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Migrating pingos in the permafrost region of the Tibetan Plateau, China and their hazard along the Golmud–Lhasa railway

Zhenhan Wu[a], Patrick J. Barosh[b,*], Daogong Hu[a], Zhonghai Wu[a], Ye Peisheng[a], Liu Qisheng[a], Zhou Chunjing[a]

[a]*Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing, 100081, PR China*
[b]*P.J. Barosh and Associates, 103 Aaron Avenue, Bristol, RI 02809, USA*

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Abstract

Most pingos in the permafrost region of the high northern Tibetan Plateau form along active fault zones and many change position annually along the zones and thus appear to migrate. The fault zones conduct geothermal heat, which thins permafrost, and control cool to hot springs in the region. They maintain ground-water circulation through broken rock in an open system to supply water for pingo growth during the winter in overlying fluvial and lacustrian deposits. Springs remain after the pingos thaw in the summer. Fault movement, earthquakes and man's activities cause the water pathways supplying pingos to shift and consequently the pingos migrate.

The hazard posed to the new Golmud–Lhasa railway across the plateau by migrating pingos is restricted to active fault zones, but is serious, as these zones are common and generate large earthquakes. Pingos have damaged the highway and the oil pipeline adjacent to the railway since 2001. One caused tilting and breaking of a bridge pier and destroyed a highway bridge across the Chumaerhe fault. Another has already caused minor damage to a new railway bridge. Furthermore, the construction of a bridge pier in the North Wuli fault zone in July–August 2003 created a conduit for a new spring, which created a pingo during the following winter. Measures taken to drain the ground-water via a tunnel worked well and prevented damage before the railway tracks were laid. However, pier vibrations from subsequent train motion disrupted the drain and led to new springs, which may induce further pingo growth beneath the bridge.

The migrating pingos result from active fault movement promoting artesian ground-water circulation and changing water pathways under the seasonal temperature variations in the permafrost region. They pose a serious hazard to railway construction, which, in turn can further disturb the ground-water conduits and affect pingo migration.

Keywords: Migrating pingos; Geologic hazards; Active faults; Golmud–Lhasa railway; Permafrost; Tibetan Plateau

* Corresponding author.
E-mail address: pjbarosh@gis.net (P.J. Barosh).

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1. Introduction

The Tibetan Plateau is an unusually active tectonic region whose great uplift has created the world's only extensive area of mid-latitude permafrost. This vast region has been raised and deformed by the continuing northward underthrusting and compression of the Indian continental plate (Wang et al., 2001; Zhao et al., 1993). This movement results in extensive fault activity in the plateau (Tapponnier and Molnar, 1977; Amijo et al., 1986; Kidd and Molnar, 1990; Yin and Harrison, 2000) and frequent strong earthquakes of magnitude $Ms \geq 7.5$ (Science and Technology Committee of the Tibetan Autonomous Region, 1982; Geology Institute of China Seismological Bureau, 1992; Wu et al., 1993; Lin et al., 2002). The style and magnitude of the fault activity and deformation of the Tibetan crust have been studied by many geologists (Amijo et al., 1986; England and Houseman, 1998; Yin and Harrison, 2000; Chen et al., 2004), but only a few Chinese geologists have researched the hazard of active faulting to engineered construction (Hu et al., 1982; Yi, 1982; Wu et al., 2003) and problems created by permafrost (Cheng, 1990; Cheng et al., 1993) (Fig. 1). The geological hazards of the central Tibetan Plateau are therefore comparatively unknown by international geoscientists and very few are aware of the relations between active faulting and seasonal environmental changes which may result in unusual dangers (Wu et al., 2004). The investigation for the 1142 km long Golmud–Lhasa Railway and its present construction have revealed much about these hazards and their controls, especially the problem of pingos.

The Tibetan Plateau generally rises northward from Lhasa before dropping off towards Golmud and has an average elevation of 4500 m. The higher part forms a rolling treeless tundra drained by the headwaters of the Yangtse River, called here the Tuotuohe, and crossed by the high glacier-studded Tangula and Kunlun Mountains. The plateau has a climate characterized by severe cold weather and large daily and seasonal temperature changes. The annual average temperature is about 7 to 8 °C and the lowest temperature in winter is about −14 to −20 °C in the lower, southern part of the Tibetan Plateau. The higher, northern part, north of the Tangula Mountains, has an annual average temperature of −4 to −5 °C and an average temperature in winter of −10° to −15 °C, with the lowest temperatures in severe winters reaching −30 ° to −35 °C. These conditions have caused a seasonal layer of frozen ground in the southern plateau and permafrost in the northern part. Drill hole data show the thickness of permafrost in the northern plateau is more than 100 m (Cheng et al., 1993; Zhang, 1983; Guo, 1985). The permafrost causes problems of ground deformation from freeze–thaw effects and mass movement and makes it necessary to employ special construction methods and to thermally isolate structures (Cheng, 1990). Unusual problems result from the combination of permafrost and active tectonic movement.

Unusual permafrost features are found to be controlled by active fault zones in the Tibetan Plateau as they affect ground-water flow (Hu and Xu, 1982; Fan and Yuan, 1982). Linear zones of ground deformation from freezing and thawing and extensive broad belts of ground fractures occur along faults to damage structures (Wu et al., 2004). Most importantly, the faults are found to control zones of pingos (Fig. 1). Pingos of different shapes, sizes and characteristics form extensively in winter and spring in the permafrost region (Wang, 1983; Fan and Yuan, 1982), and some that are protected by soil and clay last into the summer and autumn as well (Shang and Ding, 1982; Hu et al., 1982). These ice-cored domes normally drain in summer and autumn by linear alignments of springs (Hu et al., 1982; Wu et al., 2003, 2004). A geological survey of active faults and geological hazards along the Golmud–Lhasa railway, conducted between March 2001 and July 2004, gathered abundant data on the control and evolution of pingos in the permafrost region.

Pingos are found to develop under different conditions and controls in the northern-latitude permafrost regions of the world. Pingos are small conical-shaped hills composed of a core of massive ice overlain normally by about a meter of silt, sand and peat (Porsild, 1938). They are confined to nearly level, poorly drained areas in basins of former lakes in Alaska, where they range from 3 to 16 m in height (Hopkins et al., 1955) and some on the Mackenzie delta area of Canada reach upwards of 50 m in height and 300 m in diameter. Small pingos may develop