GEOGACETA, 47, 2009

Geoelectrical imaging supporting glauberite deposits evaluation in the Montes de Torrero area (Zaragoza)

Tomografía eléctrica aplicada a la evaluación de depósitos glauberíticos en el área de Montes de Torrero (Zaragoza)

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RESUMEN

La glauberita es un sulfato sódico que se explota con fines industriales. En el año 2002 en los depósitos evaporíticos miocenos de la formación Yesos y Anhidritas de Zaragoza se encontró glauberita en profundidad en una campaña de sondeos. Mediante la técnica geofísica de la tomografía eléctrica se han llevado a cabo una serie de perfiles de resistividad eléctrica del terreno. Los datos obtenidos en el estudio se han comparado con la información previa de los sondeos y se ha podido constatar que partiendo de estos, es posible obtener información de los depósitos y observar como evolucionan lateralmente. Debido a la importante presencia de encajante no se ha podido definir el rango de valores geoeléctricos de resistividad propios de la glauberita pura pero si se han reconocido estructuras kársticas y deposicionales.

***Palabras clave**: Glauberita, arcillas, yeso, anhidrita, tomografía eléctrica.*

Geogaceta, 47 (2009), 145-148
ISSN: 0213683X

Introduction

Glauberite deposits (together with gypsum, anhydrite and thenardite) are the currently exploited sulphate rocks for industrial purposes. In addition to the expensive drilling projects, geophysical techniques can be considered to estimate the economical potential of these deposits.

Glauberite is a sedimentary mineral originated by evaporation processes. It is composed of sodium and calcium sulphate ($CaNa_2(SO_4)_2$) what is usually associated with other sulphate minerals (gypsum and/or anhydrite) and halite, and embedded within a clayly, marly or carbonatic (calcite, dolomite or magnesite) matrix. The mineral compositions and their relative abundance strongly vary from one glauberite deposit to another (Salvany, 2009). After burial, glauberite deposits may experience uplift and are affected by surface and subsurface weathering processes. In this case, glauberite tend to be replaced by gypsum (togheter with accompanying anhydrite).

An important episode of glauberite deposition took place in the Ebro, Tajo and Calatayud basins during the Tertiary (Ortí and Salvany, 1991, Ortí, 2000; Ortí and Rosell, 2000). Sodium sulphates were found in the Zaragoza formation during the construction of the high velocity train railways (AVE). A drilling campaign was performed by PROVODIT Engineering in the Montes the Torrero area (between 2002 and 2005) and glauberite rocks were found at depth.

The 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 at a certain depth. After processing measured data, a trapeze shaped image displaying the 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.

Although no references exist on this topic, it is supposed as an initial hypothesis that the expected resistivity values for glauberite rocks would be higher those of the gypsum ($CaSO_4 \cdot 2H_2O$), and probably similar to those of the anhydrite ($CaSO_4$), due to their anhydre nature. In the case of gypsum rocks, the electrical current spreads along their crystallisation water. Electrical resistivity of gypsum rocks is around 1000 ohm.m (in case of high purity composition; while electrical resistivity of anhydrite ranges from 1000 to11000 ohm.m (Lugo *et al*., 2008).

The scope of this study is to characterize the geoelectrical response of glauberite rocks, to define their range of resistivities and to evaluate the influence of accompanying minerals in glauberite formations. Resistivity values for glauberite rocks or isolate glauberite minerals have not been defined in the literature.

Geological setting

The studied area is located close to Zaragoza city (Fig.1), in the Miocene Zaragoza Gypsum and Anhydrite formation. This formation, hundreds of meters thick, was deposited in the Aragón sector of the Ebro basin.

Anhydrite, glauberite and halite occur at depth (also thenardite in small quantities) while gypsum is the main evaporite mineral in exposed areas, as a consequence of hydration processes of the precursor anhydre sulphates; presence of marl and clay is ubiquitous. Salvany (2009) described 3 different units in this

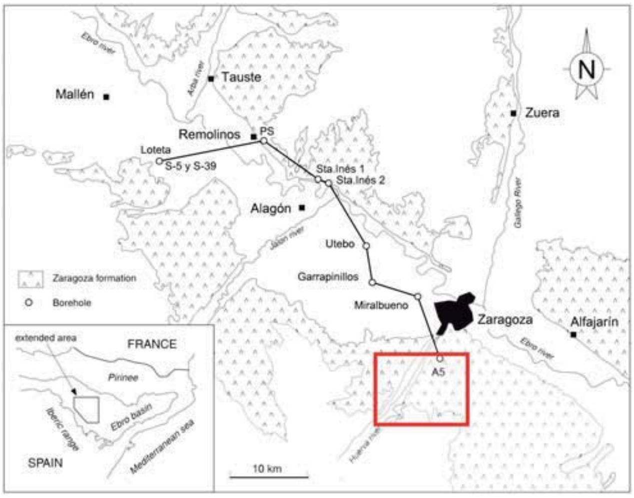

Fig. 1.- Regional map of the studied area (red square) (Salvany 2009).

Fig. 1.- Mapa regional del área de estudio (recuadro rojo) (Salvany 2009).

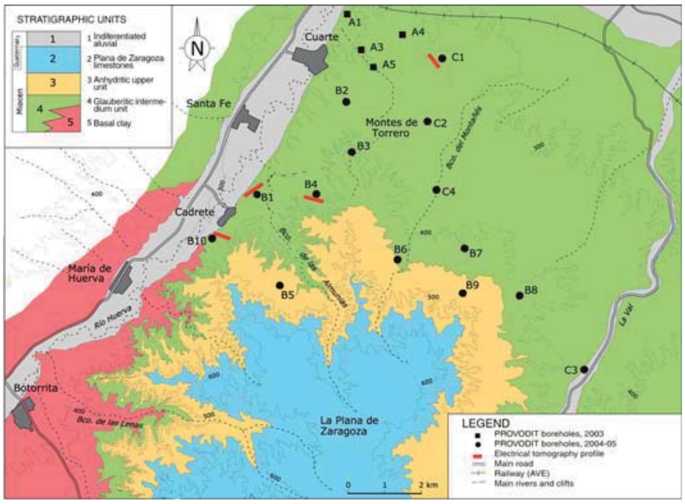

Fig. 2.- Geological map of the Montes de Torrero area and location of the performed electrical resistivity tomographyc profiles and boreholes (modified from Salvany, 2009).

Fig. 2.- Mapa geológico de los Montes de Torrero. Los lugares donde se realizaros los perfiles de tomografía eléctrica y los sondeos aparecen indicados (modificado de Salvany 2009).

formation, from bottom to top: a) halite unit, up to 150 meters thick; b) glauberite-halite unit, with a thickness between 50 and 100 meters; c) anhydrite unit, hundreds of meters thick. The Montes de Torrero glauberite deposit corresponds to the glauberite-halite unit within the Zaragoza formation.

The formation displays a monoclinal disposition, dipping up to 2º towards to the north. Minor folding and faulting is related to subsurface evaporite dissolution and collapse processes (Guerrero *et al*., 2003).

Methods

An electrical tomography survey was performed in the Montes de Torrero area (Zaragoza, Spain). Four electrical resistivity tomographyc profiles were carried out (Fig. 2) using a Syscal Pro Switch with 48 electrodes (10 meters of distance among them); reached investigation depth was close to 100 meters. Both Wenner-Schlumberger and Dipole- Dipole arrays were used because of the heterogeneous nature of the studied materials. On the purpose of processing data, RES2DINV program was used to carry out the inversion. This program uses the smoothness-constrained least-squares method (deGroot-Hedlin and Constable 1990, Sasaki 1992) in his inversion routine.

The ERT profiles were performed close to the B1, B4, B10 and C1 boreholes (Fig. 2), in order to compare drilled units with the geoelectrical data. Detailed description of the facies is meaningless because of the resolution of the method.

Results and discussion

After the processing of measured data, four electrical resistivity images were obtained (Fig. 3). In the B1 borehole profile (Fig. 3A) there is a horizontal layered distribution of the materials. The uppermost level displays the highest electrical resistivity value, interpreted as shallow filling materials (formed of gypsum fragments with gypsiferous clay matrix) and gypsum superior layers. Below these materials, the resistivity response decreases to very low values, interlayering a level with intermediate values from 40 to 60 meters depth. Good correlation with the petrological units is evidenced in the uppermost boundary (first layers and underlying low resistivity levels). The intermediate electrical resistivity value layers are related with the presence of minor amounts of anhydrite. The rest of low values correspond to glauberite levels reaching the lowest values in the clay-rich unit (in the bottom of the borehole). The profile displays lateral continuity in the defined structures, which is interpreted as the horizontal continuation of the layers related to their sedimentary deposition (Fig. 4A).

Nevertheless, the recorded geoelectrical resistivity, from 2 to 300 ohm.m, values are too low to be related to evaporite rocks. The abundance of clay-matrix in these materials decreases the resistivity importantly. At the left side of the profile (SW), the electrical resistivity appears higher, which can be attributed to a decrease in the amount of matrix within the rock.

The C1 borehole profile is very heterogeneous and asymmetric (Fig. 3B). A central body is defined with high electrical resistivity values. The rest of the line offers resistivity value changes in both horizontal and vertical directions, which make difficult to interprete any continuous structure. The borehole C1 is drilled just cutting the resistive body. The boundaries of the borehole coincide with the electrical resistivity changes. The uppermost clay unit matches with the least resistivity values and the higher ones with the levels of glauberite (mixed with anhydrite). The upper part of the resistive body (with a lower value than the part below) coincides with the gypsum-rich unit. This is coherent because the electrical resistivity values of anhydrite are higher than those of the gypsum (Fig 4A).

Laterally, variations in the image electrical resistivity are recorded, which could be related to sedimentary or karst development structures. Guerrero *et al*. (2003) described dissolution structures in evaporite rocks of the Huerva area that could be in accordance with defined structures in the C1 borehole profile. In the B4 borehole profile four subunits can be distinguished, from top to bottom (Fig. 3C): a resistive superficial layer, a low resistive thin layer, a high resistivity thick layer and a basal low resistivity layer. Although the thickness of the levels varies horizontally, the geoloelectrical resistivity tendency along the profile is maintained. This variation is principally observed at the boundary between the resistive thin layer and resistive thick layer. The first high resistive meters correspond to the superficial infillings. Below them, gypsum-rich layers have been described in the borehole (Salvany 2009). Electrical resistivity values of these levels (5-15 ohm.m) until 15 meters depth, indicates that are principally constituted of gypsum bearing clays. Dipping to 15 meters, the values increase rapidly to more than 150 ohm.m. This would be interpreted as an increasing of the gypsum quantity within the clay matrix (even the electrical resistivity values do not arrive to gypsum-pure layer values).

The transition from gypsum-rich layers to glauberite-rich layers is described at 36 meters depth in the borehole log. This depth does not fit with any resistive maximum or minimum. Indeed the electrical resistivity value increasing tendency at this depth does not vary. This means that the presence of clay is the main factor to define the average resistivity value of the rock, instead of the presence of glauberite or gypsum. In the bottom of the profile, where the resistivity tends to decrease again, the presence of clay layers increases until the clay-richest layer unit is reached. The uppermost irregular boundary of the resistive layer is interpreted as

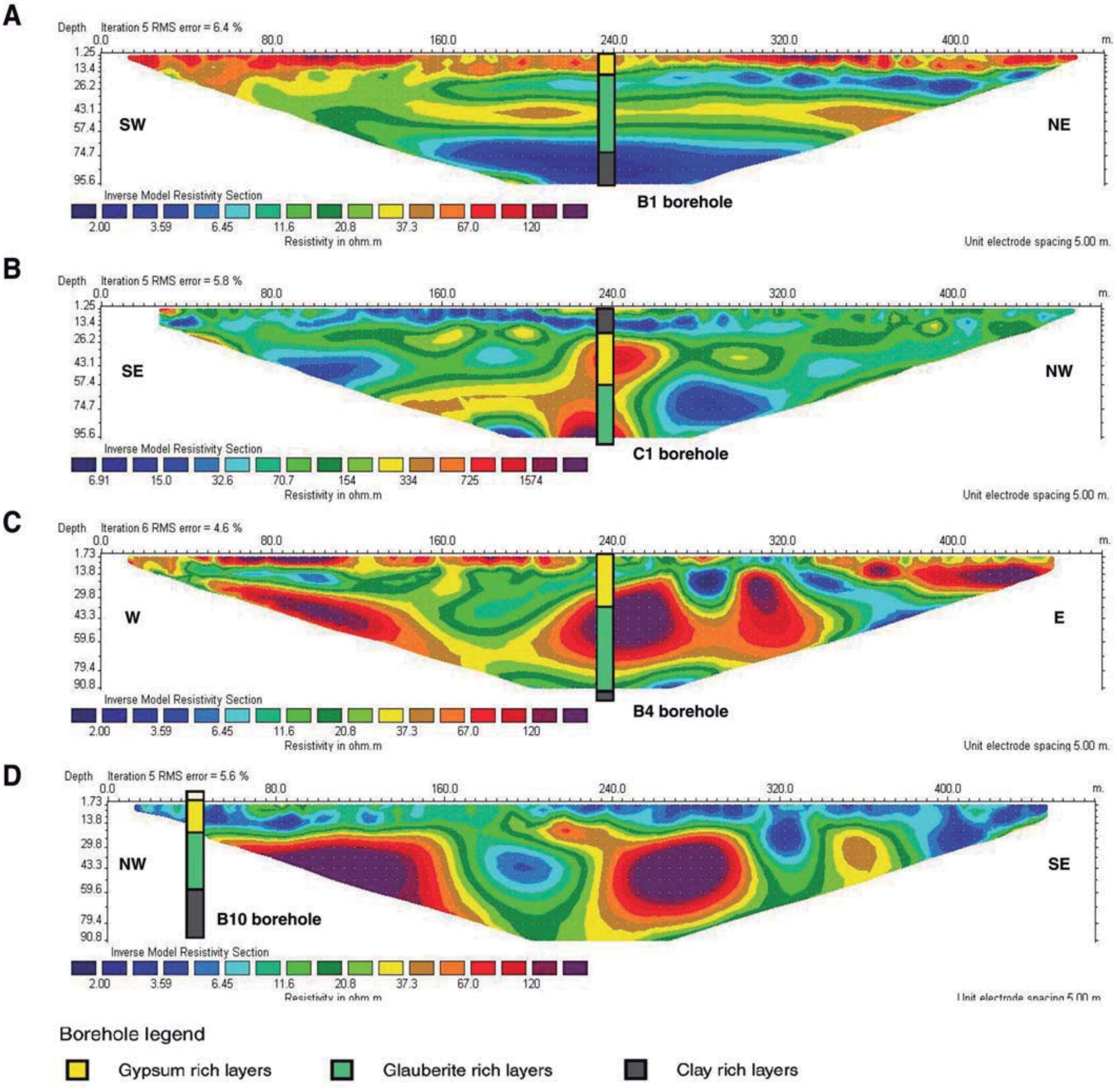

Fig. 3.- Real resistivity section and main petrological units of the B1, C1, B4 and B10 boreholes (synthesized from Salvany, 2009) A: B1 borehole section. B: C1 borehole section. C: B4 borehole section. B4 borehole section. D: B10 borehole section. Location of the profiles in the figure 2.

Fig. 3.- Secciones de resistividades reales y las principales unidades petrológicas de los sondeos B1, C1, B4 y B10 (sintetizados a partir de Salvany, 2009). A: Sección del sondeo B1. B: Sección del sondeo C1. C: Sección del sondeo B4. D: Sección del sondeo B10. La localización de los perfiles tomográficos aparece en la figura 2.

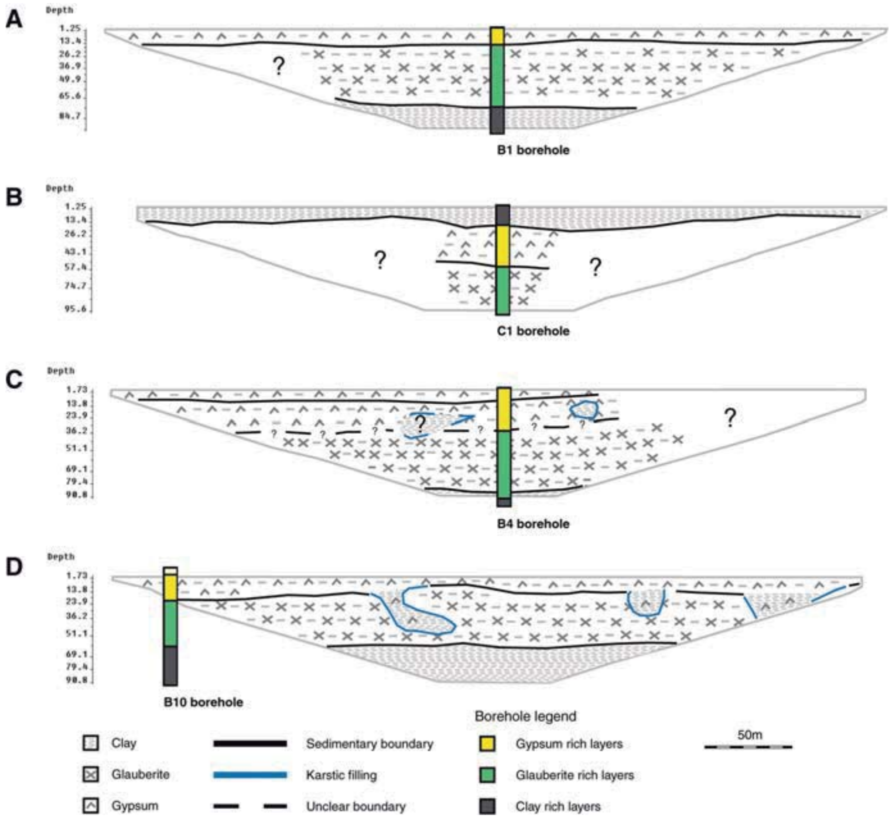

Fig. 4.- Petrological interpretation of electrical resistivity sections and main petrological units of the B1, C1, B4 and B10 boreholes (synthesized from Salvany, 2009) A) Interpretation of Fig. 3A. B) Interpretation of Fig. 3B. C) Interpretation of Fig. 3C. D) Interpretation of Fig. 3D.

Fig. 4.- Interpretaciones petrológicas de los perfiles de resistividades reales y las principales unidades petrológicas de los sondeos B1, C1, B4 y B10 (sintetizados a partir de Salvany, 2009). A) Interpretación de la Fig. A. B) Interpretación de la Fig. 3B. C) Interpretación de la Fig. 3C. D) Interpretación de la Fig. 3D.

karstification and infilling by collapse sediments (Fig. 4C).

The B10 borehole profile (Fig. 3D) shows a superficial low electrical resistivity layer, underlied by 3 higher irregular resistive bodies. The resistivity response returns to decrease values below these bodies even this phenomenon can be distorted by the «resistivity shadows» of the bodies above.

The interpretation of this image is a 3 layered depositional system. The depth of the boundaries in the electrical imaging match well with the depth of the boundaries between units in the borehole log description. The top is constituted of gypsum bearing clay layers. Below this unit, a glauberite-rich layer appears from 27 to 66 meters depth, and underneath the glauberite there are clay-rich layers. Lateral variation of these units is interpreted as karstification and infilling by collapse sediments (Fig. 4D). This profile was performed in the stream of a creek, where water circulation could have dissolved part of the evaporitic materials. These structures are very common in this region (Guerrero *et al*., 2003).

Concerning the election of array for data acquisition, all of the ERT profiles where measured with both Wenner-Schlumberger and Dipole-Dipole arrays. If the ERT device is optimized to perform the data acquisition in a relative low time it is recommendable to use both arrays because the measured structures can show important variations. If the structures displayed are vertical as in the C1 borehole profile, Dipole-Dipole array will define them more accurately. In the case of B10 borehole profile Wenner-Schlumberger image has been selected because of the distortion generated by the creep stream topography (this array is less sensitive to distortion). Horizontal structures are usually better defined by Wenner-Schlumberger array.

Conclusions

The results show that electric resistivity lines could be useful in prospection of glauberite deposits, supported by drilling works. The number of required boreholes could decrease considerably with this technique. However, imaging prospecting must be supported by an accurate petrological study of the deposits in order to properly interpret the resistivity profiles.

The knowledge about the quantity of matrix within the rock is essential because his presence decreases the electrical resistivity values hiding the real values of the evaporitic materials. As the matrix is always present in glauberite deposits it is not possible to estimate his range of electrical resistivity values.

Even the necessity of borehole information to carry out a suitable interpretation, ERT allow to detect some structures as depositional systems or karst infillings.

Acknowledgements

The present work was supported by the Programa General de Intesificación de la Investigación (Generalitat de Catalunya-UB) and the Spanish Government Projects CGL2005-05337 and CGL2006-04860. We want to appreciate the support and facilities of Dr. A. Casas (University of Barcelona, Spain).

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