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Deformation of Linfen-Yuncheng Basin (China) and its mechanisms revealed by Π-RATE InSAR technique

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ABSTRACT

The Linfen-Yuncheng Basin (LYB) in China is a region possessing severe geo-hazards, including active tectonic fault movement, land subsidence and ground fissures among others. Interferometric Synthetic Aperture Radar (InSAR) technique is applied to map surface deformation associated with various geo-hazards in this basin. The poly-interferogram rate and time-series estimator algorithm (Π-RATE) is used over forty-nine scenes of SAR data to generate the deformation maps over the entire LYB. The precision of InSAR results is around 3 mm/yr. Some active faults and ground fissures are successfully detected. The spatiotemporal characteristics of tableland uplift, faults displacement and basin subsidence are quantitatively monitored with InSAR technique ranging from 2 mm/yr to 142 mm/yr. Finally, the mechanisms of surface deformation regarding large scale Zhongtiaoshan fault, middle scale basin land subsidence and small scale ground fissures are discussed in terms of interseismic movement, underground water level changes and hydrostratigraphic heterogeneity.

1. Introduction

The Linfen-Yuncheng Basin (LYB) is located in the south-central Shanxi graben system, where the tectonic formation is extremely complex with frequent seismic events (Liu and Ji, 2014; Wang, 1995) (Fig. 1). Historically, more than ten earthquakes with magnitude (M) larger than 7.0 have occurred in this basin, including the M 8 Hongtong earthquake in 1303 and M 7.5 Linfen earthquake in 1695. The most recent significant earthquake was an M 4.4 event near Yuncheng on Mar. 12, 2016. Two large-scale piedmont normal faults control LYB, namely the Luoyunshan fault (LYF) to the northwest and the Zhongtiaoshan fault (ZTF) to the southeast. These faults slip at a rate as large as 2 mm/yr, as monitored by campaign leveling and GPS measurements (Hao et al., 2016; Cui et al., 2016). While, long-term inter-seismic movement estimated by radiocarbon (^{14}C) dating has shown the mean slip rate of the Northern ZTF is 0.75 ± 0.05 mm/a since 24.7 ka BP (Si et al., 2014), no quantitative measurement has been done on small and secondary normal faults, which strike mainly to the northeast-east and east-west within the LYB. Little is known about buried faults in the region. In addition, four large historical land subsidence areas have been recorded in LYB: Yaodu district at Linfen, Jishan County, Taocun-Xiaxian, and Hejin (Yang et al., 2016). The first three areas are also superimposed by clusters of ground fissures, and Hejin is suffering from abnormal surface subsidence and uplift (Yang et al., 2016; Ji et al., 2016). So, how can basin-scale deformation be efficiently and precisely monitored? Is it possible to separate different hazard deformation fields from each other? And what are the mechanisms of the complex hazards in LYB? These are the research questions that we attempt to address in this paper.

Conventional ground-based geodetic techniques, such as GPS and leveling, have been applied to monitor the fault movements in LYB (Hao et al., 2016; Liu et al., 2016; Cui et al., 2016). However it is difficult to detect detailed and comprehensive ground deformation due to their low spatial resolution. In contrast, InSAR can provide surface deformation measurement at meter-scale spatial resolution. Preliminary results of the land subsidence in LYB during 2008–2010 have been previously reported (Yang et al., 2016). This research addressed several challenges in applying InSAR techniques, such as decorrelation in the farmland and mountainous regions, and tropospheric delay artefacts. In addition, data from both C-band Envisat and L-band ALOS-1 PALSAR were exploited to enhance deformation measurements. So, this research is fourfold: (i) large coverage surface deformation mapping using multi-frame, multi-track SAR data, (ii) comparison of InSAR results from multiple sensors with different headings, looking angles and

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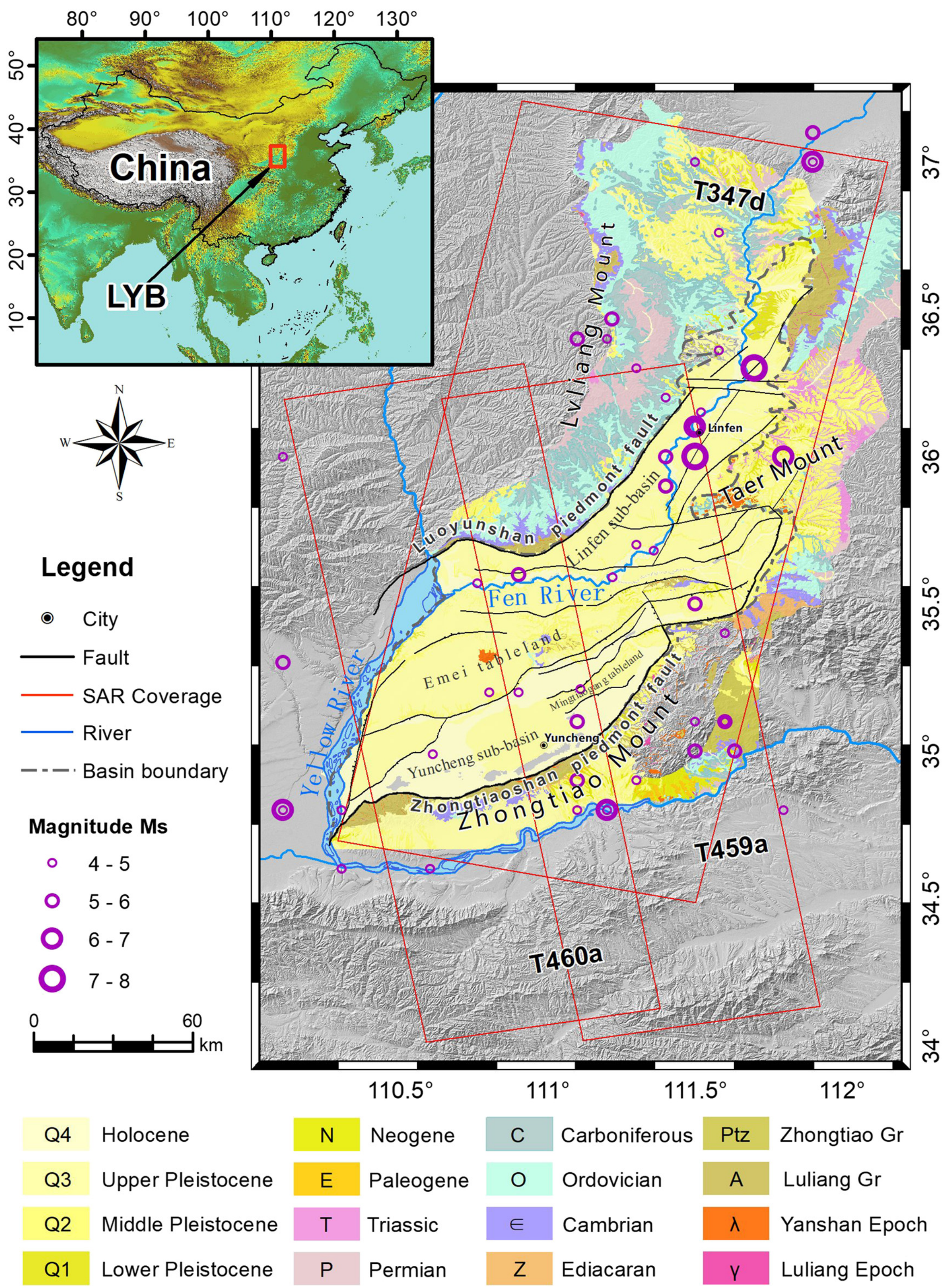

Fig. 1. Shaded relief Map of the Linfen-Yuncheng Basin (LYB). Red polygons show the coverage of the three SAR tracks, grey dashed line outlines the area of LYB, and black lines show the active normal faults. The epicenters of earthquakes with magnitude greater than M 4 that occurred from 1831 BCE to 2016 are shown with purple circles. The inset shows the location of LYB. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

wavelengths, (iii) InSAR results from different tracks and sensors were then merged for basin-wide deformation analysis of the entire LYB by considering the relative offsets in the overlapped regions and the absolute offsets, as determined by leveling and GPS measurements, and (iv) interpretation of the mechanisms of different deformation fields within the LYB at a variety of spatial scales.

2. Geological setting

2.1. Geomorphology

In Fig. 1, LYB is bounded by the Lvliang Mount to the northeast and the Zhongtiao Mount to the southwest. Taer Mount, Emei tableland,