Structure of oceanic crust in back-arc basins modulated by mantle source heterogeneity

Ingo Grevenmeyer¹, Shuichi Kodaira², Gou Fujie² and Narumi Takahashi²

¹ *GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel 24148, Germany*

² *Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama 236-0001, Japan*

DATA ACQUISITION

Along MR101c, 46 OBS recorded shots from an airgun array of 12,000 cubic inches (197 liters) shot with the RV KAYO in 2003. 44 OBS with a variable instrument spacing of 5 to 10 km provided excellent P-wave data, including arrivals sampling the crust (Pg), the crust/mantle boundary (PmP), the uppermost mantle (Pn) and a deep reflection (PnP) under the WMR (Fig. DR1). Additional details on the data and data acquisition are provided by Takahashi et al. (2008). In addition to seismic refraction data, multi-channel seismic reflection data were collected with a 444-channel, 6,000-m streamer cable (Takahashi et al., 2008). Data used in this study can be requested at http://www.jamstec.go.jp/obsmcs_db/e/data-c/OBS_all-e.html.

TOMOGRAPHIC TRAVEL TIME INVERSION

Travel times of first arrival P-waves and secondary arriving wide-angle reflections have been hand-picked. Picking uncertainties were 20-30 ms for short-offset P-waves (Pg) and reach 50-80 ms for far-offset P-waves (Pn). Secondary wide-angle reflections had larger uncertainties of 60-90 ms. The largest uncertainty of 100 ms have been assigned to the PnP arrivals from

the deep-seated reflector. For profile MR101c, picking resulted in 12670 Pg-wave arrival, 11215 Pn arrivals, 2650 PmP reflected arrivals and 4305 PnP reflected arrivals.

The 2-D seismic P-wave velocity structure of the Western Mariana Ridge (WMR) and adjacent basins has been derived using a joint reflection and refraction tomography (Korenaga et al., 2000), revealing the crustal and mantle structure, the seismic Moho, and a deep-seated reflector. The procedure uses a hybrid ray-tracing scheme, combining the graph method with further refinements utilizing ray bending with the conjugate gradients method. The iterative inversion is regularized using smoothing and damping constraints. A detailed description of this method is given elsewhere (Korenaga et al., 2000). We applied a top-to-bottom layer stripping approach (Fig. DR2) and only five iterations were required to exceed a χ^2 threshold of 1. First, we derived the structure of the sedimentary cover, using reflections from the top basement (PsP). However, PsP could only be used in the Parece Vela Basin (PVB) as the sedimentary cover was rather thin over the WMR and in the Mariana Trough Basin (MTB). In addition, sedimentary thickness has also been corroborated by the multi-channel seismic data.

Picking errors and starting velocity models may control inversion results. We therefore chose a nonlinear Monte Carlo-type error analysis to derive model uncertainties of crustal structure (Fig. DR3). The approach consists of randomly perturbing the velocity values of an initial average 1-D model to create a set of 100 2-D reference models, providing an rms misfit of 36-48 ms for the crustal P-wave (Pg + PmP) and 73 ms for the inversion of crust and upper most mantle (Pg, Pn + PmP). To yield to deep-seated reflector, we removed the PmP from the inversion procedure – added the PnP arrivals and run two iterations with the previous model as input to approximate its geometry. The final model with all phases provides a rms misfit of ~82 ms. The mean deviation of all the solutions was then used as a measure of the model parameters uncertainty. Last, we inverted for the structure of the deep-seated reflection (PnP),

damping the upper part of the mantle. The ray coverage of the models is represented by the derivative weight sum (DWS), which is a measure of the linear sensitivity of the inversion (Fig DR4).

In Fig. DR5 we show results from the profile SP5 shot across the and Kyushu-Palau Ridge which was published by Nishizawa et al. (2007). The velocity model is displayed in a similar style as our model in Fig. 2. Note that for the Parece Vela Basin both lines indicate remarkably similar features, suggesting little asymmetry with respect to the basin structure, but strong asymmetry with respect to the margin itself, which has fast lower crust in the east of the PVB and slow lower crust in the west (see text of the main manuscript for discussion of those features).

58

BATHYMETRIC DATA

The high-resolution seafloor topography shown in Figure 1 has been obtained compiling surveys archived at National Oceanographic and Atmospheric Administration (NOAA) (cruises BD0601 and EW202) and at JAMSTEC (cruises MR99-K01, MR99-K06, NT05-16, KR02-14, KR03-13, KR05-17, KR06-12, KY03-06 leg 1, KY03-06 leg 2, YK99-11 leg 1, YK99-11 leg 2, YK01-11, YK05-09 leg 1, and YK08-08 leg 1). Data have been gridded using Multibeam System (<https://www.mbari.org/products/research-software/mb-system>) and are displayed using Generic Mapping Tools (<https://gmt.soest.hawaii.edu>). Data can be accessed at <https://maps.ngdc.noaa.gov/viewers/bathymetry> and <http://www.godac.jamstec.go.jp/darwin/e>. Please note that for Figure 1 swath data are merged with predicted topography (Smith and Sandwell, 1997).

70

CITED REFERENCES

72 Korenaga, J., Holbrook, W. S., Kent, G. M., Kelemen, P. B., Detrick, R. S., Larsen, H.-C.,
73 Hopper, J. R., and Dahl-Jensen, T., 2000, Crustal structure of the southeast Greenland margin
74 from joint refraction and reflection seismic tomography, *J. Geophys. Res.*, v. 105, 21 591–21
75 614.

76 Nishizawa, A., Kaneda, K., Katagiri, Y., Kasahara, J., 2007, Variation in crustal structure
77 along the Kyushu-Palau Ridge at 15-21°N on the Philippine Sea plate based on seismic
78 refraction profiles, *Earth Planets Space*, v. 59, p. e17-e20.

79 Sandwell, D. T., Müller, R. D., Smith, W. H. F., Garcia, E., and Francis, R., 2014, New global
80 marine gravity model from CyoSat-2 and Jason-1 reveals buried tectonic structure. *Science* v.
81 346, 65-67, doi:10.1126/science.1258213.

82 Smith, W. H. F., and Sandwell, D. T., Global seafloor topography from satellite altimetry and
83 ship depth soundings, *Science*, v. 277, 1957-1962, 1997.

84 Takahashi, N., Kodaira, S., Tatsumi, Y., Kaneda, Y., and Suyehiro, K., 2008, Structure and
85 growth of the Izu-Bonin-Mariana arc crust: 1. Seismic constraint on crust and mantle structure
86 of the Mariana arc–back-arc system, *J. Geophys. Res.*, v. 113, B01104,
87 doi:10.1029/2007JB005120.

88

Figure DR1. a) Record section of OBS10, b) record section of OBS24, c) record section of OBS15, and d) record section of OBS16. Arrows indicate seismic phases identified in the recordings.

Figure DR2. Velocity structure and coverage obtained using the layer stripping or top-down-approach. a) sedimentary reflections (PsP), b) crustal first arrivals (Pg), c) crustal first arrivals waves and mantle reflections (Pg + PmP), d) crustal first arrivals, mantle reflections and mantle first arrivals (Pg + PmP + Pn), e) crustal first arrivals, mantle first arrivals and deep-seated mantle reflector (Pg + Pn + PnP).

101

102 **Figure DR3.** Results from MonteCarlo inversion of 100 different 1-D starting models hanging below
 103 the sedimentary blanket. a) average P-wave velocity model, b) Root-Mean-Square (rms) of the 100
 104 model realizations, and c) Derivative weight sum (DWS) or weighted ray coverage.

105

106

Figure DR4. Final results from tomographic inversion. A) Satellite derived free-air gravity (Sandwell et al., 2014) in the vicinity of the seismic line, note the prominent gravity low along the western margin of the WMR, b) P-wave velocity model and c) ray coverage (DWS) of all rays traced through the model space.

118

119

120

121 **Figure DR5.** Structure of the western Parece Vela Basin and Kyushu-Palau Ridge (Nishizawa et al.,
 122 2007). (top) Seismic velocity model of the western part of the profile line SP5, (bottom) Lower
 123 crustal P-wave velocity (blue) and crustal thickness. Note that the velocity adjacent to the KPR mimics
 124 the structure found in the eastern domain of the basin (Fig. 2 and Fig. DR4) and thus did not support
 125 any asymmetry neither in structure nor in the type of crustal accretion.