Proceedings of the Iowa Academy of Science

Volume 71 | Annual Issue Article 46

1964

Geologic Interpretation of Magnetic Map, Washington County, Iowa

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Abstract. In 1963, ground measurements of the vertical component of the earth's magnetic field were made in Washington County, Iowa. The magnetic variations are attributed to differences in the lithology and configuration of the Precambrian crystalline basement complex about which no direct geologic information is available. Although a unique interpretation of the magnetic data is impossible owing to the limited geologic control, it is proposed that the basement complex is at a depth of 2,600 to 5,000 feet, may be cut by a northeasterly trending fault occurring near the city of Washington, and exhibits topographic relief which controls the formation of domes and basins in the overlying Paleozoic sedimentary rocks. If the proposed interpretation is valid, it should be possible to locate Paleozoic structures in adjacent counties by magnetic mapping.

In 1963, ground measurements of the vertical component of the earth's magnetic field were made in Washington County, Iowa, to determine if a magnetic anomaly was associated with the Paleozoic, Oquawka anticline. Earlier in the year, the Natural Gas Pipeline Company of America drilled on a small structural dome with about 50 feet of closure on the base of the Burlington Limestone to determine if the structure would be suitable for storage of natural gas in the St. Peter Formation. The drilling resulted in the discovery of petroleum in the Pecatonica Member of the Platteville Formation in sec. 20, T. 76 N., R. 9 W.

A flux-gate Jalander Electronic Magnetometer, Model 1957, was used both as a hand-held, direct-reading magnetometer at discrete stations and as a continuous recording magnetrometer mounted in a vehicle to obtain chart records of relative magnetic profiles along road traverses. When used as a direct-reading magnetometer, the instrument was adjusted to the approximate magnetic latitude in the county, and all values were read to an accuracy of ± 0.5 scale unit with a sensitivity of 9.65 gammas per scale unit over a range of about 2,500 gammas. A network of 132 field stations was established with a spacing of about one station for every 4 square miles and closer spacings where the magnetic gradient is steeper. A base station was re-occupied at intervals of several hours during the course of each day's survey to obtain a diurnal-variation curve for correcting the field data. A latitude correction of 8½ gammas per

[1] Presented with the permission of Dr. H. Garland Hershey, State Geologist, and Director of the Iowa Geological Survey.
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mile was applied to the data, but the longitude correction is essentially zero and was not considered. The data were not corrected for temperature variations. The corrected magnetic values at the field stations are relative to the base station near the center of the county to which an arbitrary base value of 1,000 gammas is assigned.

When used as a continuous recording magnetometer, the Jalander was connected with a Varian Model G-11A strip-chart recorder and mounted inside an automobile along with an inverter which provides 70 watts of 110-volt power from the 12-volt storage cell of the vehicle via the cigarette lighter receptacle, a remote control potentiometer unit which provides range calibration, fiducial and off-on control, and the cables necessary to connect the various components (fig. 1). Approximately 550 line miles of traverse, most of which were oriented east-west, were made along roads in the county. Vehicle speed was maintained at 35 miles per hour as nearly as possible, and recorder tape speed was 2 inches per minute which resulted in about 3½ inches of record for each mile of traverse. The full scale chart deflection on the recorder was set at 15,000 gammas which gave the optimum response with a minimum of background "noise" resulting from instrument sway.

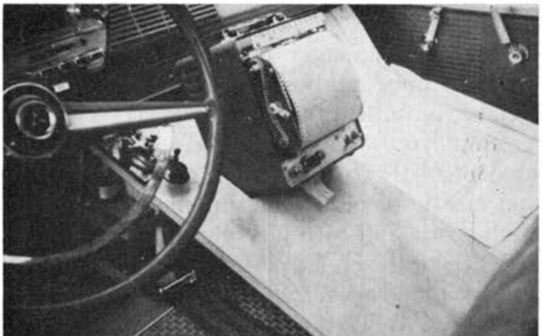

Figure 1. Varian strip-chart recorder, telegraph key fiducial control and remote control potentiometer mounted in front seat of automobile. Inverter not shown.

To measure the vertical component of the earth's magnetic field, the magnetometer must be maintained in an essentially vertical position. A major problem when using the instrument system in a moving vehicle is to provide a practically stable platform for the magnetometer so that the magnetic values can be attributed with reasonable assurance to variations in the earth's magnetic field and not to any movement of the flux-gate element in that field. To provide a gimbal and damping device for reducing the amount of swaying and bumping of the vehicle which was transmitted to the instrument, the magnetometer was mounted in a foam plastic support ring and floated on heavy oil (SAE 250) which partially filled a large plastic container (fig. 2).

Figure 2. Jalander magnetometer in foam plastic support ring floating in oil-filled container mounted in back seat of automobile.

The recording magnetometer system was found to be reliable only for reconnaissance purposes in defining anomalies greater than 1,000 gammas unless a network of magnetic control field stations was employed. When mounted inside the vehicle, only 50 to 70 per cent of the full variation of the magnetic field was recorded, and erratic records were obtained owing to instrument sway on rough roads and to traversing hilly terrain. In addition, each magnetic record is relative to the magnetic value at the starting point of the traverse and not directly correlative with other magnetic records. To overcome these difficulties and to use the records to interpolate the magnetic gradient between the network stations, the erratic records were smoothed to remove the noise and departures due to instrument sway and terrain and adjusted to conform with the magnetic values at the field stations in the network.

Geologic Setting

Washington County is underlain by Paleozoic sedimentary rocks ranging in age from Cambrian to Pennsylvanian. Except for the Pennsylvanian sandstone and shale outliers which are confined to the southern half of the county, the bedrock is Mississippian limestone, dolomite, sandstone or shale. The lower

Paleozoic section includes limestones, dolomites, shales and sandstones of Devonian, Ordovician and Cambrian age with Silurian dolomite present only in the northern half of the county. Ubiquitous Pleistocene glacial deposits of the Nebraskan and Kansan stages range in thickness from 0 to 200 feet (Morgan, 1956).

Washington County is essentially bisected by the axis of the northwest-trending, Paleozoic Oquawka anticline. Several elongate domes with closures of about 50 feet have been mapped on the base of the Burlington Limestone from well data (Parker, 1961). Recently, a structure contour map on the top of the Galena Formation (fig. 3) was prepared by Donald L. Koch, Iowa Geological Survey. The major structural feature is a broad anticline trending about west-northwest through the center of the county although the regional dip appears to be generally southwest at about 3½ to 4 feet to the mile. Several elongate domes and basins with closures ranging from about 40 to 120 feet have been mapped on the Galena Formation, and the petroleum discovery well is on the Keota dome near the western edge of the county.

The Cargill Well, SE¼, SW¼, SW¼, NW¼, sec. 16 T. 75 N., R. 7 W. and the Washington City No. 5 Well, NW¼,. SW¼,. NW¼, NE¼, sec. 17, T. 75 N., R. 7 are a little more than half a mile apart on a line bearing approximately N. 60° W. in the city of Washington. An apparently normal section was encountered in the No. 5 Well, but in the Cargill Well the Oneota Member of the Prairie du Chien Formation is apparently repeated and the top of the Jordan Formation is about 300 feet lower than in the No. 5 Well. This relationship strongly suggests the presence of a reverse fault of unknown strike and dip between the two wells.

The deepest well in the county is the Washington City No. 5 which bottomed 45 feet in the Cambrian Franconia Formation at a depth of 1,900 feet (1,138 feet b.s.l.). Employing "average" thicknesses for the Franconia Formation and the Dresbach Group in eastern Iowa, the depth to the basement complex in the center of the county is about 2,600 feet (1,800 feet b.s.l.). Applying the "average" thickness for the Mt. Simon Formation in wells which entered this formation in adjacent counties, the figures for depth to the basement complex range from 2,700 feet (2,000 feet b.s.l.) to 3,000 feet (2,300 feet b.s.l.) in the vicinity of these wells. The thickness of the Cambrian section and the basal red clastics is poorly known, however, and the depth to the basement complex in Washington County could range from 2,500 to 3,000 feet or exceed 3,000 feet if the surface of the complex exhibits considerable topographic relief.

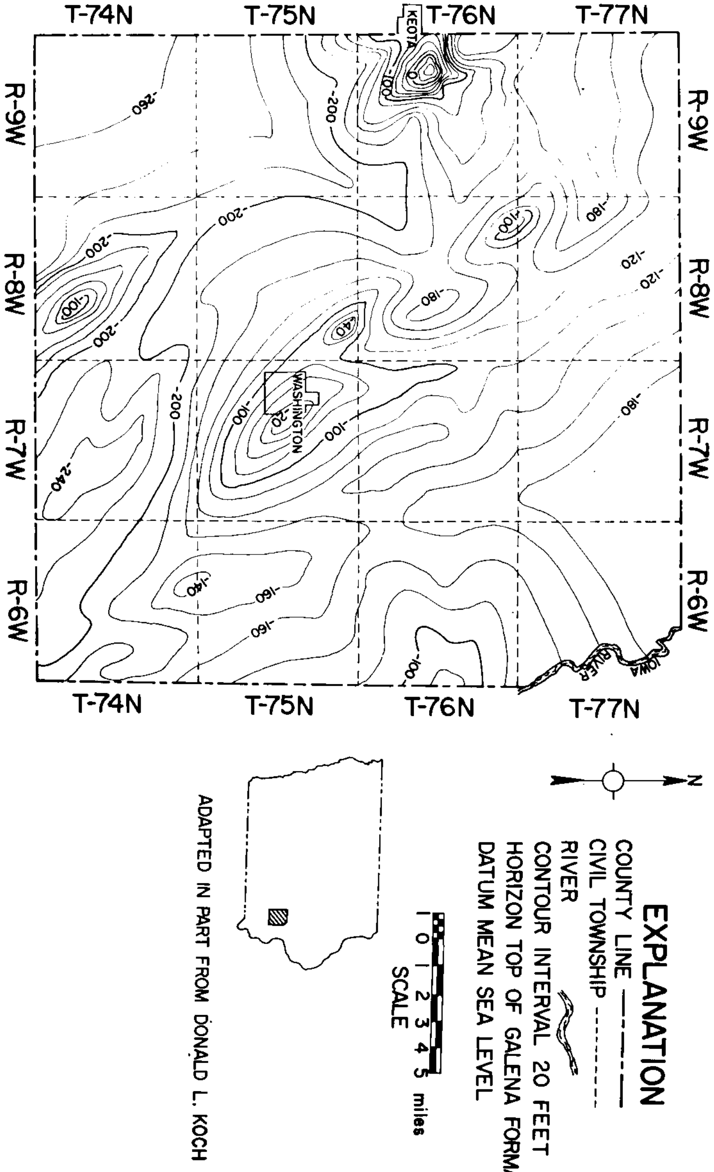

Figure 3. Structure contour map, Washington County, Iowa.

Interpretation of Magnetic Map

The assumption of a smooth variation of magnetic intensity over the surface of the earth is congruent with the concept of a laterally homogeneous magnetic earth to a depth of several tens of miles. On a magnetic map, any departures from this idealized condition would remain as anomalies that are largely the result of an unequal distribution of magnetic material which must be explained in terms of reasonable geologic conditions. The interpretation of magnetic anomalies is rarely unique, however, unless considerable geologic control data are available.

Geologic control in Washington County is limited to knowledge of the lithology, structure and probable thickness of the Paleozoic sedimentary rocks. No drill holes have penetrated the Precambrian crystalline basement complex, and consequently, its character and depth are not known. Inasmuch as the glacial drift and the known sedimentary rocks in the county do not contain significant amounts of minerals of high magnetic susceptibility, the geologic conditions responsible for the anomalies can be attributed almost entirely to differences in the lithology of the basement complex.

The more obvious features of the magnetic map (fig. 4) are the anomalies ranging from about 500 to 1,000 gammas. Although they exhibit no prominent linearity, their gradients, concentration and distribution provide the basis for interpreting certan geologic conditions in the basement complex.

Depth estimations are based on the fact that the steepness of the gradient of the sides of an anomaly is a measure of the maximum possible depth to the upper surface of the polarization contrasts within the crystalline basement complex (Peters, 1949). Applying Peters' slope method of analysis to several of the anomalies and assuming that the width of the body is considerably greater than the depth to the top of the basement complex, the average calculated depth is about 5,000 feet over a range from 4,000 to 6,500 feet. Thus the depth to the basement complex probably ranges from a minimum of 2,600 feet inferred from the estimated thickness of the Paleozoic section to a maximum of 5,000 feet inferred from the analysis of the magnetic data.

A northeast-trending line slightly convex toward the northwest and passing through the city of Washington essentially separates an area of smaller magnetic gradients in the southeastern half from an area of larger magnetic gradients in the northwestern half of the county. This change in gradient suggests a discontinuity in depth, possibly a contact between two large rock masses of rather different magnetic susceptibility, a basin or a fault. The suggested discontinuity in the basement complex may be caused by a fault for there is apparently a reverse fault in the lower Paleozoic section of the Cargill Well in the city of Washington.

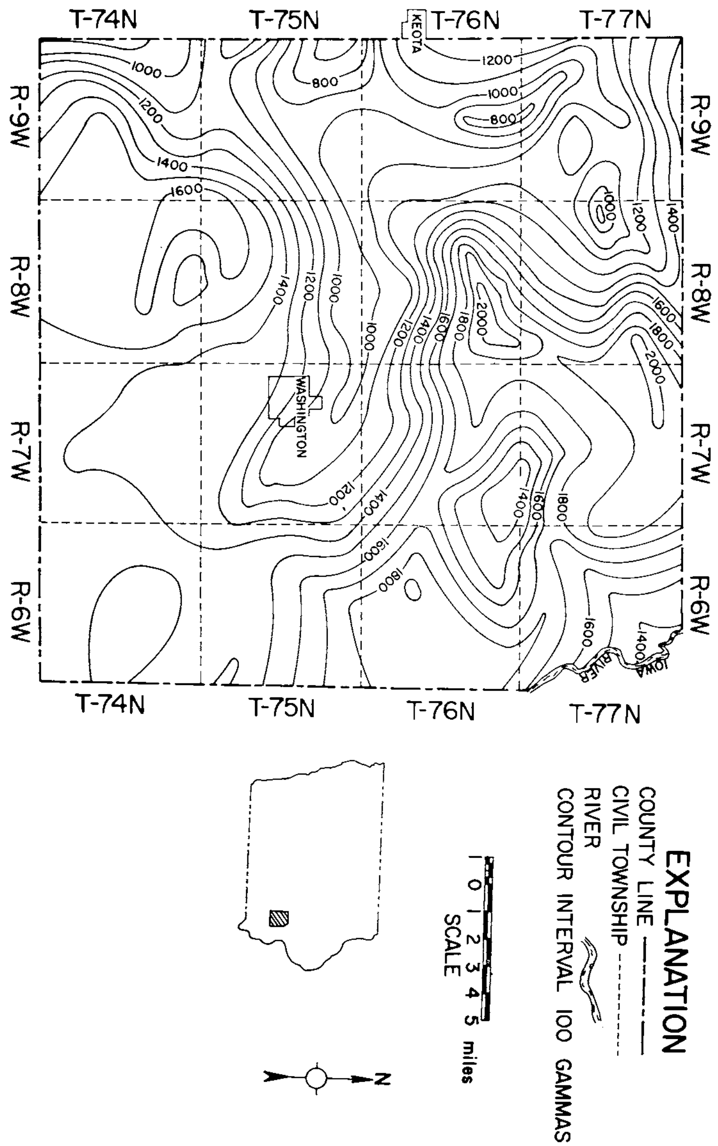

Figure 4. Vertical intensity magnetic map, Washington County, Iowa.

Comparison of the magnetic map (fig. 4) and the structure contour map by Koch (fig. 3) indicates a relationship which may be of economic significance. An inverse relationship exists between the spatial distribution of the structural and magnetic features. Essentially every magnetic high and low is displaced about 4 to 5 miles to the north-northwest relative to a structural high and low. Quite possibly the structural highs on the Galena Formation are a result of draping of sedimentary rocks over topographic highs on the basement complex surface, but it is unlikely that these topographic highs are responsible for the magnetic highs. The intensity of the anomalies suggests that they are due to susceptibility contrasts and not to relief. Furthermore, an unlikely structural movement and/or a strong and low-angle remanent magnetization would have to be assumed to account for the 4 to 5 miles of lateral displacement in a stratigraphic section probably not more than a mile thick. The magnetic anomalies may occur over a structural zone along which rocks of different magnetic susceptibility have been extruded, intruded or folded into juxtaposition on the basement complex surface. The structural highs on the Galena Formation may essentially overlie the basement surface topographic highs which could be composed of relatively more resistant but less strongly polarized rocks than those which occur at lower elevations on the basement complex surface. If this inverse relationship of magnetic and structural features is valid and persists for reasonable distances to the north and west of Washington County, it might be possible to locate Paleozoic structural features with some degree of confidence from magnetic data obtained in the southwestern part of Johnson County, the southeastern part of Iowa County, and the eastern part of Keokuk County.

Conclusions

Because of the several difficulties encountered in obtaining and correlating the magnetic records, the data from the recording magnetometer system were used only to interpolate between the magnetic values obtained at the field stations with the direct-reading magnetometer.

The geologic conditions responsible for the magnetic anomalies can be attributed almost entirely to changes in the lithology and configuration of the Precambrian crystalline basement complex about which no direct information is available. Although the interpretation of the magnetic data is inherently ambiguous owing to the limited geologic control and the numerous combinations of variables which can produce essentially the same observed magnetic field, the following interpretation of the magnetic map is proposed:

a) the depth to the basement complex is probably between 2,600 to 5,000 feet;

b) a northeast-trending discontinuity in the basement complex may correlate with a fault in the Paleozoic rocks at the city of Washington;

c) the magnetic anomalies in the northwestern half of the county may occur over a structural zone along which rocks of different magnetic susceptibility have been extruded, intruded or folded into juxtaposition on the basement complex surface;
d) structural domes in the Paleozoic rocks may be caused by draping of sedimentary rocks over topographic highs on the basement complex surface composed of resistant but weakly polarized crystalline rocks;
e) structural basins in the Paleozoic rocks may be caused by filling with sedimentary rocks in topographic lows on the basement complex surface composed of less resistant but moderately polarized crystalline rocks;
f) the inverse relationship between the magnetic and the Paleozoic structural features may be economically significant.

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Structural Analysis of the Shell Canyon Area, Bighorn Mountains, Wyoming[1]

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Abstract. The area is divided by Shell Canyon into two structurally dissimilar regions corresponding to the northern and central structural provinces of the Bighorn Mountains. The mountain trend changes abruptly from a N-S strike south of Shell Canyon to N 60°W north of the Canyon. The northern part of the area has steeper dips and fewer flexures, the uppermost being a chevron fold. The only fault in the north part is the Horse Creek Fault. It is vertical, runs oblique to axial traces for four miles in an E-W direction, attains a maximum of 450 feet of throw and may have strike-slip movement. South of the Canyon the front is lower, with more numerous and broader flexures. The upper flexure is concentric. There are two low angle thrusts dipping west with 45 feet and 210 feet of dip-slip. There are also three vertical faults. Planar fractures in the Paleozoic strata show definite preferred orientation. Each fracture pattern has one dominant direction which is interpreted as shear. This set is usually perpendicular to axial traces. The thrust faults in

[1] Deep appreciation is extended to the National Science Foundation, whose financial support made this study possible.
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