and a step. The third avalanche thus stops at the same length than the first one and this leads to the principle of a binary counter (Fig. 5 bottom). The symmetry between the two experiments is recovered even in this regime : for a very small flow rate, the emptying experiment also provides a binary counter, by succession of upward avalanches (Fig. 5 top).

FIG. 5. Evolution of the free surface profile as a function of time, in the low flow rate regime. Successive avalanches are nucleated but stop before having reached the side boundary. The successive places where they stop turn out to form a binary counter.

Conclusion – This half flat hourglass shows the richness of avalanches behaviors. It evidences the existence, not of one kind of avalanche front, but of four. The symmetries between these four fronts allow to introduce a double classification, depending on whether the front propagates upward or downward the pile and wether the grains start or stop rolling. As from now, it is clear that this classification extends to many other geometries [6]. It is the interest of the half flat hourglass to exhibit the whole four fronts in the same experiment.

A preliminary numerical simulation (Fig. 4) of the model previously proposed by the authors [10] shows that it allows to recover the main characteristics of these four fronts. This experiment turns out to be a good test case since the details of the four fronts are very sensitive to the physics involved in the model. We have shown for instance that the tendency to create shocks or to stretch the fronts is directly related to the strong velocity gradient inside the flowing layer. Moreover, the propagation of stopping fronts (as well as the binary counter regime) originates in the trapping of grains i.e. in the subcritical transition between flowing and static states. Any model [11,12] which does not take into account these mechanisms , cannot reproduce the four kinds of fronts. More work is undergoing for a precise comparison between experimental results and models [10].

The authors wish to thanks L. Quartier for his valuable help.

[1] S. Brantley and H. Glicken, Volcanic Debris Avalanches : Earthquakes & Volcanoes **18**, 195 (1986).
[2] H.J. Melosh, *Nature* **348**, 483 (1990).
[3] N. Armstrong, R. Betsy and K. Williams , "The Avalanche Book", Fulcrum Pub. (1992).
[4] R. A. Bagnold, *Proc. Roy. Soc. London* **A 225**, 49 (1954).
[5] H.M. Jaeger, S.R. Nagel and R.B. Behringer, *Rev. Mod. Phys.* **68**, 1259 (1996).
[6] A. Daerr and S. Douady, *Nature* **399**, 6733 (1999).
[7] C. Coulomb, Mémoires de Mathématiques et de Physique Présentés à l'Académie Royale des Sciences par Divers Savants et Lus dans les Assemblées, 343 (1773).
[8] O. Pouliquen, *Phys. Fluids* **11**, 1956 (1999).
[9] T. Takahashi, *Ann. Rev. Fluid Mech.* **13**, 57 (1981).
[10] S. Douady, B. Andreotti and A. Daerr, *Eur. Phys. J.* **B 11**, 131 (1999).
[11] J. P. Bouchaud, M. Cates, J. R. Prakash and S. F. Edwards, *J. Phys. France* **I 4**, 1383 (1994).
[12] T. Boutreux, E. Raphael and P. G. de Gennes, *Phys. Rev.* **E 58**, 4692 (1998).
[13] J. Rajchenbach, in "Physics of Dry Granular Media", H. Hermann et al. eds., 421 (1998).
[14] B. Andreotti and S. Douady *Phys. Rev.* **E 63**, 031305 (2001).
[15] L. Quartier, B. Andreotti, S. Douady and A. Daerr, *Phys. Rev.* **E 62**, 8299 (2000).
[16] M. Caponieri, S. Douady, S. Fauve and C. Laroche, in "Mobile particulate systems", Guazzelli and Oger eds. Kluwer, Dordrecht (1995).
[17] For a grain by grain addition, another intermittent regime is observed, K. Christensen, A. Corral, V. Frette, J. Feder and T. Jossang, *Phys. Rev. Lett.* **77**, 107 (1996).