Preliminary Results of the Southern Mariana Trench Wide-Angle Seismic Experiment

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Keywords: Southern Mariana Trench, challenger deep, wide-angle seismic

Abstract: The Mariana subduction zone is a key area of magmatism and tectonic evolution in the western Pacific, which has the deepest abyss "Challenger Deep" on the earth. An active source seismic experiment with an array of ocean bottom seismometers (OBS) were conducted across the Challenger Deep in the southern Mariana Trench during November-December 2016, and we have acquired the first significant wide-angle seismic data. We relocated the OBSs position and revised the travel-time of the phases, using the travel-time data of the direct water waves, and obtained high-quality seismic sections based on these corrections. The phase records are complex because of the topography variations but each OBS has recorded continuous and clear phases with a maximum offset of 120 km. The phases of crustal refraction were identified at 5~80 km offsets with little difference on the two sides of the southern Mariana Trench, while the reflections from Moho were found to be very different. From the seismic record profiles, those phases provide an important foundation for analyzing the structure and evolution of crust and the features of its internal velocity structure in Mariana Trench-Arc-Basin system.

1 INTRODUCTION

The OBS wide-angle seismic survey has the characteristics of large depth of exploration and wide range: its investigate depth can reach 30~40 km and the depth of the Moho interface can be reached under the continental crust. Different seismic phases and clear signals can be identified from more than 100 km distance (sometimes up to 200~300 km) (Xia et al. 2007). Thus, the OBS wide-angle seismic survey is used in the study of the crust and mantle velocity structure (Ruan et al. 2004).

All the time, the Mariana Trench is hot research with a narrow and deep-water abyss more than 6,000 m. The trench extends parallel to the island arc, with a "V" cross-section, which is located between the island arcs and the oceanic basin. In 2002, Simon Fraser University in Canada cooperated with the United States and Japan Agency for Marine-Earth Science and Technology (JAMSTEC) carried out a three-dimensional (3D) deep seismic survey of Mariana Trench subduction zone, revealing the distribution of its internal velocity structure in temporally and spatially (Caluert, et al. 2008). In 2003, JAMSTEC also carried out a deep seismic experiment which across the entire Mariana island arc and back-arc system. A wide-angle reflection-refraction seismic record was acquired that about 700 km, the crustal and upper mantle velocity structures and the arc crust evolution model were obtained. The model can explain the process of IBM (Izu-Bonin-Mariana) arc crust creation (Takahashi et al. 2008; Tatsumi Y et al. 2008). Although there have done lots of research in the Mariana island arc, rarely deep seismic experiments have been carried out in the deepest trench of the world. During November-December 2016, we have conducted an active source seismic experiment with an array of ocean bottom seismometers (OBS) across the Challenger Deep in the southern Mariana Trench. The experiment strives for a breakthrough in the study of major scientific issues in deep trench, and have great significance in revealing the formation process of the trench and the relationship with

Wen, G., Wan, K. and Sun, J.
Preliminary Results of the Southern Mariana Trench Wide-Angle Seismic Experiment.
In *Proceedings of the International Workshop on Environment and Geoscience (IWEG 2018)*, pages 364-368
ISBN: 978-989-758-342-1

magmatism and tectonic movement in Mariana Trench-Arc-Basin system.

2 THE SEISMIC DATA COLLECTION IN THE MARIANA TRENCH

The deep seismic data were acquired by R/V “Shiyan 3” of the South China Sea Institute of Oceanology, during December 2016 near the Challenger Deep in the Mariana Trench (Figure 1). Eighteen 4-component OBSs (14 were recycled), spaced in ~15 km intervals, were deployed along the 349 km NW-SE profile across the Challenger Deep and Mariana arc. The 6000 cubic inches air gun arrays were towed at ~10m depth to produce a low-frequency source (3~15 Hz), which delivered a working pressure of 2000 psi. The excitation time is about 90 s and the shot distance intervals about 223.0 m and a total of 1572 shot were fired along the survey line.

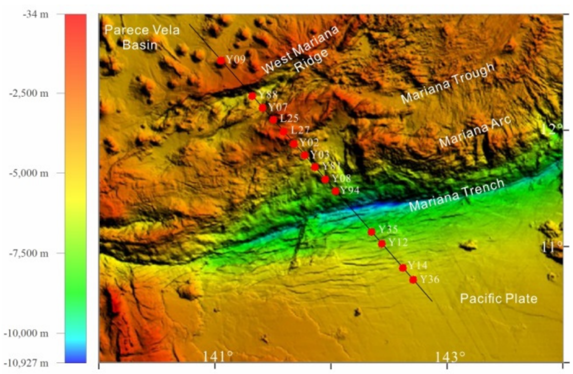

Figure 1: Topography and bathymetry map of the Mariana Trench (the red circles represent OBS stations).

3 THE PROCESSING OF OBS DATA

The original data collected by seismic exploration includes original navigation data (HYPACK files and timer files) and original OBS data. The original navigation data were processed to navigation UKOOA file. In UKOOA file, the shot number and the shot position are from the HYPACK files, the excitation time is from the timer files. The UKOOA file can be used for cropping seismic data. The original OBS data is RAW files that records two horizontal components, one vertical component and one hydrophone component which can be converted into standard SAC format by the RAW2SAC program. SAC format can show the continuously waveform data and it can enable the common operations such as seismic phases picking, filtering and so on. SAC format can be converted into standard SEGY file by the SAC2Y program (Barry, et al. 1975; Qiu, et al. 2011; Zhao, et al. 2004). Finally, the SEGY data is processed and visualized, then the seismic record profiles were obtained (band-pass filtered from 3 to 15 Hz and the reduce velocity is 6.0 km/s). According to the seismic record profiles, we can judge the quality of the seismic record data and the characteristics of travel-time that from different seismic phases.

Due to the influence of ocean currents, the location of OBS falls on the seafloor will deviate from the deployed positions, the more depth of water and the more deviation from the deployed positions. Obtaining the exact location of OBS is particularly important to the data processing because the location deviation of OBS will affect the travel-time of deep seismic phases, such as Pg, PmP and Pn (Pg is the refraction within the crust, PmP is the Moho reflection, Pn is the Moho refraction). Especially, the influence will become bigger when carried out three-dimensional (3D) seismic exploration. The Monte Carlo method is generally used to invert the location which is closest to the actual location of OBS (Ao, et al. 2010; Zhang, et al. 2013). The process is as follows: picking up the travel-time of direct water phases from the seismic record profiles and finding the corresponding shots. The curves of travel-time are fitted by the quadratic curve fitting method, then the velocity of seawater and the depth of OBS are inversed. Taking the OBS deployed positions as the center, with a radius of 2 km and the search area “R” is delineated, which is possible location that OBS on the seafloor. According to the standard normal distribution, thousands of points are randomly generated by the Monte-Carlo method within the area R (Figure 2 a and b). In that case, the area R is basically covered. By the gridded bathymetric data sets, calculate the theoretical travel-time that is between each point in area R and the shot points for pick up the direct water wave (Figure 2 c). Next, we calculate the root-mean-square residuals (RMS) between the theoretical travel-time and the observed travel-time (Figure 2 d) to find the latitude and longitude coordinates corresponding to the minimum value of RMS that as the location of the corrected OBS. If the relocated position of OBS is accurate, then the direct water wave travel-time curve must be symmetrical, so direct wave travel-time curve symmetry or not can judge whether the correction is correct.

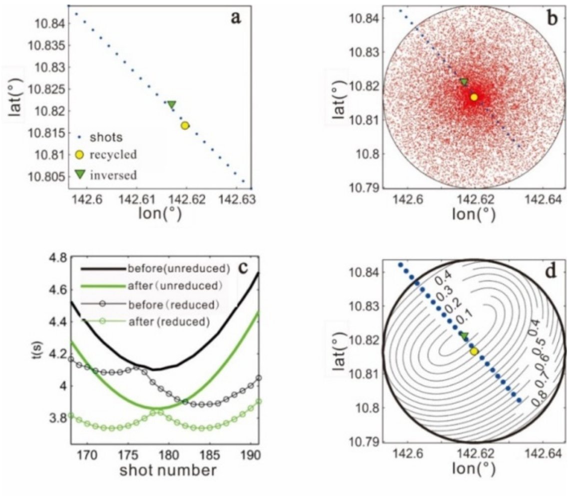

Figure 2: OBS relocation using the Monte-Carlo method (taking obsY14 as an example). (a) Contrast of OBS position and shot position before and after correction (b) The search area R. (c) The theoretical travel time and the reduce travel time curve that before and after correction.(d) The contour map of RMS.

Table 1 show that the relocation parameters of OBS stations along the survey line. From Table 1, we can know that the value of RMS is less than 6.0 ms, which indicate that the result of correction is reliable. It can be seen from Figure 3 that the symmetry of the direct water phases in seismic record profile is better than before correction, it means that the relocated position is closer to the actual position.

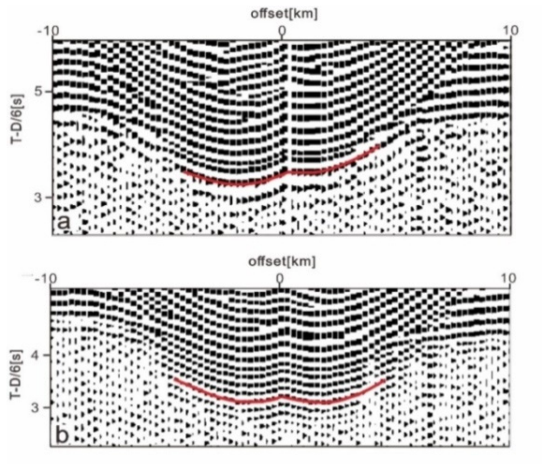

Figure 3: Contrast of direct water phases (Pw) before and after correction of obsY14. (a) before correction. (b) after correction.

Table 1: Relocation parameters of OBS stations along the survey line.

Station	Recycled position		Relocated position		RMS
	lon(°)	lat(°)	lon(°)	lat(°)	(s)
obsY36	142.709656	10.713066	142.710154	10.713349	0.005819
obsY14	142.619663	10.816673	142.616404	10.821096	0.003510
obsY12	142.439940	11.020450	142.441096	11.022307	0.005462
obsY35	142.350578	11.122969	142.351797	11.124636	0.003075
obsY94	142.041620	11.475710	142.040969	11.480242	0.003310
obsY08	141.951940	11.578050	141.950584	11.583437	0.003457
obsY81	141.862190	11.680380	141.860966	11.685728	0.003630
obsY03	141.772726	11.782211	141.774115	11.784745	0.002996
obsY02	141.681278	11.883481	141.683936	11.887525	0.003319
obsL27	141.592537	11.986747	141.593683	11.989987	0.005529
obsL25	141.502816	12.088570	141.504691	12.091123	0.004712
obsY07	141.412384	12.191542	141.413171	12.195028	0.005393
obsY88	141.321854	12.293921	141.322159	12.298346	0.003661
obsY09	141.051429	12.600061	141.053252	12.602530	0.003493

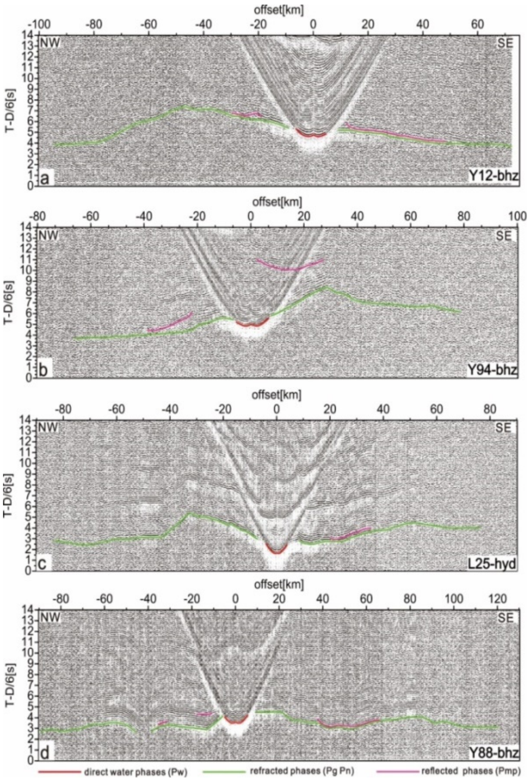

Figure 4: Deep seismic record profiles from different tectonic units. (a). Y12 station, in the Pacific Plate (b). Y94 station, in the Fore Arc (c). L25 station, in the Mariana Arc (d). Y88 station, in the Mariana Trough.

4 THE DEEP SEISMIC RECORD PROFILES

The Mariana subduction zone comprises Parece Vela Basin (PVB), West Mariana Ridge (WMR), Mariana Trough (MT), Mariana Arc (MA), Fore Arc(FA), Trench and Pacific Plate. We selected several seismic record profiles from different tectonic units (Figure 4). We find that the major phases, such as Pg and PmP, are identified and different in the seismic records. To account for the various S/N ratios and levels of data quality of the different phases and OBS records, the picks were assigned uncertainties ranging from 50 ms to 100 ms based on the empirical parameterization of Zelt and Forsyth (Zelt and Forsyth, 1994).

Pg is the refraction within the crust that is clearly visible and can be identified on four stations, but the pattern of the Pg travel-time curve varies significantly, indicate that the complex of basement topography and crustal structure in this area. The Pg phase can be tracked about 160 km on Y12 station (range of -90 km~70 km at offsets). From 70 km to -47 km, the Pg travel-time is increasing. At -47 km, it suddenly decreases. The probable reason is that the Pacific plate subducting and result in large change of basement topography near the trench (Figure 4a). On Y94 station, the Pg phase is observed at offsets from -65 km to 70 km. At 32 km, the Pg travel-time suddenly decreases, probably due to the tapering of depth from trench to forearc (Figure 4b). The Pg phase can be tracked about 160 km on L25 station (range of -85~75 km at offsets). In the range of -40~-30 km, the Pg travel-time suddenly decreases, which may be related to the underground anomalous structure (Figure 4c). On Y88 station, the Pg phase is observed at offsets from -85 km to 120 km. At -50~-40 km, the Pg travel time changes dramatically that probably related to volcano (Figure. 4d).

PmP is a reflected wave from the Moho interface. Its extension range, the amplitude and energy vary significantly on four stations, indicate that the complex of Moho interface and crustal structure in this area. On Y12 station, the Pmp phase is observed at offsets range of -30~-20 km and 10~50km. From SE to NW, the travel time of Pmp is increasing which indicate that the depth of Moho interface increases due to the subduction of Pacific plate (Figure. 4a). On Y94 station, the Pmp phase is observed at offsets range of -40~20 km and 3~28 km. The travel time of Pmp at 3~28 km is obviously greater than -40~20 km, indicate that the depth of the Moho interface is large between trench and forearc (Figure 4b). On L25 station, the Pmp phase is observed at offsets range of 20~35 km (Figure. 4c). On Y88 station, the Pmp phase is observed at offsets range of 40~65 km, -19~10 km and -35~30 km (Figure. 4d). The amplitude and energy of PmP are weak on that both stations, which shows that the complex of crustal structure in Mariana arc-back arc system.

5 CONCLUSIONS AND EXPECTATIONS

The deep seismic experiment was carried out in Challenger Deep and we have obtained all the seismic record profiles. The process includes original RAW data to SAC format, SAC format to SEGY format and the OBS position relocations. During the position relocations process, the Monte

Carlo method is used to relocate the position of OBS on seafloor. After a series of data processing, the deep seismic record profiles were obtained. The seismic record profiles indicate that seismic data are of high quality in this deep seismic experiment. We selected four seismic record profiles from different tectonic units which includes the Pacific Plate, Fore Arc, Mariana Arc and Mariana Trough. Furthermore, we described the dramatic changes of the Pg and Pmp phase from different profiles, which related to basement topography and crustal structure. The variety of phases travel-time show that the complex of the crustal structure and evolution in the Mariana Trench-Arc-Basin system.

In next step, we will construct the velocity structure model by picking up the Pg and Pmp travel-time. Combined with regional geological and geophysical information, we will study the characteristics of the deep structure of the Mariana Trench-Arc-Basin system, we also wish to explore the dynamics of Mariana subduction zone, analyze the structure and evolution of this area.

ACKNOWLEDGMENT

The field work of this study was assisted by the all staff and research workers of R/V Shiyan 3. This work is supported by the Natural Science Foundation of China (Nos. 41676042, 41376060, and 41506046).

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