Reports

Chilean Glacial Chronology 20,000 to 11,000 Carbon-14 Years Ago: Some Global Comparisons

Abstract. *Chilean glaciers at a latitude of 41°S reached a maximum extent about 19,400 carbon-14 years before the present (B.P.), shrank 50 percent by 16,000 years B.P., and readvanced to a smaller maximum after 14,800 years B.P. These fluctuations were closely in step with those of the Laurentide ice sheet east of the Mississippi River but differ somewhat from the accepted sequence in New Zealand. A corresponding pattern is not apparent in the Antarctic paleotemperature curve deduced from changes in oxygen isotope ratios.*

I have recently been engaged in a geologic study of glaciers in south-central Chile. Fieldwork was carried out near Lago Rupanco and Lago Llanquihue, the southernmost of a string of piedmont lakes of glacial origin that are located between 39°S and 41°30′S (Fig. 1).

West of Lago Llanquihue four moraine belts, each consisting of several ridges, probably date from three major glaciations which formed, respectively, the outer moraine belt 35 km west of the lake, the two moraine belts 20 and 15 km west of the lake, and the moraine belt near the lakeshore. Generally the ridges consist of 1 to 4 m of very compact till covering stratified drift. The moraine belt near the lakeshore and its associated outwash are composed of virtually unweathered material, in marked contrast to the older moraines, in which the stratified drift in particular has undergone moderate to intense weathering to depths of at least several meters. West of Lago Rupanco, a belt of little-weathered moraines lies adjacent to the shore. Older, weathered moraines lie to the west, but they are less clearly defined than those near Lago Llanquihue.

The outer part of the moraine belt near the shore of Lago Llanquihue is beyond the range of conventional radiocarbon dating. Two kilometers west of Puerto Varas (Fig. 1) till deposited by the Llanquihue glacier shortly before it reached the outermost moraine ridge covers a log lying on peat; both the log and the uppermost peat are more than 39,900 ^{14}C years old (I-4170 and I-5032). The glacier then receded and later readvanced to a slightly less extensive maximum at the lakeshore moraines. Near Frutillar Alto the end moraine of this episode consists of compact till covering stratified drift containing balls and fragments of peat. A sample of peat, thought to have been derived from near the surface of a bog because it was fibrous and unhumified, is 20,100 ± 550 ^{14}C years old (RL-116), thus suggesting that the Llanquihue glacier reached a maximum shortly after 20,000 years B.P. A more precise date for the culmination of what was evidently a regional glacier advance comes from a site 2 km west of Laguna Bonita (Fig. 1), where an end moraine of the Rupanco glacier covers peat. The moraine consists of 1 m of compact till on about 3 m of stratified drift. The stratified drift consists mainly of cobbles in a sandy matrix, but the basal 30 cm is sandy clay. The uppermost peat is fibrous and fibers project into the overlying sandy clay, thus suggesting that the vegetation that was growing on the bog surface a few years before the glacier reached its greatest extent has been preserved. The age of the uppermost 5 mm of peat is 19,450 ± 350 ^{14}C years (I-5679), showing that the Rupanco glacier reached its greatest extent at this point about 19,400 years B.P. (*1*).

Near Puerto Octay the threshold of the spillway of a former ice marginal lake lies about 100 m above Lago Llanquihue. Basal peat in the spillway, which was abandoned when the glacier withdrew from the western shore of Lago Llanquihue, is 17,370 ± 670 ^{14}C years old (RL-120). While the glacier was receding eastward, Lago Llanquihue at first drained westward by the Río Maullín, as it does today, but stood higher because the river was then not so deeply entrenched through the moraines. The glacier receded until the whole lake was ice-free. Deglaciation continued, and, when the adjacent Reloncaví glacier had shrunk to less than half its maximum length, a lower outlet opened leading from the east end of Lago Llanquihue into the tidewater Estuario de Reloncaví, causing a drop in the lake level.

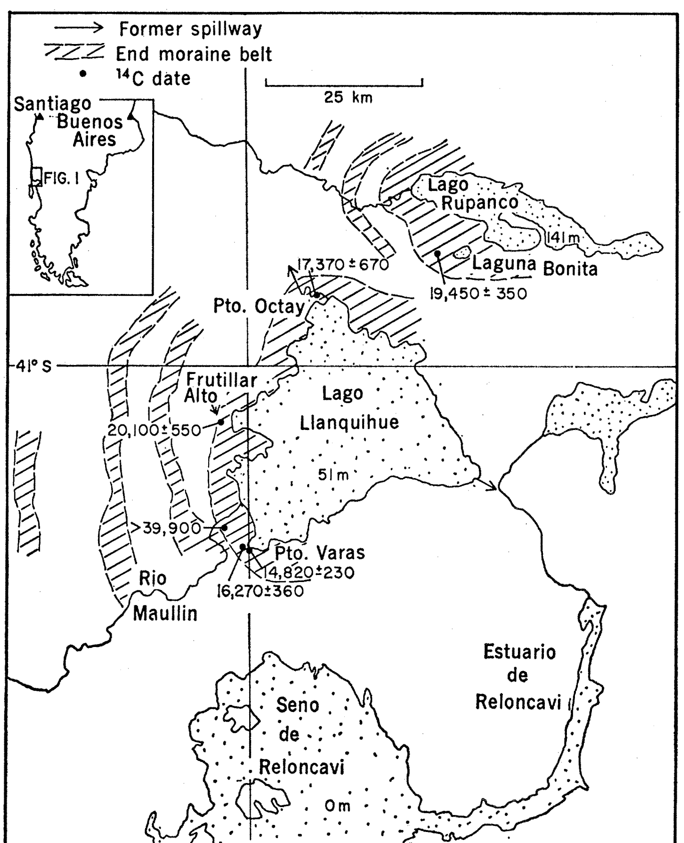
The low-water, ice-free phase of Lago Llanquihue lasted for about 1500 years on the ^{14}C time scale, from before 16,270 ± 360 years B.P. (RL-113) when gyttja containing wood fragments was accumulating at Puerto Varas about 6 m above the present lake level, to shortly after 14,820 ± 230 years B.P. (I-5033), the age of the uppermost 5 mm of peat that overlies the gyttja. This interval of shrunken glaciers is here named the Varas Interstade. Readvancing ice then closed the eastern outlet, and the lake level rose at least 20 m. The peat was covered by about 50 cm of laminated lake sediments, which abruptly give way upward to 5 m of unsorted pebbles and cobbles in a sandy matrix, covered by approximately 9 m of pumice and ash. This sequence is interpreted as showing an initial ice-dammed but drift ice–free phase of Lago Llanquihue when its eastern outlet was blocked by ice readvancing into the Estuario de Reloncaví, followed by irruption of the Llanquihue glacier into the lake with resultant ice-rafting of the pebbles and cobbles. The pumice and ash do not cover adjacent surfaces that remained above the lake level, and must have either floated or been rafted by ice into Puerto Varas bay. If the laminated sediments are varves, the ice-dammed but drift ice–free phase of the lake lasted about a century.

The maximum extent of the readvance is uncertain, but the glacier perhaps reached some moraine ridges about 25 km from the western shore of the lake; these moraines are undated, but the glacier is estimated to have reached its greatest extent a few centuries after the start of ice-rafting, that is, approximately 14,500 to 14,000 years B.P. During this ice-lake phase, the former glacial lake outlet by the Río Maullín was reoccupied; the river entrenched itself so deeply through the lakeshore moraine belt that the eastern spillway was not reoccupied when the glaciers finally receded into the mountains. The site of the eastern spillway is now covered by lahar deposits. Nothing is yet known about fluctuations of the Rupanco and Llanquihue glaciers after approximately 14,500 to 14,000 years B.P., but, by analogy with glacier behavior further south in Chile near 49°S (*2*), the ice probably retreated rapidly, although not necessarily without interruption, and had receded within its present borders by 11,000 years B.P. (Fig. 2).

In order to place these dated Chilean glacier variations in their global setting, they must be compared with those in North America and New Zealand, and also with paleotemperature trends in Antarctica. The ice on the southern margin of the Laurentide ice sheet east of the Mississippi River reached its maximum extent between 21,500 and 18,000 years B.P., withdrew several hundred kilometers during the following Erie Interstade, and then readvanced strongly to a secondary maximum after 15,000 years B.P. (*3*). At about the same time as this readvance, the Cordilleran ice sheet and the Laurentide ice sheet west of the Mississippi reached their maximum Late Wisconsin extents (*4*). Thus glacier fluctuations in Chile from 20,000 to 14,000 years B.P. were closely in step with major fluctuations of the southern margin of the Laurentide ice sheet east of the Mississippi (Fig. 2): not only were the two maxima synchronous, but in both areas they were separated by a marked recession. Because of the initially much smaller size of the Chilean glaciers, the relative deglaciation there during this interstade was much greater. After 14,000 years B.P. North American and Chilean glaciers began to recede, but the Chilean glaciers (*2*) had shrunk to their present sizes some 5000 years before the Laurentide ice sheet had disappeared. The pulsatory recession of the Laurentide ice sheet from 14,000 to 11,000 years B.P. is difficult to interpret in climatic terms because most readvances were confined to a single lobe (*5*). A possible exception is the readvance at approximately 13,000 years B.P. of a wide sector of the ice in the eastern Great Lakes and upper St. Lawrence lowland to the Port Huron moraine and its correlatives (Fig. 2) (*6*), which may imply regional cooling.

In New Zealand, the chronology of the Late Otira glaciation has been worked out mainly on the west side of South Island. Because this area is at about the same southern latitude as south-central Chile, a similar climatic history seems likely. However, recent work suggests a threefold pulsation of the New Zealand glaciers with the maximum extent about 18,000 ^{14}C years B.P. and somewhat smaller readvances culminating about 16,000 and 14,000 years B.P., after which the glaciers receded rapidly (*7*). Although the first and third Late Otira advances at approximately 18,000 and 14,000 years B.P. were approximately synchronous with the two major advances of the Chilean and North American glaciers, the second advance culminating about 16,000 years B.P. would have coincided with marked deglaciation in both Chile and North America. Thus Suggate's claim (*8*) for a general correspondence of the New Zealand and Northern Hemisphere glacial chronologies is only partly valid.

Attempts have been made to estimate Antarctic paleotemperature trends



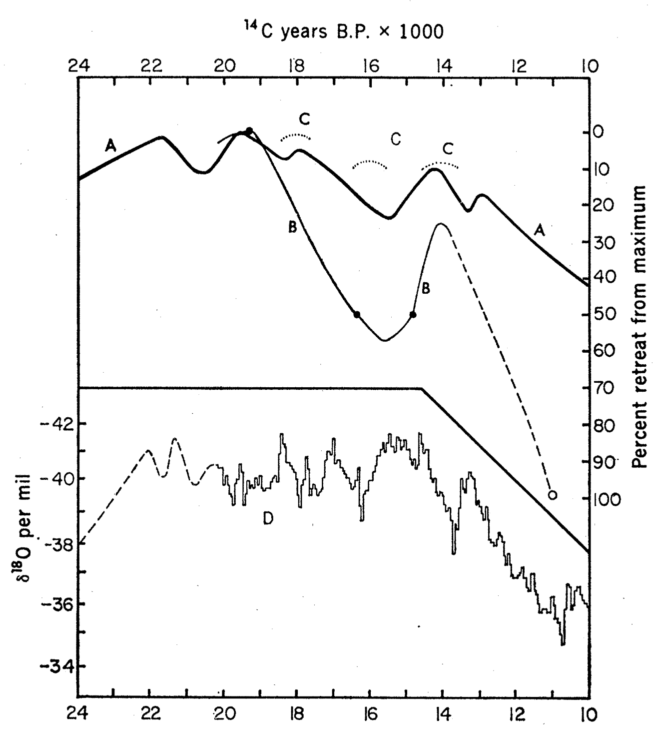


Fig. 1 (left). Location map; *Pto.*, Puerto. Fig. 2 (right). (*A* through *C*) Marginal fluctuations of glaciers between 24,000 and 10,000 ^{14}C years B.P.; 100 percent retreat implies the disappearance of the Laurentide ice sheet in Quebec-Labrador, or the attainment of the present size of the Chilean and New Zealand glaciers: *A*, Laurentide ice sheet in Ohio-Ontario; *B*, Chilean glaciers; (closed circles) ^{14}C-dated positions of glaciers near 41°S; (open circle) ^{14}C-dated position of a glacier near 49°S; *C*, New Zealand glaciers. *D*, Byrd Station, Anarctica; oxygen isotope ratios ($\delta^{18}O$) during the interval estimated at 24,000 to 10,000 calendar years ago [after Johnsen *et al.* (*10*)].

from variations in oxygen isotope ratios with depth in the long ice core from Byrd Station (80°S, 120°W). Epstein *et al.* (*9*) and Johnsen *et al.* (*10*) have calculated tentative time scales in calendar years. Epstein *et al.*, by assuming that ice thickness, vertical strain rate, and accumulation rate have remained constant, have concluded that temperatures rose after a minimum 27,000 years ago, and then fell to a lower minimum 17,000 years ago. From 17,000 to 11,000 years ago, temperatures rose without interruption. They suggest that the date of 17,000 years ago is remarkably close to the culmination of the Late Wisconsin glaciation in North America. Johnsen *et al.* believe that the glaciological regime at Byrd Station is much too complicated for simplistic assumptions to be valid. They conclude that, with present knowledge, any suggested time scale for the Byrd core will be encumbered by considerable error. Tentatively, as the best approximation that is possible with present data, they suggest an oxygen isotope curve which is reproduced in part in Fig. 2. However, it is important to remember that the ^{14}C year and calendar year time scales are not equivalent, and that these two scales perhaps diverge greatly before 14,000 ^{14}C years B.P. (*11*).

Glacier variations in Chile and eastern North America imply a pronounced interstade centered at approximately 15,500 ^{14}C years B.P., preceded by a prolonged cold interval peaking at about 20,000 to 19,000 years B.P., and followed by a brief and final return to full-glacial cold peaking at approximately 14,500 to 14,000 years B.P. This finding strongly suggests a global temperature oscillation, but, before this sequence can be more confidently so described, the evidence for a New Zealand glacier readvance at about 16,000 years B.P. needs reexamination. An oscillation of temperature that might correspond to the North American Erie Interstade and to the Chilean Varas Interstade, and the following readvances, is not evident in the Byrd Station oxygen isotope ratio curve, which shows more resemblance to the New Zealand data. However, more information is needed on the relation of calendar years to ^{14}C years before significant comparisons can be made between the Byrd Station oxygen isotope curve and glacier fluctuations dated by ^{14}C.

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References and Notes

1. These data disprove my earlier suggestion [in "American Quaternary Association Abstracts, First Meeting" (1970), p. 91] that the Late Wisconsin-age glaciation in Chile was a minor event.
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12. Fieldwork supported by NSF grant GA-24422. Field transport provided by Departamento de Geología, Universidad de Chile, Santiago, through the initiative of Dr. O. Gonzalez. Contribution No. 225 of the Institute of Polar Studies, Ohio State University.

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Oil Pollution: Persistence and Degradation of Spilled Fuel Oil

Abstract. *In September 1969, approximately 600 metric tons of number 2 fuel oil were spilled in Buzzards Bay, Massachusetts. Two years later, fuel oil hydrocarbons still persisted in the marsh and in offshore sediments. Hydrocarbon degradation is slow, especially below the immediate sediment surface and appears to proceed principally through microbial utilization of alkanes and through partial dissolution of the lower-boiling aromatic hydrocarbons. The boiling range of the spilled oil and the relative abundances of homologous hydrocarbons (for example, phytane and pristane) have been well preserved. The findings are in agreement with the known geochemical stability of hydrocarbons. Fuel oil is an appreciable fraction of whole crude oil. This fact suggests that oil products and crude oils have a considerable environmental persistence.*

Oil pollution of the sea and the public awareness of it have increased rapidly in recent years. In spite of this, little information exists on the persistence and long-term effect of hydrocarbon pollutants in the marine environment.

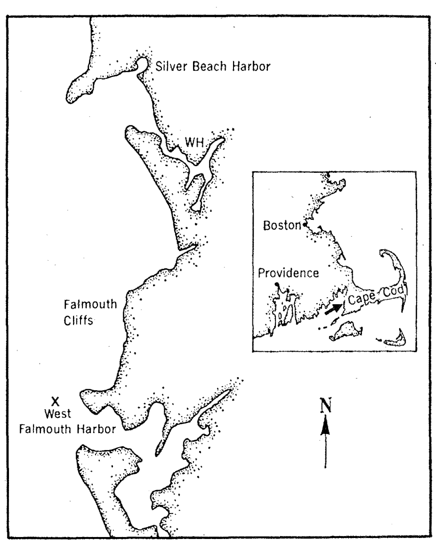

Fig. 1. Site of the September 1969 Buzzards Bay oil spill (×). Samples described here were taken at Silver Beach Harbor and Wild Harbor River (*WH*). For analyses from additional sites, see (*3*).

The fate of fuel oil from a spill in Buzzards Bay, off West Falmouth, Massachusetts, on 16 September 1969 (Fig. 1) has been under investigation for more than 2 years. The relatively small spill involved the discharge from a stranded barge of approximately 600 metric tons of number 2 fuel oil into the coastal waters and marshes. It led to persistent pollution of the sediments and of the fisheries resources (*1–3*).

Among the events that followed the 1969 spill, we can distinguish three distinct, although partly overlapping, series of events. Within the first few hours or days after the accident there was a heavy kill of organisms that came into contact with the oil; the effect extended over all phyla and over benthic and intertidal organisms (*2, 4*).

Next, within weeks or months after the spill, the oil spread to areas that had not been affected initially, and the kill extended, although in some cases more slowly than the spread of the oil, to outlying areas. For a considerable time after the spill, the oil prevented resettlement of the sediments by the original fauna. At present, degradation of the oil is evident; concurrently with the chemical changes in the oil, the immediate toxicity of the oil in the