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U. S. Geological Survey

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PREPARED IN COOPERATION WITH THE IOWA GEOLOGICAL SURVEY

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Contents

Illustrations

Table

INTRODUCTION

The U. S. Geological Survey made a 10,000 square mile aeromagnetic survey of central and southwestern Iowa in mid-1962. This work, done in cooperation with the Iowa Geological Survey, completed magnetic coverage for the approximately 220 mile section of the "midcontinent gravity high" located in Iowa.

The midcontinent gravity high was discovered and later detailed by geophysicists at the University of Wisconsin (Woollard, 1943, 1951) and Thiel (1956). Their work delineated an essentially continuous large positive gravity anomaly extending southwestward for 800 miles from Lake Superior to the Salina Basin in Kansas. The midcontinent gravity high reaches its known maximum intensity in central Iowa where the Bouguer anomaly ranges from -100 to 60 milligals.

An earlier report by Henderson and others (1963) gave preliminary results for the aeromagnetic survey made in 1961 by the U. S. Geological Survey in cooperation with the Iowa Geological Survey. This report covered 5,000 square miles in north-central Iowa over and adjacent to the main gravity high. In addition, a previously unpublished 600 square mile aeromagnetic survey centered on Manson, Pocahontas Co., Iowa was included. Figure 1 shows the location of the 1953, 1961 and 1962 surveys.

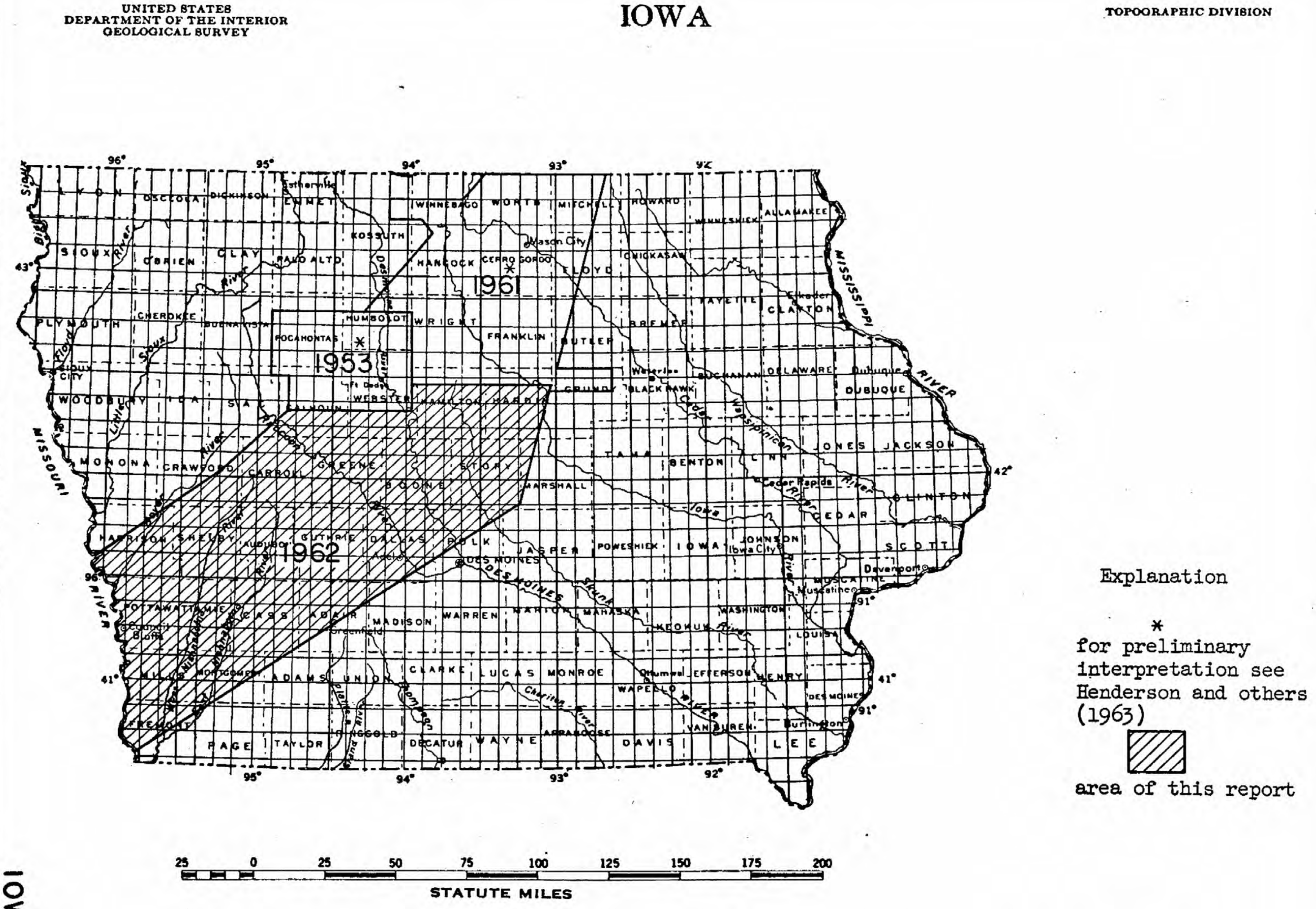

Figure 1. Index map of Iowa showing location of aeromagnetic surveys by the U.S. Geological Survey and years flown.

Both the 1961 and 1962 aeromagnetic surveys had common objectives -to prepare and interpret detailed magnetic contour maps over the midcontinent gravity high in Iowa. Analysis of the magnetic data could be expected to yield estimates of local thickness of the Paleozoic-Mesozoic sedimentary section and provide a basis for informed speculation about the character, configuration, and distribution of the Precambrian rocks. Such information would have obvious scientific and possible economic value in an area largely covered by glacial till and for which little deep subsurface knowledge was available. Henderson and Zietz (1958) had previously demonstrated in Indiana that interpretation of aeromagnetic data from the central stable region of North America could provide a significant amount of geologic information.

The report on the north-central Iowa survey (Henderson and others, 1963) and this present report were prepared to make the aeromagnetic data publically available in advance of more formal publication. Only salient magnetic features are discussed in these preliminary presentations. A more complete interpretation of the entire aeromagnetic survey is in preparation. Conclusions reached in the later report may differ from those stated in the preliminary papers.

FIELD WORK AND MAP COMPILATION

Field work for the 1962 aeromagnetic survey in Iowa was done on 24 flight days at intermittent intervals during the period May 15-August 8. J. R. Henderson supervised field operations at the beginning and end of the period. A. J. Petty and G. R. Boynton also served as party chiefs.

Magnetic measurements were made in a DC-3 aircraft equipped with an AN/ASQ-3A fluxgate magnetometer flown 1,000 feet above ground. Eastwest flight lines were used, spaced one mile apart. Pilot and observer guidance was based on county road maps. Three base lines and twice-daily test lines were flown to permit compensation for instrumental and diurnal drift. Field and map compilation procedures closely followed those described by Balsley (1952) except for the method of drift compensation.

Compilation of field data was done in Washington, D. C. under the supervision of J. L. Vargo. U. S. Army Corps of Engineers, Army Map Service 1:250,000 scale topographic maps were enlarged to 1:125,000 scale and used in compilation and in the preparation of the aeromagnetic contour map (fig. 2). Figure 2 (reduced back to 1:250,000), shows variations in the total intensity magnetic field for the survey area as delineated by 20 and 100 gamma contours. Because the AN/ASQ-type magnetometer does not measure absolute values, an arbitrary datum was chosen for figure 2. This datum is identical to the one chosen for the aeromagnetic map of north-central Iowa.

The regional magnetic gradient for central and southwestern Iowa is about 4 gammas per mile, increasing in a direction slightly east of north (U. S. Coast and Geodetic Survey, 1955). This gradient has not been removed from figure 2.

THE AEROMAGNETIC MAP

The aeromagnetic map of central and southwestern Iowa (fig. 2) is dominated by a continuation of the complex northeast-southwest trending magnetic "high" previously mapped in the north-central part of the state (Henderson and others, 1963). In general, the western border of the magnetic high is almost linear, whereas, the eastern border has several minor flexures and a major bulge to the east just north of 42°00'. Within the magnetic high are a series of notable magnetic lows. These are found intermittently along the center of the major feature and also near its borders. Broader anomalies exist along both sides of the central magnetic complex. The center of the magnetic complex coincides approximately with that of the elongate midcontinent gravity feature most recently illustrated by Steinhart and Meyer (1961, fig. 10.8). Figure 3 shows simple Bouguer gravity contours for this part of Iowa obtained from a manuscript map prepared by the Geophysical and Polar Research Center at the University of Wisconsin.

The 1:250,000 scale aeromagnetic map (fig. 2) has been reduced to 1:500,000 scale (fig. 2a) to permit direct comparison with the gravity map (fig. 3) and the geologic map (fig. 4). Similar maps for north-central Iowa at the same scale are in the open file report by Henderson, White and Zietz (1963).

The magnetic map obviously contains much more detail than does the gravity map. Additional detail was obtained because magnetic contrasts are greater than density contrasts within the region's rocks and because the aeromagnetic data were obtained along continuous traverses spaced one mile apart, whereas the gravity information was derived from observations made at discrete points spaced several miles apart. Enough gravity information is available, however, to provide a basis for estimating approximate thickness of the rock mass causing the midcontinent gravity high. The gravity data may be used to establish a "bottom" to this rock mass whereas analysis of the magnetic anomalies, because of greater detail, can better define the "top".

GENERAL GEOLOGY

Paleozoic-Mesozoic rocks

All of Iowa is part of the interior lowlands subdivision of the central stable region of North America. As noted by King (1959, p. 10) the central stable region has undergone little major deformation since the beginning of Cambrian time, but the Iowa Geological Survey has delineated numerous minor deformations.

Eardley (1962, fig. 4.3) used published isotope ages to map a Keweenawan orogenic belt that begins in the Lake Superior region and continues southwestward across parts of Wisconsin, Minnesota, Iowa, Nebraska, and into Kansas. The northern part of Eardley's orogenic belt essentially coincides with the major Lake Superior syncline as shown on the 1961 tectonic map of the United States (Cohee, chm, 1961). The geology of this area is described by Hotchkiss (1923), Butler and others (1929), and Leith and others (1935).

In central and southwestern Iowa the Precambrian basement platform is mantled by Paleozoic and Mesozoic sedimentary rocks that, in general, thicken southward toward the Forest City basin. The total thickness of Paleozoic and younger rocks is known from deep wells to be about 2,800 feet near Ogden and more than 5,200 feet near Clarinda (H. G. Hershey, written communication, 1962). Basement well locations in central and southwestern Iowa are shown on fig. 2. Between Ogden and Clarinda, depth to basement appears to increase at an average rate of about 24 feet per mile toward the deepest known part of the Forest City Basin. Meager information from deep drilling indicates that depth to basement increases to a rate of about 75 feet per mile near the basin's center. There are probably numerous other local interruptions to the average 24-foot per mile dip. One of these, now defined by drilling, is the Redfield gas storage anticline in Dallas County (location marked by cluster of wells on fig. 2).

Precambrian rocks (as interpreted from geophysical data)

On both the aeromagnetic and gravity maps all major anomalies are presumed to be due entirely to the distribution of the Precambrian rocks beneath the Paleozoic-Mesozoic blanket. Figure 4 is a simplified geologic map of the area as it might appear with this blanket stripped away. This map is wholly derived from the magnetic and gravity data and should only be regarded as tentative until the true nature of the various map units has been confirmed by drilling. The striking gravity and magnetic highs shown on figures 2, 2a and 3 continue northward through north-central Iowa and can be traced without important interruption to areas where they can be correlated beyond question with the lava series of middle Keweenawan age that is so prominent a feature of Lake Superior geology (Craddock and others, 1963 ; Zietz and Sims, unpublished data; and Thiel, 1956). Thirteen known drill holes in Iowa and 5 in east-central Minnesota penetrate to or near basement along the midcontinent high. All of these holes that reached crystalline rock bottom in mafic lava. Similar lavas crop out along the main geophysical highs in east-central Minnesota (Grout, 1910, map).

Additional geologic information about the Keweenawan and pre-Keweenawan rocks along the midcontinent gravity high in Minnesota is contained in Hall (1901), Thiel (1944, 1947) and Schwartz (1936). Goldich and others (1961) provide absolute age determination for some of the Precambrian rocks of this area.

The other geologic units shown on figure 4 have been tentatively identified on the basis of (1) their intrinsic geophysical properties and (2) their relation to the belt of middle Keweenawan lavas. Analogy with the structure of the Keweenawan basin of the Lake Superior region is an important element in the interpretation.

Two geologic units are shown on figure 4: (1) red to yellow sandstone of late Keweenawan or, less likely, Cambrian age; (2) mafic lavas flows of middle Keweenawan age, including some thin to thick units of sandstone or conglomerate.

Sandstone

A belt of "sandstone" is shown on each side of the belt of middle Keweenawan lavas. The main geophysical evidence for these belts is the gravity low associated with each; the gravity lows reach extremes that exceed -100 milligals in the western anomaly and -90 in the eastern. Magnetic contrasts are subdued in both areas.

Belts of red sandstone flank the main body of Keweenawan lavas in Michigan, Wisconsin, and Minnesota. In Michigan, the sandstone is the Jacobsville Sandstone, and in Wisconsin and Minnesota similar sandstone formations are known as the Hinckley and Fond du Lac Sandstones. These sandstones belong to the upper Keweenawan Bayfield group (Tyler and others, 1940). Where the relations are clear from surface geologic mapping, these belts of red sandstone have the form of asymmetrical troughs, fairly deep close to the lava flows and shallowing away from the lavas; the boundary between lavas and sandstones is ordinarily a fault boundary (e.g., the Keweenaw fault in Michigan, Douglass fault in Wisconsin). In these flanking troughs, the sandstone dips gently (generally less than 10°) toward the lavas, though it may be dragged up to the vertical, or even overturned adjacent to the fault boundary.

In central and southwestern Iowa, the magnetic map (figs. 2 and 2a) suggests that the northwestern boundary of the mafic lavas is abrupt and fairly straight. This boundary may well be a fault, comparable to the Douglass fault of Wisconsin and Minnesota. The southeastern boundary of the lavas appears to be more irregular, as discussed below, and locally, at least, may be an unconformity along which the flanking red sandstones overlap the mafic lavas.

Mafic lavas

The prominent positive gravity anomaly crossing the area from northeast to southwest (fig. 3), as interpreted here, is due to a geosyncline of Keweenawan mafic lavas. The lavas are more magnetic, on the average, than the other rocks of the area, and grossly the area of the gravity high is, therefore, also the area of a magnetic high. In detail, however, the magnetic map (fig. 2) shows great irregularity. Individual groups of lava flows differ appreciably in their magnetic attraction; contrasts of 1,000 gammas between contiguous groups of flows are common on aeromagnetic maps of the Keweenaw peninsula, which were flown at approximately 500 feet above the ground (Balsley, and others, 1963). There the lavas have appreciable dip, therefore, they are expressed magnetically as ridges and troughs. Many of these magnetic ridges and troughs are remarkably persistent, particularly close to the boundaries of the lava belt.

Closer to the center of the belt, however, the magnetic ridges are not so persistent, and the considerable irregularity of the pattern of magnetic highs and lows suggests that the broadly synclinal belt of lavas may actually have a complex internal structure, with many folds and faults.

The series of very prominent magnetic lows marking the western boundary of the belt of mafic lavas is interpreted as an "edge effect." Bath's study (1960) of aeromagnetic profiles, using measured magnetic properties of the rocks, has shown that such an effect exists along the western or northwestern margin of the Keweenawan lavas where the magnetic field is caused mostly by remanent magnetism (0.01 gauss) rather than by induction (0.002 gauss). Calculations for a model simulating the source of the Iowa anomaly, using approximately the same declination and dip assumed by Bath, demonstrates clearly that the west boundary of the mafic lavas occurs at the magnetic low. It is not necessary to attribute this marginal low entirely to the presence of nonmagnetic material, and, in fact, a low of this shape and magnitude would not exist here if the magnetic trough were simply underlain by nonmagnetic material.

The very prominent lows between longitudes $94^{\circ}45'$-$95^{\circ}15'$ and latitudes $41^{\circ}15'$-$41^{\circ}45'$ are less easy to interpret. The more southeasterly of the two larger magnetic troughs is too deep and sharply V-shaped in section to be attributable solely to a layer or syncline of nonmagnetic material, and is almost certainly mostly due to magnetic rock with polarity opposite to the normal polarity.

Whether such inverted polarity is due to tilting of mafic lavas with normal polarity, to the existence within the lava series of a group of flows with reversed polarity, or to the presence of mafic dike swarms with reversed polarity cannot be readily determined. It might be noted that in the Michigan Copper district, where at least 15,000 feet of northwesterly dipping lavas are exposed, extensive aeromagnetic and ground magnetic surveys have not revealed the presence of any groups of flows with reversed polarity. Where lavas dip steeply to the east or southeast, however, it is conceivable that the original attitude of dipoles is sufficiently rotated to produce negative anomalies instead of positive. The inclination of the average magnetic direction for middle Keweenawan lavas of Michigan, corrected for the tilt of strata, is 41°N. 78°W. (data of DuBois, 1957, <u>in</u> Cox and Doell, 1960, p. 688). Thus, eastward tilts of 45° or more could produce negative anomalies where a negligible fraction of the anomaly is due to induced magnetism; southeasterly or southward tilts would have to be somewhat larger to produce negative anomalies. Easterly or southeasterly tilting of the mafic lavas may, therefore, explain the strong sharp negative anomalies in the center of the mafic lava belt. It may also explain the northeast-trending negative anomaly at the eastern margin of the lava belt near the north edge of the map (Story and Hardin Counties); comparison of the gravity and magnetic maps suggest that this area of negative magnetic anomaly is underlain by mafic lava.

Sandstone or conglomerate

Three magnetically low areas along the axis of the lava geosyncline and similar areas near the geosyncline's borders are believed to mark areas where the lavas are covered by sandstone or conglomerate (see fig. 4).

The broad basinlike magnetic low centered in southwestern Hamilton Co. is thought to outline a dominantly clastic sequence that may be 4,000 - 5,000 feet thick. By analogy with the situation in Wisconsin and Michigan, these sedimentary rocks are probably equivalent to the lowermost rocks of the upper Keweenawan (Oronto group; Tyler and others, 1940), and would be older than the rocks in the troughs flanking the mafic lavas (Bayfield group of Tyler and others). Coons and others (1963) have analyzed gravity data for the midcontinent high in Iowa. Their study concludes also that a large basin of low-density clastics exists in the Hamilton Co. area. Cohen and Meyer's (1963) preliminary evaluation of a 1962 seismic investigation appears to further substantiate the presence of the postulated basin.

The sandstone or conglomerate area mapped near 41°00'N. lat in southwestern Iowa (Mills and Pottawattamie Cos.) is considered to have the thickest sedimentary section (6,000 + ft) found in any of the postulated "basins" within the lava terrane.

The long axes of these two basins cannot be reliably traced beyond the area shown as underlain by sedimentary rocks in figure 4, though synclinal axes have been projected for some distances. The long axes of magnetic highs and lows due to the mafic lavas generate patterns that could be interpreted as canoe-shaped folds, and this is the basis for the projections in figure 4; if the projections are correct, the axis of the northeastern (Hamilton County) basin (or syncline) passes northwest of the southwestern basin. The gravity map (fig. 3) suggests a similar *en echelon* arrangement of the axes of maximum gravity (equivalent to the maximum thickness of lava?).

An area between these two basins is shown as underlain by upper Keweenawan sedimentary rocks. Here, the average magnetic intensity is somewhat lower than in the surrounding areas, but the magnetic contours do not suggest the broad, strongly synclinal configuration of the basins to the north and south. The magnetic pattern indicates, instead, that a layer of sandstone and conglomerate, ranging from thin to perhaps 2,000 feet in thickness, lies between the Paleozoic rocks and the gently dipping mafic lavas. Magnetic evidence also implies that the rocks of this connecting area are somewhat broken by faulting.

The magnetic data likewise suggest that the map pattern of lava and overlying upper Keweenawan sandstone or conglomerate may be rather complex along the southeastern margin of the gravity high, although the pattern here is at least partially decipherable. In southwestern Dallas County and northwestern Boone County (94° W. and 42° N. to 94°25' W. and 41°40' N.), there is an area as much as 7 miles in width with a fairly uniform southeasterly gradient of 50 to 75 gammas per mile, which suggests that the top of the lava series here dips southeasterly beneath the overlying upper Keweenawan sediments. The rest of the interpretation of subsurface geology shown on figure 4 along the southeastern margin of the belt of lavas is a logical consequence of this relationship. The map suggests that the sedimentary rocks filling the Hamilton County basin are continuous with the filling of a narrower syncline to the southeast, and that the axis of this narrower syncline can be traced southwesterly almost to Longitude 95°; a fault, with upthrown side to the east, appears to slice across the synclinal axis from west side to east side as it is followed northeastward.

Major structural features of Paleozoic rocks

The best known major structural element in the Paleozoic rocks of southwestern Iowa is the Forest City basin. The geology of this downwarped area which includes adjacent parts of Missouri, Nebraska, and Kansas, is summarized by Lee and others (1946).

Perhaps the second most significant structural feature in the Paleozoic rocks of central and southwestern Iowa is the series of domes and anticlines aligned along what Hershey and others (1960) calls the Thurman-Redfield Structural Zone. The Iowa Geological Survey has traced the zone from where it enters the state near Thurman Co. through Redfield in Dallas County to northeastern Hardin Co.

All of the Thurman-Redfield Structural Zone either coincides with or closely parallels the postulated eastern boundary of the mafic lava syncline (see fig. 4). By extrapolation, this apparent correlation suggests that the structural zone probably continues further northeast than previously mapped. More importantly, although the domes and anticlines along the zone are not much broken by faulting, possible structural control from movement of basement rocks is indicated.

DEPTH CALCULATIONS

The magnetic contour map (fig. 2) and profiles from individual flight lines were examined for anomalies suitable for the determination of depths to the anomaly producing rock masses. Calculations were based on the method of Vacquier and others (1951, p. 9-41). Basic assumptions for this method are that the basement complex is not magnetically homogeneous but is divided into lithologic units with prescribed shapes. These shapes are considered to be prisms with horizontal rectangular surfaces, having vertical sides, and extending indefinitely downward. It is assumed, further, that the rocks are magnetized mainly by induction in the earth's field and that this magnetization is uniform and constant with depth. Other assumptions and calculation procedures are summarized by Henderson and Zietz (1958, p. 27).

Results for 12 depth determinations distributed throughout the survey area are given in table 1; location of points where depths were calculated is shown on figure 2. These depth estimates are in reasonable agreement with thickness of Paleozoic-Mesozoic sedimentary rocks known from the relatively few basement wells in the area. Calculated depths near Ames (at point 4, fig. 2) and near Dexter (point 7) reflect local interruptions to regional dip into the Forest City Basin. These interruptions are presumed to be associated with the Thurman-Redfield Structural Zone. Other possibly anomalous calculated depths were obtained at point 9 (near Oakland) and at point 12 (near Tabor).

Possible structural implications of these rather shallow estimated depths to basement are obscure. Both points lie between the Thurman-Redfield Structural Zone and the nearby Nemaha Anticline in Nebraska. Carlson's map (1961) shows major faulting along the eastern flank of the anticline with the block nearest Iowa upthrown by 1000-1500 feet.

Table 1 Estimated depths to rocks producing certain magnetic anomalies in central and southwestern Iowa

Ref. No. on Fig. 2	Located Near	Depth from ground surface (feet)
1	Gowrie	2850
2	Radcliffe	3100
3	Coon Rapids	3050
4	Ames	2800
5	Shelby	2300
6	Elk Horn	3200
7	Dexter	2950
8	Dumfries	1850
9	Oakland	2800
10	Cumberland	4200
11	Massena	4200
12	Tabor	2100

MAGNETIC AND GRAVITY PROFILES AND INFERRED GEOLOGIC SECTION

Figure 5 shows a geologic section in central Iowa as interpreted from observed gravity and magnetic data (location of the section is shown on fig. 4 as A-A'). Although not actually used in preparing this section, reasonable densities were assumed for the upper Keweenawan sandstone, the Keweenawan lava and the pre-Keweenawan rocks. These densities, 2.30 g per cm^3, 3.00 g per cm^3, and 2.70 g per cm^3, respectively, are similar to those measured by Craddock and others (1963) and Thiel (1956).

Various configurations of the Precambrian rocks were considered. The model shown in figure 5 would produce computed magnetic and gravity profiles which approximate the observed data. Faults were located from the magnetic profile shown on the figure.

ECONOMIC GEOLOGY

The interpretation of the aeromagnetic survey and lithologic control from drill holes into the basement complex indicate that the presence of rocks that in the Lake Superior region contain commercial deposits of copper. By analogy, the lavas here may contain concentrations of native copper, and if shales are present in the basins of upper Keweenawan rocks near the center of the lava geosyncline, these shales may contain copper sulfide. Only drilling would determine if such concentrations would be sufficiently high in grade to be mined at a profit, but the possibility exists.

Outside the area underlain by the Keweenawan lavas, there are no large anomalies such as would be expected over magnetic iron-formation, but the presence of nonmagnetic (hematitic) iron-formation is not precluded.

New exploration for oil and gas in central and southwestern Iowa may be justified if seismic methods or drilling should delineate favorable structures in the Paleozoic rocks overlying the basin areas postulated in this report. Also, additional drilling along the Thurman-Redfield Structural Zone and its presumed extension to the northeast may prove attractive. Drilling near Vincent in Webster Co. (N. of this report area) has confirmed the presence of a Paleozoic domal structure with more than one hundred feet of closure. Location of this feature in close proximity to the western boundary fault of the lava syncline and known faulting near Ft. Dodge suggests the possible existence of a western equivalent of the Thurman-Redfield Structural Zone.

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Dr. H. Garland Hershey, State Geologist of Iowa and Dr. Charles N. Brown, Assistant State Geologist of Iowa were most helpful in planning the aeromagnetic survey. They provided valuable access to State well logs and unpublished geologic data. Dr. George P. Woollard, Director of the Geophysical and Polar Research Center of the University of Wisconsin, generously permitted use of his organization's manuscript map for the preparation of figure 3.

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