Heat flow variations and layered mantle convection

D.B. APTER[1] AND C. HATTON[1,2]

[1] De Beers Exploration, Johannesburg, South Africa;
chris.hatton@mweb.co.za;
dave.apter@debeersgroup.com
[2] Shango Solutions, Northcliff; chris@shango.co.za

The mantle heat flow recorded in xenoliths from 210 km thick Archaean cratons is 14-18 mW/m^2, compared to 30-34 mW/m^2 in 100 km thick Phanerozoic mantle. The observation that there must be an inverse relation between the thickness of the lithosphere and the underlying convecting layer can account for this substantial difference in heat flow. Heat flow through a convecting layer is proportional to its thickness, raised to the power 4/3. If the base of the convecting layer is at 410 km, heat flow through 210 km thick lithosphere is proportional to $200^{4/3}$. For 100 km thick lithosphere heat flow is proportional to $310^{4/3}$. Heat flow through 100 km thick lithosphere is therefore $(310/200)^{4/3}$, or 1.8 times, that through 210 km thick lithosphere. The observed ratio is 2.0±0.3, so variations in thickness of the underlying convecting layer adequately explain variations in mantle heat flow.

If the base of the convecting layer were at 670 km the ratio of heat flow beween lithospheric thicknesses of 100 and 210 km would be $(570/460)^{4/3}$, or 1.3 times. This is much less than the observed ratio, and, even taking into account complexities such as the variable viscosity of the convecting layer, it is impossible to account for observed variations in mantle heat flow if the base of the convecting layer is at 670 km. A reasonable conclusion is that a layer of small scale convection underlies the lithosphere, and the base of this layer is the 410 discontinuity. Mantle convection must be layered, and the interaction between the layers controls many geological processes.

The transition zone below the 410 discontinuity has high water content and very low viscosity, so presents no hindrance to the downward passage of subducting slabs. Downward flow through the 410 discontinuity is therefore continuous. The corresponding upward return flow from the transition zone is, by contrast, discontinuous. For example, kimberlite events, which can be related to this return flow, occur in pulses separated by 2-10 million years. The episodic return flow is localised by two factors, the pattern of lower mantle convection, and variations in the depth to the 410 discontinuity.

Large scale lower mantle convection is focussed in two hemispheric cells, one upwelling below the Pacific, the other below Africa. Between these two cells is a longitudinal band of downwelling. Upwelling is minimal in this downwelling band. Variations in the geothermal gradient control the depth to the 410 discontinuity. Shoaling of the 410 discontinuity below cold Archaean cratons localises intermittent upward flow beneath them.