Fault structure and cause analysis of the 2019 Ms6.0 Changning Earthquake in Sichuan, China based on InSAR

Hua Gao[1], Mingsheng Liao[1], Wenbin Xu[2], Xiaoge Liu[2] and Nan Fang[2]

State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan, China

School of Geosciences and Info-Physics, Central South University, Changsha 410083, Hunan, P.R. China.

Email:hua.gao@whu.edu.cn

Abstract

The Changning earthquake is the largest earthquake within 50 km of the area since records. Based on InSAR, we measure the coseismic deformation and build a double fault model of the Changning event. We also analyze the cause of the earthquake in detail.

- **The event caused a maximum deformation of 17.2 cm**
- **The two sub-faults model can explain the non-double-couple character of the Changning event**
- **The salt mining and two M>5 pre-earthquakes may play important roles in advancing the Changning event.**

Introduction

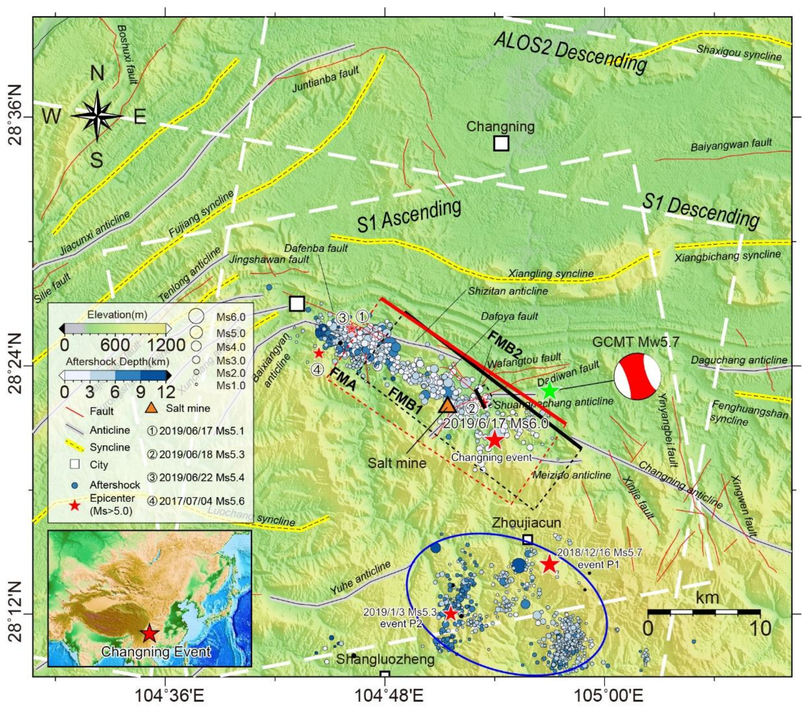

Fig. 1. Geotectonic background and aftershocks distribution of the study area.

On the night of June 17, 2019 (Beijing time), a Ms6.0 earthquake struck Changning county of Sichuan province where is one of China's important shale gas reservoirs. Before this, there were also one Ms5.7 (P1) and one Ms5.3 (P2) earthquake in the region. There are some shale gas wells and injection wells for salt mining around the earthquake area. The event shows obvious non-double coupling components, which may be caused by multi fault rupture (Liu and Zahradník, 2020).

Co-seismic deformation field

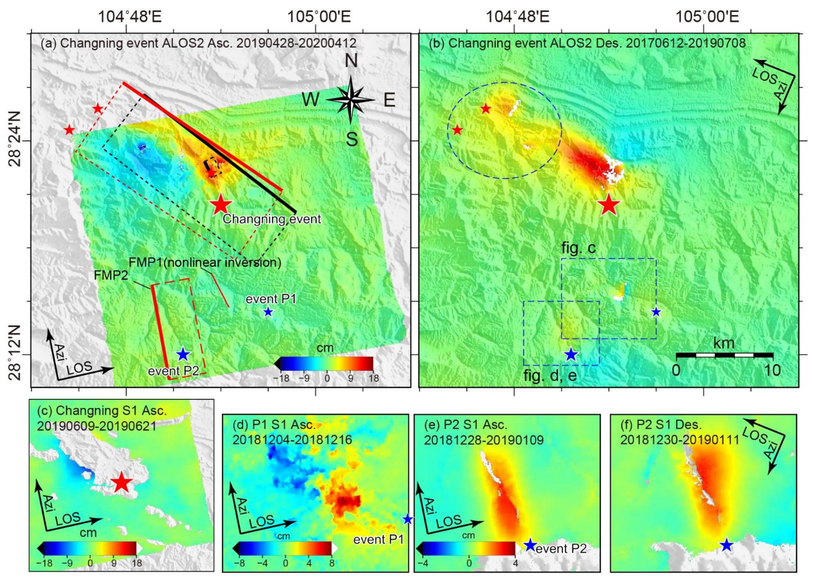

Fig. 2. The Co-seismic deformation fields of Changning, P1 and P2 events

The Changning event caused a deformation region of about 150 km^2. The deformation field extends northwest from the epicenter. The deformation direction is mainly toward satellite with a maximum of 17.2 cm (ALOS2 descending). The maximum deformation of P1 and P2 is 8.2 (S1 ascending) and 3.2 (S1 descending)cm, respectively.

Fault model of the Changning earthquake

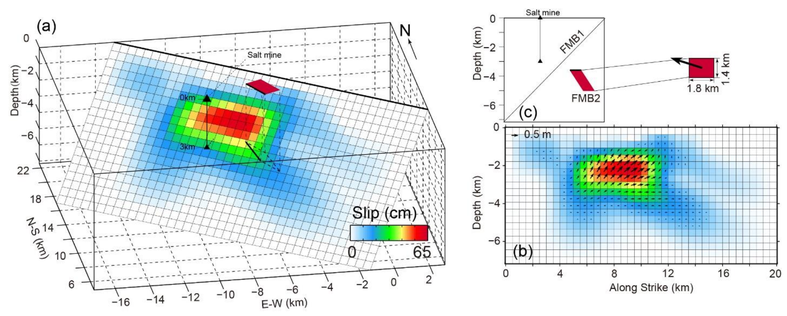

Fig. 3. (a) Three-dimensional and (b) two-dimensional slip models of the Changning event based on FMB. (c) Side view of figure a. FMB2 is located behind FMB1. Each small rectangle in the figures represents a slip unit. The color of the unit represents the slip value and the arrow represents the slip direction. Black triangles indicate the locations of the salt mine and well.

We obtain two fault models for the Changning event. The single fault model (FMA) and the two faults model. The two faults model can explain the large non-double coupling characteristics of the Changning earthquake. The final model shows that the Changning event was caused by a small fault (FMB2) and a big fault (FMB1) with a left-lateral strike and thrust slip. The strike of the main fault is 128° with a dip angle of 46°. The main slip area of FMB1 (slip > 0.2 m) is ~25 km2 at depth of 1-4 km. The slip center is at ~2.5 km depth with a maximum slip of 0.61 m. FMB2 is a uniform model because we do not expand and subdivide it. The dip angle of FMB2 is slightly larger than FMB1.

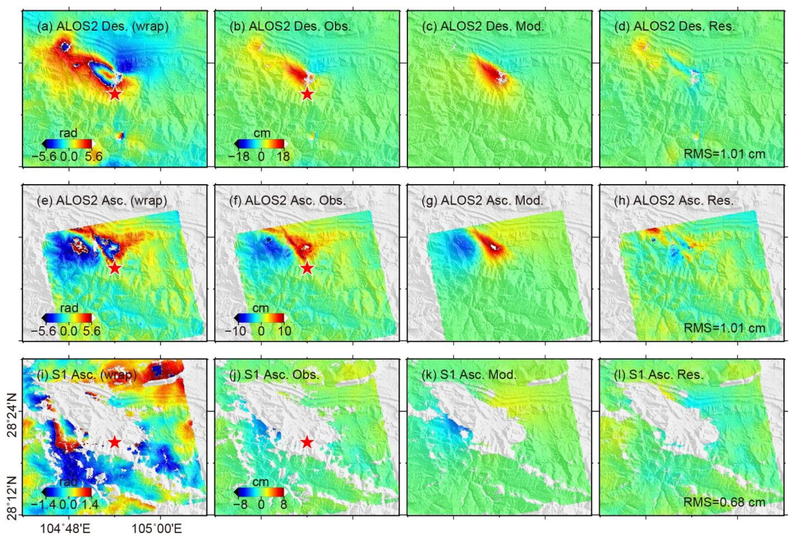

Fig. 4. The observed phase of wrapped (a, e, i), observed deformation (b, f, j), forward deformation (c, g, k), and residuals (d, h, l) of the Changning event based on FMB. Figs. a, e and i are both re-wrapped the unwrapped phase with a period of 2.8 cm.

The left-lateral and thrust slip component obtained by joint inversion is 1.64 m and 0.52 m, corresponding to the rake of 18°. The total seismic moment obtained by inversion is 6.68×10^{17} Nm, corresponding to Mw5.85. The model is roughly consistent with the double slip model provided by seismology. This provides the geodetic evidence for the double slip of the Changning event.

Cause analysis of the Changning earthquake

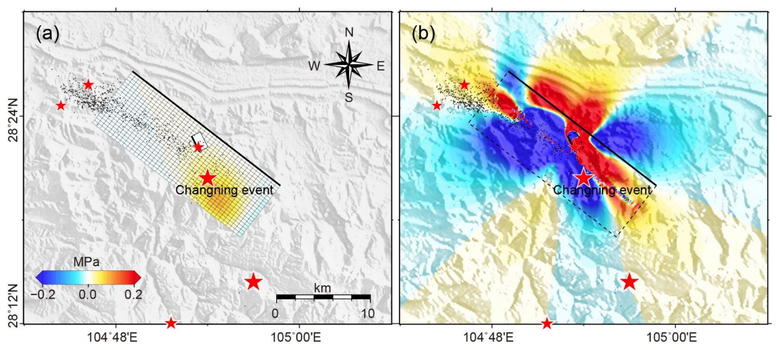

Fig. 5. The Coulomb stress changes. (a) The stress changes on the fault of the Changning event after P1 and P2. (b) The stress changes in the earthquake area after the Changning event. The reference depth is 3.2 km (the average depth of all aftershocks). The small black dots are aftershocks from Yi et al. (2019) and the small stars are the epicenters of Ms > 5.0 aftershock (CENC).

(1) Stress change. We calculate the Coulomb stress change on FMB after P1 and P2 (Fig. 5a). Overall, the stress change on FMB is main positive, with a maximum of 0.09 MPa. The stress increasing mainly occurred in the southeast of FMB1, near P1. The stress on FMB2 is almost unchanged. The results can at least prove that the P1 and P2 promote the occurrence of the Changning event.

(2) Hydraulic fracturing (HF). The affecting areas of the seismic activity induced by HF or water injection usually within 10 km of the operation site (Bao and Eaton, 2016). Therefore, shale gas fracturing and mining operations in the southern region are unlikely to affect the Changning event because most of the shale gas wells in the Changning area are located 15 km south of the epicenter.

(3) Salt mining. Until June 2019, the water loss accumulation in this area is about 1.62×10^6 m^3 based on salt mining. However, inducing an Mw5.85 earthquake requires about 2.2×10^7 m^3, which is far greater than the operation capacity of salt mines near the Changning earthquake.

Therefore, in the absence of clear evidence, we cannot arbitrarily believe that the Changning earthquake must be related to HF. We believe that the Changning event was caused by the salt mine water injection and the stress changes from P1 and P2.

Conclusions

The Changning earthquake caused a deformation area of about 150 km2 with a maximum of 17.2 cm (LOS) in the northwest of the epicenter. The FMB with two sub-faults can explain the non-double-couple character of the Changning event. There are left-lateral slip and thrust components in the Changning event. There is no direct evidence that the Changning earthquake related to HF. We believe that the Changning earthquake may be advanced by human salt mining activities, but the P1 and P2 may also play an important role in advancing the Changning earthquake.

Main References

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