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DETERMINATION OF DEPTH TO THE CURIE ISOTHERM FROM AEROMAGNETIC DATA

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The basic objective in relating the aeromagnetic field data with the structure of the Curie point isotherm is to compute the lower depth limit of magnetized masses in the earth's crust. Rocks lose their magnetism at the Curie temperature at which ferrimagnetic rocks become paramagnetic, and their ability to produce detectable magnetization disappears. Thus, the deepest level in the crust containing materials with discernible magnetization is generally interpreted as the depth to the Curie point isotherm.

The Curie point is about 580°C for magnetite. With appropriate titanium substitutions, Buddington and Lindsley (1964) calculated an average Curie point ranging betwen 520°C and 560°C for rocks in the deep crust. It is generally believed that the amount of geothermal heatflow should correlate with the Curie depth and thus, in turn, to the crustal magnetic field.

Our main goal is, therefore, to determine the <u>bottom</u> shape of the magnetized crust from a magnetic anomaly map. Since the magnetic anomalies attributable to the bottom geometry are usually quite smaller and have much longer wavelengths than those produced by shallow geological variations, the problem is comparable to searching for a needle in a haystack. Early studies include those by Vacquier and Affleck (1941) and Bhattacharyya and Morley (1965). In both cases, each isolated anomaly was filtered and separately interpreted by the empirical graphic method using a vertical-sided prism.

A more sophisticated method was proposed by Bhattacharyya and Leu (1975a, 1975b). Their method requires an extensive initial filtering of the aeromagnetic data in both regional and short wavelength domains. The filtered data is subsequently divided into a large number of blocks. For each block, a two-dimensional spectrum and its moments are computed and compared with a model of an isolated vertical-sided prism within a block in order to locate the corners of the body. The total amount of computation is tremendous since the method requires a two-dimensional Fourier transform for each block. Applying the method to the Yellowstone National Park area, they produced the Curie isotherm map well-correlated with the known geothermal area.

Employing a similar technique, it is essentially impossible to determine Curie depth with any resolution at all by fitting a vertical prism to a single anomaly. The Curie depths they derived could be changed by as much as 10 km without violating the observed data. This conclusion is seemingly in conflict with those of Bhattacharyya and Leu (1975b).

All methods reviewed here are commonly based on the assumption that there exists an isolated magnetic source for each anomaly. Each individual anomaly is assumed to be caused by a single vertical-sided prism (Bhattacharyya and Leu, 1975a, 1975b) or a truncated vertical cone. Such isolated models are apt to generate spurious anomalies, particularly due to their unrealistically well-defined corners and vertical surfaces. These spurious anomalies can induce significant errors in either direct-modeling or spectrum calculation.

Rock formations causing long wavelength magnetic anomalies at a depth close to the Curie point are more likely to have a continuous lateral distribution rather than isolated blocks of well-defined geometrical bodies. A realistic model at this depth should manifest a continuous lateral distribution of magnetic materials having variable thicknesses and susceptibilities.

Fluctuations in long wavelength magnetic anomalies can be attributed to lateral variations either in magnetization strength or in Curie depth. These double uncertainties make the task of simultaneously determining both the magnetizations and the Curie depth very difficult, if not impossible. Similar uncertainties apply to many geophysical modeling theories, e.g., a thin magnetic dike for which the anomaly is the same as long as the product of thickness and susceptibility remains the same. However, it can be shown that the statement is no longer true if the dike has a considerable thickness for which case both the thickness and the susceptibility can be independently determined from observed data (Won, 1981). The present approach is based on the classical Gauss method for solving nonlinear equations (Carbato, 1965; Johnson, 1969; Won, 1981) coupled with Marquardt's inversion method (Marquardt, 1963) to derive continuous crustal thickness and susceptibility profiles from regional magnetic data.

Figure A-9 shows the model that is used for inverting magnetic data. The model consists of laminated thick vertical prisms having flat top surfaces and linearly connected inclined bottom surfaces. The magnetic susceptibility below the lower boundary is assumed to be zero so that the bottom geometry represents the Curie isotherm topography. Although data will be confined within the laminated block region, two semi-infinite slabs are added on either side in order to reduce the edge effects of the first and last blocks. The unknown parameters to be determined are the depth (h's) at each nodal point and the magnetic susceptibility (k's) of each prismatic body.

The model is two-dimensional with an arbitrary strike angle with respect to the magnetic north. Data are assumed to be obtained at a constant altitude along a traverse perpendicular to the strike. Since the method uses total field magnetic data, there is no need for reducing the data to the polar anomalies. The magnetic anomaly generated by a single vertical block having a flat top and an inclined bottom can be derived by analytically combining two inclined dikes. By summing up these individual blocks, we can compute total field for any given set of blocks having variable depths and susceptibilities.

Techniques for determining unknown parameters of a nonlinear function involve iteratively correcting currently assumed parameters by differential amounts, thereby minimizing the rms error between the theoretical prediction and the observed data. Two predominant techniques of determining the correction amounts are Gauss' method and the gradient, or the steepest descent method. Marquardt's method combines these methods by controlling the amounts of differential correction to insure both the convergence and speed.

Using the geometrical model and the inversion technique, we analyzed aeromagnetic data of the Yellowstone Park, Wyoming (Fig. A-10). The digitized data were first low-pass filtered at a 10-km wavelength. A total of 12 east-west profiles evenly distributed in the area were then subjected to the inversion process to derive simultaneously the depth and susceptibility profiles. Figure A-11 shows the estimated Curie depth and Fig. A-12 the susceptibility structure for the entire area. A cursory check with available surface geological map of the area shows the results are reasonably correlated with local geology. Since the results derived here represent the thickness of the entire magnetized crust and its average susceptibility, it is rather difficult to compare with the available superficial geological information. The main consolation is, however, that, for the entire profiles, the rms difference between the field data and model data is mostly less than two gammas, an excellent match for the geologically complex area.

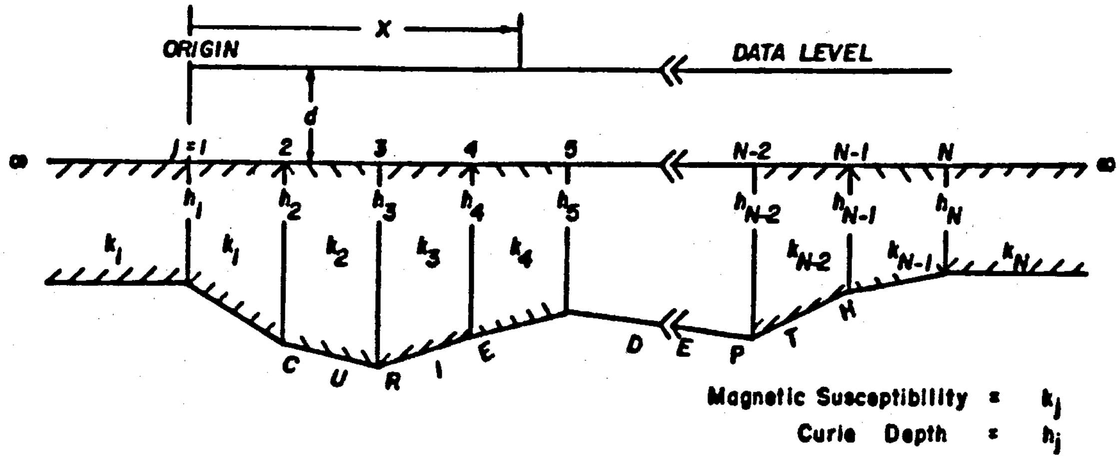

Fig. A-9.
Mathematical model of the Curie depth.

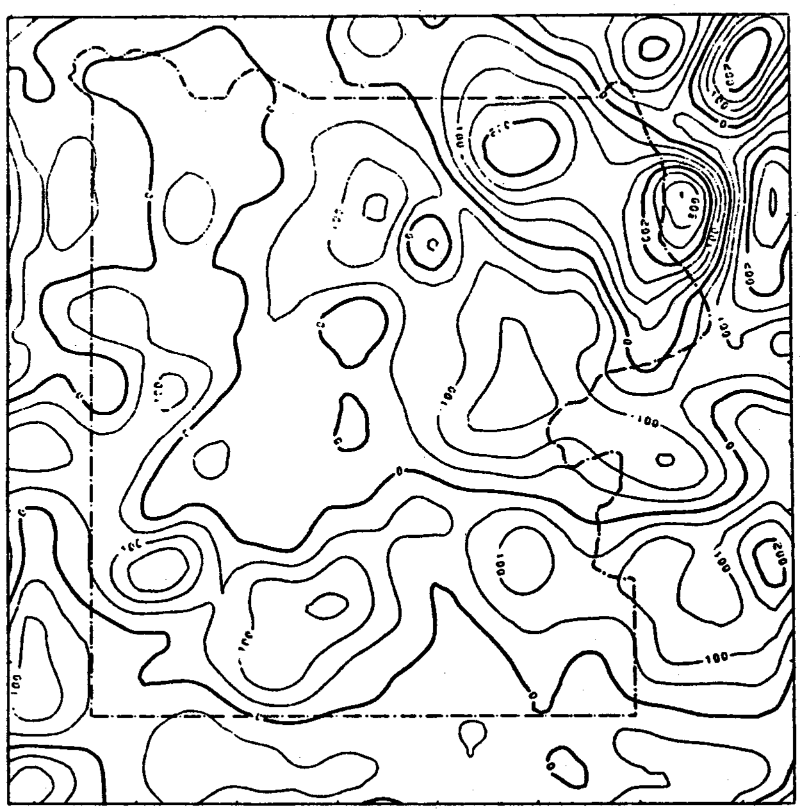

Fig. A-10.
Filtered aeromagnetic map at a 50 gamma contour interval. Broken line shows the boundary of the Yellowstone Park.

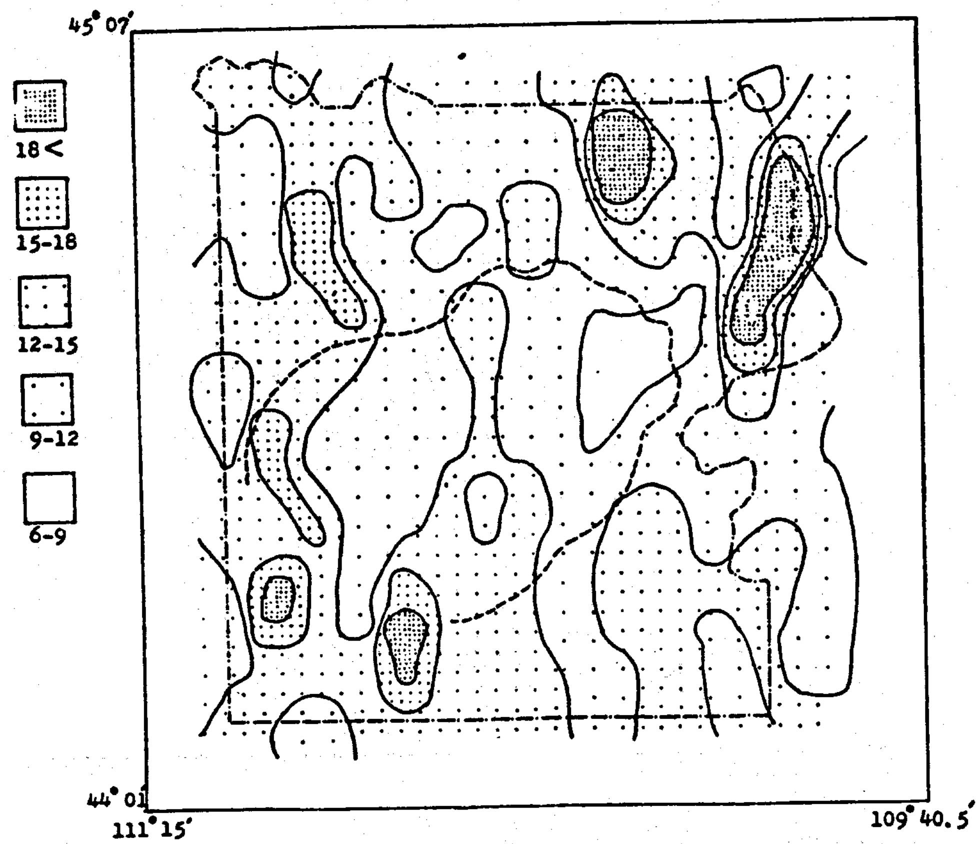

Fig. A-11.
Depth to the Curie isotherm derived from the aeromagnetic profiles: contour interval is 3 km.

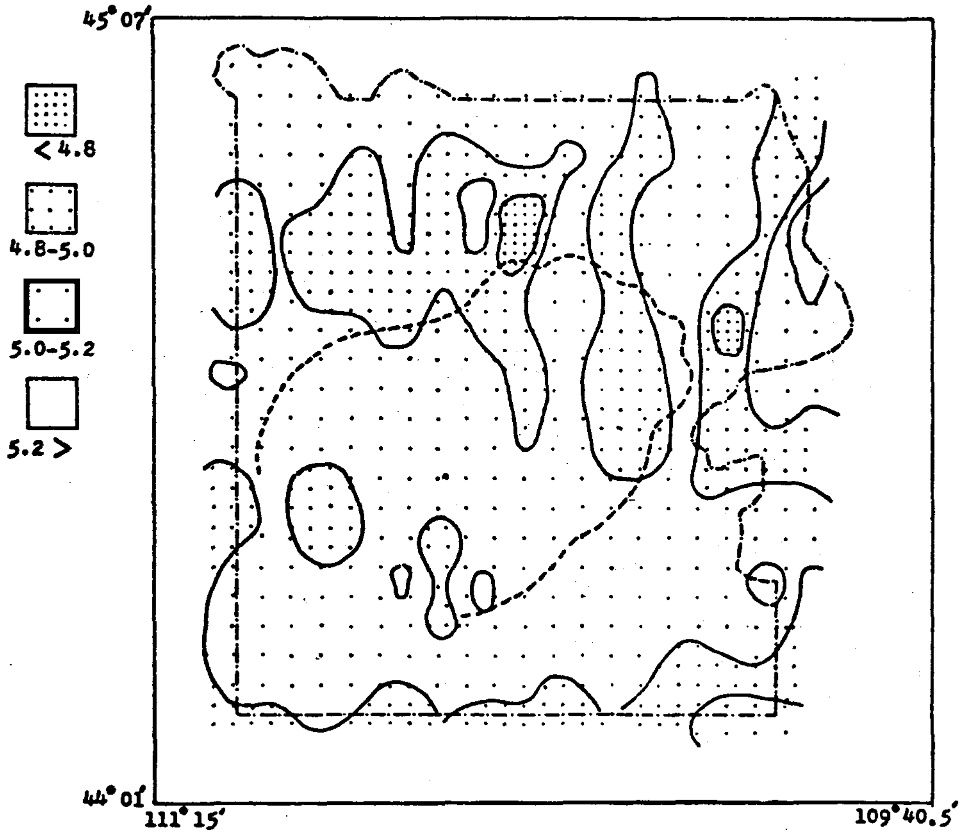

Fig. A-12.
Magnetic susceptibility map derived from the aeromagnetic profiles: contour interval is 0.0002 emu.

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