Depth of Moho surface in the central Sichuan region revealed by deep earthquake exploration

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Abstract. Deep seismic reflection technology has been recognized by the international geosciences as an effective technical means to detect the fine structure of the lithosphere and solve the deep geological problems. Since the 1970s, a large number of deep seismic reflection profiles have been collected in the Sichuan Basin and the periphery, providing a basis for deep research and seismic acquisition techniques for crustal structure research in the region. Because the deep reflection seismic method has the characteristics of large detection depth, high resolution, accuracy and reliability, deep reflection seismic technology is still the main means of deep crust fine structure research in the future. In this paper, the ultra-deep seismic data is collected to reveal the geological characteristics of the Moho surface in the Sichuan Basin in the Sichuan Basin, which is stable and shallow and has a depth of about 45 km.

1. Introduction

The Moho surface is the interface between the crust and the mantle, and is also an important interface for controlling the formation and evolution of the continental lithosphere. The Moho surface depth characterizes the crustal thickness and is an important parameter for describing the crustal structure and its evolution. It records the geodynamic processes such as low intrusion or demolition that the crust has experienced in some areas. Since the mid-1970s, the United States-led Western countries and China have successively carried out deep seismic reflection detection technology experiments, using this technology to expose the formation and evolution of the lithosphere and the geodynamic processes of the basins and orogenic belts, and applied them to oil and gas. Resources prospects, mineral resources exploration and other fields have achieved fruitful results. It provides a more reliable seismological basis for some long-standing debates on deep geological structures. Since the seismic wave propagation characteristics on the Moho surface and the strong and weak reflections are most obvious and can be visually recognized by people, the deep seismic detection technology has been developed in recent years.

2. Deep seismic exploration technology

2.1 Deep earthquake detection

The deep seismic reflection profile detection technology is recognized by the international geosciences as a high technology for detecting the fine structure of the lithosphere. It is the same as the principle of petroleum reflection exploration. It uses artificial blasting to excite seismic waves, and the geological structure features are described according to the reflection in-phase axis formed by elastic wave reflections at different physical interfaces. The difference between it and the conventional seismic
exploration method is mainly to increase the detection depth by increasing the dose, increasing the arrangement length and lengthening the record length\cite{1}. In recent years, the deep seismic reflection profile completed in China reveals the lithospheric structure of the orogenic belt, basin, basin-mountain belt, seismic zone and active fault area, and has obtained valuable information and obtained many geological understandings and new discoveries: revealing The deep environment and oil storage prospects of the Yangtze's vertical stratification, lateral block and oil storage structure \cite{2-3}. However, since the current deep seismic reflection method is mainly used to study the internal structural features of the lithosphere in the tectonic belt, the work area is generally in mountainous areas with complex topographical terrain conditions. The surface topography is undulating and the geological structure is complex. There are many difficulties in the subsequent reflection data processing. Constantly overcome.

2.2 Deep earthquake detection in the Sichuan Basin
The Sichuan Basin is a major component of the Middle and Upper Yangtze Craton. The Yangtze Craton is one of the three stable cratons in China. It has experienced long-term evolution since the Archaean period. After the collision with the Huaxia plate in the late Neoproterozoic, it overlapped with the Caledonian, Indosinian and Yanshan periods. The imprint is constructed, and its deep structure records the superposition of each of the above motions \cite{4}. As one of the main interfaces of deep structure, Moho surface has always been a hot spot in scientific research. Since the 1970s, a large number of deep seismic exploration work has been carried out in the Sichuan Basin and its periphery, covering basically the Sichuan Basin and the surrounding orogenic belt. In the past, deep seismic survey data showed that the depth of the Moho surface in the Sichuan Basin ranged from 38 to 46 km, and the depth of the Moho surface in the central Sichuan region was around 44 km. (Fig. 1).

![Contour map of the depth of the Moho surface in the Sichuan Basin and the periphery](image)

**Figure 1.** Contour map of the depth of the Moho surface in the Sichuan Basin and the periphery

3. Deep earthquake exploration in central Sichuan
In 2009, the Chinese Academy of Geological Sciences set up a 200-km deep reflection seismic line in the A-B city of the Sichuan Basin, laying the foundation for deep seismic exploration technology in the Sichuan Basin. In order to further explore whether conventional oil and gas exploration is suitable for deep seismic exploration of lithosphere, a 90-km conventional seismic line was laid in C and D cities of Sichuan Province in 2018. The main method is to lengthen the record length. The purpose is to explore whether the conventional oil and gas exploration can detect the deep fine structure and physical properties of the survey area, and obtain the Moho surface reflection characteristics in the central Sichuan area.

3.1 Seismic data collection
The study area belongs to the gentle hilly landform of central Sichuan. The altitude is mainly concentrated between 260m-500m. The terrain is not fluctuating, and the relative height difference is
240m. The surface is mainly exposed to Jurassic mudstone, argillaceous siltstone and sandstone, and the excitation conditions are better. However, the industry’s more developed agricultural rough processing industry and a certain number of medium and small machine brick factories, as well as the wide distribution of high-voltage power grids will affect the quality of collected data to a certain extent. In general, the seismic geological conditions of the surface of the study area are good, and the previous seismic data show that there is no obvious reflected wave in the shallow layer, which is beneficial to the seismic wave excitation energy transmission. In the past, the reflected seismic data showed that the structure of the abdomen in the study area was basically similar to the surface structure, and the structure was relatively flat and single, and the reflection data from the shallow to the middle and deep layers were easily obtained. Therefore, the deep seismic geological conditions in the study area are good.

It can be seen from the records of deep reflection seismic single shots that effective reflections can be seen in the shallow, medium and deep layers, and the reflected signals in 12s-15s are still clear (Fig. 2). The conventional single-shot records of oil and gas exploration show that the 0s-4s in-phase axis is clear; the 4s-8s reflection information is weak; the 8s-17s data signal-to-noise ratio is extremely low, and the original record is difficult to see the reflection information, indicating that the seismic wave energy is insufficiently transmitted (Fig. 3).

| Table 1. Comparison of observation systems |
|------------------------------------------|
| **2009 line**                          | **2018 line**                          |
| Observing system: 16780-40-20-40-16780  | Observing system: 7185-15-30-15-7185  |
| Number of coverage: 60                  | Number of coverage: 120                |
| Number of channels: 840                 | Number of channels: 480                |
| Track distance: 40m                      | Track distance: 30m                    |
| Gun spacing: 280m                       | Gun spacing: 60m                       |
| Excitation mode: 25mx2                   | Stimulate well depth: 12-15m           |
| Dosage: 40kg                            | Dosage: 8-10kg                         |
| Receiving method: Single string of 12 detectors, linear combination | Receiving method: Single point digital detector |

Figure 2. Deep reflection seismic single shot record
3.2 Crustal Structure and Moho Surface Characteristics in Central Sichuan

The two ultra-deep seismic sections in central Sichuan (Fig. 4–5) reveal that the most obvious reflection feature of the deep crust in the central Sichuan region is that the entire section is bounded by 0~2.5s, and the upper and lower reflection characteristics are different, and the inner crust is divided into upper, The next two layers show that the crust is deformed into a discontinuous deformation. It is considered that in the upper crust of 0~2.5s, there are many sets of nearly continuous strong reflection wave groups, which are typical sedimentary reflection characteristics. The sedimentary layer in the central Sichuan region is relatively thin with a thickness of 6~8km.

It can be seen from the ultra-deep profile in 2009 (Fig. 4) that the lower crust between the sedimentary layer and the Moho surface, the reflection isotropic axis still exists, and exhibits a near-flat or curved reflection characteristic, and the Moho surface reflection below it is clearer, indicating that the seismic wave transmits enough energy, and the abdomen structure in the central Sichuan region is gentle. The significant reflection layer of the Moho surface in the central Sichuan region appeared at 14s-15s and the depth was about 45km. With the reflection layer as the boundary, the upper and lower reflection characteristics are obviously different: the upper part has a complex reflection in-phase axis, the reflection intensity is different, and the continuity is different; the lower part is a relatively transparent reflection characteristic, and almost no reflection in-phase axis. At the same time, the Moho surface is a seismic velocity transition boundary or velocity transition zone, which is a velocity gradient layer. The Moho surface thickness in the Sichuan Basin in the Sichuan Basin is about 2~3km.
4. Conclusion

Conventional oil exploration and observation systems are sufficient for deep oil and gas exploration, which is insufficient to meet the ultra-deep lithosphere exploration in the geological field. However, it is only necessary to increase the depth of the well, the amount of the drug, and the offset, which can be used for the detection of ultra-deep lithosphere, and has the accuracy that other geophysical exploration methods do not have. It is of great significance for research and prevention of natural disasters and has broad prospects.

The upper crust structure of the central Sichuan Basin: the upper crust of 0–2.5s is mainly sedimentary layer, the thickness is stable 6~8km, and there is no strong tectonic movement in the sedimentary layer. The tectonic structure is basically similar to the surface structure, and the structure is relatively flat and single.

The Moho surface in the central Sichuan region occurred in 14s-15s during the two-way journey, revealing that the Moho surface depth in the Sichuan Basin in the Sichuan Basin is about 45km.

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References

[1] Jiwen Teng. China Earth Deep Seismic Exploration Research Prologue [A]. Hao Chen editor. Geophysics and China Construction Ec 1. Beijing: Geological Publishing House, 1997.342~344.

[2] Chunyong Wang. Review and prospect of research on lithospheric structure in China [J]. Chinese Journal of Geophysics, 1997, 40 (supplement): 82~109.

[3] Haiyan Wang, Rui Gao, Zhanwu Lu, et al. The deep seismic reflection profile reveals the fine structure of continental lithosphere[J]. Acta Geologica Sinica, 2010, 84(6): 818-839.

[4] Xuebo Chen, Yueqiang Wu, Pingshan Du. Characteristics of crustal velocity structure on both sides of the Longmenshan tectonic belt [M]. Research and progress of deep structure in China. Beijing: Geological Publishing House, 1988: 97~113.