field morphology (Fig. 3) to the extent that sheetlike flow fields (Types 1, 2) occur at lower elevations than digitate flow fields (Types 3–6). If digitate flow fields represent multiple individual eruptions of lower volume than sheetlike flow fields, then the fact that sheetlike flow fields appear to have been erupted at lower elevations is consistent with the above predictions. These results are only preliminary, however, and do not represent the entire population of large flow fields or take into consideration the possibility of postemplacement elevation of topography.

In addition, preliminary results indicate that topographic slope has little control on flow length or morphology (Figs. 4 and 5). Given the variation in abundance of discrete flow lobes, flow distribution, and downstream divergence among the flow field types, one might have expected a stronger correlation between flow morphology and slope. It is possible that small-scale variations in local slope beyond the resolution of our data may be associated with variations in flow field morphology.

We are currently extending this analysis to the entire population of large-volume flow fields on Venus and are further investigating implications for their origin and emplacement mechanisms.

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WRINKLE RIDGES ON VENUSIAN PLAINS: INDICATORS OF SHALLOW CRUSTAL STRESS ORIENTATIONS AT LOCAL AND REGIONAL SCALES. George E. McGill, Department of Geology and Geography, University of Massachusetts, Amherst MA 01003, USA.

The plains regions of Venus exhibit a complex array of structural features, including deformation belts of various types, wrinkle ridges, grabens, and enigmatic radar-bright linears [1,2,3]. Probably the most pervasive of these structures are the wrinkle ridges, which appear to be morphologically identical to their counterparts on the Moon and Mars. Almost all workers agree that wrinkle ridges result from horizontal compressive stresses in the crust; they either are explained as flexural fold structures, or alternatively as scarps or folds related to reverse faults [3-8]. Wrinkle ridges generally are narrow, have small amplitudes, and commonly are closely spaced as well, characteristics that imply a shallow crustal origin.

If wrinkle ridges are due to horizontally directed compressive stresses in the shallow crust, as generally has been inferred, then the trends of these features provide a means to map both local and regional orientations of principal stresses in the uppermost part of the venusian crust: maximum compressive stress is normal to the ridges, minimum compressive stress is normal to the topographic surface, and thus the wrinkle ridge trends trace the orientation of the intermediate principal stress. Because there are few plains areas on Venus totally devoid of wrinkle ridges, it should be possible to establish a number of interesting relationships on a near-global scale by mapping the trends of wrinkle ridges wherever they occur. The present study is addressing three questions: (1) Do the trends of wrinkle ridges define domains that are large relative to the sizes of individual plains regions? If so, can these domains be related to large-scale topographic or geologic features? (2) Are regional trends of wrinkle ridges affected by local features such as coronae? If so, is it possible to determine the relative ages of the far-field and local stresses from detailed study of trend inheritance or superposition relationships? (3) What is the relationship between wrinkle ridges and the larger ridges that make up ridge belts?

Mapping completed as of May 1992 includes parts of Lavinia, Guinevere, Sedna, Tinatin, and Aino Planitiae. Detailed maps of wrinkle ridge trends have been prepared by systematically displaying all of the 56 tiles making up each C1-MIDR on CDROM on a high-resolution monitor connected to a SUN SPARCstation 2. The observed trends are then plotted on the corresponding hard copies of the full MIDRs. The detailed maps are used to generate more generalized plots of wrinkle ridge trends that are digitized and combined for presentation as a global display.

The patterns defined by wrinkle ridge trends vary widely. The simplest cases occur where the ridges all have about the same trend over a very large area, as is the case for much of that portion of Lavinia Planitia imaged on C1-MIDR45s350 [3]. At many localities, however, there are two or even three definable sets of wrinkle ridges with clearly distinct trends. In places, ridges of one set curve into a merging relationship with another set; in other places, one set seems to truncate another; in still other places, sets cross each other, commonly without clear clues concerning relative age. At a few localities, the pattern made by wrinkle ridges can be described as "cellular"; in such places, it is difficult to distinguish any dominant sets defined by trend. Cellular patterns may well indicate localities where the horizontal compressive stresses in the shallow crust are very nearly isotropic. Preliminary results suggest at least partial answers to the three questions posed above.

Trends of wrinkle ridges do define domains that occupy a large fraction of the area of a single C1-MIDR or large fractions of two or more adjacent C1-MIDRs. The boundaries between these domains commonly are regions occupied by complex ridged terrain or elevated young volcanic terrains, but some boundaries do not relate to any obvious geologic or topographic feature. These more enigmatic boundaries are interesting because they may define more subtle regional crustal features. Clearly, wrinkle ridges must be mapped over a substantial fraction of the planet before the large-scale domainal characteristics can be fully understood.

The regional trends of wrinkle ridges that define the large-scale domains clearly are affected by at least some local features, especially coronae. Part of the concentric structure that characterizes coronae consists of closely spaced ridges that are morphologically indistinguishable from wrinkle ridges. The relationships commonly are complex, but in a number of cases it appears as if the regional set of wrinkle ridges both cuts across a corona and is warped into parallelism with the concentric corona structure. A good example occurs where a strong regional set of wrinkle ridges trending slightly north of east interacts with concentric structures related to Heng-O. Some wrinkle ridges parallel to the regional set cross the eastern margin of Heng-O and extend into the center of the structure. Along the northeastern margin of Heng-O the regional wrinkle ridges bend to merge into the corona concentric structure, but also appear to be in part overprinted by these concentric structures. Along the northern and southern margins of Heng-O the regional set of wrinkle ridges appears to be simply enhanced. These relationships suggest that the stresses associated with the formation of Heng-O interacted with far-field stresses; Heng-O formed in part at the same time that the far-field stresses were active, in part later than the far-field stresses. At least some smaller coronae show similar geometric and kinematic relationships with regional wrinkle-ridge sets, but much more work needs to be done before a definitive conclusion can be reached concerning relative ages.

Detailed work in Lavinia Planitia has focused attention on an apparent paradox. Using stratigraphic relationships that are clearer in the southwestern part of Lavinia Planitia than in most places, it can be shown that many of the ridge belts are older than the areally dominant plains materials on which wrinkle ridges are developed [3]. This relationship indicates that the wrinkle ridges are younger than the ridge belts, and thus suggests that locally similar trends of ridge belts and wrinkle ridges must be explained as due to stress orientations that did not change with time. Nevertheless, there are places in the same general area where it appears as if wrinkle ridges grade along their lengths into ridges of a ridge belt. Taken at face value, this latter relationship suggests that both structures were formed by the same stress field, and presumably at the same time. Because the local relationships send conflicting signals concerning the geometric and kinematic kinship of wrinkle ridges and ridge belts, it is hoped that a more regional perspective might be helpful. At the scale of the entire planitia there is not a consistent relationship between the trends of wrinkle ridges and the trends of ridge belts. This preliminary result suggests that ridge belts and wrinkle ridges are different features. Local similarities in trend and the cases where one seems to grade into the other can be explained by inferring temporal coherence of stress field or by some form of geometric inheritance.

Finally, even though wrinkle ridges appear to be relatively young features, they are evidently older than most or all fresh impact craters. This inference is based mainly on the apparent obliteration of wrinkle ridges by crater ejecta, although this may not be a foolproof criterion (wrinkle ridges might not form in ejecta materials, or might be invisible if present because of no roughness contrast). A single example of a flow emanating from an impact crater being ponded by a wrinkle ridge has been found, and this relationship is considered to be good evidence of relative age.

Wrinkle ridges are important structures on planetary surfaces because they are so common and because they provide useful clues to stresses in the shallow crust. Because so much of Venus is plains, wrinkle ridges are especially useful for inferring crustal evolution on that planet.

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ESTIMATES OF ELASTIC PLATE THICKNESSES BENEATH LARGE VOLCANOS ON VENUS. Patrick J. McGovern and Sean C. Solomon, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge MA 02139, USA.

Introduction: Magellan radar imaging and topography data are now available for a number of volcanos on Venus greater than 100 km in radius. These data can be examined to reveal evidence of the flexural response of the lithosphere to the volcanic load. On Earth, flexure beneath large hotspot volcanos results in an annular topographic moat that is partially to completely filled in by sedimentation and mass wasting from the volcano's flanks (see [1,2]). On Venus, erosion and sediment deposition are considered to be negligible at the resolution of Magellan images [3]. Thus, it may be possible to observe evidence of flexure by the ponding of recent volcanic flows in the moat. We also might expect to find topographic signals from unfilled moats surrounding large volcanos on Venus, although these signals may be partially obscured by regional topography. Also, in the absence of sedimentation, tectonic evidence of deformation around large volcanos should be evident except where buried by very young flows.

We have found two examples to date of volcanos with strong evidence for moat formation and infilling by flows. Radar images of Tepev Mons, a volcano about 125 km in radius near the southwestern corner of Bell Regio, reveal a bright flow unit draped around the northern and western flanks of the volcano. An unnamed volcano at 10°N, 275°E (southwest of Beta Regio) exhibits both circumferential flanking flows and lateral spreading of originally radially trending flows. The distal edges of these flows terminate about 240–260 km from the summit. The edges of these flows form an arc of greater than 120° to the north and west of the volcano.

Method: We use analytic solutions in axisymmetric geometry [4] for deflections and stresses resulting from loading of a plate overlying an inviscid fluid. Solutions for a set of disk loads are superimposed to obtain a solution for a conical volcano. The deflection of the lithosphere produces an annular depression or moat, the extent of which can be estimated by measuring the distance from the volcano's edge to the first zero crossing or to the peak of the flexural arch. Magellan altimetry data records (ARCDRs) from data cycle 1 are processed using the GMT mapping and graphics software [5] to produce topographic contour maps of the volcanos. We then take topographic profiles that cut across the annular and ponded flows seen on the radar images. By comparing the locations of these flows to the predicted moat locations from a range of models, we estimate the elastic plate thickness that best fits the observations, together with the uncertainty in that estimate.

Results: Figure 1 shows two cross sections through Tepev Mons. The areas covered by annular flows are marked with arrows. Figure 2 shows deflections calculated analytically for a conical load of height 10 km and radius 150 km for elastic plate thicknesses T_e of 10 km and 20 km. Arrows denote the predicted approximate extent of a moat due to loading in each model. Note that for the analytic solutions, increasing the elastic plate thickness increases both the maximum depth and the radial extent of the predicted moat. The model in Fig. 2a matches the northwestern cross section in Fig. 1a. The area of flows in Fig. 1b is somewhat larger in radial extent and is better matched by the predicted moat in Fig. 2b. Figure 3 shows a cross section through the volcano at 10°N, 275°E. Figure 4 shows calculated deflections for a conical load of height 5 km and radius 250 km, for elastic plate thicknesses of 10 and 20 km. The extent of annular flows is better matched by the smaller thickness.

Discussion: These two volcanos are apparently atypical of large volcanos on Venus in that both topography and flow morphology suggest the existence of a flexural moat. On other large shield volcanos such as Sif Mons and Sapas Mons, topographic evidence of a moat is lacking, and no flows that have convincingly ponded in annular moats can be identified. Large volcanos that form on or near large rift zones (such as Maat Mons, Ozza Mons, and others) also lack topographic evidence of a flexural moat. It should be noted that as altimetry data and stereo imaging from later cycles become available, coverage will improve, gaps will be filled in, and it may be possible to identify topographic signatures of moats that have eluded our search to date.

In contrast to Tepev Mons and the construct at 10°N, 275°E, most large volcanos on Venus are generally characterized by fractures and flow units that have dominantly radial orientations. Given this observation and the assumption that lithospheric flexure has occurred, then the moats must be filled or covered. Mass wasting,