FAULT TYPE PREDICTIONS FROM STRESS DISTRIBUTIONS ON PLANETARY SURFACES: IMPORTANCE OF FAULT INITIATION DEPTH. Matthew P. Golombek, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, Texas 77058

Geophysical models that predict fault type from stresses calculated at the actual planetary surface (zero depth) can often be misleading and incorrect because faults generally initiate at depth under a different stress regime and propagate to the surface. This abstract briefly reviews the generally accepted and most commonly employed criterion for fault prediction from calculated stresses on planetary surfaces (Anderson's, 1), points out problems in neglecting the effects of overburden stress, and shows a well known example (mascon loading on the moon) where neglecting this effect predicts a different type of fault than is actually observed.

Anderson (1) deduced that the three types of shear faults commonly seen at the surface of the earth are formed under three distinct stress states. He surmised that at or near the surface of the earth one principal stress direction is vertical and two are oriented horizontally, parallel to the surface, except in areas of extreme relief. Because the surface of a planet is a free boundary, there can be no vertical stress across it and so the vertical stress at the surface must be zero. As a result, the magnitude and signs of the horizontal principal stresses will determine the type of fault. If both horizontal principal stresses are tensile, then the maximum compressive stress is vertical (and equal to zero by definition) and normal faults, grabens, or tension cracks are expected. If both horizontal principal stresses are compressive, then the minimum compressive stress is vertical and reverse or thrust faults (evidenced by wrinkle ridges) would be expected. Finally, if one horizontal principal stress is tensile and the other is compressive, then the intermediate principal stress is vertical and strike-slip faults are expected.

Faults seen on planetary surfaces, however, initiate at some non-negligible depth and propagate to the surface. As a result, the critical stresses necessary to predict fault type must be calculated at the depth where faults initiate. Structures seen on most planetary surfaces (notably excluding the earth) probably initiate at fairly shallow depths (i.e., grabens and wrinkle ridges), so that the orientations of the principal stresses are most likely still horizontal and vertical. Nevertheless, the vertical stress is non-zero at depth, due to overburden, and the confined nature of the subsurface results in a horizontal stress as well. Thus, to correctly predict the type of fault most likely to form, theoretical model stresses must be calculated at the probable depth of fault initiation and then superposed with overburden stresses due to gravity. To illustrate the correct method to predict fault type from calculated stresses, a geometrically simple example with many previous theoretical stress calculations that do not predict the observed structures will be investigated; altering these stress calculations to the correct depth (using realistic material constants), and superposing overburden stresses correctly predicts the observed structures.

Lunar mascon basins are typically surrounded by concentric grabens while the basalts in the basin interior are deformed by wrinkle ridges. This led a number of workers to calculate bending stresses from simple axisymmetric elastic plate flexure models to explain the location and type of fault (2,3,4). Unfortunately, as Melosh (2) originally pointed out, calculations of stresses at the surface predict a central zone of reverse or thrust faults, surrounded by an annulus of strike-slip faults, followed by a still larger annulus of normal faults. Little or no evidence exists for strike-slip faults on the moon, and although wrinkle ridges are found in the interiors of basins and grabens occur
on the edges, basin flexure models predict the largest stress difference, and thus the most likely place for faulting to occur, in the strike-slip zone at about the distance at which grabens are found. This problem has been circumvented by superposing stresses due to global expansion and contraction to yield the correct stresses for graben formation followed by wrinkle ridge formation (3); however, there is no geologic evidence for, and considerable evidence against global expansion on the moon (5). Thus, simple flexure models alone do a poor job predicting the correct faults from stresses calculated at the surface. Nonetheless, using these same models to calculate stresses at the depth where faults initiate and superposing overburden stresses yields the correct stress state at the correct place for the prediction of grabens and wrinkle ridges without a zone of strike-slip faults (and without the need for an apparently ad hoc global stress).

Faults bounding lunar grabens initiate at the base of the megaregolith (material ejected during impact cratering) 1-4 km deep (6). Although the depth at which proposed wrinkle ridge faults initiate has not been investigated, lunar sounder data (7) imply a depth of about 1 km. Seismic velocities in the outer few kilometers of the moon (8) indicate Young's modulus is at least an order of magnitude less than generally assumed in plate flexure calculations (Solomon and Head use 10^{12} dyn/cm^2). Because the calculated stresses are critically dependent on the value of this assumed parameter, the correct stresses for the outer few kilometers of the moon are correspondingly lower by an order of magnitude (tens of bars as opposed to hundreds of bars). Superposing the correct vertical (~33 bars/km of depth) and horizontal (~10 bars/km of depth) stresses due to the weight of the overburden on the theoretical stresses due to the load using the correct Young's modulus yields the correct stress state for the prediction of grabens and wrinkle ridges. At the edges of mare basins concentric grabens are observed because the maximum compressive stress is vertical and roughly 30-100 bars for 1-3 km depth and the minimum compressive stress is horizontal and radial to the basin center and roughly 0-50 bars tensional. In the interiors of mare basins wrinkle ridges are predicted (as observed) because the minimum compressive stress is vertical and about 33 bars for 1 km depth and the maximum compressive stress is horizontal and roughly 50-100 bars. In general, the hoop stress is larger than the radial stress and thus predict radially oriented wrinkle ridges. Nevertheless, the two horizontal stresses are very close in magnitude and so do not preclude the possibility that the location and trend of some wrinkle ridges could be inherited from underlying structures. The strike-slip zone is eliminated because the vertical stress for grabens is calculated at greater than 1 km (to 4 km) depth while for wrinkle ridges the vertical stress is calculated at 1 km or less depth and thus quickly shifts at the edge of the basin from maximum to minimum compressive stress.

In conclusion, stresses calculated on planetary surfaces can often fail to predict observed structures because faults seen on the surface initiate at depth and propagate up. The failure of mascon loading models to predict the correct stresses at the surface for the structures observed has been amended by calculating stresses at the probable depth at which faults initiate; this procedure correctly predicts the location and fault type observed. Consequently, care should be taken in future stress models to understand probable effects of calculated stresses at the depth where faults initiate.