

## **Integration of drilling into deep oceanic crust and seafloor geophysical observations for investigation of upper mantle structure and plate aging**

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### **Abstract**

Temperature is one of the fundamental parameters controlling mantle convection although it is difficult to observe the thermal state in Earth's interior directly. Geothermal structure of oceanic lithosphere corresponding to the upper thermal boundary layer of the mantle convection is widely recognized that it is well modeled by some plate cooling models explaining the global distribution of bathymetric subsidence, heat flow, and geoid height with the lithospheric age. However, some geophysical observations revealed anomalous features from the prediction of the plate cooling models in nominally normal ocean basin. Recent progresses of geophysical and petrological observations show room of more precise discussion on this issue. Quantitative separation procedures of the parameters controlling physical observables have been available and it will allow us to discuss the mantle status associated with plate aging more closely using various new observations including drilling. Further, to develop permanent station for multidisciplinary geophysical survey in the borehole will enable us to obtain more precise mantle imaging. Drilling has strong potential for acting as a scope of the Earth's mantle much deeper than its penetration depth.

### **Geothermal structure of the oceanic upper mantle**

The key word of the study is the temperature of mantle, which is one of the fundamental parameters controlling the mantle convection. Various processes and properties are the functions of temperature; seismic velocities and electrical conductivity of mantle constituting rocks, rheology of the lithosphere and asthenosphere, geochemical differentiation through crust formation processes at mid-ocean ridges, and cooling of oceanic lithosphere with its age.

Geothermal structure for oceanic lithosphere with age has been studied through bathymetry, crustal heat flow, geoid height, seismic low seismic velocity zones, high electrical conductivity zones, and so on (e.g., Parsons & Sclater, 1977; Oldenburg et al., 1984; Nishimura & Forsyth, 1989). It is broadly recognized that the bathymetry for the

ocean younger than ~80 Ma is well explained by half space cooling model but is not the case for the older ocean and that some plate cooling models explain the bathymetry better including for older ocean basins.

The plate cooling models are good as a first order approximation for the evolution of oceanic lithosphere. However, the plate cooling models presume that the temperature at the base of the plate is not changed during its history and there is no physical premise for real Earth to assume that the temperature is constant at a certain depth. Mid-ocean ridges have not been fixed in the present location rather have moved on the Earth's surface continuously and discontinuously. Consequently, the state of mantle beneath old oceanic lithosphere when it was beneath the spreading axis is not necessary to be the same as those for the mantle beneath present spreading axis.

### **Integration of geophysics, petrology, and geochemistry**

Seafloor geophysical surveys provide information about the mantle temperature. The teleseismic and electromagnetic observations allow us to image seismic velocity structure and electrical conductivity structure in the lithosphere and asthenosphere. These parameters can be converted into temperature under some assumptions. Crustal heat flow measurement can provide boundary condition of the conductive thermal structure of the lithosphere. Control sourced seismic reflection and refraction surveys images velocity structure of the oceanic crust and uppermost mantle. The crustal thickness is dependent on the potential temperature when it was created at a mid-ocean ridge.

Recent progresses of geophysical and petrological observations show room of more precise discussion on the structure of oceanic lithosphere and asthenosphere with their age. Mantle temperature differences exert a major control on MORB chemistry and the observation is explained by the temperature difference in range of ~250 K (Klein & Langmuir, 1987; Langmuir et al., 1992), suggesting lateral variation in the mantle potential temperature. New observations of heat flow which are much higher than prediction of previously accepted plate cooling models are reported (e.g., Yamano et al., 2008). It is suspected that activities of small intra-plate and off-ridge volcanoes discovered recently (e.g., Hirano et al., 2006; Hiller and Watts, 2007) can disturb the cooling process of the lithosphere and expose the abnormal observations. Recent geophysical observations allow us to image regional upper mantle structure with higher resolutions (e.g. Isse et al., 2006). Quantitative separation procedures of the parameters (temperature, water content, ratio of Fe/(Fe+Mg), mineral assemblage, and melt fraction) controlling seismic velocities and attenuations and/or electrical conductivity

are now available (e.g., Shito & Shibutani, 2003; Ichiki et al., 2006; Baba et al., 2006). This situation makes us expect that we can discuss the mantle status associated with plate aging more closely using various new observations including drilling.

### **Expectation for deep crustal drilling**

Rock samples can provide information of mid-ocean ridge processes including the potential temperature of the mantle (e.g., Langmuir et al., 1992) and thus they should make a contribution for discussion of plate aging process together with seafloor geophysical observation studies. However, most of the rock samples were basalts obtained at mid-ocean ridges.

We can expect to obtain further information about the mantle from ultra-deep drillings by Chikyu, such as those proposed by 21st Century Mohole, and also from drillings for the seafloor of various ages. The rock cores from the lower crust and the uppermost mantle provides precise physical properties of deep-seated materials and absolute geological and geochemical evidence. Temperature measured by deep boreholes gives more reliable boundary condition of the mantle geothermal structure. Drilling for older seafloor may demonstrate difference of the source mantle conditions from that under currently active mid-ocean ridges, which will constrain for time-variation of the mid-ocean ridge process. Deep penetration is critical for older seafloor to obtain non-altered rocks beneath thick sediment layers.

The observations given by deep drilling will provide us more critical constraint on the temperature estimation from the geophysical data, which are essentially controlled by various parameters including temperature. Separation of these parameters needs to assume chemical and mineral compositions, water content, and so on. Direct information from in situ rock samples enables us to reduce the assumptions and to make the estimation more precise.

Long continuous geophysical observations using drill hole is expected to have better quality compared with conventional seafloor observations and thus is also useful for our research especially to image the mantle structure more precisely. The ocean is still large blank of the geophysical observation. New data from the ocean should give us many discoveries.

### **Conclusions**

The structure of oceanic lithosphere and asthenosphere with their age should be reconsidered beyond the plate cooling model. Seafloor geophysical observations in terms of seismic velocities, electrical conductivity, and heat flow can be used for more

precise estimation of the geothermal structure, in collaboration with petrological and geochemical inputs obtained by deep drilling.

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