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Seismic Refraction Modeling for Fractured Rock Systems: A Resolution and Sensitivity Analysis Using pyGIMLi Library

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Introduction

This work presents a numerical modeling study of the seismic refraction method to evaluate its resolution and sensitivity in fractured basement terrains, a common yet challenging geological setting for hydrogeological investigations in certain Amazonian regions. In these environments, groundwater resources are often associated with fracture zones in igneous and metamorphic rocks, requiring reliable geophysical methods for their characterization. The seismic refraction method, widely used for near-surface studies due to its cost-effectiveness and rapid deployment, shows potential for mapping fractured aquifers; however, its resolution and sensitivity in such heterogeneous media require further investigation.

Method

The computational modeling is performed using the pyGIMLi framework, a versatile open-source library for geophysical inversion and modeling, which allows for flexible parameterization and efficient forward calculations in complex 2D/3D media. A quantitative resolution and sensitivity analysis is conducted through systematic variations in velocity models, evaluating detection thresholds and inversion uncertainties. This approach explores the relationship between velocity model perturbations and key seismic survey parameters, such as geophone spacing and noise levels in the data. By simulating realistic fracture scenarios under different acquisition conditions, we assess the method's ability to detect and characterize fractured zones, as well as its limitations in hard-rock terrains.

Conclusions

The results aim to provide practical informations on the feasibility of applying refraction seismics in hydrogeological surveys, supporting decision-making for groundwater exploration in fractured rock systems. Additionally, the study discusses optimal acquisition geometries and interpretation strategies to enhance the method's effectiveness in such environments.