Study on gravity anomaly data separation methods in Qingchengzi mining area, Eastern Liaoning

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Abstract. With the rapid advancement of computer technology, gravity field data processing and interpretation methods have become increasingly important in the study of subsurface geological structures. This research systematically processes and analyzes gravity anomaly data from the Qingchengzi mining area in eastern Liaoning using various methods such as upward continuation and radial average power spectrum for potential field separation. Through detailed steps including data gridding, frequency domain analysis, and filter design, the study successfully separates shallow and deep geological anomalies, revealing the complex underground structural characteristics of the study area. Results indicate that the radial average power spectrum method enhances both high and low anomalies in the separated residual gravity anomalies, with clearer anomaly edges that closely match the positions of exposed rock bodies on the surface. This research verifies the significant advantages of modern gravity field processing technology in improving data interpretation accuracy and understanding subsurface structures, providing robust technical support for geological exploration and resource assessment, and laying a foundation for subsequent geological structure studies.

Keywords: Gravity field processing, Upward continuation, Radial average power spectrum, Potential field separation, Geological structure interpretation.

1. Introduction

In geophysics and resource exploration, the analysis of gravity field data is crucial for understanding subsurface geological structures and identifying anomalous sources [1]. With the rapid development of computer technology, the methods for processing and interpreting gravity field data have significantly improved, becoming powerful geological tools. Modern computer technology, particularly efficient data processing algorithms, provides new avenues for the visualization and quantitative analysis of gravity field data [2].

Currently, there are numerous methods for separating gravity potential fields, including higher-order derivative methods, frequency domain filtering methods, trend analysis methods, and average field methods, depending on the research object and application conditions. Given the complexity of superimposed fields, scholars at home and abroad have conducted extensive research on improving separation methods. For instance, in 1997, iterative calculations using multiple cutting methods were employed to obtain local anomalies of geological bodies [3]. In 2015, two-dimensional discrete wavelet transform and radial power spectrum analysis were used for multi-scale decomposition of gravity anomalies, calculating the average depth of layered field sources and ultimately separating potential fields of gravity anomalies in the study area [4]. In 2011, polynomial fitting algorithms, global gravity potential models, and spectrum analysis methods were compared for their accuracy in potential field separation [5]. In 2013 and 2018, fast Fourier transform and upward continuation filtering, moving average methods, minimum curvature, and Kriging interpolation, as well as polynomial fitting algorithms using moving windows, were employed for regional-residual anomaly separation of gravity potential fields [6,7].

Gravity field data processing technology typically involves the use of computers to analyze and process observational data to achieve precise data separation and interpretation, thereby obtaining key information [8]. The main areas of these technologies include digital filtering, spectrum analysis, derivative calculation, and potential field separation. Upward continuation, radial average power spectrum, and derivative calculation are currently widely applied key technologies in gravity field data processing. This paper aims to explore the application of computer technology in gravity field data processing, focusing on the role of upward continuation and radial average power spectrum methods in gravity field data separation. Through systematic processing and analysis of collected gravity field data, the effectiveness and reliability of these methods are verified. Modern gravity field processing technology significantly enhances data interpretation accuracy and understanding of subsurface structures, providing essential technical support for geological exploration and resource assessment.

2. Methods for Obtaining Residual Gravity Anomalies

2.1. Upward Continuation Method

Upward continuation is a geophysical method used in gravity field data processing. Its basic principle is to extend gravity field data from an observation plane to a higher plane to attenuate local anomalies caused by shallow geological bodies, thereby highlighting the influence of deeper geological bodies. Based on potential field theory, upward continuation mathematically simulates the distribution of the gravity field above the observation plane to achieve gravity anomaly separation and identification.

2.1.1. Potential Field Separation. In gravity anomaly studies, the value of gravity anomalies attenuates gradually with increasing continuation height, with local gravity anomalies attenuating faster than regional gravity anomalies. Therefore, there exists a theoretical optimal continuation height that maximizes the retention of regional anomalies while minimizing local anomalies. According to [9], an analysis method based on correlation coefficients is proposed. This method analyzes the correlation coefficients between the continuation field at various heights and the theoretical regional field, selecting the height with the maximum correlation coefficient as the theoretical optimal continuation height. The correlation coefficient reflects the degree of correlation between variables, calculated using the product-moment method, based on the deviation of the two variables from their respective means, multiplied to reflect their correlation. If the shapes of the function graphs of two data sets are similar but the numerical differences are large, using the correlation coefficient still yields a high correlation because it emphasizes linear relationships rather than errors between the two data sets [10].

Specifically, assuming the gravity anomaly data set is G and the theoretical regional field data set is T,the calculation formula for the correlation coefficient r is:

$$r = \frac{\Sigma(G_i - \bar{G})}{\sqrt{\Sigma(G_i - \bar{G})^2 \Sigma(T_i - \bar{T})^2}} \tag{1}$$

where G_i and T_i are the i-th data points of the gravity anomaly and theoretical regional field, respectively, and $\bar{G}$ and $\bar{T}$ are the mean values of the gravity anomaly and theoretical regional field data.

Although the correlation coefficient can reflect the linear correlation between two data sets, it cannot represent the actual error between the data sets. Therefore, when applying correlation coefficient analysis to determine the theoretical optimal continuation height, it should be combined with other geological and geophysical information to ensure the scientific accuracy of the continuation height

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selection. The correlation coefficient results of the study area are shown in Figure 1. The height corresponding to the point with the largest slope is the optimal upward continuation height. Finally, an upward continuation of 1.5 km was determined for the gravity anomaly region in the Qingchengzi mining area in eastern Liaoning. Removing the background field yields the distribution of residual gravity anomalies in the area (Figure 2).

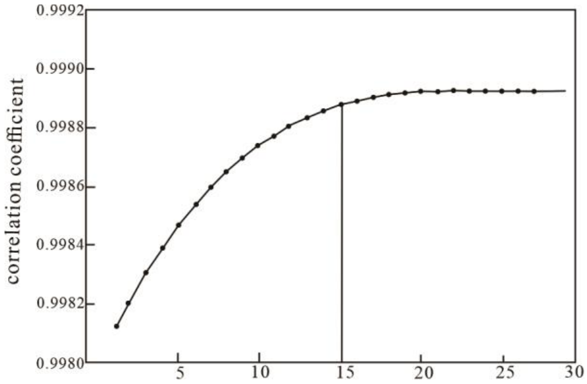

Figure 1. Correlation coefficients between anomaly values at adjacent height

By calculating the correlation coefficients between the upward continuation values of gravity anomalies at two adjacent heights and the relationship with height, the optimal upward continuation height for separating regional and residual gravity anomalies can be estimated. The separated local residual gravity anomalies (Figure 3) are compared with the original Bouguer gravity anomalies (Figure 2), with varying degrees of enhancement in both high and low anomalies. Thus, determining the optimal upward continuation height through the correlation coefficient of the upward continuation values at two adjacent heights, the obtained local residual gravity anomaly potential field separation results can be used as inversion modeling data, potentially improving the accuracy and reliability of inversion.

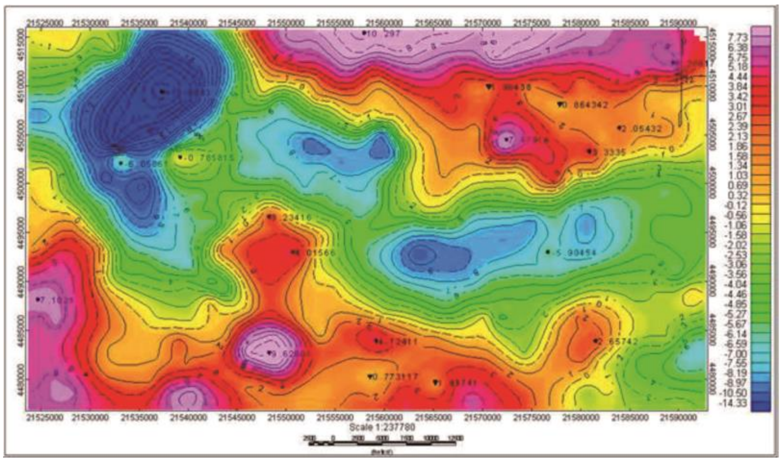

Figure 2. Original Bouguer gravity anomaly map

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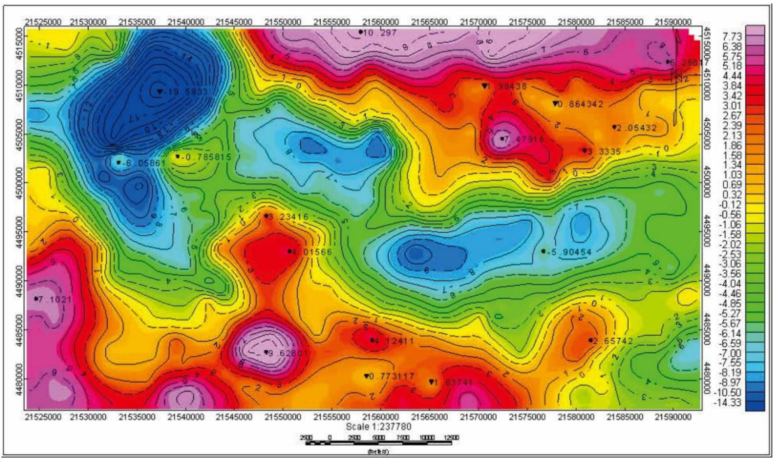

Figure 3. Residual gravity anomalies obtained by the upward continuation method

2.2. Radial Average Power Spectrum Method

The radial average power spectrum method is a commonly used geophysical processing technique to extract residual gravity anomalies from gravity data [11]. This method calculates the power spectrum of gravity anomaly data, then performs radial averaging to identify geological structure features at different depths.

2.2.1. Field Source Separation. By applying the radial average power spectrum method, the gravity anomaly data from the Qingchengzi mining area were systematically processed and analyzed. First, the gravity anomaly data were gridded. Gridding is the process of interpolating discrete gravity anomaly data points into a regular grid using interpolation methods to ensure spatial continuity and smoothness of the data. In this study, bilinear interpolation was used to achieve this process, providing a good data foundation for subsequent Fourier transforms. After gridding the data, a fast Fourier transform was applied to the gridded gravity anomaly data to convert the data from the spatial domain to the frequency domain. Fourier transform decomposes complex spatial data into superpositions of different frequency components, providing a basis for subsequent power spectrum analysis. By calculating the square of the Fourier transform results, the power spectrum is obtained, representing the energy of each frequency component and reflecting the importance of different frequencies in the gravity anomaly data. Then, the power spectrum data are radially averaged to obtain the radial average power spectrum.

The radial averaging process is as follows:

$$P(r) = \frac{1}{N_r} \Sigma_{r'=r-\Delta r}^{r+\Delta r} P(f_x, f_y) \tag{2}$$

where r is the radial distance, and N_r is the number of sampling points at distance r.

The radial average power spectrum reflects the relationship between frequency and power, helping to identify shallow and deep geological structural features. The radial average power spectrum of the Bouguer gravity anomaly in the study area is shown in Figure 4. The spectrum line shows two clear linear segments: the low-frequency regression line A corresponds to the average depth of regional anomalies, and the high-frequency regression line B corresponds to the average depth of residual anomalies. Shallow anomalies mainly reflect near-surface density heterogeneity, including the distribution of acidic granite, intermediate diorite intrusions, and shallow structural changes. Deep anomalies reveal the basic outline of the deep geological structure of the mining area and the macroscopic distribution of granite belts.

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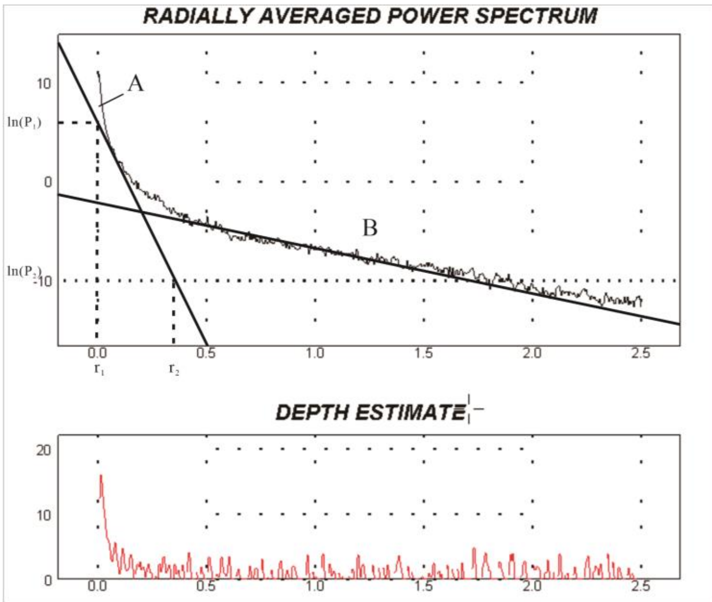

Figure 4. Radial average power spectrum of Bouguer gravity anomalies

According to the method of estimating field source depth from the power spectrum [12,13], the average depths of regional anomalies and local anomalies can be calculated using formula (3):

$$h = \frac{-(\ln(P_2) - \ln(P_1))}{2(r_2 - r_1)} \quad (3)$$

where h is the average field source depth, in units of the gravity anomaly sampling point interval, r is the radial wavenumber, and ln(P) is the logarithmic radial average power spectrum.

The average field source depth h has units of the gravity anomaly sampling point interval. Based on the coordinates of the gravity anomaly sampling points in the Qingchengzi mining area, the sampling point interval is calculated to be 1989 meters. For convenience, 2000 meters is used as the gravity anomaly sampling point interval (Figure 5).

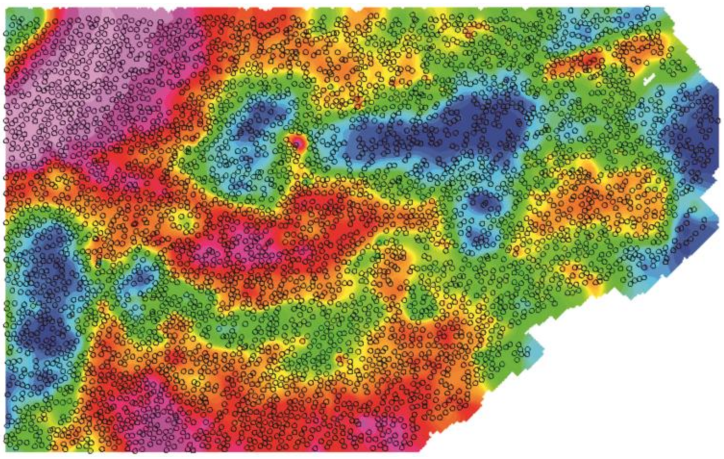

Figure 5. Gravity anomaly sampling points in the entire area

The regional and local average depths can be calculated as:

h(regional)*2km=40km

h(local)*2km =5.4km

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The low-frequency regression line A corresponds to regional gravity anomalies with an average field source depth of 40 km, while the high-frequency regression line B corresponds to local gravity anomalies with an average field source depth of 5.4 km. Based on the geological conditions of the area, it is inferred that the regional field source depth roughly corresponds to the undulations of the Anshan Group basement, which induces gravity anomalies that broadly reflect the deep structural outline and the deep background characteristics of the granite belt. The local anomaly field sources are shallower, mainly reflecting the characteristics of shallow geological structures and the local distribution of granite bodies, roughly corresponding to local gravity anomalies caused by the density difference between shallow sedimentary cover and intrusive rock bodies. High-pass filtering of the original gravity field yields the local anomaly field, as shown in Figure 6.

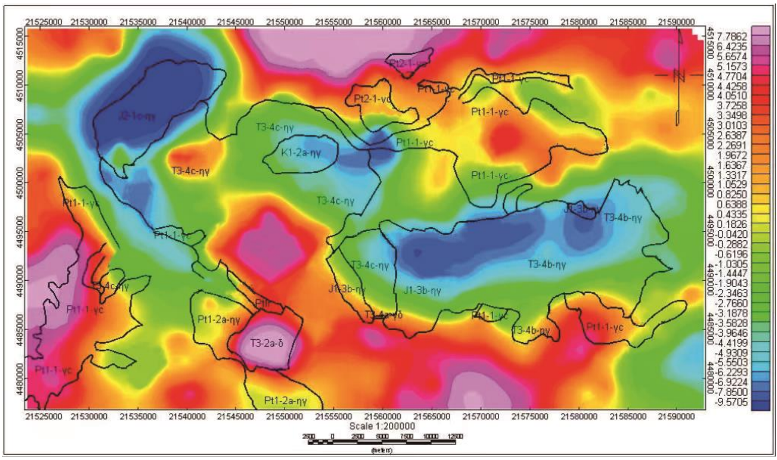

Figure 6. Residual gravity anomalies obtained using the radial average power spectrum method

2.3. Summary

By using the upward continuation and radial average power spectrum methods, the gravity and magnetic data potential fields of the study area were separated, yielding the corresponding local anomaly results and conducting a detailed analysis of the potential field characteristics. Currently, there are various potential field separation methods, but none are effective for all regions' potential field data. Each method has its limitations; hence, using multiple different methods to separate the gravity data potential fields of the study area, and validating the separation results with each other while considering geological information, improves the reliability of potential field separation. Comparison of experimental results shows that when deep and shallow anomalies are closely buried, the theoretical optimal continuation height determined by the correlation coefficient method may not be the value closest to the theoretical regional anomaly and the extended anomaly value, resulting in poor separation. Conversely, the radial average power spectrum method enhances both high and low anomalies to varying degrees, with clearer anomaly edge morphology and a higher degree of conformity with the positions of surface-exposed rock bodies. Therefore, the separation results of the radial average power spectrum method are ultimately used as the potential field data for inversion modeling.

3. Conclusion

This study systematically separates and analyzes the gravity and magnetic data potential fields of the Qingchengzi mining area in eastern Liaoning using the upward continuation method and the radial average power spectrum method. Through detailed processing steps, including data gridding, frequency domain analysis, and filter design, the study successfully separates shallow and deep geological anomalies, revealing the complex underground structural characteristics of the study area. To improve the reliability of potential field separation results, two different methods were used to separate the gravity data potential fields, with results validated against each other. Ultimately, the separation results with the highest similarity were selected, and the separation results of the radial average power spectrum

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method were used as the potential field data for inversion modeling. The study demonstrates that the radial average power spectrum method enhances both high and low anomalies in the separated residual gravity anomalies, with clearer anomaly edge morphology and a higher degree of conformity with the positions of surface-exposed rock bodies. This research verifies the significant advantages of modern gravity field processing technology in improving data interpretation accuracy and understanding subsurface structures. By comprehensively applying multiple methods for potential field separation, the study enhances the accuracy and understanding of gravity data interpretation, providing robust technical support for geological exploration and resource assessment. The results provide an important scientific basis for geological research and mineral resource development in the Qingchengzi mining area, showcasing the broad application prospects of gravity field data processing technology in geological research.

References

[1] Balogun, O.B., Akereke, O.F., Nwobodo, A.D., 2023. Understanding the Constraints to the Correct Application of the Upward Continuation Operation in Gravity Data Processing. Pure and Applied Geophysics. 180, 3787-3811. 10.1007/s00024-023-03348-1.

[2] Ulug, R., Karslioglu, M.O., 2022. A new data-adaptive network design methodology based on the k-means clustering and modified ISODATA algorithm for regional gravity field modeling via spherical radial basis functions. Journal of Geodesy. 96. 10.1007/s00190-022-01681-2.

[3] Wang, B.Z., ZhuXu, S.Z., Liu, B.H., Yan, H.J., Zhang, J.S., Liu, X.H., 1997. An example of aeromagnetic anomaly separation using multi-interpolation division. Oil Geophysical Prospecting. 431-438+462. (in Chinese with English abstract).

[4] Yang, C.W., Hou, Z.Z., Yu, C.Q., 2015. 3D crustal density structure of West Yunnan and its tectonic implications. Chinese Journal of Geophysics. 58, 3902-3916. (in Chinese with English abstract).

[5] Martin, A., Nunez, M.A., Gili, J.A., Anquela, A.B., 2011. A comparison of robust polynomial fitting, global geopotential model and spectral analysis for regional-residual gravity field separation in the Donana National Park (Spain). Journal of Applied Geophysics. 75, 327-337. 10.1016/j.jappgeo.2011.06.037.

[6] A., A.Z., L., E., A., A., M., E., E., A., 2013. Removing Regional Trends in Microgravity in Complex Environments: Testing on 3D Model and Field Investigations in the Eastern Dead Sea Coast (Jordan). International Journal of Geophysics. 2013, 341797-341791-341797-341713.

[7] Liu, J.Z., Wang, T.Q., Chen, Z.H., Zhang, P., Zhu, C.D., Zhang, S.X., Wang, Y., 2018. Regional and Residual Anomaly Separation Based on Robust 2D Polynomial Fitting with Moving Window. Geomatics and Information Science of Wuhan University. 43, 1478-1482. (in Chinese with English abstract).

[8] Eshagh, M., 2014. A theoretical study on terrestrial gravimetric data refinement by Earth gravity models. Geophysical Prospecting. 62, 158-171.

[9] Zeng, H.L., Xiu, D.S., 2002. Estimation of Optimum Upward Continuation Height. Earth Science Frontiers. 499-504. (in Chinese with English abstract)

[10] Wang, M., Wang, L.F., He, H., 2015. The application of the matched filtering technology to the separation of gravity field sources. Geophysical and Geochemical Exploration. 39, 126-132. (in Chinese with English abstract).

[11] Farhadinia, B., Liao, H., Herrera-Viedma, E., 2021. A modified class of correlation coefficients of hesitant fuzzy information. Soft Computing. 25, 1-20.

[12] Spector, Grant, 2012. To: “Statistical Models for Interpreting Aeromagnetic Data,” by A. Spector and F. S. Grant, GEOPHYSICS, v. 35, p. 293–302 (April 1970). Geophysics. 42, 1563-1563.

[13] Xue, F., Yao, Z.L., Zheng, Y.M., 2020. Influence of horizontal scale factor on power spectrum depth estimation and research on its correction method. Progress in Geophysics. 35, 1902-1910. (in Chinese with English abstract).