SEISMIC EXPLORATION IN THE MUSA-DAKE GEOTHERMAL AREA, JAPAN, COMBINING REFRACTION TOMOGRAPHY AND MDRS METHOD

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ABSTRACT

Seismic exploration in the Musa-dake geothermal area was conducted combining the refraction tomography and the MDRS method. The refraction traveltime tomography was applied to delineate near surface velocity structure, which will supplement the reflection seismic profile. Result of the refraction tomography is consistent with the surface geology such as the outcrop of the intrusive rock. The MDRS (Multi-Dip Reflection Surfaces) method was applied to improve the signal to noise ratio. Quality of the seismic section was improved, which helped better understanding of the subsurface structure.

Keywords: seismic exploration, refraction tomography, MDRS, velocity structure

1. INTRODUCTION

Seismic exploration in the Musa-dake geothermal area, Hokkaido, Japan, was conducted in 2010, which includes data acquisition and reprocessing of the existing data. From the previous studies, existence of geothermal resources below the area was confirmed and fluid flow was considered to be controlled by the fault system. Existing seismic lines give overview of the structure, but the precision was not sufficient due to the complex faulted geology. The purpose of the 2010 survey was to improve the definition of the fault location and its dip angle.

First seismic exploration was conducted in 1998 by New Energy and Industrial Technology Development Organization (NEDO). It was the regional survey of the 7.4 km line length with 25 meter receiver interval. As a large size vibrator of 19 tons was used for the purpose of the regional survey, shot density was limited through the line especially at the mountainous western part. As the current target is at the western end of the 1998 line, new data acquisition was carried out in 2010 using a medium size vibrator of 8 tons and receiver interval of 10 meters. Two seismic line data was acquired simultaneously and the line length was 1.2 kms for Line A and 0.9 kms for Line B.

In this paper, we discuss the new approach of the seismic data processing toward the better understanding of such a complex geological structure. Firstly, we will discuss the results from the refraction traveltime tomography with uncertainty analysis by initial model randomization on the newly acquired data. Then, the application of the MDRS method to the merged line of the newly acquired and existing lines will be presented. Other recent data processing technologies also contribute to improve the sections, though not stated.

2. REFRACTION TOMOGRAPHY

Combining refraction traveltime tomography with the reflection survey is widely used recently. Subsurface velocity structures from refraction tomography supplements reflection profiles and help understanding subsurface structure. Refraction tomography estimates subsurface velocity structure based on the Fermat's principle of the refraction ray path using the relationship between travel time and propagation velocities. As the refraction tomography is essentially an ill-posed problem of the nonlinear inversion, evaluation of its uncertainty is essential. Zhang and Toksöz (1998) introduced the Monte Carlo uncertainty analysis by giving random perturbation to the traveltime data and initial model. They evaluated model and field data, and pointed out that the resolution of a tomography solution may not correspond to the ray coverage.

In order to evaluate the uncertainty of the velocity model estimation by the refraction tomography more quantitatively, Korenaga et al. (2000) developed uncertainty analysis procedure using initial model randomization on the refraction tomography using rather sparse OBS data. They generated series of initial velocity model and conducted traveltime inversion for each model. Then the average of generated velocity profiles was considered as the final result of the inversion, and standard deviation of each spatial location gives the degree of uncertainty. Shiraishi et al (2010) evaluated optimum randomization parameters under the condition of dense distribution of receivers.

Results from the refraction tomography on a newly acquired line are discussed in this paper. As the line length is around 1 km, target depth of the inversion is down to about 100 to 150 meters. We generated 100 initial models with velocities at the surface ranged from 1,000 to 2,800 meter/sec and those at the 600 m depth from 2,000 to 3,500 meter/sec. Velocity grid cells size was 10 x 10 meters, and iteration was conducted 10 times. Fig.1 shows results from the refraction tomography from 1.2 km line using initial model randomization. Fig. 1a shows averaged P-wave velocity structure from 100 trials. Point A showing higher velocity near the surface corresponds to the nearby outcrops of the intrusive rock. Point B may be related with the sub-surface distribution of the intrusive rocks though the outcrops are not observed at the surface. Sufficient number of ray paths was achieved in the depth range of more or less 100 meters judging from Fig. 1b. Map of the standard deviation distribution (Fig. 1c) shows that the resolution of the tomography is not always corresponds to the ray density as stated in Zhang and Toksöz (1998).

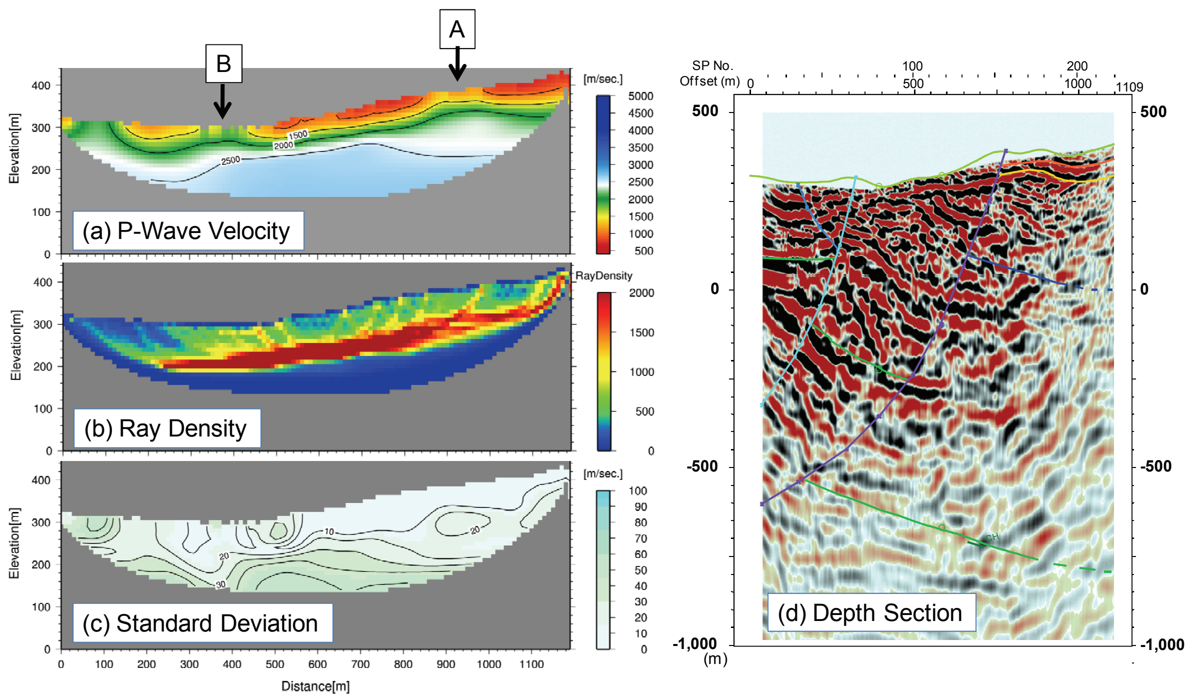


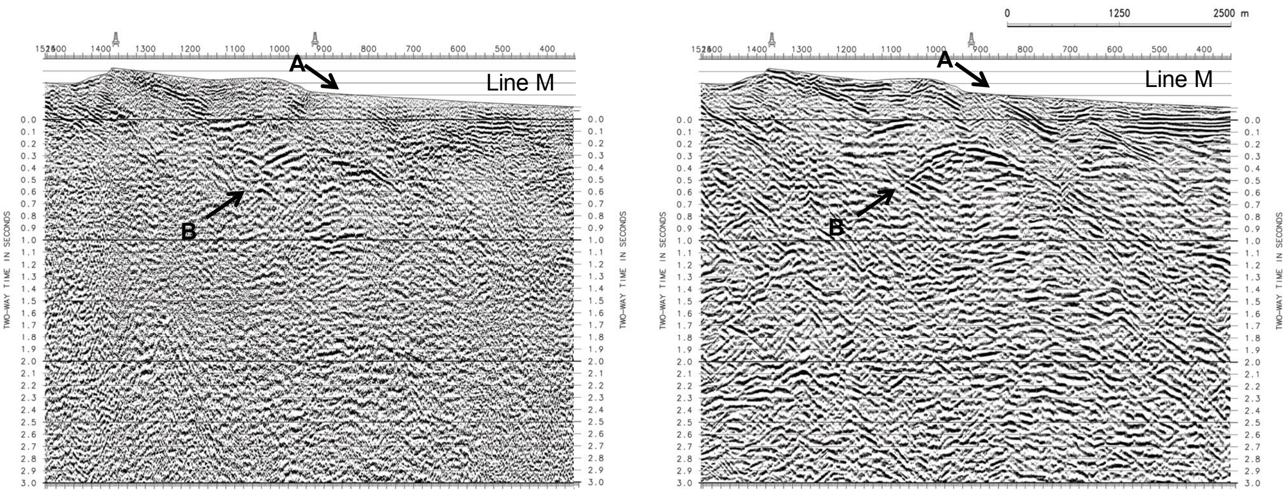
Fig.1 Refraction tomography for Line A using initial model randomization (100 cases). (a) P-wave velocity structure (averaged), (b) ray density, (c) standard deviation, (d) corresponding depth converted migrated section. Point A corresponds to the nearby outcrops of the intrusive rock. Point B may be related with the sub-surface distribution of the intrusive rocks though the outcrops are not observed at the surface.

3. MDRS METHOD

MDRS (Multi-Dip Reflection Surfaces) is an alternative stacking method based on the common-reflection surface (CRS) method. The CRS method can improve the signal to noise ratio drastically by stacking seismic traces including nearby mid-point data considering the structural dips and curvatures (Jäger et al., 2001). While enhancing the predominant dipping events, conventional CRS method can not handle secondary dipping events that would overlap the predominant ones. Such conflicting dips occur in the case of buried focus or other complex structural configuration. MDRS is a revised version of the conventional CRS method which can handle such conflicting dips in the complex structure (Aoki et al., 2010, 2011). By treating conflicting dips properly, the MDRS method can provide high fidelity of wavefield representation, which will contribute much to the following migration stage.

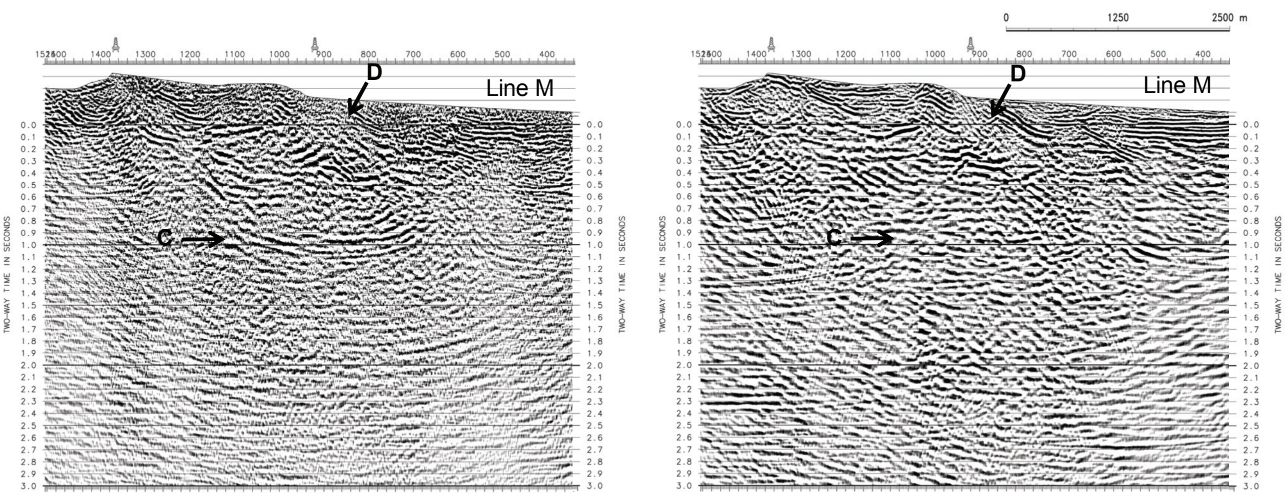
The MDRS method was applied on the merged line of existing line and new acquired line (Line M). Fig. 2 shows a comparison between the conventional stack section and the MDRS stack section. Overall signal to noise ratio is improved in the MDRS section. Shallow dipping events are clearly seen in Fig. 2a. At the position of point B, appropriate processing of confliction dips can be seen.

Fig. 3 shows comparison of migrated sections with and without the MDRS processing. Reflections around point C are properly migrated in Fig.3b, while these events generate migration noises (smiling) in Fig.3a. Possible fault plane reflections can be seen in the MDRS migrated section as indicated by D.



(a) Conventional Stack Section (b) MDRS Stack Section

Fig.2 Seismic stack sections (a) without MDRS and (b) with MDRS.



(a) Conventional Migrated Section (b) MDRS Migrated Section

Fig.3 Migrated sections (a) without MDRS and (b) with MDRS.

4. CONCLUSIONS

This study shows the possibility of further improvement of seismic sections from geothermal areas with complex geology including volcanic rocks and faulted structures. Improved seismic images and velocity structures were obtained through recent developed technologies such as the MDRS method and the refraction tomography with initial model randomization.

The MDRS method provides with not only better signal to noise ratio but also high fidelity of wavefield representation which contribute proper migration images. The refraction tomography with initial model randomization yields high precision velocity structure with its confidence level. Integrating these information, more reliable interpretation has been achieved.

5. ACKNOWLEDGEMENTS

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