RIDGE AND TROUGH TERRAIN AND THE ORIGIN OF MIRANDA'S CORONAE;
***Robert Pappalardo and Ronald Greeley**, Department of Geology, Arizona State University, Tempe, Arizona 85287*

Tectonic and magmatic models have been investigated for the formation of sets of subparallel ridges and troughs, termed ridge and trough terrain (RTT), observed on Miranda, and the results indicate that most of Miranda's ridges and troughs formed in extensional-tectonic environments, with magmatism as a common association [1]. Normal faulting models are favored based upon the morphologies, geologic settings, and associations of ridges and troughs as well as the relative ease of extensional failure of Miranda's crust [2]. Compression, if involved in shaping RTT, was of local extent. The results shed light upon the origin and evolution of Miranda's three coronae, indicating that mantle upwelling was probably the most important contributor to the formation of the coronae [3]. Despite this common thread, however, the origin and evolution of each corona may have been in many ways unique.

Arden Corona. Surrounding Arden's Inner Region of smooth terrain is the Outer Region composed of a Central Band that exhibits ridges and troughs of uncertain origin and the Southeastern Band containing ridges and troughs created by domino-style normal faulting. Arden may have originated as an impact basin, subsequently modified by volcanism and tectonism [4]. Basin formation may have fractured and thinned the crust to a great extent, permitting Inner Region volcanism, but the timing and process of Outer Belt formation may be different. Consistent with this idea, Arden's Southeastern Band shows a relatively fresh morphology, indicating relatively late tectonic activity at the corona's periphery.

Beginning from the premise that a large impact initiated Arden's evolution, an evolutionary scenario is proposed that could account for the corona's present morphology. Modeling of the stress field resulting from internal flow induced by relaxation of an icy satellite basin shows that the most commonly predicted flow pattern induces near-surface stresses that are extensional near the crater center, compressional in the region straddling the crater rim, extensional at roughly twice the crater radius, and extensional but relatively small near the basin antipode [5]. Comparison of this stress pattern has been made to mirandan geomorphology observed radially from the presumed center of Arden Corona toward Elsinore Corona, considering the extent and inferred formational stress of each region. Excepting Inverness Corona, the possible independent origin of which is discussed below, the comparison is favorable if Arden's Central Band is of compressive origin. Conversely, the comparison argues for a compressional paleo-stress in this band if we accept the likelihood of Arden as a relaxed and modified impact site. Predicted stress magnitudes of $\lesssim$ a few bar [5] are not large enough to create deep faults on Miranda, but could cause motion on pre-existing structures to depths $\lesssim$ a few km if the shear strength of Miranda's crust is very small [2]. A large impact into a thin, weak lithosphere can produce multiple normal faults concentric to the resultant crater [6], and such fractures could have been reactivated by relaxation-induced stresses to create ridges and troughs of the Arden Outer Belt. Thus, formation of the hypothetical Arden Basin with possible concentric fractures, plus subsequent viscous relaxation, fracture reactivation, and Inner Region resurfacing could have shaped Arden to its present form.

Inverness Corona. At least four observations suggest that Inverness represents the mirandan equivalent of a rift zone. First, extensional-tectonic bands, expressed as cross-sectionally asymmetrical ridges and troughs that likely originated as domino-style fault blocks, bound three sides of Inverness. Second, two RTT types identified within Inverness are believed to have had a normal-faulting origin as graben and domino-style tilt blocks. Third, topographically high shoulders of cratered terrain bound the north and western edges of the corona, likely due to isostatic rebound resulting from adjacent rifting. Fourth, flood volcanism likely occurred within Inverness, and volcanism may have contributed to the formation of an unusual RTT type in northwestern Inverness which may have originating as striae on diverging lobes of a late-stage viscous extrusion [7].

The rift zone analogy presents a simple explanation for the seemingly unusual shape of the Inverness chevron. Large-scale domal uplifts usually produce three rifts that diverge from the crestal region at similar angles; two arms of such terrestrial triple-rift junctions typically become zones of normal faulting and volcanism, while activity halts on the third arm [8]. On Miranda, the two branches of the Inverness chevron are believed to mark sites of ancient normal faulting and volcanism, and both arms were likely active at similar times. Verona Rupes, which joins the chevron at a common apex, shows no volcanism and may represent the failed arm of a triple-rift junction. If so, the apex of the chevron marks the site of ancient deep upwelling that triggered doming and active rifting of the mirandan crust.

Careful examination of the topography data of [9] shows that the dark apex of the Inverness chevron stands high relative to the light unit to the north and east. This relationship may have resulted from a sequence of normal faulting of the presumably older dark unit along both active rift arms with relative downdrop of the northern and eastern blocks, followed by infill of the chevron-shaped rift depression by a mobile light material that now forms the bright chevron. In this "hot spot" model of northern Inverness's evolution, migration of a mantle plume toward the southwest over time could account for an apparent shift of volcano-tectonic activity from the presumably oldest area of activity, where the Inverness chevron intersects Verona Rupes, to beneath the corona's northwest region, where ridges and troughs appear to be relatively young and may owe their origin to late-stage extrusion. While terrestrial rifting is invoked here as an analogue to mirandan rifting, "plate tectonics," which involves the physical separation of crustal plates with formation of newer crust in between, is not suggested to have operated on Miranda; instead a single-plate rifting model is invoked [1].

In summary, the history of Inverness probably began with mantle upwelling producing crustal doming and active rifting, creating the Verona-chevron triple junction. Normal faulting and fissure volcanism ensued in the corona's inner region, where extension, crustal thinning, and volcanism were most intense, producing the bright chevron and short-wavelength ridges and troughs of the Inverness Inner Region. The primary hot spot migrated during this time toward its final position beneath northwestern Inverness. Extrusion there might have created an unusual RTT as striae on diverging extruded lobes while causing local compression of the northwest corner of Inverness, creating folds there and in adjoining cratered terrain. Normal faulting of thicker crust surrounding the Inner Region created the relatively large wavelength ridges and troughs of the Inverness Outer Belt, increasing the lateral dimensions of the corona; however, the degree of extension and availability of magma were not great enough to permit volcanism there.

Elsinore Corona. Adjacent to the Elsinore Inner Region of intersecting ridges and troughs, the Outer Belt consists of the north-south trending "Grooved Band," simply explained as regularly-spaced grabens in a volcanically resurfaced rift, and the east-west trending "Ridged Band," containing the prominent "Elsinore Ridges" [10]. Diapirism or fissure volcanism may have shaped the Elsinore Ridges [10, 11, 4]. If so, they may have formed as viscous linear extrusions which formed a chilled carapace that inflated as magmatism continued beneath. We find such a magmatic origin likely only in combination with normal faulting. Elsinore Ridges may have formed within grabens, in some cases only partially resurfacing them to leave bounding troughs, in a manner analogous to that proposed for some ridges on Ariel [12]. This style of volcanism only in the Ridged Band suggests extrusion of a more viscous magma compared to that which resurfaced the Grooved Band, and its eruption may have been aided by a greater degree of extension and crustal thinning of the Ridged Band.

Elsinore's Outer Belt represent further expressions of mirandan rifting, as the constituent bands have experienced volcanism and extensional tectonism. Elsinore's position opposite the candidate Arden basin invites speculation that disruption due to concentration of seismic energy at the impact antipode [13] and concentrated fracture near the antipode of the viscously relaxing basin [5] might have created an initial region of fracture and volcanism where large-scale upwelling ultimately became concentrated.

Implications for general corona evolution. The preceding suggests both similarities and differences in the formation and evolution of Miranda's three coronae. All are of volcano-tectonic origin, with extensional stresses being predominant, suggesting that mantle upwelling was involved in their formation. Arden's activity may have been triggered by an initial impact that induced relaxation flow, Inverness probably developed over an upwelling mantle plume, and Elsinore may have been created by an upwelling plume localized by Arden's formation. All three coronae appear to have grown outward over time from an initial core of tectonic deformation and volcanism. Both active and passive rifting probably contributed to corona development, as formation of core regions by active rifting above large-scale diapiric upwellings might have complemented satellite expansion in triggering passive formation of the outer belts. The squared shape of each corona likely reflects a satellite-wide pattern of ancient near-orthogonal structures which influenced the development of later tectonic structures.

[1] Pappalardo and Greeley (1992), in preparation. [2] Pappalardo and Greeley (1991), *LPSC 22nd (Abstr.)*, 1021. [3] Johnson *et al.* (1987), *Sci. Amer.*, *256*, 48; McKinnon (1988), *Nature*, *333*, 701. [4] Croft (1992), *Icarus*, in press. [5] Thomas and Squyres (1988), *J. Geophys. Res.*, *93*, 14919. [6] McKinnon and Melosh (1980), *Icarus*, *44*, 454; Melosh (1982) *J. Geophys. Res.*, *87*, 1880. [7] Anderson and Fink, *Geol. Soc. Am. Bull.*, submitted. [8] Burke and Dewey (1973), *J. Geophys. Res.*, *81*, 406. [9] Wu *et al.* (1987), Topographic map of Miranda, U.S. Geological Survey. [10] Pappalardo and Greeley (1989), *LPSC 20th (Abstr.)*, 820. [11] Schenk (1991), *J. Geophys. Res.*, *96*, 1887. [12] Jankowski and Squyres (1988), *Science*, *241*, 1322. [13] Watts *et al.* (1991), *Icarus*, *93*, 159.