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Regional mapping and qualitative petroleum resource assessment of the Magdalen Basin, Gulf of St. Lawrence;

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

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Canada

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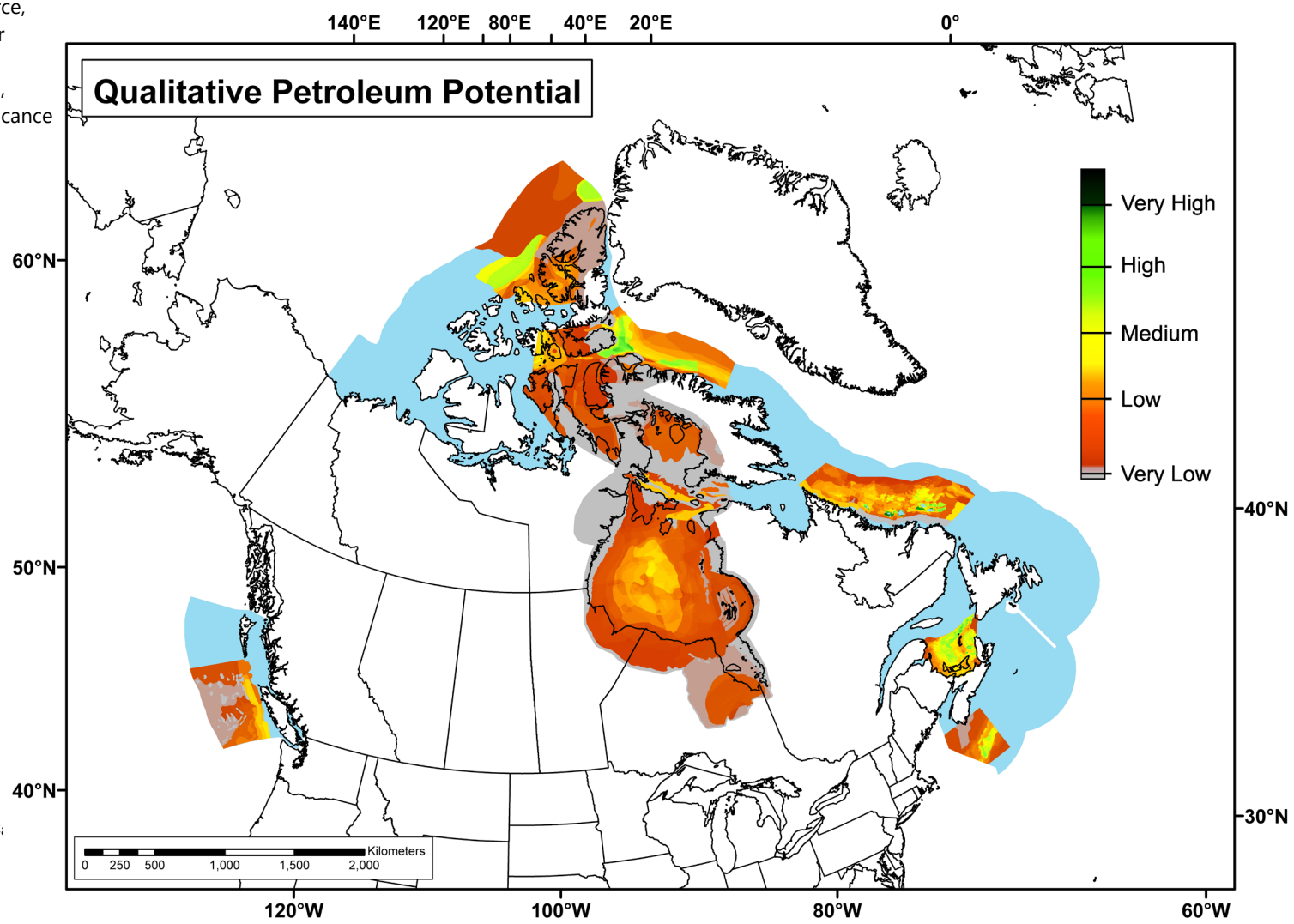
Marine Conservation Targets initiative

- Goal to protect 10% of marine area by 2020, 25% by 2025, and 30% by 2030
- GSC tasked with petroleum resource assessments in regions under consideration
  - Other resources also noted
- Given short timelines and importance of <u>where</u> 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
  - Sums all plays in a region, after weighting for significance
  - Lister et al., 2018



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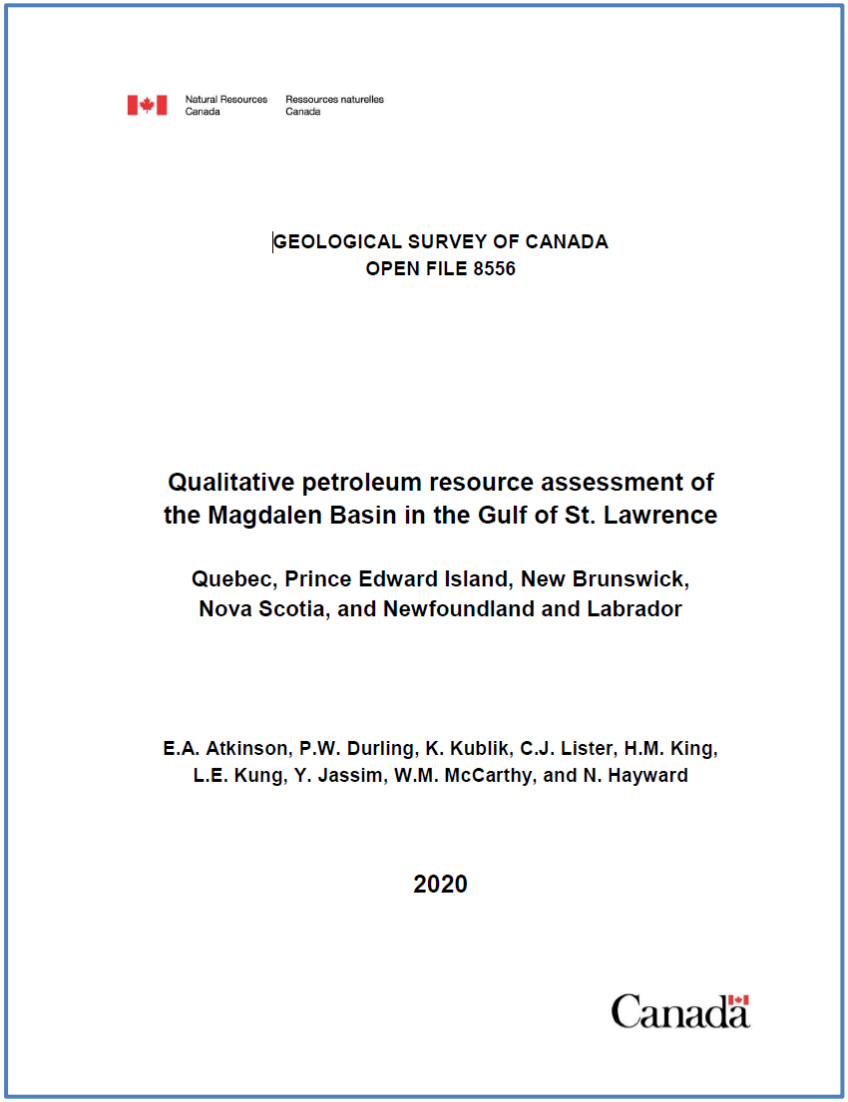
Magdalen Basin regional study

- **As part of this initiative, the GSC conducted a broad regional study of the geology and petroleum potential in the Magdalen Basin**
  - 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 8556**:
  - Atkinson, E.A., Durling, P.W., Kublik, K., Lister, C.J., King, H.M., Kung, L.E., Jassim, Y., McCarthy, W.M., and Hayward, N., 2020. 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; Geological Survey of Canada, Open File 8556, 109 p. https://doi.org/10.4095/321856
- The work presented here is a **full team effort**!
  - Several team members are now pursuing other roles
    - Delay in presenting these results due to Covid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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

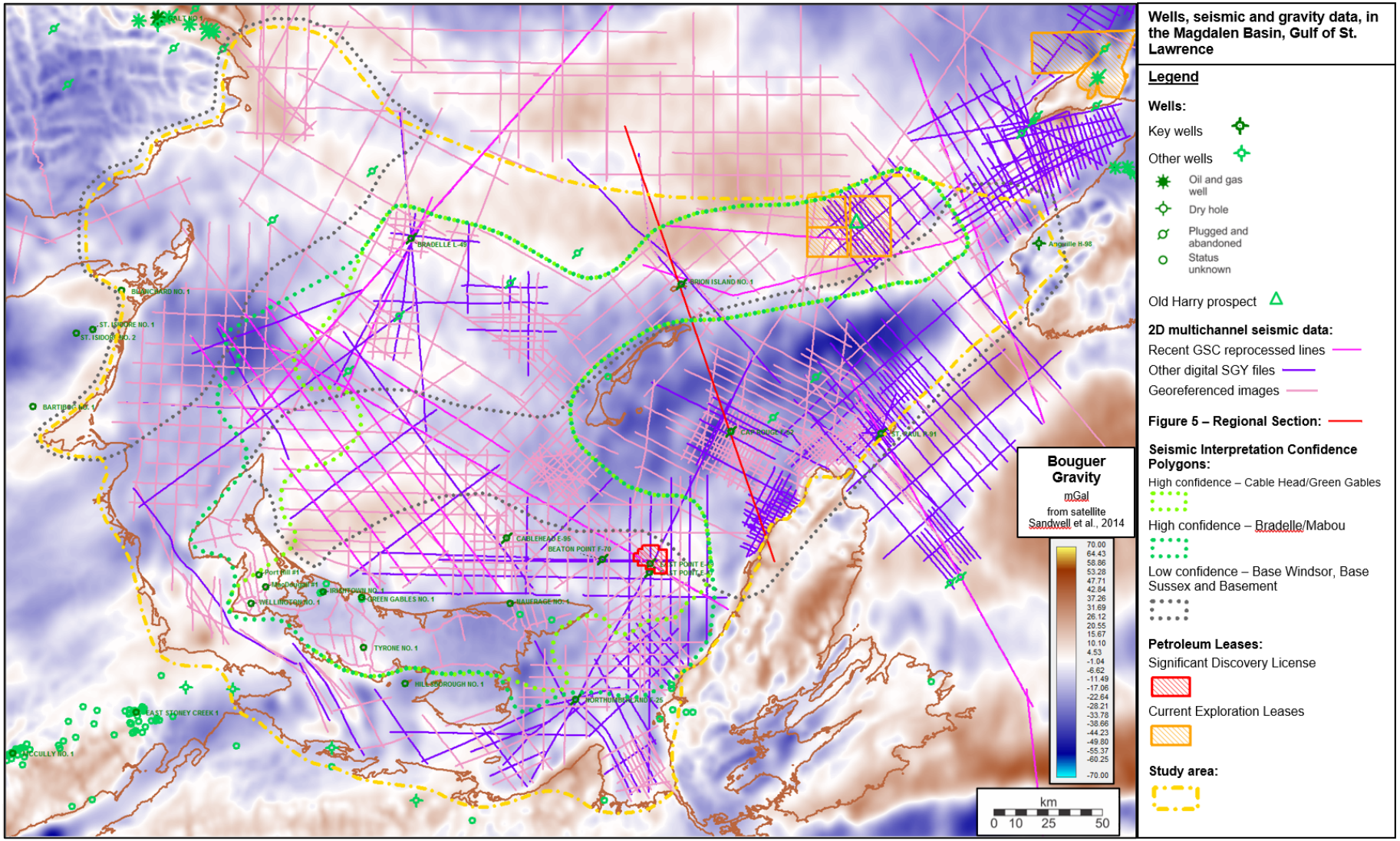
E.A. Atkinson, P.W. Durling, K. Kublik, C.J. Lister, H.M. King, L.E. Kung, Y. Jassim, W.M. McCarthy, and N. Hayward

2020

Canada

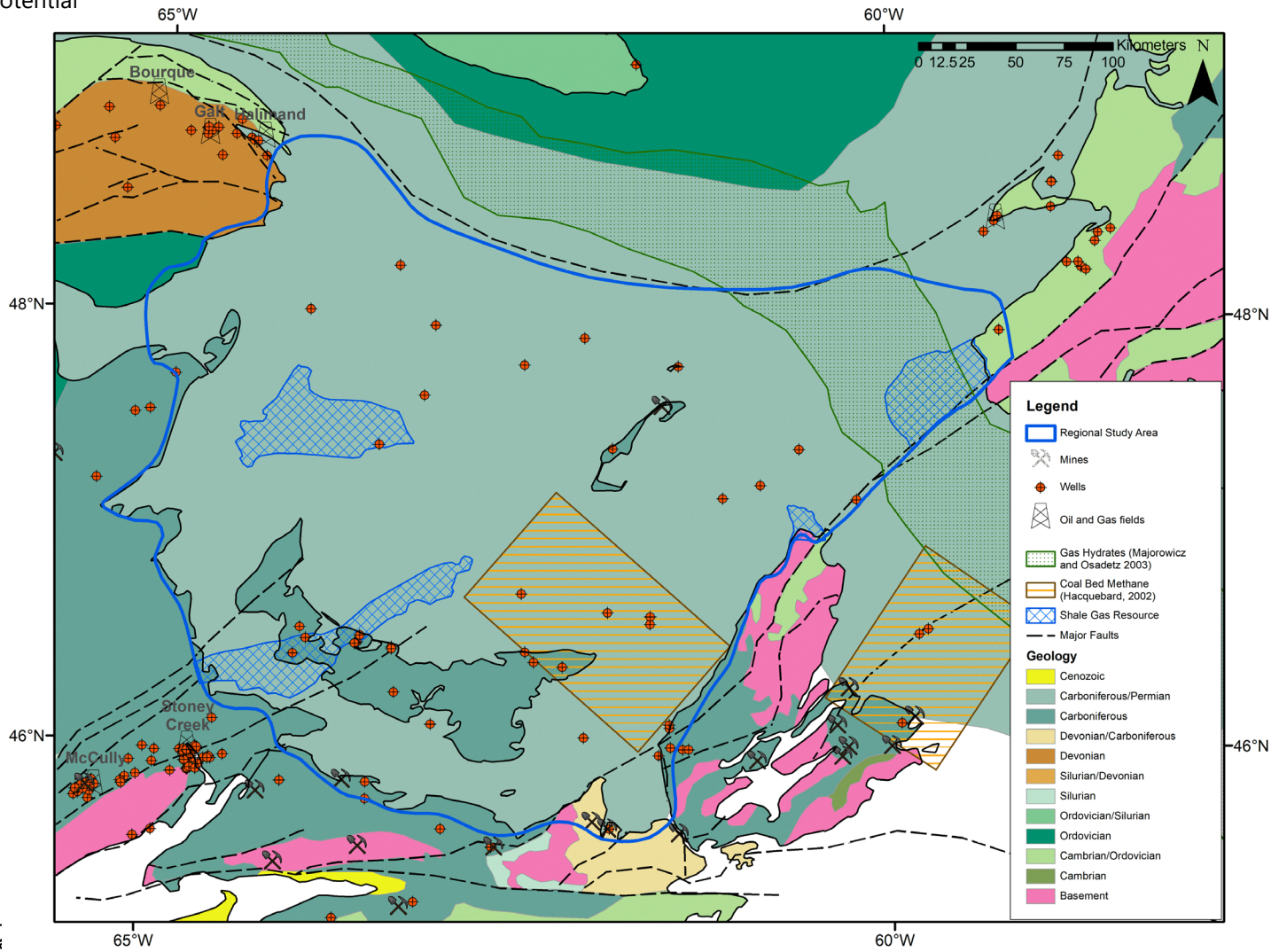
Magdalen Basin database assembly

- **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



Magdalen Basin database assembly

- **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, 1993; 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, 1986; Waldron et al., 2015
  - Unconventional petroleum potential
  - Mines
- **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
- **Consultation with GSC scientists**

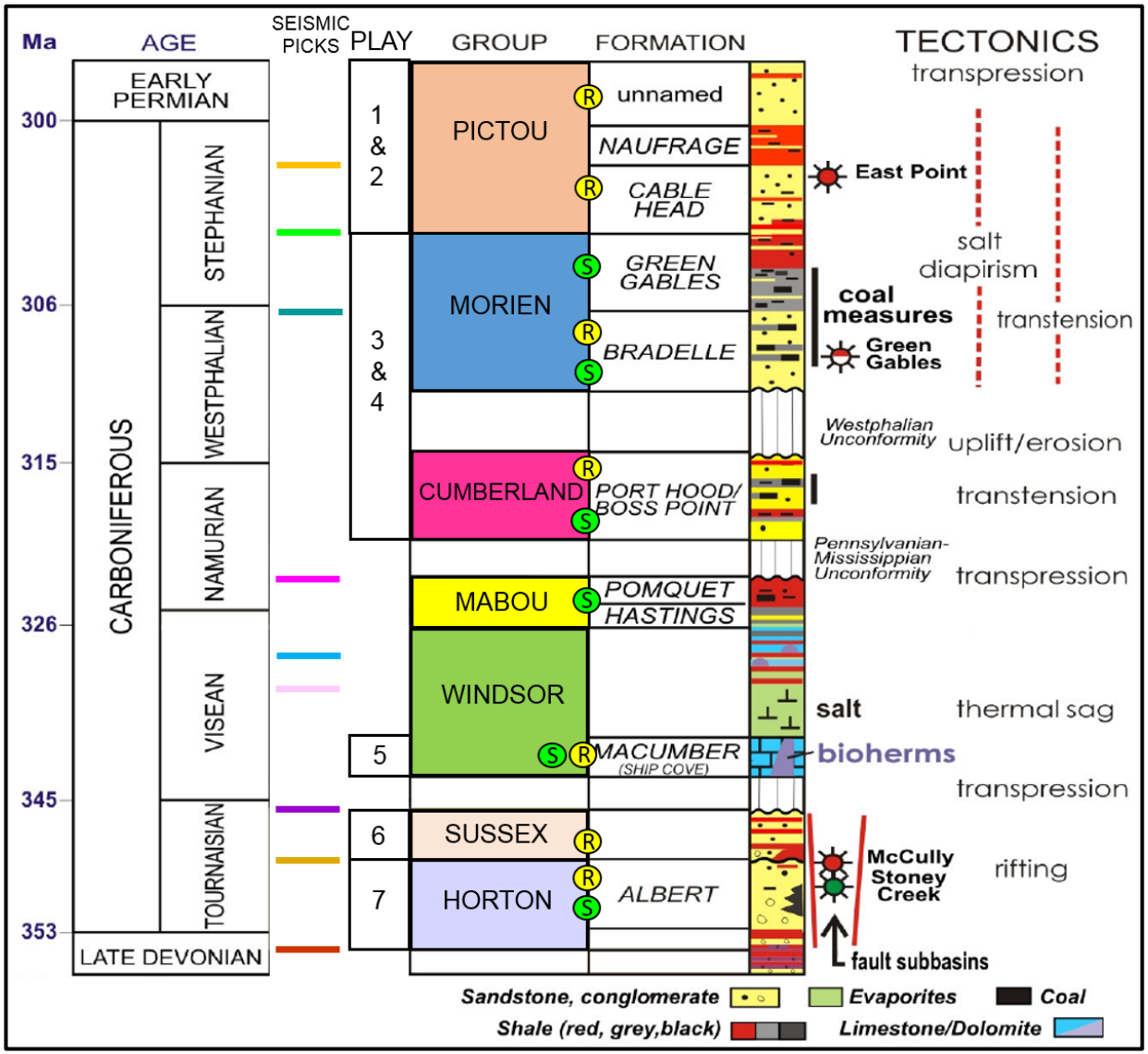


Lithostratigraphy of the Magdalen Basin

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

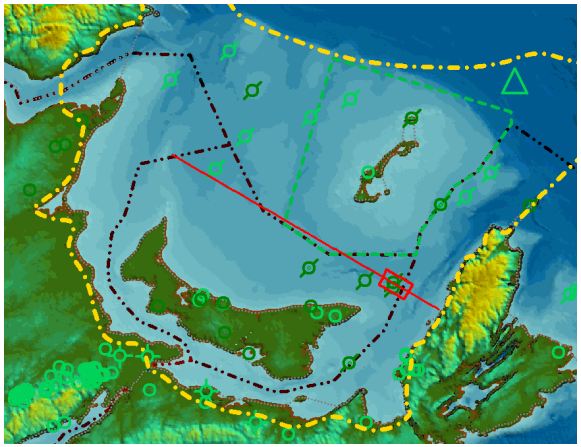
Source rocks
Reservoirs
gas field / discovery
oil field
gas show

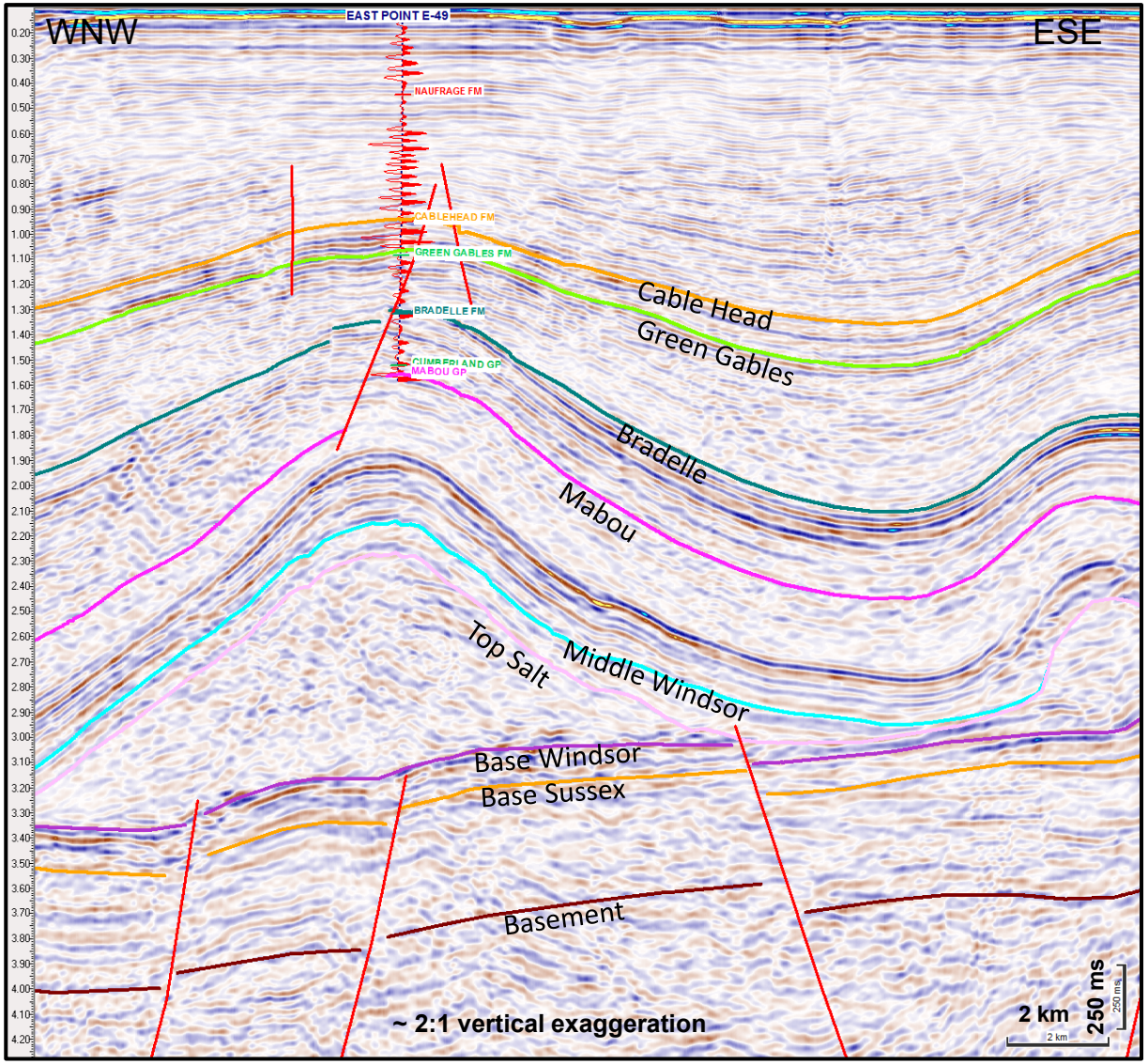
- Seismic horizons mapped and illustrated on regional cross section and seismic examples are shown in with coloured markers ("seismic picks"):
  - Cable Head Formation
  - Green Gables Formation
  - Bradelle Formation
  - Mabou Group
  - Middle Windsor Group
  - Top Salt
  - Base Windsor Group Unconformity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



Well correlation and Seismic character

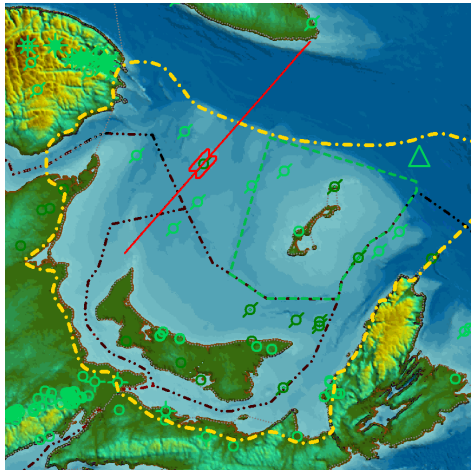
- **Synthetics** were **constructed** for key wells with logs
  - Example from East Point E-49
  - Tie to Lithoprobe Line 86-1, illustrating recent reprocessing (Hall et al., 2019)
- **Tops from literature** (Giles and Utting, 1999, 2001, 2003; Rehill, 1996) were used for well ties
- Example of **seismic 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**

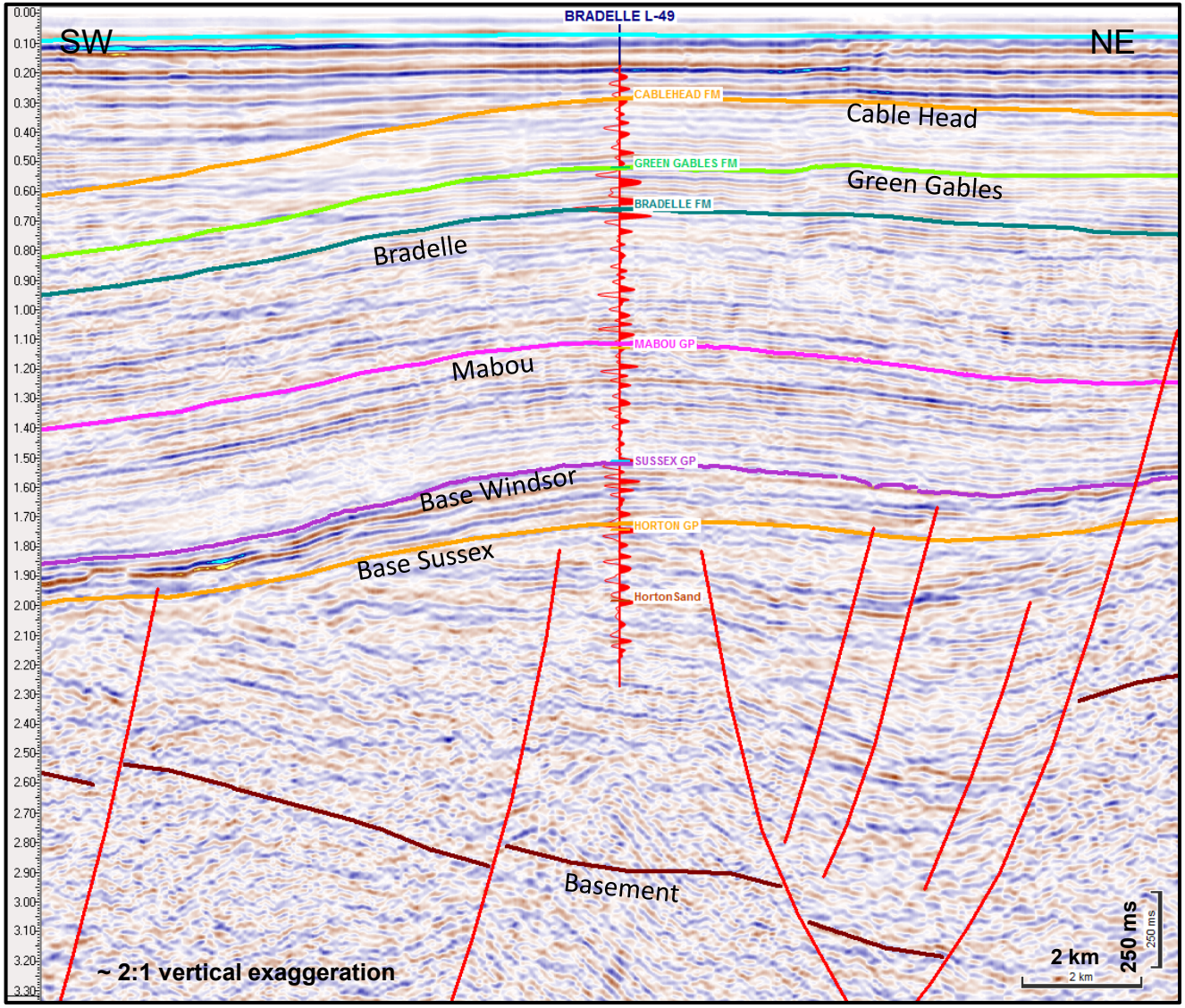




Well correlation and Seismic character

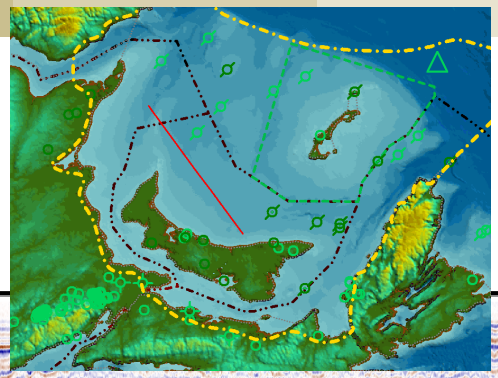
- Second example of **seismic character,** particularly Sussex and Horton Groups
  - Bradelle L-49
  - Tie to Lithoprobe Line 86-2, illustrating recent reprocessing (Hall et al., 2019)
- Seismic character (reflective and non-reflective packages) can be followed regionally
  - Consistent lateral changes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

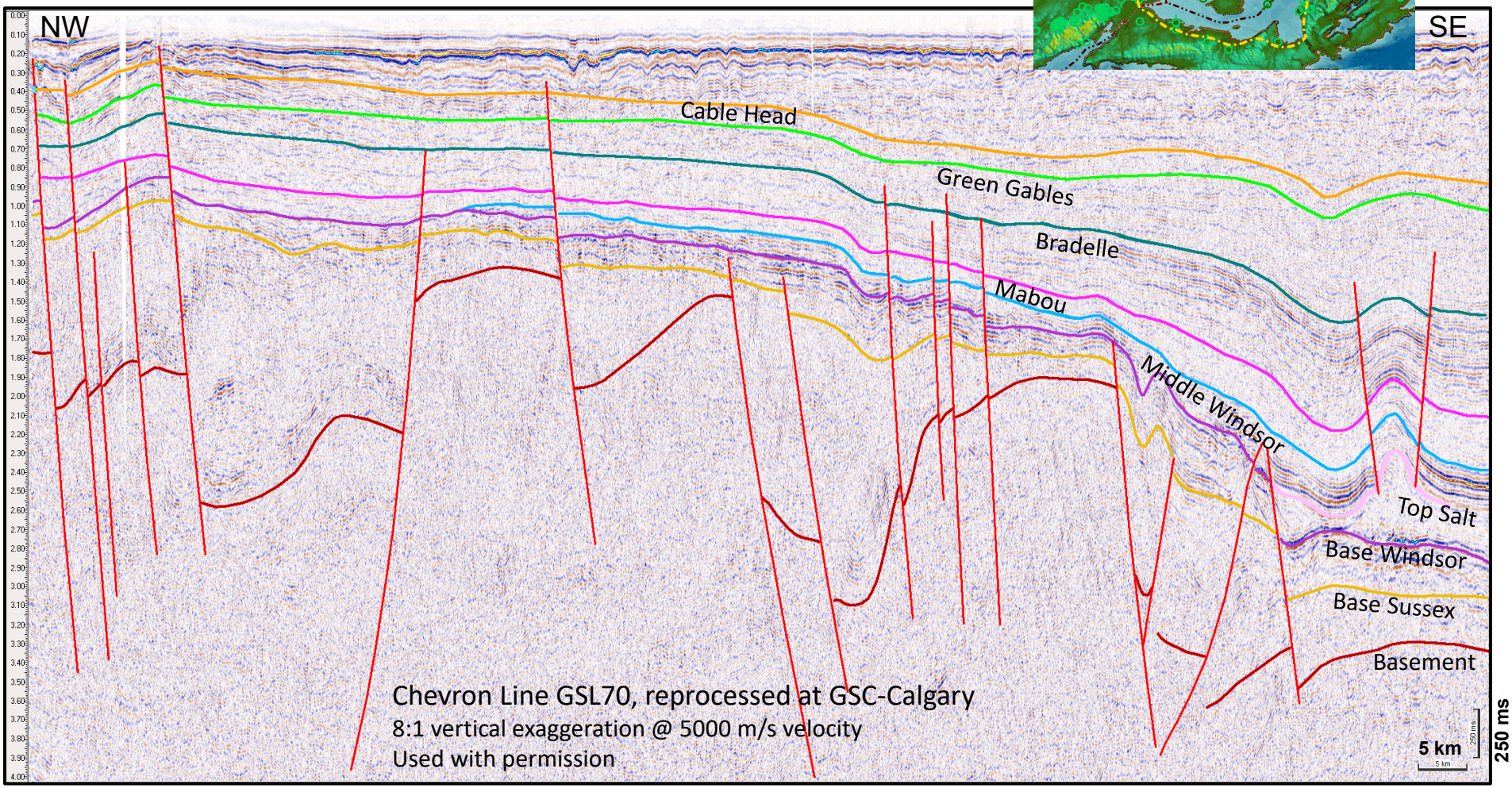




Seismic reprocessing and regional section

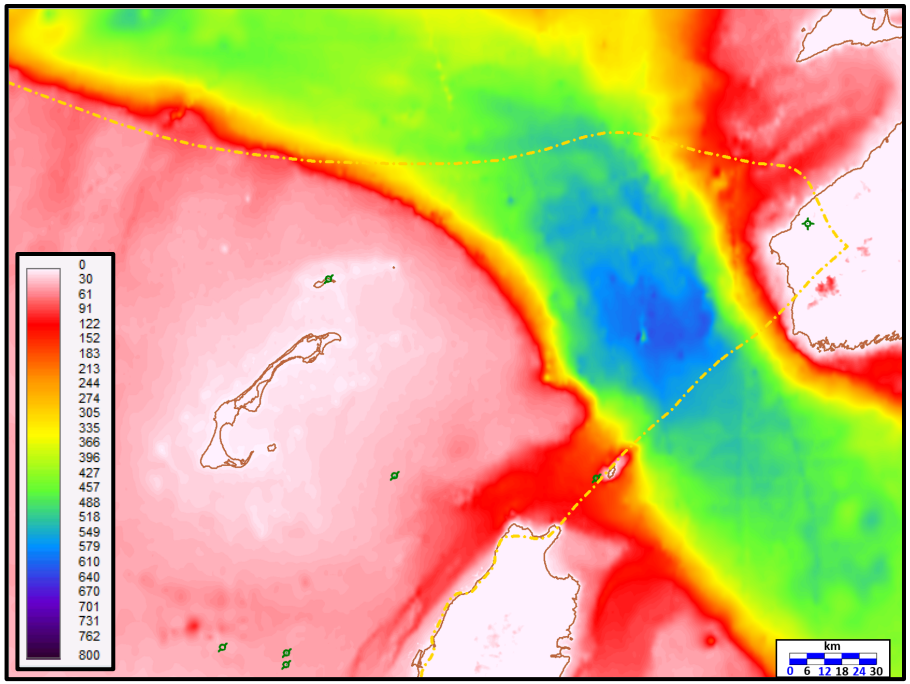
- Image quality significantly improved
- Highlights consistent reflection character and lateral changes
- Deep Horton grabens

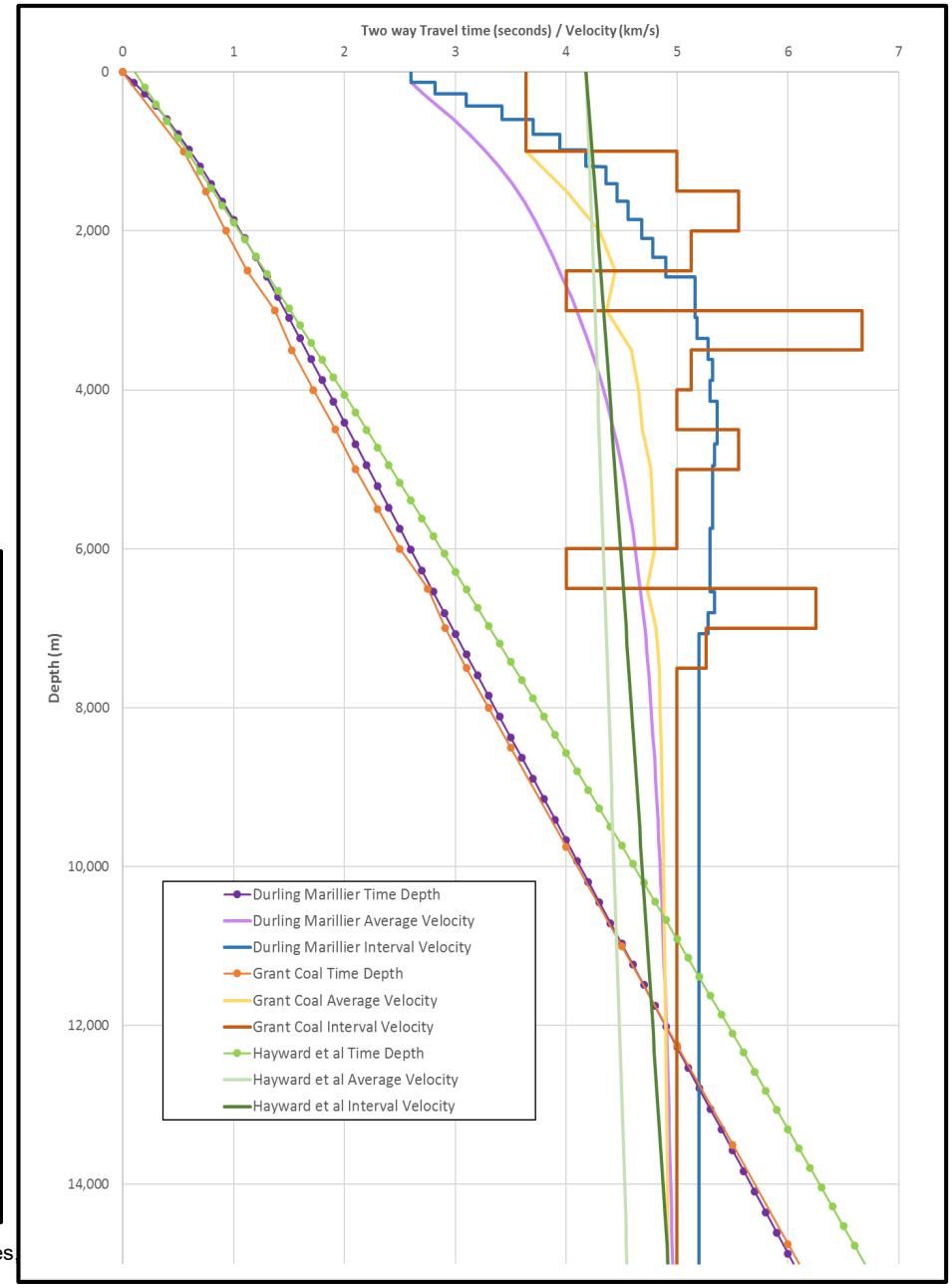




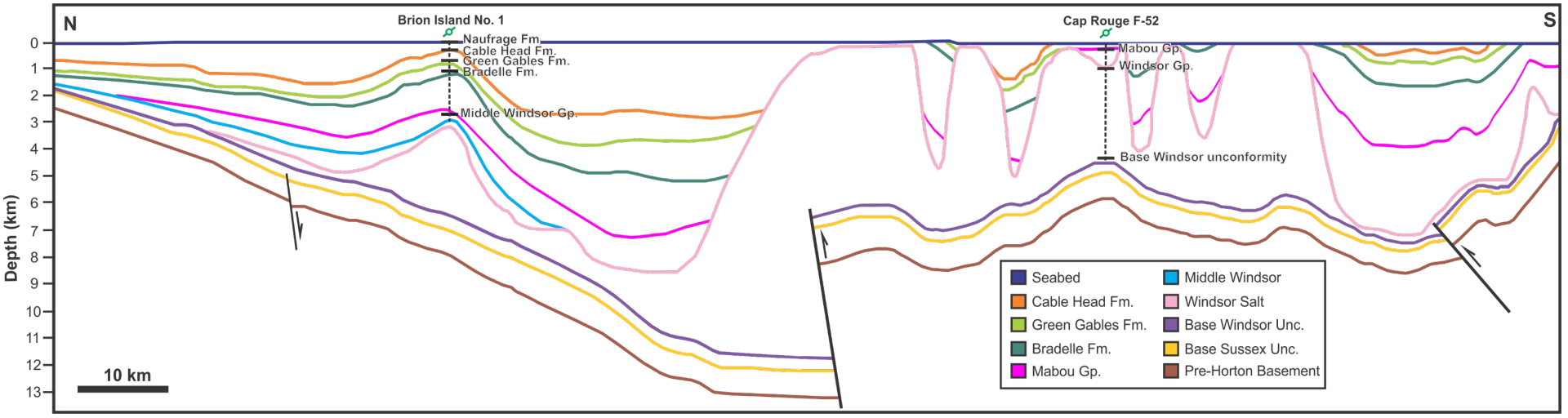
Depth conversion

- **Regional** vs. precise **approach**
- Limited well penetrations preclude more complex layer-cake models
- Three **regional time-depth curves from literature**
  - Most robust function at both deep and shallow levels is Durling and Marillier (1993)
- **Not explicitly tied to wells**, but correlations are reasonable
- **Residual correction** applied for lower velocity **water column**

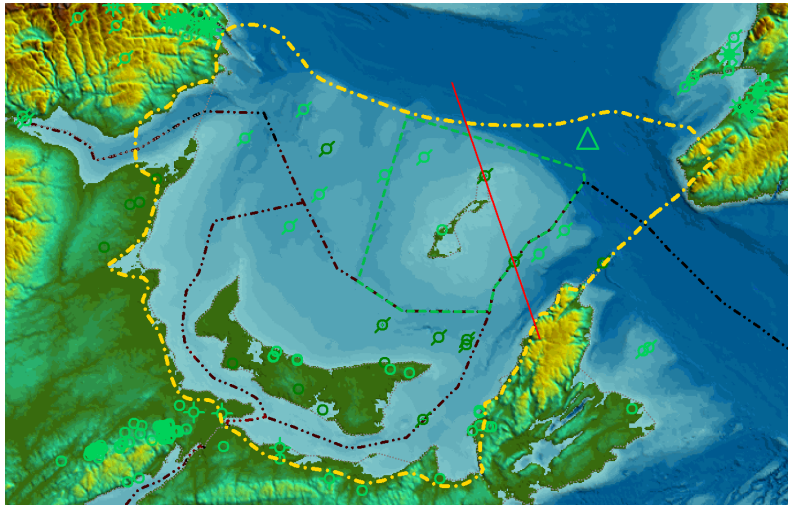




Regional depth cross section



- **Constructed from regional depth grids** in workstation
- Vertical exaggeration ~ 3:1
- This section highlights:
  - **Inversion under salt province / Cap Rouge well**
  - **Salt cored anticline under Brion Island No.1 well**



Regional Depth and Isopach maps

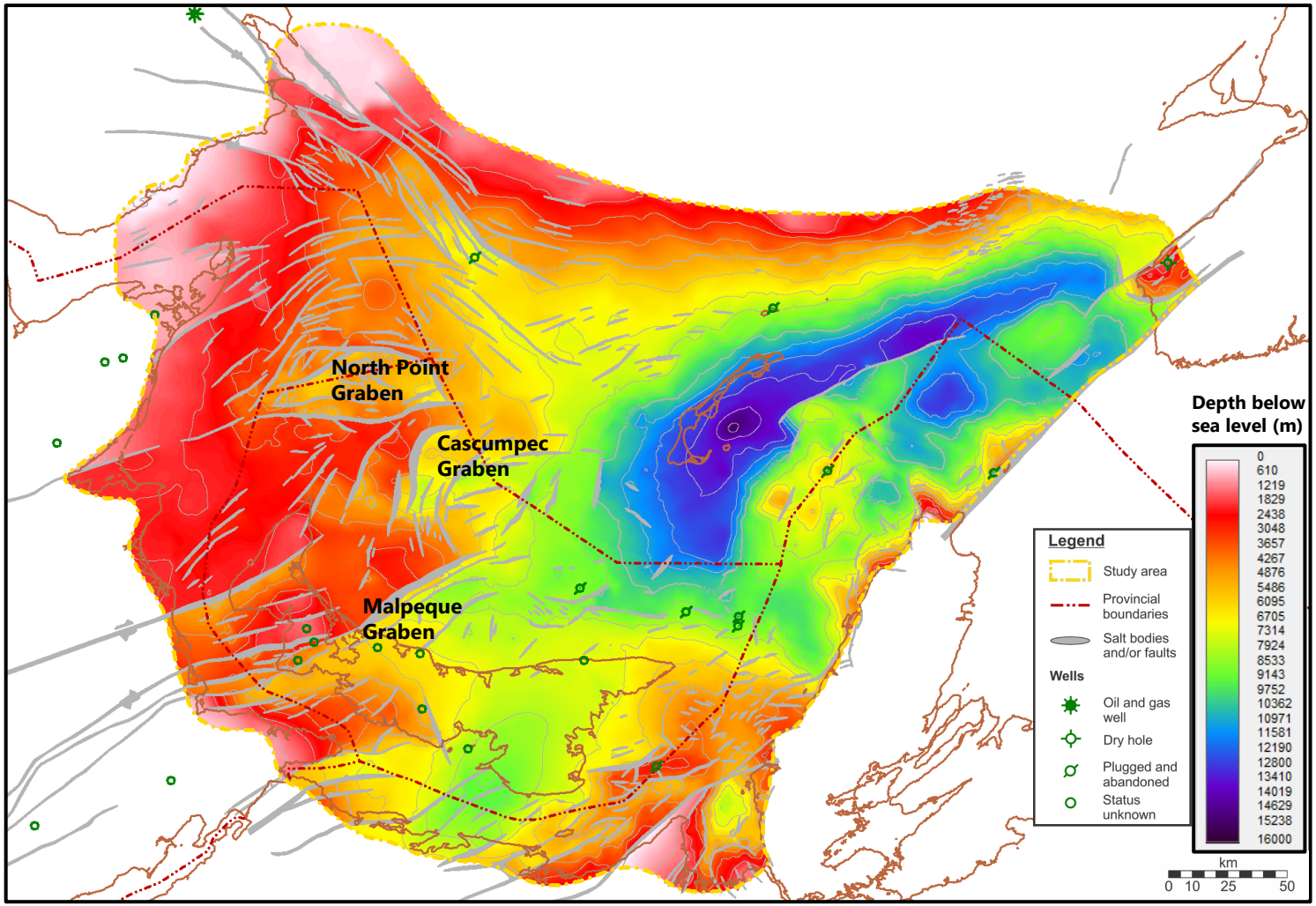
- For petroleum resource estimates, **regional maps** were used to **constrain** Chance of Success for **several petroleum system elements:**
  - Depth to reservoirs were used to estimate porosity / reservoir quality
  - Depth to source rocks were used to model maturation
  - Rate of change in isopachs were used to estimate the likelihood of stratigraphic traps
- Isopachs and regional depth / location can also be helpful for stratigraphic analysis of the various intervals

- **9 regional depth maps** were created:
  - Top of Cable Head Formation
  - Top of Green Gables Formation
  - Top of Bradelle Formation
  - Top of Mabou Group
  - Top of Middle Windsor Group
  - Top of Salt (Lower Windsor Group)
  - Base Windsor Group – Early Visean Unconformity
  - Base Sussex Group Unconformity (top of Horton Group)
  - Pre-Horton Group Basement (base of Magdalen Basin)

- These maps were used to create **8 isopach maps:**
  - Naufrage Formation isopach map – (bathymetry to Cable Head Formation)
  - Cable Head Formation isopach map
  - Green Gables Formation isopach map
  - Bradelle Formation and Cumberland Group isopach map
  - Mabou Group and Upper Windsor Group isopach map
  - Middle Windsor and Lower Windsor Group isopach map (including salt)
  - Sussex Group isopach map
  - Horton Group isopach map

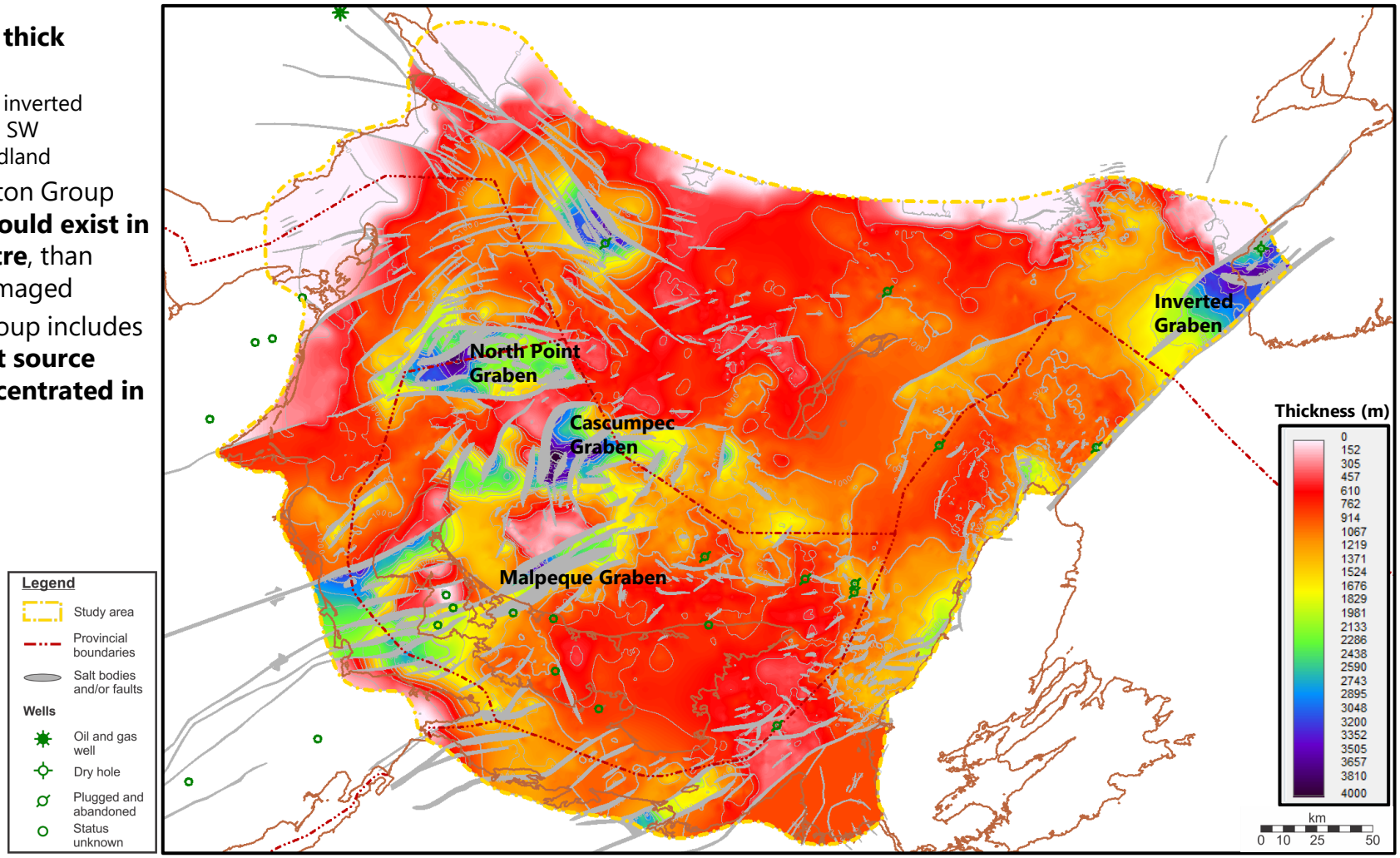
Pre-Horton Group Basement / Base Horton Group

- **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** related to underlying Appalachian structures in basin centre
  - No evidence of direct fault connection from Quebec Re-entrant to St. Lawrence Promontory (e.g. Sept-Iles transform, Allen et al, 2009)



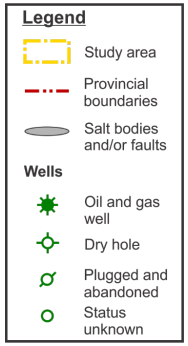
Horton Group Isopach Map

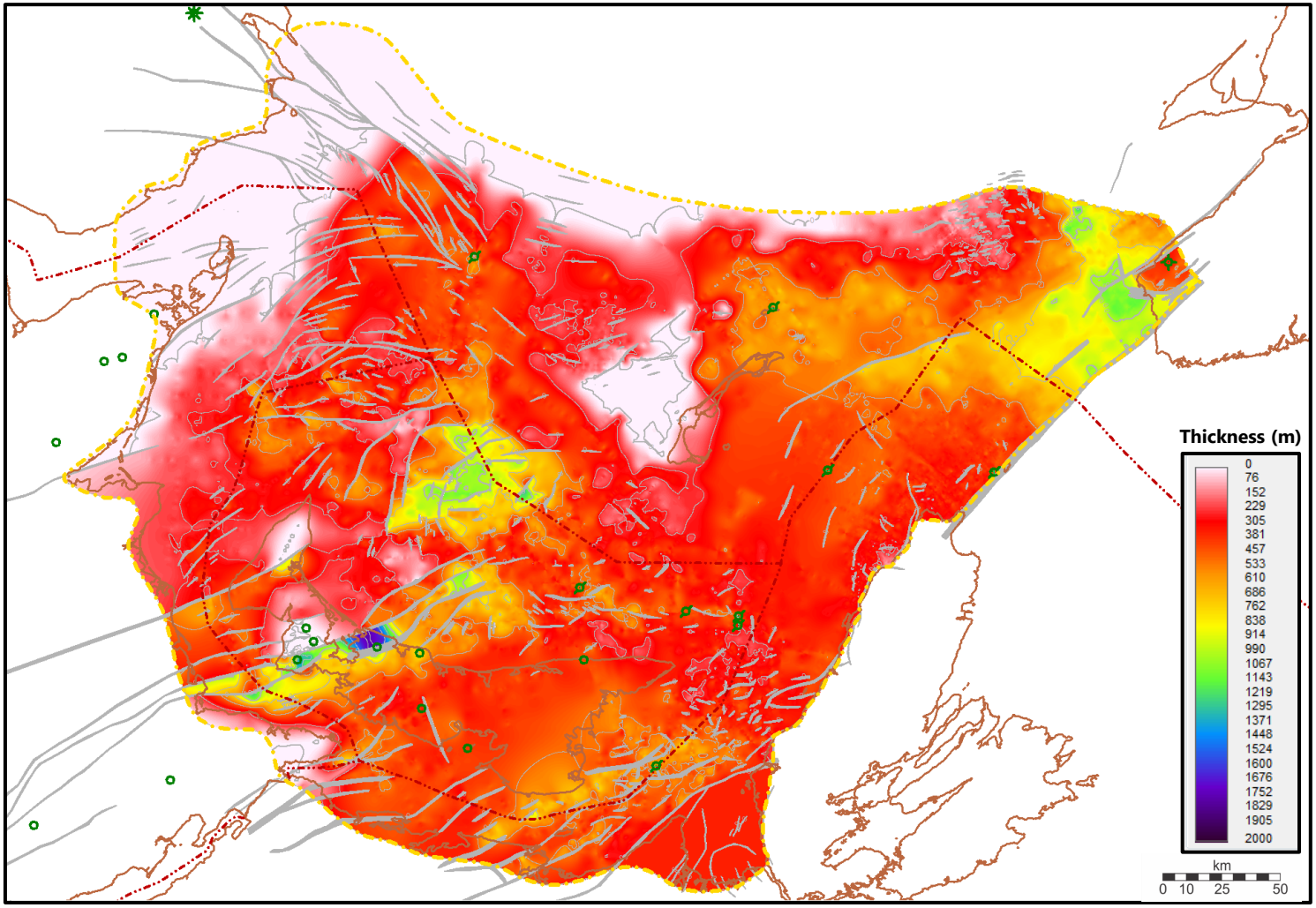
- Highlights **thick grabens**
  - Including inverted graben in SW Newfoundland
- **More** Horton Group variation **could exist in basin centre**, than currently imaged
- Horton Group includes **significant source rocks concentrated in grabens**



Sussex Group Isopach Map

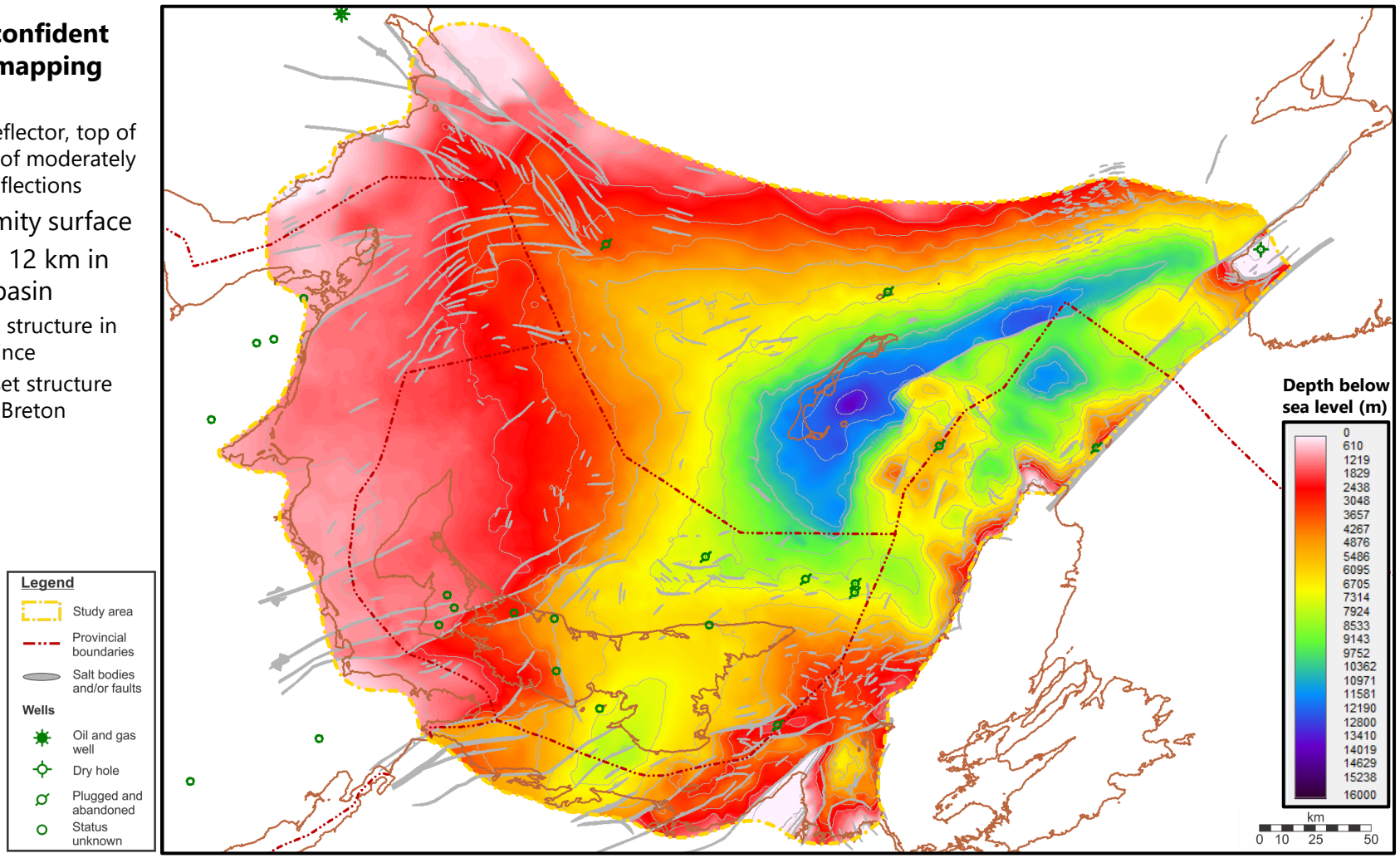
- Definition of **Sussex Group worked by Giles**
  - Dolby curated / provided **palynological data** from Natmap
  - Updated cross sections used in play analysis
  - Consistent with our mapping
- Sussex Group deposited in **thermal subsidence phase**
  - More consistent thickness
  - **Consistent moderate amplitude seismic package**
  - Note thinner scale





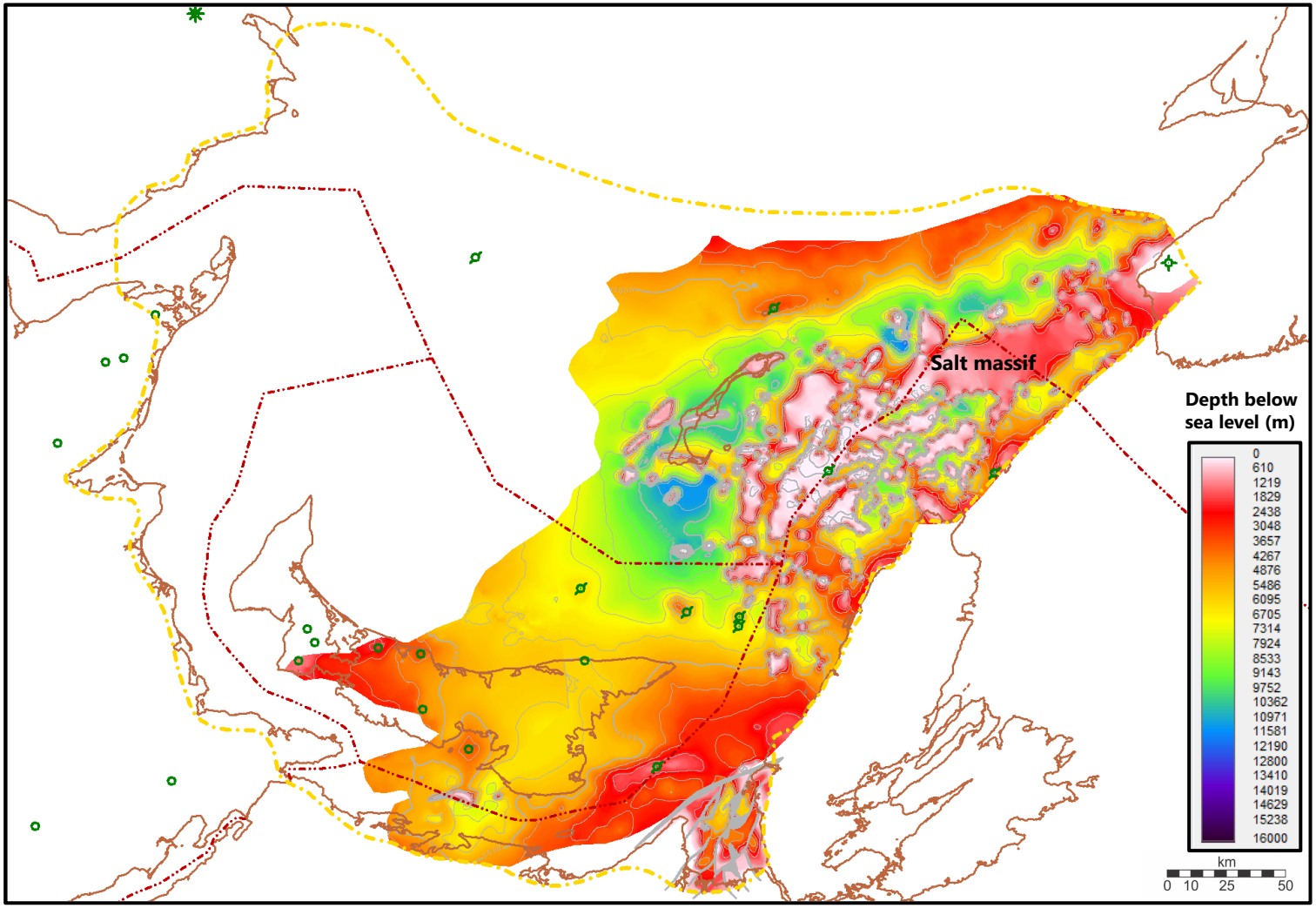
Base Windsor Group / Early Visean Unconformity

- **Deepest confident regional mapping horizon**
  - Strong reflector, top of package of moderately strong reflections
- Unconformity surface
- Reaches ~ 12 km in centre of basin
  - Inversion structure in salt province
  - High offset structure off Cape Breton



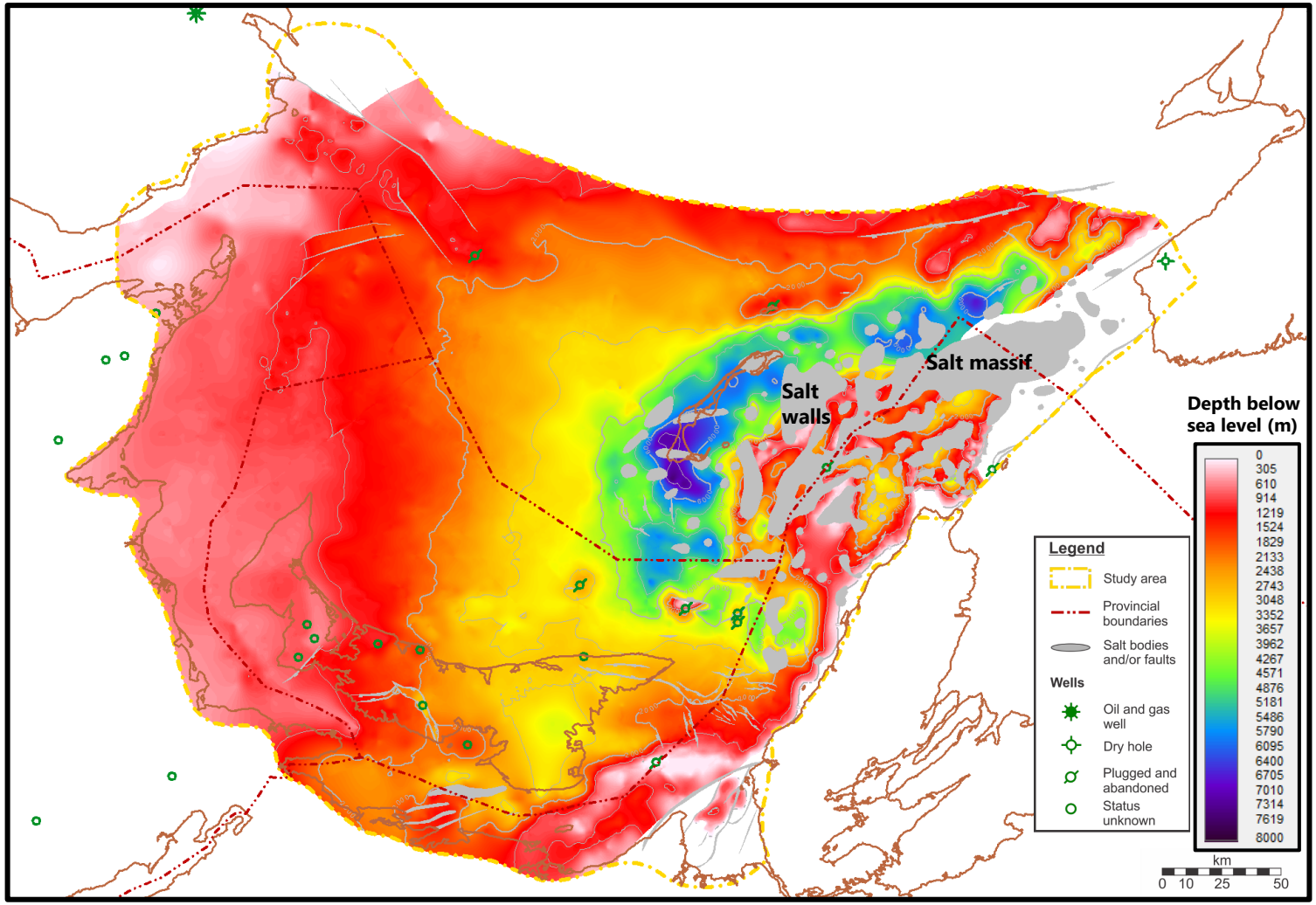
Top of Salt / Lower Windsor Group

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



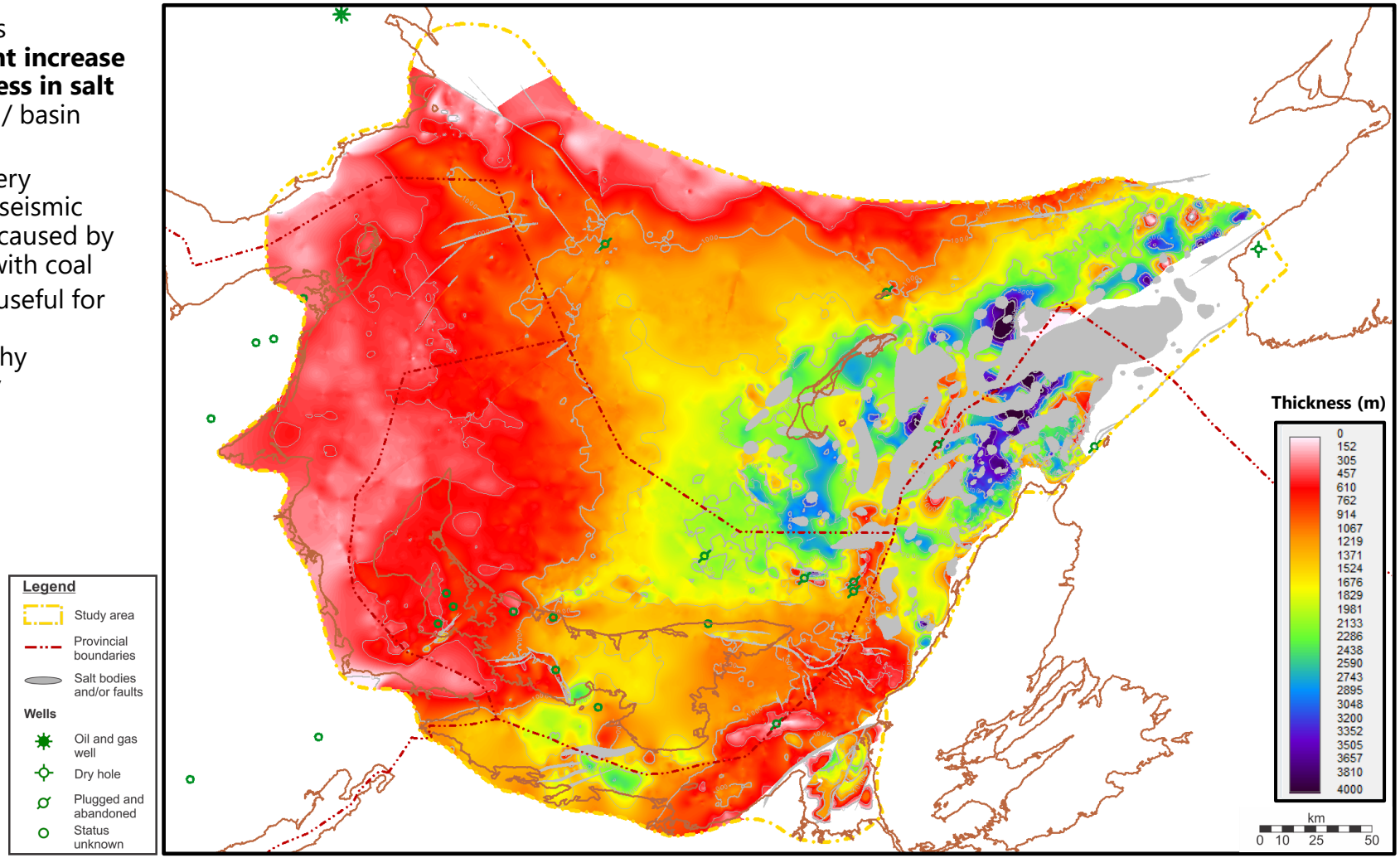
Top of Bradelle Formation

- **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.



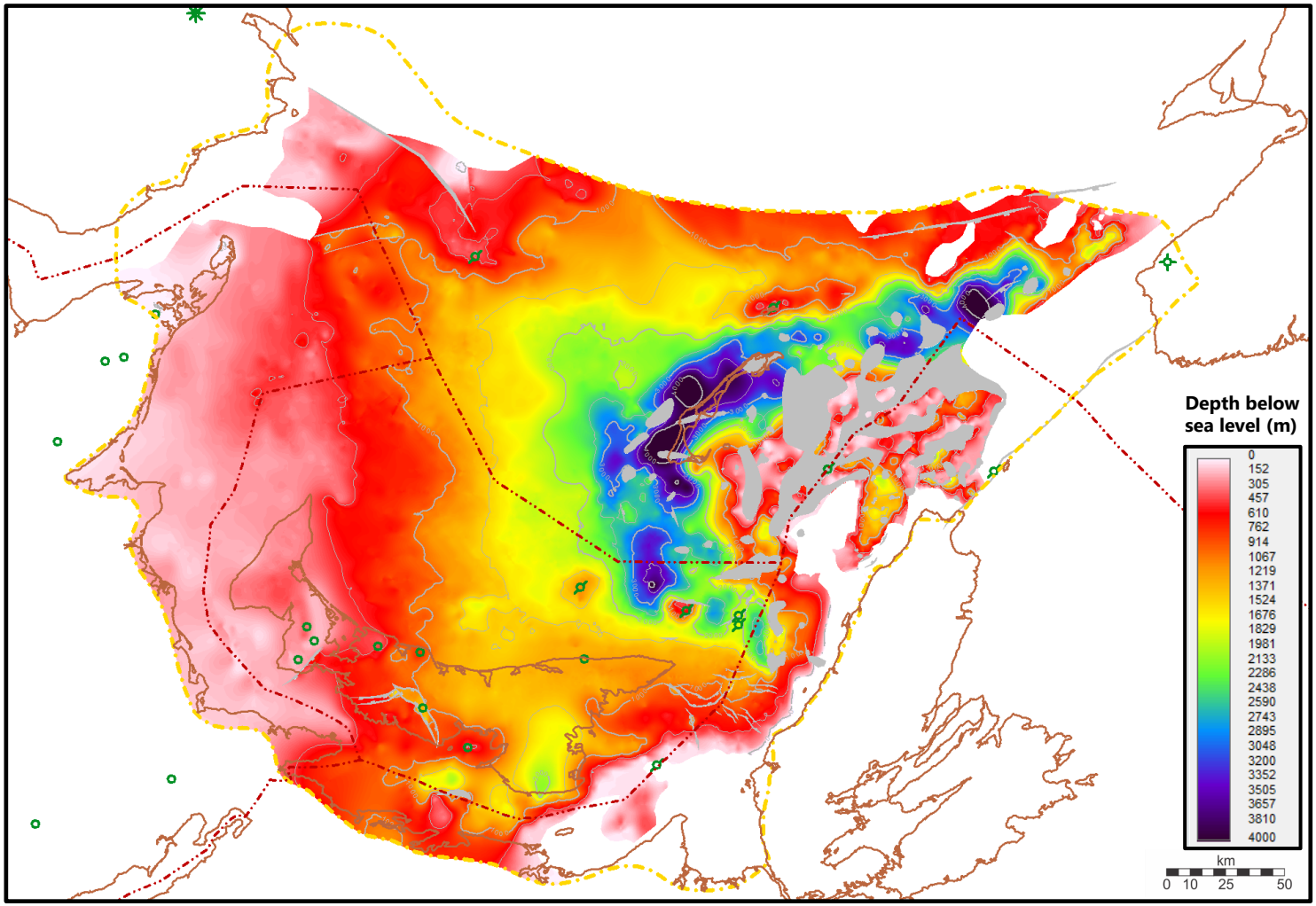
Bradelle and Cumberland Group Isopach Map

- 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



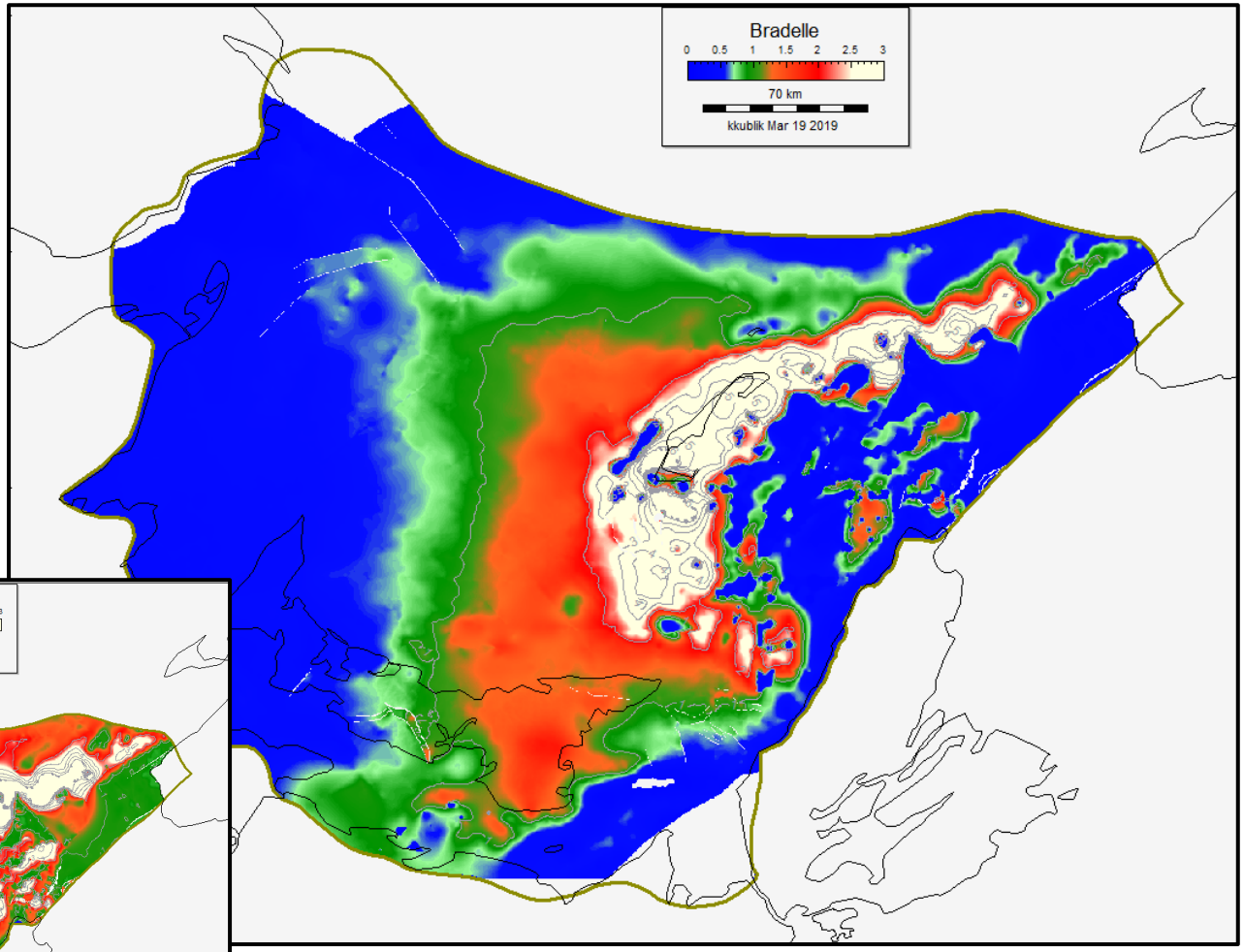
Top of Cable Head Formation

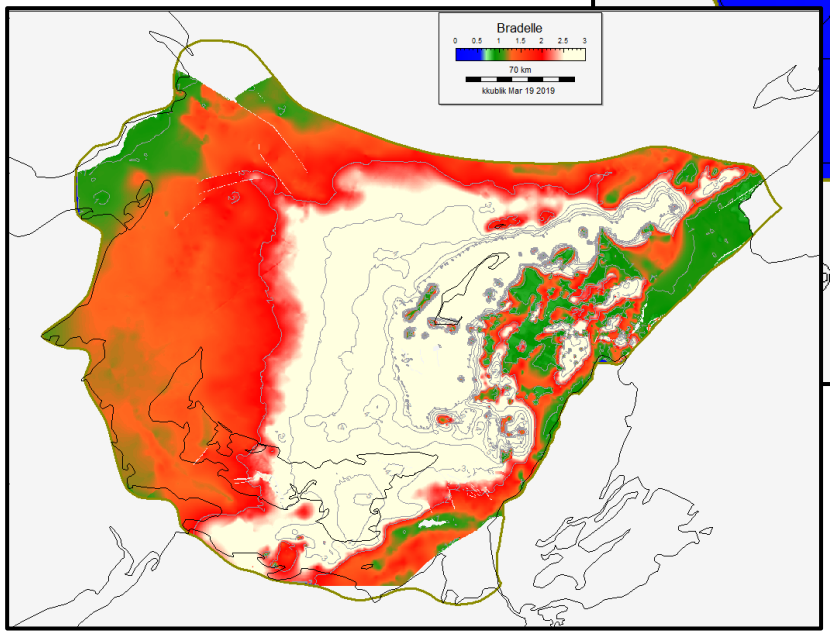
- **Most shallow regionally mapped horizon**
  - Top of a reflective zone
  - Note even shorter depth scale
- Widespread deposition
- Simple deformation
- **Strong correlation of porosity to depth**



Basin modelling

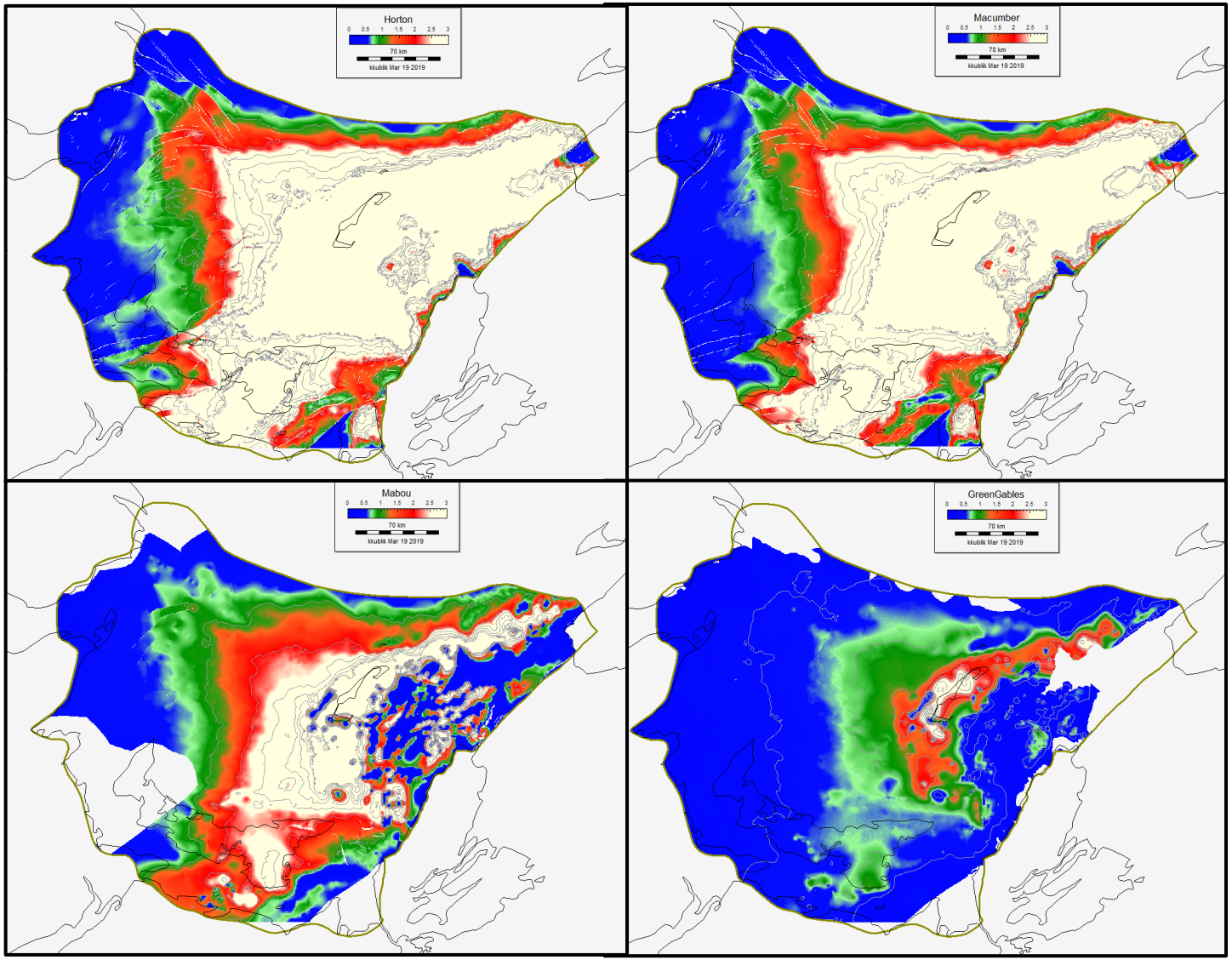
- Trinity software used to **model maturity and migration, based on the regional mapping**
- Map shows Vitrinite reflectance in Bradelle Fm. source rock
  - Modelled 200 m below top
  - 1.5 km (and 4 km maximum case) of sediment deposited in Permian and eroded in Triassic
  - **Green = oil window, red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





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)



Play Analysis

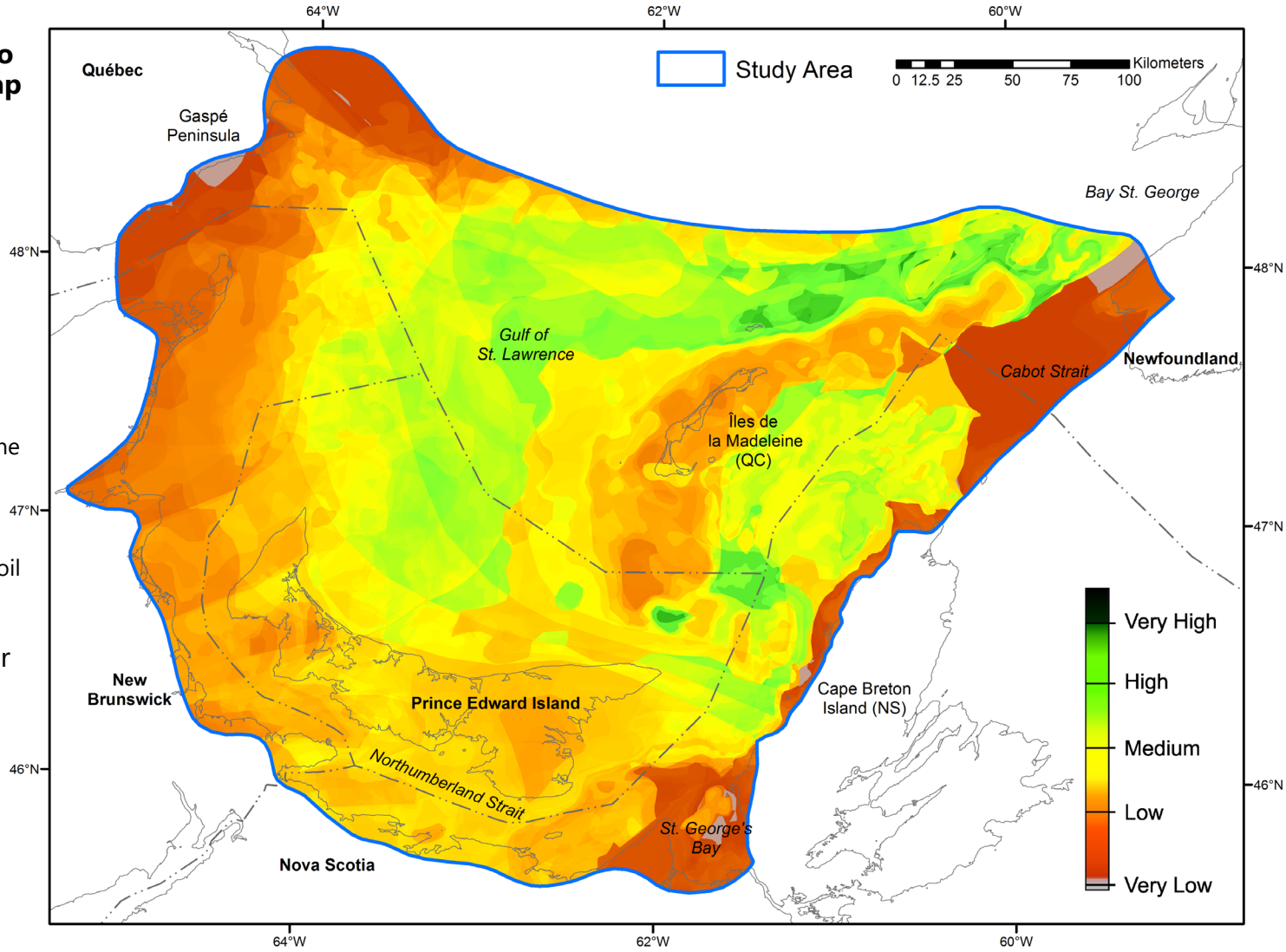
- Returning to the petroleum potential…
- Regional mapping, basin analysis and geologic inputs from literature outlined the following 7 plays
  - **Highest potential play is Morien/Cumberland structural / salt flank play**

	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
Highest potential		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	
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			

- Chance of success for each petroleum system element for each play were mapped
- Plays were weighted and summed

Magdalen Basin Petroleum Potential

- **Seven plays stacked into Petroleum Potential Map**
- The best regional petroleum potential is moderate to high
- Qualitative Petroleum Potential Map shows **greatest 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
- **Map does not illustrate individual targets**, rather regions where geologic conditions increase or decrease potential



Conclusions

- Regional maps and isopachs constructed are useful for:
  - Stratigraphic analysis
    - Further work with seismic database may bring out additional stratigraphic details
  - Petroleum system modelling and analysis
- No evidence of older Appalachian structures in the core of the basin
  - Appalachian models should be consistent with overlying Magdalen Basin geometry
- Early Horton graben geometries are consistent with trans-tensional basin concept
- Salt tectonics produce most significant structural complexity in basin
- Basin over mature in core, mature on flanks
  - Preservation of oil possible
- Locations of best potential possibility of oil:
  - North Flank of basin, north of Îles de la Madeleine
  - Complex salt province near Cape Breton
- Compiled database is a valuable asset, especially seismic
  - Open to collaboration on further regional studies

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Questions?

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