Bridging tectonic and surface processes with SNAC

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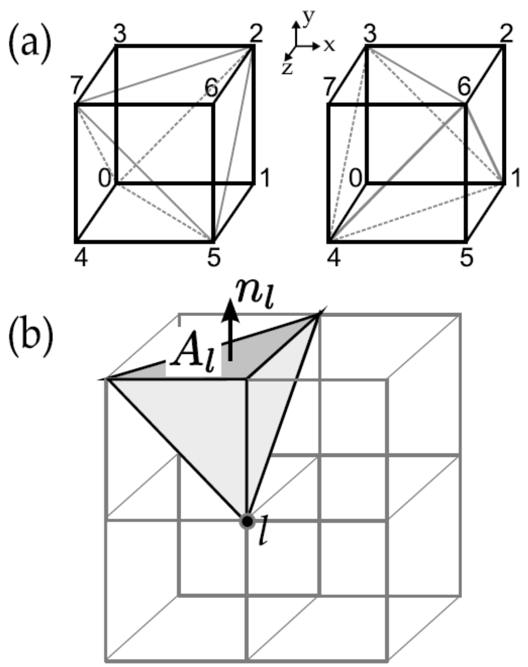
Outline

- Overview of SNAC
- Some examples of tectonic models with surface processes
  - Extensional environments.
- Future direction: Code coupling

SNAC: StGermaiN Analysis of Continua

- Principle of virtual power

$$0 = \int_\Omega \delta \boldsymbol{v} \left(\rho \frac{\partial \boldsymbol{v}}{\partial t} \right) d\Omega - \int_\Omega \nabla(\delta \boldsymbol{v}) : \boldsymbol{\sigma} d\Omega - \int_\Omega \delta \boldsymbol{v} \rho \boldsymbol{g} d\Omega$$



- Discretized momentum equation

$$M^l \frac{Dv_i^l}{Dt} = \frac{1}{3} T_i^{[l]} + \frac{1}{4} \rho^{[l]} g_i V^{[l]}$$

SNAC

- ***Explicit*** time integration
  - no need for non-linear iteration

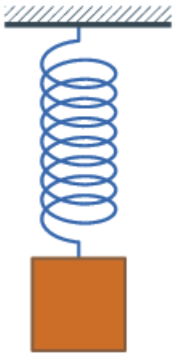
- **Lagrangian** description of motion

$$v_i^{(t+\Delta t/2)} = v_i^{(t-\Delta t/2)} + F_i^{(t)} \frac{\Delta t}{M}$$

$$x_i^{(t+\Delta t)} = x_i^{(t)} + v_i^{(t+\Delta t/2)} \Delta t$$

SNAC

- ***Dynamic relaxation*** for (quasi-)static solutions
  - Local damping



$$v_i^{(t+\Delta t/2)} = v_i^{(t-\Delta t/2)} + (F_i^{(t)} + F_d)\frac{\Delta t}{M}$$

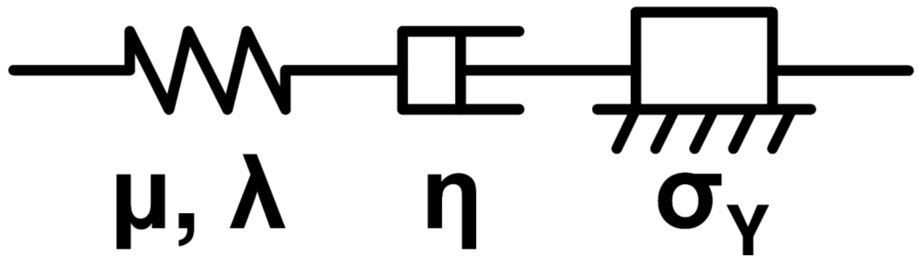
$$F_d = -\alpha |F_i^{(t)}| \mathrm{sgn}(v_i), \text{ where } 0 < \alpha < 1.$$

- ***Mass scaling*** for a large and stable Δt

$$\Delta t < \frac{\Delta x}{v_p} \qquad v_p = \sqrt{\frac{K}{m_s}} \qquad m_s \gg m_g = \int \rho \, dV$$

SNAC

- Constitutive model: elasto-visco-plastic

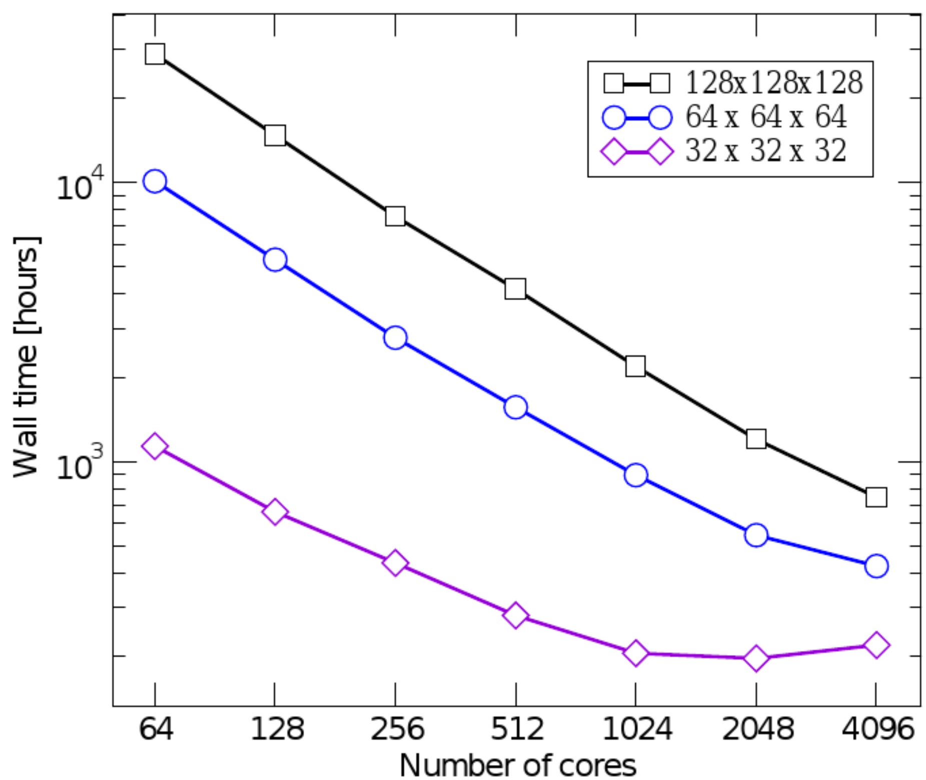


- $\eta \rightarrow \infty$: Mohr-Coulomb plasticity.
- $\sigma_Y \rightarrow \infty$: Maxwell viscoelasticity.
- $\eta = \eta(T, \sigma)$: temperature-determined brittle-ductile transition
- $\sigma_Y = \sigma_Y(\varepsilon^*)$: strain hardening/softening

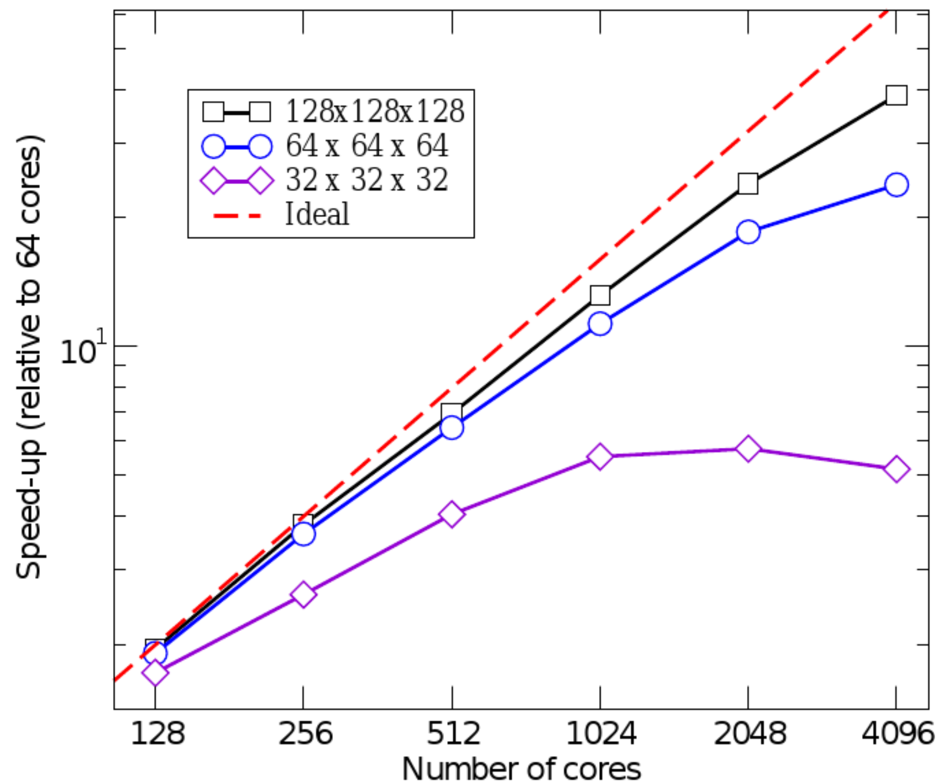
SNAC

- MPI-Parallelized

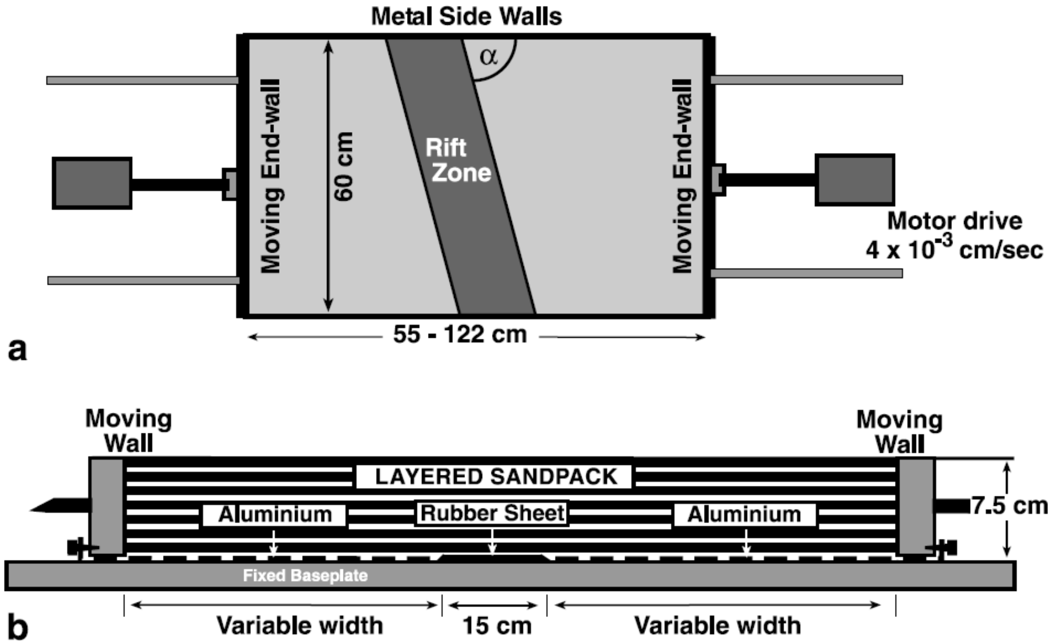
Wall clock time

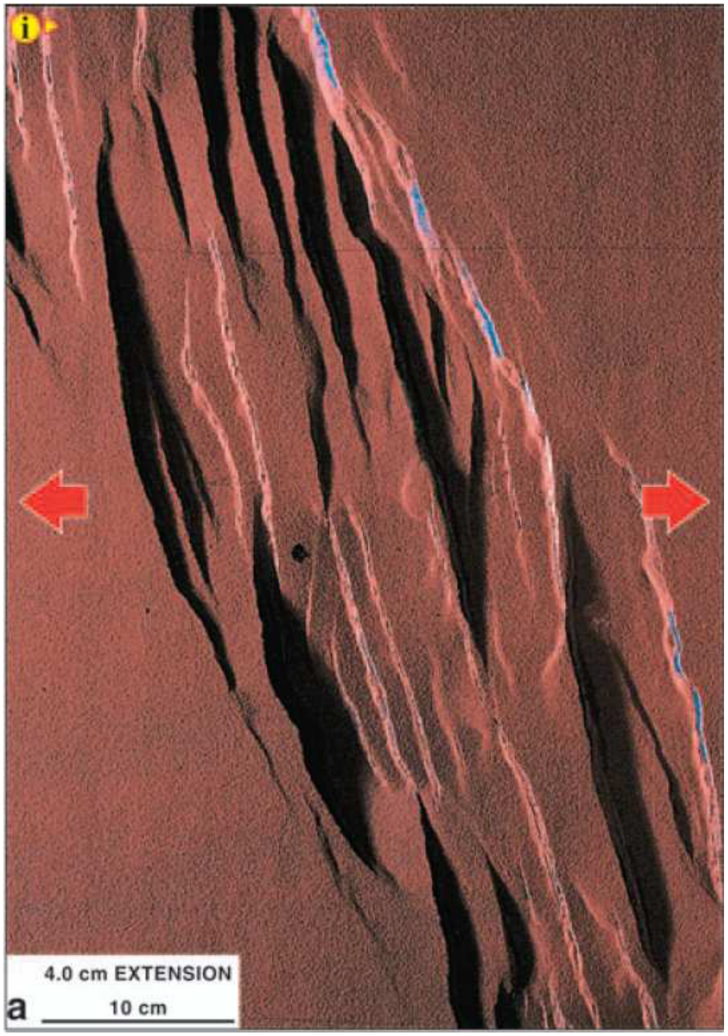


Speed-up



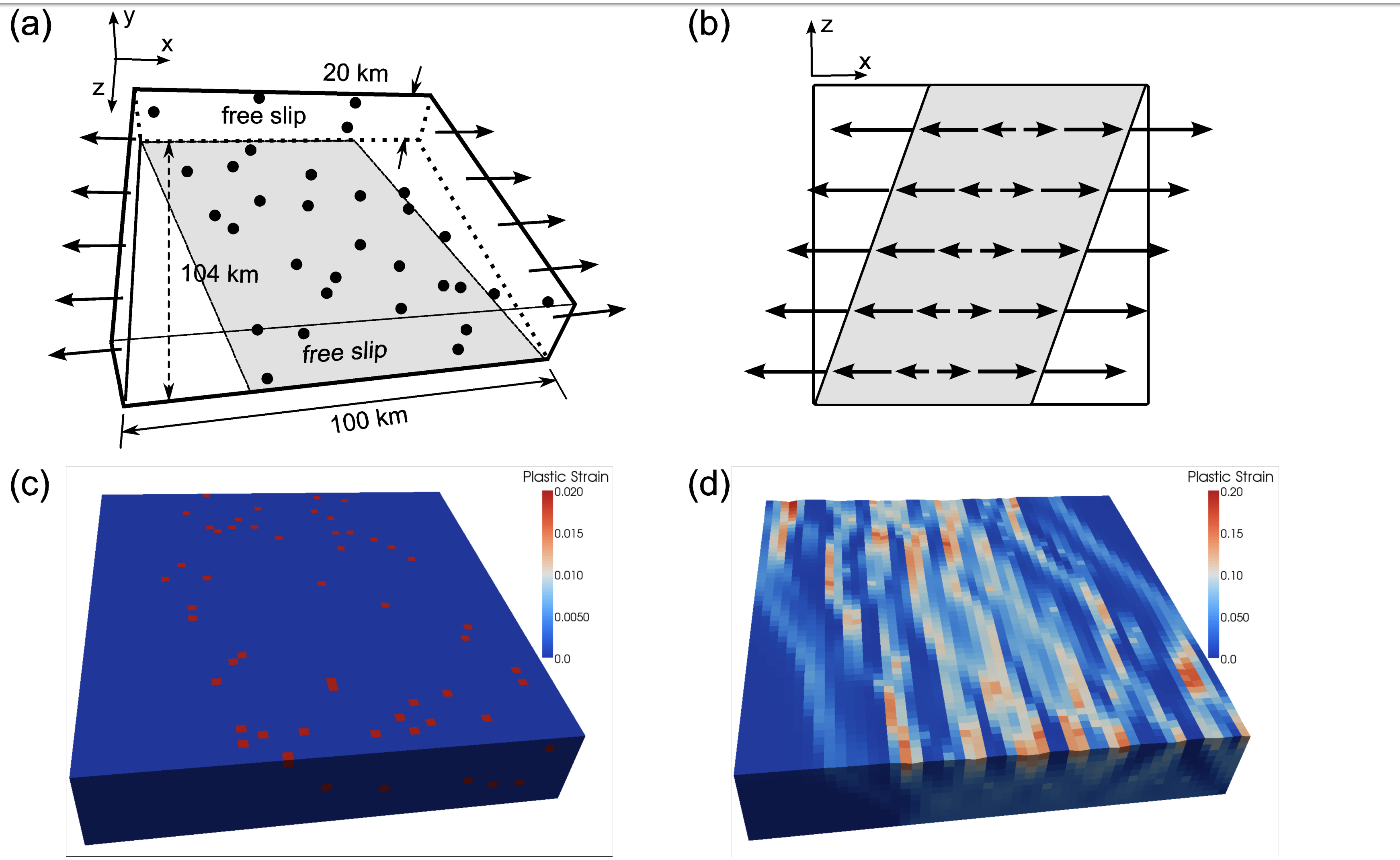
SNAC





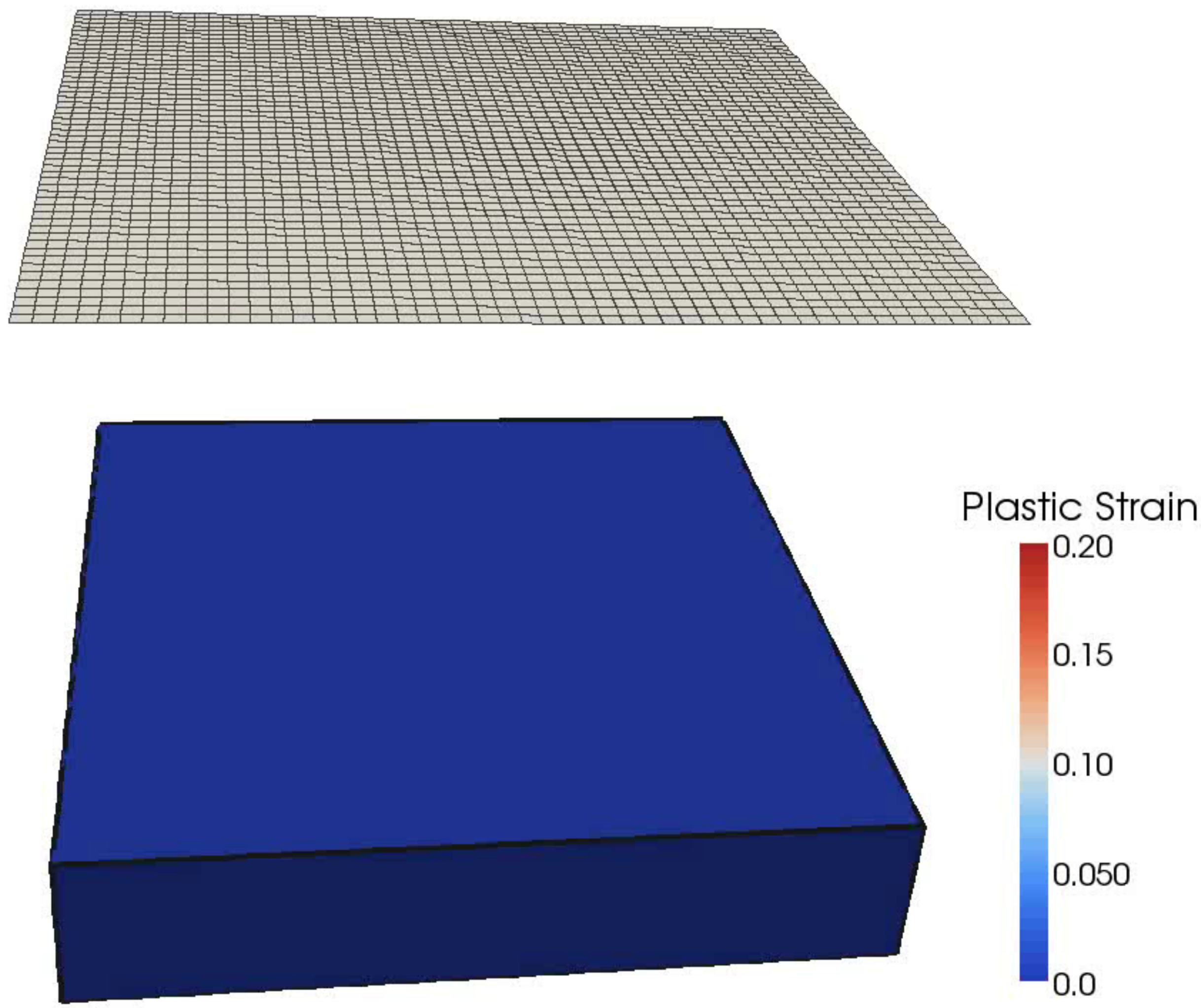
(McClay et al., 2002, AAPG Bulletin)

SNAC

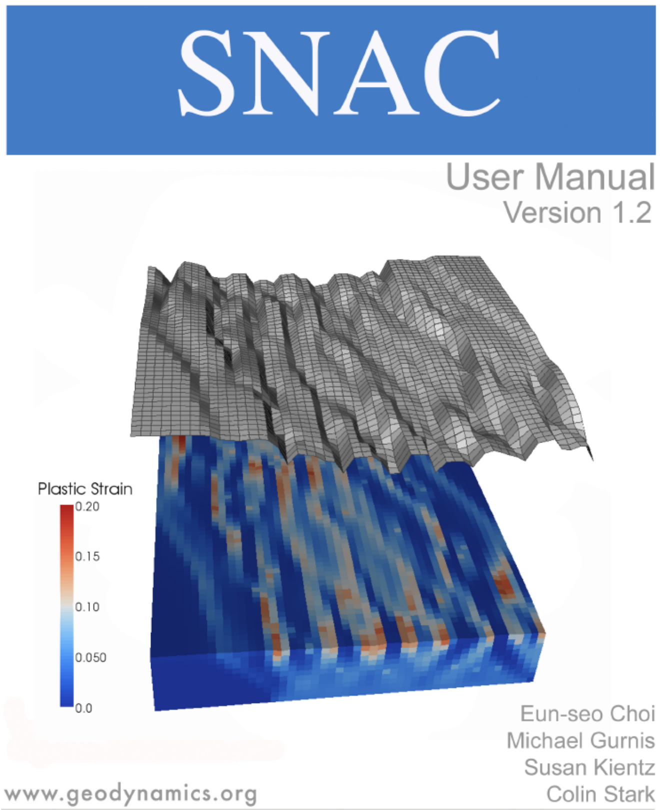


(a)
y
x
z
20 km
free slip
104 km
free slip
100 km
(b)
z
x
(c)
Plastic Strain
0.020
0.015
0.010
0.0050
0.0
(d)
Plastic Strain
0.20
0.15
0.10
0.050
0.0

SNAC



SNAC



- 3D, parallel, Lagrangian, elasto-visco-plastic
- Benchmarked and decently documented
- Open source:

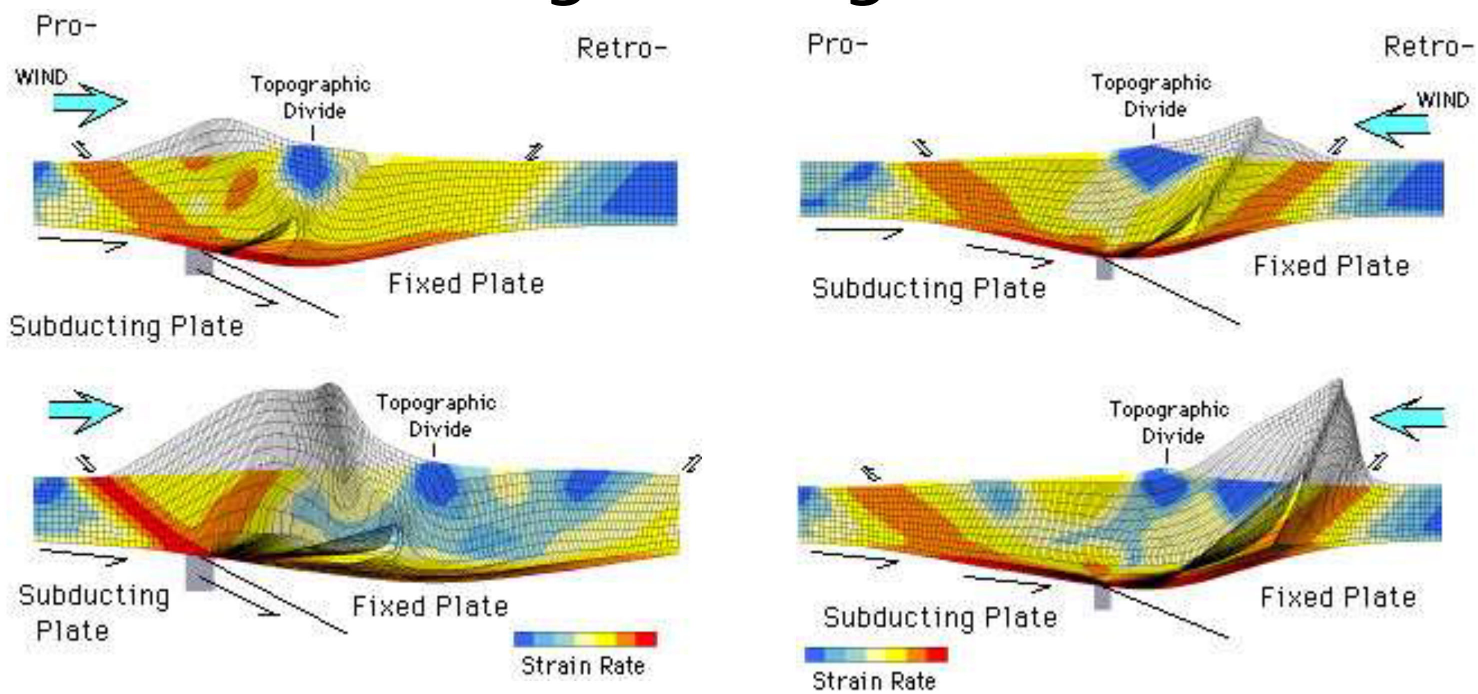
http://www.geodynamics.org/cig/software/snac

or

http://csdms.colorado.edu/wiki/Model:SNAC

Tectonic Modeling

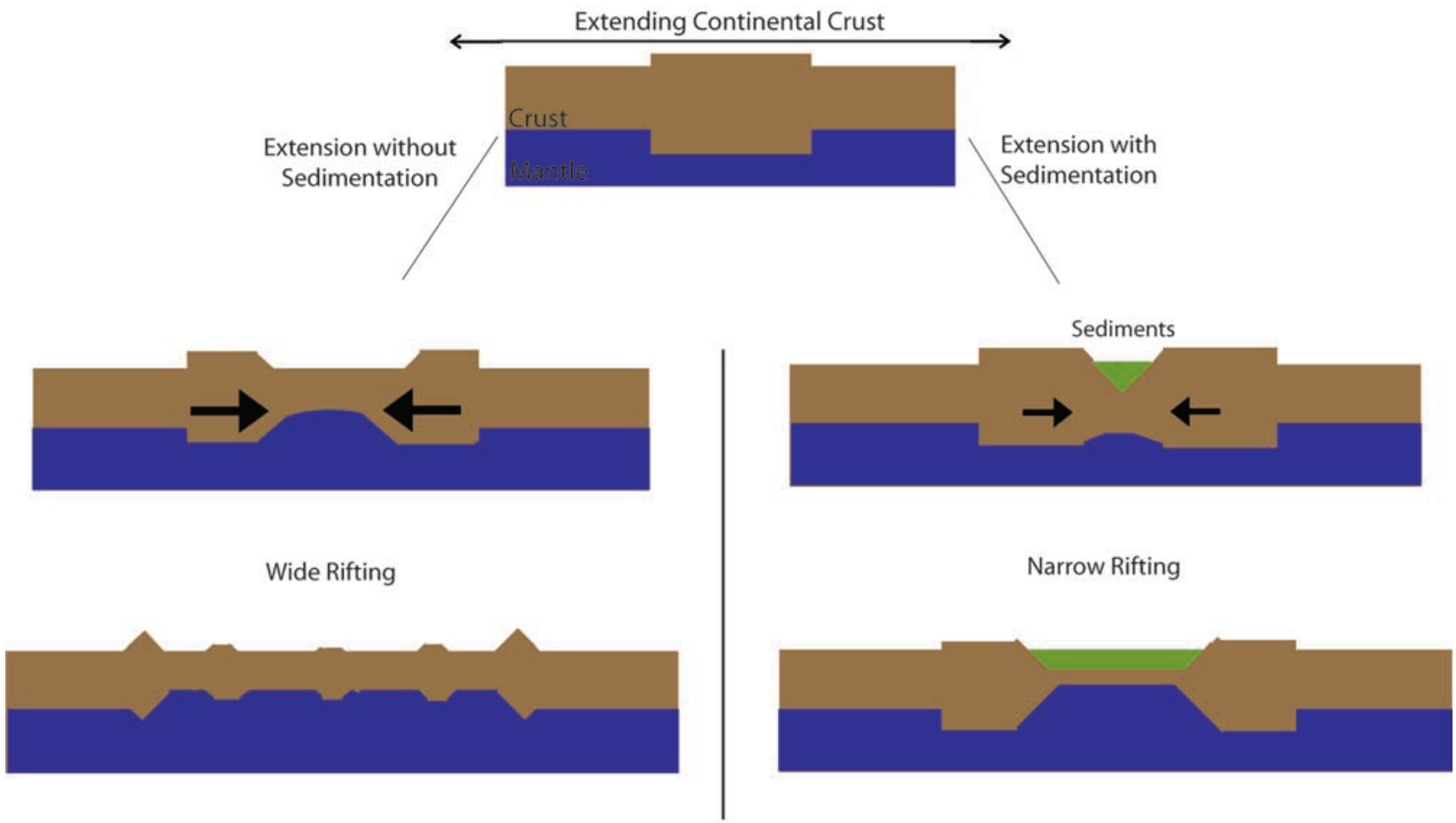
Erosion in a convergent orogen



(Willet, JGR, 1999)

Sedimentation in an extensional environment?

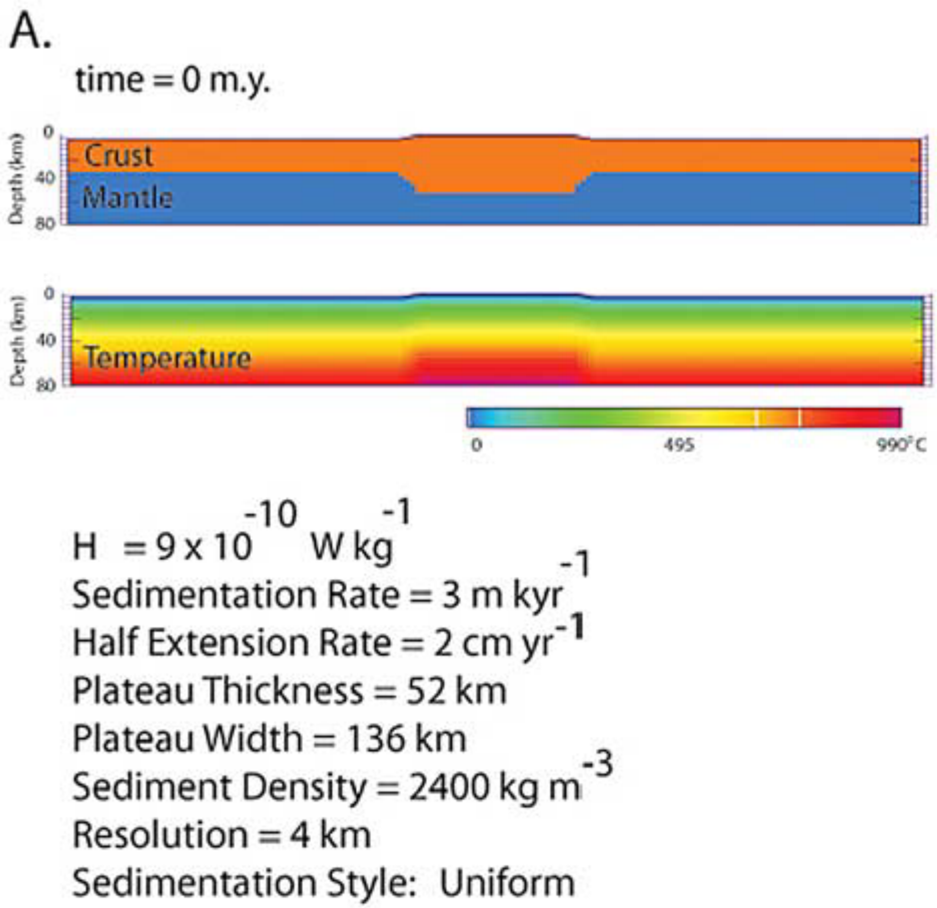
Tectonic Modeling: Rifting Style

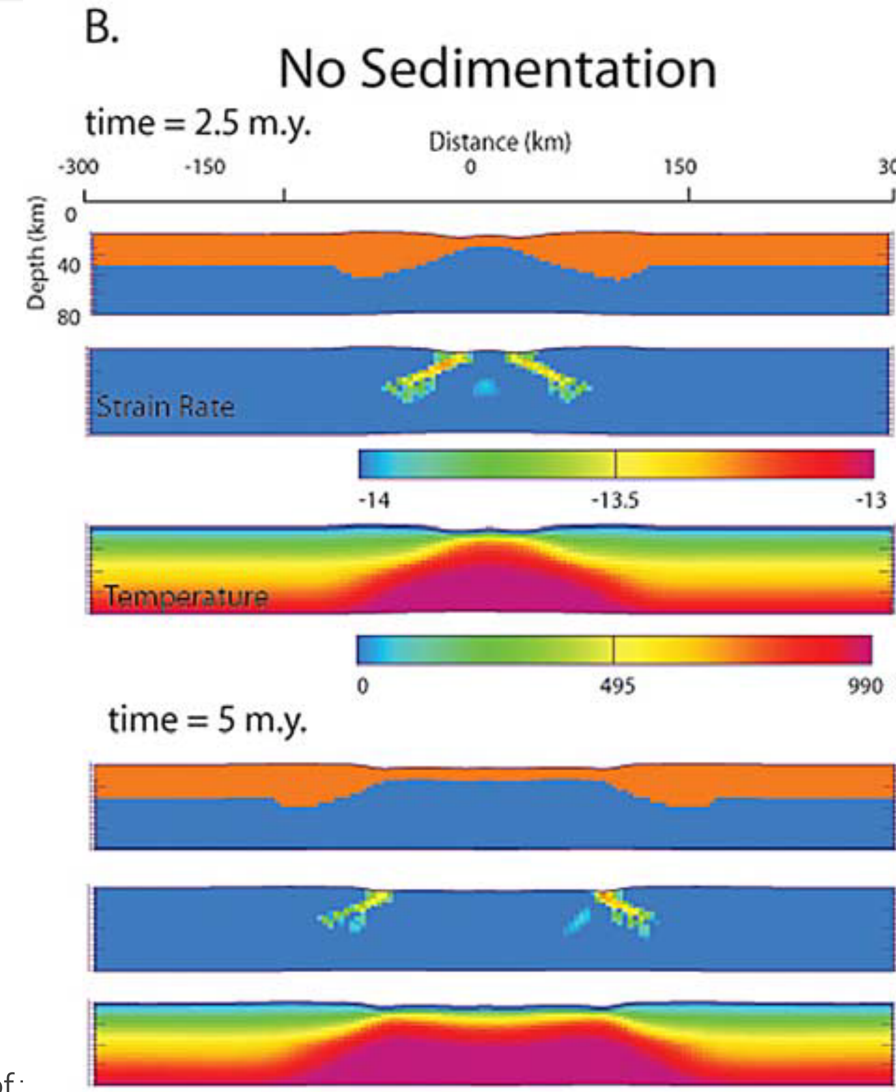


(Bialas and Buck, Tectonics, 2009)

Tectonic Modeling: Rifting Style

(Bialas and Buck, Tectonics, 2009)

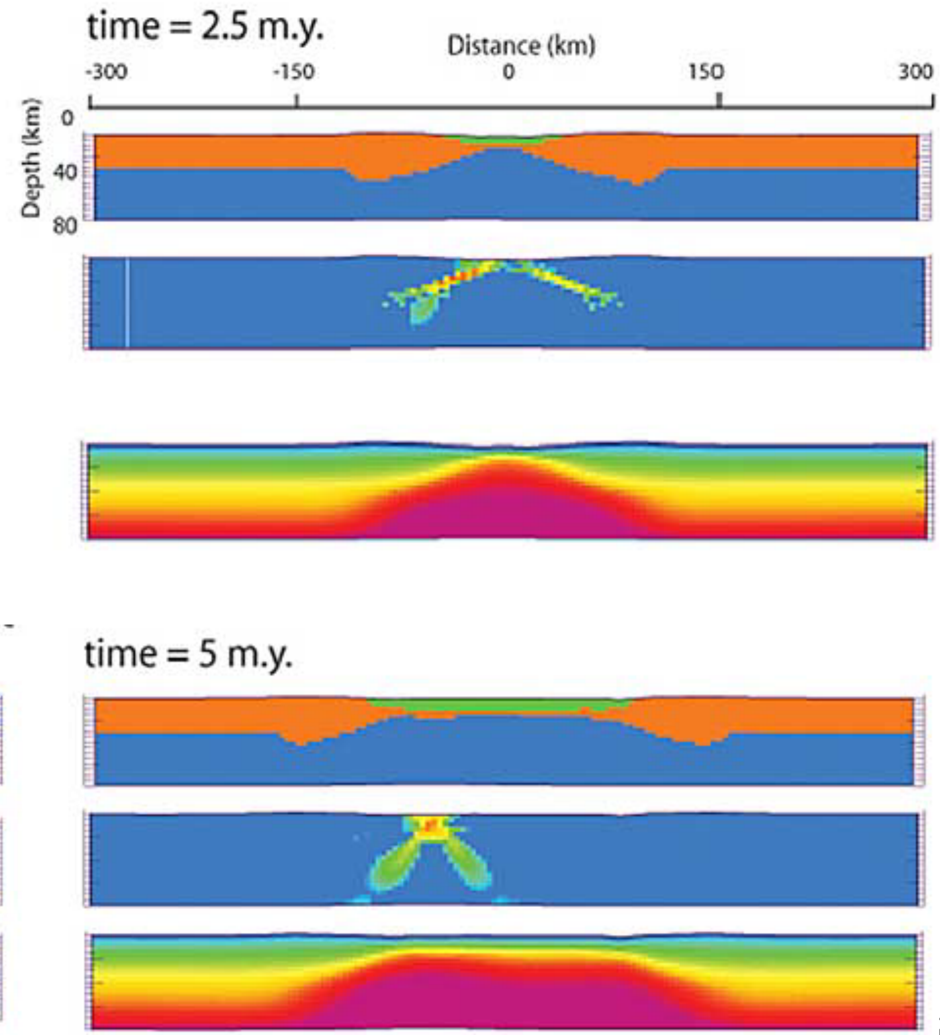




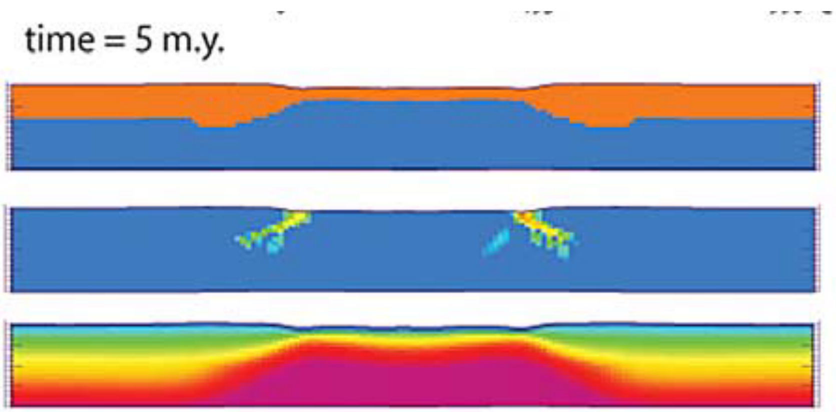
Tectonic Modeling: Rifting Style

(Bialas and Buck, Tectonics, 2009)

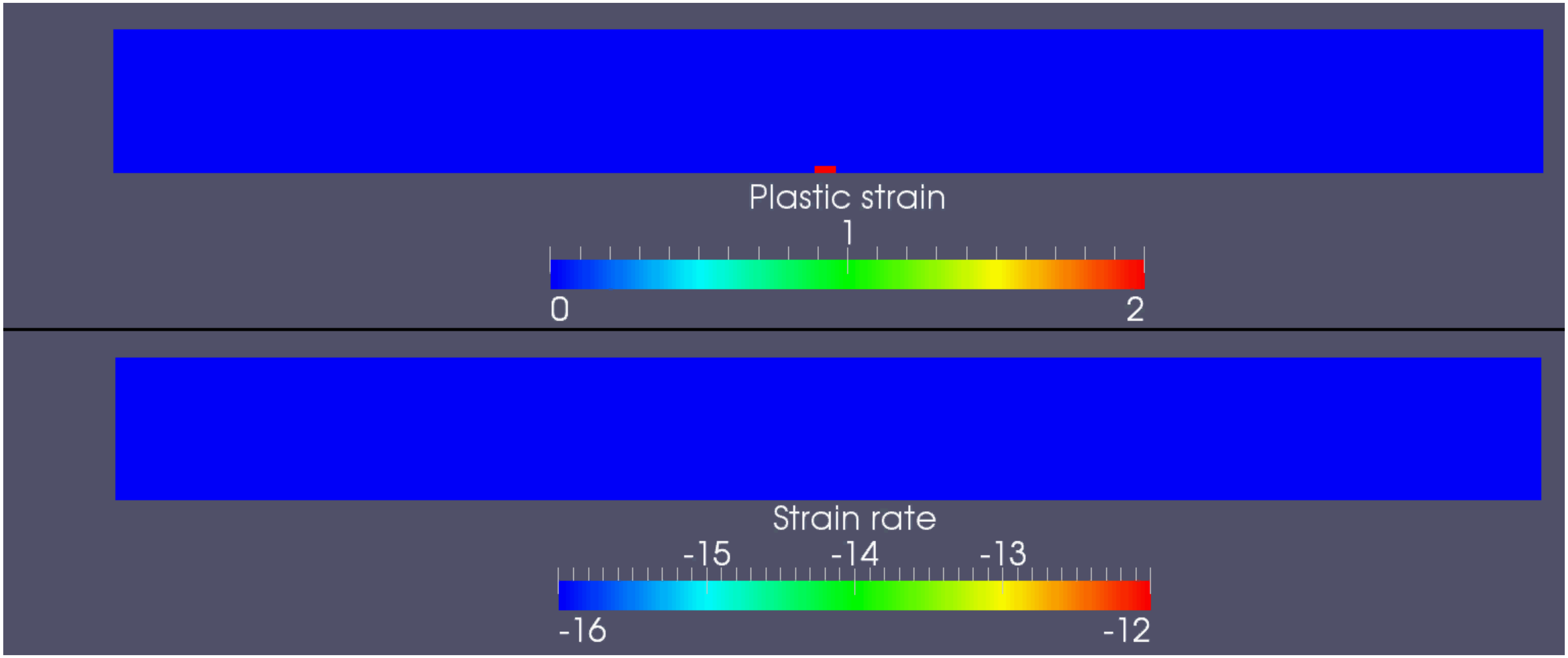
Uniform Sedimentation



No Sedimentaion



Tectonic Modeling: Rider Blocks



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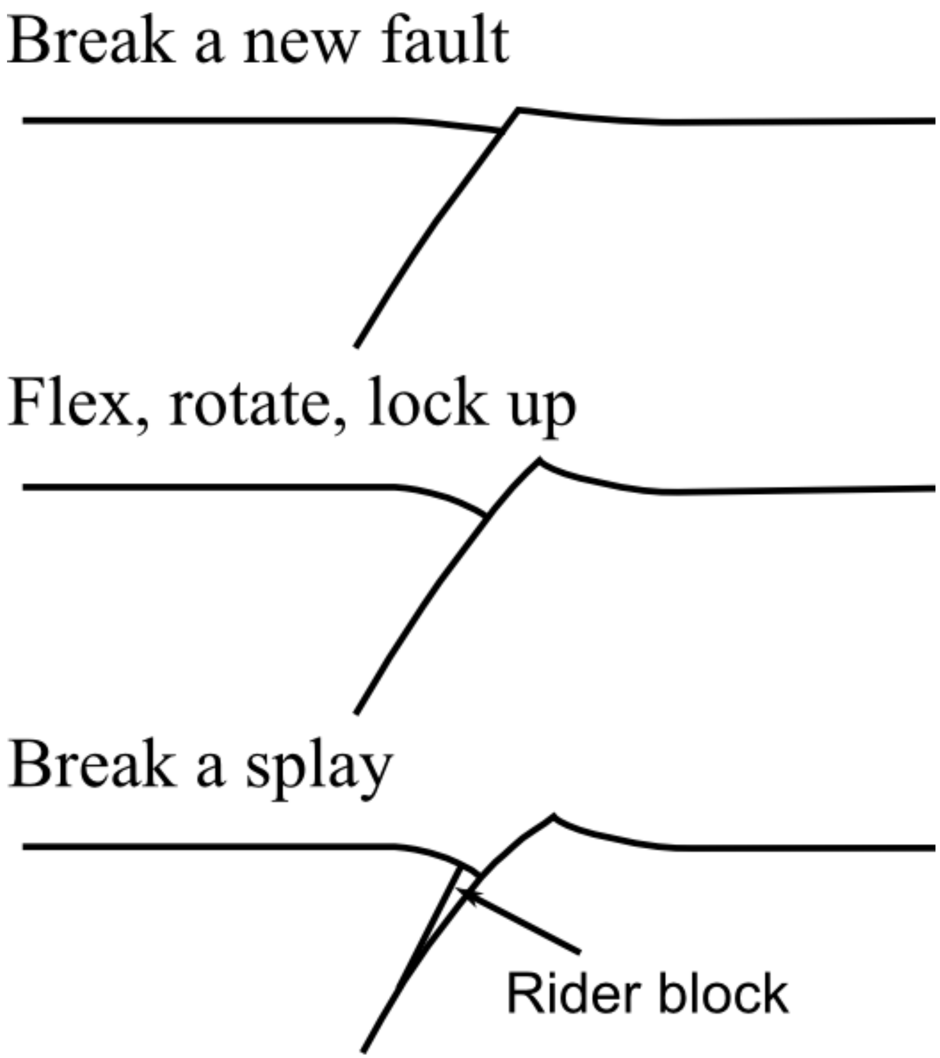
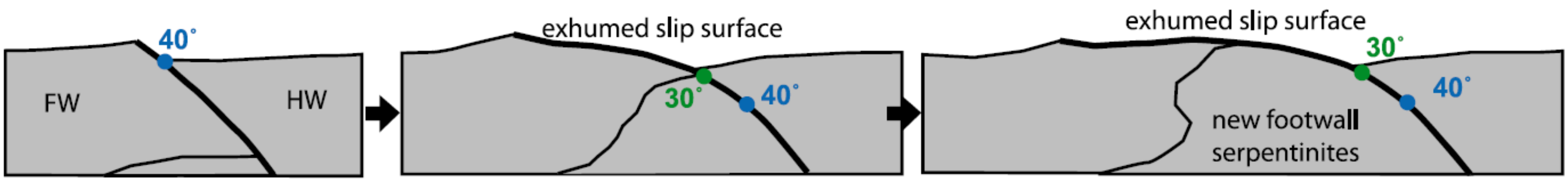
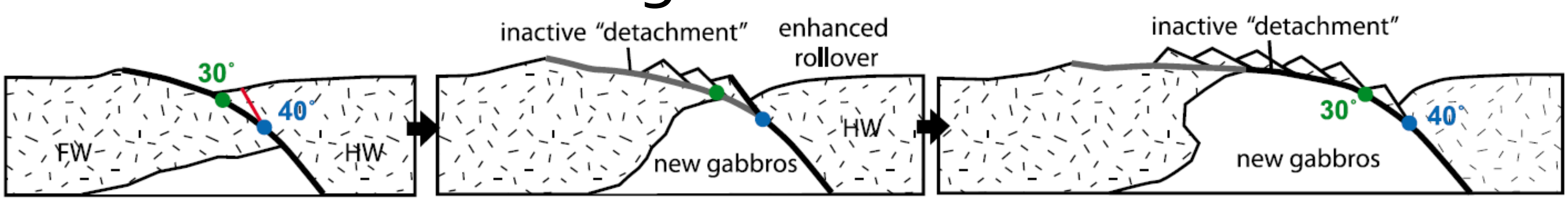


Tectonic Modeling: Rider Blocks

Weak fault or no infill → No Rider Blocks

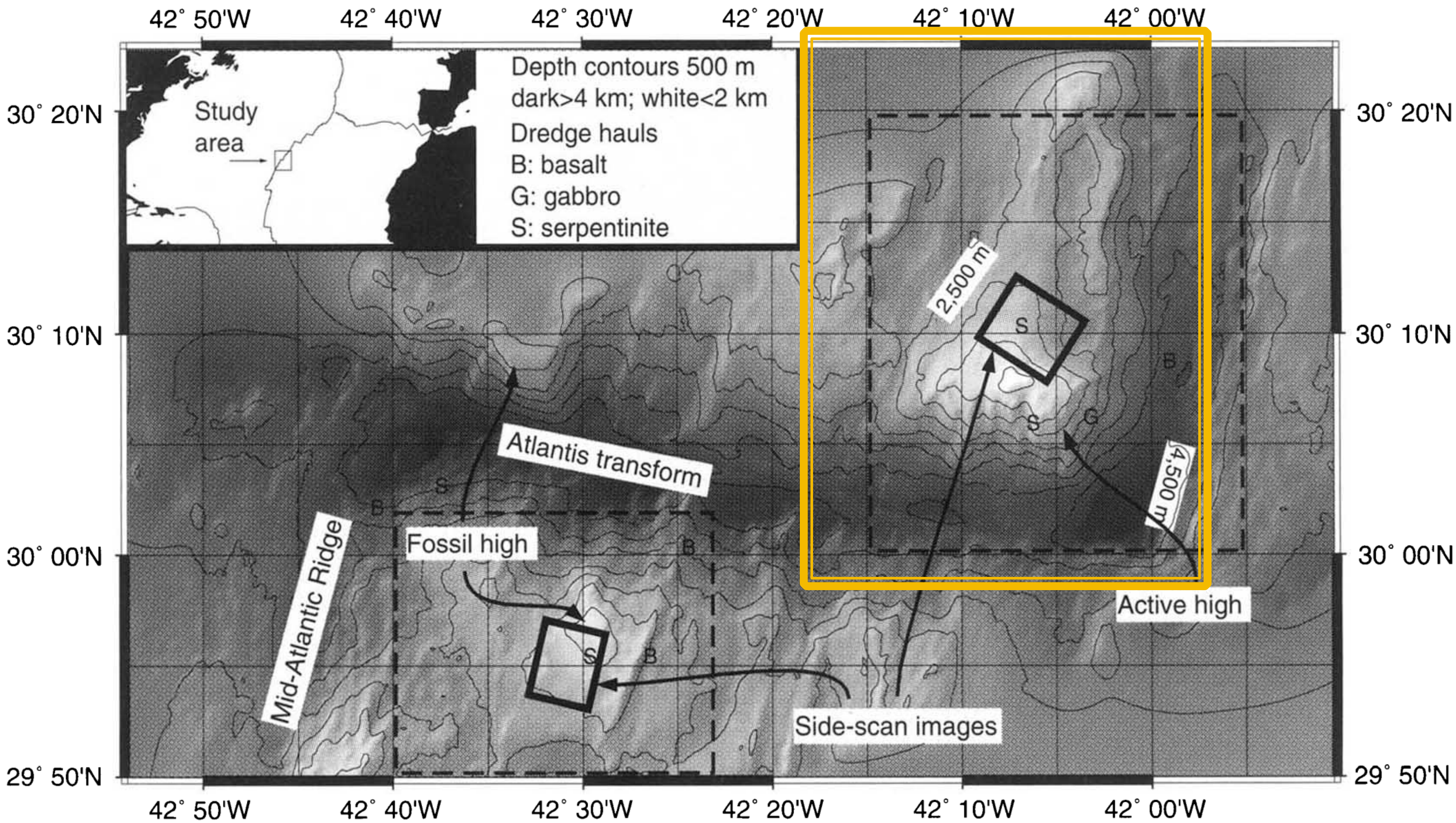


Rider blocks → Strong fault and sufficient infill



(Reston and Ranero, G3, 2011)

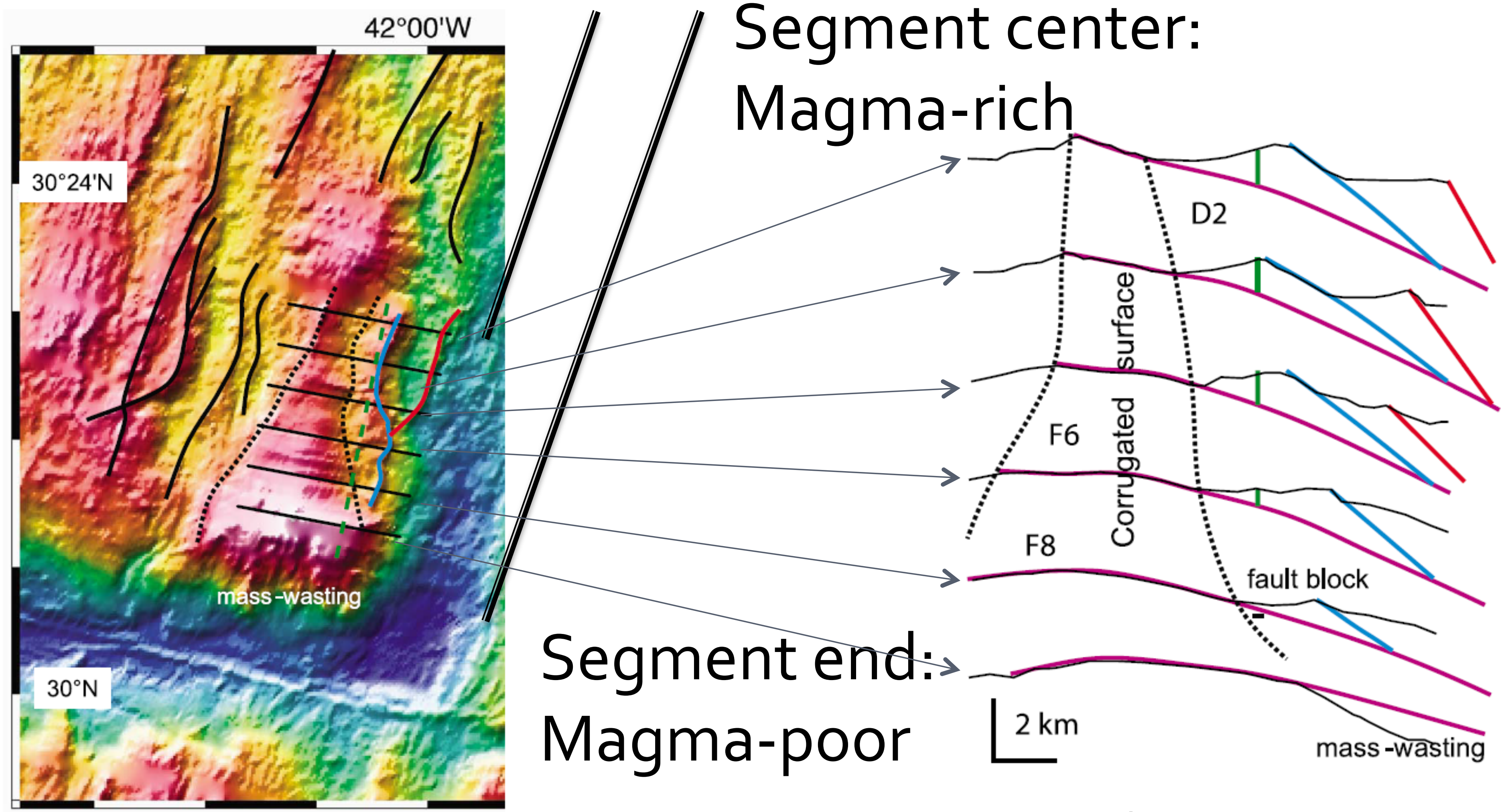
Tectonic Modeling: Rider Blocks



(Cann et al., Nature, 1997)

Tectonic Modeling: Rider Blocks

Segment center: Magma-rich



Segment end: Magma-poor

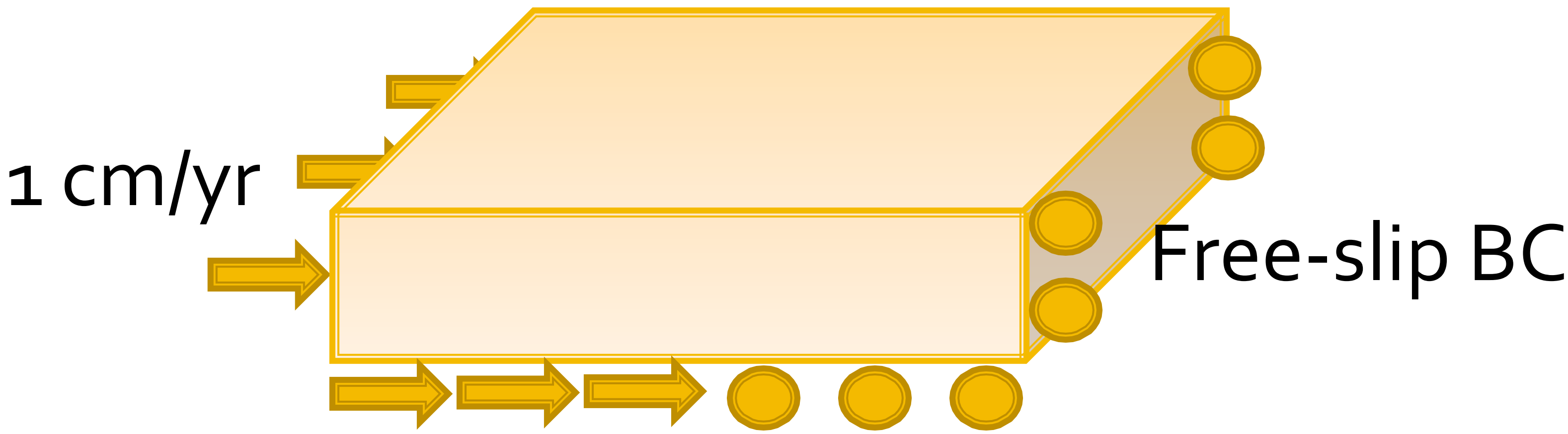
(Reston and Ranero, G3, 2011)

Tectonic Modeling

- "Sedimentation" is also important in tectonic processes.
- In 2D settings, "sediments" transported
  - along the third dimension
  - as much as needed.
- Some problems are inherently 3D.
- Physically-based 3D coupling between tectonic and surface process modeling desirable.

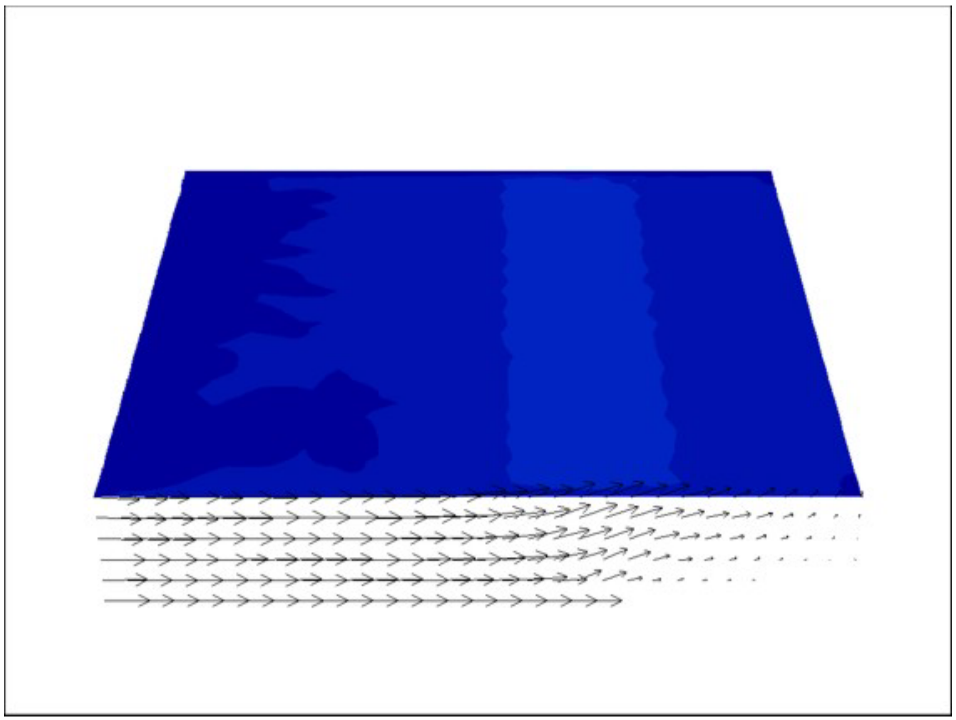
Coupling with surface processes

- On-going project by Phaedra Upton and Greg Tucker
- FLAC3D + CHILD
- 60 x 60 x 10 km, 2 km in FLAC3D and 1 km in CHILD.

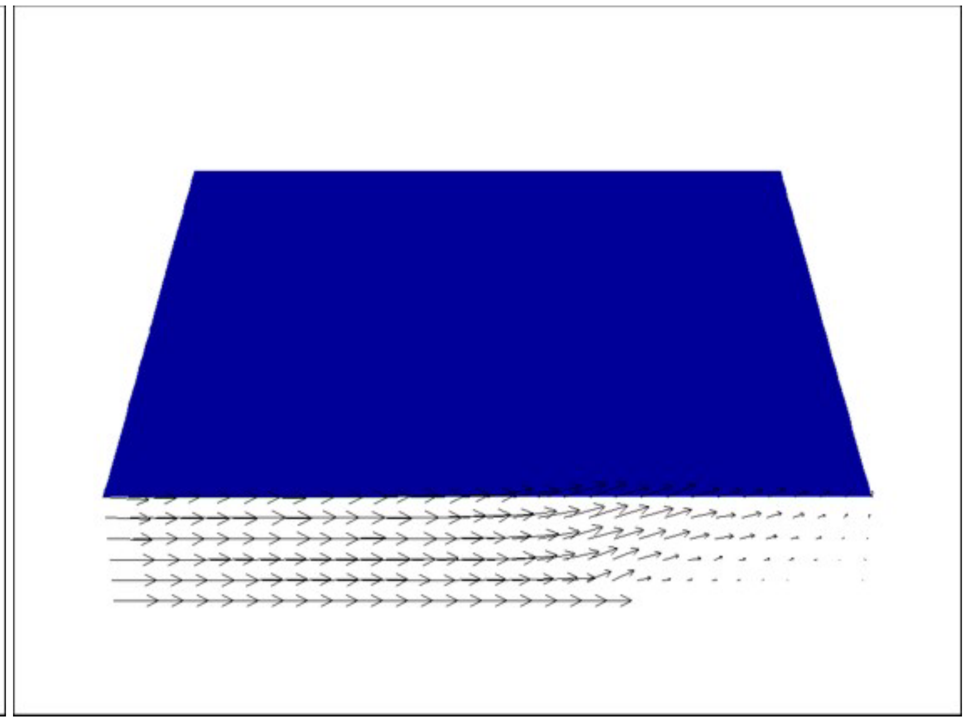


Coupling with surface processes

< Highly Erodible Material >



< Less Erodible Material >



Coupling with surface processes

Requirements	FLAC3D	SNAC
3D	✓	✓
Inelastic Deformation	✓	✓
Non-uniform BC	✓	✓
Coupling with CHILD	✓	?