

Western Canada Sedimentary Basin Petroleum Systems: A Working and Evolving Paradigm

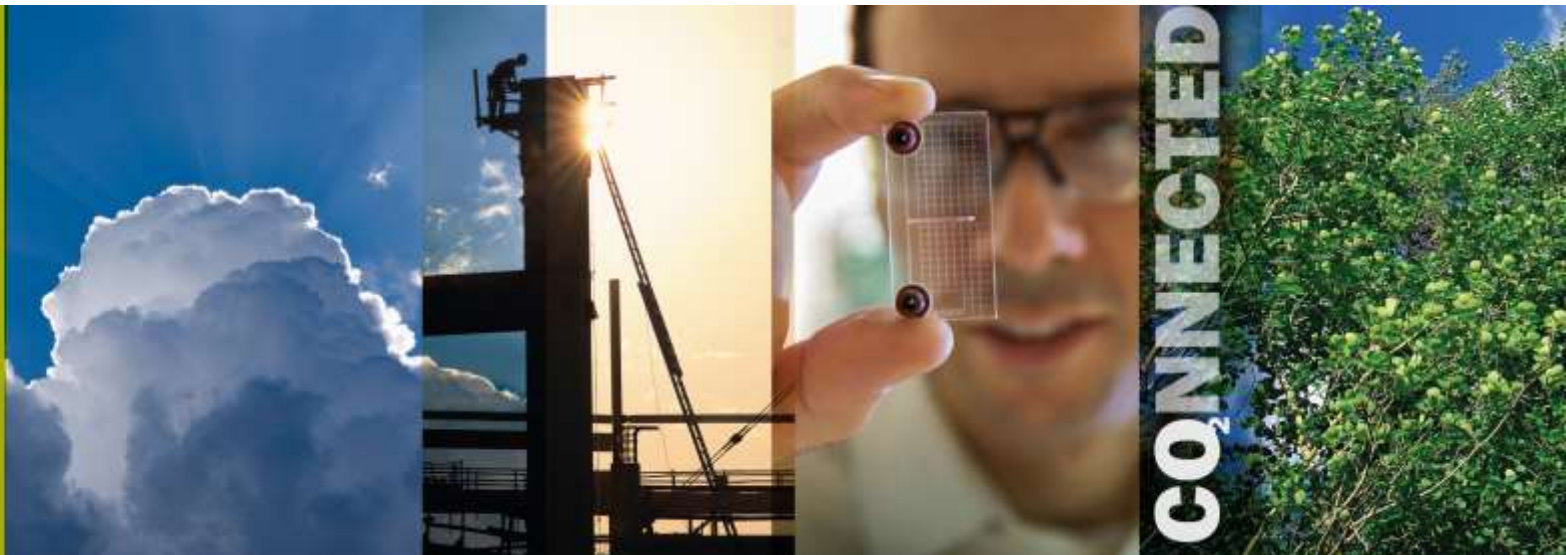
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New pathways
to reduce
greenhouse
gas emissions.



See:

Kirk G. Osadetz, Andrew Mort, Lloyd R. Snowdon, Donald C. Lawton, Zhuoheng Chen and Amin Saeedfar, 2018.

Western Canada Sedimentary Basin petroleum systems: A working and evolving paradigm

In: D. Eaton and P. K. Pedersen (eds.), Low-permeability resource plays of the Western Canada Sedimentary Basin. Interpretation (May 23, 2018) 6 (2) : SE63-SE98 <https://doi.org/10.1190/INT-2017-0165.1>

For full text:

<https://pubs.geoscienceworld.org/interpretation/article/6/2/SE63/548645/western-canada-sedimentary-basin-petroleum-systems>

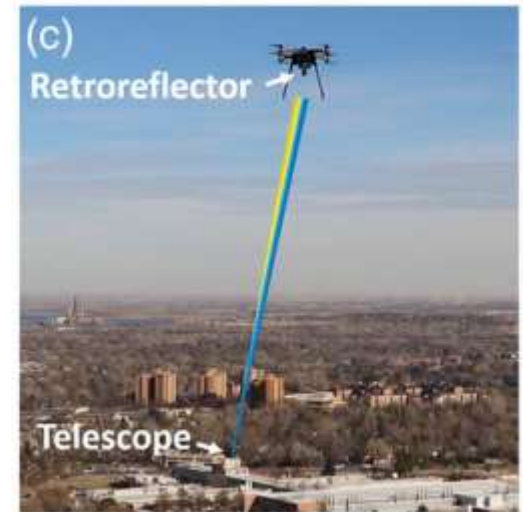
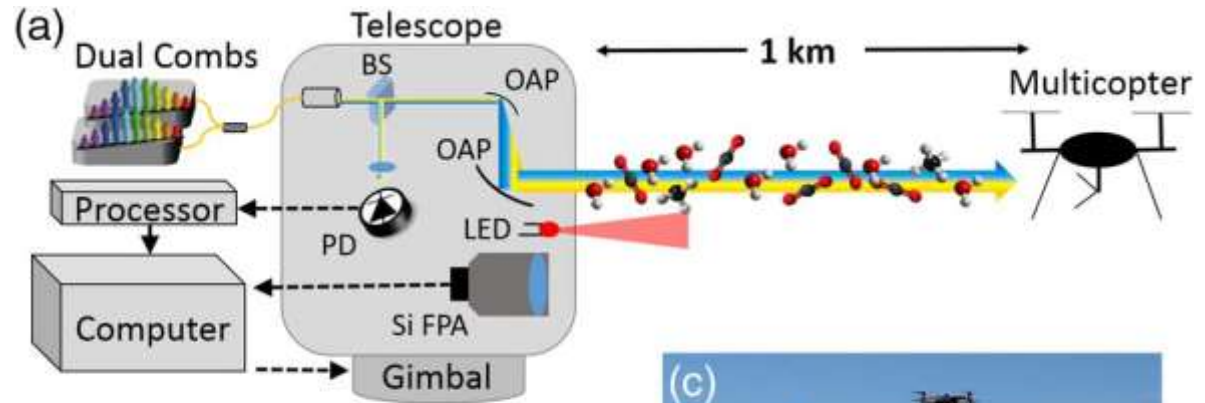
Newell County Field Research Station

- A collaboration between CMCRI and UofC.
- 200 Ha of surface and subsurface under long-term lease from Torxen Energy Ltd.
- Globally leading technology development and demonstration facility. We are not a CO₂ storage facility.
- We inject from above to simulate a leak from below and monitoring its detection threshold, containment and conformance to reservoir models, operating at depths similar to steam chambers.
- Subsurface facilities operate both as a JIP and for single client studies.
- Atmospheric studies are a new addition, part of the PTAC Methane Monitoring Consortium.



Methane Monitoring coming this winter to a Newell County Field Research Station near you.

- Installing a dual frequency comb laser interferometer for CH₄ and CO₂.
- The system uses a remarkable technology (T. Hänsch and J. Hall 2005 Nobel Prize in Physics). It is a truly continuous monitoring system and with extraordinary detection threshold and monitoring radius (<1 ppm for CO₂ and <3 ppb for CH₄ in 5 min).
- We will initially install a totally ground based system on a hub (source/receiver) and spoke (reflector) geometry.
- Placement of the reflector in a UAV has been successfully tested.



Key Messages

- **TPS crude oil component characterizations are relatively complete.**
- **Biodegradation and its implications are underappreciated, especially in Mannville gas and post-Mannville oil reservoirs.**
- **TPS natural gas components and processes are not reconciled to crude oil components.**
 - Secondary biogenic gas is not recognized or distinguished.
 - Gas migration models are incorrect.
 - Mannville oils/bitumen have marine sources generally, but most Mannville gases are interpreted to have non-marine sources.
- **Improved TPS analysis will assist effective CH₄ emission reduction policies and may contribute to improved unconventional petroleum play performance.**

Total Petroleum System

- **The discovered and undiscovered petroleum, its source rocks, reservoir, trap, migration pathway and history.**
- **Captured binomially in combination of source and reservoir stratigraphic unit names (Duvernay-Leduc (!)).**
- **Attributed a degree of certainty:**
 - (!) known,
 - (.) hypothetical,
 - (?) speculative.
- **Additional modifiers resolve geographic and trapping ambiguities and describe processes (e.g. secondary vs. primary biogenic natural gas).**
- **Once secondary biogenic gases are formally recognized the nomenclature may have to change:**
 - Mannville (oil src.) - Colorado(?) secondary biogenic gas, or
 - Duvernay-Mannville (oil src.)-Colorado secondary biogenic gas (?)

Previous and recent models indicate complicated migration pathways and mixing in the crude oil systems.

- WCSB marine Type II OM source rocks accumulated typically in “starved” depositional settings of Sloss sequence outer detrital facies belts and lesser stratigraphic cycles.

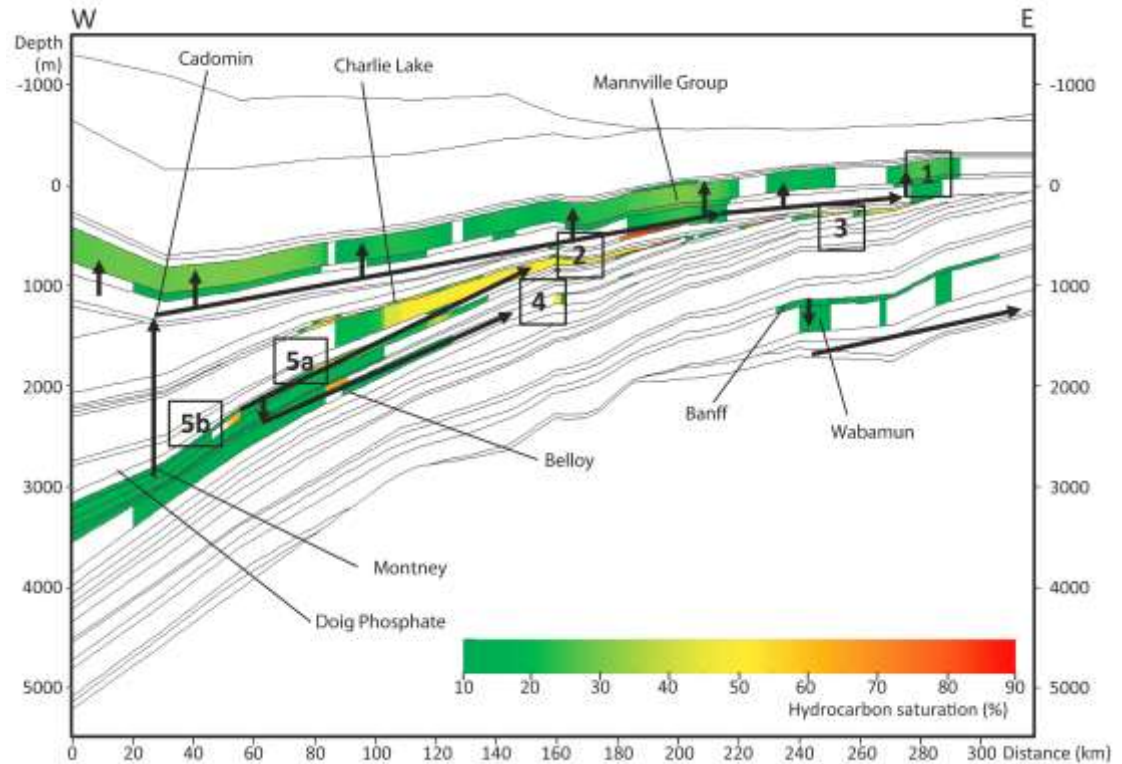


Figure from Ducros et al., 2018 AAPG Memoir Memoir 114, p. 117–134

Previous and recent models indicate complicated migration pathways and mixing in the crude oil systems.

- These produced petroleum from organic matter, kerogen and petroleum in response to burial and other processes under commonly westward-thickening, overlying successions.

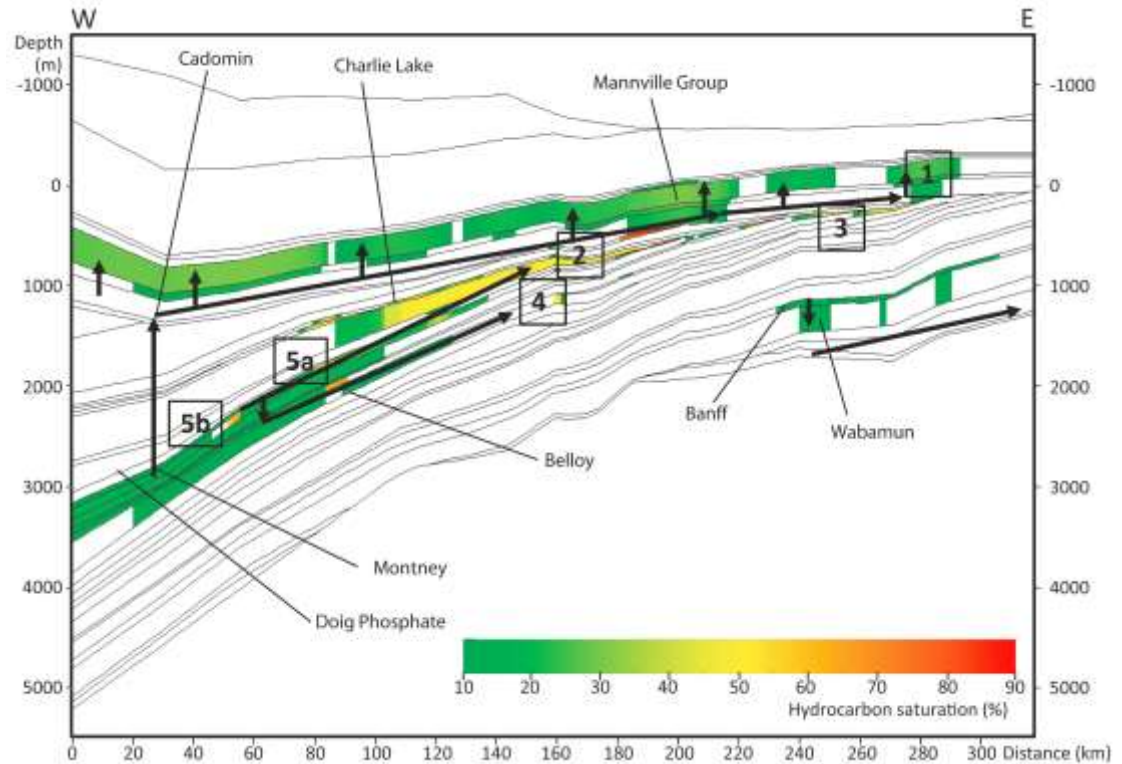


Figure from Ducros et al., 2018 AAPG Memoir Memoir 114, p. 117–134

Previous and recent models indicate complicated migration pathways and mixing in the crude oil systems.

- Crude Oil occurs commonly within the “Sloss” sequence containing its source rock, often up-dip from the “petroleum kitchen”.

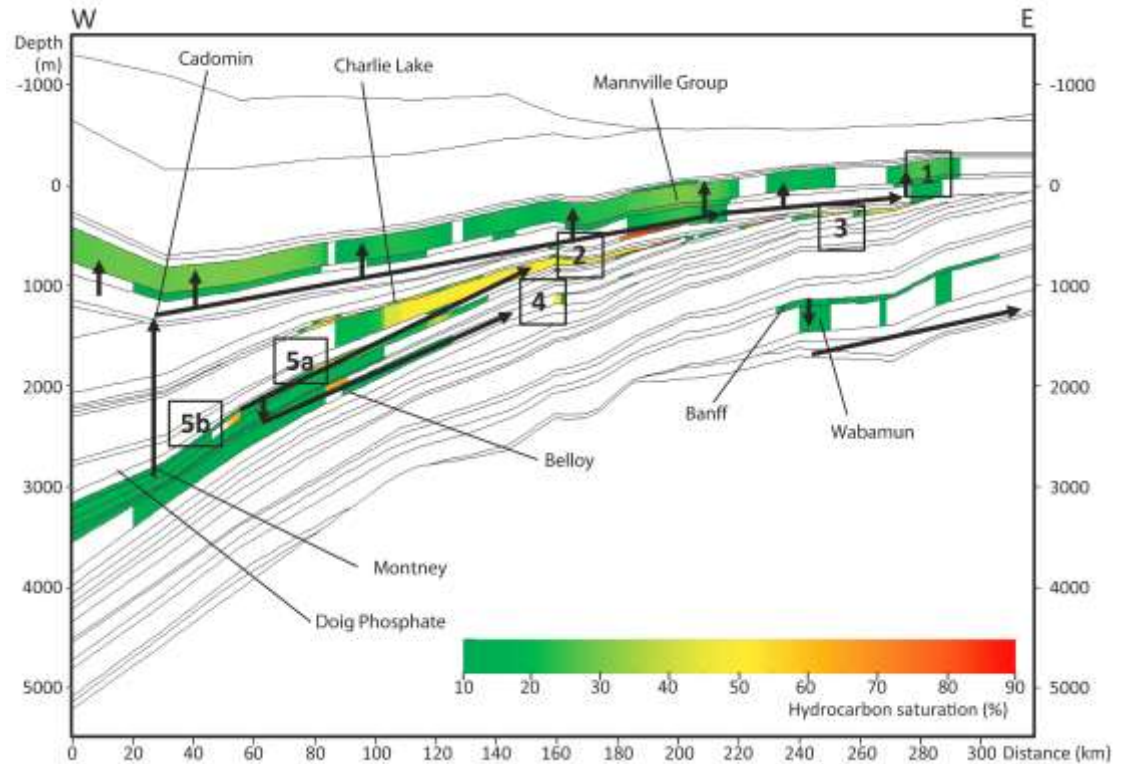


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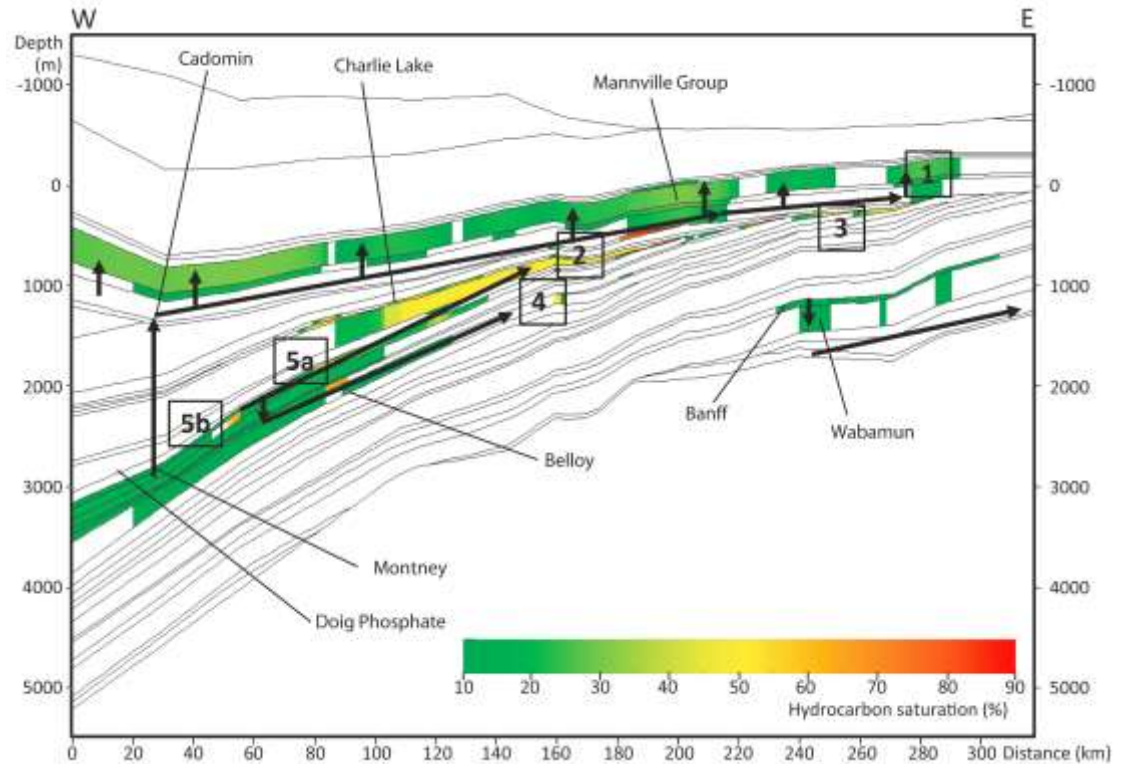


Figure from Ducros et al., 2018 AAPG Memoir Memoir 114, p. 117–134

- Migration pathways cross stratal contacts, unconformities and structures, and much oil migrates into adjacent sequences, especially into Lower Cretaceous Mannville Gp. reservoirs from Paleozoic sources.

Marine Type II OM sources predominant

- Evolutionary biochemistry, water column chemistry, lithic and organic diagenesis, subsequent thermal history, and thermal and biological alteration affect oil compositional traits.

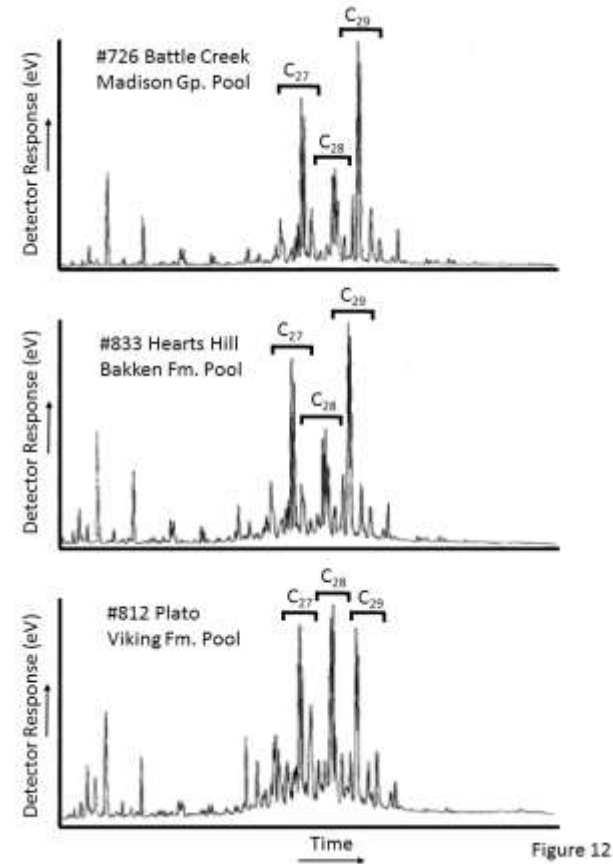


Figure 12

Marine Type II OM sources predominant

- Crude oils from Upper Cretaceous and sources are distinguished by C28/C29 sterane abundances. These compounds come from the cell walls (cholesterol) of eukaryotic organisms.

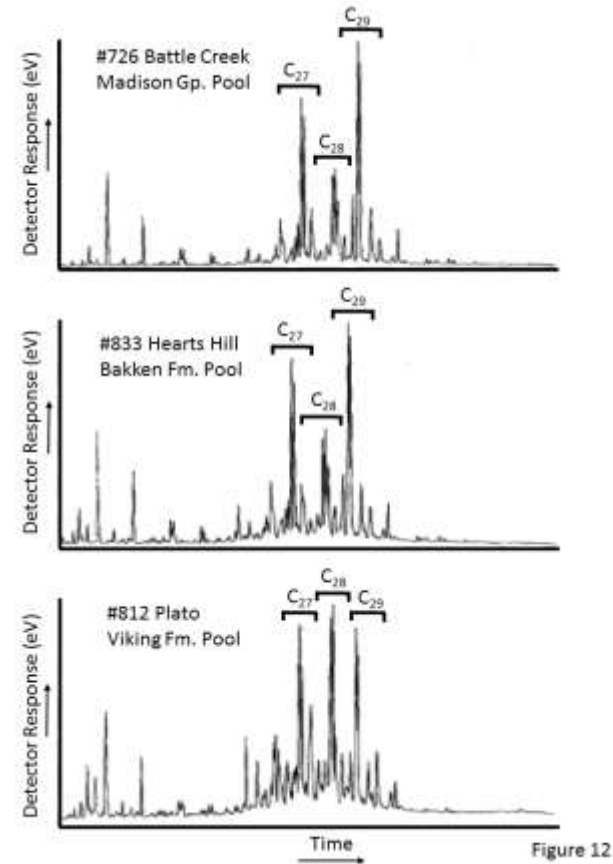


Figure from Osadetz et al., 1994 *Bulletin of Canadian Petroleum Geology*

Marine Type II OM sources predominant

- Crude oils from Paleozoic sources are mutually distinguished by their terpane and hopane abundances. These compounds come from the cell walls (bacteriohopanetetrol) of prokaryotic organisms.

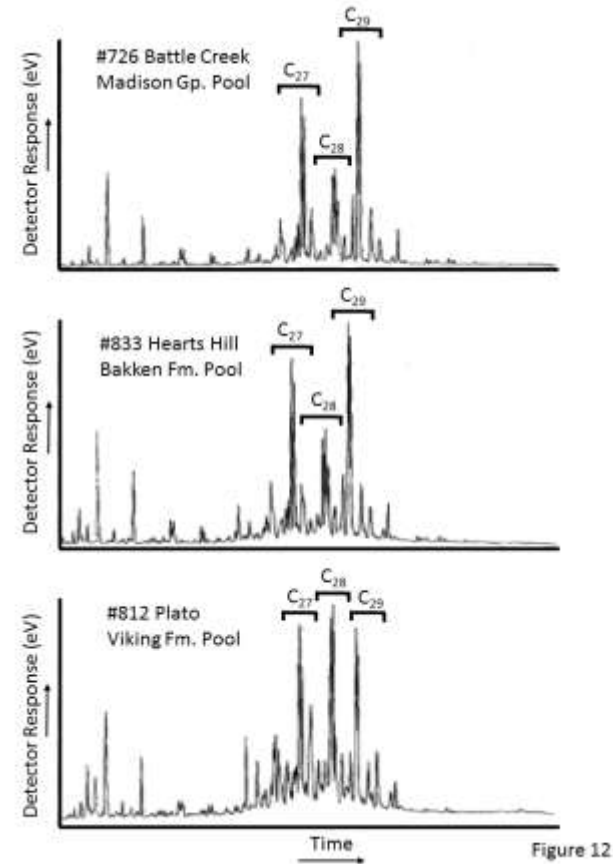


Figure 12

Figure from Osadetz et al., 1994 *Bulletin of Canadian Petroleum Geology*

Criteria for distinguishing thermal maturity from light biodegradation in WCSB Crude oils.

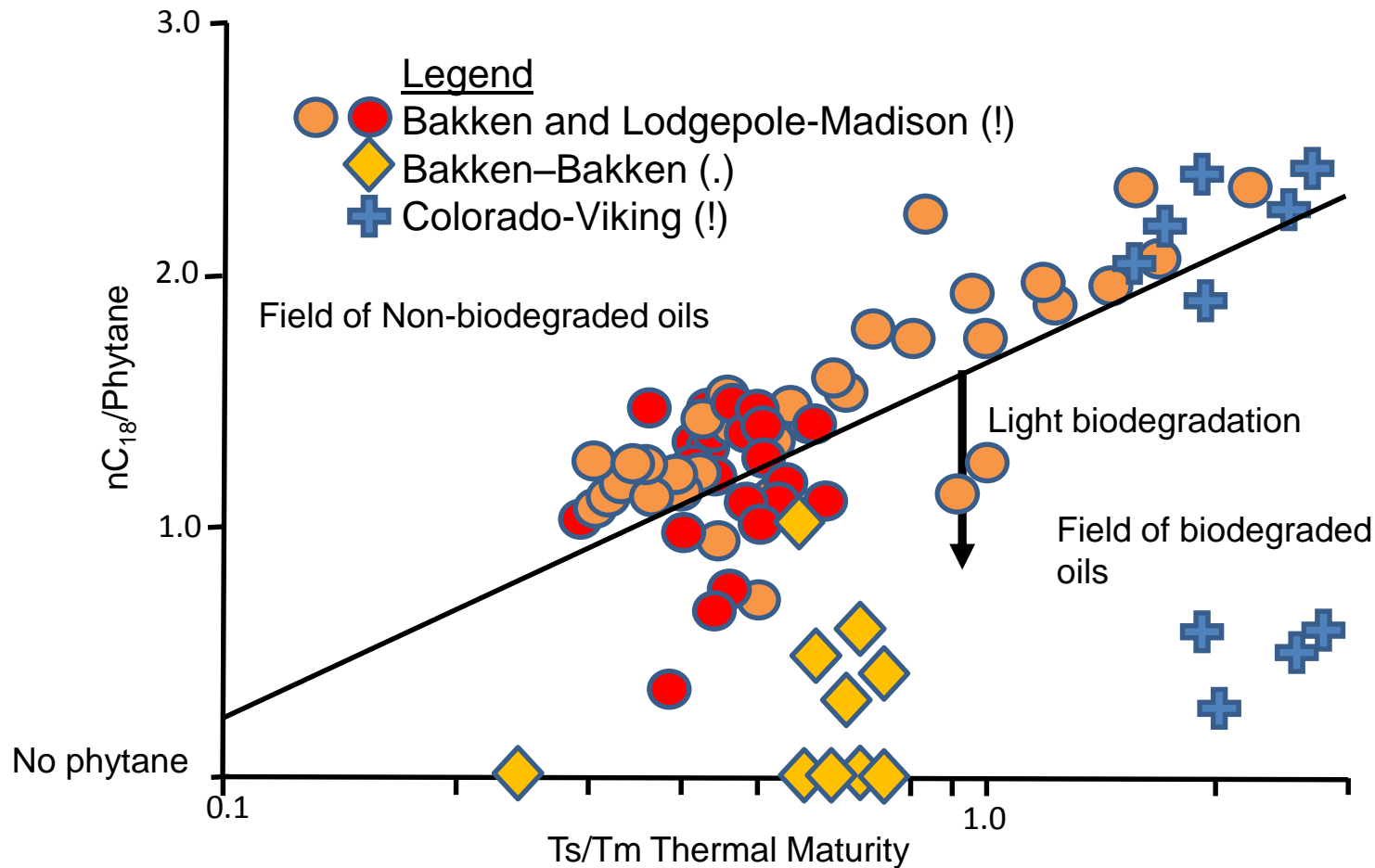
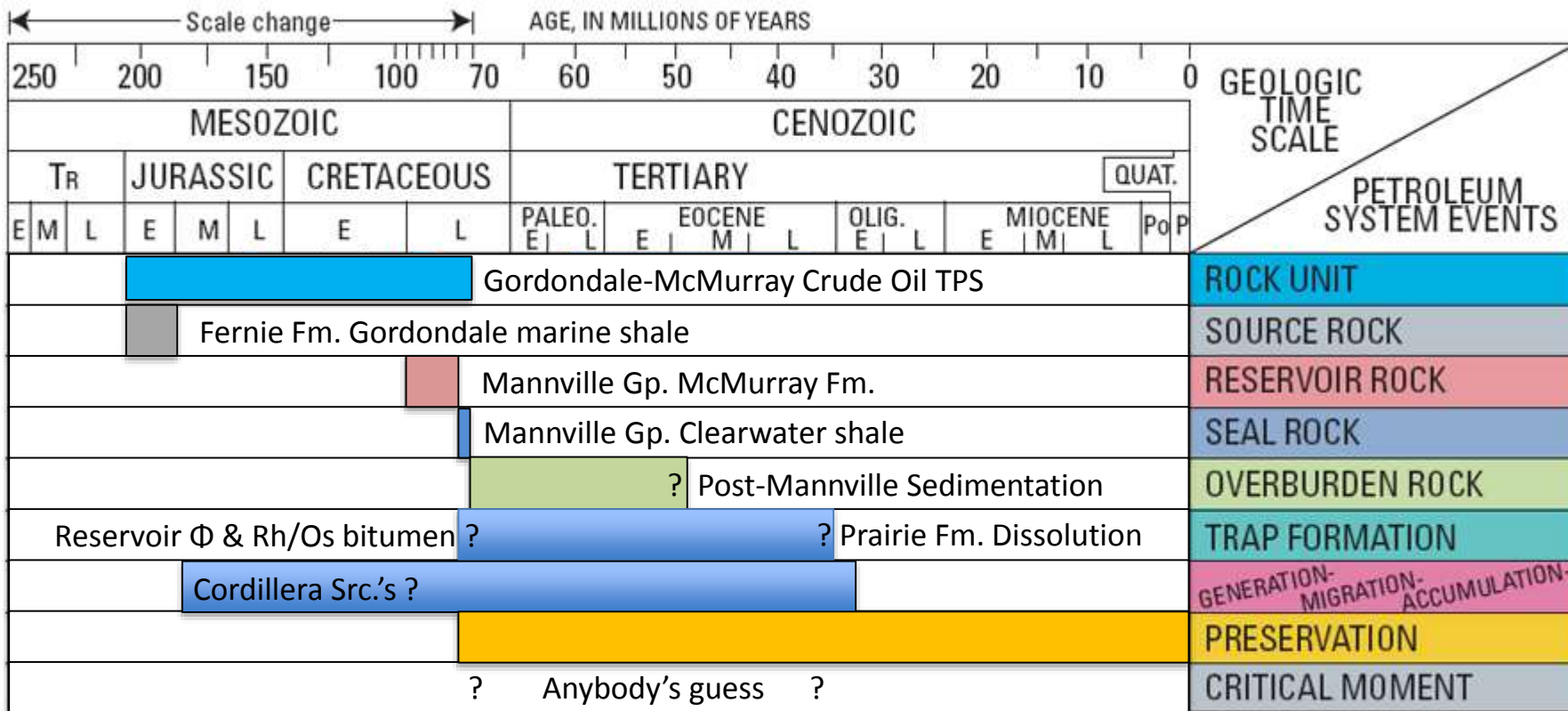


Figure from data published in Osadetz et al., 1992 and 1994 Bulletin of Canadian Petroleum Geology.

Total Petroleum Systems Chart: Gordondale-Mannville(!)



If Mannville crude oils are from extra- and intraformational marine sources what should their gases look like?

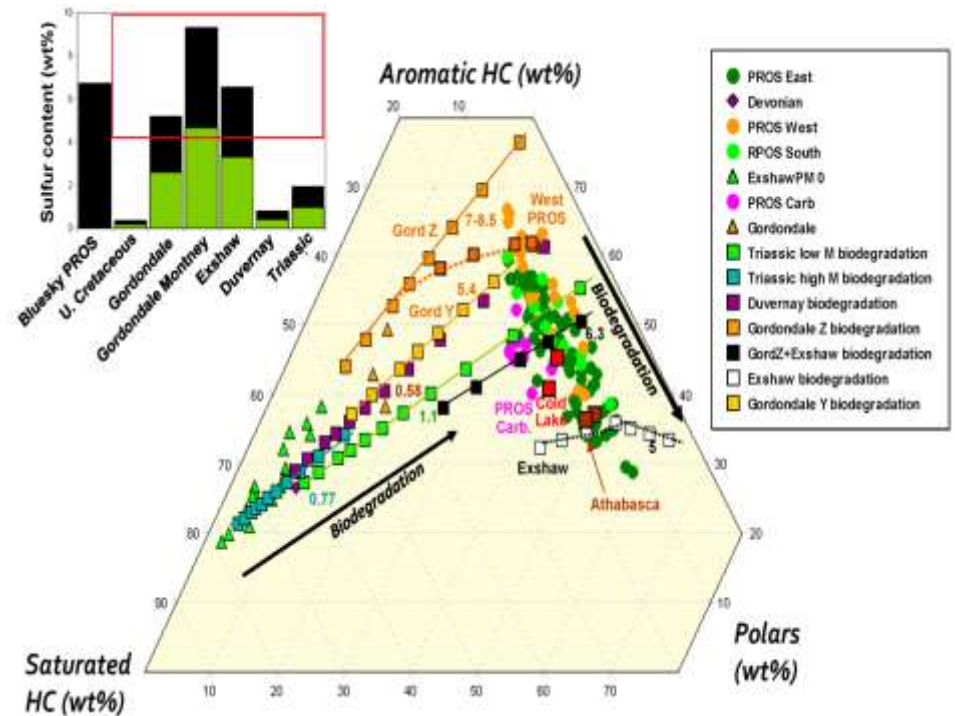
What will the composition and isotopic ratio of Mannville thermogenic gases look if they are generated from extraformational kerogen (thermogenic) or crude oils (2nd biogenic) or if they are generated from intraformational coals (various mechanisms)?

Natural Gases as part of the TPS

- Early studies (Hitchon, 1963a; 1963b; 1963c; James, 1983; 1990) considered the total gas species composition and common, primarily stable isotopic ratios in conjunction with crude oil occurrence.
- Later studies focussed progressively on the stable isotopic compositional variations of fewer compounds typically methane, ethane, propane and carbon dioxide and dihydrogen sulphide as indicators of processes.
- A few source rock and crude oil studies looked at the evolution of natural gas but natural gas studies were conducted completely without reference to crude oil components of the petroleum system.
- Studies of anaerobic crude oil biodegradation predicted that it was the most important source of natural gas in the WCSB.
- Natural gas studies still do not recognize and have no criteria for identifying and distinguishing secondary biogenic gas.

Anaerobic biodegradation of crude oils produces much secondary biogenic gas.

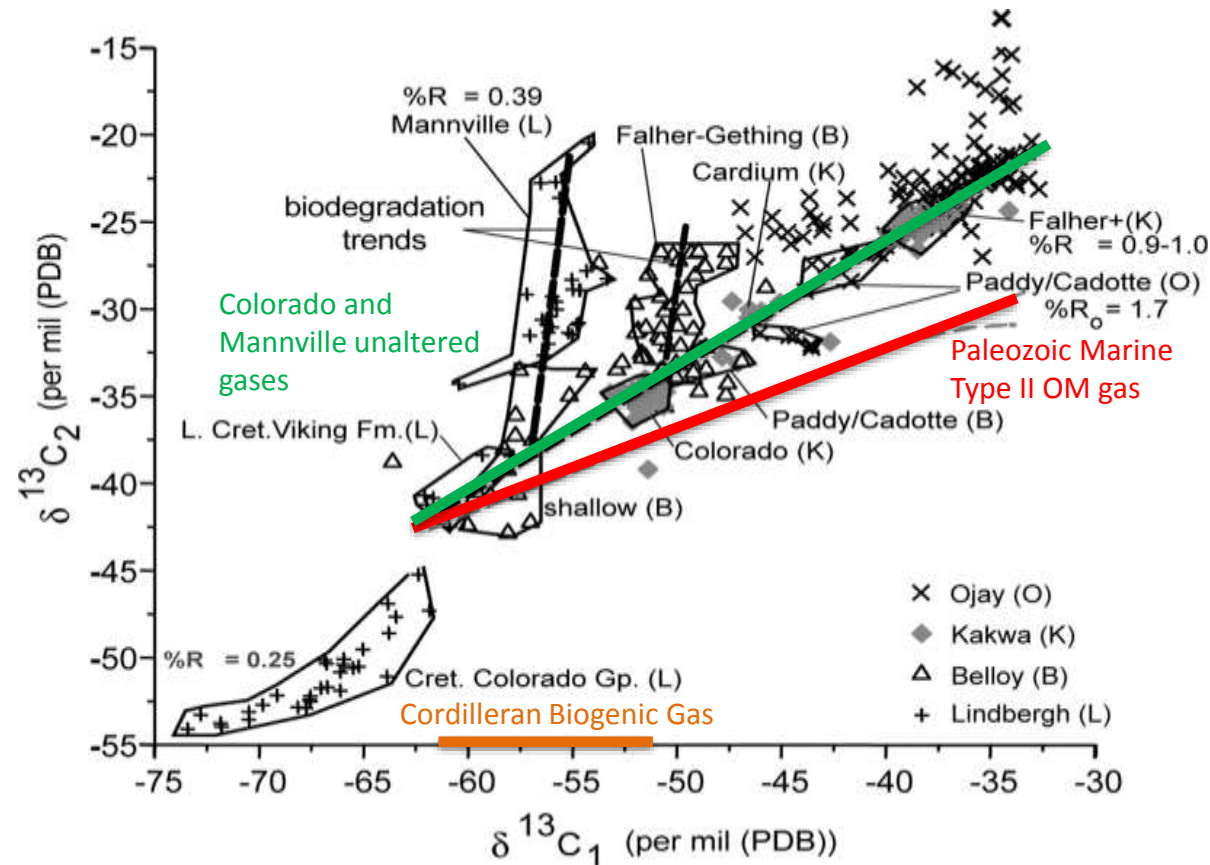
- Huang (2015) calculated ~141 trillion m³ (4991 Tcf) of secondary biogenic CH₄ formed during sub-Colorado Gp. oil biodegradation, most of which “leaked into the atmosphere”.
- Only 608.5×10^9 m³ (21.4 Tcf) of gas remains in Athabasca Mannville Gp. reservoirs (Warters et al., 1997).
- Huang (2015) reinterpreted data from other studies (Cheung et al., 1988; Rich et al., 1995; Szatkowski et al., 2002;), as secondary biogenic gas.
- If there is an unrecognized “elephant” in the WCSB, should it not look like an “elephant”?



From Adams et al., 2012 Geoconvention Abstract

Characteristics of Lower Cretaceous NG from wells and mines.

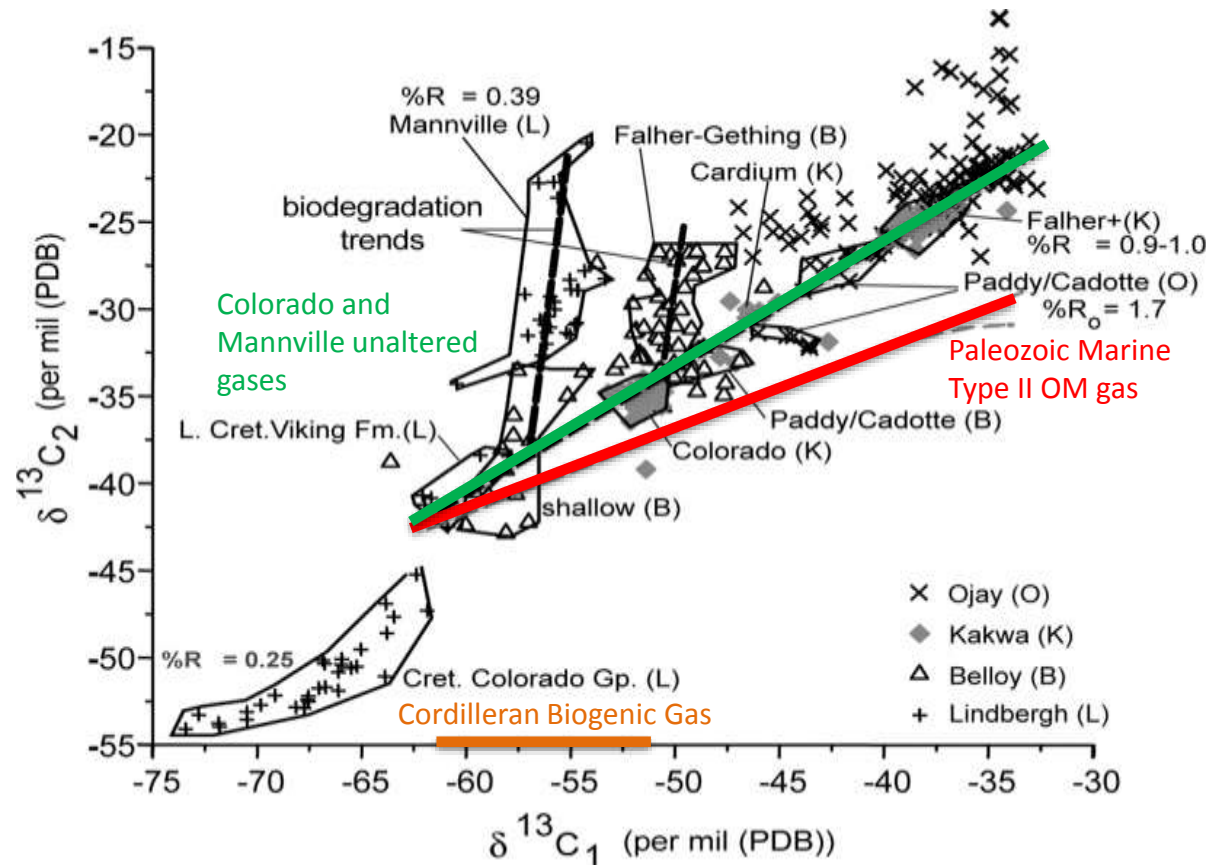
- Where L. Cretaceous oil pools have sources in underlying marine rocks, Mannville gases are attributed largely to non-marine sources.



(Aravena et al., 2003, Chemical Geology, **195**, 219-227); (Tilley and Muehlenbachs, 2006 Organic Geochemistry, **37**, no.12, 1857-1868, their Figure 6)

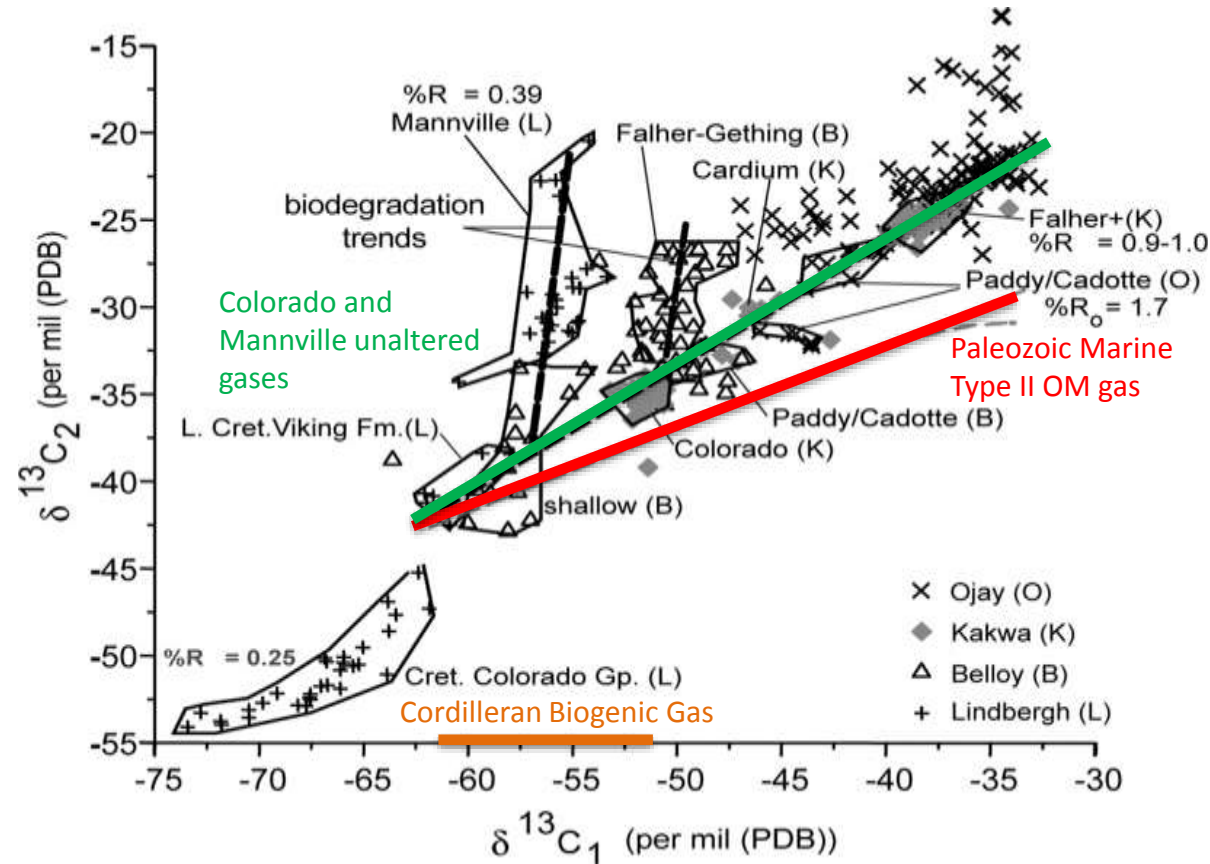
Characteristics of Lower Cretaceous NG from wells and mines.

- L. Cretaceous coalification CH_4 is between -57‰ (VR= 0.39%) and a -37‰ (VR=1.0%), and C_2H_6 is -38‰ (VR= 0.39%) and a -23‰ (VR=1.0%).



(Aravena et al., 2003, Chemical Geology, **195**, 219-227); (Tilley and Muehlenbachs, 2006 Organic Geochemistry, **37**, no.12, 1857-1868, their Figure 6)

Characteristics of Lower Cretaceous NG from wells and mines.

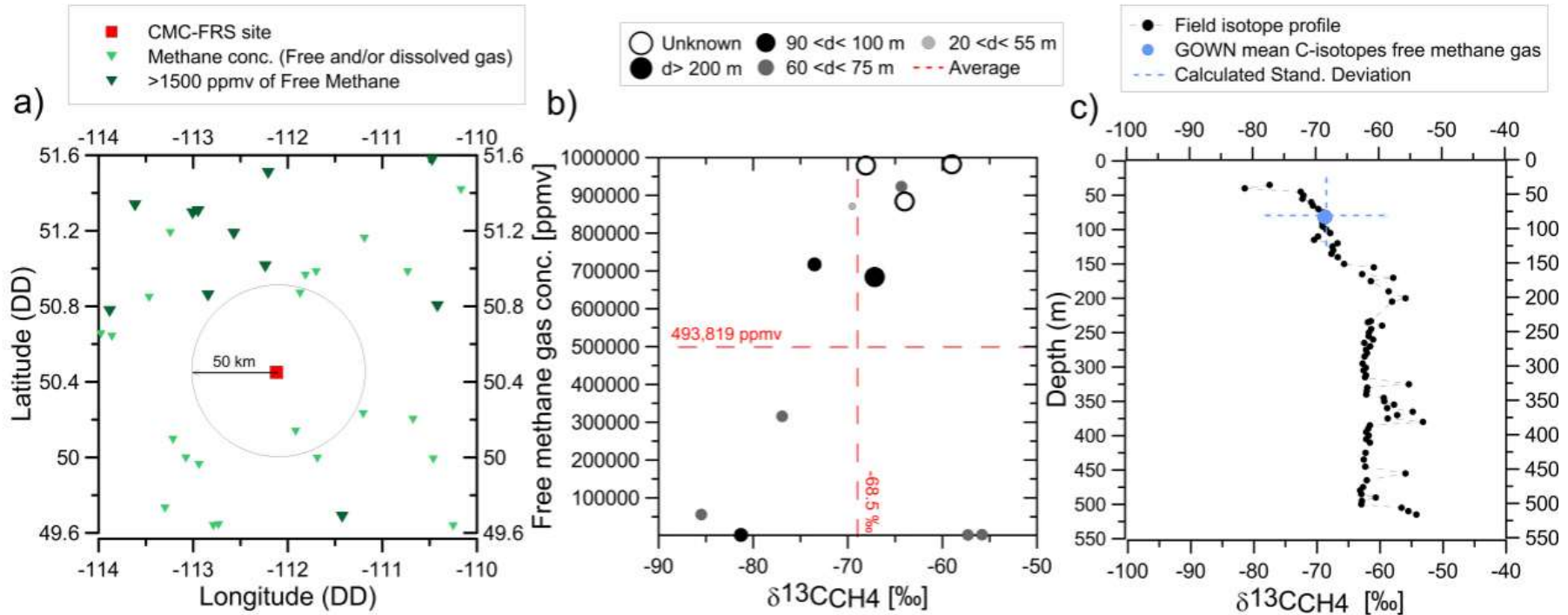


- In the Cordillera near surface Lower Cretaceous coals are biogenic, $\delta^{13}C$ -51.8‰ to -65.4‰ and δ^2H -303‰ to -415‰ .

(Aravena et al., 2003, Chemical Geology, **195**, 219-227); (Tilley and Muehlenbachs, 2006 Organic Geochemistry, **37**, no.12, 1857-1868, their Figure 6)

Characteristics of Lower Cretaceous NG from wells and mines.

(Figures from Mayer et al., 2016)



- The situation is even more pronounced in the Plains, where like the Cordillera, the near surface coalification gases are “gone”, and probably lost to the atmosphere.
- Belly River gases in are completely biogenic and much more depleted than coaly successions.
- CH_4 is between -82‰ near the surface and this becomes progressively enriched downward to -62‰ at about 200 metres depth, after which it remains constant to the top of the Pakowki Fm. shale. Similar upward isotopic depletion is interpreted as diffusion.

Is the Colorado Gp. gas trend secondary biogenic gas? Probably.

- Pair-wise variation of $\delta^{13}C_1$ and $\delta^{13}C_2$ among WCSB gas samples (Tilley and Muehlenbachs, 2006) that distinguishes gases from:
 - a) Colorado Gp. Low-temperature thermogenic gas (Rowe and Muehlenbachs, 1999a);
 - b) gas from Pre-Cretaceous sources (i.e. sub Zuni Sequence gases) identical to marine Type II OM elsewhere and associated WCSB gas in Devonian reservoirs (James, 1990; 1983);
 - c) gas in and attributed to lower Zuni sequence Type III OM sources similar to other Type III OM gas; and unaltered Mannville and Colorado gas that define the "Colorado Gp. gas trend".
- Gas on the "Colorado Gp. gas trend" is proposed as secondary biogenic from anaerobic oil biodegradation
- The Low-temperature thermogenic gas is indicated by the red star (Muscio et al., 1994) is unlike that identified by Rowe and Muehlenbachs (1999).

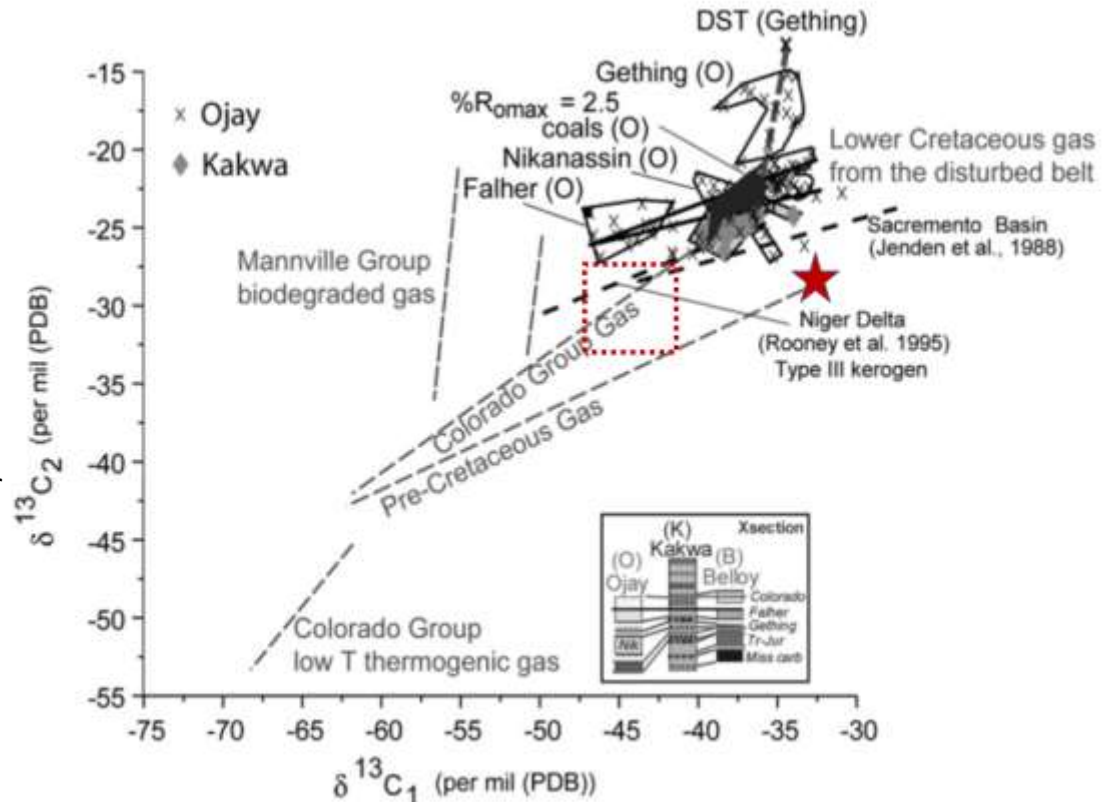
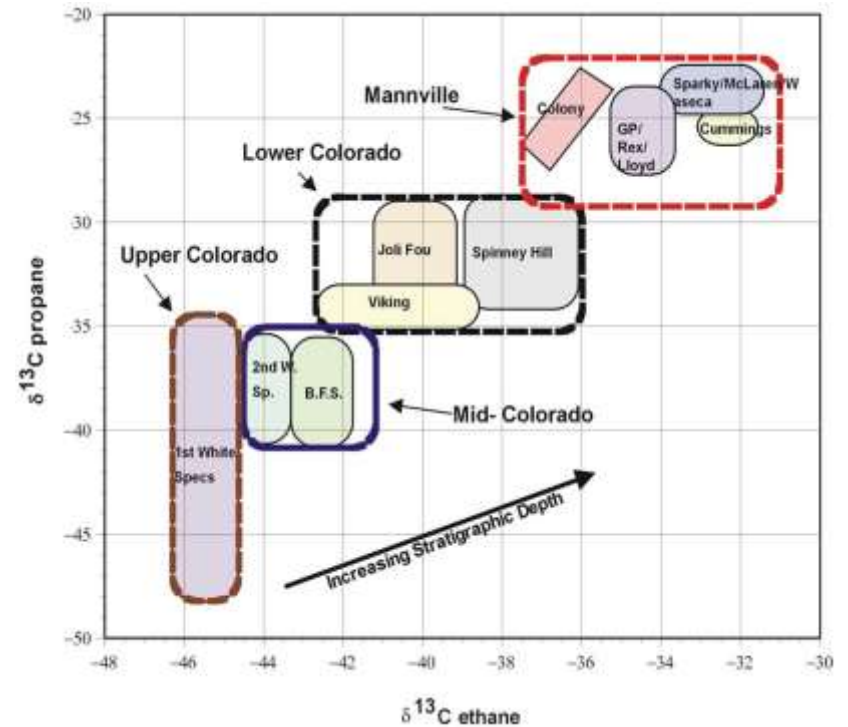


Figure 19

(modified from Tilley and Muehlenbachs, 2006 Organic Geochemistry, 37, no.12, 1857-1868)

Why is cross stratal migration more common for crude oil than natural gas?

- Currently, cross-stratal migration is inferred less common for gas than for oil.
- The inference of gas stratigraphic immobility is problematic for biodegradation studies that infer large secondary biogenic gas fluxes into soil and atmospheric sinks, the migration pathways of which, pass through Cretaceous strata.
- The inferred gas immobility studies have significant implications for, wellbore integrity issues (SCVF & GM), aquifer contamination and impending upstream petroleum industry methane emissions reduction policies and targets.



(Szatkowski et al. 2002)

Why is this important? Upstream Methane Emissions Reduction Targets and Unconventional Plays.

- Upstream petroleum emission studies (Johnson et al. (2017) and Riscioli et al. (2018) conclude “total reported venting in Alberta is low by a factor of ~2.5 (range of 2.0-3.1)”.
- They infer no additional sources from the background or (e.g.) water wells.
- Secondary biogenic gases, most of which have escaped, appear to contain ethane, which is considered an “anthropogenic signal”.
- Could the reconciliation of natural gas in the TPS be used to identify undiscovered/unconventional crude oil potential?

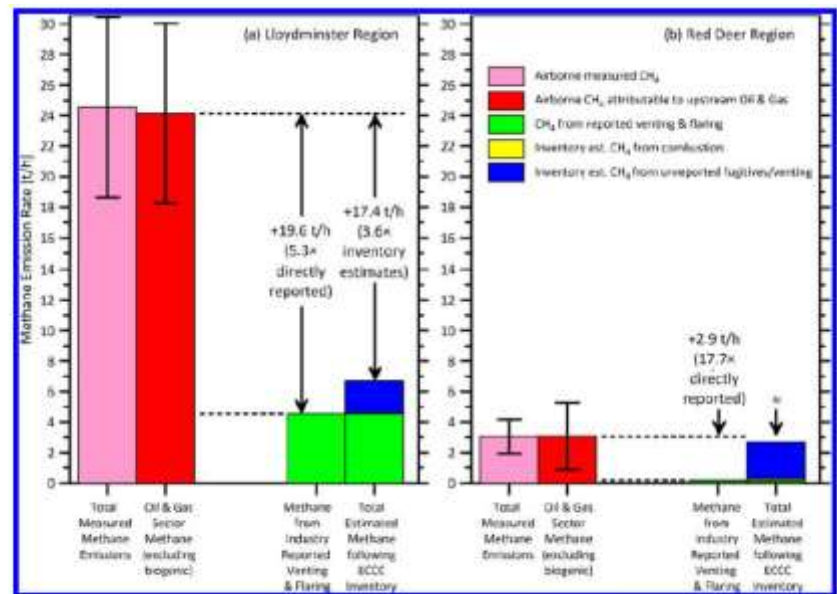


Figure 5. Top-down vs bottom-up comparison of methane emissions in the (a) Lloydminster and (b) Red Deer measurement regions.

Conclusions

- **There is a relatively robust but incomplete characterization of crude oil components of TPS's.**
- **Biodegradation, especially of oil in post-Mannville reservoirs is underappreciated.**
- **Natural gas components of the TPS's are not reconciled to the crude oil components.**
 - Secondary biogenic gas is not recognized or distinguished.
 - Mass balance and isotopic based indications for gas migration differ (the isotopic data is incorrectly interpreted).
 - Mannville oils/bitumens have marine sources but most Mannville gases are interpreted as from non-marine sources.
- **Improved TPS analysis is important for, effective CH₄ emission reduction policies, and it may contribute to improved performance of unconventional petroleum plays.**