N86-31135

IO: MOUNTAINS AND CRUSTAL EXTENSION.

M. J. Heath, Department of Extra-Mural Studies, University of London, 26 Russell Square, London WC1B 5DQ, England.

Schaber (1) has presented a preliminary map of Io detailing surface morphology of an area located between 60°W and 240°W, across the 0° meridian, and below 40°N, covering some 26.5% of the globe. Mountainous terrain, represented by separate massifs as opposed to continuous chains, occupies some 1.9% of the mapped area. Massifs may achieve altitudes exceeding 9±1km above their surroundings and it is considered (2,3,4,5) that topography of this amplitude must be supported by material of largely silicate composition. Mountains are often associated with a unit which Schaber (1) terms 'layered plains', which is characterised by 'an extensive, smooth, flat surface, boundary scarps ranging in height from 150 to 1700m, and abundant grabens'. Scarps are probably controlled by normal faults (1), and extensively eroded in places due to the escape of sub-surface SO_2 at free faces (6).

The role of extensional tectonics in controlling the edges of plateaus is well illustrated in the case of the plateau at 48°S, 320°W. This has an almost straight northeast edge, trending NW - SE. The southeast projection of this lineament passes through the volcanic centre named Aten Patera, and continues along a fissure-like feature from which dark material has effused on either side.

Studies of Earth's mountains benefit from field surveys, geophysical investigations, levelling data and data provided by engineering projects. Our knowledge of Io's mountains is more rudimentary, being based on images of resolution no better than 0.5km per line pair. Nevertheless, available images indicate that these mountains on the Solar System's most active body will provide a challenging subject for future work.

Schaber (1) speculated that massifs might be volcanic constructs or vent deposits fringing giant volcano-tectonic depressions, and identified possible volcanic vents on mountain flanks. Notwithstanding, the evident role of tectonism in controlling massif morphology may point to an origin by tectonic processes. Mountain and plateau uplift on Io may be polygenetic, however, and it is not possible to reject mechanisms for uplift which involve injection of large thicknesses of magma into the lower part of the crust, as recently discussed for terrestrial examples by McKenzie (7). Such processes might accompany crustal extension.

The mountain at 35°S, 335°W rises as a relatively simple plateau from the low relief 'intervent plains'. Many of the mountains, however, are modified by extensional features, with the implication that extensional processes were involved in mountain formation. Several massifs occur on the shoulders of graben or graben-like features. Haemus Mons (70°S, 50°W) exhibits pervasive lineations of similar trend to those of nearby terrains where extension is in evidence. This might imply a tilted 'pack of cards' structure produced by a style of extensional tectonics similar to that envisaged for certain terrestrial regions by Angelier and Colletta (8). Another possibility is that extension in some areas is accommodated by compression in others, with lateral movements and local uplift along fault planes. Schaber (1) noted a possible lateral displacement near 10°S, 280°W.

There is good reason to conclude that mountains on Io, like those on Earth, are subject to growth and decay. The decay of mountains will be assisted by the ability of SO_2 to rot silicate rock (J. Guest, personal communication) and explosive escape of sub-surface SO_2 from 'aquifers' (Haemus Mons is seen to be covered by bright material, presumably fallout from a SO_2 rich plume which had been active on the mountain flanks). On the west side of the massif at 10°S, 270°W a rugged surface consists of long ridges running perpendicular to the downslope direction, suggesting tectonic denudation with crustal blocks sliding down the mountain flank. Tectonic denudation may be assisted, as in the case of the Bearpaw Mountains, Montana (9) by overloading mountain flanks with volcanic products. The surfaces of some massifs exhibit a well developed, enigmatic 'corrugated terrain', consisting of complex ridge systems. Ridges may bifurcate, anastomose to form closed depressions and form concentric loops. One possible mechanism for their formation is the deformation of a sheet which is detached from and free to glide over underlying layers in response to gravity. Movements down mountain flanks will be encouraged if there are layers rich in sulphur, SO_2, or other sulphur compounds, providing suitable surfaces of décollement.

None of the disrupted surfaces on or around mountains bear recognisable impact craters down to the limits of resolution, with the implication that these surfaces, like the rest of Io's terrain (see ref. 10) are younger than 1 Myr, and that denudation has been rapid. The mountains on Io are ephemeral.

If this inference is correct, it follows that the presence of mountains on Io requires that mountain formation, continuous or episodic, has been active close to the present day. There is morphological evidence for uplift of massifs. For example, lobes of material debouch onto the layered plains from the massif at 47°S, 340W (northeast of Creidne Patera) in response to tilting. Corrugated terrain on mountain flanks appears to be cut or controlled by lineaments running into mountains from adjacent layered plains. On the massif at 10°S, 270°W the inner edge of a peripheral bench of layered plains seems to embay the south side of the mountain surface with no evidence of normal, thrust, or strike-slip faulting. The outer edge of the bench, however, appears to be controlled by a normal fault. Hence this scarp may represent an increment of uplift common to bench and massif.

Taken together, observations of morphology, heat flux, surface deposits and styles of volcanism may point to the existence of lithosphere domains with distinct compositions and tectonic regimes. Mountains and layered plains are concentrated around the eastern, southern and southwest peripheries of the mapped area, whilst the central part is free of mountains. Shield crater flows occur mainly on the northwest periphery of the area. From Earth based IR observations, Johnson et al. (11) found that

Io's heat flux peaked in the vicinity of Loki (within Schaber's mapped area, near 315°W), the main volcanic centre at the time of the Voyager encounters, suggesting a deep seated, persistent source of volcanism to these workers. McEwen and Soderblom (12) distinguished short lived, energetic plumes, depositing dark material (Surt, Aten and Pele) from long lived, less energetic, SO_2 rich plumes, and noted Loki as a hybrid. Aten, Pele and Loki lie within the mapped area, and Surt not far beyond it to the northwest. Nelson et al. (13) found that SO_2 frost was most abundant from 72°W to 137°W, and least abundant (in the area mapped by Schaber) between 250°W to 323°W. Images and thermal data from the forthcoming Galileo mission should provide a much improved global overview of tectonic and other crustal processes on Io.

REFERENCES

(1) Schaber, G. G. (1980). The Surface of Io: Geologic Units, Morphology, and Tectonics. Icarus 43, 302-333.

(2) Carr, M. H., Masursky, H., Strom, G. H., and Terrile, R. S. (1979). Volcanic features of Io. Nature 280, 729-733.

(3) Masursky, H., Schaber, G. G., Soderblom, L. A., and Strom, R. G. (1979). Preliminary geological mapping of Io. Nature 280, 725-729.

(4) Sagan, C. (1979). Sulfur flows on Io. Nature 280, 750-753.

(5) Clow, G. D., and Carr, M. H. (1980). Stability of sulfur slopes on Io. Icarus 44, 268-279.

(6) McCauley, J. F., Smith, B. A., and Soderblom, L. A. (1979). Erosional scarps on Io. Nature 280, 736-738.

(7) McKenzie, D. (1984). A possible mechanism for epeirogenic uplift. Nature 307, 616-618.

(8) Angelier, J., and Colletta, B. (1983). Tension fractures and extensional tectonics. Nature 301, 49-51.

(9) Reeves, F. (1946). Origins and mechanics of thrust faults adjacent to the Bearpaw Mountains, Montana, Geol. Soc. Am. Bull. 57, 1033-1047.

(10) Johnson, T. V., Cook II, A. F., Sagan, C., and Soderblom, L. A. (1979). Volcanic resurfacing rates and implications for volatiles on Io. Nature 280, 746-750.

(11) Johnson, T. V., Morrison, D., Matson, D. L., Veeder, G. J., Brown, R. H., and Nelson, R. M. (1984). Volcanic Hotspots on Io: Stability and Longitudinal Distribution. Science 226, 134-137.

(12) McEwen, A. S., and Soderblom, L. A. (1983). Two classes of Volcanic Plumes on Io. Icarus 55, 191-217.

(13) Nelson, R. M., Lane, A. L., Matson, D. L., Fanale, F. P., Nash, D. B., and Johnson, T. V. (1980). Io: Longitudinal Distribution of Sulfur Dioxide Frost. Science 210, 784-786.