ON THE RELATIONSHIP BETWEEN TECTONIC PLATES AND THERMAL MANTLE PLUME MORPHOLOGY

N94-16349

A.Lenardic and W.M.Kaula, UCLA Dept. of Earth and Space Sciences, Los Angeles, CA 90024

Introduction: Models incorporating plate-like behavior, i.e., near uniform surface velocity and deformation concentrated at plate boundaries, into a convective system, heated by a mix of internal and basal heating and allowing for temperature dependent viscosity, have been constructed and compared to similar models not possessing plate-like behavior. The simplified numerical models are used to explore how plate-like behavior in a convective system can affect the lower boundary layer from which thermal plumes form. A principal conclusion is that plate-like behavior can significantly increase the temperature drop across the lower thermal boundary layer. This temperature drop affects the morphology of plumes by determining the viscosity drop across the boundary layer. Model results suggest that plumes on planets possessing plate-like behavior, e.g., the Earth, may differ in morphologic type from plumes on planets not possessing plate-like behavior, e.g., Venus and Mars.

Models and Discussion: We employ a 2-D finite element code [1] incorporating plate-like behavior through the use of temperature dependent viscosity and narrow zones of, prescribed, low viscosity, used to mimic fixed plate boundaries [2]. Free parameters for the models employed are: the Rayleigh number defined for bottom heating and the viscosity at the base of the system (Ra); ratio of internal to bottom heating Rayleigh number (H), and the aspect ratio (AR). For all parameter combinations, a model with and without plate-like behavior is run. We refer to these as "plate" and "no-plate" runs (no-plate models employ purely temperature dependent rheology, with a three order of magnitude viscosity contrast across the cold upper boundary layer, while plate models also incorporate weak boundaries). The main qualitative conclusions from these runs are: 1) plate-like behavior suppresses secondary upper boundary layer instabilities present in high Rayleigh number or large aspect ratio no-plate runs; 2) the upper boundary layer is thinner in the plate runs; and 3) the temperature drop across the lower thermal boundary layer is greater in plate runs. The principal physical cause leading to these conclusions is that plate-like behavior enhances the mobility of the cold upper boundary layer material and allows it to be injected deep into the interior of the system at a rate comparable to the overturn rate of the weak interior [3]. This is not the case for no-plate runs, for the Rayleigh number range investigated, which show a marked differences in the rate at which the upper boundary layer is overturned vs. the rate of overturn in the weak interior, the latter being much quicker [4].

Applying model results to terrestrial planets is speculative due to simplifications employed, but the models do suggest possible differences between planets with and without plate-like behavior, which can be tested against comparisons of Earth and Venus. One key potential difference is that, as a result of point 3) above, plumes on Venus may differ in morphologic type from those on Earth. Surface feature on Venus believed to be manifestations of mantle plumes appear larger than Earth counterparts and require dynamic support of topography unlike Earth counterparts [5]. These differences may be consistent with different morphologic plume types within the two planets. If the temperature drop across the lower thermal boundary layer from which plumes form is large, then the viscosity drop from plume to host material will also be large and 'cavity plumes' will be favored, while for low temperature, and thus viscosity, drops 'diapir plumes' will be favored [6]. Cavity plumes consist of broad heads, which comprise the majority of plume mass during their lifetime, and very narrow trailing conduits (significantly narrower in radius than the thermal boundary layer thickness [7]), while diapir plumes have heads only slightly larger than their trailing conduits, which comprise the majority of diapir plume mass and have a radius comparable to the boundary layer thickness. Quasi-steady state topographic features above established plumes (this excludes deformation due to rising plume heads) should be broader for diapir plumes and, since the viscosity of a diapir plume is closer to host mantle viscosity than for cavity plumes, contain a greater component of dynamic support than for cavity plumes. Point 3) suggests that plate-like behavior could establish a larger temperature drop across a hot thermal boundary layer on Earth than exists on Venus. Thus, Venus plumes may be closer to the diapir end-member, while those on Earth are closer to the cavity end-member.

Conclusion: Numerical convection models incorporating plate-like behavior lead to thermal boundary layers quantitatively different from those of models lacking plate-like behavior. A key differences is that the temperature drop across the lower thermal boundary layer is less for models lacking plate-like behavior. This suggests that thermal plumes within the mantles of terrestrial planets may differ in morphologic type due to the presence or absence of plate-like behavior.

[1]King, S.D. et al., *Phys. Earth Planet. Inter.*, *59*, 195-207, 1990. [2]King, S.D., et al., *Geophys. J. Int.*, *109*, 481-487, 1992. [3]Gurnis, M., *Geophys. Res. Lett.*, *16*, 179-182, 1989. [4]Christensen, U.R., *Phys. Earth Planet. Int.*, *35*, 264-282, 1984. [5]Phillips, R.J., et al., *Science*, *252*, 651-658, 1991. [6]Olson, P., and H. Singer, *J. Fluid Mech.*, *158*, 511-531, 1985. [7]Stacey, F.D., and D.E. Loper, *Phys. Earth Planet. Inter.*, *33*, 44-55, 1983.

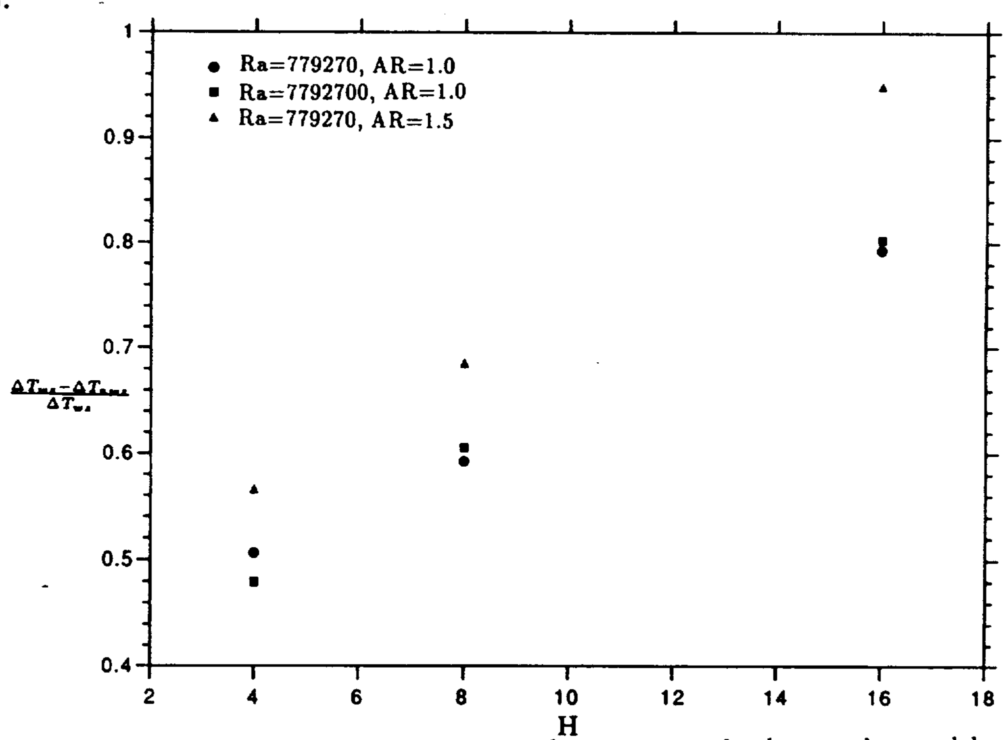

Fig. 1: A scatter plot of the temperature drop across the lower thermal boundary layer for runs with weak zones (ΔTwz), i.e., plate runs, minus the corresponding value of runs without weak zones ($\Delta Tnwz$), i.e., no-plate runs, divided by ΔTwz vs. the H value for run pairs with varied Rayleigh numbers and aspect ratios. The simplified temperature dependent viscosity formulation of these runs achieves a minimum, set by a prescribed cut off value, at a nondimensional temperature of 0.4 and a maximum at the top of the system. Large viscosity variations across the lower thermal boundary layer, which could result after a large temperature drop has been established, are not allowed for due to the numerical expense that would be incurred if a thin velocity layer needed to be resolved (these runs are not intended to study the formation of cavity plumes, rather they are intended to study the conditions that potentially favor their formation).