Reflection travel time mapping for imaging lithospheric scale reflectors.

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Introduction

In the last decade, both of quality and quantity of seismic surveys using Ocean Bottom Seismometers (OBSs) have been improved. However, most of the survey data have been analyzed using conventional traveltime analysis methods; solving an observation equation of traveltimes by the trials and errors or the inverse approach. Although these conventional methods using first arrivals are useful to determine average P-wave velocities, it is difficult to determine the geometry of interfaces, such as a plate boundary. To determine the interface geometry well, reflection traveltimes are required as well as first arrivals.

However, to use reflection traveltimes in the conventional method, accurate velocity structures are required in advance, because reflection phase identifications are indispensable. This is a crucial problem especially in the horizontally heterogeneous structures, such as the subduction zone.

In this study, we show a new approach to image lithospheric reflectors using wide-angle data. The approach is based on the same principle of the diffraction stacking method. Using actual experimental data in the Japan Trench region, we show that this approach is effective for determining reflection phases and imaging lithospheric reflectors.

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Method

In the diffraction stacking method (DSM), diffraction points are determined by both traveltime fields from a shot and a receiver (Figure 2). For example, a phase at 12sec recorded by the receiver is a superposition of diffracted waves from the thick contour in Figure 2. If a reflection phase is observed at 12sec, the corresponding reflection points are some part of this contour. Hence, stacking all the diffraction contours corresponding to picked traveltimes, reflector images will be obtained.

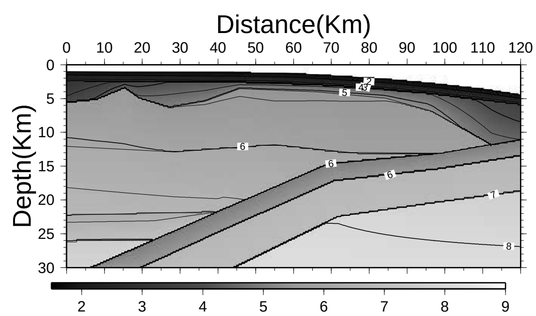

Figure 1: A velocity structure model at a subduction zone. “P.B.”, “Moho” and “2-3” represent a Plate Boundary, the Moho discontinuity and an interface between oceanic layer2 and layer3, respectively.

Although all the waveforms are projected onto the velocity structure in the DSM, only diffraction contours corresponding to the picked reflection traveltimes are projected onto the structure in our method. Therefore, we call

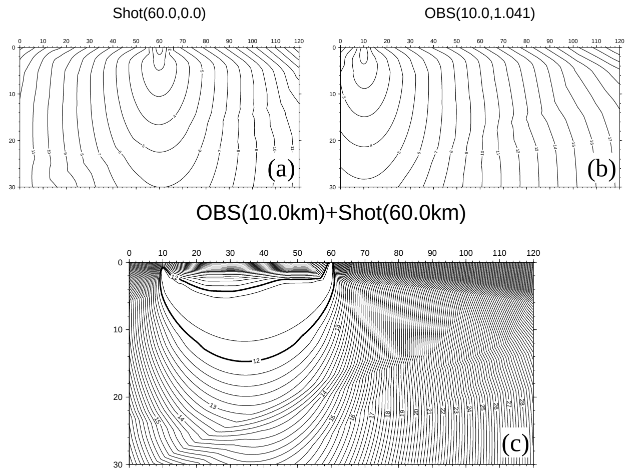

Figure 2: Traveltime fields computed in the velocity structure shown in Figure 1. The contour interval is 0.5 second. (a) Traveltime field from a shot at (60.0km, 0.0km). (b) Traveltime field from a receiver which is located at (10.0km, 1.041km). (c) Sum of both traveltime fields (a) and (b). The thick line represents 12.0sec.

our method the "Traveltime Mapping Method" (TMM).

To image reflectors accurately, an accurate velocity structure is necessary. However, the reflection waves from the same reflector must be imaged into the same group with a not so accurate model. Therefore, reflection waves can be identified and grouped easily without an accurate structure by applying the TMM. The identified reflection waves enables us to develop a more reliable velocity structure. The reflectors will be imaged more accurately using this improved velocity structure.

Numerical experiments

Figure 2(a) is a realistic velocity structure model based on the results of an actual crustal structure analysis in the Japan Trench region. One of the characteristics of this model is a sudden bending of the subducting oceanic plate. We performed numerical experiments using this model as a "true" model.

First, synthetic traveltimes of both first arrivals and reflection were computed in this "true" model under the following conditions; three reflectors, "P.B.", "Moho" and an interface between "P.B." and "Moho"; all the sources are located at the surface and the spacing is 0.25 km; OBSs are located just on the second interface and the spacing is 5 km; offset ranges for picking traveltimes are determined based on the actual observation; appropriate pick errors are added to all the synthetic traveltimes.

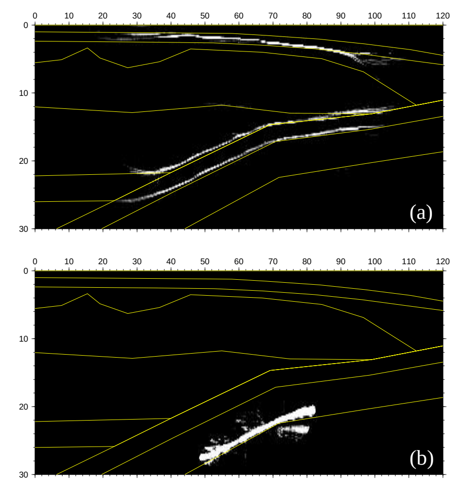

Figure 3: Result reflector images of numerical experiments using "true" velocity structure model. (a)A result image by use of all reflection traveltimes. (b)A result image by use of only Moho reflection.

Second, we applied the TMM using synthetic reflection traveltimes in the "true" model(Figure 3(a)). Moho isn't imaged clearly (Figure 3a), because number of reflection picks from Moho are fewer than those from the other reflectors; however grouping of reflection waves is possible. Therefore, Moho is clearly imaged by applying the TMM using only Moho reflections (Figure 3b). These results show the TMM

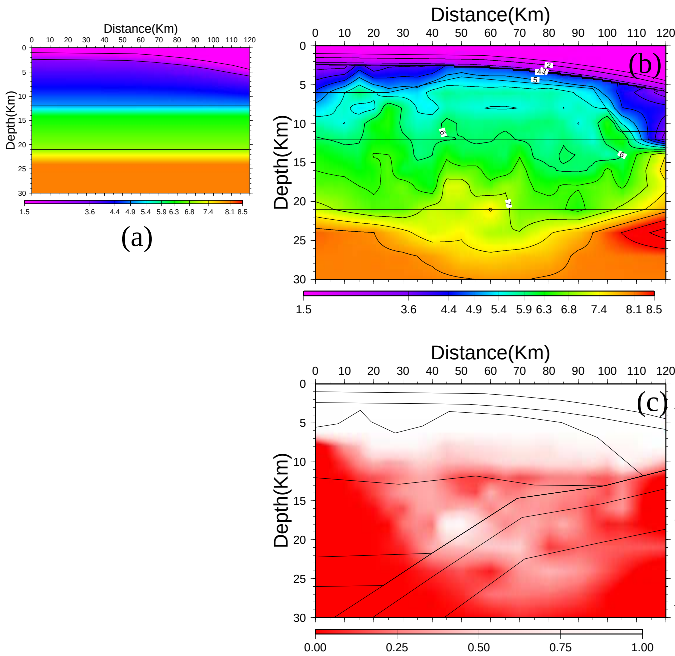

Figure 4: (a) An initial velocity structure model for the first arrival tomography. (b) A obtained velocity structure after tomography. (c) Resolution of the tomography. (c) A result image of the TMM using (b) structure.

provides a reliable image of reflectors if an accurate model is supplied.

The next numerical experiment was the case without the "true" velocity model. Since a velocity structure model is necessary to apply the TMM, first arrival tomography method was applied with a simple initial velocity structure (Figure 4(a)). Referring to the result of the tomography, we modified the initial structure and applied again the first arrival tomography. The results of the second tomography are shown in Figure 4(b) and (c).

Using the result structure of tomography(Figure 4b), the reflector image was obtained by applying the TMM (Figure 5). Although some of the reflectors' are imaged at wrong depths, it is possible to group each reflectors; identification of reflection waves are possible. In this figure, the shallowest white region, located at a few km depth, is not a true reflector.

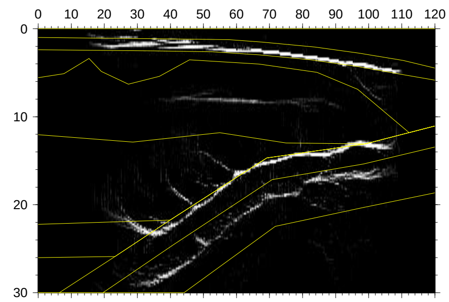

Figure 5: A result of TMM imaging in the Figure 4(b) model. Yellow lines show interfaces of the "true" model.

Since diffraction contours have shallower parts as shown in Figure 2(c), the false reflectors are imaged at shallower depth. But it is easy to distinguish the false reflectors from the true ones, because their depth are much different from each other.

Application to the actual data set

We applied the TMM to the actual seismic experiment data set in the Japan Trench region(Figure 6). Following the same procedure as the numerical experiments, the TMM was applied to the actual reflection traveltime picks in the results model of the first arrival tomography. Figure 7(a) is the results of the TMM using all the reflection picks. It shows many reflectors are imaged. Since the resolution of first arrival tomography was good at only the depth shallower than about 12km, deeper reflectors might be imaged at wrong depths; however, it is possible to group and identify the picks. Pick identifications will enable us to improve the velocity structure model.

Referring to this results, we developed a 2-

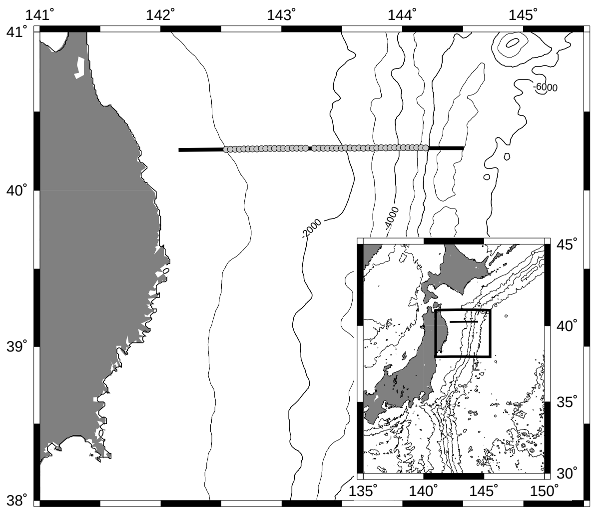

Figure 6: Location map of the seismic experiment in the Japan Trench region. 46 OBSs (circles) were deployed with a 3.3km spacing. A shot spacing was 0.2km.

D velocity structure by the conventional inversion method using first arrivals and reflection traveltimes. The results is shown in Figure 7(b). Most important point to note in this result is that the subducting oceanic plate bends at about 110km; it corresponds to 143.5 degrees east. As shown in numerical experiments, the bending point is probably determined precisely by the TMM.

Summary

We proposed a simple method to image reflectors and to identify reflection picks, which is based on the same principle of the diffraction stacking method. In this method, reflectors are imaged by stacking diffraction contours corresponding to reflection traveltimes. This method has following advantages.

- Imaging of reflectors is possible with an accurate velocity structure.

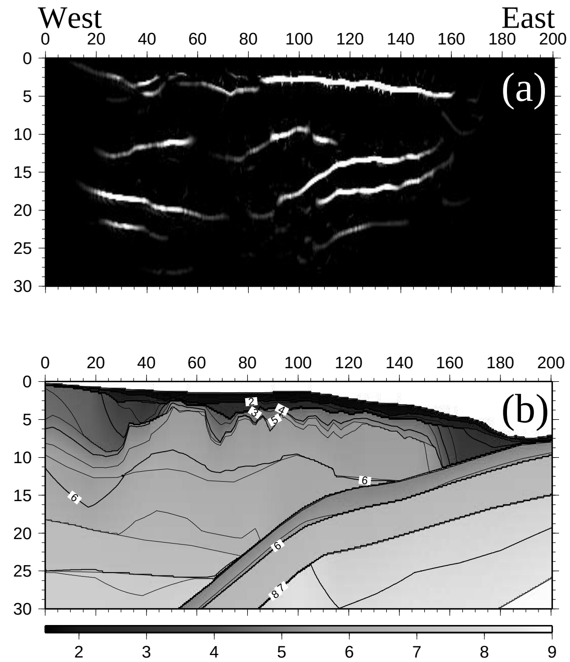

Figure 7: (a) A TMM result of the actual experiment (Figure 6). All the picked reflection traveltimes were used. (b) Final 2-D velocity structure of the experimental line.

- Identification or grouping of the reflection picks are possible even with an inaccurate velocity structure.
- P-S converted wave as well as P-wave can be dealt with.
- No contamination from refraction waves, because it uses only reflection traveltimes.