IODP INVEST White paper

Geophysical studies toward deep drilling through the oceanic crust into the upper mantle

Shuichi Kodaira[1] and IFREE Lithosphere Structure Imaging Team
(1) Institute for Research on Earth Evolution (IFREE), JAMSTEC. kodaira @jamstec.gojp

ABSTRACT

Like other deep drilling projects, such as a seismogenic zone drilling and an intra-oceanic arc drilling, drilling into the mantle requires intensive geophysical studies for, 1) selecting the best area where drilling into the mantle is feasible by CHIKYU, 2) clarifying scientific hypothesis to be tested, and 3) making further integration with coring/logging. However, an intensive pre-drilling geophysical study for deep drilling into mantle has not been implemented to date, except for regional seismic studies around a few IODP sites. Here, we propose a plan and strategy of geophysical studies toward deep drilling into upper mantle through intact oceanic crust.

INTRODUCTION

IODP Initial Science Plan (ISP) clearly stated an importance of drilling through the intact oceanic crust into the upper mantle to advance significantly our understanding of the processes governing the formation and evolution of oceanic crust. According to those descriptions in the ISP, there are two important contributions by the IODP oceanic crust drilling. One is drilling at the Atlantis Massif (Expedition 304/305) [e.g., Ildefonse et al., 2006], and the other is drilling at the fast spreading oceanic crust in the Cocos plate (Expedition 309/312) [e.g., Alt et al., 2007]. As reviewed in “IODP Thematic Review of Oceanic Crustal Structure and Formation” [Larsen et al., 2009], the expedition 309/312 successfully completed the first sampling of an intact section of upper oceanic crust through lava and the sheeted dikes into the uppermost gabbros. Seismic velocities measured by logging and discrete samples, however, indicate the velocity of the gabbro in Hole 1256D are less than 6.5 km/s, which do not fit the velocity of the oceanic layer3 [Alt et al., 2007]. The expedition 304/305 intended to sample unaltered mantle peridotite, which was interpreted by seismic data; i.e., a high seismic velocity (~ 8km/s) body below a horizontally continuous strong reflector. Unexpectedly, the predominant lithology recovered was gabbroic rocks with minor intercalated ultramafic rocks and mantle peridotites are very rare. One of the causes of the discrepancy between the interpretation of the seismic data and the drilling results might be incomplete processing of the seismic data [Larsen et al., 2009].

Those results provided significant improvement for our understanding of structures and formation processes of fast- and slow-spreading oceanic crust, but we still far from an ultimate goal; i.e., drilling through the intact oceanic crust into the upper mantle, which can be achieved by using planned new technology of CHIKYU. Since drilling into the mantle requires intensive geophysical studies for, 1) selecting the best area where drilling into the mantle is feasible, 2) clarifying scientific hypothesis to be tested, and 3) making further integration with coring/logging, here we propose a plan and strategy of geophysical studies toward deep drilling into the mantle.

GEOPHYSICSL STUDIES -PLAN AND STRATEGY-

Phase 1: Seismic imaging of typical oceanic crust in the northwestern Pacific.

Although an average seismic structure of the oceanic crust is seismologically described as a simple three-layered model consisting of layer1 (sediment), layer2 (basalt flow and dike) and layer3 (gabbro), a long history of marine geophysical studies demonstrates that detailed seismic structures of the oceanic crust are varied place by place depending on tectonic setting, even in the fast-spreading oceanic crust. Moreover, a relation between seismologically imaged Moho and a geological structure of crust/mantle transition has not been fully examined. In order to obtain fundamental seismological knowledge of the fast-spreading oceanic crust, IFREE Lithosphere structure imaging team in JAMSTEC has started a five-year term seismic project in the northwestern Pacific since 2009. The project is planned to cover a wide area of the Pacific plate at seaward side of the Kuril – Japan- Izu – Bonin trenches (Fig.1). On the basis of clearly aligned strong magnetic anomalies (M5 – M20), we believe that the oceanic crust in this area is a representative of old, stable and first-spreading oceanic crust. We will also examine, from seismic data of this project, hydration or alternation processes of crust and upper mantle due to a normal fault system near trench which may reach at the upper mantle.

In this project, we plan to acquire high resolution deep penetration seismic refraction and reflection data along a total ~ 10,000 km long profiles. A large volume of tuned air gun array (~7,200 cu. inches) and a 6,000 m long streamer cable are used for seismic reflection survey. Fig. 2 shows an on-board processed seismic reflection section which clearly images the Moho from the abyssal basin to the trench through the outer rise. For the seismic refraction survey, 4-compoment Ocean-Bottom Seismometer is deployed at every 5 km along entire profile. The seismic refraction data are expected to reveal a fine-scale seismic velocity image down to upper mantle. The data acquisition specification of the project is the same as those applied for a seismic project in an intra-oceanic arc. We, therefore, expect a high resolution deep seismic image like we showed in the intra-oceanic arc profiles [e.g., Kodaira et al., 2007].

In order to understand a geological nature of the Moho, we will compare the observed Moho reflections and synthetic Moho reflections calculated from a realistic model, which is created on the basis of filed observations of crust/mantle transitions of ophiolite. Recent improvements of numerical simulations as well as computing facilities enable us to calculate realistic synthetic Moho reflections using a laterally varied fine-scale structural model. A preliminary result of a synthetic section, for example, shows that a model having thin layered wehrlite intruded between gabbro and harzuburgite creates layered Moho reflections with the first peak of the reflection from top of the wehrlite. This demonstrates that drilling below the layered Moho reflections is necessary to reach a harzuburgite layer.

Phase 2: Integrated geophysical study at possible Mohole sites

As discussed at several workshops concerning deep drilling of oceanic crust (e.g., Mission Moho Workshop in 2006 [Ildefonse et al., 2007] and Melting, Magma, Fluids and Life workshop in 2009), possible areas of Mohole are limited due to several factors; e.g., a technological limit of riser drilling, ages of crust, weather conditions and other logistical reasons. Although the Mohole community should make a further effort for selecting the site, candidates of Mohole sites are more likely situated around the eastern Pacific. Moreover, in the recent workshop, Melting, Magma, Fluids and Life workshop, the Hawaiian arches are proposed as another possible candidate, based on the water depth, the age of the crust, clear magnetic anomaly and well accessibility.

Since geophysical data are keys to select the site, integrated geophysical surveys including seismic, magnetic, seafloor mapping and heat flow measurement to widely cover the candidate areas should be organized as soon as possible. As reported at the Melting, Magma, Fluids and Life workshop, a part of those studies is planned at the Hawaiian area under the US-Japan collaboration in the next couple of years. Data acquisition specifications of the planned seismic profiles are the same as the seismic study we carry out in Phase1. This enables us to make quantitative comparisons between the oceanic crust off Hawaii and the old/stable fast spreading oceanic crust in the northwestern Pacific. A key structure we need to examine, in those data, is an effect of the Hawaii hot spot. As shown in other hot spot regions, the oceanic crust is strongly altered, if an effect of mafic underplating by a hot spot is extended. In other words, if we will detect any alternation of the oceanic crust due to effect of the Hawaiian hot spot, this area will be recognized as an improper site as the Mohole.

In possible deep drilling areas in the eastern Pacific, there are several site survey data around the previous ODP and IODP site, but areas covered by those data are limited and qualities of the most of data are not appropriate to resolved fine structures of the lower crust, the mantle and the Moho. An international geophysical project for deep drilling in the eastern Pacific must be established.

Phase3: Geophysical studies pre-, with- and post-drilling

Once the site will be selected, an integrated study must be carried out around the site. 3D-MCS as well as 3D-OBS data are greatly helpful for determining the best position as well as making a practical drilling plan. Those data could also remarkably improve our understanding of structures and physical properties of the crust, the upper mantle and the Moho. Core-log-seismic integration using core samples, down-hole geophysical logs and the pre-drilling 3D seismic data is necessary to extend drilling results to three-dimensionally. Data from vertical seismic profile (VSP) should be also included in the core-log-seismic integration to improve spatial resolution. VSP at several levels during drilling will be necessary to improve velocity structures which are necessary for drilling plan of further deeper level.

Post-drilling geophysical/geochemical monitoring at the Moho depth is expected to reveal mechanical behavior and geochemical flux at crust-mantle boundary. Those data have never been acquired without a deep drilling into the mantle through the crust.

CONCLUDING REMARKS

An implementation plan of geophysical studies toward deep drilling through the oceanic crust into upper mantle should be created under an international cooperation. Discussions in a sort of a detailed planning group specifically focused on this topic are necessary to make a realistic long term plan. Since doing such intensive geophysical studies need long-term effort, the detailed planning group for the geophysical study toward deep drilling into the mantle must be organized.

REFERENCES

Alt, J.C., Teagle, D.A.H., Umino, S., Miyashita, S., Banerjee, N.R., Wilson, D.S., and the IODP Expeditions 309 and 312 Scientists, and the ODP Leg 206 Scientific Party, 2007. IODP Expeditions 309 and 312 drill and intact section of upper oceanic basement into gabbros. *Sci. Drill.*, 4:4–10. doi:10.2204/iodp.sd.4.01., 2007

Ildefonse, B., Blackman, D., John, B.E., Ohara, Y., Miller, D.J., MacLeod, C.J., and the IODP Expeditions 304-305 Scientists, 2006. IODP Expeditions 304 & 305 characterize the lithology, structure, and alteration of an oceanic core complex. *Sci. Drill.,* 3:4–11. doi:10.2204/iodp.sd.3.01., 2006

Ildefonse, B., D. M. Christie and the Mission Moho Workshop Steering Committee, Mission Moho Workshop: Drilling Through the Oceanic Crust and the Mantle, Scientific Drilling, 4, doi:10.2204/iodp.sd.4.02, 2007

Kodaira, S., T. Sato, N. Takahashi, S. Miura, Y. Tamura, Y. Tatsumi and Y. Kaneda, New seismological constraints on growth of continental crust in the Izu-Bonin intra-oceanic arc, Geology, 35, 1031-1034, doi:10.1130G23901A, 2007.

Larsen, H. C., et al. IODP Thematic review, Oceanic Crustal Structure and Formation, http://www.iodp.org/trc

Melting, Magma, Fluids and Life workshop in 2009 http://www.interridge.org/WG/DeepEarthSampling/workshop2009

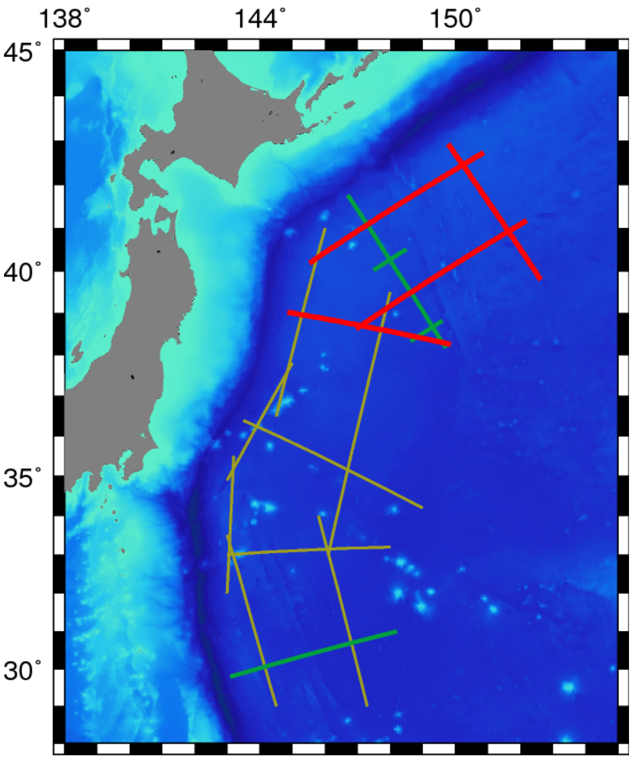

Fig. 1. JAMSTEC seismic reflection/refraction profiles in the northwestern Pacific. Green lines indicate the 2009 profiles. Red and yellow lines indicate planned profiles in 2010 and 2011-2013, respectively.

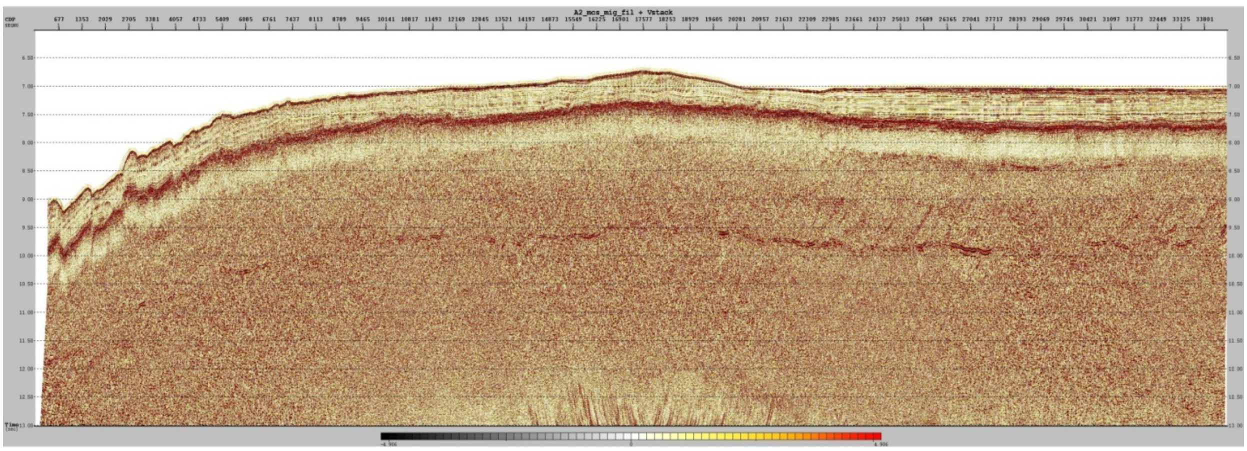

Fig.2 On-board processed seismic reflection section acquired at the northern half of the 2009 profile off the Kuril trench.