# Granular Phase Transition in Depth Hoar and Facets: A New Approach to Snowpack Failure?

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## ABSTRACT

Depth hoar and faceted crystal layers consist of a granular aggregate of polyhedral grains of ice. When left undisturbed, these aggregates exhibit the properties of a granular solid (Gs): the order, position and packing fraction of the grains remain unchanged in time. On the other hand, when mechanically disturbed, the same aggregates exhibit the properties of a granular liquid (Gl): the grains start to flow and the packing fraction can suddenly increase. Fundamental physical characteristics of this granular phase transition such as repeatability, reversibility of cycles, and energy of activation are explored in a number of simple field experiments recently carried out in the French Alps. The granular phase transition is repeatable at will in both directions but the packing fraction of the final state may not be identical with the packing fraction of the initial state. In order to activate a full Gs-to-Gl transition in a 1 dm³ container, an energy barrier of the order of 0.01 J/dm³ to 0.1 J/dm³ must be overcome. The observed granular phase transition poses new questions regarding crack nucleation and crack propagation in interfaces between slab layers and layers of depth hoar or facets. Indeed, actions such as skiing or snowboarding may activate local granular phase transitions near the interface, which in turn may activate interfacial fracture by anticracking. The study of the granular phase transition has therefore a large potential for deepening the understanding on how slab avalanches occur when depth hoar or facets are involved in the fracture process.

## WEAK LAYER AND SHOVEL EXPERIMENT


If collected on a shovel, depth hoar flows as a granular liquid (GL).

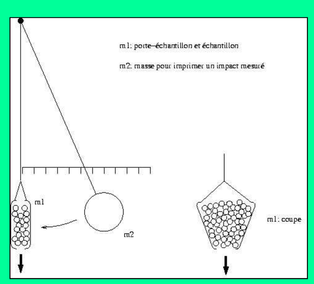

But after staying a few seconds on the shovel, it clots into a granular solid (GS)





## BOTTLE EXPERIMENT

Depth hoar rapidly clots into GS
after bottle filling is achieved.
It turns back to GL and flows out
if knocked by the pendulum
released from above a well defined height.

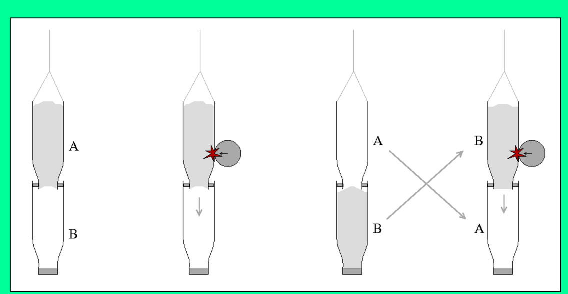


A rough estimate of GS cohesive energy
can be derived from knocking energy.
The energy barrier for the GS->GL transition is
found between 0.01 J/dm³ and 0.1 J/dm³.
It obviously depends on grain size.


A similar experiment
on a non cohesive material (rice)
shows a very different behaviour:

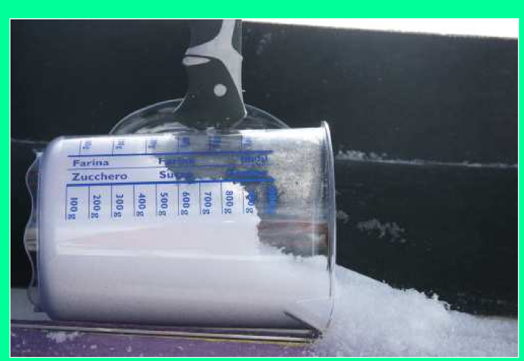
Rice flows down immediately
upon bottle opening (no clotting)

## REPEATABILITY AND REVERSIBILITY



The granular phase transition
is repeatable at will
in both directions
without significant change in density.

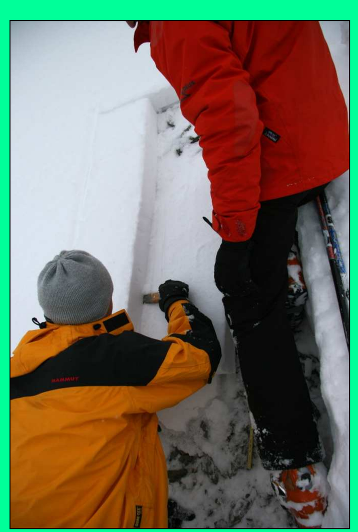
## SOFT CONTAINER EXPERIMENT



The GS->GL transition also takes place
under slower compressive loading

We expect the same transition to result
from the mechanical impulse
of a skier or a snowboarder

## PROPAGATION SAW TEST (PST)



The collapse of a weak layer (anticrack)
could occur during the first GS -> GL transition
in which the density increases.

The resulting GL phase cannot oppose slab glide
as long as it does not clot back into the GS phase



## SUMMARY AND CONCLUSIONS

- Field experiments show that granular aggregates of polyhedral grains of ice found in weak layers undergo:
  - a solid to liquid transition under mechanical loading
  - a spontaneous liquid to solid transition if left undisturbed for a few seconds

- The initial solid to liquid transformation, evidenced by PST experiments (1), takes place during the nucleation and the propagation of an anticrack (2), and is associated with a density increase, i.e. a denser packing of grains. Such a transformation is likely to be initiated by actions such as skiing or snowboarding.

- Except for the initial solid to liquid transformation, the observed transition is reversible and repeatable

- The physical parameters characteristic of such a transition (cohesive energy, clotting time, …) have been measured

- Similar experiments and measurements are being performed in cold chamber environment

- The study of these granular phase transitions has therefore a large potential for deepening the understanding of how slab avalanches occur when depth hoar or facets are involved in the fracture process.

## REFERENCES

(1) A. van Herwijnen, J. Heierli, and J. Schweizer. Field study on fracture propagation in weak snowpack layers. In Proceedings of the 2008 International Snow Science Workshop, Whistler, Canada, 2008.
(2) J. Heierli, P. Gumbsch & M. Zaiser, Science 321, no 5886, p. 240-243, 2008.