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The Würm in NW Iberia, a pollen record from Area Longa (Galicia)

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Abstract

The pollen record at Area Longa is the westernmost sequence available for investigation of the last glaciation in continental Europe. It is located in a region, NW Iberia, for which data from times earlier than the late glacial period are scarce. It comprises a series of exposed limnetic levels that lie above an Eemian (Oxygen Isotope Stage [OIS] 5e) beach and are separated by inorganic layers. The oldest limnetic level (Level I), attributed to the early glacial period (OIS 5a to OIS 5d), shows a dominance of woodland with high proportions of *Fagus* pollen and is tentatively identified with St. Germain I. The lower pleniglacial (OIS 4) Level II records a stadial landscape of grassland and shrub. Level III, from the pleniglacial interstade (OIS 3), reflects a complex period in which three warmer woodland phases alternated with periods of more open vegetation. This cyclical behavior correlates with the ice core isotope record and with the general tendencies observed in other Würmian pollen records, but the composition of our pollen profiles differs from those observed in these other records. In NW Iberia, the dominant trees were deciduous taxa, not conifers. Of particular note is the presence of lowland *Fagus* woodlands during the pre-Würm, and the occurrence of *Carpinus* considerably farther west than the boundary of its current distribution in the Iberian Peninsula.

Keywords: Pollen record; Vegetation dynamics; Late Pleistocene; Würm; Deciduous forest

Introduction

Pollen sequences from lakes and peat bogs can assist in the elucidation of climate changes, to which vegetation may respond within decades (Tinner and Lotter, 2001). Most pollen records for the Würm (or Weichselian) in western Europe show good synchrony with deep-sea cores and Greenland ice cores (see, e.g., Guiot et al., 1989; Allen and Huntley, 2000) but uncertainty persists regarding certain possible minor fluctuations in climate. Discrepancies between different records may be due to inter-regional differences in sensitivity to change (Follieri et al., 1998; Muñoz Sobrino et al., 2004; Roucoux et al., 2005), but further understanding of this issue requires sampling of currently under-represented regions (Huntley et al., 2003; Müller et al., 2003).

One such region is NW Iberia, where most of the numerous pollen records that have been obtained are for mountainous areas that underwent rhexistatic processes during the Würm (Ramil-Rego et al., 1998; Muñoz Sobrino et al., 2001, 2004), and which therefore commonly cover only the Holocene or the final period of Oxygen Isotope Stage 2 (OIS 2). Paleoenvironmental reconstructions for earlier periods have had to be extrapolated from other regions (often regions showing little or no affinity), or based on data that are indirect or otherwise unsatisfactory. For example, although two long, continuous, readily datable pollen sequences from deep-sea cores have recently thrown light on vegetation changes in continental Iberia during the Würm (Sánchez Goñi et al., 1999, 2000; Roucoux et al., 2005), like all offshore pollen records they suffer from both the probable under-representation of less mobile palynomorphs and the pooling of pollen from different source biomes. These handicaps may explain why there are striking differences between the two sequences despite the proximity of their boring sites (Fig. 1): in MD95-2042 (Sánchez Goñi et al., 2000), Poaceae always account for <15% of pollen and *Cedrus* for 10–15%, whereas in MD95-2039 (Roucoux et al., 2005) Poaceae values range from 20% to 70% and *Cedrus* is absent.

The coasts of NW Iberia feature exposed sediments formed during the last glacial–interglacial cycle (e.g., Nonn, 1966; Mary et al., 1977; Brosche, 1983; Texier and Meireles, 1991; Granja and Carvalho, 1995). Typically, their lowest levels are

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marine facies (beach or dune levels composed of sand or rounded gravels cemented by iron oxides) that are commonly related to an Eemian (OIS 5e) sea level maximum of +6 m (Nonn, 1966; Mary et al., 1977; Texier and Meireles, 1991; Carvalho and Granja, 1997). These marine facies were subsequently overlaid by post-Eemian continental levels, followed finally by the products of the current soil cycle. In most of the continental levels, inorganic layers consisting of angular blocks in a sandy matrix predominate, but there are also limnetic facies corresponding to lagoons or peat bogs formed during milder periods. These lagoon and bog sediments have been the subject of a number of palynological studies; they are easily dated (when no older than the radiocarbon dating limit), pollen has been well preserved in them, and the pollen data they yield are readily compared with those of other onshore sites. However, most of these studies have focused on the Holocene (Mateus, 1992; Santos Fidalgo et al., 1993; Queiroz and Mateus, 1994; Gómez-Orellana et al., 1998) or the late glacial period (Mary et al., 1977; Gómez-Orellana et al., 1998); although layers formed in earlier periods have also been examined (Mary et al., 1975, 1977; Diniz, 1989; Edeso et al., 1989), they have not been the subject of systematic analysis. This is all the more regrettable because NW Iberia, which is at the current distribution limit of numerous Eurosiberian plant species and shelters isolated populations of paleotropical ferns that are otherwise now restricted to southern Iberia and Macaronesia, may be expected to have undergone pronounced vegetation changes during the Würm in response to oscillations of the polar front (Frenzel et al., 1992; Florineth and Schlüchter, 2000) and modifications of oceanic circulation (Bond et al., 1992, 1993).

This paper concerns part of a systematic study of all the exposed limnetic sequences of the NW Iberian coast (Gómez-Orellana, 2002). Here we report the pollen record from the Area

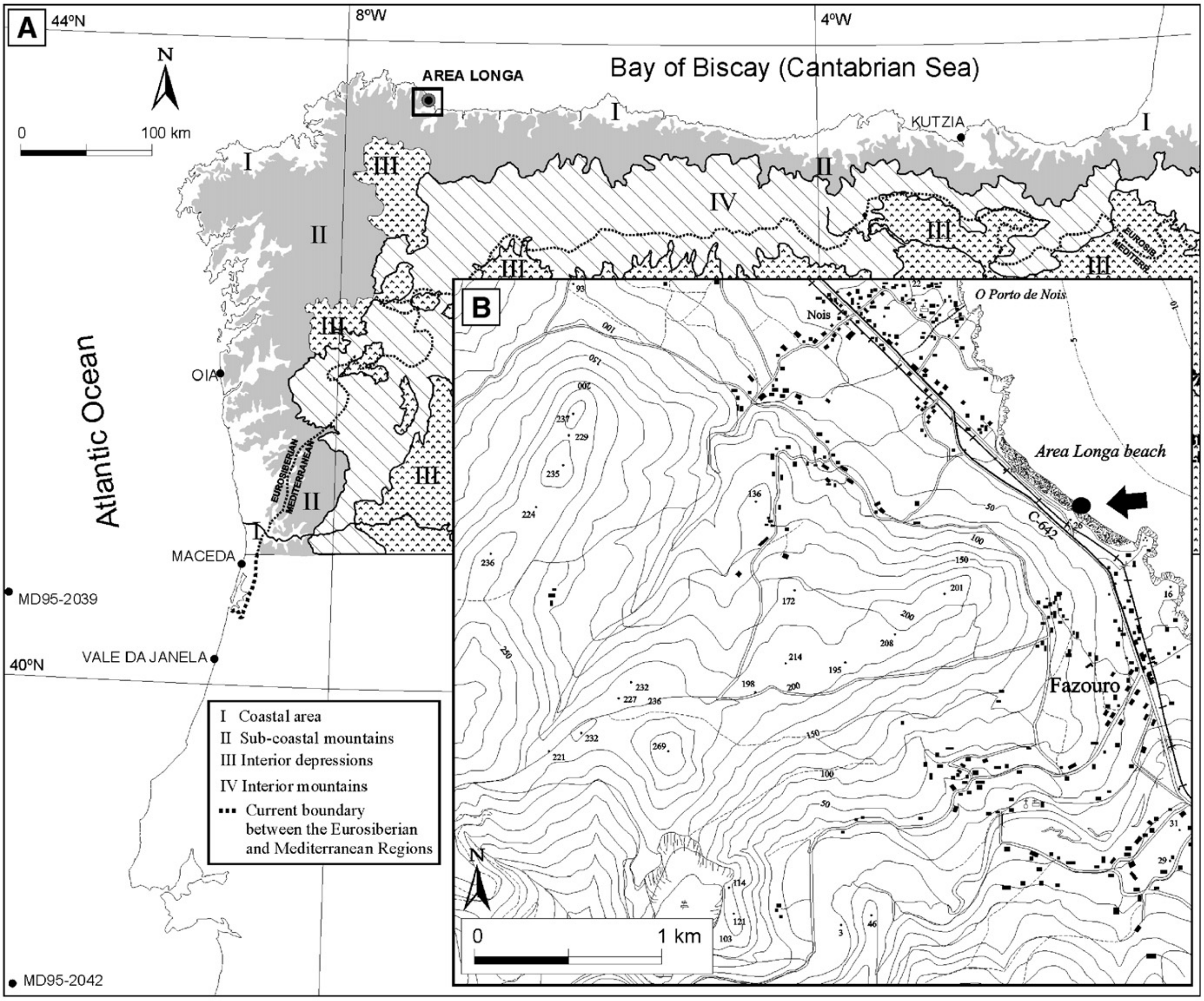

Figure 1. Location of Area Longa. (A) Coastal fringe of NW Iberia, showing major biogeographical units and the locations of the following pollen records mentioned in the text: Kutzia (Muñoz et al., 1989–1990); Oia (Gómez-Orellana, 2002); Maceda (Granja and Carvalho, 1995); MD95-2039 (Roucoux et al., 2005); Vale da Janela (Diniz, 1989); MD95-2042 (Sánchez Goñi et al., 2000). (B) Local map of the area around Area Longa.

Longa deposit (Fig. 1), the westernmost known Würmian sequence in continental Europe. This record constitutes the first reasonably continuous onshore pollen sequence allowing reconstruction of the vegetation and climate of NW Iberia during the last glacial period.

Study area

Although most of Iberia belongs to the Mediterranean biogeographical region, a fringe along its northern coast and the northern half of its Atlantic coast belongs to the Eurosiberian (Fig. 1). This fringe is very heterogeneous, with at least four well-defined biogeographical units (coastal area, sub-coastal mountains, inland depressions and inland mountains) that show different vegetation responses to major climate changes (Ramil-Rego et al., 1998; Muñoz Sobrino et al., 2005). The northern coastal area is a plain, known locally as the *rasa*, that is backed by the Cantabrian Range to the south and slopes upward towards the west. Its current climate, shared with the remainder of the coastal and sub-coastal areas, is markedly oceanic, with predominantly mild, weakly oscillating temperatures and abundant rainfall that is well distributed over the annual cycle. Its modern vegetation is mainly heath and deciduous forest dominated by *Quercus robur* L.

Area Longa is a beach located at the western end of the *rasa* (43°36′N, 7°18′W; altitude 0 m a.s.l.; see Fig. 1). The formation studied in this paper constitutes a low cliff running behind this beach for more than 1 km, with a maximum height of 18 m. Its basal facies are below the level of the current beach and are only visible near the waterline at low spring tide (Fig. 2). The first descriptions of this site were published by Mary et al. (1977), who performed carbon dating and pollen analysis on samples from three levels. The oldest [>35,000 ^{14}C yr BP (Gif-3488)] was tentatively attributed to the Würm pleniglacial period, and the other two [dated 16,780 ± 400 ^{14}C yr BP (Gif-3490) and 15,950 ± 500 ^{14}C yr BP (Gif-3489)] to the transition from the last glacial maximum to the late glacial period. The exposed part of the formation varies continually due to marine erosion, which causes the successive appearance and disappearance of certain levels. In the 1990s, we were able to locate three limnetic levels (Fig. 2): two that had not previously been described (Levels I and III), and a third (Level II) that was identified as including as its lower sublevel (see below) the oldest level mentioned by Mary et al. (1977). Levels I and II both lie over a hard crust of sand cemented by iron oxides, Level I below the sand of the current beach and Level II at the foot of the cliff. The sandy crust lies directly on the granite bedrock and, like the similar facies that appear all along the Cantabrian and Atlantic coasts of NW Iberia, is attributed to the Eemian transgression (see Nonn, 1966; Mary et al., 1977; Brosche, 1983; Mary, 1989; Texier and Meireles, 1991). Level I is a 40-cm layer of peat with an *Erica arborea/australis* rooting zone at its upper surface. Level II consists of a 130-cm lower sublevel of peat containing a considerable amount of quartz sand in its basal part, and a 240-cm upper sublevel comprising alternate bands of organic clay and sandy clay. The upper and lower sublevels are not sharply distinct but merge gradually into each other. Level III, which lies partly on bedrock and partly on the inorganic colluvial layer covering Level II (see Fig. 2), is a 172.5-cm peat layer containing fibres and sheaths of Cyperaceae and *Sphagnum* phyllode fragments.

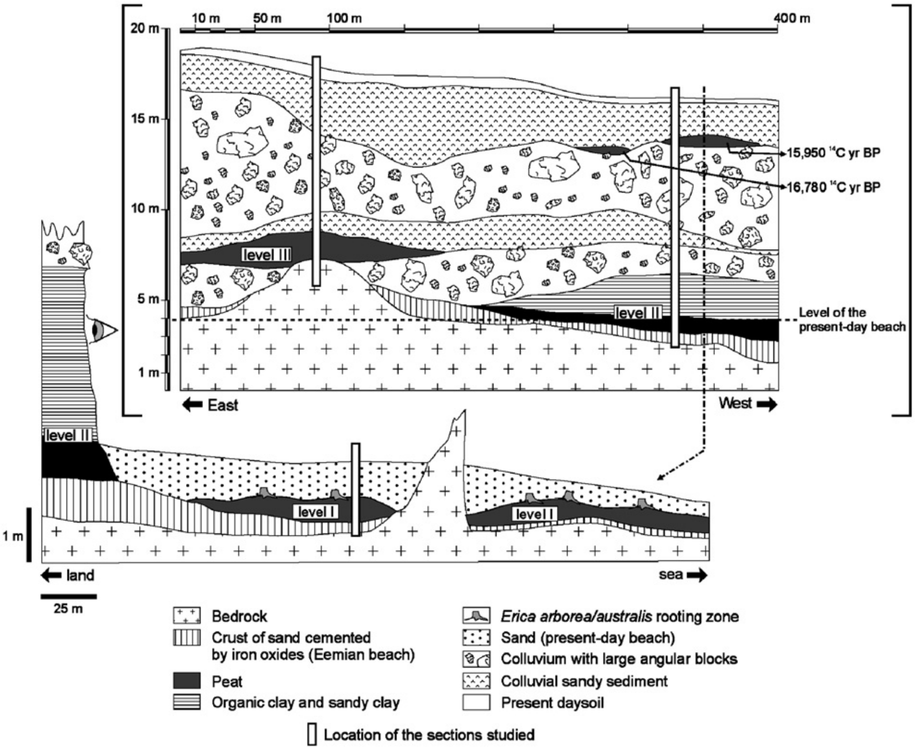

Figure 2. Sections through the Area Longa sediments parallel and perpendicular to the central sector of the present cliff face. Dates are from Mary et al. (1977).

Methods

Sampling was performed manually from naturally or artificially exposed profiles (Fig. 2). Following profile cleaning, samples were taken throughout the depths of Levels I, II and III (1-cm samples from Levels I and II, 2.5-cm samples from Level III) and were prepared for analysis by potassium hydroxide digestion and sieving (Moore et al., 1991). Calculations were performed, and diagrams drawn, using GPAL 3.0 (Université d'Aix-Marseille III) and TILIAGRAPH 1.07 (Grimm, 1990). Pollen percentage data are given relative to the total terrestrial pollen count (AP+NAP; >250 grains per sample in all cases).

A total of twelve ^{14}C datings were performed for Levels I and III, four of which by AMS (Table 1). Since the bedrock is siliceous, there should be no interference from any hard water effect (Olsson, 1986). Three AMS dates and one conventional date place Level III in Oxygen Isotope Stage 3 (see Fig. 5). All of the other dates provided only minimum ages.

The entire pollen sequence was divided into sixteen local pollen assemblage zones designated AREL-1, AREL-2, etc., with numbering from the bottom of Level I to the top of Level III. Where appropriate, these zones were subdivided to highlight particular features. Pollen determination and nomenclature follow Punt (1976), Punt and Clarke (1980, 1981, 1984), Punt et al. (1988), Punt and Blackmore (1991), Mateus (1989) and Moore et al. (1991). A complete diagram is given for each limnetic level (Figs. 2, 3 and 4).

Results of pollen analysis

Level I (Oxygen Isotope Stage 5c)

Level I is a 40-cm-thick peat layer dated >45,000 ^{14}C yr BP (GrN-21440) or >49,000 ^{14}C yr BP (GrN-20822); the latter dating is of a woody fragment in the *Erica* root zone at the top of the level. This level exhibits abundant pollen of taxa characteristic of lacustrine environments and semiterrestrial habitats (Fig. 3, Table 3), showing that local wetlands developed at this site during a marine regression following the Eemian interglacial period. Three local pollen assemblage zones were distinguished in this layer (Fig. 3 and Table 2).

Table 1
Radiocarbon dates obtained for samples from Area Longa at the Centrum voor Isotopen Onderzoek, Groningen University. GrN, conventional dates; GrA, AMS dates

Level	Depth (cm)	Material	Radiocarbon age, ^{14}C yr BP	
			Conventional radiocarbon date	AMS radiocarbon date
I	1650	Wood	>49,000 GrN-20822	
	1653–1654	Peat	>45,000 GrN-21440	
III	1017.5–1020	Peat	>37,100 GrN-22827	35,850±300 GrA-6983
	1070–1072.5	Peat	>37,900 GrN-22826	41,670±520/490 GrA-6982
	1087.5–1090	Peat	>40,300 GrN-22825	41,150±520/480 GrA-6980
	1127.5–1130	Peat	>42,200 GrN-22824	
	1160–1162.5	Peat	>40,500 GrN-22823	>50,000 GrA-6979
	1170–1172.5	Peat	39,170±2300/1800 GrN-21441	

AREL-1 is characterized by high percentages of deciduous tree pollen, mainly *Alnus* (25%), *Q. robur* type (25%), *Corylus* (10%), *Betula* (10%), *Fagus* (3%) and *Carpinus* (3–5%).

AREL-2 subzone 2a shows a decline in *Q. robur* type, *Corylus*, *Alnus* and *Fagus*, while *Betula* becomes dominant. Later (AREL-2b), *Betula* also declines, though it remains dominant, while *Fagus* and *Q. robur*-type pollen increase. Despite the changes in landscape reflected by these trends, a wide variety of other tree taxa remain present throughout AREL-2.

AREL-3 shows a decline in tree pollen percentages. *Betula*, *Fagus* and *Q. robur*-type pollen fall off quite sharply in the earlier AREL-3a period, and although these taxa recover to a considerable extent in AREL-3b, a number of conifers and a large group of warmth-requiring trees disappear (Fig. 3).

Level II (Oxygen Isotope Stage 4)

Level II comprises a 130-cm lower sublevel of peat and an upper sublevel consisting of clayey sediments (Fig. 4). The lower part of the clayey sublevel has high organic matter content, while the sediments of the upper part alternate between organic clays and clays with high quartz sand content. Although tree pollen remains present in Level II, overall this level is dominated by pollen of herb and shrub origin (see Fig. 4 and Table 2) and may correspond to a stadial period. Recurrent fluctuations in water input are suggested by marked variations in aquatic taxa (Table 3) that correlate with the alternation of high sand and organic clays. Seven local pollen assemblage zones were distinguished in Level II, AREL-4 to AREL-10 (Fig. 4).

AREL-4 is characterized by abundant *Erica* and a gradual increase in Poaceae, accompanied by a slight increase in cryophilous taxa. With the exception of a short regression, Poaceae are even more abundant during AREL-5, while heath species decline; the profile of *Erica* in particular is almost the exact complement of the Poaceae profile, with the two of them jointly accounting for about 80% of the total count throughout this period. AREL-6 is again dominated by heath species, though with short-term oscillations between *Erica* peaks (AREL-6a, AREL-6c, AREL-6e) and grass species peaks (AREL-6b, AREL-6d). AREL-7 is characterized by a number of sharp peaks in Poaceae and in Compositae Tubuliflorae (Fig. 4 and Table 2).

AREL-8 corresponds to a long period of shrub pollen dominance (Table 2). In addition, there is a decline in cryophilous taxa. Tree pollen remains present, but *Picea* is not detected and *Abies* is recorded for the last time. In AREL-9, periods showing expansion of Poaceae alternate with shorter periods of shrub pollen predominance; only minor variations in tree pollen percentages are observed. Finally, AREL-10, at the top of Level II, shows a predominance of shrub pollen and the decline of Poaceae.

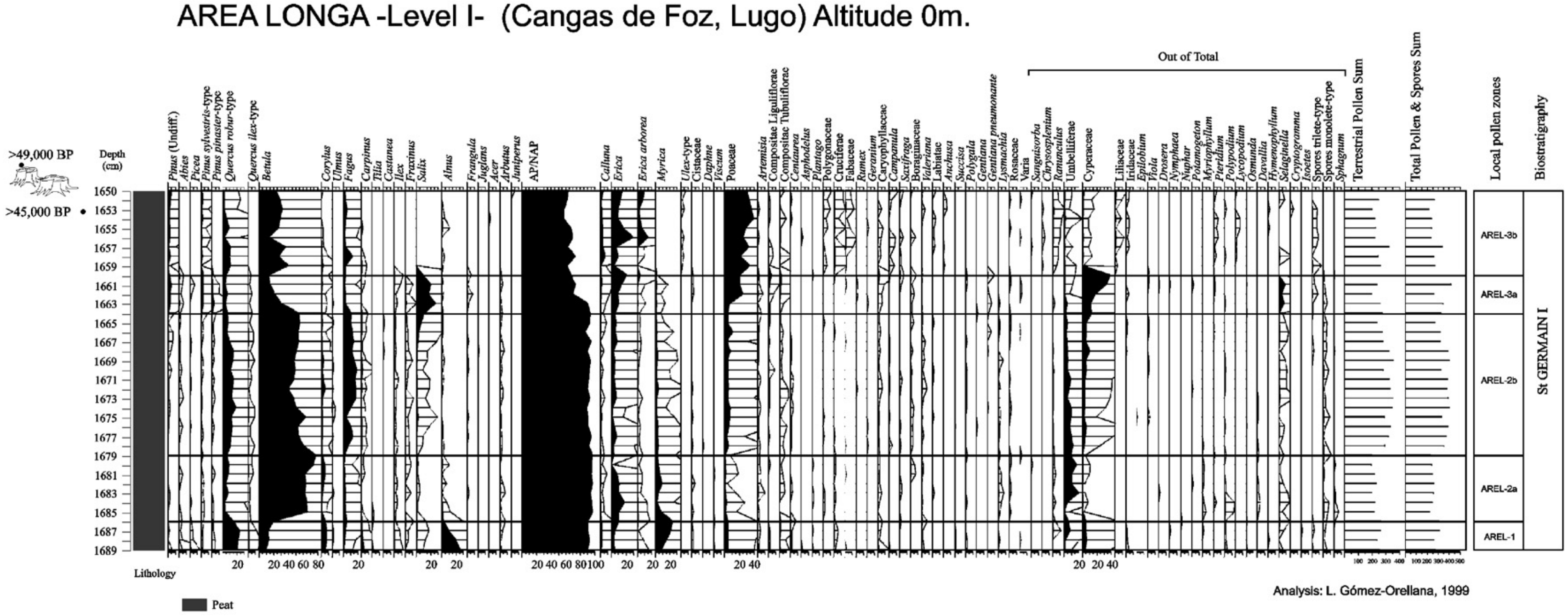

Figure 3. Area Longa: pollen record of Level I, together with radiocarbon dates in ^{14}C yr BP, local pollen assemblage zones and tentative biostratigraphic identification. Solid-shaded areas indicate pollen frequency, and overlaid unshaded areas 10× (pollen frequency).

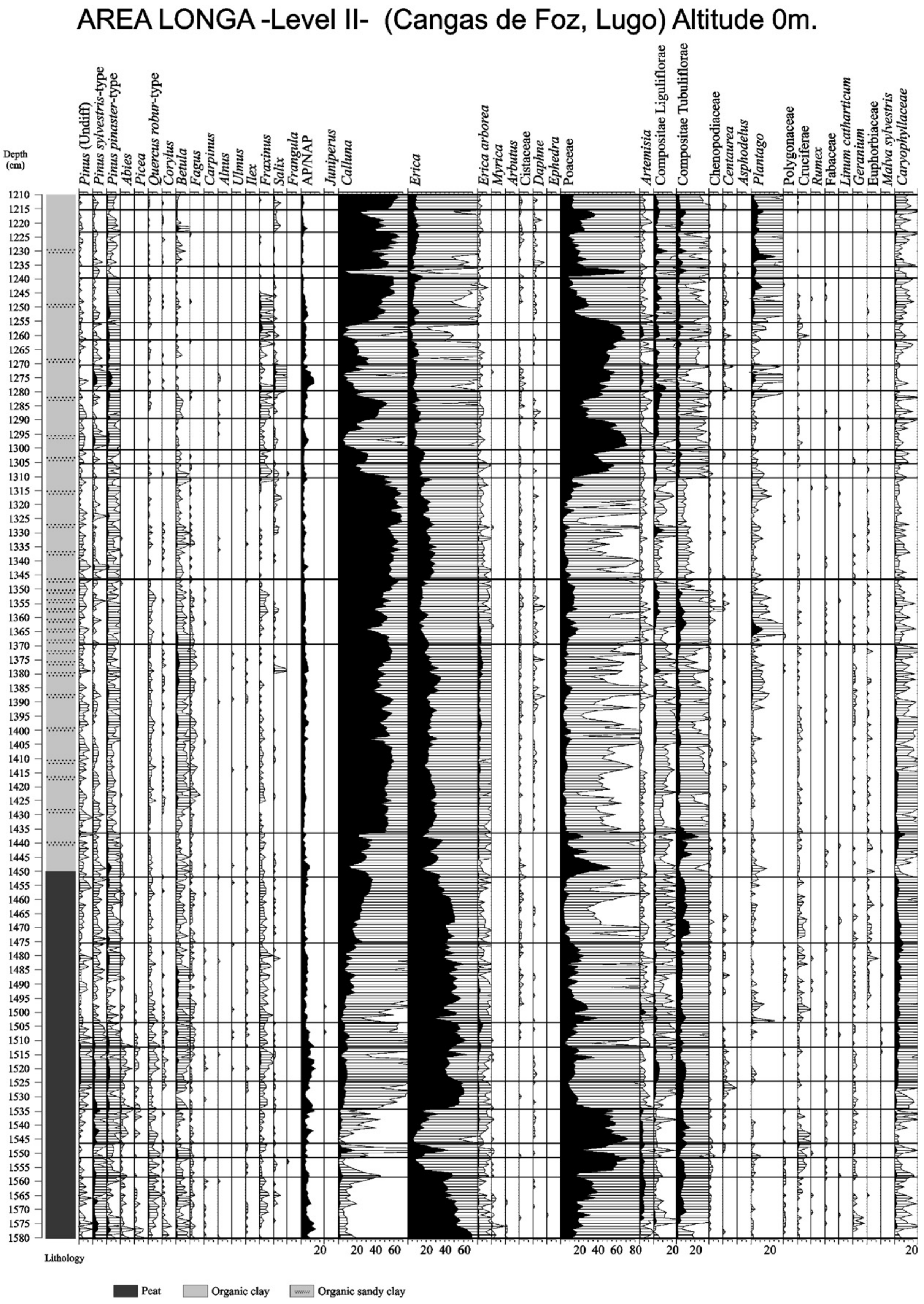

Figure 4. Area Longa: pollen record of Level II, together with local pollen assemblage zones and biostratigraphic identification. Solid-shaded areas indicate pollen frequency, and overlaid unshaded areas 10× (pollen frequency).

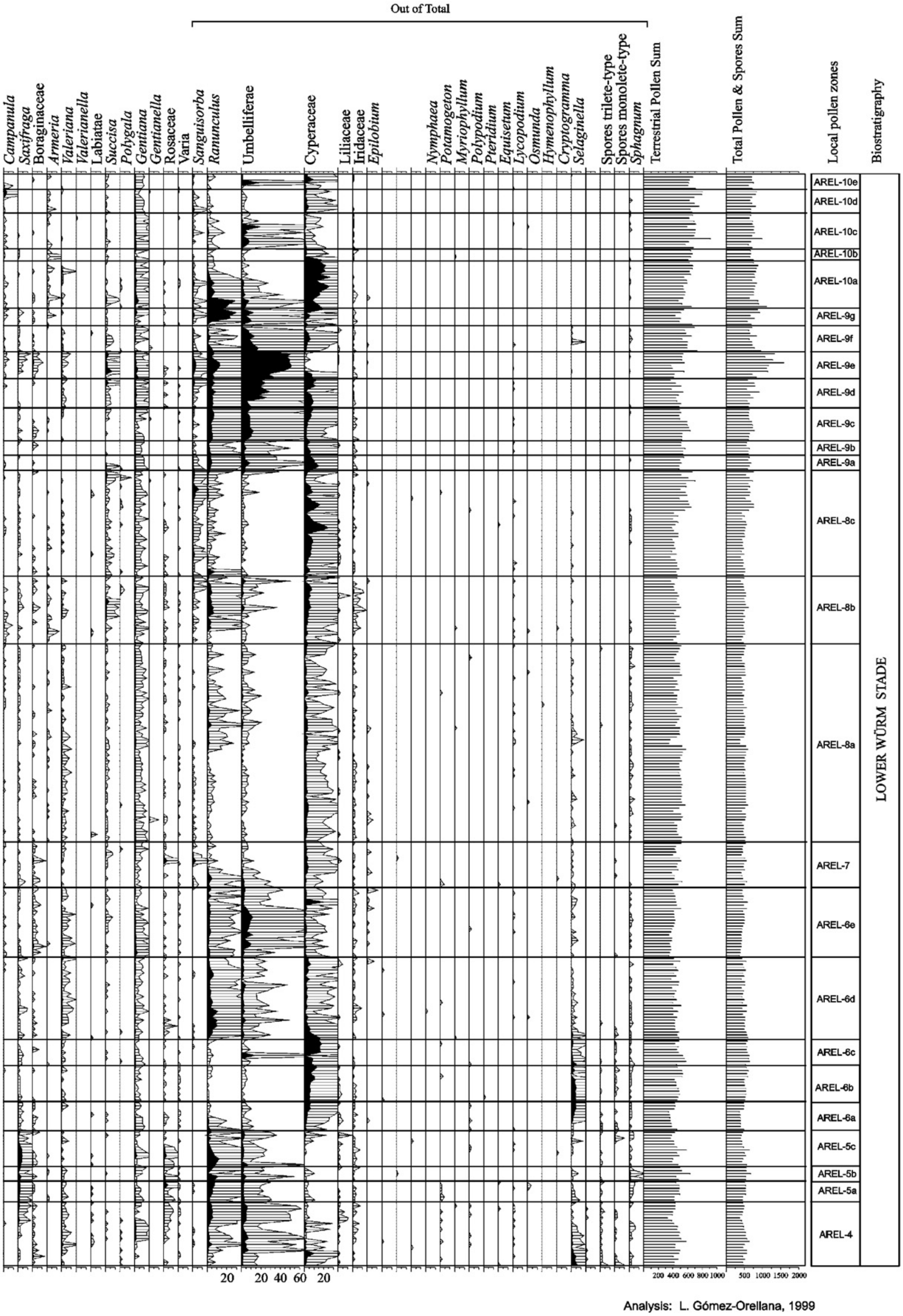

Figure 4 (*continued*).

Table 2
Denomination, depth and salient characteristics of local pollen assemblage zones distinguished in the three Würm levels of the Area Longa pollen record

Level	Pollen zone	Depth (cm)	Pollen record characteristics
I	AREL-1	1689–1686	Total woody taxa ≈90%. *Q. robur* type and *Alnus* dominant, with *Betula*, *Corylus*, *Ulmus*, *Fagus* and *Carpinus*.
	AREL-2a	1686–1679	Up to 90% forest trees. Dominant taxon *Betula*. *Q. robur* type, *Corylus* and *Fagus* also significant. Increase of *Erica*.
	AREL-2b	1679–1664	Woody taxa 80–90%. *Betula*, *Q. robur* type and *Fagus* dominant.
	AREL-3a	1664–1660	70–90% woody taxa. Decline in *Betula*, *Q. robur* type and *Fagus.* Increase in *Salix*, *Erica* and Poaceae.
	AREL-3b	1660–1650	Total woody taxa ≈60%. Recovery of *Betula*, *Q. robur* type and *Fagus. Abies*, *Picea* and some warmth-requiring trees disappear.
II	AREL-4	1580–1558	Total woody taxa <20%. *Erica* dominant. Poaceae and Compositae Tubuliflorae increase.
	AREL-5a	1558–1551	Poaceae become dominant. Decrease in *Erica*. Compositae Tubuliflorae and *Artemisia* unchanged.
	AREL-5b	1551–1546	Short peak in heath taxa. *Artemisia* and Compositae Tubuliflorae decrease.
	AREL-5c	1546–1534	New expansion of Poaceae. Decline and subsequent increase in *Erica.* Small increase in woody taxa percentages.
	AREL-6a	1534–1524	Predominance of *Erica* and *Calluna*.
	AREL-6b	1524–1512	Peak in Poaceae. Increase in Compositae and woody taxa.
	AREL-6c	1512–1503	Decline of Poaceae and Compositae. Small increase in *E. arborea.*
	AREL-6d	1503–1476	Increase in Poaceae and Compositae Tubuliflorae.
	AREL-6e	1476–1452	Decline of Poaceae. *Calluna* and Compositae Tubuliflorae increase. *Picea* disappears.
	AREL-7	1452–1436	Poaceae and Compositae dominant. *Erica* and *Calluna* also significant.
	AREL-8a	1436–1369	*Calluna* and *Erica* dominant. Decline in Poaceae and Compositae. Last record of *Abies.*
	AREL-8b	1369–1346	Small increase in Poaceae and Compositae.
	AREL-8c	1346–1310	Decrease in Poaceae and Compositae.
	AREL-9a	1310–1306	Peak in Poaceae. Decline of heath taxa. Compositae increase.
	AREL-9b	1306–1301	Increase of heath taxa. Decline in Poaceae.
	AREL-9c	1301–1289	Increase in Poaceae. Compositae abundant.
	AREL-9d	1289–1279	Decline in Poaceae. Heath taxa increase once more.
	AREL-9e	1279–1270	New increase in Poaceae. Woody taxa increase. Small rise in *Artemisia.*
	AREL-9f	1270–1261	Increase in *Calluna.*
	AREL-9g	1261–1256	Poaceae increase again. Small rise in *Artemisia.*
	AREL-10a	1256–1239	*Calluna* dominant.
	AREL-10b	1239–1235	Peak in Poaceae. Sum of woody taxa decreases.
	AREL-10c	1235–1223	Heath taxa dominant once more. Poaceae decrease.
	AREL-10d	1223–1215	Poaceae, Compositae and *Plantago* increase.
	AREL-10e	1215–1210	Rise in heath taxa. Poaceae and Compositae decrease.
III	AREL-11a	1170–1160	Poaceae and *Erica* dominant. Woody taxa sum 10–20%, dominated by *Betula*.
	AREL-11b	1160–1147.5	Decrease in Poaceae. Increase in *Calluna. Betula* gives way to *Q. robur* type (20%).
	AREL-11c	1147.5–1122.5	Decrease in woody taxa. *Calluna* and Poaceae increase.
	AREL-12a	1122.5–1100	>40% woody taxa, mainly *Q. robur* type. *Ulmus* continuous. Decrease in heathland taxa.
	AREL-12b	1100–1092.5	Short period of *Q. robur* type regression and increase in *Calluna.*
	AREL-12c	1092.5–1087.5	*Q. robur* type peaks.
	AREL-13	1087.5–1070	Decrease in woody taxa percentages; increase in *Betula*. Heathland taxa, mainly *Calluna,* dominant.
	AREL-14a	1070–1057.5	Increase in woody taxa percentages (mainly *Betula*). Decrease in *Calluna*.
	AREL-14b	1057.5–1035	Small decrease in woody taxa. Heathland taxa significant.
	AREL-14c	1035–1020	Small increase in *Betula*, *Q. robur* type and *Ulmus.* Heathland taxa also significant.
	AREL-15	1020–1005	Increase in Poaceae. Heath and woody taxa decrease.
	AREL-16	1005–1000	Increase in total tree pollen percentage, *Q. robur* type especially. Rise in *Juniperus*, Fabaceae and Rosaceae. Marked decline in Poaceae.

Level III (Oxygen Isotope Stage 3)

Level III is a 172.5-cm layer of peat. Its pollen record shows the dominance of woodland species, with several deciduous expansions interspersed by short periods of more open vegetation, probably as the result of climatic fluctuations (Fig. 5 and Tables 2 and 3). The scant presence of Cyperaceae, Umbelliferae and *Ranunculus*, together with the large proportions of *Sphagnum* pollen and the presence in the sediment of abundant *Sphagnum* phyllode fragments, indicate that at least at the start of its sedimentation this level was a peat bog, not a small lake or group of ponds with fluctuating water levels, as in Levels I and II (Table 3). Six local pollen assemblage zones were distinguished, AREL-11 to AREL-16.

AREL-11 is a phase dominated by herbs and shrubs. Cryophilous taxa are scarce or absent, while tree pollen accounts for between 10% and 25%. In AREL-12, *Q. robur*-type tree pollen shows an initial marked rise followed by a short regression and a final peak dated at around 41,000 ^{14}C yr BP. In AREL-13 shrub pollen increases again, but the percentages of Poaceae are slightly lower than in AREL-12 and total tree pollen also declines, although there is a small rise in *Betula*. AREL-14 shows another woodland expansion, though less marked than that of AREL-12, and there is also an overall rise in heath species percentages. In AREL-15, both woodland and heath species decline again, and Poaceae becomes dominant. Finally, at the top of Level III AREL-16 shows a third increase in total tree pollen (mainly *Q. robur* type).

Table 3
Changes in local vegetation at Area Longa, and inferred changes by pollen analysis

Level	Pollen zone	Local vegetation characteristics	Inferred changes
I	AREL-1	*Alnus* significant. Hygrophilous shrubs frequent (*Myrica*).	Nearby presence of alluvial (*Alnus*) forest.
	AREL-2a	Decline in *Alnus* and *Myrica*. Increase in Umbelliferae	Water level rises.
	AREL-2b	Umbelliferae replaced by Cyperaceae.	Water level falls.
	AREL-3a	Peak in Cyperaceae.	Water level falls.
	AREL-3b	Decline in Cyperaceae. Retreat of hygrophilous taxa. *Erica* rooting zone at the top.	Terrestrification of wetlands.
II	AREL-4	*Ranunculus* and Umbelliferae increase.	Water level rises.
	AREL-5a	Increase in *Ranunculus.*	
	AREL-5b	*Ranunculus* decreases.	
	AREL-5c	Increase in *Ranunculus.*	
	AREL-6a	*Ranunculus* decreases. Increase in Cyperaceae.	Water level falls.
	AREL-6b	Increase in Cyperaceae.	
	AREL-6c	Peak in Cyperaceae.	Water level falls.
	AREL-6d	Cyperaceae decrease. Increase in *Ranunculus.*	Water level rises.
	AREL-6e	*Ranunculus* decreases. Increase in Umbelliferae.	
	AREL-7	Decline in aquatic taxa. Reduced organic matter content.	
	AREL-8a	No change.	
	AREL-8b	Increase in *Ranunculus* and Cyperaceae.	
	AREL-8c	*Ranunculus* decreases. Increase in Cyperaceae.	Water level falls.
	AREL-9a	Umbelliferae, *Ranunculus* and Cyperaceae increase.	
	AREL-9b	Decline of aquatic taxa.	
	AREL-9c	Umbelliferae and *Ranunculus* increase.	Water level rises.
	AREL-9d	Increase in Umbelliferae.	Water level rises.
	AREL-9e	Peak in Umbelliferae.	Probably the highest water level.
	AREL-9f	Decline in Umbelliferae.	Decline in flood water level.
	AREL-9g	Peak in *Ranunculus*.	Water level rises.
	AREL-10a	*Ranunculus* replaced by Cyperaceae.	Progressive fall in water level.
	AREL-10b	Decline of aquatic taxa.	
	AREL-10c	Increase in Umbelliferae.	Recovery of flood water level.
	AREL-10d	Decline of aquatic taxa.	
	AREL-10e	Umbelliferae replaced by Cyperaceae.	Recovery and decline of water level.
III	AREL-11a	Increase in *Sphagnum*.	Dominance of bog habitats.
	AREL-11b	Decrease in *Sphagnum*.	
	AREL-11c	Decline in *Sphagnum*.	
	AREL-12a	Increase in Liliaceae.	
	AREL-12b	Decrease in Liliaceae.	
	AREL-12c	Increase in Liliaceae and Umbelliferae.	
	AREL-13	Decline of aquatic taxa.	
	AREL-14a	Increase in *Ranunculus.*	
	AREL-14b	*Ranunculus* decreases.	
	AREL-14c	Increase in Liliaceae.	
	AREL-15	Increases in *Ranunculus*, Umbelliferae and Liliaceae.	Flood water level rises.
	AREL-16	Cyperaceae increase. Peak in Umbelliferae.	Flood water level rises.

Discussion

The biostratigraphy proposed below is based on the stratigraphic positions of the various facies found at Area Longa, on the available radiocarbon datings, on the alternation of landscapes inferred from other European pollen sequences and on the oxygen isotope data from deep-sea cores and ice cores.

OIS 5c: St. Germain I

The end of the Eemian interglaciation at La Grande Pile was described by Woillard (1978) as comprising two forested phases, St. Germain I (OIS 5c) and St. Germain II (OIS 5a) intercalated among periods of open vegetation (Prewürm, early Weichselian or early glacial). The forested phases were subsequently correlated with the central European Brörup and Odderade episodes (Welten, 1984), which may also be represented in pollen records from sites throughout most of the continent (e.g., Pons and Reille, 1988; Behre, 1989; Tzedakis, 1994; Müller et al., 2003). In SW Europe these two interstades are commonly differentiated on the basis of *Fagus* percentages, higher during St. Germain I (when *Fagus* reached its maximum expansion) but lower or discontinuous throughout St. Germain II (see, e.g., Tzedakis, 1994; Allen and Huntley, 2000).

At Area Longa, Level I lies just above the Eemian marine facies (Fig. 2) and reflects a wooded landscape (Table 4). Its high proportions of *Fagus* pollen (up to 20%) make it unlikely that it actually belongs to the Eemian, an interglaciation characterized in Europe by the near or total absence of *Fagus* (e.g., Zagwijn, 1961; Grüger, 1989; Pons et al., 1992; Follieri et al., 1998; Müller et al., 2003). Rather, its location between the Eemian facies and the open vegetation of Level II suggests its correspondence with St. Germain I or St. Germain II, and the abundance of *Fagus* makes St. Germain I (OIS 5c) more likely than St. Germain II (OIS 5a). However, the predominance of cold-tolerant taxa such as *Betula* suggests that it belongs to the initial or the final phase of this interstade. In fact, the palynological variations within this interval indicate that it likely corresponds to the final phase of St. Germain I and the beginning of the transition to the subsequent stade: only the bottom three samples have more than 10% of deciduous *Quercus*, while the decline in tree pollen in the top samples may foreshadow the cold OIS 5b period corresponding to the Melisey II of French sequences.

Regardless of the exact correspondence of Level I, its pollen data indicate that in coastal areas of NW Iberia, as elsewhere in Southern Europe (Follieri, 1979; Magri, 1999), there was a significant abundance of *Fagus* at the beginning of the Würm. By contrast, the presence of conifers in the region around Area Longa appears to have been very limited in comparison with other European sites, which show large populations of *Pinus*, *Picea*, *Abies* or *Juniperus* during the Pleistocene (Müller, 2000). The make-up of the woodland at Area Longa during this period also differs substantially from that inferred from offshore sequences obtained off the Atlantic coast of Iberia (Sánchez

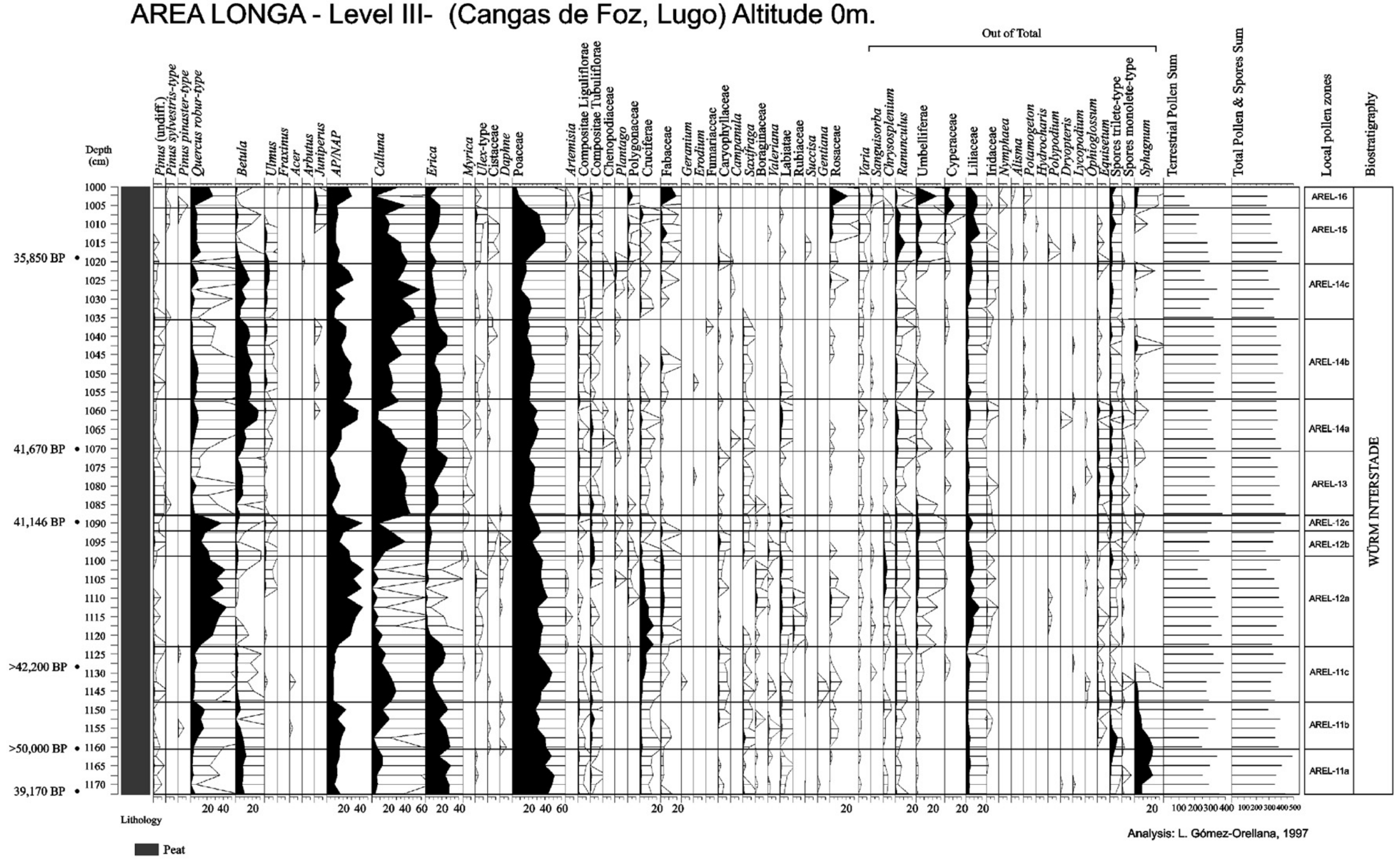

Figure 5. Area Longa: pollen record of Level III, together with radiocarbon dates in ^{14}C yr BP, local pollen assemblage zones and biostratigraphic identification. Solid-shaded areas indicate pollen frequency, and overlaid unshaded areas 10× (pollen frequency).

Table 4
Paleovegetation and climate inferred from the local pollen assemblage zones distinguished in the three Würm levels of the Area Longa pollen record

Level	Pollen zone	Inferred vegetation	Inferred climate
I	AREL-1	Regional predominance of mixed deciduous forest. Nearby presence of *Alnus* alluvial forest.	Warm–humid
	AREL-2a	*Betula* forest. A range of mesic trees, including *Q. robur* type and *Fagus.*	Temperate–humid
	AREL-2b	Forest, *Betula* dominant. *Q. robur* type and *Fagus* woods, with a range of mesic trees.	Warm–humid
	AREL-3a	Forest, *Betula* dominant. Open heathland. *Salix* forest near Area Longa.	Colder–less humid
	AREL-3b	Scattered *Quercus* and *Fagus* woods within predominant *Betula* forest and open heathland.	Less cold–more humid
II	AREL-4	Heathland, with small localized tree populations.	Cold–humid
	AREL-5a	Grassland, with small localized tree populations.	Colder–less humid
	AREL-5b	Open heathland, with small localized tree populations.	Cold–less humid
	AREL-5c	Grassland, with small localized tree populations.	Colder–less humid
	AREL-6a	Heathland, with small localized tree populations.	Cold–humid
	AREL-6b	Open heathland, with small localized tree populations.	Cold–less humid
	AREL-6c	Heathland, with small localized tree populations.	Cold–humid
	AREL-6d	Open heathland, with small localized tree populations.	Cold–less humid
	AREL-6e	Heathland, with small localized tree populations.	Cold–less humid
	AREL-7	Open heathland, with small localized tree populations.	Cold–drier than 6
	AREL-8a	Heathland, with small localized tree populations.	Cool–humid
	AREL-8b	Open heathland, with small localized tree populations.	Colder–humid
	AREL-8c	Heathland, with small localized tree populations.	Cool–humid
	AREL-9a	Grassland, with small localized tree populations.	Cold–less humid
	AREL-9b	Open heathland, with small localized tree populations.	Cold–more humid
	AREL-9c	Grassland, with small localized tree populations.	Cold–drier
	AREL-9d	Open heathland, with small localized tree populations.	Cold–more humid
	AREL-9e	Grassland, with small localized tree populations.	Cold–drier
	AREL-9f	Open heathland, with small localized tree populations.	Cold–more humid
	AREL-9g	Grassland	Cold–drier
	AREL-10a	Heathland, with small localized tree populations.	Cool–humid
	AREL-10b	Open heathland, with small localized tree populations.	Colder–drier
	AREL-10c	Heathland, with small localized tree populations.	Cool–humid
	AREL-10d	Open heathland	Colder–drier
	AREL-10e	Heathland, with small localized tree populations.	Cool–humid
III	AREL-11a	Open heathland with occasional *Betula* or *Quercus* woods.	Temperate–humid
	AREL-11b	Open heathland with occasional *Quercus* or *Betula* woods.	Warmer–humid
	AREL-11c	Open heathland, localized tree populations.	Cool–humid
	AREL-12a	Temperate open woodland, or occasional woods. *Q. robur* type dominant.	Warm–humid
	AREL-12b	Heathland. Woodland contracts.	Cooler
	AREL-12c	Temperate open woodland, or occasional woods. *Q. robur* type dominant.	Warm–humid
	AREL-13	Heathland, with localized tree populations.	Cool–humid
	AREL-14a	Increase in *Betula* and *Quercus* woods or open woodland within heathland.	Less cold than 13
	AREL-14b	Heathland. Woodland contracts.	Cool–humid
	AREL-14c	Heathland. Woodland expands.	Less cold than 14b
	AREL-15	Open heathland, with localized tree populations.	Cool–less humid
	AREL-16	Woodland expands. *Q. robur* type dominant.	Warm–humid

Goñi et al., 1999; see Fig. 1). These latter are dominated by gymnosperms (*Pinus*, *Cedrus*, Cupresaceae, *Abies*) and also feature pollen typical of the Mediterranean (*Olea*, *Phillyrea*, *Pistacia*, *Ephedra*) or steppe (*Artemisia*, Chenopodiaceae), while lacking taxa that are characteristic of Area Longa, such as *Fagus*, *Arbutus*, *Castanea* and *Juglans*. This suggests that these offshore pollen spectra mainly reflect the vegetation of central and southern Iberia, possibly with some additional contribution from North African biomes.

OIS 4

Throughout Europe, OIS 4 saw major deforestations and a predominance of open vegetation, notably Poaceae and cryoxerophilous *Artemisia* and Chenopodiaceae (see, for example, Allen et al., 1999; Müller et al., 2003). By contrast, Area Longa shows no signs of arid steppe vegetation, and coniferous taxa are also uncommon here (Fig. 4, Table 4). Instead, the high and mutually complementary percentages of *Erica*, *Calluna* and Poaceae indicate that heath and temperate grassland alternated as the predominant vegetation types throughout the Level II period. We interpret this as showing that although NW Iberia was not unaffected by the cooling that occurred globally during OIS 4, its climate continued to be relatively humid, at least close to the sea. This would be consistent with the climatic behavior here in other epochs, cold events during the Pleistocene and Holocene usually having given rise to brief but dramatic increases in the abundance of Poaceae and heath (Muñoz Sobrino et al., 2004, 2005). Furthermore, the persistence in Level II of a number of thermophilous and mesophilous tree taxa (*Picea*, *Q. robur* type, *Corylus*, *Fagus*, *Carpinus*, *Ulmus*, *Ilex*) strongly suggests

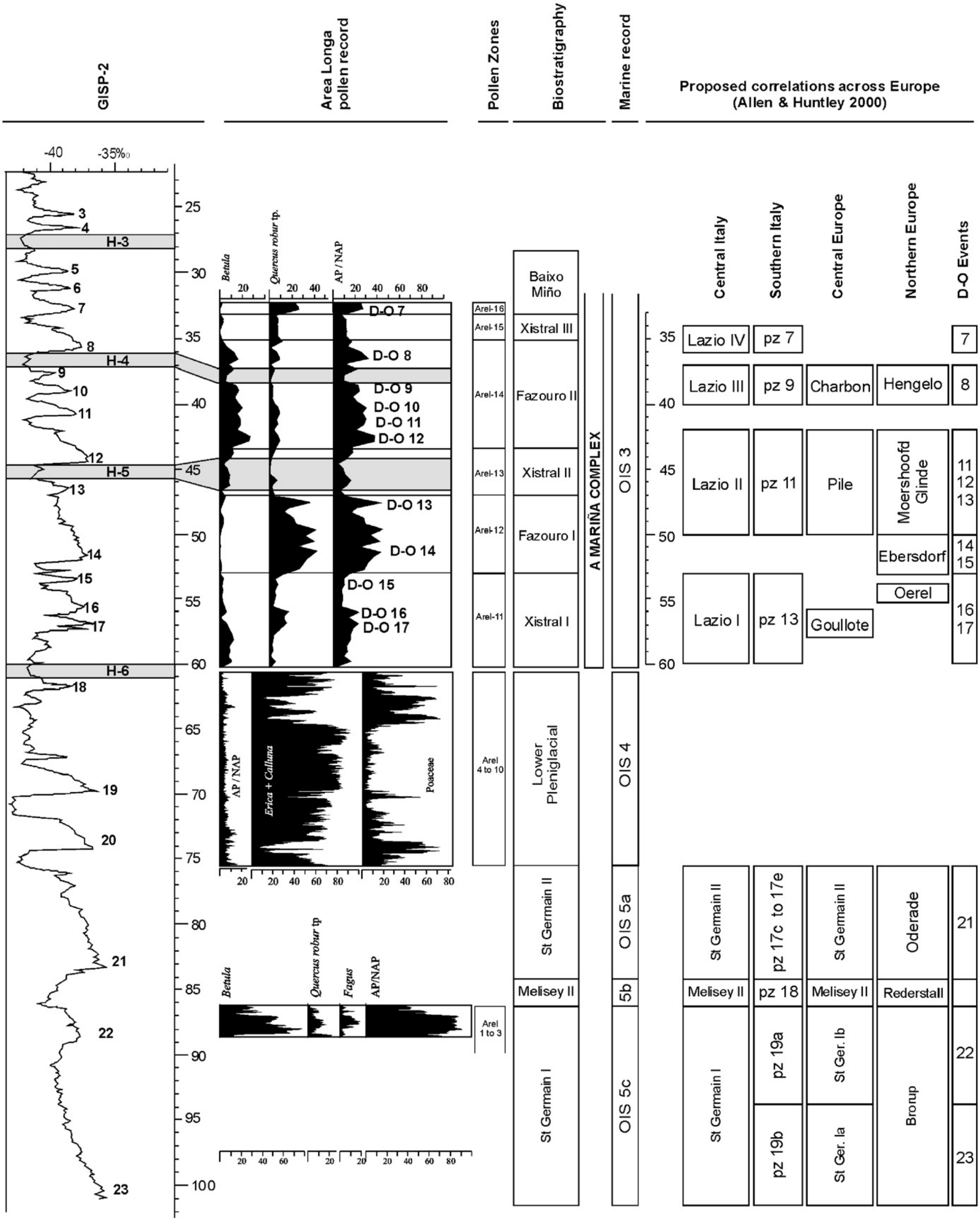

Figure 6. Tentatively proposed correlation between the main pollen levels at Area Longa, the GISP-2 isotope record (taken from Dansgaard et al., 1993), and other European pollen sequences. H-*n*, Heinrich event *n*; D-O *n*, Dansgaard–Oeschger cycle *n*.

that this region contained areas affording shelter to these less cold-resistant species. The arrival of these pollen grains at Area Longa by long-distance transport seems unlikely given the relatively well-developed local woodland (more than 20% of all terrestrial pollen is arboreal), the scarcity of contemporaneous woodland areas in SW Europe (Pons et al., 1992; Follieri et al., 1998; Huntley et al., 2003; Müller et al., 2003) and the fact that the prevailing winds at Area Longa come in from the Atlantic. The possibility of sedimentary reworking is similarly negligible, given the fine layering of the clays constituting the upper part of Level II.

OIS 3

Level III is a peat layer dated to over 35,000 ^{14}C yr BP, making it no more recent than the mid-pleniglacial period (OIS 3). The chronological data fail to clarify whether it covers all of OIS 3, although the correspondence between the observed pollen fluctuations and the Heinrich and Dansgaard–Oeschger events recorded in ice cores suggests that it spans that entire interval (Fig. 6). The effects of OIS 3 on European climate and flora, as reflected in long European pollen records, have been controversial because of dating difficulties and regional differences in biostratigraphy. It nevertheless seems clear that relatively warm and cold periods alternated throughout this stage (see, e.g., Van Andel, 2002; Mangerud et al., 2003).

Level III of the Area Longa sequence exhibits three clear phases of deciduous woodland expansion: AREL-12, AREL-14 and AREL-16. AREL-12 and AREL-14 appear to be complete records of their epochs, but AREL-16 seems to have suffered the irruption of coarse sediments with large angular blocks, possibly during the last glacial maximum (OIS 2). The first woodland expansion phase, AREL-12, started before 42,000 ^{14}C yr BP, and to judge by both the larger proportion of arboreal pollen and the dominance of deciduous *Quercus* must have been the warmest lengthy subperiod of OIS 3 at Area Longa (Table 4 and Fig. 6). The second temperate phase, AREL-14, appears to have been both somewhat less wooded and colder, the dominant tree pollen being *Betula* (Tables 2 and 4). Finally, the start of AREL-16 around 35,000 ^{14}C yr BP again shows a predominance of deciduous *Quercus*, reflecting a climate that, given the marked decline in Poaceae pollen, may have been even warmer than AREL-12. Although the interruption of the sequence limits the confidence with which this conclusion may be drawn, the occurrence of a marked climatic improvement during AREL-16 is supported by the sequence obtained at Oia on the Atlantic coast of NW Iberia (Gómez-Orellana, 2002): the temperate phase that was named Baixo Miño in the Oia sequence, which shows an even more marked dominance of deciduous woodland than AREL-16, is dated 34,250 ^{14}C yr BP and may therefore correspond to AREL-16.

Cold intervals preceding the woodland expansions of AREL-12 and AREL-14 appear to be reflected by AREL-11 and AREL-13, both of which show a predominance of temperate grassland and heath. By contrast, Poaceae become predominant in AREL-15, which may indicate both a harsher climate and hydrological changes in wetlands (Muñoz Sobrino et al., 2004).

At other points of the northern and western Iberian coasts the pollen data for OIS 3 are different from but not incompatible with the Area Longa data. The pollen spectrum of the peat layer dated 41,400 ^{14}C yr BP at Kurtzia, at the eastern end of the Cantabrian coast (Fig. 1), is dominated by *Alnus*, accompanied by significant percentages of *Pinus*, *Betula* and *Abies* and smaller proportions of *Fagus*, *Myrica*, *Corylus* and *Tilia* (Muñoz et al., 1989–1990); and although sites on the central Atlantic coast (Fig. 1) show a predominance of *Pinus* during the warmer OIS 3 phases (Diniz, 1989; Granja and Carvalho, 1995), deciduous tree pollens are also recorded (*Alnus*, *Betula*, *Acer*, *Carpinus*, *Corylus*, *Ulmus*, *Celtis*, *Salix*). By contrast, the deep ocean sequences that have been published have pollen spectra similar to those of earlier periods, the predominant conifers being accompanied mainly by cryoxeric or cryoxerophilous species, many of them characteristic of Mediterranean biomes (Sánchez Goñi et al., 2000; Roucoux et al., 2005). Thus, the deep ocean cores appear not to provide an accurate picture of NW Iberian biomes and climates during OIS 3. It seems likely that, rather than recording large-scale transmutations of the dominant NW Iberian biomes, as has been claimed (Sánchez Goñi et al., 1999, 2000; D'Errico and Sánchez Goñi, 2003), these cores may reflect relatively short-range fluctuations in the boundaries of pockets harboring climatically sensitive vegetation (see Muñoz Sobrino et al., 2004).

Though the warm phases of OIS 3 at Area Longa are not as warm as interstadials OIS 5b and 5c, and the cold phases not as cold as OIS 4 and OIS 2, their alternation suggests that this period should be regarded as an interstadial complex. Similar sequences have been recorded at sites in northern and central Europe and in the Mediterranean region, but their correlation with Area Longa is hampered by their scant biogeographical affinity with the latter. We have thus resorted to local toponymy to denominate the interstadial complex recorded at Area Longa (the "A Mariña Complex"), its three woodland phases (Fazouro I, Fazouro II and Baixo Miño, in order of decreasing age) and the three cold intervals that precede the latter (Xistral I, II and III); see Figure 6.

Conclusions

The new Area Longa sequence provides a solid basis for the biostratigraphy of the last Pleistocene glaciation in NW Iberia, a region in which the paucity of data has hindered evaluation of vegetation history prior to 18 ka. It is particularly valuable for illustrating how climatic fluctuations during OIS 3 affected vegetation composition and landscape in the Atlantic region of SW Europe. The findings for the early Würm are likewise significant, even though they represent only part of a wooded phase that can only tentatively be attributed to one of the Prewürm interstades, St. Germain I and II. The picture of NW Iberian vegetation dynamics that emerges is as follows.

As elsewhere in Europe, the landscape was dominated by deciduous woodland during the early glacial period (OIS 5c; AREL-1 to AREL-3) and by herbaceous or shrub vegetation during the lower pleniglaciation (OIS 4; AREL-4 to AREL-10). However, the scant presence of cryoxerophilous taxa during the latter period suggests that the climate must have been rather less arid than elsewhere in Europe, a circumstance that would account for the persistence of what appear to have been small populations of mesophilous and thermophilous taxa. OIS 3 (AREL-11 to AREL-16) was a more complex period than its predecessors. Woodland was more abundant than in OIS 4, but not dominant, and underwent a number of cycles of expansion and regression (at Area Longa, two such cycles, represented by AREL-12/13 and AREL-14/15, were followed by the beginnings of a third expansive phase, represented by AREL-16). These cycles, and smaller-scale fluctuations, correlate well with the ice-core record of Heinrich events and Dansgaard–Oeschger cycles (Fig. 6).

Throughout the Area Longa sequence, there are marked variations in the dominant species within both the arboreal and the non-arboreal vegetation groups. However, the best-represented trees are always deciduous taxa, mainly *Betula* and deciduous *Quercus*, which reach overall dominance in the various warm periods. Even during OIS 4 there is only a very low prevalence of conifers, which are found with higher abundances in other European sequences during stadials OIS 4 and 2. While the diversity of herbs and shrubs remains practically constant throughout the Area Longa record, the 22 tree taxa recorded for the early glacial period falls to 16 at the beginning of the colder OIS 4 period and only 9 at its end, with no recovery in numbers during the OIS 3 interstadial complex (perhaps due to the shortness of the warm phases of this complex). Of course, it is always possible that small populations of the lost tree taxa persisted in NW Iberia without representation at Area Longa (see Ramil-Rego et al., 2000; Gómez-Orellana, 2002).

Finally, there are also marked differences between the abundance of certain tree taxa in the Area Longa pollen sequence and in present-day NW Iberia. In particular, *Fagus*, which at present extends no farther west than the mountains of inland Galicia (Ramil-Rego et al., 2000), appears to have dominated the lowland woodlands of NW Iberia during the early glacial period. Similarly, *Abies*, *Picea*, and *Carpinus*, which were also present close to the sea during the early glacial and pleniglacial periods, are currently found only much farther east in the Iberian Peninsula.

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