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POSTGLACIAL UPLIFT IN NORTH AMERICA*

WILLIAM R. FARRAND

Lamont Geological Observatory, Columbia University, Palisades, New York

ABSTRACT. Tilted beaches around the Great Lakes and raised marine features throughout Arctic Canada which have been dated by radiocarbon analysis furnish sufficient data for the construction of curves of postglacial uplift *vs.* time for eleven areas. These curves show (1) a uniform pattern of strongly decreasing rate of uplift from the time of deglaciation to the present and (2) a time-displacement which seems to correlate with the time of deglaciation in a given area. These systematic relationships are additional evidence that postglacial and recent uplift around the Canadian Shield (as in Scandinavia) is a result of glacial loading.

Furthermore, these curves indicate that far northern areas such as northwestern Victoria Island and northern Ellesmere Island probably had an ice cover comparable to that over the Great Lakes. Thus the Wisconsin ice border lay considerably north or northwest of these areas. Also, if we may assume that the Wisconsin ice sheet achieved isostasy, then the major part of isostatic rebound occurred prior to complete ice removal in any given place.

INTRODUCTION

The succession of glacial lakes in the Upper Great Lakes is now well enough known and dated by the radiocarbon method that curves of uplift versus time for the past 10,500 years can be drawn for several areas. Such curves for four localities around the Lake Huron basin show the regularity of the uplift phenomenon and a systematic relationship to the Wisconsin-age ice cover. The mean pattern of uplift with respect to time at any given locality is that of a strongly exponential decrease from approximately the time of ice removal in that locality to the present day. Curves for different localities are quite similar although displaced in time, and this displacement correlates with the time of deglaciation of each locality. Therefore, these uplift curves should bear a distinct relationship to the perimeter of the Wisconsin ice sheet, if one may assume that shrinkage of the ice sheet took place uniformly, in broad terms, along all radii. Such an assumption appears to be justified by present knowledge of the southern border of the Wisconsin Laurentide ice sheet.

This relationship of uplift to deglaciation in the Great Lakes area is applied to areas of Arctic Canada in an attempt to learn more about the limits of Wisconsin glaciation in that area. Numerous raised marine features have been observed throughout the Canadian Arctic Archipelago and mainland, and recently some of them have been dated by radiocarbon. Curves constructed from these data, although fragmentary, show a systematic relationship to the Great Lakes curves and suggest that the Wisconsin ice border lay perhaps farther out onto the Arctic Archipelago than is interpreted from geomorphic studies.

This study was initiated in connection with the writer's research on the history of the Great Lakes (Farrand, 1959, 1960). At first radiocarbon-dated sequences of beach features in the Arctic were considered simply as a means of long-distance correlation of such features, which is nearly impossible by any other means at the present time. The similarity of uplift curves from the Great Lakes and the Arctic was immediately apparent, and a genetic relationship suggested itself when the curves were compared to the extent of glaciation.

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UPLIFT AROUND LAKE HURON

Lake Huron, in the center of the Great Lakes system, has a longer and better known record of glacial lake succession than any other basin. Glacial Lakes Maumee through Algonquin, as well as the postglacial Nipissing Great Lakes and Lake Algoma, have left their shorelines around this basin. In addition, the very important outlet channels at Port Huron, Michigan, and North Bay, Ontario, are integral to the Lake Huron basin. For these several reasons four localities within the Huron basin are considered in this paper: Port Huron, Sault Ste. Marie, Cape Rich, and North Bay (fig. 1).

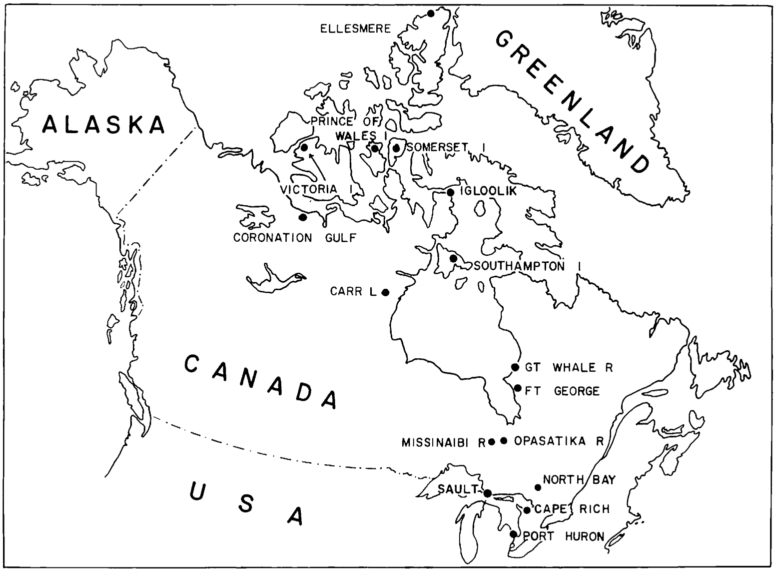

Fig. 1. Location map for stations discussed in text.

For each locality the total uplift since a given time has been plotted for several lake stages. In order to plot these points the following data for each locality are necessary: (a) the present elevation of the shoreline of the lake stage being considered: this elevation has been observed in the field in most cases, but has to be obtained by extrapolation in one instance; (b) the original elevation of that shoreline before uplift, which is known from the still horizontal portions of that same beach in the southern parts of Lakes Huron and Erie; and (c) the age of the shoreline as determined directly or indirectly from radiocarbon dating of associated organic materials. Then, (a) minus (b)

TABLE 1

Glacial Lake chronology of Lake Huron Basin

	Lake stage original elevation (after Hough, 1958)		Time of maximum water level	Source of date
	Lake Huron	580		
	Algoma	595	3200 B.P.	(M-659, Crane & Griffin, 1960)
	Nipissing	605	4200	this report & Dreimanis (1958)
Post-Algonquin low stages	Stanley	180	>9500	Terasmae & Hughes (1960)
	Korah	390(?)		
	Sheguiandah	?		
	Payette	465(?)		
	Cedar Point	493(?)		
	Penetang	510(?)	>9560	GRO-1926, Terasmae & Hughes (1960)
	Wyebridge	540(?)		
	Algonquin	605	10,500	this report, estimated
	Lundy	620		
	Grassmere	640		
	Warren III	675	10,800	Valders glacial maximum (Flint, 1957)
	Wayne	655		
	Warren II	682		
	I	690		
	Whittlesey	738	12,500	based on S-31 (below)
	III	695		
	Arkona II	700	12,660	S-31, McCallum (1955)
	I	710		
	III	790		
	Maumee II	760	ca. 14,000(?)	estimated, this report (cf. W-198, Rubin & Suess, 1955)
	I	800		

is the amount of uplift since the time (c) when that lake stage existed. Table 1 gives the lake succession in the Lake Huron basin and the absolute ages of certain stages as they are now known. Table 2 lists the total uplift at each locality since several different lake stages. The lake succession and amounts of uplift are mainly from Hough (1958). The data given in these two tables form the basis for uplift curves in figure 2.

Some explanation of these data is necessary, however, before proceeding farther. First, the time at which the Nipissing Great Lakes reached their maximum elevation has been determined by calculating the time necessary for water which covered C-14 dated logs at Blackwell, Ontario, to rise an additional 19 feet. This method was used by Dreimanis (1958) and is modified slightly by me to accord with more recent data. The date thus obtained is 4200 ± 270 B.P.[1]

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[1] B.P.—before present.

TABLE 2

Uplift in Lake Huron basin

Lake Stage	Total uplift since given lake stage (feet) Port Huron	Cape Rich	Sault	North Bay
Algoma	0	?	25	?
Nipissing	0	27	45	95
Stanley	0	?	?	520
Payette	0	159	320(?)	?
Penetang	0	174	370	?
Algonquin	0	199	410	960*
Warren (I?)	17			
Whittlesey	27			
Maumee III	60			
Maumee I	60			

* Extrapolated, not observed.
Data assembled from Leverett and Taylor (1915), Stanley (1936, 1937), and Hough (1958).

The Algoma stage of the Great Lakes has been dated recently in connection with an excavation at Saginaw, Michigan, by University of Michigan archeologists and the writer. Here an Indian burial in the crest of an Algoma beach deposit has been dated 3170 ± 300 B.P. (M-659, Crane and Griffin, 1960). Unpublished radiation absorption studies by Lewis Binford of the University of Michigan indicate that this burial has not been submerged. There-

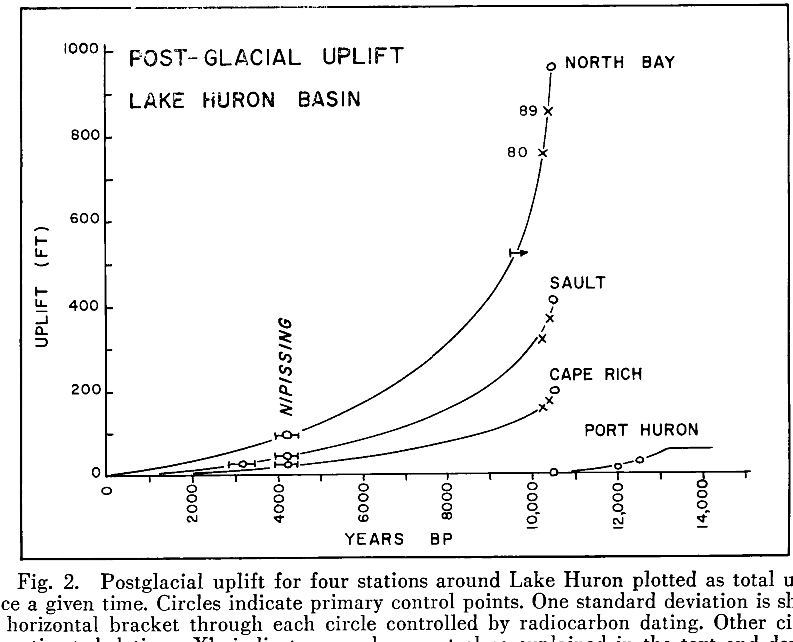

Fig. 2. Postglacial uplift for four stations around Lake Huron plotted as total uplift since a given time. Circles indicate primary control points. One standard deviation is shown by horizontal bracket through each circle controlled by radiocarbon dating. Other circles are estimated datings. X's indicate secondary control as explained in the text and derived from table 3.

fore, Lake Algoma waters must have abandoned the 595-foot shoreline prior to 3200 B.P.

Glacial Lake Algonquin has not been directly dated, but there is abundant indirect chronological information. Algonquin shorelines cut across Valders substage till in the Lake Michigan basin and are, therefore, younger than the Valders maximum, dated about 10,800 B.P. (Flint, 1957). Radiocarbon dates from Manitoulin Island (northern Lake Huron) and from near North Bay, Ontario, show that not only Lake Algonquin but also several post-Algonquin lake stages (Wyebridge through Stanley) terminated prior to 9500 B.P. The most critical of these dates relates to a peat bog, 9500 years old, near North Bay (Terasmae and Hughes, 1960). This bog must postdate deglaciation of the North Bay outlet channel, and it was this deglaciation that initiated the Stanley low-water stage. Terasmae and Hughes (1960) calculated three possible dates for this deglaciation: 9275, 9715, or 10,970 B.P. The middle date accords best with other events; the oldest date is considerably too old because it permits no time for the Valders ice advance.

To allow for at least six or seven separate lake stages between 10,800 and 9500 B.P., I have estimated the date of Glacial Lake Algonquin to be about 10,500 B.P., which is considerably older than previous suggestions (Hough, 1958).

Determination of the amount of uplift is straightforward, as explained above, except for North Bay. The Lake Algonquin shoreline did not extend as far north as North Bay, so its elevation there is imaginary and must be determined by extrapolation in order to complete the North Bay curve. Chapman (1954) has traced the Algonquin beach along the east shore of Georgian Bay to Bernard Lake, only 40 miles south of North Bay, where it lies about 1240 feet above sealevel. By projecting Chapman's curve, the elevation of the Algonquin beach at North Bay would be about 1565 feet, which is 960 feet above the original level of Glacial Lake Algonquin.

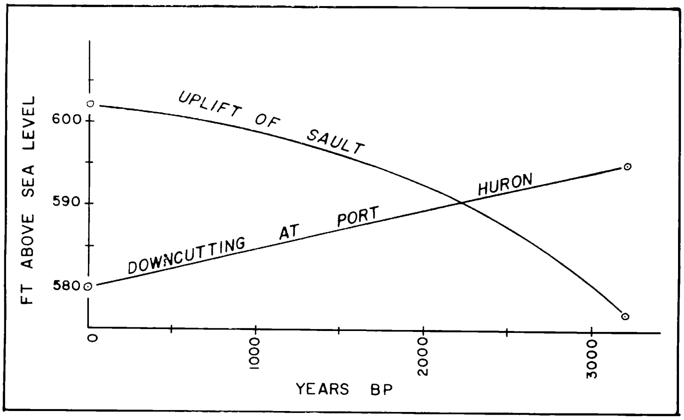

Fig. 3. Emergence of the Sault in St. Mary's River, Sault Ste. Marie, Ontario. The uplift curve is taken from figure 2, and the downcutting at Port Huron since the Algoma stage (3200 B.P.) is plotted linearly against time. The curves intersect at 591 feet above sealevel and about 2200 B.P. (250 B.C.).

The amount of uplift of the Lake Stanley beach can be determined only at North Bay. The North Bay outlet that drained Lake Stanley now is 700 feet above sealevel. The original level of the Stanley low stage, as determined from lake bottom topography in the Mackinac Straits area (Hough, 1958), was about 180 feet above sealevel. Therefore, North Bay has risen about 520 feet since the inception of Lake Stanley.[2]

Further control for the Sault and Cape Rich curves in figure 2 was derived from Stanley's (1936, 1937) work on the post-Algonquin lake stages. He showed a slight decrease in slope of successively younger water planes in the Algonquin to Payette series. Table 3, which is assembled from Stanley's data and additional information from Hough (1958, p. 231-232), shows that 93 percent of total post-Algonquin uplift has occurred since the Wyebridge stage, 89 percent since the Penetang, and 80 percent since the Payette stage. After having drawn the North Bay curve (fig. 2) from data presented in table 2, one can read from that curve the times since which 93, 89, and 80 percent of post-Algonquin uplift occurred. By this means the dates of the Wyebridge, Penetang, and Payette stages are obtained (only the latter two have been plotted) and, coupled with uplift data for these stages in table 2, additional control is available for important segments of the Sault and Cape Rich curves.

Uplift at Port Huron is less well known: the record is shorter, uplift terminated much earlier than at the other stations, and absolute dating is less satisfactory. However, a portion of the uplift curve can be drawn. The earliest shorelines recorded at Port Huron are the three Lake Maumee beaches which have been uplifted 60 feet and show no differential uplift from earliest to latest Maumee times. The Maumee lakes came into existence upon retreat of the ice sheet from the Fort Wayne moraine (Cary subage) and persisted through the advance to and retreat from the subsequent Defiance moraine. The Fort Wayne moraine must be younger than the Wabash moraine which is dated 14,300 ± 450 years (W-198, Rubin and Suess, 1955). Furthermore, the Maumee lakes must be older than Glacial Lake Arkona, which is dated 12,660 ± 440 B.P. (S-31, McCallum, 1955). Therefore, Lakes Maumee I, II, and III can be roughly bracketed between 14,000 and 13,000 B.P.

Glacial Lake Whittlesey is the next stage younger than Lake Arkona, perhaps dating about 12,500 B.P., and its shoreline at Port Huron has been uplifted 27 feet.

The Warren beach at Port Huron now lies at 707 feet above sealevel, but it is not clear which of the three Warren stages (original elevations: 690, 684, and 675 feet) is represented. If one assumes the 707-foot beach to be Warren I, which probably occurred about 12,000 B.P. (post-Whittlesey, pre-Two Creeks), a smooth curve can be drawn for Port Huron (fig. 2). The Grassmere, Lundy, and Algonquin beaches suffered no uplift here.

Thus, we see that the rate of postglacial uplift (rebound) was very great at the time of deglaciation but that it decelerated rapidly toward the present day. Because there are large gaps among some of the control points, the possibility exists that this uplift was, in fact, not a continuous phenomenon as the

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[2] Melhorn's (1959) estimate of 152 feet for the original level of Lake Stanley is not valid because he assumes no uplift whatsoever occurred between Lake Algonquin and Lake Stanley time.

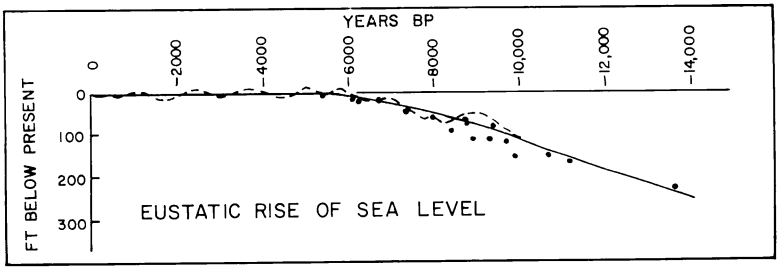

Fig. 4. Eustatic rise of sealevel in late glacial and postglacial time as interpreted by Godwin, Suggate, and Willis (1958, solid dots) and Fairbridge (1958, 1961, dashed curve). The present writer has used only the mean (solid) curve for this paper.

curves in figure 2 imply. Step-wise uplift movements are possible, as suggested by Flint (1957, p. 254-255), although the necessity for stable periods are by no means proven. For example, Hough (1958, p. 261) explains a mechanism by which the strong Nipissing beach—evidence of a stable period for Flint—could have been produced during continuing uplift. In either case, these curves apparently depict the *mean course* of postglacial rebound around the Lake Huron basin during the past 10,500 years.[3]

GREAT LAKES CHRONOLOGY

In light of these uplift curves certain other aspects of the history of the Great Lakes can be reconstructed. As previously discussed the extremely low Chippewa-Stanley stages are now known to have occurred about 9600 B.P. I have discussed elsewhere (Farrand, 1960) evidence for the contemporaneous Hougton low stage in the Lake Superior basin, but without the uplift curve for the controlling outlet at Sault Ste. Marie it was not possible to determine the original water level of the Houghton stage. Now, figure 2 shows that the Sault was about 260 feet lower, or about 340 feet above sealevel, at 9600 B.P. Therefore, the Houghton low stage was originally about 340 feet above sealevel and was separated from Lake Stanley in the Huron basin by the ancestral St. Mary's River which descended 160 feet, probably through a series of falls and rapids.

As North Bay was uplifted, lake waters rose and again flooded the Sault area, bringing the lakes in the Superior and Huron basins to a confluent level. The final emergence of the bedrock barrier at Sault Ste. Marie has occurred since the Algoma stage (3200 B.P.). The Algoma water level was controlled by the outlet at Port Huron at about 595 feet above sealevel. Since 3200 B.P. the

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[3] Confirmatory evidence of the shape of these curves comes from the Mackinac City, Michigan, area where logs have been buried by shore sediments during the rise of water level to the Nipissing beach. Their average date is 5460 ± 425 B.P. (M-855, J. B. Griffin, personal communication). The logs were found 16 feet above present lake level (or 597 feet above sealevel) and the Nipissing beach at Mackinac City is 629 feet above sealevel. The apparent 32-foot rise in water level is not the total rise, however, because the land was also rising at this place. Mackinac City lies nearly on the same isobase as Cape Rich, where about 14 feet of uplift occurred between 5460 and 4200 B.P. (fig. 2). Therefore, the total rise was 32 plus 14 feet, or 46 feet. This total rise of water level should be equal to the uplift of the controlling outlet at North Bay. And, from the North Bay curve (fig. 2) we see that about 48 feet of uplift occurred there between 5460 and 4200 B.P.

TABLE 3

Comparative uplift of Post-Algonquin beaches

	Lake Algonquin		Wyebridge Stage			Penetang Stage			Payette Stage		
	orig. 605 ft		orig. 540 ft		% post-Algonquin uplift	orig. 510 ft		% post-Algonquin uplift	orig. 465 ft		% post-Algonquin uplift
Area	now	uplift	now	uplift		now	uplift		now	uplift	
Giants' Tomb Island	875	270	785	245	91	748	238	88	686	221	82
Mackinac Island	812	207	722	182	88*	—	—	—	—	—	—
Sault Ste. Marie	1015	410	935	395	96	880	370	90	785	320	78
Little Current (Manitoulin I.)	1013	408	918	378	93	870?	360	88	782	317	78
Cape Rich	801	196	718	178	92	684	174	89	624	159	81
Averages			—	—	93	—	—	89	—	—	80

* Perhaps miscorrelated by Hough (1958) and should apply to Penetang stage.
Data are from Hough (1958) and Stanley (1936, 1937).

Port Huron outlet has been cut down to 580 feet, its present level. During this same period of time the Sault has risen from 577 to 602 feet (fig. 2). If the rate of downcutting at Port Huron is plotted linearly against the uplift curve for Sault Ste. Marie (taken from fig. 2)—this is obviously a simplification—the curves (fig. 3) cross at about 2200 B.P. (250 B.C.), which is the approximate date of final separation of Lakes Superior and Huron. Lake level was about 591 feet above sealevel at the moment of separation.

The rapid rate of uplift between 10,500 and 9600 B.P. implies that the several lake stages which occurred in that interval were quite short-lived. Six or more such stages are known from the Lake Huron basin (Hough, 1958) and sixteen to eighteen shorelines occur between the Lake Duluth and Houghton stages in the Superior basin (Farrand, 1960). The average duration of these stages apparently was between 50 and 150 years, and, as would be expected, these shorelines are rarely strongly developed and entirely absent in many places.

UPLIFT IN ARCTIC CANADA

In Arctic Canada many emerged marine features have long been recognized as indicators of relative changes of land and sea. However, until the advent of radiocarbon dating the age (interglacial, glacial, or postglacial) and nature (eustatic or isostatic) of the features were debated. Washburn (1947, p. 58-59) presents a strong case for postglacial isostatic emergence to account for raised beaches 200 or 300 feet above present sealevel throughout the northwestern part of the Arctic archipelago, but he does not suggest the age of this glaciation. Craig and Fyles (1960) suggest that raised marine features on the westernmost Queen Elizabeth Islands are possibly pre-Wisconsin (?). It is now obvious that most, perhaps all, of these marine features are late-Wisconsin or post-Wisconsin in age and, therefore, related to isostatic movements, because eustatic changes of the sea to elevations several hundred feet above the present are unknown along these stable coasts in post-Wisconsin time.

These features—marine strandlines and terraces, marine fossils, limits of wave action as determined by perched boulders, etc.—occur as high as 875 feet above sealevel and are commonly 500 to 700 feet in elevation. They have long defied correlation (but see Craig and Fyles, 1960, fig. 5) because they lack diagnostic fossils, and the relatively few observations are widely scattered through a vast and little explored territory. Elevation alone is not a sufficient criterion because of past sealevel fluctuations and because different areas were deglaciated at different times. However, with C-14 dates, we can begin gross correlation and, furthermore, analysis of uplift rates in a manner similar to that applied to the Great Lakes sheds additional light on the nature of these features and their relationship to the Wisconsin ice sheet.

A number of radiocarbon dates are now available from the Arctic (Craig and Fyles, 1960; Terasmae and Hughes, 1960), but there are relatively few localities from which we have a *series* of dates on marine features. Seven series of from two to eight dates each have been considered here and the results are plotted in figures 5 through 9.

Table 4

Dated marine features in Arctic Canada

For locations refer to Figure 1.

Location	Feature	C-14 Date	Strand Line Elev. (ft)			Lab No. and Reference	
			Observed	S.L. Corr'n	Corr. Elev.		
			A. James Bay				
Missinaibi R.	marine shells	7875±200	400-500	45	445-545	I(GSC)14	Lee, 1960
Opasatika R.	marine shells	7280± 80	400-500	30	430-530	GRO-1698	" "
Gt. Whale R.	wood in marine silt	3150± 50	90	0	90	L-441A	Lee, Eade, & Heywood, 1959
Ft. George	wood in stony silt	3700±130	175-190	0	175-190	L-433A	
			B. Keewatin Ice Divide				
Carr Lake	marine shells	6975±250	560	22	582	I(GSC)8	Lee, 1959
			C. Southampton Island				
Southampton Island	marine strands	5600±300	170	0	170	S-12	McCallum, 1955
	marine strands	3670±290	105	0	105	S-13	" "
	eskimo site	2060±200	45-60	0	45-60	P-62	Collins, 1956
	burned bone	2508±130	70	0	70	P-75	Rainey & Ralph (1959)
	burned bone	2191±120	40	0	40	P-77	" " "
	burned bone	2632±128	70	0	70	P-76	" " "
	burned bone	2183±122	70	0	70	P-74	" " "
			D. Somerset & Prince of Wales Islands				
Somerset I.	marine shells	7150±350	100	26	126	L-571A	J. B. Bird, unpub.
Prince of Wales I.	marine shells	9200±160	370	85	455	L-571B	" " " "

TABLE 4 (Continued)

Location	Feature	C-14 Date	Strand Line Elev. (ft)			Lab No. and Reference	
			Observed	S.L. Corr'n	Corr. Elev.		
			E. Melville Peninsula				
Igloolik	eskimo site	3700±150	172	0	172	K-505	Tauber, 1960
	eskimo site	600±150	26	0	26	K-504	" "
	ivory	3958±168	165	0	165	P-207	Rainey & Ralph (1959)
	antler	3560±123	165	0	165	P-208	" " "
	ivory	3906±133	165	0	165	P-209	" " "
	antler	2898±136	145	0	145	P-210	" " "
	antler	2354±135	80	0	80	P-211	" " "
	antler	2404±137	70	0	73	P-212	" " "
	ivory	2910±129	70	0	73	P-213	" " "
			F. Coronation Gulf				
	marine shells	9100±180	495+	80	575+	I(GSC)16	Craig & Fyles, 1960
	shore deposits	8290±330	320	54	374	I(GSC)13	" " "
			G. Northwest Victoria Island				
	marine shells	12,400±320	230	200	430	I(GSC)18	Craig & Fyles, 1960
	marine shells	8895±220	25	75	100	I(GSC)20	" " "
			H. Ellesmere Island				
northern coast	spruce wood	980±100	20	0	20	L261A	Crary, 1960
	spruce wood	2190±150	23	0	23	L261B	" "
	tamarack wood	6050±200	100	5	105	L261C	" "
	marine shells	7200±200	125	26	151	L248A	" "
	marine shells	7200±250	200	26	226	L248B	" "

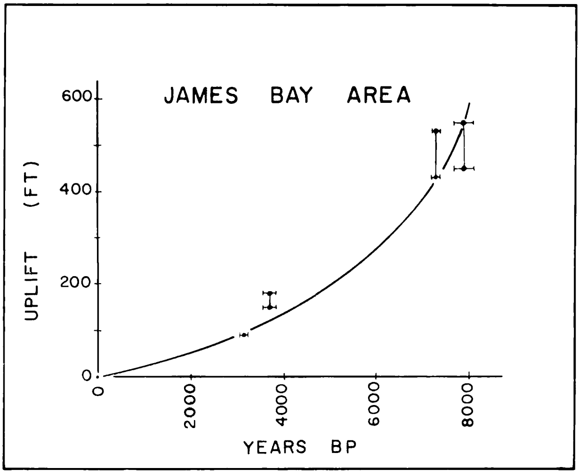

Fig. 5. Postglacial uplift in James Bay area plotted as total uplift since a given time. Horizontal brackets indicate one standard deviation for C-14 datings. Vertical brackets indicate uncertainty of former sealevel position relative to the dated feature. For source of data, see table 4.

The Arctic uplift curves are based on radiocarbon-dated marine features (table 4), some of which involve assumptions in order to approximate the sea level at the time of their formation or deposition. In all cases, I have taken the sealevel value assumed by the original investigator.

Eustatic changes of sealevel that were contemporaneous with this postglacial uplift must also be considered. The dated marine features used in this analysis must obviously be related to sealevel of the time at which they formed (not present-day sealevel) if we are to deduce the total uplift. Recent compilations of sealevel rise by Godwin, Suggate, and Willis (1958) and by Fairbridge (1958, 1961) have been plotted in figure 4. Both interpretations agree very well in generalities, although the second-order fluctuations suggested by Fairbridge (dashed curve) seem perhaps too exact for this stage in our knowledge. For the purpose of this paper I have drawn a mean line (solid)

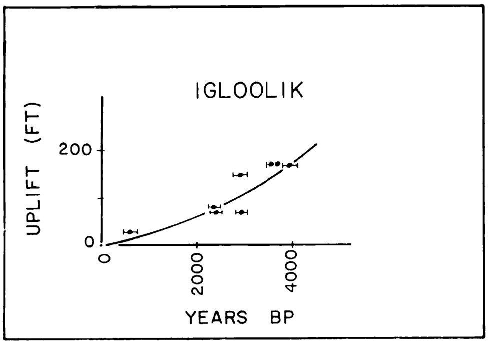

Fig. 6. Postglacial uplift near Igloolik, northern Foxe Basin, Canada. Dated features are prehistoric sites occupied near former sealevel. Conventions as in figure 5.

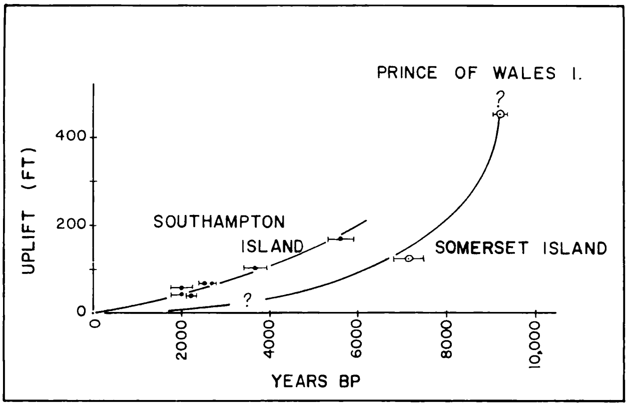

Fig. 7. Postglacial uplift of Southampton Island and the Prince of Wales-Somerset Island area. Conventions as in figure 5.

through Godwin's and Fairbridge's data for the period prior to 5500 B.P. For the period since 5500 B.P. I have used no eustatic correction. Thus, the present elevation of a raised marine feature *plus* the eustatic correction from figure 4 gives the total uplift of that feature since it formed.

A short description is necessary for the individual curves in figures 5 through 9. The basic data for these curves is given in table 4 and the locations are shown on figure 1. The limits of one standard deviation for the C-14 date are shown by the short horizontal lines; the vertical range of uncertainty in estimation of sealevel as given in table 4 is shown by short vertical lines.

The four features from the James Bay area (fig. 5) have a wider geographic scatter than the data of any other curve, but they lie in a central area with respect to the former ice sheet and were probably deglaciated essentially at one time. Only the wood from stony silt near Fort George does not lie on

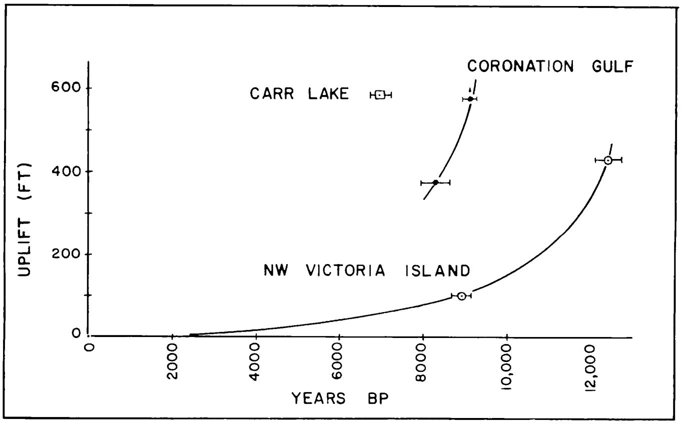

Fig. 8. Postglacial uplift at Carr Lake on Keewatin Ice Divide; Coronation Gulf, N.W.T.; and northwestern Victoria Island. Conventions as in figure 5.

the curve as drawn; perhaps the implications of that specimen need to be reexamined.

The information from Igloolik (fig. 6) is derived from prehistoric Eskimo sites which are believed to have been very near the seashore of their time, but above high tide (Meldgaard, 1960). Only one point out of eight lies significantly below the mean curve.

In figure 7, the data for Southampton Island comes partly from marine strands and partly from Eskimo sites. The internal consistency is quite good. For Prince of Wales and Somerset Islands there is one date each. Although these neighboring islands should be expected to have very similar rebound histories, the simplest curve drawn through these two points and the zero coordinate is slightly discordant in detail with the curves grouped in figure 10, from which it has been omitted for the sake of clarity. However, it does definitely agree with the general pattern.

As only two points on a rather steep portion of the Coronation Gulf curve (fig. 8) are available, it is probably not wise to continue that curve downwards at the present time. Older marine shells from Coronation Gulf dated 10.215 and 10.530 B.P. occur in bottom clay related to a much higher but unspecified strand (Craig, 1960). The record from northwestern Victoria Island is the longest from either Arctic Canada or the Great Lakes; yet it gives the same pattern of decreasing uplift. Only one dated marine feature is available from the Carr Lake area on the Keewatin Ice Divide (Craig and Fyles, 1960). It is included here simply to indicate the order of magnitude of the uplift in that central region.

Northernmost Ellesmere Island (fig. 9) is far removed from the main "centers" of the Wisconsin Laurentide ice sheet, but three of the four dated features there give a curve very similar to those from lower latitudes. The two 7200 B.P. dates for strandlines 75 feet apart vertically cannot obviously both be correct. The 125-foot strand dated 7200 B.P. is favored because it gives a curve more in accord with all other curves presented in this paper. Shells of younger age might have been blown by strong arctic winds onto the upper (200-foot) beach after it was abandoned by the sea.

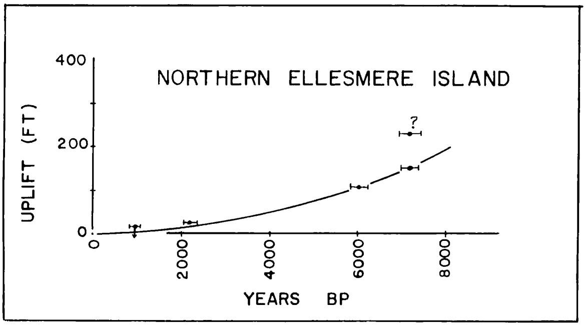

Fig. 9. Postglacial uplift of northernmost Ellesmere Island. Conventions as in figure 5. Of the two features which dated 7200 B.P. the lower one, 125 feet uplift, appears more conformable with the other data.

INTERPRETATION

The individual curves of figures 5 through 9 have been grouped for comparison with the Great Lakes curves in figure 10. Only the Prince of Wales-Somerset Island curve (fig. 6) has been omitted. The fact that all these curves nest together conformably seems to indicate a systematic relationship. Although the phenomenon of glacio-isostatic rebound is now widely accepted (Flint, 1957, chap. 14), the relationships shown by these curves strengthen it further.

In the first place, areas more centrally located, with respect to the Wisconsin continental ice cover in North America, show their most intensive uplift later than do the more peripheral areas. This most intense uplift is nearly coincident with the time of deglaciation in a given place. For example, at North Bay the uplift curve (A in fig. 10) is nearly vertical between 10,500 and 10,000 B.P., immediately *prior* to the actual moment of removal of the ice sheet (ca. 9600 B.P.). In the Coronation Gulf area, deglaciation must have taken place prior to 10,530 B.P., perhaps immediately prior to that date; and the uplift curve (no. 5 in fig. 10), although limited in length, shows rapid uplift between 10,000 and 9000 B.P. We know that the James Bay area was ice-free by 7875 B.P. (I-GSC-14, Terasmae and Hughes, 1960), a date from marine shells along the Missinaibi River, but not before about 9000 B.P., an estimate relative to the opening of the North Bay outlet at about 9600 B.P. The steepest part of the James Bay curve (no. 3 in fig. 10) would lie about 8500 to 8000 B.P., essentially coincident with deglaciation. Although only one date is avail-

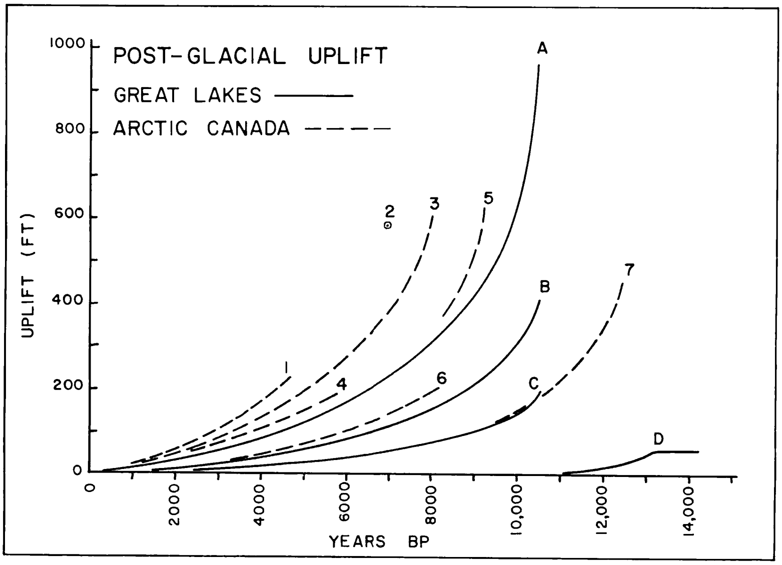

Fig. 10. Composite of all uplift curves discussed in this paper (except Prince of Wales-Somerset Island). Control is not shown for the sake of clarity. Solid curves are from Lake Huron (fig. 2); dashed curves are from Arctic Canada (figs. 5 through 9). A—North Bay, B—Sault Ste. Marie, C—Cape Rich, D—Port Huron, 1—Igloolik, 2—Carr Lake, 3—James Bay, 4—Southampton Island, 5—Coronation Gulf, 6—northern Ellesmere Island, 7—northwest Victoria Island.

able from the Keewatin Ice Divide (Carr Lake), its position (no. 2) in figure 10 suggests intensive uplift around 7000 B.P., the approximate time at which that area was freed from ice (Lee, 1959). Moreover, the historic rate of uplift at Churchill, Manitoba, near the Keewatin Ice Divide, is approximately 3 feet per century (Bird, 1959; not plotted in figure 10) which nearly coincides with the Igloolik curve and might also be considered a logical extension of the Carr Lake date.

The second relationship that appears in figure 10 is that all of these curves, in so far as they are known, can be drawn with essentially the same form,[4] but they are simply displaced in time as a function of time of deglaciation. In the Great Lakes area we know that the three localities best documented lay at least 250 miles inside the Wisconsin border. The overlying thickness of Wisconsin ice was probably nearly the same at Cape Rich, Sault Ste. Marie, and North Bay and was perhaps 10,000 feet thick—both conclusions by analogy with the present Greenland and Antarctic ice sheets in light of Nye's (1959) theoretical conclusion that the thickness of an ice sheet is only very slightly dependent on its accumulation (i.e., climatic) regime. It is plausible that a similar thickness of ice overlay James Bay, the Keewatin Ice Divide, Southampton Island, Igloolik, and Coronation Gulf. Therefore, it is unlikely that the curves in figure 10 reflect differential ice thickness at the various localities. Rather, the curves are interpreted as showing nearly identical isostatic response to nearly identical ice loads, but—as mentioned before—displaced in time.

Some important corollaries follow from this second relationship. (1) Ice loads of this same magnitude (around 10,000 ft. more or less) probably covered northwestern Victoria Island and northernmost Ellesmere Island, although both of these areas are very close to the "Wisconsin" ice border shown by Craig and Fyles (1960). It is quite possible, therefore, that the Wisconsin ice cover lay farther north and northwest than Craig and Fyles have drawn it, perhaps coinciding with their area of "pre-Wisconsin (?)" glaciation. (2) If the Wisconsin ice sheet reached or approximated a state of isostasy, then the major part of isostatic recovery upon removal of the ice load took place in a given locality before complete deglaciation of that locality. Unfortunately we know nothing of the rate of this earlier uplift. With an ice load of about 10,000 feet, there should have been approximately 3000 to 3300 feet of subsidence and recovery—the ratio of densities of glacier ice to average rock being about 1:3. Yet less than 1000 feet of recovery is recorded at any place, and the uplift curves indicate that uplift has slowed considerably and that the preglacial position has nearly been reached. Perhaps isostasy was not achieved by the Wisconsin ice sheet, although the ice sheet covered peripheral areas such as the St. Lawrence valley, apparently without a break, for 40,000 to 50,000 years (Gadd, 1960).

Isostatic recovery may be plotted as in figure 11 to show in a rough, schematic way the nature of crustal rebound. The dates and amounts of uplift are taken directly from figure 10, and the geographic (horizontal) axis has

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[4] Uplift curves of the same general form, i.e., showing a strong decrease in rate of uplift with time, have been constructed for central Spitsbergen (Feyling-Hanssen and Olsson, 1959) and for the coast of Maine (Bloom, 1959, 1960).

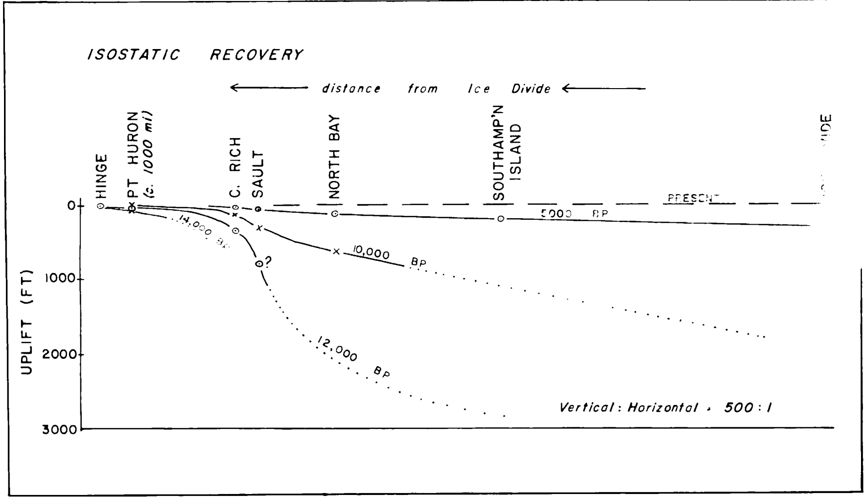

Fig. 11. Schematic representation of isostatic recovery as interpreted from uplift curves in figure 10, assuming the Wisconsin ice sheet was in complete isostatic adjustment and depressed the crust approximately 3000 feet. The approximate horizontal scale is distance from a given station to the nearest ice divide, either in Labrador (Schefferville) or in Keewatin. The dotted portions of each curve have no control whatsoever.

been arranged with respect to distance from a line connecting the Keewatin (Lee, 1959) and Labrador (Ives, 1960) ice divides across the center of Hudson Bay. (The Hudson Bay area holds the record for the greatest recorded post-Wisconsin rebound, about 900 feet at Richmond Gulf, and is perhaps the true "center" of the Wisconsin ice sheet. The Keewatin and Labrador ice divides mark the position of the last remnants of the Wisconsin ice sheet and are interpreted here as roughly the limits of this Hudson Bay ice center.) The distances between points around Lake Huron were measured orthogonally to known isobases in that region. The solid lines have a factual basis, but the dotted extrapolations have no control. This construction assumes complete isostatic compensation of an ice sheet 10,000 feet thick, resulting in about 3000 feet of subsidence.

It should be noted that the horizontal scale does not extend to the margin of the Wisconsin ice sheet, rather it stops some 200 miles short of the margin, acknowledging the fact that we know almost nothing of subsidence or rebound in this extreme peripheral fringe. Therefore, figure 11 shows a radial line through the central essentially uniformly thick portion of the Wisconsin ice sheet. Although this scheme for isostatic recovery is strictly a first approximation, it supports the idealized concept of Flint (1957, fig. 14-7) and differs from Lougee's concept (1953, fig. 3) by the absence of sharp "hinge lines."

SUMMARY

In conclusion, the radiocarbon-dated uplift curves presented in this paper show:

1) a rapidly decreasing rate of postglacial uplift in a given locality immediately following deglaciation of that locality;

2) similar curves from all localities, but these curves are displaced in time. This displacement is correlated with the pattern of deglaciation;

3) an ice cover over Victoria Island and northern Ellesmere Island comparable in thickness to that over the Great Lakes; and

4) that the major part of total isostatic adjustment occurred before complete disappearance of the ice sheet from a given locality.

The scheme presented here requires additional testing which should be forthcoming soon. Numerous geological and geographical expeditions in Arctic Canada are, among other things, observing features of marine submergence and collecting materials for radiocarbon dating. These additional data will either verify this interpretation of uplift or show that the data presented in this paper are not a fair sample. However, it seems significant that all the data available at the time of this writing are concordant with the interpretation offered here.

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