3-D CRUSTAL STRUCTURE IN SOUTHWESTERN CHINA

W. W.Chan[1], C. Y. Wang[2], and W. D. Mooney[3]

Multimax, Inc.,[1] Institute of Geophysics, Beijing, China,[2] United States Geological Survey[3]

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ABSTRACT

Using P and S arrival data of 4,625 local and regional earthquakes recorded at 174 seismic stations and associated geophysical investigations, we present a 3-D crustal and upper mantle velocity structure of southwestern China (21 º - 34 º N, 97 º - 105º E). Southwestern China lies in the transition zone between the uplifted Tibetan plateau to the west and the Yangtze continental platform to the east. In the upper crust, a positive anomaly velocity zone exists in the Sichuan basin, whereas a large-scale negative anomaly velocity zone exists in the western Sichuan plateau, which is consistent with the upper crustal structure under the Tibetan Plateau. The boundary between these two positive and negative anomaly zones is the Longmen Shan fault. The Tengchong volcanic region, as well as the strike-slip faults such as the Xianshuihe fault, the Anninghe fault, the northern segment of the Red River fault, and the southern segment of the Xiaojiang fault, are in areas with a negative anomaly zone in the upper crust.

In the mid-crustal depth, we found that there is a general consistency between the negative velocity anomaly and seismicity. The negative velocity anomalies at the depth of 50 km in the Tengchong volcanic area and the Panxi tectonic zone appear to be associated with the temperature and composition variations in the upper mantle. The Red River fault is the boundary between the positive and negative velocity anomalies at 50-km depth. The overall features of the crustal and the upper mantle structures in southwestern China are the low average velocity, the large crustal thickness variations, the existence of a high conductivity layer in the crust or/and upper mantle, and a high geothermal value. All these features are closely related to the collision between the Indian and the Asian plates.

KEY WORDS: crustal structure, southwestern China

OBJECTIVE

In this project, we provide a comprehensive database for all of China. Digital seismic waveform data from the newly operational China National Digital Seismic Network (CNSDN) will be analyzed along with the seismic bulletins prepared from this network. Tomographic inversion will be performed to obtain regional three-dimensional velocity models for calculation of travel-time correction surfaces.

RESEARCH ACCOMPLISHED

Southwestern China lies in the transition zone between the uplifted Tibetan plateau to the west and the Yangtze continental platform to the east. In this paper we present a 3-D crustal and upper mantle velocity structure of this region of China (21° - 34°N, 97° - 105°E), which is based on the P and S arrival data from 4625 local and regional earthquakes recorded at 174 seismic stations and earlier geophysical investigations. In the upper crust, a positive anomaly velocity zone exists in the Sichuan basin, whereas a large-scale negative anomaly velocity zone exists in the western Sichuan plateau. These results are consistent with the upper crustal structure under the Tibetan Plateau (Ni et al., 1995). The boundary between these two positive and negative anomaly zones is the Longmen Shan fault. The Tengchong volcanic area, as well as the strike-slip faults, such as the Xianshuihe fault, Anninghe fault, the northern segment of Red River fault, and the southern segment of Xiaojiang fault, are in regions with a negative anomaly zone in the upper crust. For the middle crust, we found that there is a general consistency between the negative velocity anomaly and the seismicity. The negative velocity anomalies at the depth of 50 km in the Tengchong volcanic area and the Panxi tectonic zone appear to be associated with the temperature and composition variations in the upper mantle. The Red River fault is the boundary between the positive and negative velocity anomalies at 50-km depth. The overall features of the crustal and the upper mantle structures in southwestern China are the low average velocity, the large crustal thickness variations, the existence of a high-conductivity layer in the crust and/or upper mantle, and a high geothermal value. All these features are closely related to the collision between the Indian and the Asian plates.

A schematic map of tectonics in southwestern China is shown in Figure 1. The Sichuan-Yuanan region (SYR) is an active transition zone between the Yangtze platform to the east and the Tibetan plateau to the west. It is generally believed that this transition zone was formed 45 Ma when the Indian plate collided with the Eurasian plate. This continental collision created a large-scale tectonic deformation in the Sichuan-Yunnan region that is still ongoing. This is evidenced by the high level of seismicity in this region, which is the most active in China. The major tectonic units in southwestern China are as follows: 1. Bomi-Tengchong Fold System; 2. Zuogong-Genma Fold System; 3. Tibet-Yunnan Fold System; 4. Songpang-Ganzi Fold System; 5. Yangtze Platform; 6. South China Fold System.

Figure 2 shows major faults and seismicity of the Sichuan-Yunnan Region. There are seven major active seismic zones in the SYR: 1. the Longmen Shan seismic belt (i.e. Songpan-Pinwu seismic belt), 2. the Xianshuihe seismic belt, 3. the Anninghe seismic belt, 4. the Xiaojiang seismic belt, 5. the Red River seismic belt, 6. the Lancang-Gengma seismic belt, and 7. the Tengchong -Longling seismic belt. A majority of the suite of large seismic earthquakes (M>7) in the region is associated with these faults. Fan (1978) also indicated that most earthquakes in the region are associated with these fault lines, including the 1970 Tonghai earthquake (M=7.7), the 1973 Lu Fu earthquake (M=7.6), the 1974 Zhaotung earthquake (M=7.1), the 1976 Longning earthquake (M=7.4), the 1976 Songpan earthquake (M=7.2), the 1988 Nanchong-genma earthquake (M=7.6), the 1995 Mengnian earthquake (M=7.4), and the 1996 Lijiang earthquake (M=7.0).

Figure 3 shows the three-dimensional Moho surface map for the Sichuan-Yunnan region. The depths to Moho in the SYR are determined by seismic reflection profiles and Bouguer gravity data. The Moho depth increases from SW to NW in the region. In the southern and SW part of Yunnan, the Moho depth is around 38 km; it increases to about 56 km in NW Yunnan. The Moho depth in the Sichuan Plateau is about 60 km, whereas in the Sichuan Basin, it is around 35 to 40 km. We have adopted the tomographic inversion using a LSQR calculation by Zhao (1991) and Zhao et al. (1992). This method takes into considerations the complex structure of the crustal and upper mantle discontinuities.

This study utilized seismic data from 174 short-period seismic stations in the SYR; the station locations are shown in Figure 4. Not all stations are operating concurrently at all times. The stations in Yunnan are more evenly distributed, whereas those in W. Sichuan are sparsely distributed. Figure 5 shows the distribution of earthquake epicenters in the SYR used in this study, based on a total of 4625 earthquakes between 1982 and 1999. The event locations are adopted from the seismic catalogues from Sichuan and Yunnan. The travel-time readings for the P phases are accurate to 0.1 s while the S phases are accurate to 0.2 s. The majority of these earthquakes are located with location errors within 10 km. Data that are accurate to over 20 km are not included in this study. In order to achieve normal convergence in the tomographic inversion, we have allowed for the following constraints:

1. station azimuthal gaps are within 160 degrees;
2. the least number of P observations is 8 for each earthquake; and
3. the largest travel-time residual is 3.0 sec.

Additional considerations are also taken into account to maximize the coverage of the region. The total number of arrival phases used in this study is 112240 readings. Among them, 65170 are P phases and 47070 are S phases.

We used over 6000 earthquakes from the regional catalogs between the period 1982 and 1999 to compile the P and S travel-time curves for the SYR (Figure 6). At about 220 km, the P phases split into Pbar and Pn. Such a feature is not observable on the S phase data. Over 50% of the phase data are considered as Pn arrivals. Our tomographic inversion uses a 3-D mesh grid model taking into consideration Moho and crustal discontinuities. The horizontal grids are divided into 0.5-degree spacings between 25 N and 34 W and 97 E and 105 E. The total number of grids is 2550 within the 3-D space. The resolution test uses the checkerboard method of Inoue et al. (1990). The test results on P phases, shown in Figure 7, indicate that the grids at different depths are quite resolvable. For example, the P wave grids at 10 km for most regions are quite resolvable except at the NW region (100.5 W, 28 N) where station-event coverage is sparse. At 30-km depth, the region of poor resolution is more confined than that at 10 km, but the overall resolution is not as good as that at the shallower depths. This reduction in resolution is mainly due to the lack of P phase data refracted from the Conrad discontinuity. Due to the abundance of high-quality Pn phase data, the resolution is quite good at about 50-km depth, comparable to that at the shallower depths.

Three-dimensional models derived from tomographic inversion of P and S wave data are shown in Figures 8 and 9, respectively. SYR has a highly heterogeneous structure with varying topography. The velocity models for as deep as 10 km are related to the surficial structural geology. The lateral heterogeneity in the SYR is characteristic of this region. The velocity in the Basin shows a negative velocity anomaly at the shallow depth of 1 km, whereas at the 10 km-layer, the velocity anomaly is positive. For the western Sichuan Plateau there is a broad region of negative velocity anomaly at 10-km depth. This agrees with the characteristics velocity structure of the adjacent Tibetan Plateau. The Longmen Shan fault is situated at the boundary between the negative and positive velocity anomalies. At the SW flank of this fault, there is an indication of a local positive velocity anomaly. For faults that are associated with strike-slip motion, the velocity model indicates a negative anomaly. These are represented by the Xiansuihe fault and Anning which are quite aseismic. The negative velocity anomaly at the Tengchun region is most likely related to heat flow activities. There is a distinct positive S-wave velocity anomaly at 10-km depth from the west flank of the Longmen Shan fault extending southward to the northern end of the Anning fault. At the 30-km depth (lower crust), most seismic belts in SYR, such as Xianshuihe and Xiaojiang, exhibit negative P-wave velocity anomaly. Similar observations are noted for the S-waves (Figure 9). The Red River fault lies in the transition between positive and negative anomalies. The region in the north shows positive velocity anomaly. The slow velocity in the north agrees with reflection profile studies of Hu et al (1986).

In the upper mantle, the inversion results at 50-km depth show broad negative velocity anomaly in the Panxi orogeny and the Tengchong geothermal region. Reflection profile results agree with our observations in the Panxi region (Xiong, 1986). Moreover, the velocity anomalies are greatly affected by the faults that extend to great depths. For example, the Longmen Shan fault separates the regions with positive and negative velocity anomalies and the Xianshuihe and the Xiaojiang faults are associated with negative velocity anomalies. Nonetheless, the degree of velocity anomalies is less than that in the Panxi region. Similar to the lower crust, the upper mantle P-wave velocity for the major seismic belts shows negative anomaly. As discussed in Figure 6, the S phase travel times do not show as clear a phase separation as the P phases for the mantle refractions, indicating that the shear velocity is less resolvable.

CONCLUSIONS AND RECOMMENDATIONS

Our study indicates strong lateral variations in crustal thickness in southwestern China. The crustal thickness for SYR shows a gradual increase from SE to NW. Near the Burma-China border in the south, the crustal thickness is 38.5 km. The Sichuan Basin has a crustal thickness of 40 km, whereas the crustal thickness of the Sichuan West Tibetan region reaches over 65 km. The crust of the adjacent the Longmen Shan belt differs by up to 13 km in thickness. The thick crust in SYR is definitely associated with the Indian plate collision.

The crust/upper mantle velocities in southwestern China are generally low. The average crustal velocity in SYR is 6.25 km/s. This relatively low average crustal velocity, accompanied by the negative velocity anomaly in the lower crustal and upper mantle layers, are characteristics of an active tectonic region (Mooney and Braile, 1987). The low velocity anomaly at 10-km depth in western Sichuan is similar to that observed for Tibetan Plateau (Ni et al., 1995). The average upper mantle velocity for the SYR is around 7.75 km/s, which is generally lower than the average global Pn velocity of 8.1 km/s. This low velocity is probably related to the heating process (Mooney and Braile, 1989). Possible intrusion of molten material into the lower crust may have caused the low-velocity anomalous zones and caused the Moho to be indistinct. At the same time, the low-velocity anomaly at the top of the upper mantle has dissipated the reflective energy from the Moho, as observed by DSS profiling in the region (Kan et al., 1986).

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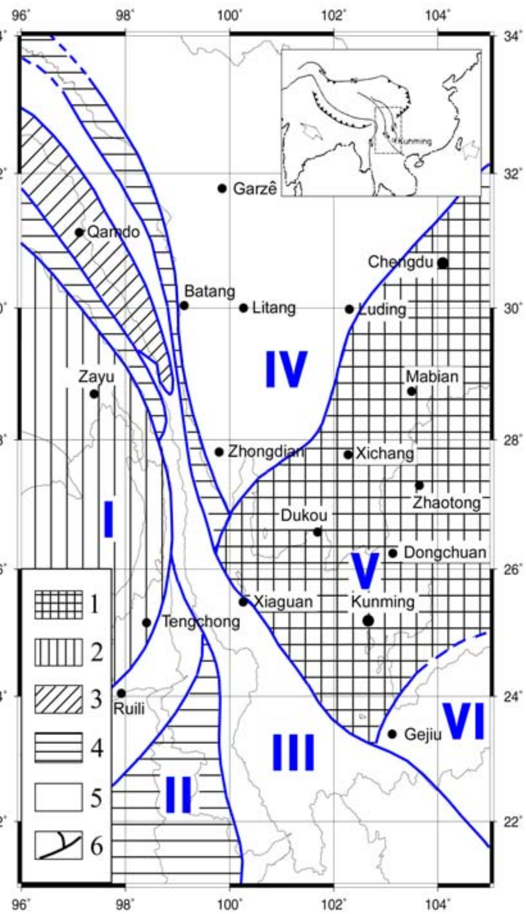

Figure 1. Schematic map of tectonics in southwestern China

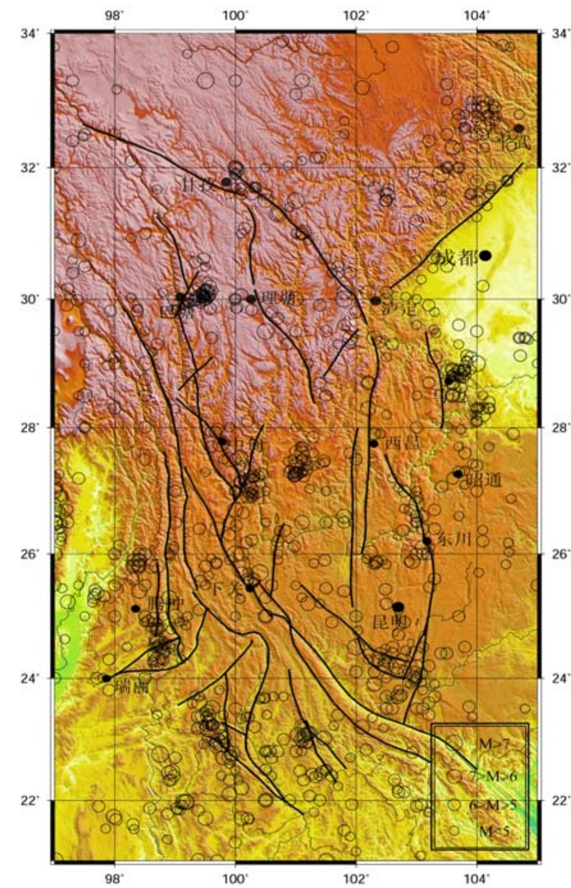

Figure 2. Major faults and the seismicity of Sichuan-Yunnan Region

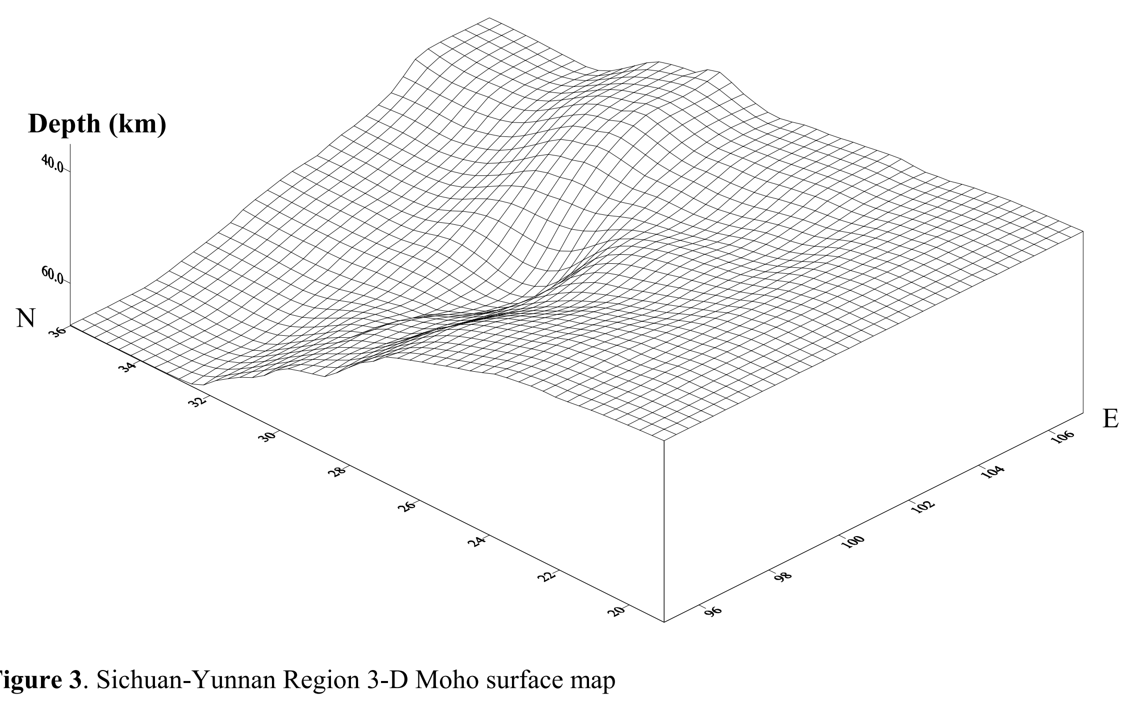

Figure 3. Sichuan-Yunnan Region 3-D Moho surface map

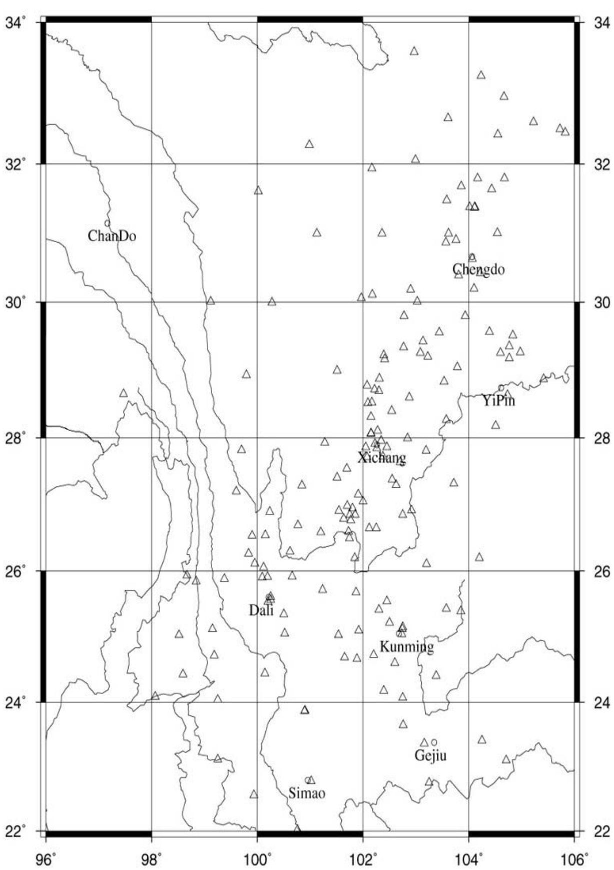

Figure 4. Station locations in SYR

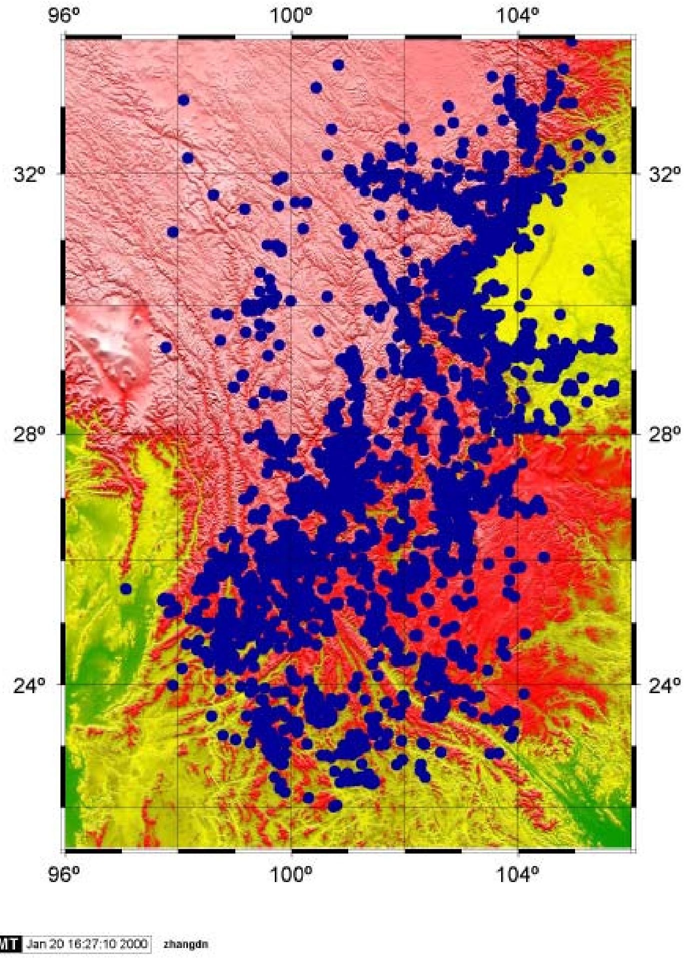

Figure 5. Earthquake distribution in the SYR

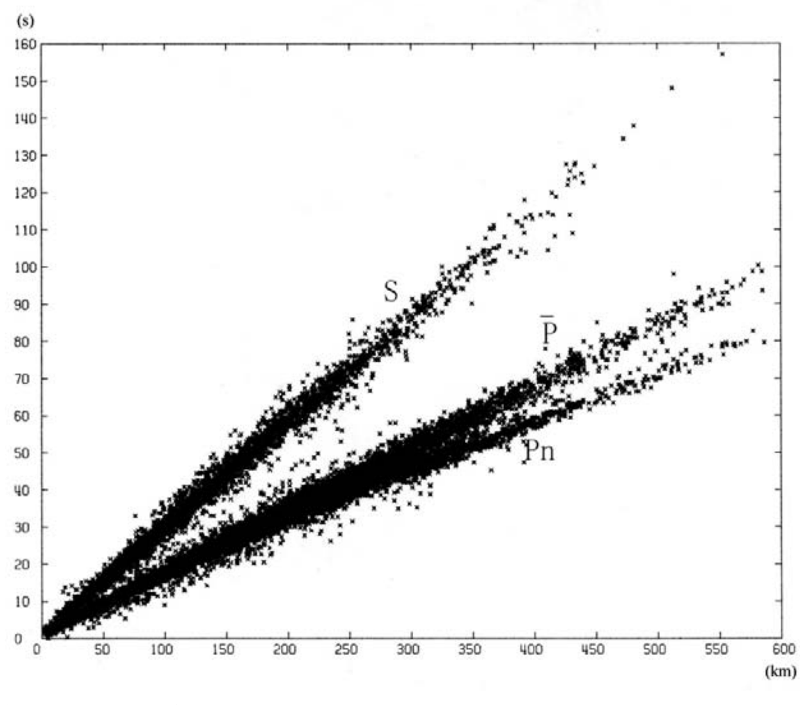

Figure 6. Travel-time curves for the SYR

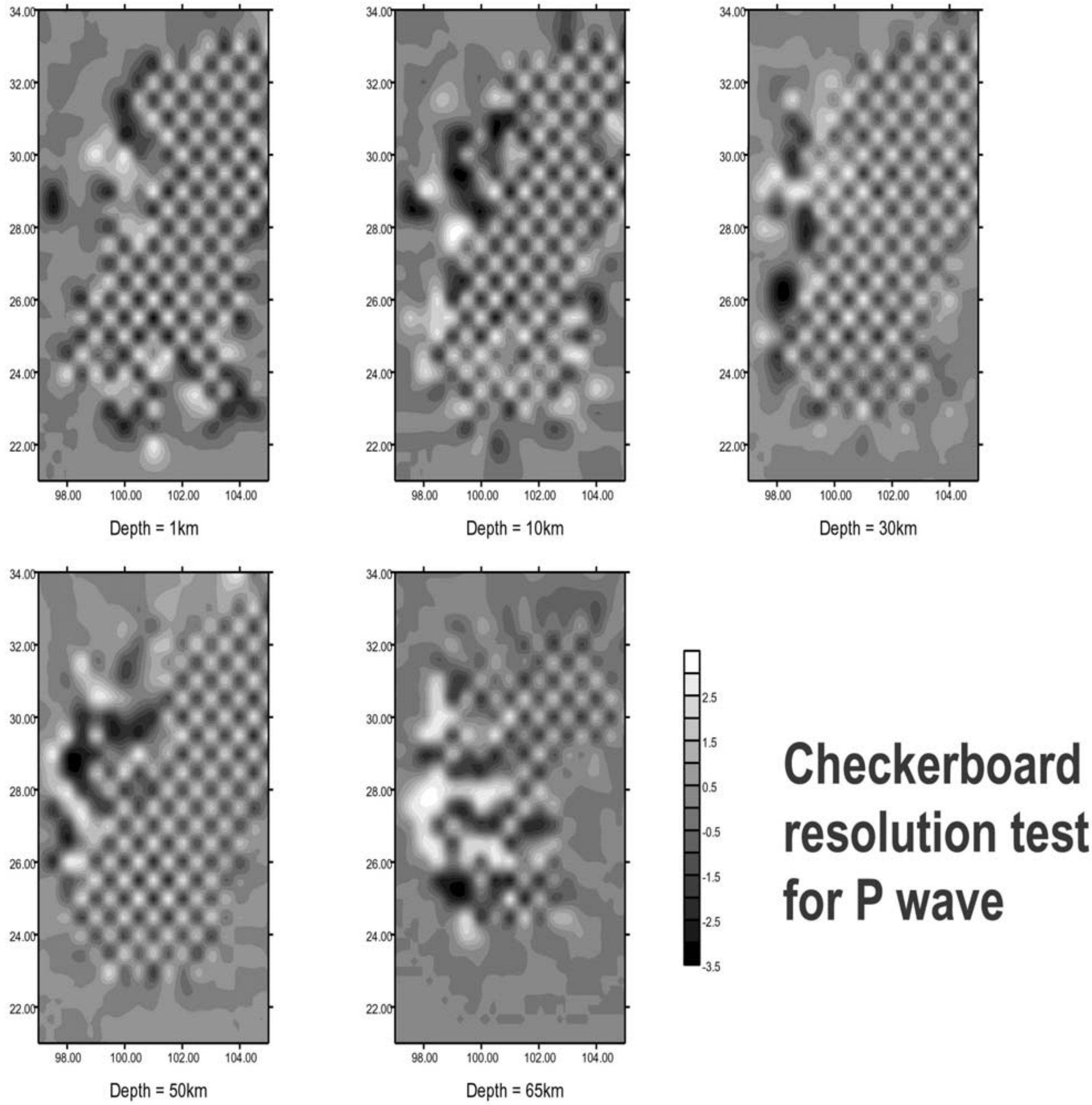

Figure 7. Checkerboard Resolution Test (CRT) on P phases

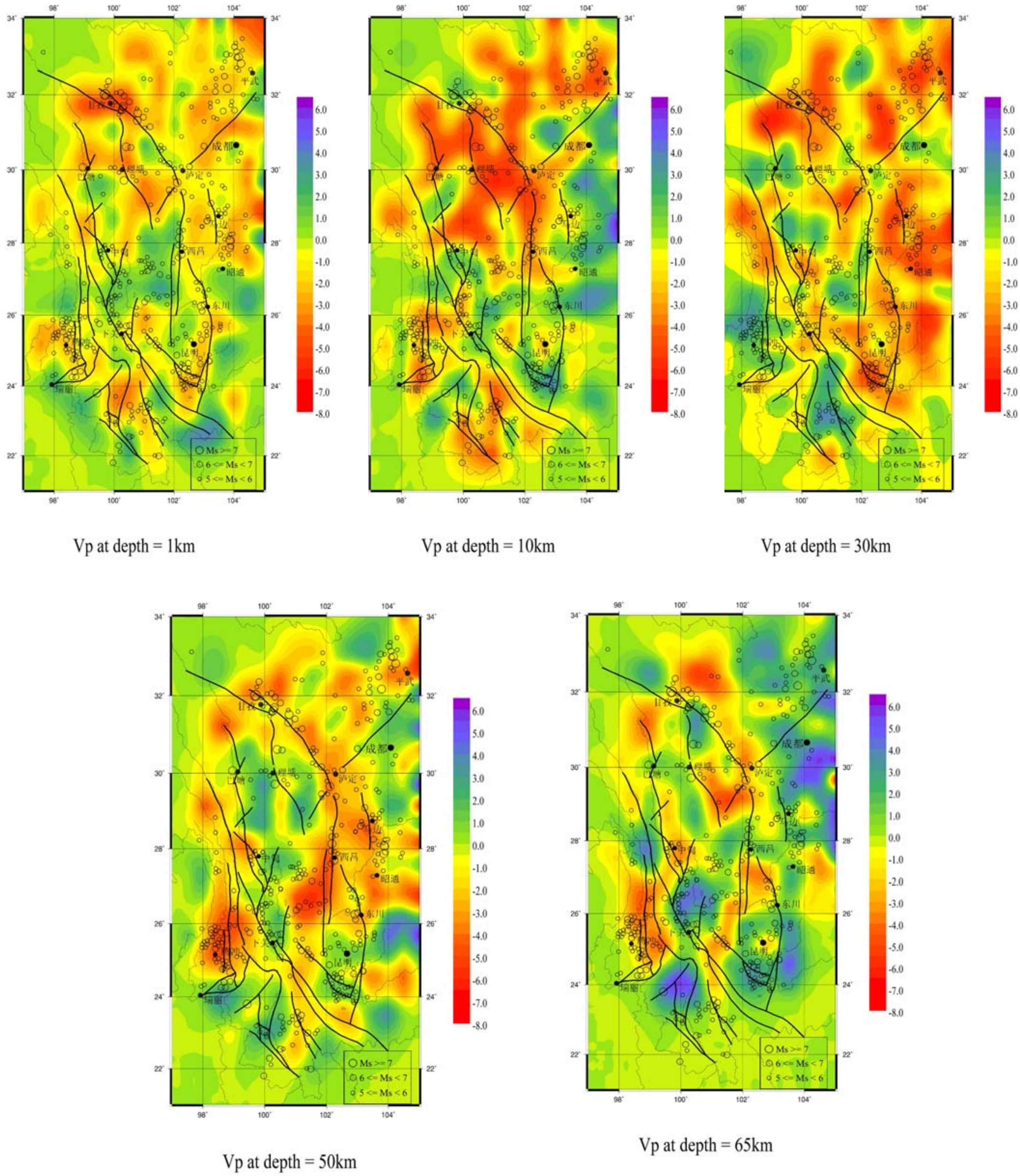

Figure 8. Tomographic inversion results for P waves

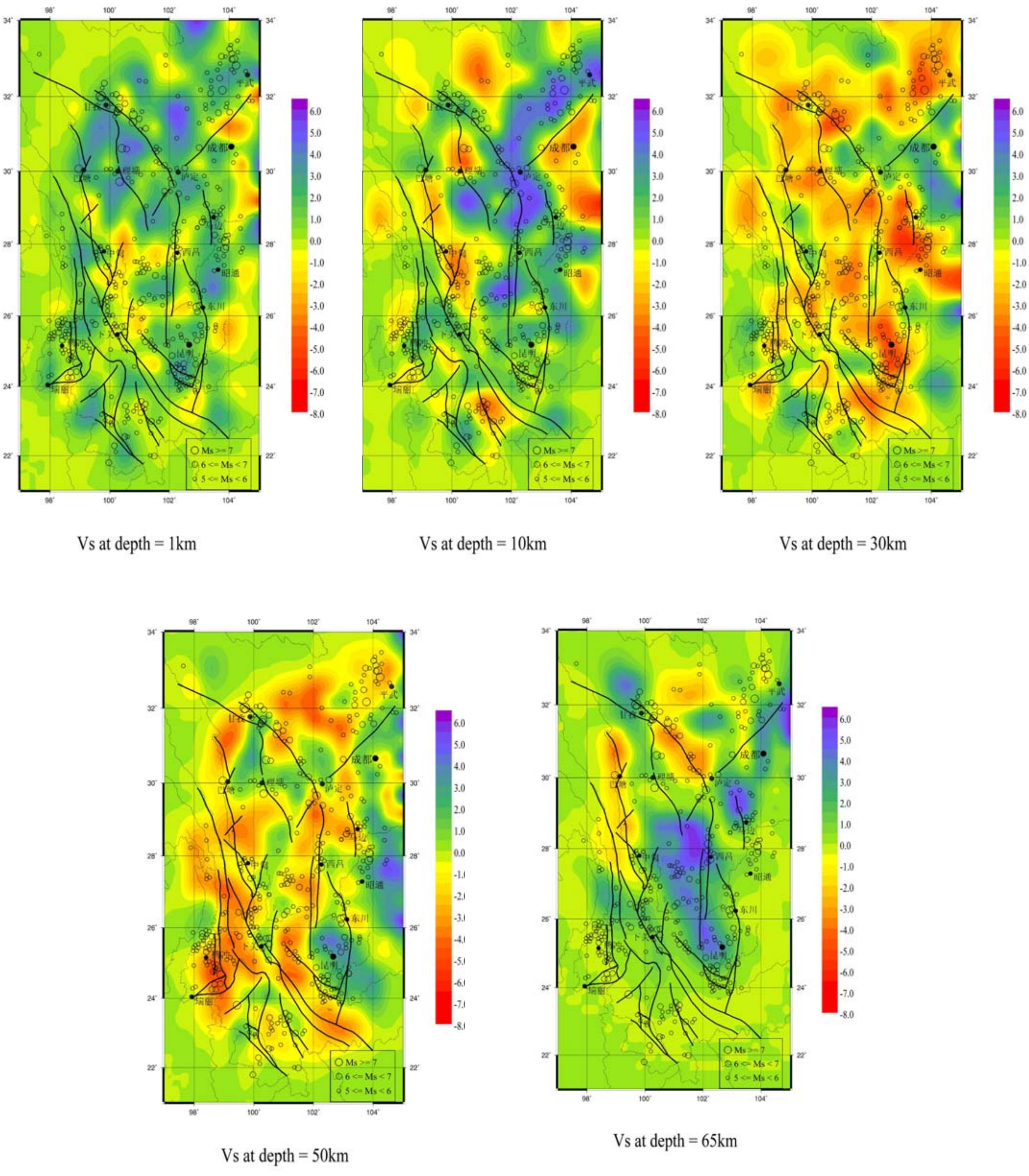

Figure 9. Tomographic inversion results for S waves