Crustal structure in Xiaojiang fault zone and its vicinity*

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Abstract Based on the integrative interpretation of travel-time data and amplitude information obtained from the deep seismic sounding experiment on the Chuxiong-Luoping profile, eastern Yunnan province, carried out in January of 2005, we present a 2-D P wave velocity structure along the profile. The crustal structure shows remarkable contrasts between the two sides of the Xiaojiang fault zone, although the whole profile is situated within the Yangtze platform. The average P wave velocities of the crust on the west and east sides of the fault zone are 6.21 km/s and 6.32 km/s, respectively, and the crustal thicknesses are 41 km and 45 km, respectively. These results imply that the crust to the east of the Xiaojiang fault zone presents characteristics of crustal structure in a stable platform, while the crust to the west is complicated with a lower velocity zone in middle of the upper crust. The average velocity of 6.21 km/s is lower than the global continental crustal average (6.30 km/s), indicating that the region is tectonically active. According to the lateral variation of velocity and depth of interfaces (including the Moho), it is inferred that the Xiaojiang fault zone has cut through the whole crust. It is also deduced that existence of low velocity zone in middle of the upper crust is conducive to the south-southeastern sliding of the Sichuan-Yunnan (Chuan-Dian) rhombus block.

Key words: Xiaojiang fault zone; crustal structure; deep seismic sounding; seismicity; low velocity zone

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1 Introduction

The Xianshuihe-Anninghe-Xiaojiang fault zone, stretching about 2 000 km, is an important tectonic zone on the eastern margin of the Tibetan plateau. It is considered as an active fault zone since the neotectonic epoch and has been frequented by strong earthquakes and severe geological disasters. On the Xianshuihe fault zone, i.e., the north segment of the tectonic zone, six earthquakes with magnitude $M > 7$ occurred in the last century, such as the Kangding $M7.5$ earthquake in 1950 and the Luhuo $M7.6$ earthquake in 1979. On the Xiaojiang fault zone (XFZ), i.e., the south segment of the tectonic zone, more than ten earthquakes with magnitude $M > 6$ have occurred. Among them, the strongest is the Songming $M8.0$ earthquake in 1833, which is only 30 km away from Kunming city.

During the last ten years, a series of moderate and strong earthquakes have occurred in Kunming and its vicinity. In the project “Exploration of Active Seismic Faults in Large Cities and Earthquake Risk Assessment” during the tenth “Five-year Plan” period proposed by China Earthquake Administration, Kunming is one of the large cities for active fault explorations. As a main part of the active fault exploration, a deep seismic sounding (DSS) experiment, named as project KS04, was carried out along the Chuxiong-Luoping seismic profile in January of 2005 to explore the crustal structure and deep configuration of active fault zones in Kunming and its nearby area. The profile traverses Kunming city and the XFZ. In this paper, we present a 2-D P-wave velocity structure along the profile based on the seismic records of explosions. The deep configurations of the XFZ and the Puduhe fault, as well as their possible influence on the Kunming area are also discussed.

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2 Geological setting and previous geophysical results

The studied area is located at the junction of three first-order tectonic units: Yangtze platform, South China fold system and Lanping-Simao fold system (Bureau of Geology and Mineral Resources of Yunnan Province, 1990). The DSS profile crosses two second-order tectonic units, i.e., the Sichuan-Yunnan (Chuan-Dian) anticline and the eastern Yunnan fold belt, both belong to the Yangtze platform. The Kunming basin is the largest Quaternary inherited downfaulted basin in the Yunnan-Guizhou plateau, where the strata developed in Quaternary are characterized by large variation of thickness and complicated facies. According to the regional plate partition, the profile is situated on the boundary between the Tibetan plate (i.e., Chuan-Dian rhombus block, shortened as CDRB) and the South China plate (i.e., South China block) (Figure 1). The XFZ, totaling a length of 400 km in north-south trending, is the southeastern boundary of CDRB and can be divided into three segments. The north segment is from Qiaojia to Menggu; the middle is divided into eastern and western branches: the east branch starts at Menggu in the north and stretches to the southern end of Yiliang basin, and the west branch starts at Daduo in the north and extends to the south of Chengjiang; the south segment lies from the southern end of Yiliang basin near Xujiadu to the southeast of Jianshui. The Quaternary tectonic activity of the XFZ is characterized by strong sinistral strike slip. The Puduhe fault, with a length of 280 km, is located within CDRB. It begins at the north of Jinshajiang river, extending to south along the Puduhe river through Kunming and Yuxi, and ends at the vicinity of Eshan. The Puduhe fault was intensively active during Indo-Chinese and Yanshan epochs.

As regards the seismicity, there are the Yimen and Puduhe seismic belts with moderately strong activity and the Xiaojiang seismic belt with strong activity in the studied area. Along the Yimen seismically active belt, several intermediate and strong earthquakes with magnitude 6 or greater have occurred in history. Among them, the strongest is the Wuding $M_{6.5}$ earthquake in 1995. Several intermediate and strong earthquakes have also occurred on the Puduhe seismically active belt, the strongest being the Luquan $M_{6.3}$ earthquake in 1985. More than ten strong earthquakes with magnitude $M > 6$ have occurred along the Xiaojiang seismic belt. The strongest is the Songmin $M_{8.0}$ earthquake in 1833.

Since the 1960's, much effort has been devoted to the study on XFZ and the seismic tectonics in Yunnan area. Xie (1958) was the first to associate the strong seismic activities with XFZ. Kan et al (1977) studied the modern stress field in western China in detail and presented the concept of "Chuan-Dian rhombus block". The first DSS experiment in Yunnan was carried out in 1982, which is called "Dian-Shen 82". Based on the seismic data, Yan et al (1985), Hu et al (1986), Kan et al (1986), Kan and Lin (1986) and Kan and Han (1992) expounded the crustal structure in Yunnan area. Zhou et al (2001) studied the petrological structure of the crust and upper mantle using the DSS results and other field and experimental data in Yunnan. Recently, Bai and Wang (2003, 2004) and Zhang et al (2005) reanalyzed these DSS data, respectively. Through the seismic tomography of the travel-time data from Yunnan seismic network, Liu et al (1989), Chen et al (1990) and Wang et al (1994, 2003) investigated the structure of the crust and uppermost mantle in Yunnan area, respectively. Most of these studies were concentrated on the western Yunnan area

Figure 1 Regional tectonic framework (after Ma, 1989) and positions of DSS profiles. 1. Boundary fault of plate; 2. Other faults; I. Qinghai-Tibet plate (CDRB); II. Southeast Asia plate (Lincang-Simao block); III. South China plate (South China block); F_1 . Xiaojiang fault; F_2 . Zemuhe fault; F_3 . Honghe fault; F_4 . Shiping-Jianshui fault; F_5 . Chuxiong-Eshan fault; F_6 . Yuanmou fault; F_7 . Puduhe fault; F_8 . Mile fault. L_1 , L_2 and L_3 denote the positions of three DSS profiles, i.e., Chuxiong-Luoping, Eryuan-Jiangchuan and Simao-Malong profiles, respectively.

and the Honghe fault zone, while paid a little attention to the eastern Yunnan area and XFZ.

3 Seismic data and phase analysis

3.1 Layout and observations

The Chuxiong-Luoping DSS profile (295.67 km in length) begins at the southern part of Chuxiong in the west, extends eastwards through the Yuanmou fault, Yimen fault, Puduhe fault, Xiaojiang fault and Mile fault, and terminates at the southern part of Luoping. The Eryuan-Jiangchuan profile and Malong-Simao profile in the “Dian-Shen 82” experiment pass through the studied area (Figure 1). Eight shots, i.e., Chuxiong (CHX), Dahaibo (DHB), Qinglongsi (QLS), Tangchi (TCH), Zhangziba (ZZB), Luliang (LUL), Xinglongcun (XLC) and Luoping (LUP), were fired along the profile.

The explosive charge of each shot varies from 1 800 kg to 3 000 kg, except for the shots TCH and ZZB, whose charges are 500 kg (Table 1). Three of the shots (i.e., LUP, XLC and DHB) were underwater explosions. The others are multi-borehole explosions. The depths of borehole explosions are 25–30 m. 150 mobile seismographs were deployed along the profile, with a station interval of about 2.0 km (Figure 2). Each set of the seismographs consists of a data acquisition system (type DAS-1), which was developed by Geophysical Exploration Center, China Earthquake Administration, and a three-component short-period sensor (type CDJ-6B). The positions of shots and receivers were measured with GPS. The horizontal error of the location is less than 5 m.

Table 1 Positions of shot points on the Chuxiong-Luoping DSS profile

Name	Code	Long /°E	Lat /°N	Elevation /m	Coordinate/km	Charge/kg
Chuxiong	CHX	101.401 7	25.203 6	1 930	0	2 500
Dahaibo	DHB	101.648 9	25.176 1	1 760	25.10	3 000
Qinglongsi	QLS	102.299 3	25.012 2	1 874	92.98	1 800
Tangchi	TCH	103.059 9	24.994 0	1 860	168.86	500
Zhangziba	ZZB	103.226 5	25.013 5	1 578	185.25	500
Xinglongcun	XLC	103.585 7	24.995 8	1 840	221.50	2 000
Luliang	LUL	103.615 6	24.963 8	1 848	224.91	1 800
Luoping	LUP	104.320 0	24.957 1	1 480	295.67	2 500

Figure 2 Locations of shot points and record stations on Chuxiong-Luoping DSS profile and epicentral distribution of strong earthquakes with $M \geq 6$. Fault marks are the same as Figure 1.

3.2 Seismic phases on the record sections

On the seismic record sections of all shots, the phase Pg can be recognized clearly. As the first arrival, Pg is the head wave or diving wave propagating in the crystalline basement. Reflected at crust-mantle boundary, phase PmP always has strong amplitude. Phase Pn, the refracted wave of uppermost mantle, can be traced on the records from some of the shots. In addition, four phases

reflected on the intracrustal interfaces can be identified on the record sections. They are named P_1 , P_2 , P_3 and P_4 according to their arriving order. Among them, P_3 has the strongest energy. In this paper, we take the reflector of phase P_3 as the boundary between the upper and lower crust. Figure 3 shows the record section of the shot CHX, which is situated in the central Yunnan basin, and 160 km away from the west branch of XFZ. The record sec-

tion provides the information of crustal structure to the west of XFZ. Figure 4 shows the record section of the shot TCH, where the phases on the two sides of the shot have different behaviors. The seismic records to the west of the shot TCH reflect the structure of CDRB, while the records to the east reflect the structure of South China block. Most seismographs were installed along the main

highway, so the ambient noise on the records is high, especially at the stations situated in Kunming and its nearby region. For example, seismic signals on the records at shot-receiver distance of 30–50 km on the west branch observation of the shot TCH (Figure 4) and 60–80 km on the east branch observation of the shot QLS (Figure 7) are almost buried by the noise.

Figure 3 Trace-normalized vertical-component record section of shot CHX. The origin of distance axis is located at the position of the shot point. The record section is plotted with reduced velocity 6.0 km/s, same as below.

Figure 4 Trace-normalized vertical-component record section of shot TCH. The shot point is located at the intermediate zone between the west and east branches of the Xiaojiang fault zone.

Shot CHX is located at the west end of the profile, and is set to be the origin of distance coordinate axis in 2-D distance-depth section. On the record section (Figure 3), P_g has a lower apparent velocity (5.80 km/s) at the distance within 80 km. P_1 is clear. P_2 and P_3 can also be traced. PmP is of stronger energy and can be traced in a distance of 80–160 km. Pn can be traced, and the apparent velocity is estimated at 8.0 km/s.

Shot DHB is an underwater explosion and located at coordinate of 25 km on the west segment of the profile. The apparent velocity of phase P_g is as low as 5.9 km/s. P_1 is clear. Both P_2 and P_3 can be traced. PmP can be traced continuously from 90 km to 160 km. Pn can hardly be identified.

Shot QLS is located at coordinate of 93 km on the west segment of the profile. The record section (Figure 7) reveals that the apparent velocities of P_g on both east and west branches are low (5.85 km/s on the east branch

and 5.90 km/s on the west) in a distance less than 80 km. P_1 can be recognized clearly. Both P_2 and P_3 can be traced. P_4 is relatively weak. PmP can be clearly traced eastwards from 80 km to 180 km. Pn does not appear.

Shot TCH is located at coordinate of 169 km, on the middle segment of the profile, just between the west and east branches of XFZ. On the record section (Figure 4), the apparent velocities of P_g on both west and east branches are relatively low (5.85 km/s on the east branch and 5.95 km/s on the west). Both P_2 and P_3 can be traced. PmP can be traced in a distance of 80–160 km. Pn does not emerge.

Shot ZZB is located at coordinate of 253 km on the middle segment of the profile and to the east of XFZ. The phase features exhibited on the record section are similar to those of the shot TCH. The apparent velocity of P_g is 5.85 km/s. P_1 is clear. Both P_2 and P_3 can be traced. PmP can be traced from 80 km to 130 km.

Shot XLC is an underwater explosion located at coordinate of 221 km on the east segment of the profile. The features of phases are similar to those of the shot LUL.

Shot LUL is located at coordinate of 224 km on the east segment of the profile. The first arrivals within 80 km displayed on the record section (Figure 8) have a low apparent velocity (about 5.80 km/s). P_1 is shown clearly. Both P_2 and P_3 can be traced. PmP of the east branch observation can be traced at distance of 80–160 km. Pn can be traced, and the apparent velocity is estimated at 8.1 km/s.

Shot LUP is located at the east end of the profile. The record section shows that the apparent velocity of first arrivals within 80 km is low (5.90 km/s). P_1 is clear. Both P_2 and P_3 can be traced. PmP can be traced from 80 km to 160 km. Pn is not identifiable.

4 Interpretation methods

4.1 Ray tracing and synthetic seismograms

The seismic records are interpreted to obtain a 2-D crustal structure by use of the method based on the asymptotic ray theory (Cerveny et al, 1977). The ray tracing algorithm can be used to construct a 2-D velocity model with multiple interfaces, where not only the thickness of each layer is variable laterally, but also the velocity within each layer is variable laterally and vertically. On the profile, all of the recognizable seismic phases, except Pg and Pn, are reflected waves. So the average velocity of overlay medium upon the interface, at which the reflected phase is generated, can be estimated, and further, the velocity of each layer can be obtained from these average velocities. The average crustal velocity is determined from the travel times of phase PmP with the $t^2-\Delta^2$ method (Giese and Prodehl, 1976).

After determining the depths of interfaces and the average velocity of overlay medium with travel times of corresponding reflected wave, the lateral variation feature of crustal structure along the profile is revealed clearly. Firstly, travel-time modeling and synthetic seismograms calculated on 1-D velocity model for each shot is carried out to understand the structure features of crustal layers around the shot and to compose the basic data for creating a 2-D initial velocity model. Then, based upon the 2-D initial model, ray tracing method is utilized to simulate the travel times of the first arrivals and later arrivals, the 2-D synthetic seismograms calculated by the code of Cerveny and Psencik (1984) pro-

vide amplitude constraint. All phases of all shots along the profile are gradually simulated from shallow to deep by modifying the 2-D velocity model. Finally, a lateral inhomogeneous crustal model is obtained. Average RMS of travel time for all phases is less than 0.05 s, while the amplitudes of all phases in the synthetic seismograms are consistent with those in the record sections. The whole interpretation process is forward modeling, or a trial-error procedure.

4.2 Finite difference tomography with the travel time of first arrival

A finite-difference algorithm for calculating travel times of first arrivals, presented by Vidale (1988), was used here to model the Pg travel-time data. With this algorithm, the travel-times of direct wave, refracted wave, diffracted wave and head wave are calculated with a finite-difference operator based on eikonal equation. In the model, velocity values are sampled on a group of unequal interval grid nodes. The finite-difference operator, using the mean slowness over each grid cell, which is equal to the plane wave approximation on the horizontal plane of grid nodes, calculates the travel-times of first arrival wave at every grid node of the velocity model. To find the ray path, the ray tracing begins at the receiver point and goes back by the gradient of computed travel-time field. According to the reciprocity theorem, the travel time from shot to receiver can be simulated by the travel time from receiver to shot. This algorithm is much faster than the two-point ray tracing method. The computation time of this algorithm is irrespective to the velocity model, and is approximately linearly correlative with the number of grid nodes. Owing to the fast calculation and generality, the algorithm adapts to the iterating inversion procedure. The spatial resolution of the solution can be estimated by counting the number of rays in each grid cell (Wang et al, 1997). This algorithm is suitable for the velocity structure inversion of the upper crust in this paper.

5 2-D velocity distribution along the profile

5.1 2-D velocity structure in the uppermost crust from travel-time tomography

The velocity model of the uppermost crust for travel-time tomography inversion is parameterized via rectangular cells of dimension 4 km (horizontal)×2 km (vertical). To maintain accuracy, a uniform 1-km spacing grid was used for travel-time calculation of the first ar-

rivals. A total of 817 travel-times of first arrival, collected from the eight shots (Table 1) and two other shots (XRR and SNM) on the seismic exploration profile for the shallow exploration of Kunming city (Yu et al, 2008), were used in the inversion. With the finite difference algorithm developed by Hole (1992), the final velocity model was obtained after five iterations. The root mean square (RMS) of travel-time residual reduces from 0.38 s to 0.17 s. The convergence of inversion is stable. The final models derived from several sets of initial parameters are basically consistent, and are in accord with the understanding from phase analysis.

The 2-D velocity model of upper crust and the 2-D ray path distribution along the profile are shown in Figure 5 as contour maps. Because the distance between shot and receiver station in the shallow seismic exploration profile is short, the penetration depths of ray paths beneath the shots XRR and SNM are shallow (3–4 km). On most sections of the Chuxiong-Luoping DSS profile, the penetration depth of ray path is as deep as 5–7 km. Each block has more than ten rays passing through at this

depth, except for a few blocks with 5–10 rays. The inversion results, therefore, are of high reliability.

The contrast of velocity structure in the upper crust of different tectonic provinces is revealed in Figure 5. The velocity structure to the east of XFZ is relatively simple, while it is relatively complicated to the west of the fault zone. The fault zones that cross the profile exhibit themselves as velocity anomalies on the 2-D velocity section. The eastern branch of XFZ is located at about coordinate 175 km, between the shot TCH and the shot ZZB, on the profile and the western branch at 160 km. The velocity contour shows that both branches of the fault zone dip westwards and can be traced downwards to the depth of 8 km. Between the two faults, there is a lower velocity anomaly zone. The velocity anomaly of Puduhe fault, located at Xishan of Kunming, as a small scale fault, extends downwards to only 3–4 km. The Mile fault at the eastern part of the profile also dips westwards, but with a small velocity anomaly. The Yuanmou fault on the western segment of the profile possibly dips eastwards.

Figure 5 2-D velocity structure of the upper crust along the Chuxiong-Luoping DSS profile derived from finite-difference travel-time inversion of Pg arrivals (top) and 2-D distribution of ray density (bottom). Star denotes the shot point.

5.2 2-D crustal velocity structure

The initial 2-D crustal velocity model consists of five layers. In view of the energy of the reflected phases on record sections, the upper crust is divided into three layers and the lower crust is divided into two. Using the ray tracing method to model the travel time of the reflected and refracted phases, we obtained the 2-D final crustal structure (Figure 6). The origin of depth coordi-

nate is set at an elevation of 1 800 m. In the 2-D velocity model, the interfaces C_i are related to phases P_i ($i = 1, 2, 3, 4$). The depths of interfaces were determined by the arrival times of the reflection and Pn waves from all the eight shots. In the upper crust, the average interface depths corresponding to phases P_1 , P_2 , and P_3 are 10 km, 17 km and 25 km, respectively. In the lower crust, the average interface depths corresponding to the phase P_4

and Moho are 30 km and 42 km, respectively. Phase P_4 reflected from the lower crust is usually weak.

In the 2-D crustal model, the velocity distribution of the first layer, within the depth of 10 km, was derived from the finite-difference inversion mentioned above (Figure 5). Lateral velocity variation to the west of XFZ is more intense than that to the east. The second layer is at the depth of 10–20 km, where the lateral velocity variation is remarkable. The velocity to the east of XFZ is normal (6.0–6.1 km/s), while to the west there is a low velocity layer (5.8–5.9 km/s). The velocity of upper crust to the east of the fault is higher than that to the west. The

velocity in the lower crust, on the contrary, is slightly lower to the east of XFZ than that to the west. As a whole, the crustal average velocity to the east of XFZ (6.32 km/s) is higher than that to the west (6.21 km/s). Meanwhile, the crustal thicknesses on the east and west sides of XFZ are 45 km and 41 km, respectively, indicating that the crust is thicker in the east than in the west.

Guided by the depth variation of intracrustal interfaces and M-discontinuity, it is inferred that the west and east branches of XFZ converge at the depth of about 25 km, and XFZ has cut through the whole crust (Figure 6).

Figure 6 2-D crustal structure along the Chuxiong-Luoping DSS profile. Velocity of uppermost crust (–2 km to 8 km) is determined from P_g using the finite difference inversion. Downward extension of the fault is denoted by dashed thick line.

Based upon the ray theory, the ray paths and seismograms in 2-D crustal structure were calculated. The ray paths, seismograms and record sections for the shots QLS and LUL are shown in Figures 7 and 8, respectively. The whole Chuxiong-Luoping DSS profile is situated in the Yangtze platform, but only the crust to the east of XFZ keeps the velocity structure of the stable platform, while the crust to the west of XFZ (belongs to CDRB) presents complicated crustal structure: a low velocity zone in the middle part of the upper crust and an average crustal velocity of 6.21 km/s (lower than the global continental average velocity 6.30 km/s), indicating that it is a tectonically active region (Mooney and Brocher, 1987).

The Chuxiong-Luoping DSS profile intersects Eryuan-Jiangchuan profile and Simao-Malong profile in the “Dian-Shen 82” project (Kan and Lin, 1986), respectively (Figure 1). The average crustal velocities on the east and west segments of the Chuxiong-Luoping DSS profile are consistent with those derived from the record section of the shot Jiangchuan on the Eryuan-Jiangchuan profile (Hu et al, 1986) and from the record section of the shot Malong on Simao-Malong profile

(Yan et al, 1985), respectively. Based on the Simao-Malong profile to the north of the Honghe fault, the crust is 43–45 km thick with an average velocity of 6.27 km/s, and the P wave velocity in the uppermost mantle is 8.17 km/s. Based on the Eryuan-Jiangchuan profile, the crust is 42 km thick, the average P wave velocity is 6.19 km/s, and the velocity in the uppermost mantle is 8.05 km/s (Kan et al, 1986; Hu et al, 1986; Kan and Lin, 1986).

6 Discussion and conclusions

6.1 Deep behavior of Xiaojiang fault zone

It can be deduced based upon features on the velocity contour map obtained by the finite-difference inversion that both east and west branches of the Xiaojiang fault zone dip westwards and extend from surface to a depth of 10 km or more. According to the phase analysis of record sections of eight shots along the profile, as well as the lateral velocity variation of crustal layers and the depth variation of the M-discontinuity, we infer that the west and east branches of XFZ converge at the depth of about 25 km, and XFZ, as an important tectonic-block boundary fault zone in southwestern China, has cut

Figure 7 Comparison between record section (a) and synthetic seismograms (b) and ray paths (c) for the shot QLS.

Figure 8 Comparison between record section (a) and synthetic seismograms (b) and ray paths (c) for the shot LUL.

through the whole crust.

6.2 Low velocity zone in the upper crust of CDRB and its tectonic implication

Analysis of the record sections on the west segment of Chuxiong-Luoping DSS profile shows that a low velocity zone exists in the middle of the upper crust, whose structure is identical with the crust structure in the central part of CDRB, i.e., the southern part of Panzhihua-Xichang tectonic zone (Xiong *et al.*, 1986). The crust structure of the east segment, which belongs to the South China block, is relatively simple, and there is no low velocity zone in middle of the upper crust, suggesting that it is a relatively stable tectonic block. As for the tectonic implications of the low velocity zone within the crust, it is generally believed that it may be relevant to the pore pressure and water-bearing property of the rock, or it is a weak geological layer resulting from thermal state variation of the medium. The existence of the low velocity zone is conducive to the sliding of CDRB in south-southeastward direction (Song *et al.*, 1998).

6.3 Earthquake risk assessment of Kunming and its nearby area

Both the east and west branches of XFZ to the east of Kunming dip westwards with depth, while the Puduhe fault in the west of Kunming dips eastwards. The low velocity zone near the surface of Kunming basin, located between the XFZ and Puduhe fault, extends downwards for only 2–3 km. Based on the velocity structure at shallow and intermediate depths, we found that, except the Puduhe fault zone, which is the western boundary of Kunming basin and represents a negative anomaly in velocity structure, the strike-slip fault zones of the north-south trend show no obvious relation with the velocity anomaly.

2-D crustal structure along the Chuxiong-Luoping DSS profile reveals strong lateral variation of the crustal structure, and the XFZ is the main structure boundary. To the west of XFZ, the crustal structure is quite complicated, while it is relatively simple to the east. The P wave average crustal velocities to the east and west of XFZ are 6.32 km/s and 6.21 km/s, respectively. The velocity distribution of the upper 10 km crust shows that there is a low velocity anomaly, which extends deeply, between the east and west branches of XFZ. The upper crust is 23–26 km thick and it becomes thinner from west to east, while the lower crust becomes thicker from west to east. The average crustal thicknesses to the east and west of XFZ are 41 km and 45 km, respectively, indicating that the

crust is thicker in the east than in the west. Based upon the depth variation of intracrustal interfaces and the M-discontinuity, it is deduced that the XFZ has cut through the crust. Although the Chuxiong-Luoping DSS profile is situated in the Yangtze platform, only the crust to the east of XFZ keeps the crustal structure feature of a stable platform, while the complex crustal structure to the west of the fault zone, which is part of CDRB, suggests where the tectonically active region should belong to (Mooney and Brocher, 1987).

Based on the features of upper-crustal velocity contours, both the east and west branches of XFZ dip westwards and extend from surface to the depth of more than 10 km. Puduhe fault dips eastwards. The surface low velocity zone in Kunming basin extends only to a depth of 2–3 km. From the velocity structure in shallow crust, we found that, except the Puduhe fault, which is the west boundary of Kunming basin and represents a negative anomaly in velocity structure, the strike-slip fault zones of north-south trending show no obvious relationship with the velocity variation.

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