
QUANTITATIVELY TESTING NUMERICAL MODELS OF CONTINENTAL BREAK-UP

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With increasing computational power the complexity of numerical models of continental break-up is ever increasing. High resolution two and three dimensional models show a rich set of behaviours in terms of rift architecture and asthenosphere to lithosphere interaction. Historically these models tend to be compared qualitatively with geological evidence from passive margins. However, to understand how continental break-up occurs we would argue that it is necessary to test plausible dynamic scenarios against a wide range of observations. For example, the structure of the upper mantle below Afar, at the northern end of the largest active rift zone on the planet, is uncertain. Based on geochemical and seismic data, there is ongoing debate as to the existence, or not, of a large thermal plume, and if the region is currently rifting or has achieved break-up [1, 2]. The likelihood of each argument can be assessed through quantitative comparisons between physically plausible forward models and observational constraints.

We have developed a relatively simple 2-D geodynamic model of decompression melting during extension that incorporates melt retention and dehydration. This model can explain the seismic structure below the East Pacific Rise as imaged by surface waves, including a double low velocity zone, with triangular anomaly above 50-60 km depth due to dry melting and low velocity layer between 60 and 200km depth mainly resulting from solid-state anelasticity in hydrated mantle [3]. When the same simple 2-D numerical model of extension is tested against the rock geochemistry and seismic structure of the upper mantle below Afar in the northern East African Rift, we find that extension above a 1450 °C hot upper mantle matches the timing and composition of the Pleistocene lavas. Furthermore, recent S and P-wave tomographic models of the region show a complex strucutre, with zones of fast and slow anomalies within the upper mantle [4]. By converting a simple 3-D numerical model of the growth of Rayleigh Taylor instabilities to synthetic tomographic images, we find that the tomographic models inverted from the true observation can be explained simply by the growth of small plumes at a wavelength of roughly 500 km. These plumes form due to an increase in temperature from 1350 °C to 1450 °C at the base of the model domain (at a depth of 700 km).

By comparing the predicted melt chemistry and seismic structure from forward numerical models against the observations, we therefore find that that it is most likely that the Afar region is still in a state of continental extension and that the upper mantle below Afar contains small-scale convective instabilities. These instabilities rise from the below the 660 km discontinuity, most probably due to the ponding of a deeper larger plume-like structure. These idealised forward numerical models therefore suggest a more complex interaction between rifting and deep mantle plumes, and they demonstrate that simple geodynamic structures can appear complex due to the resolution of seismic studies.

References

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