ANALOG MODELLING OF PRESSURIZED SUBGLACIAL WATER FLOW : *IMPLICATIONS FOR TUNNEL VALLEY FORMATION AND ICE DYNAMICS*

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1 INTRODUCTION

Fig.1 : Tunnel valley network on the southern border of Lake Ontario (NASA).

Tunnel valleys (Fig.1) are elongated incisions commonly found in formerly glaciated areas and interpreted as the result of **subglacial meltwater erosion** beneath ice sheets. They exhibit specific characteristics such as an **undulating longitudinal profile** with adverse slopes, constant width along their path, U to box-shaped cross-sectional profile and an average width-depth ratio around 1:10 (Fig. 2). An experimental apparatus has been designed to recreate a pressurized subglacial meltwater system and study how tunnel valleys form and how they can influence ice dynamics.

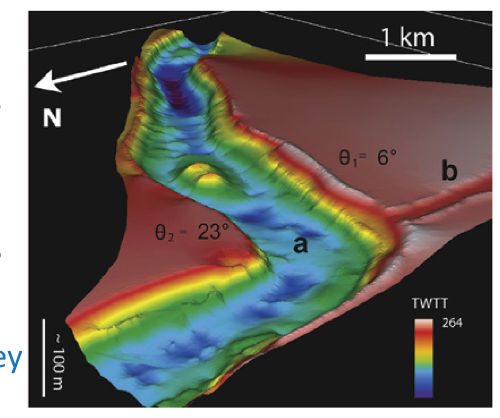


Fig.2 : 3D reconstruction of a tunnel valley in the North Sea (Stewart et al., 2013)

2 EXPERIMENTAL APPARATUS AND METHODS

A — Subglacial environment is recreated using a **3 cm thick silicon putty** to simulate the ice cap and a **5 cm thick layer of fine sand** (100µm) to simulate the subglacial substratum.

B — **Meltwater production** is simulated by a **punctual injection of pure water** whom discharge is governed by :

$$Q = \frac{2\pi K e H_{water}}{\ln\left(\frac{r_1}{r_2}\right)} \quad \text{with} \quad H_{water} = \frac{(\rho_{bulk}\, g\, h_s) + (\rho_{silicon}\, g\, h_{silicon})}{(\rho_{water}\, g)}$$

C — **Water pressure** can be followed using a **pressure sensor** placed in the injection system.

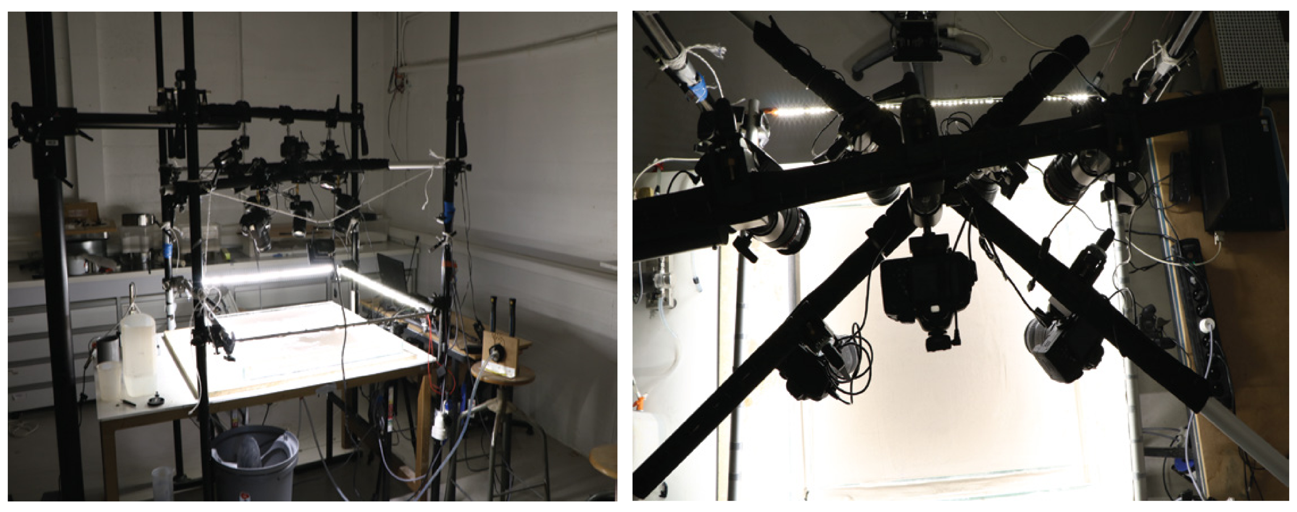


Fig.3 : Photograph of the experimental apparatus and the 8 cameras acquisition device.

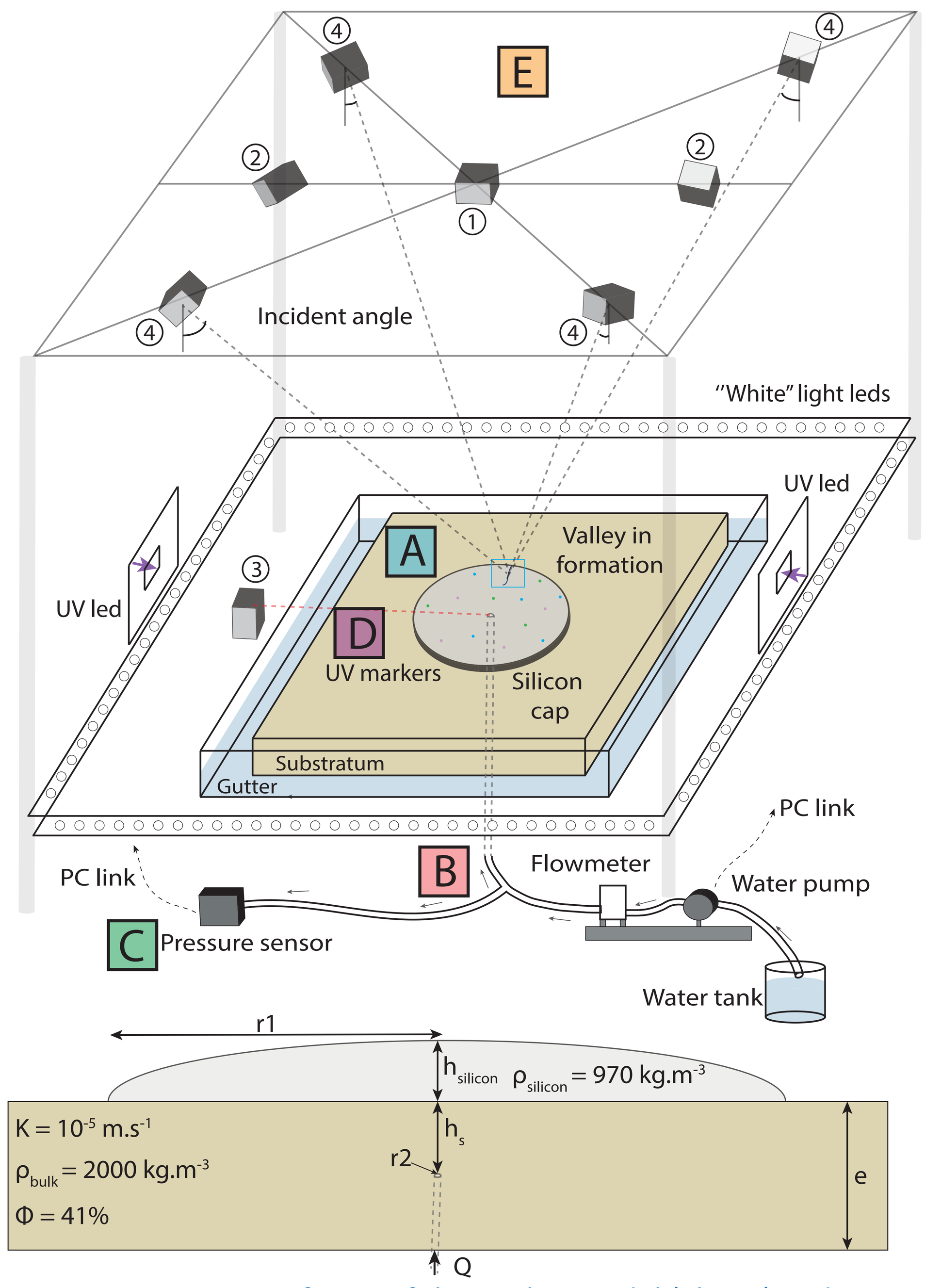


Fig. 4 : Interpretative figure of the analog model (above) and cross-sectional profile (below)

D — **3 levels of UV markers** placed in the silicon (base, mid-thickness and surface) combined with a **5 seconds switching lighting device from white leds to UV leds** allows to simultaneously follow **the formation and evolution of tunnel valleys** and the **ice dynamics.**

E — The experiment is monitored using a **8 cameras acquisition device** taking synchronous **HR photographs**

- ① - 1 calibrated for the **UV markers**.
- ② - 2 photographing the entire silicon cap
- ③ - 1 photographing a lateral silicon view to follow **vertical displacements**.
- ④ - 4 zoomed up on the valley(s) in formation used to **generate HR DEMs (resolution < 10^{-1} mm)**.

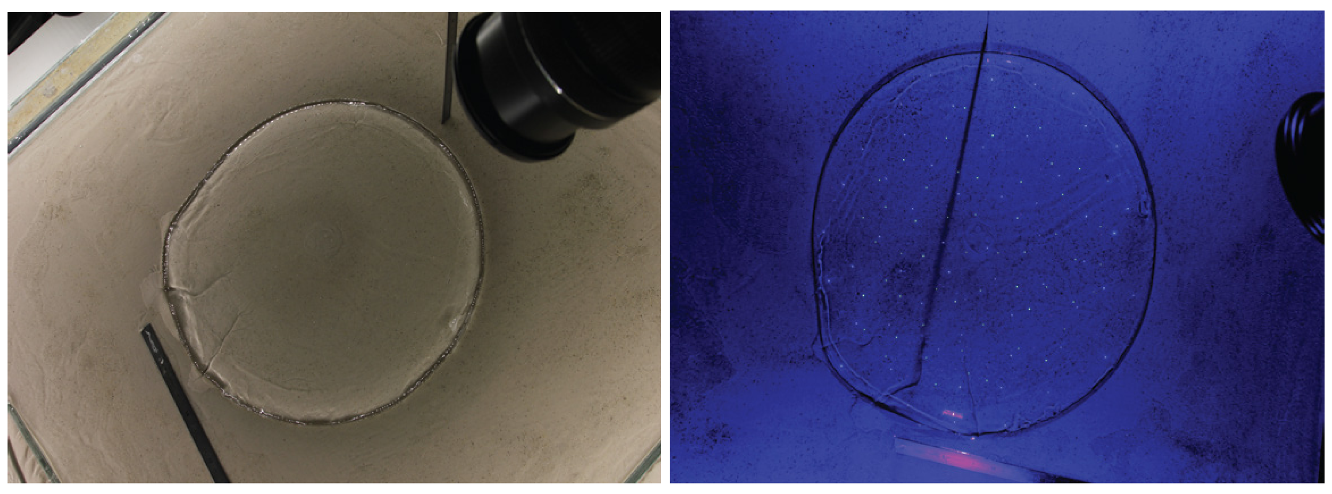


Fig. 5 : Photograph of the silicon putty in white light (on the left). Photograph of the silicon putty in black light showing the punctual UV markers

3 MORPHOLOGICAL CHARACTERISTICS OF EXPERIMENTAL VALLEYS

The experimental valleys display morphological characteristics similar to the **key morphological criteria** used to identify tunnel valleys : **undulating longitudinal profile with overdeepenings and adverse slopes** (Fig.4A) , a **constant width along their path** (Fig.6B), a statistical **width-depth ratio around 1:10** (Fig.6C) and cross-sectional profiles displaying **U-shaped** to **box-shaped morphology and steep flank slopes** (Fig.6D).

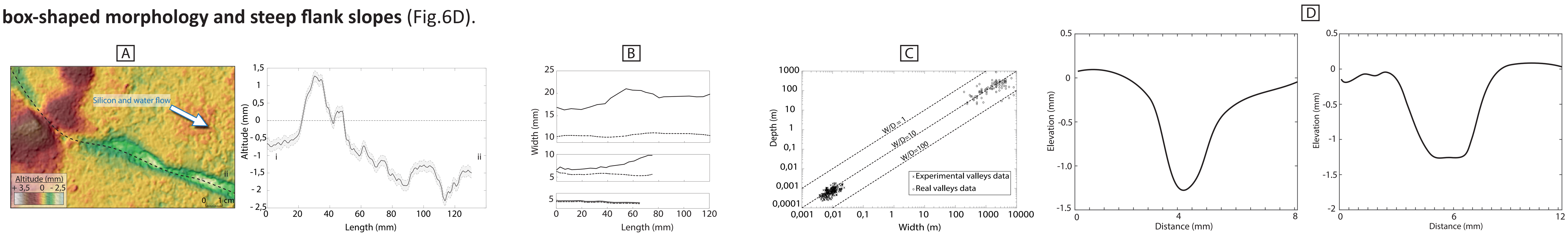


Fig. 6 : (A) : Undulating longitudinal profle of an experimental valley. (B) : Width of the incision channel (dashed lines) and valley (black lines). (C) Width-depth ratio of experimental and natural tunnel valleys . (D) : Examples of a U- and box-shaped experimental cross-sectional profile.

4 TUNNEL VALLEYS FORMATION/EVOLUTION IMPACTS ON ICE FLOW DYNAMICS

The extraction of the **positions of the UV markers** through time gives the opportunity to draw **silicon flow maps** and to establish correlations between **the ice dynamics and the evolution of the subglacial drainage system**. The punctual injection generates, **once water pressure exceeds the sum of the lithostatic and glaciostatic pressures, a water pocket** at the silicon-bed interface. Drainage of this water pocket at the silicon margin **increases significantly the silicon flow along a corridor, similar** to ice streams observed in nature (Fig. 5a). **Channelization and tunnel valley formation causes the ice stream to slow down (Fig.5b) and possibly to laterally migrate depending on the dynamics of valley formation. In Fig. 5C the ice stream switches off and the ice sheet stabilizes as the tunnel valley system becomes efficient to drain the meltwater produced and thus to reduce basal fluid pressure.**

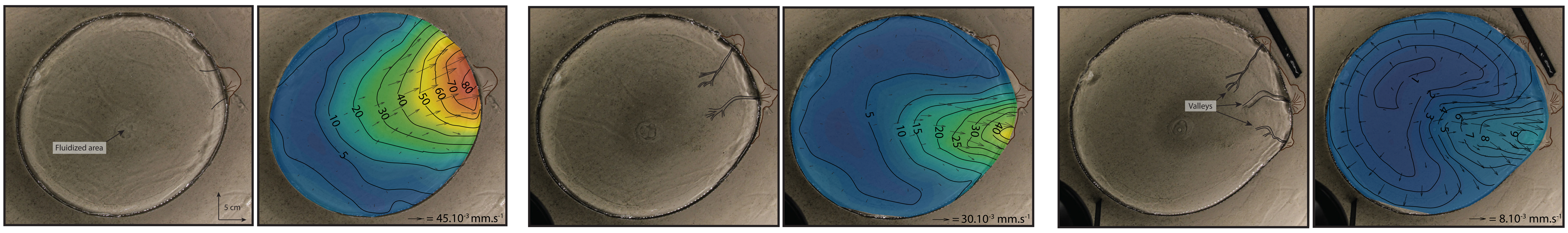
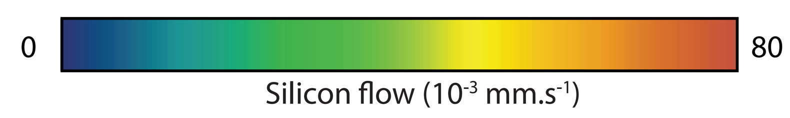


Fig.5: Snapshot and silicon flow maps interpolated from the position of the UV markers and averaged on the last 40s preceding the snapshot at t=90s (A); t=340s (B) and t=1600s=end (C).



5 CONCLUSION

Simulation of a pressurized subglacial environment using a **punctual injection of water into a permeable and erodible substratum covered by an impermeable and viscous cap** produces **analog drainage features similar to tunnel valleys**. UV markers placed in the silicon cap give access to the **temporal evolution of the silicon cap**. The silicon flow maps highlights that the **migration and drainage of a water pocket at the interface** increases significantly the silicon flow **thus leading to ice streaming. Ice stream behavior seems to be controlled by the dynamics of tunnel valleys formation and their drainage efficiency.**