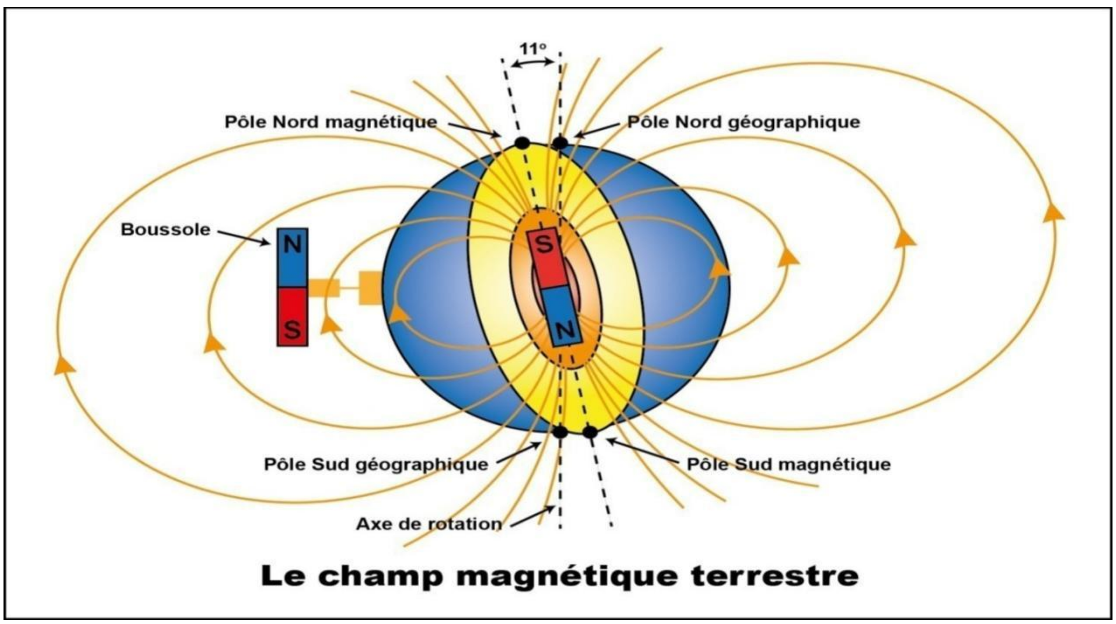
Chapter IV: Magnetic prospecting

II.4. Magnetic prospecting.

Magnetic prospecting is concerned with the earth's magnetic field, the aim of which is to study magnetic anomalies that will provide information on the deeper or shallower sources in the earth's crust that may be of interest to the prospector. In magnetic prospecting, the fundamental parameter is the magnetic susceptibility of rocks, which enables us to characterize the composition of these rocks. The magnetic field can be defined by 3 components at any given point: North, South and vertical (X, Y, Z). A value is given by the magnitude of the total field F and its declination D as well as its inclination I; where D is the angle between the horizontal component of the field and geographic North and I, the angle between F and the horizontal. This field can be likened to that of a centered dipole whose axis does not coincide with that of the earth's rotation, since they currently form an angle of 11.5°, a value that evolves over time as a function of the earth's core. Associated with the centered dipole are magnetic field lines that link the South Pole to the North Pole. The magnetic field is relatively weak, of the order of 0.5 Gauss, or 5 $*10^{-5}$ testa.

The Earth's magnetic field is not constant over time, but is affected by a slow secular variation.



1. Principle and basic theory:

Magnetic force: the expression of the magnetic force is deduced from coulomb's law for magnetic poles. Its expression is given by the following relation:

$$\vec{F} = \frac{m_1 m_2}{\mu r^2} \vec{r}$$

Where:

F: force in dynes (cm.g/s^2 = 10^{-5} N),

m1, m2: magnetic mass or poles,

r: distance between the two poles,
μ: permeability of the medium.

Magnetic field: A magnetic mass m1 brought to a point M in space is subject to the attraction emanating from another magnetic mass m located at a distance r from the point M. The intensity of the magnetic field H is defined as the force exerted on a unit pole:

$$\vec{H} = \frac{\vec{F}}{m_1} = \frac{m}{\mu r^2} \vec{r}$$

in C.G.S. units, the field unit is the oersted.

3 / Origin of the Earth's magnetic field:

The main magnetic field can theoretically be caused by an internal or external source, whose magnetism may be remanent or generated by a current flow. Several hypotheses have been put forward to explain the mechanisms of internal sources:

a) The Blackett theory: He evaluated the ratio of the kinetic and magnetic moments of the 3 stars (earth, sun and star) and found that the ratios were close. He concluded that this was a fundamental property of rotating bodies.

b) Dynamo: Suggests that the Earth's magnetic field is created and maintained by an induction process. Intense electric currents circulate in the outer core, which has very high electrical conductivity (outer core: the liquid part of the core located between r = 1300 and 3500 km). Today, we assume that the core is a combination of iron (Fe) and nickel (Ni), both of which are good electrical conductors. Even if the core were made up of less conductive elements, the enormous pressure could press the electrons together to form free-electron gases with satisfactory conductivity. The magnetic source is illustrated by the self-excited model. That is, a fluid of high conductivity moves in a complex motion and electric currents are caused by chemical variations producing a magnetic field.

4 / Magnetism of rocks and minerals:

a) The main types of magnetism: Magnetic anomalies are entirely due to the quantity of magnetic minerals contained in rocks. It is therefore necessary to study these minerals and, above all, their magnetic susceptibility.

b) Diamagnetism: Perfect diamagnetism offers great resistance to the passage of magnetic fields. H-field lines do not penetrate the material. Permeability is therefore zero. This is the attribute of a material with negative magnetic susceptibility ($k < 0$), meaning that the intensity of magnetization induced in the body by an H field will be in the opposite direction to H.

c) Paramagnetism: By definition, all materials that are not diamagnetic are paramagnetic, i.e. $k > 0$. In a paramagnetic material, each atom has a non-zero magnetic moment. Under the action of an external field, these magnetic moments orient themselves and increase the H field applied.

d) Ferromagnetism: The magnetization of a ferromagnetic material corresponds to the orientation of elementary dipoles in the same direction. Unlike paramagnetics, this orientation can occur spontaneously, in the absence of an external H field. The region of space in which all magnetic moments are oriented in the same direction is called a domain (Weiss), and the boundaries between these domains are called walls (Bloch). If a ferromagnetic material is placed in an external H field, the walls will move in such a way as to reinforce the external H field. If H increases significantly, the favorably oriented domain will occupy the entire volume of the material, which is then magnetized to saturation.The following table summarizes typical magnetic susceptibility values for different types of rock:

TYPE DE ROCHE	SUSCEPTIBILITÉ MAGNÉTIQUE (X) EN 10^{-5} SI
Roche Ultrabasique	500 - 10,000
- Péridotite	1,000 - 10,000
- Dunite	> 10,000
Roche Basique	50 - 1,000
- Gabbro	100 - 2,000
- Bascalt	50 - 1,000
Roche Intermédiaire	10 - 500
- Andésite	20 - 500
- Diorite	10 - 300
Roche Acide	< 10
- Granite	< 10
- Rhyolite	< 5
Sédimentaires Ferriques	1 - 100
- Grès ferrugineux	50 - 100
- Schiste argileux	1 - 10
Sédimentaires Non-Ferriques	< 1
- Calcaire pur	< 1
- Sable	< 1
Métamorphiques	Variable
- Gneiss	1 - 100
- Schiste quartzeux	< 1

- Ultrabasic and basic rocks generally have high magnetic susceptibility due to their high content of ferromagnetic minerals such as magnetite.
- Acidic rocks (such as granite) have low magnetic susceptibility because they contain few ferromagnetic minerals.
- Sedimentary rocks show great variability: those rich in iron oxides (such as ferruginous sandstones) have higher susceptibility, while pure limestones or sands have very low susceptibility.
- Metamorphic rocks also vary widely according to their origin and ferromagnetic mineral content.

These values are approximations, and may vary according to the specific conditions of formation and the geological history of the rocks.

5. Magnetic prospecting :

Uses methods considered to be non-destructive to provide the best possible image of the ground through a series of measurements. It involves essential preparatory work:

- precise location of the area to be prospected on a map.
- drawing up a plan of the measurement points.
- the mesh chosen must not be so large as to interfere with the results, without being too tight either, at the risk of needlessly wasting time.

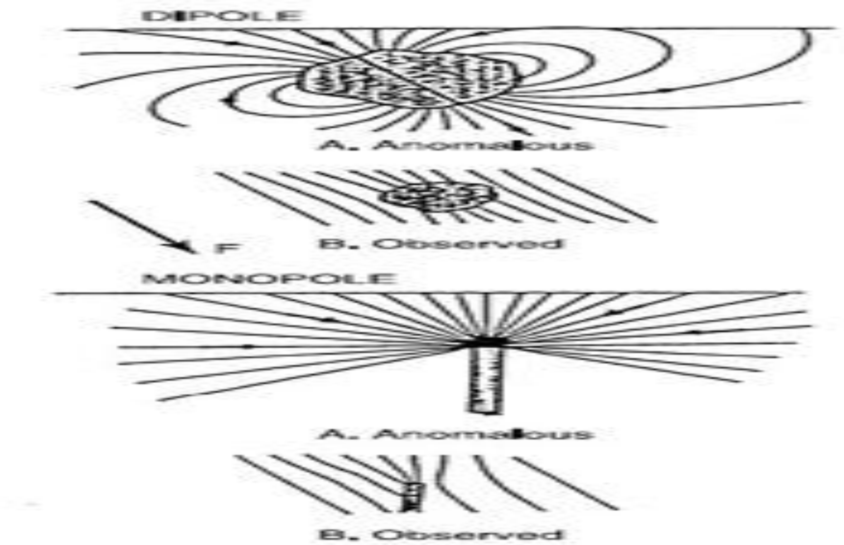
Magnetic prospecting is based on measuring local variations in the earth's magnetic field. It involves studying magnetic field anomalies associated with sources located in the Earth's crust. Based essentially on the earth's magnetic fields and the magnetic susceptibility of the minerals making up the rocks (susceptibility is the property of certain materials to become magnetized in the presence of an ambient magnetic field), magnetic prospecting consists of searching for and locating rocks and deposits by the anomalies or local variations they produce in the earth's field. Most minerals have very low magnetic susceptibility, except for magnetite (Fe_3O_4), which is ubiquitous in almost all rocks in variable quantities, with a fraction of 1% being detectable.

Small fluctuations can be caused by differences in magnetization between the soil and the buried remains: man-made soils are more magnetic than masonry structures. Stronger variations can also disrupt the magnetic field in the same way: the presence of archaeological objects linked to metallurgy (slag, offcuts, products in the process of elaboration, etc.); repeated heating in combustion structures and the firing of clays lead to the mineralogical transformation of certain iron oxides into highly magnetic minerals. This is reflected on the maps produced by very strong anomalies.

Even if the presence of magnetic minerals is easily detected by magnetic prospecting, it is impossible to assess the economic potential of a deposit or water reservoir. Magnetite has a higher susceptibility than other ferric materials, and magnetic data mainly reflect its concentration. So a small amount of magnetite in a non-magnetic rock can give a much larger anomaly than a deposit. The more basic the rock, the higher the magnetite content, and hence the higher the susceptibility. The range of possible susceptibility values for one type of rock is relatively wide, and overlaps with values for other rock types. It is impossible to identify a rock with certainty on the basis of its susceptibility alone.

6. Implementation and interpretation of a magnetic campaign:

The area to be prospected is divided into 50 m square blocks. Each block is surveyed along parallel profiles spaced at a constant distance, based on the characteristic dimensions of the structures surveyed. Along each profile, the magnetometer acquires data continuously every 10 cm. The speed with which recent magnetometers can be set up means that large areas can be covered.



a) Qualitative approach: An anomaly reflects a disturbance in the magnetic field resulting from a local change in magnetization or magnetization contrasts. Magnetic anomalies are asymmetrical, depending on the nature and shape of the source: unipole or dipole. The deeper the source, the wider the anomaly observed on the surface. This property makes it possible to calculate the depth of these sources. Moreover, the quantity of magnetite in the source relative to the host rock and the geometric shape of the disturbing body (veins, faults, mineralized clusters) have a considerable influence.

b) Quantitative approach: Consists in calculating the theoretical anomalies produced by cylindrically symmetrical disturbing bodies. Among the calculation methods we cite Talwani's method (1964).

7. Application of the magnetic method:

● **Mining exploration:** direct detection: magnetic iron deposits, magnetite and asbestos deposits (fibers are associated with magnetite and found in very basic rocks), indirect detection: Nickel associated with basic rocks and mineralization associated with structures (faulting, folding, intrusives).

● **Mapping:** used both on the ground and airborne, both local and regional, enables interpolation between outcrops without the need for drilling or digging.

● **Oil exploration:** direct detection: study of sedimentary basins based on anomalies caused by basement structures or topography, and indirect structural detection (faults, folds) and hydrographic research.