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Scientific Presentation 165

Qualitative Petroleum Resource Assessments, process and examples from Atlantic Canada

E.A. Atkinson, C.J. Lister, L.E. Kung, K.E. Dewing, A. Krakowka, A.M. Kalejaiye, P.W. Durling, and J.S. Carey

2023

Canada

Good morning, thanks for coming to our presentation about the Marine Conservation Targets initiative.

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Marine Conservation Targets initiative

- Goal to protect 10% of marine area by 2020, 25% by 2025, and 30% by 2030
  - 2020 goal met (currently 14.66% - map)
- GSC tasked with petroleum resource assessments in regions under consideration
  - Regions studied, vs. local proposed protected areas
  - Other resources (e.g. minerals) also noted
- Where warranted, quantitative resource assessments and economics are run
  - Natural Resources Canada – Energy Sector

https://www.dfo-mpo.gc.ca/oceans/maps-cartes/conservation-eng.html

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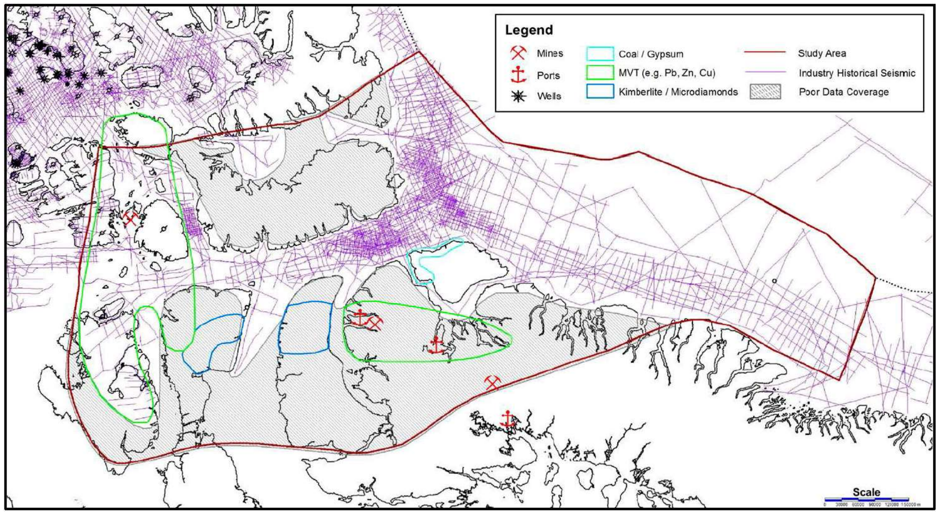
The Marine Conservation Targets initiative is a program of the Canadian Government that began in 2016, with the goal of protecting 10% of Canada's marine areas by 2020.
That goal was met, currently 14.66% of Canada's offshore is protected. Here's a map showing the many different types of parks in Canada's oceans.
There are new goals of 25% by 2025 and 30% by 2030.
The GSC's role in MCT is show stakeholders what resources may exist in areas under consideration.
We are particularly tasked with petroleum assessment, but also flag other resources.
We study full regions to assess petroleum systems, and run quantitative assessment and economics where warranted.

Qualitative Mapping Process

- Given short timelines and importance of where resources are likely to be located, GSC developed a methodology based on petroleum play analysis, to construct consistent Qualitative Petroleum Potential Maps
  - Combines chance of source, reservoir, trap and seal for each play
  - *Lister et al., 2018, GSC Open File 8404*
- Assemble broad datasets:
  - Literature and previous petroleum analyses
  - Wells
  - Seismic data (where possible)
    - From public sources and industry donations
    - Modern reprocessing of seismic to improve imaging, where feasible
  - Other geophysical data
  - Related surface geology maps
  - Bathymetry
- Combine previous work, well ties, and new mapping to create updated regional maps of key horizons
- Define petroleum plays for the region
  - For each play, analyse and map petroleum system elements (PSE):
    - Source (presence, maturity and migration)
    - Reservoir (presence and quality)
    - Trap
    - Seal potential

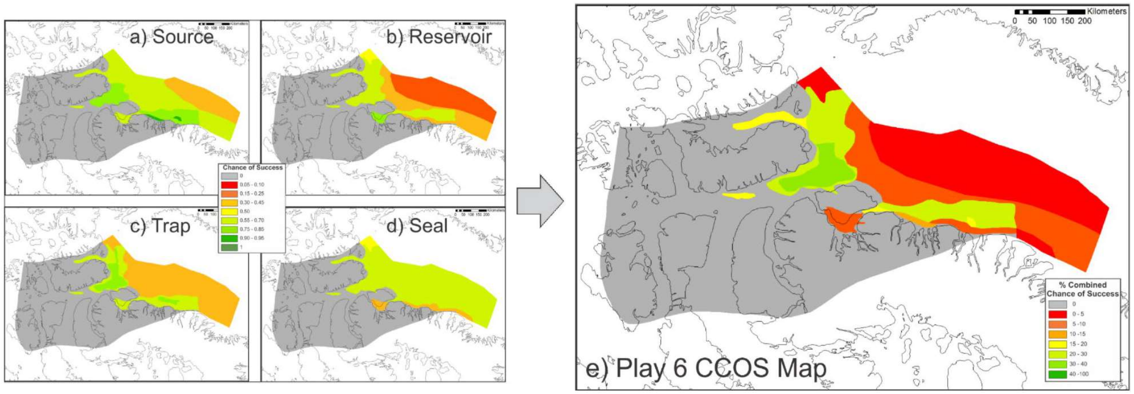


Example of assembled dataset, Lancaster Sound, Atkinson et al, 2017

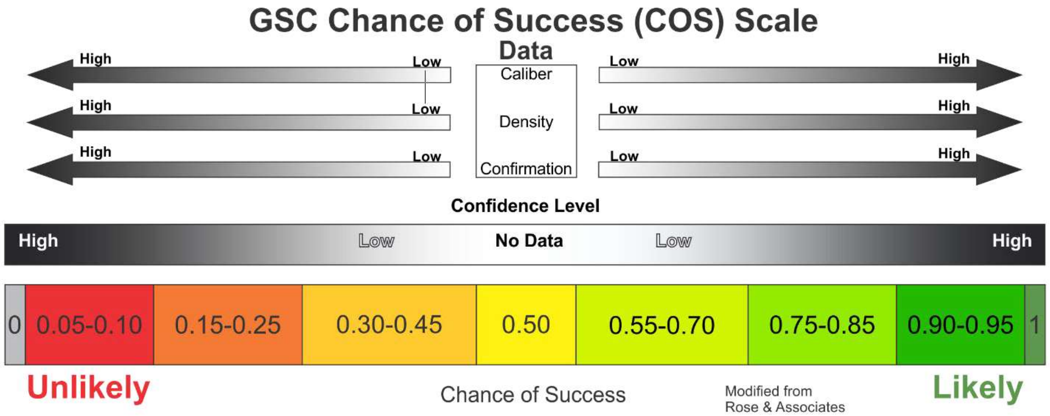
Given short timelines and the importance of where resources are likely to be located, the GSC developed a methodology based on petroleum play analysis, to construct consistent Qualitative Petroleum Potential Maps.
It combines chance of source, reservoir, trap and seal for each play.
We assemble broad datasets from literature, wells, seismic, other geophysics and geology, and combine it all to create updated regional horizons.
From that we define the petroleum plays for the region, and analyse the petroleum system elements for each – source, reservoir, trap and seal.

Play analysis and COS determination

- Draw maps of the Chance of Success (COS) of each PSE in each play, outlining polygons with similar geologic conditions.
- Assign the COS by considering:
  - Whether evidence is positive or negative (or a mix of evidence) for the PSE
  - Data quality/caliber (how good is our data)
  - Data density (how much data do we have and how is it distributed)
  - Data confirmation (how much varied evidence do we have to confirm our interpretations)



Example of petroleum system elements for a play, Lancaster Sound, Lister et al, 2018



Once we've defined the petroleum plays in the region, we draw maps of the Chance of Success of each element of each play, outlining polygons with similar geologic conditions.

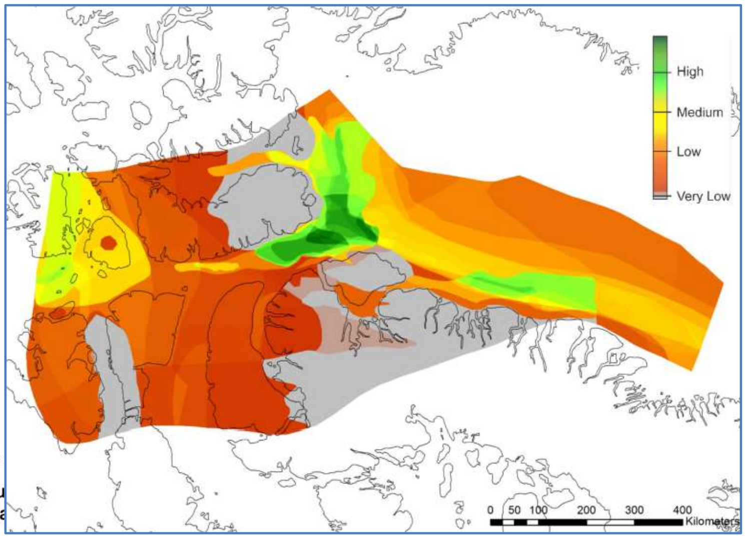
We assign the COS by considering whether evidence is positive or negative for that element, how good our data is, how much data we have, and how varied evidence confirms our interpretations.

These considerations lead to a confidence level in the interpretation, and that constrains how bullish or bearish we can be. This scale, from Rose & Associates, shows how confidence level constrains how certain we should be.

Once we've mapped out the COS for each element, we multiply them together to map the Chance of Success for that play.

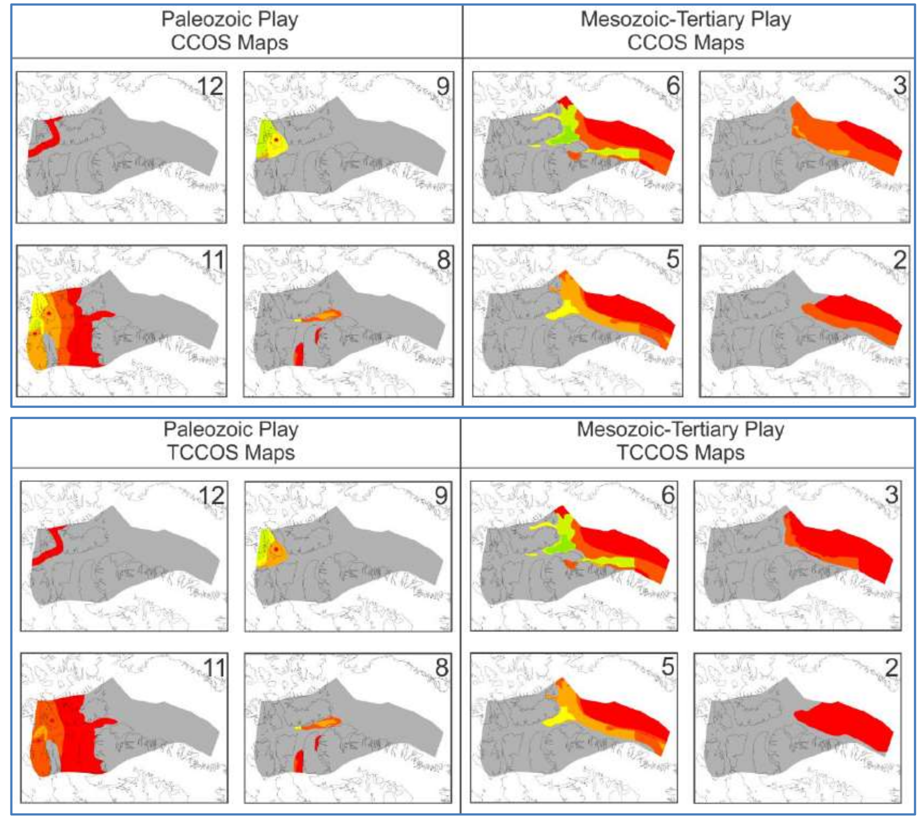
Combine play COS into Qualitative Petroleum Potential map

- Final step – combine all plays in the region
- More plays = better potential, so plays are added
- But all plays are not equal in volumetric potential
  - For example, a high chance of small volumes should not add appreciably to final petroleum potential – must add 'apples to apples'
- Must scale the CCOS maps to reflect the likely petroleum volumes associated with each play
  - Global Scale Factor (GSF)
    - Judgement based on analogs and quantitative volumetric calculations for individual prospects
    - Estimate whether the given play is globally competitive in the offshore (has potential for a giant field and at least three large fields)



SUM all plays

Example of Combined COS maps, before and after scaling, for several plays, Lancaster Sound, Lister et al, 2018



Details of GSF in Lister et al, 2018; Carey et al, 2020; Dewing et al, 2023

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Finally, we add all plays in a region into a Qualitative Petroleum Potential Map.
Since all plays are not equal in their significance or potential, we must first scale them, to add 'apples to apples', using analogs, test quantitative runs, and team judgement.
This example for Lancaster in the Eastern Arctic shows the combined COS maps for several of the plays there, and the scaled COS maps – some of the Paleozoic plays in particular are scaled back.
All 15 scaled plays in this region are added together to make the final Petroleum Potential Map, which scales from very low in grey to very high in dark green.

Detailed Example:
Magdalen Basin regional study

- As part of MCT, the GSC conducted a broad regional study of the geology and petroleum potential in the Magdalen Basin
  - South and central Gulf of St. Lawrence
  - In support of proposed National Marine Protected Area in the Îles de la Madeleine
- To conduct petroleum play analysis, an in-depth regional mapping project was undertaken
  - Database and results presented in GSC Open File:
    - *Atkinson et al., 2020. Open File 8556*
- New mapping was used to:
  - Define Plays
  - Model basin maturity
  - Map COS of Petroleum System Elements

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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8556

Qualitative petroleum resource assessment of the Magdalen Basin in the Gulf of St. Lawrence

Quebec, Prince Edward Island, New Brunswick, Nova Scotia, and Newfoundland and Labrador

E.A. Atkinson, P.W. Durling, K. Kublik, C.J. Lister, H.M. King, L.E. Kung, Y. Jassim, W.M. McCarthy, and N. Hayward

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Qualitative petroleum resource assessment of the Magdalen Basin in the Gulf of St. Lawrence; Quebec, Prince Edward Island, New Brunswick, Nova Scotia, and Newfoundland and Labrador

E.A. Atkinson[1], P.W. Durling[2], K. Kublik[1], C.J. Lister[1], H.M. King[1], L.E. Kung[1], Y. Jassim[1], W.M. McCarthy[1], and N. Hayward[3]

[1]Geological Survey of Canada, 3303 33rd Street Northwest, Calgary, Alberta T2L 2A7
[2]Geological Survey of Canada, 1 Challenger Drive, Dartmouth, Nova Scotia B2Y 4A2
[3]Geological Survey of Canada, 1500 - 605 Robson Street, Vancouver, British Columbia V6B 5J3

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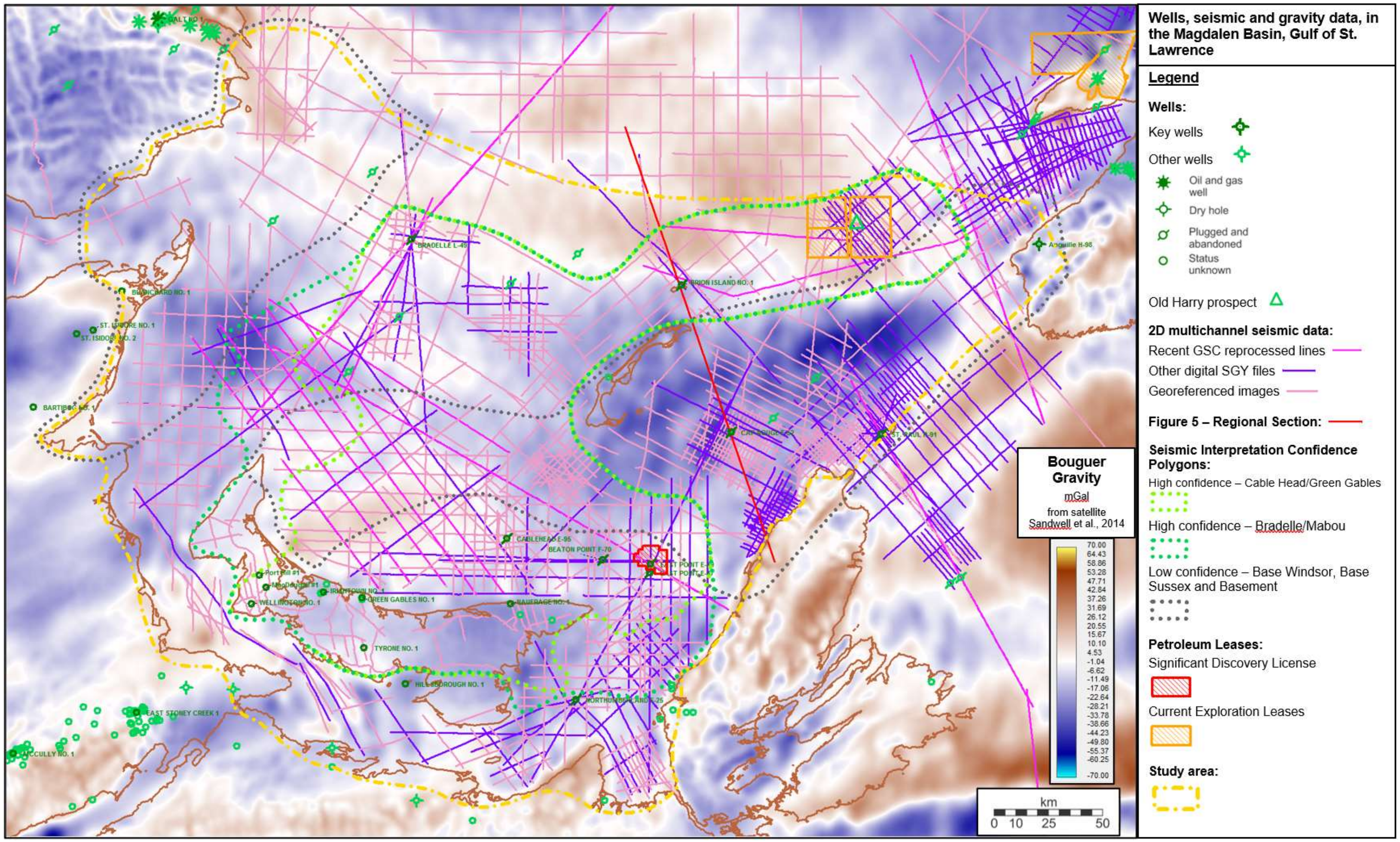
We'll now look in detail at one of our regional studies, in the Magdalen Basin of the Gulf of St. Lawrence.
Parks Canada is looking at a significant new park around the Îles de la Madeleine.
We conducted an in-depth regional mapping project over most of the Magdalen Basin to put this area in full geologic context.
New mapping defined plays and supported basin modelling, and defined Chance of Success.

Magdalen Basin database assembly

- Seismic, gravity and magnetic database assembled
  - More complete seismic database
  - Industry donations
  - Literature (e.g. *Hayward et al., 2014*)
  - Note high/low confidence polygons documenting seismic quality
- Reprocessing
  - Lithoprobe reprocessed by contractor
  - Other lines in house



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To conduct this regional study, we assembled data from a variety of sources, including seismic data from the former NEB, now Canada Energy Regulator archives, Lithoprobe, and industry donors.

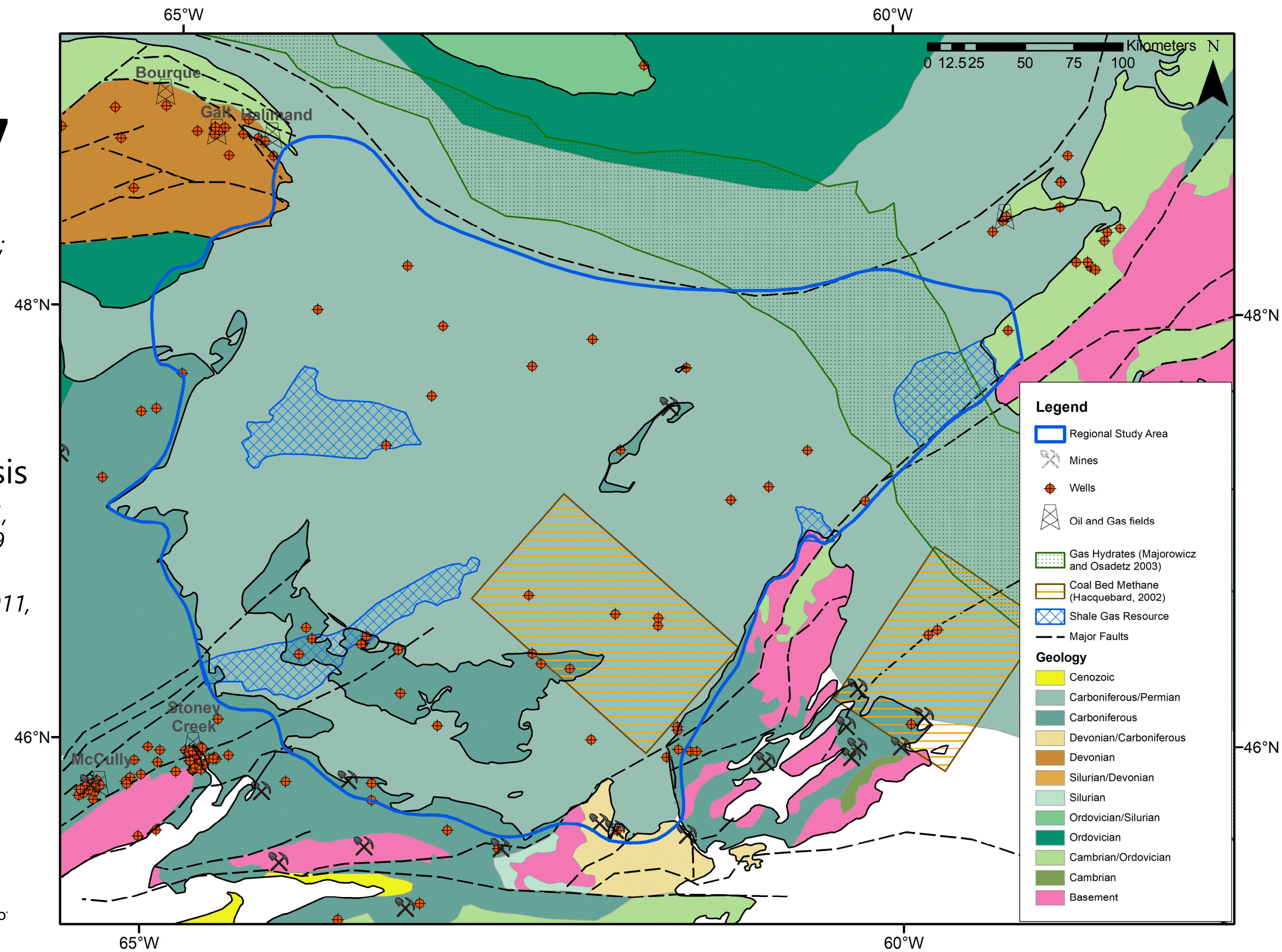
Some data is digital sgy (shown in purple), and some are images (in light pink).

Reprocessing of seismic by contractors and inhouse produced significant uplift of several regional lines (shown in hot pink).

Regional gravity was also modelled to constrain interpretations.

Magdalen Basin database assembly

- Regional geology maps
  - *St. Peter and Johnson, 2009; Lynch et al., 1995; Knight, 1983; Calder, 1998; Lavoie et al., 2009*
- Well data
  - Discoveries / fields
  - *Grant and Moir, 1992; Hu and Deitrich, 2010; Rehill, 1996; Bibby and Shimeld, 2000; Giles, 2004*
- Literature review – previous analysis
  - Stratigraphy – *Giles and Utting, 1999, 2001, 2003; Waldron et al., 2017; Gibling et al., 2019*
  - Regional cross sections – *Durling and Marillier, 1993b; Giles, 2008; Dietrich et al., 2011, Pinet et al., 2013; Pinet et al., 2018*
  - Tectonics – *Durling and Marillier, 1990; Gibling et al., 2008; Hamblin, 1989; Langdon, 1996; Waldron et al., 2015*
  - Unconventional petroleum potential
  - Mines
- Consultation with GSC scientists



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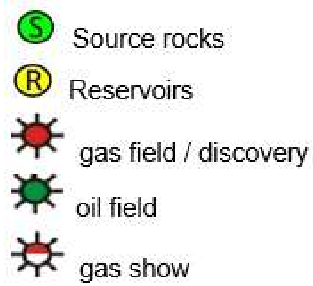
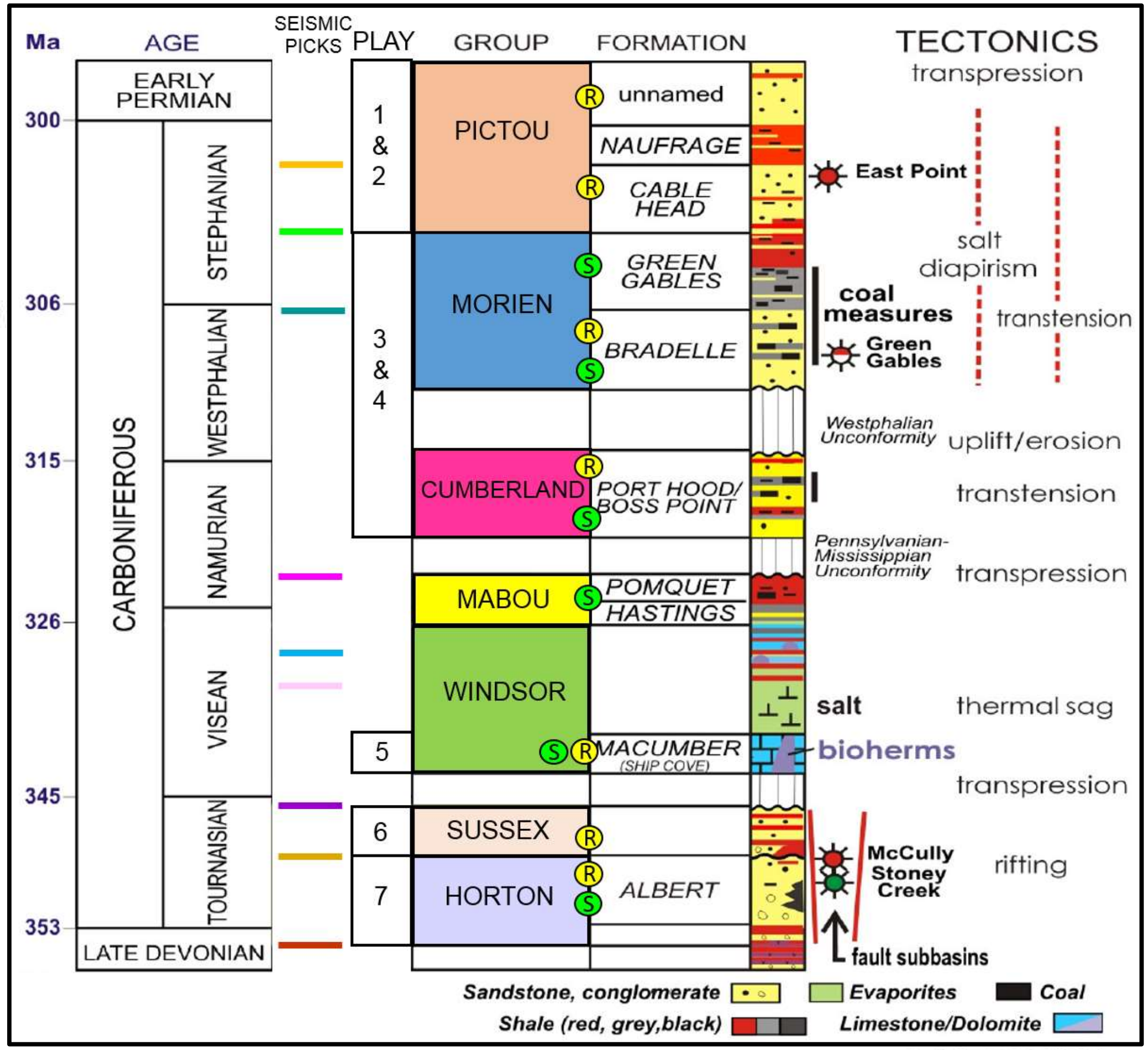
Interpretations were also constrained by wells, regional geology maps, and regional stratigraphic cross sections.
GSC scientists shared their geological expertise, and reviewed our new interpretations.

Lithostratigraphy of the Magdalen Basin

- The stratigraphic position of fields and shows are shown with well symbols, and the tectonics are summarized
  - Modified from *Lavoie et al. (2009)*



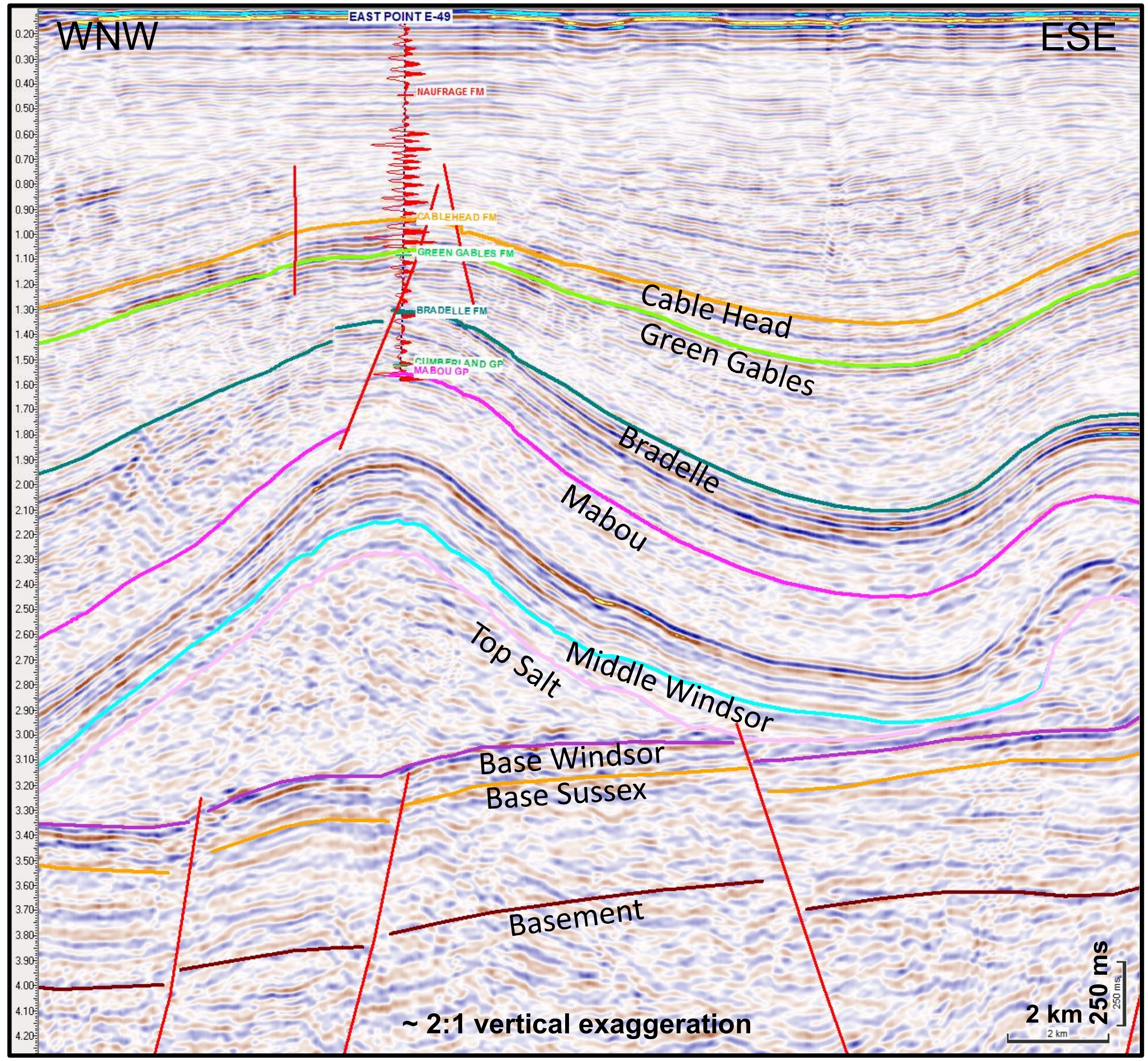
- Seismic horizons mapped and illustrated on regional cross section and seismic examples are shown in with coloured markers (“seismic picks”):
  - Cable Head Formation
  - Green Gables Formation
  - Bradelle Formation
  - Mabou Group
  - Middle Windsor Group
  - Top Salt
  - Base Windsor Group Unconformity
  - Base Sussex Group Unconformity
  - Pre-Horton Group Basement

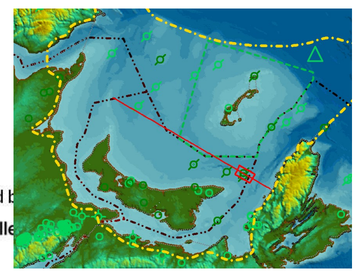


The stratigraphy and petroleum systems in the Magdalen Basin are shown here.
The Horton Group was deposited in early grabens and includes source rocks and reservoirs that are productive in New Brunswick.
Thermal sag accommodated the deposition of the Sussex, Windsor and Mabou Groups. Significant salt was deposited in the restricted basin in the Visean Windsor time. Potential source rocks are in the Lower Windsor and the Mabou, and carbonate reservoirs in the Lower Windsor.
Continued transtension over time allow the deposition of the more terrestrial Cumberland, Morien and Pictou Groups. Coal rich source rocks and clastic reservoirs exist through much of this section.
Salt diapirism occurred during the deposition of the Morien and Pictou Groups.

Well correlation and Seismic character

- Synthetics were constructed for key wells with logs
  - Example from East Point E-49
  - Tie to Lithoprobe Line 86-1, illustrating recent reprocessing (*Hall et al., 2019*)
- Tops from literature (*Giles and Utting, 1999, 2001, 2003; Rehill, 1996*) were used for well ties
- Example of seismic character of Cable Head, Green Gables, and Bradelle Formations and Mabou Group, and salt-cored anticline and adjacent salt weld.
- Seismic character (reflective and non-reflective packages) can be followed regionally
  - Self consistent regional maps over large database add confidence

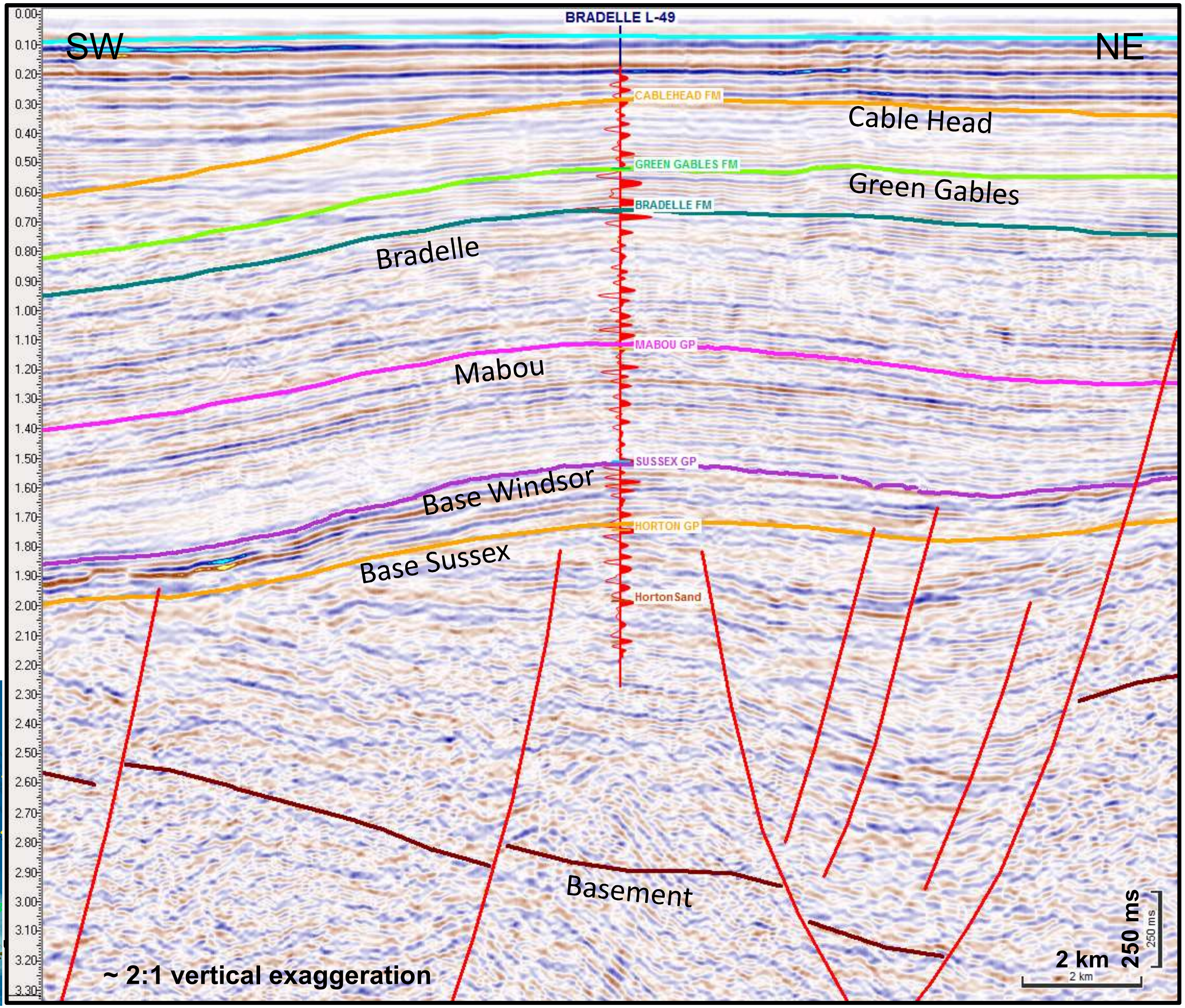


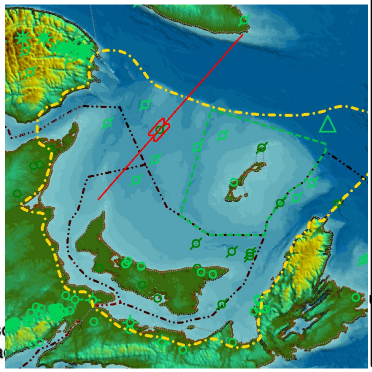


This is an example of a key well tie, E-49, which found non-commercial gas off eastern PEI. It was drilled at the crest of a salt cored anticline.
This seismic example and the next are both examples of improved reprocessed Lithoprobe lines.
The well tie constrains the seismic character of these stratigraphic packages.
The Cable Head Fm. and Bradelle Fm. as well as the Upper Windsor and Sussex Gp. are consistent reflective packages.
These packages can be followed regionally and regional consistency adds confidence to interpretations, even away from the wells.

Well correlation and Seismic character

- Second example of seismic character, particularly Windsor, Sussex, and Horton Groups
  - Bradelle L-49
  - Tie to Lithoprobe Line 86-2, illustrating recent reprocessing (*Hall et al., 2019*)
- Seismic character (reflective and non-reflective packages) can be followed regionally
  - Consistent lateral changes
  - Self consistent regional maps over large database add confidence

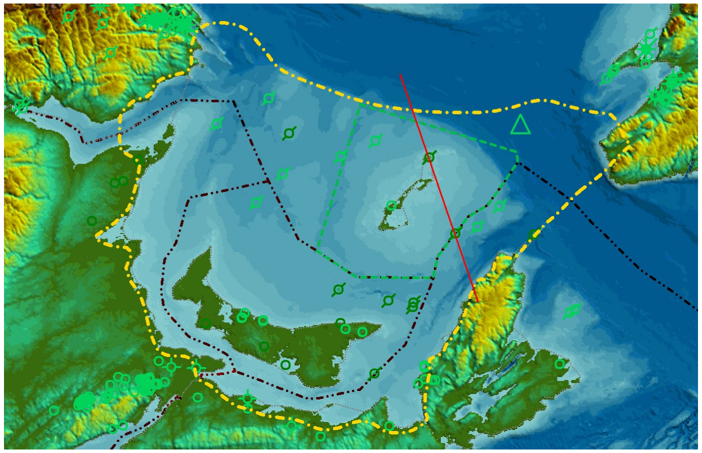


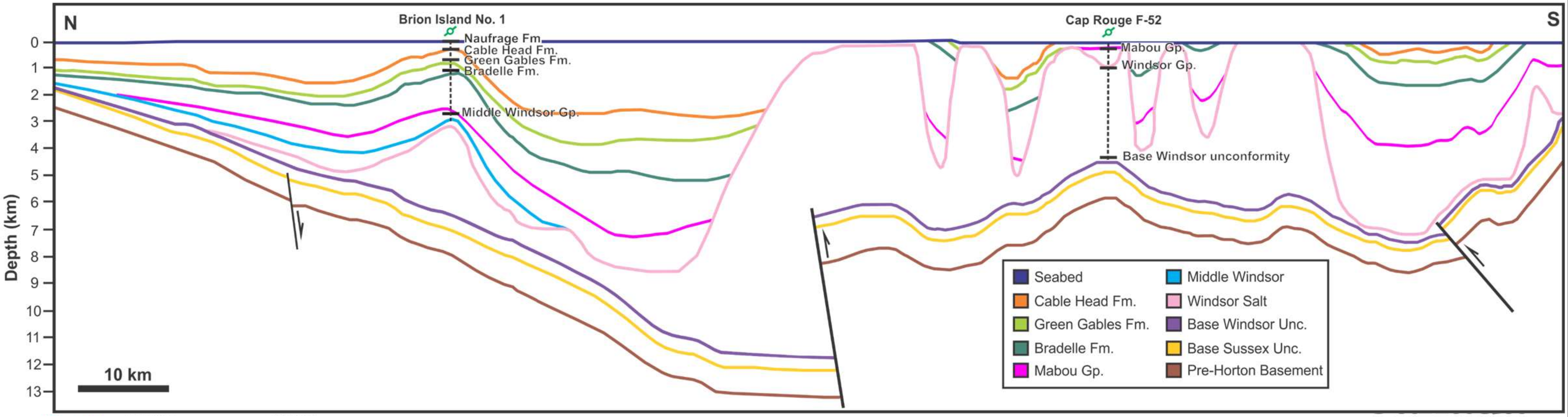


This is another example of a well tie toward the north end of the basin.
Bradelle L-49 penetrates into a Horton graben – dipping reflectors within the grabens are observed.
Bradelle Fm. reflectivity has faded somewhat, but Upper Windsor and Sussex reflection packages persist.
These time horizons were followed throughout the basin to create regional maps.

Depth Conversion and Regional depth cross section

- Depth Conversion
  - Regional vs. precise approach
  - Limited well penetrations preclude more complex layer-cake models
  - Regional time-depth curves from literature (*Durling and Marillier, 1993a*)
  - Not explicitly tied to wells, but correlations are reasonable
  - Residual correction applied for lower velocity water column
- Allowed calculation of regional depth grids
- Cross section constructed from regional depth grids in workstation
  - Vertical exaggeration ~ 3:1
- 9 regional depth maps and 8 isopachs produced

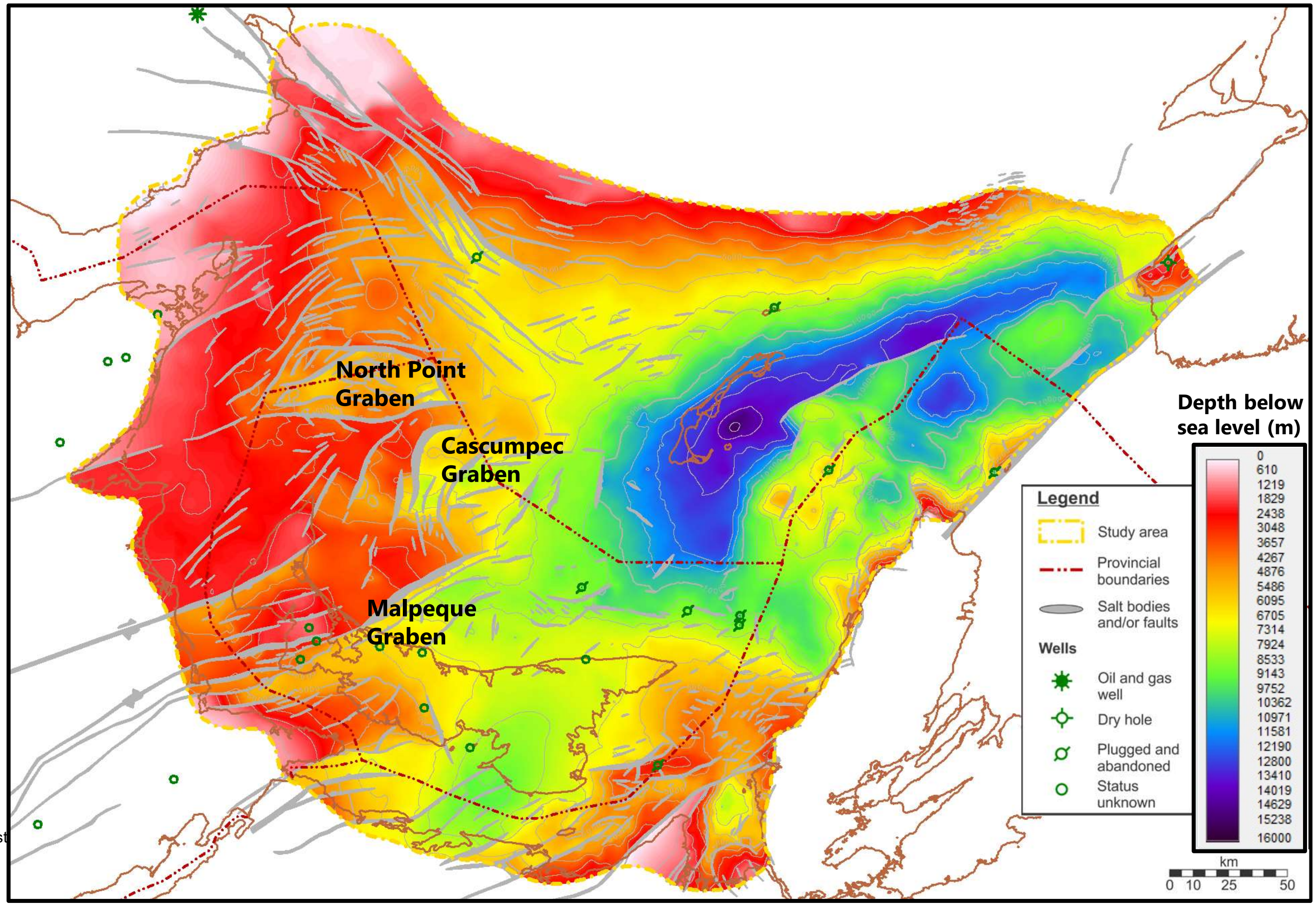




Depth conversion used a regional approach, based on a time depth function published in the literature.
Well ties were insufficient to contemplate a more layer cake approach, and correlations to wells are still reasonable.
A correction was applied for water depth, to account for the deep Laurentian Channel cutting across the Gulf.
Resulting depth grids allowed to the construction of regional cross sections, such as this one across the middle of the basin.
This section illustrates the salt cored anticline under Brion Island, near Îles de la Madeleine, and the significant salt and postulated deep inversion NW of Cape Breton.

Pre-Horton Group Basement / Base Horton Group

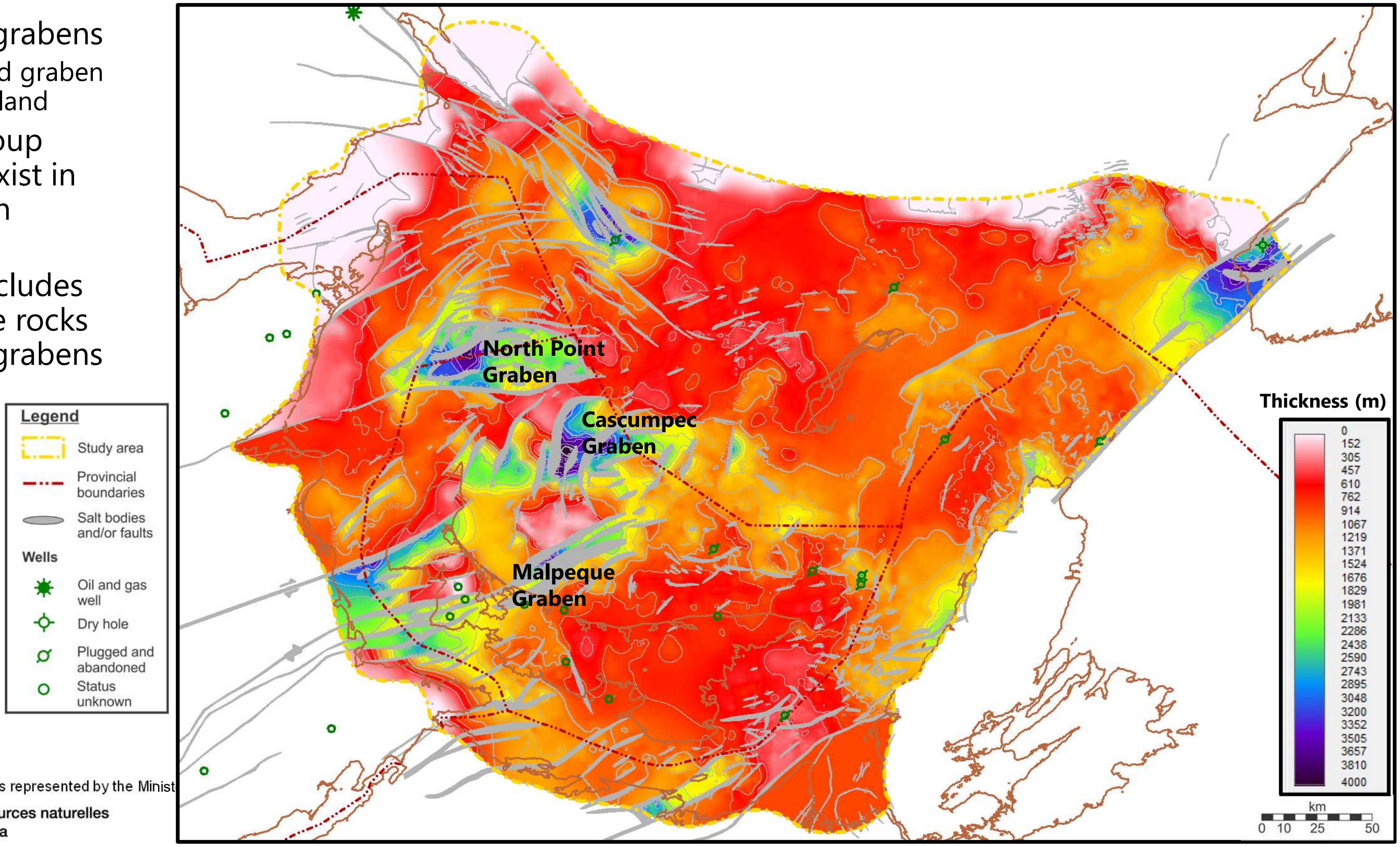
- Less confident mapping at Base Horton
  - Localized tilting reflection packages
  - Regional consistency, new processing, adds confidence
- Two main trends
  - Roughly parallel to faults seen onshore in NB and NF (NE-SW)
    - Is there an aspect of oblique movement on these grabens?
  - Roughly 60 to 70 degrees from that trend (NW-SE)
    - Could this relate to trans-tension origin of Magdalen Basin, or is it simply related to trends seen in Gaspé?
- No evidence of through going fault / fault trend related to underlying Appalachian structures
  - No direct fault connection from Quebec Re-entrant to Newfoundland Promontory



We'll now take a look at some of these regional depth maps, that ultimately constrained our petroleum potential map.
This is the Base Horton Group, which is the base of the basin. Two main fault trends are visible, and some key graben features are highlighted.
Depth maps constrain reservoir COS, and obviously the Horton Group is too deep over much of the basin. Note the core of the basin exceeds 15 km deep.
An interesting tectonic aside here is that the regional mapping shows NO evidence of a transform in the underlying Appalachian rocks, connecting the Newfoundland Promontory to the Quebec re-entrant.
Many studies of the Appalachians draw large structures across the Gulf, but the actual data suggest that the Appalachian connection must be more complex.

Horton Group Isopach Map

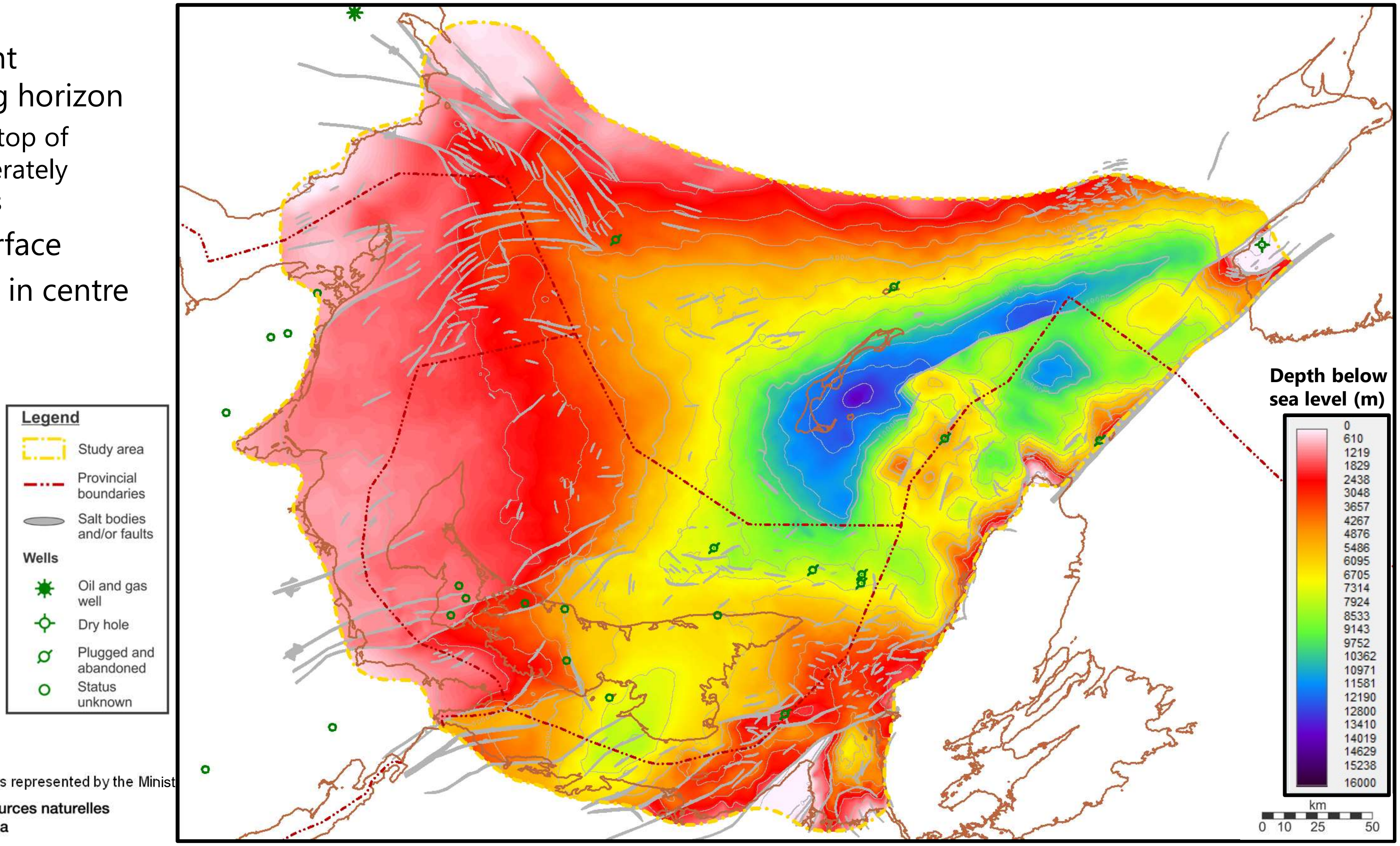
- Highlights thick grabens
  - Including inverted graben in SW Newfoundland
- More Horton Group variation could exist in basin centre, than currently imaged
- Horton Group includes significant source rocks concentrated in grabens



These depth maps were also used to calculate isopach maps. Isopachs were used to constrain seal COS, and rate of change of thickness constrained stratigraphic trap COS.

Base Windsor Group / Early Visean Unconformity

- Deepest confident regional mapping horizon
  - Strong reflector, top of package of moderately strong reflections
- Unconformity surface
- Reaches ~ 12 km in centre of basin



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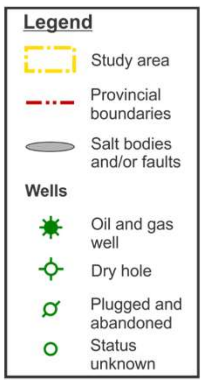
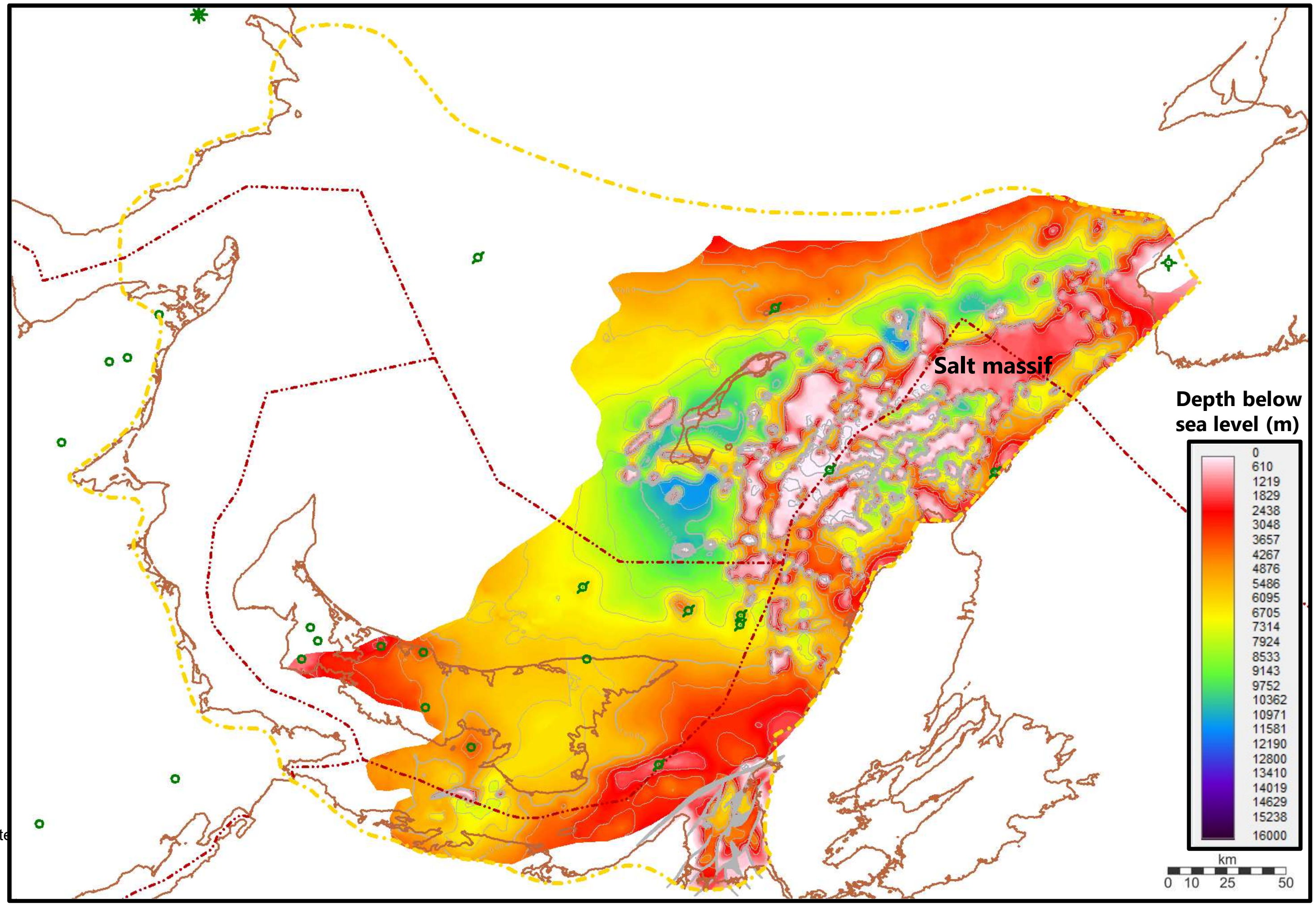
The Base Windsor Group unconformity is the deepest high confidence horizon in the basin, and reaches over 12 km in the middle of the basin.

Top of Salt / Lower Windsor Group

- Highlights salt extent and salt tectonics
- Significant salt movement creates petroleum trap potential
  - Most complex structure in basin
- Seal potential





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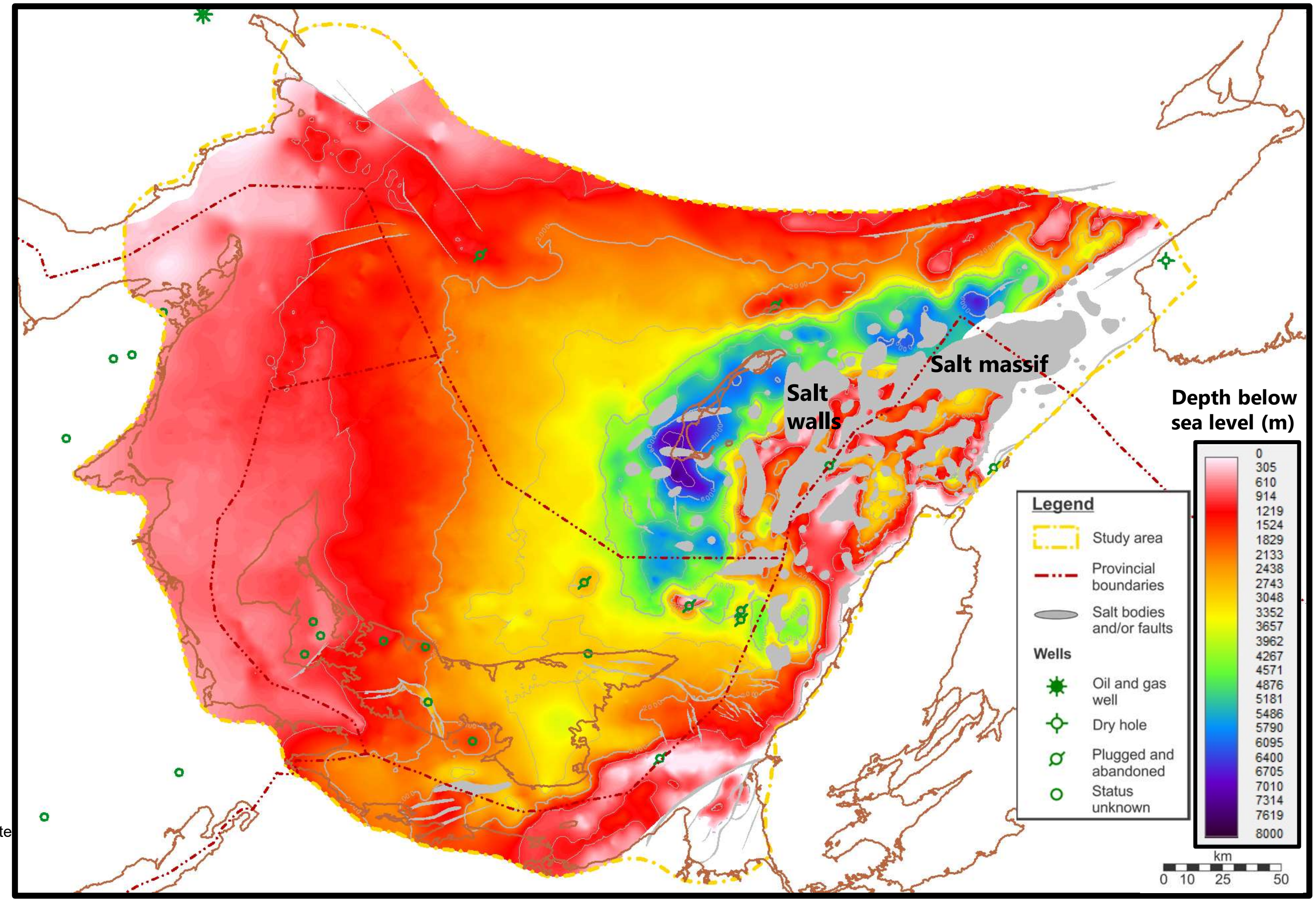
This is a map of the top of salt. Complex salt diapirism occurred between Cape Breton and Îles de la Madeleine, and produces significant trap potential. Salt is also an excellent seal, of course.

Top of Bradelle Formation

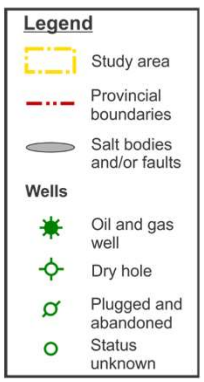
- Most reliable recognisable seismic horizon
  - Top of reflective zone
- Widespread deposition
- Simple deformation
  - More in salt province
- Significant reservoir in basin
  - Strong correlation of porosity to depth
- Source rocks within package
- Note shorter depth scale
- Further work with seismic database may bring out additional stratigraphic details
  - e.g. variation in reflectivity may indicate quantity of coal in Bradelle Fm.

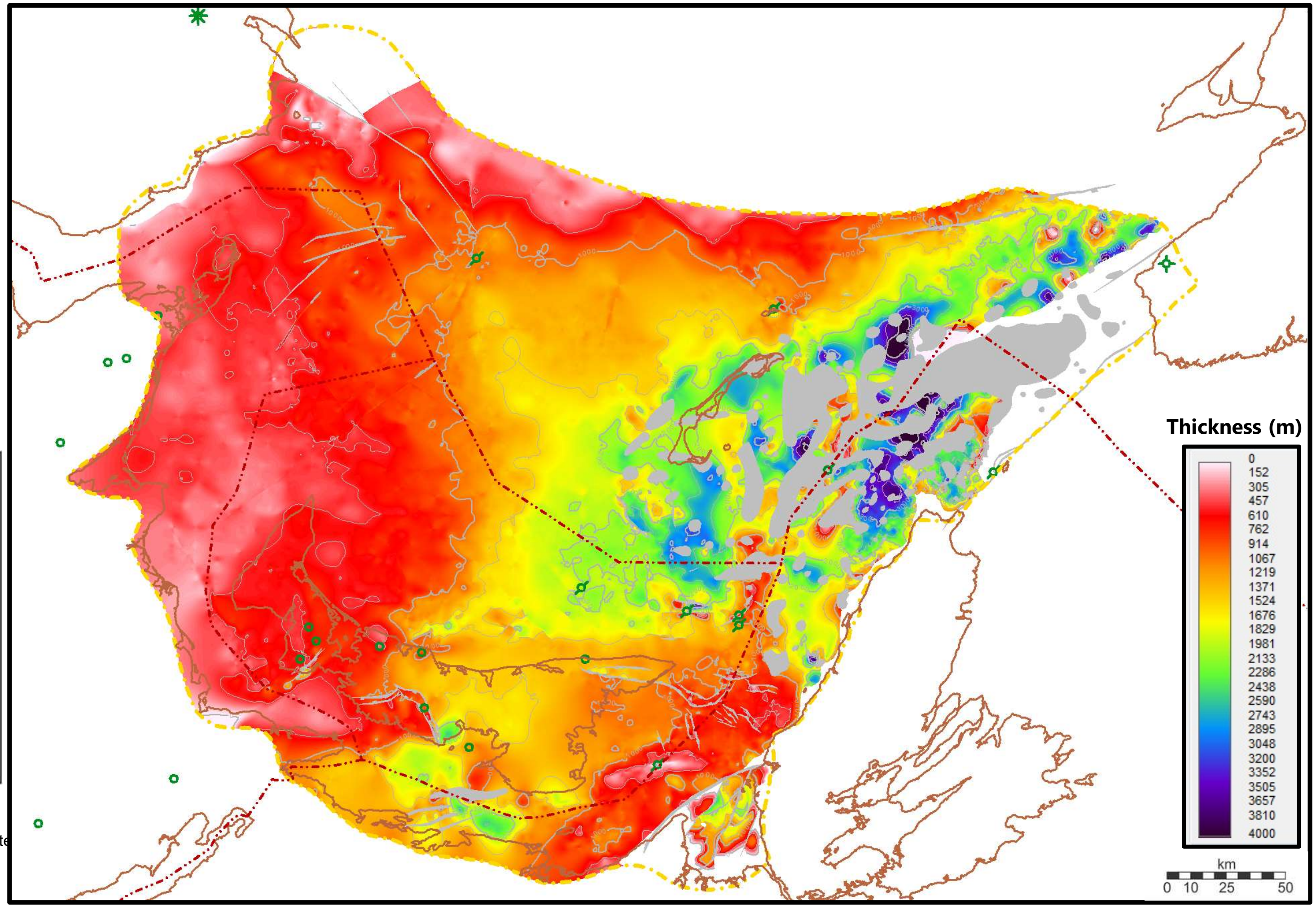


Moving up the section, this is a map of the top of the Bradell Fm., in the Morien Gp. (note the scale has changed.)
It is the most reliable recognisable horizon in the basin, at the top of a coally reflective zone.
It is a significant reservoir in the basin, with a strong correlation of porosity with depth. Thus this depth map is directly used to constrain reservoir COS.
The abundant coal is a good, though somewhat gas prone, source rock.
This unit underwent fairly simple deformation for the most part, and is deformed by salt cored anticlines and other drape structures.
The seismic could be worked further to pull out stratigraphic detail in this package.

Bradelle and Cumberland Group Isopach Map

- Highlights significant increase in thickness in salt province / basin centre
- Distinct very reflective seismic package, caused by contrast with coal
- Isopachs useful for analysing stratigraphy regionally





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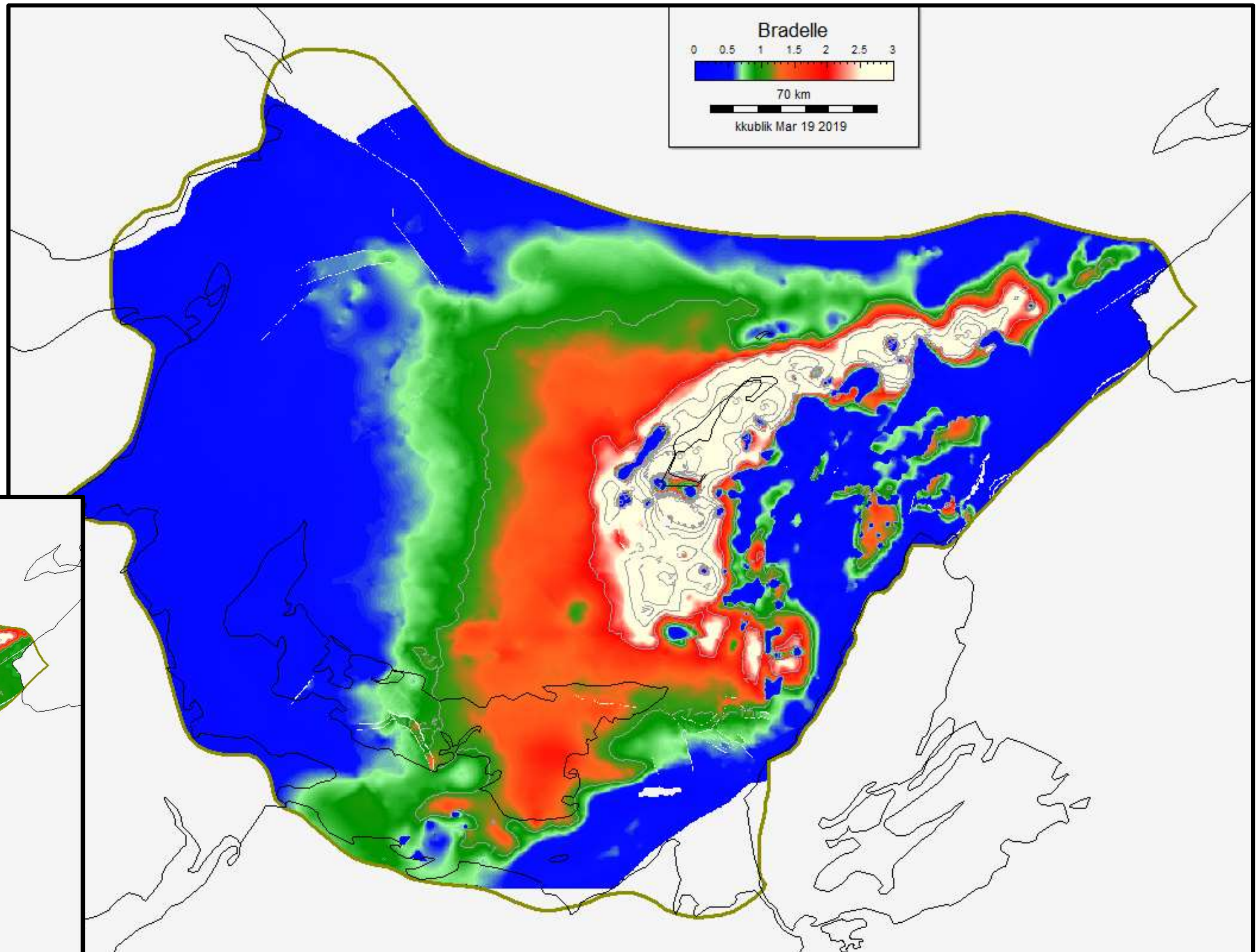
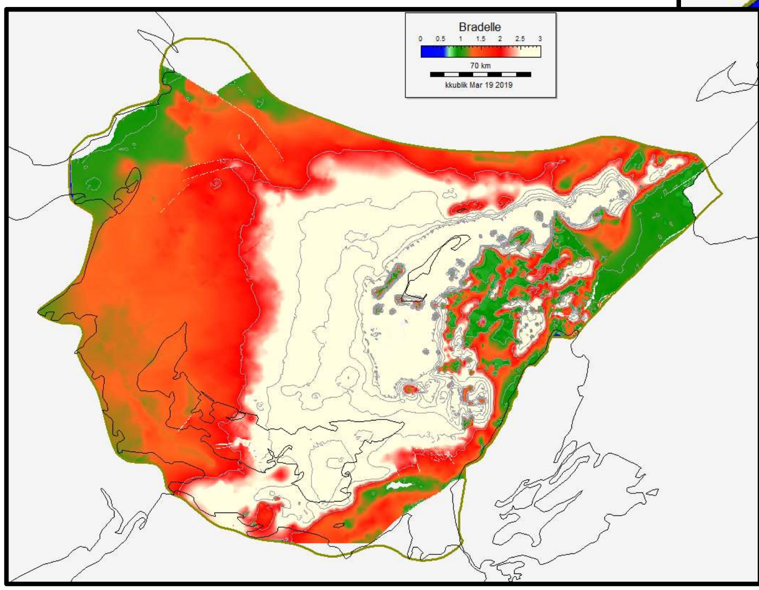
Here’s one final example of an isopach, of the Bradelle Fm and underlying Cumberland Gp.
This was again used to constrain seal COS, and rate of change of thickness constrained stratigraphic trap potential.

Basin modelling

- Trinity software used to model maturity and migration, based on the regional mapping
- Map shows Vitrinite reflectance in Bradelle Fm. source rock
  - Modelled 200 m below top
  - 1.5 km (and 4 km maximum case) of sediment deposited in Permian and eroded in Triassic

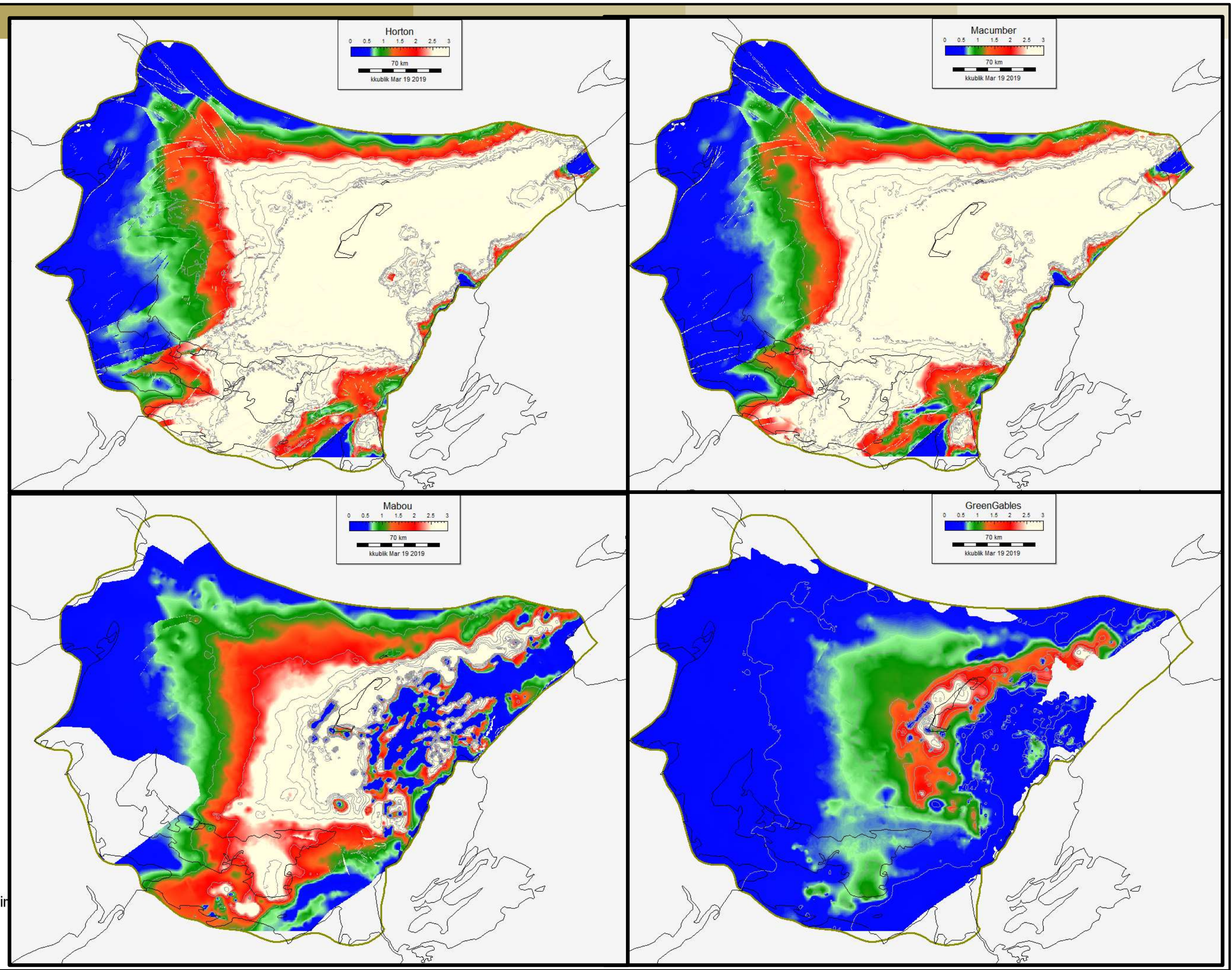




The depth maps were also used to constrain basin modelling of five different potential source rocks.
This example is the Bradelle Fm. Each source was modelled with two variations of Permian sedimentation, that was later eroded.
The scale is vitrinite reflectance, under-mature in blue, mature for oil in green, for gas in red, and overmature in cream.
The base case is 1.5 km of Permian, which results in the Bradelle being undermature on the flanks and just reaching over maturity in the basin core.
Thicker Permian results in maturity everywhere in the basin, and a significant area of over maturity in the basin centre.

Basin modelling

- Maps of Vitrinite Reflectance (maturity) of other possible source rocks in Magdalen Basin
- Basin is generally gas prone
  - Due to both maturity and source rock type
- Some migration scenarios include possibility of oil
  - E.g. if older Mabou gas does not flush Bradelle oil/mix
  - Important consideration for petroleum economics
- Details of models in Open File
  - Initial kerogen inputs from Nova Scotia Department of Energy and Offshore Energy Research Association, 2017
  - Geothermal gradient 25°C/km (*Ryan and Zentilli, 1993*)



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Here are examples of the base case of 1.5 km of Permian, for four more sources, the deep Horton Gp., Macumber – Lower Windsor, Mabou Gp., and the shallowest Green Gables Fm., with the same scale for all models.
The basin is generally gas prone, in both source type and maturity in the core.
But a very interesting conclusion was that in some scenarios, the oil produced from the mixed Bradelle source can survive on the basin flanks, in key prospects, if gas from the weak Mabou source does not flush it.
This is an important consideration for economics.

Play Analysis

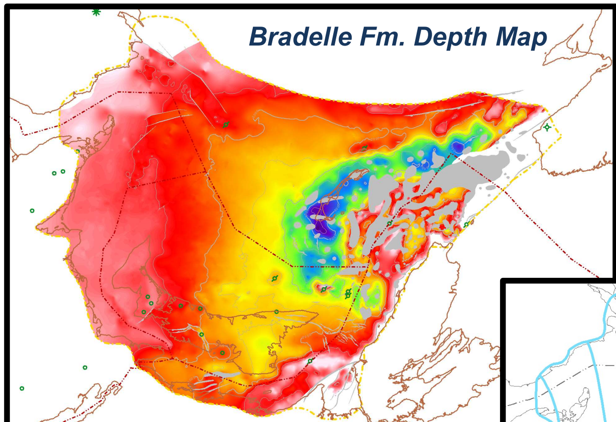
- Regional maps were used to constrain Chance of Success for several petroleum system elements:
  - Depth to reservoirs were used to estimate porosity / reservoir quality
  - Depth to source rocks were used to model maturation
  - Rate of change in isopachs were used to estimate the likelihood of stratigraphic traps
- Regional mapping, basin analysis and geologic inputs from literature outlined the following 7 plays:

	Play	Reservoirs	Trap	Seal	Source	Global Scale Factors	biggest COS challenge(s)
						fields and prospects	general phase risk (likely gas)
1	Pictou structural / salt flank play	Cable Head Fm., unnamed Permian sands	pinch-out against salt walls or overhangs or draped over salt	shales in Naufrage Fm.; low COS in many places where strata above reservoir are thin; Salt for salt flank and overhang traps	Green Gables, also Bradelle and Mabou possible	0.4	seal
			folded by structural inversion, compression, differential compaction	chance of fault breach, especially along anticlinal crests		East Point	
2	Pictou stratigraphic play	Cable Head Fm.	stratigraphic plays (pinch-outs in main basin or channels, shores, etc.)	shales in Naufrage Fm.; low COS in many places where strata above reservoir are thin	Green Gables, also Bradelle and Mabou possible	0.3	trap, seal
				strat play top-seal not affected by trap geometry lateral seal issues in massive			
3	Morien/Cumberland structural / salt flank play	Bradelle Fm.	pinch-out against salt walls or overhangs or draped over salt	Green Gables Fm. Salt for salt flank and overhang traps	Bradelle and possibly Mabou (latter gas prone)	0.8	seal
		Port Hood Fm / Boss Pt Fm	folded by structural inversion, compression, differential compaction	chance of fault breach, especially along anticlinal crests	even deeper sources possible in NW, where salt doesn't impede	Old Harry	Highest potential
4	Morien/Cumberland stratigraphic play	Bradelle Fm.	stratigraphic plays (pinch-outs in main basin or channels, shores, etc.)	Green Gables Fm.	Bradelle and possibly Mabou (latter gas prone)	0.35	seal
		Port Hood Fm. / Boss Pt Fm.		strat play top-seal not affected by trap geometry, better chance of lateral seals	even deeper sources possible in NW, where salt doesn't impede		
5	Windsor Carbonate play	bioherms/reefs - eg: porosity at Gays River	presence of bioherm/reef creates traps - best chance on basin flanks	tight carbonate and evaporites, upper Windsor	Lower Windsor - Macumber Fm everywhere basinward from bioherms/reefs	0.3	reservoir quality, trap (reservoir presence)
		reservoir quality COS is captured under "reservoir"	"trap" is COS of reservoir presence (estimate from Middle Windsor to Base Windsor isopach)		deeper Horton Gp also possible		
6	Sussex play	clastic reservoir potential poorly known	general stratigraphic traps possible	tight carbonate / salt above	Horton Gp. Below	0.2	reservoir quality, trap
		more often a seal (mainly red-beds / anhydrities)	may be enhance by drape over underlying structures	also self sealing	small chance of self sourcing		
		Bradelle well show, Cape Breton sands	not really related to Horton play, no unconventional (fractured shale) play				
7	Horton play	clastics, producing reservoir onshore NB	stratigraphic traps in grabens (unconformity truncation, strat pinchouts)	Sussex shales, intraformational seals	Horton Gp.	0.4	reservoir quality, trap, seal all moderate COS
		braided streams, beach sands - uneven across rifts	also draped into inversion structures	also Windsor Gp. carbonates and evaporites	deeper Paleozoic sources possible in shallow flanks	McCully, Stoney Creek	
		Albert Fm. - Frederick Brook Member thick rich black shale	unconventional fractured lacustrine shale play - economic onshore	self sealing			

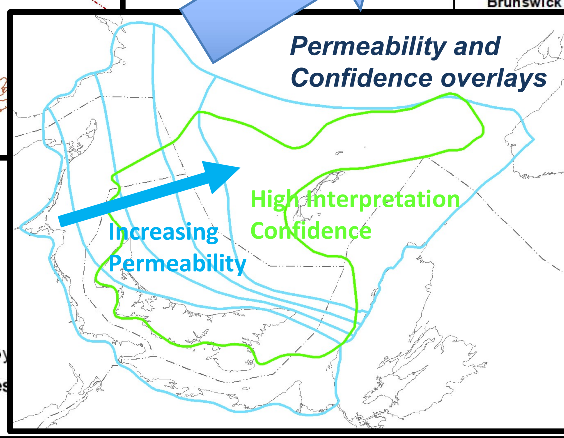
All of these regional maps and basin models were used to define the plays in the basin, and the chance of success of the reservoirs, traps, seal, and source in each play.
Seven plays were defined within the Magdalen Basin itself, and also two deeper plays on the basin flanks.
We'll use the highest potential play – the structural / salt flank play within the Morien / Cumberland Groups – as an example of this COS process.

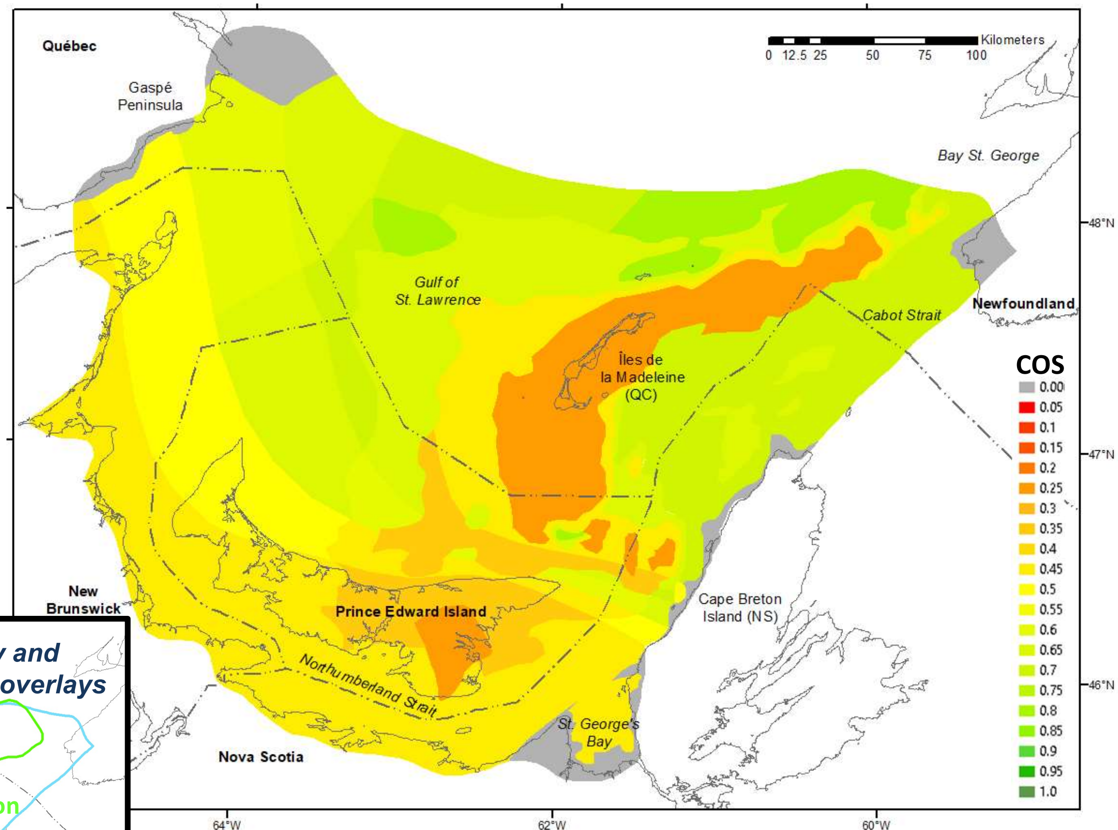
Morien Cumberland Structural Play – Reservoir COS

- Reservoirs: Bradelle Fm. (Morien Gp), Port Hood and Boss Point Fm. (Cumberland Gp.)
- COS based on top of package
  - Deeper = lower COS
- Permeability decreases to SW
  - Overlay map of general trend, decrease COS to SW
- Lower confidence areas kept closer to coin toss



Combine into polygons for Reservoir COS





The reservoir COS for this play was first defined based on the depth of the Bradelle Fm at the top of this package. For example where the reservoir package was at 0 to 2000 m, COS was judged to be 80%, 2000-3000 m is 65% and so on…

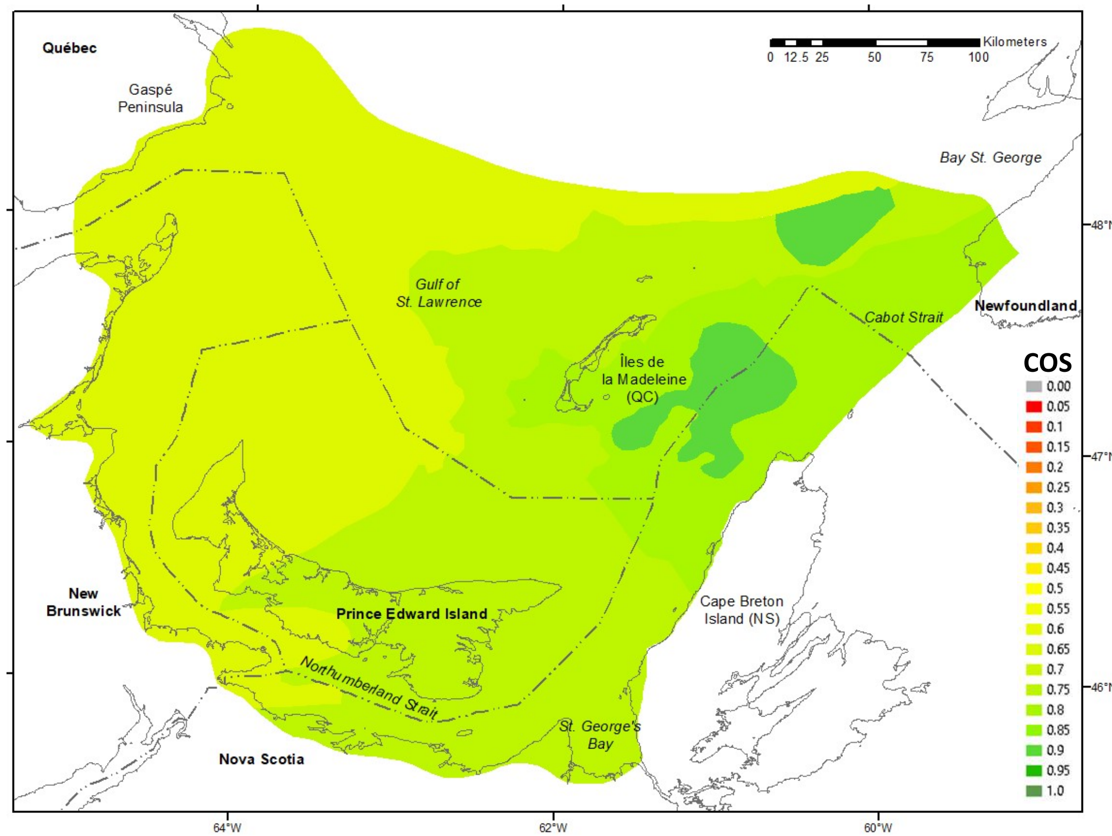
Then the confidence of the mapping was overlain on this depth map – high confidence is outline here in green – and for example, where confidence was low that same shallow depth range was lowered to 70% because of lack of confidence.

Finally, the permeability trend observed in wells and outcrop, shown in blue, was overlain on these COS polys – permeablity is best in the NE part of the basin, and decreases to the SW. COS in the shallow depths ranged from the 80%, down to 40% in the least favourable areas.

Thus, our final reservoir map shows good COS on the flanks in the NE, ranging to poor COS in the deep basin and the SW flanks due to poor permeability.

Morien Cumberland Structural Play – Trap COS

- Trap types:
  - Salt province – pinch-out against salt walls, diapirs or overhangs
    - More challenging to image, many traps likely
    - Large structures may not be tested by one failure – multiple culminations or fault seal possible
  - Salt cored anticlines
  - Other significant anticlines (compression / inversion)
  - Where little or no salt, smaller traps rely on small drapes or inversions, differential compaction
- Polygons drawn freehand around each structural region
  - Best trap COS in areas of good structure and high quality data, around best salt walls
    - High end of Medium Confidence, 85%
  - Very good COS in salt flank area, traps against walls, diapirs and overhangs, 80%
  - Good COS in salt cored anticlines and other anticlines, 75%
  - OK COS in areas with little to no salt, smaller subtler traps, 60%



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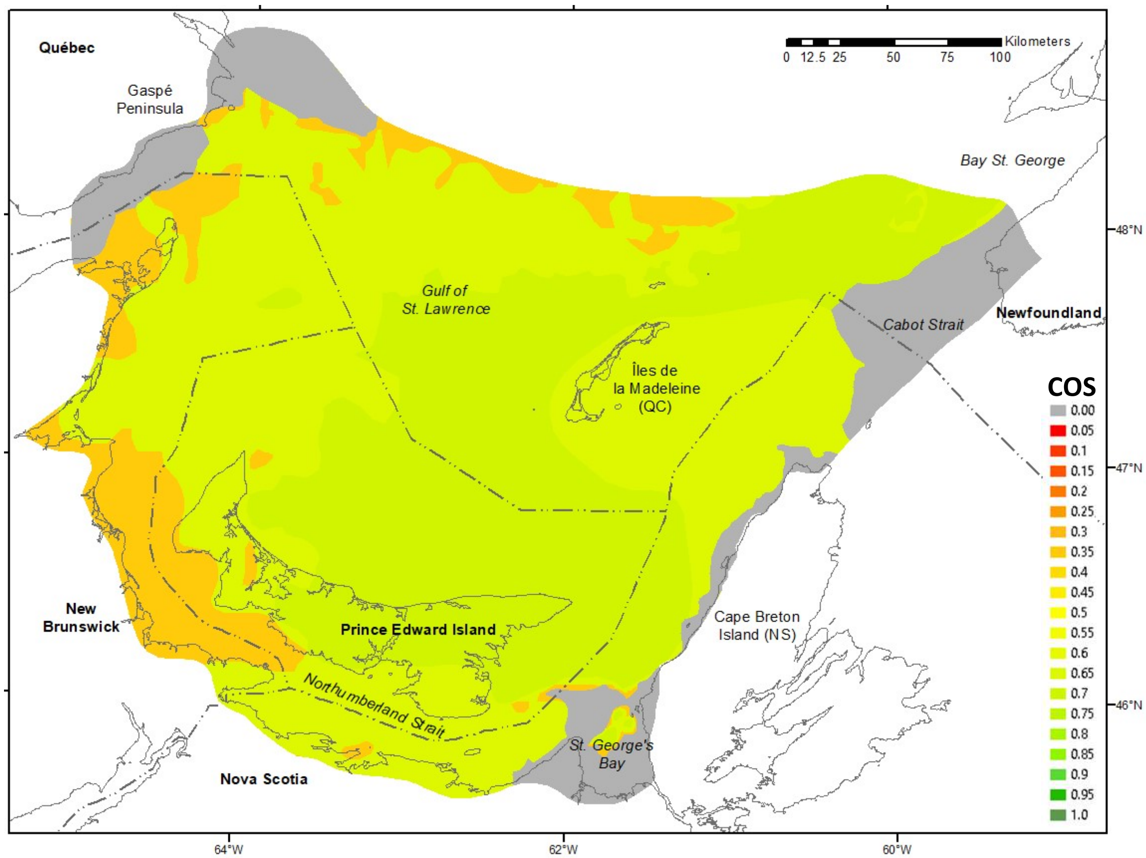
The areas favourable for various trap types where outlined freehand from our regional mapping. The best trap COS, at a favourable 85%, is in areas of significant structure around salt walls, in areas of high quality data and thus high confidence. Salt cored anticlines and other significant anticlines on the basin flanks were judged to have COS of 75%, and areas with little salt but still drape and inversion structures are 60%. There are good opportunities for structural traps in general, although more and better data would be needed to refine them.

Morien Cumberland Structural Play – Seal COS

- Green Gables Fm. (shale dominated) provides main seal above Bradelle Fm. (Morien Group)
  - Green Gables isopach used to draw seal COS polygons
  - Some aspects of seal, along salt flanks and anticlinal crests, are inverse to trap COS
    - Lowest seal COS with highest trap presence COS
- Seal risk from faults
  - E.g. Old Harry faults well imaged, Brion Island failure attributed to fault breach
  - Risk on salt flanks mitigated by increased seal from salt
- Intraformational seals in Morien and Cumberland Groups



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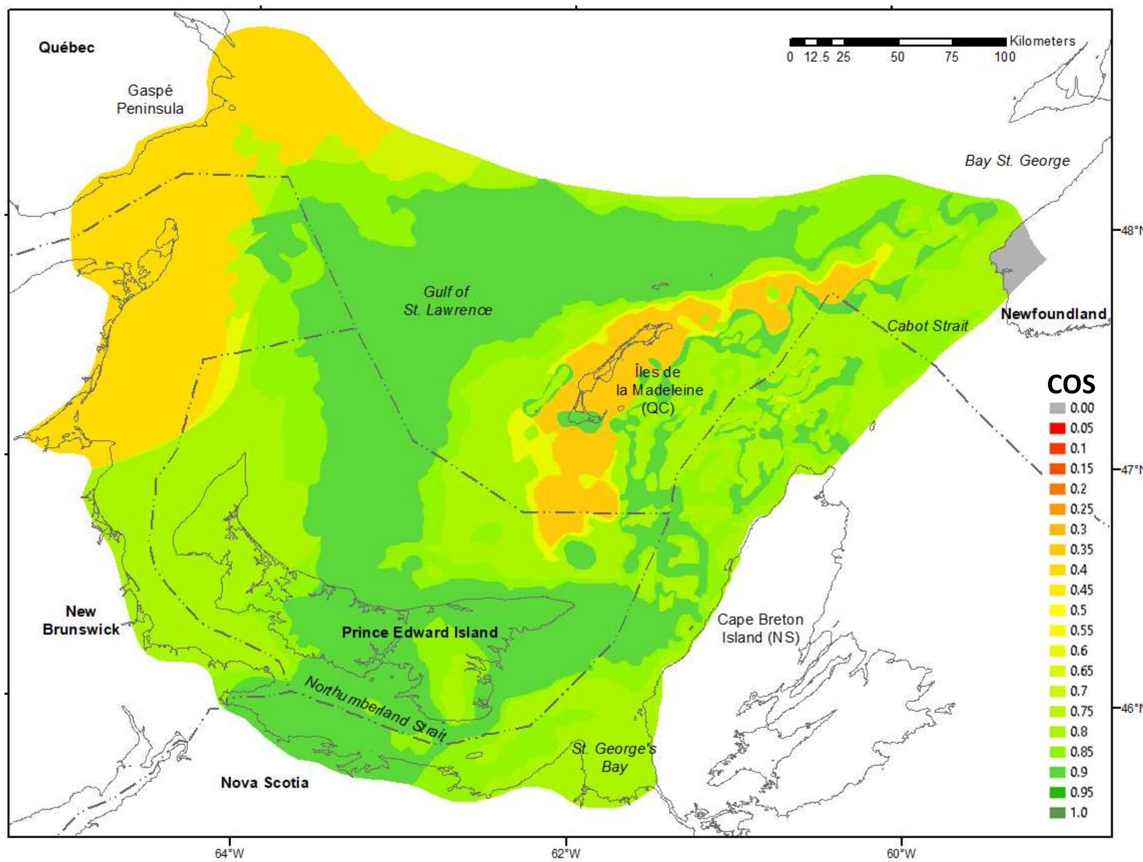
For this play, the Seal COS was calculated based on the isopach maps of the overlying shaley Green Gables Fm.
For example, where it is greater than 400 m thick, Seal COS is 70%, getting less on the basin flanks where it is thinner.
There is some seal risk from faults in some structures.

Morien Cumberland Structural Play – Source COS

- Bradelle Fm. coals and shales
  - Main source, wide spread
  - Mixed source modelled
- Mabou Gp. shales
  - Much less reliable for presence
  - Sometimes red vs. grey/organic rich
- Polygons based on maturity maps from Trinity models
  - For each source rock
- Combined chance using P(Bradelle and/or Mabou) math for final Source COS
  - Input from deeper sources only likely in NW where salt doesn't impede migration
  - Not included in already complex source layer
- Evidence for Source in Brion Island
  - Short migration path
- Phase not explicitly tracked in Qualitative Map
  - Modelling suggests that if Mabou not present or contributing, may help preserve oil from Bradelle source



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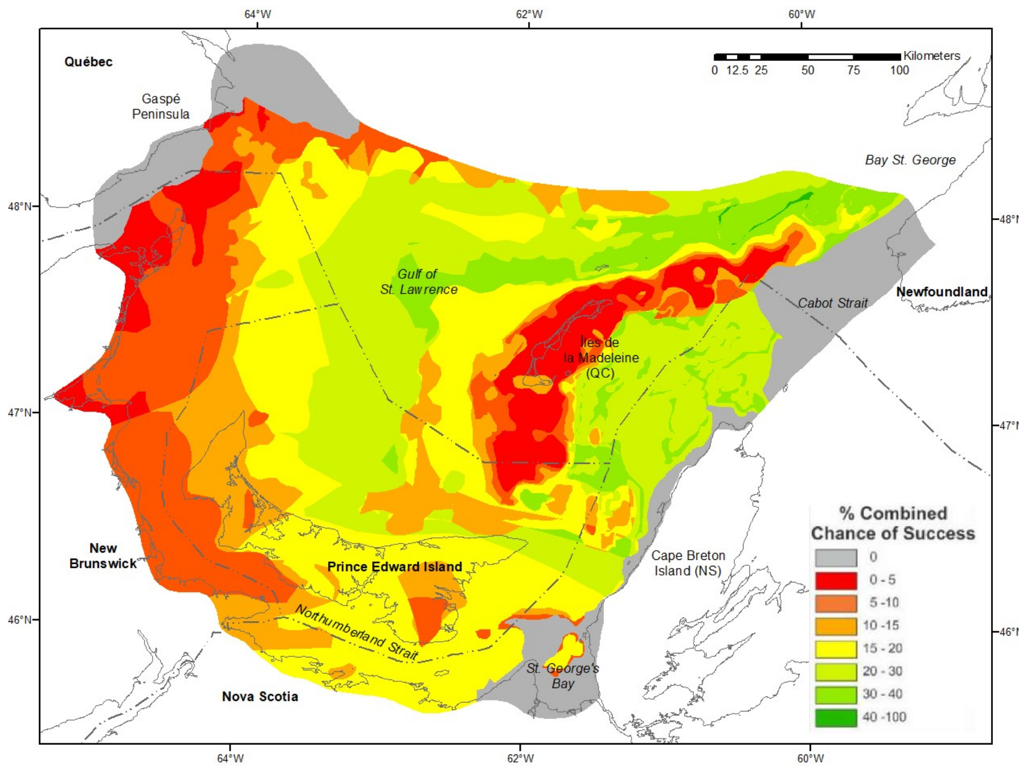
Finally, the Source COS is based on a combination of the Bradelle Fm source and the Mabou Group source. The judged COS for each source are statistically combined.

The Bradelle is a better source than the Mabou, and is judged to have a much better COS in general.

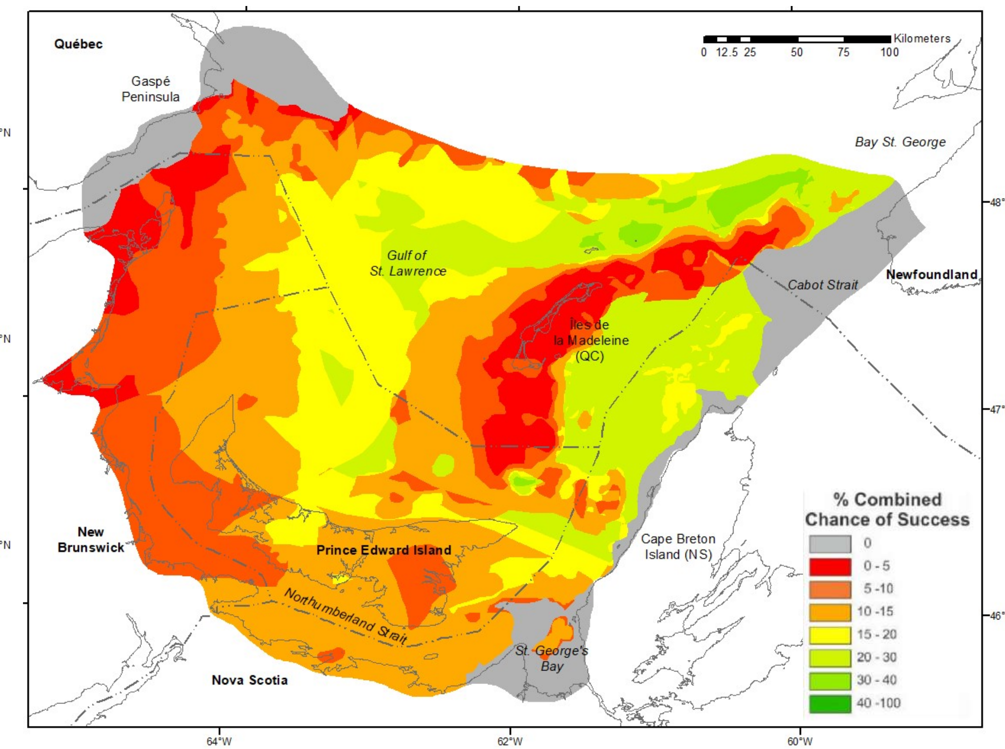
Source COS is best where Vitronite reflectance is 0.6 to 2.5, mature for oil or gas, and is less in the basin centre where it is overmature, and the basin flanks where is it is undermature, though migration to the flanks is possible.

Morien Cumberland Structural Play – Combined COS

- Four petroleum system elements are multiplied together to create the Combined COS map (CCOS)



- Play is scaled for global volume impact (Global Scale Factor) to create Technical Combined COS map (TCCOS)
  - GSF of 0.8 – one very large prospect, but rest only moderate
  - final map for Play



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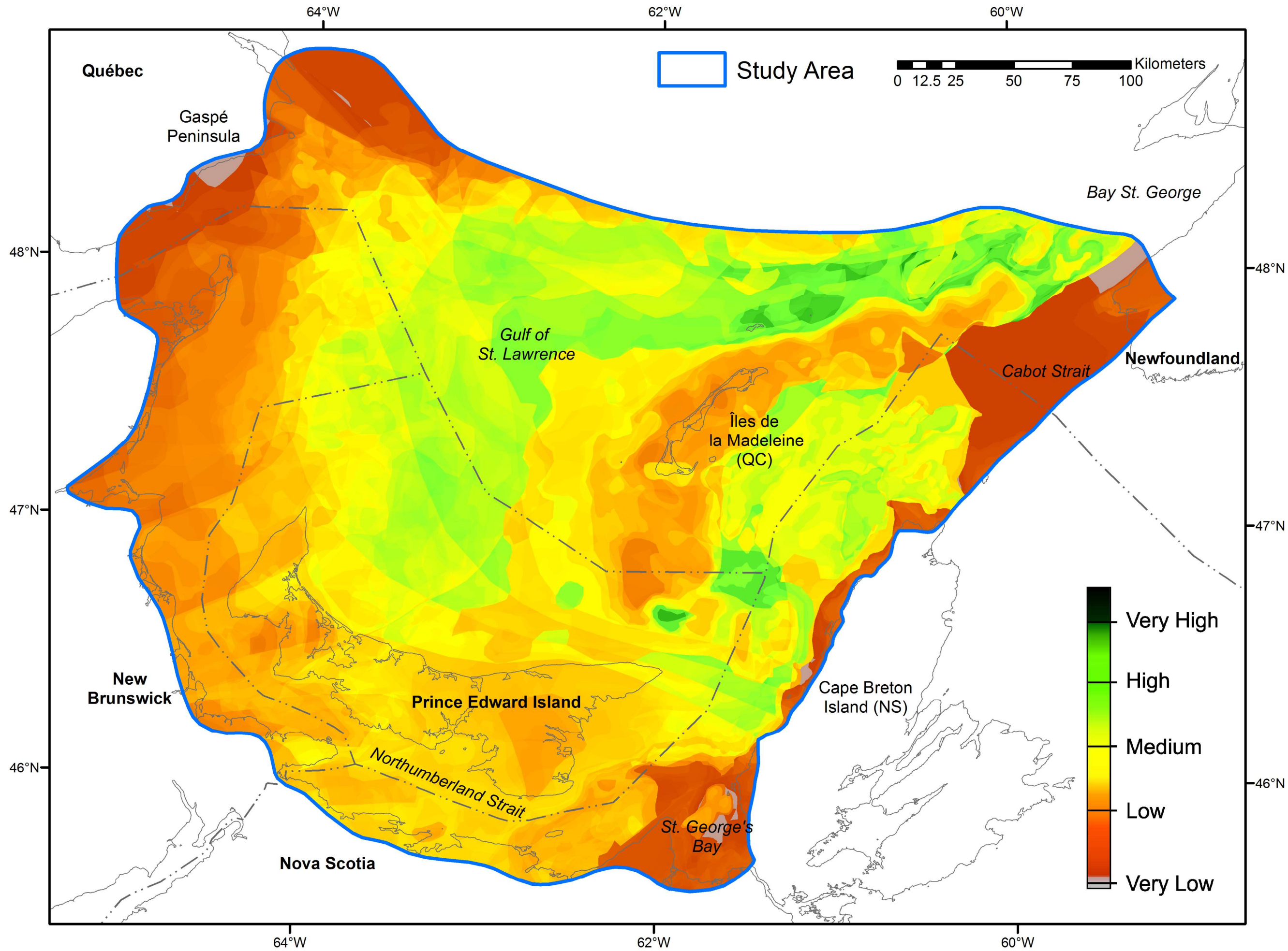
The four petroleum elements are multiplied together to create the combined COS map, on the left.
This play has one very good prospect, but other prospects are smaller, so our ‘global scaling factor’ for this play was 0.8
The final scaled map for the play is on the right, and this map is added to similar maps from all the other plays, to get the final result.

Magdalen Basin Petroleum Potential

- All seven Plays mapped, COS analysed, scaled and summed
- In the Gulf of St. Lawrence, regional petroleum potential is moderate to high
  - Strive for consistent Play scaling, leads to consistent Qualitative scale nation wide
- Best potential:
  - North of Îles de la Madeleine
  - Southeast of Îles de la Madeleine and northwest of Cape Breton
  - Beneath Îles de la Madeleine is too deep
- Map shows oil vs. gas potential combined
  - Higher chance of gas, but oil is possible
  - Phase will have a significant impact on economics
- Map does not illustrate individual targets, rather regions where geologic conditions increase/decrease potential



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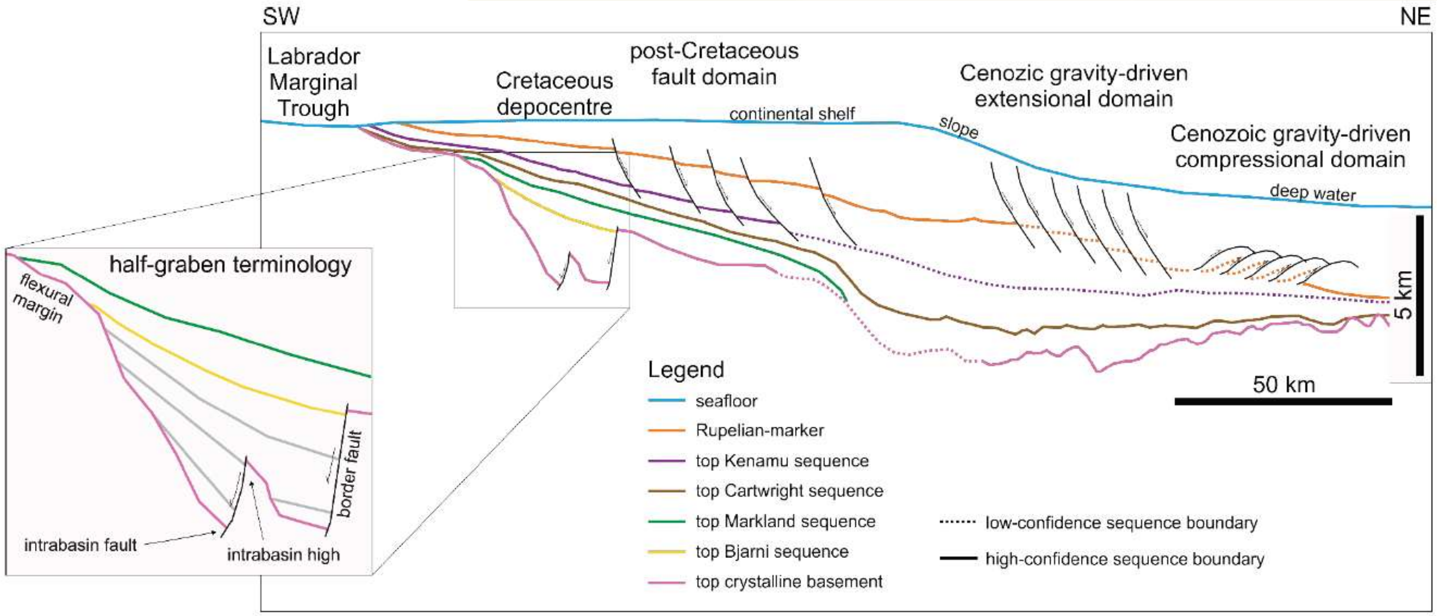
Here is the final result for the Magdalen Basin, summing all seven plays mapped in the basin itself and two deeper plays.
Petroleum Potential is moderate to high, with the best potential along the north flank of the basin, where the Old Harry prospect is located, and between Îles de la Madeleine and Cape Breton, in the salt province.
Right under Îles de la Madeleine is too deep to have good potential.
It is important to note that these maps combine oil and gas potential. In this basin, gas is more likely but oil is possible, as shown in our basin modelling. Obviously, phase will have a significant impact on economics, and it is considered if we proceed to quantitative analysis.
Also, the different shades on the maps don't illustrate individual targets, rather regions where the geologic conditions increase or decrease petroleum potential.

Other Atlantic projects: Labrador

- Major mapping project off the coast of Labrador
  - *Carey et al., 2020. Open File 8535*
- Schematic cross-section through southern Hopedale Basin illustrates horizons mapped and major features analysed
- Table of Plays

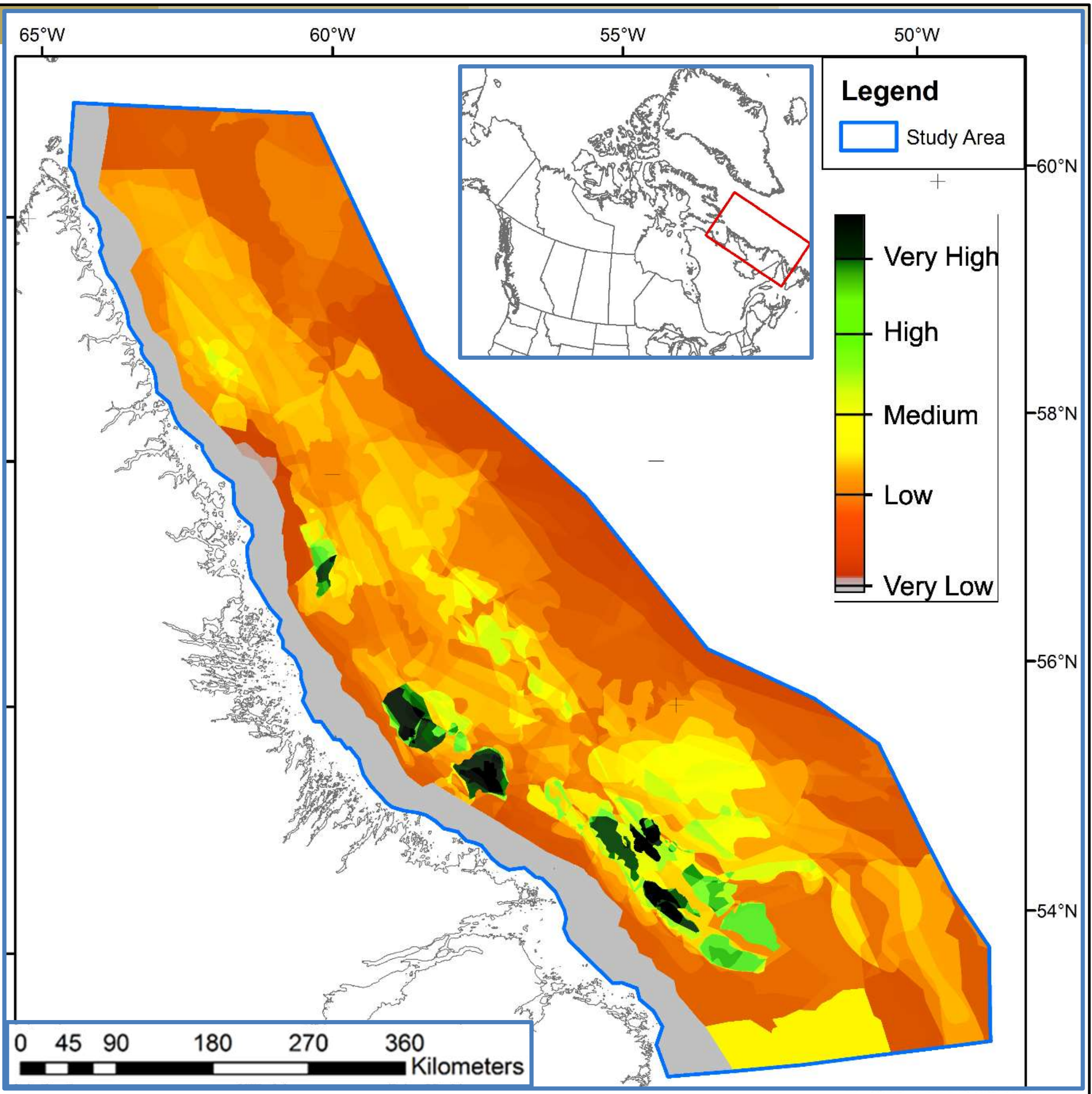


Play	Reservoir	Trap	Source	Seal	Major Risk	GSF region	GSF value
Paleozoic	Paleozoic	Paleozoic	Paleozoic Bjarni	Markland	source or reservoir	Shelf Slope Hyper-extended crust	0.65 0.35 0.2
Bjarni	Bjarni	Bjarni	Bjarni	Markland	reservoir, maturity in shallow half-grabens	Saglek basin Northern Hopedale basin Southern Hopedale basin Slope and deep water	0.35 0.85 0.75 0.2
Markland	Freydis	Markland	Bjarni Markland	Markland (Kenamu at Ogmund well)	migration, reservoir	Entire study area	0.35
Cartwright	Cartwright	Cartwright	Cartwright Markland Bjarni	Kenamu	migration	North region Central region South region	0.6 0.55 0.65
Kenamu	Kenamu	Kenamu	Cartwright Kenamu	Kenamu/Mokami	maturity, trap	North region Central region South region	0.55 0.45 0.65
Mokami	Mokami	Mokami	Cartwright Kenamu	Mokami	maturity, migration	Continental shelf Slope and deep water	0.45 0.55

Briefly, lets look at some other projects we've done in Atlantic Canada.
Another major regional study was conducted in the Labrador Sea. Here are some cross sections in the Hopedale Basin, showing regional horizons mapped and some traps styles.
Six major plays were outlined and analysed similarly to the example shown in the Gulf.

Labrador Qualitative Petroleum Potential

- Detailed database and mapping allowed this map to be very detailed
- The best regional petroleum potential is VERY high
- Again, map shows oil vs. gas potential combined
  - Gas prone basin
  - Phase has a significant impact on economics
- Map does not illustrate individual targets, rather regions where geologic conditions increase/decrease potential



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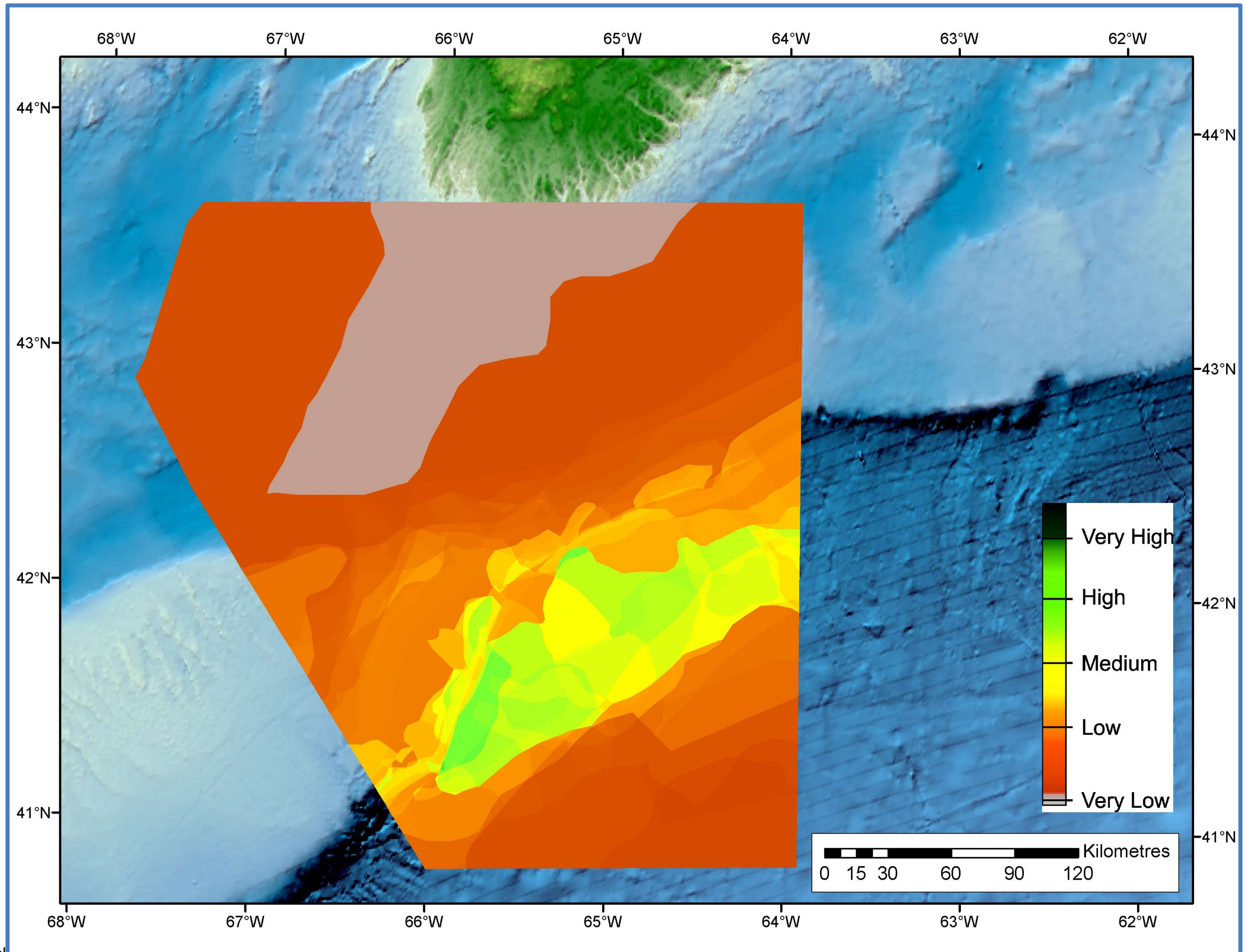
The detailed seismic database and mapping effort allowed this map to be very precise and detailed.
The best regional petroleum potential is VERY high – dark green on our scale.
Again, the map shows oil and gas potential combined, and this is a gas prone basin.

Fundian Channel Petroleum Potential

- Fundian Channel – Brown's Bank area
  - Southwestern end of Scotian Shelf
  - Based on mapping published by the Nova Scotia Dept. of Natural Resources (*Beicip-Franlab, 2015*).
- Quantitative analysis was also undertaken in this area
  - Economics by Energy Sector, Natural Resources Canada
- Open file on this analysis is in preparation
- The best regional petroleum potential is moderate to high
  - In salt province on slope
- Map shows oil vs. gas potential combined
  - Phase is uncertain, other parts of the Scotian Shelf are gas prone
  - Will have a significant impact on economics



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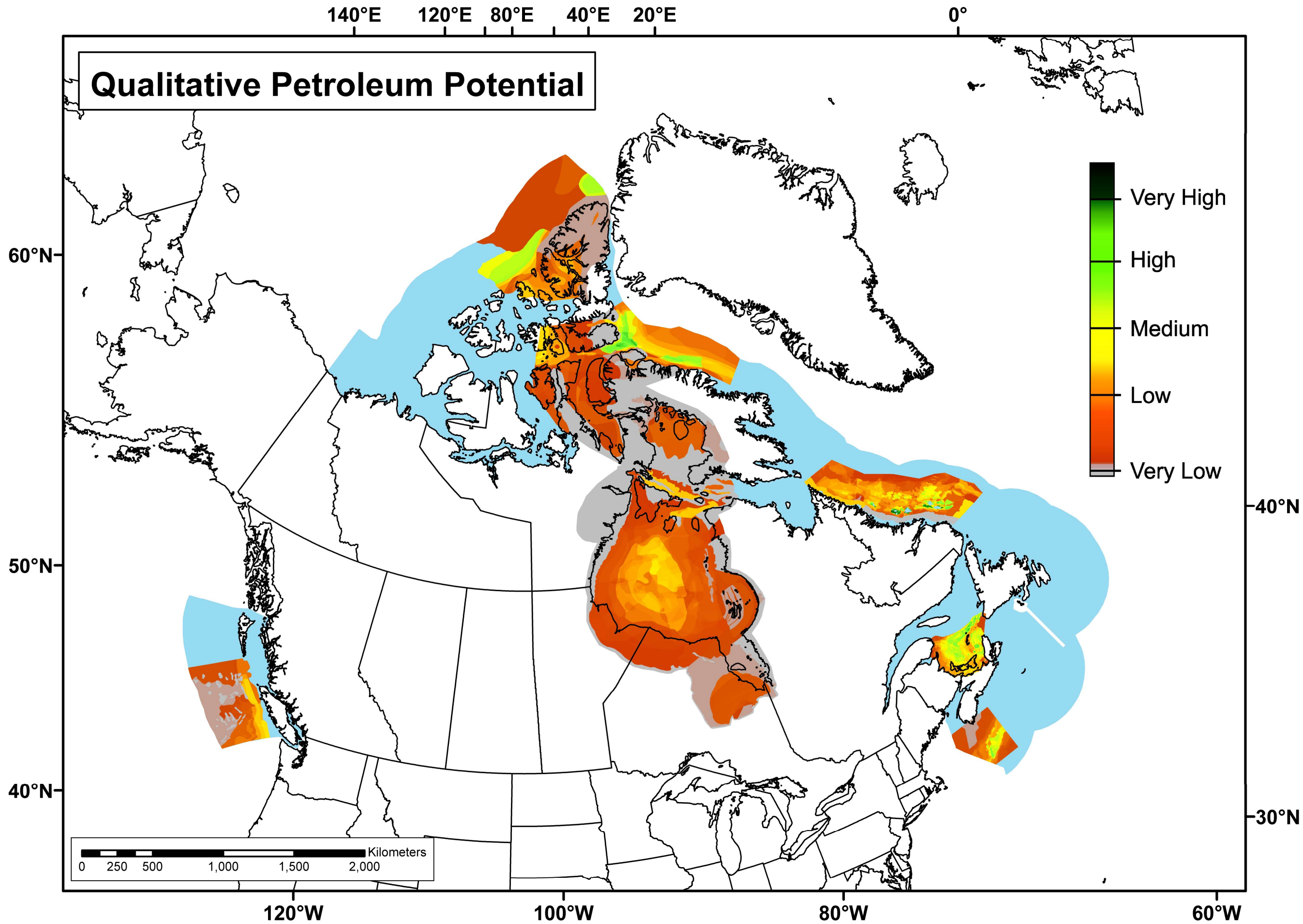
And here is a final example from the SW Scotian Shelf, adjacent to the US border, in the area of the Fundian Channel.
This qualitative map was based on the mapping of others, as published by the Nova Scotia Dept. of Natural Resources. Our COS estimates were reviewed by the CNSOPB geoscientists.
We are also working on quantitative analysis in this region, and economics with NRCAN's Energy Sector.
The best regional petroleum potential is moderate to high, in the salt province on the slope. Phase here is uncertain.

Conclusions

- A consistent Qualitative Petroleum Potential mapping process has been developed
  - Based on Play Analysis (CRS mapping)
  - Consistent scale nation-wide
  - Supports land-use decisions, with emphasis on where the best potential is located
  - Regional studies have covered about half of Canada's marine areas
- Quantitative analyses build on the qualitative work in some areas
  - Where economics are needed for decisions
- Regional maps and isopachs useful beyond petroleum, for stratigraphic, structural, and basin analysis, e.g. in Gulf:
  - No evidence of older Appalachian structures controlling Magdalen Basin geometry
  - Some early Horton graben geometries map consistent with trans-tensional basin concept
  - Basin over mature in core, mature on flanks, preservation of oil possible
- Compiled databases are valuable assets, especially seismic



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In conclusion, the GSC has developed a consistent Qualitative Petroleum Potential mapping process, based on play analysis.
We have developed a consistent scale nation-wide.
These results support land-use decisions, illustrating for stakeholders WHERE the best potential is likely to be located.
Regional studies have covered about half of Canada's marine areas, and all of our published maps to date are shown here.
We build on these qualitative maps to make quantitative analyses where warranted, and economics are needed for decisions.
In addition, the regional maps and isopachs from these studies are useful beyond petroleum analysis, for stratigraphic, structural and basin analysis.
Compiled databases are valuable assets for further study.

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This presentation will be available in GeoScan

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Thanks!

Questions?

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Questions?

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