DEPARTAMENTO DE GEOLOGIA
FACULTAD DE CIENCIAS FISICAS Y MATEMATICAS
UNIVERSIDAD DE CHILE

ACTAS

PRIMER CONGRESO GEOLOGICO CHILENO

TOMO I

A Geología Regional y Estratigrafía
B Geotectónica
C Paleontología
D Geomorfología

2 - 7 de Agosto de 1976

SANTIAGO - CHILE

PRIMER CONGRESO GEOLOGICO CHILENO (2 - 7 Agosto 1976, Santiago).

THE LAST GLACIATION IN CHILE. A RADIOCARBON-DATED CHRONOLOGY

por

J. M. Mercer*
Institute of Polar Studies
The Ohio State University
Columbus, Ohio 43210 U.S.A.

ABSTRACT

In Southern Chile, age determinations for the last glaciation have been obtained from the lake region, lat. 40° - 41° 30' S., and from the Patagonian Channels, lat. 48° S.-49° S. Interhemispheric comparisons of events before about 25,000 ^{14}C years ago cannot be made, because only minimal ages are available. The reliably dated chronology after 25,000 14_C years ago is in many respects similar to that in North America and Europe, but important differences are evident during deglaciation.

The last interglacial may have been considerably warmer than today, because much more chemical weathering occurred then than during the present interglacial so far. During the las glaciation, glaciers were largest, and the most outwash was produced, sometime before 56,000 14_C years ago. A smaller readvance culminated about 19.500 14_C years ago, at about the same time as the Late Wisconsin maximum in North America. An interstade followed during wich glaciers halved in length; this interstade was at least partly coeval with the Erie Interstade in eastern North America. A final full glacial advance followed that, on present evidence, culminated probably about 13.000 14_C years ago, at the same time as the Port Huron advance in eastern North America. No equivalent of the widespread North American advance about 14,500 14_C years ago has yet been identified.

After 13.000 14_C years ago the Chilean glaciers shrank rapidly, and they were confined to the mountains by 12,300 14_C years ago. A similar very rapid warming 13,000-12,000 years ago has been inferred from European beetle faunas, but in Chile the warming trend continued apparently without interruption, and glaciers had withdrawn to within their present margins by 11,000 14_C years ago. No equivalents of the European Younger Dryas Stade (11,000-10,000 14_C years ago) or of the North American Cochrane-Cockburn advance (8.200 - 8.000 14_C years ago) are known. The postglacial warm interval, if assumed to have coincided with the time when glaciers were smaller than they are today, lasted from 11.000 to, probably, about 6.000 14_C years ago. During the following Neoglaciation, glaciers were largest about 4.500 - 4.200 14_C years ago, in contrast to the Northern Hemisphere where this was a rather minor episode; smaller advances culminated about 2.500 14_C years ago and during recent centuries. Between these Neoglacial advances, glaciers receded to within their present margins.

RESUMEN

En el sur de Chile, las determinaciones de edad para la última glaciación han sido obtenidas en la región de los lagos, lat. 40° - 41°30' S., y en la región de los canales en la Patagonia, lat. 48°-49°S. Las comparaciones entre ambos hemisferios de eventos anteriores a aproximadamente 25.000 años A. P. (C_{14}) no pueden ser realizadas debido a que, solo se cuenta con edades mínimas para dicho período. La cronología confiable datada como posterior a 25.0 0 años A. P. (C_{14}) es en muchos aspectos similar a la de Norteamérica y Europa, pero se detectan algunas diferencias importantes durante la deglaciación.

El último interglacial debe haber sido considerablemente más cálido que el momento actual, debido a la mayor alteración química que

* Contribution N°302 of the Institute of Polar Studies, The Ohio State University, Columbus, Ohio 43210.

tuvo lugar durante dicho período en comparación con la alteración que se desarrolla en lo que va corrido del presente interglacial. Durante la última glaciación, los glaciares fueron más grandes y la mayor parte de los detritos glaciares delavado, se produjo en una fecha algo anterior a 56.000 años A. P. (C_{14}). Un reavance menor culminó alrededor de los 19.500 años A. P. (C_{14}) casi al mismo tiempo que el máximo del Wisconsin Tardío de Norteamérica. A esto siguió un interestadial durante el cual los glaciares disminuyeron su longitud a la mitad; este interestadio fue al menos parcialmente contemporáneo con el Interestadio Erie de la región oriental de Norteamérica. Un último y categórico avance glacial siguió al anterior, el que de acuerdo a las evidencias disponibles habría culminado probablemente alrededor de los 13.000 años A. P. (C_{14}), contemporáneamente al avance Port Huron de la región oriental de Norteamérica. No ha sido identificado aún ningún avance equivalente al extenso avance glaciar de cerca de 14.500 años A. P. (C_{14}) de Norteamérica.

Después de 13.000 años A. P. (C_{14}) los glaciares chilenos se contrajeron rápidamente y quedaron confinados a la zona montañosa en la fecha de 12.300 años A. P. Un calentamiento similar, muy rápido, ocurrido en 13.000 - 12.000 años A. P. ha sido inferido por medio de la fauna de cucarachas en Europa, en Chile, sin embargo, esta tendencia de calentamiento continuó aparentemente sin interrupción y los glaciares se restringieron a sus actuales límites alrededor de 11.000 años A. P. (C_{14}). No se conocen avances equivalentes al piso Europeo Younger Dryas (11.000 - 10.000 años A. P. (C_{14})) o al avance Cochrane - Cockburn (8.200 - 8.000 años A.P. (C_{14})) de Norteamérica. El intérvalo cálido postglacial, si se acepta que coincidió con el momento en que los glaciares fueron más pequeños que en la actualidad, duró desde 11 000 hasta, probablemente, alrededor de 6.000 años (C_{14}). Durante la Neoglaciación que sigue a continuación, los glaciares fueron más extensos cerca de los 4.500 - 4.200 años A. P. (C_{14}), en contraste con el hemisferio Norte donde este fué un episodio más bien menor; avances más pequeños culminaron cerca de los 2.500 años A. P. (C_{14}) y durante los siglos recientes. Entre estos avances del Neoglacial los glaciares retrocedieron a los límites que presentan en la actualidad.

INTRODUCTION

During full-glacial times glaciers north of lat 39° S. were confined to semi-arid mountain valleys. West-flowing glaciers calved into the sea as far north as lat 43°S, and east-flowing glaciers in Magallanes ended in the arid steppe. These two zones are, therefore, unsuitable for obtaining a radiocarbon-dated chronology of glacier variations during full-glacial times; the best record for this interval is preserved in the lake region and in the island of Chiloé to the south (Fig. 1). The Chilean channels in Aisén and Magallanes, and also the belt in Chilean and Argentine Patagonia close to the Andes (Fig. 2), provide a C-14-dated chronology of deglaciation and of postglacial time.

The last glaciation in the Chilean lake region was named the Llanquihue Glaciation by Heusser (1974). Glacial drift of this glaciation is only slightly weathered, in contrast to all older permeable drift which is moderately to highly weathered, as has been noted by Weischet (1964, p. 30) near Lago Puyehue, by Olivares (1967) near Lago Llanquihue, by Lauer (1968) near Lago Ranco, and by Laugenie (1971) near Lago Villarrica and Lago Calafquén. Brüggen (1950, p. 363) however, assigns Olivares' moderately weathered 'Riss-age' moraines west of Lago Llanquihue to the last glaciation on the basis of their slight weathering.

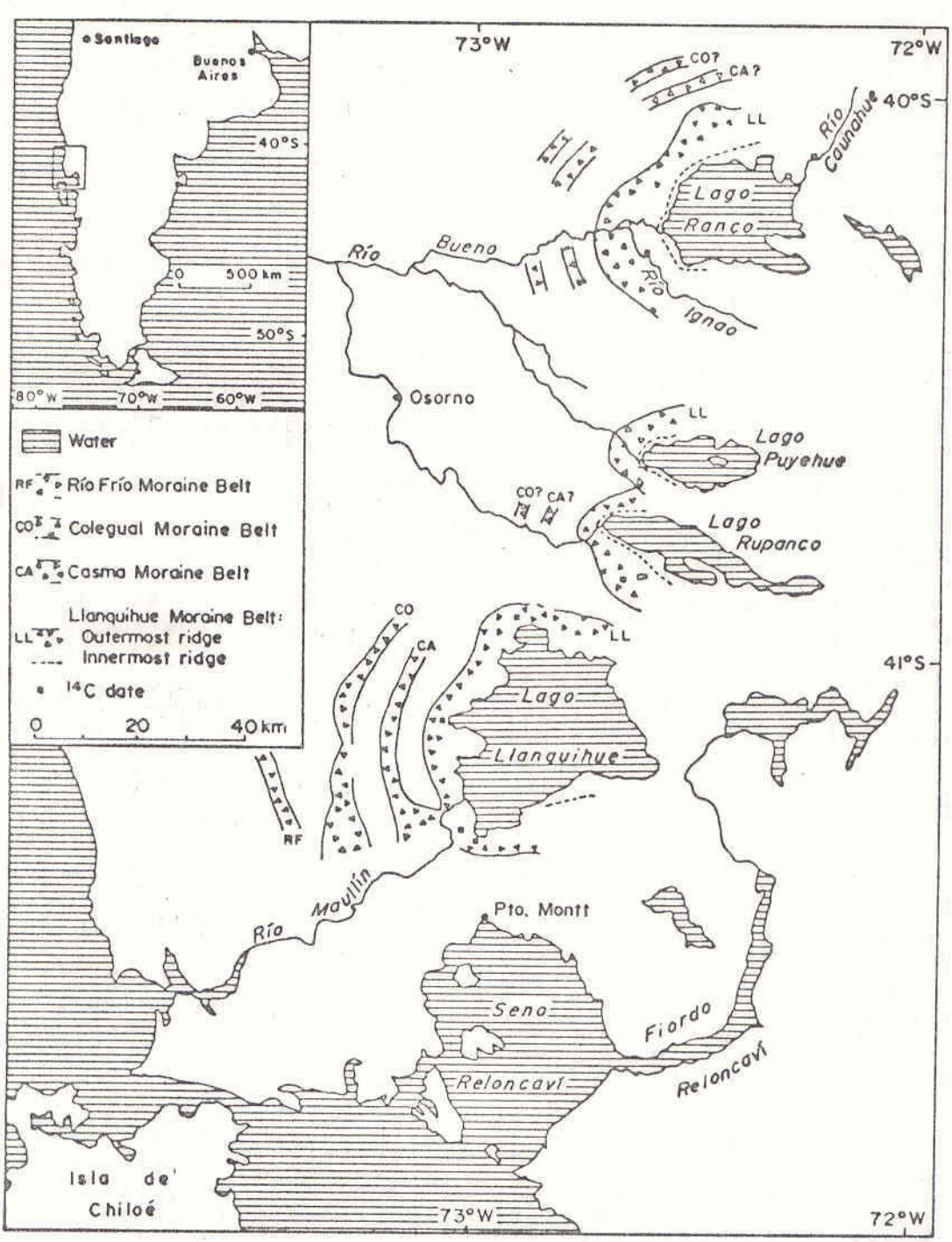

Fig. 1 Location map, southern part of the Chilean lake region, showing end moraine belts, where traced, and sites of C-14 dated samples. Reproduced from Mercer, in press.

West of Lago Llanquihue, Mercer (in press) recognizes three pre-Llanquihue moraine belts: the Río Frío, Colegual and Casma moraine belts in decreasing age order (Fig. 3). Permeable drift in all three moraine belts is highly weathered. Weathering of the Colegual and Casma drifts is similar, and is less than the weathering on the Río Frío drift: these two moraines may be part of the same glacial stage, as Olivares (1967) suggested.

Early Llanquihue time

Llanquihue drift of two ages has been recognized: Early Llanquihue and Late Llanquihue drifs. Where they have been recognized and dated, the Early Llanquihue moraines are the outermost and the most massive in the Llanquihue moraine belt. They are also associated with the greatest volume of outwash. On the surface of Early Llanquihue drift, feldspar phenocrysts in porphytic andesite are weathered to a depth of ca. 5 mm, and on Late Llanquihue drift, weathering of similar rocks is barely perceptible. By contrast the next oldest drift, the Casma drift, has weathering rinds on volcanic rocks of as much as 20 mm. The Casma drift is weathered to this degree even where covered and protected by impermeable Early Llanquihue drift, as can be seen near Puerto Varas (north side of Route V 55, 50 m. east of Route 5). Thus the weathering took place during the Casma-Llanquihue Interglacial, suggesting that this interglacial was much warmer than the present interglacial has been.

One hundred meters or so west of this exposure a non glacial sequence consisting of peat on weathered volcanic ash is exposed between two tills in another road cut (south side of Route V-50, a few meters west of its junction with Route 5) (Fig. 3). A log at the peat till interface, and also the adjacent peat, both have infinite ages of > 39.900 B. P. (samples I-4170 and I-5032).

Seven km west of Lago Ranco (road cut on south side of Route T-85, 100 m east of bridge over Río Ignao), (Fig. 1) a 5 m thick non-glacial sequence beneath Early Llanquihue till is exposed. The sequence beneath the superficial volcanic soil consists of:

2.5 m	till
2 m	interbedded ash, peat and gyttja, with logs at the peat till interface.
1.6 m	volcanic ash
0.06m	peat
1.5 m	clay gyttja
2 m	diamicton, possibly till
> 2 m	diamicton, probably volcanic mudflow.

An age determination of 56.000± 2.000 1.700 years (sample QI-61) has been obtained at the large counter at the University of Washington, where the greatest age that can be measured is 61,000 years; this age should be considered minimal (Stuiver, Mercer and Moreno, 1975). The log had previously been dated at 36.350 ± 2.750 B. P. (sample I-6.348) and the adjacent peat at 36.900 ± 3.400 B. P. (sample I- 7.145) (Mercer and Laugenie, 1973) with a smaller counter whose limit is about 40.000 years. The likely presence of both till and volcanic mudflow in the section makes interpretation difficult; whether the non-glacial sequences is interglacial, or dates from an Early Llanquihue interstadial, is uncertain. However, a suggested mid-Llanquihue advance of the Lago Ranco glacier about 36.000 years ago (Mercer and Laugenie, 1973) is now known to have been deduced from faulty evidence.

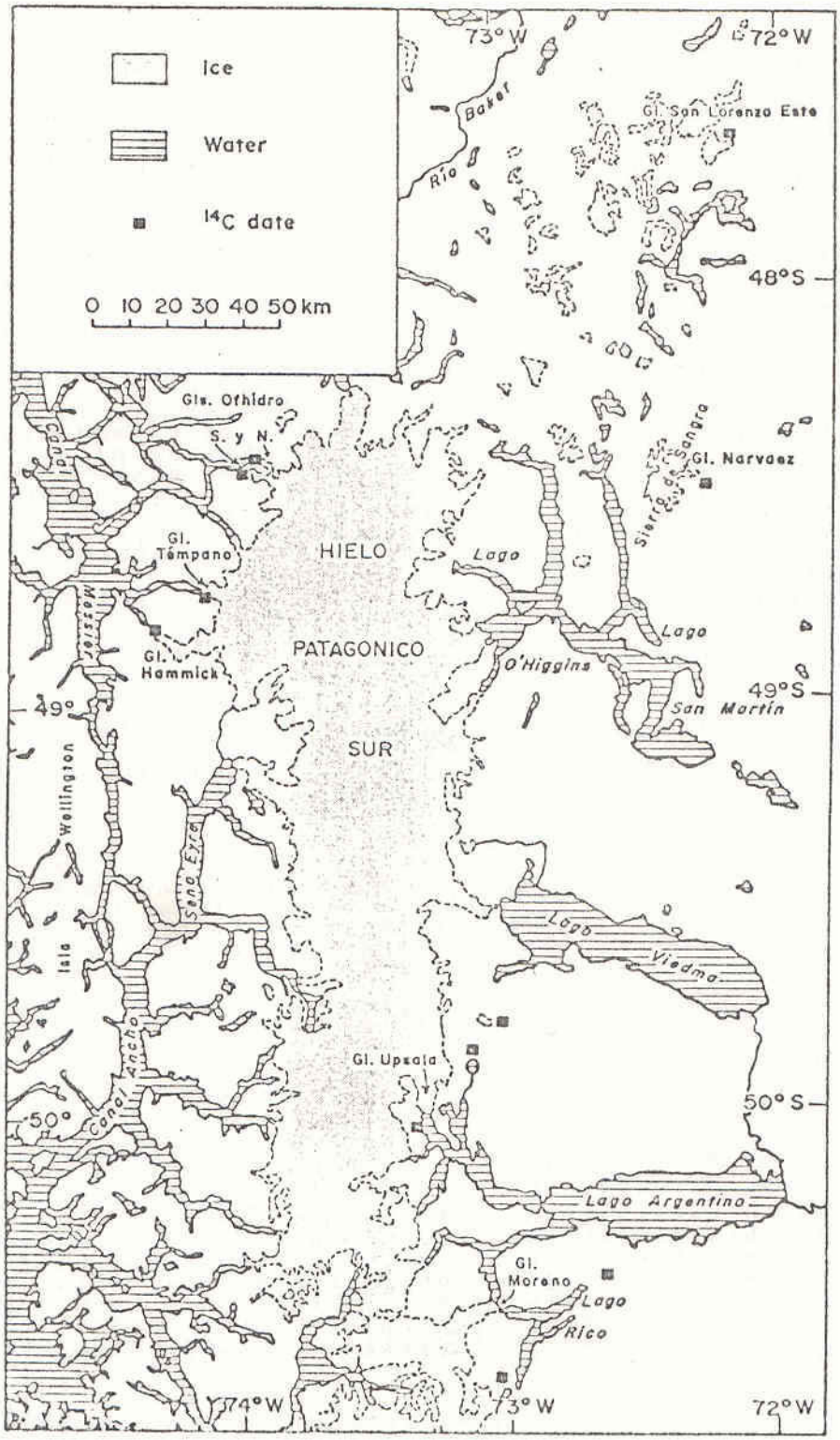

Fig. 2 Hielo Patagónico Sur and vicinity, showing sites of C-14 dated samples. Reproduced from Mercer, in press.

Late Llanquihue time

The Late Llanquihue advance culminated shortly after 20.000 B. P. Near Laguna Bonita south of Lago Rupanco an end moraine, formed by a distributary lobe of the main Rupanco glacier, covers organic sediments that are exposed in a gravel pit at the side of Route U-91, 3 km west of Laguna Bonita. The sequence consists of:

1	m	compact till
3-4	m	stratified drift
0.2	m	sandy clay
0.8	m	peat and gyttja
0.1-1	m	diamicton
1	m	gyttja
> 1	m	cobbles

A finite age of 36,300 ± 2.600 B. P. (sample I-6.564) obtained for the uppermost part of the lower gyttja should be considered a minimal age. The age of the uppermost 5 mm of the upper gyttja is 19,450 ± 350 years (sample I-5.679). Fibers project into the overlying sandy clay, which is believed to have been deposited in a short-lived ice-marginal pond. Apparently vegetation on the original surface of the bog shortly before the glacier reached its greatest extent has been preserved, suggesting that the glacier reached its maximum extent very close to 19.450 years ago. Other evidence for a glacial maximum at about that time comes from Frutillar Alto, Lago Llanquihue (lat. 41°07'25"S. long 73°02'30"W), where a pit extends into the distal flank of an end moraine. In gravel beneath a layer of compact till, a fragment of fibrous peat that was probably derived from near the surface of an overridden bog is 20.100 ± 500 years old (sample RL-116).

Events 19,500-13,000 B. P. are best recorded at sites bordering Lago Llanquihue, whose repeated changes in level are believed to have been caused by glacial fluctuations. At the northern extremity of the lake an ice-marginal lake formerly drained by a spillway now c 100 m above lake level. Basal peat from 2.7 m depth (50 m west of Route U-55-V, lat. 40°56'30"S. long. 72°52'30"W) (Fig. 3), is 17,370 ± 670 years old (sample RL-120). The spillway is about 30 m above the crests of the Llanquihue moraines near Frutillar Alto, and thus can have been occupied only when the glacier reached the shore between Puerto Octay and Frutillar Alto. Thus the glacier had receded from the western shore of the lake by about 17,370 B. P. During the next 4,000 or so years, the changes in lake level are most reasonably explained by a great retreat of the glacier, followed by readvance. As Brüggen (1950, p. 363) notes, Lago Llanquihue has had two outlets: a western outlet by the Río Maullín, and an eastern outlet to the Fiordo Reloncaví. Volcanic mudflow deposits now fill the eastern outlet, but the divide between the lake and the fiord is still less than 10 m above lake level.

The history of these two outlets can be inferred at Puerto Varas from exposures of lake sediments. Route V-55 cuts through the Early Llanquihue moraines at 80 m, and through a slumped terrace, consisting of coarsely laminated clay with dropstones, with its upper surface at 40 m and unknown vertical extent. At about 25 m above lake level is a well preserved terrace, in which an organic layer burried beneath about 15 m of lake sediments is exposed in the cliff along the lake shore, in a road cut in Calle Rosa in the center of Puerto Varas, and beneath the railway bridge over Route V-55. The lake sediments consist of 50 cm of laminated silty clay covering the peat, overlain by 13 m of coarse sand containing abundant pebbles and cobbles.

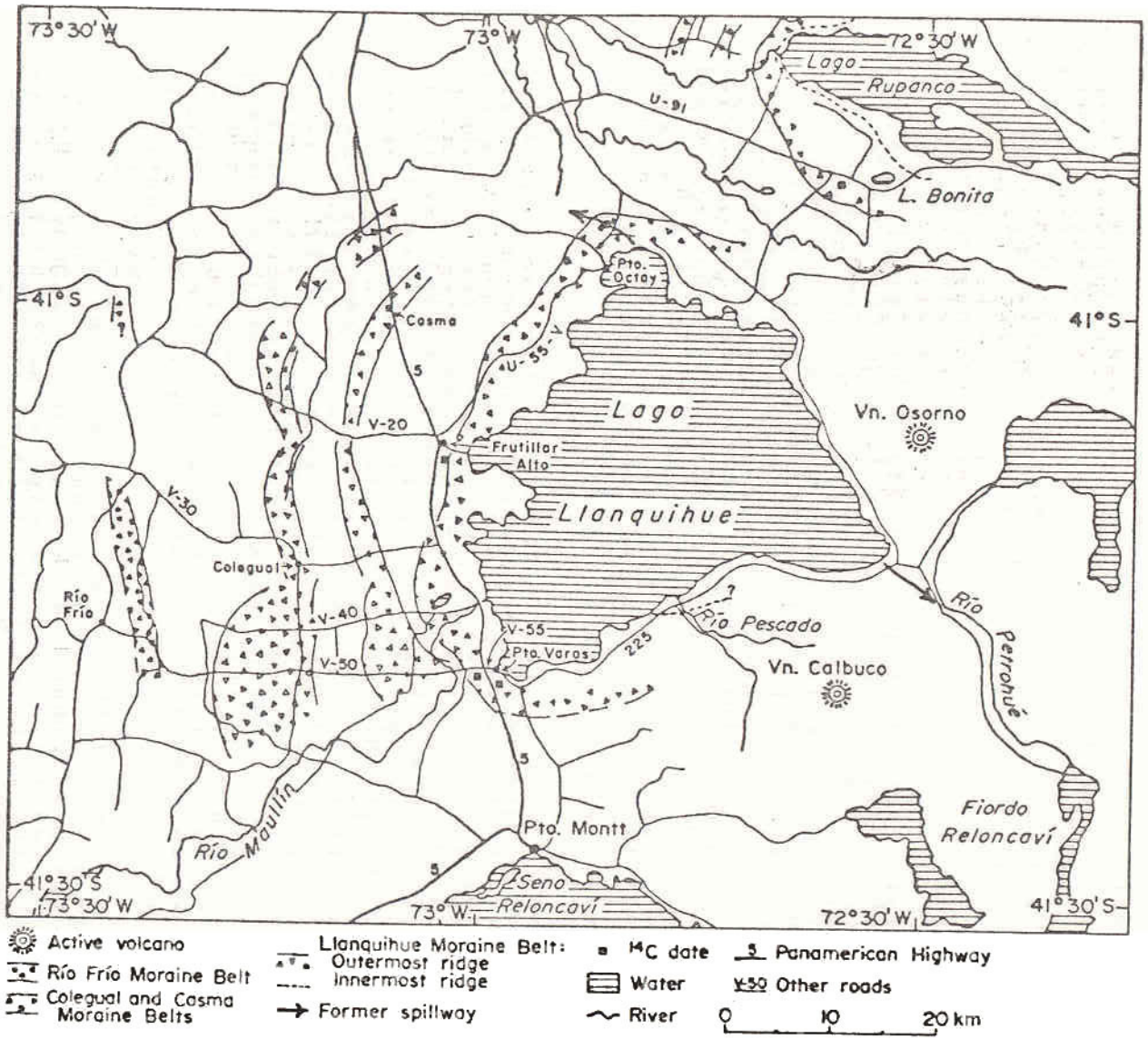

Fig. 3 Lago Llanquihue and Lago Rupanco, showing positions of end moraine belts, where traced, in relation to the road network; sites of C-14 dated samples; and former spillways. Reproduced from Mercer, in press.

Thus lake level was at first at + 40 m (relative to present lake level), fell to no more than + 10 m, and then rose to at least + 25 m, drowning vegetation. The suggested sequence of events causing these changes of level is as follows. While the glacier was receding from the western shore after ca 17,370 B. P. the lake drained by its present outlet, but water level was higher than today, although dropping, because the river was still cutting through the moraines. Dropstones from floating ice were incorporated into the lake sediments. With continued shrinkage the eastern outlet opened, resulting in a drop in lake level to + 10 m or lower. Later, readvancing ice closed this outlet, causing lake level to rise to at least + 25 m, to the contemporary level of the channel of the western outlet. Lake level then dropped slowly to present level as this channel was deepened, and during final deglaciation the eastern outlet was not reoccupied. The silty clay that covers the peat is a typical lake clay the coarser overlying material is thought to be an offshore deposit derived partly from wave erosion of older glacial deposits, and partly from ice-rafted volcanic material that was acquired by the glacier as it passed between the volcanoes Osorno and Calbuco.

The glacier in Lago Llanquihue did not reach the western shore of the lake during this advance, but it may have reached a band of moraine ridges exposed along Route 225, 500 m west of the Río Pescado (Fig. 3). The Rupanco, Puyehue and Ranco glaciers, however, are thought to have filled their respective lakes at that time, forming the moraines that are now at or close to the western shores. The readvance probably ended a few centuries after ice had closed the eastern outlet of Lago Llanquihue; that is, ca 13,000 B. P.

The inferred interval of shrunken glaciers, during which Lago Llanquihue drained by its eastern outlet, has been named the Varas Interstade (Mercer, 1972). The eastern outlet was open by 16,000 B. P. Beneath the railway bridge at Puerto Varas Lake sediments cover 10 cm of peat, resting on 2.5 m of gyttja and peat lenses. Wood 15 cm above the base of the gyttja is 16,270±360 years old (sample RL-113) (Mercer, 1972, p. 1118). At the Calle Rosa site, an age determination of 14,820 ± 230 years (sample I-5033) for the uppermost 5 mm of a 4 cm thick layer of peat was obtained (Mercer, 1972, p. 1118); at the railway bridge site, however, age determinations of 13,000 ± 550 years (sample GX-2947) and 13,200 ± 320 years (sample GX-4190) were later obtained for the uppermost part of a 10 cm thick layer of peat (Heusser, 1974, p. 308; Mercer, in press). These results imply that a date of ca 13,000 B. P., rather than 14,800 B. P. as was suggested by Mercer (1972) must be accepted as the most likely date for the damming of the eastern outlet of Lago Llanquihue. Possibly the peat at the Calle Rosa site was truncated by wave erosion as water level rose and before sedimentation had begun. The advance probably culminated a few centuries later at ca 13,000 B. P. However, the last major glacial maximum in Chile should not be considered as firmly dated at ca 13,000 B. P. until age determinations have been obtained from an end moraine or closely associated feature, rather than from a probably ice-dammed lake.

In Europe the start of recession ca 10,000 B. P. from the final major readvance is the event used for the end of the last (Weishsel/Würm) glaciation; using a similar criterion for Chile, the Llanquihue Glaciation ended considerably earlier: probably ca 13,000 B. P. and certainly well before 12,000 B. P.

Deglaciation

During the centuries following the final readvance of the Llanquihue Glaciation, probably ca 13,000 B. P., deglaciation in the lake region of Chile was very rapid. By 12,000 B. P. the lakes themselves were ice-free. Near the northeast cor

ner of Lago Ranco, on the banks of the Río Caunahue (lat. 40°07'50" S., long 72°14'45" W) (Fig. 1), a sequence consisting of till or coarse ice-lake sediments covered by clay, grading up into increasingly organic clay gyttja, covered by coarse gravel, is exposed at 70 m above lake level. The gravel merges downvalley into a large perched delta. The clay gyttja contains abundant driftwood including entire tree trunks, and also bands of leaves. The oldest datable horizon is a 5 mm thick band of leaves just above the clay-clay gyttja transition; its age is 12,200 ± 400 years (sample GX-2935). By that date, therefore, the glacier had withdrawn completely from Lago Ranco (Mercer and Laugenie, 1973). Seno Otway 1400 km to the south was also ice-free by 12,000 B. P. Seno Otway lies east of the Andes, but it is connected to the Pacific Ocean at its western end by the narrow Canal Jerónimo. During the early stages of deglaciation Seno Otway was a proglacial lake draining northeast to the Estrecho de Magellanes. The spillway was not abandoned until the ice had receded into the mountains and the Canal Jerónimo was open. Basal peat at 1.4 m depth resting on cobbles near the intake of the spillway (lat. 52°48' S, long 71°05' W) is 12,460 ± 190 years old (sample I-3512) (Mercer, 1970, p. 19).

Sixty km to the north is the El Zurdo spillway through the moraines north of Laguna Blanca. This spillway must have been abandoned considerably before the Seno Otway spillway. Basal peat at 1.5 m depth resting on 18 cm of clay covering cobbles is 11,050 ± 220 years old (sample RL-117). It is important to note that the age of basal peat in a spillway only gives a minimal age only for its abandonment, not the actual age or even a close minimal age; in the case of the El Zurdo outlet standing water, in which clay deposited, evidently occupied the sample site for some time after the glacial drainage river had stopped flowing. Marangunic (1974, p. 10), however, wrongly quotes Mercer as saying, in a personal communication, that the El Zurdo outlet was abandoned at 11,000 B. P. instead of by 11,000 B. P. Marangunic then uses this date to support the chronology of Caldenius (1932) and concludes that Lzguna Blanca was deglaciated ca 12,000-11,000 B. P. during the European Allerød Interstadial, and that Seno Otway and Seno Skyring were still ice-filled during the European Younger Dryas Stade 11,000-10,000 B. P. However, this conflicts not only with the dates of deglaciation of Seno Otway and Lago Ranco, but also with the known history of the Hielo Patagónico Sur. By 11,000 B. P. the Glaciar Témpano, an outlet on the west side of the icefield (lat. 48°45' S, long 74°00' W) (Fig. 2), had receded to within its present borders. A minor readvance of this glacier culminated probably about 1945. Between then and 1968 shrinkage uncovered 60 cm of compressed peat on till; the age of the basal peat is 11,070 ±160 years (sample I-3507). In the Banks of an old drainage channel 350 m beyond the present ice margin, 1.5 m of uncompressed peat is exposed. The basal peat is 11,100 ± 170 years old (sample I-3825) (Mercer, 1970, p. 12). The Glaciar Témpano remained at least as small as it is today from 11,000 B. P. until Neoglacial time.

The date of deglaciation of the Río Baker, which flows between the two Patagonian icefields (Fig. 2), supports the early shrinkage of the Glaciar Témpano. Lago Cochrane-Lago Pueyrredón on the east side of the Andes now drains to the Pacific Ocean by the Río Baker, as also does the much larger Lago General Carrera-Lago Buenos Aires to the north. A comparatively small advance of the southern outlet glaciers of the northern icefield would have blocked it. The former eastern outlet of Lago Cochrane-Lago Pueyrredón was sampled with a Hiller borer in Argentina (lat. 47°19' S, long 70°58' W). Peat obtained from a depth of 4 m, 10 cm above an impenetrable floor, is known to have been contaminated by younger material during the boring operation. Thus, although its age determination of 11,245 ± 245 years (sample GX-4168) gives a minimal age for the opening of the Río Baker outlet, it is unlikely to give a close minimal age because of the contamination; nevertheless it shows conclusively that the river was not closed by ice after 11,200 B. P.

Hypsithermal Interval and Neoglaciation

After 11,000 B. P. glaciers in southern Chile apparently did not advance beyond their present margins until about 4600-4200 B. P. in early Neoglacial time. Thus the Hypsithermal Interval, if defined as the interval that began when climate first became warmer than it is today and ended when climate became cooler, and assuming that this area of high rainfall glaciers mainly responded to temperature changes, began shortly before 11,000 B. P. and ended at the start of Neoglaciation, probably ca 6000-5500 B. P. (Mercer, 1970, p. 21). It must be pointed out, however, that the glacial evidence conflicts with the palynological evidence which implies that temperatures in southern Chile fell 11,000-10,000 B. P. to levels 4°C lower than today's, and that the Hypsithermal Interval did not begin until ca 8500 B. P. (Heusser, 1974, p. 310-311).

During Neoglaciation that followed the Hypsithermal Interval, glacial advances culminated ca 4600-4200 B. P. probably 2700-2000 B. P. and during recent centuries; on average, the 4600-4200 B. P. advance was the greatest. In Chile the dates connected with the advance 4600-4200 B. P. advance have been obtained from basal peat, and give lower age limits only, but just across the border in southern Argentina on the east side of Cerro Cochrane or San Lorenzo, (lat. 47°39'S, long 72°15' W) (Fig. 2) an absolute age of 4590 ± 115 B. P. (sample I-2208) (Mercer, 1968, p. 104) has been obtained from a tree drowned in a moraine-dammed lake at the glacial maximum. On the Chilean side of the Hielo Patagónico Sur, basal peat samples give minimal ages of 4120 ± 105 years (sample I-3508) for the outermost Neoglacial moraine of the Glaciar Témpano (lat. 48°45' S, long 74°00' W), and 4060 ± 110 B. P. (sample I-3510) for the next to outermost moraine ridge of Glaciar Ofhidro Sur (lat. 48°26' S, long 73°55' W) (Mercer, 1970, p. 7 and 12). Organic matter near the base of lake sediments on the moraines round Laguna San Rafael (lat. 46°45' S, long 74°00' W) is 3740 ± 400 years old (sample Y-738-2) (Stuiver et al. 1960, p. 53; Heusser, 1961).

After the first Neoglacial advance the Glaciar Hammick, an outlet on the west side of the Hielo Patagónico Sur (lat. 48°52' S, long 74°13' W), shrank within its present borders for several centuries before readvancing. Wood from the outer part of a rooted stump 1 m in diameter buried in outwash about 50 m from the present front of the Glaciar Hammick, is 2800 ± 100 years old (sample I-3506). The tree was about 300 years old when buried, implying that the site was free of ice by about 3200 B. P. The following Second Neoglacial Advance culminated at a massive moraine 700 m in front of the stumps, probably only about a century or two later (Mercer, 1970, p. 23). In Argentina the Glaciar Upsala (lat 50°02' S, long. 73°18' W) was readvancing about 2310 ± 120 B. P. (Mercer, 1965, p. 404). A regional re-expansion of the glaciers in southern South America culminating ca 2700-2000 B. P. is tentatively inferred from the behavior of these two glaciers.

The Third Neoglacial Readvance was in progress by A. D. 1250, when outwash killed trees downvalley from the Glaciar Ofhidro Norte, an outlet on the west side of the Hielo Patagónico Sur (lat. 48°25' S, long 73°53' W) (Fig. 2). The central part of a rooted stump that grew for about 100 years is 800 ± 95 years old (sample I-3827) (Mercer, 1970, p. 7). At this date the radiocarbon and conventional time scales approximately coincide, showing that tree was killed within about a century of A. D. 1250. Tree ring studies show that during the Third Neoglacial Readvance, many glaciers reached their greatest extents during the 17th, 18th or 19th centuries A. D.

The last glaciation in Chile: some comparisons with the Northern Hemisphere and New Zealand.

The earlier parts of both the Llanquihue Glacial Age in Chile and the Wisconsin Glacial Age in North America lie beyond the range of radiocarbon dating and any attempted correlation of these glaciations before ca 25,000 B. P. is speculative. Mercer and Laugenie (1973) suggested a temporal equivalent in Chile for the mid-Wisconsin Cherry Tree Stade about 35,000 B. P. in eastern North America (Dreimanis and Karrow, 1972, p. 8), but this is now known to have been based on an inaccurate radiocarbon date (Stuiver, Mercer and Moreno, 1975).

Comparison of events after about 25,000 B. P. is less speculative being within the range of reliable C-14 dating. The date of about 19,500 B. P. for the culmination of the Late Llanquihue Glaciation is similar to the second of the three pulses about 21,000; 19,500 and 18,000 B. P. that constituted the Late Wisconsin maximum in Ohio (Dreimanis and Goldthwait, 1973, p. 72). The date of the Chilean maximum falls within the limiting dates of 22,500 and 18,000 B. P. for the Late Otiran maximum in New Zealand; however, there is no evidence in Chile for an equivalent of a later glacial advance 17,000-16,000 B. P. that has been recognized in New Zealand (Suggate and Moar, 1970).

The Varas Interstade in Chile, centered sometime between 16,200 and 13,200 B. P. partly coincided with the Erie Interstade in Ohio and Ontario during which glaciers receded until about 15,600 B. P. (Mörner and Dreimanis, 1973, p. 120). The major readvance that ended the Erie Interstade culminated ca 14,800 B. P. (Mörner and Dreimanis, 1973, p. 120), about the same time as major readvances of the Cordilleran Ice Sheet in western North America (Mullineaux et al, 1965), and glaciers in New Zealand (Suggate and Moar, 1970). A single C-14 date for the rise in the level of Lago Llanquihue at first pointed to a similar date for the end of the Varas Interstade in Chile (Mercer, 1972), but the age determinations obtained later for the same event suggest that the advance in Chile was later, culminating about 13,000 B. P. The Port Huron Advance of the Laurentide Ice Sheet, an important event east of the Mississippi culminated about 13,000 B. P. also (Dreimanis and Goldthwait, 1973, p. 95), but if the Chilean glaciers responded then to a global climatic fluctuation why were they not also affected about 14,500 B. P.? Although most evidence now points to 13,000 B. P. as the date of the final major advance of the Chilean glaciers, the event dated - the rise in lake level - has not been shown beyond doubt to have been caused by glacial advance. The date should, therefore, be considered tentative until direct dating of the youngest pre-Neoglacial end moraine in southern South America has been accomplished.

After 13,000 B. P. glaciers in southern Chile and Argentina shrank rapidly and, so far as is known, continuously, until by 11,000 B. P., when ice still covered most of Canada and Scandinavia, they were within their present borders, where they remained until Neoglacial time. Immediately after 13,000 B. P. the shrinkage occurred during a time of rapid global warming and glacial shrinkage: in Europe (Mangerud et al, 1974, p. 117), in England and Wales (Pennington, 1975, p. 167) and in North America (Dreimanis and Goldthwait, 1973, p. 97).

Temperature trends in Chile during the interval 12,000-10,000 B. P., implied by the uninterrupted shrinkage of glaciers differ significantly from those in much of the Northern Hemisphere, especially Europe. They also conflict with the conclusions of Heusser (1974, p. 312), based on pollen assemblages, that temperatures 11,000-10,000 B. P. in southern Chile were 4 °C below present levels: this disagreement is at present unexplained. Heusser's inferred cooling occurred during the European Younger Dryas Stade, 11,000-10,000 B. P.; in Europe this

was an emphatic event that was reflected not only in the pollen assemblages but also in glacial resurgence. If the Younger Dryas cooling did not affect southern South America, it perhaps resulted from environmental changes that were largely confined to the northern North Atlantic, and had no estraterrestial causes (Mercer, 1969). In New Zealand, however, a probable counterpart of the Younger Dryas Stade has been recognized; according to Burrows (1975, p. 127-128), a major glacial readvance culminated sometime between 11,900 and 9500 B. P. Nevertheless, although Burrows' evidence clearly places the readvance before about 9500 B. P., it does not compellingly place the advance after 11,900 B. P. The Third Neoglacial intervals of glacial readvance in southern Chile have been recognized worldwide. However, in marked contrast to most of the Northern Hemisphere, in South America the first interval 4600-4200 B. P. was the most emphatic (Mercer, 1967).

Thus the Late Llanquihue glacial maximum in southern Chile about 19,500 B. P. more or less coincided with the Late Wisconsin-Late Weichsel maximum in the Northern Hemisphere. During Neoglacial time the direction of glacial change in the two hemispheres was the same, although not always the magnitude of events. During the long interval about 13,000-8000 B. P. when the Northern Hemisphere ice sheets were melting, however, marked differences between the two hemispheres are evident. Temperature trends in southern South America, which was far removed from the climatically disturbing influence of these decaying ice sheets, may more truly represent global temperature trends during this interval. However, this should also apply to New Zealand which, lying in similar latitudes to southern Chile, might be expected to have experienced a similar sequence of climatic change. No climatic events can be considered as typical of the south temperate zone unless it affected both New Zealand and southern South America. However, the major glacial advances that are believed to have occurred in New Zealand 17,000-16,000 B. P. and between 11,900 and 9500 B. P. would have coincided with intervals of shrinkage in Chile. Until this trans-Pacific conflict of evidence has been satisfactorily explained, and also until the last major glacial advance of the Late Llanquihue Glaciation in Southern Chile has been conclusively dated, interhemispheric comparisons of inferred climatic change for the interval ca 18,000-8000 B. P. cannot be confidently made.

ACKNOWLEDGMENTS

This research was supported by Grant 24422 from the National Science Foundation, Washington, D. C., and by The Ohio State University. The writer benefited greatly from working in the field with Dr. Oscar González F., and Dr. Hugo Moreno R., of the Departamento de Geología, Universidad de Chile, Santiago; with Dr. Claude Laugenie, formerly of the Departamento de Geografía, Universidad de Concepción; and with Dr. Calvin Heusser, Department of Biology, New York University, Tuxedo, New York. Field vehicles were provided by Dr. Claude Laugenie and by the Departamento de Geología, Universidad de Chile. This paper is a modified, shortened version of parts of Mercer, in press.

REFERENCES

BURROWS, C. J. (1975). Late Pleistocene and Holocene moraines of the Cameron Valley, Arrowsmith Range, Canterbury, New Zealand. Arctic and Alpine Research, 7, 125-140.

BRÜGGEN, JUAN (1950). Geología, 2nd ed., Editorial Nascimento, Santiago, Chile

CALDENIUS, C. C. (1932). Las glaciaciones cuaternarias en la Patagonia y Tierra del Fuego. Geografiska Annaler 14, 1-164.

DREIMANIS, A., and GOLDTHWAIT, R. P. (1973). Wisconsin glaciation in the Huron, Erie and Ontario lobes. In "The Wisconsinan Stage" (R. F. Black, R. P. Goldthwait and H. B. Willman, Eds.), pp. 71-106. Geological Society of America Memoir 136.

DREIMANIS, A., and KARROW, P. F. (1972). Glacial history in the Great Lakes-St. Lawrence Region, the classification of the Wisconsin (an) Stage, and its correlatives, In "Twenty-Fourth Session International Geological Congress, Section 12 Quaternary Geology", pp. 5-15. Montreal.

HEUSSER, C. J. (1961). Some comparisons between climatic changes in northwestern North America and Patagonia. Annals of the New York Academy of Sciences 95, 642-657.

HEUSSER, C. J. (1974). Vegetation and climate of the southern Chilean lake district during and since the Last Interglaciation. Quaternary Research 4, 290-315.

LAUER, W. (1968). Die Glaziallandschaft des Südchilenischen Seengebietes. Acta Geographica [Helsinki] 20, 215-236.

LAUGENIE, C. (1971). Elementos de la cronología glaciar en los Andes chilenos meridionales. Cuadernos Geográficos del Sur 1, 7-20.

MANGERUD, J., ANDERSEN, S. T., BERGLUND, B. E., and DONNER, J. J. (1974). Quaternary stratigraphy of Norden, a proposal for terminology and classification. Boreas 3, 109-128.

MARANGUNIC, C. (1974). Los depósitos glaciales de la pampa magallánica. Revista Geográfica de Chile "Terra Australis" N°22, 5-11.

MERCER, J. H. (1965). Glacier variations in southern Patagonia. Geographical Review 55, 390-413.

MERCER, J. H. (1967). Glacier resurgence at the Atlantic/Subboreal transition. Royal Meteorological Society Quarterly Journal 93, 528-534.

MERCER, J. H. (1968). Variations of some Patagonian glaciers since the Late-Glacial. American Journal of Science 266, 91-109.

MERCER, J. H. (1969). The Allerød Oscillation: A European climatic anomaly? Arctic and Alpine Research 1, 227-234.

MERCER, J. H. (1970). Variations of some Patagonian glaciers since the Late-Glacial: II. American Journal of Science 269, 1-25.

MERCER, J. H. (1972). Chilean glacial chronology 20,000-11,000 carbon-14 years ago: some global comparisons. Science 176, 1118-1120.

MERCER, J. H. (in press) Glacial history of southernmost South America. Quaternary Research, 6.

MERCER, J. H., and LAUGENIE, C. A. (1973). Glacier in Chile ended a major readvance about 36,000 years ago: some global comparisons. Science 183, 1017-1019.

MÖRNER, N. A., and DREIMANIS, A. (1973). The Erie Interstade. In "The Wisconsinan Stage" (R. F. Black, R. P. Goldthwait, and H. B. Willman, Eds.), pp. 107-134. Geological Society of America Memoir 136.

MULLINEAUX, D. R., WALDRON, H. H., and RUBIN, MEYER (1965). Stratigraphy and chronology of Late Interglacial and early Vashon Glacial time in the Seattle area, Washington. U. S. Geological Survey Bulletin, 1194-O.

OLIVARES, R. B. (1967). Las glaciaciones cuaternarias al Oeste de Lago Llanquihue en el sur de Chile. Revista Geográfica 67, 100-108.

PENNINGTON, W. (1975). A chronostratigraphic comparison of Late-Weichselian and Late-Devensian subdivisions, illustrated by two radiocarbon-dated profiles from western Britain. Boreas 4, 157-171.

STUIVER, M. DEEVEY, E. S., and GRALENSKI, L. J. (1960). Yale natural radiocarbon measurements V. American Journal of Science Radiocarbon Supplement 2, 49-61.

STUIVER, M., MERCER, J. H., and MORENO, H. R. (1975). Erroneous date for Chilean glacial advance. Science 188, 73-74.

SUGGATE, R. P., and MOAR, N. T. (1970). Revision of the chronology of the Late Otira Glacial. New Zealand Journal of Geology and Geophysics 13, 742-746.

WEISCHET, W. (1964). Geomorfología glacial de la región de los lagos. Communicaciones de la Escuela de Geología N°4, Universidad de Chile, Santiago.