Journal of South American Earth Sciences 19 (2005) 173–179

Journal of
South American
Earth Sciences

www.elsevier.com/locate/jsames

A Middle Wisconsin interstadial in the northern Andes

Valentí Rull*

Department of Animal Biology, Plant Biology and Ecology, Autonomous University of Barcelona, 08193 Bellaterra, Barcelona, Spain

Received 1 September 2003; accepted 1 January 2005

Abstract

This article reports the occurrence of a Middle Wisconsin interstadial, Pedregal, in the northern Venezuelan Andes, as demonstrated by high-resolution pollen analysis of a previously dated peat layer. Paleoclimatic trends are deduced mainly from changes in the abundance of tree pollen from the uppermost Andean forests. Previous calibration of this pollen with modern analogs has enabled reconstructions of prior altitudinal displacements of montane ecological belts and temperature changes. Paleotemperatures were deduced from the current lapse rate (−0.6 °C/100 m). After a glacier advance, represented by an underlying till, average temperatures increased to 3 °C lower than modern temperatures during the Pedregal interstadial and then dropped again to approximately 7 °C lower than modern. It is the oldest Quaternary paleoclimatic event reported thus far in the area.
© 2005 Elsevier Ltd. All rights reserved.

Keywords: Interstadial; Last glaciation; Paleoclimatology; Palynology; Pleistocene; Venezuelan Andes

1. Introduction

The last glacial epoch (Würm/Wisconsin) is represented in the Venezuelan Andes by the Mérida glaciation (Schubert, 1974) and characterized by two main stages: the Early Mérida, before 30^{14}C ka BP (Middle Wisconsin) and the Late Mérida (Late Wisconsin), which includes the last glacial maximum (LGM) between 25 and 13^{14}C ka BP (Schubert and Clapperton, 1990). Palynological work has contributed to the paleoecological understanding of the Late Mérida stage (Rull, 1998; Rull and Vegas-Vilarrúbia, 1996, 1998), late glacial/Holocene climatic shifts (see reviews by Salgado-Labouriau, 1989; Rull, 1996, 1999), and more recent climatic oscillations correlated with the Medieval Warm Period and the Little Ice Age (Rull and Schubert, 1989; Rull et al., 1987). However, little paleoecological information is available from the Early Mérida stage. The only pollen analysis performed thus far identifies the existence, between 51 and 34^{14}C ka BP, of a humid gallery forest a few hundred meters below the moraines of the Mérida glaciation (Salgado-Labouriau, 1984), which has been interpreted as a probable forest refuge area during glacial times. This article reports the pollen analysis of a peat layer that corresponds to the Early Mérida stage (Middle Wisconsin) and the reconstruction of the main vegetational and climatic features during its sedimentation.

2. Material and methods

2.1. Study site and chronology

The Mesa del Caballo is in the Mucubají region, where the Late Mérida stage originally was described (Schubert, 1974). Fig. 1 shows the location of the sampling site, which is close to the sampling point where the El Caballo stadial (16.5^{14}C ka BP) was reported (Rull, 1998; Rull and Vegas-Vilarrúbia, 1996, 1998). It is situated approximately 3500 m above sea level, within Páramo (*sensu stricto*) vegetation (Cuatrecasas, 1968). In the northern Andes, Páramo (*sensu lato*) refers to the altitudinal belt between the tree line and the permanent snow, as well as to the vegetation that occurs within this zone. In Venezuela, the Páramo (*s.l.*) extends from 2800 to 4700 m above sea level and coincides approximately with the 10 and 0 °C isotherms (mean annual temperatures), respectively (Fig. 1). Vegetation is open, with two well-differentiated strata: a lower that consists of

* Corresponding author.
E-mail address: valenti.rull@uab.es.

0895-9811/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsames.2005.01.002

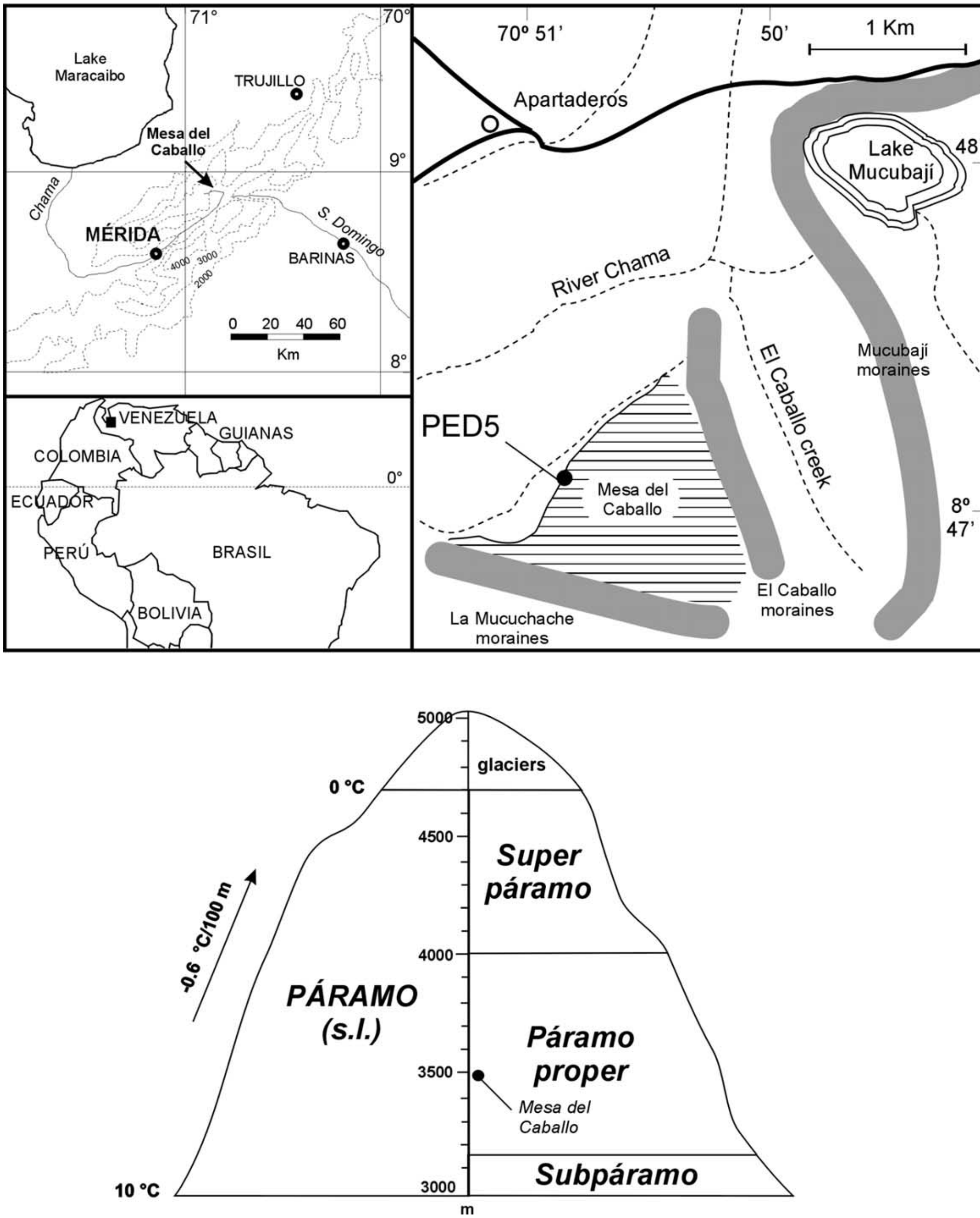

Fig. 1. Location map and altitudinal differentiation within the Páramo. The sampling site (PED5) is indicated.

graminoid and rosette herbs and an upper formed of shrubs and typical *Espeletia* (Asteraceae) caulirossulae, which is the most conspicuous plant element of these communities. The Páramo (*s.l.*) also can be subdivided into three altitudinal levels: the lower or Subpáramo, which represents a transition zone with the Andean forest; the Páramo Proper (or Páramo *s.s.*), which extends to the line of nightly freezing; and the Superpáramo, which extends to the permanent snowline, approximately 4700 m altitude. The average annual temperature decreases with altitude at a mean rate of −0.6 °C/100 m (Salgado- Labouriau, 1979).

The Mesa del Caballo is a triangular terrace of approximately 1 km^2 and 30 m thick, developed by the filling of a small intramontane basin between the lateral and terminal moraines El Caballo and La Mucuchache and subsequent cutting by La Cañada creek (Fig. 1). Schubert and Rinaldi (1987) interpret the sedimentary paleoenvironment as a fluvioglacial outwash plain that progressively accumulated when the terminal and lateral moraines of the Late Mérida stage were forming. The dates obtained for the outwash deposits by these authors (16.5–19 ^{14}C ka BP) place the sediments within the LGM.

Further studies carried out by Mahaney et al. (1997) on the same terrace show older sediments, deposited between the Early Mérida stage and the LGM. These sediments include several intercalated organic layers that give ages of 22.7 to >35 ^{14}C ka BP (conventional method), as well as several bodies of glacial diamicton that indicate the site was intermittently glaciated. A boring below the PED5 section discovered a till layer 5 m deeper, for which an Early Mérida age was proposed by Mahaney et al. (1997). Further AMS radiocarbon dates of a 20–30 cm thick peat layer (PED5-VII) overlying this till give a finite age of $58{,}350 \pm 2790$ ^{14}C BP at the top and two nonfinite ages ($>60{,}000$) at the middle and bottom (Mahaney et al., 2001). Because the finite date obtained is beyond the maximum reliable age for the dating method, the authors consider the possibility of residual contamination and conclude that the PED5-VII peat should have been deposited between 60 and 70 ka BP. Herein, a Middle Wisconsin age will be considered without any quantification attempt.

2.2. Laboratory processing, data analysis, and modern analogs

For this study, 10 regularly spaced subsamples (CAB-28–37) were taken from the PED5-VII peat layer for pollen analysis. The samples were weighed and their volume measured (averages: 10 g and 8 cm^3). After the introduction of *Lycopodium* spore tablets (batch 124961; 12,542 spores/tablet on average), sediments were treated with KOH and HF and acetolyzed. One subsample (CAB-29) was lost during this process. Mounting was done on glyceryn jelly without a seal. Pollen, fern and allied spores, fungi spores, algal remains, and *Incertae sedis* were identified and counted by scanning randomly spaced transects in three slides of each sample. Identifications were based on existing literature about the northern Andes (Van der Hammen and González, 1960; Murillo and Bless, 1974, 1978; Hooghiemstra, 1984; Salomons, 1986; Rull, 1998), and counting followed the criterion of diversity saturation, after a minimum of 200 pollen grains, to minimize the percentage and concentration confidence intervals (Rull, 1987). Average counts were 416 for pollen, 1080 for pollen and spores, and 1372 for the total (including fungi, algae, and *Incertae sedis*). The pollen sum includes all pollen and spores except *Isoëtes*, with an average of 474 (range: 359–717). Diagrams were plotted with PSIMPOLL 3.00, in which depth refers to the distance from the top of the peat.

The interpretation of the pollen spectra was based on modern analogue studies (Salgado-Labouriau, 1979; Salgado-Labouriau et al., 1988), with the assumption that modern pollen assemblages reflect the altitudinal differentiation of the Andean vegetation (montane forest, Subpáramo, Páramo Proper, and Superpáramo). Especially noteworthy is the decrease in the tree pollen with altitude. According to Salgado-Labouriau (1979), a rough estimate of the vertical distance between the treeline and a given site of pollen deposition can be obtained from the quantity of tree pollen deposited at the site. Globally, the Superpáramo is characterized by tree pollen percentages below 6%, whereas in the Páramo Proper, the percentages range from 8 to 18%, and in the Subpáramo, they are greater than 20% of the pollen sum (Salgado-Labouriau, 1984). However, not all taxa are equally useful in this respect. For example, *Alnus* has a high dispersion power, and its deposition is almost constant throughout the Páramo (*s.l.*), whereas *Podocarpus* and *Hedyosmum* show moderate dispersion capacity, and their concentration values decrease with the vertical distance to the treeline. The average *Podocarpus* pollen near the upper forest limit is approximately 9300 grains g^{-1}, whereas in the uppermost Superpáramo levels, it decreases to 1600 grains g^{-1}. Similarly, *Hedyosmum* diminishes from 14,500 to 2200 grains mg^{-1} over the same altitudinal gradient.

3. Results and paleovegetational interpretation

3.1. General

Total pollen concentration ranges from 60,000 to 300,000 grains cm^{-3}, with intermediate values at the base of the peat, a maximum in the middle, and the lowest concentrations at the top (Fig. 2). However, real values at the moment of deposition probably were lower because the analyzed peat layer has been compacted by the overlying sediments and the movement of late Wisconsinian ice (Mahaney et al., 1997, 2001). The measured bulk density of each sample was used to refer these values to weight, which resulted in a range of approximately 50,000–250,000 grains g^{-1}. Fern and allied spores (other than *Isoëtes*) show the same stratigraphic pattern, but their values are notably lower (less than 50,000 spores cm^{-3}). The concentration of fungal spores, in contrast, is higher in the lower half of the peat diagram (80,000–200,000 spores cm^{-3}) and lower in the upper half (60,000 spores cm^{-3}). *Isoëtes* spores show the same pattern as pollen and fern spores, but their maximal value in the middle of the peat is much more pronounced, reaching values of more than 1,000,000 spores cm^{-3} (880,000 spores g^{-1}). Finally, the concentrations of both algal (Zygnemataceae zygospores) remains and *Incertae sedis* are notably low (less than 2000 and 5000 per cm^{-3}, respectively) compared with the other palynomorphs.

The concentration values reported here fall within the range established by other studies from the Páramo *(s.l.)*, especially those located in the Páramo Proper and Superpáramo. Furthermore, because concentration values

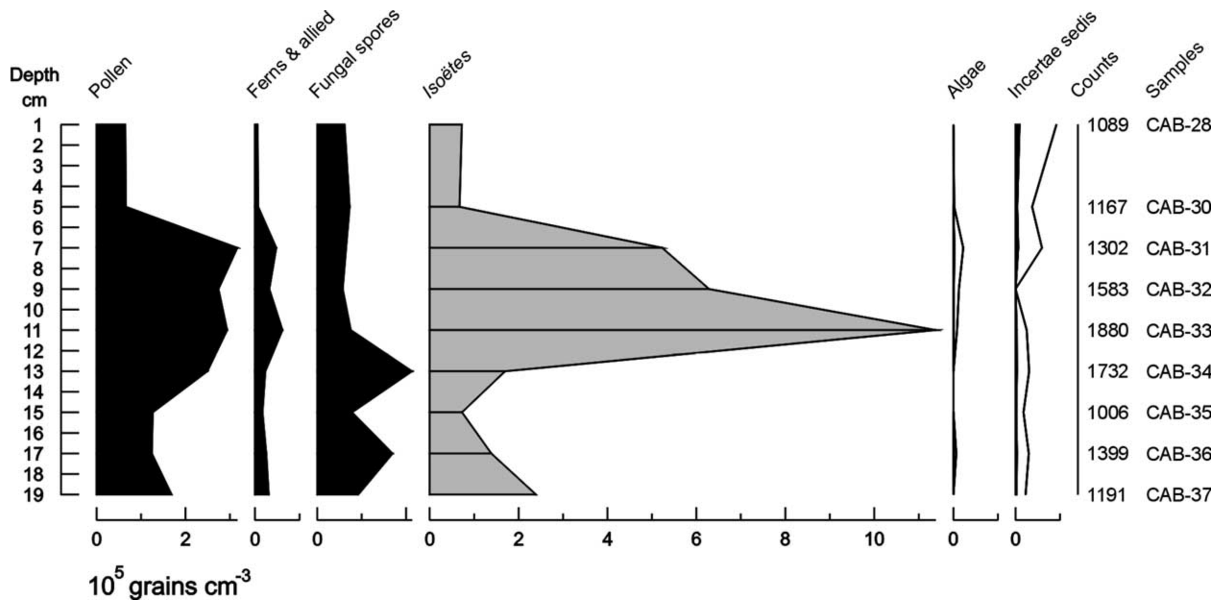

Fig. 2. Concentration diagram for the main groups of palynomorphs, Mesa del Caballo (PED5-VII).

probably are increased by compression, these numbers are similar to those found in modern sedimentation in Superpáramo communities (Salgado-Labouriau, 1979). In contrast, the values for *Isoëtes* spores (an indicator of local flooding) are similar to those found in Andean lake sediments (Salgado-Labouriau, 1979; Salgado-Labouriau et al., 1992). Therefore, the general concentration patterns are consistent with a locally flooded terrain or lake surrounded by Páramo *(s.l.)*-type vegetation (possibly Superpáramo). The vegetation density was intermediate at the start, high in the middle, and low at the end of the time interval represented. Values corresponding to very scarce vegetation, such as those found in dry areas or newly deglaciated terrains (Salgado-Labouriau, 1979; Salgado-Labouriau et al., 1988; Rull, 1998; Rull and Vegas-Vilarrúbia, 1996) were not attained. Thus, evidence indicates that the site was permanently vegetated and flooded.

3.2. Pollen and fern (and allied) spores

Pollen assemblages are dominated by Asteraceae and Poaceae throughout the interval of deposition and do not reflect changes in the vegetation type (Fig. 3). Páramo-indicator elements *(Rhizocephalum, Montia, Gentiana, Draba, Valeriana, Arenaria*) are present across the whole sequence in similar percentages. Only *Arenaria* and other pantoporates (e.g. Caryophyllaceae–Portulacaceae) show small trends in their percentages. Among forest trees, *Alnus* is most abundant, but it nearly disappears at the top of the sequence. According to the criteria of Salgado-Labouriau (1979, 1984) with regard to tree pollen abundance, all the assemblages fall within the Superpáramo, except for samples in the middle of the peat layer, which are close to the Superpáramo/Páramo Proper boundary. At the top of the peat layer, tree pollen is approximately 2%, a value attained only in the upper levels of the present Superpáramo and during cold late glacial periods, such as the Younger Dryas (Salgado-Labouriau et al., 1977, 1988). Concentration values show the same trend as total pollen does. All Páramo elements increase in the middle of the peat, in support of the hypothesis of a more dense vegetation cover, but without appreciable changes in taxa composition.

Because tree pollen is the best indicator of altitude (Salgado-Labouriau, 1979, 1984), a more detailed analysis of its percentage and concentration trends was undertaken. Globally, the tree pollen shows two percentage peaks within the Páramo Proper/Superpáramo transition (Fig. 4). However, the first (CAB 25, 15 cm from the top) is due to an increase in *Alnus*, which is not a good altitude indicator because its abundance in modern sediments is more or less constant in the Páramo (*s.l.*). Furthermore, such anemophilous taxa may exhibit artificially enhanced percentages in the Superpáramo levels because of the long-distance transport of pollen and poor local pollen production. Therefore, the observed high *Alnus* percentages and low pollen concentration values are parsimoniously explained as being deposited at the uppermost Superpáramo levels. The second peak of arboreal pollen, which occurs when overall pollen and spore concentration increases, is due mainly to *Podocarpus* and *Hedyosmum*, which are better indicators than *Alnus* of the proximity of the treeline. Percentage and concentration data (maxima at approximately 4100 grains cm^{-3} or 6500 grains g^{-1} each) indicate a real increase in these pollen types, which suggests the presence of the lowermost Superpáramo belt or the Superpáramo/Páramo Proper boundary. At the top of the section, both the percentage and concentration ($<3\%$ and <2000 grains cm^{-3} or <1000 grains g^{-1} overall) of tree

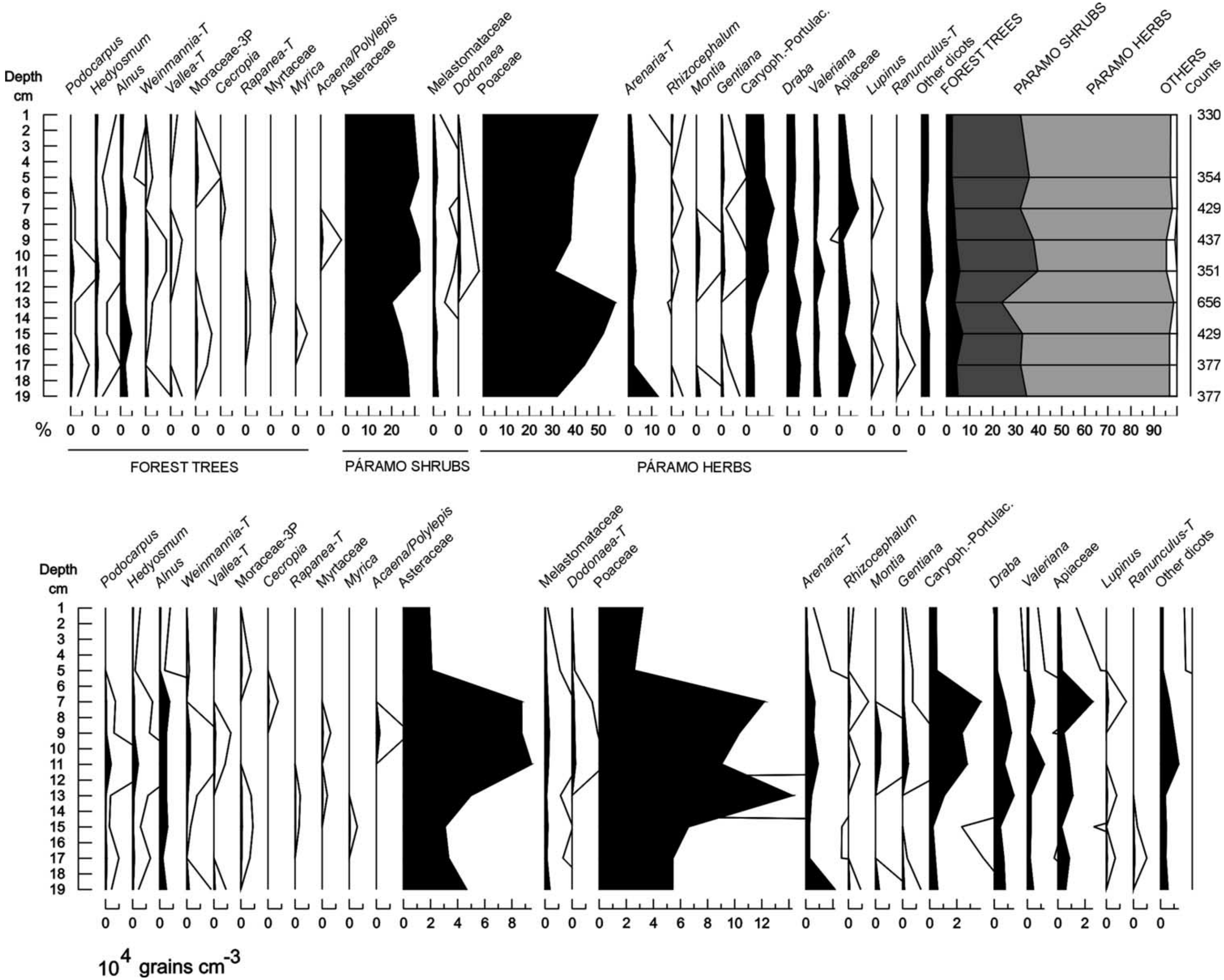

Fig. 3. Pollen percentage and concentration diagrams, Mesa del Caballo (PED5-VII).

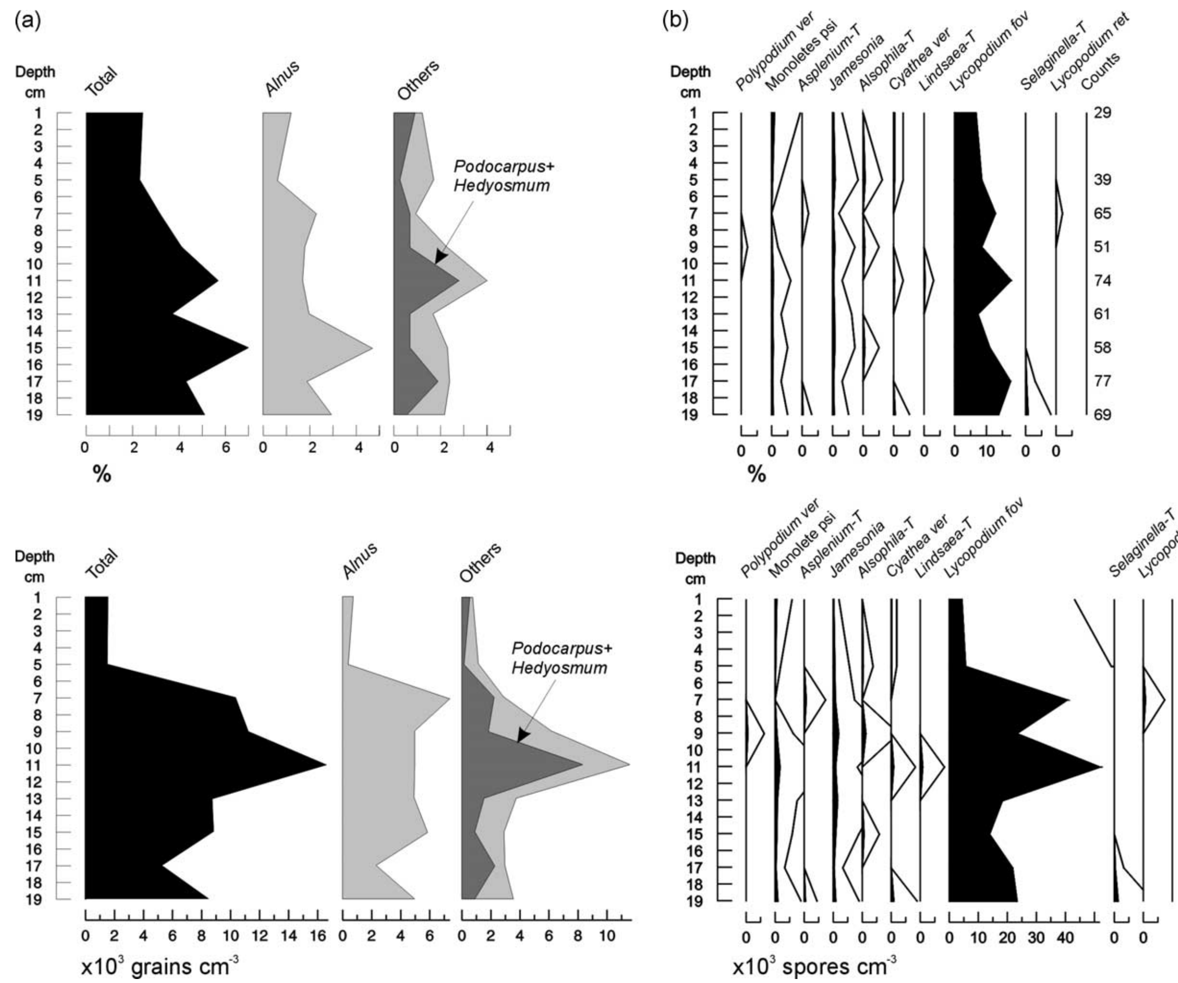

Fig. 4. Percentage and concentration diagrams for (a) tree pollen and (b) fern and allied spores, Mesa del Caballo (PED5-VII).

pollen are lower than in the previous zone. This decrease of all the tree pollen types, including *Alnus*, is consistent with the return of uppermost Superpáramo vegetation.

Except for the foveolate spores of *Lycopodium*, the spores of ferns and other archegoniate plants are very scarce (Fig. 4), which is typical of the upper Páramo (*s.l.*) (Salgado-Labouriau, 1979). *Lycopodium* is a very common Páramo element (Vareschi, 1970), well represented in the modern analogs of both the Páramo Proper and the Superpáramo. The spores of *Lycopodium* show the same increase as other Páramo elements. A strong increase in *Isöetes* is coincident with the second peak of tree pollen and thereby indicates flooding. *Isoëtes* forms dense monotypical colonies (submerged) in the present-day shore lakes and flooded bogs of the Páramo (Vareschi, 1970). Furthermore, its spores are of local deposition in modern sediments and show high numbers only in situ aquatic sediments (Salgado-Labouriau, 1979).

In summary, the studied sequence can be interpreted in terms of altitudinal oscillations in the vegetation belts. The base of the peat layer (19–14 cm, CAB-37–35) likely represents a Superpáramo with intermediate plant densities. At 13–7 cm (CAB-34–31), plant cover increases, and vegetation is intermediate between Páramo Proper and Superpáramo (probably in the transition zone). The top of the of peat layer (6–1 cm) represents a Superpáramo in its uppermost altitudinal levels.

4. Paleoclimatic interpretation and discussion

The altitudinal displacements of Andean taxa can be interpreted in paleoclimatic terms. The study site currently is covered by Páramo Proper communities, but during the time interval studied herein (Middle Wisconsin), the site was occupied by ecosystems that correspond to higher elevations. In the interval of maximum tree pollen, intermediate Páramo/Superpáramo communities, which today grow from 4000 m upward, occupied the site. Therefore, the upper Andean taxa were displaced downslope at least 500 m with respect to the present limits. Considering the modern lapse rate (−0.6 °C/100 m), estimated average temperatures for this time were approximately 3 °C less than they are today. The maximum flooding was attained at the same time, probably due to the increased glacier melting. Temperatures were notably lower during the sedimentation of the peat top, as is indicated by the proportion of tree pollen. These values are lower than those currently obtained for altitudes up to 4340 m (Salgado-Labouriau, 1979) and similar to the recorded values during the LGM, when average temperatures were 7 °C below present-day levels (Rull, 1998; Rull and Vegas-Vilarrúbia, 1996). That is, according to a glacier advance represented by the underlying till, the analyzed peat layer records a temperature increase (Pedregal interstadial), followed by a subsequent drop in atmospheric temperature of approximately 4 °C.

Because of dating uncertainties, the Pedregal interstadial cannot be correlated unequivocally with other regional events. If Mahaney et al's. (2001) opinion is correct (i.e. an age of 60–70 ka BP for peat PED5-VII), the Pedregal interstadial occurred at approximately the same time as the Colombian Bachué interstadial, which began in the Early/Middle Fuquenian transition at approximately 60,000 yr BP (Van der Hammen, 1995) and was detected through the same palynological signal. In a more general framework, it corresponds to the interval MIS3/MIS4 (Berggren et al., 1980) and Dansgrrad/Oeschger events 17–19 (Bradley, 1999). However, the Pedregal interstadial also could be older. Regardless, it is the oldest Quaternary paleoclimatic event recorded in the area, and further chronological refinements should contribute to its precise dating.

Acknowledgements

The author is grateful to M. Bezada for providing the samples and J.N. Haas and H. Hooghiemstra for their helpful suggestions on a former version. Two unknown referees contributed to the improvement of the manuscript. Data processing and editing were supported by the 'Ramón y Cajal' program of the Spanish Ministry of Education and Science.

References

Berggren, W.A., Burckle, L.H., Cita, M.B., Cooke, H.B.S., Funnel, B.M., Gartner, S., Hays, J.D., Kennett, J.P., Opdyke, N.D., Pastouret, L., Shackleton, N.J., Takayanagi, Y., 1980. Towards a quaternary time scale. Quaternary Research 13, 277–302.

Bradley, R.S., 1999. Paleoclimatology. Reconstructing Climates of the Past, second ed. Academic Press, San Diego p. 613.

Cuatrecasas, J., 1968. Paramo vegetation and its life forms. Colloquium Geographicum 9, 163–186.

Hooghiemstra, H., 1984. Vegetational and climatic history of the high plain of Bogotá, Colombia. A continuous record of the last 3.5 million years. Dissertationes Botanicae 79, 368.

Mahaney, W., Kalm, V., Bezada, M., 1997. Estratigrafía del Cuaternario Tardío en un ambiente proglacial en el área de Mucubají, Mucuchaché, El Pedregal. Andes centrales venezolanos. Memorias del I Congreso Latinoamericano de Sedimentología I, 417–424.

Mahaney, W.C., Russell, S.E., Milner, M.W., Kalm, V., Bezada, M., Hancock, R.G.V., Beukens, R.P., 2001. Paleopedology of Middle Wisconsin/Weischelian paleosols in the Mérida Andes, Venezuela. Geoderma 104, 215–237.

Murillo, M.T., Bless, M.J.M., 1974. Spores of recent Colombian Pteridophyta. I. Trilete spores. Review of Palaeobotany and Palynology 18, 223–269.

Murillo, M.T., Bless, M.J.M., 1978. Spores of recent Colombian Pteridophyta. II. Monolete spores. Review of Palaeobotany and Palynology 25, 319–365.

Rull, V., 1987. A note on pollen counting in palaeoecology. Pollen Spores 39 (4), 471–480.

Rull, V., 1996. Late Pleistocene and Holocene climates of Venezuela. Quaternary International 31, 85–94.

Rull, V., 1998. Palaeoecology of pleniglacial sediments from the Venezuelan Andes. Palynological record of El Caballo stadial, sedimentation rates and glacier retreat. Review of Palaeobotany and Palynology 99, 95–114.

Rull, V., 1999. Palaeoclimatology and sea-level history in Venezuela. New data, land-sea correlations and proposals for future studies in the frame of the IGBP-PAGES Project. Interciencia 24 (2), 92–101.

Rull, V., Schubert, C., 1989. The little ice age in the tropical Venezuelan Andes. Acta Científica Venezolana 40, 71–73.

Rull, V., Vegas-Vilarrúbia, T., 1996. Palynological evidence for the Last Glacial Maximum in the Venezuelan Andes. Preliminary results. Current Research in the Pleistocene 13, 89–91.

Rull, V., Vegas-Vilarrúbia, T., 1998. Palynomorphs other than pollen and fern spores in glacial sediments from the venezuelan Andes. Preliminary assessment on their potential palaeoecological value. Boletín de la Sociedad Venezolana de Geólogos 23 (1), 5–27.

Rull, V., Salgado-Labouriau, M.L., Schubert, C., Valastro, S., 1987. Late Holocene temperature depression in the Venezuelan Andes. Palynological evidence. Palaeogeography Palaeoclimatology Palaeoecology 60, 109–121.

Salgado-Labouriau, M.L., 1979. Modern pollen deposition in the Venezuelan Andes. Grana 18 (1), 53–68.

Salgado-Labouriau, M.L., 1984. Late-Quaternary palynological studies in the Venezuelan Andes. Erdwissenschaftliche Forschung 18, 279–293.

Salgado-Labouriau, M.L., 1989. Late Quaternary climatic oscillations in the Venezuelan Andes. Biology International 18, 12–14.

Salgado-Labouriau, M.L., Schubert, C., Valastro Jr.., S., 1977. Paleoecologic analysis of a Late Quaternary terrace from Mucubají, Venezuelan Andes. Journal of Biogeography 4, 313–325.

Salgado-Labouriau, M.L., Rull, V., Schubert, C., Valastro, S., 1988. The establishment of vegetation after late Pleistocene deglaciation in the Páramo Miranda, Venezuelan Andes. Review of Palaeobotany and Palynology 55, 5–17.

Salgado-Labouriau, M.L., Bradley, R.S., Yuretich, R., Weingarten, B., 1992. Paleoecological analysis of the sediments of lake Mucubají, Venezuelan Andes. Journal of Biogeography 19, 317–327.

Salomons, J.B., 1986. Paleoecology of volcanc soils in the Colombian Central Cordillera Parque Nacional Natural de los Nevados. Dissertationes Botanicae 95, Berlin, 212 p.

Schubert, C., 1974. Late Pleistocene Mérida glaciation, Venezuelan Andes. Boreas 3, 147–152.

Schubert, C., Clapperton, C.M., 1990. Quaternary glaciations in the northern Andes (Venezuela, Colombia and Ecuador). Quaternary Science Reviews 9, 123–135.

Schubert, C., Rinaldi, M., 1987. Nuevos datos sobre la cronología del estadio tardío de la Glaciación Mérida, Andes Venezolanos. Acta Científica Venezolana 38, 135–136.

Van der Hammen, T., 1995. La última glaciación en Colombia (Glaciación Cocuy, Fuquense). Análisis Geográficos 24, 69–88.

Van der Hammen, T., González, E., 1960. Upper Pleistocene and Holocene climate and vegetation in the sabana de Bogotá (Colombia, South America). Leidse Geologische Mededelingen 25, 263–315.

Vareschi, V., 1970. Flora de los páramos de Venezuela. Universidad de Los Andes, Ediciones del Rectorado, Mérida, 429 p.