Geoelectrical Characterization of Sulphate Rocks

Ander Guinea Maysounave

Programa de Doctorat de Ciències de la Terra

GEOELECTRICAL CHARACTERIZATION OF SULPHATE ROCKS

Ander Guinea Maysounave

2011

Advisors / Directors de tesi:

Drs. Elisabet Playà Pous & Lluís Rivero Marginedas

Departament de Geoquímica, Petrologia i Prospecció Geològica

UNIVERSITAT DE BARCELONA

Geoelectrical Characterization of Sulphate Rocks

Abstract

Ander Guinea 2011

2

Evaporites are sedimentary rocks originated from evaporitic processes; the principal evaporitic mineral groups are sulphates (gypsum, anhydrite, glauberite...) and chlorides (halite, sylvite...). Alternatively to high cost drilling projects, geoelectrical techniques can be considered to characterize these deposits.

Gypsum rocks are widely exploited in the world as industrial minerals. The purity of the gypsum rocks (percentage in gypsum mineral –$CaSO_4 \cdot 2H_2O$- in the whole rock) is a critical factor to evaluate the potential exploitability of a gypsum deposit. It is considered than purities higher than 80% in gypsum are required to be economically profitable. Gypsum deposits have been studied with geoelectrical methods; a direct relationship between the electrical resistivity values of the gypsum rocks and its lithological composition has been established, with the presence of lutites being the main controlling factor in the geoelectrical response of the deposit. This phenomenon has been quantified by means of a combination of theoretical calculations, laboratory measurements and field data acquisition. Direct modelling has been performed; the data have been inverted to obtain the mean electrical resistivity of the models. The laboratory measurements have been obtained from artificial gypsum-clay mixture pills, and the electrical resistivity has been measured using a simple electrical circuit with direct current power supply. Finally, electrical resistivity tomography data have been acquired in different Tertiary evaporite basins located in Northeast Spain; the selected gypsum deposits have different gypsum purities.

A geoelectrical classification of gypsum rocks defining three types of gypsum rocks has been elaborated: a) Pure Gypsum Rocks (>75 % of gypsum content), b) Transitional Gypsum Rocks (75-55 %), and c) Lutites and Gypsum-rich Lutites (<55%). From the economic point of view, the Pure Gypsum Rocks, displaying resistivity value >800 ohm.m, can be exploited as industrial rocks. The methodology used could be applied in other geoelectrical rock studies (such sedimentary rocks with different components), given that this relationship between the resistive particles embedded within a conductive matrix depends on the connectivity of the matrix particles.

Anhydrite ($CaSO_4$) is frequently found in gypsum quarries and in no-outcropping sulphates. Because of its highest hardness than gypsum it supposes a problem for the extraction of gypsum; the fronts of the quarries in which anhydrite is found are stopped at the moment when it appears. The electrical properties of calcium sulphates have been studied by means of geoelectrical methods. The conductivity of crystals has been tested in laboratory. As

it is difficult to obtain an anhydrite crystal large enough as to perform conductivity measures on it; gypsum crystal has been used, measuring in different crystalographical directions and showing that the plane (010) in which the water molecules are aligned is more conductive. The lack of this structure in the crystals of anhydrite explains its larger electrical resistivity.

A direct relationship between the electrical conductivity values of the calcium sulphate rocks and its lithological composition has been established being the lutitic matrix the main controlling factor when it is percolant (connected at long range). When the matrix is under the percolation threshold the dominant phases are the sulphate ones and the electrical response of the rocks depends on the percentage of each one in their composition. When the rock is matrix dominant, the electrical resistivity trend is bond to the Hashin-Shtrikman lower bound for multiphase systems (considering gypsum, anhydrite and matrix as the components). On the other hand, when the rock is calcium sulphate dominant the trend shows the one of the Hashin-Shtrikman upper bound. The reference electrical resistivity value of pure anhydrite rocks has been defined as 10^4 ohm.m and a geoelectrical classification for calcium sulphate rocks has been elaborated. With this classification it is possible to differentiate between calcium sulphate rocks with different composition according to their electrical resistivity value. This classification has been checked with field examples and calculating the theoretical resistivity value of thin section photographs with the program ELECFEM2D. The electrical behavior of calcium sulphate rocks is a good reference for other type of rocks with electrically differentiated components, and similar methods can be used to define their geoelectrical responses.

Glauberite ($Na_2Ca(SO_4)_2$) is nowadays exploited as industrial mineral. Glauberite rocks usually have high lutite content in their composition, together with other evaporictic minerals as gypsum, anhydrite or halite among others. There is no reference to the conductivity of glauberite rocks in the bibliography, but due to their impurity it is expected to observe values as the observed for other sulphates in the matrix domain (less than 55% in purity). Two areas of the Ebro river basin (the Zaragoza and La Rioja sectors) have been studied by means of electrical resistivity tomography profiles, in which glauberite has been found in boreholes. As expected, the obtained resistivity values are less than 100 ohm.m for these rocks in Montes de Torrero area (Zaragoza). In the surroundings of the village of Alcanadre (La Rioja), an uncommon layer of pure glauberite outcrops near the Ebro River. The inverted resistivity image shows a resistivity of 2500 ohm.m for that layer; which could be taken as reference. In general, glauberite rocks will show the values of lower Hashin-Shtrikman bounds, as it has been showed before in the case of other sulphates. Without the information of boreholes is not possible to identify glauberite by means of this technique, but the resistivity imaging gives information of possible structures.

The most common structures in sulphate rocks are lateral changes of purity (which are bounded to sedimentary processes) and dissolution features (cavities or infillings). Those structures may be complex and therefore difficult to interpret. Some models have been elaborated representing those structures and direct model data sets have been calculated (RES2DMOD) and inverted (RES2DINV). Those models are references for the interpretation of resistivity profiles performed on sulphate rocks. The selection of the proper array is an important factor to obtain the most accurate image of the terrain resistivity. The sensitivity of Wenner-Schlumberger and Dipole-Dipole arrays have been analyzed for different structures, aimed by direct models and field examples. Once the data is processed, is important to be aware of the limitations of the electrical resistivity tomography to identify certain phases. Some additional direct models have been elaborated in which has been demonstrated that pure anhydrite and gypsum rocks cannot be differentiated when they are below a thick layer of conductive materials.

In addition to sulphate rocks, chloride rocks have been studied with geoelectrical techniques. Rock salt deposits have been studied in Cardona and Súria areas. These rocks are banded pure halite and lutites. This layering is bended and deformed; therefore the lutite layers are connected at long range making a very heterogeneous deposit. These heterogeneities generate a different conductivity-composition trend of the one of sulphates. The obtained values are transitional between the boundaries of Hashin-Shtrikman bounds for these rocks and therefore, they are difficult to predict. Additionally to the composition, the chloride rocks are greatly affected by the presence of water. The studied deposits in wet conditions have displayed a very high conductive behavior (close to 1 ohm.m), due to the ions dissolved in water from the salty materials. Seismic tomography has been used in combination with the geoelectrical techniques in order to support identifying the salt rocks; because the wave velocity is not affected by the humidity of the rocks.

As example of application for the study of sulphate deposits, an electrical resistivity tomography survey has been carried out in the Pira Gypsum member (SE of Catalan margin of the Tertiary Ebro Basin, Spain). Additionally, a continuous coring drill was performed in order to support the study. Electrical imaging has been successfully applied to identify the gypsum deposits interlayered in lutite units. Nevertheless, the gypsum-lutite boundaries are diffuse and uncertain in the tomographyc lines. Comparison of the cores of the borehole and the electrical response shows a meaningful correlation between electrical resistivity and purity of gypsum. The electrical resistivity tomography profiles display a rather wide range of electrical resistivity values (from 20 to 1000 ohm.m) for the investigated gypsum facies. The highest values are attributed to the sulphate layers with >90% of gypsum mineral. Lutite units display higher values than expected due to the presence of evaporite minerals within them (>10 ohm.m). Additionally, induced polarisation measures have been performed in order to study the chargeability of gypsum deposits. It has been evidenced that impure gypsum rocks (with important presence of lutites within) are slightly chargeables. This property has allowed distinguishing between lutite levels and clay-rich gypsum rocks.

Another resistivity survey has been carried out in an active gypsum quarry in the Gelsa Gypsum unit (Zaragoza, N Spain). During the extraction of the rock, the most important parameters to know are the purity changes in the deposit. Sudden changes in the purity make the processing of the raw material less profitable. The performed profiles have shown different gypsum layers from which the purest layers have been identified. An extra profile has been performed in an area of future expansion of the quarry and a decreasing in the purity of certain area has been identified. With all this information, the planning of the present and future works may be improved.

Electrical resistivity tomography lines are useful in prospection of gypsum deposits. However, electrical imaging prospection should be supported by an accurate petrological study of the deposits, in order to properly interpret the resistivity profiles.