Ice shelves in a lab

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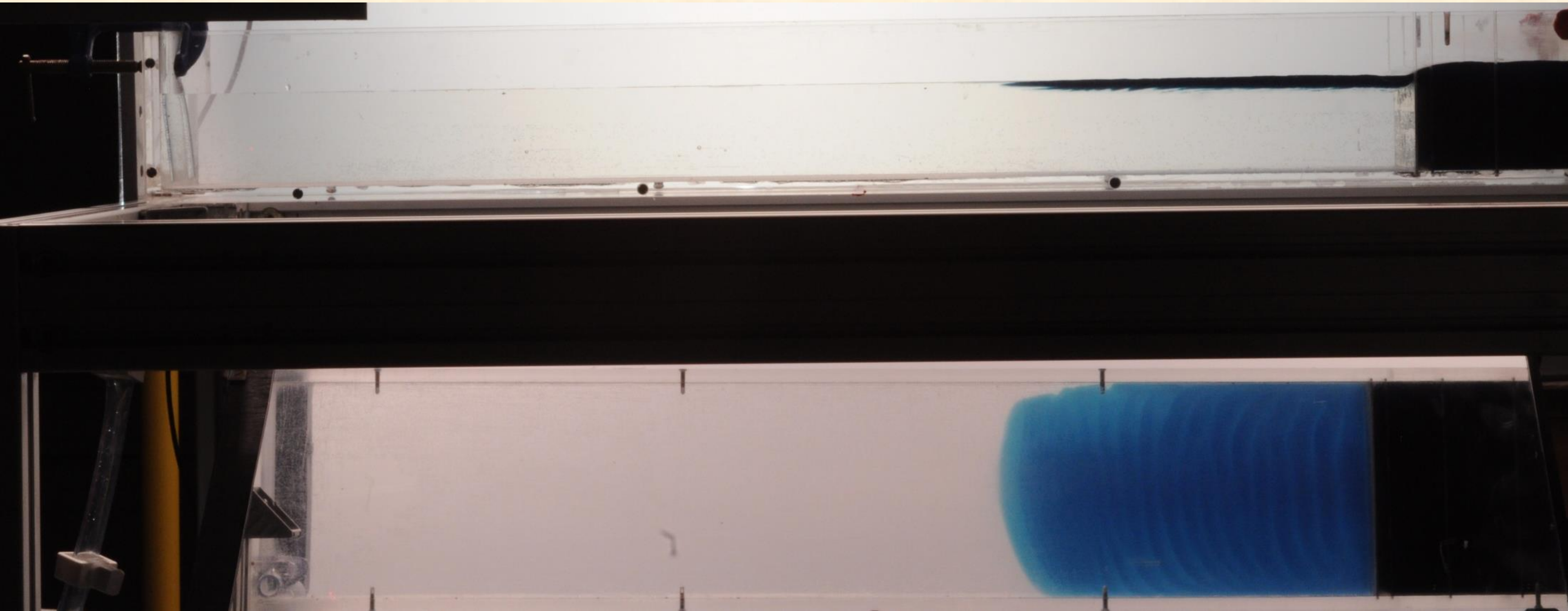
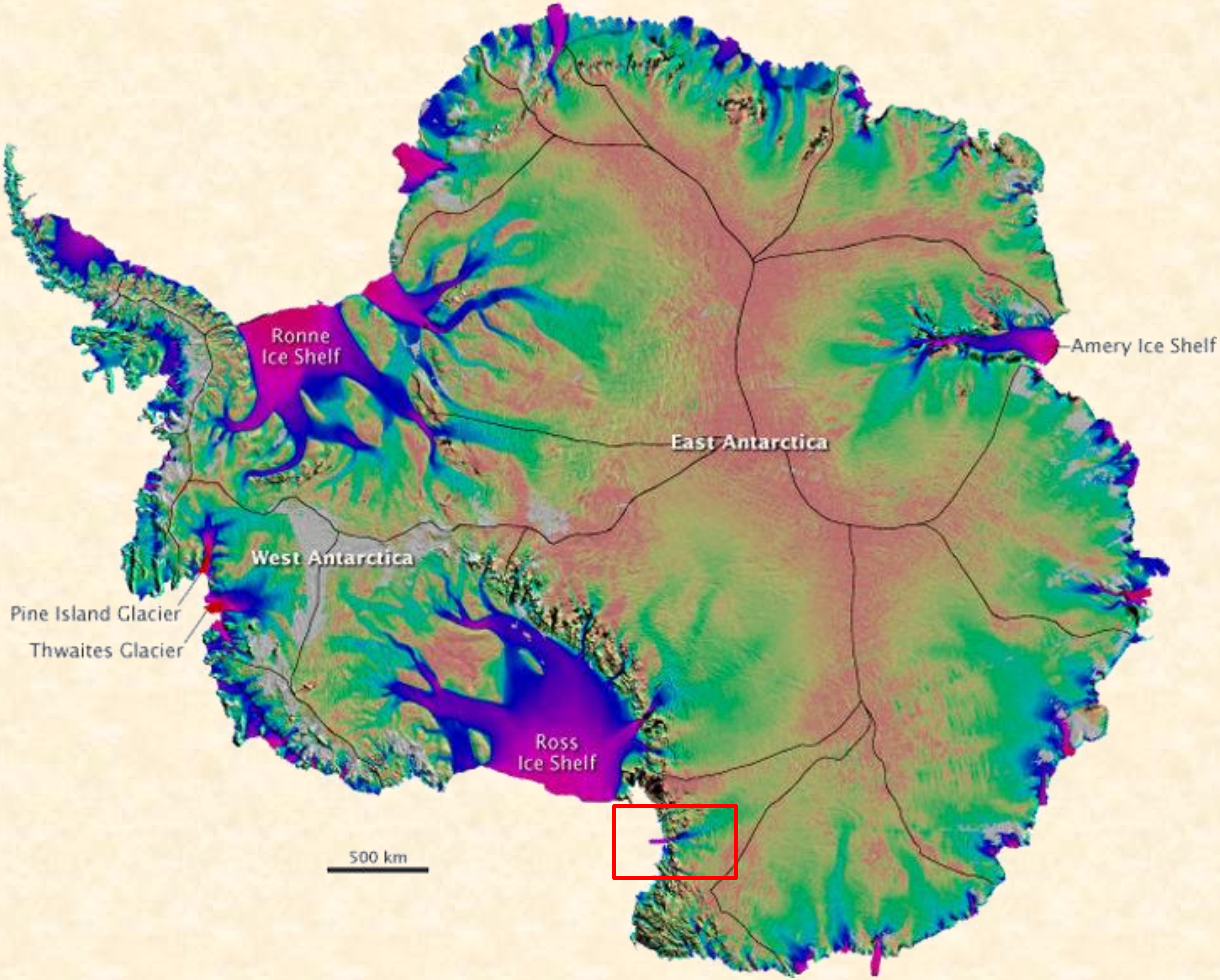
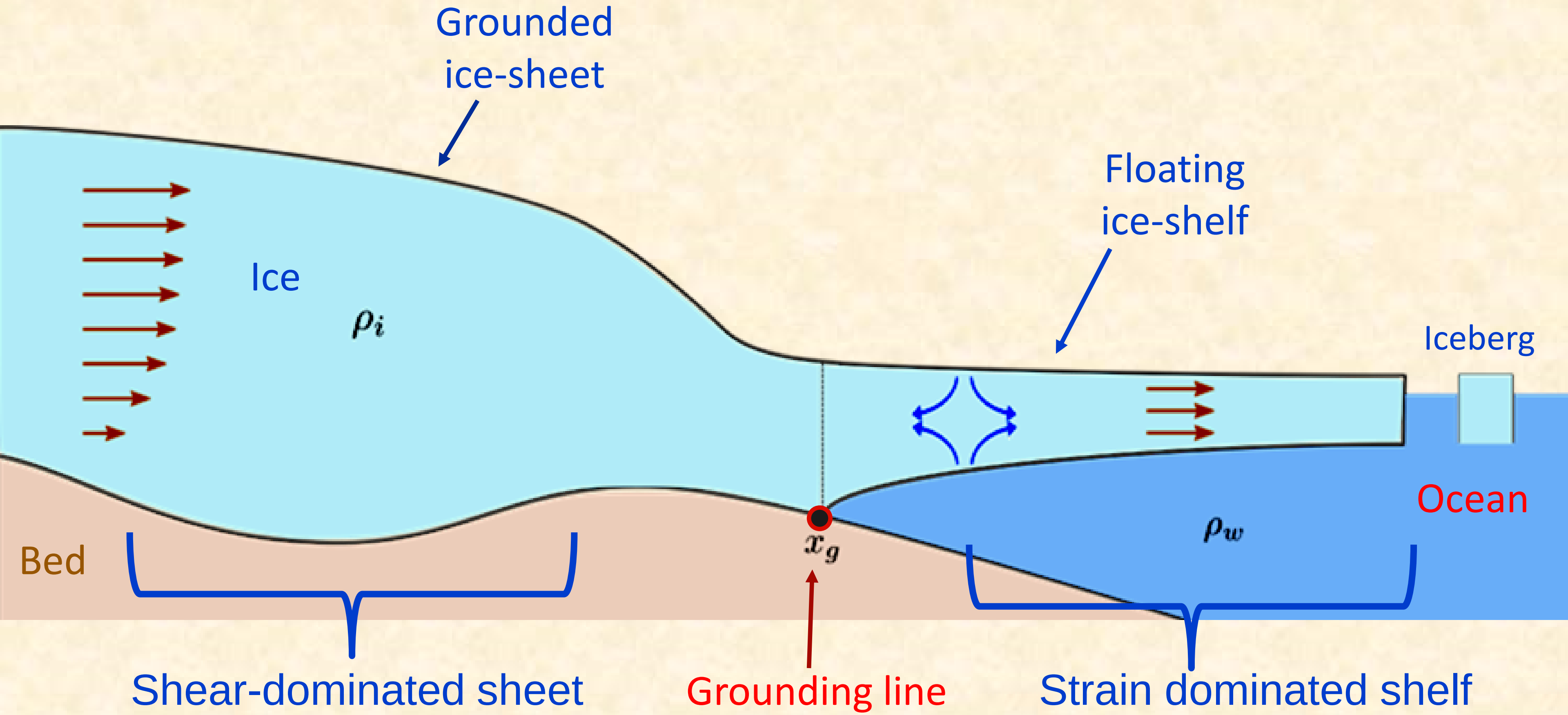


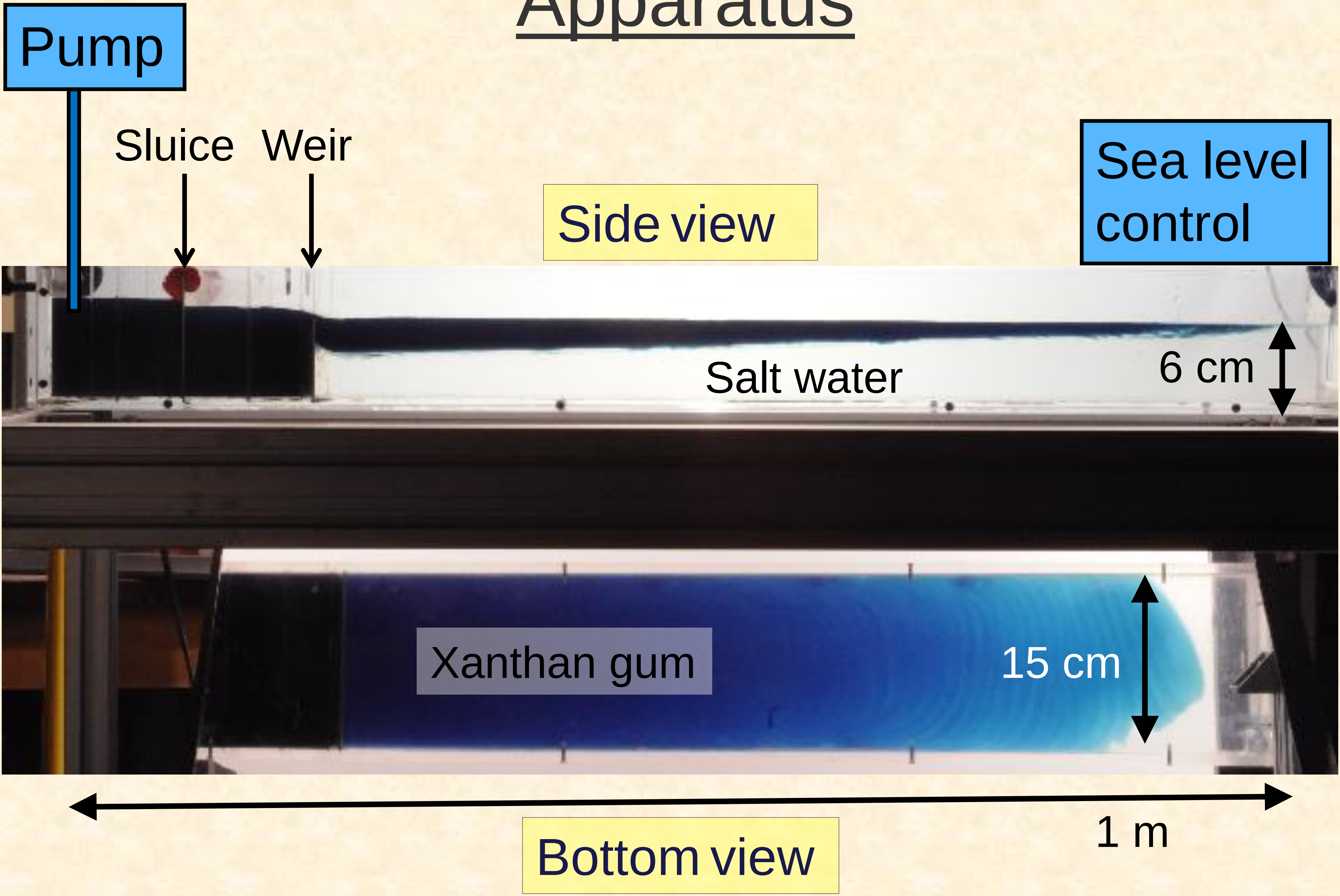

Ronne
Ice Shelf
Amery Ice Shelf
East Antarctica
West Antarctica
Pine Island Glacier
Thwaites Glacier
Ross
Ice Shelf
500 km


Glacier
(ice sheet)
Ocean

Understanding Glacier Flow

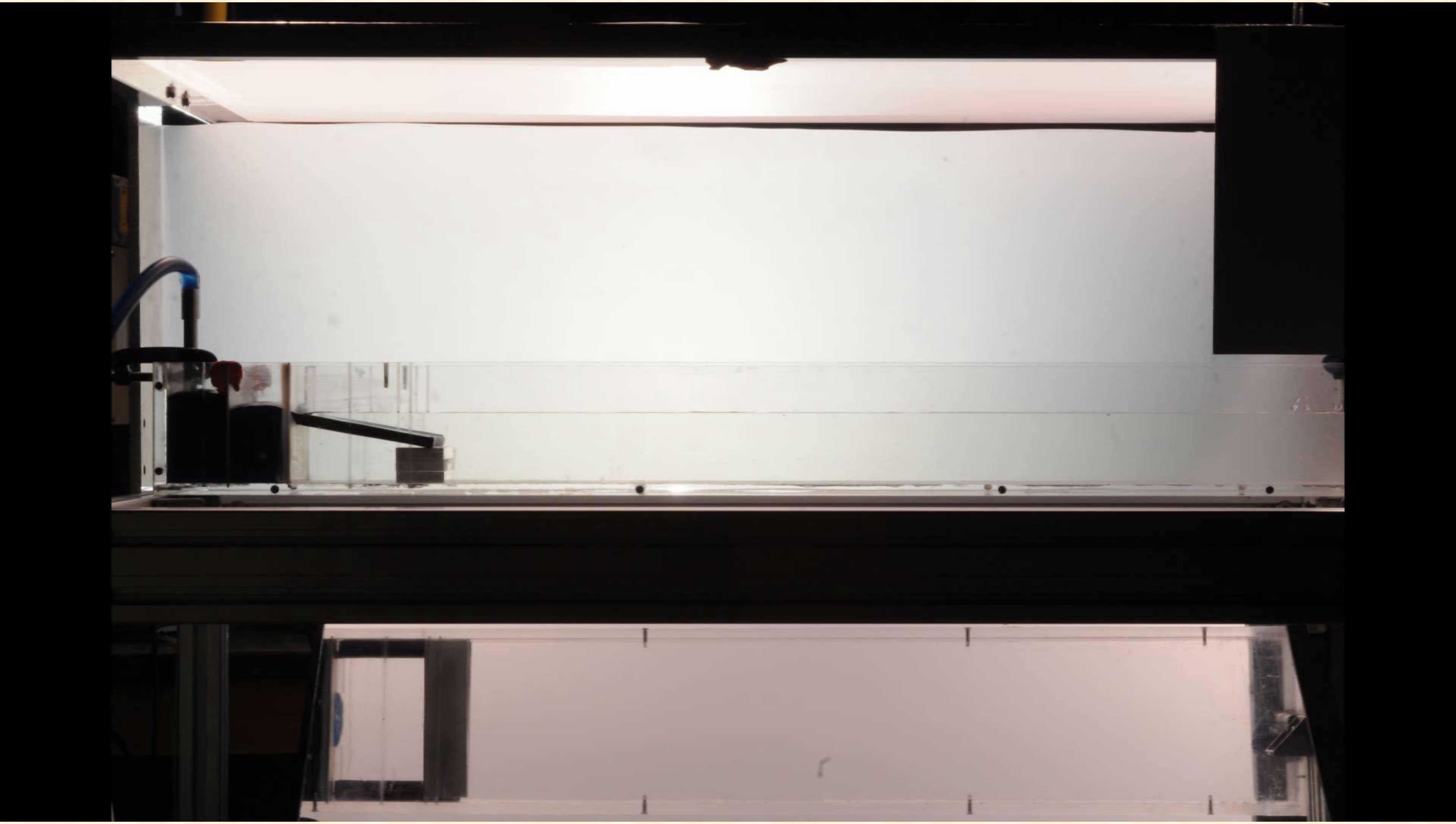


Apparatus

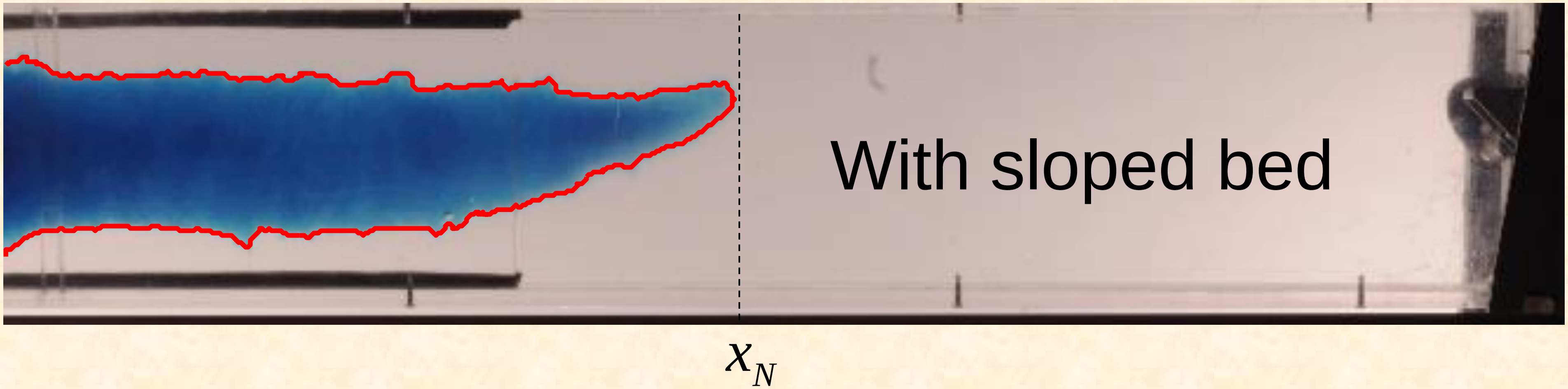


Pump
Sluice
Weir
Side view
Sea level control
Salt water
6 cm
Xanthan gum
15 cm
1 m
Bottom view

Ice tongue experiment



Experimental results



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Ice Shelves as Floating Channel Flows of Viscous Power-Law Fluids

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Abstract

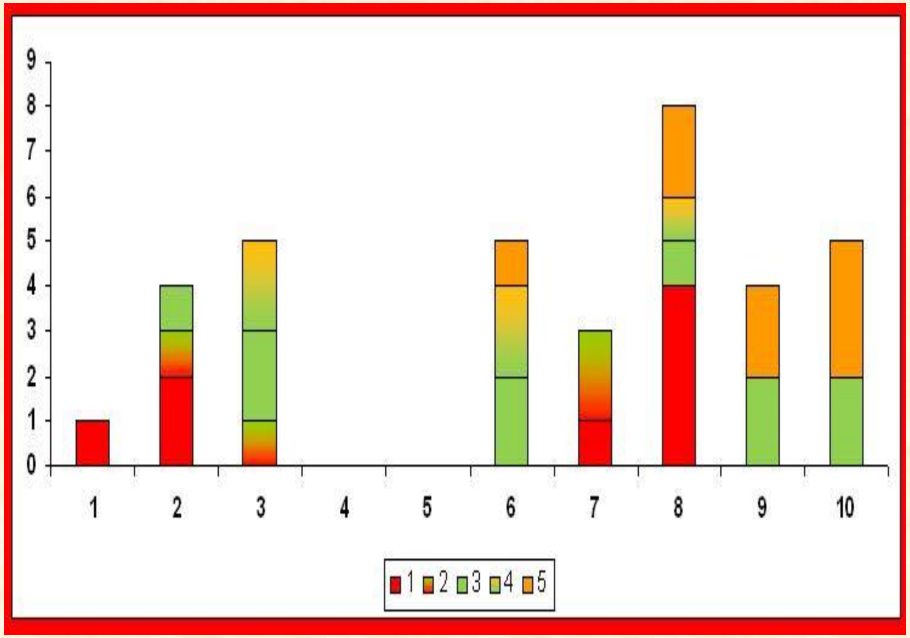
We explain the force balance in flowing marine ice sheets and the ice shelves they often feed. Treating ice as a viscous shear-thinning power law fluid, we develop an asymptotic (late-time) theory in two cases: the presence or absence of contact with sidewalls. Most real-world situations fall somewhere between the two extreme cases considered. The solution when sidewalls are absent is a fairly simple generalization of that found by Robison (JFM, 648, 363). In this case, we obtain the equilibrium grounding line thickness using a simple computer model and have an analytic approximation. For shelves in contact with sidewalls, we obtain an asymptotic theory valid for long shelves. We determine when this is. Our theory is based on the velocity profile across the channel being a generalized version of Poiseuille flow, which works when lateral shear dominates the force balance.

We conducted experiments using a laboratory model for ice. This was a suspension of xanthan in water, at a concentration of 0.5% by mass. The model has $n \approx 3.8$, similar to that of ice. Our theories agreed extremely well with our experiments for all relevant parameters (front position, thickness profile, lateral velocity profile, longitudinal velocity gradient and grounding line thickness). We also saw detailed features similar to natural systems. Thus, we believe we have understood the dominant force balance in both types of ice shelf.

Combining our understanding of the forces in the system with a basic model for basal melting and iceberg formation, we uncovered some instabilities of the natural system. Laterally confined ice shelves can rapidly disintegrate but ice tongues cannot. However, ice tongues can be shortened until they no longer exist, at which point the sheet becomes unstable and ultimately the grounding line should retreat above sea level. While the ice tongue still exists, the flow of ice into it should not be speeded up and the grounding line should also not retreat, assuming that only conditions in the ocean change. However, laterally confined ice shelves experience significant buttressing. If removed, this leads to a rapid speedup of the sheet and a new equilibrium grounding line thickness. We believe that something like this occurred in the Larsen B ice shelf.

Conclusions

- Previous summer students did only 4-6 experiments as outline of fluid flow was traced manually on the (few hundred) photographs
- Our breakthrough relied on a much greater number of experiments



- This was possible only through automated outline tracing in MATLAB.

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