Radiocarbon dating with accelerator mass spectrometry: results from Ellesmere Island, District of Franklin

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Abstract

Radiocarbon dating by means of accelerator mass spectrometry (AMS) has two great advantages over conventional dating: 1) much smaller samples can be handled and 2) counting time is significantly shorter. Three examples are given for Holocene-age material from east-central Ellesmere Island. The results demonstrate the potential use of this technique as a powerful research tool in studies of Quaternary chronology. Individual fragments of marine shells as small as 0.1 g have been dated successfully at the IsoTrace Laboratory, University of Toronto. In the case of an aquatic moss from a lake sediment core, an increment 0.5 cm thick could be used instead of a 5 cm-thick slice, thus allowing a much more precise estimate of the onset of organic sedimentation.

Résumé

La datation par le carbone radioactif exécutée au moyen d'un spectromètre de masse accélérateur (AMS), comparée à la méthode classique, présente deux avantages marqués. Premièrement, elle peut s'éxécuter sur des échantillons beaucoup plus petits. Deuxièmement, le temps de comptage est beaucoup plus court. L'auteur démontre ces phéomènes à l'aide de trois datations faites sur des échantillons de l'Holocène recueillis dans le centre-est de l'île Ellesmere. Les résultats établissent que cette technique peut constituer un outil de recherche puissant dans l'étude de la chronologie du Quaternaire. Des fragments de coquilles marines pas plus grosses que 0,1 g ont pu être datés avec succès au laboratoire IsoTrace de l'Université de Toronto. Dans le cas d'une mousse aquatique provenant d'une carotte de sédiment lacustre, on a pu utiliser une constante de progression de 0,5 cm au lieu d'une épaisseur de 5 cm; cette mesure a permis de dater avec beaucoup plus de précision le début de la sédimentation organique.

Introduction

The advent of radiocarbon dating by means of accelerator mass spectrometry (AMS) has opened up many new possibilities for refining the chronology of events during the last 40 000 to 50 000 years. Already a considerable body of literature devoted to AMS has come into existence, and several international conferences have been held since 1978. The development of this method has been described by Muller (1977), who used a cyclotron rather than a Van de Graaf accelerator, and by Bennett et al. (1977), Nelson et al. (1977), Doucas et al. (1978), and Stuiver (1978). For a recent review of accelerators and dating the reader is referred to Possnert and Olsson (1984).

A number of early reports suggested that ages beyond the limits attainable by decay counting in conventional proportional or scintillation counters were to be expected, and a figure of 100 000 years appeared in a number of articles (e.g., Gribbin, 1979). In the proceedings of the first conference devoted to dating with accelerators, Haynes (1978) listed one of the advantages of AMS to be the "extension of the datable time range to approximately 90 000 B.P. or twice the conventional range of 45 000 B.P.". It seems clear, however, that the greatest advantages of AMS, at least initially, are: 1) that extremely small samples (milligrams instead of grams) can be accommodated and 2) that the counting time required is much shorter.

This report discusses three examples of the promising results that can be expected by means of AMS. The conventional age determinations reported here were carried out in the Radiocarbon Dating Laboratory at the Geological Survey of Canada, where two proportional counters are in operation (Dyck, 1967; Lowdon, 1985). The accelerator dates were obtained from the IsoTrace Laboratory, University of Toronto, where the machine in use is one of six around the world that have been manufactured by General Ionex Corporation, Newburyport, Massachussetts (Litherland, 1984). The AMS results constitute part of a series of 'Crown' samples, whose ages have been determined as one 'task' under a developmental contract, funded in part by the Department of Energy, Mines and Resources.

This report is Contribution No. 22 from the Cape Herschel project.

Sample descriptions and results

Over the last few years my field work has been concentrated in east-central Ellesmere Island, especially in the narrow ice-free coastal zone along Smith Sound, and along the opposite shore in Inglefield Land, Greenland (Fig. 50.1). The main research objective has been to attempt to decipher the glacial history, in particular to determine when glacier ice last flowed southward from Kane Basin through Smith Sound toward Baffin Bay. Raised marine deposits, which normally constitute a major source of datable material, are relatively scarce because of the rugged fiord terrane. Likewise, there are considerable expanses of bare rock and felsenmeer, hence a major effort has been devoted to coring pond and lake sediments as a way of obtaining chronological information (Blake, 1978, 1981, 1982a; Smol, 1983; Hyvärinen, 1985).

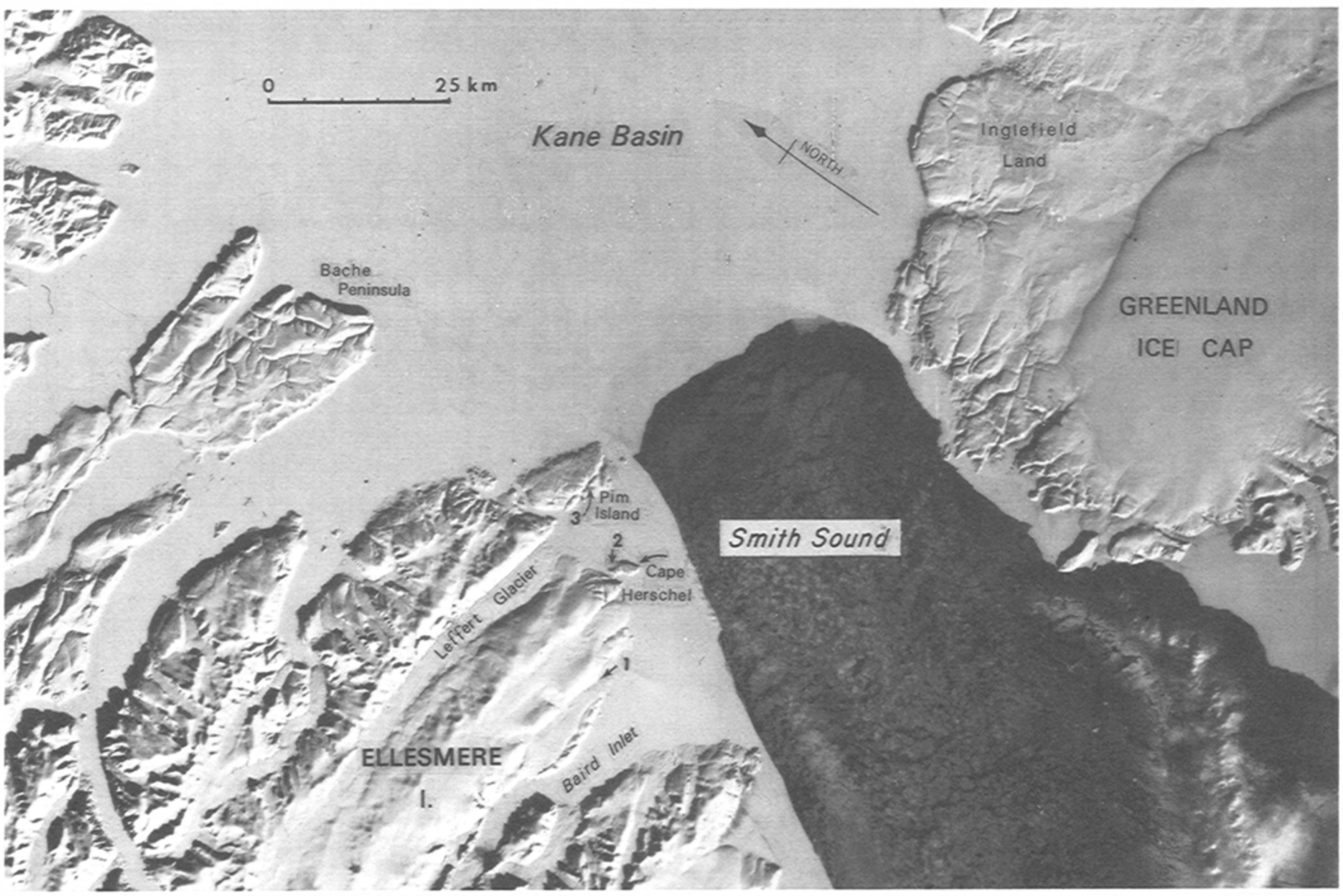

Figure 50.1. *LANDSAT image showing Smith Sound and southern Kane Basin. Numerals refer to sites discussed in the text: 1 - MacMillan Glacier; 2 - north side of Cape Herschel; 3 - Proteus Lake. The image shows the development of the 'North Water' on April 4, 1973 (image E-10255-18054, spectral band 7).*

Although raised beaches are rare, the presence of shelly till in lateral moraines indicates that fiord-bottom sediments have been picked up and incorporated into the basal ice by advancing outlet glaciers from the Central Ellesmere Island Icecap. In the field area the most striking example of this phenomenon encountered up to now is on the south side of Leffert Glacier (Fig. 50.1). Abundant mollusc shells and crustose coralline algae in an ice-cored lateral moraine along a nunatak are as young as 2280 ± 140 years (GSC-3515; Blake, 1984a, b), and they are located more than 6 km behind the present position of the glacier snout. At an elevation of 160 to 180 m the shells are well above the highest dated molluscs of Holocene age, which occur at approximately 105 m a.s.l. The presence of these shells in the lateral moraine means that approximately 2000 radiocarbon years ago the snout of Leffert Glacier was at least 7 km west of its present position.

To the south of Leffert Glacier is another outlet tongue, MacMillan Glacier (Fig. 50.1), and in 1983 and 1984 marine shells were collected from the surface and side of a small terrace adjacent to a stream flowing along the north side of the glacier (Fig. 50.2). The site is 2.7 km west of the nearest bay of Baird Inlet at an elevation of approximately 145 m a.s.l., as determined by repeated measurements with a surveying altimeter. As this terrace was close to being at the same elevation as a perched delta near Cape Herschel, there was a chance that the shells might date from the initial incursion of the sea in early Holocene time.

The first determination, on **Hiatella arctica** shells excavated from the till-like material and sand comprising the terrace, as well as from the adjacent stream channel, gave an age of 25 700 ± 890 BP (GSC-3897). This somewhat surprising age, representing a time when it could be expected that the coastal fringe of bare ground was inundated by glacier ice, suggested that the fragments comprising the dated sample might have been derived from different sources. The field situation was such that shells in till could readily have become mixed with shells of Holocene age, and **Hiatella arctica** is a particularly robust species, one which commonly occurs in till in eastern Ellesmere Island and elsewhere in the Arctic.

For this reason a second sample, consisting of a single barnacle fragment (**Balanus balanus**), and weighing only 0.35 g, was submitted to the IsoTrace Laboratory. The age of a portion of this fragment, weighing 64.0 mg after pretreatment, was determined to be 7640 ± 60 BP (TO-71; Table 50.1). This result demonstrates that Holocene shells are indeed present in the terrace adjacent to MacMillan Glacier. Because the sample is well above the elevation at which materials of this age might be expected, based on several dated samples near Cape Herschel and in Alexandra Fiord (Blake, 1978, 1982a, b), we can conclude that fiord-bottom sediments were dragged or ploughed upward as MacMillan Glacier advanced. The ice-marginal stream later reworked the fiord-bottom material, so that the terrace today includes both till, or colluviated till, and patches of washed sediment. We can conclude further that at the time the barnacles were living the front of MacMillan Glacier was several kilometres west of its present position.

The second dated site is near our base station on Cape Herschel peninsula. A small pond ('Moraine Pond') is held up by a moraine ridge along the north slope of the peninsula (Fig. 50.3). Abundant marine shells and shell fragments are present on the ground surface at the western end of the pond. They are presumed to derive by slope wash from marine sediments slightly higher up the slope, and some may have been brought to the surface by frost action. Two small pockets of raised beach occur above the level of the pond,

Figure 50.2. *Aerial view eastward from MacMillan Glacier along the north side of Baird Inlet, July 9, 1984. The shell collection site is indicated by the arrow. 201464-O*

Table 50.1. Radiocarbon age determinations, east-central Ellesmere Island

Sample elevation m a.s.l.	Dated material[1]	Field sample No.	Laboratory dating No.[3]	$\delta^{13}C$ ‰	Age (Corrected for $\delta^{13}C$)[4,5]	Sample weight (g)	Sample weight (mg)	Counter (L)	Pressure (atm)	Counting time (days)[6]	Comments
145	**Hiatella arctica**	83-BS-289+ 84-BS-160	GSC- 3897	+0.7	25 700 ± 890	6.7	-	2	2	4	10% HCl leach; mixed with dead gas for counting; aragonitic.
145	**Balanus balanus**	83-BS-289+ 84-BS-160	TO - 71		7 640 ± 60	-	268.2				>20% HCl leach; 64.0 mg after pretreatment; 3 targets counted; calcitic.
79.0	basal organic pond sediment[2]	BS-81-3 (1:406-414cm)	GSC- 3970	-25.9	7 300 ± 110	80.0 (dry)	-	2	2	3	NaOH leach omitted; slight reaction with HCl; some ice lenses; organic C content, 2.1-3.8%.
81.5-83.5	**Macoma calcarea**	BS-79-137+ BS-79-138	GSC- 2913	-0.5	8 190 ± 110	15.5	-	2	2	3	10% HCl leach; mixed with dead gas for counting; aragonitic.
78.0	**Clinocardium ciliatum**	BS-81-3 (1:532 cm)	TO - 115		8 510 ± 50	-	115.6				10% HCl leach; 104.0 mg after pretreatment; 2 targets counted.
390	aquatic moss	BS-79-27 (2:45-50cm)	GSC- 2934	-30.8	8 970 ± 190	5.0 (dry)	-	2	2	4	NaOH + HCl leaches + distilled water rinses; mixed with dead gas for counting.
390	aquatic moss	BS-81-30 (7:52.5-53.0cm)	TO - 111		9 370 ± 110		118.2				NaOH + HCl leaches + distilled water rinses; 21.2 mg after pretreatment; 2 targets counted.

1 Marine molluscs and cirripeds identified by W. Blake, Jr. The moss at the base of the cores from Pim Island has proved to be difficult to identify but is a member of the Amblystegiaceae (J.A. Janssens, personal communication, 1980).

2 Samples from 398.5-400.5 cm, 406-408 cm, and 413-414 cm all contain freshwater diatoms of the genus **Fragilaria**; freshwater diatoms were not found below this level in the core (unpublished GSC Diatom Report No. 84-8 by S. Lichti-Federovich).

3 Laboratory designations: GSC - Geological Survey of Canada; TO - IsoTrace Laboratory, University of Toronto.

4 All age determinations from the Radiocarbon Dating Laboratory, Geological Survey of Canada, are based on a ^{14}C half-life of 5568 ± 30 years and 0.95 of the activity of the NBS oxalic acid standard. Ages are quoted in conventional radiocarbon years before present (B.P.) where 'present' is taken to be 1950. All finite age determinations from this laboratory are based on the 2σ criterion; i.e., there is a 95% probability that the correct age in conventional radiocarbon years lies within the stated limits of error. $^{13}C/^{12}C$ ratios were determined at the Department of Earth Sciences, University of Waterloo, under the direction of P. Fritz and R.J. Drimmie. Relative to the PDB standard, it is GSC practice to normalize $\delta^{13}C$ values on terrestrial organic materials and bones of all types to -25.0 ‰, whereas marine shells are normalized to 0.0 ‰ (Lowdon and Blake, 1970).

5 At IsoTrace all samples are normalized to -25.0 ‰, and all quoted errors are 68.3% confidence limits. Preparation of the machine-ready sample causes the fractionation of the sample material to vary systematically from the top to the bottom of the target. The computer analysis program uses the $^{13}C/^{12}C$ ratio obtained during the measurement, which is the product of this fractionation and the natural fractionation of the sample, to correct the $^{14}C/^{12}C$ ratio appropriately. While this procedure yields a highly reliable result for the $^{14}C/^{12}C$ ratio, at no time during the measurement is a value of the natural fractionation alone obtained (see IsoTrace Laboratory, 1984 Annual Report, 84.12.31, Chapter II.2, p. 31-64, Radiocarbon Analysis, by R.P. Beukens).

6 At IsoTrace each target is given 7 to 8 runs, and each run takes 22 minutes.

Figure 50.3. *Aerial view southeastward over the Cape Herschel peninsula, with Inglefield Land, Greenland, in the distance. Location of 'Moraine Pond' is indicated by the arrow, July 12, 1979. 201464-P*

whose surface is at an elevation of 83.0 m (above the level of the ice foot, as determined by an instrumental survey). As fragments of such rugged pelecypod species as **Hiatella arctica, Mya truncata**, and **Astarte borealis** are abundant in till all over the Cape Herschel peninsula, only thin and fragile shells of **Macoma calcarea** were used for dating. The result, on a 15.5 g sample, was 8190 ± 110 BP (GSC-2913).

In May 1981 a core of frozen sediment 5.85 m long was recovered from this shallow pond. This core was the longest taken from any site in the area, either of frozen pond sediment or unfrozen sediment from larger lakes (Blake, 1981, 1982a). Fragments of **Macoma calcarea** and other marine shells were noticed in the cuttings brought to the surface when coring was under way, and their presence was the first indication that a marine sand had been penetrated. Later, in the laboratory, fragments of marine shells were recovered as selected increments of the core were melted (Fig. 50.4). A hinge fragment (115.6 mg) of **Clinocardium ciliatum**, like **Macoma calcarea** a fragile pelecypod, was extracted from the core at a depth of 532 cm. The age of this fragment, weighing only 104.0 mg after pretreatment, was determined to be 8510 ± 50 BP (TO-115; Table 50.1).

This date shows that the sea was able to penetrate to the north side of Cape Herschel peninsula a little earlier than had been indicated by the previous determination (GSC-2913; 8190 ± 110 BP). The value obtained for TO-115 also indicates that the upper part of the marine sand unit (the marine sand extends from 415 to 585 cm in the core) is presumably comparable in age to the unit from which the surface shells derive. The basal organic material in the core, from the interval 406 to 414 cm, is 7300 ± 110 years old (GSC-3970; Table 50.1).

Figure 50.4. *Detail of the* ***Clinocardium ciliatum*** *shell fragment in stony sand at 532 cm depth in the 1981 core (7.5 cm diameter) of frozen sediment from 'Moraine Pond' at Cape Herschel. 201464-J*

The third site is Proteus Lake on Pim Island (Fig. 50.1, 50.5). A sample of aquatic moss at the base of the 50 cm-thick organic sequence gave an age of 8970 ± 190 years (GSC-2934; Blake, 1981; Hyvärinen, 1985). To obtain this age determination by conventional decay counting, it was necessary to use a 5 cm-thick increment, i.e., the entire thickness of the basal moss layer in a core collected in June 1979. A certain amount of time was necessary for the moss layer to build up to a thickness such that it would compress to a thickness of 5 cm under the load of the overlying organic lake sediments. Hence, for the accelerator a 0.5 cm-thick slice (utilizing only the central part of a core taken in June 1981) provided 118.2 mg of dry moss from immediately above the grey inorganic sediment of which the bottom 37 cm of the core is composed (Fig. 50.6). The new age determination, 9370 ± 110 years (TO-111), on a sample weighing only 21.2 mg after pretreatment, provides a much closer approximation for the onset of organic accumulation in Proteus Lake. At the time of writing this date is the oldest obtained from the basal organic sediment in any pond or lake in east-central Ellesmere Island.

Figure 50.5. *Aerial view northeastward at Proteus Lake (elevation 390 m), Pim Island. The coring site was located in the northern part of the lake (approximate position indicated by the arrow). There is still only a moat of open water around the edges of the lake when the photograph was taken on July 19, 1983. 201464-R*

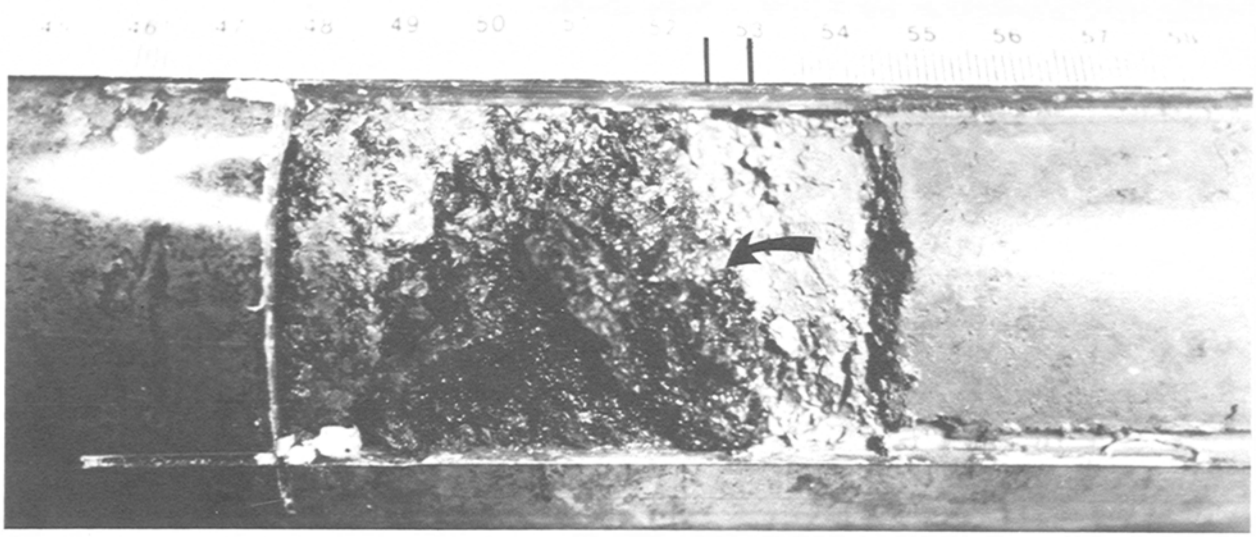

Figure 50.6. *Detail of the moss layer at the base of the organic sequence in Proteus Lake. Sample BS-81-30 (core 7) was taken on June 10, 1981 under 25 cm of snow, 286 cm of ice, and in a water depth of approximately 5 m. The increment from 52.5 to 53.0 cm depth (arrow) was used for radiocarbon age determination TO-111, 9370 ± 110 years. 201464-Q*

Summary

These three examples give an indication of the great promise of the AMS dating method. There are obviously many applications. For example, marine geologists will be able to obtain ages on milligram-sized samples of foraminifera extracted from ocean-bottom cores; archeologists will be able to date irreplaceable artifacts or miniscule pieces of charcoal; and Quaternary geologists will be able to utilize individual shells, twigs, needles, leaves, fecal pellets, or tiny bone samples.

The capability of dating small samples, as demonstrated in the case of the MacMillan Glacier shells reported here, will permit the elimination of the perennial problem of mixing materials of different ages. Much greater precision can be achieved in dating pollen peaks or zone boundaries in lake sediment cores, for it will now be possible to determine the age of an organic-rich sediment slice only a millimetre or two in thickness, instead of 5 cm or even 10 cm. By way of contrast, in the early days of radiocarbon dating, on occasion it was necessary to use much longer increments. For example, in an early palynological study of lake sediments in central Labrador – Nouveau Québec (Grayson, 1956), 30 cm-long increments of the basal sediment were required for dating, and the resultant dates, of Holocene age, still had error terms of several hundred years.

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