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***Geomagnetics and Geologic Interpretation
of a Map of Eastern Bonner County***

by

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GEOMAGNETICS AND GEOLOGY

That the earth is like a weak, natural magnet has been known as a fact for several centuries and has been exploited by explorers, map makers, and mariners. The reasons for the earth's magnetic phenomena are not fully comprehended, but its magnetism has been generally thought to be related to the planet's composition and motion in space. Recent research with ionized gases (plasmas) leads one to speculate that ionization within or without the earth, or both, may produce its natural magnetic field.

If the earth were a perfect sphere composed of a homogenous substance, its "normal" lines of magnetic force could be accurately calculated. Just as lines of magnetic force orient themselves in predictable arcs around a set of positive and negative poles in a simple bar magnet (demonstrable with iron filings), so the earth's lines of magnetic force could be expected to follow the normal paths from positive to negative poles for a nearly spherical body.

Because the earth is neither a perfect sphere, nor composed of homogenous material, its recorded magnetic intensities vary from place to place. The earth's magnetic poles behave as if they were located below its surface but were several miles away from its true geographic poles. Lines of magnetic force are directed straight towards the center of the earth at the north magnetic pole and straight away from the earth at the south magnetic pole (Figure 1). At the magnetic equator, lines of magnetic force are nearly horizontal (parallel) to the earth's surface. These facts explain why magnetic lines of force deviate differently from the horizontal in different latitudes. Such variations must be taken into consideration in geomagnetic studies.

The discovery that a magnetized needle would align itself parallel to the lines of the earth's magnetic field--dipping at the angle approximate to the latitude--led to the invention and uses of the compass. The normal compass needle must be weighted to compensate for the vertical magnetic force component, which increases toward higher latitudes; the weight serves to keep the needle horizontal. Uncompensated for such changes, a magnetized needle becomes a "dip needle;" that is, it tends to parallel and align itself with the "dipping" lines of magnetic force except at the magnetic equator where the vertical force is nil. The various components of force represented by the earth's magnetic field are shown in Figure 2.

The dip needle has been used for many years as a fairly effective device for locating certain types of iron ore in the earth's crust. Such an ore body will produce a

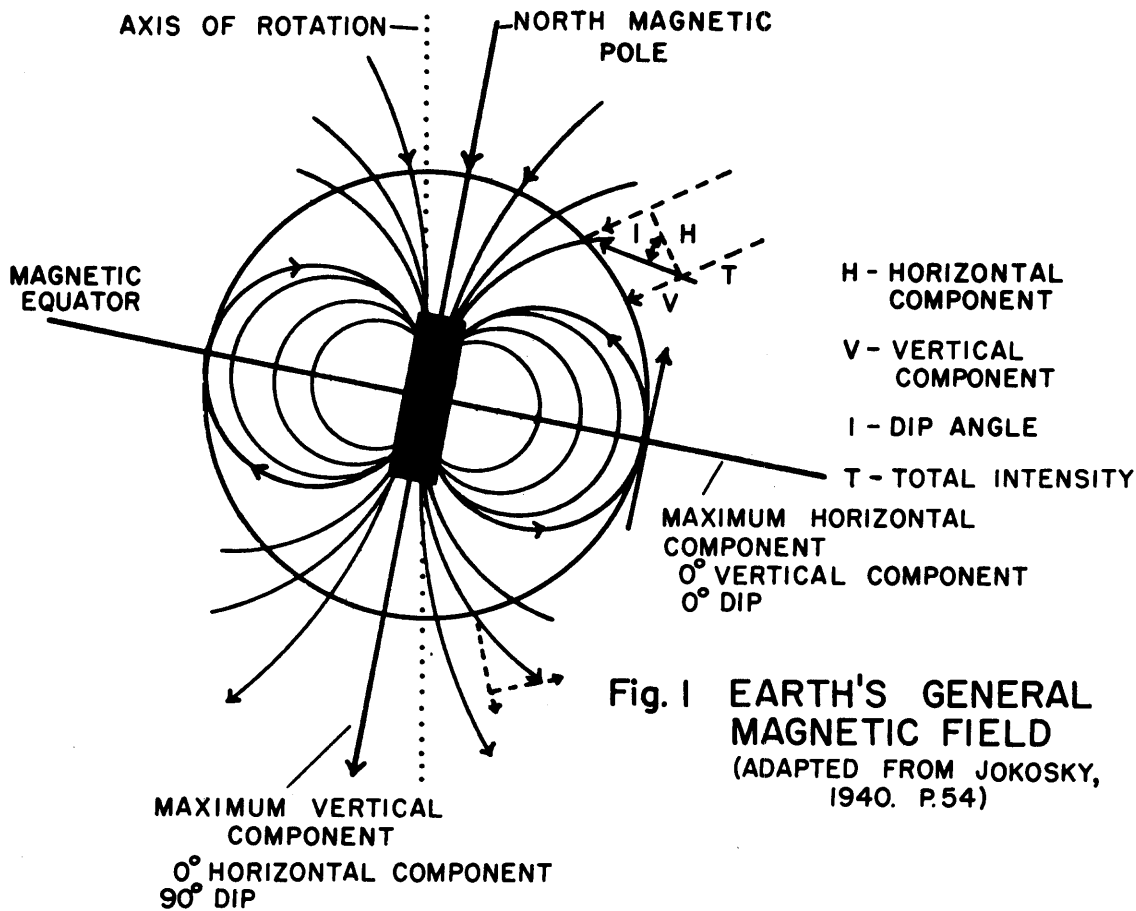
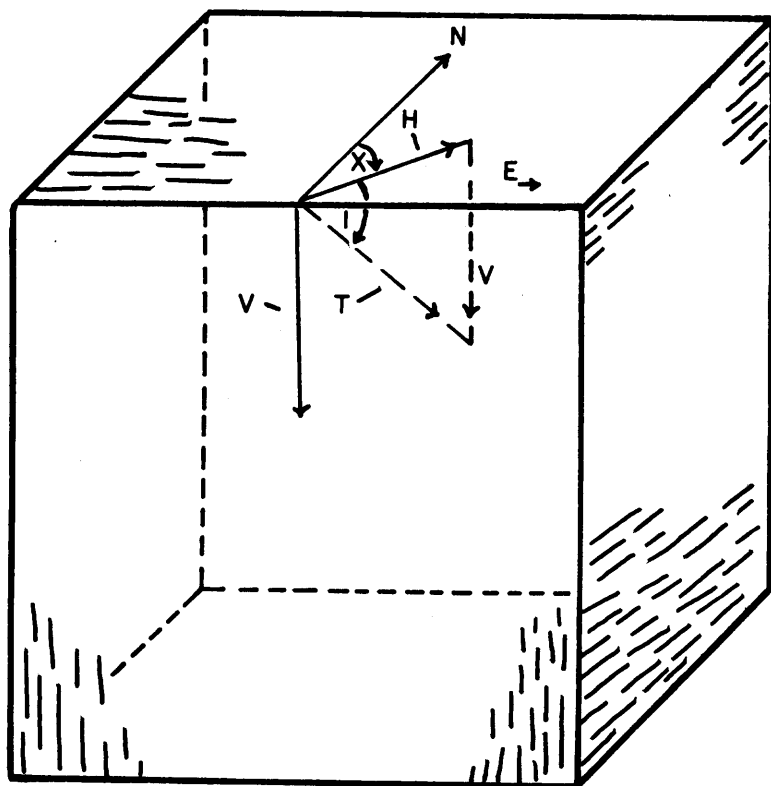


Fig. 1 EARTH'S GENERAL MAGNETIC FIELD
 (ADAPTED FROM JOKOSKY, 1940. P.54)

Fig. 2 DIAGRAMMATIC SECTION OF VECTORS IN EARTH'S MAGNETIC FIELD



- N - GEOGRAPHIC NORTH
- H - HORIZONTAL COMPONENT
- X - MAGNETIC VARIATION
- E - GEOGRAPHIC EAST
- I - DIP ANGLE
- V - VERTICAL COMPONENT
- T - TOTAL INTENSITY

variation (anomaly) in the earth's normal magnetic field, for example, and will produce its own local lines of magnetic force. Because this type of anomaly is usually readily detectable, the search for magnetic iron ore with the dip needle is one of the oldest applications of geophysics to geological problems.

Geomagnetic studies as they relate to geology are important. Of the considerable literature available on this subject some outstanding publications are mentioned later as well as included under "References Cited." From the geological standpoint, we now know that recorded variants in the earth's normal field are produced principally by the presence and attitudes of mineral-bearing rocks and rocky materials (including ore deposits), whose different degrees of magnetic susceptibility cause these variants.

In more recent years the study of geomagnetics has brought about more refined instruments which in turn have made it possible to measure quite accurately variations (anomalies) in the assumed normal magnetic field of our earth.

Ramberg (1961, p. 915) opined that magnetic exploration is more important in the geologic search for ore deposits than are other geophysical methods, such as gravitational and seismological techniques. Because the geologist working in geomagnetics attempts to use magnetic data in geologic mapping, he may indirectly therefore locate economically valuable ore deposits.

Our present knowledge and instrumentation permit reasonably accurate measurements of magnetic anomalies; however, our present ability to translate these data into sound geological information is still in its infancy. Useful techniques, whose interpretation is often mathematically complex, still remain largely empirical during field study. Thus magnetic methods of prospecting must today be considered only a reconnaissance technique, a means of delimiting potential areas of economically valuable mineralization.

No magic formula exists for successful magnetic prospecting. Profitable use of geomagnetics depends upon the availability of basic geologic field data from the area being studied, as well as the prospector's skill and experience in the interpretation of magnetic measurements. Future success in the use of geomagnetics in geology and mining will continue to depend upon corrected and reliable magnetic data given to the field geologist by the geophysicist, on intelligent interpretation of these data by the geologist, and on collaboration on the final conclusions by both specialists.

MEASUREMENT OF MAGNETIC ANOMALIES

Definitions and units

Magnetic mapping consists of instrument measurements of the strength of the earth's magnetic field recorded above the earth's surface either intermittently or continuously. The unit of measurement of the intensity of a magnetic field is usually called the oersted (sometimes gauss), but because of the relatively weak field involved in magnetic

prospecting, the unit of measurement is called the gamma. The gamma is equivalent to $\frac{1}{100,000}$ or 10^{-5} oersted. For comparative purposes, it may be noted that the strength of the earth's normal magnetic field in the United States varies from 0.4 to 0.6, or approximately 0.5 oersted (50,000 gammas): thus the gamma is about $\frac{1}{50,000}$ of the earth's field.

Rocks or rock materials (including minerals) in the earth's crust, may, like metals, have variable magnetic qualities or susceptibilities. A vacuum (free space) is considered to be truly non-magnetic. Paramagnetic substances have a permeability relative to that of a vacuum that is slightly greater than unity. Diamagnetic substances have a permeability relative to that of a vacuum that is slightly less than unity; these diamagnetic materials tend to decrease normal magnetic forces, and such substances are repelled by a magnetic field. Ferromagnetic substances have permeabilities relative to that of a vacuum that are much greater than unity; in the case of such ferromagnetics as alloys of iron, nickel, and cobalt, the term "permanent magnet" may be applied.

Locally the earth's general magnetic field varies for many reasons. Among these are the combination of slowly shifting (secular) variations in the normal polarized sphere, and relatively small diurnal variations. Or minor magnetic variations, which may be caused by changes in the magnetic permeability of rocks and rock materials in the earth's crust, modify, or may be said to be imposed upon, the normal field. Moreover, major magnetic variations may be caused by sudden changes in the ionization of the upper atmosphere: magnetic storms may interfere with the proper collection of magnetic data for a few hours or even for one or two days. Furthermore, remanent magnetism or paleomagnetism may significantly affect magnetic surveys, although at present, such magnetism is generally ignored because of our lack of knowledge of its effects. Not fully understood, remanent magnetism is probably the effect of magnetism induced in the rocks when the magnetic poles were at different locations during some past geologic age. For example, igneous rocks, upon cooling below a certain temperature, tend to retain the magnetism imposed upon them by the existing magnetic field while they were fluid. Under certain conditions ferromagnetic particles in sedimentary rocks may have had their axes aligned with the magnetic field existing at the time of their deposition.

Instruments and types of survey

Detailed description of the construction and use of magnetic instruments, as well as discussions of geomagnetics, is adequately covered by a number of publications including Nettleton, 1940; Haun, J. D. and LeRoy, L. W., 1958; Runcorn, S. K., 1960; Jakosky, 1960; Heiland, 1940; Peters, 1949; and Dobrin, 1960. The Schmidt type magnetometer or variometer is most commonly used for ground measurements of magnetic variations. Inductive instruments--those equipped with a power transmitter and receiver--have been used with some degree of success. Ground surveys may measure both vertical

and horizontal magnetic components (Figure 2), depending upon the survey requirements and type of instrument used. Continued improvement of aeromagnetic techniques, including better methods for locating the airplane and for computing the acquired data, has probably accomplished reasonably reliable results.

Among the accomplishments of the airborne survey are greater speed and coverage in mapping (from 500 to 1,000 miles of traverse per day); and greater accuracy than with ground measurements because (1) near-surface noise and artificial disturbances (such as pipelines, transmission lines, railroads, etc.) are all but eliminated, (2) swamps, vegetation, water, etc. are no obstacle to air surveying, and (3) the airborne magnetometer measures total magnetic intensity instead of only horizontal or vertical components. Also desirable are the greater detail achieved by airborne surveys from continuous profiling of variations instead of station-by-station recording, and the general overall economy of the airborne method.

Because magnetometers record relative instead of absolute data, in any type of survey, several corrections have to be applied to readings after they are obtained. Accuracy up to 1 or 2 gammas is now possible with better type of instruments. Yet, the ground type magnetometer has been refined to the point where meaningless local disturbances are picked up, and greater refinements in this direction seem improbable.

Most magnetometers now in use measure directly in the earth's primary magnetic field the changes that are the result of varying conductivities in the rock and rock materials of the crust. This measurement is the fundamental objective of the instruments and of the magnetic survey at present.

COMPILATION OF MAP DATA

After magnetic data have been collected (either by a ground or airplane survey) a number of corrections, including those for temperature and diurnal variations must be made before the resultant values are properly located on map stations. Corrections by reference to published charts of such variations must also be made for terrestrial regional change in vertical intensity. After the geophysicist has applied all his corrections to each station, he uses the resulting figures to establish contours on a map of the area surveyed; that is, equal anomalies are connected by lines called isanomalies (or isonomalies). After these contour-like lines, which represent local variations (in gammas) from the average total magnetic intensities in the area have been entered, the map is ready for geological interpretations. These data, however, are only as reliable as the degree of accuracy with which they are plotted on a good base map of the region under study.

INTERPRETATION OF MAGNETIC DATA

Magnetic characteristics of rocks and minerals

Rock types are major influences causing magnetic anomalies; particularly mafic or ferromagnesian-rich ("basic") igneous rocks seem to show the highest magnetic susceptibilities. As silica content increases--as in granitic rocks ("acid")--susceptibilities fall. In sedimentary and metamorphic rocks magnetic susceptibilities are probably related almost entirely to the magnetite content; susceptibility of these rocks to magnetism is lowest among the rock types because their magnetite content is low. In the final analysis, probably all three great rock groups--igneous, sedimentary, and metamorphic--produce local anomalies based upon the shape, size, and distribution of the portions of their rocks that are richest in magnetite concentrations.

The area and extent of general rock types interpreted from magnetic anomaly maps may depend upon relative differences in the magnetic susceptibility of igneous rocks as opposed to sedimentary rocks, metamorphic rocks as opposed to sedimentary rocks, or of any combination of variations in facies within the great rock groups. For example, granitic plutons in association with sandstones and shales may cause magnetic highs over the location of the plutons.

Some highly magnetic ore bodies may be expected to produce large anomalies, while granite, basalt, and gabbro may influence the earth's magnetic field even under great depths of sedimentary rocks or other cover. Most rocks lose magnetic susceptibility around 13 miles in depth (a temperature relation: the "Curie point"). Vacquier (1951, p. 3-4) says that studies of rock and rock materials suggest that nearly all large magnetic anomalies are deep-seated.

Some investigators determine in a laboratory the magnetic susceptibility of rock types in a given region. This technique, they assume, makes it possible to develop more accurate quantitative interpretations; however, other investigators question such an assumption, charging that laboratory methods are inadequate to duplicate the natural conditions under which the rocks undergo magnetic changes.

In the past, good results have been obtained by magnetic surveys where Precambrian gold-pyrrhotite and copper-pyrrhotite bodies exist, and where the magmatic segregation type of nickel-cobalt-copper and iron ore bodies is located. Even chromite and some base metals may exhibit magnetic susceptibilities where minute particles of magnetite are mixed with these metals (W. W. Staley, Oral communication, 1962). Such successes have encouraged further research and development in geomagnetics as a prospecting tool.

The effects of natural concentrations of heavy minerals in sedimentary and meta-sedimentary rocks by normal geologic processes, like stream, wind, and wave action, are not well known. In the past, gold and magnetite in placers have been successfully

located by magnetic methods (Dobrin, 1960, p. 316-317). Possibly in some cases, localization of ferromagnetic minerals (particularly magnetite) in sedimentary and metamorphic rocks, could produce measurable magnetic anomalies. In other cases the effects produced might be too small to show up among the major anomalies. However, one should always look for, and check, minor deviations in the general pattern of anomalies.

Basement configuration concepts

Scientists working with geomagnetics in general seem to concur with Russell's (1960, p. 386) opinion that the effect of "basement rocks" (crystalline) on the earth's magnetic field is very important. For example, when these crystalline rocks are within 5 to 6 thousand feet or less from the surface, a magnetic isanomaly map may represent the configuration of the "basement" surface. More likely, however, as Vacquier and others (1951, p. 8) have suggested, more magnetic anomalies are produced by buried lithologic rock types than by topography of the basement rock alone. Reflection of basement topography and rock structure is probably incidental to the effects of the mineral content of rock types. Possibly the approximate depth to the top of the basement complex can be determined by analyzing the magnitude of the anomalies in a specific area (Vacquier and others, 1951, p. 15-18).

Where sedimentary rocks are thick, even when these materials are Precambrian in age, magnetic anomalies tend to reflect the surfaces of local intrusive igneous rocks, probably because the igneous rocks normally have a higher magnetite content than the sedimentary or even some metamorphic rocks.

Russell (1960, p. 388-389) says that the width of the magnetic object producing an anomaly is related to its depth beneath the surface of the earth. Furthermore that depth may be assumed to be related to the distance between the points where the strength of the magnetic field is equal to half the maximum variation (height) of the anomaly. One finds this half-height by determining half the difference between the average magnetic reading in the area and the highest recorded figure in the anomaly. It has been determined that the depth of a magnetically susceptible body may vary from 0.65 to 1.0 times its width. Such calculations are only approximately reliable; for example, a broad anomaly might result from the presence of a variable at considerable depth or from a thin, wide layer (like lake sediments, glacial fill, etc.) at shallow depth. In any case, the relative relief of many isanomaly maps is probably determined by depth, shape, and size of buried plutons and by faulting.

Magnetic maps seem to show broader, less sharp anomalies when the anomalies originate at depth or when the area of a buried crystalline complex is regional rather than local. Steep anomalies suggest smaller areas of buried crystalline bodies, or crystalline bodies that are near to the surface.

Regional gradient and shift of axis

Regional variations in gradient are noted on magnetic maps and may be the result of a number of influences. The principal larger variations normally reflect changes in vertical lines of magnetic force incident to the latitude of the area. In the United States regional gradient tends to increase toward the north. In order that the possibility of confusion be eliminated, the regional gradient may be removed from a finished isanomaly map.

In some cases investigators have noted a somewhat confusing lateral shift of the center of a magnetic anomaly away from the known location of the axis of the effective structure or surface producing the anomaly. In the United States this shift tends to be toward the south, or slightly to the southwest. Possibly the earth's rotation may effect this axis shift.

Structural interpretation

Vacquier and others (1951, p. 1) noted that if applied correctly, interpretations of magnetic anomalies may yield information on (1) maximum depth of sedimentary cover; (2) location of rock contacts, including faults; and (3) locations of probable areas of differentiation and of mineralization when a locality is underlain by igneous rocks.

They further suggested that an isanomaly map may show the "grain," that is, reflect the structural history of a particular region.

As was emphasized earlier, one must have available considerable geological knowledge of the region before he attempts to interpret geologic structure from recorded anomalies. For example, the actual strike of buried structures or bodies may frequently differ from the strike of anomaly contours. This discrepancy could be very confusing and result in errors of interpretation.

When contours on isanomaly maps are steep, the contacts that account for such anomalies are between buried rock facies near the surface. On the other hand, less steep contours may result from deeper burial of such contacts.

Vertical contacts between rock types may account for steep contours on a map. Gently dipping contacts on the other hand, may account for gentle sloping contours.

When two different rock facies are brought opposite each other by faulting, this contraposition may produce observable effects in the steepness or shape, or both, of isanomalies. This case and those above depend largely on the difference in magnetic susceptibility of the rock facies involved.

If sedimentary materials contain sufficient magnetic qualities or are locally magnetically susceptible, the trend of any folding or faulting may show up in the trend of mag-

netic contours. Or insufficient magnetic susceptibility may also affect the contour pattern. For example, moderately deep limestone, dolomite, anhydrite, gypsum, or salt, with a clastic cover may produce interesting negative anomalies over anticlines in the northern latitudes. Where chemical precipitates and evaporates are at the surface, and clastic rocks are beneath, positive anomalies may be formed over an anticline.

Russell (1960, p. 388) underscored the importance of recognizing smaller effects produced by magnetic anomalies. These minor variations might be very important but could be nearly masked out by a more effective influence of basement configuration or by distribution of rock types with high magnetic susceptibilities as has been suggested.

Hydrothermal alteration

According to Herness (1955), field and laboratory research has proved that magnetic lows are produced by hydrothermal alteration. In his opinion, these lows have been brought about by hydrothermal alteration of magnetite and "other changes" produced by ascending hydrothermal solutions. He also concluded that pyrometamorphism may play an important role in the development of magnetic anomalies. Thus any tendency toward depletion of magnetite during the hydrothermal process might be reflected in negative anomalies, which, if properly interpreted, could result in the discovery of base metals, and other ore types, emplaced at the same time as the alteration.

Herness (p. 56) concluded that hydrothermal solutions migrate into structural closures presumably formed by anticlines, monoclines, faults, fissures, etc., and that magnetite content is destroyed or, in general, iron-abstracted. Therefore, structural contour maps supplement isanomaly maps as an invaluable aid to the proper identification of hydrothermally altered areas. Structural highs tend to produce positive anomalies except where hydrothermal alteration has destroyed the magnetite content of local rock. Precambrian mineralized areas in this category, however, have been observed frequently with magnetic highs instead of lows.

Artificial anomalies

One should keep in mind that old well casings, buried cables, pipelines, overhead power lines, railroad tracks and other objects may set up small local magnetic anomalies. Ground surveys are particularly susceptible to these disturbing influences, while aerial surveys are affected only slightly, if at all, by them.

GENERAL APPLICATION

If sufficient geological data are available in a specific area and if the effect of a basement complex can be partially eliminated, then isanomaly maps may be very useful in determining the trend of structures and in locating areas where ores may have been deposited. However, because of what Nettleton (1940) calls the "ambiguity of magnetic interpretation" geologic interpretation in geomagnetics still lacks definiteness and accuracy. If this type of survey suggests potentially mineralized areas, other criteria--particularly ground geological information--should be obtained before any decision is made to drill in an area indicated by an anomaly.

Vacquier and others (1959) have devised methods of interpreting magnetic surveys, which are based upon comparison of recorded anomalies with the computed patterns of ideal magnetic bodies. These methods involve mathematical computations, but also assume optimum conditions; however, such methods should still prove valuable in their application.

In practice, a few famous ore bodies have showed up as prominent magnetic anomalies when they were surveyed. The ore body at Kiruna, Sweden, is an example. The Beckham County fault in Wheeler County, Texas, (LeRoy, 1950, p. 1055) is another example. The magnetic deposit at Marmora, Ontario is a classic example. The presence of this body was unknown until it was discovered by a magnetic survey flown 500 feet above the terrain. A large tonnage of commercial grade magnetite coincided in location with a major anomaly. Because of its geological setting, however, this body would never have been revealed by field work.

On the other hand, major magnetic anomalies, upon further investigation, have failed to reveal any connection with either known geological conditions that should have produced an anomaly, or with mineral deposits of economic value. Proof of valuable deposits has failed to materialize even after drill testing in some of these instances. One outstanding example was the Thomasville anomaly in Clarke County, Alabama. The anomaly suggested a major magnetic high. Later a well drilled by a petroleum company to a depth of over 6,000 feet indicated that actually a structural low coincided with the magnetic high anomaly.

In Hobbs, New Mexico, a magnetic high was drilled and a producing oil well was brought in over the spot. On this evidence, hundreds of dry wells were drilled over other similar magnetic highs in the same region. These failures suggest that the location of the successful well coincided with the location of a magnetic high over the oil reservoir.

PRELIMINARY INTERPRETATION OF THE AEROMAGNETIC MAP
OF EASTERN BONNER COUNTY

GENERAL DISCUSSION

An aeromagnetic survey of parts of eastern Bonner County was completed by the United States Geological Survey in 1959. The data were gathered by a plane flown at 5,000 to 6,000 feet where topographic relief permitted. A map compiled from the corrected magnetic data was released in 1962 in open file by the Geological Survey. This map (Figure 3) has anomaly patterns both high and low, which produce some noteworthy local magnetic relief.

On the other hand, known mineralized areas in the vicinity of the Hope, Whitedelf, and Lawrence mines in the Clark Fork area; and near the Conjecture, Idaho Lakeview, Keep Cool, Weber, and other mines in the Lakeview area; appear to exert little, if any, effects upon the general pattern of measured anomalies.

Harrison and others (1961, p. B-159) concluded that the correspondence between the location of magnetic highs and the location of exposed igneous rocks was excellent. Positive anomalies not associated with any exposed plutons were interpreted as representing igneous intrusive rocks at depth. They contended that these same areas are underlain by Precambrian rocks of higher metamorphic grade: additional evidence of deepseated plutons.

PRELIMINARY INTERPRETATIONS OF THE ANOMALY MAP

Previous geologic investigations and magnetic survey

Fully aware of the "ambiguity" of attempts to interpret magnetic anomaly maps, I intend in the following discussion to point out certain interesting characteristics of the magnetic anomalies in the eastern Bonner County survey, and to suggest possible geological explanations for some of the variations and patterns. Geological information on the area, accumulated during the field season of 1961 I have supplemented by published reports. Anderson, (1930, 1946, 1947a, and 1947b), Gillson, (1927, and 1929); Sampson, (1928); and Wormser, (1922) published earlier reports on the geology of eastern Bonner County. More recently, geologic work has been done in the area by the United States Geological Survey, and some results have already been published (Harrison and others, (1961)).

Harrison and associates concluded that most of the magnetic highs in the Clark Fork-Pend Oreille district are related to igneous plutons. The anomaly pattern in general probably reflects the configuration of the Kaniksu ("Selkirk") batholith and dioritic dikes or sills that appear to underlie much of the region. Smaller offshoots (stocks) of the batholith, and dikes and sills, where locally exposed by erosion, do correspond with the location of magnetic highs.

Magnetic phenomena other than the major highs also merit attention and some explanation in terms of their possible relation to geologic structure or possible mineralized areas, or both.

Clark Fork area

The general broad spacing and northwest lineation of isanomalies in the area representing the Clark Fork topographic quadrangle appear to be influenced by the presence of a belt of northwest-trending faults (including the Hope fault), a sediment-filled valley (parallel to Clark Fork River), and a delta formed by the Clark Fork River at the eastern side of Pend Oreille Lake (Figure 3).

Two magnetic highs (one elongate, and one circular) are located about 4 miles southeast of the town of Clark Fork. They are difficult to explain because of their geologic setting. Although the elongate anomaly may reflect faulting, the trend of this anomaly is the same as the strike of a mineralized, quartz-filled shear zone formerly exploited at the Carpie mine about a mile east of Cabinet Gorge. If this anomaly represents southwest displacement of the axis of the magnetic phenomena that caused the variation, one may then suspect the anomaly of being related to the geology and mineralization of the Carpie-mine sheared zone.

The Carpie mine, originally a copper prospect, is in the Libby Formation, a calcareous argillite and siltite. The mineralized vein dips about 75° SW, which would place any deep major mineralization almost under this elongate magnetic anomaly. If paramagnetic and ferromagnetic minerals are more abundant at depth in the vein, then the anomaly would be nicely explained; however, such a deposit of minerals with high magnetic susceptibility is not yet known to exist at depth, nor has such a possibility been investigated.

Minerals identified in the Carpie vein at the mine are pyrite, chalcopyrite, and tetrahedrite, occurring in a gangue of ferriferous dolomite and quartz. Chalcopyrite has been reported to have a high magnetic susceptibility in some localities, for example, in Sudbury and in the Ural Mountains (Heiland, 1940, p. 310). The magnetic susceptibility of all the minerals found to date in the Carpie mine, however, is normally low.

About 3 miles east of Clark Fork a small high anomaly seems to reflect the presence of a cupola of igneous rock. Two or more miles farther east there is a possibility that a large, deeper seated pluton may produce the existing major north-south striking high. Harrison and others (1961, p. B-159) call attention to the higher grade of metamorphism of the metasediments in areas like these.

A lamprophyre dike occupying part of the fissured zone in the vicinity of the Alamo mine might also be expected to produce a magnetic high. Secondary minerals like chalcocite, covellite, and malachite are also present in the Alamo prospect, and some gold values have been reported by its operators.

Elmira area

The Elmira area has a very complex pattern of magnetic anomalies both high and low (Figure 3). There is a difference of about 400 gammas between a crescent-shaped low nearly parallel to Gold Creek on the north, and a nearly circular high approximately 5 miles south (just south of Trout Creek).

The presence of a variety of materials and probably faulting are considered mainly responsible for the interesting magnetic anomalies in the Elmira area. On the west is the Purcell Trench, a broad flat valley containing a variable depth of fluvial and glacio-fluvial sand and gravel. The glacial debris locally lies on a cemented to poorly cemented, cobble gravel. The latter, exposed in a few places, is called the Sandpoint conglomerate (Anderson, 1930).

An elongate north-south trending high was recorded immediately southwest of Elmira. Lying close to the center of the Purcell Trench, it probably represents a rise in the basement complex or a small deep-seated igneous intrusive. To investigate this high for a possible placer deposit would be interesting although the presence of a placer is probably unlikely.

The oval high about 3 miles southeast of Elmira may be caused by a number of diorite sills oriented roughly in the same direction as the axis of the anomaly. The complex anomaly lines extending northeast from this high probably reflect the presence of diorite sills, of a major fault, and of several contacts between different rock facies. Field investigations just east of Wylie Knob discovered an interesting contact zone as well as a variety of intrusives. The inextensive, high anomaly (1212 gammas), plus the favorable geological situation at this site, leads to the conclusion that a more complete geological investigation may be in order.

The interesting pattern of high and low anomalies south of Wylie Knob lie over one of the larger, known igneous intrusives in the region; this area and the two small east-west oriented highs on either side of the headwaters of Gold Creek may merit a careful examination of the local geology. However, the pattern of highs and lows, including the extensive crescentic low that tends to parallel Gold Creek, (previously mentioned), may be the result of a number of influences. For example, rather thick clay deposits are known to be present adjacent to Gold Creek; also, clay, sand, and gravel occur in Grouse Creek Valley southeast of Wylie Knob. Therefore, the configuration of the granodiorite intrusion, and the fact that it is covered locally with blankets of clay, silt, sand and gravel, could be responsible for the pattern of magnetic anomalies in the area.

Presumably one should not rule out the possibility of hydrothermal alteration, supported by Herness (1955), as an explanation of these low anomalies. These lows might be associated with roof pendants in the underlying batholith. If this is the case, the roof pendants may or may not be greatly altered and mineralized.

Russell (1960, p. 388) calls attention to the possibility that magnetic lows may be present where limestone (among other materials) occurs beneath a clastic cover. If roof pendants of limestone are present in the low anomaly areas described above, particularly near contacts with granitic rocks, then the possibility of mineralization is enhanced by the presence of carbonate rock.

Further knowledge of the geology in this region of low anomalies would be desirable; however, the amount and distribution of overburden will make further field investigations of the local bedrock difficult.

The prominent high anomaly south of Trout Creek and near the mouth of Pack River, again seems to be associated with a variety of rock types and complex geology. This anomaly may arise from a deep-seated igneous body with steeply dipping walls. That the sediment-filled valley of Pack River seems to have little effect on the anomalies suggests that the source may be deep-seated.

The less extensive, high anomaly just west of Mt. Eagen could be caused by the diorite sills reported by Anderson (1930, plate 14) in this approximate location.

Packsaddle Mountain area

The smaller, isolated magnetic highs in the Packsaddle Mountain district probably can be attributed to small stocks of granitic rock either at the surface or not too far below the surface; it seems quite possible that major faulting has helped produce some of the angular effects observable in the pattern of anomalies.

The low anomaly just north of Indian Point and over Pend Oreille Lake may result from Cambrian limestone beneath a cover of lake sediments from thick older sedimentary rocks, or from hydrothermal alteration at depth. Because the lake is deep at this site, the reason for such a magnetic low may never be positively determined.

Smaller high anomalies at Green Monarch Mountain and just to its east merit further geological exploration. These anomalies are in an area of complex faulting (Harrison and others, 1961, p. B-161), and the Belt rocks show a degree of metamorphism that suggests the presence of igneous rocks at depth.

Comments similar to the foregoing might be made about the magnetic high to the south, that is, in the headward portions of Dry Gulch.

The anomalies in the immediate vicinity of Packsaddle Mountain are unique in pattern. Such a pattern could result from the known geology. The granodiorite of which Packsaddle Mountain is chiefly composed could produce the central elongate high. Cambrian limestone occurring along the northeastern and the western flanks of the mountain might explain the prominent magnetic lows in this area. One could also cite Herness' (1955) explanation that lows are caused by hydrothermal alteration of rock.

If such alteration produced the Packsaddle Mountain anomalies, then the possibility must also be considered that potential mineral deposits exist both to the west and east of the central stock that forms the crest or axis of Packsaddle Mountain.

Talache mine, which might be expected to account for an anomaly, is located between high and low anomalies. The geomagnetic significance of this discrepancy is not known. Certainly the low to the northwest (adjacent to Mirror Lake) merits a thorough geologic investigation. The high to the southeast may reflect a rise toward the surface of granitic-type basement rocks, for example, an extension of the granitic rock exposed at Granite Point on the eastern shore of Pend Oreille Lake. The high at Granite Point, which resembles the steep, pronounced high near the mouth of Pack River (described earlier), is probably caused by the stock-like mass known to occur in this locality.

Lakeview area

Magnetic anomalies in the Lakeview area are conspicuous because of the lack of local highs and lows (Figure 3). A saddle-like pattern is developed about 2.5 miles southwest of Lakeview. This pattern may reflect the limestone and quartzite facies that make up the bedrock of the locality.

Major fault zones could be responsible for the general "open S" pattern of isanomalies as they cross Chloride Gulch and Decoration Creek south of Lakeview.

The high anomaly just northeast of Lakeview is in the vicinity of the Vulcan mine. The area about this mine has been described as a zone of intense metamorphism by Gillson (1929, p. 117). His description suggests that this might be a promising area for further detailed geologic mapping and prospecting.

Generally speaking, the anomaly patterns in the Lakeview district do not appear to reflect several areas of known mineralization; for example, localities where small mines have been or are now operating do not show prominent anomalies.

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