FEM models for lithospheric extensional deformation: Application to the North Atlantic

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Finite Element Method

- **Elements, nodes, and interpolation, 1, 2, and 3 D**
- **Constitutive Equation**
- **Element Stiffness Matrix**
- **System Stiffness Matrix**
- **Matrix Solution**
- **Linear and non-linear systems**
- **Lagrangian and Eulerian Systems**
- **Displacement and velocity approaches**

Implementation for lithosphere materials

- Yield stress model including brittle and ductile behavior
- Modeling brittle behavior as plasticity
- What do we do with elasticity?
- How do we handle isostasy?
- Non-linear behavior requires iteration at each time step
- Approaches to FEM modeling of lithosphere deformation
  - **2-D cross section modeling (example to follow)**
  - **2-D map view modeling – thin sheet approximation**
  - **3-D modeling with few elements in depth**
  - **3-D modeling (example to follow)**

Philosophy of using FEM for modeling rifting

- Can be used to build arbitrarily complicated models
  - **Good**
    - can be used to look at a particular rifting event and include local geometry/peculiarities
    - results are often surprising as the model has more ability to incorporate complex iterations
  - **Bad**
    - Run very slowly, you get few model iterations
    - Difficult to really explore parameter space (too many parameters)
    - Difficult to communicate results

Difficult for other users to extend results to their field area

Comparison to simpler models

2-D application to Atlantic Rifting

Baltimore Canyon Trough Model

Observations that motivated the study

Model setup

Results

Parana/Etendeka Model

Main conclusions

Weaknesses in either the middle crust or upper mantle can affect rifting style

Upper Mantle weaknesses “win” in the end

Offset pre-existing crust and mantle weaknesses can create apparent rifting access jumps and asymmetry in rift formation

Offset pre-existing crust and mantle weaknesses are probably a natural result of prior continental collisions

3-D Application to rifting across pre-existing crust and lithosphere heterogeneity

Concept of lithosphere “toughness”

Affects of toughness variation on the form of rifted margins

Model setup

Main conclusions

Lithosphere toughness and strength are different

Lithosphere toughness controls the amount of continental rifting and extension that precedes the initiation of seafloor spreading

Rifting across tough lithosphere produces broad margins and may produce more asymmetry in the conjugate margins

Toughness increases and strength decreases with crust thickness.

Toughness (but not strength) is less sensitive to heat flow

Suggested Reading

Dunbar, J.A. and Sawyer, D.S., 1989, How Preexisting weaknesses control the style of continental breakup, J. Geophys. Res., v. 94, p. 7278-7292.

Harry, D.L., and Sawyer, D.S., 1992, Basaltic volcanism, mantle plumes and the mechanics of rifting: The Parana Flood Basalt Province of South America, Geology, v. 20, p. 207-210.

Harry, D.L., and Sawyer, D.S., 1992, A dynamic model of lithospheric extension in the Baltimore Canyon Trough region, Tectonics, v. 11, p. 420-436.

Dunbar, J.A., and Sawyer, D.S., 1996, Three-dimensional dynamical model of continental rift propagation and margin plateau formation, J. Geophys. Res., v. 101, p. 27,845-27,863.