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Holocene environmental history and human impact in the Pyrenees

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Resum

L'anàlisi pol·línica del testimoni sedimentari de l'estany de Burg (Pirineus, Espanya) ha permès posar de manifest una important oscil·lació climàtica durant l'Holocè, que, a més de determinar el desenvolupament de la vegetació, ha tingut un rol fonamental en el desenvolupament de les activitats antròpiques i ha determinat l'ocupació humana de l'alta muntanya pirinenca.

Aquesta anàlisi també ha servit per a comprovar com diferents pertorbacions humanes de grau divers han modificat el medi natural de manera recurrent i, per tant, no es pot estudiar la dinàmica actual del paisatge vegetal sense tenir en compte la suma d'impactes humans pretèrits responsables de la seva evolució. Així doncs, si per a estudiar el canvi climàtic es fan servir dades indirectes provinents de la vegetació, com ara el pol·len o els carbons vegetals, cal tenir en compte la influència humana com a factor distorsionador del senyal climàtic.

Paraules clau: Pirineus, geohistòria ambiental, Holocè, pertorbacions humanes, dinàmica del paisatge

Abstract

Pollen analysis of the sedimentary record of Lake Burg (Pyrenees, Spain) indicates a significant climatic oscillation during the Holocene, which, in addition to determining plant development, played a fundamental role in the development of anthropic activities and in human occupation of the High Pyrenees. This analysis has also been used to show how different degrees of human perturbation have repeatedly modified the environment. It is therefore not possible to study the current dynamics of the vegetation landscape without taking into account the combined effect of past human impacts responsible for its evolution. Consequently, when vegetation proxies, such as pollen or charcoal, are used to study climate change, it is also necessary to consider human influence as a distorting factor of the climate signal.

Keywords: Pyrenees, environmental history, Holocene, human perturbation, landscape evolution

Although climatic factors clearly play an important role in plant development, paleobotanical studies have highlighted the importance of human impact as well. For this reason, discussions aimed at explaining the dynamics of vegetation landscape currently center on the reasons for these changes and the ability to distinguish between the influences of natural vs. human factors [7, 22, 23].

In order to analyze the changes that have occurred in the vegetation landscape and discriminate between short-term events and those that occurred over a longer period of time, it has been the practice to increase the temporal resolution of paleobotanical records. The need for a higher resolution has made it necessary to use an exhaustive approach to assess natural dynamics, such as by including analyses that use different proxies [15].

To this end, a number of temperature measurements were obtained from the southern Pyrenees, with a medium-resolution level for the last 15,000 years and high-resolution reconstructions for the last 900 years. This was achieved through the analysis of chrysophytes, diatoms, etc., as well as palynological studies [3, 4, 17, 18]. The accumulated data contrast with the more numerous and detailed contributions available for the northern Pyrenees [1, 2, 6, 8, 9, 11, 12, 20, 21, etc.].

As these most-recent studies combine interpretation of the vegetation landscape with climatic data, historical interpretations are also often necessary to more accurately interpret the paleobotanical information. Moreover, with the advent of a high-resolution approach, geohistorical data that were previously interpreted in a far more general way now require detailed and concrete explanations rooted in the environmental history. The current reduction in human pressure on the vegetation landscape means that it is possible to make comparisons with the landscape that existed during points in time when pressure was more intense.

This article describes the results of a multidisciplinary study (using paleobotanical and documentary sources) based on a

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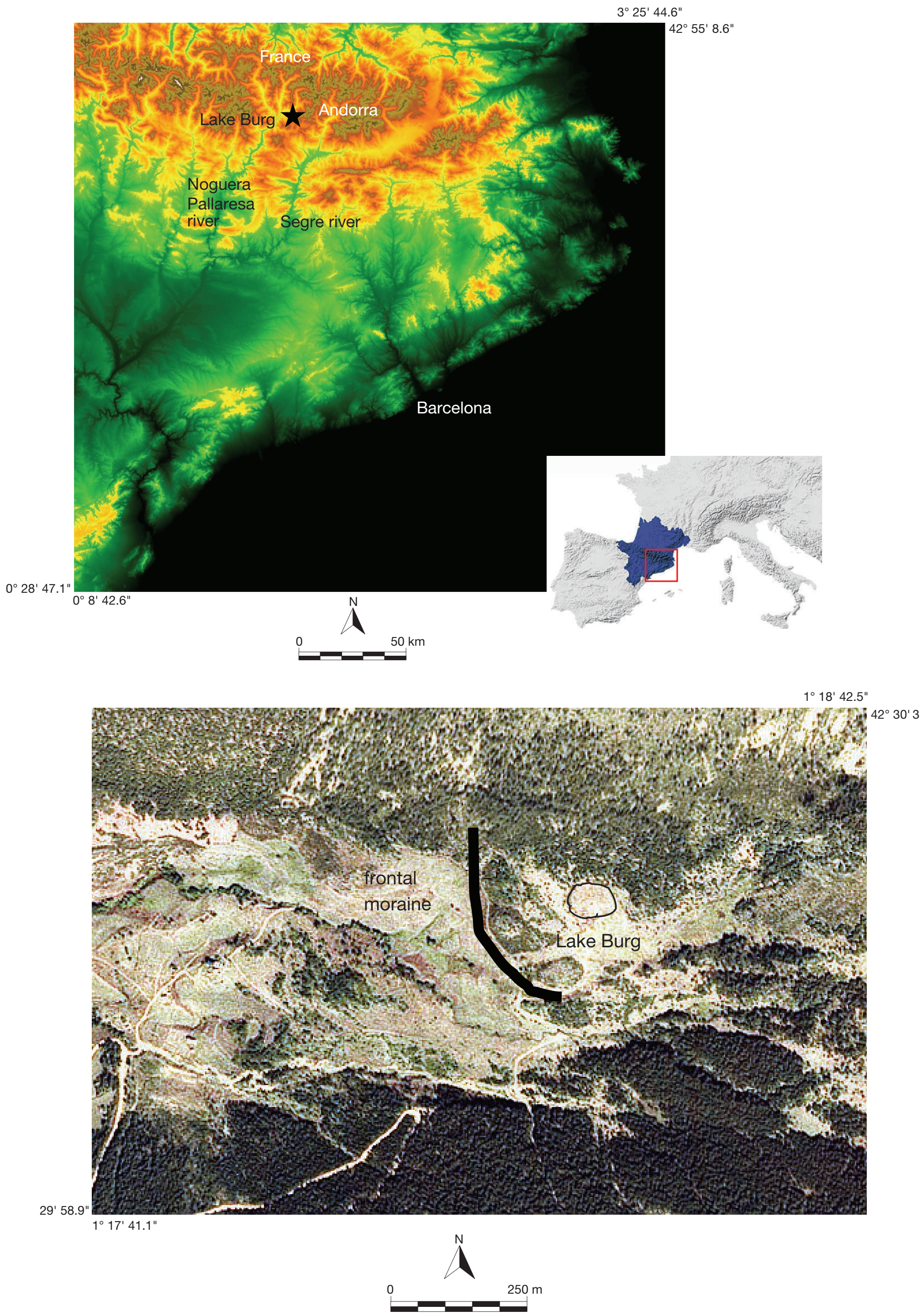

Figure 1. Location of Lake Burg.

paleolake, the Estany de Burg, located at middle altitude in the High Pyrenees (Fig. 1). Sediments from the lake record both climatic change and human impact [16].

Site description

Lake Burg is located in the Axial Pyrenees (1,821 m a.s.l.), at the eastern end of the Pyrenees and on the southern side of this mountain chain between the River Noguera Pallaresa (to the west) and the River Segre (to the east), close to where the borders of Spain, France, and Andorra meet, in the northeastern region of the Iberian Peninsula (Fig. 1). The terrain surrounding Lake Burg is characterized by a high degree of schistosity [19]. The lake's climate is the result of a transition zone between the Mediterranean mountain climate and the Atlantic climate. The mean annual rainfall varies between 500 and 900 mm/year and the mean annual temperature between 10.1ºC at the bottom of the valley and 2.3ºC at the top, according to estimates made by the Digital Climatic Atlas of Catalonia [14].

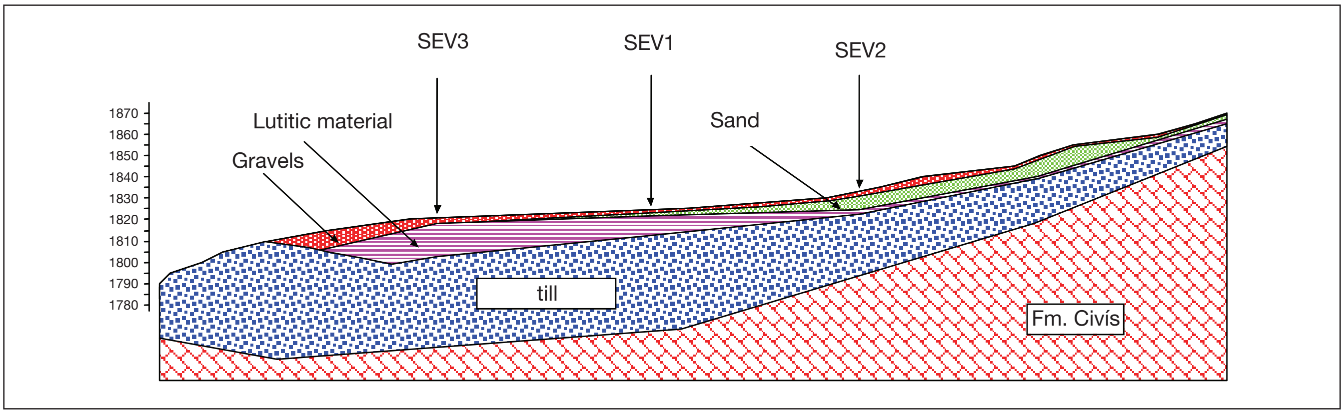

Figure 2. Vertical Electric Soundings (SEV) .

The lake is situated at the transition between the Eurosiberian and boreoalpine regions, in an area that has been severely modified by human activity. It is characterized by Scots pine forest (*Pinus sylvestris*; *Veronico-Pinetum sylvestris*), isolated silver birch (*Betula pendula*), and more open areas of shrubs (*Senecio-genistetum europapaeae*) and pastureland (*Brometalia erecti*). Higher levels are dominated by mountain pine forest (*Pinus uncinata, Saxifrago-Rhododendretum pinetosum uncinatae*) [10].

Lake Burg (42º 30' 18"N 1º 18' 22"E) is of glacial origin and was formed due to a frontal morainic obturation [25]. It is currently filled with sediment and functions as a seasonal fen. Its maximum depth throughout the year never exceeds 40 cm and it is completely dry during the summer and autumn.

The lake's maximum length is 85 m a.s.l. (east-west) and its maximum width is 64 m a.s.l. (north-south). The combined lutitic, organic, and fluvio-torrential sediments have a mean depth of 18 m and are located on a subglacial till of 14–25 m that rests on schist-like materials (Fig. 2) [24].

Materials and methods

After three vertical electric soundings (VESs), in August 1999, and taking advantage of the fact that the lake was dry, a core was removed from the central part of the lake (CMB-I). The core was extracted using an Eijkelkamp edaphic probe, which was operated manually. Samples were taken at depths of up to 6.57 m.

Analysis of the lake's sediments showed five significant peat episodes (46–121 cm; 141–161 cm; 166–327 cm; 329–350 cm; 401–436 cm), three argillaceous phases (121–141 cm; 161–166 cm, and 327–329 cm), and two intercalations of bulk sediments (350–401 cm; 436–656 cm).

The sampling mesh was set at 5 cm in order to obtain 123 samples. The physicochemical treatment used to isolate the palynomorphs was carried out on 72 samples, of which 53 were treated to analyze pollen and microcharcoals. Radiocarbon dates were obtained using peat and bulk sediments by the AMS method at the Beta Analytic Laboratory.

Results and Discussion

The pollen diagram was created using ^{14}C radiocarbon dating (Table 1) and by identification of the different palynomorphs. The pollen diagram was zoned manually, taking into account the criteria proposed by [13] as follows:

1) Pollen assemblage zones (PAZs) were designated in order to establish a biochronostratigraphy of the study area that would explain the vegetation landscape, and to compare the pollen spectrum with other regional-scale diagrams (Fig. 3).

Table 1. Calibrated radiocarbon dates

Depth (cm)	*Sample*	*Material*	*Conventional 14C age (year BP)*	*Intercept cal BP*	*Calibrated age 2σ (95% probability)*
111	Beta-167020	Peat	2310 ± 40	2340	cal BP [2360 (2310, 2230) 2190] cal BC [410 (360, 280) 240]
471	Beta-167021	Bulk sediments	4730 ± 40	5470	cal BP [5590 (5440, 5410) 5320] cal BC [3640 (3490, 3460) 3370]
511	Beta-167022	Bulk sediments	8320 ± 50	9400 – 9360 – 9310	cal BP [9470 (9220, 9180) 9140] cal BC [7530 (7280, 7230) 7190]
651	Beta-167023	Bulk sediments	9300 ± 60	10510	cal BP [10660-10260] cal BC [8710-8310]

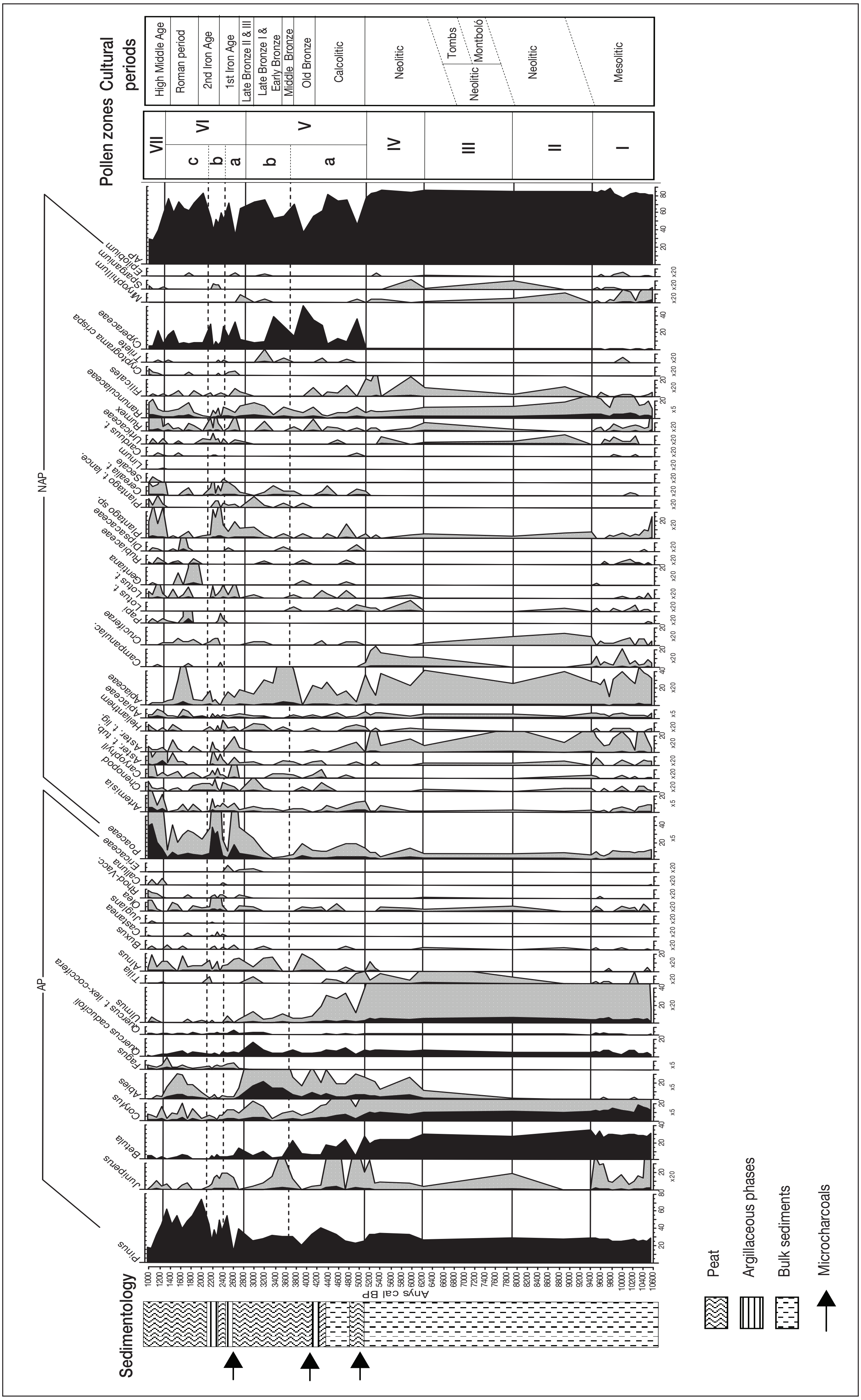

Figure 3. Pollen Assemblage Zones (PAZ) (CMB-I). Lake Burg, 1.821 meters (CMB-I). Pollen analysis: Agustí Esteban Amat.

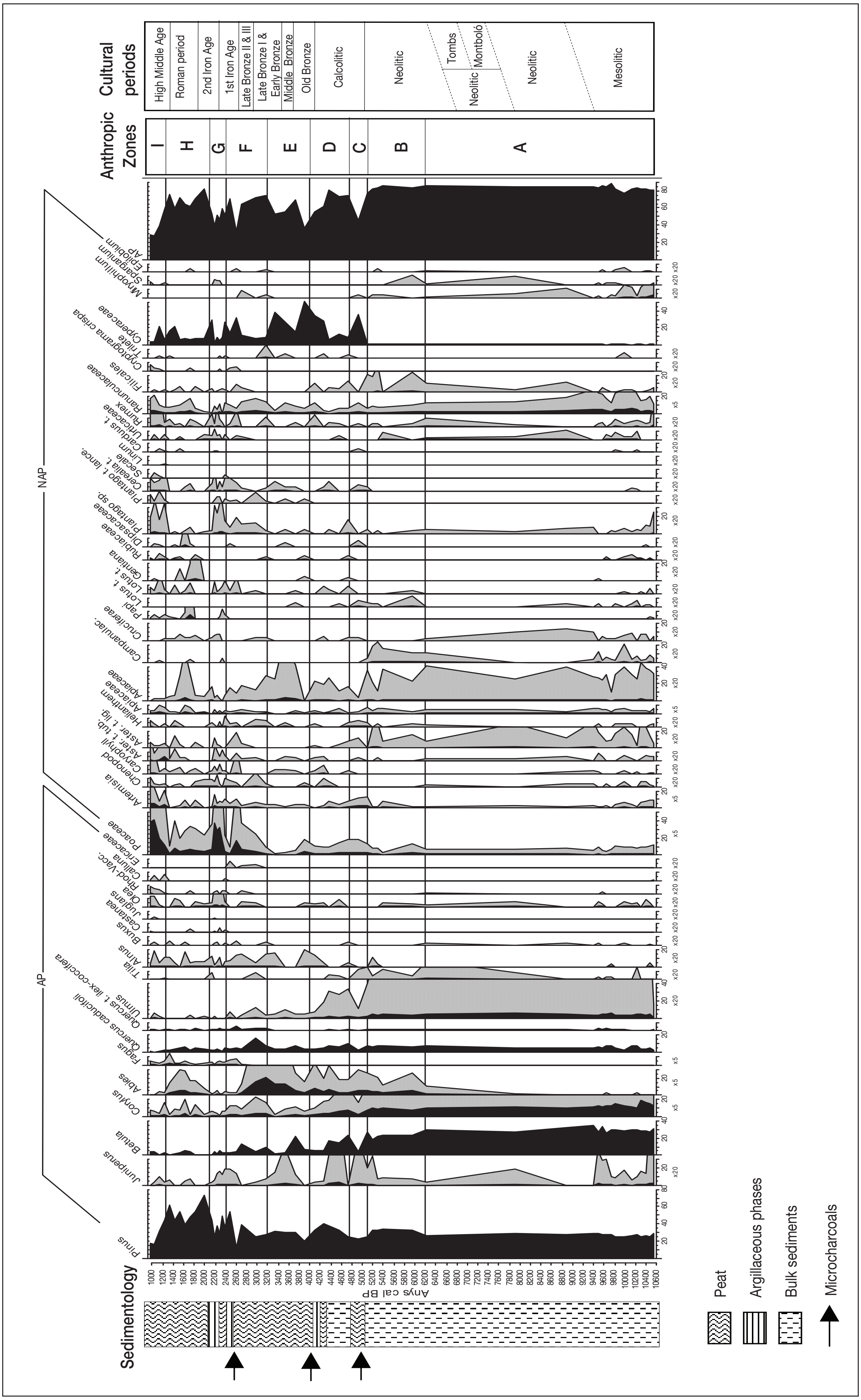

Figura 4. Anthropic Zones (AZ) (CMB-I) Lake Burg, 1.821 meters (CMB-I). Pollen analysis: Agustí Esteban Amat.

2) Anthropic zones (AZs) allowed identification of those features caused by human activity that have affected plant dynamics, and better linkage of natural and cultural chronologies (Fig. 4).

Climatic dynamics and vegetation

Based on the results, an initial bioclimatic description of the landscape of Lake Burg was obtained and clear signs distinguishing the unequal importance of the effects of climatic and human actions were identified. Accordingly, three different successional stages for the vegetation were defined:

- Birch forest (*Betula* sp.), between 9000 and 6200 calibrated years before the present (cal years BP), reflected stable and paraclimatic formations, indicative of continentality, although after 7800 cal BP silver fir (*Abies alba*) was also present.
- Silver fir forest (*Abies alba*), between 6200 and 2800 cal years BP, may have been an adaptation of the vegetation to the climate, but in the consolidation stage it cannot be disassociated from increasing human activity after 5200 cal years BP.
- Scots pine forest (*Pinus sylvestris*), between 2800 cal years BP and the present, is an indicator of the importance of climate in relation to human activity in contrast to socioeconomic specialization as a strong conditioning factor for the presence of the pine.

The evolution of the landscape highlights the fact that the climate changes which occurred throughout the Holocene had direct repercussions on the distribution and evolution of the vegetation, both as a whole and at an individual level. Silver birch forest (9400 and 6200 cal years BP), silver fir forest (5200 and 2800 cal years BP), and Scots pine forest (approximately 2800 cal years BP to the present) have been the three main kinds of vegetation and have been complemented by plant formations from two transitional periods: (1) Juniperus and Corylus, from the base of the pollen diagram and until 9400 cal years BP, and (2) the shift from silver birch forest to silver fir forest, between 6200 and 5200 cal years BP, and considered to be a mixed formation of birch and fir.

Once these plant formations were established, the data were contrasted with information that indicated the sequence of the different paleoclimates for the Holocene period in the Iberian Peninsula [5]. It was thus possible to establish that:

1) The change from pre-boreal to boreal (around the 9850 cal years BP) coincided with definitive establishment of birch forest after the previous stage had ended.
2) The change from Atlantic to sub-boreal (around 5100 cal years BP) coincided with the change from birch forest to fir forest, although no general change in the transition from boreal to Atlantic (8300 cal years BP) was observed, despite the appearance of *Tilia*.
3) In the change from sub-boreal to sub-Atlantic (around 2780 cal years BP), fir forest was replaced by pine forest.

An analysis of the evolution of the Mediterranean climate, as described by [11], offered a much more precise approach than classifications based on the great “classic paleoclimatic” periods and was used to detect significant changes. Accordingly, it was determined that the three main moments of change coincided completely with the phases described by these authors. The first (approximately between 10,900 and 9700 cal years BP) occurred at a time when vegetation characteristic of a Mediterranean climate was only present in the southeastern Iberian Peninsula; the second (5300–4200 cal years BP) occurred when these conditions had reached Cubelles, in the province of Barcelona; and the third (2850–1730 cal years BP) when they extended to the latitude of the Gulf of Lyon. These results are shown in Fig. 5 and depict the moments of change that coincided with the plant dynamics and evolution of the climate.

However, to what extent is climatic evolution a useful approach to explain the plant dynamics of Lake Burg? The key is found in the article by [11], which described how the Mediterranean climate became established around 41º north before 5700 cal years BP. Lake Burg is located at 42º30’10” north, implying that the establishment of a Mediterranean climate at the same latitude coincided with a change in the seasonality of precipitation, which occurred between 5300 and 4200 cal years BP, according to the same authors. This would have caused the fir forest to replace the birch forest. In fact, until this happened, *Alnus* did not appear in the pollen diagram of Lake Burg–a finding that may be indicative of this increase in precipitation.

However, the replacement of fir forest by pine forest seems to have occurred for the opposite reason, in other words, a fall in precipitation. How can this discrepancy be explained? From a purely climatic perspective, [11] showed that, after 2870 cal years BP, at a latitude between 41º30’and 44º north (a latitudinal band that includes the entire lake), summers tended to be increasingly dry, while precipitation continued to be variable. Thus, if only the climatic conditions are taken into account, it is probable that the climate shift itself would have manifested as a variation in precipitation, i.e., a much drier climate. If one bears in mind that this occurred in an area traditionally affected by precipitation and temperature regimes of a markedly continental nature, then the replacement of the fir forest by Scots pine would have been possible.

Climatic dynamics and society

One of the goals of this study was to determine the extent to which the relationship expressed in the second hypothesis, and considering that human activity during a large part of the period in question may have been dependent on climatic factors, was related to these plant dynamics. Therefore, using the AZs of Lake Burg and several documentary sources [16], we established classification of human intervention according to

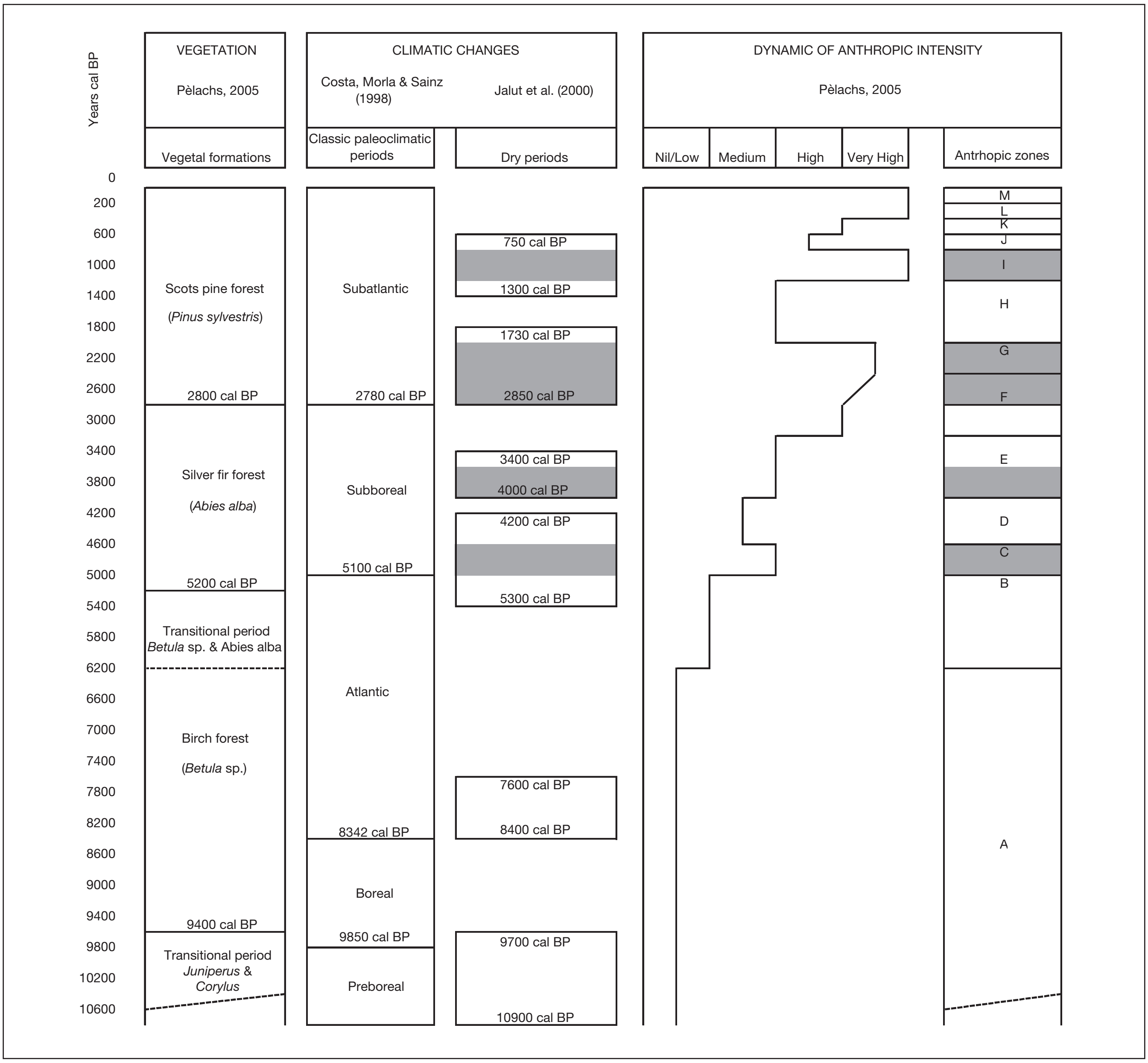

Figure 5. Vegetation, climate changes and intensity of anthropic factors (CMB-I).

different degrees of intensity (nil/low, medium, high, or very high) from 6200 cal years BP to the present. The results are presented in Fig. 5 and show that, after 5000 cal years BP, climatic variation on the eastern coast of the Iberian Peninsula [11] corresponds to an increase in the anthropic proxies of Lake Burg.

Logically, the degree of anthropic intensity has gradually increased, although it seems that these episodes did not have significant repercussions on the vegetation, at least until after 2800 cal years BP, when the perturbations detected at CMB-I coincided with the replacement of fir forest by Scots pine forest. Thus, any anthropic perturbations that had occurred until that moment most likely failed to alter the general dynamics of the fir forest. Nevertheless, two successive waves of human intervention did succeed in modifying it (Fig. 5, F and G).

Therefore, despite the fact that climate change is evident, it is not possible to rule out that further adaptation of the Scots pine forest to the subalpine habitat of Lake Burg was completely conditioned by the role played by humans, since, together with the climate, the data show that there was a considerable increase in secondary anthropic indicators. This has been directly related to the high intensity of stockbreeding practices, which coincided with an increase in the presence of microcarbons [16].

Conclusions

Based on the facts presented above, our study provides strong evidence for the following:

1) The general evolution of the climate has conditioned the evolution of the vegetation landscape, despite the particular dynamics of the valley itself.

2) There is a degree of correspondence between the climate change that occurred on the coastal region and that which occurred in the mountain areas.
3) The establishment of a Scots pine forest was totally conditioned by the coincidence of natural and human perturbations; therefore, it is not possible to study the current dynamics of the vegetation landscape without taking into account all past human impacts at least over the last 2800 cal years BP.

Acknowledgements

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The Research Group of Mountain Areas and Landscape *(GRAMP) of Departament de Geografia in the* Universitat Autònoma de Barcelona *was founded in 1982. Its main scientific focus lies on the study of changes in landscape diversity in mountainous areas and the relation established between society (socio-economic variables) and the natural world (natural variables), especially from a dynamic and diachronic point of view. The final objective of this group is to analyze the natural systems and the human actions throughout time, and how this relationship conditions the present and future dynamics of the landscape.*

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