THE INITIATION OF SUBDUCTION: THERMAL AND COMPOSITIONAL CONSIDERATIONS WITH APPLICATION TO VENUS; D.L. Herrick and E.M. Parmentier, Department of Geological Sciences, Brown University, Providence, RI 02912

An understanding of the conditions under which plate tectonics can occur is fundamental to interpreting the evolution of planets. Since plate tectonics requires subduction, and the pull of subducting slabs is a principal force causing plate motions, the initiation of subduction zones is a necessary, and perhaps sufficient, condition for plate tectonics. Given both the similarities and the differences between Venus and the Earth, it is important to understand if plate tectonics might be expected on Venus. As on the Earth, evidence has been cited for thermal elevation of the surface, e.g. (1), that would provide a gravity spreading force, and large-scale compressional features have been identified, e.g. (2). The absence of conclusive evidence for plate tectonics has prompted an investigation into the conditions necessary to initiate subduction, and the mechanisms by which this may occur.

The upper portion of the planet is divided compositionally into a basaltic crust and a peridotite mantle, and thermally into a lithosphere and an asthenosphere. The minimum crustal thickness necessary to render the lithosphere negatively buoyant with respect to the upper asthenosphere is determined. This value is a function of the cooling age of the lithosphere, since phase boundaries rise and thermal contraction occurs as the temperature decreases. (Note that the timescale for phase transformations is assumed to be much shorter than that for subduction.) The relationship coincides with the contour in Figure 1 that is labelled as infinity.

The forces acting on the lithospheric slab are modelled as in (3), and are illustrated in graphs (a), (b), and (c). Compression and subduction are driven by the ridge-push force associated with the thermally induced elevation of the hotspot region and by the trench-pull force derived from the negative buoyancy of the slab. These driving forces are resisted by interplate friction in the area of subduction. In addition, work must be expended initially in forming the thrust topography of the trench system. Due to our ignorance concerning the geometry of possible Venusian trenches and the frictional stresses along them, previous numerical values for the resistance parameters on Earth are employed (3). The driving forces, however, can be computed for Venus from the variables already incorporated into the model.

For the Earth, subduction cannot begin spontaneously, but instead requires some outside compressive stress to cause the underthrusting of about 180 km of the slab (3), after which the driving forces outweigh the resistive forces and the subduction becomes self-sustaining. Some of the present results for Venus are qualitatively similar to this (see graph (b)), but the loose constraints on the input parameters do not preclude the possibility of spontaneous initiation of subduction for a thick basaltic crust and a long cooling time (graph (c)), or the possibility of an unsinkable slab in the opposite extreme (graph (a)).

These calculations assume that the crust and mantle are emplaced instantaneously at the surface with a temperature of 1300°C and then cool conductively. Under such conditions it is possible that the lower crustal material would be fluid enough to separate from the slab and sink into the asthenosphere. Since the average density of the lithosphere would therefore decrease, the minimum cooling age necessary for negative buoyancy would increase from 70 Ma in the case of no crustal separation to 250 Ma in the case of separation at temperatures greater than 800°C.

The above analysis shows that the gravity spreading force is generally insufficient to overcome the forces that resist subduction. However, this assumes that a subduction zone forms everywhere simultaneously along its length. A subduction zone of finite length would, like a crack, create stress concentrations at its ends. This localization of the gravity spreading driving force could be sufficient to overcome resistive forces, and we are presently evaluating the conditions under which this may occur.

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References: (1) P. Morgan and R.J. Phillips, J. Geophys. Res. 88, 8305, 1983. (2) A.T. Basilevsky and J.W. Head, Ann. Rev. Earth Planet. Sci. 16, 295, 1988. (3) D.P. McKenzie, in A.G.U. Ewing Series 1, 57, 1976.

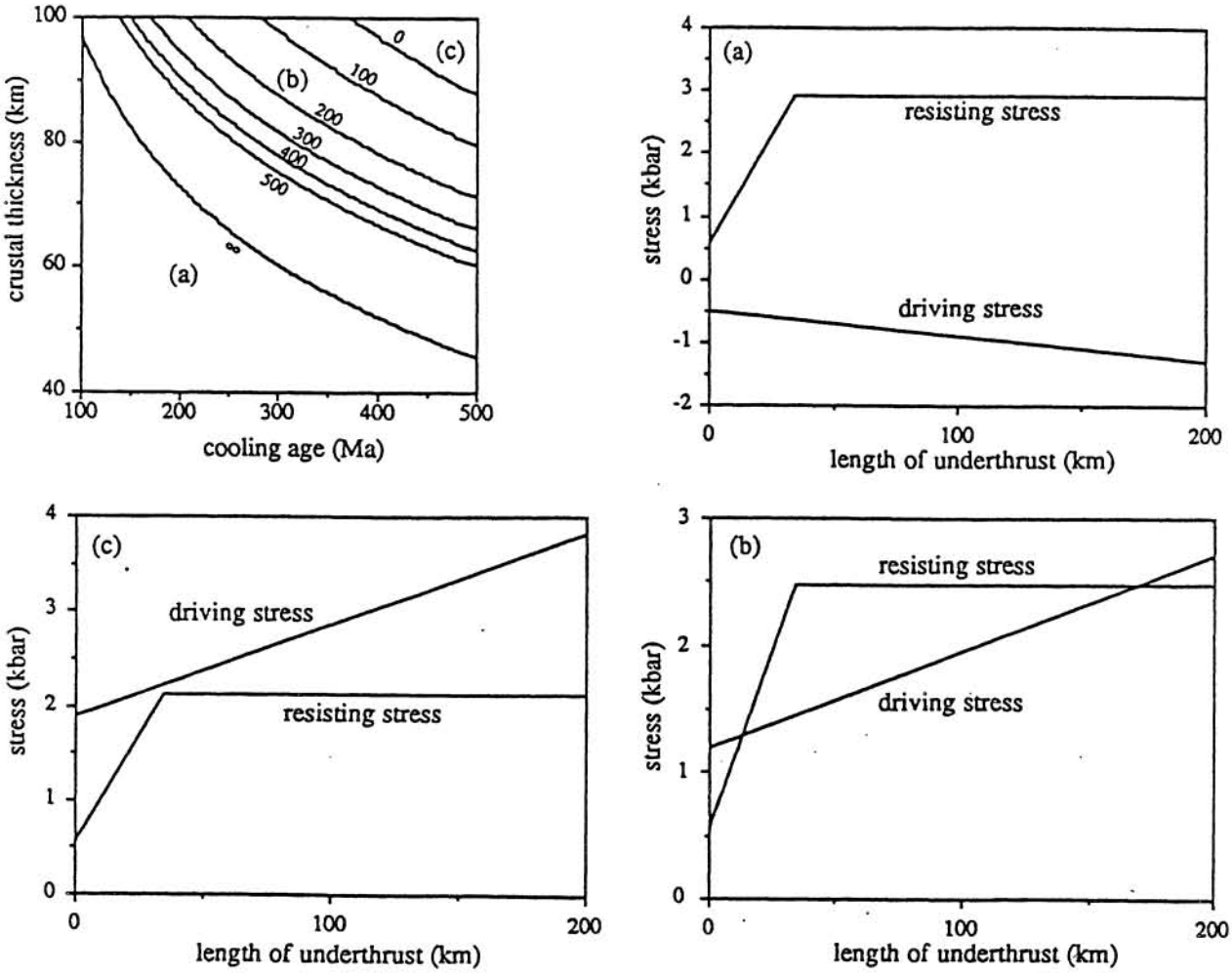

Figure 1: Contours of the amount of underthrusting, in kilometers, that a slab descending at 45 degrees must achieve in order for subduction to become a self-sustaining process, plotted as a function of cooling age and crustal thickness. Below about 70 Ma cooling time the required crust is thicker than the thermal lithosphere, and the slab cannot become negatively buoyant. Graphs labelled (a), (b), and (c) (corresponding to similarly marked data points on the contour plot) depict the total driving and resisting stresses on the slab as functions of the length of the slab that has been forced below the surface.

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