Geoelectrical Characterization of Sulphate Rocks

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7

.1 Electrical properties of sulphate rocks

The geoelectrical response of sulphate rocks has been determined by comparing the resistivity values obtained from theoretical models, laboratory tests and field examples. The set of theoretical models, representing several gypsum, anhydrite and glauberite deposits with different compositions, provide evidence of a clear relationship between the lithological composition of the whole rock and its electrical resistivity.

The relationship between the gypsum content and electrical resistivity has been quantified in several laboratory tests, by means of measuring 11 artificial pills (mixtures of different clay/gypsum proportions). The measurements show evidence for similar absolute resistivity values to those of the theoretically calculated in the models, and display two inflexion points at the same composition ranges. Nevertheless, the resistivity of the purest pills is higher than in the geological pure gypsum rocks, due to textural differences in the cryptocrystalline nature of the pills. The connectivity between the lutite particles is the main controlling factor in their geoelectrical response. The electrical resistivity values interpreted in the different field tomography profiles are consistent with the theoretical calculations and the laboratory tests carried out in the pills.

A geoelectrical classification defining three types of gypsum rocks has been generated: a) Pure Gypsum Rocks (>75 % of gypsum content with an electrical resistivity value of 700-1000 ohm.m), b) Transitional Gypsum Rocks (75-55 % of gypsum content with an electrical resistivity value of 100-700 ohm.m), and c) Lutites and Gypsum-rich Lutites (<55% of gypsum content with an electrical resistivity value of 10-100 ohm.m). The Transitional Gypsum rocks would represent the transition between the *clay-supported* and *gypsum-supported* textures. Pure Gypsum Rocks have industrial interest (with an electrical resistivity value >800 ohm.m); thus geoelectrical techniques can be applied to determine the availability of a gypsum deposit to be exploited.

The electrical behavior of calcium sulphate rocks (gypsum-anhydrite-lutite system) has been widely studied at different scales with crystals, microphotographs, synthetic pills and geological deposits. Laboratory tests in pills have shown that the matrix of calcium sulphate rocks is affected by the percolation phenomena and therefore, when the matrix quantity in a rock is greater than 40% the electrical current avoids the sulphate minerals. The percolation threshold is defined for the stretch of 60-70% in sulphate purity; when this purity is larger, the sulphate minerals are the ones conditioning the electrical resistivity of the bulk rock. The electrical resistivity of gypsum crystals is lower in the direction of the main exfoliation planes due to the electric field generated by the water molecules; this explains the reason of the larger resistivity of anhydrite, which lacks of this hydration water layers.

The electrical resistivity value of anhydrite rocks range from 10 to 10^4 ohm.m; being the larger values related to purest rocks. This value is found in the field examples where the anhydrite appears as massive. The values observed in rocks with both gypsum and anhydrite (with minor matrix) have ranged between 1500 and 5000 ohm.m depending on the quantity of each other. Large quantity of matrix in sulphate rocks have shown low electrical resistivity values been unable to differentiate between gypsum and anhydrite.

When the matrix of the calcium sulphate rocks is percolant (more than 40%), the electrical resistivity value fits with the value calculated with the Hashin-Shtrikman lower bound (HS^-), and when is embedded in the sulphate phase (30% of matrix or less) fits with the Hashin-shtrikman upper bound (HS^+). If there are large heterogeneities in the distribution of the phases, the resistivity values of rocks with a matrix quantity close to 50% can display transitional values (more than 100 ohm.m; without reaching values of the purest sulphate rocks). Therefore, it is possible to calculate any combination of these 3 components and the geoelectrical classification has been elaborated for calcium sulphate rocks. With this classification is possible to determine the purity of the sulphates and the presence of anhydrite in gypsum rocks, which is useful for the characterization of the deposit.

Glauberite rocks have been studied by means of field examples. Pure glauberite rocks have displayed an electrical resistivity value of approximately 3000 ohm.m. From this value, Hashin-Shtrikman bounds can be calculated for a 4-phase system (gypsum-anhydrite-glauberite-lutite), but due to his complexity is has been simplified to 2 and 3-phase diagrams. In the case of rocks with purity less than 55% in sulphate phases, the resistivity is bounded to the lower HS boundary; which can be considered a 2-phase system (sulphate-lutite). In the case of rocks with more purity the electrical resistivity of different compositional combinations overlap; due to the complexity of the system. From the calculations is possible to predict the resistivity of any combination of the four phases. In any case, most glauberite deposits are impure and therefore will show values of percolant matrix sulphate rocks similar to the ones of gypsum-anhydrite-lutite system.

The study of these rocks is interesting also as reference for the studies of other rocks formed of various components with differentiated electrical resistivity values, as for example a lime-sand-gravel system. With similar methods to the ones used in this survey, it should be possible to predict the electrical resistivity of these rocks depending on their composition.

.2 Methods and limitations

Lateral purity changes and dissolution features are the most common structures which are found in sulphate deposits. These structures originated by both primary and secondary processes must be carefully taken into account when selecting the appropriate array in ERT surveys. The presence of conductive materials at deep position can improve the data acquisition, especially in the case of Dipole-Dipole array. Although this array tends to be noisy and uncertain, it could be the best option in certain structures (as a conductive-arched layer) and it can be checked by performing theoretical models. In any case, Wenner-Schlumberger has been the array selected in most examples; due to its stability. The imaging of block sensitivity can be useful as criterion to check the coherence between the calculated resistivity and the maximum and minimum sensitivity values. The areas of a profile in which the sensitivity is low (especially in the bottom), the calculated resistivity during the inversion may increase largely with each iteration; so it is recommended to perform few iterations (5 or 6) if the model converges.

When different pure sulphate phases are present, the electrical resistivity tomography may not difference them if they are below a conductive material such a lutite layer. The contrast in the resistivity generates a decreasing in the sensitivity within the sulphate rocks; and because of that they are displayed as homogeneous body. The elaborated classifications of sulphate rocks consider that the studied materials are roughly homogeneous. In some cases the deposits may be anisotropic due to layering and the presence of heterogeneities. These heterogeneities have influence in the electrical conductivity of the rocks, increasing the range of transitional resistivity values (instead of fitting to Hashin-Shtrikman bounds for compositions of 25 to 75% in sulphate mineral purity).

In the case of surveys in chlorides, the deposits may be more anisotropic than in the case of sulphate rocks. The effect in the conductivity is similar to the sulphate deposits with large quantity of heterogeneities, this is, transitional resistivity values. In the case of salt rocks, the presence of water has an important influence in their conductivity (unlike the sulphate rocks). The presence of water inclusions (which are saturated in salt due the high solubility of the deposits) increases the conductivity displaying resistivity values close to 1 ohm.m. This effect has been studied by means of three electrical resistivity tomography profiles. The transition between wet and dry salt rocks has been identified thanks to the electrical imaging. In salt deposits with pure composition in salt is expected to obtain electrical resistivity values similar to the ones obtained for pure sulphate rocks. Seismic tomography is a good complementary technique to the geoelectrical surveys in chloride rocks. This method allows to identify these materials thank to their P wave velocity with any water contain; while the geoelectrical techniques may be ambiguous without additional information.

.3 Application examples

Electric imaging has been successfully applied to identify the Pira gypsum deposits (Tarragona) interlayered in lutite units. Nevertheless, the gypsum-lutite boundaries can be shown diffuse and uncertain in the tomographic lines (mainly at depth). A laboratory test was employed to measure the percentage of insoluble residue in gypsum core samples. The purity of analysed gypsum rocks is from 56 to 64 % of gypsum mineral. Accompaining minerals (insoluble residue) are clay minerals, calcite and dolomite, quartz and celestite. Three set of resistivity data have been obtained: the lutite layers, pure gypsum rocks and the lutites and gypsum-rich lutites units; with resistivity values up to 20 ohm.m, between 700 and 1000 ohm.m and from 20 to 700 ohm.m, respectively. Resistivity and chargeability measures may in certain deposits permit to distinguish between lutite levels and clay-rich gypsum rocks, with similar low electrical resistivity values than lutites. Boreholes are very useful as supporting the interpretation due to the petrological complexity of evaporitic formations.

In the active gypsum quarry of Gelsa (Zaragoza), an electrical resistivity tomography survey has been performed and useful information has been obtained for the present and future exploitation planning. Pure alabastrine nodular gypsum layers have display high resistivity (close to 1000 ohm.m) while less pure gypsum layers have shown more conductive behaviour. Additionally, an impure zone has been identified in the area in which the quarry will be developed in the future. The most recent works in the quarry fronts have confirmed the information obtained in the resistivity images.

The obtained results on those applied examples show that electrical resistivity lines could be useful in mapping and prospection of sulphate deposits. However, imaging prospection should be supported by an accurate petrological study of the deposits (identifying the different minerals present and estimating their relative abundance), in order to properly interpret the resistivity images.

.4 Final conclusions

This thesis has generated a background about the electrical properties of sulphate rocks and the utility of geoelectrical methods for its prospection. The electrical resistivities of different sulphate minerals have been established and the methods for their investigation have been discussed. The published results will be a reference for further future surveys and exploitation works.