Consequences of 3-D flow on crustal production along the Lau back-arc spreading center

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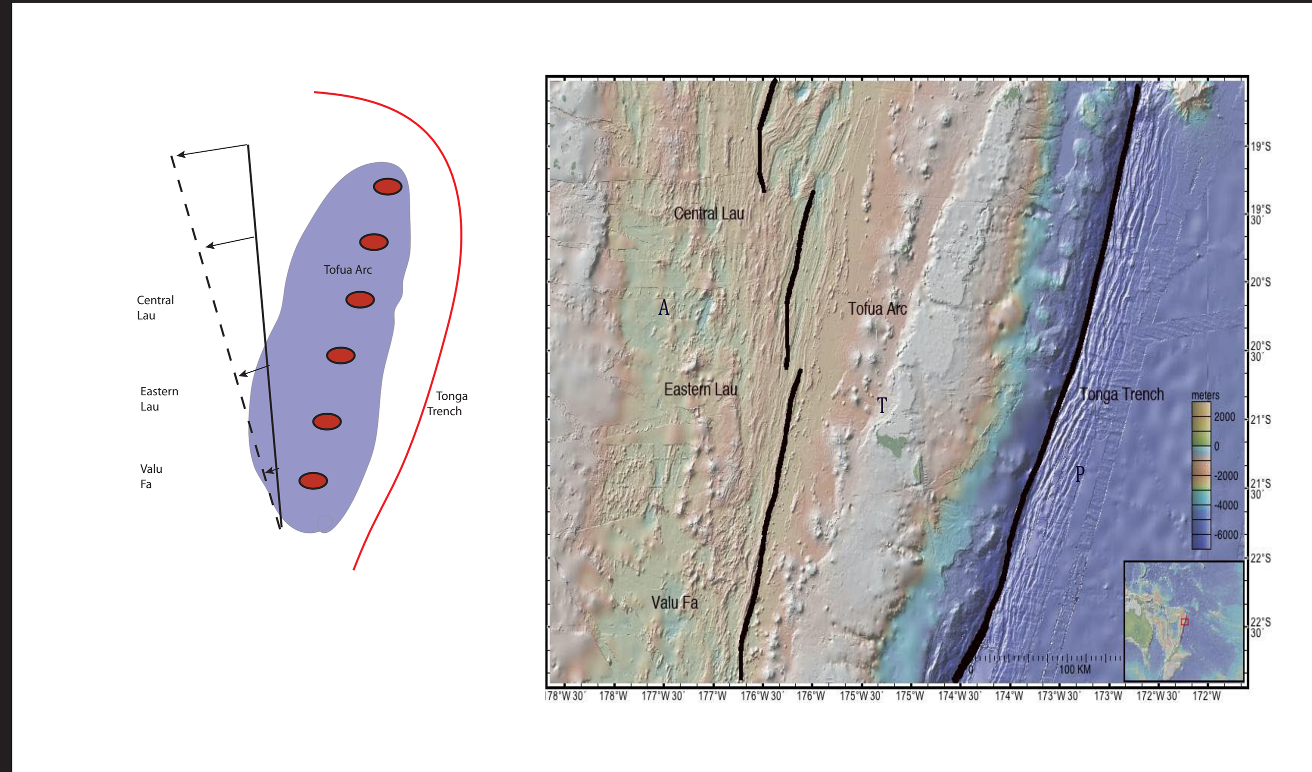
Introduction

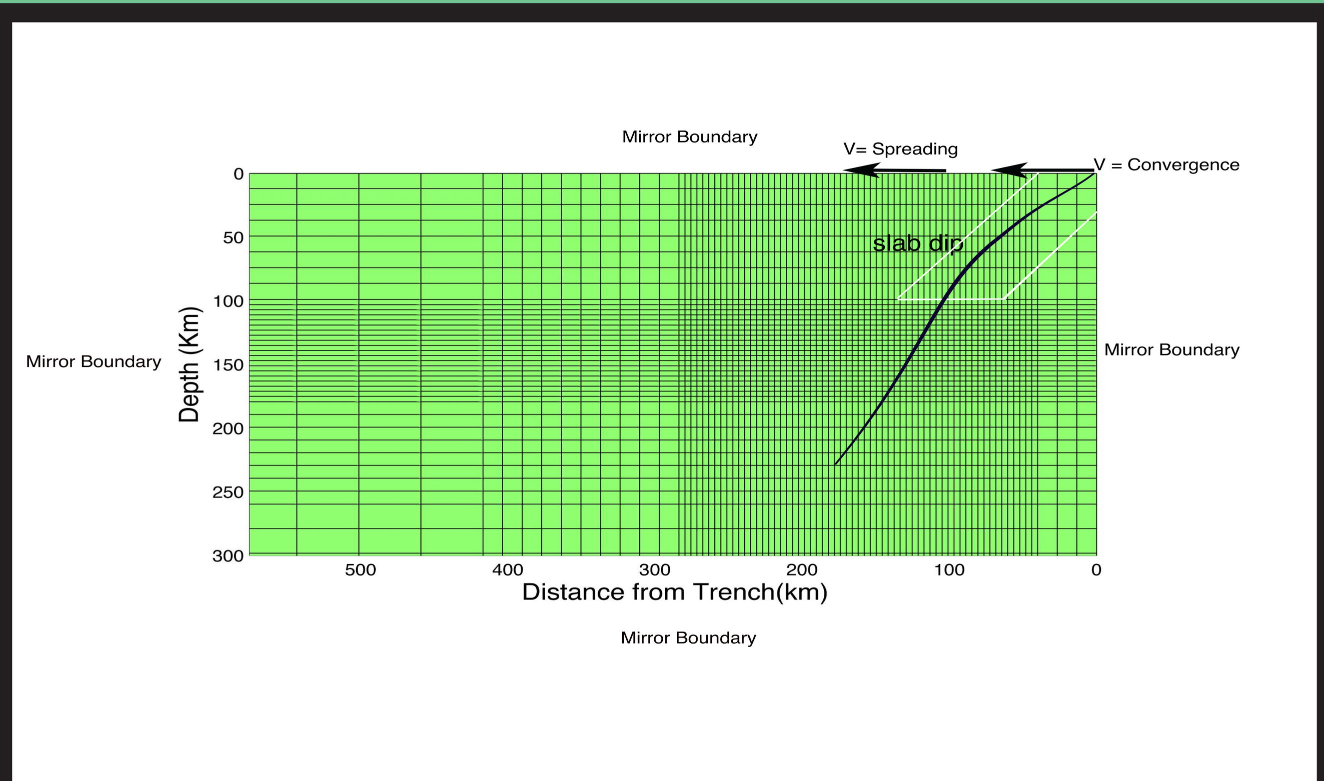
Observed axial morphology of Valu Fa (VF) and Eastern Lau (EL) (southern and central regions along the Lau back-arc spreading center suggest that VF is more magmatically robust than EL despite EL spreading nearly twice as fast as VF. Geochemical and geophysical studies show a gradiational decrease in subduction enhanced melting moving north from VF to EL. Also, geochemcial studies detail a rapid stepwise decrease in subduction influence and melt production as the spreading center axis sweeps away from the Tofua Volcanic-Arc. Furthermore, EL produces an anomolously thin crust for a robust spreading center. While 2-D numerical studies show a decrease in subduction influence and melting going from VF to EL, they have difficulty explaining the thinning of EL's crust. To explain this observation, we run 3-D (CitcomS) numerical experiments.

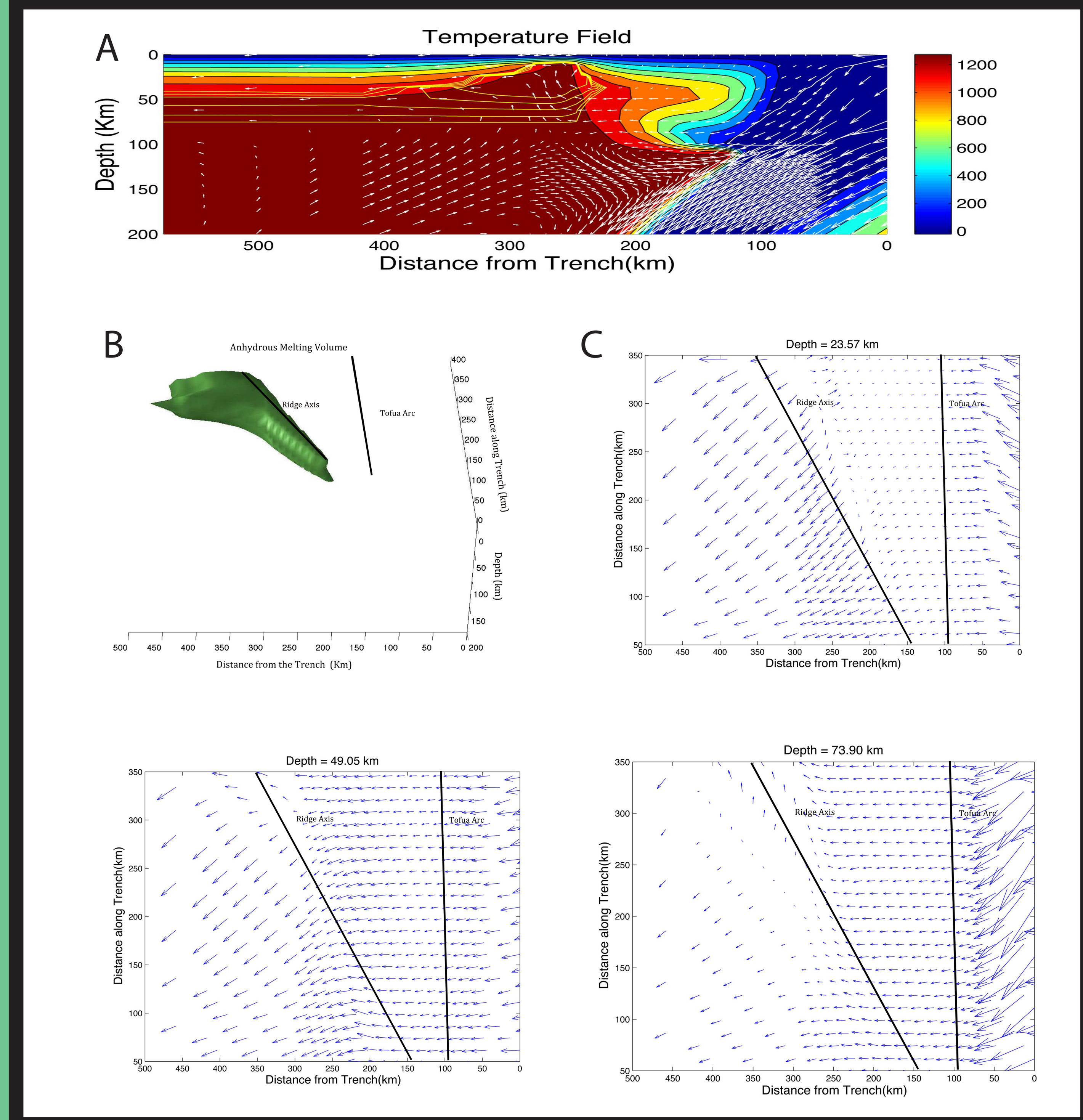


Cartoon/Map of the Tonga trench and Lau back-arc (Above)

Bathmetric map of the Tonga Trench and Lau back -arc spreading center. Thick lines west of the Tofua Arc represent spreading centers. A,T,P represent the Australian, Tonga and Pacific plate respectively.

Cartoon overhead map of the Tonga Trench - Lau back-arc spreading center. The red line represents the Tonga Trench line. The red ovals represent the Tofua volanic arc. The blue region represents an approximation of the area hydradted by Tonga's subducting slab. The solid black line represents Lau's ridge axis. The arrows represent ridge migration, with larger arrows being faster. The dashed black represents the location of Lau's ridge axis after it has migrated





1. 3-D Model, Anhydrous Melting (Above)

A. 2-D slice of the initial 3-D modeling at comparable plate boundaries today. The color bar refers to temperature in Celsius, the white vectors refer to flow velocity with the size of the vector indicating magnitude of flow, yellow contours represent the area of melt fraction with each contour representing 1% steps in melting. The white contour represents the area of weak nodes, which ranges from one order of viscosity reduction towards the edges of the contour and five orders of viscosity reduction in the center of the contour.

B. Above is the 3-D plot of 4% melt fraction of the initial 3-D model. Thick black lines represent Lau's ridge axis and the Tofua Arc. Melting is anhydrous.

C. Three cross sections of mantle flow at depths 23.57, 49.05 and 73.90 km respectively. Blue vectors represent mantle flow velocity in the direction pointing. Larger arrows represent a higher velocity while small arrows represent a smaller velocity. Thick black lines represent the spreading ridge axis and Tofua Arc.

Boundary Conditions (Left)

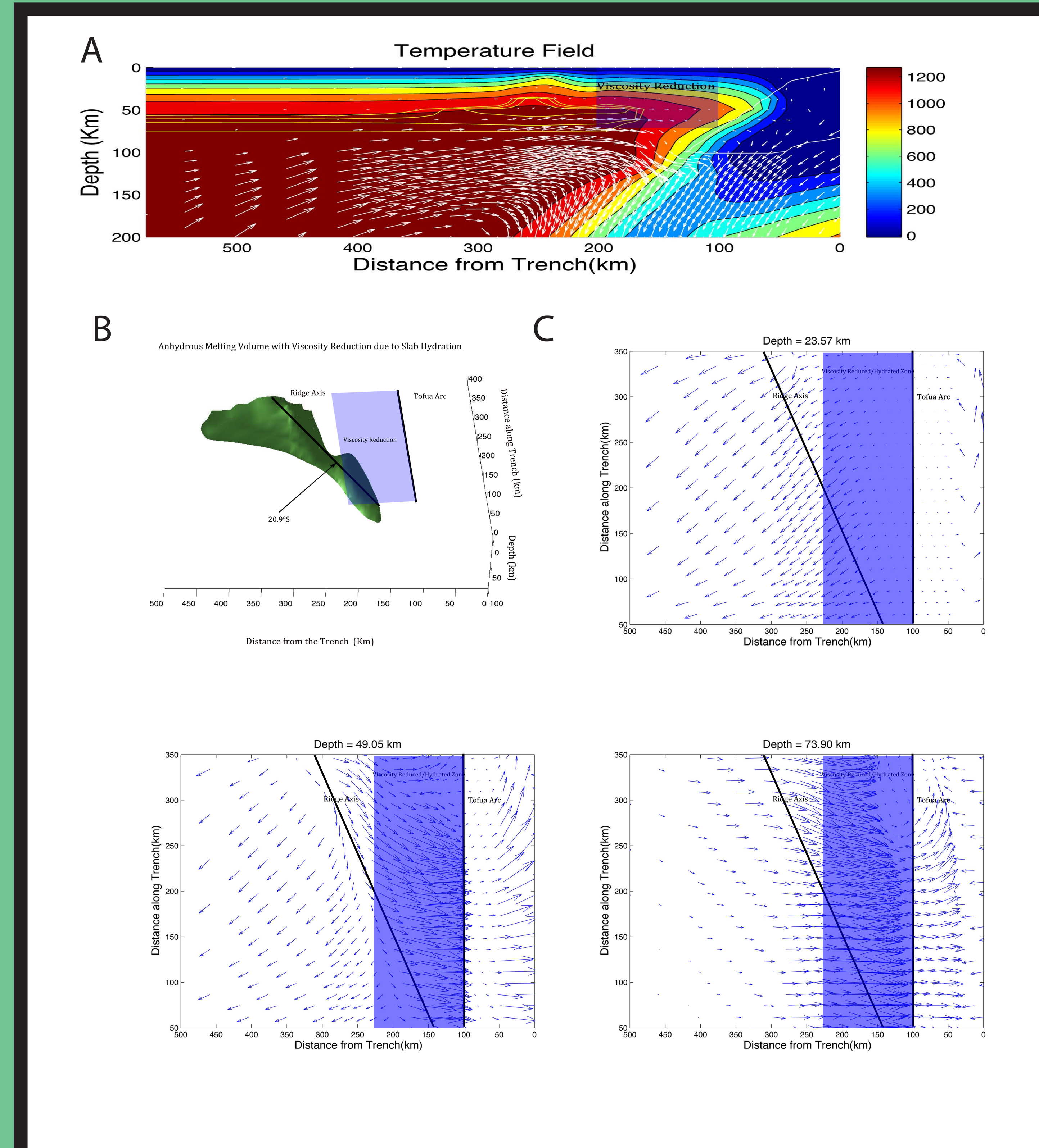
2-D slice (zy plane) of the 3-D mesh of the initial model. Shown is a closed box on all faces. On the surface, the full convergence rate is applied to nodes on the surface of the top right corner. Then, nodes on the surface are locked with zero plate velocity until 220 meters away from the trench, where the full spreading rate is then applied to the rest of the surface nodes. Slab dip is imposed by weak nodes (white lines), which allow the underlying slab to decouple from the overriding plate.

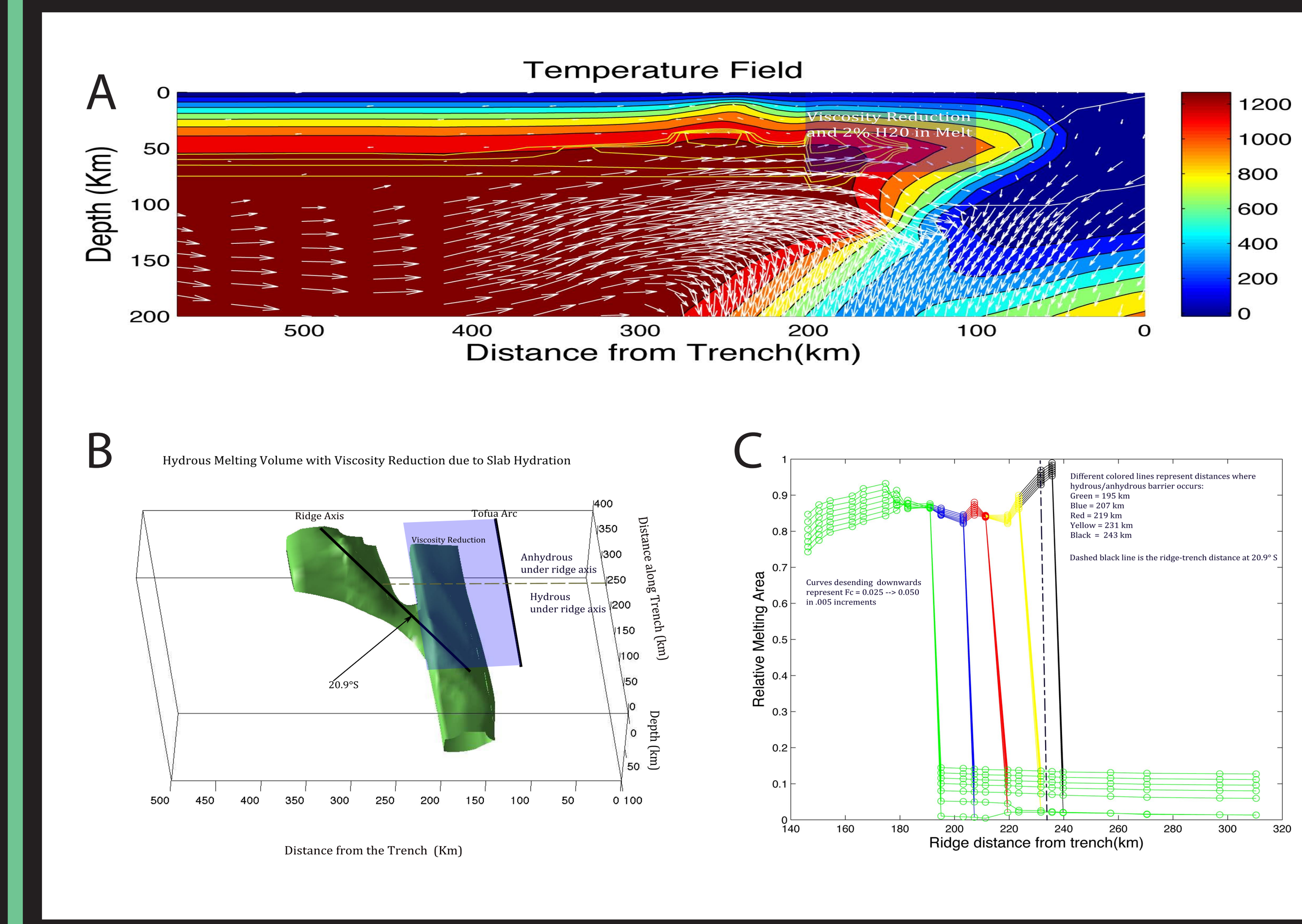
2. 3-D Model, Anhydrous Melting
Viscosity changes due to slab hydradtion (Below)

A. 2-D slices of the 3-D Model with Observed Kinematic/Plate Boundary Conditions and Viscosity reduction due to slab hydration. Modeling is at time = 5myr. The color bar refers to temperature in Celsius, the white vectors refer to flow velocity in cm/yr with the size of the vector indicating magnitude of flow, yellow contours represent the area of melt fraction with each contour representing 1% steps in melting. The white contour represents the area of weak nodes, which ranges from one order of viscosity reduction towards the edges of the contour and five orders of viscosity reduction in the center of the contour. Shaded region represents a magnitude decrease in viscosity.

B. 3-D plot of 4.5% melt fraction of the Model with Observed Kinematic/Plate Boundary Conditions and Viscosity reduction due to slab hydration. Thick black lines represent Lau's ridge axis and the Tofua Arc. Melting is anhydrous, shaded region represents a magnitude decrease in viscosity

C. Three cross sections of mantle flow at depths 23.57, 49.05 and 73.90 km respectively. Blue vectors represent mantle flow velocity in the direction pointing. Larger arrows represent a higher velocity while small arrows represent a smaller velocity. Thick black lines represent the spreading ridge axis and Tofua Arc. Shaded region represents an order of magnitude viscosity reduction.





3. 3-D Model, Hydrous Melting (Above)

A. 2-D slice of the 3-D Model with Observed Kinematic/Plate Boundary Conditions, viscosity reduction due to slab hydration and hydrous melting. H2O is 2% of the mantle melt by weight. Ridge-Trench geometry and distance is consistent with what is currently observed. The color bar refers to temperature in Celsius, the white vectors refer to flow velocity in cm/yr with the size of the vector indicating magnitude of flow, yellow contours represent the area of melt fraction with each contour representing 1% steps in melting. The white contour represents the area of weak nodes, which ranges from one order of viscosity reduction towards the edges of the contour and five orders of viscosity reduction in the center of the contour. Shaded region represents a viscosity reduction due to slab hydration.

B. Above is the relationship between relative melting area (unitless) and ridge distance from the trench (km) for the 3-D model with viscosity reduction due to slab hydration and hydrous melting. Circles represent numerically calculated areas of melting contours under and along the ridge axis. The vertical lines along the ridge distance from trench axis show different emplacements of the Hydrous/Anhydrous melting barrier along the ridge axis.

C. Above is the relationship between relative melting area (unitless) and ridge distance from the trench (km) for the 3-D model with viscosity reduction due to slab hydration and hydrous melting. Circles represent numerically calculated areas of melting contours under and along the ridge axis. The vertical lines along the ridge distance from trench axis show different emplacements of the Hydrous/Anhydrous melting barrier along the ridge axis.

Conclusions

1. A subduction model with no slab hydration generates a peak in relative melting close to EL where crust is shown to be thinning.

2. A subduction model that includes viscosity changes in the mantle wedge due to slab hydration causes subdued relative melting increase with spreading rate and a "saddle" shape in melting cuased by the reveral of along axis flow towards the southeast.

3. Finally, introducing hydrous melting in the mantle wedge increases the melt production under VF and causes a stepwise decrease in melt production at EL due to its decreased proximity to the slab-hydrated retion and its position above the saddle point in melt production; consistent with geophysical observations.