POSSIBLE HYDROISOSTATIC INFLUENCES ON THE COLLECTIVE GEOMETRY OF STRANDLINE FEATURES FORMED IN ASSOCIATION WITH ANCIENT MARTIAN OCEANS

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Overview: Some workers have proposed that large Martian basins contained extensive water bodies in the past, and have hypothesized that an ancient ocean extended over much or all of the northern lowland plains. With considerable depths over large areas, these water bodies would have represented massive surficial loads. The irregular form of some Martian basins, as well as spatial inhomogeneities in crustal and mantle properties, would have caused the magnitudes of vertical crustal displacements related to water loading to vary spatially. Similarly, the magnitudes of crustal displacements related to crustal unloading, associated with the gradual removal of water mass, would also have varied spatially. Terrestrial studies demonstrate that spatial variation in the displacement effects of oceanic loading and unloading can exceed 10% of the magnitude of vertical changes in water level (and when occurring in concert with other mass-transfer processes associated with e.g. glacial cycles, can exceed 200% of this magnitude). This suggests by analogy that hydroisostatic processes alone may be sufficient to cause ancient Martian oceanic shorelines of common age to vary in elevation today by hundreds of meters. The modern horizontality of sets of possible strandline features should therefore not be considered a necessary precondition for their interpretation as having formed in association with a large water body; in some cases, the modern horizontality of such features may in fact act as evidence against their formation in this manner. Quantitative models of large water bodies on Mars are being constructed for use in the estimation of the effects of hydrological loading and unloading on the collective geometry of strandline features.

Introduction: The past occurrence of the flow of surface water on Mars [e.g., 1-4] implies that there would likely have been, for some period of time, impoundment of water in catchment basins to form small and possibly large surface water bodies [e.g., 5,6]. Large Martian basins in both the lowlands and highlands are proposed to have contained extensive water bodies in the past [7-10], and an ancient ocean is hypothesized to have extended over much or all of the northern lowland plains [6,11-15].

Terrestrial Analogs of Differential Crustal Loading by Large Water Bodies: Both solid and liquid water bodies at the surface of the Earth act to load the crust, and changes in their size and extent can cause significant crustal displacement. For example, during continental glaciation, the formation and expansion of an ice sheet causes elastic terrain subsidence below the ice sheet and in broad regions adjacent to its margins [16-18]. In addition, this subsidence can induce lateral displacement of material within the viscoelastic mantle, resulting in the growth of peripheral bulges as well as other more distal changes to the form of the geoid [e.g., 19,20]. The reduction in the mass of an ice sheet during and following deglaciation causes terrain emergence in the region of loading through the combined processes of isostatic rebound and lateral redistribution of mantle materials [e.g., 19,21-23]. Within a region previously influenced by glacial loading, the nature and magnitude of crustal displacement will vary from location to location because of spatial variation in factors such as 1) the position and form of the loading ice sheet, and 2) the physical characteristics of the underlying crust and mantle [e.g., 19,20].

As with ice sheets, the presence and growth of large liquid water bodies at the surface of the Earth cause crustal loading and subsidence. Separate regions of both the continents and oceans respond *independently* to changes in oceanic loads, and as a result the addition or removal of a particular volume of water to the Earth's oceans does not elevate or reduce global sea levels by a geographically uniform amount [19,21,22].

When a total water volume of more than 50,000,000 km^3 [24] was transferred from the continents to the oceans during the last deglaciation, the oceans did not rise uniformly with respect to land units. Instead, water level rose with respect to land by different amounts in different areas, due to the combined effects of differential glacio-isostatic rebound, spatial variation in the nature of water loading, and far-reaching lateral movements of mantle materials [19,21,22]; all locations, even locations far from glacial melting, were affected [22]. Geophysical models [19,21] have demonstrated that both glacial unloading of the continents and meltwater loading of the oceans may have caused the total relative movement of land during deglaciation to have varied by more than 200% of the late-glacial "eustatic" rise of ~120 m; the elevations of early Holocene oceanic shorelines of common age are known to differ by hundreds of meters today [e.g., 23]. When the estimate of variation is restricted only to consideration of the changing water load on ocean basins (with no elastic rebound from glacial unloading, and with vertical shorelines and thus no change in the area of the oceans), the variation in sea level in the vicinity of the shorelines over the entire planet may be expected to be only about 6% of sea level rise [21]. Regional models that take into account the flooding and loading of new areas have been developed for the Persian Gulf region [25], and suggest possible local variations in the vertical effects of oceanic loading of about 12%, implying the potential for global hydroisostatic variations in excess of this value.

The Modern Geometry of Ancient Martian Shorelines: The identification and evaluation of possible shoreline features associated with large water bodies on Mars are typically made on the basis of the presence of gradual or distinct geomorphological or textural transitions that occur at roughly uniform elevations [6,26-29]. However, the evaluation of possible shoreline features on the basis of their collective restrictions to particular elevation ranges may not be appropriate when applied to the largest and most irregularly shaped of proposed water bodies.

For example, the bathymetry of a hypothetical northern ocean, based on the proposed “Contact 2” shoreline materials of Parker *et al*. [13] at about minus 3700 m [26] (and derived using the simplifying assumption that modern topography can be used as a gross approximation of ancient topography at the time of a northern ocean), is given in Figure 1. Such an ocean would have extended irregularly over most of Amazonis, Arcadia, Acidalia, and Utopia planitia, and Vastitas Borealis [6,13,15], and would have had water depths well in excess of one kilometer over large regions. Given the irregular form of this water body, and given the likelihood of variations in crustal properties across large regions of Mars [30], the associated spatial variation in the displacement effects of water loading and unloading could be significant.

Ancient Martian shorelines formed in association with large water bodies may therefore be differentially offset in the vertical direction over much of their extent solely as a consequence of hydroisostatic processes associated with the unloading of water mass; distorted in this manner, Martian oceanic shorelines of common age could conceivably vary in elevation today by hundreds of meters. Thus, within large Martian basins, the identification of possible shoreline features of common age and at a common elevation is not necessarily evidence in favor of a large ancient water body. Conversely, significant variation in the elevations of such features does not necessarily preclude their formation in association with a large water body.

Current Research: Quantitative models of loading by large water bodies on Mars are being constructed for use in the estimation of hydroisostatic effects on the collective geometry of hypothetical strandline features. Finite-element models of large water bodies located in both highland and lowland regions will be utilized to better constrain the magnitudes of elevation variation that should be expected for Martian strandline features of common age.

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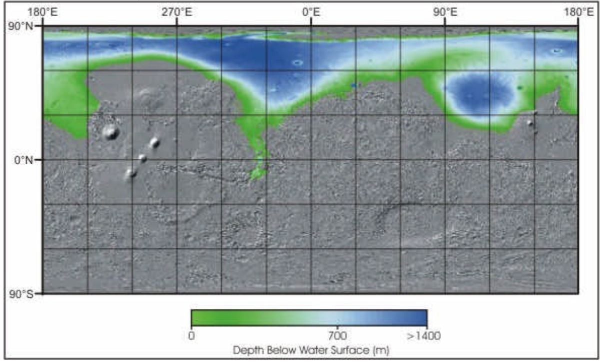

Figure 1