Reduction to the pole of the aeromagnetic data of Zaria area, north central Nigeria

K.M. Lawal and I.B. Osazuwa

Department of Physics, Ahmadu Bello University Zaria, Kaduna State, Nigeria

(Received September 16, 2002; accepted September 9, 2003)

Abstract - The reduction-to-the-pole technique was applied to the aeromagnetic data of the Zaria area, in the north central part of Nigeria. The data was obtained by digitizing six aeromagnetic maps which covered the area. Using a method from the literature, a computer software is developed to perform the general three dimensional case. After reducing the data to the pole, and comparing it to the total field, it is indicated that the technique eliminates the dipolar nature of the anomalies. The presence of positive anomalies in the reduced to the pole map, which exist in most parts of the area, validates the assumptions of induced magnetization within the area. The magnetization map also computed using the reduced to the pole field revealed some unexposed granitic intrusions within the area covered.

1. Introduction

The cost of geophysical data acquisition has forced mineral and petroleum exploration companies to rely increasingly on the aeromagnetic technique as an economical method for both reconnaissance and detailed determination of subsurface geological structures. This interest has generated an active search for better techniques to process and interpret the mass of data that is being accumulated.

The interpretation of magnetic anomalies is complicated because of the fundamental ambiguity involving the product of a physical property and a volume. This product, called the dipole moment is the product of magnetization and volume. The magnetization which is a vector quantity, is related to a surface rather than to a volume distribution of magnetic poles. This means that not only the magnetization intensity, but also the magnetization inclination and

Corresponding author: K.M. Lawal, Ahmadu Bello University Zaria, Kaduna State, Nigeria.
e-mail: kola2lawal@yahoo.com

declination may couple with parameters defining the source volume. This causes distortion of the magnetic anomaly, with the degree of distortion being a function of the magnetic latitude. Numerous authors, such as Hays and Scharon (1963) and Park (1968), have shown that the remanence can be a significant or even dominant contributor to the anomalous field. However, because reliable information in remanence is seldom available, anomalies are usually assumed to be caused entirely by induction. Baranov (1957) and Baranov and Naudy (1964) developed a method which mathematically transformed the total intensity field into an equivalent vertical field. In essence, this would be the field obtained if the geological source were physically moved to the magnetic pole. The transformation therefore is called “reduction-to-the-pole”.

Traditionally, reduction-to-the-pole has been accomplished either by space domain filtering (Bhattacharyya, 1965; Ervin, 1976) or wavenumber domain filtering (Kanasewich and Agarwal, 1970; Gunn, 1975). In the two-dimensional case, this procedure is stable regardless of the latitude, as long as the source strike is not parallel to the horizontal projection of the geomagnetic field. In the three-dimensional case, however, reduction-to-the-pole filtering is stable only at high magnetic, latitudes. At latitudes lower than 15 degrees, it is of no practical use due to a sharply increasing instability towards the magnetic equator (Silva, 1986). However, Silva (1986) has shown that the three-dimensional case can be solved by formulating the problem in the context of a general linear inverse problem from which stable solutions are found by using well-known stabilizing procedures developed for inverse linear problems. Also by windowing the data (Leão and Silva, 1989), C.P.U. time and the memory necessary for the transformation can be drastically reduced.

In this work, using the method proposed by Leão and Silva (1989), a computer program has been developed to accomplish this task for the general three-dimensional case. The area covered lies between latitude 10° 30′ N and 11° 30′ N, and longitude 7° 00′ E and 8° 30′ E within the Northern Nigerian Precambrian belt.

2. Theory of method used

Silva (1986) showed that by formulating the problem of reduction-to-the-pole as an inverse problem, stable solutions in the presence of noise could be found using well-known methods, such as that of Freund and Minton (1979), and Hoerl and Kennard (1970 a, 1970 b). Consequently, meaningful results at low magnetic latitudes, where the instability is more pronounced, can be obtained. Initially, the magnetization of an equivalent layer of doublets is computed from the observed data. All magnetic doublets are assumed parallel to the magnetization vector whose direction is supposedly constant throughout the sources. Once strengths of the doublets are found, the inclinations of the field are changed to 90 degrees and the total magnetic field is recalculated. The first stage involves the solution of an inverse problem, while the second is a forward problem. Only the first stage presents instability so that a stabilizing procedure must be applied only there.

Leão and Silva (1989) presented an efficient method which could be used to process large areas. This involves movement of an N x N data window using an M x M equivalent layer, with

M greater than N. The reduced to the pole field t_p at the central point of the data window can be obtained by using the following equation:

$$t_p = b^T A^T D \, (DAA^T D + \lambda I)^{-1} \, t_o \tag{1}$$

where,
t_o = vector of length N containing the observations
$A = N$ x M matrix whose element is the discrete Green's function
b = the central row of a matrix B, the Green's function associated with the reduction-to-the-pole transformation.
I = identity matrix
D = a normalizing diagonal matrix
λ = a real positive number between 0 and 1.

The criterion for the selection of the best value of λ is given in Hoerl and Kennard (1970b).

3. Application to the aeromagnetic data of Zaria area

Based on the work of McCurry (1970), the principal rock units in the area are:

1. meta-sediments, which are believed to have been laid down and then metamorphosed during the Pan-African Orogeny (between 850 and 650 million years ago) and occupy a linear north-south trending isoclinal belt to the west of the area (Fig. 1);
2. a crystalline complex composed of gneiss, considered to have been metamorphosed more than 2,000 million years ago;
3. older granite which included the gneissic crystalline complex from 647 to 618 million years ago.

The data used in the survey were obtained from the Nigerian Aeromagnetic Survey sheets 101, 102, 103, 123, 124 and 125. The survey for each sheet was completed in 1974, and each

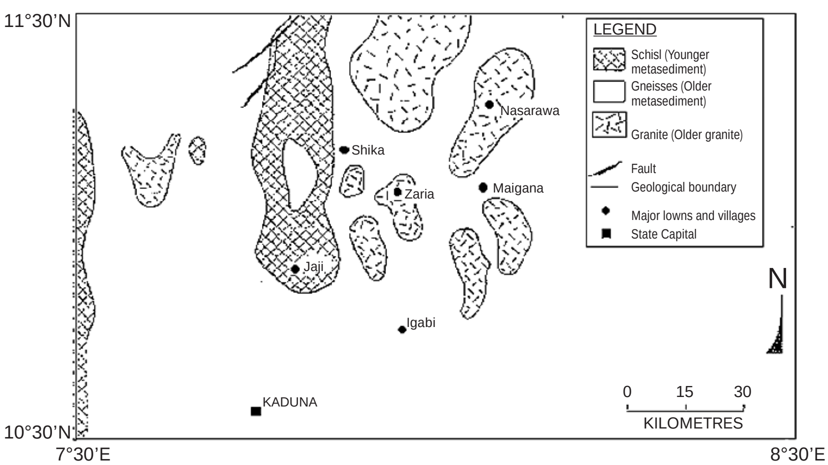

Fig. 1 - Geology of the Zaria area.

sheet has a mean terrain clearance of 152.4 m (500 ft) with the flight lines at intervals of 2 km from each other. The geomagnetic field inclination and declination within the area are 2° and 3°, respectively. The maps were digitized along flight lines by reading the total magnetic field intensity value at the point of intersection of the plotted contour and the flight line. The values of the total field with their corresponding (*x*,*y*) coordinates were recorded and then later interpolated on to a regular grid of a 2 km interval. In this manner, all the sheets combined together were digitized to obtain an 82 x 55 data matrix. Using a polynomial fitting, a regional-residual separation was done on the data and the residual field is shown in Fig. 2. This field was reduced to the pole by using a 7 x 7 data window and 15 x 15 equivalent layer with $\lambda = 0.5$. This is shown in Fig. 3.

Comparing the residual map and the reduced to the pole map it can be observed that there are more positive anomalies than there are negative anomalies on the reduced to the pole map

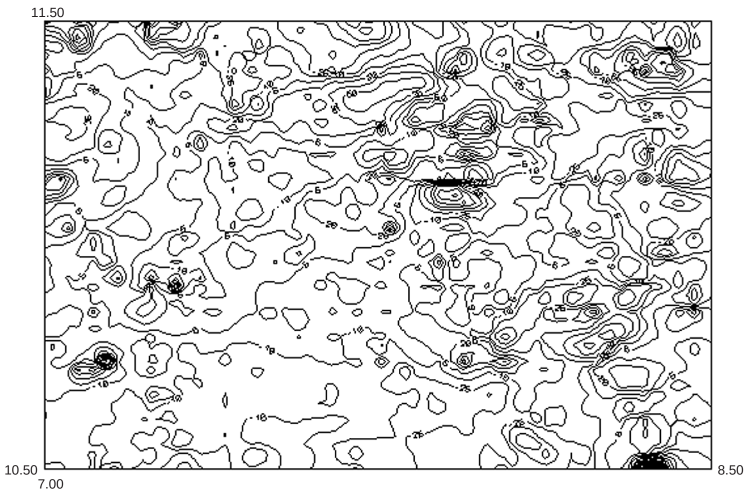

Fig. 2 - Residual field map of the Zaira area. Contur intervals is 15nT.

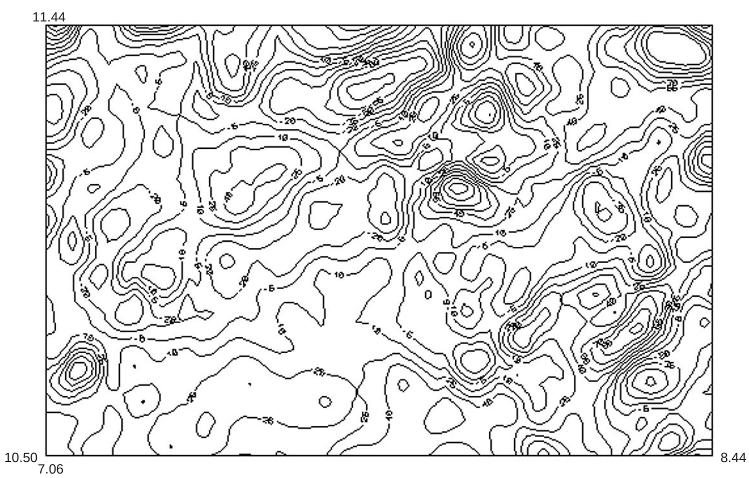

Fig. 3 - The reduced to pole field of the Zaira area. Contur intervals is 15nT.

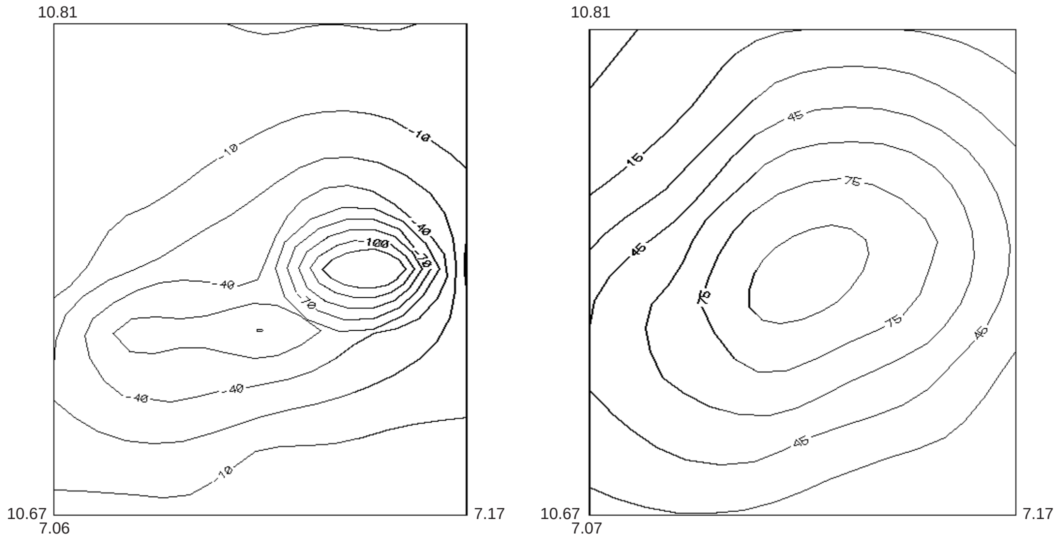

Fig. 4 - A zoomed anomaly from the residual field (a) and its corresponding reduced to he pole anomaly (b). Contour interval is 15 nT in both cases.

which indicates that the assumption of induced magnetization is a good approximation. And also the anomalies on the reduced to the pole map appear to be more symmetrical than those on the total field map, with an example shown in Fig. 4.

Fig. 5 shows the magnetization intensity map computed using the reduced to the pole field as input. Using the method of Silva and Hohmann (1984), that is by determining the region of the half-maximum contour value, the boundaries of the magnetic units within the area were mapped out as shown in Fig. 6. Comparing Fig. 6 and the geological map of the area (Fig. 1) shows that some correlations exist between the granites in Fig. 1 and the mapped boundaries of Fig. 6. Therefore, the magnetic units mapped at the south-western part of Fig. 6 represent unexposed granite intrusions in the gneiss complex.

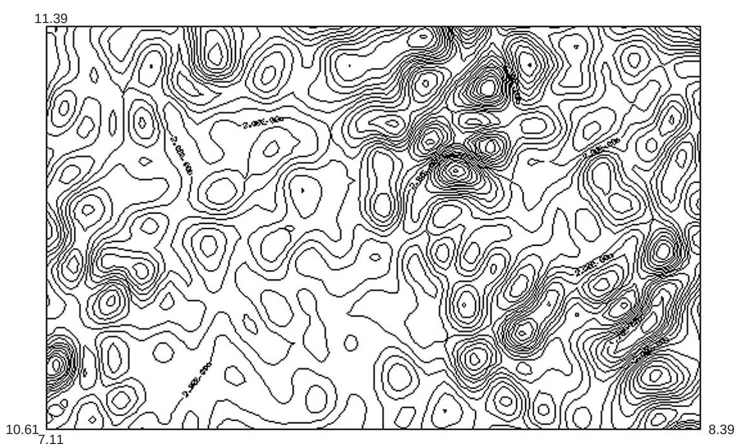

Fig. 5 - Magnetization map generated using the reduced to the pole field. Contour interval is 3.0 x 10^{-6} A/m.

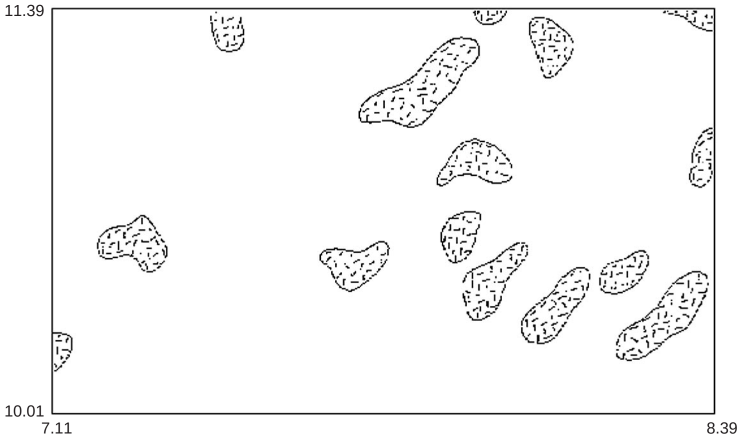

Fig. 6 - Geological map of the Zaria area showing unexposed granitic intrusions, deduced from the magnetization map of Fig. 5.

4. Conclusion

Reducing magnetic fields to the Earth's magnetic pole makes the interpretation of magnetic anomalies easier, as the anomalies are not shifted as a result of the obliquity of the normal field. Using the method of Leão and Silva (1989) the aeromagnetic data of the Zaria area of north central Nigeria was reduced to the pole and the result showed a clearer picture of the anomalies within the area. The anomalies appear to be more symmetric and their trends are better defined. Also the presence of positive anomalies in most parts of the reduced to the pole map validates the assumptions of induced magnetization within the area. The magnetization intensity map computed using the reduced to the pole field has helped in improving the geology of the area by delineating some unexposed granite intrusions around the south-western part of the area.

References

Baranov V.; 1957: *A new method for interpretation of aeromagnetic maps: Pseudo gravimetric anomalies*. Geophysics, **22**, 359-383.

Baranov V. and Naudy H.; 1964: *Numerical calculation of the formula of reduction to the magnetic pole*. Geophysics, **29**, 67-79.

Bhattacharyya B.K.; 1965: *Two-dimensional harmonic analysis as a tool for magnetic interpretation.* Geophysics, **30**, 829-857.

Ervin C.P.; 1976: *Reduction to the magnetic pole using a Fast Fourier Series algorithm.* Computers and Geosciences, **2**, 211-217.

Freund R.J. and Minton P.D.; 1979: *Regression Methods: A tool for data analysis*. Statistics textbooks and monographs, **30**, 261 pp.

Gunn P.J.; 1975: *Linear transformation of gravity and magnetic fields*. Geophysical prospecting, **23**, 300-312.

Hays W.W. and Scharon L.; 1963: *An example of the influence of remanent magnetism on magnetic intensity measurements*. Geophysics, **38**, 1037-1048.

Hoerl A.E. and Kennard R.W.; 1970a: *Ridge regression: Biased estimation for nonorthogonal problems*. Technometrics, **12**, 55-67.

Hoerl A.E. and Kennard R.W.; 1970b: *Ridge regression: Applications to non-orthogonal problems*. Technometrics, **12**, 69-82.

Kanasewich E.R. and Agarwal R.G.; 1970: *Analysis of the combined gravity and magnetic fields in wavenumber domain*. Journal of Geophysical Research, **75**, 5702-5712.

Leão J.W.D. and Silva J.B.C.; 1989: *Discrete linear transformations of potential field data*. Geophysics, **54**, 497-507.

McCurry P.; 1970: *The geology of degree sheet 21 (Zaria)*. M.Sc. Thesis, Geol. Dept., A.B.U., Zaria.

Park F.B.; 1968: *Remanent magnetism and the anomaly of Comouer Mountain, Madison County, Missouri*, Geophysics, **33**, 613-620.

Silva J.B.C.; 1986: *Reduction-to-the-pole as an inverse problem and its application to low latitude anomalies*. Geophysics, **51**, 369-382.

Silva J.B.C. and Hohmann G.W.; 1984: *Air borne magnetic susceptibility mapping*. Exploration Geophysics, **15**, 1-13.