Implementation of a method for determination of magnetization direction

Caesar Augusto Rigoti, PETROBRAS, Brazil

Abstract

The knowledge of the total magnetization direction has always been a drawback in among geological and geophysical exploration when using magnetic data. Remanent magnetization, present in almost all magnetic bodies, can significantly alter this direction. Usually the reduced to pole transform is applied to magnetic data but, without the knowledge of the total magnetization direction the data will not be reduced to pole correctly. Consequently, the interpretation will be erroneous. The need of a more precise and accurate interpretation always leads us to new methods and techniques. In this paper a method to determine the magnetization direction was tested and analyzed. The methodology is based on the cross-correlation of the vertical gradient and the total gradient of the reduced to pole anomaly. The method is only applicable to isolated anomalies and showed consistence and efficiency when applied to synthetic and real data, resulting in a more symmetrical and centered anomaly.

Introduction

A variety of interpretation techniques of magnetic data requires the knowledge of the total magnetization direction (TMD). The presence of remanent magnetization can influence this direction and consequently affect the interpretation and modeling of magnetic bodies.

The total magnetization direction of a magnetic body is the vector sum of the induced magnetization and the remanent magnetization. The induced magnetization is aligned with the magnetic field of the earth, and in most cases it is the dominant magnetization and the only magnetization assumed when treating the magnetic anomaly. However, the remanent magnetization can be strong and alter significantly the direction of the total magnetization leading to erroneous interpretation.

This paper is a reproduction and analyses of a technique used to determine the total magnetization direction of magnetic bodies. The proposed method, described by Dannemiller and Li, 2006, is based upon correlation between two quantities used in magnetic data interpretation: the vertical gradient and the total gradient of the reduced-to-pole (RTP) field.

The method was tested on synthetic data and on real magnetic anomalies.

Method

The process of reducing to the pole transforms a total field anomaly, which is asymmetrical out of the pole, into a symmetrical anomaly generated as it would occur in the pole. The reduction to pole can only be correctly applied if the total magnetization is known.

Numerically, this transformation (RTP) can be done using an estimate of the magnetization direction, but the result will not be an anomaly reduced to pole. The anomaly will still be asymmetrical when compared to that reduced to pole. So, the problem consists in finding the magnetization direction that, when applied to the reduction to pole, will generate the most symmetrical anomaly possible for our magnetic causative body.

The methodology is based on the cross-correlation of two well known quantities used in interpretation of magnetic data: the vertical gradient and the total gradient of the reduced to pole anomaly.

Once calculated the vertical and total gradient of all possible direction of magnetization, defined by the pair magnetic inclination and declination (I_M, D_M), the correct reduced to pole transformation will be the one that reaches the highest correlation between the two quantities.

The cross-correlation can be computed using the following formula:

$$C(I_M, D_M) = \frac{\sum (v_j - \bar{v})(t_j - \bar{t})}{\sqrt{\sum (v_j - \bar{v})^2 \sum (t_j - \bar{t})^2}}, \quad (1)$$

Where v is the vertical derivative of the reduced to pole anomaly, t is total gradient of the reduced to pole anomaly, j is the index of each quantity within the data set, $\bar{v}$ and $\bar{t}$ are, respectively, the means of v and t.

The position of maximum cross-correlation on a bidirectional grid of magnetic inclination and declination will determine the correct direction of the total magnetic magnetization.

Synthetic model

The synthetic model intends to represent a magnetic dyke type body, finite in length, with variable trend and strong remanent magnetization. Figure 1 shows a 3D representation of the model and the calculated magnetic anomaly can be seen in Figures 2 and 3. Figure 4 represents the magnetic anomaly calculated for the same model but with no remanent magnetization. Note that on Figure 3 the anomaly has an inverted polarity when compared to Figure 4. This effect is caused by the strong remanent magnetization.

Figure 5 is a graphic representation of the results of the cross-correlation showing a total magnetization direction value at C(I_M, D_M) = (10°,-70°) or (-10°, 150°).

Figure 6 shows how the result would be if only the induced magnetic field was used to reduce the anomaly to the pole. Observe the asymmetry of the anomaly. For comparison, Figure 7 shows the theoretical reduced to pole anomaly; in this case we removed the remanent magnetization to compute the anomaly.

Figure 8 shows the reduced to pole anomaly, using the estimate of the total magnetization direction. Note the similarity with the theoretical result in Figure 7. The anomaly is symmetrical and centered over the causative magnetic body.

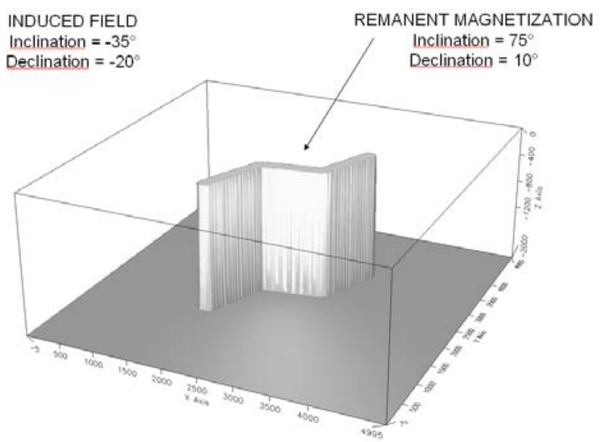

Figure 1: 3D representation of the magnetic synthetic body.

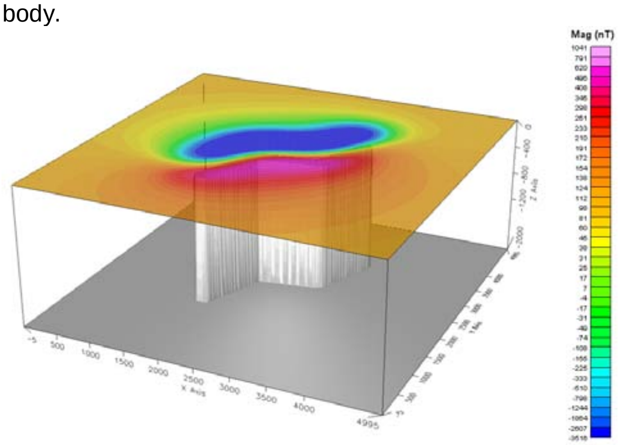

Figure 2: Magnetic anomaly calculated for the model.

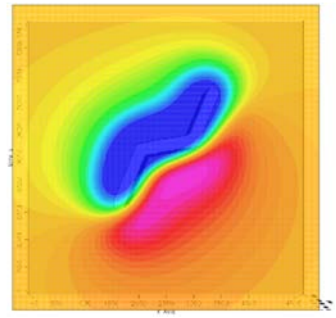

Figure 3: Calculated anomaly seen in map.

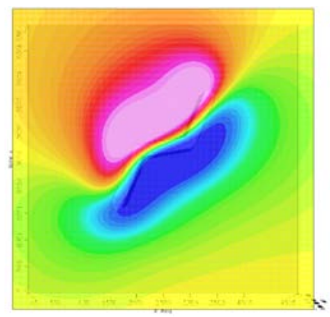

Figure 4: Calculated anomaly seen in map for the same body but with no remanent magnetization.

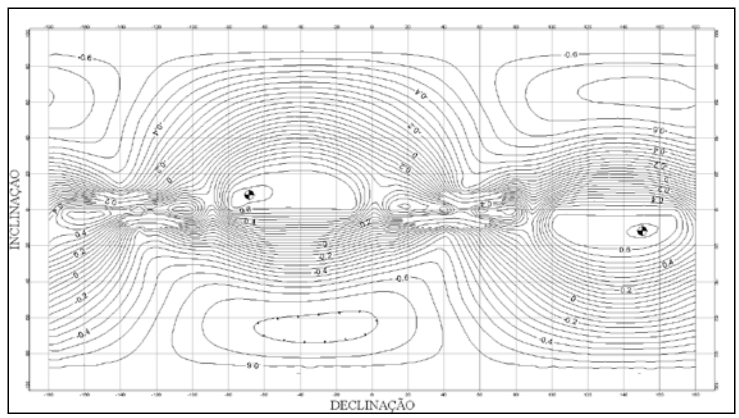

Figure 5: Graphic (Inclination X Declination) representation of the cross-correlation, showing the result of the calculated total magnetization direction for the synthetic model. C(I_M, D_M) = (10°,-70°) or (-10°, 150°).

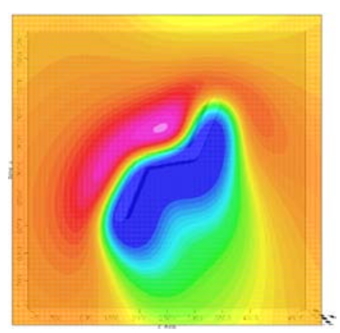

Figure 6: Magnetic anomaly reduced to pole, using the induced field as the magnetization direction.

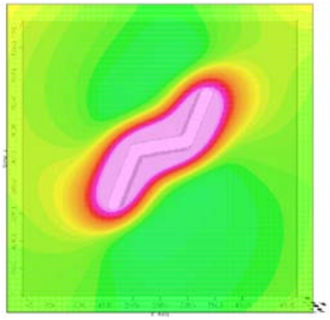

Figure 7: Magnetic anomaly reduced to using the induced field but with no remanent magnetization included in the magnetic body.

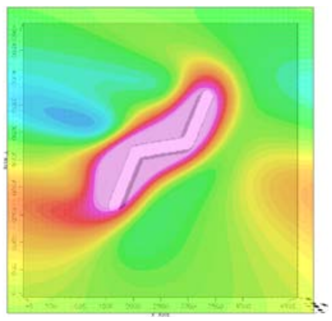

Figure 8: Magnetic anomaly reduced to pole using the total magnetization direction calculated for the model with strong remanent magnetization.

Application to real data

Two significant anomalies, denominated Kimberlito and Anomalia de Pirapora were selected due to the low interference with other magnetic anomalies (Figure 9). The data is part of a set of airborne geophysical surveys acquired in the 70s.

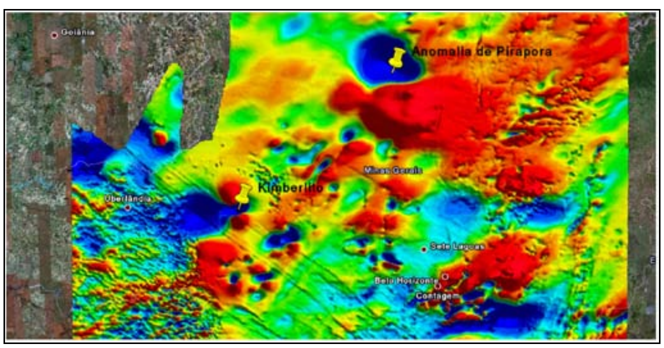

Figure 9: Magnetic total field anomaly and location of the real data anomalies tested.

Kimberlite: the magnetic anomaly represents a kimberlite body. It is located in the region of Patrocínio, Minas Gerais, Brazil. This kimberlite belongs to the Provincia Alcalina do Alto do Paranaíba that is a magmatic event that occurred in the Cretaceous. In Figure 10 circular topographic features can be seen from the satellite image. Figure 11 shows a geological map delimitating the boundaries of the kimberlite. The total field anomaly (Figure 9) shows a magnetic low in the center of the kimberliteic body indicating an inverse polarity due to remanent magnetization. The result of the estimate of the total magnetization direction (Figure 12) indicates a maximum correlation at $C(I_M, D_M) = (-42°,-7°)$, and the reduction to pole using the estimated magnetization direction can be seen on Figure 13. Note the symmetry and how well centered is the anomaly over body.

Figure 10: Topographic features of the kimberlite in the region of Patrocínio, Brazil.

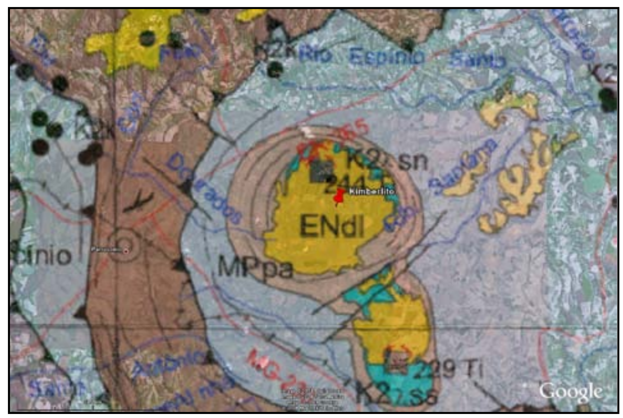

Figure 11: Geological map of the kimberlite.

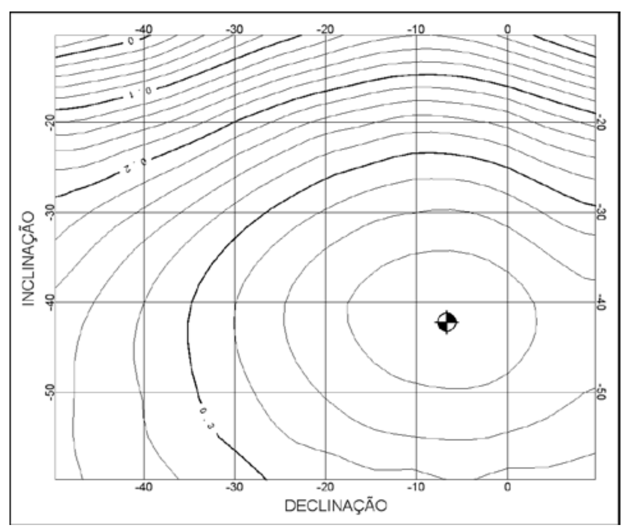

Figure 12: Graphic result of the calculated total magnetization direction $C(I_M, D_M) = (-42°,-7°)$.

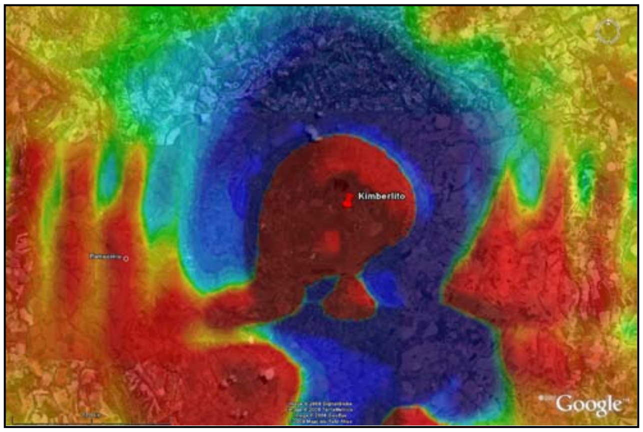

Figure 13: Magnetic anomaly reduced to pole using the total magnetization direction.

Anomalia de Pirapora: a magnetic anomaly located to the north of the quadrilatero ferrífero, Minas Gerais, Brazil. The source of this anomaly is yet not known, but certainly reflects a deep and strong magnetized body with remanent magnetization. Modeling (not shown) indicates depth of about 15km for this magnetic body. In Figure 14 we can observe the total field anomaly. Figure 15 shows the reduced to the pole anomaly using only the induced magnetization direction of $C(I_M, D_M)$ = (-16°,-18°), resulting in an asymmetric anomaly. Figure 16 corresponds to the result of the estimated magnetization direction, indicating a total magnetization direction of $C(I_M, D_M)$ = (-4°,-17°). The reduction to the pole can be seen on Figure 17. The result shows a more symmetric anomaly that could be isolated, enhancing our data for future modeling and interpretation.

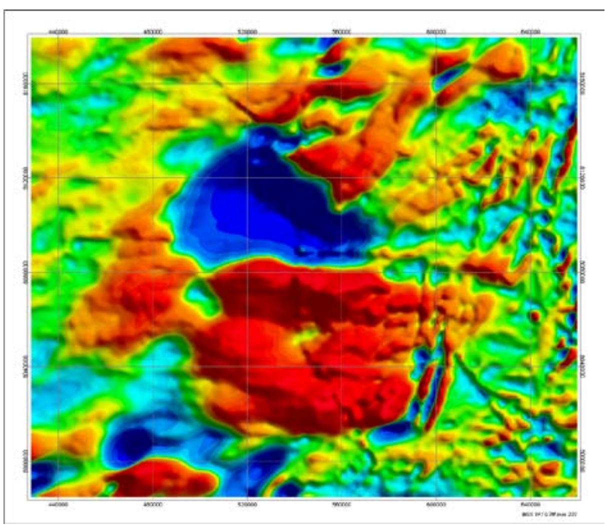

Figure 14: Total field anomaly of the Pirapora magnetic anomaly.

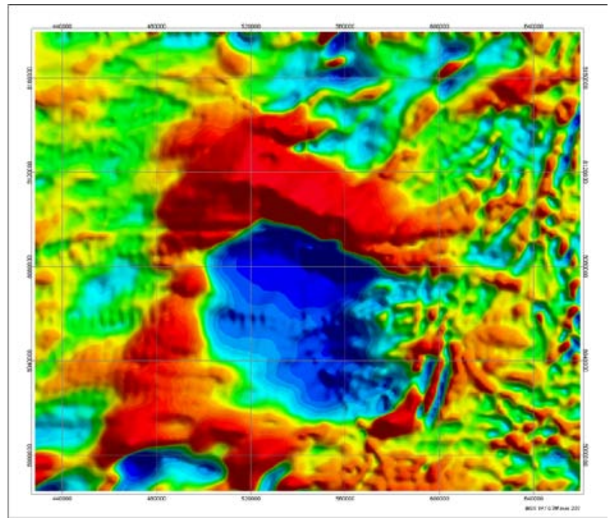

Figure 15: Magnetic anomaly reduced to pole using the induced field as magnetization direction.

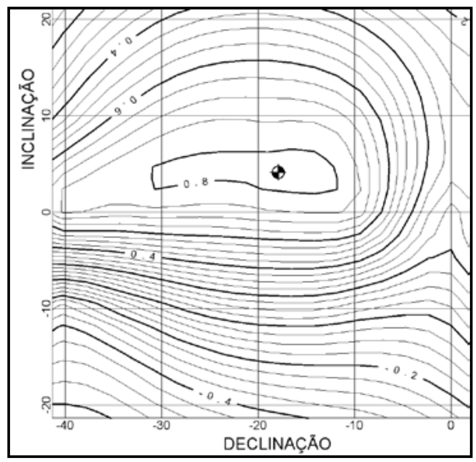

Figure 16: Graphic result for the calculated total magnetization direction.

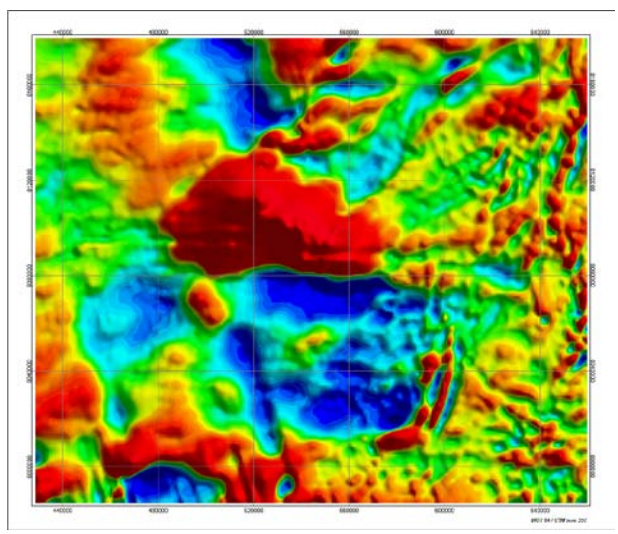

Figure 17: Magnetic anomaly reduced to pole using the total magnetization direction.

Conclusions

The study of the total magnetization direction of a magnetic body can be really important when a precise and accurate quantitative interpretation is required. Without this information the data can't be reduced to pole correctly and so the parameters of the model won't be securely recovered.

The application of the method to synthetic and real data shows that the method is consistent and efficient, resulting in a more symmetric and centered anomaly. It is important to emphasize that the real data tested over isolated anomaly with low interference of other magnetic sources. The method is not applicable to anomalies related to two or more magnetic sources with different magnetization direction.

The method shows good application to interpretation techniques and could result in a more reliable modeling and interpretation of magnetic anomalies for all segments of geological exploration.

Acknowledgements

The author would like to thank Petrobras S/A and especially thank the Petrobras' Potential Fields Team for their support and revision.

References

Dannemiller, N.; Li, Y. – A new method for determination of magnetization direction, GEOPHYSICS VOL. 71, NO. 6 (NOVEMBER-DECEMBER 2006); P L69-L73, 7 FIGS.