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Can magnetometry detect sediment-filled caves? The case study of the Sierra de Atapuerca Sites (Burgos, Spain)

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Summary

This work evaluates the potential of magnetometry to detect the inaccessible sediment-filled caves of the Sierra de Atapuerca karstic system. This karst consists of numerous caves filled with sediments that bear outstanding archaeo-paleontological remains from the Early and Middle Pleistocene. In order to find the continuity of the caves, the Sierra de Atapuerca sites have already been the target of ERT and GPR surveys, which have revealed their suitability for detecting different karstic features. Although our expectations were to find positive anomalies when crossing these filled conduits, the results showed a negative anomaly of the magnetic field where these sediments were expected. So far, the only explanation for this phenomenon is that these sediments were deposited in a reversed magnetic polarity period. This theory is supported by the fact that the Matuyama-Brunhes boundary is present in many of the studied caves.

Introduction

The Sierra de Atapuerca sites, located 14 km from the city of Burgos (Spain), consists of numerous caves filled with sediments that host one of the largest European collection of human fossils and cultural remains from the Early and Middle Pleistocene (Bermúdez de Castro *et al.*, 1997; Carbonell *et al.*, 2008; Ortega *et al.*, 2014).

A part of this karstic system has been known and explored for centuries, due to the fact that it is partially filled with air and easy to access. During the last four decades these 4.7 km of passages have also been thoroughly mapped (Martín-Merino *et al*., 1981). Another part of this system, however, was discovered by a XIXth Century railway trench that cut the southwestern flank of the hill, unveiling various caves silted up with sediments.

Identifying the development and morphology of this karstic system and the relationship between the caves' infillings, is thus one of the research team's priorities (Ortega *et al.*, 2013), as it is crucial for understanding the sites' formation processes and planning excavation strategies.

To that end, the Sierra de Atapuerca sites have already been the target of ERT (Electrical Resistivity Tomography) and GPR (Ground Penetrating Radar) surveys, which have revealed their suitability for detecting the direction and dimension of sediment-filled caves, the location of silted up cave entrances and the location and dimension of air-filled caves (Ortega *et al.*, 2010; Bermejo *et al.*, 2015 and 2017). These interpretations have been verified by a series of test pits that have been performed over last three years.

These positive results, encouraged us to evaluate the potential of magnetometry to detect the inaccessible caves filled with clayey sediments, in order to gain more information about this karst features and to enhance the knowledge about the more uncertain places. Our expectations were to find positive anomalies when crossing sediment-filled caves. Indeed, magnetometry was successfully used in the past to detect the principal fractures of the karstic system (Bergamín *et al.*, 1992).

Geological context

The Sierra de Atapuerca is a positive relief composed mainly of Upper Cretaceous limestones and dolomites, situated in the NE area of the Duero Depression. When the Duero Basin opened to the Atlantic Ocean at end of the Neogene, its alluvial and lacustrine conglomerates and clays started to be eroded by the drainage network represented by the Arlanzón River and its tributaries, the Vena and the Pico Rivers (Benito-Calvo *et al.*, 2008). This fluvial network was also responsible for generating a stepped sequence of terraces (Benito-Calvo and Pérez-González, 2015) and a multilevel cave system related to the incision of the base level (Ortega, 2009).

The Sierra de Atapuerca caves are developed in the San Vicente Hill (1085 m a.s.l.) over a thickness between 40 and 70 m and organized in three main subhorizontal levels (Ortega *et al.*, 2013) that were hydrologically abandoned in the Lower Pleistocene (Parés and Pérez-González, 1995; Pérez-González *et al.*, 2001).

As for the magnetic susceptibility of the materials that can be found in this karstic system, the element analysis indicate that the sediments that fill some of the studied caves contain between 2 and 5,6 % of iron (Campaña *et al.*, 2016), whereas the mineral analysis indicate that the iron oxide is below the limit of detection in the limestone.

Methods

The magnetic survey was performed measuring consecutive points every two meters approximately. These points were acquired following the pathways located over the caves (known and expected) and away from the disturbance points (such as scaffolds, traffic signals or fences), which narrowed the survey considerably (image 1). Each magnetic measurement was located with a GPS receiver.

We used a total field G858 Caesium Magnetometer (from Geometrics ltd.) used in dual sensor mode, with the lower sensor located at 1m above the ground and the higher sensor located at 2.5m above the ground. It appears that the higher sensor did not work properly, so we can only present and discuss the results of the lower sensor. Additionally, we used a G856 proton magnetometer (also from Geometrics ltd.) as a base station to estimate the time variation of the local mean magnetic field.

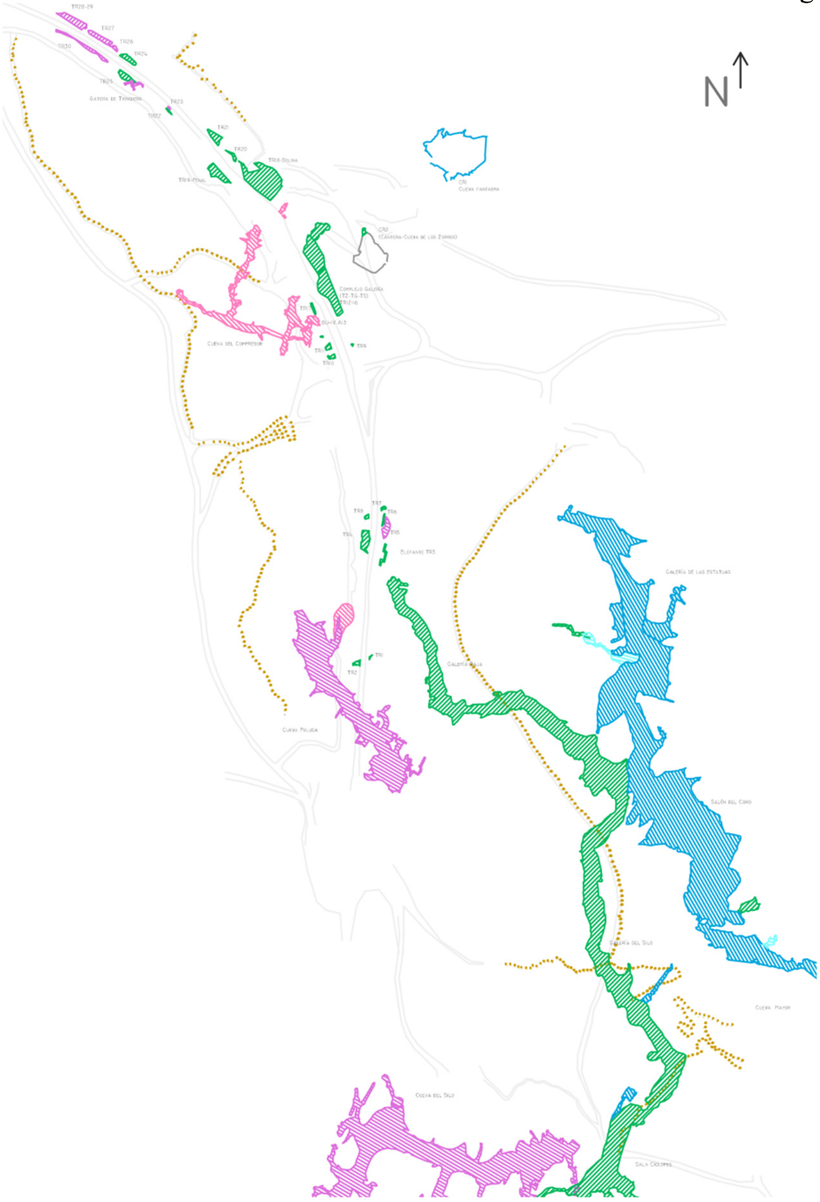

Image 1: *Location of the points of the magnetic survey (in brown) over the karstic system of Sierra de Atapuerca (blue is for the upper level, green for the intermediate and purple for the lower level of the karst).*

Results

Results show that the susceptibility of the magnetic field remains almost unaltered when crossing air-filled caves or areas where there is only limestone. However, negative values (image 2) appear in places related to the presence of clay rich sediments, as indicated by the geomorphological, geophysical and geotechnical studies.

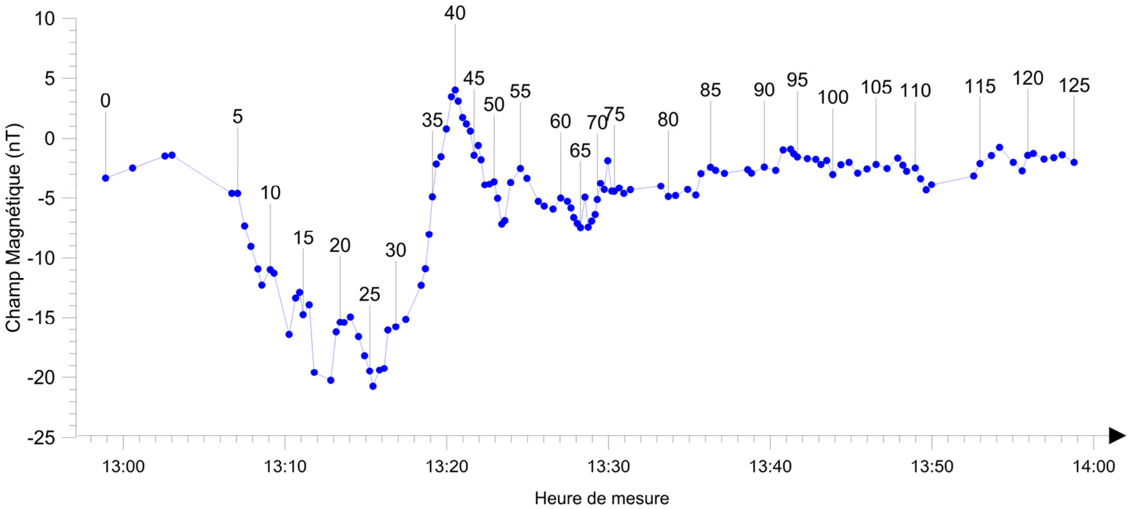

Image 2: *magnetic susceptibly measurements showing a negative anomaly of the magnetic field in an area where sediment-filled caves are expected.*

Discussion and conclusion

Despite the fact that the chemical analysis of the sediments suggested the contrary, the results of the magnetic survey show that there is a negative anomaly of the magnetic field in areas where sediments are expected. At present, the only explanation for this phenomenon is that these sediments were deposited in a reversed magnetic polarity period. This theory is supported by the paleomagnetic studies of the sites, which have found the Matuyama-Brunhes boundary in many of the caves (Parés *et al.*, 2006; Álvarez-Posada *et al.*, 2018).

However, and although more research is needed in order to clarify these results, the principal interpretations of the survey match the ones from ERT and GPR, which suggests that the results are reliable.

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