THE MAGNETOMETER IN ILLINOIS*

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INTRODUCTION

The Illinois State Geological Survey began geophysical surveys with the magnetometer during the summer of 1929. The work was done by Mr. J. S. Young under the direction of Mr. G. F. Moulton. The surveys were continued in 1930 by the writer under the supervision of Dr. A. H. Bell. Most of the magnetometer surveys have been in areas where the geologic structure is well known, namely, Eastern Illinois, LaSalle area, Waterloo and Dupo oil fields, Sparta region, Ava-Campbell Hill gas field, Alto Pass quadrangle, Hardin County, and from Duquoin to Centralia. The entire survey covers an area of 3,240 square miles or approximately ninety townships. Some 1,620 magnetometer stations were established in these areas to measure the relative vertical magnetic intensity.

This report points out some of the principal anomalies of the earth's magnetic field in Illinois as revealed by measurement of the vertical component at numerous points and describes the effect of faults on the vertical magnetic intensity.

THE EARTH'S MAGNETIC FIELD

The construction and operation of magnetic instruments is based on the fact that the core of the earth acts as a huge magnet and the earth's crust is within the magnetic field of that magnet. The cause of the earth's magnetism is not completely understood, although it is generally conceded to be a deep seated magnetic force which acts as a spherical magnet.

A magnetic field is defined by lines of force which normally undergo a symmetrical variation in direction and intensity dependent upon their distance and direction from the poles of the magnet. The lines of force are vertical at the magnetic poles of the earth where its maximum intensity occurs. At the magnetic equator the magnetic field has a minimum intensity and the lines of force are horizontal, pointing toward the magnetic poles. The symmetry of the magnetic field between

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the magnetic poles and equator is distorted by local crowding together and thinning out of the lines of force. This distortion of the normal magnetic field is due to the fact that the source of the earth's magnetism is deep seated, and the lines of force which define its field must pass through the earth's crust.

This crust is composed of different kinds of rock of varying mineral content. Rocks that contain abundant magnetite have a high magnetic permeability and readily permit the passage of lines of force, producing areas of abnormally high magnetic intensity. Rocks containing little or no magnetite have a low magnetic permeability, retard the passage of lines of force, and so produce regions of abnormally low magnetic intensity. These regions of abnormally high and low magnetic intensity are called anomalies, because they are distortions of the earth's normal magnetic field.

A small bar magnet free to move about its center of gravity will align itself tangent to the lines of force of the earth's magnetic field. As it is impractical to suspend a magnet in this way, it is customary to determine the direction of the earth's field by means of two magnets, one turning about a vertical axis and another about a horizontal axis.

The declination, dip or inclination, horizontal intensity, and vertical intensity are known as the magnetic elements. The magnetic declination is the angle which the lines of force make with the geographic meridian. An eastward declination is positive and westward declination is negative. The vertical plane defined by the lines of force at any place is called the magnetic meridian. The dip or inclination is the angle which the lines of force make with the horizontal plane.

Magnetic Exploration

History

The magnetic method of exploration was first used to prospect for iron ore in Europe and the Lake Superior region of Michigan. The Dip or Miner's Compass[1] was used in Michigan to aid in locating iron deposits as early as 1869. Later the dial compass was devised by Brooks and used with the dip needle. These two instruments are particularly adapted to rapid exploration for large iron ore deposits and have been used extensively for such work. The dip needle[2] can be operated faster than any magnetic instrument in use, but its lack of sensitivity limits its field of usefulness.

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[1] Brooks, T. B., Iron Bearing Rocks, Geol. Survey of Michigan, Vol. 1, pt. 1, p. 210, 1869-1873.

[2] Stearn, Noel H., Practical Geomagnetic Exploration with the Hotchkiss Superdip, Amer. Inst. Mining and Metallurgical Engineers Tech. Pub. 370, p. 4. 1931.

Since 1869 a large variety of magnetic instruments have been devised and applied to magnetic prospecting, from the simple mining compass to the sensitive instruments used by the U. S. Coast and Geoditic Survey.

FIG. 1. **Askania vertical type magnetometer.**

MAGNETIC FIELD BALANCE

The Adolph Schmidt field balances[3] were developed to satisfy the need for instruments to rapidly measure the horizontal and vertical components of the earth's magnetic force in the field. It was also necessary that the instruments be more sensitive and reliable than such instruments as the dip needle. The Schmidt field balances are manufactured by Askania-Werke A. G. and are generally known as the Askania magnetometers. The vertical magnetometer has found a more general use, because the vertical component bears a simpler relation to the configuration of the buried magnetic masses than does the horizontal component. From measurements of the vertical and horizontal intensity the total magnetic intensity may be calculated.

[3] **Heiland, C. A., Theory of Adolph Schmidt's Horizontal Field Balance, *in Geophysical Prospecting*, Amer. Inst. Mining and Metallurgical Engineers, p. 261, 1929.**

Principles

The construction of the magnetometer is based on the fundamental law of magnetism that a magnet placed in a magnetic field will be acted upon by a force F = M x H where F is in dynes, M is the pole strength of the magnet, and H is the field intensity in gauss. In the vertical magnetometer, a magnetic system is balanced on a knife-edge perpendicular to the magnetic meridian. The center of gravity of the magnetic system is on the south polar side and below the pivot, so that the gravitational force due to the weight of the magnet system is balanced against the magnetic force which tends to make the system take up a position tangent to the lines of force of the earth's magnetic field. The position at which the magnet system comes to rest at a given place depends first, upon the position of its center of gravity with respect to the pivot, which is kept constant, and second, upon the strength of the earth's magnetic field which varies from place to place and from time to time. If the instrument is then moved to another place where the force of the earth's field is different, the magnet system will assume a new position. The change in position indicates a change in the magnetic force of the earth's field and the magnitude of the change in position is a relative index of the change in vertical intensity of the earth's magnetic field. The angular deflection of the magnetic system is directly proportional to the vertical intensity. The tilt or deflection of the balance system is measured by a telescope fitted with a scale and Gauss eyepiece.

Interpretation of Magnetic Anomalies

The interpretation of magnetic anomalies measured with the vertical magnetometer is a difficult and complex task. Differential permeability of the subsurface rocks causes distortions in the earth's magnetic field. This means that magnetic anomalies are definitely related to geologic features and therefore susceptible to geologic interpretation. The difficulty in determining the influence of geologic features complicates the correct interpretation of magnetic data. Stearn[4] gives the following list of geologic factors, which may influence the shape and magnitude of magnetic anomalies:

1. **Variations in mineral composition of the formations**
   a. **Due to primary distribution**
   b. **Due to secondary development**
2. **Variations in the attitude of the formations**

[4] Stearn, Noel H., Application of geomagnetics to exploration, *in* Geophysical Prospecting, Amer. Inst. Mining and Metallurgical Engineers, p. 339. 1929.

3. **Variations in the distribution of the formations**
   a. **Due to structural causes**
   b. Due to erosion
4. **Variations in the shape of the formations**
5. **Variations in topography**
   a. Bedrock topography
   b. **Topography of the overburden**
6. **Variations in the overburden**
   a. **In depth**
   b. **In mineral composition**

The correctness of any interpretation then, depends upon the number of variables known or partially known. It is sometimes possible to determine the influence of certain variables by making magnetic surveys across areas where the geology is well known. If the influence of certain variables is thus determined, the information may be useful in interpreting anomalies where geologic knowledge is meager.

There are many magnetic anomalies, regional in character, which are evidently caused by heterogeneities in the basement complex and the irregular surface of the basement complex. When it is definitely determined that there is nothing in the known geologic section to cause certain magnetic anomalies, then it seems reasonable to suspect the irregularities of the basement complex as causing the magnetic anomalies.

The shape of the magnetic field at any one point is the result of the effect of all the rocks through which the field passes. A deep-seated reaction may be masked or compensated by a reaction in the overlying rock, thereby complicating the interpretation of the measured anomalies. It is obvious then, that the correct interpretation of magnetic anomalies is dependent upon the available geologic data.

Magnetic Anomalies in Illinois

The "Map Showing Vertical Magnetic Anomalies in Illinois" (fig. 2) was made by using the magnetic intensity values obtained by the United States Coast and Geodetic Survey at all county seats in Illinois. The anomalies are determined by calculating the difference between the normal vertical intensity and the actual vertical intensity. If the actual intensity is greater than the normal intensity, there is a positive anomaly, and vice versa. The map gives only a rough idea of the distribution of the vertical magnetic intensity. The vertical intensity in Illinois has a variation of more than 2,000 gammas, a gamma being 1/100,000 of a gauss.

Positive magnetic anomalies occur in LaSalle, Kankakee, Henderson, Morgan, Edgar, St. Clair, Madison, Washington, Wayne, Saline, and Massac counties. Negative anomalies occur in Boone, Whiteside, Marshall, Iroquois, Cass, Macon, Randolph, Union, and Pope counties. No attempt has been made to correlate these anomalies with the structural features of the State. Anomalies determined by stations forty to fifty miles apart are not outlined definitely enough to attempt

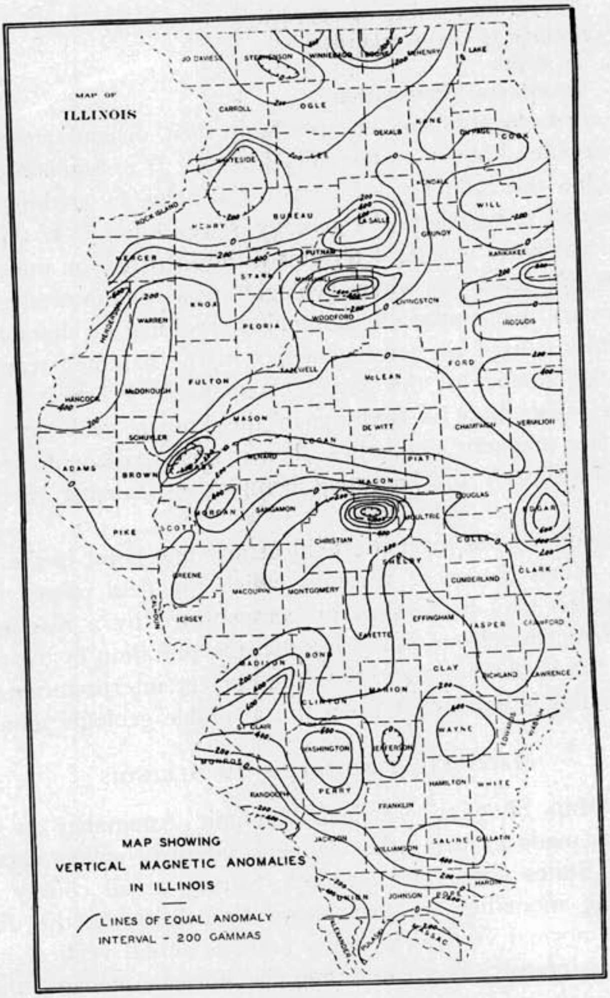
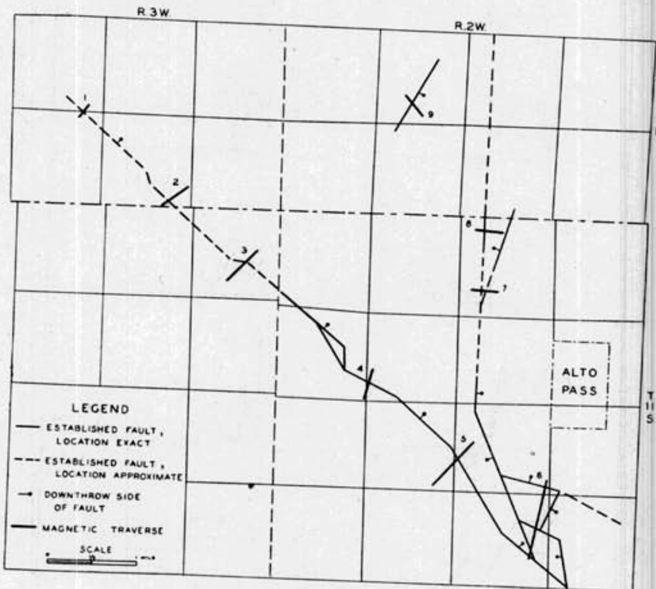


Fig. 2.

an interpretation. Reconnaissance surveys of such anomalies show that they are very irregular, although the trend of the magnetic highs and lows may remain the same.

The reconnaissance surveys in Illinois do not show a direct relationship between the vertical intensity and the structure. A magnetic high does not necessarily indicate a structural high, nor a magnetic low a structural low. In eastern Illinois, near Paris, a magnetic high occurs above the Marshall-Sidell syncline. The highest intensity across the Waterloo anticline is on the east flank of the anticline. In the area between Duquoin and Centralia there are a series of magnetic highs and lows along the axis of the Duquoin anticline. In the Ava-Campbell Hill area magnetic features follow the structure in certain places and deviate from the structure in other parts of the area.



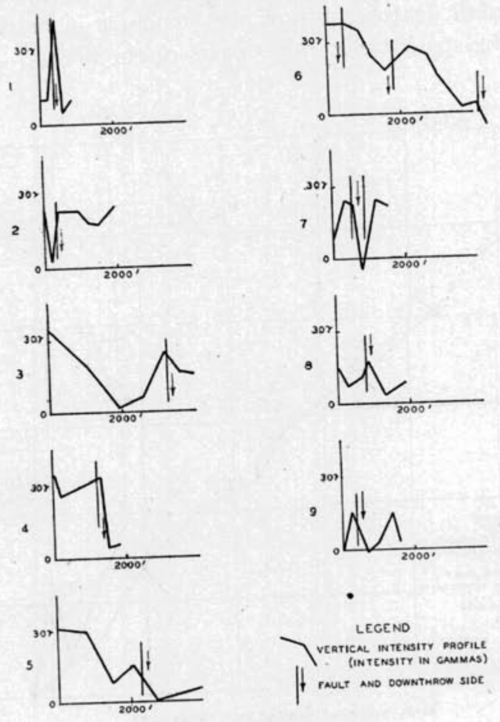
MAP SHOWING MAGNETIC TRAVERSES
IN ALTO PASS QUADRANGLE

FIG. 3.

The present status of the geophysical investigations in Illinois seems to indicate that the magnetic anomalies are caused by heterogeneities in the basement complex, irregular surface of the basement complex, or a combination of the two factors. This conclusion is based, first, on the variable relation between the magnetic features and the structural features, and second, on the fact that well-cuttings which have been examined do not contain sufficient magnetite to affect the magnetometer. In certain areas the glacial drift contains enough magnetite to affect the magnetometer, but it is improbable that it would cause the large anomalies known to be present in Illinois.

Tracing Faults With the Magnetometer

A series of magnetic traverses were run across certain known faults in Hardin and Union counties. The locations of traverses and a few faults are shown on the "Map Showing Magnetic Traverses in Alto Pass Quadrangle" (fig. 3). The faults were mapped several



MAGNETIC PROFILES ACROSS FAULTS IN ALTO PASS QUADRANGLE

FIG. 4.

years ago by Dr. Ekblaw.[5] Traverses 1 to 6 are across the major fault. This fault has a throw of 1,000 to 1,200 feet, bringing the Chester on the north in contact with the Devonian on the south. Traverses 7 to 9 are across faults affecting only the Chester strata with displacements of less than 200 feet.

Profiles of magnetic traverses across faults in the Alto Pass area are shown in figure 4. These profiles show that there is a magnetic

[5] Ekblaw, G. E., Post Chester, Pre-Pennsylvanian faulting in the Alto Pass Area, Illinois State Acad. Sci., Vol. 18, p. 379, 1925.

disturbance of 10 to 30 gammas within 200 feet of the mapped fault trace. As it was impossible to determine the exact position of the faults along the magnetic traverses, it is not certain just what relation exists between the fault trace and the magnetic disturbance. The available data seem to indicate an increase in intensity when approaching the fault on the upthrow side, then a sharp decrease in intensity after crossing the fault, followed by a gradual increase in intensity as the distance from the fault increases on the downthrow side. If this conclusion is true, the positions of some of the faults as mapped are slightly in error.

The profiles do not indicate any relation between the amount of throw along the fault and the variation in intensity. Profiles 1 to 6 show approximately the same variation in intensity as profiles 7 to 9, which are cross small faults. This absence in variation of intensity leads to the conclusion that the faulting in this area has not disturbed any magnetic beds. If magnetic beds had been displaced, the greatest magnetic variation would occur across the fault having the most throw.

The important point is that there is always a magnetic disturbance set up by a fault. This makes it possible to determine the location of faults in an area where outcrops are scare, such as tracing the major fault in the Alto Pass area west across the Mississippi flood plain.

The magnetometer then, has two principal uses in Illinois. First, in regional reconnaissance surveys it is quite possible to pick up structural trends, and second, in doing detailed work it will indicate the position of faults.

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