CHAPTER

20

Late Glacial Vegetation Records in the Americas and Climatic Implications

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Abstract

The late glacial, the transition from the last glacial maximum (LGM) to the Holocene, is a key period for understanding the mechanisms of abrupt climatic change. In terrestrial records there is considerable uncertainty about the exact timing, rate, and magnitude of these changes, and the globality of the changes is still debated. To document past environments in the Americas, we reviewed 28 published pollen records for locations between Alaska and Tierra del Fuego and between the Pacific and Atlantic coasts. In this chapter, we consider three time intervals, corresponding to the Oldest Dryas (15,500–14,500 cal. B.P.), the Bølling-Allerød (14,500–12,700 cal. B.P.), and the Younger Dryas (12,700–11,000 cal. B.P.). Each interval has a duration of more than 1000 years, and their chronologies are comparable with those obtained from laminated sediments. In spite of differences in resolution and chronological control, comparison of the data suggests that there is no synchroneity of these late glacial climate oscillations in the Americas. Some vegetation records show no late glacial vegetation changes at all, while others show several oscillations. Three main regions of comparable climate change can be distinguished in these records: (1) high-altitude sites and high northern latitude sites showing synchronous oscillations, but with different paleoenvironmental expressions; (2) midlatitude and tropical-latitude sites showing the same sequence of changes on both sides of the equator; and (3) high southern latitude sites. Because these fluctuations have abrupt onsets and terminations and are assumed to be of global distribution, they cannot be attributed to insolation forcing. Instead, changes in the Arctic heat budget through the thermohaline (North Atlantic Deep Water, NADW) circulation were proposed as the mechanism. We suggest that these changes affected climates as far as the southern extension of the Intertropical Convergence Zone (ITCZ). The mechanism explaining the observed climate fluctuation on land would relate to increased (during cold oscillations) or decreased (during the warm Bølling-Allerød oscillation) penetration of polar air. Under this scenario, the climatic fluctuations documented in records from southernmost South America could be out of phase with those in the Northern Hemisphere.

Resumen

El Tardi Glacial (TG), la transición del Último Máximo Glacial (LGM) al Holoceno es un período clave para entender los mecanismos que causan los cambios climáticos abruptos. En los registros terrestres hay una considerable incertidumbre acerca de la duración, frecuencia y magnitud exacta de estos fluctuaciones, y su globalidad sigue siendo discutida. Para documentar ambientes pasados en las Americas, hemos revisado 28 registros de polen publicados, situados entre Alaska y la Tierra del Fuego y entre las costas pacíficas y atlánticas. En este capítulo consideramos tres intervalos de tiempo, correspondientes al Oldest Dryas (15.500–14.500 cal años A.P.), Bølling-Allerød (14,500–12,700 cal años A.P.) y Younger Dryas (12.700–11.000 cal años A.P.). Estos intervalos tienen más de 1000 años de duración que es comparable con cronologías obtenidas de sedimentos laminados. No obstante las diferéncias en resolución y control cronológico, los datos demuestran que no tuvo sincronía entre Norte y Sur del los Americas durante el intervalo del Tardiglacial. Algunos registros de vegetación no evidencian cambios durante los intervalos considerados, mientras otros presentan oscilaciones repetidas. Tres areas principales se distinguieron de la comparación de los registros: (1) localidades en altura y en altas latitudes en Norte America muestran oscilaciones sincronizadas, pero con una señal ambiental diferente en diferentes sitios; (2) altas latitudes en America del Sur; (3) latitudes medias y latitudes tropicales, que muestran la misma secuencia de cambios a ambos lados del ecuador. Debido a la alta frecuencia de las fluctuaciones y a su probable carácter global, eventos como el Younger Dryas o el Bølling-Allerød no pueden ser atribuidos a un forzamiento de la insolación. Entonces se propuso un cambio en el balance térmico en el area polar debido a cambios de la circulación "thermohaline" (North Atlantic Deep Water formation, NADW). Sugerimos que estos cambios en el Atlantico Norte pudieron haber afectado el clima hasta la extensión austral de la Zona de Convergéncia Inter Tropical (ITCZ). El mecanismo que explica las fluctuaciones observadas en los registros terrestres podría ser relacionado con el aumento (oscillacion fría), o la disminución (oscillacion cálida) de la penetración de massas polares. En este caso, las fluctuaciones climáticas del Sur de Argentina y Chile no estarían en fase con los del hemisferio Norte.

20.1. INTRODUCTION

The late glacial, the transition from the last glacial maximum (LGM) to the Holocene, is a key period for understanding the mechanisms of abrupt climate change. The late glacial is characterized by three short-term oscillations, called the Oldest Dryas, Older Dryas, and Younger Dryas, respectively. They were defined at the beginning of the century in Denmark at a time when no radiometric dating was available. The distinction between the Older Dryas and the Younger Dryas interval was first established at the Allerød site in Denmark (Hartz and Milthers, 1901) based on sediment stratigraphy. Both phases, separated by a layer of gyttja that corresponds to the Allerød interstadial, are characterized by the presence of macrofossils of subarctic/alpine flora, including *Dryas octopetala*, and the absence of significant amounts of tree birch (*Betula* sp.). The Bølling interstadial in turn was identified at Bølling Sø, Denmark, from a layer of sand and silty gyttja containing a high percentage of tree birch pollen (Iversen, 1942, 1954). The underlying inorganic layer was named the Oldest Dryas interval (in Sanchez-Goñi, 1995). In subsequent years, these intervals were dated in many sites in Europe, yielding the following chronology: (1) Oldest Dryas, 15,500–14,500 cal. B.P.; (2) Bølling/Allerød, 14,500–12,500 cal. B.P., interrupted by three-decade- to century-long events of the Inter-Bølling Cold Period (IBCP), the Older Dryas, and the Inter-Allerød Cold Period (IACP); and (3) the Younger Dryas, 12,500–11,000 cal. B.P. (Fig. 1).

Recent studies on marine cores from the North Atlantic region (Bard et al., 1987, 1990, 1997; Bond et al. 1993; Bond and Lotti, 1995) and on ice cores from Greenland (Jouzel et al., 1987; Johnsen et al., 1992; Dansgaard et al., 1993) have highlighted drastic climat-

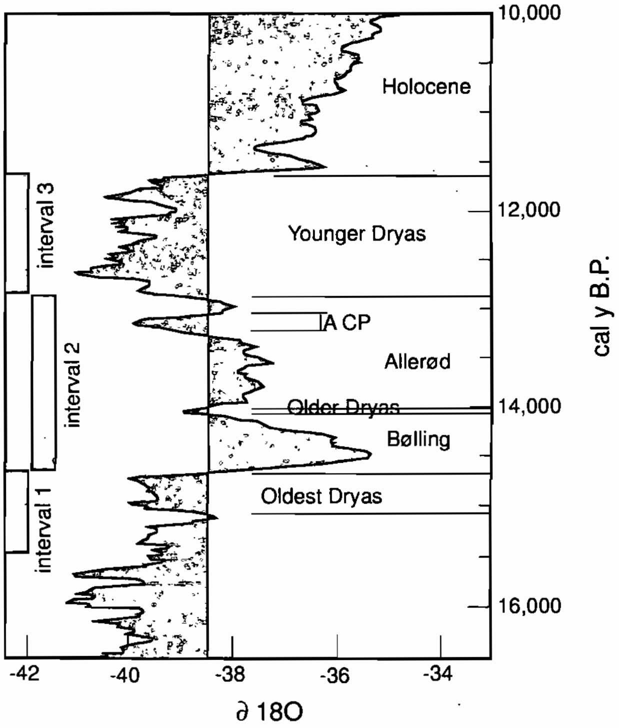


FIGURE 1 Major $\delta^{18}O$ variations and European pollen zone boundaries during late glacial times. (From Stuiver et al., 1995. With permission.)

ic changes of very short duration during the late glacial (Fig. 1). It appears that the last deglaciation was a two-step process with large and rapid fluctuations between warmer and colder conditions. Mounting evidence from marine records elsewhere has documented that these abrupt changes were not restricted to the North Atlantic region. In particular, studies from the Cariaco basin (Venezuela), close to the equator, have revealed the same sequence of short-term warmer and cooler periods identified in terrestrial records (Hughen et al., 1996). For the Arabian Sea, Schulz et al. (1998) and Overpeck et al. (1996) showed that following the last glaciation, the monsoon pattern strengthened in a series of steps coinciding with major climate shifts in the polar regions of the Northern Hemisphere. The similarities of events in records from the Cariaco basin, the Arabian Sea, and the high-latitude North Atlantic suggest a common forcing mechanism. For many years, it has been demonstrated that insolation, especially precession, was a dominant factor regulating tropical climate changes during the Pleistocene (Street and Grove, 1979; Prell and van Campo, 1986; Prell and Kutzbach, 1987; Partridge et al., 1997). However, the abrupt climatic changes evidenced during the last deglaciation cannot be accounted for by orbital forcing. Instead, these changes have been linked to rapid reorganizations of the North Atlantic thermohaline circulation (Broecker et al., 1985, 1988; Lehman and Keigwin, 1992; Broecker 1994; Zaucker et al., 1994).

Although in Antarctica the glacial–interglacial warming also occurred in two steps, interrupted by a slight cooling period, the Antarctic Cold Reversal (Jouzel et al., 1995; Sowers and Bender, 1995), it is out of phase with the sequence of climate shifts in the North Atlantic (Broecker, 1998; Blunier et al., 1998).

There is considerable uncertainty in terrestrial records about the exact timing, rate, and magnitude of these changes. The response of the land–atmosphere system to these climatic oscillations is apparently not regionally uniform. Therefore, the global extent of the changes remains in debate.

When the sequences of late glacial fluctuations in palynological continental records along the Pole-Equator-Pole: Americas (PEP 1) transect are compared, the following questions arise:

1. What is the timing of the onset of the late glacial in different types of environments? Given differences in basal ages of the records, this question is often problematic. Records located in the tropical lowlands, for example, start right after the LGM; in high-latitude, high-altitude, and midlatitude records, sedimentation in lakes or bogs generally started only after the glaciers had retreated locally at ca. 15,000 cal. B.P.
2. How are late glacial changes expressed in different vegetation types?
3. Is the sequence of cold (stadial) and warm (interstadial) fluctuations during the time interval between 17,000 and 11,000 cal. B.P. consistent and synchronous over large distances?

In the following, we will discuss three time intervals corresponding to the European late glacial stratigraphy; these intervals are the Oldest Dryas, 15,500–14,500 cal. B.P.; the Bølling-Allerød, 14,500–12,700 cal. B.P.; and the Younger Dryas, 12,700–11,000 cal. B.P.

20.2. PAST ENVIRONMENTS

To document past environments in the Americas, we reviewed 28 published pollen records located between Alaska and Tierra del Fuego and between the Pacific and Atlantic coasts. Table 1 shows geographical information (latitude, longitude, and elevation), radiocarbon dates, calibrated ages, sample resolution (when possible), and references for the 28 sites. Numbers in front of the sites refer to their locations in Fig. 2.

Our purpose was not to review all the available sites from the North American or Latin American pollen databases. Instead, sites were selected to include a wide range of analytical methods that allowed the characterization of late glacial environmental changes, according to the records' temporal resolution, dating control, type of surrounding vegetation, etc. This approach allows us to discuss many of the problems encountered when late glacial terrestrial sites are analyzed, and it enhances our ability to detect and define the character of these changes. Finally, we will refer to published regional compilations to discuss regional or local changes.

20.3. RADIOCARBON DATING CONTROL

One of the most difficult problems in reconstructing paleoclimates is generating a reliable chronology for the records. For the last 30,000 years, radiocarbon dates can be obtained on organic matter or carbonates by using conventional methods or accelerator mass spectrometry. Depending on the material dated, problems can arise. Duplicate dates on different fractions (e.g., bulk sediment, mollusks, plant or wood remains) from the same level can vary considerably. Figure 3 illustrates this problem and demonstrates that only a few records in the Americas present reliable chronologies for the late glacial. Most of the sites have poor chronologic control based on just a few radiocarbon dates. Interpolation between a few dates has to be considered

TABLE 1 Geographical Information on Pollen Records Discussed in the Text, Including Radiocarbon Dates, Calendar Ages, Temporal Resolution, and References

No.	Site	State/ country	Latitude	Longitude	Elevation (m)	Resolution (years)	^{14}C dates	Ages (cal. years B.P.)	Ref.
1	Ongivinuk Grandfather	Alaska, U.S.A.	59°31′ N	159°22′ W	163	300	13,890 ± 390	16,659 (17,575–15,590)	Hu et al., 1995
							13,150 ± 330	15,669 (16,580–14,585)	
							9,920 ± 160	11,006 (12,092–10,616)	
2	Pleasant Island	Alaska, U.S.A.	58°21′ N	135°40′ W	150	120	13,760 ± 120	15,290 (15,570–15,000)	Hansen and Engstrom, 1996
							12,280 ± 120	13,340 (13,540–13,170)	
							11,950 ± 120	13,010 (13,180–12,850)	
							11,620 ± 120	12,700 (12,860–12,520)	
							11,430 ± 120	13,340 (13,480–13,220)	
							11,040 ± 100	12,950 (13,050–12,860)	
							10,880 ± 95	12,800 (12,890–12,710)	
							10,530 ± 110	10,930 (11,010–10,520)	
							10,110 ± 100	10,200 (10,380–10,040)	
3	Olympic Peninsula	Washington, U.S.A.	48°N	123°W	165	150	11,000 ± 150	12,917 (13,230–12,610)	Peterson et al., 1983
							11,560 ± 160	13,482 (13,909–13,132)	
							12,100 ± 310	14,114 (15,031–13,380)	
							8,920 ± 100	9,922 (10,040–9,649)	
4	Little Lake	Oregon, U.S.A.	44°10′ N	123°35′ W	217		15,920 ± 230	18,800 (19,340–18,430)	Grigg and Whitlock, 1998
							13,640 ± 390	16,350 (17,300–15,180)	
							11,990 ± 120	13,980 (14,370–13,640)	
							12,720 ± 140	14,980 (15,490–14,490)	
							10,940 ± 180	12,860 (13,230–12,490)	
							11,320 ± 190	13,230 (13,680–12,850)	
							10,400 ± 70	12,300 (12,510–11,990)	
							10,790 ± 80	12,720 (12,900–12,520)	
5	Gordon Lake	Oregon, U.S.A.	44°21′ N	122°15′ W	1177		12,640 ± 150	14,860 (15,390–14,360)	Grigg and Whitlock, 1998
							11,520 ± 80	13,430 (13,700–13,230)	
							10,400 ± 75	12,300 (12,530–11,960)	
							10,010 ± 70	11,210; 11,350; 11,110 (11,840–11,000)	
6	Killarney Lake	Canada	46° N	66°37′40″ W	75		10,770 ± 120	12,699 (12,948–12,420)	Levesque et al., 1993
							11,180 ± 120	13,087 (13,369–12,838)	
7	Allamuchy Pond	New Jersey, U.S.A.	40°55′ N	74°50′ W	218	200	9,230 ± 160	10,355 (10,797–9,914)	Peteet et al., 1993
							10,740 ± 420	12,670 (13,521–11,004)	
							12,260 ± 220	14,317 (15,017–13,738)	
	Linsley Pond	Connecticut, U.S.A.	41°18′ N	72°45′ W	65	150	9,920 ± 230	11,006 (12,295–10,424)	Peteet et al., 1993
							10,440 ± 230	12,349 (12,836–11,083)	
							11,500 ± 300	13,430 (13,700–13,230)	
							12,590 ± 430	13,416 (14,154–12,814)	
8	Jackson Pond	Kentucky, U.S.A.	37°27′ N	85°43′ W	220	700	17,750 ± 630	20,274 (21,160–19,389)	Wilkins et al., 1991
							11,860 ± 250	13,825 (14,511–13,255)	
							10,040 ± 190	11,625 (12,350–10,900)	
9	Mary Jane	Colorado, U.S.A.	39°53′ N	105°49′ W	2882	100	13,740 ± 160	16,473 (16,902–16,014)	Short and Elias, 1987
							12,380 ± 180	14,478 (15,090–13,961)	
10	Yosemite NP	California, U.S.A.	38° N	120° W	1554	590	10,420 ± 100	12,323 (12,584–11,928)	Smith and Anderson, 1992
							13,690 ± 340	16,409 (17,242–15,426)	

11	Hendrick Pond	Wyoming, U.S.A.	43°45′ N	110°36′ W	2073		11,340 ± 100	13,248 (13,518–13,026)	Whitlock, 1993
							14,580 ± 150	17,459 (17,833–17,081)	
							17,160 ± 210	20,340 (21,041–19,657)	
	Lily Lake Fen	Wyoming, U.S.A.	43°45′ N	110°19′ W	2500–2650		10,170 ± 170	12,699 (12,931–12,440)	Whitlock, 1993
							11,130 ± 110	13,040 (13,292–12,808)	
							12,370 ± 120	14,464 (14,925–14,069)	
							16,040 ± 220	18,915 (19,464–18,468)	
	Fallback Lake	Wyoming, U.S.A.	43°58′ N	110°26′ W	2597		12,070 ± 120	14,077 (14,493–13,722)	Whitlock, 1993
							12,130 ± 150	14,152 (14,650–13,734)	
							15,640 ± 160	18,539 (18,890–18,196)	
	Cygnet Lake Fen	Wyoming, U.S.A.	44°39′ N	110°36′ W	2530		11,800 ± 190	13,755 (14,279–13,310)	Whitlock, 1993
							14,490 ± 70	17,358 (17,587–17,128)	
12	Browns Pond	Virginia, U.S.A.	38°09′ N	79°37′ W	620	70	13,790 ± 130	16,535 (16,898–16,155)	Kneller and Peteet, 1993
							14,300 ± 110	17,143 (17,455–16,836)	
							14,310 ± 110	17,155 (17,456–16,848)	
							13,010 ± 95	15,452 (15,813–15,019)	
							12,910 ± 100	15,292 (15,676–14,831)	
							12,940 ± 110	15,341 (15,745–14,858)	
							13,025 ± 230	15,476 (16,172–14,671)	
13	Camel Lake	Florida, U.S.A.	30°16′ N	85°1′ W	20		12,610 ± 135	14,812 (15,320–14,333)	Watts et al., 1992
							14,330 ± 275	17,177 (17,814–16,501)	
							10,980 ± 100	12,898 (13,112–12,680)	
							10,020 ± 110	11,200 (12,110–10,900)	
14	Chalco Lake	Mexico	19°30′ N	99° W	2240		14,610 ± 470	17,492 (18,473–16,371)	Lozano-García and Ortego-Guerrero, 1994
							12,520 ± 135	14,677 (15,182–14,221)	
							9,395 ± 255	10,369 (11,007–9,902)	
15	La Yeguada	Panama	8°27′ N	80°51′ W	650		10,210 ± 130	11,984 (12,419–11,009)	Bush et al., 1992
							10,530 ± 100	12,453 (12,691–12,141)	
							11,250 ± 140	13,157 (13,491–12,870)	
							11,610 ± 180	13,538 (14,014–13,143)	
							14,230 ± 370	17,062 (17,904–16,132)	
							13,670 ± 210	16,384 (16,929–15,784)	
							12,910 ± 140	15,292 (15,779–14,731)	
16	Pedro Palo III	Colombia	4°30′ N	74°23′ W	2000		11,380 ± 130	13,289 (13,629–13,012)	Hooghiemstra and van der Hammen, 1993
							11,950 ± 100	13,931 (14,284–13,629)	
	Pedro Palo V						10,280 ± 90	12,118 (12,420–11,346)	
							10,380 ± 90	12,271 (12,526–11,871)	
17	Laguna Ciega I	Colombia	6°30′ N	72°18′ W	3500		14,140 ± 120	16,957 (17,283–16,621)	van der Hammen et al., 1980/1981
	Laguna Ciega II						12,830 ± 80	15,162 (15,513–14,739)	
	Laguna Ciega III								Kuhry, 1988
18	Laguna Baja	Peru	7°42′ S	77°32′ W	3575		12,100 ± 190	14,114 (14,706–13,624)	Hansen and Rodbell, 1995
							10,865 ± 690	12,790 (14,318–10,477)	
19	Mucubaji	Venezuela	8°48′ N	70°50′ W	3650		12,650 ± 130	14,874 (15,367–14,395)	Salgado-Labouriau, 1984
							12,570 ± 130	14,751 (15,245–14,293)	Salgado-Labouriau, 1989
							12,390 ± 250	14,492 (15,304–13,823)	Salgado-Labouriau et al., 1977
							12,250 ± 150	14,304 (14,821–13,870)	
							11,960 ± 100	13,943 (14,298–13,639)	

(*continues*)

TABLE 1 *(continued)*

No.	Site	State/ country	Latitude	Longitude	Elevation (m)	Resolution (years)	^{14}C dates	Ages (cal. years B.P.)	Ref.
20	Lake Valencia	Venezuela	10°16′ N	67°45′ W	403		12,930 ± 500	15,325 (16,721–13,888)	Bradbury et al., 1981
							10,200 ± 350	11,962 (12,832–10,481)	
21	Pata	Brazil	0°16′ N	66°4′ W	400		14,230 ± 60	17,062 (17,281–18,842)	Colinvaux et al., 1996
							15,580 ± 60	18,483 (18,692–18,281)	
							17,840 ± 300	21,277 (22,100–20,375)	
22	Carajás	Brazil	6°20′ S	50°25′ W	700		10,460 ± 200	12,373 (12,800–11,228)	Absy et al., 1991
							12,520 ± 130	14,677 (15,170–14,231)	
23	Salitre	Brazil	19° S	46°46′ W	950	200–300	14,230 ± 100	17,062 (17,346–16,771)	Ledru, 1993
							12,890 ± 80	15,259 (16,719–15,066)	
							10,350 ± 200	12,228 (12,696–11,010)	
							10,440 ± 150	12,349 (12,691–11,736)	
							9,150 ± 80	10,042 (10,306–9,973)	
24	Pichihué II	Chile	42°23′ S	74°00′ W	700		12,760 ± 120	15,049 (15,504–14,560)	Villagrán, 1991
							12,405 ± 330	14,513 (15,564–13,667)	
							10,220 ± 310	12,005 (10,826–8,669)	
							10,140 ± 100	11,808 (12,269–11,007)	
25	Puerto Octay PM13 core	Chile	40°56′ S	72°54′ W		45–95	15,270 ± 165	18,191 (18,540–17,823)	Moreno, 1997
							15,290 ± 120	18,211 (18,497–17,916)	
							13,940 ± 155	16,719 (17,115–16,304)	
							13,790 ± 100	16,535 (16,838–16,220)	
							11,840 ± 140	13,801 (14,220–13,445)	
	PM12 core						14,300 ± 102	17,212 (17,511–16,907)	
							13,980 ± 95	16,767 (17,043–16,486)	
							10,560 ± 100	12,450 (12,690–12,140)	
							10,770 ± 60	12,699 (12,854–12,529)	
							10,330 ± 70	12,199 (12,440–11,821)	
26	Puerto del Hambre	Chile	53°36′ S	70°55′ W	3	150–200	15,800 ± 200	18,687 (19,132–18,280)	Heusser, 1995
							13,190 ± 80	15,728 (16,033–15,382)	
							12,740 ± 260	15,017 (15,859–14,220)	
							10,940 ± 70	12,860 (13,025–12,689)	
27	Punta Arenas	Chile	53°09′ S	70°57′ W	75	150	13,400 ± 140	16,027 (16,442–15,573)	Heusser, 1995
							11,960 ± 170	13,943 (14,451–13,514)	
							10,840 ± 70	12,766 (12,932–12,588)	
28	Harberton	Argentina	54°53′ S	67°10′ W	50	10–50	13,360 ± 280	15,971 (16,719–15,066)	Markgraf and Kenny, 1997
							11,300 ± 200	13,207 (13,682–12,809)	
							10,950 ± 170	12,950 (13,136–12,737)	
							10,490 ± 475	12,450 (12,665–12,235)	
							10,670 ± 150	12,650 (12,866–12,434)	

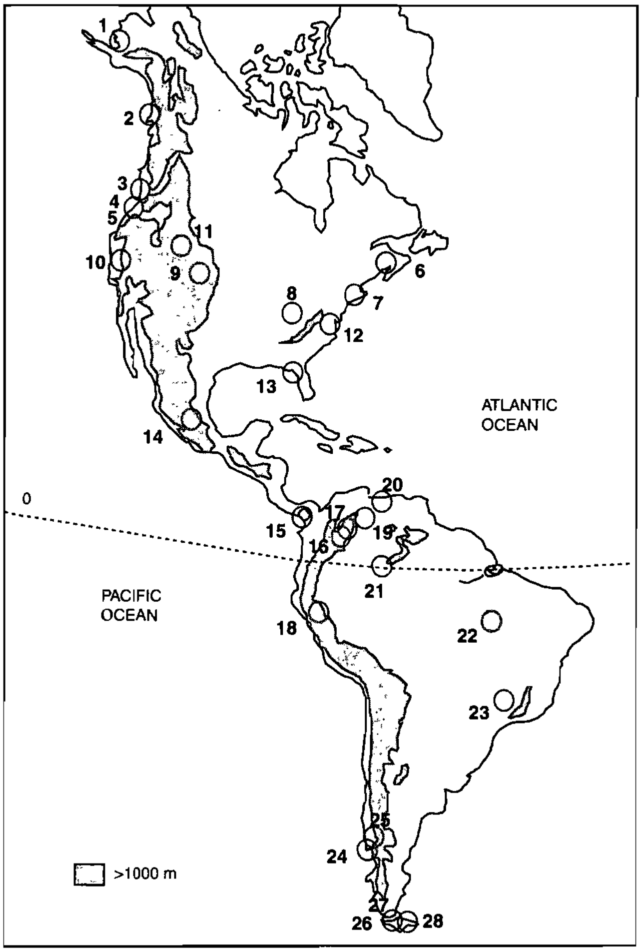


FIGURE 2 Site locations of pollen records along the PEP 1 transect. Locations are given in Table 1.

suspect when we refer to events with a duration of <1000 years. Another problem is related to the dating of carbonates. Radiocarbon dates from lacustrine sediments, at times, can be affected by old carbon (hard-water effect) which produces dates that are too old. Furthermore, the hard-water effect can vary through time in lakes or wetlands. At several coring sites, the dates obtained for different lake levels should be interpreted with great caution, especially in case of isolated ages. In the case of the late glacial, the brief nature of the intervals such as the Older Dryas, IACP, or IBCP requires high temporal resolution, taking into account changes in sedimentation processes that seem to occur in most of the records.

In this chapter, we consider three time intervals corresponding to the Oldest Dryas (15,500–14,500 cal. B.P.), the Bølling-Allerød interval (14,500–12,700 cal. B.P.), and the Younger Dryas (12,700–11,000 cal. B.P.); all intervals have a duration of ≥ 1000 years, which compares with chronologies obtained from revised sites and laminated sediments (e.g., Cariaco basin). Establishing the presence of the Younger Dryas interval has been complicated by the difficulty of precisely dating its termination with the radiocarbon method. Due to the decreasing concentration of ^{14}C in the atmosphere at that time, radiocarbon dates are nearly the same over an 800-year period (Stuiver and Reimer, 1993).

All radiocarbon dates that cover the late glacial were calibrated (Table 1) by using the CALIB 3.0 program (Stuiver and Reimer, 1993). Late glacial dates older than 10,100 cal. B.P. were calibrated with U/Th and ^{14}C coral sets (Bard et al., 1990, 1993). The 2 sigma standard deviation will be discussed. Only the mean value of the given interval is presented in the text; the whole calibrated interval is given in Table 1. However, we need to keep in mind the probability that a specific age could be the mean value or any other value within this interval. This is an important point to consider when short-term climatic changes such as the late glacial oscillations are discussed. In comparing different vegetation records, therefore, we should consider the entire sequence in order to detect whether there is synchroneity for a specific climatic event or if a temporal lag of climatic events between records is not due to chronological problems. This might be the reason why, in some cases, the interpolated ages do not exactly fit the specific time zone discussed.

We also need to define if in different records there is a difference in the timing of the signal with respect to the beginning or end of the change and if there is a difference in the climatic signal itself. The presence/decrease/increase of the frequency of indicator taxa will be discussed for each record. The presence of the considered indicator taxa will then be translated in terms of warmer/drier/wetter/cooler climatic conditions and compared with the preceding time interval and not with modern data (Figs. 4–6). This climatic reconstruction then will be compared among the records.

20.4. PALEOENVIRONMENTAL RECONSTRUCTIONS

20.4.1. Time Interval Between 15,500 and 14,500 cal. B.P.

Figure 4 shows the qualitative climate reconstructions interpreted from indicator taxa and the interpolated time interval of the occurrence of these taxa. These intervals rarely fit with the intervals defined for the Northern Hemisphere (Fig. 1), but when the standard deviations of the calibrated intervals are considered, it is still possible to compare the records.

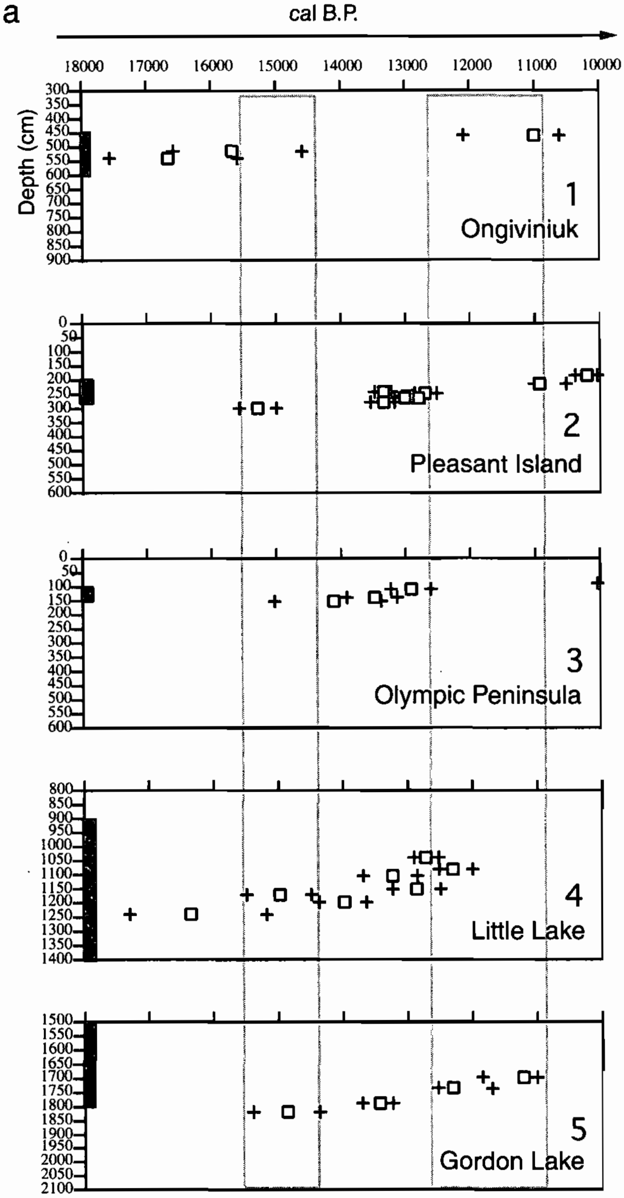
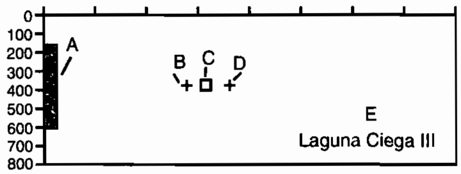


FIGURE 3 Late glacial chronological control for each discussed site. A, sediment thickness that covers the late glacial; B, maximum deviation of the calibrated age; C, mean value of calibrated age; D, minimum deviation of the calibrated age; and E, name of the vegetation record. Light gray lines show the discussed time intervals.



A - Sediment thickness that covers the late glacial.
B - Maximum deviation of the calibrated age.
C - Mean value of calibrated age.
D - Minimum deviation of the calibrated age.
E - Name of the vegetation record.
- Light gray lines show the discussed time intervals.

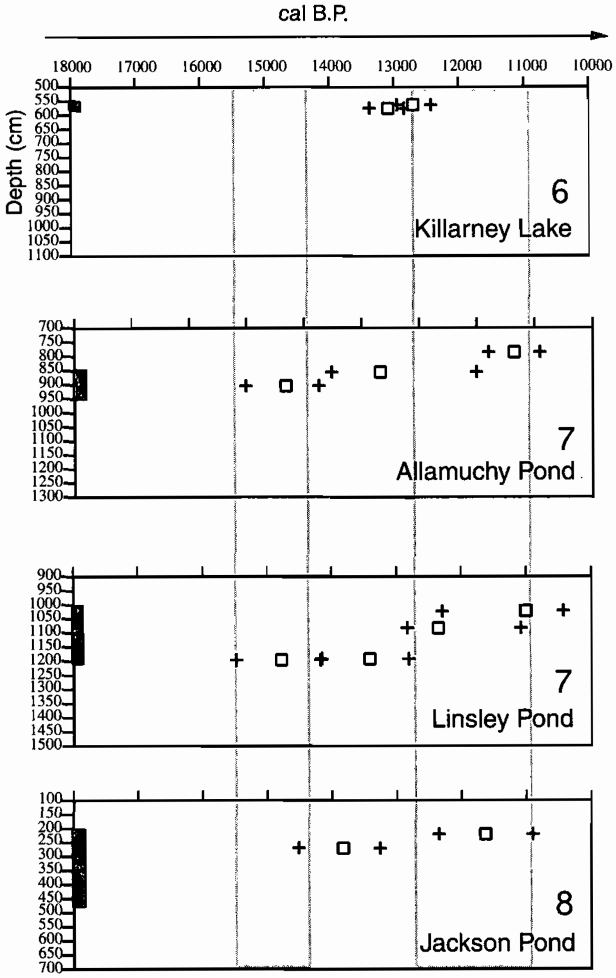


FIGURE 3 (*continued*) A2.

For Alaska, herb tundra is dominant in the Ongivinuk and Grandfather Lake records (1).* Both the absence of *Betula* and the abundance of Cyperaceae suggest low summer temperatures and abundant soil moisture. This period lasted between ca. 15,600 and 13,000 cal. B.P. In the Pleasant Island record (2), this interval represents the beginning of the record and is characterized by a *Salix* shrub tundra with Poaceae and Cyperaceae. No forest taxa were recorded. This is interpreted as a cold and dry period.

In records from the Olympic Peninsula in Washington (3), the interval between 15,000 and 14,000 cal. B.P. represents the end of a cold interval, with the persistence of open herb- and shrub-dominated communities that contained cactus. The climate is defined as dry with warm summers. For Little Lake in Oregon, record

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*The numbers in parentheses pertain to the information in Table 1.

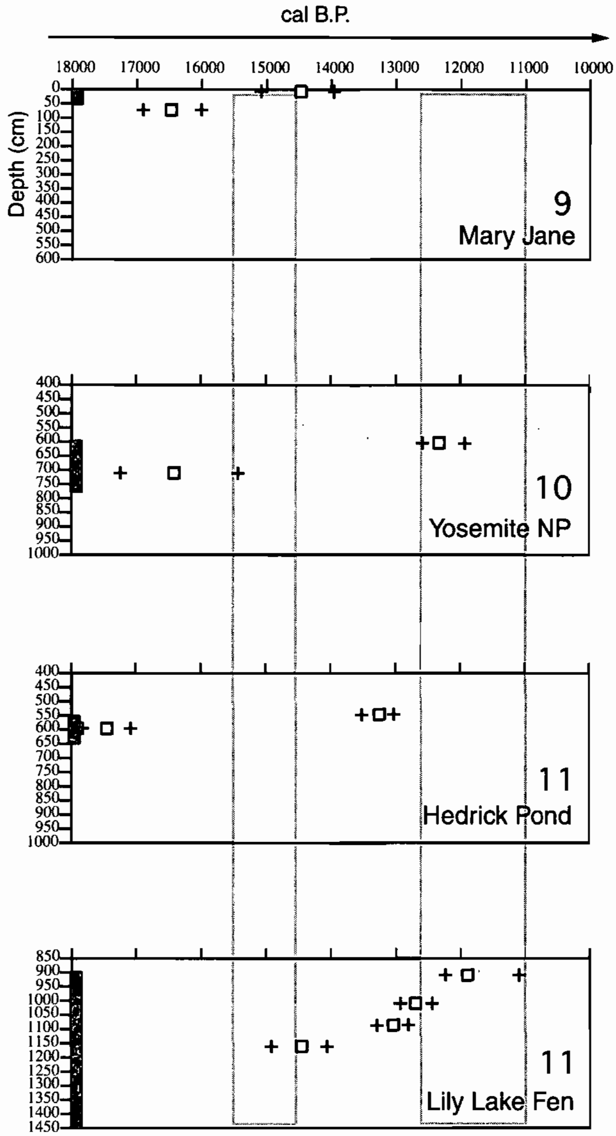

FIGURE 3 (*continued*) A3.

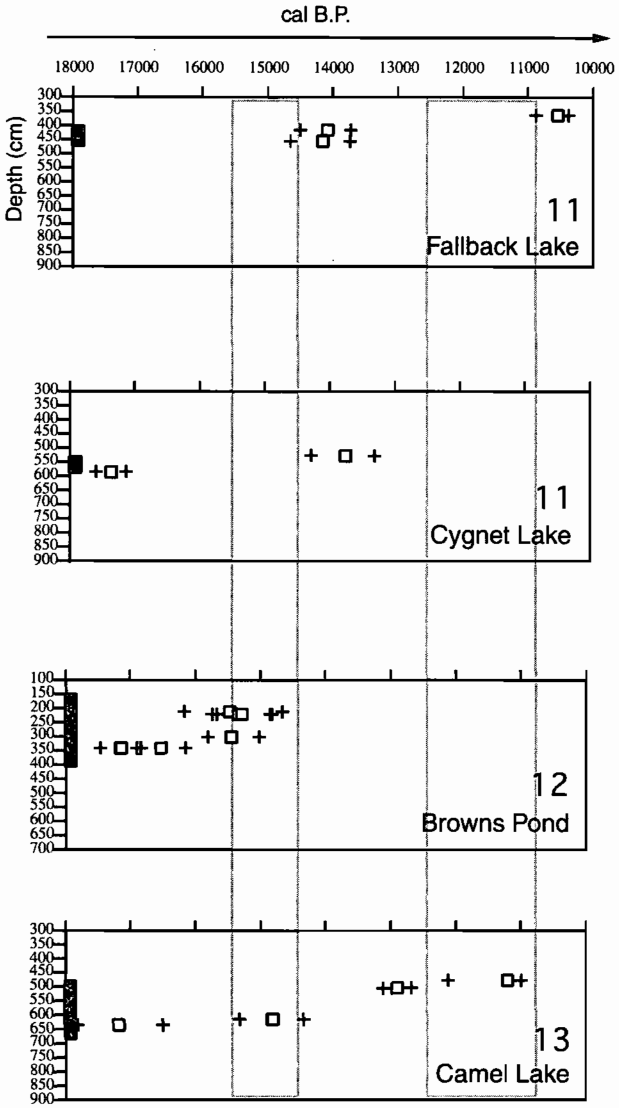

FIGURE 3 (*continued*) A4.

(4), the ability to date macrofossils allowed a high-resolution late glacial record. The record starts at 15,700 cal. B.P. with an open subalpine forest mainly represented by *Tsuga mertensiana*. Between 15,250 and 14,850 cal. B.P., a closed montane forest with primarily *Abies amabilis* is recorded. This record is interpreted to represent a warming compared to the previous interval. Between 14,850 and 14,500 cal. B.P., *Pseudotsuga* dominated in the forest, and an increase of *Tsuga heterophylla* indicates warmer climatic conditions. Between 14,500 and 14,250 cal. B.P., a return to subalpine forests indicates a reversal to a colder climate. At Gordon Lake in Oregon (5), between 15,500 and 14,500 cal. B.P., *T. mertensiana* is recorded together with *Picea* and *Pinus*, suggesting a cooler climate.

In the northeastern Atlantic region, the Allamuchy, New Jersey, and Linsley Ponds, Connecticut, records (7) show the first organic sedimentation at ca. 15,000 cal. B.P. A *Picea-Quercus* assemblage is recorded, attesting to a cool and humid climate. At Jackson Pond in Kentucky (8), with a lower age of older than 16,000 cal. B.P., a *Pinus-Picea* zone is recorded with an increase of deciduous taxa. The environment is defined as an open, taiga-like woodland. At Browns Pond in Virginia (12), *Alnus*, *Pinus*, *Picea*, and *Abies* are recorded prior to 15,000 cal. B.P. At ca. 13,000 cal. B.P., deciduous tree taxa increase—mainly *Ostrya*, *Carpinus*, and *Quercus*. This change indicates a rapid warming and increase in moisture. At Camel Lake in Florida (13), the co-occurrence of *Carya* and *Picea* between 17,000 and 14,800 cal. B.P.

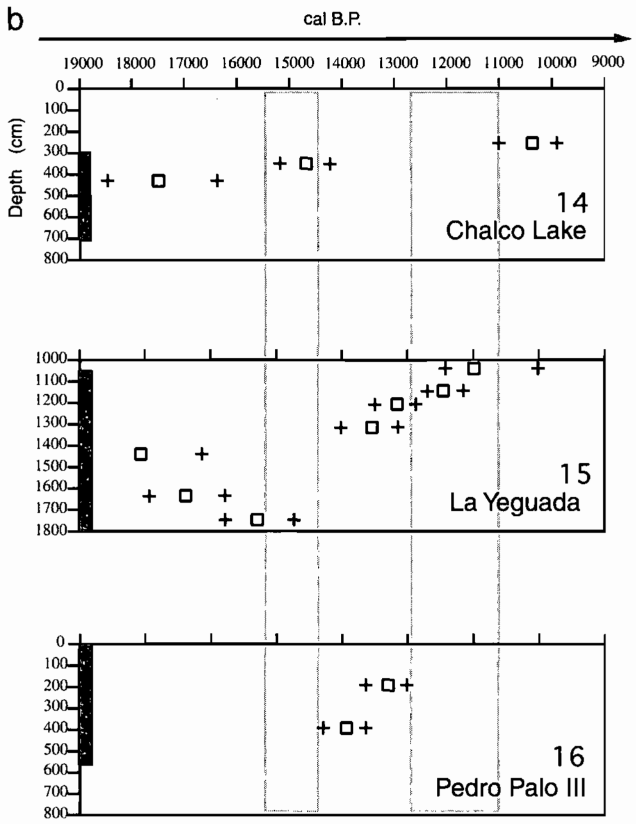

FIGURE 3 (*continued*) B1.

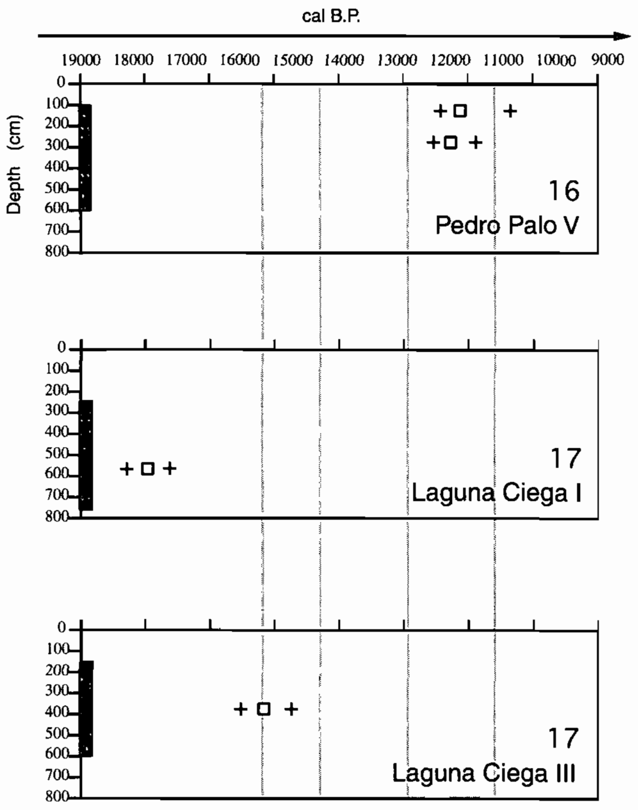

FIGURE 3 (*continued*) B2.

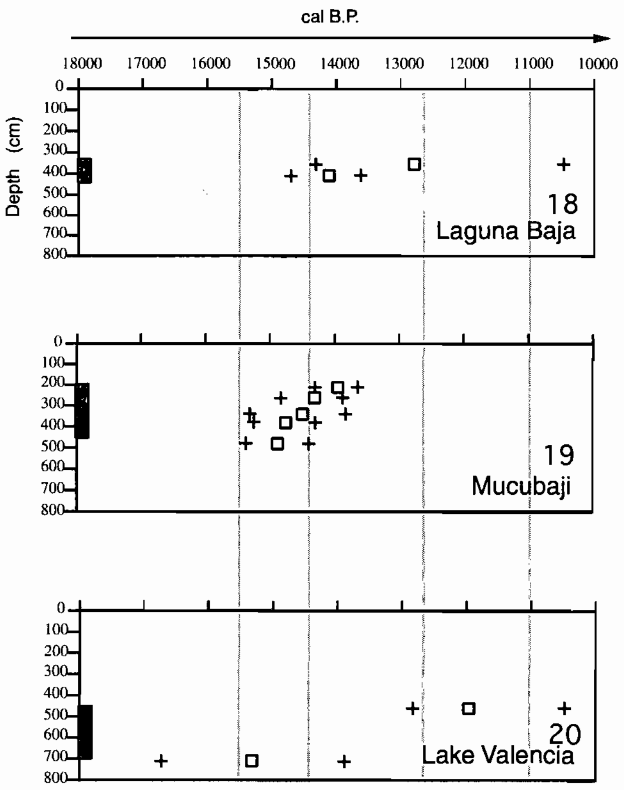

FIGURE 3 (*continued*) B3.

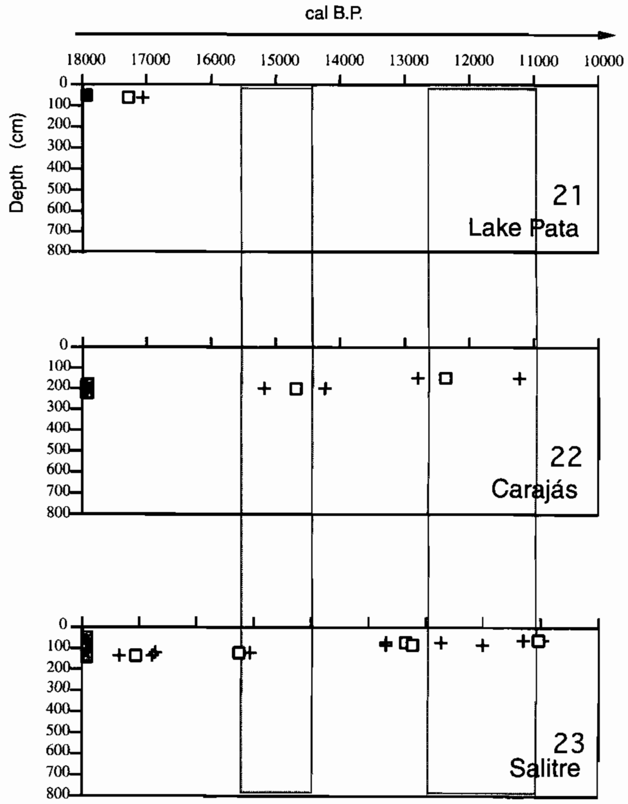

FIGURE 3 (*continued*) B4.

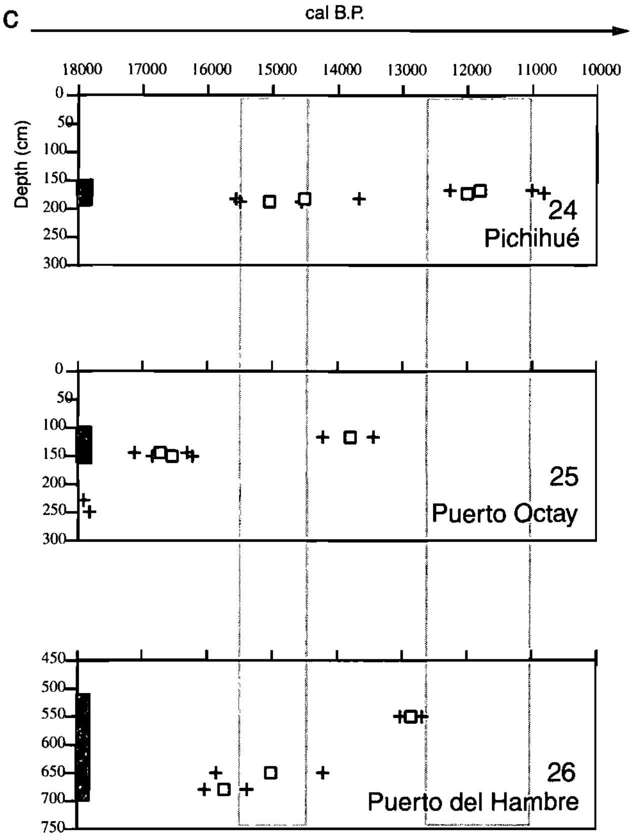

FIGURE 3 (*continued*) C1.

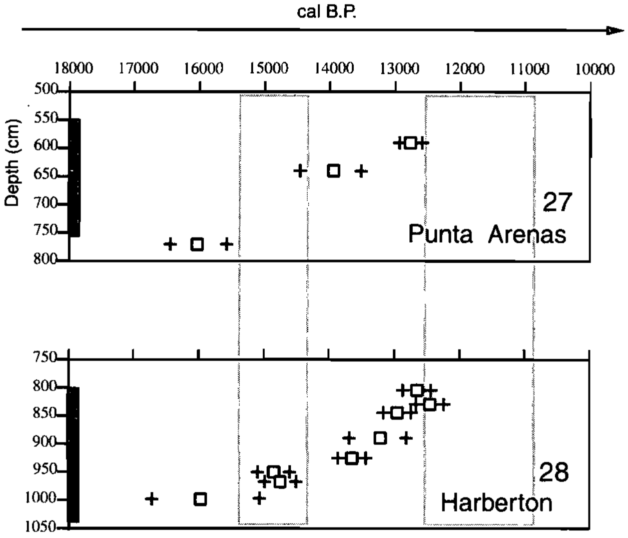

FIGURE 3 (*continued*) C2.

lacks a modern vegetation analog. It is interpreted as indicating high precipitation and frost-free climatic conditions. The end of this interval is uncertain.

In the Rocky Mountains, at the site of Mary Jane in Colorado (9), deglaciation began after 17,000 cal. B.P. A mixture of cold-adapted tundra beetles with northern boreal / subalpine vegetation elements is recorded, suggesting a lowering of the tree line by ca. 500 m and representing a cooler climate. In records from Yellowstone and Grand Teton National Parks (11), an increase of *Picea-Pinus* assemblages is recorded between 15,300 and 14,800 cal. B.P., attesting to wetter climatic conditions. In Yosemite National Park, the Swamp Lake (10) record shows vegetation composed of *Pinus*, *Tsuga*, and *Abies* between 16,400 and 12,300 cal. B.P. This assemblage has no modern analog and is interpreted as an enriched mixed forest, attesting to cooler temperatures and an increase in precipitation. Wetter climatic conditions are also interpreted from paleolake levels (Thompson et al., 1993; Webb et al., 1993) and packrat middens, indicating greater seasonality (Betancourt et al., 1990).

At Chalco Lake in Mexico (14), between 17,500 and

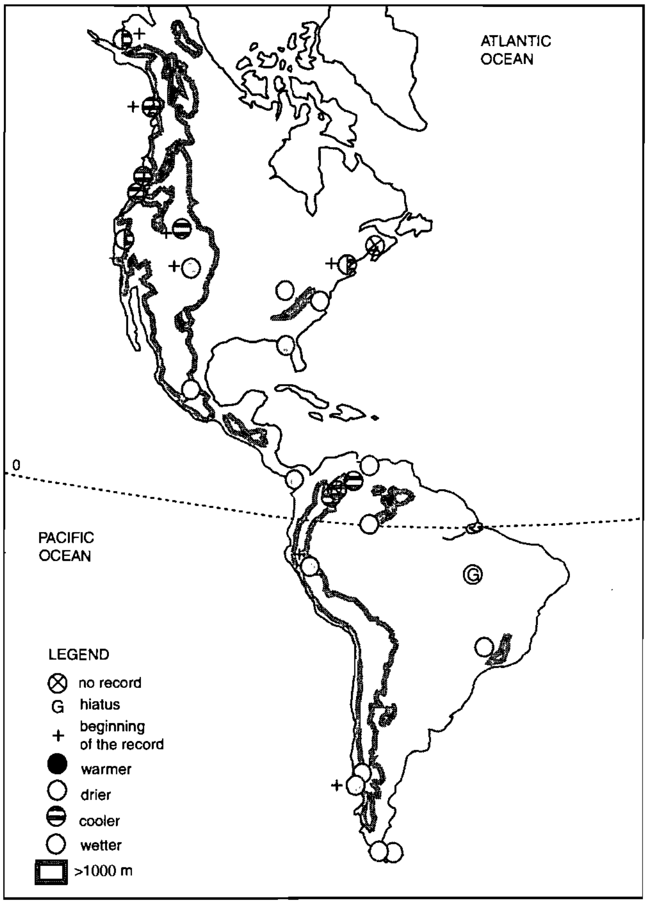

FIGURE 4 Main vegetation types and climatological information for the interval 15,500–14,500 cal. B.P.

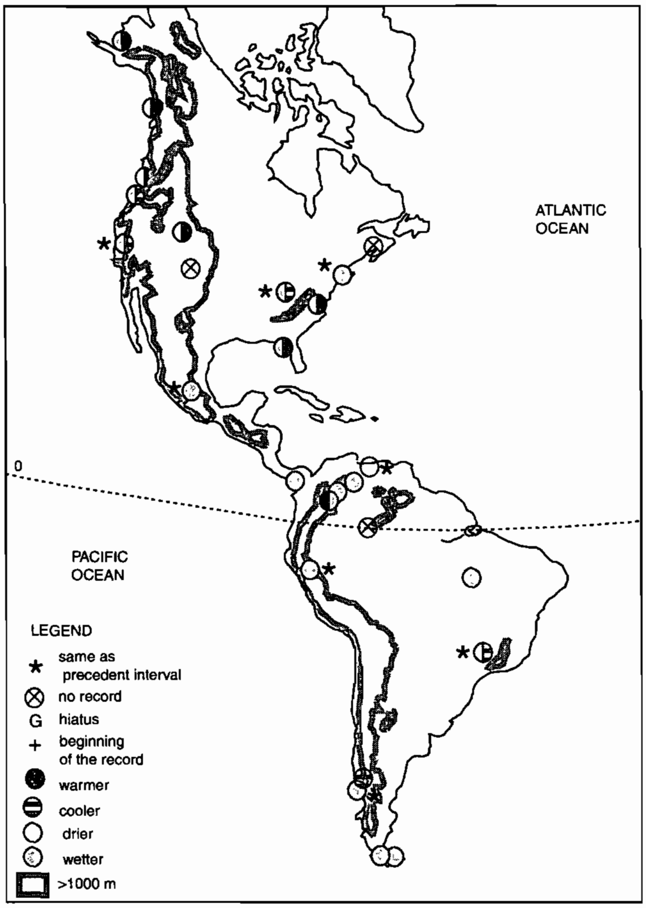

FIGURE 5 Main vegetation types and climatological information for the interval 14,500–12,700 cal. B.P.

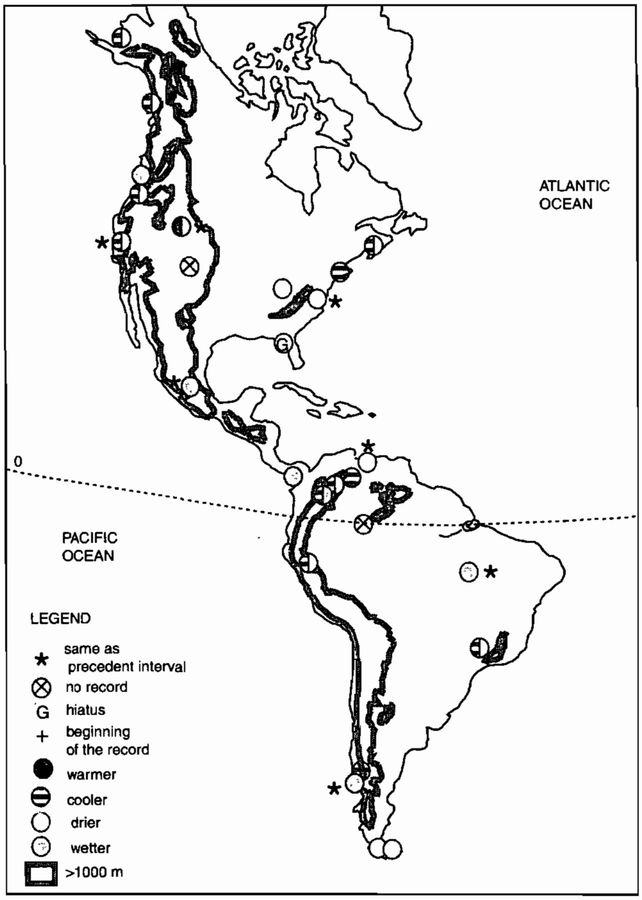

FIGURE 6 Main vegetation types and climatological information for the interval 12,700–11,000 cal. B.P.

11,500 cal. B.P., *Pinus* dominated together with mesophytic forest, including mainly *Abies, Liquidambar, Carpinus,* and *Corylus.* This assemblage reflects high-moisture conditions. The 17,500 cal. B.P. date is, in fact, the upper limit of an interval between 17,500 and 14,500 cal. B.P. At La Yeguada in Panama (15), between 17,000 and 14,700 cal. B.P., moist montane forest is recorded, suggesting humid climatic conditions.

In the high Andean cordillera, four sites were examined: two in Colombia, one in Peru, and one in Venezuela. In the Pedro Palo, Colombia, record (16), between 15,500 and 14,000 cal. B.P., the dominance of nonarboreal pollen suggests dry climatic conditions. Laguna Ciega, Colombia (17), records an increase in Asteraceae between 15,000 and 14,500 cal. B.P. that indicates cold climatic conditions. This interval is called the La Ciega interval and has also been recognized in other records in this area. The record for Laguna Baja, Peru (18), starts at ca. 16,000 cal. B.P.; moist and wet montane elements are well represented for that time. Climatic conditions are defined as having been wet, a condition that lasted until ca. 13,500 cal. B.P. In Mucubaji, Venezuela (19), deglaciation started ca. 14,800 cal. B.P. Pollen content at the onset attests to the presence of a desert paramo, suggesting cold conditions between 14,800 and 14,200 cal. B.P.

For the tropical lowlands, we discuss four sites. Lake Valencia, Venezuela (20), in the tropical lowlands, records dominance of *Alternanthera,* Cyperaceae, and Poaceae between 16,700 and 10,500 cal. B.P., suggesting generally arid conditions. For that time, only a minor increase in moisture is indicated by an increase of savanna tree taxa such as *Bursera* and *Spondias.* During the late glacial, Lake Pata, Brazil (21), recorded an assemblage of rain forest taxa with *Podocarpus* for which no modern analogs exist in present-day vegetation. This record was interpreted to indicate cold temperatures and humid climatic conditions. At Carajás, Brazil (22), a gap in sedimentation is recorded until ca. 14,500 cal. B.P. At Salitre, Brazil (23), the presence of *Araucaria* forest elements between 15,300 and 12,300 cal. B.P. attests to cold and humid climatic conditions.

Five sites are discussed for temperate South America. At Puerto Octay, Chile (25), a gap occurs between ca. 15,500 and 14,500 cal. B.P. At Pichihué, Chile (24), the presence of *Nothofagus*, a pioneer tree taxon, and moorland taxa between 15,000 and 14,500 cal. B.P. attests to humid climatic conditions. At Puerto del Hambre (26) and Punta Arenas (27), Chile, the presence of an *Empetrum* steppe-tundra (heath) is recorded between 16,000 and 14,000 cal. B.P., attesting to drier climatic conditions. At Harberton (28), Argentina, *Empetrum* heathland is also recorded between 16,000 and 15,000 cal. B.P., indicating an increase in temperature and a decrease in precipitation.

20.4.2. Time Interval Between 14,500 and 12,700 cal. B.P.

A summary of the results for the period 14,500–12,700 cal. B.P. is reported in Fig. 5 (the asterisk (*) indicates that no change in vegetation or climate occurred compared to the previous interval).

In Alaska, the Ongivinuk record (1) shows an increase of *Betula* shrubs in the tundra landscape between ca. 13,000 and 12,700 cal. B.P. This phase is related to a warmer and moister climate compared to the previous interval. The Pleasant Island (2) record shows the presence of a *Pinus* parkland with *Alnus* and *Salix*, characteristic of a wetter and warmer climate.

At the Olympic Peninsula (3), the presence of seeds of *Opuntia* (Cactaceae) suggests dry and warm summers between 15,000 and 13,000 cal. B.P. At Gordon Lake (5), a closed forest with *Abies amabilis* and *Tsuga heterophylla* is recorded between 14,500 and 12,800 cal. B.P. At Little Lake (4), an increase in the frequency of *Pseudotsuga* is recorded between 14,250 and 12,400 cal. B.P.

Allamuchy and Linsley Pond records (7) show no vegetation change since the previous interval. The same mixed thermophilous deciduous boreal forest with *Picea*, *Larix*, *Abies*, and *Quercus* is recorded, which suggests a cool and humid climate. In the Jackson Pond record (8), there is also no difference compared to the previous interval, although sampling resolution of one sample for 700 years is too low to detect any oscillation. The climate is defined as having been cool and moist. In the Browns Pond record (12), between ca. 13,000 and 10,000 cal. B.P., a *Quercus-Ostrya-Carpinus* association is recorded, attesting to warmer and wetter climatic conditions. At Camel Lake (13), *Picea* disappeared and deciduous tree taxa, *Fagus* and *Quercus*, began to dominate between 14,800 and 11,500 cal. B.P. The climate was warmer and wetter than during the previous interval.

In the Rocky Mountains, the Yellowstone and Grand Teton National Park sites (11) record an increase of *Picea* between 13,500 and 11,500 cal. B.P., attesting to wetter and warmer climatic conditions. In Mary Jane (9), sediment deposition stopped.

On the Pacific coast, pollen assemblages show no change compared to the previous interval and, although no modern analogs exist for this type of rich mixed forest, the climate is defined as cool and wet.

In Central America, no change in vegetation composition occurred at Chalco Lake (14) and La Yeguada (15). In the high Andean cordillera, the Pedro Palo record (16) shows an expansion of open scrub and grass paramo characteristic of a climatic warming between 14,000 and 13,000 cal. B.P. An increase of arboreal pollen is recorded at Laguna Ciega (17) between 14,500 and 13,000 (12,700) cal. B.P., attesting to wetter climatic conditions, particularly between 14,200 and 14,000 cal. B.P. The Laguna Baja record (18) shows no difference in vegetation composition compared to the previous interval.

In the tropical lowland records, at Lake Pata (21), no sediment deposition occurred during this time interval. At Carajás (22), when sedimentation restarts at ca. 14,600 cal. B.P., an increase of arboreal pollen is recorded, attesting to a moist climate until ca. 10,000 cal. B.P. The Salitre record (23) shows no change compared to the previous interval; the climate was still cool and wet.

In southern South America, at Puerto Octay (25), the expansion of North Patagonian rain forest species is indicative of a warming. At Pichihué (24), the development of peat and a succession of different Magellanic tundra taxa characterize a gradual evolution of the edaphic vegetation, which may indicate equally cool but wetter conditions compared to the previous interval.

In the Punta Arenas (27) and Puerto del Hambre (26) records, an increase in *Nothofagus* is recorded between 14,500 and 12,700 cal. B.P., suggesting a wet interval. In Harberton (28), the increase of Poaceae together with mesic taxa attests to an increase in moisture under continuing cooler temperatures.

20.4.3. Time Interval Between 12,700 and 11,000 cal. B.P., Younger Dryas Chronozone

The data for the time interval 12,700–11,000 cal. B.P. are compiled in Fig. 6. In Alaska, at Ongivinuk and Grandfather Lakes (1), the earlier *Betula* shrub tundra was replaced by herb tundra with Poaceae and *Artemisia*, suggesting a climate that was drier and cooler than before.

In Alaska, the Pleasant Island record (2) shows *Pinus* parkland taxa decreased and instead herb tundra returned between 12,300 and 11,400 cal. B.P. This change is interpreted as indicating a drier and cooler climate. In the Olympic Peninsula record (3), the increase in *Pinus, Picea,* and *Tsuga* recorded between 13,000 and 11,000 cal. B.P. suggests an increase of precipitation. At Gordon Lake (5), the presence of *T. mertensiana* with *Pinus* and *Abies* characterizes a cooler and drier climate between 12,800 and 11,000 cal. B.P. In the Little Lake record (4), between 12,400 and 11,000 cal. B.P., the increase of a mixed coniferous forest with *Pinus* reversed the expansion of the *Pseudotsuga* forest, attesting to a cooler climate, although there is a lack of clear modern analogs.

On the northeastern Atlantic coast, at the Killarney site (6), an increase of boreal forest taxa is recorded. The northward migration of deciduous tree species was stopped, and a two-step climate reversal was recorded. The first one, called the Killarney oscillation, occurred between 13,000 and 12,800 cal. B.P.; the second one occurred between 12,700 and 11,000 cal. B.P. In the Allamuchy and Linsley Pond records (7), there is no change in vegetation composition compared to the previous interval. The climate was still moist and warm. Records from the Yellowstone area do not show any climatic reversal. The climate was wet and cool as in the previous interval. At Browns Pond (12), no reversal is recorded, although the vegetation assemblage of *Quercus-Ostrya-Carpinus* indicates a drier climate than in the previous interval (new data do show a reversal, D. Peteet, personal communication). At Camel Lake (13), a gap in sedimentation occurred between 12,000 and 11,000 cal. B.P.

In Central America, the Chalco Lake record (14) does not show any change since the previous interval and moist montane forest elements continue. In Costa Rica, at the La Chonta 2 site (not shown), the forest line dropped from 2800–2400 m elevation; this event is interpreted as indicating a 2°–2.5°C cooling (Hooghiemstra et al., 1992). In the La Yeguada record (15), an increase of tropical lowland taxa attests to disturbances of the rain forest and was interpreted to reflect a wetter climate between 13,000 (13,300–12,700) and 12,300 (12,700–12,000) cal. B.P.

In the high Andean cordillera, the Pedro Palo record (16) shows a two-step reversal. The first step, between 13,000 and 12,300 cal. B.P., is characterized by a decrease of Andean and sub-Andean elements, which is interpreted as indicating a cooling. The second step, between 12,300 and 12,000 cal. B.P., shows an increase in paramo elements, which is interpreted as reflecting drier climatic conditions. At Laguna Ciega (17), an increase in Poaceae, together with a decrease of arboreal pollen taxa, is defined as representing a cold and dry interval called *El Abra*. In the Mucubaji record (19), superparamo plant assemblages increased between 13,500 and 10,500 cal. B.P., attesting to cooler climatic conditions. At Laguna Baja (18), between 13,500 and 11,000 cal. B.P., moist montane forest elements were replaced by Poaceae, and the charcoal concentration also increased. Three environmental and climatic scenarios could explain this observation: (1) the tree line shifted to lower elevations in response to a cooling; (2) paramo vegetation expanded, implying increased aridity, an explanation that is supported by evidence for increased fires; and (3) arboreal pollen are allochthonous and represent locally an increase in long-distance transport of montane forest pollen.

In the tropical lowlands, there is no sediment deposition during this time interval at Lake Pata (21). At Carajás (22), the vegetation composition did not change since the previous interval. At Salitre (23), a brief increase of Apiaceae and Poaceae between 12,300 and 10,000 cal. B.P. a decrease of the *Araucaria* forest elements, is interpreted as indicating a shift to drier climatic conditions.

In the Puerto Octay (25) record, a cooling is indicated by a decrease of rain forest taxa and an increase of *Nothofagus dombeyi*–type, *Maytenus disticha,* and *Podocarpus nubigena* spp. However, at the same time, charcoal particles increased, suggesting that forest fires and not climate could have produced this change in tree taxa. In the Pichihué (24) record, there is no vegetation change. In the Punta Arenas (27), Puerto del Hambre (26), and Harberton (28) records, a Poaceae-*Empetrum* assemblage suggests drier climatic conditions between 12,900 (12,500) and 11,500 cal. B.P.

20.5. GENERAL DISCUSSION: CHARACTERIZATION OF THE LATE GLACIAL

The establishment of modern forests occurred at different times and followed different patterns, probably related as much to the records' locations as to regional climate change. In spite of differences in resolution and unequal chronological control, the data from the Americas show no clear evidence for synchroneity of climatic oscillations during the late glacial interval. We will point out some of the reasons for this lack of synchroneity.

Several vegetation records show no vegetation changes during the intervals considered. In the Pacific Northwest, for instance, the conifer forest with *Pinus, Tsuga,* and *Abies* dominated between 16,000 and 14,000 cal. B.P. This forest was replaced by subalpine forest taxa between 14,000 and 11,500 cal. B.P. In eastern North America, a mixed *Picea* forest existed between

17,000 and 13,500 cal. B.P., after which it was replaced by a deciduous *Quercus* forest. In southern Central America, the semi-evergreen forest with *Abies, Liquidambar, Carpinus, Alnus, Corylus, Ulmus, Juglans, Fagus,* and *Populus* was fully developed between 18,500 and 11,000 cal. B.P. In tropical lowlands, rain forest taxa are mixed with mountain forest taxa, such as *Podocarpus* and *Hedyosmum*. This mixed forest became fully developed after 14,000 cal. B.P.

However, other vegetation records show several oscillations that are not coeval with circum-North Atlantic oscillations. For example, in the records from the southernmost latitudes, several oscillations between *Empetrum* heathland and Poaceae steppe-tundra occurred between 16,500 and 13,500 cal. B.P. and 13,500 and 11,000 cal. B.P. Repeated changes in moisture are also recorded for midlatitude records in temperate southern South America, including the onset of peat growth, fluctuations of Magellanic moorland elements, and *Nothofagus* forest taxa. Although the timing of these late glacial fluctuations is not strictly coeval, interhemispheric synchroneity is concluded by some authors (Denton et al., 1999; Moreno et al., 1999; but see the discussion by Markgraf and Bianchi, 1999).

Based on the characteristic patterns of late glacial oscillations, the records discussed previously can be divided into three groups:

1. High-altitude sites and high northern and mid-northern latitude sites showing synchronized oscillations, but with a paleoenvironmental expression or climatic signal different from the circum-North Atlantic oscillations.
2. High southern latitude sites showing oscillations diachronous from those characteristic for the circum–North Atlantic region.
3. Mid-southern latitude and tropical sites showing no oscillations or stepwise changes diachronous from the circum–North Atlantic oscillations.

In general, the late glacial climate oscillations, clearly expressed in polar and tropical ice cores (Thompson et al., 1998; Jouzel et al., 1987) and in marine cores (Bard et al., 1987, 1997; Bond et al., 1993), are rarely recorded as clearly in terrestrial records from the Americas. Instead, the character and amplitude of these oscillations in terrestrial records appear to be greatly affected by site specifics.

During the time interval from 15,500–14,500 cal. B.P., vegetation records show that temperatures were low in the high latitudes of the Northern Hemisphere, in Alaska, in the northwest Pacific, in the northeast Atlantic, and at high-elevation sites in the Colombian and Venezuelan Andes. Conditions were wet in the midlatitudes and in tropical and subtropical forest regions, although there is a severe lack of modern analogs for this period. Conditions were dry in southern South America and along the Venezuelan/southeast Caribbean coast.

During the Bølling-Allerød interval (14,500–12,700 cal. B.P.), conditions became wetter in the Americas, except at sites on the Olympic Peninsula and at Lake Valencia.

The case of the next interval (12,700–11,000 cal. B.P.), which corresponds to the Younger Dryas chronozone, is different and better documented because it has been subject to more detailed analysis and even has led to major controversies (Ashworth and Markgraf, 1989; Peteet et al., 1990, 1993; Curtis and Hodell, 1993; Kuhry et al., 1993; Markgraf, 1993; Mathewes, 1993; Francou et al., 1995; Gasse et al., 1995; Hansen, 1995; Heine, 1993, 1995; Islebe et al., 1995; Leyden, 1995; Mayle and Cwynar, 1995; Osborn et al., 1995; Peteet, 1995; Thompson et al., 1995; van der Hammen and Hooghiemstra, 1995; Clapperton et al., 1997; Menounos and Reasoner, 1997; Yu and Eicher, 1998). Changes in vegetation type and composition shown during this interval that can be attributed to temperature reversals are not clearly observed in Central America (except in Costa Rica; Hooghiemstra et al., 1992), tropical lowlands, and the Southern Hemisphere midlatitudes. Moist forests are well developed in these regions, showing few signs of short-term environmental fluctuations that might correlate with the well-documented climatic cooling in the circum–North Atlantic region. On the other hand, records from the high northern Andean and Central American cordilleras show multiple stepwise vegetation changes, suggesting repeated temperature reversals. The same patterns are also recorded in ice core records from Huascarán, Peru, and Sajama, Bolivia (Thompson et al., 1995, 1998), and by evidence of past glacier fluctuations in the Andean cordilleras (Seltzer, 1994; Francou et al., 1995; Clapperton et al., 1997). Abrupt oscillations in forest development are observed in both the North American Northwest and Southwest. In southern South America, repeated high-amplitude paleoenvironmental changes are also recorded, although the timing is apparently out of phase with the circum–North Atlantic oscillations (Markgraf, 1993; Heusser, 1995; Ariztegui et al., 1997; Moreno, 1997; Markgraf and Bianchi, 1999; Denton et al., 1999; Moreno et al., 1999).

Are all the changes evidenced in the PEP 1 transect synchronous and, therefore, can they be attributed to the same climatic forcing? This unanswered question has recently received new interest. Because of the fluctuations' high frequency and their perhaps global expression (Peteet, 1995; Broecker et al., 1998; Lowell et al., 1995), events like the Younger Dryas or Bølling-Allerød interval cannot be attributed to insolation forcing (Milankovitch cycles). It is now generally thought that the reorganization of the ocean–atmosphere interaction in the Atlantic Ocean (changes in the intensity of the thermohaline circulation) must have played a major role in synchronizing climate oscillations during full glacial and late glacial times (Broecker et al., 1985; Broecker and Denton, 1989). It appears that synchroneity of late glacial oscillations is well established among Greenland, the Cariaco trench, and the Andean cordilleras (in Costa Rica, Colombia, and Peru). We suggest that these oscillations affected climates even as far equatorward as the southern extension of the Intertropical Convergence Zone (ITCZ), with a speculative southernmost limit of the ITCZ during the Northern Hemisphere winter months (Fig. 7). The mechanism explaining the observed climate changes on land would relate to increased (or decreased during the warm Bølling-Allerød interval) penetration of polar air masses (Latrubesse and Ramonell, 1994; Bradbury, 1997; Bradbury et al., 2000; Lézine and Denèfle, 1997), as presented by the mobile polar high concept of Leroux (1993, 1996). This atmospheric phenomenon today plays an important role in subtropical precipitation patterns, especially during the winter months (Vuille and Ammann, 1997; Marengo and Rogers, 2000).

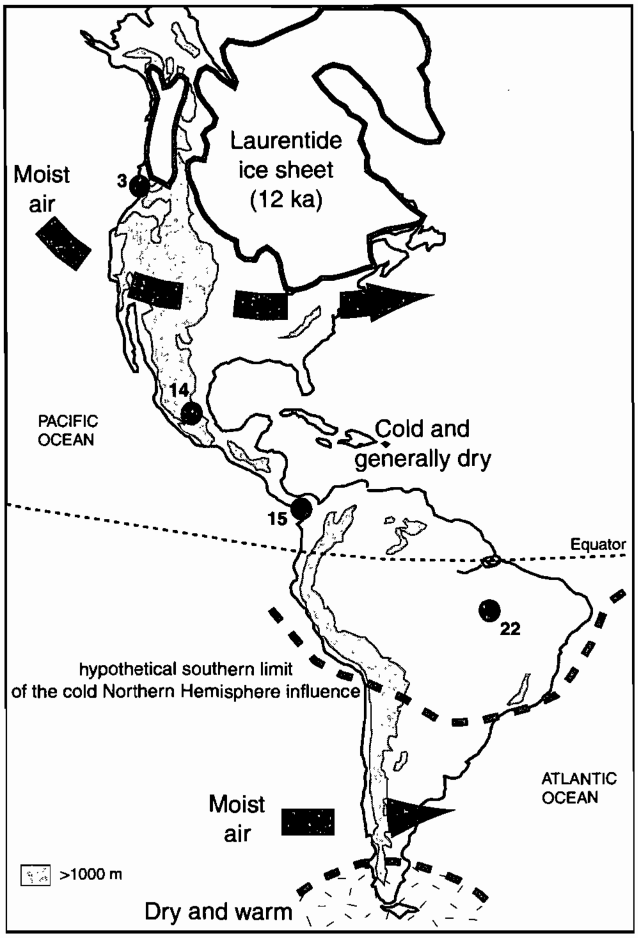

FIGURE 7 The Younger Dryas chron (interval 3) for the Americas as deduced from paleovegetation reconstructions, showing the hypothetical southern limit of the influence of cold Arctic air during the Southern Hemisphere summer months. Full circles indicate records where no change is detected.

The major unsolved problem concerns the differences in climatic signal of apparently synchronous events between the North Atlantic (Greenland) and Antarctica, especially during the Younger Dryas chronozone. While several of the Antarctic records (Byrd, Vostok) suggest an opposition of the climate signal, i.e., a Younger Dryas cooling in Greenland opposed to a warming in Antarctica (Blunier et al., 1997; Broecker, 1998), a new Antarctic record (Taylor Dome) is thought to be in phase with the Greenland temperature reversal (Steig et al., 1998). The climatic changes in southern Argentina and Chile (Tierra del Fuego) appear to be supporting the opposition of climate signal; hence, it is likely that the Taylor Dome record is problematic (Markgraf, 1993; Pendall et al., submitted).

20.6. CONCLUSION AND RECOMMENDATIONS

From this overview of late glacial vegetation and inferred climate changes along the PEP 1 transect, several recommendations can be made to advance the issues related to interhemispheric correlation of intervals of rapid change.

20.6.1. Precipitation Versus Temperature Sensitivity

When sites are located in areas where the vegetation is not highly sensitive to temperature change, e.g., sites where precipitation is permanently high (parts of the tropics and temperate rain forest areas), short-term climatic reversals, known to reflect primarily temperature changes elsewhere, are unlikely to be detected. Temperature-sensitive vegetation would be found at high elevations (e.g., tree line) or at least in areas where precipitation is seasonally low and where temperature changes could be perceived by vegetation as moisture changes. In every case, regional aspects greatly affect the character of these oscillations.

20.6.2. Modern Analogs

Another problem in dealing with late glacial climate oscillations is the lack of modern analogs for the vegetation compositions at that time. Assemblages of species that do not occur today complicate interpretations in terms of temperature and precipitation. In eastern North America, pollen records at 14,000 cal. B.P. have the highest number of nonanalog samples (48%), compared to 40% at 17,000 cal. B.P. and 26% during full glacial times (Webb et al., 1993; Thompson et al., 1993; Overpeck et al., 1992).

20.6.3. Radiocarbon Dates

In addition to the problems with radiocarbon plateaus occurring at the time of the short-term climate oscillations, most records discussed have insufficient radiocarbon dates to establish a high-resolution chronology (Fig. 3). This complicates comparison of late glacial fluctuations as well as detection of hiatuses and/or changes in sedimentation rates.

20.6.4. Temporal Resolution

Temporal resolution is often too low in the analyzed records (i.e., sampling intervals are too large) to allow to distinguish short-term oscillations. When a 1- to 2-cm thin sand layer is present in a sediment that is analyzed in a 5- or 10-cm sampling interval, changes in vegetation or climate will go unnoticed. In some cases, when sites show no change compared to the previous interval, this may be due to a low-resolution sampling. This problem might also explain why short-term climatic events such as the Older Dryas are rarely recorded in terrestrial records.

20.6.5. Synchroneity

When dates are calibrated in terms of calendar years, which may produce several ages, synchroneity cannot be proved. For example, in the Gordon and Little Lake records, the Younger Dryas is estimated to date either between 12,400 and 11,000 cal. B.P. or between 12,800 and 11,000 cal. B.P., respectively. For the North Atlantic marine cores, an age of 12,900–11,600 cal. years B.P. is calculated. These calibration ages represent the mean value of a 2 sigma calibration and may represent only one time period. In the Allamuchy and Linsley Pond records, a change is detected between 13,000 and 11,500 cal. B.P. Calibration estimates suggest that this change occurred between 14,000 and 11,000 cal. B.P. or between 12,300 and 10,400 cal. B.P. In La Yeguada, a change in vegetation, characterized by an increase in lowland rain forest taxa, is dated at between 13,000 and 12,300 cal. B.P. Calibration suggests that it happened between 13,300 and 12,700 or 12,700 cal. B.P. and 12,000 cal. B.P. This finding implies that it does not fall into the Younger Dryas time period as defined in the circum–North Atlantic region.

Acknowledgments

We thank Vera Markgraf for inviting us to participate in the PEP 1 meeting in Mérida (Venezuela) and for asking us to organize this interhemispheric review. Pollen records were selected from lists provided by Vera Markgraf, Cathy Whitlock, and Eric Grimm. A constructive review from Vera Markgraf, Dorothy Peteet, and Cathy Whitlock considerably improved this manuscript.

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Interhemispheric Climate Linkages

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ACADEMIC PRESS
A Harcourt Science and Technology Company

San Diego San Francisco New York Boston London Sydney Tokyo

This book is printed on acid-free paper. ♾

Academic Press
A Harcourt Science and Technology Company
525 B Street, Suite 1900, San Diego, California 92101-4495, USA
http://www.academicpress.com

Academic Press
Harcourt Place, 32 Jamestown Road, London NW1 7BY, UK
http://www.academicpress.com

Library of Congress Catalog Card Number: 00-104375

International Standard Book Number: 0-12-472670-4

PRINTED IN THE UNITED STATES OF AMERICA
00 01 02 03 04 05 MM 9 8 7 6 5 4 3 2 1