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Analyzing the status of the Kalateh Khij fault using gravity data and genetic algorithm

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Extended Abstract

Summary

This study presents a comprehensive methodology for estimating the characteristics of geological faults with finite thickness using gravity data and a genetic algorithm. Gravity methods are widely employed for subsurface mapping in oil and gas exploration, mining, and structural geology, where faults represent key tectonic features. The main aim of this research is to use a global optimization approach for accurate and robust estimation of major fault characteristics, including thickness, upper depth, lower depth, and dip angle, even in the presence of significant noise. Both synthetic and real gravity datasets were analyzed. Synthetic gravity data were generated for normal and reverse faults, with and without Gaussian noise up to 10%. The applied genetic algorithm framework efficiently recovered model parameters, demonstrating errors generally below 1% for noise-free data, below 6% for 5% noise, and below 10% for 10% noise. To further improve estimation quality, a second-order moving average filter was employed, especially for reverse faults under high noise-achieving errors below 2%. For real-world validation, the proposed inversion approach was applied to gravity measurements collected over the Kalateh Khij fault in northeast Iran. Fieldwork involved acquiring eight perpendicular gravity profiles along the fault strike, with data collected over a region spanning from latitudes 4055893 to 4056757 and longitudes 345870 to 346670 in the UTM metric system using a CG5 gravity meter. The results from analyzing the gravity data were in good agreement with geological evidence, confirming the robustness of the methodology.

Introduction

The gravity method is one of the oldest geophysical techniques for detecting and characterizing buried geological structures. However, the inversion of gravity data for faults of finite thickness is a complex, nonlinear, and ill-posed problem, especially in the presence of noise. This study investigates the effectiveness of genetic algorithm as a global optimization tool for gravity data inversion, aiming to deliver stable and automated solutions for both synthetic and real cases.

Methodology and Approaches

The fault model is represented by an inclined slab of finite thickness. Unknown characteristics of the fault including the thickness, upper depth, lower depth, and dip angle in the genetic algorithm are each coded as a 16-bit chromosome within. The optimization iteratively minimizes the least-squares misfit between observed and modeled gravity anomalies. Sensitivity analyses confirm the importance of population size and search interval in convergence and accuracy. The algorithm is validated first by synthetic datasets (with varying noise), then by real gravity data of the Kalateh Khij fault, before and after noise suppression using a moving average filter.

Results and Conclusions

The proposed method was first validated by a suite of synthetic models. Without noise, the genetic algorithm successfully recovered the fault characteristics with less than 1% relative error. For synthetic datasets with 5% noise, the inversion still provided reliable results, with errors in the estimated characteristics generally remaining within 6-10%. For the real data covering the Kalateh Khij fault, the results were geologically plausible and consistent with field mapping and borehole data. In this real case, the gravity data were collected along eight survey lines spaced 50 meters apart, and gravity measurements were made in 88 gravity stations. The inversion outcomes were compared to geological evidence, confirming the method accuracy and practical reliability, and demonstrating the capability and flexibility of genetic algorithms in addressing geophysical data inversion challenges. This study provides a validated and practical workflow for fault characteristics estimation, highlighting the advantages of intelligent optimization in geophysical applications.