Electrical resistivity imaging survey around the caves of the Ojo Guareña Karst complex (Merindad de Sotoscueva, Burgos, Spain)

L. Bermejo
Centro Nacional de Investigación sobre Evolución Humana (CENIEH). Paseo Sierra de Atapuerca 3, 09002 Burgos, Spain and Equipo Primeros Pobladores de Extremadura, Casa de la Cultura Rodríguez Moñino. Avda. Cervantes s/n, 10003 Cáceres, Spain
lucia.bermejo@fa.cenieh.es

A. I. Ortega
Centro Nacional de Investigación sobre Evolución Humana (CENIEH). Paseo Sierra de Atapuerca 3, 09002 Burgos, Spain and Grupo Espeleológico Edelweiss, Excma. Diputación Provincial de Burgos, C/Paseo del Espolón s/n, 09071, Burgos, Spain

R. Guérin
Sorbonne universités, UPMC Univ Paris 06, UMR 7619, METIS, F-75005, Paris, France

A. Benito-Calvo & J. M. Parés
Centro Nacional de Investigación sobre Evolución Humana (CENIEH). Paseo Sierra de Atapuerca 3, 09002 Burgos, Spain

M. A. Martín
Grupo Espeleológico Edelweiss, Excma. Diputación Provincial de Burgos, C/Paseo del Espolón s/n, 09071, Burgos, Spain

E. Aracil & U. Maruri
Análisis y Gestión del Subsuelo, S.L. c/ Luxemburgo, 4; portal 1, oficina 3; 28224-Pozuelo de Alarcón, Madrid, Spain

J. A. Porres
Área de Ingeniería del Terreno. Dpto. de Construcciones Arquitectónicas e I.C.T. Escuela Politécnica Superior. Universidad de Burgos, 09001 Burgos, Spain

Abstract
Electrical Resistivity Imaging measurements were carried out around Kaite and Palomera Cave in order to identify their detrital infilling morphologies. These two caves are part of the Ojo Guareña Karst complex and contain different archaeological remains dating from the Upper Paleolithic to the Iron Age. At Palomera Cave, the proposed models show complex geological formations that mark the evolution of Palomera Sinkhole as well as the location of interesting infills where archaeological remains may have been preserved. In Kaite, the results suggest the presence of sediments prior to the ceiling breakdown, which, as this is one of the oldest caves in the karstic system (Ortega et al.*, 2013), may preserve early prehistoric phases of occupation remains. This information adds to a better understanding of the karst formation processes and may be used in the planning of a future excavation.*

Keywords: *Ojo Guareña Karst, Electrical Resistivity Imaging, archaeology, speleogenesis*

Résumé
Des prospections géophysiques ERI (Imagerie de Résistivité Électrique) ont été conduites dans les grottes de Kaite et Cueva Palomera, dans l'intention d'identifier la morphologie de ses remplissages terrigènes. Ces deux grottes font partie du Karst d' Ojo Guareña et préservent des restes archéologiques allant du Paléolithique Moyen à L'Age de Fer Les modèles proposés montrent des formations géologiques complexes qui peuvent avoir

identifié, pour Cueva Palomera, l'évolution de la Doline Palomera et aussi la localisation des remplissages susceptibles de garder des restes archéologiques. À Kaite les résultats suggèrent la présence des sédiments qui pourraient appartenir à un moment antérieur à l'enffondrement du plafond, or comme c'est l'une des grottes des plus vielles du système karstique, cela pourrait indiquer l'existence des restes des occupations le plus anciennes. Cette information permet de mieux comprendre les processus de la formation du karst, et peut aider la planification d'une future fouille archéologique.

Mots clés: *Karst d'Ojo Guareña, Imagerie de Résistivité Électrique, archéologie, spéléogèness*

Introduction

Geophysical prospection is increasingly being used in archaeological research because it allows recognizing buried structures and features without invasive methods. This facilitates the interpretation of sites, excavation planning and conservation policies (Conyers 2012; Bermejo *et al*. 2010; 2013b; Lowe 2012; Cardarelli & Di Filippo 2009; Benech & Hesse 2007; Hesse 1999; Wynn 1986).

Among the geophysical methods, geo-electric surveys, and in particular ERI, are commonly used in the investigation of archaeological karstic sites (Bermejo *et al*. 2014a; Porres *et al*. 2013; Ortega *et al*. 2010; Valois *et al*. 2010; Piro *et al*. 2001). This is because electrical resistivity surveys can determine the size, location and potential of different karstic features with high accuracy (Chalikakis *et al*. 2011; Guérin *et al*. 2009), based on the contrast of the different resistivity values such as between the limestone host rock and the detrital sediments.

The aim of the electric resistivity surveys at the Ojo Guareña Karst complex was to locate sediments that may contain archaeological remains or fills of ancient cave entrances, as well as to find void passages impassable to speleological exploration, which may help understand the evolution and features of this underground environment.

The Ojo Guareña Karst is located in Northern Spain, in the southern spurs of the Cantabrian Range (Figure 1). The Ojo Guareña Karst complex consists of more than 400 cavities with 14 entrances and a network of underground conduits that reaches a total length of 110 km. These caves are developed in Cretaceous limestone and distributed over six overlapping sub-horizontal levels, constituting one of the longest multilevel cave systems in Europe.

The dimensions and variety of these conduits offer countless possibilities for human occupation, as is reflected by the cultural sequence that dates from the Middle Palaeolithic to the Middle Ages (Ortega

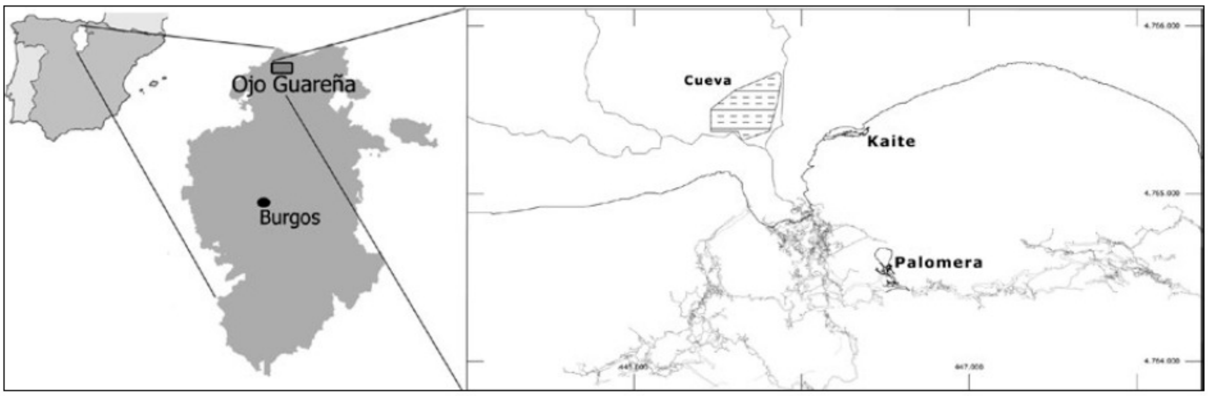

Figure 1. Detail of the Ojo Guareña Karst. Kaite and Palomera Cave are highlighted in dark grey (based on Ortega *et al*. 2013).

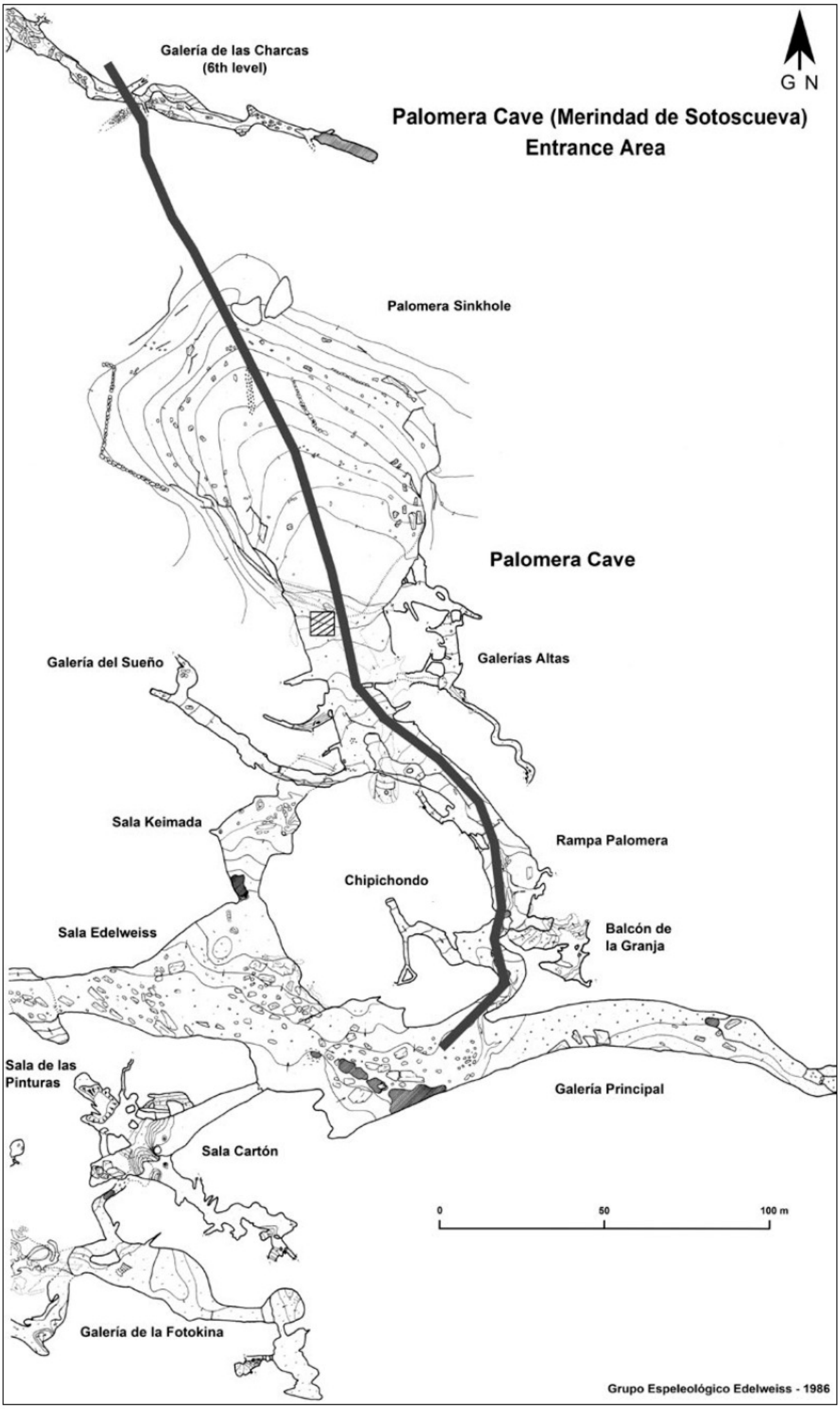

FIGURE 2. PALOMERA CAVE ENTRANCE AREA PLAN. THE ERT PROFILE LAYOUT IS MARKED IN DARK GREY. THE APPROXIMATE LOCATION OF CORCHON'S 1972 EXCAVATION IS MARKED BY A BLACK GRILLE (BASED ON G. E. EDELWEISS, 1986).

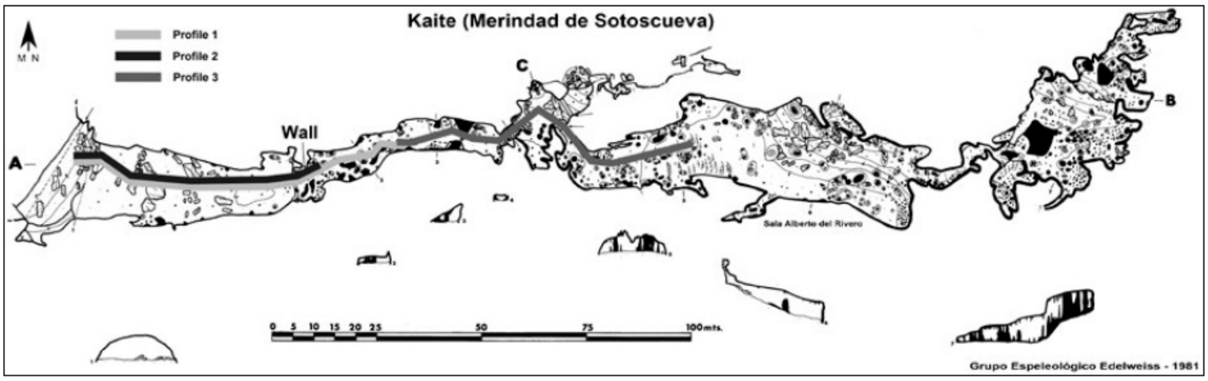

FIGURE 3. KAITE PLAN: A IS THE ANCIENT ENTRANCE; B THE SANCTUARY AREA; C THE CURRENT ACCESS. PROFILE 1 IS MARKED IN BLACK, PROFILE 2 IN LIGHT GREY AND PROFILE 3 IN DARK GREY (BASED ON G. E. EDELWEISS, 1986).

et al. 2013; Ortega & Martín 2011). Kaite and the entrance area of Palomera Cave are among the best-known caves in the complex because of their archaeological records (Ortega & Martín 1986).

Palomera Cave, the main cave of the karstic complex, contains numerous sites dating from the Upper Palaeolithic to the Iron Age. Soledad Corchón's 1972 excavation in the cave entrance uncovered a 5 m deep stratigraphy related to Chalcolithic and Bronze Ages, but did not reach the sedimentary sequence bottom. Therefore, unknown Palaeolithic deposits may still be buried in the lower stratigraphical levels (Ortega & Martín 1986) (Figure 2).

Kaite is a horizontal passage which constitutes an isolated higher level of the Ojo Guareña Karst complex. Neolithic and Bronze Age habitation areas are preserved in its two entrances: a valley facing entrance (A) where a habitation area was demarcated in prehistoric times by a wall; and the current access (C) which is the result of a ceiling collapse (Figure 3). In addition, it preserves sepulchral/symbolic areas inside the cave (B) with semi-naturalistic rock art (Uribarri and Liz 1973; Ortega *et al*. 2013). Its strategic location, perched 140 m above the Sotoscueva Valley, has protected it from the erosive action of the Guareña River and gave it a strategic location for territory control. Therefore, Kaite offers great potential for the presence and preservation of Pleistocene occupation remains.

Methodology

Electrical Resistivity techniques have proven their suitability for characterizing complex karstic environments (Martínez-Moreno *et al.* 2014; Bermejo *et al.* 2013a; 2014b; Cardarelli *et al.* 2006; Zhou *et al.* 2002) even when interpreted through 2D profiles, as they can determine both horizontal and vertical electrical resistivity contrasts.

2D ER imaging renders data compiled by a combination of four aligned electrodes: two of them inject an electrical current into the ground, whereas the other two measure the electrical potential difference. When multiple electrodes are combined along a rectilinear profile, different resistivity values can be recorded at various depths.

Depending on the array geometry, different imaging resolution and penetration depths can be obtained. Wenner-Schlumberger (WS) and Dipole-Dipole (DD) are the commonly used arrays for this type of surveys. WS usually offers good depth determination but poorer spatial resolution, while DD is better at locating vertical and dipping structures but is poorer in depth resolution (Dahlin &

Zhou 2004). Due to the unpredictable nature of the karst subsurface both arrays were used in the present study.

The ER acquisition was performed using a Syscal Pro-resistivity meter (IRIS instruments). In Palomera Cave a single profile with a length of 355 m and 5 m inter-electrode spacing was laid out from Dolina Palomera to Galería Principal, reaching a gradient of more than 80 m (Figure 2). For logistical reasons, the profile was laid out close to the eastern wall of the cave, and in some occasions the electrodes had to be placed on the limestone host rock. In Kaite, three profiles were measured. Profile 1, with a length of 87.5 m and 2.5 m electrode spacing, was placed over the valley-facing entrance area (*A* in Figure 3). In order to gain resolution at interesting features seen at profile 1, profile 2 was arranged in the same area but with less electrode spacing (1.25 m) and was therefore shorter (66.3 m –Figure 3). Finally, profile 3, with a length of 87.5 m and 2.5 m electrode spacing, was laid out over the actual access area (*C* in Figure 3).

In regards with data, effects C and P were filtered using the X2ipi software (© Alexei A. Bobachev) (Ritz *et al.* 1999). Subsequently, data was processed using the Res2dinv software (version 3.59.119, Geotomo Software) to produce a two-dimensional model of the subsurface from the apparent electrical resistivity values, represented in model blocks (Loke & Barker, 1996). Inversions were performed using the Robust option; topographic adjustments were carried out based on the geomorphological maps of the endokarst system provided by the Speleological Group Edelweiss. Special attention was paid to the inversion's absolute error, which is calculated from the difference between the measured and the calculated apparent resistivity values. The logarithmic color scale was designed to display the resistivity values of the geophysical surveys with respect to local geological observations and global knowledge of the karstic system.

Following this process, 225 Ω.m was established as the maximum resistivity value attributed to the different detrital sediments of Palomera Cave. For Kaite, the limit of 350 Ω.m was chosen, as the high resistivity values of the upper layers influence the underlying layers which yielded low resistivity values. These limits are indicated in each profile by a thick black line (Figure 5).

Results and discussion

The model proposed by the ERI profile for Palomera Cave shows a complex geology (Figure 4). In the profile's first 100 m there is a 70 m wide low resistivity anomaly at about 8 m under the subsurface (a in Figure 4), with an inclination which coincides with the slope of Palomera Sinkhole. These low resistivity values, which likely correspond to detrital sediments, cannot be attributed to any known cave passage and must therefore be linked to Palomera Sinkhole and/or to the continuation of Galerías Altas level, as they match this conduit's height (Figure 4).

In relation to it, there is a conductive anomaly around the profile's 150 m (b in Figure 4) associated to a vertical discontinuity (marked by a discontinuous line in Figure 4) that matches the cave's current entrance cliff. If this is a collapse sinkhole type, it is possible that the former anomalies represent detrital sediments related to the cave's ceiling/walls collapse, whereas the vertical discontinuity may be associated with a fracture that caused this collapse.

The first 50 m from the cave's current entrance reveal a conductive area (c in Figure 4) that reaches 15 m in depth. The resistivity values of this area are consistent with the sediments that host the archaeological site of which the upper 5 m are known from Corchón's excavation (Figure 2). Consequently, these may contain remains associated with human occupation.

Finally, the three conductive anomalies (d-f in Figure 4) found between the profile's 200-300 m could represent three filled passages with an E-W orientation, related to the fourth level of the karst (Figure 4). This level, the longest one, corresponds to Galería Principal (Figure 2) and is indeed developed E-W, which is the preferential direction of the Ojo Guareña Karst (Figure 1). Contrastingly, the

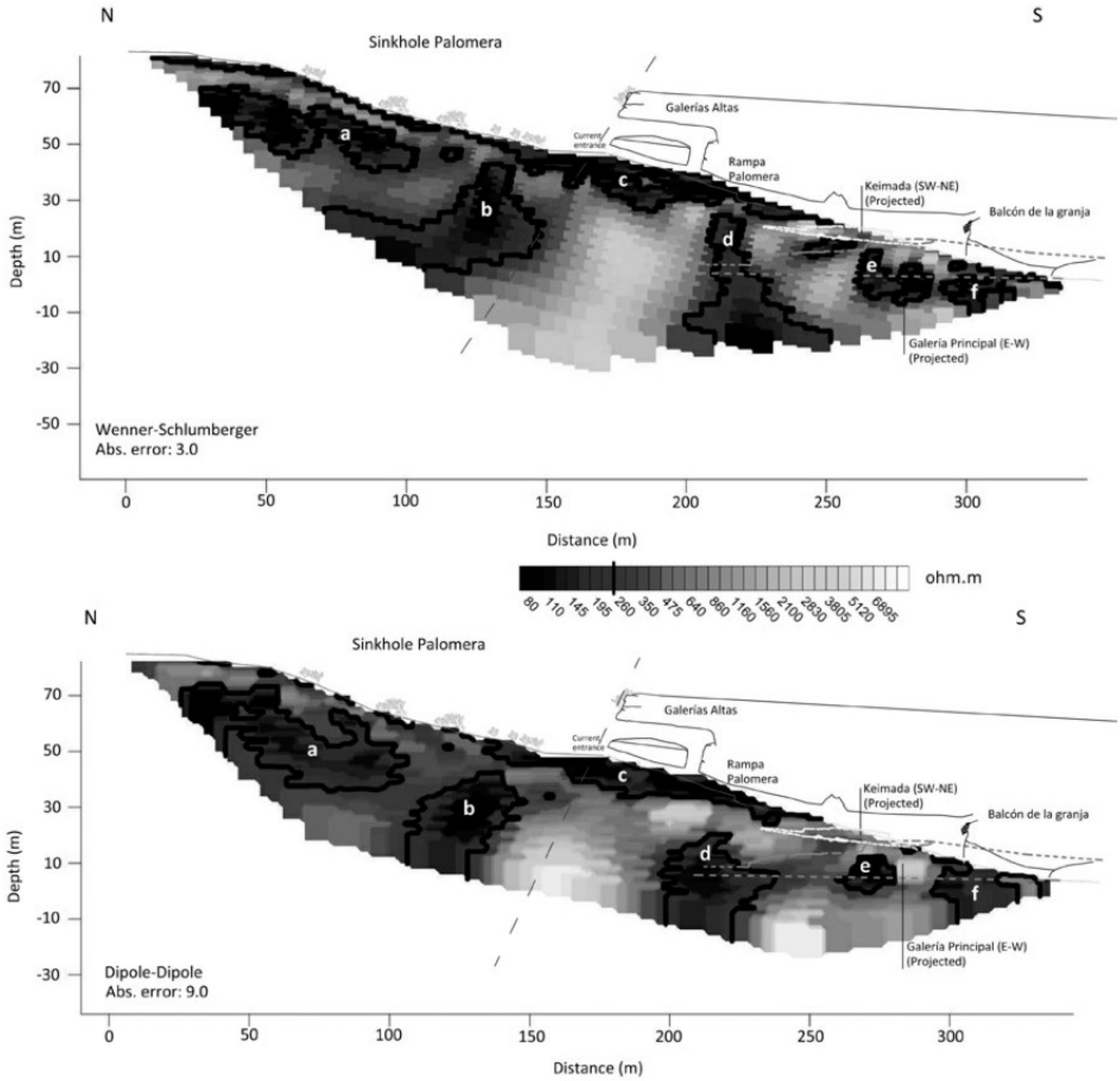

FIGURE 4. PALOMERA'S ERT PROFILE WITH BOTH WENNER-SCHLUMBERGER (WS) AND DIPOLE-DIPOLE (DD) RESULTS.

continuity of Sala Keimada is not visible in the ER survey (Figure 4). This could be due to the fact that the ER profile was placed too close to the eastern wall of the cave, or that the horizontal narrow, visible from Sala Keimada but not accessible to speleological prospection, ends near-by. The last infill (f in Figure 4), at 310 m, is the only one apparently connected with the surface and located near a connection with the Balcón de la Granja passage (Figure 4), a higher level where prehistoric hearths have been identified (Ortega & Martín 1986).

In summary, this latter infill and the one near the cave's entrance are the most accessible for archaeological excavation and may be considered in the planning of future archaeological work. Since the results of both arrays (WS and DD) are similar and their absolute error low, these data can be taken as reliable.

Kaite's profiles 1 and 2 (Figure 3) were laid out over a prehistoric habitation area, delimited by a prehistoric manmade wall (nowadays covered by a thin flowstone), corresponding to the twilight

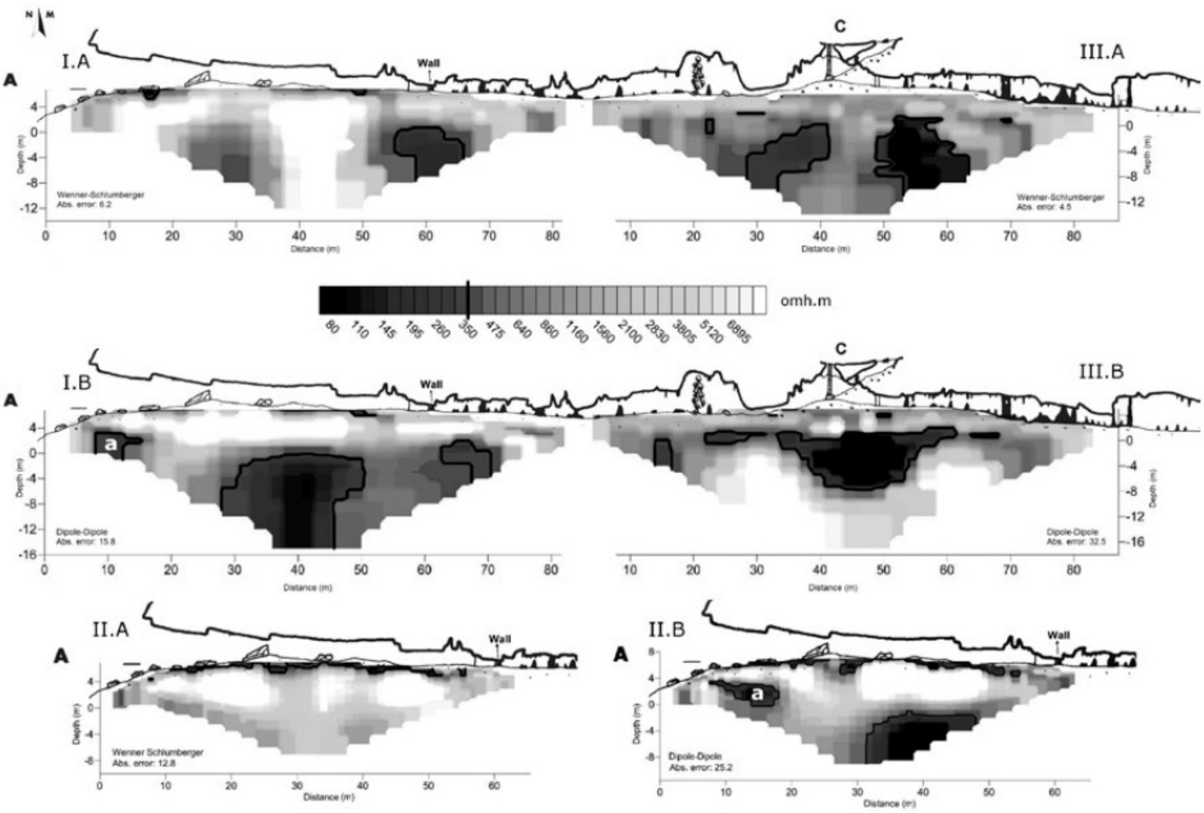

FIGURE 5. KAITE'S ERT PROFILES: I.A –WS PROFILE 1; I.B – DD PROFILE 1; II.A – WS PROFILE 3; II.B – DD PROFILE 3; III.A – WS PROFILE 2; III.B – DD PROFILE 2.

zone, where light is sufficient to permit human vision. In both profiles, the two applied arrays (WS and DD) show low resistivity values in the upper layers, which can be attributed to the sediments visible on the surface. These barely reach one meter deep and disappear laterally before reaching the prehistoric wall, which highlights their relationship to an occupation area (Figure 5 I.A, I.B, II.A and II.B).

The sediments of this upper layer sit on an irregular surface of high resistivity values that reach a depth of up to 7 m. This anomaly may be attributed to the ceiling breakdown blocks, which are visible on the surface and in roof, where the negatives of the blocks can be appreciated (Figure 6). Indeed, they disappear at the profile's 50 m, where the vault morphology changes into a phreatic type (Figure 5).

From this depth downwards it is difficult to make a proper interpretation about the subsurface nature: WS shows high resistivity values (Figure 5 I.A and II.A) whereas DD, at higher absolute error, reveals conductive anomalies consistent with the detrital sediments resistivity values (Figure 5 I.B and III.B). In any case, the conductive anomaly detected by DD at abscissa 15 m in profiles 1 and 2 (a in Figure 5 I.B and II.B) should be considered for a future excavation, as it is close to the surface and therefore easy to gain access to. Moreover, since it is located within the habitation area and below the high resistive anomaly, it is susceptible of hosting a pre–ceiling breakdown occupation. Given the fact that this is one of the oldest caves in the Ojo Guareña Karst complex, these deposits could be Pleistocene.

Profile 3 was conceived as the extension of profile 1, with the aim to cover the cave's length and gain more insight in the cave's current access collapse (Figure 5 III). The results show a very simple

Figure 6. Detail of Kaite's ancient entrance. Notice the stepped ceiling and the big blocks on surface that match the vault's negatives.

geological model that features high resistivity values reaching at least 4 m in depth (Figure 5 III), which can be related to the surface flowstones as well as to the actual access (C in Figure 3) ceiling collapse. In the underlying layers both WS and DD show a conductive anomaly that may indicate the presence of a previously unknown lower karstic filled conduit with N-S orientation. Another possibility is that the anomaly represents the bottom of Kaite's passage, which was filled with sediments and then covered with thick flowstones and/or blocks.

Conclusions

ER prospections at the Ojo Guareña Karst reveal a complex geology, as can be expected from a multilevel karstic system. In Palomera Cave, anomalies a and b may be interpreted as sediments related to the collapse of Palomera Sinkhole. The conductive anomaly a can be interpreted as the continuation of Galerías Altas passage. Moreover, the vertical discontinuity in both profiles could be linked to a fracture responsible of this collapse.

Inside Palomera Cave, different detrital infills possibly related to human occupation have been identified. The one at the cave entrance and the one related to the Balcón de la Granja passage are interesting for further work because of their accessibility and relationship with other known archaeological sites. In both cases, further geophysical work (including complementary methods such as GPR), together with excavations or archaeological test pits are necessary for a better understanding of the karstic formation processes.

In Kaite the presence of a pre-ceiling breakdown occupation in the valley-facing entrance area is still up in the air, as the different arrays (WS and DD) offer contradictory results. However, the results show more than 7 m of breakdown potential, which otherwise is witnessed in the geometry of the vault's negatives. Furthermore, the existence of detrital sediments filling an unknown lower karstic level or deposited at the bottom of the conduit, offers new possibilities for the interpretation of this singular cave. Additional geophysical prospection could be helpful in order to plan a future excavation and to elaborate a proper speleogenesis reconstruction of one of the highest and oldest caves of the Ojo Guareña Karst.

The different results obtained in both caves, especially with regards to the cave morphologies, illustrate the potential of ER imaging for archaeological site detection in karstic environments.

Acknowledgments

The corresponding author is beneficiary of a Fundación Atapuerca Pre-doctoral Grant. A.I.O. has been supported by a postdoctoral grant from Juan de la Cierva Subprogram (JCI-2010-06792) and a 2014 Mineco CGL2009-1273-C03-01 contract. This study was partly funded by the financial aid "Jóvenes Excelentes 2013" from the Gutierrez Manrique Foundation, managed by the Caja de Burgos Foundation, awarded to the corresponding author. The authors wish to thank Grupo Espeleológico Edelweiss for its constant scientific and logistic support and Laura González Navarro who participated in the field survey. This work has benefited from discussions with Isidoro Campaña Lozano. Authors thank the anonymous reviewer for their comments which helped improve the manuscript.

References

BENECH, C.; HESSE, A. 2007. Some considerations on the integration of geophysical data into archaeological research. In Geophysik und Ausgrabung. Einsatz und Auswertung zerstörungsfreier Prospektion in der Archäologie, Internationale Archäologie Naturwissenshaft und Technologie. p. 175-186.

BERMEJO, L.; CANALS, A.; GONZÁLEZ, J. M.; FERNÁNDEZ, F.; CAMPAÑA, I.; CARBONELL, E. 2013b. Aplicación de técnicas de prospección geofísica al estudio de la Cueva de Santa Ana (Cáceres, España). Actas del X Congreso Ibérico de Arqueometría. p. 451-452.

BERMEJO, L.; GUÉRIN, R.; CANALS, A. 2010. Subsoil Characterization by Electrical Resistivity Tomography around Rosières-la-Terre-des-Sablons site (Lunery, Region Centre, France). Annali dell'Università di Ferrara Museologia Scientifica e Naturalistica, 6.

BERMEJO, L.; ORTEGA, A. I.; ARACIL, E.; GUÉRIN, R.; PÉREZ-GONZÁLEZ, A.; BENITO- CALVO, A.; HUGUET, R.; MARURI, U.; PÉREZ, R.; VALLVERDÚ, J.; CAMPAÑA, I.; PORRES, J. A.; BERMÚDEZ DE CASTRO, J. M.; CARBONELL, E. 2013a. Aplicación de ERT (Electrical Resistivity Tomography) para la identificación de la morfología sub-superficial del yacimiento de Elefante, Sierra de Atapuerca (Burgos, España). Actas del X Congreso Ibérico de Arqueometría. p. 352-363.

BERMEJO, L.; ORTEGA, A. I.; GUÉRIN, R.; PARÉS, J. M.; BENITO-CALVO, A.; MARTÍN, M. A.; ARACIL, E.; MARURI, U.; PORRES, J. A. 2014a. Electrical Resistivity Tomography (ERT) for identifying Torcas area passages connecting Gran Dolina, Galería Complex and Sima del Elefante sites (Sierra de Atapuerca, Burgos, Spain). In XVII Congreso Mundial de la UISPP. Burgos: p. 39-40. Libro de resúmenes.

BERMEJO, L.; ORTEGA, A. I.; GUÉRIN, R.; PARÉS, J. M.; BENITO-CALVO, A.; MARTÍN, M. A.; ARACIL, E.; MARURI, U.; PORRES, J. A. 2014b. Técnicas de prospección geofísica aplicadas a yacimientos kársticos: Tomografía de Resistividad Eléctrica (ERT) en el Karst de Ojo Guareña (Ojo Guareña, Merindad de Sotoscueva, Burgos). In Cubía 18. Grupo Espeleológico Edelweiss. Diputación de Burgos. p. 48-55.

CARDARELLI, E.; DI FILIPPO, G. 2009. Integrated geophysical methods for the characterisation of an archaeological site (Massenzio Basilica – Roman forum, Rome, Italy). Journal of Applied Geophysics. 68, p. 508-521.

CARDARELLI, E.; DI FILIPPO, G.; TUCCINARDI, E. 2006. Electrical resistivity tomography to detect buried cavities in Rome: a case study. Near Surface Geophysics. 4, 387-392.

Chalikakis, K.; Plagnes, V.; Guérin, R.; Valois, R.; Bosch, F. 2011. Contribution of geophysical methods to karst-system exploration: an overview. Hydrogeology Journal. 19, p. 1169-1180.

Conyers, L. 2012. Interpreting Ground-penetrating Radar for Archaeology. Left Coast Press, Walnut Creek, California.

Dahlin, T.; Zhou, B. 2004. A numerical comparison of 2D resistivity imaging with 10 electrode arrays. Geophysical Prospecting. 52, p. 379-398.

Grupo Espeleológico Edelweiss (Ed.) – 1986. Monografía sobre Ojo Guareña.

Guérin, R.; Baltassat, J. M.; Boucher, M.; Chalikakis, K.; Galibert, P. Y.; Girard, J. F.; Plagnes, V.; Valois, R. 2009. Geophysical characterisation of karstic networks? Application to the Ouysse system (Poumeyssen, France). Comptes Rendus Geoscience. 341, p. 810-817.

Hesse, A. 1999. Multi-parametric survey for archaeology: how and why, or how and why not? Journal of Applied Geophysics. 41, p. 157-168.

Loke, M. H.; Barker, R. D. 1996. Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method. Geophysical Prospecting. 44, p. 131-152.

Lowe, K. M. 2012. Review of geophysical applications in Australian archaeology. Australian Archaeology. 74, p. 71-84.

Martínez-Moreno, F. J.; Galindo-Zaldívar, J.; Pedrera, A.; Teixido, T.; Ruanoa, P.; Peña, J. A.; González-Castillo, L.; Ruiz-Constán, A.; López-Chicano, M.; Martín-Rosales, W. 2014. Integrated geophysicalmethods for studying the karst system of Gruta de las Maravillas (Aracena, Southwest Spain). Journal of Applied Geophysics. 107, p. 149-162.

Ortega, A. I.; Benito-Calvo, A.; Pérez-González, A.; Porres, A.; Martín, M. A. 2010. Applying electrical resistivity tomography to the identification of endokarstic geometries in the Pleistocene sites of the Sierra de Atapuerca (Burgos, Spain). Archaeological Prospection. 17, p. 233-245.

Ortega, A. I.; Martín, M. A. 1986. La Arqueología del Karst de Ojo Guareña. In Grupo Espeleológico Edelweiss (Ed.). Monografía sobre Ojo Guareña. Kaite. 4-5, p. 331-389.

Ortega, A. I.; Martín, M. A. 2011. El Karst de Ojo Guareña. Merindad de Sotoscueva, Burgos. In Cubía 15. p. 20-39.

Ortega, A. L.; Martín M. A.; Grupo Espeleológico Edelweiss 2013. Cuevas de Ojo Guareña. Una visión de la mano del Grupo Espeleológico Edelweiss. Diputación Provincial de Burgos.

Piro, S.; Tsourlos, P.; Tsokas, G. N. 2001. Cavity detection employing advanced geophysical techniques: a case study. European Journal of Environmental and Engineering Geophysics 6, p. 3-31.

Porres, J. A.; Ortíz, S.; Ibáñez, S. J. 2013. Subsoil caves characterization by means of the interpretation of electrical resistivity tomography: Application to Clunia and Atapuerca archaeological sites. 4th International Conference on Site Characterization, ISC-4. 2, p 1435-1440.

Ritz, M.; Robain, H.; Pervago, E.; Albouy, Y.; Camerlynck, C.; Descloitres, M.; Mariko, A. 1999. Improvement to resitivity pseudosection modelling by removal of near-surface inhomogeneity effects: application to a soil system in south Cameroon. Geophysical Prospecting, 47, p. 85-101.

Uribarri, J. L.; Liz, C. 1973. El arte rupestre en Ojo Guareña. La Cueva de Kaite. Trabajos de Prehistoria, 30, p. 69-108.

Valois, R., Bermejo, L.; Guérin, R.; Hinguant, S.; Pigaud, R.; Rodet, J. 2010. Karstic Morphologies identified with Geophysics around Saulges Caves (Mayenne, France). Archaeological Prospection. 17, p. 151-160.

Wynn, J. C. 1986. A Review of Geophysical Methods Used in Archaeology. Geoarchaeology: An International Journal, 1(3): 245-257. In Selected Papers on the Application of Geophysical Instruments for Archaeology (1986). Geonics limited, Ontario.

Zhou, W.; Beck, B. F.; Adams, A. L. 2002. Effective electrode array in mapping karst hazards in electrical resistivity tomography. Environmental Geology. 42, p. 922-928.