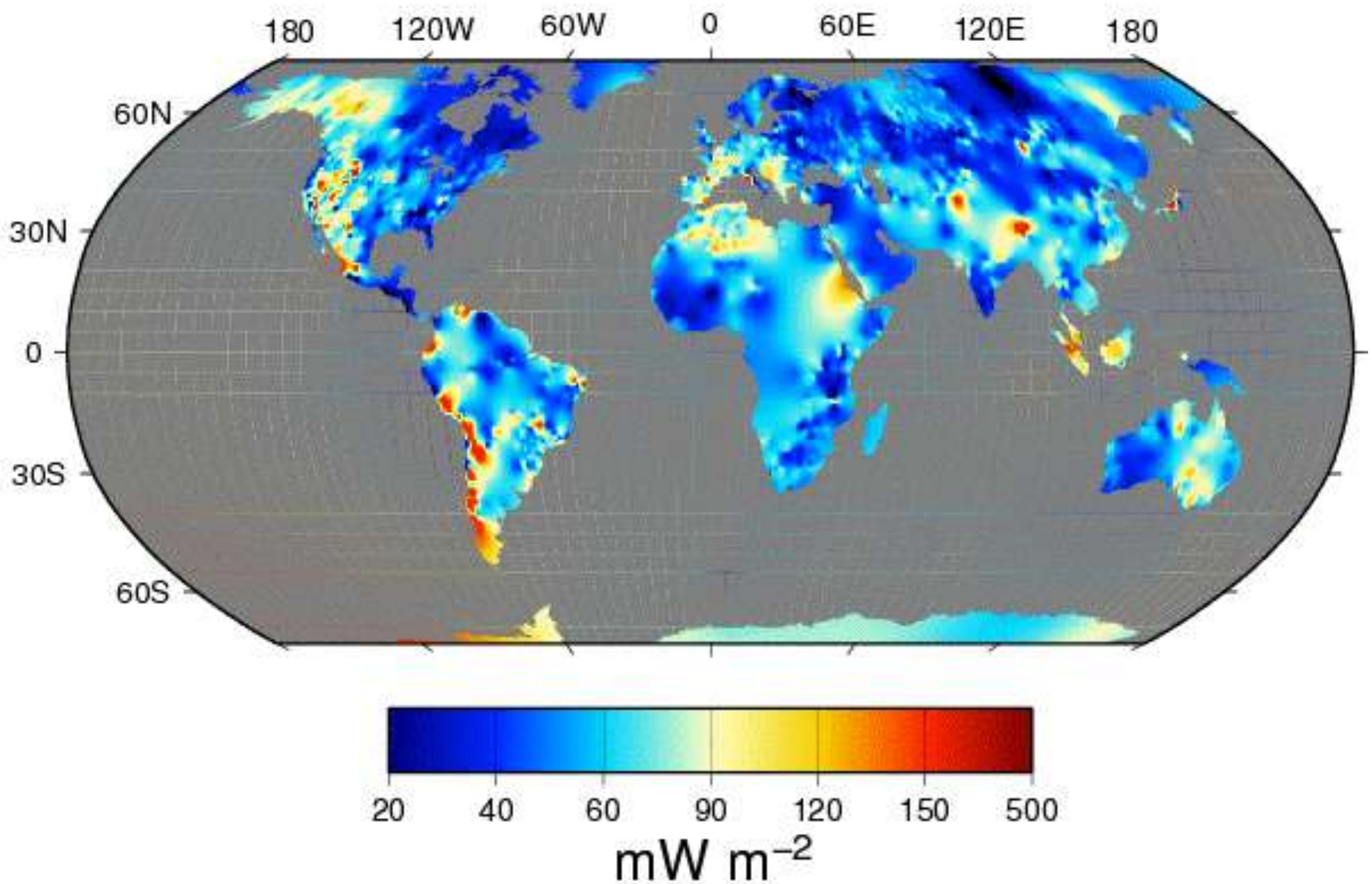
Deep thermal structure of the cratonic lithosphere

Jean-Claude Mareschal, with a little help from my friends, Claude Jaupart, Genevieve Savard, and many others…

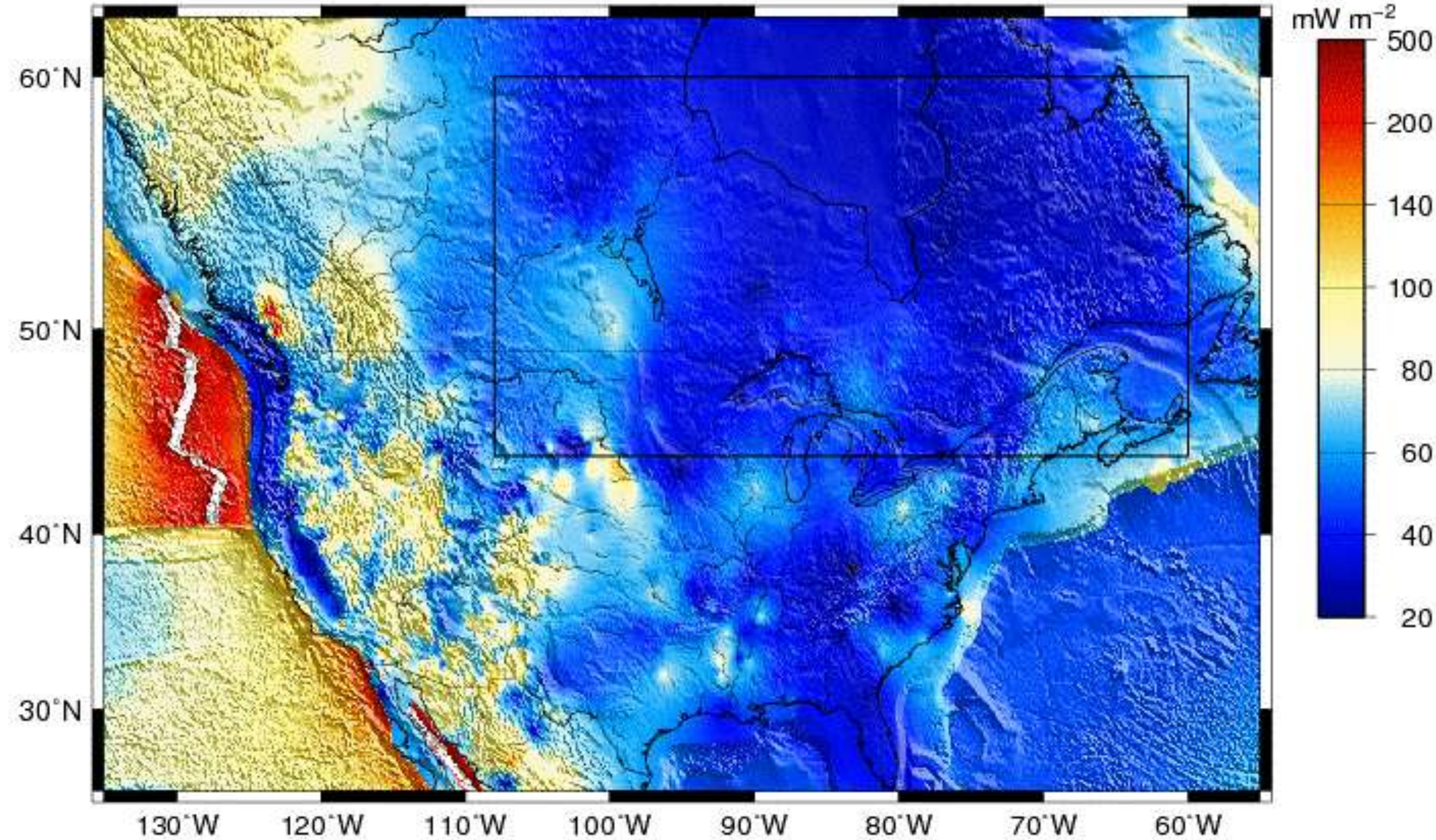
Deep thermal structure of lithosphere?

- What determines mantle temperature?
  - Surface heat flux
  - Vertical distribution of HPEs
- Controls on temperature models?
  - Xenoliths
  - Shear wave velocity profiles

Continental heat flux
Cold cratons: EOS?

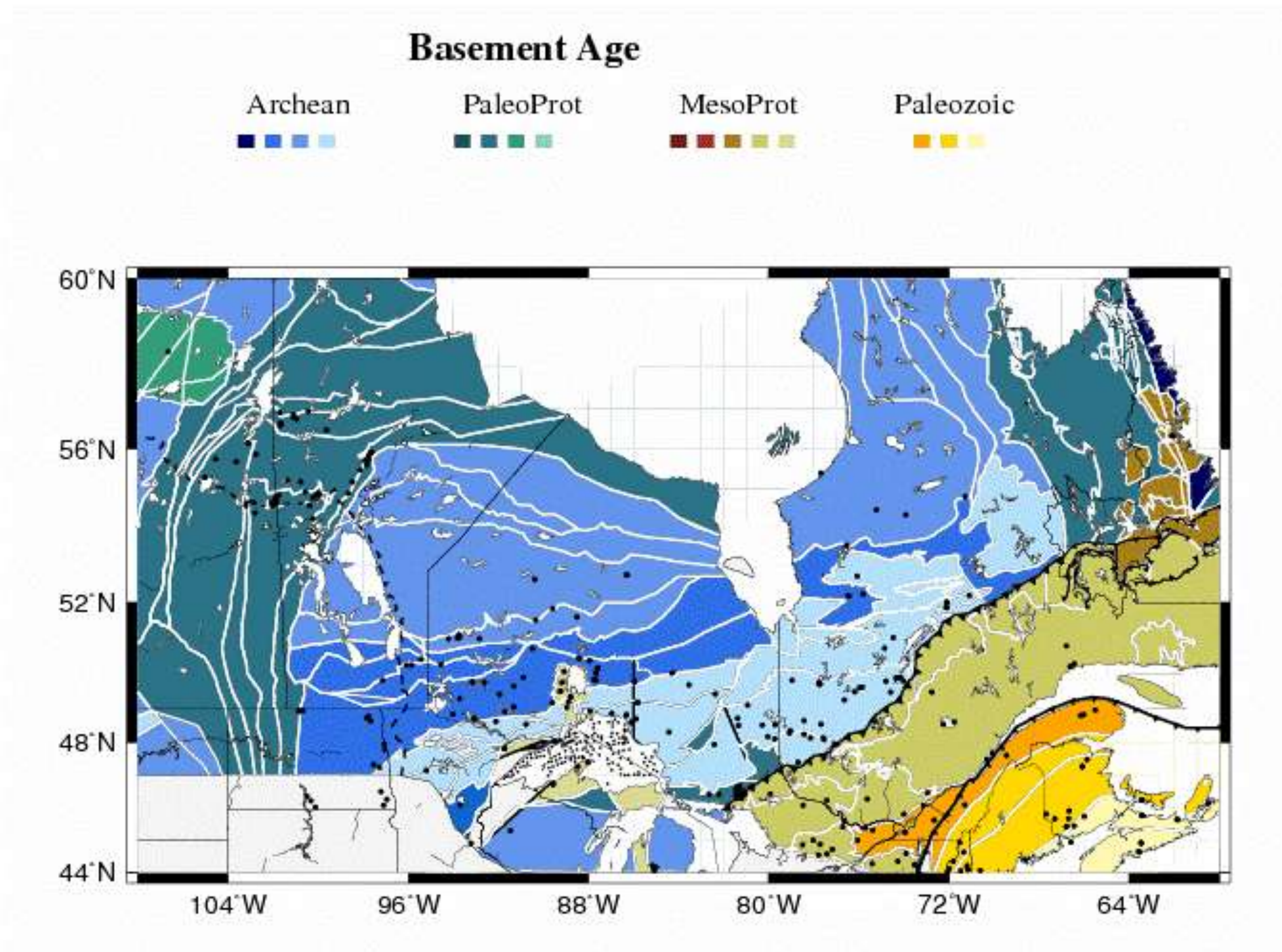


Heat flow



mW m^{-2}
500
200
140
100
80
60
40
20
60˚N
50˚N
40˚N
30˚N
130˚W
120˚W
110˚W
100˚W
90˚W
80˚W
70˚W
60˚W

Canadian Shield



How do we calculate temperature?

Steady-state 1-D equation for <T(z)>

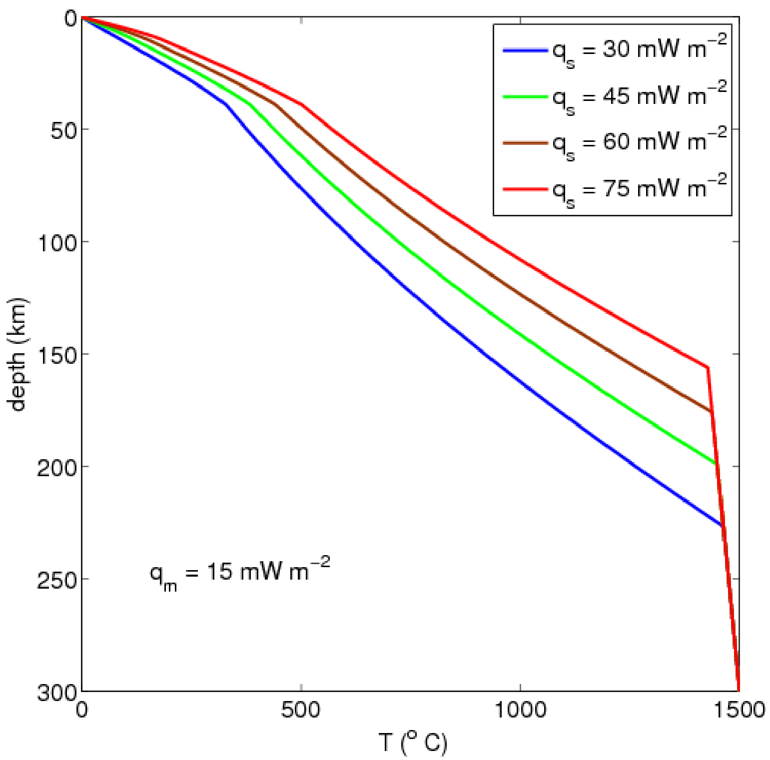
- $Q(z) = -\lambda(T)\frac{dT}{dz}$
- $\frac{dQ}{dz} = H(z)$
- $\frac{d}{dz}\lambda(T)\frac{dT}{dz} = -H(z)$

- $T(z = 0) = T0$
- $Q(z = 0) = Q0$
- $\lambda(T)$ thermal conductivity
- Heat production $H(z)$?

Controlling parameters for temperature profile

- Q_0
- $Q_m = Q_0 - \int_0^{zm} H dz$
- H_m ? small?
- H_c in crust characterized by differentiation index, DI
- $DI = \frac{z_m <H_0>}{Q_0 - Q_m}$

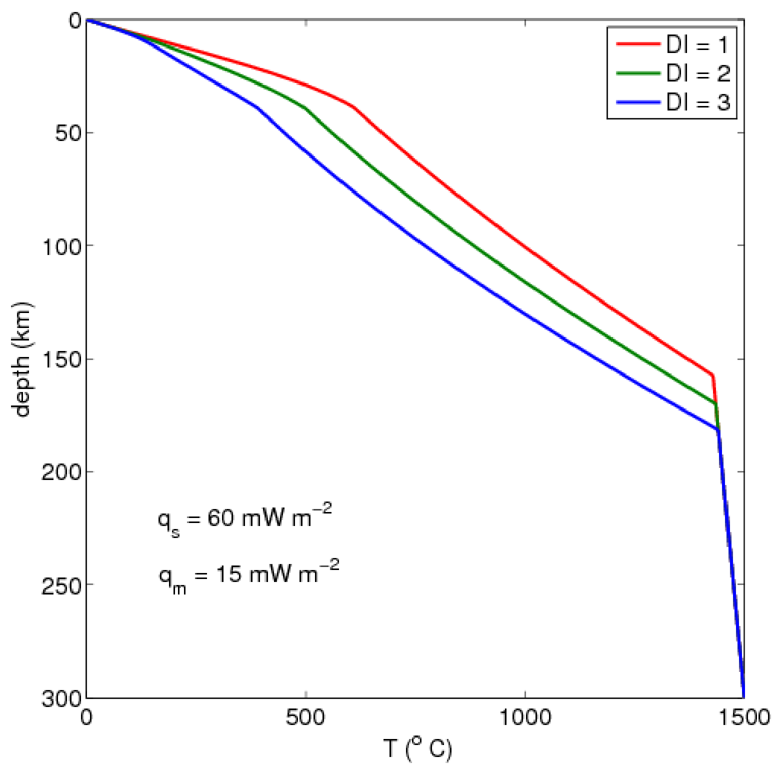
Surface heat flux?



- In shields,
  $20 < Q_0 < 80 mWm^{-2}$
- In Canadian Shield
  $26 << Q_0 >< 60\ mWm^{-2}$

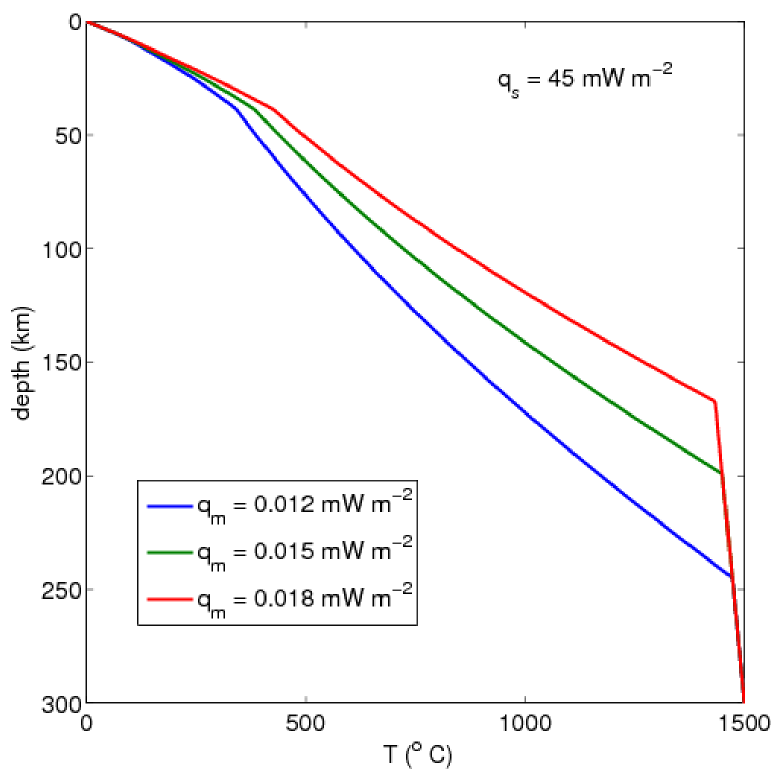
Crustal HP uniform,

Differentiation index



- In Canadian Shield
  - $DI = 0.7$ (Abitibi Subprovince)
  - $DI = 2.2$ (Slave Province)

Moho heat flux

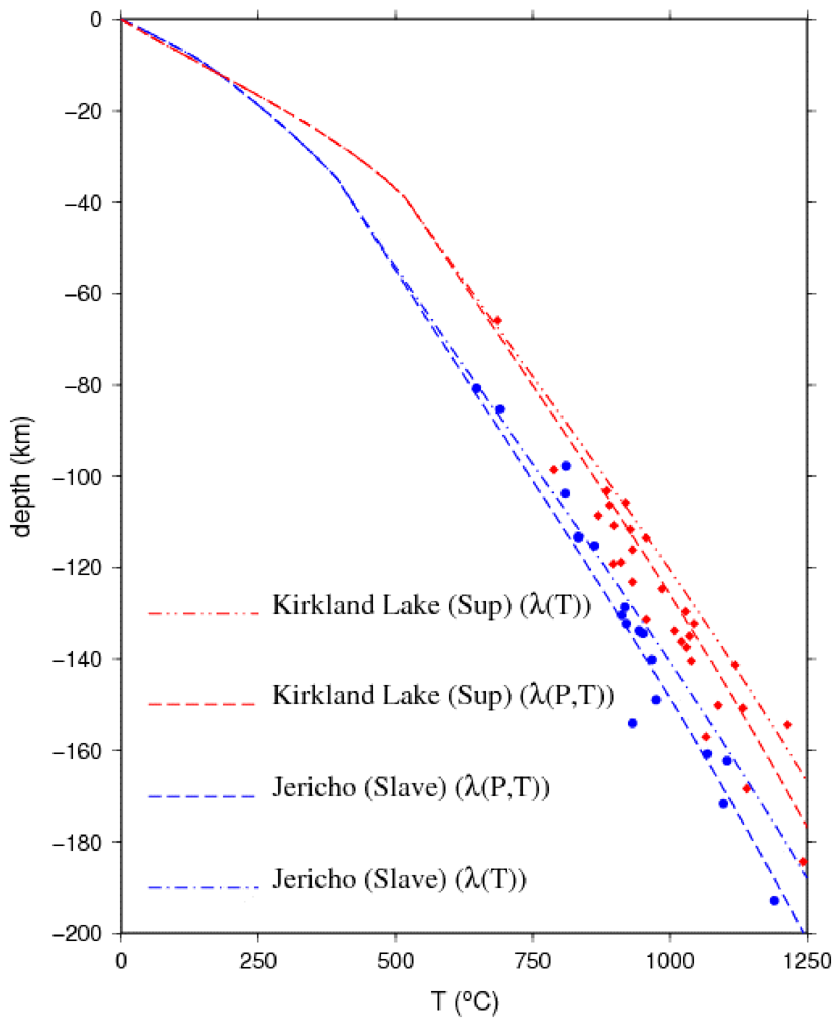


- Largest differences in mantle temperatures come from small differences in Qm
- Difficult to resolve Qm to < 3mWm^{-2} from surface heat flux only

Mantle heat flux variations in stable continents

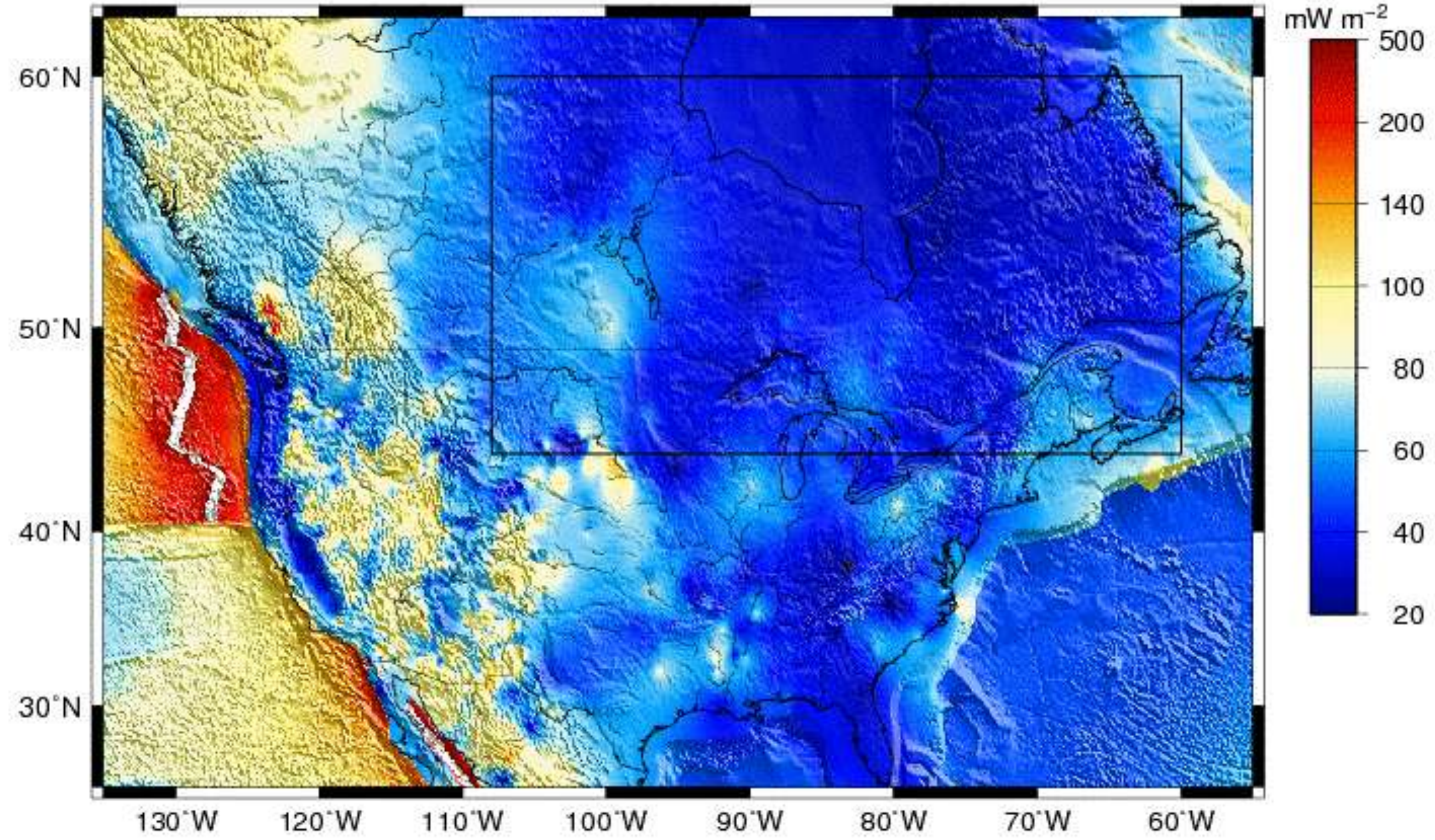
- $Q_m < 22$ mWm^{-2} (lowest heat flux measured)
- Best estimates $13 < Q_m < 15$ mWm^{-2}
  - Kapuskasing & other crustal sections
  - Grenville province
  - Gravity, crustal thickness, and heat flux data inversion
- Q_m can not vary by more than +/- 3 mWm^{-2}
- Variability small but very significant

Geothermobarometry on xenoliths from Slave and Superior Provinces



- Mantle xenoliths in kimberlites
- Phase equilibrium relationships => (P T) conditions at time of eruption
- Mantle temperature profile and heat flux
- Q0 higher in Slave, but mantle temperature higher in Superior

Heat flow



mW m^{-2}
500
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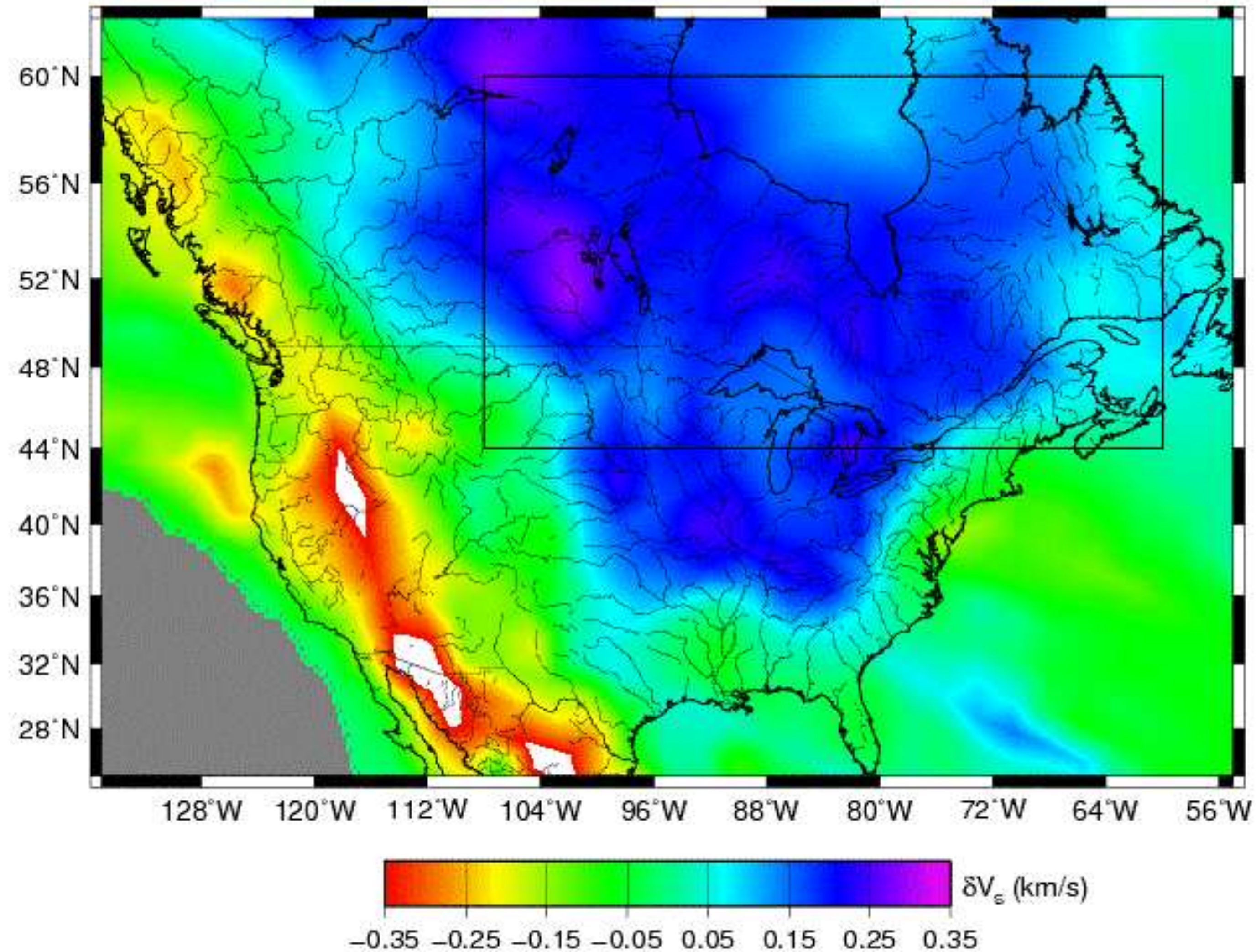
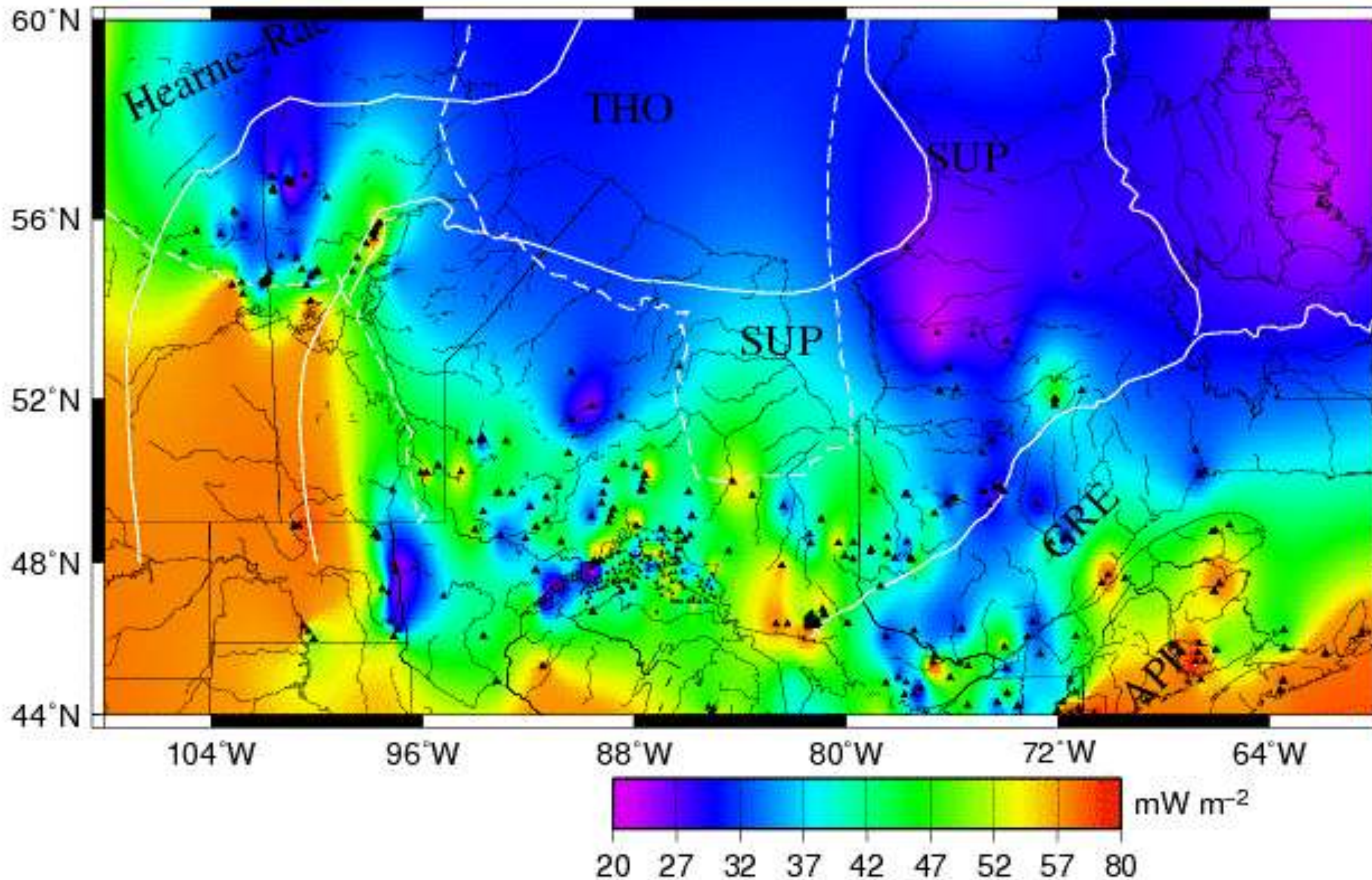
60°N
50°N
40°N
30°N
130°W
120°W
110°W
100°W
90°W
80°W
70°W
60°W

ΔV_s 150km (NA07)

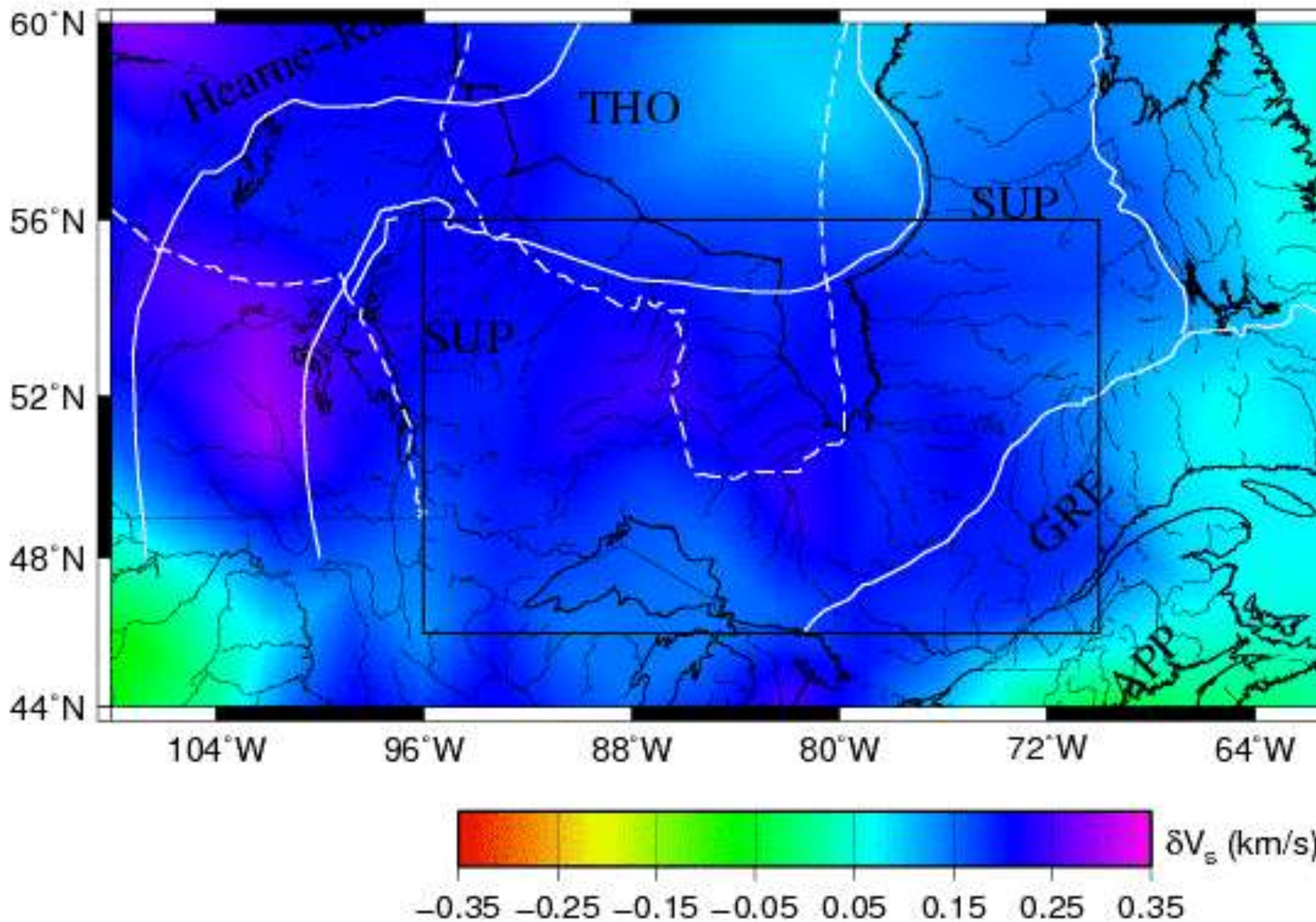


Beddle, H. and Van der Lee, S., 2009, JGR, 114, B7, B07308 .

Surface heat flux in SECS

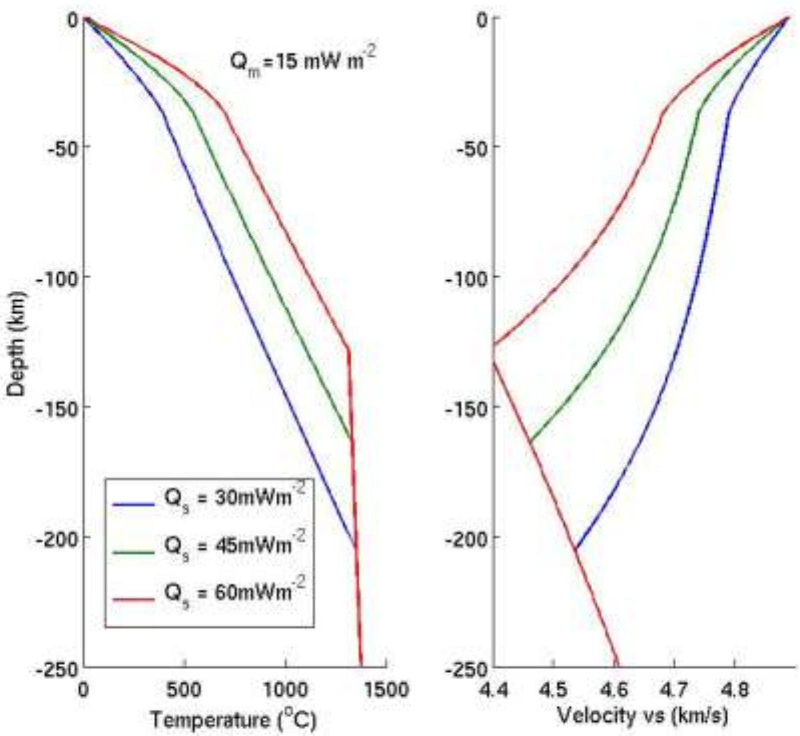


Shear wave velocity anomaly (150km)

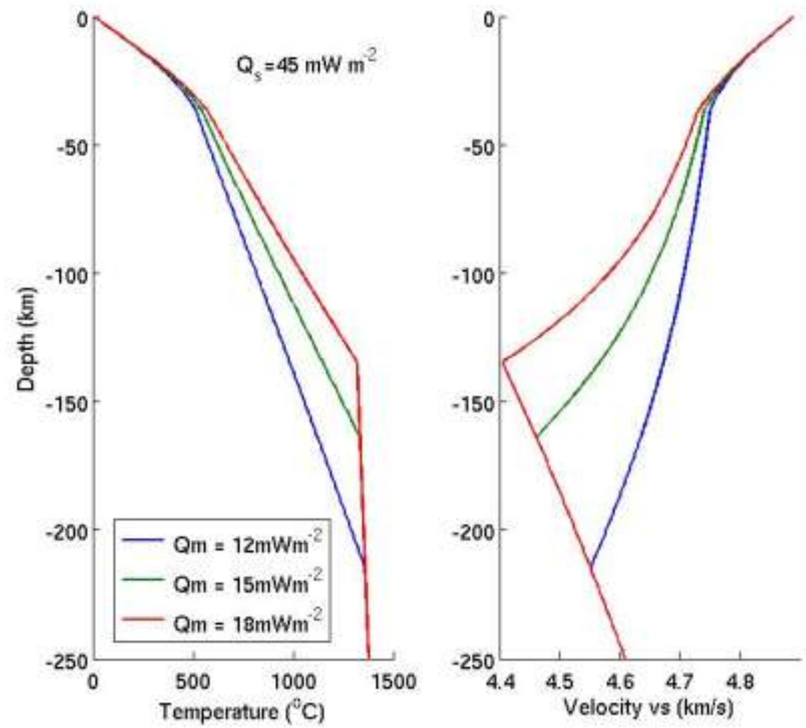


Temperature and velocity profiles

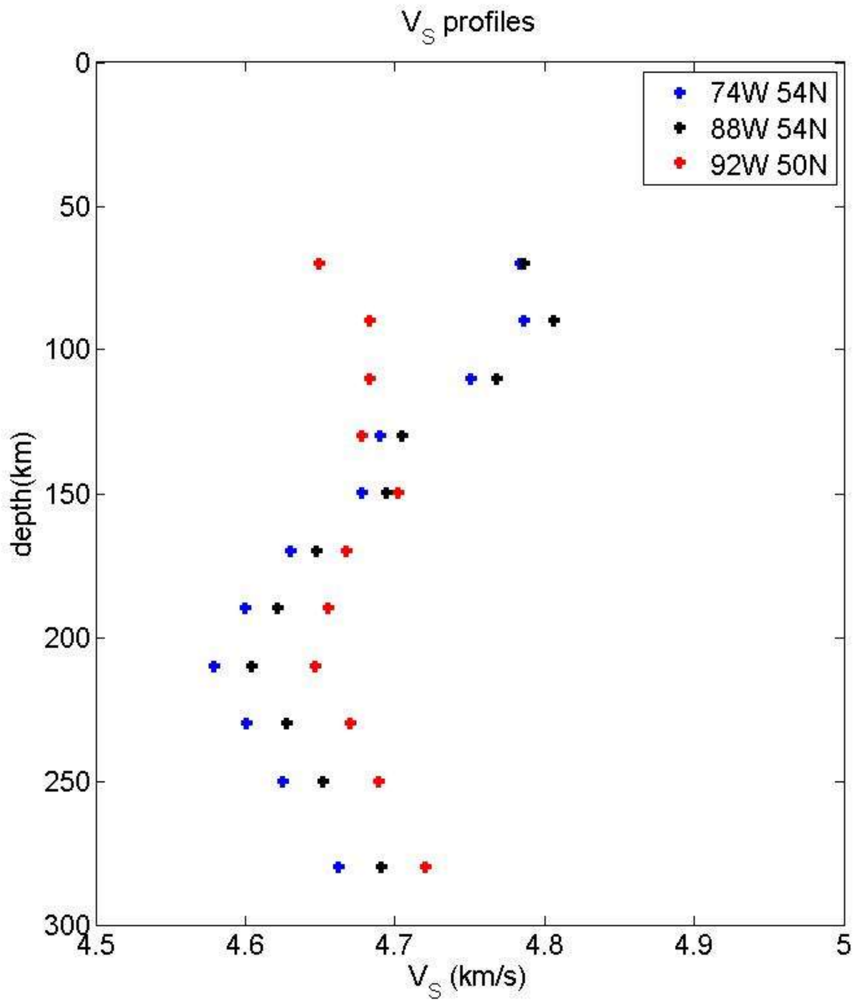
Large change in Qs
No change in Qm



Small change in Qm
No change in Qs



Composition Griffin’s Archon

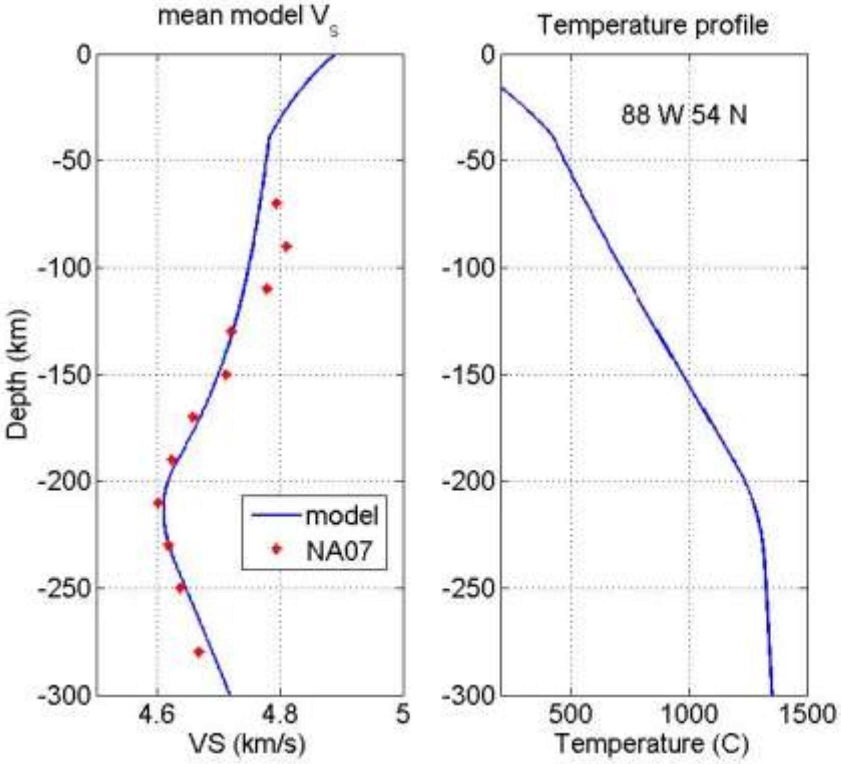


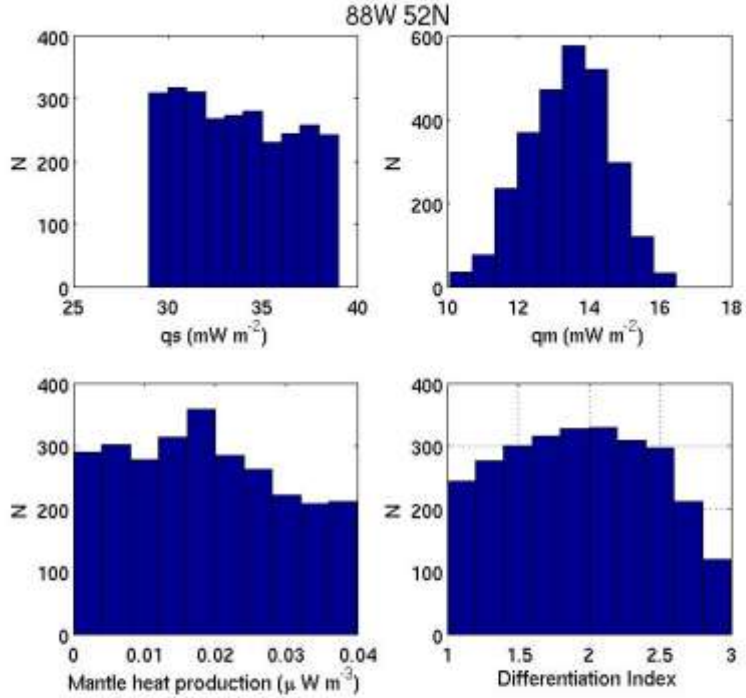
- Variations due to temperature
- Lithospheric temperatures depend on:
  - Qs
  - Vertical distribution of HPEs (Qm <= total crustal HP and DI = crustal differentiation, mantle HP small)

Monte Carlo inversion of vertical velocity profiles and surface heat flux

- Free parameters for calculating temperature profiles
  - Q_0 (varies +/- 4 mWm^{-2} around average value in cell)
  - Qm
  - <hp>=(Qm-Qs)/zm
  - DI = hp (surface) / <hp>
  - Mantle heat production (<0.04 μWm^{-3})
- Crustal thickness constrained by seismic refraction or receiver functions.
- Different compositions (McDonough & Rudnick, Griffin Archon,…)

Example best fitting model and parameters for 1 cell



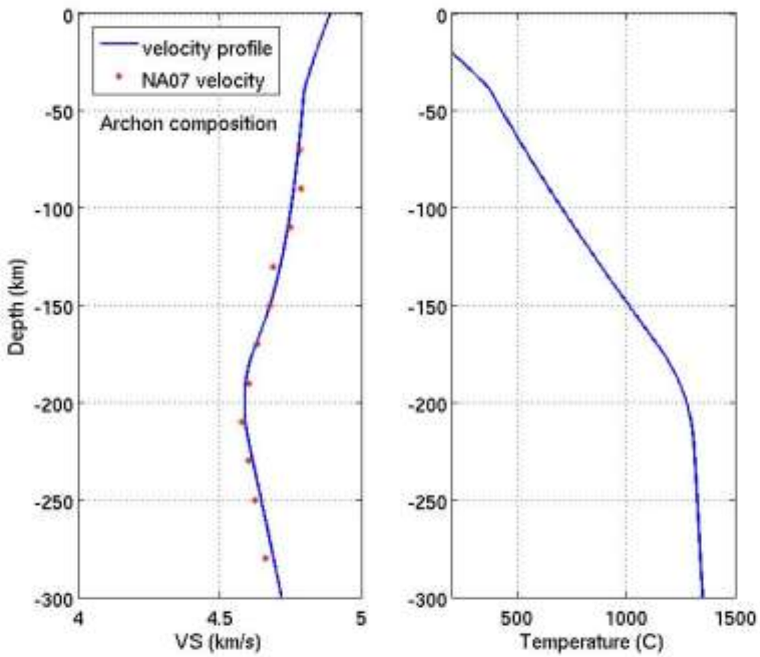


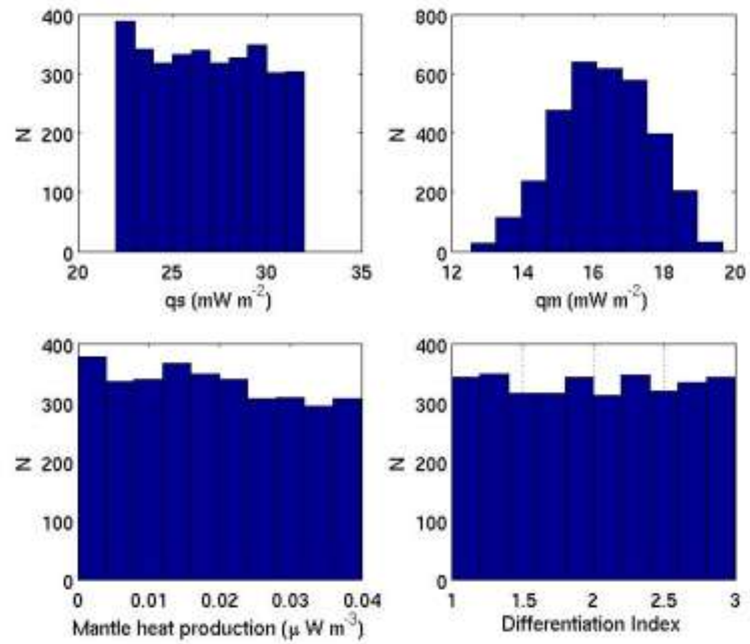
Composition Griffin Archon

Measured Qs = 34 mWm^{-2}

Location West of James Bay

Example best fitting model and parameters



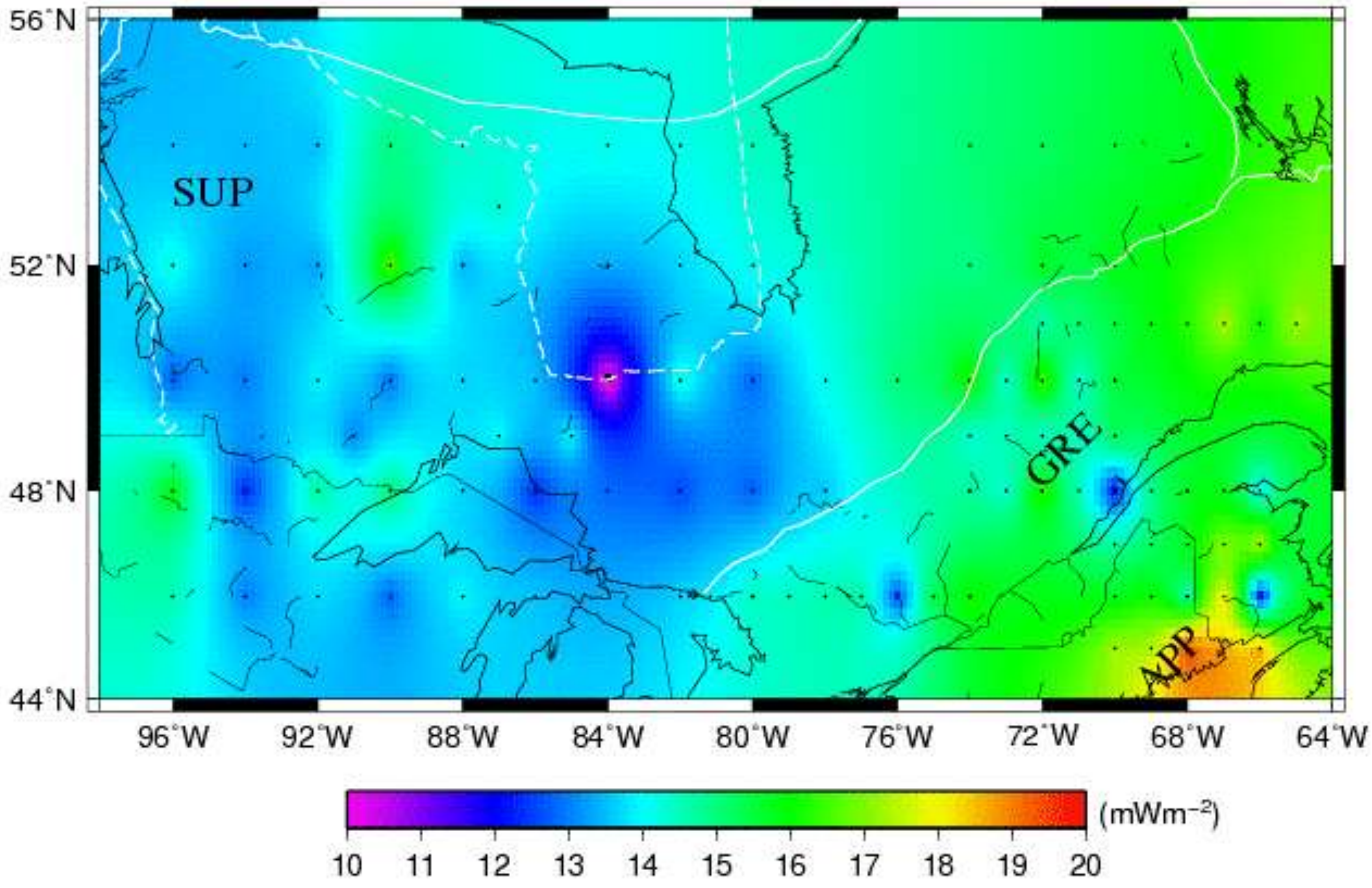


74 W 54 N
Location East of James Bay

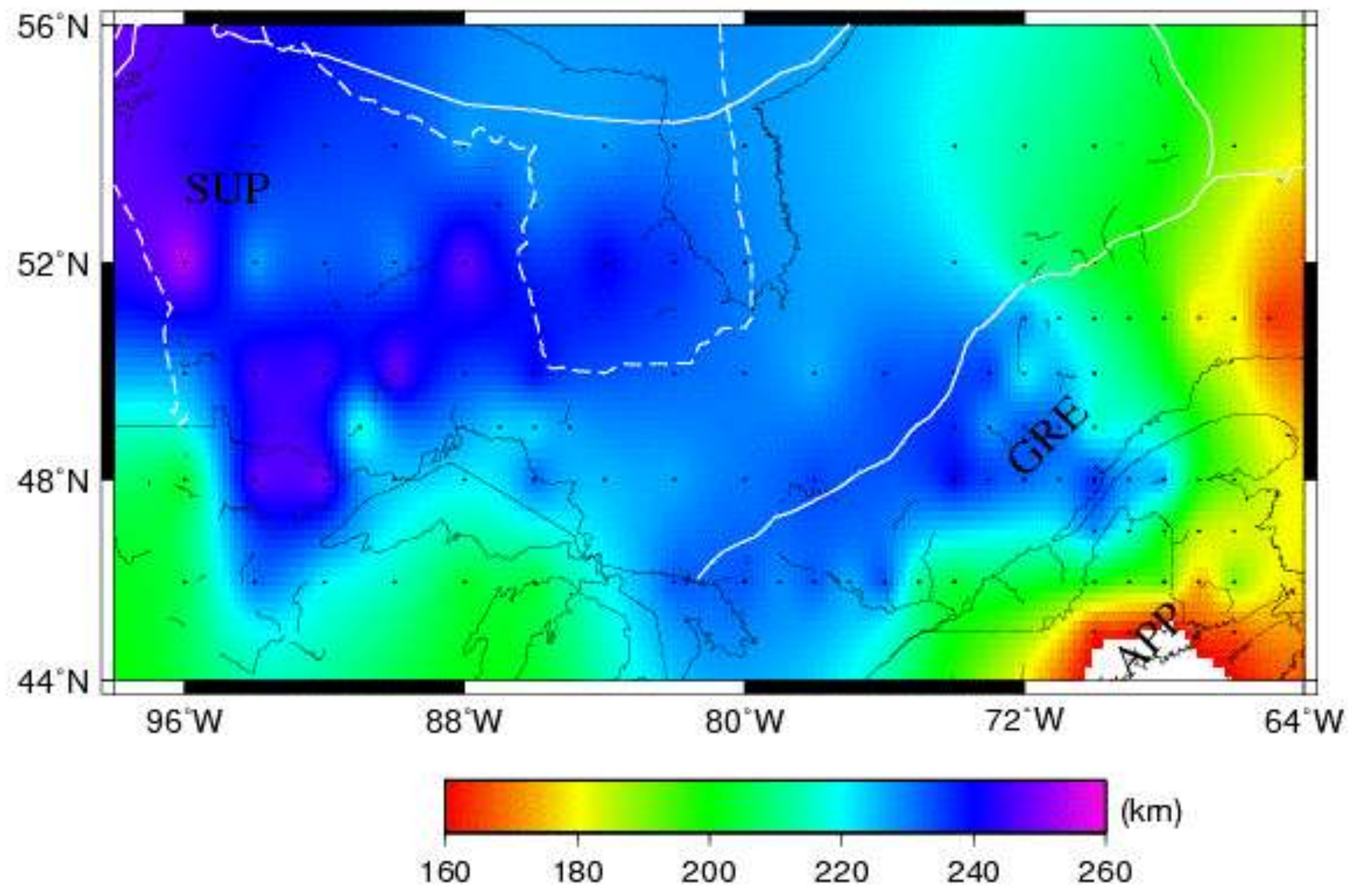
Mean surface heat flux 28 mWm^{-2}

Moho heat flux from inversion

$\mu = 14.5 \quad \sigma = 1.3\ mWm^{-2}$



Lithospheric thickness from inversion
μ = 225   σ = 15 km



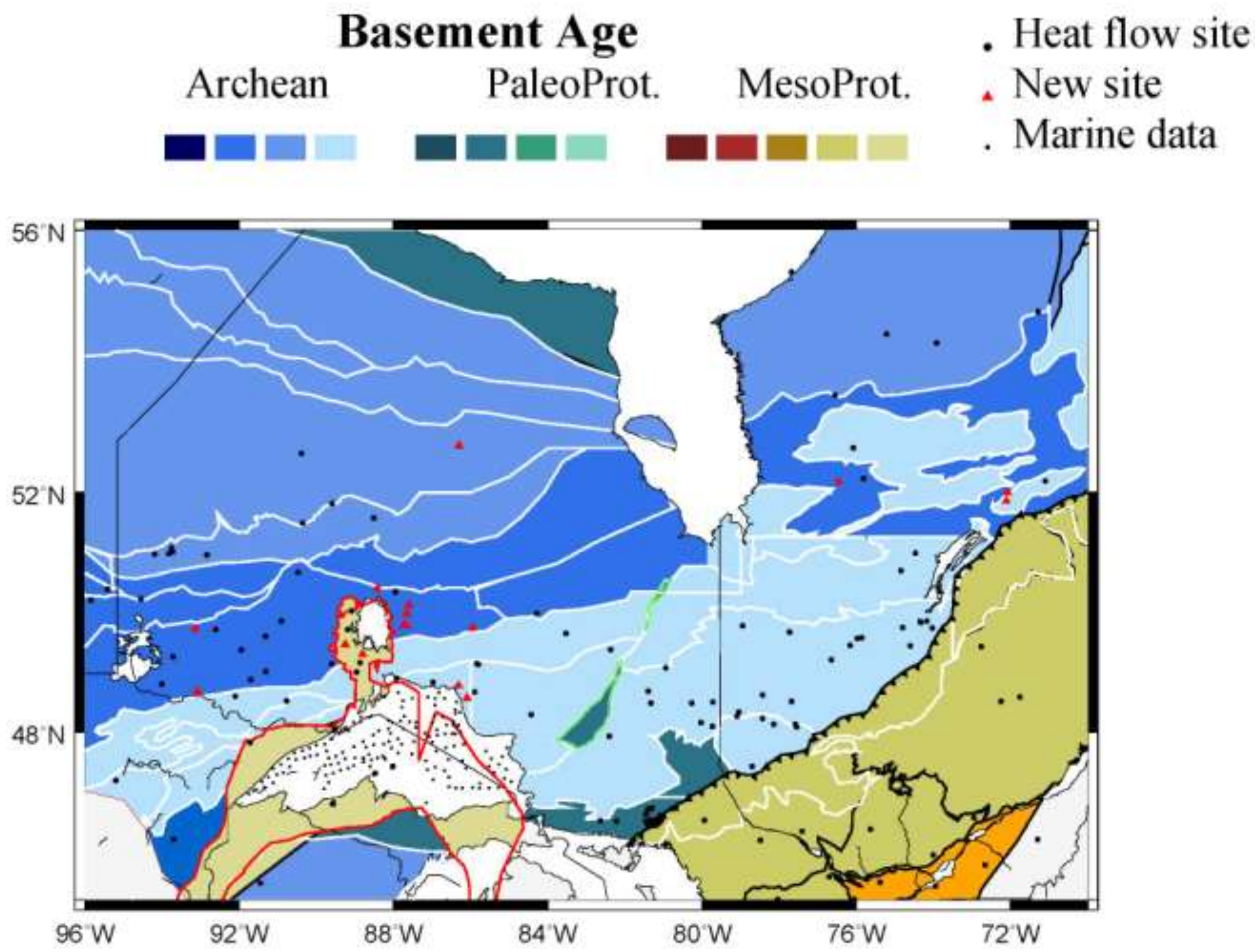
Summary

	mean Qm mW m^{-2}	std Qm mW m^{-2}	mean LT (km)	std LT (km)
SUPERIOR	14.7	1.3	225	16
GRENVILLE	14.9	1.3	220	19

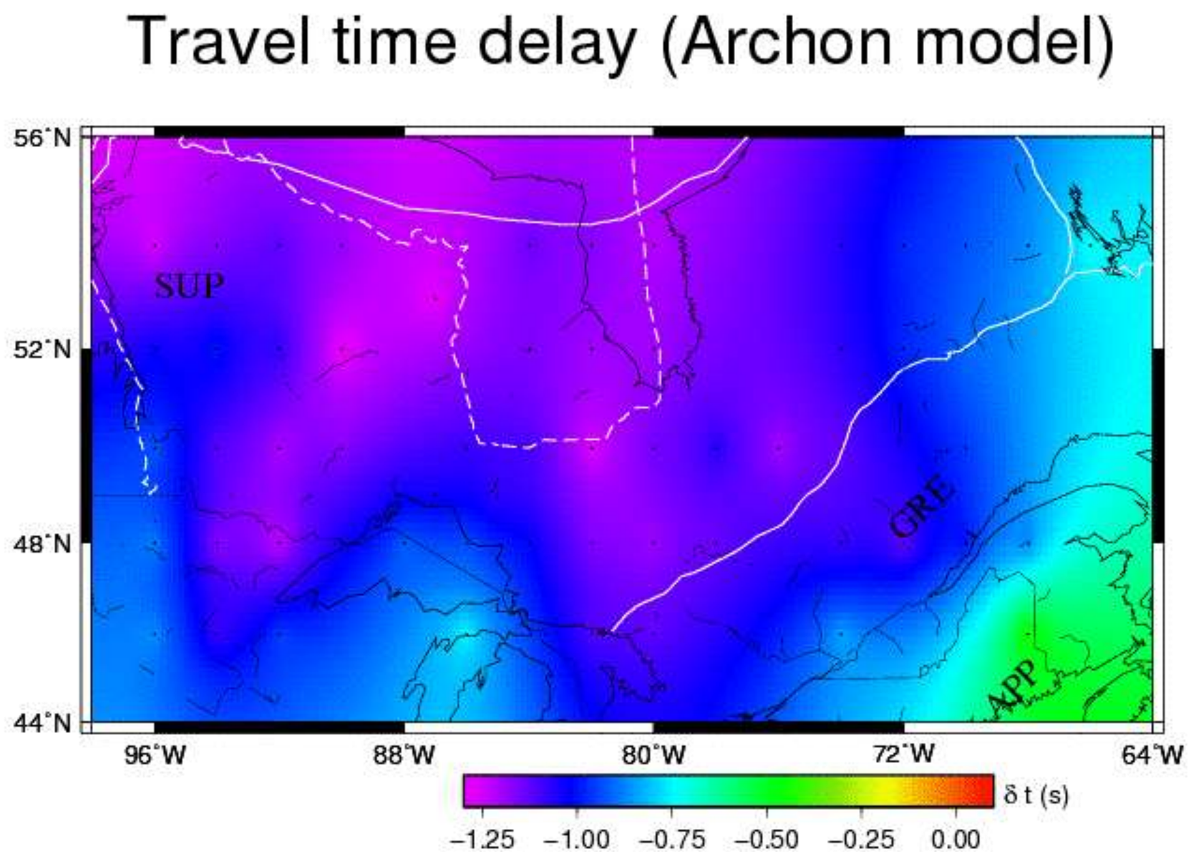
Conclusions

- Combining surface heat flux and shear wave velocity profiles works
- Moho heat flux and lithospheric thickness very strongly constrained
- Central value for heat flux at Moho Q_m 15mWm^{-2} in southeastern Canadian Shield. Consistent with previous estimates.
- Variations in Q_m small (+/- 2mW m^{-2}) in southeastern Canadian Shield.
- Lithospheric thickness 220 +/ 25 km
- Lowest Q_m and thickest lithosphere do not always coincide with lowest surface heat flux.
- Is it EOS?
    - THO?
    - East West James Bay?

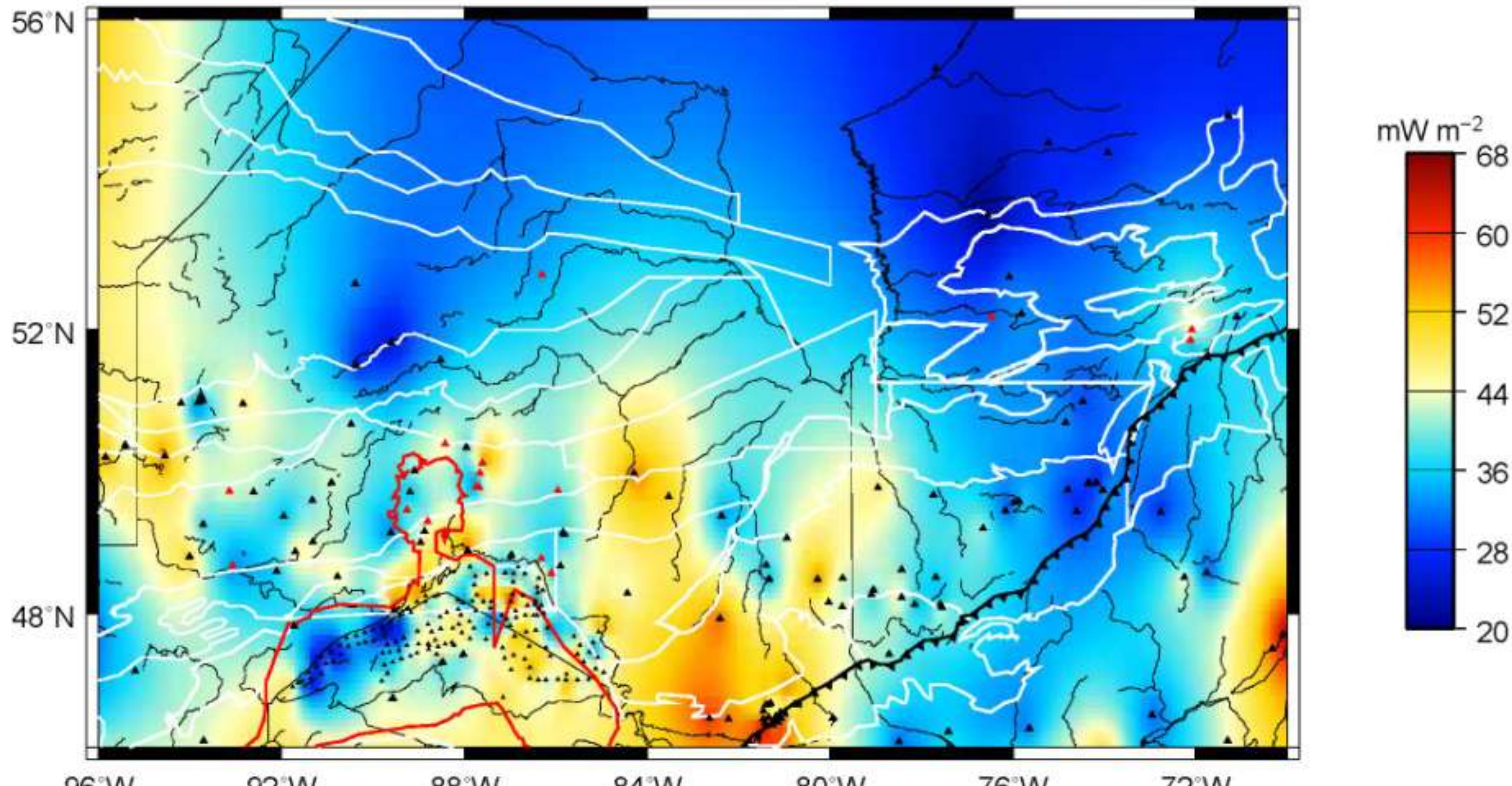
Southwestern Superior Province final assembly ~2.65 Ga



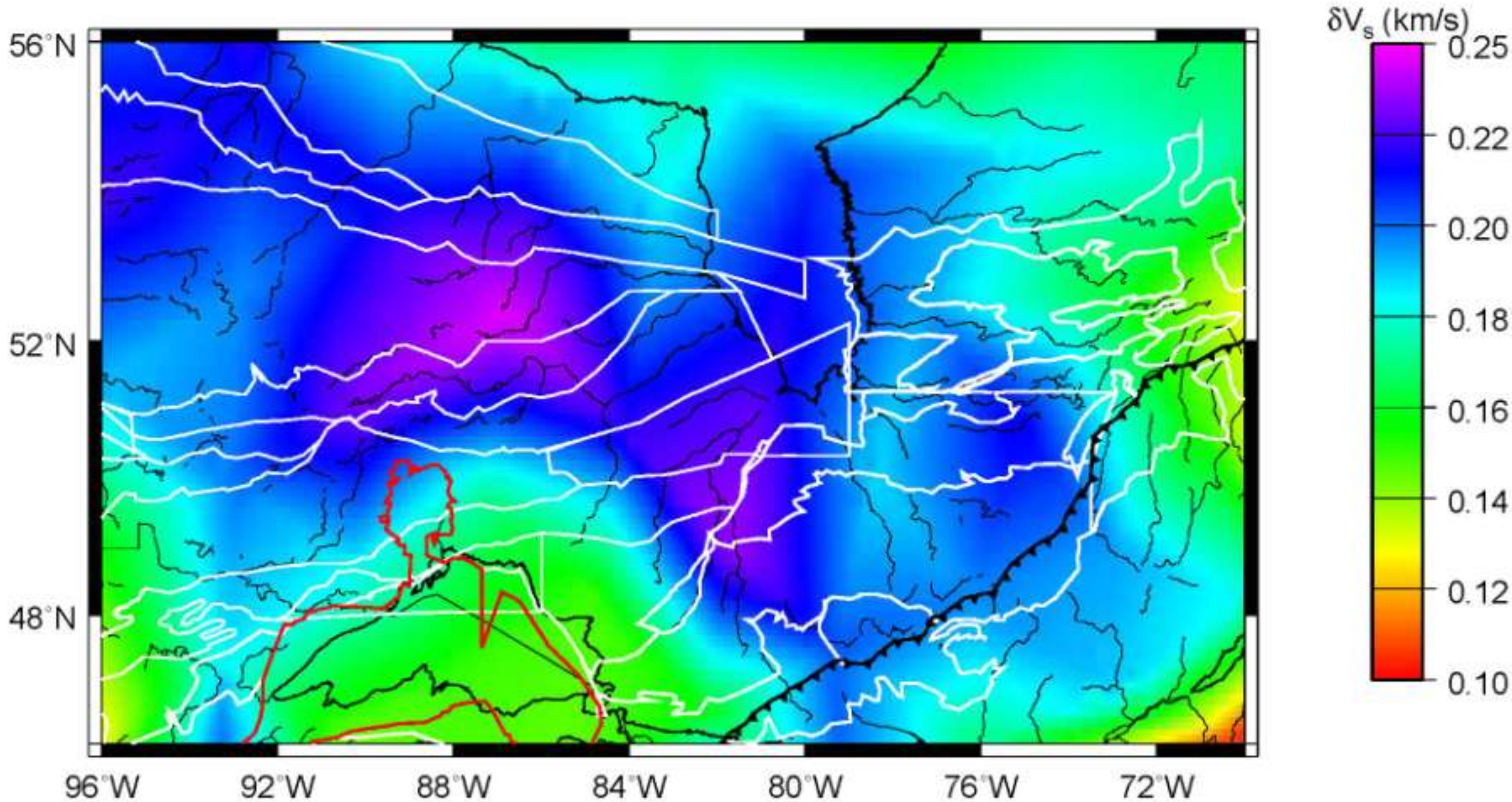
Travel time delays (60-260km) from inversion



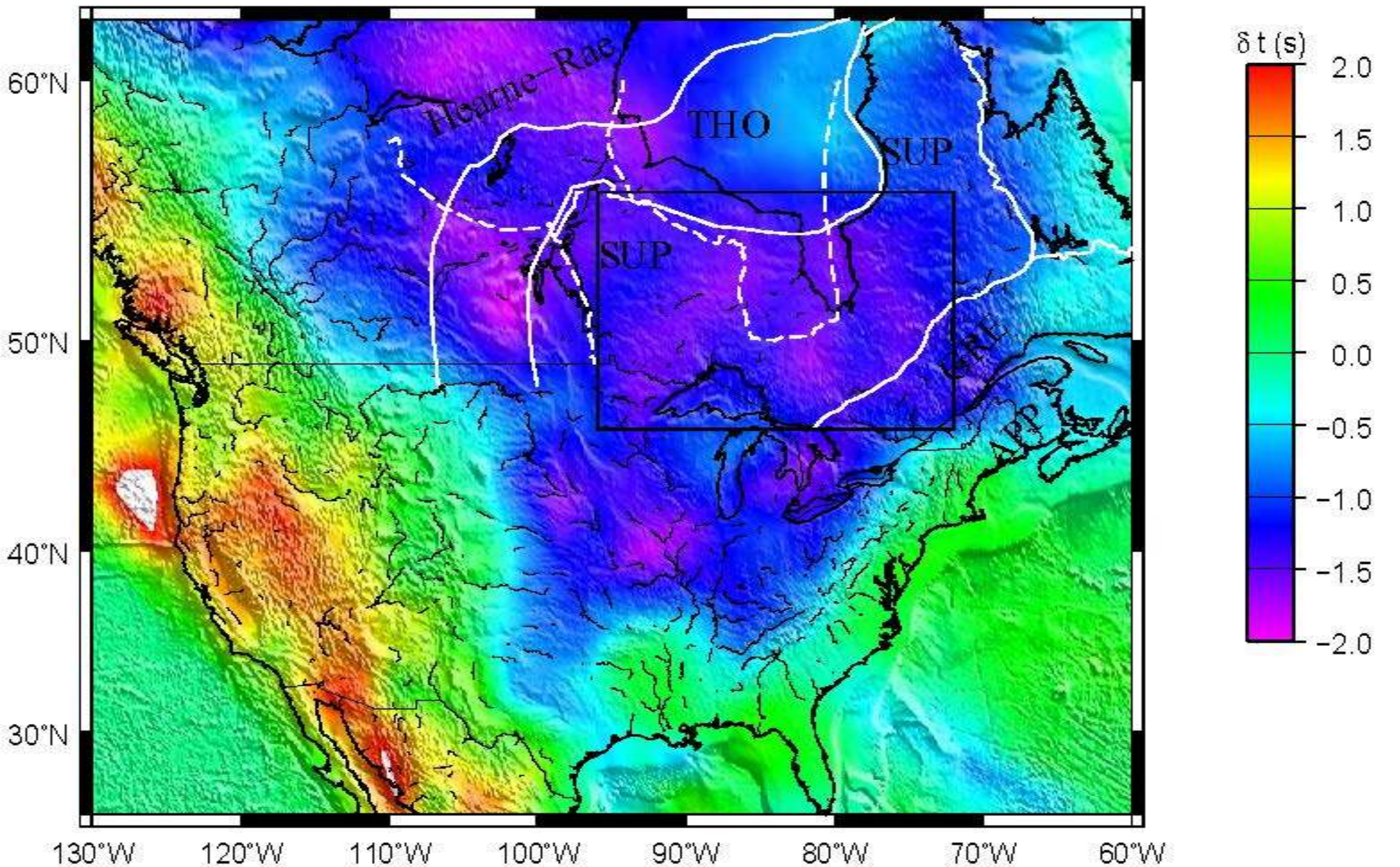
Heat flux

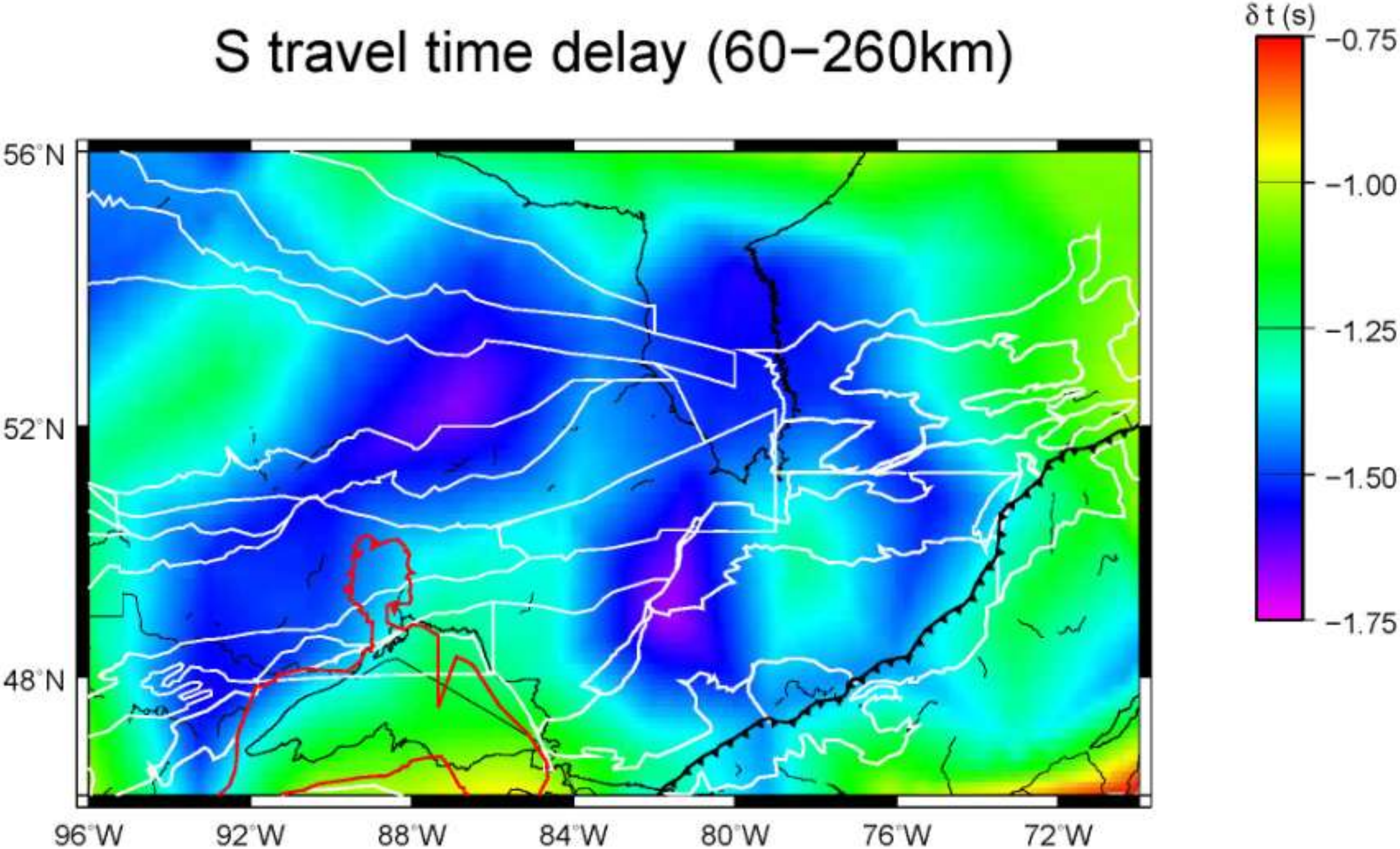


ΔV_s 150km (NA07)

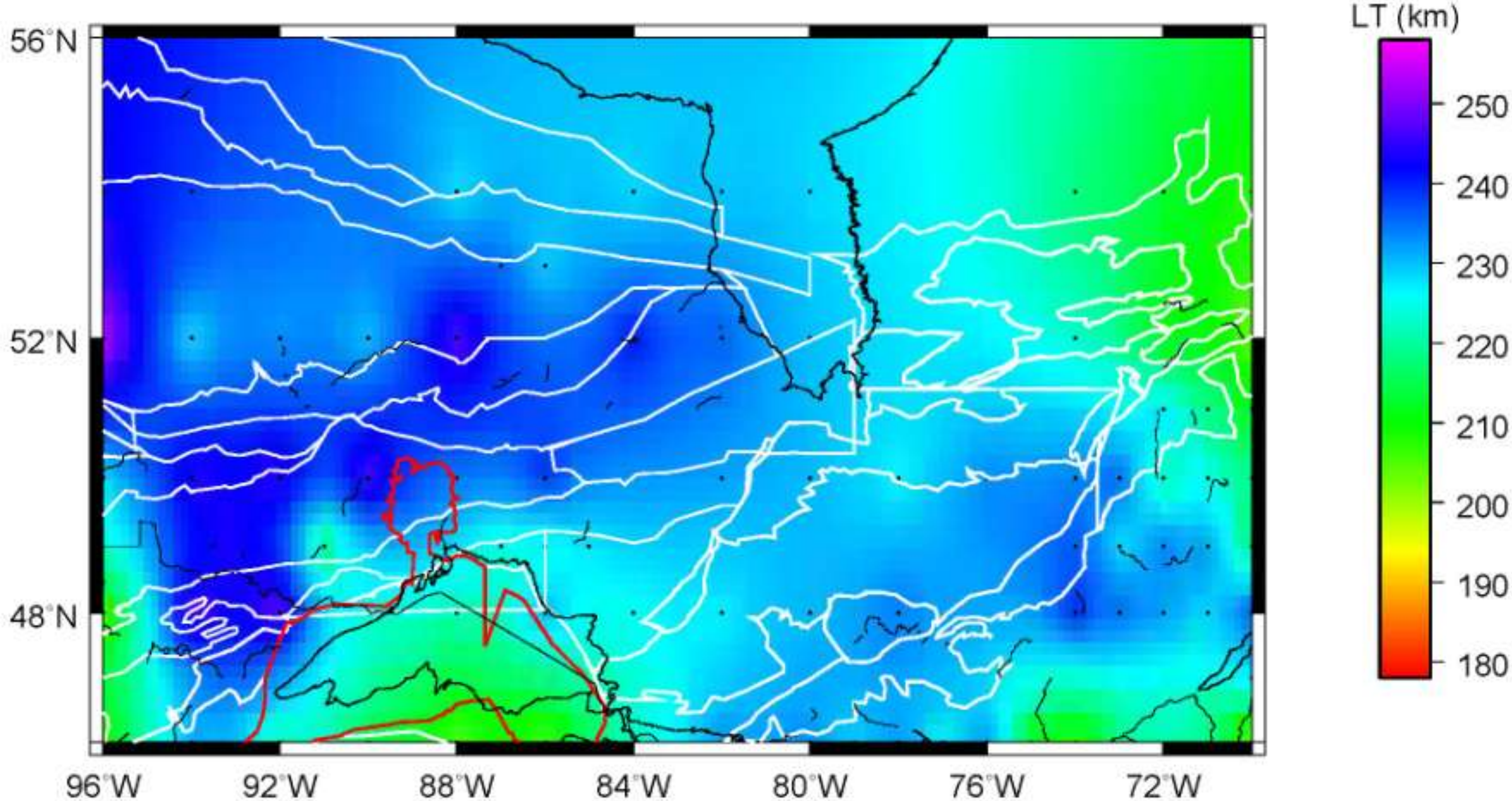


S travel time delay (60−260km)




S travel time delay (60−260km)
56°N
52°N
48°N
96°W
92°W
88°W
84°W
80°W
76°W
72°W
δ t (s)
−0.75
−1.00
−1.25
−1.50
−1.75

Lithospheric thickness



Not constrained south of 48N

Travel time delay (Archon model)