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A Review of Pseudogravimetric Transformation of Magnetic Anomalies: Advantages and Applications.

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ABSTRACT

Pseudogravimetric transformation has been a promising technique in geophysics for converting magnetic anomalies into gravity-like effects thereby simplifying interpretation and gaining insights into the geometry of subsurface geology. This article aims to provide a comprehensive review of the advantages and applications of the pseudogravimetric transformation. Firstly, the article elucidated the underlying principles and assumptions, highlighting the conversion of the magnetic anomalies into gravimetric signal. Subsequently, the advantages are mentioned which includes the removal of the characteristic asymmetry associated with magnetic anomalies, amplifying the long wavelength anomalies that are due to deeper sources and attenuating the small wavelength that are due to shallow sources, and the use of gravity methods for the interpretation of the resulting pseudogravimetric anomalies. The review further showcases the wide range of applications where pseudogravimetric transformation can be deployed. From geological mapping to basement mapping, mineral and hydrocarbon exploration to environmental studies. It can also be used to complement the seismic method. As the field of applied geophysics continues to evolve, pseudogravimetric transformation would be a valuable toolkit in the hands of the exploration geophysicist for advancing the understanding of subsurface geology.

Keywords: pseudogravimetric transformation, pseudogravimetric anomaly, magnetic anomaly, geological mapping, basement mapping.

Introduction

The magnetic method in applied geophysics generally refers to the collection of techniques, which images the full crustal signal based on the physical property of magnetism (Arora, 1989). Just like the gravity method, it is a potential field and Laplacian which varies smoothly and continuously in space without any abrupt change or discontinuity. From measurements of the Earth's geomagnetic field in space, inferences can be made about the subsurface geology and structures based on the magnetization of the Earth's material.

Through the magnetic method, applied geophysicists have been able to successfully map the geology and magnetic basement of the Earth's subsurface, search for minerals and oil, and carry out environmental and groundwater studies. Most commonly, the term refers to those applications by means of which investigations are carried out regarding the subsurface geology and processes guided by the presence of magnetic materials (magnetization) in the Earth's crust (Reynolds, 1997).

The interpretation of magnetic anomaly is generally more complex than the corresponding gravity anomaly. Firstly, is the dipolar nature of the magnetic field in contrast to the simpler monopolar gravity field. Secondly, the total magnetization of the source body is a vector summation of the induced and remanence magnetization. For the above reasons, magnetic anomalies are asymmetric over their perturbing sources in contrast to gravity anomalies which are symmetrically centered on their mass concentrations.

Baranov (1957) first introduced the term Pseudogravimetric transformation, the purpose of which was to remove the complexities associated with the measured magnetic anomalies. The pseudogravimetric transformation is based on the Poisson's relation which is a linear relation between the gradient of the gravity potential (∇U) and magnetic potential (V). The Poisson's relation is valid under the assumption that for the geology of the subsurface, the ratio of the magnetization distribution and the density distribution (i.e., $\frac{M}{\rho}$) is consistent and uniform throughout and that also the remanent magnetization is negligible.

The method requires a knowledge of the direction of magnetization which is often taken to be the direction of the present-day ambient field or is determined by other methods. The transformation also requires the value of the ratio of magnetization to density of the surrounding rocks which is often arbitrarily chosen by inspecting the rocks of the area (Williams, Ralph & Afif, 2012). The result (pseudogravimetric map) is the map that would be observed if the magnetization contrast is replaced with a proportionate density contrast. Although the pseudogravimetric map appears as gravity maps, they only reflect the magnetic properties of the area and not density.

Pseudo-gravity transformation among other things helps to eliminate the asymmetry that characterizes magnetic anomaly with respect to their causative bodies and centering them on their perturbing bodies (Baranov, 1957; Tandrigoda, 1982). The transformation may also be carried out to filter out shot wavelength anomalies that complicate most observed fields and mask out the deeper anomalies, thereby making their interpretation easier and more reliable (Ofoegbu, 1985). It also helps in determining the possible common source of observed magnetic and gravity fields over an area under investigation (Tandrigoda & Ofoegbu, 1989).

Because of the above-mentioned properties that it has on magnetic anomalies, it can be used to enhance subsurface imaging of areas with complex geological settings. By attenuating the shallow and often high frequency anomalies, it can be helpful for the investigation of deep magnetic sources that are hidden from the interpreter in conventional magnetic image display (Pratt & Zhikun, 2004); (Panepinto et al., 2014). It is also suitable for the exploration of deep-seated ore forming minerals associated with known occurrence of minerals at the surface (Mashhadi & Safari, 2021).

Additionally, the pseudogravimetric data and gravity data can play supporting roles when they are compared. Such comparison may help in determining a possible gravity effect in the magnetic anomalies of the area under investigation thereby permitting the investigation of the ratio of magnetization to density ($\frac{M}{\rho}$) and how it varies within the source (Blakeley, 1995). The comparison of gravity and pseudogravimetric anomalies may also be used to enrich gravity data that have been sparsely measured. Also, comparing it with the reduced to the pole magnetic anomaly can be used to discriminate between the shallow magnetic sources from the deeper ones.

Researchers have not given much attention to the interpretation of aeromagnetic anomalies using pseudogravimetric transformation. This may perhaps be attributed to the assumptions or constraints made during the transformation that are hardly practicable: that the ratio of magnetization to density ($\frac{M}{\rho}$) is constant and remanence is negligible throughout the source body. The direction of magnetization is also required which may be assumed to be due to present day geomagnetic field or may be determined by other methods. However, despite all those constraints, it is still a useful strategy for a comprehensive analysis of subsurface structures and geological features.

Magnetic Anomaly

A Geophysical anomaly according to Isles and Ranking (2013) is the difference between the measured (observed) field value and the value that would be observed at the same location if the Earth were uniform. The heterogeneous nature of the physical properties of rocks gives rise to geophysical anomalies. Magnetic anomalies arise because of variation in the total magnetization (induced and remanence) of rocks within the Earth's crust. It is a deviation from the expected background magnetic field in the Earth's crust and may be analyzed using either the total magnetic intensity (TMI) maps or residual maps. The physical rock property that links magnetic anomalies to rock composition is the magnetization that is due to present geomagnetic field (induced) and the magnetization due to past geomagnetic field (remanence).

Magnetic surveys measure the scalar strength of the local field. This measurement is a combination of the Earth's core field (documented worldwide as the International Geomagnetic Reference Field, IGRF) and the field induced in crustal rocks. The TMI is the measurement from the magnetometer after a model of the Earth's normal magnetic field, the International Geomagnetic Reference Field (IGRF) is removed (Reeves, 2005). It is generally a reflection of the average magnetization of small and broad large scale geological features within the crust (regional and residual). The residual is the anomaly that remains after the regional magnetic trend is removed from the TMI. The regional can be calculated using several techniques: running averages, polynomials, low pass filters or upward continuation.

Magnetic anomalies are more complicated to interpret than those of gravity. While in gravimetry, the residual anomaly is a function of the subsurface scalar density distribution only, in magnetism, the magnetic anomaly is a function of two independent parameters: the subsurface distribution of the magnetization vector and the dipolar nature of magnetic field. Because of the above, a traverse across a local magnetic body would produce an anomaly that has both positive and negative parts (Figure 1). As a result, the magnetic picture of the tectonic feature will be asymmetrical with respect to their perturbing bodies, and the degree of asymmetry will depend on the orientation of the body with respect to the local Earth's field. The commonly used methods of removing the asymmetrical nature of magnetic anomalies and centering them vertically on the perturbing sources are reduction to the pole (RTP), pseudogravimetric transformation (PSG) and analytic signal.

Poisson's Relation

In potential field theory, the linear relationship between magnetic potential V and the gradient of the gravity potential ∇U is commonly referred to as Poisson's relation. Consider a source body with density contrast with the surrounding bodies given by ρ and total magnetization $\boldsymbol{M}$ given by:

$$|\boldsymbol{M}|\mathbf{t} = \chi|\boldsymbol{H}|\mathbf{f} + |\boldsymbol{M}_r|\mathbf{m} \qquad \mathbf{1}$$

$\boldsymbol{m}$ is a unit vector in the direction of remanent magnetization $\boldsymbol{M_r}$ and $\boldsymbol{f}$ is the unit vector in the direction of ambient magnetic field $\boldsymbol{H}$ and $\boldsymbol{t}$ is a unit vector in the direction of total magnetization $\boldsymbol{M}$. The gravity potential U at the observation point $P_{x,y,z}$ at a distance r from a source $Q_{x',y',z'}$ is given by the expression (Blakely, 1995);

$$\boldsymbol{U(r) = G\rho \int_v \frac{1}{r} dv}$$

$$\int_v \frac{1}{r} \boldsymbol{dv} = \frac{\boldsymbol{U(r)}}{\boldsymbol{G\rho}} \qquad \mathbf{2}$$

The magnitude of the difference between the vectors of observation position and source points is defined as:

$$r = [(x - x')^2 + (y - y')^2 + (z - z')^2]^{1/2}$$

$$dv = (dx', dy', dz')$$

G is the gravitational constant and ρ is the density which varies from point to point throughout the volume.

Similarly, the magnetic potential V at the observation point $P_{x,y,z}$, a distance r from the source is given by the expression;

$$\boldsymbol{V(r) = C_m M_t \frac{d}{dm} \int_v \frac{1}{r} dv} \qquad \mathbf{3}$$

where $\boldsymbol{M}$ is the total magnetization along the direction $\boldsymbol{t}$, $\frac{d}{dm}$ is a directional derivative along the direction of the unit vector $\boldsymbol{t}$.

From the two equations (2) and (3), the Poisson's relation is obtained. The Poisson's relation connects the gravity potential U and the magnetic potential V at the observation point $P_{(x,y,z)}$ for a common source of uniform density ρ and magnetization M, in the direction given by:

$$r = [(x - x')^2 + (y - y')^2 + (z - z')^2]^{1/2}$$

$$\boldsymbol{V}_{(x,y,z)} = \frac{\boldsymbol{C_m M_t}}{\boldsymbol{G\rho}} \frac{\boldsymbol{dU(x,y,z)}}{\boldsymbol{dm}} \qquad \mathbf{4}$$

It states that the magnetic potential of an arbitrary volume is proportional to the gradient of the gravitational potential of the same volume with respect to the direction of magnetization **t** provided the magnetization and density are uniform (Roy, 2008). Poisson's relation is applicable where within the boundary containing the gravitational and magnetic source, the intensity of magnetization is everywhere proportional to the density and the direction of magnetization is constant. The relationship is assuming that the magnetization is induced and the remanence is zero everywhere within the source.

Pseudogravimetric Transformation

The pseudogravimetric computation is based on Poisson's relation which shows that the magnetic potential (V) and the gravitational potential (U) for a body with the ratio of density to magnetization constant at each point, and the magnetization vector in a constant direction are related by directional derivatives in three-dimensions;

$$\boldsymbol{V = \frac{C_m M}{G\rho} (m. \nabla U)}, \qquad \boldsymbol{\frac{M}{\rho} = constant} \qquad \mathbf{5}$$

$$\frac{dV}{dz} = \frac{C_m M}{G\rho} \frac{d}{dz} (\boldsymbol{m}. \Delta \boldsymbol{U}) \qquad \mathbf{6}$$

where ρ is the density contrast, M is the intensity of magnetization contrast, **m** is a unit vector in the direction of total magnetization and G is the gravitational constant.

The magnetic field anomaly $T_{x,y,z}$ at an external point due to a body is related to the magnetic potential (V) as;

$$\boldsymbol{T_{x,y,z} = f. \nabla V} \qquad \mathbf{7}$$

where **f** represents a unit vector in the direction of Earth's total field. Substituting equation into equation we obtain:

$$T_{x,y,z} = \frac{C_m M}{G\rho} f. \nabla(m. \nabla U) \qquad 8$$

It is possible therefore to compute a theoretical gravity potential U from any given measured magnetic anomaly T(x,y,z) and from this gravitational potential, a pseudogravity anomaly ∇U can be computed. This pseudogravity anomaly is not the true gravity anomaly due to the body, but a fictitious anomaly completely derived from a true magnetic anomaly assuming the ratio $\frac{M}{\rho}$ to be constant throughout the source body. From equation 3.15, the pseudogravimetric potential is obtained:

$$U = \frac{G\rho}{C_m M} \int\int_{-\infty}^{\infty} T_{x,y,z}\, dfdm \qquad 9$$

Taking the fictitious density contrast to be equal to:

$$\rho = \frac{C_m M}{G}, \qquad 10$$

The pseudogravimetric anomaly is then given by:

$$g_{x,y,z} = \frac{dU}{dz} = \frac{d}{dz} \int\int_{-\infty}^{\infty} T_{x,y,z} dfdm. \qquad 11$$

And the reduction to the pole is given by:

$$\frac{dV}{dz} = \frac{d^2}{dz^2} \int\int_{-\infty}^{\infty} T_{x,y,z} dfdm \qquad 12$$

Taking Fourier transform of both sides of equation 12, we obtained:

$$\boldsymbol{\mathcal{F}(g_{x,y,z}) = \frac{\mathcal{F}\left[\frac{d}{dz}\right]}{\mathcal{F}\left[\frac{d}{df}\right]\mathcal{F}\left[\frac{d}{dm}\right]} * \mathcal{F}(T_{x,y,z})} \qquad 13$$

$$\boldsymbol{F(g_{x,y,z}) = F(H_f) * F(T_{x,y,z})} \qquad 14$$

H_f = Filter that transforms the total-field anomaly $\boldsymbol{T_{x,y,z}}$ measured on the horizontal surface into the Pseudogravity anomaly $\boldsymbol{g_{x,y,z}}$.

The Fourier transform of the pseudogravity transform filter is given by (Blakely, 1995):

$$F(H_f) = \frac{|k|}{\left(|k| f_z + i k_x f_x + i k_y f_y\right)\left(|k| m_z + i k_x m_x + i k_y m_y\right)} \qquad \mathbf{15}$$

k_x, k_y are wavenumbers in the direction of x and y axis respectively, ($\boldsymbol{m} = m_x, m_y, m_z$) and $\boldsymbol{f} = f_x + f_y + f_z$ are unit vectors of ambient magnetic field and magnetization field with respect to x, y, z axis.

The process consists of three steps; Fourier transformed the magnetic field anomaly $\mathcal{F}(T_{x,y,z})$, multiplied by the filter $\mathcal{F}(H_f)$ and then inversed Fourier transformed the product. The process requires a 2D gridded magnetic field map.

Pseudogravity transform can also be carried out by the vertical integration of the reduction to the pole aeromagnetic data (Blakely, 1973).

Advantages Of Pseudogravimetric Transformation

A pseudogravimetric transformation has some important effects on magnetic anomalies which serves as advantages to the interpreter.

- Simplification of interpretation: By converting magnetic anomalies into pseudogravimetric anomalies, the characteristic distortion of the magnetic anomaly with respect to the causative will be removed. This would make the interpretation and visualization of the magnetic anomalies more intuitive and simplified like that of gravity data interpretation. Furthermore, the methods of interpreting gravity anomalies can be applied to the pseudogravimetric anomalies since it is like gravity anomalies including the units in milli Gal.
- Acting as a filter and amplifier: Pseudogravimetric transformation often acts like a filter, suppressing the short wavelength anomalies that are due to shallow sources and enhancing the long wavelengths features from deeper sources. (Figures 1 and 2).

Applications Of Pseudogravimetric Transformation

The pseudogravimetric studies of areas of interest allows for the interpretation of magnetic anomalies in terms of subsurface geological structures and can be applied in various practical applications:

- Geological mapping: Acting as an amplifier to the long wavelength anomalies that are due to deeper sources, it would be helpful in the study of deep magnetic sources and basement geometry which may be obscured by shallow magnetic sources. It is a suitable tool for the exploration of deep-seated mineral plumbing systems associated with shallow mineral resources (David & Zhiqun, 2004; Panepinto, et al., 2014).
- Edge detection: Gravity anomalies have the steepest gradients over the edges of tabular bodies and this property can be exploited in edge detection. This can be archived by converting a magnetic anomaly into a pseudogravimetric anomaly and searching it for maximum horizontal gradient (Blakely, 1995). Cheney, Hill & Linford (2011) have demonstrated the effectiveness of Pseudogravity transformation of magnetic datasets for delineating archaeological sites by detecting the edges of the magnetic sources.
- Basement mapping in sedimentary basins: Magnetic anomalies are influenced by both shallow and deep-seated structures. Pseudogravimetric transformation can help in highlighting the deeper magnetic basement that may be concealed by near-surface magnetic anomalies. This is helpful in mineral exploration or oil and gas prospecting where understanding deeper structures is crucial (Salem et al., 2014).
- Oil and Gas Exploration: magnetic exploration is an essential part of oil exploration. Pseudogravimetric transformation can assist in identifying hidden basins which are potential reservoirs and understanding subsurface structures which is critical for drilling decisions.
- Integration with gravity data: Pseudogravimetric anomaly and gravity anomaly can reveal a lot about local geology when they are compared or correlated (Ofoegbu, 1986). Firstly, it may help in determining a possible common source of the observed magnetic and gravity anomalies over an area under investigation (Blakely, 1995; Tandrigoda & Ofoegbu 1989). Secondly, it may permit the investigation of the ratio of magnetization to density in a source (Blakely, 1995; Bilim & Ates, 2004). Thirdly, the comparison of gravity and pseudogravity anomalies may also be used to enrich gravity data that are sparsely measured, and finally, comparing it with magnetic anomaly can be used to delineate the anomalies that are due to density variations, shallow magnetic sources or locating magnetic sources that are not evident in the magnetic anomaly map (Sutasoma et al., 2022).
- Environmental Studies: As a low pass filter, pseudogravimetric transformation can help in archeological studies by delineating shallow high frequency archeological features from a magnetic intensity anomaly map (Cheney et al., 2011). It may also be suitable in detecting underground water resources by locating where they may be trapped such as fractures or fissures in basement complexes.
- Complements Seismic exploration: magnetic survey cannot replace seismic but can complement it. Pseudogravimetric transformation would be helpful in areas with complex geological settings where seismic exploration is not possible. Seismic exploration is not suitable in all geological settings. It is suitable in a more or less horizontal layered-cake geology. Magnetic and gravity surveys are suitable in geological settings that have lateral variabilities in magnetization and density.

Limitations of Pseudogravimetric transformations

i. The transformation has problems when magnetization and ambient field has low inclination as can be expected at low latitudes. The anomalies of feature trending north- south would be smeared.

ii. Because of the characteristic nature of transformation of amplifying the anomalies of king wavelength feature, it would also amplify long wavelength noise contained in the authentic measured magnetic data.

iii. The assumption that the ratio of total magnetization (***M)*** to the density () to be constant may introduce errors because of the non-homogeneity of the subsurface.

iv. The assumption also that the remanence of the sources is negligible, and the direction of the total magnetization is constant and in the direction of the induced magnetization may introduce errors if the area of study is large. Remanence may be significant for deep magnetic sources.

Summary and Conclusion

Overall, pseudogravimetric transformation, despite the limitations attributable to the process, is still a versatile and useful strategy in the interpretation of magnetic anomalies. It can be applied to a wide range of applications, from geological mapping to resource exploration and environmental. It enhances the interpretation of magnetic anomalies by removing the characteristic asymmetry associated with magnetic anomalies and making it like gravity anomalies, leading to a simpler interpretation and a better understanding of the underlying geological structures and processes.

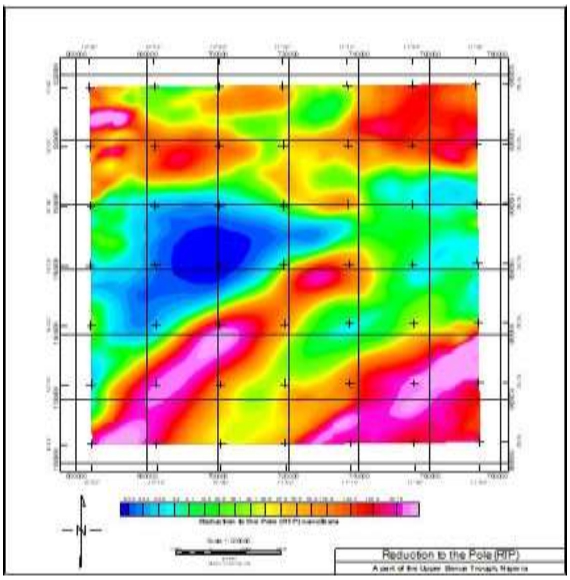

Figure 1: Total magnetic intensity (TMI) map of part of the Upper Benue Trough, Nigeria.

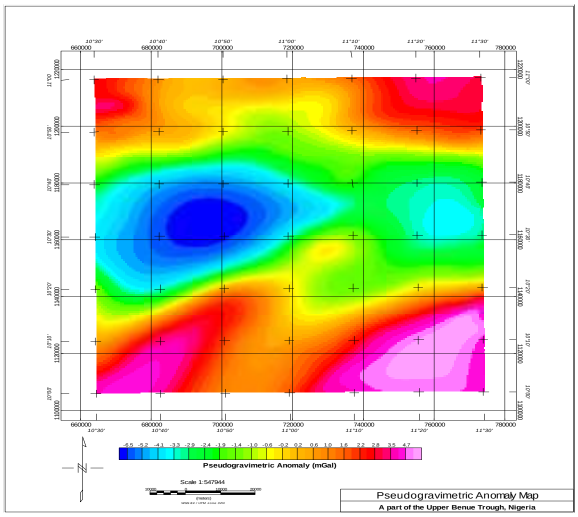

Figure 2: Pseudogravimetric anomaly map of the Total magnetic intensity map of Figure 1.

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References

Arora, K. (1989). Magnetic Methods Principles. In Gupta, H. K. (Eds). Netherlands: Springer. *The Encyclopedia of Solid Earth Geophysics*, 736-740.

Baranov, V., (1957). A new method for interpretation of aeromagnetic maps pseudo-gravimetric anomalies. *Geophysics, 22,* 359-363.

http://dx.doi.org/10.1190/1.1438369

Blakely, R.J., (1995). *Potential Theory in Gravity and Magnetic Applications*. U.K: Cambridge University Press.

Bilim, F., & Ates, A. (2004). An enhanced method for estimation of body magnetization direction from pseudogravity and gravity data. *Computers and Geosciences*, *30*(2). https://doi.org/10.1016/j.cageo.2003.09.003.

Cheney S , Hill, I. & Linford, N. (2011). Advantages to using the Pseudogravity transformation to aid edge detection of total field archaeological dataset. *Archaeological Prospection, 18(2).* http://DOI.10.1002/arp.408.

David, A.P. & Zhiqun, S. (2004); An improved pseudo-gravity magnetic transform technique for investigation of deep magnetic source rocks. *Research Gate, ASEG Extended Abstract. December DOI:10.1071/ASEG2004ab116*

Isles, D.J. & Rankin, L. R. (2013). *Geological Interpretation of aeromagnetic data.* Australian Society of Exploration Geophysicists. http://www.aseg.org.au.

Lowrie, W. (1992). *Fundamentals of Geophysics*. United Kingdom: Cambridge University Press.

Mashhadi, S. R. and Safari, M.; The Effectiveness of Pseudogravity Transformation in Mineral Exploration: an example from a Placer Magnetite Deposits. [Conference Presentation] Dec, 2021. London. UK.

Nabighian, M.N., Grauch, V.J.S., Hansen, R.O., Lafehr, T.R., Li, Y. Pearson, T.R., Pierce, J.W., Phillips, J.D., & Ruder, M.G., (2005): The historical development of the magnetic method in exploration. *Geophysics, 70,* 33-61.

http://doi.org/10.1190/1.2133784

Ofoegbu, C. O. (1986). Preliminary results from a pseudogravity study of the Benue Trough, Nigeria. *Journal of African Earth Sciences, 5(2*). https://doi.org/10.1016/0899-5362(86)90009-6

Panepinto, S., luca, L.D., Mantovani, M., & Sfolciaghi, M. (2014) *Using Pseudogravity functional transform to enhance deep magnetic sources and enrich regional gravity data.* [Conference presentation]. Denver, 1275-1279

Pratt, D.A. & Zhiqun, S. (2004). *An improved pseudo-gravity magnetic transform technique for investigation of deep magnetic source rocks.* [Conference presentation] *ASEG* 17th Geophysical Exploration and Exhibition, 1-4, DOI; 10.1071/ASEG2004ab116

Reeves, C. (2005). *Aeromagnetic Surveys. Principles, practice and interpretation.* Geosoft E-book. http://www.geosoft.com/media/uploads/resources/technicalpapers/Aeromagnetic_surveys_Reeves.pdf .

Reynolds, J. M. (1997). *An introduction to Applied and Environmental Geophysics*. England: John Wiley.

Salem, A., Green, C., Cheyney, S., Fairhead, J. D., Aboud, E., & Campbell, S. (2014). Mapping the depth to magnetic basement using inversion of pseudogravity: Application to the Bishop model and the Stord Basin, northern North Sea. *Interpretation*, *2*(2). https://doi.org/10.1190/INT-2013-0105.1

Sutasoma, M., Susilo, A., Sunaryo, Suryo, E. A., Minardi, S., & Cahyo, R. H. D. (2022). Comparison between the magnetic method data of pseudogravity transformation with gravity anomaly data from satellite imagery in the surrounding of the Sutami Dam to identify subsurface formations. *Journal of Physics: Conference Series, 2165(1).* https://doi.org/10.1088/1742-6596/2165/1/01201.

Tandrigoda, D.A, & Ofoegbu, C.O (1989). A Routine for the Rapid Computation of the Pseudogravity field. *Inverse modelling in the Exploration Geophysics. Friedr, Vieweg and Sohn, Wiesbaden, 93-109.*

William, J.H., Ralph, R.B.V., & Afif, S. (2012). *Gravity and Magnetic Exploration: Principles, Practices and Applications (*1st Ed). Cambridge University Press.