Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT05-03 会場:315 時間:4 月 28 日 09:30-09:45

Mantle flow and overriding plate stress state in 3-D models of thermo-mechanical subduction

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The formation of back-arc basins is a fundamental component of plate tectonics, yet the dominant mechanism for their formation, and whether an individual mechanism is dominant over different tectonic settings, is not entirely clear. On top of the classic mechanism of extension being driven by basal tractions due to poloidal return flow, recent numerical and experimental modeling studies have indicated that, for slabs with finite widths, toroidal return flow around slab edges plays an important role. We investigate the relative contribution of poloidal and toroidal flow field components to back-arc extension by examining the overriding plate stress regime in conjuction with the flow field for various model setups. We characterize the velocity field by decomposing it into toroidal and poloidal components at various stages of subduction, and calculating the ratio of the toroidal to polodial RMS velocities (TPR).

Models are carried out using a thermo-mechanical setup of the finite element code, CitcomCU. We find that the presence of an overriding plate reduces the development of trench curvature, and so 3-D modeling studies that neglect the presence of the overriding plate may be significantly overestimating the rate of development of trench curvature. Within the overriding plate, we observe long wavelength back-arc extensional stresses at a large distance from the trench and more localized forearc compressive stresses. Fixing the position of either the subducting or overriding plate causes the amplitude of back-arc extension to be greater than that for the case when both plates are free. This occurs because, for the fixed overriding plate models, all of the slab rollback is forced to occur at the expense of overriding plate thinning/extension, and for the fixed subducting plate models, increased rollback causes heightened toroidal flow. For all models with significant slab rollback, the poloidal RMS velocity is maximum in the very upper and lower portions of the model whereas toroidal flow is maximum at mid-domain depths due to return flow around slab edges, indicating that slab rollback-induced toroidal flow is focussed at sub-lithospheric depths, where it has the potential to contribute to back-arc extension. Reducing the width of the plate vastly reduces the rate of slab rollback, yet increases the degree of back-arc extension and focuses it closer to the trench. In such models, toroidal flow magnitude is approximately constant throughout the domain resulting in only minor TPR variation with depth, and yet the magnitude of overriding plate extensional stress is large, possibly suggesting an alternate control on back-arc extension.

Finally, we investigate the effect that Byerlee plasticity and a laterally confining side plate has on both overriding plate stress state and the flow field. Including a side plate does not modify the slab dynamics and overriding plate stress state, yet significantly reduces the toroidal RMS velocity component throughout the model, while retaining the systematic variation, which results in uniformly reduced TPR throughout the domain. The inclusion of plasticity, intended to approximate brittle failure, gives rise to elevated forearc compression, due to increased plate convergence, and reduced backarc extension.

キーワード: subduction, mantle flow, slab rollback, overriding plate stress
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