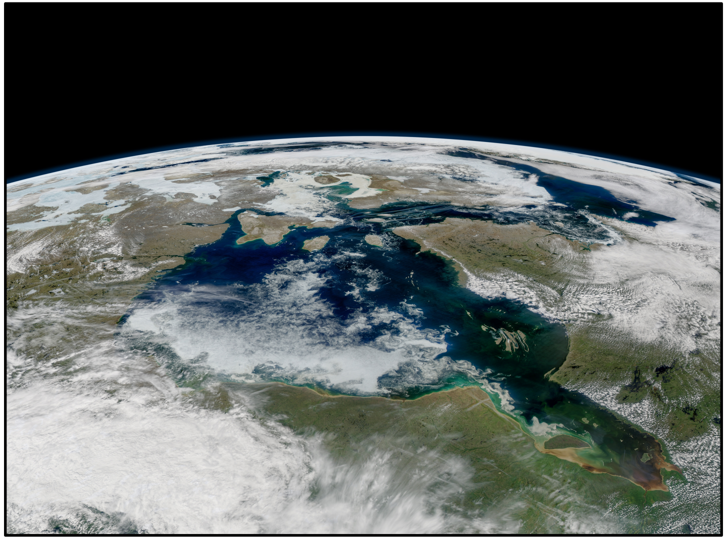
vEGU21

Gather Online I 19–30 April 2021

Thermochemical Structure Of The Superior Craton From Multi-observable Probabilistic Inversion

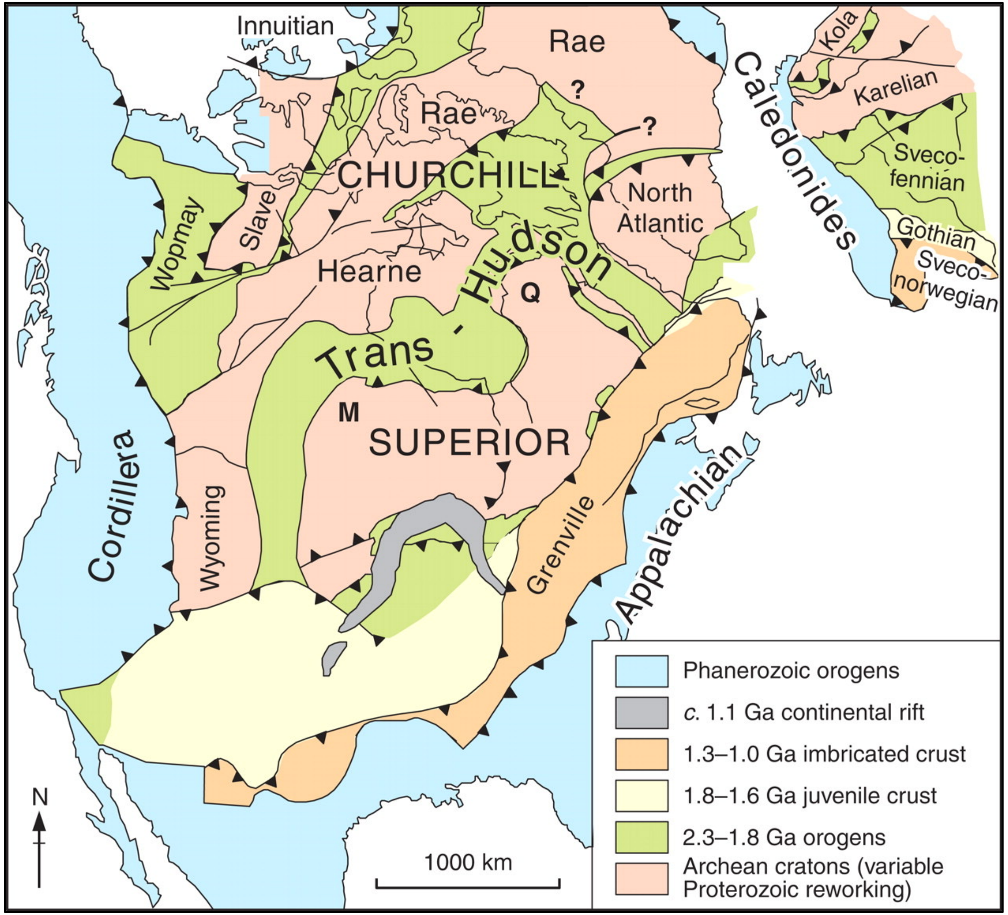


Riddhi Dave

MG3
Macquarie's Geophysics and Geodynamics Group

De Beers Group

Geological Map



[Modified from *Hoffman, 1988*]

- Superior craton: largest and best preserved Archean craton, assembled by 2.5 Ga
- Assembly of Laurentia via orogenesis throughout the Proterozoic
- Closure of Rheic and Iapetus Oceans during the Phanerozoic
- Double-indentor shape of the Superior craton → likely entrapment of juvenile material in the Trans-Hudson Orogen

An Interesting Problem

- ❖ The thermochemical structure of the lithosphere is a key factor in modulating or controlling surface processes
- ❖ Reliable estimates of the 3-D temperature distribution and compositional structure beneath continents are difficult to obtain and surrounded by methodological controversy

Questions:

(i) How can we obtain reliable models of the first-order thermochemical structure of the lithosphere?

(ii) To what extent are different tectonic models and processes actually supported or required by independent geophysical, geological, and geochemical evidence?

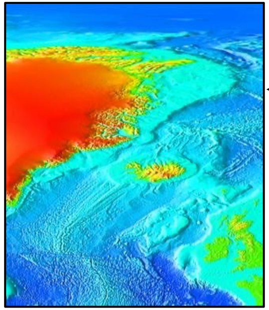
(iii) How can we combine multiple observations with complementary sensitivities into a thermodynamically and internally consistent framework?

Answer:

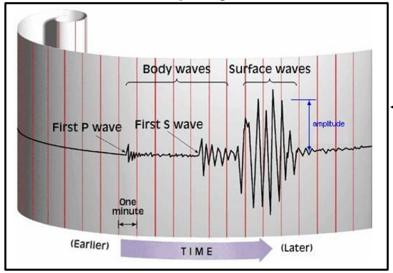
Multi-observable probabilistic tomography

Integrating Geological and Geophysical Data

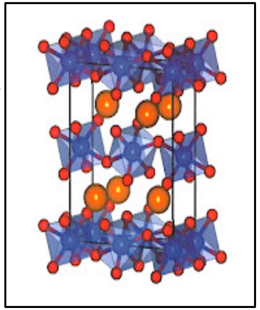
Surface Observables



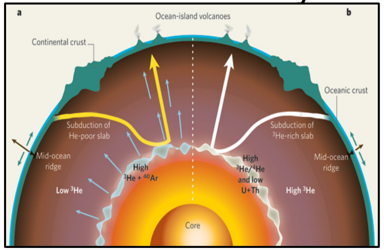
Geophysics



Mineral physics

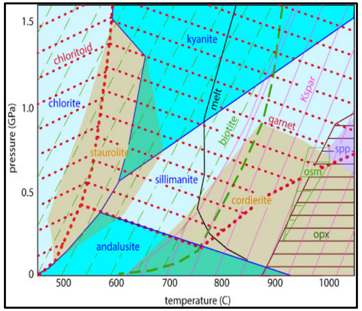


Geochemistry



Probabilistic, Multi-Observable, Internally-Consistent Inverse Framework

Thermodynamics



Petrology and mineralogy

How is it done?

First Part (MC search in 1-D)

Input

Dispersion curves	**Elevation**
1D geoid anomaly	**Surface heat flow**
Xenolith data*	**Sediments**
Vp structure	**Moho depth**

*From global petrological database- When this information is reliable, it serves as a priori constraints

↓

Nonlinear inversion

(Search for acceptable models "column by column" and their PDFs using Delayed Rejection Adaptive Metropolis Algorithm (DRAM))

↓

Output

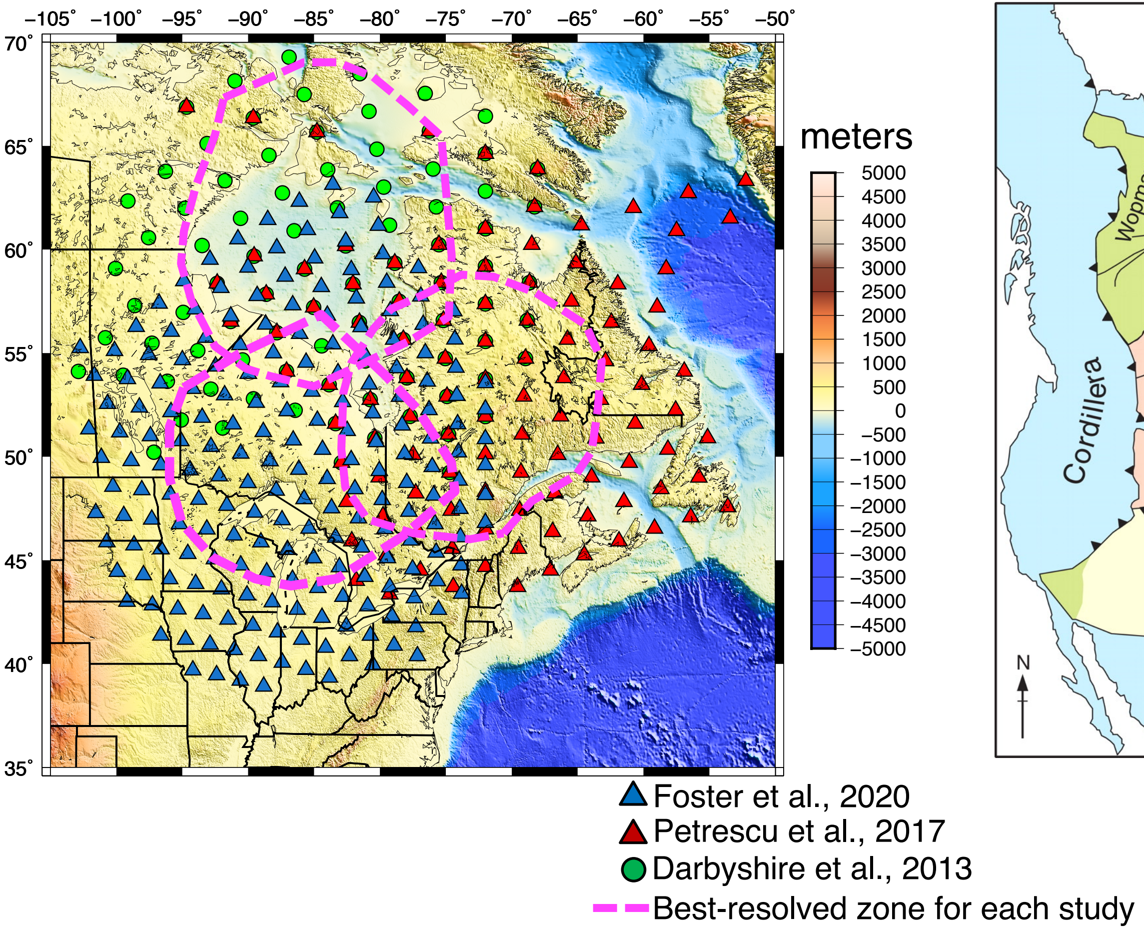
(PDFs for all parameters in all individual columns)

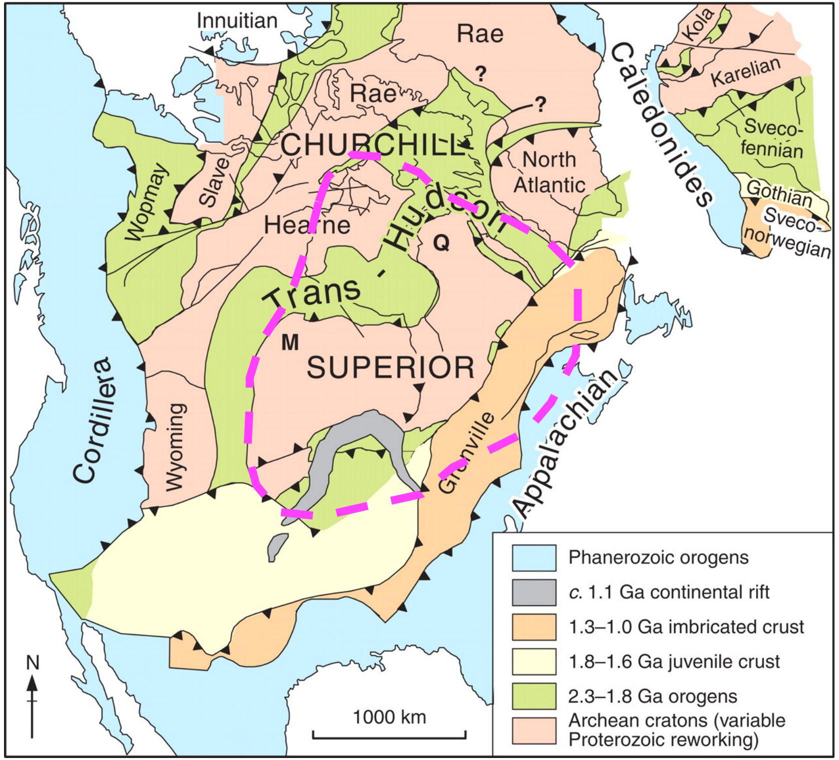
→

Second Part (refinement in 3-D)

Posterior PDF: In a Bayesian framework, the solution to the inverse problem is given by the Posterior Probability Density Function (PDF), which contains the ensemble of acceptable models as allowed by data and a prior information.

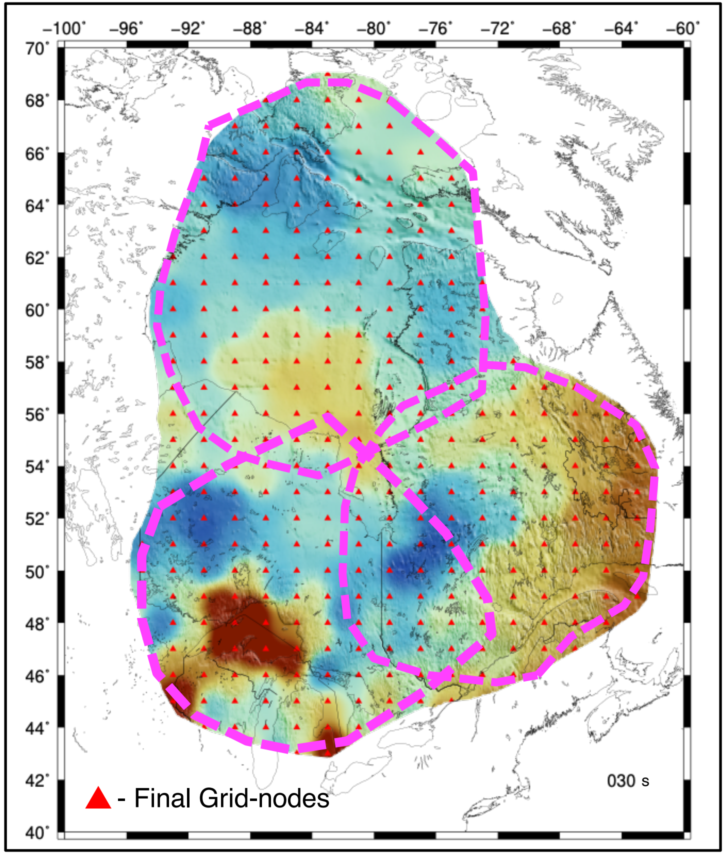
Surface Wave (Rayleigh Wave) Tomography

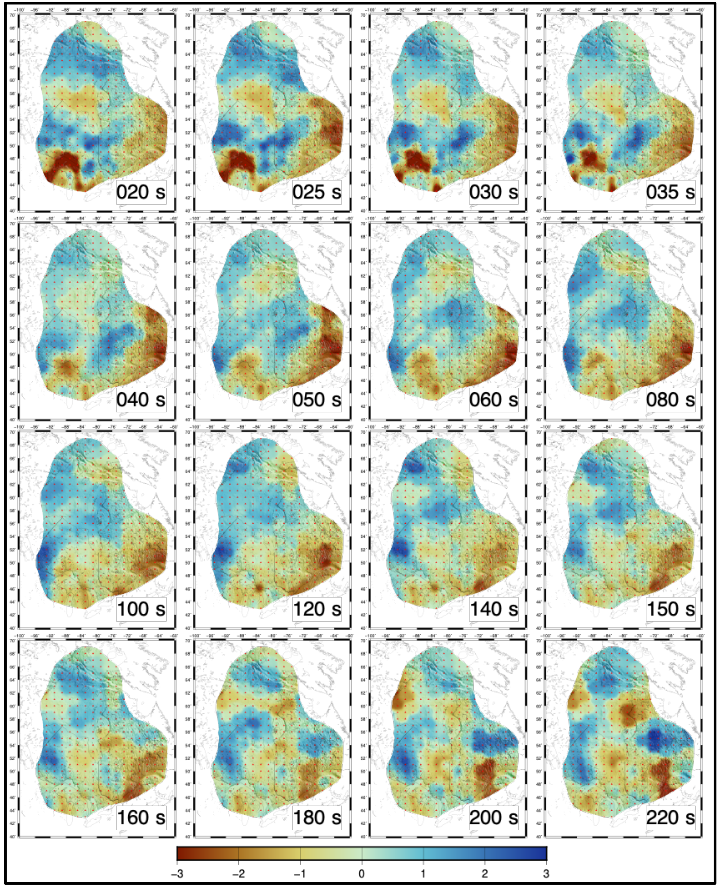




[Modified from *Hoffman, 1988*]

Composite Phase Velocity Maps





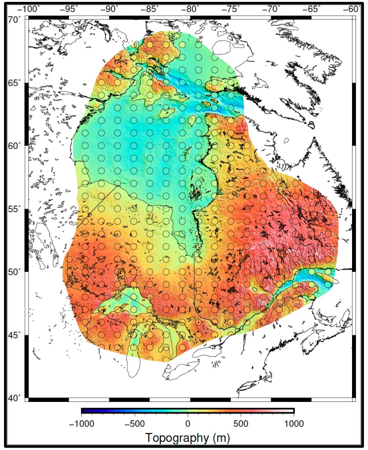
Phase velocity anomaly (%)

Data and Data processing steps:

- ❖ Shortest 20 s to the longest 220 s
- ❖ Clipping of each data-set based on ray-path coverage and resolution
- ❖ Weighted-average of regions of overlap
- ❖ Interpolating and gridding
- ❖ 312 Grid-nodes

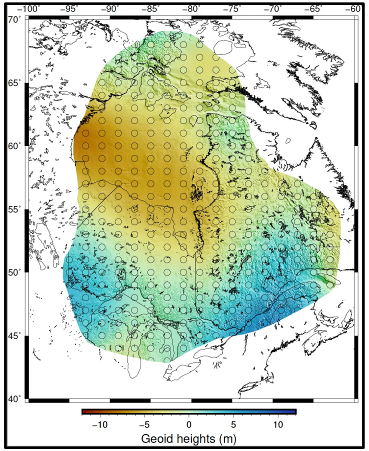
Surface Observables

Topography



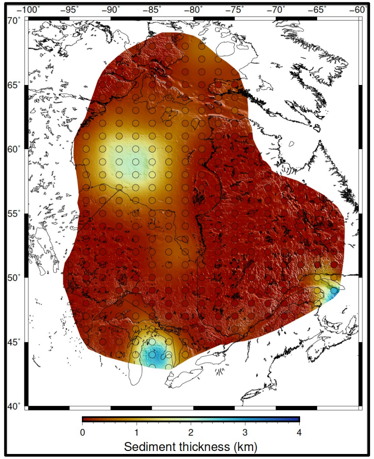
Etopo1

Geoid anomaly



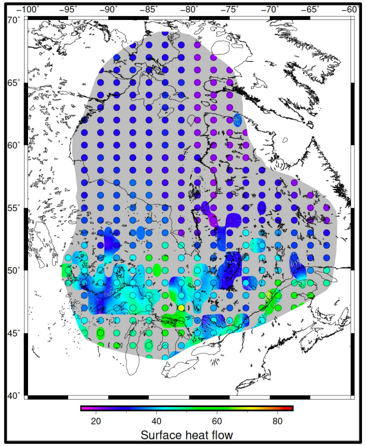
EGM2008

Sediment thickness

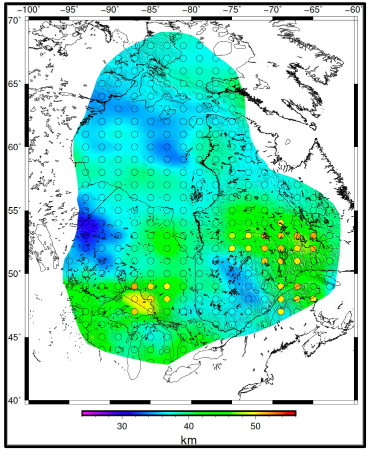


Crust1.0

Surface heat flow



-Mareschal
-Pers. comm.



Moho Depth

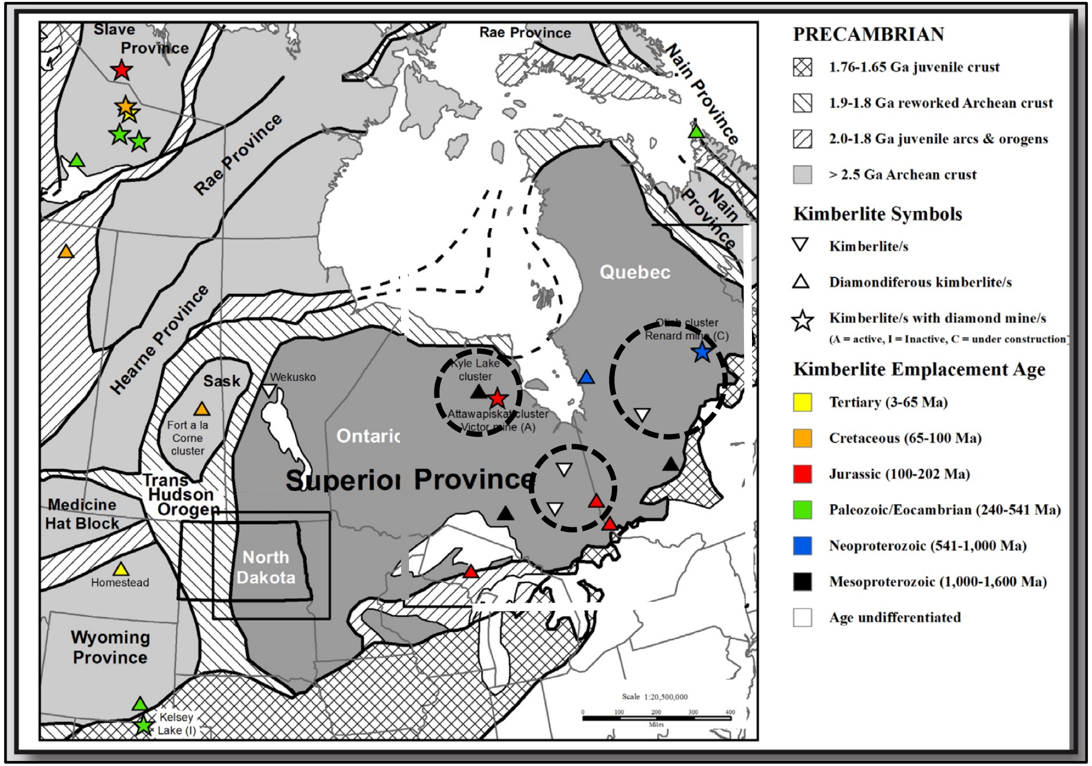
-CRUST1.0 Laske et al., 2013
-Tesauro et al., 2014
-Shen & Ritzwoller, 2016
-LITHOPROBE
-Receiver function studies

Other Geophysical Inputs :

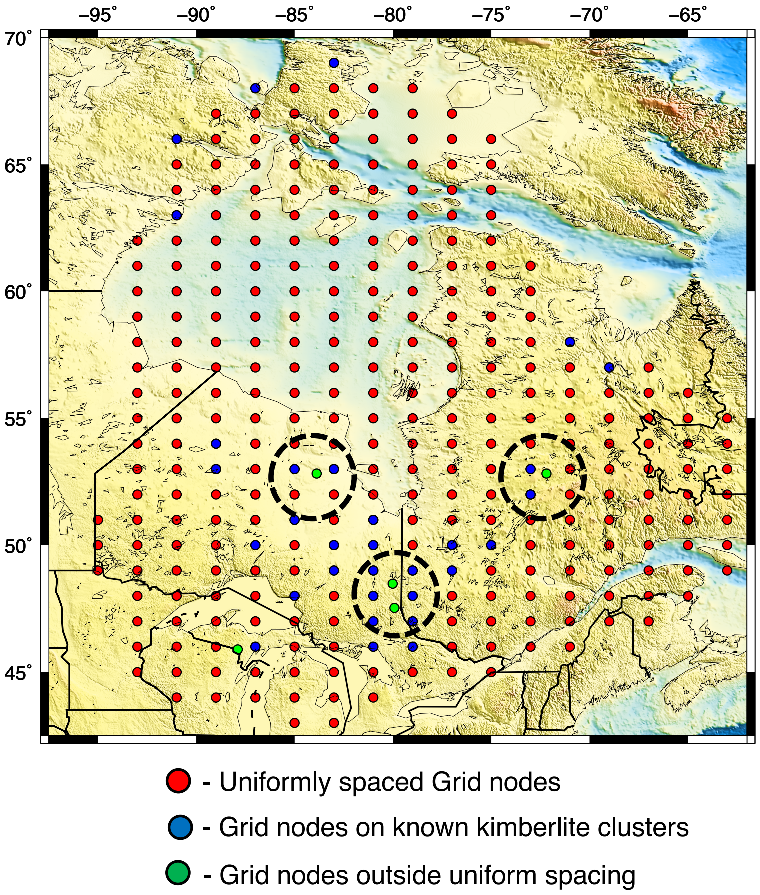
- Body wave data
(BBNAP19: Boyce et al., 2019)

- Global tomography model
(GYPSUM: Simmons et al., 2010)

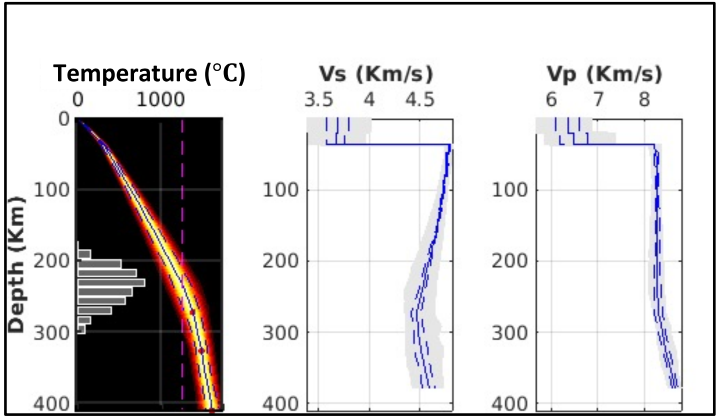
Tectonic Map with Kimberlites

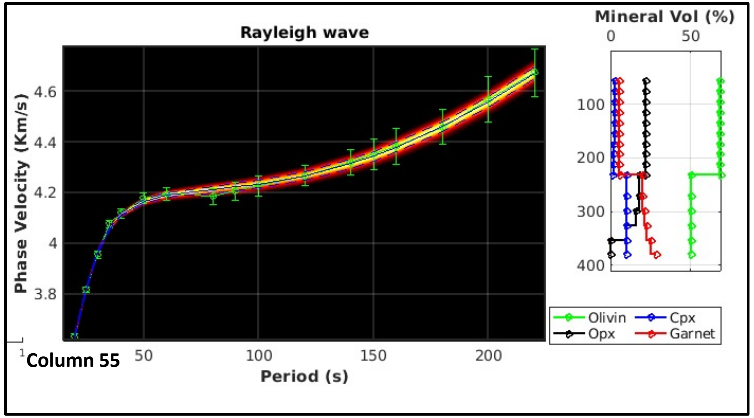


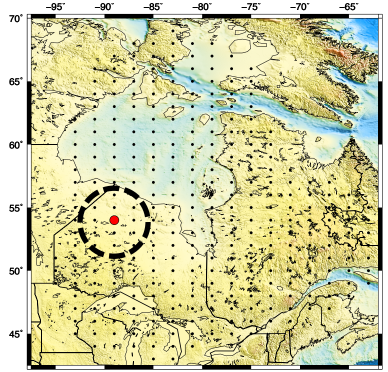
[Nesheim, *2016*]



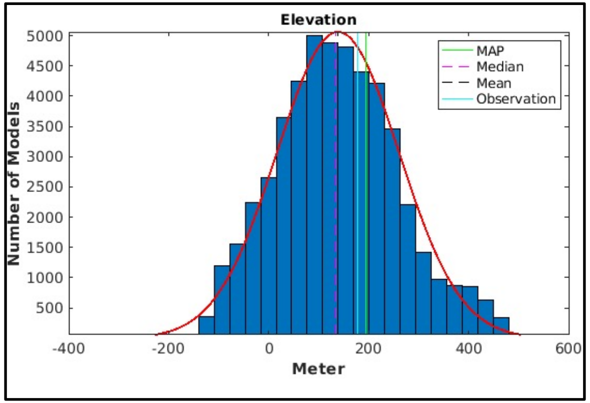
1D Outputs – Column 55

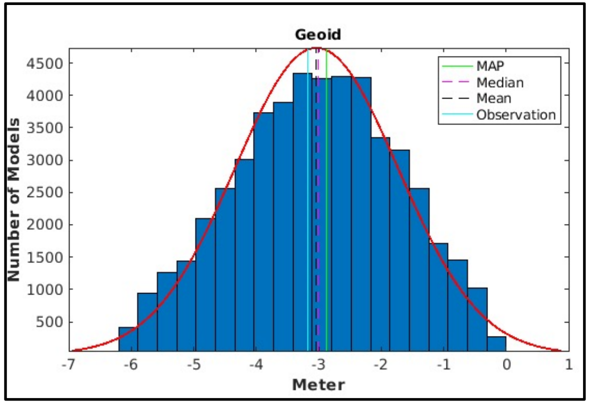


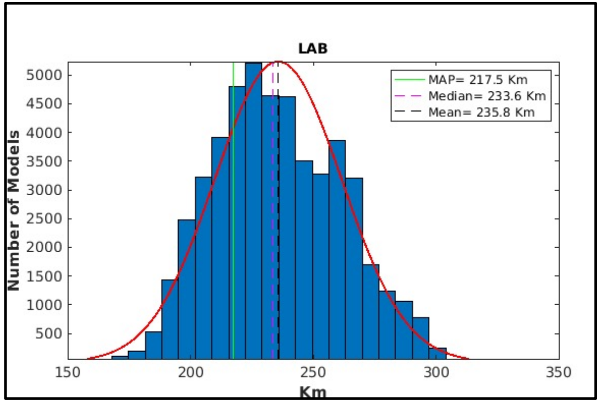




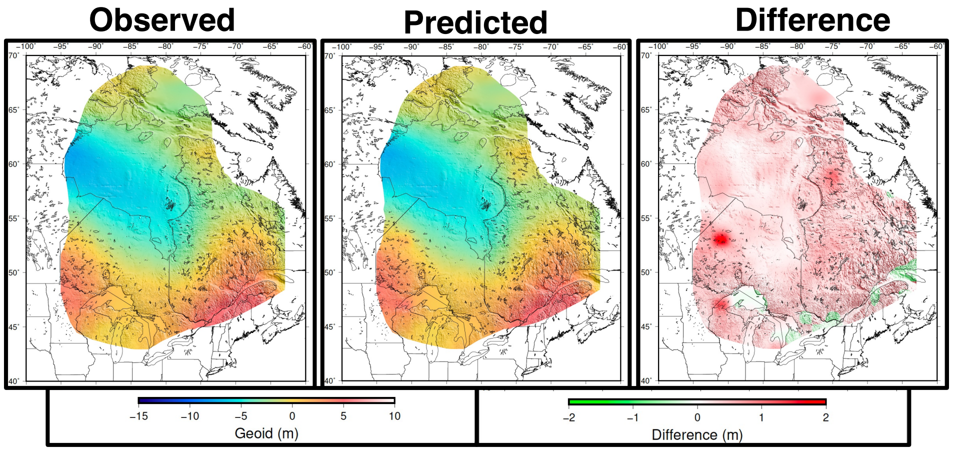
- 1000s of accepted models; histograms show most likely values & uncertainties



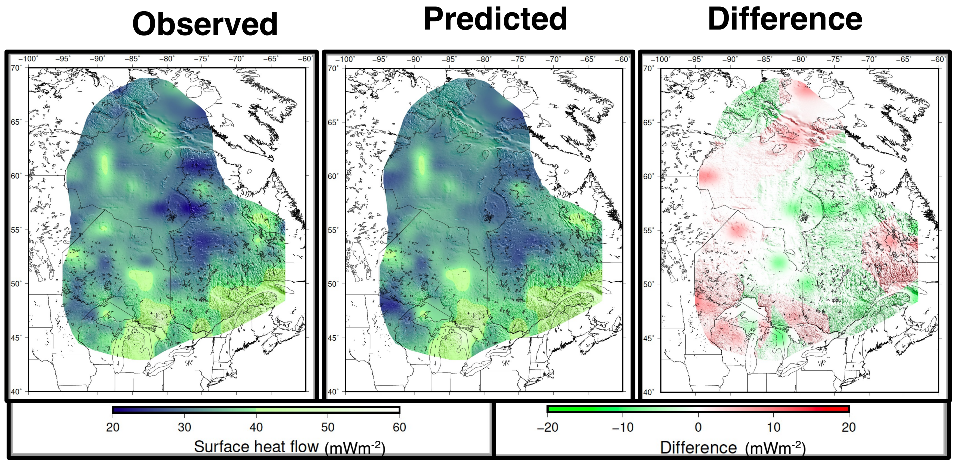


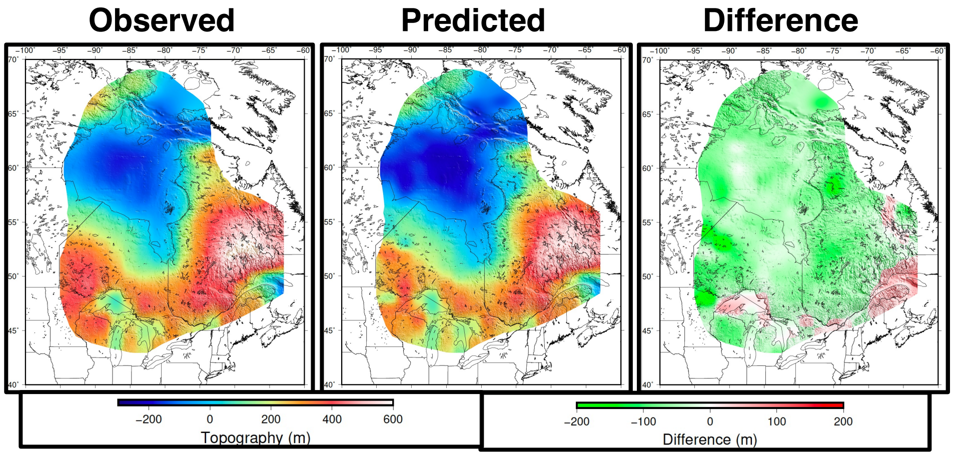


Geoid, Surface heat flow, and Topography



- ❖ Predicted data are depicted as the means of their respective posterior PDFs
- ❖ The fit to dispersion data remains within uncertainties in most of the study area
- ❖ Both predicted geoid and elevation fit closely the observed values within their assigned uncertainties

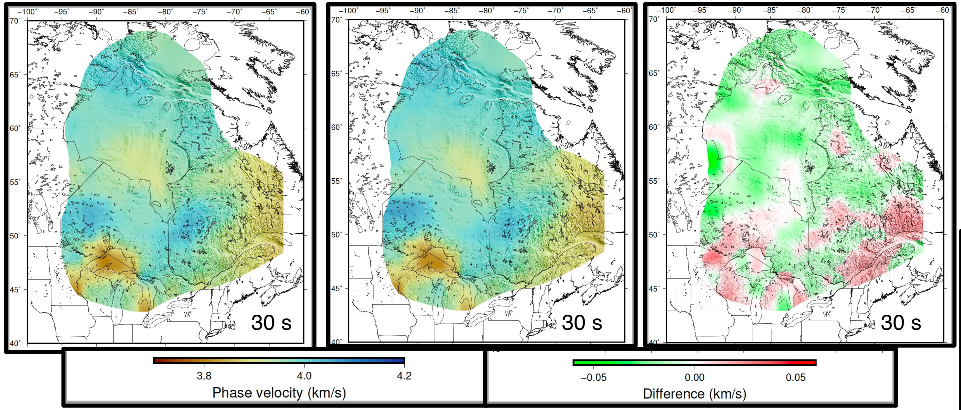




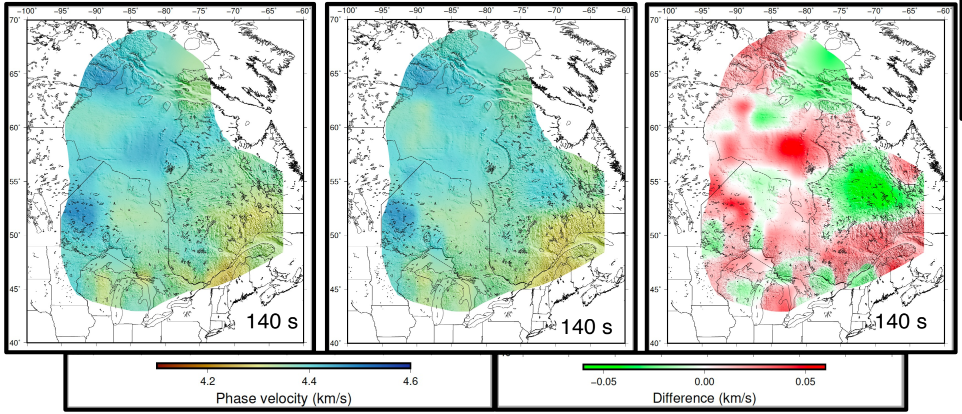
- ❖ The predicted SHF data shows an average value of ~ 40 mWm^{-2}
- ❖ Differences between observed and predicted are within the assumed uncertainty of ± 15 mWm^{-2}

Phase Velocities

Observed　　Predicted　　Difference

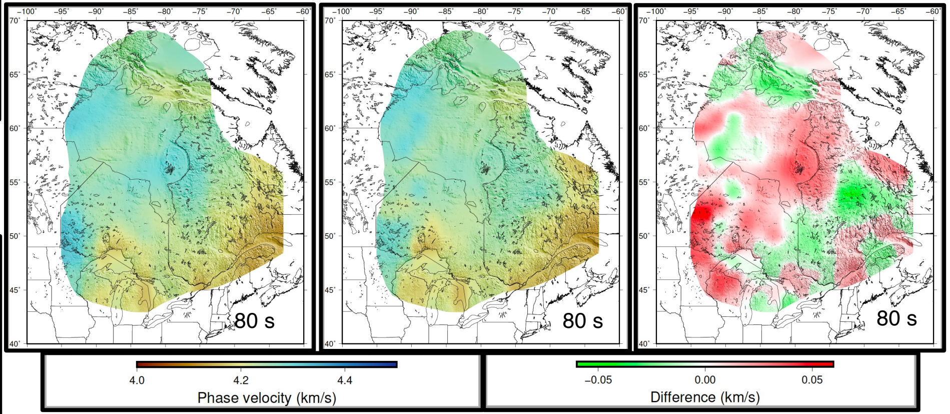


Observed　　Predicted　　Difference



❖ Predicted data are depicted as the means of their respective posterior PDFs

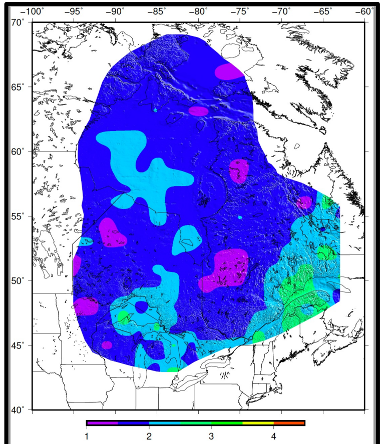
Observed　　Predicted　　Difference



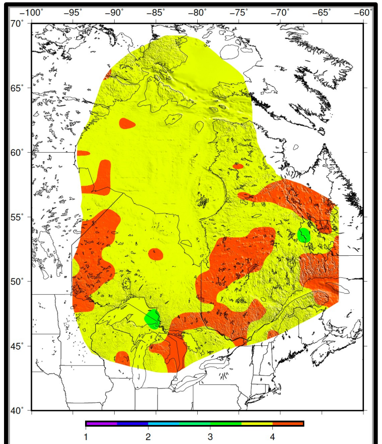
❖ The fit to dispersion data remains within uncertainties in most of the study area

Upper Mantle Compositions

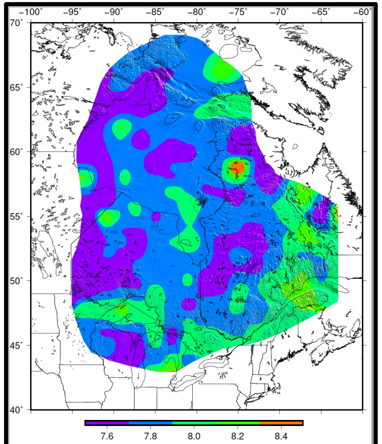
Layer 1 = Lithosphere, Layer 2 = Sub-lithosphere



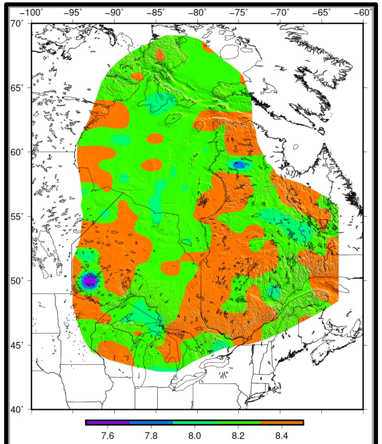
Al2O3 Layer 1



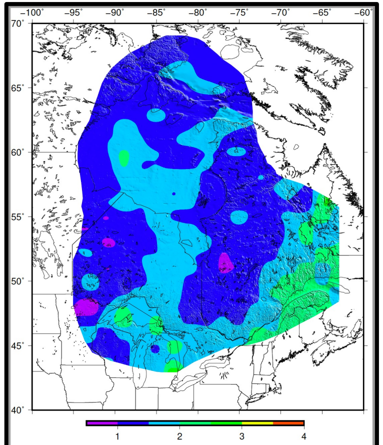
Al2O3 Layer 2



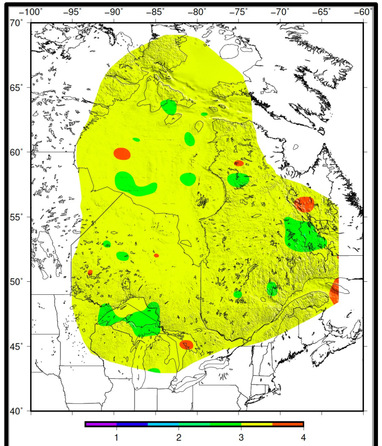
FeO Layer 1



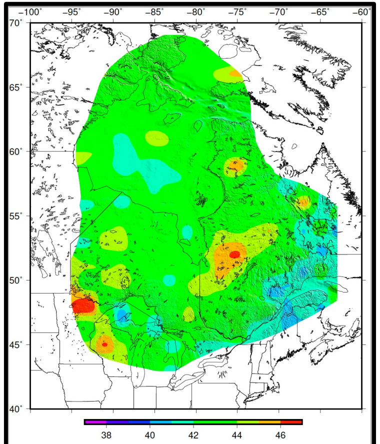
FeO Layer 2



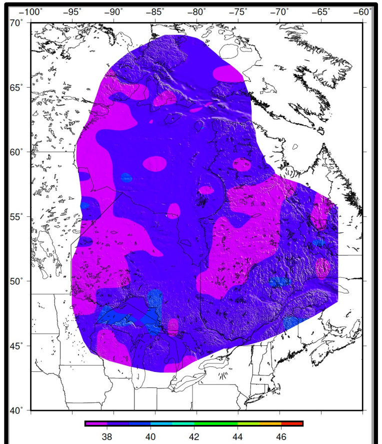
CaO Layer 1



CaO Layer 2



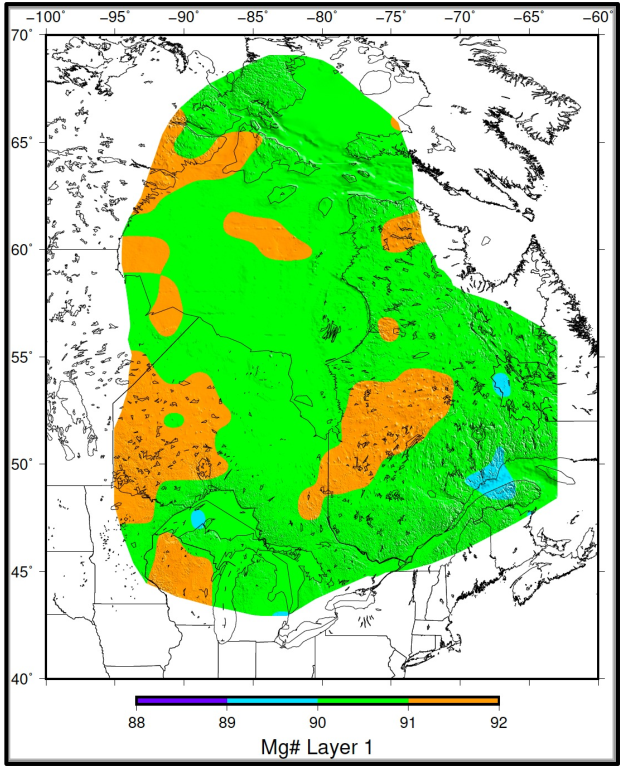
MgO Layer 1



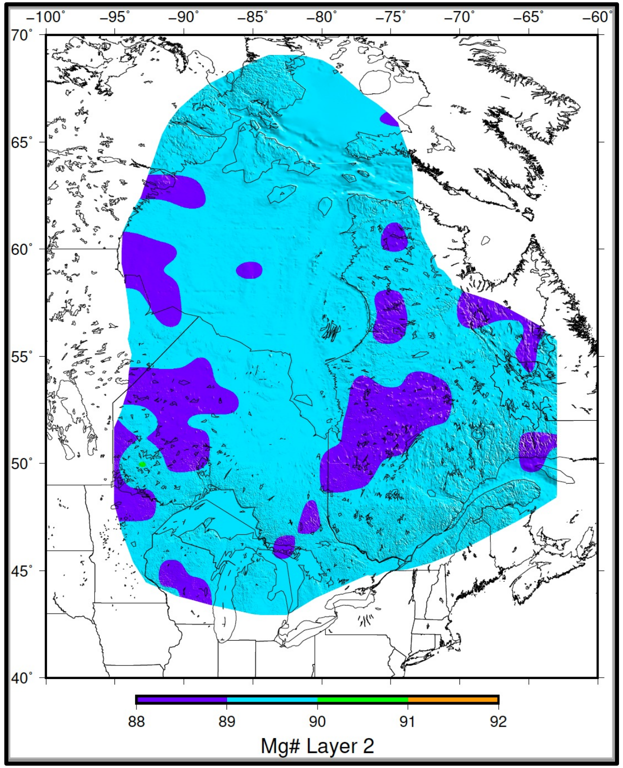
MgO Layer 2

Upper Mantle Compositions

Lithosphere



Sub-lithosphere



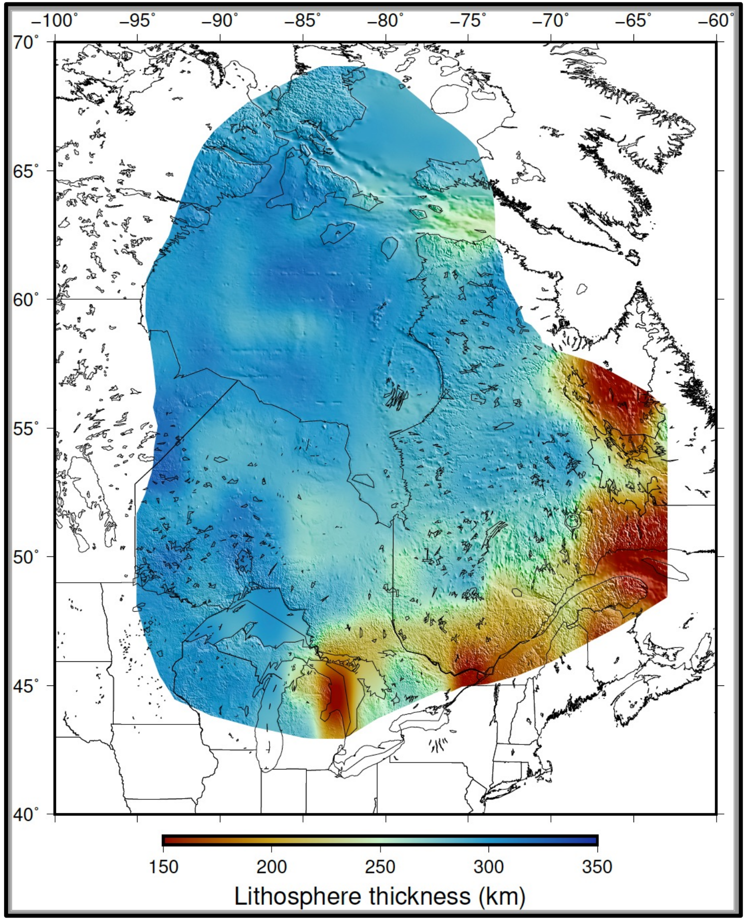
- Magnesium Number:
  Mg# = (Mg/40.30)/((Mg/40.30) + (Fe/71.84))*100

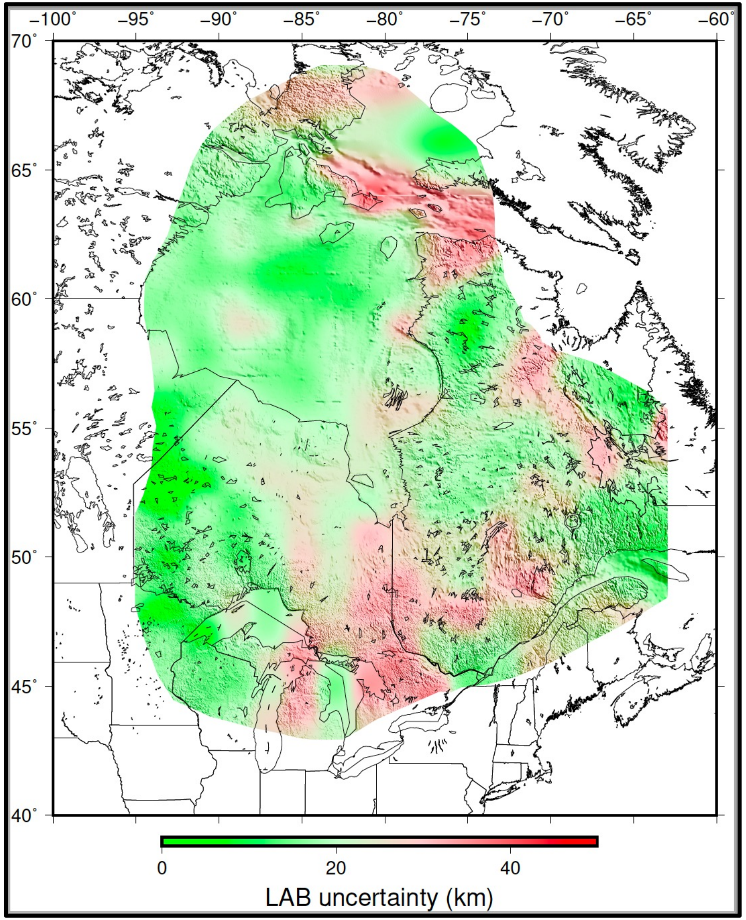
- High Mg# (>90) – refractory, depleted mantle

- Low Mg# (<90) – fertile or refertilized mantle

- Lithosphere (Layer 1) is more depleted than sub-lithosphere (Layer 2)

LAB Depths and Uncertainties





Future Work

- Integration of Vp data in the inversion
- Further tests for the appraisal of various parameters
- Possibility of adding Mid-Lithospheric Discontinuities (MLDs) if the data demands
- Opportunity for comparison of model LAB depths (and thus geotherms) with xenolith constraints
- Refinement in 3D inversion to yield compositional and thermal structure of the lithosphere and upper mantle