A note on the implications of two radiocarbon dated samples from Qaleragdlit imâ, South Greenland

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Two shell samples were collected from the zone of moraine of the 19th century ice advances. One sample, which came from marine sediments seen to have been overridden by the ice, was dated to 7570 B. P. This indicates that the area had been deglaciated since the early Holocene until the 18–19th centuries. The second sample, of shell bearing calcium carbonate concretions, gave a date of 4540 B. P. for a whole concretion. It's δC^{13} value suggests derivation either by subaerial precipitation of carbonate from groundwater and dissolved shells, or by submarine diagenesis from decayed organic matter. The latter mechanism is preferred and the date is considered to indicate a mid-Holocene age for the parent sediments. The reported widespread occurrence of the concretions in these moraines suggests that there was a major recession of the ice sheet in the mid-Holocene to well behind its present limits.

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There is evidence at many places in West Greenland that the ice sheet is overriding marine sediments, or has overridden them in the recent past, suggesting that there have been periods when the ice sheet was significantly smaller than at present. Weidick (1972) has listed this evidence, comprising marine fossils and fossiliferous concretions in the moraines of the nineteenth century and at the present ice margin. He suggests that although some may come from interglacial marine deposits, most derive probably from Holocene sediments. This phase of ice retreat he dates tentatively on indirect evidence to 6500 B.P. and after. The two radiocarbon dated samples from Qaleragdlit imâ in South Greenland provide information about this phase.

The field relations of the samples are shown in fig. 1. Sample A is from sparsely fossiliferous marine silts which lie apparently *in situ* 500 m behind the terminal moraines of the advances dated by Weidick (1963) at this locality to 1750 and 1890. Demonstrably the marine sediments have been overridden by the ice advances.

Sample B is from fossiliferous carbonate concretions which occur fairly abundantly in the tills of the moraines. Concretions, however, were not found in the sediments from which sample A came and the location of their parent sediments is unknown. Similar concretions have been described before from here and elsewhere along the adjacent ice margin north of Bredefjord in the moraines of the last century, including at nunataks up to 300 m above sea level (Weidick, 1963). Another significant erratic component of the tills is well rounded cobbles of sandstones identical lithologically with the Eriksfjord Formation (Allaart, 1973). This does not outcrop in the immediate vicinity and the erratics must come from fluvial gravels derived from a solid outcrop, both of which are now beneath the ice.

On the ridge between the main fjord and the tributary valley of Marraq the nineteenth century moraines appear to truncate an horizon, poorly defined by the lower limit of perched blocks, which probably marks the Holocene limit of marine transgression at 60–70 m above sea level.

The carbon isotope content of the samples was determined by the Geology Department, University of Birmingham (Shotton, Williams & Johnson, 1974).

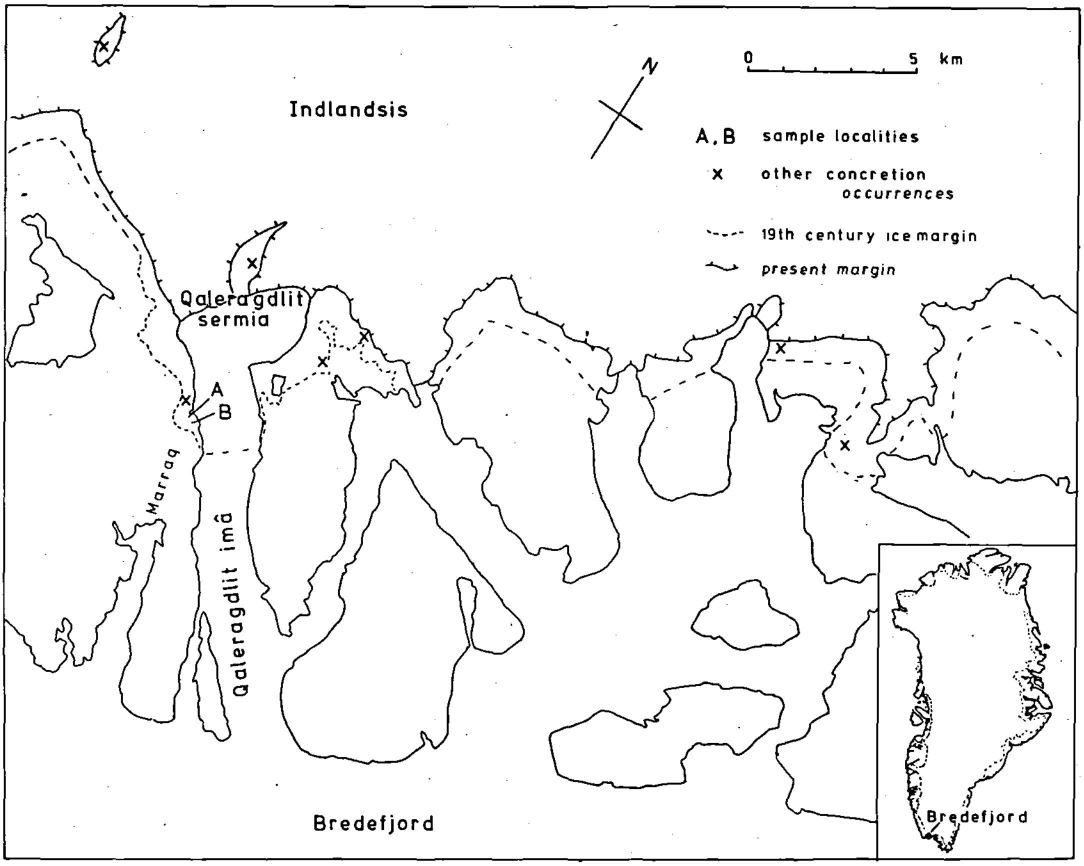

Fig. 1. Map of localities mentioned in the text. Details of the nineteenth century ice margin and the known distribution of concretions are from Weidick (1963).

Results and discussion

Sample A

Shell fragments of *Mya truncata* from the marine sediments gave a radio-carbon age for their inner fractions of 7570 ± 150 B.P. (table 1). This data is in the form usual for West Greenland radiocarbon shell dates and is not corrected for apparent fractionation relative to the wood standard (normalisation), unlike the values quoted by Shotton, Williams & Johnson (1974). If the depletion in C^{14} in the ocean due to circulation is the same as at present in the area, equivalent to 300–400 years (Krog & Tauber, 1974), then this effect cancels out that due to fractionation. The

Table 1. Carbon isotope data

Sample	Lab. No.	δ^{13}C ‰	δ^{14}C ‰	Date B. P.
A (shells)				
outer	Birm. 455	+ 0.80	—600.5	7370±150
middle	455	— 0.46	—593.2	7230±150
inner	455	— 0.27	—610.1	7570±150
B (concretion)	454	—15.64	—431.7	4540±130

The dates are not normalised or corrected in any way.

Table 2. Fossil faunas from Qaleragdlit Imâ

	Sample A (shells)	Sample B (concretions)
Cardium ciliatum		3*
Hiatella arctica	rare	6*
Macoma calcarea		1
Mya truncata	abundant	1?*
Mytilus edulis	frequent	8*
Pecten islandicus	frequent	
Serripes groenlandica	rare	
Gasteropoda		1
Balanus balanus	frequent	1*
Strongylocentrotus droebachiensis		*
Pisces		2

The figures are the number of individuals identified. Species recorded by Weidick (1963) from concretions along the Bredefjord ice margin are starred.

δC^{13} value is normal for shells of modern arctic molluscs (Keith, Anderson & Eichler, 1964; Andrews, 1973), implying the absence of major post depositional modification of the isotope ratios.

The composition of the fauna (table 2) is consistent with this date when compared with the numerous dated faunas from West Greenland. It represents a mixing of infaunal and epifaunal benthos from different habitats. The faunal diversity and the particular occurrence of *Mytilus edulis* suggests that the ice margin was sufficiently far away not to be contributing too much silt so as to inhibit growth.

It is clear that the original deglaciation of the site must have been before 7570 B.P. and that the marine limit, which itself may be synchronous with deglaciation, is at least as old as this date. Little is known about the early history of deglaciation in the Julianehåb district, except that the marine limit at Narssaq (35 km away) is older than 9410 B.P. (Weidick, pers. comm.).

Sample B

The concretions are more or less elongate and flattened ovoids in shape, typically 5 × 3 × 1 cm in size. Many are associated with a large skeletal fragment belonging to a variety of organisms (table 2). Although the fauna is somewhat different to that of sample A it could still be a Holocene assemblage. Thin sections showed the concretions to be made of microcrystalline calcite enclosing detrital silt grains. There was no textural evidence in those examined that the shell material had undergone any diagenetic recrystallisation.

Similar concretions are found in situ in uplifted Holocene marine sediments at several places in West Greenland. The stage at which such concretions form is not known, with the possibilities ranging from submarine early diagenetic formation, e. g. due to an increase in the dissolved bicarbonate in interstitial waters associated with anaerobic bacterial oxidation (Presley & Kaplan, 1968) or via the reduction of CO_2 by ammonia produced by decomposition (Berner, 1968a); to subaerial diagenesis by freshwater after uplift, as is the case with many limestone cements (Friedman, 1964).

The stable carbon isotope content of a concretion has been used as a clue to the source of the carbon and hence to its mode of formation (e. g. Hodgson, 1966). The two broad categories of sources possible here are given below with the δC^{13} values (in brackets) of the likely individual sources taken from Degens (1969) (1σ range), unless otherwise stated.

(a) *material deposited with the sediment* i. e. dissolved skeletal carbonate (+ 4.2 to — 1.7 $^{0}/_{00}$) (Keith, Andrews & Eichler, 1964); or decomposed marine organic matter (invertebrate and vertebrate tissue — 11 to — 18 $^{0}/_{00}$, plankton — 18 to — 28 $^{0}/_{00}$ depending on temperature); or decomposed derived terrestrial material (— 23 to — 27 $^{0}/_{00}$). Whilst direct aerobic or anaerobic bacterial oxidation produces dissolved CO_2 with δC^{13} close to that of the parent organic matter, derivation via fermentation or via the action of methane bacteria involves major isotopic fractionation, greatly increasing the possible δC^{13} range of an ultimate aqueous CO_2 precursor to precipitated carbonate (e. g. $<$ — 80 to 0 $^{0}/_{00}$, Cheney & Jensen, 1965; Hoefs, 1970).

(b) *material post depositionally introduced by fresh groundwater* i. e. dissolved atmospheric CO_2 (— 9 $^{0}/_{00}$) and CO_2 derived from plant respiration and soil humus decay (— 24 to — 25 $^{0}/_{00}$, Hendy, 1971). At least in temperate climates groundwater CO_2 is initially in equilibrium with the latter source. However, solu-

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tion of skeletal carbonate (+ 4.2 to — 1.7 ‰) from the sediment could lead to dissolved carbon species with intermediate δC^{13} values dependent on the nature of the system (Hendy, 1971).

All the figures given refer to aqueous CO_2, the solid carbonate formed indirectly from this should be enriched in C^{13} by about 10 ‰ (Emrich, Ehhalt & Vogel, 1970).

Although the original work on carbon isotopes in concretions related the C^{13} content to the depositional environment of the host sediment, i. e. marine or freshwater (Weber et al, 1964), the later work has shown that the diagenetic process excercises the overriding control; and that in many cases decaying sedimentary organic matter is the source of the carbon. Thus δC^{13} values for marine and non-marine concretions prove to have a considerable overlap: – marine, + 2.4 to — 54 ‰ (Hodgson, 1966); non-marine, + 12.8 to — 19 ‰ (Whelan & Roberts, 1973; Fritz et al., 1971). A figure of 14 ‰ also has been obtained for an early Holocene concretion from glacial lake sediments in Sweden (Ehlin, 1974).

It would appear, therefore, that the measured δC^{13} of the concretion (— 15.6 ‰ is compatible with either an early diagenetic origin as a product of the decomposition of the organic matter in the marine sediment, or with subaerial formation from a mixed carbon source of soil CO_2 and sedimentary carbonate.

These two alternatives require different interpretations of the C^{14} data. In both cases the apparent age of the concretion, determined using a wood standard, must be corrected for the relative carbon isotope fractionation using the normalisation equation of Broecker & Olson (1961). This gives the mean age of the concretion as 4690 years. If of submarine origin a further fractionation could have occurred between the source material and the concretion, which could give a maximum change in the age of ± 100 years, corresponding to a ± 15 ‰ δC^{13} difference. In addition there would need to be a reduction of some hundreds of years (currently 300–400 years, Krog & Tauber, 1973) to allow for the age of the oceanic dissolved bicarbonate. Without allowing for the duration of concretion growth and any delay in its commencement, as discussed below, this model would date the deposition of the sediment to around the mid-Holocene.

If subaerially formed, the C^{14} date will relate to the time of formation of the concretion but not to the deposition of the sediment. Again the source of the carbon will have to be precisely identified if any fractionation is to be allowed for using a normalisation process. Derivation from soil CO_2 (δC^{13} — 25 ‰) alone yields a date of 4700 B.P. In the more likely case of solution of carbonate by groundwater a date provides only a maximum age for the concretions. Of the two modes of solution described by Hendy (1971), solution in the soil in contact with gaseous CO_2 has only a slight effect on isotope ratios. Solution in a closed system below the water table however can result in up to half the total carbon in solution being derived from the shell carbonate. This puts a limit on the minimum age of the soil CO_2, and hence on the actual date of formation of the concretion. Thus for a measured date of 4500 B.P. a contribution of nearly 50 % from interglacial shell carbonate would date the soil CO_2 to the present, whilst if it was from early Holocene shells (8000 B.P.) the age of the soil CO_2 should be 2000 B.P. Smaller proportions of shell carbon would imply dates of formation between the measured and minimum ones.

In all cases the possible ages quoted so far for the concretion represent mean ages since no account has been taken of the duration of its growth.

Little is known about their growth rates, although Berner's (1968b) theoretical model of carbonate concretion growth suggests that periods of several hundred to several thousand years are required for a 5 cm diameter spherical concretion. Ehlin (1973) also has shown by C^{14} dating of a 5 cm concretion that growth occupied several thousand years, and began several thousand years after deposition of the sediment. Because of their concentric growth a mean age will be weighted towards the young end of its growth period. Hence it is necessary to assume that the age of the earliest carbonate precipitated may be several hundred to over a thousand years earlier than the various ages suggested by the models discussed above.

Which ever model is accepted for the formation of the concretion it seems that it began to form at the earliest in the mid Holocene. However, whilst a submarine diagenetic origin implies a broadly similar age for the parent sediment, a pre-Holocene age for the sediments would be allowed by other models.

Of all Weidick's (1972) published records of derived concretions only two were definitely assigned to pre-Holocene sources, based on their contained pollen flora (Bryan, 1954). Recent information on the Holocene pollen floras of Greenland suggest that of these two the concretions from Gódthåbsfjord may well be interglacial because of the high content of conifer pollen (Fredskild, 1973), but that those from nineteenth century moraines at Frederikshåbs Isblink could be Holocene. Their pollen assemblage is broadly comparable with that of mid-Holocene lake sediments in the same area (3500 to 5700 B.P.), allowing for a different local contribution from pteridophytes (Kelly & Funder, 1974). However pre-Holocene shells have also been found at the same ice margin (21,710 B.P. Weidick, pers. com.). No pollen has been found in the Qaleragdlit imâ concretions.

Conclusions

It is clear that at Qaleragdlit imâ the area adjacent to the present margin of the Greenland ice sheet was deglaciated before 7570 B.P. and that it was not reglaciated until the ice advances of the last few hundred years. During this interval, in the mid-Holocene or later, calcium carbonate was being precipitated as concretions in marine sediments. Although the data so far obtained about these concretions does not allow their origin to be identified with certainty, it seems likely that they are associated with the early diagenetic decomposition of organic matter in the sediments. If this is so then the sediments themselves can be dated to the mid Holocene. However, even if subaerially formed after uplift it would seem to require that the area was deglaciated at the time of concretion formation.

The particular significance of the concretions lies in their wide distribution along this sector of the ice margin, if they are all of the same age. A common source for these can only be marine sediments now buried beneath the ice and not just occurring between the present and nineteenth century ice limits.

There is therefore evidence, of varying degrees of reliability, that the period from before 7570 B.P. to after 4500 B.P. was one when the ice margin lay well behind its nineteenth century limit and probably well behind the present margin. The subsequent readvance of the ice, which culminated in the nineteenth century advances, could be associated with the long period of climatic deterioration in the late Holocene known from pollen studies in South Greenland to date from about 2000 B.P. (Fredskild, 1973).

A more thorough study of derived carbonate concretions in moraines and of the concretions in marine sediments in Greenland in general could lead to further information about the ice sheet during the mid Holocene, and to a better understanding of diagenesis in these sediments.

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Dansk sammendrag

For at kaste lys over de holocæne gletscherbevægelser i Sydgrønland er der foretaget C^{14}-datering og C^{13}-analyse af to muslingeskal-prøver, der er indsamlet foran gletscheren Qaleragdlit Sermia ved Bredefjord; de stammer begge fra et område, der var dækket af gletscheren i sidste århundrede.

Den første prøve (A) bestod af skaller forekommende *in situ* i en marin aflejring, – den anden (B) var en skalførende kalk-konkretion fra den unge moræne. Prøverne gav aldre på 7570 og 4540 år BP og, selvom C^{13}-indholdet i kalk-konkretionen ikke entydigt viser, om konkretionen er dannet submarint eller subaërisk, tyder dateringerne og den hyppige forekomst af konkretioner i de unge moræner i området på en betydelig afsmeltning i mellem-holocæn, således at gletscherfronterne lå væsentligt længere tilbage end de gør nu.