Precambrian Geophysical Provinces in Indiana

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Abstract

Regional statewide gravity and magnetic surveys in Indiana reveal large areas of high and low intensities. The source of these variations are lithologic changes within the Precambrian basement. A generalized map of basement provinces, constructed from both gravity and magnetic data, identifies regions of basement lithologies as either dense or magnetic-rich rocks or combinations thereof.

Analyses of intense, magnetic anomalies reveal the basement surface to vary from 2,000 to 11,000 feet below sea level. Many of the anomalies appear to be concentrated along the Cincinnati Arch. Detailed studies of two regions suggest that the sources may be basaltic pipe-like intrusions into a granitic country rock. Lava flow structures may be associated with the individual pipes.

Introduction

Geophysical surveys today constitute an important and integral part of almost every modern effort at geologic exploration. For many years the petroleum industry has routinely utilized seismology, gravity and magnetic methods in the search for oil beneath both the land and sea. However, the cost of geophysical surveys in the past have limited their use to major companies. With advances in technology, the cost of such surveys is not necessarily prohibitive. This paper summarizes data that are applicable to the study of Precambrian basement in Indiana and emphasizes regional interpretation based on the most recent gravity and magnetic studies.

Gravity Data

The first extensive gravity survey in Indiana (Fig. 1A) was conducted by the Indiana Geological Survey during 1951 and 1952 (3). Control was based upon a grid density of approximately one station for each congressional township. Elevation and locations were determined from several sources including U. S. Coast and Geodetic and U. S. Geological Survey bench marks, U. S. Geological Survey topographic maps, U. S. Engineering maps and Indiana State Highway Commission maps.

Contours show equal values of Bouguer anomaly relative to an arbitrary datum with an interval of 5 milligals. Bouguer corrections were based on an average density of 2.6 gm/cm^3 for the sedimentary rocks above sea level. In addition to the statewide gravity survey, the Indiana Geological Survey and the Department of Geology at Indiana University have conducted detailed surveys over selected anomalous regions in Hamilton, Pulaski, Newton, Randolph, Wayne and Fayette Counties. These data are available on file with the Department and the Survey.

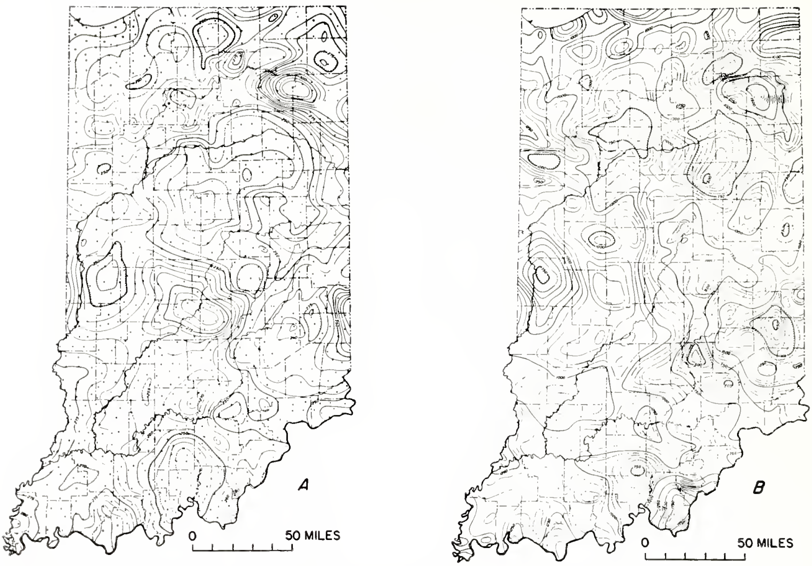


FIGURE 1. *A) Map of Indiana showing gavitational intensity (3). Contour interval 5 milligals relative to an arbitrary datum. B) Map of Indiana showing average aeromagnetic intensity (4). Contour interval 50 gammas relative to an arbitrary datum.*

Magnetic Data

From 1949 to 1952, the United States Geological Survey, in cooperation with the Indiana Geological Survey, conducted a statewide aeromagnetic survey of Indiana. Ninety-two county maps were published on a scale of 1″=1 mile (1:63,360) with a contour interval of 10 gammas (0.0001 oersteds). In 1958, Henderson and Zietz compiled the county maps into a statewide map on a scale of 1″=8 miles (1:500,000) (Fig. 2). Contours represent equal values of the total magnetic intensity at an elevation of approximately 1,000 feet above the surface. Contour interval is 50 gammas relative to an arbitrary datum.

Comparison of the aeromagnetic and gravity maps is difficult because of the discrepancy in control between the two maps. The gravity map, based on few control points, emphasizes broad scale regional features; the aeromagnetic map with continuous north-south control at 1-mile east-west flight line intervals shows great detail and thereby obscures broad scale features.

In 1953, an average magnetic intensity map of the state was compiled from the aeromagnetic data (4) (Fig. 1B). Control was based on average values obtained for the mid-point of each township by computing the arithmetic average of the magnetic intensity at the corners, the midpoint of each side, and the center of each township. Average values were further reduced by removing a south to north earth dipole gradient of 6.5 gammas per mile. Contour interval is 50 gammas relative to an arbitrary datum. Station density and contour intervals for the average mag-

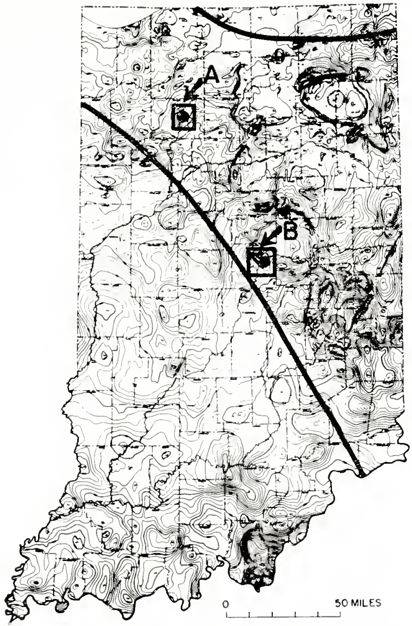


FIGURE 2. *Map of Indiana showing total aeromagnetic intensity (2, Plate 4). Solid heavy lines show the approximate position of the Cincinnati Arch. Area A outlines the Pulaski County anomaly. Area B outlines the Hamilton County anomaly.*

netic intensity map are comparable to the gravity map and allow comparative interpretations to be made.

In recent years, the Indiana Geological Survey and Department of Geology at Indiana have conducted detailed magnetic surveys in Hamilton, Pulaski, Newton, Wayne and Fayette Counties.

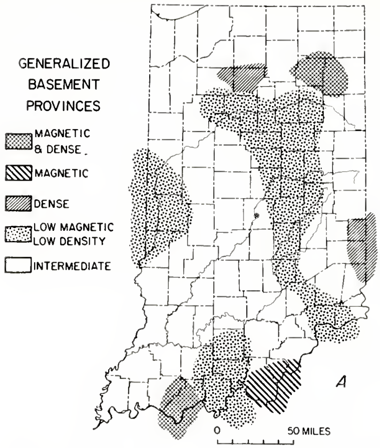
Analysis of Gravity and Magnetic Data

Lithology

Regional studies of the statewide gravity map (Fig. 1A) and average aeromagnetic map (Fig. 1B) begin with two simple assumptions:

1) The source of the anomalous gradients on both maps arise from lithologic changes within the basement complex (the top of the basement is 2,000 to 11,000 feet below sea level). The anomalies are not an expression of topographic relief on the basement surface. Lateral changes in density and magnetic susceptibility in the overlying sedimentary section are also not sufficient to create the anomalous contour patterns displayed on these maps.

2) Areas of high gravity values are underlain by dense rocks within the basement. Areas of high magnetic values are underlain by rocks with a relatively high content of magnetite (an iron oxide mineral common to certain igneous and metamorphic rocks).



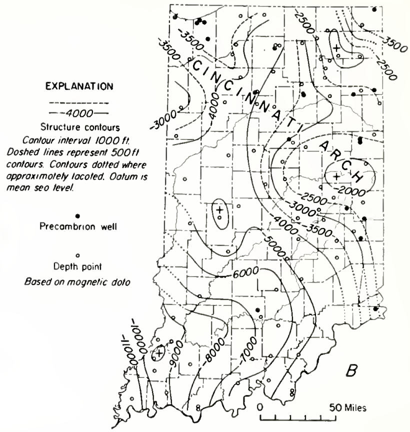


FIGURE 3. *Map of Indiana showing Precambrian provinces derived from gravity and aeromagnetic data.*

FIGURE 4. *Map of Indiana showing structure on top of the Precambrian basement. (modified from (2), Fig. 11).*

With the above assumptions, we have studied the statewide maps (Fig. 1) and generalized areas of extreme high and low values. Figure 3 identifies areas of basement lithologies associated with either dense or magnetic rocks or combinations thereof. For example, the stippled pattern throughout the central part of Indiana (and isolated areas on the western and southern edges of the state) delineate areas of low density-low magnetic rocks. This combination could represent metamorphosed sediments, or, perhaps a weathered granitic terrain. Magnetite-rich dense basalts (the cross-hatched pattern) could underlie the magnetic and dense areas to the northwest and southwest. A magnetite-rich zone of granitic rocks would explain the strong magnetic region in southwest Indiana (heavy diagonal pattern) and a very basic, but magnetite-poor lithology might produce the isolated region in north central Indiana (light diagonal pattern).

Studies of lithologies in the midwest (7) indicate that the average Precambrian terrain may be granitic in nature and we suggest that the areas labeled as "intermediate" basement rock in Indiana is a granitic country rock.

Depth

Studies of individual gravity and magnetic anomalies can yield estimates of a minimum depth to the top of the lithologic source of the anomaly. Henderson and Zietz (2) used 79 isolated well defined magnetic anomalies for depth calculations. Combining their results with seven deep wells, they constructed a generalized contour map of the basement surface (Fig. 4). Since the original work by Henderson and Zietz, there have been 12 additional basement wells drilled and extensive seismic reflection coverage (5, 6). None of these data have been incorporated into Figure 4.

There are several recent publications which represent the Indiana basement surface to be a smooth topographic surface (*e.g.*, 1); it is our belief that the differences between the Henderson and Zietz interpretation and more recent versions are primarily due to lack of control. Recent maps use only deep test wells and these are poorly distributed, generally confined to the central part of the state along the Cincinnati Arch. The basement map based on magnetic analysis depends on numerous, widely distributed control.

Geometry of Basement Intrusives

We have earlier suggested that the source of many of the gravity and magnetic anomalies be within the Precambrian basement. Various rock types intruded into the granitic country create a lithologic contrast responsible for the observed anomalies. It is a curious observation that many of these anomalies are concentrated along the Cincinnati Arch (outlined by the heavy lines in Figure 1). Detailed studies of two of these anomalies have been moderately successful in defining the geometric and lithologic sources.

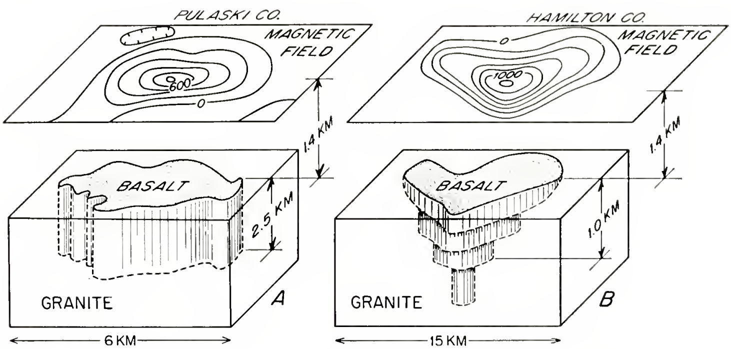


FIGURE 5. *Schematic representation of Precambrian bodies interpreted as sources for the gravity and magnetic anomalies observed in A) Pulaski and B) Hamilton Counties.*

Area A in Pulaski County (Fig. 1) is an isolated, well-defined anomaly approximately circular in form (Fig. 5A). Analysis of seismic, gravity and magnetic data (8) suggest that the source is a vertical, prismatic body of basaltic material intruded into a country rock of granite. Area B in Hamilton County (Fig. 1) is also a well-defined anomaly, but more complex in its form (Fig. 5B). In a recent study we suggested that the source of this anomaly is a vertical pipe, with a series of overlying flow-like sheets of basalt (9).

Viewing the interpretation of these two anomalies as part of a larger geologic picture, the Cincinnati Arch appears to be the site of numerous intrusive pipes, now represented by a concentration of magnetic anomalies. These intrusions were sources for flow-like basalts that covered the

Precambrian surface in isolated patches. We encountered flow-like basaltic rocks in several of our basement tests and this interpretation thus seems geologically reasonable. The age of the intrusions and flows is questionable, but it is suggested that they may be Keweenawan related.

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