SURFACE TECTONICS FROM SINKER INDUCED MANTLE CONVECTION: APPLICATION TO MIRANDA. D.M. Janes and H.J. Melosh, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

Few images returned by Voyager 2 during its encounter with the Uranian system were more unexpected than those of the small inner moon, Miranda. In particular, three areas of complex terrain, trapezoidal to ovoid in shape, had no known counterpart. These features are characterized by an inner core of intersecting ridges and troughs surrounded by a series of subparallel and concentric bands which at least at their outer margins represent outward facing scarps. One proposed explanation for these tectonic features is that the body was 'catastrophically disrupted and reaccreted several times' [1]. The purpose of the present study is to determine the surface stresses set up by a late accreting silicate impactor as it sinks down through an icy mantle toward a rocky core and their expected surface expression.

Miranda is modeled as a rigid silicate core surrounded by an icy mantle which can flow viscously under continuous stress and overlain by a thin, elastically deforming lithosphere. The sinking late impactor (sinker) is modeled as a point mass representing the anomalous mass of the sinker over the less dense mantle material, producing a force equal to $g(r_s) \cdot \Delta m$. A spherical coordinate system is adopted with origin at the center of the planet and theta axis coincident with the sinker (Fig. 1). Following a procedure developed by Pekeris [2], it is assumed that the flow field set up by this force can be represented by a stream function of the form:

$$\Psi = -\sum_j b_{j(r)} (1-\xi^2) \frac{\delta}{\delta\xi} P_j(\xi) \qquad (1)$$

where $\xi = \cos(\theta)$. Assuming incompressibility of the mantle material and stress equilibrium, it is found that $b_{j(r)}$ is given by:

$$b_{j(r)} = C_{1,j} \cdot r^{-j} + C_{2,j} \cdot r^{-j+2} + C_{3,j} \cdot r^{j+1} + C_{4,j} \cdot r^{j+3} \quad (2)$$

The Green's function for stream function is then constructed by assuming it is discontinuous at the radius of the sinker with the same form but different constants above and below the radius of the sinker and the eight constants for each Legendre order are solved for from the boundary and patch conditions to order 20. Stream lines are functions only of r_c/r_1 and r_s/r_1. Magnitudes of the stream function depend upon the mass anomaly of the sinker, its local gravitational field and r_1. The stresses on the base of the lithosphere are then determined from the inverse equations of motion. The viscosity of the mantle material has no effect on the stresses produced at any given time but does control the length of time that a given stress field pertains by controlling the velocity of the sinker. Stream lines for r_c/r_1=0.5 and r_s/r_1 are shown in Figure 2.

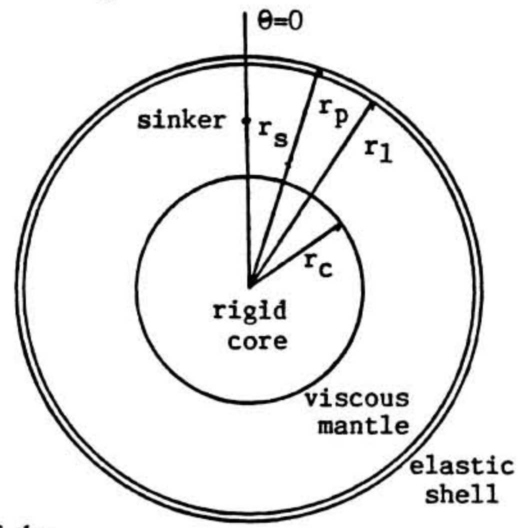

Fig. 1: Model

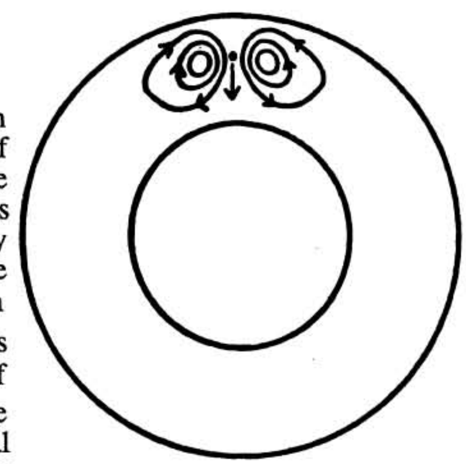

Fig. 2: Streamlines for r_c/r_1 = 0.5 r_s/r_1 = 0.8

Miranda's lithosphere is modeled as a thin (20 km) elastic shell with a shear rigidity of 4.528×10^9 kg/m • s^2 [3] in which displacements can be given as:

$$U_r = \sum_j \alpha A_j r^n P_j(\xi) \tag{3}$$

$$U_\theta = -\sum_j A_j r^n (1-\xi^2)^{\frac{1}{2}} \frac{\delta}{\delta\xi} P_j(\xi) \tag{4}$$

TABLE 1

constant	n	α
$A_{1,j}$	$j-1$	j
$A_{2,j}$	$-j-2$	$-j-1$
$A_{3,j}$	$j+1$	$(j+1)\left[\frac{(j-2)\mu + (j)\lambda}{(j+5)\mu + (j+3)\lambda}\right]$
$A_{4,j}$	$-j$	$(j)\left[\frac{(j+3)\mu + (j+1)\lambda}{(-j+4)\mu + (-j+2)\lambda}\right]$

Using strain definitions and Hooke's Law, the radial dependency is again found to be a sum of four terms, summarized in Table 1. The constants are solved for from the boundary conditions at the base and surface, again to order 20. At the planetary surface equations of stress based on these displacements and taking $\mu = \lambda$ yield a pattern of expected tectonic expression based on Anderson criteria (Fig. 3). The θ dimensions used in the following discussion are for $r_c/r_1=0.5$ and $r_s/r_1=0.8$. Other sinker depths yield qualitatively similar results. The magnitude of the stresses has the same dependence on mass anomaly, gravity and r_1 as the mantle stream function from which they are derived. Directly over the sinker and extending outward 15° is a zone of both latitudinal (θ) and longitudinal (ϕ) compression producing folding and thrust faults extending radially from the sinker epicenter. From 15° to 36° latitudinal stresses are extensional while longitudinal stresses remain compressional producing a zone of strike-slip faulting. Between 36° and 55° both longitudinal and latitudinal stresses are extensional with $|\sigma_{\theta\theta}| > |\sigma_{\phi\phi}|$, producing a zone of normal faulting concentric about the sinker. Generally values for stresses decrease away from the sinker and with increasing sinker depth. At some point lithospheric strength will exceed the applied stress and tectonic expression will cease.

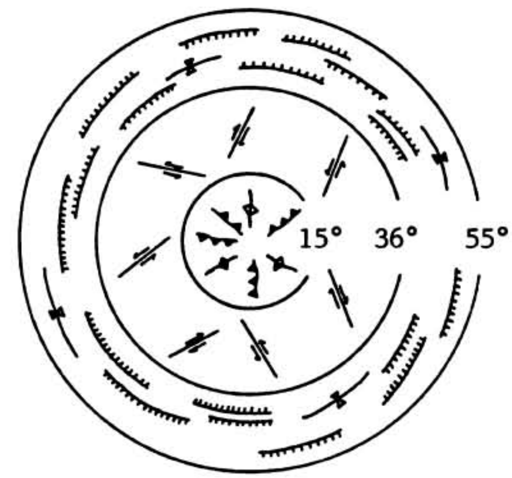

Fig. 3: Expected Tectonic Expression for $r_c/r_1 = 0.5$
$r_s/r_1 = 0.8$
MAP VIEW

Although this model does not as yet explain all the tectonic features of Miranda it is in good first-order agreement with the topography of the banded and ridged terrains as they were imaged by Voyager 2 and such a mechanism cannot be ruled out as a possible explanation for the strange surface of that body.

References: [1] Smith, B.A., *et al.* (1986) Voyager 2 in the Uranain System: Imaging Science Results, *Science* **223**, pp. 43-64. [2] Pekeris, C.L. (1935) Thermal Convection in the Interior of the Earth, *Mon. Not. Roy. Astr. Soc. Geophys. Suppl.* **3**, pp. 343-367. [3] Cassen, P. and Reynolds, R.T. (1979) Is There Liquid Water on Europa?, *Geophys. Res. Let.* **6**, No. 9., pp. 731-734.