Gravitational Salt Tectonics Triggered by Deposition of Turbiditic Lobes: a New Experimental Modeling Approach with Applications to Salt Tongues in the U.S. Gulf of Mexico*

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Abstract

So far, there have been two drastically different approaches at modeling the effects of deposition of clastic sediments wedges along passive margins. First, the stratigraphic approach models sediment transport and deposition, focusing on the resulting stratigraphic architecture, but neglecting the impact of syndepositional deformation. Many flume experiment simulating turbidity deposits were designed to understand the stacking patterns of deep-sea turbiditic fan systems. But most experiments did not account for syndepositional deformation. Second, there has been some extensive experimental and numerical work by structural geologists on deformation of sediment wedges above weak substrates (salt or shale), but using rather crude and simple ways of sedimentation processes (by adding episodically one sediment layer uniformly, regardless of the potential influence of the bathymetric relief on depositional patterns).

We designed a new tectono-stratigraphic modeling tank that comprises a channel connected to a main basin. The basin can be filled with different kind of substrates either rigid (sand) or viscous (silicone polymer, simulating a salt layer of varying length and thickness). A mixture of fine-grained sand powder and water (50 to 150µm in diameter) were released, then channeled into the basin.

We investigated the effect of depositing several consecutive turbiditic lobes on the deformation of a viscous salt body. The dynamics of turbidity currents lead to deposits whose thickness varied laterally: thick in the proximal area, and thinning progressively distally, thus creating a gentle regional surface slope. In addition, salt's response to even minor local differential loading was vigorous. In models, lobe deposition generated sub-marine dunes sub-millimetric in scale. The underlying salt immediately subsided beneath each

sedimentary ridge, and rose passively in between the dunes. Furthermore, with growing maturity of the sedimentary lobe, regional spreading/collapse of the entire overburden started. Spreading induced shortening at the distal salt basin's edge and radial extension in the proximal area, which generated multidirectional grabens and normal faults, in a ROHO fashion, and associated salt ridges that evolved into piercing diapirs.

We also conducted a series of systematic experiments varying the length and thickness of the salt body, as well as the sediment input. The outcome varies from ROHO-like structures to counter-regional faults.

Selected References

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Gravitational Salt Tectonics Triggered by Deposition of Turbiditic Sediments:
A New Experimental Approach with Applications to Salt Tongues in the U.S. Gulf of Mexico

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Scientific question

- What is the mutual influence between sedimentation and gravitational salt tectonics?

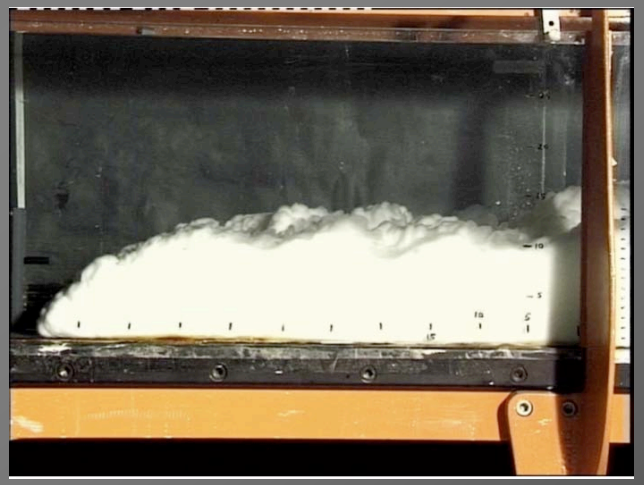
Outline

- Introduction
- New experimental approach and set up
- Salt response to *local* differential loading
- Salt response to *regional* differential loading
- Conclusions and perspectives

INTRODUCTION

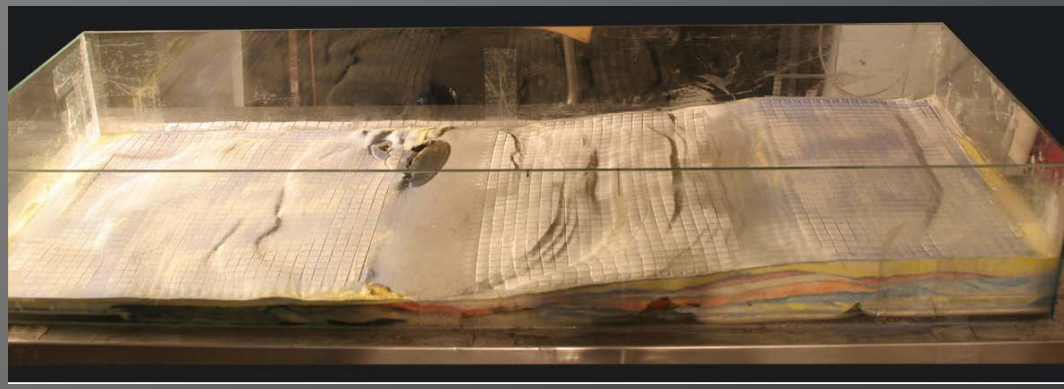
Two different ways for modeling the effects of deposition of turbiditic sediments wedges along passive margins:

- Turbidity current deposits modeling (Flume experiments)



Baas et al., 2005

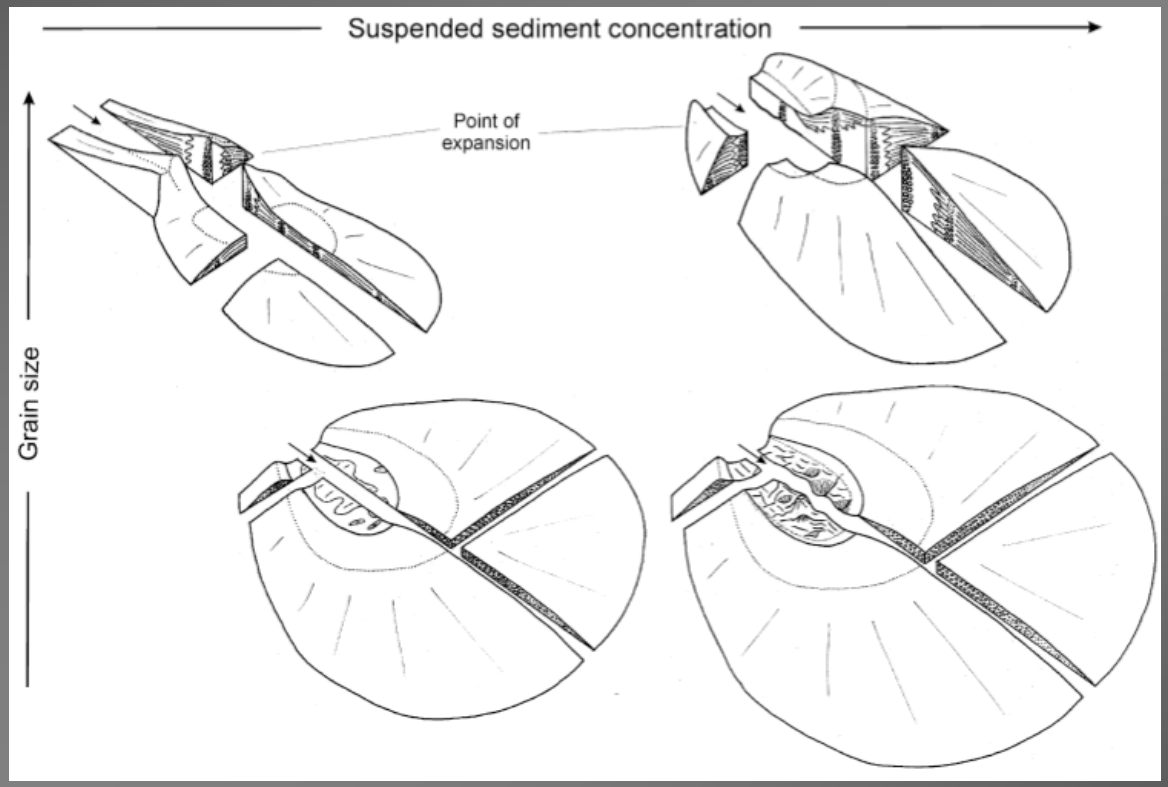
- Classic (sandbox) physical modeling



Turbidity current modeling (Flume)

Flume experiments have focused mainly on:

- Flow properties
- Stacking pattern and lobe switching (Parsons et al., 2002)
- The geometry of sediment bodies (Baas et al.,2004)



Baas et al., 2004

Lobes with proximal channel-levee system:

- Structureless sediments filling in the channel and lobe's centre

- Laminated levee bodies and lobe fringe

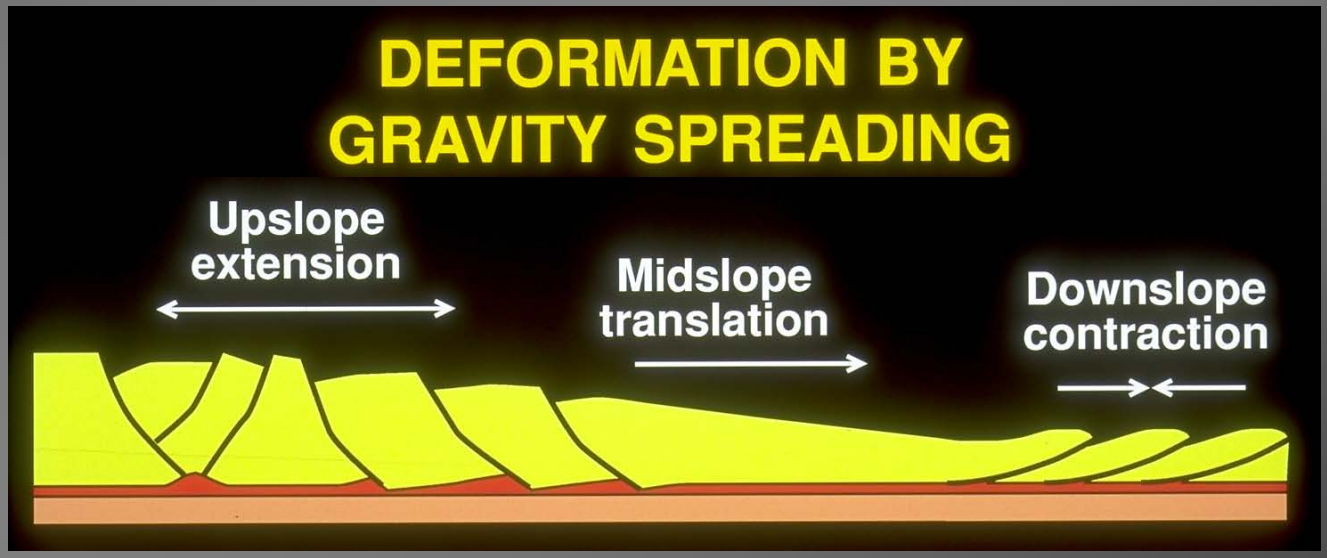
Turbidity current modeling (Flume)

However, most flume experiments have not combined **sediment** ***transport*** *and* **deposition** *with* **synsedimentary deformation**

Salt Tectonics modeling

Numerical and experimental models (Ings et al.,2004; Vendeville, 2005) demonstrate that deposition of successive sediment wedges onto a weak substratum (salt or shale) triggers:

- Vertical collapse of the sedimentary wedge.
- Lateral spreading of the lobe.



Vendeville (2005)

Salt Tectonics modeling

But this approach is strictly tectonically oriented:

➔ deposition of each lobe is crudely modeled by adding a new layer uniformly, regardless of the influence of bathymetric highs or lows on the depositional pattern.

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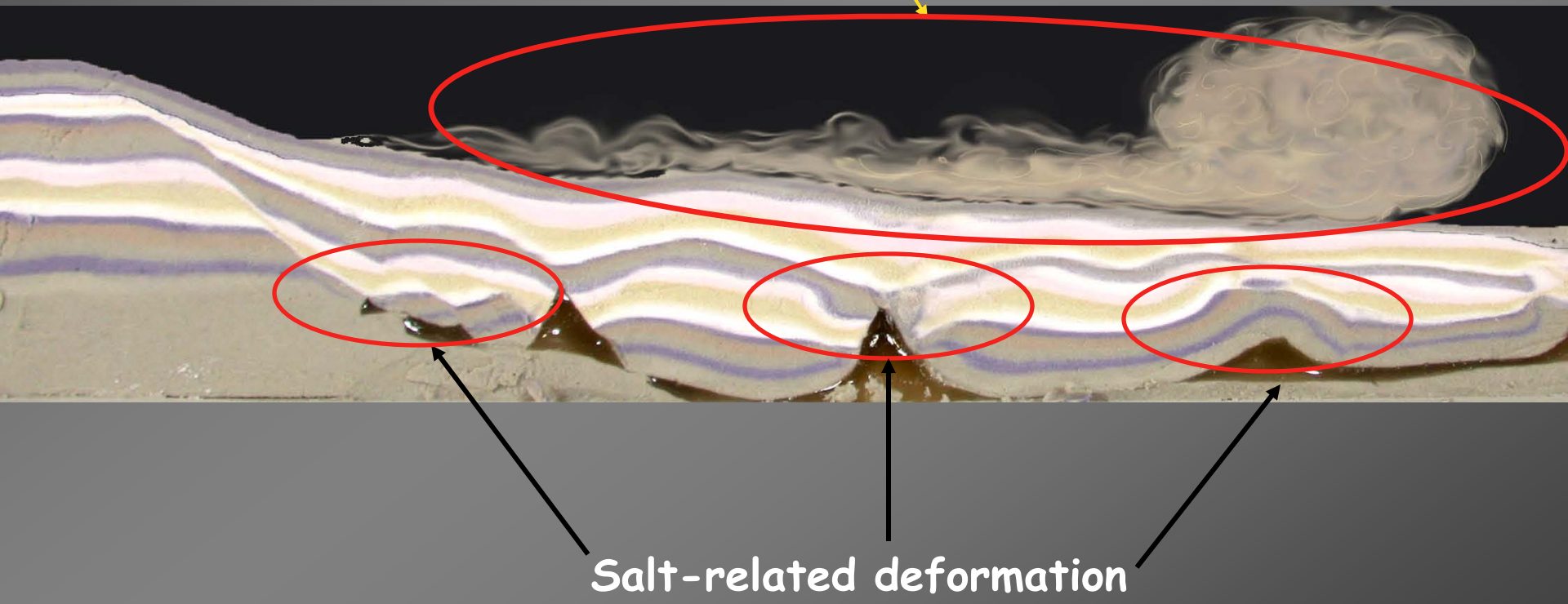
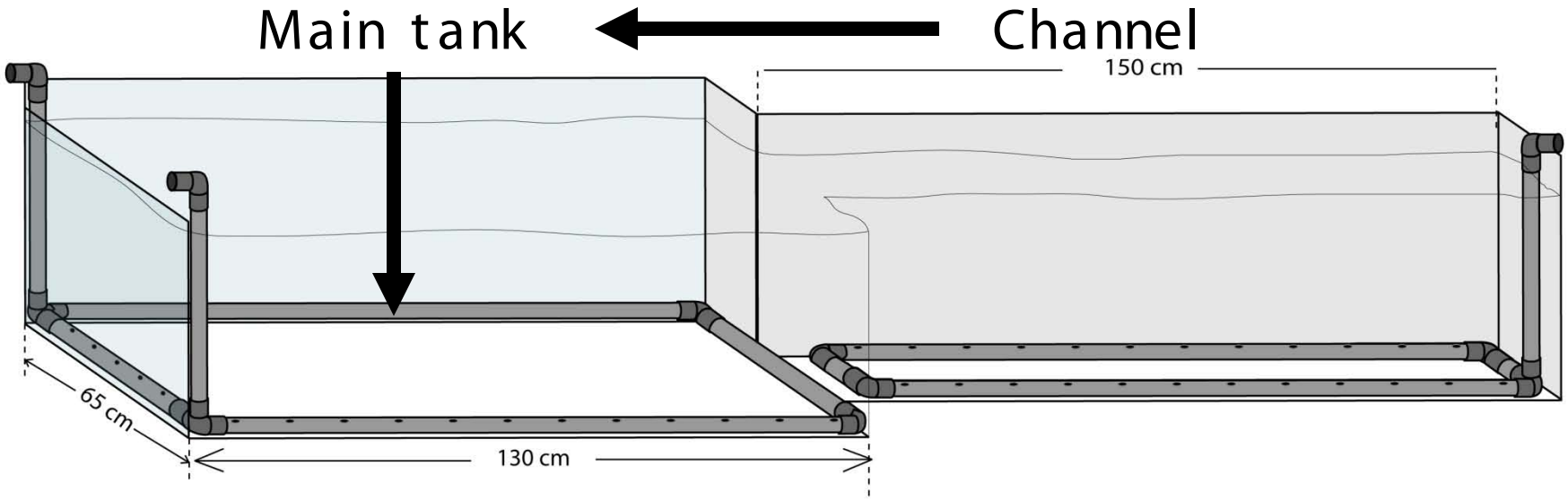
A new experimental approach

Aim of the study :

To design a new tectono-stratigraphic tank that combines modeling:



Experimental set-up



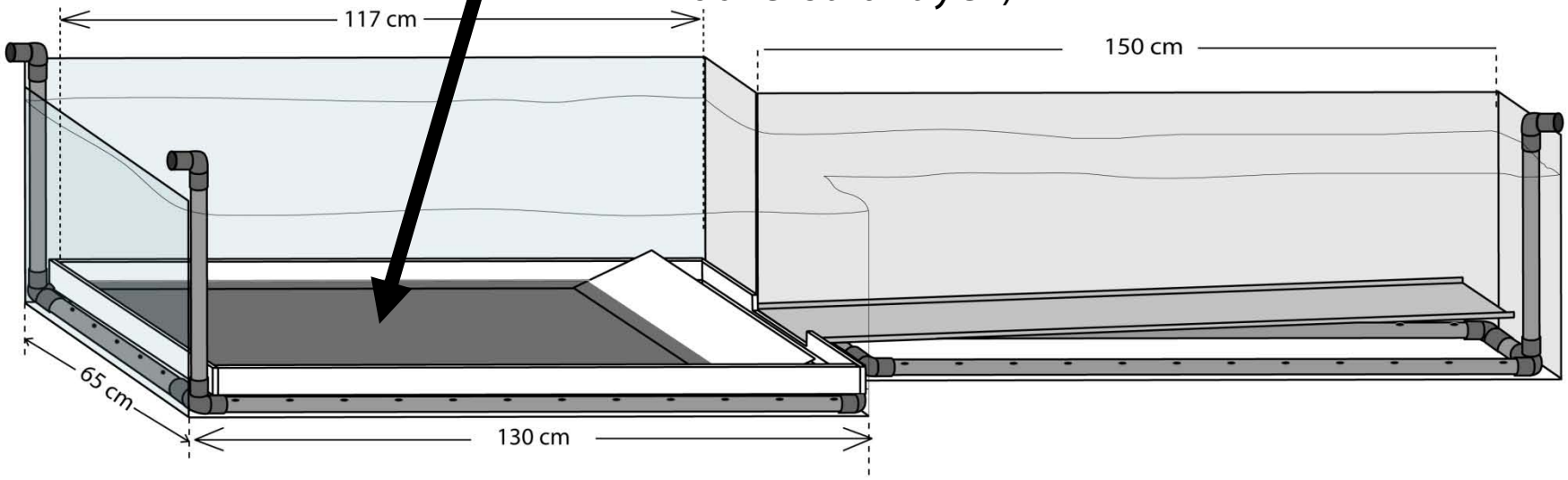
Sellier and Vendeville (2008)

Experimental set-up

Deformation tank:

➔ can be filled with various substrates:

- Rigid (sand)
- Viscous (silicone polymer, simulating mobile salt layer)

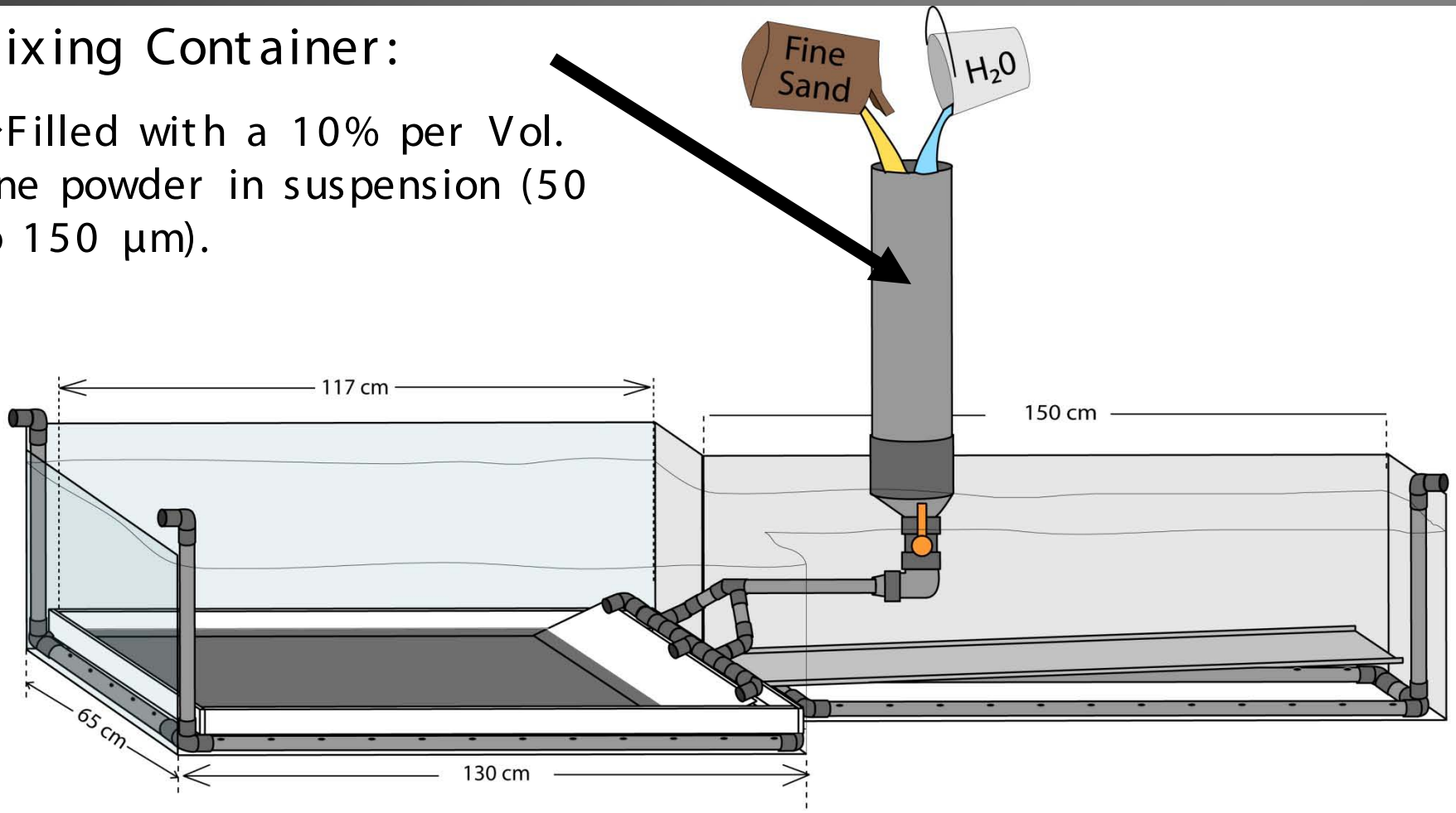


Sellier and Vendeville (2008)

Experimental set-up

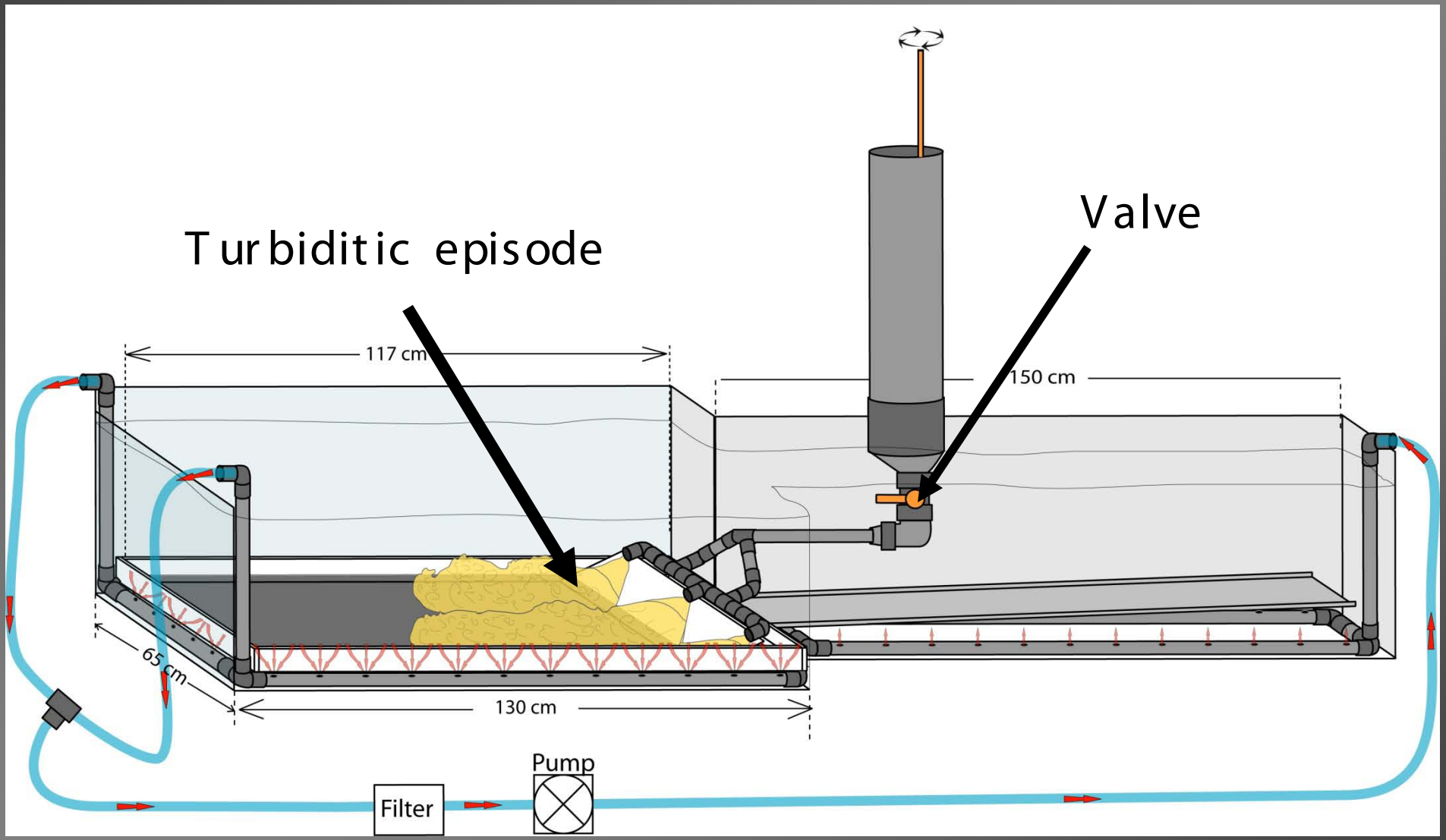
Mixing Container:

➔Filled with a 10% per Vol. fine powder in suspension (50 to 150 µm).



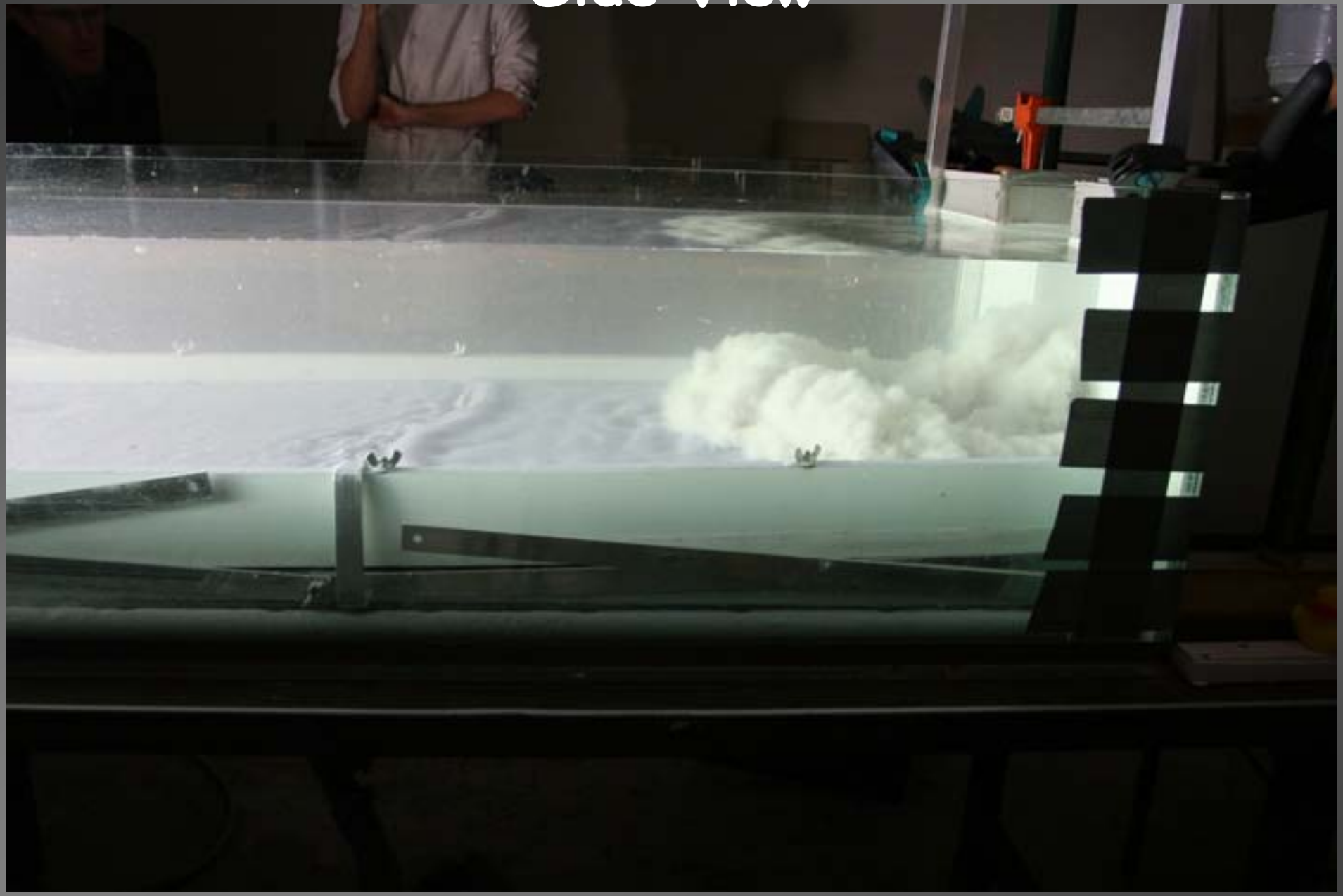
Sellier and Vendeville (2008)

Experimental set-up



Sellier and Vendeville (2008)

Side View



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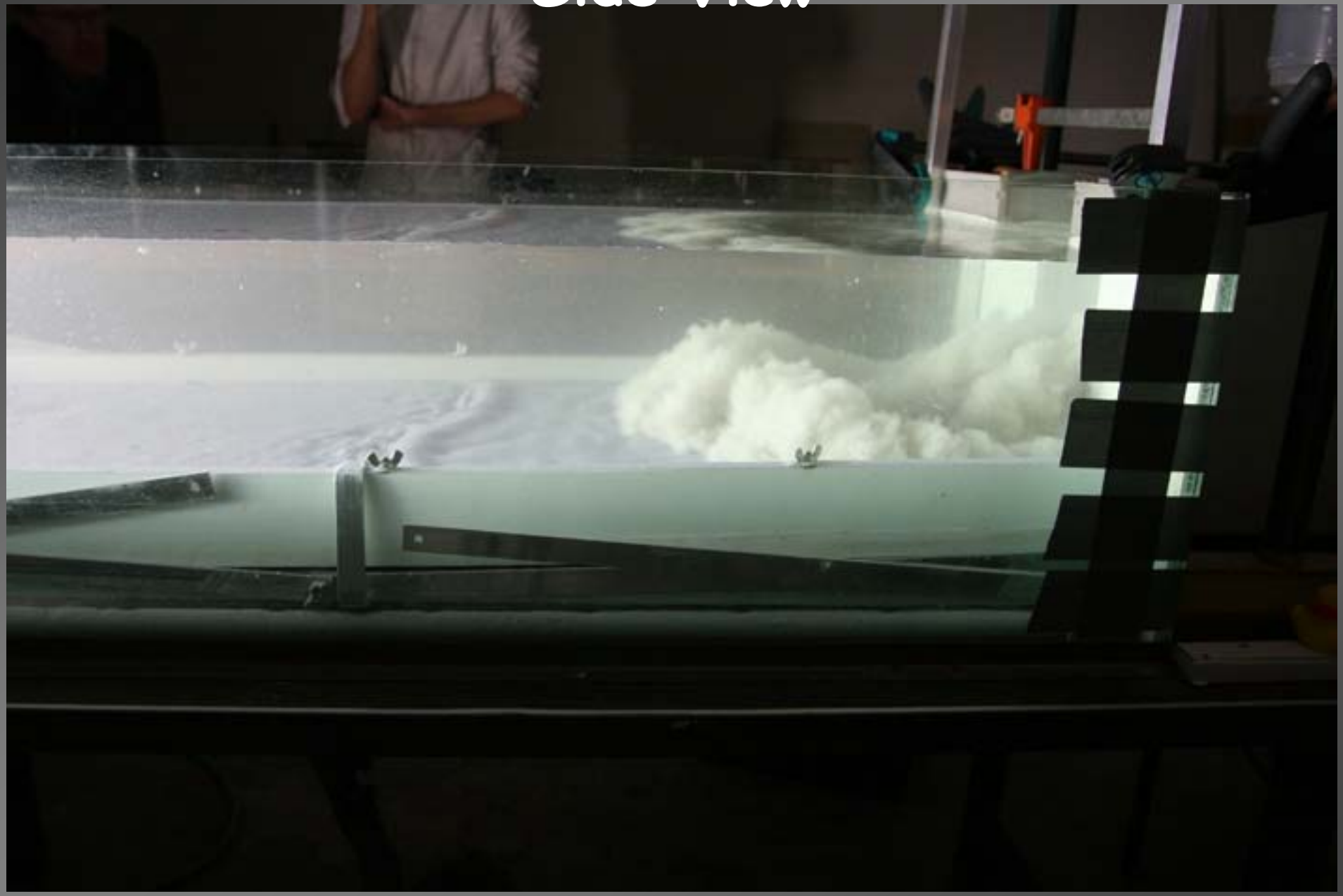
Side View



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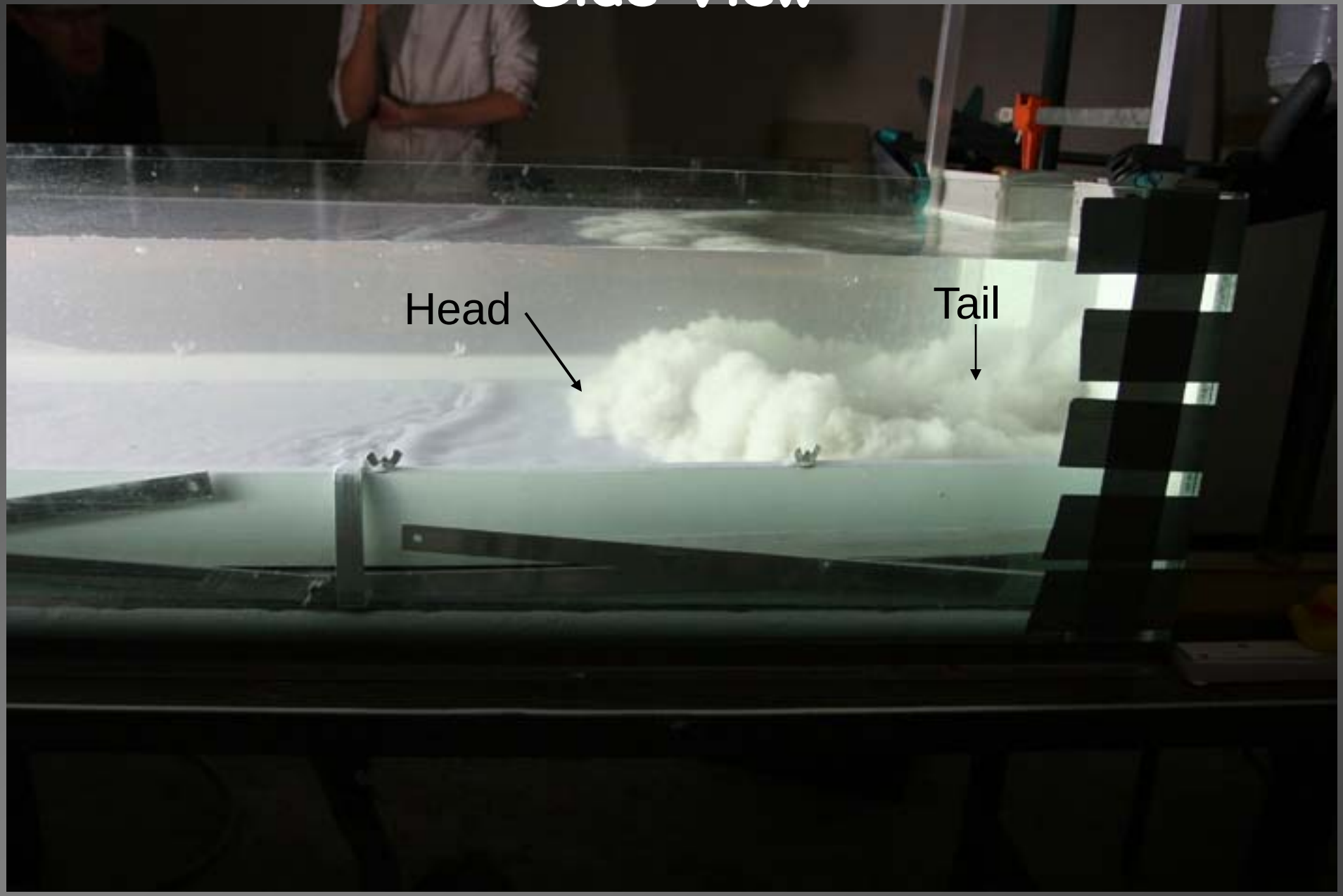
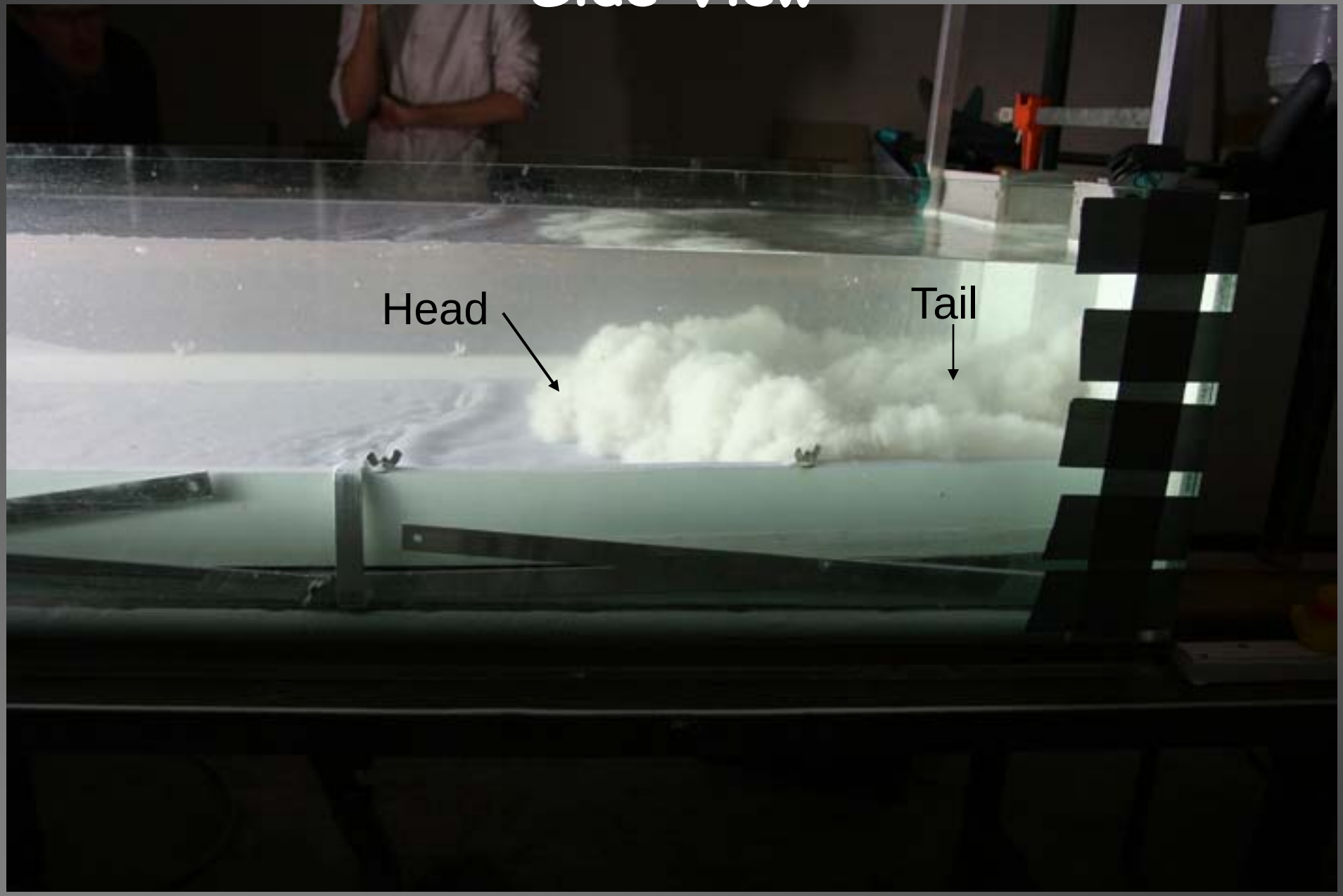
Side View



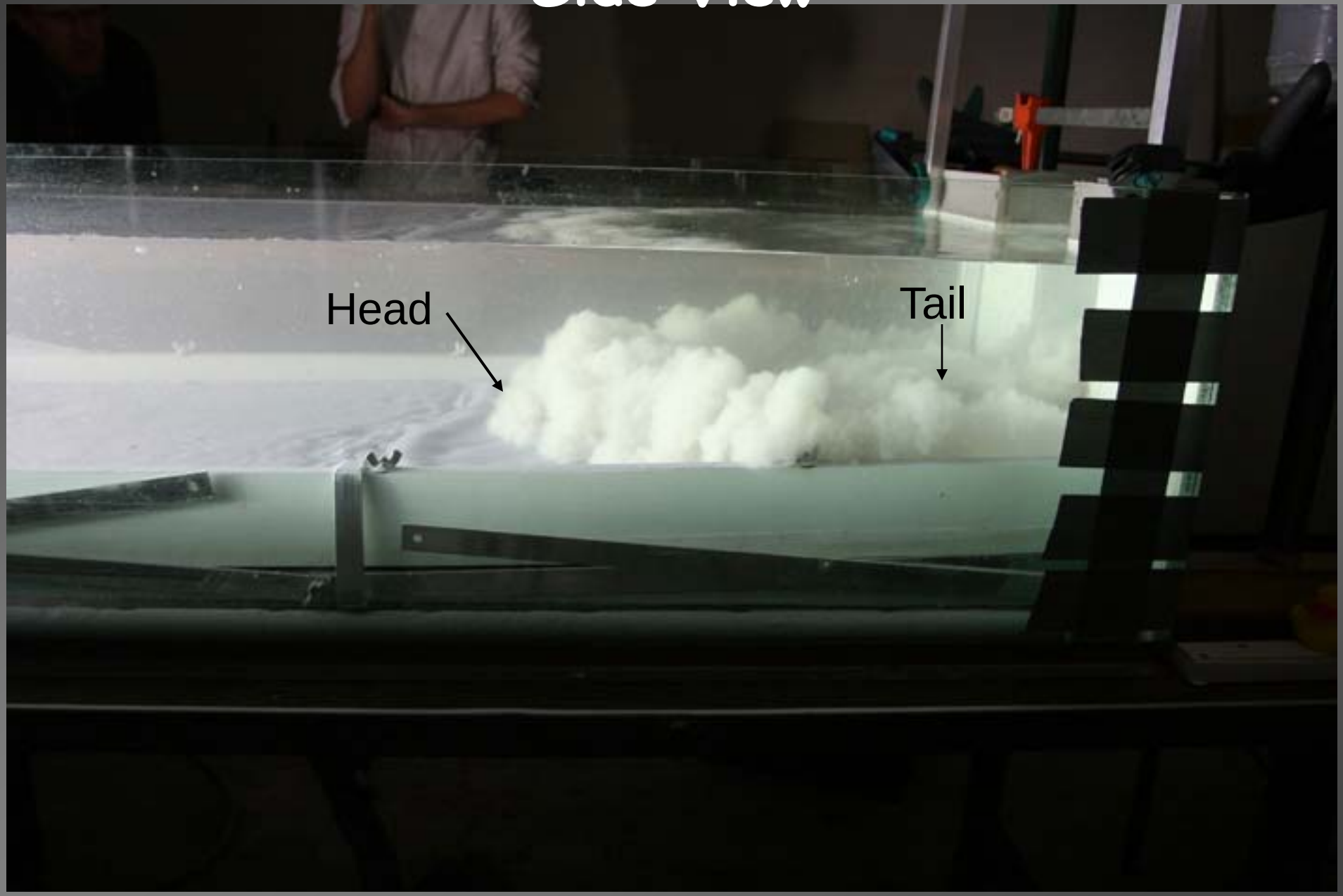
Sellier and Vendeville (2008)

Side View



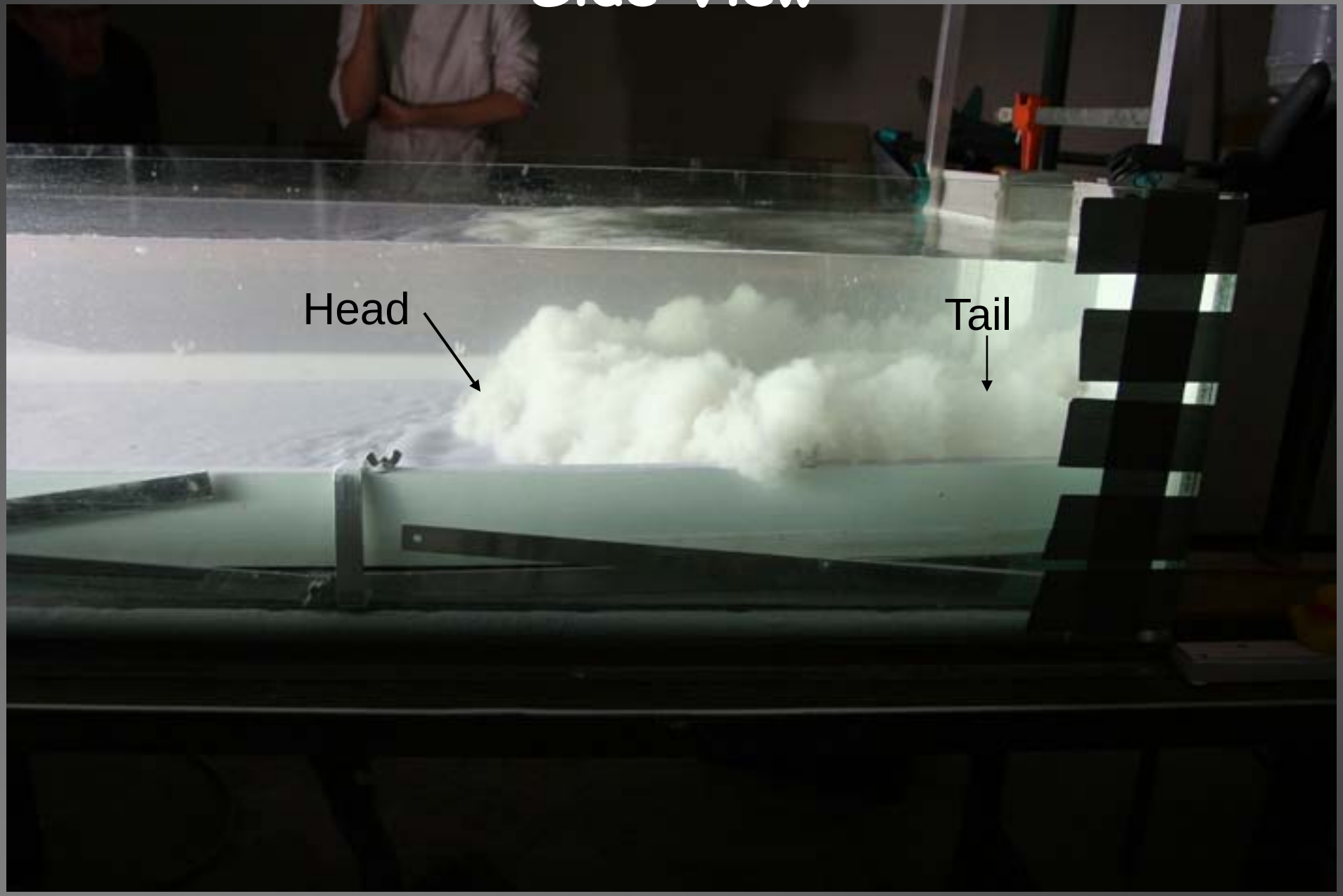
Sellier and Vendeville (2008)

Side View



Sellier and Vendeville (2008)

Side View



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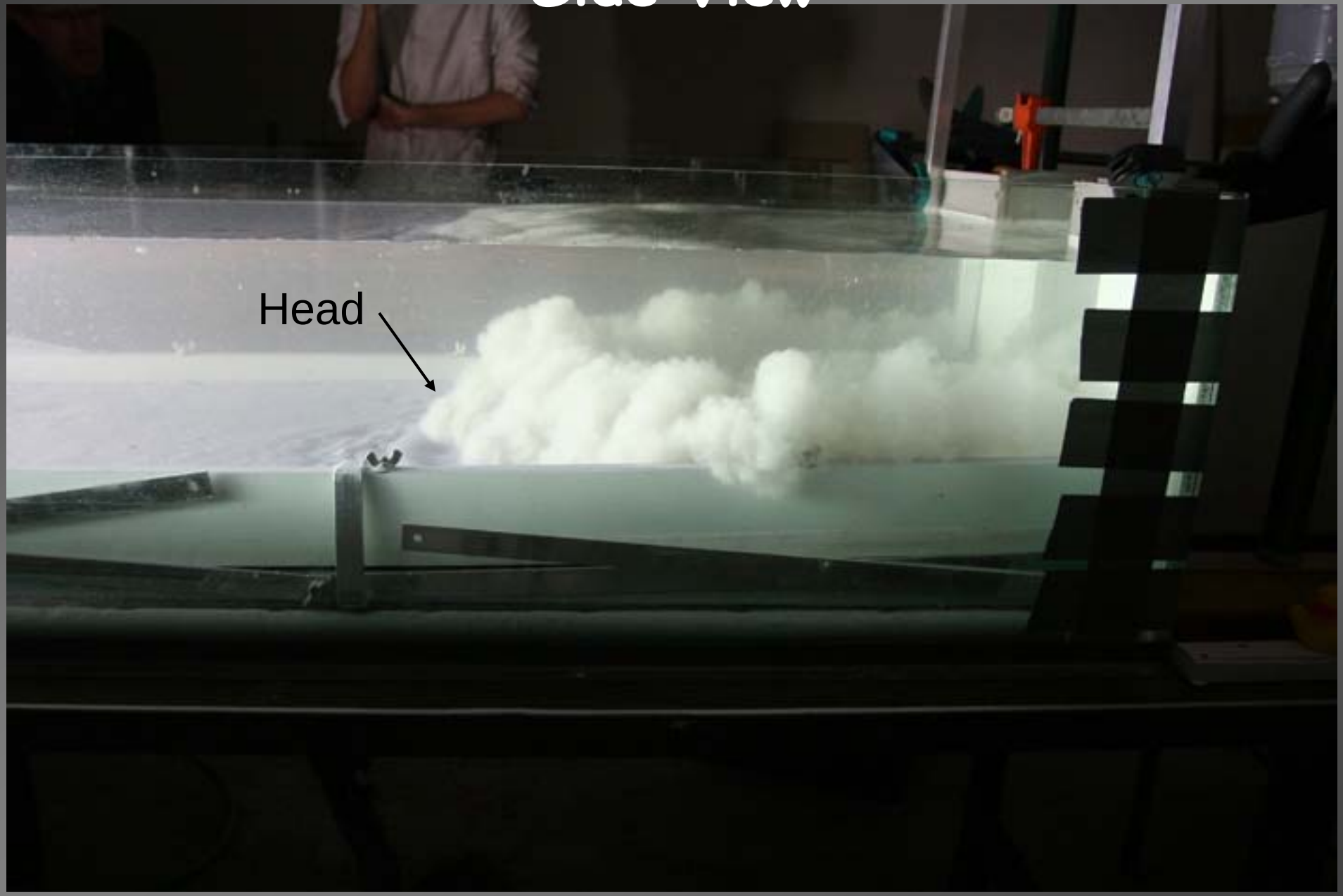
Side View



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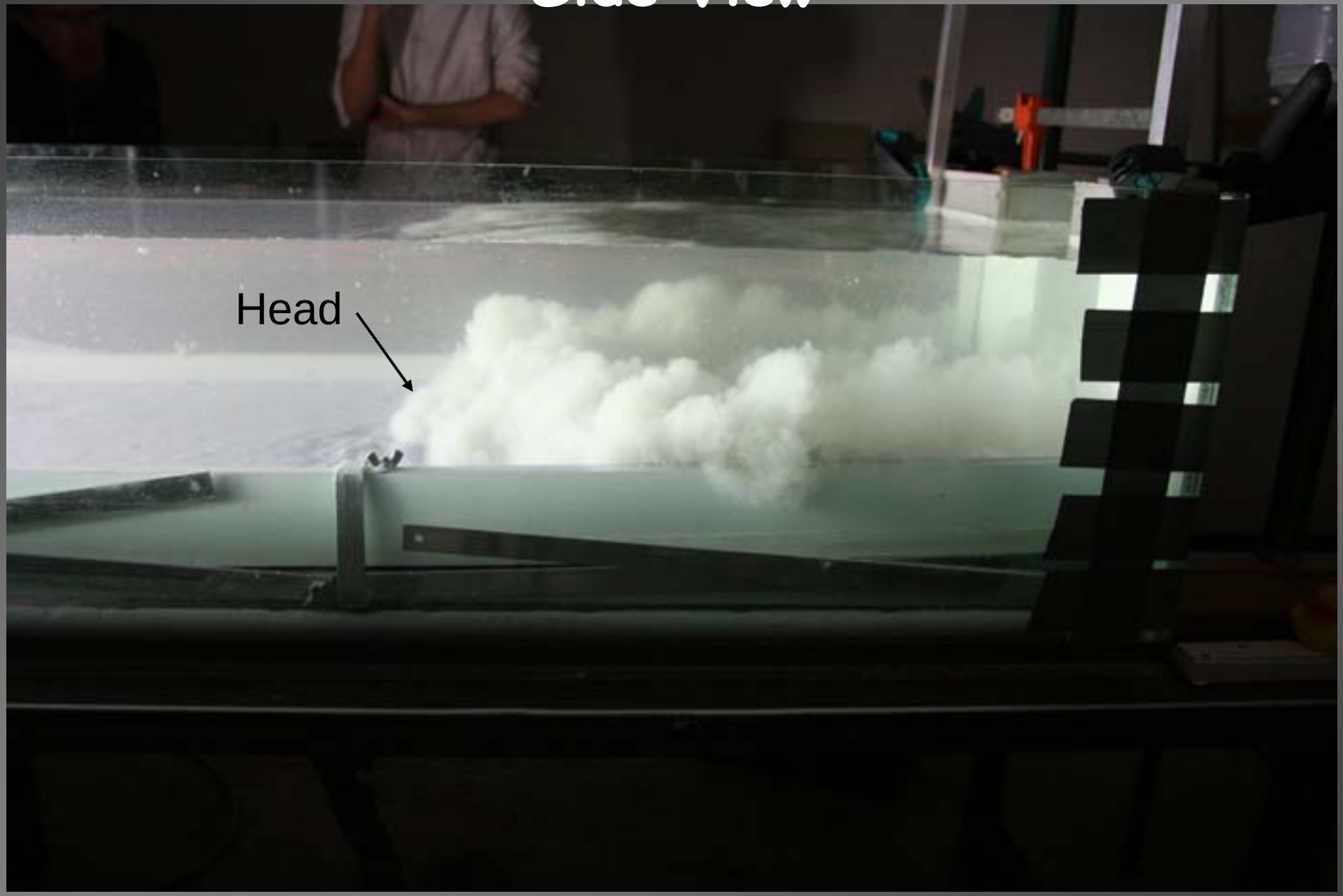
Side View



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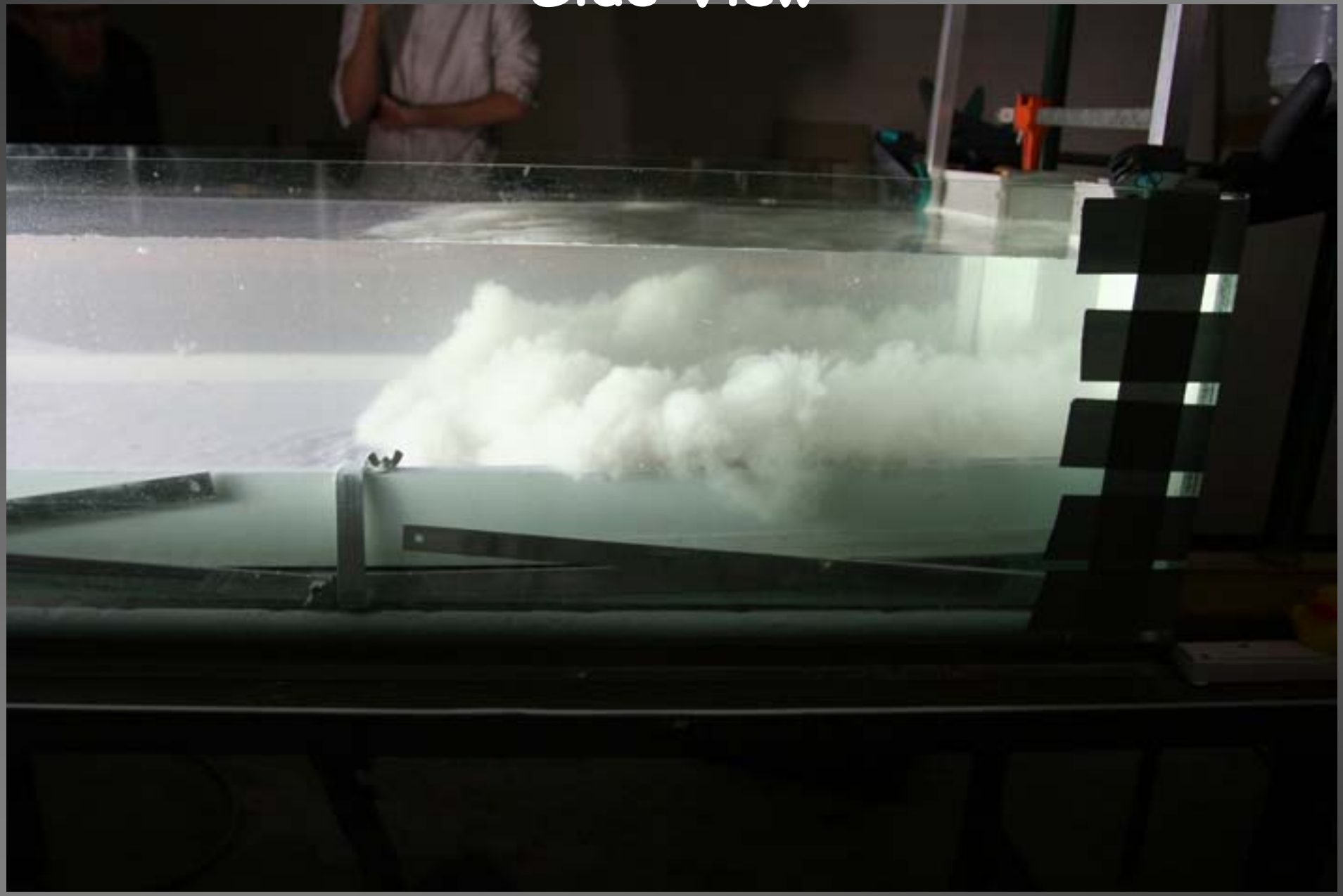
Side View



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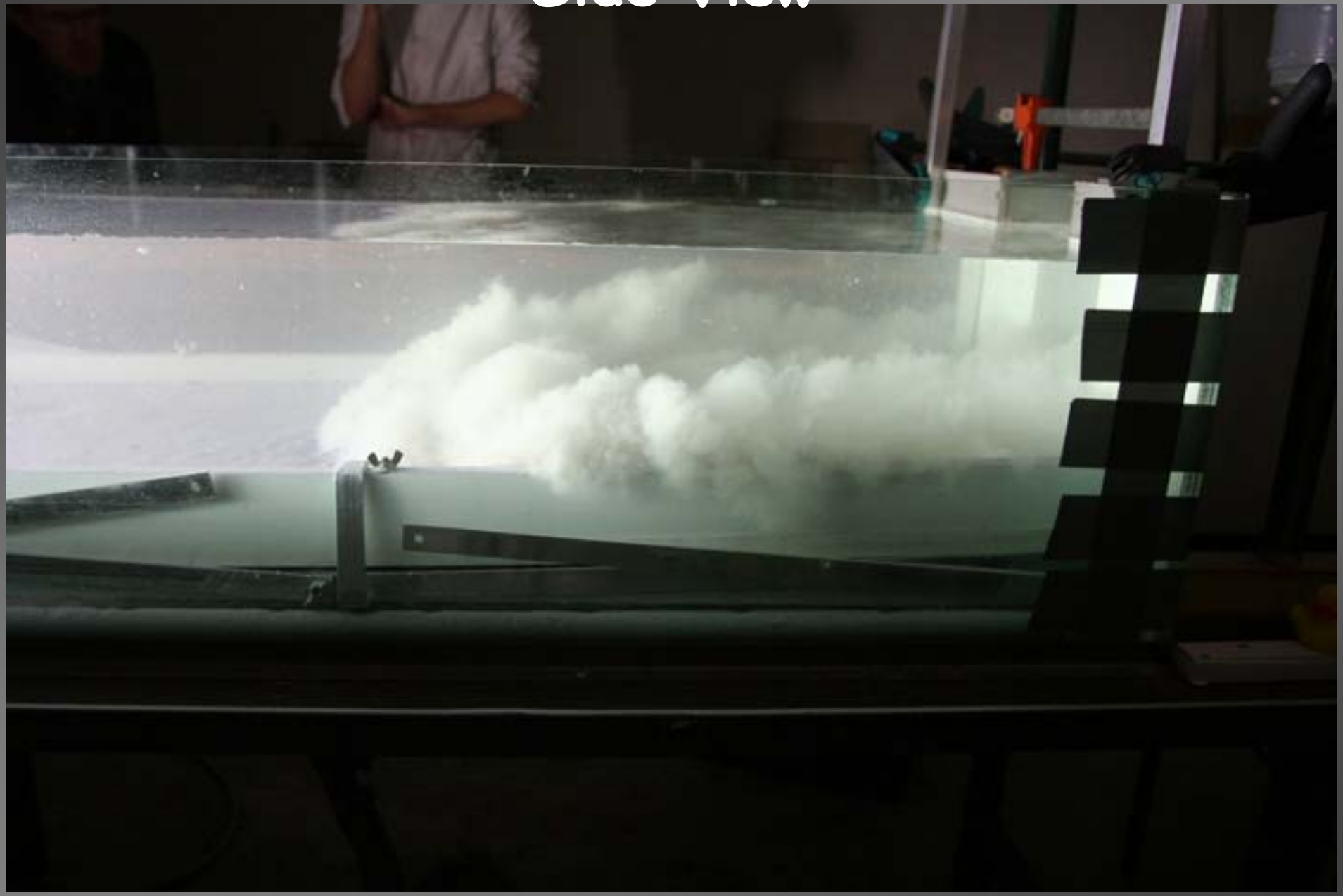
Side View



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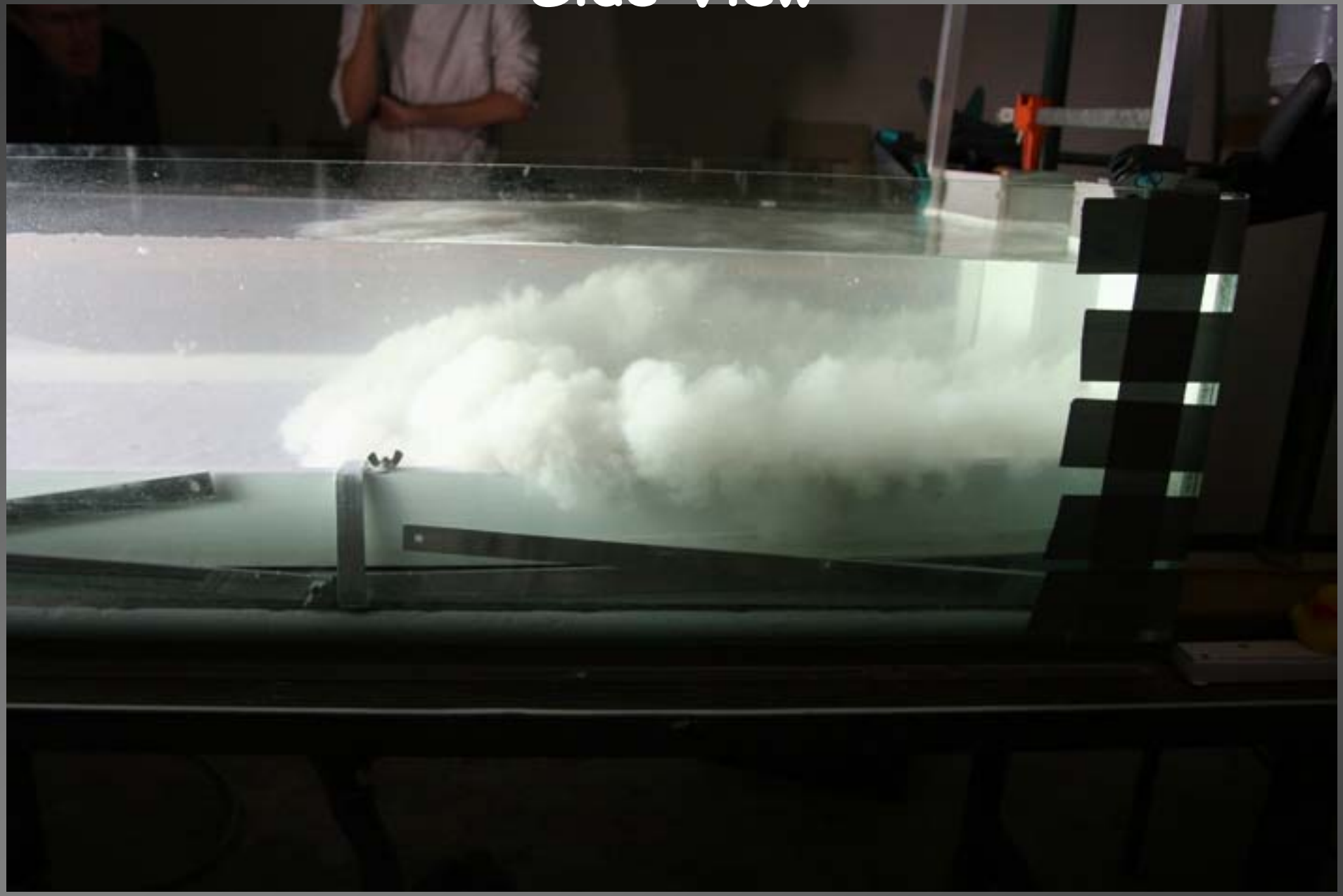
Side View



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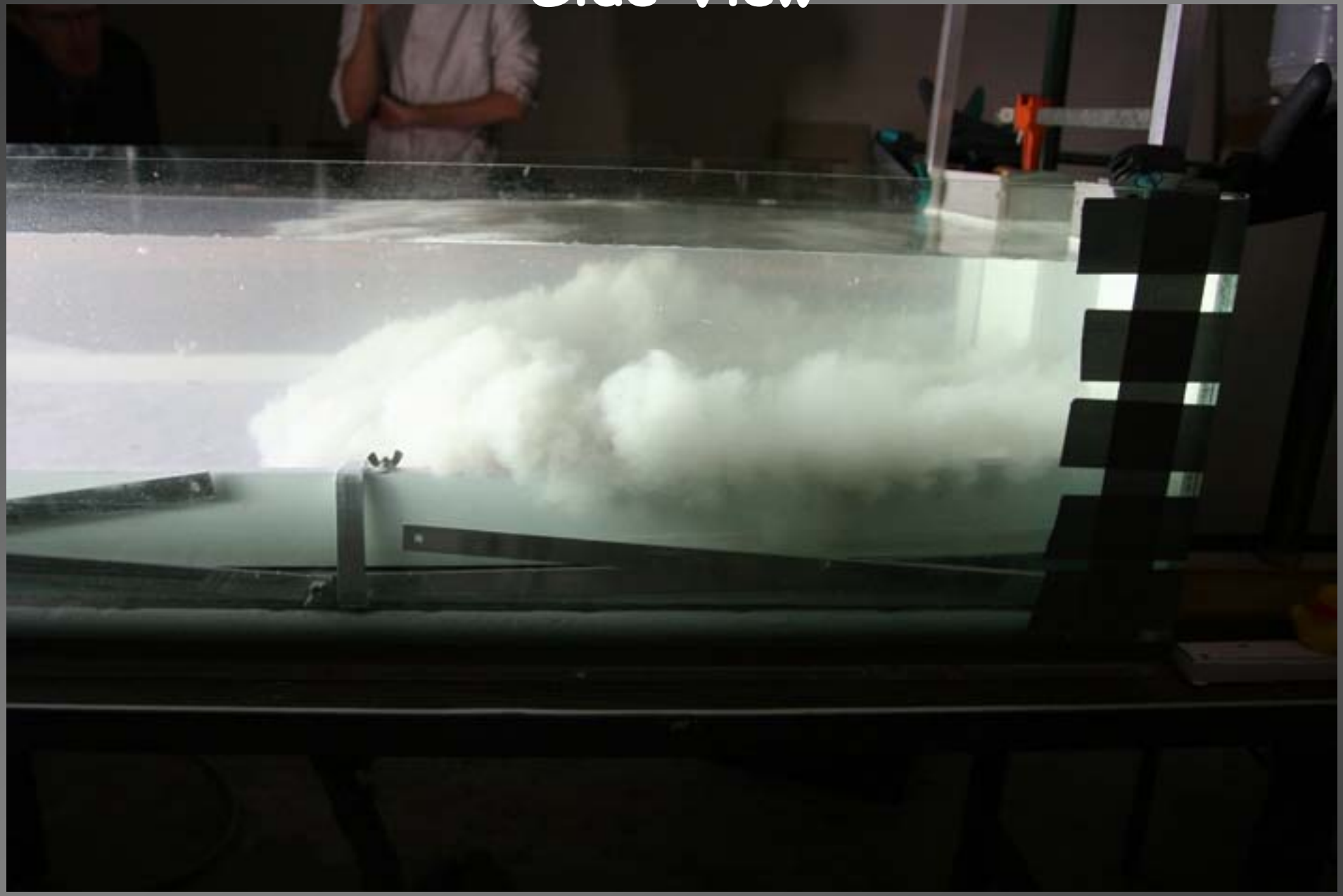
Side View



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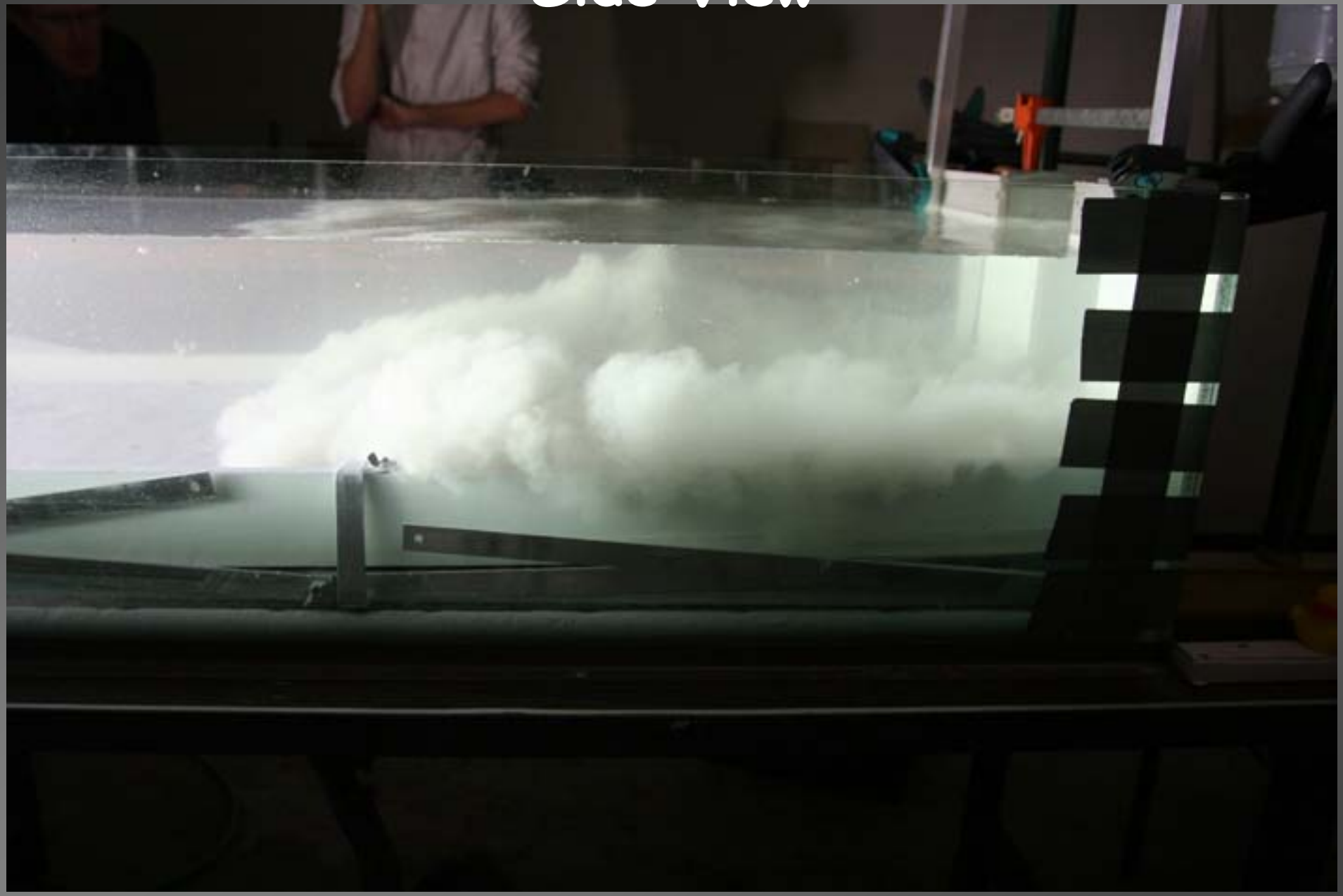

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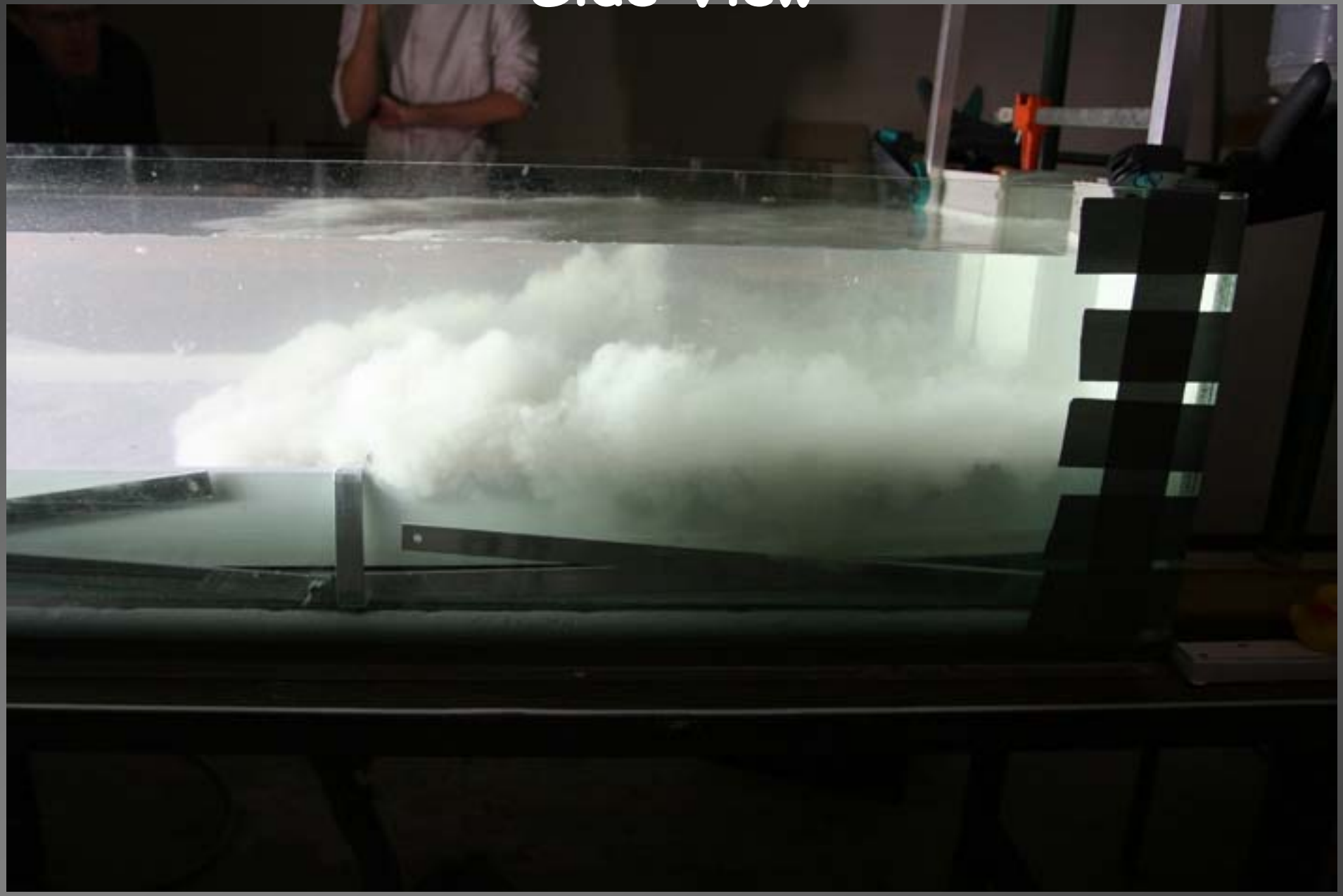
Side View



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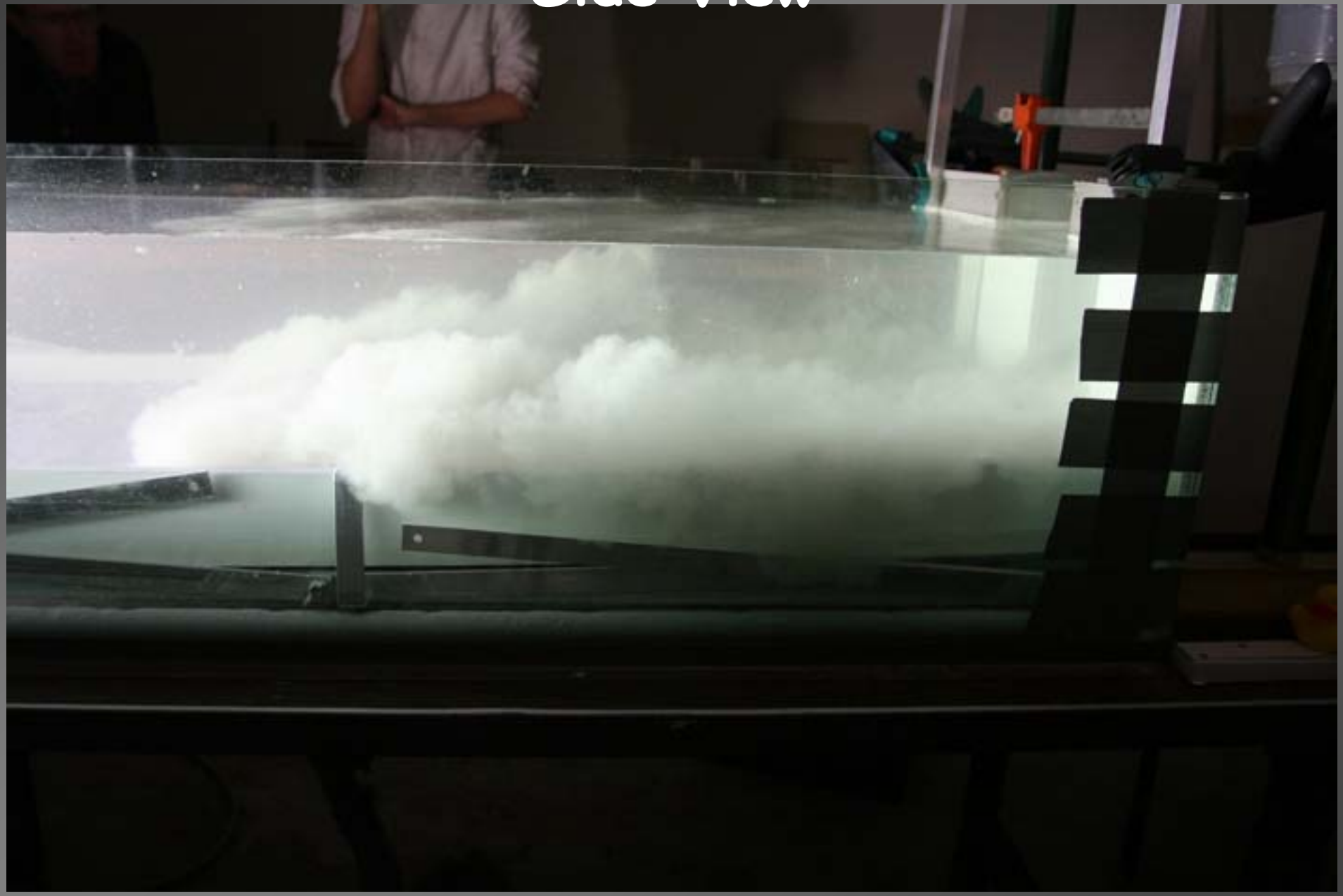
Side View



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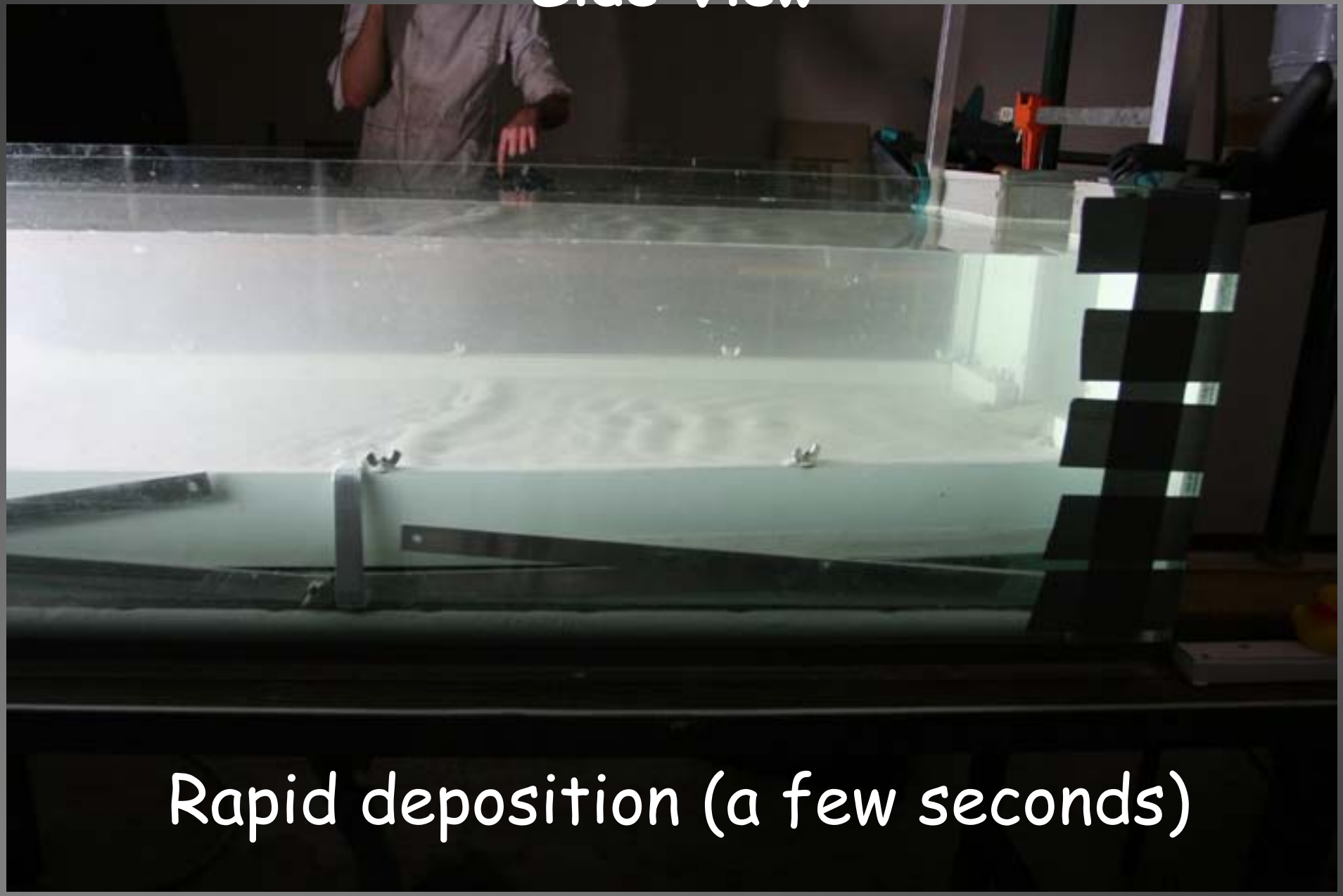
Side View



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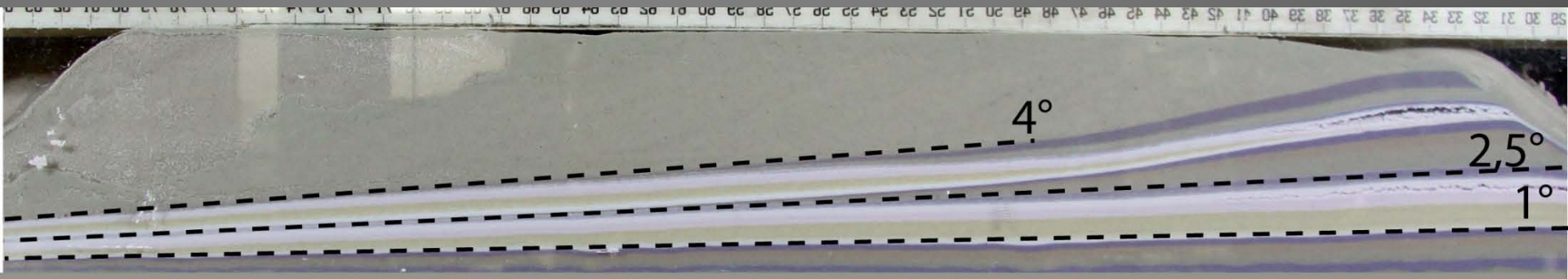
Results

We conducted several consecutive turbiditic episodes

Dynamics of turbity currents leads to differential deposition:

- Each lobe is thick in the proximal area (5 mm)
- Thins progressively towards the distal area (<1mm)

↳Building of a very gentle bathymetric slope

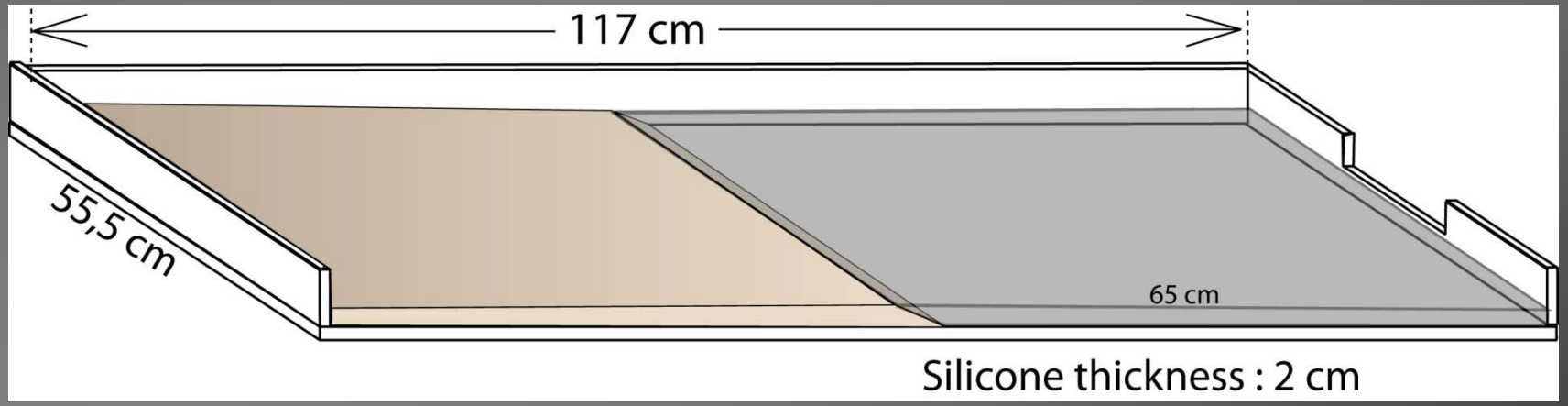


Side view of an non-deformed turbiditic fan (19 turbiditic events)

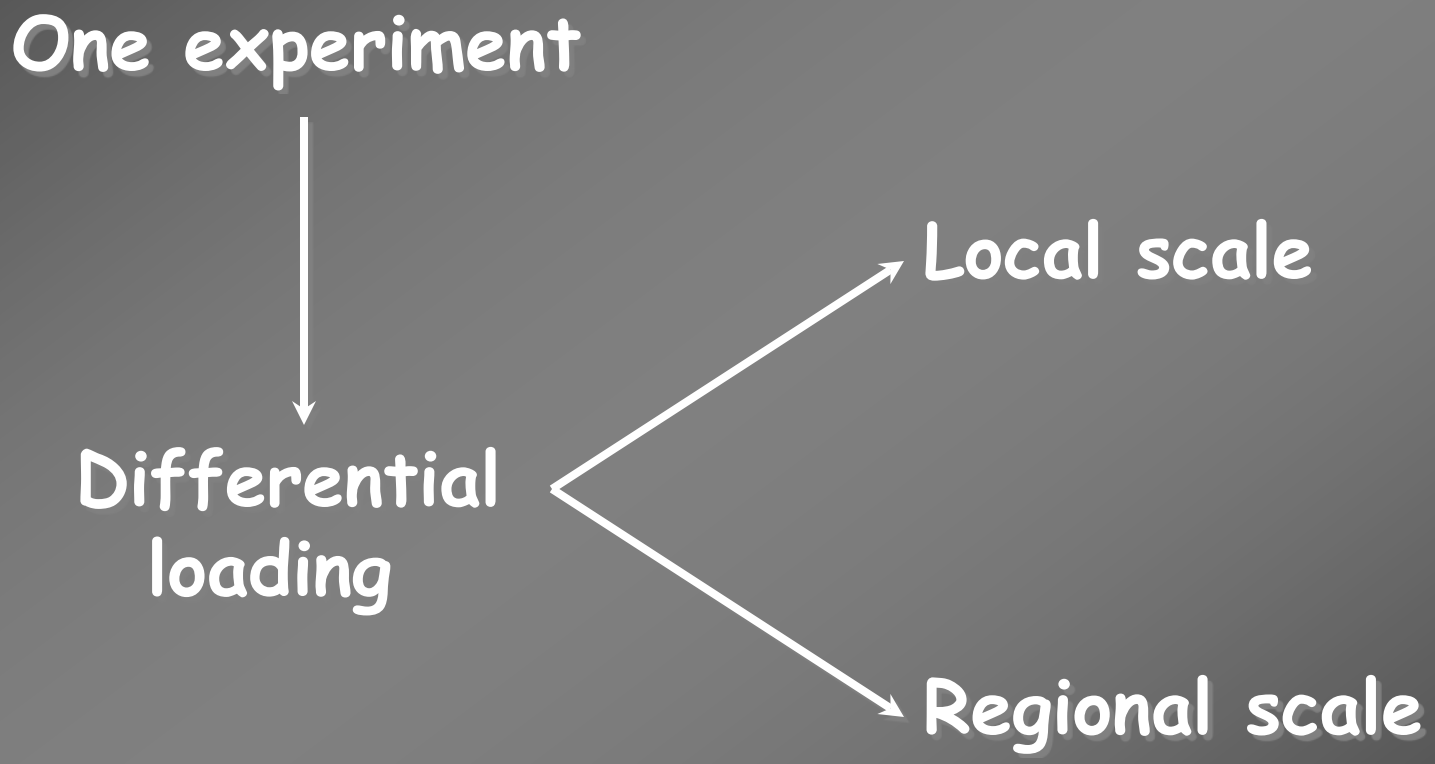
Experimental approach

Each turbiditic fan was deposited onto a viscous layer of silicone polymer (mobile salt).

We investigated the effect of depositing several consecutive lobes on mobile salt.



One experiment, two different responses at two different scales



Outline

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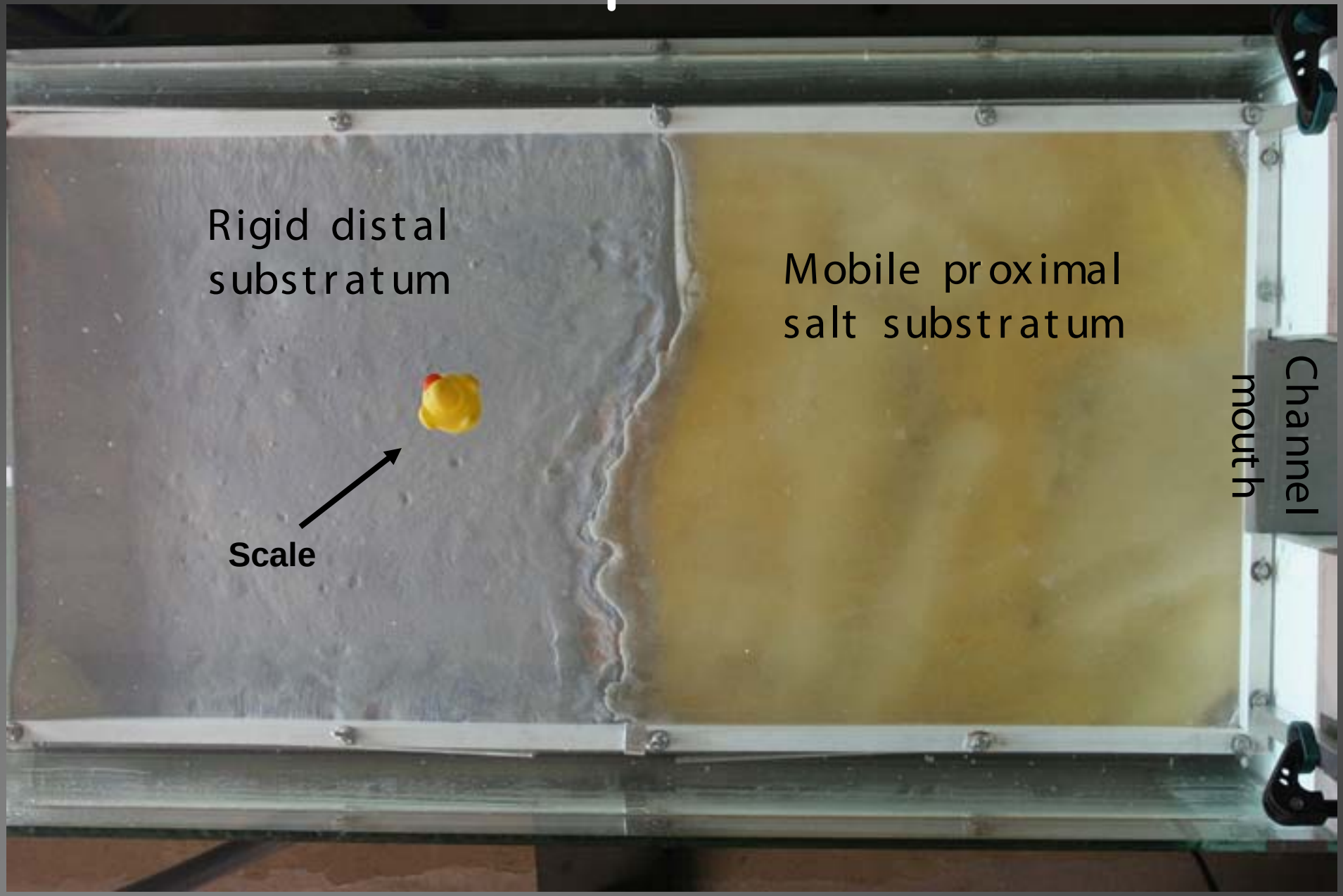
Top View


Rigid distal substratum
Mobile proximal salt substratum
Channel mouth
Scale

Sellier and Vendeville (2008)

Sellier and Vendeville (2008)

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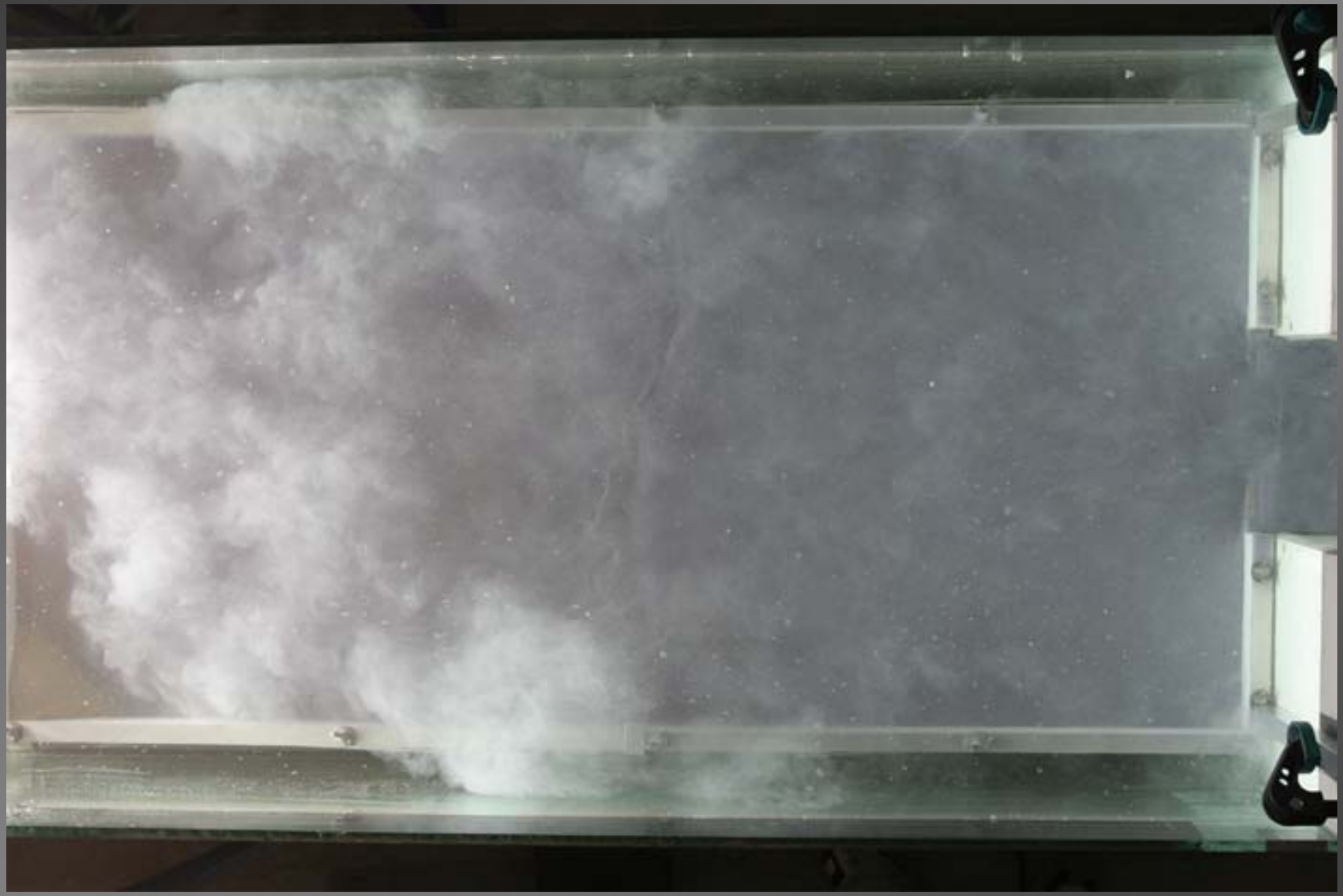
Sellier and Vendeville (2008)



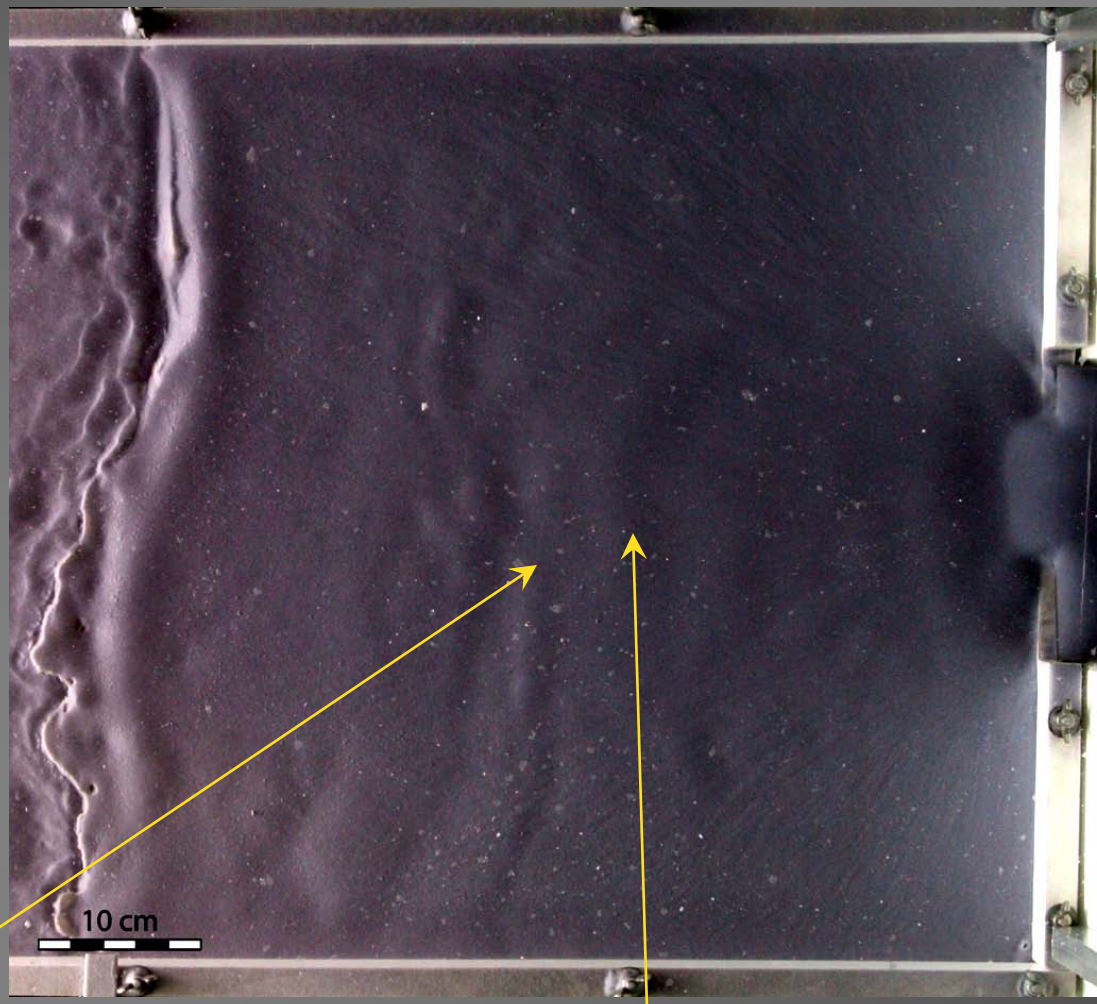
Sellier and Vendeville (2008)

Sellier and Vendeville (2008)

Results: Salt response to *local* differential loading

In the model, lobe deposition generated sub-marine sedimentary ridges (sub-millimetric in height)

↳ The ensuing differential loading was low.

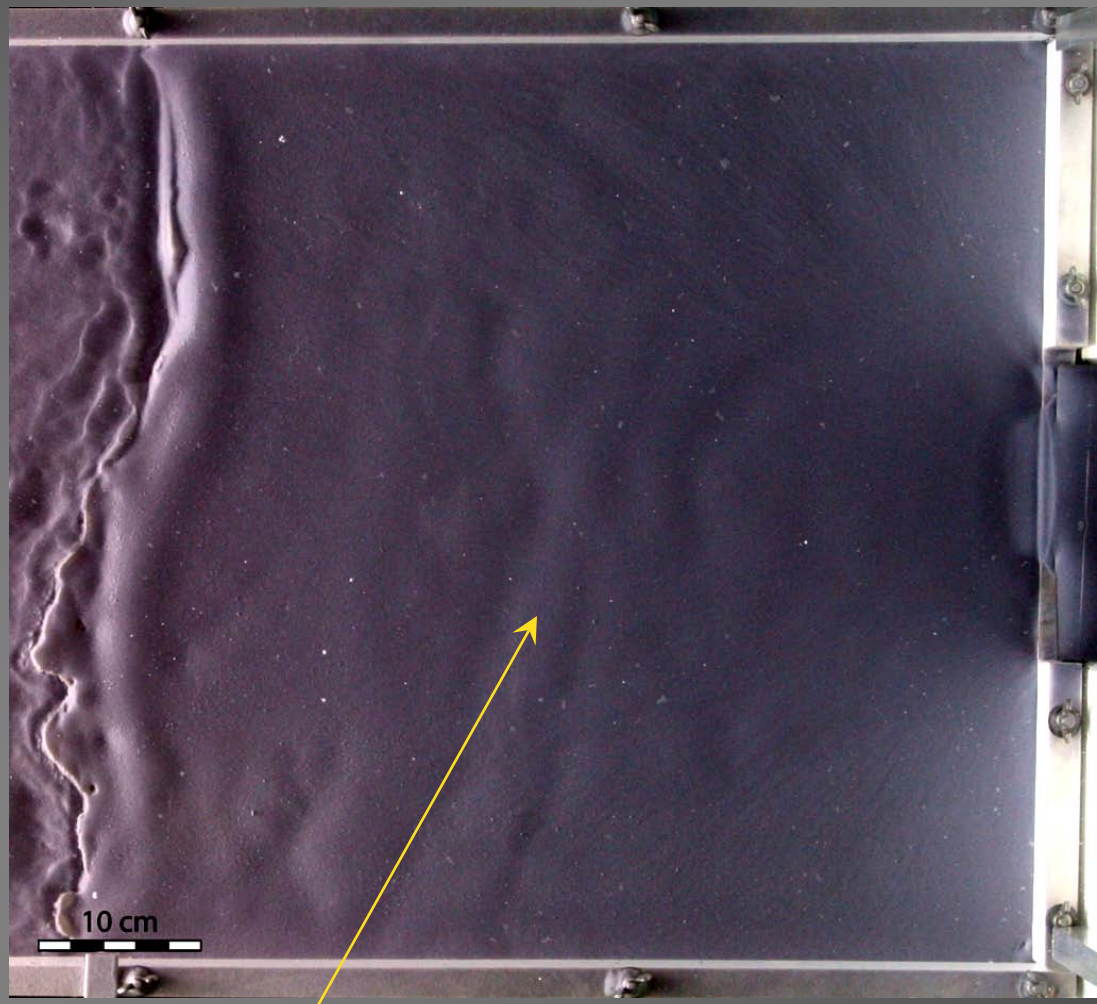


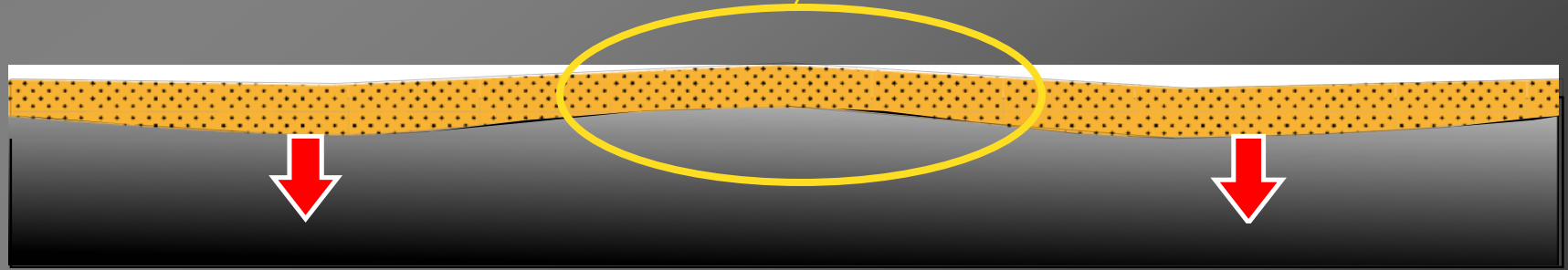
Sand Ridge

Sand Ridge

Results: Salt response to *local* differential loading

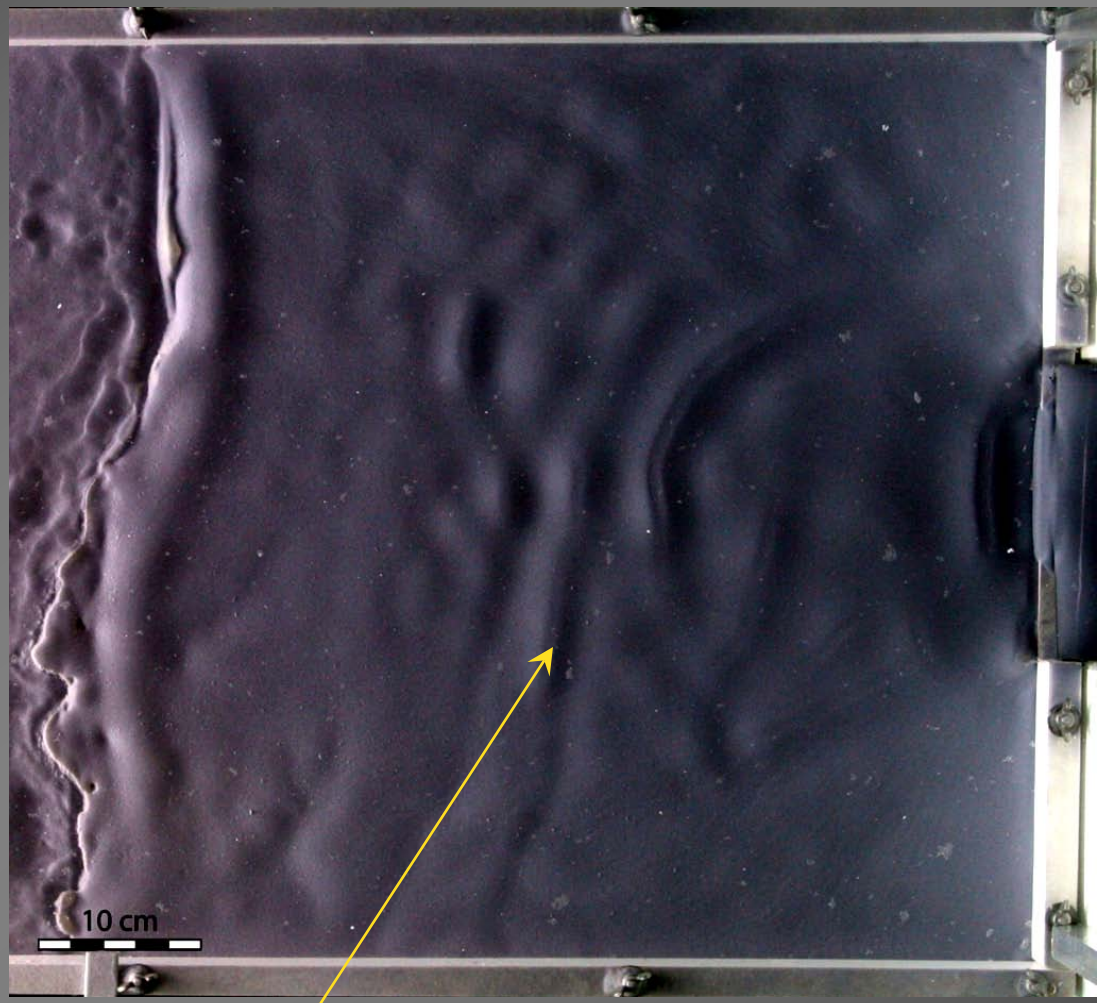
- Deformation of the underlying salt was fast, the sand ridges subsided rapidly
- The bathymetry was inverted:
  - What used to be a high has become a low

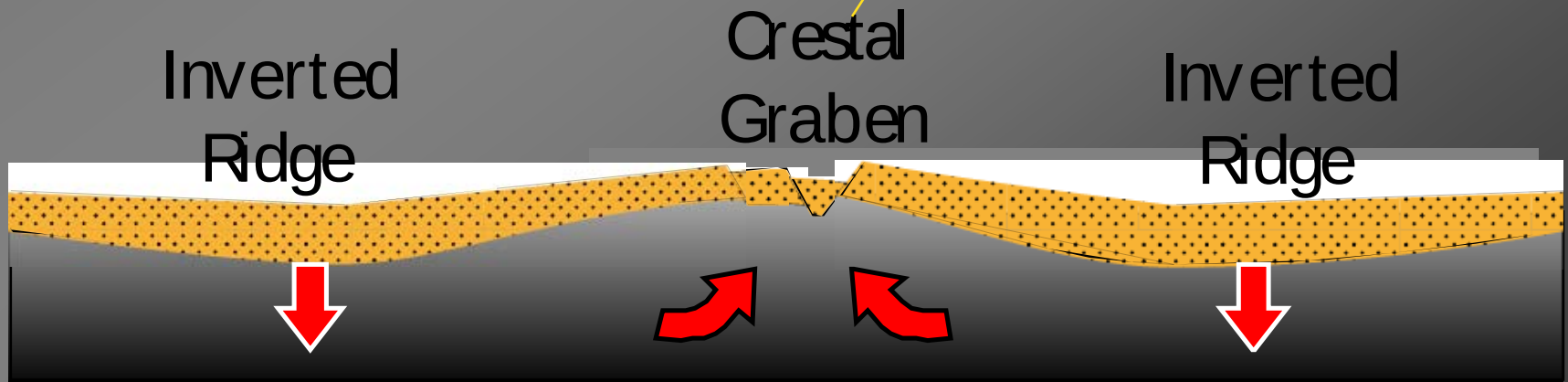




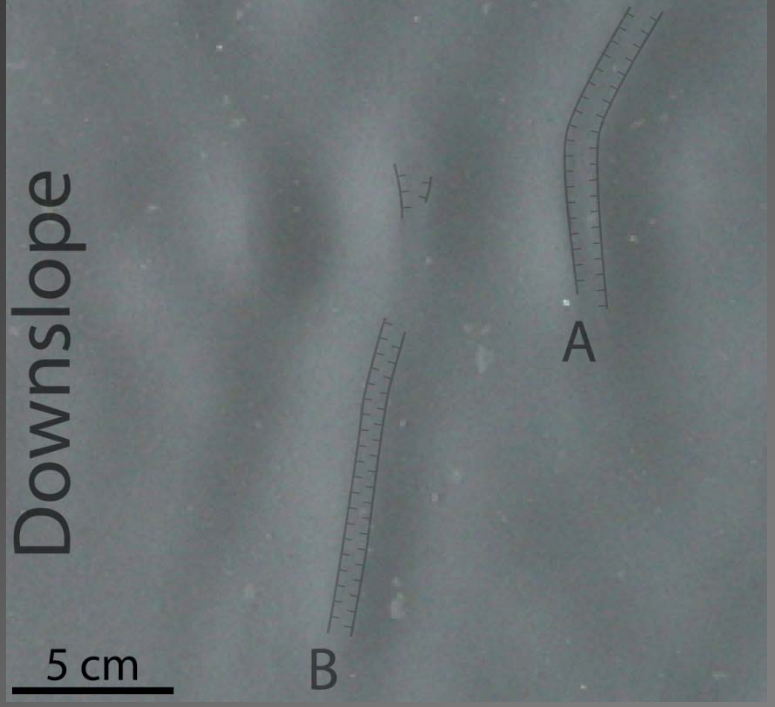
Results: Salt response to *local* differential loading

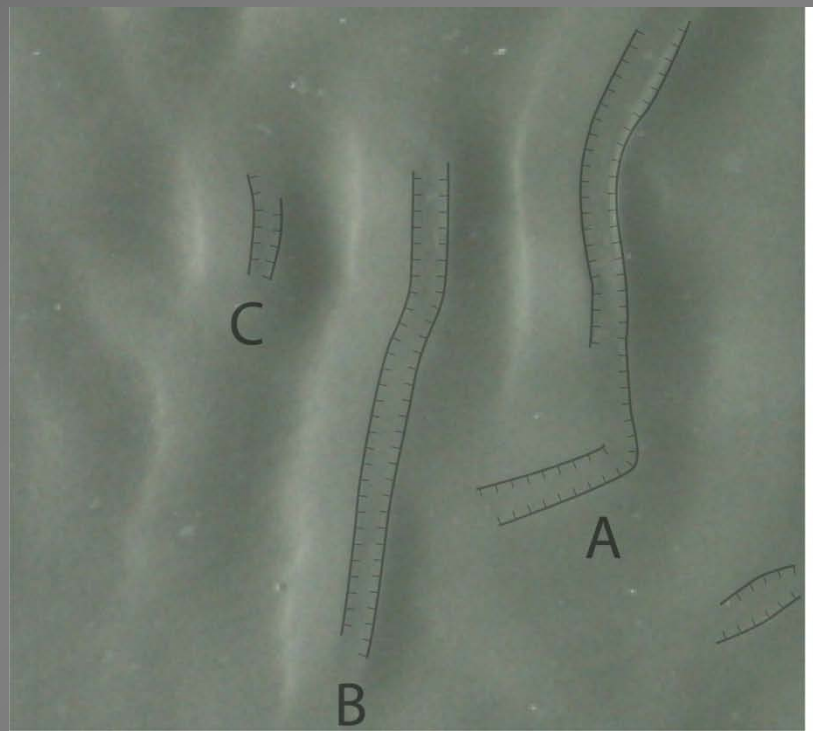
- The salt rose passively beneath the inter ridge segments (thinner overburden)
- Crestal grabens formed

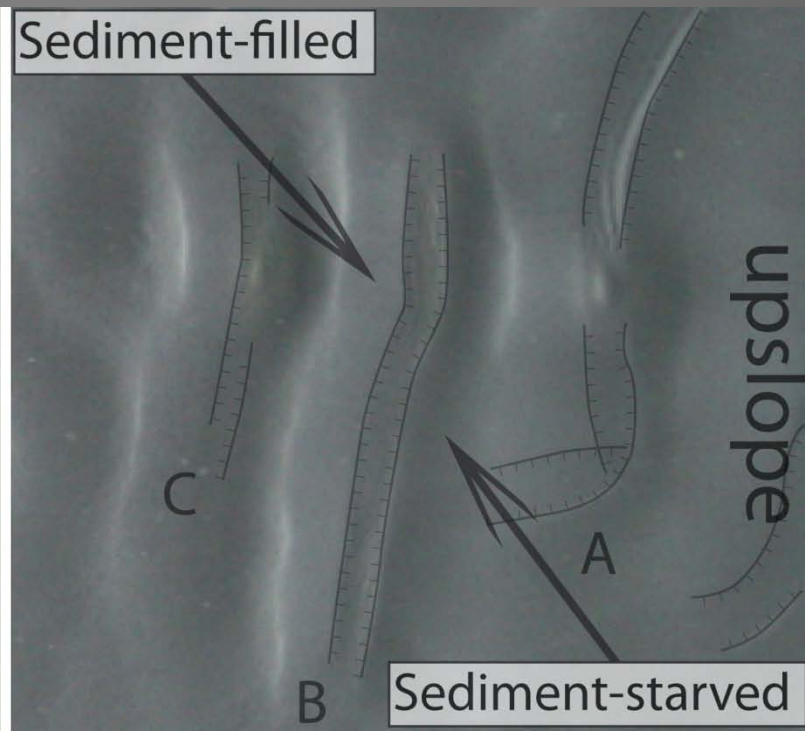




Results: Influence of salt structures on *local* sedimentation (asymmetric deposits)







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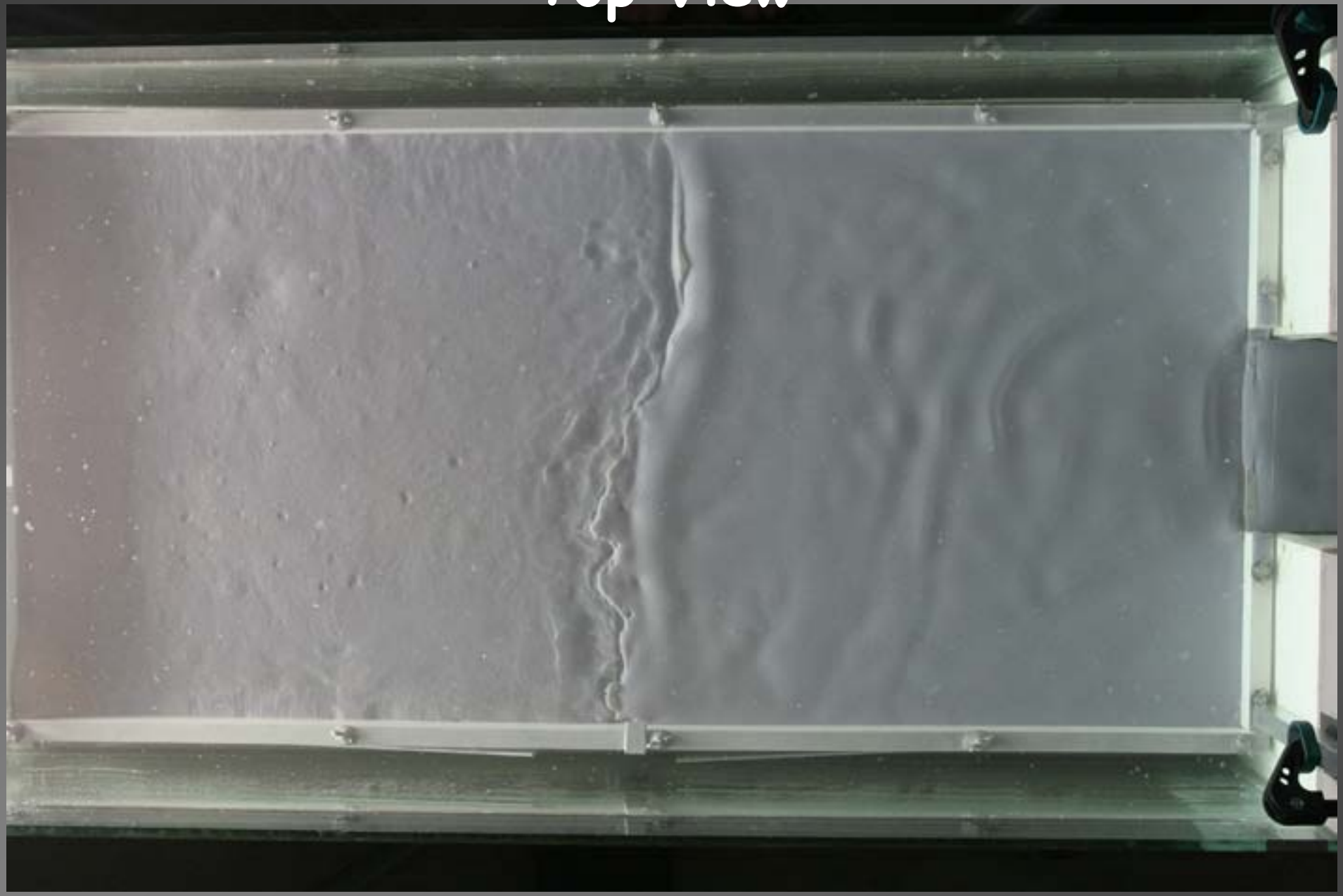
Top View



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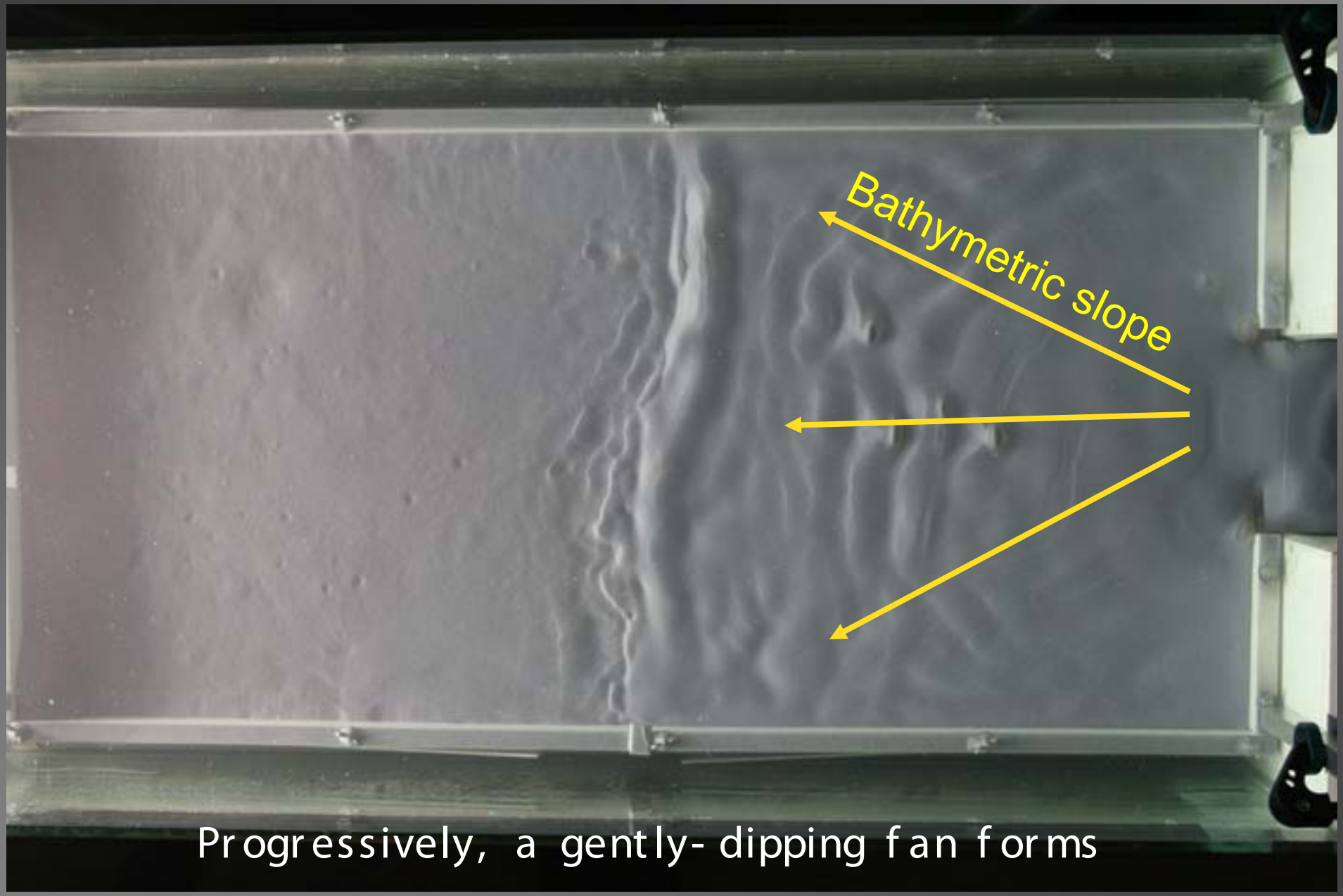
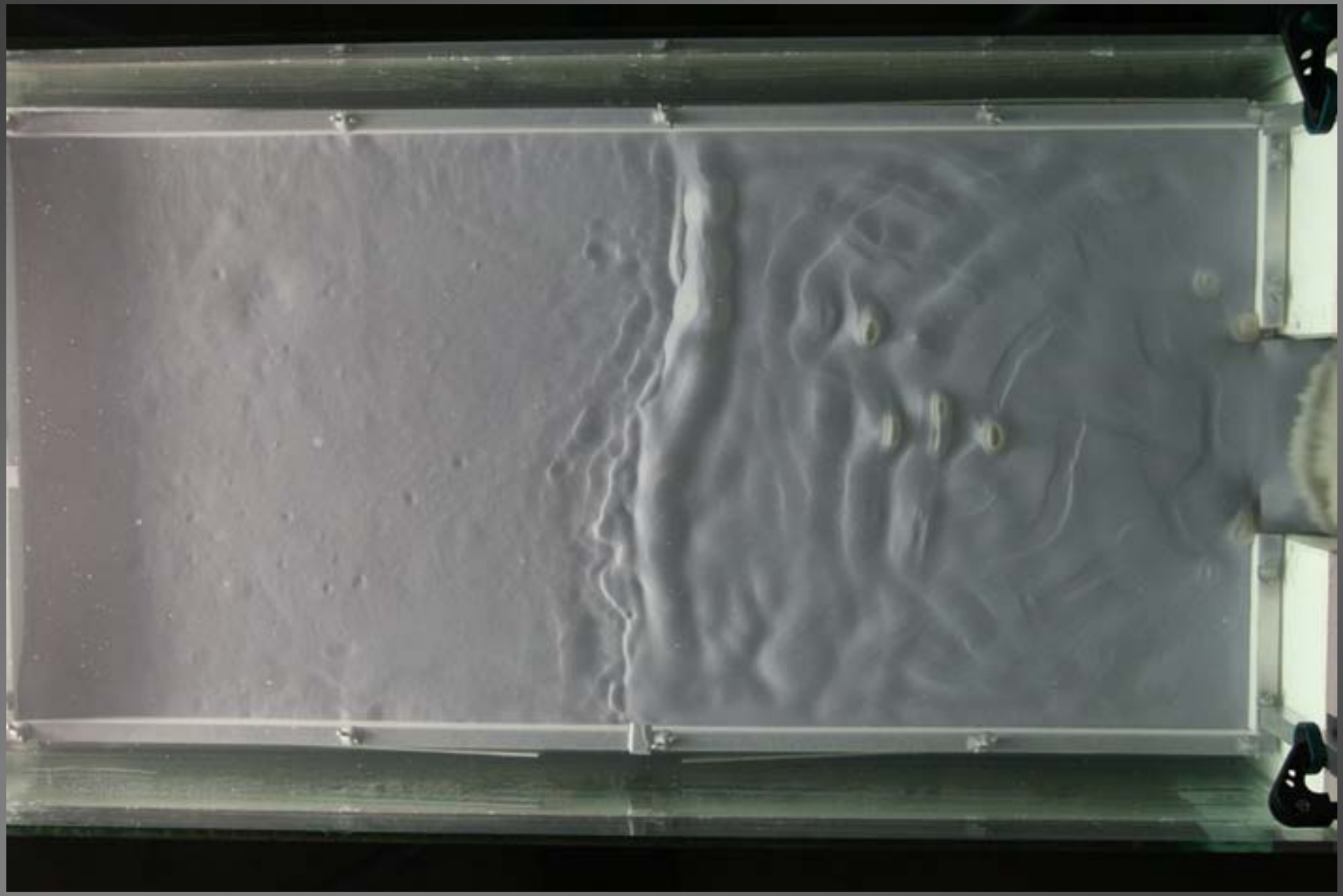


Progressively, a gently-dipping fan forms

Sellier and Vendeville (2008)



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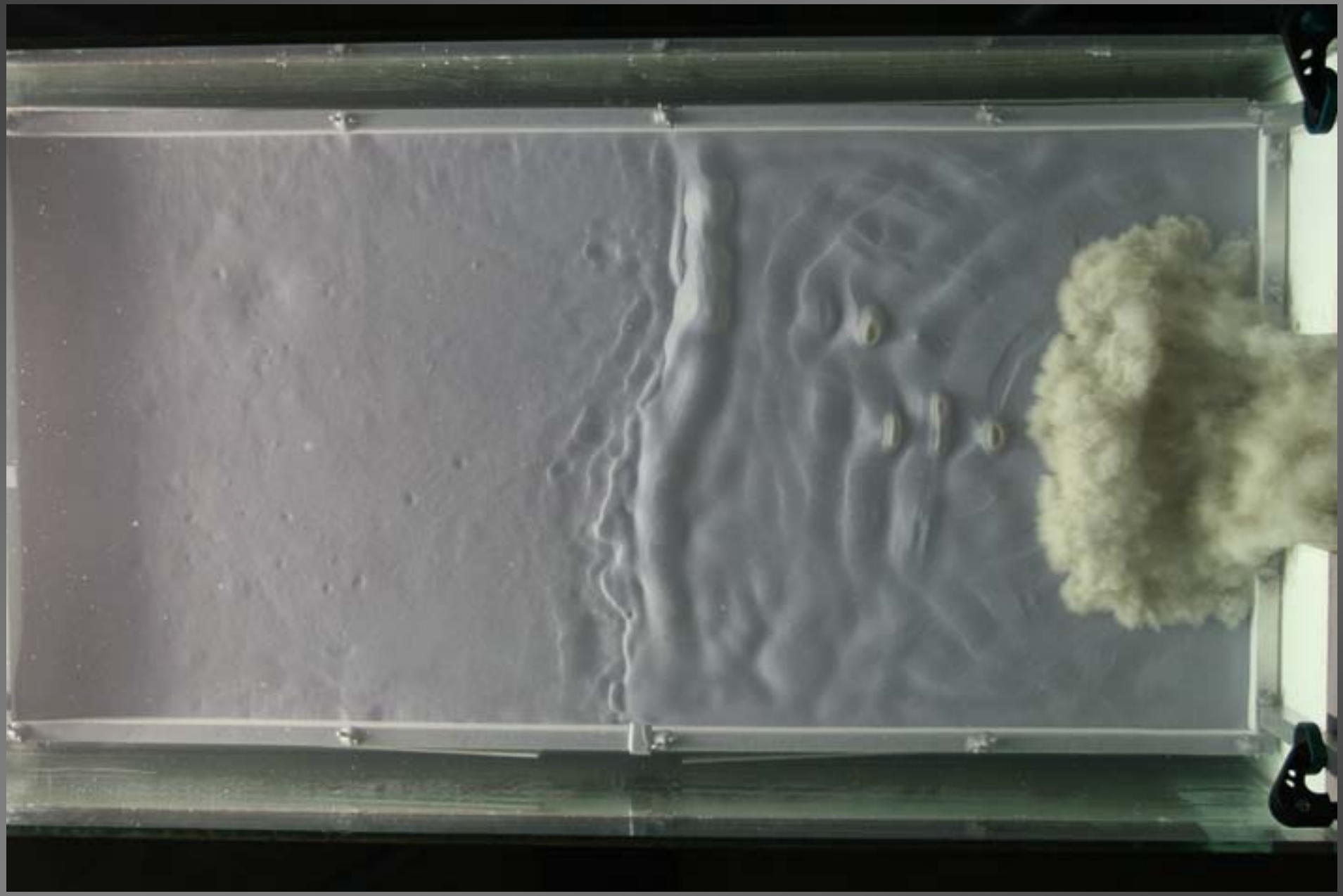

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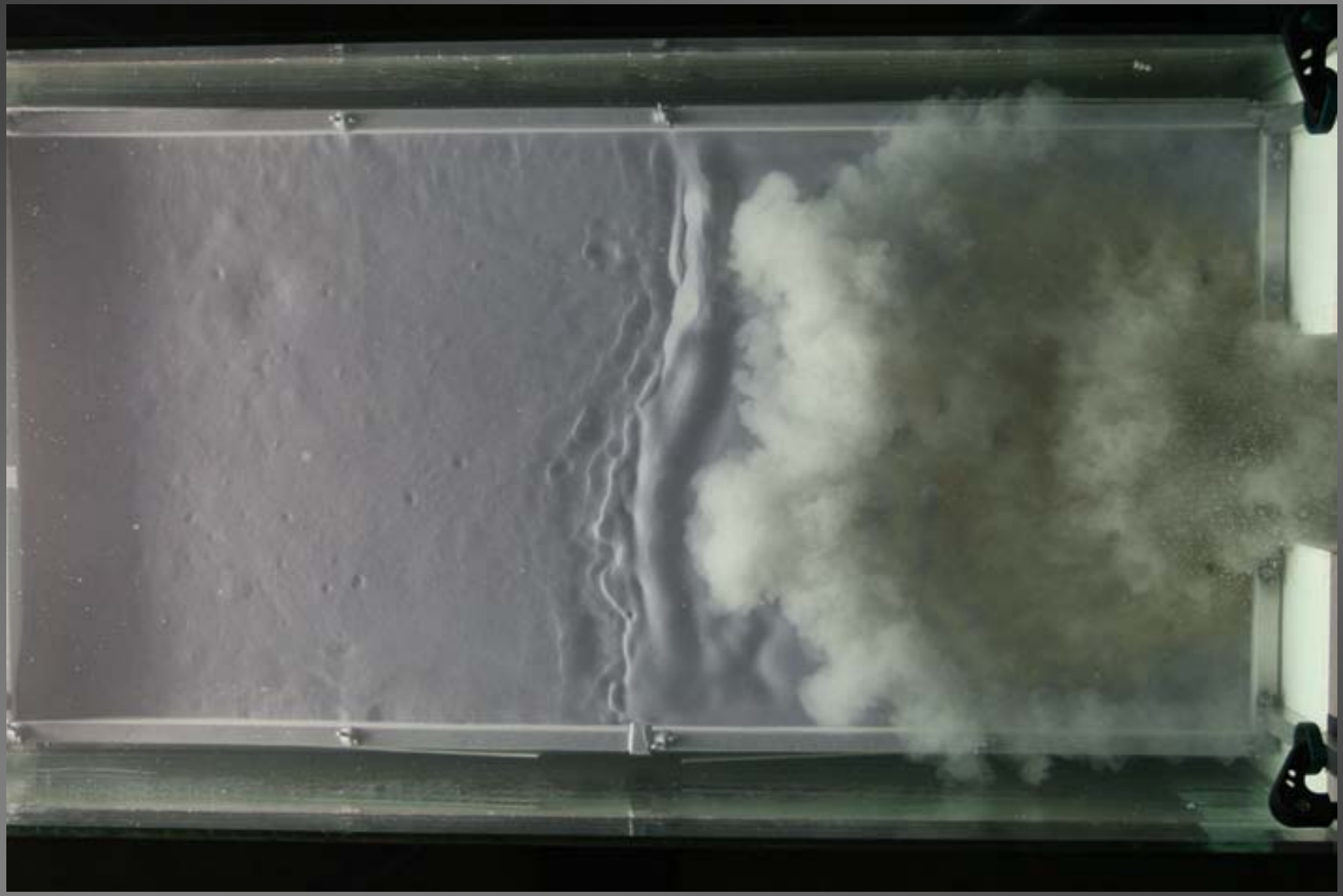
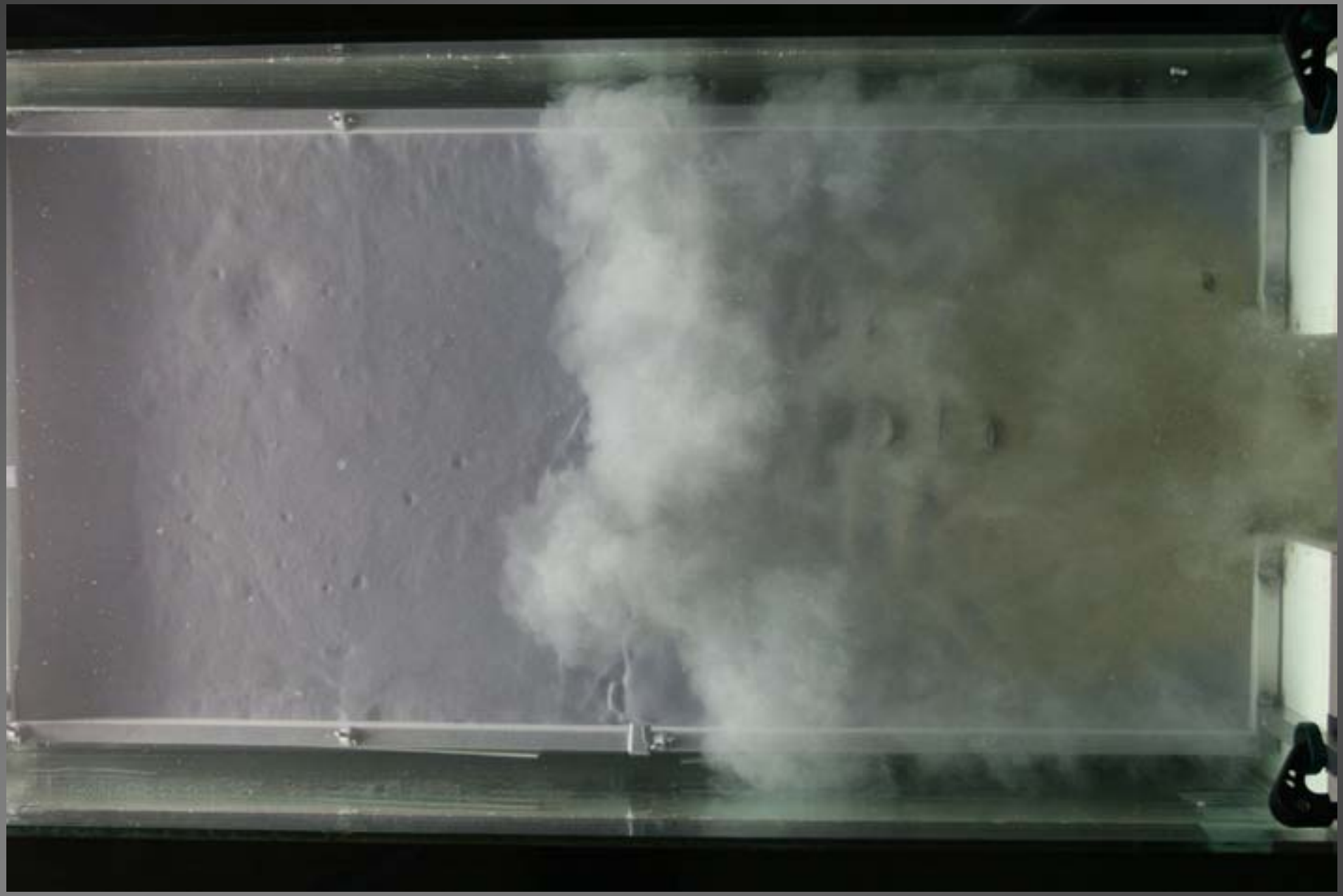
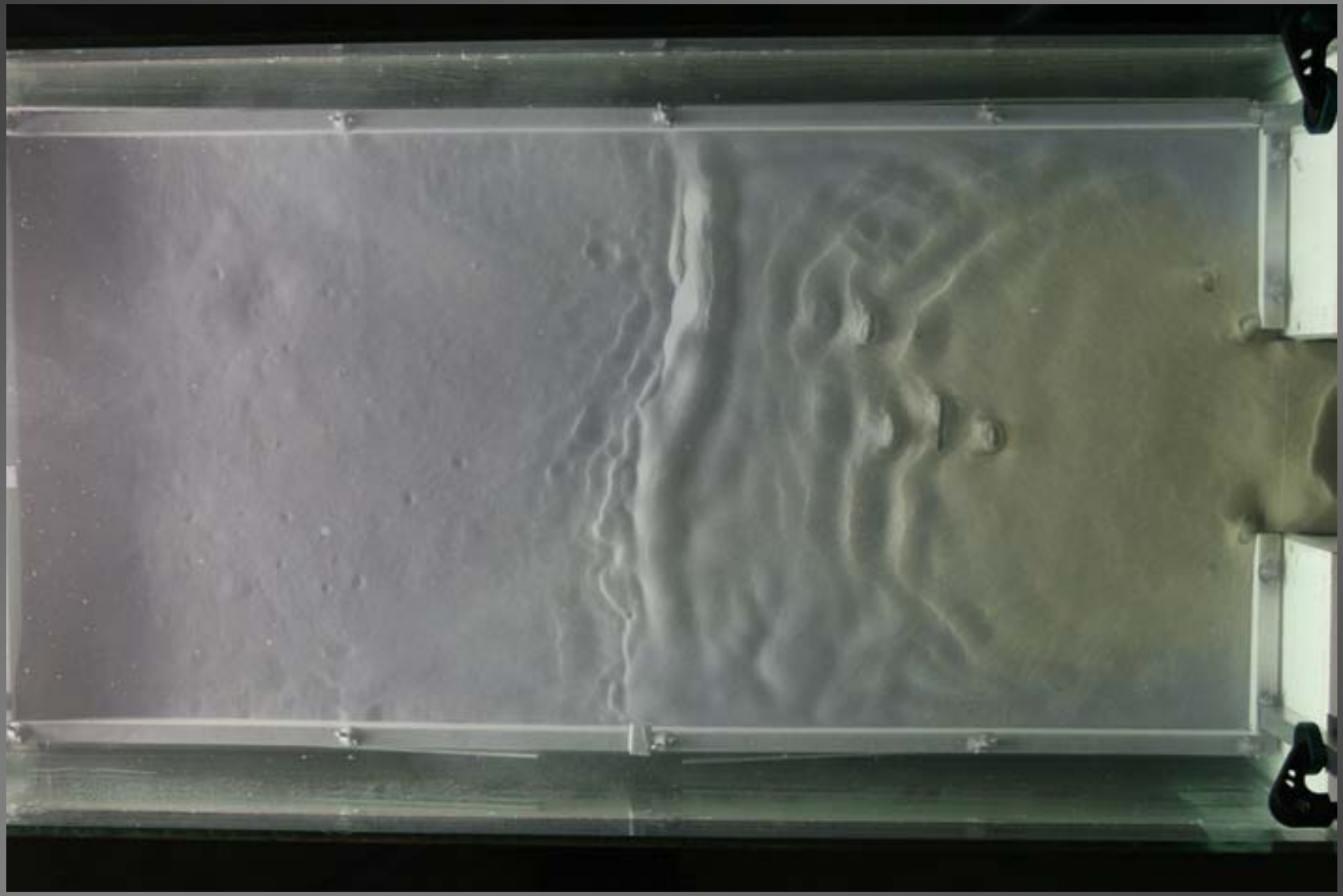


Sellier and Vendeville (2008)



Sellier and Vendeville (2008)



Sellier and Vendeville (2008)

Radial spreading and collapse of the fan

Sellier and Vendeville (2008)

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Radial spreading and collapse of the fan

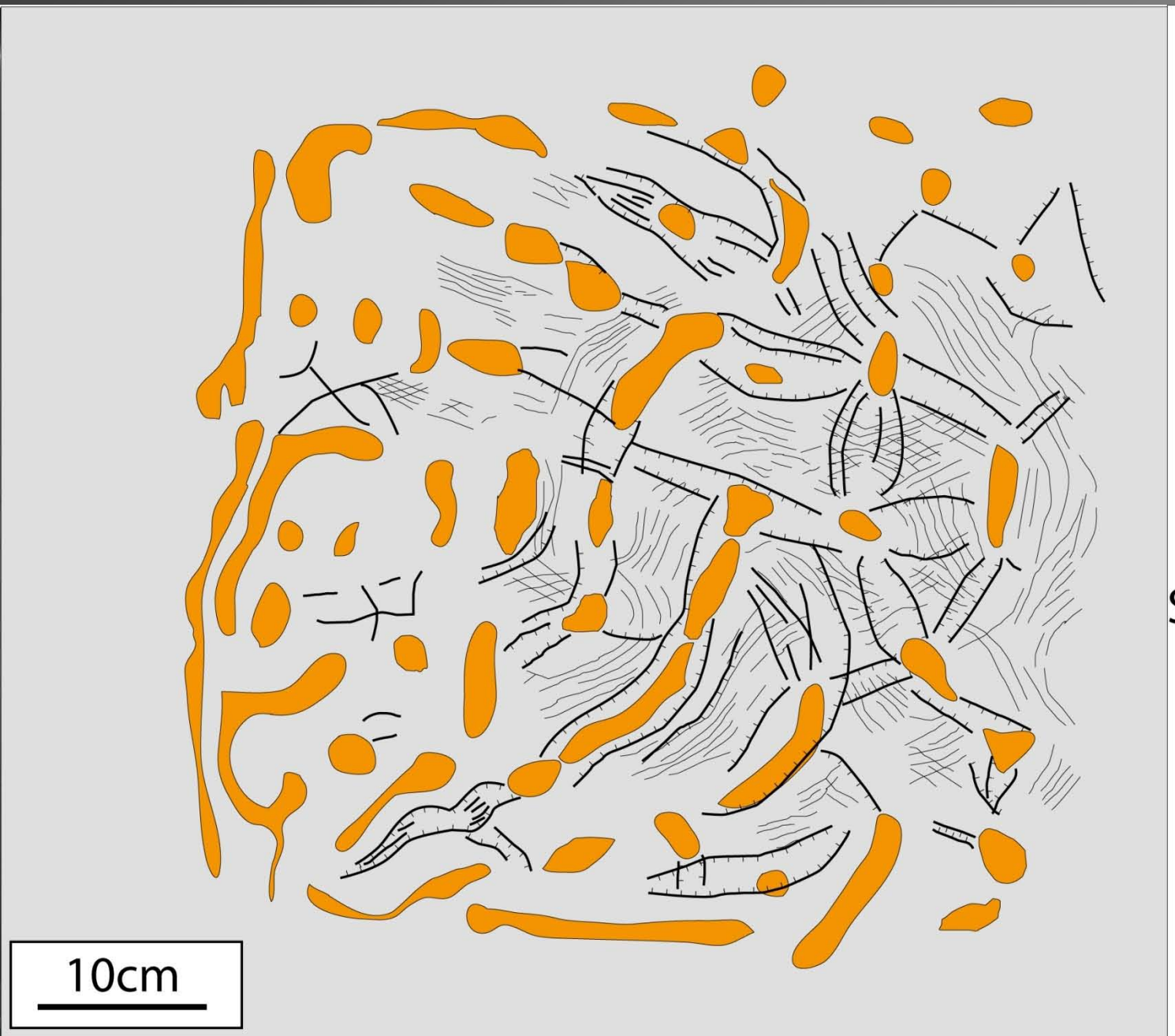
Sellier and Vendeville (2008)

Radial spreading and collapse of the fan

Sellier and Vendeville (2008)

Middle stage

Final stage

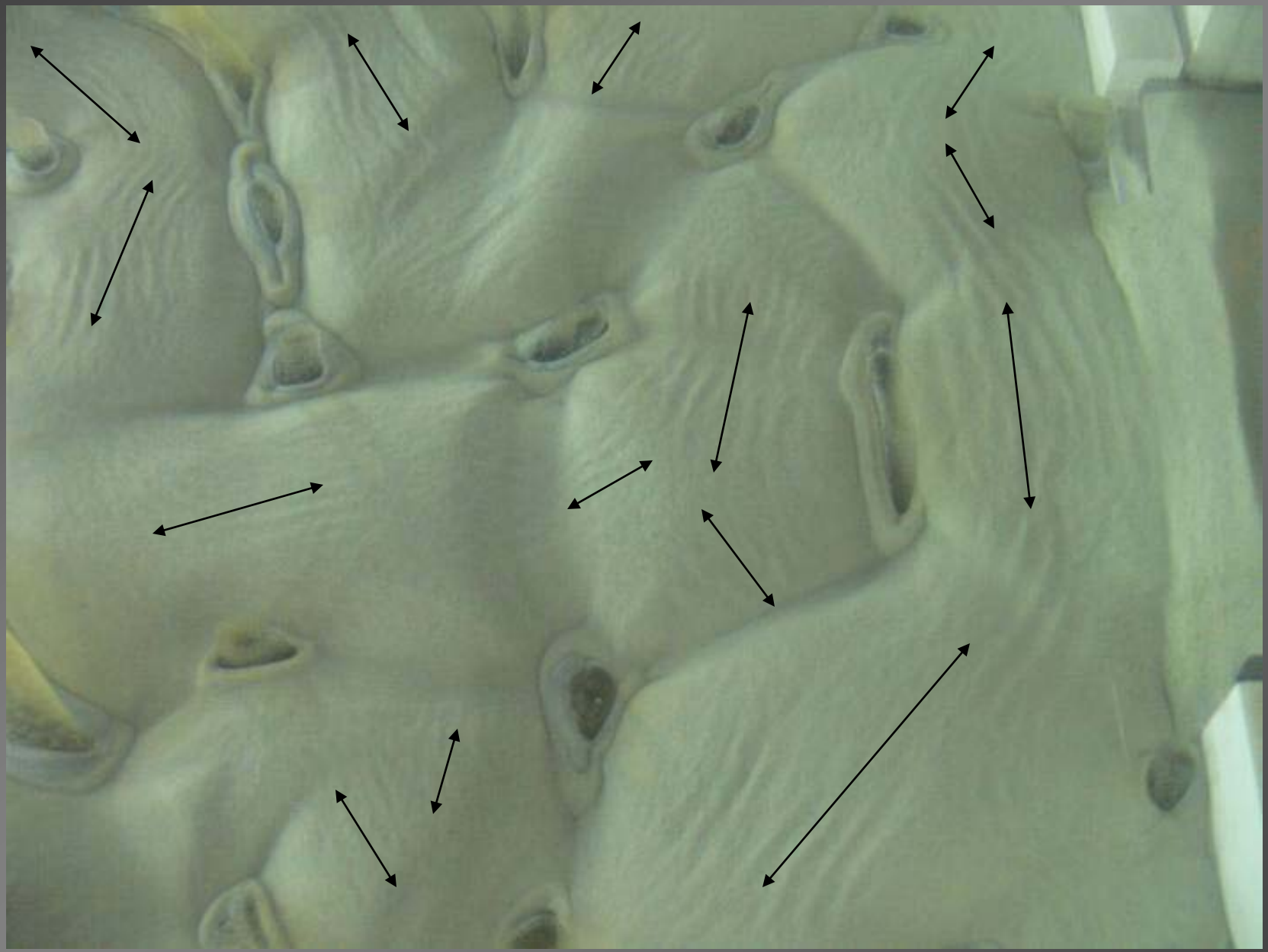


Diapirs

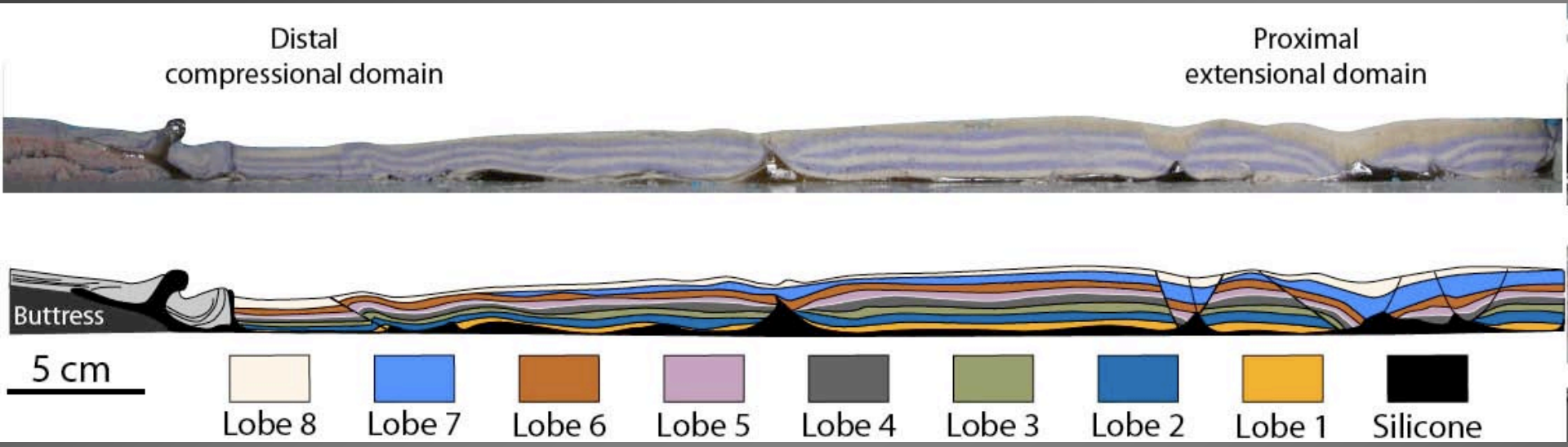
Main normal faults scarps

Secondary faults (turtle crestal faults)

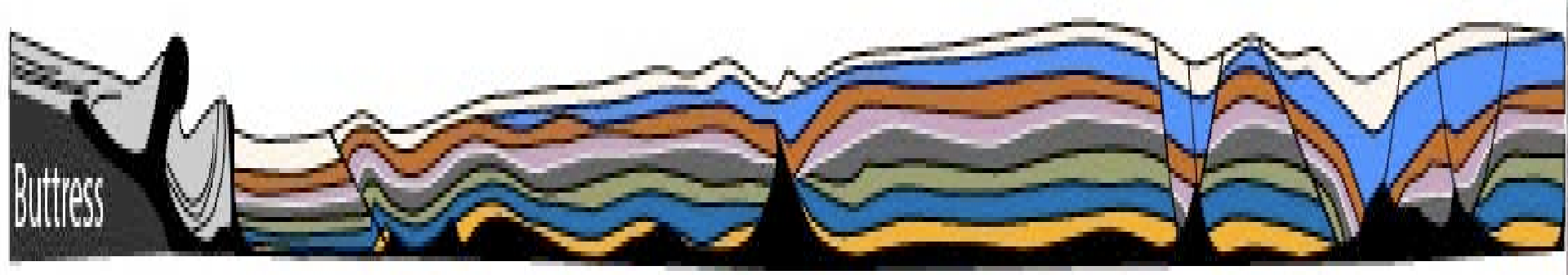
Turtle structures and multidirectional crestal grabens



Sellier and Vendeville (2008)



Vertical exaggeration: 3



Sellier and Vendeville (2008)

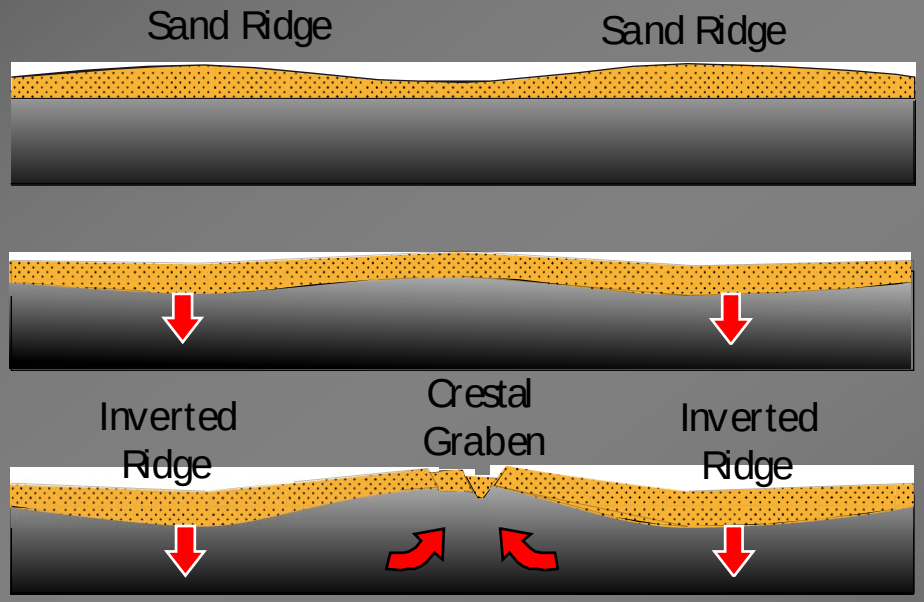
Outline

- Introduction
- New experimental approach and set up
- Salt response to *local* differential loading
- Salt response to *regional* differential loading
- **Conclusions and perspectives**

Conclusions

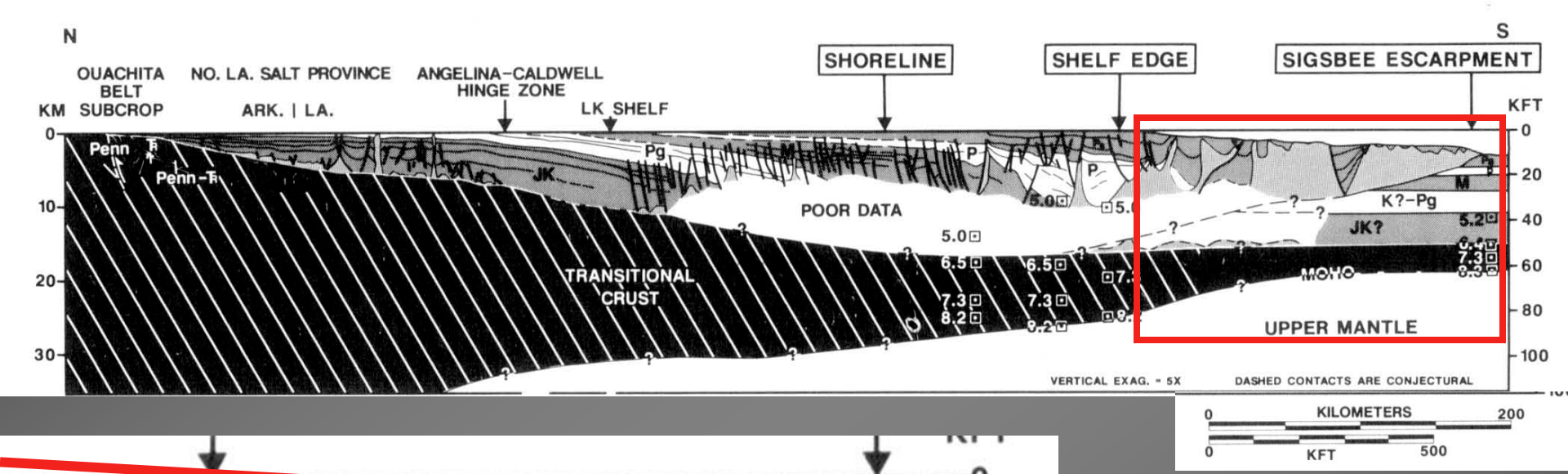
The tectono-stratigraphic approach demonstrates that:

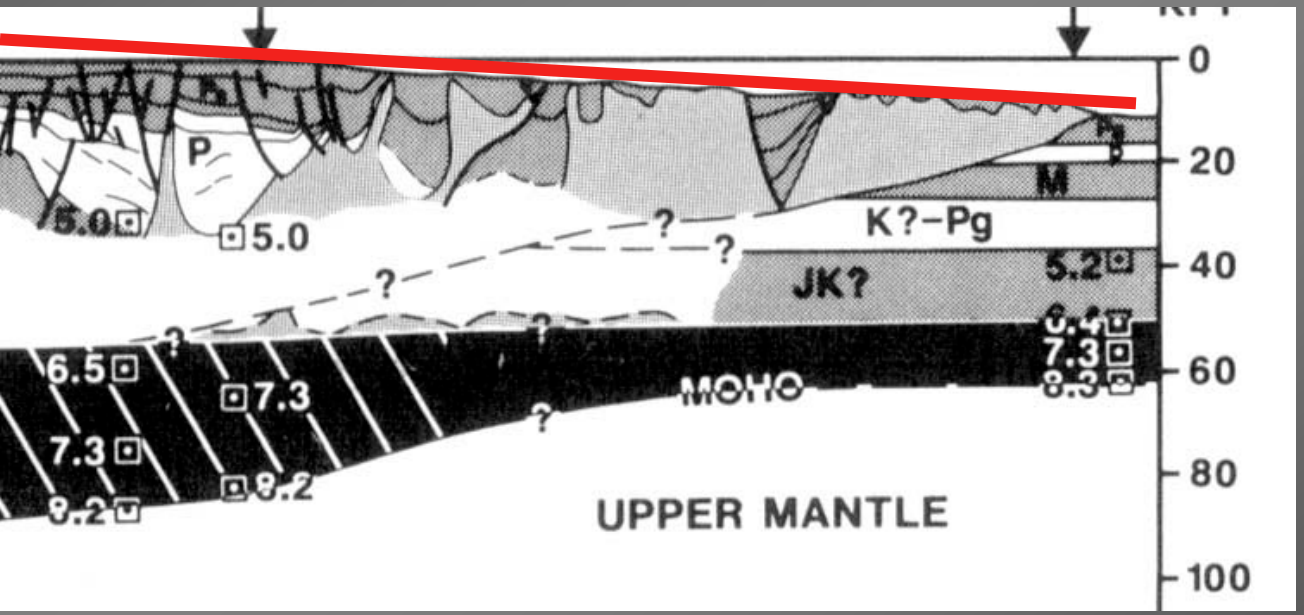
1. Swift salt movement can occur in response to low local differential loading



2. Gravity spreading and collapse can occur, even with a very gentle bathymetric slope (~ 1°)

Gentle slope in the presently active part of the U.S. Gulf of Mexico



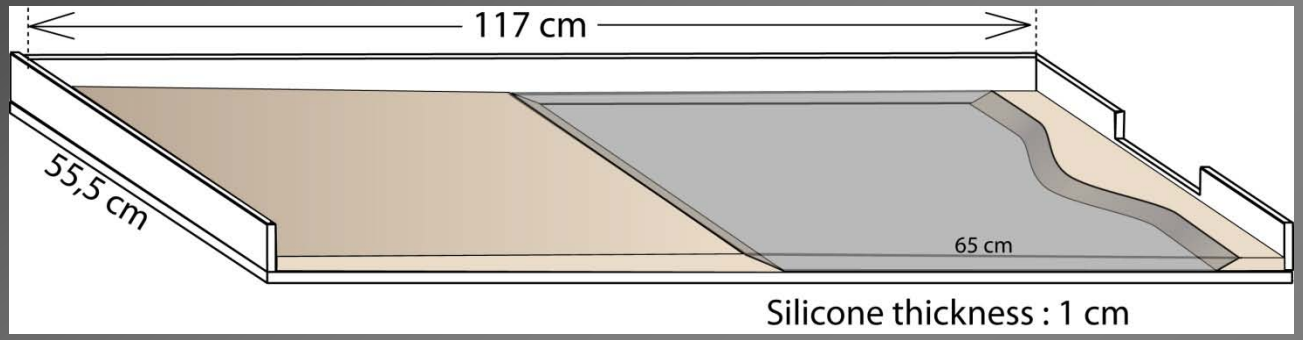


Vertical exaggeration: 5

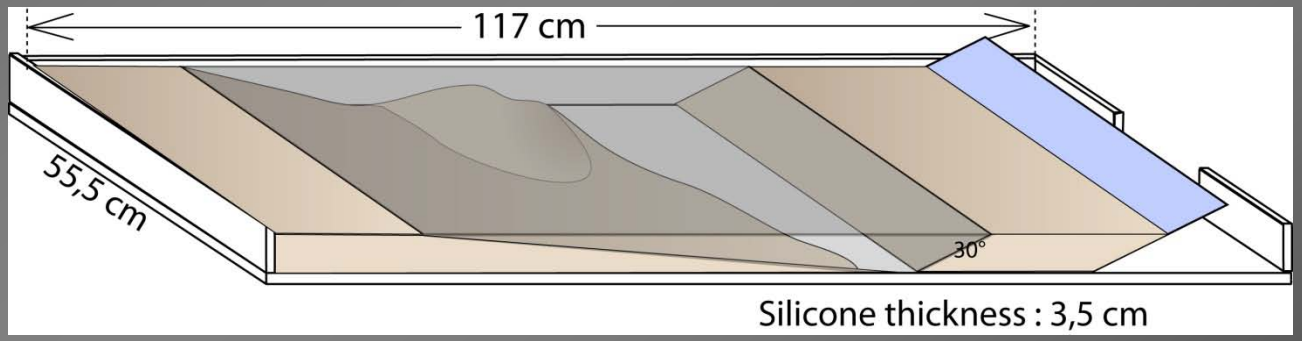
Worrall and Snelson (1989)

Perspectives

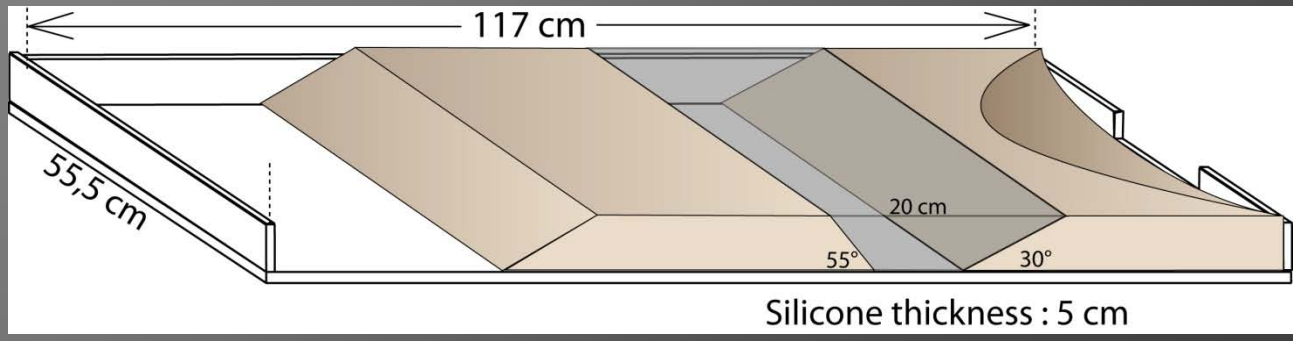
We are investigating the effect of depositing several consecutive lobes on salt bodies having various shapes : salt tongue to salt stock.



Salt tongue

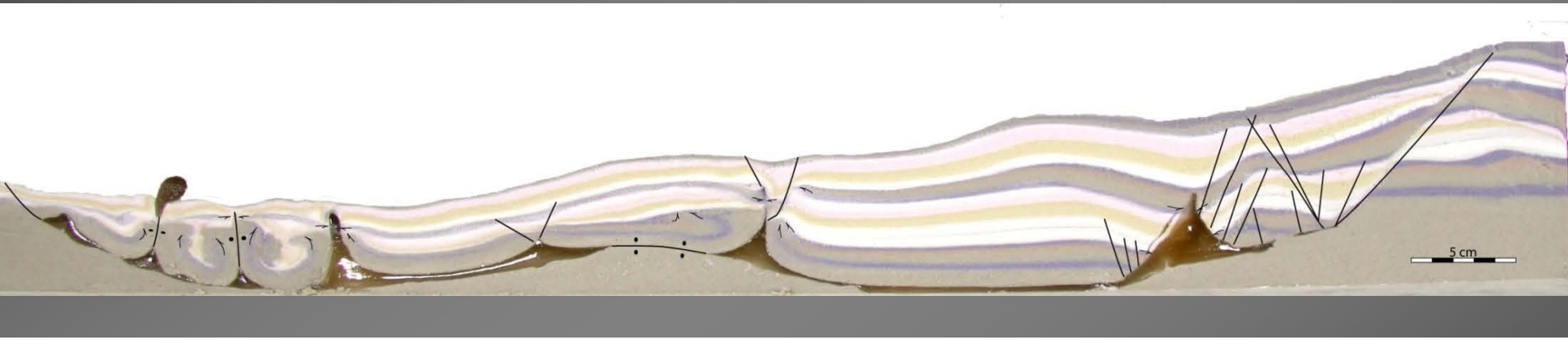


Salt stock

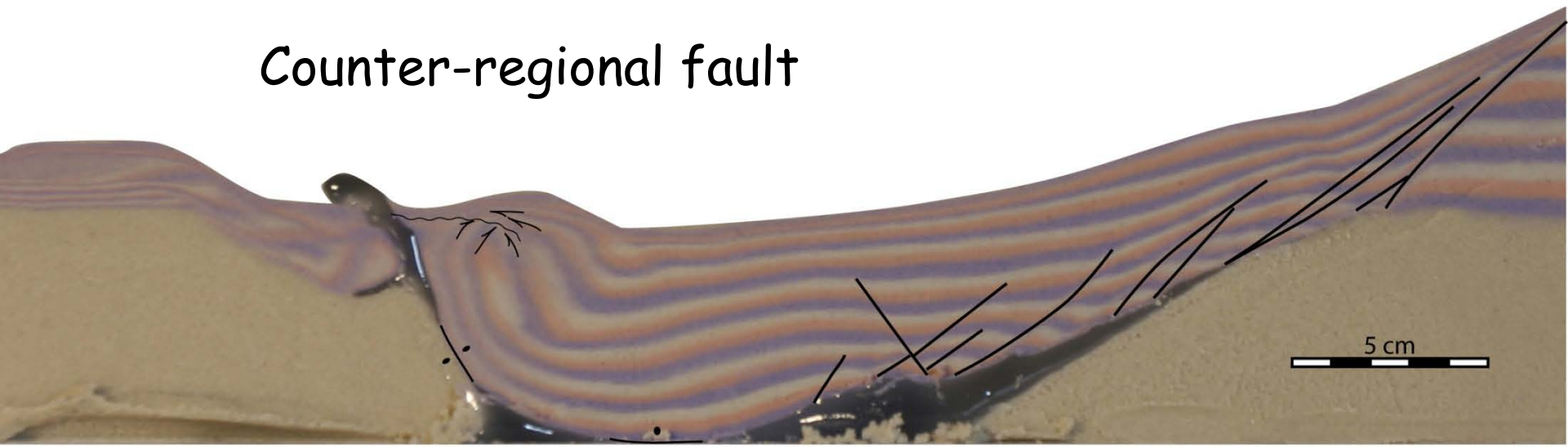


Perspectives (preliminary results)

Roho style



Counter-regional fault




THANK YOU

Example of early deformation: Gulf of lions (Western Meditteranean)