Testing the upper-mantle seismic signature of plume-lithosphere interaction in the northern East-African Rift

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Introduction

Below the northern East African Rift two low seismic velocity zones are imaged. **Are these due to the rising thermal anomalies?** We will explore this hypothesis by generating synthetic tomography from models of the convective destabilization of hot mantle.

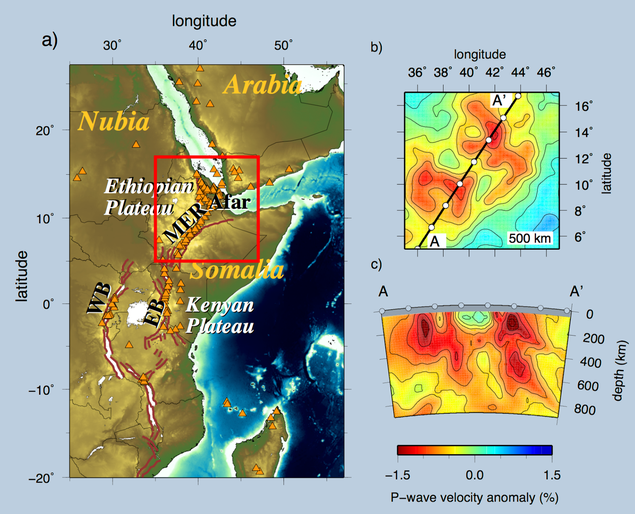

Figure 1: The northern East African Rift and slices from the P-wave tomographic model NEAR-P15 [1].

Geodynamic to Seismic

Both Rayleigh Bénard convection and Rayleigh Taylor instabilities are generated using by solving for modified Stokes flow in a Cartesian box using the code Stag3D [6]. Temperature and pressure are converted to mineral phases assuming a pyrolite composition for the mantle and harzbugite for the lithosphere. This gives the anharmonic seismic velocity. This is corrected for attenuation using the Q_g model [4].

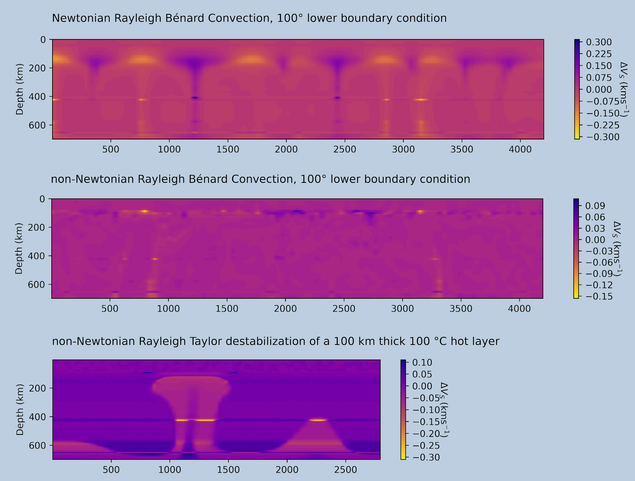

Figure 2: 2D slices through the model domains for Rayleigh Bénard convection with a Newtonian rheology, a non-Newtonian rheology, and the Rayleigh Taylor destabilization of a hot layer.

References

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Rayleigh Bénard or Taylor?

For Raleigh Bénard (RB) convection the wavelength between plumes, λ, varies as $Ra^{1/6}$ [3]. For Raleigh Taylor (RT) destabilization of a hot layer, λ, varies as a linear function of the model height [5]. The observed spacing of the two low seismic velocity structures is ~ 700 km (Figure 1). We find that for RB convection this implies a $10^6 < Ra < 10^7$ (e.g. Figure 3). For RT destabilization this is consistent with a model aspect ratio of 3x3x1 (Figure 4a). Plume development for RT destabilization is also time dependent with early, mid and late stage plumes (ES, MS, and LS, Figure 4b).

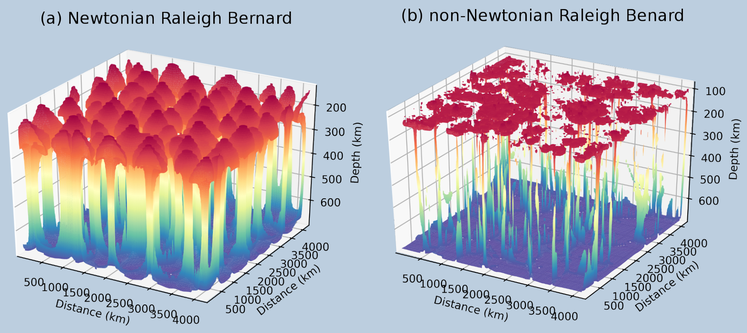

Figure 3: RB convection for (a) Newtonian and (b) non-Newtonian creep with a 100 °C hot lower boundary condition.

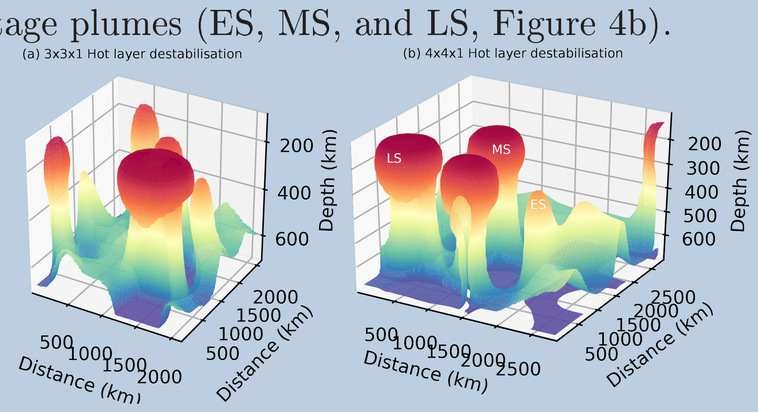

Figure 4: RT destabilization for a 100 °C 100 km thick hot layer. Aspect ratios of (a) 3x3x1 and (b) 4x4x1. ES - Eary stage; MS Mid-stage; and LS Late stage plumes.

Synthetic Tomography: Rayleigh Taylor wins

It was found that while the spacing of Newtonian RB plumes was consistent with observations, the anomalies are too weak. The RT destabilization of a hot layer however gives a pattern of seismic anomalies that matches the observations (Figure 5). The RT destabilization of a 200 °C hot layer perhaps has a magnitude reduction in seismic velocity that is in closer agreement to the observed anomalies (Figure 6).

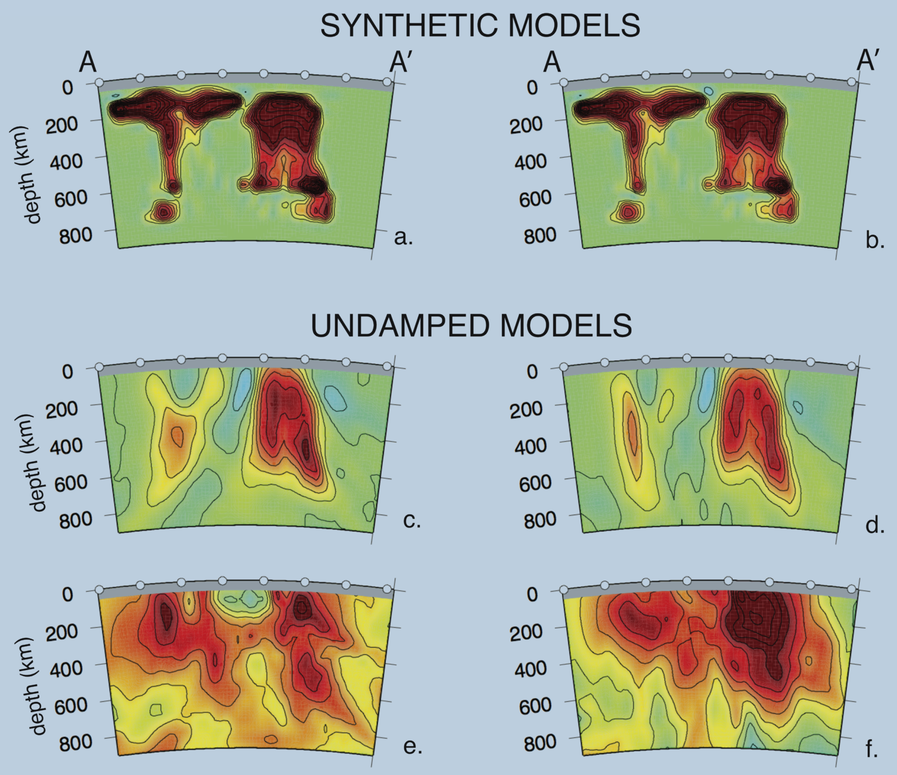

Figure 5: Conversion of RT destabilization (Figure 4a) to synthetic seismic tomography using the same parameters as for the observed tomography (Figure 1).

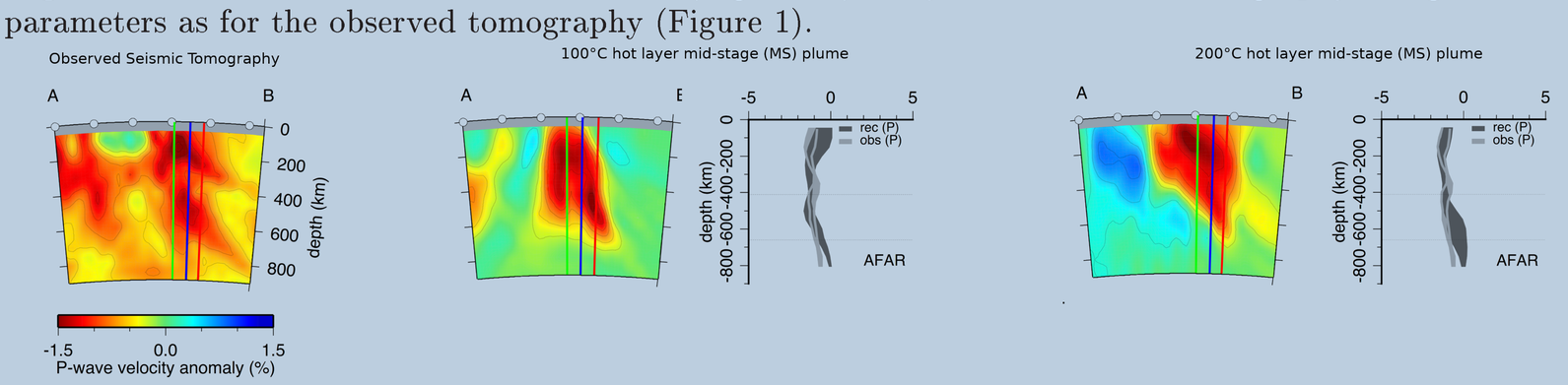

Figure 6: Comparison of the observed magnitude of V_P below Afar with two mid-stage plumes (MS in Figure 4b) with different hot layer temperatures.

Conclusions and Implications

1. The thermal anomalies below Afar and the Main Ethiopian Rift are the form of rising plumes.
2. Seismic tomography from the dense array of seismometers in the northern East African Rift is consistent with the Rayleigh Taylor-like destabilization of a hot layer of mantle at or below the 660 km discontinuity.
3. The plume-like structures are not secondary plumes from a stalled super-plume, but the hot material has its origins in the lower mantle. The hot material subsequently destabilized.
4. One possible mechanism for such destabilization of ponded material is internal heating, which can give additional buoyancy to thermo-chemical plumes [2].