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Quantitative Drawing of Seismic Calm Images Before the Main Earthquake in Wenchuan Earthquake Sequence

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Abstract: Using zmap grid technology, the temporal and spatial changes of Wenchuan earthquake, Lushan earthquake and Jiuzhaigou earthquake aftershock area and extended aftershock area were calculated. It was found that Lushan earthquake was calm before and after the earthquake, but the degree of calm was low. Jiuzhaigou is located in the Coulomb stress shadow area, and there was remarkable earthquake calm before the earthquake, which may be related to the self-excitation of small earthquakes in the extended aftershock area outside the aftershock area. In addition, the Lushan earthquake also played a certain unlocking role in Jiuzhaigou, because the change of seismic activity rate in the extended aftershock area of Jiuzhaigou after the Lusha n earthquake showed a calm increase but a regional decrease.

Keywords: Change of seismic activity rate, Earthquake calm, Stress triggering, Self-triggering.

1. Introduction

Earthquake quiescence is put forward as an earthquake precursor, which is defined as the decrease of the average earthquake velocity in a volume compared with the background velocity [1]. Only when each magnitude decreases can it be considered as earthquake calm, thus avoiding the interference of man-made phenomena. This is achieved by the grid technology of ZMAP software, and its significance is given. Clear cases of this relatively calm earthquake prediction are the Landes earthquake and the Great Bear earthquake. Around the focal volumes of the two earthquakes, the seismic activity rate dropped significantly before the earthquake, with the former dropping by 75% and the latter dropping by 100% [1]. Before the 8.1 Iquiquedizhen earthquake in northern Chile, a seismic activity ring [2] was formed around the quiet zone, similar to Mogi's doughnut [3]. The mechanism of earthquake calming has been proposed [4], which mainly involves dilatancy hardening and slip weakening.

The Wenchuan earthquake occurred on the Longmenshan fault, which is located in the Bayan Kara block of the Qinghai-Tibet Plateau. It was squeezed and collided by the Eurasian continent and the Indo-Australian plate, and rotated in the southeast direction. Even though the sliding rate was not high, the accumulated stress was great. Lushan earthquake has been in the strong trigger zone of 20Mpa five years after Wenchuan earthquake. After Wenchuan earthquake and before Lushan earthquake, there were 19 earthquakes with magnitude above 5. So, did the Coulomb stress caused by Wenchuan main earthquake trigger Lushan earthquake or did these medium-sized earthquakes unlock Lushan earthquake? Also more puzzling is the Jiuzhaigou earthquake, which is located in the Huya fault and is left-handed strike-slip, while the Wenchuan earthquake is a thrust mechanism. From a distance, the Jiuzhaigou earthquake is not in the aftershock zone of the Wenchuan earthquake and is almost perpendicular to the Longmenshan fault. If only the conventional trigger threshold of 0.02bar is considered to trigger the earthquake, the Wenchuan earthquake can suppress Jiuzhaigou earthquake by 20Mpa. There are different opinions on whether Jiuzhaigou earthquake was triggered by Wenchuan earthquake, and a few people think that Wenchuan earthquake has a triggering effect on Jiuzhaigou [5, 6]. Because the change of seismic activity represents a weak stress change, we discuss how these two earthquakes occurred from the change of seismic activity before and after the main earthquake.

After briefly introducing the grid analysis strategy of zmap in the second section, this method is applied to the aftershock area and extended aftershock area of three main earthquakes in Wenchuan earthquake sequence in the third section. Among them, the diameter of the aftershock area of Wenchuan earthquake has only expanded by 20km, and the diameter of other aftershock areas has doubled respectively. Section 4 discusses in detail whether the occurrence of earthquake calm leads to the inevitable trigger of Lushan earthquake and the potential trigger of Jiuzhaigou earthquake, even though it is located in such a strong Coulomb stress shadow area.

2. Research methods and data

2.1. Research Methods

Wiemer & Wyss [1] gave a detailed gridding technique for drawing earthquake calm, and only gave a simple summary here. There are two functions to calculate the change of seismic activity rate. One is AS function, which constructs a grid approximately equal to the longitude distance between epicenters, and then calculates the cumulative curve of the nearest N earthquakes at grid nodes. Then, the seismic activity rate in the window with duration of Tw is compared with the background rate of declustering, and the significance test is given. The formula of the AS function is:

$$z(t) = (R_1 - R_2)/(\sigma_1^2/n_1 + \sigma_2^2/n_2)^{1/2} \tag{1}$$

Where R_1 is the average rate of the first period (from t_0 to t), R_2 is the average rate of the second period (from t to t_e), and the variances are S_1 and S_2 respectively, where t is the "current" time ($t_0<t<t_e$).

Z-values are viewed by time slicing frame by frame to identify anomalies. This function is sensitive to the abnormal value at the end of the data, but the detection result is not ideal if there is other abnormal activity during the data period. LTA function is to compare the seismic activity rate within the window with the total rate of removing the time window, so multiple anomalies can be detected. So we use LAT function in this paper. Samples n1 and n2 with constant number of events are randomly selected, and their significance is judged by standard deviation Z test. This method is applied to the aftershock area and extended aftershock area of three main earthquakes, and then the seismic activity changes of Lushan earthquake and Jiuzhaigou earthquake in strong trigger area and strong shadow area are investigated in order to find the relationship between them.

2.2. Research Data

The analysis of earthquake calm needs the homogeneous earthquake catalog, and determines the optimal starting time and the minimum complete magnitude. The Wenchuan earthquake sequence since May 2008 is a remarkable event in Longmenshan fault zone in recent years. The "China Digital Seismic Observation Network" was officially put into use in April 2008, and the observation stations were encrypted after October 2008. On January 1, 2009, the unified cataloging of the national seismic network and the regional seismic network was realized, which made the complete magnitude of the subsequent earthquakes increase rapidly, and the occurrence of Lushan earthquake and Jiuzhaigou earthquake could be comprehensively analyzed. Because it takes nearly 10 years of background seismic activity information before a target event, 429,679 earthquakes with a depth of 50 kilometers and a magnitude of 0.1-7.2 were obtained from the Center of China Seismological Network from January 11, 1983 to December 7, 2025, and the complete magnitude decreased to 3.5. The upper left of Figure 1 shows the seismic activity of Wenchuan-Lushan-Jiuzhaigou from 1983 to 2025.

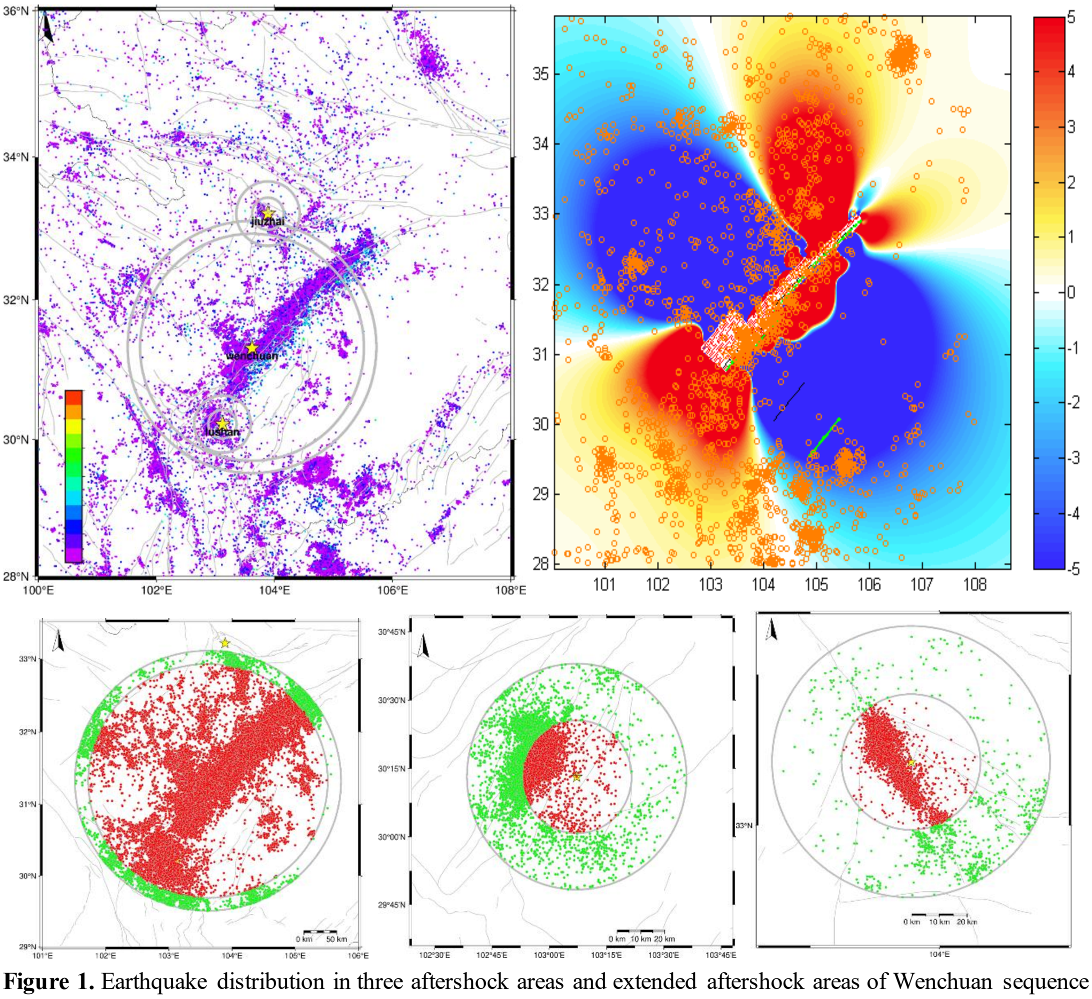

Figure 1. Earthquake distribution in three aftershock areas and extended aftershock areas of Wenchuan sequence

The upper left panel shows the structure and seismic activity distribution of the whole study area. The upper right panel is the sliding model of Wenchuan earthquake obtained by SCRMOD model library and the Coulomb stress calculated by COULOMB3.3 software. In Figure 1, from left to right, the source areas of Wenchuan earthquake, Lushan earthquake and Jiuzhaigou earthquake are selected in turn. The inner circle is the aftershock area and the outer circle is the aftershock extension area, which are divided by gray circles respectively. The red dot represents the earthquake in the aftershock area, and the green dot represents the earthquake in the extended aftershock area. The aftershock area of Wenchuan earthquake is 180km in diameter and 200km after expansion. The aftershock area of Lushan earthquake is 46 kilometers in diameter, which is twice as large as the other earthquake areas, and just located in the aftershock area of Wenchuan. The aftershock zone in Jiuzhaigou is 50km in diameter and the extended aftershock zone is 100km in diameter.

3. Results and Analysis

It is advisable to study these three earthquakes separately. Obviously, Lushan earthquake is located in the aftershock area of Wenchuan earthquake. Considering the nature of Coulomb stress trigger, Lushan earthquake is obviously stimulated by Wenchuan main earthquake and Wenchuan aftershock. We pay special attention to how the Jiuzhaigou earthquake happened.

3.1. Wenchuan Aftershock Area and Extension Area

Figure 2 shows the temporal and spatial Z-value changes of seismic activity rate before and after the Wenchuan earthquake in the aftershock area. The LTA function clearly shows that there was a remarkable calm one year before the Wenchuan earthquake, and the z value reached (-5), which is consistent with Wiemer's finding that the abnormal calm before the Great Bear earthquake lasted for 1.6 years when analyzing the LANDERS earthquake sequence, although the obvious rate decline before the Landers earthquake began 4.5 years before the main earthquake.

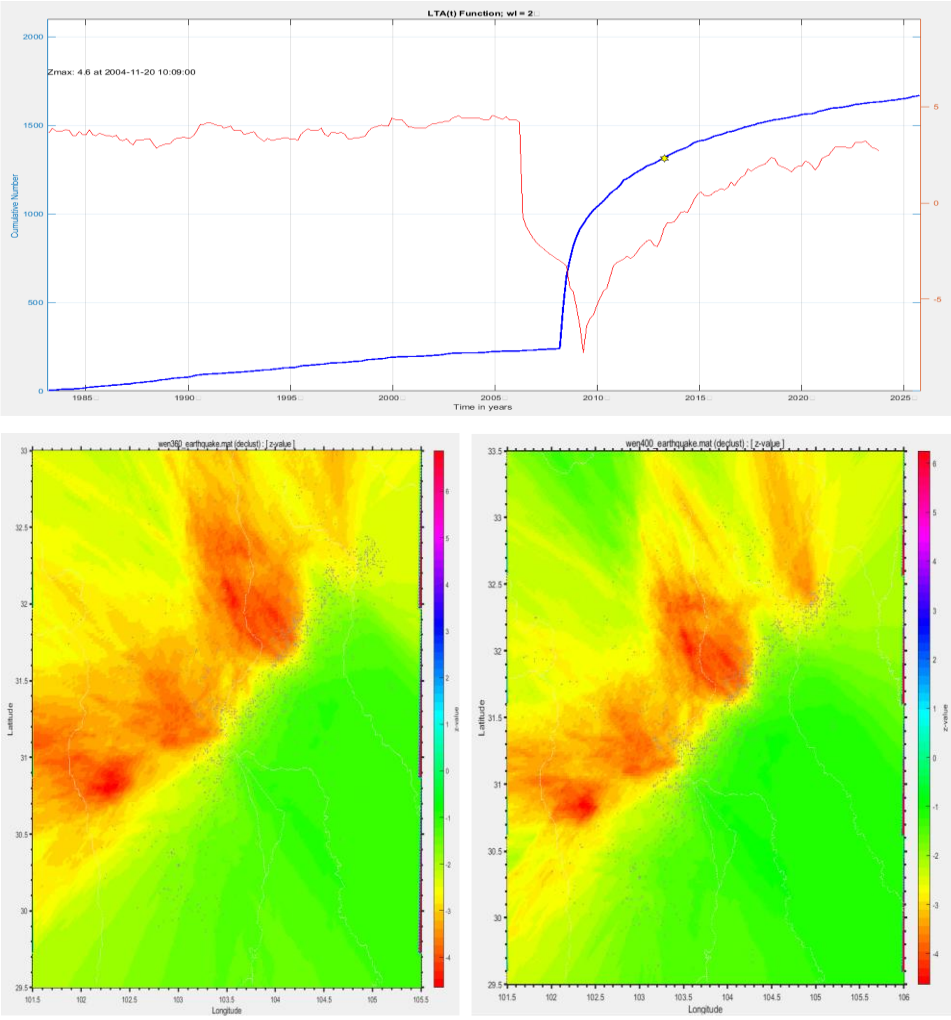

Figure 2. Temporal Z-value changes in Wenchuan aftershock area and spatial Z-value changes in aftershock and extended aftershock area

The above panel shows the temporal Z-value change of the aftershock area, and the lower left panel and the lower right panel show the spatial Z-value change of Wenchuan aftershock area and extended aftershock area respectively.

3.2. Lushan Aftershock Area and Extension Area

The LTA function clearly shows the significant rate change of seismic activity in Lushan aftershock area on August 28, 2010, and the Z value reached 7.7, which was remarkably calm until the main earthquake occurred. Although Lushan earthquake was in the trigger area of Wenchuan earthquake, the seismic activity decreased obviously, and increased obviously after Lushan earthquake, as shown in Figure 3. The spatial variation of z value shows that there is an obvious rate increase on the northwest side, especially on the northwest side.

In the extended aftershock area, the spatial Z-value changes, except for the obvious seismic activity on the west side of Lushan earthquake, and the main earthquake area of Lushan is obviously calm. The acceleration zone on the west side is surrounded by moderate seismic activity. From the trend of activity, it is reasonable to speculate that Lushan earthquake has a certain triggering effect on Jiuzhaigou earthquake.

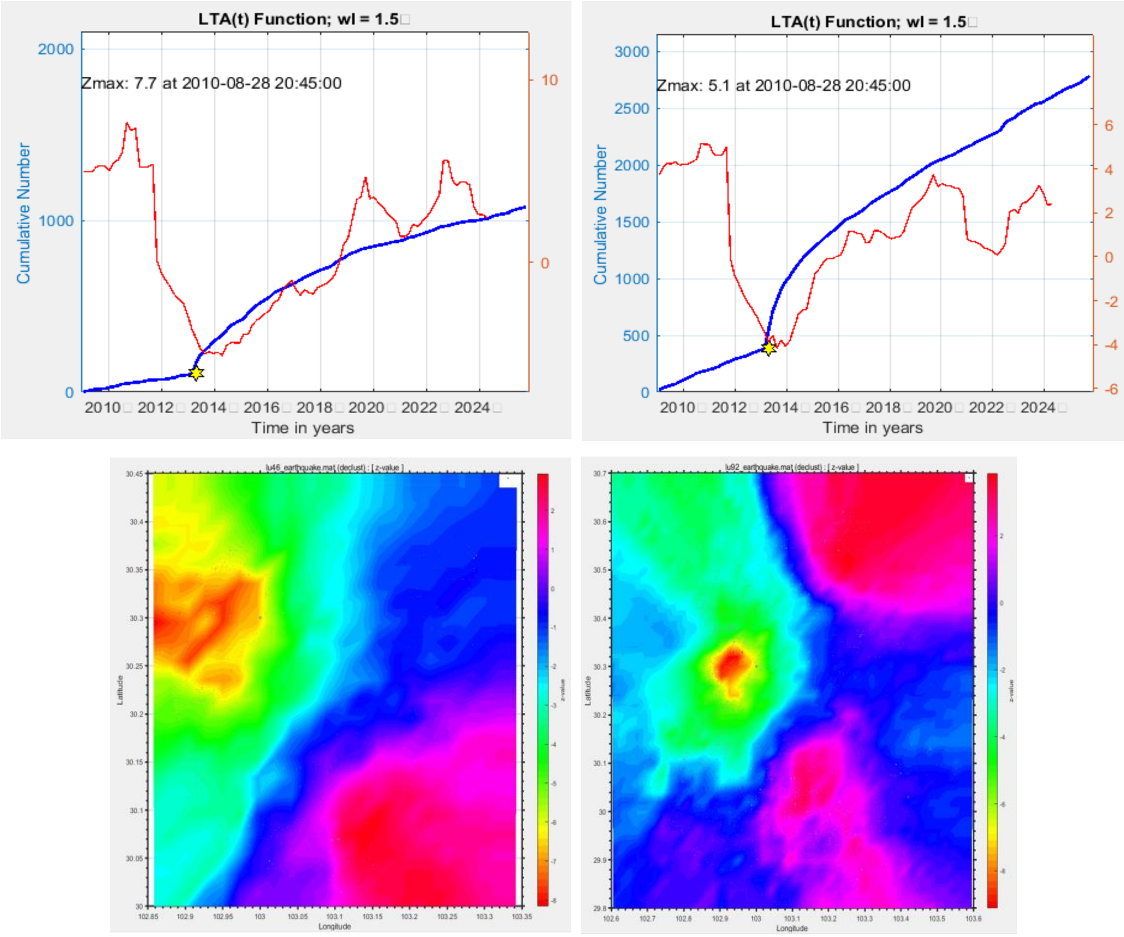

Figure 3. Time Z-value changes in Lushan aftershock area and spatial Z-value changes in aftershock and extended aftershock area

The upper panel shows the temporal Z-value changes of the aftershock area and the extended aftershock area, and the lower panel shows the spatial Z-value changes of the Wenchuan aftershock area and the extended aftershock area respectively.

3.3. Jiuzhaigou Aftershock Area and Extended Aftershock Area

Considering the possible triggering effect of Lushan earthquake on Jiuzhaigou earthquake, we divide Lushan earthquake and Jiuzhaigou earthquake into two periods when analyzing the change of spatial Z value.

Figure 4 shows that the seismic activity of Jiuzhaigou earthquake fluctuated slightly after Lushan earthquake, and it declined rapidly at the end of 2015. The change of seismic activity in Jiuzhaigou is divided into two time periods by Lushan earthquake. The spatial change of Z value shows that the second stage is obviously calm compared with the first stage, and the standard deviation is from 4 to 6. For the extended aftershock area of Jiuzhaigou, the LTA function was in a remarkably calm state before the Jiuzhaigou earthquake, and the z value reached the highest value of 7.6. Referring to the time division of Jiuzhaigou aftershock area, the spatial change of Z value is also divided into two sections with Lushan earthquake as the boundary. Compared with the changes of spatial Z value in the two stages, it is found that the spatial Z value range in the second stage is narrowed, but the calm is strengthened.

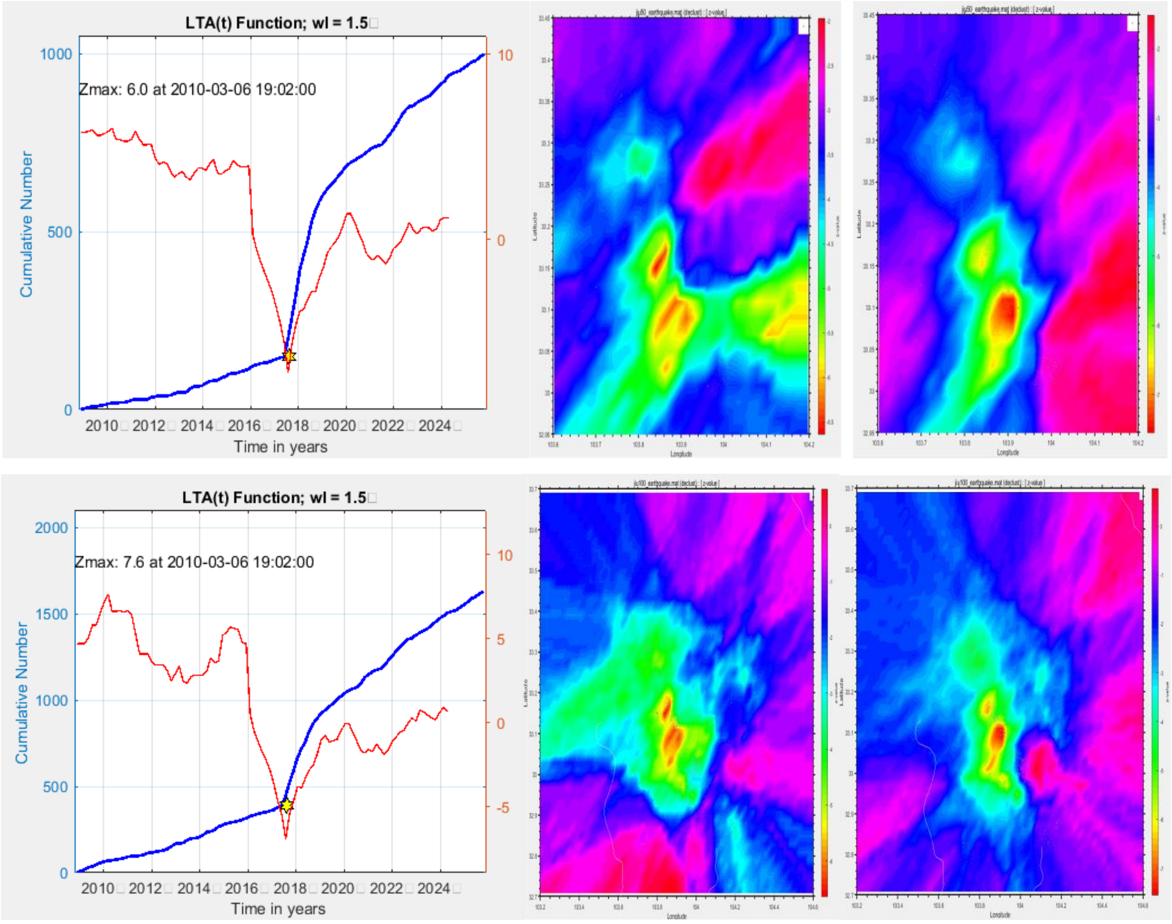

Figure 4. Time Z-value change and space Z-value change in Jiuzhaigou aftershock area and extended aftershock area

The upper panel shows the temporal Z-value changes in the aftershock area and the spatial Z-value changes in different stages. The lower panel is the time z-value change and space z-value change of the extended aftershock area.

4. Discussion and Conclusion

The three aftershock areas all showed the occurrence of calm before the earthquake, especially in the Jiuzhaigou earthquake source area after the Lushan earthquake.

Weak seismic activity is sensitive to the static stress of a few tenths of bar, which exceeds the results given by geodetic survey. Where Coulomb stress changes are insensitive, the keen capture of seismic activity changes can make up for this gap. In particular, the calculation of Coulomb stress involves too much uncertainty [7, 8].

The degree of calm before the three main earthquakes in Wenchuan sequence is different, but they all show the adjustment of stress before the main earthquake, especially the Jiuzhaigou earthquake is under the stress shadow suppression of 20Mpa, which is not difficult to understand. However, the Lushan earthquake further enhanced this calm, but the calm area narrowed, suggesting that the stress field was partially adjusted, which eventually led to the Jiuzhaigou earthquake.

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