PRELIMINARY REPORT ON AN EXPERIMENTAL AEROMAGNETIC SURVEY IN NORTHWESTERN INDIANA

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H. R. Joesting and J. R. Henderson

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Introduction

The desirability of an aeromagnetic survey of the entire State of Indiana was discussed in December 1946 at a conference held at Bloomington, Ind., by officials of the U. S. Geological Survey and the Indiana Department of Conservation. It was concluded that such a survey might furnish valuable qualitative information on the configuration of the crystalline basement rocks and therefore on structure and variations in thickness of the overlying sedimentary rocks, on variations within the basement rocks, and on the location and approximate configuration of any younger igneous rocks which may have intruded the sediments.

Information on the positions of ridges and other topographic highs on the surface of the crystalline rocks and on variations in thickness of the overlying sedimentary rocks would be of considerable economic importance in that they would indicate the position of possible structures favorable to the accumulation of petroleum. Information permitting delineation of unfavorable areas would also be of value, since it would permit concentrating on areas considered to be more favorable.

In order to determine the usefulness of an aeromagnetic survey of the entire State, which would cover some 35,000 square miles and require some 40,000 miles of traverse, a 1,500-square-mile area in northwestern Indiana was chosen for a trial survey. This area, which is shown on the accompanying aeromagnetic maps, includes all or parts of Newton, Jasper, Pulaski, White, Porter, and Lake Counties.

Field work was carried out during the period February 10-13, 1947, by W. J. Dempsey, Mary E. Hill, and J. R. Henderson, geophysicists of the U. S. Geological Survey. A preliminary isomagnetic map was completed during February 1947 at Bloomington, Ind., by J. R. Henderson, assisted by students of the University of Indiana, whose help was made available by Dr. Charles Deiss, State Geologist. A residual magnetic map was later prepared in Washington. Depth computations based on plausible theoretical considerations were made by R. G. Henderson and I. Zietz, geophysicists of the U. S. Geological Survey.

Preliminary study of the magnetic data indicates that the anomalies, though comparatively complex, are in general indicative of variations in the magnetism and in the depth to the underlying crystalline basement rocks. The aeromagnetic survey should permit, to a limited extent, delineation of areas of possible economic importance and elimination of unfavorable areas. It should be stressed, however, that it is not possible, on the basis of magnetic data alone, to distinguish between magnetic anomalies resulting from topographic highs of the crystalline rocks and those resulting from variations in magnetic properties of those rocks. Such information must be obtained by correlating the magnetic results with geological information, with data obtained by other geophysical methods, or by drilling.

Geology

Glacial drift, increasing in thickness to the north, covers almost all of the area surveyed, and outcrops of consolidated rocks are small in number and extent. Most information regarding structure and stratigraphy is derived from a comparatively small number of deep well logs such as those assembled by Logan (1).[1/] A geological map of northwestern Indiana by Shrock (2) shows bedrock of Devonian age in the northeastern and southern sectors of the area and an embayment of Mississippian rocks in the Goodland-Remington region. Silurian formations underlie the drift in a broad band extending from the northwest to the southeast corners of the area surveyed.

In marked contrast to the nearly flat-dipping rocks in most of the area, nearly vertical beds of faulted and crushed Middle Ordovician rocks are exposed in quarries 3 miles east of Kentland. This remarkable structural feature has been attributed to ~~cryptovulcanism~~ cryptovolcanism (2) (3). No information is available concerning its extent, nor are any intrusive rocks known to occur in the area.

A major structural feature is the Kankakee Arch, a geanticline extending southeastward from the Wisconsin highlands and separated from the related Cincinnati Arch by the synclinal Logansport Sag. Ekblaw (4) states that the initial uplift of the Kankakee Arch, totalling 500 to 600 feet, occurred in early Ordovician time and that subsequent uplifts totalled 200 feet. The Kankakee Arch is said to extend diagonally across the area surveyed from the northwest toward the southeast, to T. 28 N., R. 7 W. A part of the Logansport Sag occupies the extreme southeast part of the area shown on the magnetic map.

1/ See reference list at end of report.

Field Work

Equipment used for the survey consisted of an AN/ASQ-3A magnetometer with detector, control box, and recording milliameter; a gyro-stabilized Sonné continuous-strip camera; and a radar altimeter, all installed in an AT-11 twin-engined Beechcraft plane.

After a delay of a week because of unfavorable weather, aeromagnetic flights were begun February 10 from a base at Indianapolis and completed February 13. A total of 20 hours was spent in flight, of which 14 were spent in surveying the 1,500 square mile area.

Traverse lines spaced one mile apart were flown in an eastwest direction at an average elevation of 1,000 feet above the ground. Indiana State Highway maps corrected to 1937 were used as a base for flight control.

Upon completion of the regular traverse lines, the area was bounded by a series of base lines flown a short distance inside each border. Each base line was flown in two directions to permit correcting for diurnal variation and instrument drift. The closing error for the 160-mile base line series was 18 gammas, for which compensation was made.

Magnetic Maps

Results of the survey are presented on two ~~isoanomalic~~ iso-anomalic maps. Preliminary Map No. 4, plate 1, shows the anomalies in total intensity as measured. Preliminary Map No. 4, plate 2, is a map with the regional magnetic gradient removed. Since the magnitude and direction of the regional gradient for a given area cannot be determined precisely, an arbitrary correction must be applied. Corrections for the area considered here were computed using horizontal intensity and inclination charts of the Coast and Geodetic Survey.

A large area was outlined which included all of Indiana and half of Illinois and Ohio, to insure smooth curves as free from the effects of local anomalies as possible. Total intensity was determined by using the formula $T = H/\cos I$, and values were computed for points uniformly distributed over the area. Smooth curves were then drawn through points of equal intensity. They were found to compare closely with the tabulated measurements for individual stations.

The computed average regional gradient in total intensity was found to be $+$ 8 gammas per mile North and $+ \frac{1}{2}$ gamma per mile East. Corrections were applied by means of a grid to Preliminary Map No. 4, plate 1, and Preliminary Map No. 4, plate 2, was drawn.

Both maps are considered to be accurate to within one half the contour interval, or within about 12 gammas.

Interpretation

Inspection of the accompanying magnetic maps shows that correction for regional gradient did not materially alter the magnetic picture. The individual anomalies were only slightly changed in magnitude and position, and the positive westward gradient remains dominant.

Since the corrected magnetic map shows essentially all departures from the assumed normal magnetic field, it is used here for interpretation. This map exhibits two dominant features:

1. A positive westward gradient over most of the area, on which is superimposed a number of broad, closed anomalies of comparatively low intensity.

2. An east-southeast-trending zone of prominent highs along the southern boundary with accompanying lows.

In the comparatively small area considered here, the regional trend is partially obscured by the zone of intense anomalies along the southern border, and to some extent by minor irregularities in other parts of the area. Nevertheless, the positive westward gradient totalling several hundred gammas may be indicative of a westward decrease in depth to the crystalline basement in the northern two-thirds of the area.

No close correlation is apparent between the magnetic map and the southeast-trending Kankakee Arch or the Logansport Sag. If these are simple features, as indicated by available drill data, then it is apparent that any basement elevation was too small to affect the magnetic field appreciably. On the other hand it is not improbable that these structures are more complex than indicated by the scant geologic data available.

The large low centered in T. 31 N., R. 7 W., may indicate either a depression in the basement surface or variation in the magnetization of the rocks comprising the basement. Minor highs such as the two centering southwest of Francesville may indicate topographic highs in the basement complex, but positive interpretation of these and similar features is not possible without additional geological or geophysical evidence.

Possible causes of the zone of high-gradient anomalies along the southern border are: variations in magnetic susceptibility of the underlying crystalline rocks, topographic irregularities of the surface of the crystalline rocks; and younger igneous intrusives into the sedimentary rocks.

Unique interpretation is not possible from magnetic evidence alone, and the available geologic evidence is largely negative. No igneous rocks are known to have intruded the sediments, nor are there any known major folds or faults in the area, or magnetic horizons in the sediments.

On the basis of available evidence, the most probable major source of the anomalies is a zone of high-susceptibility basement rocks. The high and the accompanying low east of Wolcott, for example, apparently result from susceptibility differences in the basement rocks. Topographic highs in the basement rocks may also be a contributing factor, but it is unlikely that they are the sole or even the major cause, since no structures in the sediments that might be expected to result from major topographic highs are known to exist.

Although no igneous rocks are known to have intruded the sedimentary rocks anywhere in the area, they cannot be entirely ruled out as a possible

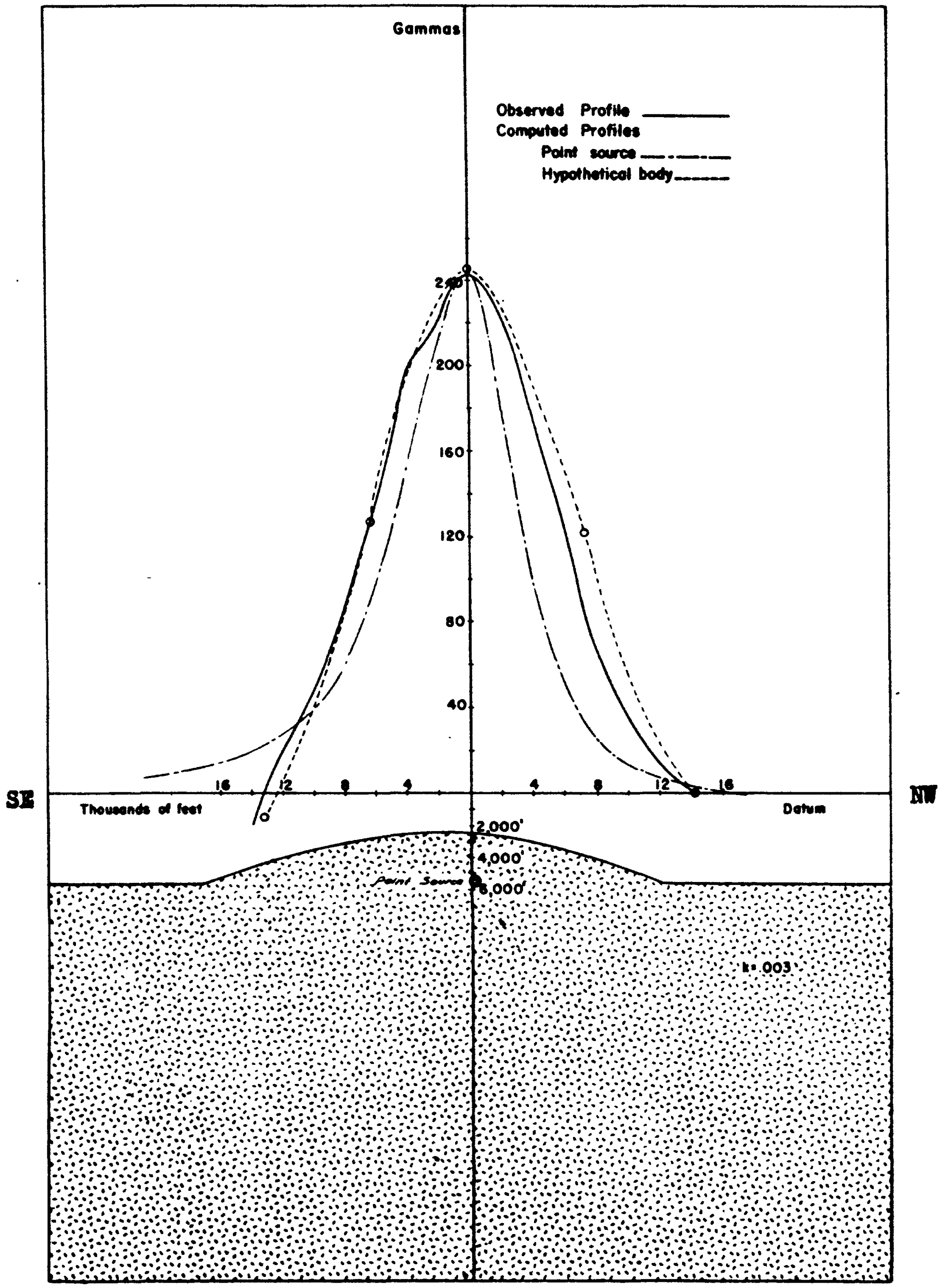

Fig. 1 TOTAL INTENSITY ANOMALY NEAR KENTLAND, IND.

source of the anomalies. The magnetic data indicate that any intrusion would be comparatively deep, of the order of several thousand feet beneath the surface. It should be mentioned, however, that anomalies of small areal extent, such as might be associated with small, shallow intrusions, would probably not be delineated by the trial survey, in which the flight lines were spaced 1 mile apart.

No magnetic indication of a shallow intrusion was observed over the Kentland "cryptovolcanic" structure, but its igneous origin is not thereby disproved, especially since no aeromagnetic traverse passed directly over the structure. The prominent high on the south flank of which the Kentland structure occurs, and indeed the entire zone of highs extending eastward, may be caused by comparatively deep-seated intrusives to which the Kentland "cryptovolcanic" structure is related.

Preliminary computations were made to determine the probable depth to the source of the anomaly centered 3½ miles northeast of Kentland. It was found that a magnetic point pole 5,500 feet beneath the surface would produce a magnetic profile of the same amplitude as that of the observed SE-NW profile as shown on figure 1. The actual depth to the basement rocks, however, would be somewhat less than 5,500 feet, since any point source of magnetism would be within the magnetic body.

A more reasonable depth approximation was obtained by assuming that the anomalous field was produced by a flat-bottomed granite mass with a susceptibility contrast between the granite and the overlying sedimentary rocks of 0.003 c.g.s. units, resting on a granite basement at the depth computed for

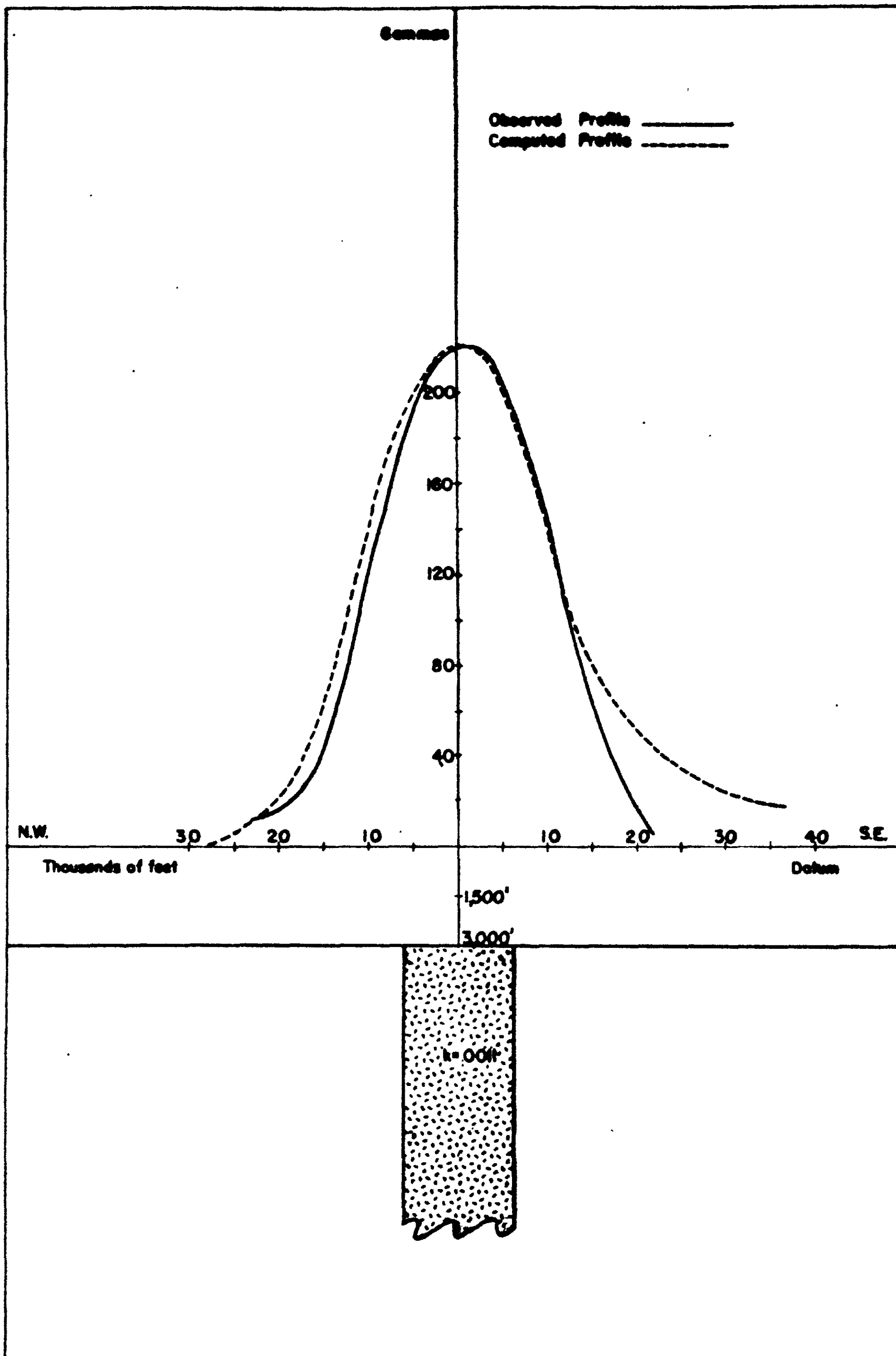

Fig. 2 TOTAL INTENSITY ANOMALY NEAR KENTLAND, IND.

the point source. The field produced by this body was then compared with the observed field, and the shape of the body altered until the computed and observed fields were in approximate agreement.

As shown in figure 1 the minimum depth to such a hypothetical mass would be 2,400 feet and the relief above the granite base would be 3,000 feet. It must be stressed that these computations are based on assumed susceptibility contrasts of the basement rocks and on an assumed shape of the top of the basement, consequently they are correct only to the degree that these underlying assumptions are correct. If, for example, a higher susceptibility contrast were assumed, equivalent to that of a rock more basic than granite, the computed minimum depth would be correspondingly greater and the relief less.

Despite such uncertainties it seems likely that too great a topographic relief in the surface of the basement rocks would be required to produce the observed anomaly, on the basis of reasonable assumptions of susceptibility contrasts. In the absence of confirming structural evidence in the overlying sedimentary rocks it is concluded that topographic relief is not the main cause of the anomaly.

Additional computations were made to determine the theoretical depth to basement if the anomaly is assumed to be caused solely by susceptibility contrasts in the basement rocks. The technique employed follows the Vacquier method.

A NW-SE profile was taken across the Kentland anomaly at approximately the same place as the previous one, and is shown in figure 2. Curvature of the observed field was computed and compared with theoretical models to determine probable size and depth. It was found that a prism 2.1 mi. by 4.2 mi.

extending indefinitely vertically downward, with the top at a depth of 3,000 ft. below the earth's surface, could reasonably produce the essential features of this anomaly. If a susceptibility contrast of .0011 c.g.s. is assigned to this body, a magnetic profile will be produced with the same amplitude as the observed SE-NW profile. Both the observed and computed profiles are plotted on figure 2.

It should again be pointed out that these results are dependent for their accuracy upon the correctness of the underlying assumptions. Until more direct evidence is available, it will not be possible to attribute the Kentland anomaly to its proper source.

Conclusions and Recommendations

The magnetic pattern for the 1,500-square-mile area under consideration is relatively complex. Interpretation of the observed results was further made difficult by a lack of correlative geologic information concerning the deeper sedimentary formations and the basement complex.

In general the isomagnetic maps are believed to indicate variations in the magnetism and depth to the underlying crystalline rocks with the sedimentary rocks having little controlling effect.

In planning further work, consideration should be given to the possible existance of a major belt of intrusives along the southern border of the area. Since it is not possible, on the basis of magnetics alone, to distinguish between anomalies resulting from topographic highs in crystalline rocks and those resulting from variations in magnetization of these rocks, additional geologic or geophysical information is needed to provide unique interpretations. This information could be obtained by deep drilling to the basement rocks, supplemented by a seismic survey for detailed information on variations in thickness of the overlying sedimentary rocks.

On the basis of the experimental survey it is believed that an aeromagnetic survey of the entire State would be of value. Such a survey should furnish information on changes of facies and major topographic irregularities in the basement rocks, the presence of igneous intrusions in the sediments, and major structural features in the sedimentary rocks where they are controlled by the underlying crystalline rocks. It should thereby serve as a guide for more detailed geological and geophysical work.

References

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