RADIOCARBON, Vol 41, Nr 3, 1999, p 287–293

^{14}C AGE OF GLACIATION IN ESTRECHO DE MAGALLANES–BAHÍA INÚTIL, CHILE

C J Heusser

100 Clinton Road, Tuxedo, NY 10987 USA

ABSTRACT. Basal ^{14}C dates from a core of the mire at Puerto del Hambre (53°36′21″S, 70°55′53″W), located within the area of glaciation in Estrecho de Magallanes–Bahía Inútil, Chile, are no older than 14,455 ± 115 yr BP. The ^{14}C dates are on samples from which screening isolated autochthonous plant remains. Previous ^{14}C dates of 15,800 ± 200, 16,590 ± 320, and 16,290 ± 140 yr BP are from bulk samples collected from similar basal increments at the site during 3 separate, independent coring operations. The previous suite of ^{14}C dates was suspected to be contaminated by older carbon in the light of chronological evidence, which indicates a ^{14}C age of approximately 14,850 yr BP for glaciation elsewhere in southern Chile. Contamination by "infinitely old" carbon reworked from nearby Tertiary beds and redeposited at Puerto del Hambre is evidently the cause for the older ^{14}C dates.

INTRODUCTION

Basal ^{14}C dates for the mire at Puerto del Hambre (53°36′21″S, 70°55′53″W), located about 50 km south of Punta Arenas (Figure 1), have been problematical with regard to the age of deglaciation in Estrecho de Magallanes–Bahía Inútil. The site, originally ^{14}C-dated to 15,800 ± 200 yr BP (Heusser 1984), later gave dates of 16,590 ± 320 yr BP (Porter et al. 1992) and 16,290 ± 140 yr BP (McCulloch and Bentley 1998). The original ^{14}C dating was found to be older than expected, which explains the subsequent effort to recore Puerto del Hambre to confirm its age. Other ^{14}C dates for deglaciation from within the glaciated area are between 14,260 and 13,280 yr BP (McCulloch and Bentley 1998), and deglacial ^{14}C dates relevant elsewhere in southern Chile are 14,640 yr BP at 54°52′S in Canal Beagle (Heusser 1998) and 14,355 yr BP at 46°25′S on Península de Taitao (Lumley and Switsur 1993). The glacial maximum in the Southern Lake District–Isla Chiloé (41°00′–42°30′S) is ^{14}C-dated to 14,870–14,810 yr BP (Denton et al. 1999).

Contamination by an allochthonous component serves to explain the antiquity of the deposit at Puerto del Hambre. The contaminant occurs as black, amorphous, noncrystalline, microscopic particulates without cellular differentiation, found only in basal core samples. It is believed to be carbonaceous material derived from Tertiary fossil beds that crop out in the vicinity of Estrecho de Magallanes and Bahía Inútil (Servicio Nacional de Geología y Minería 1982). The material, constituting a form of palynodebris (Boulter 1994), is part of rock flour produced by glacial abrasion, suspended in proglacial lake waters, and redeposited during the lacustrine phase of sedimentation.

An opportunity was provided in 1998 to recore the mire at Puerto del Hambre, as part of a high-resolution reconstruction of late-glacial, subantarctic paleoclimate and chronology (Heusser et al. 2000). AMS ^{14}C dates reported from the new core HE98–1C are on the remaining organic matter after removal of suspected Tertiary contaminant.

METHODS

Core HE98–1C was taken from the late-glacial portion of the deposit with a 5-cm-diameter square-rod piston sampler (Wright 1967). Increments were extruded and wrapped successively in plastic film and aluminum foil, boxed, and air-freighted directly to the Deep-Sea Sample Repository at Lamont-Doherty Earth Observatory, Palisades, New York, for archiving and storage. Cores were cut lengthwise into working and archival halves, photographed, and stored in plastic film in sealed containers under refrigeration prior to sampling. Total length of core (not including section breaks) is 262 cm at a depth below surface of between 534 and 816 cm.

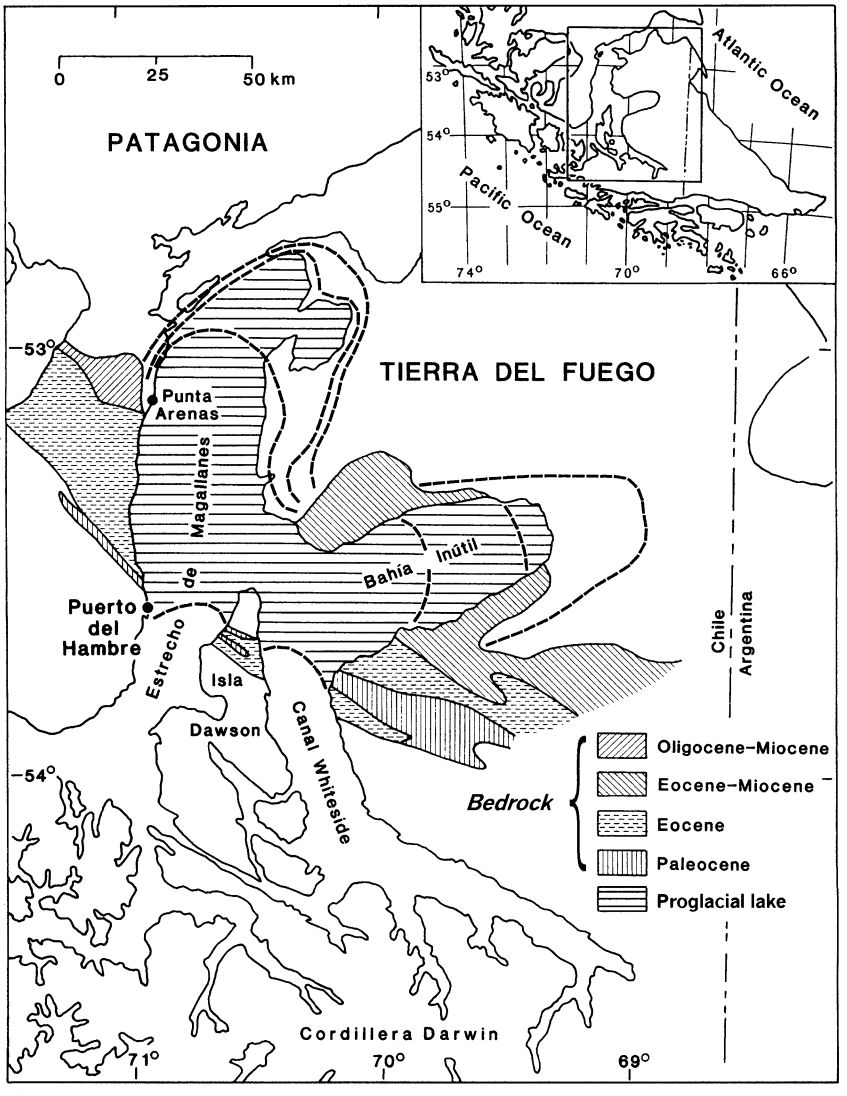

Figure 1 Location of the mire at Puerto del Hambre in southern Patagonia, subantarctic Chile. At the time of the last ice age, glaciers (———), whose source was largely in the Cordillera Darwin, terminated in and about Estrecho de Magallanes and Bahía Inútil (Clapperton et al. 1995). During the last glacial maximum, ice fronts extended to just beyond Punta Arenas in the Estrecho de Magallanes and at midpoint in Bahía Inútil. Following retreat of the ice, a proglacial lake occupied much of the area prior to the latest glacial advance, which appears to have culminated between 12,010 and 10,050 ^{14}C yr BP (McCulloch and Bentley 1998). Ages and locations of Tertiary bedrock are from Mapa Geológico de Chile (Servicio Nacional de Geología y Minería 1982).

Samples of the core taken at 2-cm intervals were processed for black microscopic particulates, pollen analysis, loss on ignition, and carbonate content (Berglund 1986; Faegri et al. 1989). Particulates were measured under the microscope ($\mu m^2\ gm^{-1}$ dry weight) from known concentrations of exotic spores added to samples during laboratory preparation.

https://doi.org/10.1017/S0033822200057143 Published online by Cambridge University Press

Upon completion of processing and diagramming of results, samples from 20 horizons were selected for AMS ^{14}C dating. Deflocculation was effected by boiling in dilute KOH solution, after which suspensions were passed through 120-μm nylon screens and the black particulates measuring ≤90 μm removed in the process. Screened autochthonous material for dating was thoroughly washed with filtered water and oven-dried overnight at 105°C. Fibrous plant remains, leaf fragments, indeterminate plant detritus, and organic silt were AMS ^{14}C-dated at the NSF-Arizona AMS Facility. INTCAL98 (Stuiver et al. 1998) data were used for calibration (cal BP).

RESULTS AND DISCUSSION

Black particulate contaminant was found only in the basal 40 cm (300–340 cm) of core HE98–1C. The contaminant measured as much as 25.8 $\mu m^2\ gm^{-1} \times 10^6$ at depth (322 cm), but less than 1 $\mu m^2\ gm^{-1} \times 10^6$ at the top of the interval (Table 1). Of 7 ^{14}C AMS dates applicable to screened samples from this portion of the core, none is older than 14,455 ± 115 yr BP (332 cm). While the entire suite of dates lacks a consistent age-depth relationship, 2 other dates at 14,251 ± 91 (306 cm) and 14,204 ± 124 ^{14}C yr BP (310 cm) are similar within statistics to the date of 14,455 ± 115 ^{14}C yr BP. A much younger AMS ^{14}C date of 11,834 ± 186 yr BP is from the deepest level dated in the core (336 cm).

Figure 2 shows an age-depth plot of the 20 AMS ^{14}C dates for the screened samples from core HE98–1C. The average sedimentation rate of 16.2 ^{14}C yr cm^{-1} is based on selected ^{14}C dates of 10,089 ± 74 yr BP at 540 cm and 14,204 ± 124 yr BP at 786 cm. At the average rate, the age of the core is estimated at approximately 14,700 ^{14}C yr BP. Noticeably younger, with reference to dates closely allied to the average rate, are the variable ^{14}C dates in the lower third of the core. Variability appears to be attributable to a reservoir effect, which created a low $^{14}C/^{12}C$ ratio or an impoverished quantity of ^{14}C from atmospheric CO_2 versus total dissolved inorganic carbon (Olsson 1979, 1986; Geyh et al. 1998). Carbonate at Puerto del Hambre (Table 1), mostly <3.5% and not more than 8.4%,

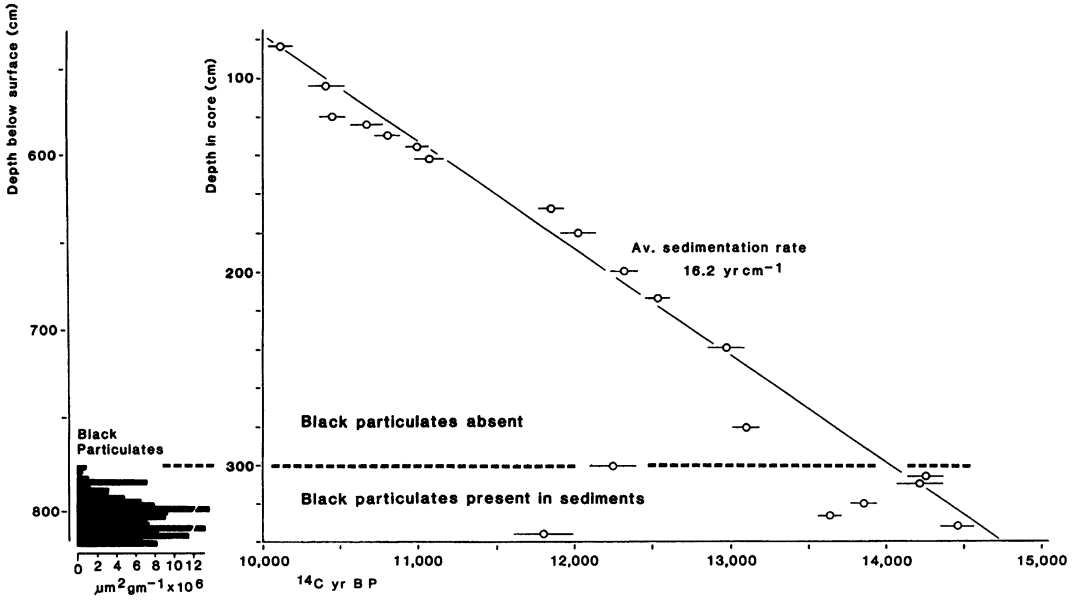

Figure 2 Age-depth plot of AMS ^{14}C dates of screened samples from core HE98-1C and distribution of black particulates in naturally occurring sediments at depth

https://doi.org/10.1017/S0033822200057143 Published online by Cambridge University Press

may have contributed to the variable chronology at depth. Groundwater, a supplemental factor for the initial age-inverted ^{14}C dates, is possibly the cause of the much younger ^{14}C date of 11,834 ± 186 yr BP at 336 cm.

Among $\delta^{13}C$ values (Table 1), ranging from approximately –10.6‰ to –22.5‰, isotopic enrichment apparent in the set of samples is suggestive of low productivity, which is also implied by low loss-on-ignition measurements (2.4–7.3% at 314 cm and below; 11.4–17.0% at 300–312 cm). A C_4 pathway of carbon assimilation in the vegetation may also be involved where values are between –10‰ and –19‰ (Olsson 1986). Pessenda et al. (1998) report amounts of $\delta^{13}C$ between –15‰ and –21‰ for C_4-type, non-forested vegetation, whereas amounts for C_3-type forest communities range from –27‰ to –29.5‰. Pollen data from Puerto del Hambre (Heusser et al. 2000) imply the presence of dominant grass and heath communities in the basal part of core HE98-1C, consistent with δ^{13} enrichment from C_4-type nonarboreal vegetation.

The sequence of late-glacial pollen assemblages is consistent with previously published ^{14}C-dated pollen diagrams (Clapperton et al. 1995; Heusser 1995). Although depths differ in the respective diagrams, a consequence of coring locations on the mire, each records the presence of southern beech (*Nothofagus*) in the basal increment. The initial ^{14}C-dated assemblage containing southern beech, presumed to be a product of long-distance wind transport, is taken as the basis for both biostratigraphic and chronostratigraphic correlation.

Contamination by 50% old carbon, causing age determinations to be a half-life too old (Olsson 1986), can account for the excessive ages of unscreened bulk samples first ^{14}C-dated at Puerto del Hambre. The maximum age difference between the unscreened and screened samples amounts to >2300 ^{14}C yr. As Olsson and Eriksson (1965) indicate, removal by screening of the fine-grained matrix reduces the chance of error in assigning an age to the autochthonous component. Sources of old carbon in the case of Puerto del Hambre ^{14}C-dated samples are evidently coal beds and associated organic remains contained in regional Paleogene rock formations (Figure 1). The formations, underlying Estrecho de Magallanes-Bahía Inútil, were scoured by overriding glacial ice. Carbonaceous matter, which was in suspension when the proglacial lake formed as the ice wasted, became part of sediment deposited in the early lacustrine phase at Puerto del Hambre.

That reworking has taken place is made more convincing by the presence in the basal core sediment of palynomorphs similar to those described and figured from the local Loreto Formation of Oligocene-Miocene age by Fasola (1969). These include *Cyathidites*, *Phyllocladidites*, *Podocarpidites*, *Nothofagidites*, *Tricolpites*, and dinoflagellate cysts. The palynomorphs are readily distinguishable from similar late-glacial pollen by their differential staining, thicker and denser exines, and otherwise altered morphological features. Moreover, *Cyathidites* and *Podocarpidites* are unrelated in the existing flora, while taxa resembling *Phyllocladidites* are extinct.

CONCLUSION

^{14}C dates of 14,251 ± 91, 14,204 ± 124, and 14,455 ± 115 yr BP as maximum ages for screened samples from the basal portion of core HE98-1C at Puerto del Hambre are uniformly younger than the previous series given at 15,800 ± 200 yr BP (Heusser 1984), 16,590 ± 320 yr BP (Porter et al. 1992), and 16,290 ± 140 yr BP (McCulloch and Bentley 1998). Samples on which the ^{14}C dates were determined are from the same basal pollen zone and thus biostratigraphically correlative among cores collected.

Table 1 AMS ^{14}C dates, $\delta^{13}C$ values, and lithological data for basal 300–340 cm of core HE98-1C

Core depth (cm)	Material dated[a]	^{14}C Age (yr BP)	cal age (yr BP)[b]	$\delta^{13}C$ (PDB‰)	Laboratory number	Black particulates ($\mu m^2\ gm^{-1} \times 10^6$)	Loss on ignition (%)[c]	Carbonate (%)[c]
300	Detritus silt	12,247 ± 126	14,270	−20.909	AA-30646	0.9	14.7	2.7
302						0.5	12.7	2.4
304						0.2	11.4	7.7
306	Detritus silt	14,251 ± 91	17,070	−12.001	AA-30647	1.3	17.0	2.3
308						7.3	13.8	8.4
310	Detritus silt	14,204 ± 124	17,040	−17.604	AA-30648	1.4	12.6	6.8
312						3.5	11.7	2.7
314						3.2	7.3	7.2
316						4.8	5.9	6.3
318						6.5	4.6	3.5
320	Organic silt	13,865 ± 85	16,640	−15.712	AA-30649	7.7	5.1	2.1
322						25.8	3.9	2.0
324						9.4	3.1	2.0
326	Leaf fragments	13,625 ± 80	16,360	−12.978	AA-30650	9.0	4.6	1.4
328						7.1	5.2	2.3
330						7.5	3.3	3.5
332	Organic silt	14,455 ± 115	17,320	−10.582	AA-30651	15.8	3.9	1.9
334						8.3	2.4	1.3
336	Organic silt	11,834 ± 186	13,830	−22.482	AA-30652	11.5	3.3	1.1
338						6.5	2.9	1.7
340						8.1	2.7	1.4

[a] Sample ±1 cm interval centered at core depth.
[b] From INTCAL98 extended ^{14}C calibration set (Stuiver et al. 1998).
[c] Data provided by T V Lowell.

The older series of ^{14}C dates, now considered to be unreliable, is attributed to contamination of samples by allochthonous, "infinitely old" carbon derived from nearby Tertiary deposits. With the retreat of the glacier at Puerto del Hambre, contamination occurred during the initial lacustrine phase of sedimentation, when a proglacial lake formed along the receding ice front. Redeposited Tertiary palynomorphs associated with the old carbon are similar to types found in the regional rock formation of Oligocene-Miocene age.

Glaciation of Estrecho de Magallanes–Bahía Inútil is dated close to 14,455 ± 115 ^{14}C yr BP. The event is apparently coeval with ^{14}C-dated glaciation in the Chilean Lake District–Isla Chiloé at 14,870–14,810 yr BP (Denton et al. 1999). From similar ^{14}C dates at other sites, the inference is that much of southern Chile at latitudes beyond 42°S was glaciated at this time.

ACKNOWLEDGMENTS

This study was supported by the National Atmospheric and Oceanic Administration (grant NA 77 RJ 0453), as part of the Lamont-Scripps Consortium for Climate Research, and by the National Science Foundation (grant ATM92-19249). I am much indebted to associates T V Lowell, L E Heusser, A Moreira, and S Moreira for assistance in the field and laboratory. I thank G H Denton and W S Broecker for arranging grant support, A J T Jull for reporting of AMS ^{14}C dates, and R Lotti, curator, and P Priore for curating and storage of cores at the Deep Sea Sample Repository of Lamont-Doherty Earth Observatory; the Repository is supported by grants from the National Science Foundation and Office of Naval Research.

REFERENCES

Berglund BE, editor. 1986. *Handbook of Holocene palaeoecology and palaeohydrology*. New York: John Wiley & Sons. 869 p.

Boulter MC. 1994. An approach to a standard terminology for palynodebris. In: Traverse A, editor. *Sedimentation of organic particles*. Cambridge: University of Cambridge Press. p 199–216.

Clapperton CM, Sugden DE, Kaufman DS, McCulloch RD. 1995. The last glaciation in central Magellan Strait, southernmost Chile. *Quaternary Research* 44: 133–48.

Denton GH, Heusser CJ, Lowell TV, Moreno PI, Andersen BG, Heusser LE, Schlüchter C, Marchant DR. 1999. Interhemispheric linkage of paleoclimate during the last glaciation. *Geografiska Annaler* 81A:107–53.

Faegri K, Kaland PE, Krzywinski K. 1989. *Textbook of pollen analysis*. New York: John Wiley & Sons. 328 p.

Fasola A. 1969. Estudio palinológico de la Formación Loreto (Terciario Medio), Provincia de Magallanes. *Ameghiniana* 6:3–49.

Geyh MA, Schotterer U, Grosjean M. 1998. Temporal changes in the ^{14}C reservoir effect in lakes. *Radiocarbon* 40(2):921–31.

Heusser CJ. 1984. Late Quaternary climates of Chile. In: Vogel JC, editor. *Late Cainozoic palaeoclimates of the Southern Hemisphere*. Rotterdam: Balkema. p 59–83.

Heusser CJ. 1995. Three late Quaternary pollen diagrams from southern Patagonia and their palaeoecological implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 118:1–24.

Heusser CJ. 1998. Deglacial paleoclimate of the American sector of the Southern Ocean: Late glacial–Holocene records from the latitude of Canal Beagle (55°S), Argentine Tierra del Fuego. *Palaeogeography, Palaeoclimatology, Palaeoecology* 141:277–301.

Heusser CJ, Heusser LE, Lowell TV, Moreira A, Moreira S. 2000. Deglacial palaeoclimate at Puerto del Hambre, subantarctic Patagonia, Chile. *Journal of Quaternary Science*. Forthcoming.

Lumley SH, Switsur R. 1993. Late Quaternary chronology of the Taitao Peninsula, southern Chile. *Journal of Quaternary Science* 8:161–65.

McCulloch RD, Bentley MJ. 1998. Late glacial ice advances in the Strait of Magellan, southern Chile. *Quaternary Science Reviews* 17:775–87.

Olsson IU. 1979. Radiocarbon dating of material from different reservoirs. In: Suess HE, Berger R, editors. *Radiocarbon Dating: Proceedings of the Ninth International Conference, Los Angeles and La Jolla, 1976*. Berkeley: University of California Press. p 613–8.

Olsson IU. 1986. Radiometric dating. In: Berglund BE, editor. *Handbook of Holocene palaeoecology and palaeohydrology*. New York: John Wiley & Sons. p 273–312.

Olsson IU, Erikkson KG. 1965. Remarks on C^{14} dating of shell material in sea sediments. *Progress in Oceanography* 3:253–66.

Pessenda LCR, Gouveia SEM, Aravena R, Gomes BM, Boulet R, Ribeiro AS. 1998. ^{14}C dating and stable carbon isotopes of soil organic matter in forest-savanna boundary areas in the southern Brazilian Amazon area. *Radiocarbon* 40(2):1013–22.

Porter SC, Clapperton CM, Sugden DE. 1992. Chronology and dynamics of deglaciation along and near the Strait of Magellan, southernmost South America. *Sveriges Geologiska Undersökning* 81:233–9.

Servicio Nacional de Geología y Minería. 1982. Hoja 6, 49°30′–56°30′S. In: Escobar T. F, editor. *Mapa Geológico de Chile.* Santiago: Instituto Geográfico Militar. Scale 1:1,000,000.

Stuiver M, Reimer PJ, Bard E, Beck JW, Burr GS, Hughen KA, Kromer B, McCormac G, van der Plicht J, Spurk M. 1998. INTCAL98 radiocarbon age calibration, 24,000–0 cal BP. *Radiocarbon* 40(3):1041–83.

Wright, HE Jr. 1967. A square-rod piston sampler for lake sediments. *Journal of Sedimentary Petrology* 37: 975–6.