Miranda Geology and Tectonics: A Non-Catastrophic Interpretation;
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Miranda, the smallest of the major Uranian satellites (Radius = 242 km), is surprisingly the most diverse, exhibiting extensive fractures, canyons, and surface flooding in addition to the expected heavy cratering. Initial impressions of Miranda suggested that the different terrains might be the result of a few large fragments (some rotated to show internal layering) that had re-coalesced at low velocity after a catastrophic impact rupture of a primordial "Miranda" (1,2). The analysis presented here indicates that a less catastrophic interpretation is perhaps more plausible.

General Geology. The visible surface of Miranda (slightly less than half) consists of three dark, diverse terrains (youngest in the Uranian system) imbedded in an otherwise continuous unit of bright, heavily cratered terrain (the oldest surface in the Uranian system, see ref. 3). Craters and tectonic structures on the old cratered terrain fall into two morphology classes: fresh and "softened" or mantled (edges and corners rounded), with virtually nothing in between. A layer of higher albedo material on the order of a kilometer thick occurs in the walls of craters and the tops of scarps in many places, and thus probably represents the immediate subsurface layer over most of the visible hemisphere. The mantling effect appears to be a discreet episode and may be the result of the emplacement of the light layer. Some limited areas of dark material exposed by fresh craters existed prior to the mantling event. The dark material of both Inverness Corona (the "Trapezoid" of reference 1) and Arden Corona (the "Banded Ovoid") appears to be fluid material emplaced on the floors of pre-existing depressions. The Inverness depression has square edges and straight sides and is probably entirely tectonic. The Arden depression on the other hand is interpreted as a modified impact basin about 300 km across (4). Evidence of volcanic emplacement of the materials in these two coronae include lobed edges, a rippled texture reminiscent of successive lava flows, irregular (non-impact) depressions, and flows of dark material over older topography.

Tectonics. Numerous fractures and canyons ranging from inconspicuous to spectacular cross the face of Miranda. The fractures trend in two directions at nearly right angles to each other: 160 to 340E (best example is the 340° chasma bounded in part by the Verona Rupes) and 50-220E (best example is the SP Tangent chasma parallel to the "short" side of Inverness Corona). Fractures along these two trends form the sides of Inverness Corona. The fractures occurred over a period of time: some are mantled (e.g. Argiers Rupes) and some are quite fresh (e.g., Verona Rupes). The canyons are graben or rift-like in structure, frequently with multiple terraces and scarps between rim and floor. A horst-and-graben structure is apparent in the SP Tangent chasma, where a cratered terrain-topped horst 2 to 4 km wide and about 40 km long dominates. These features are probably extensional in origin and represent a 5% to 6% volumetric expansion of the satellite interior. The inferred expansion is fairly evenly split between mantled and fresh scarps. The post-mantling scarps have largely appeared along the same trends as the pre-mantle scarps, implying continued movement along old deep-seated fractures. In addition, the 340° scarp family appears to have "borrowed" concentric trajectories around the Arden Depression, probably along concentric terrace fractures. The Elsinore Corona (the "ridged Ovoid") is also heavily affected by tectonics, again largely sub-parallel to the two dominant fracture directions. Cratered terrain appears to be broken up by

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tectonic processes, particularly in the corner bordering Silicia Regio. Several ridges, particularly those near the terminator, appear structurally similar to the SP Tangent horst. The structure as a whole bears resemblance to the floor of the SP Tangent chasma. However, much of the surface material appears volcanic: most of the border consists of a raised, lobed edge extending over pre-existing cratered terrain with tongues of material extending into, and in one case poised on the lip of, bordering craters. Several craters are cut by ridges of material that show no evidence of a displaced crater rim. Hence the ridges cannot be entirely tectonic. The smooth materials of Elsinore Corona thus appear to be the result of extrusion of fairly viscous materials along the main faults of a tectonically fractured valley reminiscent of a dike swarm.

Inferred Geologic History. The earliest era visible in Miranda's present geology is one characterized by a uniformly heavily cratered surface. Hypothetical disruptions prior to this era are neither required nor excluded; they simply are not seen. This first era was presumably near the end of accretion. The interior underwent radioactive heating with concomitant expansion and surface fracture, establishing the initial fault systems. The Inverness tectonic depression formed during this time. Some melting (possibly by impact) occurred, forming the sub-mantle dark patches. The next major event was the formation of the Arden Basin and the mantling event. The two events may be linked, the mantling material possibly consisting of direct or indirect (ejected to orbit and re-accumulated) ejecta. Though the Arden Basin is large, it is short by a large amount of disrupting Miranda. In addition to ejecta and secondary cratering, a new basin-concentric set of fractures was formed. After the impact, cratering tapered off while the interior continued to heat, resulting in continued expansion (with new movement along both basin and pre-basin fracture systems) and flooding. The flooding of Arden and Inverness was nearly complete before the bulk of post-mantling expansion occurred since there are only a few examples of dark material flowing on top of the fractures. Volcanic activity also formed much of the smooth material of Elsinore Corona at this time, flowing up through pre-existing fractures (modified by Arden antipodal shock effects?). The last era, extending to the present, saw only minor cratering.

Thermophysical Considerations. The tectonics and resurfacing on Miranda are evidence of extensive heating and melting in the interior. The heat source for such activity is an obvious problem. For H_2O ice and rock, the internal temperature rise due to radioactive heating is only a few tens of degrees. But if the ice is instead a methane clathrate, with a thermal conductivity an order of magnitude smaller than H_2O ice at near-surface temperatures in the Uranian satellites (5), then radioactivity alone is enough to drive temperatures above the ≈ 174K necessary to initiate ammonia-water melting in Miranda's core. Thus, if clathrate is present, some resurfacing may occur on Miranda, consistent with observation. Preliminary calculations also indicate that if Miranda's canyon systems initiate at the bottom of a lithosphere as the furrows on Ganymede, then the inferred thermal conductivity of Miranda's lithosphere is 3-4 times smaller than the conductivity in Ganymede's presumably H_2O ice lithosphere - into the range of clathrate conductivities. **References** 1. Smith B.A. et al. (1986) Science 233, 43-64. 2. Gore R. (1986) Nat. Geographic 170, 178-195. 3. Strom R.G. (1987) this volume. 4. Croft S.K. (1987) P.G.G.P.I. Reports 1986, in press. 5. Andersson P. and R.G. Ross (1983) J. Phys. C: Solid State Phys. 16, 1423-1432.