A re-assessment of the Present day Heat flux due to Mantle Secular Cooling

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The reduced mantle heat flux, the global surface heat flux of the Earth minus the crustal and lithospheric radioactive heat production, reflects contributions from internal heating by 1) radioactive decay within the mantle, 2) secular cooling within the mantle, and 3) basal heating from the core. An updated estimate of the present day heat flux due to secular cooling of the whole mantle ($Q_{M\mathrm{secular}}$) is calculated here using the thermal properties (T_a, α) of a pyrolite mineral physics model and an independent estimate of the present day cooling rate of the mantle. The mantle temperature structure is used to calculate a refined estimate of the total heat capacity (Φ_M) via Stacey and Loper (1984):

$$\Phi_M = \int_{r_{cmb}}^{r_{surface}} \left(\rho C_P T_a / T_{cmb} + \alpha P\right) 4\pi r^2 dr$$

where r_{cmb} is the outer core radius, and an updated estimate of the average cooling rate of the mantle (assuming whole mantle convection) calculated via (Turcotte & Schubert, 1982):

$$\left(\frac{\partial T_M}{\partial t}\right)_{\mathrm{NOW}} = -\frac{\frac{3}{4}\lambda\left(\bar{T}_{\mathrm{NOW}} - T_{surface}\right)}{1 + \frac{E_a}{4R\bar{T}^2_{\mathrm{NOW}}}\left(\bar{T}_{\mathrm{NOW}} - T_{surface}\right)}$$

where $\bar{T}_{NOW}$ is the present day volume averaged mantle temperature, λ is the average decay constant for the radiogenic isotopes in the mantle, and $(E_a/R\bar{T})$ is a parameter that may be evaluated from empirical mineral flow laws where R is the gas constant and E_a is the activation energy for viscous creep. From a pyrolite mineral physics adiabatic geotherm that is anchored to the average MORB potential temperature, I calculate a mean mantle temperature of 2117 K and adopt l = 2.77 10^{-1} yr^{-1} and $E_a/R\bar{T}$= 30. These values result in Φ_M = 6.52 10^{27} J/K and $\left(\frac{\partial \bar{T}_M}{\partial t}\right)_{\mathrm{NOW}}$ = -48 K/Gyr and are higher and lower, respectively, than typical values adopted and estimated in parameterized cooling models of the Earth's thermal history. When these updated values for these parameters are combined, they result in a mantle secular cooling heat flux of = 10.0 10^{12} W.

Together with the global surface heat flux (42.5 10^{12} W) and independent estimates of the radioactive heat production in the crust (~9.13 10^{12} W), lithosphere

(~0.38 10^{12} W) and depleted mantle (2.00 10^{12} W), the updated value determined here for constrains the calculated net core heat flux via:

$$Q_{\text{global}} = \left(Q_{\text{crust}} + Q_{\text{lithosphere}} + Q_{\text{mantle}}\right)_{\text{radioactive}} + Q_{M\text{secular}} + Q_{\text{net core}} \cdot$$

This gives =20.96 10^{12} W.