Gale: Large Scale Tectonics Modeling With Free Software

Gale Adapts to the Terrain

Complexity: Gale solves the Stokes and heat transport equations with a large selection of viscous and plastic rheologies. Material properties are tracked as particles, allowing Gale to accurately track interfaces and simulate large deformations. In addition, Gale has a true free surface and supports a wide variety of boundary conditions, including incompressible, fault, and stress. Thus, while classic analog focus was on progress, Gale has been extended to include diverse processes as a core feature.

Usability: Gale has run on everything from laptops to 200+ processor clusters.

Quality: Gale is executively documented with a full page manual. Computer simulations were performed to see if an accurate rheology can be evolved in 2D extension models. The right half of the sandbox is translated to the right, giving rise to a velocity discontinuity in the middle of the bottom. The box has been extended from 20 cm to 25 cm.

Figure 2: Strain rate invariant for the extension model

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Analog Benchmarks

Buiter et al. (2006) compared the results of numerical and analog sandbox experiments. Figures 2 and 3 show the results of those benchmarks for Gale. While it is difficult to perform exact comparisons, Gale does reproduce the qualitative features seen in other numerical experiments. This serves as a rough test of Gale's Mohr-Coulomb rheology, Stokes solver, and ability to track the surface.

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Geologic Model

Working with Robert Bialas (LDEO), CIG has developed a geologic model to look at the transition from a wide rifting regime to a narrow rifting regime as the rift develops through time. While these models are still rough, they do showcase the ability of Gale to simulate interesting geologic models.

Figure 5. 2D Model of Rift Evolution Under Extension

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Analytic Benchmarks

Circular Inclusion

For incompressible viscous materials, Schmid and Podladchikov (2003) have derived simple closed-form analytic solutions for an isolated elliptical inclusion. This provides a strong test of the ability of Gale to follow a changing surface.

Figure 6. 3D Extension Model With Imported Initial Topography

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Figure 3. Strain rate invariant for the shortening model

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Figure 4. Space dependence of the shortening model. The model starts with a weaker layer sandwiched between two layers of sand. For both models shown in Figures 4 and 5, the crust has a visco-

clastic rheology, with three layers: a purely viscous, a purely plastic, and an impenetrable. Each of the models were run on a Cray C90, the 460 node computer located in the Center of Geophysical and Remote Sensing at CIG. The model covers a region 1000 km x 100 km with a resolution of 2 km x 2 km. For the 2D model, the crust has a viscosity of 10^19 Pas, a thickness of 1 km, and a temperature of 1730 K. The mantle has a viscosity of 10^20 Pas, a thickness of 1 km, and a temperature of 1500 K. The crust is fixed at the bottom and the top is left free. Both models contained 2 million elements, and the entire simulation was run on 256 processors with an average of 10 million elements. Both models used an iterative solver (GMRES). Because we used an iterative solver, we had to modify the cohesion so that it does not soften as the crust is thickened. The model was run with 512 processors and used a direct solver (Mumps). For both models shown in Figure 4, 3, the crust has a visco-

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Figure 8. A purely viscous material starting with a sinusoidal pressure and a stress-free boundary.

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Figure 7. Strain rate invariant and velocity of the circular inclusion benchmark. The model starts with a uniform bed of sand and a purely viscous material embedded inside. The right half of the sandbox is translated to the right, giving rise to a velocity discontinuity in the middle of the bottom. The box has been extended from 20 cm to 25 cm.

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Figure 1. Circular Inclusion

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Figure 9. Space dependence of the shortening model. The model starts with a uniform bed of sand and a purely viscous material embedded inside. The right half of the sandbox is translated to the right, giving rise to a velocity discontinuity in the middle of the bottom. The box has been extended from 20 cm to 25 cm.

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