Petroleum Systems of the Scotian Basin*

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Abstract

The Scotian Basin extends over an area of ~260,000 km^2 in the Atlantic, offshore Nova Scotia, eastern Canada. It is a classic, passive volcanic conjugate margin containing up to 15 km of Mesozoic-Cenozoic sediments. There have been 127 exploration wells drilled since 1967 as well as 78 development wells. To date, there has been 25 discoveries, mostly in the Sable Island area, but only one has been made since 1986. Production of light oil from the Cohasset-Panuke fields has occurred since 1993 and gas from the giant Venture and surrounding fields since 1999. Starting in 2008, the Offshore Energy Research Association of Nova Scotia (OERA) financed a Play Fairway Analysis Program in order to stimulate renewed exploration which included a series of studies of petroleum systems studies. This presentation use the results from these studies as well as data from on-going analyses and some older Geological Survey of Canada unpublished reports to provide an updated understanding of the area. Mostly gas discoveries with minor amounts of condensate/light oil have been made on the Scotian Shelf. Determining the source of these hydrocarbons has been difficult because accumulations are dominated by light hydrocarbons with very low concentration of biomarkers. Additionally rock samples in many wells have been compromised by drilling practices. Rock-Eval/TOC data indicates that the most significant source rocks are Tithonian deltaic ('Verrill Canyon') shales containing Type III-II organic matter. The characteristics of hydrocarbons agree with those expected from this interval although there is still not an unequivocal oil-source rock correlation. There is a possibility of contributions from other Late Jurassic and Early Cretaceous shales, but, to date, there is no strong evidence for a contribution from a more oil-prone Lower Jurassic source rock. Evidence from the conjugate margin, offshore Morocco, suggests that this could be a possibility on the deep water Slope. Some geochemical data (e.g. gasoline range hydrocarbons, carbon isotopes) suggests that it is possible to split Scotian Shelf light oils into sub families that likely reflect regional variations in the Tithonian source rock. Based on some previously reported data from the Annapolis G-24 well and initial results from the 2015 piston coring cruise, thermogenic hydrocarbons, as represented by wet gas, are present on the deep water Scotian Slope. The source of these hydrocarbons remains undetermined.

References Cited

Fowler, M.G., and M. Obermajer, 1999, Reassessing the Petroleum Geochemistry of the Scotian Shelf, Offshore Eastern Canada - A Cautionary Tale for Geochemists: 19th International Meeting on Organic Geochemistry, September 1999, Istanbul, Turkey, Abstracts, Part 2, p. 469-470.

Magoon, L.B., and W.G. Dow, 1994, The Petroleum System, *in* L.B. Magoon and W.G. Dow (eds.), The Petroleum System from Source to Trap: AAPG Memoir 60, p. 3-24.

PFA, 2011, Play Fairway Analysis (PFA) Offshore Nova Scotia, Canada: Published Report, Nova Scotia Energy Department. http://www.oera.ca/offshore-energy-research/geoscience/play-fairway-analysis/ Website accessed October 2016.

Natural Resources Canada Ressources naturelles

PETROLEUM SYSTEMS OF THE SCOTIAN BASIN

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NOVA SCOTIA

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GSC Calgary/Natural Resources Canada has provided support over the years to Fowler, Obermajer and Mort

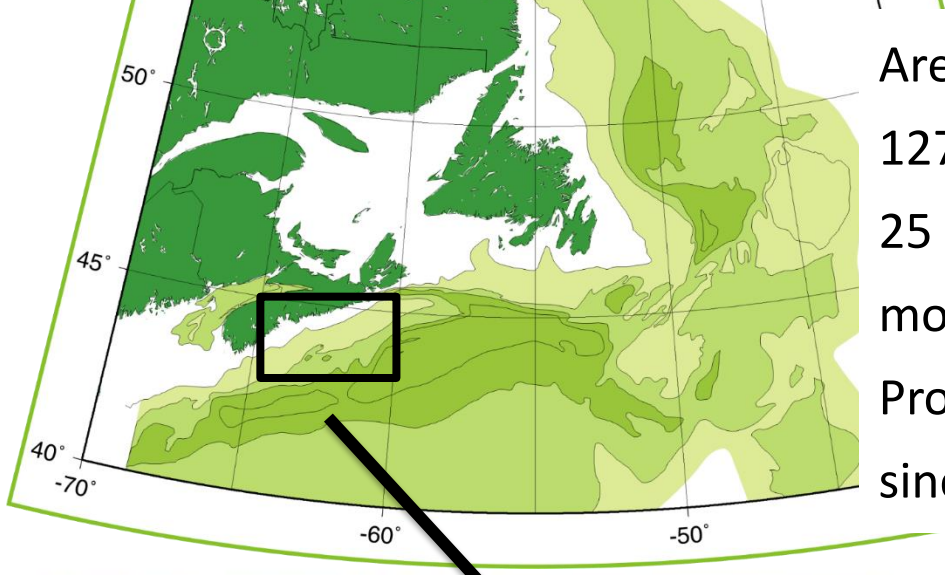
Presentation in the context of this session

"A petroleum system… a natural system that encompasses a pod of active source rock and all related oil and gas and includes all the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist"

Magoon and Dow, 1994 AAPG Memoir 60

This presentation concerned with an area with large discovered resources but where components of the petroleum system, especially the source rock, are not all well understood.

Here the emphasis is on defining the source rock(s) responsible for Scotian Basin hydrocarbons

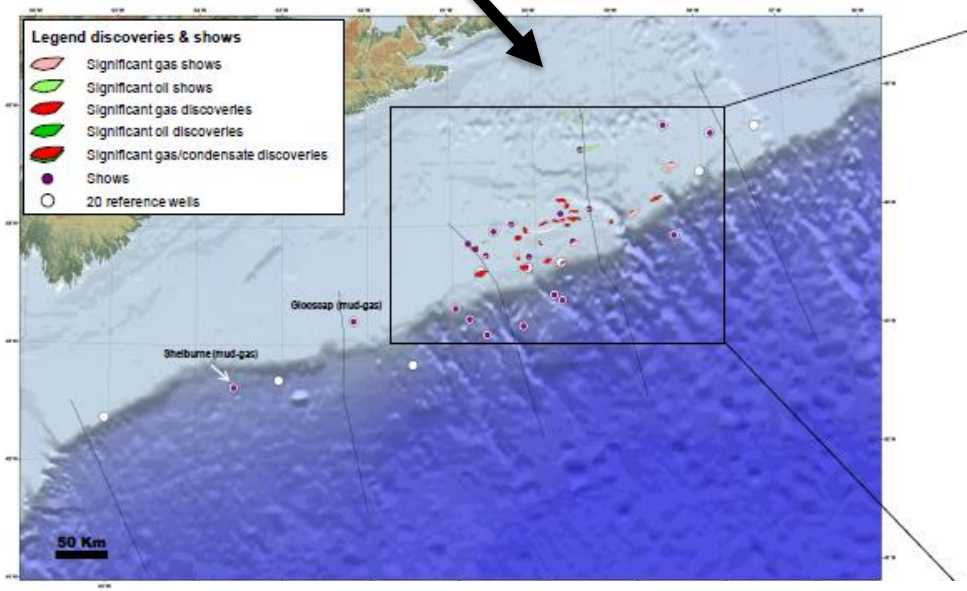


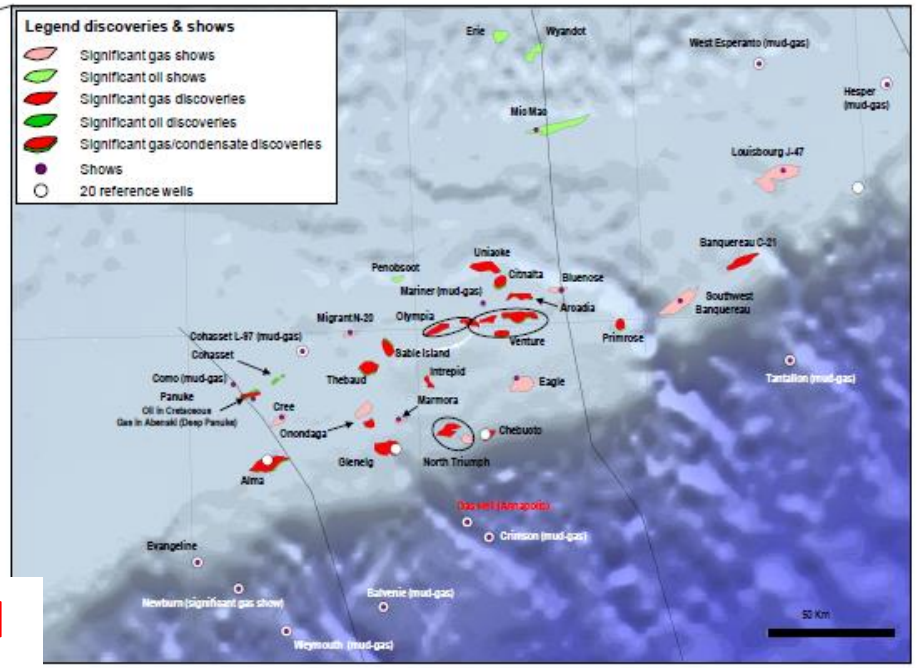
Area: ~260,000 km2

127 Exploration Wells + 78 Development Wells

25 Gas, Condensate and Light Oil Discoveries, mostly in Sable Island area

Production of light oil from Cohasset-Panuke since 1992 and gas since 1999 from Venture



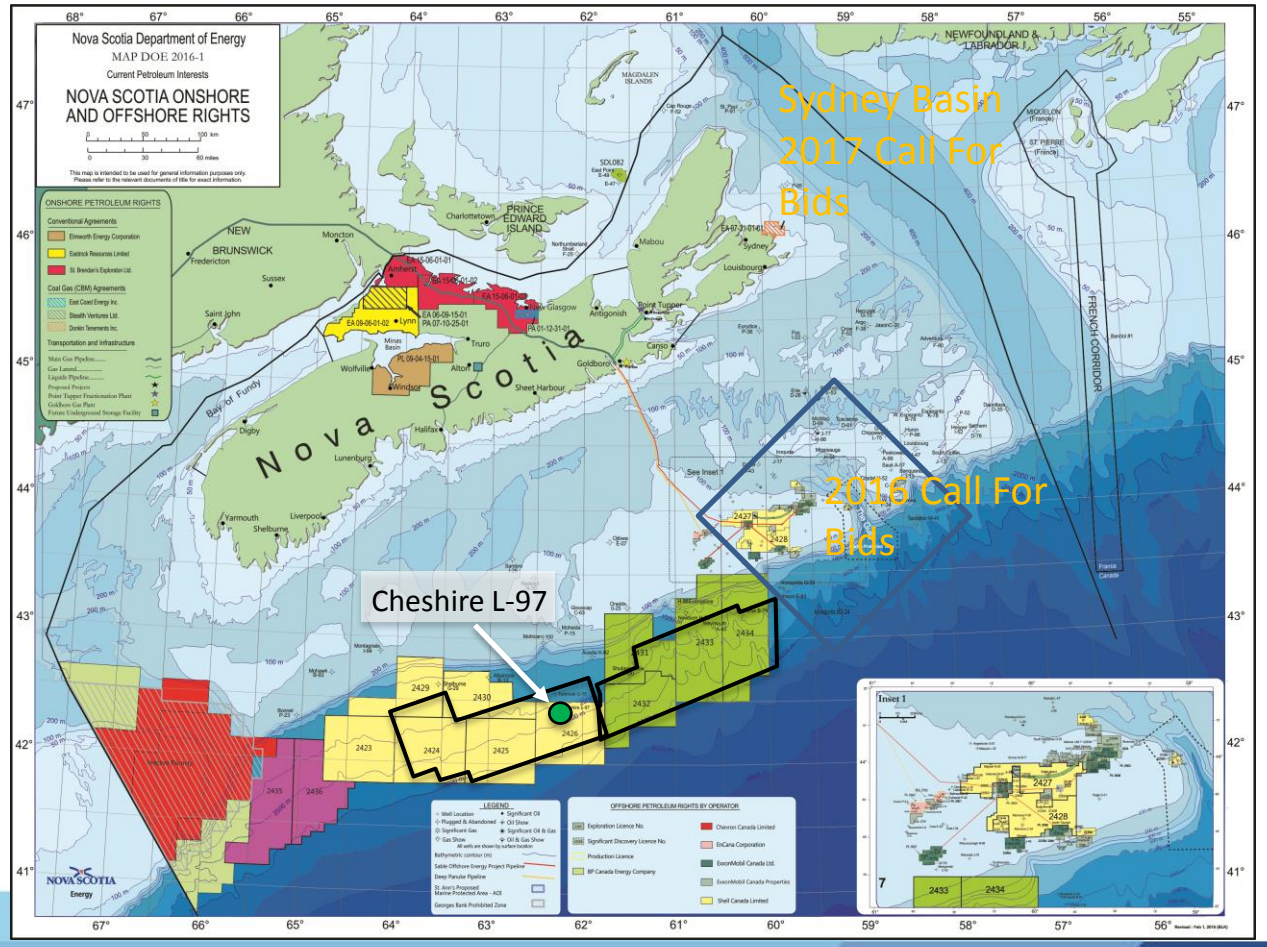


Estimated 120 TCF gas and 8 bn bbl oil
PFA 2011

Most older wells drilled in shallow water Scotian Shelf, in vicinity of Sable Island

Deep Offshore Nova Scotia is an area of current active interest

Shell presently drilling a well in deep water, Cheshire L-97



Shell 3D-2013
10,000 km2

1st well
2015

Partners:
- *ConPhil.*
- *SunCor*

Statoil

BP 3D-2014
7400 km2

1st well
2017

Partners:
- *Hess*
- *Woodside*

Outline

- Scotian Shelf Petroleum Systems
- Scotian Slope Deep Water Petroleum Systems
- Evidence from Morocco Conjugate Margin
- Conclusions

SCOTIAN SHELF GEOCHEMISTRY - PROBLEMS

Limited amount of work on offshore Nova Scotia petroleum systems in the past. None of it giving conclusive information on source rocks and families of oils.

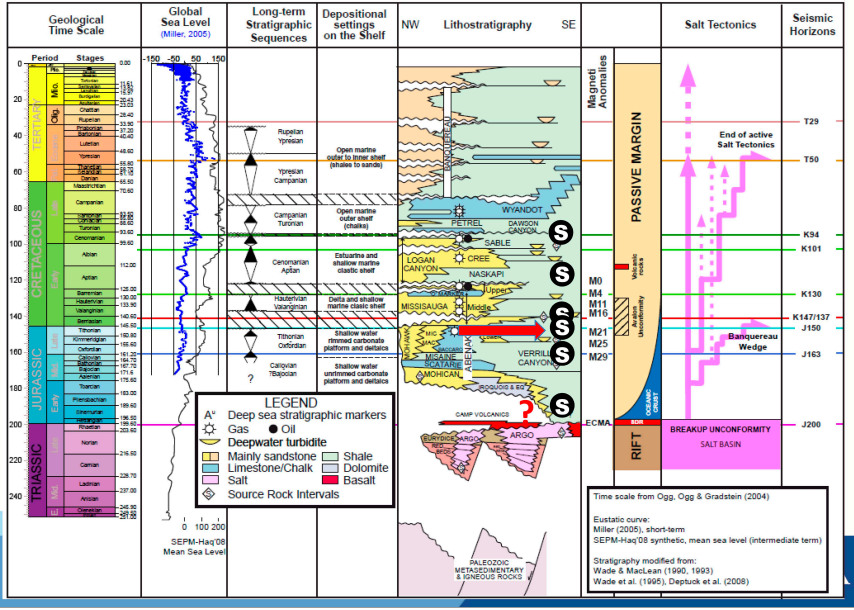
Why?

Sample type – gases, condensates and light oils with very low concentrations or no biomarkers making correlation studies difficult.
Where biomarkers are found, they often appear to be highly mature, the result of contamination, either geological (i.e. picked up during migration) or drilling/sampling.

Sample contamination – Rock samples (mostly cuttings) contaminated by OBM or other drilling additives, making data very hard to interpret. Also high maturity of potential SRs

Sample quality – evaporation a problem after 30+ years with the light oils, even if stored well

PFA Atlas 2011 Proposed Source rocks +poss Cen-Tur int



Presenter's notes: So in summary we have 5 source rocks offshore Nova Scotia with 2 major sources – Tithonian Type II/III and an Early Jurassic marine Type II source

Source rocks offshore NS

Source rock	Evidence
Cenomanian - Turonian	Not present on Scotian Shelf but might be present in deeper waters. Rare occurrences in W. North Atlantic are very thin (<1m). Maturity also a problem.
Aptian	Good evidence for widespread, elevated, TOCs (1-3%) on shelf and slope but associated with very low HI (usually <100) despite low maturity. Very little hydrocarbon potential
Valanginian	Good evidence for widespread, elevated TOCs (up to 2%) but low HI (<100) No or very little hydrocarbon potential
Tithonian-Kimmeridgian	Reasonable evidence for a good source rock containing Type III-II OM – complicated by contamination and maturity. **The major source of gas and liquids on Scotian Shelf**
Callovian	Very limited evidence for an organic-rich interval which when present contains Type III OM
Early Jurassic	Presently no strong evidence for occurrence in Nova Scotia offshore. Evidence from conjugate margin (offshore Morocco) suggests possibility on the Slope

Hydrocarbons found offshore Nova Scotia

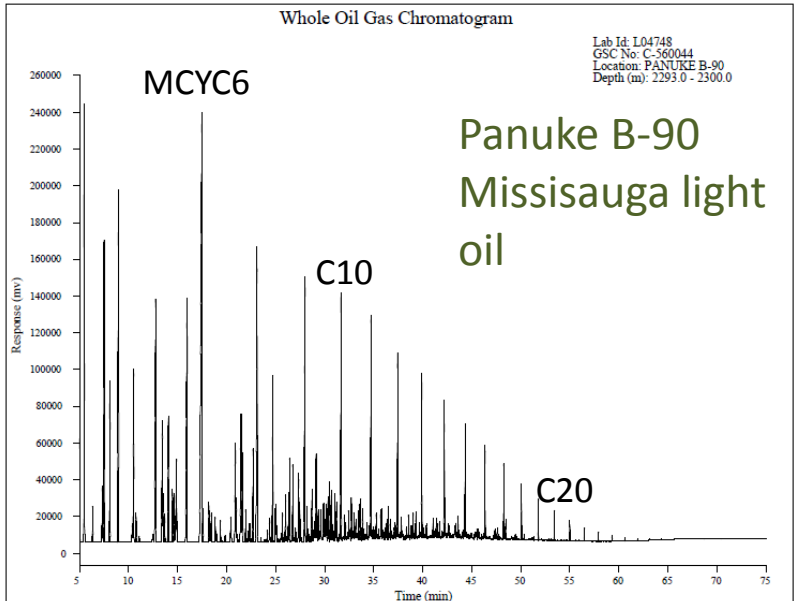
Fluid	Characteristics
Gases	Generally wet gas, dryer in some wells, likely because of higher maturity Dominant hydrocarbon phase
Condensates/Oils	Liquids are generally light oils/condensates

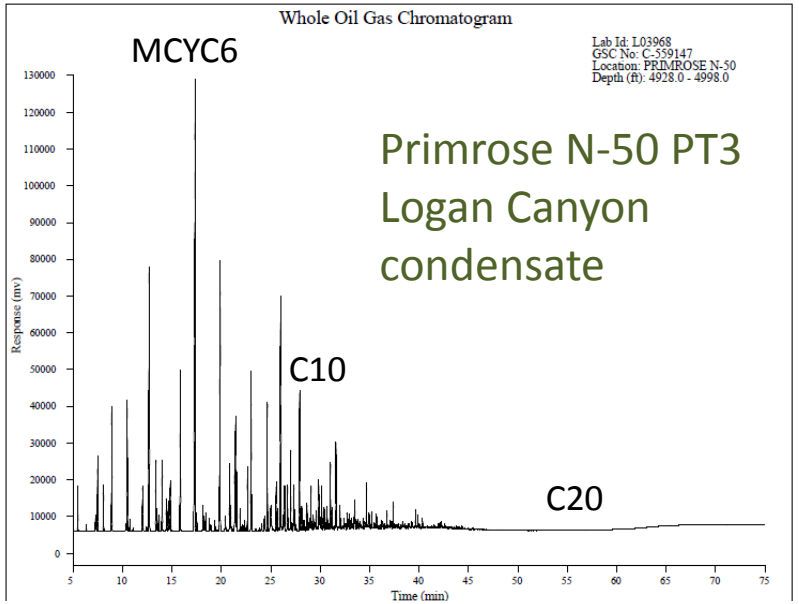
Geochemistry of Scotian Shelf hydrocarbons suggests most/all are all sourced from intervals containing Type III/II organic matter with a large terrestrial contribution

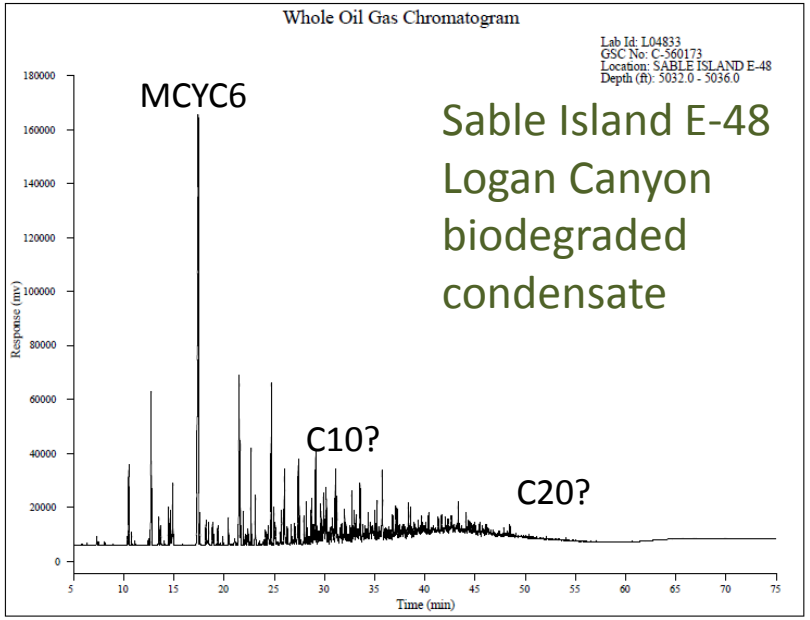
e.g. high pristane/phytane, C_{29} steranes >>C_{27} steranes, rearranged steranes > regular steranes

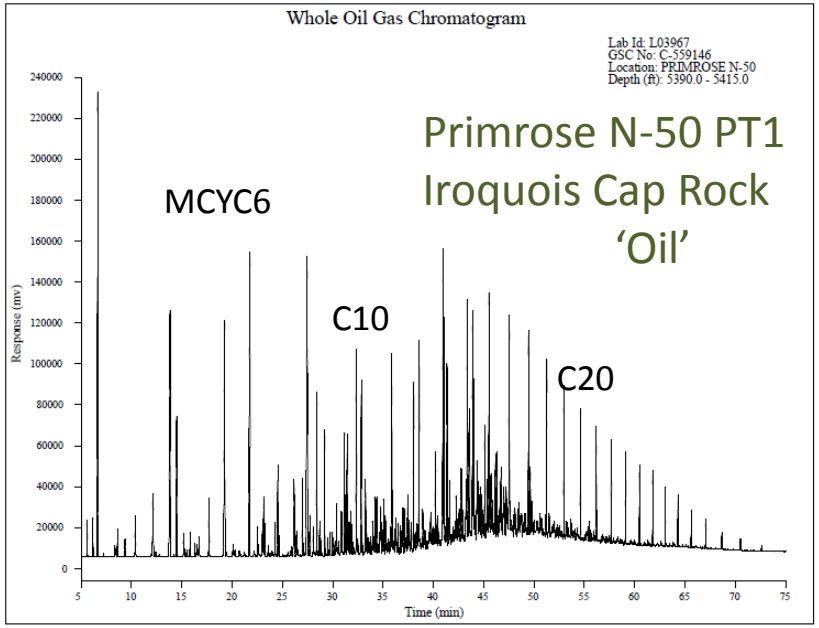
This agrees with the Tithonian being the major source rock for the Scotian Shelf as it was deposited in a deltaic environment.

Representative Whole Oil Gas Chromatograms



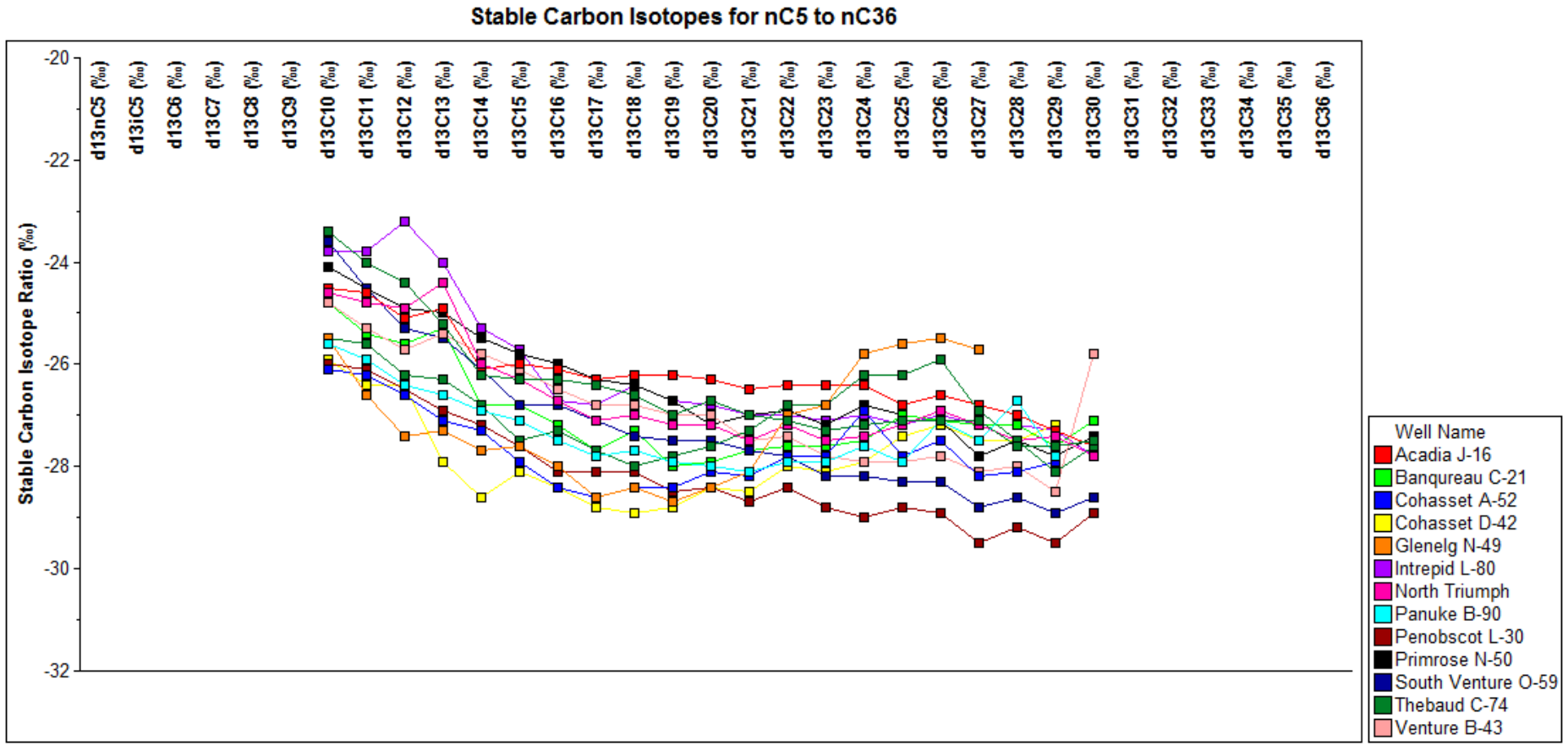






There are variations in reservoired liquid hydrocarbon characteristics

C10-C30 n-alkane compound specific isotope analysis (CSIA) data for suite of Nova Scotia oils



Oils generally similar, suggesting all had similar source rock. Some variation is associated with maturity and *there <u>may</u> be some* due to minor variation in organic facies.

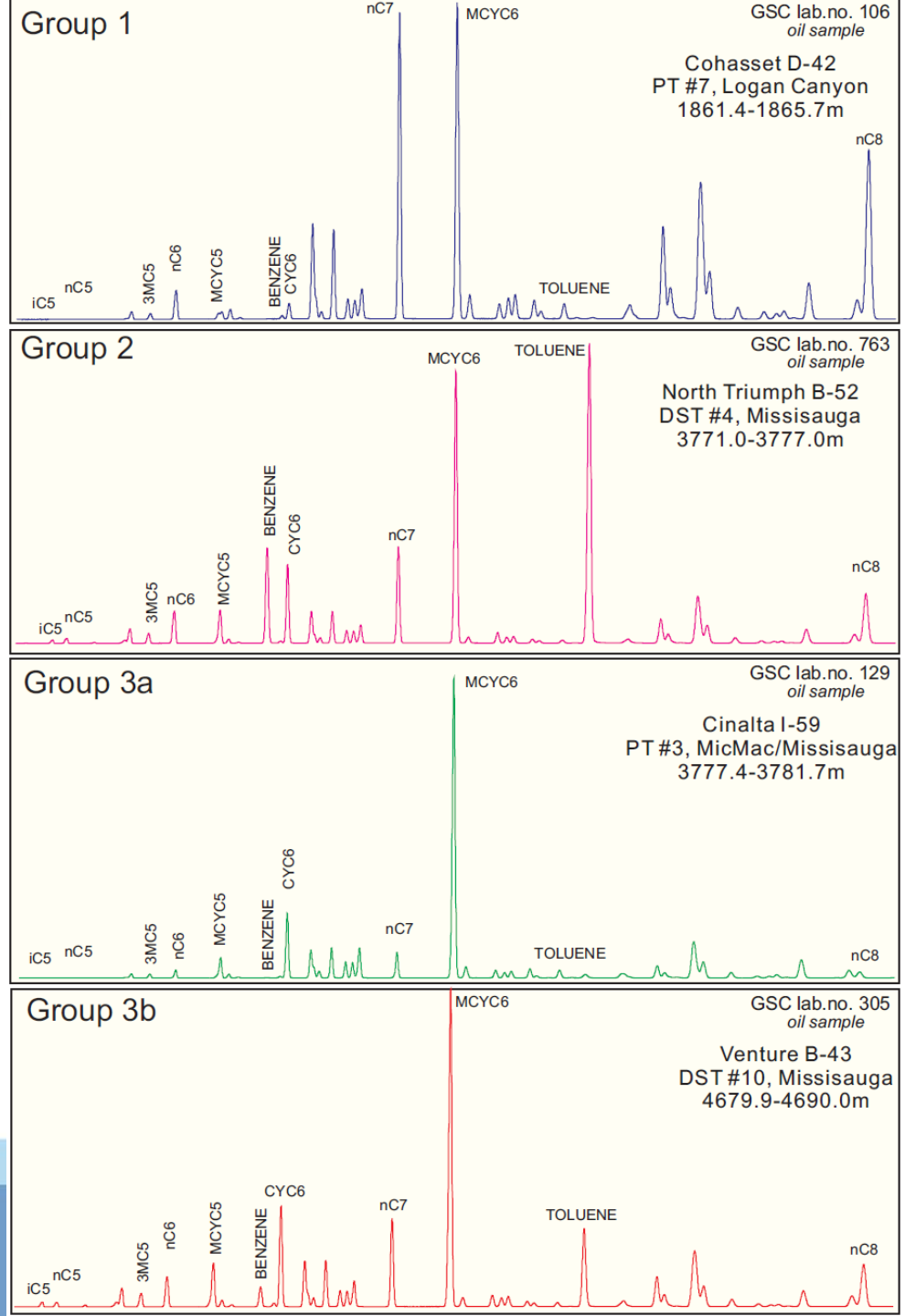
DIAMONDOID DATA (14 Scotian Shelf samples

Total diamondoids	4385-16153 ppm
MDI maturity parameter	0.34-0.46

MDI ratio suggests a Vroequiv of ~1.28-1.5% using Chen et al (1996) correlation

Rough correlation of increasing diamondoid concentration with increasing GOR

Oils from Cohasset, Panuke (Missisauga res), Penobscot (Gp 1oils) with very low toluene have lower concs of diamondoids than other oils, also diamondoids and other parameters suggest somewhat lower maturity



Representative gasoline range GCs showing variable concentrations of n-heptane, methylcyclohexane and toluene in Scotian Shelf oils/condensates assigned to Groups 1, 2, and 3a and 3b by Fowler and Obermajer (1999)

Suggesting possibility of different families

Other workers have also suggested different families based on isotopic, gasoline range and aromatic distributions (Powell, Mukhopadhyay, Peters et al.)

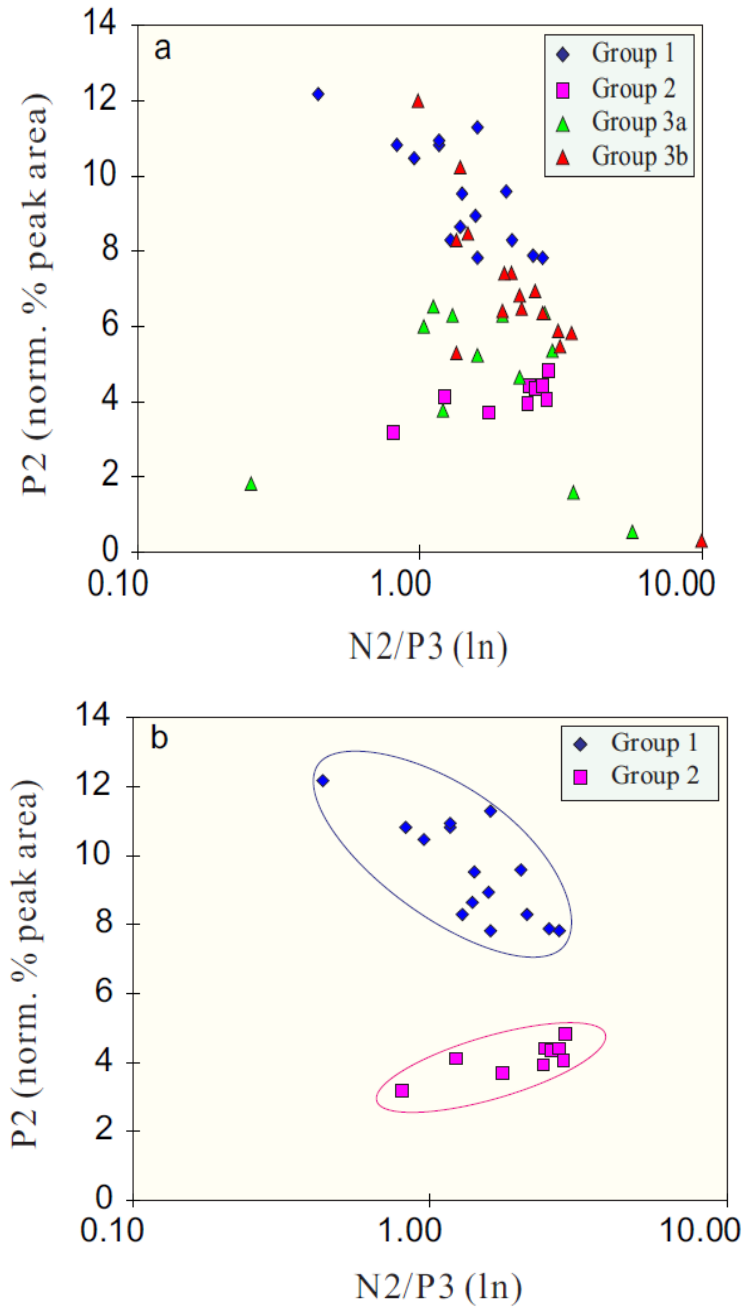


Figure 8. Cross-plots of the normalized % peak area of "pseudo" Mango parameters N2/P3 versus P2. On cross-plot a oils plot in terrigenous or mixed regions (as empirically defined by ten Haven, 1996). On the cross-plot b, the separation of groups 1 and 2 is more obvious (oils assigned to Group 3 are not plotted).

Cross-plots of the normalized % peak area of 'pseudo' Mango parameters N2/P3 vs P2

On cross-plot a, oils plot in terrigenous or mixed regions as defined empirically by ten Haven, 1996.

Cross-plot b more obviously shows the separation between groups 1 and 2 once group 3 are not plotted.

NOVA SCOTIA

Conclusions from Light Hydrocarbons

Three Families

Group 1 Cohasset, Panuke, Balmoral and Penobscot Mic Mac to Wyandot reservoirs but mostly Missisauga and Logan Canyon, mostly SW of Sable Island

Group 2 Arcadia, Banquereau, Glenelg and North Triumph from Missisauga or Mic Mac reservoirs – situated on Shelf edge

Group 3 Jurassic and Cretaceous reservoirs from Sable Island area with exception of Primrose

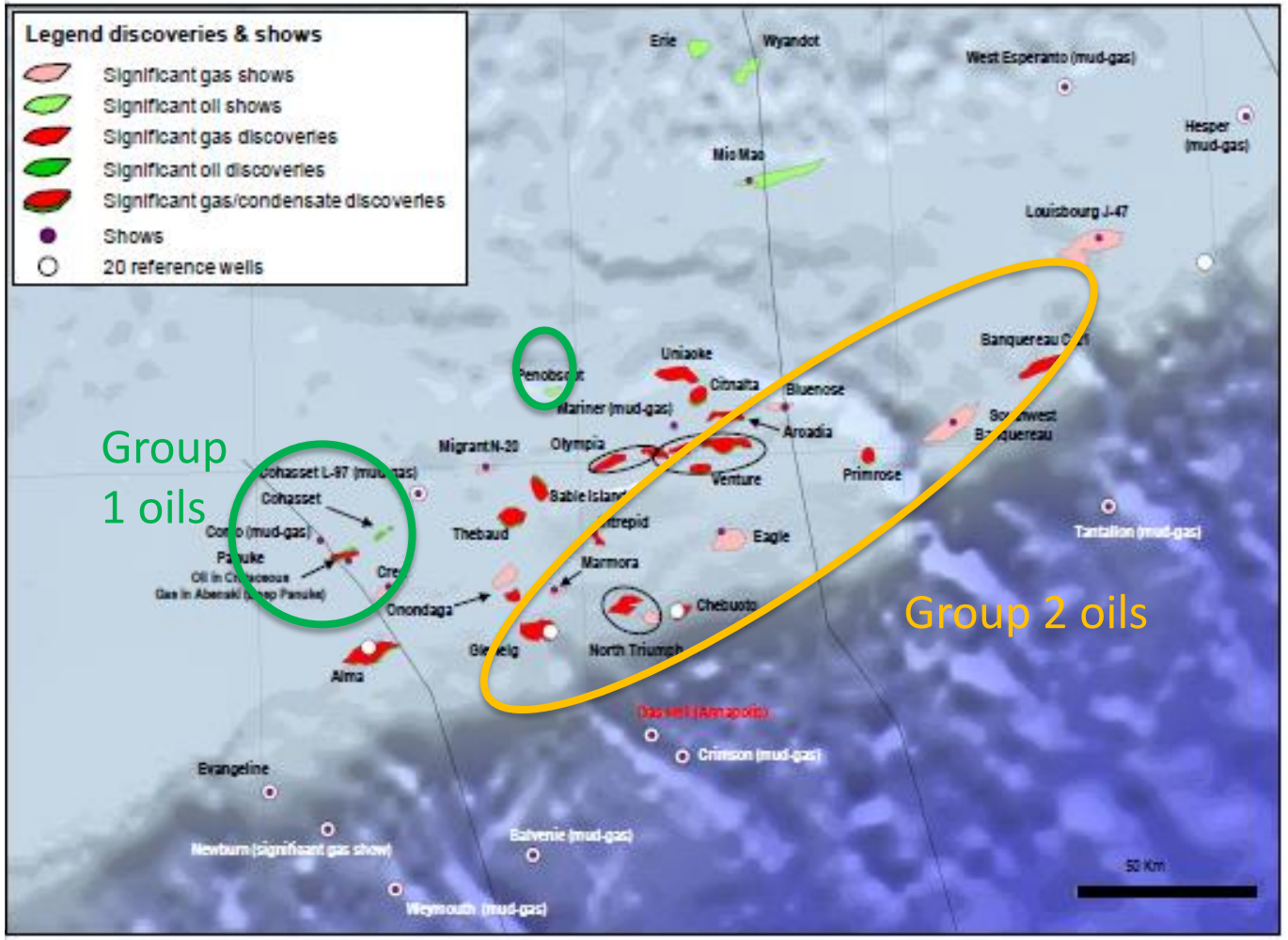
Possible Reasons for Families? *(none completely convincing at present)*

Source Group 1 more algal and Group 2 more terrestrial, Group 3 mixed

Maturity Group 1 are a little less mature than Group 2, Group 3 generally most mature

Evaporative Fractionation ? two phase fluid fractionates into a gas phase and volatile-depleted residual oil. The gas phase migrates preferentially in to shallower reservoirs. Light aromatic HCs preferentially partition into residual oil relative to sat HCs.

Geographic distribution of light hydrocarbon oil families



Group 3 oils are all remaining oils

Some are biodegraded

Oils with different characteristics are geographically rather than stratigraphically controlled

SCOTIAN SHELF LIGHT OILS/CONDENSATES

There is some geochemical variation between Scotian Shelf light oils/condensates. These could be for the following reasons:

Different major source rocks - unlikely

Contributions from other source rocks besides Tithonian – possible

Variations in organic facies in the Tithonian – possible

Reservoir process such as evaporitic fractionation – ?

The differences between Cohassett/Panuke type oils and North Triumph/Glenelg type oils such as low vs high GOR, high vs low sat/arom and low vs high toluene, with minor isotopic variation, supports a combination of source and a reservoir process being responsible for the variation in oil types. **Tentative conclusion presently**

Evidence for an Lower to Middle Jurassic oil-prone source rock on Scotian Shelf

Early Jurassic source intervals were thought to be important contributors the hydrocarbons on the Scotian Shelf. However,

No evidence from rock samples

The presence of gammacerane in some oils that was cited as evidence of a more oil-prone SR than the Tithonian is not convincing - more probable that its occurrence is either due to contamination or its somewhat higher thermal stability compared to hopanes

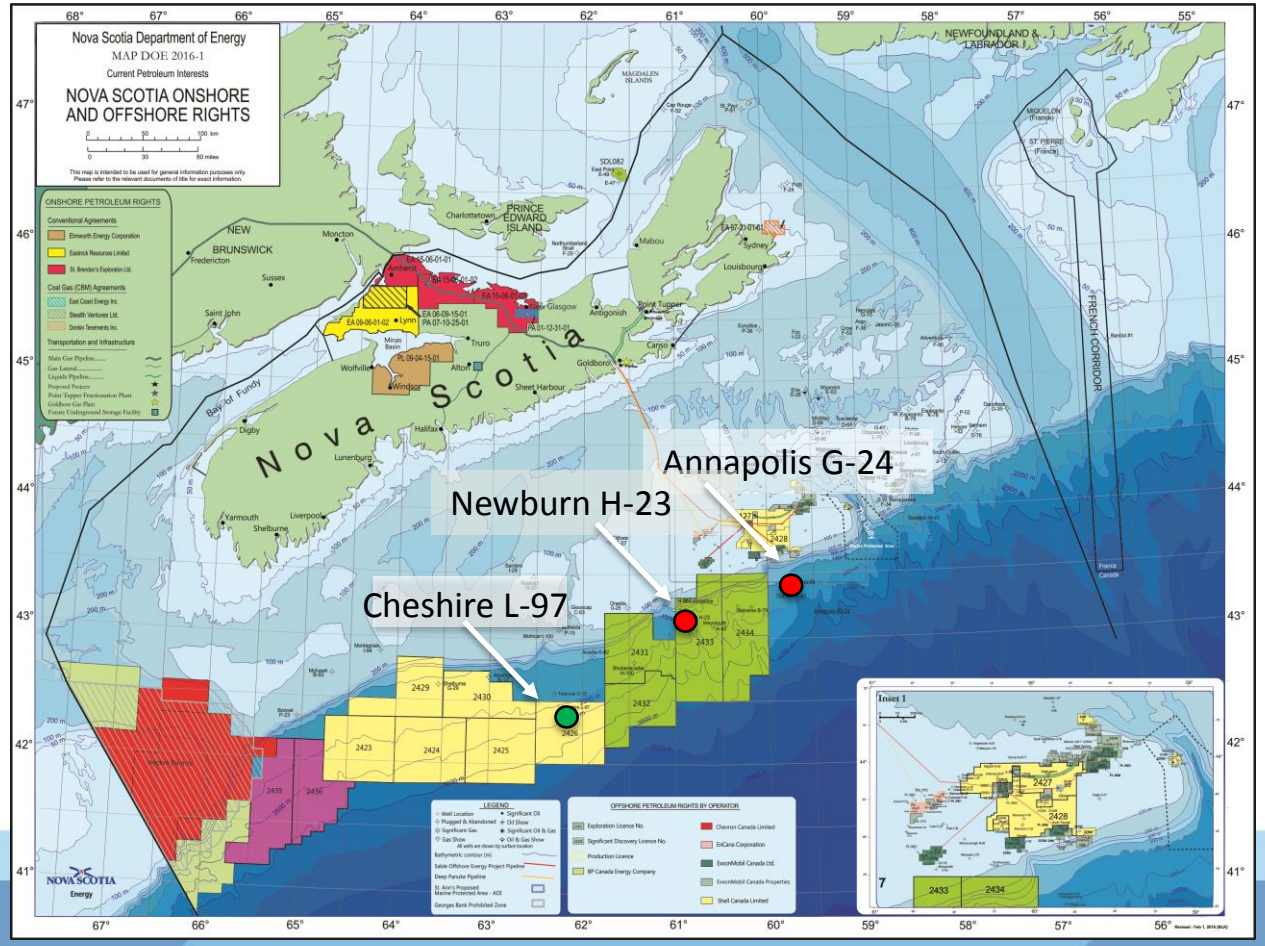
Not supported by other Scotian Shelf oil/condensate geochemical data such as CSIA data or Diamondoids.

DEEP WATER INDICATIONS OF HYDROCARBONS

Wet Gas at Annapolis G-24; Gas shows at Newburn H-23 (also oil staining??)

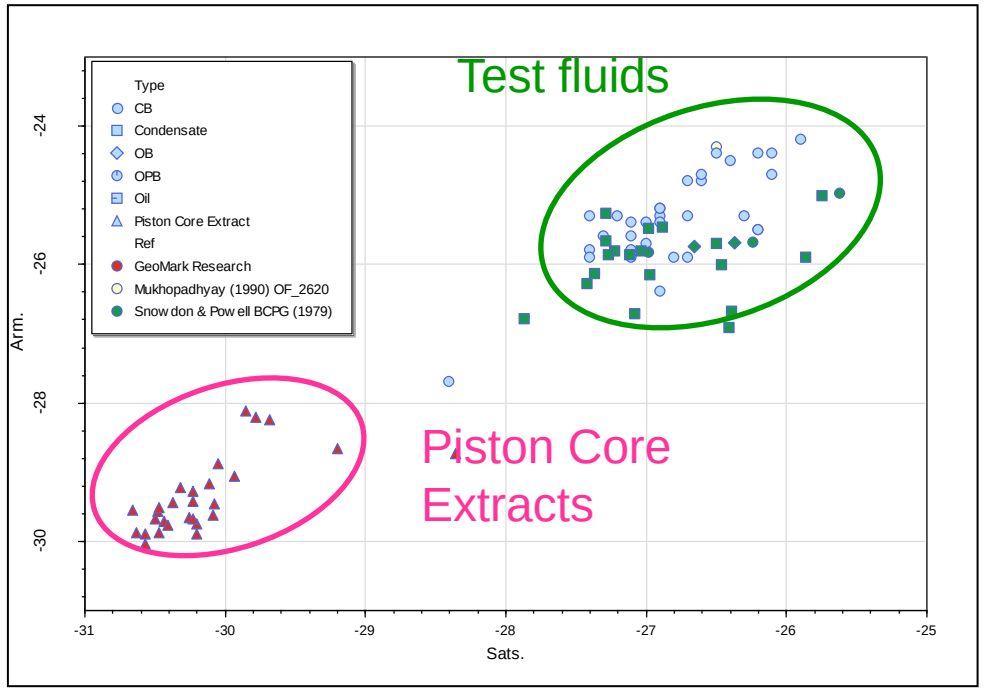
Cheshire L-97 drilled in greatest water depth on Scotian Slope to date at 2143 m

Is there a more oil-prone source rock on the Scotian Slope?



Satellite and seismic evidence of oil seeps in several places along the slope, especially in south west

Isotopic evidence for oil-prone source on slope?
TDI-Brooks 2000 Piston Coring Data



Sofer plot of $\delta^{13}C$ saturate HCs versus $\delta^{13}C$ aromatic HC of Scotian Shelf oils and piston core extracts

Samples from many different sites isotopically similar – lighter than Scotian Shelf SRs – possibly indicating older SR

Extracted hydrocarbons biomarker data difficult to reconcile with potential source rocks

Some headspace gases have a possible mixed thermogenic-biogenic signature

No convincing evidence for an oil-prone source rock

2015 NS DOE PISTON CORING CRUISE

Used CCGS Hudson

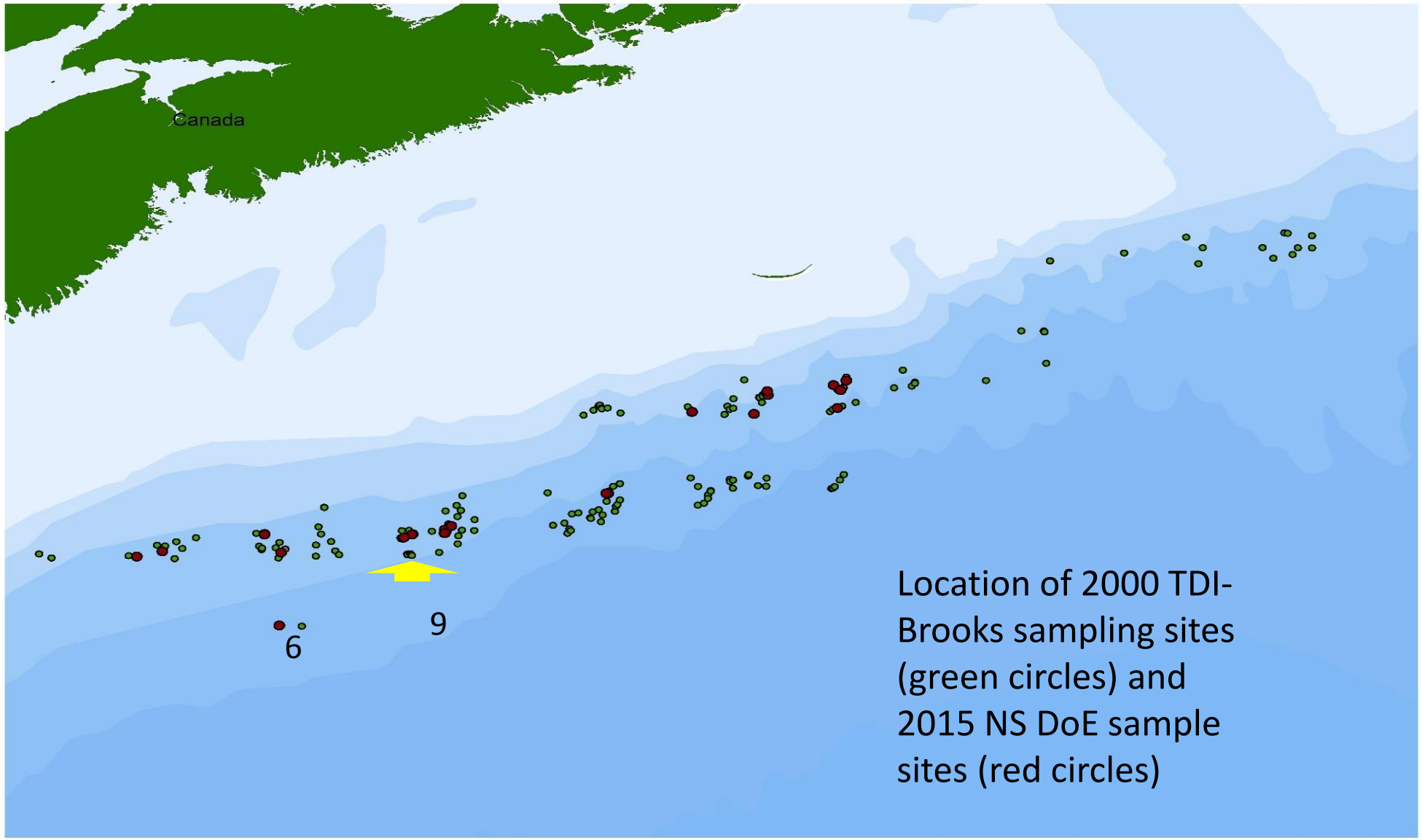
Pre-cruise effort to identify potential seep sites, most >2500 m water depth

Cruise took place June 26 to July 9, 2015

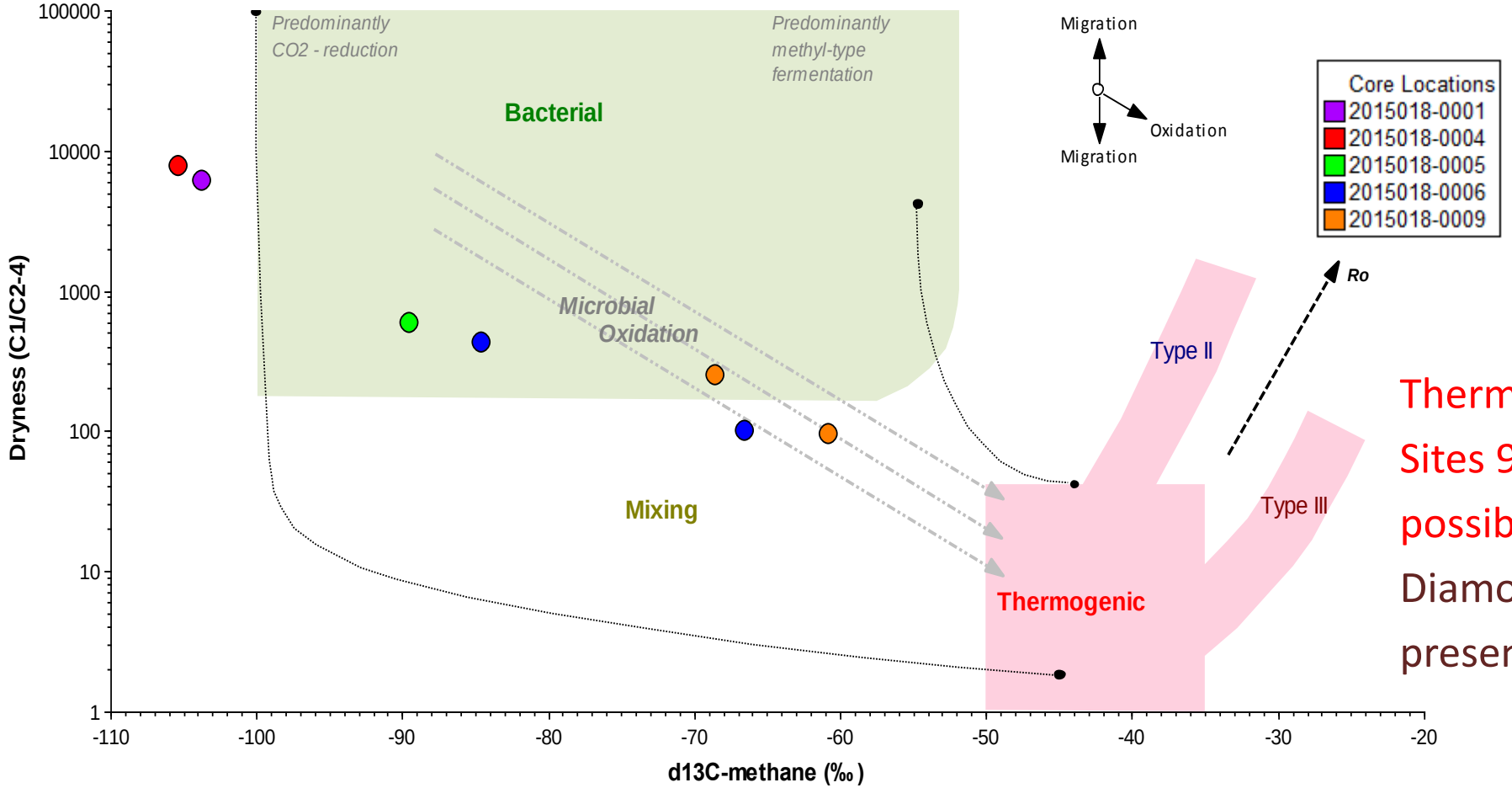
Shipboard problems – difficult to sample surface seeps

unable to piston core at depths >2500 m for most of the cruise; hence 'best' potential seep sites were mostly not cored

Piston Core Locations



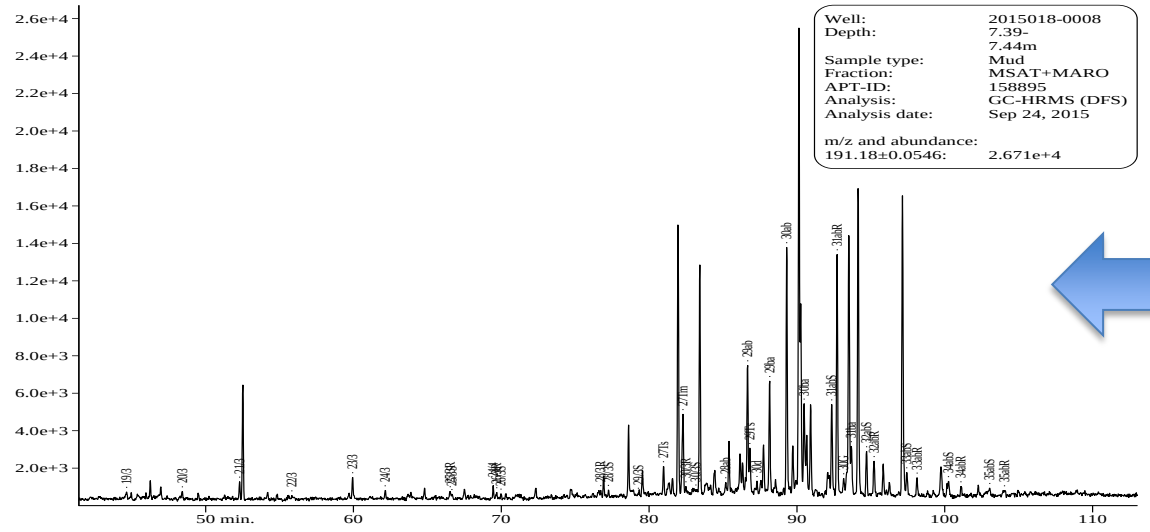
Bernard Diagram of δ13C methane versus Gas Dryness to illustrate Headspace Gas Results

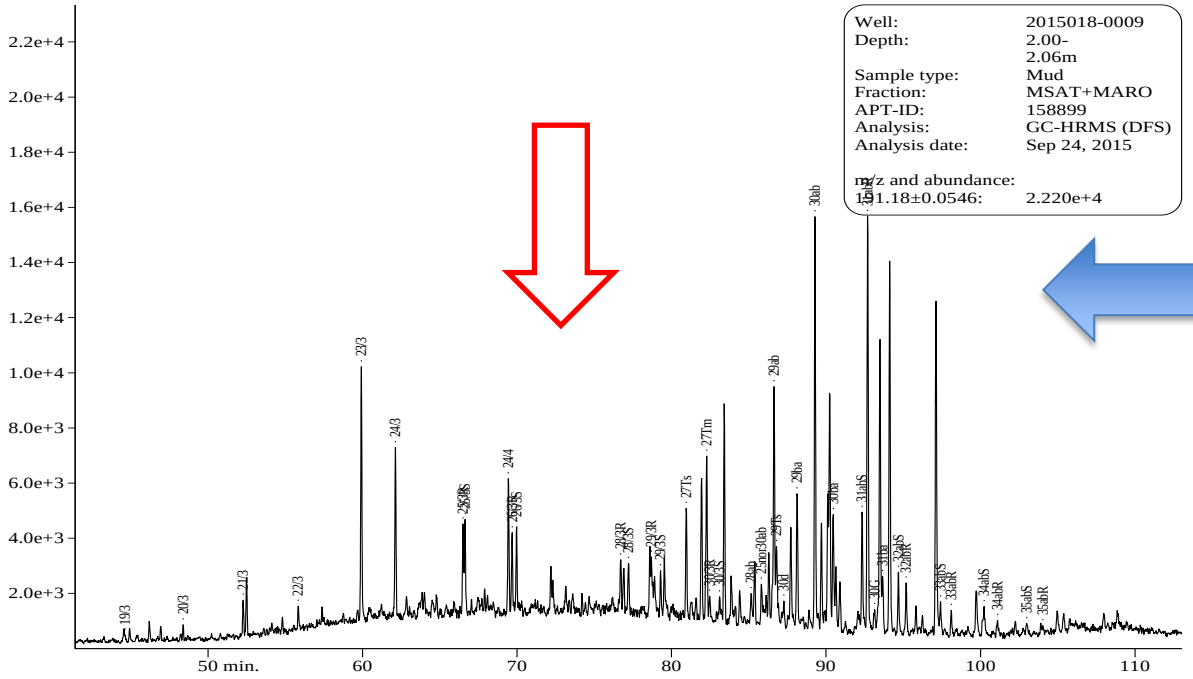


Thermogenic gases at Sites 9 and 6, and possibly site 5?

Diamondoids also present at site 9

m/z 191 mass chromatograms showing terpane distributions





Core 2015018-008

Similar to most other cores

High conc of immature biogenic compounds

Core 2015018-009 depth 2 – 2.06 m showing higher concentration of thermogenic compounds (e.g. tricyclic terpanes) and thermogenic isomers of hopanes

Steranes in this sample also show a higher abundance of thermogenic isomers compared to other samples

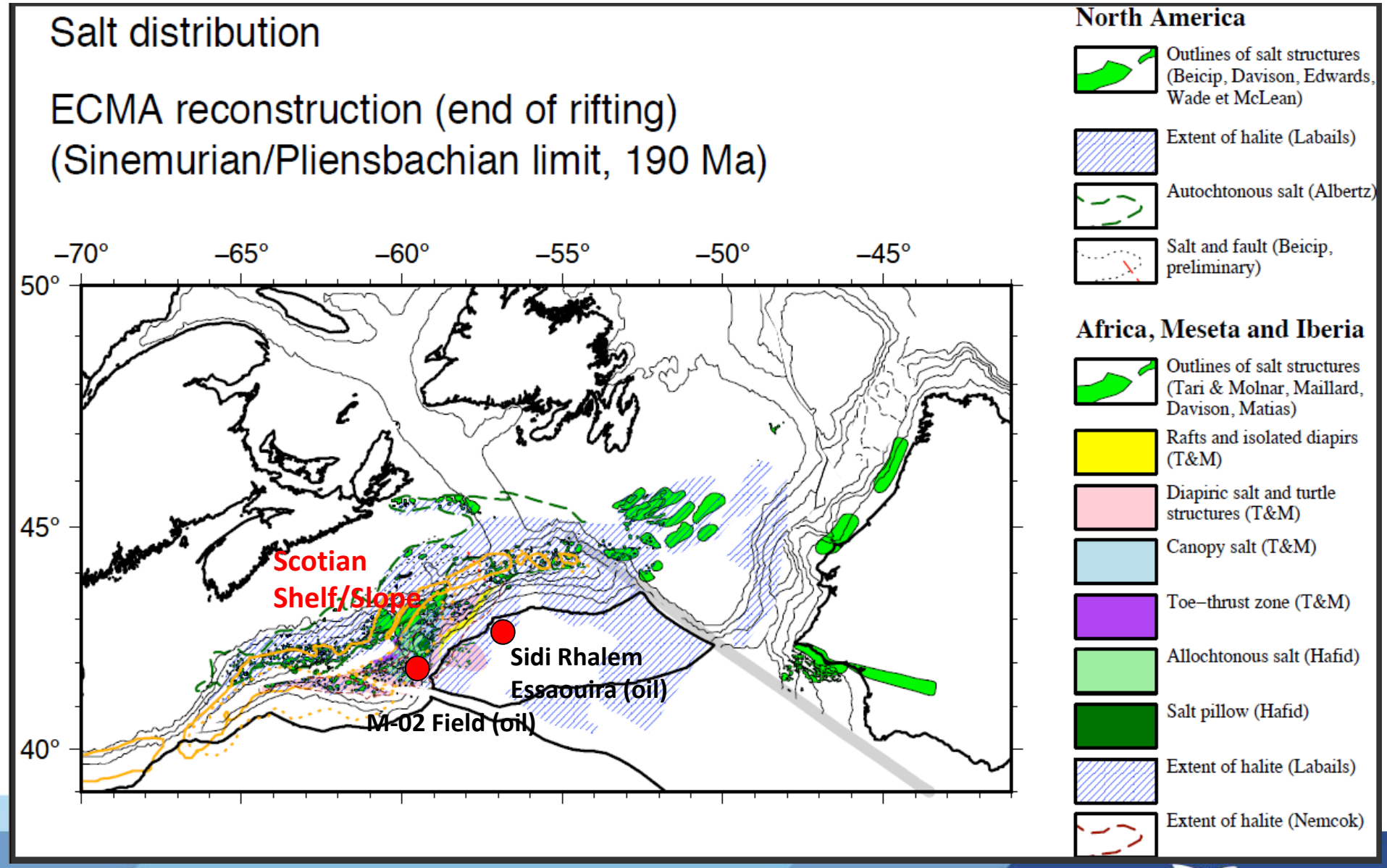
SUMMARY OF 2015 PISTON CORING GEOCHEMICAL RESULTS

Evidence for thermogenic gases at two deep water sites. Diamondoids were also found in the extracts at one of these sites.

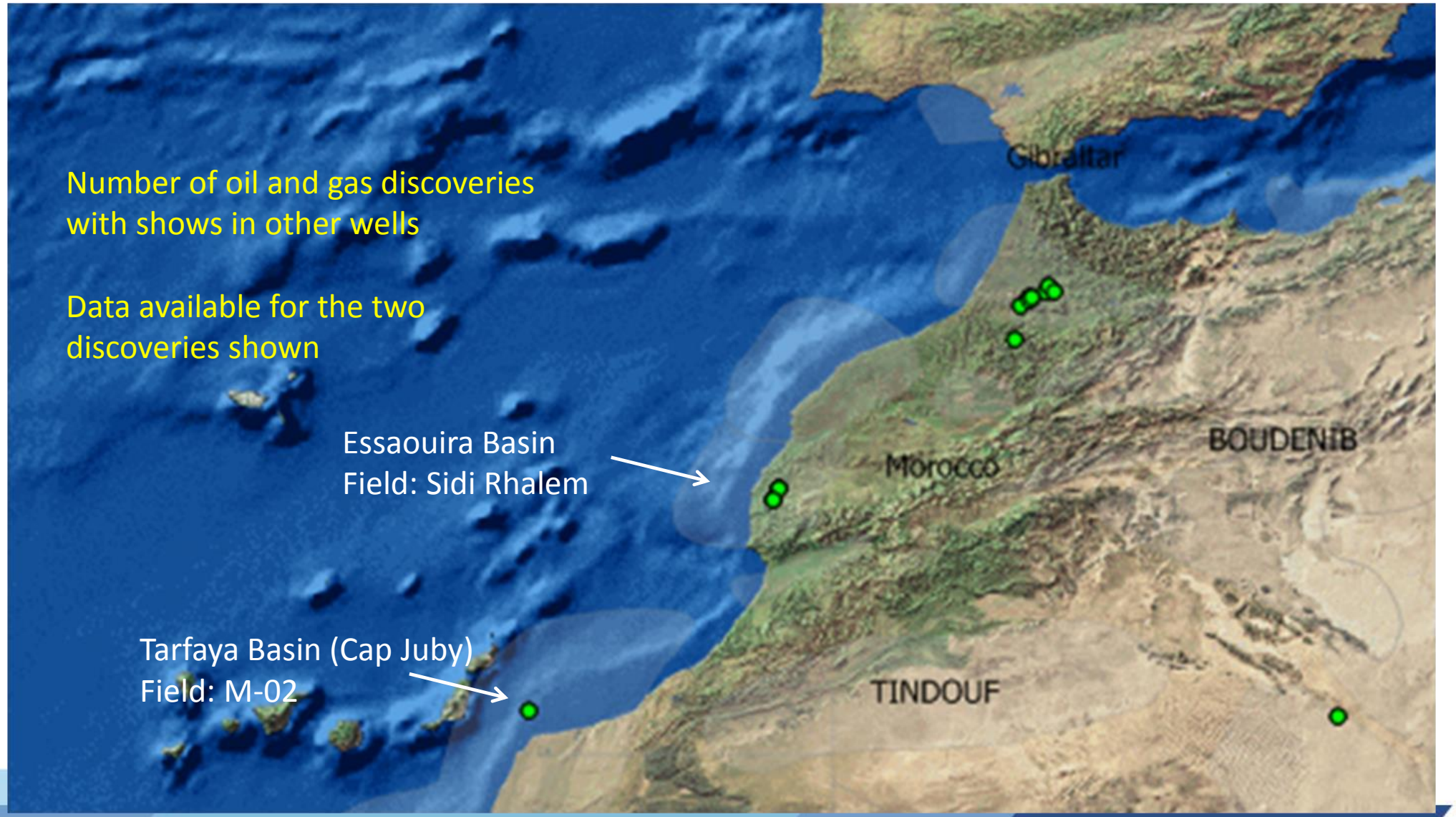
A sample from one of these sites contained petrogenic-like hydrocarbons, however, the amount of extract was very low and similar results were not obtained from other samples extracted from this core.

A cruise commenced last week where the intention is to sample more of the deeper, highly rated potential seep sites.

Conjugate Margins – offshore Nova Scotia and Morocco



Morocco


Number of oil and gas discoveries with shows in other wells
Data available for the two discoveries shown
Essaouira Basin
Field: Sidi Rhalem
Tarfaya Basin (Cap Juby)
Field: M-02
Gibraltar
Morocco
BOUDENIB
TINDOUF

MOROCCAN JURASSIC SOURCE ROCKS

What do we know based on publicly available data

Appears to be at least two Jurassic source rocks:

Offshore Tarfaya Basin, Cap Juby area

Heavy biodegraded oil from a presume Upper Jurassic restricted carbonate with Type II marine derived OM (poss Type IIS) e.g. MO-2

Onshore Essaouria Basin, e.g. Sidi Rhalem

Oil from a restricted carbonate (but some differences to MO-2), with marine Type II OM

Isotopes imply older age than for that of MO-2; Oxfordian has been suggested

Note MO-8 in Cap Juby area recovered light unbiodegraded (38°API) oil from Middle Jurassic reservoir that has been reported as having different biomarker characteristics and being isotopically lighter than MO-2 suggesting an older source.

NEEDS TO BE CONFIRMED

CONCLUSIONS

Upper Jurassic Petroleum system predominates on the Scotian Shelf with a Type III-II source generating most gas with some light oil.

No evidence at present for a deeper oil-prone source rock on Scotian Shelf

Indications of a working petroleum system(s) on deep water Scotian Slope, presumably Jurassic

At present not possible to say if Scotian Slope is oil-prone as Morocco conjugate Margin or is similar to that on the Scotian Shelf (i.e. gas prone)

Results from Shell Cheshire well later this year or from piston-coring cruise will hopefully confirm deep water prospects offshore Nova Scotia

QUESTIONS

Many of the reports referred to in this presentation can be found at the web site of the Offshore Energy Research Association of Nova Scotia (OERA)

oera.ca/offshore-energy-research/geoscience/play-fairway-analysis

Data from the GSC and others can be found at the NRCan BASIN Database

basin.gdr.nrcan.gc.ca