# Electrical Resistivity Tomography (ERT) geophysical prospection around the caves of Ojo Guareña Complex (Merindad de Sotoscueva, Burgos, Spain)

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Figure 1. Ojo Guareña karstic Complex detail over ortho-photo. Kaite Cave and Palomera Cave are highlighted and geophysical surveys are drawn in grey.

Image 1. Geophysical survey at Kaite Cave.

Image 2. Geophysical survey at Palomera.

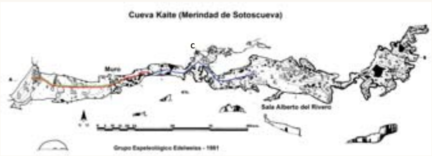


Figure 2. Kaite Cave plan with geophysical profiles. Red: 1. Green: 2. Blue: 3.

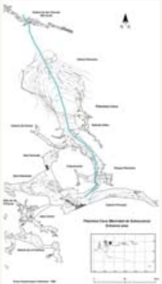

Figure 3. Palomera Cave plan with the geophysical profile drawn in cyan.

## INTRODUCTION

The Ojo Guareña karstic Complex is a multilevel system consisting of a 110km network of underground conduits, with about 400 cavities and fourteen entrances (Figure 1). The dimensions and variety of these conduits offer unlimited possibilities for human occupation, as reflects the archaeological importance of their sites. These preserve a cultural sequence that date from the Middle Paleolithic to the Middle Ages (Ortega *et al.*, 2013). Kaite Cave and the entrance area of Palomera Cave are one of the most outstanding ones.

Kaite preserves Neolithic and Bronze Age habitat areas in its two entrances (an ancient collapsed entrance –A- and the current entrance –C- see figure 2) and sepulchral symbolic areas inside the cave (Ortega and Martín, 1986). Its strategic location, perched 140 meters above the Sotoscueva Valley, has protected it from the erosive action of the Guareña River, making it one of the points of greatest potential to host Pleistocene occupation. In Palomera, main entrance to the karstic Complex, there are numerous sites that date from the Upper Paleolithic to the Iron Age. An excavation made in the entrance by Soledad Corchón in 1972 uncovered a 5m deep stratigraphy related to Recent Prehistory, but was abandoned not detecting all its potential which most surely will reach Paleolithic deposits. (Ortega and Martín, 2011).

Geophysical prospecting methods, for its non-invasive or destructive nature, are increasingly being used in archaeological research due to the fact that they allow recognizing buried structures and morphologies without previous excavation. This facilitates sites' interpretation, excavation planning and conservation policies (Hesse, 1999; Benech & Hesse, 2007; Wynn, 1986).

Among the geophysical methods geoelectric surveys, and in particular ERT (Electrical Resistivity Tomography), are being used lately in the investigation of karstic sites (Piro *et al.*, 2001; Bermejo, 2009; Bermejo *et al.*, 2010, 2013a, b and c; Ortega *et al.*, 2010; Valois *et al.*, 2010) as they can determine with enough accuracy the size, location and potential of the different infillings and caves (Guérin *et al.* , 2009; Chalikakis *et al.*, 2011) providing interesting information about the conduits' geometry and its surroundings.

## METHODOLOGY – ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

The geoelectric methods measure the resistivity (ρ) of rocks, which is expressed in ohm.m. Rock's physical behaviour depends on several aspects (such as porosity, fracture, saturation, temperature, etc.) what prevents to attribute a single resistivity value to a particular rock. Therefore, it is necessary to know the geological characteristics of the studied area. However, in calcareous environments where karst develops mainly, lower resistivity values are usually attributed to clastic infills (10-1000 ohm.m) whereas high resistivity values are attributed to the limestone substrate (1000-100.000 ohm.m) (Figure 4).

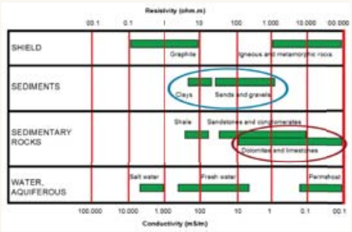


Figure 4. Resistivity and conductivity values of the more common rocks (modified from http://www-ig.unil.ch/cours/geophyse/c_rese.htm).

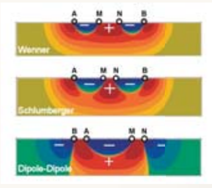


Figure 5. Schematic diagrams of the sensitivity patterns of the different geometric arrays for 2D terrain profiles. Referenced patterns are just an example of the combination of electrodes shown in this figure (modified from Dahlin and Zhou, 2004).

The Electrical Resistivity Tomography (ERT) sensor system (Dahlin, 2001) consists of a set of electrodes placed equidistantly along a rectilinear profile. A current is injected between two electrodes (A and B) and two other (M and N) measure the electrical potential difference (Loke and Barker, 1996). According to the geometric organization of these four electrodes different devices can be configured, although the most applied ones are Wenner-Schlumberger (WS) and Dipole-Dipole (D-D) (figure 5). WS has better depth resolution and lower noise but worse spatial resolution, while DD locates better vertical structures but has lower depth resolution (Dahlin and Zhou, 2004). We used both devices due to the unpredictable nature of the karst subsurface.

Data was processed with the Res2dinv software (Geotomo Software) to produce a two-dimensional model of the subsurface from the apparent electrical resistivity data (Loke and Barker, 1996). Topography adjustments where carried out during the inversions.

## RESULTS

### PALOMERA CAVE

A single 355 m long and 5 m electrode spacing profile was carried out from Dolina Palomera to Galería Principal (see figure 3). The limit of the resistivity values attributed to clays or terrigenous infills (up to 350 omh.m) has been marked in black (figure 6).

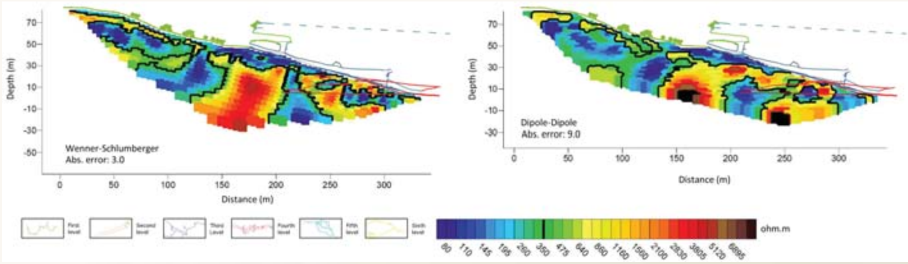


Figure 6. WS and DD 2D ERT profiles from Palomera Cave projected over the cave's profile.

### KAITE CAVE

Three different profiles were carried out in Kaite Cave (see figure 2). Profile 1 and 3 were 87.5 m long and 2.5 m electrode spacing, whereas profile 2 was arranged in the same area than profile 1 but was made 66.30 m long and 1.25 m electrode spacing in order to gain resolution on the anomalies. The limit of the resistivity values attributed to clays or terrigenous infills (up to 350 omh.m) has been marked in black (figure 7).

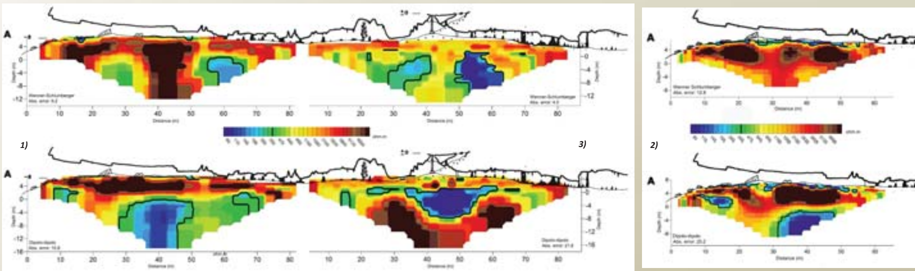

Figure 7. WS and DD 2D ERT profiles 1, 3 and 2 from Kaite Cave projected over the cave's profile.

## DISCUSSION AND CONCLUSIONS

The first one hundred metres from Palomera profile show low resistivity values at about 8 m under the subsurface. These cannot be attributed to a known conduct and must therefore be related to the collapse of the doline. Indeed, the vertical discontinuity shown at 150 m seems to be in relation with the cave entrance. In the inside, the cave's first 50 m, could host up to 15 m deep of deposits, only 5 of which are known to the present by Corchón's archaeological excavation, as aforementioned. Finally, the conductive anomalies found between 200-300 m can be related to the fourth level of the karst, the more developed one, which corresponds to Galería Principal (see figure 3). These last two possible infills are the more accessible ones and thus interesting for a future excavation planning.

Kaite's profiles 1 and 2 show barely 1 meter deep of sediments. Then they both indicate up to 7 metres of resistive values that may be attributed to the ancient entrance (A in figure 2) ceiling breakdown blocks (see image 1). From that depth on we cannot be sure of the subsurface nature, as WS show high resistivity values but DD (with much higher absolute error) reveals low resistivity values. Profile 3 indicates at least 4 m of high resistivity values that are related in surface to speleothems and may also be related to the actual entrance (C in figure 2) ceiling collapse. However, they both show a possible conduct underneath those 4 m which may indicate the presence of an unknown lower karstic level.

Kaite data present, in profiles 1 and 2, interesting infills likely to contain older deposits but difficult in terms of excavation planning due to the breackdown level thickness and the infrastructure required to remove it.

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