www.csiro.au

Turbidity current flow over an obstacle and phases of sediment wave generation

Michael E. Glinsky (CEO Science Leader)

Moshe Strauss (Nuclear Research Center, Israel)

CSIRO

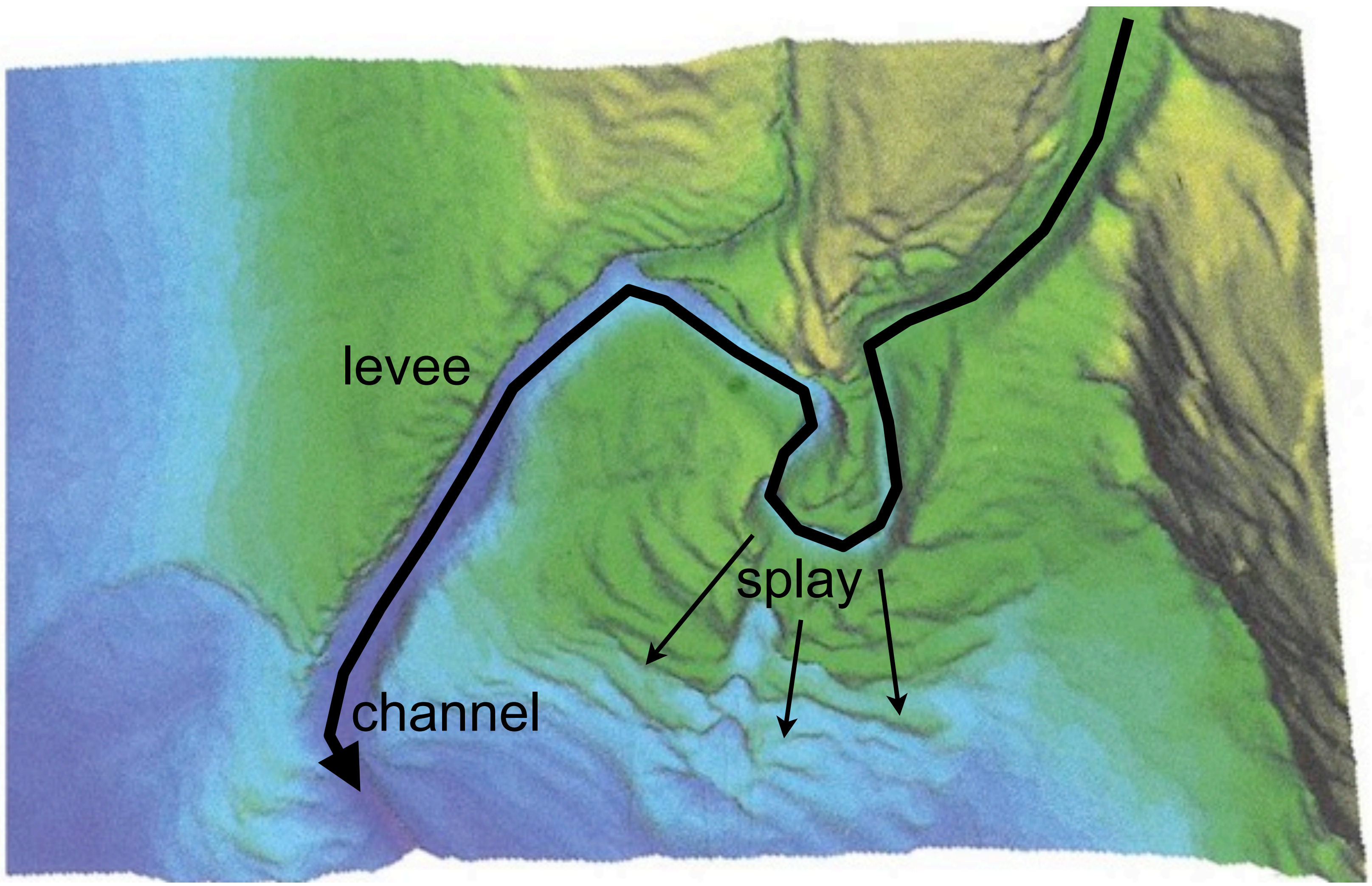
“Three Sisters” -- aboriginal womans’ place for doing business, near BHPB Yandi iron ore mine

Roadmap

- description of the system & computations
- what is a physical phase and phase diagram (example of water)
- self sustainment of single flow, single grain
  - two phases of flow and phase diagram
- sediment wave formation with multiple flows
  - three phases of erosion/deposition
  - relationship to self sustainment
  - wavelength
- structure of deposited substrate (geologic facies)
- conclusion
  - it’s the physics
  - self sustainment ==> phases of SW ==> geologic facies
  - one-to-one correspondence between geologic facies and phases of physical self organization of system

A real example of a sediment wave

Monterey Channel, offshore California USA



breached channel levee (splay)

Parts of the computer simulation

Simulation of the fluid + suspended grains

Interaction between the fluid and the bottom

Keeping track of what is deposited on or eroded from the bottom

Simulation of the fluid and suspended grains

mass continuity equations for each grain size

$$\frac{\partial c_i}{\partial t} + \left(\vec{u} + u_{si}\hat{g}\right) \bullet \nabla c_i = \frac{1}{S_c R_e} \nabla^2 c_i$$

settling velocity particle diffusion

momentum continuity equation, ma=F

$$\frac{\partial \vec{u}}{\partial t} + \left(\vec{u} \bullet \nabla\right)\vec{u} = -\nabla p + \frac{1}{R_e} \nabla^2 \vec{u} + c\hat{g}$$

pressure force viscous drag force gravity force

incompressibility, EOS

$$\nabla \bullet \vec{u} = 0$$

x and y scaled by L_0 = 250 m

c scaled by c_0 = 0.8 %

u scaled by $u_b \equiv \sqrt{g R_* L_0 c_0}$ = 5.4 m/s

t scaled by L_0 / u_b = 46 s

d_i scaled by $d_0 \equiv \sqrt[3]{\nu^2 / R_* g}$ = 41 μm

scale of particle dissipation

$$R_* \equiv \frac{\rho_g - \rho_f}{\rho_f}$$

$R_e \equiv u_b L_0 / \nu = \left(L_0 / d_e\right)^{3/2}$ = 10^9

$d_e \equiv \sqrt{\nu^2 / R_* c_0 g}$ = 200 μm

scale of fluid dissipation

$R_{pi} \equiv \left(d_i / d_0\right)^{3/2}$ = 42

$u_{si} = f(R_{pi})$

Simplified equations

eliminate pressure, set S_c=1 (particles transported as fluid) and write in terms of stream function and vorticity

$$\frac{\partial c_i}{\partial t} + \left(\vec{u} + u_{si}\hat{g}\right) \bullet \nabla c_i = \frac{1}{R_e}\nabla^2 c_i$$

$$\frac{\partial \omega}{\partial t} + \left(\vec{u} \bullet \nabla\right)\omega = \frac{1}{R_e}\nabla^2 \omega + \left(\hat{g} \times \nabla c\right)_z$$

where

$$\omega = -\nabla^2 \psi = F(\psi) \qquad \omega \equiv \left(\nabla \times \vec{u}\right)_z$$

$$\vec{u} \equiv \left(\hat{x}\frac{\partial}{\partial y} - \hat{y}\frac{\partial}{\partial x}\right)\psi = G(\psi)$$

only $\{c_i\}$ and ψ to solve for

parameters are: $\left(\{\overset{d_i}{\cancel{u}_{si}}\}, \overset{\theta_0}{\cancel{\hat{g}}}, \cancel{R_e}; \overset{HW = HL_0 \sim H}{\cancel{\psi}_0}\right) \rightarrow (d, \theta_0, H)$

Resuspension brings initial concentration back into problem

Garcia and Parker resuspension model

$$J_i = u_{si}(\hat{g}_y c - \varepsilon_{si})$$

settling resuspension

$$\varepsilon_{si} = \frac{a}{c_0}\frac{z_i^5}{1+\frac{a}{0.3}z_i^5}$$

explicit dependance on c_0

$$z_i \equiv \alpha_1 \frac{u_*}{u_{si}} R_{pi}^{\alpha_2} = f(u_*, R_{pi})$$

$$u_* = \sqrt{\frac{1}{R_e}\frac{\partial u_x}{\partial y}}$$

limit to

$$u_* = \sqrt{\frac{\omega_b}{f_{\mathrm{shr}} R_e}}$$

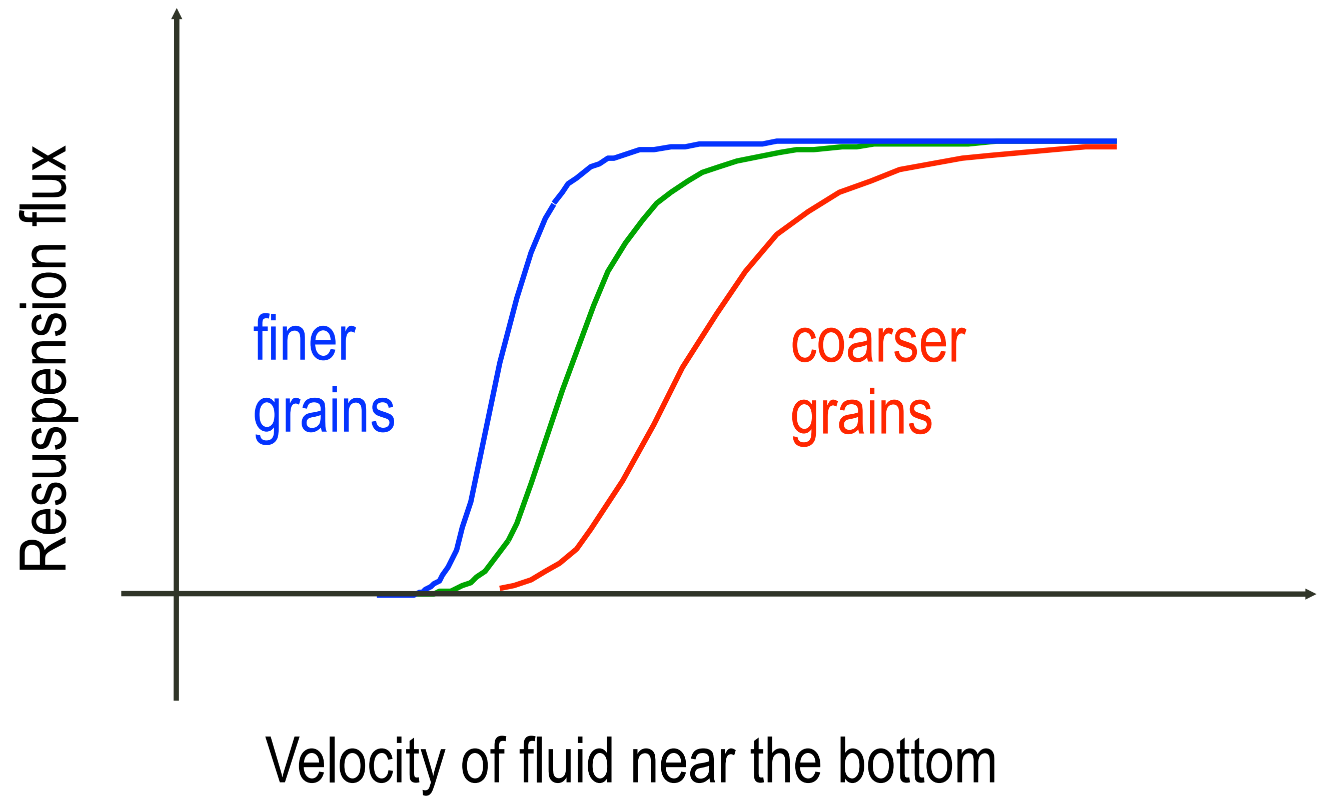
turbulent closure

since R_e simulated is 10^3 instead of real value of 10^9

parameters are: (d, θ_0, H, c_0)

Interaction between the fluid and the bottom

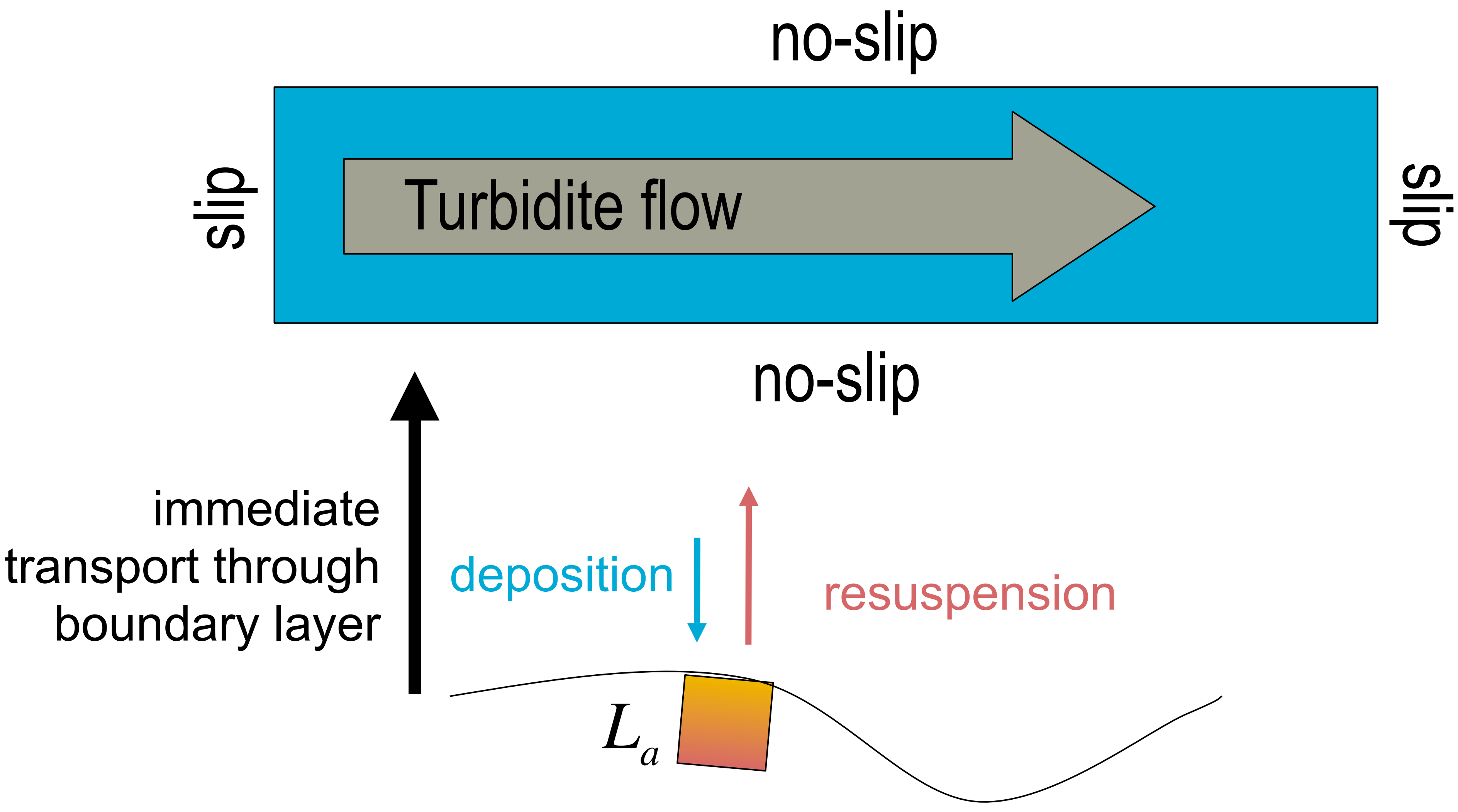
Resuspension of grains from the bottom is described using Garcia-Parker empirical relationships



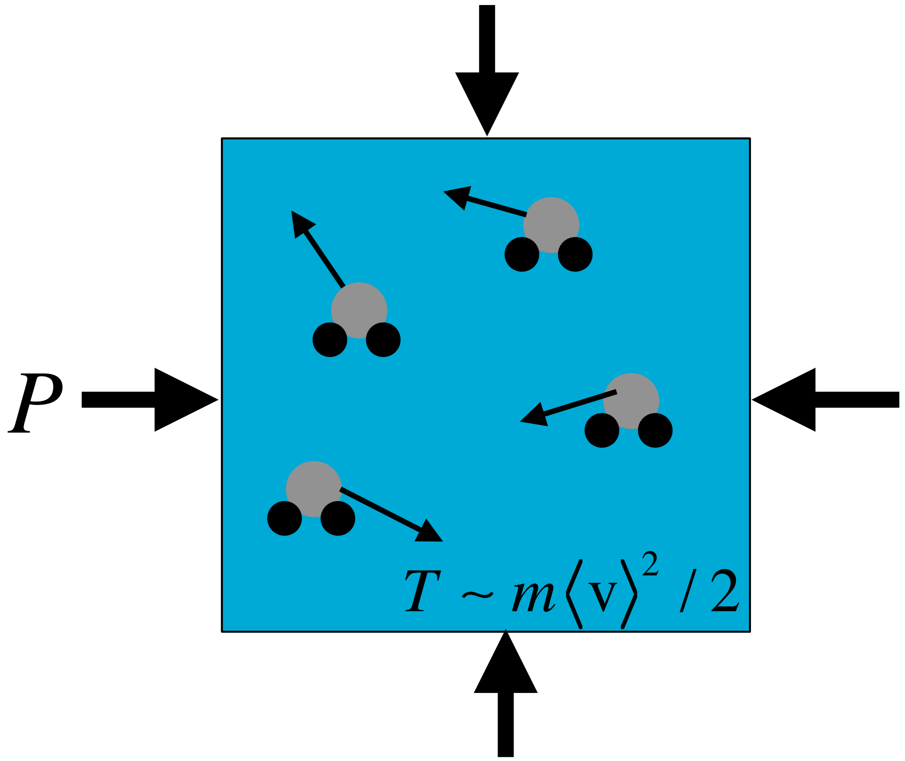
For grains of different sizes

$$\text{deposition} = \text{settling velocity} \times \text{concentration}$$

Boundary conditions on the fluid



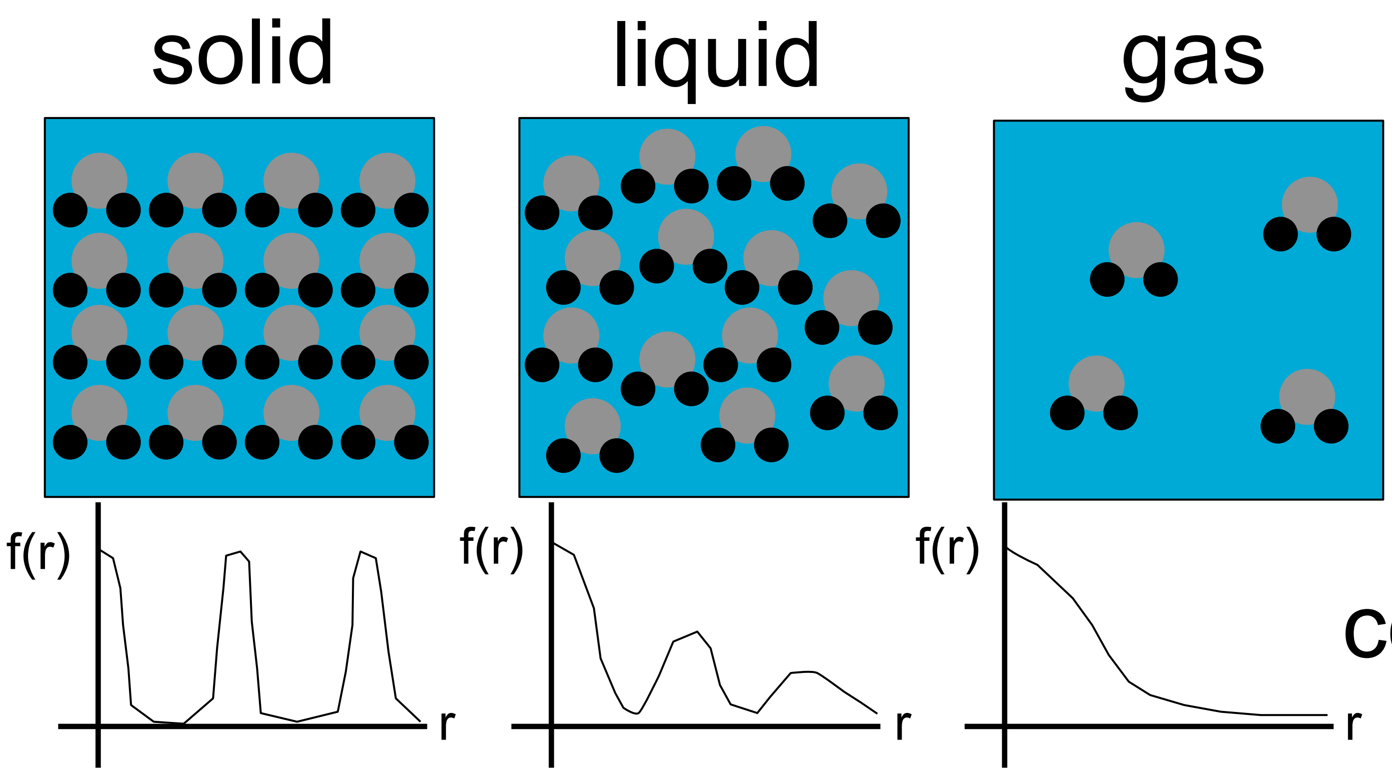
Phases of water



system parameters:

(a) temperature, T

(b) pressure, P



phases:

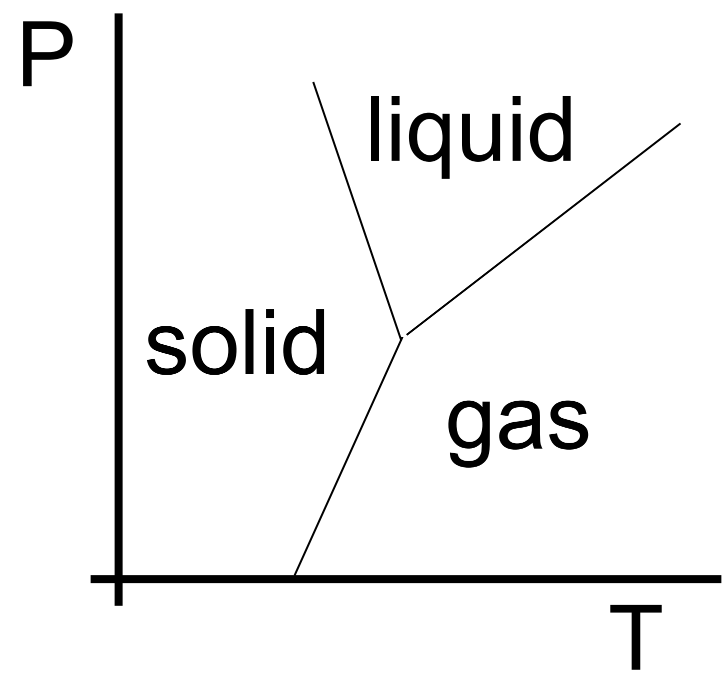
(a) solid

(b) liquid

(c) gas

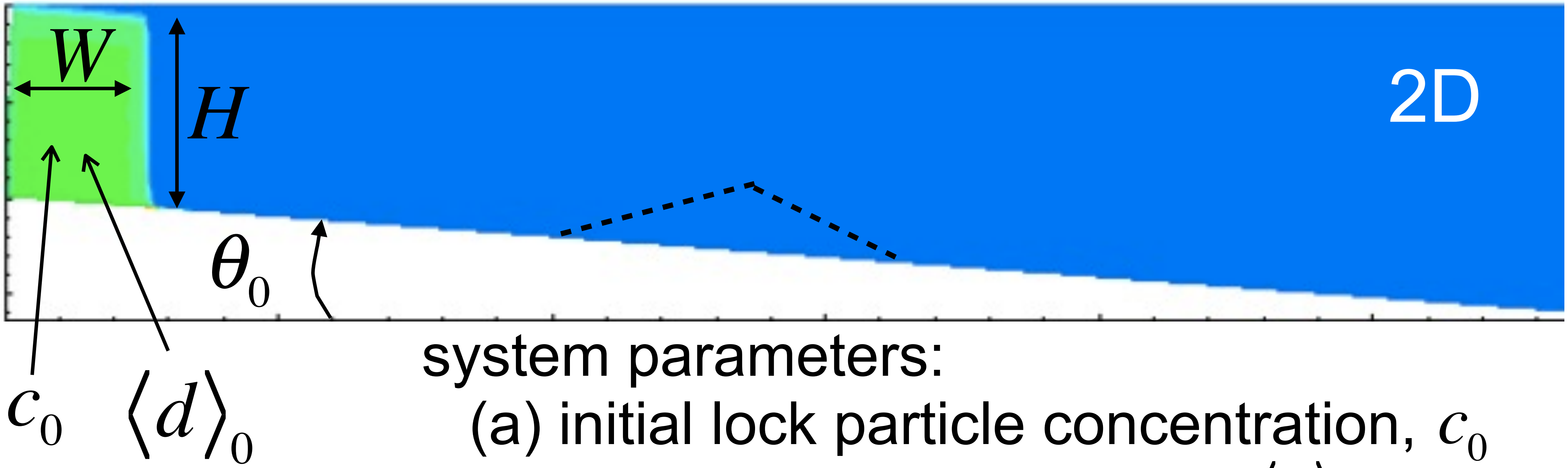
correlation properties

Phase diagram of water



phase is determined by the value of the system parameters, system parameter space is divided into regions for each phase

What are the phases of turbidite deposition in a channel



system parameters:

(a) initial lock particle concentration, c_0

(b) average particle diameter, $\langle d \rangle_0$

(c) slope angle, θ_0

(d) current size, $HW \sim H$

(e) initial aspect ratio, H/W (insensitive)

What are the phases of:

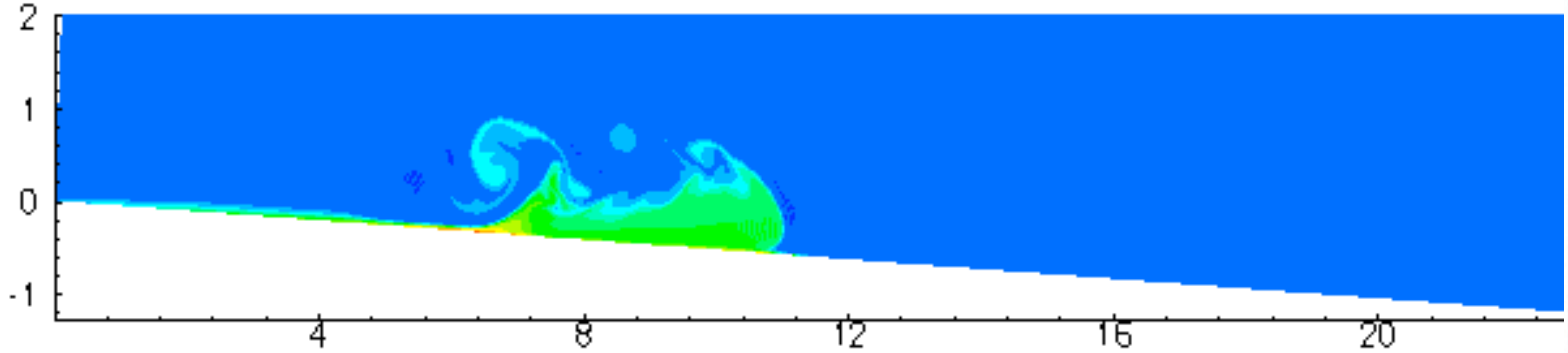
(a) single flow ?

(b) multiple flow substrate surface ?

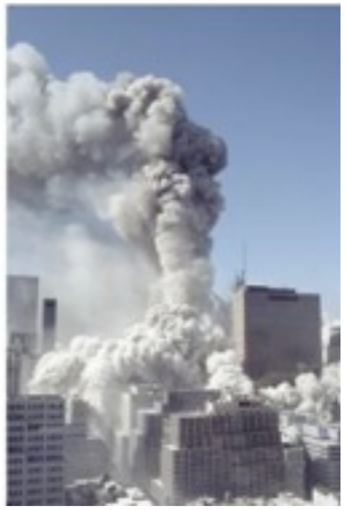
(c) multiple flow deposited substrate ?

Two phases of single flow

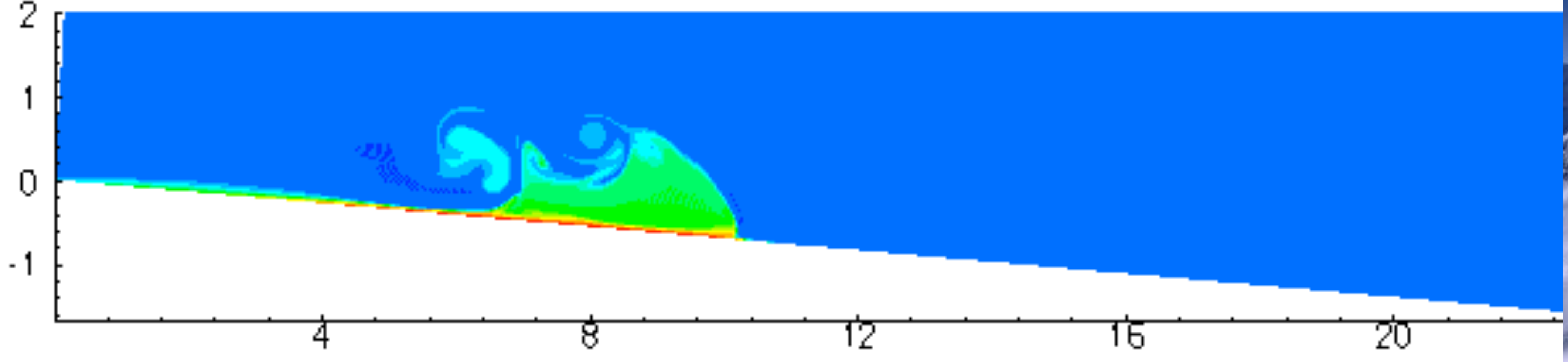
slope = 3 degrees, deposition outweighs erosion,
decaying turbidity current (“depositing” phase)



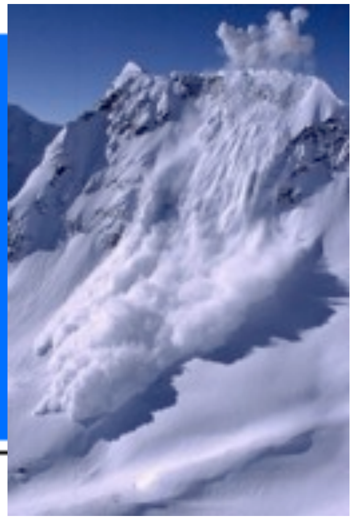
collapsing building



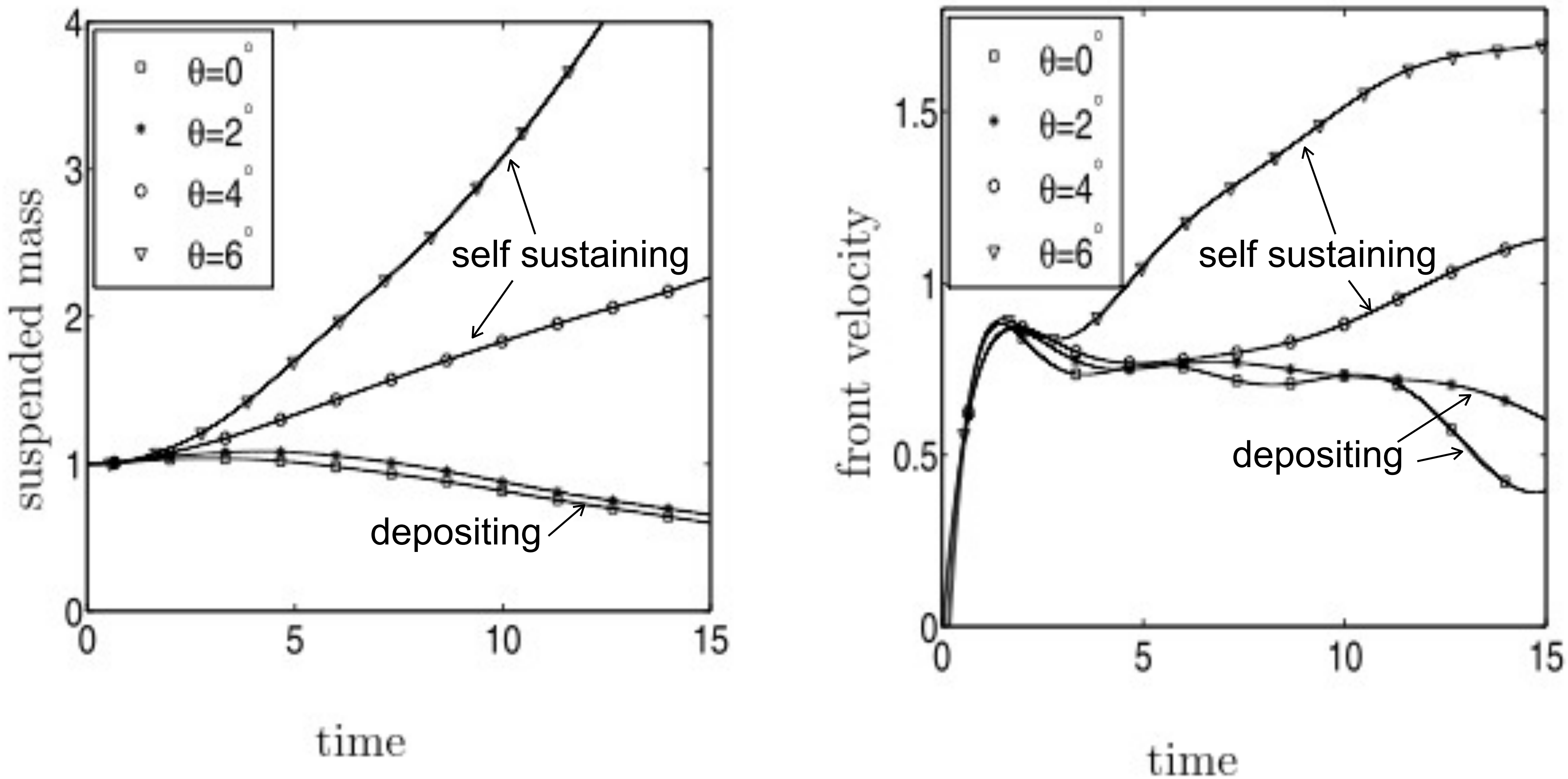
slope = 4 degrees, erosion outweighs deposition,
growing turbidity current (“self sustaining” phase)



avalanche



Closer look at evolution of single flow

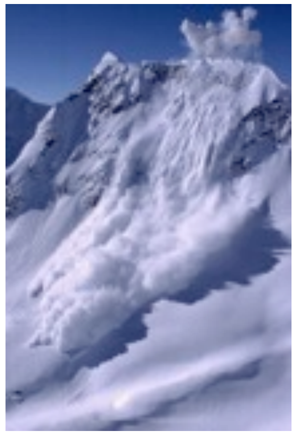


Characteristics of phases of single flow

depositing

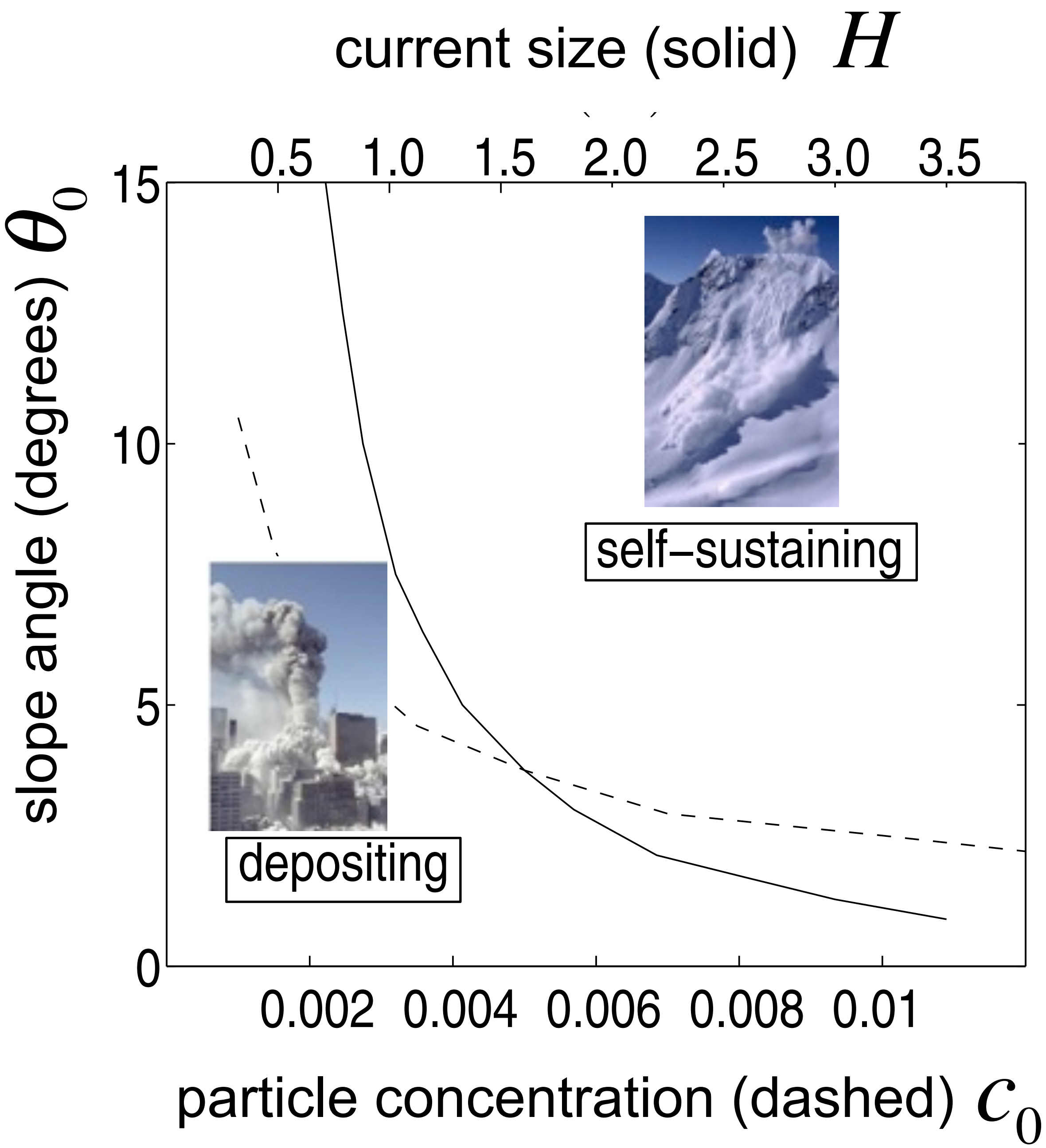
(a) monotonically decreasing mass to 0
(b) suppressed and decaying front velocity
(c) ill-defined head of current with un-elevated density

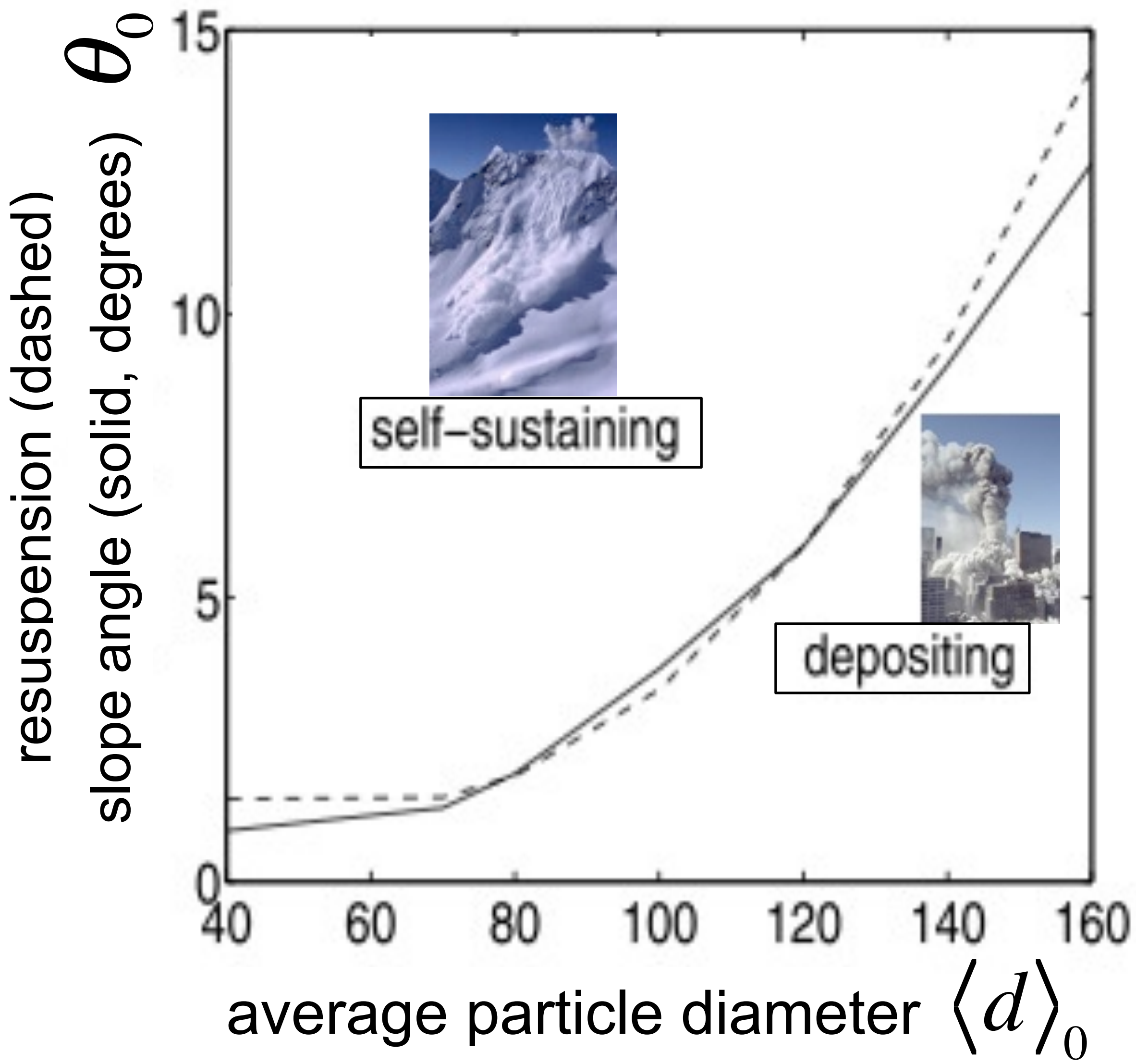
self sustaining



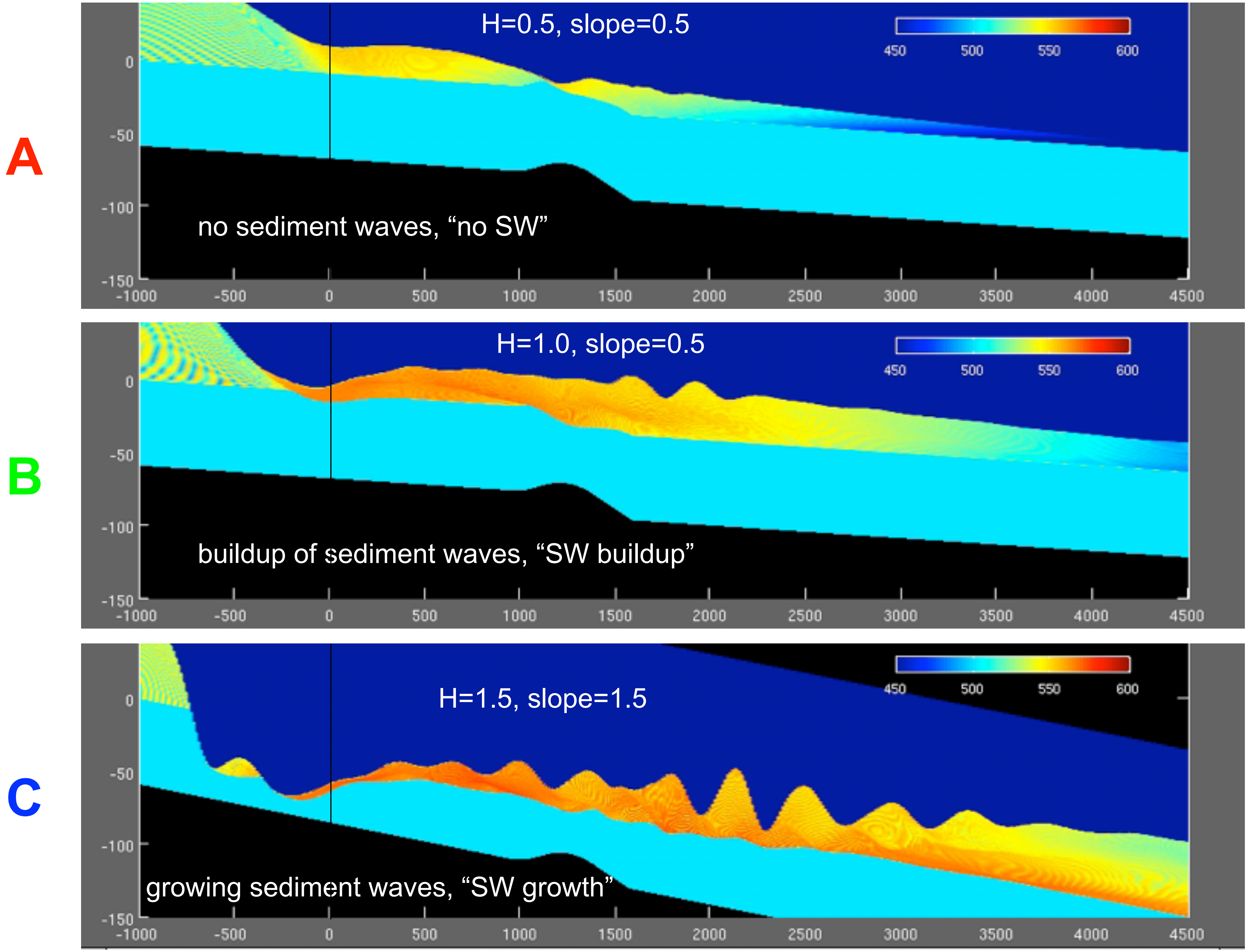
(a) exponentially increasing mass
(b) elevated front velocity, asymototing to constant
(c) well-defined head of current with elevated density

The phase diagram of single flow

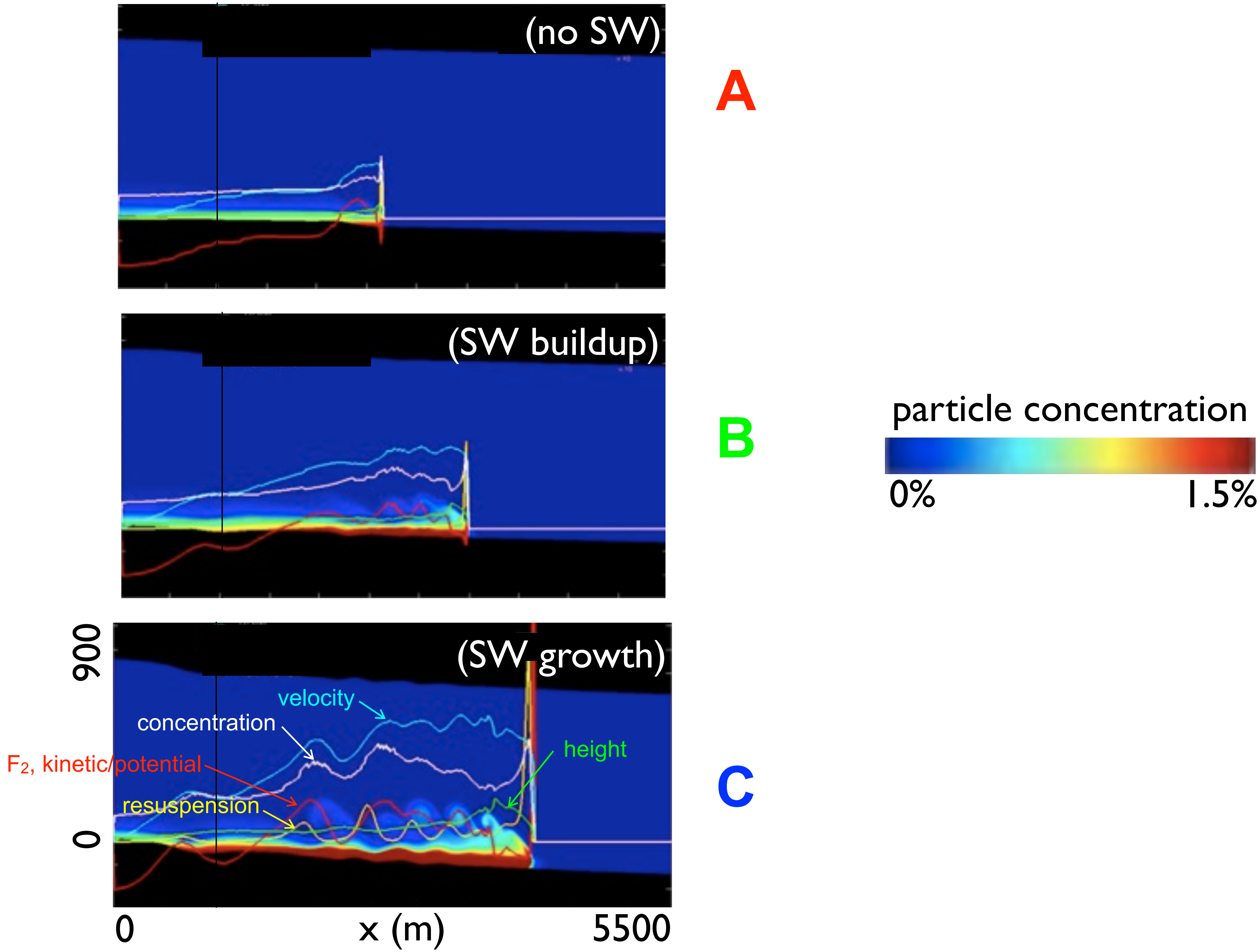




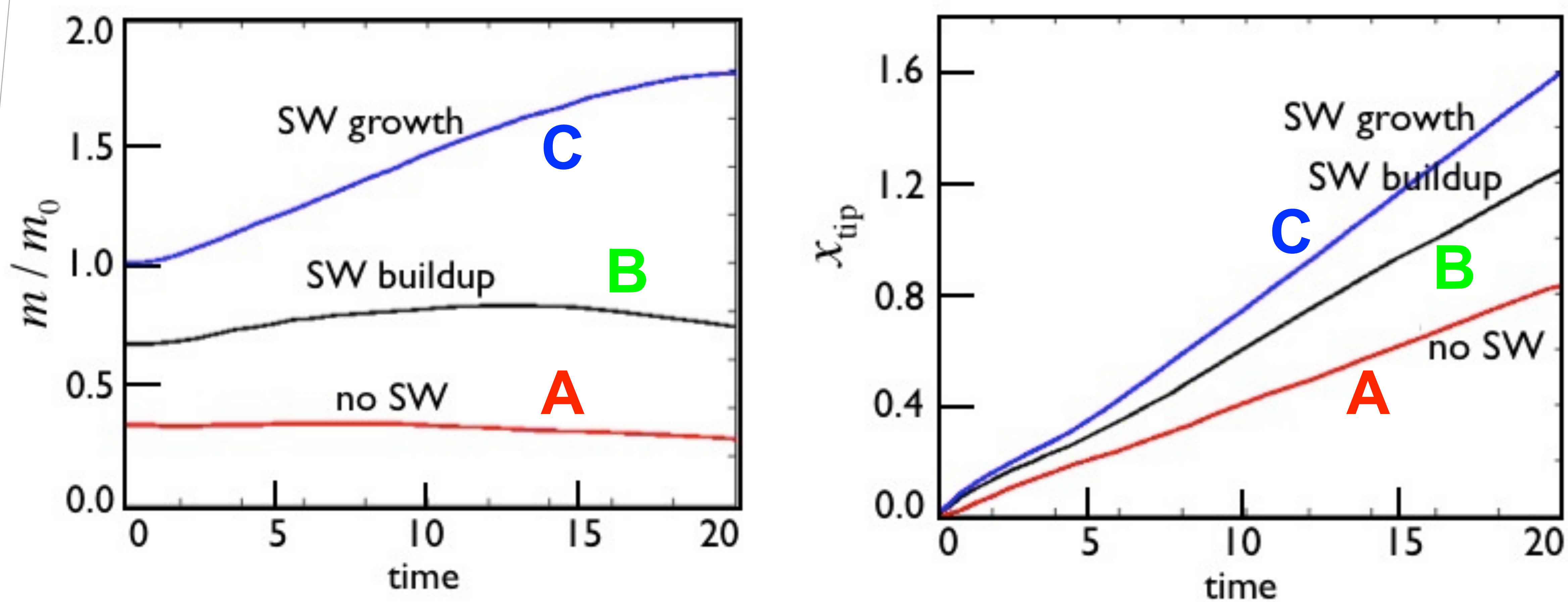
Three phases of multiple flow turbidite deposition



Closer look at evolution of turbidite deposition

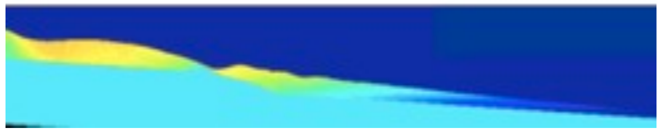


Closer look at evolution of turbidite deposition (continued)



Characteristics of multiple flow turbidite deposition

no SW



slope never unstable to SW growth

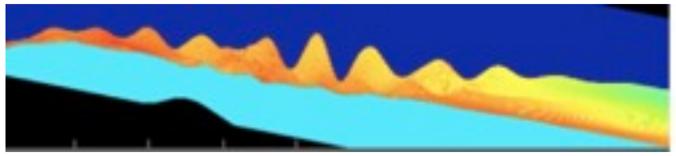
(a) no development of SW
(b) no periodic structures in flow
(c) monotonically decreasing mass
(d) no significant erosion
(e) suppressed front velocity
(f) no evidence of individual flows in bedding
(g) one massive bed fining downslope, coarsing from bottom to top

SW buildup

slope sometimes unstable to SW growth

(a) rapid local SW development to steady state profile
(b) periodic flow structure
(c) relatively constant mass with maximum
(d) no appreciable erosion
(e) reference front velocity
(f) little evidence of individual flows in bedding
(g) one massive bed fining downslope, oscillatory bottom to top structure

SW growth



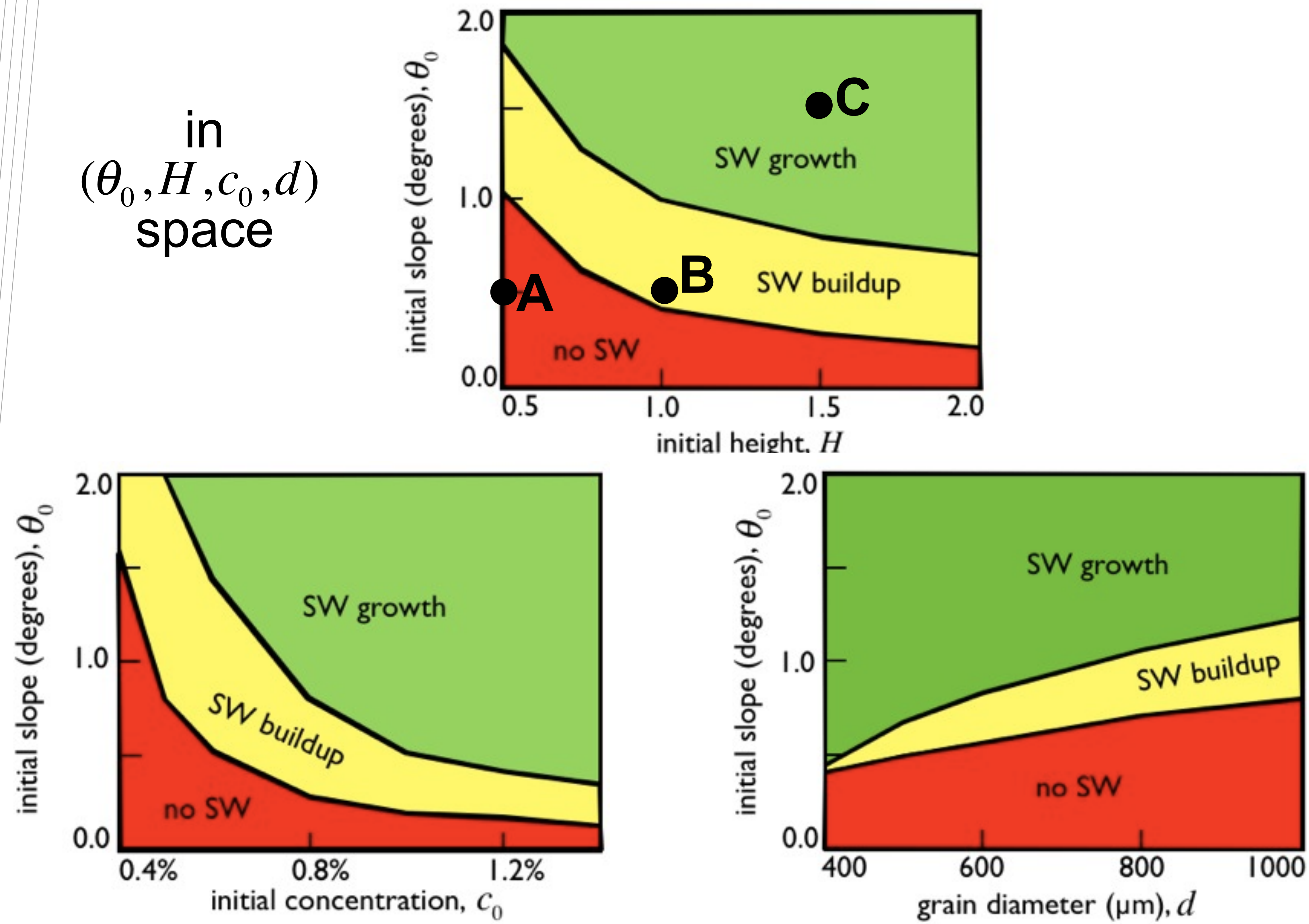
slope always unstable to SW growth

(a) initially exponential growth of global SW
(b) periodic flow & erosion structure
(c) monotonically increasing mass
(d) significant erosion, exponentially growing updip within flow
(e) enhanced front velocity
(f) evidence of individual flows in bedding
(g) complex bed structure

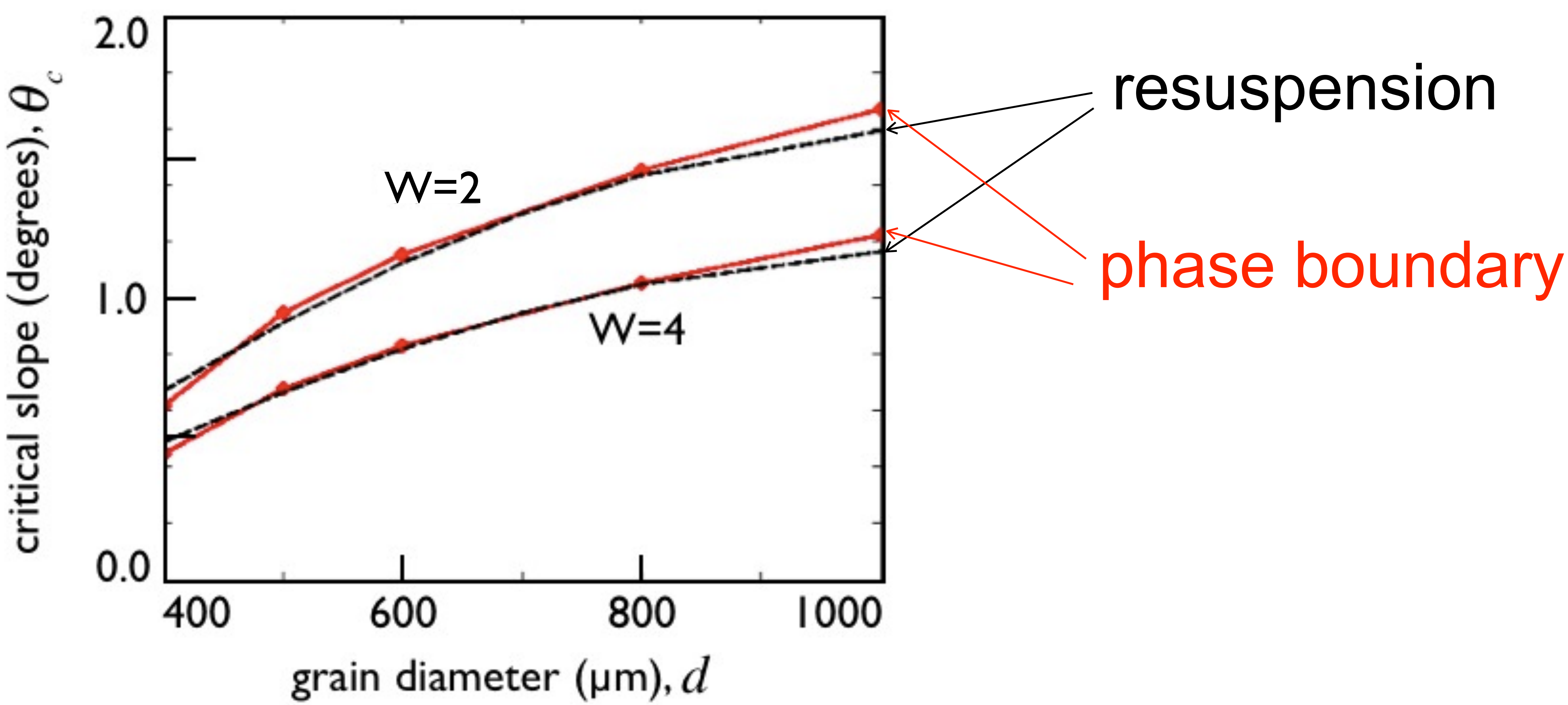
CSIRO

Phase diagram of multiple flow turbidite deposition

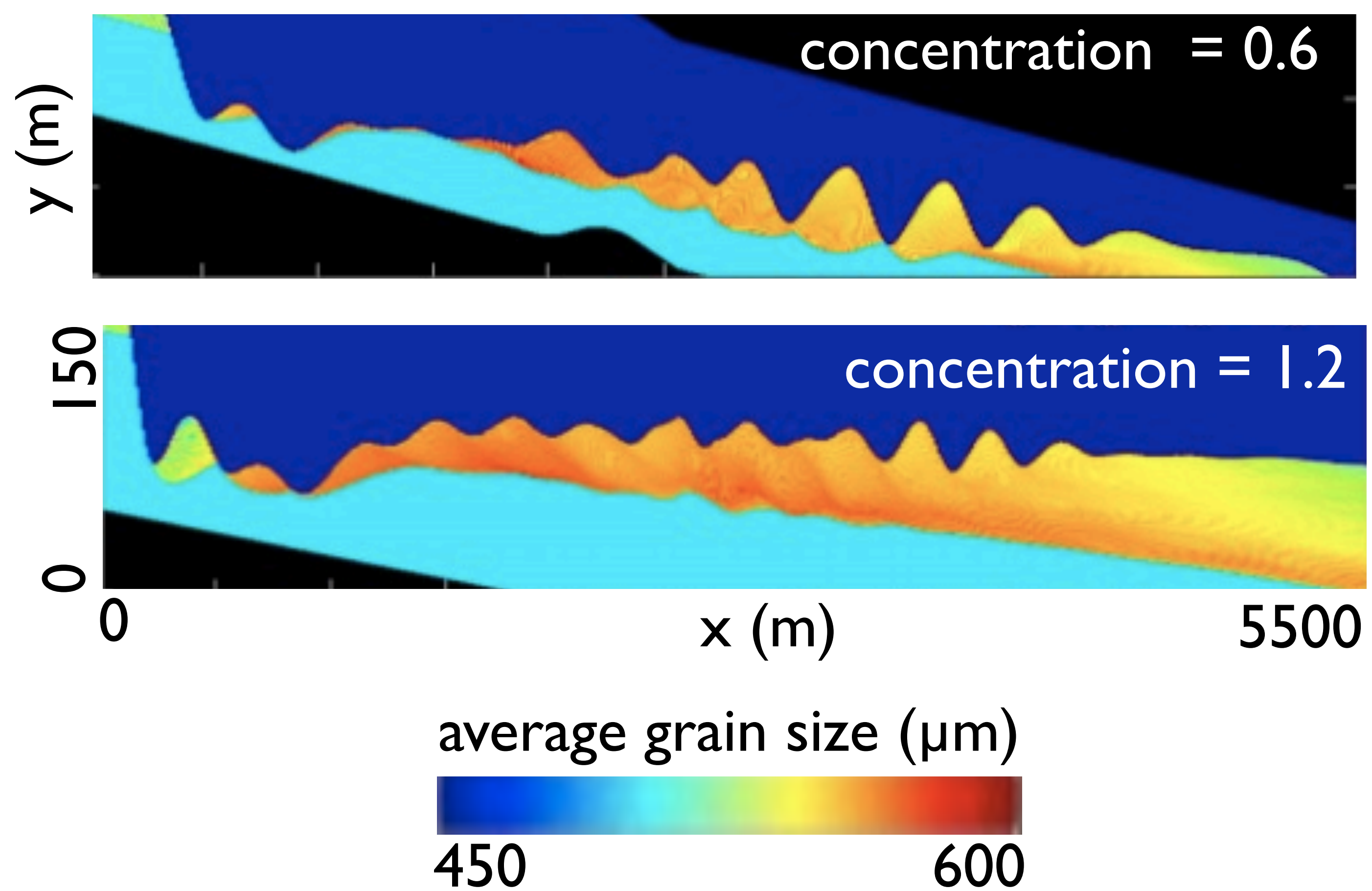
in
(θ_0, H, c_0, d)
space



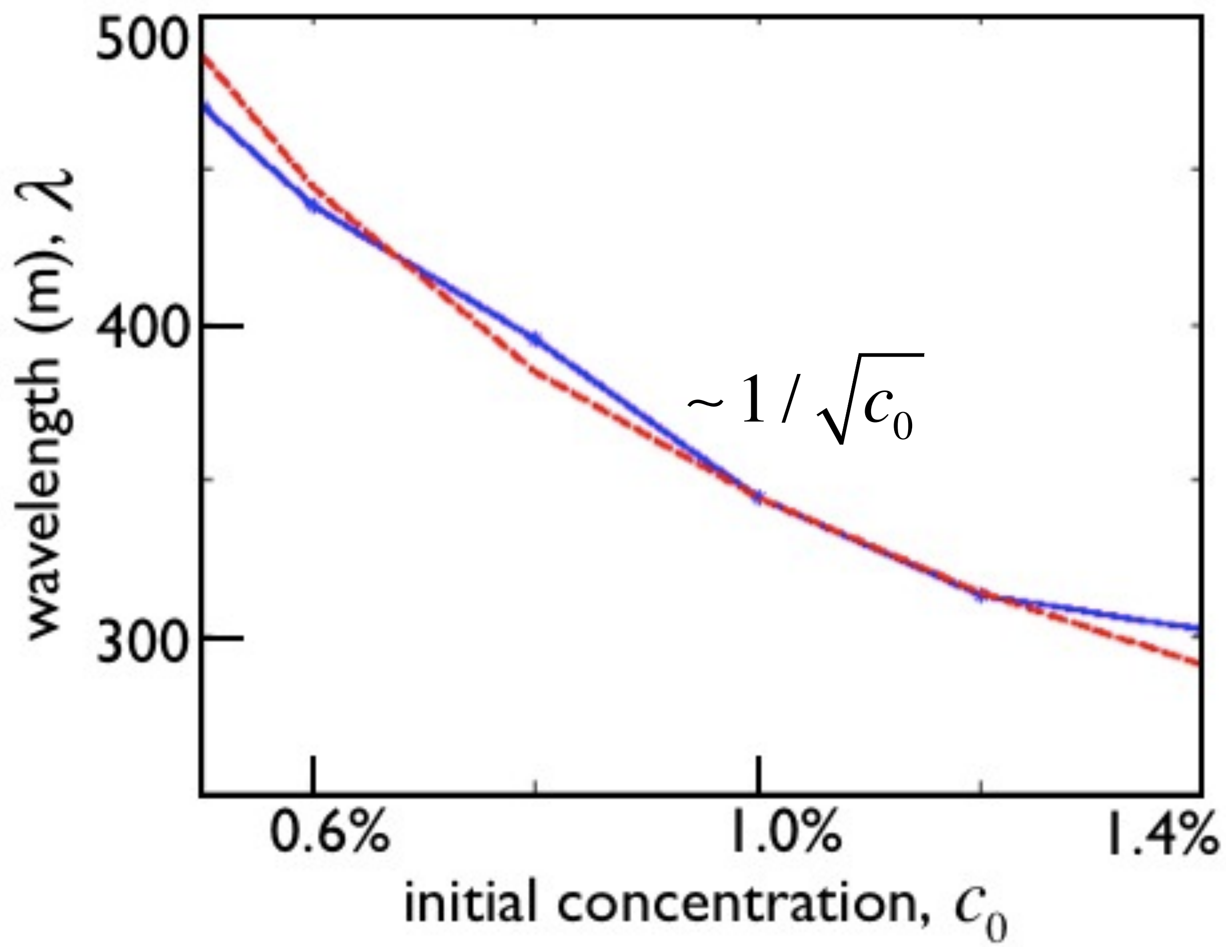
Resuspension is driving phase boundary as for single flow



Study of dependance of SW wavelength on particle concentration



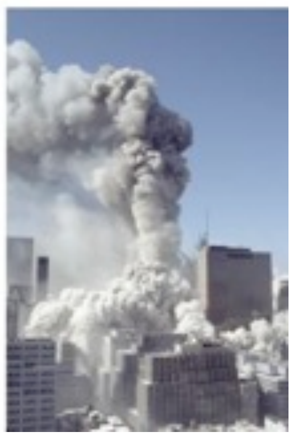
Dependance of particle concentration on wavelength



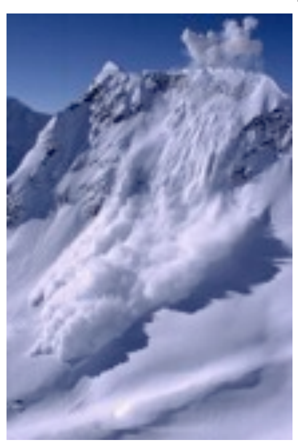
wavelength is insensitive to other parameters

Geologic facies are physical phases

single flow

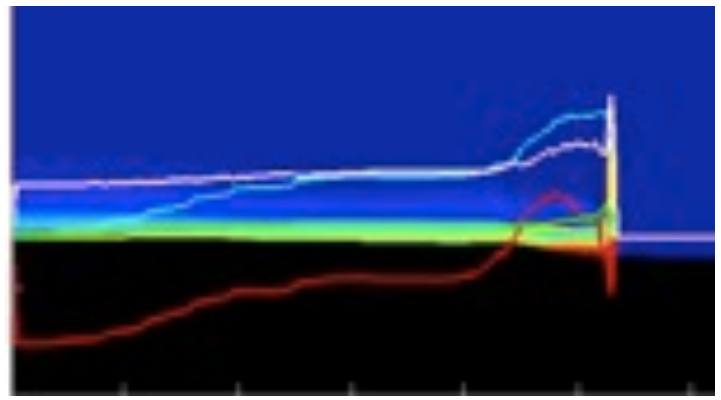


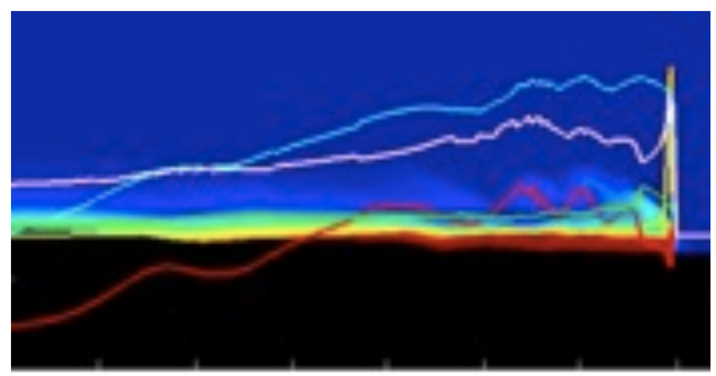
physics

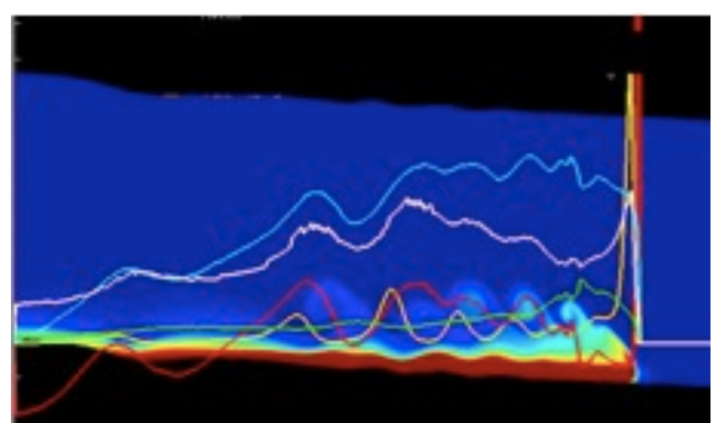


self sustainment

multiple flow
substrate surface

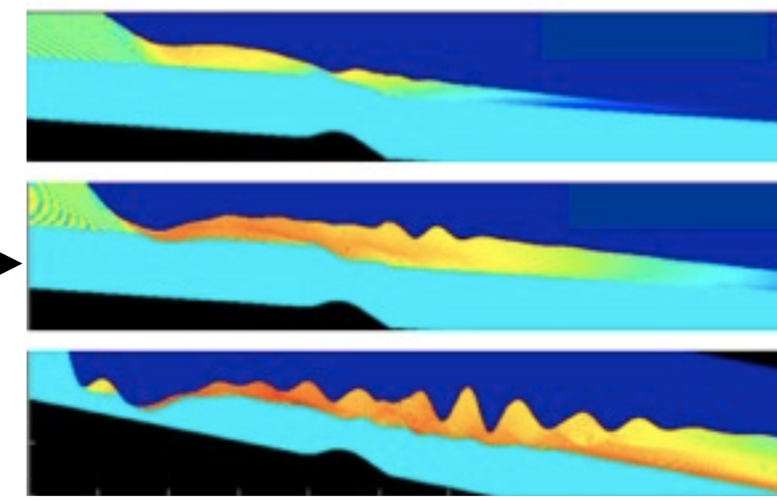






sediment wave phases

deposited substrate

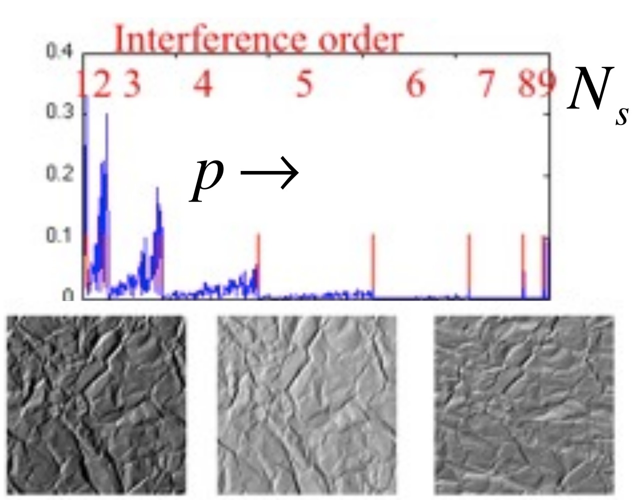


geologic facies !

The future: phases could be identified by new texture “attributes”

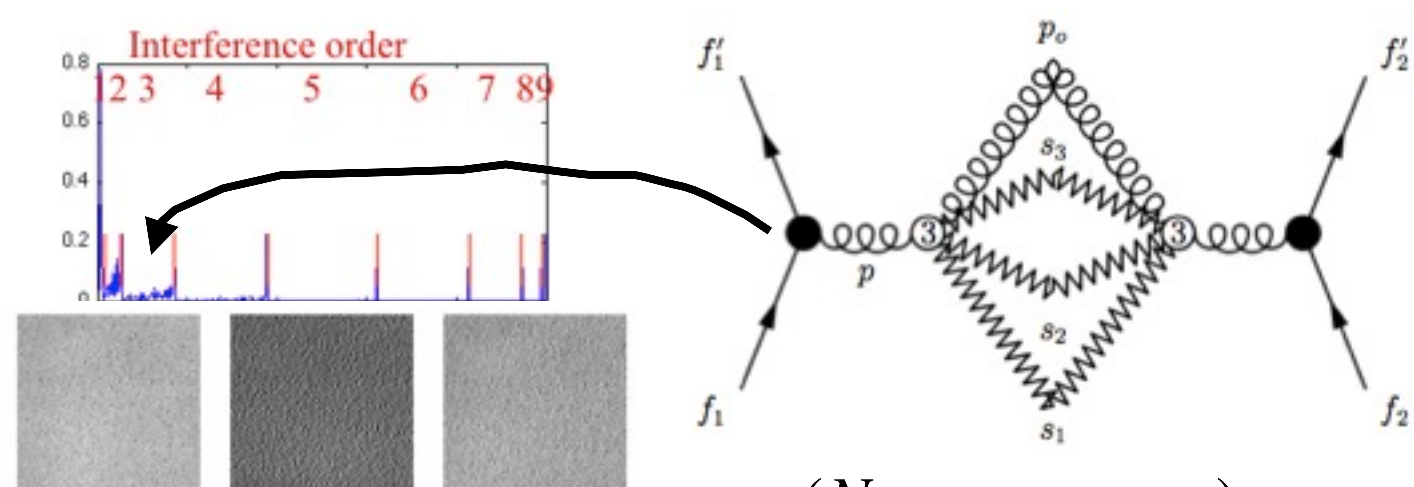
- path integral formulation of data assimilation
  - monte carlo
  - eliminate implicit time step
- fundamental coordinates of dynamics (related to fundamental excitations of physical system)
  - best coordinates to identify phase of self organisation, based on iterative wavelet transformation
  - data assimilation or synchronisation of “fundamental variables” leading to prediction of effective parameters of texture

unique fingerprint of texture



independent of chaotic “phase”

excitation of order 3



$$p = (N_s; s_1, s_2, \ldots, s_{N_s})$$

$$N_s = \text{order of exitation}$$

Conclusion

It's the physics

Geologic facies are physical phases