LYOT CRATER MARS: THE ROLE OF SNOW AND ICE IN THE FORMATION, EJECTA EMPLACEMENT AND MODIFICATON OF A MAJOR AMAZONIAN-AGED IMPACT. **James W. Head, David K. Weiss, and Ashley Horan.** Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912 USA. (james_head@brown.edu)

Introduction: The ~222 km diameter peak-ring Lyot Crater (Fig. 1) is located in the Northern Lowlands of Mars (50.5°N; 29.3°E), just north of the dichotomy boundary. The lowest point on its floor lies at ~4 km below the rim crest, ~7.3 km below the Mars datum and is the lowest point in the northern hemisphere [1]. Lyot and its deposits are very well-preserved and its age has been estimated to be Middle Amazonian [2-6].

In this analysis, we build on previous work and new analyses and set the stage to address the following questions: What is the relationship between the formation of Lyot crater and the global and regional climate at the time of the event? How did the formation of Lyot affect the regional/global surface and atmospheric environment? What is the evidence for long-lasting climatic influence and effects from the Lyot crater-forming event?

Lyot Crater Geology and Previous Interpretations: Lyot has historically been of interest due to its large size, relatively young age, location in the northern hemisphere, and the possible role of such a large, young impact event in the evolution of the climate and atmosphere [7-9], in its potential for sampling the structure of the hydrological system and deep groundwater [10-11], and the suggestion that regional channeled scablands surrounding parts of Lyot could be related to the emplacement of Lyot ejecta [12].

The location of Lyot in the Northern Lowlands (Fig. 1) leads to the prediction [10] that at several kilometers below the surface in this region, the global geothermal gradient should permit melting of ground ice. At this location and depth, if significant groundwater were present, it should be under hydrostatic head, and a drill hole to these depths should produce artesian outflow. Russell and Head [11] pointed out that Lyot crater formation represents a transient 'drill-hole' into the martian hydrosphere/cryosphere system and that cratering mechanics predict that the event should have penetrated the cryosphere and released groundwater held under artesian conditions. Russell and Head [11] found no evidence for groundwater outflow, however, and suggested that a plausible explanation for the lack of evidence for hydrologic activity within Lyot is an absence of abundant subsurface groundwater in the region at the time of impact in the Middle Amazonian.

Harrison et al. [12] used new image data to document the presence of an extensive channeled scabland covering ~300,000 km^2 and extending to the north, west, and east of Lyot. The configuration and morphology of the channels supports a water flow origin, and Harrison et al. [12] propose that the scablands result from impact-induced overland fluid flow. They considered two possible formation mechanisms: 1) mobilization of shallow groundwater by seismic energy from the impact event, and 2) dewatering of the ejecta blanket, with the water derived from excavation of permafrost and sub-permafrost groundwater. Harrison et al. [12] cite the following points as lines of evidence against an ejecta blanket dewatering mechanism: 1) the general lack of large channels incising the ejecta deposit, 2) the location and fully-formed nature of the channels near the ejecta deposit margin, and 3) the areal extent of the channels and scour. On the basis of these points, they favor the process of seismic triggering of a shallow unconfined groundwater aquifer by the Lyot event as the primary formation mechanism of the channels.

Dickson et al. [2] mapped fluvial valley networks (regional drainage patterns suggesting liquid water stability at the surface, and typically confined to near the Noachian/Hesperian boundary) within, and thus post-dating Lyot crater. These large (tens of km long) fluvial systems have the youngest well-constrained ages reported to date (Middle-Late Amazonian) and are linked to melting of near-surface ice-rich units [2, 13]. Following Haberle et al. [14], they [2] point out that the interior of Lyot crater is an optimal micro-environment for melting; its extremely low elevation leads to high surface pressure, and temperature conditions at its location in the northern mid-latitudes are sufficient for melting during periods of high-obliquity. Thus, during the Middle-Late Amazonian (unassociated with the Lyot event), the interior of Lyot was characterized by a microenvironment that included the deposition of regional surface snow and ice deposits, and their melting during periods of high obliquity.

Robbins and Hynek [15] analyzed the distribution of secondary craters surrounding Lyot. The north-northeast ejecta deposit distribution (Fig. 1a) conflicts with the southeast dominance of the secondary clusters (Fig. 1b); Robbins and Hynek [15] explain this by preferential modification and burial of secondaries. The formation of secondary craters into surface glacial deposits, and subsequent modification of the deposit (through flow and sublimation) could produce a paucity of secondary craters [27] north of Lyot, where surface ice is predicted to accumulate during periods of high obliquity [23].

Large impact craters are thought to have had a major influence on the regional and global climate [e.g., 7-9], particularly in the earlier history of Mars when formation of a Lyot-scale event in a denser atmosphere is thought to have caused emplacement of large amounts of water into the atmosphere from the substrate, produced profound heating of the atmosphere from hot ejecta, and resulted in fallout of both hot debris and water vapor (rainfall) to create runoff and to carve valley networks. Later in martian history, however, the atmosphere may not have been thick enough to have produced such effects [9]. Analysis of the geology and evidence for climate conditions prior to, during, and following the Lyot event provide an opportunity to test these hypotheses.

The Pre-Lyot Crater Substrate and Climate Setting: Critical to the understanding of the formation of Lyot, the emplacement of its ejecta, and the interpretation of the resulting landforms and climate effects, is the definition of the baseline climate and surface conditions during the Amazonian. Currently, Mars is a hyperarid, hypothermal polar desert climate [16] with surface water concentrated in the polar caps and near-surface pore water concentrated as ice cement in a global permafrost layer, lying above a kilometers-deep warmer layer capable of holding liquid groundwater. This horizontally-stratified hydrological system [17] is thought to characterize the vast majority of the Amazonian period [10, 18-19]. Variations in spin axis/orbital parameters, primarily obliquity [20], cause polar ice to be redistributed to lower latitudes, forming widespread mid-latitude glacial deposits and even tropical mountain glaciers [21] at ~45^o obliquity. Laskar et al. [20] have shown that the most likely mean value for obliquity during the Amazonian is ~35^o, and Head et al. [22], Madeleine et al. [23] and Fastook et al. [24] have shown that in this obliquity configuration, a significant part of the mid-latitudes is covered with decameters of snow and ice [25], with a wide variety of glacial landforms developed in a range of sub-environments throughout the mid-latitudes in the Amazonian [26].

A large Lyot-scale impact could produce meltwater to form the observed exterior fluvial channels (Fig. 2) in the following ways: 1) *Substrate effects*: groundwater, ground ice, surface ice incorporated into the ejecta; (2) *Ejecta Effects*: shearing, melting of surface ice during emplacement; post-emplacement raising of the melting isotherm into surface ice, causing melting [27]; and (3) *Impact Vapor Plume effects*: Lyot-induced vapor plume heats atmosphere, causing regional-global rainfall, heating, melting [7-9]. On the basis of these data and our analyses, we conclude that a plausible configuration for the nature of the substrate in the Lyot target latitude band during the Middle Amazonian when Lyot formed is a regional, decameters thick snow and ice-covered regolith permafrost surface; the presence of surface glacial ice at the time of the Lyot impact is clearly indicated and influenced the emplacement and modification of Lyot ejecta.

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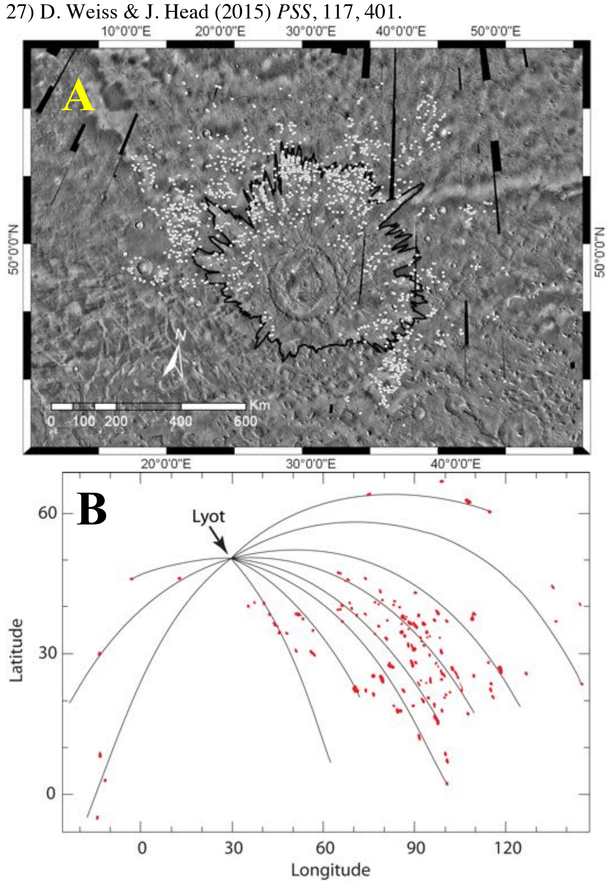

Fig. 1. A) Lyot continuous ejecta deposit (black line) and near-field secondaries (white circles).B) Distant secondary craters (red markers) with great circles (black lines) between clusters and Lyot. (From [14]).

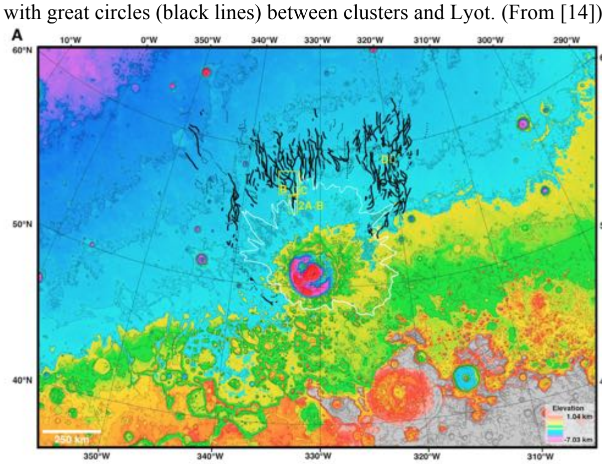

Fig. 2. Lyot and surrounding terrain (MOLA topography) showing mapped channels and areas of scour (black lines) and candidate scour (dotted) (from [12]).