THE RHEOLOGY OF ICE-ROCK MIXTURES INFERRED FROM ANALOGUE MODELS: APPLICATION TO THE GRAVITATIONAL FLOW OF MARTIAN SUPERFICIAL FORMATIONS.

O. Bourgeois, D. Devismes and M. Cevatoglu, Laboratoire de Planétologie et de Géodynamique, UMR 6112, CNRS, Université de Nantes, Faculté des Sciences et Techniques, 2 chemin de la Houssinière BP 92208, 44322 Nantes Cedex 3, France. olivier.bourgeois@univ-nantes.fr

Introduction: Several features of the surface of Mars display morphological characteristics suggesting that they are composed of a ductile material flowing under its own weight similarly to terrestrial glaciers. These features include the two large polar caps, smaller dome-shaped crater fills, lineated valley fills and lobate aprons surrounding table mountains. These later features have been interpreted as rock glaciers composed of ice mixed with various amounts of rock particles [1].

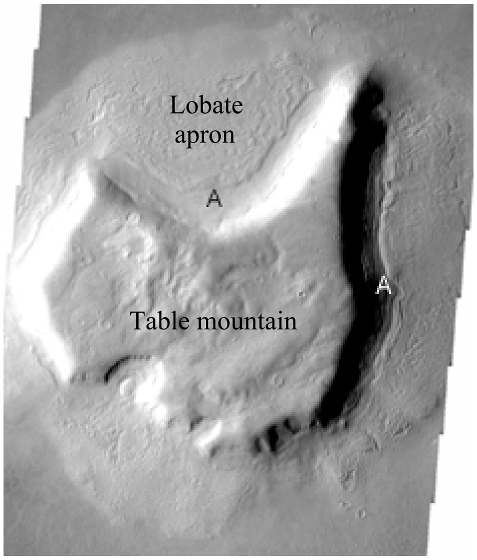

***Figure 1**: Example of a lobate apron flowing around a table mountain in the northern lowlands of Mars. THEMIS Image V11583002. The table mountain is approximately 20 km in diameter.*

Classical glaciological laws can help derive the respective amounts of ice and rock particles in these superficial formations from their morphology, provided that the rheology of ice-rock mixtures is known. Experimental constraints on the rheology of such mixtures have been obtained on laboratory samples by various authors [2,3,4]. However the extrapolation of these laboratory measurements to the gravitational flow of natural bodies is difficult for the following reasons: (1) experimental strain rates are generally much larger than natural ones; (2) stress intensities and stress regimes in laboratory samples submitted to classical uni-axial or tri-axial compression tests differ markedly from those of natural viscous bodies flowing under their own weight; (3) scaling effects can induce significant differences between the rheological behavior of a 1-10 cm-sized sample and that of a whole, 0.1-1000 km-sized body of mixed ice and rock particles. Therefore, we use an alternative and complementary approach, based on the modeling of the gravitational collapse of an experimental cap made of analogue materials. From these scaled analogue experiments, we derive laws that link the rheological behavior of ice-rocks mixtures to their volumetric rock content.

Analogue modelling: We prepared several models made of silicon putty (a viscous material used as an analogue for ice) mixed with various amounts of dry sand (a granular material used as an analogue for rock particles). The experiments were scaled so that the dimensionless ratio between the resistance of the material to deformation and the gravitational stress is the same in the model and in the nature (Table 1).

	$\rho_{Ice} - \rho_{rock}$ *(kg/m³)*	g *(m/s²)*	h *(m)*	τ_0 (ice) *(Pa)*	τ_0 / ρgh *(dimensionless)*
Model	1000 - 2600	10	0.001	0.1	0.01
Earth	1000 - 2600	10	500	50 000	0,01
Mars	1000 - 2600	3.7	1350	50 000	0,01

***Table 1**: Values of physical parameters for Mars, Earth and experimental gravitational flows.*

Cylindrical caps made of these mixtures were let to flow radially under their own weight on a horizontal plate. Topographic profiles were measured after complete gravitational collapse of the models. Under the assumption that the mixture behaves as a perfectly plastic material, the final topographic profile is governed by the following equation [5]:

$$h^2 = (2d\tau_0)/(\rho g) \qquad (1)$$

where h is the thickness at a distance d from the front of the cap, τ_0 is the plastic yield stress and ρ the specific weight of the mixture, and g is the acceleration of gravity. The experiments show that the yield stress (τ_0) of silicon-sand mixtures increases with their volumetric sand concentration (Φ) as follows:

$$\tau_0(\Phi) = \tau_0(0\%) \cdot 0.3 \cdot (\Phi_{max} - \Phi)^{-2.4} \qquad (2)$$

where $\tau_0(0\%)$ is the yield stress of pure silicon putty and Φ_{max} is the maximal theoretical concentration of particles in the mixture ($\Phi_{max} = 0.635$ for spherical particles of identical size).

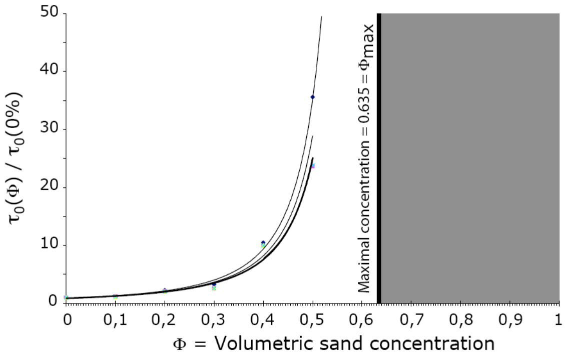

***Figure 2**: Yield stress of experimental silicone-sand mixtures as a function of their volumetric sand concentration.*

Application to Martian gravitational flows: From equations *(1)* and *(2)*, and using the values listed in Table 1, we computed theoretical topographic profiles for natural ice-rock mixtures on Earth and on Mars (Figures 3 and 4). The theoretical profiles computed for Earth are consistent with topographic profiles of real glaciers and rock glaciers with various concentrations of rock particles (Figure 3).

Topographic profiles of Martian debris aprons, derived from the MOLA topographic grid, are generally very close to (or a bit flatter than) theoretical profiles computed for pure ice (Figure 4). This suggests that Martian debris aprons are composed mostly of ice, and that rock particles form only a superficial veneer covering the ice.

References: [1] Mangold N. and Allemand P. (2001) GRL 28, 407-410. [2] Durham W.B. et al. (1997) JGR 102, 16293-16301. [3] Durham W.B. et al. (1999) GRL 26, 3493-3496. [4] Mangold N. et al. (2002) PSS 50, 385-401. [5] Paterson W.S.B. (1994) The Physics of Glaciers.

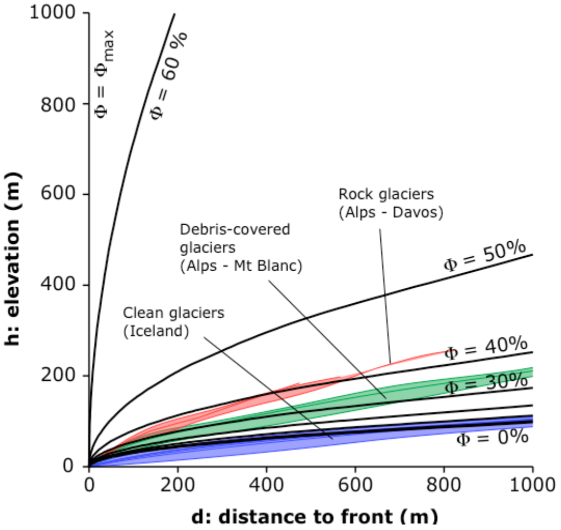

***Figure 3:** Topographic profiles of terrestrial glaciers and rock glaciers (colored fields) compared to theoretical profiles computed from equation (2) for various concentrations of rock particles (Φ).*

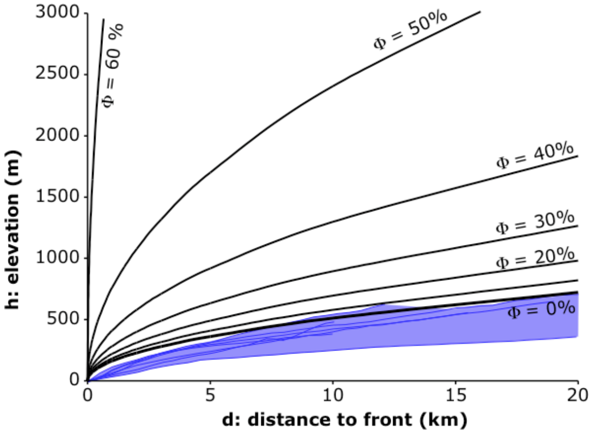

***Figure 4:** Topographic profiles of Martian debris aprons (blue field) compared to theoretical profiles computed from equation (2) for various concentrations of rock particles (Φ).*