



Research article

Airborne Magnetic Data Analysis of Gol-Gohar Mining Complex, Sirjan

Abdolhamid Ansari^{1*}, Abdullah Ezam Ahmady¹, Seyyed Hossein Mojtahedzadeh¹

1- Dept. of Mining and Metallurgical Engineering, Yazd University, Yazd, Iran

(Received: 18 May 2025, Revise: 21 September 2025, Accepted: 08 November 2025)

DOI: [10.22034/anm.2025.23140.1677](https://doi.org/10.22034/anm.2025.23140.1677)

Keywords

Aeromagnetic data
Pseudo-Gravity Transform
Upward Continuation
Tilt Derivative Angle
Gol Gohar Sirjan

English Extended Abstract

Summary

This study presents a comprehensive geophysical analysis of airborne magnetic and pseudo-gravity data from the Gol Gohar iron ore district in Iran. By integrating spectral analysis, upward continuation, tilt angle derivative mapping, and 3D inversion techniques, we aimed to better understand the distribution and depth of subsurface sources and to enhance the delineation of ore-related structures. Spectral results indicate that the magnetic field is dominated by shallow sources at depths between 300 and 600 meters (Spector & Grant, 1970), while the pseudo-gravity data suggest deeper contributions from sources located between 800 and 1000 meters (Ravat, 2007). Multi-level upward continuation effectively suppressed shallow noise and highlighted deeper anomalies, particularly anomalies An1 and An3 (Blakely, 1996). Tilt angle derivative maps, especially those derived from the pseudo-gravity field, provided sharp, noise-free boundaries of the main structures (Salem et al., 2008). Inversion modeling further revealed high-susceptibility volumes extending to about 1500 meters and positive-density anomalies reaching depths over 2000 meters (Li & Oldenburg, 1996). These overlapping zones suggest a common structural and magmatic control over the mineralization processes. The novelty of this work lies in its integrated approach, combining multiple geophysical filters and modeling techniques to build a more accurate and detailed subsurface image. This workflow demonstrates strong potential for application in similar mineral exploration contexts.

Introduction

Airborne magnetic data, alongside transformations such as pseudo-gravity, play a pivotal role in mineral exploration by offering insights into the subsurface distribution of magnetization and density. In the Gol Gohar region, a major iron ore district located within the Sanandaj–Sirjan structural zone, these techniques are particularly valuable for tracing deep-seated mineralized bodies and related tectonic features. One of the main challenges in interpreting magnetic data is the dipolar nature of the Earth's magnetic field, which causes lateral displacement of anomalies and blending of signals from both shallow and deep sources. To address this, geophysicists have developed spectral and spatial filtering techniques aimed at isolating contributions from different depths and reducing the influence of near-surface noise. Power spectral analysis (Spector & Grant, 1970) has long been used to estimate source depths, while upward continuation techniques (Blakely, 1996) help to emphasize deeper anomalies. The tilt angle derivative method (Salem et al., 2008) has emerged as a robust tool for edge detection. Finally, 3D inversion (Li & Oldenburg, 1996) allows quantitative modeling of subsurface susceptibility and density models, yielding a volumetric image of ore-related structures.

Despite many studies of Gol Gohar, the deep structure controlling its Kiruna-type magnetite mineralization

*Corresponding author: E-mail: h.ansari@yazd.ac.ir



remains incompletely characterized. Several near-surface anomalies are known, but it is unclear how (or whether) they connect at depth. This work aims to optimize the geophysical interpretation of Gol Gohar by integrating power-spectral depth estimates, multi-stage upward continuation, pseudo-gravity transformation, tilt-derivative mapping, and 3D inversion. Together, these tools should improve discrimination of shallow vs. deep sources and clarify structural controls on mineralization.

Methodology and Approaches

This study employed a comprehensive geophysical workflow that was applied to both synthetic and real datasets to optimize the interpretation of airborne magnetic and pseudo-gravity data over the Gol Gohar iron ore district. The goal was to distinguish between shallow and deep sources, identify structural boundaries, and construct reliable subsurface models through a combination of spectral, spatial, and inversion-based techniques.

The input datasets were airborne total-field magnetic measurements (already reduced to the pole and residual field) and the corresponding pseudo-gravity grid derived by FFT integration of the magnetic field (constant magnetization assumption). All data were gridded on a common datum. Standard preprocessing included removing the geomagnetic reference field and interpolating to a regular grid.

Before processing the real data, we constructed three synthetic dyke-like models to evaluate filter performance (Table 1). Each model is a vertical prism (dip = 90°) with specified length, width, thickness, depth, and azimuth, representing (1) a deep linear structure, (2) a shallow linear body, and (3) a narrow vertical source. These synthetic models reproduce the linear complexity of Gol Gohar's geology and allow controlled testing of depth filters.

Table 1. Synthetic dyke models used for forward modeling

Model	Dimensions (Length × Width × Depth) (m)	Bottom Depth (m)	Azimuth (°)
Dyke 1	4000 × 200 × 250	550	135
Dyke 2	2000 × 200 × 20	320	90
Dyke 3	500 × 500 × 100	400	0

Power spectrum analysis was then used to estimate the depth of source bodies by converting both magnetic and pseudo-gravity datasets into the frequency domain using a fast Fourier transform (FFT). The radial average of the power spectrum, plotted on a logarithmic scale versus wavenumber, revealed two dominant depth ranges. On the synthetic datasets, shallow magnetic sources (primarily from Model 2) yielded steep high-frequency slopes, while the deeper pseudo-gravity sources (Models 1 and 3) resulted in gentler slopes at low frequencies. Similarly, spectral analysis on real field data revealed that the magnetic field was dominated by shallow sources, with depths between approximately 300 and 600 meters, whereas the pseudo-gravity spectrum was influenced by deeper structures estimated to lie between 800 and 1000 meters below the surface.

To further refine the interpretation, upward continuation filtering was applied to both magnetic and pseudo-gravity datasets at progressive elevation steps ranging from 100 to 1200 meters. This filtering technique progressively attenuated short-wavelength components, which are typically associated with near-surface noise, and enhanced the signatures of deeper sources. In the synthetic models, upward continuation effectively isolated deeper structures by eliminating the influence of shallow anomalies. When applied to the real data, lower continuation levels (100–300 meters) retained both shallow and intermediate anomalies, while higher levels (500 meters and above) revealed major deep-seated anomalies such as An1 and An3. Pseudo-gravity data required less continuation to reach this level of clarity, indicating a stronger sensitivity to deeper structures.

Following continuation, the tilt angle derivative (TDR) was calculated to enhance structural boundaries. Defined as the arctangent of the vertical derivative over the horizontal gradient of the potential field, this



operator is particularly effective for edge detection and is inherently scale-independent. On synthetic magnetic data, tilt maps were able to approximate anomaly boundaries, although background noise persisted due to the inherent amplification of high-frequency components. In contrast, tilt maps derived from synthetic pseudo-gravity data were remarkably clean, with well-defined and continuous edges. This trend held for the real datasets as well: the magnetic TDR revealed known near-surface structures but included scattered noise artifacts, while the pseudo-gravity tilt maps showed coherent, noise-free contours that closely matched mapped geological contacts and faults. These results confirmed the superiority of pseudo-gravity TDR in boundary delineation.

Lastly, 3D inversion was performed to reconstruct the spatial distribution of magnetic susceptibility and density contrasts. For magnetic data, the Mag3D software was employed with susceptibility constrained between 0.01 and 0.3 SI, based on known geological properties of the area. For pseudo-gravity data, Grav3D inversion was used to estimate density contrasts, applying a minimum-support regularization to focus the inversion results. The outputs revealed high-susceptibility bodies extending to depths of approximately 1500 meters, aligned with the regional NE–SW structural trend. Correspondingly, high-density bodies were found to extend beyond 2000m depth. The strong spatial overlap between magnetic and gravity anomalies suggests that both intrusive bodies and iron-rich hydrothermal fluids contributed to ore formation, controlled by the same structural framework.

In summary, this integrated methodology, combining spectral, continuation, derivative, and inversion techniques, enabled a more accurate and nuanced understanding of the Gol Gohar subsurface. It not only improved depth estimates and boundary clarity but also provided a consistent structural framework connecting shallow and deep mineralized zones. Among the various techniques, the pseudo-gravity transformation and its application in tilt angle mapping proved particularly effective in enhancing the visibility and geometry of deep-seated, edge-like sources.

Results and Conclusions

The integrated geophysical analysis of the Gol Gohar dataset produced consistent and interpretable results regarding the vertical distribution of sources and their structural configuration. Power spectral analysis of the residual magnetic field revealed that shallow sources dominate the high-frequency components, corresponding to depth ranges of approximately 300 to 600 meters. These depths align well with previously known near-surface magnetite mineralization. In contrast, the spectral response of the pseudo-gravity data highlighted deeper contributions, with peak energy concentrated at lower frequencies, suggesting source depths in the range of 800 to 1000 meters. Upward continuation filtering, applied at elevations between 500 and 1000 meters, effectively attenuated short-wavelength, near-surface anomalies, particularly those associated with outcropping ore bodies and enhanced the expression of deeper, regionally significant anomalies such as An1 and An3. These anomalies exhibited stable and coherent geometries at higher continuation levels, confirming their deep-seated origin.

The application of the tilt angle derivative to the pseudo-gravity field further improved boundary resolution. Resultant tilt maps exhibited crisp, noise-free edge definitions, with the $\theta = 0$ contours delineating elongated structures that coincided with known tectonic trends, including mapped faults and intrusive dike systems. Collectively, the filtering techniques suggest a two-tiered source model: a shallow, magnetized horizon above ~500 meters, and deeper, more massive bodies centered around 1000–1500 meters.

Three-dimensional inversion modeling reinforced these interpretations. The magnetic inversion revealed extensive volumes of high magnetic susceptibility reaching depths of ~1500 meters, which spatially coincide with regions of negative magnetic anomaly, characteristic of vertically extensive magnetite accumulations. Corresponding density inversion results indicated positive density contrasts extending beyond 2000m depth. Crucially, there is significant spatial overlap between the zones of elevated magnetic susceptibility and increased density, suggesting a shared structural control. This overlap implies the presence of deep-seated, magnetite-rich magmatic intrusions and the migration of iron-rich hydrothermal fluids along the same



conduits. Such a configuration supports a combined magmatic–hydrothermal model for iron oxide mineralization in the district.

In conclusion, the multi-method framework adopted in this study yielded a far more comprehensive structural interpretation than any single technique in isolation. The pseudo-gravity transformation, especially when coupled with tilt derivative filtering, proved particularly effective in isolating and delineating deep, steep-edged anomalies with minimal noise interference. Power spectrum and upward continuation methods provided consistent and reliable depth estimates, while 3D inversion enabled quantitative reconstruction of the geometry and physical properties of subsurface bodies.

References

- [1] Blakely, R. J., Connard, G. G., & Curto, J. B. (2016). Tilt derivative made easy. U.S. Geological Survey.
- [2] Jekeli, C., Erkan, K., & Huang, O. (2010). Gravity vs pseudo-gravity: A comparison based on magnetic and gravity gradient measurements. In D. Gubbins & E. Herrero-Bervera (Eds.), *Gravity, Geoid and Earth Observation* (IAG Symposia, Vol. 135, pp. 123–127). Springer.
- [3] Li, Y., & Oldenburg, D. W. (1996). 3-D inversion of magnetic data. *Geophysics*, 61(2), 394–408.
- [4] Portniaguine, O., & Zhdanov, M. S. (1999). 3-D focusing inversion of magnetic data. *Geophysics*, 64(3), 874–887.
- [5] Pratt, D. A., & Shi, Z. (2004). An improved pseudo-gravity magnetic transform technique for investigation of deep magnetic source rocks. *ASEG Extended Abstracts*, 2004(1), 1–4.