CHASMA BOREALE : THE ROLE OF SUPRA-GLACIAL EROSION. F. Costard, L. Dupeyrat and J.P. Peulvast, FRE2566, Orsayterre, Université Paris-Sud, bat. 509, 91405, Orsay Cedex, France. fcostard@geol.u-psud.fr,

Introduction: Chasma Boreale is a large reentrant in the north polar cap 520 km in length, 200 km in width and an average depth of 1300 m (fig. 1). The permanent ice cap represents a thick sequence of thin alternating bright deposits made of water ice layers and a mixture of low albedo dust or sands with frozen volatiles (mainly water). Various mechanisms have been proposed for the origins of Chasma Boreale. Wallace and Sagan [1] suggested a catastrophic outflow fed by an ice-covered lake disrupted by an impact. Clifford [2] proposed a jökulhlaup triggered by basal melting in association with a thermal anomaly. Benito et al. [3] suggested a catastrophic outflow of meltwater induced by a tectono-thermal event. An another hypothesis suggested by Howard [4] proposed an erosional process involving a sublimation of the icy deposits by katabatic winds. More recently, Fishbaugh and Head [5] proposed a catastrophic discharge of a subglacial volume of meltwater at the base of a polar ice sheet, with later modification by katabatic winds and sublimation. From the outflow hypothesis, after a subglacial eruption, with a supra glacial erosion in the distal parts of Chasma Boreale.

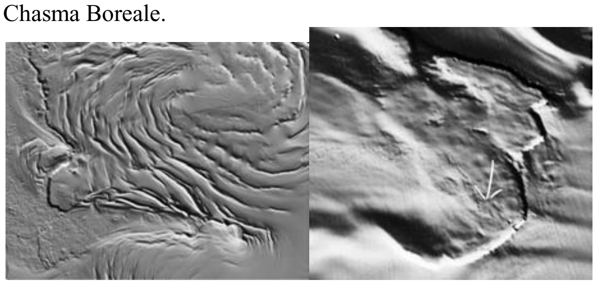

Fig. 1: (Left) Topographic shaded relief map of Chasma Boreale in polar projection. MOLA data. (Right) Aligned crater like forms suggesting possible volcano-tectonic activity at the head of the chasma.

In Iceland, it is common to observed deep depressions created by collapse just above subglacial lakes [6]. After a subglacial phase, basal water bursts out on the glacier surface as a flood wave and spreads over the outwash plain. Various measurements of the lake temperature in Iceland vary from 1°C to 4°C [7]. Supraglacial streams in terrestrial polar regions are powerful rivers characterized by a melting enlargement of the flood. Meltwater accumulated in the subglacial lake is then drained in a catastrophic jökulhlaup [8]. Thermal and mechanical erosion are relatively active and contribute to the enlargement of the supra glacial stream.

Geological context: The two enclosed depressions, 40 km in width, located at the head of the chasma show some evidence of volcano-tectonic activity. The chasma floor shows collapses and low albedo features in relation with aligned crater like subsidence pits. The floor of the Chasma Boreale exhibits the outlines of an elongated tongue whose distal lobe overlap the surrounding plain by a 250 m high scarp. These supposed deposits are linked, either to an aeolian origin [9], or to a fluvial or glacial deposition of sediments [5].

High resolution images of parts of the chasma walls (fig. 1-right) show several topographic and lithologic discontinuities. The upper part of the slope reveals the existence of numerous horizontal layers of a dark dusty material interbedded with icy layers (Polar Layer Deposits - PLD unit). Beneath the PLD unit lies a dark unit, associated with a break in slope (fig. 2). Further investigations of this basal unit [10] suggest that this unit is made of a thick sequence of presumably massive icy beds. Such massive icy beds occurs in terrestrial permafrost as relatively dark layers of several meters thick (fig. 3). They represent either buried surface ice (frozen lakes) or segregated ice [11].

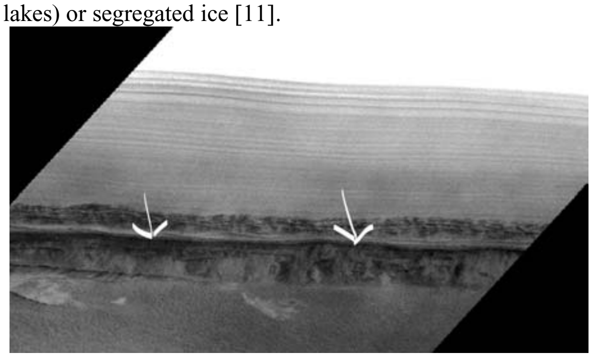

Fig. 2: Stratified deposits in Chasma Boreale (MOC E0300375) with possible massive icy beds.

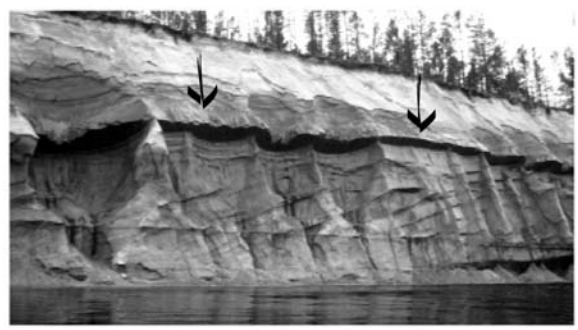

Fig. 3: 60 m high river banks along the Lena river (Central Yakutia, Siberia) characterized by several massive icy beds within stratified eolian deposits.

The supraglacial stream hypothesis: Considering an entirely erosional origin of the chasma, the volume of the chasma is ~4 x 10^4 km^3. Taking into account the presence of massive icy beds and numerous relatively thin dust layers (saturated with ice), one can suppose an eroded volume of ~1.6 x 10^4 km^3 of silt and ~2.4 x 10^4 km^3 of ice [5]. What would be the origin of such an intense removal ? A first hypothesis supposes a wind erosion which can be partly explained by the presence of katabatic wind regime. A second possibility is to suppose an outflow of meltwater as proposed by Fishbaugh and Head [5]. Several questions remain unresolved : 1 – why the volume of the apparent head of Chasma

Boreal is small by comparison with the present volume of the large reentrant ? 2 – was it a subglacial event along the whole length of the Chasma ? - 3 - what was the volume and the longitudinal profile of the Chasma floor during the flooding event ? The purpose of that study is to characterize the efficiency of the erosional process which would take place during a catastrophic flooding event(s).

Proposed modelisation of a supra glacial event: To study the efficiency of fluvial thermal erosion along the Chasma walls, we performed a more detailed numerical analysis of the main parameters affecting the erosion rate during the flooding event. The interesting case for us is a typical situation where the melted sediments are progressively swept away by the supraglacial stream. Our model corresponds to a system undergoing a permanent thermal regime where the surface temperature is constant and equal to the phase change temperature (due to the rapid removal of melted material). The erosion rate (or ablation velocity) of the permafrost can be expressed as a function of the convective heat flux (q_c) at the water/permafrost interface (eq.1):

$$V_a = \frac{q_c}{\rho\left[L_f + c_p(T_f - T_i)\right]} \quad (1)$$

in which T_f, T_i, L_f, c_p, and ρ are respectively the fusion temperature (=0°C), the initial temperature, the latent heat of fusion, the specific heat and the density of the permafrost and ice layers.

The convective heat flux is controlled by the heat transfert coefficient h between the water flow and the permafrost (eq. 2). In order to determine this heat transfer coefficient related to the Nusselt number (eq. 3), we used an empirical relation (eq. 4) between the Nusselt number (Nu) and the Reynolds (Re) and Prandtl (Pr) numbers characterizing the water flow.

$$q_c = h \cdot (T_w - T_f) \quad (2)$$

$$h = Nu \cdot \frac{k_w}{d_w} \quad (3)$$

$$Nu = A \cdot \Pr^{\alpha} \cdot Re^{\beta} \quad (4)$$

in which T_w is the water temperature, k_w the thermal conductivity of the water and d_w the water depth, A=0,003031, α=1/3, β=1,1211.

First determination of the empirical coefficients has been done by Lunardini et al. [12] and is presently improved through a statistical approach based on repetitive experiments within a cold room. This numerical model was validated by some laboratory experiments with a hydraulic channel within a cold chamber [13].

The water depth (d_w) is calculated from the Manning empirical equation (eq. 5) adapted to a wide, shallow and open channel [14, 15] :

$$V_w = \frac{{d_w}^{2/3} \cdot \sqrt{S}}{n^*} \quad (5)$$

in which Vw is the water velocity, S is the longitudinal slope, and n* is the Manning roughness coefficient (as Mars presents a lower gravity, n*=2.n).

Results: Our ablation model can be applied to the Chasma. Channel slopes were estimated using the MOLA data. The present Chasma floor slopes downward on average 0.1°, but probably was lower during the first stage of the flooding event. The trigger mechanism that began this flow may have been lower in scale than the present geometry of the Chasma. Previous calculations of discharge rate (~10^9 m^3 s^{-1}) [3] using the current chasma dimensions are probably overestimated. Considering the diameter of the head of the Chasma, a reasonable width of the valley of 40 km is proposed. We consider a typical outflow 40 km wide with a longitudinal slope S equal to 0.01 and a Manning coefficient adapted to Mars equal to 0.06. Thermal calculations of the polar basal melting [2] indicate a total thickness of 3 km. With a mean annual temperature of 157 K and a geothermal heat flux of 3 x 10^{-2} W m^{-2}, the ice temperature within the polar cap can reach –72°C and –28°C respectively at a depth of –1 km and –2 km. In our model, we suppose an average temperature of the permafrost equal to –40°C.

The thermophysical characteristics of the ground ice are for w = 40% (massive ice content), c_p = 1146 J kg^{-1} K^{-1}, ρ = 1715 kg m^{-3}; and L_f = 96 kJ kg^{-1}; for pure ice ($w \to \infty$), c_p = 2040 J kg^{-1} K^{-1}, ρ = 917 kg m^{-3}; and L_f = 335 kJ kg^{-1}.

Considering a water temperature equal to +1°C, and a discharge of 40.000 m^3 s^{-1}, the model predicts a water depth of 0.7 m and an erosion rate equal to 5.7 m/day and 3.5 m/day for ground ice (w=40%) and H_2O ice respectively. Considering a Chasma Boreale of 520 km in length, these values correspond to an eroded volume of 114 km^3/day and 73 km^3/day. For a discharge rate as high as 5x10^5 m^3 s^{-1}, the model predicts a water depth of 3.35 m and an erosion rate equal to 21 m/day and 13 m/day for ground ice and H_2O ice respectively.

Conclusion: Calculations show that even relatively small values of water depth, water temperature, longitudinal slope as low as 0.01 and low discharge rate (40.000 km^3 s^{-1}) produce an active thermal erosion. A supra-glacial hypothesis together with an initial subglacial phase can easily explain the present volume of the Chasma Boreale. This model supposes a local melting of the ice, followed by the collapse of the thawed ground and the subsequent transport of sediments by water flow. Consequently, this ablation model is supposed to be active for a limited period of time.

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