LEVEE-CHANNEL DEPOSITS IN DRY OR WET DEBRIS FLOWS: A TOOL TO UNDERSTAND GULLIES FORMATION. N. Mangold[1], A. Mangeney[2], F. Bouchut[3], [1]Laboratoire IDES-Orsay, CNRS, Bat 509, 91405 Orsay, France, nicolas.mangold@u-psud.fr., [2]IPGP, CNRS, Université Denis Diderot, 4 Place Jussieu, 75005 Paris, France, mangeney@ipgp.jussieu.fr, [3]Département de Mathématiques et Applications, ENS, CNRS, 45 rue d'Ulm, 75005 Paris, France, francois.bouchut@ens.fr

Introduction: Recent gullies on Mars are observed on the wallslopes of the mid-latitude regions. They might sign the presence of fluid flows, likely involving liquid water, in a recent past [1]. However, authors have shown that dry flows might be an alternative to the formation of Martian gullies [e.g.2]. Levees are frequently present together Martian gullies independently of their location (dunes, crater wallslopes, isolated hillslopes) [1,3,4]. Levees morphometry is different in a dry or a wet flow therefore enabling us to measure Martian levees and to compare which case fits best. The high resolution images HiRISE allow us to look in detail to levees characteristics and measure their size using photoclinometry. Despite levees are not ubiquitously observed together gullies, many leveed channels have been identified on several images of gullies with HiRISE (Fig. 1, Fig. 2). Thus, the aim of this work is to identify critical parameters that discriminate the processes of the levees formation and test them on Mars from levees observations on HiRISE images.

Physical basis for levees morphometry: Terrestrial wet debris flows are often modeled using the Bingham fluid properties [5]. A Bingham plastic material has a linear relation between the strain rate and the stress but with a finite yield strength [4, 5]. This means that it does not deform until a critical shear stress is reached, after which it deforms as a Newtonian fluid (linear relation). The occurrence of the critical shear stress is the main reason of the presence of lateral deposits: As the flow gets thinner near the lateral shoulders of the channel, the gravity force which is proportional to the thickness of the flow gets smaller. As a result, the driving forces are not strong enough for the material to exceed the critical shear stress, thus leading to the formation of lateral levees.

For granular flows, laboratory experiments show that self-channeling lobes and levee-channel deposits can be obtained when the slope higher than 20° [e.g. 6]. The appropriate flow law to describe dissipation in dry granular flows is still under debate. An empirical parameterization of the friction law has been suggested in the recent years [7]. This theory shows that the friction coefficient involved in the classical Coulomb friction law increases with decreasing thickness and increasing velocity. The thickness h_{stop} left on an inclined plane by a steady granular flows when the supply is cut is an empirical parameter of the friction law [7, 8].

Difference between levees formed by dry and wet flows: A dry granular flow compared to a wet debris flow can show very similar characteristics, but details of the shape of levees show differences. We describe hereafter three main parameters:

(1) Occurrence of sinuosities: Granular flows can present changes of direction when the slope changes downward and, in some conditions of grains angular texture and diversity, they can show changes of directions [9]. However, they never show cyclic sinuous changes of direction resembling to meanders.

Bingham fluids are viscous materials that can exhibit properties of fluid flows with inertia leading to produce sinuosities, resembling those of channels meandering, when the slope decreases and the fluid slows down. Parameters controlling the sinuosities are likely different from meanders in channels and are not well understood despite they are frequently observed on Earth [10]. Therefore, the presence of cyclic sinuosities is an argument in favor of wet debris flows.

(2) Shape at the end of flows: The end of granular flows is always constituted by a terminal tongue which corresponds to the progressive decrease of levees size and a simultaneous increase of the channel before it stops to flow [6,7,8]. Terrestrial debris flows controlled by liquid water mixed with rocks present end of flows frequently with terminal levees [10]. This possibility is not unique because terminal tongues with no levees can also exist, as well as debris deposits with a various of shapes. Therefore, the presence of terminal levees rather than a tongue favors wet debris flows, whereas the presence of a tongue is not discriminating.

(3) Slope at the end of the flows: Granular flows have their final tongue controlled by the critical angle of repose. This angle is generally >20° for usual spherical grains, sand size grains [e.g. 6]. Inertial effects could significantly decrease the slope of the deposit. Actually, deposit's slope < 20° are possible in certain conditions: when a large amount of material is transported with large elevation difference, or when the flow is permanently fed by material, as for pyroclastic flows [6, 9]. However, in most case, the shape of the flow is different at low slope because accumulation dominates [9]. The final slope of Bingham flows is controlled by the critical shear stress that can be very low if the material is enough fluid [10]. End of flows over slopes at 1° to 10° are frequent [5, 10]. At such low slope, wet flows can show the

same shape at low slope (leveed channels) as on steep slope, at the difference of the dry material. Therefore, the end of flows on slopes <10° favors wet flows when they still shows a leveed channel, whereas dry flows would better stop over relatively steep slopes (>20°) or show different shape on lower slopes. This argument nevertheless requires a close look to the overall shape of the flow and can not be used blind as a "yes or no" test. These parameters are under tests using numerical models [11].

Martian examples: HiRISE images of gullies show a larger variety of landforms than visible with MOC images. Levees are frequent, despite not everywhere. Here we report preliminary results.

Images of Russell dunes gullies show 1 km long sometimes sinuous leveed flows (Fig. 1). These gullies were previously interpreted as wet debris flows from their shape and sinuosity [4]. Given the difference in properties of dry and wet flows, the three parameters are positively in favor to wet debris flows. For example, the end of flows are often terminal levees different from tongues observed in dry cases, sinuosities exist for several channels, and the slope on which flow this material is of about 10° over 100s of meters. Notice that these channels have ends often showing small pits suggesting that some specific processes also concur at these locations such as sublimation or infiltration of volatiles.

One image of a typical crater wallslopes show lot of gullies with some of them showing sinuous channels (Fig. 2). Despite we can not tell if this flow was unique, they might be different episodes to explain the observed landforms, the presence of cyclic and well expressed sinuosities favor a wet debris flow.

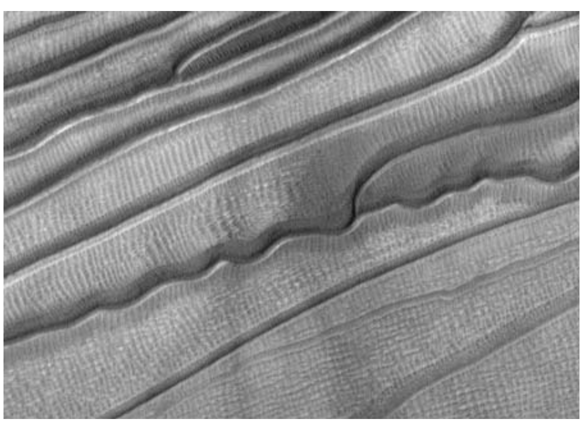

Fig. 1: Close-up on HiRISE4038_1255 with straight and sinuous gullies over Russell crater dune megadune.

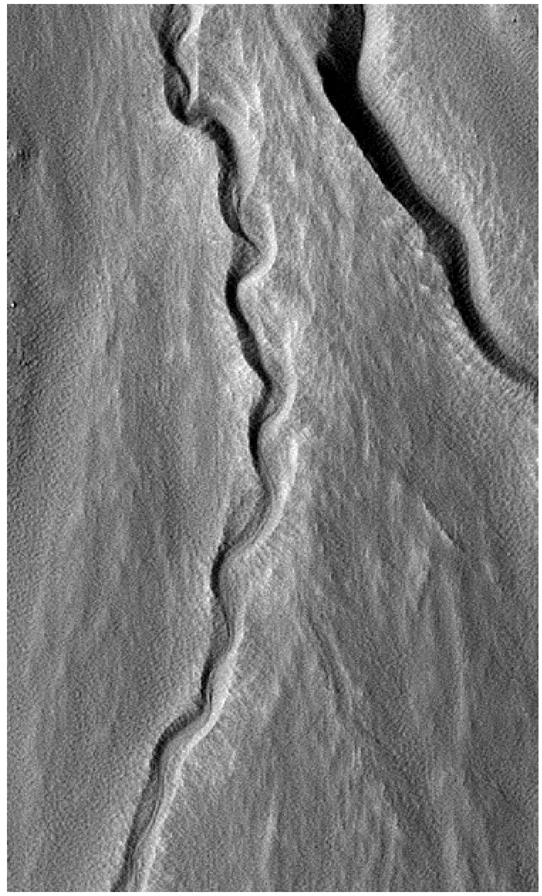

Fig. 2: Close-up of HiRISE 3464_1380 showing sinuous channel. Levees are less visible than on figure 1 possibly due to multiple episodes of flows.

Conclusion: The morphometry of levees can be used as a discriminator between granular and wet flows for those of the Martian gullies having levees around channels. The shape of several levees channeled flows match better wet flows than dry flows for the examples studied. These examples are preliminary and require more statistical study.

.**References:** [1] Malin, M. C., and Edgett, K. S. (2000), *Science*, *228*, 2330-2335, 2000 [2] Treiman, A. H. and Louge, M.Y. (2004), *Lunar and Planet. Sci.* XXXV. [3] Costard F., Forget, F. Mangold, N., Peulvast, J.-P., *Science*, 2002 [4]. Mangold, N. et al., (2003), *JGR*, *108(E4)*, 5027, 2003. [5] Allen, P. A., Earth Surface Processes, Blackwell [6] Felix, G. and Thomas, N. (2004), *EPSL*, *221*, 197-231. [7] Pouliquen, O., and Y. Forterre (2002), *JFM*, *453*, 133-151. [8] Mangeney, A. et al. (2007), *JGR*, *112*, F2017. [9] T. Shinbrot, N.-H. Duong, L. Kwan, and M. M. Alvarez, PNAS , 2004. [10] Corominas, Jet al., Debris flow, in Landslide Recognition, R. Dikau et al., pp. 161 –180, John Wiley, New York, 1996. [11] Mangeney et al., 2008, this conf.