GLOBAL MAP OF LITHOSPHERE THERMAL THICKNESS ON A 1°X1° GRID: DIGITALLY AVAILABLE, WWW.LITHOSPHERE.INFO

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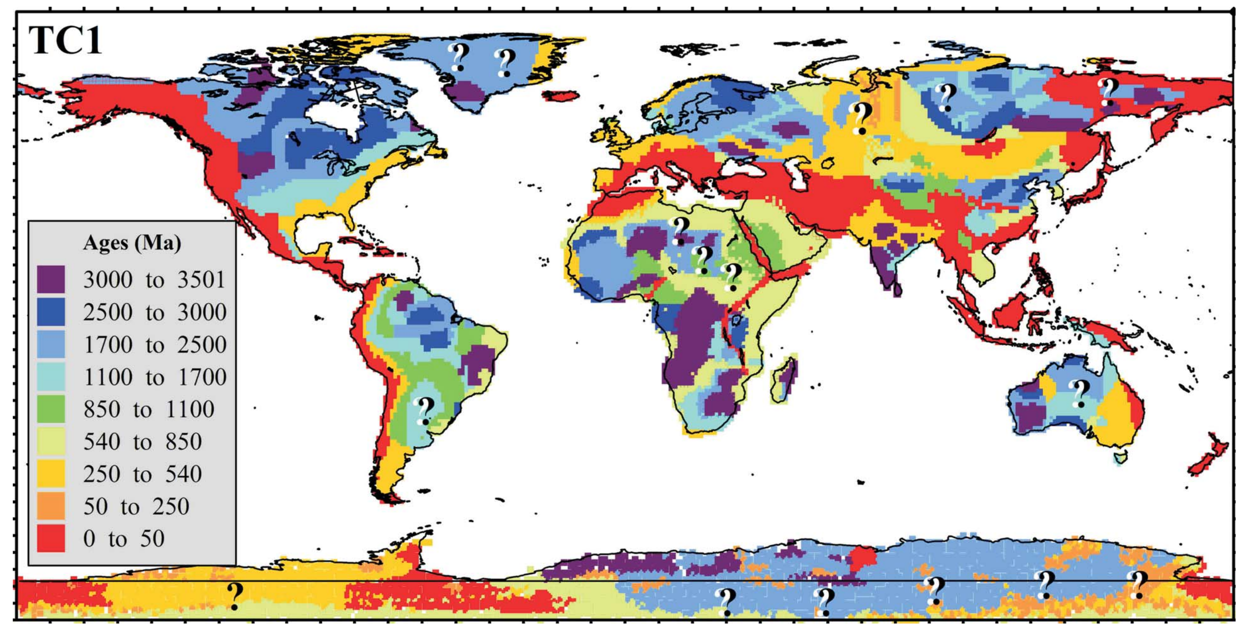
Abstract

The present study reports a global thermal model TC1 for the continental upper mantle constrained on a 1°x1° grid. Surface heat flow measurements allow us to constrain the thermal state of the upper mantle only for about 40% of the continents, which is sufficient to perform a statistically significant analysis of lithospheric geotherms for continental terranes with different tectonic settings and different geological ages.

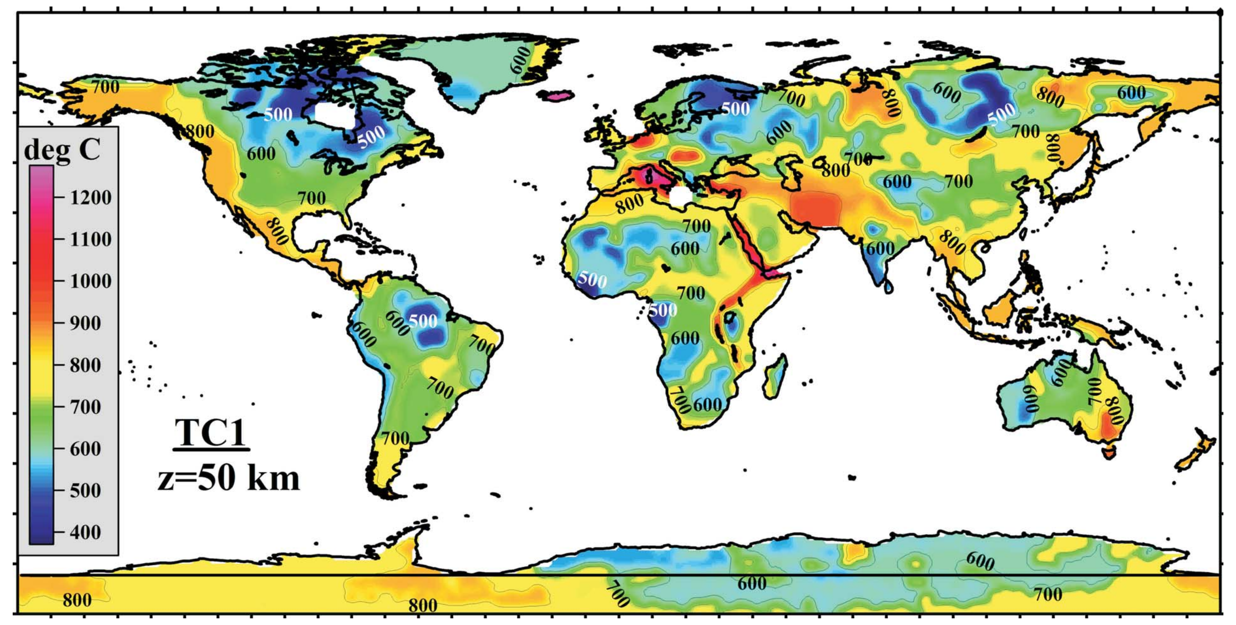
A compilation of tectono-thermal ages of the continental crust averaged on a 1°x1° grid formed the basis of the present global thermal model (Artemieva, 2006). A major assumption for the analysis is that lithospheric mantle has the same age as the overlying crust.

Data on the crustal ages together with previously reported geotherms for stable continental regions (Artemieva and Mooney, 2001) form the basis for the analysis. For tectonically active regions with transient thermal regimes, lithospheric temperatures are based primarily on xenolith geotherms. These data are supplemented by electrical conductivity profiles for cratonic regions.

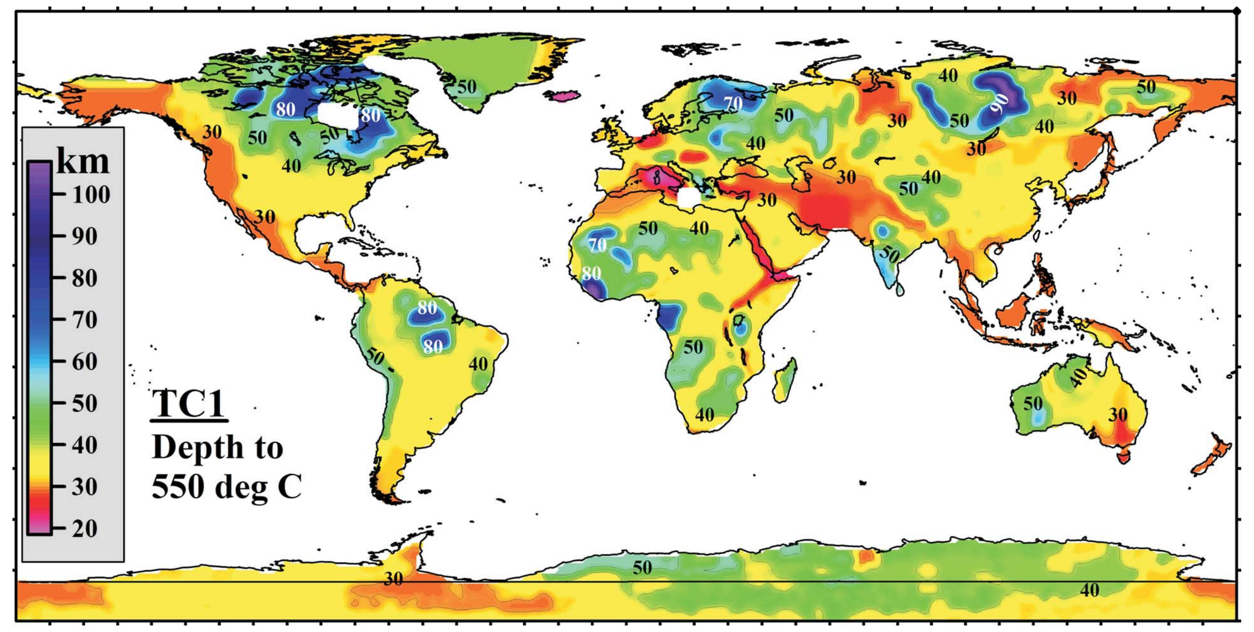
Data on lithospheric thickness constrained by statistical relations between geological ages and mantle geotherms are used next to calculate the growth rate of lithospheric mantle since the Archean. Its comparison with growth models for the crust and with the age distribution of juvenile crust permits speculations on the dynamic and tectonic evolution of the continents since the Archean.



A compilation of ages of the continental crust averaged on a 1°x1° grid formed the basis of the present global thermal model.



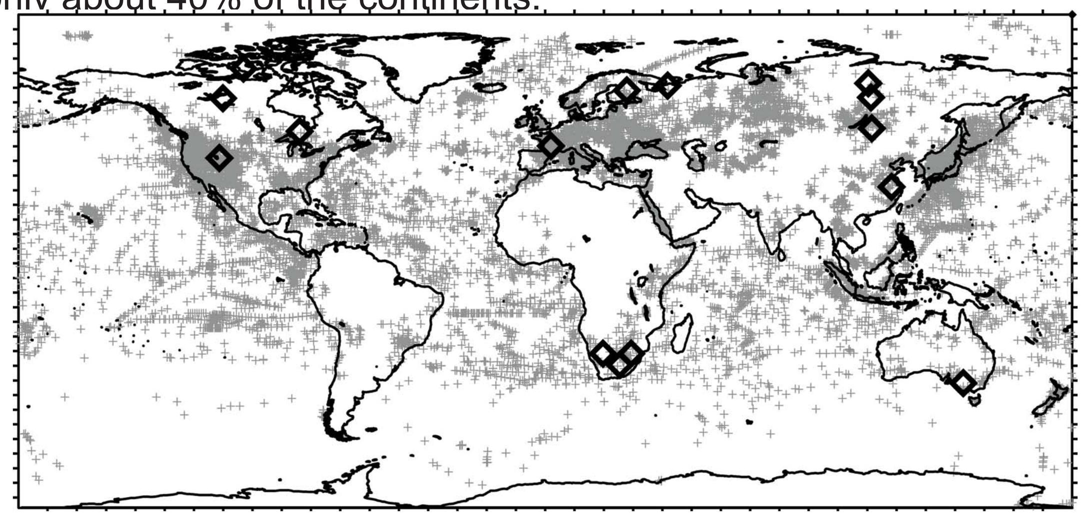
Temperature at 50 km depth in the mantle Interpolated with a low-pass filter.



Depth to 550 oC isotherm as a proxy for the thickness of magnetic crust and for the depth to the brittle-ductile transition in mantle olivine

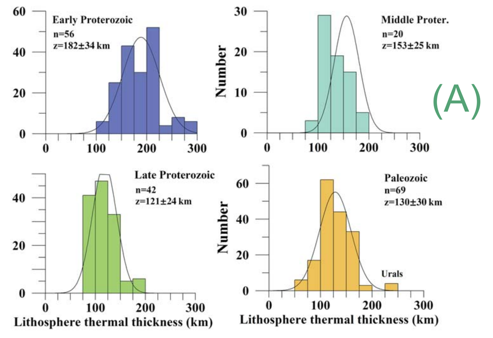
Statistical analysis of thermal data

A thermal model for stable continental lithosphere constrained by reliable surface heat flow (Artemieva and Mooney, JGR, 2001, B8) provides the basis for the present study. However, because the coverage of borehole measurements is uneven and sparse in many regions, heat flow data permit constraints on lithospheric geotherms for only about 40% of the continents.

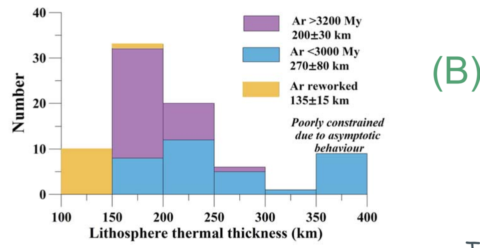


A number of heat flow measurements in continental terranes of different geological ages permits statistically significant analysis of lithospheric geotherms for different tectonic settings allowing expansion of the previous thermal model to all continental areas.

Statistics of lithosphere thermal thickness constrained by heat flow data;
(A) Proterozoic-Paleozoic terranes;
(B) Archean terranes.



(A)

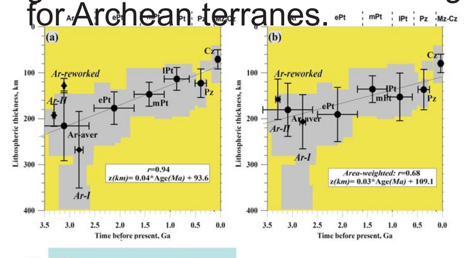


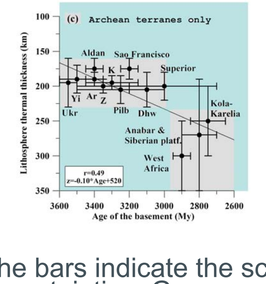
(B)

Correlation between lithospheric thermal thickness and geological age

Statistical analysis of lithospheric geotherms based on heat flow data reveals a striking correlation between the age of terranes and their thermal regime (a).

However, this correlation can be biased by the uneven distribution of heat flow measurements (b - similar to (a) but area-weighted on a 1°x1° grid for terranes of different ages; c) correlations for Archean terranes.

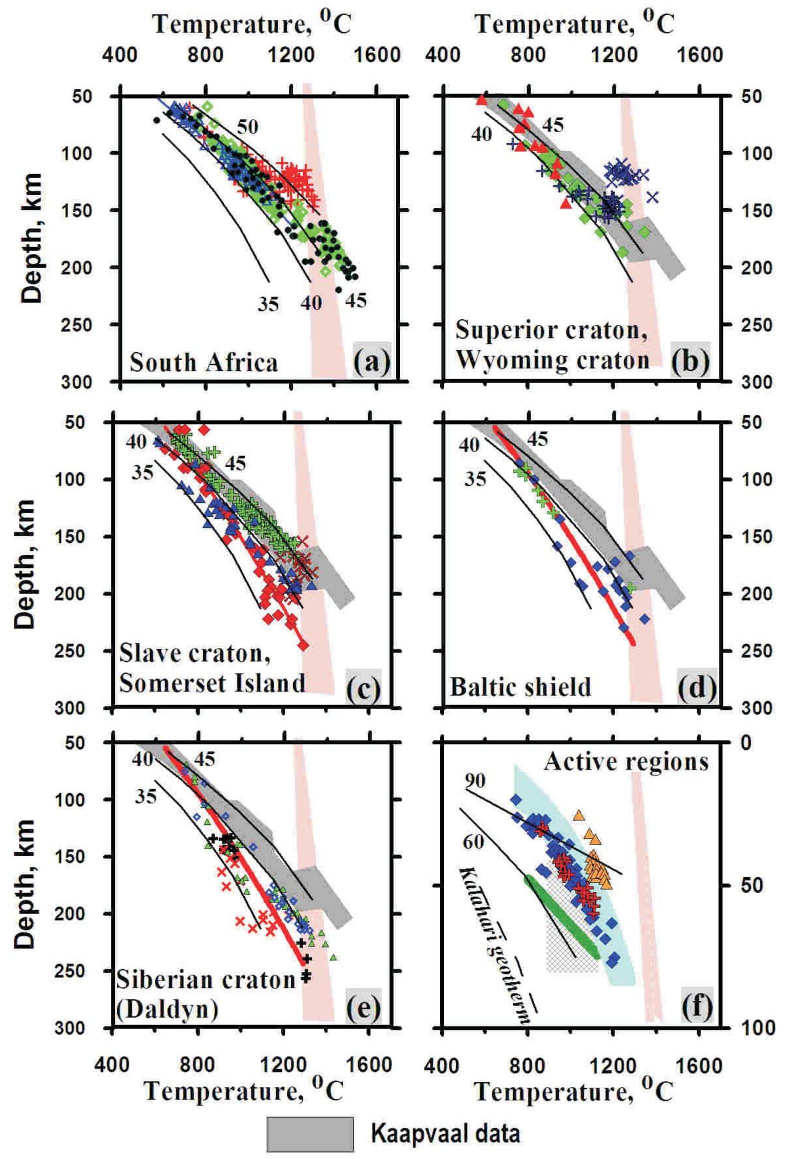




Contrary to the global trend, lithospheric thickness in the Archean terranes increases from late Archean (>3.0 Ga) to young Archean (<3.0 Ga) terranes. Thick lithospheric roots (250-350 km) are found solely for 2.5-3.0 Ga terranes.

The bars indicate the scatter in the values, but not their uncertainties. Gray area shows the general trend of lithospheric thickness variations with age (Artemieva and Mooney, 2001);

Analysis of xenolith P-T arrays



Xenolith geotherms for continents.

Since xenolith P-T arrays constrained by different geothermobarometers are significantly different, the data are shown mostly for the BKN method; where non-availbale other calibrations were used.

Thin lines conductive geotherms of Pollack and Chapman (1977), values are surface heat flow in mW/m^2.

(a) blue Kimberly (Kaapvaal), green Lesotho, red Gideon, Namibia (all three BKN-NT, Grutter and Moore, 2003); black circles several locations in Kaapvaal (compilation of Rudnick and Nyblade, 1999); the latter are shown in plots (b-e) by gray shading;

(b) green - Kirkland Lake, Superior craton (Pearson et al., 1998); blue - Wyoming craton (pluses: NT-NT, Pizzolato and Schultze, 2003; crosses: BKN, Hearn, 2003); red SW Arkansas (BKN, Dunn et al., 2003);

(c) Slave craton: red rhombs low-T peridotites (red line best-fit, also shown in plots (d-e)) (BKN, Kopylova et al., 1999), red crosses high-T peridotites (BKN, Kopylova and McCammon, 2003); blue Lac de Gras (BKN, Menzies et al., 2003); green Somerset Island (MC-NT, Grutter and Moore, 2003);

(d) blue - central Finland (BKN, Kukkonen and Peltonen, 1999; Lehtonen et al., 2003); green Arkhangelsk, pipe Grib (BK-MC, Malkovets et al., 2003); red line best fit for the Slave craton;

(e) blue and green (FB and ONW, Griffin et al., 1996); black Zarnitsa pipe, red Irelyakhskaya pipe (both NT-NT, Aschepkov et al., 2003);

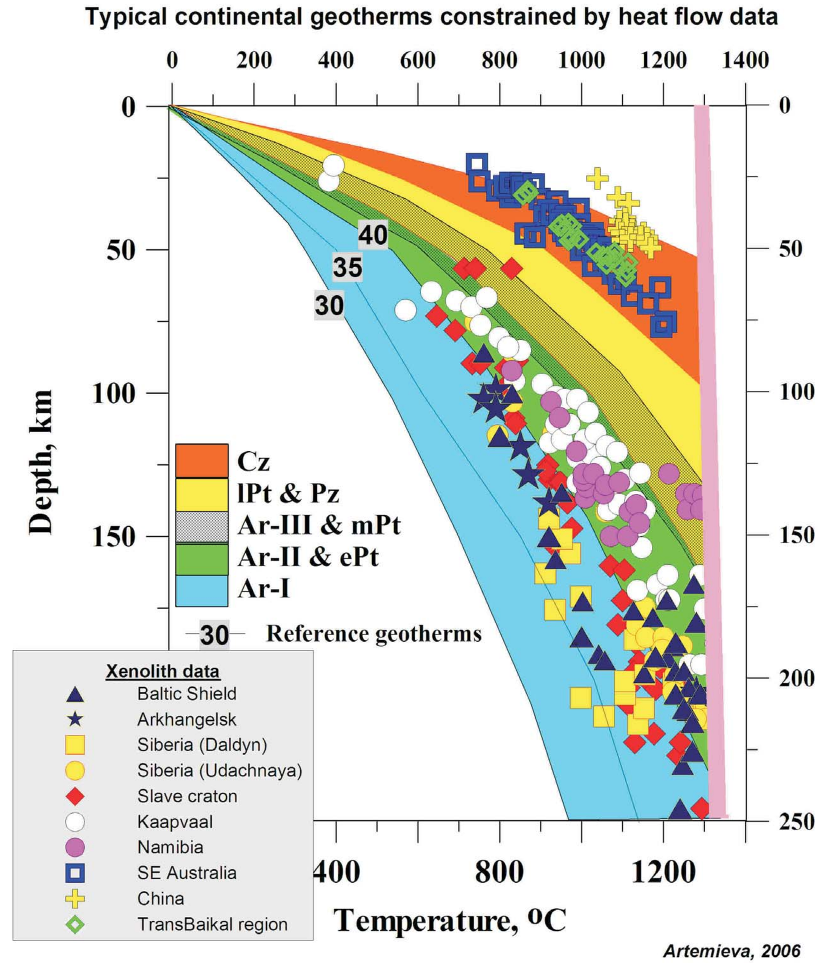
(F) orange SE China (Xu et al., 1996); blue SE Australia (O'Reilly and Griffin, 1985); red Mongolia (Ionov et al., 1998); blue shading TransBaikalia: Sayans, Vitim, and Udokan (Litasov et al., 2003); green line Rhenish massif (after LeBas, 1987); hatched area Massif Central (after Coisy and Nicolas, 1978; Masse, 1983); dashed line - a typical Kalahari geotherm (Rudnick and Nyblade, 1998). Note different depth scale of the plot.

Xenolith P-T arrays confirm the results of the thermal model and suggest that there are two groups of Archean cratons with significantly different thermal regimes. Cratons with lower mantle temperatures follow a ca. 35-38 mW/m^2 conductive geotherm and include Archean terranes of the northern hemisphere (Slave craton, Fennoscandia (central Finland and Arkhangelsk region), and Siberia). Xenolith P-T arrays for Kaapvaal, Namibia, Superior and Wyoming cratons, and Somerset Island follow a 40-45 mW/m^2 conductive geotherm.

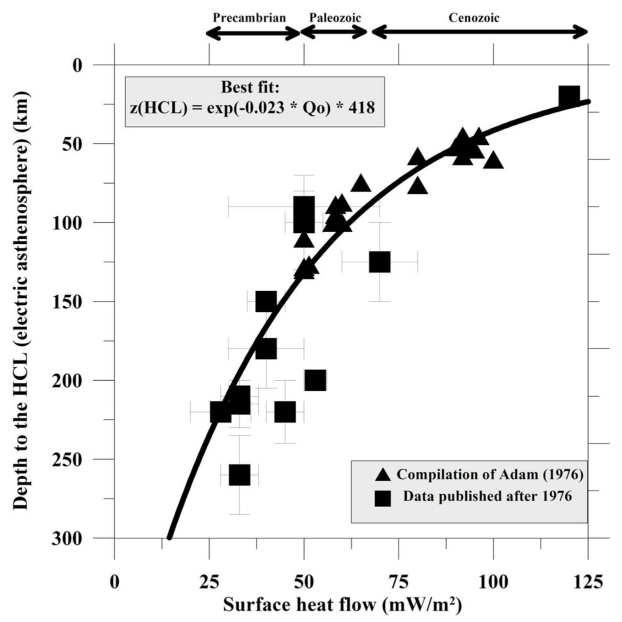
The difference between the 37 and 42 mW/m^2 geotherms implies ca. 80-100 km difference in the lithospheric thickness between the cratons of two groups.

Ignoring the existence of a rheologically active boundary layer with perturbed geotherm between the conductive thermal boundary layer and the convecting mantle, a 42 mW/m^2 geotherm intersects the mantle adiabat at ca. 220 km depth, while a 37 mW/m^2 geotherm at ca. 300 km depth.

Global continental geotherms



Correlation between surface heat flow and depth to the high-conductive layer (HCL) in the mantle (electrical asthenosphere).



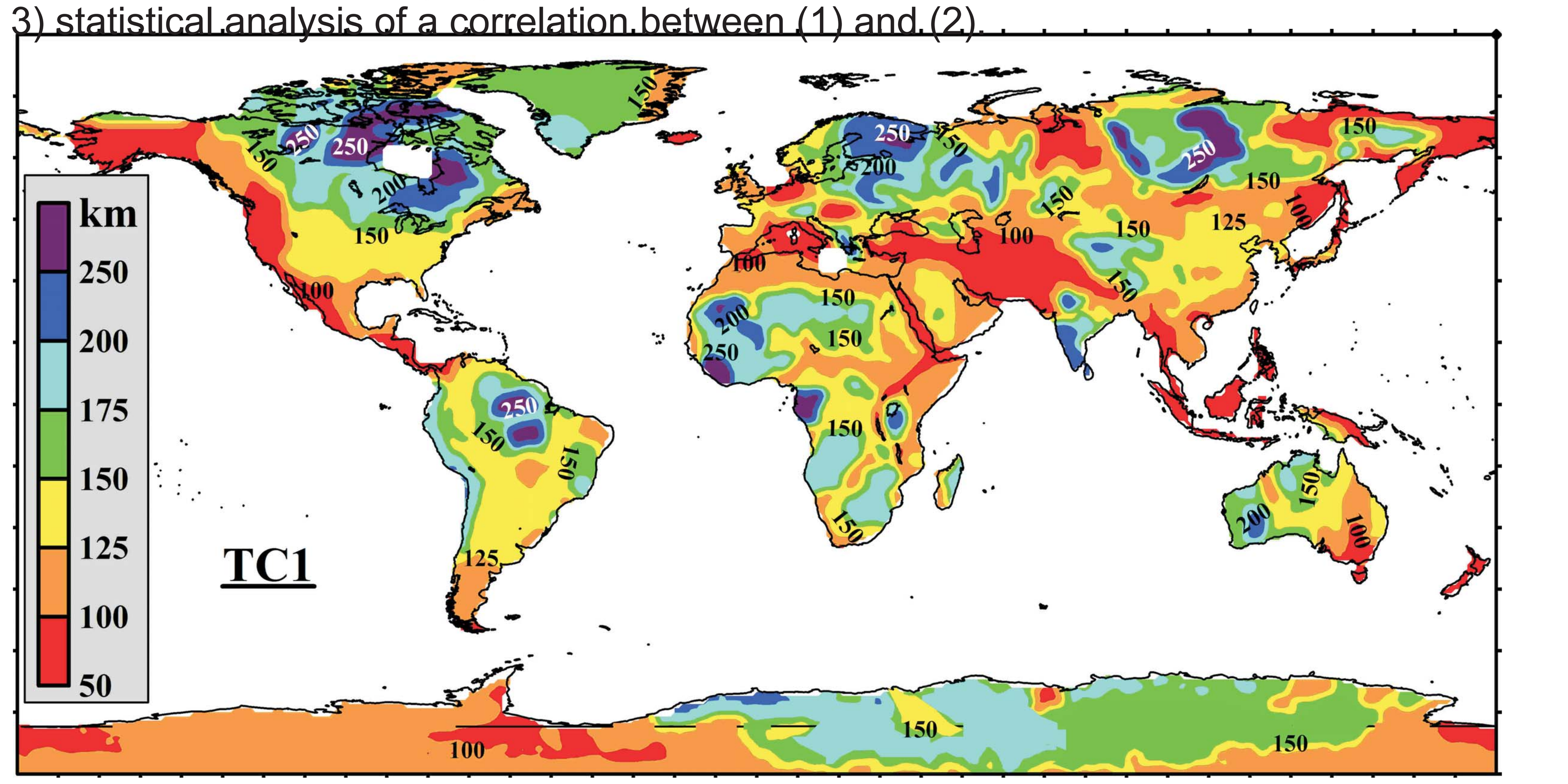
Under certain assumptions, surface heat flow can be used as a rough proxy for the depth of HCL (high conductivity layer ~ electric asthenosphere).

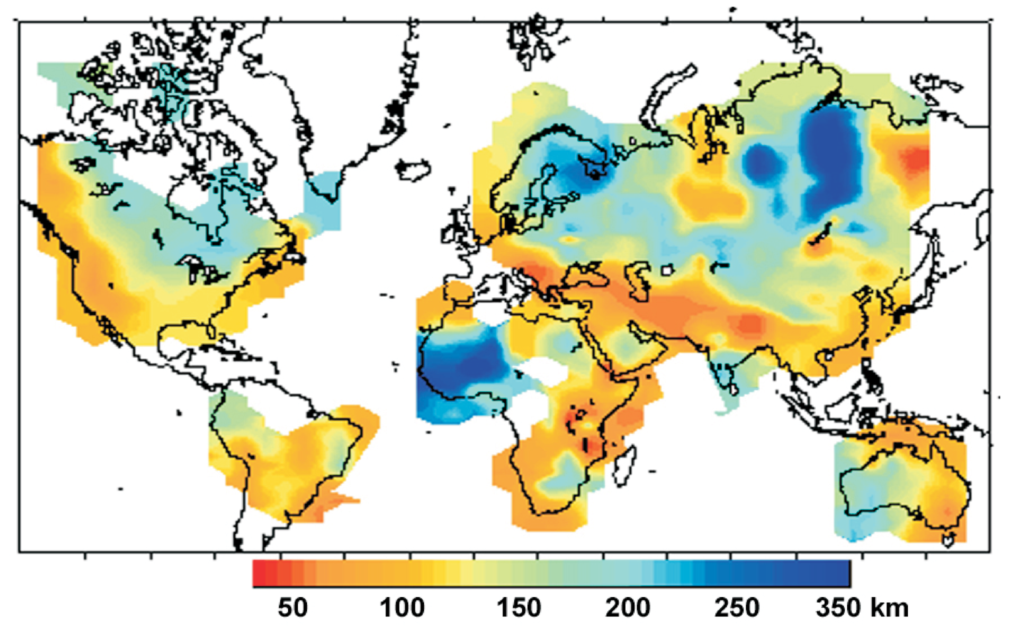
Since surface heat flow, in general, increases from older terranes to the younger ones, the depth of HCL also shows a general correlation with age.

Lithosphere thermal thickness on a 1deg x1 deg grid

Constrained by:

1) lithospheric geotherms based on:
   surface heat flow data for stable regions and on
   xenolith P-T geotherms for active regions (Artemieva & Mooney, 2001);
2) data on tectono-thermal ages of the crust;
   The age of the underlying lithospheric mantle is assumed to be the same;
3) statistical analysis of a correlation between (1) and (2).





Lithosphere thermal thickness based on surface heat flow data only (Artemieva and Mooney, 2001)

References:
Artemieva I.M. And Mooney W.D., 2001, JGR
Artemieva I.M., 2006. Tectonophysics