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Physical Damage Assessment in Iron Caves Using Resistivity-Based Predictive Models: Insights from Plateau N4, Carajás, Brazil.

Marcelo Roberto Barbosa (Federal University of Rio de Janeiro), Pedro Henrique Alves Novaes, Renata Schmitt, Vithor Di Donato (Federal University of Rio de Janeiro), Maria Filipa Perez da Gama, Patrick Dal' Bó (CPGA - UFRJ), Maurícius Nascimento Menezes, Francisco Manoel Tognoli (Federal University of Rio de Janeiro), Eloá Oliveira, Carlos Calle, Ramon Araujo, Marco Braga (CPGA-UFRJ)

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Introduction

The Carajás Mineral Province is widely recognized not only for its extensive iron ore deposits but also for its high concentration of natural underground cavities. Although the caves also occur in iron mines in other regions of Brazil and in countries such as Canada and Australia, studies on structural stability and potential physical damage due to proximity to operations need to be continually updated, despite the growing number of technical and scientific studies observed in the last decade. While environmental laws and regulations concerning natural underground caves vary across countries, there is a broad consensus that these formations require specific technical investigations to ensure both the safety of those who visit them as well as the preservation of their ecosystems. The study area is in Carajás, Brazil, in Serra Norte, Plateau N4, at the N4E-0026 iron cave within a mining area operated by Vale S.A. This cave was monitored over four years as part of a Pilot Project in collaboration with environmental agencies, allowing for a robust investigation into the evolution of breakdown mechanisms leading up to the cave's collapse.

Method

The study is based on the integration of a direct approach, through geostructural mapping of the cave, and an indirect approach, via the acquisition and interpretation of electrical resistivity sections. The objective was to understand and model the stability dynamics of the caves present in the plateau. The methodology consisted of combining two previously developed and applied approaches at the same cave N4E-0026: (i) a predictive model of physical damage based on three types of resistivity contrasts – Low-Resistivity Contrast (abrupt shifts from a high-resistivity background to low resistivity zones with $\rho < 761$ ohm-m), High-Intermediate Resistivity Contrast (identified when parts of the cave ceiling or walls are located within a transitional zone with resistivity values near 2718 ohm-m), and Angular-Resistivity Contrast (identified when the electrical signature changes abruptly from a subhorizontal to a subvertical geometric pattern); and (ii) a model based on breakdown mechanisms in iron caves, which identified four distinct processes during the Pilot Project: Fragment Downfall, Block Downfall, Controlling Structure Reactivation, and Open Discontinuity Movement.

Results and Conclusions

The results indicated that Low-Resistivity Contrast, associated with moisture and located in the ceiling, revealed weakness zones susceptible to Block Downfall mechanisms. High-Intermediate Resistivity Contrast zones, coinciding with the edges of the cave spans – whether on the ceiling or walls – indicated fragile portions of the rock mass, resulting in both Block Downfall and Fragment Downfall mechanisms. In areas with Angular-Resistivity Contrast, it was possible to identify electrical patterns whose geometry corresponds to discontinuity plans, where Controlling Structure Reactivation mechanisms were observed. The correlation between these two models allowed for a deeper understanding of the influence and presence of breakdown mechanisms triggered during mining advancement, which resulted in the observed physical damage. Furthermore, there was a precise match between the structurally weakness points indicated by the breakdowns and the fragility zones highlighted through geophysical resistivity contrasts.