Deep Seismogenic Environment in the Southern Section of the Longmenshan Fault Zone on the Eastern Margin of the Tibetan Plateau and Lushan $M_s$ 7.0 Earthquake

LI Dahu1,2,*, DING Zhifeng1, ZHAN Yan3, WU Pingping1 and YE Qingdong1

1 Institute of Geophysics, China Earthquake Administration, Beijing 100081, China
2 Earthquake Administration of Sichuan Province, Chengdu 610041, Sichuan, China
3 Institute of Geology, China Earthquake Administration, Beijing 100029, China

Abstract: The 2,026 earthquake events registered by the Sichuan regional digital seismic network and mobile seismic array after the April 20th, 2013 Lushan earthquake and 28,188 pieces of data were selected to determine direct P waves arrival times. We applied the tomographic method to inverse the characteristics of the velocity structure for the three-dimensional (3D) P wave in the mid-upper crust of the seismic source region of the Lushan earthquake. The imaging results were combined with the apparent magnetization inversion and magnetotelluric (MT) sounding retest data to comprehensively study the causes of the deep seismogenic environment in the southern section of the Longmenshan fault zone and explore the formation of the Lushan earthquake. Research has shown that there are obvious differences in velocity structure and magnetic distribution between the southern and northern sections of the Longmenshan fault zone. The epicenter of the Lushan earthquake is located near the boundary of the high and low-velocity anomalies and favorable for a high-velocity section. Moreover, at the epicenter of the Lushan earthquake located on the magnetic dome boundary of Ya’an, the development of high velocity and magnetic solid medium favors the accumulation and release of strain energy. Low-velocity anomalies are distributed underneath the area of seismogenic origin. The inversion results of the MT retest data after the April 20th Lushan earthquake also indicate that there a high-conductor anomaly occurs under the area of seismogenic origin of the Lushan earthquake. Therefore, we speculated that the presence of a high-conductivity anomaly and low-velocity anomaly underneath the seismogenic body of the Lushan earthquake could be related to the existence of fluids. The role of fluids caused the weakening of the seismogenic layer inside the mid-upper crust and resulted in a seismogenic fault that was prone to rupture and played a triggering role in the Lushan earthquake.

Key words: The Longmenshan fault zone, Lushan earthquake, the three-dimensional velocity structure, the apparent magnetization inversion, magnetotelluric sounding

1 Introduction

On May 12, 2008, the Wenchuan $M_s$ 8.0 earthquake occurred in the middle and northern sections of the Longmenshan fault zone on the eastern margin of the Tibetan Plateau. The surface rupture began to extend unilaterally in a northeast direction from the initial rupture point to the southwest of Yingxiu along the middle and front section of the Longmenshan fault zone. The middle northern section of the Beichuan-Yingxiu fault zone ruptured thoroughly, and the southwestern section of the Chaba-Linansi fault zone ruptured at the surface. However, the southern section of the Longmenshan fault zone was not involved in this earthquake. For the $M_s$ 7.0 earthquake in Ya’an City, Lushan County, Sichuan Province at 08:02:46 on April 20th, 2013, the epicenter (30.3°N, 103.0°E) occurred at the unruptured southern section of the Longmenshan fault zone of the Wenchuan earthquake (Fig. 1). In less than five years, the Wenchuan $M_s$ 8.0 and Lushan $M_s$ 7.0 earthquakes occurred in succession along the Longmenshan fault zone, although it is unclear whether the latter was an aftershock or “infection” and whether the southern section of the Longmenshan fault zone will produce an earthquake.

* Corresponding author. E-mail: lixiang2006@sina.com

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greater than $M_s$ 7.0 (Perkins, 1987). Potential earthquake risks have focused domestic and international researchers on seismology (Parsons et al., 2008; Todas et al., 2008; Nalbant et al., 2011; Chen et al., 2013; Yi et al., 2013; Zhang et al., 2013; Liu et al., 2014). Thus, the deep seismogenic environment in the southern section of the Longmenshan fault zone and background earthquake risk level are worthy of additional research.

The Longmenshan fault zone on the eastern margin of the Tibetan Plateau trends in a N40°–50°E direction for approximately 500 km and consists of four main faults: the Maowen-Wenchuan fault, Beichuan-Yingxiu fault, Pengxian-Guanxian fault and Longmenshan piedmont buried fault, which occurs as a 30–40 km thrust belt and develops mountainous Klippen structures (Deng et al., 1994; Tao et al., 1995). The southern section of the piedmont structure is more complex than the middle section. In the piedmont fault or footwall of the Shuangshi-Dachuan fault, there are several inverse fault-fold belts and multiple slip surfaces at different depths, including the Dayi buried fault, Pujiang-Xinjin fault, Longquanshan fault, relevant Xiongpo anticline, and Longquanshan anticline (Hubbard et al., 2009, 2010). Since the late Cenozoic, India-Tibet collisions have led to the rapid uplift of the Tibetan Plateau and massive crust escape eastward along a large arc fault system, with the
Longmenshan fault zone as the southeastern boundary of the Sichuan-Qinghai sliding block, which exhibits a strong over-thrust nappe effect. Based on current data, the Tibetan Plateau uplift process that is moving easterly and relative stable blocking effect of the Sichuan block have caused the inverse blocking and shortening of the southern section of the Longmenshan fault zone and dextral strike-slip motion. The Longmenshan fault zone is a first-class boundary of active blocks and a huge potential structure background for strong earthquakes (Xu et al., 2013).

In recent years, studies based on geological research results and geophysical prospecting methods and imaging results have revealed that in the Longmenshan fault zone and region to its west on the eastern margin of Tibetan Plateau, a low-velocity and high-conductivity anomaly occurs that is closely related to the middle and lower crust material flow channel. The high conductive layer (HCL) to the east of the Tibetan Plateau, namely the crust of the Songpan-Ganzi block, is suggested to have relatively low viscosity and be easily deformed or flowable; thus, it is also known as a "channel flow layer" (Royden et al., 1997; Clark et al., 2000; Sun et al., 2003; Unsworth et al., 2005; Xu et al., 2007; Burchfiel et al., 2008; Wang et al., 2003, 2007, 2008; Zhao et al., 2008; Zhang et al., 2009; Bai et al., 2010; Liu et al., 2014). However, current research results have not yet provided a clear explanation of the formation mechanism of the deep-media environment in the seismic source region of the Lushan earthquake in the southern section of the Longmenshan fault zone and its deep tectonics (Liu et al., 2009; Lei et al., 2009; Pei et al., 2013). Therefore, in this paper, the 2,026 earthquake events registered by the Sichuan regional digital earthquake network and mobile earthquake array after the April 20th Lushan earthquake and 28,188 pieces of data were selected to determine direct P waves. We applied the tomographic method to inverse the characteristics of the velocity structure for the three-dimensional (3D) P wave in the mid-upper crust of the seismic source region of the Lushan earthquake. The imaging results were combined with the apparent magnetization inversion and magnetotelluric (MT) sounding data to comprehensively study the causes of the deep seismogenic environment in the southern section of the Longmenshan fault zone and explore the formation of the Lushan earthquake. The research results presented here are of scientific significance for understanding the deep geodynamic mechanism that leads to earthquakes in the southern section of the Longmenshan fault zone, determining the deep seismogenic background and earthquake structure pattern that led to and caused the Lushan earthquake and assessing the future trends of seismic activity.

2 Observation Data and Imaging Methods

In this study, we collected the travel time data of the earthquake that were registered by the Sichuan digital seismic station network and mobile seismic stations (Fig. 2a) after the Lushan earthquake from April 20, 2013 to June 23, 2013. In particular, 60 fixed earthquake stations are located in Sichuan province. The mobile earthquake stations were jointly implemented by the Institute of Geophysics, China Earthquake Administration; Hubei Seismological Bureau, Yunnan Seismological Bureau, Sichuan Seismological Bureau, and Chongqing Seismological Bureau in agreement with the Monitoring and Forecasting Bureau of the Chinese Earthquake Administration after the Sichuan Seismological Bureau developed an on-site monitoring plan for the Lushan Ms 7.0 earthquake. The 15 constructed mobile seismic stations are mainly located in the seismogenic region of the Lushan earthquake on the southwestern end of the Longmenshan fault zone and surrounding area. The earthquakes studied in this paper were rigorously selected, and a total of 2,026 earthquake events in the range of $M_{L}$ 1.0–7.0 were selected (Fig. 2b). Of these earthquake events, 86.5% were mainly distributed near the seismogenic region and its vicinity, including 1,966 $M_{L}$ 1.0–3.9 earthquakes and 52 $M_{L}$ 4.0–4.9 earthquakes. The reading accuracy of the P-wave travel time was 0.05–0.15 s, and the number of observation data of the P-wave travel time for each earthquake was not less than 10. In the last inversion, we selected 28,188 P-wave travel time datasets, which reflected 2,026 events (Fig. 2c). In this paper, we adopted the tomographic method of travel time proposed by Zhao et al. (Zhao et al., 1992, 1994, 2001) to retrieve the 3D velocity structure of the P-wave in the seismogenic region of the Lushan earthquake and surrounding area. This method allows for arbitrary velocity changes in 3D space. By setting a series of 3D grid nodes in the model space, velocity perturbations at the node are solved as an unknown in the inversion. In the model, however, the velocity perturbation at any other point can be derived from a linear interpolation of the velocity perturbation at the adjacent eight nodes. To rapidly and accurately calculate the theoretical travel time and seismic ray paths, this method improves the pseudo-bending algorithm proposed by Um and Thurber (Um and Thurber, 1987) in the ray-tracking process and iteratively applies the pseudo-bending technique and Snell's law for the 3D ray tracing; therefore, this method is suitable for situations that present complicated inter-velocity sections. In the reversal process, we adopted the least squares with QR factorization (LSQR) method with damping factor (Paige et al., 1982) to solve the large sparse observation.
Fig. 2. Distribution of seismic stations, earthquake epicenters used and earthquake events in this study. (a), Seismic stations; (b), Earthquake epicenters; (c), Earthquake events.
equations, and the damping met the requirement that the variances of the model and data are all minimized. Finally, we adopted a method utilizing a checkerboard to test the resolution of the inversion results and evaluated the reliability of the velocity anomaly region of the inversion results (Zhao et al., 1994; Ding et al., 1999). The results from the checkerboard indicate that in the 1–24 km depth range of the research region, the crustal recovery is relatively good; therefore, the results confirm the reliability of the 3D velocity structure.

3 Characteristics of the Velocity Structure in the Southern Section of the Longmenshan Fault Zone

In this study, we used the large number of earthquake events recorded by the mobile earthquake stations and digital seismic station network in the seismogenic region of the Lushan earthquake in the southern section of the Longmenshan fault zone and surrounding area. Therefore, we mainly focused on investigating the 3D characteristics of the velocity structure in the seismogenic region of the Lushan earthquake in the southern section of the Longmenshan fault zone and its surrounding area. Figure 3 shows the distribution of the P-wave velocity anomalies at different depths from 1 km to 24 km in the seismogenic region of the Lushan earthquake and surrounding area. As shown in the figure, in the 1 km depth range of the shallow upper-crust, the distribution characteristics of the P-wave velocity anomaly are closely related to the surface geological structure, topography and lithology. A local high-velocity anomaly of the P wave occurs in the surface outcropped area of the Baoxing and Kangding complex rock areas. Because there is a zonal distribution of mafic

Fig. 3. P-wave velocity perturbation images around the source region of Lushan earthquake at six depth slices (Green star denotes the Lushan mainshock).
volcanic and volcanic-clastic rocks in this area, this anomaly is mainly related to the distribution of intrusive rocks in Baoxing and Kangding; as the depth changes gradually from 1 km to 12 km, the trend of the velocity anomaly distribution also changes. The Longmenshan fault zone gradually becomes clear as one boundary for the high and low-velocity anomaly and is roughly bounded near Kangding and Beichuan. The Chengdu Basin to the southeast of the fault zone exhibits a low-velocity anomaly area of P waves. In addition, the distribution of velocity anomalies presents differences in the different sections of the Longmenshan fault zone, and the high-velocity anomaly is mainly concentrated in the area from Wenchuan to Beichuan in the northern section of the Longmenshan fault zone. Near the 16 km depth range in the seismogenic profile, the distribution characteristics of the P-wave anomaly in the southern and northern section of the Longmenshan fault zone exhibit variations. The seismogenic area of the Lushan earthquake and its surrounding area located in the southern section of the Longmenshan fault zone exhibit an anomaly distribution of relatively high velocity, and this distribution trend is more obvious at the 20 km depth layer. Concurrently, the distribution characteristics of a low-velocity anomaly are clear for the Minshan Block. In particular, a large distribution area of low-velocity anomalies occurred in the 20 km depth profile in Heishui-Maerkang area, which is located to the northwest of the Longmenshan fault zone. The research results of three MT survey profiles deployed across the Longmenshan fault zone also clearly revealed that electrical structure characteristics of high conductors occur at the 20 km depth of the Sichuan-Qinghai Block to the west of the Longmenshan fault zone (Zhao et al., 2012), with a crustal high-conductor layer occurring in the high-resistance layer of the upper crust of the Sichuan-Qinghai Block. The top buried depth is approximately 20 km, which is consistent with the tomographic results of this paper. As the depth increases, there is relatively clear variation in the wave velocity near the seismogenic origin of the Lushan earthquake. At the 24 km depth of the seismogenic body of the Lushan earthquake, a closed low-velocity anomaly occurs. The velocity structure at this depth has a more distinct trend of low-velocity anomaly than that shown in the previous tomographic results from the P waves in the southern section of the Longmenshan fault zone, and the distribution region is also more focused at the seismogenic origin and in its vicinity. This result is mainly related to the distribution of earthquake events in the seismogenic origin area of the Lushan earthquake and its vicinity as well as the dense distribution of seismic rays. The imaging results of Lei (2009) mainly focused on the velocity structure in the mid-northern section of Longmenshan without fully covering the southern section of the Longmenshan fault zone and seismogenic origin of the Lushan earthquake and its vicinity.

Figure 4 shows sectional views I and II of the two-wave velocity anomalies passing through the seismogenic region of the Lushan earthquake (the cross section is shown in Fig. 2b). Differences were observed between the deep and shallow tectonic environments among the imaging results for the southern section of the Longmenshan fault zone, which is where the seismogenic region of the Lushan earthquake is located, and mid-northern section of the Longmenshan fault zone, which is where the Wenchuan earthquake occurred. The center of the Lushan earthquake is located along the boundary of the high- and low-velocity anomalies and tilted toward the high-velocity anomaly. Low-velocity anomalies are distributed underneath the area of seismic origin (Figs. 4a, 4b), and the P-wave velocity structure near the range of focal depth between the Longmenshan fault zone of the Lushan earthquake and Wenchuan earthquake exhibits the characteristics of a high-velocity anomaly (Fig. 4b). The unique characteristics of the velocity structure are conducive to the accumulation of stress in the upper brittle crust, and the development of a high-velocity rigid medium is more favorable for the accumulation and concentrated release of strain energy (Yi et al., 2011). Sectional profiles I and II show that the mainshock of the Lushan earthquake occurred near the boundary of the high- and low-velocity anomalies and was tilted toward the side of high-velocity anomaly. Significant low-velocity anomalies occurred underneath this area, which provided a deep medium condition and led to the Lushan earthquake.

4 Apparent Magnetization Inversion

The results of the apparent magnetization inversion can be used to divide magnetic rocks, determine the boundary of rocks, and highlight the boundary of geological tectonic units. According to the morphology of the magnetic anomaly, amplitude, gradient, trending feature, and distribution range, we can analyze the strong and weak regions of the magnetic fields in the southern section of the Longmenshan fault zone and boundary characteristics. Therefore, we can study the distribution range of magnetic materials within the crust in the southern section of the Longmenshan fault zone and properties of the crystalline basement and explore their relationships with the Lushan earthquake.

We used the 1:200,000 aeromagnetic survey data of the China Aero Geophysical Survey & Remote Sensing
Center for Land and Resources for the preprocessing and processing of aeromagnetic anomaly data and then conducted an inversion of the apparent magnetization to construct the inversion map of apparent magnetization at a depth of 5-30 km (Fig. 5). In particular, the southern section of the Longmenshan faults at a depth of 5 km exhibits different apparent magnetization characteristics from that of the mid-northern section. The apparent magnetization is relatively high in the southern Ya’an-Lushan area, whereas the mid-northern section exhibits a relatively low apparent magnetization. The Chengdu Basin exhibits a low-magnetization trap, and the variation trend of apparent magnetization at a depth of 10 km is more obvious than at 5 km. The range further expands, and the magnitude of magnetization slightly increases. The figure shows that the obvious beaded anomaly zone with relatively low and high values is mainly distributed on two sides of the Longmenshan fault zone and forms the distinct magnetic boundary, which is especially clear in the Kangding low anomaly region and Ya’an high anomaly region. The Ya’an-Shimian high anomaly zone has a high anomaly value, large scale and wide distribution range. At a 20 km depth, high-magnetic anomaly characteristics occur and reflect the magnetic features of the southern base of Longmenshan. In the apparent magnetization map at 20 km, the Sichuan Basin east of the southern section of the Longmenshan fault exhibits large-scale characteristics of an oval slow gradient and high magnetization magnitude, which reflects the rigid block structure of the Sichuan Basin basement, and the gentle gradient, large range, and moderate intensity of the magnetic anomaly are manifestations of the mafic volcanic complex buried deep beneath the sedimentary rocks and developed in the Precambrian basement. The deep apparent magnetization map mainly reflects the magnetic properties of the deep magnetic basement, and variation range of the high-magnetic anomaly region in the Longmenshan fault zone ends at the Mabian fault zone on the western margin of the Sichuan Basin. However, the reduced magnetic field strength reflects relatively weak magnetism of the deep substance in the southern section of the Longmenshan fault zone (for example, as shown in Figure 5, the sharp reduced apparent magnetization retrieved for the depth of 30 km); it also reflects that the thickness of upper crust (sialic layer) in this area is relatively large, which is based on the following: the range of reduced magnetic field
The apparent magnetization inversion map in the southern section of the Longmenshan fault zone.

Background is large and consistent with the distribution range of surface Triassic and the existing crustal thickening region calculated from the gravity inversion (Zhang et al., 2009).

After repositioning, the focal depth of the Lushan earthquake was determined to be approximately 17 km (Zhao et al., 2013), which is within the range of a high-magnetization medium. The seismic source is located on the boundary line of the Ya'an magnetic dome on the western margin of the Sichuan Basin. Therefore, we concluded that when the substance in the mid-lower crust of the Tibetan Plateau was subjected to an eastward plastic flow, the rigid substrate in the Ya'an-Kangding-Shimian area in the southern section of the Longmenshan fault zone caused the northern section of the Longmenshan fault zone to present as a dive back-stepping structure. The substance flow in the lower crust on the southern section changed direction from east to south-south/southeast, which is a deep constraint that caused variations between the southern and northern sections of the Longmenshan fault zone. In addition, because the region inside the crustal block or region with significant differences in basement properties between the blocks are often favorable for a relative concentration of stress, the region with low intensity inside the brittle crust is prone to rupture under the action of laterally extruded tectonic stress and may have provided conditions necessary for the Lushan earthquake.

5 Discussions

1) We performed a statistical analysis of the focal depth with longitude and latitude changes that occurred with destructive earthquakes ($M \geq 4.7$) in the Longmenshan fault
zone and adjacent areas between 26 BC and December 2012 (Fig. 6). The advantageous seismogenic layer in the southern section of the Longmenshan fault zone on the eastern margin of Tibetan Plateau was 10–20 km, which indicates a shallow earthquake and coincides with a high-velocity and magnetic brittle medium mostly found at 10–20 km depth, which contains low-velocity and highly conductive layers with depths less than 20 km. The low-velocity layers in the southern section of the Longmenshan fault zone forced the crust to float on top as a plastic layer. With the thickening and uplift of the Tibetan Plateau crust, the Sichuan-Qinghai block to the west of the Longmenshan fault zone move in a southeast-east direction and collide with the relatively stable southern China block near the Longmenshan fault zone (Tao et al., 1995; Burchfiel et al., 2008). The Moho surface of the Sichuan basin uplift and strong solid basement of the Yangtze platform uplift resist the Sichuan-Qinbai block, fasten the fold deformation of the base magnetic rock layer in the Ya'an district, and form a strong stress accumulation. Research has shown that there are obvious differences in velocity structure and magnetic distribution between the southern and northern sections of the Longmenshan fault zone. The epicenter of the Lushan earthquake is located near the boundary of the high- and low-velocity anomalies and favorable for a high-velocity section. Moreover, at the epicenter of the Lushan earthquake located on the magnetic dome boundary of Ya'an, the development of high velocity and magnetic solid medium favors the accumulation and release of strain energy.

2) The MT profiling results for the southern (near Baoxing) and middle section (near Beichuan-Yingxiu) indicated the presence of a high conductive layer underneath the upper crust high-resistance layer in the Songpan-Ganzi block to the west of the northern section of the Longmenshan fault zone at a depth of approximately 20 km. However, the western high conductive layer (relative solid crust depth) in the southern section of the Longmenshan fault zone of the Lushan earthquake is approximately 10 km, which is shallower than the high-conductive layer to the west of the middle section of the Wenchuan earthquake. Moreover, the high resistance body scale of the seismic source zones of the Lushan earthquake is less than that of the Wenchuan earthquake, and the initial rupture point of the Lushan earthquake is located near the boundary of the high-resistance block and southeast second low-resistance block (Zhao et al., 2012; Zhan et al., 2013). After the April 20th Lushan earthquake and under the leadership of the Institute of Geophysics, Chinese Earthquake Administration, the scientific investigations were implemented for the Lushan Mw 7.0 large earthquake. According to the inversion of the outcome of the MT retest of the seismogenic origin of the southern section of the Longmenshan fault zone, 2D deep geo-electric structure in this region was retrieved. The inversion results of the MT retest data after the April 20th Lushan earthquake also indicate that there a high-conductor anomaly occurs under the area of seismogenic origin of the Lushan earthquake; thus, the reliability of our imaging results are confirmed from another aspect. Therefore, we speculated that the presence of a high-conductivity anomaly and low-velocity anomaly underneath the seismogenic body of the Lushan earthquake could be related to the existence of fluids. The role of fluids caused the weakening of the seismogenic layer inside the mid-upper crust and resulted in a seismogenic fault that was prone to rupture and played a triggering role in the Lushan earthquake. In recent years, studies in China and other countries have focused on the triggering effect of fluids on earthquakes. The occurrence of large-magnitude earthquakes is closely related to the surrounding tectonic environment (such as the subduction zone and the physical and chemical properties of the crustal material, magma, and fluids). The existence of fluids underneath the seismogenic layer in the crust affect the structure and

Fig. 6. The profile of focal depth with longitude and latitude changes in the Longmenshan fault zone and adjacent areas.
properties of earthquake faults and reduce the fault strength, which causes changes in the regional stress field and lead to a concentration of stress on the fault (Sibson et al., 1992; Hickman et al., 1995; Zhao et al., 1996, 1997, 2002; Kato et al., 1997; Huang and Zhao, 2004, 2005; Lei et al., 2009). Because of the long-term impact of fluids, the structure and composition of faults are affected; these processes change the stress stage of the fault zone and cause a weakening of the seismogenic zone that triggered the Lushan $M_c$ 7.0 earthquake. Such effects represent the deep tectonic background required for the Lushan $M_c$ 7.0 earthquake.

3) Currently, seismic activity has shown that the Lushan earthquake was adjacent to the Y-shaped trench mouth connecting the northeast-trending Longmenshan fault zone, northwest-trending Xianshuihe fault zone, and near north-south-trending Anninghe fault zone, and represented the most major earthquake in recent years at the closest distance from the Y-shaped trench mouth. Thus, a question remains as to whether the Lushan earthquake started silent seismic activity at the near north-south-trending Anninghe fault zone and vicinity to the south (Chen et al., 2013; Yang et al., 2005). Moreover, the tectonic position of earthquakes at the eastern margin of the Tibetan Plateau and Longmenshan fault zone indicated the development of a northwest-trending Mabian-Yanjin earthquake tectonic zone and Daliangshan fault zone at the southern section of the eastern margin. The Lushan $M_c$ 7.0 earthquake occurred in the southern section of the Longmenshan fault zone; thus, it is unclear how the newest tectonic deformation zone in the Mabian-Yanjin zone and Daliangshan zone is related to the deep dynamic mechanisms of seismic activity. Our research results indicate that a low-velocity anomaly is distributed under the seismogenic body of the Lushan earthquake in the southern section of the Longmenshan fault zone at the eastern margin of Tibetan Plateau. Does there exist the prevalence of a "channel flow layer" or "crustal flow" inside crust at the eastern margin of Tibetan Plateau? In recent years, Zhao et al. (2008) studied the MT data of the Shimian-Leshan profile and found that the overall resistivity is low in the crust on the eastern margin of the Tibetan Plateau. The western crust is divided into upper, middle, and lower layers. The middle crust is the high-conductive layer and has a thickness of approximately 10–15 km, and its resistivity can be as low as 3–10 $\Omega$m, which is prone to deformation and flow. This layer is the "channel flow" layer formed under extrusion in the southeast direction at the eastern margin of the Tibetan Plateau. Zhao et al. also discussed the geophysical proof required for the presence of lateral flowing deep substances and crustal "channel flow" layers on the eastern margin of the Tibetan Plateau. Wan et al. (2010) analyzed the inversion results of the Mianning-Yibin MT profile and further explored the presence of the large area high-conductive layer in the crust, and they also discussed the presence of an inter-crustal flow layer and its relationship with deformation and earthquake activity at the eastern margin of the Tibetan Plateau (Wan et al., 2010). After the Wenchuan earthquake in 2008, the imaging results of Lei et al. (2009) on the P-wave velocity in the crust provides reliable seismological evidence for the upward intrusion of the low crustal flow along the Longmenshan fault zone. Thus, sustained attention and study of deep seismogenic environment at the eastern margin of the Tibetan Plateau is of great scientific significance for providing a deeper understanding of seismogenesis in this region and the dynamic mechanisms that drive new tectonic deformations of the seismogenic zone.

6 Conclusions

(1) In this paper, The 2,026 earthquake events registered by the Sichuan regional digital seismic network and mobile seismic array after the April 20th, 2013 Lushan earthquake and 28,188 pieces of data were selected to determine direct P waves. We applied the tomographic method to inverse the characteristics of the velocity structure for the three-dimensional (3D) P wave in the mid-upper crust of the seismic source region of the Lushan earthquake. The imaging results were combined with the apparent magnetization inversion and magnetotelluric (MT) sounding data to comprehensively study the causes of the deep seismogenic environment in the southern section of the Longmenshan fault zone and explore the formation of the Lushan earthquake. Research has shown that there are obvious differences in velocity structure and magnetic distribution between the southern and northern sections of the Longmenshan fault zone. The epicenter of the Lushan earthquake is located near the boundary of the high- and low-velocity anomalies and favorable for a high-velocity section. Moreover, at the epicenter of the Lushan earthquake located on the magnetic dome boundary of Ya'an, the development of high velocity and magnetic solid medium favors the accumulation and release of strain energy.

(2) Our research results demonstrate that Low-velocity anomalies are distributed underneath the are of seismic origin. The inversion results of the MT test data after the April 20th Lushan earthquake also indicate that there a high-conductor anomaly occurs under the area of seismogenic origin of the Lushan earthquake, Therefore, we speculated that the existence of a high-conductivity anomaly and low-velocity anomaly underneath the seismogenic body of the Lushan earthquake could be
related to the existence of fluids. The role of fluids caused the weakening of the seismogenic layer inside the mid-upper crust and resulted in a seismogenic fault that was prone to rupture and played a triggering role in the Lushan earthquake.

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About the first author

Li Dahu: Male; born in 1982 in Suzhou City, Anhui Province; Doctor; Engineer of Earthquake Administration of Sichuan Province; He is now interested in the study on seismic tomography and seismic active fault detection.

Email: lixiang2006@sina.com; phone: 028-85447105, 13882141716. Postal code: 610041.