The thermal evolution of the Earth

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The problem of thermal evolution of the Earth is long standing and has sometimes been called "the missing heat paradox". This problem arises because most cooling models of the Earth, based on parameterized convection, are unable to get a present–time heat flow at Earth's surface that matches the observations, unless an unrealistically high value for the radiogenic heat production is used. In other words, the present Urey ratio of these models is higher than what is implied by geochemistry. In order to solve this problem, new scaling laws for heat transfer by mantle convection have been proposed, mainly decreasing the exponent β of the Rayleigh number in the a relationship of the form $q = ARa^{\beta}$, using arguments like temperature dependence of viscosity (Christensen, 1984) resistance of plates to bending (Conrad and Hager, 1999) or depth of melting (Sleep, 2000; Korenaga, 2003). The difficulty in such approaches is to ascertain the validity of such scaling laws for the Earth which may be influenced by other effects.

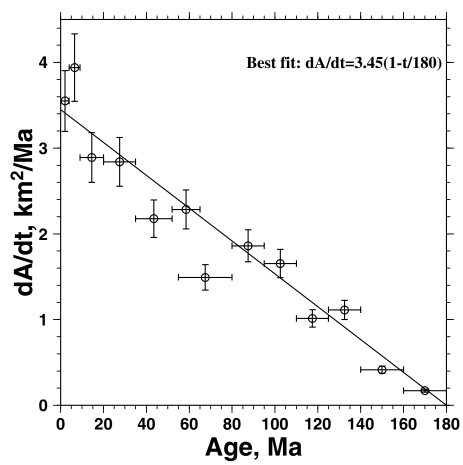

Figure 1: Distribution of seafloor age. Adapted from Sclater et al (1981).

Instead, we use an empirical approach, based on the present observation of distribution of seafloor ages and a few assumptions. The total heat flow at the surface of oceans can be shown to be controlled only by the maximum age of oceanic lithosphere, the potential temperature of the mantle and the shape of the seafloor age distribution. The observed present time distribution (fig. 1) shows that lithosphere of any age is subducted with equal probability, irrespective of its buoyancy. Even ridges can be subducted. This observation contradicts models of convection that assume a heat flux controlled by the boundary layer instabilities (Howard 1964).

Using the observed distribution, we find that the characteristic time scale for the thermal evolution of the Earth is about 10 Gyr so that an almost constant heat flow and a modest evolution of the temperature give a reasonable solution (fig. 2). However, the smooth evolution heat flow curve should be modulated by variation due to changes in the shape of the distribution in seafloor ages. The amplitude of such fluctuations can be estimated as 25%, on the timescale of the Wilson cycle, about 500 Myr. Such fluctuations dominate over the long term evolution, at least since the establishment of plate tectonics.

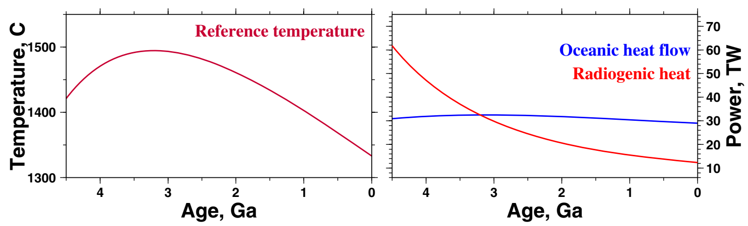

Figure 2: Thermal evolution of the Earth based on the observed distribution of seafloor ages.

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