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GEOPHYSICAL SURVEYING

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Introduction

For over one hundred years geologists have been interested in the possible relationship between certain physical properties of the earth and the occurrence of mineral deposits. Von Wrede in 1843 suggested that local variations in the earth's magnetism might be used as a guide for locating certain metallic ore deposits. The practical relationship of magnetism to geological investigations was not fully recognized until 1879 when Thalen published his work "On the Examination of Iron Ore Deposits by Magnetic Measurements." In the past seventy-five years, particularly since 1900, intensive research by geologists and physicists, has developed a new field of geological investigation known as Geophysics.

Geophysics may be broadly defined, as the physics of the earth, or, in a more practical sense, the term implies measurement of certain physical properties such as magnetic attraction, the pull of gravity, the elasticity of rocks and the behavior of electrical currents and their application to geological investigations. Geophysical methods are used extensively in the search for ore deposits, oil-bearing structures, ground-water supplies and in geologic research. The development of many new oil fields and mineral deposits can be credited to the use of geophysical methods.

Geophysical Methods and Instruments

Geophysical surveying involves the making and interpretation of certain measurements of physical properties of rocks and minerals to obtain more information on subsurface geological relationships. Surveys are made by sensitive instruments which have been developed for the particular type of geophysical results desired. These studies measure either a potential function or some of its components (physical properties inherent in the rock), or reactions from induced energy at a point. The most important potential functions are variations in density, magnetic susceptibility and natural earth currents. Physical properties measured from induced energy are resistivity (the resistance of a rock to an induced electrical current) and elasticity. The instruments used for the detection and measurement of the physical properties are: Gravimeter (gravity meter) or Torsion balance for density, magnetometer for magnetic susceptibility, electronic devices for natural earth currents and resistivity, and seismic instruments for elasticity.

Gravity Method

Gravity is defined as the force of attraction by the earth on an object. This force is theoretically perpendicular to the earth's surface at any point. If the earth were a sphere of uniform composition and at rest, then gravity would be the same everywhere. The earth is not a sphere; its outer crust is variable in composition, and it is spinning on its axis and rotating around the sun. The diameter at the poles is slightly less than the diameter at the equator; for this reason the pull of gravity increases from the equator to the poles; a latitude correction compensates for this increase. Differences in altitude affect gravity measurements, and are compensated for by an elevation correction. There are several other factors which affect the mechanism of gravity recording devices, such as temperature and local topography. When these corrections are made, the results obtained show only variations in the density of the earth's crust.

The gravimeter is the instrument used to measure slight variations in gravity. It can be used to map a rock which is lighter or heavier (see Fig. 1) than the surrounding rock, and to locate subsurface geologic structures in which rocks of varying densities are present (see Fig.2).

Gravimeters are used in the Gulf Coast region of the United States to locate structures with which oil may be associated, such as faults, anticlines (convex folds), and salt domes. Gravity studies have also been successfully used to find and map ore deposits in many areas, particularly in the Lake Superior Iron District.

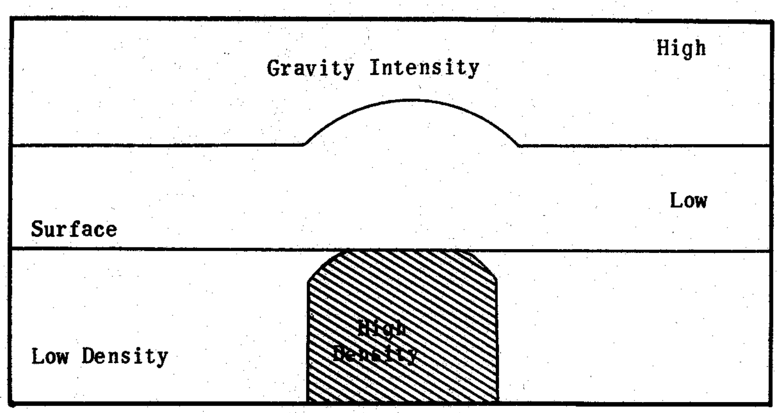

Figure 1. - Gravity intensity curve over a section of relatively high density. For a similar low density section the curve would be downward.

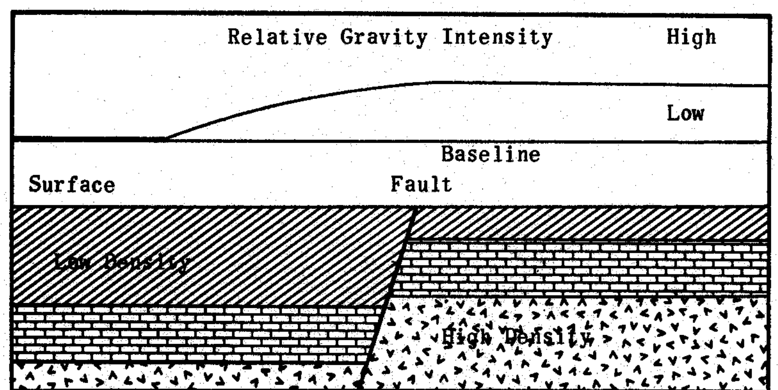

Figure 2. - Relative gravity intensity showing the presence of a fault by the intensities as affected by distance below the surface.

Self-Potential Method

The self-potential or natural earth current method of locating ore deposits is unique in that no electricity is induced into the ground. The orebody itself produces the electricity by which it is detected.

The principle of the self-potential method is most easily illustrated (Fig. 3) by using an oxidizing sulfide vein, such as pyrite (FeS_2). Rain and ground water seeping into the earth tend to chemically activate the upper portion of the vein (B) more than the lower portion (C), and a natural electrochemical reaction similar to that which takes place in a common storage battery is produced. As a result of such electrochemical reaction, differences in electrical potential exist between B and C. Because of this difference in potential, currents of electricity, which may amount to more than half a volt, will flow down the ore vein (a good conductor) and return through the surrounding country rock (a relatively poor conductor). It is these currents in the ground which are measured by the self-potential method.

The instrument used consists of two non-polarizing electrodes, usually porous pots filled with a solution of zinc or copper sulfate, which produce no electric current of their own. These electrodes are connected to an ammeter or other electrical measuring device, and the differences in potential are recorded.

This method is extremely useful in the detection of sulfide orebodies and in locating some types of complex iron-oxide bodies, such as magnetite. The self-potential method is limited by the amount of current produced by the orebody, which in practice restricts this method to the detection of ore deposits within 50 to 100 feet of the surface.

Resistivity Method

The resistivity method is somewhat similar to the self-potential method except that in the former an electric current, either direct or alternating, is induced into the earth and the resistance of the rock or earth is measured.

In the resistivity method (see Fig. 4) four electrodes are usually placed in a straight line an equal distance (D) apart, say 25 feet. Current is sent through the electrodes at C_1 and C_2 from either a hand generator or batteries, and this current is measured by an ammeter. Non-polarizing electrodes are placed at P_1 and P_2 and a potentiometer is connected in series with them.

The effective depth of this method is approximately equal to the distance (D), in this case 25 feet, so when the readings are taken and calculated the result is the resistance of the material between P_1 and P_2 to a depth of D. By increasing the distance (D) between electrodes the accurate depth and position of an orebody within the earth can be mapped.

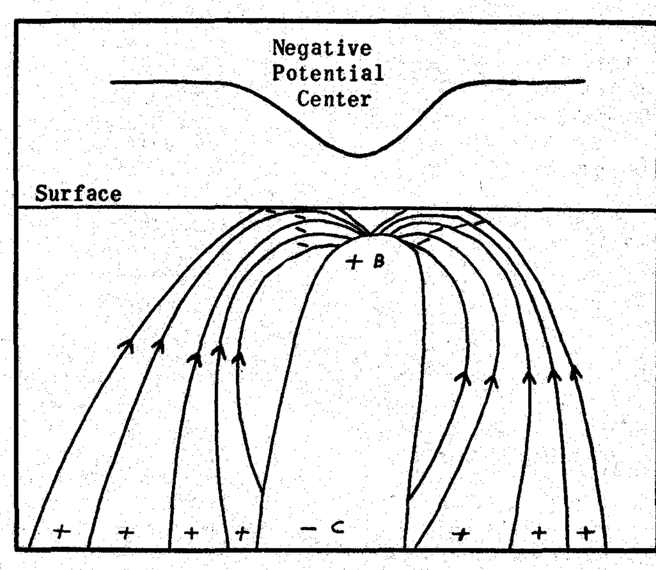

Figure 3.- Oxidizing sulfide vein with corresponding electrical potential.

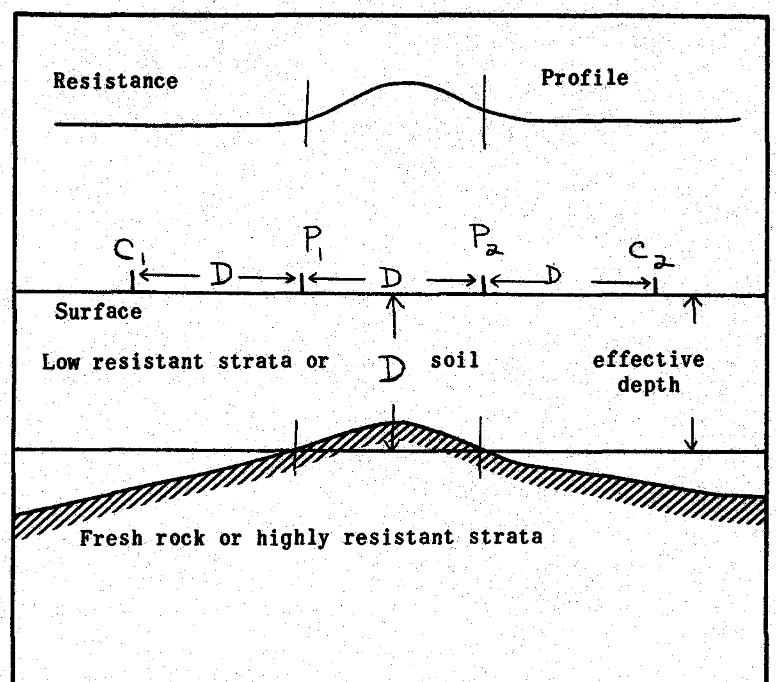

Figure 4.- Resistivity as used to determine depth of a type of rock.

This method is very useful in mapping orebodies and geologic structures which vary in the conductivity of electric currents. The Virginia Department of Highways uses along new highway sites, the resistivity method to determine the amount of soil and overburden present above bedrock.

Seismic Method

Seismic apparatus is used to measure the physical property of elasticity. An explosive (usually dynamite), detectors or geophones, and recording equipment are employed in seismic exploration.

All rock strata have, to some degree, elasticity which will vary according to the density, the type of rock, and the depth below the surface. The same strata may vary irregularly in elasticity along their length or width; however this variation seldom affects the interpretation of the seismic results.

In the seismic method an induced shock wave is produced by an explosion which will be reflected and refracted from the denser strata. This reflected wave can be detected by telephone-like receivers and transmitted to a recording device. The depth of the reflecting strata is a function of the time interval between the detonation of the shot and the receiving of the reflected wave. By using a series of geophones spaced on both sides of the shot point, the dip of reflecting strata can be determined by the difference in depth at each point.

This method is largely relied upon to help the geologist in determining oil-bearing structures and finding the depth of the denser basement rocks.

Magnetic Method

The earth behaves as a large magnet whose magnetic force varies from place to place. This complex system of magnetic forces is referred to as the earth's magnetic field.

If a small compass needle is suspended at its center of gravity in the earth's magnetic field so as to swing freely in all directions, it will come to rest in a definite position. It will not lie in exactly a north-south direction, and the needle will not be level, but slightly tilted from the horizontal. The compass needle will point toward the magnetic poles which are several miles from the geographic poles. This slight variation from true north is the declination, and in a given area is the number of degrees from the magnetic pole to the geographic pole. The amount of tilt from horizontal is the inclination or magnetic dip.

Several types of recording devices have been devised to measure magnetic effects. The dip needle and superdip needle measure the total effect of both horizontal (declination) and vertical (inclination) magnetic intensities. The horizontal magnetometer (declinometer) measures only the horizontal force, and the vertical magnetometer (inclinometer) measures only vertical intensity. In this article only the vertical magnetometer will be discussed.

As in the case of the gravimeter, the magnetometer recordings are subject to several corrections. Theoretically the earth's magnetism is horizontal at or near the equator and vertical at the magnetic poles; it is therefore necessary to make a latitude correction for the determination of absolute magnetic intensities. The earth's magnetic field is also subject to daily changes which are corrected, in the field, by selecting a base station at which readings are made several times a day; the diurnal changes at the base station are then added to or subtracted from the readings at the other stations. If an area is surveyed over a period of several days, the day-to-day variations at the base station are also corrected to give the effect of all the stations being read at the same time on the same day. Depending on the desired accuracy of the survey, temperature corrections can be made, although most of the newer magnetometers are to some degree temperature compensated.

Rocks and minerals have varying degrees of magnetic susceptibility (see Table I). Certain rocks or minerals, such as magnetite, are paramagnetic; they tend to concentrate lines of magnetic force due to high susceptibility. Other rocks or minerals, like quartz, are diamagnetic and tend to repel lines of magnetic force; they have little or no magnetic susceptibility.

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Mineral	Formula	Relative Susceptibility
Magnetite	Fe_3O_4	97,300
Franklinite	$(Zn,Mn)Fe_2O_4$	35,600
Ilmenite	$FetiO_3$	30,700
Specularite	Fe_2O_3	3,200
Chromite	$Fe(Cr,Fe)_2O_4$	240
Hornblende	Complex Ca,Mg,Fe silicate	120
Sphalerite	ZnS,Fe up to 26%	58
Pyrite	FeS_2	4
Rock		**susceptibility**
Olivine-Gabbro		5,600
Gabbro		3,300
Basalt		600

Table I.- Relative magnetic susceptibility of rocks and minerals.

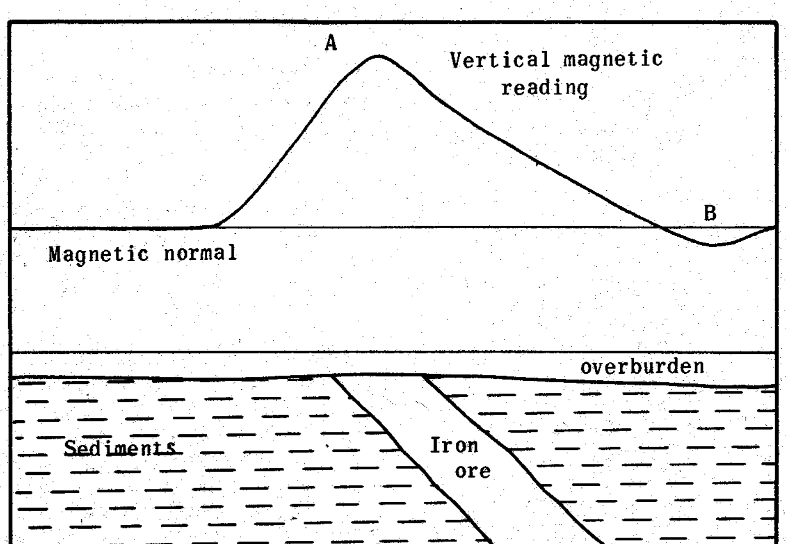

Figure 5.- Magnetic profile across iron ore deposit.

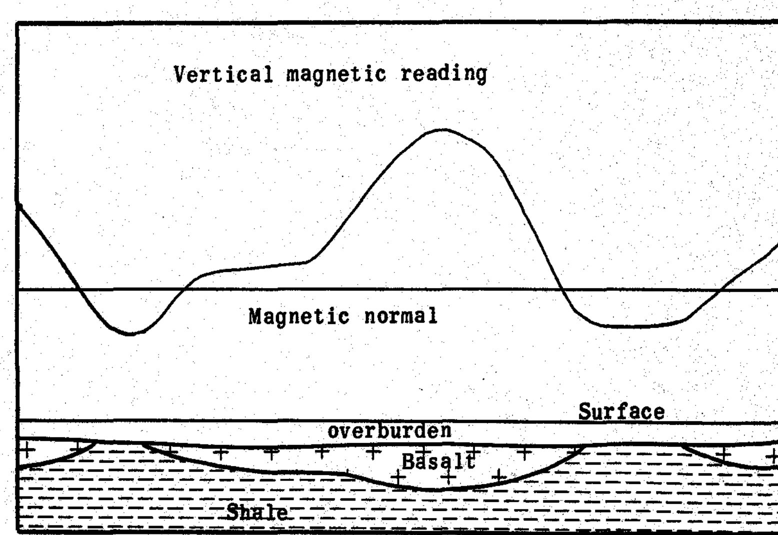

Figure 6.- Magnetic profile showing location and relative thickness of basalt flows.

In ore deposits, as in magnets, there is a north and a south pole (see Fig. 5). The high reading (A) is over the north end of an inclined iron orebody which slopes to the north, as seen by the magnetic profile. The reading at B is over the south or negative pole of the orebody. The reading at A is a positive magnetic anomaly, and the reading at B represents the negative magnetic effect of the same ore deposit. An anomaly is a reading or series of readings above (+) or below (-) the magnetic norm in an area.

The relationship of a basalt flow to the underlying shale and a relative determination of thickness, are shown in Fig. 6.

The magnetometer is used to assist the geologist in locating and mapping magnetic ore deposits and in determining structural relationships such as folds or faults. Thickness can be determined on a relative basis, and the amount and direction of dip can be calculated to a fairly accurate degree.

Airborne Surveying

In recent years many improvements have been made in geophysical surveying. Airborne surveys, primarily with the magnetometer and electromagnetic instruments, have been developed to a fairly high degree of accuracy. Airborne surveys have the advantages of covering a larger area in less time, giving a continuous record instead of a point-to-point reading, and eliminating small anomalies and local disturbing effects such as pipe and transmission lines. These new techniques make it possible to survey, at a minimum cost, areas which in the past could not have been economically surveyed.

Relationship of Geophysics to Geology

In most areas geological relationships cannot be determined primarily by geophysics. Geophysical studies are an aid to the geologist and must be correlated with the known geology of an area, and the interpretation of both the geological and geophysical data must be consistent with the known facts.

In most cases the results of geophysical surveying may be interpreted in several ways. If more than one interpretation seems consistent with known facts, then either the most probable concept must be accepted or further geological information should be obtained by core drilling.

Geophysical Prospecting

In economic geological investigations a geologist must first examine an area for surface indications of an orebody. If the findings warrant it, a geophysical survey, or series of surveys, is made and the results correlated with the known geology. If a promising orebody has been found and its limits generally defined, core drilling or other exploratory methods may be employed to determine the depth,extent and richness of the mineral deposit. In this way a fairly accurate concept of the value of the deposit can be determined before mining has begun.

Geophysical Studies in Virginia

At least two mineral companies operating in Virginia have employed concerns to make airborne geophysical surveys of areas in which they are carrying on exploratory work. The apparently continuing demand for the base metals, will probably result in further exploratory activity by some of the larger mining companies. It seems probable in such investigations that geophysical surveying will be employed.

The Virginia Division of Geology, anticipating the need for geophysical studies of certain areas in the State, recently acquired a magnetometer and is now planning preliminary magnetometer surveys of several of the known iron-bearing districts in Virginia. During the summer of 1956, a preliminary investigation of the Lynchburg hematite and magnetite district, in the central Piedmont region was initiated, by the writer. Upon completion of this investigation, it is planned to make a similar study of the Carrol-Grayson Counties magnetite district, and of the structural relationships and possible occurrence of mineral deposits in other parts of the Piedmont. The results of the geological and magnetometer studies will be published by the Division.

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PERSONAL NOTES

R. S. Young gave an illustrated talk on "Explorations for Sulfides in the Southeastern United States," before the Appalachian Geological Society at its meeting in Charleston, W. Va., on April 9.

A. A. Pegau gave a talk on "Virginia Mineral Collecting Localities," before the Georgia Mineral Society at Atlanta, on April 30.

W. M. McGill attended, during April, the annual meeting of the Association of American State Geologists, at Kentucky Lake State Park in southwestern Kentucky, and the annual meeting of the American Association of Petroleum Geologists in Chicago.

E. O. Gooch, W. T. Harnsberger, W. M. McGill, A. A. Pegau, and R. S. Young of the Division and C. W. Massie, of the Department of Conservation and Development, attended the annual meeting of the Section of Geology of the Virginia Academy of Science, in Richmond on May 11-12. R. S. Young was re-elected Secretary of the Section of Geology for 1955-56 year.

W. T. Harnsberger, Fuels Geologist of the Division, resigned on June 15 to accept a position as Assistant Professor of Geology at Madison College.

RECENT ACTIVITIES

During the past three months, leasing and exploratory activities for sulfide ores have been in progress by some six or seven companies locally throughout the central Piedmont region and in southwestern Virginia, particularly Wythe and Smyth counties. Tri-State Zinc, Inc., announced, in June, plans to begin at an early date the construction of a mill and the mining of sulfide ores in the Timberville district in Rockingham County.

Prospecting for radioactive materials continues locally in the southwestern and north-central parts of the Piedmont region, and several samples of reported uranium-bearing materials have been submitted to the Division for examination. Faint indications, not now considered to be of commercial importance, were found in a few specimens tested and the people submitting them were advised to send similar samples of material to the U. S. Geological Survey, the U. S. Bureau of Mines, and the U. S. Atomic Energy Commission, Washington, D. C. for further testing.

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NEW TOPOGRAPHIC MAPS

On April 27, copies of the new topographic map of the Halifax 15-minute quadrangle were received at the Division offices. This map, on a scale of 1:62,500 (1 inch = 1 mile) and with a contour interval of 20 feet, embraces mostly the north-central part of Halifax County and a small adjoining part of western Charlotte County. It is one in a series (13) of 15-minute quadrangles, along the central southern boundary of the State being mapped under the Federal-State Cooperative Mapping Program.

On May 14, copies of the new topographic map of the Clover quadrangle, another in the series of 15-minute quadrangle maps above referred to, were received. This map is also on a scale of 1:62,500, with a contour interval of 20 feet. It covers the southeastern part of Charlotte County and adjoining parts of Halifax and Mecklenburg counties.

Copies of any of the standard 15-minute and 7.5-minute quadrangle maps of Virginia may be obtained from the Division offices, or from the Topographic Branch of the U. S. Geological Survey, Washington 25, D. C., at a charge of 20 cents each.

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Edited by W. M. McGill