HANDBOOK OF GEOPHYSICAL PROSPECTING
METHODS FOR THE ALASKAN PROSPECTOR

MIRL REPORT No. 19

by

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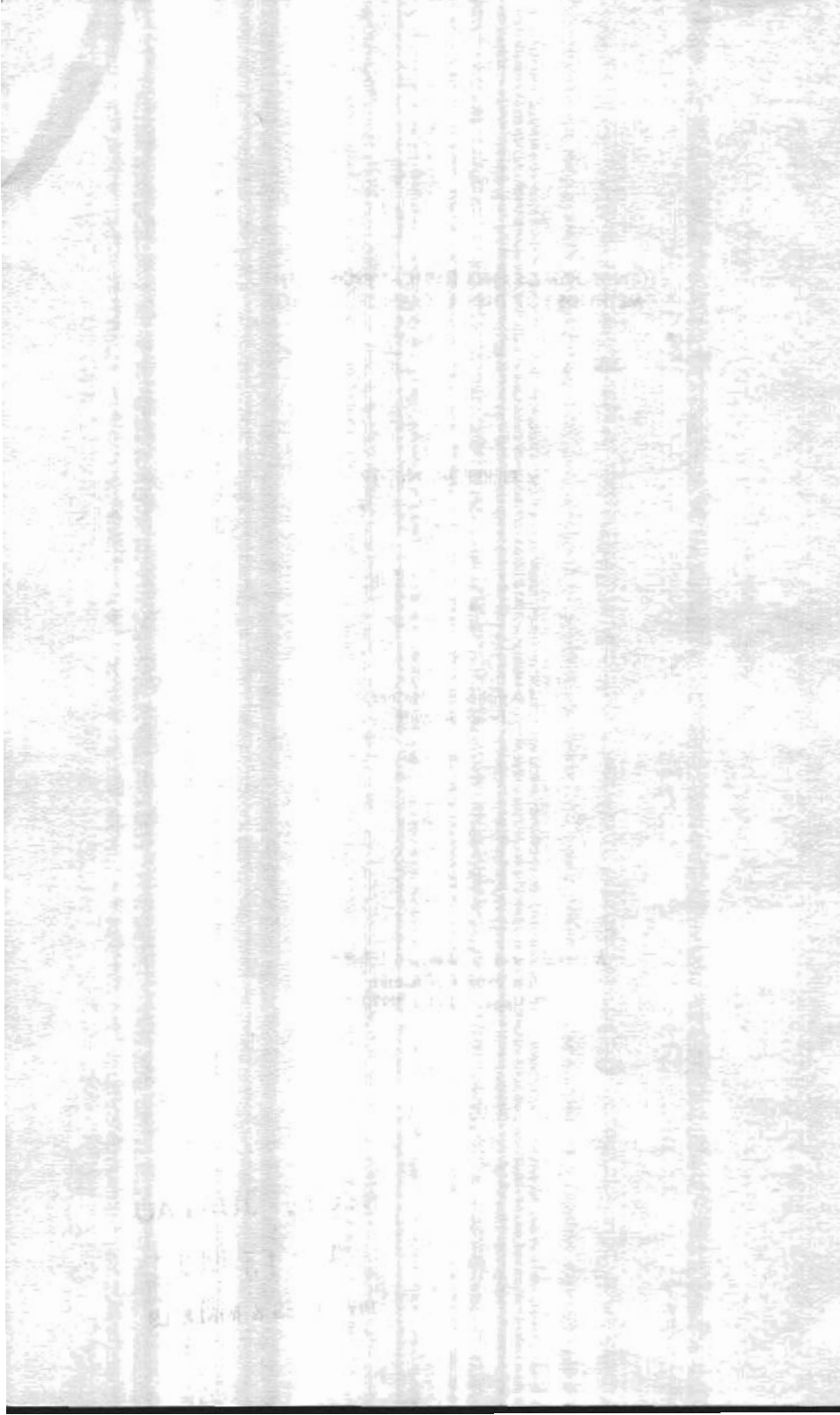Mineral Industry Research Laboratory
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FORWARD

This Handbook has been compiled to acquaint the Alaskan Prospector with the more recent application of geophysics for locating economic metallic minerals. For this reason, well documented subjects such as the use of the dip needle and mineral detectors have been excluded.

Because of continuous research in the field, new techniques tend to outmode current geophysical prospecting methods. Consequently, the reader is advised to keep abreast of new geophysical developments through literature pertaining to the subject. Developments in the field will be forthcoming through the continuous advance of science and technology. Perhaps Heinrichs Geoexploration Company's motto, "Search plus Research equals Discovery," best explains this fact. For this reason, the Mineral Industry Research Laboratory of the University of Alaska is continuing its research toward the development of the *tools for mineral search*.

Earl H. Beistline, Dean
College of Earth Sciences and
Mineral Industry

ACKNOWLEDGEMENTS

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INTRODUCTION

Man's progress is measured by his increasing use of metals; the terms: Stone Age, Bronze Age, Iron Age, and Atomic Age connote the steps of this progress and demonstrate the importance of mineral wealth and technology to our society. Our civilization is built upon the use of minerals and for civilization to survive, a continuous supply of minerals must be developed.

As our use of and need for minerals increases, it becomes more and more important that we find new deposits and reserves of minerals for both present and future use. It is unfortunate that as our needs increase the location of mineral deposits becomes more difficult. The surface indicators of ore deposits are becoming fewer as these orebodies are developed and used and it is becoming more important to be able to "see" beneath the surface so that ore deposits that do not extend to the surface can be found.

A concentration of minerals in sufficient quantity to constitute an orebody (a mineral deposit which can be mined at a profit) is usually accompanied by a measurable variation in one or more of the physical properties associated with rocks and minerals, such as their magnetism, electrical conductivity, or gravitational attraction, to name a few. This brings geophysical prospecting into the picture. Geophysical prospecting involves the systematic measurement of physical properties of rocks and minerals. These measurements are made in a search for unusual variations in these physical properties known as anomalies. Although these physical properties are fairly simple to understand, their measurement and interpretation is often quite complex and requires a considerable amount of equipment and knowhow. There are many geophysical methods. This has come

about from necessity rather than as a matter of choice, since unfortunately, no one geo-physical method can find all ore deposits.

This handbook is intended to provide the layman prospector with an introduction to the methods of geophysical prospecting. Due to the highly technical nature of some of the methods, this handbook will only briefly explain the theory and procedures involved with the common methods, list the types and where possible the cost of the equipment, and act as a guide for further study into each method as well as a guide to where geophysical services and supplies can be obtained. If the prospector knows what can and cannot be done with geophysics, he may then use this knowledge to his benefit. Geophysical methods are a valuable tool, but by itself geophysics will not provide all the answers. A sound understanding of geological principles, of mineralogy, and of ore deposits will never be out-dated in the search for ore. Geophysics can be helpful not only in locating a prospect but also in the exploration of the prospect, that is, in determining the size and shape of the orebody.

Table I lists the common geophysical methods and the physical property of which each depends. It also indicates the nature of the measurement that is made. If no external manmade force (magnetic, electrical, etc.) is applied to the rock in order to measure the desired physical property, the method is classified as passive. If, on the other hand, some force must be applied, as in passing a current through a wire in order to measure its resis-tance, the method is classed as active.

Table II shows some of the 113 world discoveries of metals and minerals as listed by Roger H. Pemberton, in the April 1966 issue of ENGINEERING AND MINING JOURNAL. The listing includes discoveries of deposits containing a wide variety of metallic and non-metallic minerals.

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Table I - Common Geophysical Methods

Method	Active	Passive	Physical Property Dependency
Gravity		X	Density
Magnetics*		X	Magnetic Susceptibility
Resistivity	X		Electrical Conductivity
Electromagnetics*	X		Electrical Conductivity
Induced Polarization	X		Frequency Dependence of Conductivity
Self Potential		X	Chemical Activity (Not Physical)
Radioactivity*		X	Natural Radioactive Decay
Seismic			Sonicvelocity
a.Reflection	X		Has only limited use in mineral exploration.
b.Refraction	X		

*Method can be used by airborne or ground surveys.

Table II - Mineral Deposits found with Geophysical Methods

Type of Mineral	Number of Deposits	Type of Mineral	Number of Deposits
Nickel	4	Uranium	3
Copper	49	Iron	24
Lead	24	Gold	7
Zinc	34	Silver	3
Tin	3	Asbestos	2
Molybdenum	2	Phosphate	3
Bauxite	1	Titanium	1
Columbium	2	Kaolin	1

Table III indicates the location of a few of the more important discoveries listed by Pemberton (1966). These deposits represent several millions of dollars production of metal each year.

Both ground and air geophysics have contributed greatly to Canada's mineral production. Seigel (1967) has summarized the direct contribution of geophysical instrumentation to Canada's post war mineral development: in 1966, $86 million of copper production, $32 million of lead production, $107 million of nickel production, $9.3 million of silver production, $3.8 million of gold, and $153 million zinc or a total of $378 million of production of these metals was derived from mines discovered as a direct result of geophysics.

Table III - The Locations of Discoveries of Metals and Minerals
Made with Geophysics

Name of Deposit	Location	Metal	Method of Discovery
Thompson Lake	Manitoba	Nickel	Mag. & E. M.
Craigmont	British Columbia	Copper	Mag. & I. P.
Blind River	Ontario	Uranium	Radiometric
Quebec Cartier	Quebec	Iron	Magnetometer
Pima	Arizona	Copper	Mag. & E. M.
Desert Eagle	California	Iron	Magnetometer
Copper Queen	Southern Rhodesia	Copper	Induced Polarization
Noranda 'C' Body	Quebec	Copper	Self Potential
Portage Creek	Alaska	Placer Gold	Magnetometer
Texas Gulf, Timmins	Ontario	Copper, Zinc Silver	Electromagnetic
Middle River	New Brunswick	Lead, Zinc, Copper	Electromagnetic
Stikine Copper	British Columbia	Copper	Induced Polarization
Yauricocha	Peru	Iron	Self Potential
Universal Atlas	Pennsylvania	Kaolin	Self Potential, Resistivity
Buchans	Newfoundland	Lead, Zinc	Resistivity

Field Work

Before any geophysical surveying is undertaken, the prospector should collect all the information available about the area he intends to explore. This includes topographical, mineralogical, and geological information. Literature which may help him are the publications of the United States Geological Survey, the United States Bureau of Mines, the Alaska Division of Mines and Minerals, the Geological Society of America, and articles listed in the Annotated Bibliography of Economic Geology. Table IV on the following page lists some specific publications dealing with Alaskan ore deposits and geophysical prospecting. This list is by no means complete, but it can serve as a guide. There is a great quantity of information available covering almost all parts of Alaska, and a person can waste time and money by ignoring what has been done by others.

The literature often indicates which of the geophysical methods is most likely to produce successful results in a particular area or in a particular geologic setting. It should be remembered that a good guide to ore is ore, that is, it is reasonable to search for an orebody in an area where other orebodies have already been discovered or in areas where geologic conditions are similar to areas of known ore deposits.

In areas of very rugged topography most geophysical methods become very difficult to run, and the interpretation of the results will be uncertain due to the effect that vertical relief has upon the survey measurements. Under these conditions the value of geophysical prospecting may be doubtful. Occasionally geological conditions will work against the use of the geophysical methods; for instance, an area which contains a large amount of graphitic schist not associated with ore will produce anomalies by methods which measure conductivity. There may be ore deposits in the area, but their presence would be "masked" by the anomalous readings of the schist even though the ore might also produce

Table IV - Publications Dealing with Geophysical Prospecting
and Alaskan Ore Deposits

1. Annual Reports of the Division of Mines and Minerals, State of Alaska,
   Box 5-300, College, Alaska 99701.

2. Berg, H. C., and Cobb, E. H., 1967, Metalliferous Lode Deposits of
   Alaska: U. S. Geological Survey Bulletin No. 1246, price $1.25.

3. Cobb, E. H., and Kachadoorian, R., 1961, Index of Metallic and
   Nonmetallic Mineral Deposits of Alaska compiled from published reports
   of Federal and State Agencies through 1959: U. S. Geological Survey
   Bulletin No. 1139, price $1.50. Both of the above papers available
   through the Superintendent of Documents, U. S. Government Printing
   Office, Washington, D. C. 20402.

4. Dobrin, M. B., 1960, Introduction to Geophysical Prospecting: McGraw-
   Hill Book Company, Inc., New York.

5. Geophysical Instrument & Supply Company, Fundamentals of Selecting
   & Using Electrical Prospecting Equipment for Mining Geophysics:
   GISCO, 900 Broadway, Denver, Colorado 80203.

6. Orth, D. J., 1967, Dictionary of Alaska Place Names: U. S.
   Geological Survey Professional Paper 567, Superintendent of
   Documents, U. S. Government Printing Office, Washington, D. C.,
   20402, price $8.50 - Hardbound.

7. Parasnis, D. S., 1966, Mining Geophysics: Elsevier Publishing Co.,
   New York.

8. Wolff, E. N., 1964, Handbook for the Alaskan Prospector: College
   of Earth Sciences and Mineral Industry, University of Alaska, College,
   Alaska 99701.

an anomaly. That is, there will be many anomalies but no way to distinguish those caused by the orebodies from those caused by the graphitic schist.

One of the most important tools of the prospector is a good field map. It is essential that he knows where measurements are made and how measurements are related spatially. It is a good practice to pick a well defined, convenient point, preferably one that can be located easily with reference to existing geographic features or found on a topographic map and establish a "base line" from this point. Cross lines are then established at 90° to the base line as shown below in Figure 1; these are spaced along the base line in accordance with the type of survey to be run and the degree of detail required. This is known as a grid system. Each point on the crossline where a measurement is to be made should be marked, usually with a wooden stake with the identification or "name" of the point on it. If a high degree of accuracy is not required a bright flag or a blaze on a tree will suffice to mark a point. If points are properly staked and
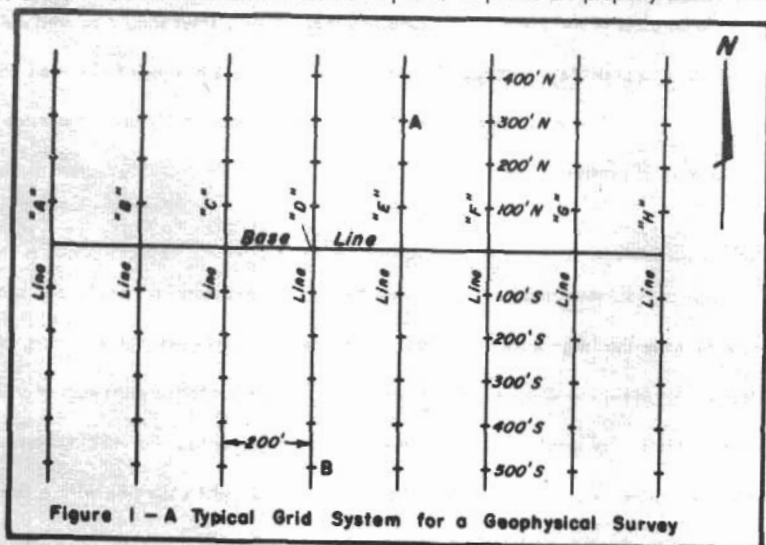
Figure 1 – A Typical Grid System for a Geophysical Survey

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identified, field work will be easier and mistakes will be fewer.

If a large area is to be covered, it may be convenient to identify points by coordinates rather than by the system shown in Figure 1. With coordinates all points are identified by their position or distance from the point of origin. Point A of Figure 1 which is 300 feet north and 800 feet east of the point of origin would be designated: 300N, 800E; similarly, point B would be 500S, 600E.

There is no necessity to establish the base line in an east-west or a north-south direction, in fact, many geophysical methods will give the best results if the cross lines along which measurements are to be made intersect the trend or strike of the deposit at approximately right angles. This, of course, may not be possible to determine but in many instances some evidence of structural trends will be apparent in an area or the trend of other, nearby deposits may act as a guide.

Regardless of the identification method used, survey lines should be laid out with as much care as possible. Although it is not necessary to use a transit (a brunton compass survey is usually sufficient), measurements should be made carefully and lines established as accurately as possible.

Geophysical Maps

Once field measurements have been made, the data must be compiled in such a way as to make the large number of readings and observations meaningful. Data, after necessary corrections and computations have been made, are plotted on a map at points corresponding to the location at which measurements were made. For making maps, ruled graph-paper is a very convenient medium especially when working with a coordinate system. Figure 2 shows a plot of corrected or adjusted data which might have been obtained from a magnetometer survey over the grid system of Figure 1. As can be seen, the results

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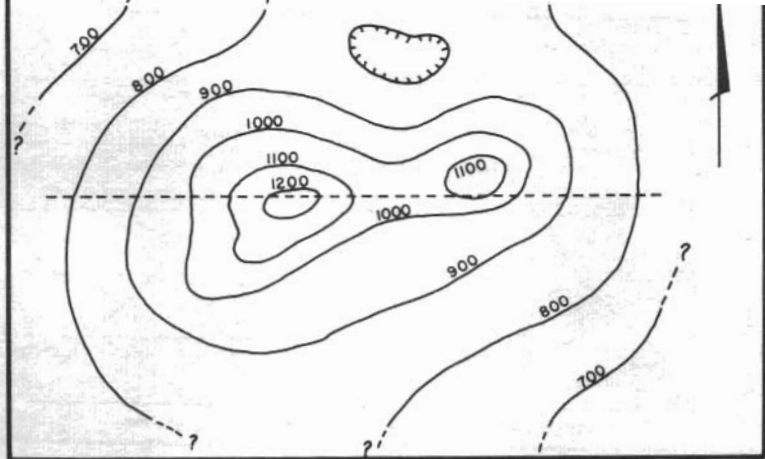
Figure 3 — Isoanomaly Contours from Magnetometer Data (Gammas)
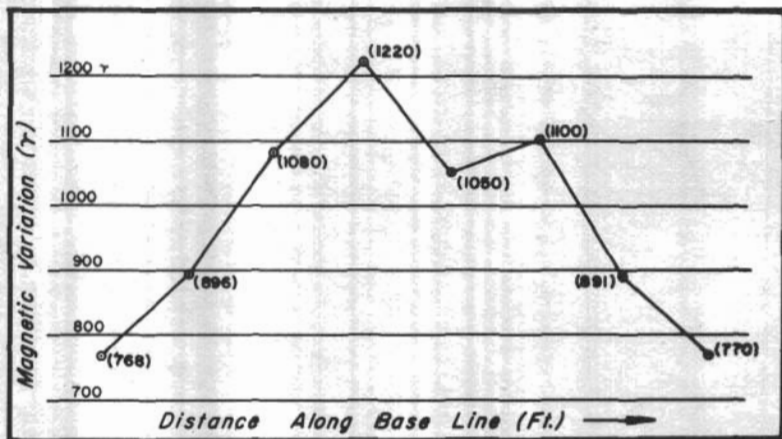
Figure 4 — Profile of Values Along Base Line

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INDUCED POLARIZATION METHOD

Introduction

If a current is introduced into the ground at two points, a voltage will appear between two other points and this voltage is indicative of the type of rock or mineralization in the area. When the current flow is stopped this voltage does not generally fall to zero immediately but seems to decay slowly. In some cases it has been found that there will still be a measurable voltage two minutes after the current source is disconnected. This is the induced polarization effect.

Induced polarization is apparently caused by mineral grains and clay particles becoming polarized by the flow of electricity between the current electrodes. This polarization tends to oppose the flow of current; the grains or particles acting like many small capacitors. After the polarizing current is removed, these "capacitors" then discharge at a rate characteristic of the polarized material. By using equipment with a variable frequency a. c. source of current, geophysicists are sometimes able to determine the source of the induced polarization, that is, whether it is due to discrete mineral grains or to clay particles.

Induced polarization is a valuable tool, because ore deposits which will not respond to electromagnetic methods, or resistivity methods, will sometimes produce pronounced IP anomalies. For a deposit of conductive material to respond to the EM method, the conductive minerals must be arranged in a continuous latticework of some kind, that is, there must be an interconnection between the mineral grains. For the IP effect, just the opposite can be true: even when the grains are separate and discrete

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the induced polarization phenomenon can occur. However, even highly interconnected bodies of conductive minerals can give strong IP effects. The reason for this is that the IP effect is a surface-area phenomenon arising from capacitive-like properties at interfaces between electronic (e.g., sulfides) and ionic (ground moisture with dissolved salts) conductors. Even interconnected massive sulfide zones, which have a considerable electronic-ionic surface area due to the interstitial and fracture moisture, almost invariably present, polarize strongly. This method will find some of the deposits that might be missed with EM or might not be well defined by resistivity. Deposits such as the famous "porphyry" coppers of some of the western states would probably have been missed by an EM survey but would undoubtedly be located by IP.

The greatest disadvantage of the IP method is that it is complicated and the equipment is quite expensive. Of all the ground-contact geophysical methods, IP is one of the slowest and costliest to run. This method would generally not be suggested to the layman prospector as something he should do himself. If it is desired that an IP survey be made of an area, the best course to follow would be to hire an experienced geophysical exploration company to do the work and evaluate the results. It is still necessary for the prospector to know what he is buying, and he should therefore understand at least the rudiments of the method.

Field Work

There are two commonly used IP methods, the time-domain method and Frequency-domain techniques. Although they are equivalent in their end results, the methods are quite different in field procedure and will be discussed separately.

Time-domain method: In this method a direct current is introduced to the ground at two points and allowed to flow for a few seconds. At the end of this time the current

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is shut off and the induced voltage between two other points is observed for several seconds. The recorded measurement is usually the amount of voltage remaining after a certain number of seconds divided by the voltage at the instant the current was shut off. This is necessary since the total induced voltage will not be the same for each set of points and therefore to be able to compare readings a relative difference must be found. Several sets of measurements are taken and averaged at each station while reversing the direction of the current flow to minimize adverse SP drift and polarization "memory" effects. Generally speaking, the voltage at the time the current is stopped is measured in volts and the decay voltage is measured in millivolts. Therefore, readings for the time-domain method are recorded in millivolts per volt (mV/V). If both the initial and residual voltages are recorded in mV the division is made, multiplied by 100 and referred to as percent IP. Although any of the electrode arrays discussed with the resistivity method can be used for these measurements, the Wenner and Dipole-Dipole arrays are most frequently used, however, the three array or pole- dipole array has proved most useful in certain instances.

Frequency-domain method: It has been found that the resistivity of some rocks will decrease when the frequency of an a.c. current, it is apparent that an IP effect exists. One measure of this IP is known as the percent frequency effect (PFE). The resistivity of the rock is measured at two different frequencies, for example, usually 0.1 and 10 cycles per second, and the percent frequency effect is:

$$PFE = \left(\frac{\rho_{0.1} - \rho_{10}}{\rho_{10}} \right) 100$$

where: $\rho_{0.1}$ = resistivity @ 0.1 cps

ρ_{10} = resistivity @ 10 cps

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Another measure of IP with the frequency-domain method is known as metal factor (M.F.) and, in essence, the percent frequency effect divided by the low frequency resistivity. Since this number is very small, the M.F., by definition, includes this value multiplied by 2000 π. Metal factor is therefore:

$$\text{M.F.} = \left[\frac{\rho_{0.1} - \rho_{10}}{(\rho_{0.1})(\rho_{10})}\right] 2000\,\pi = \frac{2000\,\pi\,(\text{PFE})}{\rho_{0.1}}$$

Resistivities are expressed in ohm-feet or ohm-meters, depending upon the units used to measure the electrode spacing, and since M.F. calculations produce values of 1/ohm-ft., the M.F. is really a measure of the change in the inverse of resistivity, namely, electrical conductivity.

Whether from time-domain or frequency-domain measurements, IP values are usually plotted as profiles along the lines surveyed. Figures 5 and 6 courtesy of Heinrichs Geoexploration Company are excellent examples of theoretical profiles.

The dipole-dipole electrode array is usually used for frequency-domain measurements. With this array the resistivity, percent frequency effects and metal factor values produced are assigned to a point midway between the electrodes as shown in Figure 7 and down from each dipole midpoint at an angle of 45° from the horizontal. Values of IP and resistivity are then found for various depths and locations in the area of interest by varying the distance "nx" between the dipoles of the array and by moving the entire array laterally along the survey line. Profiles similar to that shown in Figure 8 are produced. In this figure both profiles are of the same area, the top profile is the resistivity data, the bottom that of the M.F. data. PFE is not shown in this particular example but is often displayed similarly. The numbers n = 1, n = 2,

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Figure 5

Figure 6

etc., in this figure refer to the multiple "n" in the electrode configuration and indicate the separation of the current and voltage dipoles and, therefore, suggest the relative depth of the measurements. It should also be noted that resistivity in the area of interest is higher at depth and lower at the surface, and that there are other nearby areas where resistivity is low, as would be expected near a mineral deposit, but these do not coincide with the IP anomaly or with the mineralization indicated by diamond drilling. This, then, is a case where IP has located an area which might otherwise have been missed.
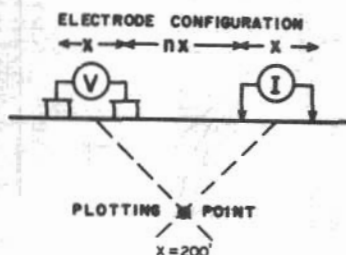
Figure 7 - The Dipole-Dipole Array for an IP Survey
Showing the Plotting Point.

IP Equipment

The equipment required for running an IP survey consists of a transmitter, receiver, power supply (either batteries for low-power systems or an engine-generator), and accessories such as cables, electrodes and spare parts.

Variable-frequency IP equipment ranges in price from about $8,500 for battery operated equipment to over $17,000 for some a.c. equipment with five or more kilowatts of input power. Spare parts packages for these systems, suggested when this equipment is to be used in remote areas, run from about $2,500 to $4,500 respectively. Pulse-type,

INDUCED POLARIZATION AND DRILLING RESULTS FROM
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WISCONSIN LEAD-ZINC DISTRICT.
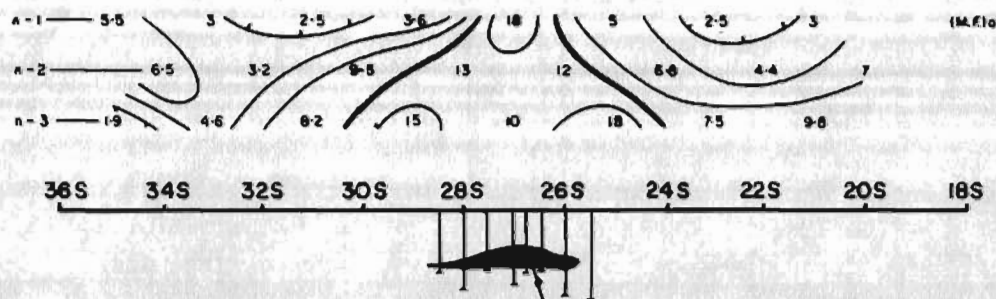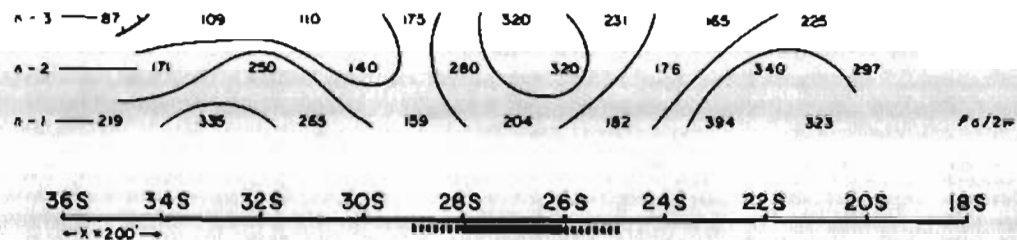
Figure 8 - Profiles of data from an IP Survey. IP Case #26 of McPhar Geophysics Limited and printed by permission of McPhar Geophysics.

APPROXIMATE OUTLINE OF MARCASITE ZONE WITH

time-domain equipment costs slightly less, varying in price from $8,000 to about $13,000, depending upon the input power source and requirements. Figure 9 shows a transmitter and receiver for time-domain IP measurements. This equipment is manufactured and distributed by Huntec Linited of Ontario, Canada.

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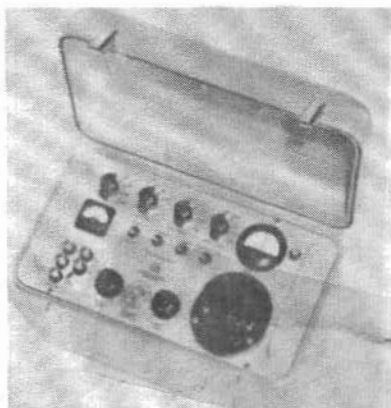
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Figure 9 – Transmitter and Receiver for Time-Domain I.P.

Figure 10 shows a solid state time domain I.P. Unit, the Scintrex IPC-7 transmitter and IPR-6 receiver manufactured by Seintrex Ltd.

Figure 11 shows a complete set-up for frequency-domain IP surveys. This includes the transmitter, receiver, generator, electrodes, cable reels with cable, and all the spare parts suggested with this equipment including a complete spare engine for the generator unit. This equipment is manufactured by McPhar Geophysics

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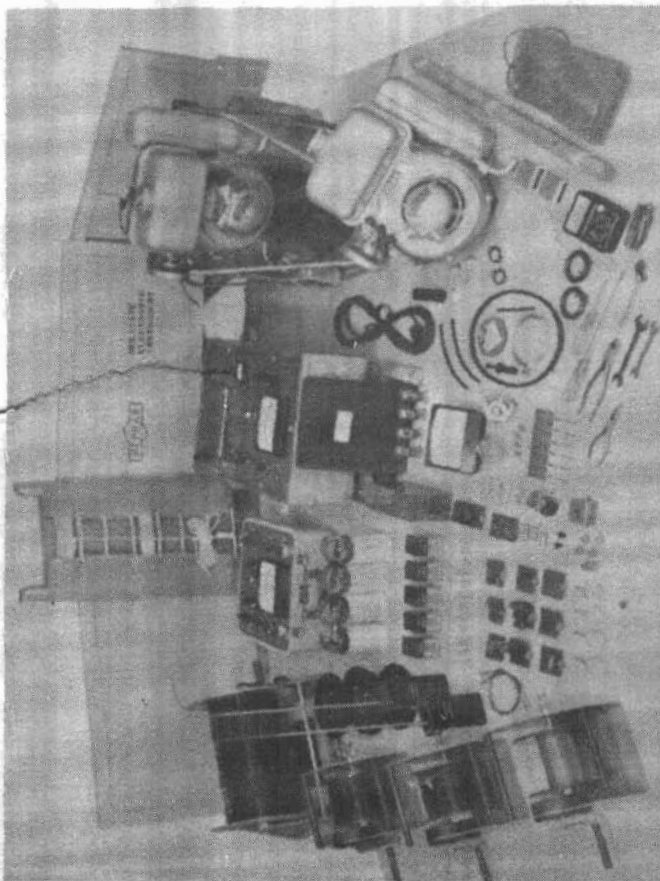
Figure 11)

Transmitter, Receiver, Engine Generator, Accessories and Spare Parts — Model 2005

(Model P654 Similar)

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Limited of Ontario, Canada.

Manufacturers and distributors of IP equipment are listed in Appendix I.

One geophysical exploration company, Heinrichs Geoexploration Co. of Tucson, Arizona, lists $170.00 to $350.00/work day as the base charges for combination induced polarization, resistivity, and self-potential surveys, depending upon the type of equipment used, and the number of men required. This does not include costs of transportation, living expenses or other contingencies. Other companies that do contract IP work are Seigel Associates Limited, and McPhar Geophysical Limited, both of Canada, Geoscience Incorporated, and Mineral Surveys Inc. Canadian firms' estimates of survey costs are not given for the U. S., and this work would have to be arranged on the basis of the specific job, the location, and extent of work to be done.

Huntec Limited of Canada lists the following prices for rental of IP equipment:

	1st Month	2nd Month	Daily Rate
7.5 kw I.P. system (Complete)	$1,600	$1,325	$80.00
2.5 kw I.P. system (Complete)	$1,350	$1,100	$68.00

The prices shown above are in Canadian funds and would be somewhat less in U. S. dollars. IP equipment can also be rented from Geoscience Incorporated, Heinrichs Geoexploration Company and Scintrex Ltd. with cost depending upon type of equipment and period of use.

The addresses of the companies listed above can be found in Appendix I.

SELF-POTENTIAL METHOD

Introduction

The self-potential method is one of the simplest, easiest to perform, and least expensive of the geophysical methods. Due to this ease and simplicity of operation, it is highly recommended to the prospector searching for sulfide mineralization, but it must be remembered that this method, like all other geophysical methods, will not locate all sulfide deposits. Instrumentation is neither expensive nor complicated, and qualitative evaluation of results is not difficult.

If two non-polarizing electrodes are but in contact with the ground and connected to a sensitive voltmeter, a small difference in electrical potential (voltage) will usually be observed to exist between them. These voltages normally range from a few to a few tens of millivolts. (1 volt = 1000 millivolts). In the vicinity of some sulfide bodies, notably those containing pyrite, chalcopyrite, and pyrrhotite, voltage differences may run as high as hundreds of millivolts to a volt or more. The difference in potential at two locations is due to the difference in chemical activity in the ground. These voltages are in essence caused by natural wet-cell "batteries" in the ground. Since these voltages are naturally-occuring, self-potentials are sometimes referred to as spontaneous-potentials, and the method is usually called, simply, SP.

There is no universal agreement as to the source of self-potentials. One of the most commonly accepted explanations for this phenomenon attributes self-potentials to the difference in the rate of oxidation between the top and bottom of a sulfide body, thus creating an electrochemical cell and a subsequent difference in electrical potential.

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Whatever the cause, self-potentials have proven to be simple guides to ore.

The self-potential method will indicate a deposit only when that body is undergoing oxidation and when other conditions are favorable. It will not work if the surface material is a bad electrical conductor and may not give satisfactory results in frozen ground or permafrost.

The SP method is a qualitative method, that is, it will only indicate the presence of a sulfide body and sometimes give an indication of its size. Other important factors, such as the depth of burial, must be determined by some other means.

Field Work

There are two field methods which are commonly employed for running SP surveys. Both of these methods involve the measurement of the natural potential that exists between two electrodes placed some distance apart.

The first method produces a series of natural potential readings all relative to one base station or location. In this method, one electrode is left stationary at the base location while the other electrode is moved from station to station generally along one line of a grid system. The magnitude of the potential difference is recorded along with its sign (plus or minus voltage relative to the base station) for each station. As cable length runs out, or when one line is completed and another is to be started, a new "temporary base" is established; the potential of the new base is first measured relative to the original base so that the potential of all points along this line can be converted to readings relative to the original base. For instance, if the difference between the base station and the temporary base is +150 mV (millivolts), all readings, with the fixed electrode at the temporary base, must then be increased by 150 mV; these station readings then bear the same relation to the original base station as if

the fixed electrode had been at the original base. In this manner, the entire area of interest is covered, the spacing between stations being determined by the detail desired. Readings are then plotted on a suitable map and isoanomaly curves of equal electrical potential are drawn or profiles of electrical potential along individual lines are plotted.

By the nature of self-potentials, areas of interest will demonstrate negative potentials, but from field work this depends upon the location chosen for the base station. If the base station were located directly above an oxidizing sulfide deposit, all other readings would likely have a positive sign. In the SP method as in many others, it is advisable to select a base station away from the immediate effect of any suspected mineralization. A simple method of determining the sign of a reading is as follows: Most SP meters have positive (+) and negative (-) terminals, the sign of each station reading will be the same as the terminal that the cable from the electrode must be attached to produce a positive reading on the volt meter.

In the second procedure, both electrodes are moved continually, with a fixed distance of separation between them, usually 25 to 100 feet depending upon the detail desired. The electrodes are moved along each survey line in a leap-frog fashion. If the points along a line are designated A, B, C, the first reading is taken between A and B, the second between B and C, and so on until the entire area has been covered. This method produces the gradient of the potential or electric field along the lines surveyed. The sign of the gradient is established in much the same manner as that described for the fixed electrode method. Data from this type of survey is usually plotted as a profile.

An examination of the above descriptions of the two SP methods will show that they are equivalent in that gradient values can be derived from fixed base potentials

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and vice versa. The chance of finding a weak SP anomaly is greater with the fixed base method because of less adverse drift effects and in general fixed base potential maps are easier to interpret.

Instruments and Equipment

The equipment required for an SP survey is simple and relatively inexpensive; it consists of two electrodes, a potentiometer (or voltmeter) and cables for connecting the electrodes to the voltmeter.

Electrodes: Contact must be made with the ground to measure the SP. Metal stakes of copper or stainless steel have been used for this purpose, but it has been found that these metals often create a potential when in contact with the ground which masks the natural potentials. To avoid this phenomenon, known as polarization, some sort of non-polarizing electrode must be used. The most common non-polarizing electrode consists of a copper rod placed in a porous pot which is then filled with a saturated solution of copper sulfate. It is through the porous pot that contact is made with the ground. To enhance this contact, copper sulfate solution is sometimes poured directly on the ground where the pot is to be set. Another non-polarizing electrode often used is made of calomel. Both are commercially available.

Potentiometer: The measurement actually made in SP surveying is the difference in potential or voltage between the two electrode locations. With the potentiometer, an internal voltage in the instrument is varied until it just balances, that is, exactly opposes the natural voltage. The reason for using this instrument is that none of the natural voltage is used to "run" the meter. Direct-reading voltmeters can also be used so long as they have a fairly high internal impedance; 20,000 to 50,000 ohms for porous pot electrodes.

Cable: Almost any type of well-insulated, lightweight, multi-strand copper wire will suffice. Since field conditions are often wet, it is well to have a cable with water proof insulation.

The University of Alaska, Mineral Industry Research Laboratory has published a paper (MIRL Report #17) describing an SP meter that can be made from commercially available parts by nearly anyone. According to Mr. Zonge, the author and builder, these parts should cost in the vicinity of forty dollars and no special equipment or knowledge will be necessary to build a good working instrument. This price does not include the cost of electrodes, cable and cable reels which must be purchased separately. There are, of course, many good SP outfits available commercially and since much of this equipment is part of combination SP and Resistivity outfits, the descriptions and prices of these will be covered under the Resistivity Method.

There are many manufacturers and distributors of SP equipment, among these are: Geoscience Inc., Geophysical Instrument and Supply Co., Heinrichs Geo-exploration Co., McPhar Geophysics Ltd., and Scintrex Ltd. Spare porous pots cost about $30 each for the pot and copper electrode. Sharpe lists rental prices of $120 for the first month, $110 for succeeding months, and $7.00 per day for one of their SP units.

RESISTIVITY METHOD

Introduction

The resistivity method is one of the more common methods and, although some-what complicated, is not too difficult to be utilized by the layman prospector. This is a method which measures the electrical properties of the earth and it is quite often applied in combination with the Self-Potential method.

With the resistivity method a direct current or a current from a very low frequency a.c. source is fed into the ground at two points and the voltage difference between two other points is measured, allowing the prospector to determine the apparent resistivity of the ground. Good conductive bodies, such as most sulfides and zones of fractured rocks which are filled with conductive ground water, will display low resistivities; where-as, most solid unmineralized rocks, being poor conductors, will show high resistivities. In crystalline rock, such as granite, the resistivity is largely dependent upon the amount of fractures and fissures in the rock and the amount of conductive water in these openings. In this way knowledge can be gained of the condition of the rock with the resistivity method.

Most metallic ore minerals (minerals with a metallic luster), such as galena, chalcopyrite, magnetite, etc., are good conductors, and generally ore deposits con-taining these minerals have low resistivities; hematite and sphalerite are two metallic or submetallic minerals which are poor conductors and are not responsive to the resistivity method. Graphite and graphitic schists, which are common in Alaska, are also good conductors and must be watched for when doing many kinds of geophysical work,

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because they will produce unproductive anomalies.

An important factor in determining the resistivity of a deposit is the mode in which conductive minerals are distributed in the rock. Often, if the conductive mineral grains are not in contact with one another, the deposit will display a high resistivity, although there is a considerable metal content. This is caused by the rock between the grains acting as insulators.

Along with its use as a prospecting tool, the resistivity method is often used for subsurface determinations of geologic structure, mapping the relief of bedrock, and for identifying subsurface rocks.

The measurement produced in a resistivity survey is known as apparent resistivity. This is neither the true resistivity of the rock in the area of the survey nor the average resistivity of this rock, but is rather an idealized value which can be used to interpret the results of the survey in a qualitative manner. Apparent resistivity is actually"...the resistivity that a semi-infinite homogeneous earth must have, if a potential difference equal to that actually observed between the probes of an electrode configuration is to be obtained, on placing the configuration on the surface of the imaginary homogeneous earth, and keeping the current unaltered." (Parasnis 1966). As can be seen, this is a rather complicated concept, but in general it can be said that areas with low apparent resistivities suggest good conductors and high apparent resistivities suggest poor conductors.

Like the SP method, the resistivity method may not give meaningful results when the surface material is a very poor conductor, or when this material is frozen.

Field Work

Resistivity surveys are generally carried out, using one of the electrode configurations shown in Figure 12, along the lines of a grid system in a point-to-point manner until the entire area of interest is covered. Since there is some variation in interpretation of results as the electrode configuration is changed, these various configurations will be discussed one at a time. The configurations shown in Figure 12 and discussed below are only three of many used but are the more common methods. In each case, current flow is induced between two electrodes and the voltage, i.e., the electrical potential, between two other electrodes is measured. Many types of electrodes may be used for the current electrodes; often stainless steel rods about $2\frac{1}{2}$ feet long are used. The potential electrodes should be of the non-polarizing type discussed under the SP method. When taking resistivity readings with some d.c. equipment, the spontaneous potential between the two points where the potential electrodes are set must first be determined without any flow of current between the current electrodes. This value is then either added to or subtracted from the final resistivity reading, depending upon the sign (+ or -) of the natural potential. For instance, if the spontaneous potential between points 2 and 3 of Figure 12-A were +250 mV (from 2 to 3), then, this value would have to be subtracted from any positive reading between these points and added to any negative reading, when readings are taken with current flowing between the current electrodes 1 and 4. For this reason some resistivity equipment is also capable of measuring self-potentials, and it is a good practice to record the SP while doing resistivity work. In this way two geophysical methods are performed at once.

A. Wenner array - In this configuration the electrodes are equally spaced along a line; the spacing "a" being determined by the detail and depth of measurement

Circuit to provide
current to ground

Circuit to measure
voltage

a = a = a

|← a →|← a →|← a →|

A. Wenner array

Circuit to provide
current to ground

Circuit to measure
voltage

b < 0.2a

|← a →|← a →|
→|b|←

B. Schlumberger array

Circuit to provide
current to ground

Circuit to measure
voltage

|← c →|← a →|← b →|
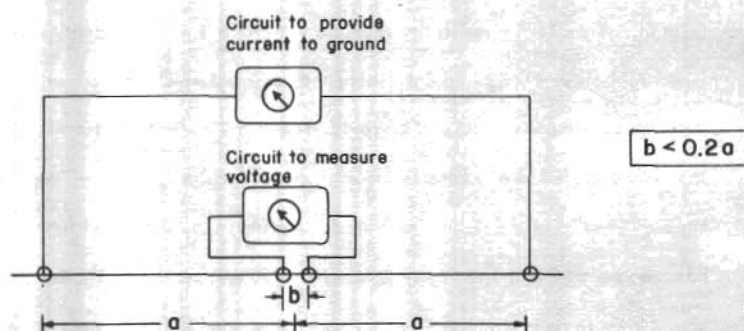
C. Dipole array

Figure 12 – Commonly Used Electrode Arrangements for Measuring Earth Resistivity

desired. The outer two electrodes are used to provide current to the ground and the inner two are used for measurement of the voltage. The apparent resistivity is computed from the following formula:

$$P_a = 2\pi a \, \frac{\Delta V}{I}$$

where: P_a = apparent resistivity in units of ohm-feet.

π = (3.1416 approx.)

a = "a" spacing in feet.

ΔV = voltage between inner electrodes + SP (both measured in volts or millivolts).

I = current applied between outer electrodes (measured in amperes or milliamperes consistent with V units).

The apparent resistivity value determined from the above formula is assigned to a location midway between the two voltage electrodes in the Wenner array.

B. Schlumberger array - (pronounced slumber-jay). The four electrodes are placed along a line but with the distance between the two inner electrodes less than two-tenths the distance between the inner and outer electrodes. The inner and outer electrodes serve the same functions as with the Wenner array. Apparent resistivity is:

$$P_a = \frac{\pi}{b} \, \frac{(a^2 - x^2)^2}{a^2 + x^2} \, \frac{\Delta V}{I}$$

where: P_a = apparent resistivity.

b = distance between inner electrodes.

a = one-half distance between outer electrodes.

x = distance between mid points between inner and outer electrodes.

V = voltage between inner electrodes $\pm$ SP.

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$$I = \text{current applied between outer electrodes.}$$
(use consistent units as with Wenner array).

In Figure 12-B there is no separation between the center of the outer electrodes and the center of the inner electrodes and therefore "x" in the above equation is zero (0) and the equation becomes:

$$\rho_a = \frac{\pi}{b} \; a^2 \; \frac{\Delta V}{I}$$

As in the Wenner configuration, the apparent resistivity value is assigned to a point midway between the two voltage electrodes.

C. Dipole array - With this configuration sometimes also known as the dipole-dipole array, the potential electrodes are outside the current electrodes as shown in Figure 12-C. The distance (c) between the two current electrodes is generally kept the same as the distance (b) between the two voltage electrodes and the smallest distance (a) between a current and voltage electrode is some multiple (n) of this distance (b or c). As in this case a = nb, where n = 2, then a = 2b. When b is equal to c, apparent resistivity is:

$$\rho_a = \pi n(n+1)(n+2) a \; \frac{\Delta V}{I}$$

With this configuration, the apparent resistivity is assigned to a point half-way between the centers of the two electrode layouts, that is, at a distance of a/2 along "a".

The above arrays can also be used for making so-called depth soundings by keeping the geometric center of the arrays fixed and increasing the electrode spacing. In the case of the dipole-dipole array, this amounts to increasing "n" thereby moving the two sets of electrodes further apart and causing the method to "look" deeper into the ground.

After resistivity values are obtained for an area of interest, they are generally

plotted on a map and isoanomaly curves of equal apparent resistivity are drawn.

From these maps the interpretation of the survey results is made.

Resistivity Equipment

The essential components of resistivity equipment are a current source, either low frequency a.c. or d.c.; a mA-meter for measuring the current put into the ground; a voltmeter for measuring the SP and the potential induced between the electrodes; four suitable electrodes, preferably two of which are of the non-polarizing type for use as potential electrodes; and suitable, well-insulated, cables for connection.

There are many manufacturers of resistivity equipment and there is a great variety of resistivity equipment available both for purchase and rental. The price of this equipment depends primarily on the type of current source used with the equipment. Generally, equipment using d.c. sources of current are less expensive. These do not, of course, have the capability of range or depth of examination of the high power a.c. equipment.

Resistivity equipment ranges in price from about $1000 to over $2,700, depending upon the power source and sensitivity of the equipment. This equipment can be obtained from: Geoscience Inc., Geophysical Instrument and Supply Co., Heinrichs Geo-exploration Co., Hoskin Scientific Ltd., McPhar Geophysics Ltd., Scintrex Limited, and Soiltest Inc. Rental costs are about $180 per month. Contract surveys are run by Geoscience Inc., Heinrichs Geoexploration, McPhar Geophysical and Seigel Associates Limited. The cost of this work depends upon the job and a general estimate cannot be given.

Introduction

Magnetic methods are the oldest form of geophysical prospecting; they are also among the cheapest, easiest, and fastest. It is generally a good policy to include a magnetometer survey in any extensive geophysical program.

The earth is completely surrounded by its own magnetic field. Much simplified, this can be thought of as the field a very large bar magnet would produce if the magnet were placed roughly parallel to the earth's axis. (See Figure 13)
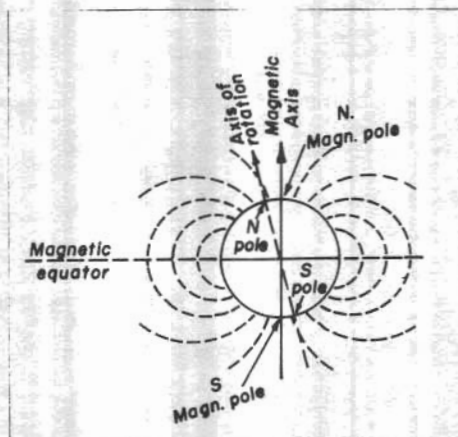
The geomagnetic field is, of course, not as simple as that pictured in Figure 13. Due to variations in the earth's composition, the magnetic field lines (imaginary lines used to illustrate the magnetic field) are not even and symmetrical about the poles, but vary in direction and concentration according to the material

Figure 13 - Magnetic Field of an Earth having Characteristics of Homogenous Sphere. From "Introduction to Geophysical Prospecting" by Dobrin. Copyright 1960, McGraw-Hill Book Company. Used by permission of McGraw-Hill Book Company.

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through which the magnetic field is passing. It is this variation in the magnetic field that is used in magnetic prospecting.

All rocks have some degree of magnetic susceptibility. This can be thought of as the ability of the rock to support or transmit the geomagnetic field. Areas of rocks with a high susceptibility, such as some basalt and diabase rocks, will give higher readings with a magnetometer than limestone and dolomite rocks which have a low susceptibility. The susceptibilities of ore minerals also vary considerably; magnetite, ilmenite, pyrrhotite, and some chromite and manganese ores generally have high susceptibility, while pyrite, hematite, sphalerite and galena have a low susceptibility. Some minerals, notably magnetite, show a magnetic action even when they are not subjected to an external magnetic field. This is known as permanent or remanent magnetism.

Magnetic prospecting deals with the detection of deviations (anomalies) in the geomagnetic field. It is therefore necessary to have some understanding of the nature of this field. As shown by Figure 13, the magnetic field does not have the same orientation to the earth's surface at all points. Near the equator the field is nearly horizontal, while in interior Alaska the field is entering the earth at about 75° to the horizontal. A magnetometer may measure variations in strength in either the vertical (Z), horizontal (H), or total (F) field directions of the geomagnetic field, depending on the type of magnetometer being used and the purpose for which it was designed.

Magnetic prospecting is somewhat complicated by the fact that the geomagnetic field is not constant with time, but fluctuates in field strength. The changing position of the sun relative to a spot on the earth's surface causes a fluctuation called diurnal variation. There is generally an increase in field strength as the sun approaches the

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zenith. Another cause of magnetic fluctuation is magnetic storms which cause large and erratic changes in the field strength. Diurnal variation and mild storm variation can be compensated for in doing field work, but work must be halted during periods of an intense magnetic storm. Figure 14 shows the variation in vertical intensity in three different days at College, Alaska. Day (A) was a very quiet day. Day (B) shows some mild storm activity but field work could have been conducted if corrections for the variation in intensity were made (this is discussed under Field Work). Day (C) was a fairly stormy day, magnetically. Variations are so abrupt that results of surveying on such a day would be questionable. After some field experience it is relatively easy to detect periods of magnetic storms because of the rapid and erratic variations in readings. The United States Coast and Geodetic Survey, with whose kind permission the data for Figure 14 was obtained and reproduced, maintains magnetic observatories in several parts of the world. Two of these are at Sitka and College, Alaska. Before magnetic prospecting is done, it would be wise to obtain information concerning storm activity from this agency.

The standard unit of magnetic field strength is the gauss. For geophysical purposes, a sub-unit, the gamma (γ) which is $1/100,000$ of a gauss, is more convenient and most magnetometers are calibrated to read in gammas. The normal strength of the earth's magnetic field is about 0.6 gauss or 60,000 gammas. Ore bodies may produce fields on the order of hundreds or thousands of gammas in addition to the normal geomagnetic field.

Field Work

When doing magnetic field work the instrument operator should be careful to wear a minimum of iron or steel objects; this includes sidearms, knives and belt buckles.

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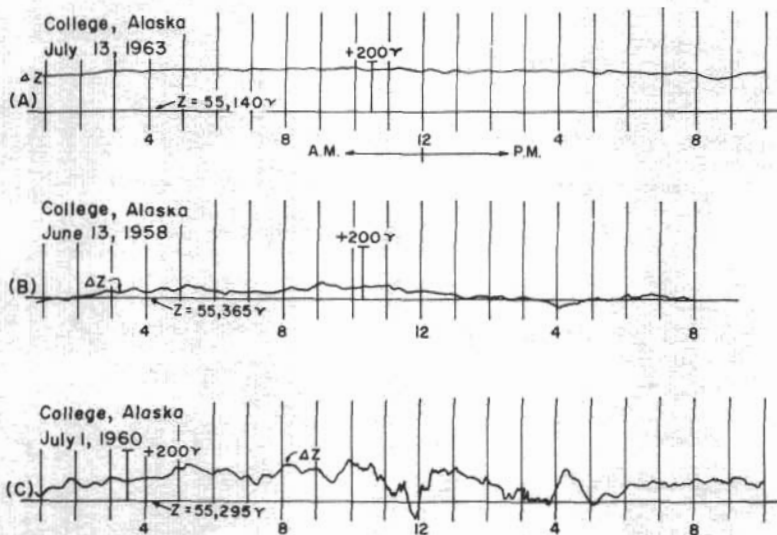
Figure 14 - Variation in vertical Intensity (Z) at College, Alaska, on
(A) a quiet day, (B) a moderate day, and (C) a stormy day.

He must also avoid large metal objects, according to Heiland, 1963, there should be
no railroad tracks within 125 yds., no automobiles within 30 yds., and no wire fencing
within 35 yds.

Diurnal variation, discussed earlier, may be compensated for in one of two ways.
The first involves the use of two magnetometers. One magnetometer, the field instrument,
is used for field measurements while the other, usually a continuously recording type, is
left running at some convenient base station. The diurnal change at any instant is read
directly from the base instrument and this is added to or subtracted from the station
reading. This method is costly in that two expensive instruments are required and this
degree of precision is not usually necessary.

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For most prospecting surveys it is usually sufficient to pick some base station, preferably in a magnetically "flat" area, and take readings at this station at some regular time interval, usually every one or two hours. As field readings are taken the time of each reading should be recorded. If when checking into the base station after two hours work it is found that diurnal change has increased the base station reading by fifty gammas, it will then be necessary to subtract twenty-five gammas from a field reading taken one hour earlier, thirty-seven and one-half gammas from a reading taken one-half hour earlier, and so on. This assumes a linear diurnal change, which is not necessarily true (see Figure 14), but as was stated before, this is accurate enough for most prospecting work.

Figure 15 shows another method for making diurnal variation corrections, this graphical method is often the most convenient when a great number of readings are to be corrected. On the day for which Figure 15 is the correction graph, magnetic observations were made between ten a.m. and one p.m. At ten a.m. the magneto-meter was set to read the previously determined value for the base station and the survey was begun. When checking into the base one hour later, it was found that the base reading was now eleven gammas less than when the survey was started, at twelve the base reading was again the same as the original reading, and at one the base reading was fourteen gammas greater than when the survey was begun. Since all readings were taken at the same station the differences in readings must be due to diurnal and/or instrument drift variations. It is now simple to correct readings taken during this time period. A vertical line is drawn from a point on the graph corresponding to the time at which the field observation was made and the point where this line intersects the graph indicates the amount of correction in gammas

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to be made to that reading. If, for instance, a reading was made at 11:40, a line
is drawn down from this time on the zero correction scale and the correction value
of about three gammas is read on the vertical scale at the left. The field reading
plus three gammas is now the correct value for the point at which the reading was
taken. It should be noted that an increase in the base station reading requires a
negative correction, and vice versa.
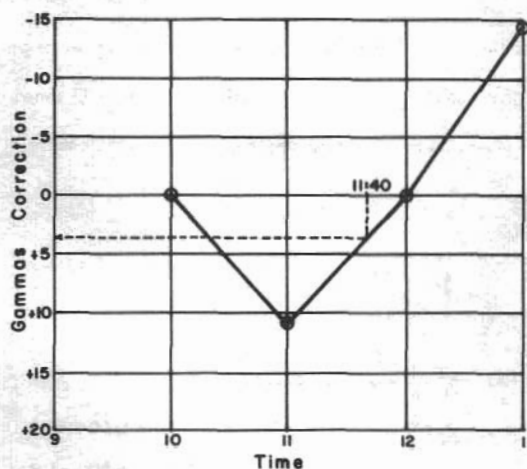
Figure 15 - Correcting for Diurnal Variation.

The essential result of a magnetic survey is the relative change in the field
strength with location, not necessarily the absolute value of the field strength. Most
magnetometers are adjustable so that if one sets his instrument at some convenient
value (in gammas) at his base station each day, all readings, after diurnal correction,
will have the same basis. This simplifies the reduction and plotting of data. Magnetic
results are usually presented as contour maps or profiles of field readings minus back-

ground, that is, the local value of magnetic intensity away from the ore deposit.

With the fluxgate or nuclear precession magnetometer it is possible to measure the vertical gradient of the earth's magnetic field. This method involves taking two readings at each station with as much vertical separation as practicable, but over the same spot. (See Figure 16) The fluxgate magnetometer must be roughly leveled, therefore only about a three-foot separation is generally possible. The nuclear precession magnetometer which requires little or no orientation and usually has an external sensing probe can be used more readily for this purpose. The vertical gradient is the magnetic reading at the higher height minus the magnetic reading at the lower height divided by the distance between these positions. Figure 17 shows a man making vertical gradient measurements with a nuclear precession magnetometer.

Vertical Gradient

$$\frac{\partial \Delta Z}{\partial h} = \frac{\Delta Z_2 - \Delta Z_1}{h_2 - h_1}$$

where $h_2 - h_1 << h_1$
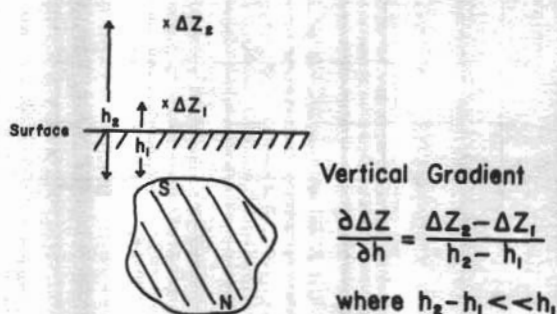
Figure 16 – Vertical Gradient Defined.

Figure 17

Measuring Vertical
Gradient

Figure 18 is a comparison of data for a single magnetic survey presented in two ways; this illustrates the added interpretive value of vertical gradient contours compared with the commonly used total field or vertical intensity contours.
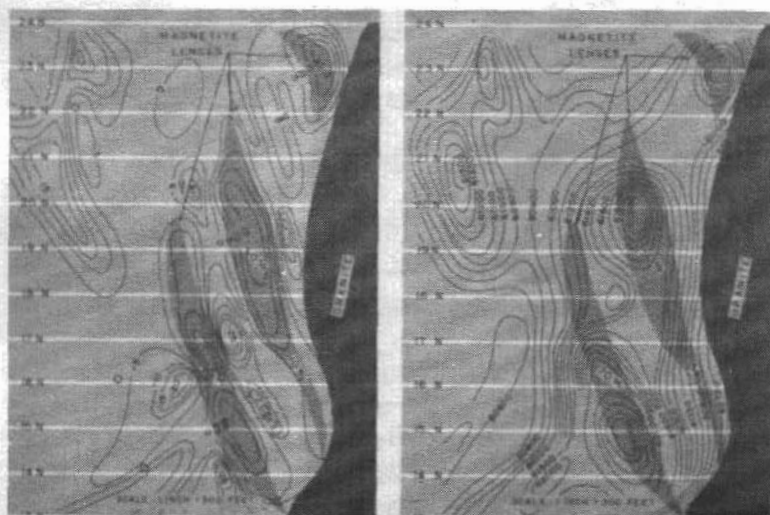
(A) Vertical gradient of total magnetic field contour interval 5 gammas foot. (B) Total magnetic field —contour interval 100 gammas

Figure 18 – Vertical Gradient and Total Magnetic Field Contour Maps

Figure 19 shows a profile of magnetic readings along one survey line. This again demonstrates the value of the vertical gradient method as opposed to the total field or vertical intensity method. Although the plot of vertical intensity does indicate an anomaly over the magnetite veins, the vertical gradient plot gives a very good indication of the exact location of the vein outcrops. This would be a particular advantage when working in areas of considerable overburden or narrow veins.
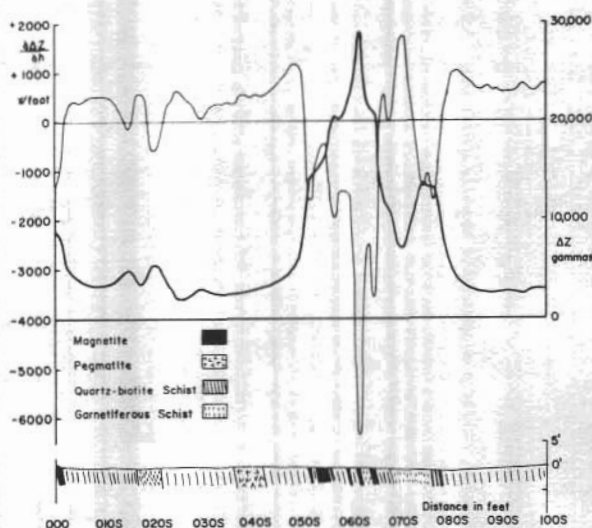
Figure 19 - Magnetic Profiles

Magnetometers can also be used for mapping geologic structures; this is made possible by the variations in susceptibility or different rock types. Figure 20 shows the effect of a lateral susceptibility change in bedrock which is overlain by soil cover. ("k" is the rock susceptibility factor). The magnetometer is also used to help locate the paystreak in placer gold deposits when the gold is associated with concentrations

of black, (magnetite) sands. This method must be used with caution, since as described

above, changes in bedrock or changes in depth of overburden can also effect the results.
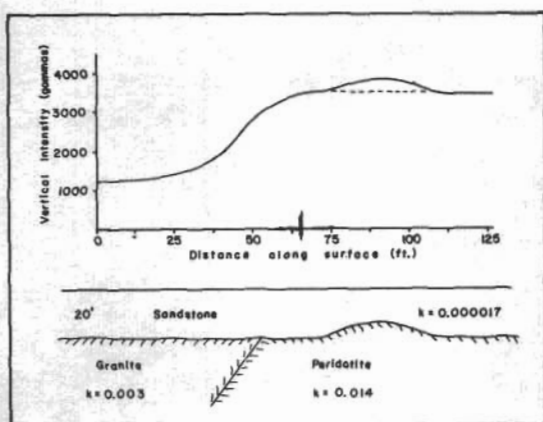
Figure 20 - Comparsion of Magnetic Effect of Lateral Susceptibility Change in Base-
ment with Effect of Structural Feature on Basement Surface.

Magnetic Equipment

There are several instruments that are used to measure magnetic field strength.
Prior to modern electronics and the miniaturization of electronic components the most
commonly used instruments for field measurements were the Schmidt-type magnetic
balance and the torsion magnetometer; both of these instruments require a tripod mount,
are rather bulky and delicate, are slower and require a more experienced operator than
modern portable, electronic equipment.

The modern electronic magnetometers are of two types, the fluxgate and the
nuclear precession magnetometers. Most fluxgate magnetometers measure the intensity
or strength of the vertical magnetic field (Z). Figure 21 shows three fluxgate magneto-
meters; one, Figure 21-A, made by Scintrex Limited of Toronto, Canada, and Figure
21-B, Jalander is made by Optillinen Tehdas, Helsinki, Finland. As can be seen,

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A

B

GM-102 Magnetometer Counter Unit, Noise Cancelling
Sensing Head, Staff Connector, Headphones, and Battery Belt.

C

Figure 21 - Examples of Available Magnetometers. (A) MF-1-100 Fluxgate,
(B) Jalander Fluxgate, and (C) GM-102 Nuclear Precession.

both of these instruments are small, portable and can be easily read; this is typical of most fluxgate magnetometers. Depending upon the sensitivity of the instruments, fluxgate magnetometers range in price from about $2000 to about $3500. These instruments are available from Exploration Methods Inc., Geophysical Instrument and Supply Co., Heinrichs Geoexploration Co., Huntec Ltd., McPhar Geophysics Ltd., and Scintrex Limited. See Appendix for the addresses of the above firms.

The nuclear precession magnetometer measures the total strength (F), of the magnetic field. These instruments need not be oriented for readings, but are generally somewhat larger and heavier than the fluxgate magnetometers. These instruments are usually more expensive than fluxgate magnetometers and range in price from about $3200 to $4000 for portable ground equipment, and up to more than $13,000 for sophisticated systems for airborne surveys. Figure 21-C shows a nuclear precession magnetometer made by Barringer Research Ltd. Nuclear precession magnetometers are available from Barringer Research Ltd., Geophysical Instrument and Supply Co., and Varian Associates.

ELECTROMAGNETIC METHODS

Introduction

There are several electromagnetic methods and types of equipment available. Some of these are extremely simple to run and relatively inexpensive, while others are highly sophisticated and require considerable experience and money to produce meaningful results. When compared to other methods, electromagnetic surveys must be classed as fast.

This method is used quite extensively for exploration in Canada where both ground and airborne techniques are utilized. Electromagnetic surveying is primarily used for the location of massive and vein type deposits. The method is good for locating minerals with high conductivities such as galena, graphite, chalcopyrite, pyrite, pyrrhotite and magnetite. Due to low conductivity, minerals such as hematite, sphalerite and chromite will not produce anomalies unless they also contain sufficient amounts of conductive minerals such as those listed above. Electromagnetic disturbances can also be caused by faults, fractures, zones of crushed rock and fissures containing water.

The electromagnetic method is based on the interrelation of two fundamental physical phenomena—electricity and magnetism.

When a strong alternating current passes through a wire, usually wound in a coil for this purpose, it produces an alternating magnetic field (referred to as the primary field) about the coil. If there is a conductive mass near the coil, the primary alternating magnetic field produces an alternating electrical current in this mass. This secondary electrical current then produces its own alternating magnetic field, known as the seconda

field. The secondary field, along with the primary field, produces a resultant total field. (See Figure 22-A). It is measurements of the differences between the primary field and the resultant field that are used in electromagnetic surveying. Figure 22-A shows the most common and easiest measurement that can be made of the total field, that is, the difference in direction between the total field and the primary field; as can be seen, the greater the secondary field, the greater the direction difference.

Figure 22-B shows other measurements that can be made of the resultant total field; the vertical and horizontal components of the total field.

Figure 22 - Resolution of Magnetic Field Vectors into Space Components.

In addition to the obvious direction distortion of the primary field, the time reference or the "phase" is usually changed so that a portion of the total field is "in-phase", that is, similar in time to the transmitted field; and a portion is "out-of-phase", this is, changed in time reference. (See Figure 23-A). In general, the poorer the conductivity of the mass, the greater the out-of-phase portion of the total field. In a perfect conductor the field is all in-phase (no time distortion). Figure 23-B shows the relationship between the transmitter current, (the primary field), and the receiver voltage (from the secondary field) with its in-phase and out-of-phase components. Many electromagnetic methods are based on the measurements of the amplitude (strength) of either the in-phase or the out-of-phase component, or both of these.

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Phase shift

Current at transmitter

Voltage at receiver
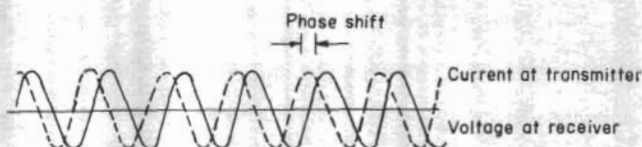
PHASE SHIFT BETWEEN THE VOLTAGE OBSERVED AT THE RECEIVER AND THE CURRENT SUPPLIED TO THE TRANSMITTER

(A)

Current to transmitter

Phase angle

Voltage at receiver

In-phase component

Out-of-phase component
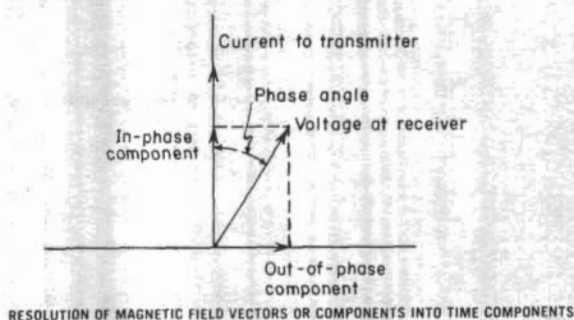
RESOLUTION OF MAGNETIC FIELD VECTORS OR COMPONENTS INTO TIME COMPONENTS

(B)

Figure 23 - Phase Shift and Resolution of Electromagnetic Field

A great variety of methods differing in primary field source-total field receiver layouts are employed in electromagnetic prospecting. The most convenient manner of classifying these is to divide them into two main catagories: (1) methods in which the source of the primary field is stationary and the receiver mobile (called fixed-source); (2) methods in which the source as well as the receiver is mobile (called moving-source). It is important to consider the differences between fixed-source and moving-source methods in selecting the best method for a particular type of exploration problem. The depth of

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search which can be achieved with moving-source equipment may not be adequate for some types of problems, so that a large fixed-source method must be employed. Generally, the greatest depth of search is no more than half the distance between the source and receiver. The separation between the source and the receiver is limited by the intensity of the magnetic field that can be developed by the transmitter, and this in turn is limited by the amount of weight which can be carried with mobile equipment. Standard moving-source equipment can be used with a separation of 300 to 400 feet, implying a maximum depth of search of about 150 to 200 feet under ideal conditions; best results are obtained with moving source methods when the target is no more than 50 to 100 feet in depth. With fixed-source equipment, it is reasonable to prospect to depths of several hundred feet, and under ideal conditions, manufacturers of some equipment claim search depths of up to 1000 feet. Fixed-source equipment is somewhat more difficult to use than moving-source equipment and is generally slower. They are, however, far more effective in mountainous areas. If a large area is to be surveyed in detail and to a great depth it would seem advisable to consider hiring a professional geophysical exploration concern with the proper equipment and experience.

Field Methods

The two most popular methods, the tilt angle and phase angle methods will be discussed briefly. The tilt angle method is probably the simplest and fastest of the electromagnetic systems available.

Tilt Angle:

Tilt angle electromagnetic instruments are among the cheapest available, starting at approximately $1400. Figure 24 illustrates the three configurations commonly used. To initiate an EM survey, a grid is cut with lines 200 to 600 feet apart and

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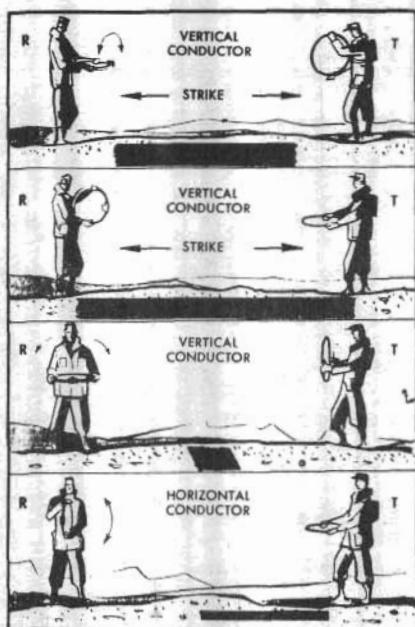
Figure 24 - Dip Angle Configurations

stations on line 50 to 100 feet apart. The parallel line method requires that configuration A, Figure 24 be used. In this case the transmitter is held in a vertical position and the coil is rotated about a horizontal axis which points toward the transmitter. This is illustrated by Figure 25. The traverse lines are aligned at approximately 90° to the expected strike. Both coils are moved up two parallel lines stopping at each station for a tilt reading. Figure 26 illustrates the type of profile plot to be expected from a grid survey over an orebody. Manufacturers specifications for these methods are very explicit. For this reason further details concerning other tilt angle configurations will not be considered here.

Phase Angle Methods:

II PARALLEL LINE METHOD

Figure 25

These methods generally utilize a source coil fed by a 1-5 watt oscillator. Some units provide 2 or more source frequencies. A reference voltage is needed and for this reason the transmitter and receiver are connected by a cable. The receiver generally produces readings in terms of phase angle or real and imaginary components;
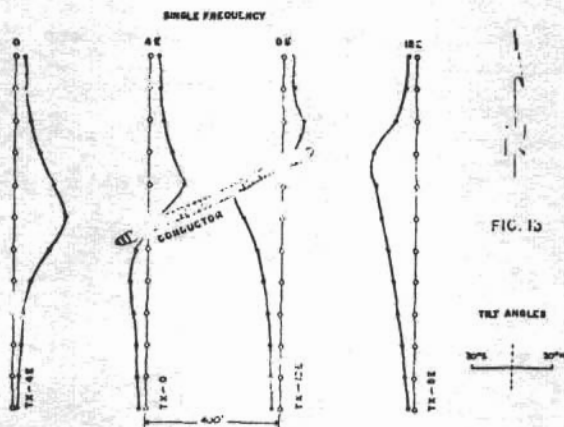
Figure 26 – Broadside Technique – Typical Survey Results

in either case the readings obtained may be directly plotted. Figure 27 illustrates

one such unit.
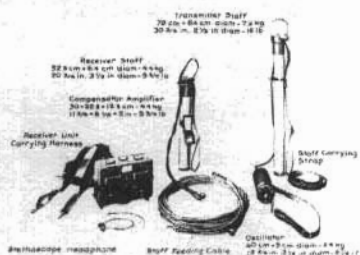
Figure 27 – Typical Two Frequency Electromagnetic Unit

A survey is run with the receiver either leading or following the transmitter down lines, stopping at each station for a reading. The lines are again layed out perpendicular to the assumed strike of the area. Readings are plotted at the midpoint between

the transmitter and receiver. Figure 28 illustrates a typical profile over an orebody.

The phase angle method offers more information than the tilt angle method. The real and imaginary component readings help to discriminate between good and poor subsurface conductors. If the real/imaginary ratio is large, the conductor is good; conversely, if it is small the conductor is poor. The ratio is obtained simply

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by dividing the real component by the imaginary component. An average conductor is often considered as one which has a real-imaginary ratio of 1.0.
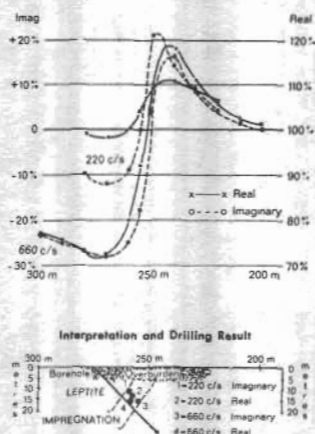
Figure 28 - Typical Electromagnetic Profile

EM Equipment and Consulting Rates

Both the moving source tilt angle method and phase angle methods require a transmitter and receiver. The phase angle equipment also generally require a device known as a compensator and interconnecting wire between the transmitter and the receiver. Fixed source equipment require a variety of auxillary equipment, including portable electrical generating sets. Tilt angle EM gear is priced from approximately $1400 to $3500. Phase angle equipment starts at approximately $3500. Fixed source equipment starts at approximately $3500.

Rental rates for reconnaissance tilt angle units are approximately $120/mo. minimum with daily rates on the order of $12. Rates for other EM gear run from about $360 to $700 per month. Firms which sell Electromagnetic equipment are listed in the appendix. Some of these firms will do contract surveys. Bids may generally be obtained on a job, its location, terrain, etc. One figure of $250 per day was obtained from an exploration company. This does not include expenses.

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GRAVITY METHODS

Introduction

The gravity method can provide valuable information for mineral prospecting, but due to the high cost of this equipment and the cost and time required for making gravity surveys, their use is usually limited to detailed exploration work. This method is also used quite extensively by the petroleum industry in exploration for deep oil bearing formations.

If an object is allowed to fall towards the earth, it will attain a velocity of about 980 centimeters per second (32 ft./sec.) after falling for one second, and 1960 cm per sec. (64 ft./sec.) after falling for two seconds. This time rate of change of velocity is known as gravitational acceleration; near the earth the acceleration due to gravity is about 980 cm/sec.^{2} (32 ft./sec.^{2}). Gravitational acceleration (g) is due to the force of attraction that exists between any two objects between the earth and the sun, between a person and the earth, and between two balls on a billiard table. The magnitude of this force depends on the masses of the objects and the distance between them. If you could weigh yourself very accurately first over the Carlsbad Caverns and then over Fort Knox, you would find that you weighed slightly more when over Fort Knox (neglecting latitude, elevation factors and rock density). This is because the mass (the density) of the material beneath you is greater and therefore exerts a greater force on you.

In gravity surveying the acceleration due to gravity is the quantity that is measured. This is known as the gal (g) and is the distance in centimeters an object

would fall from rest in one second. Since the acceleration due to gravity is about 980 cm/sec.^{2}, this is then equal to 980 gal. According to Resnick and Halliday, 1960, "g" varies in a systematic manner from 978.039 gal at the equator to 983.217 gal at the poles and at 45° latitude, the variation of "g" with altitude is from 980.6 gal at sea level to 959.8 gal at 100,000 meters.

The gravity method involves the systematic measurements of "g". This is not very difficult, although precision instruments for this purpose are very expensive. The difficulty with gravity surveying lies with the amount of associated data and the number of corrections that need to be made to the raw reading in order to make the gravity measurements meaningful. As seen from the above discussion of gravity, g varies with altitude and latitude as well as with the density of the material beneath where g is being measured. For these reasons, the gravity method is not generally employed for reconnaissance prospecting; it is sometimes applied as a method for the detailed examination of a property. One instance where the gravity method is of value would be to determine whether an electromagnetic anomaly is caused by a massive sulfide deposit or by a thin sulfide vein or a graphite zone.

As was stated earlier, the cost of gravity equipment is very high, generally beyond the means of an average prospector, and unless a great deal of work were to be done, such an investment would not be justified by even a fairly large company. With this consideration in mind, this handbook will not go much further into the subject of the gravity method except to introduce some of the terminology, the major uses of the gravity meter, and present the cost of some of this equipment and rental price from geophysical companies.

Field Work

Most gravity work in mineral exploration is involved with the detailed examination of a property; for this reason, most surveys are carried out over a fairly "tight" grid pattern, that is, the grid points are relatively close together – usually about 100 feet or less. For most surveys a base station is chosen, away from the influence of the ore body, and readings are taken at this station at 1-2 hour intervals, much in the same manner as magnetic surveys. This is required because of the drift inherent to all gravity instruments.

Each field reading must be corrected before the data can be mapped; these corrections are as follows:

1. Latitude correction. Gravity increases with latitude.

2. Elevation or free-air correction. This compensates for the difference between the station elevation and base elevation.

3. Bouguer correction. The elevation correction does not account for the material between the elevation of the station and the base but only for their differences in distance from the center of the earth; the Bouguer correction accounts for the extra gravitational attraction due to the material between these two elevations.

4. Terrain correction. This correction is necessary to account for any material above or absence below the level of the station where a reading is taken. This higher material (or absence below) will, in effect, produce a negative reading, that is, it will detract from the attraction of the material beneath the station and therefore must be corrected for.

As can be seen from the corrections listed above, a great deal of information is required of an area that is to be examined by the gravity method.

Once all corrections have been applied to the raw readings, the differences between station and base are usually plotted on a suitable map grid and isoanomaly contours are drawn.

Gravity Instruments

Since gravity anomalies are very small in comparison to the earth's gravitational force, gravity meters are by necessity very sensitive instruments measuring in units of thousandths of a gal, known as a milligals. Many of these instruments have a very high precision, giving measurements to the nearest 0.01 milligal. The gravity meter works on a counter-balance system; when the gravitational attraction is greater, a weight suspended by a spring in the meter will cause the spring to be stretched, and it is this displacement of the weight and spring that is actually measured. A calibration factor is applied to convert the displacement reading to a gravity reading in milligals.
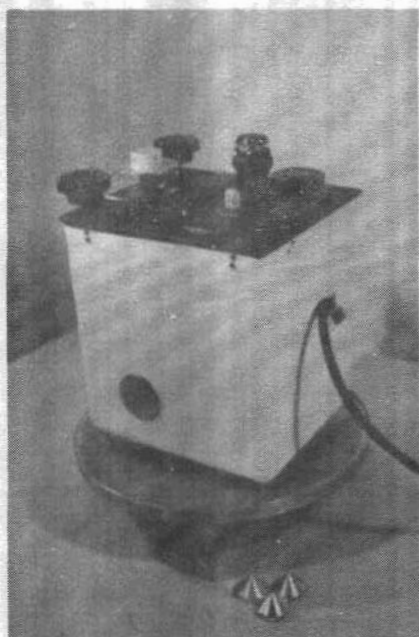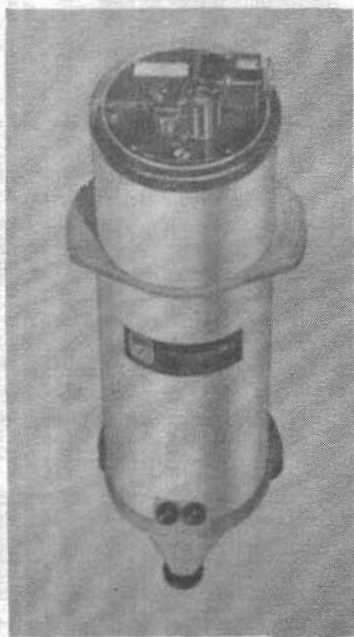
A   B

Figure 29 — (A) The Land Gravity Meter made by LaCoste & Romberg of Austin, Texas. (B) Model CC-2 Gravity Meter made by Sharpe Instruments of Canada.

Two commercially available gravity meters are shown in Figure 29; these instruments are very accurate and surprisingly durable when the sensitivity of measurements is considered.

New gravity meters cost from about $6000 to $10,000 depending upon the sensitivity of the instrument; this equipment is available from Geophysical Instrument and Supply Co., LaCoste & Romberg, Sharpe Instruments of Canada, and Texas Instruments Inc. Rentals are available through Huntec Ltd., Scintrex Ltd., and Texas Instruments, LaCoste and Romberg and Radar Exploration Company.

RADIOMETRIC METHODS

Introduction

The radiometric method is one of the most restricted of the geophysical methods in that it is useful in the search for only a very few minerals. This method is quite easy to perform and equipment is relatively inexpensive; but generally speaking, this method is useful only in search of minerals containing uranium and thorium.

Some minerals contain elements which undergo a natural process known as radioactive decay. These elements break down into other more stable elements by emitting subatomic particles (alpha and beta particles) and electromagnetic radiation called gamma rays. Alpha particles are quite weak, that is, they will not penetrate more than a very small thickness of matter and will not even penetrate the human skin. Beta particles will travel further, but still a relatively small distance through solid material. Gamma rays, like x-rays, will penetrate quite far through most materials and an almost infinite distance in air, but even these will be weakened beyond the detection level by about twenty inches of solid rock and a somewhat greater thickness of soil. As can be seen, in general, a radioactive source must be exposed to be detected or it must at least be very close to the surface.

There are several naturally-occuring radioactive elements, but most of the *radioactivity encountered is caused by the disintegration of uranium, thorium, or* potassium. There is always some radiation at any point, this is the normal "background" level of radiation caused by cosmic rays and the small amounts of radioactive material found in most rocks.

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Field Procedure

In using radiation counters in the field, the common procedure is to walk over the area, usually on some sort of a grid pattern so that readings can be located on a map, and continuously monitor the radiation counts. An area of interest should give readings at least 2 to 3 times greater than the normal background count. Radioactive ore deposits often produce readings 10 to 100 times background. Since a radioactive deposit is easily obscured by overburden, it is often a good practice to take readings close to the ground and to remove some of the surface material to see how this affects the counter readings.

Equipment

There are two types of instruments commonly used to detect radiation. These are the geiger counter and the scintillation counter. The geiger counter has a tube filled with a gas, such as helium or argon, which is normally not an electrical conductor, with a high voltage wire extending through the center of the tube. When a gamma ray or a beta particle passes through the tube, it will sometimes hit one of the gas molecules causing it to become ionized, that is, to become an electrical conductor. This charged molecule is then attracted to the wire and causes an electrical pulse. These electrical pulses are amplified and appear either as dial readings of some number of counts (pulses) per minute, as a flashing light, or as a sound in earphones. The problem with a geiger counter is that only about one in every hundred gamma rays which pass through the tube will hit a molecule and cause a pulse, therefore, the geiger counter is somewhat insensitive. It cannot, for instance, be used for airborne work.

The scintillation counter uses certain crystals which emit a flash of light (scintillate) when a gamma ray passes through them. The scintillations are detected by a

photomultiplier tube, amplified, and indicated on a meter. The advantage of the scintillation counter is that it reacts to every gamma ray which passes through the crystal and therefore this is a much more sensitive instrument. Figure 30 illustrates one model which is available from Scintrex Ltd.
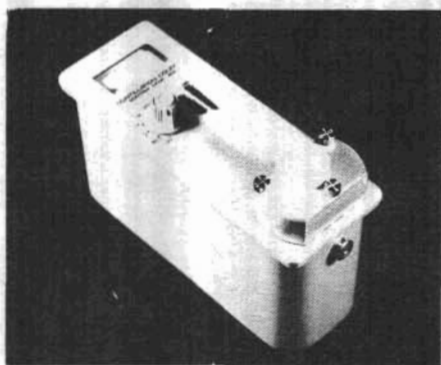
Figure 30-Scintrex BGS-1 Scintillation Counter

Geiger counters usually range in price from $125 to $150, depending upon the accessory equipment included. The cost of scintillation counters starts at about $500 and ranges upwards to more than $8000 for some very sensitive equipment for airborne surveys. More information about this equipment and its cost can be obtained from the following manufacturers and distributors: Geophysical Instrument and Supply Co., Scintrex Ltd., Universal Atomics Corp., McPhar Geophysic and Ward's Natural Science Establishment Inc.

SEISMIC METHOD

Introduction

The seismic method is not generally used for mineral exploration, but a brief discussion of the method will be included here for the sake of completeness. The primary applications of the seismic methods are in petroleum exploration, geological engineering and civil engineering. Seismic surveys are used to determine the thickness of overburden for mining or civil engineering projects (depth to bedrock), location of minor faults and other near surface geologic features, and mapping of deep geological structures in search of possible oil bearing formations.

The rate at which a seismic wave propagates through the earth, whether the wave is due to an earthquake or a dynamite blast, depends partly upon the density of the material through which the wave is passing. Loose material, such as soil or unconsolidated sand and gravel, has a lower bulk density than solid rock, and therefore a seismic wave will travel more slowly in this material than in solid rock. Also, since different rock types have different densities, the rate of propagation of a shock wave in rock will vary, and some knowledge of the rock type can sometimes be deduced from this information.

There are two seismic methods, refraction and reflection seismology. Refraction seismology is used for shallow or near surface investigations, such as for engineering purposes, while reflection seismology is used for deep investigations for natural oil traps such as anticlines and faults. It is so highly unlikely that the prospector or even the average engineer will ever encounter reflection seismology that nothing more will

be said here about that method.

Field Work

Since the possibility exists that the prospector may have occasion to use refraction seismology for determining the depth to bedrock, a brief description of this technique will be given here.

Figure 31 shows a section of a simple bedrock-soil profile in which the thickness of the soil layer is unknown. A line is laid out on the ground with points at some interval such as that shown. Geophones are set at points A and B and a shock wave is produced at point B by dripping a heavy weight to the ground or by detonating an explosive charge. The time required for the shock wave to travel from B to A is measured by connecting the geophones to a seismic timer. This same procedure is followed for each successive point, measuring the travel time of the shock wave first from B to A, then C to A, and so on. Some commercially available seismic timers are built so that the timer is started by the pulse received from the geophone at the point where the shock is initiated and stopped when the shock reaches the second geophone and its pulse is received by the timer.

The standard method of computing the depth to bedrock from seismic observations is by means of a semi-graphical solution. With this method, a graph is constructed of travel time in milliseconds versus geophone separation, see Figure 32. The recorded data from a sewsmic survey is shown below and Figure 32 is a graph of this data.

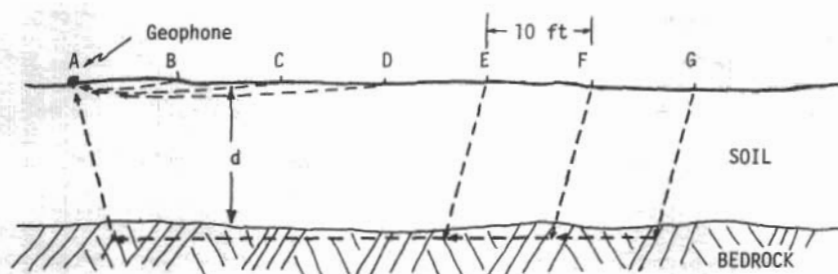| Stations	Separation	Travel Time
B to A	10 ft.	10 milliseconds
C to A	20 "	20 "
D to A	30 "	30 "
E to A	40 "	38 "
F to A	50 "	40 "
G to A	60 "	43 "

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Figure 31- Bedrock-soil profile showing the travel path of the first arrival seismic wave from each point.
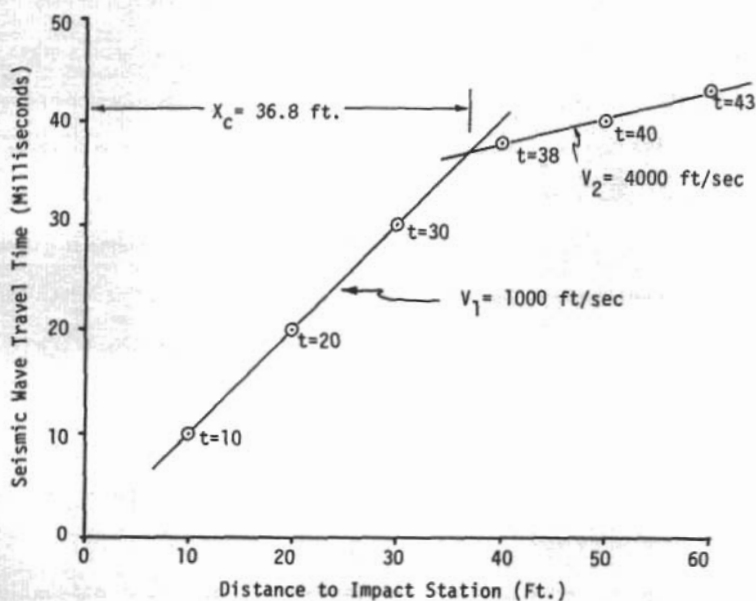

Figure 32- Graph of Travel Time vs. Separation

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As shown in Figure 31, the path of the seismic wave which will first reach point A depends on the relative location of the shock, the density of the material, and the depth of burial of bedrock. From points B, C, and D to A the velocity of sound in the soil, called V_1, is such that the seismic wave transmitted through the soil will arrive at A before any wave traveling any other path. This is not the case with the travel path from points E, F, and G to A, it can be seen that travel of the seismic wave, strictly in the soil from E to A, would take 40 milliseconds; this does take place, but it is not the first wave to arrive at A. This difference lies in the fact that a wave can travel more quickly from E, down through the soil at velocity V_1 to bedrock, then through the bedrock at a much higher velocity V_2, and then back up through the soil at velocity V_1, arriving in this case at A two milliseconds before the wave traveling only in the soil layer.

From the graph (Figure 32) the velocities V_1 and V_2 are computed by finding the reciprocal of the slopes of their respective lines. Slope is the increase in value in the upward direction on the graph as this increase is related to an increase in values across the graph. For instance, the difference in travel time with an increase in geophone separation from 20 to 30 feet is 10 milliseconds, the slope of this line is then 10 milleseconds/10 feet or 1 millisecond per foot. The reciprocal of a number is one (1) divided by that number, in this case, this is 1 divided by 1 millisecond per foot which equals 1 foot per millisecond or 1000 feet per second, since 1000 milliseconds equal 1 second. Similar comutations made of the upper line of the graph will indicate a velocity of 4000 feet per second for V_2.

The point on the graph at which the two lines cross is known as the critical point, and the distance of separation that this point represents is known as the critical distance (X_c), in this case $X_c = 36.8$ feet.

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Once the critical distance and the two velocities are computed, the depth to bedrock can be calculated with the following formula:

$$\text{Depth } (d) = \frac{X_c}{2} \quad \frac{V_2 - V_1}{V_2 + V_1}$$

In The example cited above, the depth to bedrock is:

$$d = \frac{36.8}{2} \quad \frac{4000 - 1000}{4000 + 1000} \quad = 18.4 \quad \frac{3000}{5000} \quad = 18.4 \quad 0.60$$

$$d = 18.4 \, (0.775) = 14.3 \text{ feet}$$

Seismic Equipment

The seismic timer - There are many models of seismic timers available; the simplest of these has a needle which indicates motion at a geophone, this needle leaving a trace on graph paper which moves at a certain time rate past the needle, usually one millimeter per millisecond. In this way, the time interval between seismic wave arrival at two geophones can be determined.

The geophone - Most geophones are small, sturdy, electro-mechanical devises which generate a small electrical pulse when seismic waves pass them.

Since there are a great many companies who make seismic equipment and it is difficult to compare this equipment due to the great variation in it, only the names of several of these companies will be given here and no comparison or prices will be given. It is sufficient to say that equipment capable of good service will usually cost in the vicinity of $2000, although there may be exceptions to this. Seismic equipment and supplies can be obtained from any of the following companies: Dyna Metric Inc., Electrodynamic Instrument Corp., Geophysical Specialties Co., Hoskin Scientific Ltd., Huntec Ltd., Mandrel Industries Inc., and Soiltest Inc.

Geoscience Incorporated and Mandrel Industries Incorporated rent seismic equipment. Geoscience Incorporated also offers contract crews for refraction seismic for mining and engineering applications.

AIRBORNE GEOPHYSICS

Applications and Types

The principal objective of airborne geophysics is the separation of areas which appear to be barren from those which appear to hold promise of ore. In addition, a considerable amount of regional structural information can be obtained from airborne measurements. Airborne work permits rapid accumulation of data over very large areas. Therefore, the costs of airborne surveys per line mile are many times smaller than the costs of corresponding ground surveys, provided that the area being surveyed is large. Fixed costs of airborne surveys usually rule them out for use in small areas. Aerial work can be carried out over areas covered with alluvium, lakes, glaciers, swamps, etc., to which access may be difficult for ground parties.

Costs of airborne surveys depend upon a number of factors:

1. Size of the project.

2. Logistics.

3. Instrumentation.

4. Type of aircraft.

5. Topography.

Airborne geophysical methods may be classified as magnetic, electromagnetic, and radiometric. There are available on the market a great many variations to each of these methods. Only the basic approach for the general methods will be discussed.

Magnetic Methods

Magnetic instruments measure variations in the local geomagnetic field which

are produced by differences in the intensity of magnetization in various rock formations. The magnetic method is a valuable tool, therefore, for regional geological mapping. Corrected data are plotted on maps, and the maps are evaluated, often resulting in good "guesses" as to the regional geology of the area being flown. Ground geologic mapping programs are greatly assisted when airborne magnetic maps are available.

Canada has published an enormous number of magnetic maps through the office of the Geological Survey of Canada. These maps outnumber those produced by all other countries of the free world.

Electromagnetic Methods

All electromagnetic systems detect the presence of electrically conductive material by measuring the change that takes place in the mutual coupling between two coils when they are brought near conductive material. A variety of airborne electromagnetic systems are available, differing in the aircraft employed, frequencies, coil separations, flight height and so on.

Electromagnetic systems employ a transmitting and receiving coil; if the trans-mitting coil is carrying an alternating current, it will create an electromagnetic field which induces a voltage in the receiving coil proportional to the mutual coupling between coils. This coupling is inductive; the induced voltage must, therefore, be in phase with the electromagnetic field and the current in the transmitting coil.

If conductive material is brought into the vicinity of the coil system, it will introduce additional coupling between the coils. The additional voltage induced in the receiver coil produces components both in phase and quadrature ($90°$ out of phase). Both of these components are used as the "detector" in many electromagnetic systems.

Graphite, pyrrhotite, pyrite, chalcopyrite, galena and magnetite are good

conductors of electricity, while hematite, zinc blende, braunite and chromite are almost insulators (Parasnis, 1968). Ores not directly suited to electromagnetic detection can be found with this method, if suitable quantities of an accessory mineral having good electrical conductivity are contained in the deposit.

False anomalies may result due to graphite beds, faults, fractures in the bedrock, zones of crushed rock, fissures bearing conductive water, etc. These anomalies may, in some cases, have an indirect connection with ore deposits.

Depth penetration of electromagnetic methods is limited. There is considerable controversy concerning the actual depths which may be reached by the various airborne systems. Certainly the depth is less than 500 feet; probably 200 to 300 feet is more realistic.

The ultimate result of an airborne electromagnetic survey is, of course, the map, which provides "targets" for mineral exploration.

Radioactive Methods

Scintillation counters have been developed which differentiate counts due to radiation from different elements. It is, therefore, possible to obtain individual counts for potassium, uranium and thorium. These counts are mapped, and areas high in any of the three elements stand out as anomalies. Radioactive methods are also helpful for geologic mapping. All rocks, igneous as well as sedimentary, contain traces of radio-active elements. If the different rocks, strata and facies have significantly different radioactivity, they can be distinguished and mapped.

Combined Methods

Each airborne method will produce an anomaly map. By combining magnetic,

electromagnetic, radiometric, topographic and geologic maps, it is possible to eliminate many false anomalies. Figure 33 illustrates a combined setup using a helicopter. Figure 34 shows a Canso aircraft towing a bird.

Costs of airborne geophysics are not considered within the scope of this report. Roughly speaking, however, magnetic surveying ranges from approximately $8 to $20 per line mile and combined methods from approximately $25 to $50 per line mile.
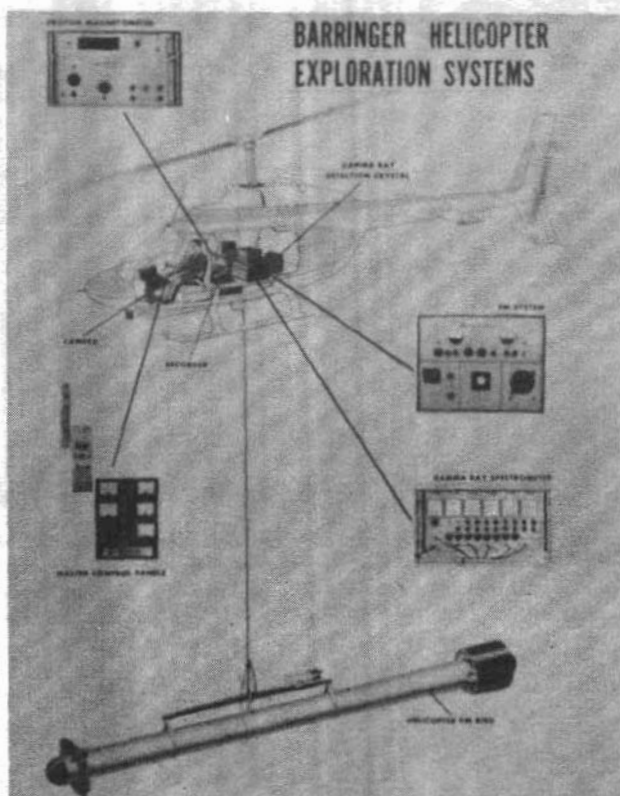

Figure 33 - Barringer Helicopter Exploration Systems

Figure 34 - Airborne Magnetometer System with Bird

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   Dyna Metric Inc.
   Geophysical Instrument & Supply Co.
   Geoscience Inc.
   Heinrichs Geoexploration Co.
   Huntec Ltd.
   LaCoste & Romberg
   McPhar Geophysics Ltd.
   Sharpe Instruments of Canada, Ltd.

10. **Mining Geophysics Vol. I, CASE HISTORIES, Vol. II, THEORY, SOCIETY OF EXPLORATION GEOPHYSICISTS, Tulsa, Oklahoma.

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    COLLINEAR DIPOLE-DIPOLE ARRAY, Heinrichs Geoexploration Co., Tucson,
    Arizona.

**Very highly recommended to those who desire a thorough understanding of the
  geophysical exploration techniques.

MANUFACTURERS AND DISTRIBUTORS OF GEOPHYSICAL EQUIPMENT

Name	Type of Equipment
1. Barringer Research Limited 304 Carlingview Drive Rexdale, Ontario, Canada	Magnetic, E. M., Contract surveys Rental: E. M. & Magnetic
2. Dyna Metric Inc. 330 W. Holly Street Pasadena, California 91103	Seismic
3. Electrodynamic Instrument Corp. 1841 Old Spanish Trail Houston, Texas 77025	Seismic
4. Exploration Methods Inc. P.O. Box 392 Iron River, Michigan 49935	Magnetic
5. Geophysical Instrument & Supply Co. 900 Broadway Denver, Colorado 80203	Magnetic, S. P., I. P., E. M., Resistivity, Radiometric
6. Geophysical Specialties Co. 110 Shores Boulevard Wayzata, Minnesota 55391	Seismic
7. Geoscience Incorporated 199 Bent Street Cambridge, Massachusetts 02141	I.P., MT, Geophysical Research Seismic
8. Geo-X Surveys Limited 627 Hornby Street Vancouver 1, B.C., Canada	Contract Surveys: Ground-E.M. Magnetic & Radiometric Airborne-Magnetic & Scintillation
9. Heinrichs Geoexploration Co. P.O. Box 5671 Tucson, Arizona 85703	Magnetic, S.P., I.P., E.M., Resistivity, Radiometric Contract Surveys – all

10. Hoskin Scientific Limited   Seismic
    1096 Victoria Avenue
    St. Lambert, Montreal 23
    Quebec, Canada

11. Huntec Limited   Contract Surveys
    1450 O'Connor Drive   Magnetic, I.P., Seismic, E.M.
    Toronto 16, Ontario, Canada   Scintillometers

12. LaCoste & Romberg   Gravity
    6606 North Lamar
    Austin, Texas

13. Mandrel Industries Inc.   Seismic, Gravity
    Electro-Technical Division
    P.O. Box 36306
    Houston, Texas 77036

14. McPhar Geophysics Limited   I.P., E.M., Magnetometers, S.P.,
    139 Bond Avenue   Scintillometers, Resistivity
    Don Mills, Ontario, Canada   Gravity

15. Mineral Surveys Inc.   Contract I.P.
    955 Maryvale Drive
    Buffalo, New York

16. Radar Exploration Co.
    Toronto, Ontario, Canada

17. Scintrex Limited   Contract Surveys
    79 Martin Ross Avenue   Magnetic, S.P., I.P., Resistivity,
    Downsview, Ontario, Canada   E.M., gravity, radiometric

18. Soiltest Inc.   Seismic, Resistivity
    2205 Lee Street
    Evanston, Illinois 60202

19. Texas Instruments Inc.   Gravity, Seismic
    3609 Buffalo Speedway
    Houston, Texas 77036

20. Universal Atomics Corp.   Radiometric
    19 East 48th Street
    New York, New York

21. Varian Associates   Magnetic
    Quantum Electronics Division
    611 Hansen Way
    Palo Alto, California

22. Wards Natural Science Establishment   Radiometric
    P.O. Box 1712
    Rochester, New York

Appendix II

TERMS AND GENERAL APPLICATION

IP - INDUCED POLARIZATION - Generally used to locate disseminated sulfide ores.

SP - SELF POTENTIAL - Used in the search for subsurface sulfide mineralization.

RESISTIVITY - Measures resistivity of subsurface rocks. Often used in conjunction
with SP and IP.

MAGNETIC - Methods employ a magnetometer. A general purpose tool for most
mineral surveys.

EM - ELECTROMAGNETIC - Generally used to locate subsurface massive sulfides.

GRAVITY - Helpful in oil prospecting. Can be useful in mineral property evaluation.

RADIOMETRIC - Useful in the search for radioactive ores.

SEISMIC - Most common application is in the petroleum industry.