Application of Predictive Modeling to the Early Cretaceous Sedimentary Sequences of the Central Scotian Basin

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Offshore Energy Research Association

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Collaborative project between

- Saint Mary's University (SMU)
- Offshore Energy Research Association (OERA)
- Beicip-Franlab

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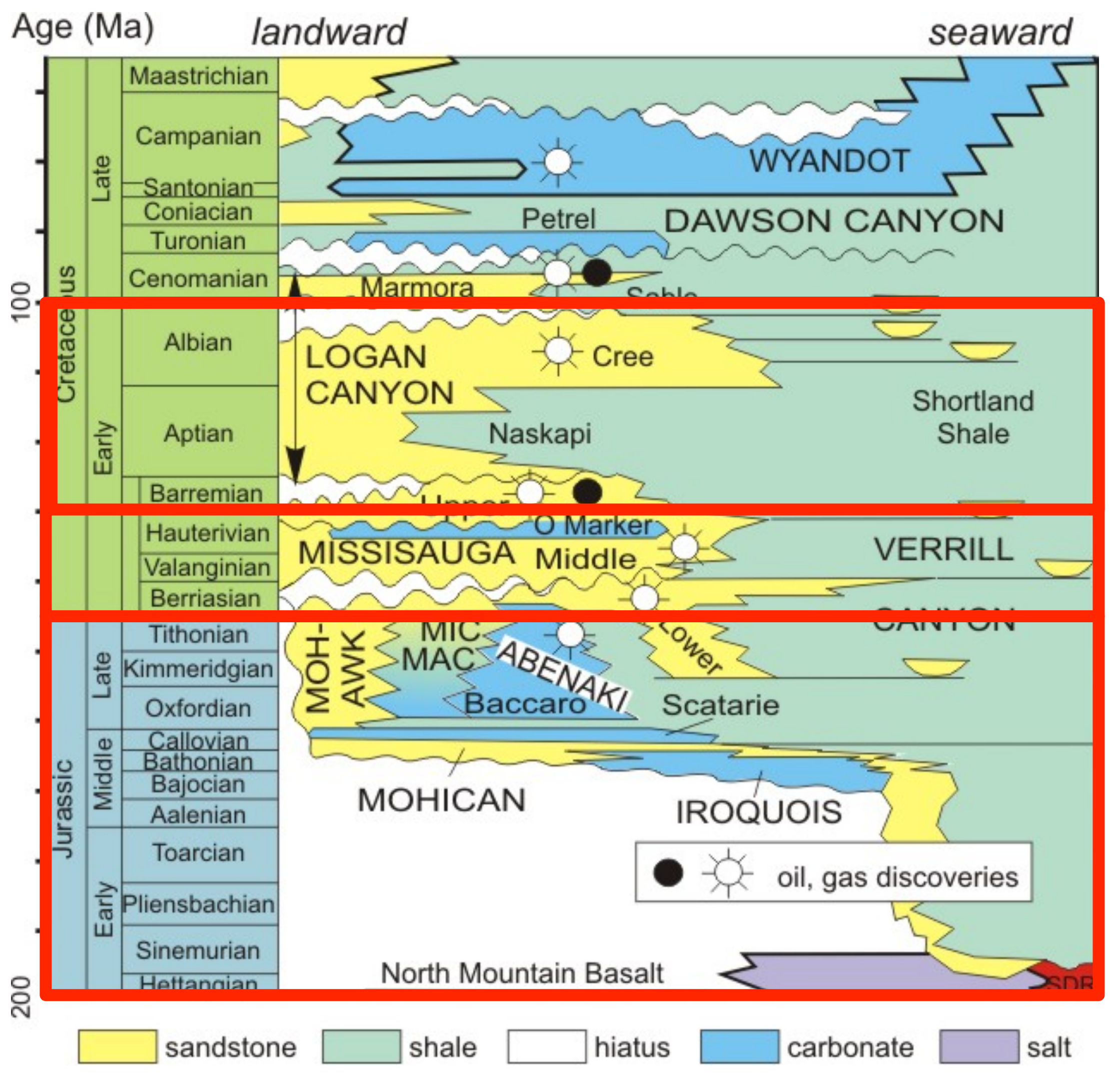
Introduction

- The Nova Scotia offshore has been the site of several major hydrocarbon discoveries
- Further exploration is complicated as a result of 2 main factors
  - Wide spread salt tectonics in the area
  - The influence of diagenesis on reservoir intervals
- Model the reservoir sandstone intervals in the central Scotian Basin using *DionisosFlow,* forward stratigraphic modeling software

Objectives

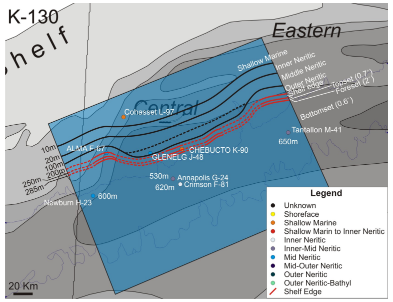
- Test if provenance pathways are validated by observed sediment distribution
- Determine the distribution and extent of reservoir sandstone intervals in the Scotian Basin
  - Whether they are trapped on the slope or bypass into the basin
- Determine the factors which control the distribution of sands within the study area

Regional Geology

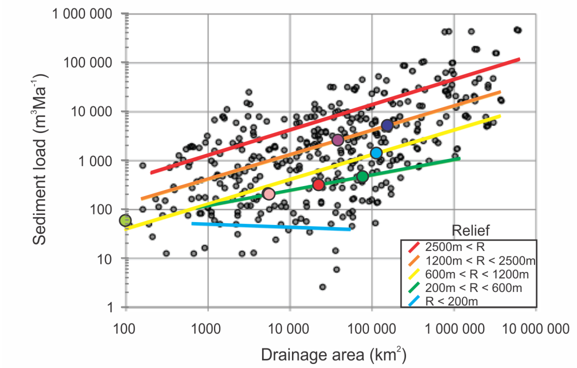


- Rifting in the Late Triassic
- Salt deposition
- Missisauga Formation
  - Upper Missisauga Formation
- Logan Canyon Formation
  - Naskapi Member
  - Cree Member

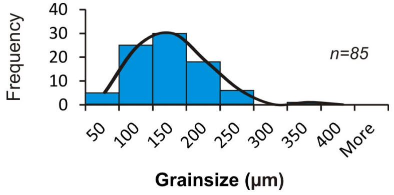
Model Inputs



Bathymetric maps

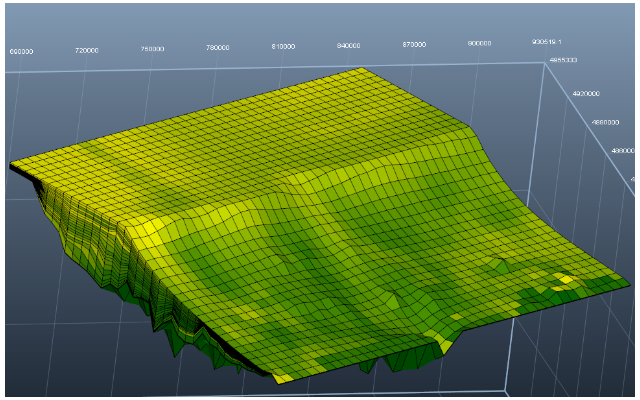


Catchment area reconstructions

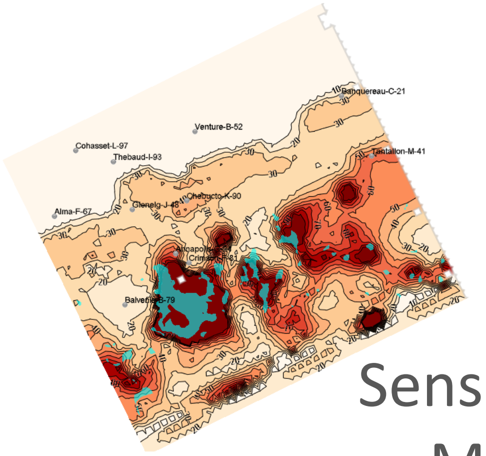


Sediment Properties

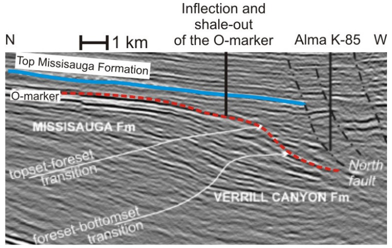
DionisosFlow



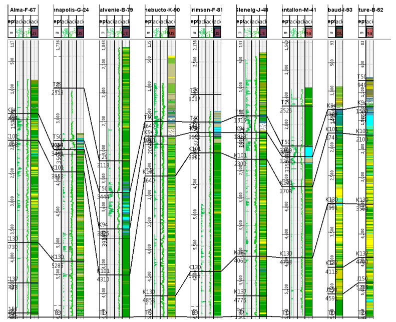
CougarFlow



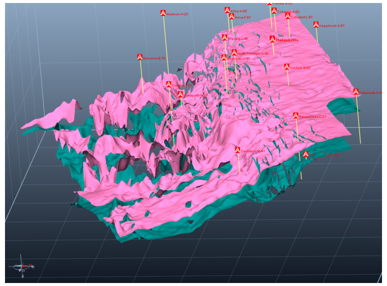
Sensitivity Maps



Seismic interpretations



Well logs



Surfaces

Study Area

- 185 km x 215 km

Grid Size

- 5 km x 5 km

Time Steps

- 0.25 Ma

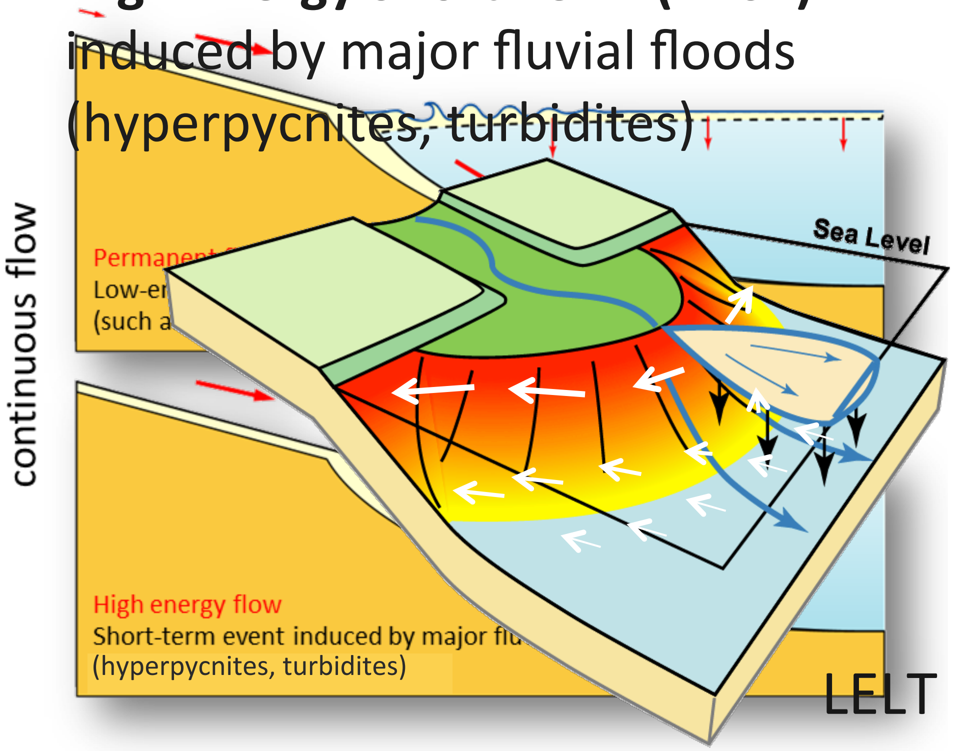
Principles of DionisosFLow

- **Low Energy Long Term (LELT)**: slow gravity permanent fluvial transport
  - Gravity Driven
  - Water Driven
  - Wave Driven
- **High Energy Short Term (HEST)**: induced by major fluvial floods (hyperpycnites, turbidites)

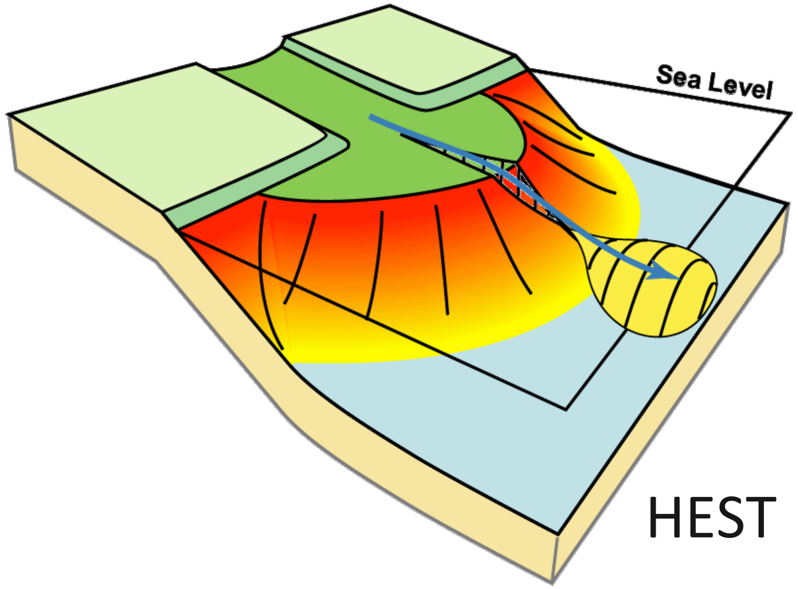
The transport rate is proportional to basin slope and water discharge:

$$Q_s = K\,Q_w\,S$$

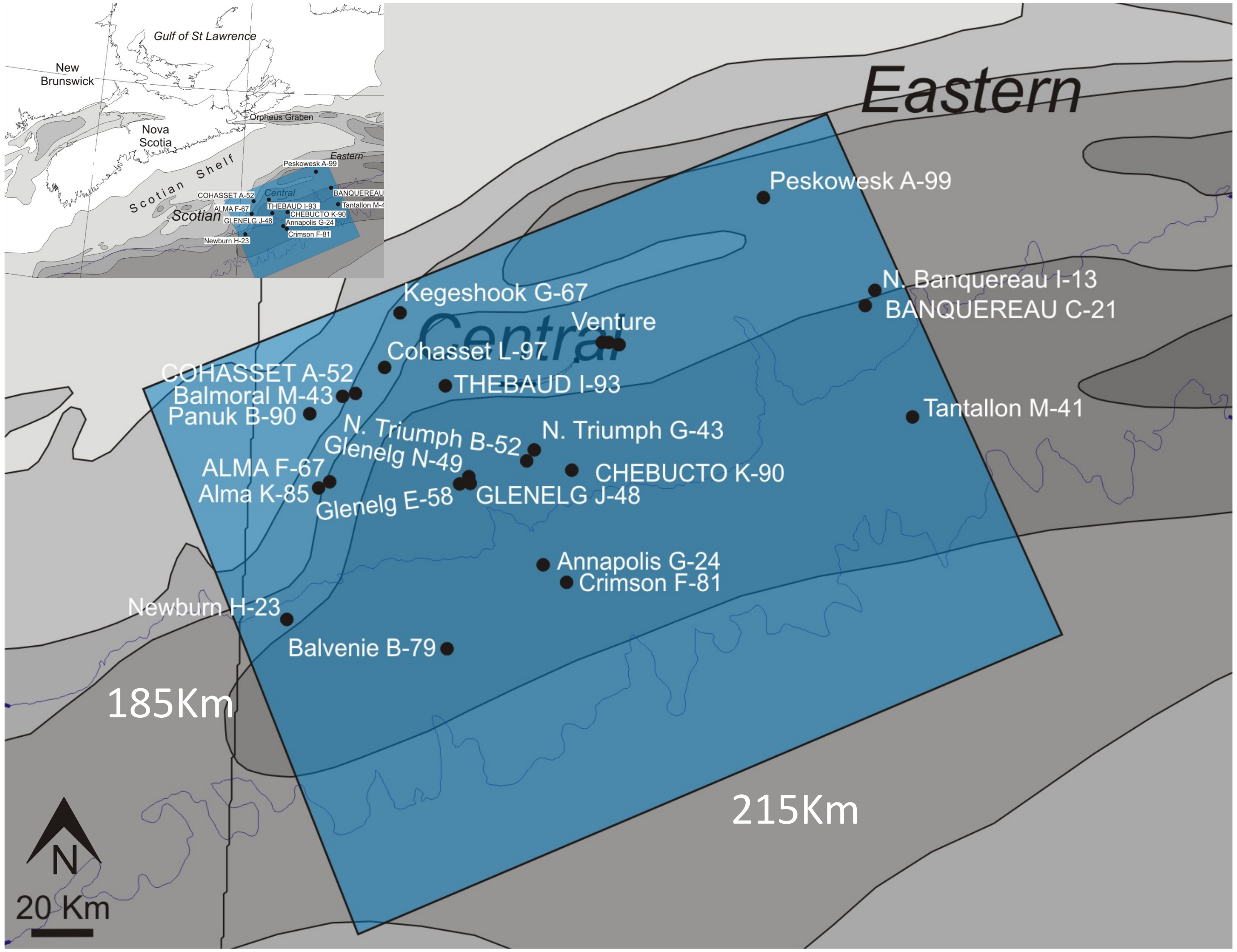
- Qs = sediment inflow
- Qw = Water flow
- S = depositional slope degree
- K = Diffusive coefficient



- **Paleo-bathymetry**
- **Sediment sources**
- **System inputs**
  - Water discharge
  - Sediment load
  - Sediment properties

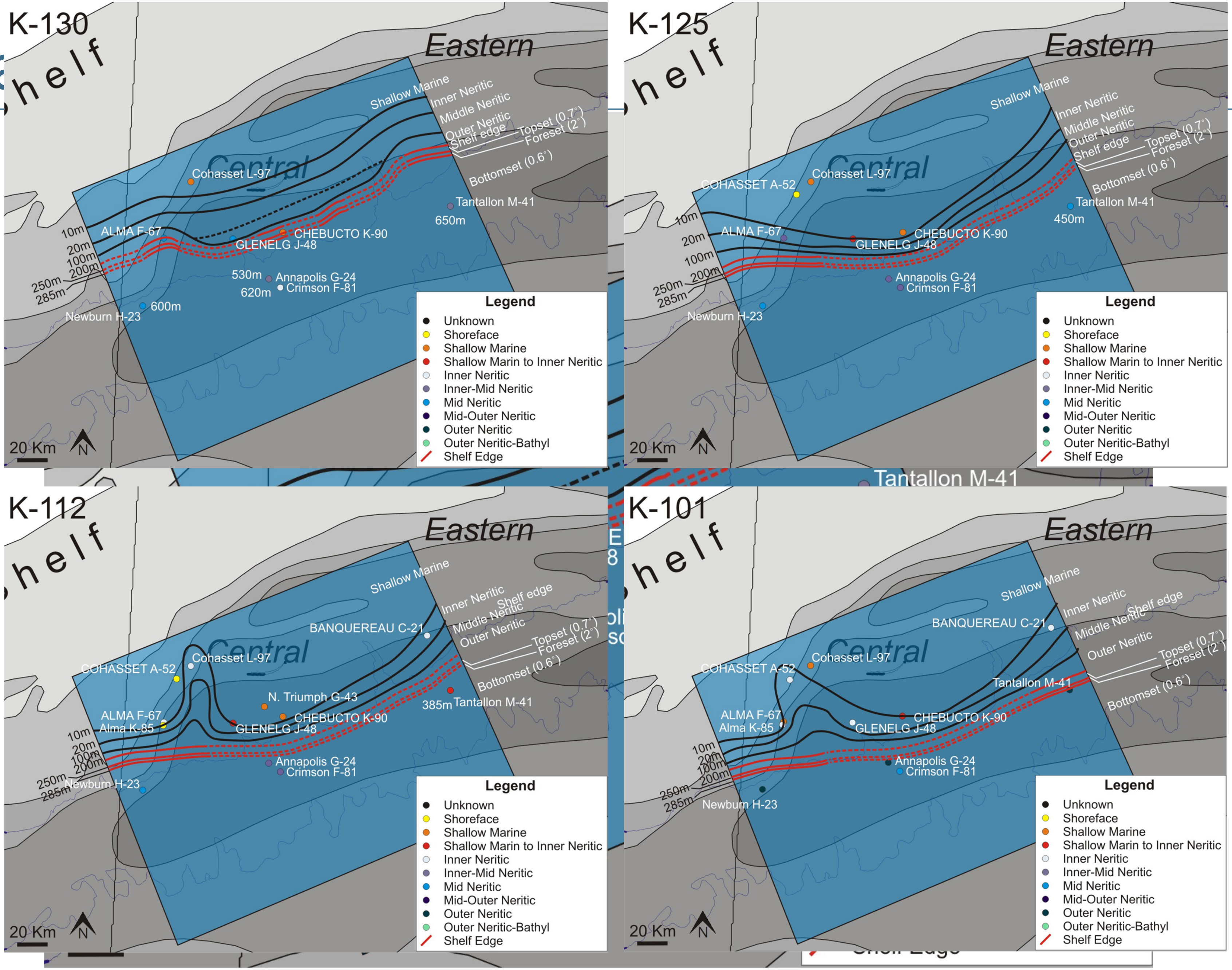


Multi-disciplinary Approach



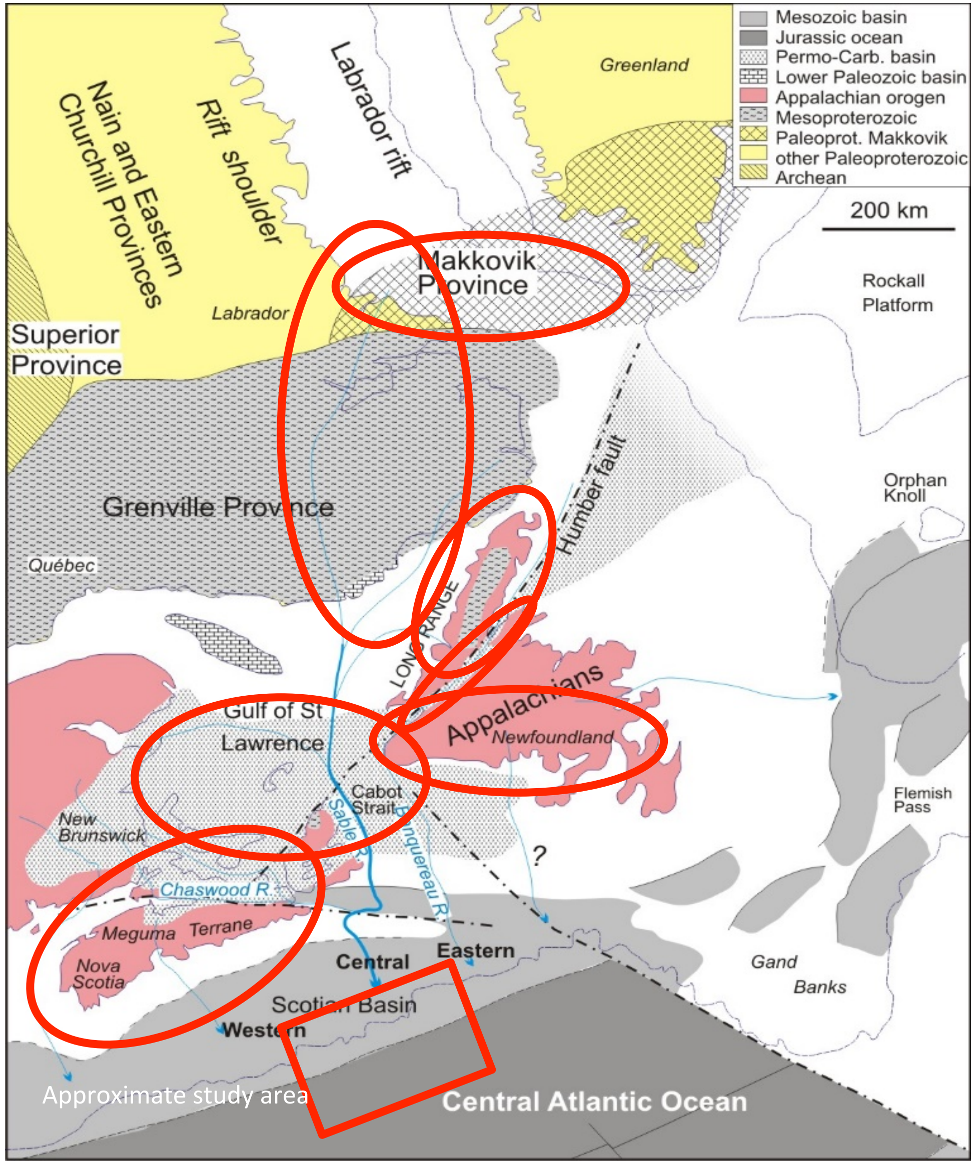
- **Bathymetry**
  - Biostratigraphy
  - Lithofacies classification
  - Shelf edge interpretations
- **Sources**
  - Provenance
  - Apatite fission track modeling
  - Modern system comparisons
- **Sediment properties**
  - Point Counting
  - grain size
  - Lithology from cores

Ba



K-130
Shelf
Eastern
Central
Shallow Marine
Inner Neritic
Middle Neritic
Outer Neritic
Shelf edge
Topset (0.7°)
Foreset (2°)
Bottomset (0.6°)
Cohasset L-97
Tantallon M-41
650m
ALMA F-67
CHEBUCTO K-90
GLENELG J-48
530m
Annapolis G-24
620m
Crimson F-81
Newburn H-23
600m
10m
20m
100m
200m
250m
285m
20 Km
N
K-125
COHASSET A-52
450m
K-112
BANQUEREAU C-21
N. Triumph G-43
385m
Alma K-85
K-101
Legend
Unknown
Shoreface
Shallow Marine
Shallow Marin to Inner Neritic
Inner Neritic
Inner-Mid Neritic
Mid Neritic
Mid-Outer Neritic
Outer Neritic
Outer Neritic-Bathyl
Shelf Edge

Source Areas



The Meguma terrane

- Mainland Nova Scotia

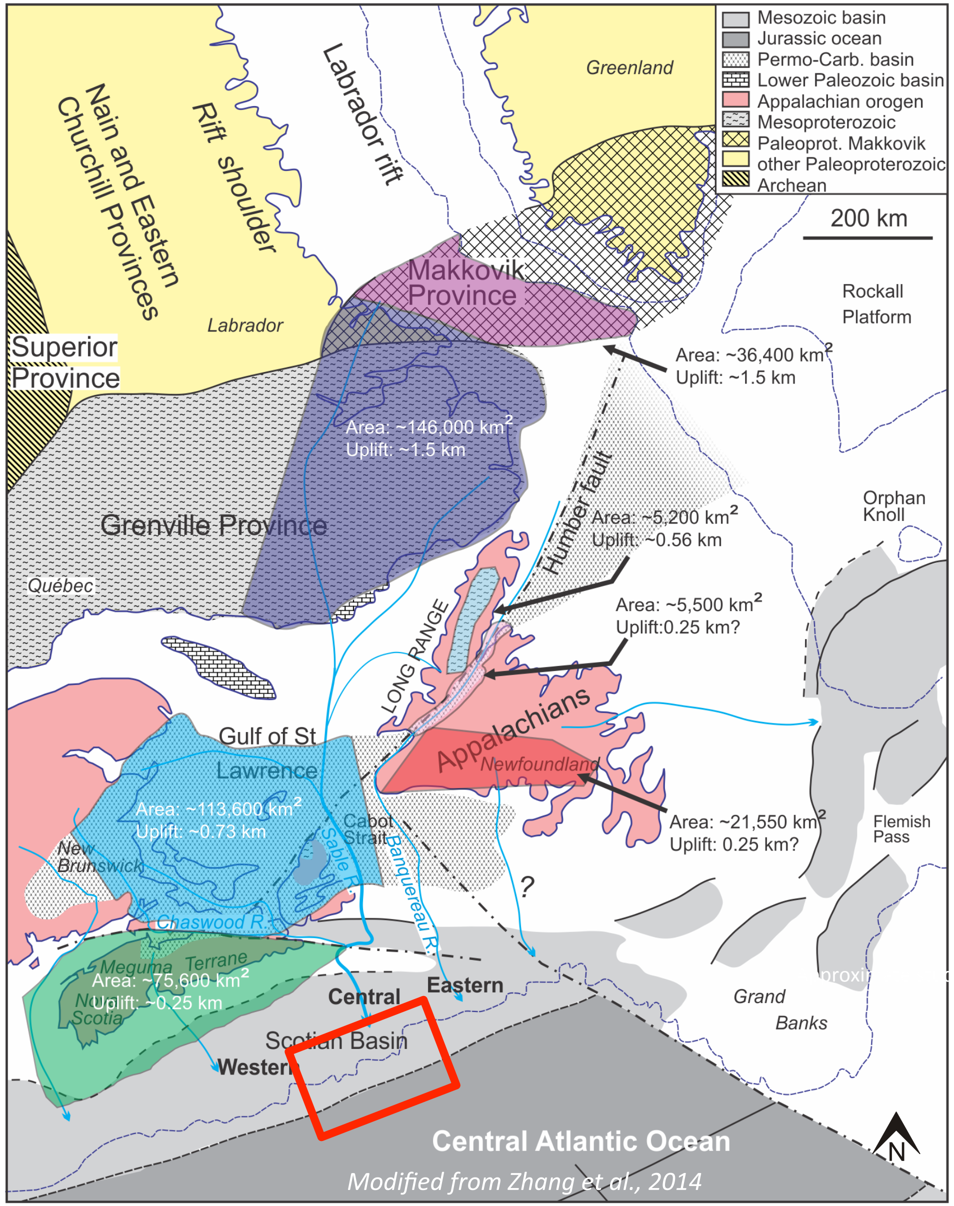
The Sable River

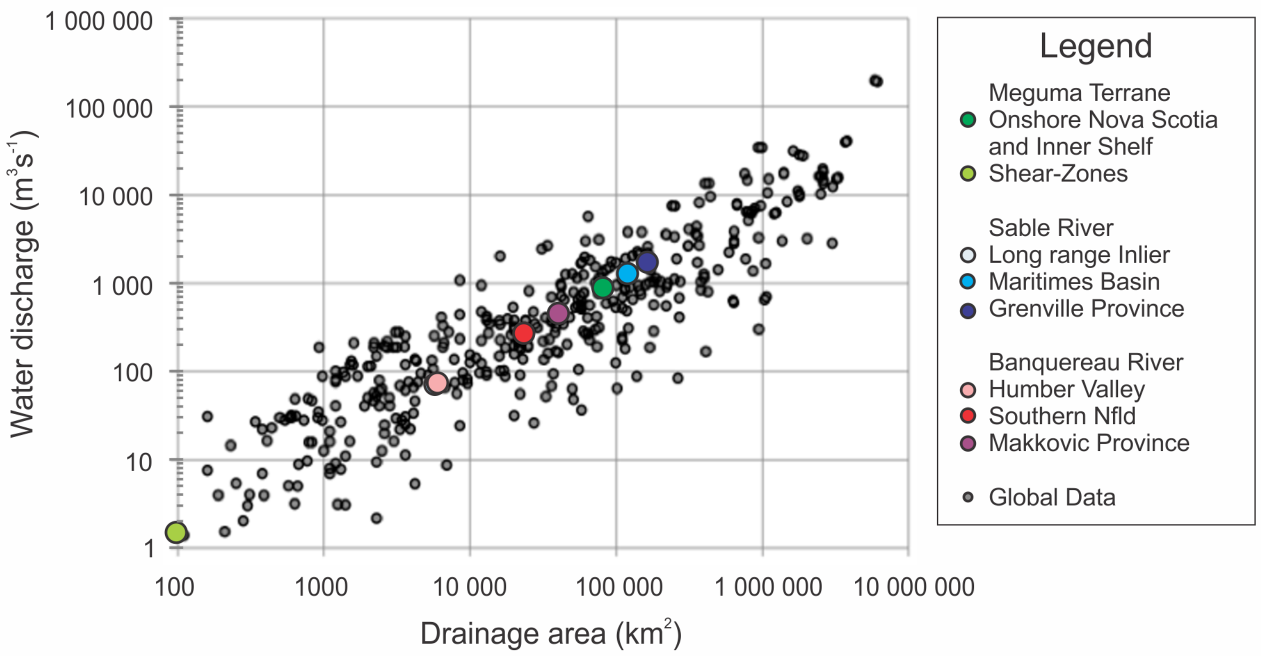
- Southern Labrador, the long range inlier of Western Newfoundland, and the Maritimes Basin

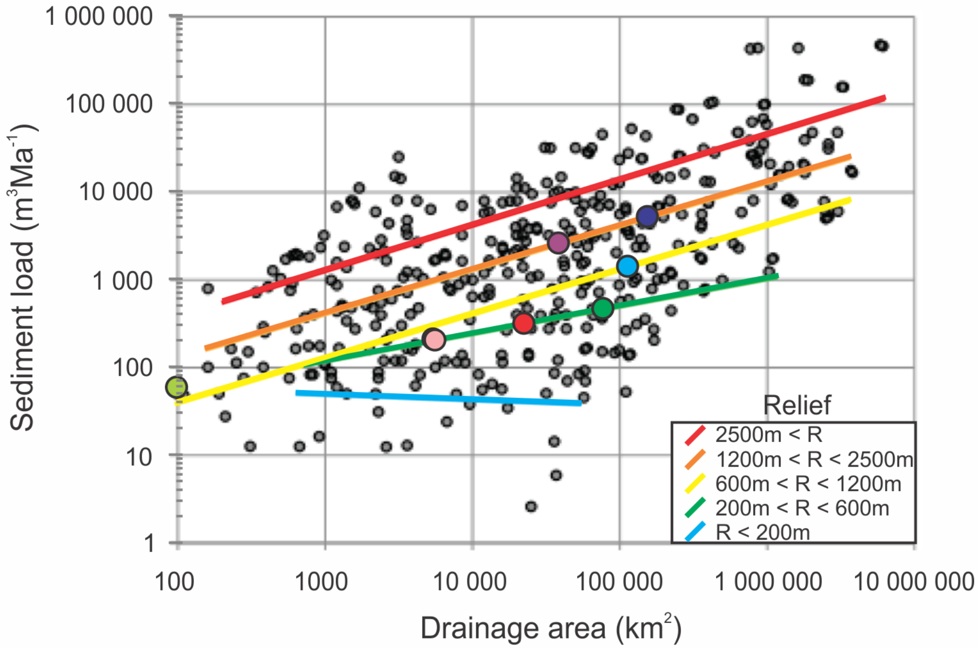
The Banquereau River

- Humber Valley of Western Newfoundland, the Makkovik Province, and Southern Newfoundland

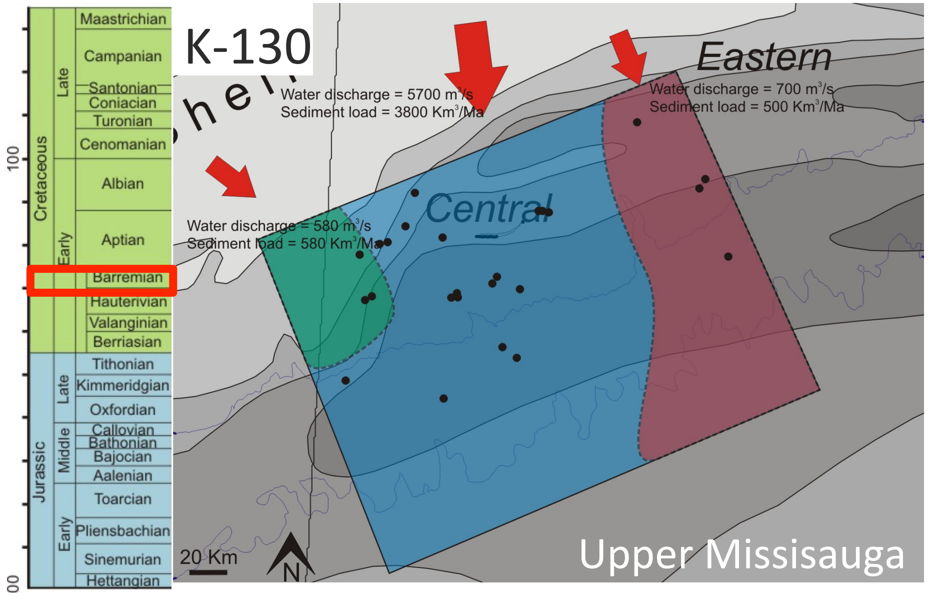
Catchment Areas

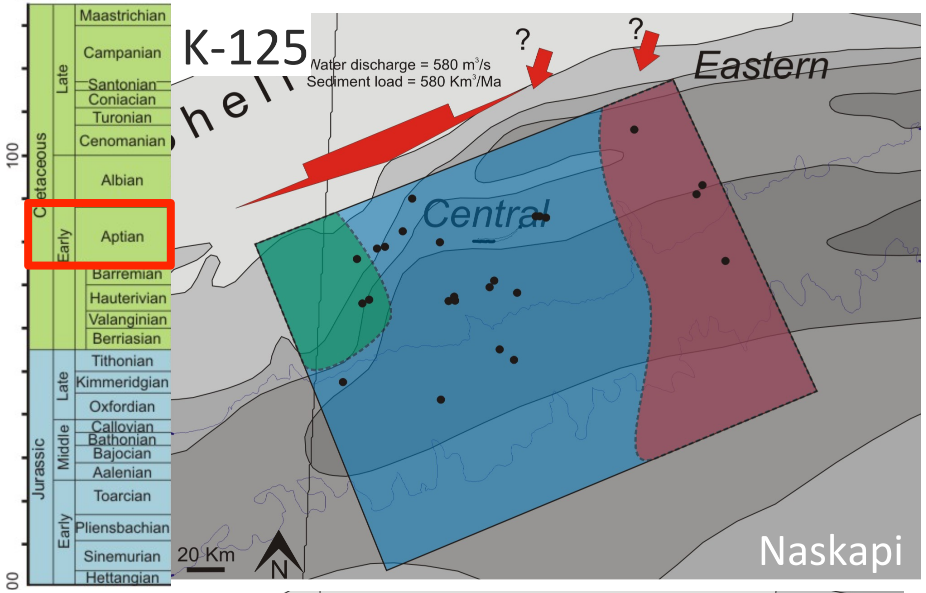


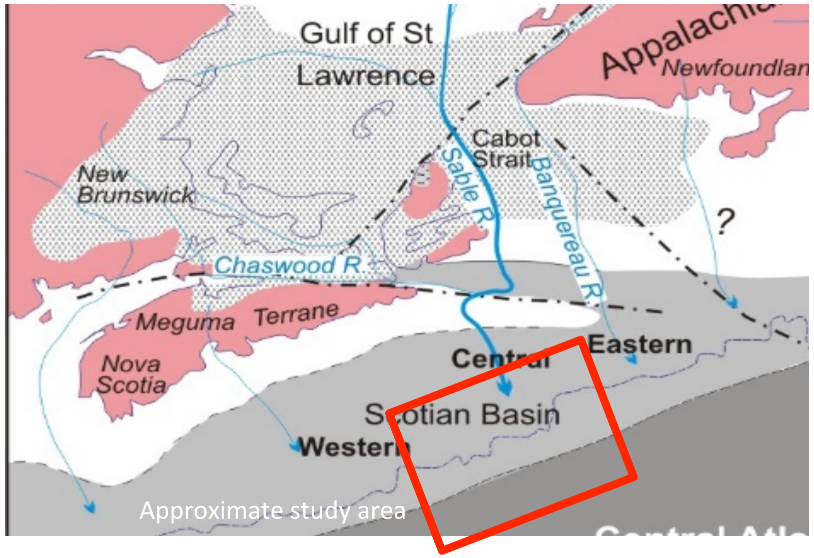


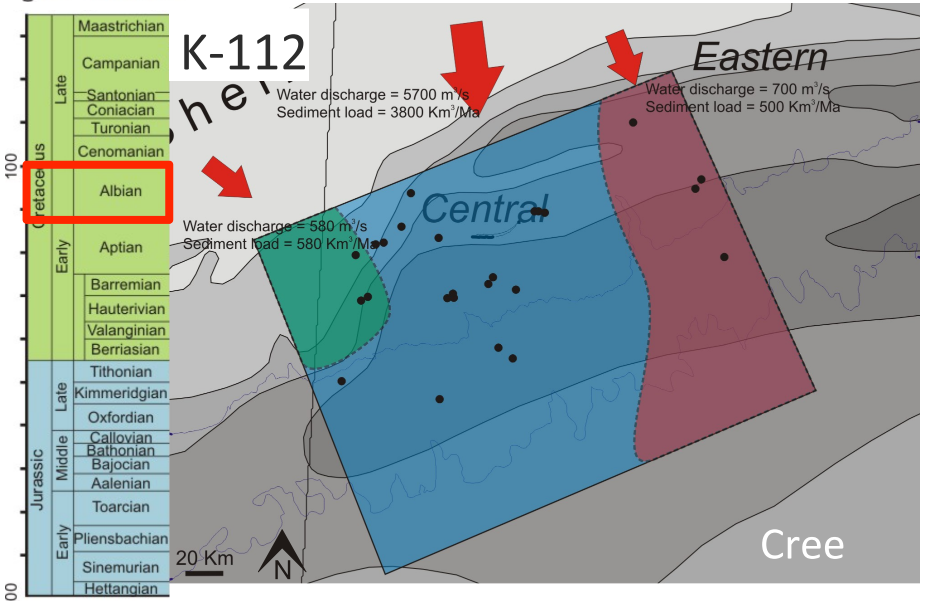


System Inputs (Flow Paths)

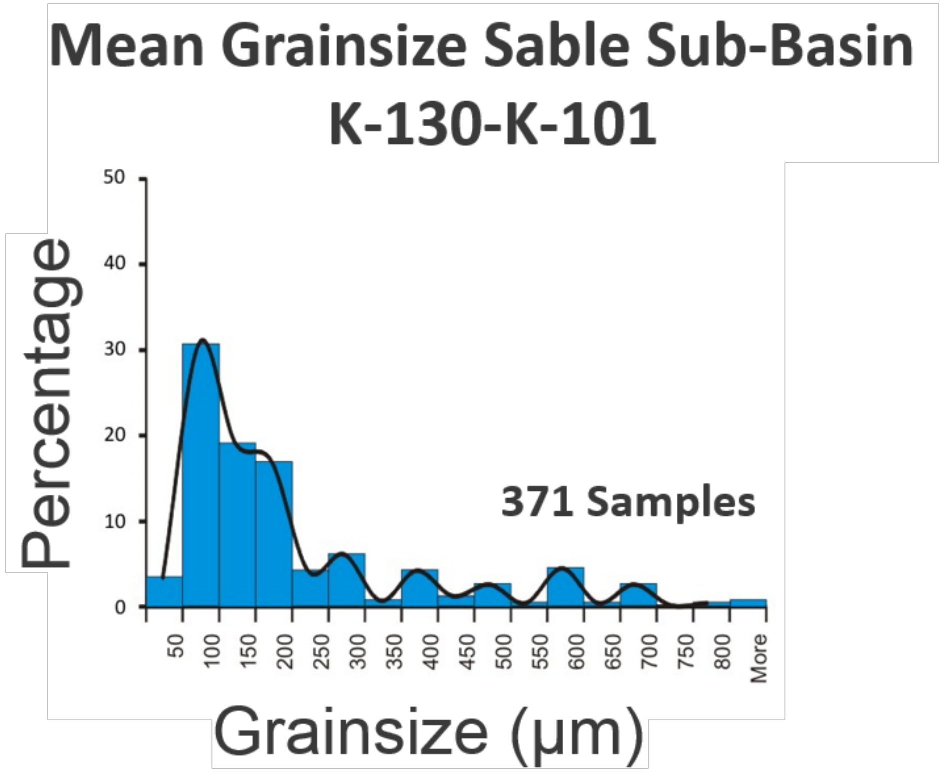








Grain Size (Average)



Based on compiled point counting data

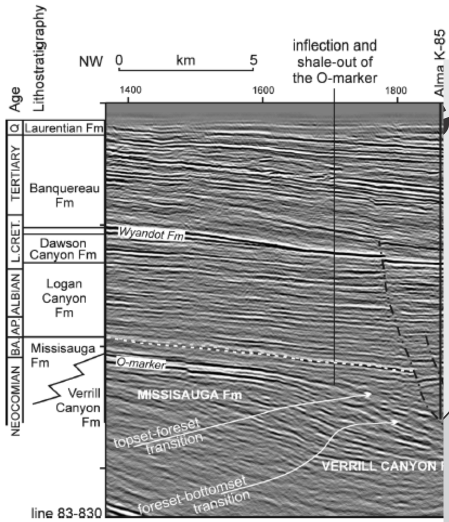
grain sizes used during simulation

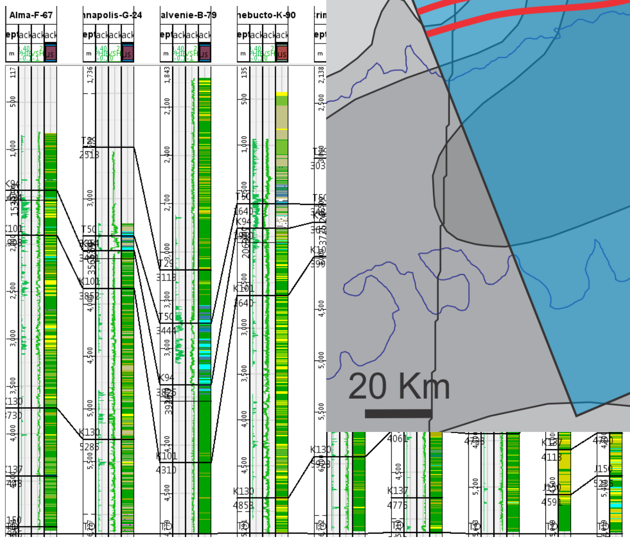
Sediment	Grain Size (mm)
Shale	0.04
Silt	0.06
Very fine sand	0.075
Fine sand	0.2
Medium sand	0.4
Coarse sand	0.65

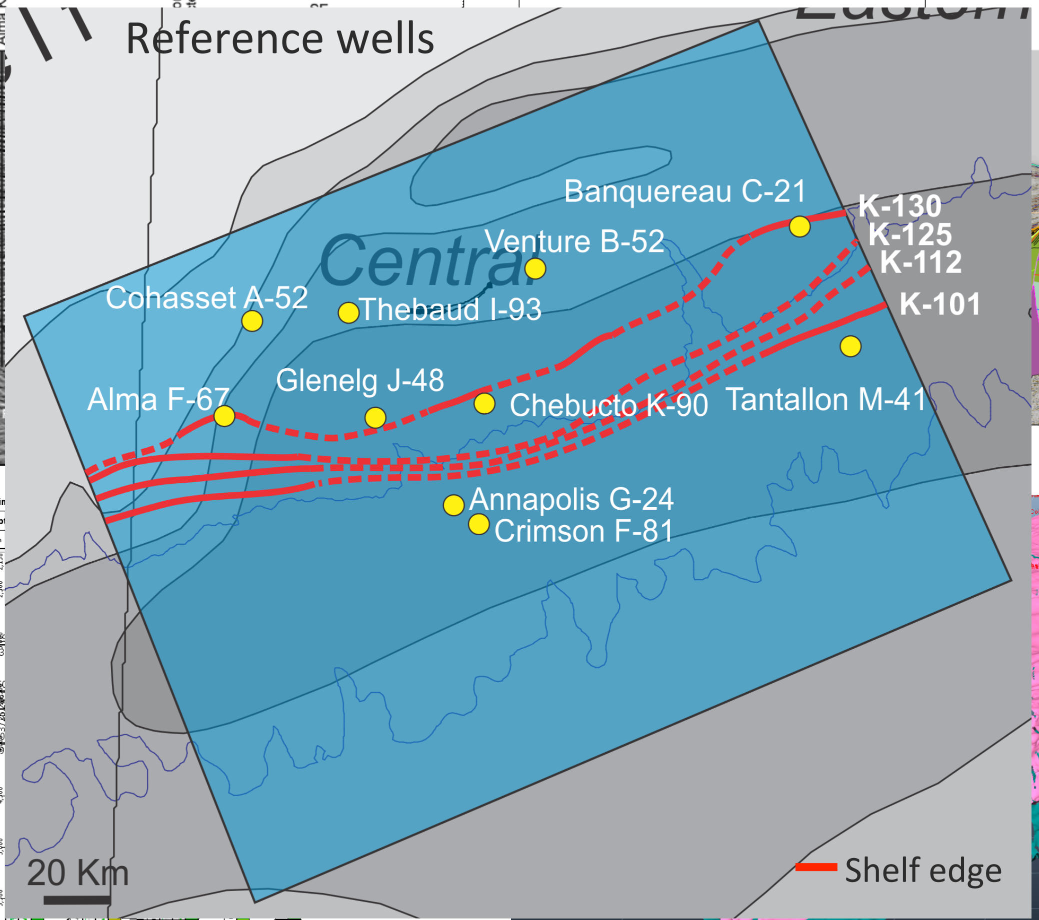
Reference Case Models

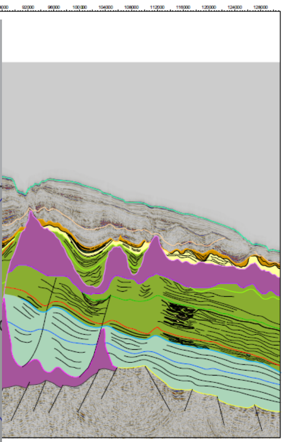
Calibration

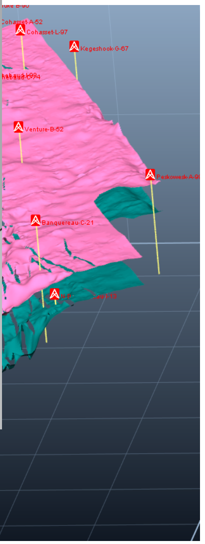
Seismic, stratigraphic, and facies analysis











Well logs

Interpreted Surfaces

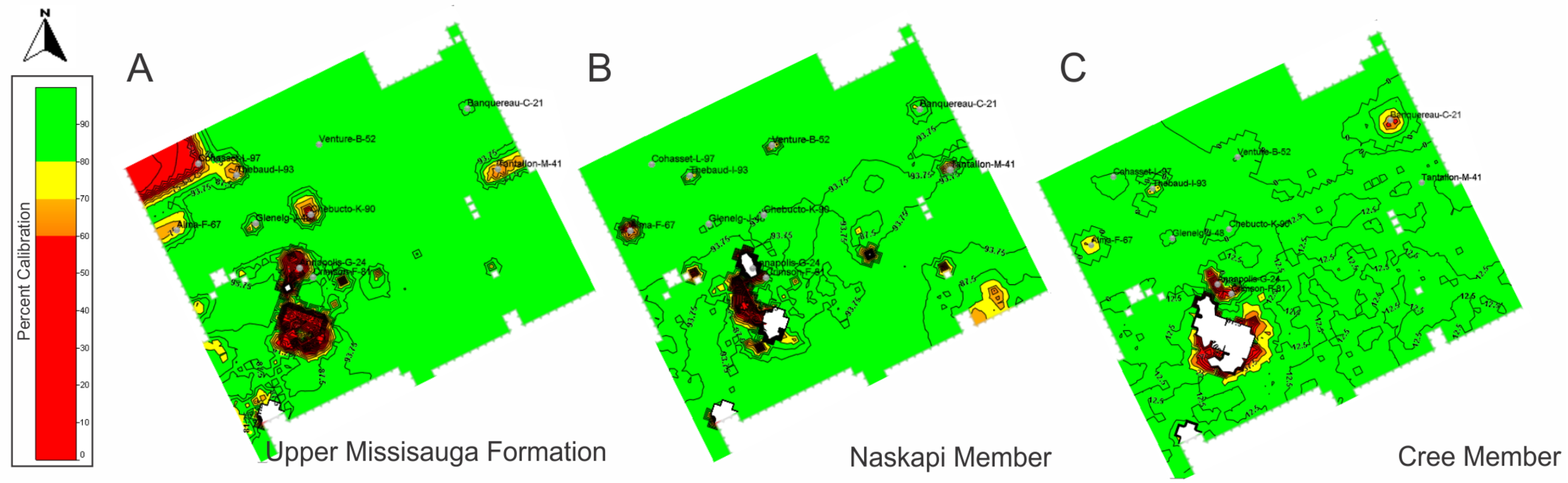
Unit Thickness Calibration

- Interval thickness interpreted from seismic surfaces
  - Only available for K-130 and K-101

- Individual unit thickness based on average thickness of units from well picks in calibration well

Unit	Avg. Thickness (m)	% Total Thickness
Upper Missisauga	684	40.5
Naskapi	175	11.0
Cree	746	48.5

Unit thickness calibration



- Calibration generally greater than 80%
  - Error on wells to obtain high well thickness calibration
  - In association with salt
- Suggests that provenance model is viable

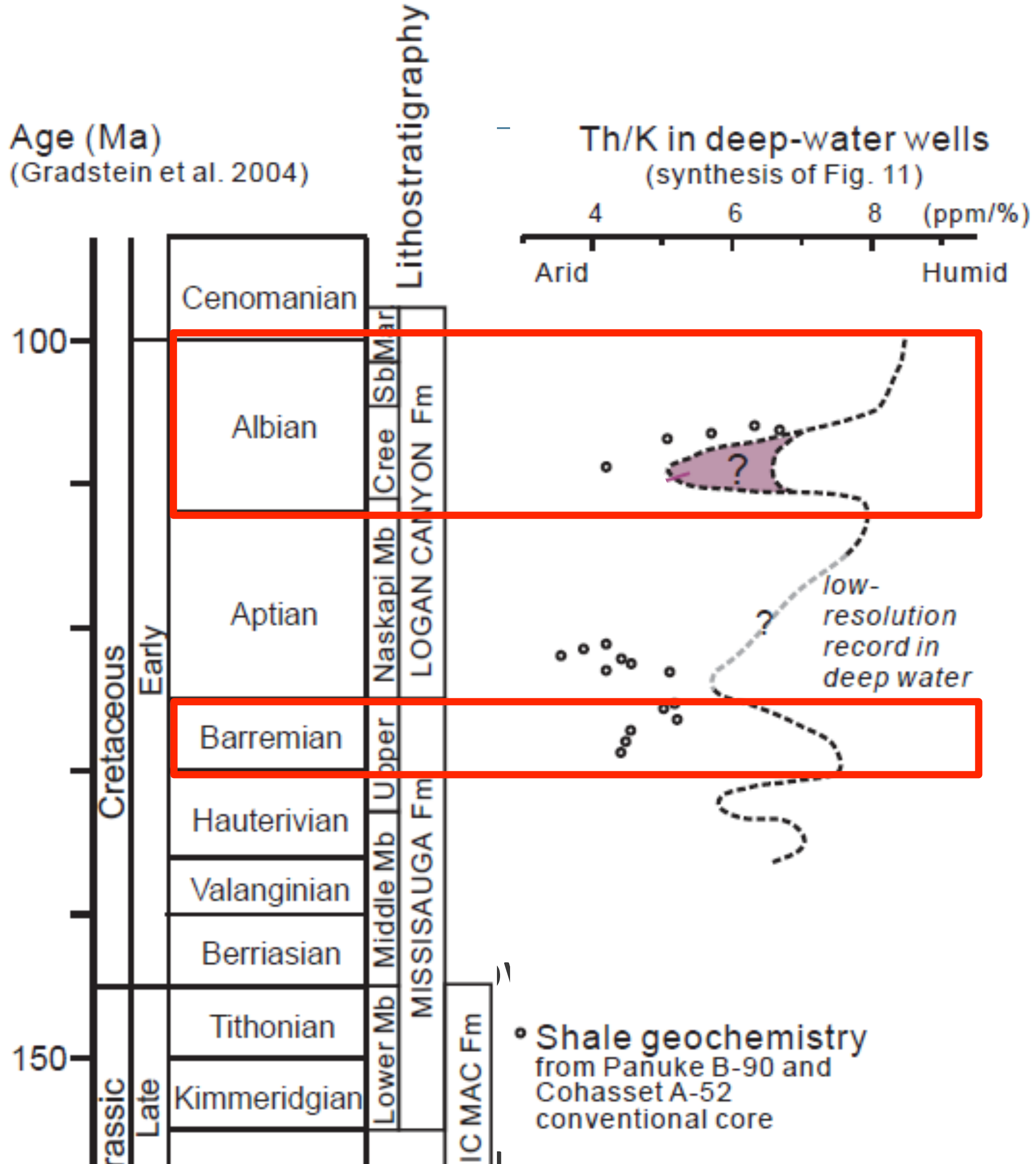
Sediment supply

- The Upper Missisauga Formation and Cree Member have similar sources and thickness
  - The Upper Missisauga Formation formed in half the time (5 Ma vs 11 Ma)
  - Drastic decrease in sediment supplied by the Sable and Banquereau rivers
- Supply controlled by
  - Climate
  - Source rocks
  - Relief

Unit	Sediment Supply (km^3/Ma)	
	Upper Missisauga	Cree Member
Sable River	3450	2000
Meguma	450	300
Banquereau	300	175

Sedime

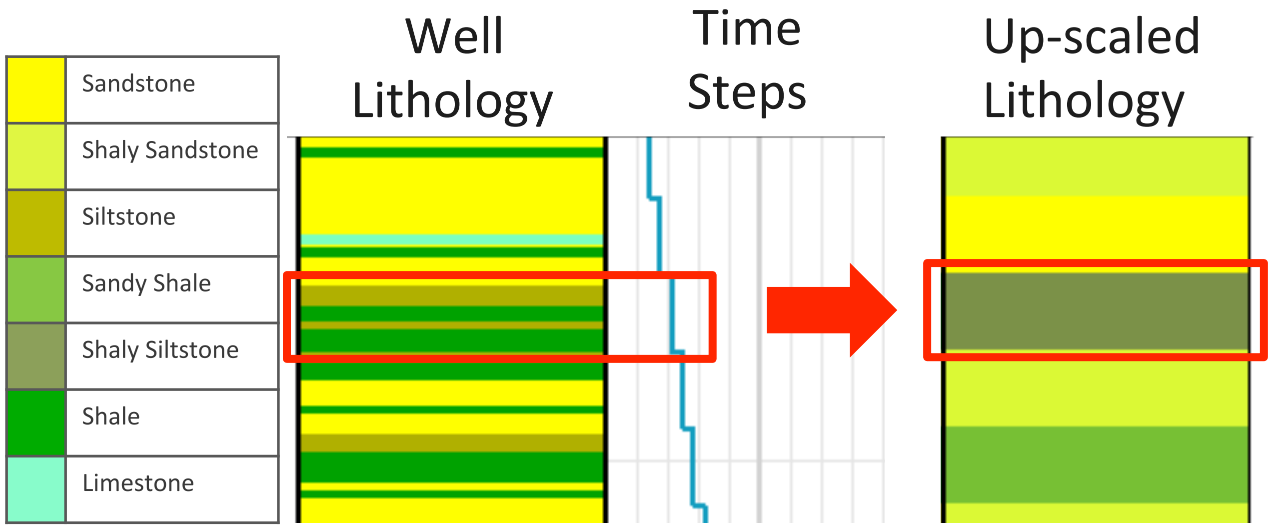
- Climate
  - Similar tr
- Source ro
  - Provena ... urce rocks
- Relief
  - Apatite fi
    - Mariti
    - Long r
  - Basemen ... nce
    - Labrac
- Episodic d ... vers



Modified from Gould et al. 2014

Facies Calibration

- Comparison of well log lithologies and simulated lithologies
  - Calculations are performed using a script
- Well logs are at much higher resolution than the simulated logs due to the number of time steps
  - Well logs are “up-scaled” to the size of the simulated logs



Simulated log

Facies log

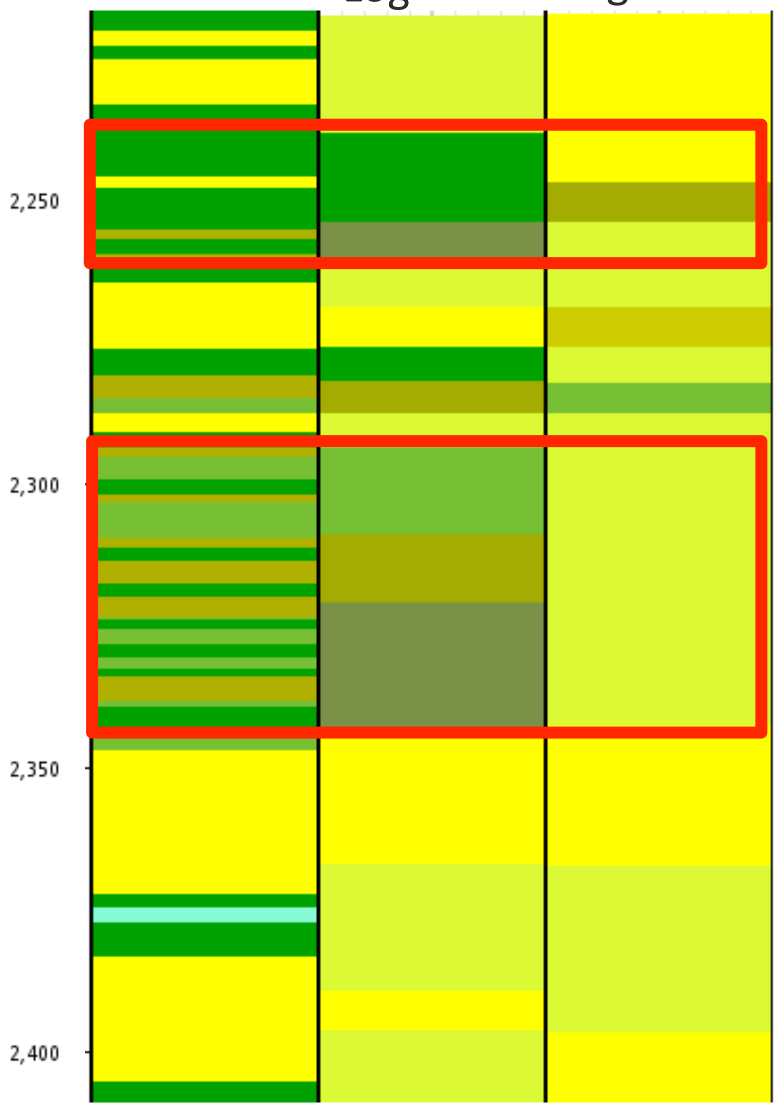
Name	Sandstone	Silt	Shale
Sandstone	0	5	10
Silt	5	0	5
Shale	10	5	0

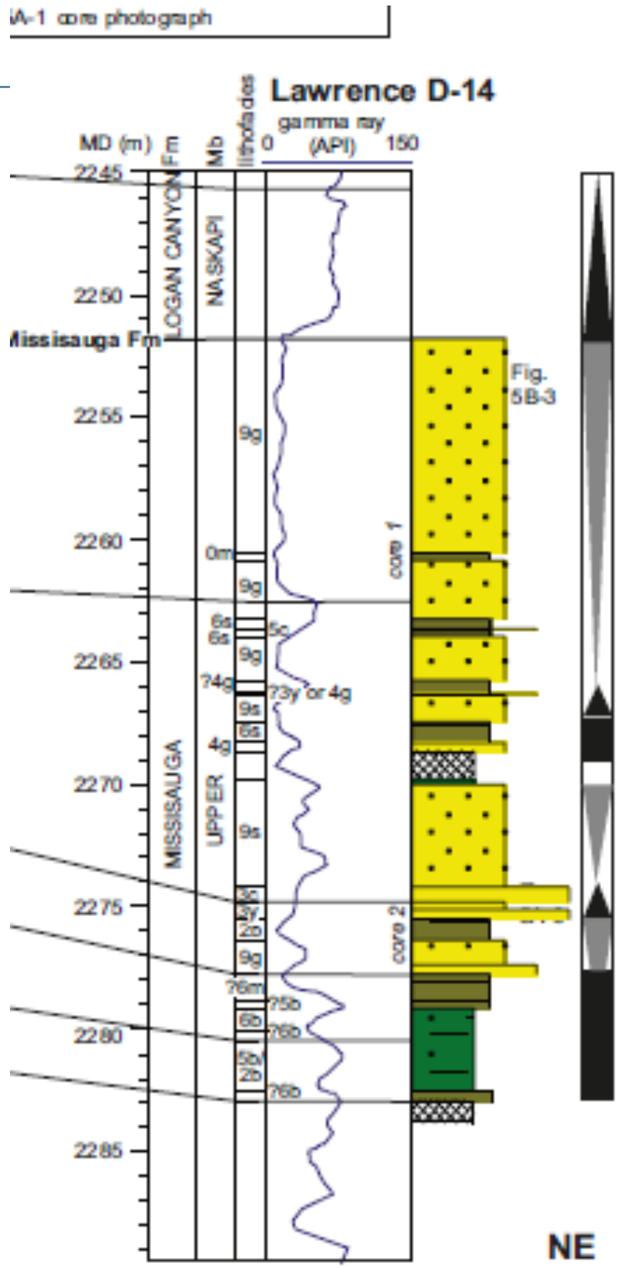
Facies calibration

- The majority of well calibrate to at least 80%
  - Highest calibration typically in the basin
- Three wells show low calibration
  - Cohasset L-97
  - Venture B-52
  - Banquereau C-21

	Upper Missisauga	Naskapi	Cree
Average calibration	81.1	87.4	81.2

Cohasset L-97





Gould et al., 2012

ɔer Missisauga

alibration of 72%

ll is located on the

e of study area

ccumulation of coarse

ediments

hin three cells of the

ulated grid other wells

w 35% more sand

uld et al., 2012).

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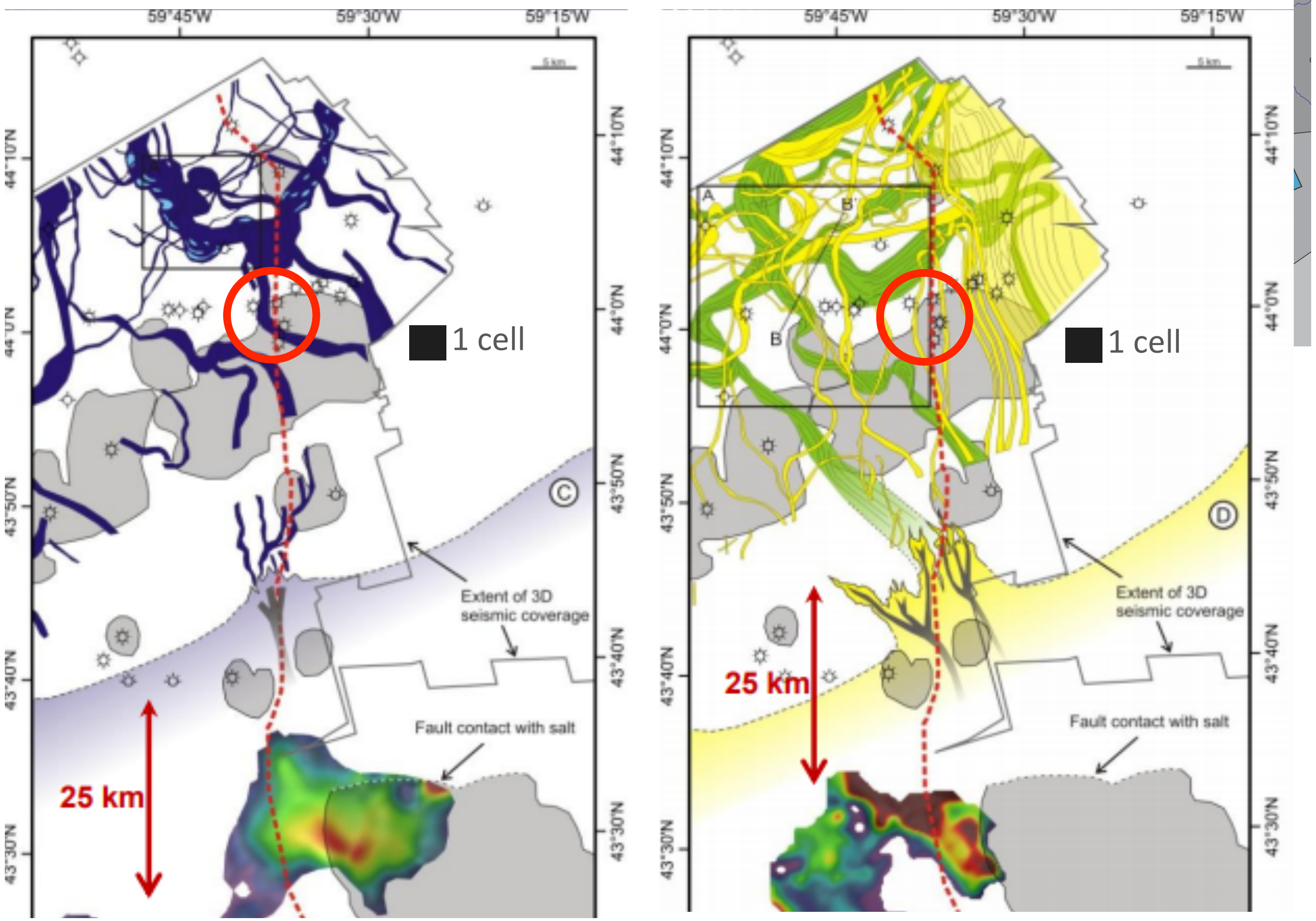
Venture B-52

Well Log | Up-scaled Log | Simulated Log

Upper Missisauga | Cree

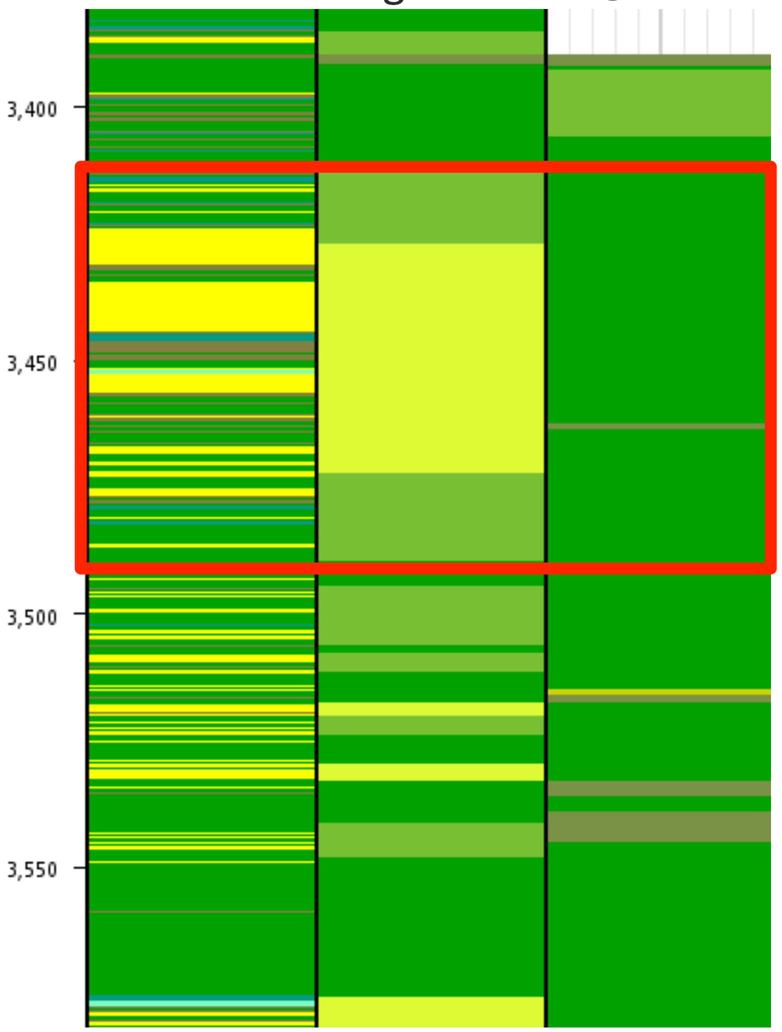


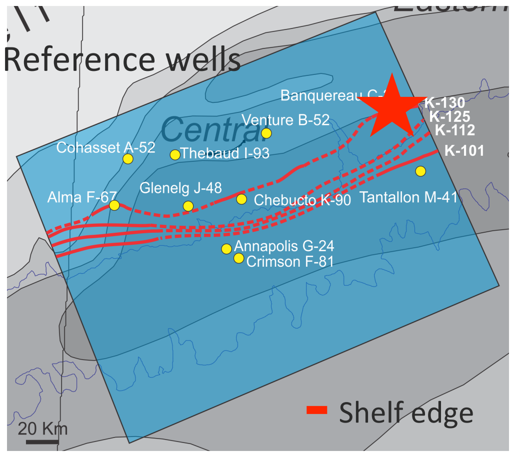
Smith and Kendell 2011

- Upper Missisauga Formation and Cree Member
  - Calibration of 74% and 61%
- Abundant channels in the eastern Sable Sub-basin
- Local autocyclic variability in sand and mud deposition in estuarine and tidal flat depositional systems takes place on a spatial scale less than the grid size

Banquereau C-21

Well Log | Up-scaled Log | Simulated Log



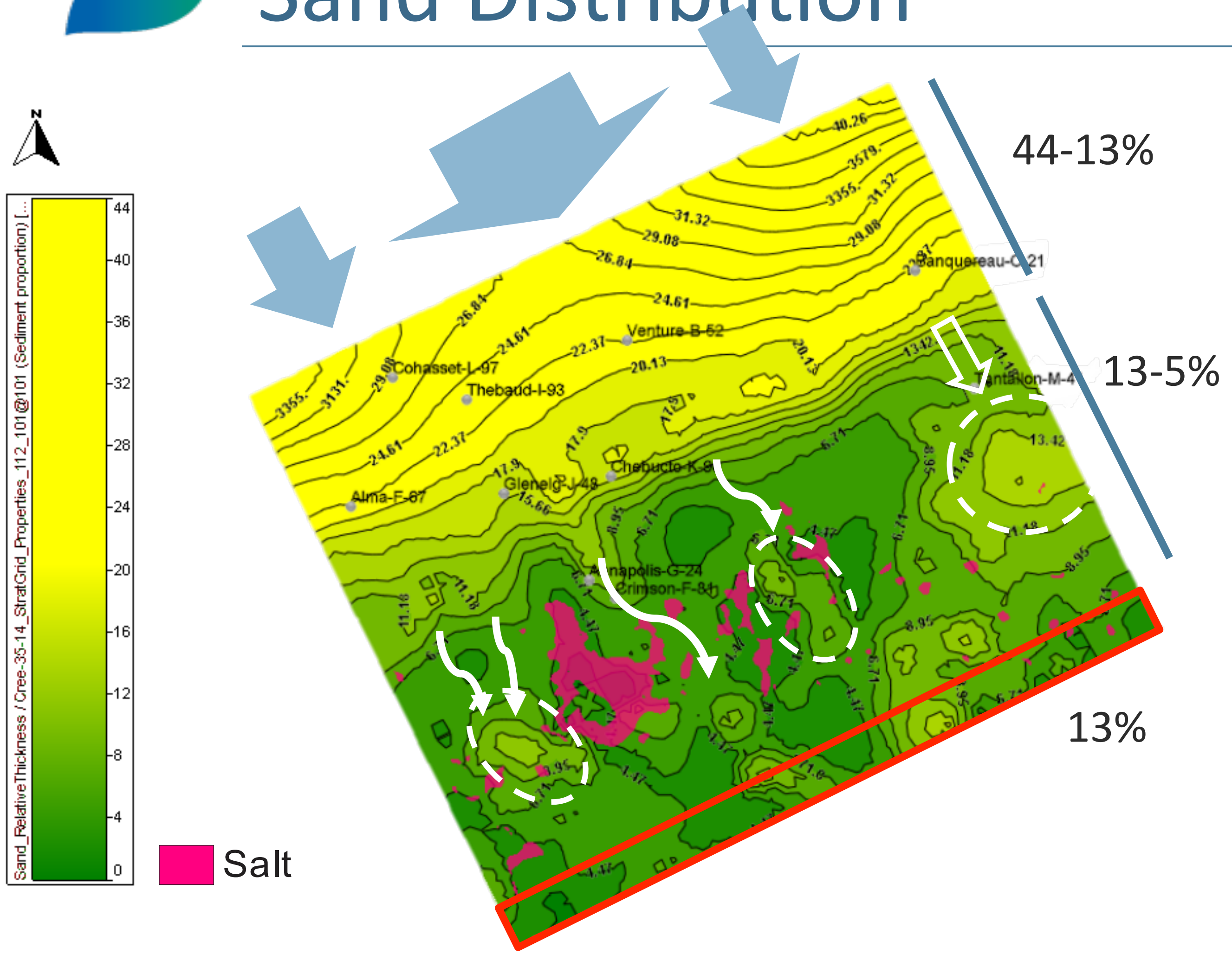


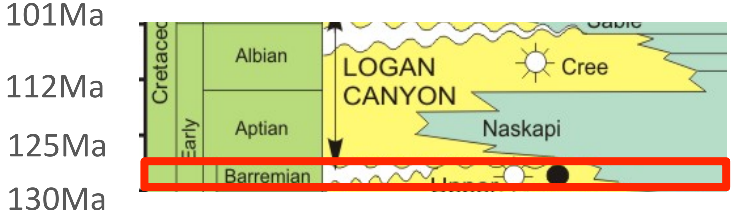
- Sandstone
- Shaly Sandstone
- Sandy Shale
- Shale
- Shaly Siltstone
- Siltstone
- Limestone
- Calcareous Sandstone

- Naskapi Member
- Calibration of 75%
- Too shaly
- May indicate an occasional return of the Banquereau River to the region

Sand Distribution

Sand Distribution

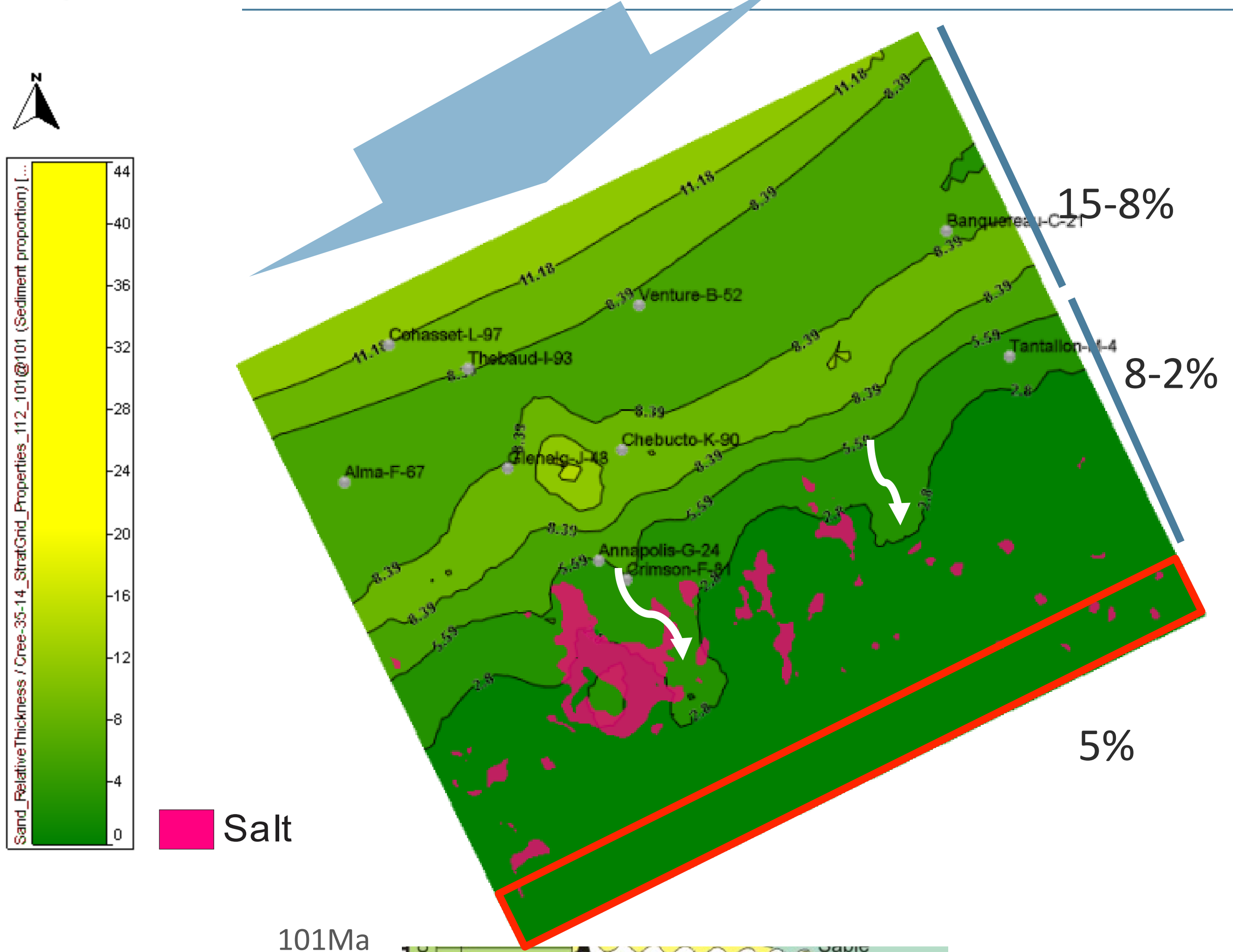


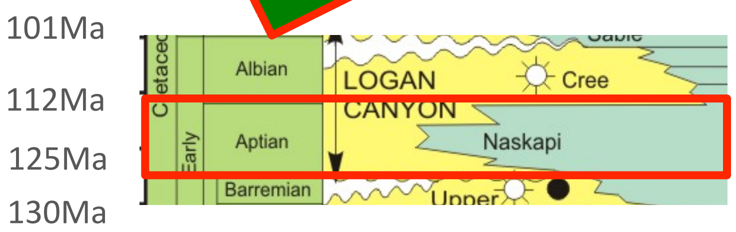


Upper Missisauga

- Dominant sand trapped on shelf
  - Decreasing from East to West
- Sand collects in minibasins and is pushed deeper into the basin
- Western basin has more sediment corridors
  - Increased salt activity
- Eastern basin shows direct sediment transport to the basin
- 13% of basin sediments accumulate at the simulation boundary

Sand Distribution





Naskapi Member

- Sand proportion is low and dominantly on the shelf
  - Consistent with maximum transgression depositional setting
- Low sand in deep basin
- 5% of basin sediments accumulate at the simulation boundary

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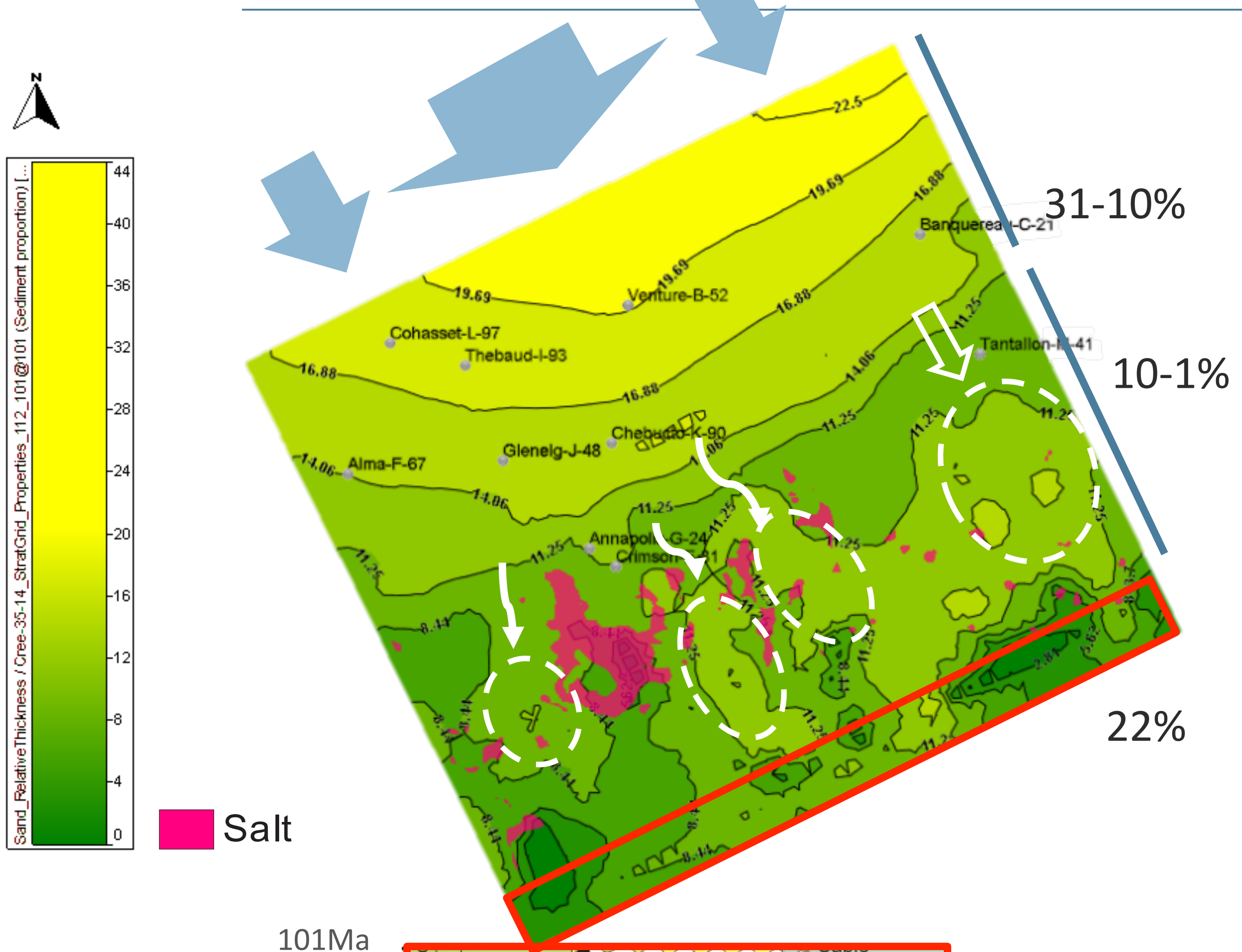
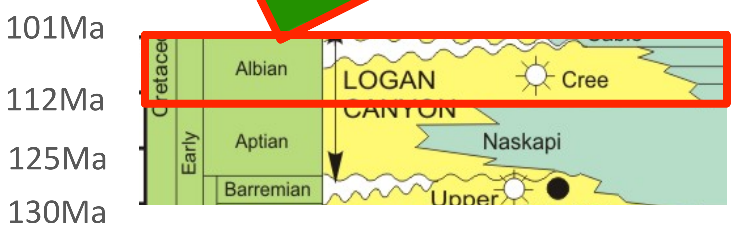
Sand Distribution





Cree Member

- Dominant sand trapped on shelf
  - Decreasing from East to West
- Sand collects in minibasins and is pushed deeper into the basin
- Western/central basin has more sediment corridors
- Eastern basin shows direct sediment transport to the basin
- 22% of basin sediments accumulate at the simulation boundary

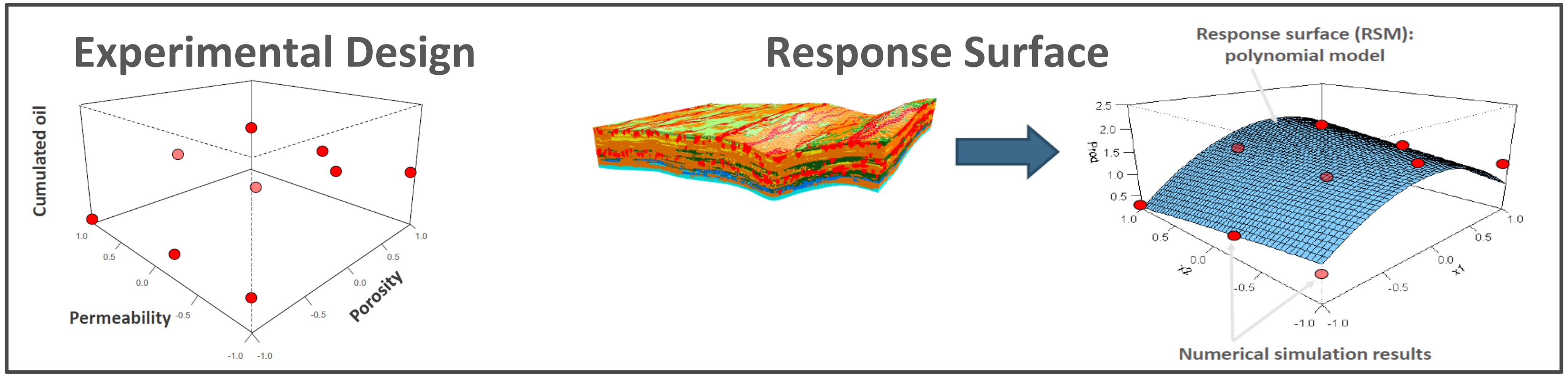
Sensitivity Analysis

CougarFlow

- Used to determine the contribution of parameters **(Sensitivity analysis)** and the range of possible values for these parameters **(Risk analysis)**

- Runs large numbers of DionisosFlow models altering uncertain parameters
  - Experimental design

- CougarFlow replaces the models with a response surface on the basis of the simulation results
  - Applies statistical analysis to the response surface



Sensitivity Analysis Parameters

- Test the sensitivity of sand distribution
- Testable parameters
  - Sediment composition
  - Water discharge and sediment supply
  - Subsidence

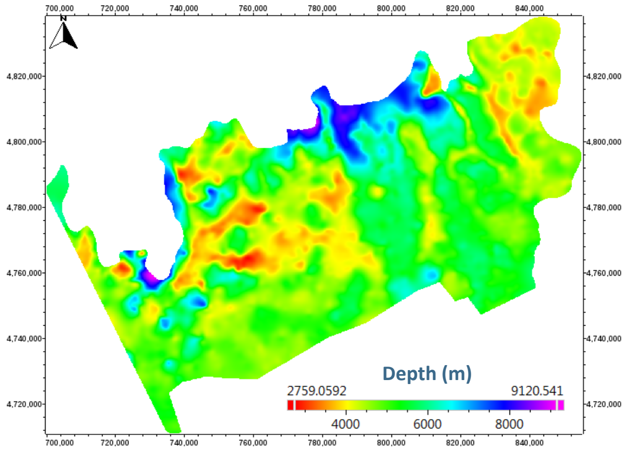
Source	Maximum	Minimum
Clay Proportion	+25%	-25%
Sediment Supply	+20%	-20%
Water Discharge	+10%	-10%

Subsidence ranges

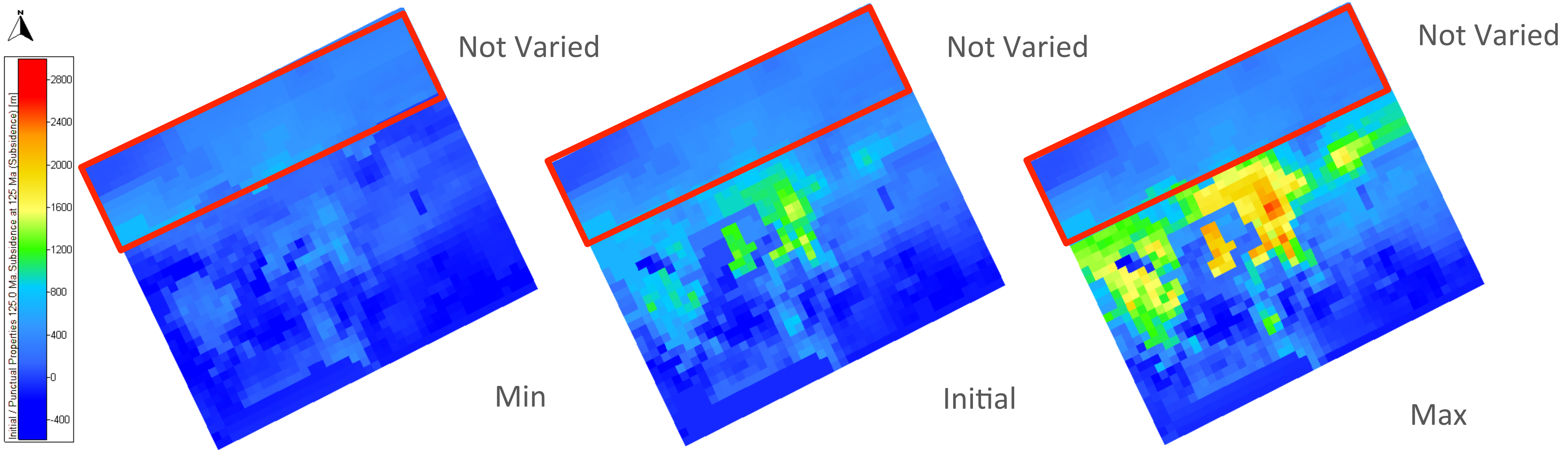
- Subsidence variation based on the range in percent total thickness of the calibration wells

Unit	Max (%)	Min (%)	Difference (%)
Upper Missisauga	59.7	17.0	42.6
Naskapi	49.5	7.0	42.3
Cree	65.1	29.1	36.0

Top Salt Canopy extent

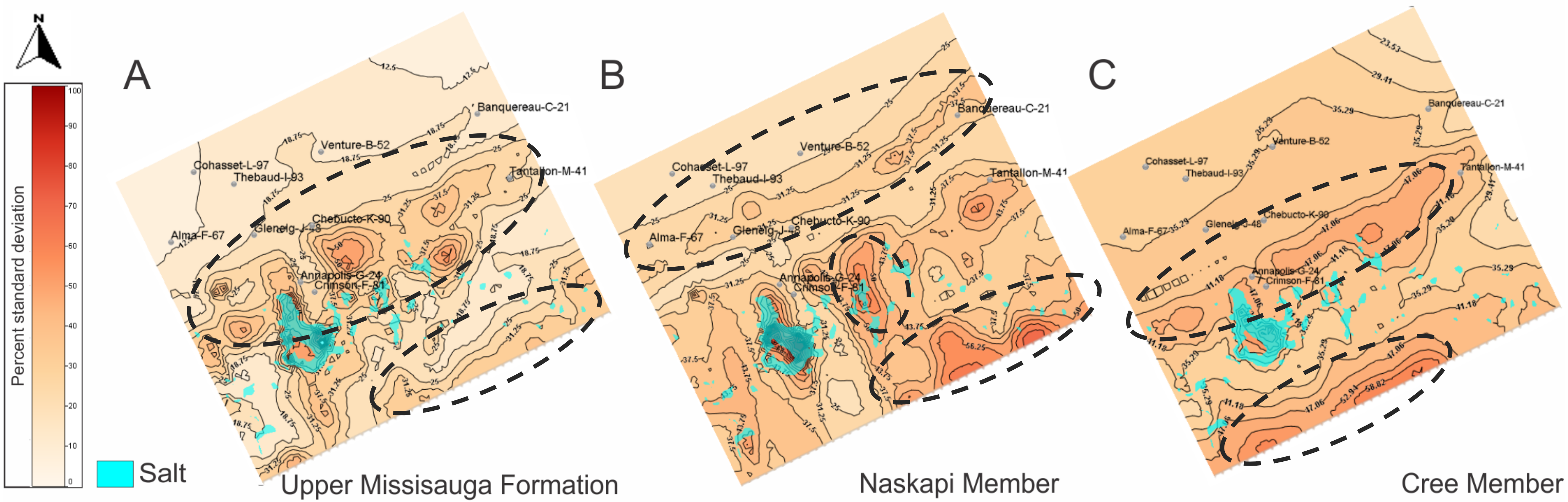


Subsidence Ranges Upper Missisauga



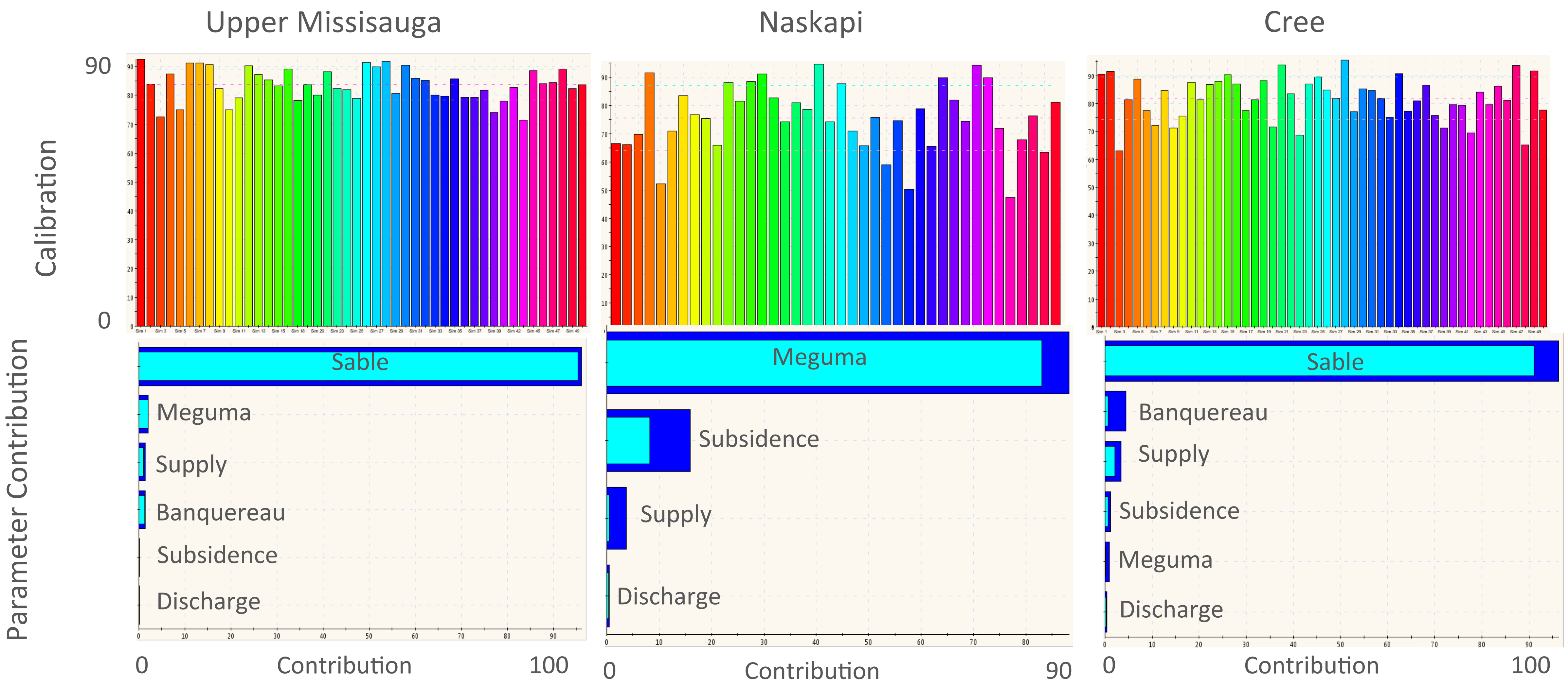
CougarFlow Results

Sand variation



- Sand distribution most effected in the basin around areas where salt is present
- Very limited effect on the shelf
- Upper Missisauga and Cree show large impact along the slope and base of the slope
- Naskapi shows large variations in the deep basin
- Little variation in areas where sand accumulation was identified

Statistical Results



Conclusions

- Proposed provenance pathways for the Early Cretaceous can be used to generate predictive stratigraphic models of overall sediment distribution
  - Modelling suggests that the shaly nature of the Naskapi Member may be the result of tectonic diversion of the Sable River
  - Differential sediment supply suggests episodic diversion of the Sable and Banquereau Rivers during the Albian
- Sand is dominantly trapped on the shelf, with transport into the basin along salt corridors occurring in the Upper Missisauga Formation and Cree Member
  - This led to sand accumulation in minibasins with large deposits seaward of the Alma F-67, Annapolis G-24 and Crimson F-81, and Tantallon M-41 wells
- Extended area simulations show sand transport beyond the study area, suggesting that there is potential for exploration in the deep basin
- Sensitivity analysis suggest that source composition is the controlling factor for sand distribution in the central Scotian Basin

Acknowledgements

- Dr Andrew MacRae
- Beicip-Franlab basin modeling, geology, and support teams
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  - Mark Deptuck
  - Kris Kendell
- Nova Scotia Department of Energy
  - Adam MacDonald

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Questions