**1.1 Introduction**

Applied geophysics involves studying, observing, and measuring a physical field on the Earth's surface or within the ground. This physical field is generated and depends on one or more parameters that characterize the materials we seek to determine the distribution of within the terrain. The physical properties exhibit significant variability depending on the terrain's state parameters (density, porosity, water content, etc.). Geophysical measurement methods are cost-effective, utilizing robust devices that are easy to deploy in the field. A physical property can be measured in several ways, depending on the terrain's characteristics, ease of use, and the sensitivity of available instruments.

**1.2 Definition of Geophysics**

Geophysics encompasses various methods that measure the physical parameters of rocks (elastic wave propagation velocities, density, resistivity, etc.). Measurements can be made from the surface (in contact with the ground or water), in the air, or in boreholes. When processed, interpreted, and combined, these measurements allow for identifying the nature of rocks, their content, and the geometry of the subsurface (see Table 1.1) (Shout, 2012).

**Table 1.1 – Physical field and property (source: INSA; modified)**

| **Method** | **Physical Field** | **Parameter** | **Source of Physical Field** |
| --- | --- | --- | --- |
| Gravimetry | Gravitational field | Density | Natural |
| Seismic | Vibration | Mechanical wave velocity | Induced |
| Electric (Injected Current) | Electric field | Resistivity | Induced |
| Magnetic | Magnetic field | Magnetic susceptibility | Natural |
| Electromagnetic | Electromagnetic field | Resistivity and permittivity | Induced |
| Radioactivity | Radioactive field | Radioactivity of rocks | Natural or Induced |

**1.3 Objectives of Geophysics**

**1.3.1 Objectives**

Geophysics, or the physics of the Earth, aims to study the physical properties of the Earth's globe. To achieve this, the geophysicist navigates in space and time. The three key terms they always keep in mind are: dynamics, structure, and scales. The primary objective of geophysics is to deduce the physical properties and constitution of the Earth (or other bodies in the solar system), based on associated physical phenomena, such as the geomagnetic field, heat flow, seismic wave propagation, gravity force, etc. (Dubois et al, 2011).

**1.3.2 Areas of Intervention and Interest in Geophysics**

**1.3.2.1 Oil Exploration**

Geophysics is involved in the exploration and characterization of potential reservoirs.

* Main disciplines: Seismics and logging.
* Complementary methods: Gravimetry, magnetism, and magnetotellurics (MT).

**1.3.2.2 Mining Exploration**

Geophysics is involved in exploring all types of ores and contributing to the development of deposits or mines. The disciplines used include:

* Electrical methods (PP, Pi, or PS) and electromagnetic (EM, AMT), radiometry, and logging.
* Seismics, gravimetry, and magnetism can also be applied.

**1.3.2.3 Water Resources Exploration**

Geophysics is used in the exploration of groundwater resources (shallow and phreatic aquifers).
Main disciplines: Electrical methods.
Complementary methods: Gravimetry and AMT.

**1.3.2.4 Seismic Monitoring**

Geophysics is used in monitoring major seismic risks (earthquakes) or minor ones (related to large engineering works such as dams, bridges, etc.) through the installation of fixed and/or mobile monitoring networks.

**1.3.2.5 Archaeological Research**

Geophysics is also used in archaeology to search for buried relics in the soil. Various techniques are used depending on the research objectives. Gravimetry is primarily used for searching cavities (tombs, caves, galleries). Magnetism is used to locate furnaces or cooked objects, as well as ferrous objects. Electrical methods are used to locate structures.

**1.3.2.6 Forensic Research**

Today, forensic units (police or gendarmerie) use geophysics to solve criminology issues. These methods are used to search for buried bodies or those thrown into rivers, lakes, or reservoirs. Ground-penetrating radar, magnetism, and electrical methods are particularly used.

**1.3.2.7 Civil Engineering**

Geophysics is essential in soil studies for construction or large infrastructure projects (highways, pipelines, airports, bridges, etc.).
Main disciplines: All surface electrical and electromagnetic methods, microgravimetry, and seismics.

**1.3.2.8 Environmental Studies**

Geophysics is useful in the study of natural and/or artificial pollution and land use planning:

* For searching for land pollution by heavy metals or other ferrous substances.
* To determine the extent of polluted areas that are sometimes not visible on the surface.
Main disciplines: Surface magnetism and electromagnetism, all electrical methods, microgravimetry, and radiometry.

**1.3.3 Geophysical Equipment and Instruments**

Each geophysical method has its own specific equipment:

1.3.3.1 **Seismology**: Seismograph consisting of a seismometer, a recorder, and a clock that gives the corrected time relative to a reference (Omega relay, GPS).

1.3.3.2 **Seismic**: Seismic reflection and refraction laboratories connected to a geophone system and a seismic source (TNT, hammer, compressed air truck (air gun), vibratory truck).

1.3.3.3 **Gravimetry**: Absolute gravimeter, field gravimeter, and microgravimetry.

1.3.3.4 **Magnetism**: Magnetometers, gravimeters, and flux gates.

1.3.3.5 **Electrical Methods**: Various resistivity meters at different investigation depths.

1.3.3.6 **Electromagnetic Methods**: Several EM devices designed for different investigation depths.

* MT and AMT stations.

1.3.3.7 **Radiometry**: Several devices developed to measure radiation energy (e.g., scintillometers).
1.3.3.8 **Logging**: Several logging probes designed to acquire physical parameters in boreholes. Each logging has its specific probe (e.g., AIT for resistivity, GR for natural radioactivity, CNL for neutron logging, etc.).

1.3.3.9 **Positioning**: Various devices designed to determine the coordinates of measurement points: theodolites, total stations, and navigation GPS and DGPS.

**1.4 Physical Properties of Rocks**

**1.4.1 Porosity**

Porosity refers to a rock’s ability to store a fluid (air, water) within its interstitial spaces, also called pores. It is primarily dependent on the arrangement of the grains rather than their size.
Porosity is a physical quantity defined as the ratio of the volume of voids (Vv) to the total volume (Vt) of a porous medium, with a value between 0 and 1 (or between 0 and 100% when expressed as a percentage):
Φ = Vv/Vt × 100
Where Φ is the porosity, Vv is the volume of pores, and Vt is the total volume of the material, which is the sum of the solid volume and pore volume.
The porosity of a substrate determines its flow and retention capacities.

**1.4.1.1 Types of Porosity**

Porosity can have various origins, specific to the material and its evolution over time, leading to pores of different sizes and geometries, more or less interconnected.
Three types are distinguished:

* A: Based on the shape and origin of the pores
* B: Based on the size of the pores
* C: Based on the nature of the pores

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**Figure 1.1** - Rock voids — forms of groundwater (subsurface hydraulics).

**1.4.1.2 Porosity and the Exploitation of Subterranean Resources**

In the context of underground resource exploitation, we distinguish (Fig. 1.1):

* Occluded or closed porosity: This is the porosity of pores not accessible to external agents (and thus unusable for resource exploitation).
* Free porosity: In contrast to occluded or closed porosity.
* Trapped porosity: This is free porosity that does not allow recovery of trapped fluids.
* Usable porosity: This is the porosity that allows recovery of the trapped phase (mainly used by petroleum companies).
* Residual porosity: This is the porosity due to pores that do not communicate with each other or with the external environment.
* Total porosity: This is the sum of usable porosity and residual porosity.
* Effective porosity: This term is mainly used in hydrogeology and characterizes the pore network through which water circulates and can be recovered.

**1.4.2 Bulk Density**

Bulk density is a physical quantity that characterizes the weight of a material per unit volume. It is obtained by multiplying the density by the acceleration due to gravity (g = 9.81 m/s²). This quantity is denoted γ and expressed in kN/m³ for soils.The mass of a solid is calculated by dividing its mass (g) by its volume (cm³).



**1.4.3 Void Ratio**

The void ratio, denoted e, is the ratio (expressed as a percentage) between the volume of voids and the solid volume. The void ratio expresses the compactness of a soil’s granular arrangement: a low void ratio corresponds to a low proportion of voids in a soil, thus indicating a compact granular arrangement.

The void ratio is e = Vv / Vs, where Vs is the volume occupied by solid grains.

**1.4.4 Water Content**

The water content of a material corresponds to the mass of water in a sample relative to its dry mass. It is expressed as a percentage and refers to weight-based water content.
[(Ph - Ps) / Ps] × 100 = Water Content (W)
Where Ph is the wet weight and Ps is the dry weight.

**1.4.5 Seismic Wave Velocity and Rock Nature**

The composition of the Earth's crust is well known through the study of surface rocks and numerous boreholes. The Earth's interior consists of several superimposed layers that differ by their solid, liquid, or plastic states, as well as their density.
When an earthquake occurs on the Earth's surface, waves are emitted in all directions. There are two main types of wave propagation: surface waves, which travel along the Earth's surface and cause all the associated damage, and body waves, which propagate through the Earth's interior and can be recorded at several points around the globe. Among body waves, there are two main types: P-waves (longitudinal or compressional waves) and S-waves (transversal or shear waves).

The propagation speed of seismic waves depends on the state and density of the material. Some types of waves propagate equally in liquids, solids, and gases, while others only propagate in solids.
P-waves propagate in solids, liquids, and gases, while S-waves only propagate in solids. It is also known that the speed of seismic wave propagation is proportional to the density of the material they propagate through.

An increase in the speed of P- and S-waves indicates an increase in the material's density as we go deeper. A sudden drop in P-wave speed is related to a state change of the material (from solid to liquid), but the relative speeds continue to increase, indicating an increase in density. The abrupt interruption of S-wave propagation indicates the presence of a liquid material.
Thus, the existence of two very different Earth envelopes is revealed.

**1.4.6 Resistivity and Electrical Conductivity**

In electrical prospecting, we measure the effect produced when an electric current passes through the subsurface. There are many techniques using electrical methods. Methods based on measuring the "resistivity ρ of a medium" (its ability to allow electrical current to pass) are the most widespread, developed, and diversified.

**1.4.7 Magnetic Susceptibility (Magnetism)**

Magnetic susceptibility refers to a material's property that characterizes its ability to become magnetized when exposed to an external magnetic field.

**1.4.8 Radioactivity**

The ability of rocks to generate radiation energy can be measured and gives an important indication about the characteristics of the rocks.