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HYDROLOGIC ACTIVITY DURING LATE NOACHIAN AND EARLY HESPERIAN DOWNWARPING OF BOREALIS BASIN, MARS

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Introduction. Pronounced global volcanism as well as fracturing and erosion along the highland-lowland boundary (HLB) during the Late Noachian (LN) and Early Hesperian (EH) [e.g., 1, 2] led McGill and Dimitriou [3] to conclude that the Borealis basin formed tectonically during this period. This scenario provides a basis for interpretation of the initiation and mode of formation of erosional and collapse features along the HLB. The interpretation, in turn, is integral to hypotheses regarding the development of ancient lakes (or an ocean) and their impact on the climate history of Mars.

Hydrologic features. These features are considered to include all structures and terrains that I interpret to have formed or been modified by fluvial erosion or piping (erosion and removal of subsurface debris by fluid flow). They include sapping, runoff, outflow, and fretted channels [4]; fracture-controlled but widened troughs; warped, chaotic, fretted, knobby, and pitted terrains; and floor-fractured craters. The examples discussed below may be LN or EH in age as determined by previous work [5] or by stratigraphic relations seen on maps [6, 7]; they are concentrated in highland rocks along and near the HLB and account for its degraded appearance. These temporal and physiographic relations suggest that the basic mechanism for the origin of the hydrologic features was the drainage of ground water from highland regions toward Borealis as the basin lowered. The instigation of ground-water outbreaks and associated channeling by vertical tectonic movement elsewhere on Mars has been proposed for eastern Tharsis/Valles Marineris and the circum-Chryse channels [8, 9] and western Tharsis and Mangala Valles [10].

Runoff channels include Al-Qahira, Ma'adim, Nanedi, Nirgal, Parana, and Samara Valles [4]; the latter three fed the Ladon-Ares Valles outflow-channel system that debouches into Chryse Planitia. Other outflow channels include Mawrth Vallis and an unnamed channel that originates near lat 36° N., long 350°; these channels terminate in Acidalia Planitia. The unnamed outflow channel issues from a discontinuous chain of large craters that extend south for more than 600 km. Some of these and other nearby craters have fractured floors, suggesting that liquefaction and drainage took place in the crater-floor material. The impacted crustal rocks were probably highly permeable [9], facilitating high ground-water discharges from them.

Fretted channels and troughs have irregular morphology; some are discontinuous and appear to have formed by collapse. Previous workers [e.g., 4, 11] proposed a ground-water sapping origin for these features. Because lowering of the Borealis basin was contemporaneous with high surface discharges, as noted above, I suggest that ground-water sapping discharges may also have been high and sufficiently vigorous to induce piping. Piping may have been largely responsible for the fretted channels and the fracture-controlled troughs along the HLB that include Huo Hsing, Auqakuh, and Mamers Valles [4]; Ismeniae (south of Deuteronilus Mensae) and Mareotis Fossae; and Aeolis and Nylosyrtis Mensae. Also, warped and chaotic terrains at Cydonia Mensae (along the HLB) are thought to result from removal of subsurface material and catastrophic collapse, because Late Hesperian outflow channels south of Chryse Planitia head in such terrains. Subsurface channels may have emerged in lower parts of the HLB scarp, where chaotic and knobby terrains and dispersed mesas occur; these areas obviously underwent more extensive erosion. However, these suggestions are speculative, because the early geomorphologic record in the lowland plains north of the HLB was largely erased by sedimentation and reworking during the Late Hesperian. The degree of erosion in some of these areas indicates that considerable water discharge was involved, although wind or sublimation of ground ice later augmented the erosion.

Why, though, was piping apparently the dominant degradational process only in the high-latitude (lat 30°-50° N.) areas of fretted terrain, whereas runoff channels were dominant in lower latitude regions? This latitude relation suggests that ground ice may have provided an impermeable barrier to upward ground-water flow [8, 9] at high latitudes. In a permeable material, a hydraulic gradient (induced, say, by tectonism) should simply result in ground-water flow and, wherever the water table intersects the surface, in effluence and runoff. However, where permeable material is capped by impermeable material, tectonic tilting may result in high pore-water pressure and eventual liquefaction of the permeable material. This condition may lead to catastrophic debris flows, as has been proposed for the development of the circum-Chryse chaotic terrain and channels [9, 12].

Implications for paleolakes and climate history. Ground-water runoff from highland rocks near the HLB may have produced large, temporary paleolakes or even a vast (though shallow) ocean in the Borealis basin. (If so, the period when they were formed would have been the earliest lacustrine period on Mars.) Such bodies of water could have led to voluminous carbonate formation at the expense of atmospheric CO_2 [13], resulting in a thinner atmosphere and a cooler climate than before. If these conditions indeed occurred, they may have had some geologic implications. First, precipitation that may have occurred through much of the Noachian Period could have ceased, resulting in no further valley-network formation. Alternatively or in addition, valley-network formation by hydrothermal means may have shut down with the cessation of widespread highland igneous activity during the EH [14]. Second, equatorial regions may have been frozen at the end of the EH. This change is consistent with the following channel history deduced for the equatorial region: (1) during the Noachian and Early Hesperian, shallow runoff, sapping, and outflow channels formed from discharge of near-surface ground water (and perhaps from runoff of precipitation); and (2) during and following the Late Hesperian, deep outflow channels (including the circum-Chryse and Elysium channels and Mangala Valles) were carved by processes presumably instigated by high pore-water pressure buildup at depth (probably a kilometer or more) beneath frozen rock; sites of outbreak include fractures and chaotic terrain.

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