Crust deformation and the model deduction about generation mechanism of Wenchuan M_S8.0 earthquake

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Keywords: Wenchuan earthquake; earthquake generation mechanism; deformation; leveling; GPS.

SUMMARY

This is a summary on the paper on crust deformation and the model deduction about generation mechanism of Wenchuan M_S8.0 earthquake. The ground rising of the area to the south of the epicenter of Wenchuan China M_S8.0 earthquake obtained from years' mobile leveling, the variation curve of Gengda short leveling across the fault on the epicenter, Pre-earthquake horizontal deformation by GPS observation during two periods in Sichuan Yunnan area, and the vertical and horizontal co-seismic crust movement monitored by GPS in the area around the epicenter are showed in this paper. A model for the generation of intra-plate thrust strong earthquake, shortly called PUTDOWN (Press-Up then Thrust-Down) model, is given by integrated analysis and deduction. And then all the anomalies showed in the figures from different measurement can be understood well coincidently. The result in the paper showed that crust deformation can be monitored precisely with leveling and GPS. And with the accumulation of monitoring data and earthquake samples, some regulation of crust deformation before earthquake occurrence may be found. This may indicate us a significant way to use surveying data for earthquake prevention and disaster reduction.

摘要：

下面是汶川 M_s8.0 地震孕震机理的地壳形变模型推演一文的摘要。本位给出了中国汶川 M_s8.0 地震震中区南面通过流动水准测量得到地面上升的结果，给出了震中区耿达跨断层短水准测量变化的曲线、四川云南地区 GPS 观测得到的震前两期水平形变和震中及周围地区由 GPS 监测给出的同震地壳垂直和水平运动的结果。通过综合分析与推演，给出了一个板内逆冲型强震的孕震模型，称为“先挤压-上升后插入-下降”模型。按此模型，通过不同测量手段由图中给出的所有异常变化可以得到一致性的解释。本文结果显示用水准和 GPS 等手段可以精确监测地壳变形，随着监测资料和地震震例资料的增加，可望找到地震发生前地壳变形的规律。这意味着测量数据在防震减灾工作有着重要的应用途径。

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1 INTRODUCTION

A M_S8.0 earthquake, shocking China and the world, occurred in Wenchuan County, Sichuan province of China on 12th May 2008. It caused disastrous losses both of life and property. This is the first thrust earthquake with magnitude 8.0 that has been recorded detailedly in china since different precursor monitoring methods had been set up. Prior to such a great earthquake we had not found any doubt phenomenon because of the lack of cases and experiences about great thrust earthquake. After all, current earthquake predictions mainly rely on the experiences. Thus, as the great earthquake occurred, by recollecting and studying different data, to research the generation mechanism of the great thrust earthquake and to study the evolution features of crust deformation around the epicenter in the period of the earthquake generation are very important and urgent. With the good chance for understanding the nature, all the data and experiences from the special quake should be full utilized.

2 PRE-EARTHQUAKE UPLIFT SHOWN BY MOBILE LEVELING MEASURE- MENTS

Fig.1 has given the distribution of the vertical deformation in the area near the south part of the epicenter of Wenchuan great earthquake. The basic data are from repeat first grade leveling with the random error less than 0.5mm per km. This is a large mountainous area with complicated environment. Thus all the repeat interval of leveling for different section cannot be accorded with each other. The repeat interval of the leveling for main circle is 27 years in average, in which the shortest is 21 years and the longest is 32 years. So the velocity adjustment method has been used. And then the standard error of the vertical velocity of ground movement is 0.04 mm/km• *a* (Wang Q L, *et a1*., 2008). The reference point is supposed to be the bench mark in Yibin, Sichuan province of China (Bo W J and Yang G H, 2008).

The study area is located in the North-South seismic belt，which is a transitional zone between a relative1y uplifted region in the west and a relatively stable region in the east. The crust here is varied actively and it is difficult to find a stable bench mark around as reference. So it is important to analyze the relative variations between different bench marks. As shown

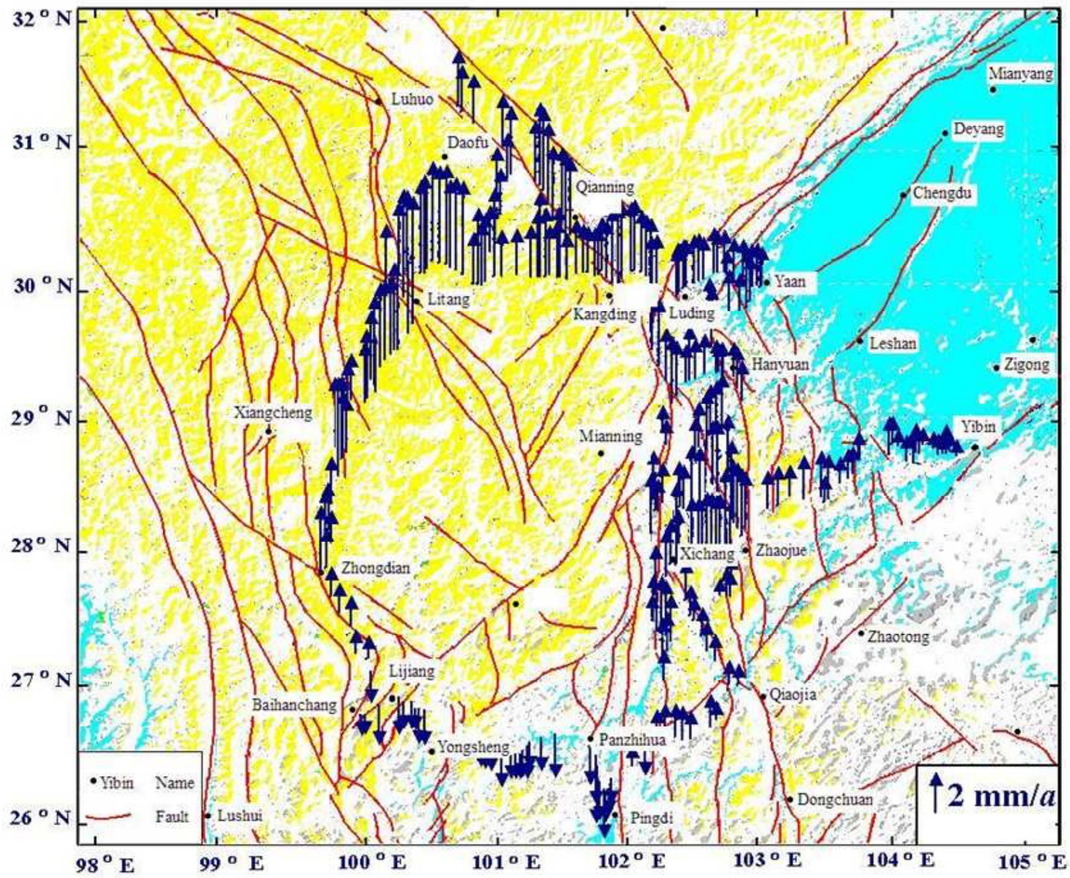
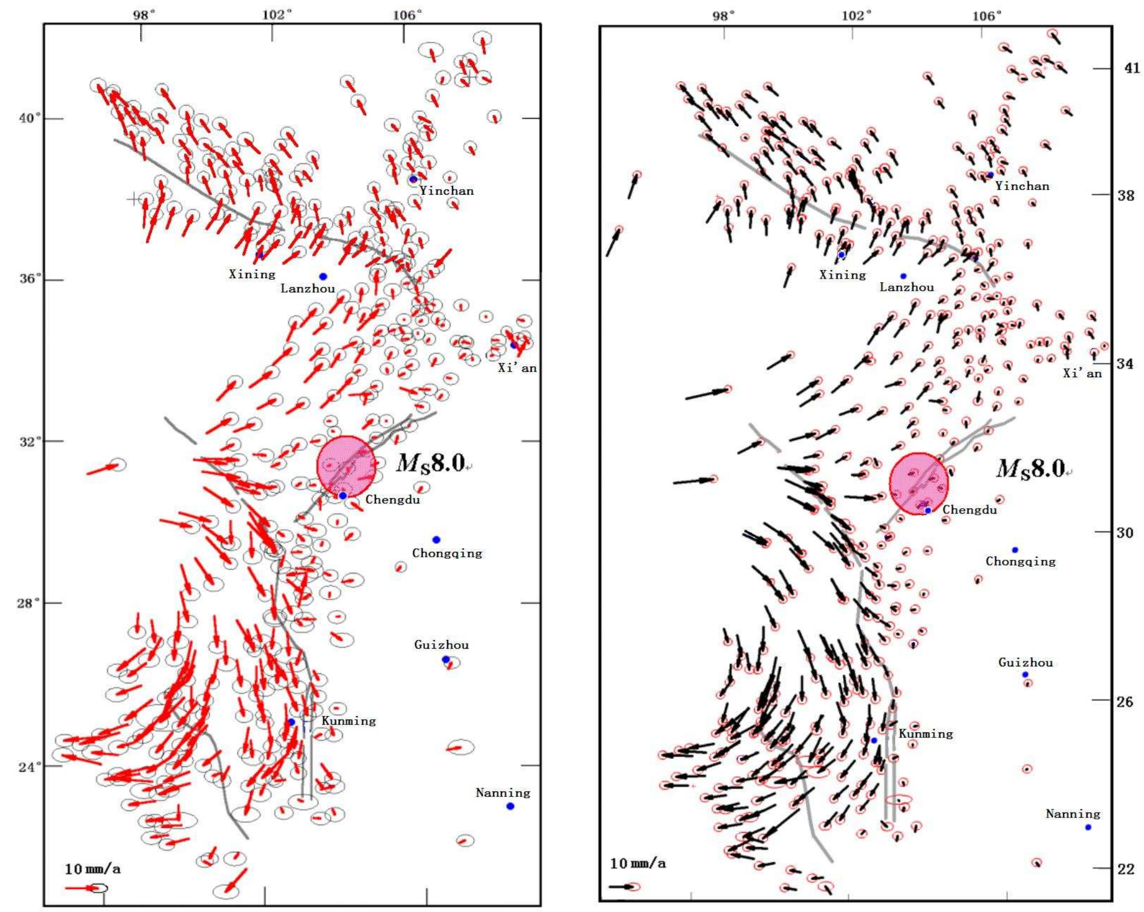


Fig.1 Vertical velocity of bench marks in Yunnan-Sichan area

in figure 1, there was a gradual increase in uplift from south to north. Even the reference point at Yibin was rising about 2 mm per year relatively to Pingdi in the south of this area. The rise around Litang and Qianning amounted to more than 7 mm/a, or a total of almost 200 mm during the average interval of 27 years. Further north is the epicenter, where no leveling data is available, but the trend should have continued. Thus may be assumed that, before the earthquake, the crust was deformed elastically and that the uplift reached 200 mm or more at the epicenter.

3 PRE-EARTHQUAKE HORIZONTAL CRUST DEFORMATION

Based on the No-Net-Rotation principle (Hu X K, et al., 2007; Zhu W Y, et al., 2003), we processed the GPS data in 1999，2001 and 2004 from a mobile regional network in Yunnan-Sichuan region, and obtained horizontal-movement vectors during the two periods in this area(Fig. 2). The result shows that during these periods the western part was moving eastward rapidly while the eastern part remained nearly stationary, which is in accordance with other results (Deng Q D, *et al*, 2002；R. Tapponnier, *et al*, 1982). This implies that Wenchuan area was under a strong west-east compression. We had noticed this feature in 2004 and suspected that a thrust earthquake would occur in Longmenshan fault zone, but did not give a definite conclusion (Bo W J, et a1. 2008). The reason why we had misjudged the seismic situation was



a、 1999—2001 b、2001—2004

Fig.2 Horizontal deformation vectors from mobile GPS net in Yunnan-Sichuan area

the long-term stability of this area(the stable Chengdu basin in the east, and the maximum historical earthquake recorded along Longmenshan fault had a magnitude of only about 6(Jiang D C, 1995; Yu T and He C R, 2000; Zhao H X and Duan Z L, 1996) and a lack of experience about intra-plate strong thrust earthquakes. From figure 2 we can see now that, under the push of India plate, the NE movement of Qinghai-Tibet plateau diverged here toward N, NW and SE, S, respectively. This feature was due to the hindrance of Longmenshan fault zone, which was locked under a strong compression. To correspond with the uplift shown in figure 1, the uplift of ground surface, as a free boundary, in Wenchuan area should presumably have been larger.

4 DEFORMATION SHOWN BY CROSS-FAULT MEASUREMENT

Several short-baseline leveling sites had been set up across Longmenshan faults more than 20 years ago. Authors of this paper have done preliminary study with the leveling data (Bo W J and Zhang L C, 2008.). No remarkable abnormal deformation appeared before the quake at most of these sites. This was understandable because the Longmenshan area rose up broadly under a long-term compression and, most of faults were locked and perpendicular to the stress direction, thus, the deformation could not be detected by the short baseline leveling measurements. However, an anomalous change with large scale was recorded before the earthquake across Wenmao fault at Gengda site(Fig. 3). After analyzing the data, it was pointed out that, although suspicious disturbing sources might have existed, there had been examples in which big-scaled deformation appeared and were accompanied by disturbances before great earthquakes (Bo W J and Zhang L C, 2008; Bo W J, 1992; 2010); it was thus difficult to prove quantitatively that such anomaly was induced only by disturbance. Thus it was permissible to conjecture that the anomalous change at Gengda was possibly induced by certain pre-earthquake fault-creep activity. A concern here is that the change shown in figure 3 implies that the Wenmao fault acted like a normal fault, whereas during the earthquake it showed thrust movement. If the recorded change was a precursor of the quake, how do we give an explanation for this apparent contradiction under a unique generation mechanism? This is one of the questions we attempt to consider later in this paper.

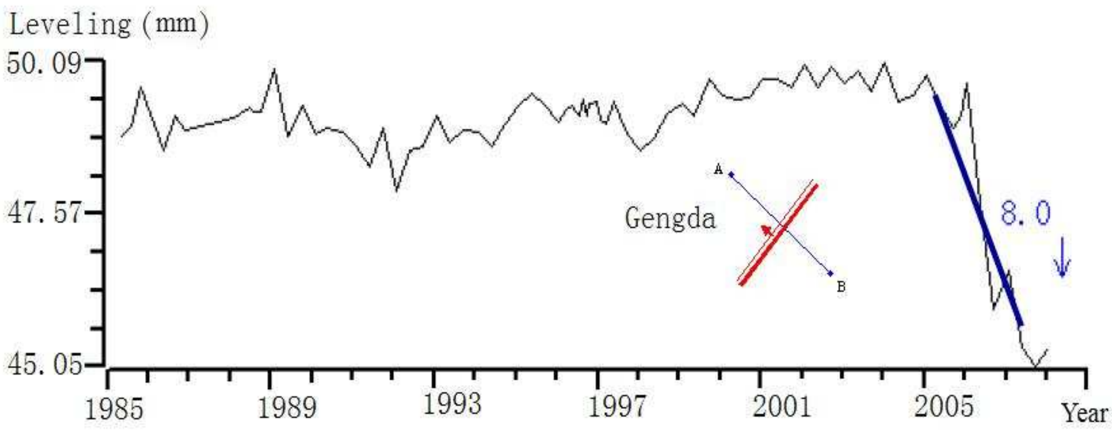


Fig.3 B－A leveling observation curve at Genda station

5 NEAR-FIELD CO-SEISMIC DEFORMATION

After the earthquake, China Earthquake Administration (CEA), Bureau of Surveying and Mapping (BSM) of China and other organizations promptly made some intensified re-measurement with different methods in order to know the size and distribution of co-seismic deformation. The results were announced in early September 2008，in a joint meeting of BSM and CEA(http://www.enorth.com.cn. 2008-09-03 14:09). Figures 4 and 5 show, respectively, the co-seismic horizontal and vertical vectors from GPS observation. From figure 4 we may see a much larger westward movement of the eastern foot-wall side than the eastward movement of the western hanging-wall side, in contrast to the long-term background crust movement in Chinese mainland, which shows a prominent north-eastward movement of Tibet-Qinghai Plateau, From figure 5 we see a large subsidence of as much as 700 mm resulted from the thrust movement that should have caused uplift instead (http://www.enorth.

com.cn. 2008-09-03 14:09). What is the mechanism responsible for these seemingly contradictory observations?

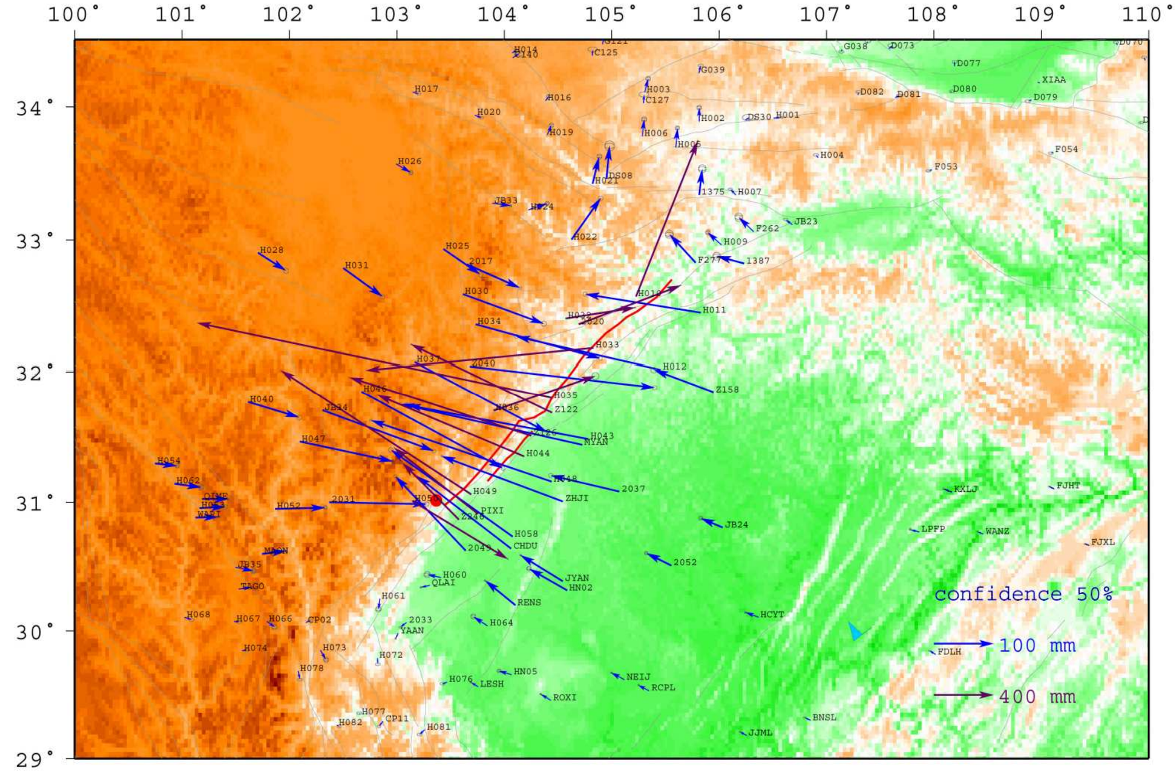


Fig. 4 Co-seismic horizontal vectors of GPS

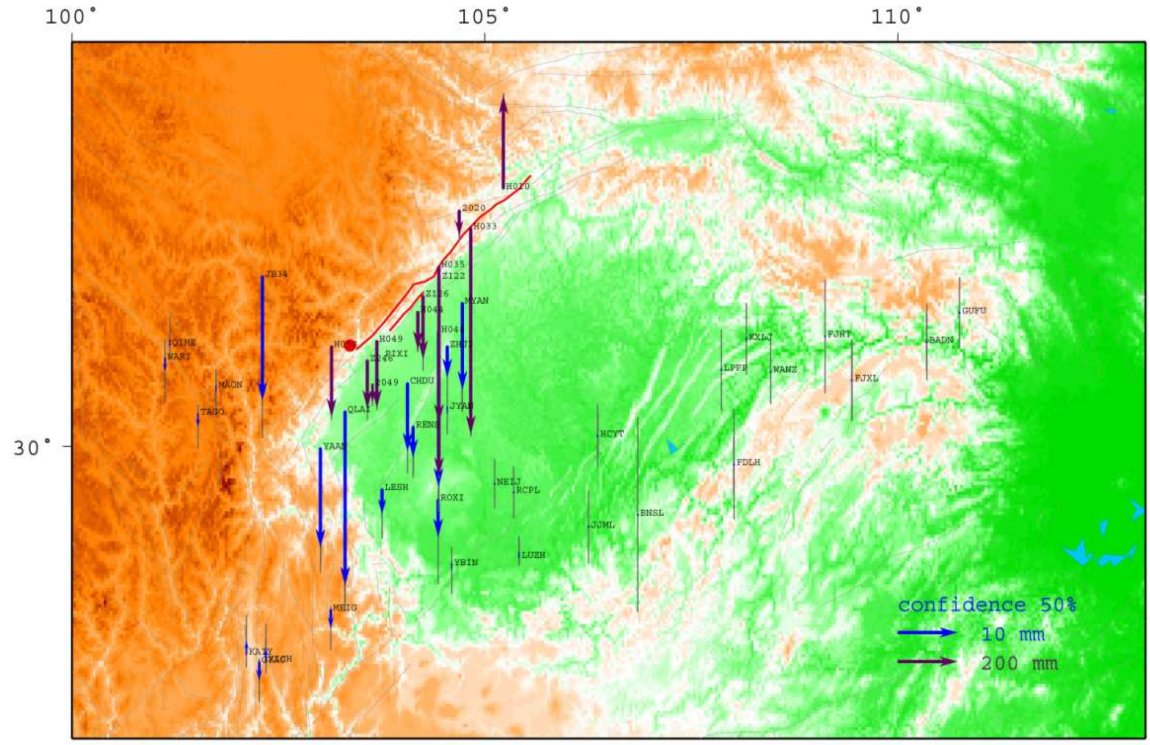
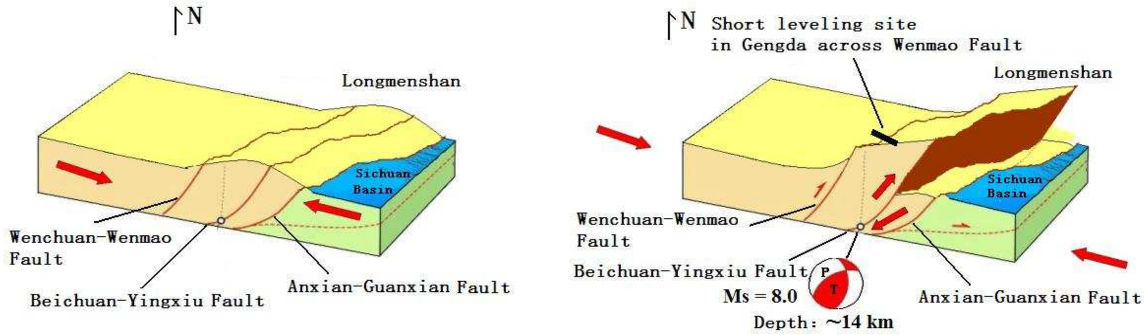


Fig. 5 Co-seismic vertical vectors of GPS

6 A COMPREHENSIVE EXPLANATION OF EARTHQUAKE PREPARATION PROCESS AND THE OBSERVED CRUST DEFORMA-TIONS

There have been many studies on earthquake-generation mechanism, and the result accepted by most people is the elastic rebound theory (Vere-Jones D, 1970; Zhuang J C and Ma L, 1998). In the case of the Wenchuan thrust earthquake, the process involved an uplift caused mainly by a long-term horizontal compression and a sudden rupture in a direction nearly perpendicular to the compression. To give a reasonable and comprehensive explanation for the previously described crust deformation, we propose here a "Press-Up and Thrust-Down" model for this earthquake, and possibly other intra-plate thrust earthquakes(Fig. 6). Figure 6(a) is a sketch of "Press-Up" of the ground around three located faults under long-term horizontal compression, until sufficient elastic energy was accumulated to cause some thrust-type ruptures. The "Press-Up" concept is supported by the results shown in figure 1 and figure 2.



a. Press-Up b. Thrust-Down

Fig.6 "PUTDOWN" model for Wenchuan earthquake generation

Figure 6(b) is a sketch of the co-seismic elastic rebound "Thrust-Down" movement at the Beichuan-Yingxiu fault; it converted horizontal compression to vertical shear strain and thrust movement parallel to the shearing direction. Before the earthquake, as the vertical shear strain was accumulating, thus some kind of fault-creep activity might have tended to occur. However, we do not have a direct evidence for this along Beichuan-Yingxiu fault because of lack of monitoring. In the other hand, this possible activity may explain the pre-earthquake normal-fault movement observed at the short-leveling site at Gengda across the Wenmao fault (Fig. 3). Some scholars attributed the normal-fault movement at Gengda to certain house-building activity near the site(Su Q et al, 2009), and we would disagree. First, in a large-scaled deformation process, there is usually a critical stage immediately before a major rupture, during which according to nonlinear theory the system is very sensitive to even very weak outside disturbance (Bo W J, 1992; Bo W J, 2010); In other words, such rupture might occur sooner or later after a slight disturbance. Secondly, there is no sufficient reason or reliable evidence to show that ordinary house-building activity within tens of meters could have influenced in such remarkable way on a bench mark that had been stable for decades.

Although based on figure 3 alone it is very difficult to reach the right conclusion before the quake, afterward it is not difficult to conclude that the slight disturbance by the house-building activity might have served only as a possible trigger for the observed slip event at the critical stage. Thirdly, the reason that the normal-fault kind of leveling change was regarded by many as being induced by house-building was that it was different from the expected thrust movement like the earthquake. However, according to “Thrust-Down” model presented herein, there is a local squeezed-up zone between Beichuan-Yingxiu fault and Wenmao fault (Fig. 6(b)), so that the large pre-earthquake movement of 4.26 mm could be a result of the squeeze-caused pre-slip. Otherwise, the normal faulting activity should have weakened, disappeared or become thrust in type. Yet in fact, the normal slip increased even to 243.1 mm (Su Q et al, 2009). This observation further shows the existence of a local squeeze-out zone caused by the particular condition in geological structure and stress environment, which required a model more complicated than purely “elastic rebound”.
Sichuan basin belongs to the relative old foot-wall side, and it has always been pulled up passively by the hanging-wall side of the locked fault during the long-term compression. When the up-pulling force exceeded the critical force to cause the rupture of Longmenshan faults, the Wenchuan earthquake occurred, and the up-pulling force disappeared suddenly, resulting in a strong downward rebound for the foot-wall side in the Sichuan basin. Thus the pre-earthquake uplift decreased or disappeared and co-seismic subsidence occurred in the epicenter area near the faults, except some local uplift due to the thrust faulting movement. This subsidence was larger on the foot-wall side, because of the down-thrust action. Thus the co-seismic crust deformation shown in figure 4 and figure 5 may be reasonably explained.

7 DISCUSSION

The“elastic rebound’’model was proposed on the basis of crustal-deformation observation a long time ago, and is accepted widely (Vere-Jones D, 1970; Zhuang J C and Ma L, 1998). The *M*s 8.0 Wenchuan earthquake is a very rare large thrust-type event that occurred in an inland area for which a relatively large set of crustal-deformation data were recorded. The results indicated that the earthquake’s generation was basically in accordance with the “elastic rebound’’mode1. But because of some special structural and stress conditions, the zone between Wenmao and Beiehuan-Yingxiu faults was squeezed out near the epicenter. With the help of the crustal-deformation data recorded before and after the earthquake, we have proposed the “Press-Up and Thrust-Down” model, which may better explain the various complicated phenomena of crustal deformation recorded before and after the quake; it may help us to better recognize the complexity and variety of the development process of earthquakes, provide some new understanding for the crustal-deformation mechanism, and illustrate the existence of diversity among different earthquake occurrences.
Not-being aware of the coming of the great Wenchuan earthquake was a big blow to many of us who hoped to recognize certain regularity in earthquake preparation an d occurrence. Many scholars had the opinion that there was no premonitory information recorded at al1. This study shows, that this is not true. Our problem was that due to the lack of similar experience we did not recognize beforehand the complexity of a great inland thrust earthquake, nor did we know what kind of premonitory signals to expect. This is a critical deficiency of the our

current earthquake-prediction efforts, which are based mainly on experiences. The occurrence of Wenehuan earthquake brought not only regrettable disasters and shocks, but also data and opportunity for study. We should cherish and make full use of these precious data and this rare opportunity.

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BIOGRAPHICAL NOTES

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