Numerical modeling for the geodynamic formation of the Tamu Massif the largest single volcano on Earth

Jinchang Zhang[1] (jzhang@scsio.ac.cn), Min Ding[2], Zhiyuan Zhou[1]

[1]CAS Key Laboratory of Ocean and Marginal Sea Geology, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, China [2]School of Earth and Space Sciences, Peking University, Beijing, China

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Background

- Shatsky Rise, No.3 largest oceanic plateau
- ODP, IODP cored basaltic rocks
- Formed at ridge-ridge-ridge triple junction
- Plume-ridge interaction
- Two important questions:
  - ~Where do oceanic plateaus come from?
  - ~How do these volcanic mountains erupt?

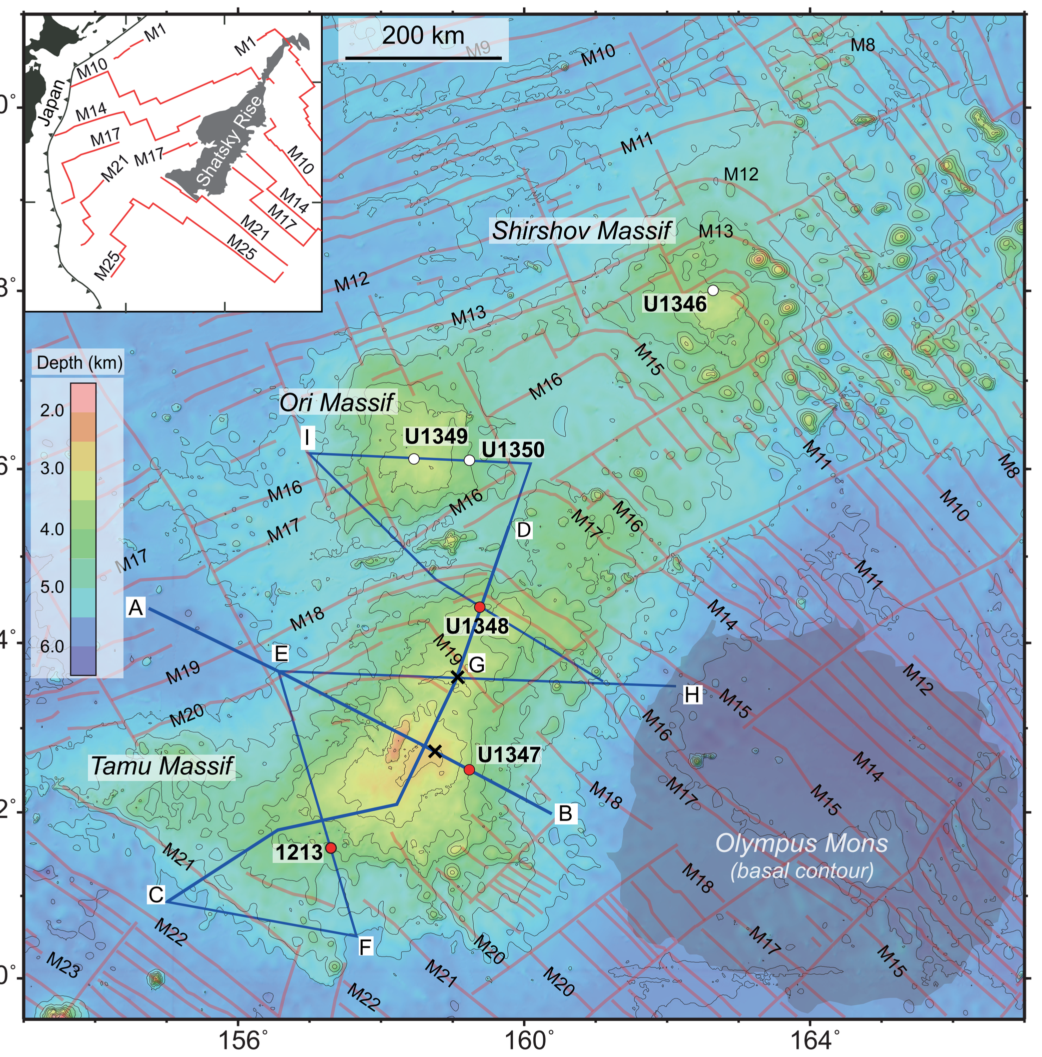

Figure 1. Shatsky Rise bathymetry, tectonic map, and seismic lines. Background is satellite-predicted seafloor bathymetry with 500-m contours. Red lines denote magnetic lineations and fracture zones (Nakanishi et al., 1999). Blue lines are Multichannel seismic (MCS) lines. Red filled circles are ODP and IODP drill sites. Dark area in lower right corner represents the basal contour of Olympus Mons (Mars) at the same scale. Letters identify MCS profiles in Figs. 3 & 4.

Morphology

- Huge, dome-like edifice
- Gentle flank slopes, declining from summit
- Different from seamounts in the oceans

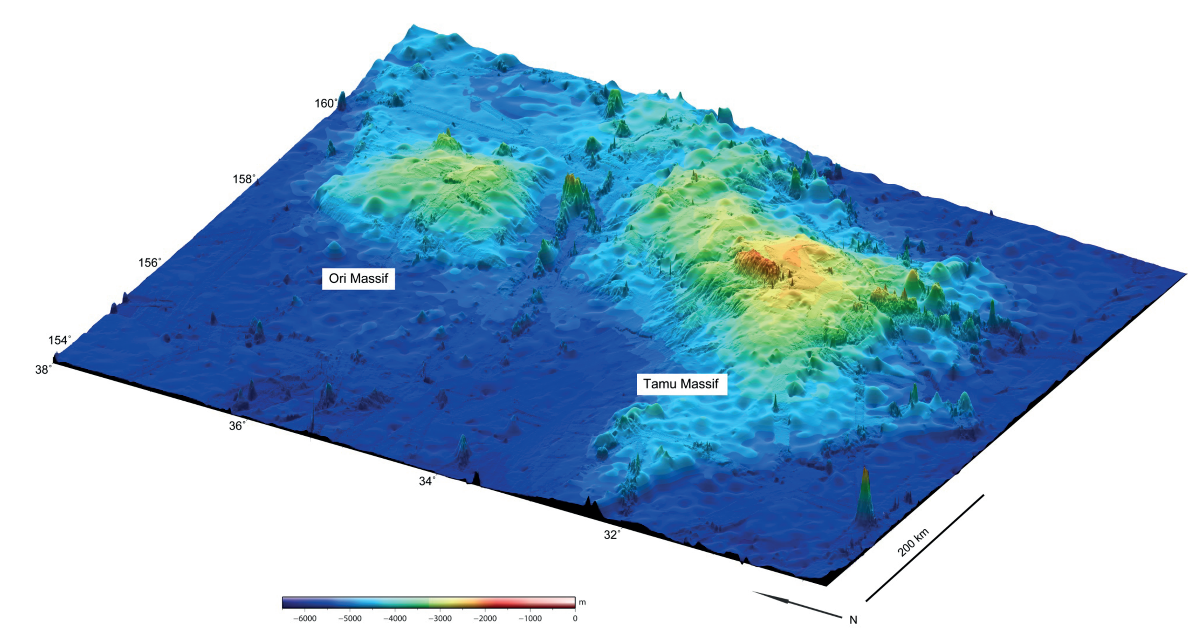

Figure 2. Oblique perspective view of Tamu Massif, & Ori Massif.

Crustal Structure

- Shallow flank slopes (<0.5°-1.5°) constructed by sub-parallel lava flows emanating from the volcano center and extending hundreds of km down to the surrounding seafloor
- Formation by extensive and far ranging lava flows emplaced at small slope angles
- Tamu Massif is an immense single, central volcano
- Moho is shallow (~7 km) beneath normal crust near the distal flanks of Tamu Massif and dips (~3°-5°) downward towards the center, reaching maximum thickness of ~ 30 km
- Seismic Moho (reflection and refraction) generally matches the Airy isostatic Model

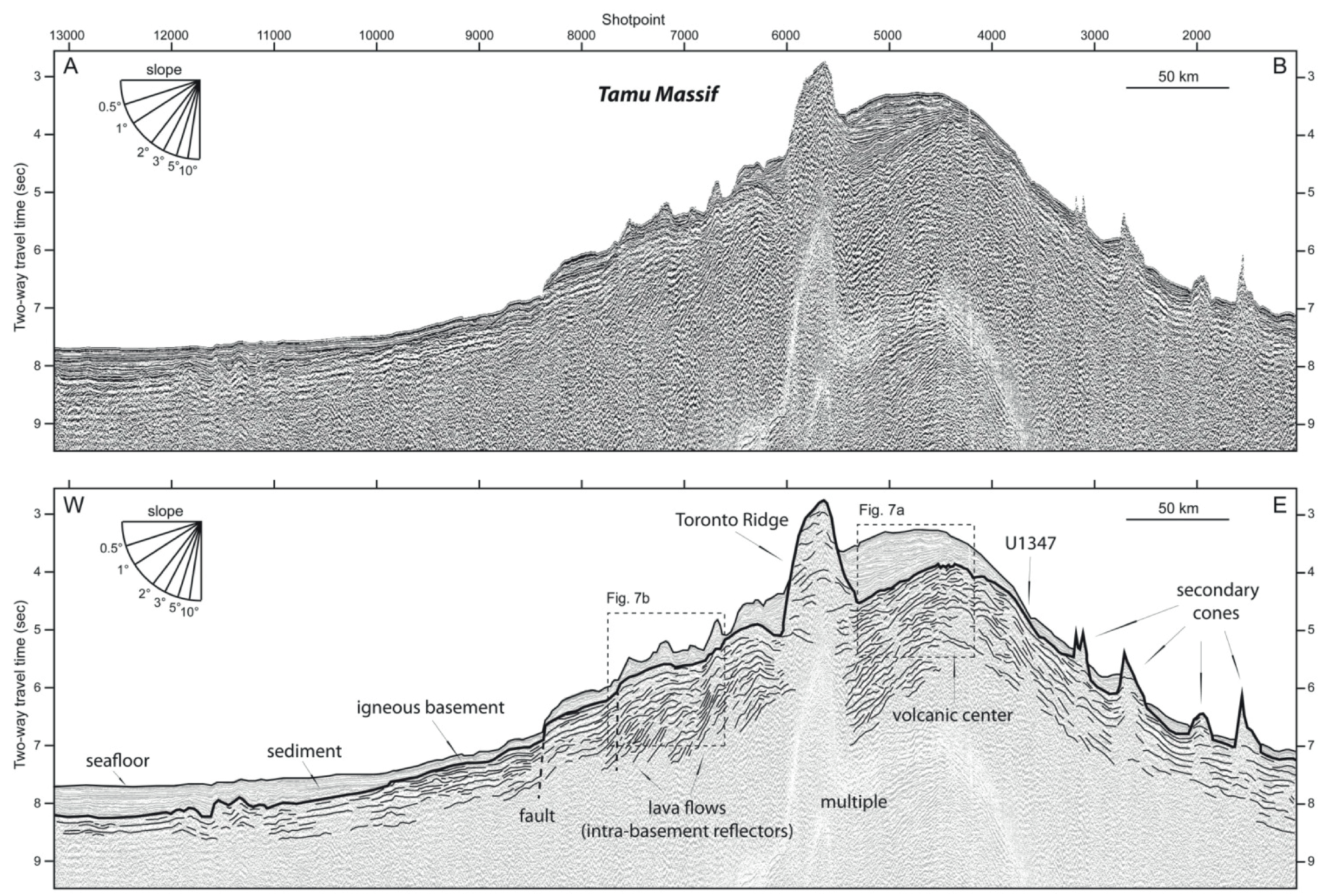

Figure 3. MCS reflection profile of Line A-B, modified from Sager et al. (2013). Top panel shows uninterpreted MCS data whereas bottom panel shows geologic interpretations. The heavy black horizons represents the seafloor and sediment-basalt interface (igneous basement). Thin dark lines represent selected intra-basement reflectors (lava flows) (Note: for clarity, not all intra-basement reflectors are highlighted in this and other large scale figures). Dashed lines represent faults. The arrow labeled "U1347" shows the position of that drill site. Slope indicator refers to the seafloor (vertical exaggeration = 37:1).

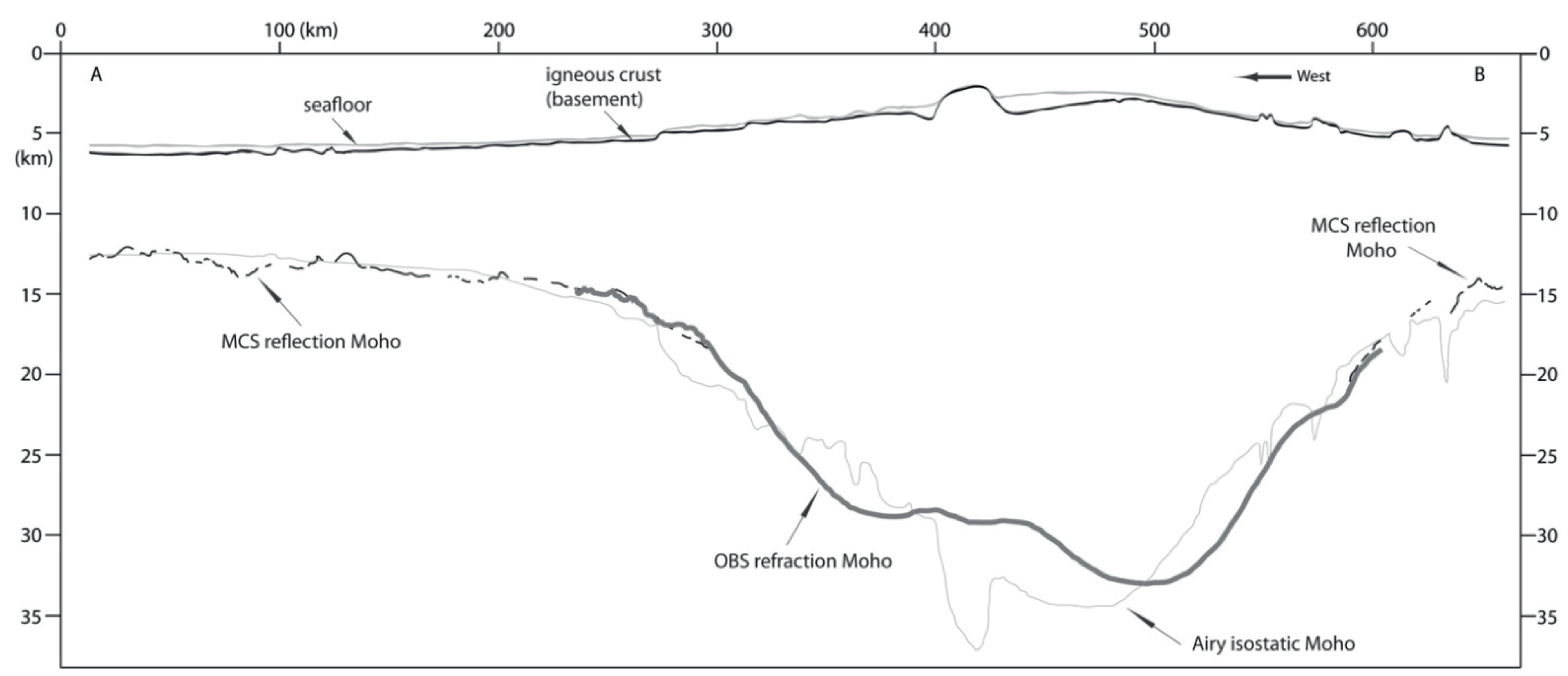

Figure 4. Crustal structure of line A-B, across the center of Tamu Massif. The light gray and black lines represent the seafloor and top of igneous crust, respectively. The intermittent heavy black lines show the MCS reflection Moho. The heavy dark gray line shows the Moho traced by OBS refraction data (Korenaga and Sager, 2012). The light gray line shows the predicted Moho from Airy isostasy.

Numerical Modeling

- The fast ridges are SW and SE branches (both 10 cm/yr) and the slow ridge is NE branch (3 cm/yr). *Note that the triple junction moved towards NE together with the formation of Shatsky Rise, and the NE branch has been subducted underneath Aleutian.
- For upwelling velocity structure, the slowest-spreading branch (the NE branch), model predicts a significantly stronger along-axis velocity increase toward the triple junction (Georgen and Lin, 2002).
- For thermal structure, the two fastest-spreading branches (SW and SE branched in this case) dominate the thermal structure of the region, and the temperature increases toward the triple junction (Georgen and Lin, 2002). *Note that the temperature increases sharply with depth, especially >20 km depth mostly >1000 °C . The visible temperature gradients only show up in a very thin layer (<20 km deep) relative to the 100 km thick model.

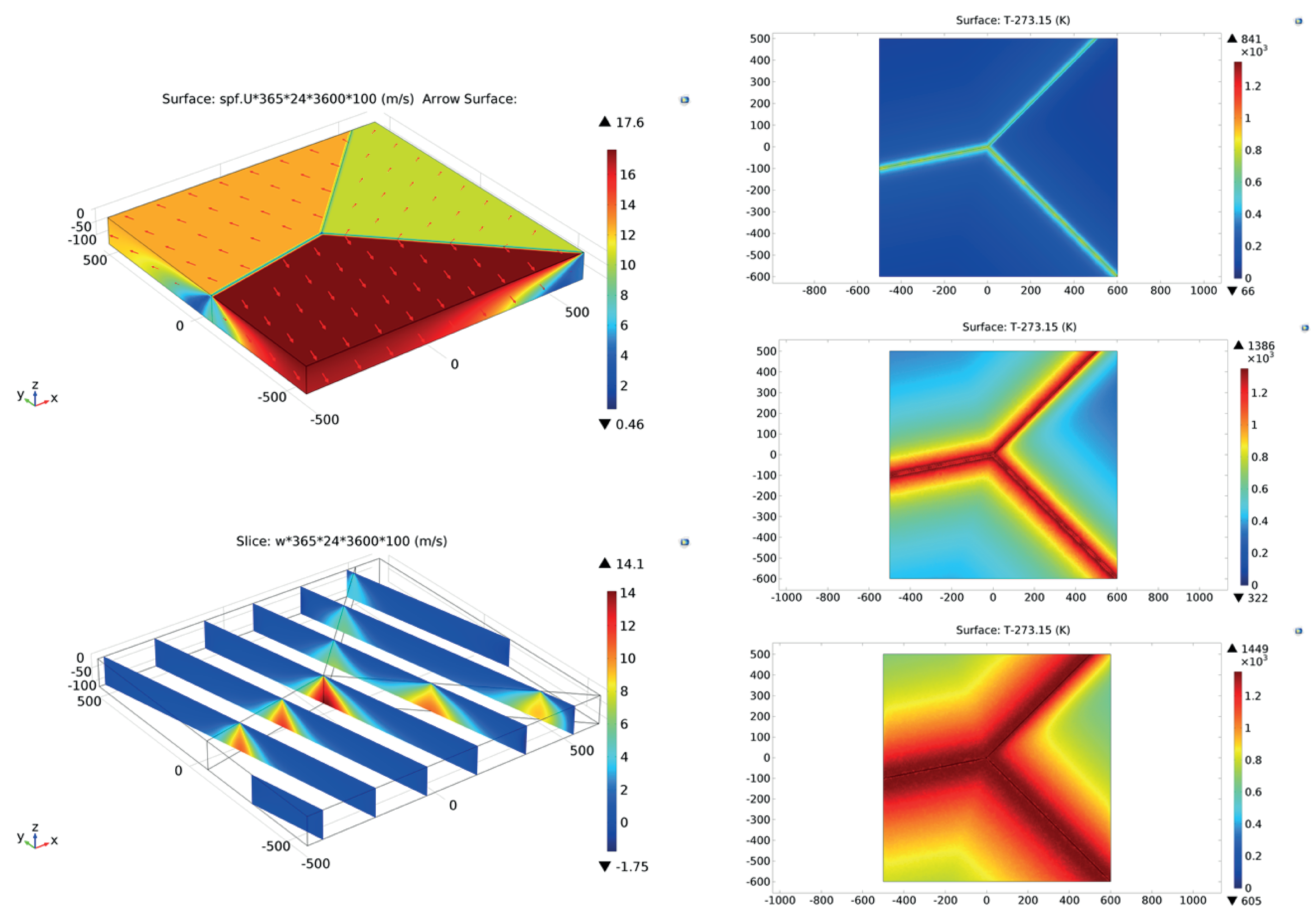

Figure 5. 3D velocity and temperature structure of of ridge-ridge-ridge triple junction of Shatsky Rise, from COMSOL Multi-Geophysics. Top left shows surface velocity. Bottom left shows upwelling velocity. Three right panels show temperature slices at 1, 5, & 10 km depths.

What Next

- Calculate the degree of melting in the mantle, and consider variable reference viscosity for the case of temperate- and pressure-dependent viscosity
- Add a hotspot to numerical model to simulate the plume-ridge interaction
- Given the total crustal volume from seismic and bathymetry studies, see how modeling can fit: solely by triple junction or mantle plume? or their combination?