**Title 1**: Integrated monitoring network and numerical simulation for a deep slope open-pit mine

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**Abstract**:

The Changshanhao gold open-pit mine experienced a significant horizontal displacement of 3.5 m and a vertical displacement of 1.0 m on the northern wall in 2021. A series of cracks, spanning 300 m in length and 300 mm in width, emerged along the bench strike, aligning with both the bedding structures and geological faults. This occurrence poses a substantial threat to the mine's operational safety and slope management. Consequently, an integrated monitoring network is proposed to comprehensively predict and mitigate open-pit mining hazards. The monitoring network comprises seismicity monitoring, inclinometers, Radar, GNSS, and RTK manual measurement. Analysis of monitored seismic events shows the pattern aligned with the existing anti-inclined bedding planes, indicating microcracks located hundreds of meters behind the slope surface. To gain a comprehensive understanding, a numerical model has been developed for the back-analysis of historical slope movement and failure, accounting for the anisotropic characteristics of consistent anti-bedding structures and a complex geological fault model. The improved unified constitutive model (ICUM) has been applied in the numerical simulation, yielding results that exhibit a robust correlation with historical slope failure location and magnitudes. Three **distinct failure mechanisms** have been captured in the modeling process. In response to these findings, *an early-warning platform* is underdeveloped with the aim of integrating multiple data sources to forecast future slope hazards to enhance overall mining safety. This paper underscores the meticulous analysis of microseismic data, inclinometers data and numerical modelling results, most importantly, **an early-warning criteria** has been proposed in this paper for forecasting the hazardous event.

**Keywords:**

Slope Monitoring, Micro Seismicity, Early-warning Platform, Numerical Modelling, Open-pit Slope

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Introduction

Slope instabilities of varying magnitude frequently threaten the life, health or property of humans in all parts of the world. Massive rock slope failures alone, including rock slides, rock avalanches and rock falls caused 58% of the global disasters from single landslide events (downslope mass movements in general) in the last millennium. Under the current ongoing climatic changes, landslide risk is expected to increase critically and therefore, cost-efficient mitigation measures with a wide applicability are needed. Such measures as alarm systems or evacuation of endangered zones require reliable forecasts of the imminent event. Local monitoring systems provide important data that can be used to predict the time of slope failures. However, to meet social, economic and scientific requirements, existing forecasting methods need amendments in the real-time processing of modern monitoring data and a conceptual basis that is valid for diverse failure processes.

Changshanhao Gold Mine is located in