# PREDICTIVE MODELING OF SANDSTONE RESERVOIR DISTRIBUTION IN THE SW SCOTIAN BASIN

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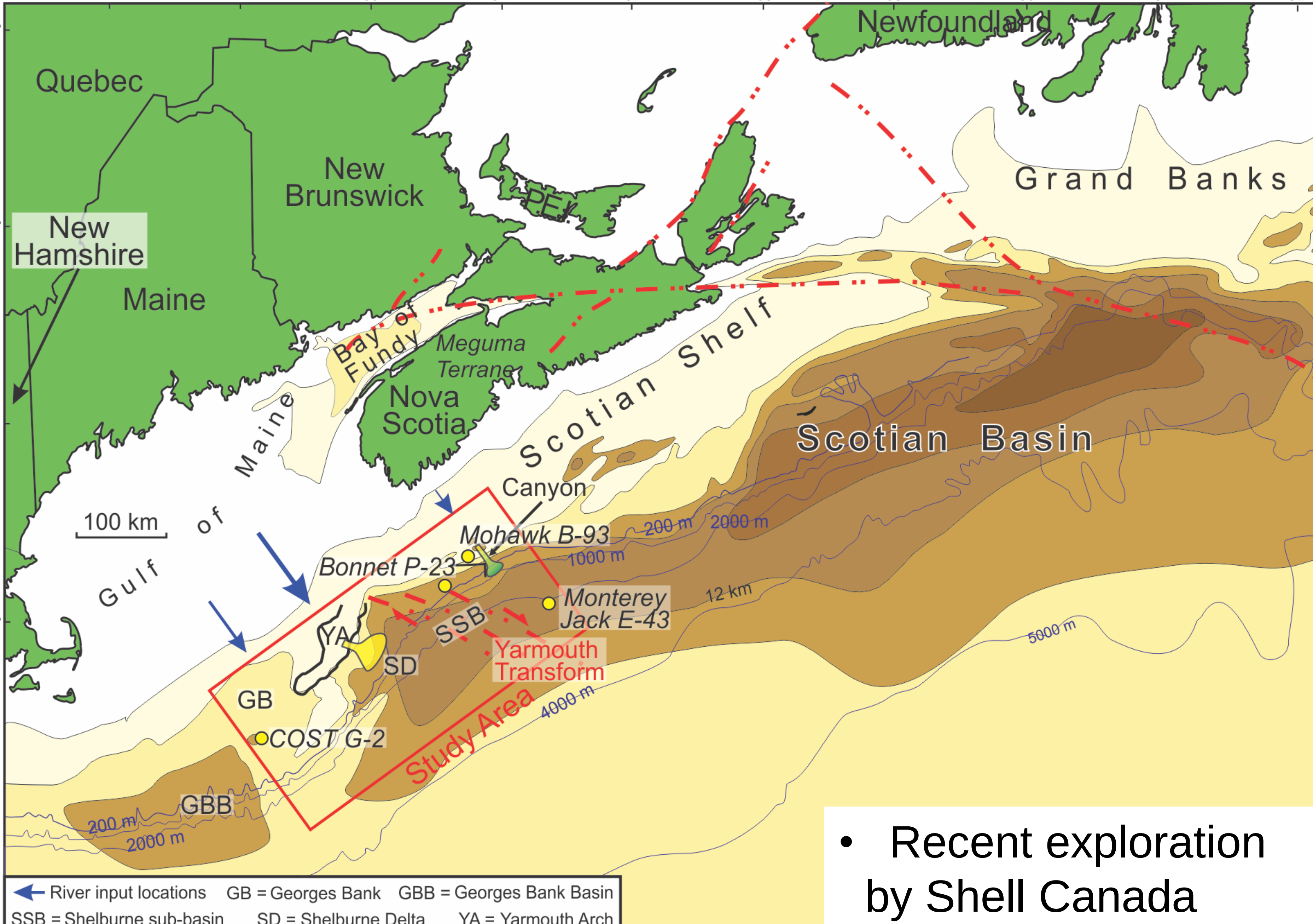
# Outline

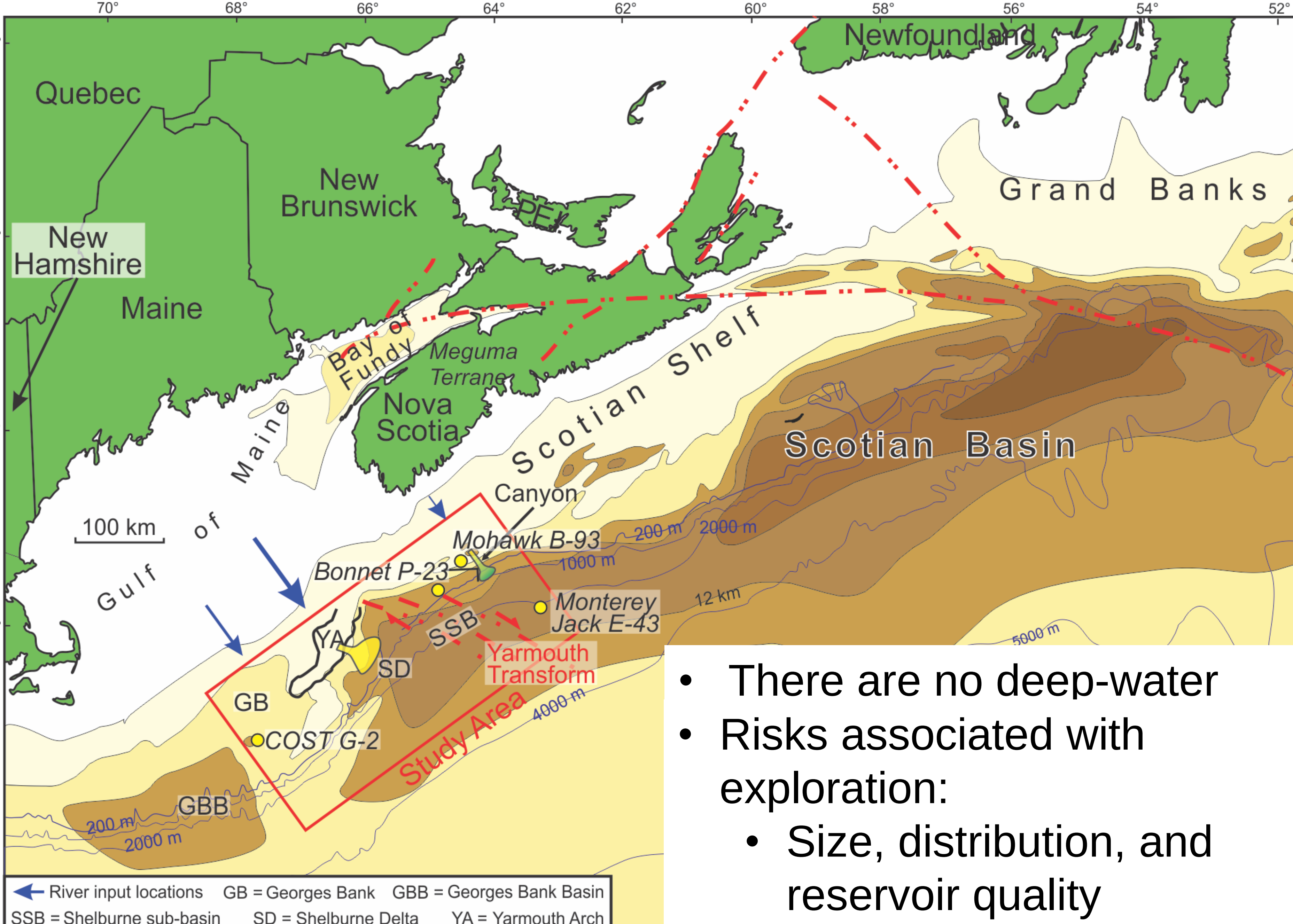
# Objectives

- Develop a model of sediment distribution for the SW Scotian Basin in the Mid–Late Jurassic:
  - How was sediment dispersed from the Shelburne Delta? Were progradational packages present in the Jurassic, and if so, was sand transported into deep-water?
  - Did the initial bathymetric depth in the Callovian (J163) have a large effect on sediment accumulation in the basin?



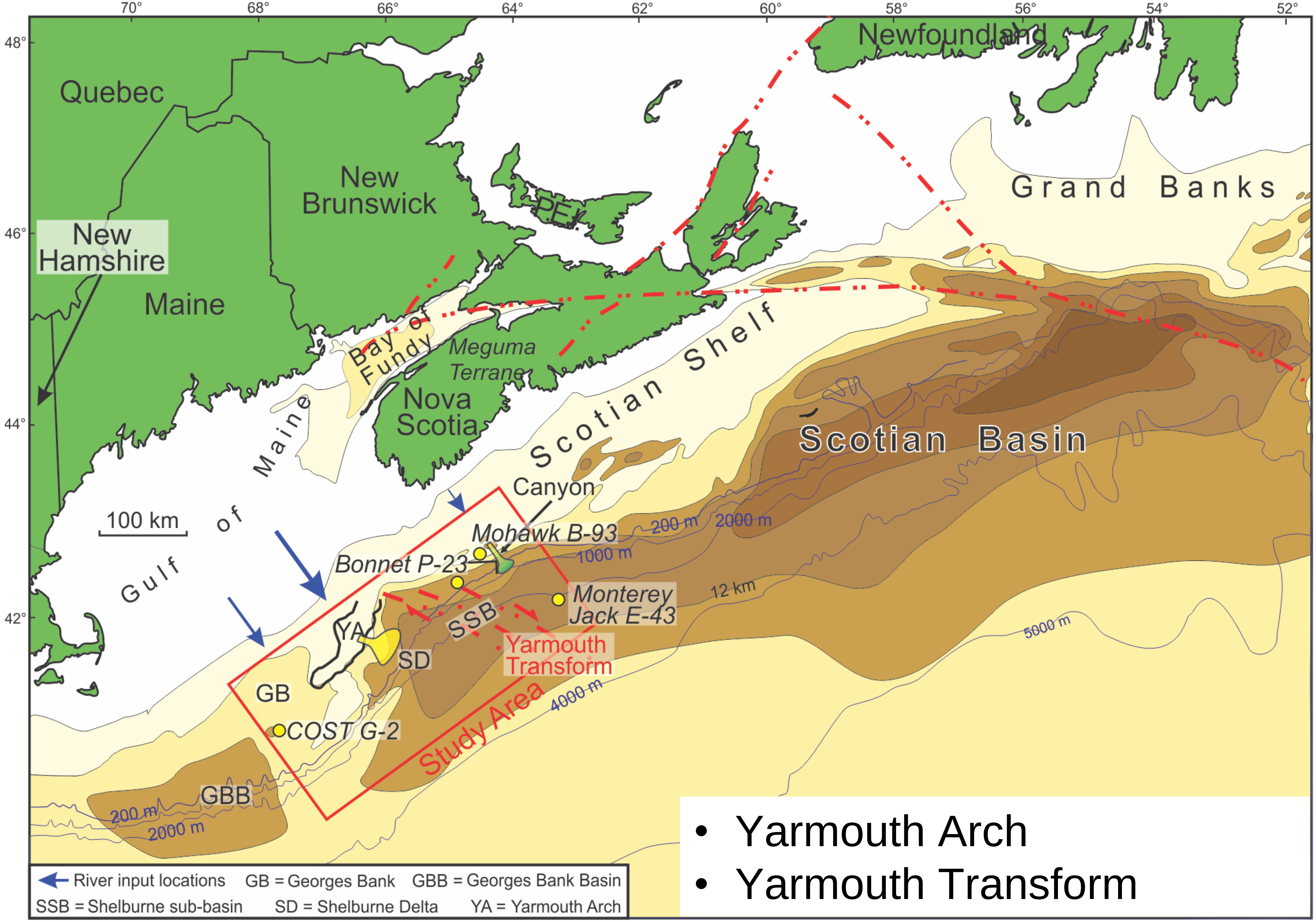

- Recent exploration by Shell Canada

Modified from Wade and MacLean (1990), and Williams and Grant (1998)



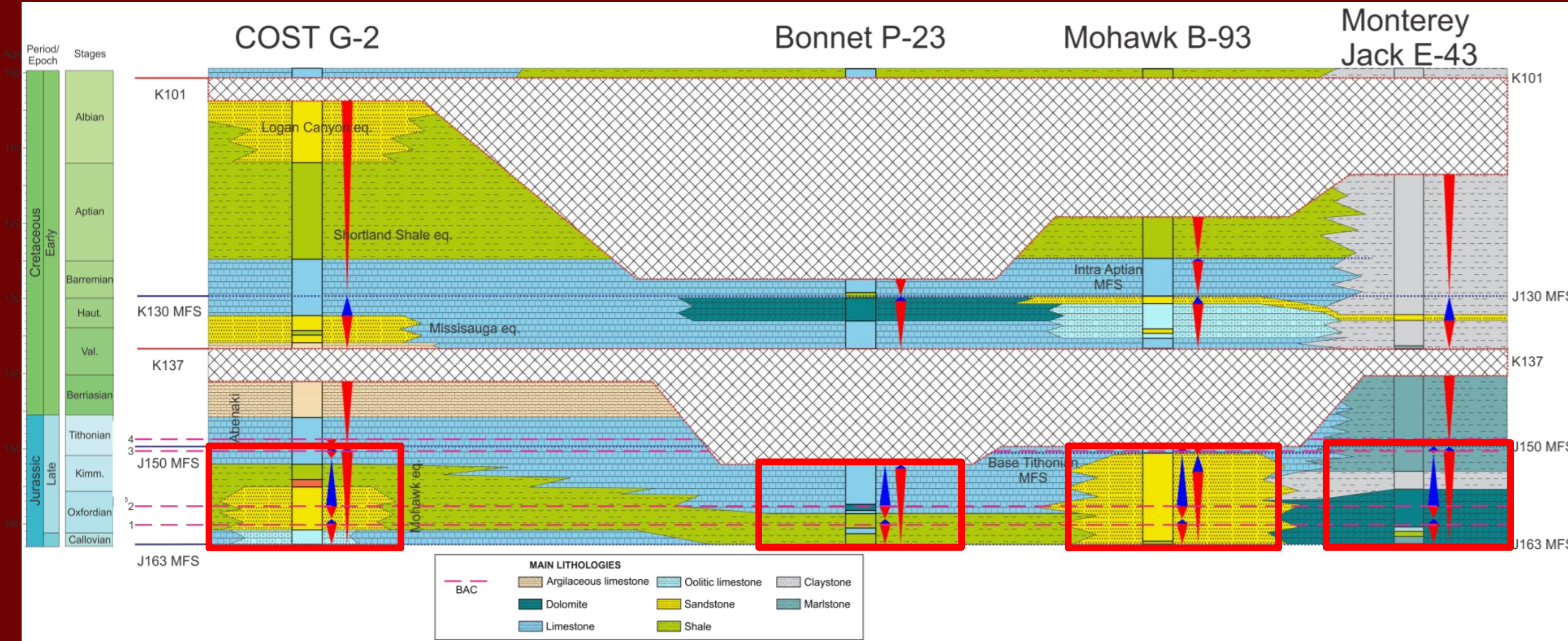

- There are no deep-water
- Risks associated with exploration:
    - Size, distribution, and reservoir quality

Modified from Wade and MacLean (1990), and Williams and Grant (1998)

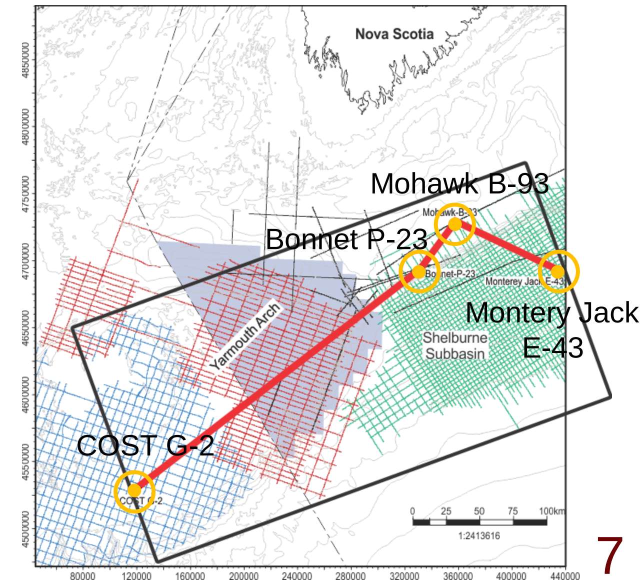



- Yarmouth Arch
- Yarmouth Transform

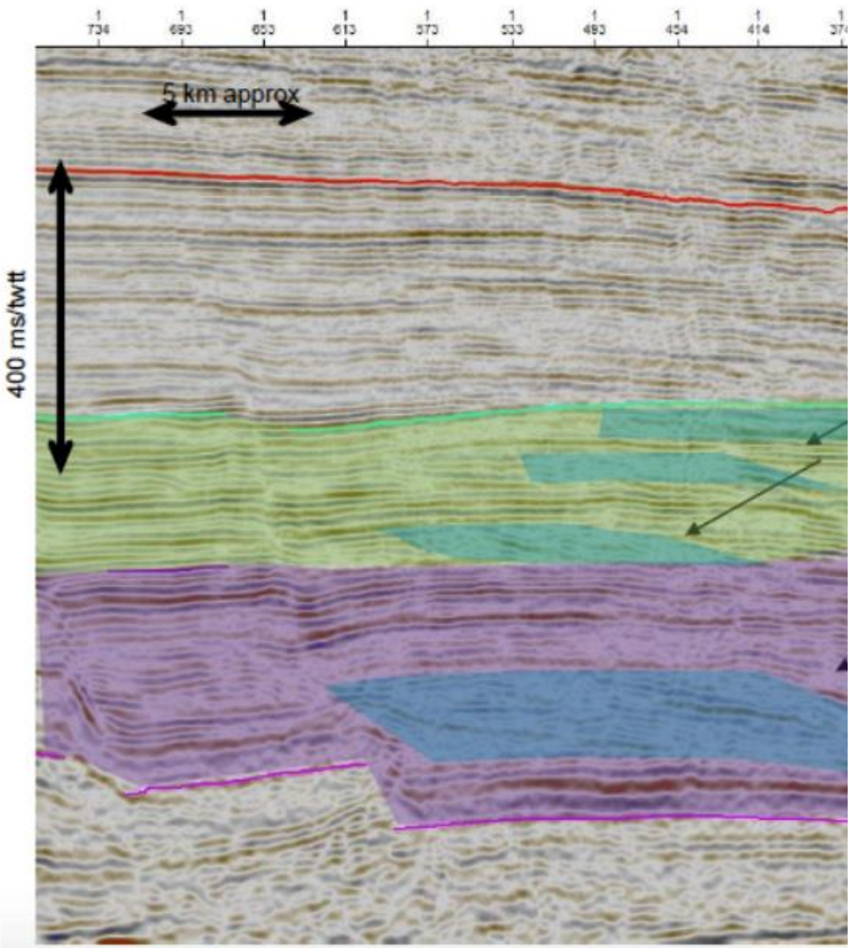
Modified from Wade and MacLean (1990), and Williams and Grant (1998)




- COST G-2
  - Shallow water
- Bonnet P-23
  - Prodeltaic / shallow water
- Mohawk B-93
  - Very shallow water / shoreface?
- Monterey Jack E-43
  - Outer ramp / deep marine?



# Shelburne Delta




MacDonald (2011)

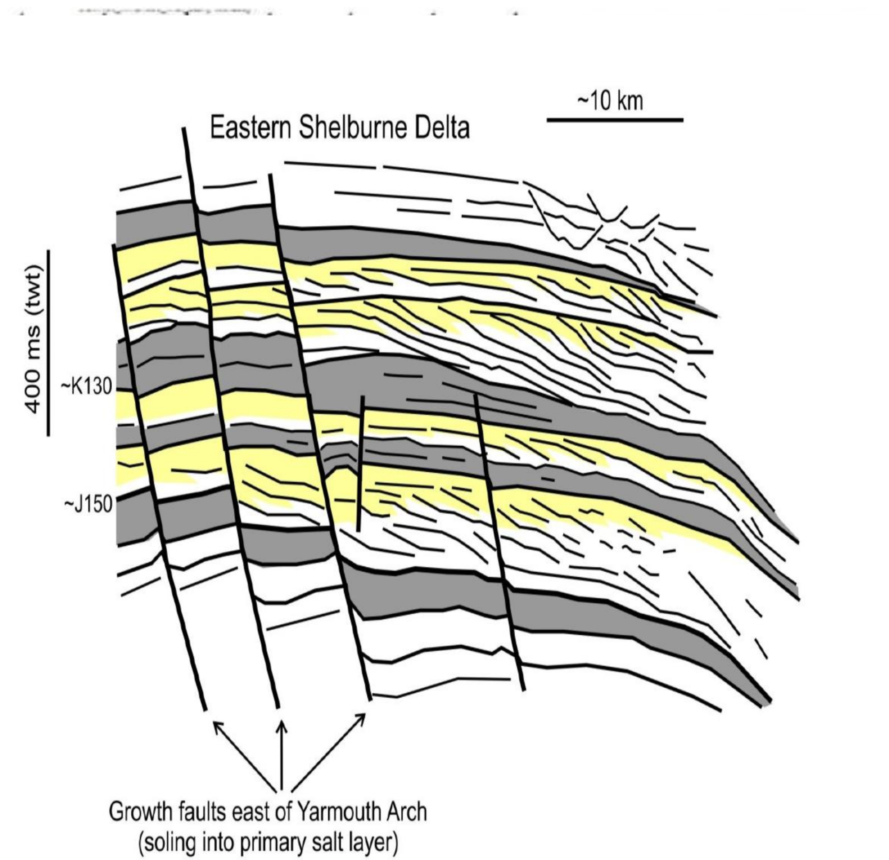
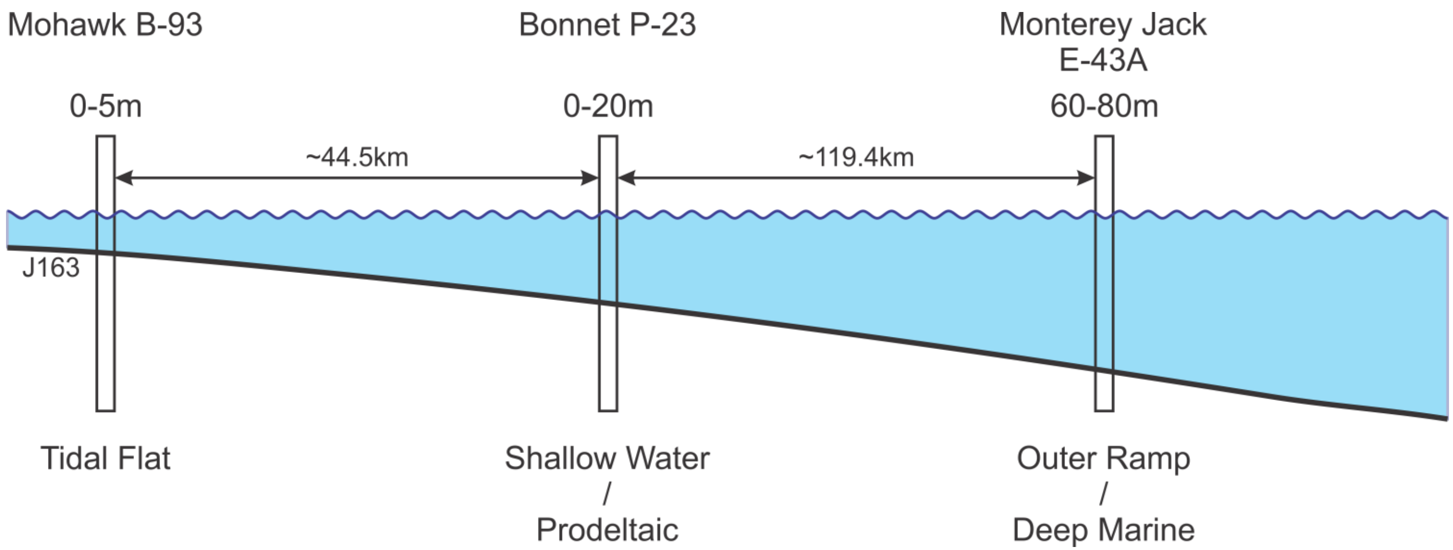



**Figure 2.14** Line drawing interpretation from a seismic profile presented in MacDonald (2011) across the eastern Shelburne Delta, showing multiple stacked Cretaceous transgressive (grey) and regressive (yellow) cycles above the J150 marker, immediately west of Parcels 1 and 2.

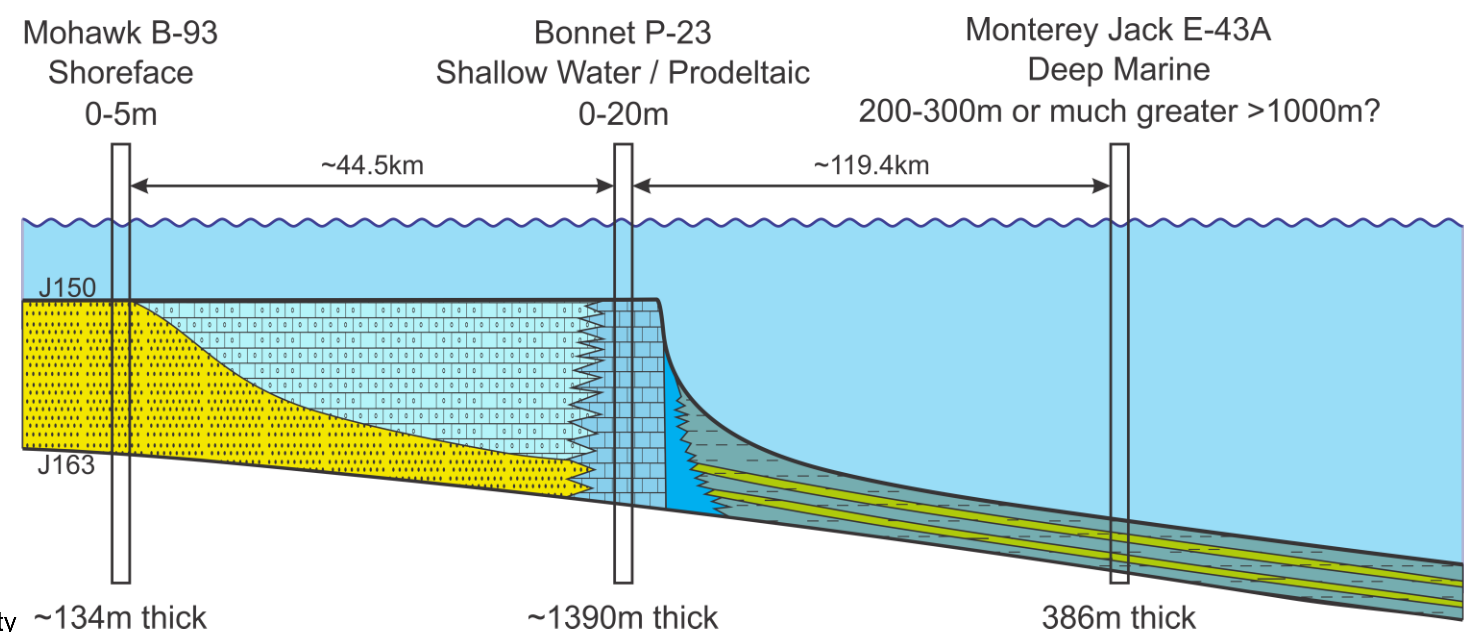
Deptuck et al. (2015)

# Depositional Environments

Initial Bathymetry

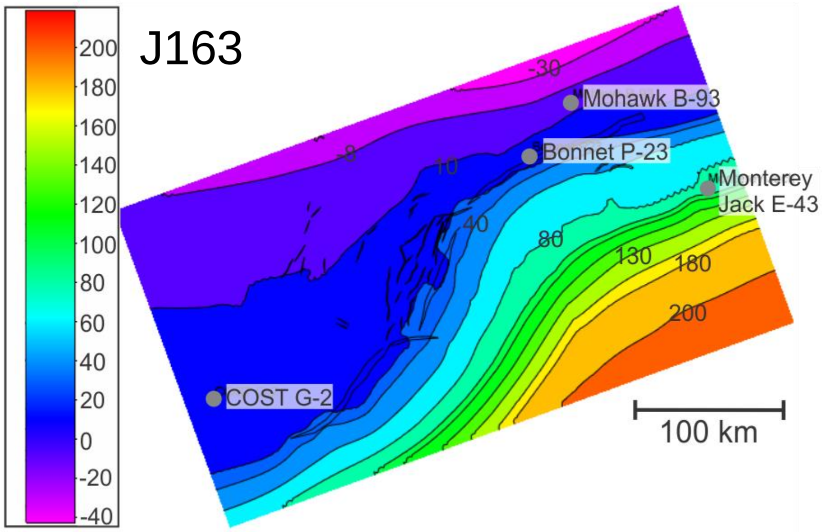



J150–J163

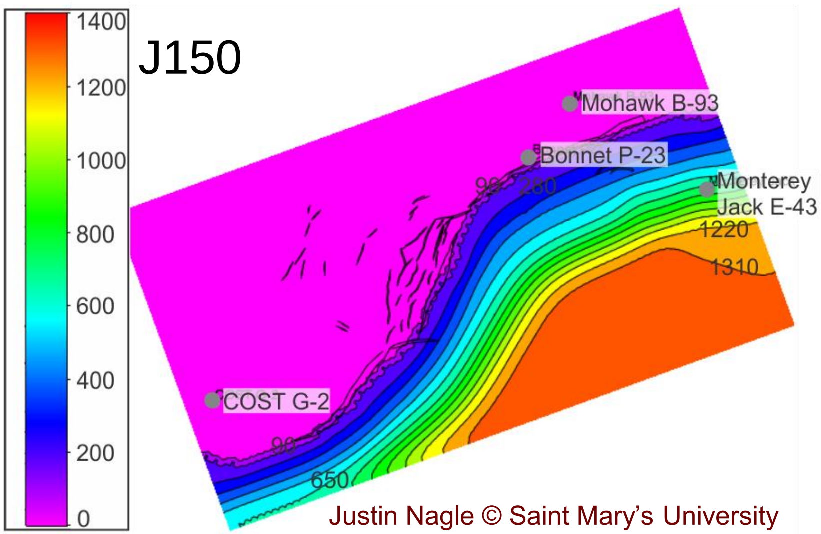


# MODEL INPUTS

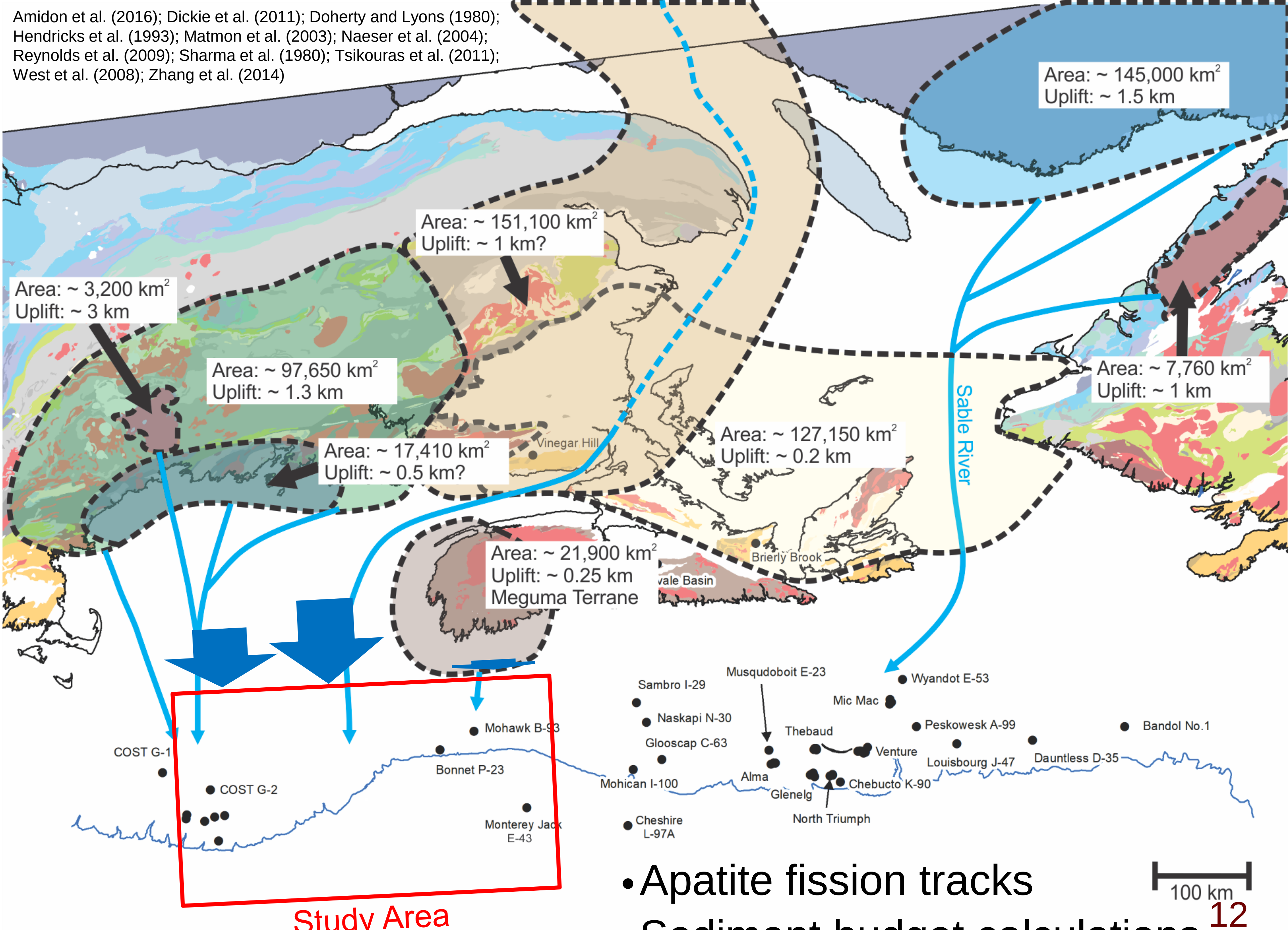
# Bathymetry



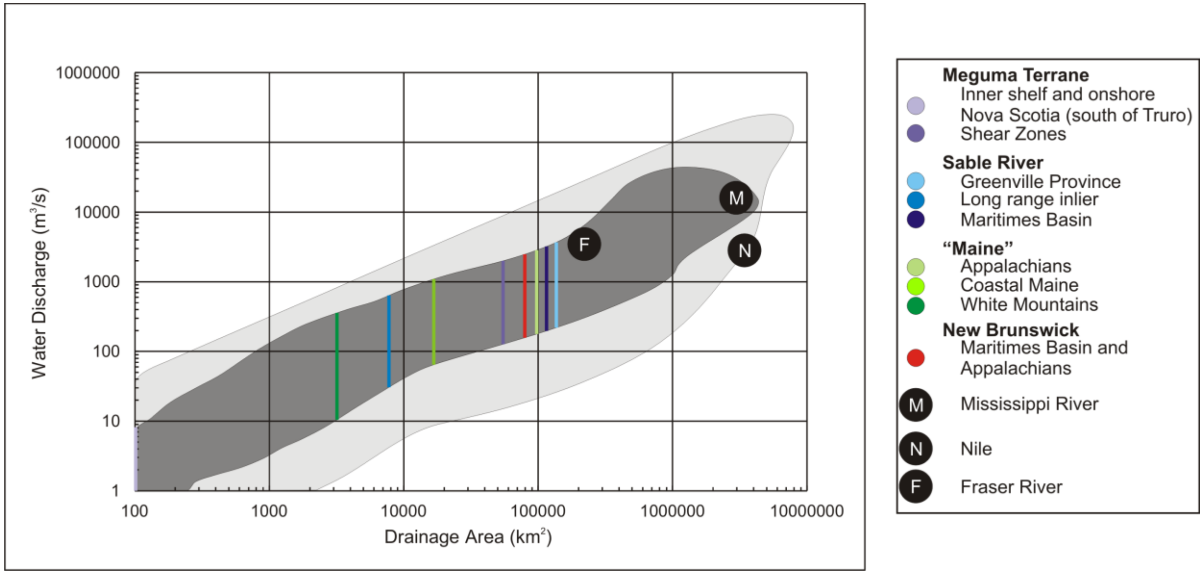

- Shallow water facies present at wells
- Nearby wells show a paralic (Mohedia P-15) to inner neritic – shallow marine (Mohican I-100, Glooscap C-63)
- Monterey Jack cuttings show limestone that appears pelloidal to oolitic
- Conjugate margin studies find a Early–Middle Jurassic carbonate ramp analogue in Morocco (Pierre et al. 2010)

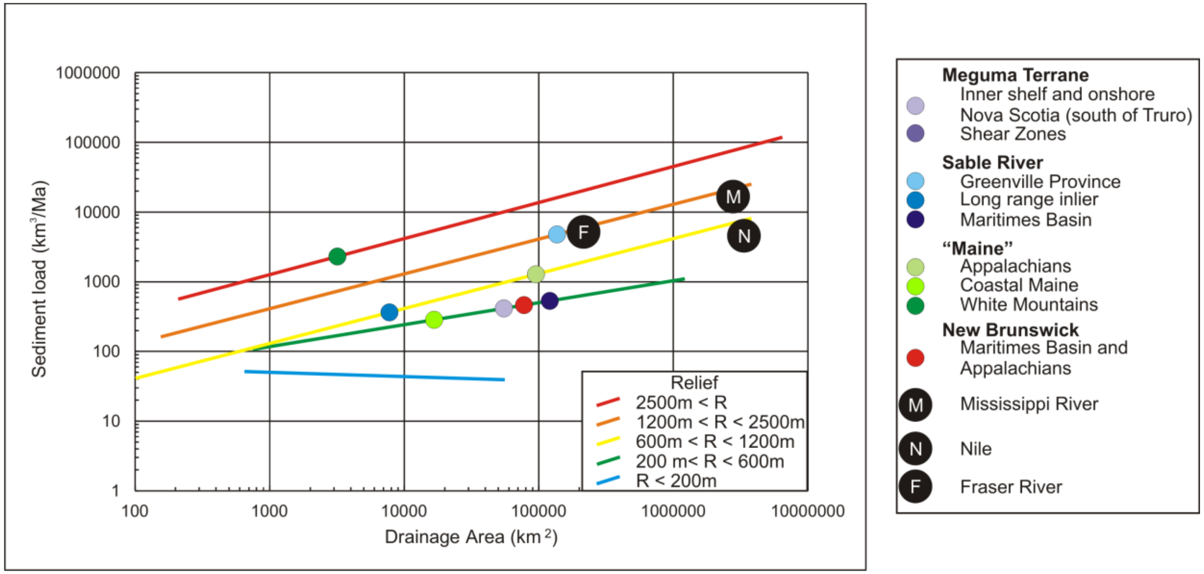



- By the Late Jurassic, there are widespread carbonate reefs (as indicated at Bonnet P-23)
- Monterey Jack records marls and claystones in cuttings
- Mohawk B-93 records clastic deposition
- COST G-2 records mixed sedimentation

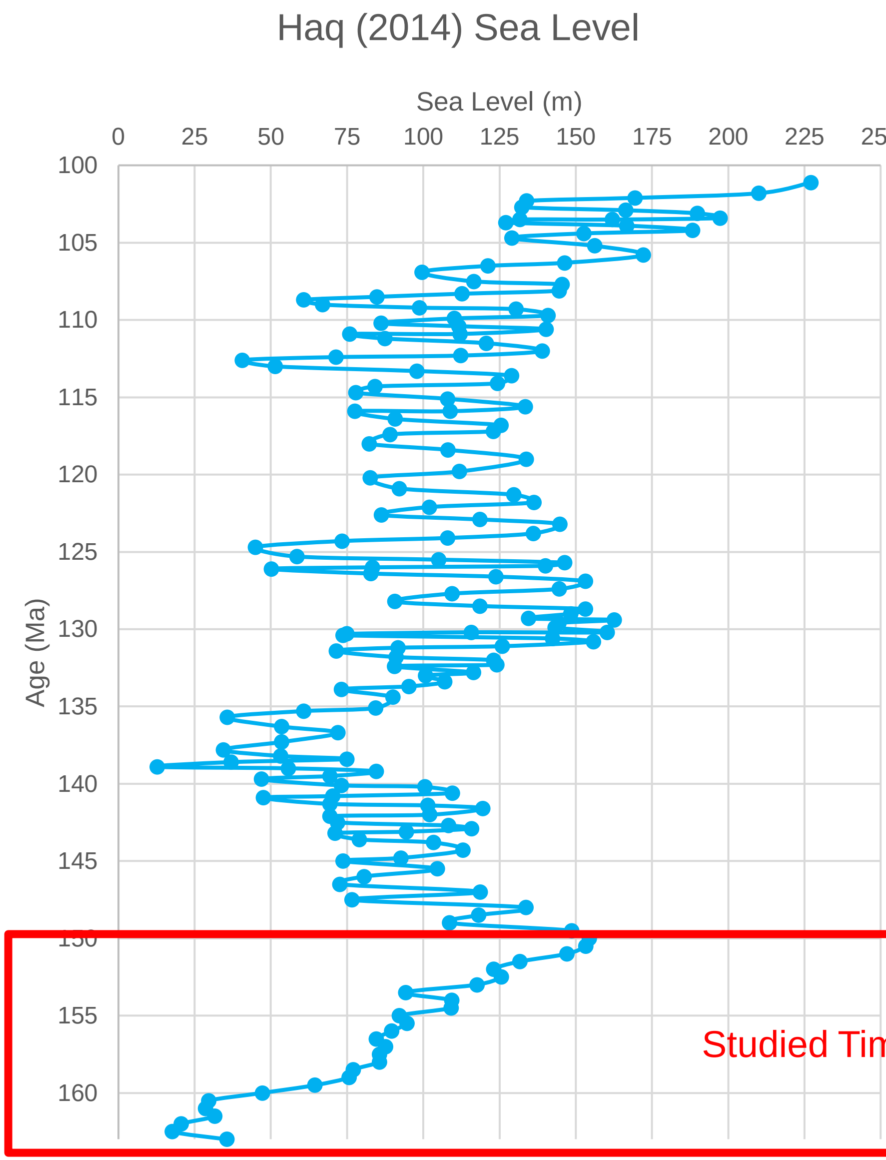


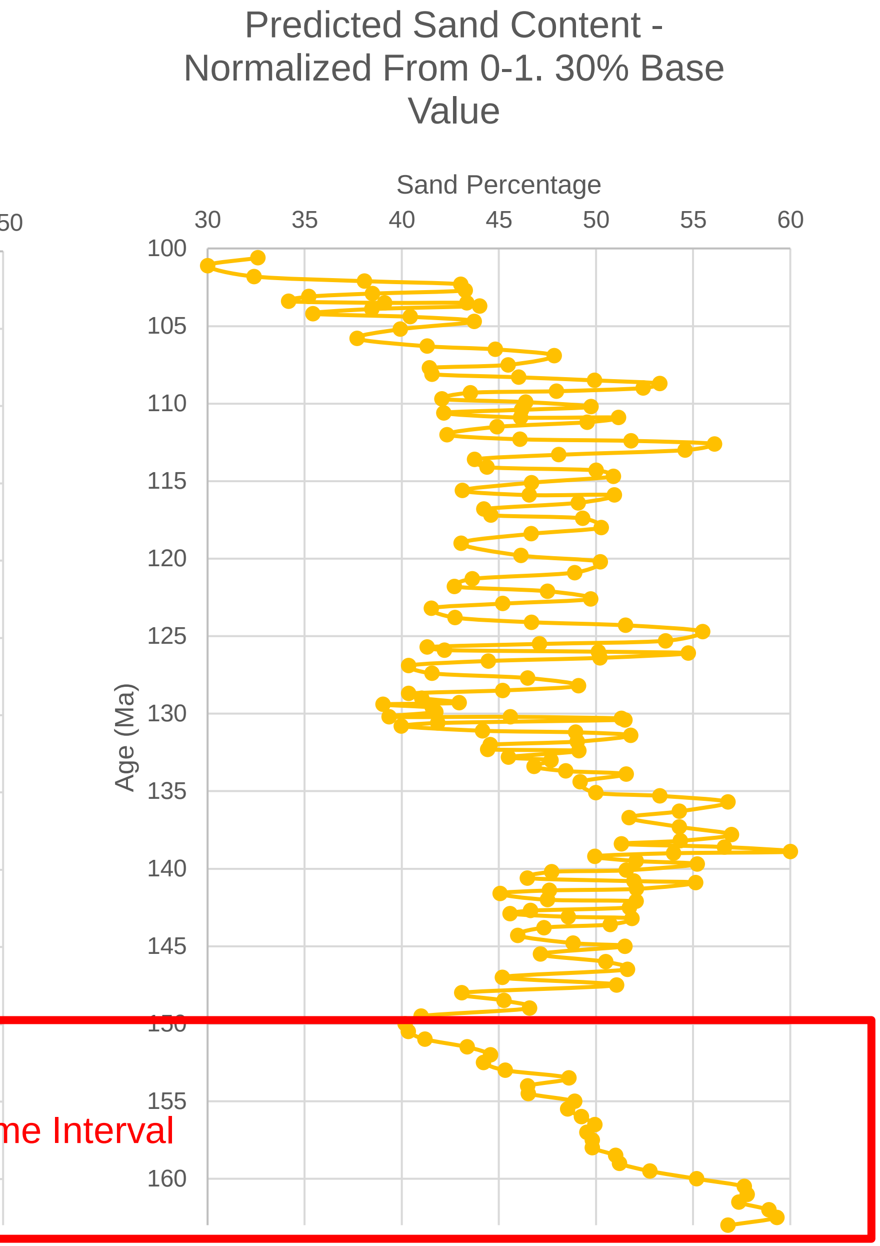

- Apatite fission tracks
- Sediment budget calculations




Modified from Milliman and Syvitski (1992)

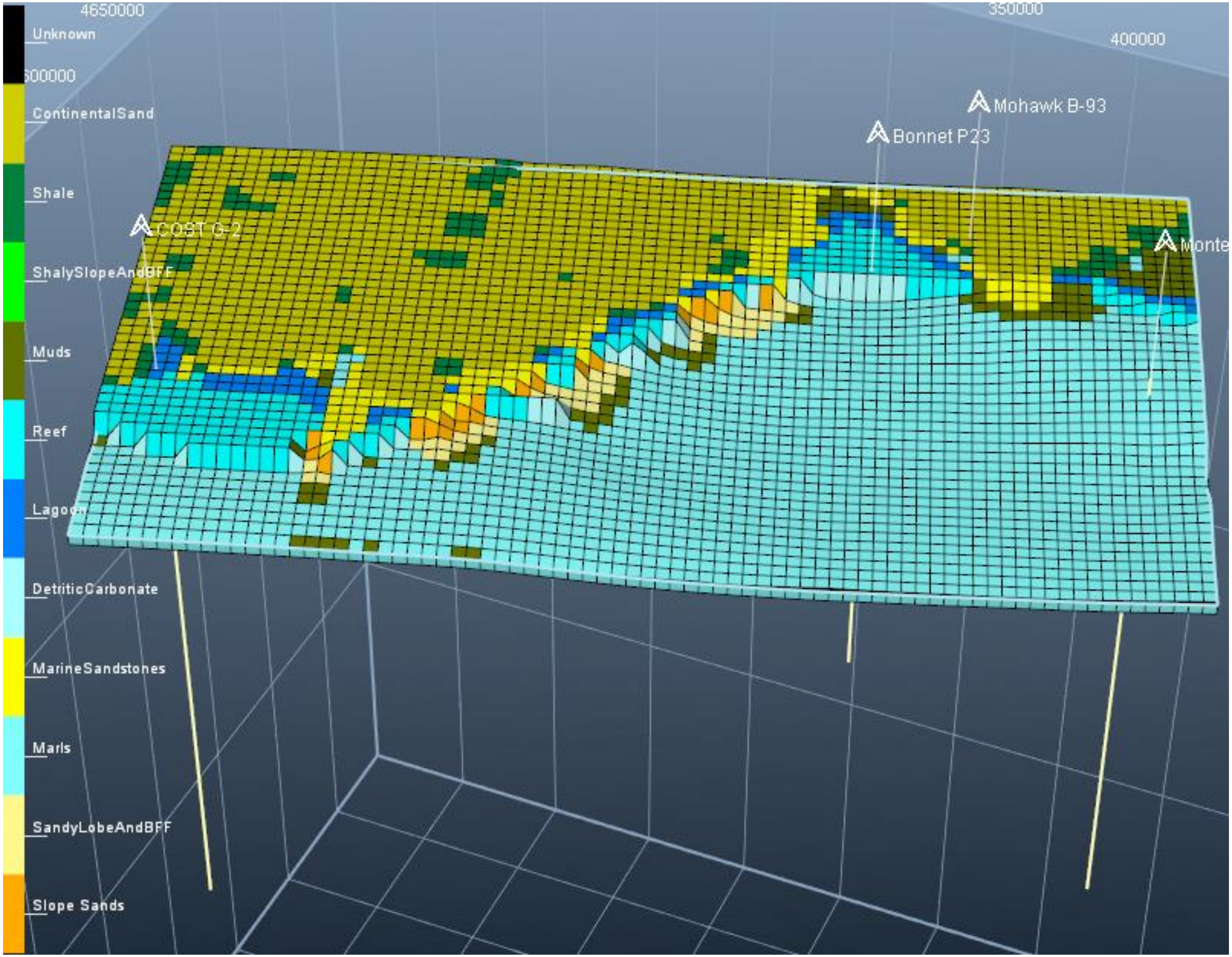


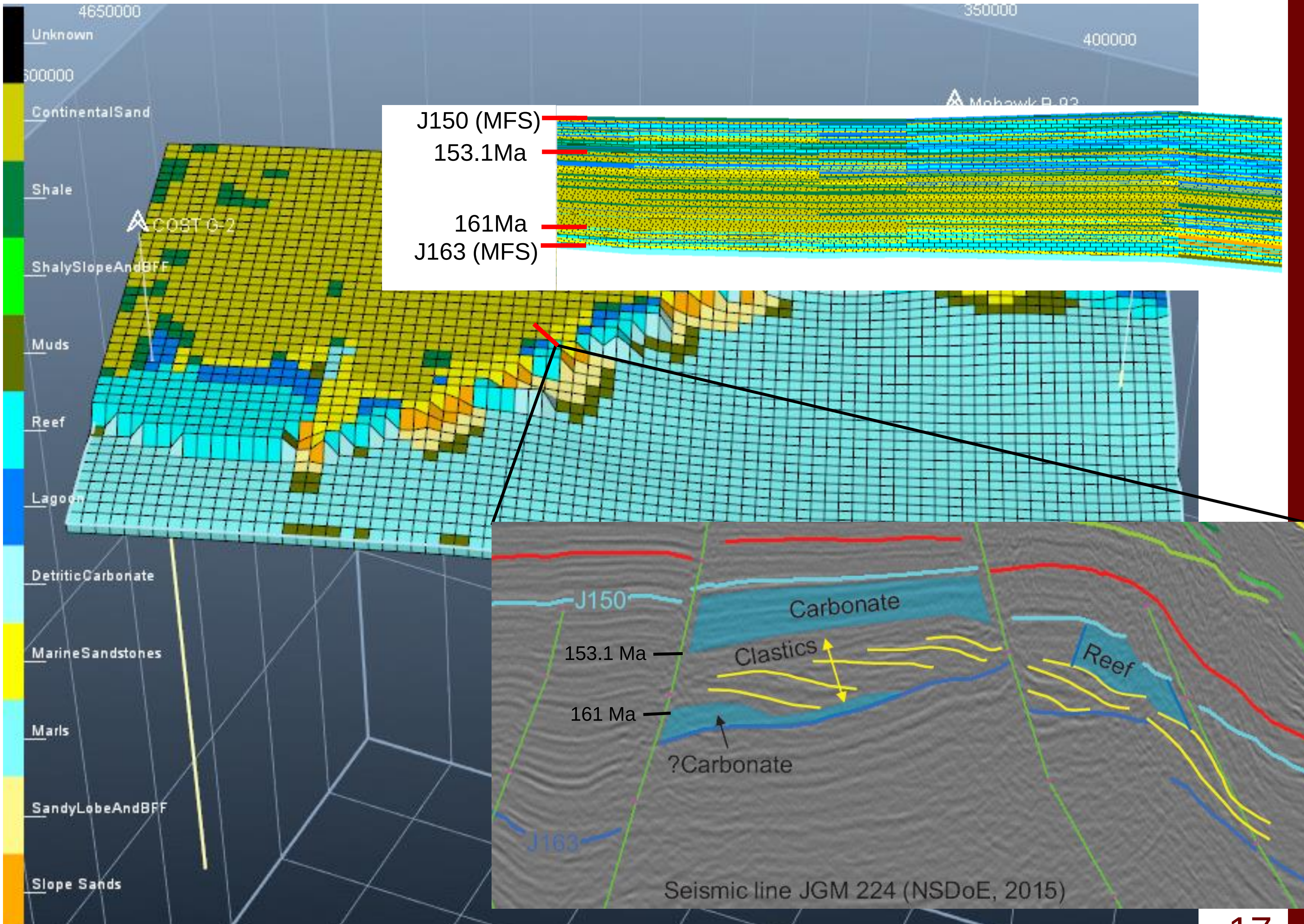

- Sand content predicted from eustasy curve

# REFERENCE CASE MODEL

# 161Ma


4650000
350000
400000
600000
Unknown
ContinentalSand
Shale
ShalySlopeAndBFF
Muds
Reef
Lagoon
DetriticCarbonate
MarineSandstones
Marls
SandyLobeAndBFF
Slope Sands
COST G-2
Bonnet P23
Mohawk B-93
Monte

# 161Ma



4650000
350000
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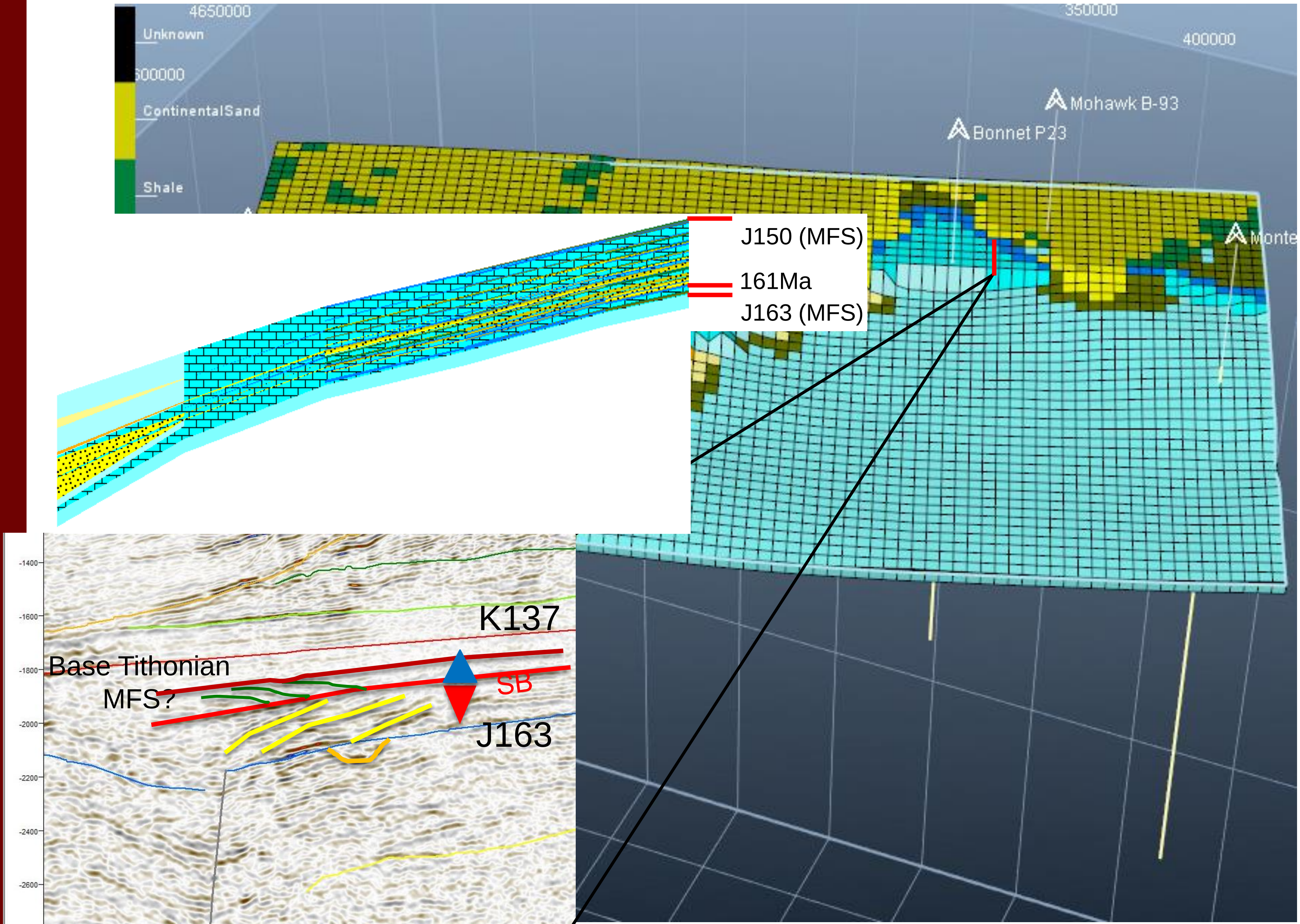
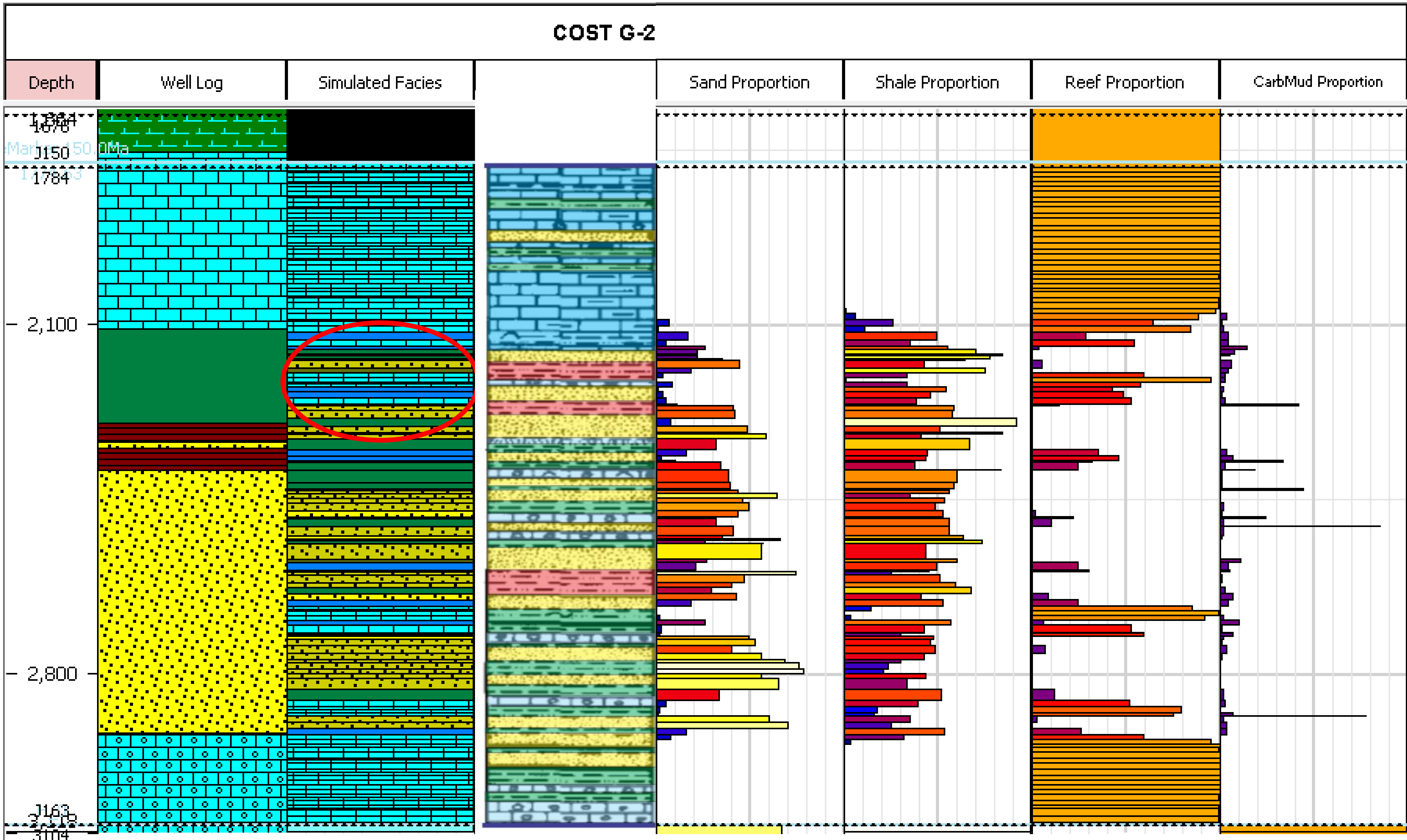
Unknown
600000
ContinentalSand
Shale
ShalySlopeAndBFF
Muds
Reef
Lagoon
DetriticCarbonate
MarineSandstones
Marls
SandyLobeAndBFF
Slope Sands
COST G-2
J150 (MFS)
153.1Ma
161Ma
J163 (MFS)
J150
Carbonate
153.1 Ma
Clastics
Reef
161 Ma
?Carbonate
J163
Seismic line JGM 224 (NSDoE, 2015)

# 161Ma

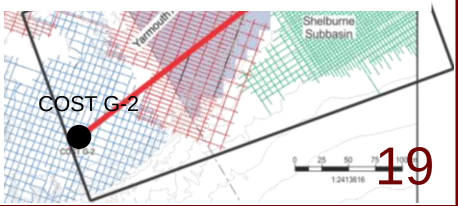


4650000
Unknown
600000
ContinentalSand
Shale
350000
400000
Mohawk B-93
Bonnet P23
Monte
J150 (MFS)
161Ma
J163 (MFS)
K137
Base Tithonian
MFS?
SB
J163
-1400
-1600
-1800
-2000
-2200
-2400
-2600

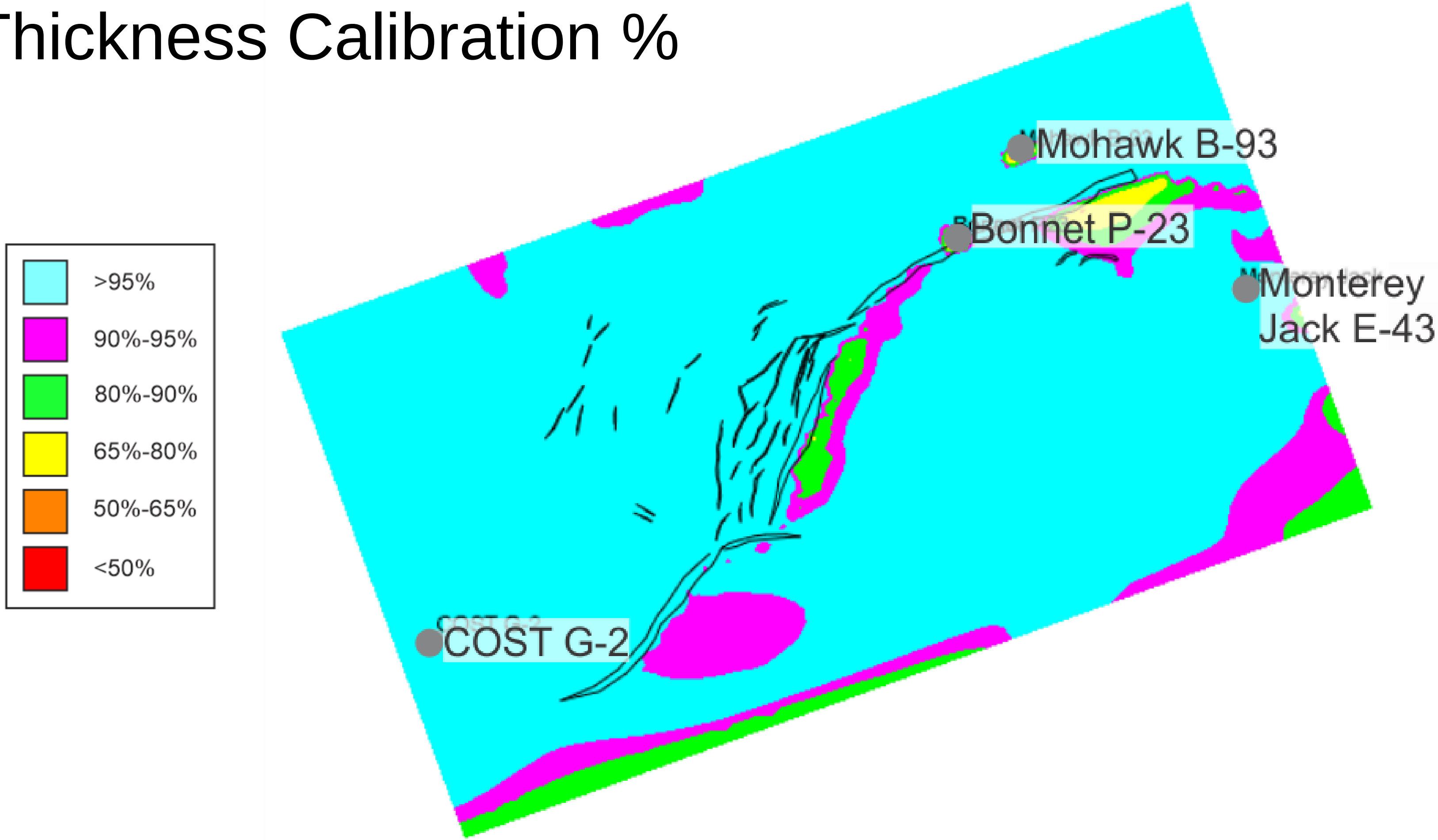
# Well Facies Calibration




| Well Thickness | Facies Calibration |
|---|---|
| 99.34 % | 67.26 % |

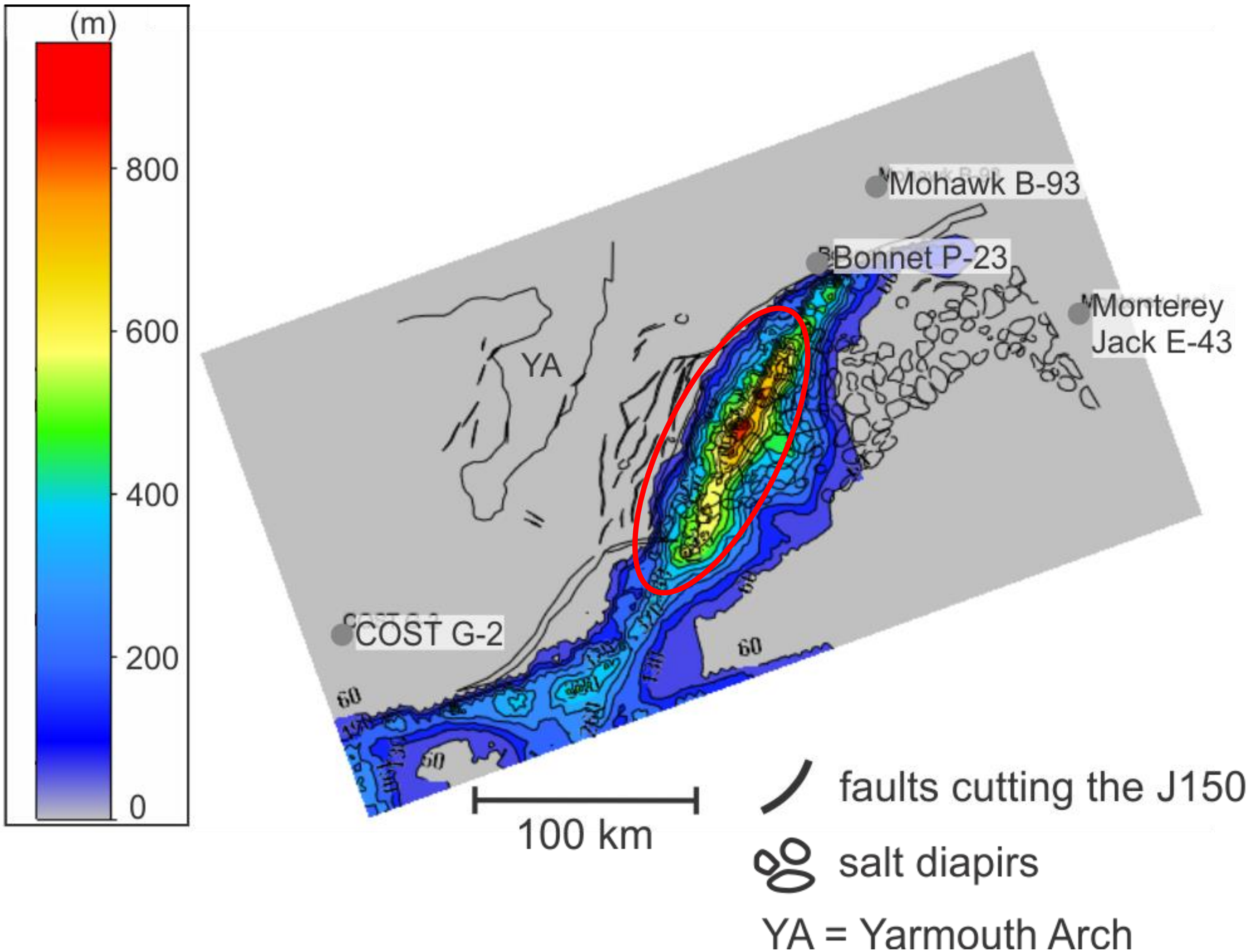


# Thickness Calibration %




- Most of the map is >90% thickness calibration. Areas with less calibration are due to the negative sources, forcing the location of the reef landward of Monterey Jack, and errors in the thickness map with actual well thickness

# Basin Floor Fan Facies Thickness 163-150Ma



# SENSITIVITY ANALYSIS

- Used to test which uncertain parameters are the most sensitive to change and the range of values for these parameters

Test the sensitivity of:

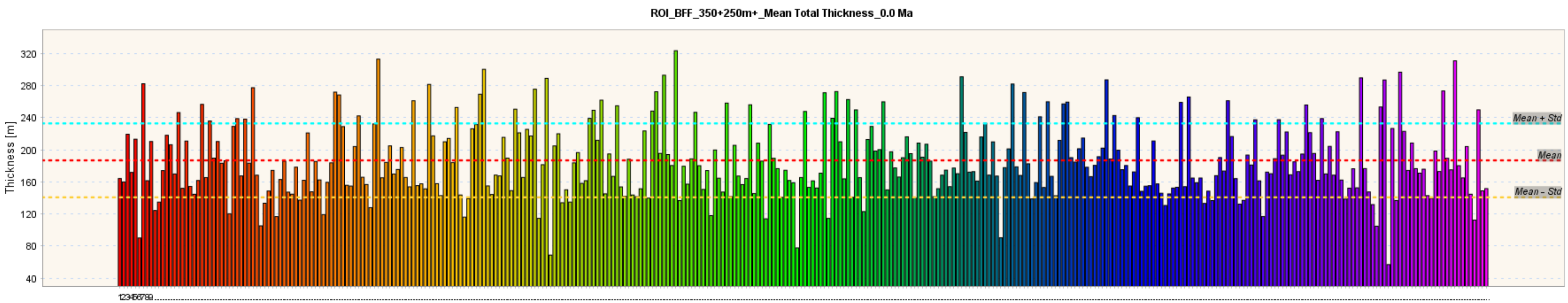
- Sand distribution
- Sequence thickness
- Basin floor fan thickness
- Reef thickness

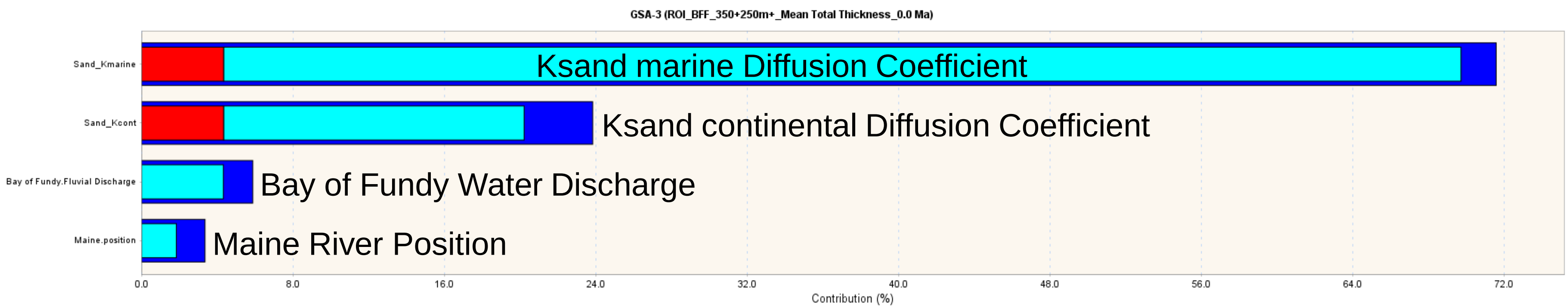
| Uncertain Parameters | Minimum Value | Maximum Value |
|---|---|---|
| Initial Bathymetry | +32% | - |
| Bay of Fundy Water Discharge | -20% | +50% |
| Maine Water Discharge | -20% | +50% |
| Meguma Water Discharge | -20% | +50% |
| Bay of Fundy Source Location | -30km | +30km |
| Maine Source Location | -30km | +30km |
| Meguma Source Location | -30km | +30km |
| Bay of Fundy Sediment Proportion | -20% | +20% |
| Maine Sediment Proportion | -20% | +20% |
| Meguma Sediment Proportion | -20% | +20% |
| Production vs Time | -20% | +20% |
| Sand Kcontinental | 20 | 2000 |
| Sand Kmarine | 0.05 | 5 |
| HEST/LELT ratio | 1.6 | 10 |
| Eustasy Curve | -20% | +20% |

# Basin Floor Fans Facies Thickness

*Greater than 250m water depth

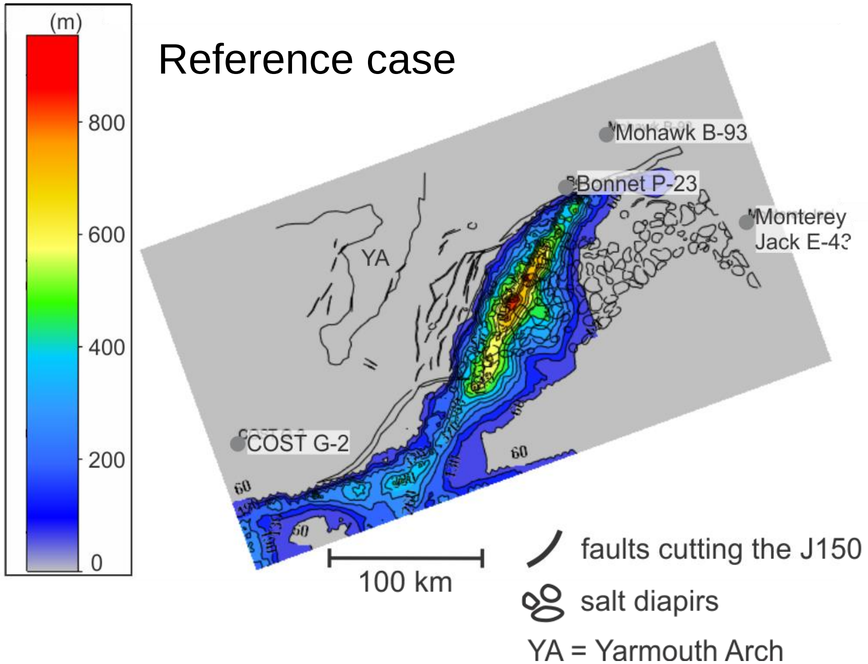
- 350 simulations
- Mean thickness ~ 190 m

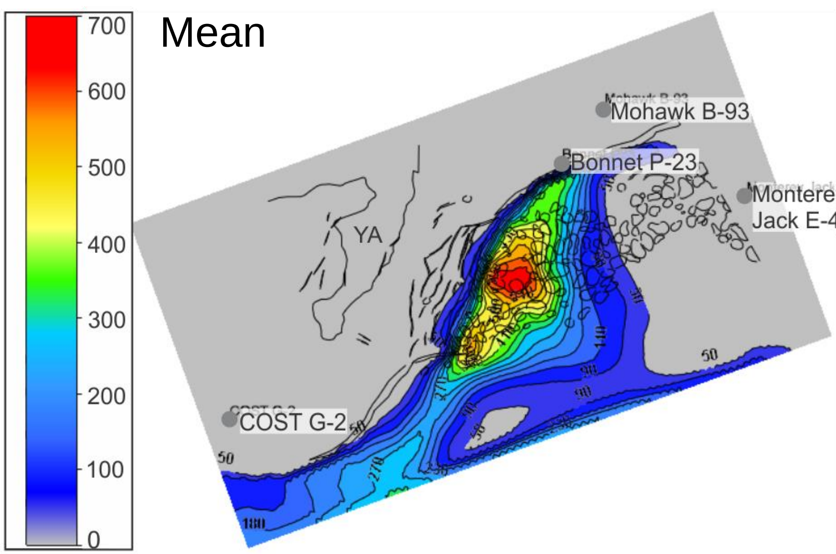


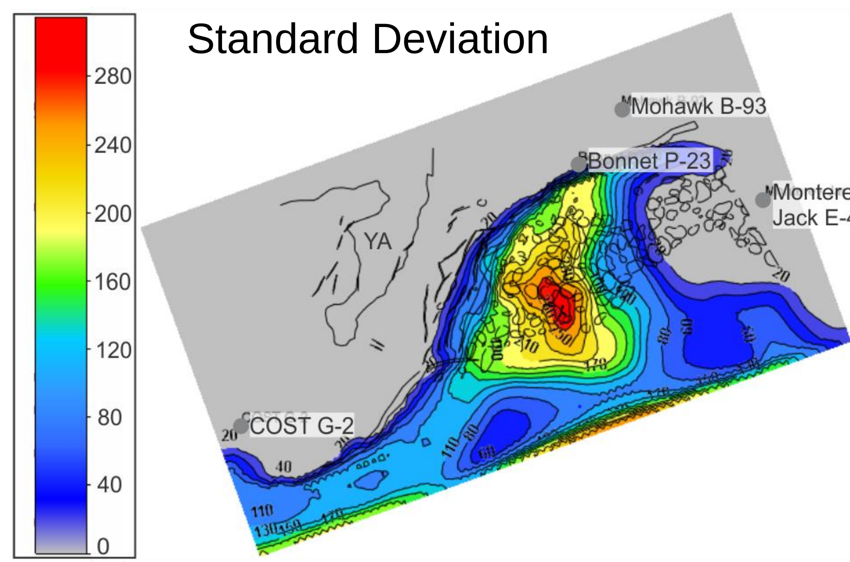



# CougarFlow results for 350 simulations

Basin floor fan facies thickness (m)

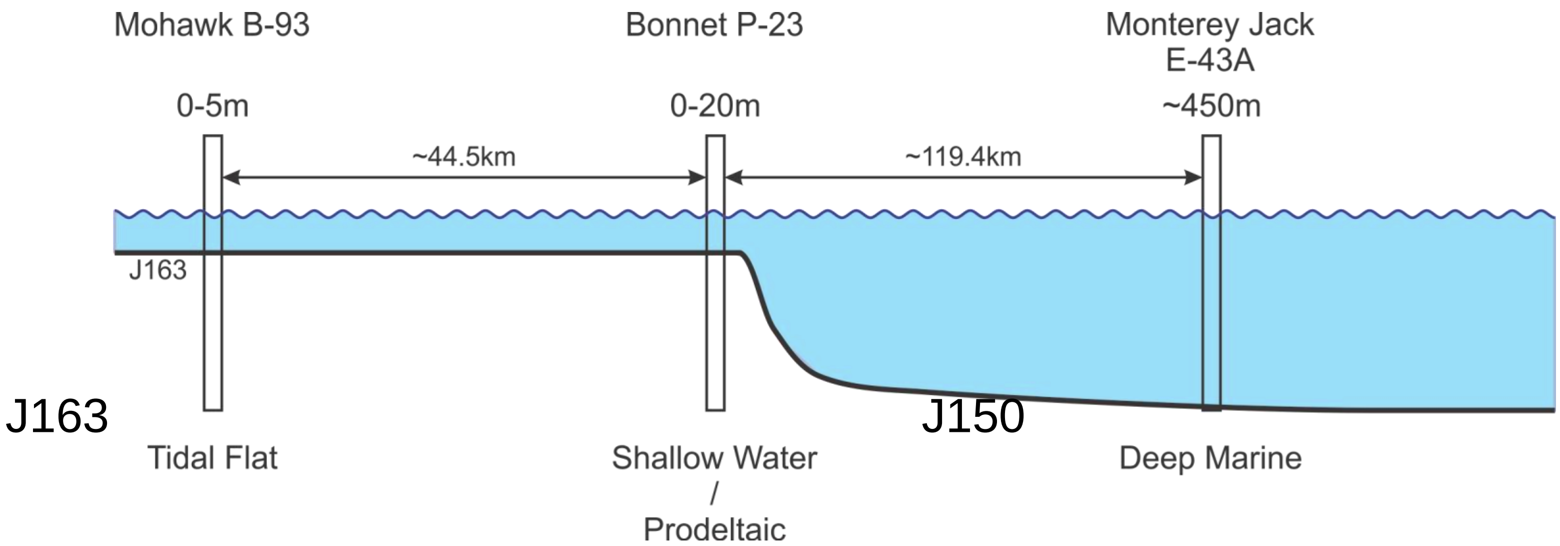


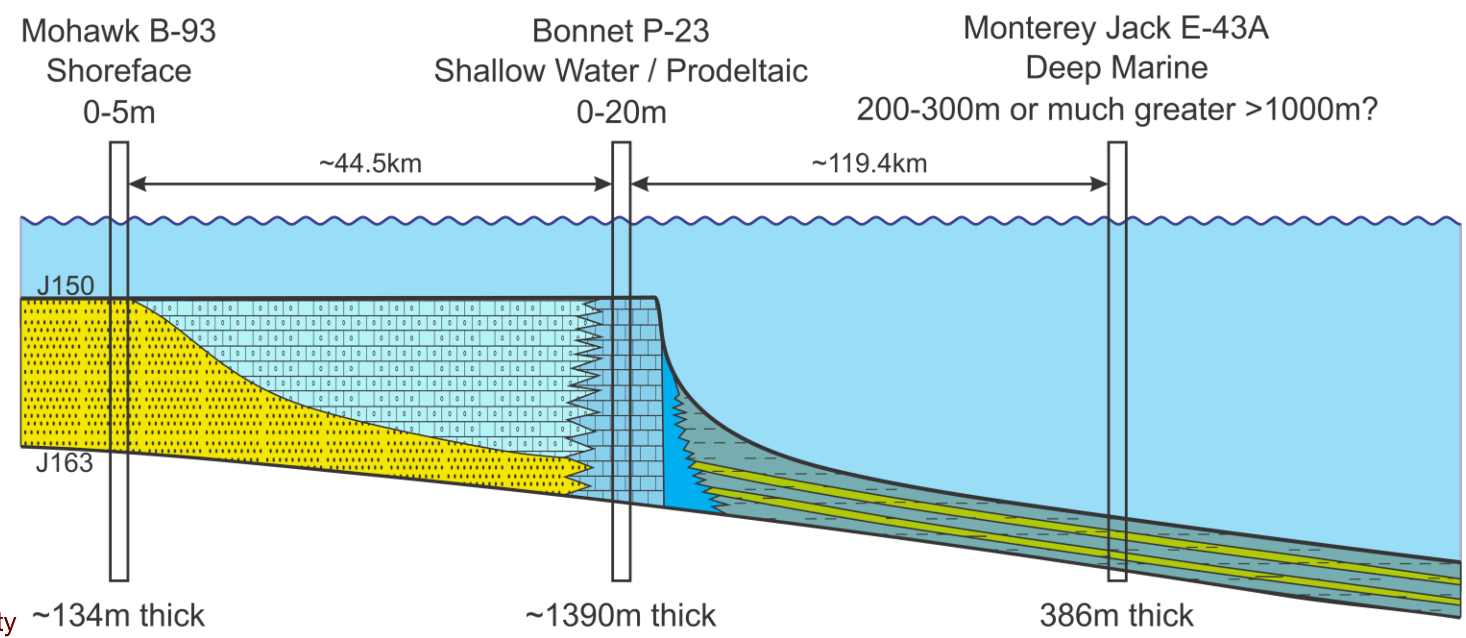



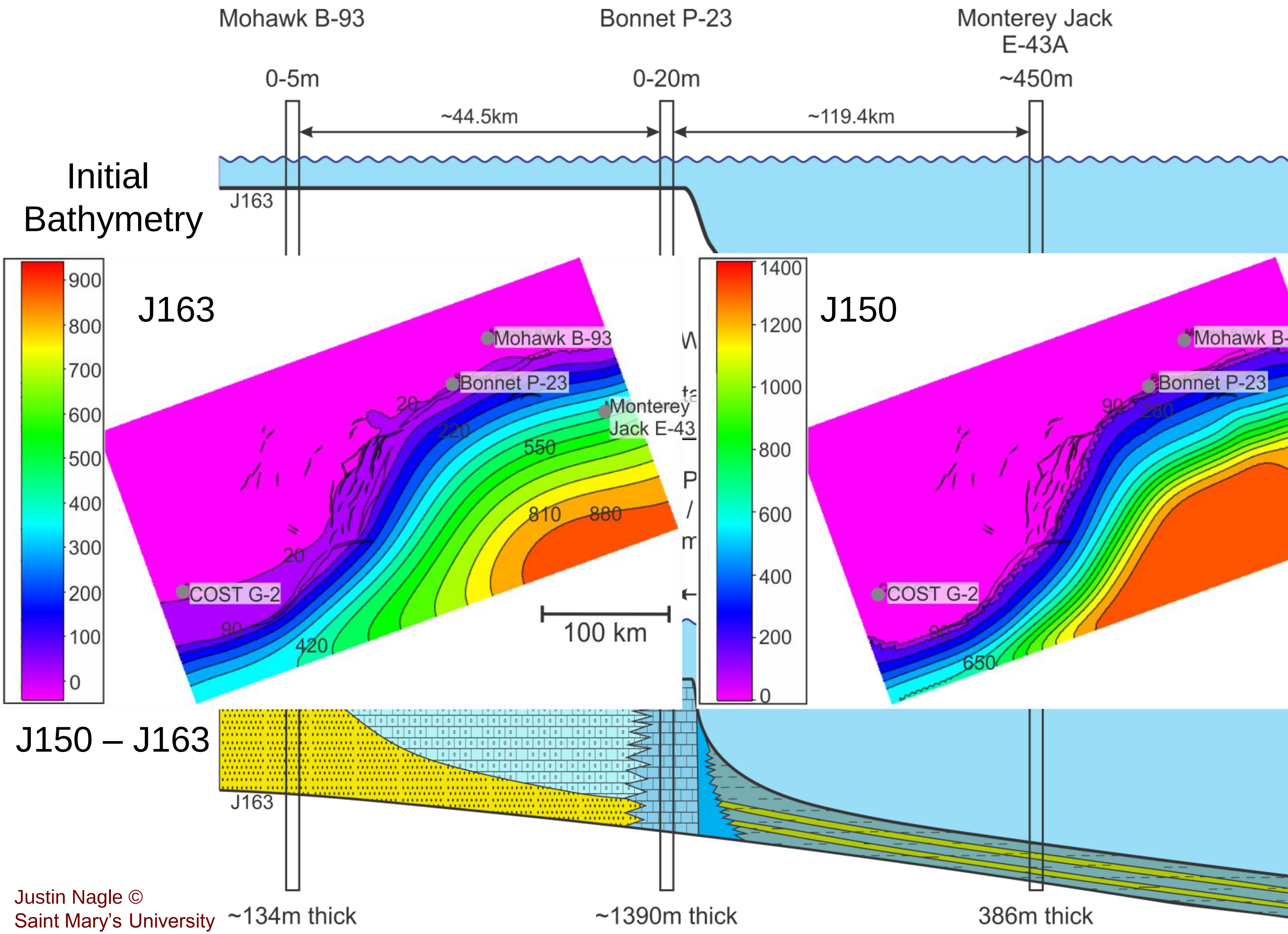
# DIFFERENT BATHYMETY

# Model B – Persistent Reef



# Model B – Persistent Reef

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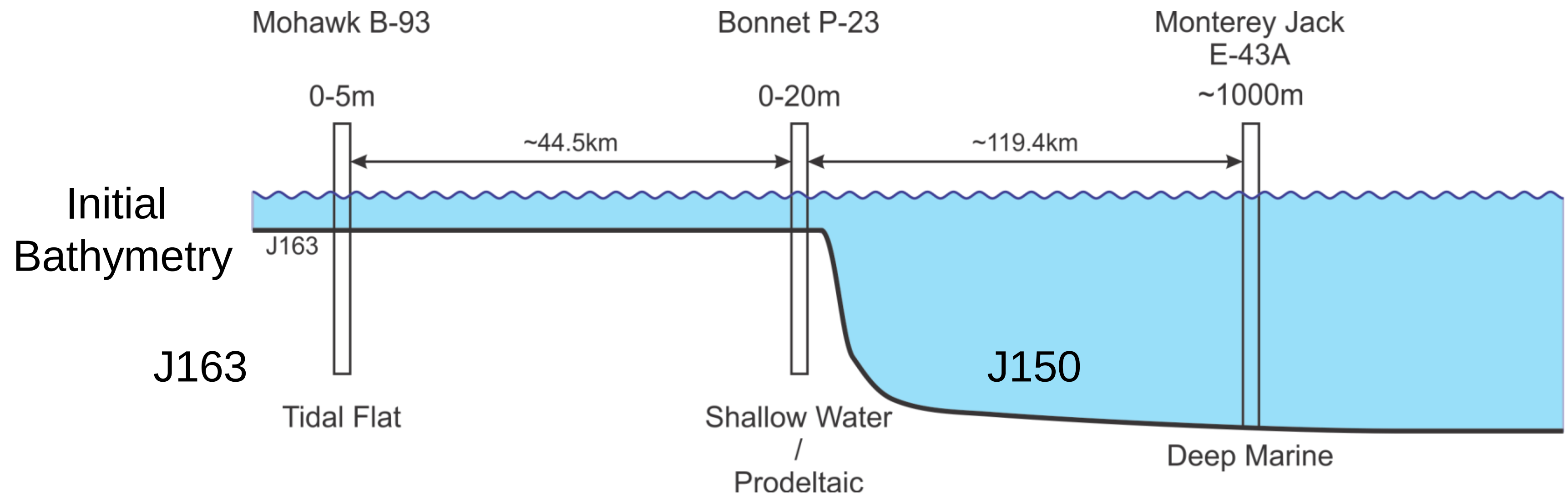
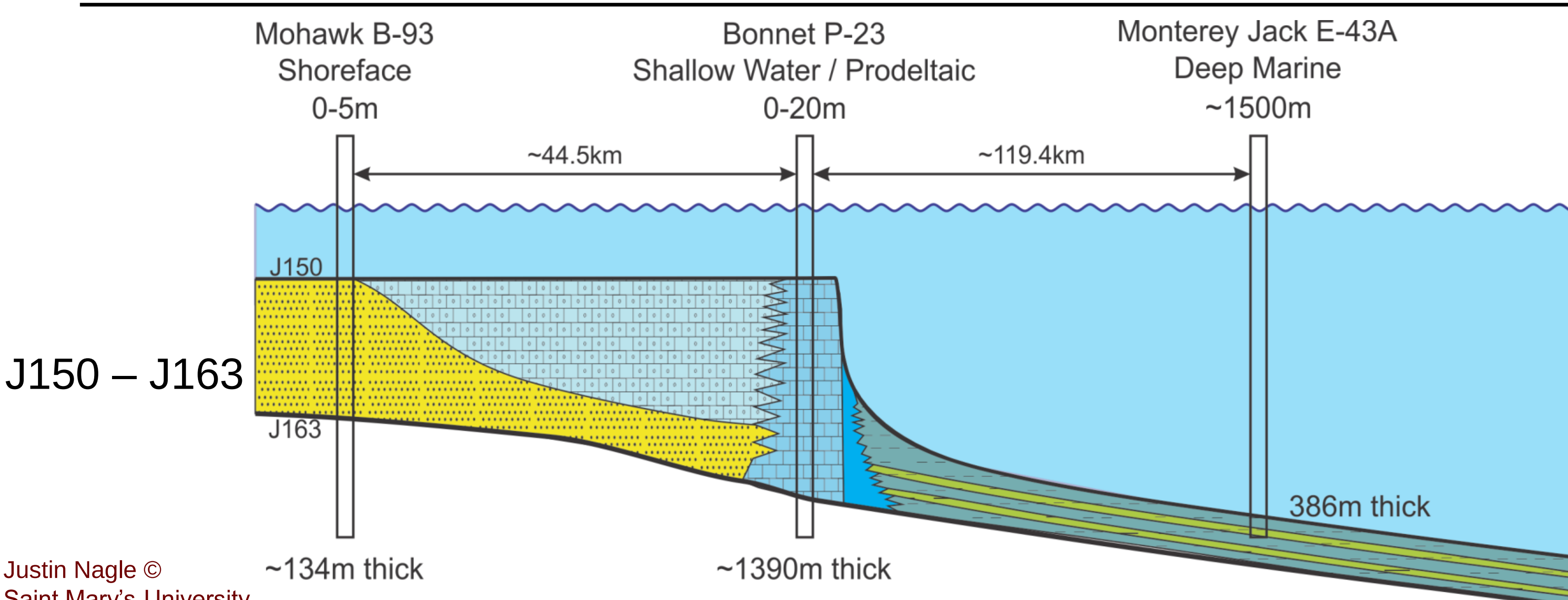
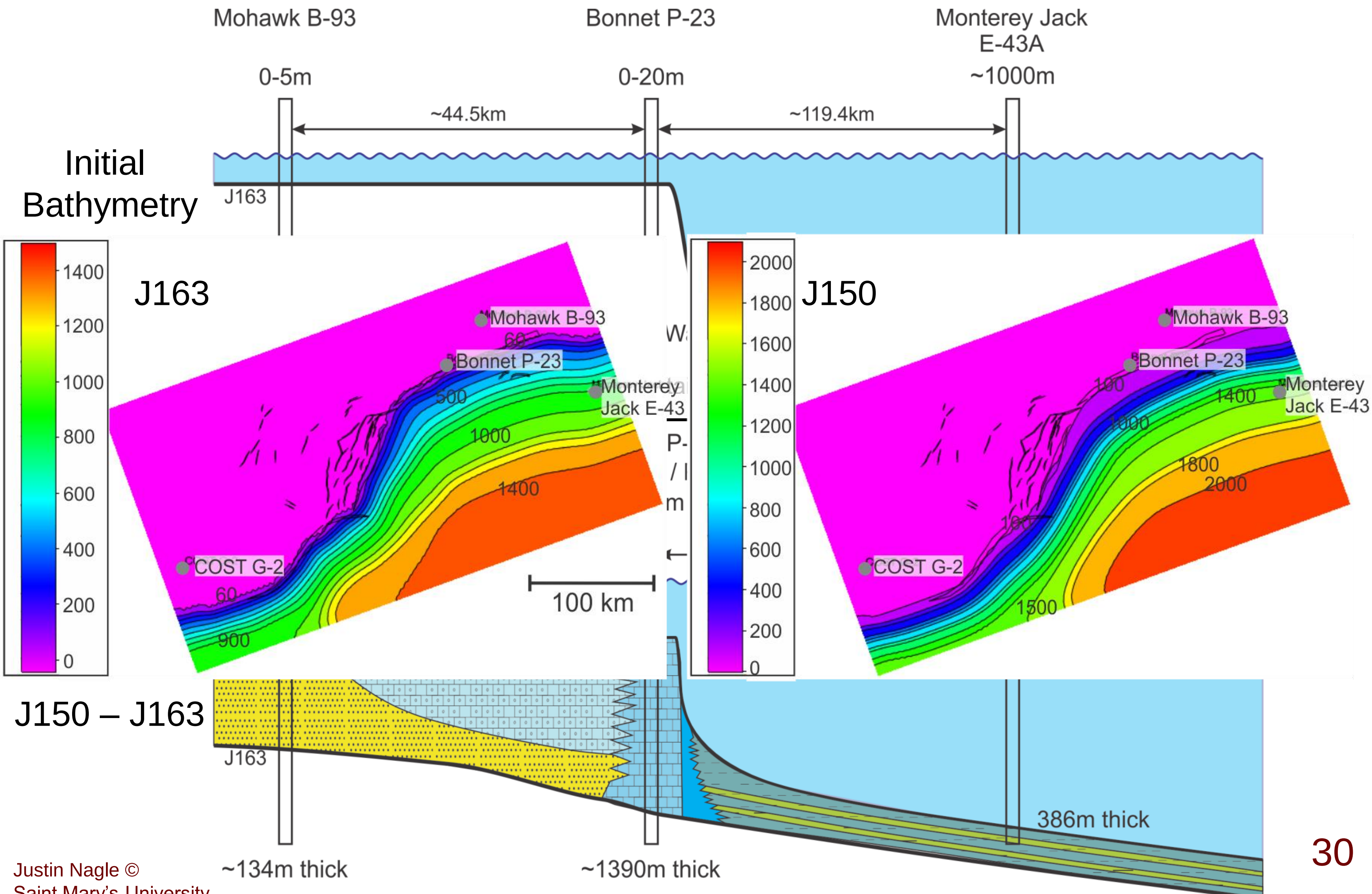
# Model C – Deep Basin

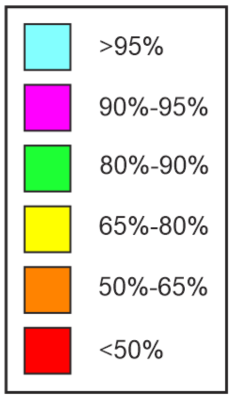


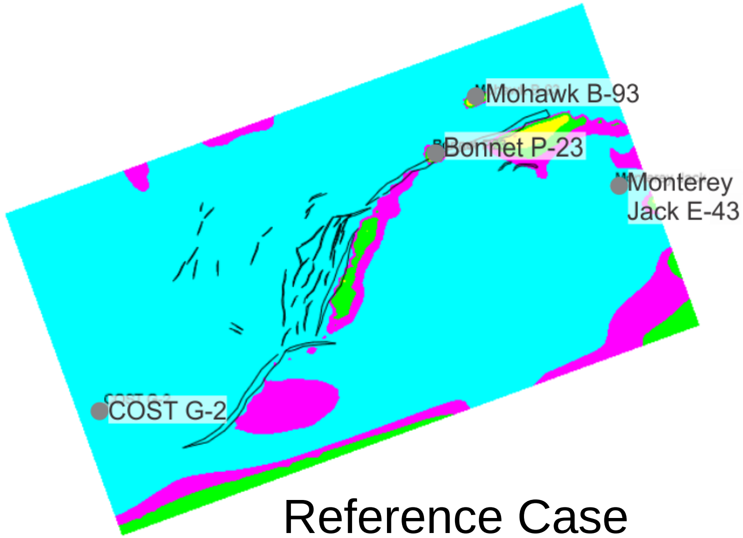



# Model C – Deep Basin

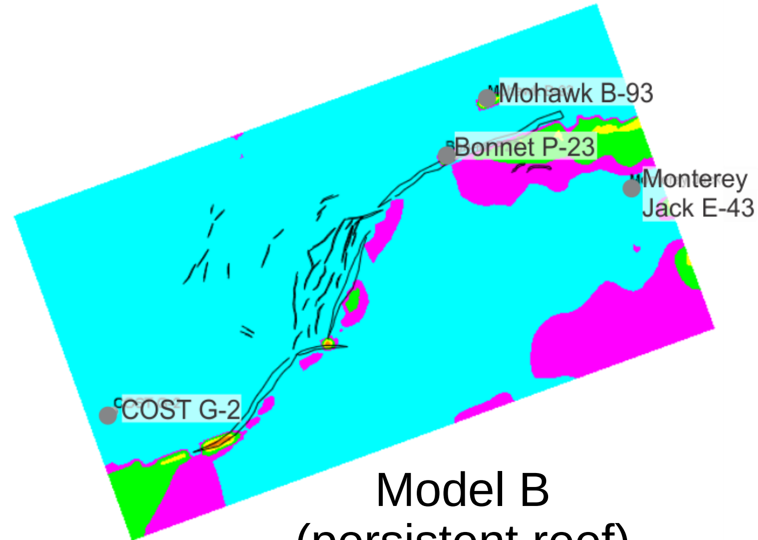


# Thickness Calibration % (J163-J150)

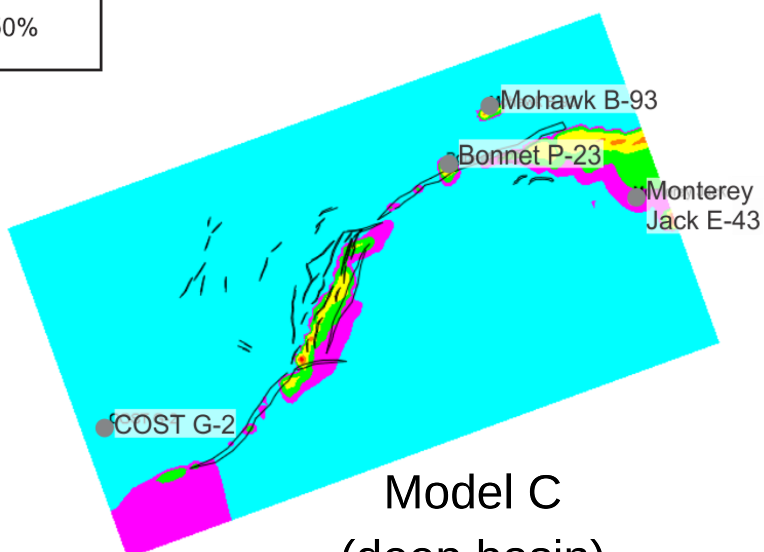



Reference Case



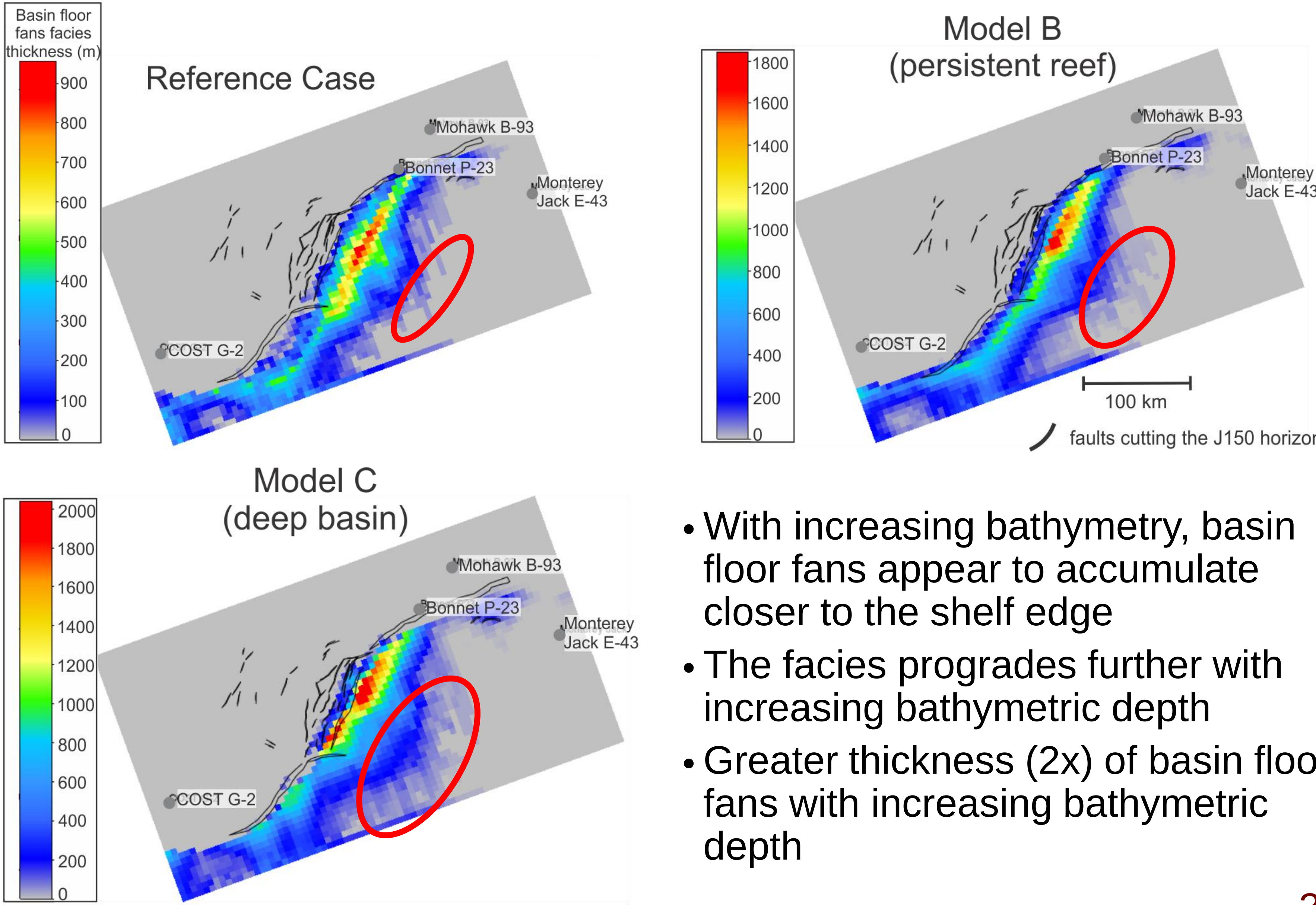

Model B
(persistent reef)




Model C
(deep basin)

- Models show very high thickness calibration, except in areas where the reef has been forced, the location of the negative source, and at wells where reported thicknesses were respected
- In general, all models show greater than 90% thickness calibration

# Basin Floor Fan Facies Thickness (m) J163-J150




- With increasing bathymetry, basin floor fans appear to accumulate closer to the shelf edge
- The facies progrades further with increasing bathymetric depth
- Greater thickness (2x) of basin floor fans with increasing bathymetric depth

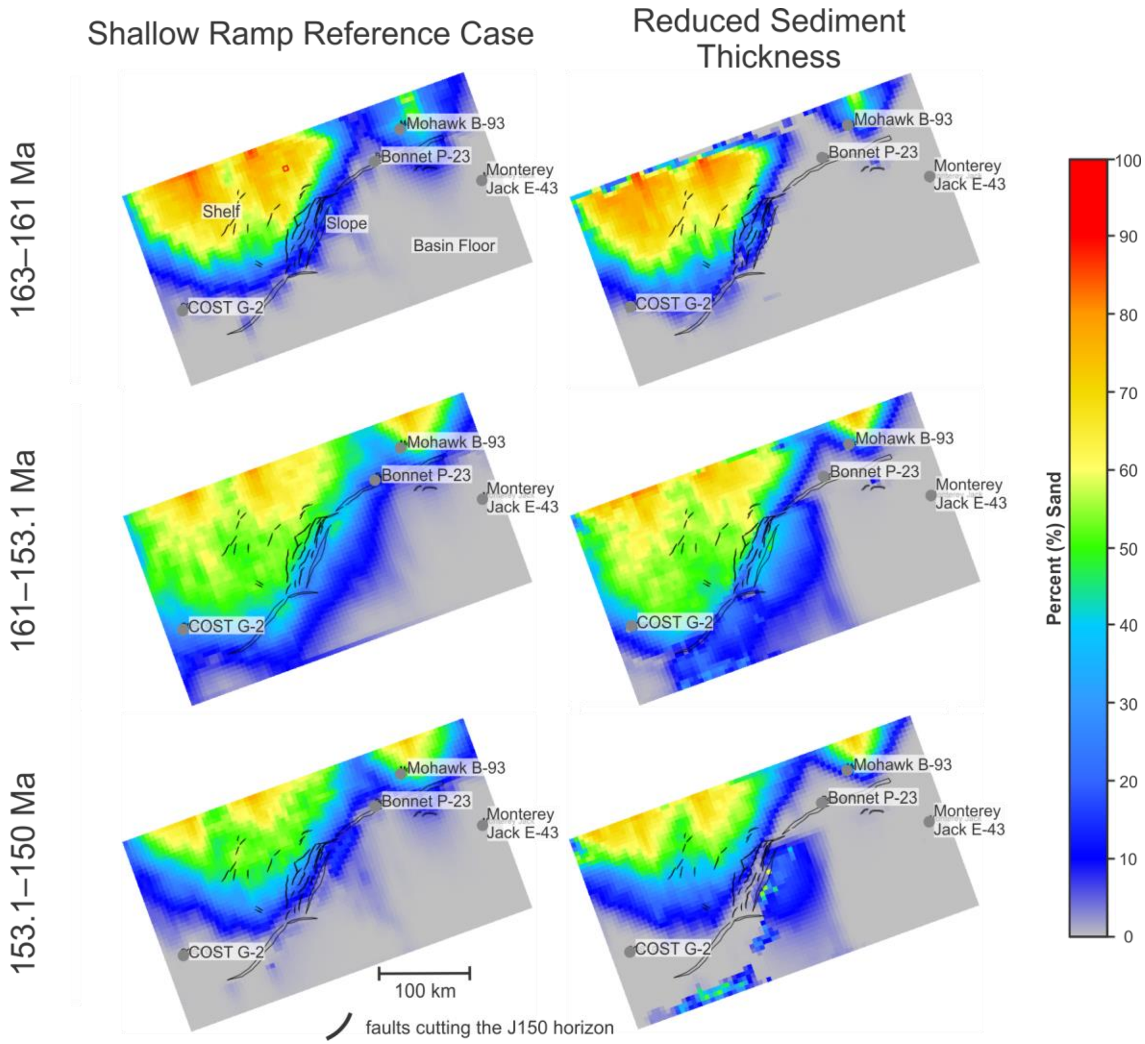
# CONCLUSIONS

- Modeling of the SW Scotian Basin is possible with data from sparse wells and limited seismics.
- The Yarmouth Transform was an important feature that allowed for a carbonate ramp environment at the J163 and helped focus drainage from the hinterlands to the area of the Shelburne Delta.
- The model successfully predicts basin floor fans down-dip of the Shelburne Delta, with the most probably location close to the shelf edge.

# PITFALLS WITH MODELING FRONTIER BASINS

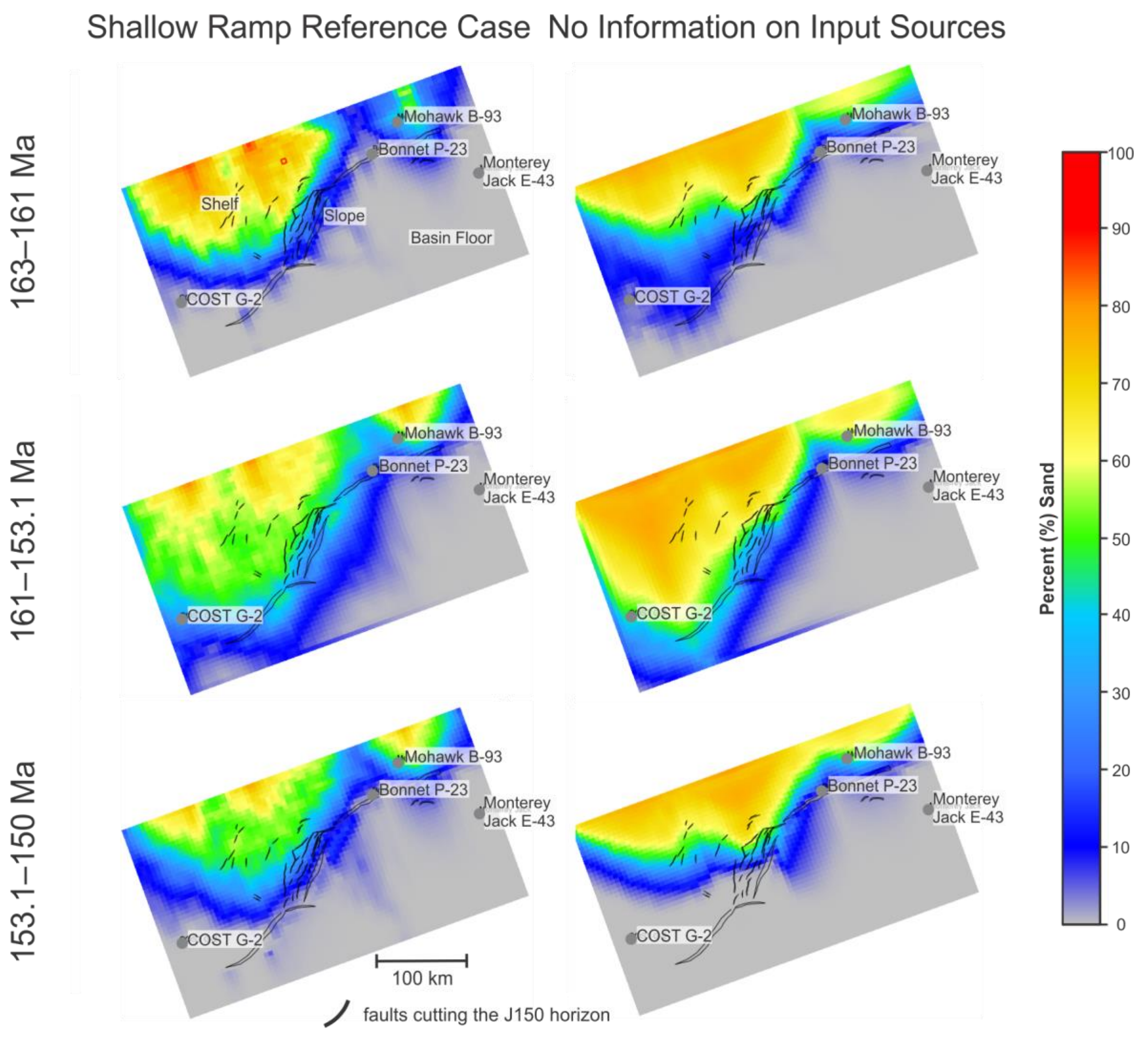
# Wrong Seismic Pick

- Reduced sediment thickness of modeled interval by ~65 %
- Model required reduced sediment supply, hemipelagic sedimentation rates, and subsidence
- At the first phase of sedimentation (163-161 Ma) the majority of sand is found on the shelf



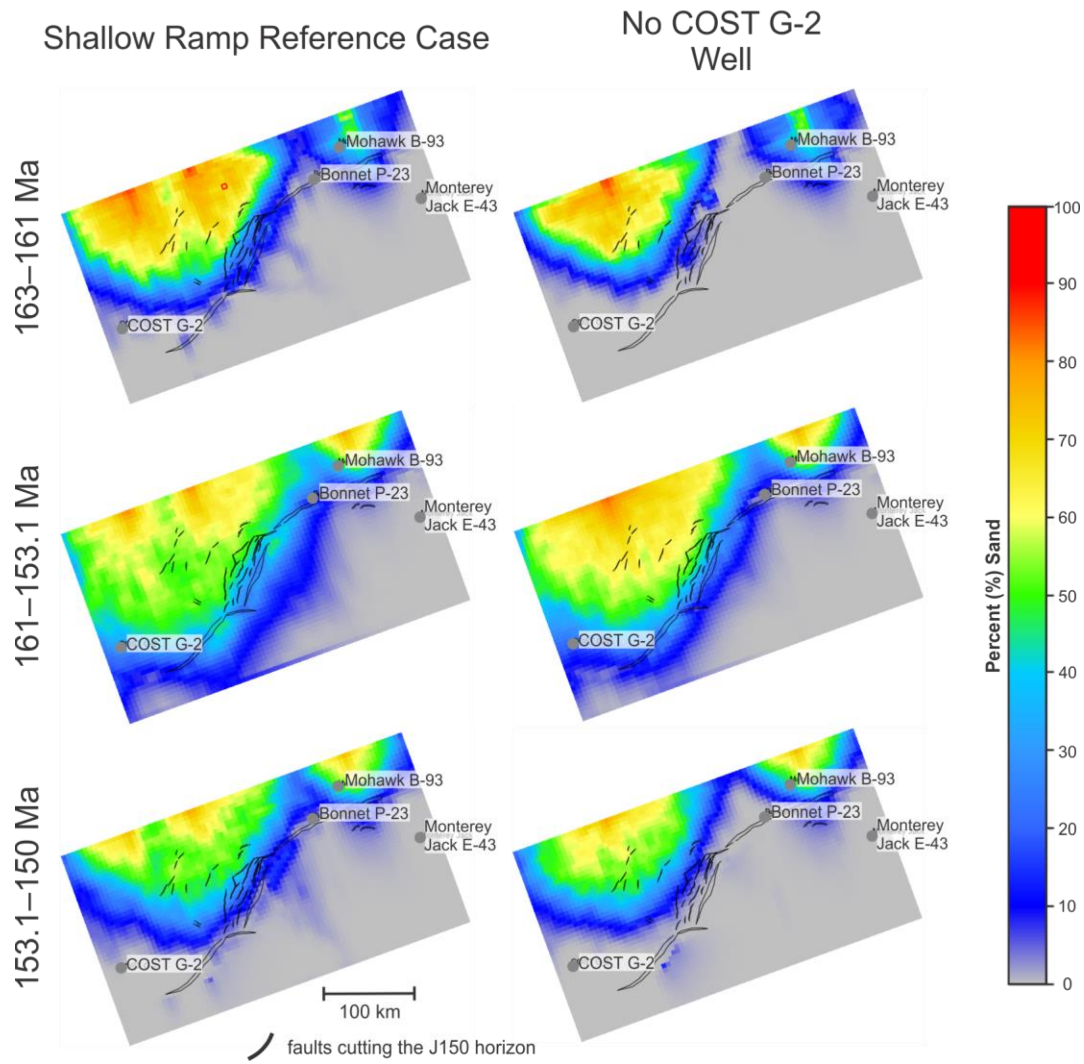
# No Information on Sources

- Three river systems are required to maintain calibration
- Rivers are relatively constant throughout the model duration at ~50 % sand and ~50 % mud.
- Sedimentation is more uniform in distribution

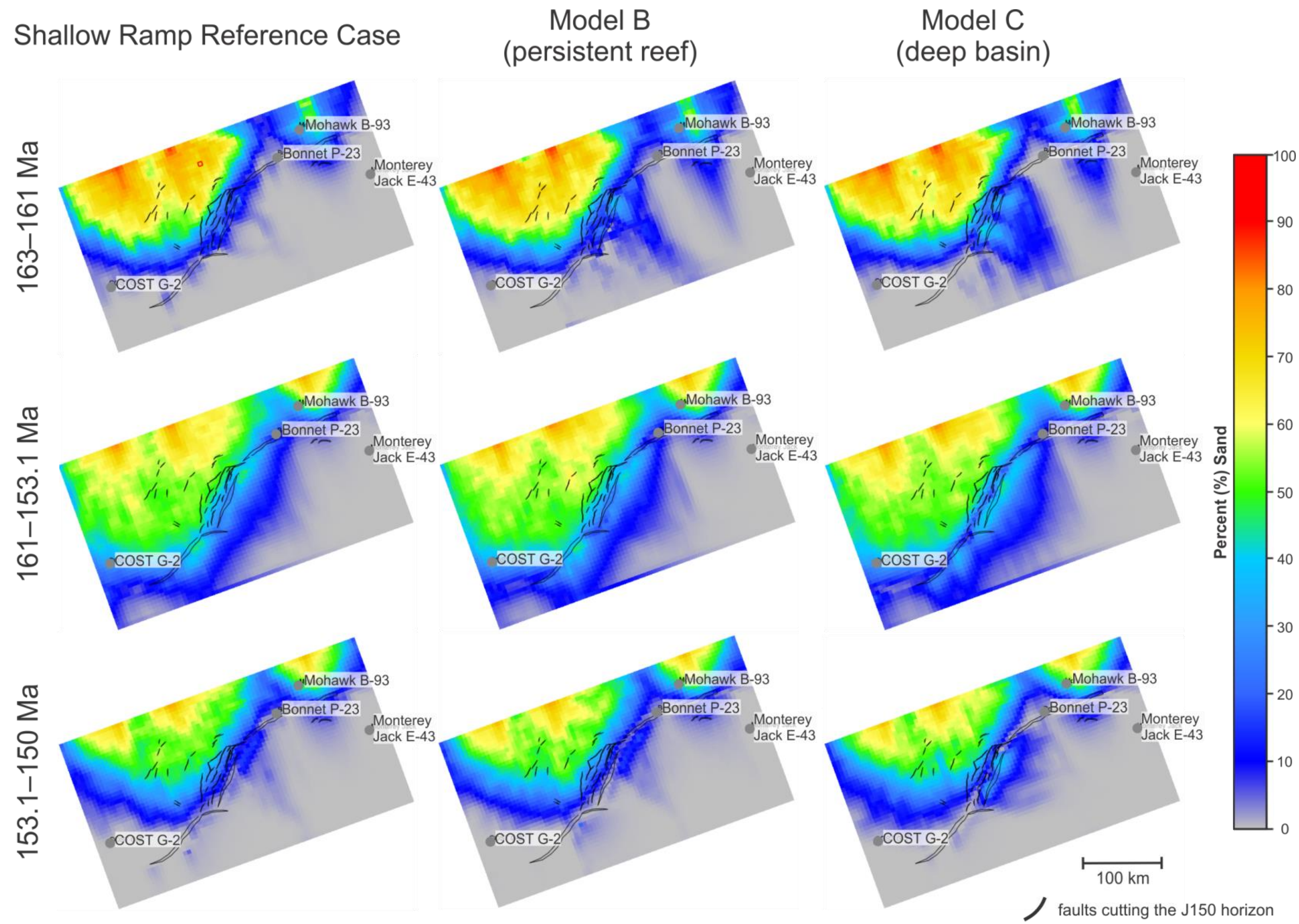


# No Information on COST G-2

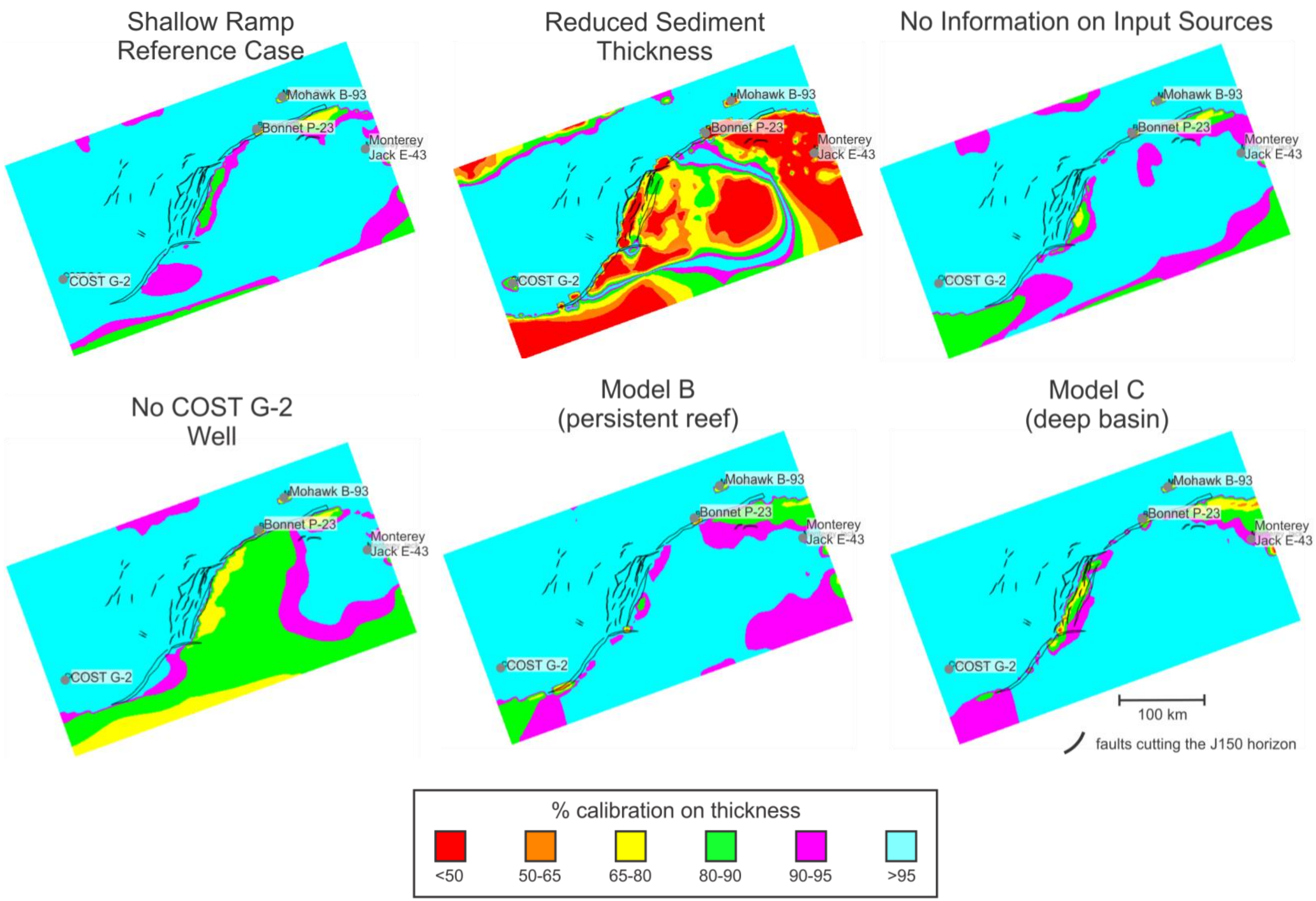
- Only two river systems are required for calibration
- The Bay of Fundy source required slightly more water discharge and sediment load
- No sand progrades from the Shelburne Delta into deep-water for the first phase of sedimentation
- Slightly more uniform in distribution on Georges Bank



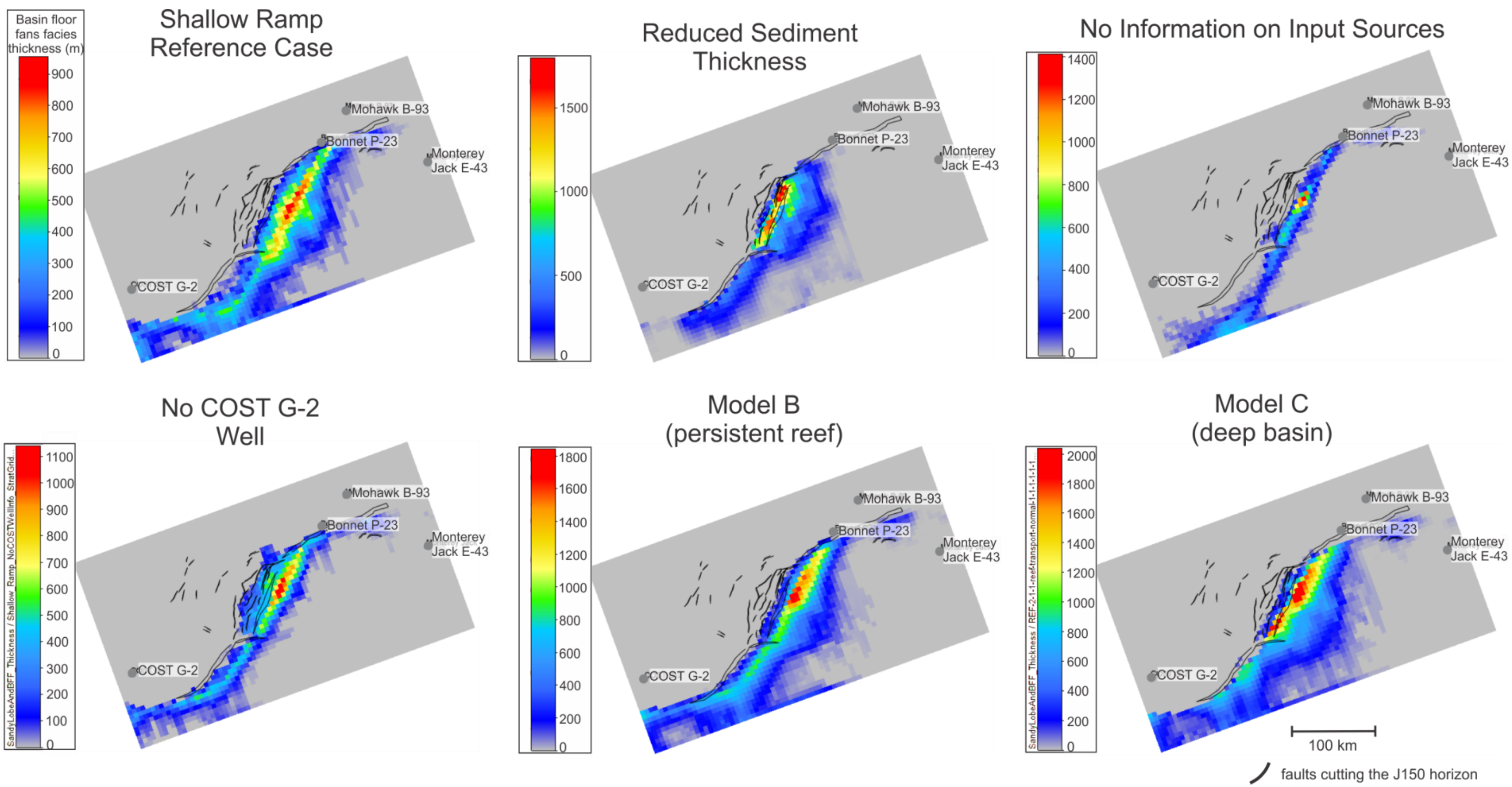
# Different Bathymetries



# Calibration Percent

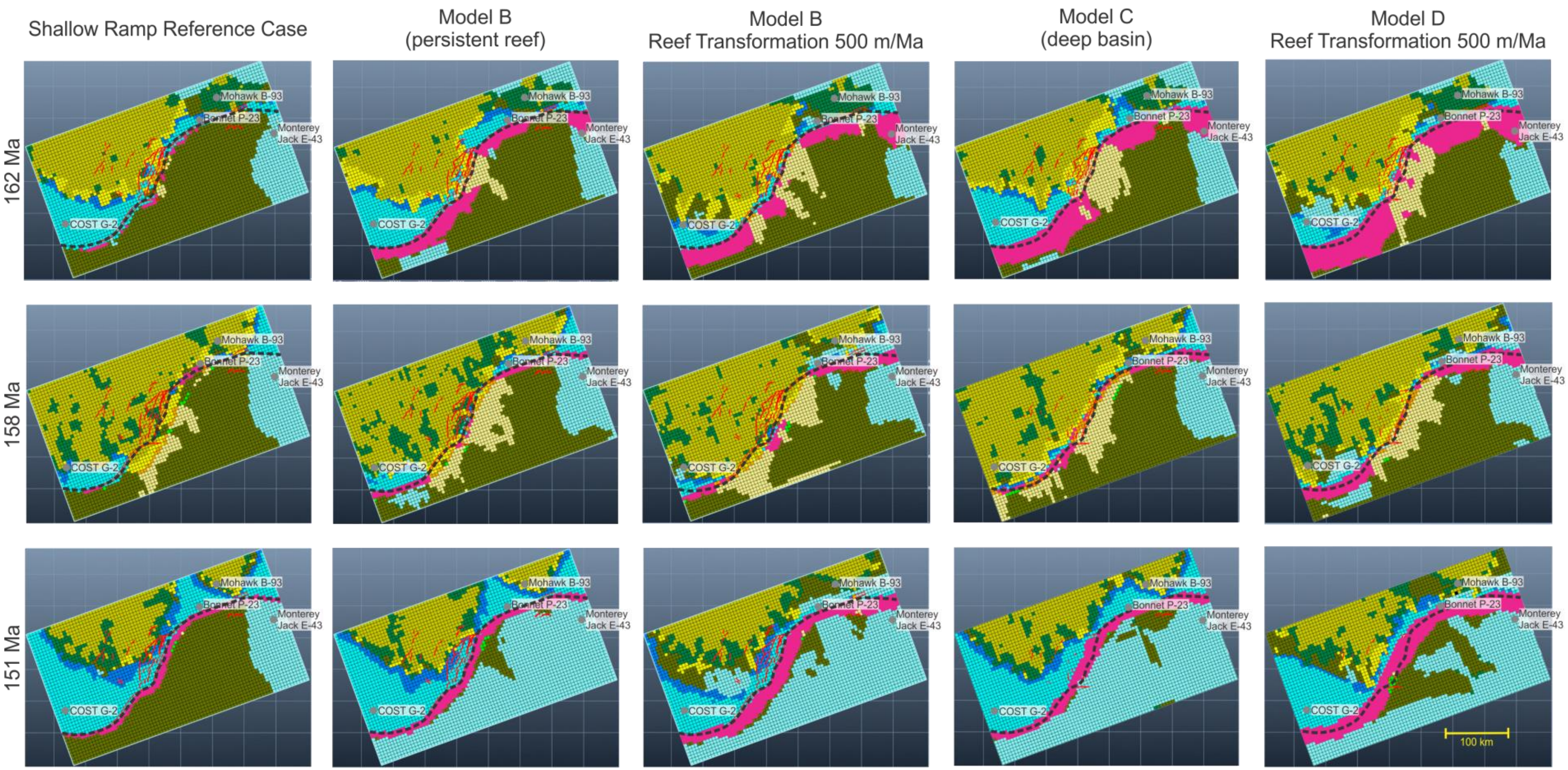


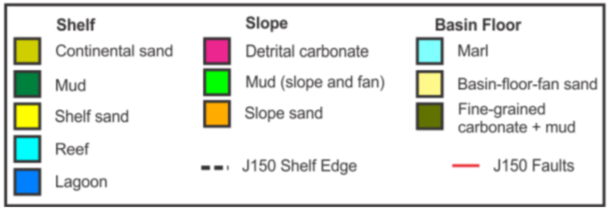
# Basin Floor Fans Facies Distribution




- Between all of the models, the best place to find deep-water sand in the basin appears to be immediately down-dip of the Shelburne Delta, close to the shelf edge

# Carbonate Extent




- With increasing water depths, reworked reef sediments are more easily transported into the basin

# CONCLUSIONS

- The most important parameters to define in frontier basins are the paleobathymetry and sediment thickness from seismic analysis
- Fine-scale control between carbonate and clastic sediments are not always possible in frontier basins
- Unconstrained models are useful when modeling frontier basins
    - They offer a first overview of the probable architecture of the basin
    - They have shorter computational run times compared to geologically constrained models

# SUMMARY AND CONCLUSIONS

Objectives

- Simulate sediment distribution in the Middle–Late Jurassic
- Observe the development of the Shelburne Delta
- Observe the impact of different initial paleobathymetries

Data

- Sediment supply, uplift, river catchment areas, and bathymetry have been well defined

Calibration

- The model is well calibrated for thickness and facies distribution
- Clastic sediments tend to be found on the shelf
- Sediment bypassing the reef occurs near the Shelburne Delta, or large canyon near Mohawk B-93

Sensitivity Analysis

- Most sensitive parameters are the diffusion coefficients for sand, water discharge values for the Bay of Fundy river system, and the position of the Maine river system

Reduced Exploration Risk

- The most probably location to find sand in the basin is down-dip of the Shelburne Delta, close to the shelf edge

Pitfalls of Stratigraphic Modeling

- Modeling of frontier basins is possible even with limited information from sparse wells, seismic analysis, and lithofacies interpretation
  - Fine-scale interaction between carbonate and clastic sediments is not always possible

# Acknowledgements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  - Adam MacDonald
  - Natasha Morrison
- Beicip-Franlab

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OERA Offshore Energy Research Association

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Department of Energy

NSERC CRSNG

# References

Amato, R. V, and Simonis, E.K. 1980. Geologic and Operational Summary, Cost no. G-2 well, Georges Bank area, North Atlantic OCS. U.S. Geological Survey Open-File Report 80–269.

Chavez, I., Pe-Piper, G., Piper, D.J.W., and MacRae, R.A. 2019. Late Mesozoic sediment provenance on Georges Bank: enlargement of drainage to the Atlantic Ocean in the Late Jurassic – Early Cretaceous. AAPG Bulletin, **103**(6), 1321–1350.

Deptuck, M.E., Brown, D.B., and Altheim, B. 2015. Call for Bids NS15-1 – Exploration history, geological setting, and exploration potential: Western and Central regions. CNSOPB Geoscience Open File Report, 2015-001MF, 49 p.

Dutuc, D.C., Pe-Piper, G., and Piper, D.J.W. 2017. The provenance of Jurassic and Lower Cretaceous clastic sediments offshore southwestern Nova Scotia. Canadian Journal of Earth Sciences, **54**(1), 33–51.

Haq, B.U. 2014. Cretaceous eustasy revisited. Global and Planetary Change, **113**: 44–58. Elsevier B.V. doi:10.1016/j.gloplacha.2013.12.007.

Li, G., Pe-Piper, G., and Piper, D.J.W. 2012. The provenance of Middle Jurassic sandstones in the Scotian Basin: petrographic evidence of passive margin tectonics. Canadian Journal of Earth Sciences, **49**: 146–1477.

MacDonald, A. 2011. Play Fairway Analysis – Shelburne Delta. Available at: https://energy.novascotia.ca/sites/default/files/AAPG%2BSeminar%2B-%2BAdam%2BMacDonald.pdf

Milliman, J.D., and Syvitski, J.P.M. 1992. Geomorphic / Tectonic Control of Sediment Discharge to the Ocean : The Importance of Small Mountainous Rivers. Journal of Geology, **100**: 525–544.

NSDoE 2015. South West Nova Scotia Expansion. Report to Nova Scotia Department of Energy. Available at: https://energy.novascotia.ca/oil-and-gas/offshore/play-fairway-analysis/analysis/Shelburne-basin.

Pierre, A., Durlet, C., Razin, P., and Chellai, E.H. 2010. Spatial and temporal distribution of ooids along a Jurassic carbonate ramp: Amellago outcrop transect, High-Atlas, Morocco. Geological Society Special Publication, **329**: 65–88.

Tsikouras, B., Pe-Piper, G., Piper, D.W.J., and Schaffer, M. 2011. Varietal heavy mineral analysis of sediment provenance, Lower Cretaceous Scotian Basin, eastern Canada. Sedimentary Geology, **237**: 150–165.

Wade, J.A. and MacLean, B.C. 1990. Aspects of the geology of the Scotian Basin from recent seismic and well data. *In* Geology of the Continental Margin of Eastern Canada. Edited by M.J. Keen and G.L. Williams. Geology of Canada, **2**: pp. 182–186.

Weston, J.F., MacRae, R.A., Ascoli, P., Cooper, M.K.E., Fensome, R.A., Shaw, D., and Williams, G.L. 2012. A revised biostratigraphic and well-log sequence-stratigraphic framework for the Scotian Margin, offshore eastern Canada. Canadian Journal of Earth Sciences, **49**: 1417–1462. doi:10.1139/e2012-070.

Williams, H., and Grant, A.C. 1998. Tectonic assemblages, Atlantic Region, Canada. 1:3 000 000 map. Geological Survey of Canada, Open File 3657.

# QUESTIONS?