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Characteristics and mechanism of the Longyao ground fissure on North China Plain, China

Jianbing Peng [a,b,c,*], Jishan Xu [d], Runyong Ma [a], Feiyong Wang [a]

[a] School of Geology Engineering and Geomatics, Chang'an University, Xi'an 710064, China
[b] Institute of Geo-hazards Mitigation, Chang'an University, Xi'an 710064, China
[c] Key Laboratory of Western Mineral Resources and Geological Engineering, Ministry of Education, Chang'an University, Xi'an 710064, China
[d] China University of Mining and Technology, Xuzhou 221116, China

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ABSTRACT

Among more than 1000 ground fissures developed over the past 30 years having induced severe geohazards in the North China Plain, the Longyao ground fissure in Hebei Province is famous for its longest length and causing the worst damage and widest influence in this region. In order to reveal the origin of its formation, the geological background, developmental characteristics, and genetic mode of the Longyao ground fissure were investigated in detail by geological surveys, measurements, trenching, drilling and seismic exploration. This fissure has a total length of 39 km and is characterized by normal fault extension, left-lateral slip, and dominant along-polyline distribution. These characteristics are well consistent with its underlying fault — the Nei-jv fault. The fissure causes the damage to buildings (structures) along a polyline and in the form of a horizontal tensile crack, subsidence, and shear failure. According to the trenching, drilling and shallow seismic profiling, this fissure possesses the characteristics of synsedimentary faults reflecting the historical stages of fissure activities. Regarding its genesis, this fissure was generated under the coupling action of multiple factors, which took shape after the earthquake, and was enlarged under the action of groundwater pumping. The regional extension first caused a fracture system in the surface strata, and then the action of seismic activities started to control the fracture, and finally the pumping action of excessive groundwater and other influential factors promoted the formation of the current ground fissure.

1. Introduction

Ground fissure is a type of geohazard that occurs after the soil-rock bodies on the ground surface are fractured (Jianbing et al., 2007; Peng, 2012; Rogers, 1967; Xu et al., 2015). Ground fissures are usually found on plains or basins where tectonic and human activities are active, such as the southwest America basins, the Aguascalientes Valley in México, the Gangetic Plains in India, the West Asian valleys, and the Somalia Peninsula in northeast Africa (Bankher and Al-Harthi, 1999; Baruni, 1994; Hauksson, 1983; Rogers, 1967; Pacheco-Martinez et al., 2013).

On the North China Plain, more than 1000 ground fissures are distributed on about 700 sites (Xu et al., 2015). The longest and most active one among them is the Longyao ground fissure.

Survey investigations and research on the geohazards in Longyao started in the 1960s. Some researchers believe that the activity of the Longyao fissure was probably correlated with earthquakes. Relevant research worldwide shows that ground fissures are correlated with earthquakes to some degree, such as the 1988 Saguenay earthquake in Canada (Ms 8.0) (Tuttle et al., 1990), 1989 Loma Prieta earthquake in California (Ms 7.1) (Ponti and Wells, 1991), 1995 Egio earthquake in Greece (Ms 6.1) (Lekkas et al., 1996), and 2010 Yushu earthquake in China (Ms 7.1). These earthquakes induced different scales of surface fractures (ground fissures) in the formation, accompanied by the occurrence of sand-soil liquefaction. To some extent, the ground fissures inherited the activity characteristics of seismogenic faults and would instantly damage the ground surface and buildings. However, after the ground surface was modified by later human activities, the traces of surface ruptures were buried and could not be identified. Nevertheless, these ground fissures will be reactivated by modern crustal deformation or human activities and thereby be exposed on the surface and damage human settlements.

After the 1980s, with the rapid economic development in Longyao, higher demands of water in life and production led to extensive exploitation of groundwater. Such activities induced different degrees of land subsidence and two large subsidence funnels separated by a fault were formed there (Xu et al., 2008): the Ning-bai-long land subsidence funnel mainly induced by exploitation of shallow groundwater (Fig. 1D1)

* Corresponding author at: School of Geology Engineering and Geomatics, Chang'an University, Xi'an 710064, China.
E-mail addresses: dicexy_1@chd.edu.cn (J. Peng), xujs@cumt.edu.cn (J. Xu).

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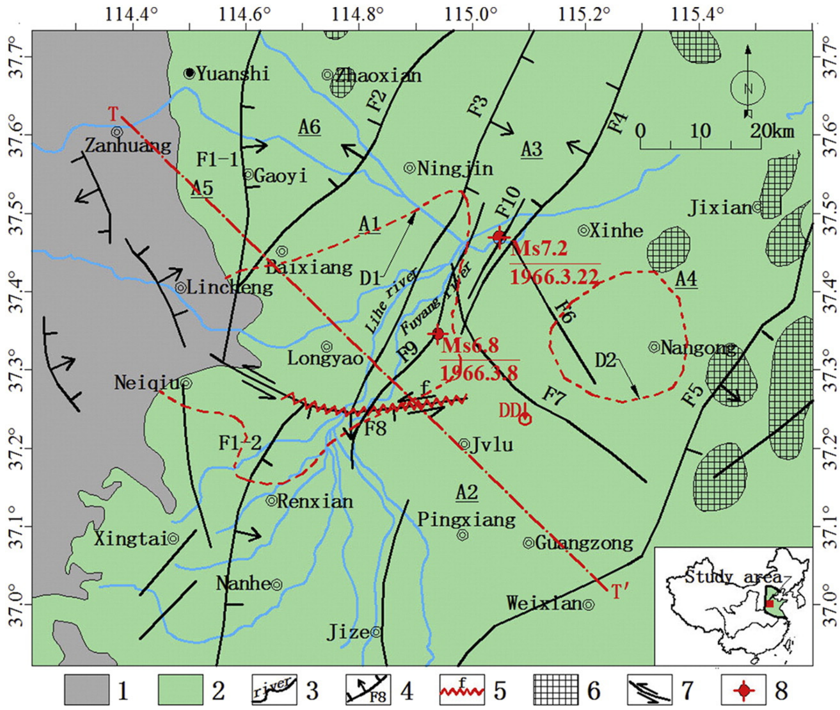

Fig. 1. Brief geologic map in the Longyao region. 1 — Uplifting area, 2 — plain area, 3 — river, 4 — fault, 5 — ground fissures, 6 — bed rock, 7 — fault movement, 8 — earthquake, F1–1 — north Taihang mountain fault, F1–2 — southern Taihang mountain fault, F2 — Baixiang fault, F3 — western Shulu fault, F4 — eastern Shulu fault, F5 — Minghuazhen fault, F6 — Xin-nan fault, F7 — Jv-lin fault, F8 — Nei-jv fault, F9 — Niujiaqiao fault, F10 — Baichikou fault, A1 — Ningjin faulted uplift, A2 — Linqing faulted depression, A3 — Shulu faulted depression, A4 — Jixian faulted uplift, A5 — Zanhuang faulted uplift, A6 — Zhaoxian faulted depression, D1 — Ning-bai-long land subsidence funnel, D2 — Jv-xin-gong land subsidence funnel, DD — deep drilling, TT′ — profile line, f — Longyao ground fissures.

and the Jv-xin-gong land subsidence funnel induced by exploitation of deep groundwater (Fig. 1D2). Thus, the researchers studied the correlation between the formation of fissure and groundwater activities and established some interpretation models. However, definite explanation lacks for the response of near-surface ground fissures to historical earthquakes and modern groundwater extraction.

Recent research on another tectonic unit (the Fen-Wei Basin) on the North China Plain showed that besides excessive pumping of groundwater, the occurrence of ground fissures was more associated with the dynamic continental background (Jianbing et al., 2007). The North China Plain constituted of faulted basins since the late Tertiary was also correlated with the formation of ground fissures to some extent. Research on the Rift Valley in Northeast Africa showed that the material upwelling from the upper mantle would control the scale and development of ruptures in the upper crust, thereby inducing seismic, volcanic, and rupture hazards (Ebinger et al., 2010; Nooner et al., 2009; Wright et al., 2006, 2012).

In fact, the Longyao ground fissure was formed in a deeper and wider tectonic background. To further explore the causes of its formation, the authors did field exploration and theoretical analysis to interpret its basic characteristics and illustrate the formation mechanism for researchers in this field.

2. Geological conditions

In terms of geotectonics, the study area is located in the North China Plate (secondary plate) which is different from the plates in the west of China regarding the form and consequence of tectonic movement (Kusky et al., 2007; Tapponnier and Molnar, 1977; Tianfeng, 2013). Since the end of the Cretaceous, the Pacific Plate in the east of China and the Philippine Sea Plate in Southeast China subducted from NEE and SE, respectively, to the Eurasian Continent. The subduction of oceanic plates led to the upwelling and extrusion of high-temperature and low-wave-speed melted or semi-melted materials from the mantle to the crust. Two different consequences occurred at the crust surface layer and deep layer in the North China Plate. First, the crust surface layer became thinner after extension and experienced rift-type faulting, thus forming the NW-SE extension. Second, at deep upper-mantle, the Pacific Plate extruded the Eurasian Plate from the SWW-trending. Thus, the two actions decided the deep force source for the splitting of ground fissure in North China.

The study area is located in the Longyao County (N 37.24°–37.42°, E 114.59°–115.03°), Xingtai City, Hebei Province. It is the southwest end of the Hebei-Hejian-Tangshan strong-earthquake tectonic belt (Yang, 1987) where two destructive earthquakes occurred in 1966: an Ms 6.8 earthquake in March 8th and an Ms 7.2 one in March 22nd. The focal depth was in the range of 10–33 km (below the ground surface). The seismogenic faults were Niujiaqiao fault (Fig. 1, F9) and Baichikou fault (Fig. 1, F10. F9 and F10 have the same trend in Fig. 1, but there is no further evidence to show that they have the same extension length) (the former corresponds to the Ms 6.8, and the latter corresponds to the Ms 7.2; the distance between the two epicenters is 24 km). There is a relationship between the two faults, that is, they are subject to a detachment surface in the upper crust (Meng-Lin et al., 2000).

Regarding the regional geology, Longyao is located in the south of the Jizhong depression of North China Plain subsiding belt, connecting the Ningjin faulted uplift, Xingheng uplift, and Linqing faulted depression (Fig. 1). These normal fault blocks were formed under extension in the Pliocene in East China and experienced phased differential uplifting. No striking surface faulting exists on North China Plain, even at the western limit of the plain (Tapponnier and Molnar, 1977), because the deposition process and the fault formation occurred in the same tectonic environment. The study area is located in the east part of the North China Plain. Several NNE or nearly-EW faults developed there and most were covered by very thick Quaternary strata (Fig. 2, up to 300–550 m). These faults included the Taihang Mountain fault, the eastern Shulu fault, the western Shulu fault, and several secondary faults (Fig. 1). The largest one among them is the Taihang Mountain