Reports

Glacier in Chile Ended a Major Readvance about 36,000 Years Ago: Some Global Comparisons

Abstract. *About 36,000 carbon-14 years ago, a glacier in southern Chile reached the culmination of a major readvance. Severe global cooling at about that time, preceded and followed by warmer conditions, is implied also by other glacial, floral, and some oceanographic evidence, but not by other oceanographic evidence nor by studies of past eustatic sea levels. Severe global cooling at about that time is incompatible with the Milankovitch theory of climatic change.*

In Chile a string of glacially formed piedmont lakes extends from 39°S to 41°30′S. Organic matter embedded in or interbedded with glacial drift becomes progressively more abundant southward—or, at least, it is easier to find—so that the most detailed glacial chronology dated by ^{14}C has been obtained from around the two southernmost lakes, Lago Llanquihue and Lago Rupanco. Mercer (*1*) has shown that during the last major glaciation (the probable counterpart of the entire Wisconsin glaciation in North America), glaciers in these lake basins were most extensive before 40,000 years before the present (B.P.) and reached successively smaller maxima about 19,500 years B.P. and 14,500 to 14,000 years B.P. Because of the rather confused pattern of closely spaced and overlapping end moraines near these two lakes, we were unsure whether every stade had been identified. Therefore, in 1972 and 1973 we sought datable material in the clearer and more detailed pattern of end moraines of the last glaciation that lie west of Lago Ranco (Fig. 1), 50 km north of Lago Rupanco. We came across little organic material in this moraine belt, but one important find was wood (*Austrocedrus chilensis*) (*2*), thought to be branches attached to a fallen tree (Fig. 2), beneath an end moraine and lying on a sequence (5 m thick) consisting of the following: 140 cm of highly compressed peat with bands of white volcanic ash; 24 cm of sand and clay; 150 cm of dark volcanic ash and lapilli; 6 cm of peat; and 150 cm of clay, resting on till. Westward from this point, the basal till appears to continue as the uppermost till sheet, ending 5 km away at the outermost moraine of the last glaciation which is believed, by comparison with the dated sequence at Lago Rupanco and Lago Llanquihue, to be >40,000 ^{14}C years old. Two younger moraines, one 3 km and the other 5 km east of the interstadial site, are believed, on the same grounds, to be ~19,500 and ~14,500 to 14,000 ^{14}C years old, respectively. The age of 12,200 ± 400 (sample GX-2935) for basal lacustrine peat that accumulated on glaciolacustrine sediments after the glacier had withdrawn completely from the lake (Fig. 1) supports this estimate of the age of the youngest moraine.

We have obtained two ^{14}C age determinations from the top of this interstadial sequence: 36,250 ± 2,750 years (sample I-6348) for wood resting on peat and covered by till and 36,900 ± 3,400 years (sample I-7145) for the uppermost layer of peat in contact with till. The wood and peat were sealed in by 4 m of compact, impervious till after burial, before being exposed during recent road-making, so that contamination is likely to have been minimal. The similarity of the age determinations on both wood and peat gives

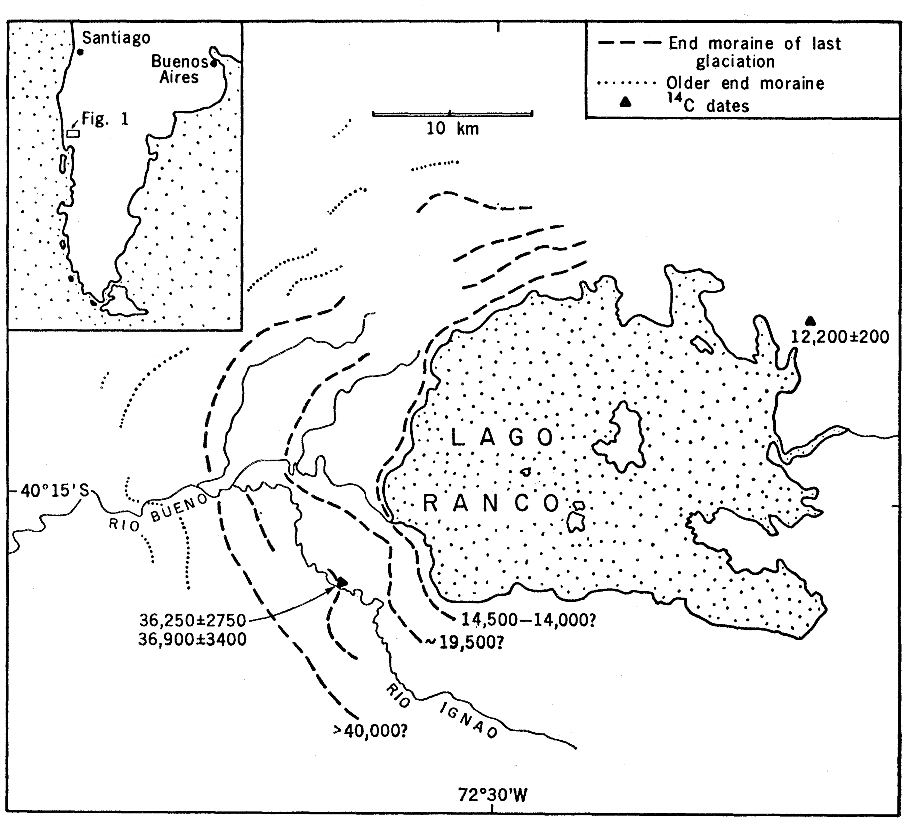

Fig. 1. Location map, showing approximate positions of main end moraine ridges, Lago Ranco, Chile. The outermost and two inner moraines at Lago Ranco are undated; suggested ages (in ^{14}C years) followed by question marks are from the dated sequence near Lago Rupanco and Lago Llanquihue (*1*).

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added grounds for confidence; moreover, the ages are compatible with the stratigraphic position of the sequence in the middle part of the last glacial stage.

An advance of the Lago Ranco glacier in Chile, culminating ~36,000 years B.P., supports evidence from other parts of the world for an episode of severe cold sometime during the interval from 37,000 to 30,000 years B.P. (*3*), inferred from glacial advances, floral changes, and changes in marine cores. However, other evidence from studies of marine cores and fluctuations of eustatic sea level is incompatible with cooling at that time.

Outside Chile, major advances of glaciers during the interval from 37,000 to 30,000 years B.P., preceded and followed by interstades, have been recognized in the Pacific Northwest centered ~35,000 years B.P. (*4*), in Wisconsin and Illinois 35,000 to 30,000 years B.P. (*5*), in Ontario and probably also in adjacent Pennsylvania ~34,000 years B.P. (*6*), and in Siberia 33,500 to 30,500 years B.P. (*7*). The floral records imply an emphatic cool episode in the Pacific Northwest from ~40,000 to 34,000 years B.P. and low temperatures in equatorial Africa ~33,000 years B.P. (*8*). In Holland and France, however, although the floral record implies lower temperature ~36,000 to 33,000 years B.P. between the Hengelo and Denekamp interstades, the cooling seems to have been minor (*9*).

An episode of severe cooling of surface waters, culminating 36,000 to 35,000 ^{14}C years ago, has been deduced from the faunal contents of marine cores in the eastern Mediterranean (*10*), in the eastern North Atlantic (*11*), and in the southeastern tropical Pacific (*12*). In cores from southern California waters, on the other hand, a warmer interval centered ~33,000 ^{14}C years ago, preceded and followed by cooler conditions, has been inferred from the faunal and carbonate contents (*13*).

The evidence in the Caribbean is ambiguous. Emiliani (*14, 14a*) has interpreted past variations in the oxygen isotopic composition of faunal tests in terms of changes of temperature; his well-known curve has two cold peaks, one at ~20,000 years B.P. and one at ~60,000 years B.P. separated by a warmer interval consisting of two warm peaks 55,000 and 35,000 years B.P. with a slight cooling between. Emiliani (*15*) has equated the entire warmer interval with the combined Port Talbot and Plum Point interstades in North America, ignoring the stade that separates them (*6*). Many workers (*16–18*) believe that changes in the ^{18}O content of marine tests reflect mainly the changing isotopic composition of seawater, caused by the extraction from and return to the oceans of large amounts of water by the repeated buildup of ice sheets deficient in ^{18}O: the curves are thus essentially curves of paleoglaciation, recording the volume of land ice, rather than curves of paleotemperature. Imbrie *et al.* (*16*), who hold this view, have recently examined both the faunal content and the oxygen isotopic ratios of a Caribbean core. The temperature curve deduced from faunal indices suggests that, during the last major glaciation, the temperatures of surface waters reached three minima, one at 19,000 ^{14}C years ago, and the others at dates estimated at 31,000 and 45,000 ^{14}C years ago. The cooling ~31,000 years B.P. apparently was the most severe; however, the δ^{18}O curve, which is similar to Emiliani's except that the time scale is ~30 percent longer, does not suggest any increase in the amount of land ice at that time.

Fig. 2. Two branches of *Austrocedrus chilensis*, probably parts of the same fallen tree, beneath compact, impervious till and resting on compressed peat, west of Lago Ranco. The ^{14}C age of the wood is 36,250 ± 2750 years; the ^{14}C age of the uppermost layer of peat is 36,900 ± 3,400 years.

Dansgaard *et al.* (*19*) believe that a short, sharp cooling ~41,000 calendar years ago on their revised (but still tentative) time scale for the ice core from Camp Century, Greenland, may correspond to the stade between the Port Talbot and Plum Point interstades, which Goldthwait *et al.* (*20*) estimate occurred ~41,000 ^{14}C years ago. However, this stade is now believed to have culminated ~34,000 ^{14}C years ago (*6*). The problem of relating calendar to ^{14}C dates makes correlation of these two events highly speculative.

Most workers believe that eustatic sea level during at least the last 100,000 years has been overwhelmingly glacially controlled and thus was higher during interstades than during stades. High sea levels, although not necessarily as high as now, have been deduced from uranium series dates of ~30,000 years B.P. in Florida (*21*), from ^{14}C dates of 35,000 to 30,000 years B.P. from continental shelves (*22*), and from ^{14}C dates of ~35,000 years B.P. in North Africa (*23*). Veeh and Chappell (*24*) conclude, from uranium series and ^{14}C dating of raised coral reefs in New Guinea, that the eustatic sea level was rising at ~50,000 years B.P. and reached a high stand at −25 m ~35,000 ^{14}C years ago. Shackleton (*25*), however, suspects that the ^{14}C dates are unreliable; he interprets the evidence from New Guinea as showing that a high stand at about −50 m was reached about 50,000 years B.P., which is a uranium series date on coral. Shackleton and Opdyke (*18*) have recently analyzed a core from the western equatorial Pacific in which the oxygen isotopic curve closely parallels that obtained from Caribbean cores. They interpret this curve as a paleoglaciation curve and, by inference, as a curve of eustatic sea level also. The curve shows sea level falling smoothly from an interstadial high of −50 m at 50,000 years B.P. to a low of −120 m at 20,000 years B.P., passing through −80 m at 35,000 years B.P.; in other words, it does not reflect the threefold interstade, stade, interstade sequence that the terrestrial record along the southern margin of the Laurentide ice sheet suggests (*6*).

Thus evidence about global temperature levels and trends ~35,000 years B.P. is conflicting. Much glacial evidence, some floral evidence, and some interpretations of marine cores indicate a cold episode of full-glacial severity, preceded and followed by warmer conditions; some floral evidence suggests only moderate cooling; some evidence from marine cores and sea level changes implies interstadial warmth; and some evidence from marine cores implies that the temperature was halfway between interstadial and stadial levels, and falling.

Many workers have studied and reevaluated Milankovitch's theory that variations in global temperatures have resulted from changes in insolation caused by changes in the earth's orbital parameters. Some (*14a, 24, 26–28*) favor the theory (although with different degrees of conviction) largely because they believe that the resemblance of the calculated insolation curve to many deduced paleotemperature curves, for example, Emiliani's (*14, 14a*), is too great to be coincidental. A few (*14a, 27, 28*) are sufficiently confident to believe that the calculated dates of past insolation values can be used as the chronologic framework for climatic and glacial events. Most investigators follow Milankovitch in believing that summer radiation in the Northern Hemisphere would have been the controlling variable. Although slightly different adaptations of Milankovitch's original curve have been used, they have essentially similar major trends: a radiation maximum ~11,000 calendar years ago that many believe ended the last glaciation, and two minima, one ~25,000 and the other ~70,000 years ago, thought by these same workers to correspond to Late and Early Wisconsin age glacial maxima. The Middle Wisconsin interval has intermediate radiation values and no pronounced dip that could correspond to severe cooling ~35,000 years B.P.; indeed, Veeh and Chappell (*24*) consider that a high stand of the sea ~35,000 years B.P. favors the astronomic theory of climatic change. Kukla (*27*) believes that the controlling variable was the rate of change of winter radiation in the Northern Hemisphere; but his paleoclimatic inferences are similar. Other workers (*29–31*) are, in varying degrees, skeptical about the Milankovitch theory. Shackleton (*30*) warns against a semireligious belief in it, and Sellers (*31*) tentatively concludes that multiple steady states of global climate are possible for the same set of input variables, so that we can perhaps never know the climatic effects of past orbital variations without knowing the initial climatic conditions.

Evidence is growing, from independent lines of research, for severe global cooling centered ~35,000 ^{14}C years ago, preceded and followed by markedly warmer conditions. The apparent absence of any reflection of such an event in the oxygen isotopic curve of the oceans is puzzling: a short, sharp cooling that allowed mountain glaciers to build up while leaving ice sheets shrunken seems to be ruled out by evidence for an expansion of the Laurentide ice sheet. Thus the evidence for severe cooling is not compelling, but it is strengthened by this new information from Chile. Consequently, the Milankovitch theory of astronomic control of climatic change, which is incompatible with such an event, should at present be viewed with skepticism.

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References and Notes

1. J. H. Mercer, *Science* **176**, 1118 (1972).
2. In a road-cut on route I-85, 100 m east of the Río Ignao bridge, 40°18′S, 72°36′W; wood identified by Señora Fresia Torres, Departamento de Botánica, Universidad de Concepción, Concepción, Chile.
3. In view of the large standard deviations in the age determinations and the great differences in apparent age that a small amount of contamination can cause in samples as old as this, it is uncertain how much real difference in timing this spread of ages represents.
4. D. R. Crandell, *U.S. Geol. Surv. Prof. Pap. 388-A* (1963), p. 62; D. J. Easterbrook, *Geol. Soc. Am. Bull.* **80**, 2273 (1969).
5. R. F. Black and M. Rubin, *Trans. Wis. Acad. Sci. Arts Lett.* **56**, 99 (1967–68); J. S. Frye, H. D. Glass, J. P. Kempton, H. B. Willman, *Ill. State Geol. Surv. Circ. 437* (1969).
6. G. W. White, S. M. Totten, D. L. Gross, *Bull. Penn. Geol. Surv. G-55* (1969); A. Dreimanis and P. F. Karrow, in *Quaternary Geology* [International Geological Congress (24th session), Montreal, 1972], sect. 12, p. 5 (copies available from 24th International Geological Congress, 601 Booth Street, Ottawa K1A 0E8).
7. N. V. Kind, in *Quaternary Geology* [International Geological Congress (24th session), Montreal, 1972], sect. 12, p. 55 (copies available from 24th International Geological Congress, 601 Booth Street, Ottawa K1A 0E8).
8. J. A. Coetzee, in *Palaeoecology of Africa*, E. M. van Zinderen Bakker, Ed. (Balkema, Cape Town, South Africa, 1967), vol. 3, p. 86; C. J. Heusser, *Quat. Res. (N.Y.)* **2**, 189 (1972).
9. T. van der Hammen, G. C. Maarleveld, J. C. Vogel, W. H. Zagwijn, in *The Late Cenozoic Glacial Ages*, K. K. Turekian, Ed. (Yale Univ. Press, New Haven, Conn., 1971), p. 391; Y. Guillien, *Bull. Ass. Fr. Étude Quaternaire* **16**, 155 (1968).
10. Y. Herman, *Nature (Lond.)* **238**, 394 (1972).
11. C. Sancett, J. Imbrie, N. G. Kipp, *Quat. Res. (N.Y.)* **3**, 110 (1973).
12. K. R. Geitzenauer, A. McIntyre, M. B. Roche, *Geol. Soc. Am. Abstr. Programs* **5** (No. 7), 632 (1973).
13. D. S. Gorsline and P. W. Barnes, in *Stratigraphy and Sedimentology* [International Geological Congress (24th session), Montreal, 1972], sect. 6, p. 270 (copies available from 24th International Geological Congress, 601 Booth Street, Ottawa K1A 0E8); A. Kheradpir, *Micropaleontology* **16**, 102 (1970).
14. C. Emiliani, *J. Geol.* **63**, 538 (1955); *ibid.* **74**, 109 (1966); *Science* **166**, 1503 (1969); *ibid.* **168**, 822 (1970).

14a. ———, *Science* **178**, 398 (1972).
15. ———, *ibid.* **154**, 851 (1966).
16. J. Imbrie, J. van Donk, N. G. Kipp, *Quat. Res. (N.Y.)* **3**, 10 (1973).
17. E. Olausson, *Prog. Oceanogr.* **3**, 221 (1965); N. Shackleton, *Nature (Lond.)* **215**, 15 (1967); W. Dansgaard and H. Tauber, *Science* **166**, 499 (19[illegible] J. C. Duplessy, C. Lalou, A. C. Vinot, *ibid.* **168**, 250 (1970).
18. N. J. Shackleton and N. D. Opdyke, *Quat. Res. (N.Y.)* **3**, 39 (1973).
19. W. Dansgaard, S. J. Johnsen, H. B. Clausen, C. C. Langway, in *The Late Cenozoic Glacial Ages*, K. K. Turekian, Ed. (Yale Univ. Press, New Haven, Conn., 1971), p. 37.
20. R. P. Goldthwait, A. Dreimanis, J. L. Forsyth, P. F. Karrow, G. W. White, in *The Quaternary of the United States*, H. E. Wright and D. G. Frey, Eds. (Princeton Univ. Press, Princeton, N.J., 1965), p. 85.
21. J. K. Osmond, J. P. May, W. F. Tanner, *J. Geophys. Res.* **75**, 469 (1970).
22. K. O. Emery, H. Niino, B. Sullivan, in *The Late Cenozoic Glacial Ages*, K. K. Turekian, Ed. (Yale Univ. Press, New Haven, Conn., 1971), p. 381.
23. J.-C. Fontes and J.-P. Perthuisot, *Nature Phys. Sci.* **244**, 74 (1973).
24. H. H. Veeh and J. Chappell, *Science* **167**, 862 (1970).
25. N. J. Shackleton, in *The Phanerozoic Time-Scale: A Supplement* (Geological Society of London Special Publication 5, London, 1971), p. 106.
26. W. S. Broecker, *Science* **151**, 299 (1966); ——— and J. van Donk, *Rev. Geophys. Space Phys.* **8**, 169 (1970); P. Evans in *Quaternary Geology* [International Geological Congress (24th session), Montreal, 1972], sect. 12, p. 16 (copies available from 24th International Geological Congress, 601 Booth Street, Ottawa K1A 0E8); J. M. Mitchell, *Quat. Res. (N.Y.)* **2**, 436 (1972).
27. G. J. Kukla, *Geol. Mijnbouw* **48**, 307 (1969).
28. N.-A. Mörner, in *Quaternary Geology* [International Geological Congress (24th session), Montreal, 1972], sect. 12, p. 72 (copies available from 24th International Geological Congress, 601 Booth Street, Ottawa K1A 0E8); G. J. Kukla and H. J. Kukla, *Quat. Res. (N.Y.)* **2**, 412 (1972).
29. D. M. Shaw and W. L. Donn, *Science* **162**, 1270 (1968); W. D. Sellers, *J. Appl. Meteorol.* **8**, 392 (1969); *ibid.* **9**, 960 (1970); B. Salzmann and A. D. Vernekar, *J. Geophys. Res.* **76**, 4195 (1971).
30. N. J. Shackleton, in *The Phanerozoic Time-Scale: A Supplement* (Geological Society of London Special Publication 5, London, 1971), p. 35; A. D. Vernekar, *Meteorol. Mongr.* **12** (No. 34) 1 (1972).
31. W. D. Sellers, *J. Appl. Meteorol.* **12**, 241 (1973).

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