Numerical study of melting in subduction zones with variable viscosity

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Numerical modeling and calculations have been carried out to estimate melting
in subduction zones with a realistic rheology.

First, spatial distribution of viscosity in the mantle wedge is estimated with thermal structures calculated based on an analytic corner flow solution,in order to elucidate the controlling factors of viscosity in the mantle wedge. Considering these analyses for viscosity,the effect of temperature and H2O is found to be important.Based on the flow and thermal structures with the temperature-dependent viscosity, first, the effect of water on melting has been studied.The amount of water in the mantle wedge was varied from 0wt% to 0.40wt%. No melting occurs between CH2O = 0wt% and CH2O = 0.06-0.07wt% (depending on the thermal activation energy of viscosity). A weak melting starts to occur from CH2O = 0.07-0.09wt%. Melting region expands in proportion to CH2O between CH2O = 0.07wt% and CH2O = 0.20wt%.

On the other hand, melting region expands less over CH2O = 0.20wt%.This is because the depression of temperature becomes small and the effect of compression melting becomes weak due to the depression of negative Clausius-Clapeyron slope of the hydrous solidus curve.The predicted distribution of melt and melting rate is compared with the width of volcanic arc and seismic tomography in northeast Japan.The comparison shows that the model results of
melting is close to observational data when CH2O=0.15wt%.

Second, mechanisms of melting in subduction zones have been investigated,with a special reference to the relationship between the flow-thermalstructure and melting. The flow-thermal structure is controlled by the activation energy E, and E is varied from 0kJ/mol to 420kJ/mol.The calculation results show that three mechanisms of melting can operate in subduction zones, depending on E and CH2O. When CH2O=0.15wt%,
in the case of constant viscosity,
melting proceeds only beneath the backarc due to flux melting,when a rock packet enters the hydrous corner region that is fluxed from below.Note that the melt can exist under the volcanic front as
the temperature of the mantle wedge is above the hydrous solidus temperature, but a positive melting rate occurs only under the backarc.In other cases (E = 125, 250, 420kJ/mol), melting proceeds in a broader region, and the three different mechanisms of melting can occur even along a single streamline: continuously from the flux
melting under the backarc, decompression melting can occur when the rock packet upwells. Compression melting can occur within the downwelling flow along the subducting slab, due to a negative Clausius-Clapeyron slope of the hydrous solidus curve under some conditions.The intensities and locations of decompression and compression melting are rather sensitive to the flow-thermal structure, hence the activation energy E under a constant CH2O.

Finally, the model results with realistic parameter values
(E = 125, 250, 420kJ/mol and CH2O = 0.15wt%)
are compared with the observed volcanic eruption rate in northeast Japan arc,
assuming that the melt production rate is roughly proportional to the real eruption rate.
In the results for E = 125, 250, 420kJ/mol,
the peak and the region corresponding to
flux melting at the backarc, decompression melting at the center part,
compression melting at the volcanic front
are recognized.
The observed volcanic eruption rate in northeast Japan arc is
divided into three peaks or areas as in the model results.
In northeast Japan arc, the eruption rate at the volcanic front
is larger than in the center part.
This trend is reproduced in the result for E = 250kJ/mol.
A peak in the back arc is the largest in all cases,
but this trend is in contradiction to the observational data.
This contradiction may be derived from the assumption that
water content is constant spatially in the mantle wedge corner,
and may be caused by neglecting melt ascent and
solidification processes through the crust.