FLUID VOLCANISM ON MIRANDA AND ARIEL, Paul M. Schenk, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109

The intermediate-sized Uranian icy satellites Miranda and Ariel have been extensively resurfaced, but the nature and composition of the resurfacing materials remains uncertain. On Miranda, resurfacing occurs in the three banded ovoid regions (coronae) consisting of ridged and grooved resurfaced material, while on Ariel it occurs as flat plains topographically restricted to graben or depressions. In the case of Miranda, a hypothesis for the development of the coronae is the catastrophic breakup and reassembly hypothesis [1]. Stresses generated as a result of mantle convection driven by density anomalies (either reassembled fragments of a proto-Miranda, or low density rising diapirs) have been modeled [2], resulting in either compression or extension over the source. Ridges and other features within coronae could be either compressional folds or thrusts or extensional graben and ridges. Alternatively, they could be complex volcanic constructs [e.g., 3]. Some of the features on Ariel may have been emplaced in the solid-state [4]. No consensus has been reached on the tectonic/volcanic origins or on the physical states of any of these features on Miranda or Ariel, however. In this paper I examine the relative importance of tectonics/volcanism in the resurfacing of Miranda and Ariel, focusing on the morphology, topography and distribution of such features on the surface, and what can be determined about composition or state.

MIRANDA. Two types of volcanic units have been identified on Miranda [5]. A narrow band-like unit ~10 km across can be traced for at least 250 km along the south margin of Elsinore Coronae (Fig. 1). It is separated from the main part of Elsinore by a narrow strip of preserved cratered plains. It crosses several crater-like depressions but does not fill them and maintains a constant width, although its apparent thickness varies from a few hundred meters to ~1.7 km. This band is interpreted as a linear volcanic ridge emplaced on top of preexisting cratered plains. A second type of volcanic unit are ridges up to 500 m high, 10 km wide and 50 km long, with narrow crest grooves (Fig. 2). These are not as flat-topped as the band described above but are very similar to ridges on Ariel (Fig. 2; which have been ascribed to solid-state volcanism [4]). One of these ridges crosses a depression, maintaining constant elevation, consistent with a volcanic interpretation. Apparently most of Elsinore Coronae is constructed of coalesced units similar to those described above, which can be best discriminated near the margins of Elsinore where construction is incomplete. The existence of numerous linear source fractures throughout Elsinore is suggested by lineaments in cratered plains parallel to the edge of Elsinore. This interpretation requires extension throughout the outer zone of Elsinore, which would be consistent with a rising diapir in the 'sinker' model of [2].

ARIEL. In contrast to Miranda, resurfacing on Ariel is generally confined to wide linear valleys 40-100 km wide and 3-to-4 km deep (usually interpreted as graben), and are referred to as 'flood plain' units. With one exception (the ridge unit of [4], this material is relatively smooth and covers large areas. The resurfaced valley floor is usually broadly convex, bowed upward by ~1 km (Fig. 3). The floor is occasionally separated from the valley walls by a narrow groove [1] ~1 km deep, with a narrow groove up to 500 m deep running down the center of some valleys. The central groove could be due to coalescence of two solid-state flows emanating from the central regions of the valley [4], but the convex valley floor suggests viscous relaxation (triggered by high heat flows in the region) or continued intrusion beneath and uplift of a chilled surface layer could have caused fracturing along the center of the arch. Stresses in such a bending layer (1 km thick for example) could be on the order of 50 to 100 bars. The flood plains unit also form an irregularly shaped plain roughly 100 by 100 km wide, centered near 45° S, 35° W. Here it is more nearly at the elevation of the cratered plains but is also defined by either a scarp or a narrow groove. The stubby margins of the flood plains and ridge units indicate that they formed from materials with a significant viscosity [1].

COMPOSITION AND STATE. In principal, the topography of the ridge features can be used to estimate material parameters. Using a newtonian creep model [6] a viscosity of $10^{16}$ Pa was estimated for the ridges on Ariel [4]. It was suggested that the ridges were emplaced as water ice in the solid state, flow being facilitated by interstitial volatile phases [4]. There are several problems with the application of analytical models such as [6]. In terrestrial applications, it overestimated viscosities by 4-to-6 orders of magnitude [6-7], primarily due to assumptions of flow rates and a newtonian flow law, and a failure to account for the formation of both a rigid outer skin and a debris apron around the foot of the flow. Some mass-wasting will probably have modified the shapes of the ridges as well. The results of [4] are thus more appropriate to the whole body part way through the freezing process. Viscosities of the order $10^{12}$ Pa or less may be more appropriate. Viscosities of partially crystallized NH$_3$-H$_2$O melts have been measured experimentally at $10^4$ Pa or higher for crystal contents of 10-20% [8]. If viscosity and
yield strength increases with crystal content, and decreases with temperature in a manner similar to terrestrial silicates [e.g., 7], then extrusion of such a partially congealed fluid might explain the observed morphology without 'solid state' flow. Extrusion of such a low-T melting fluid (Tm=175 K) would also be consistent with the lack of evidence for the high heat flows necessary for the melting of pure water ice, based on the lack of viscous relaxation in craters on Miranda (Fig. 4). The 250 km long flow on Miranda (Fig. 1) also has a lower reflectance (~0.32) than surrounding cratered plains (0.37-0.40), consistent with differing compositions. A simple bingham model, assuming extrusion of a viscous material which piles up at the source until some yield strength is exceeded [7,9], gives yield strengths of ~10^2 bars. This is similar to values estimated for lunar basalt flows and common terrestrial lava flows [e.g., 10]. Topographic profiles derived from this model do not fit the observed shapes of flows on Miranda and Ariel very well, however. Evidence for a non-pure water ice composition may come from the presence of a number of visously relaxed craters in the plains unit on Ariel [11]. The amount of relaxation is consistent with a (post-cooling) surface viscosity of 10^{22-24} Pa for relaxation in a 1-2 km thick layer (10^{24-26} Pa for relaxation in a uniform half-space [11]). Such extremely low viscosities (given the surface temperatures) are more consistent with a NH_3-H_2O rather than a pure water ice composition [11].