Spatio-temporal variation and focal mechanism of the Wenchuan $M_S8.0$ earthquake sequence*

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Abstract Based on abundant aftershock sequence data of the Wenchuan $M_S8.0$ earthquake on May 12, 2008, we studied the spatio-temporal variation process and segmentation rupture characteristic. Dense aftershocks distribute along Longmenshan central fault zone of NE direction and form a narrow strip with the length of 325 km and the depth between several and 40 km. The depth profile (section of NW direction) vertical to the strike of aftershock zone (NE direction) shows anisomeric wedgy distribution characteristic of aftershock concentrated regions; it is related to the force form of the Longmenshan nappe tectonic belt. The stronger aftershocks could be divided into northern segment and southern segment apparently and the focal depths of strong aftershocks in the 50 km area between northern segment and southern segment are shallower. It seems like 'to be going to rupture' segment. We also study focal mechanisms and segmentation of strong aftershocks. The principal compressive stress azimuth of aftershock area is WNW direction and the faulting types of aftershocks at southern and northern segment have the same proportion. Because aftershocks distribute on different secondary faults, their focal mechanisms present complex local tectonic stress field. The faulting of seven strong earthquakes on the Longmenshan central fault is mainly characterized by thrust with the component of right-lateral strike-slip. Meantime six strong aftershocks on the Longmenshan back-range fault and Qingchuan fault present strike-slip faulting. At last we discuss the complex segmentation rupture mechanism of the Wenchuan earthquake.

Key words: Wenchuan earthquake, strong aftershock, spatio-temporal variation, focal mechanism solution

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1 Introduction

The Wenchuan $M_S8.0$ earthquake at 14:28 pm on May 12 in 2008 occurred on Longmenshan tectonic zone of NE direction in Sichuan province. Immediately following the earthquake, seismic experts from China Earthquake Administration and Earthquake Administration of Sichuan province measured arrival time of $\bar{P}$ and $\bar{S}$ according to digital seismic records and applied MSDP to get the earthquake parameters. The software SEIS-DPS developed by the Earthquake Administration of Sichuan province was used to check the former result. The location accuracy had a great improvement as the portable seismic station had been settled after the time of 18 pm 17th May by Earthquake Administration of Gansu, Sichuan and Shaanxi provinces. Errors of epicenter and focal depth are 1–2 km and 3–5 km respectively. Before that time the errors of epicenter and focal

depth are 3 km and more than 5 km respectively. From the main shock to that time mentioned above, there were relative few earthquakes in northern segment.

According to the monitoring result, earthquakes greater than $M_L2.0$ are complete. In the aftershock area of Wenchuan earthquake, 14 904 aftershocks with magnitude 2.0–6.4 were recorded during the period from 14:28 pm 12th May to 9:46 am 30th September 2008. Among them, there are 11 160 $M_L2.0$ –2.9 events, 3 126 $M_L3.0$ –3.9 events, 554 $M_L4.0$ –4.9 events, 56 $M_S5.0$ –5.9 events, 8 $M_S6.0$ –6.9 events. The largest aftershock is $M_S6.4$ occurred on 16:21 pm 25th May. According to aftershock sequence with magnitude 2.0 to 6.4 the sequence parameter $b=0.89$ and $a=6.18$ can be fitted under term that interval of bracketing magnitude is 0.2. The fitting correlation coefficient R equals to 0.99. Aftershocks of the Wenchuan earthquake distribute along central fault of the Longmenshan tectonic zone and stretch to 330 km as narrow strip.

The Wenchuan earthquake has become few earthquake case of discovering continental earthquake rupture mechanism for its rich aftershocks, long duration

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time and distinct staged rupture characteristic. Instability extension in the time of faulting within source region range is determined by many kinds of factors or status. In this paper, some results obtained by field investigation after large earthquake happened are given including segmented characteristic of aftershock activity and focal mechanism etc.

2 Spatio-temporal variation of aftershock

2.1 Distribution of aftershock belt

The aftershocks of the Wenchuan earthquake mainly distribute in Wenchuan, Beichuan, and Qingchuan of north Sichuan province. Dense aftershocks distribute along the Longmenshan central fault of NE direction and form a narrow strip with the length of 330 km (Figure 1). The Longmenshan fault belt is a thrust fault belt which is the east edge of middle segment of north-south seismic belt, and it is the transition zone from eastern steady Yangtze block with thin crust and mantle to western plateau with thick crust and mantle as well. The Longmenshan tectonic belt consists of a series of left lateral echelon main faults and secondary fault system with NE direction. It form a complex thrust belts named Longmenshan back range, central, front range faults from west to east, respectively (Zhu, 2008).

According to aftershock distribution image of the Wenchuan earthquake, the stronger aftershocks could be divided into two segments obviously. Strike of aftershock distribution above and below Huya fault south end are different and present southern and northern segments (Figure 1).

At southern segment of aftershock area, aftershocks mainly distribute along central and back-range fault of the Longmenshan tectonic belt. The serious catastrophic regions spreading from initial rupture area toward NE direction are in sequence of south of Wenchuan, north-west of Dujiangyan, north of Pengzhou, north of Shifang, southeast of Maoxian, north of Mianzhu, north of Anxian, Beichuan and Jiangyou counties. Around rupture segment of Wenchuan $M_s8.0$ earthquake, there have been three $M_s6.0$ – 6.1 earthquakes in one day after the main shock. According to straight-line distance on surface of aftershock distribution we give that the width of south segment of aftershock area is about 60 km, and concentrated distribution area is about 40 km width. Aftershock distribution on some fault segments is ir-

regular, but it will not affect us to understand overall distribution scale of aftershock.

At northern segment of aftershock area, aftershocks mainly distribute along the Longmenshan central fault zone, and extend to Shaanxi province through Qingchuan fault zone. The serious catastrophic regions spreading toward NE direction are in sequence of southeast of Pingwu, Qingchuan, and area from northwest of Guanyuan to Ningqiang county of Shaanxi province. There were five $M_s6.0$ – 6.4 aftershocks including the largest strong aftershock of May 25 Qingchuan $M_s6.4$. The width of north segment of aftershock area is about 40 km, and concentrated distribution area is about 25 km width.

Figure 2 displays the depth profile of $M_L \geq 4.0$ aftershocks along the strike of aftershock area (NE direction). Within 100 km length of main shock rupture segment, there are dense distribution zone of $M_L \geq 4.0$ aftershocks and the depth distribution of aftershocks is between several kilometers and over 40 km on the Longmenshan central fault zone. At northern segment from 220 km to over 300 km distance to the epicenter, aftershock distribute at the depth range is also from several kilometers to over 40 km. However, there is a 50 km long area between southern segment and northern segment in which aftershock depths are shallow relatively and distribute from several kilometers to over 20 km. This gap between 20 km deep and 40 km deep seem to correspond to ‘deficit area’ or ‘to be going to rupture’ segment in image of main shock rupture evolvement. From depth profile of strong earthquake the distribution difference of aftershock depth at various fault segments is distinct.

2.2 Aftershock distribution and structure of southern segment

At southern segment of aftershock area, Aftershocks of the Wenchuan earthquake densely distribute on central fault of middle segment of the Longmenshan fault zone and form a narrow strip. This fault is named Yingxiu-Baishuihe-Beichuan fault, which is imbricate structure with tendency of NW direction, the dip angle of 60° . It consists of several secondary faults. The Wenchuan earthquake and three $M_s6.0$ – 6.1 events successively occurred on this segment from May 12 to 13. Plenty of aftershocks including 25 $M_s5.0$ – 5.9 events distribute at the initial rupture segment of main shock also. The aftershocks densely distribute along the Longmenshan central fault of NE direction and mainly

Figure 1 Distribution of aftershocks of the Wenchuan earthquake. The earthquakes of $M_L \geq 2.0$ occurred in the period from 12 May to 19 August 2008. F_1 . Longmenshan fault; F_2 . Longquanshan fault; F_3 . Fubianhe fault; F_4 . Minjiang fault; F_5 . Huya fault; F_6 . Qingchuan fault; F_7 . Huayingshan fault; F_8 . Xianshuihe fault; F_9 . Wenxian-Lueyang fault.

Figure 2 The depth profile along the NE-striking of aftershock area.

Figure 3 The depth profile of aftershocks at southern segment of aftershock area (Perpendicular to strike of the Longmenshan fault zone).

distribute in incline section of NW direction, the distribution zone with length of 160 km and width of 40 km, this segment was just the transported segment of main rupture confirmed by field investigation.

The Wenchuan event and aftershocks present characteristic of convergent compression between

Chuanqing block and Sichuan basin. According to data of Sichuan seismic network and location results from spot expert team, the depth distribution of aftershocks at southern segment of aftershock area are shown in Figure 3. Major axis of aftershock area trends in NE direction, and the depth profile (NW direction) vertical to major

axis trend shows the depth distribution of aftershocks from west to east. Distribution of aftershock become narrow with depth and presents a wedgy distribution with gentle at west and steep at east which is 40 km width on the surface and 20 km width below 40 km. At two sides of depth profile, aftershocks become sparse gradually, and this clearly shows the whole image of aftershock activities that aftershock extending to front-range and back-range fault zone.

According to regional lithosphere structure, Moho depth of Sichuan basin on the section is about 40 km and that at west of the Longmenshan fault zone is about 62 km. The Longmenshan fault zone is the geotectonic boundary belt of different lithosphere structure, which is thin crust and thin mantle at east and thick crust and thick mantle at west. The Longmenshan tectonic zone converge to the west and disappear in low resistivity layer or detachment surface in crust. The fault plane of intensive distribution of aftershocks presents a wedge image and reflects nappe structure.

Partial aftershocks distribute on back-range fault which is called Wenchuan-Maoxian fault at the middle segment of the Longmenshan fault zone. According to regional geologic mapping it disappears at the Shenxi valley in Maoxian and links with Pingwu-Qingchuan fault approximately, and then extends northeastward to the neighborhood of Mianxian in Qinling area. Prophase aftershocks at southern segment of aftershock area form salient distribution image of NW direction. This is related to the secondary fault activities of NW direction which is near the Maoxian and Longmenshan fault zones.

A few aftershocks with magnitude below 5.0 are scattered on front-range fault of the Longmenshan fault zone, which is the boundary between Sichuan basin and east edge of Qinghai-Tibet plateau. The middle segment of the Longmenshan front-range fault is named Dayishuanghe-Anxian fault. Because three parallel faults of Longmenshan fault zone are all tendency of NW direction, the depth profile of aftershocks approximately reflect this gradient and their difference.

There are historical strong earthquake with magnitude over 6.0 on central fault at middle segment of the Longmenshan fault zone. They are Wenchuan $M6$ earthquake in 1657, Beichuan $M6\frac{1}{3}$ earthquake in 1958 and the west Dayi $M6\frac{1}{4}$ earthquake in 1970. Intensity and frequency of strong earthquake activity is not high, but the epicenter is shallow. Diexi area in Maoxian on

Minjiang fault zone which obliquely link to the Longmenshan faults zone occurred $M7.5$ earthquake in 1933 and caused serious damage and earthquake disaster (*A Compilation of Sichuan Earthquake Data* editorial group, 1981).

2.3 Aftershock distribution and structure of northern segment

At northern segment of aftershock area, aftershocks mainly distribute Nanba-Guangyuan Shuimo fault which is at NE segment of the Longmenshan central fault zone, and extend to Shaanxi province through Qingchuan fault zone. The serious catastrophic regions spreading along NE direction are in sequence of southeast of Pingwu, Qingchuan, and area from northwest of Guangyuan to Ningqiang county of Shaanxi province. There were five $M_{\geq 6.0-6.4}$ aftershocks at northern segment of aftershock area. The concentrated distribution length of $M_{\geq 5.0}$ aftershocks is 130 km. The May 25 Qingchuan $M_{\geq 6.4}$ earthquake is the largest aftershock of the Wenchuan earthquake.

At northern segment of aftershock area, the concentrated distribution width is about 40 km in surface, at the depth of 40 km, the distribution width is 20 km. The depth profile of strong aftershocks along the strike of aftershock area is shown in Figure 4, the depth distribution of stronger aftershocks at northern segment of aftershock area is obvious different from the depth distribution of southern segment. The focal depth of northern segment is shallower than southern segment. In addition, the earthquake with depth between several and 15 km or below 25 km is very rare at northern segment of aftershock area, the depth of focal profile is between 15 km and 25 km.

According to the depth profile (from NW to SE direction) vertical to the strike of aftershock area (Figure 5), aftershock distribution of this profile shows anisomalous wedgy distribution characteristic. Aftershock concentrated regions show that west side of image is slower and east side is steeper. The dense aftershock area of NE direction through Qingchuan fault zone is about 20 km from front-range fault, the front-range fault shows that the depth profile is steeper, it is related to thrust characteristics and motion mode on both sides of blocks.

In addition, the focal depth gradually become shallow with time variation at southern and middle segment of aftershock area, however the focal depth distribution do not appear above phenomenon at the northern segment, pre- and post-change is not obvious.

Figure 4 The depth profile of strong aftershock of whole aftershock area (Along NE strike of the Longmenshan fault zone, $M_s \geq 5.0$).

Figure 5 The depth profile of aftershocks at northern segment of aftershock area (Perpendicular to strike of the Longmenshan fault zone, $M_L \geq 2.0$).

Aftershocks distribute from northeastern segment of the Longmenshan fault zone through Pingwu-Qingchuan fault zone at northern segment of aftershock area, the strong earthquake of this segment have no historical record. There were $M6\frac{1}{2}$ earthquake in 1630, the $M6\frac{1}{2}$ earthquake in 1973 and $M7.2$ earthquake in 1976 between Songpan and Pingwu on Huya fault zone.

Zhu (2008) gives the detachment surface of the Longmenshan nappe structure, the depth of Santai-Mianyang-Wenchuan profile is between 16 and 20 km, the depth of Shuangliu-Wenchuan-Aba profile is about 25 km, this crustal depth is just the main seismic interval. According to the research of Zhu (2008), P wave velocity along the Longmenshan fault zone is between 6.2 and 6.6 km/s at the depth of 10, 15 and 20 km. the P wave velocity provided by Wang et al (2002), at depth of 10 and 30 km show all the velocity of crust is relatively high, the lateral heterogeneity of wave velocity along the Longmenshan nappe structure zone reflects difference of subsurface medium structures. The aftershock distribution zone locates in transition layer between high and low wave velocity of crust.

3 Focal mechanisms

After the Wenchuan earthquake, the focal mecha-

nism solutions of main shock were determined by some research institutions in China and abroad. Such as the research reports from Chen et al (2008), Zheng (The focal mechanism research results of 47 aftershocks provided by <http://www.cea-igp.ac.cn/>), National Earthquake Information Center (NEIC) of United States Geological Survey (USGS) (URL: http://neic.usgs.gov/neis/eq_depot/2008/eq_080512_ryan/neic_ryan_cmt.html) and Harvard University (URL: http://neic.usgs.gov/neis/eq_depot/2008/eq_080512_ryan/neic_ryan_hrv.html), they all provided the results of the Wenchuan earthquake, table ellipsis. These four results are almost identical, the principal compressive stress azimuth is NW direction, i.e., P-axis azimuth between 102° and 122° , the elevation (6° – 20°) closes to horizontal direction, the focal mechanism solutions show that the nodal plane I strikes are between 228° and 238° , i.e., in the NE direction, the nodal plane II strike in NNE or near SN direction (352° – 7°). We consider the nodal plane I which is identical to the strike of rupture zone or aftershock distribution area as the main rupture, the dip of fault in NW direction, we believe that the Longmenshan central fault is causative structure of the Wenchuan earthquake, the faulting of this earthquake is mainly characterized by thrust with the component of right-lateral strike-slip.

The rupture of the Wenchuan earthquake spreads from SW to NE direction, this event is unilateral rupture process. According to source characteristic analysis report of the great Wenchuan earthquake (Chen et al, 2008), the focal depth of southern segment is about 20 km, and more deeper, however, the northern segment is relatively shallow, the depth is about 10 km, this event ruptures toward north by east 49° direction with an average velocity of 2.8–3.1 km/s, the total rupture duration is about 120 s, the release time of main energy is about 70 s, the fault length is at least 300 km, the fault width of southern segment is 30 km, the northern segment is 15 km, the most slide quantity is up to 9 m, the scalar moment tensor of this earthquake is 4.4×10^{21} N·m.

Because aftershock sequence are rich, the distribution scale is longer and aftershocks distribute on different secondary faults, the focal mechanism solutions present variety, the source mechanical mechanism and regional tectonic stress filed are very complex. The focal mechanism solutions of 14 aftershocks with magnitude greater than or equal to 5.5 are given in Figure 6. P wave onset solutions are given in Figure 1. Among them,

the former two namely Wenchuan event and Pengzhou $M_{S6.0}$ event are results worked out by Yong Zheng (Personal communication, 2008).

Figure 6 The focal mechanism solutions of Wenchuan $M_{S8.0}$ earthquake and strong aftershocks. 13 $M_{S5.5-6.4}$ strong aftershocks, the number of fault zone are the same as that in Figure 1.

At southern segment of aftershock area, we give out the focal mechanism solutions of six strong aftershocks which all occurred near the initial rupture area of the Wenchuan earthquake. The main shock and three strong aftershocks are located on the Yingxiu-Dujiangyan secondary fault. These three strong aftershocks contain the northern Pengzhou $M_{S6.0}$ event on 12th May, the northern Pengzhou $M_{S5.6}$ event on 13th May and southern Wenchuan $M_{S6.1}$ event on 13th May, the focal mechanism solutions of these three strong aftershocks and main shock all show that the faulting mainly present thrust with the component of right-lateral strike slip, the strike of fracture plane is also similar to the result of main shock in the main. The residual three $M_{S5.6-6.0}$ strong aftershocks occurred on the Longmenshan back-range fault, whose sources are on NE trending Wenchuan-Maoxian secondary fault. They are all mainly characterized by strike-slip faulting, the focal mechanism solutions are obviously different from the results of the Longmenshan central fault zone.

At northern segment of aftershock area, the focal

mechanism solutions of seven $M_{S5.6-6.4}$ aftershocks are given. $M_{S6.0}$ and $M_{S6.1}$ earthquakes occurred between Pingwu and Beichuan are at the central fault of the Longmenshan tectonic zone on 18th May and first August. The focal mechanisms of these two earthquakes present thrust with the component of right-lateral strike slip. Between 25th May and 24th July, there occurred Qingchuan $M_{S6.4}$ (the largest aftershock so far) on 25th May, Ningqiang $M_{S5.7}$ 27th May and Qingchuan $M_{S6.0}$ on 24th July. The focal mechanisms of these three events take on strike-slip faulting. Meanwhile, the two other events Ningqiang $M_{S5.6}$ and Qingchuan $M_{S6.1}$ on 24th July and 5th August have the focal mechanisms which present more thrust component characteristic. This group strong aftershock cross Qingchuan fault and distribute densely in the north end of aftershock region.

According to the focal mechanism solutions of 52 strong aftershocks of the Wenchuan earthquake with magnitude greater than or equal to 5.0, among which 31 are first motion solutions based on clear P wave onset, the other 21 solutions are provided by Zheng (2008).

Table1 The focal mechanism solutions of $M_S \geq 5.5$ aftershocks of the Wenchuan $M_S 8.0$ earthquake

Origin time		Location	Lat /°N	Long /°E	M_S	Depth /km	Nodal plane I			Nodal plane II			P-axis		T-axis		B-axis		R
Date mo-d	Time h:min:s						Strike /°	Dip /°	Slip /°	Strike /°	Dip /°	Slip /°	Az /°	Pl /°	Az /°	Pl /°	Az /°	Pl /°	
5-12	14:28:04.0	Wenchuan	31.00	103.24	8.0	14	228	33	141	352	70	63	102	20	226	56	2	25	1)
5-12	14:43:14.0	Pengzhou	31.15	103.39	6.0	33	134	60	90	314	30	90	224	15	44	75	134	0	1)
5-12	19:11:00.0	Wenchuan	31.18	103.25	6.0	10	213	82	172	305	76	14	259	4	168	16	3	74	0.06
5-13	04:08:49.0	Pengzhou	31.25	103.49	5.6	20	243	31	176	336	88	59	93	35	218	39	338	31	0.04
5-13	15:07:07.0	Wenchuan	30.57	103.12	6.1	33	198	41	115	347	54	70	91	7	203	73	359	16	0.16
5-14	10:54:36.0	Wenchuan	31.19	103.23	5.6	43	220	83	173	310	88	2	85	4	175	6	323	83	0.00
5-16	13:25:46.0	Wenchuan	31.21	103.11	5.9	15	246	79	-179	156	89	-11	111	8	202	7	333	79	0.05
5-18	01:08:25.0	Pingwu	32.15	104.54	6.0	22	262	68	112	35	31	47	335	20	205	61	73	21	0.04
5-25	16:21:49.0	Qingchuan	32.33	105.20	6.4	16	245	70	160	336	86	4	109	11	202	17	347	70	0.00
5-27	16:37:51.0	Ningqiang	32.47	105.36	5.7	11	74	79	-169	340	69	-22	298	23	205	7	99	66	0.02
7-24	03:54:44.0	Ningqiang	32.50	105.29	5.6	14	342	25	109	141	66	82	238	21	36	68	145	8	0.05
7-24	15:09:29.0	Qingchuan	32.49	105.29	6.0	12	286	87	-3	18	61	-151	232	22	336	18	101	61	0.05
8-01	16:32:42.0	Pingwu	32.05	104.39	6.1	21	18	25	77	213	66	96	298	20	135	69	30	6	0.11
8-05	17:49:16.0	Qingchuan	32.46	105.27	6.0	10	152	64	80	353	28	109	250	18	42	70	157	9	0.04

Note: 1) stands for the results of Zheng (2008). R represents ratio of inconsistent signs.

It should be noted that by comparing the results of Zheng (2008) with P wave onset solutions for the same event. The two results are almost identical. Based on these focal mechanism solutions, we analyze the principal stress azimuth of tectonic stress field in aftershock area. We further adopt the calculating method of mechanical axis tensor (Zhong et al, 2006) to calculate the mean stress tensors σ_1 , σ_2 and σ_3 of whole aftershock area, southern and northern segment of aftershock area from multiple focal mechanism solutions (Table 2). The mean stress tensors of whole aftershock area are that the maximum principal stress axis σ_1 azimuth is 101.3° , i.e. in the WNW direction, the elevation of mechanical axis

is 5.0° , which presents horizontal force. According to the focal mechanism solutions of 38 $M_S \geq 5.0$ aftershocks at southern segment of aftershock area, the maximum principal stress axis σ_1 azimuth is also in WNW direction (292.0°), with the same method, using 14 $M_S \geq 5.0$ aftershocks to calculate the maximum principal stress axis σ_1 azimuth of northern segment of aftershock area, the result is in WNW direction (96.7°). By comparing the results from segmentation areas with whole aftershock area, it can be seen that the principal compressive stress direction of segmentation areas and entire fault zone are almost identical (Figure 2).

Table 2 The results of the average stress tensor in aftershock area ($M_S \geq 5.0$)

Regional name	N	σ_1		σ_2		σ_3	
		Az/°	Pl/°	Az/°	Pl/°	Az/°	Pl/°
Whole aftershock area	52	101.3	5.0	10.5	8.4	221.7	80.2
Northern segment of aftershock area	14	292.0	7.4	22.8	6.1	331.8	80.4
Southern segment of aftershock area	38	96.7	10.3	6.0	4.0	255.0	78.9

According to the focal mechanism solutions of aftershocks, we consider that the nodal plane of NE direction is identical to the strike of aftershock distribution zone, we seek out and analyze the NE direction nodal plane parameters from focal mechanism solutions at southern segment and northern segment of the aftershock area, respectively.

Figure 7a displays the results at southern segment of aftershock area, the NE direction nodal planes with strike between 40° and 70° , dip angle between 40° and 90° , rake angle between 90° and 150° are in the majority, most of earthquakes are dominantly characterized by right-lateral dip-slip reverse faulting, other small part

have the rake angle between 170° and 190° , the faulting presents right-lateral strike-slip.

Figure 7b displays the results at northern segment of aftershock area, the NE direction nodal planes with strike between 70° and 80° , dip angle between 60° and 80° , rake angle between 90° and 130° are in the majority, most of earthquakes are also dominantly characterized by right-lateral dip-slip reverse faulting, the faulting of other small part present right-lateral strike-slip. According to statistical results of source rupture faulting types, the proportion of faulting types at southern to northern segment of aftershock area is identical in the main. It looks that the difference of aftershock faulting types

mostly embody on the diversity of tectonic geometric structure of secondary fault segment, which is controlled by local tectonic stress filed. As shown in Figure 6, the strong aftershocks of the Longmenshan central fault zone (F_1) and Qingchuan (F_6) fault zone show the difference of source faulting types.

Figure 7 The analysis results of NE direction nodal plane from focal mechanism solutions at southern segment (a) and northern segment (b) of the aftershock area.

4 Discussion and conclusions

This article studies spatial distribution of the Wenchuan $M_S8.0$ earthquake sequence on May 12, 2008, the distribution scale of rich aftershocks is longer and the dense spreading presents a narrow strip of NE direction. The depth profiles which are perpendicular to the extension direction of aftershock (NW direction) are given in Figures 3 and 5. At thrust front edge earthquake number is greater in shallow part than in deep part. Aftershocks on profile image distribute like an asymmetry wedge with the characteristic of wide shallow part and narrow deep part. It is related to the force form of the Longmenshan nappe tectonic belt. The Chuanqing block which takes the Longmenshan and Huya tectonic zones as east border compress Sichuan basin. Its moving direction namely 102° shown in Table 2 may be determined according to the slip vector of focal mechanism.

The activities of the stronger aftershocks present obvious segmented spatio-temporal rupture variation character. At southern segment of aftershock area, the stronger aftershocks occurred at initial rupture segment of $M_S8.0$ earthquake along the Longmenshan central fault zone. At the northern segment of aftershock area, the stronger earthquakes occurred along the Longmen-

shan fault zone and through the Qingchuan fault zone including five $M_S6.0$ – 6.4 earthquakes. The largest strong aftershock of the Qingchuan $M_S6.4$ just occurred on this fault zone. The area between northern and southern segment of aftershock area (Figure 6) is M_S6 earthquake gap. According to the image of damaged and rupture process for the Wenchuan earthquake from seismic expert in China and abroad (Chen et al, 2008, Toda et al, 2008), this location also exist “deficit area” and residual “to be going to rupture segment”. We consider that future moderately earthquake may fill up the “to be going to rupture segment” about moderately strong earthquake risk of this segment.

According to the focal mechanism solutions of the Wenchuan earthquake and strong aftershocks, the principal compressive stress azimuth is in WNW direction, which is consistent with the azimuth of the Longmenshan tectonic stress filed. Because aftershocks distribute on different secondary faults, the regional tectonic stress field is very complex.

The research results of focal mechanism show that the strong aftershocks of the Longmenshan central fault zone are mainly characterized by thrust with the component of right-lateral strike slip faulting. The difference of aftershock faulting types mostly embody on different secondary faults. Sources of $M_S8.0$ mainshock and three $M_S5.6$ – 6.1 events on 12th–13th May are on Wenchuan-Yingxiu-Dujiangyan secondary fault. And sources of three $M_S5.6$ – 6.1 events are on Wenchuan-Maoxian secondary fault with NE trending. At the northern segment of narrow and long aftershock zone, that is Qingchuan fault zone on which the faulting of some earthquakes presents strike-slip, especially the largest strong aftershock of May 25 Qingchuan $M_S6.4$ earthquake and July 24 $M_S6.0$ earthquake all present strike-slip faulting. This probably demonstrates that the source mechanical mechanism of prophase and late stronger aftershocks change obviously in aftershock area.

The source fracture spreads successively toward NE direction and secondary faults form echelon pattern. If the late strong aftershocks do not spread sequentially along original direction, but deviate an angle from original direction, focal mechanism would change a lot and form connected extended branch area inside adjacent end, Figure 6 shows the inflection and bifurcation. The stronger aftershock array at NE segment of aftershock area is inconsistent with NE direction array of prophase aftershock. Meantime their focal mechanism solution varied too. This kind of condition is similar to

late manifestations of Batang strong earthquake sequence in 1898, Sichuan (Cheng, 1992; Cheng and Chen, 1994) and other last stage strong earthquake of large earthquake sequence (Zhang et al, 1990). In this sense, the seismic activities of aftershock area gradually become reductive and sparse, based on change of the spatio-temporal variation image and focal mechanism for aftershocks, we estimate that the probability of occurring M_s7 earthquake will decrease in the further, and certainly we remains to further more data and new research results.

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