Earth and Planetary Science Letters 476 (2017) 111–121

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Structural variation of the oceanic Moho in the Pacific plate revealed by active-source seismic data

Akane Ohira[a,b,*], Shuichi Kodaira[a,b], Yasuyuki Nakamura[b], Gou Fujie[b], Ryuta Arai[b], Seiichi Miura[b]

[a] *Yokohama National University, Tokiwadai 79-1, Hodogaya-ku, Yokohama 240-8501, Japan*
[b] *R&D Center for Earthquake and Tsunami (CEAT), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Showa-machi 3173-25, Kanazawa-ku, Yokohama 236-0001, Japan*

ARTICLE INFO

Article history:
Received 27 December 2016
Received in revised form 30 July 2017
Accepted 3 August 2017
Available online 1 September 2017
Editor: P. Shearer

Keywords:
oceanic Moho
crust–mantle transition layer
multi-channel seismic reflection data
ocean-bottom seismometer
Shatsky Rise

ABSTRACT

The characteristics of the oceanic Moho are known to depend on various factors, such as seafloor spreading rate, crustal age, and accretionary processes at a ridge. However, the effect of local magmatic activities on the seismic signature of the Moho is poorly understood. Here an active-source reflection and refraction survey is used to investigate crustal structure and Moho characteristics along a >1000-km-long profile southeast of the Shatsky Rise in a Pacific Ocean basin formed from the Late Jurassic to Early Cretaceous and spanning the onset of Shatsky Rise volcanism. Although the seismic velocity structure estimated from the refraction data showed typical characteristics of the oceanic crust of the old Pacific plate, the appearance of the Moho reflections was spatially variable. We observed clear Moho reflections such as those to be expected where the spreading rate is fast to intermediate only at the southwestern end of the profile, whereas Moho reflections were diffuse, weak, or absent along other parts of the profile. The poor Moho reflections can be explained by the presence of a thick crust–mantle transition layer, which is temporally coincident with the formation of the Shatsky Rise. We inferred that the crust–mantle transition layer was formed by changes in on-axis accretion process or modification of the primary Moho by off-axis magmatism, induced by magmatic activity of the Shatsky Rise.

1. Introduction

The oceanic Moho is influenced by the various mantle processes that contribute to the seismic signature of the crust–mantle boundary. In multi-channel seismic (MCS) reflection data, reflection events from the crust–mantle boundary are referred to as the "Moho reflection," and the characteristics of the Moho reflection depend on various factors such as seafloor spreading rate, crustal age, and local effects (Mutter and Carton, 2013). The seafloor spreading rate is one important factor: where the rate is fast to intermediate, the Moho is often imaged as a sharp boundary interpreted to be the lithological contact between gabbros and residual peridotites (e.g., Sinton and Detrick, 1992; Nedimović et al., 2005), whereas at slow-spreading ridges, the Moho tends to be comparatively unclear, perhaps because the lithology is more complex (Cannat et al., 1995) or because rough topography has caused scattering and attenuation of the seismic signal. However, detailed surveys of the fast-spreading East Pacific Rise (EPR), indicate a wide range in Moho reflection character from a bright impulsive reflection to a shingled or diffusive event to no signals over short spatial scales (Kent et al., 1994; Barth and Mutter, 1996; Aghaei et al., 2014). In addition, unclear Moho reflections are often observed in old oceanic crust that formed at fast-spreading centers (Eittreim et al., 1994; Reston et al., 1999; Kaneda et al., 2010; Kodaira et al., 2014). Notably, Kaneda et al. (2010) obtained a clear, continuous Moho image in an ocean basin in the western Pacific classified as fast-spreading except beneath Cretaceous seamounts. Their result suggests that magmatic activity occurring after the formation of the oceanic crust at a mid-ocean ridge can also alter the Moho. However, because there are few studies designed to image Moho structure in the ocean basins as their primary objective, the possible effect of variations in crustal formation and off-axis magmatic processes on the characteristics of the Moho has not been examined in detail.

To address this issue, we studied oceanic crust formed at fast to intermediate spreading rates that may have been influenced by off-axis magmatic activity associated with the development of a nearby large igneous province. For our survey area, we chose

---

[*] Corresponding author at: Yokohama National University, Tokiwadai 79-1, Hodogaya-ku, Yokohama 240-8501, Japan.
E-mail address: oohira-akane-jp@ynu.jp (A. Ohira).

http://dx.doi.org/10.1016/j.epsl.2017.08.004
0012-821X/© 2017 Elsevier B.V. All rights reserved.

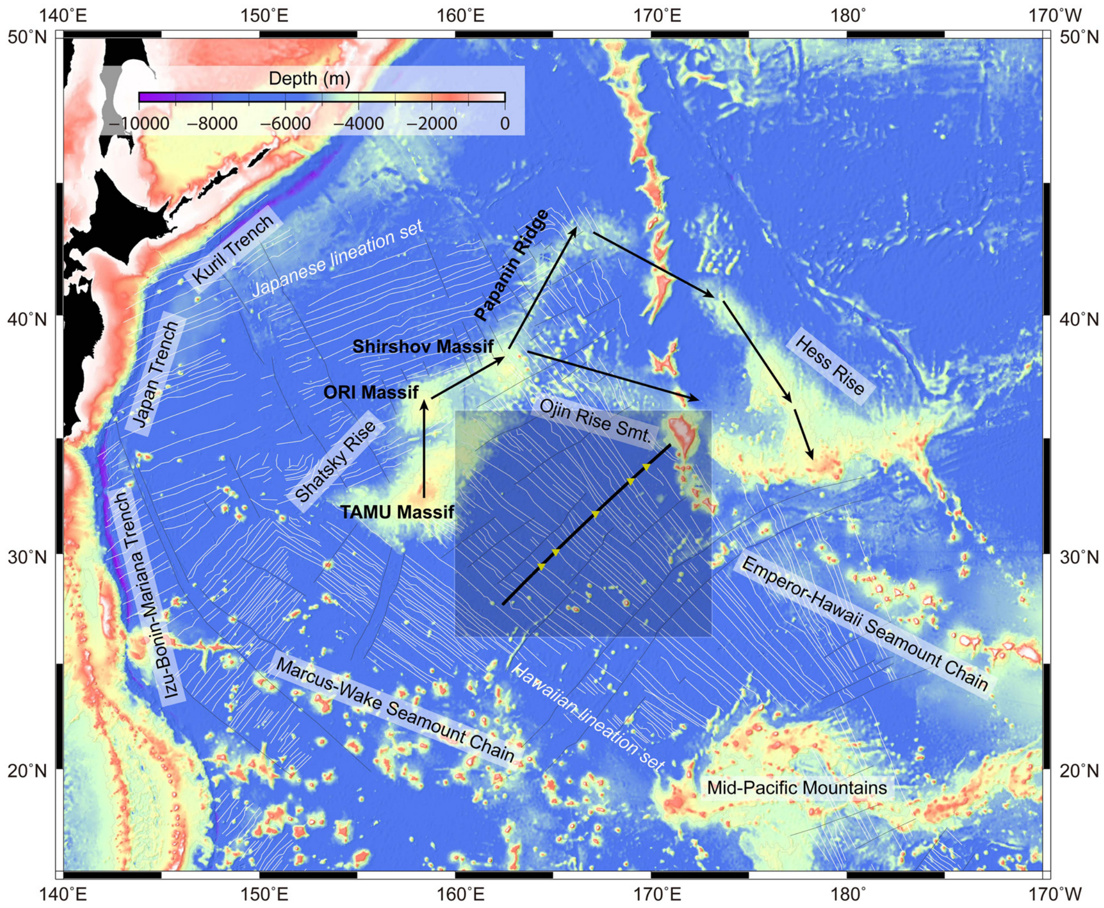

Fig. 1. Seafloor map of the northwestern Pacific. Our seismic reflection and refraction survey line is shown by a solid black line with yellow triangles showing the position of ocean-bottom seismometers (OBSs). Thin white lines are magnetic anomaly lineations, from Nakanishi et al. (1992). Black arrows show possible hot spot tracks from the Shatsky Rise to the Hess Rise (Sager et al., 1999; Sager, 2005; Tejada et al., 2016). The shaded box indicates the area shown in Fig. 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the area southeast of the Shatsky Rise, where the seafloor ages are known owing to the presence of clear magnetic anomalies (Nakanishi et al., 1992) and where the crust was formed at the same time as the Shatsky Rise volcanism occurred. The aim of this study was to elucidate the relationship between variability of the oceanic Moho and crustal formation and off-axis magmatic processes.

2. Geologic background

The northwestern and western Pacific is characterized by old Pacific plate, formed from the Jurassic to the Cretaceous, as well as by many traces of past igneous activity, including large-scale volcanism that generated oceanic plateaus, intraplate igneous volcanism, and hot spot activity. The formation of the Shatsky Rise, which is classified as a submarine large igneous province (Coffin and Eldholm, 1994), is one of the largest examples of igneous activity in the northwestern Pacific Ocean basin. Seafloor magnetic studies have revealed that the igneous activity associated with the Shatsky Rise began around chron M21 (149 Ma; ages for magnetic lineations used hereinafter are based on the timescale of Gradstein et al., 2012). The Shatsky Rise is situated at the confluence of the southwest–northeast-trending Japanese lineation set and the northwest–southeast-trending Hawaiian lineation set (Fig. 1), an indication that the Shatsky Rise formed at the Pacific–Izanagi–Farallon triple junction (Sager et al., 1988; Nakanishi et al., 1989, 1999). The Shatsky Rise consists of three major volcanic domains, the TAMU Massif, the ORI Massif, and the Shirshov Massif (Sager et al., 1999); it includes, northeast of the Shirshov Massif, the northeast–southwest-oriented Papanin Ridge, which extends to 43°N before it bends eastward. In addition, a series of small to medium-sized seamounts, the Ojin Rise seamounts, are distributed in the area east of the Shirshov Massif (Sager et al., 1999; Nakanishi et al., 1999). Both the Papanin Ridge and the Ojin Rise seamounts formed at a later stage of the Shatsky volcanism (Sager et al., 2016; Tejada et al., 2016), which appears to continue toward the Hess Rise, a large, neighboring oceanic plateau similar to the Shatsky Rise, suggesting that a possible hot spot track points from the Shatsky Rise to the Hess Rise (Fig. 1, arrow) (Sager et al., 1999; Sager, 2005). The north-trending part of the Emperor–Hawaiian seamount chain crosses between the two rises.

Our seismic profile was obtained ∼600 km southeast of the Shatsky Rise and perpendicular to the Hawaiian magnetic anomalies, extending from a point between M21 and M20 (148 Ma) to M1 (128 Ma) (Fig. 2). The oceanic crust along our profile was formed at the Pacific–Farallon spreading ridge, whose half-spreading rate is estimated to be fast to intermediate, about 40 $\mathrm{mm\,yr^{-1}}$ (Nakanishi et al., 1992). The Koko Guyot, one of the Emperor seamounts, is at the northeastern end of our seismic profile. The seafloor depth in the survey area is 5500–6000 m except at knolls and along the flank of the Koko Guyot.

3. Data acquisition and processing

In 2014, we carried out seismic reflection and refraction/wide-angle reflection surveys during cruise KR14-06 of R/V *Kairei* (Fig. 2). The survey line was approximately 1130 km long; it is thus one of the longest single seismic profiles in the northwestern