GEOPHYSICAL PROSPECTING METHODS

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INTRODUCTION

Geophysical techniques have been used in mineral prospecting for the past 300 years, beginning in Sweden around 1640 with the use of magnetic compasses in exploring for iron ore. Resistivity measurements followed in the 1800's in the search for base metals, and by the early 1900's the Schlumberger brothers were successfully using self potential (SP) and resistivity for this purpose. By 1912 Conrad Schlumberger had patented the induced polarization (IP) method, and had used the technique for finding economic sulfide deposits.

The use of applied geophysics for mineral and hydrocarbon exploration as we know it today, probably began in the 1950's, with the advent of sensitive magnetometers, gravity meters, battery-powered electronic equipment, and the application of information theory and computer processing to seismic data acquisition.

Since that time, several different frequency and time-domain electromagnetic (FEM and TEM) systems were developed to map out low resistivity anomalies for massive sulfide exploration. Many of these systems came from Canada, although the first TEM system was imported from Russia in the 1950's.

During the porphyry copper heydays of the 60's and 70's, a number of different geophysical exploration methods were used with varying degrees of success: gravity, magnetics, induced polarization and self potential. Gravity was used to map basement topography and to search for altered intrusive bodies; magnetics were used to search for altered rocks; and IP and SP were used to locate disseminated sulfides, mainly pyrite and chalcopyrite.

Today, these same methods are applied, but can be used with greater accuracy and sensitivity due to technological advances over the past 20 years, especially in the field of electrical geophysics and seismics. For example, IP has evolved from the traditional time-domain approach to multi-frequency IP, now called complex resistivity (CR) or spectral IP, which can be used to differentiate between anomalous responses from alteration, sulfide type, and electromagnetic coupling (an unwanted artifact of the measuring process). Vertical sounding methods such as controlled source audio-frequency magnetotellurics (CSAMT) and time domain or transient electromagnetics (TDEM or TEM) can be used for mapping structure and massive sulfide bodies. CR and TEM are used in both surface and downhole survey configurations. Downhole techniques are being developed for in-hole assaying. Cross-hole tomography is being developed which can be used to assess mineralization and alteration features between drill-holes. Airborne radiometric techniques have been developed which will aid in large-scale alteration mapping. And seismic equipment development and data processing have greatly increased resolution and interpretation capabilities for both deep and shallow applications.

A SUMMARY OF THE DIFFERENT METHODS

Geophysical techniques are routinely used in an exploration program to help the project geologist delineate areas favorable for the type of target being pursued. Geophysical techniques can look beneath alluvial cover. They can be used to directly detect some minerals, indirectly detect others, and to map geological and structural features in exploration programs.

Direct detection includes using induced polarization (IP) to find disseminated sulfides, magnetics to delineate magnetite hosting rocks, and gravity and electrical techniques for massive sulfides.

Examples of indirect detection of targets include using IP to detect pyrite in association with sphalerite and gold (both non-responders to IP geophysical techniques), and copper and molybdenum in porphyry systems. Magnetics are routinely used to search for hydrothermal alteration in association with porphyry systems, and can be used to map buried stream channels (magnetite sands) that might host placer gold.

Geologic mapping applications include using gravity and seismics to map faults and thickness of alluvial fill; magnetics and seismics for mapping structure, and possible signatures associated with different rock types; radiometrics for mapping alteration and geology; and electrical techniques for mapping depth to bedrock, structure, and different rock units.

Often, one of the most difficult tasks in putting together an exploration program is getting geologists and geophysicists to speak the same language - that is, to understand each other in order to effectively use geophysics to help solve the problem at hand. The following table is an effort to list some of the more common topics that might be encountered in such a discussion.

GEOLOGIST'S CONCERN:	*GEOPHYSICIST THINKS IN TERMS OF:*	*APPLICABLE GEOPHYSICAL METHOD:*
permeability, porosity	• resistivity • density	Resistivity, Seismics, Gravity
foliation, bedding	• anisotropy	Resistivity, Seismics, CSAMT, IP, CR
faults and fractures	• abrupt changes in resistivity and density	Resistivity, Seismics, Gravity, Magnetics, CSAMT, TEM, FEM
Metallic luster minerals:		
disseminated	• 0.2 to 5% minerals • weak conductor • low resistivity • moderate to strong IP	Resistivity, IP, CR, SP, Magnetics, Seismics
massive	• greater than 10% mineralization • strong conductor • very low resistivity • moderate to weak IP	Resistivity, CSAMT, TEM, FEM, Magnetics, Seismics, SP IP, CR
alteration	• high or low resistivity depending upon alteration type • weak magnetics • moderate to weak IP	Resistivity, IP, CR (CLAYS), Magnetics, CSAMT, TEM, FEM, Radiometrics, SP
silicification (dike-like) features)	• large resistivity contrasts • potassium	Resistivity, CSAMT, Seismics, Radiometrics
hydrothermal alteration	• low resistivity • weak magnetics • potassium	Resistivity, Magnetics, Radiometrics, Seismics, IP, CR
weathering	• low over high resistivity • weak magnetics	Resistivity, CSAMT TEM, FEM, Seismics, Magnetics, (IP), CR, Radiometrics
buried stream channels	• subtle resistivity changes • magnetic sands • density changes	Resistivity, NanoTEM, Magnetics, Seismics, (TEM, CSAMT)
leaking dams and ponds	• resistivity changes • streaming potentials	Resistivity, CSAMT, SP, NanoTEM, TEM, FEM

GLOSSARY

The following is an abbreviated description of the geophysical methods mentioned above and some of the typical units that are used:

Resistivity: Any of the techniques (including IP) using transmitter and receiver electrodes where the depth of exploration is based on the geometry of the array.

Schlumberger, Wenner, dipole-dipole, pole-dipole are examples of the types of arrays used for measuring and calculating resistivity vs depth sections or profiles.

Resistivity units: ohm-meters.

Magnetics: Total field or vertical gradient magnetic measurements.

Units: gammas or nano-Teslas.

Gravity: The acceleration of gravity. Units: gals, milligals.

Seismics: Refraction or reflection. Depth of exploration is a function of time.

Units: milliseconds vs distance for refraction, milliseconds and feet per second, feet per millisecond, etc., for reflection seismics.

SP: Self potential. Units: millivolts.

IP: Induced polarization. Depth of penetration same as resistivity.

Units: milliseconds in time domain, milliradians or PFE (percent frequency effect-now obsolete) in frequency domain, ohm-meters for resistivity.

CR: A multifrequency generalization of IP. Measurements are made over two or three decades of frequencies in an effort to determine the source of the IP response.

Units: milliradians for phase and ohm-meters for resistivity.

CSAMT: Controlled source audio-frequency magnetotellurics. Depth of exploration is controlled by frequency and earth resistivity.

Units: ohm-meters for resistivity, milliradians for phase.

FEM: Frequency domain electromagnetics. Depth of exploration is controlled by frequency, earth resistivity and receiver/transmitter separation.

Units: percentage for in-phase and quadrature components, ppm or field strength ratio, tilt angle degrees, etc.

TEM: Transient or time-domain electromagnetics. Depth of exploration is controlled by the size of the transmitting loop, earth resistivity and decay time.

Units: milliseconds for time–decay plots, ohm-meters for calculated resistivities.

NanoTEM: A shallow sounding TEM system. Depth of exploration is controlled as above for TEM.

Units: microseconds and milliseconds for time-decay plots, and ohm-meters for calculated resistivities.

Radiometrics: Airborne or ground surveys mapping out natural gamma radiation from uranium, thorium and potassium.

Units: counts per minute, roentgens per hour, electron volts (energy).

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