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Fast landslides travelling on permafrost with application to Mars: preliminary modelling studies

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Abstract

Long-runout landslides on Mars and especially in Valles Marineris present similarities with terrestrial landslides collapsing on glaciers. Because it is much unlikely that ice, if any, has remained exposed in the equatorial Valles Marineris for a time span >2 Gy, this could indicate that ancient failures occurred on subsurface ice. It would be interesting to develop simulation codes for landslides in permafrost and compare the numerical prediction to case studies on the Martian surface.

1. Introduction

Landslides in Valles Marineris (Mars) resemble terrestrial landslides falling onto glaciers. Similarities include long run-out, front bulges, a flat landslide body, and especially the presence of longitudinal furrows (Fig. 1). Perhaps this resemblance is not merely superficial but may unveil the mechanics of flow during the collapse; it could possibly lead to significant information on Mars climatic history. The morphology and flow mechanics of landslides on Mars has been addressed in numerous studies [1]. We are currently planning to simulate numerically the collapse onto glaciated ground and permafrost. The challenges are better understanding the effective friction for such events; whether such a landslide will be capable of melting the pore ice at the basal layers, how will the rheological behaviour be affected, and put this information in a numerical code to simulate the run-out and final morphologies. This research program will also be beneficial to studies of terrestrial landslides in comparable environments.

2. Modelling

One possibility is to consider a Bingham fluid as a rheological model for the contact area between the landslide and glaciated soil. For the moment the horizontal dimension perpendicular to flow is suppressed, so the landslide travels with constant width. The rheological equation is (list of symbol at the end of the abstract) $\tau = -\tau_y + \eta\ \partial u / \partial y$. A landslide described with this rheology will develop an outermost plug region where the shear stress is lower than a critical value equal to the Bingham yield stress τ_y and where the landslide travels rigidly; and a basal shear layer where shearing occurs. The rheology can be extended to include frictional behaviour by summing a term of the kind $\mu \cos\beta \rho g\ (D-y)$ (the ploughing component of friction of rock on ice is probably important, [3]). Inertia terms in the momentum equation are fundamental in describing the time-dependent behaviour of the fluid and thus the thickness of the shear layer must be calculated iteratively. A possible framework is BING, a depth-integrated Lagrangian model, suited for extension to complex rheologies and changes of the material properties with time [3]. The model landslide is divided into a number of sectors, each one travelling in accordance with momentum and continuity equations. The depth integration allows for a much easier formulation of the flow; as a drawback, however, the vertical velocity is not resolved as a function of the height, but is imposed externally like that of a fluid of infinite extension

$$u(y) = \frac{\rho g\ \sin\beta - \mu \cos\beta}{\eta} \left[D_S\, y - \frac{y^2}{2} \right] \quad (\text{if}\ \ y < D_S) \qquad (1)$$

The power dissipated by the fluid at a certain level *y*

$$dE/dt = \tau \frac{\partial u}{\partial y} = \ \rho g \sin\beta\ ^{2} (D-y)(D_S - y)/\eta \qquad (2)$$

If advection and conduction of the generated heat are not considered, the temperature reached at time *t* at this level can be calculated as

$$\Delta T(t) = \left[C_W \rho_W p + C_R \rho_R \left(1 - p\right) \right]^{-1} \int_0^t (dE/dt)\, dt \qquad (3)$$

Figure 2 shows the results of a model simulation. Temperature sufficient to melt pore ice at the sliding surface may be reached within 10 s from start, but several simulations with different initial conditions show that this conclusion depends much on the velocity, depth of the landslide and the acceleration (in turn, sensitive to the shape of the sliding surface).

After the melting point is reached, heat is used up to melt the ice; the fraction of molten ice is the cumulated heat $10^6 - 10^7 \times \text{time J m}^{-3}$ divided by average density and latent heat $\lambda = 3.3\times10^5$ J Kg^{-1}; it turns out that >100 s are necessary for complete melting. It will be important to understand how the rheological properties may be affected by partial melting and how changes in rheology will affect the behaviour of the landslide; we are working at implementing the code along this line. Note that shearing occurs only at the base, and not at all in the plug layer.

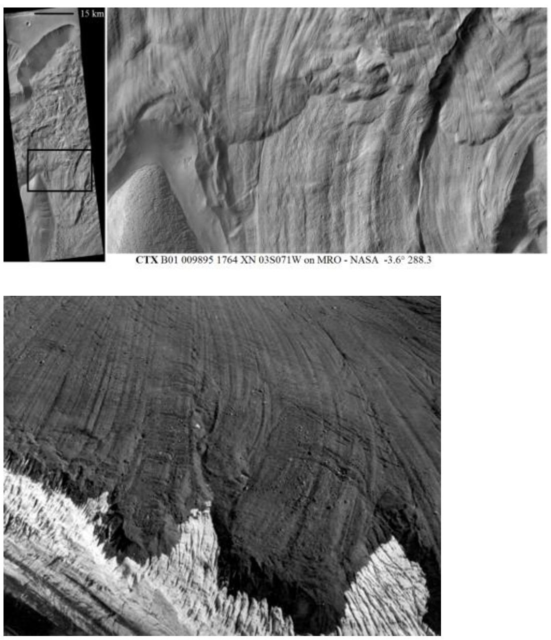

Figure 1. Landslides in Valles Marineris (top) exhibit longitudinal furrows similar to those in the Alaskan landslide of Sherman (bottom). Top and bottom figures courtesy of NASA and USGS respectively.

This implies that the top of the landslide maintains the same pore ice, which is consistent with the observation that landslides falling on top of previous landslide deposits still travel as they do on undisturbed soil (see e.g. the small landslide on the right of Fig. 1). The model will also be extended to deal with landslides changing width, as it is the case for many events in Valles Marineris.

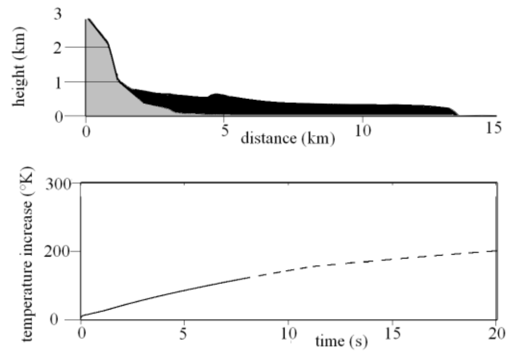

Figure 2. Top: Simulation result with constant rheological properties. Landslide profile after 120 s from start is shown in black. Bottom: Temperature increase at 1/3 the height of the shear layer.

List of symbols

C_W : specific heat of water; C_R : specific heat of rock;

D : landslide thickness; D_S : thickness of shear layer;

dE/dt : power; $g = 3.7$ m s^{-2} : gravity acceleration;

p: pore fraction of soil; y : vertical coordinate

β : slope angle; λ : latent heat; μ : friction coefficient;

η: Bingham viscosity; ρ_W : density of water; ρ_R : density of rock;

ρ : density of rock-ice mixture; τ : shear stress; τ_y : yield stress

References

[1]. Bigot-Cormier, F., Montgomery, D.R. 2007. EPSL 260, 179-186. Harrison, K.P., Grimm, R.E., 2003. Icarus, 163, 347-362. Lucchitta, B.K., 1979. J. Geoph. Res. 84, 8097-8113. Shaller, P.J. 1991. Ph.D. Thesis, CALTECH. Soukhovitskaya, V., and Manga, M. 2006. Icarus 180, 348-352. Quantin, C., Allemand, P., Mangold, N, Delacourt, C., 2004. Icarus 172, 555-572. Bulmer, M. H. 2012. In: Landslides, J.J. Clague and D. Stead (Eds.), Cambridge. Lucas, A., Mangeney, A. GRL 34, 10. [2]. De Blasio, F.V. 2011. Planetary and Space Science 59, 1384-1392. [3]. Imran et al. 2001. Comp. Geosc. 27, 721-733.