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The 2008 Yutian normal faulting earthquake (Mw 7.1), NW Tibet: Non-planar fault modeling and implications for the Karakax Fault

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ABSTRACT

The ENE striking Altyn-Tagh Fault and the WNW striking Karakax Fault are two major strike–slip fault systems in northern Tibet, and form a prominent ~2000 km long fault system. The 2008 Yutian normal faulting earthquake (Mw 7.1) struck near the southern edge of the Tarim Basin, where the two fault systems converge. While there are numerous NS-trending normal faults particularly in southern Tibet, their tectonic origins have remained contentious. Based on crustal deformation data sets obtained from synthetic aperture radar (SAR) as well as aftershock distribution, we developed a non-planar fault source model for the 2008 Yutian earthquake that exhibits a large normal-fault slip on a west-dipping surface with a nearly NS strike, thus suggesting a localized EW trending extensional stress field. The extensional stress was presumably generated at a step-over region of two NE-trending left-lateral strike–slip faults, which would probably belong to the Altyn-Tagh and Longmu–Gozha Co Fault Systems. In the epicentral area, there exists a fault scarp that coincides with the top edge of our fault model, and thus similar earthquakes must have occurred over geological time. Such normal faulting earthquakes must have been repeatedly suppressed the left-lateral slip behavior of the Karakax Fault. In addition, if the slip along the Altyn-Tagh Fault is transferred to the Longmu–Gozha Co Fault, which is SE across the normal fault system, the slip rate of the Karakax Fault would be less than that of the adjoining Altyn-Tagh Fault.

1. Introduction

While a variety of observations have shown that north–south (NS) striking normal faults are broadly distributed in Tibet (e.g., Armijo et al., 1986; Avouac and Peltzer, 1993; Elliot et al., 2010; Molnar and Lyon-Caen, 1989; Molnar and Tapponnier, 1978; Sun et al., 2008; Tapponnier and Molnar, 1977), it remains unclear why east–west (EW) extensions are generated over a wide area in Tibet. Molnar and Tapponnier (1978) proposed a gravitational spreading model, which considers that the thick crust cannot be supported by its mechanical strength and will tend to collapse. To account for the extensional stress as well as the compressional stress associated with the convergence between India and Asia, England and Houseman (1989) considered the thermal evolution of the thickened lithosphere and suggested a convective instability of the lower lithosphere and its subsequent replacement by the hot and light asthenosphere. In addition, noting the systematic changes in rift spacing from north to south, the overall similarities in the age of rift initiation, and the systematic NS trends in rift orientation, Yin et al. (1999) and Yin (2000) pointed out the importance of a regional boundary condition at a scale of thousands of kilometers. Recently, Copley et al. (2011) pointed out a clear contrast in the tectonic regime between northern and southern Tibet, considering the normal faulting in northern Tibet as minor, and indicated that a strong mechanical coupling of Indian lower crust in southern Tibet could explain the EW-extension in southern Tibet. The focus of this paper is not in the numerous normal faults in southern Tibet but in the rather localized normal faults in the northwestern Tibet.

On March 20, 2008 at 22:33 UTC, an earthquake (M7.2/USGS) struck the Yutian county, Xinjiang, China. The event was the largest normal faulting earthquake ever instrumentally recorded in northern Tibet (Fig. 1; Ekström et al., 2005; Elliot et al., 2010; Global Centroid Moment Tensor project, 2008). Hence, the 2008 Yutian earthquake provides us with an opportunity to better understand not only the mechanism of normal faulting but also its significance with respect to tectonics in northwestern Tibet.

The epicenter of the 2008 Yutian earthquake is located near the southern border of the Tarim Basin (Fig. 1), where the Altyn-Tagh Fault, a major sinistral strike–slip fault system in northern Tibet, meets the Karakax Fault (West Altyn-Tagh Fault) in northwestern Tibet (Styron et al., 2010; Tapponnier and Molnar, 1977; Taylor and Yin, 2009). To the southwest of the epicentral area, there is another ENE-striking sinistral strike–slip fault system, the Longmu–Gozha Co Fault (Fig. 1). It should be noted that the Ashikule volcano group, where the latest eruption was witnessed in 1951 (Global Volcanism Program, Smithonian Institution), is located at ~30 km to the north

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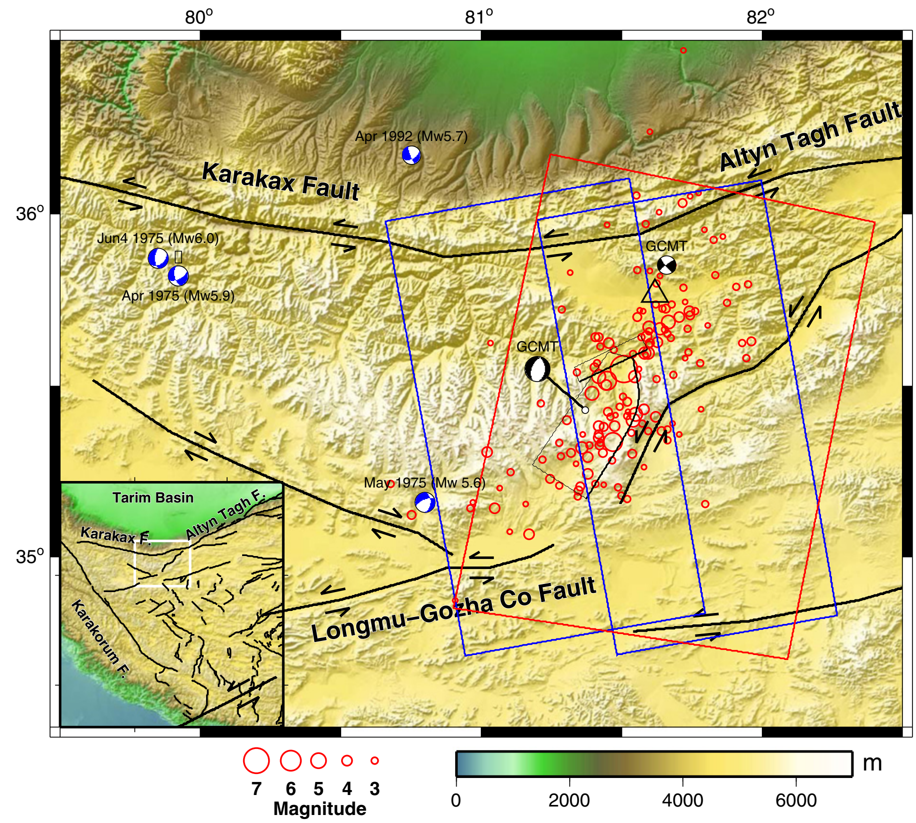

Fig. 1. Location map of the epicentral area of the Yutian earthquake and the regional topography. Main shock and aftershock locations from the International Seismological Centre are shown with red circles, and the centroid moment tensor (CMT) solution for the main shock (Mw 7.1) determined by Global CMT (GCMT) project is also shown. Previous earthquakes in the area are shown in blue and the mechanisms are based on Molnar and Chen (1983) for the three 1975 events and on GCMT for the 1992 event. Major fault traces are drawn from HimaTibetMap-1.0 by Styron et al. (2010): see also Taylor and Yin (2009). Three rectangles represent the areas observed by two ascending tracks of ALOS/PALSAR (blue) and one descending track of Envisat/ASAR (red). The Ashikule volcano group is located near the triangle.

of the epicenter (Fig. 1). Although the Ashikule volcano group seems dormant at present, Liu and Maimaiti (1989) documented NS-trending Quaternary-active volcanoes and spatter cones. Because the existence of volcanoes could be used as indicators of tectonic stress orientation (e.g.. Nakamura, 1977), we may interpret Liu and Maimaiti's observation as reflecting an EW extensional stress field over the area. The EW extensional stress may be relevant to the generation of NS-striking normal fault earthquakes around the area. Moreover, based on isotopic and geochemical data for the trachyandesite samples at the Ashikule Basin, Cooper et al. (2002) concluded that it is unlikely that the magma was produced due to the subduction process, and that it was due to extension induced by the development of pull-apart basins along the major strike–slip faults.

Elliot et al. (2010) reported the crustal deformation signals associated with several normal faulting earthquakes in Tibet, using synthetic aperture radar (SAR) data sets. They developed fault slip distribution models using rectangular dislocation Green's functions devised by Okada (1992). For the 2008 Yutian earthquake, Elliot et al. (2010) presented three planar surfaces, based on their consideration of topography and surface rupture mapping using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery. However, their use of rectangular planar geometry generates mechanically incompatible overlaps in the fault model, because the observed data indicate that the fault geometry is non-planar. Moreover, Elliot et al. (2010) suggested two interpretations of the tectonic origin of the 2008 Yutian earthquake. In one interpretation, two ENE-striking left-lateral strike–slip faults in the Longmu–Gozha Co Fault system generated dilatational extension at a step-over region.

In the other interpretation, noting that the earthquake occurred in the highest region on earth when averaged over a 100 km scale, they also suggested that the extension regime conformed to the gravitational spreading model. Both interpretations can account for the extensional stress responsible for the normal faulting earthquake.

Although essential features of our crustal deformation observations are similar to those in Elliot et al. (2010), we show both InSAR and pixel offset data that were not presented in Elliot et al. Based on these observation data sets, we present a non-planar fault source model that is free from mechanically incompatible overlaps. While it is well known that Green's functions based on a triangular dislocation element (TDE) are useful to this end (e.g., Comninou and Dunders, 1975; Jeyakumaran et al., 1992; Yoffe, 1960), and Poly3D software has been widely used in the literature (Maerten et al., 2005; Thomas, 1993), we demonstrate our own approach for generating a non-planar fault model. Considering mechanical interaction of the nearby multiple faults, previous studies of nearby earthquakes (e.g., Molnar and Chen, 1983), and paleomagnetic data (Rumelhart et al., 1999), we discuss the possible implications for the present activity of the Karakax Fault.

2. Data analysis and results

2.1. Observation

We use ALOS/PALSAR data on two ascending paths and Envisat/ASAR data on one descending path to observe crustal deformation signals (Fig. 1); see Table 1 for the data sets. Our SAR data processing procedures are basically the same as those in our previous