Late Quaternary Environmental and Climatic Changes in Central Brazil

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Paleoenvironmental changes dating back to 30,000 yr B.P. documented in a pollen record from central Brazil (lat. 19°S) permit the reconstruction of climatic changes related to shifts of the Antarctic polar fronts. The paleoclimatic inferences were obtained by a study of modern vegetation and pollen distribution, taking into account present-day climatic parameters. At 30,000 yr B.P. the climate must have been warmer and moister than today judging from the high amount of tree pollen taxa characteristic of floodplain forest. From 17,000 to 14,000 yr B.P. the climate was drier although tree pollen percentages were relatively high. After 12,000 yr B.P. *Araucaria* forest elements increased, suggesting a moister and cooler climate. The *Araucaria* forest disappeared during a short interval between 11,000 and 10,000 yr B.P. This could be related to the Younger Dryas event. At the beginning of the Holocene the climate became cool and moist again, as indicated by the reexpansion of the *Araucaria* forest. The latter was progressively replaced by a mesophytic semideciduous forest indicating warmer and drier climate after 8500 yr B.P. At 5000 yr B.P. an arid interval was followed by the expansion of mesophytic semideciduous forest elements. ©1993 University of Washington.

INTRODUCTION

Despite great efforts for many years, only few paleoenvironmental and paleoclimatic records have been presented from the tropical and subtropical lowlands in South America (Wijmstra and Van der Hammen, 1966; Liu and Colinvaux, 1985; Bush and Colinvaux, 1990; Bush *et al.*, 1990; Markgraf, 1989; Absy *et al.*, 1991). Central Brazil, between 15° and 25°S lat, represents such an unexplored area where very little is known, even about modern conditions. Biogeographical studies (Klein, 1975) suggested that most of the present-day vegetation types of this area bear no relation to the local climate and soils. Klein (1975) ascribed this either to anthropogenic influences or to climatic changes leaving a relict vegetation. Geomorphological studies (Bigarella and Andrade-Lima, 1982; Ab'Saber, 1982) indicated at least two dry periods in the past: one very severe during the Pleistocene and another less intense during the Holocene. Salo *et al.* (1986) and Räsänen *et al.* (1987) detected fluvial perturbation in the floodplain dynamics of Amazonia during the Pleistocene that was able to provoke changes in the forest composition and explain its high endemism. In Amazonia, biological and botanical studies (Haffer, 1969; Prance, 1973; Gentry, 1982) suggested that during dry periods of the Pleistocene, rainforests were restricted to refuge areas. However, Liu and Colinvaux (1985) demonstrated that in one of the refugia called Napo (Ecuador), the forest was not a broad-leaved lowland forest but a *Podocarpus*-dominated tropical Andean montane forest during full-glacial times. More recently, a dry period of Holocene age has been documented in sediments from the Rio Doce Valley, eastern Brazil (18°–20°S), by Servant *et al.* (1989).

The area studied, central Brazil, between 15° and 25°S lat, is located between the tropical rainforest area to the north and the semideciduous subtropical forests to the south. The climate is influenced by the presence of southerly polar fronts in winter and by tropical air masses in summer. Northward shifts of polar fronts greatly affect the local climate and vegetation. For example, coffee crops were destroyed in 1908, 1963, 1975, and 1976 when polar air masses moved northward. The present study shows the first palynological data obtained from this area, and also records past shifts in the position of the polar fronts.

STUDY AREA

Central Brazil is affected by two main types of climate, a tropical climate with a dry and a moist season, and a climate without seasonality. Seasons are regulated by the position of the ITCZ (Intertropical Convergence Zone): in January the ITCZ moves southward and remains at the latitude of the central plateau where the convergence of the winds induces strong precipitation; in July the ITCZ moves northward toward Amazonia, effectively reducing the humid area to the Amazon region. In the southern part of central Brazil polar fronts meet the tropical warm air, resulting in heavy precipitation (Pagney, 1976; Vaughan-Williams, 1988). The region can also be affected by El Niño events which by intensifying the jet stream circulation block the polar fronts above the southern part

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of Brazil and provoke abnormally strong rainfall there (Virji and Kousky, 1983; Nobre and Oliveira, 1986). Precipitation throughout the study area averages 1500 mm. However, variations in the duration of the dry season and the average winter temperature allow the distinction of three zones. The northern part is the driest zone, characterized by a dry season 4 to 5 months long and mean winter temperatures above 15°C. The central area experiences dry season 1 to 2 months long and mean winter temperatures range between 10° and 15°C; the southern part has no dry season and winter temperatures fall below 10°C, with occasional freezing days.

These three climatic zones can be related to the three main types of vegetation in this area (Fig. 1 and Table 1), from north to south: Cerrado, mesophytic semideciduous forest, and *Araucaria* forest. The vegetation/climate relationship was obtained by overlying a climatic map, assembled with the help of meterological data collected in the study area, and a vegetation map (Hueck and Seibert, 1981). The vegetation types indicated in small print (Table

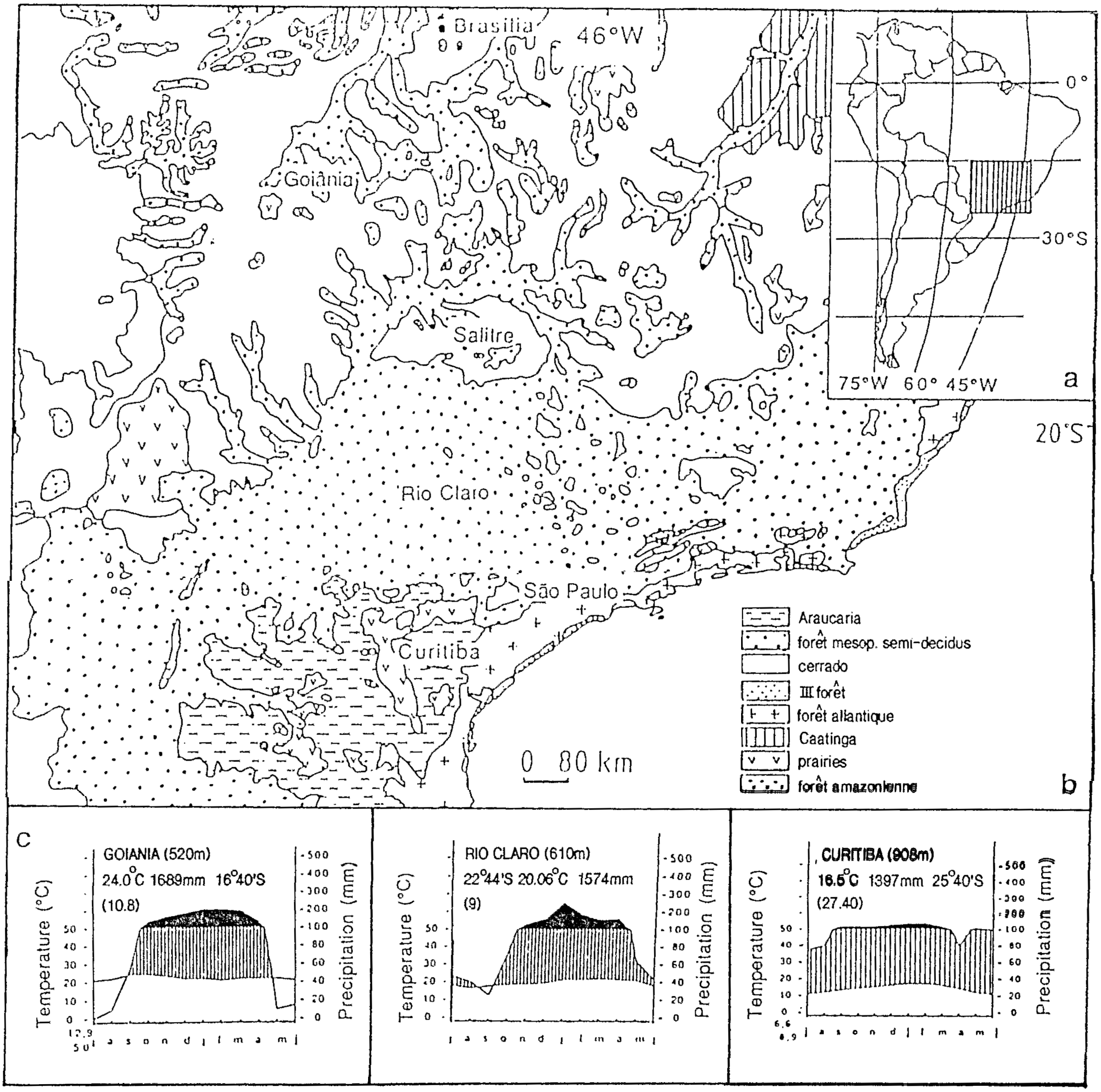

FIG. 1. (a) Map showing the location of the study area in central Brazil. (b) Vegetation map of the study area (based on Hueck and Seibert, 1981) and location of the pollen record site at Salitre. (c) Climatic diagrams of the three main climatic types of the study area from north to south.

TABLE 1
Vegetation Types, Climatic Conditions and Associated Pollen Indicators for Central Brazil (MWT°C = Mean Winter Temperature)

Vegetation	Climate	Pollen indicator
	Zone III	
Cerrado	Dry season: 4 months	*Qualea* *Caryocar*
Cerradão galery forest	Rainfall: 1500 mm MWT°C > 15	*Connarus*
	Zone II	
Mesophitic semideciduous forest	Dry season: 1 to 2 months Rainfall: 1500 mm	*Esenbeckia* *Copaifera* *Tecoma*
Cerrado	10 < MWT°C < 15	
	Zone I	
Araucaria forest	No dry season Rainfall: 1500 mm MWT°C < 10	*Araucaria* *Podocarpus* *Drymis*

1) do not correspond to the climax of the zone but relate to specific edaphic conditions. The relation between pollen rain and vegetation was defined by collecting surface samples inside the different forest types (Ledru, 1991). Our paleoclimatic interpretation is based on the definition of this relationship.

Cerrado, sensu stricto, extends over 23% of the Brazilian territory. It was first supposed to be an anthropogenic formation caused by repeated fires and logging (Lund, 1835; Loefgren, 1898). Botanical and palynological studies (Prance, 1973; Van der Hammen, 1983; Absy *et al.*, 1991) demonstrated, however, that climate and substrate were determining factors for its development and that it predates human impact. The main area where it occurs today is the central Planalto of Brazil (10° to 20°S lat). Other Cerrado areas near São Paulo and in Amazonia are presumed to be relicts of past warmer and drier climates. Cerrado can grow today in these regions because of soils that are very poor in nutrients (Souza Reis, 1971; Van der Hammen, 1983; Absy *et al.*, 1991). The Cerrado is a wooded savanna. The vegetation is sclerophylous with many species adapted to frequent fires and to the high aluminium content of the soils. The main tree species are *Qualea parviflora, Q. grandiflora, Sclerolobium paniculatum, Caryocar brasiliense, Byrsonima verbascifolia,* and *Kielmeyera rubriflora.*

Very little is known about the mesophytic semideciduous forest because of its scarcity. Its original area, between 20° and 25°S lat in Brazil, is now used primarily for agriculture (Schnell, 1987). The species composition of this semideciduous forest is very different from the Amazonian and the Atlantic rain forests (Silva and Shepherd, 1986). The mesophytic semideciduous forest develops in a more temperate climate, with a short dry season and mean winter temperatures of 10° to 15°C. It is a dense forest with a reduced herbaceous stratum and lacks epiphyts. The main tree species are *Hymenea stilbocarpa, Copaifera langsdorfii,* and genera of the Rubiaceae family (*Gallesia, Esenbeckia,* and *Metrodorea*).

Araucaria forests grow today either at high altitudes, above 1800 m in the Serra de Mantiqueira, Campos de Jordão near São Paulo between 16° and 17°S lat, or at high latitudes, between 25° and 30°S lat in southern Brazil above 900 m altitude. It has been suggested that these forests would have in the past extended over a wider area during a cold and moist phase of the Quaternary. A warming of the climate and increased winter moisture stress would have reduced this area to relic populations in sites where climate is suitable for their development (Aubreville, 1961). The *Araucaria* forest requires regular rainfall, no dry season, and low mean winter temperatures. The conifer taxa in this forest are *Araucaria angustifolia, Podocarpus lambertii,* and *P. sellowii,* accompanied by the broadleaved trees *Ilex paraguariensis, Ocotea pulchella, Sloanea monosperma, Symplocos uniflora, Drimys brasiliensis, Cedrela fissilis,* and *Mimosa scabella* (Rizzini, 1979; Ferri, 1980; Schnell, 1987).

MATERIAL AND METHODS

Salitre de Minas (or Salitre) is a shallow depression 2 km wide at 19°S lat, 46°46'W long. and 1050 m altitude, about 300 km west of Belo Horizonte, capital of the Minas Gerais province in central Brazil. The highest surrounding point reaches 1283 m. The depression is dammed by a peat bog where a 6-m core (LC3) has been drilled by ORSTOM. The results of the pollen analysis of the upper 2 m are presented in this paper.

Present-day natural vegetation in this area is greatly altered by agriculture, but topographic maps refer to Cerrado as the native vegetation. The climate is characterized by a 4-month dry season and mean winter temperatures above 15°C (Fig. 1).

Sediments consist mainly of peat, with little or no mineral content. Samples for pollen analysis were taken at 2 or 4 cm intervals.

Samples were treated followed the Lüber technique using 50% HNO_3 solution and 10% KOH solution (Faegri and Iversen, 1975). Palynomorphs were separated using a $ZnCl_2$ solution of density 2 and mounted in glycerine for light microscopy analysis.

Pollen and spores were identified by comparison with our reference collection of about 600 brasilian forest taxa and a published pollen flora (Salgado-Labouriau, 1973). At least 300 pollen grains were counted at each level. Pollen proportions of all taxa were calculated as percentage of the total sum of arboreal and nonarboreal types. Aquatic taxa, other wetland taxa, and sporeproducing taxa were excluded from the sum. The frequencies of pollen of the principal taxa identified are plotted in Figure 2. Arboreal pollen is represented by *Araucaria, Podocarpus, Alchornea*, Arecaceae C1 (Palmae monocolpate grains), *Celtis, Chomelia, Copaifera, Drymis, Ilex*, Melastomataceae/Combretaceae, *Miconia* type (size discrimination of a Melastomataceae following Van der Hammen and Gonzalez, 1960), Mimosaceae, *Myroxylon* type, Myrtaceae, *Rapanea, Symplocos, Tecoma*, and *Zanthoxylum*. Nonarboreal pollen includes Poaceae (Gramineae), Asterceae (Compositae) type I (grain size <20 μm) and Asteraceae type II (grains size >20 μm), Apiaceae (Umbelliferae), and Ericaceae. Wetland taxa are Cyperaceae and Xyridaceae. *Sphagnum*, a moss common on peat bogs, is also present.

The diagram (Fig. 2) shows the proportions of arboreal pollen (including tree species and their associated shrubs, vines, and parasites) and nonarboreal pollen (including wetland taxa and ferns), as well as the total pollen sum. Taxonomic nomenclature follows Salgado-Labouriau (1973) or more recent plant taxonomic literature (Ledru, 1991).

Fourteen radiocarbon dates (Table 2) for peat and bulk peat samples provide chronologic control (Fig. 3).

Based on changes in pollen proportions, eight paleoenvironmental zones were distinguished. Interpretation of the characteristic climate of each pollen assemblage zone was based on a study of the relation between modern pollen rain, vegetation, and climate in this area (Ledru, 1991). This study defined indicator pollen taxa for each vegetation type and its respective climatic type. Winter temperature and the duration of the dry season were identified as the primary climatic parameters distinguishing the different vegetation types.

RESULTS

Eight paleoenvironmental zones, numbered from VII (oldest) to 0 (youngest) can be distinguished in the ca. 30,000-yr interval represented by the section (Fig. 2).

Zone VII, radiocarbon dated 28,740 +1970/−1580 yr B.P. (No. 470), is characterized by 72 to 91% arboreal pollen. Woody taxa represented in this zone are Myrtaceae (68%), *Alchornea* (7%), *Celtis* (3%), *Miconia* type (5%), *Podocarpus* (5%), *Rapanea* (4–8%), and *Ilex* (2%). Such an assemblage is quite common in modern floorplain forests in Amazonia (called Igapó; Absy, 1980), if we infer that the recorded *Podocarpus* represents the lowland species *Podocarpus sellowii*. An Igapó is actually defined as a marshy forest, seasonally flooded, with permanently damp soil. These forests are isolated from the rivers and are generally dominated by *Eugenia inundata, Campsiandra laurifolia*, and two other species of *Eugenia*, all genera of the Myrtaceae family (Schnell, 1987). This could account for the high amount of Myrtaceae pollens in this section. However, the assemblage of Myrtaceae, *Celtis, Alchornea, Miconia* type, and *Rapanea* can also be found in almost every lowland tropical pollen spectrum (Absy *et al.*, 1991; Bush and Colinvaux, 1990). As no modern analogs of Igapó forest are recorded today in the area, this assemblage could be related to a wet forest edge with swamp Myrtaceae. On the other hand, it is not a pure lowland community. The presence of *Drymis* and *Podocarpus* (if we assume that the recorded *Podocarpus* represents the montane species *Podocarpus lambertii*) indicates an assemblage of mixed lowland and montane species. A similar assemblage has been recorded at San Juan Bosco and Mera (Ecuador) for the same period (Bush *et al.*, 1990). The Salitre spectrum differs, however slightly, in that lowland taxa remain dominant. Low percentages of wetland taxa and the presence of Ericaceae and Xyridaceae indicate acidity of the soils typical of the Igapó. Nonarboreal taxa are poorly represented and consist mainly of Poaceae (6 to 20%) and Asteraceae (3 to 20%), also confirming the presence of a floodplain forest.

The presence of both lowland and montane species suggests a cool climate, but the lack of modern analogs for this assemblage makes it difficult to propose climatic parameters quantitatively. The analysis of the environmental and climatic changes in the rest of the core (2 to 6 m) should help us to define more accurately climatic data of zone VII.

Sedimentation was probably interrupted between 28,740 and 16,800 +440/−420 yr B.P. (No. 552) as indicated in Figure 3 where the age/depth plot shows a marked jump between 157 and 170 cm.

Zone VI extends from 164 to 119 cm and is dated between 16,800 +440/−420 yr B.P. (No. 552) at 157 cm, and 14,230 +610/−570 yr B.P. at 135 cm. It is characterized by a reduction in arboreal taxa from 72 to 24%, mainly due to a decrease in Myrtaceae pollen (from 37 to 3%), *Celtis* (from 2.5 to 0%), *Alchornea* (from 2 to 1%), *Miconia* (from 3.5 to 0.5%), and *Rapanea* (from 3.5 to 0%), all taxa characteristic of the floodplain forest.

Podocarpus (2%) remains constant, as in the previous zone, but *Ilex* is more consistent (2%), and other taxa including *Lithraea/Tapirira, Symplocos, Drimys, Tecoma*, and *Zanthoxylum* increase. Nonarboreal taxa increase and are still dominated by Poaceae (24 to 59%) and Asteraceae (7 to 13%), with Apiaceae progressively increasing (from 0.3 to 36%), together with other herbaceous taxa such as *Artemisia*-type, *Borreria*, Euphorbiaceae, *Gomphrena, Alternanthera*, and *Ranunculus*. Cyperaceae and Ericaceae remain constant. *Sphagnum* begins to increase suggesting that flooding has ceased and that marshy conditions have become established.

The climate suggested by this pollen assemblage is marked by a short dry season and average winter temperatures of less than 15°C, lower than during the pre-

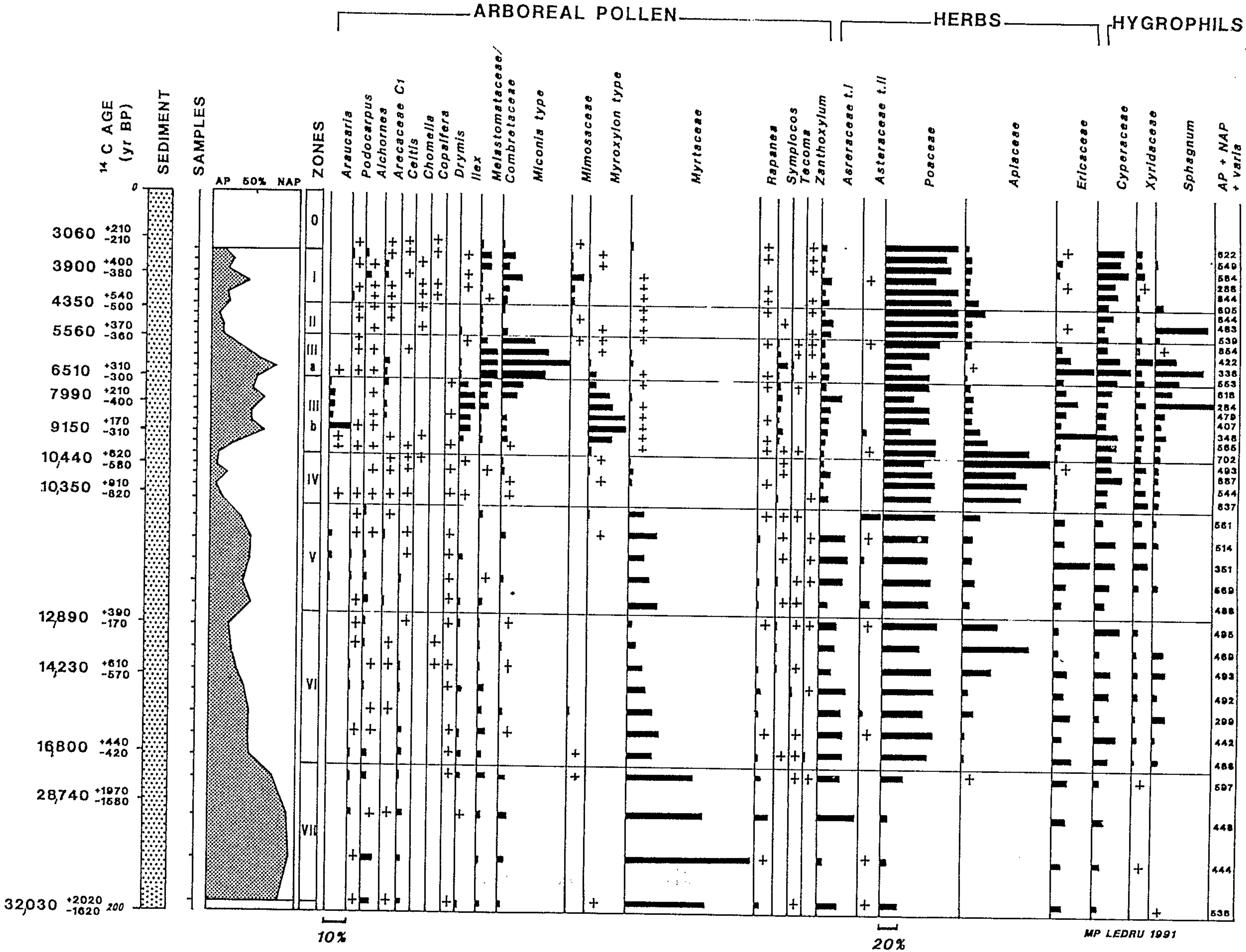

FIG. 2. Pollen diagram of the Salitre LC3 record (19°S, 46°46′W). Only selected pollen taxa are shown.

TABLE 2
Radiocarbon-Dated Samples

Lab. number	Material	Depth (cm)	Age (yr B.P.)	
551	Peat	18	3060	(+210)
574	Peat	25	3900	(+400 −380)
556	Bulk peat	32	4350	(+540 −510)
555	Bulk peat	42	5560	(+370 −360)
554	Bulk peat	50	6510	(+310 −300)
569	Peat	55	7990	(+360 −350)
570	Peat	60	9150	(+330 −320)
495	Bulk peat	72	10,440	(+620 −580)
496	Peat	84	10,350	(+910 −820)
550	Peat	121	12,890	(+390 −170)
571	Peat	135	14,230	(+610 −570)
552	Peat	157	16,800	(+440 −420)
470	Peat	170	28,740	(+1970 −1580)
471	Peat	204	32,030	(+2020 −1620)

ceding interval. Support for this interpretation comes from the joint presence of *Drimys*, *Podocarpus*, and *Symplocos* taxa which grow today in the upper-elevation forest.

Zone V lies between 117 and 89 cm, and dates between 12,890 +390/−170 yr B.P. (No. 550) at 121 cm, and 10,350 +910/−820 yr B.P. (No. 496) at 84 cm. During this interval, arboreal taxa, whose frequencies had dropped in zone VI, increase again, due mainly to an increase in Myrtaceae (7 to 17%). Other arboreal taxa are the same as in the previous interval (*Drimys*, *Tecoma*, *Zanthoxylum*, *Lithraea/Tapirira*, *Symplocos*). The presence of *Araucaria* (0.5 to 2%), which in Brazil grows today at higher latitudes or higher elevations, confirms the lowering of temperature. Frequencies of Poaceae remain constant, but Apiaceae are decreasing. The disappearance of *Sphagnum* spores and the increase of Myrtaceae suggests the return of a floodplain forest. However, the additional presence of the other taxa (such as *Araucaria* and *Drimys*) indicates that the vegetation is a mix of floodplain forest and *Araucaria* forest. The dry season is perhaps not as prominent as in zone VI and mean winter temperatures are too low to allow full development of a floodplain forest; instead they allow the development of an *Araucaria* forest (Fig. 4).

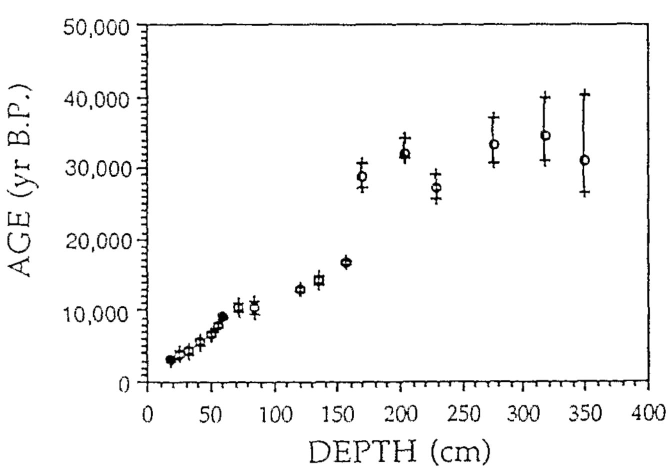

FIG. 3. LC3 core. Age data plotted against the depth intervals of the samples.

In zone IV, between 89 and 72 cm and radiocarbon-dated to ca. 10,500 yr B.P. [2 dates of 10,350 +910/−820 yr B.P. (No. 496) and 10,440 +620/−580 yr B.P. (No. 495)], total tree pollen frequency is lower than before, decreasing to 6%. All the arboreal taxa are affected by this decrease: *Ilex* (1 to 0.2%), *Lithraea/Tapirira* (2 to 0.6%), *Miconia* type (2 to 0.3%), Myrtaceae (3 to 1%), and *Symplocos* (0.7 to 0.3%). Other arboreal pollen taxa disappear altogether. Herbaceous taxa are dominated by Apiaceae that increase from 28 to 47%. Poaceae are present with the same frequency as before; *Mabea* and *Ranunculus* are also present. *Sphagnum* frequency shows no variation either. Conditions, during this period were not favorable for forest development, probably because of a prolonged dry winter season combined with low temperatures. At this level, sedimentation rates change from 0.011 cm/yr below 85 cm to 0.0075 cm/yr above 85 cm (marked in Figure 3 by a shoulder at this level).

Zone III, between 72 and 42 cm, 9150 +330/−320 yr B.P. (No. 570) to 5560 +370/−360 yr B.P. (No. 569), is characterized by a sudden increase in arboreal taxa from 33 to 72%. Considering the different ecological requirements of the trees, 2 subzones, IIIa and IIIb, can be distinguished.

Zone IIIb, between 72 and 54 cm (ca. 9200 to 8000 yr B.P.) is characterized by a high frequency of *Araucaria* (up to 11%) (Figs. 3 and 4) associated with *Ilex* (4 to 11%), Melastomataceae/Combretaceae (1 to 7%), and *Myroxylon* type (5 to 20%). The ecology of the latter taxon is not well defined but it seems to co-occur with *Araucaria*, *Symplocos* (1 to 5%), *Drimys*, *Lithraea/Tapirira*, Myrtaceae, *Podocarpus*, *Rapanea*, and *Alchornea*. *Sphagnum* is well represented along with other wetland taxa. The arboreal taxa *Araucaria*, *Ilex*, *Symplocos*, *Podocarpus*, and *Drimys* are dominant, indicating the development of the *Araucaria* forest which is today associated with a cold and humid climate without any dry season and low

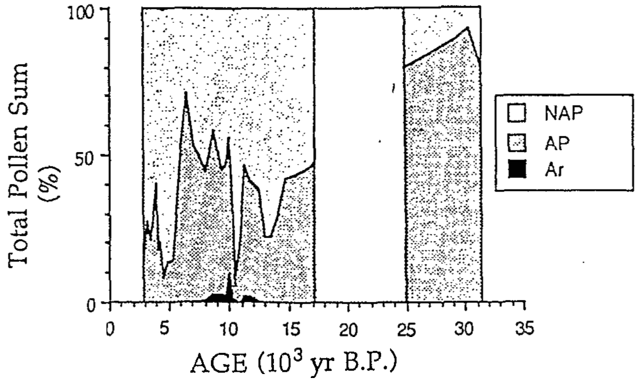

FIG. 4. Summary time-scale diagram of the Salitre LC3 record with Ar, *Araucaria;* AP, other arboreal pollen; NAP, nonarboreal pollen; all are calculated as percentage of total pollen sum.

winter temperatures (below 10°C average). The peat bog is maintained and soils are acid. Moist conditions are optimum, but temperatures remain cold during this period.

In zone IIIa, *Araucaria* and *Drimys* disappear and *Ilex* and *Myroxylon*-type decrease from 2.5 to 0.4%, whereas *Miconia* type (18 to 37%) and Melastomataceae/Combretaceae (5.5 to 11%) increase. Other pollen taxa recorded include *Tabebuia, Tecoma, Zanthoxylum, Alchornea, Lithraea/Tapirira,* and Palmae. Herbaceous taxa are dominated by Poaceae (27 to 62%). This pollen association suggests that the *Araucaria* forest was replaced by mesophytic semideciduous forest which reflects higher temperatures during this period, probably with a 2-month dry season and mean values of winter temperatures between 10° and 15°C. The climate is still moist but with warm temperatures.

In zone II, between 42 and 33 cm (ca. 5500 to 4500 yr B.P.), total tree pollen frequency become very low (between 8 and 14%). Herbaceous taxa are mainly represented by Poaceae (80%), Apiaceae, and Asteraceae. The proportion of the Cyperaceae decreases (8 to 2.5%), wetland taxa and Ericaceae have disappeared, and *Sphagnum* shows a peak. This probably is due to a strong moisture stress during a long dry season of 5 months or more.

In zone I, between 33 and 15 cm, 4350 +540/−510 yr B.P. (No. 556) to 3060 ±210 yr B.P. (551), arboreal pollen frequency increases to 45%. The tree taxa are represented primarily by *Miconia* type (3.5 to 11%), Mimosaceae (1.5 to 7%), and Melastomataceae/Combretaceae (0.2 to 7.5%). The presence of *Chomelia, Copaifera,* and *Tecoma* indicates moister climatic conditions than in the previous zone. This pollen association is characteristic of a mesophytic semideciduous forest which today is related to a short dry season, 1 to 2 months long, and mean winter temperatures ranging from 10° to 15°C.

Because of disturbances during the drilling operation, no sediment was recovered for the last 3000 years (zone 0).

DISCUSSION

The section studied reveals marked changes in the forest composition during the last 30,000 yr indicating major climate changes. In order to relate these variations to climate changes throughout South America, a time-scale diagram was plotted (Fig. 4) which shows more detail and changes in the frequency of tree pollen than the depth-scale diagram. The most significant changes are (1) the initially high proportions of arboreal pollen, declining after 17,000 yr B.P.; (2) the low proportions of tree pollens between ca. 14,000 and 13,000 yr B.P.; (3) the high proportion of arboreal pollen between ca. 13,000 and 11,000 yr B.P.; (4) the abrupt and short-term decline of forest between 11,000 and 10,000 yr B.P.; (5) forest expansion at the beginning of the Holocene, initially by expansion of the *Araucaria* forest between 10,000 and 8500 yr B.P. and followed by expansion of the mesophytic semideciduous forest between 8500 and 5500 yr B.P.; and (6) the abrupt decline of arboreal pollen at ca. 4500 yr B.P.

Apart from the recently analyzed pollen record from Carajás (6°20′S lat) in Amazonia (Absy *et al.,* 1991), the Salitre record is the only other well-dated paleoclimatic record from the tropical lowlands to extend back through the full-glacial period. Between 30,000 and 23,000 yr B.P., the floodplain forest was present in Salitre. In Amazonia (Absy *et al.,* 1991), at San Juan Bosco and Mera, Ecuador (Bush *et al.,* 1990), and in central America, at El Valle in Panama (Bush and Colinvaux, 1990), rainforests were well developed at this time, indicating moist climate.

The lower proportion of arboreal forest between 17,000 and 13,000 yr B.P. and development of a transitional forest indicate cold (low mean winter temperature) and relatively dry (2-month dry season) conditions, but not as dry as suggested by geomorphologists (Bigarella and Andrade-Lima, 1982; Ab'Saber, 1982). This tends to confirm the hypothesis that the southern polar fronts remained at a near-equatorial position until the early Holocene.

Conditions were especially cold and dry when arboreal pollen was very low. The low proportion of tree pollens at ca. 14,000 yr B.P. was also recorded in Carajás (Absy *et al.,* 1991) and in the lowlands of Panama (Bush and Colinvaux, 1990) where it was interpreted as a temperature lowering of 6°C. At the end of the Pleistocene, between 13,000 and 11,000 yr B.P. the forest expanded at Salitre and conditions became progressively moister, as pointed out by the development of the *Araucaria* forest at the end of this interval. This suggests that the polar fronts remained permanent at this latitude. Such cold and moist conditions were also reported in the Carajás record for the same period.

Between 11,000 and 10,000 yr B.P. at Salitre, the forest disappeared suggesting a return to a cold and dry climate. This episode was very short and abrupt, culminating at

10,500 yr B.P. This event may correspond to the Younger Dryas event of the circum-North Atlantic region, expressed there as a cold and dry interval. At 11,000 yr B.P., in Rio Grande do Sul, (Lorscheitter and Romero, 1985) a drier episode is also documented. This event, however, was recorded neither in Amazonia at Carajás (Absy *et al.*, 1991) nor in Panama (Bush and Colinvaux, 1990).

Other similar episodes were recorded at other South American sites at high and mid-latitudes but most records do not have a sufficiently high resolution (sample spacing) to allow correlation of data (Markgraf, 1991). The hypothesis of local disturbances that could mask a Younger Dryas event in South America or that could create such an event locally still must be proven before we understand the possible cause of this event and judge the long-distance climatic connections.

The beginning of the Holocene in the tropical lowlands is characterized by the onset of moist climates, indicated by the development of forests (Markgraf and Bradbury, 1982; Markgraf, 1989; Bush and Colinvaux, 1990; Absy *et al.*, 1991). The succession of a cold and moist episode between 9500 and 8500 yr B.P. followed by a higher temperature episode between 8500 and 5500 yr B.P. indicating climatic warming was also recorded in Venezuela (Bradbury *et al.*, 1981; Leyden, 1985) and in Panama (Bush and Colinvaux, 1990). For southern Brazil, the climatic implications of this succession are that polar fronts persisted near the equator until 8500 yr B.P. when they shifted progressively farther southward; temperatures remained cold at Salitre but moist conditions are present.

The driest episode during the Holocene occurred at Salitre between 5500 and 4500 yr B.P. Other South American sites also record a dry phase but they do not show any synchrony. In Carajás, Amazonia (Absy *et al.*, 1991) and in Lac Moreiru, Guyana (Wijmstra and Van der Hammen, 1966), this episode was recorded at ca. 6000 yr B.P. In the tropical lowlands, the Colombian Llanos (Van der Hammen, 1974), Venezuela (Bradbury *et al.*, 1981), and Brazil (Absy, 1980; Absy *et al.*, 1991) lake levels began to fall between 8000 and 6000 yr B.P. and reached their lowest level between 6000 and 4000 yr B.P. This arid episode can be recognized as a widespread event in South America. However, its precise age may differ, depending on the latitude of the site.

Latitude seems to be an important factor in South America, where the expression of global climatic changes may vary and are not necessarily synchronous between sites. More data from the tropical lowlands should help bridge the gap between the different climate scenarios proposed for South America.

In summary, prior to 13,000 yr B.P. the climate of central Brazil appears to have been cooler and perhaps drier than today but not sufficiently different that the forest was eliminated. A short and abrupt climatic event marked by drier conditions is recorded between 11,000 and 10,000 yr B.P., suggesting a possible link to the Northern Hemisphere Younger Dryas event. At the beginning of the Holocene, the climate became moister but remained cold until 8500 yr B.P.; after this date, the climate became warmer while remaining moist. A very arid and warm episode occurred during the mid-Holocene. After 4000 yr B.P., the climate became moister, essentially resembling modern conditions.

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