

Artigo

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Recent dynamics of vegetation and landscape in the Minho region (Portugal) in relation to human occupation of the territory

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Abstract New pollinical data from the area surrounding the city of Braga (NW Portugal), and linked to the construction of *Bracara Augusta*, have allowed us to obtain an image of the landscape and vegetation of this area during the Iron Age and Romanization, continuing through the Middle Ages and all the way to the present time. The new data was compared with existing data from the Minho region. This revealed a regional sequence of landscape modifications, in which one can appreciate the increasing incidence of various human activities on land configuration. The new data revealed similar dynamics in both territories, with small differences based on latitudinal position and topographic characteristics.

Key words Landscape, vegetation, pollen analysis, *Bracara Augusta*, NW Portugal.

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Introduction

The work presented here shows the results from a pollen study carried out on a set of samples recovered in three columns: one from a paleosol located under the artificial pavement of the Roman Theatre of *Bracara Augusta* and two from polycyclic soils located in Alto da Forca, Vilanova de Sande (Guimaraes). These new data were linked to existing data from Sierra do Bustelo and Sierra da Arga (Figure 1) to obtain an image of the changes in landscape and vegetation associated with human presence in the territory, in particular during the founding and growth of the city of *Bracara Augusta*.

The Roman Theatre of *Bracara Augusta* is located at Alto da Cividade, next to the Roman public baths and has been in excavation phase since 2004. During the digging works, a paleosol associated with the theatre's perimeter wall was identified. It is located directly on the disturbed bedrock and across a net boundary under a foundation level of the theatre structure (Figures 1, 2). Therefore, it is considered to be contemporary to the construction of the building and was likely sealed during the construction work. The available data indicate that the construction of the building would have taken place in the early second century AD, coinciding with the maximum expansion of the city and at a time of great economic development (Martins et al. 2015).

In order to compare the pollen information from the building environment of the theatre with pollen from a natural environment nearby, two columns were collected on two current soils in courts located in Alto de Forca Mountain, near Vilanova de Sande (Guimaraes) (Figure 1).

In addition, a correlation of the sequence obtained with the records available in the territory is carried out, in order to obtain a regional sequence that typifies the main environmental changes in the Minho region during the last third of the Holocene. In this sense, in the regional space of Minho there are two pollen sequences that reflect the last third of the Holocene. To the north of Braga, in the Serra do Bustelo area (Figure 1), there is a set of pollen analyzes

from which a sequence for this area was obtained (Taboada Castro et al. 1995). Further north and closer to the coastline (Figure 1) there is a sequence obtained in a fossilized peat bog, located in the Serra da Arga (Gómez-Orellana et al. 2010).

Material and methods

Sampling

The samples recovered to carry out the pollen study correspond to a column collected manually in an open profile during excavation and two others collected taking advantage of cuts made in the opening of forest tracks in Alto de Forca Mountain (Figure 3). In all three cases, the samples were recovered after cleaning the profiles. A total of

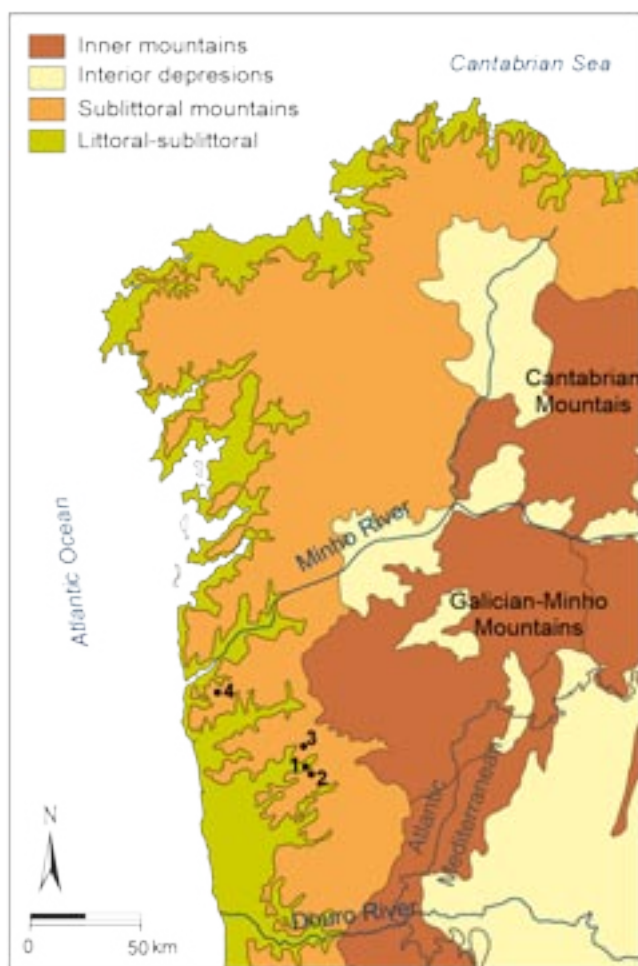


Figure 1.- Location of analysed sequences and other sequences mentioned in the text. 1: Roman Theatre of Bracara Augusta; 2: Alto da Forca; 3: Serra do Bustelo; 4: Serra da Arga. The palaeoecological division of the NW Iberian Peninsula and the Atlantic/Mediterranean boundary are also shown

51 samples were obtained (23 samples corresponding to the paleosol associated with the theatre and 12 and 16 respectively in Alto de Forca soils). The samples, at the time of sampling, were stored in properly labelled plastic bags. Subsequently, they were kept at 5°C in the Laboratory of Biodiversity of GI-TB-1934 of USC, located in Lugo, until the moment of their extraction.

In the excavations of the Roman Theatre of *Bracara Augusta*, the presence of a dark-colored sediment with a high content of organic matter was discovered. It was located above the alteration horizon of the basal rock and through a net limit, under a highly compacted 10 cm-thick and light color, narrow layer, so it was identified as an artificial level of theatre paving (Figure 2). This organic level would correspond to the existing paleosol prior to the construction of the theatre. On an open profile (Figure 2), the paleosol level was sampled, obtaining a total of 23 one-cm-thick samples. In addition, several samples of the altered bedrock level, the level of paving and the fill level that bury the profile were recovered (Figure 2). These samples were collected in order to evaluate possible percolations of pollen material from the surface or the upper profile levels towards the paleosol.

In Alto da Forca, located near Vila Nova de Sande (Figure 1), two polycyclic soil profiles were recovered (Alto da Forca I and II) on two existing cuts in forest tracks (Figure 3). The sedimentological characterization of the profiles is shown in figure 3. In both cases, the soils present a decomposition horizon of the bed rock (C horizon), on which a B horizon and a superficial A horizon, with a high content of organic matter. Profile 1 has a thickness of 75 cm while Profile 2 reaches 55 cm. The sampling was carried out collecting 5 cm-thick samples, respecting the different levels present in the column and recovering the most superficial 5 cm of the C horizon and all of the B and A horizons.

A radiocarbon date was obtained at the base of the paleosol recovered in the Roman Theatre (Table 1). The sediment was radiocarbon dated by ICA. The dating of sediments was done by AMS in organic matter. Unfortunately, it has not been possible to obtain any date on the basal part of the two profiles of Alto da Forca, due to the low organic matter content and the low pollen concentration, that required the use of a large amount of sediment in the pollen analysis.

Pollen analyses

The samples were prepared for pollen analysis using standard methods in palynology (Faegri et al. 1989; Moore et al. 1991). The mounted slides were analysed using light microscopy. The total sum of pollen in all samples is between 411 and 789 grains. Terrestrial pollen percentages, were calculated using a total terrestrial pollen sum (>300 grains), including trees, shrubs and herbs. The total pollen sum was used in calculating percentages of all aquatic plants, including cryptogams. For the calculation and graphic representation of the results, the TILIA 1.7.14 software was used (Grimm 1990-2015). The pollen diagram was zoned using constrained incremental sum of squares (CONISS) cluster analysis.

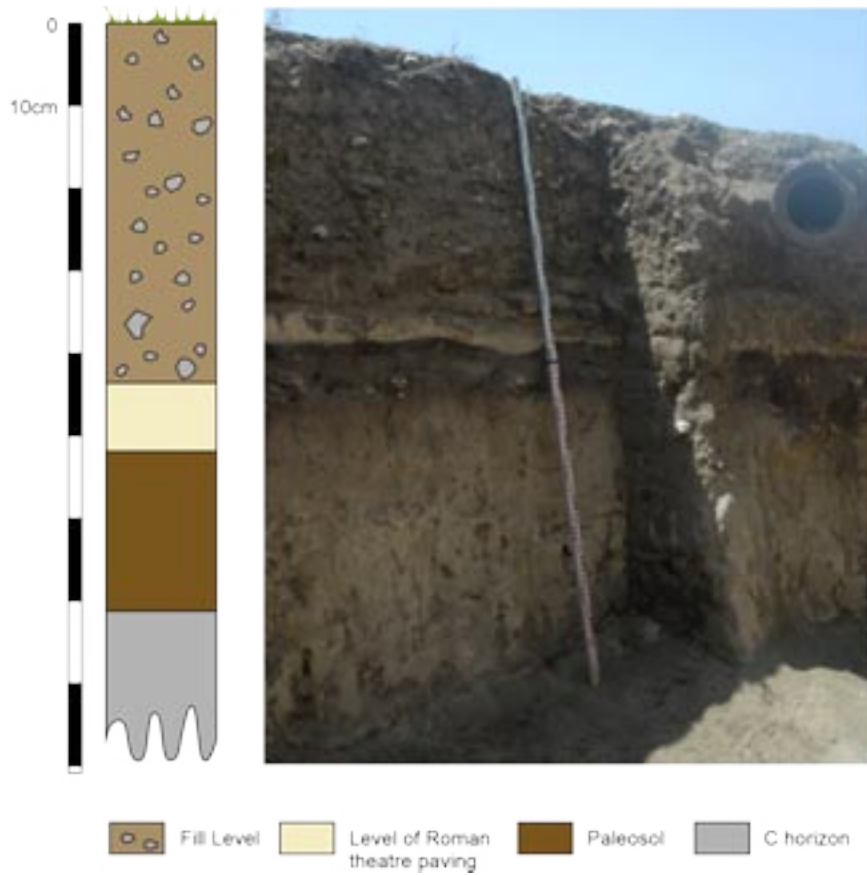


Figure 2.- Photograph and idealized diagram of the column sampled in the paleosol located under the pavement of the Bracara Augusta theatre building

Fig 3

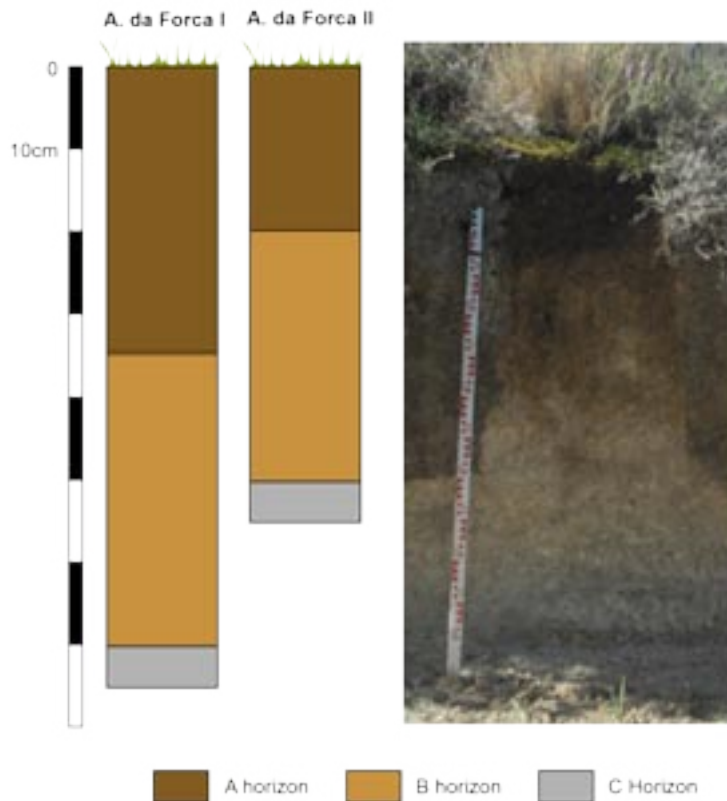


Figure 3.- Photograph of one of the sections and idealized representation of the profiles sampled in Alto da Forca

Laboratory number	Material	Radiocarbon age uncal. a BP	2 σ cal. BP age ranges (relative area)	Cal. BP age median probability
ICA-5449	Sediment	3030 \pm 30	3148-3277 (0,69)	3212

Table 1. - Radiocarbon and calibrated ages from Roman Theatre. The date was calibrated by using CALIB Rev 8.2 program and IntCal20 data set (Stuiver et al. 2020). 2 sigma (95.4%) confidence intervals and their relative areas were used as well as the median probability

Results

Table 1 shows the result of the dating obtained in the Roman Theatre and the calibration obtained. The calibration of the date was performed with the program Calib 8.2 using the IntCal20 calibration curve (Stuiver et al. 2020).

The results of the three pollen analyses are presented in Figures 4, 5 and 6. The local pollen zones established in each analysis (LPAZ) are shown on the right side. Further to the right, we present the correlation between the local zones to form a new regional zonation (RZ), called Braga (Br-). Along with this, we show the zonation for the littoral and sublittoral territory of the North of Portugal, which has been called Minho (Mh-), and that integrates the data from other available sequences.

Roman Theatre of Bracara Augusta

In the samples not corresponding to the paleosol, no sporopollinic residue was identified. The results of the pollen analysis of the paleosol are shown in Figure 4.

The diagram obtained (Figure 4) shows a predominance phase of non-arboreal vegetation, mainly *Poaceae* (50-70%), during which the deciduous forests undergo an important development marked by the values of *Quercus robur*-type (20-40%). The sequence was divided into two pollen zones marked by the detriment of *Quercus robur*-type and the increase in taxa associated with ruderal environment, mainly of Asteraceae, during pollen zone 2. Throughout the diagram, a continuous presence of cereal pollen can be observed.

The fact that the paleosol analysed is buried and fossilized under the foundation pavement of the Roman Theatre of Braga, has allowed us to date its formation at a time prior to the Roman occupation of the Iberian Northwest. The low arboreal values, as well as the continuous presence of cereal in the record, could be related to the generalization of agricultural practices and consequent increased deforestation activity in lowland and mid-altitude areas. This allows us to associate the sequence with an advanced moment of the Cultural Steppe, related to the settlement of the Iron Age.

The intensification of the landscape anthropization represented by the pollen zone 2 could be associated with the Romanization of the Iberian NW and the development of the city of *Bracara Augusta* and its socioeconomic growth.

Alto da Forca I

In the Alto da Forca I profile, a total of 16 samples were recovered, while in profile II, 12 samples were analysed. The results of the pollen analyses obtained in these profiles are shown in Figures 5 and 6.

The sequence obtained in Alto da Forca I was divided into 5 pollen zones (Figure 5), which represent a succession of landscape changes associated with anthropic activity, as indicated by the continuous presence of cereal and the predominance of non-arboreal pollen, which place the diagram in a moment where the landscape would have been marked by human influence on the environment. Despite obvious signs of anthropization on the landscape, the diagram registers a constant arboreal presence, representing the existence of forest masses, dominated by deciduous trees, until the final part of the diagram.

The beginning of the diagram (LPAZ-1) is characterized by the predominance of a deforested landscape, with a predominance of shrub elements, primarily *Erica*, *Cistus*. Later, the LPAZ-2 shows a detriment of arboreal pollen and an increase of *Poaceae*. The subsequent zone marks a slight recovery of the forest, which could be related to the recovery phases observed in the NW Iberian sequences after the Roman occupation (Muñoz Sobrino et al. 2005; Ramil-Rego et al. 2009). The LPAZ-4 zone marks a sharp decrease in arboreal percentage, mainly *Quercus robur*-type, together with an increase in scrub communities, represented primarily by *Cistus*. The registered increase in *Asphodelus* could also be associated with the deforestation process. Finally, the upper limit of the sequence reflects a strong increase in *Pinus*, which would represent the recent reforestation. This area registers also a change in the dynamics of shrub formations, with a marked detriment of *Cistus* and an increase of *Erica* and, to a lesser extent, of *Calluna*.

In the penultimate sample, *Acacia* pollen is recorded and, in the upper sample, *Eucalyptus* pollen, which shows the change in forest policy trends in the last decades.

Alto da Forca II

The pollen spectrum obtained (Figure 6) was divided into three local pollen zones, which correlate with the three upper zones of the Alto da Forca I diagram. The basal zone (LPAZ-1) would represent a moment of increase in arboreal pollen, mainly *Quercus robur*-type. Subsequently, a sharp drop in this taxon and a slight increase in *Pinus pinaster*-

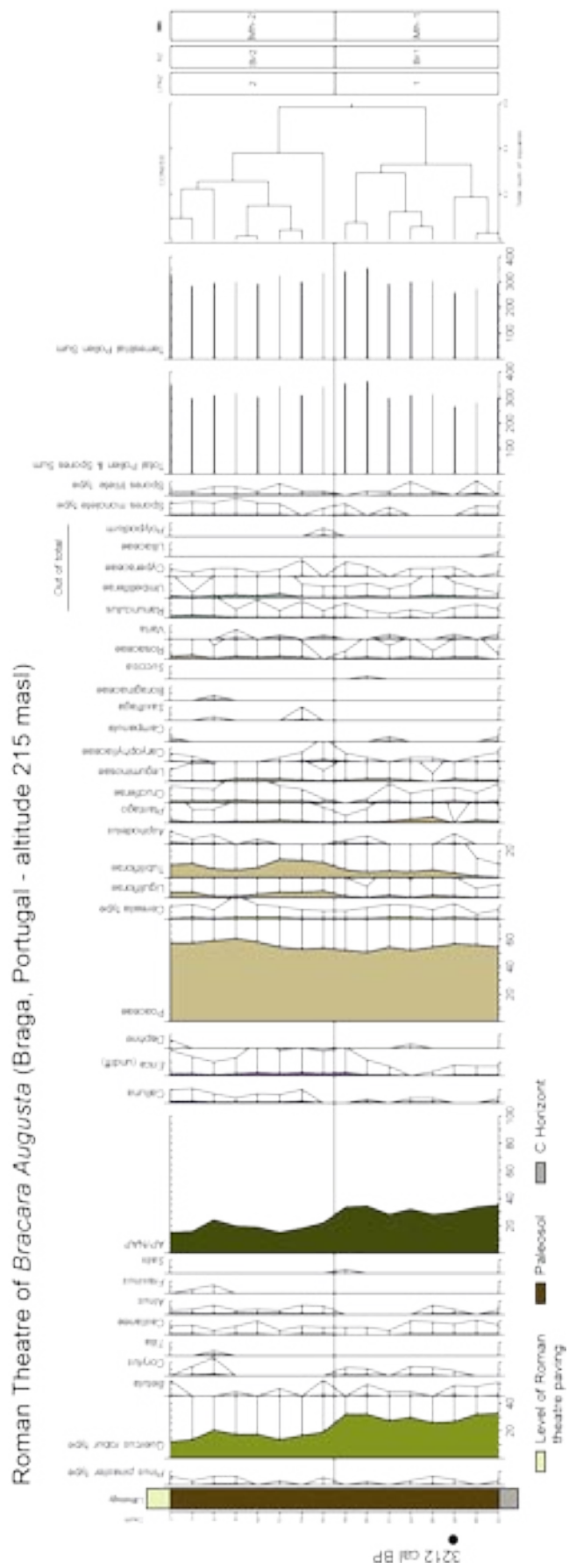


Figure 4.- Result of the pollen analysis carried out in the Roman Theatre of Bracara Augusta

Alto da Forca - I (Vila Nova de Sande-Guimaraes, Portugal - altitude 200 masl)

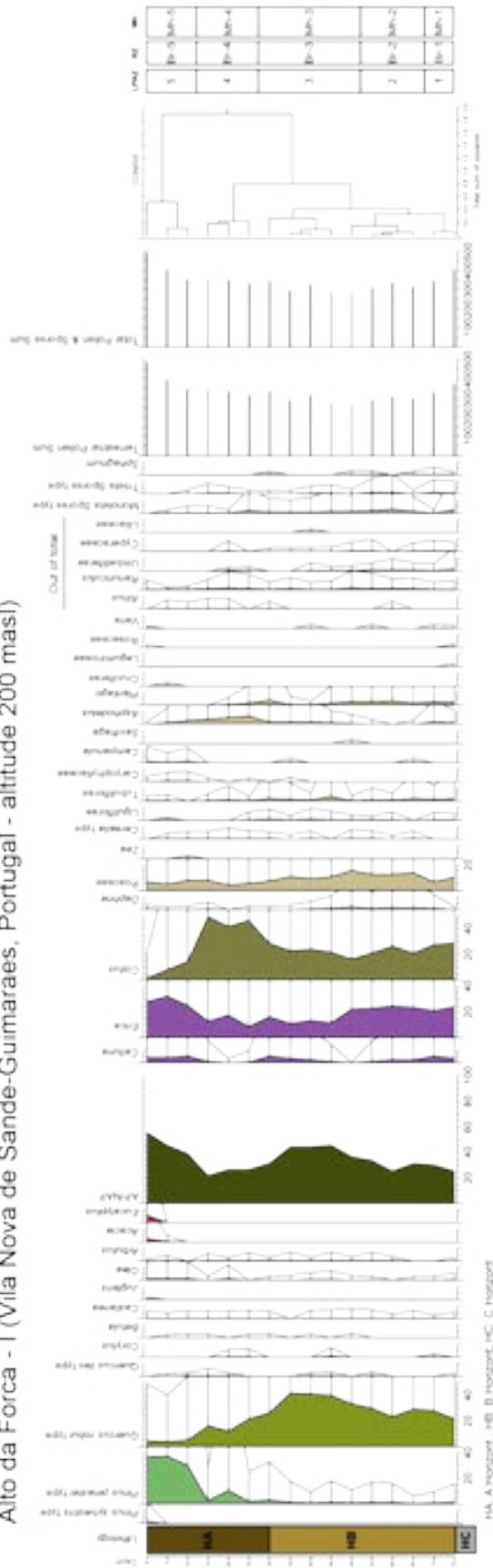


Figure 5.- Result of the pollen analysis carried out in Alto da Forca - I

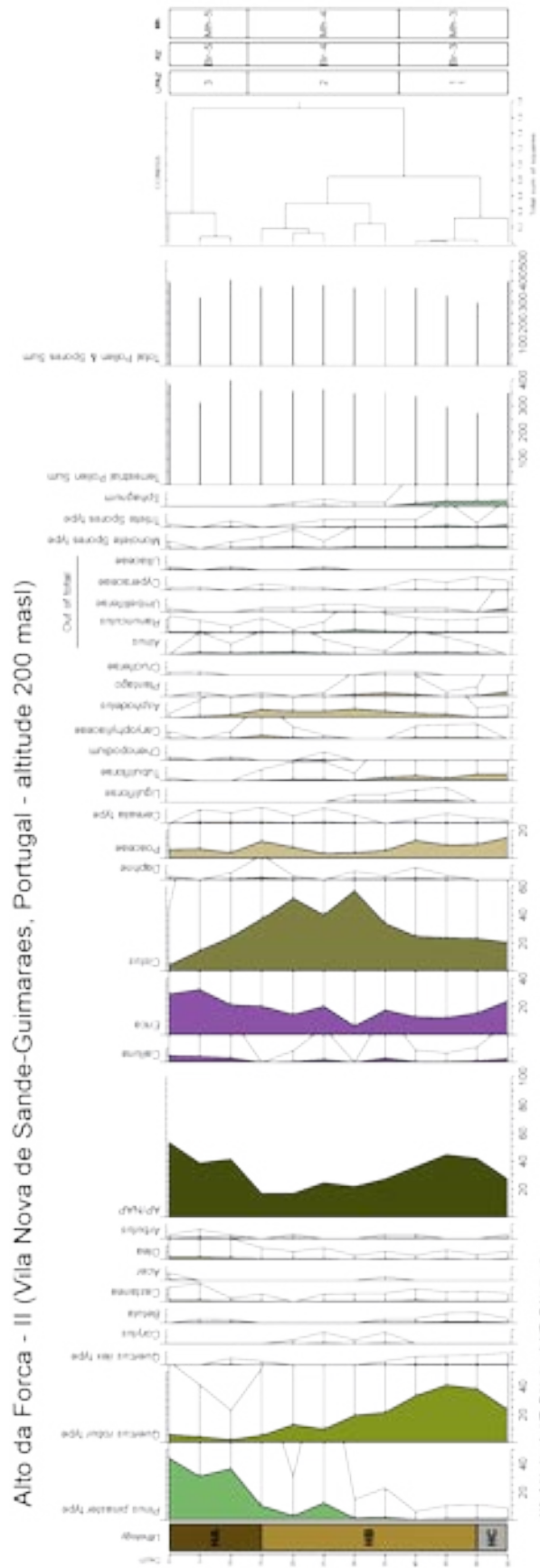


Figure 6.- Result of the pollen analysis carried out in Alto da Forca - II

type were recorded. This decline was coupled to an increase in shrub taxa, mainly *Cistus* along with a slight increase in *Asphodelus*. Finally, the top of the sequence is marked by a moment of strong increase in *Pinus*, related to recent reforestations. In this area, in turn, there is a replacement of *Cistus* by *Erica* and a slight increase in *Calluna*.

Paleoecological interpretation and contextualization

Based on the pollen characteristics described in the different diagrams, a correlation of the local pollen zones established in each diagram (LPAZ) was carried out, obtaining a regional zonation for the territory (RZ), which can be observed in Table 2 and in each of the diagrams (Braga: Br-). This interpretation is based on the dating obtained from the profile of the Roman Theatre of *Bracara Augusta* and on the fact that the chronology of the current edaphic cycle does not exceed 3,000 years (Ramil-Rego et al., 1996), with which this date would represent the oldest possible age of the two soil profiles recovered in Alto da Forca.

In the surroundings of the study area, there is a regional sequence elaborated from several pollen diagrams obtained in polycyclic soils and peat bogs in Serra de Bustelo (Vila Verde). Due to its biogeographic proximity, this existing sequence (Taboada Castro et al. 1995) is of great interest in the analysis of the new sequence and would enable us to establish a sequence of a broader territorial scope, encompassing the littoral and sub-littoral space of the North of Portugal.

In the regional space of Minho, there is another available pollen sequence that was obtained in Serra da Arga (Figure 1). However, this sequence only reflects the beginning of the Holocene and the last centuries, presenting a sedimentological hiatus that encompasses the middle and an ending part of the Holocene, and, therefore, missing a

large part of the period represented in the new sequence (Gómez-Orellana et al. 2010).

Finally, the new data were contrasted with reference sequences available in the different paleobiogeographic areas of the Iberian NW (Ramil-Rego et al. 1996, 1998, 2006, 2009, 2011, 2018; Gómez-Orellana et al. 2010; Muñoz Sobrino et al. 2005; Iriarte Chiapuso et al. 2015).

Table 2 shows the correlation between the diagrams and the characteristics of the 5 zones that were recognized in the new sequence (Regional Zonation: Braga), as well as their correlation with the sequence available in the nearby Serra do Bustelo (Bustelo), taken from Taboada Castro et al. (1995). From both zonings, a new zonation proposal is established for the regional territory of Minho (Mh-).

The beginning of this sequence would be placed at the beginning of the catathermic phase of the Holocene, during the full development of the cultural steppe. The sequence reflects a landscape highly influenced by human communities as well as agricultural and livestock activity, as is also the case in the rest of the Iberian NW territories. Despite this notable intervention, the basal zone (Mh-1) shows an important presence of *Quercus robur*-type, which has allowed us to relate this very initial phase to a time before the Iron Age, known as NW Iberian *Castreja Culture*. Along with *Quercus robur*, an important group of deciduous arboreal elements are present in a minority, including *Castanea*, *Betula*, *Corylus* or *Tilia* and evergreens, among which the presence of *Olea* stands out throughout the entire sequence, with continuous curves in almost all diagrams, although always with values below 3%. Interestingly, the absence of this taxon can be noted in Serra da Arga diagram (Figure 1), which represents the northernmost pollen record available in the studied territory. In general, the dynamics of *Olea*, with a marked increase towards the most recent phases, suggests that its presence must be related to its cultivation.

Theatre	A Forca I	A Forca II	Regional zonation (Braga)	Bustelo	Minho
			Pinus-Erica		
	5	3	Br-5 Strong increase of <i>Pinus</i> . <i>Cistus</i> replacement <i>Erica</i> and <i>Calluna</i>	4-5	Mh-5
			Cistus-Poaceae-Asphodelus		
	4	2	Br-4 Arboreal minimum. Maximum of <i>Cistus</i> . Increase of <i>Asphodelus</i>	3	Mh-4
			Quercus-Erica-Cistus		
	3	1	Br-3 Increase and maximum of <i>Quercus robur</i> -type. Slight decrease of <i>Cistus</i> and <i>Erica</i>	2	Mh-3
			Poaceae-Cistus-Erica-Quercus		
	2	2	Br-2 Slight detriment of <i>Quercus robur</i> -type. Increase of <i>Poaceae</i> and <i>Asteraceae</i>	1	Mh-2
			Poaceae-Quercus-Erica-Cistus		
	1	1	Br-1 Values of <i>Quercus robur</i> -type between 30%. Important presence of thickets of <i>Erica/Cistus</i> and dominance of <i>Poaceae</i> in the surroundings of the city of Braga		Mh-1

Table 2.- Correlation between the local pollen zones of the new diagrams to develop a new regional pollen zonation (Braga: Br-). The right column shows the correlation with the Serra de Bustelo sequence (Taboada Castro et al. 1995) and the new regional zonation proposed for the Minho region (Mh-)

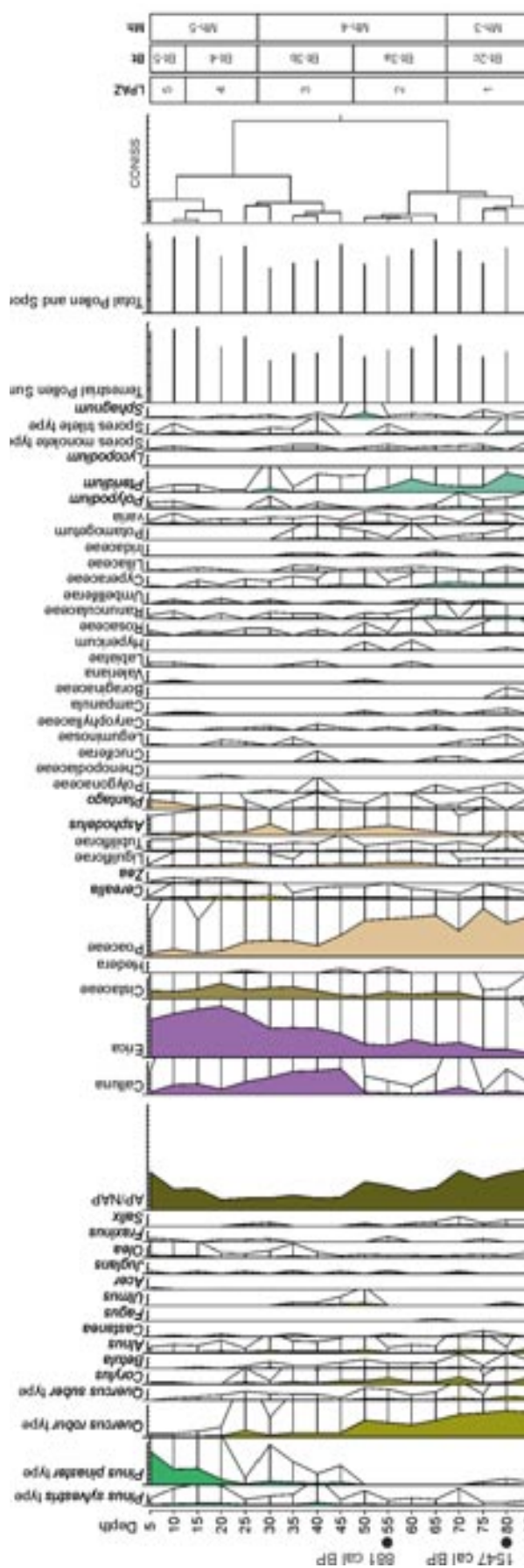


Figure 7.- Pollen diagram of Chao da Cheira - I peat bog (from Taboada Castro et al. 1995)

Chao da Cheira peatbog - II (Vila Verde, Portugal - altitude 504 masl)

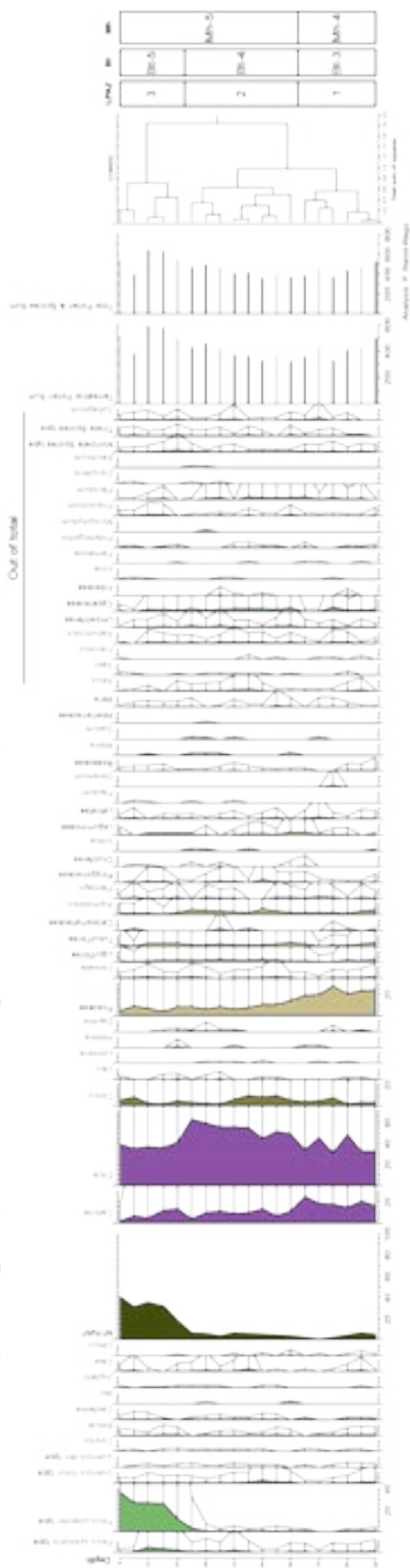


Figure 8.- Pollen diagram of Chao da Cheira- II peat bog (from Taboada Castro et al. 1995)

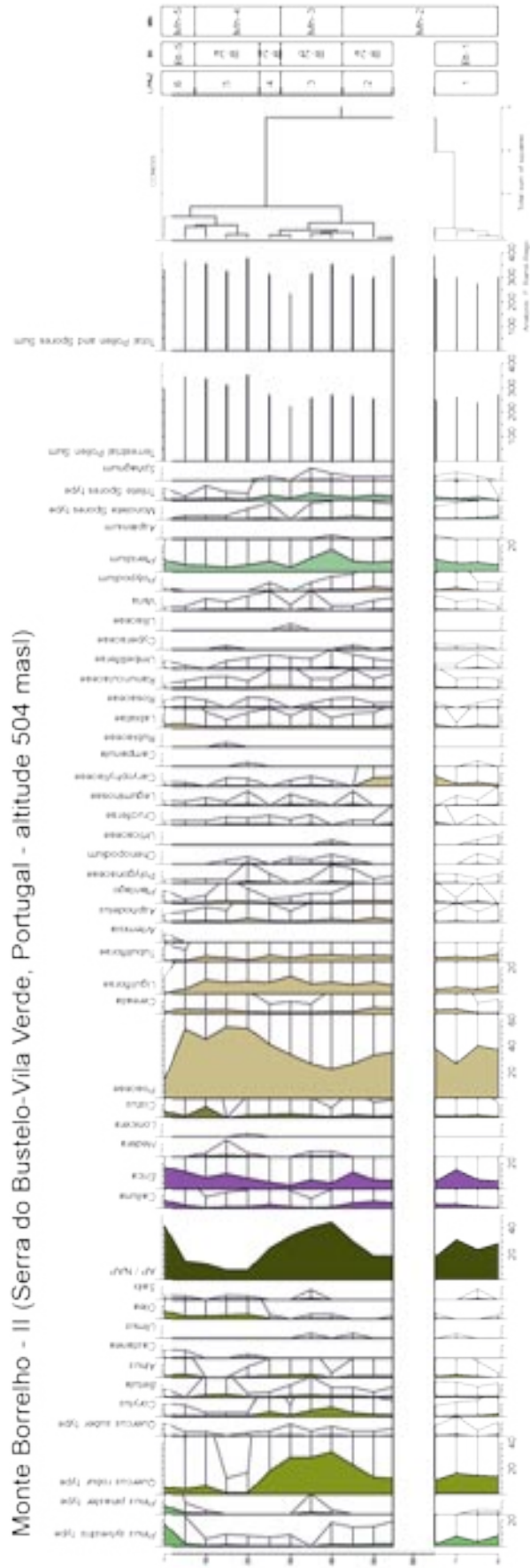


Figure 9. - Pollen diagram of Monte Borrelho - I (taken from Taboada Castro et al. 1995)

The subsequent tree detriment and increasing ruderal vegetation, which are represented in the Mh-2 zone, would coincide with the full development of the Castreja Culture and the Romanization. During this time, increasing signs of anthropization are recorded in the NW of the Iberian Peninsula, determined by both a rising population and a growing number of settlements and, consequently, by an intensification of agricultural processes, mainly in the coastal and sub-coastal areas (Ramil-Rego et al. 1996, 2009, 2018; Ramil-Rego and Gómez-Orellana, 2016).

Despite the uniformity of the Iberian NW sequences for this period, divergences can be observed based on the paleobiogeographic variations of each territory. In the new sequence, a greater intensity of deforestation and ruralizing processes can be observed in the diagram obtained in the city of Braga, compared to those recovered in the mountainous surroundings of the city, both in Alto da Forca diagrams (Figures 6 and 7) and in Serra de Bustelo sequence (Figures 7, 8 and 9). This fact would respond to the greater agricultural aptitude of the lands where the city of Braga is located, in Cavado Valley, where the altitude is lower and the topographic or edaphic limitations fewer than in the surrounding mountainous territories, where the implantation of agriculture would have faced greater difficulties.

Thus, the diagram obtained in the Roman theatre of Braga shows lower values of *Quercus robur*-type, as well as a greater presence and diversity of elements related to agricultural activity (*Cerealia*, *Leguminosae*, *Rosaceae*) and ruderal environment (*Compositae*, *Plantago*, *Cruciferae*, *Ranunculus*, *Umbelliferae*).

The new data are consistent with those obtained in the surrounding Iberian NW, which represent the initial occupation phases of the territory during the Bronze-Iron period. During this time, despite the obvious presence of signs of deforestation, an important rate of arboreal pollen remains, although later on, it decreases, as the occupation of the territory intensifies, reaching the maximum deforestation during the Roman invasion.

In the pollen sequences of the Iberian NW (Ramil-Rego et al, 1996, 1998, 2018; Muñoz-Sobrino et al. 2005; Ramil-Rego and Gómez-Orellana 2016), the predominance of the deforestation and ruderalization processes appears interrupted by a short phase of arboreal recovery, with an unequal incidence in the territory. This period is related to the end of the Roman occupation and is identified with a phase of crisis that would slow down deforestation and clearing for a few centuries, thus allowing a partial recovery of the forests.

During this phase, both in the new sequence (Br-3) and in the sequence from Serra de Bustelo (Bustelo-2), the composition of the arboreal spectra also shows a net predominance of *Quercus robur*-type and a continuous presence of other taxa such as *Betula*, *Corylus*, *Castanea*. The beginning of this phase was dated at 1,547±58 cal BP in Chao da Cheira-I diagram (Taboada Castro et al. 1995). This date places the tree recovery process in the Minho region in line with that of other NW Iberian territories.

During this time of arboreal recovery, various diagrams of the Iberian NW show an increase in the presence of *Castanea*, particularly in the SW area of Galicia (Van Mourik 1986). In the new sequence, as in many other NW Iberian territories, this dynamic of gradual increase in the presence of *Castanea* is not noticeable during the post-Romanization tree recovery.

After this phase of partial recovery of arboreal vegetation, there is a period of generalized detriment of arboreal pollen values, which coincides with an increase in the percentages of *Poaceae* and *Ericaceae*. The chronological data available for Iberian NW set the beginning of this phase at around 1,200 BP. In Chao da Cheira I peat bog, a radiocarbon dating of 881±52 cal BP is available (Taboada Castro et al. 1995), obtained during the deforestation phase (Figure 7). The destruction of the forest continues in subsequent centuries, mainly in the lowland areas close to the sea, with a strong degradation of the arboreal masses. This process will be further intensified from the 14th century AD on, due to the intense activity of shipyards and foundries, leading to a massive destruction of Iberian NW tree formations and the extinction in the wild of numerous minority taxa that had been present in the territory since the tertiary, such as *Carpinus*, *Tilia*, *Juglans*, *Castanea* or *Pinus*.

In the new sequence (Mh-4) we observed a dynamic similar to that of known sequences from the Iberian NW. However, Mh-4 shows some particular characteristics, such as a lower representation of *Ericaceae* and the presence of important values of *Cistus*, with higher incidence in the diagrams located towards the South (Alto da Forca), as compared to the Northern ones (Serra do Bustelo). The presence of *Cistus* during this phase is also much lower in the sequence available for Serra da Arga (Gómez-Orellana et al. 2010), which is located further North (Figure 1). This could be due to higher temperatures and lower humidity of the southern areas. In the new sequence (Mh-4) there is also a slight increase in *Pinus*, which suggests there was afforestation in this territory prior to the 18th century A.D.

Finally, the area that marks the top of the sequence (Mh-5) would represent the intensive afforestation process that would eventually lead to have pine plantations as the dominant tree masses in most of the coastal and subcoastal territories of the Iberian NW territories at the beginning of the 20th century A.D. With regards to the shrub vegetation, the sequence shows an increase in *Erica* and a decrease in *Cistus* values (Figures, 5, 6, 7, 8 and 9).

The pollen presence from *Acacia* and *Eucalyptus* has been recorded in the surface sample recovered in Alto da Forca - I diagram (Figure 5). This represents a change in forest policy trends in the Iberian NW during the last third of the 20th century AD, marked by the introduction and mass cultivation of these fast-growing and invasive alien species.

Conclusions

The new data, together with the available sequences for Serra de Bustelo and Serra da Arga, has allowed us to establish a regional pollen sequence for the coastal and

subcoastal territory of Northern Portugal. The data show the evolution of different occupation and anthropization phases in the territory. The new sequence would begin during the initial phases of the development of the *Castreja Culture* (Bronze-Iron Ages), reflecting the beginning of the implantation of the *Castrejo-Roman* agrosystem, marked by a strong anthropization of a territory in which forests still maintain a significant presence.

The intensification of settlements along with agricultural and livestock practices during the rise of the Iron Age and Romanization, is reflected in the decrease of forests and the increase of ruderal taxa. The forest decline slowed down slightly after the Romanization, although it restarted later on and intensified particularly during the Middle Ages, the Modern Age and the Anthropocene. The last centuries have been marked by a strong increase in forestry operations, mainly pine afforestation, which reached a strong territorial representation. Finally, the recent introduction of new massive forest crops is recorded, primarily fast-growing invasive alien species such as *Acacia* and *Eucalyptus*, that end up displacing the pine plantations.

The new sequence is in agreement with the data available for the rest of the NW Iberia, although it shows also some characteristics of its own, such as the importance of *Cistus* among the shrub vegetation, more in the Southern parts of the territory. The distribution of *Cistus* in the diagrams could be related to a humidity gradient in the studied territory, consistent with a dryer environment towards the South. This may also apply to *Daphne*, although this taxon is less important in the sequence. The continuous, although scarce, presence of *Olea*, except in the northernmost part of the territory, is also noteworthy. This *Olea* presence could be related to its cultivation. Overall, the sequence seems rather influenced by the incidence of the agriculture and livestock booms in areas at the bottom of the valley, as well as by the presence of the urban area of *Bracara Augusta* and its socioeconomic activity.

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