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Influence of viscosity structure on mantle flow in the mantle wedge

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The study of mantle convection in the mantle wedge by numerical simulation is important in order to understand the cause of arc magmatism. Until recent, because of limited capacity of computer and complexity of model, two-dimensional model has been adopted in many cases. However it is not clear how exactly the two-dimensional flow model can represent the reality. Recently, based on the analysis of volcano and Bouguer anomaly distribution and three-dimensional seismic velocity structure around the Tohoku island arc, Tamura et al.(2002) showed that they are changing with the wavelength of about 50km along the arc. They interpreted this observation as a result of the 'fingering' of the high temperature area coming from the mantle beneath the Japan Sea to the mantle wedge beneath the Northeast Japan. These variations along the island arc can be expected more or less from the side-cooling convection experiment done by Nataf et al.(1981). The problem here is what determines the wavelength. In this study, we consider the cause of 'fingering' as a result of viscosity layering.

The present model consists of the incompressible viscous fluid with infinite Prandtl number confined in a three-dimensional rectangular box. By this, we consider the mantle wedge intervened by the lithosphere and the lower mantle. For simplicity, we only consider the cooling effect of the subducting plate and suppose that the temperature at one side of box is same as that of the upper surface. The temperature at the upper and bottom surfaces are kept constant and all sides are reflection boundaries except for one side representing the subducting plate. All the surfaces are impermeable and except for upper surface the rests are all free-slip boundaries. Upper surface is either free-slip or fixed boundary. Viscosity only changes in the vertical direction. Fundamental equations that control the flow are 1)equation of conservation of mass 2)equation of motion 3)constitutive relation 4)equation of conservation of energy. Under the conditions mentioned above, we solve these equations by using 'stag3d'(Tackley,1993).

The model is essentially the same as that of convection experiment done by Nataf et al. (1981). We obtained the similar results to theirs; when the Rayleigh number is low, two-dimensional flow with long aspect ratio is formed perpendicular to the low temperature side. As the Rayleigh number is increased, small-scale convection, parallel to the low temperature side, is induced. This is cause by the so-called thermal boundary layer instability. When the upper surface is free-slip, the wavelength of small-scale convection is almost the same thickness as that of the convection layer. However when the upper surface set to be fixed boundary, the wavelength is reduced by half. In addition, in order to examine the effect of low viscosity layer right below the lithosphere, we set the low-viscosity layer, whose thickness and the magnitude are 0.17 times (100km) the thickness of the convection layer and 0.01 times the viscosity of the surrounding area, respectively. In this model, the wavelength of lateral variation is similar to the thickness of the low viscosity layer. These results suggest that the cause of 'fingering' proposed by Tamura et al.(2002) may be the small-scale convection along the island arc. The velocity distribution near the top surface related to the small-scale convection shows the existence of the ascending flow. This velocity field may give a major influence on the mechanism of magma ascending. We shall present another case with different thickness of low viscosity layer in this talk.