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# Mining-induced ground deformation in tectonic stress metal mines: A case study

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ABSTRACT

In situ monitoring data of ground deformation in the western area of Chenchao Iron Mine were collected over eight years. Results were analysed to conduct a preliminary investigation into the ground movement induced by underground mining: (1) in the northeastern area, the ratios of horizontal to vertical displacement increase gradually, and the horizontal displacement may be as much as an order of magnitude larger than the vertical displacement at a large distance, which induces regional horizontal movement. Curves of the ratio of horizontal to vertical displacement with respect to time can be categorised as: fluctuation-, fallback-, convergence-, and increase-types; (2) in the mine road, stack-site, and southern area around the high-voltage tower, ground deformation can be divided into two stages: stable deformation and rapid deformation. While in the southeastern area of the transport tunnel, service shaft, and road tunnel, it can be divided into three stages: stable deformation, rapid deformation, and subsequent stable deformation. Three categories are found in the time–displacement curves: folding-, S-, and linear-types. (3) The ground deformation of the footwall underwent a significant change in January 2010, because the large horizontal tectonic-stress in the mine was released at that time. Surrounding rock masses were subjected to toppling deformation along the major structural plane in the northeastern area, while tensile deformation occurred perpendicular to the major structural plane in the northern area.


## 1. Introduction

In metal mines, ground deformation is influenced by many factors, such as geological structure, in situ stress, existence of ore bodies, the hydrogeological conditions, and the method of mining (Brady and Brown, 1985; Cai et al., 2000; Bruneau et al., 2003a, 2003b; Li et al., 2004; Ma et al., 2007; Liu et al., 2011; Zhao et al., 2013b; Fu et al., 2015), leading to an obvious difference between the ground deformation induced by underground mining of metal and coal mines, and thus has distinctive characteristics. For instance, in Copper Mine, Mount Isa, Australia, under the influence of the W41 and W42 faults, there is a tension zone resulting in vertical displacement around the shaft at level 11, and therein, vertical displacements appear offset (Bruneau et al., 2003a, 2003b); In the Jinshandian Iron Mine, China, deep deformation of the rock mass may cause fracture, and is thus discontinuous. However in the ground, the deformation is continuous (Fu et al., 2015); in the Longshou Mine, under the influence of open-pit slope extrusion and underground mining, buckle folding deformation occurs at the pit bottom, and the central part of the pit bottom is rising while the surrounding areas are subsiding (Zhao et al., 2011, 2013a).

More complex factors cause the ground deformation induced by underground metal mining to be complicated, especially in tectonic stress metal mines which have suffered from many intensive tectonic movements in the formation of their orebodies (He, 2003; Huang, 2008). Such metal mines may frequently be subjected to horizontal tectonic stresses greater than those applied in the vertical direction (up to several tens of times higher), thus the mining-induced secondary stress field can significantly affect the ground deformation characteristics. Chenchao Iron Mine is typical of the tectonic-stress metal mines in China (Chen and Xia, 2013; Huang, 2008). In its western area, as reported by Chen et al. (2012), ground collapse occurred suddenly with no evident pre-warning on 17 April, 2006, and resulted in a 4140 $m^2$ subsidence area and severe economic loss. Furthermore the subsidence area spread rapidly as the mining depth increased (Chen et al., 2013). Excessive ground deformations were measured at greater than 10 metres from the mine road of the footwall: ground subsidence and cracking spread to the southeast area around the transport tunnel: this has cost more than ¥30 million in maintaining the transport tunnel to date. Analysis of monitoring results revealed that ground deformation may differ in mining-influenced areas or may remain relatively unchanged, even showing distinctive characteristics compared to those seen in other mines. Thus comprehensive investigation of mining-induced ground deformation from the ground collapse (17 April, 2006) to date will facilitate more effective safe production in Chengchao Iron Mine,

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and further may possibly offer a reference to other tectonic stress metal mines.

In this study, in situ monitoring of ground deformation in the western area of the Chenchao Iron Mine was conducted for an eight year period, including horizontal and vertical displacement information. Firstly the distribution characteristics of the ratio of horizontal to vertical displacement and characteristics of the time–displacement curves were investigated. Then, based on the relative position and orientation of the maximum principal stress, the strike of the major structure plane, and the strike of the mined-out area in the footwall, the failure process affecting the rock mass in mining-induced areas was deduced. Eventually three kinds of the time–displacement curves types were found, and the corresponding curve characteristics were studied to deduce the failure mechanism of the associated deep rock masses.

## 2. Description of the mine

### 2.1. Distribution of rock masses

Chengchao Iron Mine lies in a complex geological environment with either a hilly or mountainous topography, and all the known orebodies mostly existing in gully areas. The rock mass surrounding the hanging wall near the ore body is diorite, with hornstone found at greater distances therefrom; the footwall is high-quality granite, which is also the main rock mass in the mine. The surrounding rock mass, from the top of the ore body to its outcrop between the hanging wall and the footwall, is a metamorphic belt composed of marble and hornstone (see Fig. 1).

### 2.2. Geological structure

Three groups of structural planes are found in the granite of the footwall (Chen et al., 2013), respectively striking N 8°W, N 63°E, and N 61° W, all of which were designated as compression-shear structure planes. Among them, that striking N 8°W was the most developed, in accordance with the observed tensile fault with a NS strike in the Chengchao area, and it had a dip angle of about 82° to the NE with a spacing of about 0.1 m: its plane was smooth and slickensided, with high persistence. The second strikes N 63°E, and had a dip angle of about 80° to the NW with a spacing of about 0.25 m, and its plane was smooth and slickensided, with intermediate persistence. That striking N 61°W was filled by clay, which dipped at 38°.

### 2.3. Hydrogeological conditions

The mining area lies within a continental climate zone, with heavy rains, and an average annual rainfall of 1331 mm (Huang, 2008). The forms of groundwater in the mining area are fissure and karst water: the water-rich zone is mainly distributed from 0 to −180 m depth. Currently, the replenishment source of the groundwater is atmospheric precipitation, and surface water in the mining area mainly flows into the collapse area by means of surface runoff, small amounts of which, infiltrates and become groundwater through vertical fissure flows. The permeability of the granite gradually increases from the north to the south and from deep ground to shallow surface: it reaches its maximum value in the rock mass adjacent to the transition zone between the granite and marble formations.

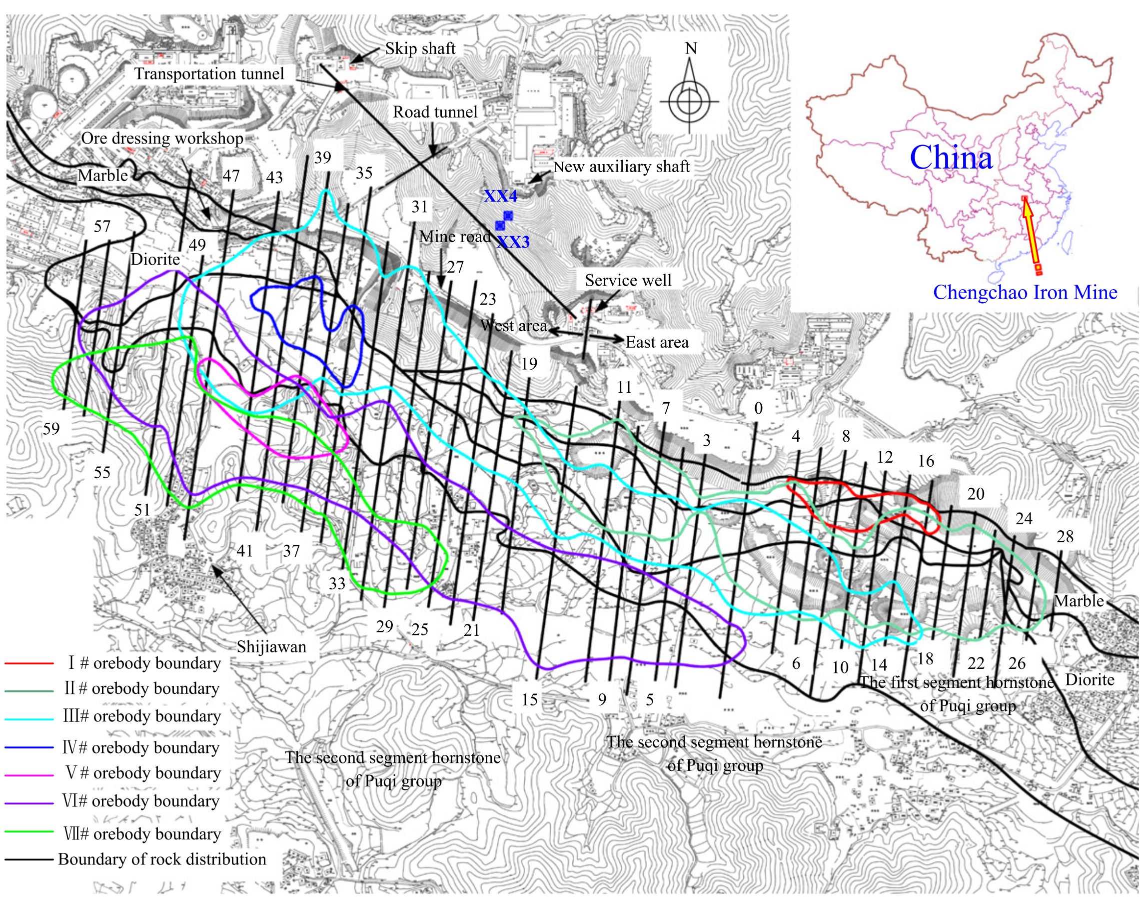


**Fig. 1.** Distribution of rock masses in the mine (the black numbers 0,3, 4, 6, 8, to 59 refer to exploration lines).