Connecting Hyperpycnal Flow Deposits to River Flood Dynamics*

Michael Lamb[1], Brandon McElroy[2], David Mohrig[2], John Shaw[2], Bryant Kopriva[2], Steff Lazo-Herencia[2] and Jim Buttles[2]

Search and Discovery Article #40637 (2010)
Posted November 15, 2010

* Adapted from an oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, USA, April 11-14, 2010

[1]Caltech, Pasadena, CA. (mpl@gps.caltech.edu)
[2]University of Texas, Austin, TX.

Abstract

Hyperpycnal flows are turbid river plumes that can plunge to form turbidity currents where they enter a water body of lesser density. Because these flows provide one of the most direct connections between terrestrial sediment sources and marine depositional sinks, their deposits preserve an important record across a variety of climatic and tectonic settings. A leading hypothesis assumes that hyperpycnal-flow velocity scales directly with river discharge, such that individual turbidites record the rising and falling discharge of a flooding river. Using a 1D numerical model and flume experiments, we test this hypothesis and find that turbid river flow must move through a backwater zone, depth-limited plume, and plunging zone before becoming a turbidity current. These zones can extend tens of kilometers offshore and significantly affect the transfer of momentum from river to turbidity current. Counter to the proposed hypothesis, our results indicate that local flow velocities within hyperpycnal flows can be uncorrelated or even anti-correlated with inlet river discharge because of translation of the plunge point resulting from temporal variations in discharge and sediment concentration through the course of a river flood. Furthermore, hyperpycnal flow deposits can be influenced by both local plunge-point dynamics and inlet river conditions, and the relative degree of influence depends on the advection length scale of settling sediment. Results also suggest that the criteria used to identify plunging hyperpycnal flows (a flow density in excess of the ambient fluid) is a necessary, but not sufficient condition. The basin also must be deep enough, in cases greater than tens of meters, in order for the plume to collapse and form a turbidity current.

References

Akiyama, J. and H.G. Stefan, 1984, Plunging flow into a reservoir – Theory: Journal of Hydraulic Engineering, v. 110, p. 484-499. DOI: 10.1061/(ASCE)0733-9429(1984)110:4(484).

Lamb, M.P. and D. Mohrig, 2009, Do hyperpycnal-flow deposits record river-flood dynamics?: Geology, v. 37/12, p. 1067-1070.

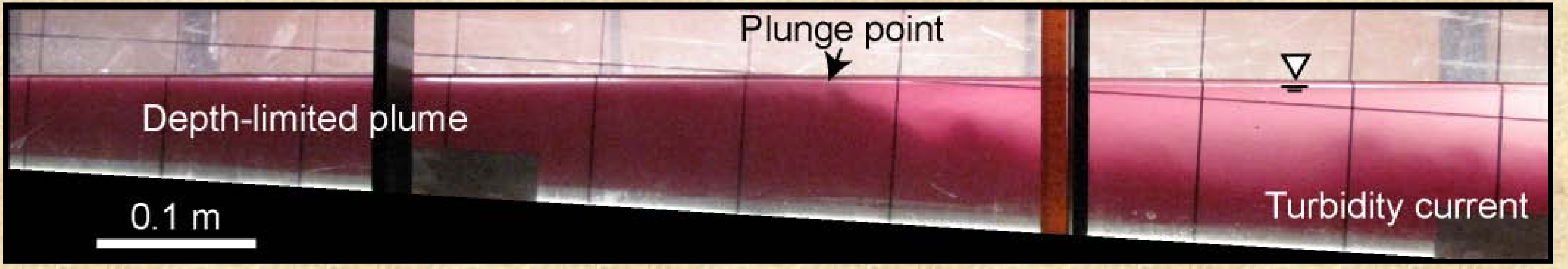
Lamb, M.P., B. McElroy, B. Kopriva, J. Shaw, and D. Mohrig, 2010, Linking river-flood dynamics to hyperpycnal-plume deposits; experiments, theory, and geological implications: GSA Bulletin, v. 122/9-10, p. 1389-1400.

Mulder, T. and J. Alexander, 2001, The physical character of subaqueous sedimentary density flows and their deposits: Sedimentology, v. 48/2, p. 269-299.

Mulder, T. and J. Alexander, 2001, Abrupt change in slope causes variation in the deposit thickness of concentrated particle-driven density currents: Marine Geology, v. 175/1-4, p. 221-235.

Parker, G. and H. Toniolo, 2007, Note on the analysis of plunging of density flows: Journal of Hydraulic Engineering-Asce, v. 133, p. 690-694. DOI: 10.1061/(ASCE)0733-9429(2007)133.6(690).

Connecting Hyperpycnal Flow Deposits to River Flood Dynamics



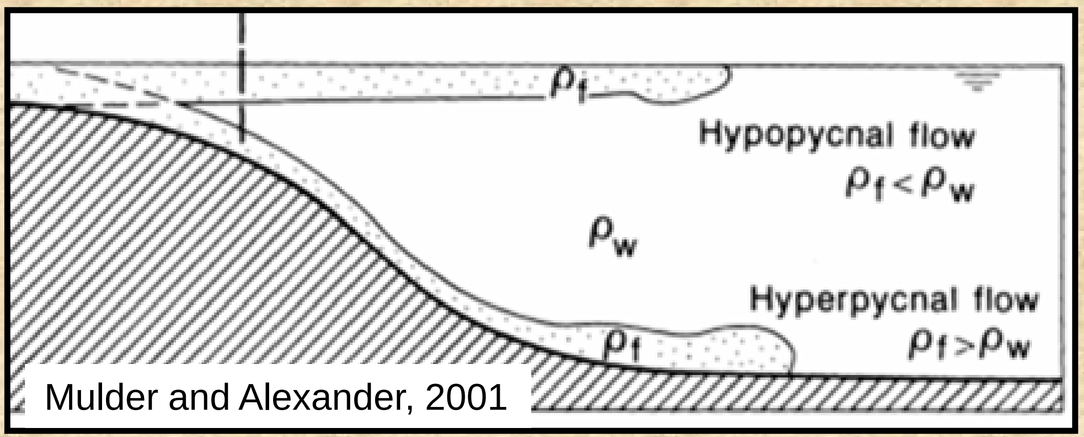
Michael Lamb
Assistant Professor
Geological and Planetary Sciences
California Institute of Technology

Collaborators: Brandon McElroy, David Mohrig, John Shaw, Bryant Kopriva, Steff Lazo-Herencia and Jim Buttles

Funding: RioMAR Industrial Consortium and U.T. -Austin

Plunging hyperpycnal river plumes

Current Ideas:



Mulder and Alexander, 2001


River Reuss, Switzerland, 2005

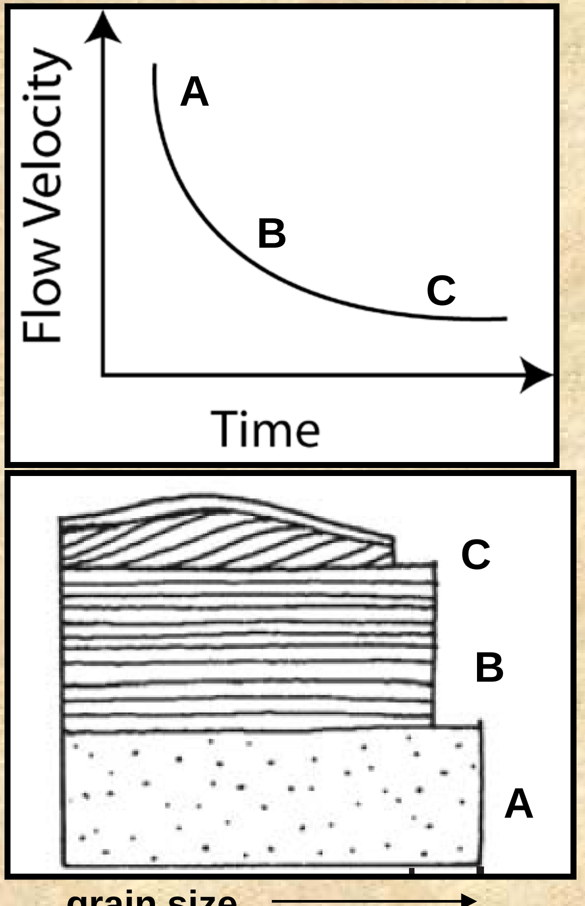
1. River plumes plunge when denser than seawater

2. Depositional record of river floods (river response to climate change)

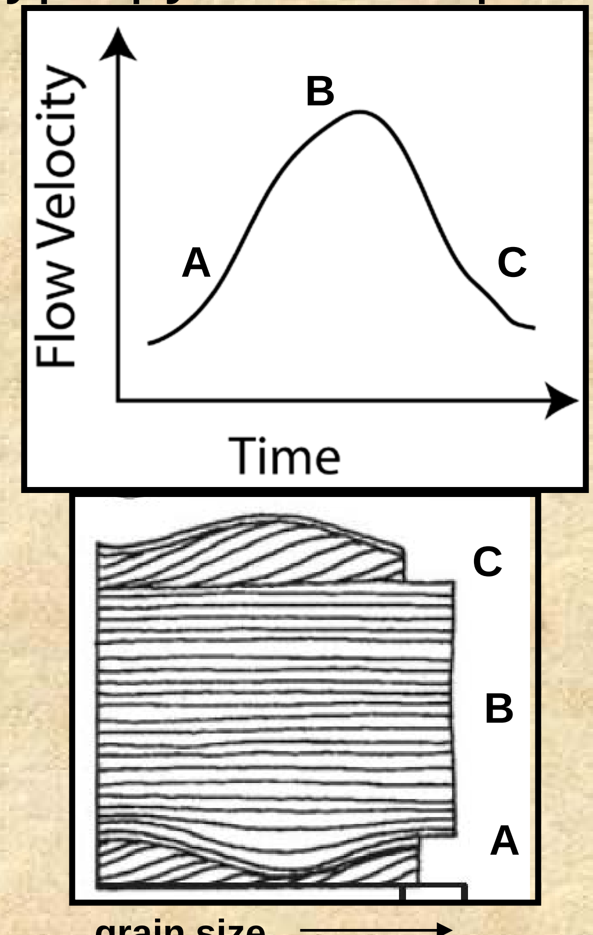
3. Deposits track the hydrograph of a flooding river

Do hyperpycnal-flow deposits record river flood dynamics?

Slump-generated vs. Hyperpycnal river plume



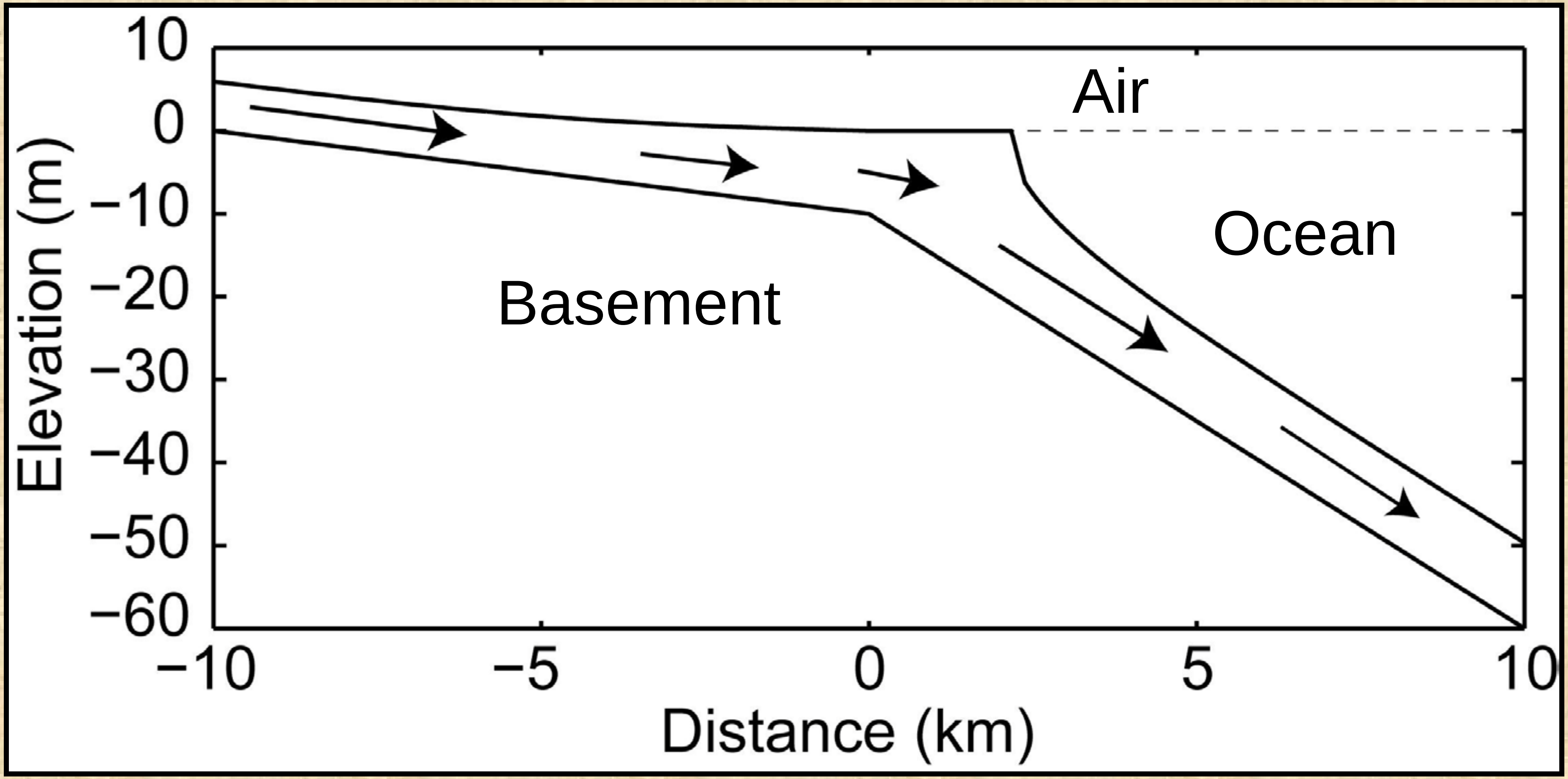
- Deposition under decelerating flow



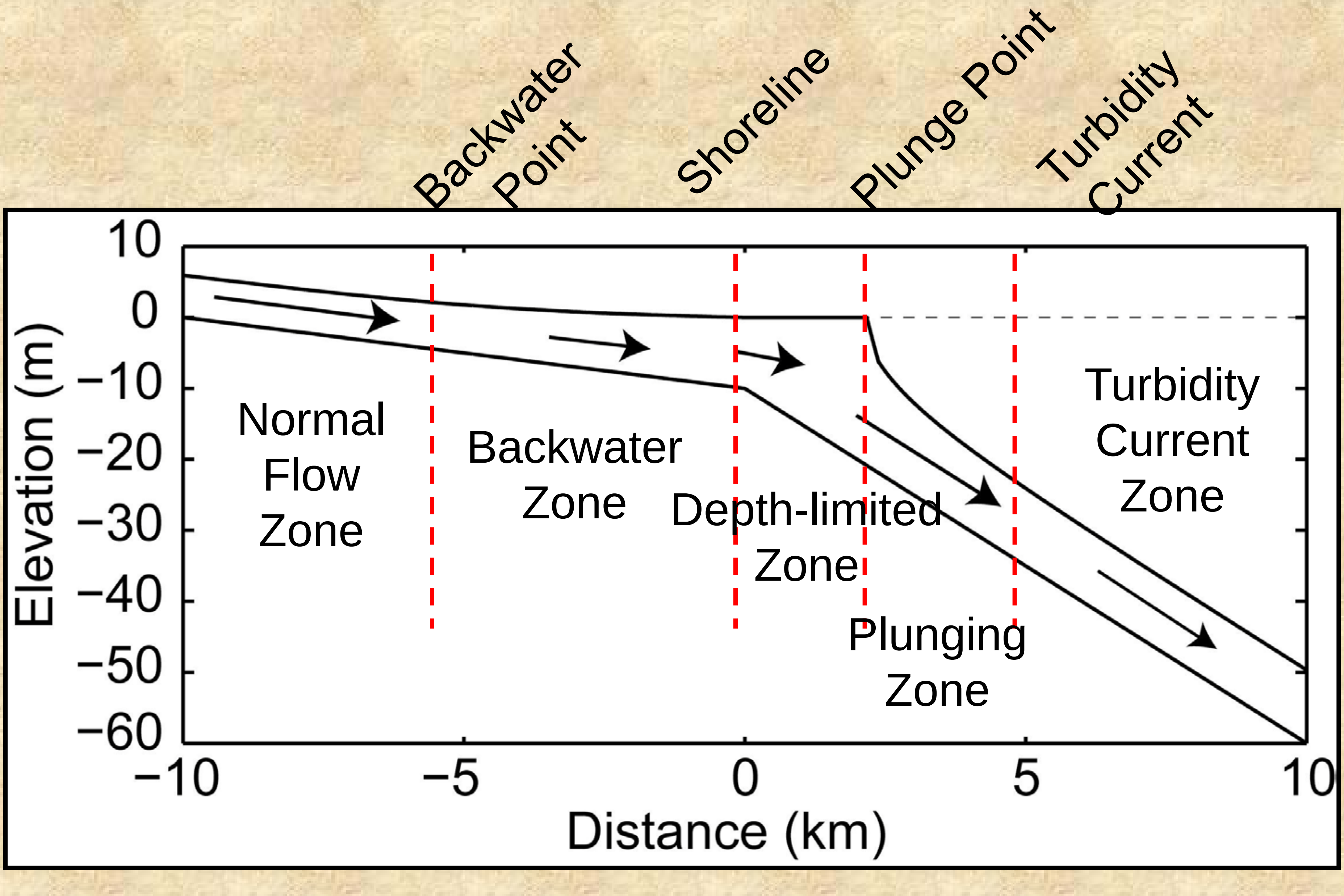
- Deposition following river hydrograph
- Reverse to normal grading

(after Mulder and Alexander, 2001)

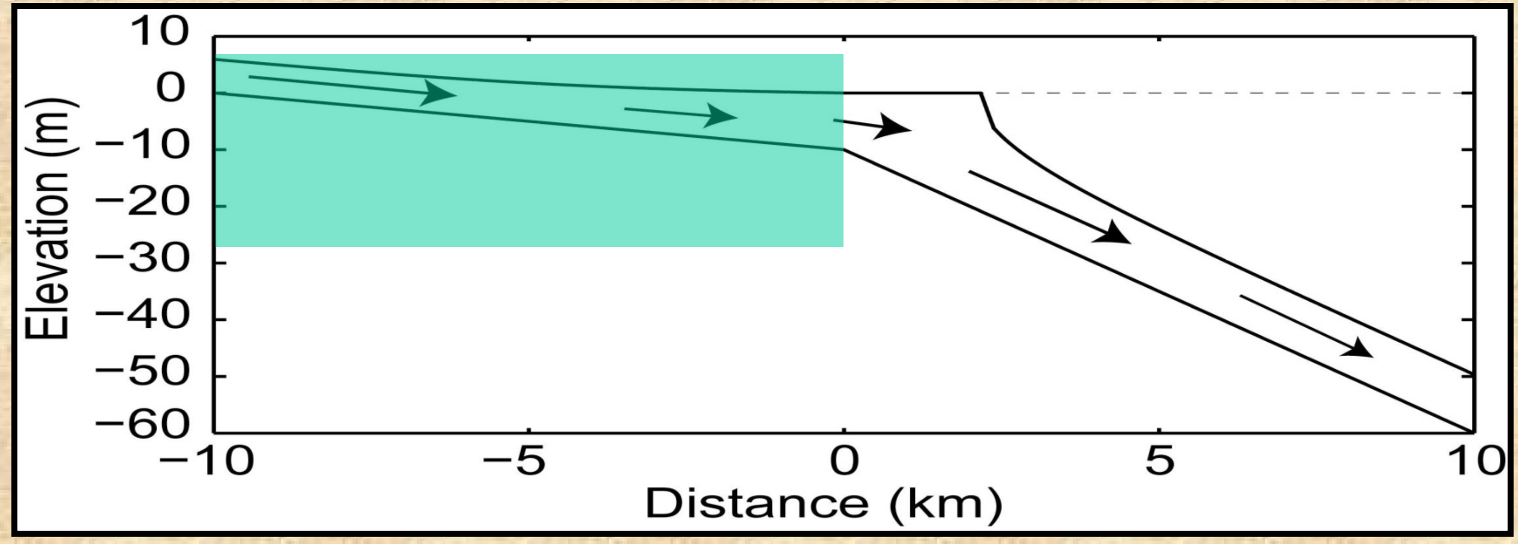
Zones of flow: Hyperpycnal Plume



Zones of flow: Hyperpycnal Plume



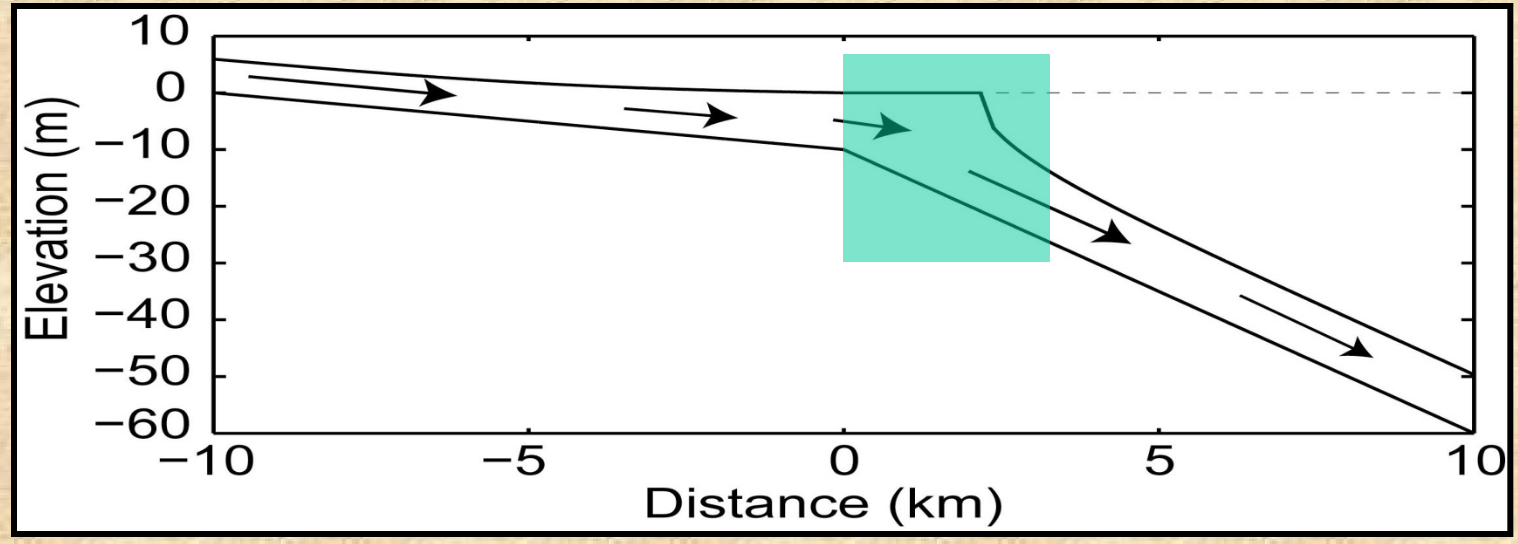
Numerical Formulation



1. 1D Layer averaged equations of motion (St. Venant)
2. Conservation of fluid mass and momentum
3. No erosion or deposition
4. Upstream of shoreline: backwater equation

$$\frac{dh}{dx} = \frac{S_b - C_f F^2}{1 - F^2}$$

Numerical Formulation



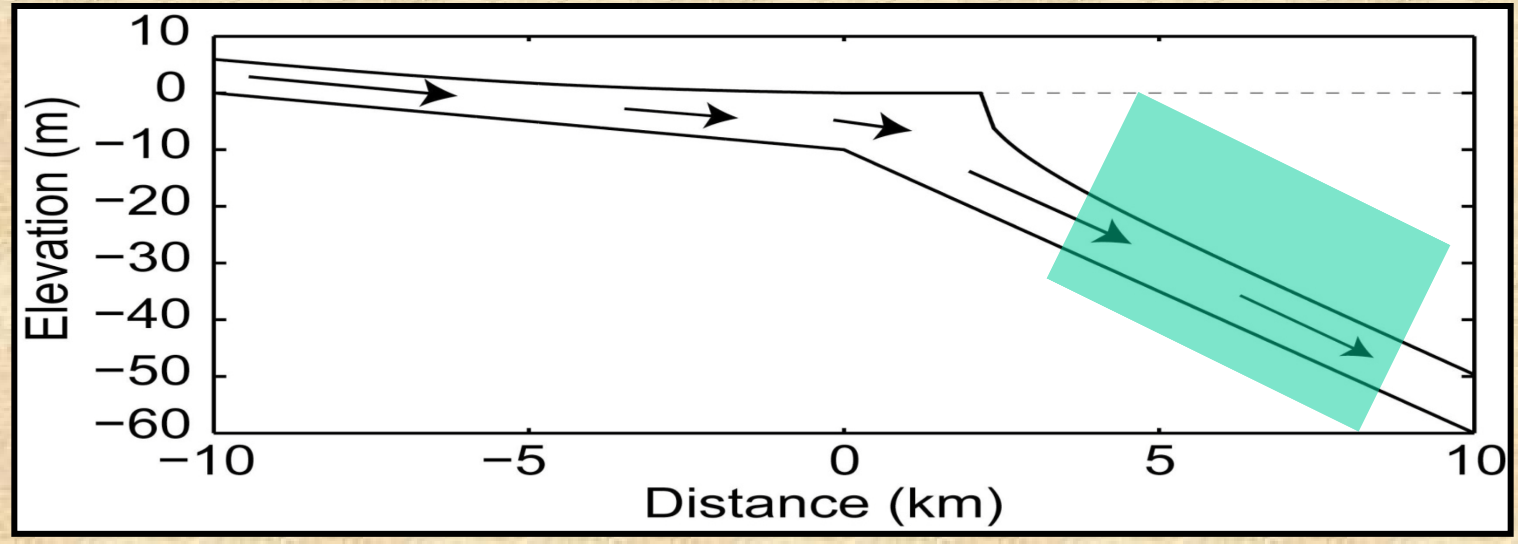
1. 1D Layer averaged equations of motion (St. Venant)
2. Conservation of fluid mass and momentum
3. No erosion or deposition
4. Upstream of shoreline: backwater equation

$$\frac{dh}{dx} = \frac{S_b - C_f F^2}{1 - F^2}$$

5. Plunge zone: $F_{dp} = 0.5$ at plunge point (Akiyama and Stefan, 1984; Toniolo and Parker, 2007)

$$h_p = \left(\frac{{q_p}^2}{\left(\Delta\rho/\rho_a\right) g F_{dp}^2} \right)^{1/3}$$

Numerical Formulation



1. 1D Layer averaged equations of motion (St. Venant)
2. Conservation of fluid mass and momentum
3. No erosion or deposition
4. Upstream of shoreline: backwater equation

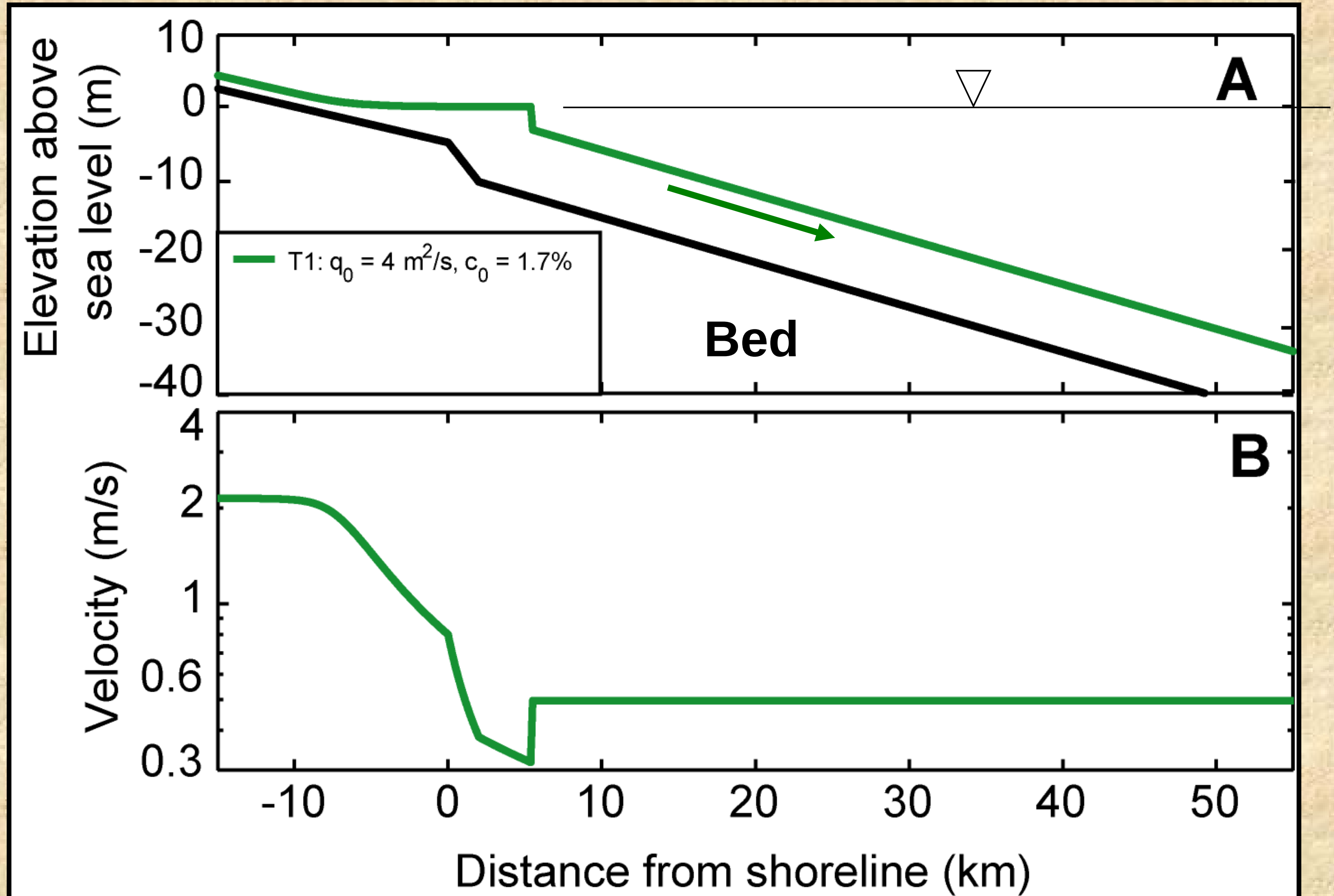
$$\frac{dh}{dx} = \frac{S_b - C_f F^2}{1 - F^2}$$

5. Plunge zone: F_{dp} = 0.5 at plunge point (Akiyama and Stefan, 1984; Toniolo and Parker, 2007)

$$h_p = \left(\frac{{q_p}^2}{(\Delta\rho/\rho_a)\, g F_{dp}^2} \right)^{1/3}$$

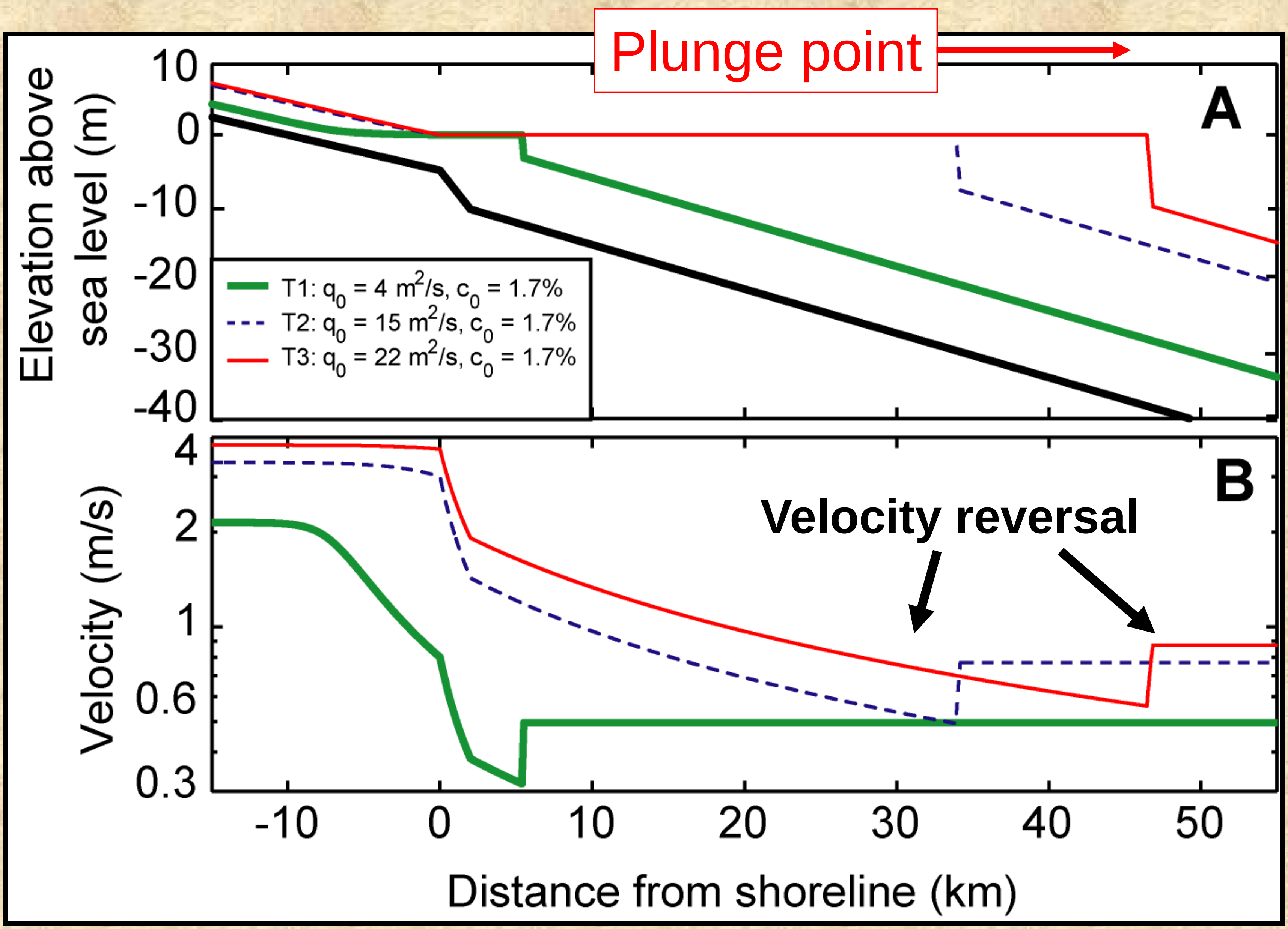
6. Turbidity current zone: steady and uniform

Example case: Huanghe River, China

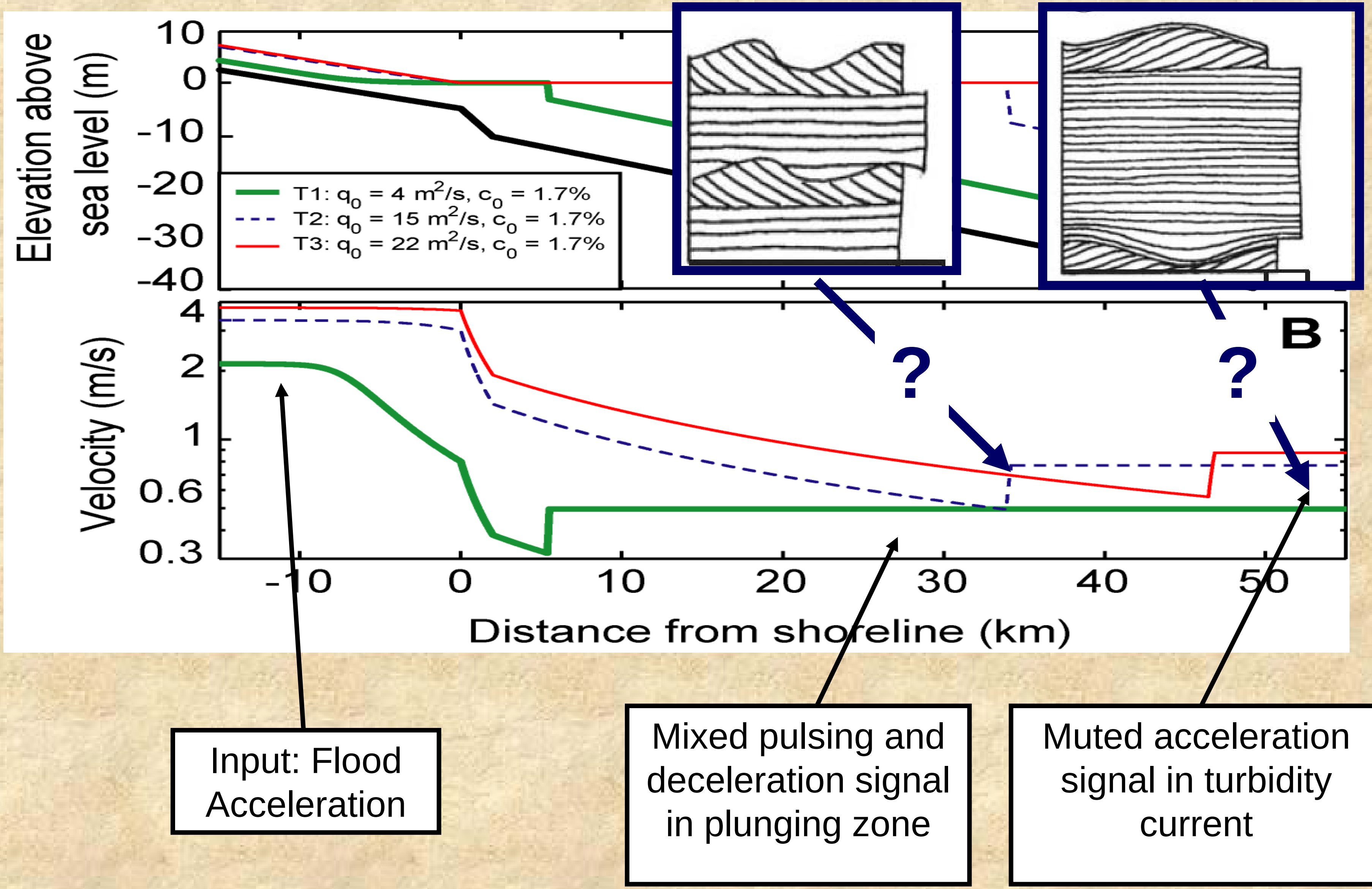


Lamb and Mohrig, 2009, Geology

Source to sink signal transfer

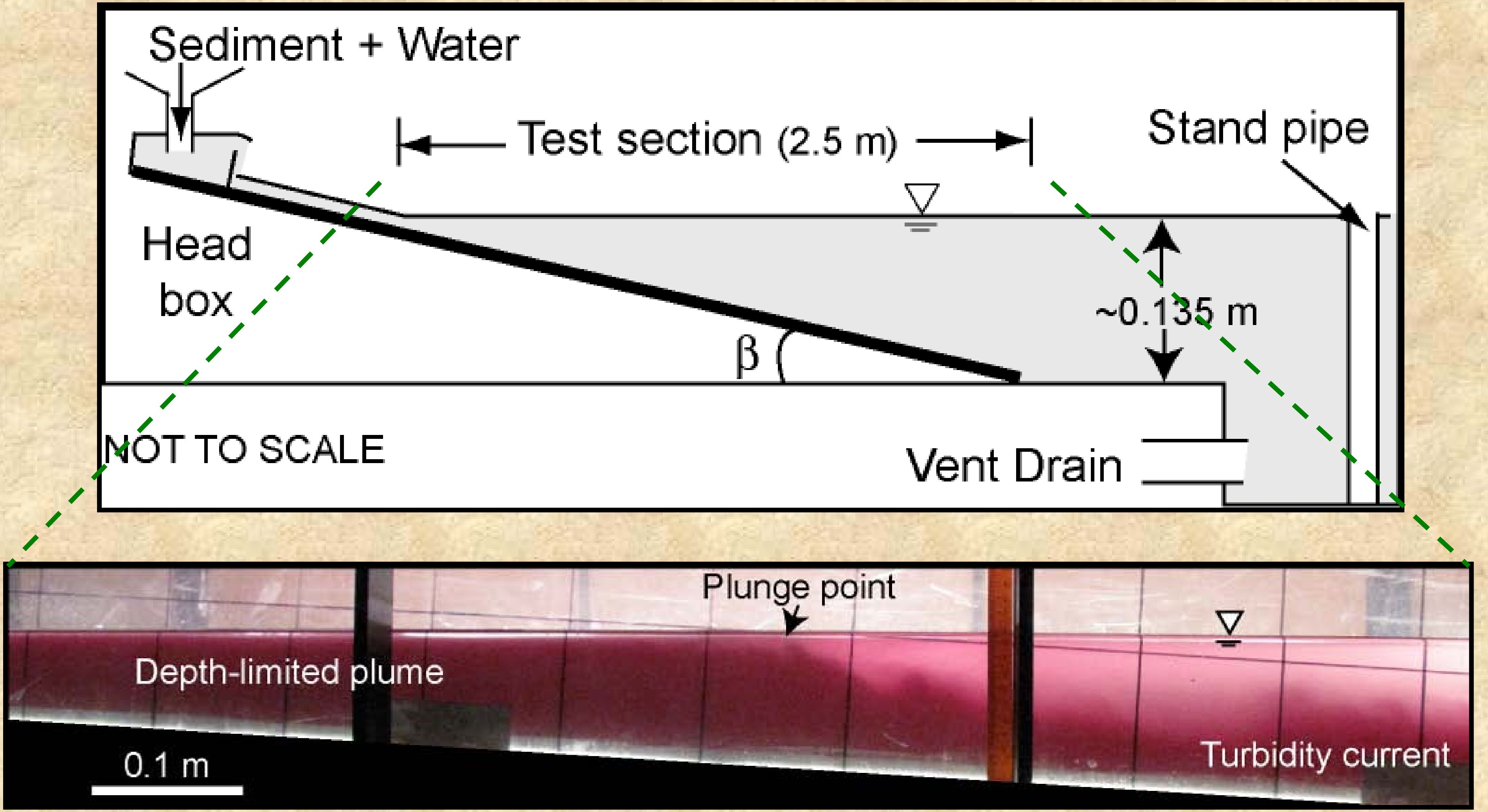


Source to sink signal transfer



Lamb and Mohrig, 2009, Geology

2-D experimental facility



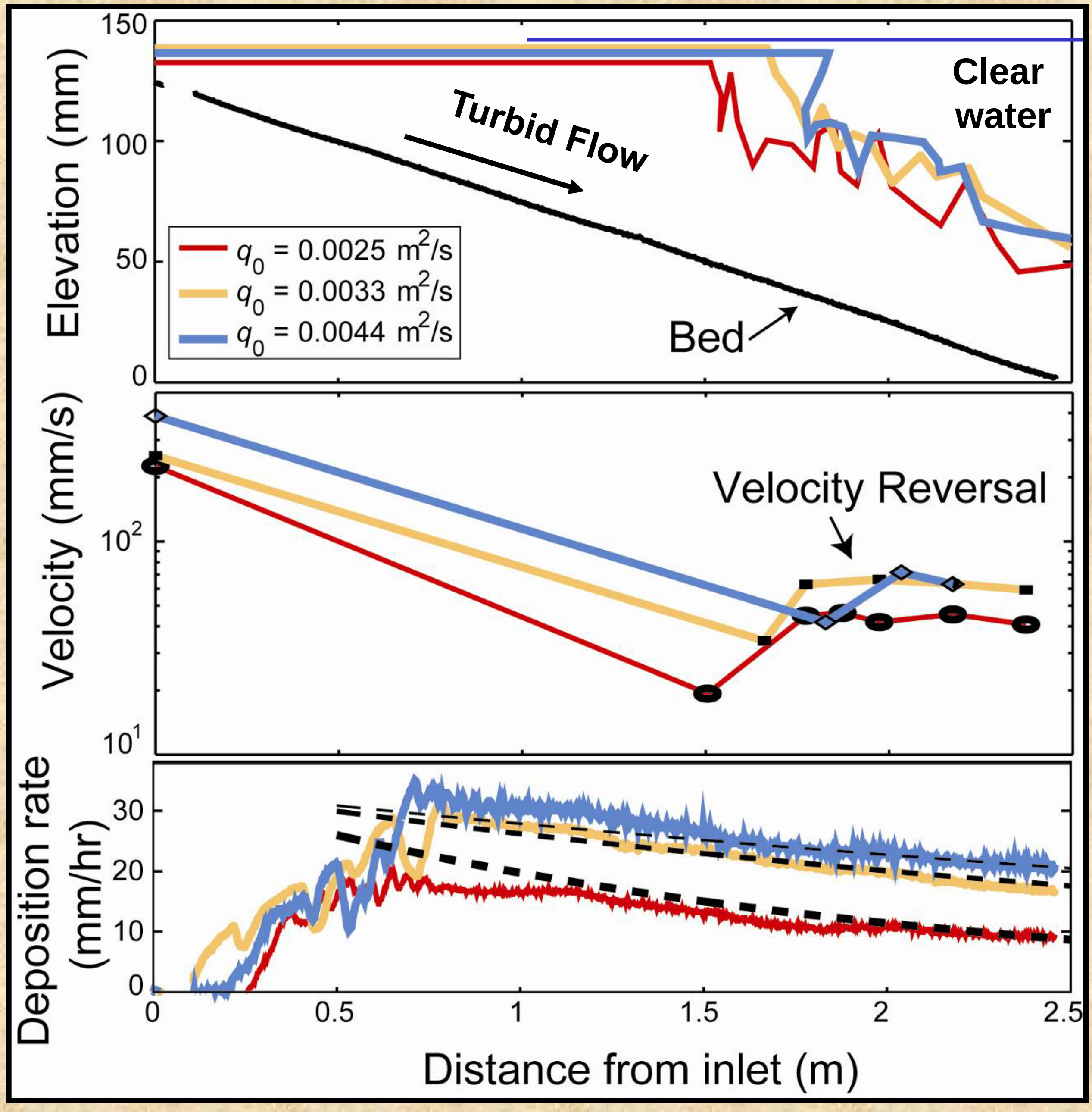
Lamb et al., in press, GSAB

Flume Results

• Increasing discharge results in seaward movement of the plunge point.

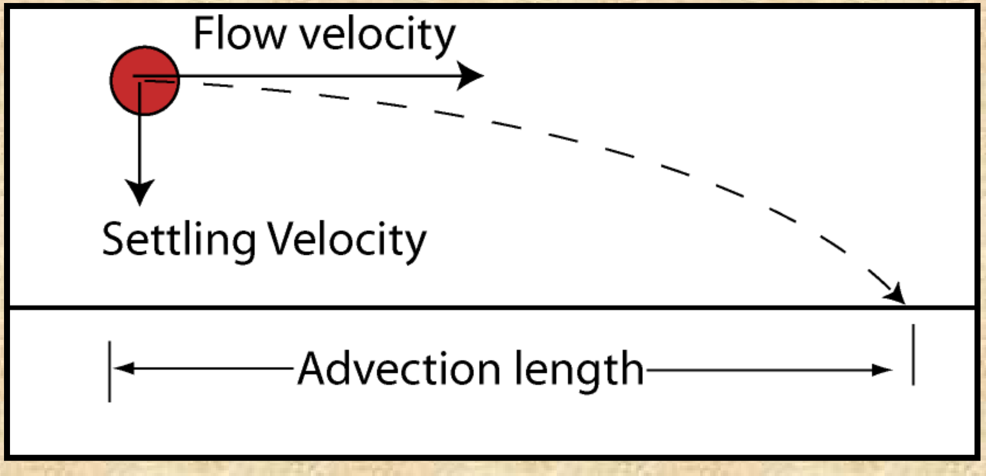
• Local velocity is anti-correlated with discharge in plunge zone.

• Despite complex local flow dynamics, deposition rate is most sensitive to inlet discharge.



Lamb et al., in press, GSAB

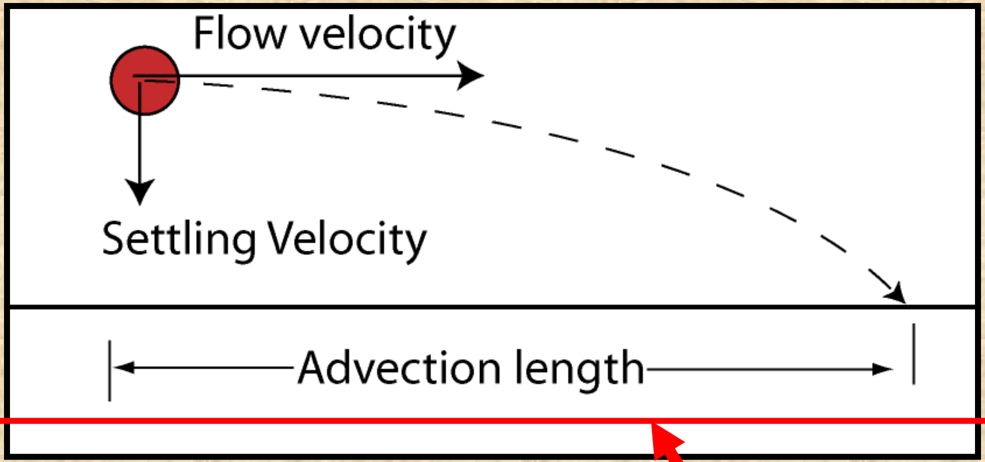
Advection length scale



$$l_a = \frac{UH}{r_0 w_s}$$

= Flow Velocity x settling time

Advection length scale



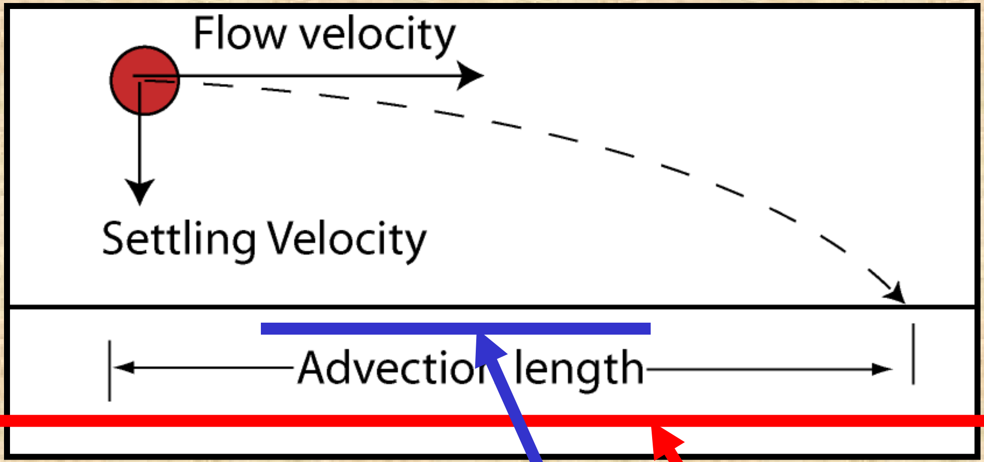
$$l_a = \frac{UH}{r_0 w_s}$$

= Flow Velocity x settling time

If plunge point translation > l_a $\quad q_s = q_{sc}$

Deposition governed by divergence in local transport capacity.
Deposits record local plunge point dynamics.

Advection length scale



$$l_a = \frac{UH}{r_0 w_s}$$

= Flow Velocity x settling time

If plunge point translation > l_a $\quad q_s = q_{sc}$

Deposition governed by divergence in local transport capacity. Deposits record local plunge point dynamics.

If plunge point translation < l_a $\quad q_s = q_{s0}$

Settling sediment cannot respond to local flow. Deposition governed by inlet boundary conditions. Deposits record river flood dynamics.

Example calculations of advection length scale

$$l_a = \frac{UH}{r_0 w_s}$$

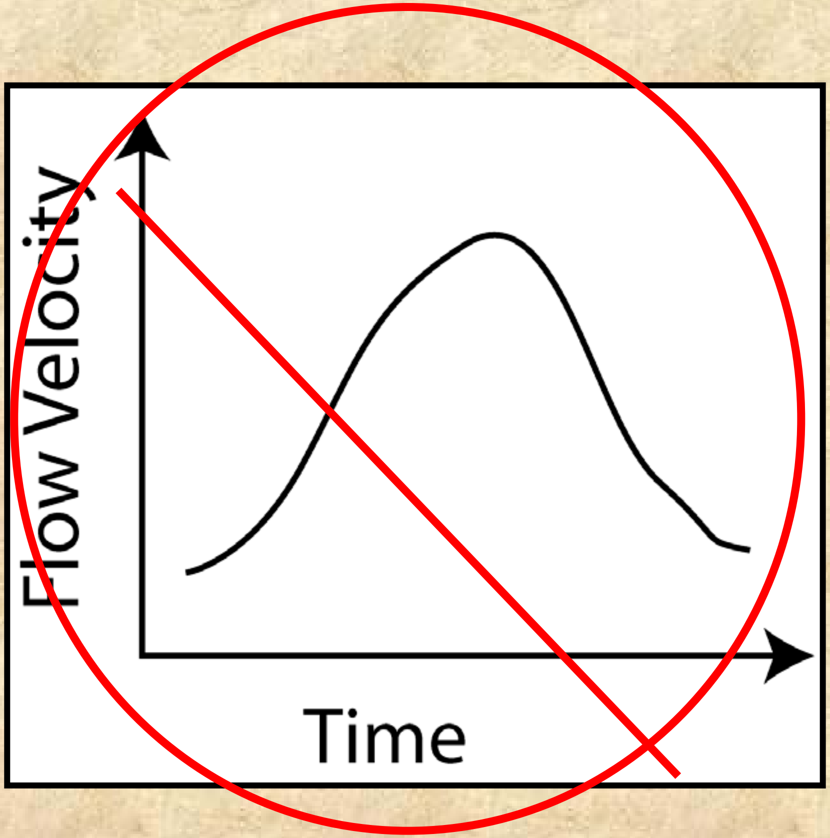
	q (m^2/s)	w_s (m/s)	l_a	Plunge point translation	
Laboratory	1 to 4 x 10^{-3}	4.4 x 10^{-4}	1.5 to 6 m	0.5 m	**Inlet conditions**
Field (silt)	5 to 20	4.4 x 10^{-4}	7.5 to 30 km	10s km	**Inlet conditions or local dynamics**
Field (sand)	5 to 20	9 x 10^{-3}	0.3 to 1.2 km	10s km	**Local dynamics**

Sand is likely to record plunge point dynamics (not river flood discharge) at field scale

Lamb et al., in press, GSAB

Conclusion 1: Flow Dynamics

Hyperpycnal plume *velocities* do not linearly follow the flood discharge curve.



Depth-limited and plunging zones: anticorrelations, uncorrelations, and multiple accelerations and decelerations are possible due to the movement of the plunge point.

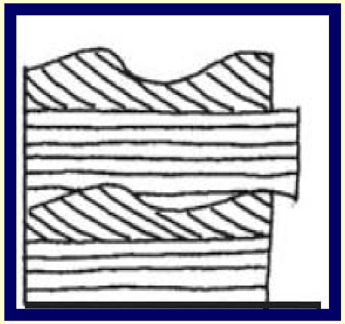
Conclusion 2: Depositional signature

Despite complex spatial changes in flow, plume deposits might still record inlet discharge and sediment concentration depending on the advection length scale.

Low discharges and coarse sediment:

$$l_a \rightarrow 0$$

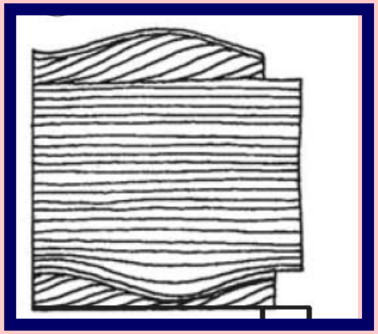
Deposits record local dynamics (plunge point translation – multiple pulses)



High discharges and fine sediment:

$$l_a \rightarrow \infty$$

Deposits record inlet conditions (fluvial discharge and sediment concentration)



Please email me for preprints

Michael Lamb

mpl@gps.caltech.edu

Assistant Professor

Geological and Planetary Sciences

California Institute of Technology