We A10 12

Common Reflection Angle Migration Revealing the Complex Deformation Structure beneath Forearc Basin in the Nankai Trough

K. Shiraishi* (JAMSTEC), M. Robb (Emerson Paradigm), K. Hosgood (Emerson Paradigm), Y. Yamada (JAMSTEC)

Summary

In order to better understand the deformation structures within the thick accreted sediments beneath forearc basin, we apply an advanced beam migration to a legacy 2D seismic data acquired in the deep-water area in the Nankai Trough, Japan. In this region, many seismic surveys have been conducted to study the geophysical and geological features in the seismogenic zone related to the plate subduction. However, the details in the accreted sediments beneath the Kumano forearc basin are still unclear due to the poor seismic images caused by difficult geological structures. The common reflection angle migration is an advanced depth migration technology and an effective method for imaging such complex structures. By applying this method, deeper reflections that were difficult to image previously are clearly revealed. The newly imaged geometric features (e.g., the folds in the shallow part and the deep reflectors with stepwise discontinuities and the land-ward thickening of the lower layer) implies that the deformation is characterized by development of multiple thrust faults in the thick accreted sediments. The common reflection angle migration provides new seismic evidences that are essential for understanding the Nankai Trough seismogenic zone and the accretionary prism development.

Introduction

Common reflection angle migration is an advanced beam migration technique based on reflection angle at subsurface image points (Koren and Ravve, 2011). When imaging complex geological areas that involve complex wave paths (e.g., multi-pathing and turning rays) and poor illumination, generating common image gathers directly in the subsurface angle domain rather than the surface offset domain has advantages to image subsurface more accurately and better.

In the Nankai Trough, many seismic surveys have been conducted to study the geophysical and geological features in the seismogenic zone related to the plate subduction. The regional crustal structures and the detailed structures in the forearc basin and in the frontal thrust zone have been uncovered. However, the structural details within the thick accreted sediments beneath the Kumano forearc basin are still unclear. One reason for the imaging difficulties is the difficult geological structures in the lower accreted sediments. In order to better understand the deformation details, we apply the common reflection angle migration to the legacy 2D seismic data.

Method

The common reflection angle migration was developed as a kind of beam migration (Koren and Ravve, 2011). The asymptotic ray tracing is performed as one-way diffraction rays from the subsurface image points to the surface sources and receivers (Figure 1). The take-off angles from the image point are measured around a given local normal to a background reflection surface for each "source ray" and "receiver ray". Forming a system of the source and receiver ray pairs, the recorded seismic data could be mapped into local angle domain based on the reflection angles at the subsurface image points. Generating common image gathers directly in the subsurface local angle domain rather than the surface offset domain has advantage when imaging complex geological areas. The angle-dependent amplitude variation can be used for reliable amplitude versus angle analysis.

In general beam migration methods, seismic wavelets decomposed to "beams" by slant stack are mapped in the model space along each ray center with spatial weights (e.g., Sherwood et al., 2009). In the common reflection angle migration, a local slant stack operation is performed for each central ray pair for the source and receiver rays (Koren and Ravve, 2011). The size of the beam operator is related to the computed Fresnel zones, and the optimal beams are computed along image points in the vicinity of the central image points. This procedure enhances the primary event imaging with substantially attenuating different types of multiples and various kinds of noise.

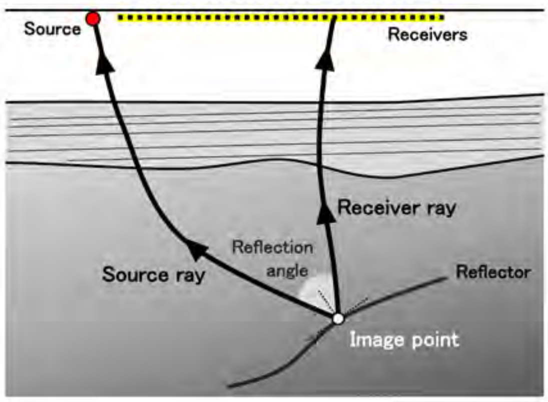

Figure 1 *Schematics of the common reflection angle migration method. The local reflection angle is defined based on the source ray and receiver ray from subsurface imaging point to surface sources and receivers.*

This migration method constructs true angle gathers at the imaging points by summing all seismic events with the same reflection angle. By performing a uniform illumination of the image point, all arrivals are included, and all amplitudes and phases are preserved. The energy computed along the directional angle gather values also used as a weighted stack operator. Subsurface structure continuity can be emphasized by the specular weighted stacks. In addition, the reflection angle gathers are used to extract residual moveouts, which measure the accuracy of background velocity model used for ray tracing. Using the residual moveouts, together with the directivity information, the velocity model is iteratively updated via tomographic solutions to optimize the seismic reflection image.

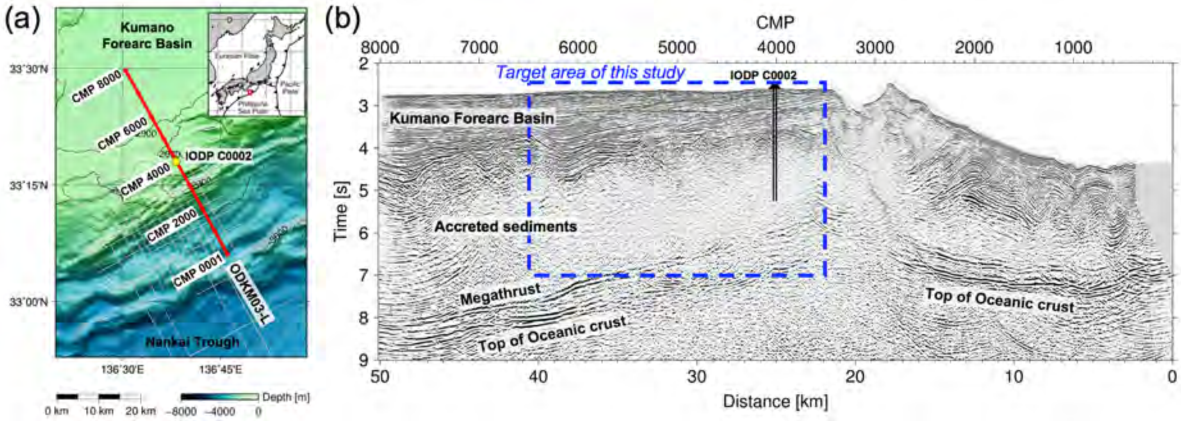

***Figure 2** (a) Map of the 2D seismic survey in the Nankai Trough off the Kii Penisula, southwest Japan. The red line is the processed line, ODKM03-L, and the yellow circle indicates the scientific ocean drilling hole IODP C0002. (b) The legacy section obtained by pre-stack time migration in 2004. Our target area is indicated with the blue dashed line box.*

Data

The 2D seismic data acquisition was carried out in the Nankai Trough off the Kii Peninsula, southwest Japan (Taira et al., 2005). The seismic survey lines comprise a total of approximately 1,500 km of full-fold, multichannel 2-D seismic data in the 2,000 – 4,000 m deep water area. The seismic data were recorded with a 6-km hydrophone streamer with 480 receiver groups at 12.5 m spacing. The depth of the air guns and streamer were 6 m and 10 m, respectively.

In this study, we selected a line, ODKM03-L (Figure 2a), which is crossing the International Ocean Discovery Program (IODP) scientific drilling hole at C0002 (e.g., Tobin et al., 2015). A single 4,240 cubic-inches source array was fired at 50 m spacing, and total number of shooting was 943 along the 47-km survey line. The initial data processing had been done with the conventional preconditioning and pre-stack time migration in 2004 (Figure 2b).

To improve the quality of data preconditioning, we reprocessed the data from original field records using recent techniques: air gun bubble removal, swell noise suppression, random noise attenuation, source-receiver ghost removal, multiple reflection attenuation, surface consistent deconvolution, Q compensation, and zero phase conversion. For effective attenuation of the severe multiple reflections around the target depth, a surface related multiple attenuation and an apex parabolic radon demultiple were applied.

The final velocity model was built via the iterations of reflection tomography and the common reflection angle migration. A starting velocity model was extracted from the velocity model inverted by full waveform inversion using the ocean-bottom seismograph wide-angle seismic data (Kamei et. al., 2013). After smoothing the extracted velocity model, iterative tomographic updates were conducted based on the residual moveout on the migrated image gathers to optimize the reflection image. Finally, we obtained a depth section by stacking the image gathers with angle domain mute applied on the common image gathers.

Results

Figure 3 shows the final common reflection angle migrated section of the target area indicated in Figure 2b. The Kumano forearc basin is composed by slightly dipping sedimentary layers with about 1-km thickness (partially 2 km). Just below the sedimentary layers, several folded structures can be observed (yellow triangles). In the 2 – 6 km thick accreted sediments between the forearc basin and the megathrust fault, some curved reflectors with stepwise discontinuities are clearly recognized around 4 - 6 km in depth (red triangles). The depth of these reflectors decreases from the trench-ward side to the landward side, in other words, the thickness of the lower layer between the reflectors and the megathrust increases towards land-ward side.

The newly imaged geometric features (e.g., folds in the shallow part, the horizons with stepwise discontinuities, and the land-ward thickening of the lower layer) implies that the deformation is characterized by development of multiple thrust faults in the thick accreted sediments. The new seismic evidences of the detailed structure within the accreted sediments are essential for understanding the Nankai Trough seismogenic zone and the accretionary prism development related to the plate subduction.

Figure 4 shows a comparison of migration results by the two different migration methods using the same pre-processed data and migration velocity model. While the reflectors in the accreted sediments are clearly imaged by the common reflection angle migration, they could not be imaged by the conventional Kirchhoff migration. This comparison shows the advantages to image the deep complex structures by generating the common image gathers in the subsurface angle domain and involving all arrivals from different wave paths at the image points.

Conclusions

The common reflection angle migration, an advanced beam migration base on the subsurface local angle domain image gathers, is an effective method to better image complex structures. By applying this technology to the legacy 2D seismic data, the deformation structures in the accreted sediment beneath the forearc basin in the Nankai Trough are clearly imaged. The new reflection profile clarifies the geometric features of the multiple thrust fault populations. The seismic evidences are essential to better understand the accretionary prism development and the current status above the megathrust in the seismogenic zone related to the plate subduction. Our results show the advantages of this method to image such complex geological structures in the deep water.

Acknowledgements

We thank Center for Deep Earth Exploration in Japan Agency for Marine-Earth Science Technology (CDEX/JAMSTEC) for permission to use the seismic dataset of ODKM03. We used a starting model extracted from the velocity model obtained by the full waveform inversion by Rie Kamei (University of Western Australia).

References

Kamei, R., Pratt, R. G., and Tsuji, T. [2013] On acoustic waveform tomography of wide-angle OBS data – strategies for pre-conditioning and inversion. *Geophysical Journal International*, **194**, 1250-1280, doi:10.1093/gji/ggt165.

Koren, Z., and Ravve, I. [2011] Full-azimuth subsurface angle domain wavefield decomposition and imaging Part I: Directional and reflection image gathers. *Geophysics*, **76**, S1-S13, doi:10.1190/1.3511352.

Sherwood, J. W. C., Sherwood, K., Tieman, H., and Schileicher, K. [2009] 3D beam prestack depth migration with examples from around the world. *The Leading Edge*, **28**, 1120-1127, doi:10.1190/1.3236382.

Taira, A., Curewitz, D., Hashimoto, T., Ibusuki, A., Kuramoto, S., Okano, T., and Tanaka, H. [2005] *CDEX Technical Report Volume 1: Nankai Trough seismogenic zone site survey: Kumano basin seismic survey, Philippine Sea, offshore Kii Peninsula, Japan*. The Center for Deep Earth Exploration, Yokohama.

Tobin, H., Hirose, T., Saffer, D., Toczko, S., Maeda, L., Kubo, Y., and the Expedition 348 Scientists [2015] *Proceedings of the Integrated Ocean Drilling Program, Volume 348*, Integrated Ocean Drilling Program, College Station, TX, doi:10.2204/iodp.proc.348.2015.

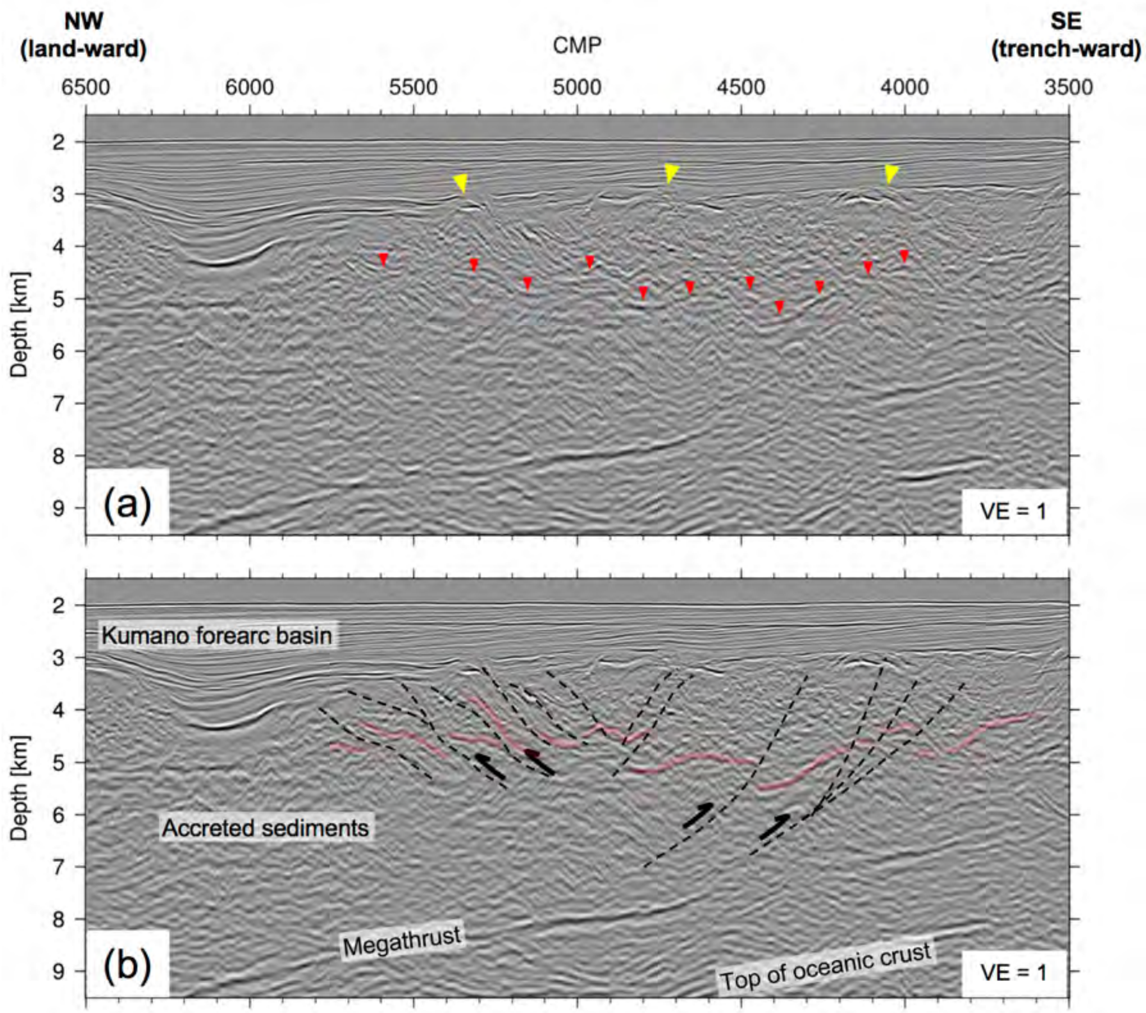

Figure 3 *(a) Final common reflection angle migrated section of the target area indicated in Figure 2b. Yellow triangles indicate folded structures just below the forearc basin, and red tritangles indicate reflectors in the accreted sediments. (b) The same section as (a) with interpretation of multiple thrust faults (black dashed lines).*

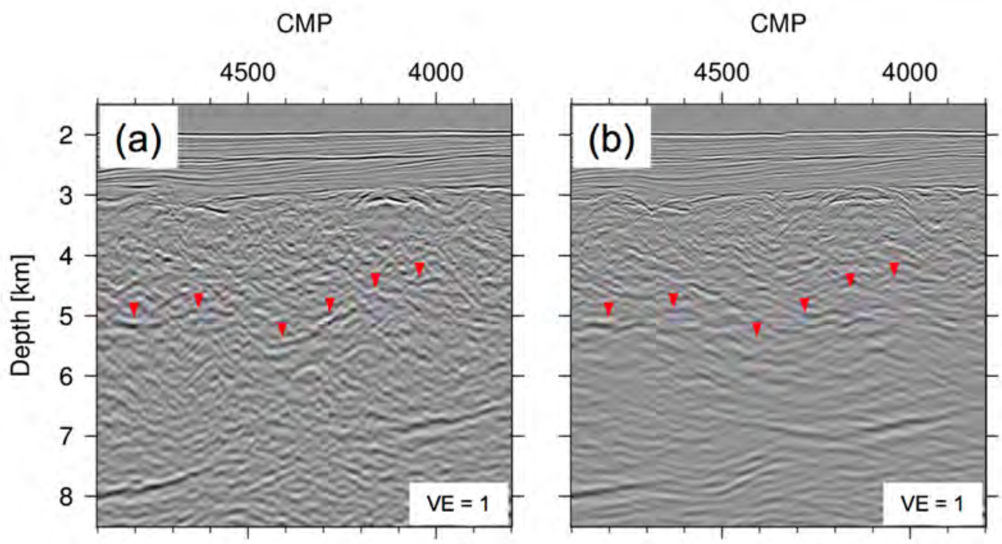

Figure 4 *Comparison of migration results by (a) common reflection angle migration, and (b) conventional Kirchhoff migration using the same pre-processed data and velocity model.*