Geophysics of Exploration for Water

Introduction

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Geophysics

Geophysics belongs to the group of Earth Sciences:

- integrates the knowledge coming from geology, mathematics, physics, and scientific computing,
- uses physical measurements, mathematical models as well as the geological and physical laws of nature to solve problems related to the Earth's interior and surrounding space environment.

Two scientific areas of Geophysics (by the object of investigation):

- Earth's physics,
- applied geophysics.

Geophysics

Earth's physics

deals with the solution of large-scale or global problems.

The research is based on observations coming from global networks of measurement stations (gravity, magnetic, seismographic etc.) and satellites.

Some studied areas:
the investigation of Earth's shape, its gravitational and magnetic fields, its internal structure and composition etc.

Applied Geophysics

Applied geophysics

Its main objective is to help in solving different practical problems related to the subsurface by using physical measurements.

It tries to provide useful information for mining industry, hydrological, environmental, geotechnical and archaeological surveys.

The investigated volume is limited to the upper part of Earth's crust and ranges from the surface to a maximum few 1000 metres.

Near-surface geophysics

is a special area of applied geophysics which focusses on the investigation of small-scale objects and structures of the shallow subsurface (from the surface to a few 100 metres).

Applied Geophysics

Applied geophysics can be divided into further fields on the basis of problems to be solved:

- exploration geophysics,
- hydrogeophysics,
- engineering geophysics
- environmental geophysics
- archaeological geophysics
- forensic geophysics.

Exploration geophysics

Its primary objective is to discover natural geological objects which may be related to the deposits or reservoirs of raw materials and energy sources (e.g. ores, coal, natural oil and gas, evaporites, and geothermal energy) by means of different geophysical methods.
It is also used for obtaining qualitative and quantitative information about the targets of interests, the surrounding media and the geological settings.

Applied Geophysics

Hydrogeophysics

is a cross-disciplinary area of hydrology and geophysics.

It uses geophysical methods to find water resources, to provide quantitative information about hydrogeological parameters of the subsurface structures, and to monitor processes connected to water resources, contamination, and ecological studies.

By means of combining the geophysical and hydrogeological methods the cost of research and the application of invasive (or destructive) methods (drilling and taking soil samples which often disturb the study site) can be decreased or minimized.

Engineering and environmental geophysics

uses geophysical methods to provide information which helps in engineering planning, calculations and design of infrastructural, energy and environmental projects.

Applied Geophysics

Archaeological geophysics

The main objective of designing and implementing geophysical surveys in archaeology is to detect, delimit and define buried archaeological structures and features without using destructive methods.

The geophysical measurements are generally performed before starting different building projects (such as road, pipe corridors, building of houses or estates and development of industrial zones or mining sites).

Forensic geophysics

is the application of geophysical methods for searching, localizing and mapping of buried objects (e.g. weapons, human burials and hiding-places) during the process of criminal investigations.

It can help in finding the evidences of criminal acts.

Geophysical methods

The main groups of geophysical methods by their physical principles:

- gravity method,
- magnetic method,
- geothermal method,
- electric methods,
- electromagnetic (EM) methods,
- seismic and acoustic (or sonic) methods,
- radioactive or nuclear methods.

Each method is based on the sensitivity of its measurement techniques to the spatial and/or temporal variations in one or more quantitative physical property of subsurface media (rocks or rock / fluid systems).

Geophysical methods

name of the physical property influencing the measured quantity	name of the method
mass density	gravity
magnetic susceptibility	magnetic
concentrations of radioactive isotopes	radioactive
thermal conductivity	geothermal
(electrical) resistivity	geoelectric
dielectric constant+ (electrical) resistivity + magnetic permeability	electromagnetic
velocity of elastic waves	seismic and acoustic

Surface geophysics

Three branches of applied geophysics according to the site of measurements:

- surface geophysics (airborne and marine geophysics are included),
- borehole geophysics,
- mining geophysics.

Major objectives of the surface geophysics:

- detecting the physical effects of the wanted geological objects (which may be perspective from the point of view of the exploration),
- determining the position and dimension (both horizontally and vertically) of an indicated object,
- delimiting the structural units of the given geological environment, and detecting the major structural directions,
- determining the locations of the planned boreholes in each phase of the exploration.

Borehole geophysics

Major objectives of the borehole geophysics:

- investigating the physical properties of the formations traversed by the borehole,
- determining the technical condition of the borehole,
- performing the geological correlation among the neighbouring boreholes,
- providing information for the interpretation of surface geophysical measurements,
- reinterpreting the results of former geophysical measurements.

Mining geophysics

Major objectives of the mining geophysics:

- determining the microtectonic lines crossed by the subsurface pits and shafts,
- investigating the quality and ore content of the rocks by means of in situ measurements,
- forecasting some dangerous events (e.g. water inflow, downfall, minefire, inflow of fire damp).

Range of investigation:

surface geophysics	from the surface to max. n x 1000 m
borehole geophysics	from the borehole wall to max. 2-3 m
mining geophysics	typically n x 10 m, max. 100 or 200 m from the wall of the shaft

Workflow and phases

A typical workflow of an applied geophysical survey includes the following steps in sequence:

- survey design,
- data acquisition,
- data processing,
- data interpretation,
- and generating reports.

The entire exploration process of a larger area is divided into different phases which follow one after another:

- reconnaissance,
- prospecting,
- general exploration,
- detailed exploration.

Exploration phases

The design of the next phase is always based on the information derived from the previous one.

So, the quantity of collected data and the knowledge about the subsurface structures and formations gradually grow as the exploration goes ahead.

More and more exact methods with higher and higher resolution are required in a subsequent phase.

Of course, this process entails the increase of costs and time expended on the exploration.

At first, the less expensive but quick mapping methods are used for getting an overall view of the main geological features.

The expensive methods are applied only if the results obtained from the previous methods are positive.

Exploration phases

The interpretation of the measured data is an iterative process during the exploration, since the results of the newer methods can strengthen or discard some assumption. So, the modification of the previous geological-geophysical model may be required.

It means that the re-processing and re-interpretation of the gradually broadening set of data and observations are regularly needed.

In such a way, we can gradually limit the further, more detailed investigation to the more perspective parts of a larger area in order to save money and other resources.

The *general exploration* phase can only be started if the *prospecting phase* has been closed with positive results.

And the necessary condition of starting the *detailed exploration* is the positive result of the *general exploration*.

Exploration phases

Thus, the *detailed exploration* phase cannot bring a negative result.

Negative result of this phase is always the consequence of a serious professional mistake.

So, opening the mining activity (designed on the basis of exploration results) should necessarily follow the detailed exploration phase.

In fact, the exploration is not over when the mining activity begins, because the *field development*, the *design of the production* and *solving the occurrent mining problems* quasi continuously require additional information of the geologist and geophysicist.

Drilling investigations

However, drilling boreholes is the only way of getting direct information about the deeper subsurface, the high cost of drilling strongly limits the number of boreholes may be drilled during the exploration.

Mainly the first phase of the exploration is critical from the point of view of drilling because of the higher level of risk.

The determination of the exact sites of the first few *exploratory boreholes* (generally 1 or 2) are fundamentally based on the geological and geophysical maps summarizing the results of former measurements and data acquisition.

For an exploratory drilling, the most important aim is collecting as many data as possible.

Drilling investigations

The main fields of subsurface data acquisition:

- drilling data acquisition (ROP, WOH, WOB, bit depth, torque, RPM etc. are recorded as a function of rig time)
- wellsite mud logging (cuttings descriptions, gas analysis of the mud returning to the surface, hydrocarbon indications in cuttings etc.),
- core acquisition or coring (the core analysis is performed in a laboratory)
- well logging or borehole logging (wide variety of logging sondes - probes or tools - were developed to implement different geophysical methods and sampling techniques in borehole circumstances)
- well testing (used in fluid exploration and production, fluid sampling for analysis, measurements of initial pressure, flow rate, pressure change etc.)

Drilling investigations

An exploratory borehole should penetrate the depth interval of possible deposit(s) or reservoir(s) to help in the determination of vertical dimensions.

A suitably designed and implemented data acquisition program provides very useful information for refining the geological-geophysical model and designing the next phase of the exploration.

In the next phase, further boreholes are usually drilled to obtain additional information in more evenly distribution on the area.

The information coming from these boreholes (called *appraisal wells* in petroleum industry) significantly contributes to the mineral resources assessment.

Borehole logging

As the geological conditions of the perspective area are gradually unravelling, the application of the most expensive data acquisition methods (e.g. coring) is decreasing (because of the economy).

The significance of borehole logging does not decrease during the exploration, but the special (more expensive) logging methods are less used and the range of measured logs is limited to a fundamental or standard suit of logs in the further exploration phases (mainly in the detailed exploration).

The suit of standard logs depends on the type of raw material and the geological relations, but it must be suitable to help in solving the general problems (e.g. lithology and rock type determination, identification of perspective zones, estimation the values of some parameters related to these zones …).

Borehole logging

It can be said that it is more and more difficult and expensive to find new and high-quality sources of raw materials.

Therefore, it is very important to maximize the collection and use of data obtained from the exploration and production.

This is the reason why the application of advanced logging methods primarily developed for the petroleum industry (e.g. borehole imaging methods, nuclear magnetic resonance method) are becoming more and more usual in the other fields of exploration (e.g. water exploration, coal mining).