National Cheng Kung University
Hydraulic & Ocean Engineering

MORPHOHYDRAULICS
imaging laboratory

The 2017 Workshop on Processes and Products of Deep-Sea Sediment Gravity Flows

Experiments of Submarine Canyons and Braided Turbidites

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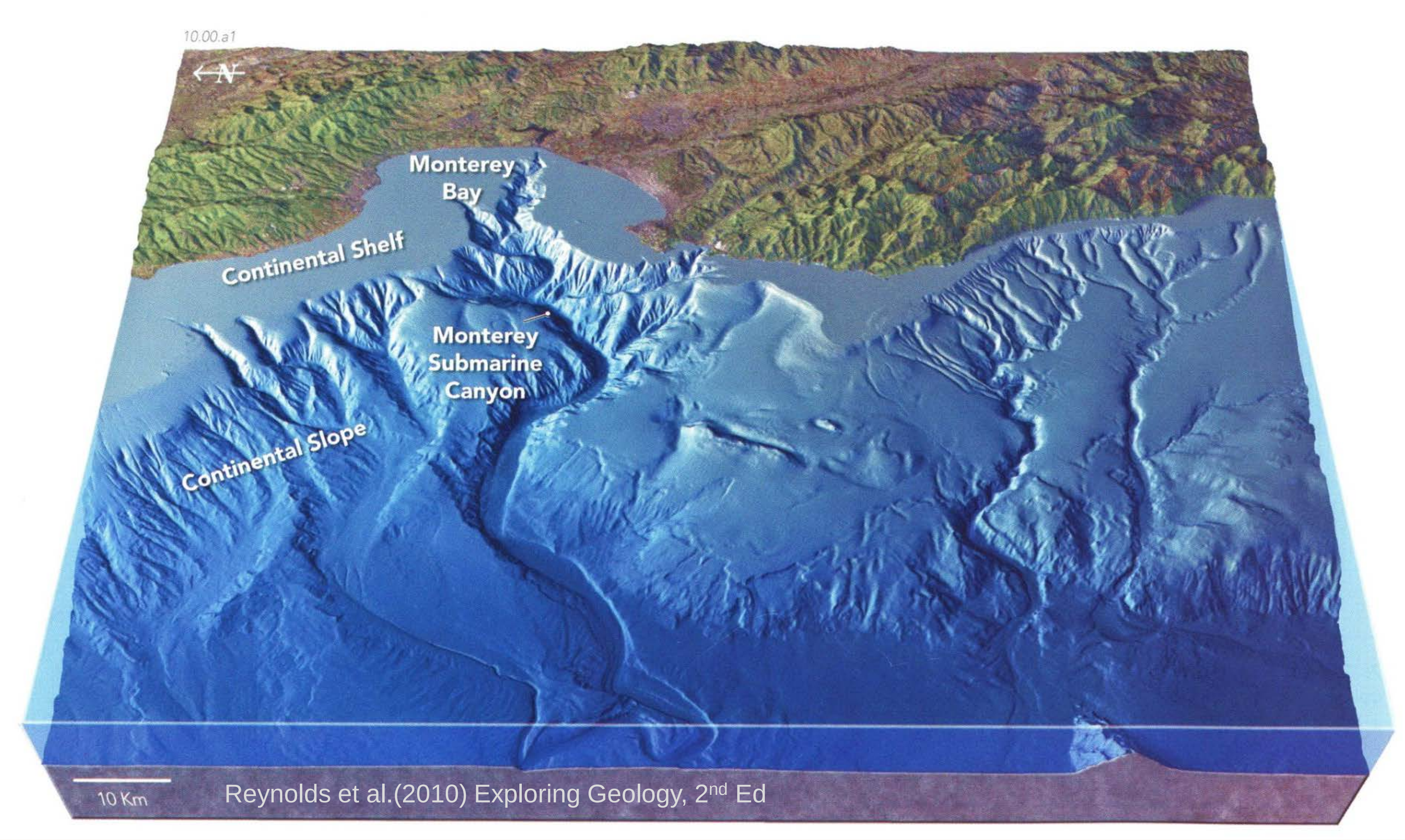
National Central
University

Date: 2017.08.10

Seascape: submarine canyons in active margin

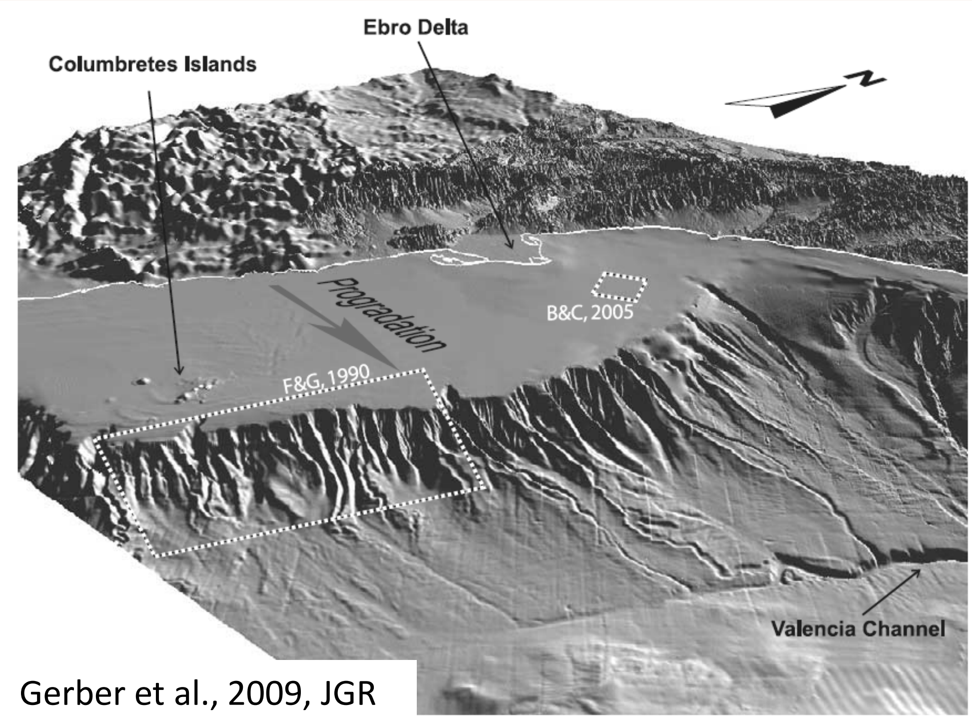
Shelf, shelf-indenting canyons, slope-confined canyons



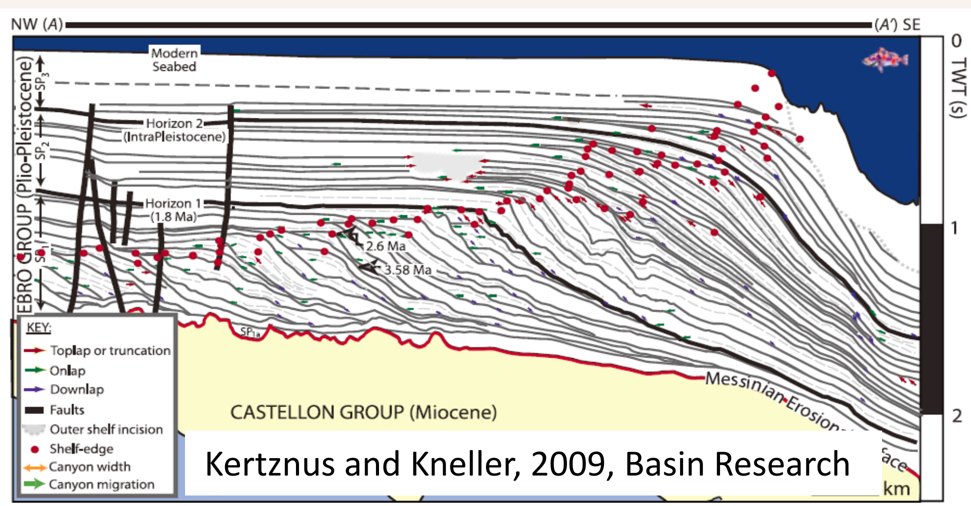
Reynolds et al.(2010) Exploring Geology, 2nd Ed

Seascape: submarine canyons in passive margin

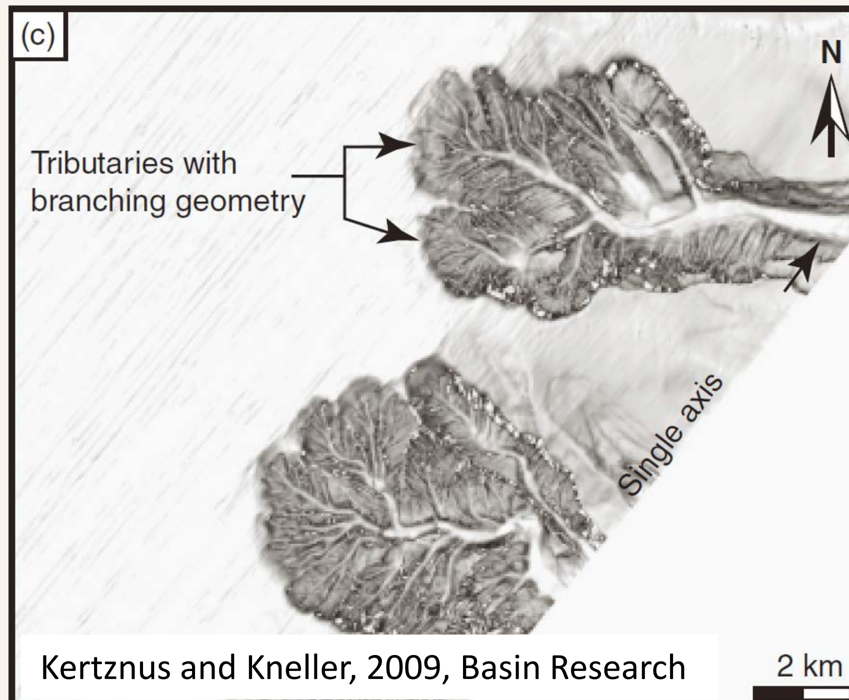
- The Mediterranean Sea
- Prograding Ebro margin
- Dendritic channel networks



Gerber et al., 2009, JGR



Kertznus and Kneller, 2009, Basin Research

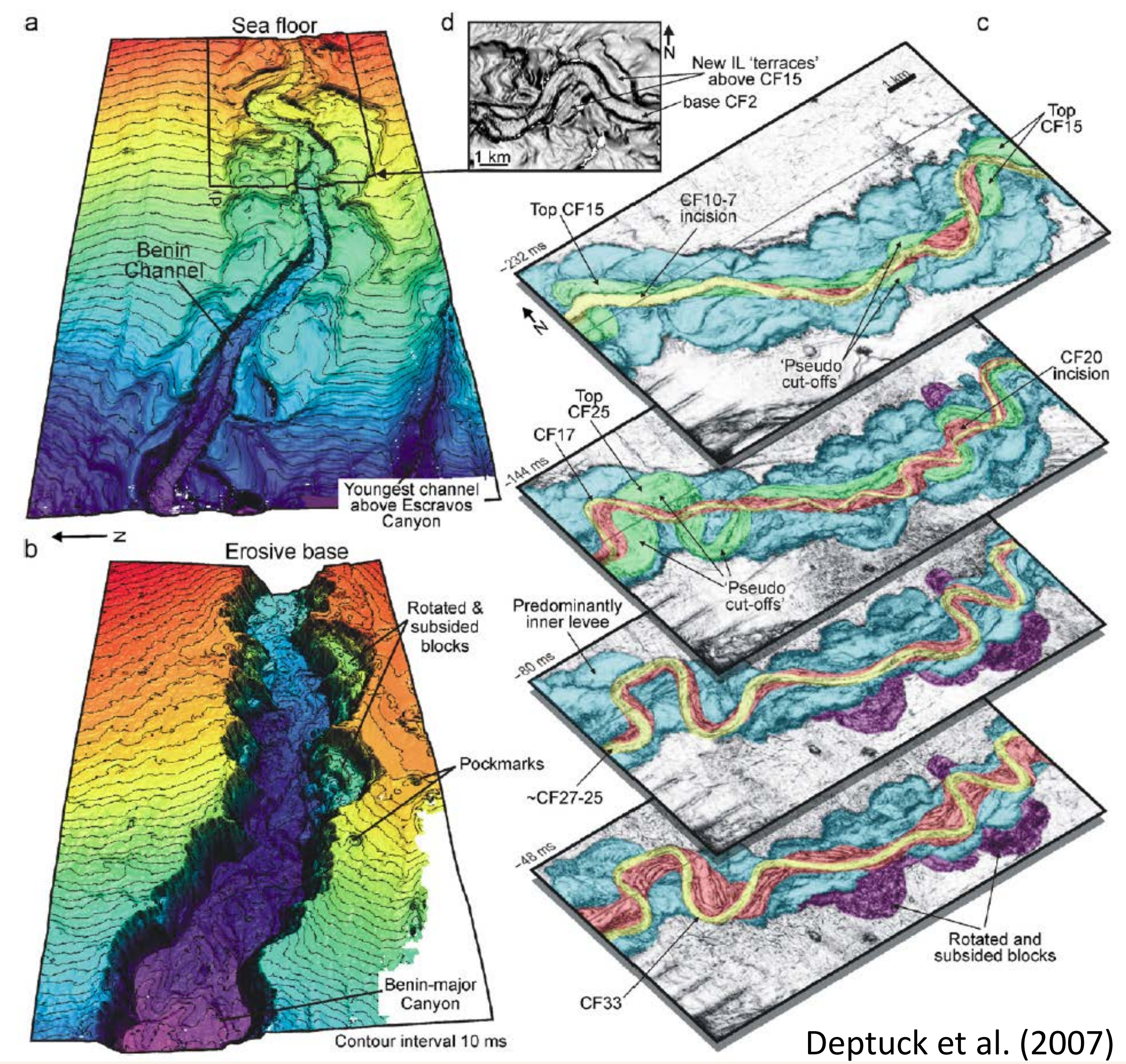


Kertznus and Kneller, 2009, Basin Research

Seascape: submarine channels

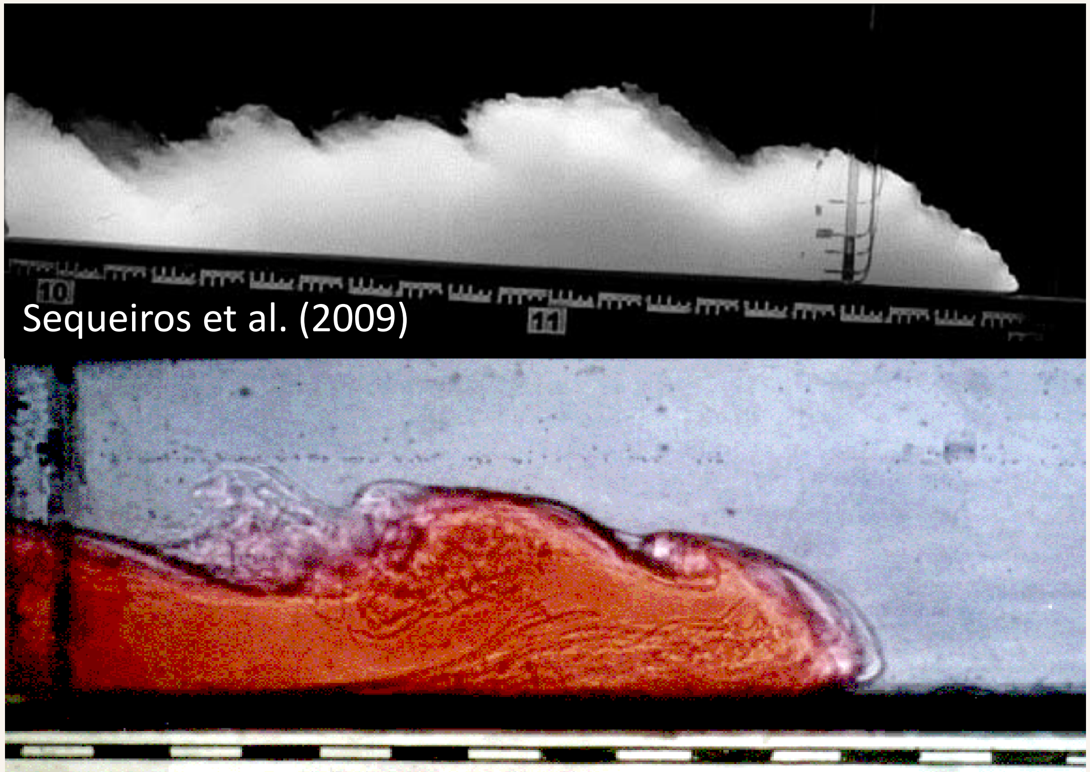
Technology, high resolution sonar bathymetry and in situ measurements

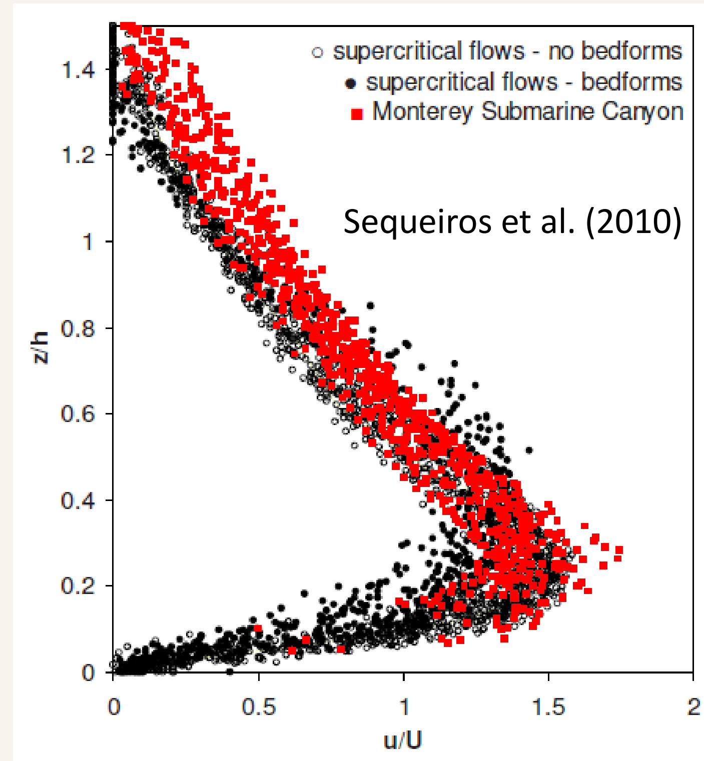
Benin-major Canyon, western Niger Delta slope



Deptuck et al. (2007)

Turbidity currents


Sequeiros et al. (2009)



Sequeiros et al. (2010)

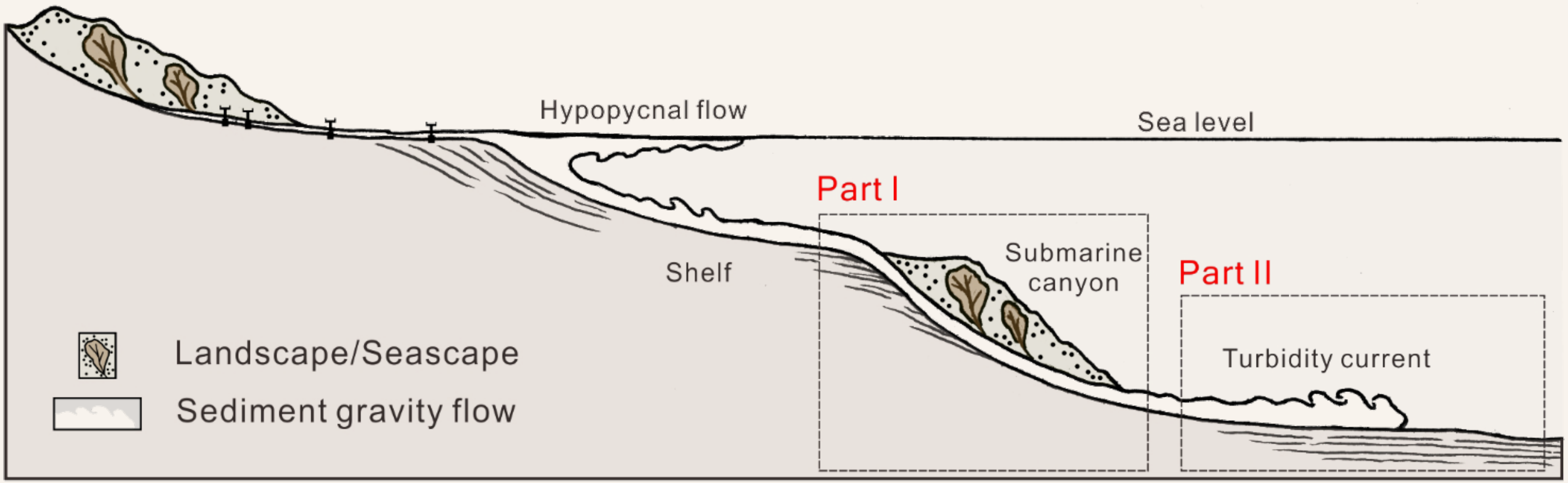
For long-term geomorphic actions,

Turbidity currents ~ saline currents ~ Field-scale sediment gravity flows

Agenda

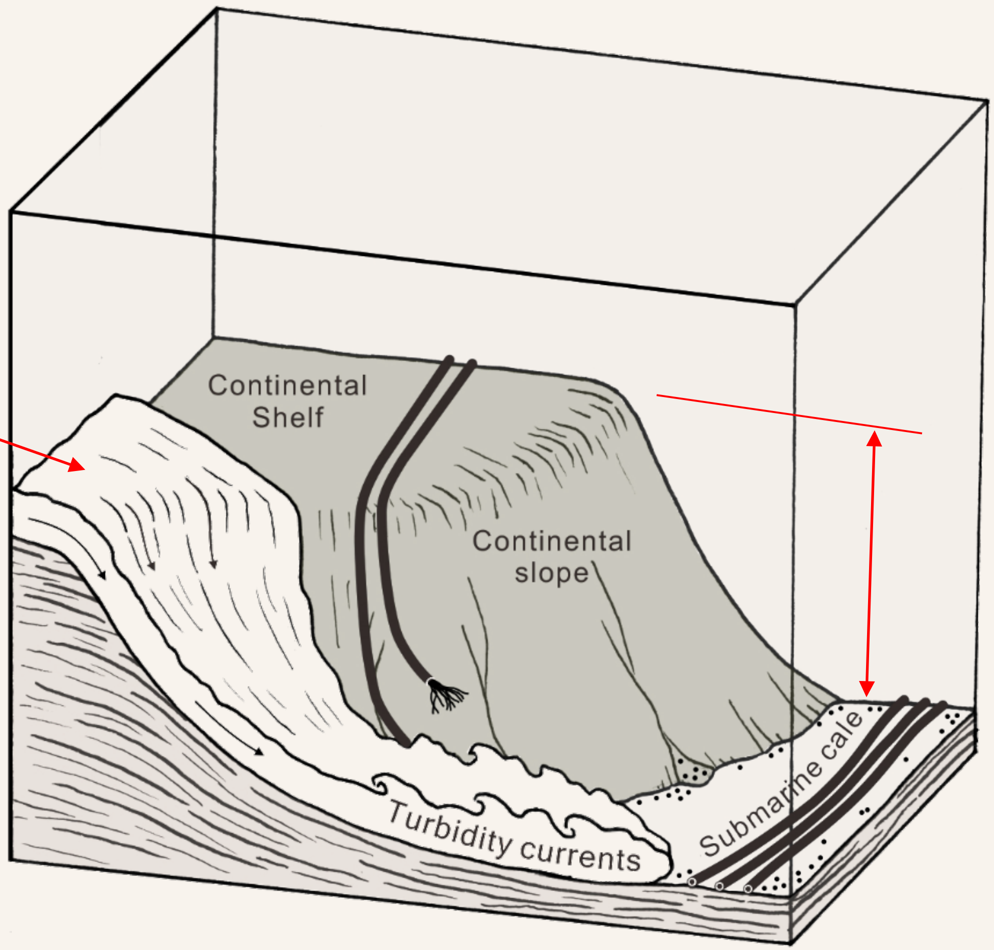
1. How do submarine canyons evolve?

2. What causes submarine channels braid?



Part I – Submarine Canyon Evolution

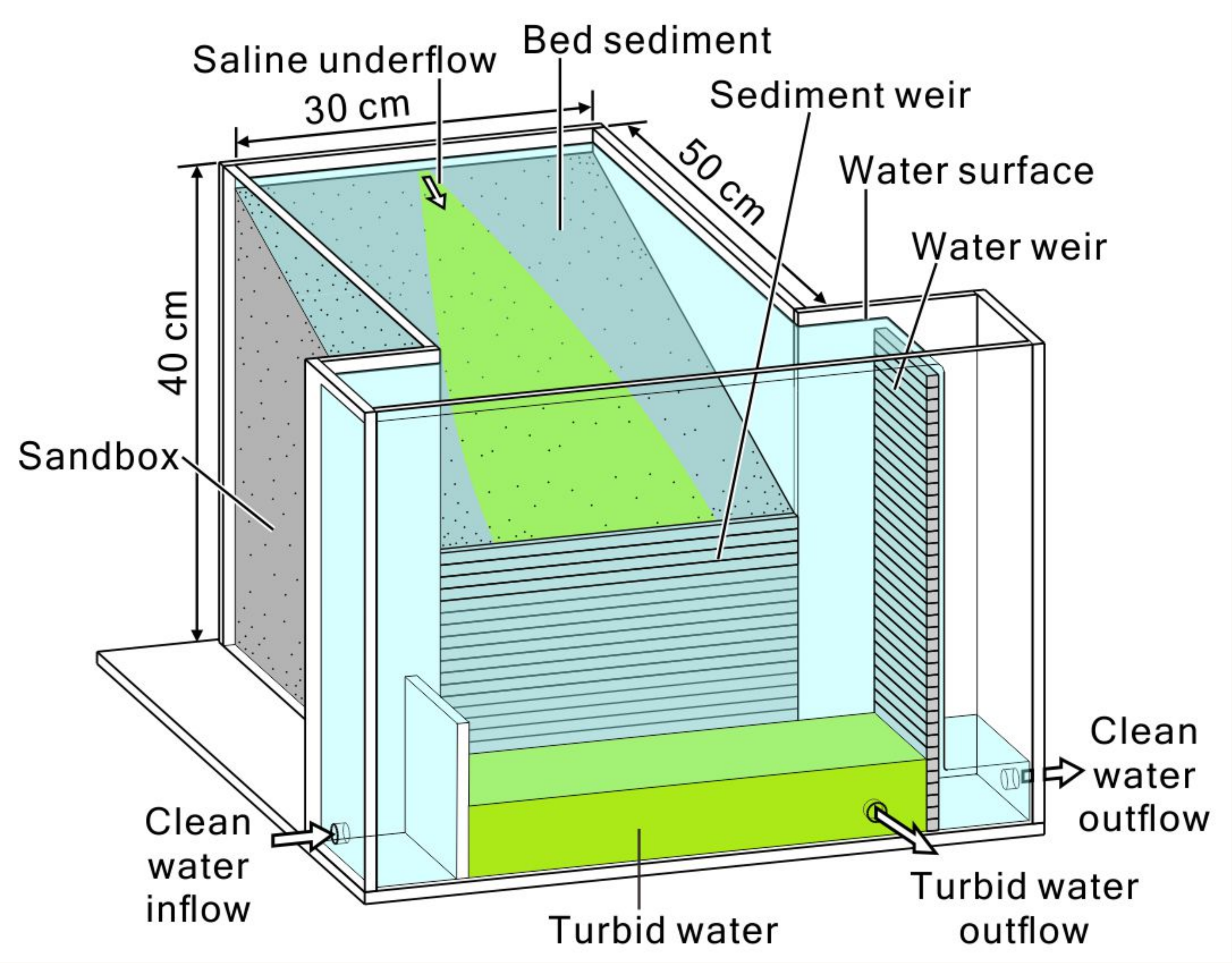
Unconfined sediment gravity flow



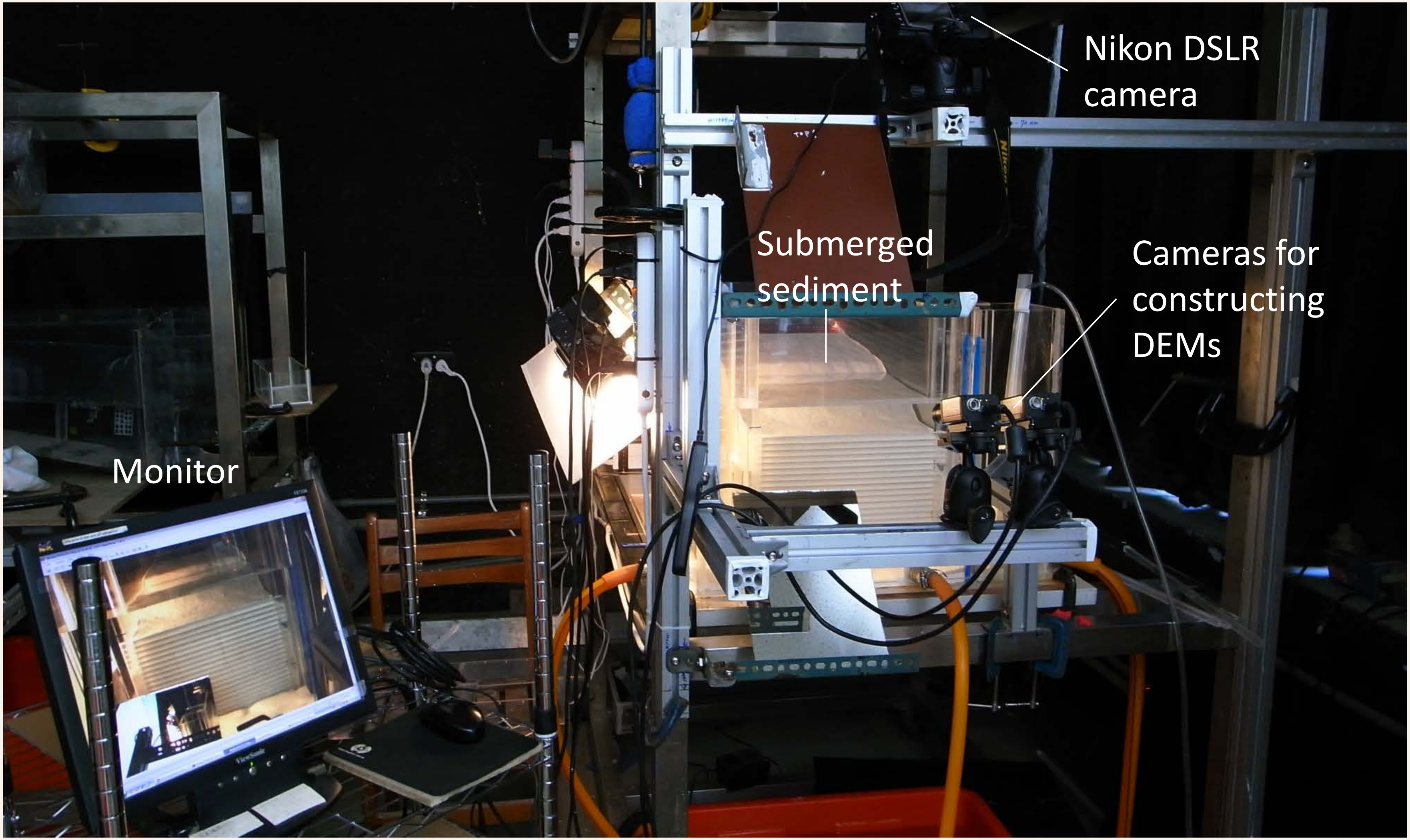
Two key parameters

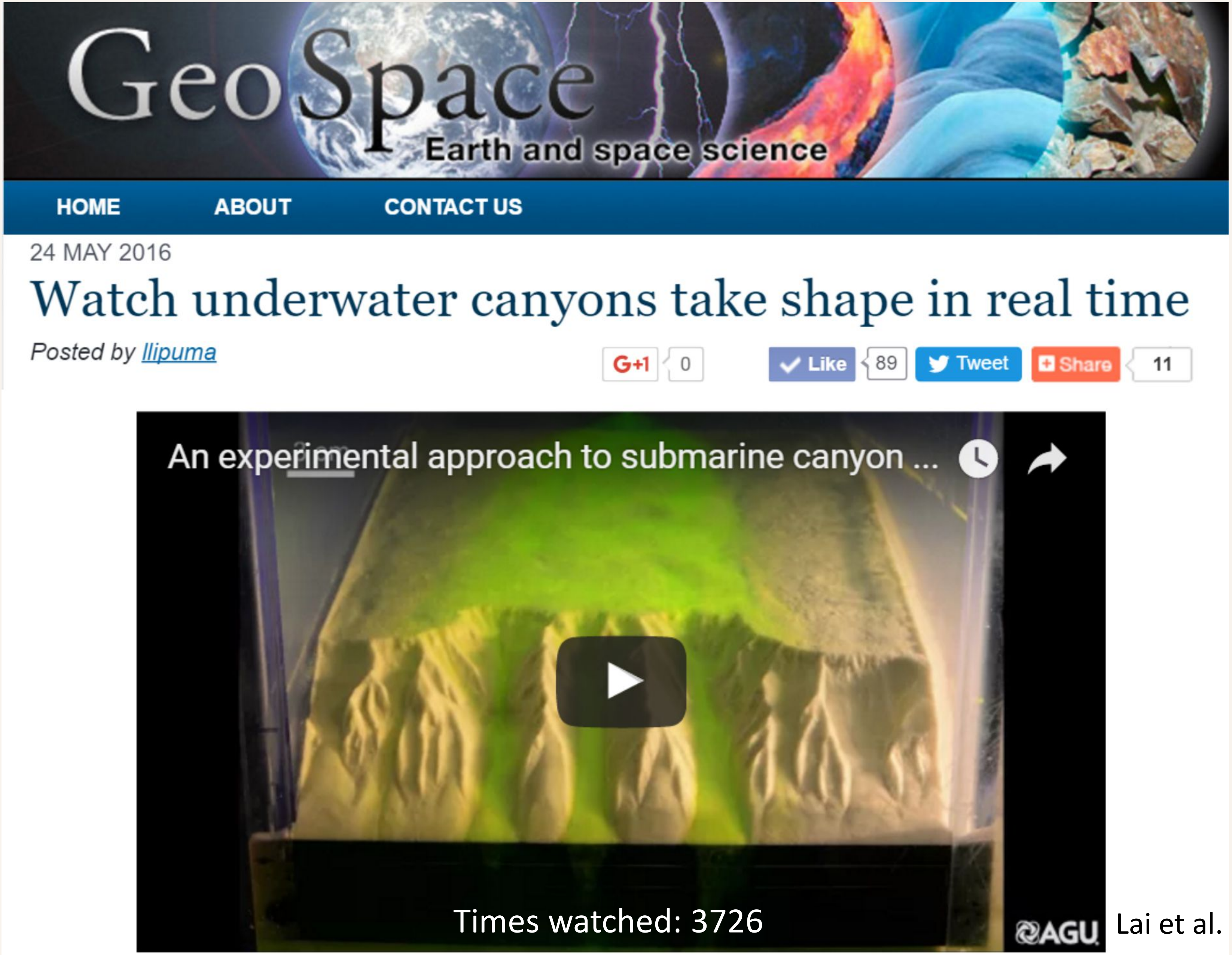
Increasing relief (growth of continental slope)

Experimental Design



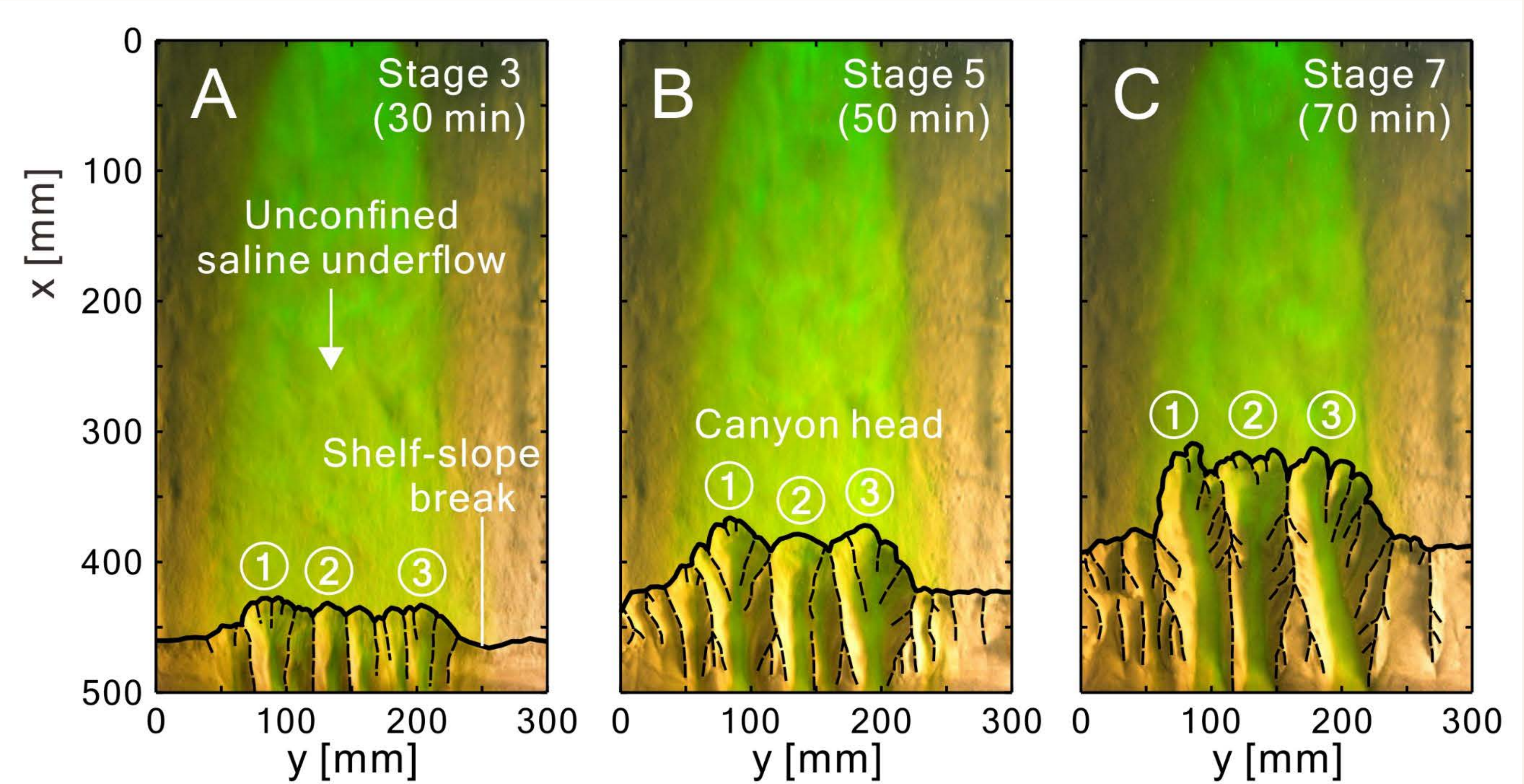
Experimental Set-up





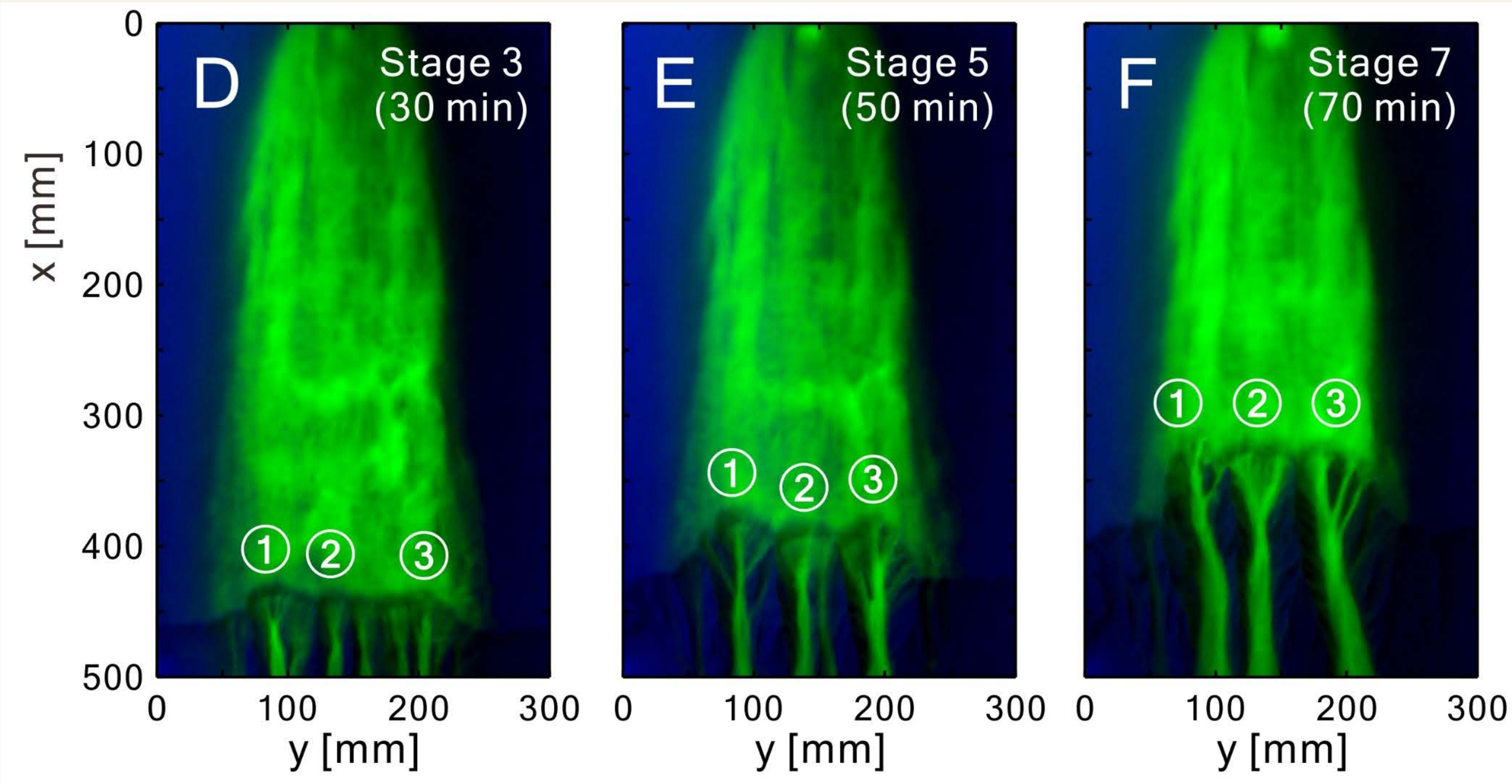
Lai et al. (2016), GRL

Planform of the evolving submarine canyons



Lai et al. (2016), GRL

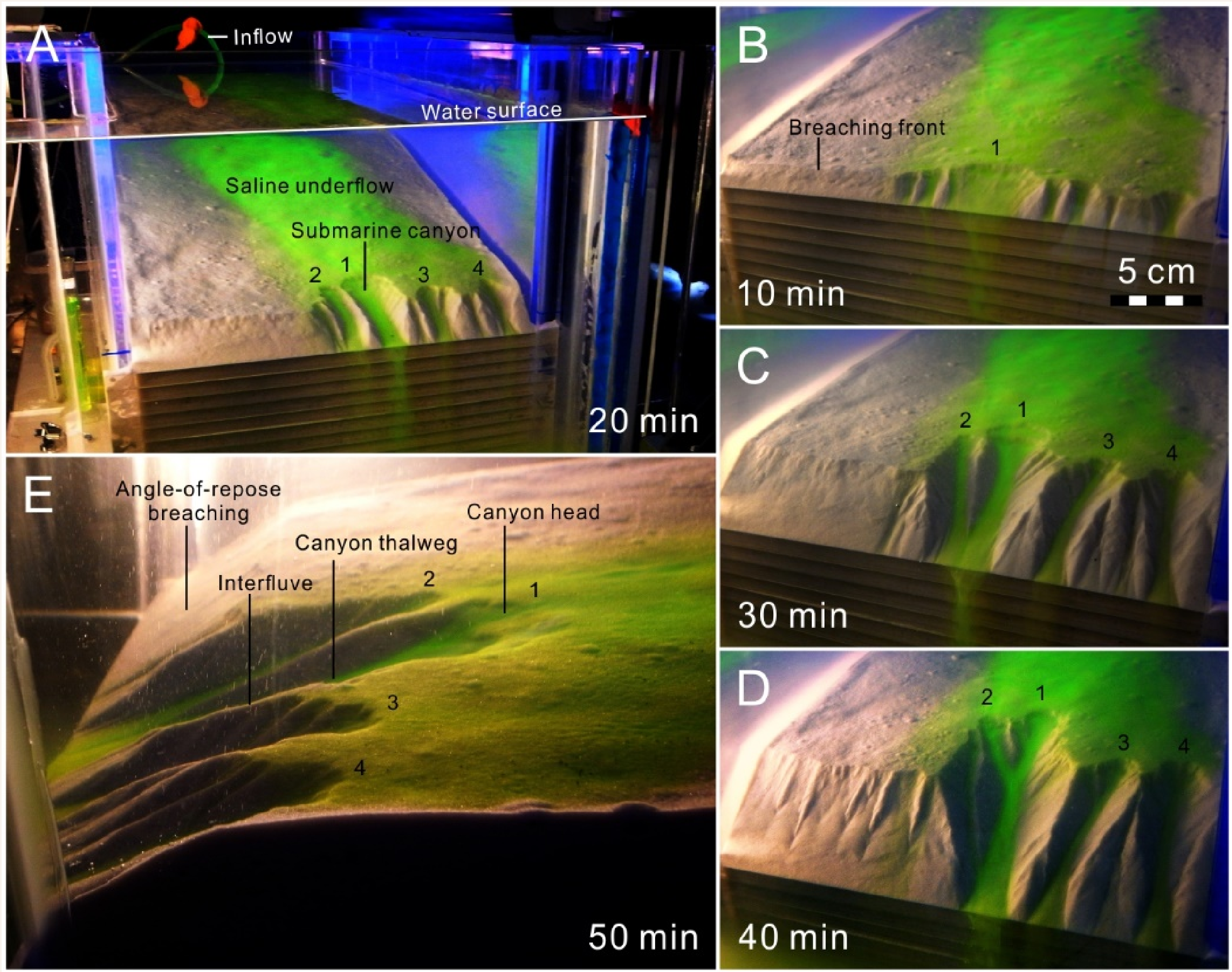
Flow pattern of density currents on shelf and in canyons



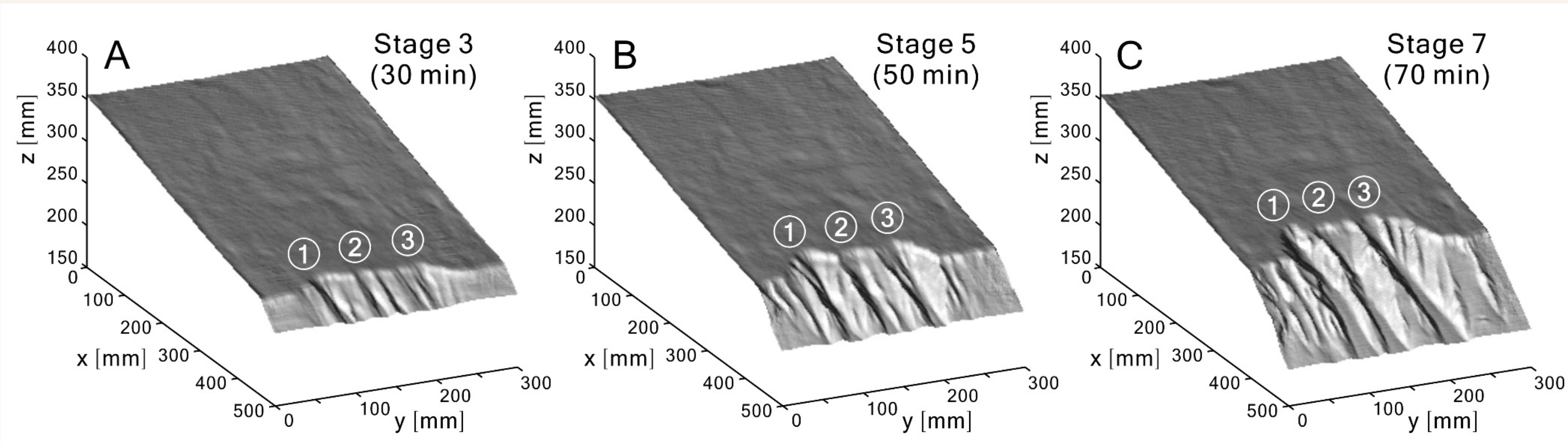
Lai et al (2016), GRL

Oblique view of canyons

Experimental observations

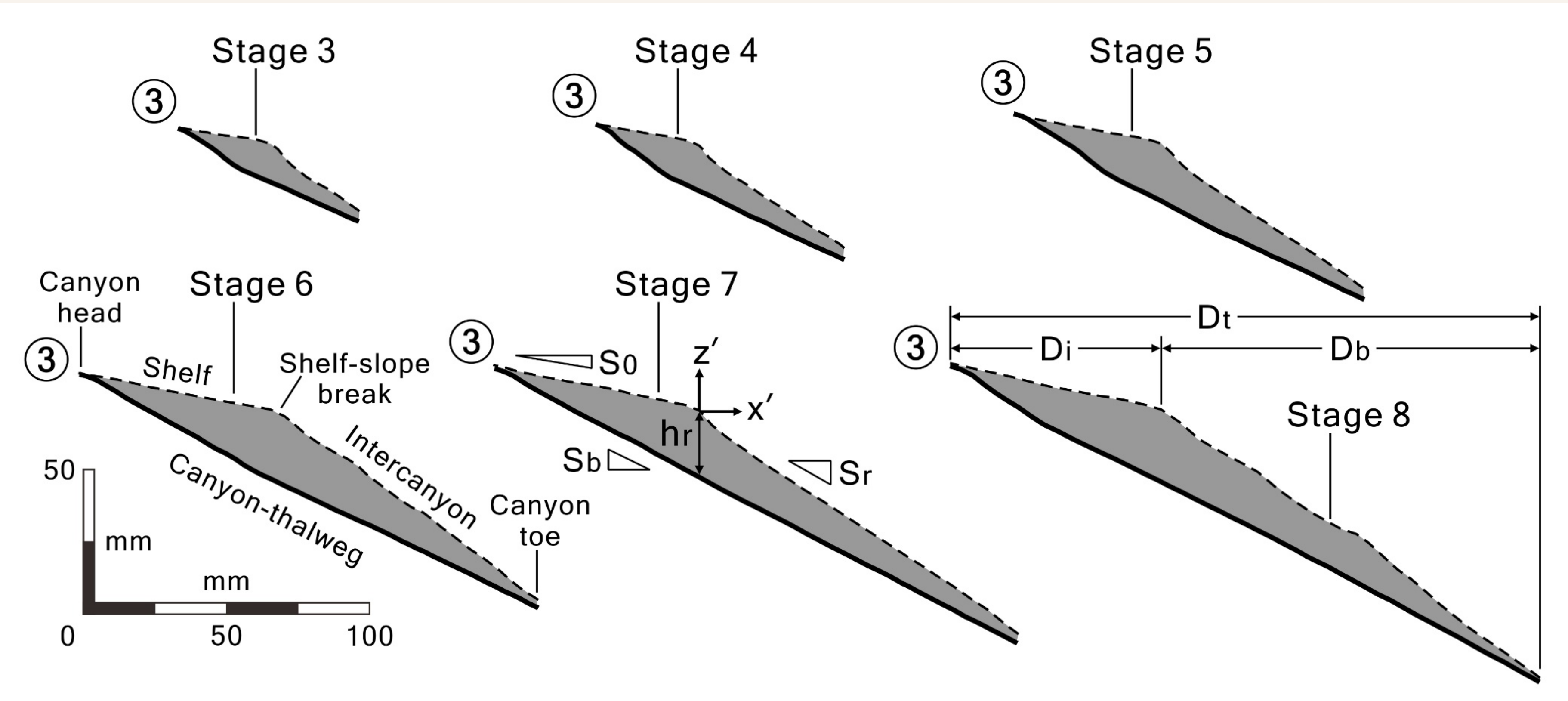


Hillshaded Digital Elevation Models (DEMs)



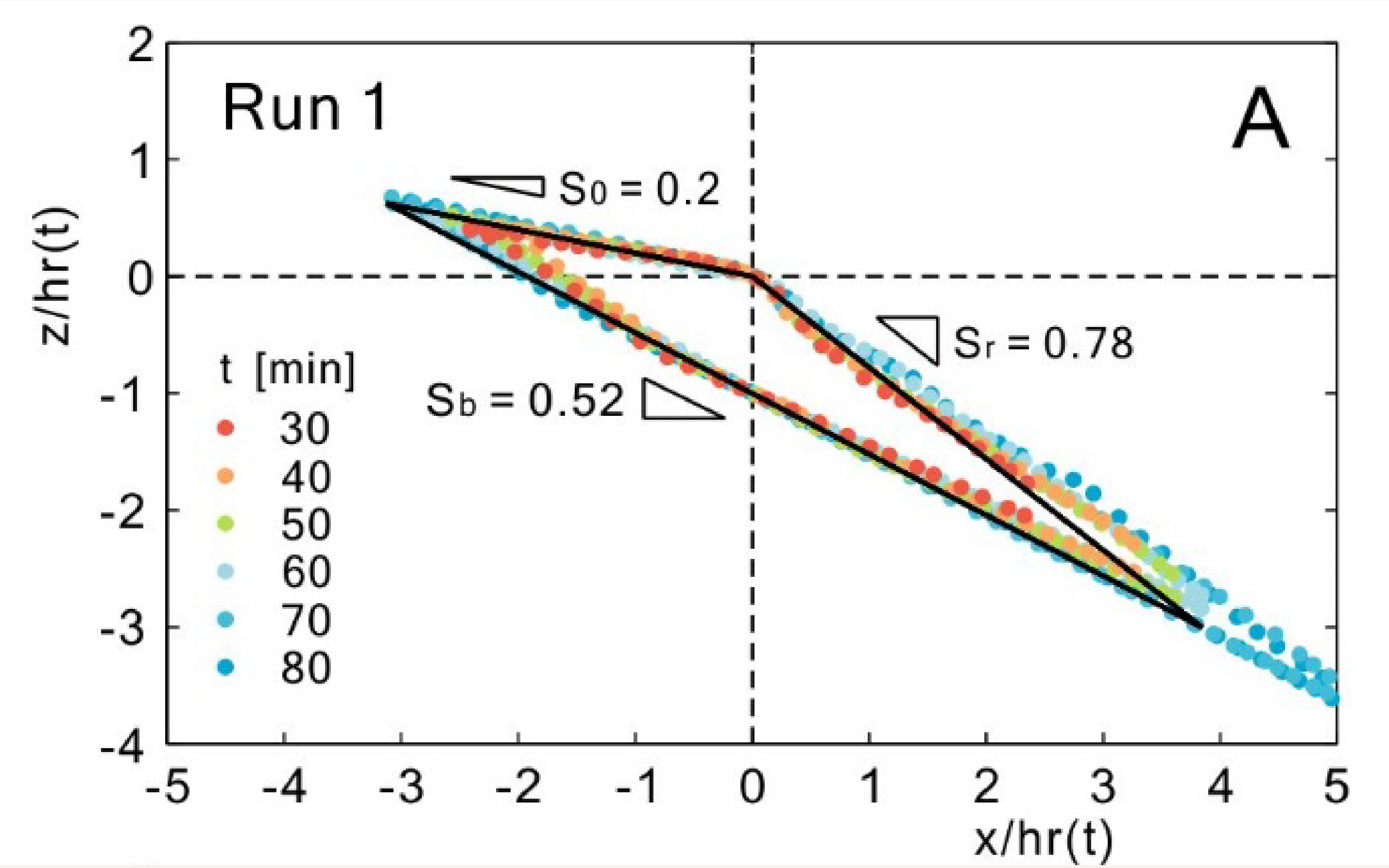
Lai et al (2016), GRL

Canyon Long Profiles



Lai et al (2016), GRL

Self-similarity of canyon long profiles



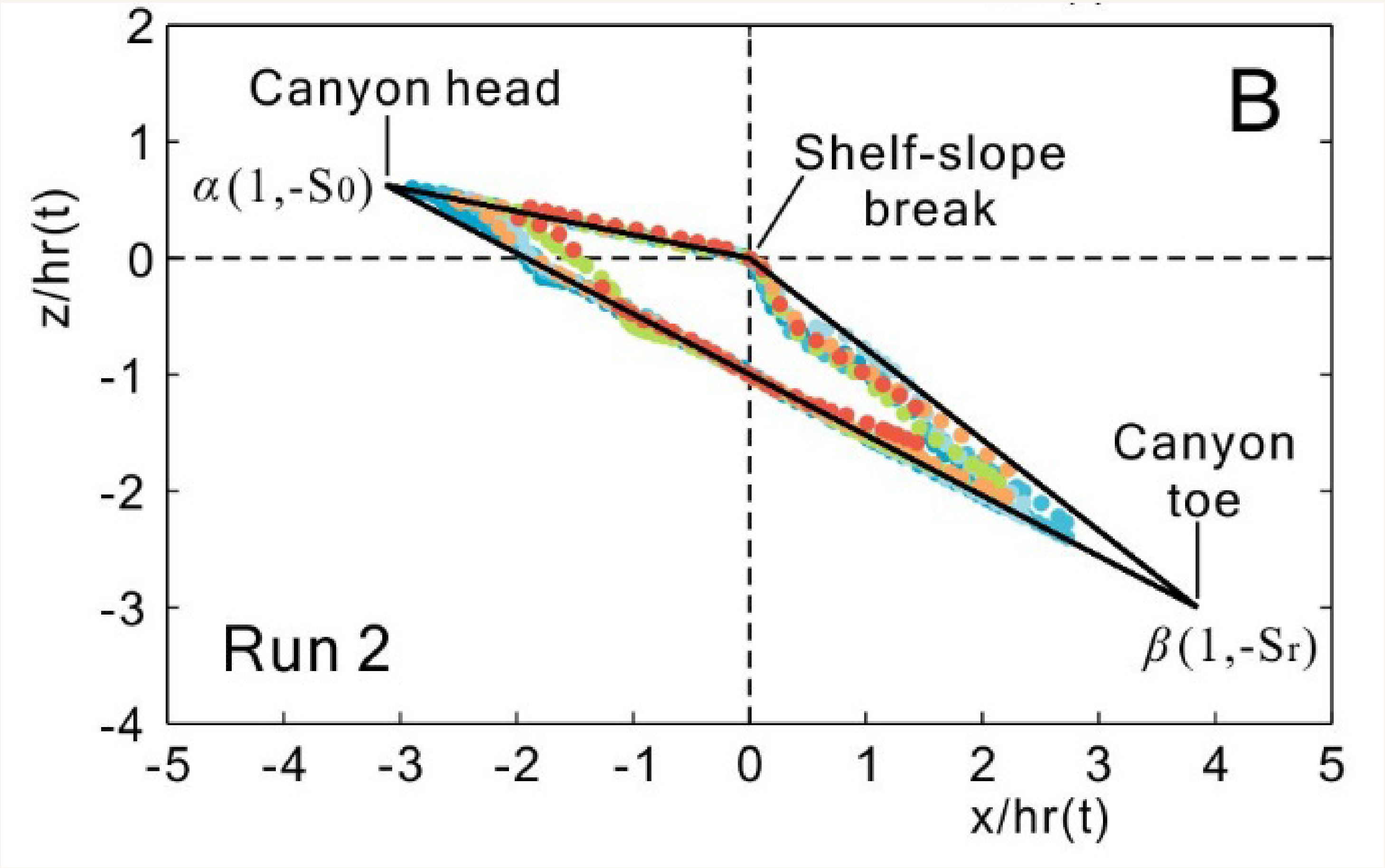
Lai et al (2016), GRL

Simple geometric relation

Canyon head: $\alpha(1, -S_0)$

Canyon toe: $\beta(1, -S_r)$

where $\alpha = 1/(S_0 - S_b)$ and $\beta = 1/(S_r - S_b)$

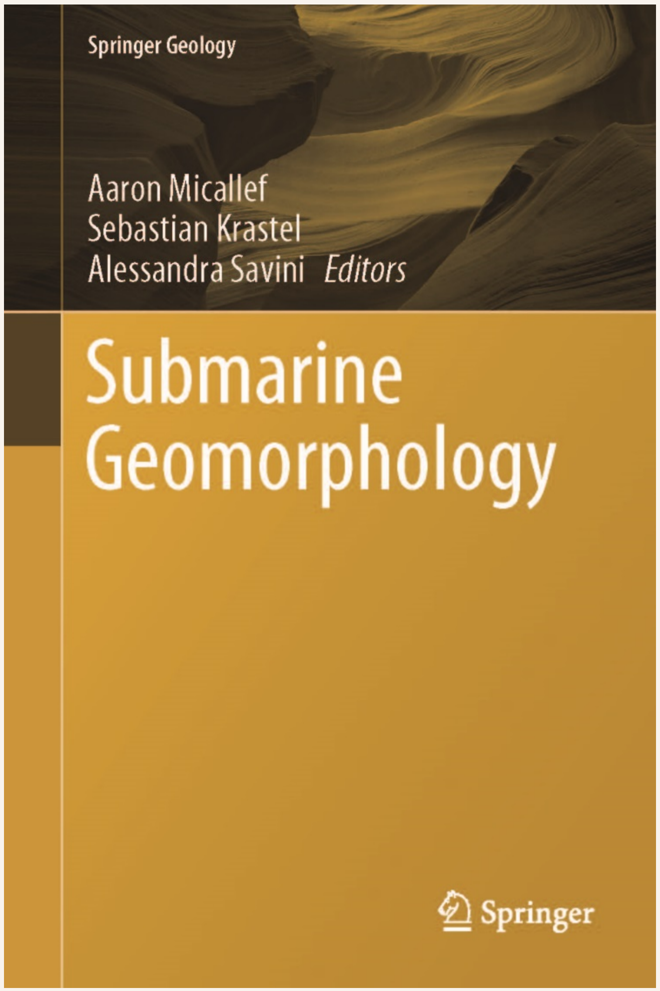


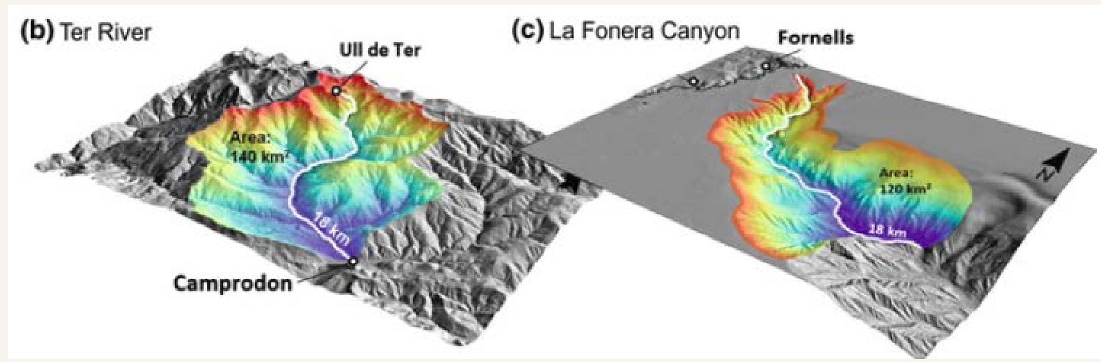
Summary of Part I

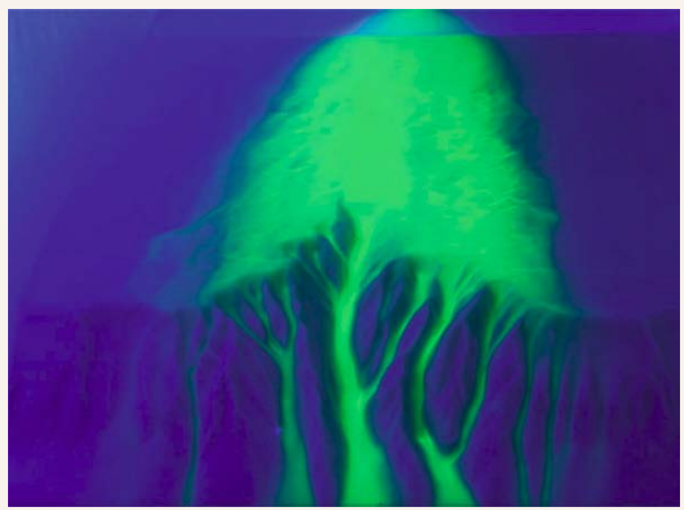
- Reduced scale sandbox experiments combine unconfined sediment gravity flows with a falling base level to produce evolving submarine canyons
- Analysis of quantitative topographic imagery shows that the canyons grow in a self-similar form
- Experimental canyon-intercanyon long profiles and planform drainage networks resemble those observed on continental slopes

Book chapter

Amblas et al. (2018), Submarine canyons and gullies, in *Submarine Geomorphology*, pp. 251-272, Springer.

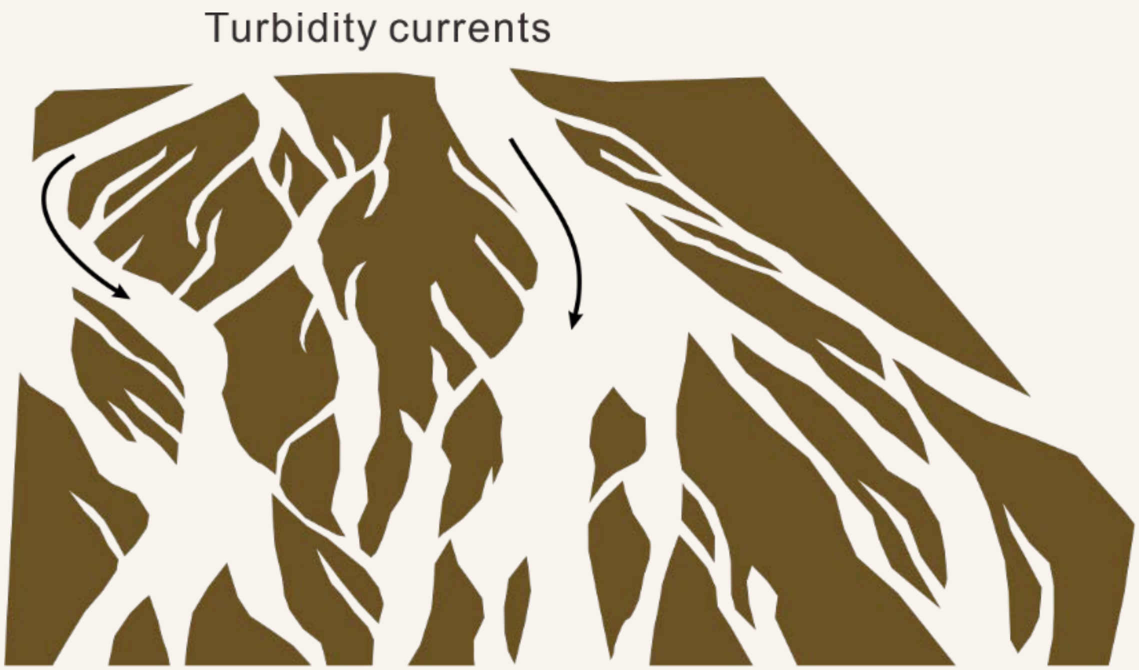






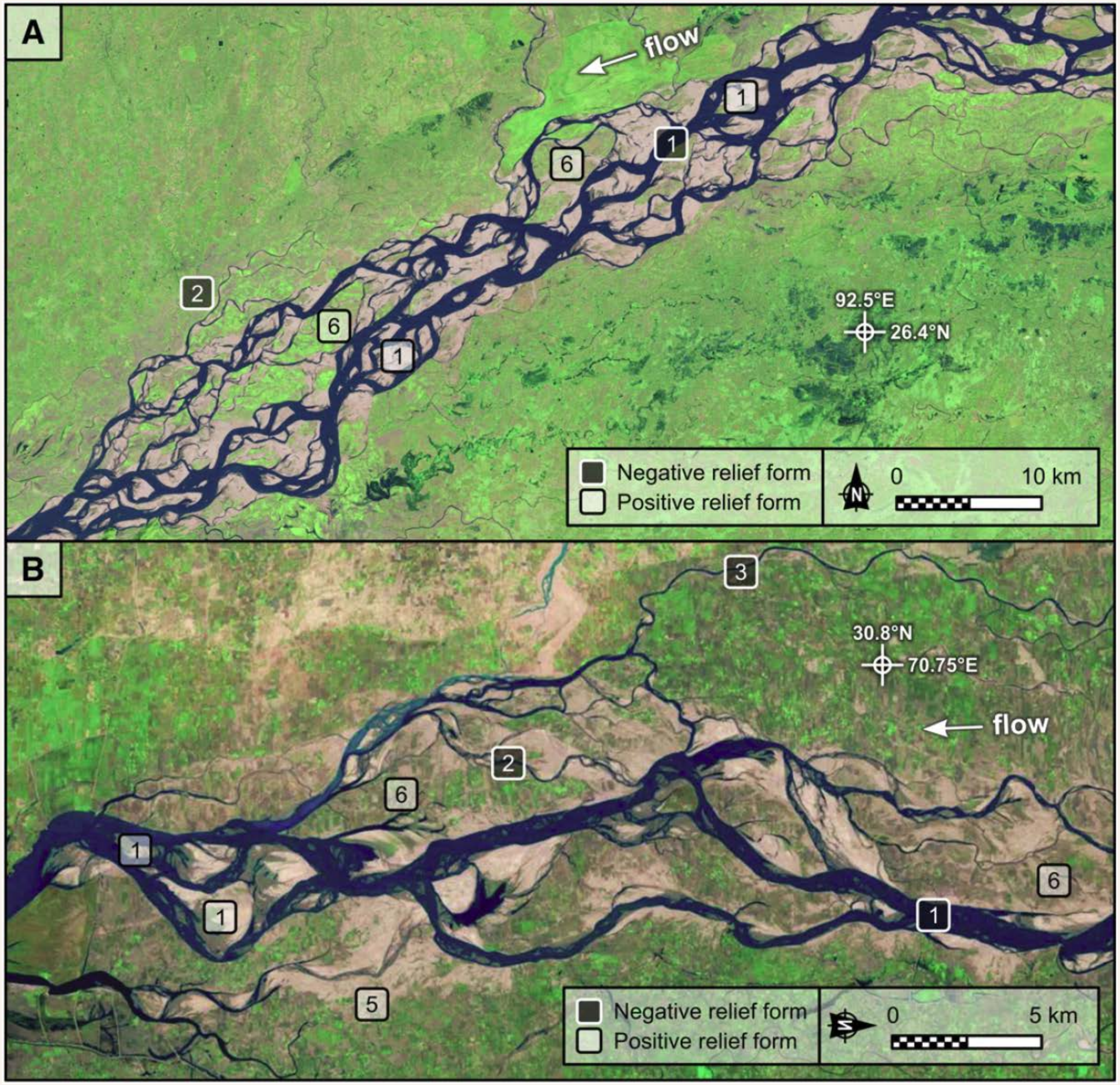
Part II – Submarine Braided Channels

What causes submarine channels braid?
How do submarine braided channels evolve?
Do submarine braided channels act similarly to rivers?



Braided rivers

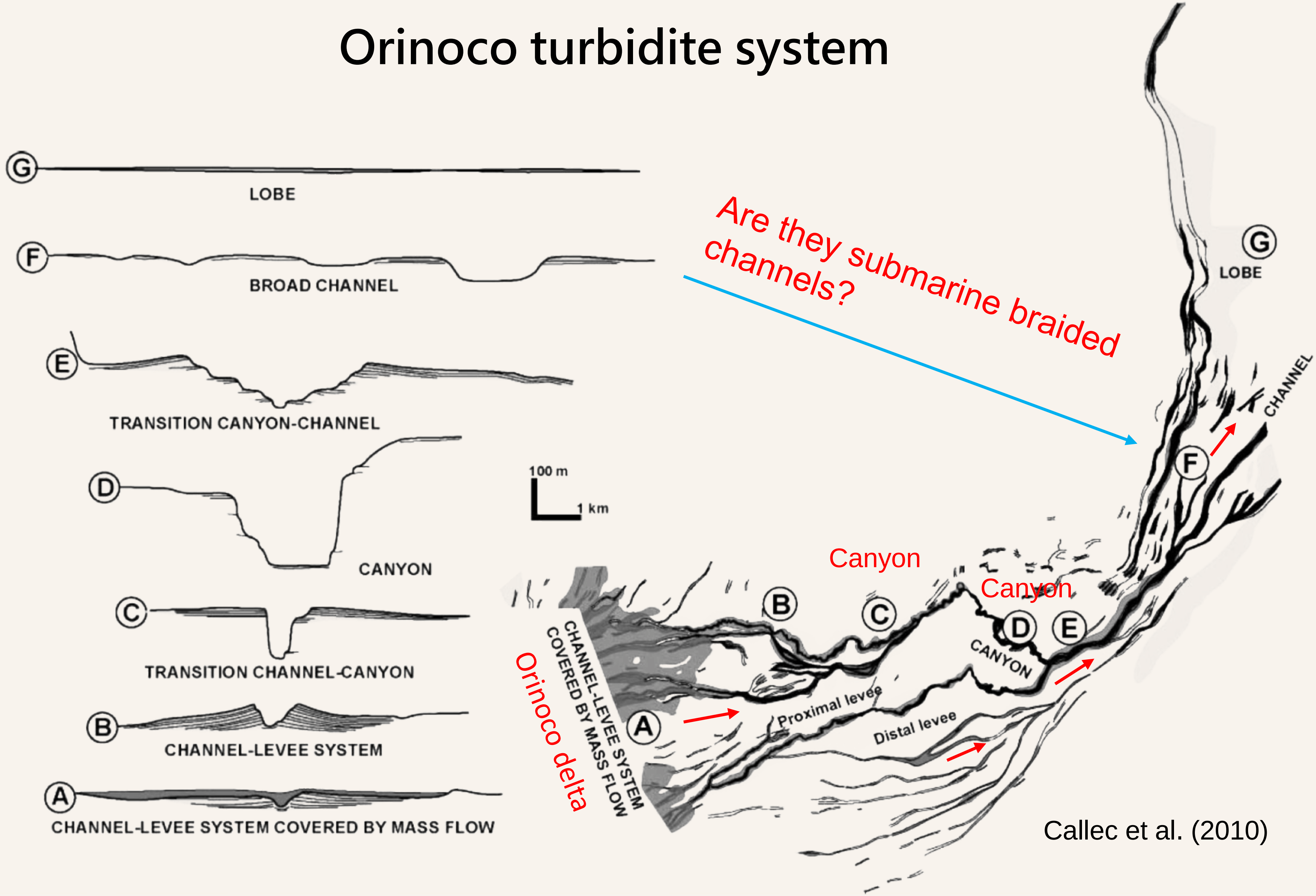
Steeper slope
High bed load
Relative unstable



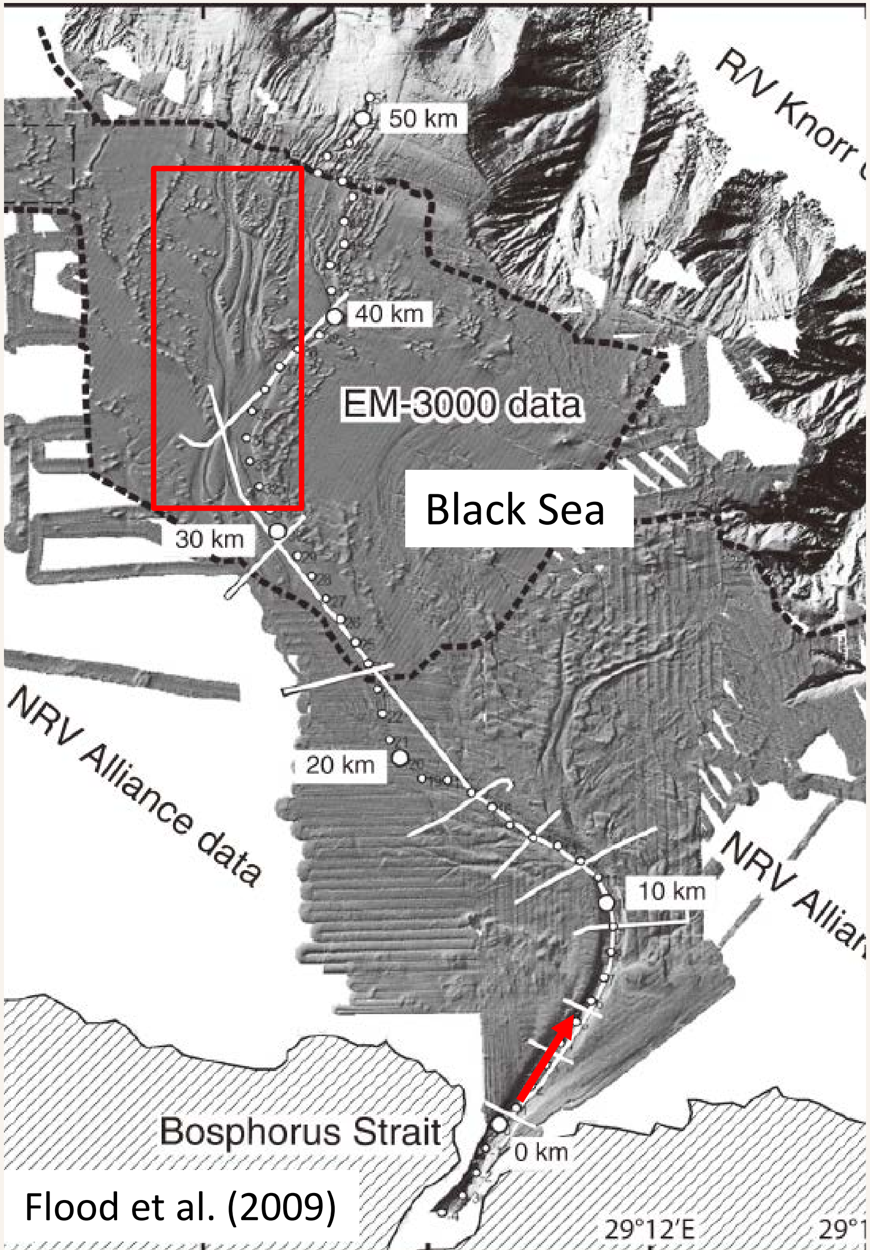
Lewin and Ashworth (2014)

see turbidite system

Orinoco turbidite system



Callec et al. (2010)



Are they braided?

True Braiding

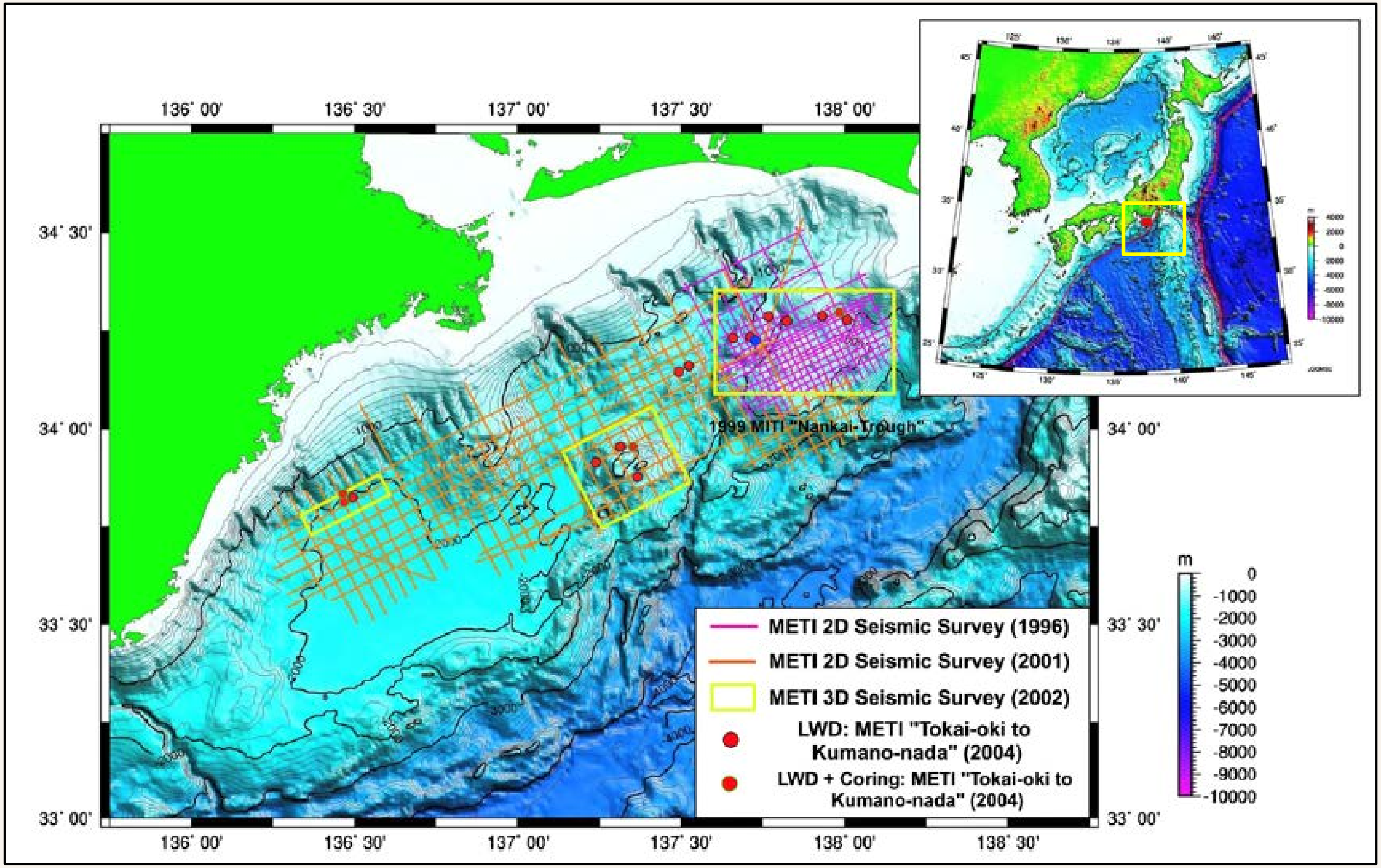
- multi-thread depositional channels
- true braid bars occur due to flow instabilities and are depositional

Apparent Braiding

- scoured, erosional channel networks
- bars nucleated by seafloor topography (e.g., mud volcanoes, fluid seepage)

Nankai Trough turbidite systems, offshore Japan

The reservoir architecture of methane hydrate (MH)

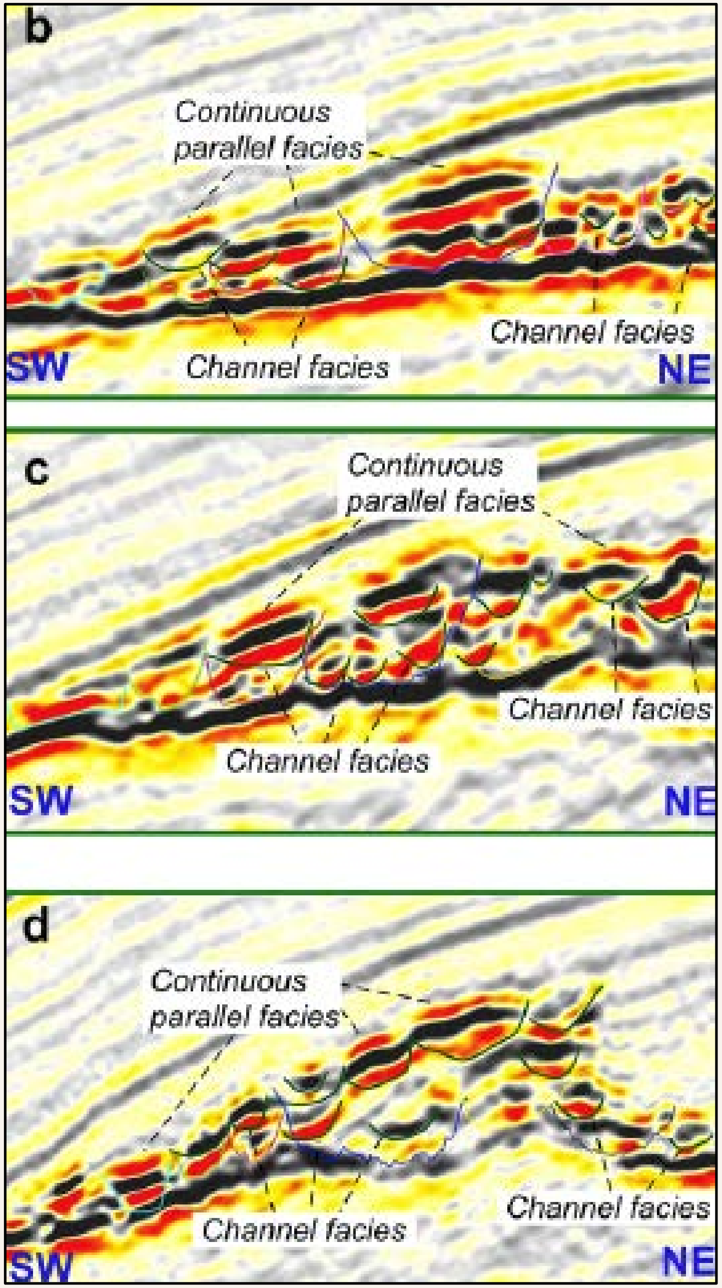


Noguchi et al. (2011)

3-D seismic profiles

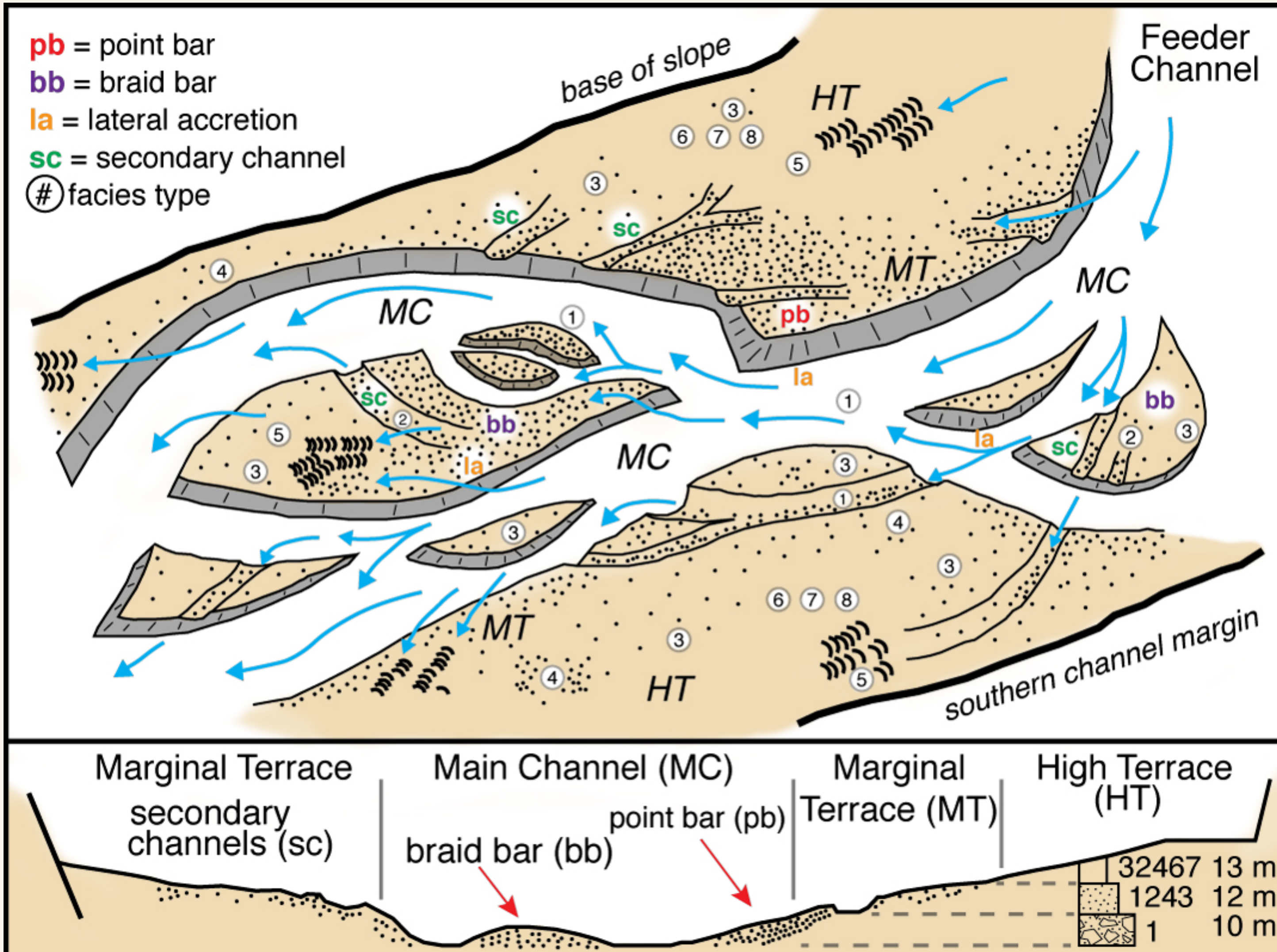
Fujii et al. (2008, 2009b) reported that the MH reservoir is comprised of thin alternating sand and mud layers with an average sandy layer thickness of around 20 to 30 cm (the maximum thickness is greater than 1 m).

The distributions of coarse clastic supplies in the turbidite system are key to recognizing the MH bearing sediments.



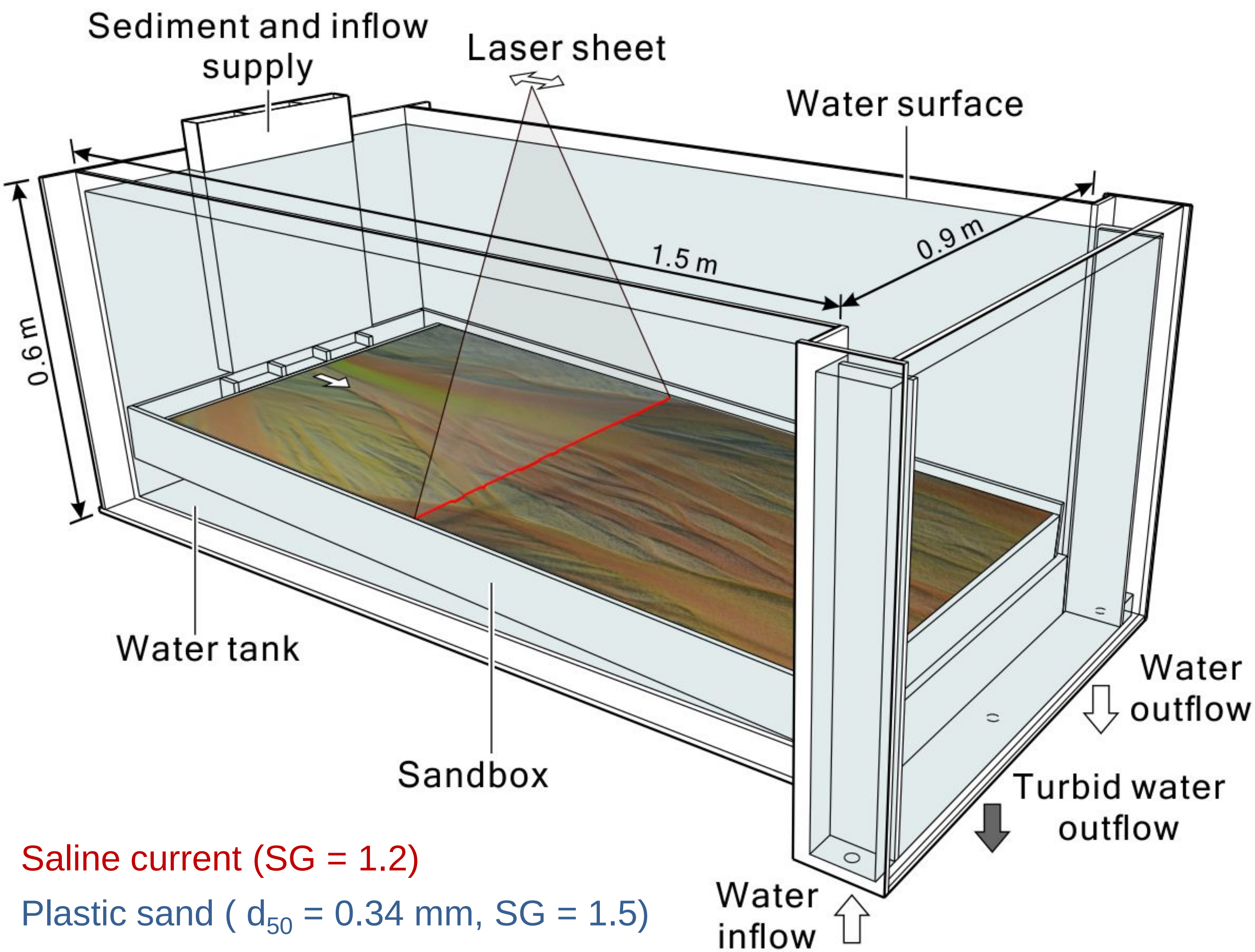
Noguchi et al. (2011)

Cambrian-Ordovician Turbidite System: Quebec



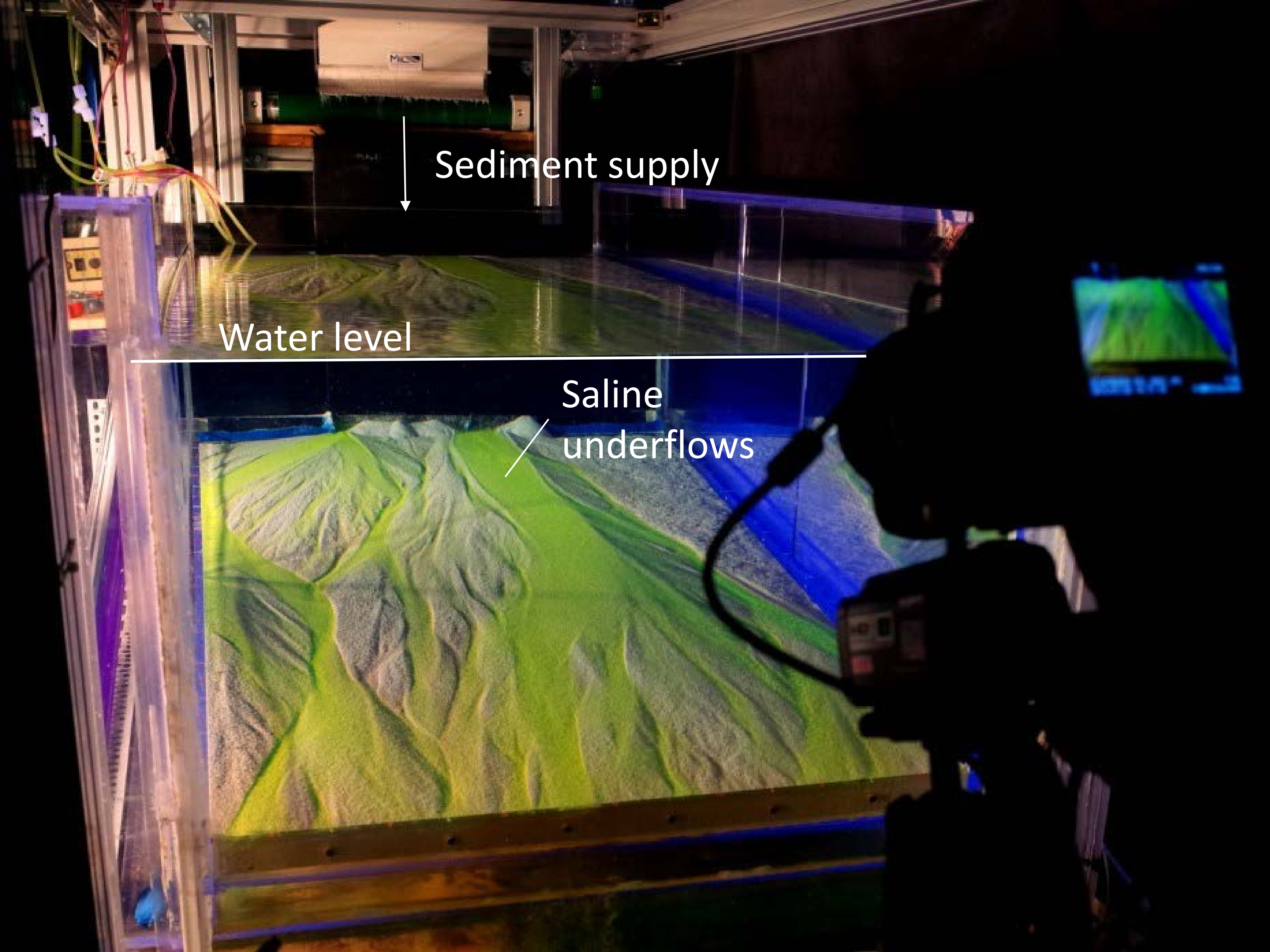
Hein & Walker (1982); Modified by Brady Z. Foreman

Experimental Set-up



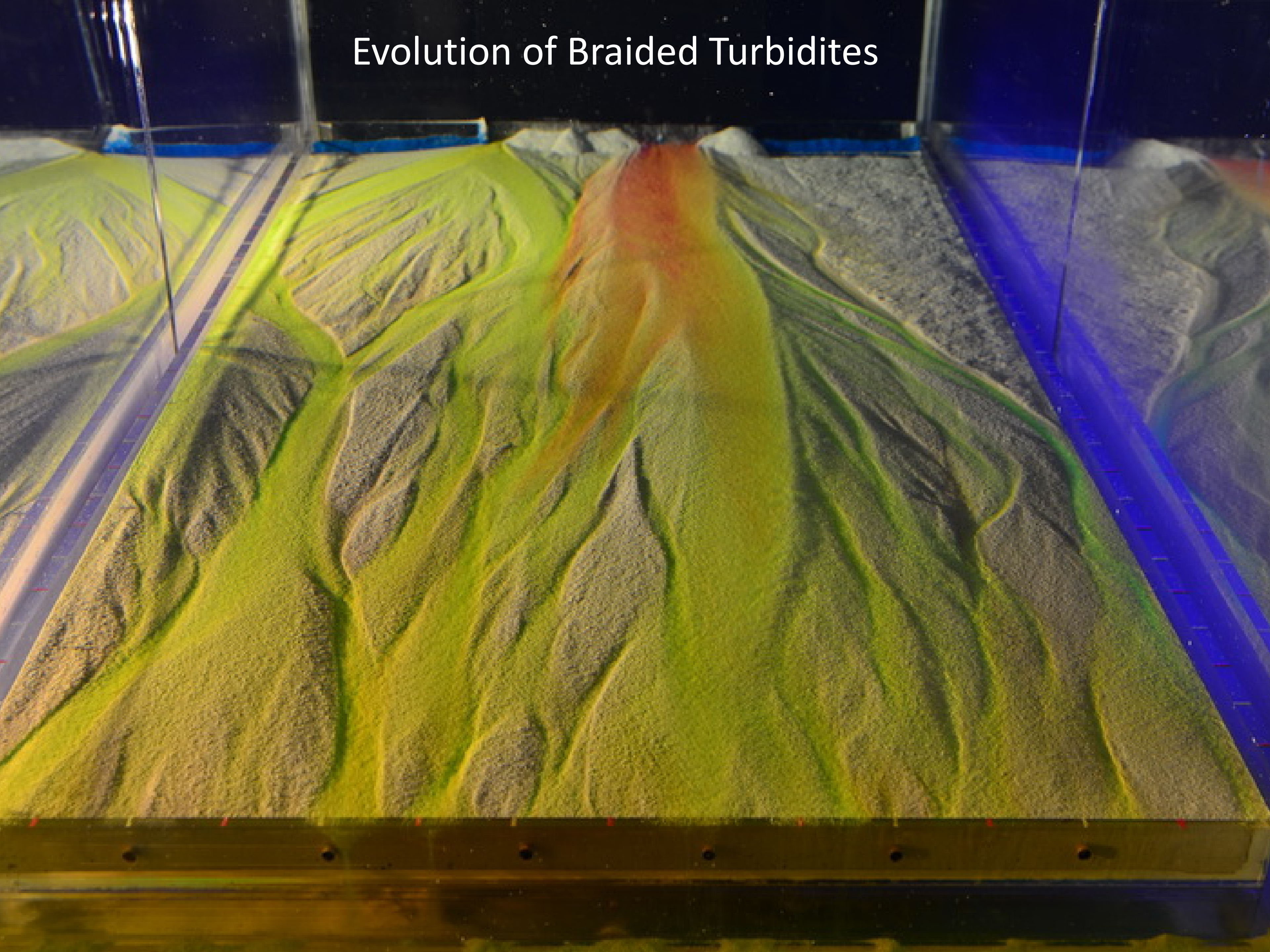
Saline current (SG = 1.2)

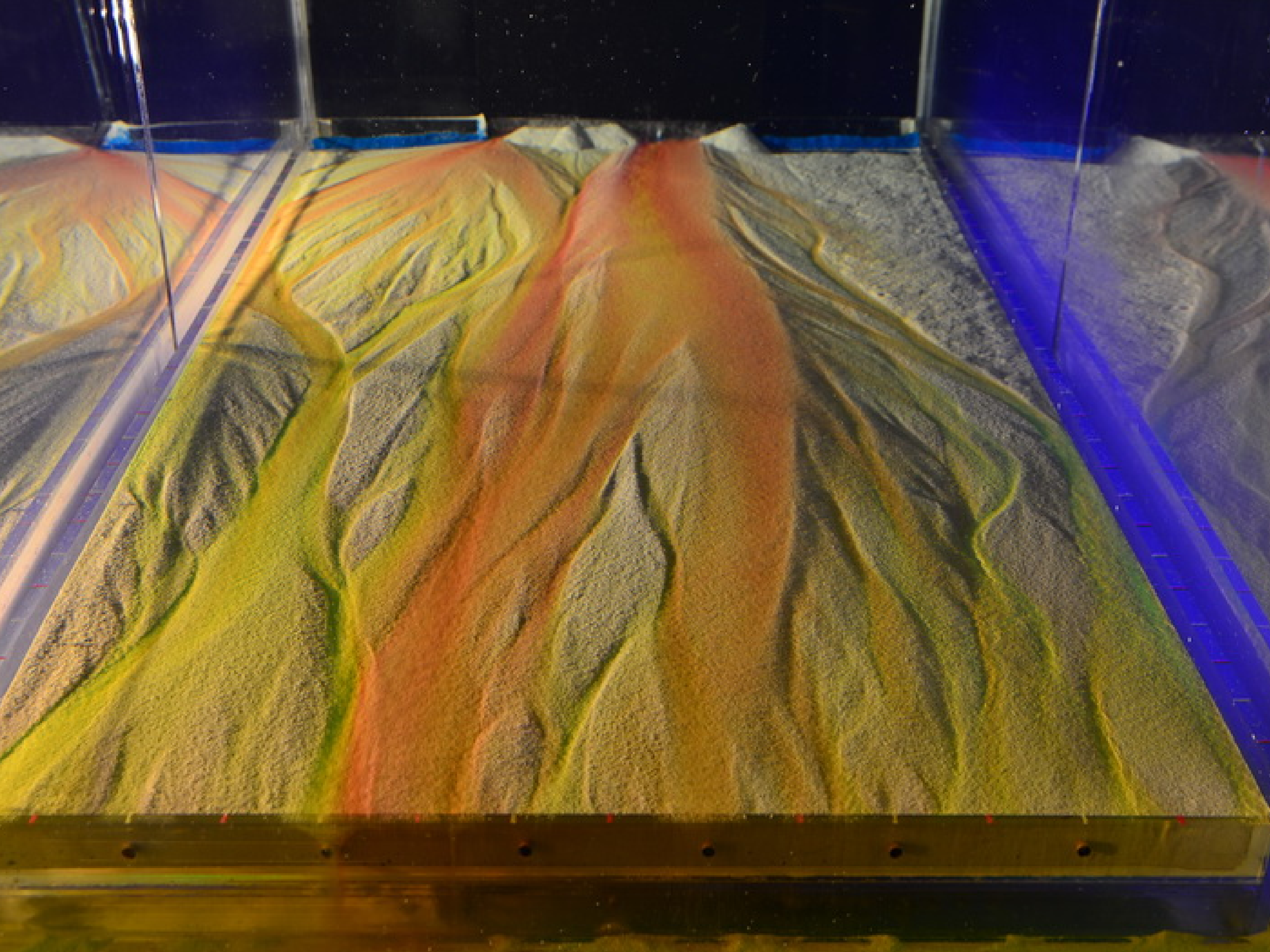
Plastic sand (d_{50} = 0.34 mm, SG = 1.5)

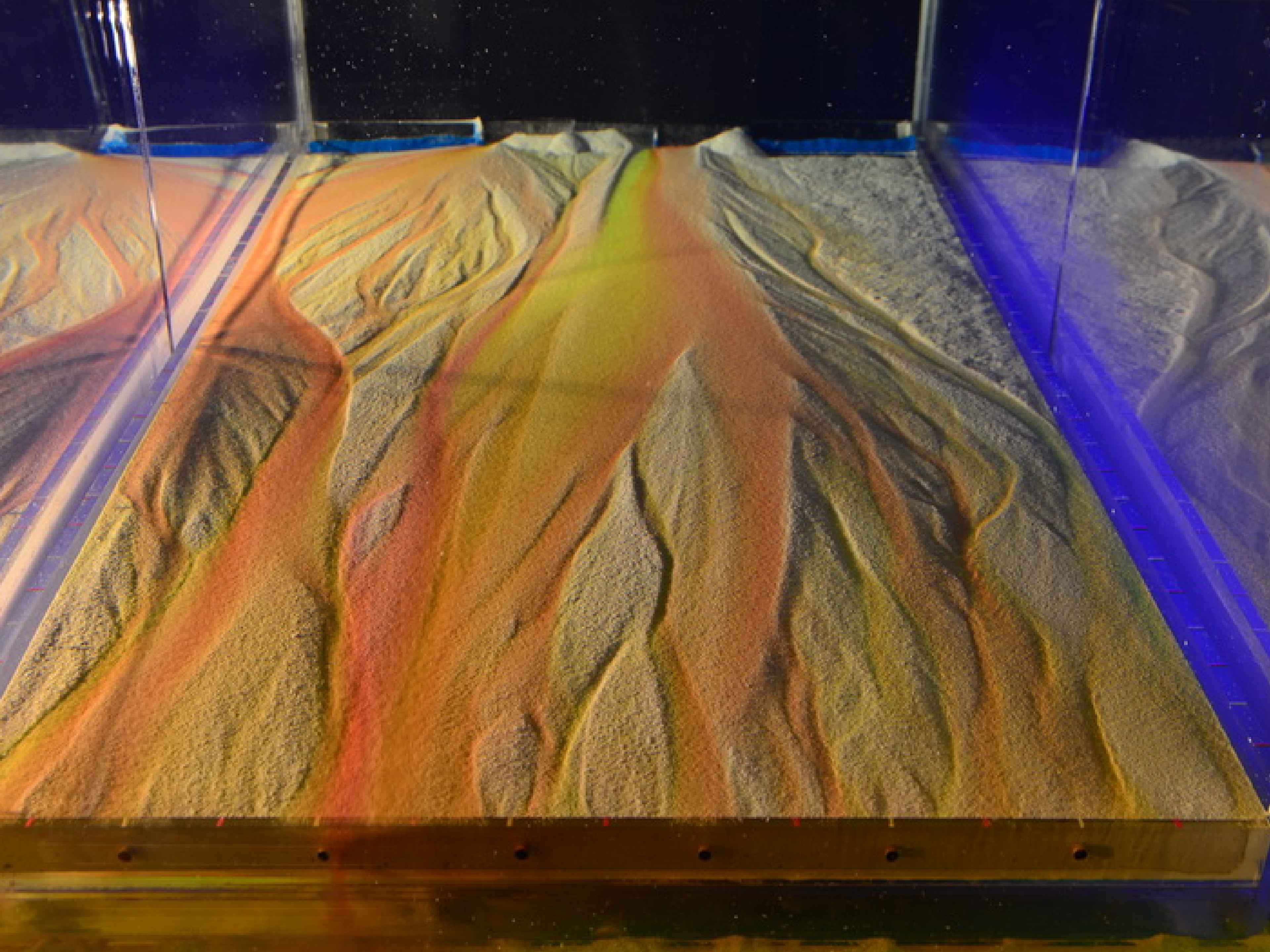

Sediment supply
Water level
Saline
underflows

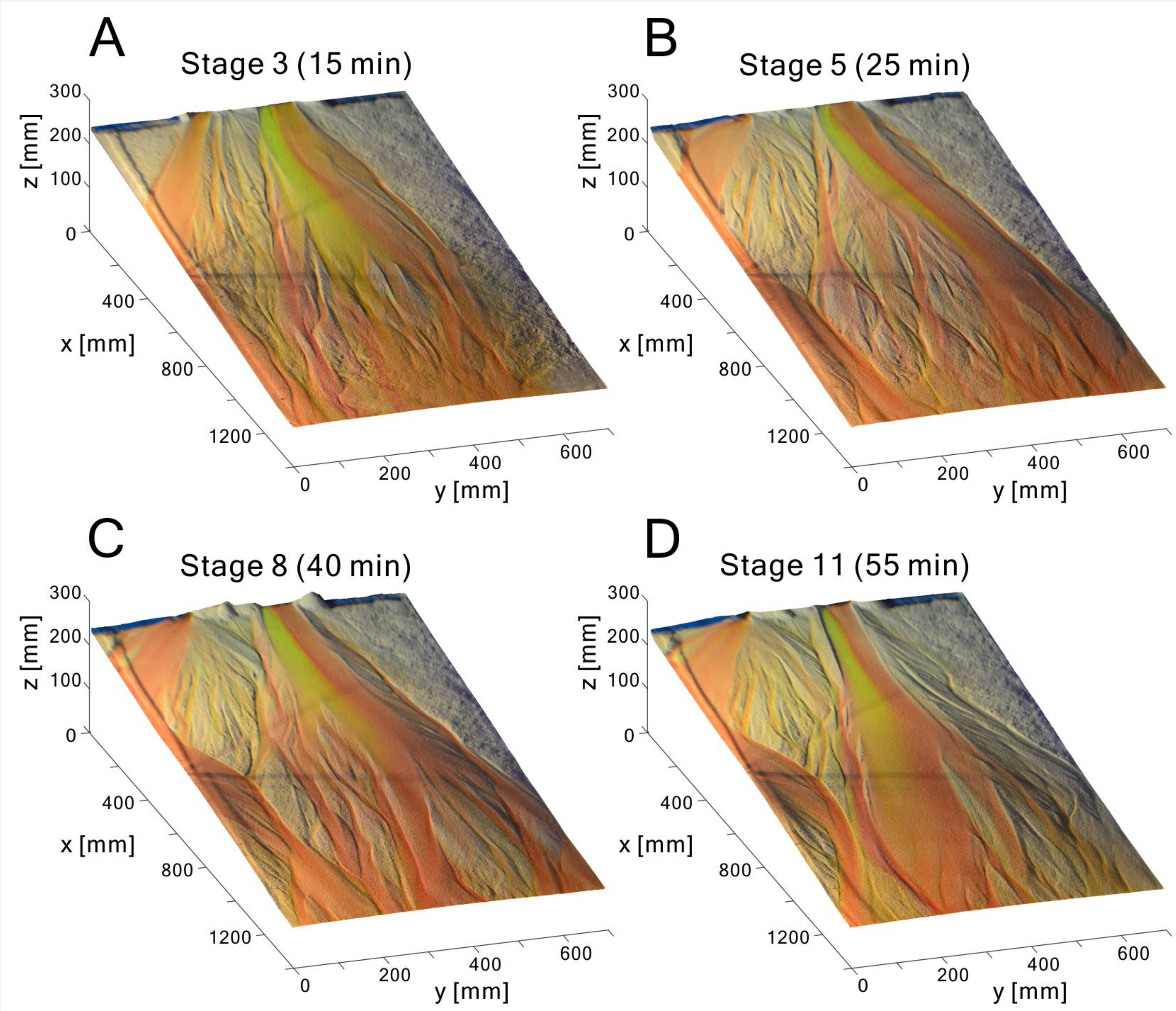
Video – Run A3

Evolution of Braided Turbidites





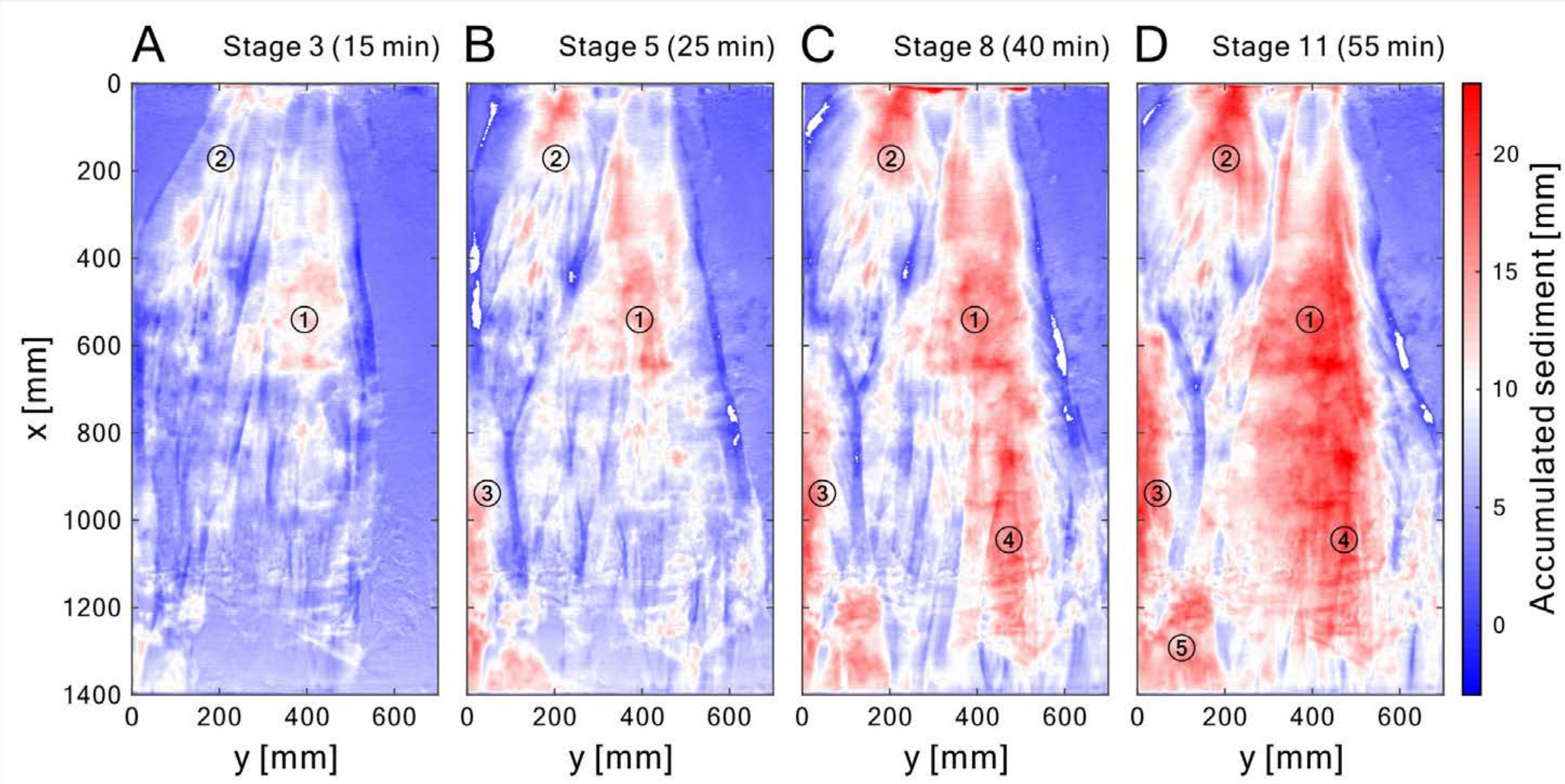




Digital Elevation Models

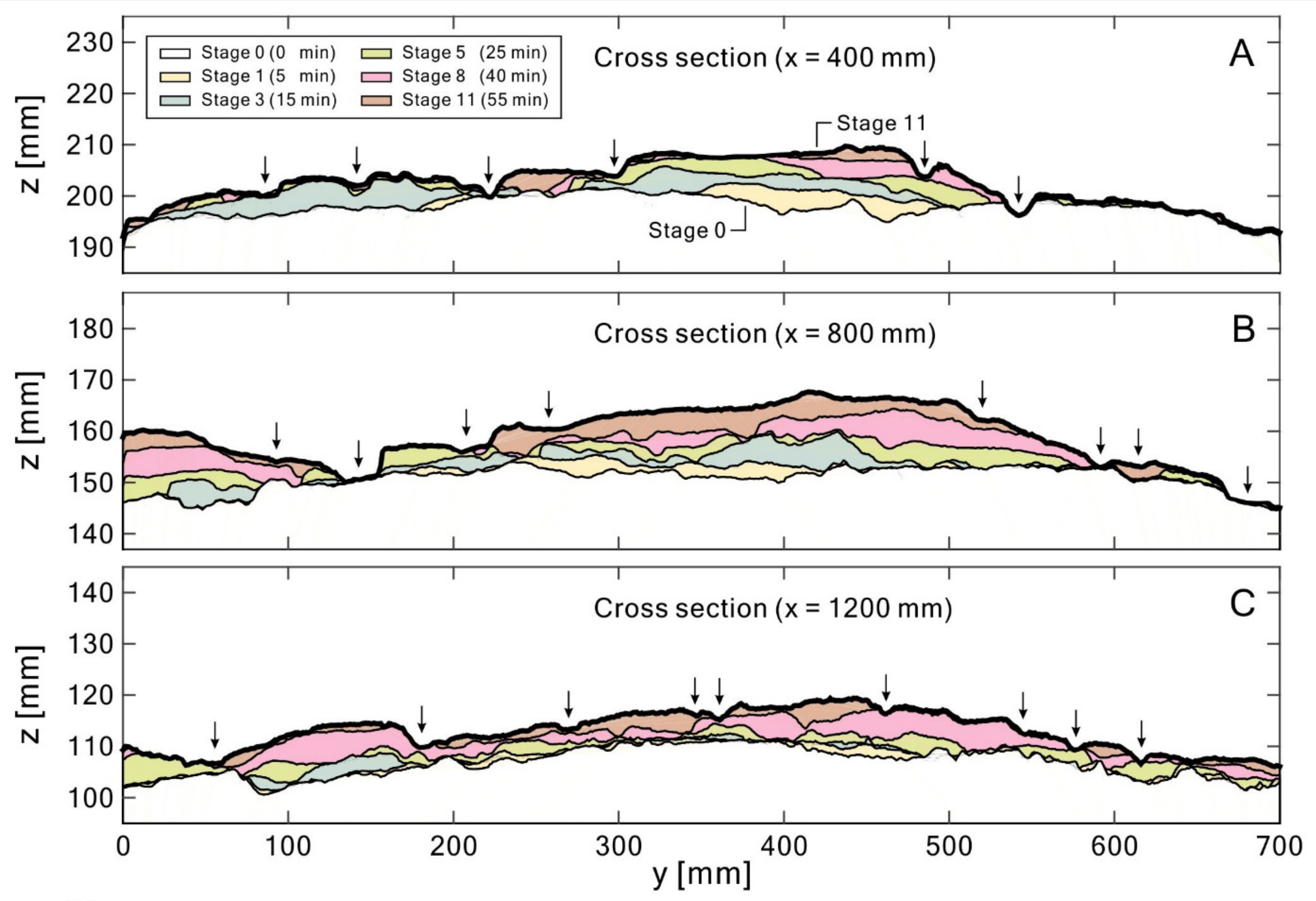
Lai et al. (2017), GRL

Depositional map (net aggradation)

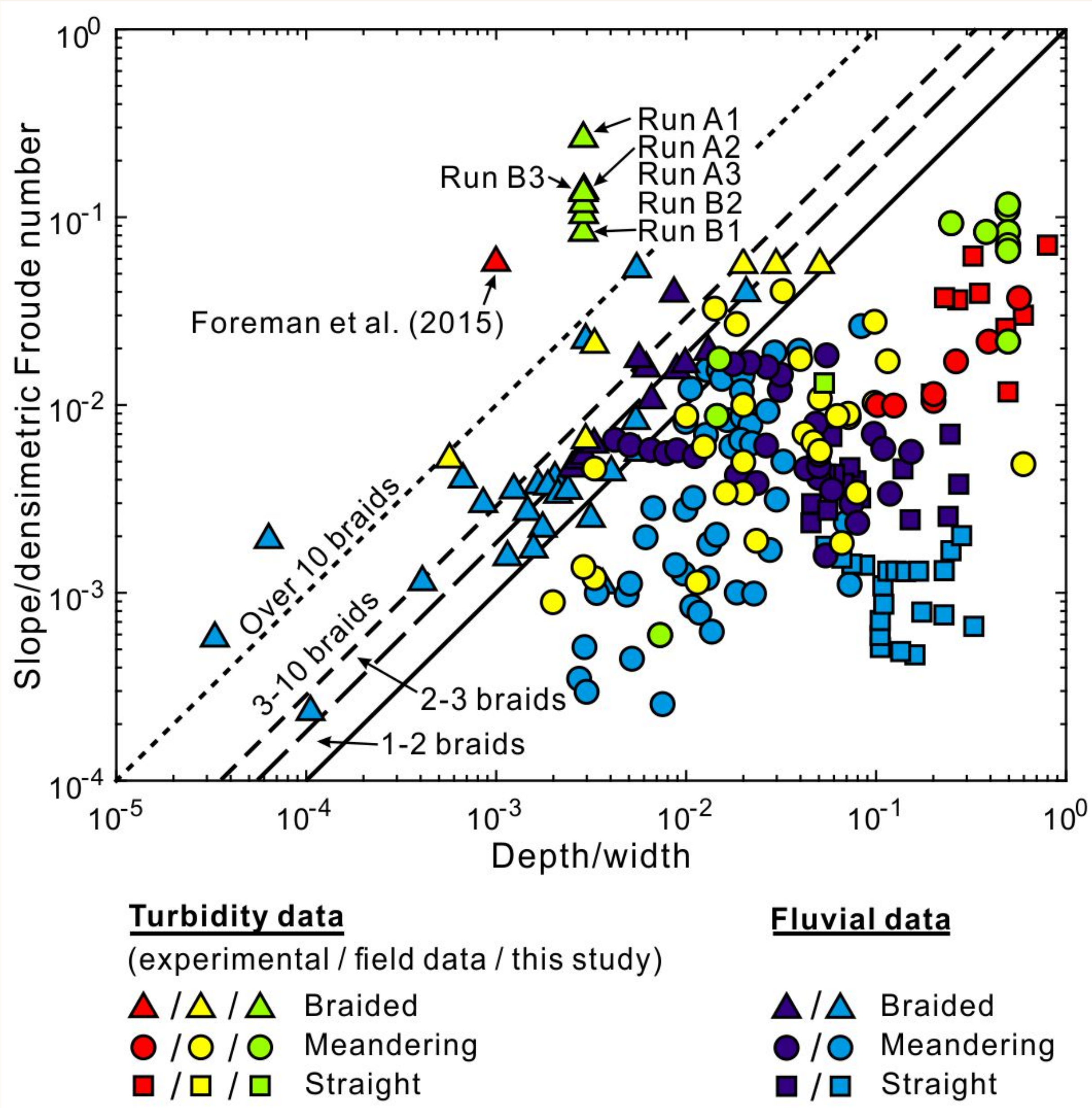


Lai et al. (2017), GRL

Cross sections



Lai et al. (2017), GRL



Comparison with River Planform

8 experimental braided channels

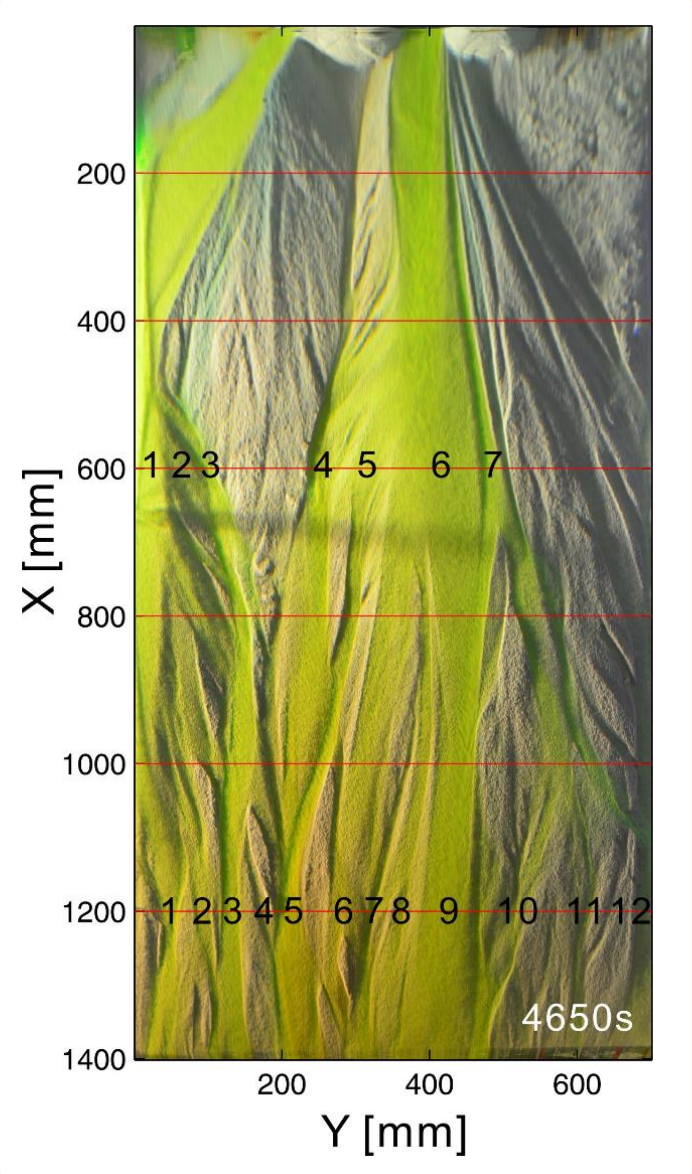
6 field cases of multi-thread submarine channels

58 single-thread submarine channels (field and experimental)

150 fluvial channels (field, manmade, and experimental)

Parker (1976)
Foreman et al. (2015)
Lai et al. (2017)

How to quantify submarine braided channels by braiding intensities (BIs)?



BI_A	BI_T
2	6
4	11
7	11
12	13
11	14
12	14
8	11.5

BI measurement

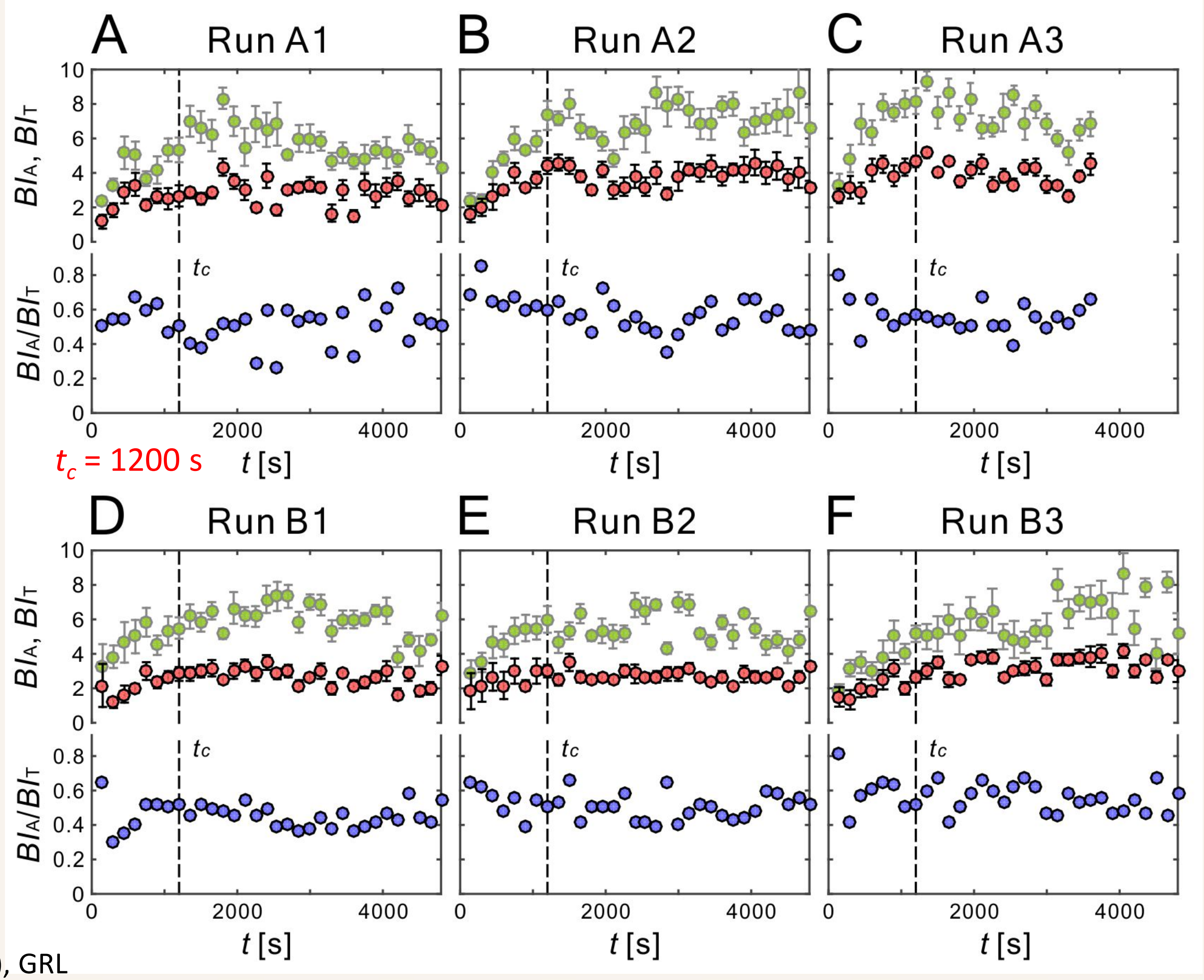
Egozi and Ashmore (2009)

Every 150 sec we select a image and calculate BI_A and BI_T as simultaneous braiding intensities

Braiding intensities of submarine braided channels

Discharge (Series A)

Slope (Series B)



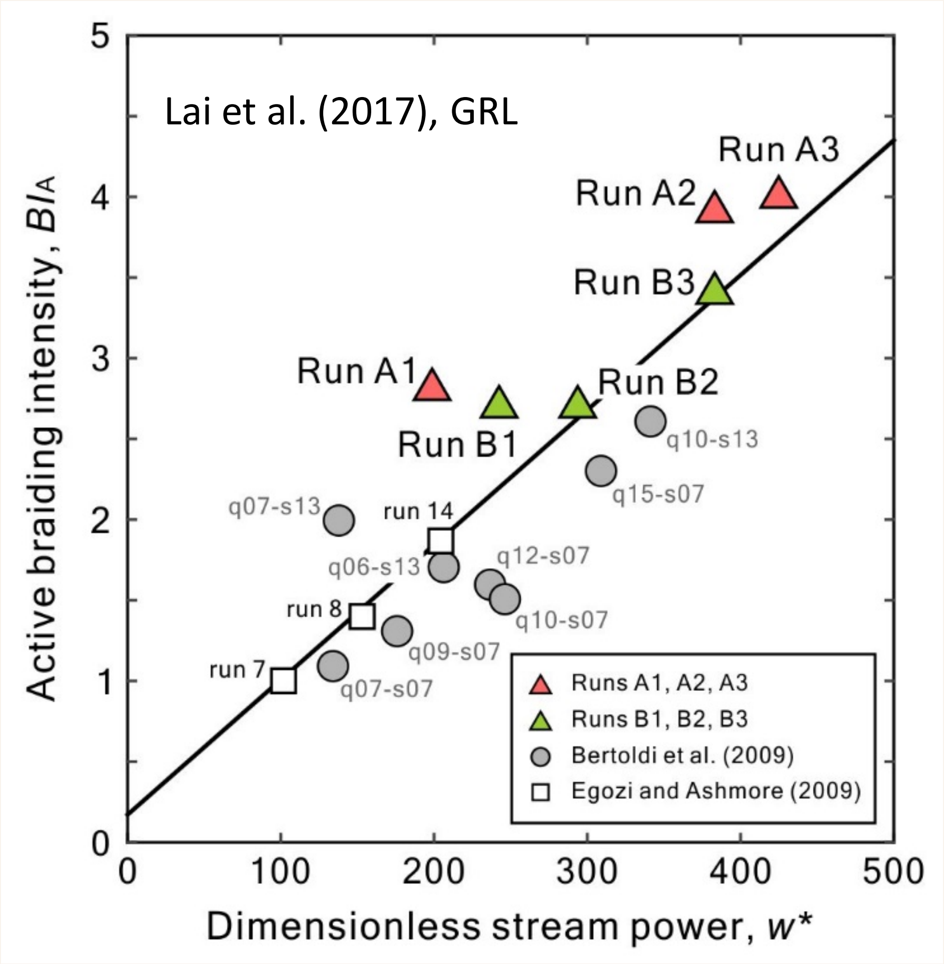
Lai et al. (2017), GRL

Dimensionless stream power

$$\omega^* = \frac{(\rho_{in} - \rho_a)QS}{\rho_{in} w_s {d_s}^2}$$

where ρ_{in} is inflow density (saline, ρ_{in} = 1200 kgm^{-3}); ρ_a is ambient density (water, ρ_a = 1000 kgm^{-3}); Q is inflow discharge; S is bed slope; d_s is median grain size diameter (d_s = 0.34 mm); w_s is sediment settling velocity based on Ferguson and Church [2004]

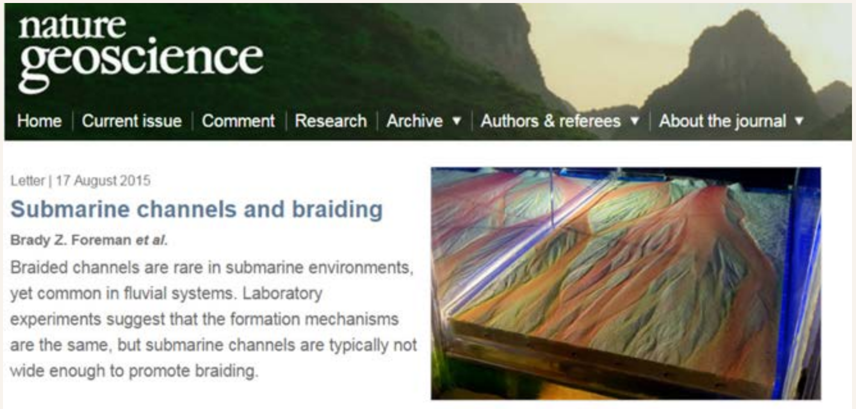
$$w_s = \frac{Rg{d_s}^2}{C_1 \nu + \left(0.75 C_2 Rg{d_s}^3\right)^{0.5}}$$

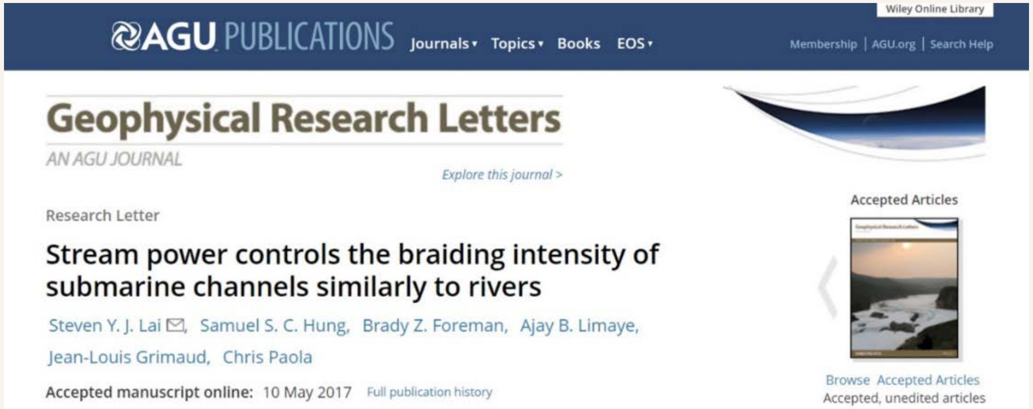


where $R = (\rho_s/\rho_{in} - 1)$ is submerged relative density of sediment (R = 0.25 in this study); ρ_s is sediment density (plastic sand, ρ_s = 1500 kgm^{-3}); ν is water kinematic viscosity (ν = 10^{-6} m^{2}s^{-1}); C_1 = 18 and C_2 = 1 are constants for typical natural sands [Ferguson and Church, 2004].

Summary of Part II

- Submarine braided channels on a submarine fan exhibit active channels and non-active channels, similarly to rivers.
- Active and total braiding intensities of experimental submarine braided channels are proportional to discharge and slope at steady state.
- Active braiding intensity of experimental submarine braided channels scales linearly with dimensionless stream power.

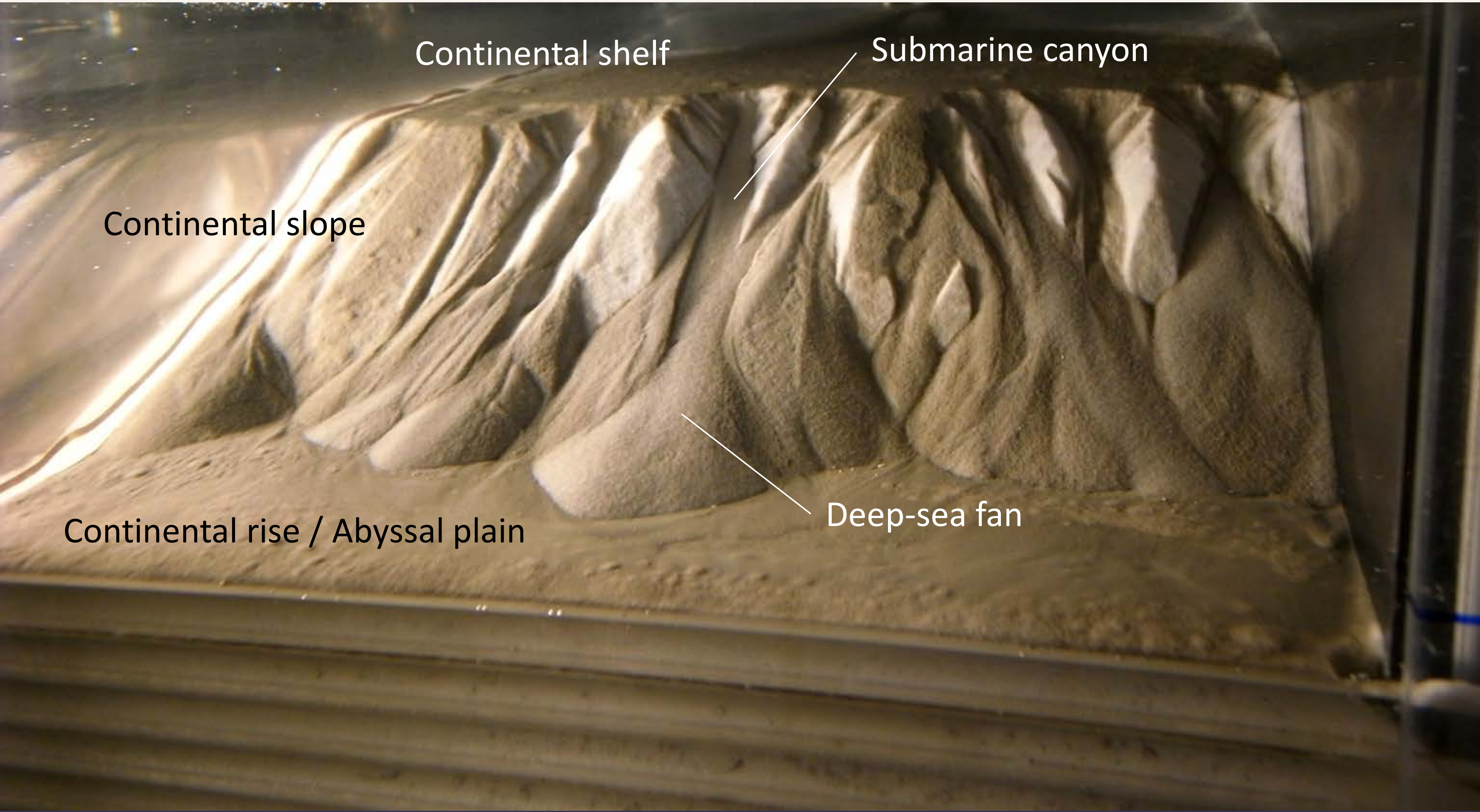




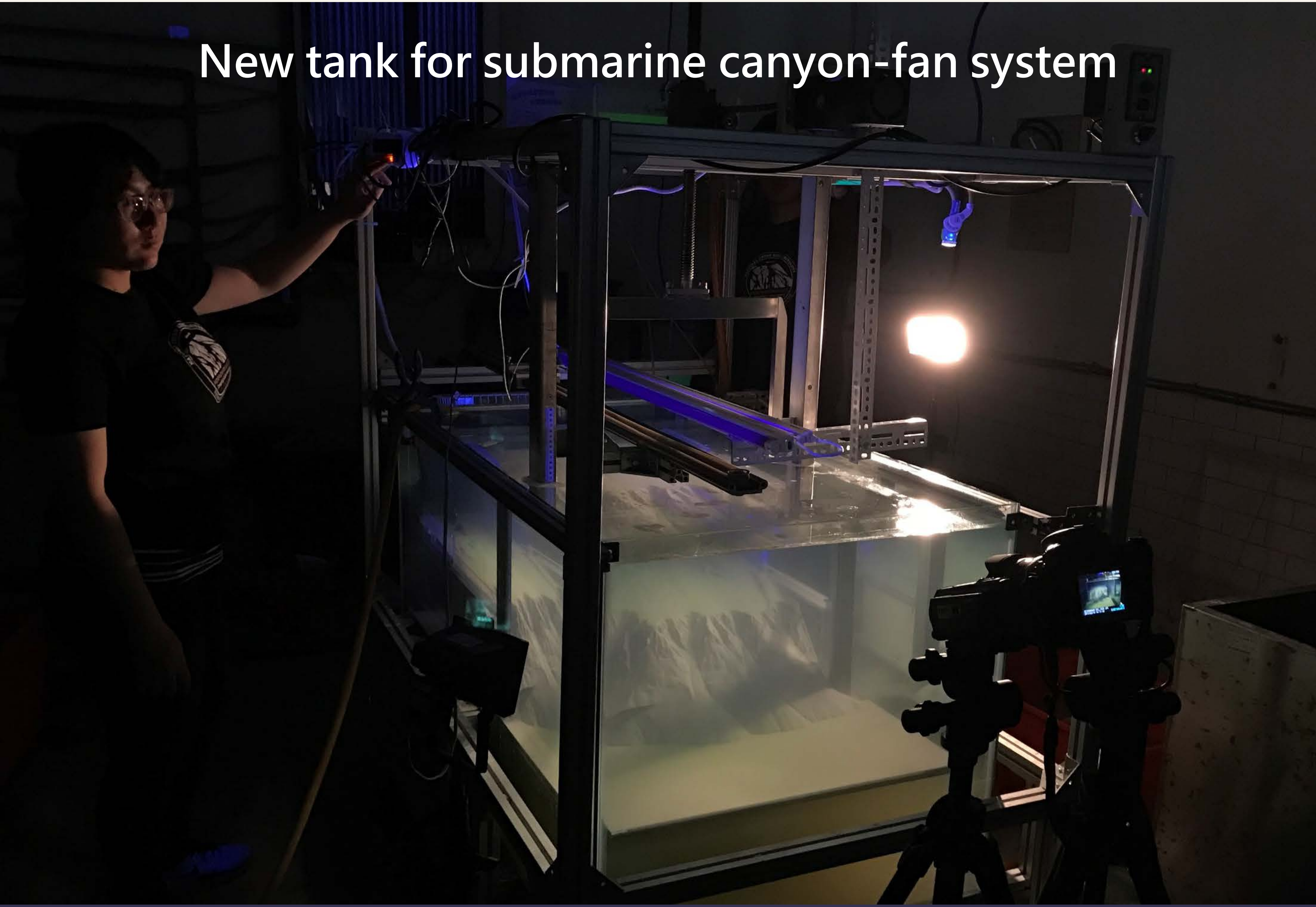
Next step?

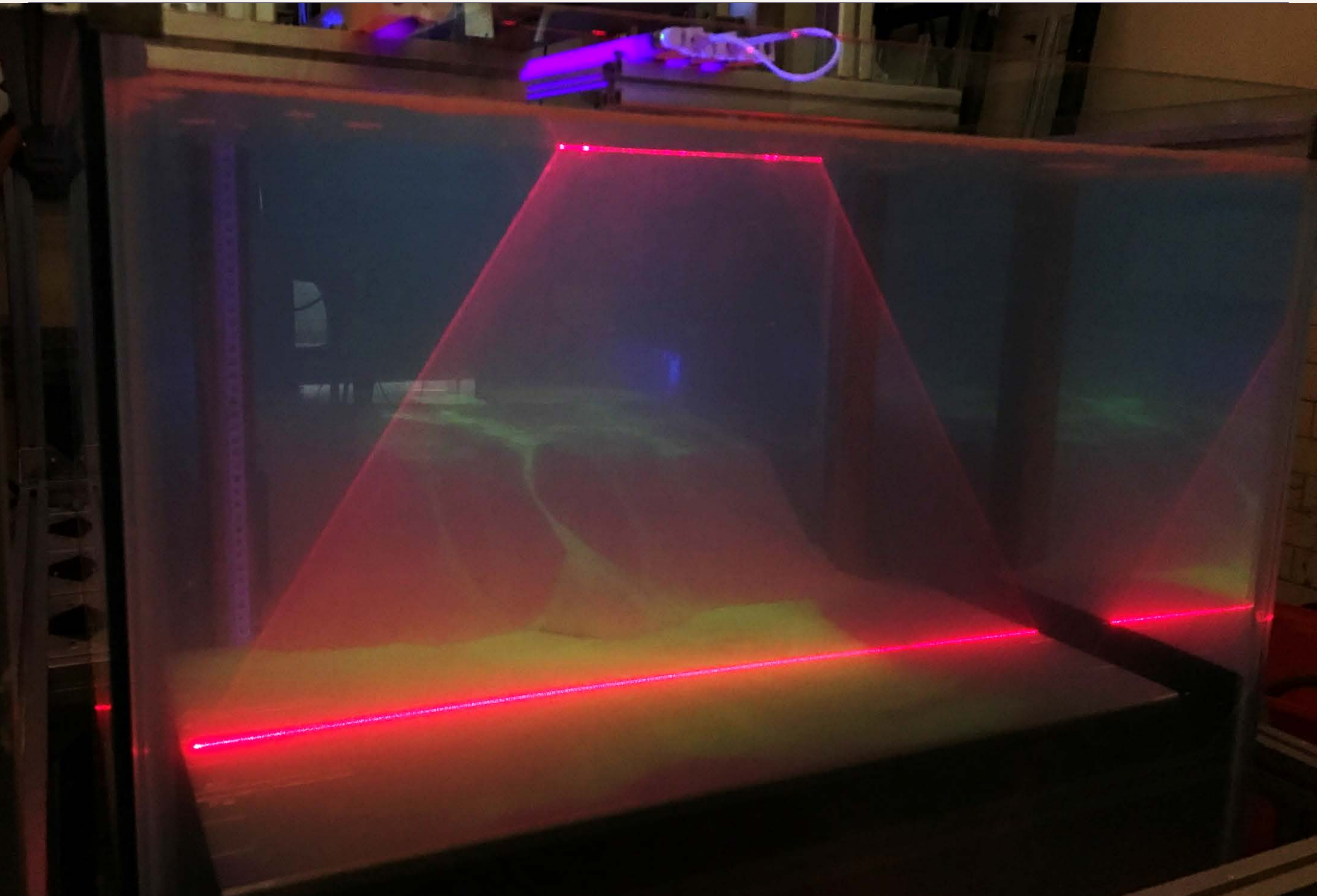
Submarine canyon-fan system

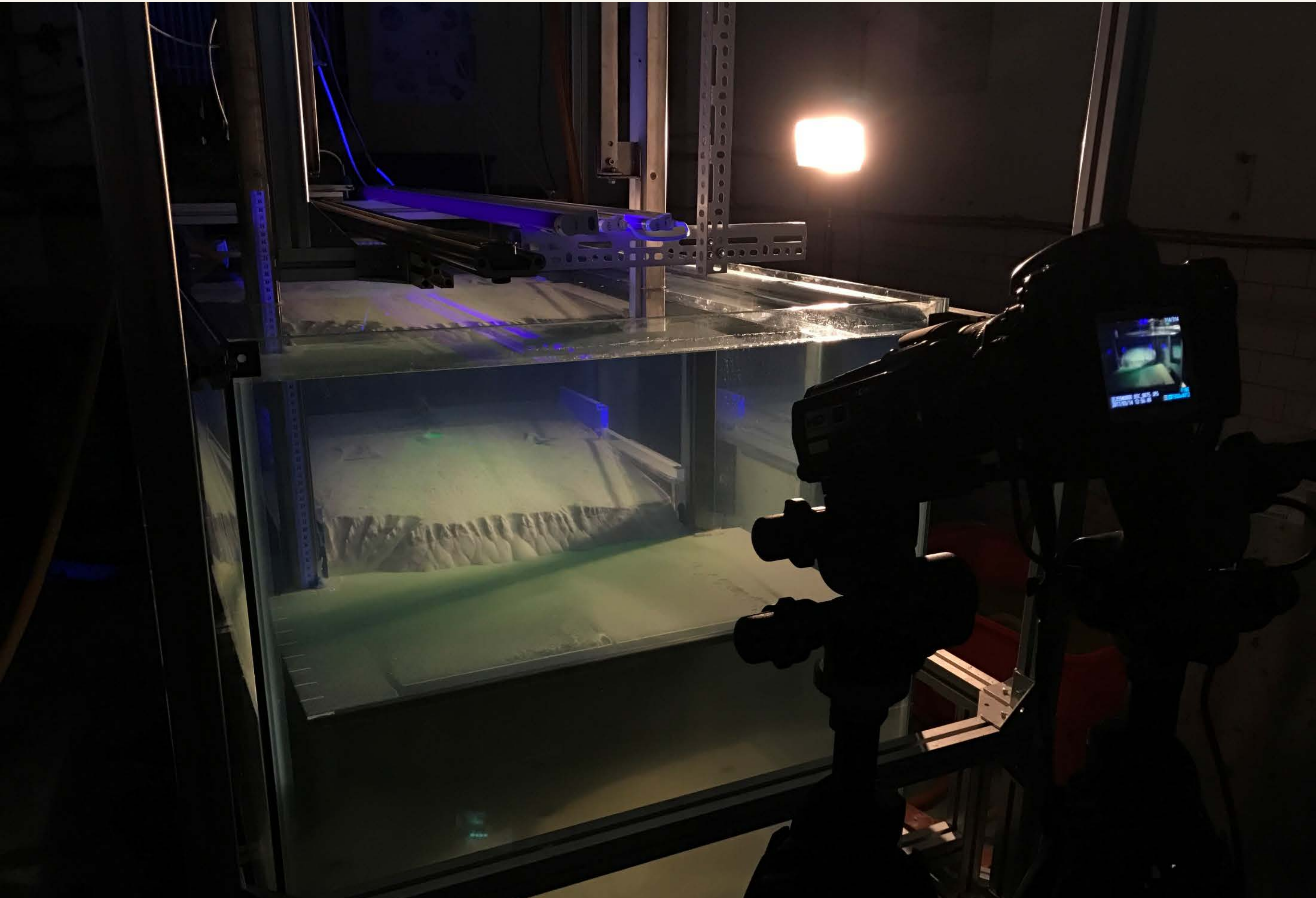
How to make continental slope, canyons and fans grow together?

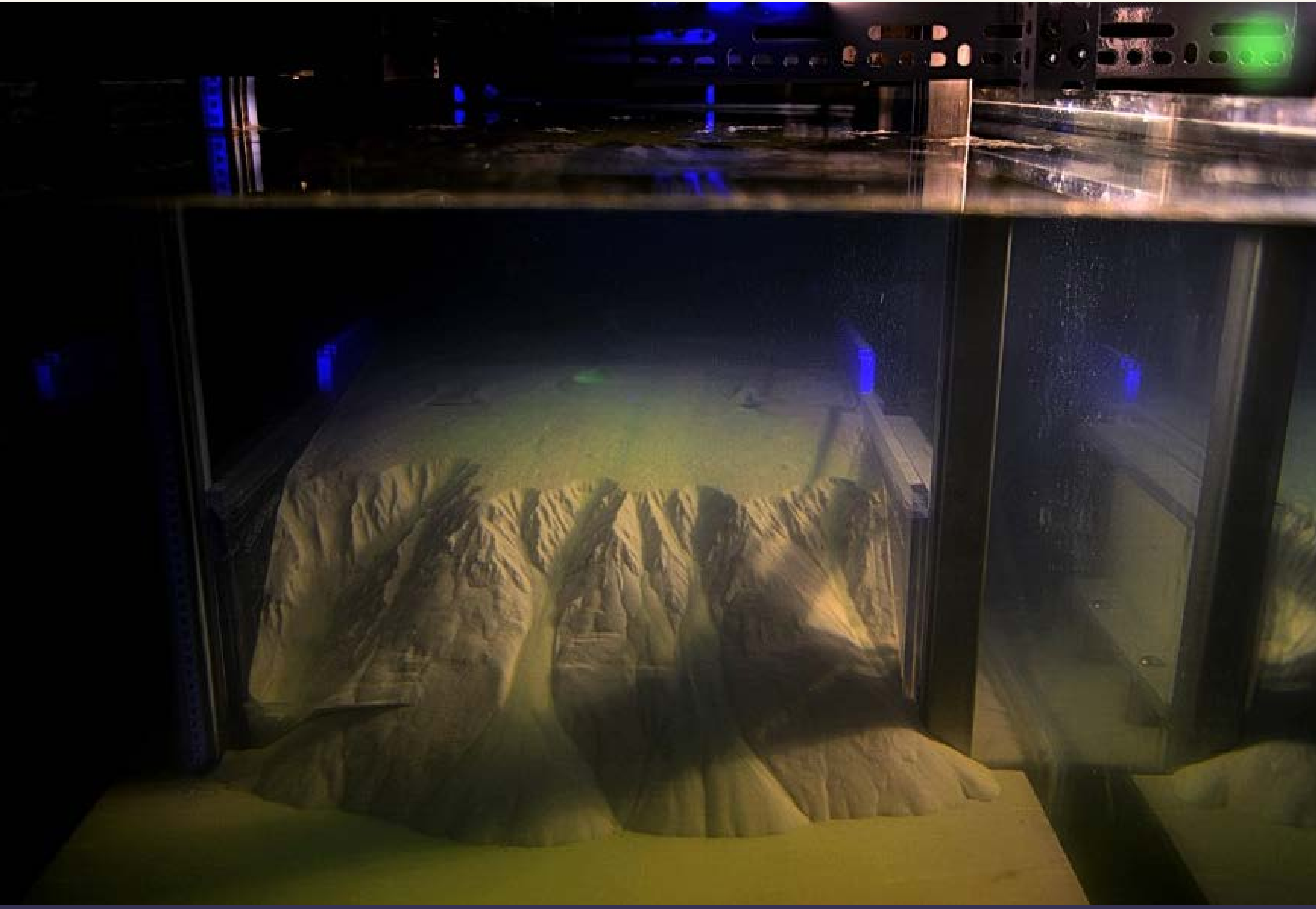


New tank for submarine canyon-fan system

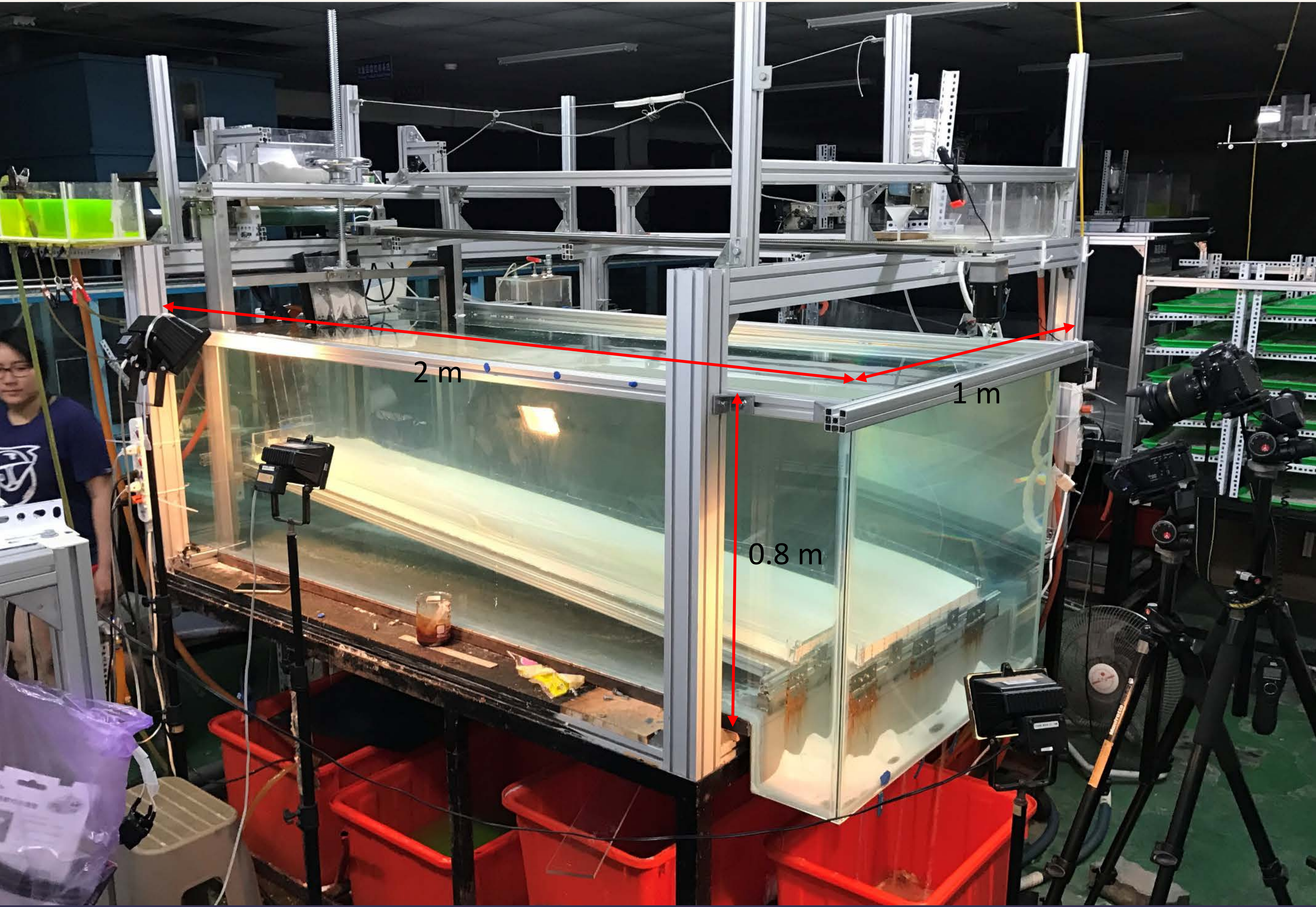




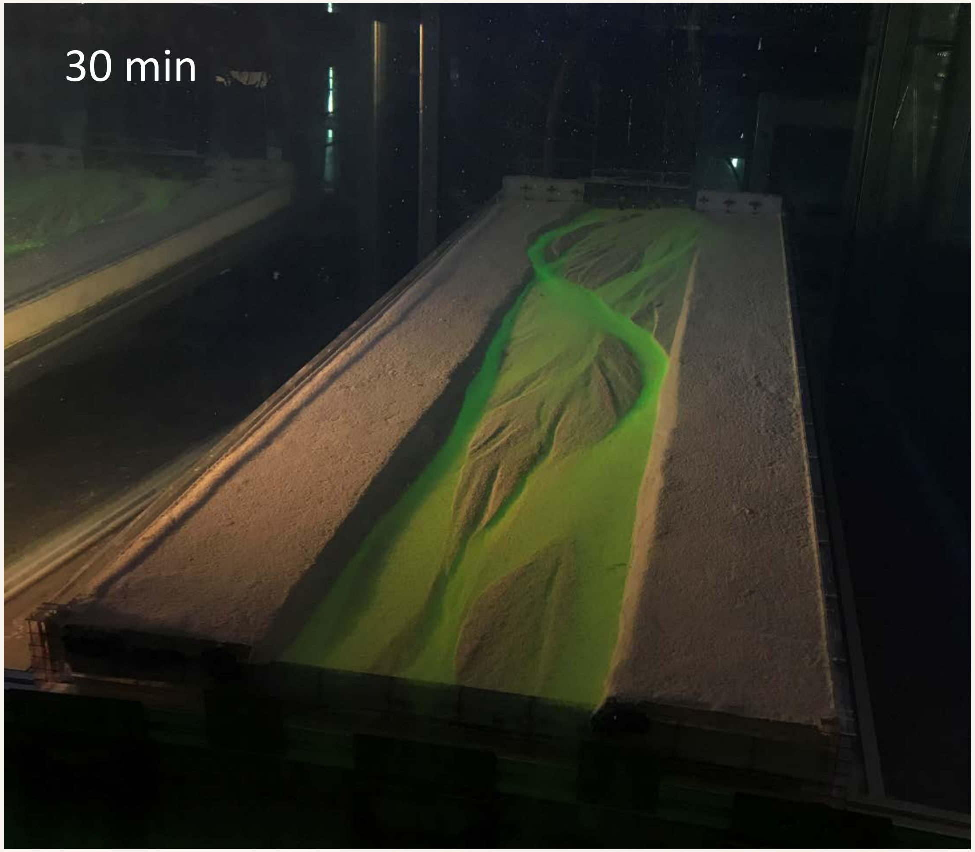


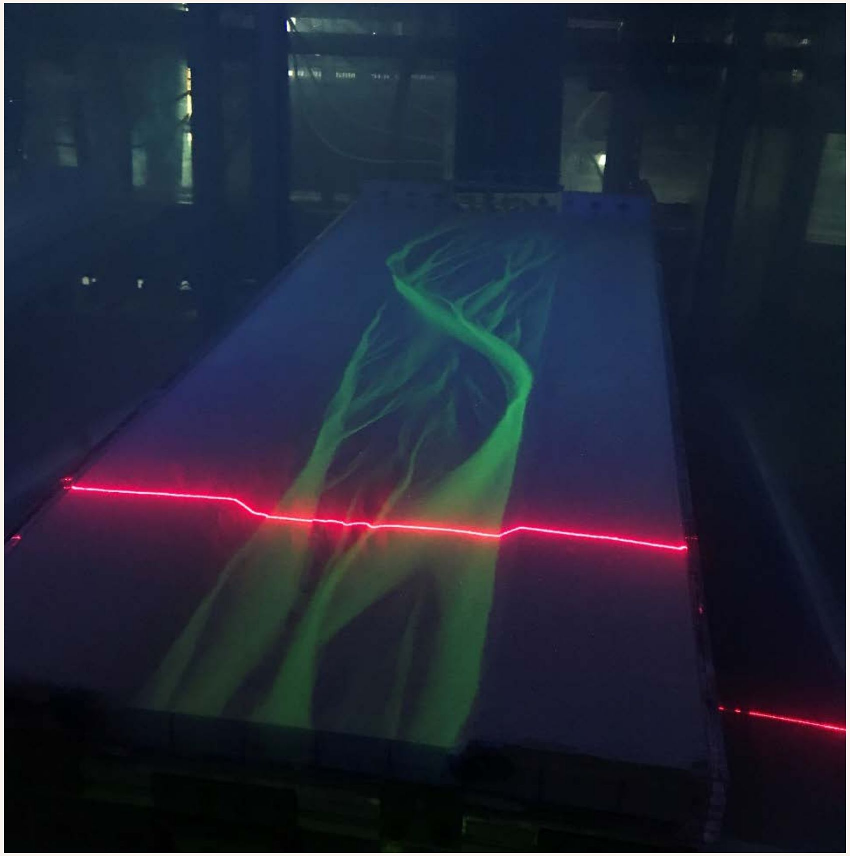


New tank for submarine braided channels

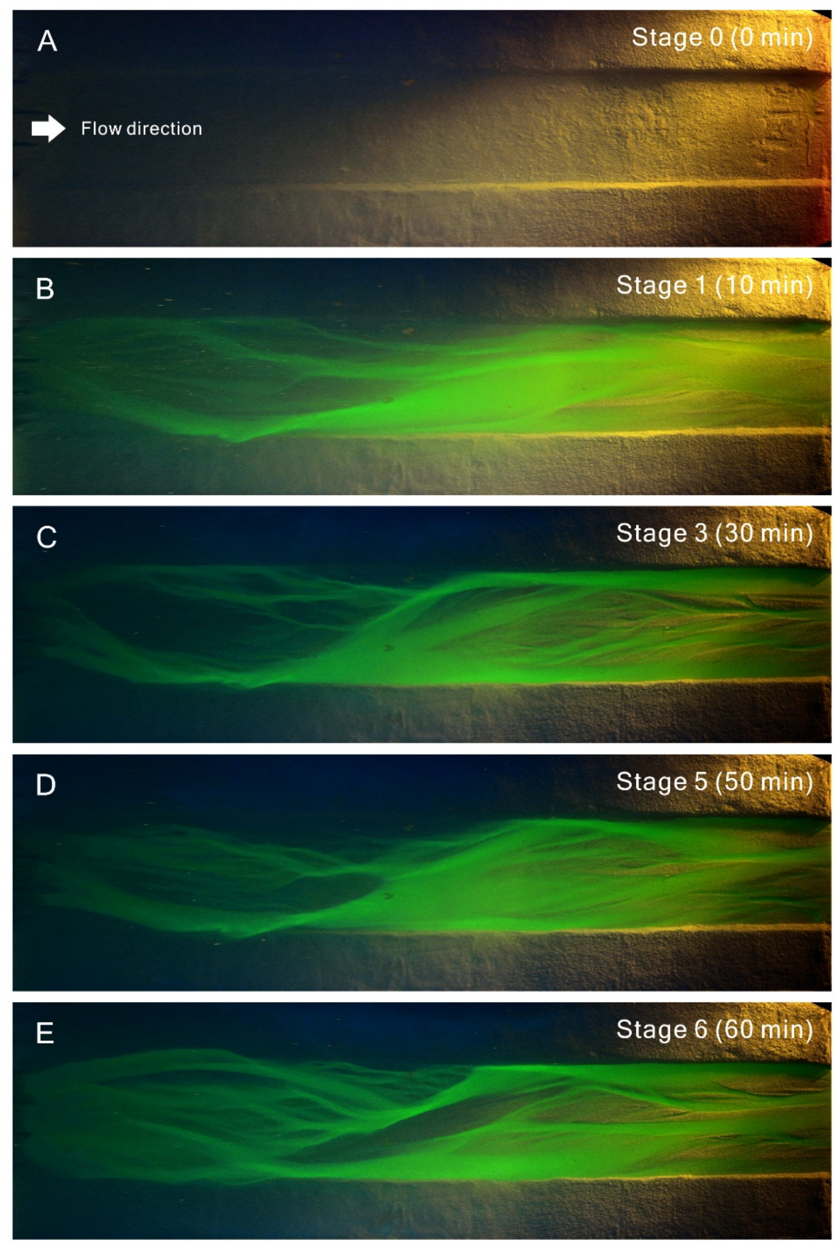

2 m
1 m
0.8 m

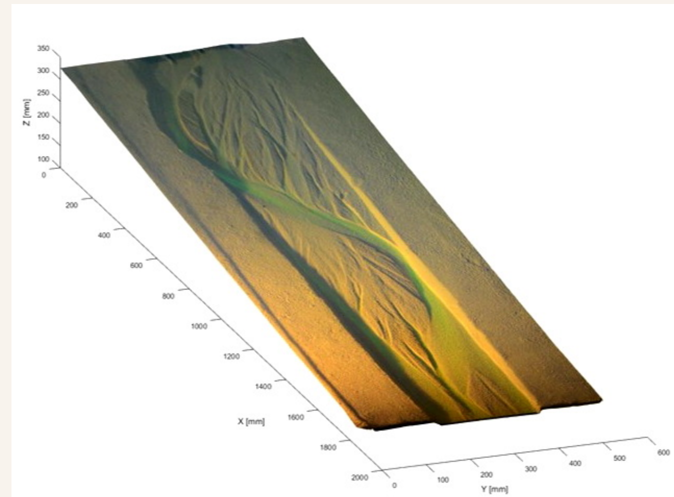
Preliminary results of submarine braided channels

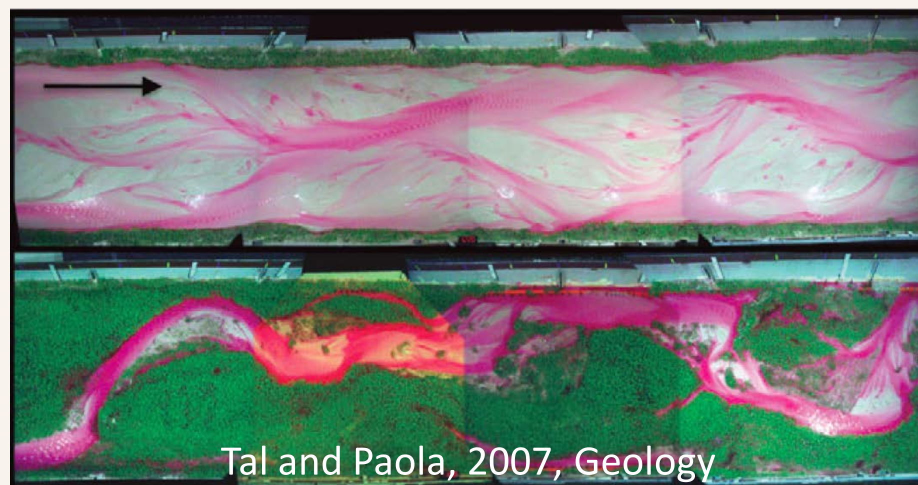




Quantitative comparison between braided rivers and submarine channels






Tal and Paola, 2007, Geology