TECTONIC FEATURES ON ARIEL: EVIDENCE FOR COLLAPSE OF A TIDAL BULGE

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Introduction: Voyager II images of Ariel reveal a geologically young surface characterized by a moon-wide system of linear tectonic cracks and large fault controlled chasma. Crater density analysis indicates Ariel experienced at least one episode of resurfacing after the period of population I bombardment [1]. The tectonic cracks, scarps, pit chains, and similar lineaments are pure extensional features, while flow features within the large chasma appear to be formed in an extensional environment as well [2].

Tectonic features in general can arise from a variety of processes including large impacts, stresses induced by changes in the planet's volume during melting or refreezing, and stresses induced by tidal distortion. An analysis of lengths and frequency of occurrence of the tectonic cracks should indicate the origin of the crack-producing stress. Several researchers have suggested that Ariel may have been locked in an orbital resonance with Umbrial at some point in its history [2,3], although no resonance with other moons is observed today. If Ariel were subsequently ejected from such a resonance, then the tectonic features should reflect this. Specifically, we should expect to see tectonic cracks preferentially aligned in a predictable pattern about Ariel's sub-Uranian point [4].

Procedure and observations: A tectonic map of Ariel was constructed using selected enlargements of Voyager 2 images and the polar stereographic map provided by the USGS. Only features which occur on the map and could be confirmed by the images of Ariel were considered in the analysis. Resolution of the images limited the analysis to slightly less than the approximate 2/5 of Ariel's surface covered by Voyager 2. The giant chasma (Kachina Chasmata, Sylph Chasma, etc.) were analyzed separately because of the disproportionate effect they would create on the statistical base. The positions of the tectonic features were recorded and their lengths and angles from azimuthal north were calculated and sorted into 5° increment bins. Both lengths and frequency of occurrence vs. azimuthal north were plotted in a method similar to Moore *et al.* [5] and Thomas [6].

Figure 1 shows a sample of the data, for the cracks seen from longitude 0° to -90°. Peaks near the 55°and 145° bins occur for all longitudinal groupings, the precise location of the peak varying with change in longitude. Few tectonic features are oriented within 15° of the north-south direction. Furthermore, few tectonic features occur in the longitudes of the sub-Uranian point (around 0°longitude) or within 20° of latitude from Ariel's south pole. Several very large chasma and large resurfaced areas occur in the equatorial region. In addition, the distribution of the major chasma cracks is such that they appear to be selected from within the distribution of tectonic lineaments, suggesting that these cracks are merely enlarged versions of the smaller lineaments. Most of the major chasma are oriented at roughly 80° from north.

Comparison with theory: Melosh [4] considered the collapse of a tidal bulge on Earth's moon and calculated the resulting stress which should result from such a collapse. He predicted that the highest stresses should occur at the sub-planetary point and at points on the equator 90° and 180° from that point; that around the sub-planetary point should be a region, roughly 30° in radius, dominated by thrust faulting; that about each pole should be regions, roughly 20° in radius, dominated by normal faulting; and that the rest of the planet should exhibit strike-slip faulting. Assuming that the lithosphere is made of uniform, isotropic material, the direction of the strike-slip faults will be at a 45° angle from the direction of the stress.

A simple cartoon illustrating the direction of stresses predicted by this model was given in [4]; an adaptation of this figure is shown in figure 2. Also in figure 2, we illustrate simplified rose diagrams. The cumulative lengths of cracks in the most prevalent orientations are given for 30°x 30° sections of the surface where the coverage was most complete. Melosh predicted the stress fields would be symmetric around the sub-Uranian and anti-sub-Uranian points. Thus we have added, with dotted lines, the rose diagrams for latitudes -90° to -120° and -120° to -150° onto the blocks from -60° to -90° and -30° to -60°.

Several trends in agreement with the predictions can be seen. First, few cracks are seen near the pole where Melosh predicts normal faulting. The polar regions are predicted to have the lowest stresses,

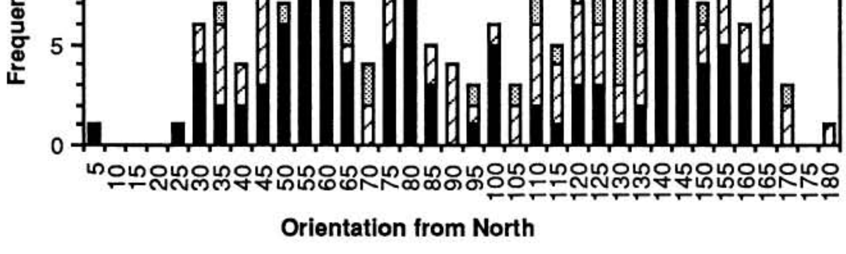

Figure 1. Frequency of tectonic feature orientations.

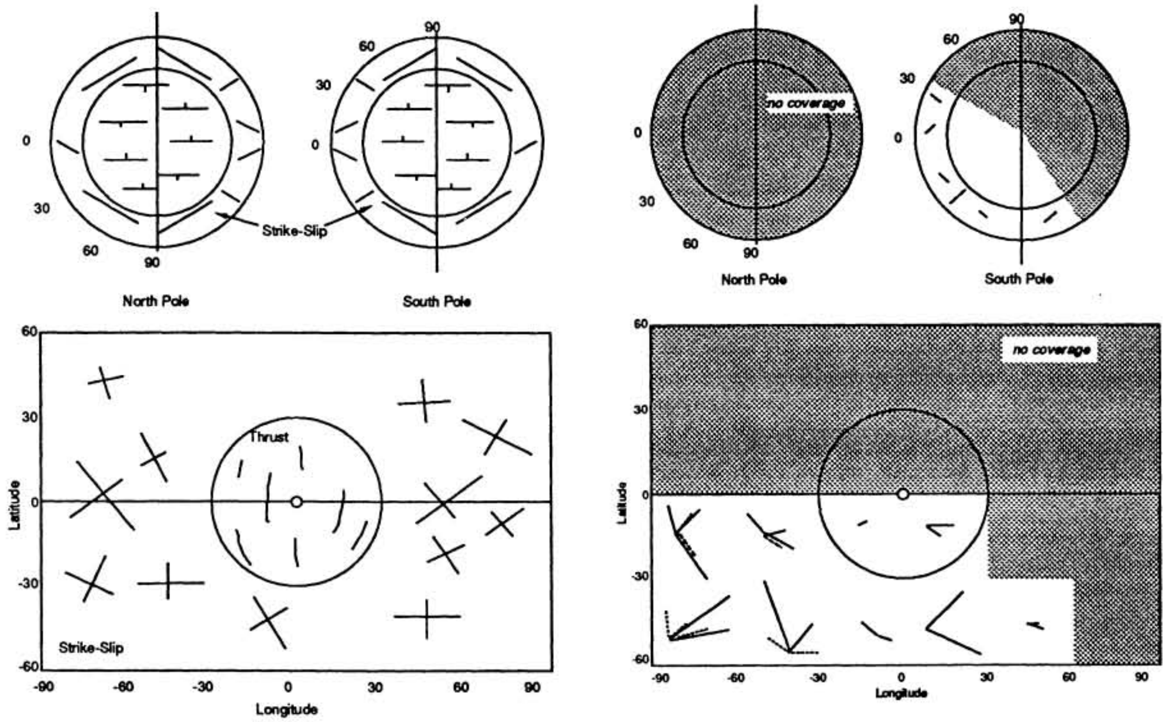

Figure 2. The cartoon on the left, adapted from Melosh [4], indicates his predictions for the orientation of tectonic features due to the collapse of a tidal bulge. On the right is a similar map showing simplified rose diagrams of the major trends of tectonic cracks on Ariel. Similarities between the two maps include the strike-slip faulting in the polar map, which ends at roughly 20° from the pole (where Melosh predicts normal faulting to begin). Likewise, note the 45° faulting at equatorial latitudes west of the sub-Uranian point. However, some cracks in other regions, notably southwest of the sub-Uranian point, do not follow his predicted trends.

and the icy lithosphere may be less likely to fail under normal faulting conditions. Next, the strike-slip faults just south of 60°S (seen in the polar map) mimic closely the directions predicted by Melosh. In mid-latitudes, the rose diagrams indicate many cracks at a roughly 45° angle to the direction of the sub-Uranian point. And finally, the regions closer to the equator show most cracks oriented roughly 45° from north, in agreement with his conclusions. Few cracks are seen around the sub-Uranian point; this region is, in fact, heavily resurfaced and several major chasms (including Brownie and Pixie Chasma, and the Sprite and Leprechaun Valles) have obliterated most of the older features in this area. Likewise, Sylph and Korrigan Chasma south of this region may have obliterated earlier tectonic features, so that fewer cracks are seen now at southern latitudes near longitude 0°.

However in the region from 30°S to 60°S, from longitude -30 to -90 (but *not* seen in the symmetric areas from -90° to -150°) there is significant cracking at an angle 45° from north, roughly *parallel* to the stress direction predicted by Melosh. It seems unlikely that these cracks were formed by the stress accompanying the collapse of a tidal bulge. Instead, they may be associated with the stresses accompanying the formation of Kewpie Chasma, which also is oriented in this direction and which ends in this region.

Implications for evolution: The existence of a global tectonic pattern and its agreement with theory strongly support the idea that Ariel's evolution involved tidal distortion. Such distortion could generate the energy necessary to melt and resurface most of Ariel [3]. Breaking of the tidal resonance would result in the collapse of the tidal bulge and the emplacement of the global tectonic pattern. Expansion due to freezing would then occur along the previously emplaced cracks. The major chasma were probably formed early in this cooling stage, by large scale extensional faulting followed by fissure-style viscous ice volcanism [2]. Tectonic features which deviate from theoretical tidal collapse patterns may have resulted from extensional stresses in the lithosphere during this period.

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