Three-dimensional numerical assessment of mid-ocean ridge migration and its influence on mantle flow and material transport

Report by Loes van Dam

In order to gain a more comprehensive understanding of the various factors that affect mantle flow at migrating mid-ocean ridges, I have used the InterRidge Fellowship to work with the Earth Modeling Group at the University of Oslo (UiO). I was specifically interested in learning from Dr. Clint Conrad and Dr. Fabio Crameri. During my time there, we have set up a numerical model that is ideally suited for comparisons with recent analogue modeling studies that I have done as part of my PhD studies with Dr. Chris Kincaid at the University of Rhode Island (URI). Since observational data collection for mid-ocean ridges, and especially the mantle, is both difficult and costly, the combination of numerical and analogue modeling studies is a unique opportunity to leverage the benefits of each method for a result that we can be more confident in.

In the past years, I have run three-dimensional analogue experiments to investigate the importance of ridge migration on upwelling in an isoviscous, isothermal reservoir of glucose syrup. While these experiments result in valuable insight into the first-order processes that govern material transport towards the ridge, they are limited by design. Due to the size of the reservoir, migration distances cannot go beyond 1,000 kilometers and transform offsets cannot be larger than 400 kilometers. Thermal effects, whether from a heated boundary layer or a plume, are difficult to control precisely in the laboratory.

To rectify some of these limitations, we turn to numerical modeling. The code we have used is StagYY (Tackley, 2008), with minor changes to suit our needs. For analysis, further calculations, and plotting we have used StagLab (Crameri, 2018). An initial set of two-dimensional models probed the appropriate boundary conditions for our purposes. The model had to simulate mantle flow in the upper mantle realistically, but with prescribed boundaries that are reminiscent of the reservoir used for analogue models. This assumes that rheological differences between the upper and lower mantle are great enough to warrant the use of a rigid or free-slip boundary. We implemented a true migrating ridge, rather than using a moving bottom boundary to simulate this indirectly (Figure 1).

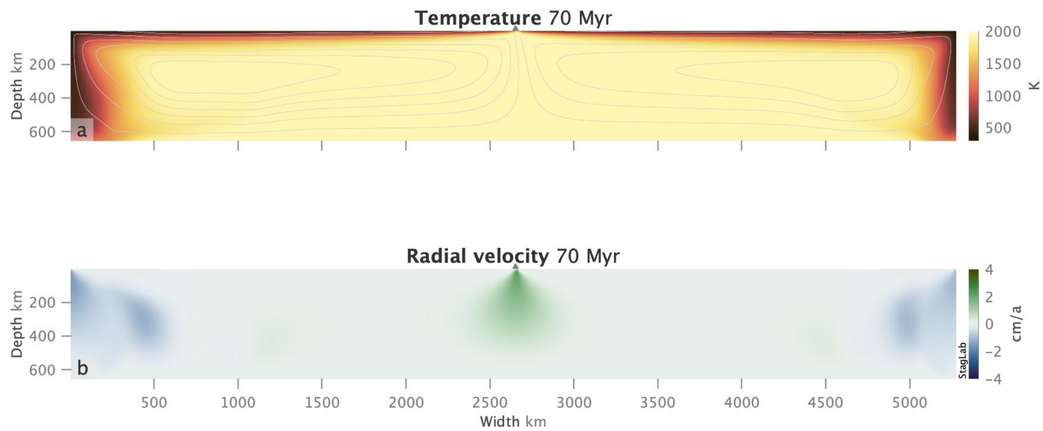

Figure 1: Plot of (a) temperature that highlights mantle flow patterns, and (b) vertical velocity that shows areas of enhanced upwelling beneath a migrating mid-ocean ridge.

This setup was then used to run experiments that mimic those from the analogue model. These results highlight the importance of three-dimensionality in geodynamic studies. Adding complexity incrementally, we began studying the influence of a migrating ridge on plumes of various strengths in two dimensions and later in three dimensions (Figure 2). We also implemented a transform offset through the velocity boundary conditions, and considered how a migrating ridge might impact a uniformly heated thermal boundary layer at the base of the transition zone. This work builds on in-progress research at URI as well as that of other researchers (e.g. Kincaid et al., 1996).

Now that the model is set up and verified, we are working to tie the two modeling methods together to tell a comprehensive story of melting and material transport at migrating mid-ocean ridges. With the help of the InterRidge Fellowship, I was able to: connect with a research group that has very similar interests to me, open a door for continued collaborations going forward, and learn valuable new skills in the field of numerical geodynamic modeling.

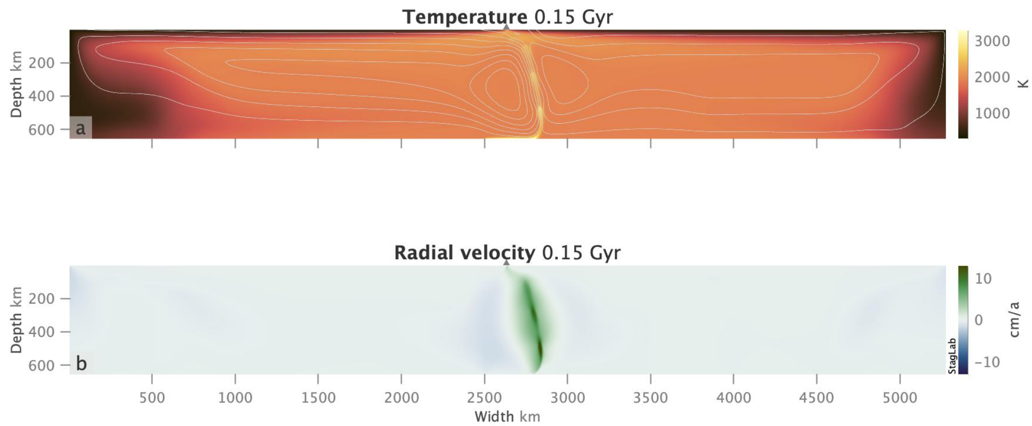

Figure 2: Plot of (a) temperature that highlights mantle flow patterns, and (b) vertical velocity that shows areas of enhanced upwelling beneath a migrating mid-ocean ridge with a heated patch at the bottom causing the formation of episodic plumes.

<u>References</u>

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