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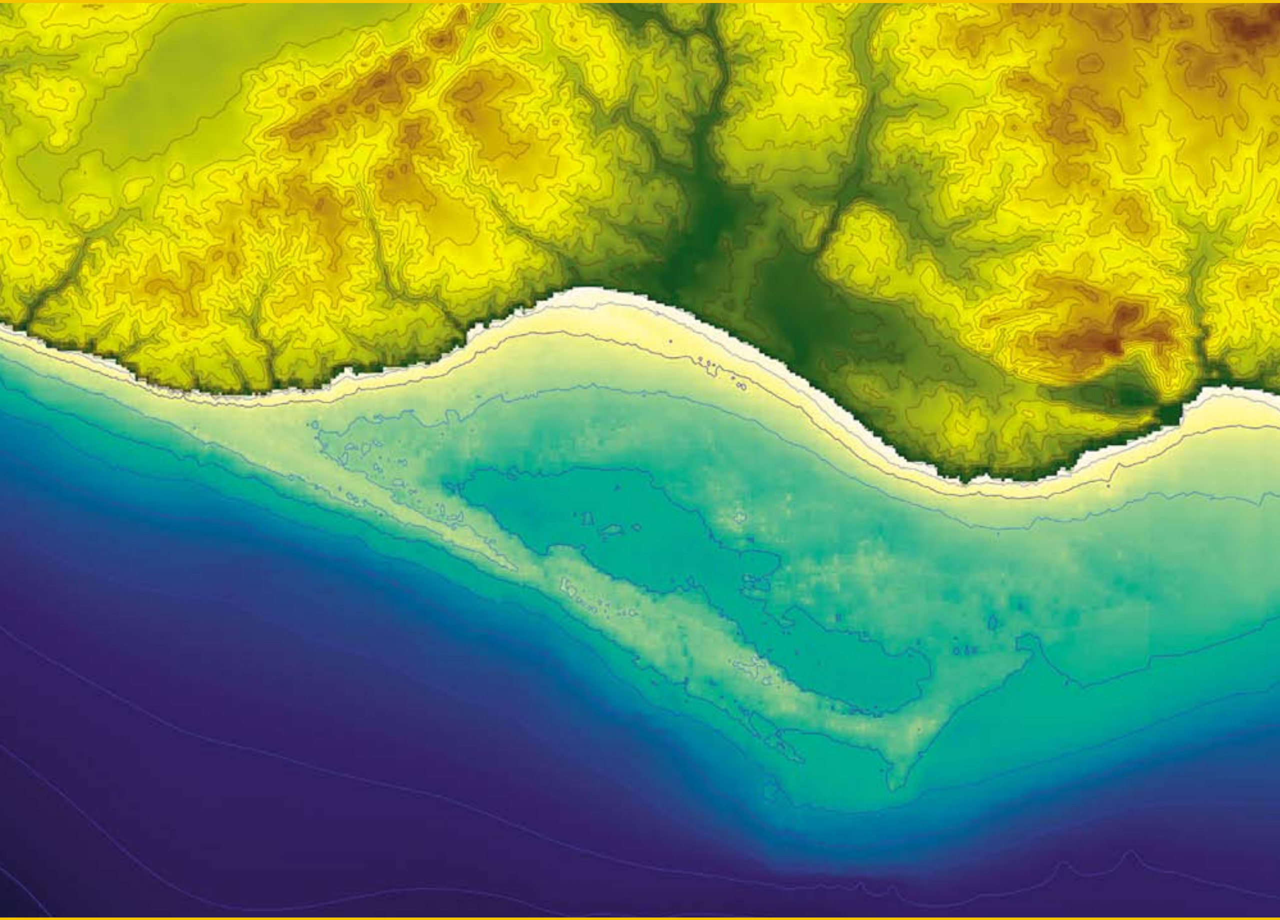

ENVIRONMENTAL CHANGES AND HUMAN
INTERACTION ALONG THE WESTERN ATLANTIC EDGE

MUDANÇAS AMBIENTAIS E INTERAÇÃO HUMANA
NA FACHADA ATLÂNTICA OCIDENTAL

IMPRINT / FICHA TÉCNICA

Title: ENVIRONMENTAL CHANGES AND HUMAN INTERACTION ALONG THE WESTERN ATLANTIC EDGE
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Eds. A. Campar Almeida, Ana M. S. Bettencourt, D. Moura, Sérgio Monteiro-Rodrigues and Maria Isabel Caetano Alves

Editors:
APEQ - Associação Portuguesa para o Estudo do Quaternário
CITCEM - Centro de Investigação Transdisciplinar "Cultura, Espaço e Memória", financiado por Fundos Nacionais, através da FCT – Fundação para a Ciência e Tecnologia, no âmbito do projeto PEstOE/HIST/UI4059/2011.
CEGOT - Centro de Estudos de Geografia e Ordenamento do Território
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Cover image: Digital terrain model of the Armação de Pêra, Algarve, Portugal (by Leandro Infantini)

Composition, printer and bound by Sersilito-Empresa Gráfica, Lda.

Edition: 500 Exemplares

Legal deposit: 350801/12

ISBN: 978-989-97140-1-4

Coimbra, October 2012

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UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

A. Campar Almeida, Ana M. S. Bettencourt,
D. Moura Sérgio Monteiro-Rodrigues, Maria Isabel Caetano Alves (eds.)

Environmental changes and human interaction along the western atlantic edge

Mudanças ambientais e interação humana na fachada atlântica ocidental

2012

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RECONSTRUCTING HOLOCENE EVOLUTION IN THE ARCHAEOLOGICAL SITE OF CAMPO LAMEIRO (NW SPAIN): AN INTERDISCIPLINARY APPROACH TO GEOARCHAEOLOGY

Manuela Costa-Casais[1], Antonio Martínez Cortizas[2], Joeri Kaal[1], Maria Isabel Caetano Alves[3] & Felipe Criado-Boado[1]

Abstract: The objective of this research was to evaluate the potential of sedimentary deposits to be used for the reconstruction of Holocene environmental changes in the Campo Lameiro area (NW Spain). We focused on the evolution of landforms as a key factor in the configuration of alluvial and colluvial sequences. The geomorphological and sedimentological studies indicate that the distribution of landforms is a main factor to understand the formation of colluvial soils. Granitic macroforms dominate the present landscape, constituted by alveolar depressions surrounded by crests and slabs. The thickest sedimentary deposits were found in the depressions. We identified two main stratigraphic units: a basal inorganic layer represented by alluvio-colluvial sediments, formed in a highly energetic environment, probably dating to the Younger Dryas (>11000 years BP), and a younger unit of thick sandy, blackish, organic matter rich, colluvium. The oldest radiocarbon age obtained for this unit indicates that it may have started to form by 11240-11130 cal. BP. The Holocene colluvial soils show discontinuities in grain size, soil reaction, elemental composition of the inorganic phase and molecular composition of the soil organic matter. These features are evidence of the occurrence of several phases of erosion/sedimentation (i.e. landscape instability), some of which were coeval with known periods of Holocene abrupt climate change – the 8.2 ka event, the beginning of the Neoglaciation (ca. 6 ka BP) or the 2.8 ka wet/cold event. But some of the most intense phases coincided with increased human pressure on landscape during the Neolithic, Bronze Age, Roman Period, and the Middle Ages. Charcoal layers, burnt soil layers and the highly aromatic nature of the soil organic matter point to frequent fire episodes. Pollen studies also indicated a sharp decrease in forest cover beginning by ca. 6000 cal BP, which seems to have been accompanied by a progressive soil acidification with time. Our research suggests that both climate and human activities played an important role in the formation of colluvial deposits in the area, confirming that they are valuable geoarchives of Holocene environmental change from a geoarchaeological approach.

Key-words: Geoarchaeology; Geoarchives; Palaeoenvironmental reconstruction; Holocene.

Resumo: Neste trabalho estudaram-se os depósitos sedimentares na área da estação arqueológica de Campo Lameiro (NW Espanha), com o objetivo de avaliar o seu potencial para a reconstrução

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das mudanças ambientais holocénicas, no que diz respeito à evolução do relevo como um fator determinante na configuração das sequências aluviais e coluviais. Os estudos geomorfológicos e sedimentológicos indicam que a distribuição das geoformas é um fator principal para compreender a formação dos solos coluviais. Na paisagem atual da área de estudo dominam as macroformas graníticas, constituídas por depressões alveolares rodeadas por cristas e lajes. Os depósitos sedimentares mais espessos ocorrem nas depressões. Identificaram-se duas unidades estratigráficas principais: uma camada basal inorgânica, representada por sedimentos aluvio-coluvionares, formados em ambiente altamente energético, provavelmente datados do Dryas recente (> 11000 anos BP) e uma unidade mais recente, arenosa, escura, rica em matéria orgânica, de solos coluviais. A datação mais antiga, obtida por radiocarbono para esta unidade, indica que ela pode ter começado a formar-se há 11240-11130 cal. BP. Os solos holocénicos coluviais apresentam descontinuidades na dimensão das partículas, na reação do solo, na composição da fase inorgânica e na composição molecular da matéria orgânica do solo. Estas características comprovam a ocorrência de diversas fases de erosão / sedimentação (ou seja, de instabilidade da paisagem), algumas das quais são contemporâneas dos períodos de mudança climática abrupta conhecidos no Holocénico – o evento a 8,2 ka, no início da Neoglaciação (ca. 6 ka BP) ou o evento húmido e frio a 2,8 ka. Mas, algumas das fases mais intensas coincidiram com o aumento da pressão humana sobre a paisagem durante o Neolítico, a Idade do Bronze, o Período Romano e na Idade Média. A ocorrência de camadas de carvão, de solos queimados e a natureza distintamente aromática da matéria orgânica do solo apontam para episódios de incêndios frequentes. Os estudos polínicos também indicaram uma diminuição acentuada da cobertura florestal, com início a ca. 6500 cal BP, que parece ter sido acompanhada por uma progressiva acidificação do solo ao longo do tempo. O trabalho de investigação realizado, sugere que as mudanças climáticas e as atividades humanas desempenharam ambos um papel importante na formação dos depósitos coluviais na área. De acordo com estudos anteriores, isto indica que os referidos depósitos são geoarquivos valiosos para reconstruir as mudanças ambientais holocénicas, a partir de uma abordagem geoarqueológica.

Palavras-chave: Geoarqueologia; Geoarquivos; Reconstrução paleoambiental; Holocénico.

1. INTRODUCTION

Geoarchaeology applies techniques and methods of the Human Sciences and Geosciences to reconstruct landscape evolution at different geographical scales. Huckleberry (2000), slightly modifying the perspective offered by Gifford & Rapp (1985), defines geoarchaeology -as “the application of Earth Science method and theory to understanding the human past”, a definition broad enough to include experts from a range of scientific backgrounds to contribute towards the comprehension of human prehistory. The recent application of Earth Science techniques for the analysis of soils and sediments at archaeological sites has generated new levels of understanding of human activities and use of the landscape. Soils and sediments are composed of similar components, and form a continuum over the landscape. Their study can reveal how humans in prehistory used it and defined space through their activities. However, the techniques do not fully address several persistent problems associated with making inferences about past human activity from soils. The presence or absence of elements alone may be inadequate to effectively understand the relationship between soil properties and pedogenic, diagenetic and/or anthropogenic processes. As a result, multi-method approaches are becoming standard practice in pedoarchaeology (Walkington 2010).

Soil is an archive that can be used to interpreted archaeological deposits (Mandel & Bettis 2001). Soil processes can contribute to an understanding of archaeological sites because the soil can act as an archive in a variety of ways (Walkington 2010): (a) soils represent process-response systems through the unique interaction of the soil forming factors at a particular site; (b) soils reflect soil processes occurring both vertically and laterally; (c) soils can store palaeoecological indicators such as pollen, phytoliths, bones, etc, and are thus archives of environmental change (Lowe & Walker 2006); (d) soils are geoarchives, even when transport has occurred, the resulting colluvial soils can still store environmental information (Leopold & Völkel 2007); and (e) soils can record human use and management of a landscape.

A pedogeomorphological approach at a landscape scale (Gerrad 1992) linked to multiproxy indicators for dating and climate reconstruction can help to track past processes in detail. Surface formations contain information inherent in their geomorphological evolution. Climate and human activities played an important role in the formation of the alluvial- colluvial deposits. The geomorphological data together with other palaeoenvironmental proxies define them as useful geoarchives for the reconstruction of Holocene environmental change (Costa-Casais *et al.* 2008). Colluvial soils, given their wide distribution and the time expand covered by them, may also be crucial to decipher and understand human responses to climate change and the impact of anthropogenic activities on the environment at the local and regional scales (Leopold & Völkel 2007).

This work is part of an interdisciplinary study made in the area of the Rock Art Park of Campo Lameiro (Galicia, NW Spain). In this survey the Earth Science´s disciplines played a major role in complementing the archaeological research. Our paper focuses on the evolution of landforms – rocky substrate, sediments and soils – as a key factor for geoarchaeological analysis, with the objective to evaluate the potential of sedimentary deposits to be used for the reconstruction of Holocene environmental changes. This approach is particularly important in the studied area because of the scarcity of available archaeological remains. Granite landforms, soils and sediments are unique archives that have recorded transformations in the landscape linked to cultural evolution (Costa-Casais *et al.* 2009).

2. REGIONAL SETTING

The study area is located within Rock Art Park of Campo Lameiro (Pontevedra--Galicia, NW Spain), on the upper part of the Monte Paradela hill (330 m a.s.l.) and 25 km E of the Atlantic Ocean, in the Eurosiberian (Atlantic) phytogeographic region (Fig. 1). The area appears as an almost isolated hill, at the centre of the watershed, defined by the river network, and surrounded by fractures running from N-S and E-W as well as by numerous joints that break the substrate running N-S, EW, NW-SE and NE-SW. The lithology is homogenous throughout the park. It is comprised of two mica granitic rocks with megacrystals of K-feldspars, with minerals showing a certain degree of

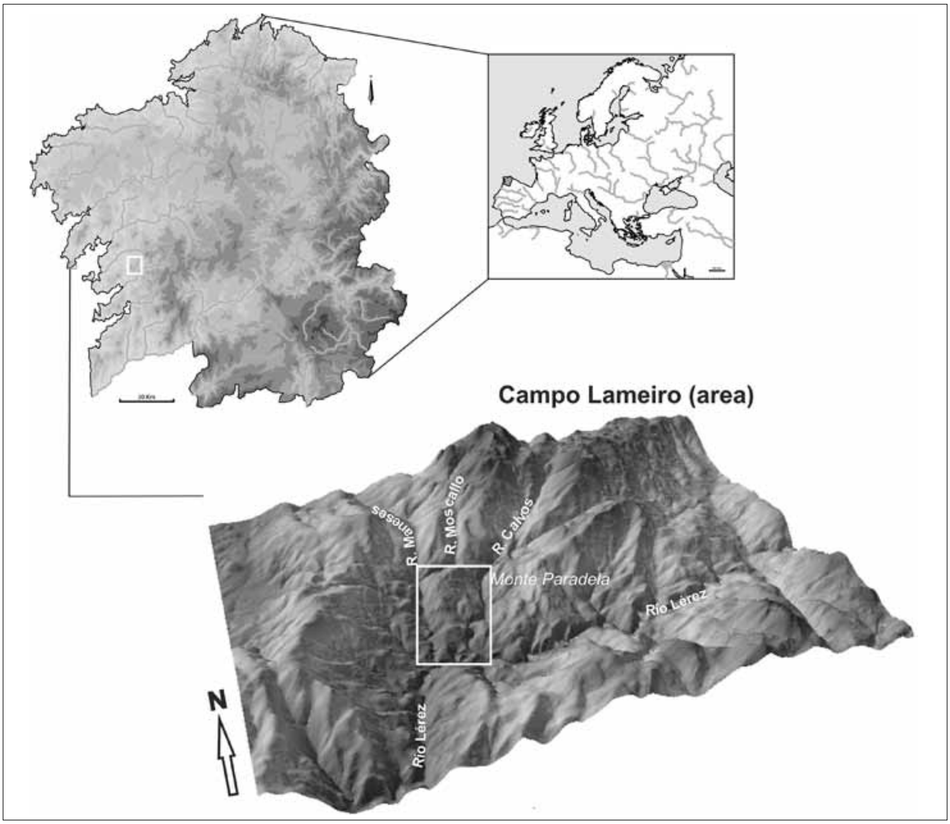

Fig. 1. Location of the study area indicating the sectors cited in the text.

orientation towards the north of the area (IGME,1982a, 1982b). The general rolling topography, with tops and troughs, is the result of a combination of granitic macro and microforms. Granitic modelling dominates the slopes, with granitic outcrops separated by small thalwegs.

It is an area of transition between the coast and mountain range, with temperate humid climate. Present mean annual temperature is 14.5 °C, and mean annual precipitation is 1500 mm (Martínez Cortizas & Pérez Alberti 1999). Current vegetation of the site is a mosaic of pine (*Pinus pinaster*), pedunculate oak (*Quercus robur*), heather (*Calluna vulgaris*), *Erica* spp. and herbaceous species. Along the valleys, the riverside vegetation is mainly composed of common alder (*Alnus glutinosa*), hazel (*Corylus avellana*), *Quercus robur* and birch (*Betula alba*). Cultivated land is located within a distance of 300 m, at lower elevations.

3. MATERIAL AND METHODS

Geoarchaeology applies techniques and methods of the Human Sciences and Geosciences to reconstruct landscape evolution at different geographical scales. These include several disciplines of the Earth Science, related to the study of the fossil – plant and animal – record and those dedicated to the study of the material remains of cultures. The study on past environmental changes in the Rock Art Park of Campo Lameiro has been carried out using the colluvial formations to reconstruct changes in the landscape. The disciplines involved in the study were: (a) disciplines of Earth Sciences: geomorphology, sedimentology, pedology, geochemistry, mineralogy, as well as computer techniques applied to geographic studies and geographic information systems; (b) disciplines that are responsible for studying the fossil or subfossil record: palynology and anthracology; (c) disciplines that deal with the study of material culture remains: archaeology and prehistory. The archives showed information about past soil erosion and landscape change. The signals are geomorphological features, morphological soil features, physico--chemical properties, changes in elemental and mineral composition, information

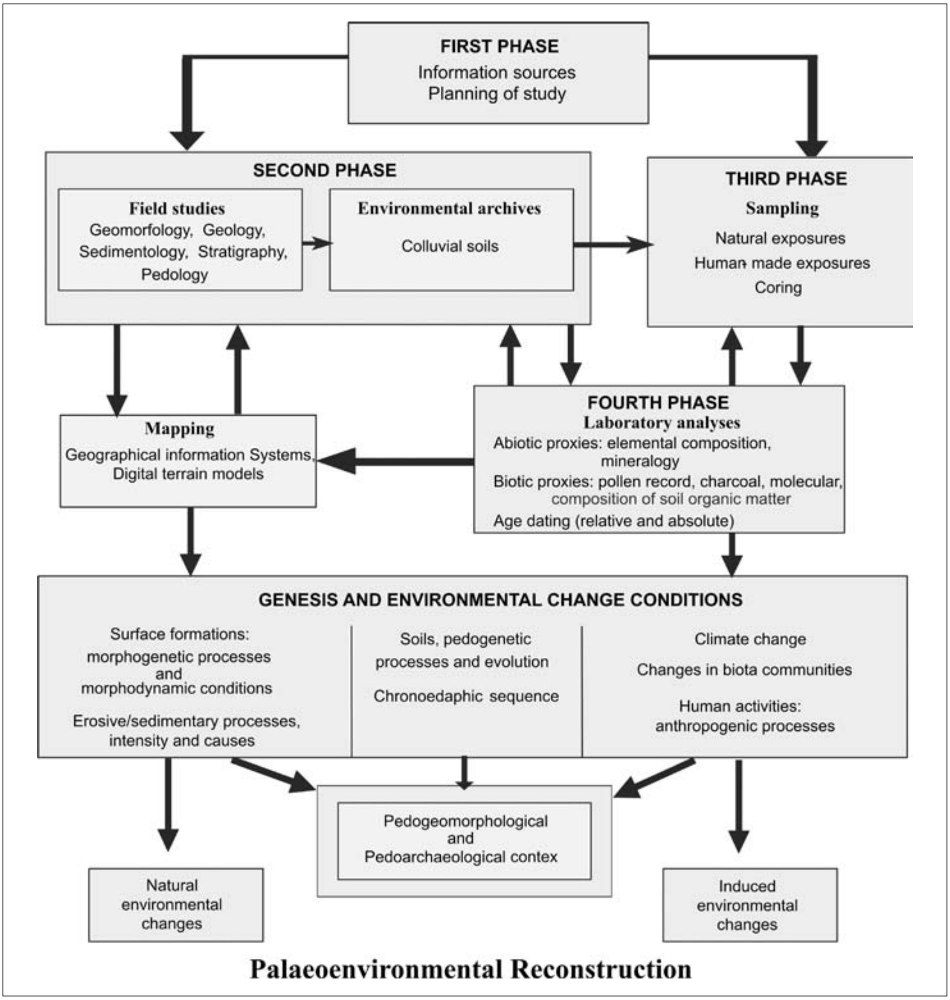

Fig. 2. Steps followed in the multi-archive, multi-proxy, approach to palaeoenvironmental reconstruction in NW Iberia. Modified from Martínez Cortizas (2000).

on past vegetation, etc. Methodological point of view, the study was divided into four phases, following the guidelines suggested by Martínez Cortizas (2000) (Fig. 2).

The first phase implied an inventory of all available information about the area (maps, climatic data, geology, hydrography, previous studies, etc.), which aided to the current understanding of the peculiarities of the landscape under study. This phase was the basis for setting the strategies to follow in the planning the work.

In a second phase, fieldwork was carried out in order to differentiate landforms. The work started with the interpretation of aerial photographs, to define relief units

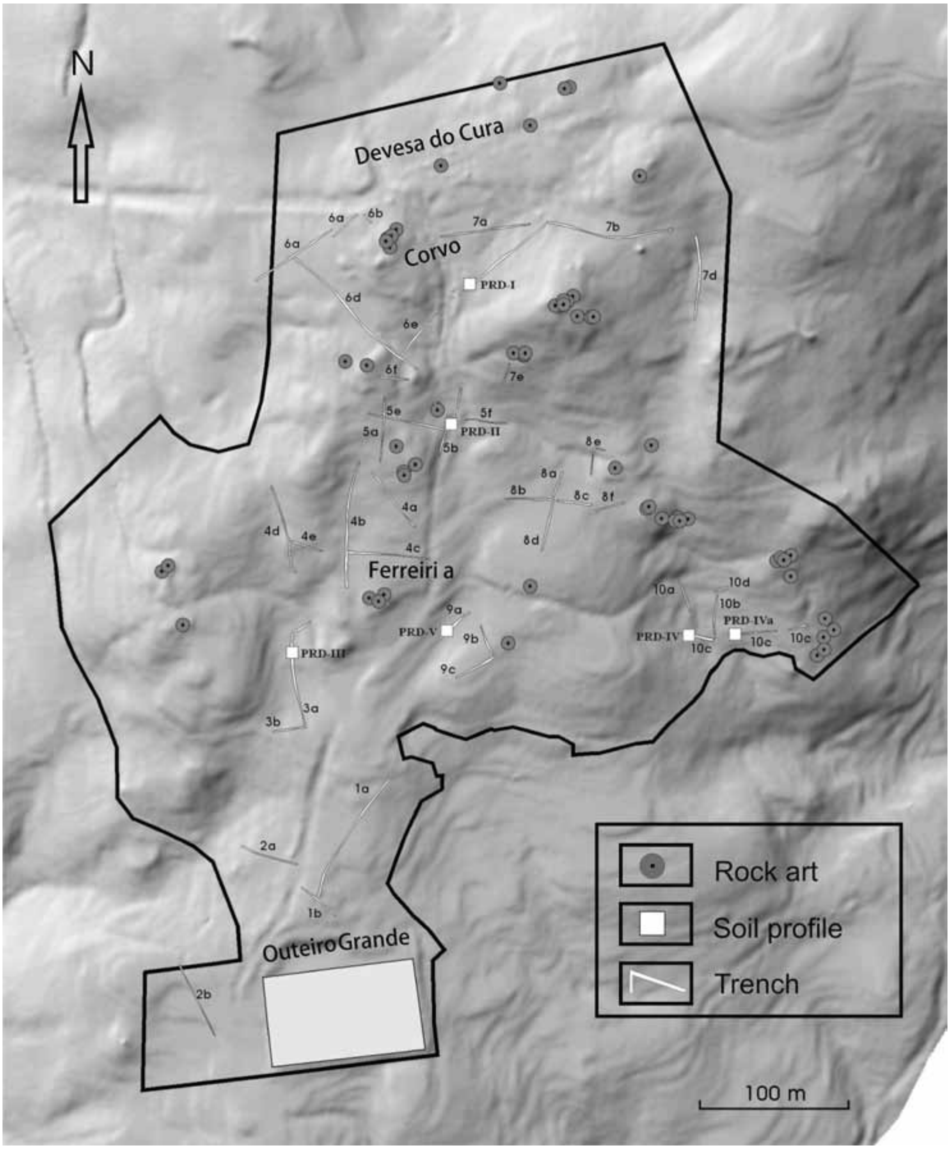

Fig. 3. Georeferenced trenches, soil profiles and rock art pannels were incorporated into a digital terrain model to conform a GIS database. Modified from Costa-Casais et al. (2009).

and how they are related to the regional geomorphologic context. This information was used for designing and subsequent opening of 43 ditches in ten sectors, with a total length of 2.5 km. Two main criteria were followed: (a) the variety of morphological units, their location in sectors prone to sediment/soil accumulation, in erosive/accumulative or erosive areas, and (b) their proximity to the rock carvings. Systematic descriptions of the sedimentary facies were made in order to define the vertical and lateral stratigraphic changes. More detailed descriptions were performed for a small number of sedimentary sequences in each ditch, which generally coincided with the deepest ones and showing the greatest diversity of facies. The location of the trenches, the sedimentary sequences and the rock art panels were incorporated into a digital terrain model, then combined with the information obtained from the other disciplines involved – geomorphology, archaeology and pedology – to conform a GIS database (Costa-Casais *et al.* 2009) (Fig. 3).

In the third phase, eleven pedo-sedimentary sequences (with depths between 1.5 and 3 m) were selected for high-resolution sampling of soils and sediments. Of these, five were studied in more detail. Sampling was systematic and took into account the variability of each sediment layer or soil cycle.

The fourth phase concerned the analytical procedures. These included abiotic (physico-chemical properties: soil reaction, elemental composition of the inorganic phase, mineralogy, etc.) and biotic (pollen record, charcoal, molecular composition of the organic matter, etc.) proxies. In a relatively small area several colluvial formations were analysed and supported by extensive radiocarbon dating.

4. RESULTS AND DISCUSSION

4.1. Geomorphological context: granite landscape

The landscape of the study area is dominated by granite outcrops separated by small thalwegs. The tops are organized following a polygonal pattern resulting from long-term granite weathering that is controlled by a joint system running from N-S and E-W directions. This tectonic pattern defines an alignment with a series of tops and granitic slabs interspersed with small low-lying areas known as alveolar depressions or *alveoli* (Fig. 4). The lithological, structural and geomorphological variety corresponds to that of granitic landforms, classified into two groups, depending on their size. The megaforms or large-scale forms are divided into convex – castle-kopje, tor, block – located in a high topographic position, and concave forms – *alveoli* or weathering basins – at lower topographic positions. The microforms or smaller forms, consist of: (a) microforms without any evident relationship to the rock structure – linear forms (gutters) and pointed forms (*gnammas*, *tafone*); and (b) microforms with an evident relationship with the rock structure – linear forms (polygonal cracking, nerviate forms), and flat forms (broken blocks) (Godard 1977; Twidale 1986, 1989). At an intermediate topographic position are the granitic slabs, minor forms that are related

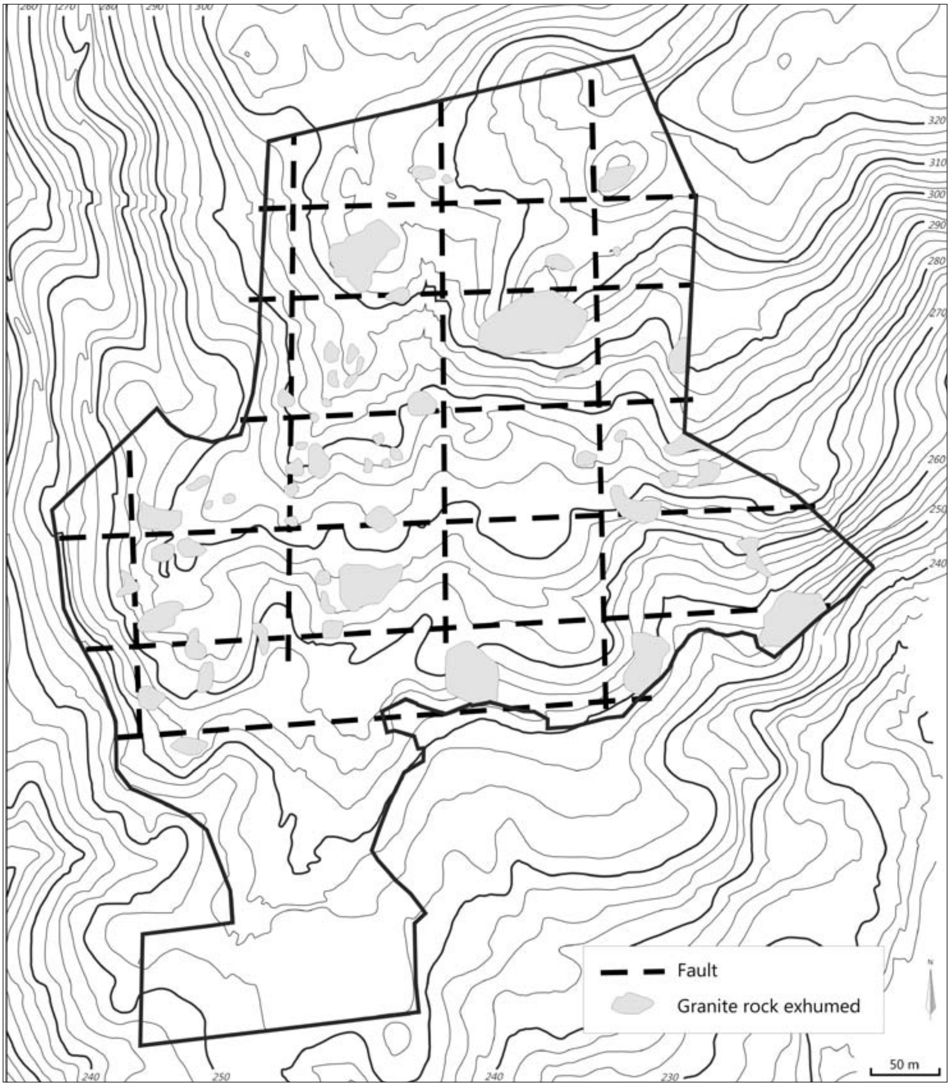

Fig. 4. The tops are organized following a polygonal pattern resulting from long-term granite weathering that was controlled by a joint system running from N-S and E-W directions. Modified from Costa-Casais et al. (2009).

to the structure of the rock (mainly joints), flat in shape and slightly tilted down. Granitic macroforms dominate the landscape, constituted by alveolar depressions surrounded by crests and granitic slabs. The rock art panels of *Os Carballos* and *Os Cogoludos* are good examples, carved on slabs, in which the joints, narrow channels and other linear features are observed (Costa-Casais *et al.* 2009).

Granite morphogenesis is the result of the interaction of a number of factors: rock type, tectonics, climatic changes, human activities and the associated morphogenetic systems, which acted either directly or indirectly on the granitic substrate to form the present landforms seen in Campo Lameiro. Alveolar depressions are the most representative major landforms. Their formation, as already mentioned, has been controlled by the joint system that channelled both the upwards and downwards alteration processes (hydrothermal/thermal), and the downwards weathering and pedogenetical processes (Vidal Romaní 1989). Their final shape is also linked to fluvial and alluvial processes that gradually uncovered the megaforms. These *alveoli* are covered by alluvial-colluvial deposits and colluvial soils. They played a decisive role in the preservation of sedimentary sequences in Campo Lameiro.

4.2. Sedimentary sequences: alluvial deposits and colluvial soils

The thickest sedimentary deposits are located in the alveolar depressions, where sedimentation was favoured over erosion. The *alveoli* shape types have conditioned the evolution of the surface formation. Depending on where they are located, superficial formations can be classified into four main groups: (a) *erosive-cumulative alveoli*: situated in high potential energy areas prone to both erosion and sedimentation in comparable intensities; (b) c*oalescing alveoli:* located in low energy areas where accumulation dominated, such as the channelled depressions; (c) *asymmetric alveoli:* formations that cover *alveoli* found at intermediate positions, located next to the base of a granite slab and with their external border eroded; and (d) *type alveoli:* covered *alveoli* floors (Costa-Casais *et al.* 2008) (Fig. 5). The sedimentary sequences show two types of stratigraphic units: a basal inorganic sedimentary layer, covering the granitic substrate or the deeply weathered saprolite, with varying thickness (50 to 100 cm) and a younger, thicker (up to 250 cm) layer represented by colluvial, polycyclic soils, rich in organic matter.

The basal inorganic sedimentary unit is the result of the erosion and transport of the strongly weathered saprolite mantle, generating a large amount of material. The mineralogical composition, shape of the clasts, degree of weathering and the type of fine matrix refers to a morphogenetic system controlled by water. The sedimentary facies are quite varied. There are heterogeneous and chaotic layers: cross-bed, linear structures and lenticular sand layers, related to alluvial transport, which are only preserved in *alveoli* bottoms (Costa-Casais *et al.* 2009) (Fig. 6). They were formed under an alluvial morphogenetic system, probably as small alluvial fans, with three main channels following the natural thalwegs in the area (Fig. 7). Fans are dynamic systems that can temporarily store sediments (Gómez Villar 1996) as a result of a sporadic yet continuous supply, in geological terms, in a highly energetic environment. Alluvial fans depend equally on torrential rainfall and its ability to produce large amounts of sediment. At PRD-I (Fig. 6) this basal unit is fossilized by a palaeosol that provided a radiocarbon age of 8480-8320 cal BP (Costa-Casais *et al*. 2009) and in PRD-IV (Fig. 6) it is covered by a soil cycle dating back to ca. 11260-10905 cal BP (Kaal *et al*. 2011), indicating that the fans are at least late Pleistocene or early Holocene in age. Their formation in the study area may be associated with the Younger Dryas

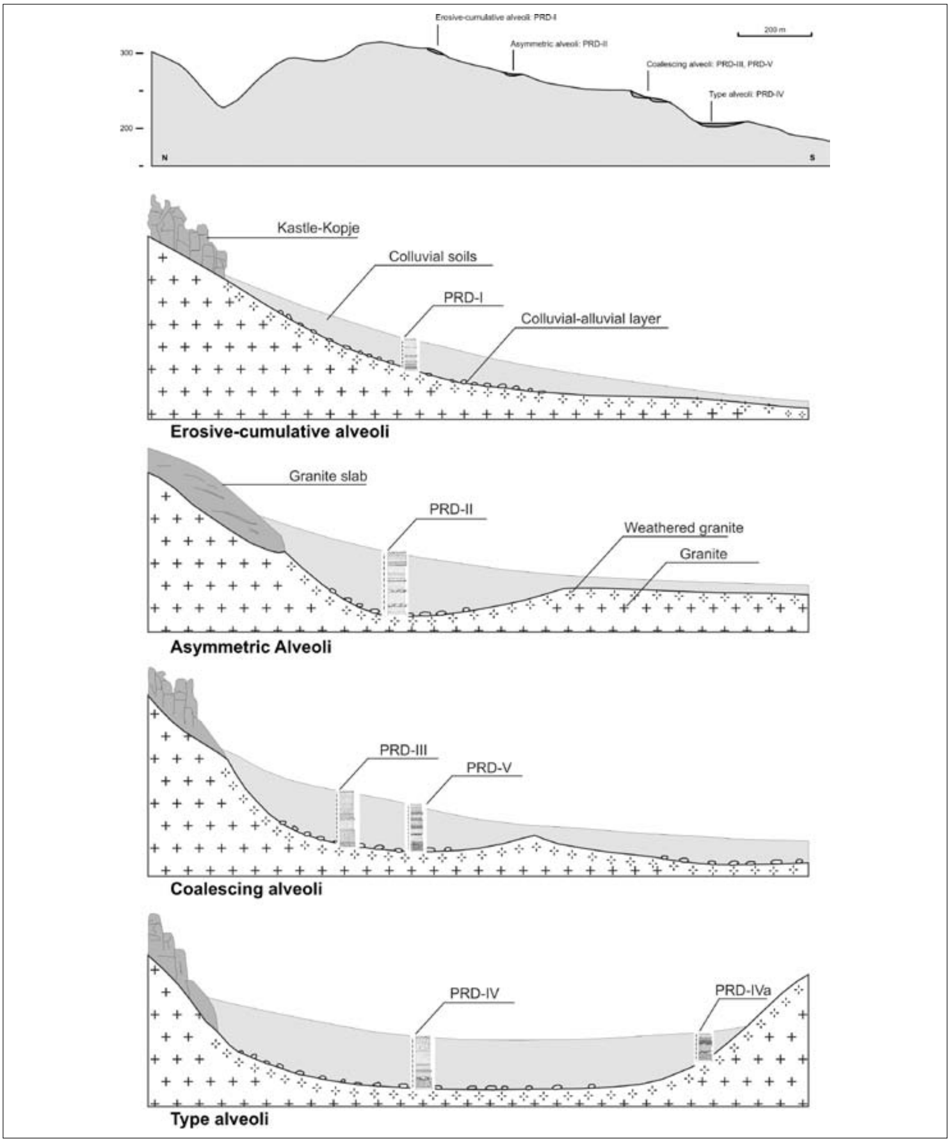

Fig. 5. Different types of small depressions (*alveoli*) identified in the Campo Lameiro Rock Art Park area. The eroded soil from the slopes was accumulated in these reduced areas named "*alveoli*", where sedimentation was favoured. Modified from Costa-Casais *et al.* (2008).

(11000-10000 BP), a severe coold spell with rainy conditions, as represented in sedimentary levels by important alluvial-colluvial accumulations that are well defined in the northwestern Iberian Peninsula (Martínez Cortizas & Moares Domínguez 1995; Valcárcel Díaz 1998). This is consistent with recent research on fluvial activity in Spain that suggests increased activity by 11170-10230 BP and 9630-8785 BP (Thorndycraft & Benito 2006).

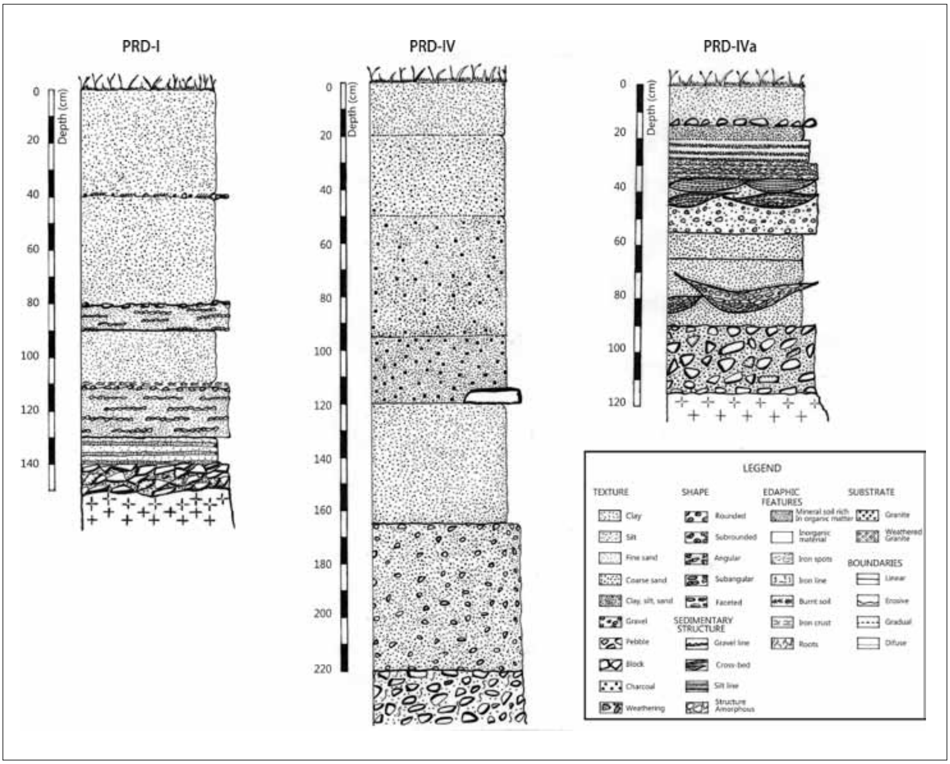

Fig. 6. Three examples of sedimentary sequences in the Campo Lameiro Rock Art Park area. Sedimentological and stratigraphic schemes and legend of PRD-I, PRD-IV, PRD-IVa alluvial and colluvial soils.

The younger unit is represented by colluvial layers that show an apparently homogeneous morphology: black to dark brown A horizons (mineral soil rich in organic matter), loamy sand to sandy loam texture, with abundant quartz and muscovite, acidic and with high C/N ratios. Nonetheless these soils exhibit significant vertical changes in grain size, charcoal layers, burnt soil layers, pH, elemental composition of inorganic phase (Ti, Zr, Fe, Al). Also, the highly aromatic nature of the soil organic matter, originating from pyrogenic material formed during palaeofires points towards recurrent fire episodes (Kaal *et al*. 2008). Sedimentary and geochemical features, supported by extensive radiocarbon dating, are evidence of the occurrence of several phases of erosion/sedimentation (i.e. landscape instability), some of which were coeval with known periods of Holocene abrupt climate change – the 8.2 ka event, the beginning of the Neoglaciation (ca. 5500 ka BP) and the 2.8 ka wet/cold event (Costa-Casais *et al.* 2009). But some of the most intense phases coincided with increased human pressure on the landscape during the Neolithic, Bronze Age, Roman Period, and the Middle Ages.

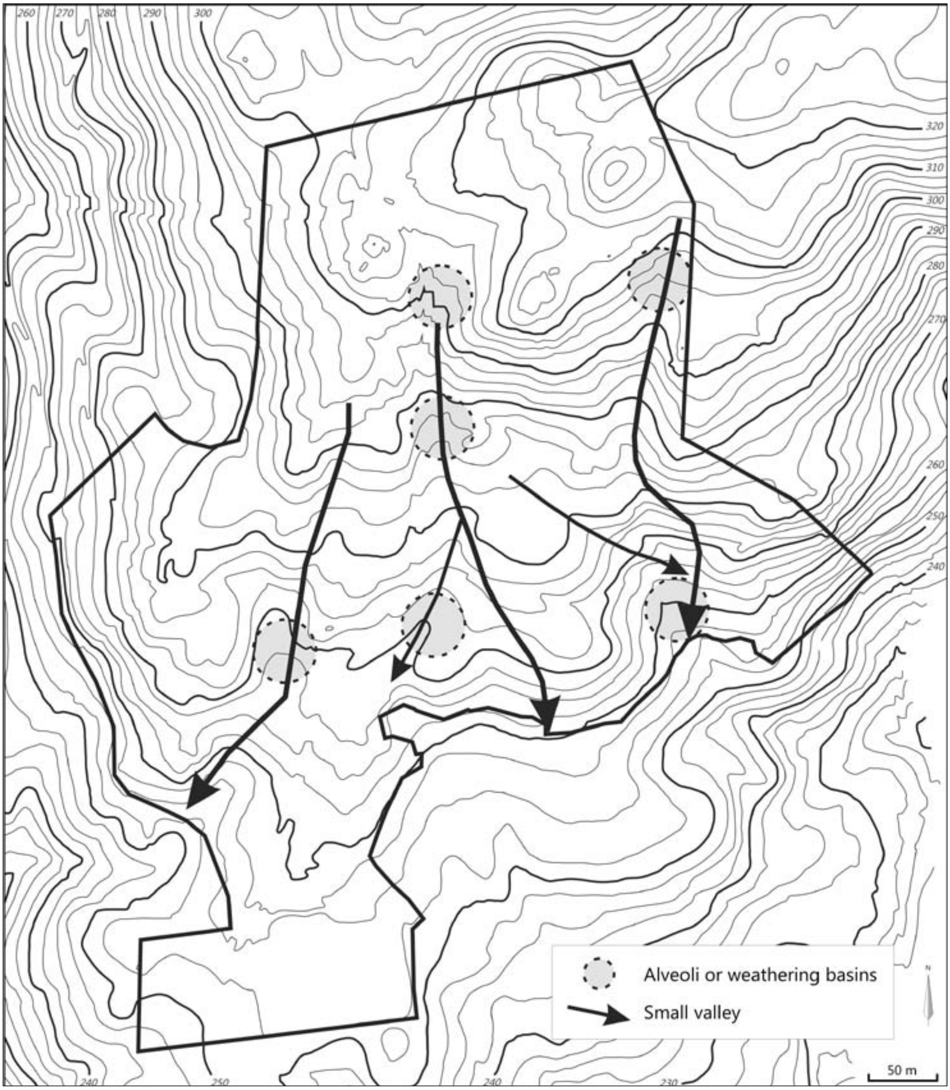

Fig. 7. The location of the granite outcrops and the alveolar depressions defines three main flow paths within the area that channelized the transport of water and sediments to the valleys. Modified from Costa-Casais *et al.* (2009).

4.3. Landscape change vs induced environmental changes

Colluvial soil dynamics

Martínez Cortizas *et al.* (2009a, 2012) analyzed changes in soil accumulation/erosion rates in the Rock Art Park of Campo Lameiro – in a relatively small area (less than 1 km^2) – using several colluvial formations and based on high-resolution sampling of soils and sediments and extensive radiocarbon dating. The record of average soil accumulation rates revealed sixteen erosion/accumulation periods, eight of them with an equivalent accumulation rate greater than 10 tm ha^{-1} a^{1} (Fig. 8). The estimated duration of these phases was between 410 and 130 years, except the oldest one, which may have lasted for 500 years. The length of these phases seems to have decreased substantially in two steps: one around 6500 cal BP and other one around 2700 cal BP. The average duration prior to 6500 cal BP was 600 years, between 6500 and 2700 cal BP was 310 years and after 2700 cal BP it was 160 years (Fig. 8). As a result of increased erosion the transport of soil and sediments caused a progressive accretion and infilling of the alveolar depressions. It was possibly at this time, around 6000 cal BP (the Neolithic), when the granite outcrops started to become exhumed together with the upper part of the slabs. Studies on landscape evolution in NW Spain indicate

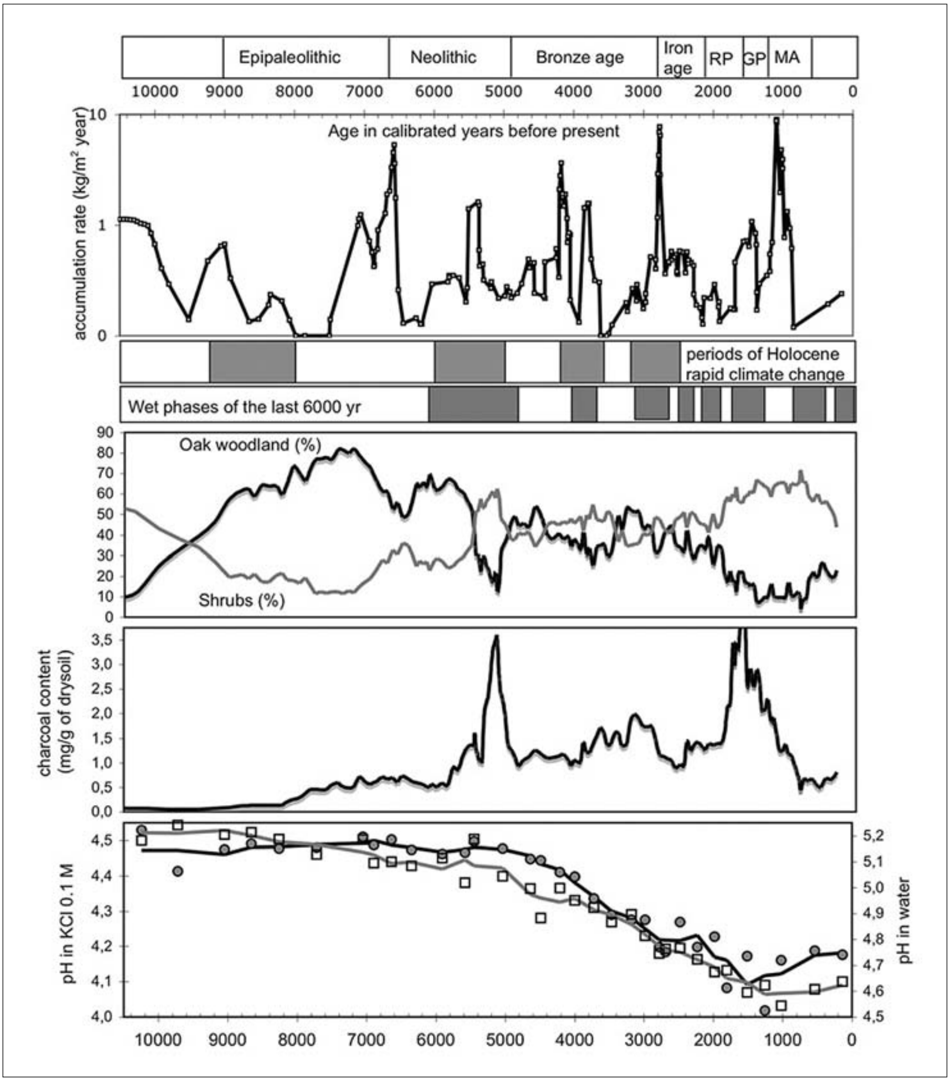

Fig. 8. Holocene changes in soil accumulation/erosion rates, vegetation change, charcoal content in colluvial soils and soil reaction in Campo Lameiro, Pontevedra (Martínez Cortizas *et al.* 2009a).

that soil erosion began to be a widespread phenomenon at least from 6000-5500 cal BP. Most of these phases were also detected by synchronous erosion episodes in other areas of NW Spain (Benito *et al.* 1991; Martínez Cortizas & Moares Domínguez 1995; Martínez Cortizas *et al.* 1999, 2000).

The role of climate changes in the formation of colluvial soils was also addressed by Leopold and Völkel (2007), particularly related with extreme rainfall events. In Campo Lameiro some of the erosion phases correlate with wet periods during the last 6000 years, but there is not a direct relationship between the change in rainfall and the intensity of erosion. The erosive effect of rainfall may overlap with human-induced transformations. The oldest erosion phases coincided with abrupt climate changes (Younger Dryas – >10000 cal BP or the 9000-8000 cal BP period, including the 8.2 ka event; Mayewski *et al.* 2004). These events occurred in periods of weak environmental repercussions of human activities. Other phases (Neoglaciation 5500-5000 cal BP, the 4200-3800 or 2750--2450 cal BP event; Magny *et al.* 2006; van Geel *et al.* 2000; Lal *et al.* 2007), characterized by wetter and cooler conditions, occurred in periods of higher human impact, which probably led to higher landscape sensitivity. The results suggest that since 6800-6500 cal BP, human activities seem to have been coupled to climate changes and in that period became a relevant force that accelerated landscape evolution. The same chronology has been found in other areas of NW Spain (Martínez Cortizas *et al.* 2009b).

Forest dynamics and fire use

The anthracological study of the macroscopic charcoal (>2 mm, obtained by wet sieving) in five colluvial soils from the Campo Lameiro area linked the fire history to vegetation change and slope processes (Fig. 8) (Kaal *et al.* 2011). Fires often cause accelerated soil erosion through elimination of the protective vegetation cover and litter. The direct result is the exposure of the mineral soil to wind and water erosion. Soils located in the upper part of the slopes (i.e. geomorphologically active areas) can be completely eroded. The black colour of the resulting colluvial soils seems to be, at least partially, associated with the abundance of vegetation fire residues ("black carbon") not only as macroscopic charcoal fragments but also as fine-grained material incorporated into the soils' microgranular fabric (Kaal & Van Mourik 2008). The formation of black-coloured soils rich in organic matter is often the consequence of pyrogenic material accumulation from long-term fire regimes: chernozemic soils of the lower Rhine basin (Gerlach *et al.* 2006), Australia (Skjemstad *et al.* 1996), and *Terra Preta* soils in South America (Glaser & Amelung 2003).

The early phases of the Holocene in Campo Lameiro (10000-7000 BP) were characterized by the expansion of forest vegetation, dominated by deciduous *Quercus* (Martínez Cortizas *et al.* 2009b; Kaal *et al*. 2011) which remained dominant up until ca. 6000 cal BP, when it started to be gradually replaced by shrub communities. Pollen studies have found a sharp decrease in forest cover beginning by ca. 6500 cal BP. The effect of fire on the forest in this area is clear since ca. 6000 cal BP, and the charcoal record shows a decline in the contribution of oak and an increase in shrub species

(*Erica* sp.) that seems to be a good indicator of fire-induced environmental degradation (Fig. 8) (Kaal *et al.* 2011). The episodes of accelerated deforestation (ca. 5500-5000 cal BP and ca. 2000-1500 cal BP) coincided with periods of increased human pressure and cultural changes reflected in many areas of Europe (6000 BP Neolithic expansion of agriculture and pastoralism, 3000 BP Bronze Age/Iron Age transition and the 1700--1500 BP Roman/Germanic shift; Tinner *et al.* 1999; Mighall *et al.* 2006) and climate deterioration (especially the Neolithic that coincides with the Neoglaciation; Martínez Cortizas *et al.* 2009b).

Charcoal layers identified in colluvial soils are often covered by high accumulation rates which confirm that fire was an important agent in the geomorphological evolution of Campo Lameiro landscape. Pedo-anthracological analyses by Kaal *et al.* (2011) showed that: i) the deforestation initiated on the upper part of the Monte Paradela hill and probably had a local character; ii) the low degree of chronological precision, which is inherent in fire history reconstructions from colluvial soils, made it impossible to distinguish climatic from human-induced fires, but the abundance of synanthropic pollen indicators (e.g. *Plantago lanceolata and Urtica dioica*) since at least ca. 6000 cal BP strongly suggests that humans used fire to generate and maintain pasture; and iii) in NW Spain, macroscopic charcoal records in colluvial soils seem to provide an excellent proxy for local fire-induced vegetation change.

These colluvial soils, traditionally referred to as Atlantic Rankers (Carballas *et al.* 1967), should therefore be added to the list of black-coloured soils probably formed upon frequent anthropogenic fire starting in the Neolithic period (Martínez Cortizas *et al.* 2009a)

Soil acidification

Another possible effect of human activities since prehistoric times was soil acidification. The results of the study of the Campo Lameiro colluvial soils reflected that pH started to decrease ca. 6000-5000 cal. BP (Fig. 8), an acidification trend that would continue for several Millennia. It is only in the last 1000 years that pH seems to have stabilized at its lowest values (Martínez Cortizas *et al.* 2009a).

The beginning of acidification was synchronous with one of the most critical phases of forest decline, an increase in shrubs in the charcoal record, and an abrupt increase in total charcoal content in the colluvial soils. In soil layers generated during periods of high accumulation rates, pH values tend to be slightly higher than in layers formed in periods of low accumulation rate. The substitution of the forest by a more acidophilous vegetation, the disruption of the biocycling of nutrients and increased leaching may have been the processes leading this forced acidification of soils (Martínez Cortizas *et al.* 2009a, 2012).

A decline in forest cover and the first appearance of cereal pollen indicated by palynological studies (Ramil 1993; Martínez Cortizas *et al.* 2005), the erosive discontinuities, stone and charcoal lines in colluvial soils, as well as the start of a progressive soil acidification point to human activities as the main trigger. By 3000

BP, a critical threshold must have been crossed in NW Spain because many indicators show an acceleration of environmental degradation (Costa-Casais *et al.* 1996, 2009).

5. CONCLUDING REMARKS

Our research suggests that both climate and human activities played an important role in the formation of colluvial deposits of the study area. The geomorphological and sedimentological analyses indicate that the distribution of present landforms is a primordial factor to understand the formation of the colluvial deposits. In agreement with previous studies, this indicates that they are valuable geoarchives to reconstruct Holocene environmental change from a geoarchaeological approach. Given their wide distribution and the time expand covered by them, they may also be crucial to decipher and understand human responses to climate change and the impact of anthropogenic activities on the environment at the local and regional scales. The lack of archaeological remains for the studied area makes colluvial deposits an important archive that allows to trace the chronology of human activity. In this sense, we can briefly summarize palaeoenvironmental information provided by these archives as follows:

Climatic changes dominated the environmental evolution until ca. 7000 years ago. After this date human modifications became an important driving force.

Increasing landscape instability phases since the mid-Holocene. Some of which were coeval with known periods of Holocene abrupt climate change – the 8.2 ka event, the beginning of the Neoglaciaton (ca. 5500 ka BP) or the 2.8 ka wet/cold events. But some of the most intense phases are coincident with increased human pressure on landscape during Neolithic, Bronze Age, Roman Period and Middle Ages.

Features such as charcoal layers, burnt soil layers and the highly aromatic nature of the soil organic matter point to frequent fire episodes; pollen studies indicate a sharp decrease in forest cover beginning by ca. 6500 cal. BP, that was accompanied by a progressive soil acidification.

Therefore, the geomorphological evolution is controlled by climatic and anthropogenic causes. The anthropogenic processes manifested as an acceleration of an existing pedogeomorphological process. Direct effects of the geomorphological change in the landscape are: slope processes (erosion/sedimentation, i.e. landscape instability), fire use accelerated soil erosion, modification of the vegetation cover and redistribution of soil resources and preferential concentration of soil in the *alveoli* megaforms.

ACKNOWLEDGEMENTS: Manuela Costa-Casais is supported by a Research Program "Isidro Parga Pondal 2007" – Xunta Galicia. This research was partly funded by the Project "Paleopaisaje y prehistoria del Futuro Parque de Arte Rupestre de Campo Lameiro, Pontevedra" (PGIDT02CCP60601) and the Project 09SEC015606PR (2009-2012) "Xeoarqueoloxía e reconstrución paleoambiental. Metodoloxía aplicada a contextos arqueolóxico-culturais" (Consellería de Economía e Industria. Xunta de

Galicia) and by Portuguese National Funds through the FCT (Fundação para a Ciência e a Tecnologia) under the project "PEst-OE/CTE/UI0039/2011".
The authors are deeply grateful to the reviewers for their helpful comments and contributions on the manuscript.

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ISBN: 978-989-97140-1-4
9 789899 714014