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A discussion on the cause of high electrical conductivity in the oceanic upper mantle

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Distribution of electrical conductivity in the oceanic upper mantle is estimated by inverting electromagnetic data obtained regionally by an array of electric and magnetic field measurements in the ocean basin. Then physical interpretation is made, sometimes jointly with seismological parameters, by referring to results of mineral physics. There are a number of possible ways to invert regional electromagnetic data in the form of one-dimensional (1-D), 2-D and 3-D models. Among them, the regionally averaged 1-D profile provides a mean feature of the study region and is considered as conservative but robust estimate that can be extracted from a regional observation. Here we show most recent result of seafloor EM study carried out in the Philippine Sea and western Pacific regions, installing total of 39 sites for 3 years (2006-2008) in the Stagnant Slab Project (Baba et al., 2010). Both profiles show high conductivity of about 0.3-0.5 S/m in the upper mantle under a low conductivity layer. The Philippine Sea profile reaches this value at the depth of 60-70 km, while it is about 200 km depth for the western Pacific profile. These two profiles are almost identical at depths greater than 200 km and down to the top of the transition zone. Baba et al. (2010) discussed the differences in these two conductivity profiles by considering the seafloor age (geothermal), the degree of (silicate) partial melt, and the water content. In this paper we make further discussion on the cause of the high conductivity in the upper mantle in terms of effects of silicate and carbonatite partial melts with reference to recent experimental results (Gaillard et al., 2008; Yoshino et al., 2010). We also refer to the calculation of the stability of partial melts by Hirschmann (2010), and examine whether observed profiles can be explained by the effect of partial melts and by existing knowledge. The two experimental results are not completely consistent with each other, and therefore lead us to different conclusions as follows:

(a) Yoshino et al. (2010) presented a diagram showing the melt fraction dependence of electrical conductivity of partially molten mantle both for silicate and carbonatite melts. We directly compared it to our observation and found that the high conductivity at 60-70 km depth of Philippine Sea result can be explained by 0.5 % partial silicate melt. However, if we take the melt fraction of 0.024 % at the boundary between stability regions of silicate and carbonatite melts (Hirschmann, 2010), conductivity values are expected to be as low as that of dry olivine, and therefore inconsistent to the observed profile.

(b) We calculated the melt fraction dependence of the partially molten mantle conductivity based on Gaillard et al. (2008), by assuming the Hashin-Strickman upper bound model. From this diagram, the high conductivity values both at 60-70 km and at 200 km can be explained by partially molten mantle either with 2-3 % silicate melt or with 0.02-0.04 % carbonatite melt. Explaining the observed profiles by the effect of partial silicate melt requires too high melt fraction and therefore seems difficult. On the other hand, observed profiles may be explained by the effect of partial carbonatite melt with melt fraction that could be stable at respective depths. However in this case, the consistency with seismological evidence (e.g. Kawakatsu et al., 2009) may still remain a problem.

Such a comparison as shown above does not give us a solid conclusion because of still insufficient knowledge. However, it is possible for us in principle to constrain a product of the melt fraction and the melt conductivity from electrical conductivity profiles. Furthermore if the melt fraction is constrained somehow by seismological observations, for example , electrical conductivity profiles will consistently constrain the melt conductivity, from which the volatile content in the melt that is responsible for the high conductivity can be inferred.

Keywords: oceanic upper mantle, electrical conductivity, ocean bottom observation, partial melt