Dynamics Research on Strong Shock Gestation in Sichuan-Yunnan and Its Adjacent Regions

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Abstract To know the dynamic environment of seismogenic progress, we try to get the underground medium information by studying the physical characteristics of the lithosphere and upper mantle, such as the regional P-wave velocity structure, spatial distribution of S-wave attenuation, spatial distribution of *Q*c value of coda wave. And we try to get the underground dynamics information by studying the regional stress field which is partitioned in horizontal orientation and detached at vertical direction, as the crustal S-wave splitting, the seismic mechanism of middle and large earthquakes, the strain field of GPS, the anisotropy of Pn-wave, the upper mantle SKS splitting, and so on. Then, with the dynamic models, the coupling extent of different spheres has been analyzed. The results show, the most important dynamic environment of seismogenic progress in Sichuan-Yunnan and its adjacent regions is the lithosphere asymmetry at the structure, physical characteristics, dynamical operation, and so on, especially the flow trait of lower crust and the drag force of upper mantle acting on the crust.

Keyword: Sichuan-Yunnan and its adjacent regions, medium structure, stress field of different layers, simulation of finite element

Introduction

Sichuan-Yunnan region locates in the southeast side of Tibetan Plateau. The collision of India plate and Eurasian plate in the past 45 Ma not only shortens and uplifts the crust of the Tibetan Plateau, but also makes the material of the plateau extrude laterally toward east[1-7]. All these effects caused the strong tectonic activities of Sichuan-Yunnan region in the past and still play an important role in present tectonics (fig. 1).

For seismicity, Sichuan-Yunnan region is one of the most tectonic active regions in China. In Sichuan and Yunnan, according to the report of *Catalog of Chinese strong earthquakes* edited by Chinese Earthquake

Bureau, there are 639 earthquakes from 26 B.C. to 2001 with magnitude larger than M5. Among them, amplitudes of 475 earthquakes are between M5.0 and M5.9, 124 earthquakes are between M6.0 and M6.9, 39 earthquakes are between M7.0 and M7.9, and the last one is larger than M8[8]. According earthquake data in in the 20th century, there are 65 earthquakes whose magnitude is larger than M7. Just in Sichuan-Yunnan region there are 21 earthquakes whose magnitude is larger than M7, which equals to 30% in total big earthquakes happened in China. Besides, most earthquakes over M7 are concentrated in the major faults between tectonic blocks, and the source depths are concentrated between 5~25 km.

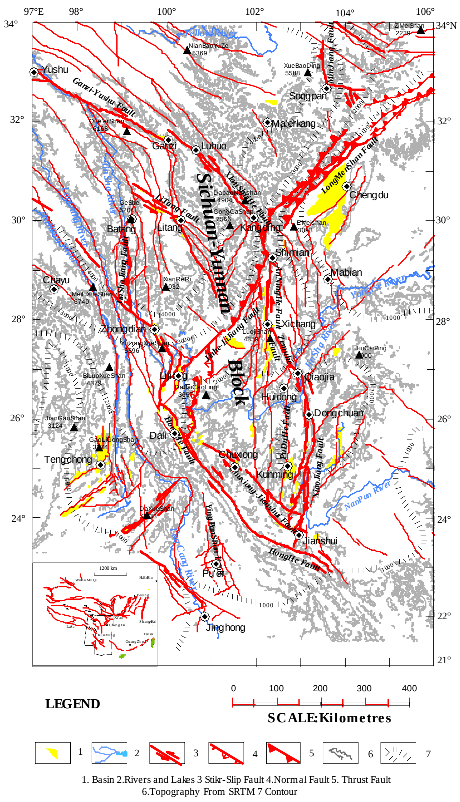
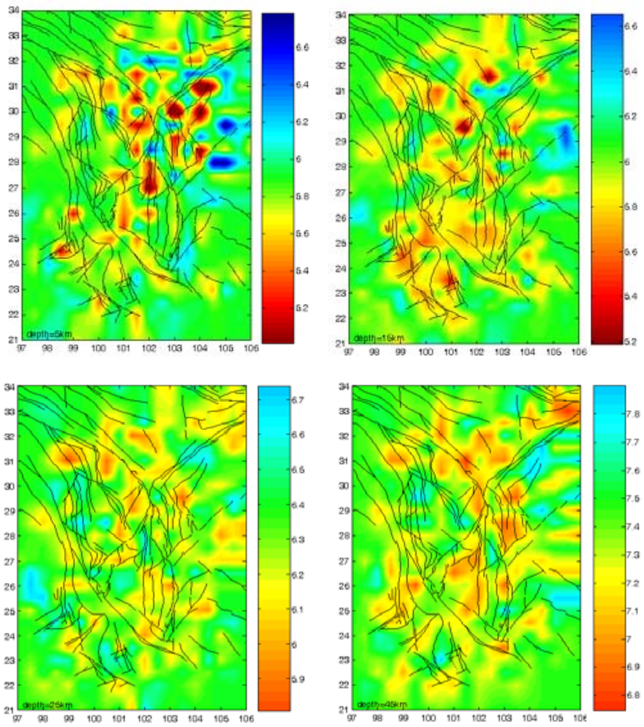


Fig1 Active faults and blocks in southwest China

In this research, we try to get the underground medium information by studying the physical characteristics of the lithosphere and upper mantle, and the dynamics information by studying the regional stress field which is partitioned in horizontal orientation and detached at vertical direction. Then, with the dynamic models, the coupling extent of different spheres has been analyzed, and the cognition of lithosphere structure, physical characteristics of medium, stress and strain field has been increased, and the dynamic environment of seismogenic progress has been made certain further.

Underground medium information

We have selected about 60,000 arrival times recorded by 205 regional stations, with the seismic tomography theory[9] and three dimensional ray tracing method[10,11], to determine a detailed three-dimensional (3-D) P wave velocity structure of the lithosphere in southwest China (fig. 2). Then we figure out the medium structure and tectonic characteristics of different depth which are reflected by the 3-D P wave velocity image in this area, associating with the previous geological features and geophysical data. The results suggest that, 1）low-velocity layers exist far and wide in the middle and deep crust under the large fault zones around the Sichuan-Yunnan block, which can be taken as the decoupling layer adjusting the faults and blocks movement; 2） some deep structures related with paleo-block boundaries, and the trends and extending depths of primary active faults, can be distinguished from the P wave velocity image.



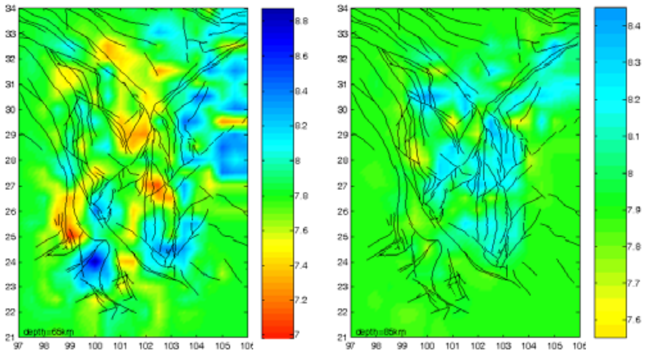


Fig 2 *P* wave velocity structure at different depth in southwest China

We have selected 27,530 M_L amplitude records from 5,897 events recorded by 149 stations, as reported in the Annual Bulletin of Chinese Earthquakes (ABCE) and regional seismic network of Yunnan province and Sichuan province, and have used tomographic imaging to estimate the lateral variations of the quality factor Q_0 [12~14](Q at 1Hz) beneath the crust of Sichuan-Yunnan and its adjacent regions. Estimated Q_0 values vary from 200 to 600 with an average of 400 (fig. 3). Q_0 value is consistent with tectonic and topographic structure. Q_0 is low in the active tectonic regions with many faults, such as the Haiyuan-Qilian, Fenhe-Weihe, East Kunlun zones, Western Sichuan – Northwestern Yunnan – Baoshan area and Joint of Yunnan and Guizhou – Kunming– Simao area, and high in the stable regions, such as Sichuan Basin, Markem block, Western Guangxi – Eastern Yunnan block, Ordos Craton and Qinling – Dabie area.

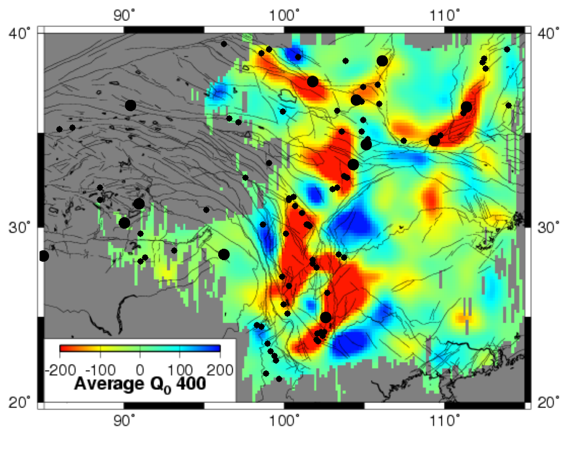


Fig.3 Imaged Q_0 lateral variations and large earthquakes distribution

The coda-wave attenuation quality factor Q_c of the areas in Yunnan Province were estimated using the single-scattering attenuation model of Sato[15~21] from 5668 local seismic events recorded by a regional network of 22 digital stations from the latter half of 1999 to 2003. The used events were in epicentral distances up to 50 km. According to the variation of Q_0 and η, we classified the quality factor Q_c to two types (fig. 4). The classified results showed that there was regional distributing characteristic in medium structure of the areas in Yunnan Province, and this characteristic could be elementarily interpreted by geological structures, seismic activity and heat flow. Generally speaking, the quality factor Q_c of Central Yunnan Block and its boundary area are notably less than those of other regions, as the intensity of tectonic activity of these areas. According to seismic activity, there were large earthquakes in the areas with lower Q_c, and there are few or only some little earthquakes at the areas with higher Q_c. Besides, there is negative relation between quality factor Q_c and heat flow of the areas in Yunnan Province, namely higher heat flow corresponding to lower Q_c and lower heat flow corresponding to higher Q_c.

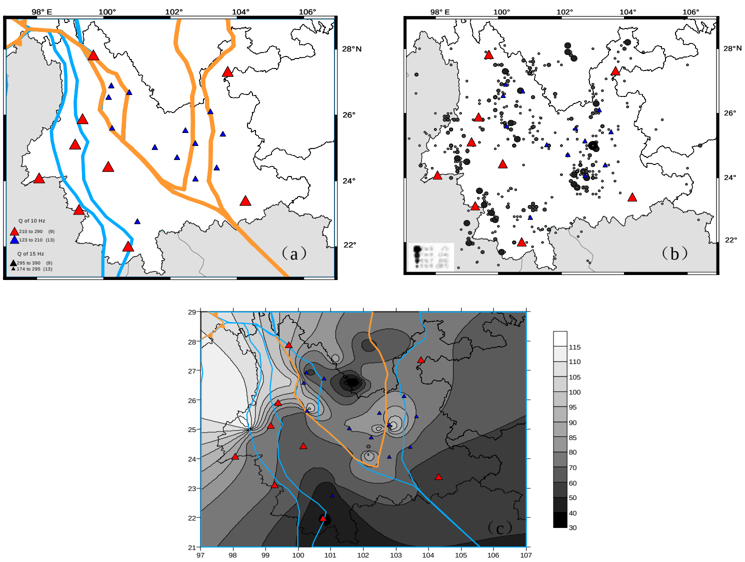


Fig.4 Distribution of Coda *Q*c in Yunnan and its adjacent areas

(a) Coda *Q*c and the active tectonic block boundaries;(b) Coda *Q*c and the large earthquakes;(c) Coda *Q*c and the heat flow

Dynamics environment

We collect 6 361 waveform data to calculate the shear wave splitting parameters from a regional seismic network of 22 digital stations in Yunnan and its adjacent area from July 1999 to June 2005. By using the cross-correlation method[22~25], 64 splitting events of 16 stations are processed. We also collect the splitting results of 8 earthquake sequences[26~32] to present the characteristics of shear wave splitting in Yunnan and its adjacent areas(fig. 5).

The orientations of maximum principal compressive stress of 3 sub-regions in this area are derived from the CMT focal mechanism solutions of 43 moderate-strong earthquakes provided by Harvard University by the P axis azimuth-averaging method. The principal strain rate[33] at each observatory is deduced from the observations of Crustal Movement Observation Network of China during the period from 1999 to 2004. In addition, the data of Pn anisotropy[34] and SKS splitting[35] of Yunnan and its adjacent areas are also collected(table.1).

Table.1 GPS maximum principal compressive strain, P axis of focal mechanism, Pn fast wave velocity and SKS fast wave axis in Yunnan and its adjacent areas

Region	GPS maximum principal compressive strain			P axis of focal mechanism			Pn fast wave anisotropic velocity			SKS fast wave axis		
	Number	$\bar{\theta}$ /(°)	R	Number	$\bar{\theta}$ /(°)	R	Number	$\bar{\theta}$ /(°)	R	Number	$\bar{\theta}$ /(°)	R
Central Yunnan	54	151	0.85	11	158	0.96	24	169	0.94	17	84	0.90
Southwestern Yunnan	75	15	0.81	12	28	0.95	53	110	0.88	14	101	0.97
Northwestern Yunnan	16	134	0.73	6	108	0.65	16	108	1.00	4	9	1.00

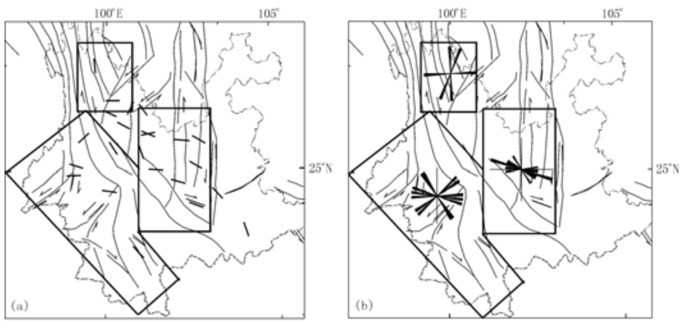


Fig.5 Fast wave polarization direction and zoning predominant direction of 16 stations and eight earthquake sequences in Yunnan and its adjacent areas

(a) Fast wave polarization direction; (b) Zoning predominant distribution

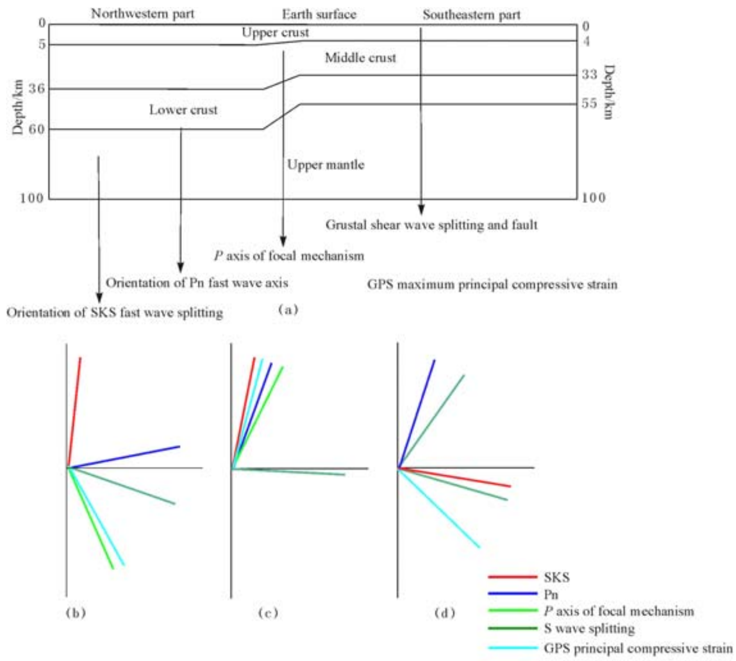


Fig.6 Physical parameters manifesting stress-strain orientation of each layer in Yunnan and its adjacent areas and zoning distribution of average orientation of each layer

(a) Layer sketch manifested by different physical parameters;(b) Distribution of average direction of each layer in the Central Yunnan block;(c) Distribution of average direction of each layer in the southwestern Yunnan; (d) Distribution of average direction of each layer in the northwestern Yunnan

We have discovered from this study(fig.5 and fig.6) that the continental lithosphere, as a main seismogenic environment for strong earthquake, can be divided into blocks laterally; the mechanical behavior of lithosphere varies with depth and can be divided into different layers in the vertical orientation; the information of crustal deformation obtained from GPS might be affected by the type of blocks, since there are different types of active blocks in Yunnan and its adjacent areas; the shear wave splitting in this region might be affected mainly by the upper crust or even the surface tectonics.

Simulation of finite element

Considering previous work of different people, and the new results of different research[36~39], as active faulting, three dimensional velocity structure, geodesy, seismicity, we give a new three-dimensional dynamic model of Sichuan-Yunnan and its adjacent regions. The whole model is divided to three regions horizationally, and four layers vertically. For Sichuan-Yunnan region（98°-106°E，21°-33°N）, there are 5890 elements, and 3050 nodes distributed horizationally; the whole model consists of 100130 elements and 62 075 nodes.

From GPS data[40], we define the velocity of the finite element model’s edge. From SKS’s anisotropy data[35], we determine the flow pattern of the upper mantle’s material(fig.7).

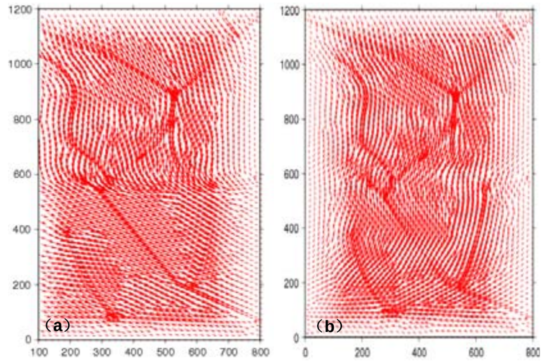


Fig.7 Drag force on the model bottom

（a）Drag to the east at south of 26°; （b）Drag to the west at south of 26°

Considering all these above-mentioned situations, we built five models: model 1、2、3、4、5. Conditions of different finite element model are shown in table 4. In model 1, we only used elastic bodies; constraints on boundary do not change with depth; constraints are on the upper 60 kilometers; we don’t take the drag force from the bottom into account. In model 2, we used elastic bodies for every layer; constraints are on the upper 25 kilometers; the drag force of the upper mantle is 5 kPa, as shown in figure 7a. In model 3, we also used elastic bodies for every layer; constrains are on the upper 25 kilometers; the drag force of the upper mantle is 5 kPa, shown in Figure 7b. Model 4 is based on model 2; considering the rheology of the material of the lower crust in Sichun-Yunnan Diamond block, we used viscoelastic bodies (Maxwell bodies) ; constraints are on the upper 25 kilometers; the drag force of the upper mantle is 1 MPa, shown in figure 7a. Model 5 is based on model 3. Considering the rheology of the material of the lower crust in Sichun-Yunnan Diamond block, we used viscoelastic bodies; constraints are on the upper 25 kilometers; the drag force of the upper mantle is 1 MPa, shown in figure 7b.

Table. 2 Distinguish stress azimuth at 10km from at 40km in different subarea of different models

model	Northwest Sichuan Block		Central Yunnan Block		Baoshan-Pu’er Block	
	10km	40km	10km	40km	10km	40km
1	119.4	119.4	146.0	146.1	3.3	3.2
2	119.3	118.8	150.5	154.4	4.7	3.0
3	120.0	120.0	145.9	143.1	3.6	3.5
4	120.0	124.6	141	149.0	16.0	9.4
5	119.6	128	149.2	126.3	5.2	12.4

The simulation results show, 1) the phenomena that the material of Sichuan-Yunnan and its adjacent areas flows clockwise around Himalaya’s east tectonic node is related to the special boundary condition, and the stress field （seismic mechanism）in middle and upper crust is also related to the special boundary condition; 2) when we changed the lower crust from elastic material to viscoelastic material, the stress field of different crustal layers decoupling come forth in the Central Yunnan block and its neighbor area（100.9° -103.4° E，22.9° -27.6° N）, but this phenomena can not be found in other areas (table.2, some are alike fig.6).

Conclusions

The mechanism of tectonic earthquake formation is an important issue in seismology. And the conclusion may be drawn as that the markedly heterogeneous of the crustal structure and medium may cause the stress concentration and strain accumulated which may be the places of large earthquakes occurrence (epicenter areas). The seismogenic process is the result of reciprocity between the crustal movement of circumjacent regions and inelastic deformation of epicenter areas, under the control of regional tectonic stress field. And it is the result and representation of the crustal movement.

With the upwards systemic studies, we can get a whole cognition as that, the most important dynamic environment of seismogenic progress in Sichuan-Yunnan and its adjacent regions is the lithosphere asymmetry at the structure, physical characteristics, dynamical operation, and so on, especially the flow trait of lower crust and the drag force of upper mantle acting on the crust.

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