TECTONIC DEFORMATION ON ICY SATELLITES: A MODEL OF COMPENSATING HORSTS; *Robert Pappalardo and Ronald Greeley, Department of Geology, Arizona State University, Tempe, Arizona 85287*

Voyager images demonstrate that the icy satellites have been shaped by a variety of magmatic and tectonic processes, of which ridge and trough terrain is a manifestation. This terrain is observed on Ganymede, Enceladus, Miranda, and Ariel, and many models have been proposed to explain its origin. A likely model is horst-and-graben style normal faulting, in which horizontal extension results in a series of downdropped grabens and relatively uplifted horsts. The apparent negative elevation of ridges and troughs relative to surrounding terrain has been used to argue such an extensional-tectonic origin for ridge and trough terrain on Ganymede [1] and Enceladus [2]. A ridge or ridge set which stands above a presumed original base level, on the other hand, might be suspect of having a magmatic or compressional origin.

It has been demonstrated that rotation of "domino-style" normal faulting, which involves rotation of fault blocks about a fulcrum, can allow ridges to stand slightly above the original base level [3], and this relative uplift may be amplified by isostatic uplift [4]. Isostatic compensation of an individual graben underlain by a ductile layer is commonly manifest as upraised rift flanks, as predicted theoretically [5,6] and manifest in laboratory experiments of horst-and-graben normal faulting [7].

Compensation might also be accomplished through uplift of adjacent horsts [6,8]. Although in nature compensation is likely partitioned between uplift of horsts and internal deformation of blocks, we examine the case of a series of horsts and grabens underlain by a ductile material in which compensation of graben downdrop is accomplished exclusively through horst uplift. This allows geometrical estimation of the absolute amounts of graben downdrop and horst uplift relative to the original (pre-faulting) base level.

Figure 1 illustrates the downdrop by an amount h_1 of a series of identical trapezoidal grabens, displacing a volume proportional to this downdrop and the length L_1 of each graben's base. Ductile material flows beneath the two adjacent horsts causing their uplift, and each horst is forced upward by material displaced by its two neighboring grabens. Equating the volume displaced by a graben to that causing horst uplift, as for the case of a single horst and graben pair [6],

$$L_1 h_1 + \frac{h_1^2}{\tan\delta} = L_2 h_2 + \frac{h_2^2}{\tan\delta} \tag{1}$$

where L_2 is the base length and h_2 the vertical uplift of each horst, and δ is the dip of each graben's downward-converging bounding faults, assumed to remain constant with depth. Friction on the faults is taken to be negligible. The base length of each graben is related to its observable surface width T_w as

$$L_1 = T_w - \frac{2t}{\tan\delta} \tag{2a}$$

and horst base length is related to surface width R_w as

$$L_2 = R_w + \frac{2t}{\tan\delta} \tag{2b}$$

where t is the original (unfaulted) thickness of the brittle layer. The assumed geometry of the fault blocks constrains the layer's thickness to $t \leq 0.5\,T_w \tan\delta$. The relation

$$h_1 + h_2 = d \tag{3}$$

links displacements h_1 and h_2 to the observed final elevation difference d between two neighboring blocks. Equations (1), (2), and (3) combine to give

$$h_1 = d\,\frac{R_w \tan\delta + 2t + d}{(R_w + T_w)\tan\delta + 2d} \tag{4}$$

and h_2 can be obtained from equation (3). In this way the absolute vertical displacement of horst and graben blocks relative to an original base level can be related to model parameters.

Figures 2a and 2b illustrate the effects of brittle layer thickness t and fault dip (δ = 40-90°) on the total vertical displacement of horsts and grabens. Figure 2a shows a "grooved" case ($R_w > T_w$), which could pertain to areas of "grooved terrain" on Ganymede (R_w = 8 km; T_w = 4 km); Figure 2b is for a "ridged" case ($R_w < T_w$) and may pertain to Elsinore Corona, Miranda (R_w = 4 km; T_w = 8 km). In both examples, d is taken to be 0.4 km. Relative horst uplift increases with increased fault dip, decreased t, and a greater difference $T_w - R_w$.

As illustrated by Figure 2b, if horsts are more narrow than their intervening grabens, there exists a critical layer thickness

$$t_{crit} = 0.25\,(Tw - Rw)\tan\delta \tag{5}$$

MODEL OF COMPENSATING HORSTS: ***R. Pappalardo and R. Greeley***

at which $h_2 = h_1 = d/2$. If $t < t_{crit}$, then a greater portion of the total observed elevation difference d is due to horst uplift above the original base level rather than to graben downdrop. In the example of Figure 2b, for $\delta = 50°$, $t_{crit} = 1.2$ km. The thinner the brittle plate relative to t_{crit}, the greater the difference between ridge uplift and trough downdrop.

The compensating horsts model demonstrates that horsts may stand above the level of surrounding unfaulted terrain if isostatic compensation is accomplished through (or significantly partitioned into) horst uplift. Indeed, the magnitude of horst uplift may exceed that of graben downdrop if horst width is less than graben width. This should be considered when evaluating ridge-and-trough-forming processes on icy satellites and elsewhere.

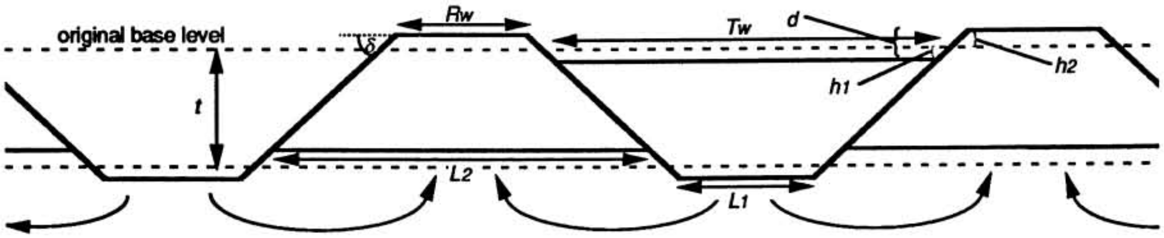

Figure 1.

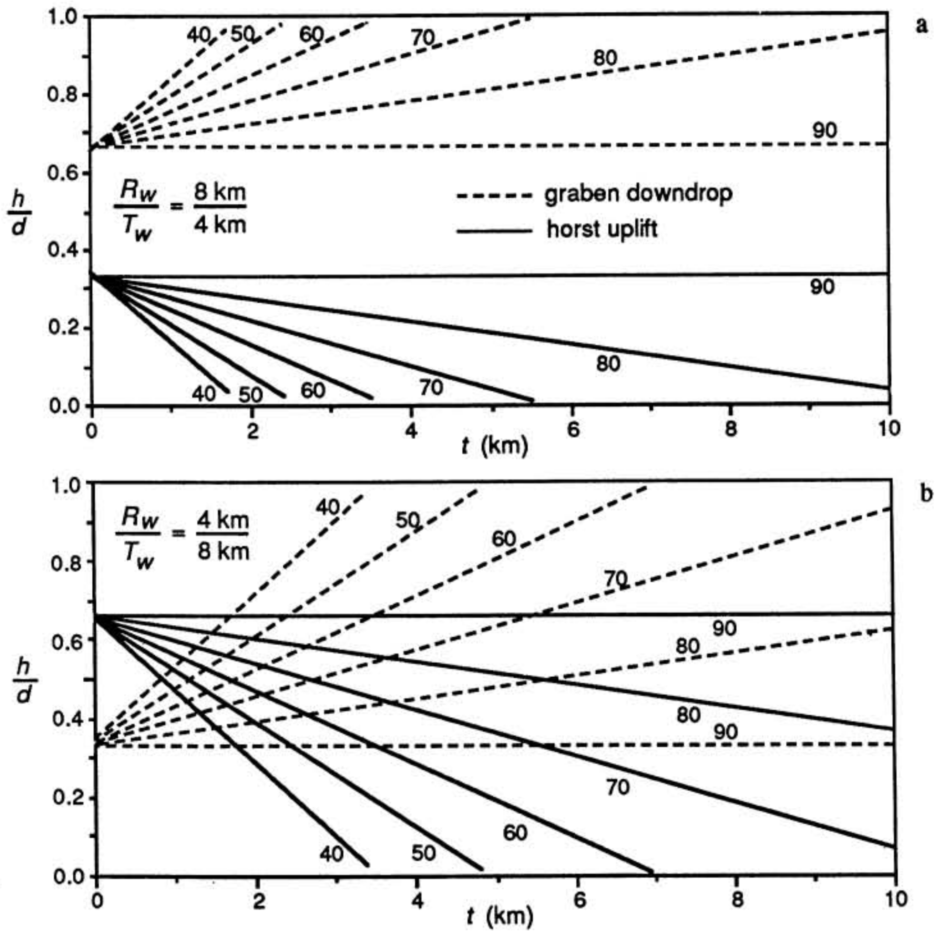

Figure 2.

[1]Shoemaker, E.M. *et al.*, in *Satellites of Jupiter*, p. 435, 1982. [2]Squyres, S.W *et al.*, *Icarus*, *53*, 319, 1983. [3]Leeder, M.R. and R.L. Gawthorpe, in *Continental Extensional Tectonics*, p. 139, 1987; Barr, D., *J. Struct. Geol.*, *9*, 491, 1987. [4]Jackson, J.A. and D. McKenzie, *J. Struct. Geol.*, *5*, 471, 1983. [5]Heiskanen, W.A. and F.A. Vening Meinesz, *The Earth and its Gravity Field*, 1958. [6]Bott, M.H.P., *Tectonophys.*, *36*, 77, 1976. [7]McGill, G.E. and A.W. Stromquist, *JGR*, *84*, 1979; Vendeville, B. *et al.*, in *Continental Extensional Tectonics*, p. 95, 1987. [8]Lonsdale, P., *Mar. Geophys. Res.*, *3*, 251, 1977.