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REVIEWING THE ART OF AEROMAGNETIC DATA INTERPRETATION IN GEOPHYSICAL SURVEYS

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Abstract

The study delves into the theory, application, and interpretation of aeromagnetic surveys, drawing insights from foundational publications in the field. Emphasizing the significance of aeromagnetic data in mapping magnetic anomalies, the paper discusses advancements such as computer-aided depth estimation and their applications in environmental evaluations and mineral exploration. The review underscores the challenges inherent in interpreting aeromagnetic data, acknowledging the complexities and ongoing efforts in achieving accurate and efficient data interpretation in geophysical surveying. A detailed overview of various geophysical survey techniques, including seismic surveys, electromagnetic surveys, ground-penetrating radar, and gravity surveys, set the stage for a focused examination of aeromagnetic surveys as a versatile geophysical tool. Aeromagnetic surveys, conducted from aerial platforms, have gained prominence in geologic mapping, environmental studies, and mineral exploration due to their high spatial resolution and cost-effectiveness. The subsequent section explores the characteristics and applications of aeromagnetic maps, emphasizing their role in identifying magnetic anomalies and offering insights into subsurface geological structures. The article also delves into data interpretation techniques, discussing the preparation and enhancement of raw magnetic data and analytical methods for locating and describing magnetic anomalies. Real-world case studies illustrate the practical applications of aeromagnetic data interpretation in mineral exploration, environmental studies, and geological mapping. The versatility of aeromagnetic data interpretation is showcased through applications in mineral exploration, environmental monitoring, geological structure mapping, and archaeological surveys. Future directions anticipate further integration with diverse geophysical datasets, advancements in inversion techniques, enhanced 3D visualization, increased automation, and continued interdisciplinary cooperation. In conclusion, the article emphasizes the indispensable role of aeromagnetic data interpretation in geophysical surveying, contributing to our understanding of the Earth's magnetic properties, geological formations, and vital resources. The dynamic nature of the field, marked by ongoing advancements and interdisciplinary collaboration, positions aeromagnetic data interpretation as a cornerstone in the quest for knowledge about the Earth's subsurface.

Keywords: Art, Aeromagnetic data, Interpretation, Geophysical, Survey

Introduction

Understanding the Earth's subsurface and uncovering the mysteries of its geology and ecosystem has long depended on geophysical surveys (Macnae, 1979; Keating, 1995, Power et al., 2004). Aeromagnetic surveys are one of the many geophysical techniques used in subsurface research, and they have proven to be an effective and adaptable instrument for mapping magnetic anomalies over large geographic areas. In these surveys, fluctuations in the Earth's magnetic field are measured. These variations are frequently used to identify mineral deposits, underlying geological structures, and other subterranean phenomena. As essential to geophysical surveying, the creation and interpretation of aeromagnetic maps offer important insights into the composition and history of the Earth. Aeromagnetic data has been used for many practical purposes over the years, ranging from basic geology study to geologic mapping, environmental evaluation, and mineral prospecting. The goal of this review study is to investigate the complexities involved in interpreting magnetic data from aeromagnetic surveys. This work attempts to disentangle the complexities of this important geophysical instrument by looking at the fundamentals of aeromagnetic data collection, the subtleties of aeromagnetic maps, and the various approaches utilized for data interpretation. We will illustrate the practical implications of interpreting aeromagnetic data with the presentation of real-world case studies.

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It is crucial to understand that interpreting aeromagnetic data is not without its difficulties and constraints. Error and uncertainty may originate from a variety of sources, including human and natural phenomena that produce magnetic anomalies. To achieve this, this review will also explore the complexities of the problems encountered in the field, go over recent developments, and look ahead, highlighting the necessity of ongoing study and creativity in this ever-evolving sector. A vast array of methods is used in geophysical surveying to look into subsurface geological structures, locate mineral deposits, evaluate environmental factors, and much more. An overview of the different geophysical survey techniques will be given in this section, with an emphasis on aeromagnetic surveys as a subset of these techniques. A non-invasive method of measuring and examining the physical characteristics of the Earth's subsurface is called geophysical surveying. Without the need for direct drilling or excavation, it enables geoscientists and researchers to learn more about the composition, structure, and characteristics of the Earth's interior (MAT, 2019). In numerous scientific, industrial, and environmental applications, these surveys are essential. There are many different geophysical survey techniques, and they all make use of different Earthly physical characteristics to obtain important data. Several of the most popular techniques are as follows:

Seismic surveys: To produce images of subsurface structures, seismic waves are generated and recorded. According to (Sheriff & Geldart 1995), this method is frequently applied in civil engineering and oil and gas exploration projects. Electromagnetic surveys. To determine the presence of subsurface conductive materials, electromagnetic surveys measure variations in electromagnetic fields. According to Malehmir et al. (2012), they play a crucial role in environmental studies and mineral exploration.

Ground-Penetrating Radar (GPR): GPR is useful for applications in civil engineering and archaeology because it uses radar pulses to image the subsurface (Daniels, 2004; Sansalone et al., 1989).

Gravity Surveys: To map variations in subsurface density, gravity surveys measure variations in gravitational fields. According to Telford et al. (1990), these surveys are essential for comprehending subsurface geology.

Magnetic Surveys: To identify magnetic anomalies brought on by subsurface features, magnetic surveys, including aeromagnetic surveys, concentrate on detecting variations in the Earth's magnetic field (Revees, 2005).

Aeromagnetic Surveys as a Geophysical Tool

In the last few years, aeromagnetic surveys—a subset of magnetic surveys—have become increasingly well-known. To map magnetic anomalies over large areas, they entails gathering magnetic data from an aerial platform, such as an aircraft or drone. These anomalies are frequently associated with subterranean geological features such as igneous intrusions, fault lines, and ore bodies.

Aeromagnetic surveys are now used in a wide range of fields, including geologic mapping (Nabighian et al. 2005, Pilkington 2007), environmental studies (Magaia, 2009; Luyendyk, 1997), and mineral exploration. Aeromagnetic data collection is a useful tool for comprehending the magnetic properties of the Earth because of its high spatial resolution and affordability.

Aeromagnetic Maps

Aeromagnetic maps, which offer important insights into the Earth's magnetic properties over vast geographic areas, are an essential part of geophysical surveying. These maps, which are created by gathering magnetic data from aerial platforms like drones or aeroplanes, are now a vital resource for environmental research, geologic exploration, and resource assessments. We will examine the elements, traits, and applications of aeromagnetic maps in geophysical research in this section.

The representation of magnetic anomalies is the main characteristic of an aeromagnetic map. These anomalies are variations in the strength of the Earth's magnetic field, usually brought about by mineral deposits, subterranean geological features, or other magnetic sources. On an aeromagnetic map, contour lines join locations with comparable magnetic field intensities. These lines make the location and strength of magnetic anomalies throughout the surveyed region easier to see. A common method for depicting the size of magnetic anomalies is colour gradients. Cool colours, like blue or green, indicate lower magnetic intensity, while warm colours, like red or orange, typically indicate areas of high magnetic intensity. To contextualize the magnetic data, aeromagnetic maps incorporate geographic features like rivers, coasts, and topographic details. Aeromagnetic maps are an invaluable resource for geophysical interpretation due to the number of attributes they have. The high spatial resolution of aeromagnetic surveys makes it possible to identify magnetic anomalies in great detail. They are suited for fine-scale exploration because of this characteristic. Aeromagnetic data collection is faster and more efficient than ground-based magnetic surveys, making it an economical method for large-scale geological investigations. Applications for aeromagnetic maps can be found in many different domains, such as geologic mapping, environmental assessments, and mineral exploration. There are multiple uses for the same dataset. To create a more complete subsurface picture, aeromagnetic data is frequently combined with other geophysical data, such as seismic surveys or gravity measurements.

Aeromagnetic maps are essential for many different uses: Different magnetic signatures are often observed in mineral deposits. Aeromagnetic maps aid in identifying potential locations for mineral exploration, facilitating resource assessment and mining operations Sylvanus et al. (2023). According to WorldWideScience (2023), aeromagnetic surveys have the potential to identify submerged or buried structures, such as landfills or pipelines, and thus aid in environmental assessments. To comprehend subsurface geological structures such as fault lines, igneous intrusions, and sedimentary basins, geologists employ aeromagnetic maps. To gain a deeper understanding of the Earth's magnetic properties and underlying geology, geoscientists and researchers continue to rely heavily on aeromagnetic maps, which offer a comprehensive view of magnetic anomalies and subsurface geology.

Data Acquisition

The process of acquiring, processing, and interpreting aeromagnetic data is a complex yet crucial aspect of geophysical surveying. This section delves into the technical intricacies of aeromagnetic data acquisition, emphasizing current methodologies and providing mathematical explanations for key technical terminologies.

Aeromagnetic surveys utilize advanced instrumentation and aerial platforms, typically aircraft or drones, to collect magnetic data. The choice of instrumentation and platform significantly influences the quality and resolution of the acquired data. Mathematical representations of key instruments include:

The fundamental instrument used in aeromagnetic surveys, the magnetometer measures the Earth's magnetic field. Mathematically, it is represented as:

$F_{total} = F_{Earth} + F_{anomaly} + F_{noise}$

Where:

- F_{total} is the total magnetic field measured.
- F_{Earth} is the Earth's magnetic field.
- $F_{anomaly}$ is the magnetic anomaly caused by subsurface features.
- F_{noise} represents various sources of magnetic noise

The choice of aerial platform impacts survey efficiency and coverage. Mathematically, the magnetic signal measured by the airborne system is a convolution of the Earth's field and the anomaly signal:

$F_{measured} = F_{Earth} * F_{anomaly}$

Here, $**$ denotes the convolution operation.

The measurement process involves capturing variations in the Earth's magnetic field caused by underlying geological structures. Understanding the intricacies of this process is essential for accurate data interpretation.

The magnetic data acquired during the survey is a composite signal comprising the Earth's magnetic field, anomalies, and noise:

$D_{measured}(t) = D_{Earth}(t) + D_{anomaly}(t) + D_{noise}(t)$

Where:

$D_{measured}(t)$ is the measured magnetic data at time t.

$D_{Earth}(t)$ represents the Earth's magnetic field.

$D_{anomaly}(t)$ is the magnetic anomaly signal.

$D_{noise}(t)$ accounts for various sources of noise.

Mathematical transformations, such as Fourier analysis, are applied to the measured data to highlight anomalies and reduce noise:

$D_{processed}(f) = F\{D_{measured}(t)\}$

Here, F denotes the Fourier transform.

Adjusting for fluctuations in the Earth's magnetic field involves tie line compensation, expressed as:

$D_{compensated}(t) = D_{measured}(t) - D_{Earth}(t)$

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This compensation minimizes external influences on the measured data.

Current approaches in interpreting aeromagnetic data involve advanced mathematical and computational techniques. Key methods include:

- Reduction to the Pole

Transforming the data to a reference pole location aids interpretation:

$D_{pole} = D_{measured} - D_{Earth} + D_{pole\_noise}$

Where Dpole_noise represents noise introduced during the reduction process.

- Upward Continuation

Florio (2018) By integrating these approaches, researchers can extract meaningful information from aeromagnetic data, tackling various geophysical problems. The mathematical formulations presented here underscore the academic rigour required for a comprehensive understanding of aeromagnetic survey methodologies.

Data Interpretation Techniques

In geophysical surveying, interpreting magnetic data from aeromagnetic maps is essential. The magnetic anomalies depicted on these maps are analyzed, and relevant information is extracted using a variety of software tools and analysis techniques. The common methods for interpreting data in aeromagnetic geophysics will be discussed in this section. Preparing and improving the raw magnetic data is the first step in interpreting aeromagnetic data. Usually, this includes:

Applying different filters to data can help highlight anomalies and eliminate noise.

Adjusting for fluctuations in the Earth's magnetic field is known as tie-line compensation.

Reduction to the Pole: simplifying interpretation by transforming data to a reference pole location (Nabighian et al. 2005).

A variety of analytical techniques are used to locate and describe magnetic anomalies:

The Signal of Analysis: This transformation of numbers emphasizes the location and amplitude of magnetic sources. It makes interpreting complicated magnetic data easier (Nabighian et al., 2005).

By using the upward continuation technique, magnetic data can be moved from the observation height to a higher reference plane, allowing deeper-seated sources to be revealed (Nabighian et al., 2005)

Case Studies

Case studies give aeromagnetic data interpretation techniques practical applications. They illustrate how useful this geophysical instrument is in a variety of contexts. Some instances include:

Interpreting aeromagnetic data is essential for mineral exploration. Geologists can locate possible mining sites by locating magnetic anomalies linked to ore bodies. For example, the Pilbara region of Western Australia's iron ore deposits were located largely through the use of aeromagnetic surveys (Sylvanus et al., 2023)

Aeromagnetic data interpretation is useful in environmental studies for determining the presence of contamination and locating subterranean structures. For example, environmental impact assessments require the identification of buried pipelines, landfills, and buried waste materials.

Geologists can map subsurface geological structures with the use of aeromagnetic data interpretation. The U.S. Geological Survey maps and studies different geological features in the United States, such as fault lines and volcanic structures, using aeromagnetic data.

These case studies highlight the usefulness and significance of this geophysical tool in actual situations, highlighting the practical applications of aeromagnetic data interpretation across various industries.

Challenges and Limitations

Aeromagnetic data interpretation is a useful tool, but it has drawbacks and restrictions as well. To guarantee accurate and trustworthy results, geophysicists and researchers need to be aware of the following factors:

Accurate data can be affected by both man-made and natural magnetic noise sources, including power lines, steel buildings, and changes in the Earth's magnetic field. Differentiating real anomalies from noise is crucial.

Shallow features are the main targets of aeromagnetic surveys. Accurately estimating the depth of subsurface magnetic sources can be difficult, and anomalies can show up at different depths.

Overlapping anomalies and the presence of multiple magnetic sources can make it difficult to interpret magnetic data in regions with complex geology. Because there are so many magnetic sources in urban areas, including buildings, pipelines, and subterranean utilities, it can be challenging to distinguish between man-made and natural geological anomalies.

Advances in Aeromagnetic Interpretation

Recent years have seen significant improvements in the interpretation of aeromagnetic data due to technological and methodological advances. These advancements have increased this geophysical tool's precision and capabilities. Key developments consist of:

Even in complex geological settings, the location, depth, and shape of magnetic sources can be estimated with greater accuracy thanks to the development of sophisticated inversion techniques (Revees, 2005).

Higher-resolution aeromagnetic data is made possible by modern instrumentation and data collection techniques, which enable more thorough mapping of magnetic anomalies.

Aeromagnetic data can be used to better identify magnetic sources and gain a better understanding of subsurface geology by combining it with other geophysical and remote sensing data, such as multispectral imagery or gravity surveys. Geoscientists can now more accurately depict subsurface geological structures thanks to advancements in 3D visualization techniques, which can be extremely useful for resource exploration and environmental assessment.

Aeromagnetic data interpretation is set to become even more accurate and versatile as technology and geophysical surveying research continue to progress. This will enhance our comprehension of the Earth's magnetic properties and subsurface features.

Applications

Aeromagnetic data interpretation is a versatile geophysical tool with numerous important applications across a wide range of fields. A few noteworthy applications are given below:

The interpretation of aeromagnetic data is essential to the identification and characterization of ore bodies in the field of mineral exploration. Minerals like iron, copper, and gold are frequently found in areas where magnetic anomalies are present. By using this data, geologists can find possible mining sites, which lowers exploration costs and enhances resource assessment.

Environmental scientists can locate landfills, pipelines, underground structures, and other subsurface features with the help of electromagnetic surveys. According to Mohamed and Al Deep (2021), this data is essential for monitoring subterranean infrastructure and evaluating environmental contamination.

Aeromagnetic maps are a useful tool for geologists to better understand subsurface geological structures. This involves the mapping of sedimentary basins, fault lines, and volcanic features. The evaluation of groundwater resources, seismic hazards, and geologic history is facilitated by the visualization of these features. For archaeological surveys, the interpretation of aeromagnetic data is useful. It assists in locating subterranean archaeological sites that contain artefacts made of metal, pottery, and ancient structures. According to Daniels (2004), this application aids in the preservation of history and culture.

Future Directions

Aeromagnetic data interpretation is a field that is always changing due to research and technological advancements. There are several possible paths and upcoming developments to consider:

There's a good chance that aeromagnetic data will more easily integrate with other geophysical and remote sensing datasets. Integrating magnetic data with electromagnetic, hyperspectral, and gravity data will yield a more thorough understanding of subsurface characteristics. It is anticipated that inversion techniques will advance, providing improved shape characterization and depth estimation for magnetic sources. More accurate subsurface modelling will result from this. The ability to visualize and model in three dimensions (3D) will enable geoscientists to produce intricate depictions of subsurface structures. This will be especially helpful for geological research and resource exploration. Aeromagnetic data analysis is predicted to become more accurate and efficient as a result of an increase in automation of data processing and interpretation tasks. Prospects for the interpretation of aeromagnetic data seem bright as long as technology keeps developing and interdisciplinary cooperation keeps expanding. The exploration of Earth's subsurface by geoscientists will lead to a greater comprehension of the planet's geology, natural resources, and atmospheric conditions.

Conclusion

To sum up, understanding the Earth's subsurface properties through geophysical surveying requires the interpretation of aeromagnetic data. Magnetic anomalies are a sign of underlying geological features and resources, and aeromagnetic maps offer detailed insights into these anomalies. This review has looked at several topics related to the interpretation of aeromagnetic data, including the elements and traits of aeromagnetic maps as well as the difficulties encountered in the field. Aeromagnetic surveys are an affordable way to conduct in-depth geological research because they provide fast data collection and high spatial resolution. Numerous fields have found extensive uses for them, including geologic mapping, environmental studies, mineral exploration, and even archaeological surveys. Aeromagnetic data interpretation is not without difficulties, despite its effectiveness. Accurately identifying and characterizing subsurface features can be challenging due to factors like depth estimation, complex geology, and magnetic noise. High-resolution surveys and advanced inversion techniques are just two examples of the methodology and technological developments that are poised to address some of these issues. Future developments are anticipated in the field of aeromagnetic data interpretation. It is anticipated that greater automation, sophisticated 3D visualization, and improved data integration will be essential to raising the effectiveness and precision of data analysis. Aeromagnetic data interpretation will continue to be a fundamental component of geophysical surveying as we uncover more of the planet's hidden mysteries. This will help us gain a better understanding of the Earth's magnetic characteristics, geological formations, and the priceless resources they contain. Future developments in this dynamic field could significantly impact resource assessment and geoscientific exploration. The interpretation of aeromagnetic data in the dynamic field of geophysics is a tribute to the strength of interdisciplinary cooperation, technological advancement, and the never-ending search for knowledge about the planet's subsurface.

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