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GROUND-LEVEL MAGNETIC STUDY OF GREENE COUNTY, OHIO[1]

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Abstract. We performed a ground level geomagnetic survey of Greene County, Ohio in the fall of 1976. The geomagnetic map showed a positive magnetic anomaly running from the northwestern section to the southeastern section of the county while the remainder of the map was relatively undisturbed. We analyzed the localized anomaly of the southeastern section by the Peters methods and by fitting to the model of a vertical rectangular prism magnetized along the earth's field. The Peters slope and half-slope methods gave maximum depth limits to the top of the body of 1.16 km and 1.08 km respectively. The best fit to the vertical prism model yielded a depth of 1.04±0.05 km, a width of 2.5±0.2 km, and a susceptibility contrast of +0.0039 cgs units. From the depth, we concluded that the source of the anomalies is intra-basement susceptibility variations.

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A regional aeromagnetic survey of west-central Ohio performed by the U.S. Geological Survey in 1960 (Philbin *et al* 1965) indicated some strong, localized variations of the geomagnetic field in Greene County, Ohio. The purpose of our survey was to obtain more detailed magnetic data by a ground survey and to interpret these data in terms of the sources of the anomalies.

Greene County is on the eastern flank of the Cincinnati arch with the sedimentary strata dipping gently to the northeast. The sedimentary section consists primarily of limestone and dolomite rocks with lesser amounts of shale. The sedimentary rocks are covered with glacial till over most of the area and are underlain by the igneous and metamorphic rocks of the basement complex. No wells have penetrated to the basement in Greene County, but there are a few wells in neighboring counties that give an approximate depth of 1000 m to the basement. Some seismic reflection work has been done in neighboring Clinton County substantiating this depth (Tobin 1961).

THEORETICAL BACKGROUND

The usual source of magnetic anomalies is the magnetization of the basement rocks (Nettleton 1976). If the source of the magnetic anomaly were due to topographic relief of the basement surface, the overlying sedimentary layer might be deformed, but if the source of the anomaly is composition variations within the basement complex, the sedimentary layers might not be disturbed.

Many types of rocks possess an appreciable magnetic susceptibility due to a small percentage of magnetite in the rock. When subjected to the earth's magnetic field, these rocks obtain a magnetization which manifests itself by causing local anomalies in the regional magnetic field. The size of local anomalies usually observed is between 0.1% and 10% of the earth's field. Rocks with appreciable susceptibility are primarily igneous or metamorphic while sedimentary rocks do not usually contain enough magnetite to possess a significant susceptibility. In addition to induced magnetization, some rocks may possess a permanent magnetization called natural remanent magnetization. This magnetization is usually aligned with the local direction of the earth's field at the time the rock was last heated above the Curie temperature. The direction may be quite different from the present direction due to magnetic reversals, continental drift, or magnetic pole wandering.

In our study, it was assumed that the only magnetization is induced magnetization in the igneous and metamorphic basement rocks. Although the induced magnetization of the basement rocks usually predominates, this is not always the case; occasionally the natural remanent magnetization predominates and some sedimentary rocks may have an appreciable magnetic permeability. For our study,

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there was insufficient auxiliary information to differentiate the natural remanent magnetization from the induced magnetization.

If volume, V, of rock is magnetized with a magnetic dipole moment per unit volume, $\vec{P}$, then the magnetic scalar potential, ϕ, at an external point is given by:

$$1.\quad \phi(\vec{r}) = -P\frac{\partial}{\partial\epsilon}\int_V \frac{d^3\vec{r}_1}{|\vec{r}-\vec{r}_1|}$$

In this equation, ϵ is a distance in the direction of $\vec{P}$, $\vec{r}$ gives the position of the observation point, and $\vec{r}_1$ gives the position of volume element $d^3\vec{r}_1$ in the rock volume. In the case where all of the magnetization is induced by the earth's field $\vec{H}_0$, the body would possess a magnetization of $\vec{P} = k\vec{H}_0$ with magnetic susceptibility denoted by k (and the effects of demagnetization assumed to be negligible).

The magnetic field intensity produced by the body $\Delta\vec{H}$ in the region outside the body is given by:

$$2.\quad \Delta\vec{H}(\vec{r}) = -\nabla\phi(\vec{r})$$

The maximum horizontal gradient of the anomalous magnetic field relative to the magnitude of the anomalous field (hereafter called the relative gradient) gives an estimate of the maximum depth to the magnetized body. This estimator is based on the fact that a point source will produce the largest possible relative gradient and that this relative gradient decreases with the depth of burial. Any larger body will produce a weaker relative gradient. Thus, for an observed relative gradient, the greatest possible depth that could produce the gradient is the depth corresponding to a point source. Any horizontal extension of the source would reduce the gradient. Several empirical approaches exist to utilizing these facts for depth estimation; the one used in our paper was described by Peters (1949).

Another approach to the analysis of well-defined anomalies is the comparison of the observed field with the field calculated for particular models. The model used in this work was a vertical rectangular prism extending to infinite depth. The equation for the field due to such a body was derived by Bhattacharyya (1964). Equation 10 of the Bhattacharyya paper gives the magnitude of the anomalous field as a function of the distance, x, along a traverse perpendicular to the axis of the body.

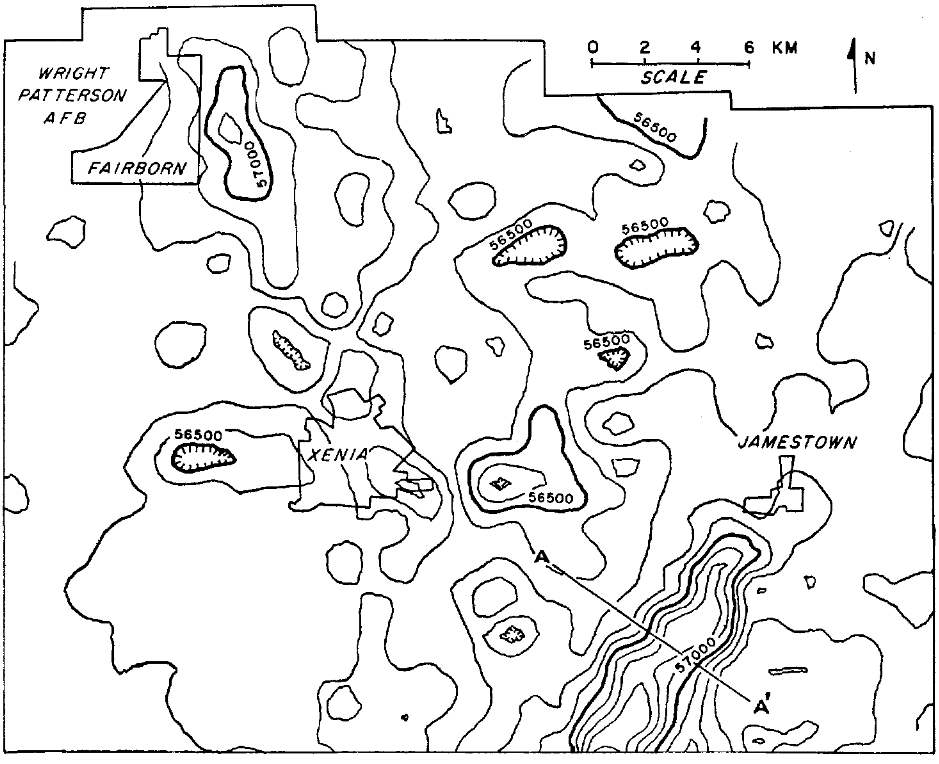

FIGURE 1. Geomagnetic map of Greene County, Ohio. The contour interval is 100 gammas. Line A–A' indicates the profile that was analyzed.

DATA ACQUISITION AND MAGNETIC MAP

The area was surveyed with a proton precession magnetometer that had an instrument accuracy of ±5 gammas (γ). ($1\ \gamma = 10^{-5}$ oersted). The total magnetic field was measured at 600 stations spaced approximately 1.3 km apart throughout the 1050 km^2 area of Greene County. Urban areas were avoided because of their excessive artificial fields, and readings were not taken near metal structures. Magnetic storms were avoided by using the forecasts of the National Magnetic Observatory and by ceasing operations if readings became irreproducible. A base station measurement of the field was made once per hour during each day of survey, and base station geomagnetic field variations were used to remove time dependence from the results. The overall error was less than $\pm 10\ \gamma$.

The data were computer contoured to produce a preliminary magnetic map, which contained some noise due to small surface disturbances and position errors. Using a standard contouring computer program package (Stampede), a 17-point smoothing operator, which acts as a low-pass spatial filter, was applied to reduce this noise. Figure 1 is the resulting magnetic intensity contour map for Greene County.

The map shows a major positive magnetic anomaly in the southeastern section of the county. There is also a long, positive anomaly extending diagonally from the northwestern section to the southeastern section while the rest of the area is relatively undisturbed. The regional aeromagnetic survey (Philbin *et al* 1965) showed similar anomalies in the surrounding regions. To the east, the magnetic field is generally disturbed, but to the west it is generally undisturbed, a difference that may mark the western edge of the Grenville province of the continental craton in this region.

If the sources of the observed anomalies are at different depths, the anomaly that is most likely to be due to a shallow source is the large one in the southeast. This anomaly shows the steepest gradients, so it would set the shallowest maximum depth limit.

ANALYSIS OF MAJOR ANOMALY

Because the southeastern anomaly is strong, well isolated, and has the steepest gradients, we analyzed it in detail using a magnetic profile taken perpendicular to the anomaly and reasonably far from the ends, and we determined the regional magnetic field value to be 56500 γ from studying the undisturbed portions of the map. The resulting profile for the anomalous magnetic field is shown in figure 2.

The Peters slope and half-slope methods (Nettleton 1976) were applied to the steeper side of the profile. These methods use the relative gradients to estimate the maximum depth to the source of the anomaly. The slope method gave a maximum depth of 1.16 ± 0.05 km and half-slope method gave a depth of 1.07 ± 0.05 km.

The anomaly is well isolated from other major disturbances and it shows a relatively simple elongated shape suggesting that the body producing it can be approximated by a long, narrow rectangular body. To determine the dimensions and susceptibility contrast of a body that would produce such a field, it was assumed that the body was a vertical rectangular prism extending from depth h to an infinite depth and that the magnetization was along the present direction of the earth's field. The length of the body (26 km) was determined from the northeast end of the anomaly indicated on figure 1 and the southwest end seen in the aeromagnetic survey of Philbin *et al* (1965).

The position of the edges of the prism, the depth to the top of the prism and the magnetization were determined for the model that best reproduced the observed field. We performed this optimization procedure by varying the parameters until the mean square error between calculated values using Bhattacharyya's equation and observed values was minimized. The resulting field due to the optimum model is shown in figure 2.

The computer modelling indicated that the depth was $1.04 \pm .05$ km, the width was 2.5 ± 0.2 km, and the magnetization was 220 ± 20 dyne/oersted/cm^2. The magnetization corresponds to a

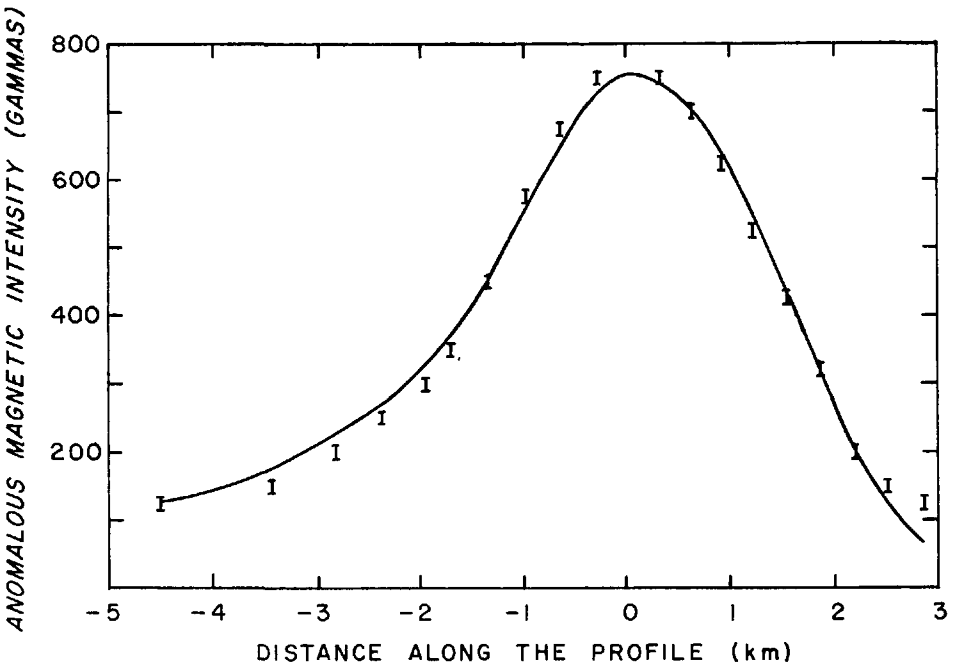

FIGURE 2. Magnetic profile along A-A' of figure 1. The data points were picked at equal intervals from the contour map. The continuous curve is the best fit for the magnetic anomaly of a vertical rectangular prism magnetized in the direction of the earth's field (A to A' as seen in figure 1).

+0.0039 cgs units contrast between the susceptibility of the body and the surrounding rocks.

The asymmetry of the anomaly (figure 2) is due primarily to the inclination of the earth's field producing an inclined magnetization. It is also evident that the theoretical field of the prism has a systematic deviation from the observed field, which is probably due to the simplifying assumption made for the model. The two assumptions that are most likely to be responsible for the differences are that the magnetization is exactly along the present direction of the earth's field and that the sides of the prism are vertical. There is no certain way to separate these 2 effects without information from other sources such as core drilling.

To test the consistency of the optimization program and to obtain limits on the possible variations that could exist, the computer model was used again with the depths kept fixed at different values and the width and magnetization adjusted to produce the best fit of the calculated to the observed magnetic anomaly. It can be seen that as the depth to the body is increased, the magnetization to produce the observed anomaly will increase and the width of the body decrease (figure 3). The model with the depth fixed at 0.61 km was

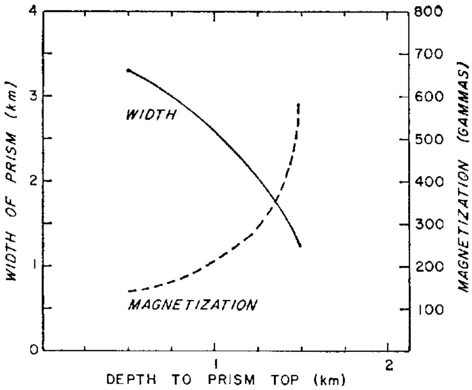

FIGURE 3. Width and magnetization of the vertical rectangular prism that best fits the data for various choices of depth.

found to fit the left side of figure 2 better than the calculated curve shown. The right side, however, had a poorer fit with depth at 0.61 km, suggesting the possibility of slope to the interfaces.

The results of our calculations for the vertical rectangular prism gave a slightly shallower depth than the Peters (1949) method. Since the Peters method gave the maximum depth to local anomalies, the close agreement with the model analysis suggests that the body has sharply defined edges and is at a depth of 1.04±0.05 km.

A well drilled in neighboring Clinton County showed the basement to be at 1.054 km (Summerson 1962), which is in good agreement with the value determined in our study. The seismic reflection study of Tobin (1961) to the southeast of Greene County obtained a depth of 1.06 km. These data suggest that the source of the Greene County anomaly is susceptibility variations within the basement complex rather than an upward lifted section of basement rock. The type of structure that might produce the observed positive anomaly is a near vertical mafic igneous intrusion into the basement complex. The top of the basement consists of a nonconformity which truncates the intrusion.

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