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# Stress interactions between normal faults and adjacent strike-slip faults of 1997 Jiashi earthquake swarm

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**During a 4-month period starting from 21 January, 1997, an earthquake swarm of seven major events ($M_s$≥6.0) struck the Jiashi region at the northwestern corner of the Tarim Basin in Xinjiang, China. Previous relocation studies suggested that these strong earthquakes had occurred along at least two parallel rupture zones. According to the relocated hypocenters and focal mechanisms of the events, we have constructed fault models for these seven earthquakes to calculate the Coulomb stress changes produced by each of these events. Furthermore, we extended our model calculations to include an adjacent 1996 $M_s$=6.9 Artushi earthquake, which occurred one year before the Jiashi earthquake swarm. Our calculations show that the Coulomb stress change caused by the preceding events was around 0.05 MPa at the hypocenter of the 4th event, and higher than 0.08 MPa at the hypocenters of the 2nd, 3rd, 5th and 6th events. Our results reveal a Coulomb stress interactive cycle of earthquake triggering between two adjacent normal and strike-slip faults.**

Jiashi earthquake swarm, normal fault, strike-slip fault, Coulomb stress change, earthquake triggering

The 1997 Jiashi earthquake swarm occurred at the west end of the collision zone between India and Eurasia plates, where the Pamir syntaxis, South Tianshan folding belt, and Tarim Basin block join each other. The continuous north-south convergence which caused crustal shortening of more than one thousand kilometers from Tibet Plateau to Tianshan Mountains has also resulted in frequent large earthquakes in this area[1−5]. Geological studies show that this conjunction area consists of the Maigaiti slop zone, the Kashi depression on the west side of the Tarim Basin and Yishilakekalawuer-Kepingtage thrust zone, and the Mushi-Kashi-Artushi thrust and fold system on the south side of Cenozoic orogene of South Tianshan[6]. Previous studies of master-event relocation[7] and 3D crustal structure of S-wave velocity[8] show that the hypocenters of the 1997 Jiashi earthquakes are mainly located at the transition boundary between the Maigaiti slop zone and Kashi depression where the thickness of Cenozoic sediments exceeds 6000 m and no fault trace related to the 1997 earthquakes was found at the surface[6]. Moreover, the seismicity is not active in the Jiashi region since the 1970s when seismic records were collected for this area[9]. Previous relocation studies showed that the epicenters of the 1997 Jiashi earthquakes are approximately constrained in the area of 76°50'—77°10'E in longitude and 39°25'—39°45'N in latitude. That during the period of four months, such a dense earthquake swarm occurred in the relatively stable intracontinental basin is quite unique .

Results of a previous local shear wave splitting study[10] indicate that the principle pressure axis is in nearly north-south direction in the Jiashi region and in east-west direction in the basin's adjacent marginal fold belts such as the Keping faulting zone; these results are

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in agreement with GPS observations[11] that revealed that the crustal deformation of Jiashi region is mainly due to north-south compression. GPS observations show further that the tectonic stress pattern in the Jiashi earthquake swarm area is consistent with that in the Tianshan orogene as both are influenced by the collision of India and Eurasia plates. According to the focal mechanisms from Harvard CMT catalogue and relocation of aftershocks[7], the 1997 Jiashi earthquake swarm probably occurred on faults striking northwest or northeast. Most of these faults are right-lateral strike-slip faults or normal faults and a few are left-lateral strike-slip faults with slight normal slip component. In the South Tianshan folding belt, however, most earthquakes occurred on thrust faults dipping to the south. Therefore, on a large scale, the seismicity in the Jiashi area and South Tianshan folding belt is controlled by the same tectonics force but their faulting structures and mechanisms are quite different due to the difference in local geology. According to the results of relocation of the earthquakes during 1997—1998, Zhou et al.[7] suggested that several groups of parallel faults striking northwest or northeast have been developed in the Jiashi area and the 1997 Jiashi earthquakes occurred on at least two northwest-striking en echelon faults[7,12].

In this paper, we investigate if and how the distribution of normal and strike-slip faults and the earthquake-induced co-seismic Coulomb stress increase contribute to the triggering between the events of the 1997 Jiashi earthquake swarm.

## 1 The 1997 Jiashi swarm and earthquake source models

The 1997 Jiashi earthquake swarm is located 30 km south of the $M_S \geqslant 6.9$ Artushi earthquake on 19 March, 1996 (Figure 1(a)). Zhou et al.[7] applied the method of master event to relocating the events of $M_S \geqslant 3$ in the Jiashi swarm. Their study used records of the 13 regional stations on the west of the source region, three temporary stations to the northeast, and 1—2 regional stations to the southeast and southwest respectively; on the north side, two stations in Kyrghizstanm were also used for relocation. They increased the precision of hypocentral locations by less than 1.2 km horizontally and 3.0 km vertically[7]. According to these relocation results, the epicenters align approximately in the north-south echelon style, and by inference, the main strike-slip events might occur on at least two parallel ruptures striking north-northwest. Figure 1(a) illustrates the main tectonic faults in the Jiashi area based on results from investigation of active tectonics[13] and exploration for oil and gas[6] in the region. The solid lines, dotted-dash lines, and dash lines represent surface cutting faults, blind faults and inferred or doubted faults, respectively. The Keping rupture, an east-west trending fault dipping at 45° to the northwest, is the boundary between the Keping block and the Tarim Basin. On the north side of the Keping rupture, focal mechanisms are always related to the orogenic process of the South Tianshan orogene where thrust faults with east-west orientation dominate. The 1996 Artushi earthquake of $M_S = 6.9$ occurred on the Hapaleike fault within the Keping rupture zone. On the south side of the Keping rupture zone, most earthquakes in the Tarim Basin occurred on northwest or east-west trending normal faults. In the west of Maidan fault, the Taras-Fergana fault strikes north-northwest and separates east Tianshan Mountains from west Tianshan Mountains. The northern segment of the Taras-Fergana fault (outside China's territory) had experienced significant right-lateral movement[14]. With a GPS velocity of about 2—3 mm/a[15], the southern segment of the Taras-Fergana fault extends into China's territory and it is characterized by low seismicity, which is also indicated by earthquake relocation results[16]. As shown by satellite images, the Taras-Fergana fault turns to nearly east-west trending at the south end of the southern segment (see the starting point of dash line in Figure 1(a)), exhibiting thrust movement without extending across the ridge of the south Tianshan Mountains and reaching the basin[6]. Seismic profiles of oil and gas exploration indicate that the Bashituopu rupture zone may extend through and below the Jiashi seismic area[6]. In order to focus our attention onto the Coulomb stress interactions between the major events of the 1997 Jiashi earthquake swarm, the area for calculation in this study is selected by the black and dash frames in Figure 1.

Relocated epicenters[7] of the 1997 Jiashi earthquake swarm shown in Figure 1(b) clearly show that the seven major events are distributed along at least two northwest trending en echelon ruptures. The first quake occurred on the south rupture, then the next occurred on the north rupture, and again the third shocked the south rupture, thus the seismic activities transferred repeatedly be-

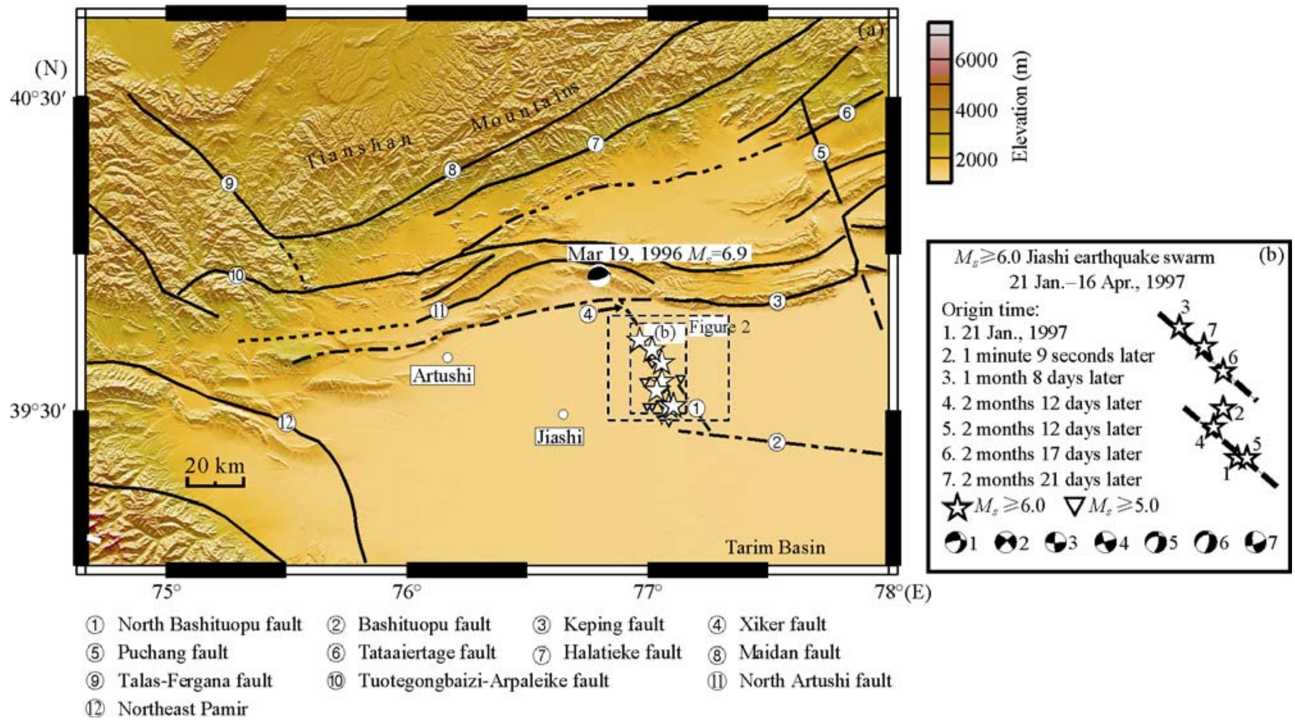


**Figure 1** Tectonics of the 1997 Jiashi strong earthquake swarm in Xinjiang and its adjacent regions.

tween the en echelon ruptures. Focal spectrum studies suggested that the size of the rupture of these $M_S \geqslant 6.0$ earthquakes of the Jiashi swarm is about 10—20 km and the stress drop is as low as about 0.1 MPa[17]. Previous S-wave velocity tomography shows that the source region of the Jiashi swarm is located at a low S-wave velocity zone[8], corresponding to the low value of the Young's Modulus of $7.2\times10^4$ MPa, which is estimated from P-wave velocity[18]. Both the focal mechanism and displacement on the fault surface inverted from the broadband digital data of GDSN and the data of regional network indicated that the ruptures of these 1997 Jiashi events are simple and the shapes of rupture surfaces are proximately square[19]. Taking the seismic moment $M_0$ and the focal mechanisms from Harvard CMT, we constructed a simplified source model for each of these events. The sources are small planes and without an obvious rupturing direction. Thus assuming the fault planes are squares and the displacement is uniform, we can constrain the average slip on each fault plane using seismic moment of the source earthquake. Parameters of each of the sources are given in Table 1. Due to limited information of local rock property, the Poisson ratio and the friction on the fault plane are assigned to be 0.25 and 0.4, respectively.

By simulating the P-wave waveform provided by GDSN, He Yumei et al.[20] inverted the displacement of the 1996 Artushi earthquake and found that the source was a thrust fault with minor strike-slip component and unilateral rupture propagating from west to east. Striking at 252º and dipping at 30º, the source fault of the 1996 Artushi earthquake has slipped up to 1 m. In this study, we divided the Artushi fault plane into 7×15 square elements, and the magnitude and direction of slip are the same for these elements.

## 2 Coulomb stress interactions between earthquakes

In order to investigate how each major event of the Jiashi swarm affects the adjacent faults, we calculated static co-seismic Coulomb stress change[21,22] induced by the earthquake. According to Coulomb failure criterion, the Coulomb failure stress change ($\Delta\sigma_f$) on a receiving fault resulting from an earthquake on the source fault takes the form of $\Delta\sigma_f = \Delta\tau_s - \mu'\cdot\Delta\sigma_n$. Here the $\Delta\tau_s$ and $\Delta\sigma_n$ represent the shear stress change and normal stress change on the receiving fault, respectively, and the $\mu'$ is the apparent friction coefficient, which includes the effect of pore pressure. Note that a compressive stress

**Table 1** Source parameters of $M_S \geqslant 6.0$ strong events of the 1997 Jiashi swarm[a)]

| No. | Epicenter | | Magnitude ($M_S$) | Depth (km) | Strike (°) | Dip (°) | Rake (°) | Moment ($10^{17}$ N·m) | Fault plane (length×width) (km×km) | Slip (m) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Longitude (°E) | Latitude (°N) | | | | | | | | | |
| 1 | 77.09 | 39.51 | 6.4 | 17 | 4 | 50 | −163 | 7.74 | 11.5×11.5 | 0.2 | [2] |
| 2 | 77.06 | 39.59 | 6.3 | 15.5 | 315 | 75 | −177 | – | 11.5×11.5 | 0.2 | [1] |
| 3 | 76.97 | 39.72 | 6.0 | 20 | 180 | 80 | −173 | 3.35 | 13.5×13.5 | 0.065 | [1] |
| 4 | 77.04 | 39.56 | 6.3 | 26.5 | 161 | 78 | 179 | 7.73 | 12.5×12.5 | 0.17 | [1] |
| 5 | 77.11 | 39.51 | 6.4 | 21 | 253 | 43 | −36 | 10.5 | 16.5×16.5 | 0.13 | [1] |
| 6 | 77.06 | 39.65 | 6.6 | 23.5 | 240 | 37 | −133 | 20.6 | 20×20 | 0.23 | [2] |
| 7 | 77.02 | 39.69 | 6.3 | 18 | 170 | 66 | −162 | 6.56 | 18.5×18.5 | 0.067 | [1] |

a) For strike, dip angle, and rake, please refer to ref. [19], for epicentral location and depth, please refer to ref. [7], $M_0$ is from Harvard CMT, and for area of fault plane, please refer to ref. [17].

here is defined as the positive normal stress[21]. A positive Coulomb stress change is believed in general to encourage occurrence of an earthquake on a nearby fault if the tectonic stresses accumulated are high and close to the threshold of failure. Therefore, this static Coulomb stress change can be calculated to investigate the triggering effect of an earthquake on any subsequent events nearby and aftershocks. This method has been widely used in the past two decades and the results indicated that the static Coulomb stress change could significantly influence the seismicity in the vicinity of a major event in a short term[23]. Further, previous studies indicated that a static Coulomb stress increase larger than 0.01 MPa could have significant triggering effects[23].

The Jiashi swarm is dominated by right-lateral strike-slip earthquakes according to published focal mechanisms (Table 1), accompanied by normal faulting events or oblique-slip events with significant normal slip component at 10 km interval (Figure 1). Zhou et al.[7] relocated the Jiashi earthquakes and suggested that these events had occurred along two en echelon strike-slip ruptures. Based on published results we constructed the Coulomb failure model for each event of the Jiashi swarm to calculate stress changes (Figure 2). In each panel of Figure 2(a)—(f), the focal mechanism of the receiving fault is denoted at top left corner. The tensor of stress change induced by the source fault is expressed as the slip vector on the receiving fault plane. The red and blue beach balls denote the focal mechanisms on the receiving fault and the source fault, respectively. Each panel is plotted at the focal depth of the receiving fault. As denoted by the color bar in Figure 2, the earthquakes of the Jiashi swarm had caused about 0.4—0.8 MPa stress increase in the vicinity of the hypocenters of subsequent events. The calculated results show clearly the triggering interactions between earthquakes, leading to the transfer pattern of seismicity in the Jiashi swarm region. The horizontal and vertical accuracy of the relocated hypocenters is about 1 km and 2.5 km, respectively; however, uncertainties on the fault rupture length and slip scale were not provided. Assuming the uncertainties in measuring the rupture dimension are similar to those in locating the hypocenters, these uncertainties will only affect the results of Coulomb stresses calculations slightly, and thus the main conclusion would hold.

We also calculated the stress effects from the 1996 Artushi strong earthquake, using parameters from the previous study[20]. Calculations indicate that a small positive stress change of less than 0.02 MPa had resulted in the 1st event of 1997 Jiashi swarm (Figure 3). There were not any earthquakes of $M_S \geqslant 3.0$ occurring in the Jiashi region in the 30 years before the 1997 swarm. Considering the active tectonics between the southern Tianshan orogene and the Tarim Basin, perhaps the fault system in the Jiashi region had been in critical state and could be ready to be triggered, suggesting the possibility that the seismicity in Tianshan orogene might affect the seisimicity in Jiashi region.

## 3 Interactions between adjacent normal and strike-slip faults

In order to investigate the co-seismic stress interactions between strike-slip and adjacent normal faults similar to those in the Jiashi earthquake swarm, we construct simple models consisting of a right-lateral strike-slip fault (270°/90°/180°) and a normal fault (0°/50°/–90°). In the simple model, the minor component of focal mechanisms of Jiashi earthquakes is ignored and the rock property is the same as that in the calculation discussed above. The results are shown in Figure 4, in which the white thick line with arrows represents the source fault,

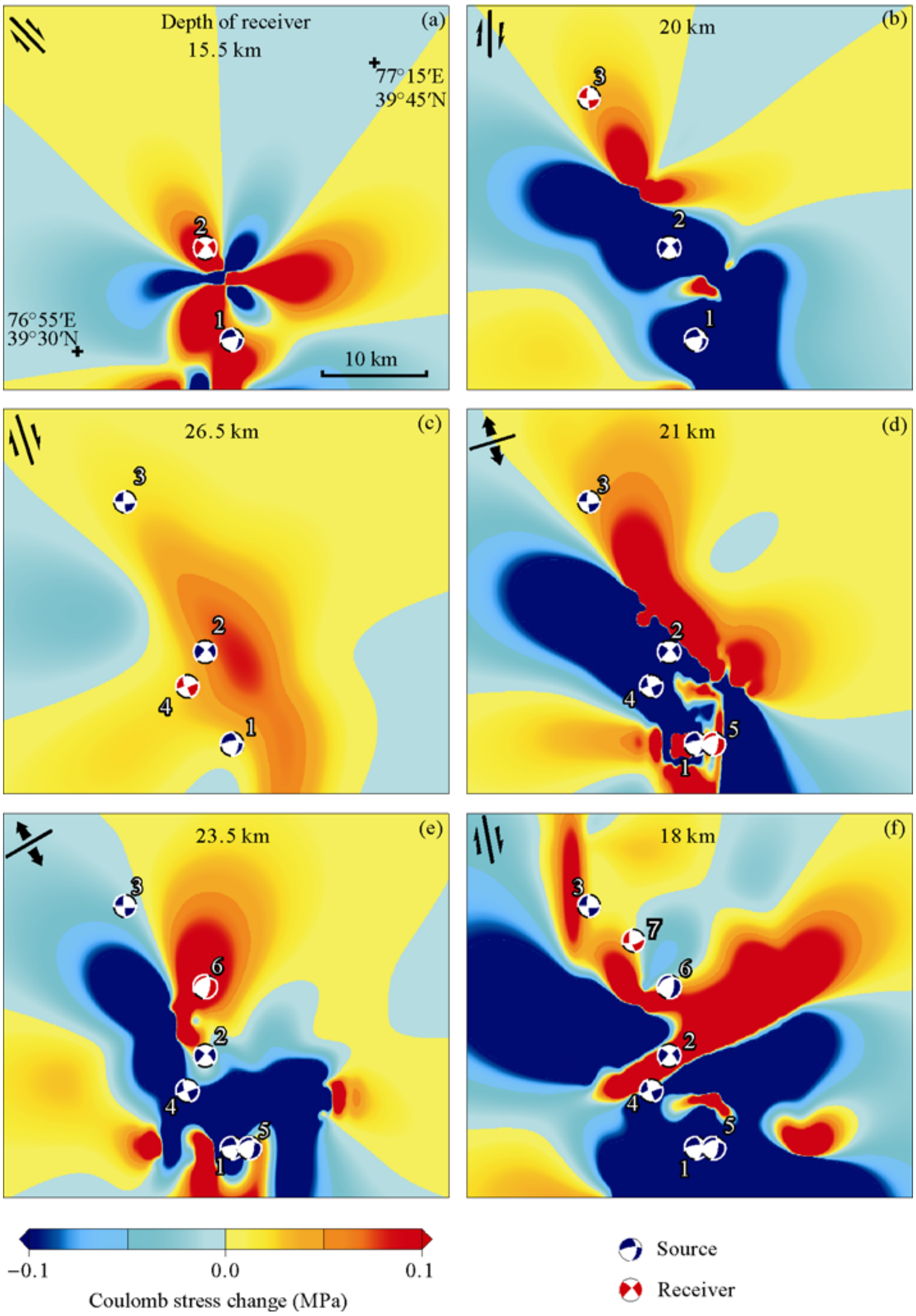


**Figure 2** Co-seismic Coulomb failure stress change calculated based on source parameters of the Jiashi earthquakes. The focal mechanism of the receiving fault in each panel is the same as that of corresponding event (cf. number of red beach ball) in the Jiashi swarm.

and the black line with arrows on the top left corner in each panel represents the focal mechanism of the receiving fault.

Figure 4(a) shows the Coulomb stress change by a source normal fault on parallel receiving normal faults; clearly the Coulomb stress has decreased significantly on the two sides of the source fault. Figure 4(b) displays the Coulomb stress change caused by a source normal fault on a receiving strike-slip fault perpendicular to the source fault. Stress increases are mainly on the left side of the region outsides the two ends of the source fault.

Figure 4(c) shows the Coulomb stress change by a right-lateral source earthquake on parallel right-lateral receiving faults. There is significant Coulomb stress decrease, i.e., stress shadow, on both sides of the source fault, indicating that the triggering effect is not significant. Besides the Coulomb stress increases in regions along the strike direction extending from two ends of a

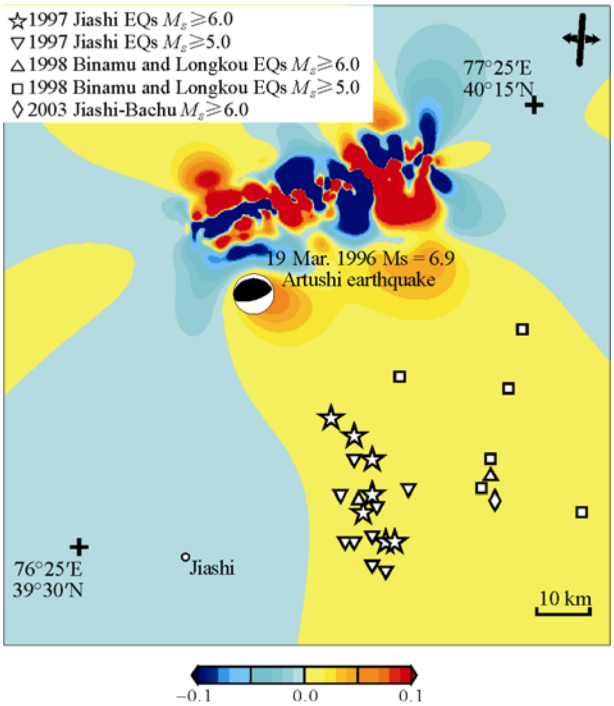


**Figure 3** Coulomb stress change on right-lateral strike-slip fault induced by the Artushi with $M_S$=6.9 earthquake. The mechanism of the receiving fault is the same as that of the 1st major event of 1997 Jiashi earthquake swarm. Coulomb stress change resolved on right-lateral strike-slip fault with component (MPa).

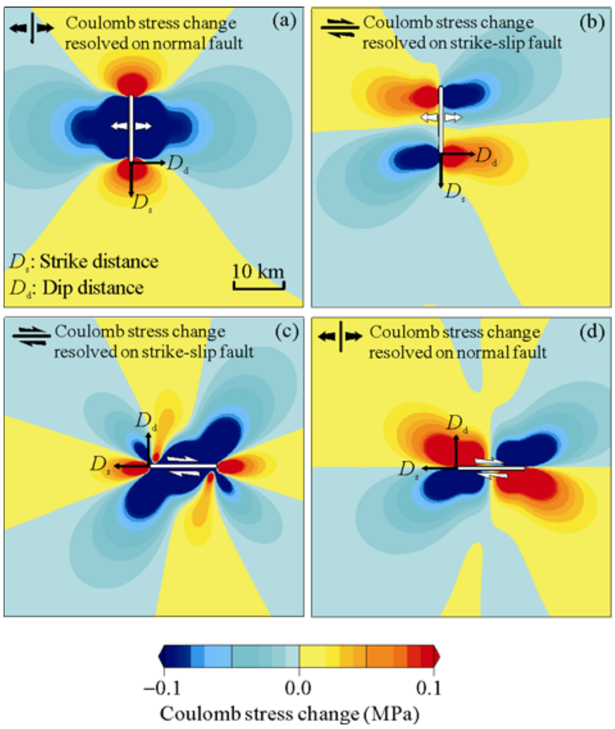


**Figure 4** Stress interactions between idealized faults in a simplified model.

strike-slip fault, the Coulomb stress only increases in narrow belts on the outer right-sides at the end of the source fault. On a receiving normal fault located along the strike of right-lateral strike-slip fault, the stress increase is compensated by decrease, that is, the triggering effect is not obvious (Figure 4(d)). By contrast, the strike-slip fault could significantly trigger the normal faults in the front right area.

To quantify the discussion, we plotted stress change curves in Figure 5 for receiving faults at different distances in dipping direction ($D_d$) and strike direction ($D_s$) from the source fault. The source fault in Figure 5(a) and (b) is a normal fault, while the receiving fault is a parallel normal fault in Figure 5(a) and a perpendicular strike-slip fault in Figure 5(b). The calculations show that a normal fault would cause significant stress change on both a normal fault and a strike-slip fault if $D_d$ is shorter than 5 km. Because our interest in the interactions between faults with a relatively long distance like those in the 1997 Jiashi swarm, and the magnitude of stress change decreases rapidly with the decreasing distance from the source fault, we only show the results of $D_d$ larger than 5 km in Figure 5(a) and (b). The source fault in Figure 5(c) and d is a right-lateral strike-slip fault, and the receiving fault is a strike-slip fault in Figure 5(c) and a normal fault in Figure 5(d), respectively. Similar to Figure 5(a) and (b), Figure 5(c) and (d) only shows the stress change of $D_s$ larger 5 km.

When the receiving fault is a normal fault (Figure 5(a)), in the region near the ends of the source, for example, $D_s$=0.5 km, the stress change is negative since the $D_d$ is larger than 5 km. Comparison of curves of $D_s$ being 0.5, and 15.5 km implies that the magnitude of stress increase reduces with increasing $D_s$. Since $D_d$ is large than 10 km, the stress increase is very small and even the stress decreases. These results indicate that it is not easy for a normal fault to trigger parallel normal faults at a remote distance. If the receiving fault is a perpendicular strike-slip fault (Figure 5(b)), the stress increase could reach up to 0.04–0.08 MPa when $D_s$=0.5 km and $D_d$ is in the range of 5–15 km. When $D_s$ is larger than 5 km, stress increases slightly with an increase of $D_d$. Although the magnitude of the increase is getting smaller with increasing $D_s$, the stress change could be positive at remote distance, which means a normal fault has a triggering effect on an adjacent strike-slip fault.

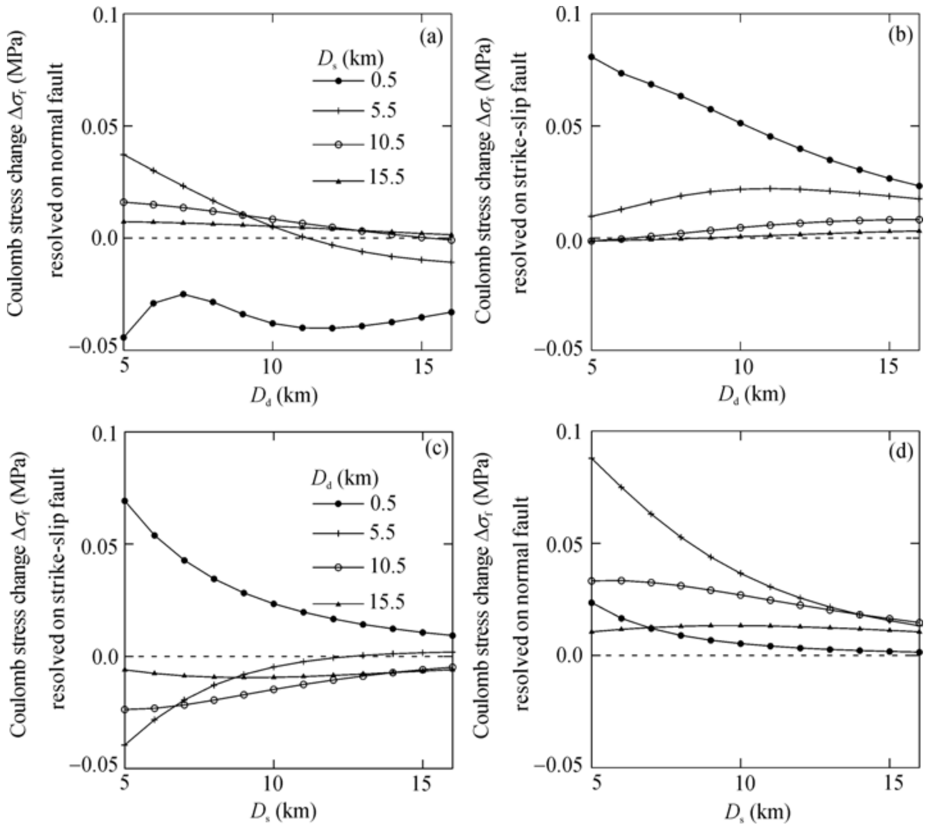


**Figure 5** Spatial variation of Coulomb failure stress change induced by either a normal faulting or a strike-slip faulting event. The dash lines represent zero Coulomb stress change.

The curve of $D_d$=0.5 km in Figure 5(c) shows that the stress increase can be up to 0.025 MPa at $D_s$=10 km. However, comparison of results corresponding to $D_d$ of 5.5, 10.5, and 15.5 km suggests that in the area some distance away from the source fault if $D_s$ is large than 5 km, a strike-slip fault would not promote earthquakes with the same focal mechanism. As shown by the curve of $D_d$=0.5 km in Figure 5(d), a strike-slip fault has triggering effect on a nearby normal fault. The triggering effect becomes weaker with increasing $D_s$. The results of $D_d$ being 5.5, 10.5 and 15.5 km indicate that the stress increase could still be about 0.01—0.02 MPa on a normal fault at $D_s$ larger than 5 km.

In summary, the above results indicate the strong geometric dependence on the seismicity to be transferred back and forth between right-lateral strike-slip source fault and parallel receiving fault with the same mechanism. The presence of a perpendicular receiving normal fault weakens that geometric requirement. A normal fault is capable to trigger a right-lateral strike-slip fault in the left front; likewise, a normal fault is also likely to be triggered by a strike-slip fault in the same direction. As a consequence, seismicity is able to transfer back and forth along the direction oblique to the strike-slip faults.

Similar to the simple model of Figures 4 and 5, the normal fault events in the Jiashi swarm might also play an important role in the observed seismicity pattern. The normal fault can be easily triggered by a nearby strike-slip fault, and vice versa. Like the principal compressive stress in South Tianshan folding belt, that in the Jiashi region is along the north-south direction. In addition, most events of the 1997 Jiashi earthquake swarm occurred on the northwest or north-south trending faults. As a result, the northwest trending normal fault, the north-south trending strike-slip fault, and oblique-slip fault with intermediate focal mechanisms developed in the Jiashi earthquake region. Even if the source is not a perfect normal fault, e.g. a strike-slip earthquake with some normal slip component, it could do better than a perfect strike-slip fault in triggering an adjacent strike-slip fault. Actually, the observed focal mechanisms reflect the discrepancies in strike, dip angle, and rake between the real strike-slip fault and an ideal fault, which further suggests that the en echelon ruptures consisting of only strike-slip faults are unlikely to be responsible for the seismicity transferring pattern on the strike-slip faults of the 1997 Jiashi swarm. The most important point here is that the seismicity on normal faults in the Jiashi region contributes to the recurrence of triggering between strike-slip ruptures.

## 4 Discussion

Zhou et al.[9] proposed an en echelon rupture model consisting of several strike-slip faults and oblique-slip faults to simulate the fault displacement pattern in the Jiashi region. By strain loading, their model calculations indicated that the en echelon faulting geometry could explain the observed earthquake cluster in this region. Their model results had also suggested that the slip on a right-lateral en echelon fault could facilitate the normal faulting at the southeast end of the fault. Located between the Juan de Fuca Ridge and the Gorda Rise in the northeast Pacific, the Blanco transform fault zone is constituted by parallel right-lateral strike-slip faults and pull-apart basins, which separate the strike-slip faults from perpendicular normal faults[24]. The structure of the Blanco transform fault zone is similar to the distribution of strike-slip faults and normal faults of the 1997 Jiashi earthquakes. Therefore, we propose that the faulting system of the 1997 Jiashi earthquake swarm also consists of northwest trending right-lateral strike-slip faults segmented by pull-apart basins. Figure 6 is the schematic cartoon of this simplified model for this faulting system. The thick arrows represent a northwestward principal compression axis of tectonic stress, which controls the development of right-lateral slip faults striking northwest or southeast. For opposite shear process near the fault ends, a pull-apart basin is likely to develop between neighboring strike-slip faults. Similar structures of segmented strike-slip fault with pull-apart basin have been studied in some other continents[25,26].

As shown in Figures 4 and 5, within the segmented strike-slip faulting system, it is easier to transfer earthquakes between strike-slip faults with the existence of a normal fault in the pull-apart basins. As indicated by beach balls and thin arrows in Figure 6, the epicenters shown here are roughly the same as the epicentral distribution of the 1997 Jiashi earthquakes. As shown in Figure 6, the 1st normal fault event in basin 1 contributed to the occurrence of the 2nd strike-slip event. A possible normal fault may exist in basin 2 (an $M_S$=5 earthquake with little information about its focal mechanism occurred in the time interval between the 2nd and the 3rd events). The possible normal fault may have been subjected to an increase in Coulomb stress from the 2nd strike-slip event, and then this possible normal faulting

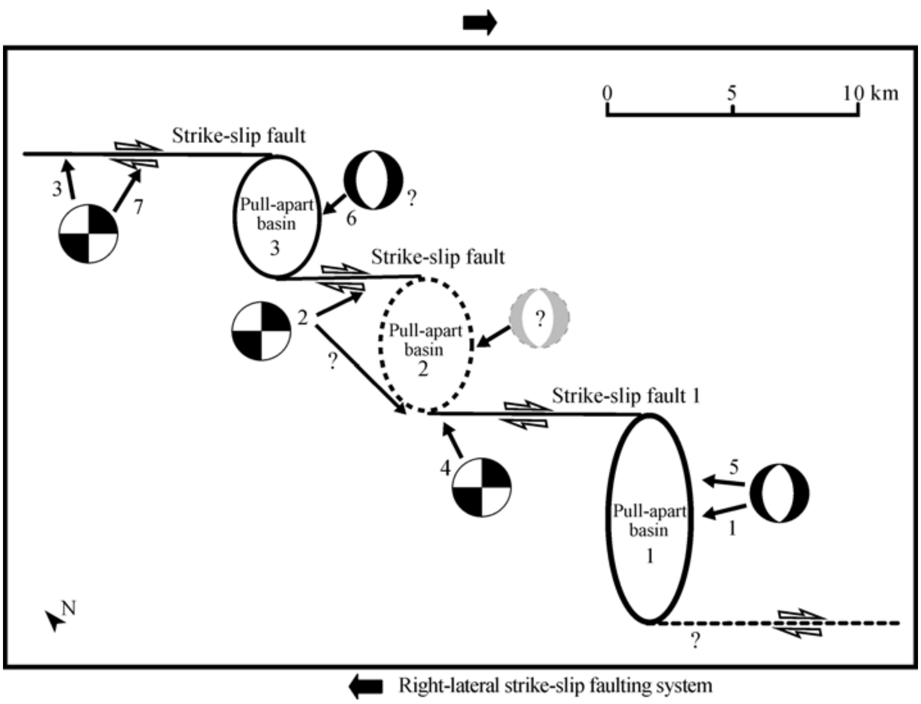


**Figure 6** Schematic map of the echelon strike-slip faults and normal faults. The numbers at the line connecting beach balls show the order of occurrence. The beach balls represent focal mechanisms of the idealized faults. No earthquake of $M \geqslant 6$ with corresponding mechanism actually occurred in basin 2. The normal fault earthquake denoted by gray beach ball and question mark denotes inferred result. The other question marks indicate uncertainty in the interpretation.

event contributed to the 3rd and the 4th strike-slip events. The 4th strike-slip event had positive effect on both the 5th and the 6th normal fault events. The 6th normal fault event obviously triggered the 7th strike-slip event.

However, there exist some shortcomings using the system of segmented strike-slip faults with pull-apart basin to interpret the faulting system for the 1997 Jiashi swarm. For example, the distance between strike-slip fault 1 and strike-slip fault 3 is about 5 km, which is far shorter than the estimated fault length of the 6th event, i.e., the the 6th event is outside the stress influence range of the pull-apart basin. Of course, errors do exist in the seismic moment estimation. Another problem is that the southernmost strike-slip fault (dash line) could not be located, therefore, the north-south width of the pull-apart basin 1 is not well constrained. Because of the absence of local station data, the results of previous studies, e.g. the earthquake relocation, have some uncertainty, which may lead to different interpretations. In the study made by Zhou et al.[9], the strike-slip events occurred only on two parallel ruptures.

Different from ideal earthquake model, the sources of the Jiashi swarm in our calculations are neither perfect normal faults nor perfect strike-slip faults. In addition, the normal faults are not completely perpendicular to the strike-slip faults, but the comparison made by us does suggest the interaction between normal fault and strike-slip fault of the Jiashi swarm. For example, according to observation, the 1st earthquake strikes northeast by north and the 2nd source is strike-slip fault striking northwest. Although not completely perpendicular to the 2nd source fault, the 1st source fault triggered the 2nd event with a significant stress increase. The calculation results shown in Figure 2 also indicate that multiple strike-slip quakes (the 2nd—4th events) obviously triggered the 5th and the 6th normal fault events, and the stress increase induced by normal faults further advanced the occurrence of the 7th strike-slip event.

Despite controversies on the tectonics models of the 1997 Jiashi earthquake swarm, the stress interaction between strike-slip fault and normal fault in the Jiashi swarm is quite important. Gregg et al.[27] studied the transform fault near the East Pacific Rise and found that a strike-slip fault with proper geometric features can have significant triggering effect on adjacent perpendicular normal faults. While the system of strike-slip faults with perpendicular normal faults had been extensively developed at mid-ocean ridges, and few studies have focused on the Coulomb stress interaction between earthquakes in a similar system on continent.

## 5 Conclusions

Our study of the 1997 Jiashi earthquake swarm indicates that normal faults play an important role in the seismicity transfer. By changing the Coulomb failure stresses on adjacent faults, an earthquake could trigger subsequent quakes. According to previous studies, we calculated the stress interactions between seven major events of the 1997 Jiashi swarm. We also analyzed the influence of the 1996 Artushi earthquake on the first event of the 1997 Jiashi swarm. Our calculation reveals that the Coulomb stress was increased by about 0.05 MPa at the hypocenter of the 4th event, and by about 0.08 MPa at the focuses of the 2nd, 3rd, 5th, and 6th events. Our study also reveals obvious stress interactions between at least two adjacent ruptures. The 1st event of strong quakes in the swarm occurred on the south end of the south rupture, increasing Coulomb stress at the source of the 2nd event between the south and the north ruptures. The total stress change induced by these two events triggered the 3rd event on the north end of the north rupture. Then these previous events increased Coulomb stress at the source of the 4th event on the north end of the south rupture. The 5th and the 6th events shocked the south end of the south and the north ruptures, respectively, and both occurred in the area with stress increase. The 7th strike-slip event occurred in the area with stress increase after two continuous normal fault events. These results as a whole indicate that earthquakes on the south and the north ruptures can interact with each other. More importantly, the earthquakes on normal faults in the Jiashi region might facilitate the earthquake triggering among the en echelon strike-slip faults. It is interesting to note that the Jiashi region has remained seismically active since the 1997 earthquake swarm and the distribution of the epicenters displays a trend leading into the interior of the Tarim Basin.

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