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Recent ground fissures in the Hetao basin, Inner Mongolia, China

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ABSTRACT

Ground fissures are a geological hazard with complex formation mechanisms. Increasing amounts of human activity have created more ground fissures, which can destroy buildings and threaten human security. Some ground fissures indicate potentially devastating earthquakes, so we must pay attention to these hazards. This paper documents recently discovered ground fissures in the Hetao basin. These ground fissures are located along the frontal margins of the terraces of the Sertengshan piedmont fault. These fissures are 600–1600 m long, 5–50 cm wide, and at most 1 m deep. These ground fissures emerged after 2010 and ruptured newly constructed roads and field ridges. The deep geodynamic mechanisms within this extensional environment, which is dominated by NE-SW principal compressive shear, involve N-S tensile stress, which has produced continuous subsidence in the Hetao basin and continuous activity along the Sertengshan piedmont fault since the late Quaternary. Trenches across the ground fissures reveal that the fissures are the latest manifestation of the activity of preexisting faults and are the result of creep-slip movement along the faults. The groundwater level in the Hetao basin has been dropping since the 1960s because of overexploitation, resulting in subsidence. When the tensile stress exceeds the ultimate tensile strength of the strata, the strata rupture along preexisting faults, producing ground fissures. Thus, the Sertengshan piedmont fault planes are the structural foundation of the ground fissures, and groundwater extraction induces the development of ground fissures.

1. Introduction

Ground fissures involve the rupturing of rock or soil at the surface of the Earth by natural factors (crustal motion, water action, etc.) or human factors (water pumping, mine exploitation, etc.). Some ground fissures are related to earthquakes and can be seismic precursors or residual deformation after an earthquake. Ground fissures destroy buildings on the ground surface and underground, including residential buildings, roads, water supply pipelines, gas pipelines, cultural relics, historic sites, etc. Ground fissures can greatly influence economies and societies and inconvenience residents. The formation mechanisms of ground fissures are complex. Crustal motion and groundwater extraction are regarded as the most important factors. The causes of ground fissures have represented a main topic of discussion at several scientific conferences (UNESCO, 1984; Fisols, 1991; Eisols, 2010). Under the current technical level and understanding of ground fissures, a reasonable setback distance to the ground fissures would be the a priori choice for construction.

Ground fissures have been investigated and documented in several regions around the world, including Arizona, Nevada, New Mexico, and California in the United States and the North China Plain and Fen-Wei basin in China (Eisols, 2010; Geng and Li, 2000; Pacheco-Martínez et al., 2013; USGS, 1995, 1997, 2003). The most serious ground-fissure hazards in China have formed in the Fen-Wei basin, which includes the Shanxi basin in the eastern Ordos block and Weihe basin in the southern Ordos block (Fig. 1). In total, 500 ground fissures have been found in > 50 cities in the Fen-Wei basin since the mid-1990s, and the cities of Xi'an, Datong, Yuci, Lingfen and Yuncheng have experienced the most serious ground-fissure hazards (Peng et al., 2007). The > 200 ground fissures in the Weihe basin are primarily distributed around active normal faults and are generally parallel to these faults (Peng and Deng, 2009). In Datong city in the Shanxi basin, > 10 ground fissures have been found since 1983. These NNE-SSW to NE-SW striking fissures cut across the city area and destroyed buildings, roads, and underground pipelines (Xu et al., 1994). Most studies have concluded that the ground fissures in the Fen-Wei basin are caused by active faults or blind faults and not by groundwater extraction (Xu et al., 1994; Chen and Wu, 1996; Jiang et al., 1997; Wu et al., 2003). However, the study by the Institute of Geology, China Earthquake Administration, found that the ground fissures in Datong city are mainly caused by groundwater extraction and are unrelated to tectonic activity (Institute of Geology, China Earthquake Administration, 1992).

Different views exist regarding the causes of ground fissures. The view that ground subsidence causes ground fissures was popular in the

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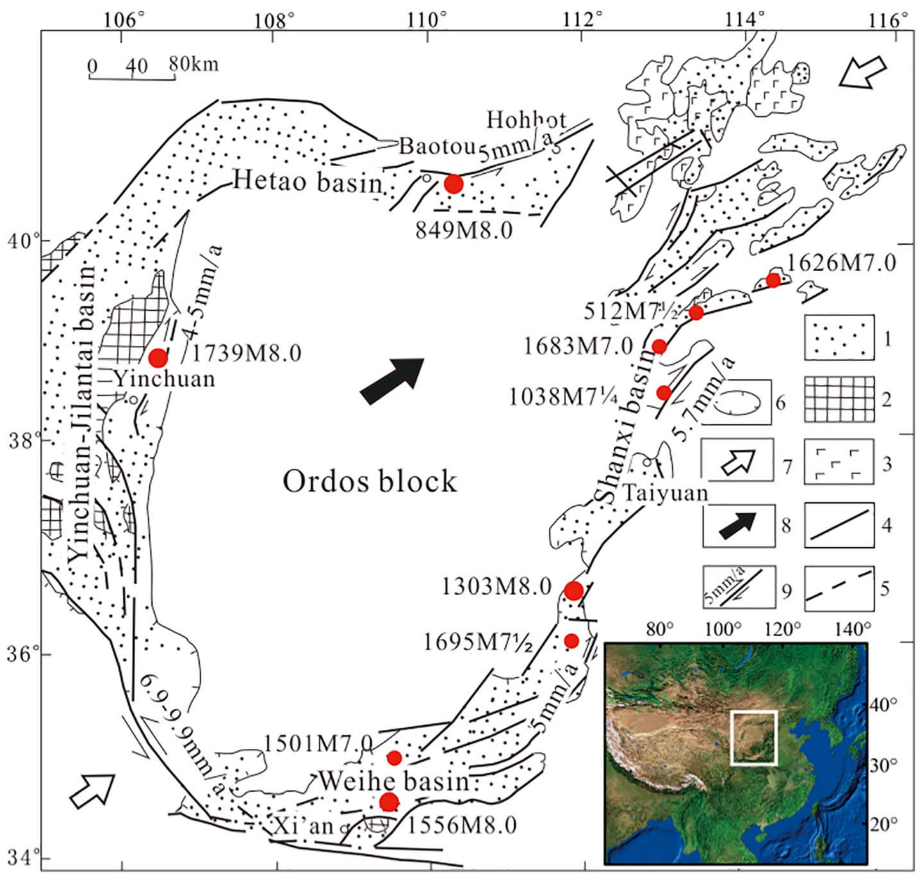

Fig. 1. Tectonic pattern of the Ordos block and its adjacent regions: 1. depressed area; 2. upwelling area; 3. basalt; 4. fault; 5. buried fault; 6. basin boundary; 7. regional stress orientation; 8. block movement direction; 9. strike-slip fault and the Holocene slip rate.
(Modified from the Research Group on Active Fault System around Ordos Massif, 1988; historical data from Jiang et al., 2000)

early 1980s (Yi, 1984; Zhong, 1986). This view states that groundwater extraction causes the nonuniform subsidence of the surface. When the stress that is produced by the nonuniform subsidence of the surface exceeds the strain limit of the soil, ground fissures form. However, with further research, more researchers now believe that faults produce and control ground fissures. Thus, ground fissures are thought to be the surface expression of subsurface faults. However, groundwater extraction has accelerated ground-fissure development (Li, 1992). Additionally, the extensional environments of basins can promote the development of ground fissures (Wu and Liao, 1990; Li, 1992).

As peripheral active fault-system basins around the Ordos block, the Hetao and Weihe basins exhibit similar tectonic structures (the Research Group on Active Fault System around Ordos Massif, 1988). The two basins are Quaternary extensional graben basins that are related to upper-mantle uplift and are totally controlled by Holocene normal faults (He, 2015). Large destructive earthquakes have historically occurred in both basins (Jiang et al., 2000). However, unlike the frequent reports of ground fissures in the Weihe basin, few ground fissures have been reported in the Hetao basin. This paper documents ground fissures along the Sertengshan fault in the Hetao basin. These ground fissures are located along the frontal margins of the T1 and T2 terraces of the Sertengshan piedmont fault. The fissures are 600–1600 m long, 5–50 cm wide, and at most 1 m deep. These ground fissures emerged after 2010 and ruptured newly constructed roads and field ridges. We dug trenches across the fissures and studied the hydrogeological data, regional tectonic dynamics, and stress field data to determine the genesis and evolution of these ground fissures.

2. Tectonic setting

The Ordos block is a unique uplifted region that contains little interior deformation. The extensional Shanxi and Yinchuan-Jilantai basins, which are characterized by right-lateral shear, lie on the eastern and western sides of the Ordos block respectively. The extensional Weihe and Hetao basins, which are characterized by left-lateral shear, lie on the southern and northern sides of the Ordos block respectively. Transpressional left-lateral arcuate faults are located along the southwestern side of the Ordos block (Fig. 1; the Research Group on Active Fault System around Ordos Massif, 1988; Jiang et al., 2014). The NE compression of the Tibetan Plateau to the Ordos block from the southwestern side leads to the high strike-slip rates in the Ordos peripheral fault system (Fig. 1). Over the past 1500 years, 10 disastrous earthquakes with $M \geq 7$ occurred in the Ordos peripheral faults system, four of which were M8.0. The 1556 CE Huaxian M8.0 earthquake in the Weihe basin caused the largest number of deaths in the worldwide historical record (Fig. 1; Jiang et al., 2000). Many large cities, four of which are provincial capitals with millions of residents, are located in the Ordos peripheral fault system. Potential earthquakes in this location must be considered.

The Weihe basin contains 6500 m of Cenozoic sediments and > 1300 m of Quaternary sediments. This basin is controlled by the northern margin faults of the Qinling and Huashan piedmont faults. The Hetao basin is located between the Ordos block and the Yinshan Mountains. The basin is bounded to the west by the Langshan fault and to the east by the Helingeer fault. The northern margin of the basin is marked by the Sertengshan piedmont fault, Wulashan piedmont fault, and Daqingshan piedmont fault; and the southern margin of the basin is marked by the northern margin fault of the Ordos block. The Hetao basin is oriented in an E-W direction and is 440 km long E-W and 40–80 km wide N-S. The topography of the east-west high-low of the Hetao basin is 1040–990 m above sea level. The maximum thicknesses of the Cenozoic and Quaternary strata are 12,000 and 2400 m respectively, and these strata are located in the western area of the basin.

The faults along the northern margin of the basin greatly moved during the Quaternary. The mountains to the north of the faults uplifted, and the Hetao basin declined during the Quaternary. The