Primer: Interpreting Magnetic Data

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER and is produced by M. Ray Thomasson of the AAPG Geophysical Committee. This month's column is the first of a two-part series on interpreting magnetic data.")

By DALE BIRD
AAPG Geophysical Committee

Traditionally, magnetic data have been used in early phases of exploration programs to map depth to magnetic basement and define the basin architecture.

Recent improvements in acquisition and processing technology, together with more detailed understanding of structural styles in exploration areas, allows us to now say:

"Magnetic data are not just for the basement anymore."

This month's "Geophysical Corner" describes methods of interpreting magnetic anomalies. Fundamental concepts, or "rules-of-thumb," are also included.

Although there are certainly alternative approaches and/or techniques that may be used, the purpose here is to provide a framework for geoscientists who may be unfamiliar or do not regularly work with magnetic data.

Rules of Thumb

❒ Wavelength.

In general, the wavelength of an anomaly is proportional to the depth of the magnetic source body that produces it (Figure 1). More correctly, depth is related to the horizontal distance of the slope of the anomaly.

As with other geophysical data, long "wavelengths" are related to deep sources (or events), and short "wavelengths" are related to shallower sources.

Outcrops of the San Juan volcanics in southwestern Colorado have narrow, high frequency anomalies, while the deep basement in the Williston Basin causes relatively broad highs and lows.

High frequency anomalies are also observed over the Devil's River Uplift in West Texas. Adjacent to the Uplift, anomalies are broader indicating a dramatic deepening of the basin.

When looking at a magnetic map, an anomaly high is not necessarily produced by a structural high. Rather

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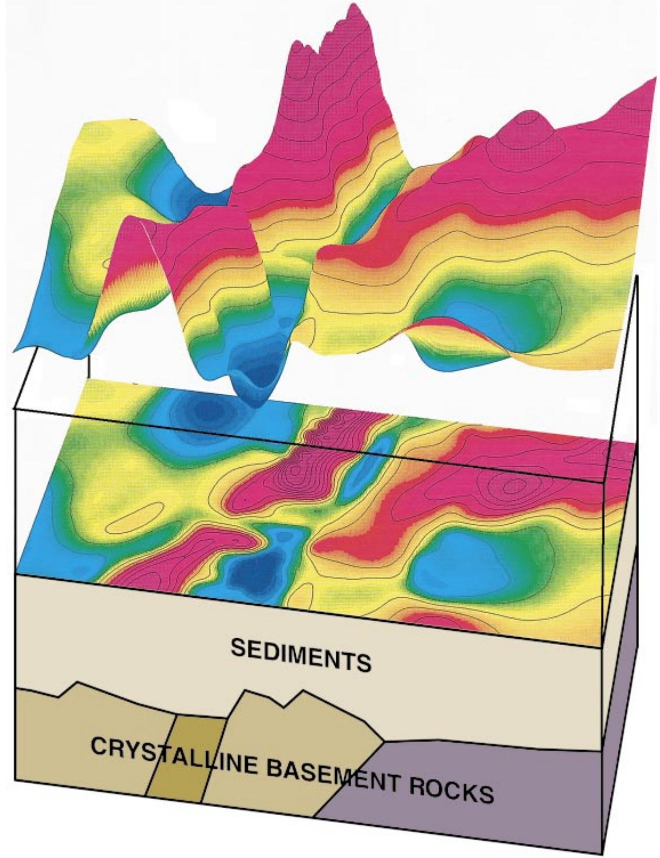

Graphics courtesy of Aerodat Inc.

Figure 1: Three-dimensional perspective of magnetic data and Earth model.

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an area of closely spaced, sharp, short wavelength anomalies implies shallow basement and an area of smooth, broad, long wavelength anomalies implies deep basement.

With a practiced eye an interpreter can quickly pick deeper from shallower areas.

❒ Amplitude

The amplitude value is proportional to the magnetic susceptibility contrast in the rocks beneath the magnetometer.

"Susceptibility" is a measure of the ease with which a rock can be magnetized. Geologically it can be thought of as a measure of the magnetite content, although a few other minerals may contribute under special circumstances.

Amplitude does decrease with increasing distance from the source, but not to an extent that effects the following concepts.

Amplitudes can generally be divided into categories of hundreds of nanoteslas (nT), tens of nT, and ones of nT. The nanotesla (nT) has been adopted by our industry as the "official" unit of measure for magnetics. It replaces the gamma (y); in other words, 1 nT is equal to 1 gamma (y).

Lithologic variations in magnetic basement, or the presence of igneous rocks within the sedimentary section, generally produce anomalies with the highest amplitudes. For example, the magnetization of intra-basement features may be stronger than surrounding basement rocks.

In this case, large amplitude anomalies would be observed where basement structures are not present.

The East Coast Magnetic Anomaly, with an amplitude of several hundred nT, is related to the contact between oceanic and continental crust and to possible intrusive rocks along it. In the Black Warrior Basin of northwestern Mississippi, an area of low magnetic intensity is bordered by high amplitude anomalies and is, in fact, structurally high.

The basement in this area is, in fact, structurally high – as proven by several exploration wells.

To summarize, high amplitude anomalies typically reflect lithologic contrasts. While anomalies produced by structures are usually more subtle.

Anomalies with amplitudes on the order of:

✔ 100s nT – are related to lithologic variations in basement or igneous rocks with the sedimentary section.

✔ 10s nT – are related to basement structures (supra-basement).

✔ 1s nT – are related to sedimentary magnetization contrasts.

❒ Methodology

A typical approach for interpreting magnetic data involves geologic research including an assessment of existing geologic and geophysical control, depth-to-magnetic source estimation, 2-D and 3-D forward modeling, data inversion, analyses of anomaly trends (using observed data and its derivatives), and data filtering.

It is not necessary to follow a specific order when applying these elements, but final products usually involve producing geologic map(s) that incorporate information from one or more elements.

❒ Geologic Concept

The most important element required for interpreting magnetic data is a geologic concept or structural model. We are never blind; that is, even if the only data available in an area are magnetic data, we know the area is in a rift setting, or a foreland basin, or along a passive margin, etc.

We also know the survey's location, hence, we know the attitude of the magnetic field or its inclination and declination and strength.

The poles of the Earth's magnetic field are not aligned exactly with its geographic poles, and therefore inclination, declination and field strength indicate the direction and magnitude of the field relative to geographic position.

When interpreting geophysical data

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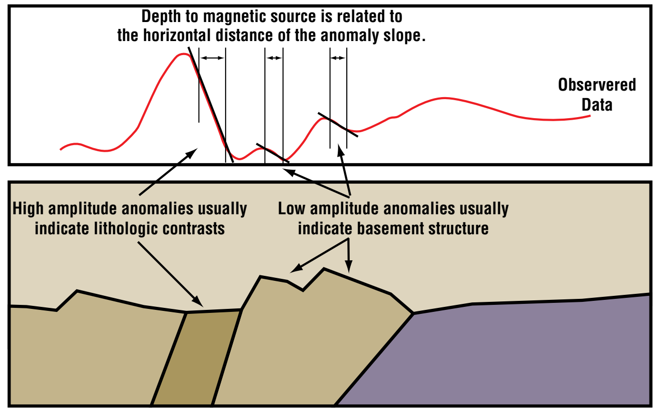

Figure 2: Two-dimensional cross-section

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it is most important to apply known geologic control to constrain the interpretation.

❒ Depth-to-Magnetic Source

Depths determined from magnetic data can be confidently estimated to about ±7 percent. When an entire data set is interpreted by consistent methods, the interpretation map will show structural highs and lows which are relative to each other. Although depths are not known exactly, the horizontal positions of anomalies are directly related to locations of interpreted sources, so there is no ambiguity with regard to geographic position (Figure 2).

There are many depth-to-magnetic source estimation techniques, manual and automated. The important thing to remember when applying these techniques is to be consistent. The end product will then be a map of posted values that are all relative to each other.

It is helpful to generate hypothetical 2-D models, incorporating the appropriate magnetic field attitude and strength in order to see relationships between structures and the position of anomalies over them (Figure 2, page 19).

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Next month: Two-D modeling, data inversion, trend and lineament analysis and filtering.

(Editor's note: Dale Bird is general manager of Aerodat Inc., in Houston.)

Geology Should Rule Interpretation

By DALE BIRD
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Last month's "Geophysical Corner" was the first part in a two-part series on "interpreting Magnetic Data." In it, "rules of thumb," methodology, interpretation concept, and depth-to-magnetic source analyses were discussed.

This month's column continues with techniques for interpreting magnetic data including: modeling, trend and lineament analyses, and filtering.

Modeling

A two-dimensional magnetic model (Figure 1) can be created along a seismic line in order to check, for example:

❒ If an interpreted depth to magnetic basement is reasonable.

❒ If a sedimentary structure is supported by a basement structure.

❒ If a feature on a seismic section is salt or igneous, etc.

This type of modeling is called forward modeling.

For inverse modeling, the observed data and a starting model are used. Then either model geometries or magnetic susceptibilities are modified until the calculated field produced by the model "fits" the observed field.

Three-dimensional modeling is similar, utilizing gridded data and surfaces.

Two variables are involved in modeling: magnetic susceptibility and geometry of source bodies. Using control such as seismic, gravity and well data, geometries may have little variability – thus modeling involves adjusting magnetic susceptibility. If there is no control other than magnetic data, then it is best to keep susceptibilities constant and modify geometries.

Magnetic data also can be used to constrain interpretations of other data sets. For instance geological cross-sections are interpretations, and magnetic interpretations can improve such work in areas of ambiguous geology.

It is easy to create a complex model, with an excellent match between computed and observed magnetic anomaly profiles, that far exceeds available control. Therefore, it is:

❒ Not appropriate to modify geometry and susceptibility in magnetic models randomly with no control.

❒ Not appropriate to model using filtered data, because we do not know if the component of the magnetic field removed by the filter is also removed in our model.

Trend and Lineament Analyses

Depth-to-magnetic source estimation and modeling are

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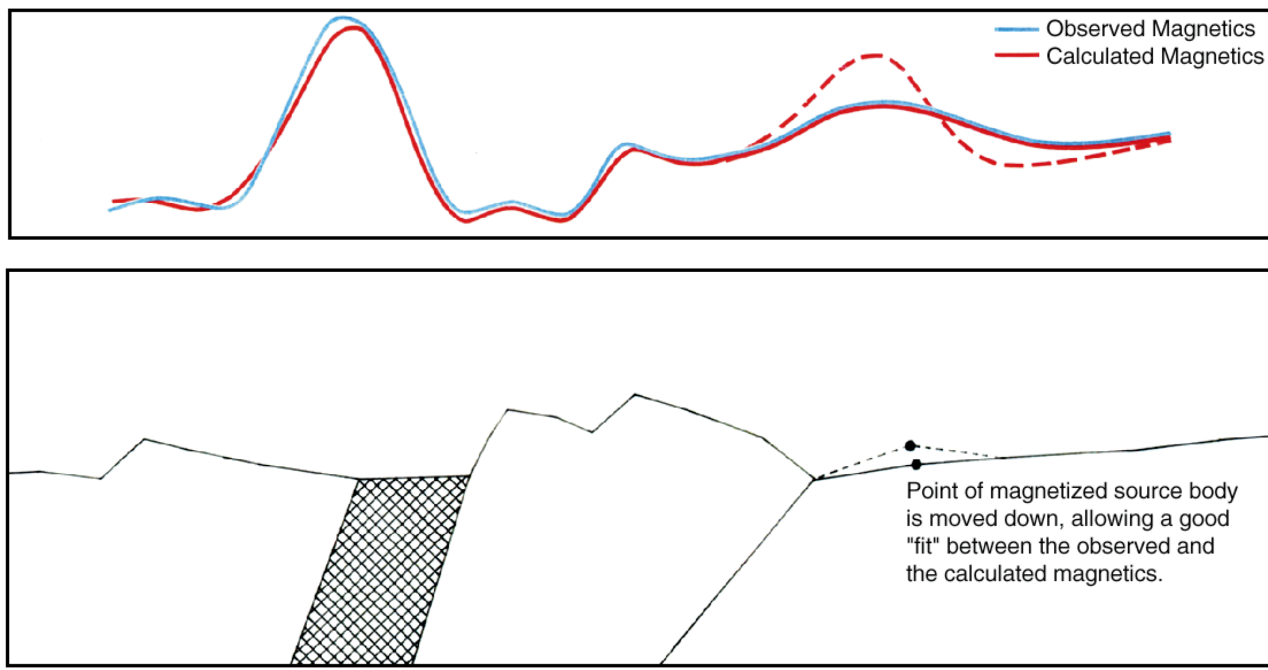

Figure 1.

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quantitative techniques. An important qualitative technique is analyses of trends and linears.

Trends can be analyzed using profiles or gridded data and generally consists of drawing lines on a map that may correspond to edges of structures, faults, or partitions of the data character (Figure 2).

Subtle linear breaks in magnetic data, especially when correlated with features identified from other data sets, may indicate positions of complex structures in the prospective section.

For example, part of the data may be characterized by short wavelength, high amplitude anomalies, and another part of the data may be characterized by longer wavelength anomalies.

Geologic examples are accommodation zones in rifts, wrench anticlines in convergent settings and even zones of fracturing.

Trends also may be defined as the termination of linear anomalies.

Filters

Filtering magnetic data is also a qualitative aspect of interpretation (Figure 2). The objective of filtering data is to separate anomalies by wavelength, and this operation can be performed several ways through manual and automated techniques. The most effective way to filter is with an understanding of the geologic control and an idea of the desired filtered results.

A typical process involves producing suites of filtered maps and assessing their character with geologic control.

Filtering data is a powerful tool and often leads to important conclusions, but its use should be driven by the nature of the geologic problem to be solved.

Recent advances in navigation (Differential GPS positioning), computer systems and processing now allow extremely subtle anomalies to be resolved. For example, anomalies produced by small magnetization contrasts within sedimentary rocks can be confidently mapped.

Filtering and trend analyses are techniques especially suited for interpreting these subtle anomalies.

Summary

Interpretation of magnetic data should include elements of both qualitative and quantitative analyses, which in turn should be guided by geologic concepts. This does not mean that the interpretation should be forced to a rigid concept, but that the end result must be geologically plausible given the control.

The interpretation should contribute to the overall geologic picture, and our understanding should be modified and improved by the data.

On the other hand, quite often we generate more questions that may be as useful as the geologic questions already answered by our interpretation of magnetic data.

Fundamental understandings of magnetic data and interpretation techniques, as outlined here, are valuable tools that geoscientists can use to gain insight and improve their geologic knowledge of an area.

As with geology, often the subtle features of the data – and their meaning – are most important.

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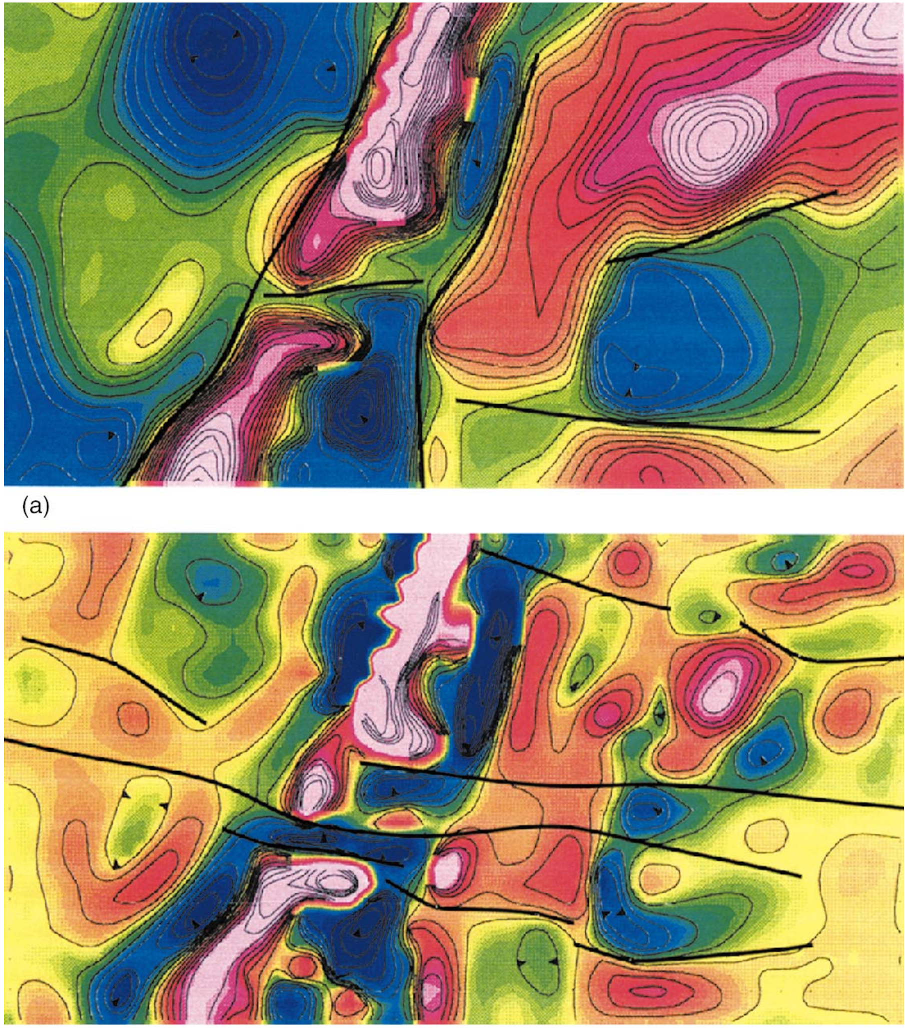

(a)

(b)

Graphics courtesy of Dale Bird

Filtering magnetic data is a qualitative aspect of interpretation. Graphic (a) shows total intensity magnetic anomalies, with major trends identified. Graphic (b) shows filtered magnetic anomalies, with additional – more subtle – trends identified.