AN ASSESSMENT OF THE CRUSTAL REMELTING HYPOTHESIS FOR VOLCANISM IN THE FREYJA MONTES DEFORMATION ZONE; Noriyuki Namiki and Sean C. Solomon, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139.

Introduction. The linear mountain belts of Ishtar Terra on Venus are notable for their topographic relief and slope and for the intensity of surface deformation [1,2]. The mountains surround the highland plain Lakshmi Planum, the site of two major paterae and numerous other volcanic features and deposits [3,4], and evidence is widespread for volcanism within the mountains and in terrain immediately outward of the mountain belt units [2,4]. While the mountains are generally regarded as products of large-scale compression of the crust and lithosphere [2,5], whether western Ishtar Terra is a site of mantle upwelling and consequent hot spot volcanism [6-8] or of mantle downwelling and consequent convergence of lithospheric blocks [9,10] is currently a matter of debate. If the upwelling model holds, then volcanism in Lakshmi Planum and presumably within the mountains and adjacent terrain is likely a result of pressure-release partial melting in the upwelling mantle [6-8]. If the downwelling model is appropriate for western Ishtar Terra, then partial melting in the underlying mantle is less likely and the volcanism may require remelting of thickened crust [9,10]. While these two hypotheses for magmatism can be distinguished on the basis of the chemistry of the melts [11], chemical data are presently lacking for the Ishtar region.

The competing hypotheses for magmatism in western Ishtar Terra can also be tested with thermal models, given a kinematic or dynamic model for the evolution of the region. In this paper we assess the crustal remelting hypothesis, utilizing the kinematic scenario of Head [12] for the evolution of Freyja Montes. In that scenario Freyja Montes formed by a sequence of large-scale underthrusts of the lithosphere of the North Polar Plains beneath Ishtar Terra, with successive blocks of underthrust crust sutured in imbricate fashion onto the thickened crust of Lakshmi Planum and the mantle portion of underthrusting lithosphere episodically detached [12]. The time scales and several important length scales for this process are not presently derivable from geological observations but may be treated as free parameters in numerical models.

Thermal Model. The adopted kinematics of convergence, crustal underthrusting, detachment of the mantle portion of the lithosphere, crustal imbrication, and corresponding crustal thickening are depicted in Fig. 1. The time-dependent temperature field for this kinematic model is obtained by solving a finite-difference approximation to the two dimensional heat equation [13,14]. The base of the thermal lithosphere is assumed to be defined by a homologous temperature, that is, a fixed fraction s of the mantle solidus temperature, and the asthenosphere is assumed to be well mixed and isothermal. The initial condition (i.e., prior to convergence and underthrusting) is taken to be a laterally uniform structure in thermal equilibrium. The ranges in key but poorly constrained parameters in the model are summarized in Table 1.

Numerical Results. Remelting of the crust can take place in two different ways. One is by direct contact of the crust with hot asthenosphere; the other is by heat generation in a thickened crust. If the melting temperature of crustal material at the pressure corresponding to the normal base of the crust is lower than the asthenospheric temperature, then crust melts from the time of detachment of the subcrustal portion of the lithosphere. Melting continues until a new segment of underthrust lithosphere shuts off the imbricated blocks from the asthenosphere and allows them to cool. The second mechanism for crustal melting is heating of a thickened lower crust by radioactive heat generation. Melting of this type is strongly dependent on the asthenospheric temperature, the crustal abundance A_C of radioactive heat sources and the maximum depth h_D of underthrust crust. As A_C increases, the minimum value of h_D required for melting decreases. If h_D is larger than the lithosphere thickness, then the lower parts of imbricated blocks are surrounded by asthenosphere. The imbricated blocks are then heated efficiently, and more melt is produced.

An approximate estimate of magma production rate may be made by converting, at each time step and for each partially molten zone in the model, the temperature in excess of the melting temperature into heat of fusion. The variations in estimated melt volume per time step (about 2 My) for three representative models are shown in Figure 2. (In model 1, 2, 3: h_c = 20,20,29 km; q_s = 35, 50, 65 mW/m^2; s = 0.90, 0.91, 0.96; A_c = 20, 25, 50 x 10^{-11} W/kg; h_D = 40, 100, 100 km; for all models: v = 5 mm/yr, dip angle of thrust = 15°.)

Discussion. The numerical experiments thus show that volcanic activity associated with the formation of the Freyja Montes deformation zone can be explained by crustal melting, due either to direct contact of crustal material with the hot asthenosphere or to heat generation in a thickened crustal layer. Time variations in rate of magma generation show different patterns for the two different mechanisms of melting. If crustal melting is due principally to direct heating by the asthenosphere, magma generation can show sudden increases and more gradual decreases (Fig. 2) controlled by the timing of lithospheric delamination events. Alternatively, if melting is due principally to crustal thickening, then the magma generation rate generally grows monotonically with time (Fig. 2). Such temporally distinct magmatic behavior may ultimately be distinguishable by analysis of *Magellan* imaging data.

References. [1] V.L. Barsukov et al., *JGR, 91*, D378, 1986; [2] S.C. Solomon et al., *Science*, in press, 1991; [3] K.M. Roberts and J.W. Head, *EMP, 50/51*, 193, 1990; [4] J.W. Head et al., *Science*, in press, 1991; [5] L.S. Crumpler et al., *Geology, 14*, 1031, 1986; [6] A. A. Pronin, *Geotectonics, 20*, 271, 1986; [7] A. T. Basilevsky, *Geotectonics, 20*, 282, 1986; [8] R. E. Grimm and R. J. Phillips, *GRL, 17*, 1349, 1990; [9] K. M. Roberts and J. W. Head, *GRL, 17*, 1341, 1990; [10] D.L. Bindschadler and E.M. Parmentier, *JGR, 95*, 21329, 1990; [11] P.C. Hess and J.W. Head, *EMP, 50/51*, 47, 1990; [12] J.W. Head, *Geology, 18*, 99-102, 1990; [13] P. Bird et al., *JGR, 80*, 4405, 1975; [14] M.N. Toksöz and P. Bird, *Tectonophysics, 41*, 181, 1977; [15] D. McKenzie and M. J. Bickle, *J. Petrol., 29*, 625, 1988.

Table 1. Ranges in Assumed Parameters for Thermal Models

Parameter		Range
Crustal Thickness	h_c	5-100 km
Surface Heat Flow	q_s	25-75 mW/m^2
Homologous Temperature	s	0.85-0.96
Crustal Radioactive Heat Production	A_c	0-70x10^{-11} W/kg
Convergence Rate	v	1-100 mm/yr
Crustal Solidus	-	1373 + 6.0x10^{-8}P[Pa] K
Mantle Solidus	-	P[GPa] = $(T-T_0)/a+b\times\exp(c(T-T_0))$*
Maximum Depth of Underthrust Crust	h_D	40-100 km

*) a = 136, b = 4.968x10^{-4}, c = 1.2x10^{-2}, T_0 = 1373 °K [15].

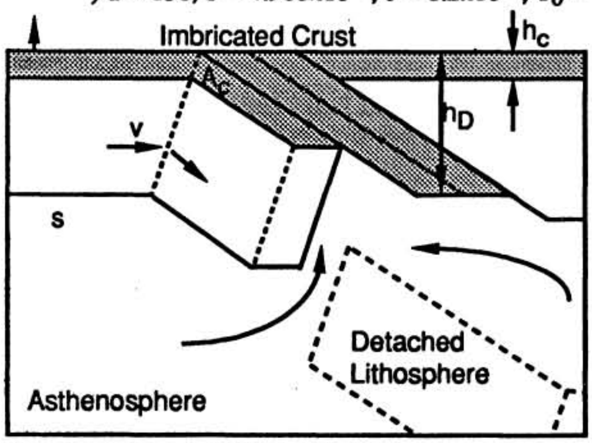

Fig. 1. Assumed kinematics of underthrusting and parameters assumed in the thermal models.

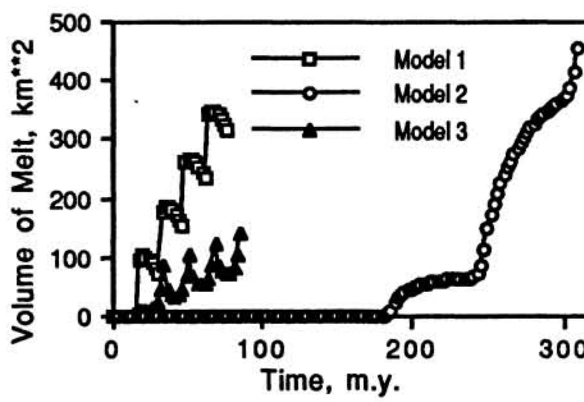

Fig. 2. Melt volume versus model time step. Remelting of the crust occurs by (1) direct contact with the asthenosphere, (2) basal melting of thickened crust, or (3) both.