# Low Hadean Heat Flow and Heat Transport by Melt Segregation in the Early Earth and Io.

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Recent thermo-barometry of Hadean-age (more than 4Gyr old) zircons [1] has revealed a surprisingly low value of the thermal gradient at the time the granitic parent magma was emplaced, suggesting that the rocks were emplaced in a convergent margin setting with depressed heat flow, akin to modern subduction zone settings. An alternative explanation for the low thermal gradient observed is that melt segregation dominated the surface heat transport in the Hadean as is observed today on Jupiter's moon Io. This heat transport mechanism (sometimes called the heat-pipe mode) allows large amounts of heat to be advected by magma through a thick lithosphere. This is how Io transports more than 1 W/m$^2$ of heat to the surface and yet can maintain mountains over 20 km high. The high rate of crust formation depresses the geotherm by continuously burying the surface under new flows. Two dimensional simulations of rigid-lid mantle convection with melt transport (figure 1) show that the stresses induced in the lid by lateral variations in crustal production are large, and may be sufficient to break the lithosphere as crustal production diminishes, causing a natural transition to a plate tectonic mode of heat transport.

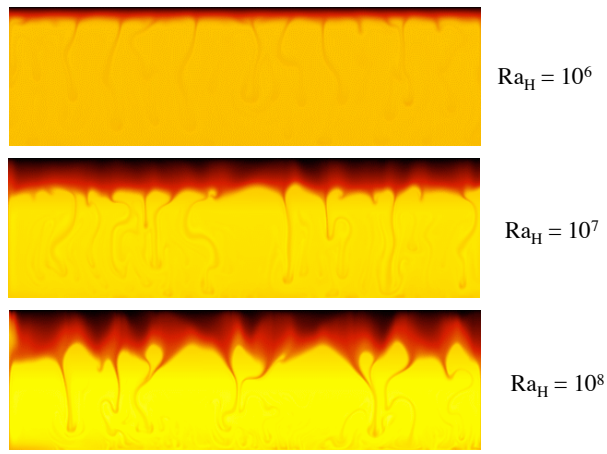


Figure 1: Temperature fields in convection simulations for increasing internal heating rate given by RaH.

Heat transport by melt segregation was undoubtedly more important in the Hadean than it is today, but detailed modeling studies have not been performed with sufficient fidelity to predict the relative amounts of heat transport by melting, plate tectonics, and conduction. This study provides the first systematic look at the influence of melt transport on the thermal structure and stress state of the lithosphere in a convecting mantle. Figure 2 shows the maximum lid stresses as a function of RaH. There are two sources of stress in the lid: convective stresses and lid thickness variaitons. This leads to a minimum in stress as the melt transport reduces convective stresses, but the lid has not become extremely thick and variable (see fig 1).

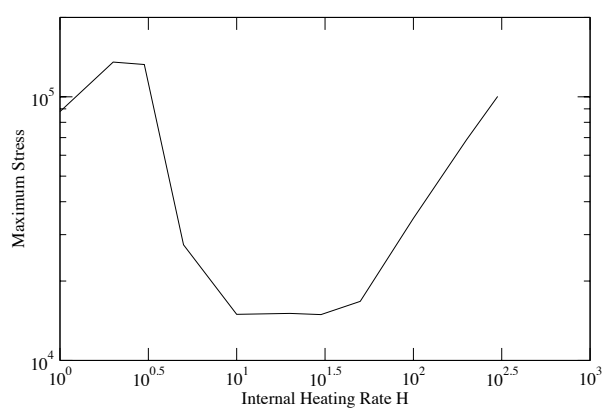


Figure 2: Maximum lithoshperic stresses in the model domain as a function of RaH.

The heat flow value of 1/3 the heat production rate [1] implies that the Hadean Earth was near the minimum in lid stresses (figure 2), while the present Earth with 1/3 the Hadean heat production is near the maximum.

## References

[1] M. Hopkins, T. M. Harrison, and C. E. Manning. Low heat flow inferred from >4Gyr zircons suggests Hadean plate boundary interactions. *Nature*, 456:493–496, November 2008.