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Pre-seismic Deformation in the Seismogenic zone of the Lushan M_S7.0 earthquake detected by GPS observations

XiaoXia Liu[1] ; YanQiang Wu[2] ; ZaiSen Jiang[1]; Wei Zhan[2]; Qiang Li[1]; WenXin Wei[1] ; ZhenYu Zou[1]

1. Key Laboratory of Earthquake Prediction, China Earthquake Administration, Beijing 100036, China;

2. First Crust Monitoring and Application Center, China Earthquake Administration, Tianjin 300180, China

Contact: Xiaoxia Liu (lxxia_0422@163.com)

Abstract

A continuous GPS array across the southern segment of the Longmen Shan fault zone(SSLMSF) recorded the deformation during the process of the Lushan M_S7.0 earthquake that occurred on April 20, 2013.Such data can provide meaningful information regarding the dynamic evolution of crustal deformation in the seismogenic zone. Our studies have shown that the occurrence of the Wenchuan earthquake led to the loading of compressive and sinistral shearing strain on the southern segment of the Maoxian-Wenchuan fault (MWF), whereby the extrusion strain accumulated at a greater rate than before the Wenchuan earthquake. The strain time series in the seismogenic zone revealed that the principal compression strain rates decreased from west to east in the direction of N30° -45° W. Furthermore, the area to the east of Beichuan-Yingxiu fault(BYF) behaved as a zone of compressive deformation with obvious sinistral shearing deformation. The surface strain and the first shearing strain time series decreased with time, while the area to the west of the BYF behaved as a zone of dextral shear deformation that increased with time. Furthermore, the regional deformation field before the Lushan earthquake showed the rate of extrusion strain accumulation in SSLMSF being obviously larger than before the Wenchuan earthquake. Moreover, the sinistral shearing strain accumulated in the area of the southern segment of the MWF. Based on the above analysis, we consider that the eastward movement of the Bayan Har block increased considerably following the Wenchuan earthquake, which enhanced the accumulation of compression strain in the SSLMSF.

Data

We collect about observations from the CMONOC regional stations that are observed from 1999 to 2011, and the figure presents the velocity (Fig.1) referring to Huanan block the estimated with GAMIT/GLOBK software. Furthermore, the GPS continuous stations (Fig. 1b) that cover three principal faults(i.e. MWF BYF, and AGF) of the southern segment of the longmensha fault zone are used in this study.

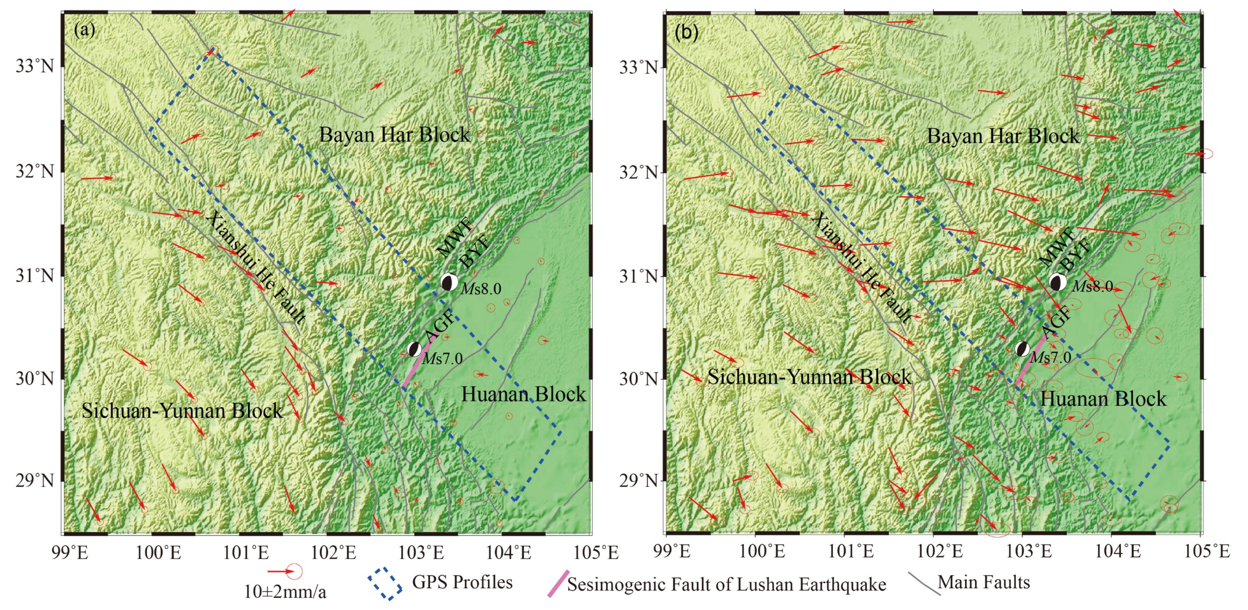

Fig.1 GPS velocity field before the Lushan earthquake referring to Huanan block
(a) Results in 1999-2007; (b) results in 2009-2011

Results of preseismic deformation for Lushan earthquake

Fig.2 shows the dextral shear and extrusion strain accumulation in the southern segment of the Longmen Shan fault zone before Lushan earthquake. During 1999-2007, the crustal shortening rate was 5.0 mm/a (strain rate was about 1.4×10⁻⁸/a) within a range of 350 km to the west of the MWF. During Wenchuan earthquake, the SE displacement in the Hanging Wall of the MWF was about 80 mm with no decrease over the range of 300km which shows no response features of fault dislocation and strain relief movement. Furthermore, the amount of crustal shortening in the fault zone and over a range of 90 km to the east reached at least 100 mm, behaving as continuous deformation. Fig.2d showed the largest dextral shear movement was in the area within 20 km of the fault (amount of displacement reached 79.8 mm), and it behaved similarly to strain release on the hanging wall of the fault. Apart from this, it displayed continuous sinistral shear strain in the area to the east.

Ten continuous GPS stations established by Institute of Earthquake Science, CEA was included during 2009-2011 with high reliability. The extrusion strain accumulation was maintained，especially from the results of the continuous stations with a shortening rate of 5mm/a within the range of 90 km larger than that before Wenchuan earthquake. Fig.2 (f) and (d) show obvious dextral shearing deformation along the southern segment of the MWF at 7.0mm/yr. However, there was sinistral strain accumulation in the area to the east of the fault with a deformation. The above results indicate that the Wenchuan earthquake strengthened the extrusion strain in the southern segment of LMS fault zone.

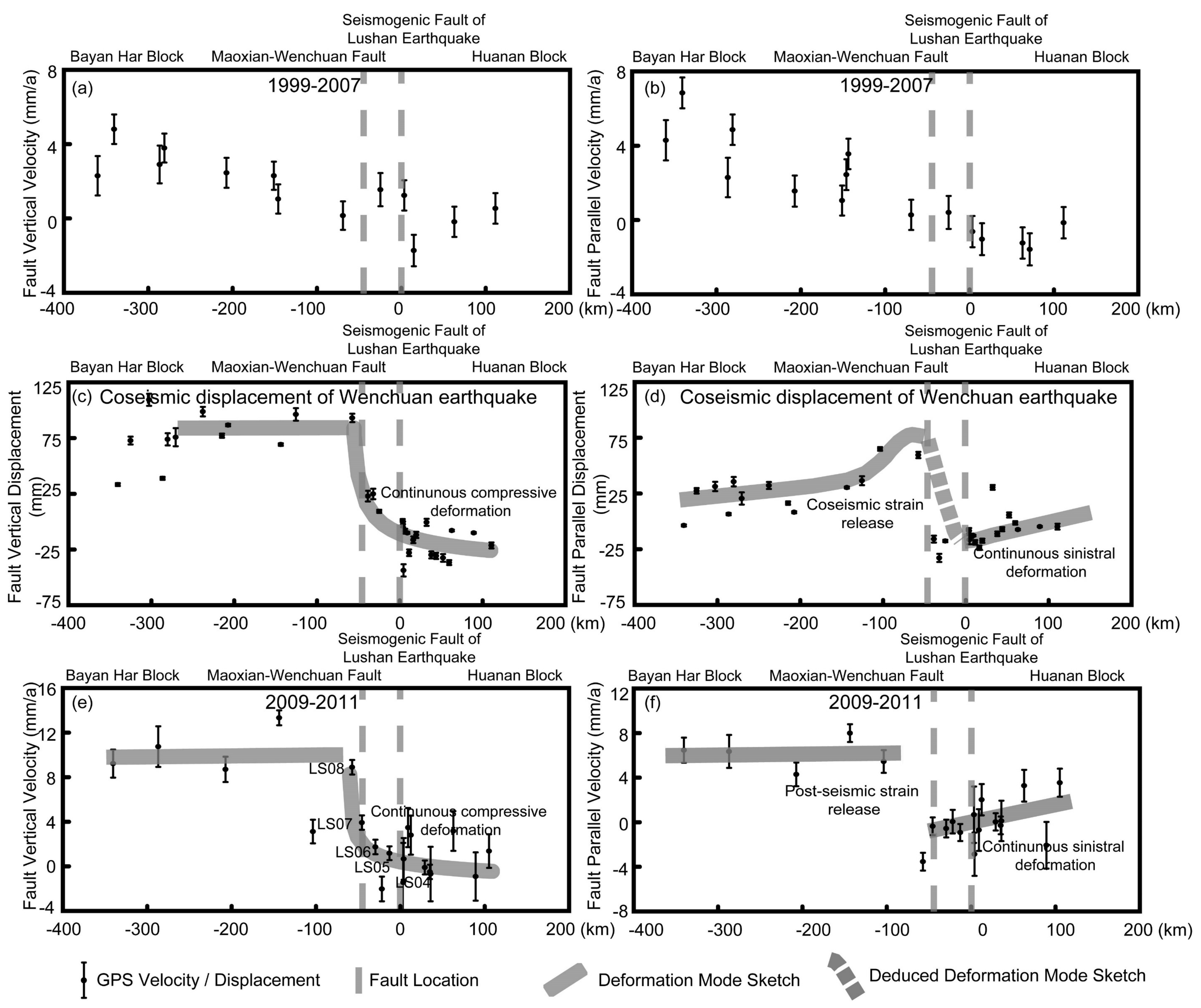

Fig.2 GPS displacement profile results in the SSLMSF.
Conventions: Negative slope indicates extrusion or dextral shear

Time series of GPS cross-fault baselines

Fig.3 shows that all the baseline time series decrease quickly except LS04_LS10, and the shortening rate is about 8–12 mm/a with an average shortening rate in unit length of (7～8)×10⁻⁸/a, which is clearly faster than the rate of 1×10⁻⁸–3×10⁻⁸/a before the Wenchuan earthquake. The time series of baselines LS01_LS03, LS04_LS08and LS04_LS10 clearly decrease nonlinearly with time, and their average annual shortening rates decrease year by year. The shortening rate of baseline LS01_LS03 decreases from 16 mm/a in 2008–2009 to 7 mm/a in 2012–2013, that of baseline LS04_LS08 decreases from 12 mm/a in 2008–2009 to 8 mm/a in 2012–2013, and that of baseline LS04_LS10 decreased from 7 mm/a in 2008–2009 to 1.7mm/a in 2012–2013.

The average shortening rate of baseline LS05_LS06 across the AGF and of LS06_LS07 across the BYF and MWF are both about 1–1.5 mm/a. The average crustal shortening rate per unit length is about 5.3×10⁻⁸–7.8×10⁻⁸/a, and it has decreased year by year since 2010. The time series of baseline LS04_LS05 decreases nonlinearly with an annual shortening rate diminishing from 3.4 to 1.5 mm/a and an average crustal shortening rate per unit length reducing from 6.7×10⁻⁸ to 3.0×10⁻⁸/a.

According to statistical results, if the fault is not totally locked, the variation of cross-fault baselines should be larger than those that are not cross-fault, and the strain rate of small-scale baselines should be larger than large-scale baselines. However, the statistical results for the baselines across the southern segment of the Longmen Shan fault zone reveal the converse.

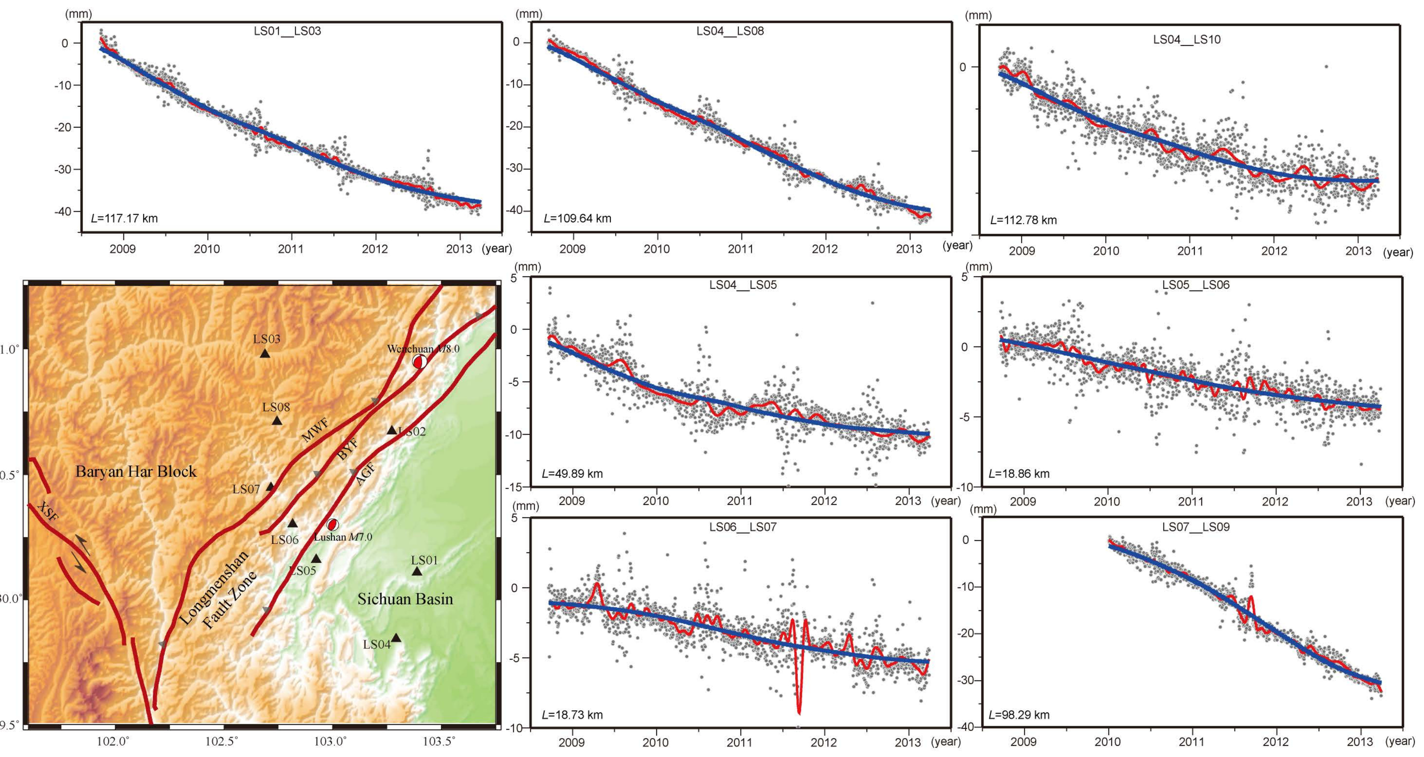

Fig.3 Ten continuous GPS stations and the time series of GPS baselines across main faults of SSLMSF
The ordinates are the variation of baseline length, the gray circles represent the original observations, red lines represent the filtering results of the Least Squares Collocation method, thick blue lines represent the secular trend with the wavelet filter, and the number in lower left corner of each picture is the length of each baseline.

Time series of strain parameters

Fig.4 shows that the principal compressive strain dominates most triangles except for the two formed by LS02, LS03, LS08 and LS09, in which the principal extensional strain rate is larger. Fig.4 also shows that the SSLMSF was mainly dominated by compressive deformation. The principal compressive strain was higher in the area to the west of the MWF than to the east. The principal strain rate was relatively low in the focal region of the Lushan earthquake, and the principal compressive strain increased gradually from east to west in the direction of the principal compressive strain (i.e., about N30° –45° W). Sinistral shearing occurred on the eastern side of the BYF, setting N45° E as the direction of the main fault zone (hereinafter the same), dextral shearing occurred at the northern and southern ends of the western side, and the area formed by LS02, LS08, LS09 and LS07 also underwent sinistral shearing deformation. The principal compressive strain rate increased gradually from 3.5×10⁻⁸/a on the eastern side to 16.9×10⁻⁸/a on the west.

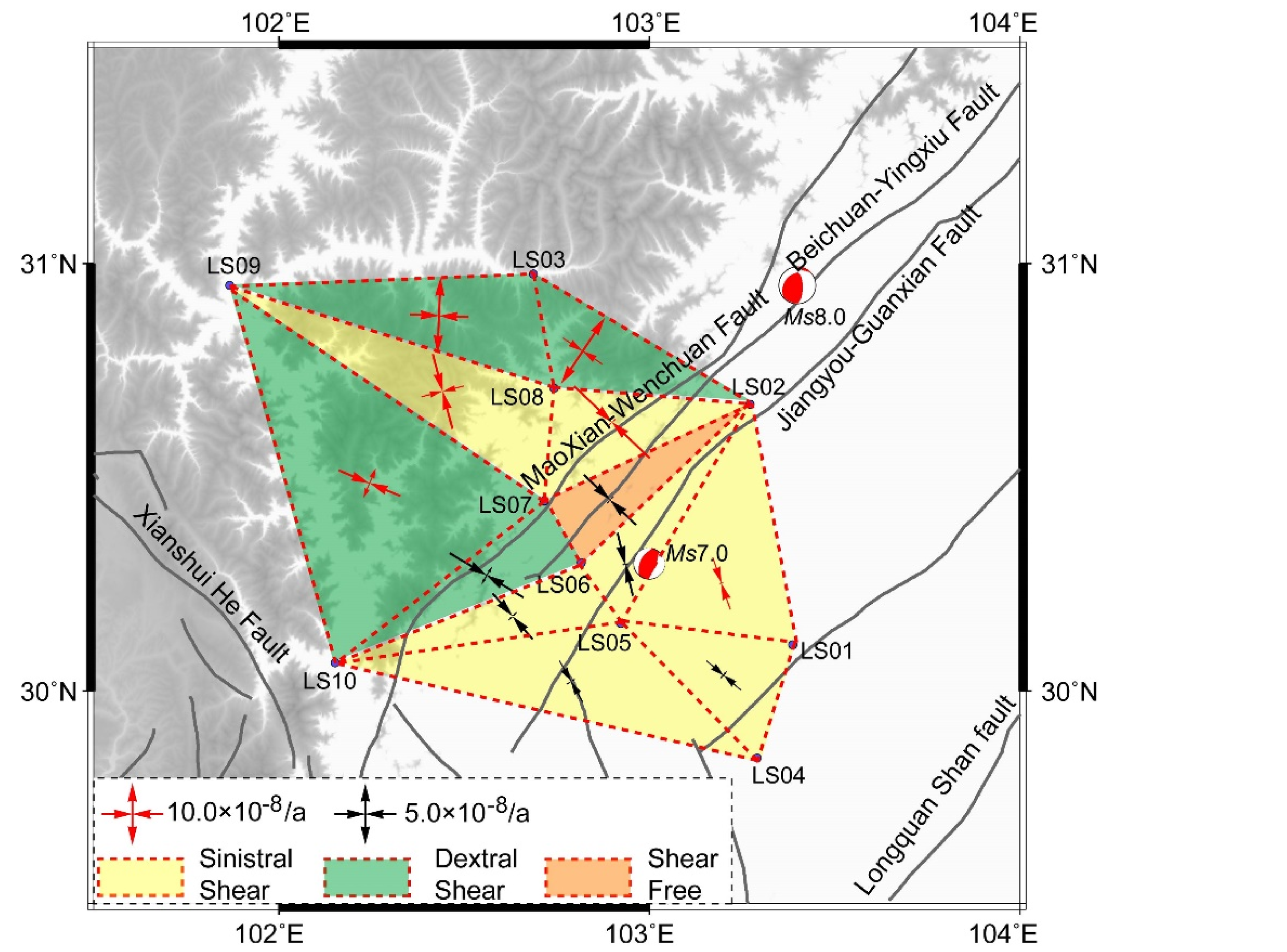

Fig.4 Principal strain rate in the SSLMSF. Triangles enclosed by the red dashes are calculating units of the strain time series and different cover colors represent different shearing features. Annotation: As there are large differences between different triangle strains, two scales are used in Fig.4, indicated by red and black arrows. Arrows pointing toward each other indicate compressive deformation; arrows pointing away from each other indicate extensional deformation.

Summary

The regional GPS deformation field before the Lushan earthquake indicated that the Wenchuan earthquake accelerated the preparation process of the Lushan earthquake.The extrusion component in the SE direction on the southern section of the MWF exhibited features of continuous deformation with an increasing extrusion rate, caused by the Wenchuan earthquake. The coseismic displacement of the Wenchuan earthquake showed that the distribution of the extrusion deformation was continuous in the SSLMSF, whereas features of strain release were apparent in the middle and northern segments, which indicated a lockout state of the SSLMSF in recent. Furthermore, the comparison of different scales in this paper showed that the southern segment of the Longmen Shan fault zone was in a state of strong extrusion strain accumulation.

The time series of GPS cross-fault baselines and strain parameters showed that the eastward movement of the Bayan Har block accelerated the deformation of SSLMSF after the Wenchuan earthquake. However, the internal extrusion rate of the fault was relatively slow, especially in the seismogenic zone of the Lushan earthquake, which revealed a strong strain accumulation feature. All these results indicate the increasing risk of an earthquake.

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