Integrated deep seismic profiling from towed streamer and ocean-bottom seismograph surveys

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ABSTRACT

To investigate deep crustal structures in the plate subduction zone, we conduct multi-channel seismic (MCS) surveys with towed streamers for reflection imaging and ocean-bottom seismograph (OBS) wide-angle seismic surveys for regional velocity estimation (Figure 1a). However, we often face difficulties, such as poor reflection image in the deep beneath thick sedimentary basins because of scattered weak reflections from the complex geological structures, and depth discrepancy between the deep geological boundaries of the MCS reflection profile and corresponding velocity variation inferred from OBS data analyses. Generally, those results are derived from two different datasets separately. In this study, we aim to improve the reflection profile for comprehensive understanding of the geological structures and physical properties by applying a signal enhancement processing and subsequent integrated seismic imaging.

We conducted two types of seismic surveys along the same line approximately 100 km long in the Nankai Trough, Japan (Fujie, 2019; Nakamura, 2020). We acquired the MCS data with a single 5.5-km streamer cable towed at 25 m depth and an air gun array (7,800 inch^3 in total) towed at 10 m depth and fired every 50 m. We acquire wide-angle seismic data with an air gun array (10,600 inch^3 in total) towed at 10 m depth and fired every 200 m, and recorded with 51 OBSs at 2 km spacing in the middle and 6 km spacing in the edge part of the survey line.

In the original processing of the MCS reflection data, we preprocessed the data by standard methods, including noise and multiple attenuation, deghosting and debubbling, and then applied pre-stack depth migration (PSDM) with velocity model building through reflection tomography based on residual moveout (Nakamura et al. 2022). In this study, we additionally applied multi-dip reflection surface (MDRS) method (Aoki et al., 2010) to enhance reflection signals, which is an extended technique of common-reflection surface (CRS) method (Jager et al., 2001) to address conflicting dips of reflection surfaces and recently to produce pre-stack gathers that are available subsequent procedure (Narahara et al., 2021). We used the signal-enhanced pre-stack MDRS gathers as the input data for subsequent PSDM process.

The OBS wide-angle data were used to obtain a reliable regional velocity model down to the depth of the Moho boundary by means of a full waveform inversion (FWI) in the frequency domain (Górszczyk et al., 2017). The FWI provided a velocity model with higher resolution velocity variations, including significant low-velocity zones in the accretionary wedge, than that built through the conventional PSDM velocity analysis. In this study, we integrated this FWI velocity into the velocity model for PSDM and updated it minorly to be optimized for reflection imaging of the MCS data.

As a result of the integrated profiling from the reprocessed MCS data and the velocity model based on the OBS data, we successfully improved the seismic reflection profile with reliable depth of the deep reflections consistent with the velocity structure. The signal-enhanced profile revealed dipping reflectors obviously, which may suggest complex deformation structures of large imbricate thrust faults developed in the accretionary prism (Figure 1b and 1c). The bottom simulating reflectors (BSR) crossing the dipping reflectors are also clearly identified in the shallow depth.

On the other aspect, the velocity model derived from OBS data by FWI is well consistent with the MCS reflection profile, and it suggest the existence of several low velocity zones in the accretionary wedge. The low velocity zones imply fluid-rich layers with possibly high pore pressure and fluid path through fractures from the deep high pore pressure layers to the possible shallow gas accumulation nearby the BSRs or to the seafloor where seepages were observed in the previous studies (e.g., Ashi et al., 2002). The geological architecture and physical property also suggest potential factors controlling earthquakes in the Nankai Trough plate subduction zone.

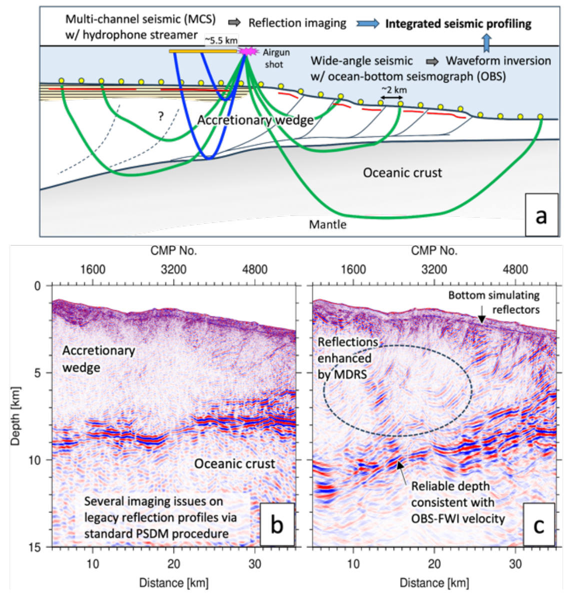

Figure 1: (a) Conceptual image of crustal-scale marine seismic survey with towerd streamer and ocean-bottom seismographs. (b) A legacy PSDM section of from the MCS data only, and (c) new PSDM result by integrated seismic profiling of the reprocessed MCS data and FWI velocity derived from the OBS wide-angle data.