A PHYSICAL MODEL OF THE IMPACTED MARTIAN CRUST: HYDROLOGIC AND MECHANICAL PROPERTIES AND GEOLOGIC IMPLICATIONS; *David J. MacKinnon and Kenneth L. Tanaka, U.S.G.S., 2255 N. Gemini Dr., Flagstaff, AZ 86001*

Photogeologic evidence suggests a close association of many outflow [1,2], intermediate [3], and sapping [4] channels with regions affected by uplift, fracturing, and geothermal heating [1, 5]. The magnitude and diverse morphology of the channeling are impressive by terrestrial standards, especially because there is little evidence that significant rainfall has occurred on Mars [6]. By the end of the heavy bombardment, outgassed water probably had been emplaced in the upper crust [7]. Nearly all the channels originated from or are associated with ancient cratered terrain, some of which has been resurfaced by lava flows and eolian processes. Because high impact fluxes during bombardment probably fragmented most of the materials that resurfaced the impacted surface, we believe that a simple physical and structural model of the impacted, ancient cratered terrain can reasonably describe physical properties fundamental to interpreting subsequent channel formation, as well as other geologic activity.

On this basis, we developed a two-layer model for the impacted crust: an ejecta (impact breccia) zone overlying a zone of fractured basement rock [see 8, 9]. The proposed ejecta zone is 1 to 2 km thick and consists of well-mixed, very poorly sorted impact breccia that grades into the fractured zone. The fractured zone is composed of meter-size or larger blocks of basement rock, and it extends to the depth of lithostatic closure (10 km or more, depending on pore-water pressure [10]). The porosity and permeability of these zones depend on the size distribution and packing of the breccia and fractured blocks. From the results of measurements from terrestrial impact and explosion craters, laboratory analyses, and experimentally verified theoretical models for porosity and permeability, we determined that in such an impacted crust, clast size and degree of sorting increase with depth. These trends cause (1) porosity to decrease with depth throughout the affected crust, (2) permeability to increase with depth to the top of the fractured zone and then to decrease as fracture width and frequency decrease with depth, and (3) material strength to increase with depth from cohesionless to that of solid bedrock. Extrapolating from typical size distributions and packing among ejecta and fractured blocks, we estimate the porosity of the ejecta zone as 10-20 percent and the porosity of the upper part of the fractured zone as less than a few percent; the permeability of the ejecta zone would be less than 0.01 darcys, and the permeability of the upper part of the fractured zone would be about 1000 or more darcys.

We recognize two major limitations of our model: (1) few terrestrial impact and explosion craters provide empirical data for the analysis of the effects of single and multiple impacts on rock structure, and (2) the subsurface stratigraphy of Mars is poorly known. Thus some of our basic assumptions are speculative, allowing for different possibilities regarding the nature of the Martian crust. In one alternative view [10], the crust is more heterogeneous than we have portrayed; thus its hydraulic properties may be more varied, and impact fractures in the basement rocks, if filled, would appreciably lower the bulk permeability.

In spite of such problems, we feel that our two-layer model is generally valid, because it can account for a great diversity of Martian geologic phenomena. Photogeologic evidence suggests mechanical discontinuities in the Martian crust at 1- to 3-km depths, which in some places may form the contact between the ejecta and the fractured zones. Generally, lower layers of the ancient crust have progressively greater resistance to erosion. Within the deeply eroded Kasei Valles, for example, erosional discontinuities in the

channels are evident at depths of 1.0 and 2.6 km. The upper discontinuity has been interpreted as the ejecta/basement contact [11], the interface between ice-laden and dry or wet regolith [12], or the zone between pristine and cemented regolith [13]; the lower discontinuity is consistent with the depth to the base of sapping channels along the Valles Marineris and has been interpreted as the ejecta/basement contact [12]. Such discontinuities are consistent with observed graben widths and collapse pits proposed to originate by collapse of cohesionless material into tension fractures at depth in basement rocks [12, 14].

The Chryse channels may be explained by high pore pressures and fluidization of the base of the ejecta zone by the fractured zone, causing enormous retrogressive debris flows [15]: after removal of the overburden, floods from the fractured zone could have easily eroded ejecta-zone breccia. Late-stage debris flows, sapping channels, and landslides along the channel margins completed the morphology seen today. If debris flows played a central role in the formation of the large outflow channels, their mobilization would require much less water [16] than the flood model [7]. The breccia of the ejecta zone is poorly sorted and rich in clay-size particles, analogous to the clast distributions of terrestrial debris flows [9]. An explanation for the great runout distances of debris flows over very low gradients, however, has not yet been offered.

Other geologic features consistent with our model include (1) outflow channels produced by catastrophic floods erupted from joints or faults that tap the fractured zone and act as high-volume conduits [13,17]; (2) sapping channels where the permeability of the ejecta zone was sufficient to promote sapping of exposed, saturated ejecta; (3) chaotic terrain, possibly formed by liquefaction of breccia at depths of hundred of meters to more than a kilometer [18]; (4) complex channels such as Nirgal Vallis, which can be explained as a combination of outflow along a tension fracture that taps the fracture zone (lower part of channel) and sapping from the ejecta zone (upper part of channel); and (5) high-latitude debris aprons and channels with modest wall slopes (e.g., Auqakuh Vallis) composed of ice-rich impact breccia of low yield strength [19].

Our physical model for the ancient, impacted Martian crust, coupled with local volcano-tectonic histories, enables a more complete understanding of the formation of many common geologic features on Mars. Previously, catastrophic flood models have not addressed the dependence of permeability on clast and fracture distributions and the cohesion of the cratered terrain material, and debris-flow models have not addressed the physical mobility of the material. Furthermore, the ejecta/fractured zone stratigraphy explains many observations of Martian erosional and structural discontinuities.

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