An early Holocene short climatic event in the northwest Iberian Peninsula inferred from pollen and diatoms

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Abstract

Pollen and diatom analyses have been carried out in a 490-cm long core collected from Laguna Lucenza (1420 m a.s.l.; northwest Iberian Peninsula), spanning the last 10,000 years. Pollen analyses show a decrease in deciduous *Quercus* pollen percentages and total pollen concentration after radiocarbon date 8,350±80 yr BP. The estimated age by linear interpolation for the peak of this event is about 9,200 cal. yr BP. Diatom analyses have been carried out at same samples in order to obtain complementary information about past environmental conditions within the water body. Pollen and diatom records show a response to changes in the paleoenvironmental conditions. Diatom concentrations are relatively low, indicating low productivity within the lake. *Fragilaria* species are dominant and *Fragilaria exigua* is notably more abundant than during previous periods. These changes in the diatom community reflect a decrease in lake pH. This would be consistent with longer periods of ice cover and cold conditions in the lake at this time. We interpret this episode as a response to climatic change probably due to climatic deterioration. This interval coincides, at least in part, with an episode of abrupt and short widespread climate change lasting from 9,000 to 8,000 yr BP.

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1. Introduction

In the last few years, the climatic variability during the Holocene has been a subject of debate. Recent palaeoclimatic research suggests that the Holocene may have been characterized by a more dynamic climate than previously thought (i. e. O'Brien *et al.*, 1995; Bond *et al.*, 1997). While detailed examination of high-frequency climatic variability in the present interglacial has focused mainly on ice-cores (Alley *et al.*, 1997; Meese *et al.*, 1994) and marine records (Bond *et al.*, 1997), little is known about Holocene climatic variability from continental records of southwest Europe and there is a need to gather more information from terrestrial sources. If changes in the thermohaline circulation are the main driving force of this climatic variability, it might be expected that a decrease in thermohaline circulation would have an influence on local or regional climate. These changes would have had an impact on the vegetation of the Iberian Peninsula and, as a consequence, on the pollen records of this region.

In this paper we present palaeolimnological and palaeoecological data from a lake sediment sequence from northwest Iberian Peninsula (Laguna Lucenza, Courel Sierra), which suggest a shift to cooler climatic conditions between 8,600 and 8,000 yr BP. At Laguna Lucenza, Santos *et al.* (2000) report palynological data showing a decrease in both deciduous *Quercus* pollen percentages and total pollen concentration at c. 8,300 yr BP. A complementary proxy record of palaeolimnological conditions from this site is available from the study of the diatoms. The combined study of these two proxies allows greater insight about the nature of this event, demonstrating a climatic deterioration coinciding with a short cooling event recorded on marine and ice cores (Duplessy *et al.*, 1992; Bond *et al.*, 1997).

2. Environmental Setting

Laguna Lucenza (latitude 42°36'N; longitude 3°24'W; altitude 1420 m a.s.l.) is a small lake (0.5 hectares) located in the Courel Sierra, northwest of the Iberian Peninsula (Fig. 1). This sierra is formed by a mountain chain folded in a north-easterly and highly fractured by parallel faults. It displays high altitudinal contrasts reaching elevations greater than 1600 m (Formigueiros, Pía Paxaro) and somewhat lower ones (400-500 m), through which Lor River flows (Fig. 1). Abrupt relief and enclosed valleys make up the profile of the zone. From a geological point of view, the most prominent feature of the area is that it has suffered numerous tectonic processes which have caused an extremely complex distribution of the different strata, resulting frequently in the superimposition of older materials over more recent ones (IGME, 1981). The outcrops are rocks of sedimentary origin, subsequently deformed and metamorphized. Apparent here is the presence of sandstone, slate and quartz combined with formations of limestone and dolomites.

The climate of this sierra is complex. The upper slopes are open to the effects of oceanic influences, whereas, in the shelter of the valleys, summer droughts reflect the distance from the coast. Mean annual precipitation is around 2500 mm, while the mean annual temperature oscillates between 7°C and 12°C (Aira Rodríguez, 1986). The flora displays various phytogeographic characteristics reflecting the transitional position of this sierra between Eurosiberian and Mediterranean regions (Izco Sevillano *et al.*, 1982). It is possible to identify Eurosiberian-type deciduous forests belonging to the phytosociological class *Querco-Fagetea* (beech-forest, *Quercus pyrenaica*-forest, *Alnus*-forest, *Betula*-forest), as well as Mediterranean-type perennial vegetation composed mainly of *Quercus ilex*. However, the present-day vegetation of the sierra is basically scrubland and pasture (Amigo Vázquez, 1985;

Guitián Rivera, 1985). The most abundant scrub includes heather (*Calluna* and *Erica*) and Atlantic and Mediterranean-Iberoatlantic species of *Ulex*.

The dominant vegetation of the surrounding area is basically scrubland and pasture. A small stand of *Salix* sp. is located near Laguna Lucenza and a few specimens of *Betula* sp. are scattered on the upper slopes.

3. Materials and methods

A 490-cm long core was taken at the central part of the lake (Fig. 1) using a 50-cm long, 4-cm diameter Russian corer (Jowsey, 1966). The core was transferred in the field into plastic gutter pipes wrapped with plastic foil and stored in the lab at 4°C. Sediments were characterized using the Troels-Smith (1955) system. Conventional radiocarbon dating was carried out in the Laboratorio de Isotopos Ambientais (ICEN) in Sacavem (Portugal), while the Tandem Laboratory (Ua) at the University of Uppsala (Sweden) provided the AMS dates (Table 1). A calibrated age range within two sigma confidence limits was obtained using the Calibration Program of Stuiver and Reimer (1993, Mac Test Version #7).

Sampling at 10-cm intervals was conducted for pollen and diatom analyses. Pollen grains were counted using a Nikon Labophot II microscope at x400 and x1000 (oil immersion) magnifications. Pollen identifications were based on the pollen reference collection at the Department of Earth Sciences of the University of A Coruña as well as on M. Reille's atlas (Reille, 1992). An average of 300 grains and 20 pollen taxa per sample was carried out, and the pollen concentration was calculated according to Cour's Method (Cour, 1974). The pollen percentage for terrestrial taxa is based on the main pollen sum which excludes aquatics and spores. The sum used for the percentage calculation of aquatics and ferns was the total sum, inclusive of aquatics, spores, indeterminables and unknowns.

Diatoms were extracted and slides prepared according to standard procedures (Renberg, 1990) with minor modifications. Diatom valves were counted in strewn slides (Naphrax mountant, r. i. = 1.74) with a Nikon Optiphot II phase-contrast microscope at x1000. Raw counts were converted to percent abundances. Counting techniques followed Battarbee (1986). Diatom concentration was determined using microsphere markers (Battarbee and Kneen, 1982). Identification of the diatom species was made using several floras (Hustedt, 1930; Cleve-Euler, 1951-1955; Patrick and Reimer, 1966-1975; Krammer and Lange-Bertalot, 1986-1991).

Pollen and diatom stratigraphical diagrams were prepared using the PSIMPOLL computer program (Bennett, 1992), and the descriptive presentation of both the pollen and diatom data is based on the concept of the "assemblage zone" (Birks and Birks, 1980).

Diatom data were analysed using stratigraphically constrained agglomerative method; the method applied was constrained incremental sum of squares cluster analysis (CONISS; Grimm, 1987), as implemented in the PSIMPOLL program (Bennett, 1992). Square root transformation was used in order to optimise the signal to noise ratio. The "brocken-stick" model was used to assess the significance of diatom assemblage zones (Bennet, 1996).

4. Results

4.1. Sediment lithostratigraphy

Coring reached a depth of 490 cm and the sediment is relatively uniform. A layer of bluish-grey compacted clay occurs at the base of the sequence. This is overlain by a layer of highly organic silt and clay with various changes in colour and texture, an organic silty layer containing some slender roots, and a highly organic clay layer with abundant roots at the top. A detailed sediment lithology of the Laguna Lucenza sequence is shown in Figs. 2 and 3.

4.2. Radiocarbon chronology

The results of radiocarbon dating are displayed in Table 1. Eight ^{14}C dates were obtained on bulk samples of sediment. Assuming the chronological model detailed in Santos *et al.* (2000) the estimated age for the bottom of the sequence is of ca. 9,800 yr BP. The overall sedimentation rate is of 0.5 cm $year^{-1}$.

4.3. Pollen analysis

The pollen record was divided into thirteen pollen assemblage zones (PAZs). These are numbered upwards from the base of the sediments and referred to using the prefix LUC- (Fig. 2). A brief description of the pollen assemblage zones is given in Table 2.

4.4. Diatom analysis

The diatom data are presented in the form of a stratigraphical diagram with depth as the principal y-axis (Fig. 3); the series of diatom assemblage zones (DAZ) are numbered from the bottom upwards. Six zones are distinguished. Brief descriptions are given in Table 3.

This paper is focused on the discussion of the significance of both proxy records in the 450-350 cm interval dated between 9,000 yr BP (radiocarbon date 8,950±85 yr BP) and 7,500 yr BP (estimated age).

5. Discussion

5.1. Palaeoenvironmental reconstruction

The summary diagrams for the pollen and diatom data and an outline of the sediment lithology are presented in Fig. 4. The palaeoclimatic reconstruction for the interval between 450 and 350 cm depth has been inferred using the combined information from these sources.

A detailed palynological study of the Laguna Lucenza sequence (Santos *et al.*, 2000) shows an abrupt decrease in *Quercus* pollen frequency and total pollen concentration at about 8,300 yr BP. This decrease combined with the increase in herbaceous taxa suggests a reduction in the forest cover at that time. However, Santos *et al.* (2000) interpret that the expansion of *Corylus* during this phase argues against such a cold period. Furthermore, in Laguna Lucenza this event coincides with the increase in microcharcoal particles; suggesting that an increase in the frequency of fires could cause a reduction of *Quercus* woodland and the subsequent recolonisation by *Corylus* (Santos *et al.*, 2000). A retreat of *Quercus* at c. 8,300 yr BP is also recorded in various palynological diagrams of the Iberian Peninsula: Sanabria Marsh (Menéndez Amor and Florschütz, 1961; Turner and Hannon, 1988), Padúl (Pons and Reille, 1988), Lagoa Comprida (Janssen and Woldringh, 1981; Van der Knaap and Van Leeuwen, 1995). Although, the explanation for the coincidence in various palynological diagrams of this retreat would be a general climatic deterioration, Santos *et al.* (2000) also point out that other diagrams from the Iberian Peninsula (e.g. Quintanar de la Sierra, Peñalba, 1994; Las Pardillas, Sánchez Goñi and Hannon, 1999) do not record this climatic event. This could be explained by local factors which mask the global climatic and vegetational signals. Moreover, none of the pollen records from the Iberian Peninsula reflect a millenium-scale climatic variability similar to that suggested by the recent studies on marine and ice cores (Bond *et al.*, 1997), as it is discussed further on.

Diatom analyses were performed at the same samples in order to obtain parallel independent information wich may complement the previous palynological interpretation. This stage is characterized by a decrease in diatom concentrations, denoting low productivity in the lake at about 8,300 yr BP. *Fragilaria* species are dominant and *Fragilaria exigua* is markedly more abundant than in previous periods. *Fragilaria exigua* is an acidophilous taxon abundant at several Antarctic sites today (Flower *et al.*, 1996), and at shallow oligotrophic lakes with low light penetration in tundra regions (Pienitz *et al.*, 1995). This change is followed by a decline in the relative abundance of *Fragilaria construens* f. *venter*, an increase in the proportion of benthic taxa and low pH values. *Fragilaria construens* f. *venter* is associated with more aquatic habitats (Krammer and Lange-Bertalot, 1986-1991; Patrick and Reimer, 1966-1975) and its dominance has been related with a warmer climate during the mid Holocene (Brown *et al.*, 1994; Wilson *et al.*, 1997). So the decline of *F. construens* f. *venter* and dominance of *F. exigua* may suggest a lowering water level and a decrease of water temperature.

The pollen-based palaeoclimatic reconstruction may be of markedly colder conditions. This is consistent with the changes in the diatom assemblages, which indicate a cooling and lengthening of the winter with greater duration of the ice-cover on the lake, limiting mixing and hence nutrient availability. Cooler years with high inputs of acidic spring meltwater and lowered in-lake alkalinity generation led to lower pH relative to warmer, drier years (Psenner and Schmidt, 1992). The sensitivity of diatoms to pH has been well documented and, in poorly buffered lakes where alkalinity can be related to climatic change (Fritz, 1996), diatoms can provide a tool for inferring climate-driven shifts in alkalinity.

Between 450 and 350 cm depth both records exhibit a comparable fluctuation that we have interpreted as a response to environmental changes probably due to climatic deterioration. Pollen data were also used to make a quantitative reconstruction of palaeoclimatic conditions. Values for mean temperature of the coldest month were obtain using the transfer function of Guiot and Goeury (1999). The preliminary results of palaeotemperature reconstruction according to Guiot and Goeury (1999) reflect an important decrease during this interval.

5.2. Comparison with other sequences

Recent studies on marine and ice cores indicate several short cooling events dated at 9,800, 9,100, 8,600, 7,400, 5,200, 4,000, 2,700 and 1,600 yr BP reflecting a pervasive millenial-scale cycle in the North Atlantic Holocene which would coincide with abrupt changes in the atmospheric circulation above Greenland (Bond *et al.*, 1997). If real, these changes would have had an impact on the vegetation of the Iberian Peninsula and, as a consequence, on the pollen records of this region (Sánchez Goñi, 1999).

Only some of these cooling events are detected on the Iberian pollen records and there is not a chronological coincidence in all sequences. In Sanabria marsh (northwest Spain; Allen *et al.*, 1996) and in core CC-17 (southeast Spain; Dorado Valiño *et al.*, 1999) the 8,600 yr BP cold event could be registered. In addition in Navarrès (southeast Spain; Carrión and Dupré, 1996), Balearic islands (Yll *et al.*, 1997) and also in core CC-17 (southeast Spain; Dorado Valiño *et al.*, 1999) the 5,200 yr BP cold event could be evident. On the other hand, Las Pardillas Lake (north central Spain; Sánchez Goñi and Hannon, 1999; Sánchez Goñi, 1999) seems to detect vegetational changes at the well known "8,200 cal. yr" cooling event (7,400 yr BP) and at the 4,000 and the 1,600 yr BP cooling events.

Pollen and diatom records from Laguna Grande, a site close to Laguna Lucenza but in a different catchment, exhibit a similar fluctuation coinciding temporally with the event recorded in Laguna Lucenza. Pollen data indicate that pollen production decreases for a short time (Maldonado Ruiz, 1994). Diatom concentration also appears to have decreased and the lowered pH values suggest that the lake productivity fell in the aquatic system (Leira, 2000).

Recent palaeoclimatic research in Mediterranean coastal sites identifies six major climatic changes in holocene vegetation cover that correspond to aridification phases (Jalut *et al.*, 2000). In the Swiss Plateau and at timberline in the Alps, palaeoecological studies have found a cold phase at 8,600-8,150 yr BP (Haas *et al.*, 1998). Thus, this cooling episode can be considered of regional importance (Haas *et al.*, 1998). Furthermore, on the basis of a high-resolution lacustrine record from Le Locle (Swiss Jura) has been reconstructed a short-lived but well marked event dated at c. 9,100-8,000 yr BP (Magny and Schoellammer, 1999). This phase coincides with the Central European cold phase CE-2 in the Swiss Alps dated between 8,600-8,200 yr BP (Haas *et al.*, 1998).

The dry event suggested by the study of pollen and diatoms in the Laguna Lucenza sequence could be linked with the marine cooling event dated at c. 8,600 yr BP. This climatic event marked by cooler conditions appears to coincide with a major change in the North Atlantic Ocean. Thus, Sea Surface Salinity (SSS) and Sea Surface Temperature (SST) reconstructed from a core off Portugal (Duplessy *et al.*, 1992) shows a significant reduction in both salinity and temperature during the Early Holocene. A high -resolution diatom record from a core from the Norwegian sea shows a low in winter SSTs around 8,800-7,800 BP (Karpuz and Jansen, 1992).

Andrews *et al.* (1995) observed a detrital carbonate event dated to c. 8,400 yr BP present in sediments along the Labrador margin and Hudson Strait younger than a YD Heinrich-like event (H0). Other works along the east Greenland margin show a return to iceberg rafted debris (IRD) conditions centered at 9,000 cal. yr BP (Andrews *et al.*, 1997). These events might represent the final collapse of the ice sheet within Hudson Strait and Hudson Bay (Andrews *et al.*, 1995). As a result, an important flux of freshwater into the northwestern ocean ocurred. This water influx would be sufficient to weak the thermohaline circulation, resulting in a reduced heat transport and cold conditions over the North Atlantic and the European continent (Duplessy *et al.*, 1992).

In the Greenland ice records a number of proxies also shown a fluctuation lasting from 9,000 to 8,000 cal. yr BP (Alley *et al.*, 1997). Taking into account the error of the depth-age scale

(Alley *et al.*, 1993) this phase could be synchronized, at least in part, with Laguna Lucenza event. Moreover, it can be noted that this cool period appears to be coincident with an abrupt decline in the $\delta^{18}O$ of the sedimentary carbonate composition of Devil Lake in Minnesota, U.S.A. (Hu *et al.*, 1999), indicating a pronounced climate cooling from 8,900 to 8,000 cal. yr BP.

Overall indications are consistent with evidence in north Europe that indicate a phase of water level lowering during the early Holocene (Harrison and Digerfeldt, 1993).

6. Conclusions

The millenial-scale climatic variability deduced from marine and ice records is far from being detected in continenetal records of the Iberian Peninsula. Only the marine cooling event dated at c. 8,600 yr BP could be linked with the cold event suggested by Laguna Lucenza record. Although there are differences with other reconstructions due to geographical location and in the vegetation response to climatic change, most records are contemporaneus suggesting the relevance of this cooling event

Until now, none of the pollen records from the Iberian Peninsula reflects a millenium-scale climatic variability similar to that suggested by marine and ice cores. This could be explained by several factors such as the intensity of these climatic cycles that trigger vegetational changes, the influence of local factors which mask the global climatic and vegetational signals and/or the low resolution of the pollinic studies. Complementary information provided by other proxies such as diatoms allows greater insight about the interpretation of past environmental conditions of the lake.

Whereas the two proxies exhibit a comparable response to climatic change, the relative magnitude of their responses differs. Although the pollen data exhibit some qualitative changes, the most significant changes seen in pollen percentages are small shifts in the relative abundance of taxa that are represented throughout. In contrast, changes in the diatom assemblages appear more pronounced because they are often qualitative changes involving numerically dominant species. The effect over the vegetation suggests, perhaps, that there may been a decrease in winter temperatures and precipitation.

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FIGURE CAPTIONS

Figure 1.- Detailed map of the Courel Sierra showing the location of the Laguna Lucenza sequence

Figure 2.- Pollen diagram from Laguna Lucenza (selected taxa)

Figure 3.- Diatom frequencies diagram along with the lithology; selected taxa only are shown

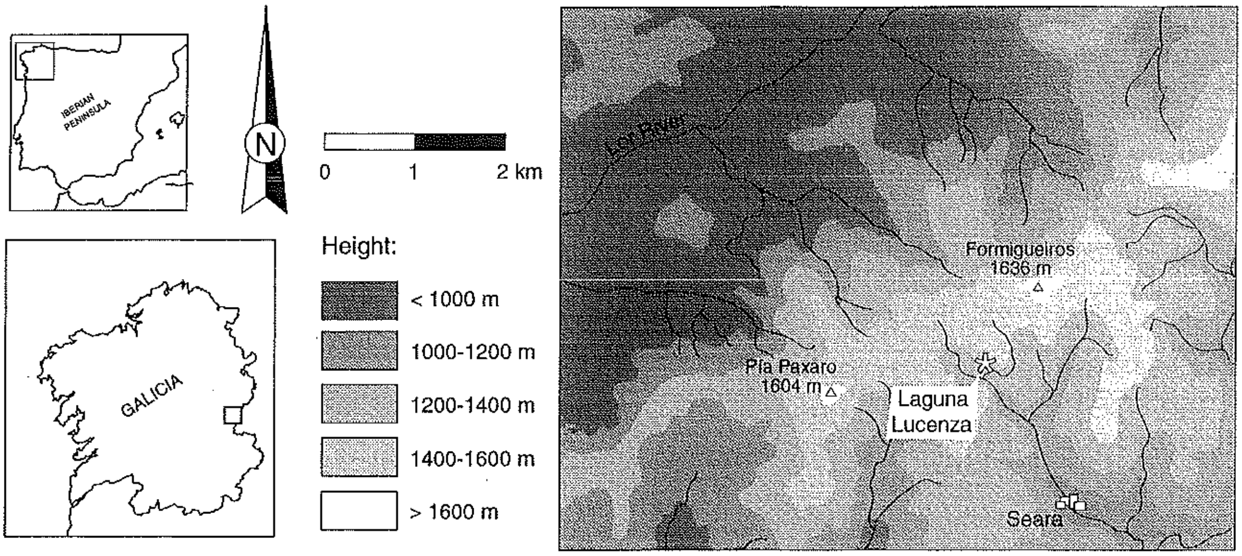
Figure 4.- Summary diagrams showing the pollen and diatom stratigraphy. Diatom inferred pH reconstruction according Renberg and Hellberg (1982)

TABLE CAPTIONS

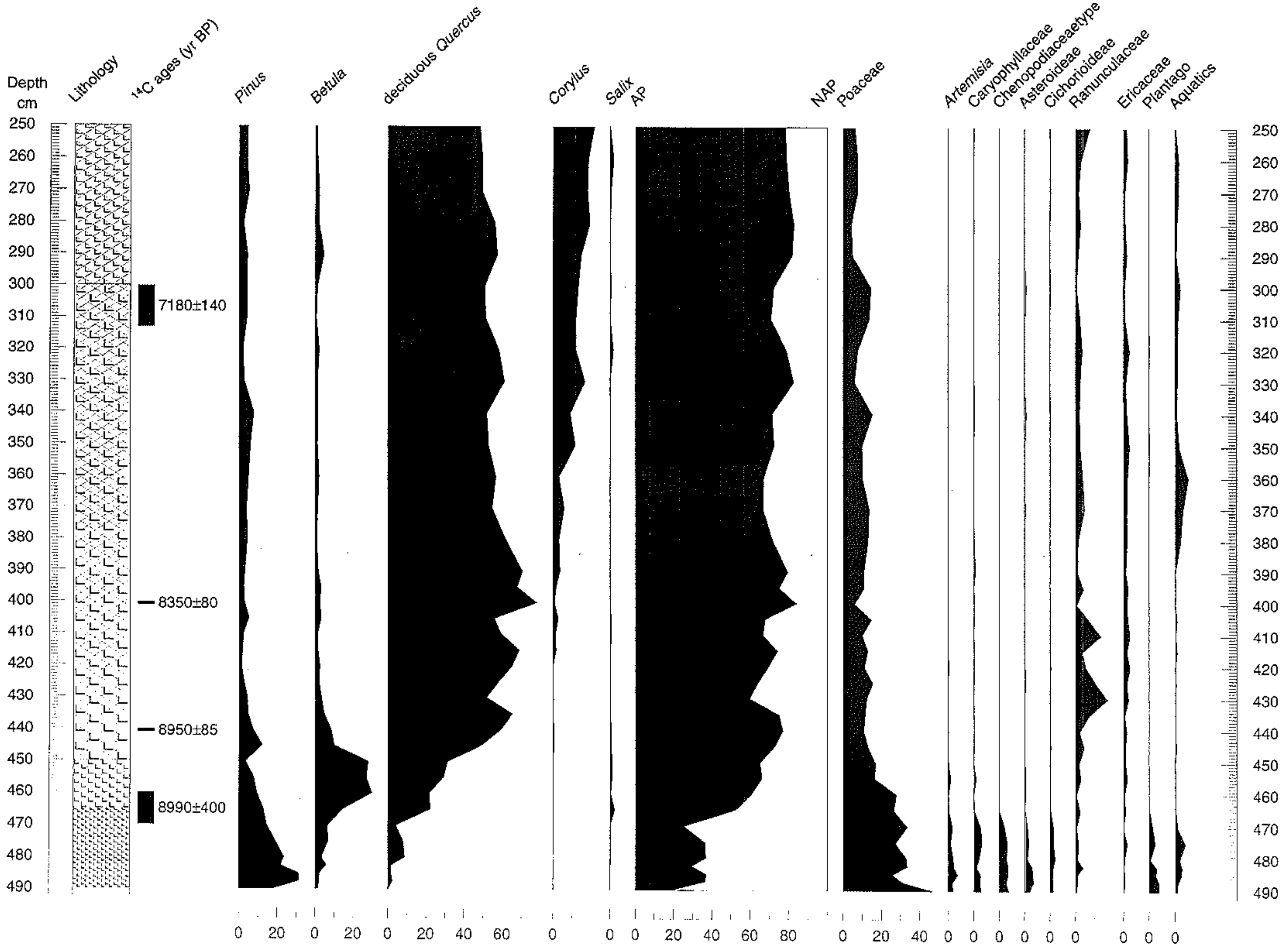
Table 1.- Radiocarbon dates from the Laguna Lucenza sequence (Santos *et al.*, 2000). The calibrated age range (Stuiver & Reimer, 1993) was calculated with a probability of 95,4% (two sigma). LS, lacustrine sediment; MLS, massive lacustrine sediment

Table 2.- Description of the pollen assemblage zones (PAZ)

Table 3.- Description of the diatom assemblage zones (DAZ)

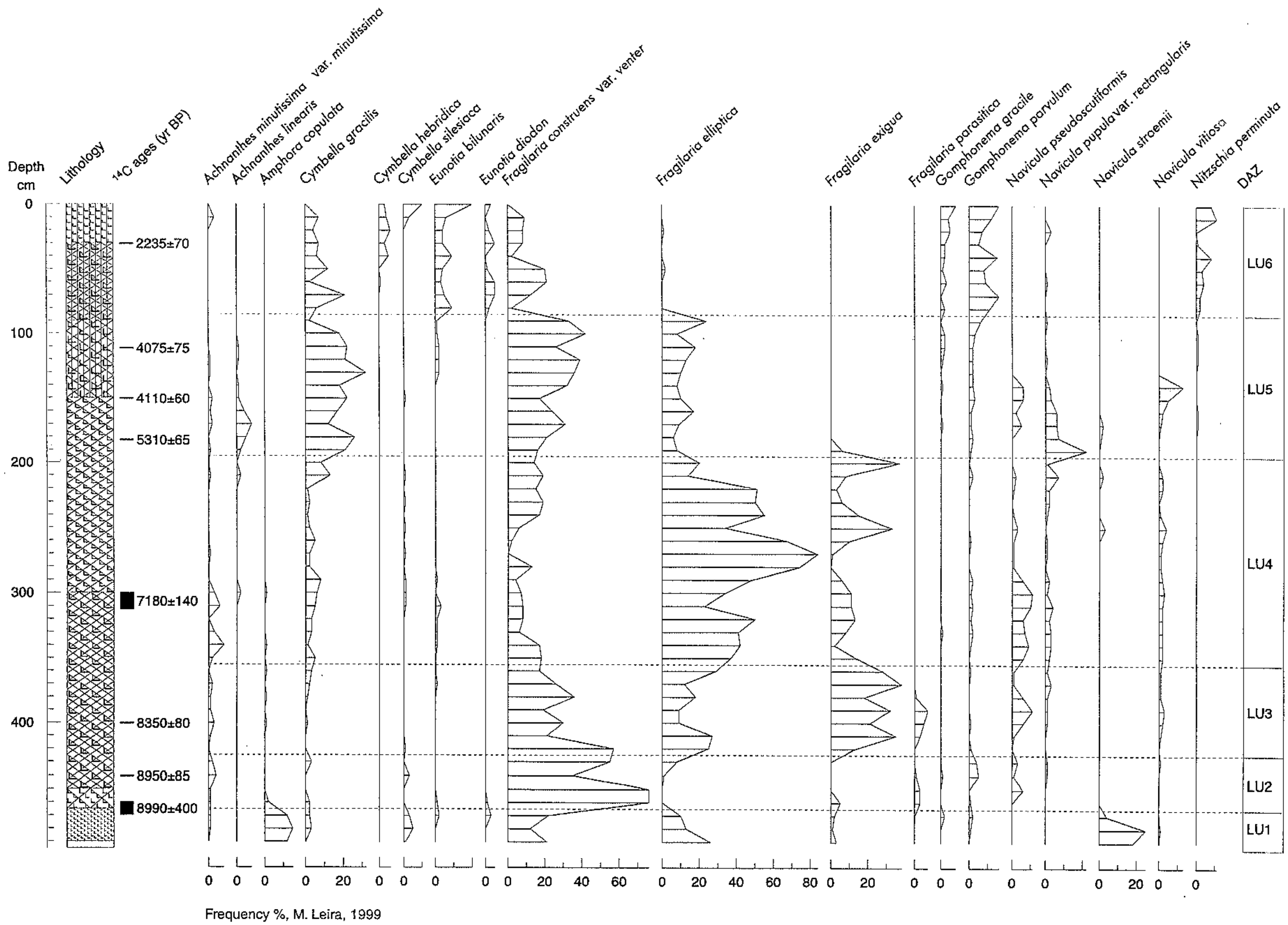

IBERIAN PENINSULA
GALICIA
N
0
1
2 km
Height:
< 1000 m
1000-1200 m
1200-1400 m
1400-1600 m
> 1600 m
Lor River
Formigueiros
1636 m
Pía Paxaro
1604 m
Laguna
Lucenza
Seara

Laguna Lucenza, 1420 m a.s.l. (Courel Sierra, NW Iberian Peninsula)

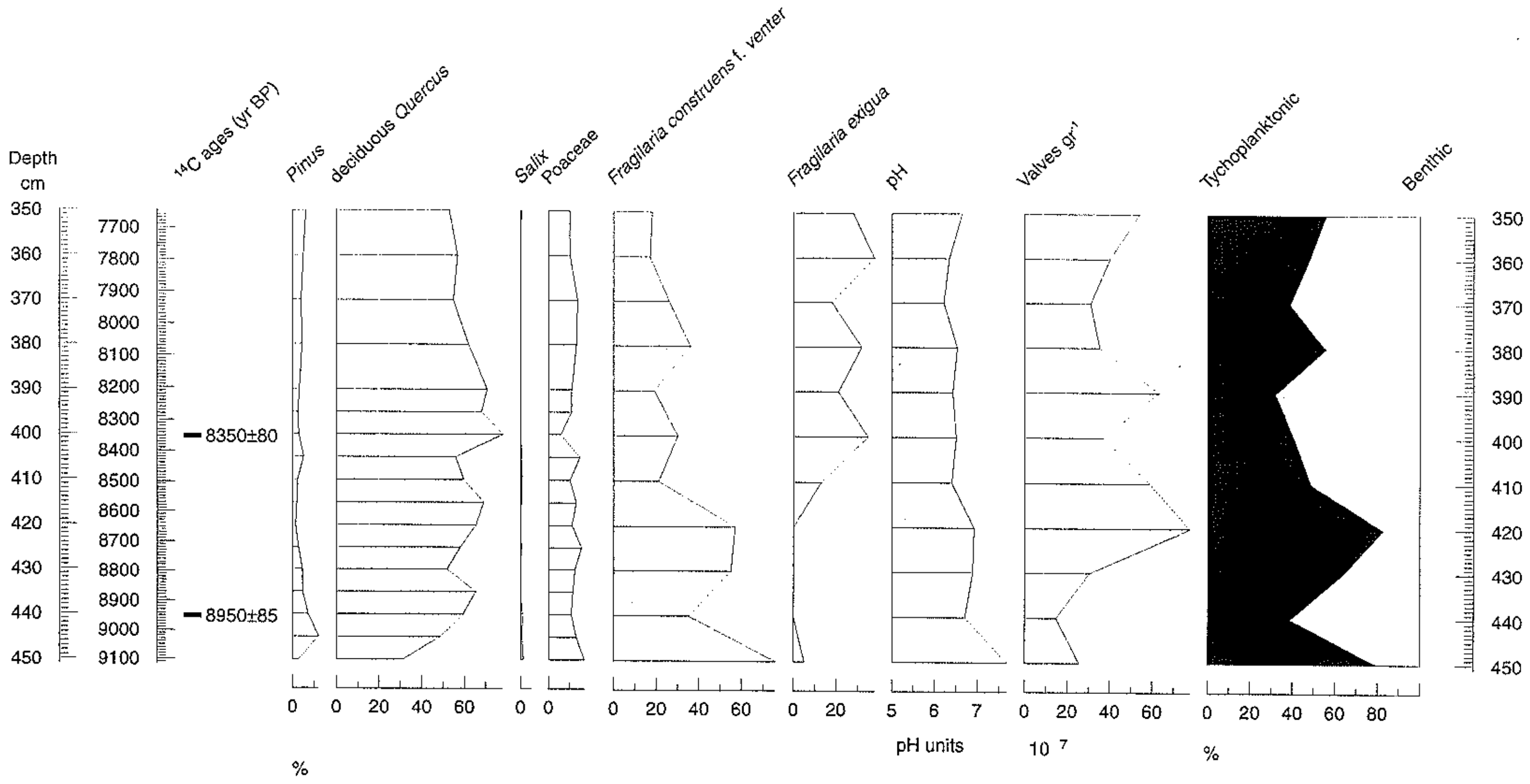


Frequency %, L. Santos, 1995

Laguna Lucenza, 1420 m a.s.l. (Courel Sierra, NW Iberian Peninsula)



Laguna Lucenza, 1420 m a.s.l. (Courel Sierra, NW Iberian Peninsula)



Site	Depth (cm)	Material dated	Reference laboratory	Age years (BP)	Calibrated age (BP)	Calibrated age (AD(+); BC (-))	δ^{13} C (‰)
LUC	30	LS	Ua-10832	2235±70	2351-2052	-401 -102	-26,77
LUC	111	LS	Ua-10833	4075±75	4735-4409	-2785 -2459	-27,64
LUC	150	LS	Ua-10141	4110±60	4734-4503	-2784 -2553	-29,10
LUC	182	LS	Ua-10834	5310±65	6209-5935	-4259 -3985	-28,74
LUC	300-313	LS	ICEN-1253	7180±140	8195-7661	-6245 -5711	-30,35
LUC	400	LS	Ua-10142	8350±80	9485-9185	-7535 -7235	-30,32
LUC	440	LS	Ua-10143	8950±85	10047-9807	-8097 -7857	-29,12
LUC	460-470	MLS	ICEN-1252	8990±400	10975-9204	-9025 -7254	-29,28

PAZ	Age (yr BP) Depth (cm)	Description
LUC-12 and LUC-13	2200-0 30-0	The reduced forest cover c. 2000 BP (Roman times), combined with the elevated values of Poaceae and Ericaceae reflect the opening up of the landscape. Deforestation is evident and cultivated plants appear.
LUC-10 and LUC-11	4000-2200 110-30	Arboreal pollen values continue to fall, except for *Salix* which increases locally. Poaceae and Ericaeae expand. There is an increase in Ranunculaceae pollen, perhaps associated with a sedimentary change, after which peat is recorded in the sequence.
LUC-6 to LUC-9	7500-4000 340-110	LUC-6 reflects maximum *Corylus* values. Development of the *Quercetum mixtum* around the site may have occurred during the climatic optimum of the Holocene. The consistently high concentrations of pollen are maintained practically up to the end of LUC-8 (4110 yr BP), where there is a slight general decrease in arboreal pollen values, together with the local colonisation of *Salix*. The vegetation composition appears to have remained stable for approximately 3500 years. In LUC-9 there is a gradual decrease in tree cover. Around 4500 BP, herbaceous plants re-expand, suggesting a reduced forest cover, possibly of anthropogenic origin.
LUC-5	8350-7500 400-340	A decrease in *Quercus* pollen percentages is recorded. This is accompanied by a slight increase in Poaceae and *Pinus*.
LUC-4	9100-8350 450-400	Values of *Quercus* continue to increase, indicating that the regional ecological conditions continue to favour expansion. The beginning of the continuous curve of *Corylus* before 8800 yr BP dates the expansion of the local population of this taxon. The herbaceous cover was poor and the lake is thought to have been surrounded by denser woodland than in the previous zone.
LUC-3	> 9300-9100 465-450	A general development of arboreal vegetation is evident. Thermo-mesophilous taxa expand from this point onwards. *Betula* pollen values display a brief maximum, and *Quercus* begins its expansion here. At the same time, the previously significant herbaceous taxa diminish or virtually disappear from the area.
LUC-2	> 9300 487.5-465	Represents the onset of the Holocene. Local development of aquatic taxa appears to indicate a transition to a more nutrient-rich environment and the beginning of the colonisation of the lake. *Quercus* and *Betula* forests begin to develop. *Corylus* was also present, indicating pockets of relatively mesic woodland. *Pinus*, Poaceae and heliophilous taxa pollen decrease within this zone. Some patches of herbaceous and dwarf shrub vegetation (*Artemisia*, Ericaceae, *Rumex* and Apiaceae) are also present.
LUC-1	> 9750 490-487.5	Represents approximately the final period of the Younger Dryas chronozone. Characterised by low pollen concentrations and reflects an open vegetation. Relatively high values of Poaceae and the significant presence of other heliophilous taxa (*Artemisia*, Caryophyllaceae, Chenopodiaceae, *Plantago* and Asteraceae) suggest an open environment and perhaps somewhat cooler conditions. *Pinus* pollen percentages make up 10-30% of the pollen recruited to the site.

DAZ	Age (yr BP) Depth (cm)	Description
6	3473-0 85-0	Zone of dramatic species overturn. The proportion of tychoplanktonic forms is markedly reduced at the transition to this zone. This is attributable to the decrease and near dissapearance of *Fragilaria elliptica* and decrease of *Fragilaria construens* f. *venter*. Benthic species increase in relative abundance and a vartiety of benthic forms are consistently present (*Gomphonema*, *Pinnularia*, *Eunotia* and *Cymbella*).
5	5484-3473 195-85	*Fragilaria construens* f. *venter* reappears and a substantial decrease is seen in the relative abundance of *F. elliptica* and *F. exigua* virtually disappears. Rapid increase in the relative abundance of *Cymbella gracilis*. A variety of benthic species exhibits small peaks in the relative abundance during this zone: these include *Navicula pupula* var. *rectangularis* and *Navicula vitiosa*.
4	7715-5484 355-195	The transition from DAZ3 is marked by the reappearance and subsequent rise to dominance of *Fragilaria elliptica*. *Fragilaria construens* f. *venter* decreases and *Fragilaria exigua* exhibits peaks in relative abundance during this zone. The proportion of tychoplanktonic species reaches a minimum in the middle of the zone.
3	8719-7715 425-355	This zone is marked by the appearance and rise of *Fragilaria exigua*. *Fragilaria construens* f. *venter* decreases.. Other species present in low abundances are *Fragilaria elliptica*, *Navicula pseudoscutiformis* and *Navicula pseudoventralis*.
2	9317-8719 465-425	A rapid increase in the relative abundance of the tychoplanktonic *Fragilaria construens* f. *venter* (peak relatively abundance ca. 76%) and the accompanying decrease in *Fragilaria elliptica* and disappearance of *Amphora copulata* and *Navicula stroemii* mark the start of this zone. *Pinnularia interrupta* exhibits a peak in relative abundance (22%).
1	>9750-9317 490-465	Small benthic *Fragilaria* (*F. elliptica*) are dominants. Other benthic species, *Amphora copulata* and *Navicula stroemii*, are relatively abundants.