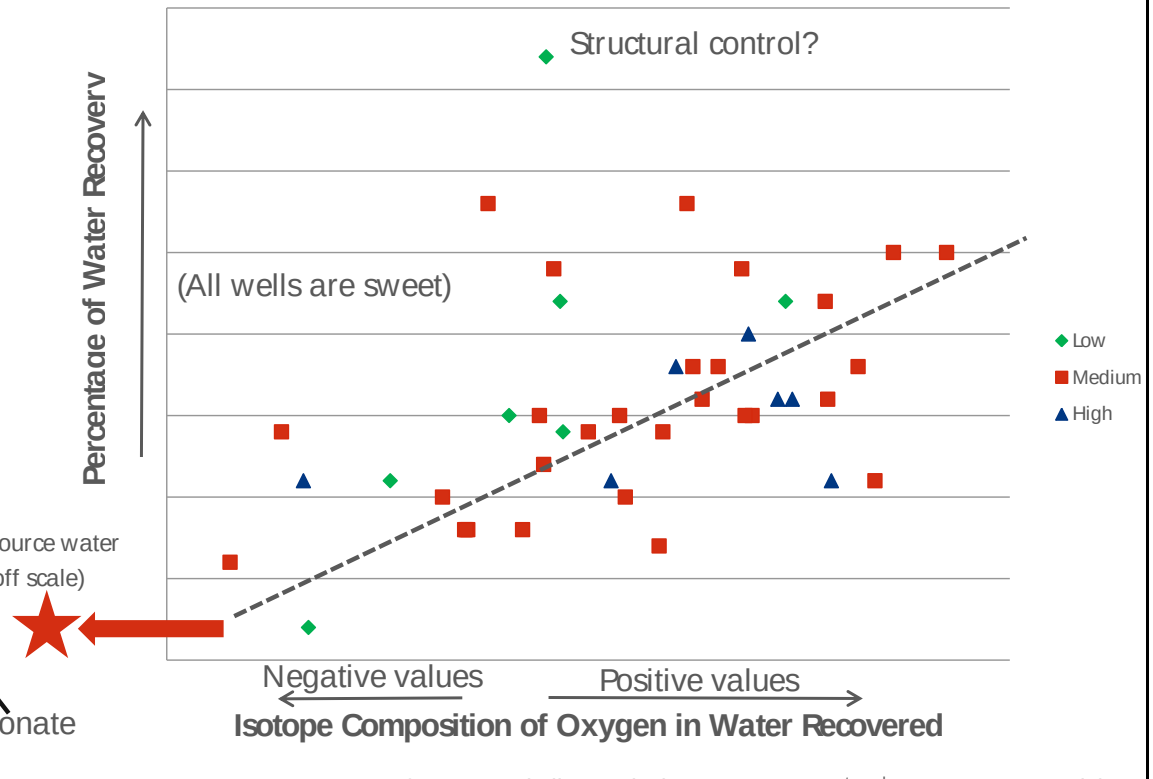


Presenter's notes: SHM and Leduc carbonates are critically sour (1-30%) while DVRN sour wells are in the ppm range indicating the fracs that are communicating are ineffective tortuous fracs.
Initially sour wells were seen only within the high risk area surrounding the Leduc reefs but this risk expanded to include wells souring further away from the Leduc Reefs and a new model developed that included the thickness of Waterways Formation and sour wells developed where high intensity fracs we placed in wells over thin Waterways Fm and porosity developed within the Swan Hills Mbr below.

BHL WATER PLOT VS SOUR RISK MAP

- The percentage of water recovery after 1 year
- Oxygen Isotopic signature of flow back water after 1 year,
  - higher % flowback water = heavier oxygen isotope in water (& higher TDS)





- Waterways Carbonate

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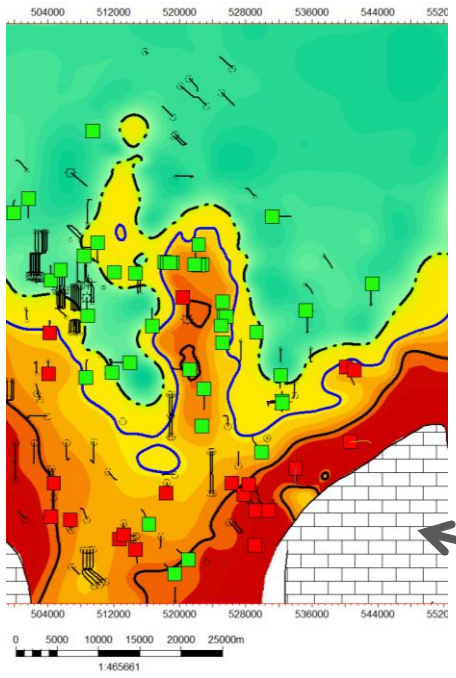
- Courtesy of Mat Fay, Shell Canada (URTEC, august, 1st-3rd, 2016 –San Antonio)

Presenter's notes: Water chemistry shows that with DVRN well that have a higher water recovery during production (1 year) heavier the oxygen isotope from the water is, with respect to the sourced frac water, these wells are still sweet wells but show that even these wells are penetrating into the Waterways and sourcing water from the water-bearing carbonates in the Waterways Formation.

CARBON ISOTOPIC COMPOSITION OF PRODUCING FLUIDS



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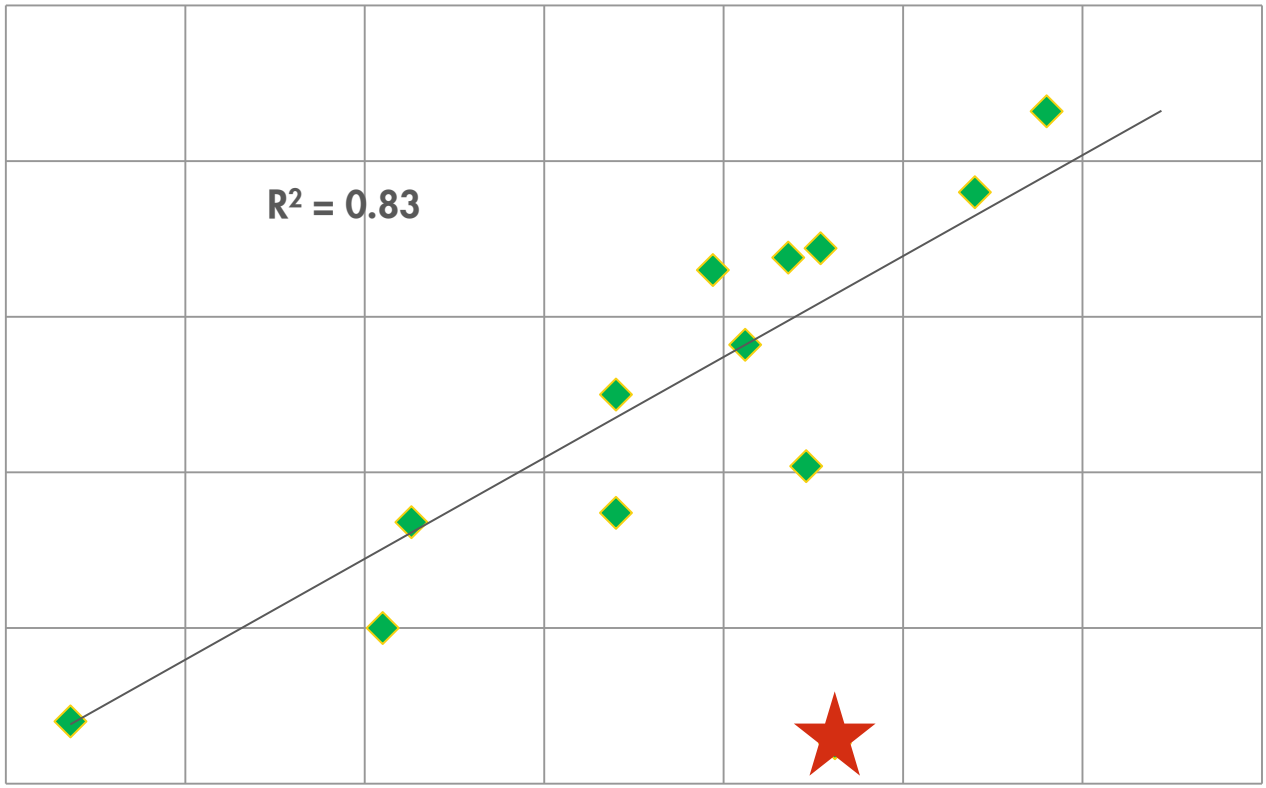
Carbon Isotope Ratio vs VRE



VRE (%)

More mature

Isotopically heavier

13-Carbon Isotope Composition of Producing Ethane (‰)

Well within 2 km of Leduc Reef

CONCLUSIONS

- DVRN reservoir is considered a baffle that creates ineffective fracs (high tortuosity) with some growing into underlying strata
  - This is highlighted by H2S, carbon and oxygen isotopic compositions of flowback water
  - H2S concentration is in ppm from producing DVRN wells which are sourced from critically sour BHL (30%) - indicating fracs are inefficient
- Risk of souring increases with thinning of Waterways Fm and/or an increase in frac intensity (increase fluid and proppant volumes/metre)
- Mapping the BHL group should be used in conjunction with the frac design as part of the risk management when developing the DVRN play