Int J Appl Earth Obs Geoinformation 73 (2018) 99–106

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

The 2016 Mw 6.7 Aketao earthquake in Muji range, northern Pamir: Rupture on a strike-slip fault constrained by Sentinel-1 radar interferometry and GPS

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A R T I C L E I N F O

Keywords:
Aketao earthquake
InSAR
GPS
Listric fault
Coseismic slip model

A B S T R A C T

On 25 November 2016, the Aketao, Xinjiang earthquake occurred on the Muji fault, which is located at the northernmost end of the right-lateral Karakorum Fault (KF). This event provides a rare chance to gain insights into how the stress accumulates in Pamir margin as the Indian plate collides with the Eurasian plate. Space geodetic measurements including InSAR and GPS were used to obtain coseismic surface displacements associated with this earthquake. Based on a finite fault model, the coseismic slip distribution inverted by the combined datasets indicates that the 2016 Aketao event is caused by a primary shallow strike-slip with minor normal-slip at a steep-dipping angle. To explore the real structure of Muji fault, listric fault model inferred by relocated aftershocks as well as the planar fault model, were used in our slip distribution inversion. The results suggest that the optimal fault model should be a highly-dipping planar fault with two separated asperities. The large slip zone is beneath the surface near the epicenter with a maximum slip of 1.1 m, while the small one in the east breaks the surface, in a good agreement with the field seismic geological survey. The total geodetic moment is $1.35 \times 10^{19} N{\cdot}m$, equivalent to Mw 6.7. The nearly pure dextral strike-slip Aketao earthquake, and the recent 2015 Mw 7.2 sinistral strike-slip Tajikstan earthquake in this region, to some extent, manifest the extension motion is dominated in northern Pamir Plateau, in response to the northward convergence between Indian and Eurasian collision.

1. Introduction

The Pamir mountains lie at far to the north of the collision between the Indian sub-continent and the Eurasian lithosphere, and are bounded by four major crustal blocks: the Tarim Basin, Hindu Kush, Tajik Depression and Tien Shan to the east, south, west and north separately (Fig. 1a) (Chevalier et al., 2011). As the north of the western Himalayan syntaxis, the Pamir has been experienced more than 300-km N-S compression since the late Cenozoic, and many interior mountain ranges are characterized approximately by the E-W extension (Burtman and Molnar, 1993; Strecker et al., 1995). The dome-shaped Pamir reflects sense of radial and lateral extrusion movement (Rutte et al., 2017a), resulting in the development of overthrust fault to the north, as well as normal and strike-slip fault to the east and west (Chevalier et al., 2015). Present geodetic measurements reveal that the Pamir accommodates a greater amount of strain over a shorter north-south distance than further east in Tibet (Zubovich et al., 2010; Ge et al., 2015), thus it is deemed as one of the most intra-continental tectonically active regions of Eurasia Plate (Sobel et al., 2013; Chevalier et al., 2015).

Most of the present-day contractional strain is concentrated at the arcuate boundary of Pamir, rather than limited deformation in its interior (Zubovich et al., 2010). Abundant active faults at the arcuate boundary of Pamir have been found and studied by satellite images (Robinson, 2009), field geochronological data (Robinson et al., 2015; Chevalier et al., 2015), geodetic measurements (Yang et al., 2008), seismic records (Schurr et al., 2014) and so on. But the sparse database with different timescales are far from enough to constrain the tectonic motion and local tectonic structures well, and there are discrepancies for some certain faults (e.g., the Muji fault) (Robinson et al., 2015). From the Global Centroid Moment Tensor (GCMT) catalog (Fig. 1), more than 10 Ms > 5.5 shallow events (< 30 km in depth) were recorded on the arcuate boundary of Pamir between 1976 and 2016, but little seismicity in the Pamir interior. In particular, four main earthquakes occurred near the Main Pamir Thrust (MPT) in last decade,

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https://doi.org/10.1016/j.jag.2018.06.001
Received 14 February 2018; Received in revised form 21 May 2018; Accepted 4 June 2018

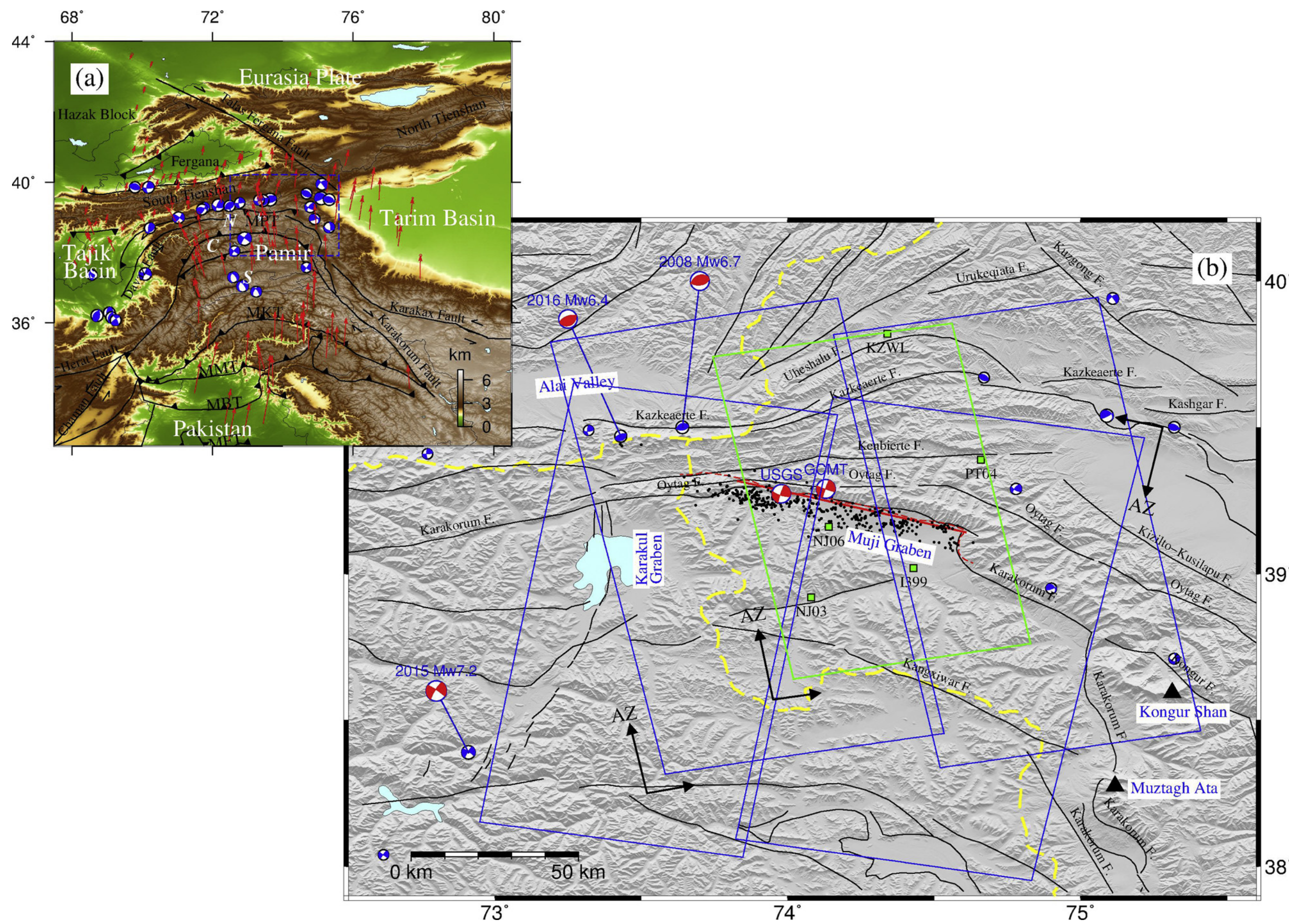

Fig. 1. Topographic and tectonic setting map surrounding the 2016 Aketao Mw 6.7 earthquake. Blue and green rectangles depict the footprints of the Sentinel-1 A/B images and ALOS-2 images used in this study separately. Black lines depict active faults (Schurr et al., 2014), while the red dashed line describes the Muji fault rupture trace from field geological survey (Chen et al., 2016). Beach balls represent the focal mechanism solutions of events with magnitude larger than Ms 5.5 at < 30 km depth during the 1976–2016 period from the GCMT. Black points are the relocated aftershocks within five days after the main shock from Chen et al. (2016). Green squares labeled with 4-char codes represent GPS sites used in this study. The inset map is a simplified tectonic map showing the location of the Pamir Plateau in the India-Eurasia collisional system. The dashed blue box shows extents of the main figure in our study region. Red arrows represent GPS-derived interseismic velocities with respect to stable Eurasia. All abbreviations: MPT, Main Pamir Thrust; MKT, Main Karakorum Thrust; MMT; Main Mantle Thrust; MBT, Main Boundary Thrust; MFT, Main Frontal Thrust; PFT, Pamir Frontal Thrust. Letters of N, C, and S show the three tectonostratigraphic comprised units of Pamir (Schurr et al., 2014).

including the 2008 Mw 6.7 Nura (Teshebaeva et al., 2014), the 2015 Mw 7.2 Tajikistan (Sangha et al., 2017), the 2016 Mw 6.4 Nura, and the 2016 Mw 6.7 Aketao (also known as Muji) (Wang et al., 2017) earthquakes. They have a diversity of focal mechanisms, including reverse thrust-slip, strike-slip or both. However, there remains rather limited understanding of this region due to the harsh terrain and political conditions in this remote national border region.

On 25 November 2016, an Mw 6.7 event struck the Aketao County, Xinjiang, western China, resulting from a rupture along the Muji fault on northern side of the Muji Graben (Fig. 1). Since this event occurred in a relatively remote boarder region with sparse population, no loss of life has been reported (Feng et al., 2017). The location of epicenter from the U.S. Geological Survey (USGS) was 73.978 ˚E and 39.273 ˚N, with a ~ 10 km focal depth. A dextral strike-slip offset of 10–15 cm has been found near the surface from field investigations, and rupture on the Muji fault with a strike of 110˚ was confirmed by the relocated aftershocks within 5 days (Chen et al., 2016). Field geological work and teleseismic data provide an approximate epicenter location and surface rupture of this event, but they are still not sufficient to resolve the detailed subsurface structure of the Muji fault. Space-borne Interferometric Synthetic Aperture Radar (InSAR) observations with high spatial coverage afford a good opportunity to determine the source characteristics of earthquakes in this remote region(Wang et al., 2017; Feng et al., 2017). However, InSAR only measures deformation along the satellite line-of-sight (LOS) direction, which is not very sensitive to horizontal displacements. In addition, a listric fault of this event inferred by the relocated aftershocks has not been taken into account yet in the published slip models. Therefore, different from previous studies from InSAR measurements only (Wang et al., 2017; Feng et al., 2017), we use both InSAR and GPS data to determine the coseismic deformation of the 2016 Aketao Mw 6.7 event, and further to invert the seismogenic fault geometry and slip distribution.

2. Regional setting

The Pamir Plateau consists of a 500 km-long series of arcuate ranges and extensional basins with a mean altitude of 5000 m (Zubovich et al., 2016). A series of dome-shape structures with orogen parallel extrusion in the Pamir Plateau developed during the Paleozoic and Mesozoic period, and are interspersed with Paleozoic-Mesozoic magmatic arc and subduction-accretion systems (Rutte et al., 2017a). Using geothermochronologic data, Rutte et al. (2017b) inferred that there were three main stages during the evolution of Pamir, and the orogen-parallel extension and dextral wrenching occurred throughout the convergence history. According to the differences of geological setting and deformation activity, the Pamir Plateau can be subdivided into three