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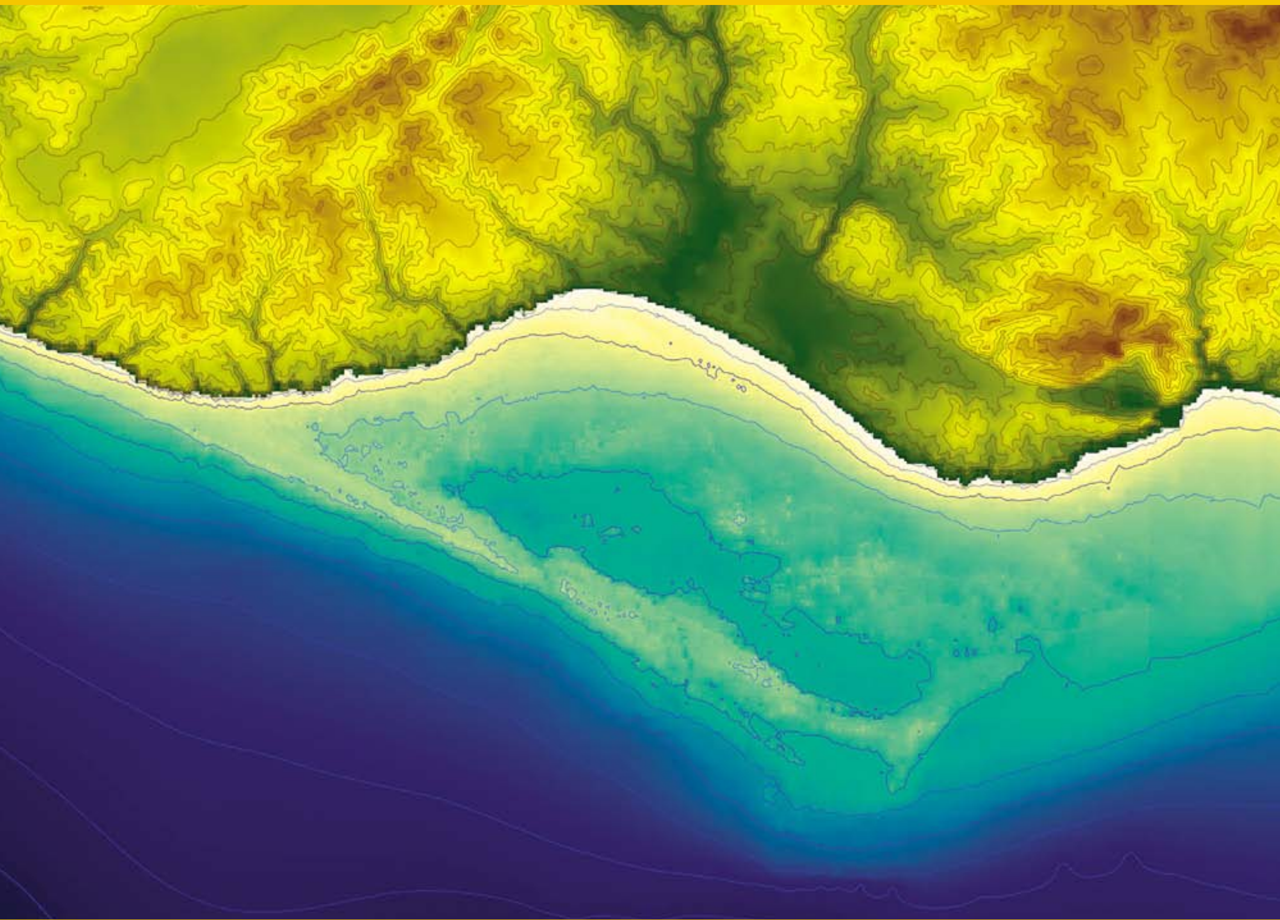

ENVIRONMENTAL CHANGES AND HUMAN
INTERACTION ALONG THE WESTERN ATLANTIC EDGE

MUDANÇAS AMBIENTAIS E INTERAÇÃO HUMANA
NA FACHADA ATLÂNTICA OCIDENTAL

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Eds. A. Campar Almeida, Ana M. S. Bettencourt, D. Moura, Sérgio Monteiro-Rodrigues and Maria Isabel Caetano Alves

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Cover image: Digital terrain model of the Armação de Pêra, Algarve, Portugal (by Leandro Infantini)

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Environmental changes and human interaction along the western atlantic edge

Mudanças ambientais e interação humana na fachada atlântica ocidental

2012

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FOREWORD

This book is part of the project on Paleoenvironmental Changes and Anthropisation in the Quaternary of Western Iberia, a study carried out in 2010-2011 by the Portuguese Association for Quaternary Research (*APEQ*). The aim of the project was to bring together a number of research efforts leading to an explanation of environmental changes during the Quaternary, of how human communites responded to those changes, and of the role played by man in altering the landscape of the Western part of the Iberian Peninsula.

The present publication is a follow up to *Paleoenvironmental Changes and Anthropisation in the Quaternary of Western Iberia*, first published in 2010, although this time the geographical scope has been expanded to include the Western Atlantic edge and thus put the Iberian Peninsula in a wider research perspective.

For the most part the articles in this book are based on the papers first presented at "IV Jornadas do Quaternário" / 1st International Conference: Environmental Changes and Human Interaction Along the Western Atlantic Façade, held at the University of Coimbra in 9-10 December 2011.

Coming from a variety of universities and research centres in Portugal, Spain, Scotland, Switzerland, Morocco, Angola and Brazil, the authors of these studies belong to different scientific areas, from geophysics to geology to geography, archaeology and biology, thus reflecting the multidisciplinary nature of Quaternary studies.

The articles are divided into five thematic sections, according to the research interests of the authors involved.

Part I is devoted to methodological issues and opens with Philippa Ascough's article. Ascough's topical theme deals with the need to be cautious when using C14 for absolute ratings of marine samples or man-related remains, as they appear to be older than their terrestrial counterparts. What we have here is the marine reservoir effect (MRE). In the next article, António Monge Soares and his collaborators show how radiocarbon dating carried out in Portugal allowed them to determine the age of a number of apparently contemporary consolidated dunes, dating from somewhere between the last interstadial and the early Holocene. In their study, Ana Gomes, Tomasz Boski and Delminda Moura use the specificity of diatom communities in terms of ecological preferences to carry out paleoenvironmental reconstructions in the Guadiana estuary (S of Portugal) during the Holocene.

Part II is made up of articles on paleoenvironmental change and human activity. Based on their interdisciplinary study of sedimentary deposits found in the archaeological area of Campo Lameiro (Pontevedra, NW of Spain), Manuela Costa Casais and her team offer a model of Holocene environmental evolution. Their findings confirm the occurrence of significant erosion/sedimentation processes starting in the Younger Dryas and throughout the Holocene. According to the authors, some of the discontinuities found in Holocene colluvia coincide with abrupt climate events known to have occurred in the past 10,000 years, namely the 8.2 ka event, the beginning of Neoglaciation, and the 2.8 ka event. But since at least the Neolithic period, human intervention in the landscape must have played an important role in the way the landscape evolved, sometimes with far greater repercussions than those caused by natural phenomena. Alexandre Trindade, Gonçalo Vieira and C. Schaefer used the micromorphology of sediments and of soil slopes to come to a better understanding of their morphogenetic significance and thus arrive at a chronological framework of the late Quaternary in Serra da Estrela (Portugal). Using isotope datings and marine records, C. Muñoz-Sobrino, L. Gomez-Orellana and P. Ramil-Rego draw correlations between pollen sequences that help us understand the regional migration of plant species in the western end of the Cantabrian range (North of Spain) during the Post-glacial. From their pollen analysis of coastal wetlands in northwestern Iberia, L. Gomez-Orellana, P. Ramil-Rego and C. Muñoz-Sobrino derive the conclusion that between 100,000 and 32,000 BP there were conifers alongside temperate deciduous trees on the coast of northwestern Iberia, a region that served as a refuge for mesophilic and thermophilic species. Based on the study of charcoals found in a marsh, João Araújo and his colleagues offer a variation of Serra da Estrela (Portugal) vegetation dating from the end of the last glacial and the Holocene. The authors noticed that this higher concentration of charcoal was concurrent with deforestation between 3,000 and 900 BP. The paleobotanical study of Chalcolithic and Bronze Age sites located in northwestern Iberia, presented in the article by M. Seijo-Martín and his collaborators, uses the logic of operational chains as applied to the exploitation of wood resources. Using this method, the authors attempt to characterise the various stages of this particular activity – from the procurement of timber to its end use –, and from there they proceed to make inferences of a paleotechnological and paleoethnological nature. Their results show a broad-spectrum strategy for procuring firewood and timber, through the use of the resources available in the various landscape units around the habitats: climax forests, brushwood and riparian zones.

Part III covers both the fauna and human activity, *i.e.*, the ways in which humans have used a number of wildlife resources. Mariana Diniz and Pablo Arias's work on the Mesolithic shell middens of Portugal's Sado river aims, among other things, to draw attention to the specificities of these prehistoric sites. For although it is broadly possible to include them in *a typically Euro-Atlantic culturescape* to which the Muge shell middens also belong, there are certain peculiarities that have to be taken into account if one is to build an explanatory model of regional Mesolithic settlement. More specifically, the authors believe that the analysis of these peculiarities may help assess the exact extent to which ecological and cultural factors determined how Mesolithic communities came to choose this territory. While also dealing with Mesolithic shell middens, the study carried out by Rita D. S. Dias and her team focuses on Muge (Portugal) and their article discusses the consequences of the use of spatial distribution models at Cabeço da Amoreira. Their methodology aims at identifying concentrations of artifacts and ecofacts, establishing relationships between lithic materials and osteological remains, and obtaining data on the site formation processes. Olivia Figueiredo, on the other hand, gives us a state-of-the-art type of review on the burial practices identified in Muge's diverse mounds. According to the author, there is ample evidence of the fact that the approximately three hundred skeletons found in Muge were actually the object of intentional, albeit nonstandard, burials. In the context of a much later chronological framework, Cleia Detry and Ana Margarida Arruda sought to identify the causes of the decrease of cockle (Cerastoderma edule) remains and the increase in grooved carpet shell clam (Ruditapes decussatus) and mussel (Mytilus edulis) remains at Monte Molião (Lagos, Portugal) during its Roman occupation. The findings suggest that the variation may be due to environmental changes caused by some sudden, brief event such as a storm or tsunami, leading to the disruption of this cockle-rich estuarine ecosystem. While giving this hypothesis its due, the authors do not rule out the possibility that the changes in the frequency of these molluscs were caused by habit changes with regard to the exploitation of water resources. This study also led to a dietary reconstruction of the inhabitants of Monte Molião.

In Part IV, devoted to mining and its impact on the environment, Nuno Inácio and his collaborators assess the environmental impact of copper mining and metallurgy in the Huelva region (Sw of Spain) in the third millennium BC. Palynological data, chemical analyses of sediments and other biomarkers of the Guadiana, Tinto, Odiel and Guadalquivir drainage basins for the period in question point to severe deforestation with consequent soil erosion as well as land and water contamination by various heavy metals. Based on these impacts, the authors suggest the possibility of copper mining and metallurgy as a specialised activity in the 3rd millennium BC. The Chalcolithic period is also the focus of the research carried out by Patricia Jordan and Nuno Pimentel, who submit a model for the management and movement of lithic resources, namely flint, in the Nazareth-Peniche region (central Portugal). Methodologically, this model derived from the petroarchaeological approach used for the Village of S. Mamede (Óbidos), which in turn resorted, among other things, to petrographic analyses and to studies based on lithic technology.

Part V deals with coastal evolution in four different geographical areas: the Algarve (SW of Iberian Peninsula), Galicia (NW of Iberian Peninsula), Morocco (NW of Africa) and Angola (West Africa). As far as the Algarve is concerned, Delminda Moura, Ana Gomes, Selma Gabriel and J. Horta discuss the relationship between the mean sea level and the coastline and how that relationship is reflected in terms of archaeological finds. L. Infantini, on the other hand, shows the occurrence and probable dynamics of an immersed lagoonal form in the Armação de Pêra bay (Algarve). J. M. García-Rey and X. Vilaseco Vasquez analyse the loss of sand on an island in the ria de Arousa (Galicia) to study its archaeological sites and trace the island's evolution throughout the Quaternary. Pedro Dinis and his colleagues seek to explain the sedimentary dynamics of two river deltas near Benguela, in Angola, an area marked by a sharp seasonal contrast. Finally, El Khalidi, B. Zourarah and A. Aajjane use sequential analysis of aerial photos as well as a geographical information system to explain landscape and coastline changes on a stretch of the Moroccan coastline.

This book is thus the materialisation of APEQ's goals as expressed in the above-mentioned project and in the Association's activity over a two-year period.

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ENVIRONMENTAL CHANGES IN THE WESTERNMOST CANTABRIAN RANGE DURING THE POSTGLACIAL PERIOD: THE PENA VELOSA (MUNIELLOS, ASTURIAS) POLLEN RECORD

C. Muñoz Sobrino[1], F. J. Suárez Pérez[2], H. S. Nava Fernández[2], M. A. Fernández Casado[2], L. Gómez-Orellana[3], M. A. Rodríguez-Guitián[4], J. A. Fernández Prieto[2] & P. Ramil-Rego[3]

Abstract: The westernmost corner of the Cantabrian Range (NW Spain) is a territory of good possibilities for palaeoecological reconstructions. Nevertheless, vegetation dynamics in this area is still imprecise, mainly because the available environmental data are scarce, particularly those regarding its northern façade. New pollen and radiocarbon data obtained in the Pena Velosa peatbog, located at 1350 m above sea level (asl), on the northern slope of the Valdebueyes peak (Biosphere Reserve of Muniellos), support the notion that pinewoods had a relevant role in this region during most of the Late-Glacial and Early-Holocene. During this interval, several well-established global climatic events may be recognised (namely, the Oldest Dryas, Younger Dryas, GH11.2-Event, GH8.2-Event), some of them being described for the first time for the seaward slopes of this mountains. Subsequently, the coniferous vegetation retreated, and pinewoods were definitively removed from this area throughout the Holocene. Such regional dynamics of *Pinus* might be attributed to pinewoods persisting in the Cantabrian highlands during the coldest stages of the Late-Glacial, where they could find a suitable combination of temperature and humidity, but being displaced during the warmer stages, when the deciduous forests shifted upslope. Alternatively, a number of hiatuses have been identified along the Mid-Holocene and Recent Holocene in the new record, which might correspond with other intercalated rhexistasic/drought events. Similar episodes have also been identified in other nearby sites, suggesting a regional character. Therefore, they might be, at least in part, climatically induced.

Key-words: Palaeoecology; Pollen; Western Cantabrian Range; Holocene.

Resumo: O extremo mais ocidental da cordilheira Cantábrica (NW de Espanha) é um território com boas possibilidades para reconstruções paleoecológicas. No entanto, a dinâmica da vegetação nesta área é ainda imprecisa, principalmente porque os dados ambientais fiáveis são escassos, em particular os respeitantes à fachada virada a norte. Novos dados polínicos e de radiocarbono obtidos na turfeira de Pena Velosa, localizada a 1350 m de altitude, na vertente norte do pico de Valdebueyes (Reserva da Bio-

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sfera de Muniellos) sugerem que os pinhais desempenharam um importante papel nesta região durante a maior parte do final do Glacial e início do Holocénico. Durante este intervalo, foram reconhecidos vários eventos climáticos globais bem determinados (nomeadamente, Dryas Antigo, Dryas Recente, evento GH11.2, evento GH8.2), sendo alguns deles descritos pela primeira vez nas vertentes expostas ao mar destas montanhas. Em seguida, a vegetação de coníferas recuou e os pinhais foram definitivamente removidos da região ao longo do Holocénico. Esta dinâmica regional de *Pinus* devia ser atribuída a pinhais persistindo nas terras altas cantábricas durante os episódios mais frios do Glacial final, onde podiam encontrar uma combinação favorável de temperatura e humidade, sendo todavia deslocados durante os episódios mais quentes, quando as florestas caducifólias subiam as encostas. Em alternância, foram identificados, no novo registo, numerosos hiatos ao longo do Holocénico Médio e Holocénico Recente, que devem corresponder a outros eventos rexistásicos/secos intercalados. Episódios semelhantes têm sido reconhecidos noutros locais próximos, sugerindo caráter regional. Portanto, deviam ser, pelo menos em parte, climaticamente induzidos.

Palavras-chave: Paleoecologia; Pólen,; Cordilheira Cantábrica Ocidental; Holocénico.

1. INTRODUCTION

NW Iberia (Fig. 1) is a transition area between territories where the climate may be typically Atlantic or Mediterranean, with continental tendencies appearing in the inner slopes and depressions. This climatic diversity is a consequence of the main environmental parameters (i.e., precipitation, temperature and distance from the sea, the oceanic or continental character) showing a notable gradualness in the area, with the rainfall and the oceanic influence generally decreasing from NW to SE, but mean temperature rising in this course. Moreover, the abrupt orography also introduces a number of local variants (Rodríguez Guitián & Ramil Rego 2008).

This intrinsic complexity may be taken into account for palaeoenvironmental reconstructions in the area, even more so if it is assumed that some territories have still been poorly studied, and that some regional/local conclusions cannot be extrapolated to other different zones (Muñoz Sobrino *et al.* 2007a). Particularly, the westernmost extreme of the Cantabrian Range is an area of excellent possibilities where the postglacial dynamics is still not well known. Major lack stem from most of the available sequences were obtained at the southern slopes or nearby potential sources of limestone or Stephanian dead carbon (e.g., Allen *et al.* 1996, Jalut *et al.* 2010). Therefore, a number of key points remain unclear, particularly those related to environmental dynamics in the northern façade.

The systematic recognition of a series of events supported by helpful independent proxies (e.g., isotopic data, marine records, etc.) may be a functional way to correlate pollen sequences in a large and dissimilar area such as this. Furthermore, this method allows that intra-regional migrations or un-coupled vegetation changes occurring during the postglacial period were detected (Muñoz Sobrino *et al.* 2007a). The existence of this spatial component might assist in better explaining the palaeoenvironmental characteristics of each territory and the unequal human influence on the landscape occurring during the Holocene. In this regard, to be able to precise/extent the interval of palaeobotanical and chronological data available in the Cantabrian highlands (see

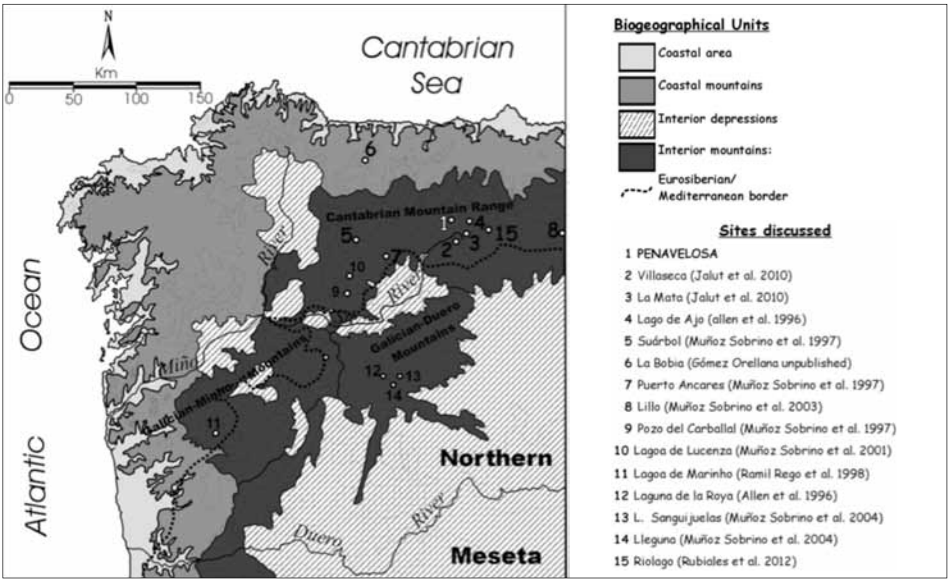

Fig. 1 – Main biogeographical units in NW Iberia and localization of the sites discussed.

Ramil Rego *et al.* 1998; Muñoz Sobrino *et al.* 2003, 2005, 2007a; Rubiales *et al.* 2012) will enhance its comparison with other regional sites (see Fig.1). Thus, it may contribute to deciphering the main environmental changes affecting the whole NW Iberia during the postglacial period and, particularly, their incidence in the westernmost extreme of the Cantabrian Range.

2. STUDY AREA

The new pollen site discussed here is located in the western part of the Cantabrian Range, the most important mountain chain in north-western Iberia, which straddles the boundary between the current Eurosiberian and Mediterranean biogeographical regions. The range extends over *ca.* 350 km in a prevailing east-west direction, parallel to the sea, but becomes more complex to the west. There, it divides towards the W and SW into two different mountain extensions surrounding the Bierzo depression: the Galician-Duero Mountains to the south and east; and the Ancares and Courel Mountains to the north and west (Fig. 1).

Geology, topography and climate make this area ecologically diverse. Palaeozoic siliceous bedrock predominates (slate, sandstone, schist and quartzite), although limestone is also present (and even dominates locally), with a physiography ranging from undulating hilly lands to deep valleys and sharp relief that are widely found. Peña Ubiña (2417 m asl) is the highest peak in the western half of the Cantabrian range, with a few other summits peaking over 2000 m. Abundant glacial landforms are over 1000 m in altitude, due to the influence of oceanic winds that have resulted in greater snowfall rates during colder stages of the Pleistocene (e.g., Alonso 1998).

Climatic differences between northern and southern slopes of the Cantabrian Mountains have had a great impact on the local paleoecology (Ramil-Rego *et al.* 1998). The summit determines a sharp divide in the amount and distribution of precipitation, mostly due to a rain shadow effect. These differences cause dramatic contrasts between north and south slopes: i.e., over 1650 mm in the Atlantic façade and ca. 560 mm in the León area. The variability in precipitation also corresponds to strong variations in the duration of the frost season and in the water availability during the summer. Furthermore, there is little or no water stress in the northern slopes, while summer drought is generally severe in the southern side. Furthermore, the differences of insolation between the two slopes intensify this dissimilarity. In the western Cantabrian Range, the current tree line is consistently lower in the northern façade (Muñoz Sobrino *et al.* 2009), where it is stated below 1450/1650 m asl, and higher in the southern slopes (1700/1850 m asl).

At a regional scale, modern vegetation clearly responds to the climatic gradient of oceanicity-continentality. Today, a mild, humid climate favours the development of deciduous forests, dominated by *Quercus robur* L., *Q. petraea* (Matt.) Liebl., *Q. x rosacea* Bechst., *Fagus sylvatica* L. (which are scarce in the western part of the region) and *Betula pubescens* Erhr. on the upper slopes. Fluvial gorges, slope scree deposits and deep soils are covered by diverse mixed forests (including *Fraxinus excelsior* L., *Corylus avellana* L., *Acer pseudoplatanus* L., *Ulmus glabra* Huds., *Tilia platyphyllos* Scop. and others). By contrast, on the inner and southern slopes, other types of woodlands are found, mostly dominated by *Quercus pyrenaica* Willd., patches of *Q. faginea* Lam., *Juniperus thurifera* L. and, on both slopes, shrub communities including Ericaceae and Fabaceae (*Genista, Cytisus* and others) within a well-developed Poaceae herbaceous communities under nival-periglaciar conditions near the summits. Pine forests are almost absent from the natural vegetation of the Cantabrian Mountains. Small, natural-looking stands of *Pinus sylvestris* L. only exist in the headwaters of the Porma and Carrión Rivers, of which the Lillo populations have the largest and best specimens (García Antón *et al.* 1997; Muñoz Sobrino *et al.* 2003).

3. THE SITE

The site of Pena Velosa (Muniellos, Asturias), forming part of the Biosphere Reserve of Muniellos), is located in the western corner of the Cantabrian Range. This is a small lake (0.13 ha) created in a basin of glacial origin, at 1350 m asl, on the northern slope of the Valdebueyes peak (1507 m). The current vegetation around the site consists of birch forests with rowan (*Sorbus aucuparia* L.), characteristic of the supratemperate (altimontane) belt (Fernández Prieto & Bueno 1996), shrublands (*Erica*, Fabaceae), peatbog vegetation, and herbaceous *Nardus stricta* L. grasslands. Furthermore, vegetation appears associated with the abundant periglacial screes surrounding the site, and also with the rocky outcrops.

4. MATERIAL AND METHODS

The core (195 cm depth) was obtained using a Russian corer (Moore *et al.* 1991), the sampling point being in the *Sphagnum* peatbog formed at the eastern margin of the pool. 39 subsamples of 3 cm^3 were taken at regular 5 cm intervals for pollen analysis. They were processed and prepared using standard methods, which included an initial sieving through a 150 μm mesh sieve and potassium hydroxide (10%) treatment (Moore *et al.* 1991).

The chronology of the core was primarily supported by three AMS radiocarbon dates determined on bulk sediment (Tab. 1). The ^{14}C dates were obtained in the Angstrom Laboratory (University of Uppsala, Sweden), and calibrated using the CALIB 6.0 software (Stuiver *et al.* 1986-2010) and the INTCAL09 calibration curve (Reimer *et al.* 2009). The chronology of the most recent horizons (Fig. 2) is based on the same combination of pollen markers and historical information (Tab.1) previously used by Muñoz Sobrino *et al.* (2007b).

Tab. 1 – Chronological benchmarks using pollen criteria for to establish the relative chronology upper levels, and radiocarbon dates for the deepest 120 cm

Depth (cm)	Age 14C BP	Age cal. yr BP	Pollen event	Probability distribution 95.4 (2 Sigma)
10	1650	200	*Pinus* cultivation since 17th century	---
55	1100	850	*Castanea* cultivation since 12th century	---
60	2960±55	2955 – 3266	---	0.973
125	9470±100	10495-11139	---	0.997
180	12055±115	13601-14219	---	1.000

More than 250 pollen grains were counted at each of the 39 levels, with percentages calculated on the basis of a terrestrial pollen sum. Percentages of aquatic taxa and percentages of ferns and mosses spores were calculated on the basis of the total identified pollen and spores sum. Percentages of other non-pollen palynomorphs (NPP), mainly the colonies of the green algae *Pediastrum* that were very abundant at different levels, were represented on the basis of the total identified remains sum. The TILIA 1.7.14 programme (Grimm 1990-2011) was used for processing the data and preparing diagram. The pollen record was divided into 9 local pollen assemblages zones (LPAZ) using a Constrained Incremental Sum of Squares (CONISS) cluster analysis (Fig. 3).

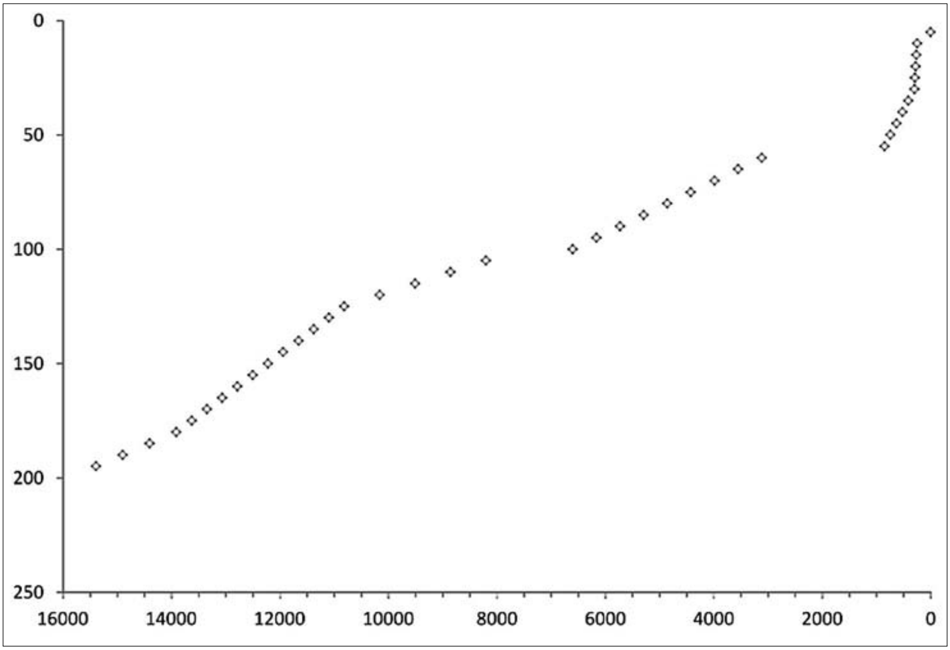

Fig. 2 – Depth/Age curve for all the samples analysed in Pena Velosa, following the criteria showed in Tab. 1. Depth represented in cm; Age in cal. yr BP.

5. RESULTS

5.1. Lithology

From the top to the base, the first 15 cm of the core corresponds with living or unhumified *Sphagnum* remains. Below, a level of 90 cm of humified peat exists, which is overlying a second layer (40 cm) of well-humified peat, also characterized by the abundance of wood macro-remains. In this second cycle of peat, a thin level richer in detrital materials appeared at 132 cm depth. The deepest 50 cm mainly corresponds with fine humified gyttja, but eventually they are intercalated some layers richer in sand and mid-size gravels (Fig. 3).

5.2. Chronology

Radiocarbon dating (Tab.1) indicates that the sediments from the Pena Velosa peatbog may range in age from *ca*. 15,000 cal. yr BP at 195 cm depth to *ca*. 8500 cal yr BP at 110 cm (Fig.3). At this point, several facts strongly suggest the existence of a hiatus: i.e., the resulting anomalous rates of sedimentation (Fig. 3), the abrupt changes observed in the lithology, and the sudden variations in the composition of the pollen assemblages (see below). Also, according to the radiocarbon dates, the section corresponding to the upper 60 cm may be younger than 3100 cal. yr BP. Additionally some pollen events have been correlated with contrasted historical data in order to enhance

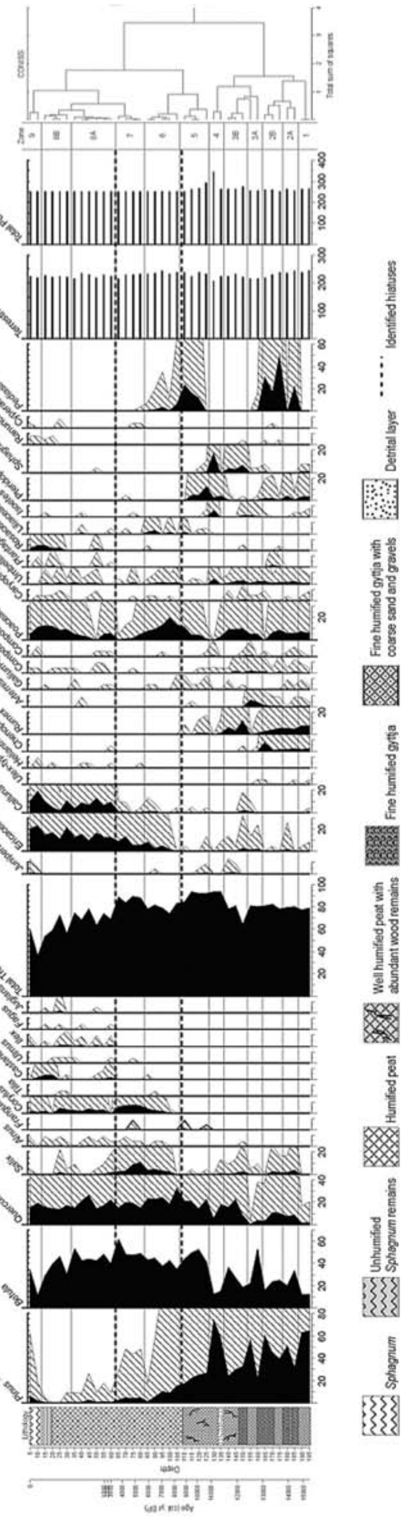

Fig. 3 – Lithology and percentage pollen diagram (selected taxa only) from the Pena Velosa (Muniellos, Asturias. 1350 m asl). Hatching denotes 10 x magnification of the percentage values. Dash lines represent the two sedimentary gaps described in the text.

the chronology of the most modern assemblages (Tab.1). In view of the fact that the sedimentation rates deduced using these chronological benchmarks become erratic, it is proposed here that another gap may exist over the last three millennia (Fig. 3).

5.3. Pollen analysis

The 9 LPAZs that were identified are described below, from base to top, some of them divided into subzones (Tab. 2, Fig. 3).

Tab. 2 – Main vegetation changes during the last 15000 cal. yr BP in the surroundings of Penavelosa

Age cal. yr BP	Event	Pollen zone	Main vegetation changes
200	Late Holocene	9	Tree minima. Modern repopulations with pines
350		8B	AP retreat. Modern repopulations with chestnut
<850		8A	Expansion of *Calluna.* Mediaeval repopulations with *Castanea*
<8200-3000	Mid-Holocene	7	Maximum development of *Betula*, *Salix* and *Corylus. Erica* increases
		6	Most of the regional pinewoods decay. Mixed deciduous forest prevailing
10,900-8200	Early Holocene	5	Pinewoods retreating. Hygrophilous and mesophilous forests expand
11,200-10,900	GH11.2 Event	4	Regional pinewoods overrepresented
11,700-11,200	Early Holocene	3B	Mixed deciduous forests begin to expand
12,600-11,700	Younger Dryas	3A	Local heliophilous/hygrophilous birch overrepresented. *Artemisia* increases
14,800-12,600	LG Interstadial	2	Increase of deciduous trees and local vegetation
>14,800	Oldest Dryas	1	Local vegetation scarce. Pinewoods overrepresented

LPAZ-1 (185-195 cm): this first zone is characterized by the domain of *Pinus* (60%) and the low presence of deciduous trees (*Betula*, *Quercus*). Furthermore, noticeable percentages of heliophilous/cryophilous herbs (*Rumex*, Compositae, Poaceae) and ferns (Pteridophyta) may be appreciated, with a lower evidence of cryoxerics (Chenopodiaceae, *Artemisia*) and the scant presence of local hygrophilous/aquatic vegetation.

LPAZ-2 (160-185 cm): deciduous trees increase throughout this second zone, mainly *Betula* (30%), but also *Quercus* (10%) and *Salix* (2%). Meanwhile, *Pinus* percentages retreat. Besides, Ericaceae and the green algae *Pediastrum* notably increase in the first subzone LPAZ-2a (185-175 cm). Subsequently, *Pediastrum* reaches its maximum in the subzone LPAZ-2b (175-160 cm), where other new hygrophilous/aquatic taxa (Ranunculaceae, Cyperaceae) appear for the first time, although Poaceae retreat.

LPAZ-3 (135-160 cm): this entire zone is characterized by the highest recorded percentages of typically cryoxerophilous taxa and a moderate fall in the total tree pollen percentages. In the first subzone LPAZ-3a (160-150 cm), noticeable retreats of

Pinus (<30%) and the mesophilous broadleaved trees (*Quercus*, *Salix*) are recorded. Nevertheless, *Betula* peaks over 50%, a species that may be considered heliophilous and cold tolerant (Rubiales *et al.* 2012). Furthermore, the retreat of the previously developed hygrophilous and aquatic forms (*Pediastrum*, Ranunculaceae, Cyperaceae) and the highest continuous presence of a number of cryoxeric taxa (namely, *Artemisia* and other Compositae, Chenopodiaceae, *Plantago*, Caryophillaceae, or Monolete-type spores) are also recorded in this subzone, all of them including plants able to colonize barren screes and rocky habitats. Deciduous forest (*Quercus, Salix, Alnus*) recovers in the subsequent subzone LPAZ-3b (135-150 cm); meanwhile, other heliophilous trees (*Pinus, Betula*) retreat, and new increases are recorded of upland herbs (*Rumex*, Poaceae), ferns and mosses (Trileta-type).

LPAZ-4 (125-135 cm): this pollen zone, which corresponds with the layer of detrital materials described above, represents the maxima values of *Pinus* (70%) recorded in the profile; and therefore, also the highest values of total tree pollen (90%) are found in the Pena Velosa pollen record. Nevertheless, most of the broadleaved trees (*Betula, Quercus, Salix*), shrubs (*Juniperus*, Ericaceae), and herbs (*Galium*-type, *Rumex*, Poaceae) retreat (or even disappear) at this point. Alternatively, only minor increases of Asteroideae and Umbelliferae, occur, but the highest representation of ferns and mosses (Monolete-type, Pteridophyta, Trilete-type) is also found.

LPAZ-5 (105-125 cm): *Pinus* values fall below 30% in this zone. Nevertheless, total tree pollen percentages remain very high (90%), in view of the fact that *Betula* expands (50%) and also that other tree taxa characteristics of mesophilous forest (*Quercus*, *Frangula*) increase. Certain shrubs (*Calluna*), herbs (Poaceae, *Galium*--type, Liliaceae), ferns (Pteridophyta) and green algae (*Pediastrum*) also increase. These pollen assemblages suggest the surroundings of the site being colonized by birch forest, with the local pollen productivity increasing, and the mesophilous forest expanding upslope from the lowlands.

LPAZ-6 (80-105 cm): pollen spectra reveal a clear change at this point. As regards the tree taxa, this zone begins with a peak of *Quercus* (30%) that subsequently holds about 20%. Meanwhile, *Betula* oscillated between 30-40% throughout this zone, with *Pinus* gradually decreasing to below 20%. Furthermore, they are some other remarkable facts, i.e., the notable increase of *Salix*, the sudden irruption in the pollen profile of other deciduous trees (*Corylus, Alnus*), and the appearance of the first pollen evidences of other mesothermophilous trees such as *Castanea* and *Tilia*. Nevertheless, total tree pollen percentages are relatively low in this zone (about 70%). In this connection, the expansion of Ericaceae may be highlighted, which also begins at the base of this zone, and the maximum development of Poaceae (20%) recorded throughout the profile. Furthermore, the percentages of the green algae *Pediastrum* notably decrease in this zone, which suggests that a reduction of the water table occurred, perhaps due to the partial silting of the lake basin.

LPAZ-7 (60-80 cm): this zone represents a new peak of total tree pollen in the profile. *Salix* (10%) and *Corylus* (>5%) reach their maximum development in the earlier assemblages, but *Betula* (60%) peaks at the top of this zone. Meanwhile, main herbaceous taxa (Poaceae, Umbelliferae, Caryophyllaceae, Liliaceae) and aquatics (*Pediastrum*) retreat.

LPAZ-8 (10-60 cm): this reflects the course of deforestation in the area. Total tree pollen drops below 60% in subzone LPAZ-8a (30-60 cm), mainly due to the falls of *Betula* (30%) and *Salix*. Furthermore, several major changes in pollen spectra may be described from the base of this zone: namely, the apparent increase of *Castanea*, which seems to be linked to the appearance of other broadleaved mesothermophilous trees (*Ilex, Fagus, Juglans*), the abrupt expansion of *Calluna,* or the new increase of Poaceae. In the subsequent subzone LPAZ-8b the maximum development of *Ulmus*, *Tilia*, *Juglans* and *Castanea* is recorded, but the total tree pollen drops below 50%. Parallel to this, Poaceae reach a new relative maximum (20%), and likewise Rosaceae and several hygrophilous taxa (*Salix*, Ranunculaceae, Cyperaceae) increase.

LPAZ-9 (0-10 cm): this latter zone reflects the total tree pollen minimum (<40%) recorded in the diagram, which coincides with the maximum values recorded for *Calluna* (20%), and the pollen evidence of the recent afforestation activities with both chestnuts and pines (Rubiales *et al.* 2012).

6. DISCUSSION

6.1. The Late-Glacial Period in the western Cantabrian Range highlands

Upper Würm and Oldest Dryas (LPAZ-1: > 14, 800 cal. yr BP)

Evidence from the Greenland ice cores suggests that global cooling conditions prevailed over the eastern North Atlantic between 16,700–15,000 cal. yr BP (Vinther *et al*. 2006; Rasmussen *et al*. 2006); and also that the period 15,400–14,600 cal. yr BP, also known as the *Oldest Dryas*, was particularly arid (Muñoz Sobrino *et al.* 2007a). In this scenario, the main environmental limitations for the persistence of woodlands in the Cantabrian Range may be low temperatures and dryness. Even so, significant differences between both slopes are expected, due to the barrier effect resulting from the east-west disposition of the Cantabrian Range: i.e., mean temperatures might be particularly low in the northern highlands, and the aridness more severe in the southern lowlands. Accordingly, at the end of the last glacial cycle, it is expected that most of the demanding tree species had persisted in this region on the seaward faces, where temperature and precipitation were sufficient at lower altitudes (Muñoz Sobrino *et al*. 2007a).

In the case of coniferous trees, in the Courel Mountains (Lagoa de Lucenza, Fig. 1), it has been proposed that pines keep on mid-slope positions between 16,600–15,200 cal. yr BP, but that they retreat during the subsequent drier period, dated at 15,400 cal BP; and, finally, they almost disappear from this region at the beginning of the Holocene (Muñoz Sobrino *et al*. 2001, 2007a). Contrarily, some other higher and more interior mountains could have acted as refuges for *Pinus* during the Late-Glacial and Early Holocene (e.g. the Galician Duero Mountains in Fig. 1, see Allen *et al*. 1996;

Muñoz Sobrino *et al*. 2004, 2007a). In this line, the pollen assemblages that may be chronologically attributable to the cold/dry *Oldest Dryas* event in Pena Velosa (LPAZ--1) also reveal very high percentages of pine. However, other herbaceous taxa and ferns are also consistently recorded at the same levels, all of them corresponding with cryophilous vegetation living in altimontane/subalpine rocky habitats. This composition of the pollen assemblages may indicate that the local pollen input was very low at this moment; and therefore, that the regional pinewoods contribution becomes overrepresented. In this connection, a number of pine macrofossils have been recently found and dated in the southern highlands of the Western Cantabrian Range, rising to a height of 1750 m, which supports that pinewoods were persisting in this region at the end of the Late-Glacial period (Rubiales *et al*. 2012).

Late-Glacial Interstadial (LPAZ-2: 14,800-12,600 cal. yr BP)

After the *Oldest Dryas,* the isotopic records of Greenland reflect a succession of relatively warmer stages that might be dated as a whole between 14,800–12,600 cal. yr BP (Vinther *et al*. 2006; Rasmussen *et al*. 2006). In northwest Iberia, the same period may be globally understood as an interval of tree succession (interstadial), but data suggesting climatic improvement in its first half (14,800–13,400 cal. yr BP); and after 13,400 cal. yr BP, a progressive deterioration that was to conclude in the hardest stages of the *Younger Dryas* (Muñoz Sobrino *et al*. 2007a).

In the Galician-Minho Mountains (Fig. 1), an initial increase in deciduous *Quercus* is dated around 14,300 cal. yr BP in Lagoa de Marinho (Ramil Rego *et al*. 1998). No other pollen sequence from northwest Iberia shows, such an early spread of deciduous woods during the Late-glacial Interstadial, and this has been interpreted as evidence that climatically demanding deciduous vegetation survived at the end of the last glacial cycle at the seaward side of the main mountain barriers (Muñoz Sobrino *et al*. 2007a). Oak percentages retreat in Lagoa de Marinho after 13,000 cal. yr BP, but a strong expansion of *Pinus* is recorded at this site between 13,000–12,400 cal. yr BP (Ramil Rego *et al*. 1998). Furthermore, the slight oscillation seen in Greenland around 14,200–13,800 cal. yr BP (the *Older Dryas,* see Hoek 1997) is well synchronised with minor retreats of *Pinus* detected, at different mountain sites from NW Iberia (see Muñoz Sobrino *et al.* 2007a). Even so, this event does not seem to have caused noticeable changes in the regional landscapes, and even then only in the more sensitive localities, in sites close to the tree limit and with markedly oceanic influence where slight pollen oscillations may be recognised (Muñoz Sobrino *et al*. 2007a). Accordingly, pollen data from Pena Velosa (Fig. 3) confirm a progressive improvement between 14,500-13,400 cal. yr BP affecting the highlands of the western Cantabrian Range, with a number of deciduous trees shifting upslope during the warmer stage of the Late-glacial intestadial, and with the local vegetation in the pool also increasing. Nevertheless, and even where this locality may be potentially sensitive to minor climatic reversals, the local occurrence of the *Older Dryas* is not clearly identified, perhaps because a higher resolution in the pollen analysis would be required.

Younger Dryas (LPAZ-3: 12,600–11,700 cal. yr BP)

The progressive climatic deterioration observed in Greenland between 13,400–11,700 cal. yr BP (Vinther *et al.* 2006; Rasmussen *et al.* 2006), strongly affected most of the northwest Iberian mountains, where landscapes underwent noticeable changes, which can be seen as perceptible variations in the distribution of the vegetation. These modifications were especially intense during the cold and drier interval 12,600–11,700 cal. yr BP, which could be associated with the classical *Younger Dryas*. Noticeable increases in Poaceae are recorded at the more oceanic sites between 13,400–11,700 cal. yr BP. Furthermore, minor increases in *Artemisia* and other xerophilous are also detected at the westernmost upland sites from NW Iberia, between 12,600-11,700 cal. yr BP; but usually, peaks are lower than those recorded in the same sites before the Late-glacial Interstadial (Muñoz Sobrino *et al.* 2007a).

In the particular case of Pena Velosa (Fig. 3), it might be considered that evidences of cryophilous vegetation contradict this trend, in view of the fact that during the *Younger Dryas* they are higher than they were in LPAZ-1, interpreted above as the *Oldest Dryas*. Nevertheless, a notable peak of *Betula* (50%) is also recorded in Pena Velosa during this period (Fig. 3), probably as hygrophilous local vegetation. During the same period, other moderate increases to <20% in *Betula* are recorded in Serra do Gerês (Ramil Rego *et al.* 1998) and also at the waterlogged lowlands from Segundera Mountains (Muñoz Sobrino 2004, 2007a). This recalls the known pattern of a cold event associated with drought episodes, less severe than those recorded before the interstadial, affecting all of northwest Iberia. The incidence of these changes in temperature might be more intense in seaward uplands but, in contrast, drought was especially evident in the more continental territories, which could explain the noticeable peaks of *Artemisia* in the southern slopes and the inner lowlands (Muñoz Sobrino *et al.* 2004, 2007a). Therefore, during this period the pollen assemblages from Pena Velosa may reflect a combination of the different biocoenosis contributing: the open cryophilous vegetation being dominant in the northern Cantabrian highlands and the local presence (wood remains) of hygrophilous birch; but also the regional pinewoods retreating in terms of the previous interestadial phase and, hence, the greater development of more xeric grasslands in the southern expositions.

6.2. The Holocene in the western Cantabrian Range highlands

Early Holocene (LPAZ-3b, LPAZ-4, LPAZ-5: 11,700–8200 cal. yr BP)

The general climatic improvement and the elevation of the dew-point during the postglacial warming would contribute to reduce the rain-shadow effect over the landward slopes and the inland basins; and this new configuration could support the colonization by trees of any previously open landward landscapes. Evidence shows that the first recovery of *Quercus* started about 12,000–11,800 cal. yr BP in most of the mountains from NW Iberia (Muñoz Sobrino *et al.* 2007a); and the same pattern is observed in our new site (Fig. 3). Nevertheless, many sites show minor *Quercus* declines during the interval 11,400–11,200 cal. yr BP (Muñoz Sobrino *et al*. 2007a), a regional dynamics that may be connected with the short cold GH11.2 event described in the Greenland proxy records (Vinther *et al*. 2006; Rasmussen *et al*. 2007).

The major influence of this period of relative instability in NW Iberia were some oscillations in the tree line, which eventually stunted the development of deciduous woods in certain mountain areas (Muñoz Sobrino *et al*. 2007a). This may be the case of the northern Cantabrian highlands where, at this time, higher proportions of detrital material exist in the sediment of Pena Velosa (Fig. 3) and pollen evidence suggests the lack of local vegetation, with the deciduous forest retreating downslope, and the regional pinewoods being overrepresented. The subsequent LPAZ-5 in Pena Velosa (Fig. 5) denotes a new ascension of the tree-line, and also higher local pollen productivity at the beginning of the Holocene Climatic Optimum (Muñoz Sobrino *et al*. 2005). Very similar pollen evidence may be found at this moment in other nearby sites (Fig. 1): e.g., Suárbol, in the Ancares Mountains (Muñoz Sobrino *et al*. 1997); and Lago de Ajo, at the southern side of the Cantabrian Range (Allen *et al*. 1996). Furthermore, all these three pollen sequences have in common the existence of notable hiatuses in the sedimentation at the end of this period, which might be related to the incidence in NW Iberia (Muñoz Sobrino *et al*. 2005, 2007a) of other short and cold event (GH8.2-Event) described in the Greenland Ice cores (Vinther *et al*. 2006; Rasmussen *et al*. 2007).

Mid-Holocene (LPAZ-6, LPAZ-7: <8200-3000 ca. yr BP)

At some time during the Mid-Holocene, the sedimentation starts again, both in the Pena Velosa peatbog (Fig. 3), and in Lago de Ajo (Allen *et al.* 1996). Furthermore, evidence from pollen assemblages reveals a quite similar dynamics in both sites: a first stage showing the highest peaks of *Quercus,* following a moderate retreat of the total tree pollen and the local aquatic vegetation becoming very abundant; and finally, a new total tree pollen maximum, where *Betula* peaks again, dated in both sites (and also in the nearby Ancares Mountains, see Muñoz Sobrino *et al*. 1997) about 3000 cal. yr BP. In Sierra da Bobia, a relief about 1000 m high and very close to the Cantabrian Sea (Fig. 1), a stage of waterlogging has been consistently dated about 5800 cal. yr BP. There, the sedimentation forming at this time buried a number of pre-existing *Quercus* woods, dated at 6600 cal. yr BP (Ramil Rego *et al*. 2000).

Late Holocene (LPAZ-8, LPAZ-9, LPAZ-10: <1500 cal. yr BP)

During the Recent Holocene, the deciduous forest retreated in most of the regions of NW Iberia (Ramil Rego *et al.* 1998) and also the last regional pinewoods declined (Garcia--Antón *et al*. 1997; Muñoz Sobrino *et al.* 2003, 2004). Furthermore, sedimentary gaps are very commonly found in many peat bogs and lakes in the NW Cantabrian Mountains (e.g., Allen *et al*. 1996; Ramil Rego *et al*. 1998; Muñoz Sobrino *et al*. 1997, 2001, 2004); a number of them are most probably related to the regional incidence of the 2.8 Event cold period, but also anthropogenic causes may be involved (Muñoz Sobrino *et al.* 2009). In Sierra da

Bobia (Fig. 1), a gap existing between the two upper cycles of peat is dated at *ca.* 3000-1500 cal. yr BP (Ramil Rego *et al.* 2000). Subsequently, the pollen sequence starts again showing evidence of afforestation with chestnuts since mediaeval times (Manuel Valdés & Gil Sánchez 2002). Using these pollen criteria linked to the historical data and also the available radiocarbon dated in this region, a rather similar gap may be deduced between LPAZ-7 and LPAZ-8 in Pena Velosa (Fig. 3).

7. CONCLUSIONS

The new pollen and radiocarbon data obtained in the Pena Velosa peatbog may substantially enhance our present-day knowledge about the postglacial dynamics in the northern façade of the Cantabrian Range (Tab. 2). In fact, this may be considered to be the most complete pollen sequence recording the Late-Glacial period at the northern side of the Western Cantabrian Range.

In this context, several well-established global climatic events may be recognised (namely, the *Oldest Dryas*, *Younger Dryas*, GH11.2-Event), all of them being described here for the first time for the seaward slopes of this mountains. The fact that the major peaks of *Pinus* appear in the Pena Velosa diagram when pollen evidence of cryophilous vegetation is also more apparent (LPAZ-1, LPAZ-3a an LPAZ-4 in Fig. 3) may indicate the regional pinewoods being predominantly overrepresented when the local vegetation becomes scarcer, i.e., during the colder/drier periods of the Late-Glacial. Subsequently, the coniferous vegetation retreated, and pinewoods were definitively removed from this area throughout the Holocene. Such regional dynamics of *Pinus* might be attributed to pinewoods persisting in the Cantabrian highlands during the coldest stages of the Late-Glacial, where they could find a suitable combination of temperature and humidity, but being displaced during the warmer stages, when the deciduous forests shifted upslope. Alternatively, a number of hiatuses have been identified over the Mid-Holocene and Recent Holocene in the new record, which might correspond with other intercalated rhexistasic/drought events. These hiatuses have been dated from between *ca.* 8200->6600 cal. yr BP and *ca.* 3000-<850 cal. yr BP. Similar episodes have also been identified in other nearby sites, which suggests that they might have a regional (climatic) character. Respectively, we attribute them to the cold GH8.2 Event and the 2.8 Event (or Iron Age Cold Period).

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