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## Short Report

# An Upper Palaeolithic Landscape Analysis of Coastal Portugal Using Ground-penetrating Radar

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ABSTRACT Ground-penetrating mapping radar allows for the three-dimensional reconstruction of ancient landscapes by interpreting geological horizons associated with archaeological sites. When the geological framework of a site can be placed in both time and space, ancient environments and people's usage and adaptation to landscapes can be studied. In coastal Portugal late Ice Age people discarded stone tools within aeolian sands that were deposited directly on a bedrock surface, which could be mapped using ground-penetrating radar. That surface was then studied in three-dimensions and the palaeotopography at the time people were using this area was mapped. It was found that these ancient people probably took shelter behind a small elevation rise on the edge of a series of streams that flowed toward a nearby floodplain. Using this type of analysis the environmental context of prehistoric activities and human behaviour of these people is provided in a way not possible using traditional archaeological methods. Copyright © 2013 John Wiley & Sons, Ltd.

*Key words:* Ground-penetrating radar; landscape archaeology; palaeogeography; coastal Portugal; Upper Palaeolithic

## Introduction

Archaeologists have recently begun to recognize and analyze past landscapes within an archaeological context, placing people and behaviours within ancient environments. In this way an understanding of the complex relationships between physical features of a landscape and peoples' perception and usage of them is potentially possible (Stern, 2008). One of the first tasks in an analysis of ancient landscapes is placing archaeological materials within a geological framework of soils, sediments and stratigraphy, which can then be used to arrive at a palaeogeographical context. Only then can behavioural information be extracted within a holistic analysis of both archaeological and environmental variables. This type of study can be especially rewarding if done on a broad geographical scale, which is not usually possible if sites are buried and not visible on the surface. If buried sites contain artefacts encased within geological layers that are visible and can be mapped broadly with GPR, the environmental context determined from those layers can be integrated with the archaeological data. The overall package of geological and archaeological information then becomes a natural candidate for geophysical mapping. While some geophysical applications have been applied to broad landscape studies (Kvamme, 2003; Campana and Piro, 2008; Conyers, 2008; Gaffney *et al.*, 2012), ground-penetrating radar (GPR) is just beginning to be used in this way for complex buried sites on a scale

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that allows the reconstruction of ancient environments (Conyers, 2010; Conyers and Leckebusch, 2010).

One such study using GPR is presented here from the Lagoa Seca area (Figure 1) in coastal Portugal where a buried Upper Pleistocene landscape surface is preserved below sand dunes. A concentration of stone artefacts was excavated and studied on that ancient living surface, producing some basic information on human activities. However, when information from those cultural materials is placed within a three-dimensional geographical framework, the ancient environment as it existed at the time people discarded those materials can be studied in a very different way, and new insights about Upper Palaeolithic settlement and use patterns are possible.

The location where humans performed certain activities is always interesting, but the process through which people used an ancient landscape and interacted with the natural world, both physical and biological, is just as interesting and important in terms of understanding ancient people. One variation of this type of archaeological analysis is to study models of human activity through mobility strategies (Binford, 1980, p. 10) within an ancient landscape. To do this it is necessary to understand how environmental conditions affected those strategies, which is often difficult when only limited excavations are available that expose artefacts in one spot and adjacent ancient living surfaces remain covered (Bruno and Thomas, 2008). With buried sites of the sort reported here the three-dimensional capability of GPR was applied with

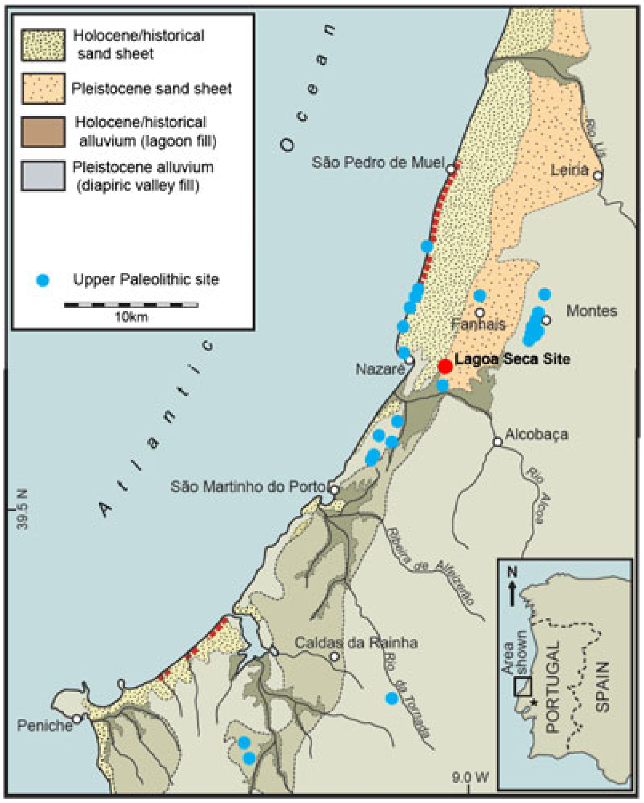

Figure 1. Location of the Lagoa Seca site in Portugal, with other Upper Palaeolithic sites noted and the basic bedrock geology. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

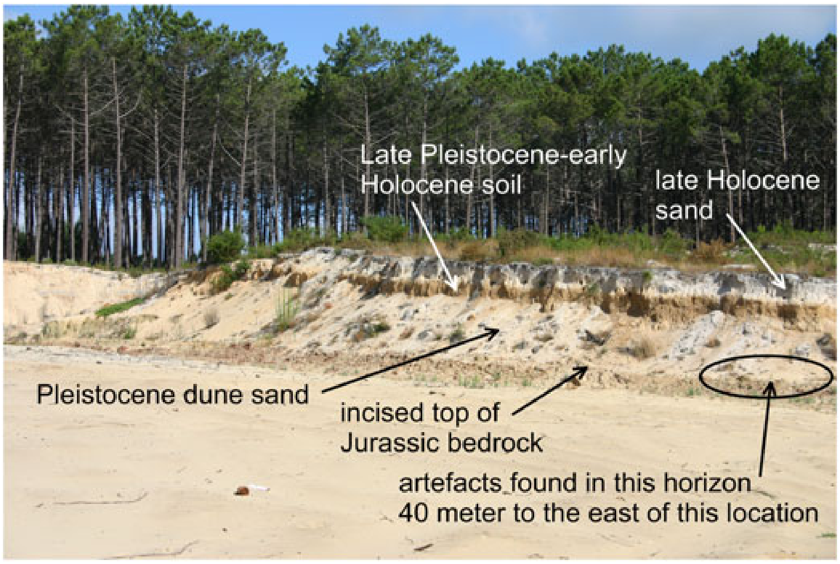

Figure 2. Geological context of the site located within the Pleistocene dune sand between the Jurassic bedrock and the overlying Late Pleistocene soil. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

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great utility because the buried horizons of interest were identified in GPR profiles and then the archaeological information integrated with those GPR maps.

## Background

In 2011 during the construction of an industrial park just east of Nazaré, Portugal (Figure 2), Upper Palaeolithic stone artefacts were discovered in a Pleistocene sand deposit near the base of a buried soil horizon. The site is dominated by large chert flakes, which appear to be core preparation debris, all from local stone sources. Today the closest sources for this material are about 5 km away from the site (Bicho and Haws, 2012). Artefact analysis suggests that this recently quarried chert was being reduced into usable artefacts here. While these materials have not been directly dated, their general form suggests a Gravettian-age occupation (27–21 kyr BP), which is supported by an optically stimulated luminescence (OSL) date of about 27 kyr BP from a similar site about 3 km away. The artefacts at Lagoa Seca, however, are not readily diagnostic as to age, so they could also be much younger (perhaps Magdalenian age: 11.5 kyr BP), which would make occupation of this site coincident with several other sites of this age nearby (Figure 2). Those Magdalenian-age sites nearby, however, contain a somewhat different lithic assemblage of microliths, micro-blade cores, retouched tools and small debitage. It is equally possible that lithic materials of both ages are present at Lagoa Seca, which could have been occupied over a long period of time and artefacts of both ages are mixed and therefore difficult to differentiate.

The geological context of the Lagoa Seca site is also important for dating the materials. The artefact-bearing horizon is found within aeolian sand dated with OSL to 11 480 ± 820 yr ago. Capping this sand is a buried soil, termed the Caldas da Rainha geosol (Klinefelter *et al.*, 2012) that contains two prominent soil horizons: a humus-rich Bh horizon and a well-developed E horizon. It was formed during the Late Pleistocene and early Holocene on the earlier deposited dune sands that had covered and preserved the site. This soil extends over much of coastal Portugal where it was formed on a number of stable landscape features. Its approximate date near the end of the Pleistocene provides a minimum age for the artefacts at Lagoa Seca, which were found within the aeolian sand just above a very sharp contact with underlying Jurassic bedrock (Figure 2).

The erosion surface created on Jurassic bedrock, which provided the living surface on which people at Lagoa Seca discarded tool-making artefacts, formed sometime during the Late Pleistocene. This erosion may have been coincident with the Late Glacial Maximum cold period (LGM) between 26 000 and 19 000 yr ago when this area of coastal Portugal was much drier, and colder than today. The artefacts were deposited and preserved just above that bedrock surface and covered by aeolian sand blown in from the coast, to the west of the site (Figure 2). Sometime after they were discarded additional sand was deposited on them and they were preserved. Additional time elapsed and after further sand deposition the landscape became stable and the overlying soil was formed. The site is therefore packaged between an underlying erosion contact and the overlying Holocene soil. It is these layers that were mapped using GPR in order to study the ancient landscape.

The GPR method's ability to generate accurate reflection profiles allows for the production of accurate subsurface maps of the units of interest and therefore place this archaeological site in three-dimensions (Conyers, 2011, 2012, p. 57). In this way a limited amount of archaeological information from relatively limited excavations can be interpreted in the context of an ancient landscape. This provides additional information about the behaviour of these Upper Palaeolithic people within a broader environmental framework.

## The GPR data collection

Immediately to the west of the 2011 archaeological excavations (Figure 3) an outcrop was created by heavy equipment during the levelling of the ground for planned construction. In this exposure the Jurassic bedrock was partially exposed and the overlying Pleistocene sand is visible (Figures 2 and 3), providing an excellent two-dimensional stratigraphic study area as a model with which to place the excavations within a geological framework.

A number of GPR reflection profiles were collected using a GSSI SIR-3000 system along portions of the nearby exposures to determine if radar energy penetrated deeply enough to resolve all units of interest including the Late Pleistocene soil horizons and the underlying Jurassic bedrock surface (Figure 4). These GPR reflection profiles, used for stratigraphic testing, determined that both the Jurassic bedrock surface and the overlying soil that caps the sediment package of interest are readily visible as high-amplitude reflections (Figure 4). Using measured depth measurements taken from correlative exposures the reflections visible in GPR profiles could be integrated and velocity of radar travel in this sediment estimated. Velocity of radar energy was also calculated using hyperbola fitting, and a relative dielectric permittivity of about 6 was calculated (one-way travel velocity

Figure 3. Excavations of the site in 2011 with the exposure of the Late Pleistocene, early Holocene sand and underlying Jurassic bedrock (shown in Figure 3) in the background. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

of 12 cm/ns$^{-1}$). This velocity was used to convert measured travel times in reflection profiles to approximate depth. The 270 MHz antennae transmitted energy to more than 6 m in this electrically resistive sediment and soil package, whereas it was a little less for the 400 MHz antennae.

What was also apparent in these initial GPR stratigraphic tests was the presence of distinct channels that had been incised into the Jurassic bedrock, which were not immediately visible in the exposures (Figures 4 and 5). This discovery suggested that the landscape, at the time people were discarding artefacts nearby, was much more rugged and complex than originally thought. When people were in this area the region must have also been quite dry and windy, as sand was periodically blowing into the area and covering the incised Jurassic surface. This is consistent with what the LGM was like in much of the rest of Europe at about 26–19 kyr ago.

Both the 400 and 270 MHz antennae were then used to collect profiles directly on top of the exposure just to the west of the excavations (Figures 3 and 4). There, and elsewhere, direct correlations were made between the stratigraphic horizons of interest (Figure 2) and the radar reflections in profiles. It was discovered that a number of channels had been incised into the Jurassic bedrock (which mimics the ancient living surface of interest), which were not immediately visible in outcrop (Figures 5 and 6). The Jurassic surface was also

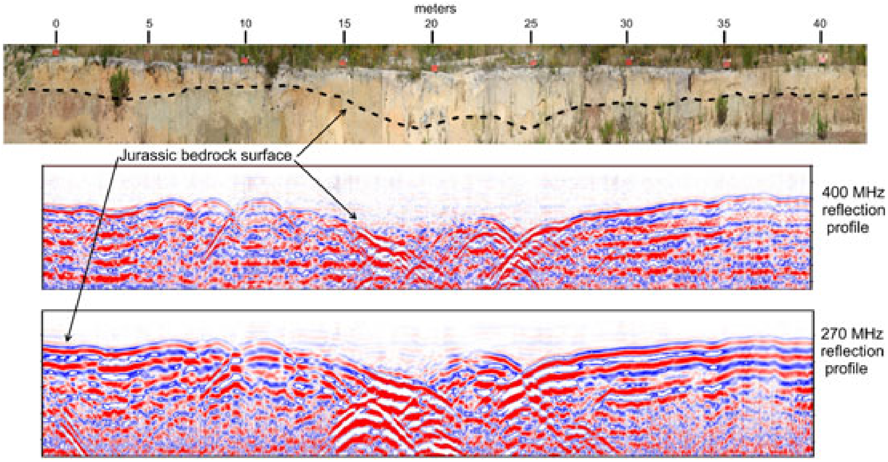

Figure 4. A comparison of the exposure of the Jurassic surface with overlying Late Pleistocene to early Holocene sand for 400 and 270 MHz GPR reflection profiles collected on the ground directly above this outcrop. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

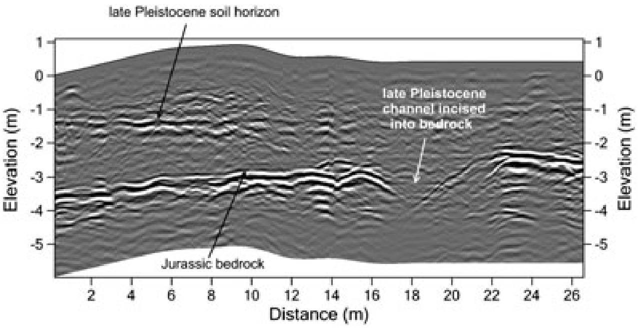

Figure 5. Reflection profile showing excellent resolution of the Jurassic bedrock, channels and the Late Pleistocene to early Holocene soil horizon using the 270 MHz antennae.

cored in this area to further ensure correct stratigraphic correlation to the reflections visible in GPR profiles. Resolution of very small features on this surface was very good using the 400 MHz data. As expected the 270 MHz antennae produced more averaged reflections, but were also useful as they were less affected by ground surface coupling variations. The reflection profiles generated using both antennae were excellent at resolving buried topographic variations in the buried Jurassic bedrock surface, and also placing the archaeological materials within that stratigraphic framework (Figure 5).

A 50 × 30 m grid of reflection data was collected to the east of the outcrop (Figure 7) surrounding the archaeological excavations. This grid consisted of 22 reflection profiles spaced 5 m apart collected with both 270 and 400 MHz antennae, which provided comparable depth penetration but differing resolution. Data were collected with both antennae within a 60 ns time window, 30 traces per metre, and traces were placed in space using a calibrated survey wheel. There was no horizontal filtering of traces and reflections were regained, corrected for time-zero offset and adjusted for depth and horizontal distance prior to interpretation in individual profiles. The depth of the Jurassic horizon of interest was highly variable throughout the grid and therefore amplitude mapping was not attempted as reflections would cross through slices, producing unusable maps (Conyers, 2012, p. 51).

The top Jurassic bedrock surface reflection was measured every 50 cm along all profiles within the grid. The incised Jurassic bedrock surface of interest dips to the east from the outcrop visible in Figure 3 and is covered and preserved under the Pleistocene sand within the GPR grid. As the ground surface is almost perfectly flat, no topographic adjustments were necessary prior to interpretation of the profiles.

## Landscape interpretation

The relative elevations of the incised Jurassic bedrock surface obtained from all GPR profiles in the 50 × 30 m grid were placed in a digital database and the elevation of the Jurassic surface was then gridded and contoured using Surfer 9 to create an image map of the bedrock surface surrounding the excavations (Figure 7). The resulting image map shows two roughly parallel gullies that flowed from a topographic high located to the west. They probably merged into one larger channel just to the south of the GPR grid. Artefacts were deposited on the edge of a small stream just to the northwest of the small topographic high area. The streams that flowed adjacent to the site were approximately 2 m deep during the time that Upper Palaeolithic people occupied this locality.

An additional small stream was located to the east of the bedrock high on which the artefacts were discarded, which was probably part of a complex natural drainage system. All these deep gullies flowed from the highlands just to the west and flowed toward the

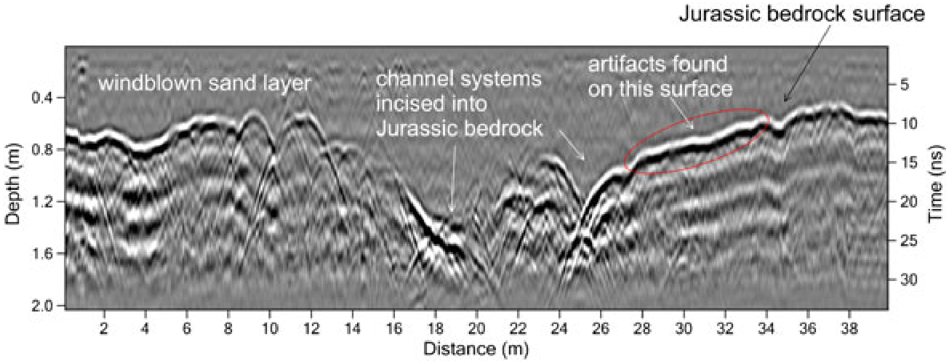

Figure 6. A 400 MHz reflection profile showing the detail on the Jurassic bedrock layer including two channels and a number of other undulations and possible large stones on this buried living surface.

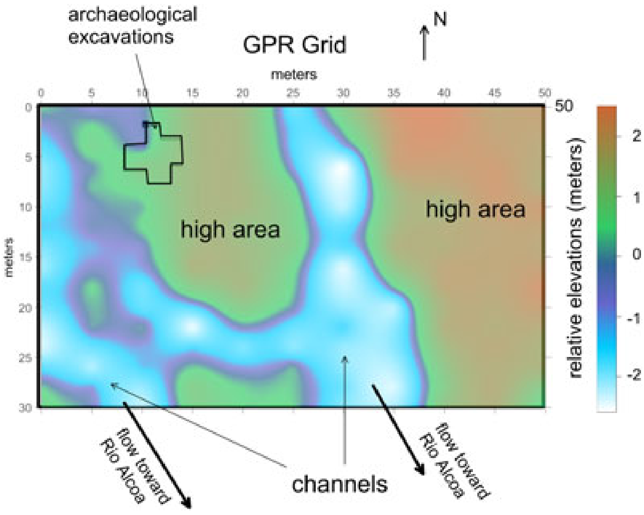

Figure 7. The GPR grid with the relative elevation of the Jurassic bedrock surface. The archaeological excavations and the ancient streams and high topographic areas are noted using relative elevations. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

south and southeast. The ancient Rio Alcoa floodplain was located about 700 m to the southeast of the site (Figure 8).

The area where the artefacts are concentrated would have been a protected area, well concealed by the small bedrock high, making people there invisible to game in the floodplain to the east. This area would have been close to water in the small streams and provided a good lookout for game in the nearby floodplain. People who discarded tools here probably spent their time in this protected location manufacturing tools necessary for their survival in this dry, cold and highly channelled Ice Age landscape.

On a broader scale the surrounding area of Lagoa Seca contained other notable landscape features that would have been of interest to these Upper Palaeolithic hunters and gatherers. Just to the east of the site (Figure 8), on the margin of the Rio Alcoa, a number of lakes had formed sometime in the Pleistocene due to subsurface salt collapse (Benedetti *et al*., 2009: Klinefelter *et al*., 2012), the closest of which is only 400 m away from the site. This lake is still visible today as a dry circular depression, and would have been a favored exploitation area in the prehistoric past for both animal and plant resources (Figure 6). A number of time-coincident lithic scatters of the same type of chert found at the Lagoa Seca site were found around the margin of that lake, documenting that

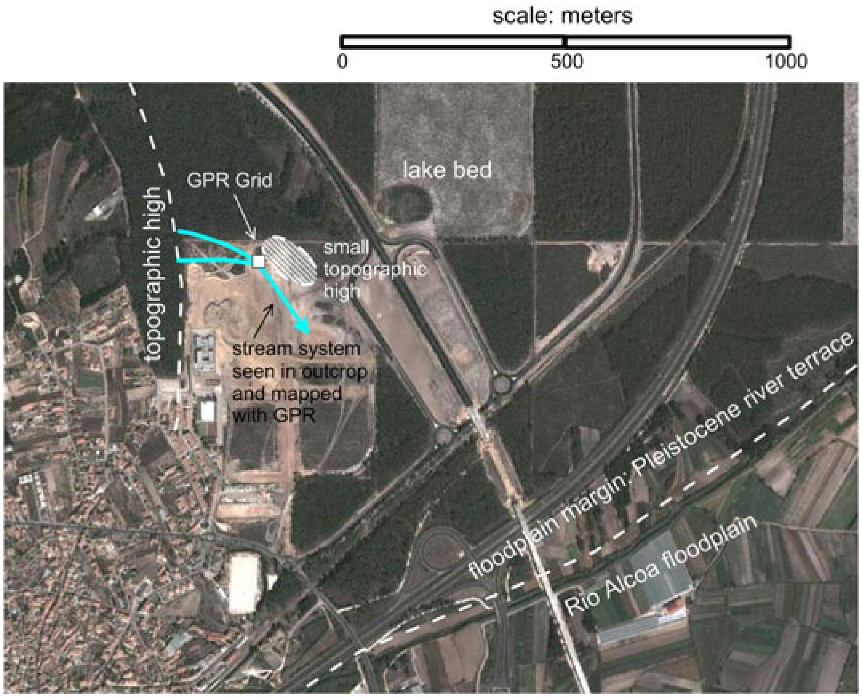

Figure 8. The GPR study area superimposed on a modern aerial photograph. This places the GPR study area in a larger geographical context where the small stream system flowed east and then south into the floodplain of the Rio Alcoa. The lake, still prominent today as a depression, but otherwise dried out, is to the northeast. The coastal highlands, which were the origin of the streams that flowed through the study area, are to the west, noted as a topographic high. Image modified from Google Earth photograph. This figure is available in colour online at wileyonlinelibrary.com/journal/arp

this ancient landscape feature was probably used repeatedly by people in the ancient past.

## Conclusions

The small stream gullies along which Upper Palaeolithic hunters prepared their tools merged with a larger stream that appears to have flowed to the south into the Rio Alcoa floodplain, which ultimately flowed into the Atlantic Ocean. Along the margin of this river, floodplain environments existed that would have been especially useful for Pleistocene hunters and gatherers. The nearby lake would also have provided a wetland resource with many uses. In the location of the GPR grid it appears that people prepared tools on a small topographic rise, shielded from the floodplain below and adjacent to water sources in the small streams flowing from the nearby highlands to the west.

In this project an integration of archaeological information with the geological matrix of the site was necessary first in order to understand the context and age of these materials. This work provides a case study to demonstrate that geophysical analysis can be very useful in order to place archaeological data into a three-dimensional framework. Artefact information merged with GPR mapping of the buried units leads directly to an ancient landscape reconstruction. Without the GPR dataset to provide this broad three-dimensional analysis, this type of study would not be possible.

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