A NUMERICAL STUDY OF FORCED LITHOSPHERIC THINNING; G. Schubert, UCLA, C. A. Anderson, Los Alamos National Laboratory, and E. Fishbein, UCLA.

Subsolidus lithospheric thinning by mantle plumes may be involved in the creation of swells, hotspots, and rifts. Among the major questions concerning this process are the timescale on which it occurs and the structure of the plumes. The lithosphere is known to have been substantially thinned in 10 Ma or less[1,2].

Previous studies(3-6) of the time required to thin the lithosphere by subsolidus convection are not in accord about the timescale of the process. Spohn and Schubert[5,6] concluded that sufficiently vigorous plumes could thin the lithosphere in 10 Ma, but the model only simulates the dynamics of the plume-lithosphere interaction in a way that does not specifically incorporate the material rheology or flow pattern. Emerman and Turcotte[4] found that the lithosphere cannot be thinned in 10 Ma, but their stagnation point solution cannot be matched to an external plume and boundary layer. Studies by Roberts[7] and Olson[8] indicate that within the corner region, at least for isoviscous vigorous convection, horizontal temperature variations are important. For fluids with strongly temperature dependent viscosity, the overlying rigid lid should enhance these effects that are not contained in the stagnation point solutions. We have sought to clarify this disagreement through a numerical finite element analysis of the subsolidus thinning mechanism.

Subsolidus lithospheric thinning is a process in which hot plume material warms the base of the lithosphere, entrains the heated lithospheric material in its flow, and carries the material away from the region of thinning. The phenomenon is basically one of forced convective heat transfer in a fluid with strongly temperature (and stress) dependent viscosity. Accordingly, we model the process as shown in Fig. 1. The parameters of the model are: T = temperature, u = horizontal velocity, w = vertical velocity, τ = shear stress, σ_x = normal stress, t = time, T_s = surface temperature, T_p = plume temperature, w_p = plume velocity, q = heat flux, and q_c = conductive heat flux. At time $t = 0$ we place hot plume material with temperature T_p at the base of a constant thickness lithospheric slab. The initial temperature in the lithosphere increases linearly with depth. Plume material is forced to enter the base of the computational box with conditions w_p, T_p. The MANTLE finite element code[9] is used to integrate the initial boundary value problem (heat, momentum, and continuity equations) with respect to time (and space) and to follow the thinning of the lithosphere (Fig. 1b). Plume plus lithospheric material is forced to leave the computational box along the right boundary as shown in Fig. 1b. The viscosity of the incompressible medium is taken to be proportional to the exponential of its inverse absolute temperature and to depend on the stress by a power law relation (some calculations were carried out with viscosity independent of stress). All other thermal, mechanical, and rheological properties are assumed to be constant. Lithospheric thinning times will be reported as functions of rheological parameters, w_p, and T_p.

Morris and Canright[10] have argued that in steady or quasi-steady convection of a strongly temperature dependent viscosity fluid the temperature difference across the plume is roughly a few times the temperature difference needed to decrease the viscosity by a factor of e (provided the rigid lid remains intact). This provides an important constraint on subsolidus thinning rates by convective plumes. Current studies are focused on the lithospheric thinning by time-dependent plumes hypothesized by Morris to have large temperature differences across them.

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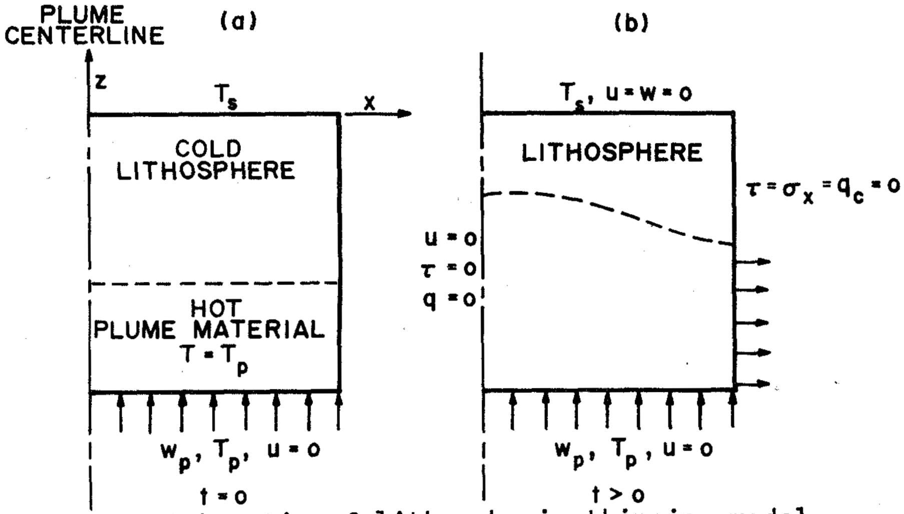

Figure 1. Schematic of lithospheric thinning model.