Moving into the 3-D Realm of Tectonic Modeling

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I. Introduction

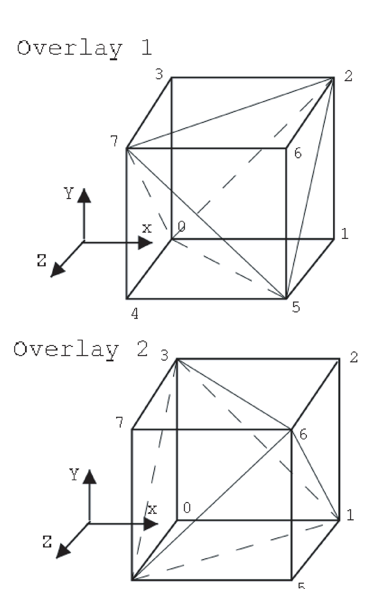
SNAC (**S**tGermai**N** **A**nalysis of **C**ontinua) [Choi *et. al.*, in prep] is a code for modeling numerically the tectonic-scale deformation of lithosphere in 3-D and in spherical coordinate system. Many geophysically interesting problems are inherently 3-D: *e. g.*, propagation of mid-ocean ridge, branching of continental rifts, or crustal response to dynamic mantle source. The curvature of the Earth's surface cannot be neglected any more when the size of domain grows (> ~ 1000 km). However, most of the numerical models have been limited to 2-D or 3-D Cartesian geometry. Equipped with the ability to deal with higher dimensional domain in spherical coordinate system, SNAC will shed light on unexplored domain of computational tectonics. In this poster, we introduce numerical techniques adopted in SNAC and present preliminary results from a model of 3-D graben formation.

II. SNAC: Technical Aspects

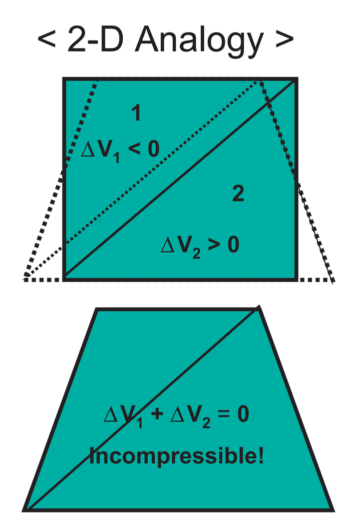
- 3-D Lagrangian Explicit Finite Difference code
  - Solves a force balance equation $\frac{\partial v_i}{\partial t} = \frac{\partial \sigma_{ij}}{\partial x_j} + \rho g_i$
  - Explicit and Lagrangian $v_i(t+\Delta t) = v_i(t) + \Delta t \frac{F_i(t)}{M(t)}$, $x_i(t+\Delta t) = x_i(t) + \Delta t v_i(t+\Delta t)$

Mixed Discretization

- Two overlapped discretization schemes for *mixed discretization*
- Linear tetrahedral element
  - Constant strain-rate within each element
- Zone
  - an 8-node hexahedral element
  - Composed of *two overlays*, each of which is a collection of 5 tetrahedra
  - Symmetric response for symmetric loading

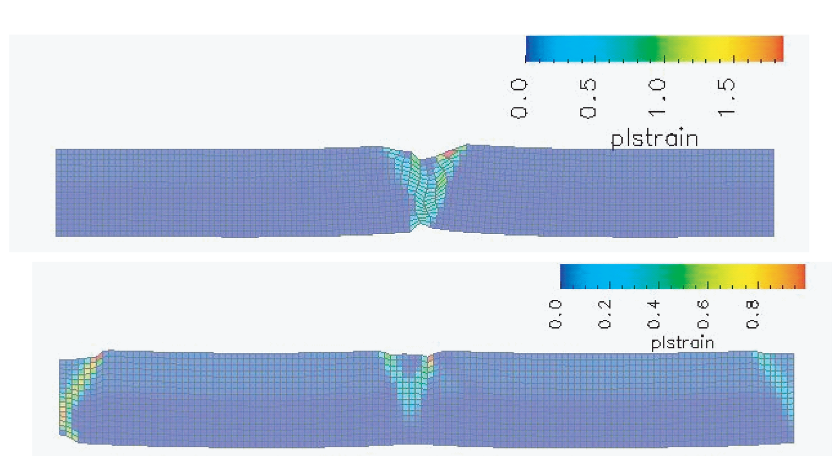


- Tetrahedral elements cannot deform individually without volume change in particular situations (*e.g.* incompressible plastic flow)
- Substitute the *first invariant* of each tetrahedron with that of a *zone*

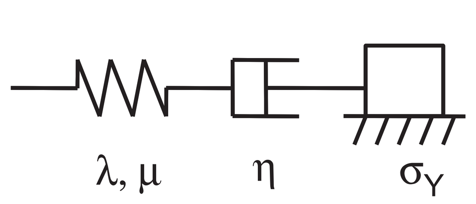


Remeshing

- Lagrangian mesh deforms severely as deformation accumulates.
  - degrades accuracy of the solution
  - eventually leads to crash
- Nodal values: interpolated on the new regular mesh
- Element values: transferred to the nearest neighbor element in the new mesh

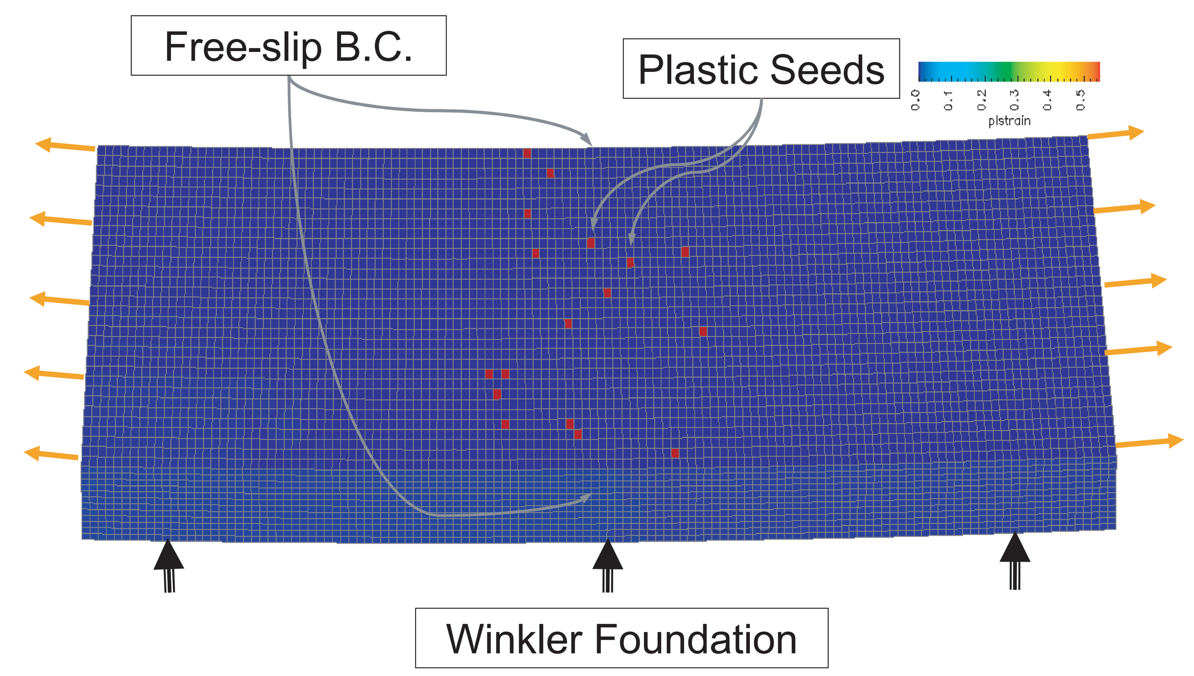


Constitutive Relation



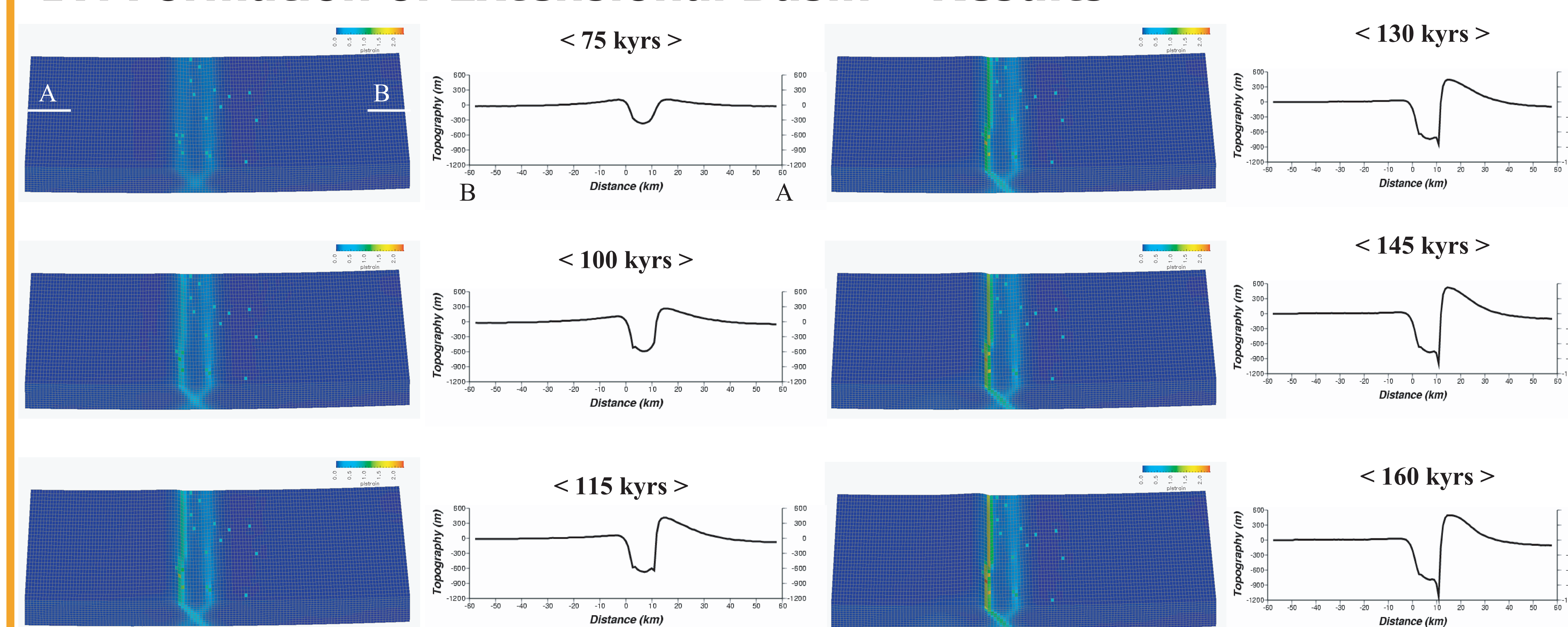
- Adds Rate-dependence to elastoplasticity
- Drucker-Prager or Mohr-Coulomb yield criteria
- Elasto-plastic and viscoelastic rheology as end-members
- Deformation mode is determined by the thermal state when viscosity is temperature-dependent.

III. Formation of Extensional Basin – Model Setup

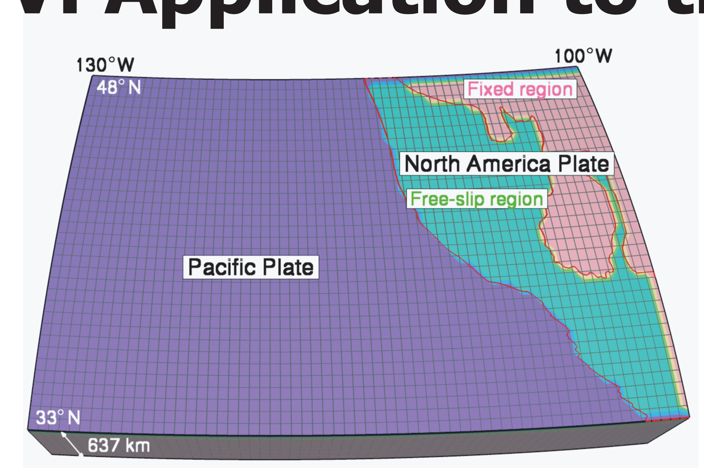


- **Temperautre B.C.**: 0 °C on top, 300 °C on top. Linear radial distribution as I.C.
- **Velocity B.C.**: ±2 °/Myrs w.r.t. the Euler pole at the north pole. Applied only on two side walls (with orange arrows in the left figure).
- **Viscosity**: Temperature-dependent. ~ 10^{28} Pa.sec. → Essentially elasto plastic.
- **Elastic parameters**: λ, μ = 10 Gpa.
- **Plastic parameters**: friction angle = 30 deg, dilation angle = 10 deg, cohesion = 44 Mpa to 4 Mpa at 50 % of plastic strain.
- **Domain size**: Longitude: 87 ~ 93 deg, latitude: 80 ~ 80.45 deg, depth: 10 km (133 x 33 x 13 nodes).

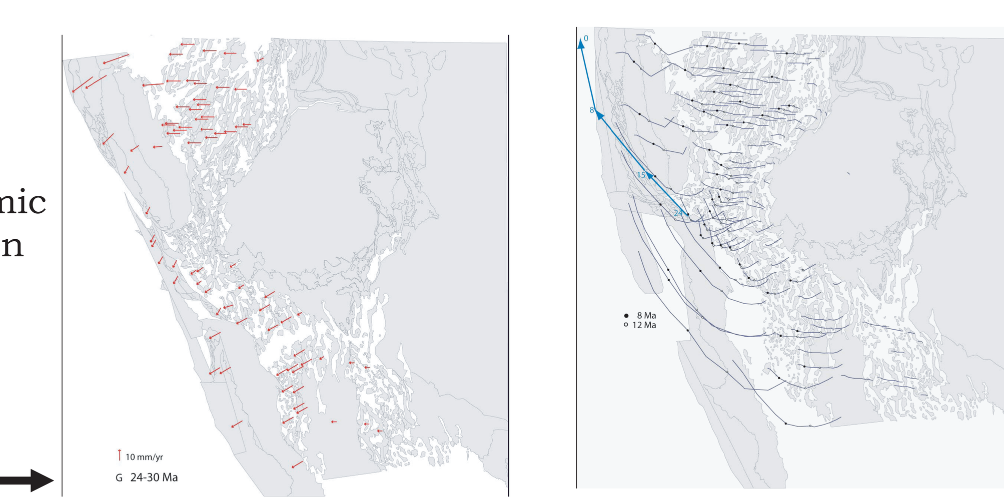
IV. Formation of Extensional Basin – Results



V. Application to the western U.S.



Using SNAC, we can construct a dynamic model which allows detailed comparison between the model outcome and geologically reconstructed deformation history (e.g., McQuarrie and Wernicke, 2005).



[McQuarrie and Wernicke, 2005]

References

1. Choi, E., P. Thoutireddy, L. Lavier, S. Quenette, E. Tan, M. Gurnis, M. Aivazis, and B. Appelbe, GeoFramework Part II: Coupling models of crustal deformation and mantle convection with a computational framework, *in prep.*
2. McQuarrie, N. and Wernicke, B.P., An Animated Tectonic Reconstruction of Southwestern North America since 36 Ma, *Geospheres*, 2005.