Geoelectrical Characterization of Sulphate Rocks

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Programa de Doctorat de Ciències de la Terra

GEOELECTRICAL CHARACTERIZATION OF SULPHATE ROCKS

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2011

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Introduction

Ander Guinea 2011

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.1 EVAPORITE ROCKS

Evaporites are sedimentary rocks originated from evaporitic processes, this is, have been precipitated from water following the evaporative concentration of dissolved salts. The source of water can be both marine and continental (lacustrine water). On average, seawater contains 36 g/L of dissolved ions; mainly chloride, sodium, sulphate, magnesium, calcium and potassium (figure 3.1A). As the water evaporates, the concentration in ions increases and least soluble compounds saturate and precipitate. Thus, calcium carbonate is the first precipitated mineral, followed by calcium sulphate, sodium chloride and potash salts as the water becomes more concentrated (figure 3.1B). Other evaporitic mineral existed with different formation conditions (table 3.1). Depending on the morphology of the evaporitic basin and in the water source, the deposition of the evaporitic minerals can be developed in different patterns (figure 3.2). In the case of lake water, the chemistry varies but usually with the same principal anions in different proportions.

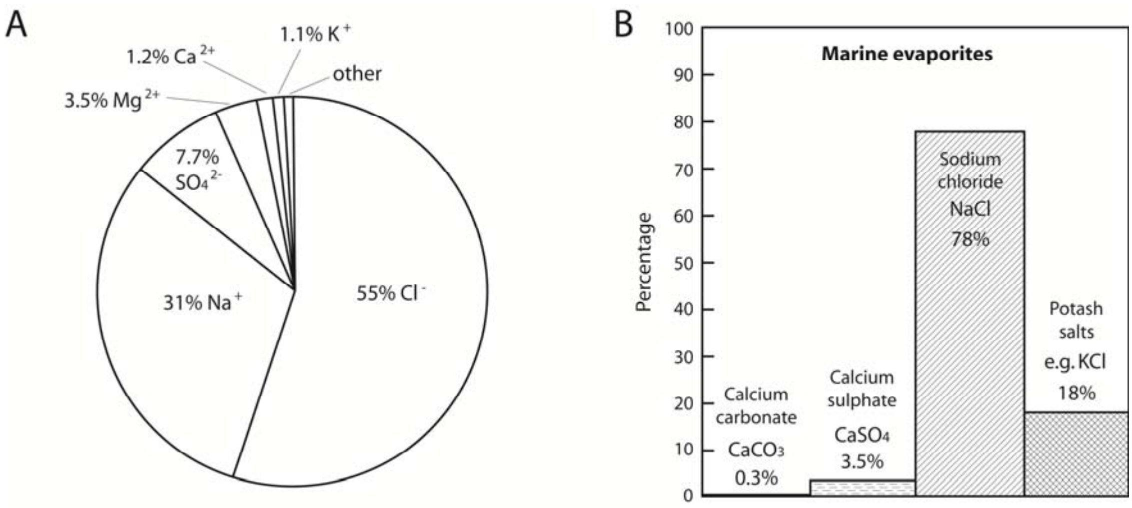

Figure 3.1: A) The proportions of the principal ions in average seawater and continental water. B) The proportion of minerals precipitated by the evaporation of seawater of average composition. (Modified from Nichols 1999).

Texturally, evaporitical rocks are mainly crystalline; even they also can appear with clastic textures when they are reworked. Evaporitic rocks have high solubility (from 2.4 to >5000 g/l) and relatively low density (an average of 2.3 g/cm^3). They have no primary porosity (less than

CALCIUM SULPHATES	
Anhydrite	$CaSO_4$
Gypsum	$CaSO_4 \cdot 2H_2O$
Basanite	$CaSO_4 \cdot 1/2H_2O$
Polihalite	$Ca_2MgK_2(SO_4)_4 \cdot 2H_2O$
MAGNESIUM SULPHATES	
Epsomite	$MgSO_4 \cdot 7H_2O$
Hexahidite	$MgSO_4 \cdot 6H_2O$
Kieserite	$MgSO_4 \cdot H_2O$
Langbeinite	$Mg_2K_2(SO_4)_3$
SODIUM SULPHATES	
Mirabilite	$Na_2SO_4 \cdot 10H_2O$
Thenardite	Na_2SO_4
Glauberite	$Na_2Ca(SO_4)_2$

CHLORIDES	
Halite	$NaCl$
Silvite	KCl
Carnalite	$KMgCl \cdot 6H_2O$
Bischofite	$MgCl_2 \cdot 6H_2O$
DOUBLE SALTS	
Cainite	$KMg_4Cl_4(SO_4)_4 \cdot 11H_2O$
CARBONATES	
Natron	Na_2CO_3
Trona	$Na_2CO_3NaHCO_3 \cdot H_2O$
Gaylusite	$Na_2CO_3 \cdot CaCO_3 \cdot 5H_2O$
BORATES	
Borax, Ulexite, Colemanite...	

Table 3.1: Main evaporitic minerals and their chemical composition

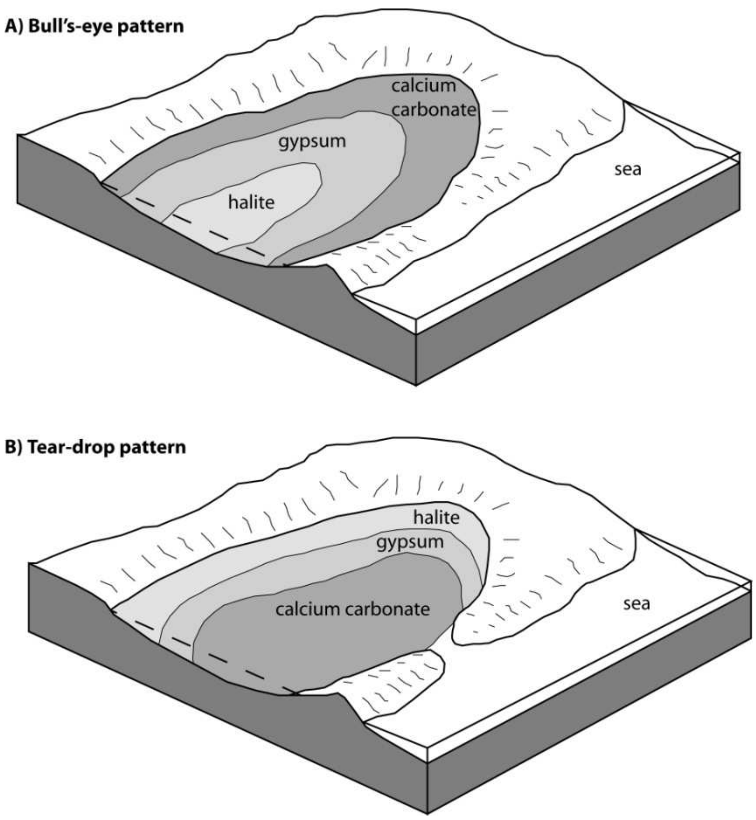

Figure 3.2: Examples of tipical modern marine evaporitic basins. A) Bull's-eye pattern basin. In this case the basin is isolated from the seawater, experiencing regular influxes when the tide rises. B) Tear-drop pattern basin. This pattern is bounded to a water inlet which generates a constant interaction between the brine and the seawater. (Modified from Nichols 1999).

1%) with a restricted mineralogical (and geochemical) composition. Fossils are rare in evaporitic rocks but exceptionally it is possible to find some, mainly reworked. The deposits are principally autochthons but they are widely affected by diagenetic processes (figure 3.3).

Nowadays in marine environments, the deposition of evaporites takes place in coastal regions like lagoons and shabkha mudflats. In any case, bounded to larger extensive marine settings, deposition episodes have been observed in the stratigraphic record.

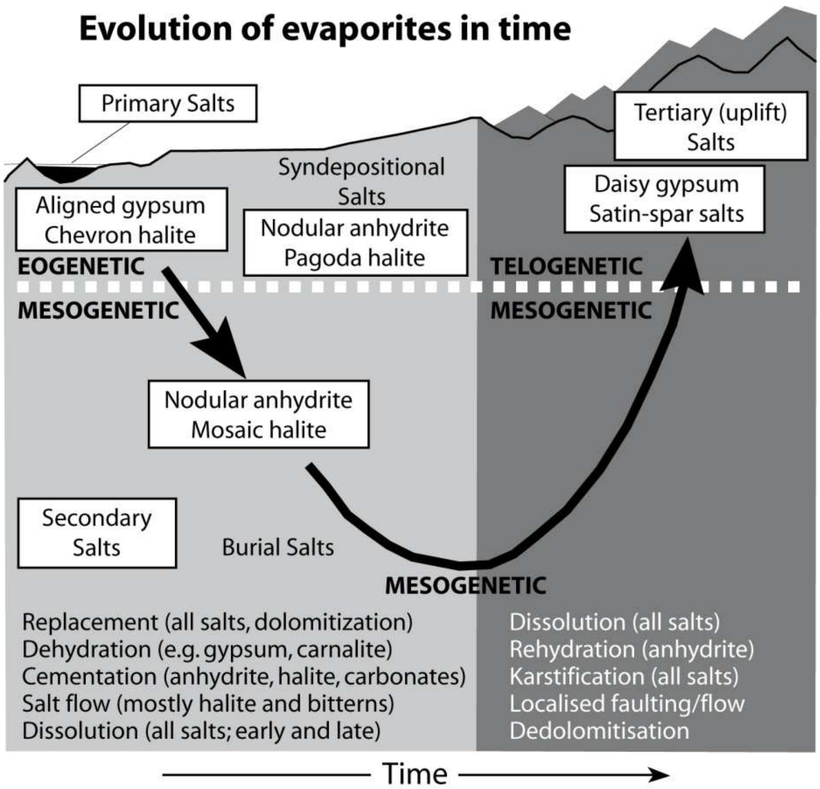

Figure 3.3: Textural and mineralogical evolution of evaporite rocks. (Modified from Warren 2006).

.2 GEOELECTRICAL PROSPECTION

The geophysical methods of electrical prospection (geoelectrical methods), study the distribution of any of the electromagnetical properties of the terrain by measures performed in surface. There are 3 electromagnetic properties: the magnetic permeability μ, the dielectrical constant or permittivity ε and the resistivity ρ (Orellana 1972). Usually, the property studied by means of geoelectrical surveys is the electrical resistivity of the terrain. Electrical resistivity of the rocks is measured in Ω.m or, in the case of displaying the conductivity instead of the resistivity, in mS/m.

In geoelectrical surveys it is very important to know the materials under study in order to interpret the obtained values. Each type of rock has its own range of electrical resistivity value; different authors have elaborated tables displaying the values of different matherials (figure 3.4). The value of the electrical resistivity of a certain lithology depends on different factors as its weathering, porosity, temperature, humidity, etc. One of the advantages of these techniques respecting other geophysical techniques is the wide range of resistivity values we can measure and therefore permit us to differentiate matherials and structures in which there is a noticeable resistivity change.

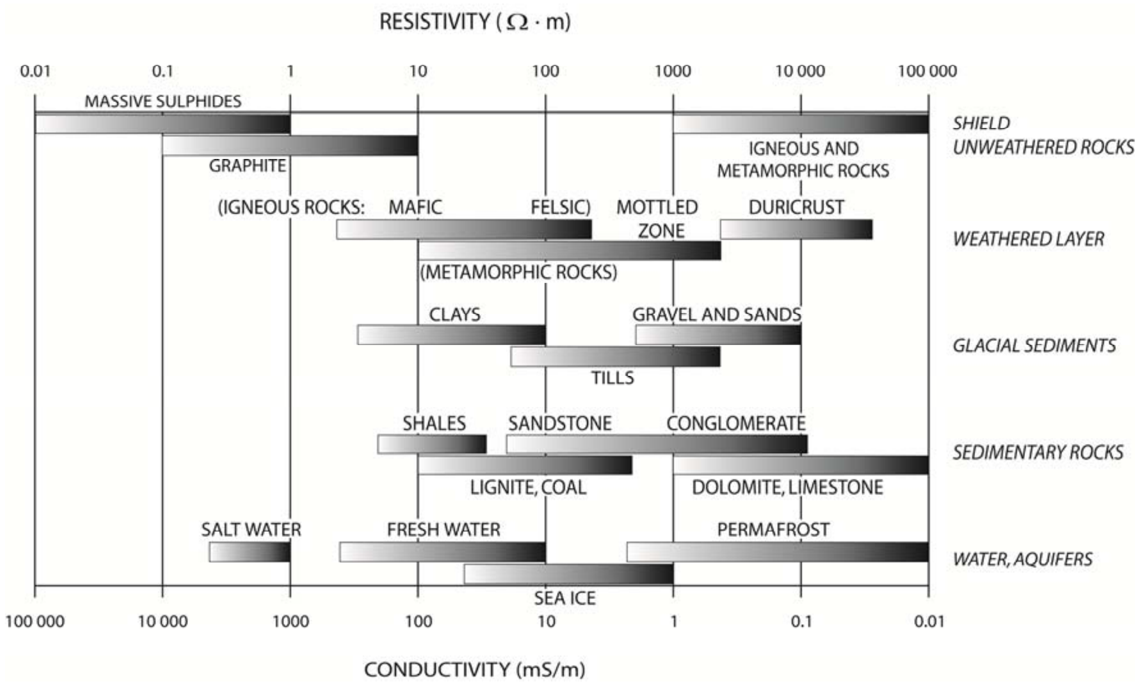

Figure 3.4: Electrical resistivity value-ranges for different type of geological matherials (modified from Palacky 1987).

Electrical resistivity tomography (ERT) is a geophysical technique whose objective is to determine the real electrical resistivity distribution in the subsurface. On this purpose, a DC current is injected in the terrain by two electrodes and the voltage passed through the terrain is measured in two different electrodes along a 2D profile. Measures with different spacing between electrodes measure at different depths (figure 3.5). All the measures are saved into a central unit which is placed in the center of the 2D profile. From this central unit 2 cables are spread in both directions in the same plane; these cables bring the electrical current to the electrodes (figure 3.6). The measured values are not real resistivity values of the terrain butr apparent ones. This is due to the fact that the current spread along different materials when the terrain is heterogeneous and thus, the measured value correspond to the mean value of the whole path of the electrical current. Therefore, the electrical apparent resistivity value must be inverted with some software. After processing measured data, a trapeze shaped image displaying the real electrical resistivity values is obtained. This image allows us to interpret the distribution of the different materials below the area where the survey took place. The advantages of this method are its non-invasive nature and relative low cost. The measures obtained are indirect and, as it occurs in all geophysical techniques, the accuracy of the method decreases with depth.

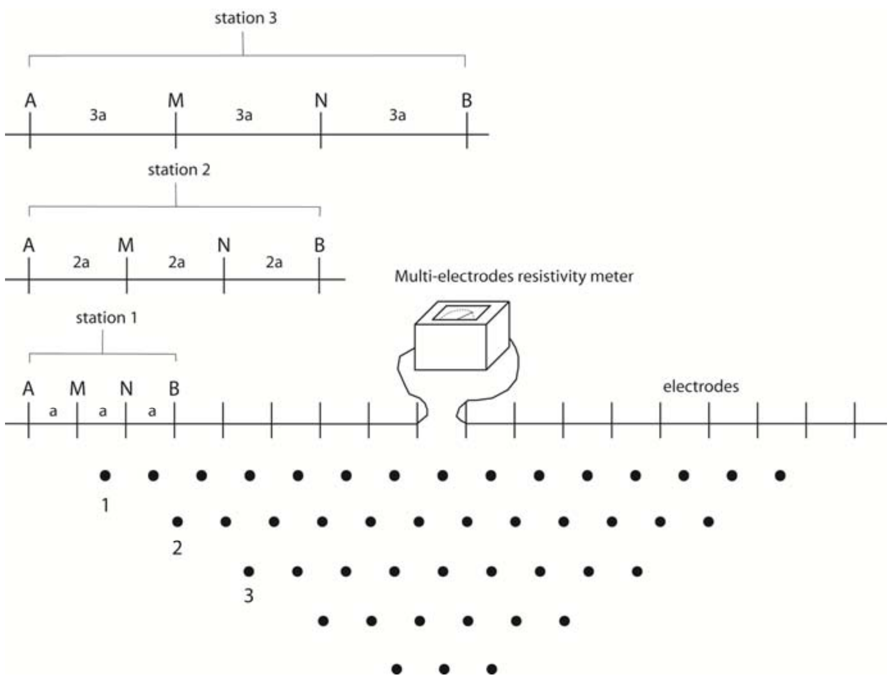

Figure 3.5: Measure of pseudosection whith Wenner array. A and B are the current electrodes and M and N the potential ones. The depth of the point measured (1, 2, 3…) depends on the spacing (a) (modified from Batlle-Aguilar et al. 2009).

Induced polarization (IP) is an electrical current stimulated phenomenon observed as delayed voltage response in earth materials (the chargeability of the terrain is measured). The fact of measuring different values is enough to define an anomaly (Sumner 1976). The measuring of chargeability in gypsum rocks has not been the object of previous researches but the chargeability properties of clay have been widely studied (Takakura and Nakada 2006; Deucester and Kaufmann 2009). Nevertheless, the range of chargeability values for clays has not been specifically determined given that many variables are involved (grain size, composition, measure time etc). As a general trend, the clay chargeability values are rather low compared to the chargeability anomalies given by the presence of metallic minerals.

Figure 3.6: Photograph displaying the disposition of an ERT device spreaded in field. The central unit (a Syscal Pro Switch with 48 electrodes is displayed in the photograph) links the two cables with 24 electrodes each. In this case the spacing between electrodes is of 2 meters.

.3 OBJETIVES

Alternatively to high cost drilling projects, geoelectrical techniques are proposed to be considered to characterize sulphate deposits. In the bibliography, the different studies assign a wide range of resistivity values to these rocks and their characterization is poorly developed (see tables 4.1 and 4.4 in chapter 4). The main objective of this thesis is to establish geoelectrical classifications of the principal sulphate rocks on the basis of their mineralogical composition (mainly matrix and sulphate percentages) and their electrical resistivity values. This classification would properly interpret the data obtained by means of electrical methods (as vertical electrical soundings, or ERT) performed in sulphate rocks.

The development of a protocol to perform ERT surveys in sulphate rocks is also one of the aims of this research. This consist in establishing which is the most suitable electrode array for each case and correct data processing and interpretation methods; as well as to define the limitations of the technique for the determination of the mineral phases and structures in sulphate rocks. Besides the field acquisition, a protocol to measure the geoelectrical response of samples at laboratory level is intend to be developed, since the laboratory measurements would support the electrical resistivity ranges obtained by the theoretical and field methods.

Additionally to the definition of the electrical properties of sulphate rocks and to establish the methods for their study, the utility of the ERT lines for sulphate exploitation is aimed to be showed by means of applied examples.

In general terms, the objective of the thesis consist on generating a background in the knowledge of the electrical properties of sulphate rocks; which is lacked in the bibliography.