DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
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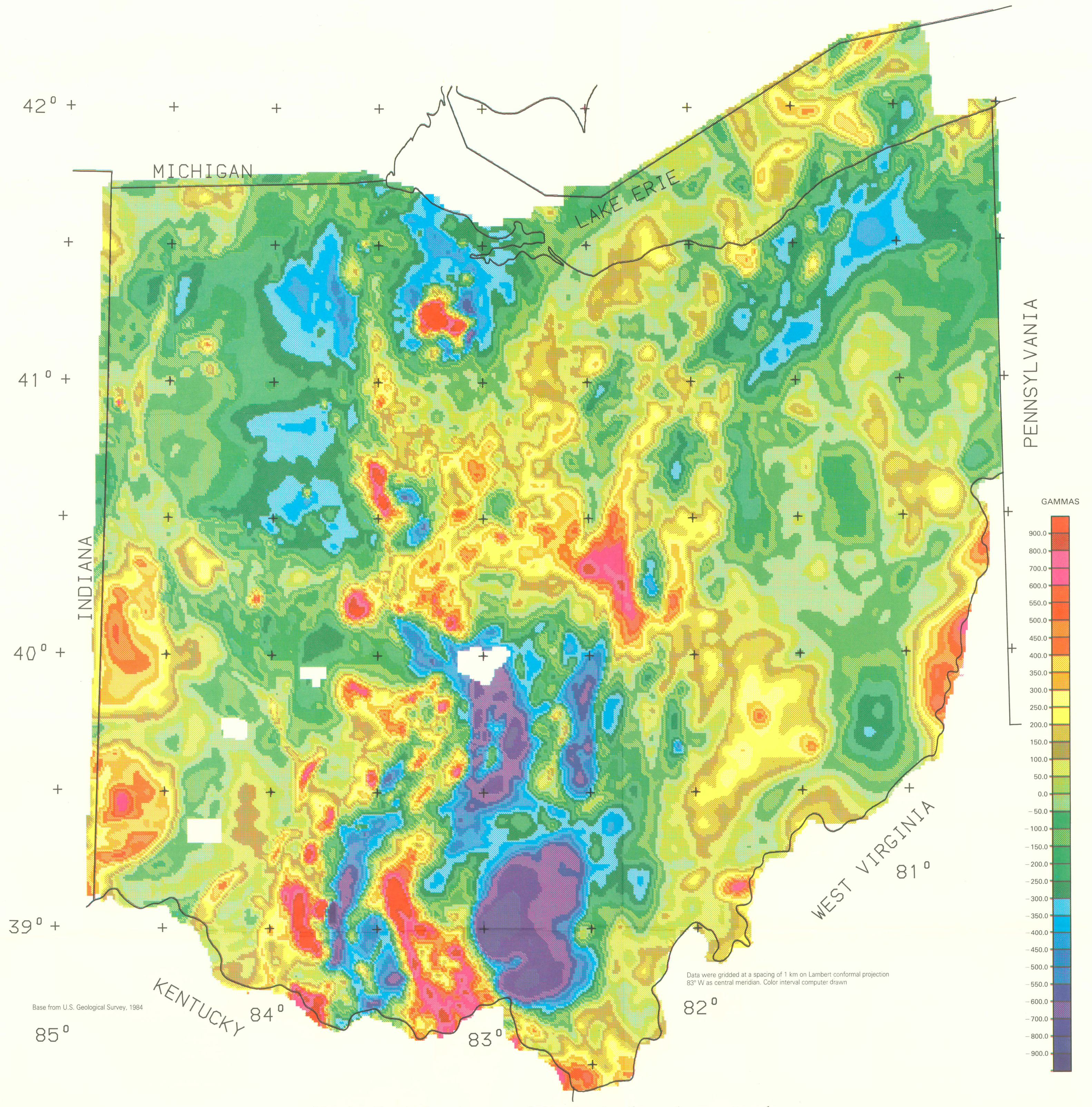
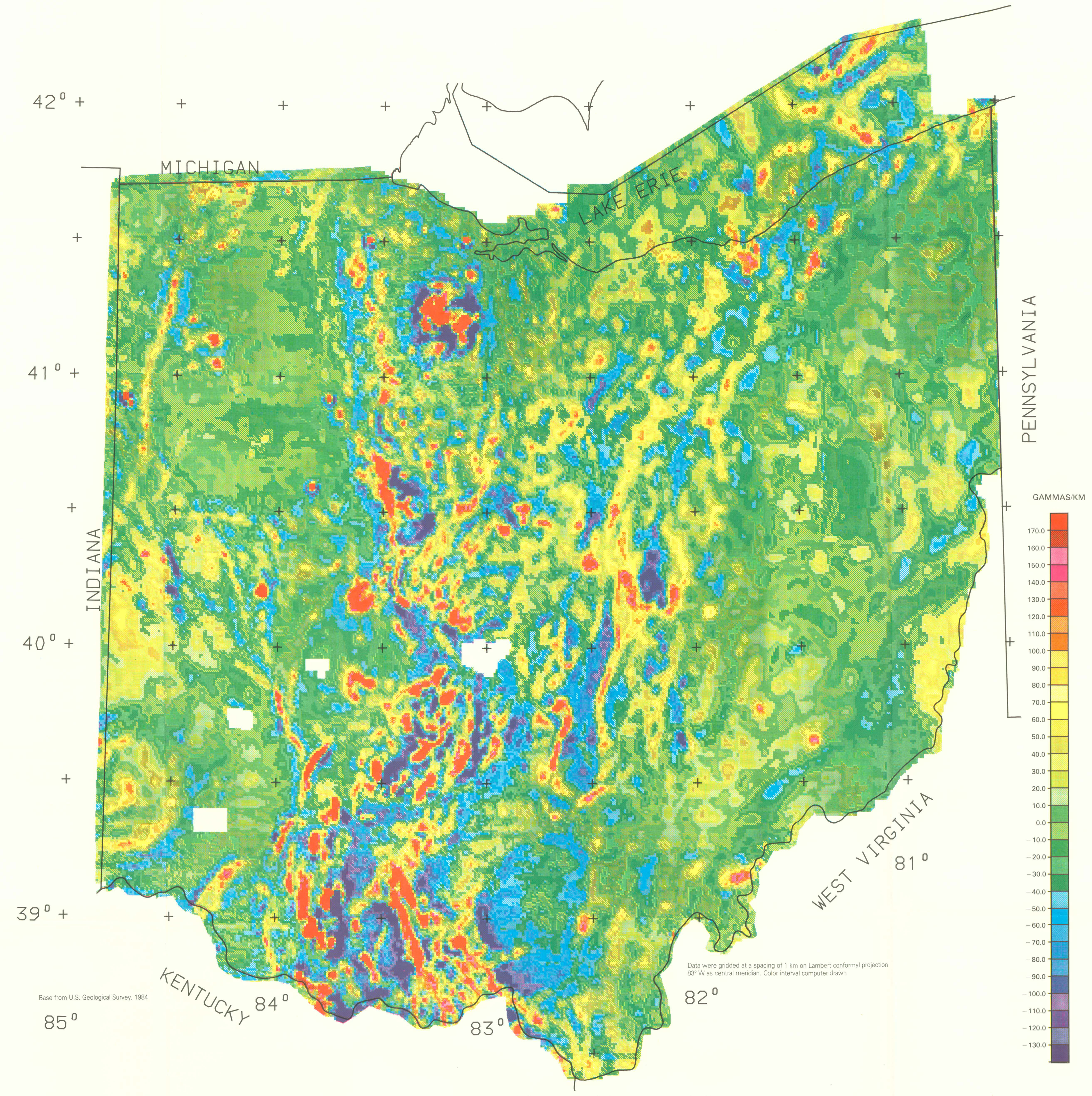
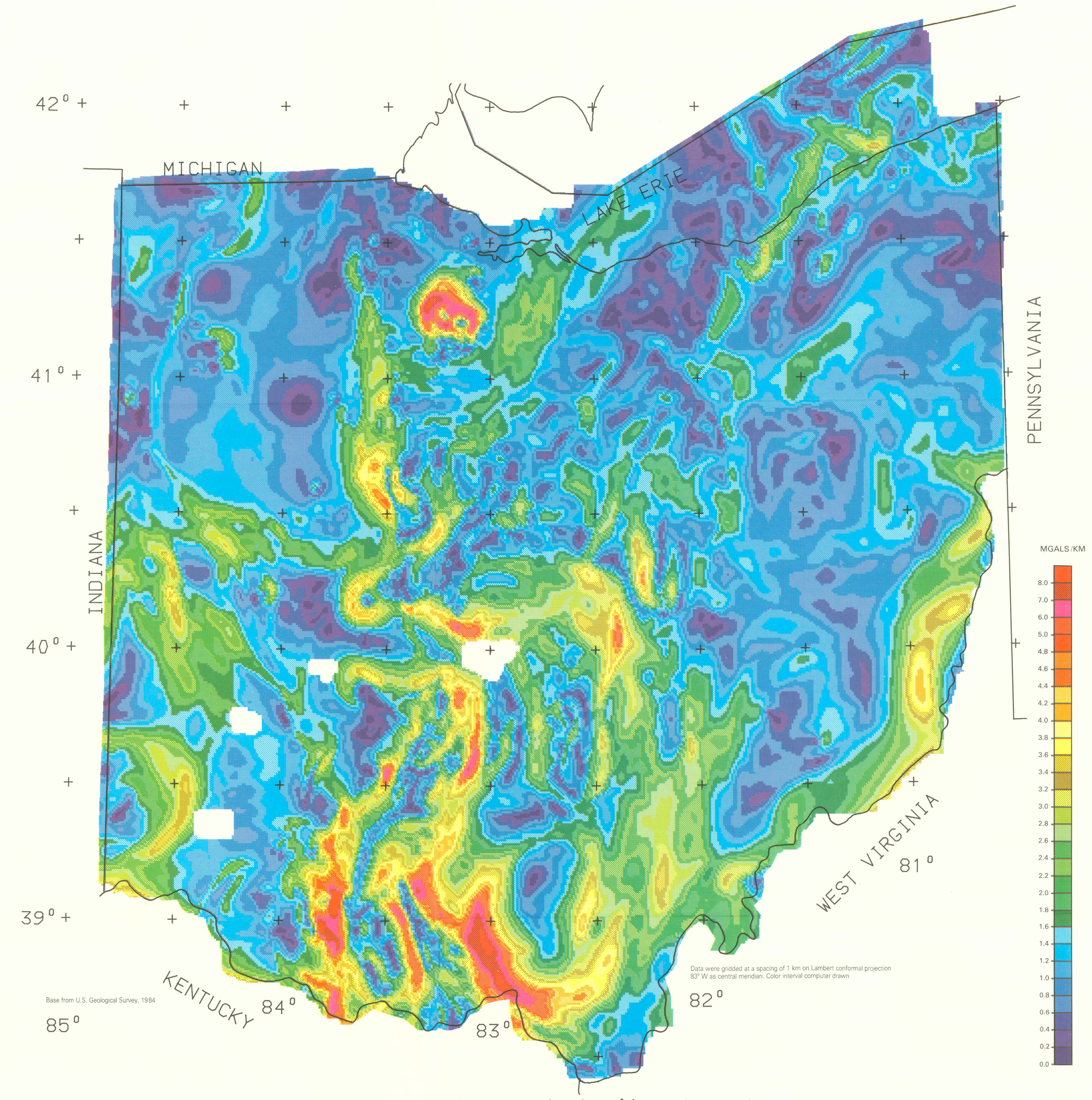
GEOPHYSICAL INVESTIGATIONS
MAP GP–967



Map A.—Residual total magnetic field reduced to the north magnetic pole.



Map B.—First vertical derivative of the magnetic field.



Map C.—Magnitude of the horizontal gradient of the pseudo-gravity field.

Map D.—Shaded magnetic relief map illuminated from the northeast (shown by arrow).

Map E.—Shaded magnetic relief map illuminated from the northwest (shown by arrow).

SCALE 1:1 000 000
25 0 25 50 75 100 125 150 175 KILOMETERS
25 0 25 50 75 MILES

FILTERED MAGNETIC ANOMALY MAPS OF OHIO

By
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INTRODUCTION

An aeromagnetic anomaly map of Ohio at a scale of 1:500,000 (Hildenbrand and Kucks, 1984) has been compiled recently from digital data. Although the shipborne and airborne surveys used to construct the magnetic anomaly map were conducted at different times, spacings, and elevations, a consistent data set was obtained by removal of an appropriate geomagnetic reference field and by analytical continuation to a common surface of 1000 ft (305 m) above ground. The availability of compatible digital data allowed application of a variety of analytical techniques to enhance different aspects of the anomalies to provide new interpretive information. The application of these techniques would have been impractical had the data been in other than digital form.

Filter analysis in geophysical applications involves conversion of the data into a form that enhances particular anomaly characteristics, such as wavelength and trend. I have considered four filtering operations: (1) reduction to pole, an attempt to shift anomalies directly above the associated sources; (2) first-vertical derivative, to sharpen or resolve anomalies of small areal extent; (3) gradient of pseudo-gravity, to delimit lithologic or structural boundaries; and (4) shaded-magnetic relief analysis, to enhance short-wavelength anomaly trends. Although a considerable amount of information can be obtained by studying these filtered anomaly maps, they have their limitations and thus should be used with caution and only in a qualitative analysis. More detailed discussions on the usefulness of the compiled maps (maps A-E) are given below.

The unfiltered data set used in the filtering process was gridded at a spacing of 1 km (0.62 mi) (Hildenbrand and Kucks, 1984). A computer program using the principals of Fourier analysis (Hildenbrand, 1983) was utilized to prepare reduced-to-pole, pseudo-gravity, and first-vertical-derivative data sets. After completing the filtering operations, the data sets were regridded to a finer spacing of 0.813 km (0.51 mi.), for plotting with Applicon Incorporated[1] proprietary software. The shaded-relief maps were compiled and plotted using software developed by Don Sawatzky (U.S. Geological Survey, unpub. data). A Lambert conformal conic projection (standard parallels of 33°N. and 45°N.) with a central meridian of 83°W. was used to prepare all maps.

Four regions of missing data in the southwest part of the maps coincide with three major cities and a Radio Free Europe station. Cultural noise from these cities and the radio station prohibited collection of data.

FILTERED MAGNETIC ANOMALY MAPS

Reduction-to-pole operation

The shape of a magnetic anomaly depends on many factors, including the direction of magnetization and the direction of the Earth's ambient magnetic field. For example, at moderate to high latitudes in the northern hemisphere, a magnetic intrusion with normally polarized magnetic minerals will be expressed as a magnetic high with a maximum amplitude located several kilometers south of the intrusion's central location and with a less intense polarization low flanking it on the north. To remove these types of polarization effects from a map, the data are analytically reduced to the north magnetic pole (Bhattacharyya, 1965). The advantages of the transformation are that the anomalies become symmetrical around the source and thus are centered above the source.

Rocks may contain magnetic minerals such as magnetite that have a magnetization proportional to and in the direction of the Earth's present-day magnetic field. This type of magnetization is called "induced". Induced magnetization can also be accompanied by a permanent magnetization, with highly variable orientations, acquired during the rock's history. This permanent magnetization is known as remanent magnetization. The polarization vector of a magnetic body is the sum of the remanent and induced magnetization vectors.

Both the directions of polarization and of the Earth's magnetic field are needed in making the transformation to the North Pole. Although the orientation of the Earth's magnetic field vector is known in Ohio (inclination = 70°N. and declination = 5°W.), it was necessary to assume the polarization vector associated with the magnetic body. A problem therefore arose in assigning one particular direction of magnetization, especially because Ohio spans a large region. It was assumed that all the rocks' magnetizations are due solely to induction. In other words, remanent magnetization with a direction other than nearly coincident with the Earth's inducing field was considered negligible. The dominance of induced magnetization over remanent magnetization is normally assumed to be the rule, rather than the exception, in rocks of the crust in the stable craton of central United States. I do not believe, moreover, that the errors in assuming only induced magnetization in Ohio are important in studying anomalies (Map A) at the present scale of 1:1,000,000.

First-vertical derivative operation

In areas of steep, broad magnetic gradients, small anomalies (related to near-surface features) and other subtle features or trends tend to escape notice on the reduced-to-pole map. This is especially the case for features having amplitudes less than 50 or 100 gammas, the color contour intervals of map A. To resolve these small-wavelength anomalies, a first-vertical-derivative filter (Bhattacharyya, 1966) was applied to the reduced-to-pole data. The first-vertical-derivative map shown in Map B thus enhances local features and reduces the effects of regional gradients.

[1] Use of a specific brand name does not necessarily constitute endorsement of the product by the U.S. Geological Survey.

Pseudo-gravity gradient

Cordell (1979) made use of gravity gradient maxima to map graben-bounding faults. The principal of this technique, to delineate lithologic or structural boundaries, was later extended to the analysis of magnetic data through use of the pseudo-gravity transformation (Cordell and Grauch, 1982).

Gravity and magnetic anomalies caused by a common source of magnetization and density contrast are related to each other by Poisson's equation. Baranov (1957) suggested using the Poisson's relation to calculate what he termed a "pseudo-gravity" anomaly map from magnetic data. In the present study, the transformation of the magnetic field to the pseudo-gravity field requires no assumption regarding a common source of magnetization and density. The magnetization contrast related to a source is simply converted to a hypothetical density contrast to take advantage of analyses in terms of "gravity", as will be evident below. Uniform magnetization direction was assumed. We also assumed induced magnetization with an inclination of 70°N. and declination of 5°W.

Having made the pseudo-gravity transformation, the magnitude of the horizontal pseudo-gravity gradient g' is determined by a computer program (R. W. Simpson, U.S. Geological Survey, unpub. data) using the following equations:

$$|g'(x,y)| = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2},$$

$$\frac{\partial g}{\partial x} \simeq \frac{g_{i+1,j} - g_{i-1,j}}{2\Delta x},$$

and

$$\frac{\partial g}{\partial y} \simeq \frac{g_{i,j+1} - g_{i,j-1}}{2\Delta y},$$

where x is the longitudinal coordinate, y is the latitudinal coordinate, and $g_{i,j}$ is the pseudo-gravity field defined at grid point i,j.

The above development is based on a property of the pseudo-gravity gradient, mainly that the maxima occur immediately over steep or vertical boundaries or contacts separating contrasting magnetizations. On the pseudo-gravity gradient map (Map C), lines drawn along ridges formed by enclosed high-gradient magnitudes correspond to contacts. (However, if the contact dips, if remanent magnetization is strong, or if contribution from adjacent sources is significant, the maximum gradient will be shifted a certain distance from the contact).

Shaded-relief analysis

Reduced-to-pole magnetic data, treated like topographic data, can be artificially illuminated from any azimuth and elevation angle for the preparation of shaded-relief images. The detection of lineaments is often facilitated by the presence of shadows. Shaded-relief analysis has two additional advantages: (1) lineaments perpendicular to the direction of illumination show the strongest illumination contrast, whereas those aligned parallel to the illumination direction have no shadows and (2) like the vertical-derivative operator, small wavelength anomalies associated with local sources are enhanced, whereas regional gradients are suppressed.

The shaded-relief map illuminated from the northeast (Map D), therefore, sharpens anomalies related to predominately northwest-trending, near-surface features. The complementary shaded-relief map compiled with an illumination direction from the northwest is shown in (Map E).

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