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THE EFFECTS OF STRAIN HEATING IN LITHOSPHERIC STRETCHING MODELS

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Simple kinematic models of lithospheric stretching (1) require increased heat flow at the surface as the lithosphere is thinned. In these simple stretching models rock in the lower crust (material points in the mathematical models) will follow a particle path which curves upward towards the surface. A specific rock mass, thus, may actually decrease in temperature due to conductive heat loss even though the surface heat flow is increased. Widespread silicic igneous activity accompanying stretching suggests, however, that the lower crust is heated and we suggest that strain heating associated with stretching may be a source of the temperature increase in the lower crust. Numerical solutions to a simple stretching model show that the localization and magnitude of viscous strain heating is most significant in the uppermost mantle and lower crust as temperature increases above initial temperatures for these rocks can be as large as 70°C. It should be noted that in areas where extensive underplating of magmatic material occurs, the effect of strain heating in crustal rocks may be small compared to the heat from gabbroic intrusions (2).

The deformation by stretching of a continental type lithosphere has been formulated so that the problem can be solved by a continuum mechanical approach. The deformation, stress state, and temperature distribution are constrained to satisfy the physical laws of conservation of mass, energy, momentum, and an experimentally defined rheological response. The conservation of energy equation including a term for strain energy dissipation is expressed by:

$$2T'_{xy}\dot{\varepsilon}_o/B = -k\frac{\partial^2\theta}{\partial z^2} + \rho c\frac{\dot{\varepsilon}_o}{B}(a-z)\frac{\partial\theta}{\partial z} + \rho c\frac{\partial\theta}{\partial t}$$

where $2T'_{xy}\dot{\varepsilon}_o/B$ is the source term due to strain heating.

The continental lithosphere is assumed to have the rheology of an isotropic, incompressible, nonlinear viscous, two layered solid with the following constitutive law:

$$D_{ij} = A_n \exp(-Q_n/R\theta)\, J_2'^{\,m}\, T'_{ij}$$

where A_1 and Q_1 are material constants for layer 1, the continental crust, which is assumed to be of a quartz rich composition and A_2 and Q_2 are material constants for the mantle which is assumed to consist of an olivine dominated material. The materials are further limited by upper yield stresses. The deformation field is prescribed in a manner to be consistent with simple stretching such that the model is two dimensional with an originally rectangular region (parallel to the axis) remaining rectangular (and parallel) after stretching.

Preliminary results (see figure 1) show that strain heating can provide significant temperature increases of up to 70°C for material points in a fairly wide zone in the crust and uppermost mantle. The initial model was assummed to have a high initial geologic strain rate of $10^{-14}s^{-1}$ and a normal continental crustal thickness of 35 km. Strain energy production is centered in a much narrower zone in the uppermost mantle where temperatures in the mantle which controls the strength of the continental lithosphere (3) are lowest. Some of the heat produced from strain heating is conducted into the crust raising temperatures at material points inside the crust. The temperature increases in these zones may indicate that the previous estimates of the strength of the lithosphere undergoing stretching may have been overestimated. Results of temperature response in the lower crust due to strain heating suggests that large volumes of lower crust may be partially melted by strain heating during stretching without large scale heat influx from the invasion of mantle material into the crust.

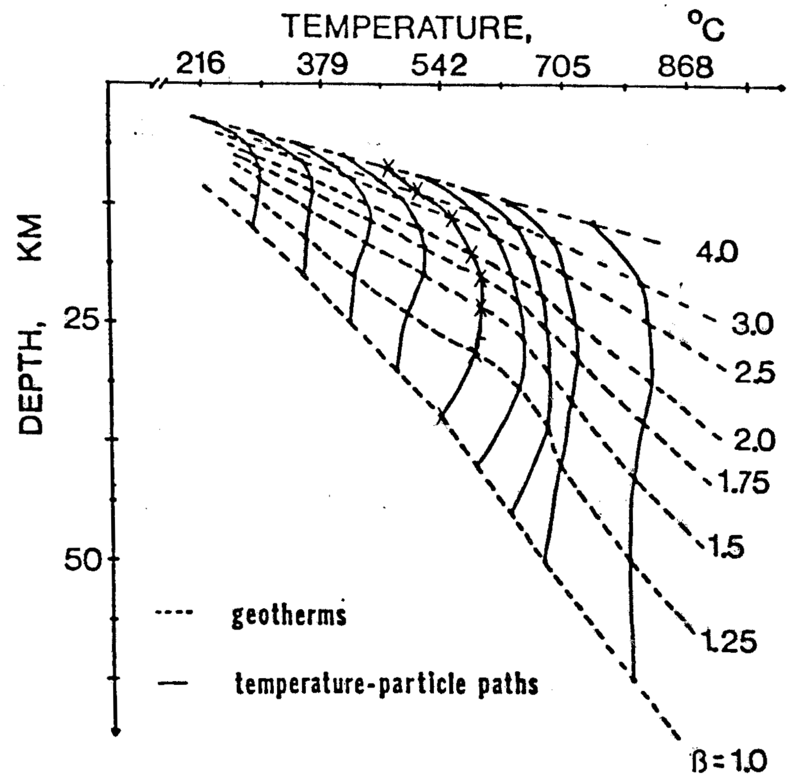

Figure 1 Geotherms for stretching with stain heating (in dashed lines) for different values of stretching, β. Temperature paths for particles which rise with stretching are shown in solid lines. The X mark the crust-mantle interface for different amounts of stretching. The strain rate is given by with $= 10^{-14} s^{-1}$.

References

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