THE MARTIAN HYDROSPHERE/CRYOSPHERE SYSTEM: IMPLICATIONS OF THE ABSENCE OF HYDROLOGIC ACTIVITY AT LYOT CRATER. P. Russell[1] and J. W. Head[1], [1]Dept. Geological Sciences, Brown University, Box 1846, Providence RI 02906. Patrick_Russell@Brown.edu.

Introduction: The hydrologic model of Clifford [1] provides an interpretive framework for groundwater-surface interactions on Mars. One of the major implications of a global interconnected sub-cryosphere groundwater system over which hydraulic pressure head may be transmitted is that a disruption on the cryospheric seal has the potential to produce massive outflow under "artesian"-like conditions. We consider one of the most likely places to have triggered such an event to be the 215 km-diameter Lyot crater in the northern lowlands. Here, we examine the evidence for hydrologic activity at Lyot and discuss possible implications for a global hydrosphere/cryosphere system on the basis of the lack of detection of such activity

Background: *Stratigraphy of the Northern Plains* A summary of the stratigraphic, physical, and thermal structure of the Northern Lowlands as best currently known provides geologic context for discussion of subsurface hydrologic processes. The most extensive surface cover of the northern lowlands is the Vastitas Borealis Formation (Hv); the crater material of Lyot is mapped as superposed on Late Hesperian channel materials and extensive Amazonian-aged knobby and smooth plains units [2]. Hv is a sedimentary deposit averaging ~ 100 m thick overlying plains with ridges interpreted as Hr-like wrinkle-ridged volcanic flows ~ 1 km thick [3]. The number and sizes of subdued craters and impact basins indicates that a Noachian-aged surface is present below, probably similar to that visible in the southern highlands today [4].

Physical structure of the martian crust The constituents and structure of the average martian megaregolith and upper crust are summarized by Clifford [1] using analogies with the lunar crust. Impact ejecta interbedded with lava flows, sediments, and weathered materials comprise the ~ 2 km-thick megaregolith [5, 6], below which is an autochthonous breccia of fractured basement rock [7]. Porosity within the entire upper crustal column can be represented by exponential decay of surface porosity, due to lithostatic pressure, to near-zero at the depth of self compaction [8]. On Mars, a maximum surface porosity of 35 to 50 % yields a self-compaction depth of 10 to 11 km, above which large quantities of water may reside within the subsurface [9]. High porosity and analogy to the terrestrial permeability structure of the crust allows for global-scale communication of groundwater to depths of ~ 26 km on Mars [9]. The model of an impact-fractured martian crust probably best applies to the heavily cratered highlands. As similar crustal terrain is postulated to exist below the Northern Lowlands [4], we consider this physical structural profile to be reasonable for the crust beneath the Hr-like lavas and Hv of the northern lowlands.

Thermal Structure of the Martian Crust [1] Under current martian climatic conditions, a cryosphere (zone of the crust in which temperature is always below the freezing point of water) extends from the surface to a depth that depends on the freezing temperature of water, latitudinally-dependent surface temperature, geothermal heat flux, and thermal conductivity. The elevation of the theoretical base of the cryosphere reflects relief in surface topography to the first order. Below the base of the cryosphere, liquid water is stable. Ice may or may not be present in the cryosphere, and water may or may not be present in its stability zone (above the depth of self compaction). Any water entering this cryosphere, from above or below, will freeze, restricting any water transport to diffusion processes and effectively inhibiting passage of water.

The hydrologic model of Clifford [1] The structure of the martian subsurface reviewed above leads to the possibility of a globally interconnected groundwater system below the base of the cryosphere [1]. Given enough water in the global inventory [10] and sufficient variation in surface relief, subsurface water may accumulate above the depth of self compaction and remain confined beneath the cryosphere under hydrostatic pressure as long as the local lithostatic pressure of the cryosphere is greater than the hydrostatic pressure exerted by saturated ground at higher elevations [9]. In such a scenario, hydraulic potential at a point on the planetary surface at a relatively low elevation will be lower than that of subsurface water at a higher elevation. If hydraulic pressure head becomes too great or the cryosphere is disrupted by some means, water may flow to the surface on its own, under "artesian"-like conditions. Variations on this model have been used to explain outflow channels near Tharsis and Elysium [1, 6, 11]

Investigations at Lyot Crater: *Rationale for choosing Lyo*t According to Clifford's [1] model, global hydraulic pressure head should be greatest in the topographically lowest areas of Mars, comprised of Hellas Basin and the Northern Lowlands. Large impacts are strong candidates among several geological processes potentially able to perturb a cryosphere kilometers thick. Lyot was chosen for assessment of the proposed hydrologic model [1] because it is a) within the Northern Lowlands (no large craters exist within Hellas), b) Amazonian in age, when evolving cryosphere thickness is able to contain the greatest volume of water, c) furthest south among Northern Lowland craters, thus minimizing the local cryospheric thickness.

Expected Results of the Lyot Impact At the latitude of Lyot crater, 50°N, the Nominal predicted thickness of the cryosphere is 4 km [1]. The base of present-day Lyot crater lies 3 km below the level of the surrounding plains; its final topography is thus not quite sufficient to extend below the base of the Nominal cryosphere into the zone where liquid water may exist.

However, depth of the transient crater better indicates the depth to which physical disruption of the ground, and hence the cryosphere, is likely to have resulted from the cratering event. Estimates of transient crater depths at Lyot based on scaling from simple lunar and complex craters [12], range from 5 - 10 times the depth of the currently observed crater (~15 - 30 km) to 39 km, respectively.

Besides fracturing and excavation, an impact also imparts heat to the target. For any reasonable estimates of the properties of the impactor and surface at 215 km-diameter Lyot [12], delivery of a significant amount of the kinetic energy of the impactor to the surface [13] would easily raise the temperature of the ground hundreds of Kelvin to depths of several kilometers. In a Nominal cryosphere at the latitude of Lyot, the ground temperature is ~60 K below melting at the surface and increases to melting (252 K) at ~ 4 km [1].

Either or both the physical and the thermal disruption of the cryosphere associated with Lyot can be expected to have penetrated through the Nominal thickness of the local cryosphere and to have enabled effusion of groundwater to the surface, given the hydraulic pressures implied in the model presented above.

Observations at Lyot Lyot crater and surroundings are examined in Viking, MOLA, and MOC data, with particular attention to possible evidence of aqueous activity. Lyot is > 200 km in diameter with a high broad inner ring and a ~400 m-tall central peak. Most surfaces within the crater are rough and show no signs of gullies, channels, or theater-head alcoves. Small local depressions in the walls and floor are smoothed or softened, but are not very flat. Ejecta around the northern half of the crater is very extensive, with a fresh appearance and pristine secondaries extending out > 1 crater diameter. In the SE, patches of ejecta are visible, as if partially covered or destroyed. To the S/SW, amidst the mesas of Deuteronilus Mensae there are no signs of an ejecta blanket beyond the rim. The rim of Lyot is rugged but shows no signs of incision, breaching, or erosion by aqueous activity, and fluvial features to the south (and uphill) do not appear to emanate from Lyot. We find no evidence for water having effused or erupted within the interior of Lyot crater or poured over the rim. Smoother sloping areas probably result from eolian activity. Processes of erosion, sediment transport and deflation in Deuteronilus may have eliminated much expression of ejecta, or the impact may have been oblique.

Discussion: The lack of evidence for hydrologic activity or sedimentary deposits sourced in Lyot crater has several possible explanations and carries major implications for the state of the subsurface, distribution of groundwater, and the role of cratering in groundwater-surface interaction on Mars. We investigate several classes of possible explanations here.

1) The global hydrologic system does not now contain abundant groundwater or the cryosphere is much thicker than envisioned [1]:

a) The amount of water in the global groundwater system below the base of the cryosphere, and hence the hydraulic pressure head of the groundwater, may not be sufficient for water to be forced up to the elevation of the base of the present crater, -7 km. Given evidence for the level of saturated ground at ~ 0.5 to -3.0 km at the Chryse channels in the Mid-Late Hesperian [1, 6] and at ~ -3.5 km at Elysium in the Early Amazonian [11], an enormous amount of water would have to be lost to another sink (regolith, cryosphere, polar cap, space) in a relatively short time for this level of saturated ground to be below -7 km at the time of the Amazonian Lyot impact.

b) The cryosphere may be thicker than is predicted in the Nominal case [1]. In order to prevent the physical disruption associated with the transient crater from reaching through the entire cryosphere to liquid water below, the cryosphere would have to be at least 15 km, and probably more like ~ 39 km thick (barring any additional disruptive effects of hydrostatic pressure of the groundwater). In order for impact-related heating not to raise the temperature above freezing through the thickness of the cryosphere, the cryosphere would have to be tens of km thick. These thicknesses are more comparable to the Maximum predicted thickness of the cryosphere in [1], 16 km at 50°N. The low value of heat flux in the Maximum case, 15, is more consistent with the latest best estimates for the northern plains, 15 - 22 mW/m^2 in Utopia [14]. In addition, a Maximum-thickness cryosphere would require a higher melting temperature and thermal conductivity, implying that salts play a relatively minor role in freezing point depression, and thus may not be abundant at depth, and that the effective thermal conductivity is towards the higher end of the range of values obtained for frozen soils and basalts summarized in [1].

2) The global hydrologic system is not as interconnected as envisioned [1]:

a) The megaregolith of Mars may be more inhomogeneous or impermeable relative to that of the Moon, upon which this model is based [1]. New insight into the stratigraphy of the Northern Lowlands [3, 4] suggests crustal structure below ~ 1 km may well be similar to that of the ancient cratered southern highlands, the martian terrain expected to most closely resemble the lunar crust. More prevalent volcanic, magmatic, and hydrologic activity on Mars may have emplaced more dikes, sills, lava flows, and fine-grained sediments than considered in a lunar-regolith model. These structures could cause a more locally controlled distribution of groundwater, such as perched aquifers or relatively isolated pockets of high porosity material.

3) Explanations consistent with the hypothesized groundwater system [1] *and* the lack of hydrologic activity at Lyot:

a) The martian regolith may be physically interconnected as postulated [1], but permeabilities may be too low to allow significant flow within and from a saturated groundwater zone to the crater surface before impact-related heating is overcome by refreezing from the cold atmosphere.

b) If the thickness of the cryosphere were to exceed ~11 km, as considered above, any water tapped by extension of the disruptive effects of the impact to greater depths would be below the depth of self-compaction. While permeability on a large scale may still allow groundwater flow [9], the volume of water present locally may not have been enough to produce significant outflow.

c) The ability of impact processes to disrupt the upper crust is much less than should follow from predictions.

Conclusions: To a first order, tests of the Nominal cryosphere/ hydrosphere model of Clifford [1] based on predictions and observations at Lyot Crater fail to support the expected presence of groundwater, suggesting the model may need revision. We are presently testing conditions of the martian hydrosphere and cryosphere by examining variations in impact cratering and other disruptive processes, by identifying and distinguishing amongst possible scenarios as presented here, and investigating alternative scenarios [15].

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