Crustal thicknesses and Poisson’s ratios beneath the Chuxiong-Simao Basin in the Southeast Margin of the Tibetan Plateau

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Abstract: In the Southeast Margin of the Tibetan Plateau, low-velocity sedimentary layers that would significantly affect the accuracy of the $H$-$κ$ stacking of receiver functions are widely distributed. In this study, we use teleseismic waveform data of 475 events from 97 temporary broadband seismometers deployed by ChinArray Phase I to obtain crustal thicknesses and Poisson’s ratios within the Chuxiong-Simao Basin and adjacent area, employing an improved method in which the receiver functions are processed through a resonance-removal filter, and the $H$-$κ$ stacking is time-corrected. Results show that the crustal thickness ranges from 30 to 55 km in the study area, reaching its thickest value in the northwest and thinning toward southwest, southeast and northeast. The apparent variation of crustal thickness around the Red River Fault supports the view of southeastern escape of the Tibetan Plateau. Relatively thin crustal thickness in the zone between Chuxiong City and the Red River Fault indicates possible uplift of mantle in this area. The positive correlation between crustal thickness and Poisson’s ratio is likely to be related to lower crust thickening. Comparison of results obtained from different methods shows that the improved method used in our study can effectively remove the reverberation effect of sedimentary layers.

Keywords: receiver functions; sedimentary layer; southeast margin of the Tibetan Plateau; crustal thickness; Poisson’s ratio; Chuxiong-Simao Basin

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1. Introduction

Yunnan area, located in the southeast margin of the Tibetan Plateau, is to the east of the continental collision zone of the Indian and Eurasian plates. It is one of the most active seismic zones in continental China, with frequent occurrences of volcanoes, hot springs, strong earthquakes, and severe earthquake hazards. The two major faults in the area are the Red River and Xiaojiang Faults. The south end of the Xiaojiang Fault converges with the east segment of the Red River Fault, forming a convergence area. The Chuxiong-Simao Basin, like a wedge, is located to the north of this convergence area. Both the Xiaojiang and the Red River Fault are boundaries of major tectonic blocks within the Chinese continent (Figure 1).

Many previous studies of this area’s tectonic features and deformation mechanisms have been performed. Bai DH et al. (2010) found two major channels of high electrical conductivity at depths of 20 to 40 km in the eastern Tibetan Plateau, supporting the hypothesis that crustal flow can occur in orogenic belts and contribute to uplift of the plateau. Li R et al. (2014) found the existence of low resistance anomalies in the mid-lower crust of the Qiangtang terrane and the eastern Tibetan Plateau, as well as the Sichuan-Yunnan rhombic block, which indicates southeast movement of crustal materials in the Tibetan Plateau. Fu YV et al. (2017) observed low velocity anomalies along or near the major faults in the middle crust and forming a broad zone in the lower crust of the southeast margin of the Tibetan Plateau, indicating that crustal flow exists in the lower crust in this area. Accurate knowledge of deep seismic structure will improve understanding of crustal flow and movement of mantle materials in the southeast margin of the Tibetan Plateau. Therefore, it is of great importance to achieve accurate seismic structure and Moho depth in this convergence area. During the past several decades, numerous studies have investigated various aspects of this particular area. Kan RJ et al. (1986) studied crustal structure of Yunnan from seismic refraction profiles; Wen XZ et al. (2008) studied historical patterns and behaviors of earthquake ruptures around the Red River Fault, the eastern boundary of the Sichuan-Yunnan faulted-block. Zhang X and Wang YH (2009) used a finite-difference travel time inversion to achieve crustal and upper mantle P wave velocity structure in Yunnan. Wang Q and Gao Y (2014) investigated the relationship between velocity structure and earthquake activity on the southeast margin of the Tibetan Plateau. Specifically, there are plenty of studies that use receiver function technique to invert 5 wave velocity structures (Wu JP et al., 2001; He CS et al., 2004; Hu JF et al., 2005; Wang CY et al., 2008) or to detect the crust and upper mantle structure around this area (Li YH et al., 2008,
It has always been one of purposes of seismological research to determine the interior structure of the Earth from seismic waves, which are affected by the joint influences of source time function, travel path, media under the station, instrument’s response, and other factors. Receiver functions—Presented as time series with the impacts of earthquake source, travel path, and other factors removed—can show the relative response of Earth structure under the stations. They mainly contain the information of P-to-S converted waves and their multiples (including PmS, PPmS and PSmS, as shown in Figure 2) generated from the velocity discontinuities under the receivers (Phinney, 1964; Jordan et al., 1975; Vinnik, 1977; Langston, 1977, 1981). With the quick development of digital seismic observation techniques, receiver functions method has been widely used in recent years to obtain descriptions of crustal and upper mantle structures under seismic stations (Kosarev et al., 1999; Yeck et al., 2014; Hansen and Schmandt, 2017). Clearly, receiver functions analysis is an effective method to study the structure of Earth crust and upper mantle.

Previous studies have shown that the existence of a low-velocity sedimentary layer in the upper crust will strongly affect the determination of seismic structure achieved by conventional receiver function method (Cassidy, 1992, 1995; Sheehan et al., 1995; Zelt and Ellis, 1998). Velocity discontinuities caused by low-velocity layers can give rise to strong reverberation in the near-surface area, significantly masking seismic P-to-S phases associated with the Moho. Consequently, applying the conventional H-κ stacking method (Zhu LP and Kanamori, 2000) would likely lead to erroneous results of crustal thickness and Vp/Vs ratio. For a crust model with sedimentary layer, there are several possible Ps phases and their reverberations (PbS, PmS, PPmS and PSmS, see Figure 2). Some previous studies have shown that the crustal thickness of the Yunnan area reaches its highest value in the northwest, and decreases toward the northeast, southeast and southwest (He RZ et al., 2014; Li YH et al., 2014). However, these studies barely took into consideration the effects of low-velocity sedimentary layers.

In this paper, we conduct receiver function analysis using teleseismic data recorded in the Chuxiong-Simao Basin and adjacent area. In order to achieve better and more precise results, we apply a sediment removal filter to the selected receiver functions (Yu YQ et al., 2015). Furthermore, instead of directly using the conventional H-κ stacking method (Zhu LP and Kanamori, 2000), we employ a time-corrected H-κ stacking method (Yu YQ et al., 2015) to eliminate the effect of reverberation in sedimentary layers.

2. Data
The study area of this paper is 21°N–28°N, 97°E–105°E, located in the southeast margin of the Tibetan Plateau. This rectangular zone contains the Chuxiong and Simao Basins, and the majority of China’s Yunnan Province (Figure 1). A dense temporary seismic array observation project (ChinArray-Himalaya Phase I) was conducted by the Institute of Geophysics, China Earthquake Administration (CEA), from May 2011 to January 2014. During this project, 350 broadband seismometers were deployed in the southern North-South Seismic Belt in China, i.e. the southeast margin of the

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Figure 2. Schematic diagram of Ps phases and their reverberations in sedimentary layer. The blue solid lines and red dashed lines indicate ray paths for P wave and S wave, respectively. (a), (b), (c) and (d) show simple crust without sedimentary layer. (a) shows direct P phase without conversion at the Moho; (b), (c) and (d) show PmS, PPmS and PSmS phases, respectively; (e), (f), (g) and (h) are their reverberations in sedimentary layer, respectively.

Figure 3. Distribution of earthquake events used in this study against epicentral distance. The red triangle indicates the center of the study area, and the blue dots indicate the location of earthquake events used in this study. Most of the earthquakes are located in the western and southern Pacific, as well as the Indonesia subduction zones.

Tibetan Plateau. In this study, we focus on data from 97 of these, located within our study area (Figure 1). We choose teleseismic events with \( M > 5.0 \) and epicentral distances within the range of 30° to 90° from these stations. The total number of events selected is 475. The distribution of selected events is shown in Figure 3.

Seismic waveform data were filtered in the frequency range of 0.04–0.8 Hz to enhance the signals. Filtered seismograms with SNR of 4.0 or greater were then converted into receiver functions using a water level deconvolution method (in the frequency domain), following Ammon (1991). The water level and Gaussian width factor used in the method are 0.05 and 5.0, respectively. We further applied an SNR-based procedure to reject low quality receiver functions. Examples of selected receiver functions are shown in Figures 4–7. For station 53060 (Figure 4), station 53181 (Figure 5), station 51086 (Figure 6), and station 53193 (Figure 7), 43, 56, 116, and 91 receiver functions, respectively, remained after the selection procedure.

3. Method

Following Ammon (1991), the P-to-S converted phases (hereinafter referred to as Ps phases) in the receiver functions can be expressed as

\[
F(t) = A_s \delta(t-t_s),
\]

where \( \delta \) is a Dirac delta function; \( A_s \) and \( t_s \) represent the amplitude and time delays of the Ps phases, respectively.

For a crust model with low-velocity sedimentary layer, the primary and multiples of the converted S waves can be expressed as

\[
H(t) = \sum_{n=0}^\infty (-r_0)^n \times F(t-n \times \Delta t),
\]

where \( r_0 \) is the strength of the reverberations in the sedimentary layer, \( n \) is the index of the \( n \)th reverberation of the Ps phases, \( \Delta t \) is the two-way travel time of the reverberations in the sedimentary layer, and \( F(t) \) is the receiver function without the influence of the low-velocity sedimentary layer.

This equation can be expressed in the frequency domain as

\[
H(i\omega) = F(i\omega) \sum_{n=0}^\infty (-r_0)^n e^{-i\omega \Delta t},
\]

where \( i \) is the complex symbol.

Note that \( \sum_{n=0}^\infty (-r_0)^n e^{-i\omega \Delta t} = (1 + r_0 e^{-i\omega \Delta t})^{-1} \); from the geometric series, this equation can be further expressed as

\[
H(i\omega) = F(i\omega) (1 + r_0 e^{-i\omega \Delta t})^{-1}.
\]

Therefore, receiver function \( F \) can be obtained in the frequency domain from

\[
F(i\omega) = H(i\omega) (1 + r_0 e^{-i\omega \Delta t}).
\]
In other words, the reverberations caused by a low-velocity sedimentary layer can be eliminated by applying a filter in the form \((1 + r_0 e^{-i\omega \Delta t})\) (Yu YQ et al., 2015).

We then use the time delay and two-way travel time of the PbS phase, the first Ps phase from the bottom of the sedimentary layer (Figure 2e), to time-correct the \(H-\kappa\) stacking equation. The resulting formula can be expressed as

\[
A(H_i;k_j) = \sum_{m=1}^{N} w_1 \times S_m \left( t_1^{(i,j)} + \delta t_m \right) + w_2 \times S_m \left( t_2^{(i,j)} + \Delta t_m - \delta t_m \right) - w_3 \times S_m \left( t_3^{(i,j)} + \Delta t_m \right),
\]

(6)

where \(A\) is the stacking amplitude, \(N\) is the number of receiver functions participated in the stacking, \(S_m(t)\) represents the amplitude of the receiver function at the time \(t\) after the direct P wave, \(w_1, w_2\) and \(w_3\) are weighting factors that satisfy \(w_1 + w_2 + w_3 = 1\) (Zhu LP and Kanamori, 2000), and \(\delta t_m\) and \(\Delta t_m\) are, respectively, the time delay and the two-way travel time of the PbS phase.

The major difference between this time-corrected \(H-\kappa\) method and the conventional method is the time terms. To better understand these time terms, we now consider a simplified situation of vertical incidence. Figure 8a shows the PbS phase under this circumstance. Apparently, the time delay for the PbS phase is

\[
\delta t = \frac{H_d}{V_S} - \frac{H_d}{V_P},
\]

(7)

and the two-way travel time is

\[
\Delta t = \frac{2H_d}{V_S},
\]

(8)

where \(H_d\) is the thickness of the sedimentary layer, \(V_P\) and \(V_S\) are

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the P wave and S wave velocities for the sedimentary layer, respectively. For the PmS phase (Figure 8b), there is one S wave leg traveling through the sedimentary layer; thus the PmS phase time term (S and P wave differential time after traveling through the sedimentary layer) is $H_d/V_S - H_d/V_P = \delta t$. For the PPmS phase (Figure 8c), travel through the sedimentary layer occurs twice as P wave and once as S wave; thus the time term for the PPmS phase is $2H_d/V_P + H_d/V_S - H_d/V_P = \Delta t - \delta t$. Finally, for the PSmS phase (Figure 8d), one P wave leg and two S wave legs travel through the sedimentary layer; thus the time term for PSmS is

Figure 6. Receiver functions for station 53086. (a) shows the original receiver functions for this station, and (b) shows the filtered RFs processed by the resonance removal filter. The RFs are plotted against back azimuth.

Figure 7. Receiver functions for station 53193. (a) shows the original receiver functions for this station, and (b) shows the filtered RFs processed by the resonance removal filter. The RFs are plotted against back azimuth.

Figure 8. Ps phases in crustal model with sedimentary layer under assumption of vertical incidence. The blue solid lines and red dashed lines indicate ray paths for P wave and S wave, respectively. (a), (b), (c) and (d) refers to PbS, PmS, PPmS and PSmS phase, respectively.
By using this time-corrected $H$-$\kappa$ stacking method, we remove the travel time associated with the sedimentary layer, so that the stations are downward projected to the bottom of the sedimentary layer. Consequently, the optimal sub-sediment crustal thickness and $V_p/V_S$ ratio can be obtained (Yu YQ et al., 2015).

### 4. Analysis and Results
Previous studies (Zhu LP and Kanamori, 2000) show that a 0.1 km/s uncertainty in $V_p$ could produce about 0.5 km uncertainty of crustal thickness. According to the studies of P wave velocity structure in the study area (Cui ZZ et al., 1987; Xiong SB et al., 1993; Wang CY and Gang, 2004), we set crustal P wave velocity at 6.30 km/s during the $H$-$\kappa$ stacking of receiver functions. Table 1

| Station | Latitude (°N) | Longitude (°E) | Crustal thickness (km) | $V_p/V_S$ Ratio |
|---------|--------------|----------------|------------------------|-----------------|
| 53022   | 26.87        | 99.38          | 47.82                  | 1.7266          |
| 53023   | 26.74        | 99.15          | 45.1                   | 1.809           |
| 53025   | 26.46        | 99.42          | 41.09                  | 1.8351          |
| 53026   | 26.46        | 99.14          | 46.03                  | 1.6374          |
| 53028   | 26.20        | 99.13          | 47.2                   | 1.662           |
| 53030   | 26.37        | 100.18         | 41.2                   | 1.8008          |
| 53032   | 26.20        | 99.43          | 37.35                  | 1.812           |
| 53036   | 25.82        | 99.83          | 35.2                   | 1.848           |
| 53037   | 25.54        | 99.73          | 35.29                  | 1.7688          |
| 53039   | 25.34        | 99.78          | 35.52                  | 1.7758          |
| 53040   | 25.35        | 100.49         | 35.53                  | 1.7906          |
| 53042   | 25.49        | 99.99          | 39.88                  | 1.7138          |
| 53043   | 25.24        | 100.32         | 41.39                  | 1.6973          |
| 53044   | 25.05        | 100.52         | 44.51                  | 1.6518          |
| 53050   | 26.84        | 99.90          | 51.13                  | 1.6513          |
| 53054   | 27.00        | 100.79         | 51.97                  | 1.6343          |
| 53056   | 26.99        | 101.00         | 54.56                  | 1.6542          |
| 53060   | 26.44        | 101.03         | 50.29                  | 1.7057          |
| 53062   | 25.22        | 98.34          | 35.53                  | 1.6585          |
| 53063   | 24.90        | 98.67          | 32.35                  | 1.6971          |
| 53064   | 24.75        | 98.49          | 35.73                  | 1.6285          |
| 53065   | 25.49        | 99.24          | 35.08                  | 1.7158          |
| 53068   | 24.69        | 98.84          | 33.59                  | 1.7953          |
| 53069   | 24.56        | 99.03          | 30.67                  | 1.6895          |
| 53070   | 24.32        | 99.04          | 33.1                   | 1.6436          |
| 53071   | 25.05        | 99.48          | 33.75                  | 1.7584          |
| 53073   | 25.00        | 99.84          | 31.33                  | 1.7708          |
| 53074   | 24.53        | 99.34          | 35.75                  | 1.626           |
| 53081   | 24.50        | 98.03          | 35.03                  | 1.6443          |
| 53086   | 24.14        | 98.57          | 32.92                  | 1.7022          |
| 53087   | 24.87        | 100.09         | 42.39                  | 1.8424          |
| 53089   | 24.71        | 100.20         | 39.13                  | 1.6757          |
| 53090   | 24.32        | 99.95          | 35.73                  | 1.6423          |
| 53092   | 24.16        | 100.37         | 39.3                   | 1.631           |
| 53093   | 24.21        | 99.55          | 35.41                  | 1.6141          |
| 53094   | 23.90        | 99.03          | 33.53                  | 1.618           |

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Continued from Table 1

| Station | Latitude (°N) | Longitude (°E) | Crustal thickness (km) | \(V_P/V_S\) Ratio |
|---------|---------------|----------------|------------------------|-------------------|
| 53095   | 24.02         | 99.73          | 35.03                  | 1.6128            |
| 53097   | 23.55         | 99.39          | 31.28                  | 1.667             |
| 53098   | 23.56         | 98.88          | 34.14                  | 1.6191            |
| 53099   | 23.47         | 99.84          | 31.75                  | 1.706             |
| 53100   | 23.43         | 100.04         | 33.92                  | 1.6434            |
| 53101   | 23.29         | 99.10          | 33.35                  | 1.6155            |
| 53102   | 24.64         | 100.72         | 39.55                  | 1.6465            |
| 53105   | 24.20         | 100.78         | 41.7                   | 1.621             |
| 53110   | 23.07         | 100.63         | 32.37                  | 1.6754            |
| 53111   | 23.22         | 100.22         | 36.9                   | 1.61              |
| 53112   | 23.01         | 101.05         | 33.81                  | 1.7021            |
| 53113   | 22.78         | 101.46         | 37.79                  | 1.722             |
| 53114   | 23.28         | 101.39         | 31.01                  | 1.7384            |
| 53115   | 23.60         | 101.28         | 33.2                   | 1.7148            |
| 53116   | 23.03         | 101.63         | 34.25                  | 1.7085            |
| 53121   | 22.87         | 99.76          | 30.99                  | 1.6723            |
| 53122   | 22.80         | 100.20         | 33.57                  | 1.6258            |
| 53127   | 22.49         | 102.21         | 34.3                   | 1.621             |
| 53130   | 22.50         | 101.05         | 35.45                  | 1.6376            |
| 53133   | 22.31         | 100.51         | 30.67                  | 1.6587            |
| 53140   | 21.65         | 101.37         | 32.91                  | 1.6322            |
| 53142   | 21.27         | 101.29         | 33.9                   | 1.621             |
| 53144   | 26.36         | 101.19         | 49.57                  | 1.8463            |
| 53145   | 26.01         | 101.08         | 49.95                  | 1.7465            |
| 53146   | 26.06         | 101.65         | 43.22                  | 1.7638            |
| 53148   | 25.83         | 102.10         | 42.9                   | 1.655             |
| 53150   | 25.15         | 102.08         | 40.01                  | 1.7344            |
| 53152   | 24.76         | 101.24         | 38.7                   | 1.724             |
| 53154   | 24.38         | 101.59         | 43.6                   | 1.6235            |
| 53155   | 26.17         | 102.57         | 48.35                  | 1.7137            |
| 53156   | 25.87         | 102.46         | 45.16                  | 1.6269            |
| 53160   | 24.98         | 102.34         | 39.45                  | 1.646             |
| 53162   | 25.07         | 103.39         | 40.7                   | 1.6268            |
| 53163   | 24.79         | 102.60         | 40.54                  | 1.6208            |
| 53165   | 24.63         | 103.00         | 44.025                 | 1.6595            |
| 53167   | 24.44         | 102.44         | 38.3                   | 1.641             |
| 53169   | 24.05         | 102.01         | 40.08                  | 1.7555            |
| 53171   | 24.54         | 103.76         | 37.36                  | 1.6571            |
| 53172   | 24.25         | 103.64         | 36.04                  | 1.6763            |
| 53174   | 24.02         | 103.13         | 38.19                  | 1.6516            |
| 53175   | 23.85         | 102.36         | 37.37                  | 1.6579            |
| 53176   | 23.70         | 103.24         | 38.04                  | 1.6268            |
shows crustal thicknesses and V_P/V_S ratios in the study area obtained by the improved method.

4.1 Determination of Crustal Thickness by Improved Method

We use both the conventional method and the improved method to calculate the crustal thicknesses. With the conventional method, we directly apply the conventional H-κ stacking to the receiver functions. With the improved method, we first process the receiver functions by applying the resonance removal filter, and then apply the time-corrected H-κ stacking. In order to achieve a clear comparison of results between these two methods, we present results of four stations as examples to illustrate the advantage of the improved method.

Station 53060 (see Figure 1) is located in Chuxiong Basin. There are 43 high quality receiver functions at this station after the SNR-based selection, as previously shown in Figure 4. The H-κ stacking plots of both methods for this station are shown in Figure 9. Crustal thickness beneath station 53060 is calculated as 53.0 km by the conventional method, and as 50.2 km by the improved method. Station 53181 (see Figure 1) is located in Simao Basin, the RFs of which can be found in Figure 5. The H-κ stacking plots of both methods for this station are shown in Figure 10. Crustal thickness beneath station 53060 is 36.0 km by the conventional method, and 32.7 km by the improved method. For these stations, the effect of the low-velocity sedimentary layer is effectively elim-
Station 53086 and station 53193 (see Figure 1), located out of basin area, have 116 and 91 high quality receiver functions, respectively, after the selection procedure (previously shown in Figure 6 and Figure 7). The $H\kappa$ stacking plots for these two stations are shown in Figures 11 and Figure 12. For station 53086, crustal thickness is 33.2 km by the conventional method and 33.1 km by the improved method; for station 53193, crustal thickness is 36.9 km by both methods. Since these stations have no sedimentary layer underlying, the improved method gives nearly the same results as the conventional method.

There are 31 stations located within the basins in this study. We compare the crustal thickness obtained by conventional and improved methods at all these stations (Figure 13). Table 2 presents,...
4.2 Overall Features of Crustal Thicknesses and Poisson’s Ratios

Our calculations of crustal thicknesses and $V_p/V_S$ ratios under each station in the study area are shown in Table 1. Figure 14 presents a better, clearer, picture of these results. Figure 15 employs spatial smoothing to show the overall distribution of crustal thicknesses and Poisson’s ratios.

Overall, from Figures 14a and 15a, we find that, the crustal thickness decreases from about 55 km in the northwest toward northeast, southwest and southeast. The thinnest crust appears in the south of the study area, with a thickness of about 30 km. The crustal thicknesses are a little higher in the northeast, at about 37 km. These general variation features are consistent with previous studies using different methods, including joint inversion (Li YH et al., 2014) and receiver functions (He RZ et al., 2014; Wang WL et al., 2017).

Moreover, our results show that the Red River Fault, a large strike-slip fault situated at a NW-SE orientation, draws an apparent boundary for crustal thickness in the study area (Figure 15a). Crustal thicknesses are thinner to the west of the Red River Fault and thicker to the east, indicating that the fault cuts the crust (Xu MJ et al., 2006). However, it is interesting that the crustal thickness between Chuxiong City and the Red River Fault is a little thinner than the surrounding area nearby, indicating that there seems to be an uplift of upper mantle in this area, which could result from movements of deep mantle materials. This phenomenon is consistent with previous studies (Zhang XM et al., 2011; Deng JM et al., 2014).

On the west side of the study area, the variation of crustal thickness is relatively gentle, with most of the stations colored red (Figure 14a), indicating that the crustal thicknesses are less than 40 km. On the east side of study area, crustal thickness varies greatly across the Red River Fault, from thicker north to thinner south, which suggests that the Sichuan-Yunnan rhombic block, the southwest boundary of which is the Red River Fault, possibly takes a large amount of the southeast-direction escape of the Tibetan Plateau. However, in the middle part of the Red River Fault, there is no obvious variation in crustal thickness. In the east side of the study area, it seems that the Xiaojiang Fault is a boundary to abrupt variations in crustal thickness. Crustal thickness appears to be thicker within the Sichuan-Yunnan rhombic block and thinner outside, suggesting that the Xiaojiang Fault blocks the material flow of the Tibetan Plateau in the southeast direction.

Poisson’s ratio is an elastic constant that measures the compressibility of material perpendicular to applied stress, or the ratio of lateral to longitudinal strain. For regular rocks, the Poisson’s ratio ranges from 0.20 to 0.35, and is very sensitive to the composition of rocks. According to the relationship between Poisson’s ratio and $V_S/V_p$ ratio $\sigma = \left[ 0.5(V_p/V_S)^2 - 1 \right] / \left[ (V_p/V_S)^2 - 1 \right]$, we calculate the Poisson’s ratio in the study area from $V_p/V_S$ results (Table 1 and Figure 14b). Poisson’s ratios are shown beneath each station in Figure 10b. Figure 15b shows the overall distribution of Poisson’s ratios. We find that the Poisson’s ratios beneath the stations in this area range from 0.18 to 0.30, which is generally consistent with other studies (Li YH et al., 2009; Wang WL et al., 2017).
Overall, Poisson’s ratios distribute unevenly in the study area, with a general characteristic decrease from north to south, although with local complications positively correlated to the variation of crustal thickness. The correlation between crustal thickness and Poisson’s ratio can provide a valuable constraint on the tectonic process of continental crust. Ji SC et al. (2009) concluded that if crustal thickening is caused mainly by the lower crust, the Poisson’s ratio would be positively correlated to crustal thickness; whereas if crustal thickening is caused mainly by the upper crust, the Poisson’s ratio would be negatively correlated to crustal thickness. Our results indicate that the variation of Poisson’s ratio in the study area is likely related to lower crustal thickening, which is consistent with other studies (Zhang ZJ et al., 2005).

### 5. Discussions and Conclusions

Using seismic data from a dense temporary seismic array, ChinArray Phase I, we obtained crustal thicknesses and Poisson’s ratios beneath 97 seismic stations within the Chuxiong and Simao Basins and adjacent area. In particular, our data were from filtered receiver functions of 475 earthquake events, analyzed by a time-corrected H-κ stacking method. The method’s resonance removal filter and time-corrected H-κ stacking can eliminate reverberations and travel time associated with the sedimentary layer.

We find that the crustal thickness varies strongly in the study area. The northwest part has a relatively thicker Moho, with crustal thickness over 50 km. Crustal thickness becomes lower from

### Table 2. Two kinds of crustal thicknesses beneath seismic stations located within Chuxiong Basin and Simao Basin and their differences

| Station | Latitude (°N) | Longitude (°E) | H1 (km) | H2 (km) | ΔH (km) |
|---------|---------------|----------------|--------|--------|--------|
| 53040   | 25.35         | 100.49         | 32.39  | 34.76  | –2.37  |
| 53042   | 25.49         | 99.99          | 35.12  | 37.65  | –2.53  |
| 53044   | 25.05         | 100.52         | 40.88  | 41.97  | –1.09  |
| 53060   | 26.44         | 101.03         | 50.3   | 53     | –2.7   |
| 53073   | 25.00         | 99.84          | 31.33  | 34.37  | –3.04  |
| 53102   | 24.64         | 100.72         | 39.55  | 40.9   | –1.35  |
| 53105   | 24.20         | 100.78         | 41.7   | 43.3   | –1.6   |
| 53110   | 23.07         | 100.63         | 32.37  | 34.5   | –2.13  |
| 53112   | 23.01         | 101.05         | 33.81  | 36.3   | –2.49  |
| 53113   | 22.78         | 101.46         | 37.79  | 38.9   | –1.11  |
| 53114   | 23.28         | 101.39         | 31.01  | 35.3   | –4.29  |
| 53115   | 23.60         | 101.28         | 33.2   | 34.6   | –1.4   |
| 53116   | 23.03         | 101.63         | 34.25  | 37.8   | –3.55  |
| 53130   | 22.50         | 101.05         | 35.45  | 37.1   | –1.65  |
| 53140   | 21.65         | 101.37         | 32.91  | 34.8   | –1.89  |
| 53145   | 26.01         | 101.08         | 49.95  | 38     | 11.95  |
| 53148   | 25.83         | 102.10         | 42.9   | 44.8   | –1.9   |
| 53150   | 25.15         | 102.08         | 40.01  | 41.5   | –1.49  |
| 53152   | 24.76         | 101.24         | 38.7   | 32.8   | 5.9    |
| 53154   | 24.38         | 101.59         | 43.6   | 38.5   | 5.1    |
| 53155   | 26.17         | 102.57         | 48.35  | 39.9   | 8.45   |
| 53156   | 25.87         | 102.46         | 45.16  | 39     | 6.16   |
| 53160   | 24.98         | 102.34         | 39.45  | 42.3   | –2.85  |
| 53163   | 24.79         | 102.60         | 40.54  | 43.49  | –2.95  |
| 53167   | 24.44         | 102.44         | 38.3   | 40.9   | –2.6   |
| 53169   | 24.05         | 102.01         | 40.08  | 40     | 0.08   |
| 53175   | 23.85         | 102.36         | 37.37  | 39.1   | –1.73  |
| 53180   | 23.36         | 102.34         | 36.9   | 39.4   | –2.5   |
| 53181   | 22.96         | 101.96         | 32.73  | 36.08  | –3.35  |
| 53182   | 22.99         | 102.39         | 34.48  | 32.3   | 2.18   |
| 53184   | 23.18         | 102.79         | 35.53  | 37.23  | –1.7   |

Notes: H1 and H2 indicate crustal thickness obtained by the improved method and the conventional method, respectively. ΔH = (H1 - H2).
| Station | $H_1$ (km) | $H_3$ (km) | $\Delta H$ (km) |
|---------|-----------|-----------|---------------|
| 53022   | 47.82     | 50.3      | -2.48         |
| 53023   | 45.1      | 47.9      | -2.8          |
| 53025   | 41.09     | 48.1      | -7.01         |
| 53026   | 46.02     | 50        | -3.98         |
| 53028   | 47.2      | 47        | 0.2           |
| 53030   | 41.2      | 47.1      | -5.9          |
| 53032   | 37.35     | 47.4      | -10.05        |
| 53036   | 35.2      | 43.5      | -8.3          |
| 53037   | 35.29     | 44.1      | -8.81         |
| 53039   | 35.52     | 41.2      | -5.68         |
| 53040   | 32.39     | 44.5      | -12.11        |
| 53042   | 35.12     | 42.8      | -7.68         |
| 53043   | 41.39     | 42.3      | -0.91         |
| 53044   | 40.88     | 45.9      | -5.02         |
| 53050   | 51.13     | 50.2      | 0.93          |
| 53054   | 51.97     | 58.3      | -6.33         |
| 53056   | 54.56     | 54.3      | 0.26          |
| 53060   | 50.3      | 60.3      | -10           |
| 53061   | 54.29     | 39.3      | 14.99         |
| 53062   | 35.53     | 37.8      | -2.27         |
| 53063   | 32.35     | 35.7      | -3.35         |
| 53064   | 35.73     | 37        | -1.27         |
| 53065   | 35.08     | 43.4      | -8.32         |
| 53068   | 33.59     | 35.8      | -2.21         |
| 53069   | 30.67     | 34.8      | -4.13         |
| 53070   | 33.1      | 33.3      | -0.2          |
| 53071   | 33.75     | 38.9      | -5.15         |
| 53073   | 31.33     | 38.9      | -7.57         |
| 53074   | 35.75     | 31.9      | 3.85          |
| 53081   | 35.03     | 34.6      | 0.43          |
| 53086   | 32.92     | 33.1      | -0.18         |
| 53087   | 42.39     | 40.5      | 1.89          |
| 53089   | 39.13     | 40        | -0.87         |
| 53090   | 35.73     | 34.6      | 1.13          |
| 53092   | 39.3      | 39.5      | -0.2          |
| 53093   | 35.41     | 34.7      | 0.71          |
| 53094   | 33.53     | 32.5      | 1.02          |
| 53095   | 35.03     | 36.1      | -1.07         |
| 53097   | 31.28     | 34.1      | -2.82         |
| 53098   | 34.14     | 33.8      | 0.34          |
| 53099   | 31.75     | 35        | -3.25         |
| 53100   | 33.92     | 30.1      | 3.82          |
| 53101   | 33.35     | 32.4      | 0.95          |
Continued from Table 3

| Station | \( H_2 \) (km) | \( H_3 \) (km) | \( \Delta H \) (km) |
|---------|----------------|----------------|-------------------|
| 53102   | 39.55          | 45             | -5.45            |
| 53105   | 41.7           | 43.1           | -1.4             |
| 53110   | 32.37          | 34.9           | -2.53            |
| 53111   | 36.9           | 36.4           | 0.5              |
| 53112   | 33.81          | 34.8           | -0.99            |
| 53113   | 37.79          | 36.2           | 1.59             |
| 53114   | 31.01          | 36.8           | -5.79            |
| 53116   | 34.25          | 34             | 0.25             |
| 53121   | 30.99          | 35.2           | -4.21            |
| 53122   | 33.57          | 37.8           | -4.23            |
| 53130   | 35.45          | 35.5           | -0.05            |
| 53144   | 49.57          | 48.5           | 1.07             |
| 53145   | 49.95          | 53.8           | -3.85            |
| 53146   | 43.22          | 47.9           | -4.68            |
| 53148   | 42.9           | 47.1           | -4.2             |
| 53150   | 40.01          | 44.3           | -4.29            |
| 53152   | 38.7           | 42.9           | -4.2             |
| 53154   | 43.6           | 42.7           | 0.9              |
| 53155   | 48.35          | 45.6           | 2.75             |
| 53156   | 45.16          | 50.8           | -5.64            |
| 53160   | 39.45          | 43.7           | -4.25            |
| 53162   | 40.7           | 46.6           | -5.9             |
| 53163   | 40.54          | 45.4           | -4.86            |
| 53165   | 44.03          | 43.4           | 0.63             |
| 53167   | 38.3           | 43.2           | -4.9             |
| 53169   | 40.08          | 40.8           | -0.72            |
| 53171   | 37.36          | 41.5           | -4.14            |
| 53172   | 36.04          | 40.4           | -4.36            |
| 53174   | 38.19          | 40.9           | -2.71            |
| 53175   | 37.37          | 41.9           | -4.53            |
| 53176   | 38.04          | 40.4           | -2.36            |
| 53179   | 32.93          | 36.9           | -3.97            |
| 53180   | 36.9           | 37.3           | -0.4             |
| 53181   | 32.73          | 33.6           | -0.87            |
| 53182   | 34.48          | 36.5           | -2.02            |
| 53184   | 35.53          | 38.3           | -2.77            |
| 53185   | 32.56          | 37.9           | -5.34            |
| 53186   | 34.36          | 37.4           | -3.04            |
| 53187   | 33.67          | 39             | -5.33            |
| 53188   | 38.43          | 38             | 0.43             |
| 53193   | 37.03          | 38.9           | -1.87            |
| 53195   | 36.15          | 38.3           | -2.15            |
| 53211   | 38.91          | 40.9           | -1.99            |
Continued from Table 3

| Station | $H_1$ (km) | $H_3$ (km) | $\Delta H'$ (km) |
|---------|------------|------------|------------------|
| 53216   | 36.26      | 46.4       | -10.14           |
| 53218   | 37.43      | 47.2       | -9.77            |
| 53219   | 36.82      | 48.4       | -11.58           |
| 53223   | 42.78      | 54.1       | -11.32           |
| 53224   | 39.91      | 50.9       | -10.99           |
| 53225   | 36.78      | 49.1       | -12.32           |

Notes: $H_1$ and $H_3$ indicate crustal thickness obtained in this study and Wang W et al. (2017), respectively. $\Delta H' = (H_1 - H_3)$.

Figure 14. $H$-$\kappa$ stacking results beneath each seismic station. (a) Crustal thickness; (b) Poisson’s ratio. The results are shown beneath each seismic station. The shadow area indicates the Chuxiong-Simao Basin, same as in Figure 1.

Figure 15. Overall distribution of $H$-$\kappa$ stacking results in the study area. (a) Crustal thickness; (b) Poisson’s ratio. Distribution of crustal thicknesses and Poisson’s ratios are spatially smoothened. The shadow part indicates the Chuxiong-Simao Basin. The location of Chuxiong City is marked; HHF and XJF indicates Red River Fault and Xiaojiang Fault, respectively.
northwest toward southwest, southeast and northeast, the geometry and range of which seems to be related to the Sichuan-Yunnan rhombic block surrounded by the Red River Fault and the Xiaojiang Fault, indicating that the crust is thicker within this rhombic block than in the adjacent area. Also, we find that the Red River Fault separates the study area in terms of crustal thickness, suggesting that the Sichuan-Yunnan rhombic block takes in the escape material of the Tibetan Plateau or leads the direction of escape. In addition, relatively thin crustal thickness in the center of study area indicates possible uplift of upper mantle. Poisson’s ratios, inferred from Vs/Vs ratios obtained by H-κ stacking, distribute unevenly in the study area. Overall, Poisson’s ratios decrease from northwest to southeast direction, which is correlated with the variation of crustal thickness in this area. This correlation is likely to be related to lower crust thickening.

Comparison of H-κ stacking results from the conventional and the time-corrected (i.e. improved) method shows that the improved method can effectively remove the effect of low-velocity sedimentary layers. After applying the improved method, crustal thickness results beneath most of the stations are 2–4 km thinner than those obtained from conventional methods. Some stations show no correlation of the results by these two methods, the reason for which might be that the reverberation in these sedimentary layers is especially strong. Results at other stations show no change, perhaps indicating that no low-velocity sedimentary layer exists beneath those stations, or that the sedimentary layer has solidified.

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