# Can we see the Earth's core from a seismic observation below see floor?

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Abstract

Seismic observation for core phases in oceanic areas is important to fully understand the Earth's core. An observatory below sea floor is strongly required to detect small seismic core phases. Considering Japanese facilities, the candidate areas are the Philippine Sea for the observation of *PKP* phases, and the southwestern Pacific Ocean for *SmKS* phases. To obtain a significant achievement, a multiple-hole observatory constituting a large-span seismic array is highly desired.

## Introduction

Seismological studies have revealed many aspects of the Earth's core such as seismic heterogeneity and anisotropy as well as possible temporal changes [*Souriau*, 2007]. So far, all of the achievements are coming from the seismic observations on lands (continents and islands). Unfortunately, we have no important results for the Earth's core from seismic observations on sea floor because small amplitudes of core phases are masked by large noises. Furthermore, pilot borehole seismic experiments have not considered whether the core phases are observable. In order to fill the observational gap, seismologists thirst for observations in the deep oceanic areas. Here we discuss the outlook of the seismic study on the Earth's core with seismic observation below sea floor.

## A brief review of seismological core studies

Seismic phases called *PKP* are transmitted in the mantle and core as *P*-waves, which are suitable for the studies of the inner core and the bottom of the outer core (see Figure 1a). Although we can observe them in a wide frequency range, short period components around 1 seconds are particularly important in order to discriminate complicated branches. Seismic anisotropy has been a robust feature in the inner core [*Morelli et al.*, 1986]. Recent studies are focusing lateral and radial variations of the anisotropy [*Sun and Song*, 2008]. To date, the hemispherical structure of inner core anisotropy observed by *Tanaka and Hamaguchi* [1997] is confirmed by recent many observations. Furthermore, *Aubert et al.* [2008] proposed an interesting interpretation for the hemispherical inner core dynamics. However, finer structure is not clear because of the insufficient sampling. Especially, we have still a small number of data sampling the arctic area where is important for understanding the tangent cylinder in the outer core. Also, the discovery of inner core super rotation [*Song and Richards*, 1996] is standing on long-term observations at a very small number of stations in the polar regions. The innermost inner core proposed by *Ishii and Dziewonski* [2002] is examined by antipodal *PKP* phases. This discovery is confirmed by new observations using dense seismic arrays in China and Venezuela [*Niu and Chen*, 2008].

On the other hand, *SmKS* phases are transmitted in the mantle as *S*-wave, in the outer core as *P*-wave, and returned to mantle as *S*-waves after (m-1) time reflection under the core-mantle boundary, which are suitable for the studies of the outermost core (see Figure 1b). We can observe them in the period of 5-30 seconds. So far, available *SmKS* data in a global scale suggests a low velocity region in the outermost core compared to that of PREM [*Alexandrakis and Eaton*, 2007; *Tanaka*, 2007]. However, the covered area is less than half of the total surface.

Importance of an observatory below sea floor

We should understand that the noise level at a deep-sea seismic station is particularly crucial for our purpose. *Suyehiro et al.* [2006] summarize the seismic noise spectra observed at pilot borehole broadband stations, e.g., WP-1 in the Philippine Sea, WP-2 in the northwestern Pacific, and OSN in the central Pacific. At all of the stations, the sensors are deployed in the basement below a sediment layer. The amplitude of the noise spectra are much lower than that of a sea floor observation, especially for the vertical component around the period of 1 seconds, and the horizontal components in the period of several tens seconds. Comparing to the Low Noise Model (LNM) and High Noise Model (HLM) that are defined from typical noise characteristics on lands, the noise spectra of a borehole stations do not exceed the HNM for the periods that we concern. This indicates that a borehole broadband seismic observation has enough potential for the study of the Earth's core. Actually, the broadband seismograms at WP-1 detect possible signals of *PKP* and *SmKS* phases from South American deep earthquakes but we do not find good signals in the seismograms at NOT1, a pop-up ocean bottom seismograph deployed near WP-1.

## Candidate areas for future drilling sites

The International Ocean Network (ION) proposed 27 sites for future drilling sites to install broadband seismograph [*Stephen et al.*, 2003]. Some of the ION proposed sites are certainly appropriate for sampling unexplored regions such as arctic by stations in North Atlantic as well as the other interesting area where can not be obtained by land observations. However, the aim of the configuration in the ION's proposal is mainly to fulfill the gap in a global mantle tomography.

Since appropriate epicentral distance ranges for *PKP* and *SmKS* phases are narrow and distribution of earthquakes is so limited, it is worthwhile to discuss preferred drilling locations for the future construction of an observatory below sea floor. Figure 2 shows a map indicating the distribution of *PKP* observable regions. I count the number of deep earthquakes (focal depths greater than 100 km) with epicentral distance range of 150-160° at 5° x 5° blocks. Strong colored areas mean favorable areas for *PKP* observations. The highly suitable areas are located in the Central Atlantic Ocean, Europe, Africa, and South America. Secondary good areas are in Asia. Considering the collaboration with the existing seismic observatories on lands and the maintenance by the current Japanese facilities, the Philippine Sea is the best site for our Japanese seismologists. If European seismologists want to maintain the observatories by their efforts, the Central Atlantic should be considered. Similarly, a map for *SmKS* is shown in Figure 3. In this case, I count the deep earthquakes with the distance range of 130-140°. It is obvious that the observation chance in the oceanic area is largest in the North to Central Atlantic Ocean. From the viewpoint seeking regions where Japanese can contribute to the maintenance of the observatory below sea floor, the southwestern Pacific around Papua New Guinea is a good area.

## Concluding remarks,

Finally, I would like to briefly mention my hope. Recent large-scale mobile broadband seismic arrays have been deployed in many continental tectonic areas, successfully resulting in detailed seismic imaging not only for the crust and uppermost mantle just beneath an array but also for the deep Earth structure. To achieve a significant scientific result being comparable with that obtained by continental seismic observations, it would be insufficient that an isolated single station is deployed in the middle of an ocean as the ION proposed. A multiple borehole station that forms a seismic array or collaboration with land stations would be effective in searching for new discoveries and highly reliable observations. As the incident angles of the core phases are nearly vertical, a large span greater than 100 km with the high accuracy of clocks is ideal to measure the spatial derivative of the travel times.

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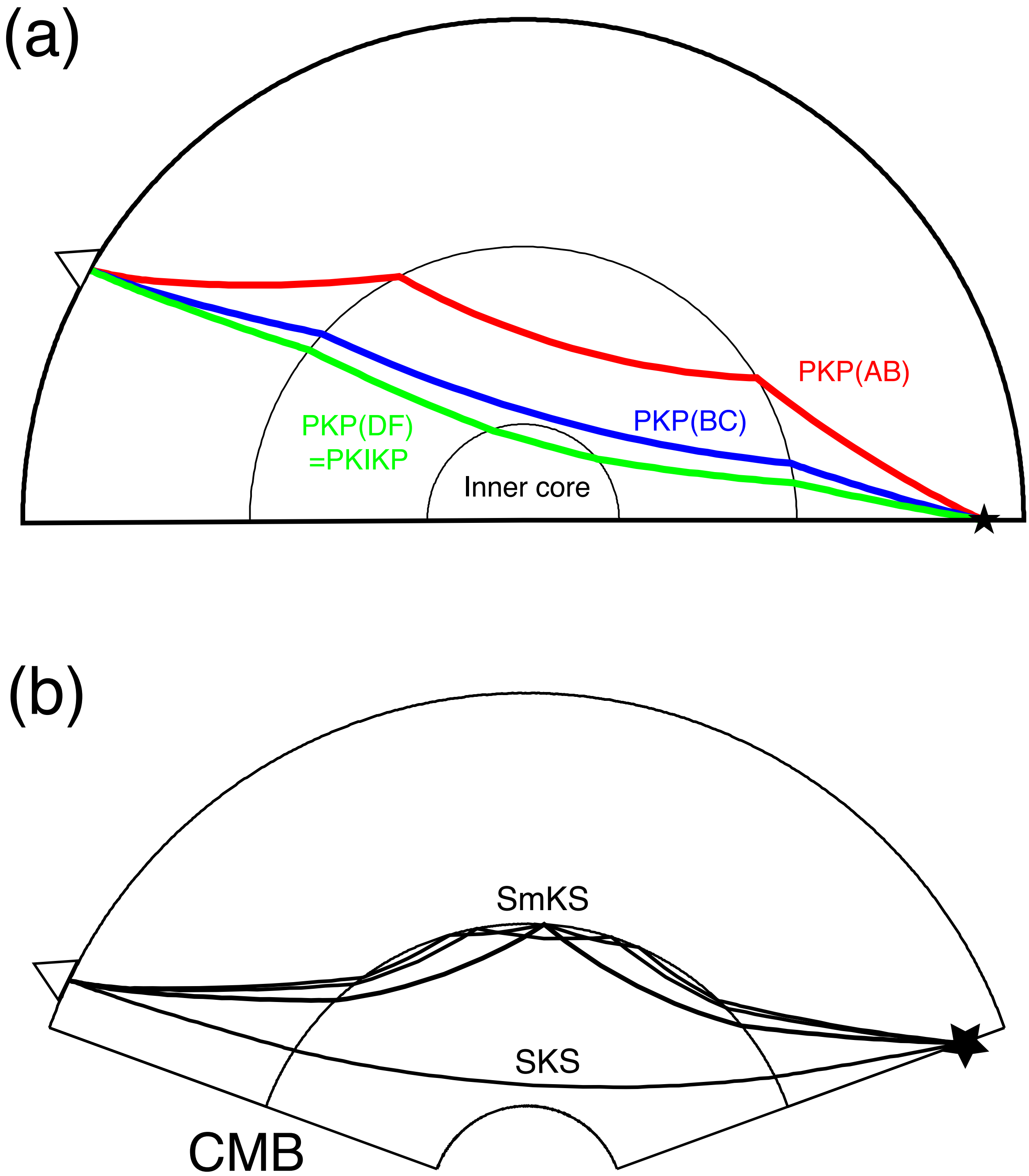


Figure 1. Seismic ray paths of (a) *PKP* and (b) *SmKS* phases. (a) Branches of *PKP* phases are colored as follows: Red; *PKP*(AB), blue; *PKP*(BC), green; *PKP*(DF) also called *PKIKP*. (b) *SmKS* (m□4) are plotted.

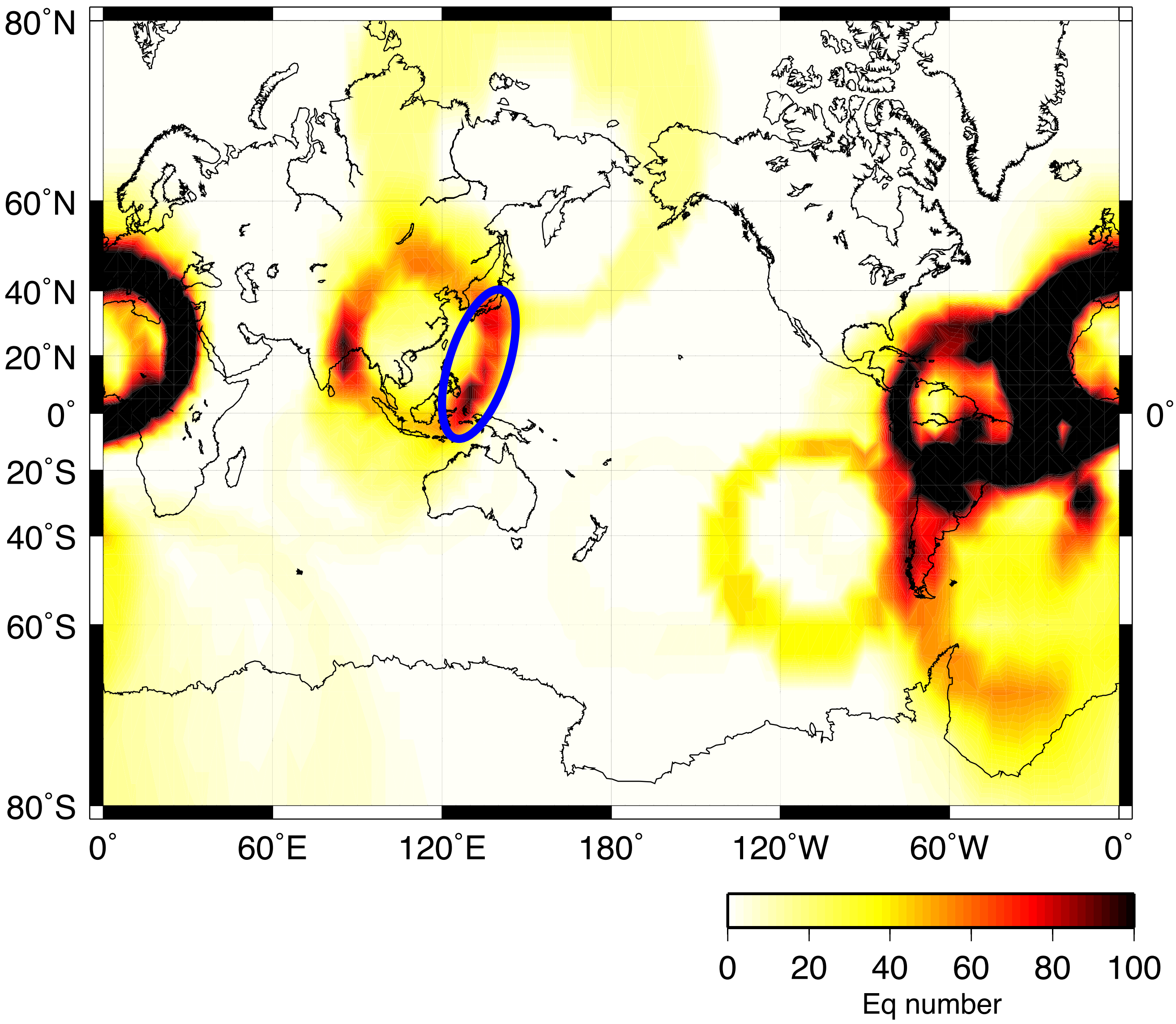


Figure 2. Distribution of earthquake numbers that are observable in a 5  x 5  block for the epicentral distance range of 150-160 . Deep earthquakes with focal depths greater than 100 km listed in the USGS earthquake catalog for the period of 1990-2005 are counted. A blue ellipsode shows a candidate area for the observation of *PKP* phases (see text for detail).

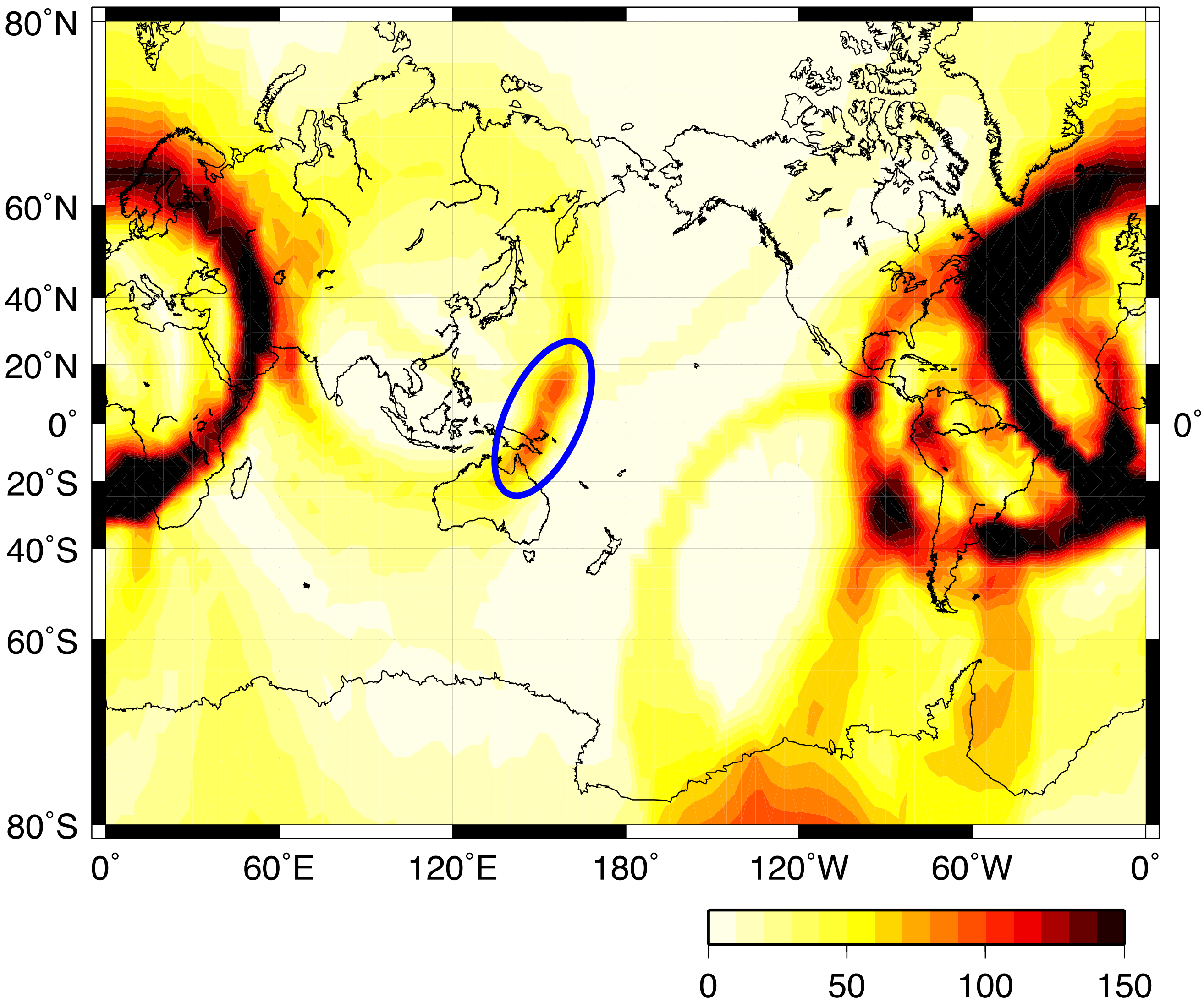


Figure 3. Distribution of earthquake numbers that are observable in a 5  x 5  block for the epicentral distance range of 130-140 . Deep earthquakes with focal depths greater than 100 km listed in the USGS earthquake catalog for the period of 1990-2005 are counted. A blue ellipsode shows a candidate area for the observation of *SmKS* phases (see text for detail).