Lithosphere-Hydrosphere interactions: Stokes flow with a free surface

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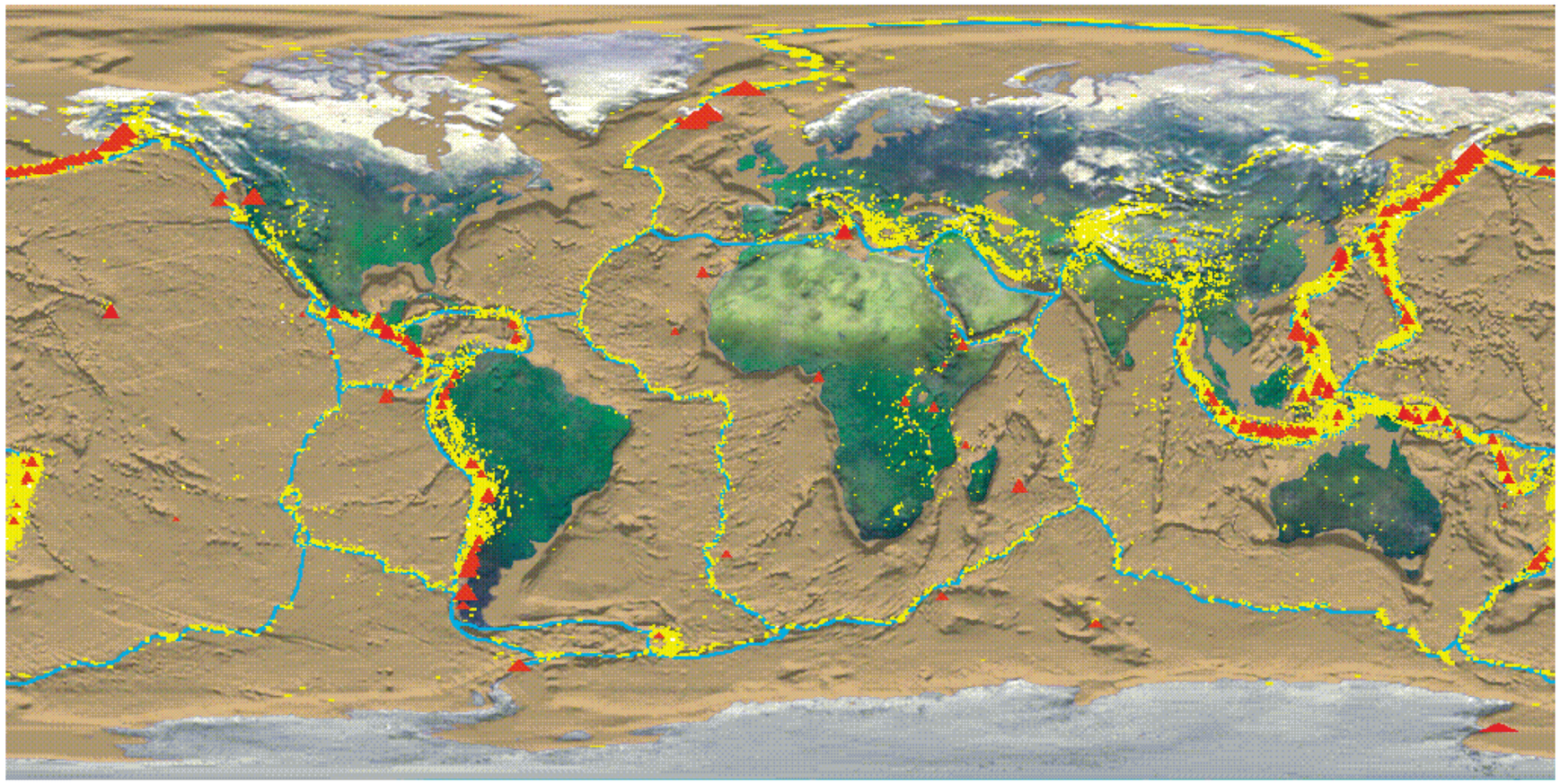
Basic problem

- Deformation of the Earth's lithosphere and underlying mantle @ low Re and infinite Pr: Stokes flow

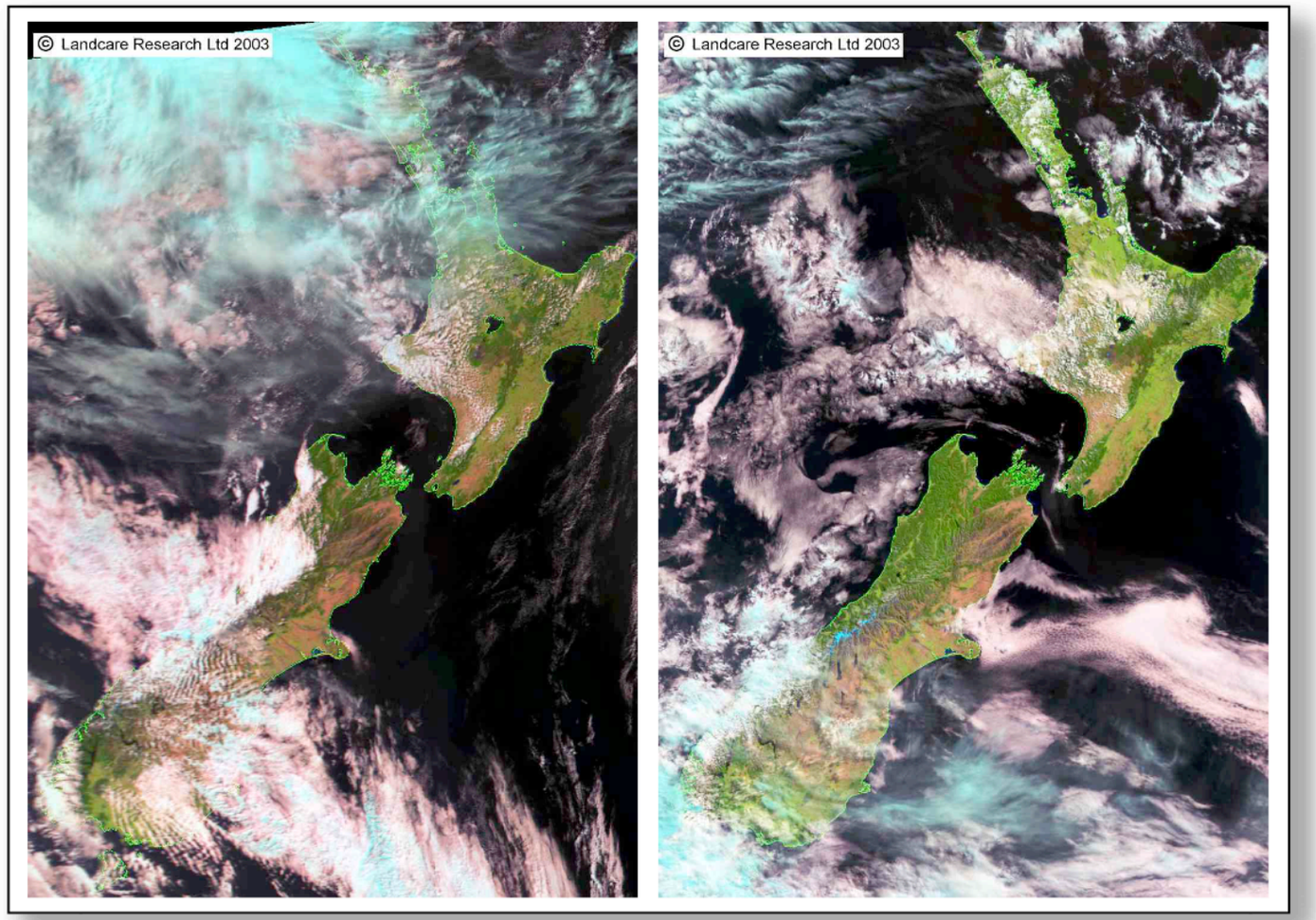
- Free upper surface with a geometry determined by interactions with hydrosphere (erosion/sedimentation)

Challenge 1:
Strain localization

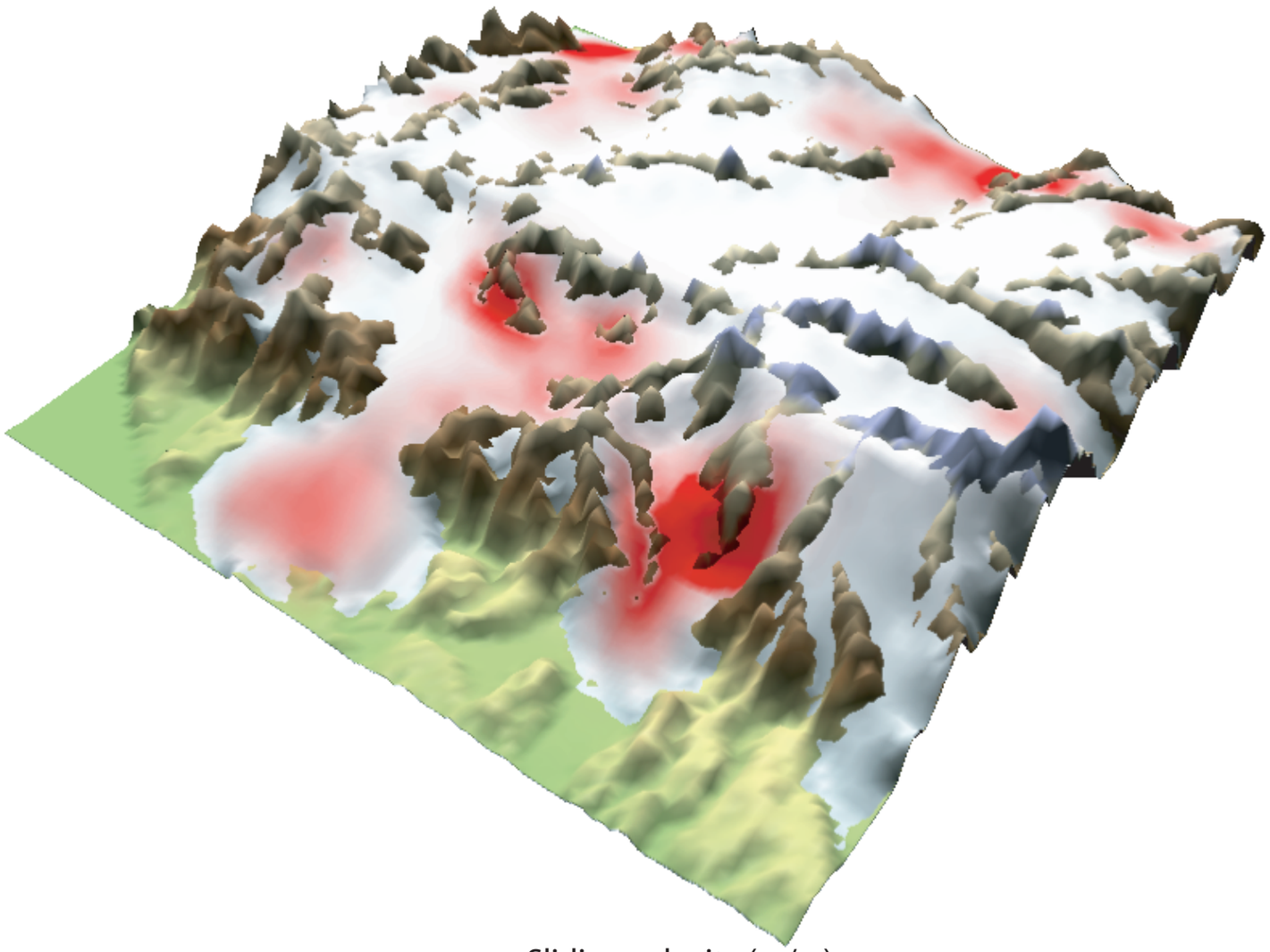


At plate boundary scale, but also at "structural scale",
i.e. the formation of faults and mylonitic fabrics

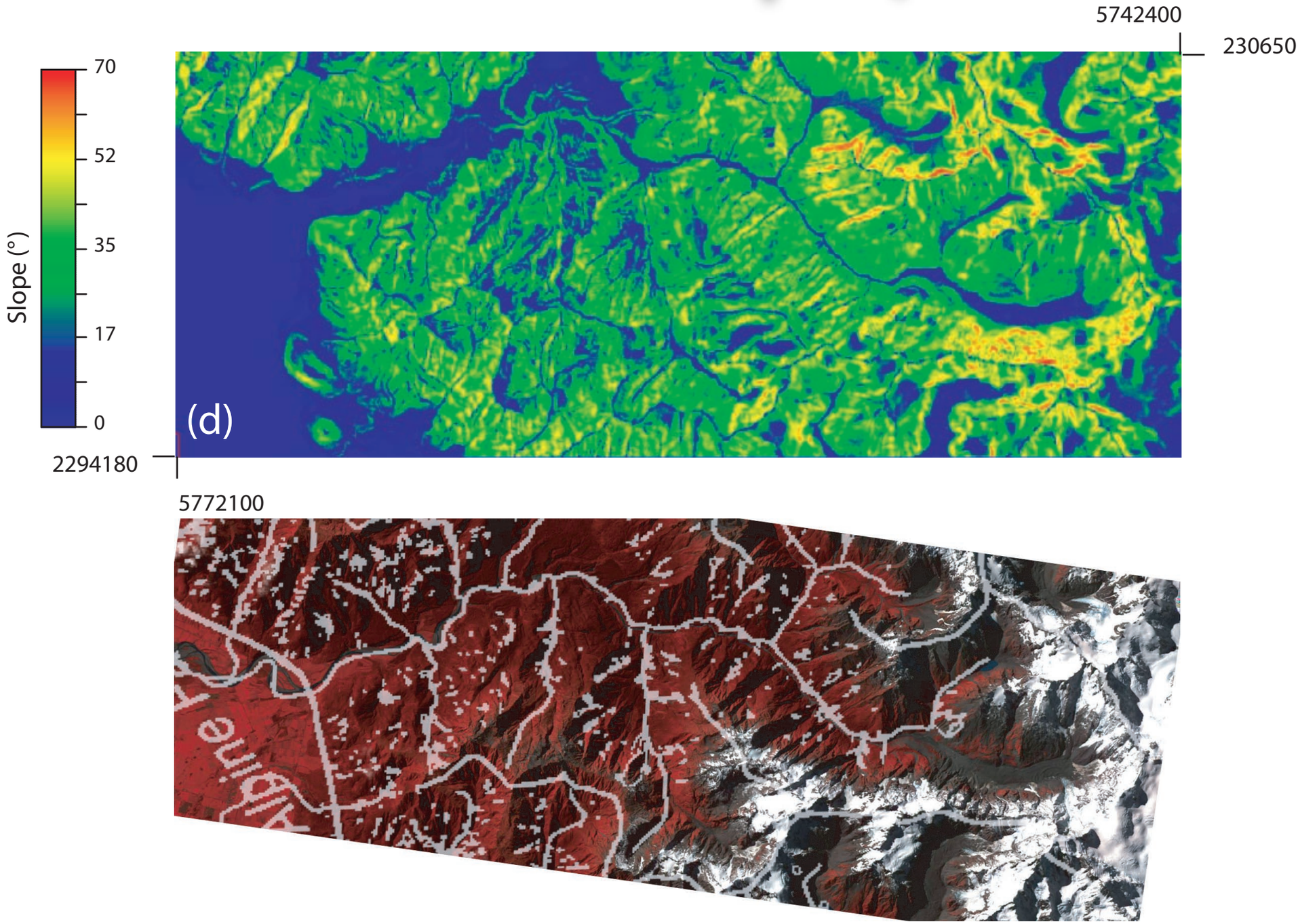
Challenge 2:
coupling with surface



Challenge 2:
coupling with surface

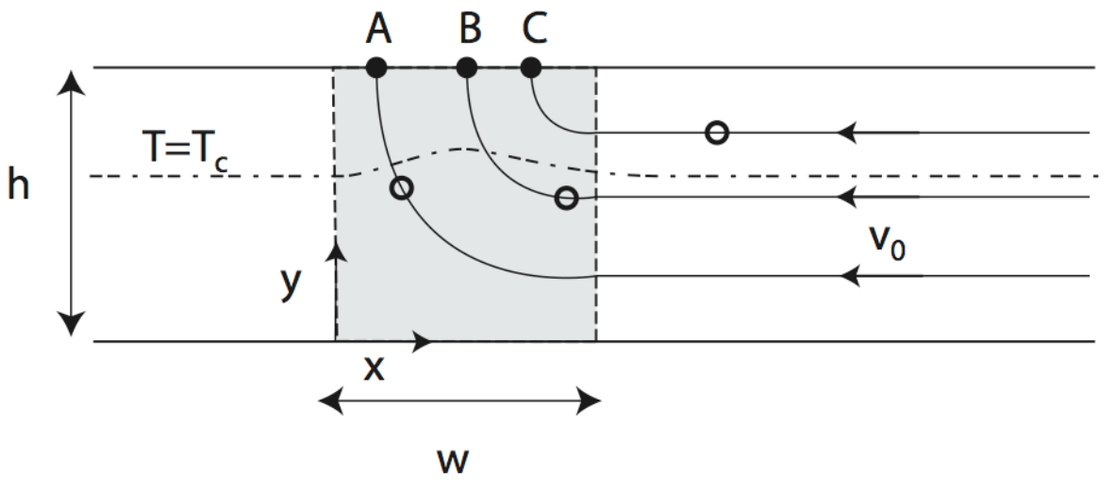


Coupling efficiency depends on tectonic uplift rate

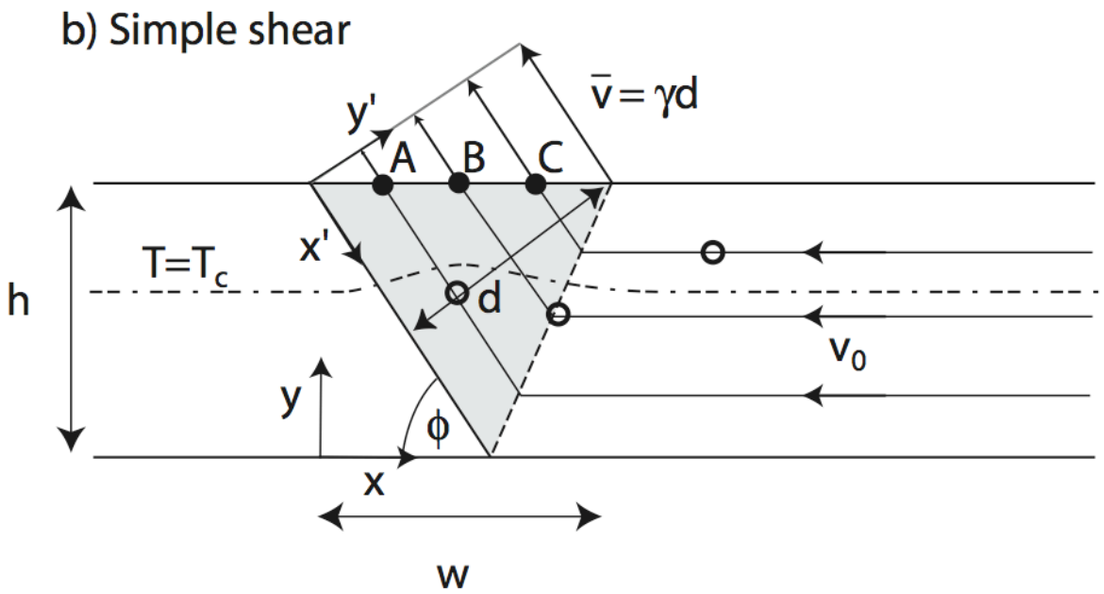


Erosion: kinematic effect

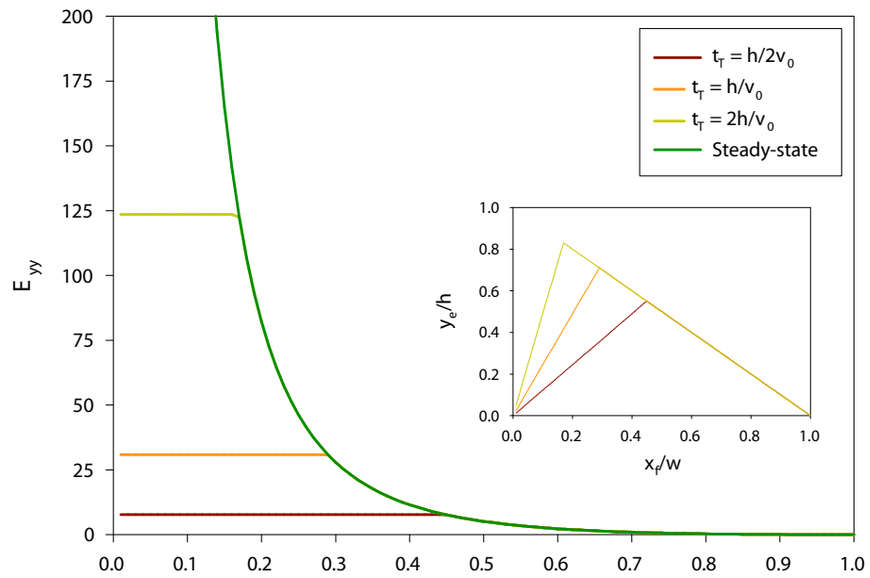
a) Pure shear



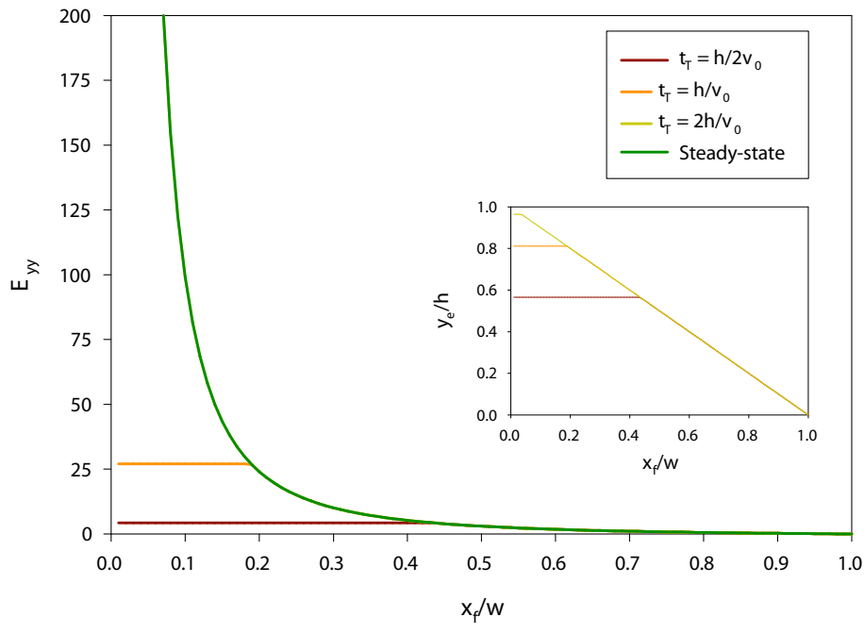
b) Simple shear



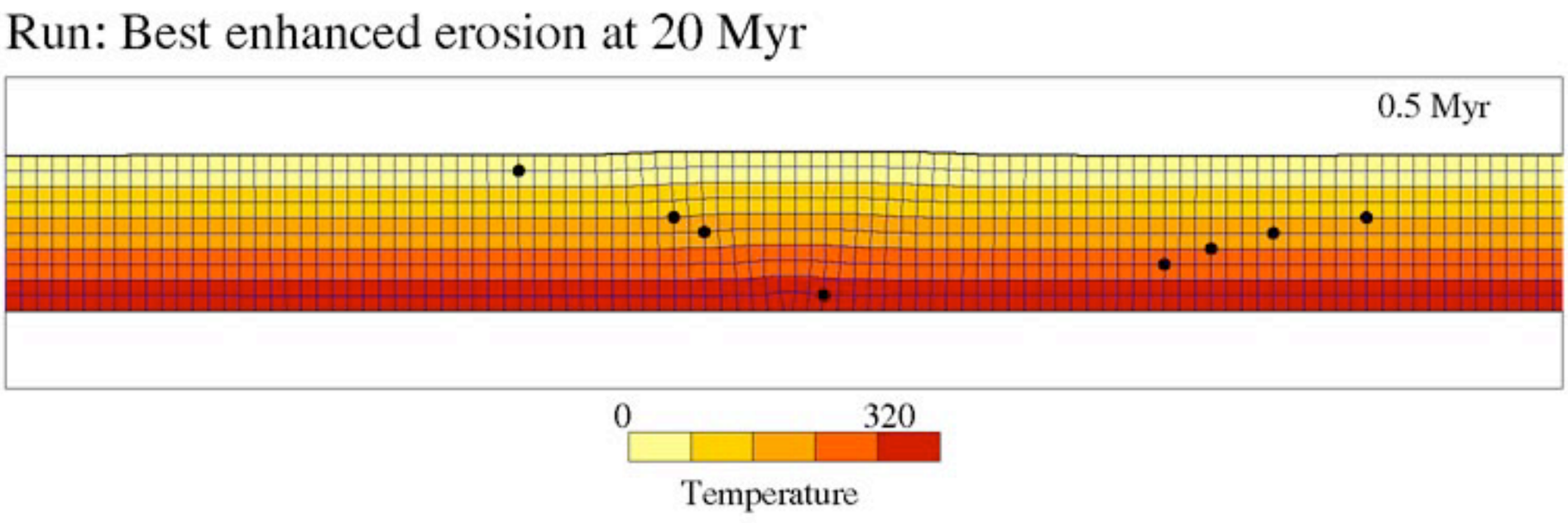
a) Simple shear



b) Pure shear

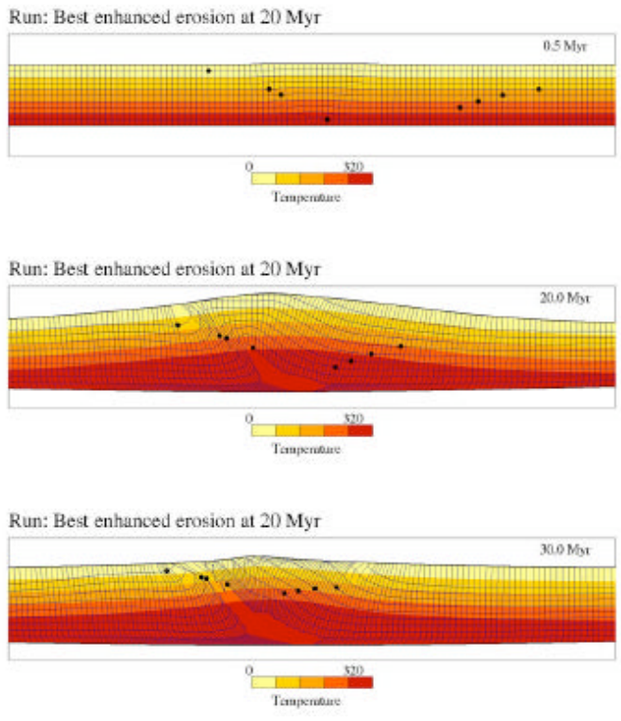


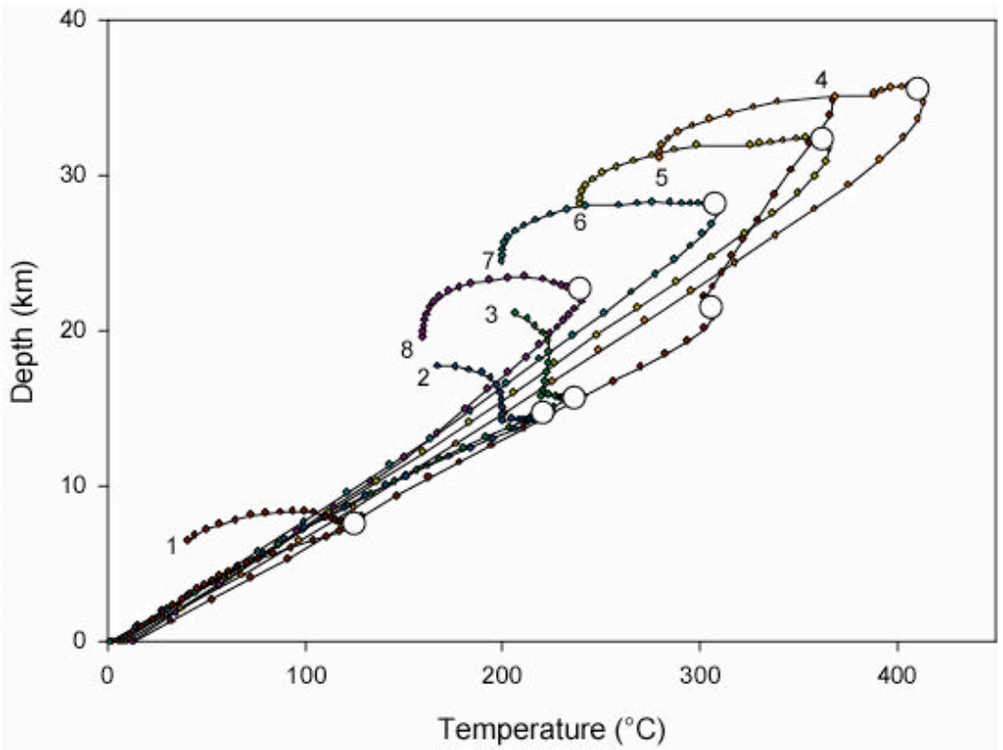
Erosion:
Unloading effect



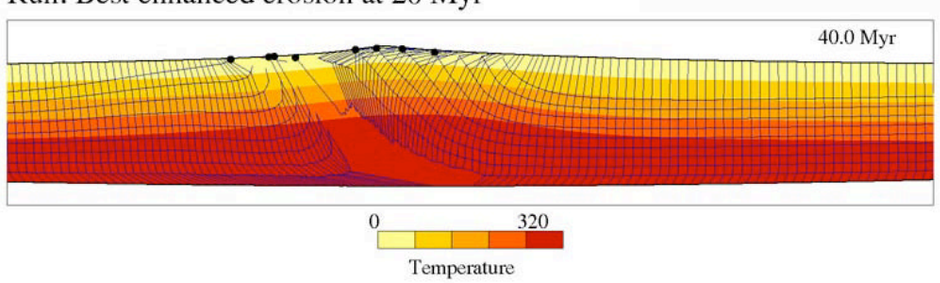
Erosion: predicting geology

Chemins PTt

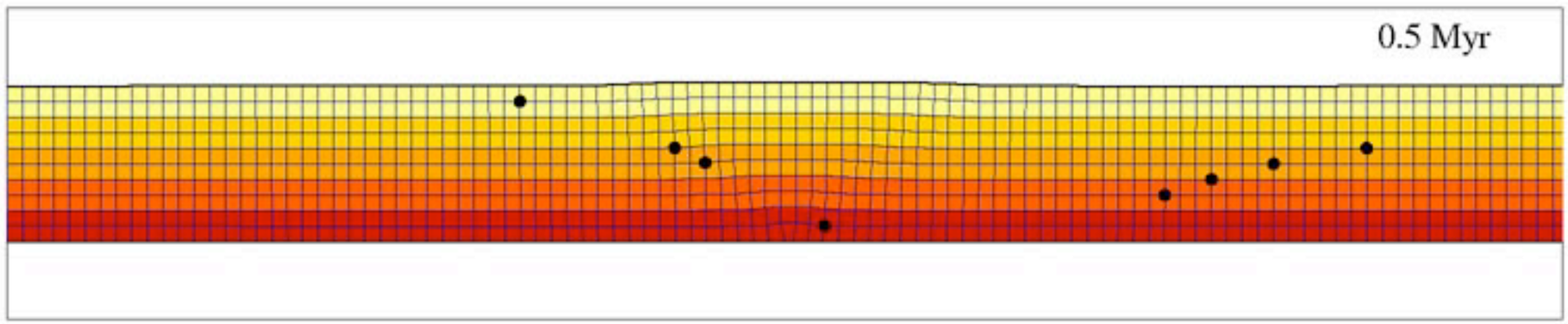


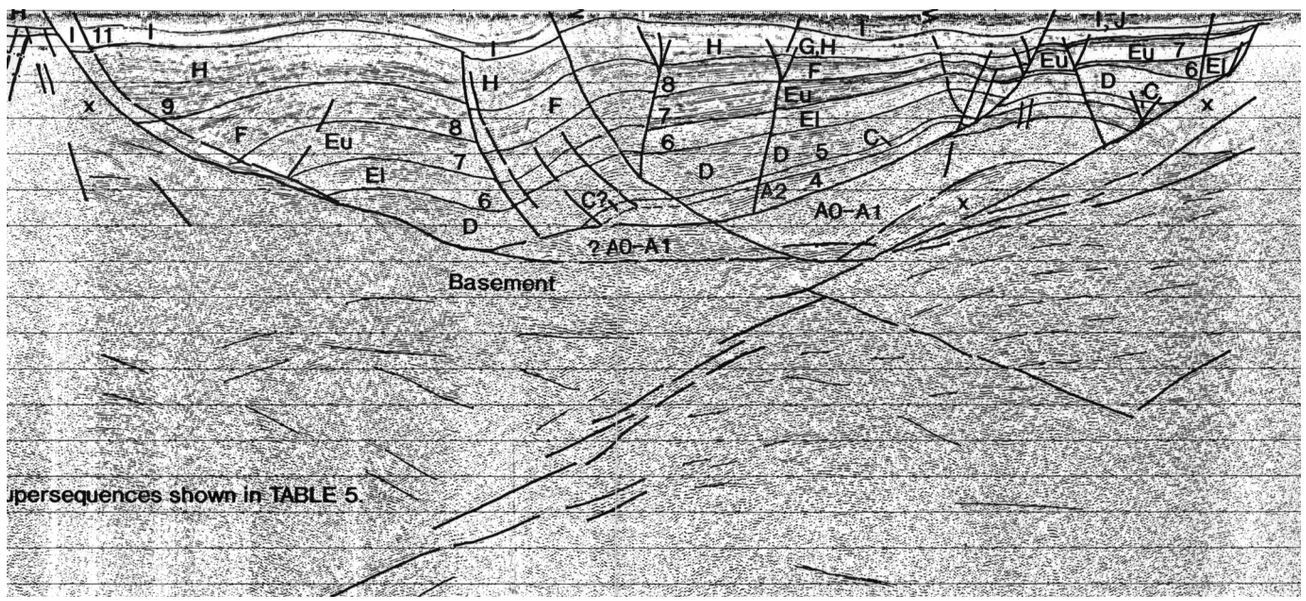


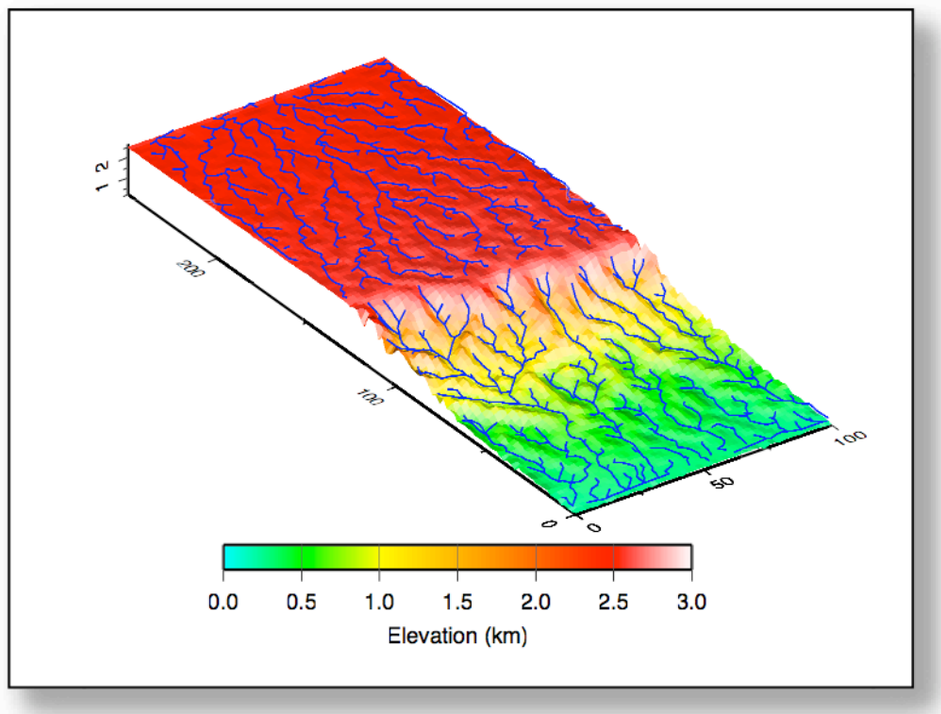
Run: Best enhanced erosion at 20 Myr



Predicting geology: sedimentary basin formation

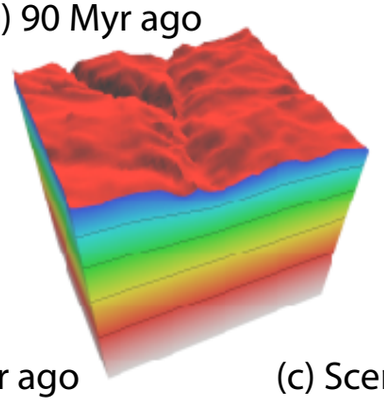




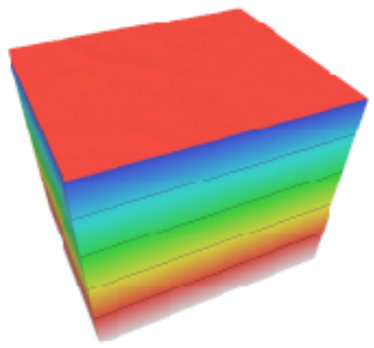


Predicting geology: Thermochronology

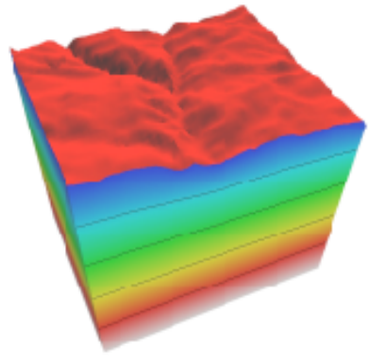
(a) 90 Myr ago



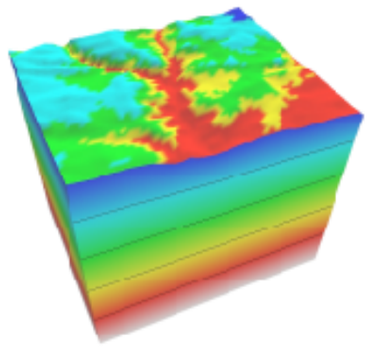
(b) Scenario 1 - 70 Myr ago



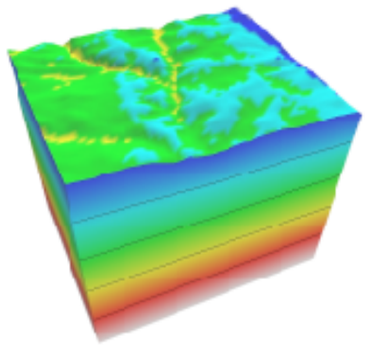
(c) Scenario 2 - 70 Myr ago



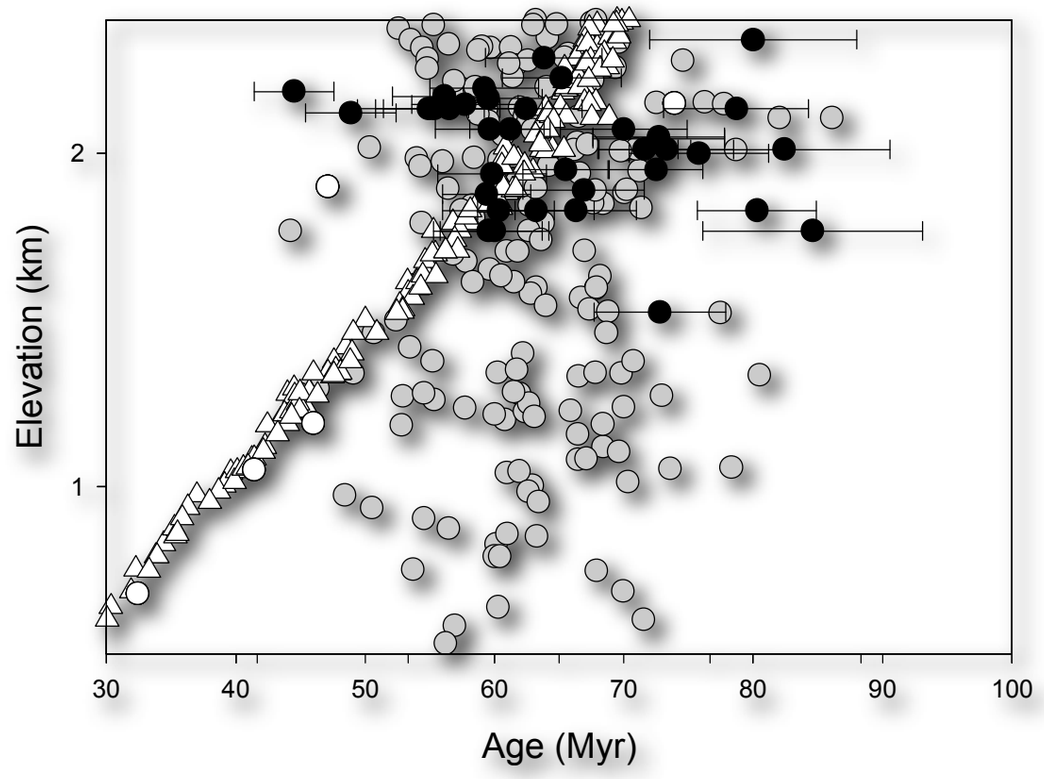
(d) Scenario 1 - today



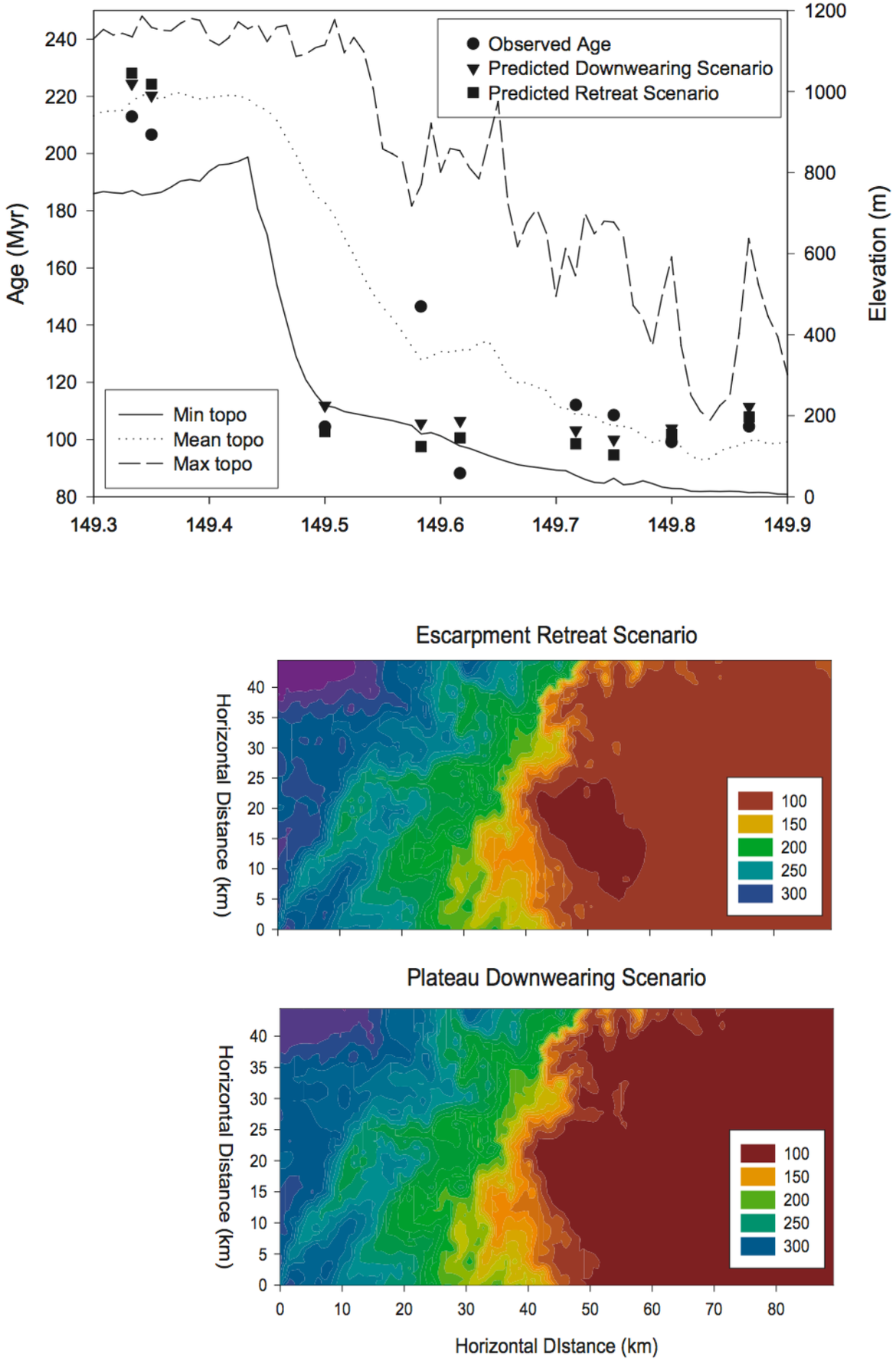
(d) Scenario 2 - today

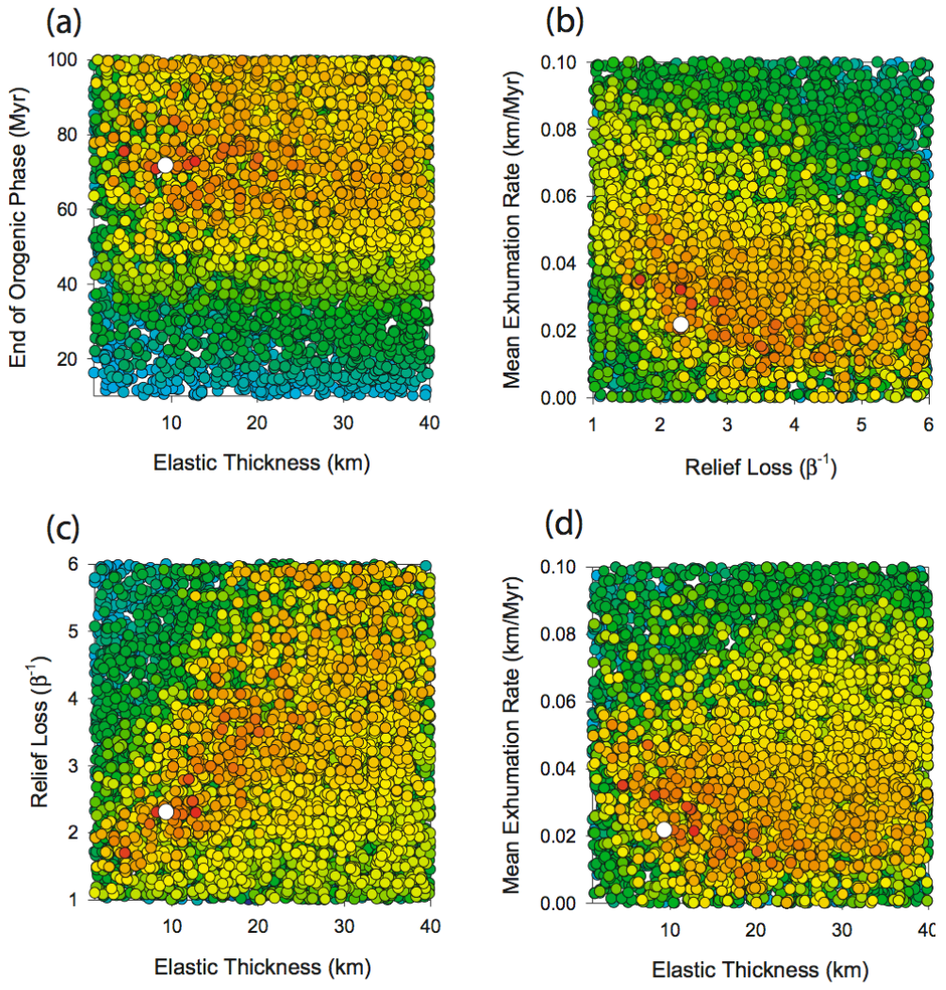


Age (Myr)

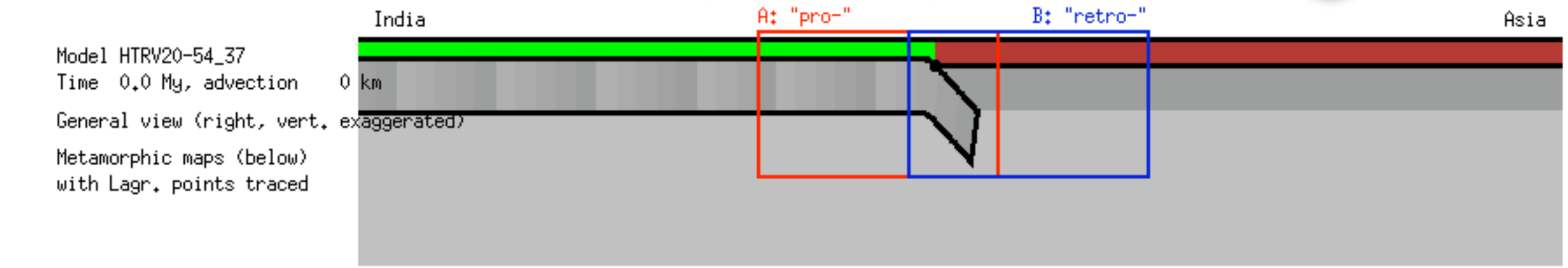


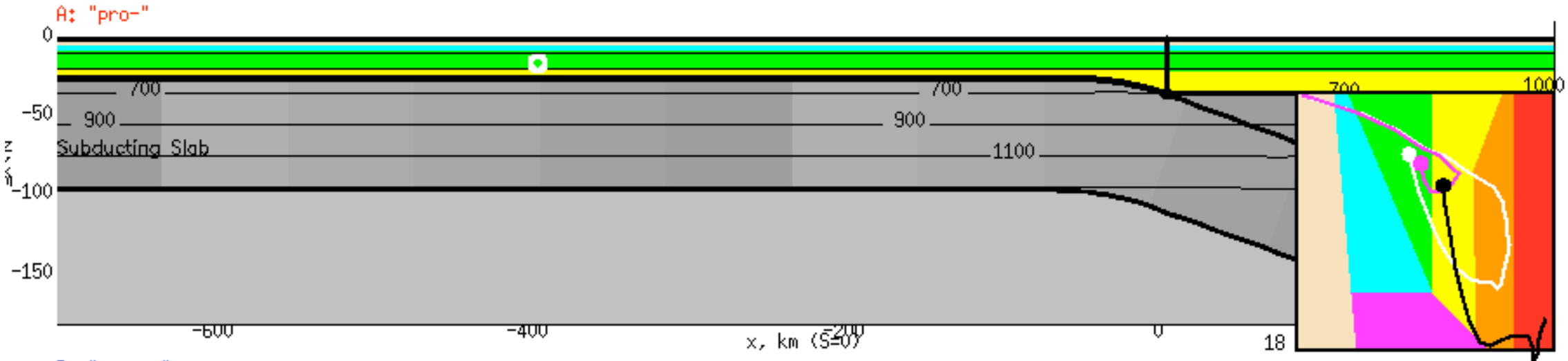
Inverse modelling

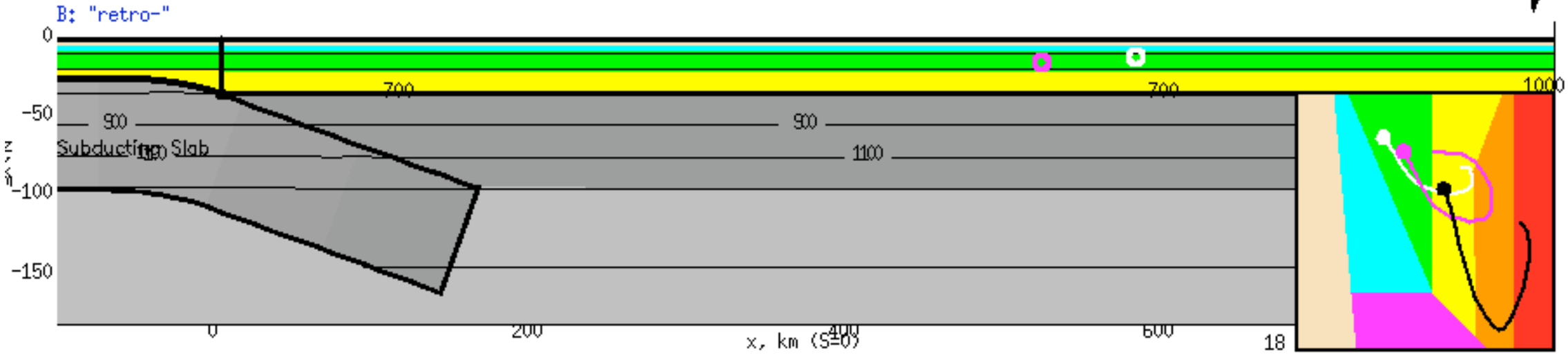




Predicting Geology: Metamorphic petrology





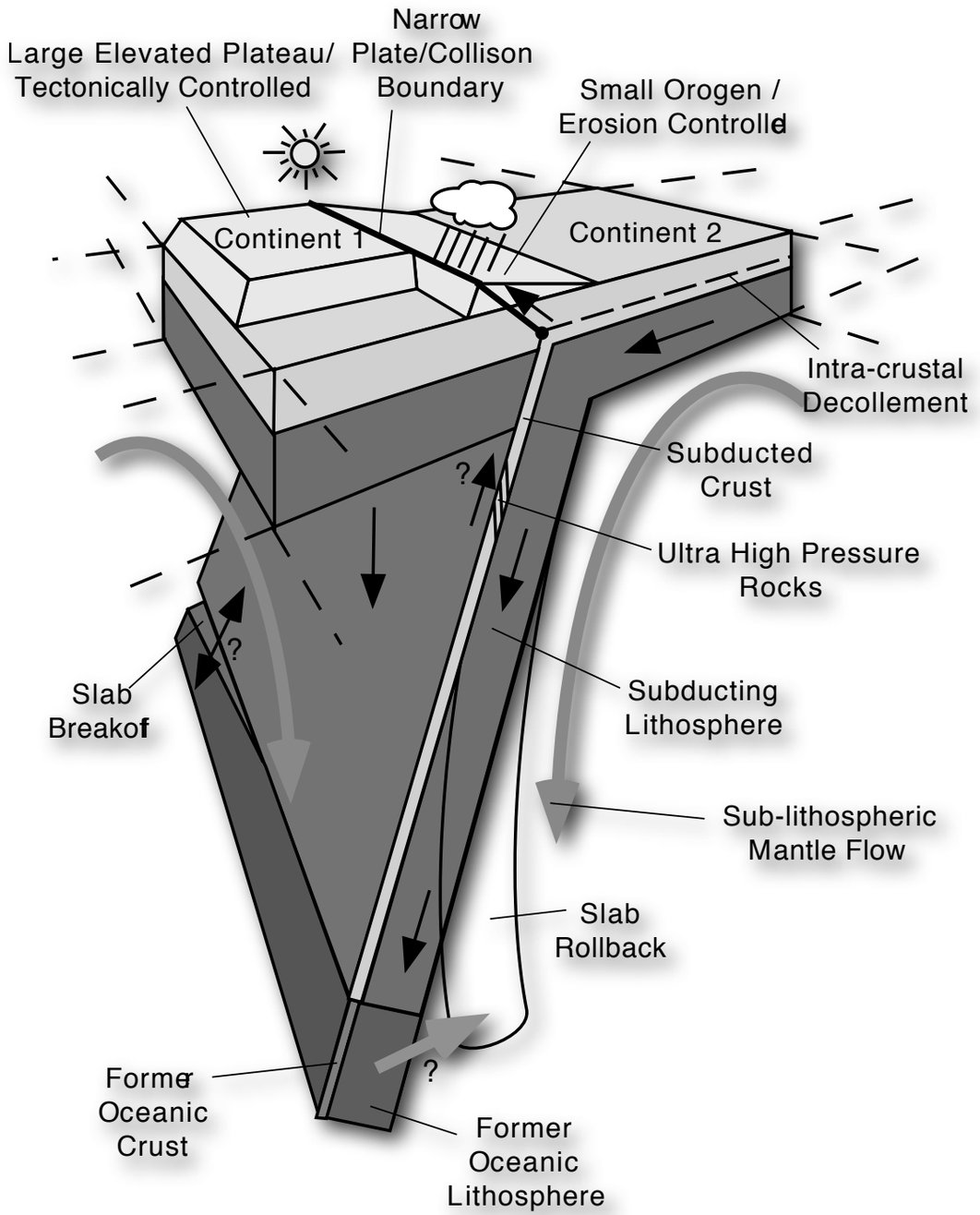


Modelling methods

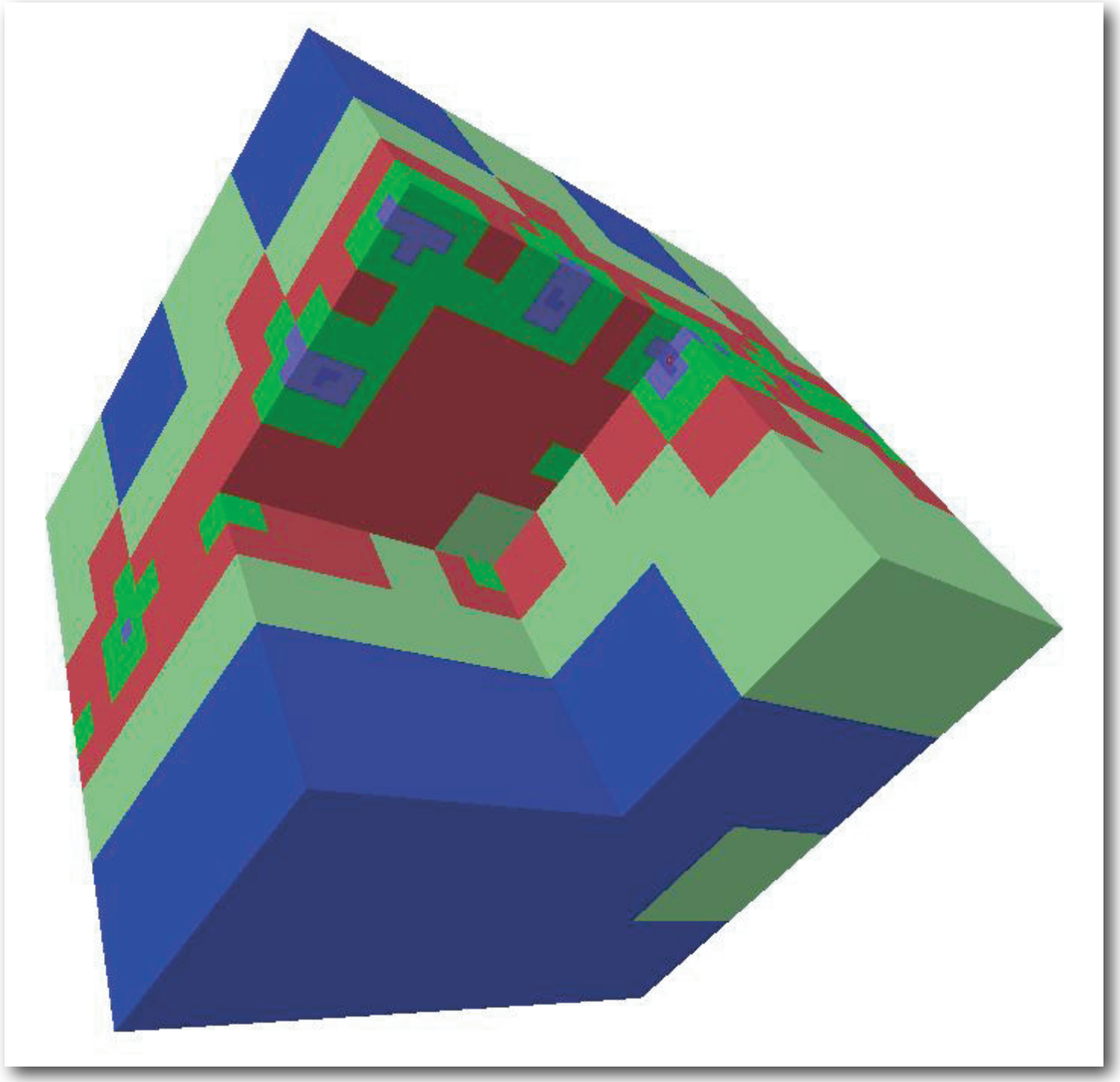
To address large deformation, free surface and memory issues:

- DLR (Dynamic Lagrangian Remeshing)
- ALE (Aritrary Lagrangian Eulerian)
- PIC (Particles in cell)
- etc ...

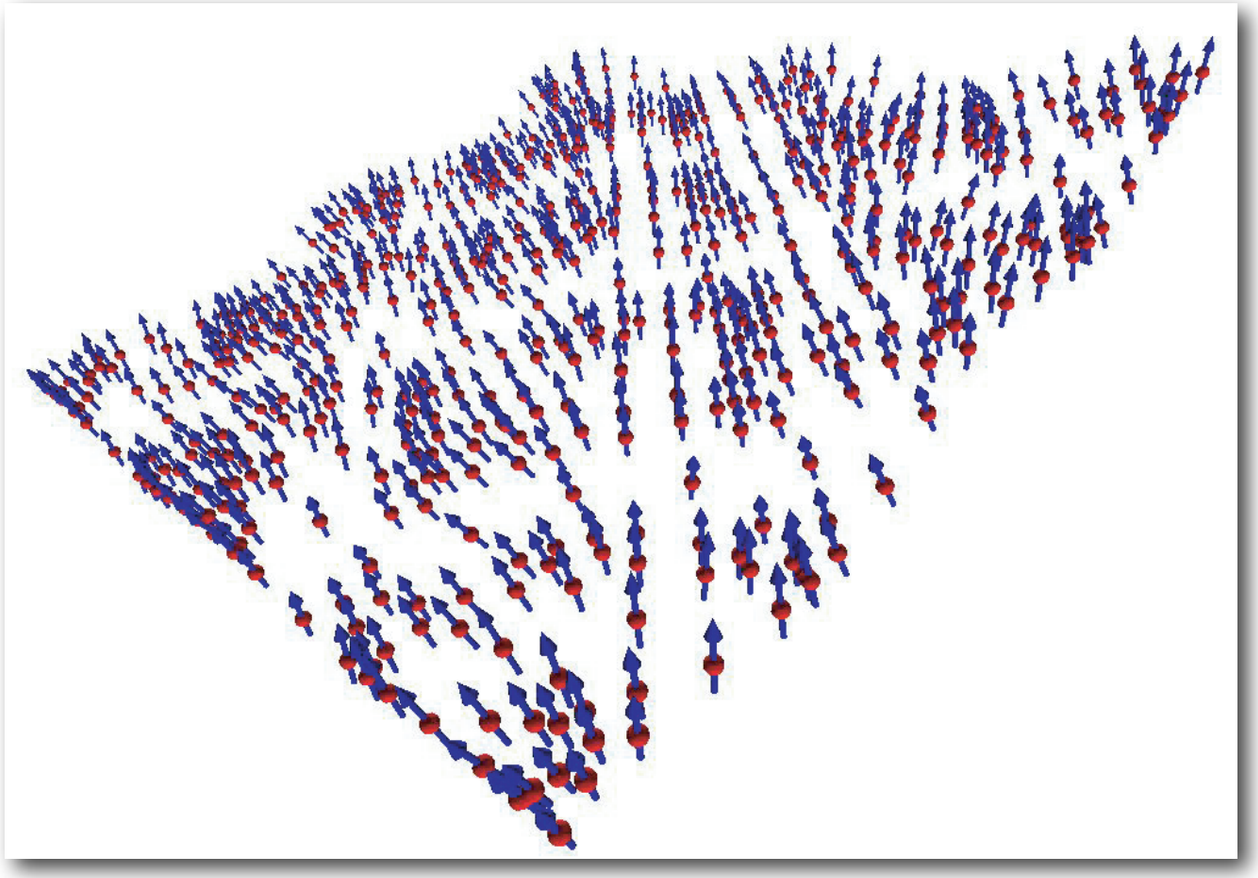
3D Coupled System

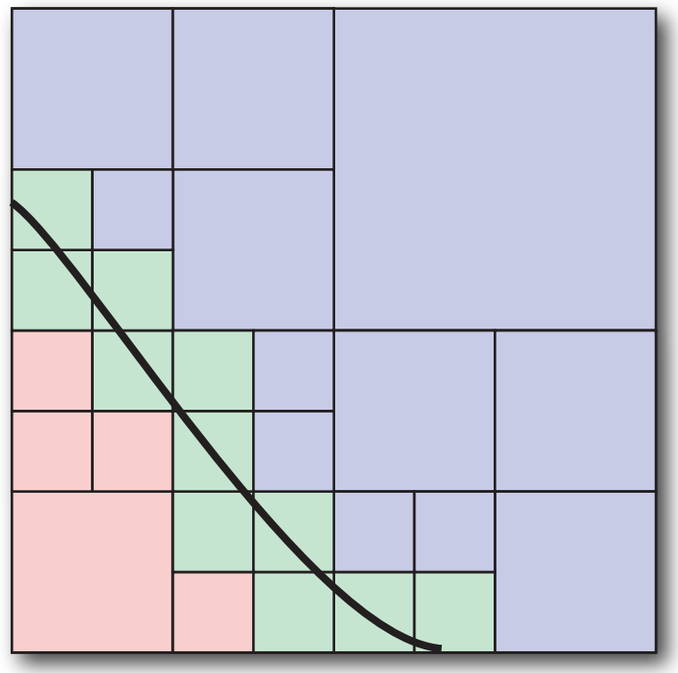


OCTREE division of Unity



Dual Representation of Surfaces

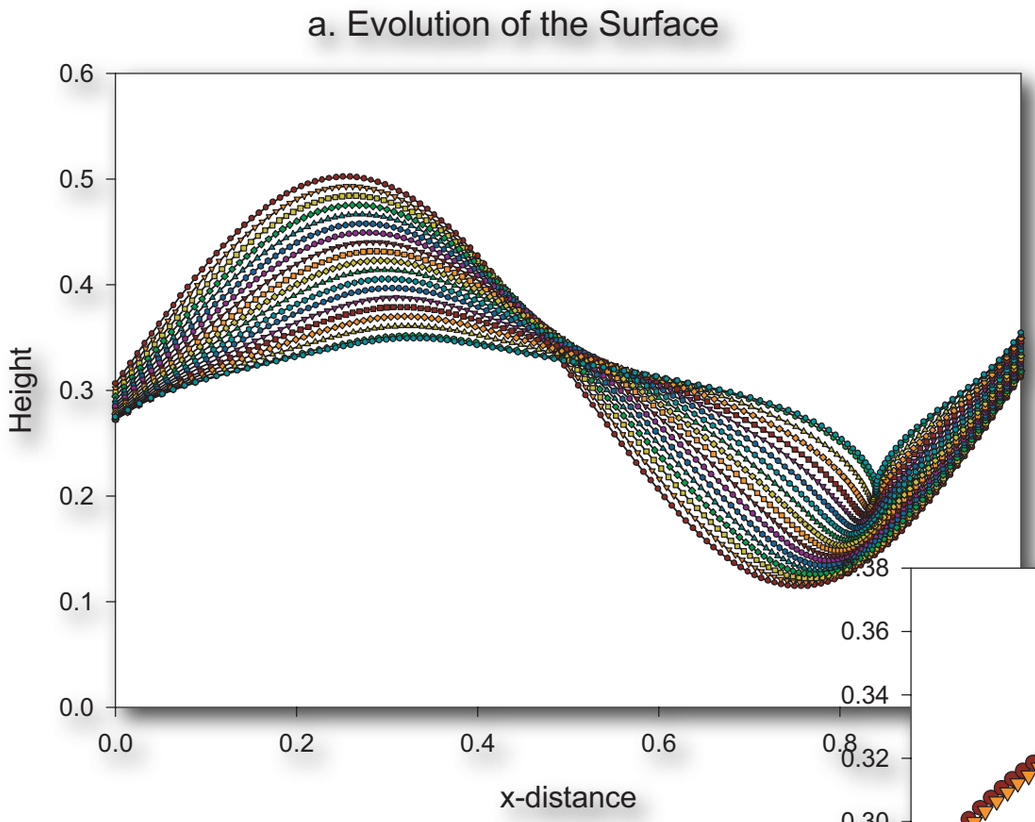


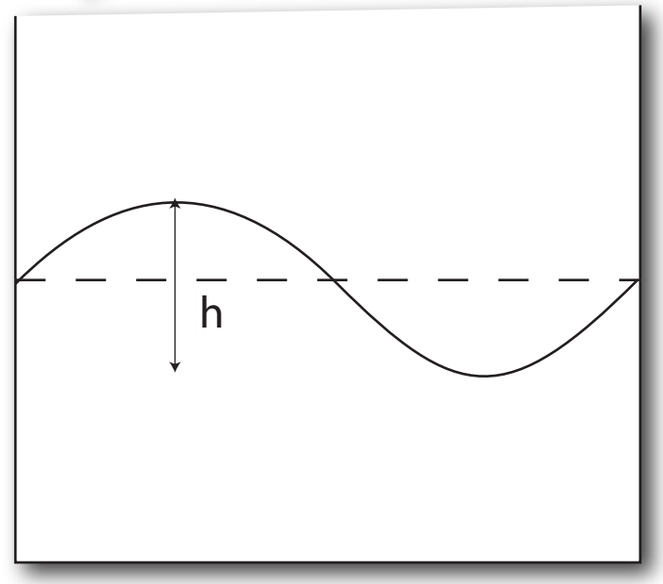


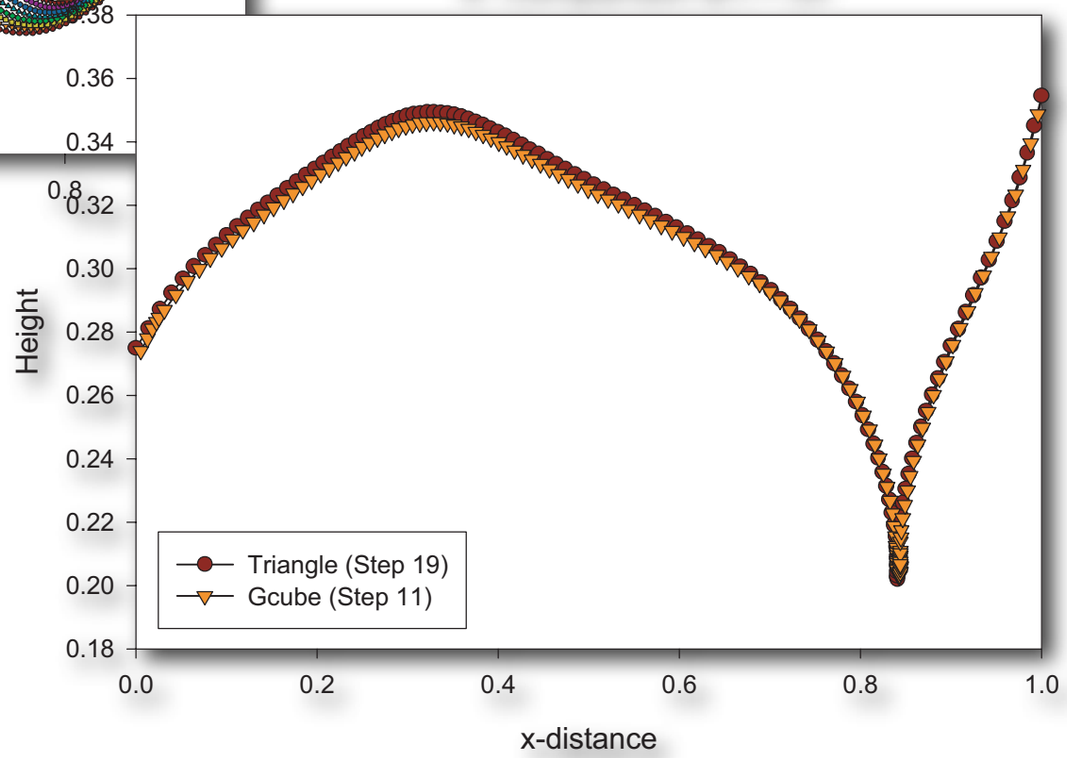
Direct solver

- MUMPS, WSMP, etc.
- parallel, frontal solver
- can deal with poorly conditioned matrices
- limited by memory (128 Gb = ~~75x75x75~~)
- Ideal for irregular discretization

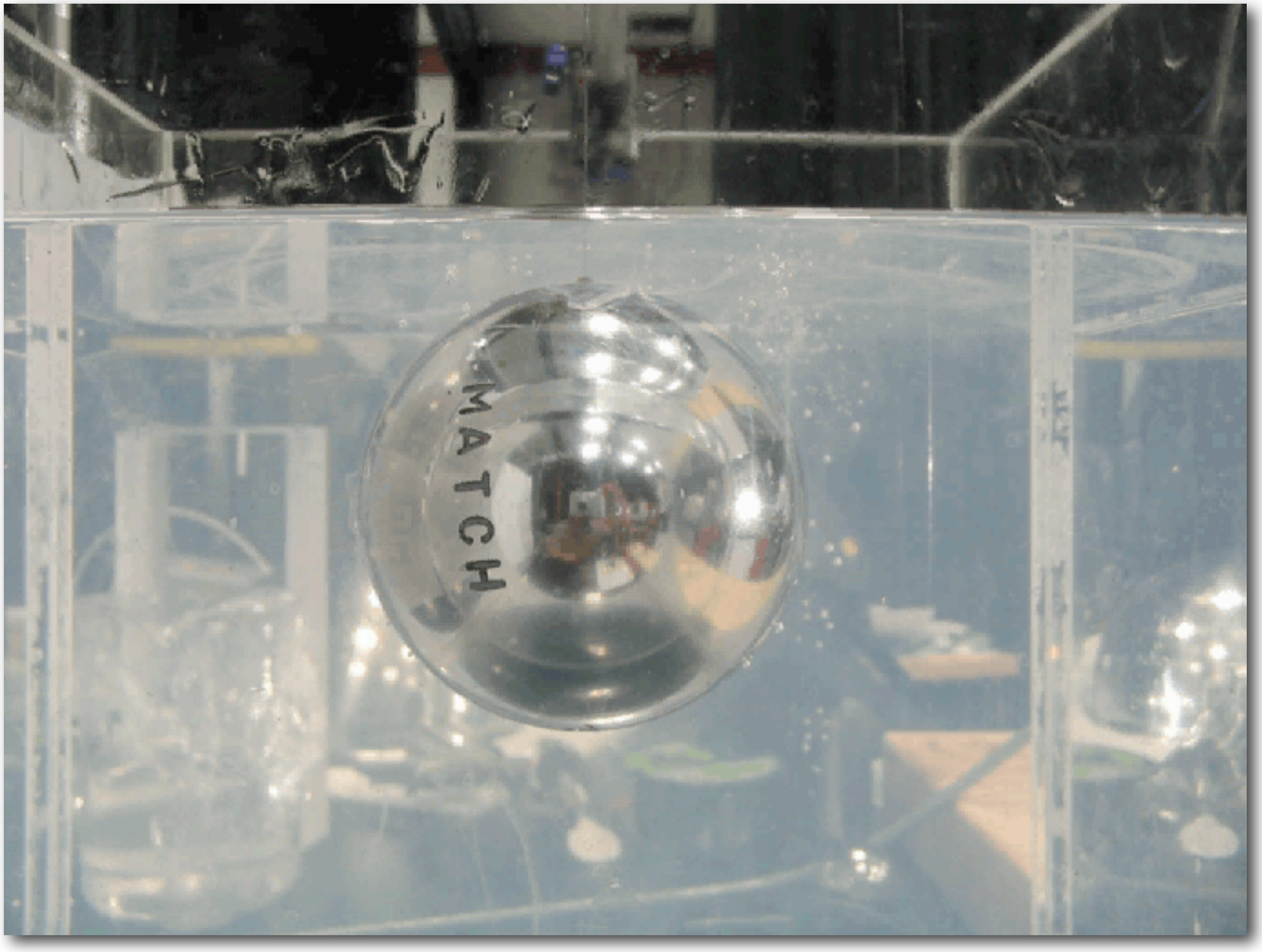
Benchmarking: "Simple" 2D problem





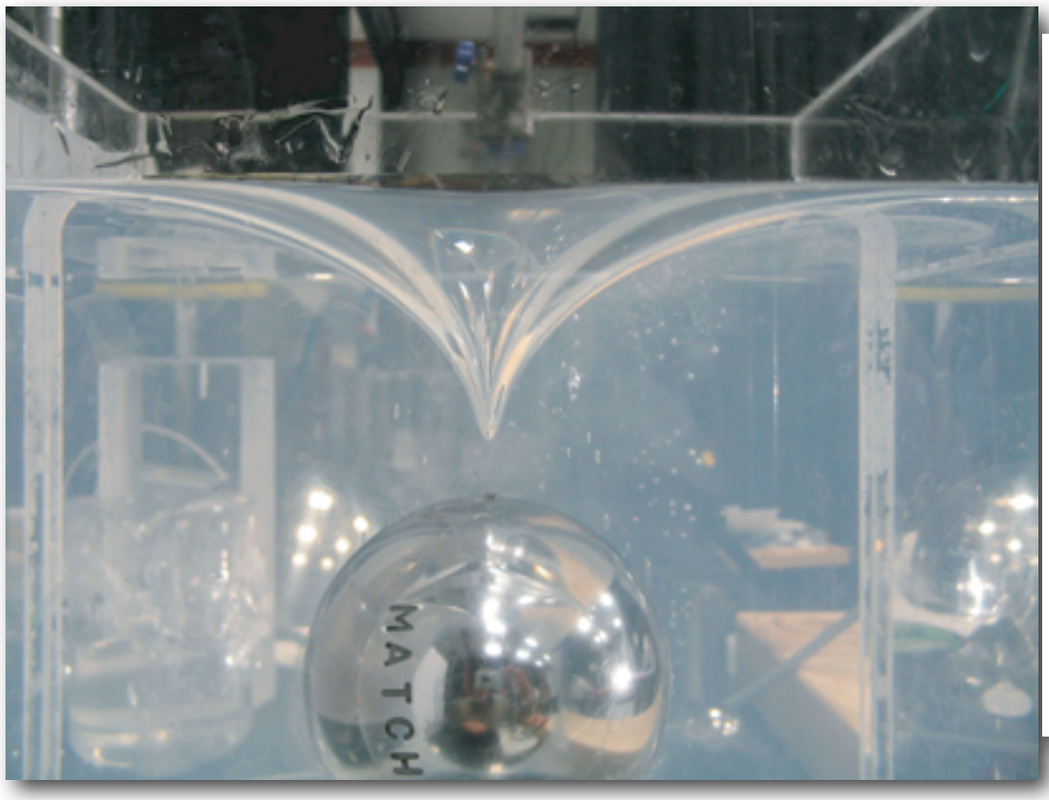


Benchmarking:
"Simple" 3D problem



"Simple" 3D problem

(a) Scaled laboratory experiment



(b) Numerical experiment

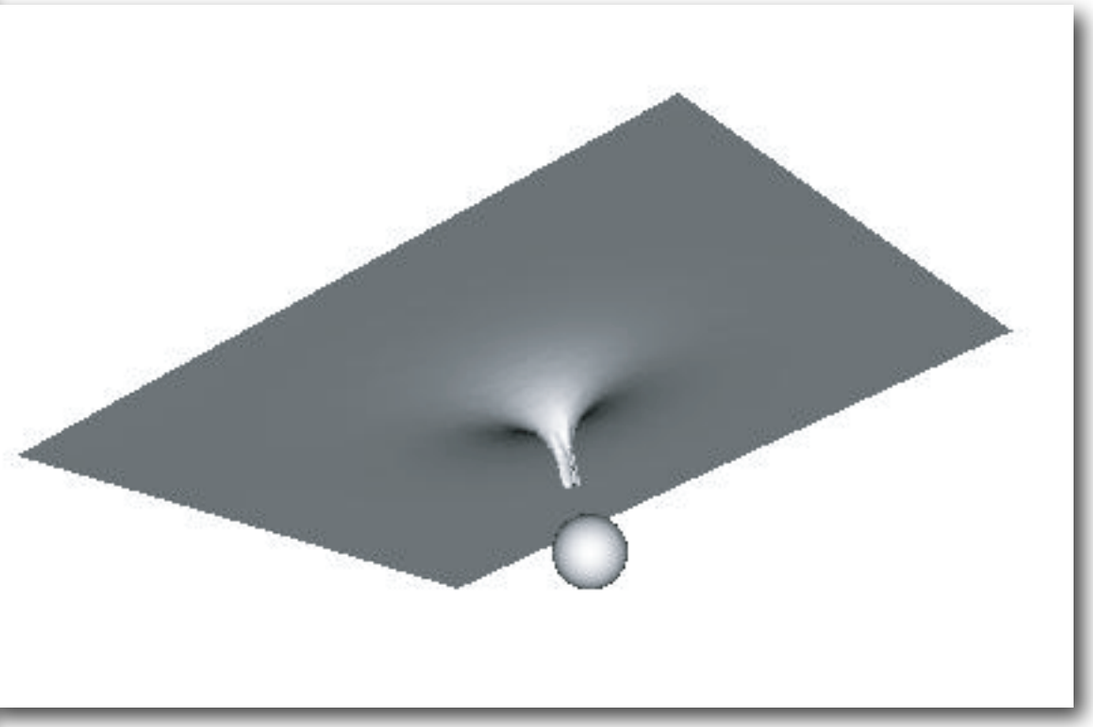
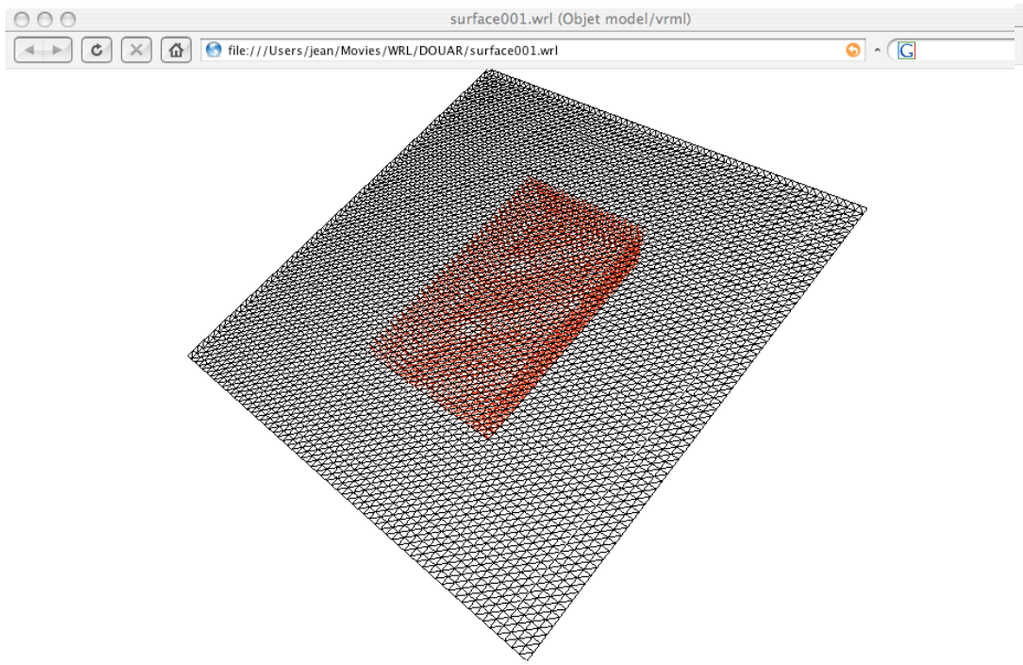
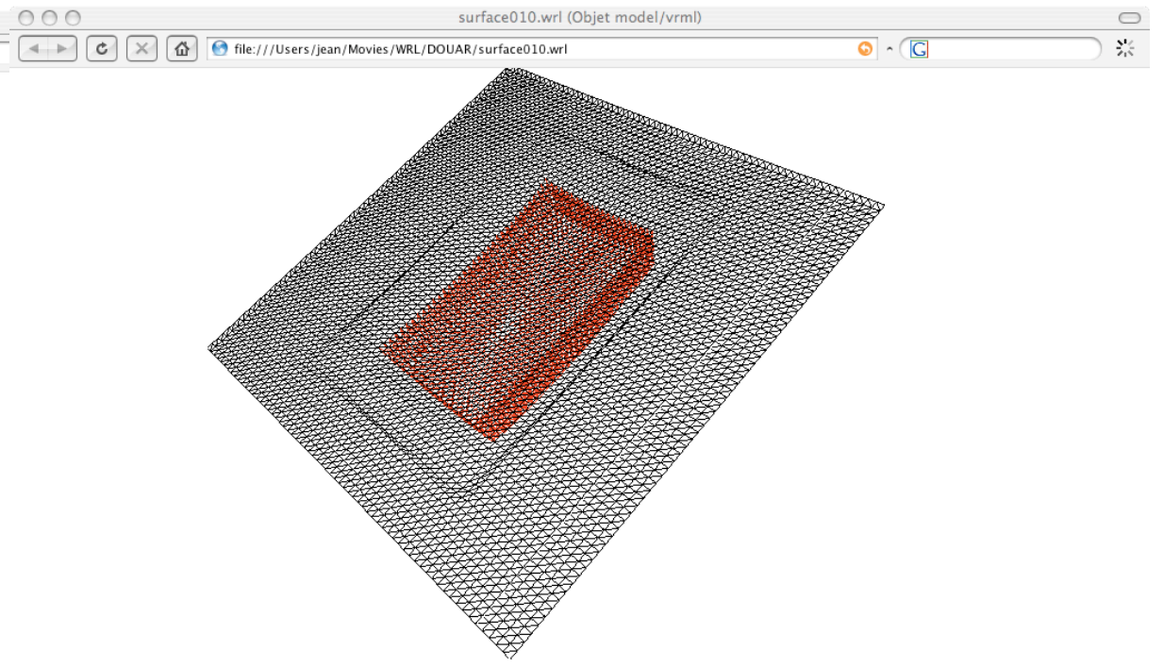
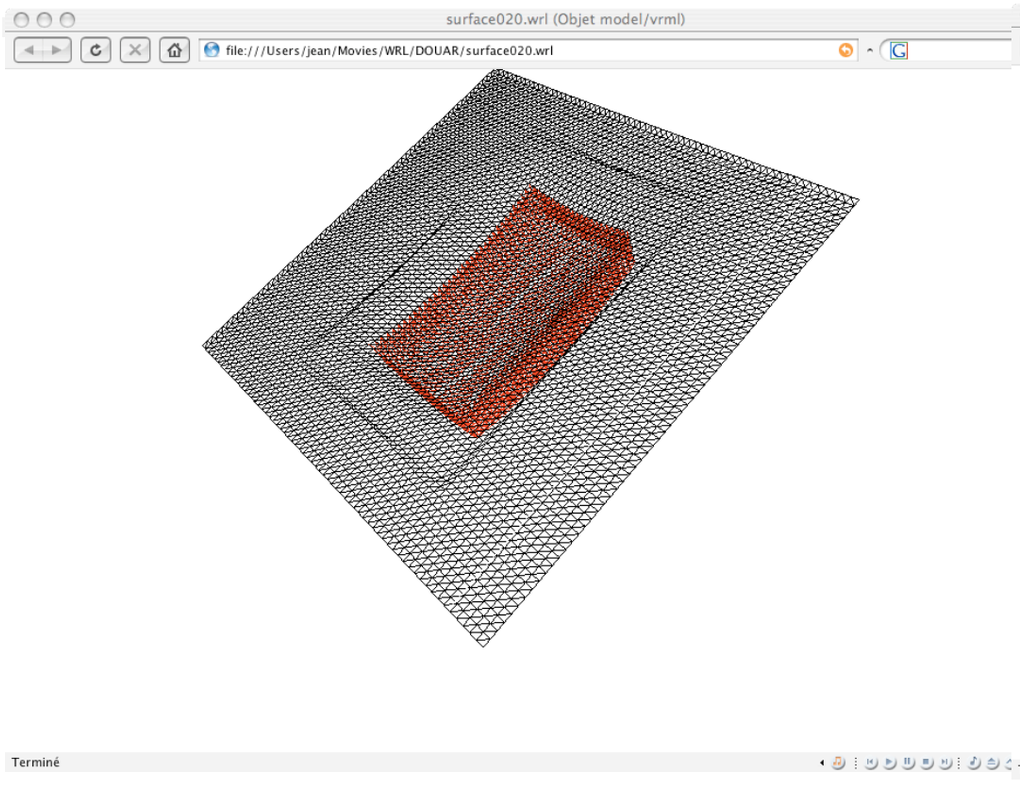
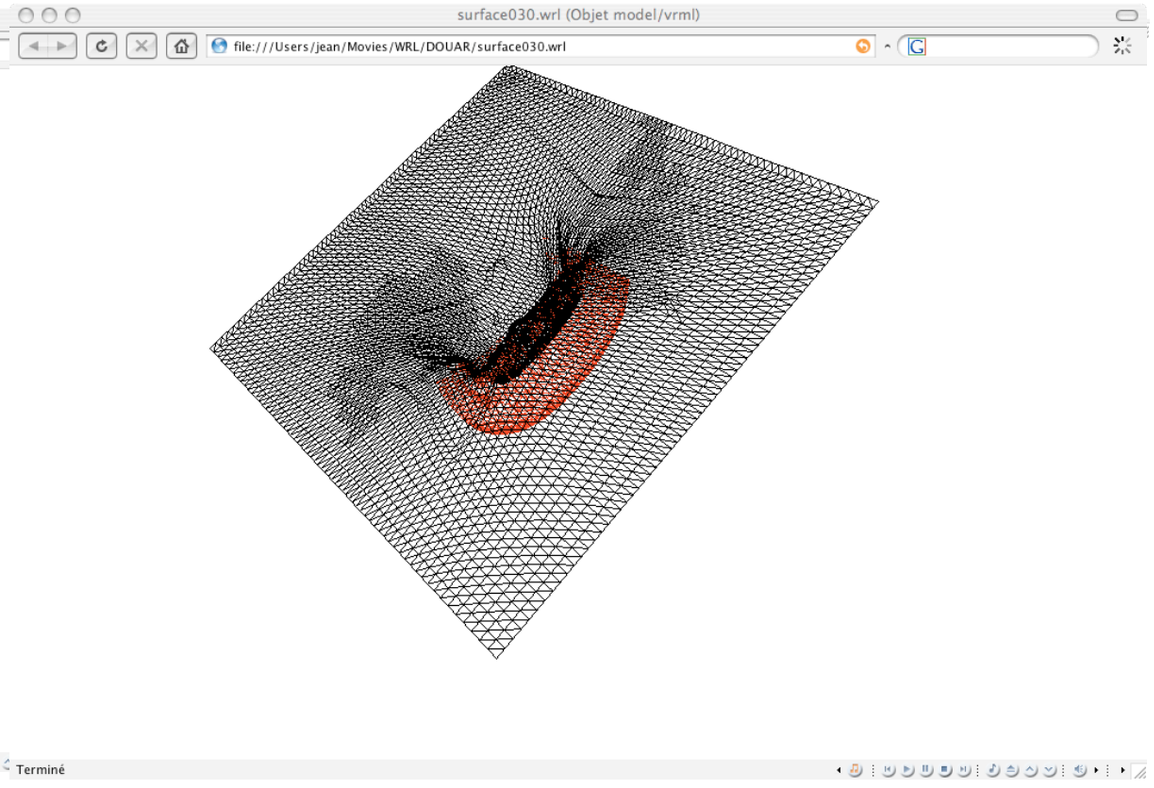


Plate sinking problem









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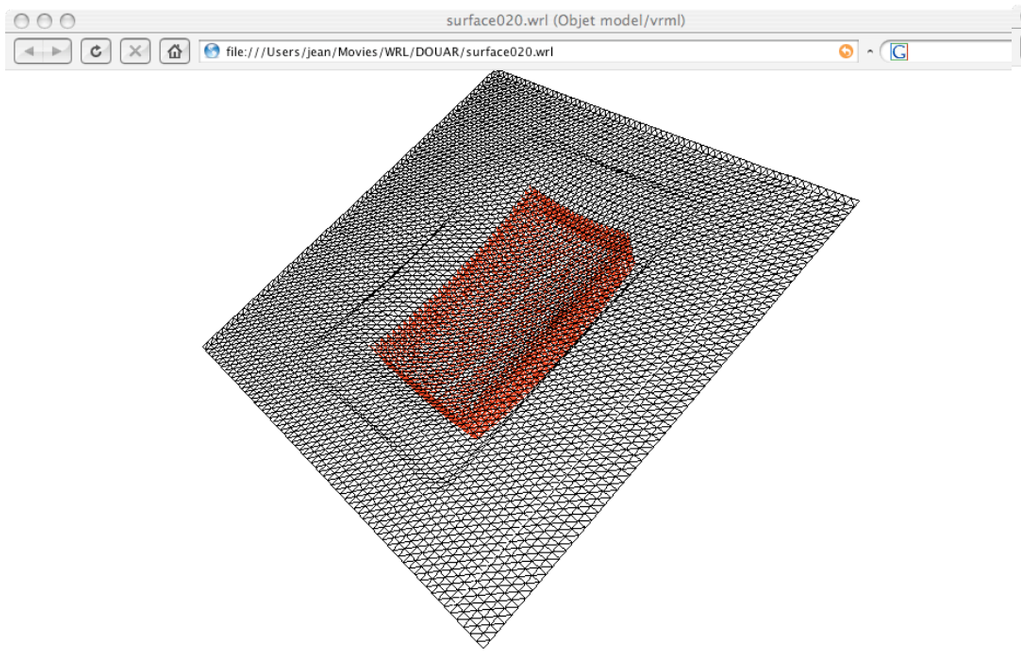

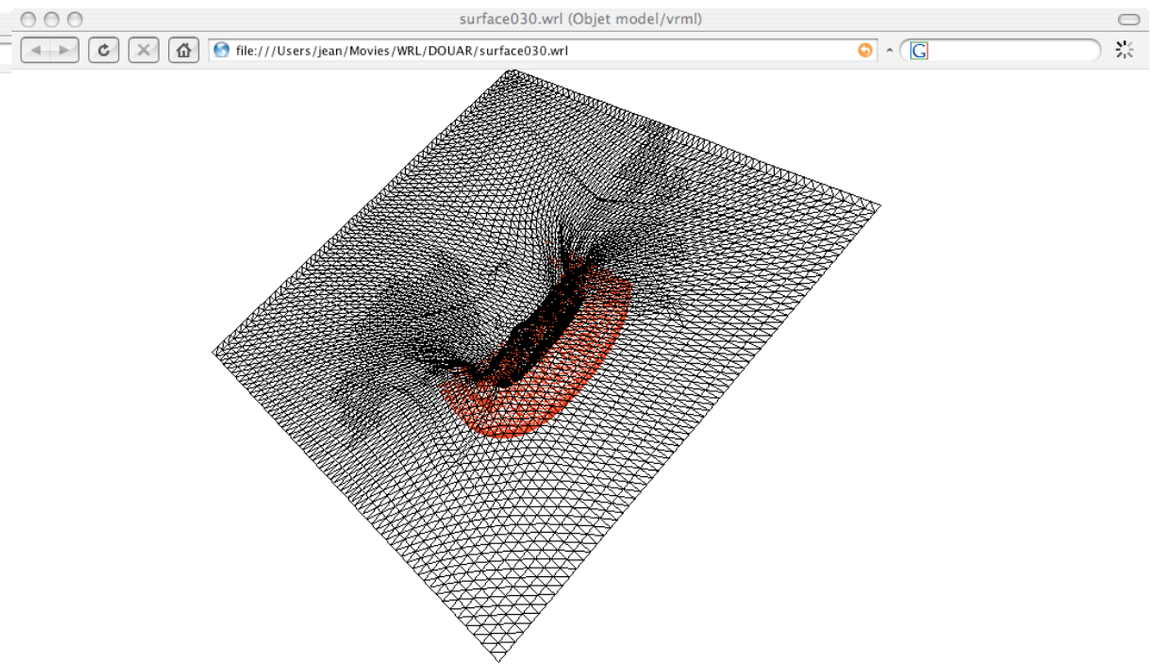

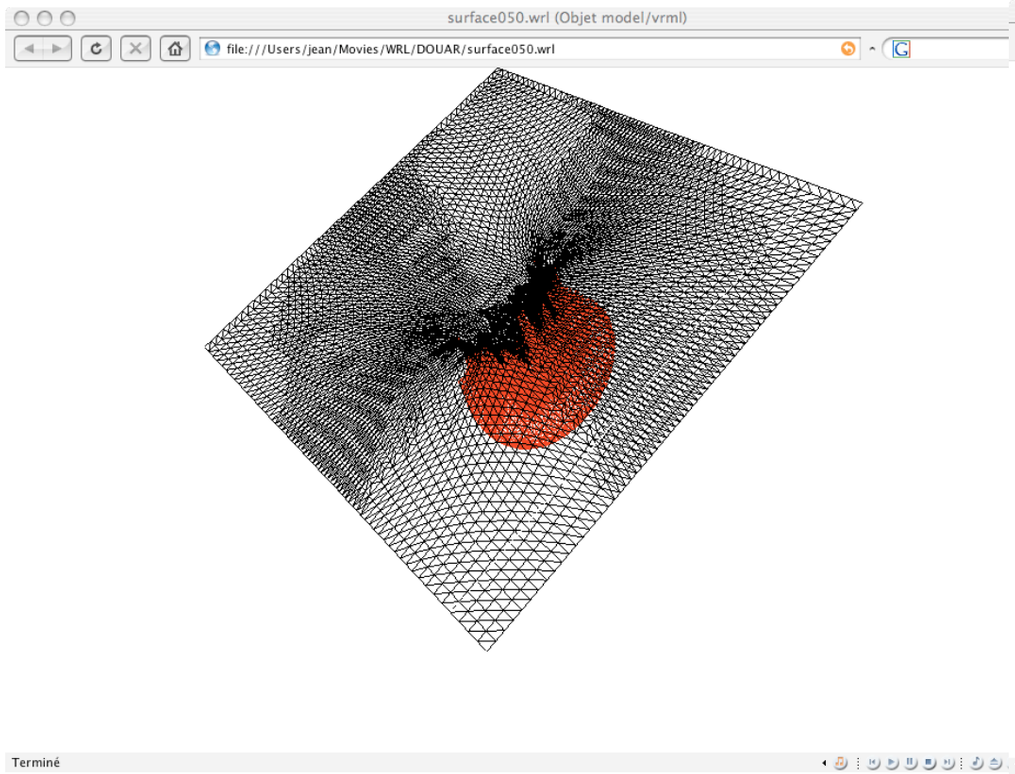

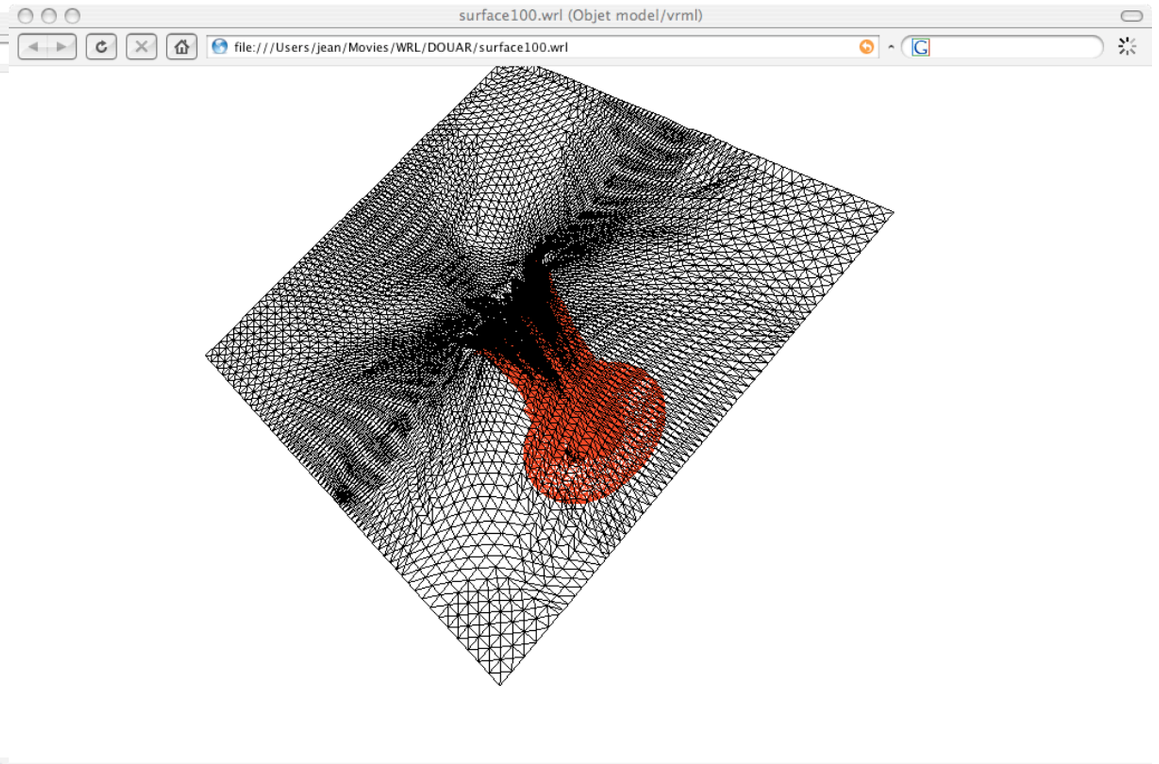

Conclusions

- Erosion plays an important role in dictating the morphology of orogenic zones (and potentially tectonic plate velocities)
- Erosion exhumes geology
- Accurate description of lithosphere-hydrosphere interactions (in 3D) is essential; benchmarking...