MINNESOTA GEOLOGICAL SURVEY

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INTERPRETATION OF LAKE WASHINGTON MAGNETIC ANOMALY, MEEKER COUNTY, MINNESOTA

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MEEKER COUNTY
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ABSTRACT

A magnetic anomaly centered at Lake Washington, in southeastern Meeker County, has been outlined by a ground magnetometer survey. The anomaly is arcuate in outline, about 8.5 miles long and a maximum of 5 miles wide, and has a maximum amplitude greater than 3,000 gammas. A gravity traverse was made across the anomaly to aid in interpretation.

Combined magnetic and gravity data are interpreted to indicate that the source is a basin-shaped body having a substantially greater density than the adjacent rocks that lies at a shallow depth. The lithology of the source is not known because of a lack of subsurface data, but is inferred to be either Precambrian iron-formation or mafic igneous rock. The anomaly warrants further investigation.

INTRODUCTION

Ground magnetometer surveys of anomalies in south-central Minnesota, disclosed by airborne magnetometer traverses made by the United States Geological Survey in 1961, have been carried out by the Minnesota Geological Survey to aid in determining the sources. A U-shaped magnetic anomaly of possible economic interest near Hutchinson in northwestern McLeod County was described earlier (Sims and Austin, 1963). This report describes a second anomaly of potential interest located at Lake Washington in southeastern Meeker County, about 10 miles north of the Hutchinson anomaly. To assist in interpreting it a gravity profile was made over the anomaly.

The ground magnetometer survey was made by Austin in August, 1962, Barton Gross in August and September, 1962, and Austin and R. K. Hogberg in January, 1964. The gravity profile was made by Ikola and Sims in May, 1964; the gravity computations were made by Ikola. Isidore Zietz, William G. Joyner, and Gordon Bath critically read the manuscript.

The Lake Washington area, Meeker County, is in the Central Lowland physiographic province, adjacent to the Canadian shield in the Lake Superior region. The area is mantled by Pleistocene glacial materials to depths of 200 or more feet. The nearest exposures of Precambrian bedrock, which is the source of the anomalies, are in the vicinity of St. Cloud, about 30 miles to the north, and in the Minnesota River valley, about 50 miles to the southwest.

GEOLOGY

Knowledge of the bedrock geology in the vicinity of the Lake Washington anomaly is meager because of the thick, continuous mantle of Pleistocene glacial deposits that cover the underlying solid rock. Judging from available logs and samples of scattered water wells, a thin succession of Cretaceous sedimentary rocks lies immediately beneath the glacial drift throughout most of the area; these strata in turn probably lie directly on Precambrian rocks, without intervening Paleozoic rocks.

Cretaceous rocks have been encountered in deeper wells throughout all but the northwestern part of Meeker County (Thiel, 1944, p. 299; Sloan, 1964). However, because of the difficulty of distinguishing Cretaceous strata from the clays and sands of Pleistocene age, little is known of the thickness and lithology of the Cretaceous. A water well in Collinwood township, just north of Lake Jenny in the southeastern part of the county--which was drilled in 1956--penetrated 241 feet of blue, green, and brown shale with interbedded sand layers of probable Cretaceous age below 250 feet of Pleistocene clay and sand. The well bottomed in a water-bearing shale. A hole drilled near Pigeon Lake (fig. 1, hole 5) penetrated approximately 400 feet of Cretaceous blue and brown clay beneath 220 feet of glacial drift (Stauffer, C. R., written communication, 1929). The Cretaceous strata directly overlie Precambrian rocks.

Precambrian crystalline rocks have been penetrated by drilling at a few localities in Meeker County. The locations of seven holes reported to have reached Precambrian rocks are given in figure 1. Except for hole 5 (fig. 1), the locations of the holes are known accurately; the site of hole 5 was determined as accurately as possible from the description in the files of the well driller followed by inquiries of residents in the area. The depth to the basement rocks, the approximate altitude of the upper surface of the Precambrian rocks, and the described lithologies of the holes shown on figure 1 are listed in Table 1.

The available subsurface data indicate that the upper surface of the

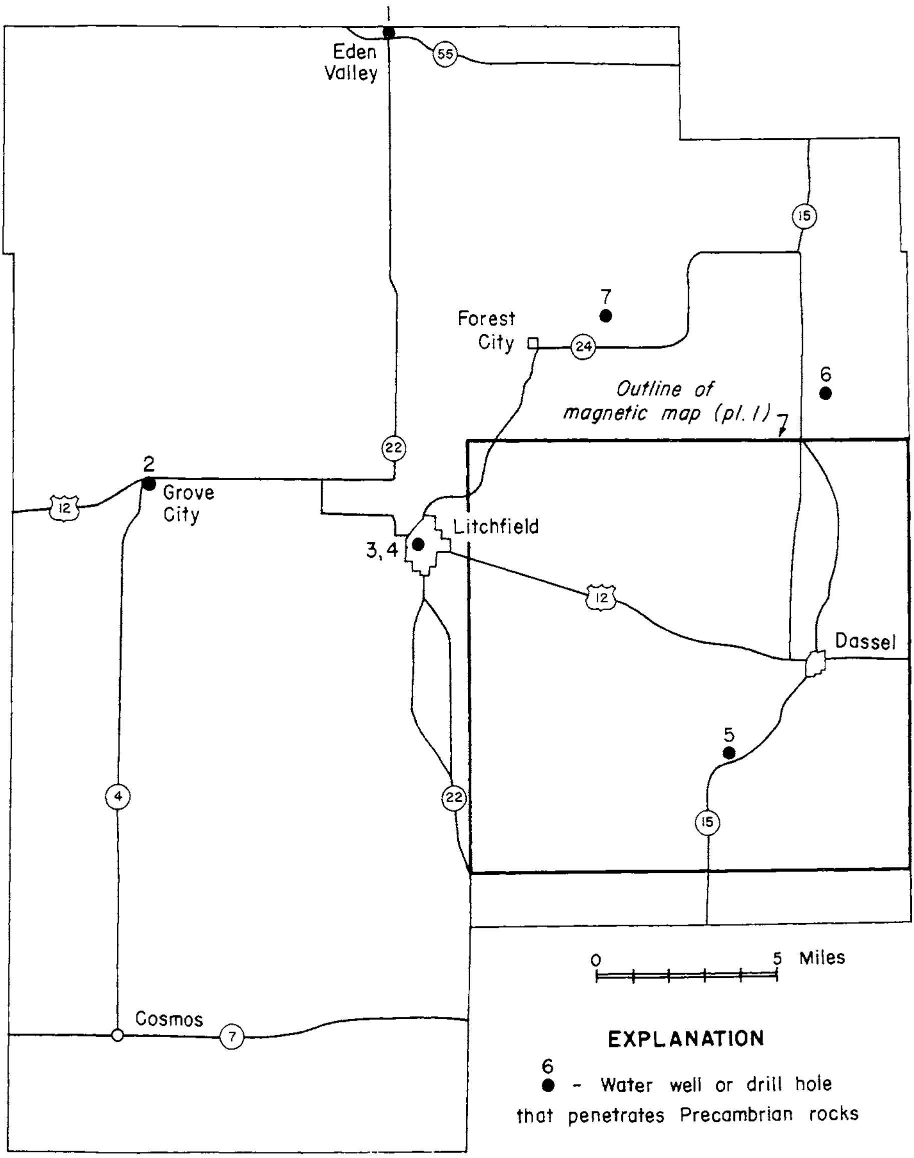

Figure 1--Index map of Meeker County, Minnesota

Precambrian rocks is somewhat irregular. Possibly well 2 (fig. 1) at Grove City and well 5 near Pigeon Lake are in a bedrock valley cut a considerable depth below the adjacent bedrock surface. The bedrock valley may enter southeastern Meeker County from McLeod County, extend northward to a latitude slightly north of Litchfield, then turn westward to pass through western Meeker County into the central part of Kandiyohi County. Data are not available to determine the width of the postulated buried valley.

Table 1--Wells that penetrate Precambrian rocks in Meeker County, Minnesota (Locations shown on figure 1)

No.	Location	Upper surface of Precambrian rocks		Lithology
		Depth (in feet)	Altitude (approximate)	
1.	Eden Valley	300	820	Biotite schist[1/]
2.	Grove City	530	660	-
3.	Litchfield	276	850	-
4.	Litchfield	283	845	-
5.	Near Pigeon Lake	620	500	Gneiss[2/]
6.	North of Dassel	240	850	Decomposed "granite"[3/]
7.	East of Forest City	212	908	-

1/ From notebook of C. W. Hall (about 1900)

2/ From notebook of C. R. Stauffer, 1929; refers only to uppermost 50 feet of the Precambrian rocks. Location of well is not accurately known.

3/ Reported by Thiel (1944, p. 301)

The lithologies of the Precambrian rocks in Meeker County are not accurately known except at the localities of holes 1 and 5 (see table 1). Drillers commonly report the first hard rock encountered as granite, and unless samples are saved and subsequently examined they are not accurately classified. The Precambrian rock from the interval 300-360 feet in well 1 at Eden Valley was described by C. W. Hall as biotite schist. This description is thought to be reliable; however, Thiel (1944, p. 302) reports the same interval in the well to consist of "granite rock." The gneiss from the uppermost 50 feet of hole 5 also is thought to be reported reliably, but because of the uncertainties in the exact location of the hole the information must be used with caution. Hole 5 is reported (McCarthy Well Company, oral communication, 1964) to have continued to a depth of 1,393 feet.

Any interpretation of the geology of the Precambrian rocks of Meeker County must be highly subjective, but is aided by the availability of a regional aeromagnetic map (Sims and Zietz, in press). We infer from the known presence of biotite schist in the well at Eden Valley, the geology of areas adjacent to the north, and the pattern of aeromagnetic anomalies that schist or related shaly sedimentary rocks constitute the Precambrian bedrock throughout much of the county. The areas inferred to be underlain by schist are characterized by a low magnetic background (see aeromagnetic map, Sims and Zietz, in press). Presumably the schist is roughly equivalent to the Animikian Thomson Formation (Goldich and others, 1961, p. 102-108) exposed near Little Falls, about 40 miles to the north of Meeker County; similar sedimentary rocks of lower metamorphic grade occur in the Cuyuna iron district (Schmidt, 1963). In Meeker County, scattered positive magnetic anomalies within the neutral background--as indicated by the regional aeromagnetic map (Sims and Zietz, in press)--could be caused by either intermediate to mafic intrusive rocks or magnetite-rich sedimentary rocks. One such anomaly is the Lake Washington anomaly.

MAGNETIC SURVEY

Method and Data

The ground magnetic survey of the Lake Washington anomaly was made with a Jalander magnetometer, which measures the vertical component of the earth's magnetic field. The general highway map of Meeker County was used as a base for field work, but the magnetic readings were replotted on the U. S. Geological Survey topographic map of the Dassel 15-minute quadrangle (pl. 1). The primary base station, located in an area of no anomaly, was established in McLeod County in NW1/4 NW1/4 SW1/4 sec. 36, T. 116 N., R. 30 W. A secondary base station was established in the Dassel area, in SW1/4 SW1/4 SE1/4 sec. 35, T. 119 N., R. 29 W., at a point 45 feet north of the warning sign at the intersection of Meeker County roads 208 and 211. Loop traverses were made from these stations. Readings were taken at 0.1 mile intervals along all roads within the anomalous area; a similar spacing between readings was used in traverses across the ice on Lake Washington. The error in the magnetic readings is less than 50 gammas and the error in location generally is less than 200 feet.

The magnetic data obtained during the survey are presented as a magnetic contour map (pl. 1). Readings made at the separate stations were plotted and lines were drawn to connect all points of the same magnetic intensity. The form of the resulting contour map reflects the geometrical configuration as well as local variations in the magnetization of the rocks underlying the area; the magnetic field of the earth is essentially uniform and is eliminated by use of a local base station located in an area of no anomaly.

Discussion of Magnetic Anomalies

The variations in magnetic intensity, or anomalies, shown on plate 1 reflect the inherent magnetic properties of the Precambrian basement rocks, for the sedimentary rocks and the unconsolidated glacial deposits that overlie the basement rocks are virtually nonmagnetic. Although the sources cannot be identified directly because of the absence of information regarding the composition of the basement rocks, they can be inferred with some degree of certainty by comparing actual anomalies with those obtained above known sources and by considering the general geologic framework. In the final analysis, however, buried sources can be identified definitely only by the drill.

It is known from airborne magnetometer surveying and analysis of magnetic anomalies, by Gordon Bath and others of the U. S. Geological Survey, that most Precambrian rock units in the State contain sufficient magnetite to yield magnetic anomalies. The actual anomaly recorded is mainly a function of magnetite content, the relation of induced to remanent magnetization, the geometric form of the source, and the distance from the point of measurement to the magnetic poles of the source. In general, the available data (Bath, 1962; Mooney and Bleifuss, 1953; Jahren, 1963) indicate that induced magnetization--which is related directly to the magnetite content of the rock--dominates the total magnetization of intrusive and metamorphic rocks of intermediate and felsic composition, whereas remanent magnetization is an important component of the total magnetization for iron-formations and igneous rocks of mafic composition. The slates and schists in the State are virtually nonmagnetic.

Analysis of airborne magnetic anomalies in areas within the State having abundant rock exposures (Gordon Bath and G. M. Schwartz, written communication, 1963) has emphasized the difficulty of distinguishing anomalies produced by iron-formation from those given by intrusive rocks of intermediate or mafic composition. Both types of rocks yield moderate to high anomalies, and lacking other information the sources cannot always be distinguished. Anomalies produced by the iron-formations of the Cuyuna district, in particular, are difficult to distinguish from intrusive igneous rocks. In general, though, iron-formations yield narrow, high-amplitude anomalies of greater linear continuity than intrusive rocks.

Lake Washington Anomaly

The Lake Washington anomaly has an arcuate outline and is about 8.5 miles long and a maximum of 5 miles wide. The maximum amplitude of the anomaly is in excess of 3,000 gammas. The highest magnetic readings lie within a relatively narrow U-shaped zone near the southern, eastern, and western margins of the anomaly. The maximum reading is above the western part of Lake Washington; similar "highs" occur in the keel and near the termination of the western leg of the "U". Amplitudes generally decrease northward, particularly on the eastern leg, and are moderately low in the inner part of the anomaly. A continuous "low" borders the western and southern parts of the anomaly, adjacent to the zone of maximum magnetic intensity.

Calculations of the maximum depth to the source were made at two localities by a half-width method described by Peters (1949). In sec. 36, T. 119 N., R. 30 W., at the "high" on the southwest side of the anomaly, the maximum depth is estimated to be 825 $\pm$ 200 feet. A calculated depth at the bottom of sec. 7, T. 118 N., R. 29 W., south of the main peak of the anomaly, is 650 $\pm$ 125 feet.

By comparison with known aeromagnetic anomalies in the State, the Lake Washington anomaly could be produced by either a relatively mafic igneous source or a magnetite-rich sedimentary rock. The aeromagnetic anomaly at Lake Washington has an amplitude of about 1,800 gammas. This exceeds the maximum aeromagnetic anomalies above the near-surface intermediate-composition intrusive rocks near St. Cloud by about 500 gammas (Sims and Zietz, in press); however, it accords with anomalies that might be expected above more mafic igneous sources. On the other hand, the anomaly is comparable but has somewhat smaller amplitudes than aeromagnetic anomalies above iron-formations in the Cuyuna district. Aeromagnetic anomalies above these iron-formations have amplitudes of as much as 4,000 gammas, but many are approximately 2,000 gammas (see published aeromagnetic maps of northern Minnesota; Bath, 1962, p. 628).

The arcuate outline of the ground magnetic anomaly (pl. 1) can be interpreted to indicate that the source is either a folded basin-shaped body or a steep-walled pluton of intrusive igneous rock having irregular magnetization. An interpretation of a basin-shaped body is favored by the U-shaped belt of magnetic "highs" around the periphery of the anomaly and by the steeper magnetic gradients locally present along the outer margins. The anomaly could overlie a nearly closed basin or a northward-plunging syncline, the keel of which is occupied by relatively non-magnetic rocks. With this hypothesis, irregularities in the anomaly, particularly above the southeastern margin, might represent either minor drag(?) folds along the limbs of the magnetic unit or local differences in the degree of oxidation of magnetite. The folded rock unit could be either an iron-formation (or less likely a magnetic schist) or a nearly conformable igneous rock. The alternative interpretation of a steep-walled irregularly magnetized igneous source is supported by the presence of large irregularly magnetized plutons of intermediate composition in the St. Cloud area (Sims and Zietz, in press). Also, if hole 5 (fig. 1) is located accurately, gneiss should underlie the southern margin of the Lake Washington anomaly.

GRAVITY SURVEY

Observations and Reduction

A gravity traverse across the Lake Washington anomaly was made with Worden gravity meter No. 76 to aid in interpreting the anomaly. Observations at 500-foot intervals were taken along the Great Northern Railway tracks from the vicinity of Lake Darwin to Dassel. Wider spaced observations were extended for 3-4 miles beyond to determine the regional gravity gradient. Vertical control was determined by leveling to an accuracy of about a tenth of a foot for the readings between Lake Darwin and Dassel; for the wider-spaced readings, altitudes were determined from the U. S. Geological Survey Dassel 15-minute topographic quadrangle. Horizontal control was established from the Dassel quadrangle.

The observed readings were corrected for instrumental drift, altitude and latitude, and the residual values were plotted as a profile (figs. 2 and 3). The reference datum for the altitude correction is sea level; an assumed density of 2.67 g/cm^3 was used for the rock between the station and sea level. Latitude corrections were made by assuming a uniform gravity gradient throughout the area under study. Absolute values of gravity were not obtained, and no corrections were applied for terrain effects.

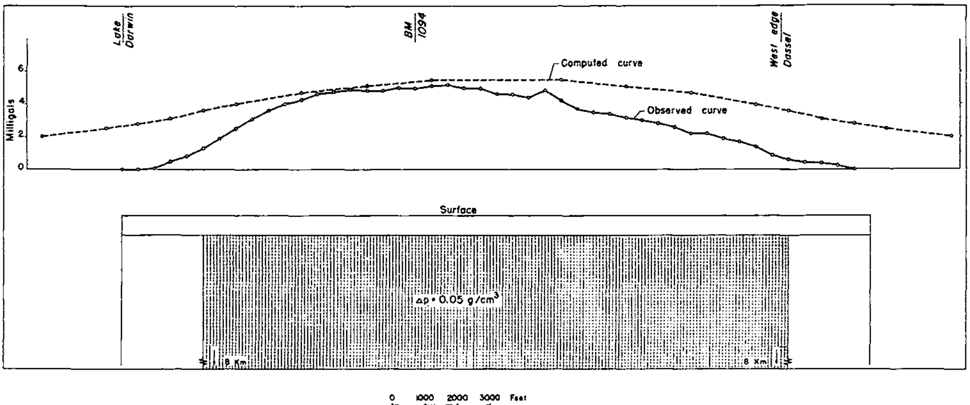

Figure 2--Residual gravity curves and geologic section for assumption of steep-walled igneous pluton.

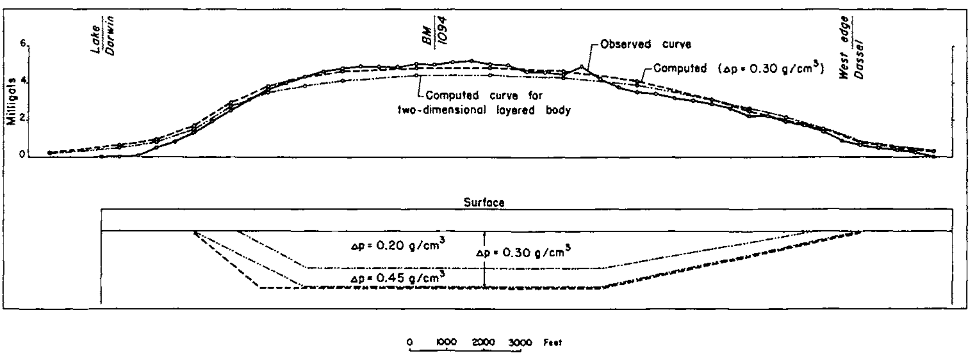

Figure 3--Residual gravity curves and geologic section for assumption of basin-shaped body of sedimentary or igneous rocks.

Interpretation

The residual gravity profile indicates a positive gravity anomaly of about 5 mgals that coincides in position with the magnetic anomaly at Lake Washington (figs. 2 and 3). This feature cannot be accounted for by strata that overlies the Precambrian surface and must be related to the mass distributions in the Precambrian rocks.

To test the two possible types of sources inferred from analysis of the magnetic data, curves were calculated for (1) a vertical-walled igneous pluton and (2) a basin-shaped layered body. The position of the geologic contacts was inferred from the magnetic data to coincide with the steep gradient at the margins of the anomaly. The gravity attraction of the different structures was computed for bodies of varying density contrast and depth, using a program developed by Talwani and others (1959); the results of selected computations are shown in figures 2 and 3. The vertical and horizontal scales are equal on figures 2 and 3. Calculations were made on a C.D.C. 1604 digital computer at the University of Minnesota. End corrections (Nettleton, 1940) were applied in a few cases, but the assumption of two-dimensional structure has little effect on the shape of the gravity profile.

Computed residual gravity curves for the first assumption--a vertical-walled plug-like body of rock having a density greater than the surrounding rocks--do not fit the observed curve. Computed curves for varying density contrasts and depths are all flatter than the observed curve, and are much too high along the margins. Figure 2 is based on an assumed density contrast of 0.05 g/cm^3, which is geologically feasible, and a depth of 8 kms. If the contact of the source is assumed to slope outward, the fit would still be worse.

The second assumption (fig. 3)--for a basin-shaped layered body--provides the best fit for the observed profile. Several curves were calculated for inward-dipping bodies of varying density contrasts and thicknesses, and each fits the general form and amplitude of the observed profile. Two of the calculated curves are shown in figure 3. One curve is for a basin-shaped mass having a density contrast of 0.3 g/cm^3; the other is for a two-dimensional layered body, the lower one having a density contrast of 0.45 g/cm^3 and the upper one a density contrast of 0.20 g/cm^3. Because of the ambiguity of gravity interpretations, a unique solution of density contrast and thicknesses of units is not possible.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded from combined magnetic and gravity data that the Lake Washington anomaly overlies a basin-shaped magnetic unit that has a substantially greater density than the adjacent rock strata. Two rock types best fit the limitations imposed by the magnetic and gravity data--a sedimentary iron-formation and an intermediate or mafic igneous rock.

An iron-formation of Cuyuna type or a related dense sedimentary rock is considered the most probable source for the anomaly. The magnetic anomaly is comparable to anomalies found in the Cuyuna district. Also, if the adjacent rock is biotite schist or a similar rock, as inferred from regional geologic relations, iron-formation can account for the density contrast required to explain the gravity data. Although specific measurements of densities are not available because of the complete lack of subsurface samples, an iron-formation can be presumed to have an average density at least 0.3 g/cm^3 greater than schist. A possible interpretation is that the anomaly represents a synclinal body of iron-formation overlain and underlain by less dense sedimentary rocks; perhaps a ferruginous sedimentary rock of an intermediate density contrast overlies the iron-formation--an interpretation compatible with one of the assumptions shown in figure 3. Such an interpretation is consistent with observations in the Cuyuna district that positive gravity anomalies are associated with synclinal structures (Durfee, 1957); the iron-formation in the synclines is substantially more dense than the stratigraphically lower schists and quartzites.

A relatively mafic igneous rock source could also account for the anomaly. Rocks of dioritic or gabbroic composition yield magnetic anomalies of approximately the magnitude of the Lake Washington anomaly, and several examples can be seen on the published aeromagnetic maps of northern Minnesota. To satisfy the mass distributions required for the assumption of a basin-shaped body (fig. 3), however, the igneous rock body would need to be a few thousand feet thick assuming a density contrast of about 0.2 g/cm^3, which is near the maximum contrast to be expected for a diorite-gabbro and a biotite schist. Bodies of such structure and thickness are geologically possible, but are not known in nearby exposed areas in east-central Minnesota. Possibly the Cedar Mountain Complex of the Minnesota River valley (Goldich and others, 1961, p. 131-132) is a body of the type that would yield magnetic and gravity anomalies similar to the Lake Washington anomaly, but it appears to be much steeper-walled than the inferred source at Lake Washington.

The possibility of the Lake Washington anomaly being an iron-formation is sufficiently promising to warrant exploration. The depth to the source is estimated to be in the range 600 to 700 feet. The major target, to judge from the magnetic data, would be the southern part of the anomaly.

REFERENCES CITED

Bath, Gordon, 1962, Magnetic anomalies and magnetizations in the Biwabik Iron-formation, Mesabi area, Minnesota: Geophysics, v. 27, p. 627-650.

Durfee, G. A., 1957, A regional gravity study of the Cuyuna iron range, Minnesota: U. S. Geol. Survey Open-file Rept., 27 p.

Goldich, S. S., Nier, A. O., Baadsgaard, Halfdan, Hoffman, J. H., and Krueger, H. W., 1961, The Precambrian geology and geochronology of Minnesota: Minn. Geol. Survey Bull. 41, 193 p.

Jahren, C. E., 1963, Magnetic susceptibility of bedded iron-formation: Geophysics, v. 28, p. 756-766.

Mooney, H. M., and Bleifuss, R. L., 1953, Magnetic susceptibility measurements in Minnesota--Pt. 2, Analysis of field results: Geophysics, v. 18, p. 383-393.

Nettleton, L. L., 1940, Geophysical prospecting for oil: McGraw-Hill Book Company, 444 p.

Peters, L. J., 1949, The direct approach to magnetic interpretation and its practical applications: Geophysics, v. 14, p. 290-320.

Schmidt, R. G., 1963, Geology and ore deposits of the Cuyuna North Range, Minnesota: U. S. Geol. Survey Prof. Paper 407, 196 p.

Sims, P. K., and Austin, G. S., 1963, Geologic interpretation of magnetic map of McLeod County, Minnesota: Minn. Geol. Survey Rept. Inv. 1, 7 p.

__________, and Zietz, Isidore, Interpretation of the aeromagnetic map of east-central Minnesota: U. S. Geol. Survey Geophysical Map GP (in press).

Sloan, R. E., 1964, The Cretaceous System in Minnesota: Minn. Geol. Survey Rept. Inv. 5, 64 p.

Talwani, M., Worzel, J. L., and Landisman, M., 1959, Rapid gravity computations for two-dimensional bodies with application to the Mendocino fracture zone: Jour. Geophys. Res., v. 64, p. 49-59.

Thiel, G. A., 1944, The geology and underground waters of southern Minnesota: Minn. Geol. Survey Bull. 31, 506 p.