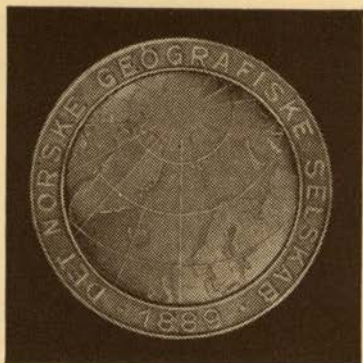


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**PROBLEMS OF RADIOCARBON DATING  
OF RAISED BEACHES, BASED ON  
EXPERIENCE IN SPITSBERGEN**

I KOMMISJON HOS UNIVERSITETSFORLAGET, OSLO

# Problems of radiocarbon dating of raised beaches, based on experience in Spitsbergen<sup>1</sup>

BY

INGRID OLSSON and WESTON BLAKE, JR.

DURING THE summers of 1957 and 1958 the junior author served as glacial geologist with the Swedish Glaciological Expedition to Nordaustlandet (North-East Land), Spitsbergen (Fig. 1). One of the main objectives was to establish an absolute chronology of events leading to the partial deglaciation of this island.

Twenty-two samples of driftwood, whale bones, and shells were collected from the raised beaches, and these have been dated by the senior author at the C<sup>14</sup> laboratory in Uppsala. The ages of several other samples have also been determined, but because they do not pertain to the problem of dating the raised beaches they are not discussed in this paper. All the dates have been published by Olsson (1959, 1960) in the standard dating lists. In the present paper Olsson is responsible for the section discussing problems connected with the laboratory procedure, Blake for the geological part.

## I. PROBLEMS CONNECTED WITH THE LABORATORY PROCEDURE

### *Introduction.*

W. F. Libby first carried out C<sup>14</sup> datings using the solid carbon method. Today C<sup>14</sup> dates are more reliable as gas proportional counting is used and because the samples are given a more thorough pretreatment before

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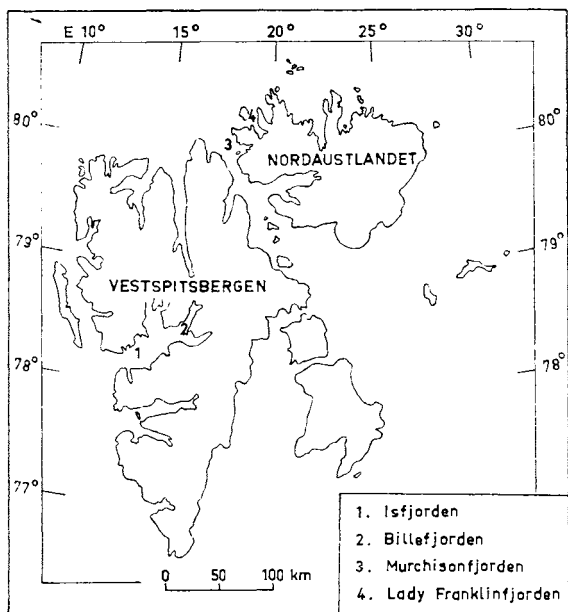


Fig. 1. General map of Spitsbergen, showing the areas where material for radiocarbon dating was collected.

they are combusted or before  $\text{CO}_2$  is liberated from carbonates. The samples must be gathered carefully, and one should always consider the probability that the samples really do belong to the time or event to be dated. It must be remembered that the initial relative  $\text{C}^{14}$  concentration in the carbon reservoirs has not been constant but shows variations of at least  $\pm 2$  percent. These variations have been measured on tree rings, e.g. by de Vries (1958), Willis, Tauber and Münnich (1960), and Suess (priv. comm.). Small variations in isotopic composition may affect the result, but corrections can usually be made if mass spectrometric analyses are performed in order to determine the  $\text{C}^{13}/\text{C}^{12}$  ratios. These in turn are compared with the ratio for the reference sample used. The half-life for  $\text{C}^{14}$  is  $5\,568 \pm 30$  years according to the most reliable measurements already published (Libby, 1955), but three precise remeasurements are almost completed. An incorrect half-life will affect all dates in the same direction and by the same percentage. Thus a sample with one-half the activity of the reference sample would have its date changed by the same amount as the change in the value of the half-life.

*Treatment of the samples.*

Wood samples have been treated in the manner which is used in most  $C^{14}$  laboratories. The outer parts of a sample are removed, and the remaining core is cut into small pieces and then treated with hydrochloric acid and sodium hydroxide. The samples are dried when the pH is about 4. Carbonate material and humus can be removed with this treatment.

Shell samples and the inorganic fraction of bones have often been regarded with some suspicion since there exists a certain risk that the calcium carbonate has been exchanged with dissolved carbonate in groundwater. Such contamination may result in either too high or too low ages. For further information on the  $C^{14}$  content of groundwater the reader is referred to the investigations of Münnich (1957) and Münnich and Vogel (1959).

Shells usually are treated with hydrochloric acid so that the outer parts are removed. In order to see if contamination has occurred we have introduced a standard method of treating shells. After the initial scraping and cleaning, the remainder has been separated into different fractions by removing layer after layer with hydrochloric acid. The two or three innermost fractions have been used for age determinations. If the ages of these fractions agree within the limits of error it can be assumed that the cores of the shells have not been contaminated.

The bone samples were too small to allow thorough treatment. Their outer parts (a few mm of sample B8A and more than 1 cm of B13) were removed before the chemical treatment, but it would have been safer to remove more of the samples. The two fractions, inorganic and organic, correspond to the carbon dioxide liberated by the addition of hydrochloric acid and the carbon dioxide obtained from the combustion of the remaining parts of the bone, respectively. The age differences between the fractions indicate that the ages probably are too low. (See p. 9, however, for an error in the other direction).

*Contamination and statistical errors.*

The same percentage contamination with modern material will affect a very old sample much more than a rather young one. Fig. 2 gives the error in age as a function of the percentage of recent contamination with modern material. Fig. 3 gives the error as a function of the percentage contamination with infinitely old (dead) material.

Even if the different fractions of the core have been dated at ages

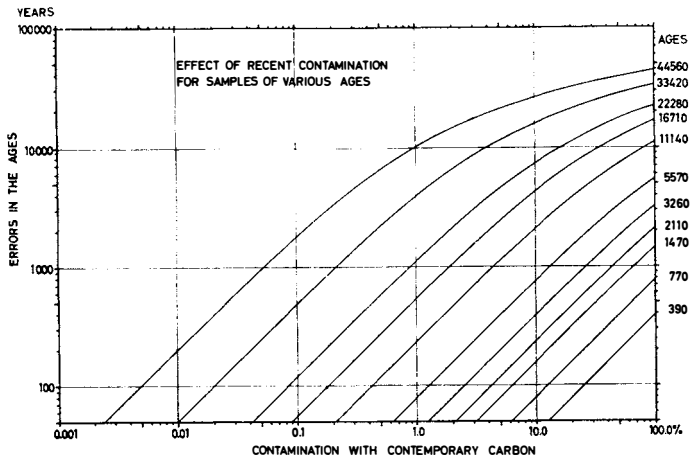


Fig. 2. The error in age as a function of the percentage of recent contamination with contemporaneous carbon for samples of different ages. Each curved line corresponds to one sample whose age is indicated to the right in the diagram.

which agree with each other, there exists a risk that diffusion of young material from the contaminated outer layers can affect the result seriously if the shell is very old. It is difficult to differentiate between the individual layers as the pieces always vary somewhat in size and thickness. Broecker (priv. comm.) has suggested checking the reliability by measuring the content of uranium and radium. One of the shell samples, B30, for which a possible finite age of roughly 35000 years existed according to the  $C^{14}$  datings, has been analysed by Broecker. The U/Ra determinations showed it to be very much older than it was according to the  $C^{14}$  measurements. Whereas the  $C^{14}$  determinations on very old samples usually gave increasingly higher ages for the fraction from the outside toward the core, the U/Ra method gave successively lower ages. However, it is too early to draw definite conclusions from these comparisons, partly because the U/Ra method is still in the experimental stages. It should be mentioned that the  $C^{14}$  ages for two samples with an age of about 10 000 years, B35 and B8B, are the same as or lower than the U/Ra ages (average of the two inner fractions). The U/Ra determinations are made with the assumption that there was only a negligible amount of  $Th^{230}$  in the water, and thus likewise in the shells, when the mollusks were living. In the oceans there are usually small amounts of  $Th^{230}$  even if 0.6 % of the amount required for secular equilibrium has been measured. As a rule

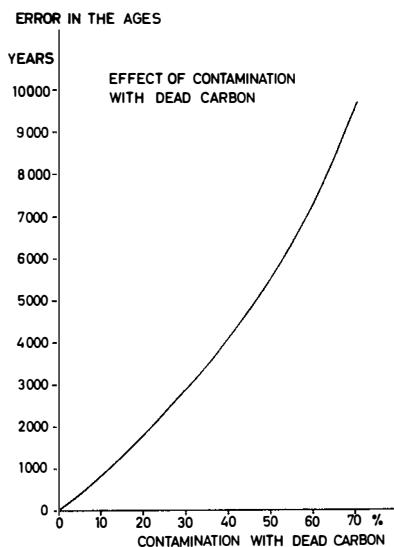


Fig. 3. The error in age as a function of the percentage of contamination with infinitely old (dead) carbon. The curve is valid for samples of all ages.

the concentration is higher near to the coast. No measurement of the concentration in the area around Spitsbergen is known by the present author.  $\text{Th}^{230}$  is in secular equilibrium with  $\text{Ra}^{226}$  after about 10 000 years. An initial amount of  $\text{Th}^{230}$  in the shells of 1 % of what is required for secular equilibrium with  $\text{U}^{238}$  will cause the age to appear 1200 years too high.

The danger of contamination is much more serious for thin samples than for thick samples in the same collection. Whenever possible we tried to use thick shells of equal size and without pitted surfaces.

In Fig. 4 the result of the washing procedure is shown for the shell samples. The letter 'B' before a number of a sample indicates that the sample belongs to the series submitted by W. Blake, the junior author. In the figures the sample numbers are given without this 'B'. An 'U' together with a number indicates an Uppsala dating number. The shells collected by Feyling-Hanssen in Vestspitsbergen are also included in this diagram (Feyling-Hanssen and Olsson, 1959-1960). Every sample is represented by a rectangle in which the side parallel to the abscissa represents the fraction which has been used, and the standard deviation ( $\sigma_1$ ) is shown along the ordinate. The chance that the age of a fraction is between these limits ( $\pm$

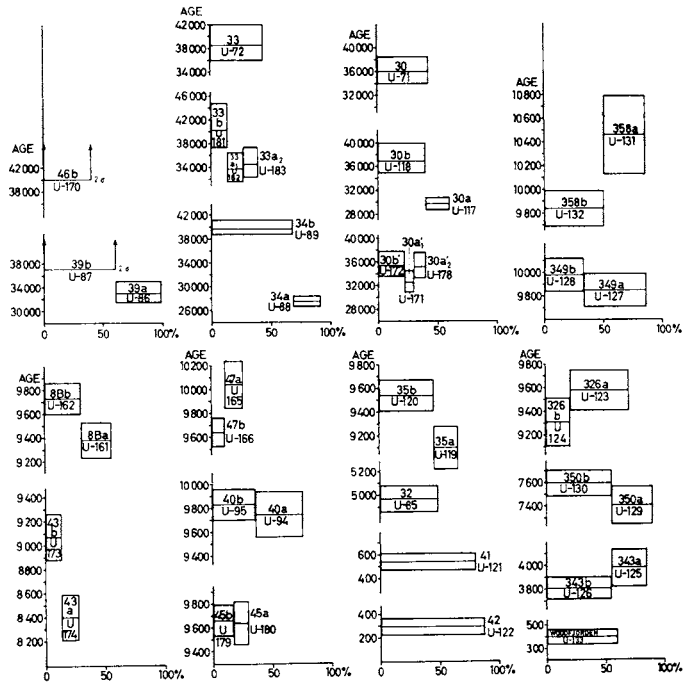


Fig. 4. The rectangles illustrate the result of the washing procedure for all shell samples determined at the Uppsala C<sup>14</sup> laboratory prior to 1960. Every fraction is represented by a rectangle in which the U-numbers indicate the Uppsala dating number, the other numbers are the original sample numbers. The side parallel to the abscissa indicate the fraction used for the different measurements. The percent used is measured from the core outward. The sides parallel to the ordinate indicate the age interval determined by the standard deviation. The age is represented by the middle horizontal line in each rectangle. For the very old samples having too low an activity the arrows indicate that all values above a minimum value are possible.

$\sigma_i$ ) is 68 percent, and between twice these limits ( $\pm 2 \sigma_i$ ), 95 percent. When comparing two independent measurements on the sample or dating the same event, both given with their statistical errors, one should calculate the age difference and its corresponding statistical error. If the statistical errors are  $\sigma_1$  and  $\sigma_2$  for the two measurements the resulting statistical error  $\sigma$  for the difference can be written as:  $\sigma = \sqrt{\sigma_1^2 + \sigma_2^2}$ .

The age differences for the shell samples are given in Fig. 5. Of the five samples from Vestspitsbergen and six samples from Nordaustlandet with ages below 11 000 years, seven had a greater age for the inner of the

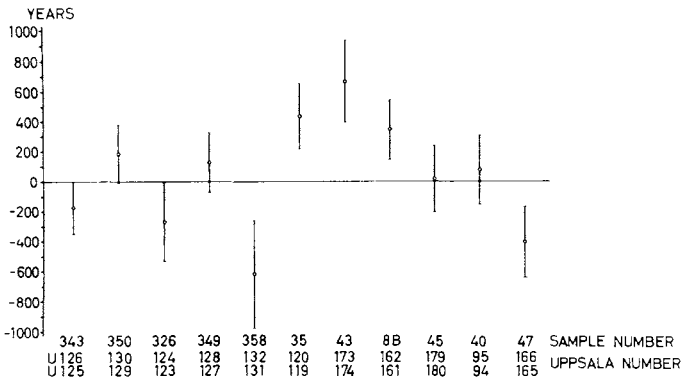


Fig. 5. Age differences between the innermost and outer dated fractions of the shell samples. The standard deviation for every sample is indicated and the numbers of the samples are given for identification. All shell samples determined in Uppsala prior to 1960 are included for which  $C^{14}$  ages below 11 000 years were obtained on two different fractions.

two fractions. These eleven samples are too few to allow definite conclusions regarding the statistical spread of the difference in age between the two fractions of each sample. However, B43 had a difference greater than  $2\sigma$  and must be regarded with suspicion.

In the group of old samples one series for B30 shows differences between three fractions indicating that the ages may be true (Fig. 4). The differences for B33 are greater than  $\sigma$  but are still so small that it must be regarded as possible that the three fractions do not differ in age. For both these samples the  $C^{14}$  dating indicates that the probability that they are contaminated and give too low ages is about the same as the probability that they are not contaminated. Because of this and because of what Broecker's (1960) result indicate, we conclude that the dates must be regarded as lower limits for the ages.

The condition of the samples must be taken into consideration. All of the wood samples were in good condition, but some of the shell samples were pitted (especially B8B and B34) or consisted of many small and thin fragments (B39 and B43) so that they might have been contaminated more easily.

*Variation of the background during the measurements.*

Since part of the background of a proportional counter is due to cosmic rays, the background cannot be expected to be constant. It has been shown



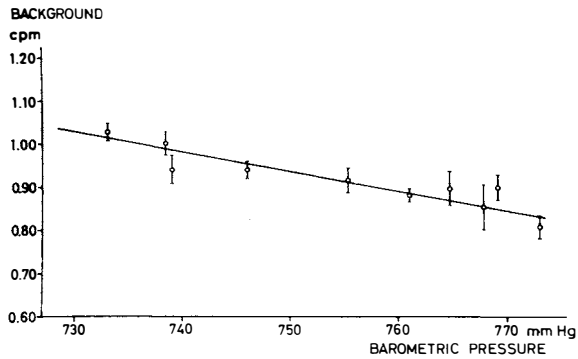


Fig. 6. The background (counts per minute) measured at the  $C^{14}$  laboratory in Uppsala for an arbitrarily chosen period as a function of the barometric pressure, measured in mm Hg. The standard deviations are indicated. The line is drawn after calculations with the least square method.

by de Vries (1956, 1957) that the background varies with the barometric pressure in such a way that part of the background can be attributed to the nucleonic component of the cosmic rays. In Uppsala we have a change of 0.035 cpm for a change of 10 mm Hg of the barometric pressure (de Vries, Stuiver, and Olsson, 1959). The difference between the extreme values is almost 50 mm Hg at the  $C^{14}$  laboratory in Uppsala. We usually try to date samples when the barometric pressure is such that the corrections for this will be negligible. The change in the resulting age will be much more pronounced for an old sample than for a young one as shown in Table 1.

Age, years	Net counting rate, cpm	Correction, cpm, per 10 mm change in barometric pressure.	Correction, years, per 10 mm change in barometric pressure.	
			+	-
0	8.800	0.035	31	31
5 570	4.400	0.035	64	64
11 140	2.200	0.035	130	130
22 280	0.550	0.035	530	500
33 420	0.138	0.035	2 320	1 845

Table 1. The correction in years for samples of different ages corresponding to a variation of 10 mm Hg in the barometric pressure. Plus is for decreasing and minus for increasing barometric pressure. The correction to be applied is  $0.035 \pm 0.010$  cpm per 10 mm change in the barometric pressure.

However, the last measurements on B33 (U-181, U-182 and U-183) all had to be performed at a barometric pressure of about 10 mm Hg above the mean value. The other samples have been remeasured if the error in the corrections may have influenced the result seriously. A 10 mm change in the barometric pressure corresponds roughly to a 10 percent change in the nucleonic component of the cosmic rays. However, the variation of the nucleonic component is not solely dependent on the barometric pressure. We have tried to correlate the variation of the background with the variation of the nucleonic component (both corrected for changes in barometric pressure), but the data available were insufficient to prove the expected relationship with any accuracy. The nucleonic component is continuously measured by Dr. A. E. Sandström *et al.* at Flogsta, about 2 km from the C<sup>14</sup> laboratory. The decrease of the nucleonic component in May 1959 gave rise to a very low background. In Fig. 6 the background is shown as a function of the barometric pressure for an arbitrarily chosen period.

*Discussion of the isotope ratios and the apparent age of sea water.*

The proportions of the isotopes of any element are not constant, as physical and chemical processes may alter the ratio. Slight deviations from the normal C<sup>14</sup> concentration because of such processes will, as a rule, result in rather small errors, but for the shells the proportion is such that the correction corresponds to about 400 years in comparison with wood. The expected fractionation of C<sup>14</sup> can be calculated from the fractionation of C<sup>13</sup> as measured with a mass spectrometer. Part of the CO<sub>2</sub> from each sample has been sent to Stockholm, where Dr. R. Ryhage and his collaborators have compared the C<sup>13</sup>/C<sup>12</sup> ratio with that of the Uppsala reference sample (Olsson, 1959, 1960). Each date is related to this sample after a correction for isotopic fractionation has been applied.<sup>1</sup>

From three determinations carried out in Uppsala (U-133, U-121, and U-122) and several measurements at other laboratories one can expect that samples from the sea give ages about 400 years too high. This is due to the fact that it takes some time before the C<sup>14</sup> is mixed between the different reservoirs. Since various laboratories have had their own reference samples, and not all of these samples are related to the international

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<sup>1</sup> Note added in proof: To convert the old Uppsala time-scale to the new one (NBS oxalic acid),  $135 \pm 35$  years should be added to the dates published here, if one wants the dates B.P. To get the dates before 1950, 125 years should be added.

reference sample from the National Bureau of Standards, it is too early to compare all dates on recent shells. For this reason, and because we do not know if the same correction should be used for whale bones as for shells, we have not subtracted 400 years from the ages of the samples of marine origin in the preliminary diagram showing land uplift (Fig. 9). This diagram is presented without corrections for systematic errors.

## II. GEOLOGICAL SITUATION

### *Introduction.*

Some observations have already been published concerning the raised beaches in Nordaustlandet (Blake, 1960, 1961 b), and full details will appear in the scientific results of the expedition, to be published in 'Geografiska Annaler'. The purpose of the present paper is to provide a geological background to Olsson's discussion of laboratory procedure and to draw attention to some of the problems connected with the dating of raised beaches.

Raised beaches are exceptionally well developed in the narrow, ice-free coastal zone of Nordaustlandet. In the Murchisonfjorden — Lady Franklinfjorden area these beaches often rise in an unbroken series from sea level to over 100 m (Figs. 1 and 7). Driftwood, whale bones, and shells at various levels up to 77 m have been collected and dated in an attempt to determine the rate of land uplift since the island has become partially deglaciated.

### *Sample collection.*

The fact that the driftwood samples were partially buried in the well preserved beaches indicates that they floated ashore when the beaches were forming, and that they have not been carried up to their present position at a later date by some agency such as wind, polar bears, or man. It is possible that driftwood has been lifted to higher levels during eustatic transgressions, and it is also possible that it has floated around in the Arctic Ocean for some time, but it seems most unlikely that such drift would last more than a few tens of years, even if the wood were on top of pack ice. Most of the samples are logs at least 10 cm in diameter and 1 to 2 m in length, and none of them shows signs of having been worked (Fig. 8).

The whale bones were deposited, presumably, when whales died and their carcasses washed ashore. Later the bones may have been redistributed



Fig. 7. View northwest from the inner part of Lady Franklinfjorden at a typical series of raised beaches. The prominent beach on which driftwood and pumice are abundant is indicated by the arrows.

by storm waves or sea ice action, but because the bones, like the driftwood, are imbedded in smooth slopes of beach shingle, there is no indication that they have been pushed or carried to *higher* levels than those at which they were originally deposited.

Lack of time did not permit detailed excavations to be made in the raised beaches in order to collect shells bed by bed, and good natural exposures are rare. Instead, samples were collected from the surface of the beaches, usually in muddy places where the beach shingle was not well developed; i.e., commonly shells were not found among pebbles and coarser material. Thus most shells occurred where the underlying till was exposed at the surface or where frost action had pushed plugs of till up

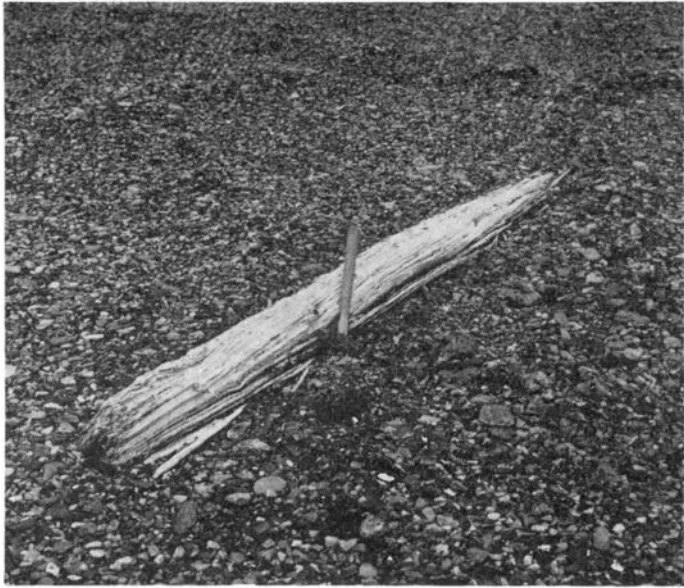


Fig. 8. Driftwood log at 36.7 m on the south shore of Murchisonfjorden (sample U-70,  $9270 \pm 130$  years old). Note how this log is partially imbedded in the left foreground and is completely buried under undisturbed beach shingle at its far end.

through the shingle. The dated shells were predominantly *Hiatella arctica* (L.) and *Mya truncata* L., both species which can live at depths from the intertidal zone to over 100 m (Odhner, 1915, pp. 120-129; Feyling-Hanssen, 1955, pp. 148, 150). Because of intense frost action near the surface, shells were never found in living position, but care was taken not to collect from the comparatively few localities which had obviously suffered from the effects of solifluction. It is nevertheless difficult to determine whether the shells have: 1) been washed downward by wave, current, or stream action, 2) been moved to their present positions by a glacier advance which scraped them up from the fjord bottom and incorporated them in the till, or 3) burrowed into the till covering the fjord bottom after the ice had retreated, but when the land was still lower relative to sea level than it is today.

For instance, sample U-173, found 9 m a.s.l., was *Mytilus edulis* L., a pelecypod which attaches to a hard substratum, chiefly in the intertidal zone. As noted in Part I the date of  $9070 \pm 190$  years on this sample represents a minimum age because the core was so much older than the adjacent layer of shell. On the basis of other dates on shells and driftwood

we know that the land was much lower relative to sea level 9-10 000 years ago. For this reason it is very likely that these shells have been washed downward to their present position by wave or current action.

On the other hand, in several localities where good exposures existed shells were seen in till, and these have unquestionably been moved by a glacier. Shells collected 2.5 to 6 m above sea level from one such exposure have been dated at >40 000 years B.P. The shells *at least* 35-40 000 years old, found on the surface of the till among beach material at elevations (44 to 77 m) just slightly above the 9-10 000 year old shells (highest at 44 m), have probably been moved by a glacier also. These old shells indicate an ice-free period more than 40 000 years ago; they are, as far as can now be judged, unrelated to the age of the beaches on whose surfaces they are found, for despite the lack of 9-10 000 year old shells above 44 m, it is believed that all the raised beaches (up to over 100 m) postdate the last ice advance.

Thus any given strandline will in most cases be the same age as, or younger than, the included organic matter, although if the strandline has taken a long time to form it may be in part older. If, because of a sinking of the land or an eustatic rise of sea level, the sea reoccupies a strandline, then the latter may contain organic remains of different ages.

#### *Land uplift.*

Since this preliminary curve showing land uplift (Fig. 9) was first presented (Blake, 1961 b, p. 143), the tidal computations have been completed. The tidal range, mainly according to measurements made in Murchisonfjorden by the Swedish-Finnish-Swiss IGY Expedition during 1958, is about 0.6 m, and the greatest tidal correction for any point leveled is also 0.6 m. However, the curve remains essentially the same as that published earlier.

It is evident from the diagram that the six shell samples collected at various elevations all lived at about the same time; i.e., five of them have been dated between  $9540 \pm 130$  and  $9830 \pm 130$  years B. P., and as noted earlier the date of  $9070 \pm 190$  years B. P. on sample U-173 must be considered as a minimum age. Therefore only the uppermost shell sample (U-166) has any value for determining sea level, and all that can be said is that when these mollusks were living sea level was an unknown height above the shells which have now been uplifted to 44 m.

As indicated in Fig. 9 six of the driftwood samples, plus one whale bone,

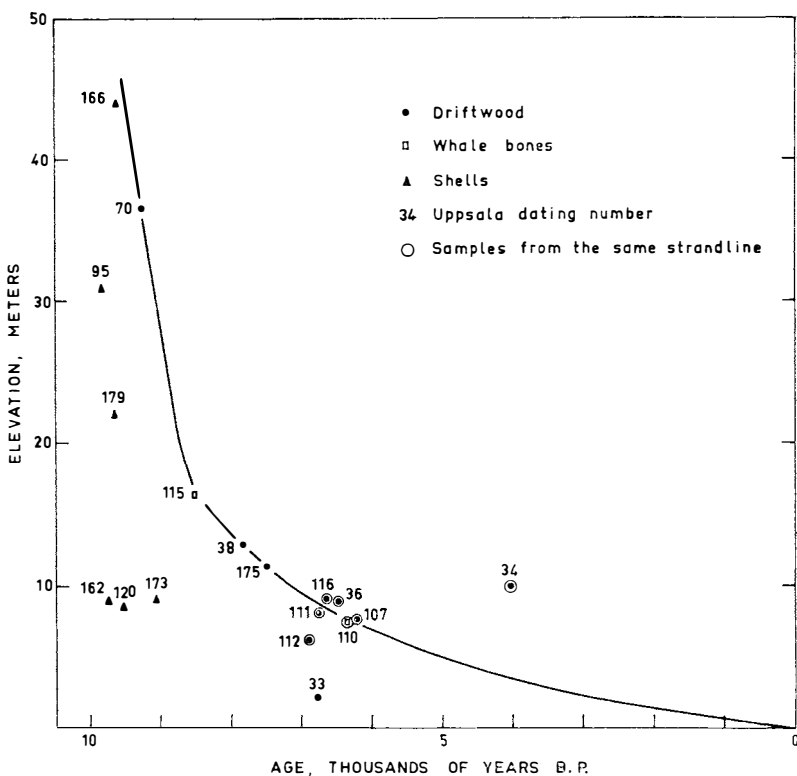


Fig. 9. Preliminary land uplift diagram for the Murchisonfjorden — Lady Franklinfjorden area, Nordaustlandet.

came from the same beach level, a prominent strandline often cut in bedrock and marking the upper limit at which dark brown pumice is common (Fig. 7). Five of the samples gave ages between  $6200 \pm 100$  and  $6900 \pm 110$  years B. P., suggesting that this beach was forming at that time. No correction for differential uplift in the various parts of the fjords has been made in this preliminary diagram; i.e., the samples (lowest, U-112, at 6.5 m) lying below the curve come from the outer parts of the fjords where uplift has been less, those lying above the curve come from the inner areas of greater uplift.

The sixth and highest sample (U-34, 9.8 m elevation) from this beach level was only  $4020 \pm 90$  years old. It was collected nearer the inner part of Murchisonfjorden than the other samples, hence it has undergone the greatest uplift. No difficulties were encountered in the dating of this

sample, so there is nothing to indicate that the date is not valid except the possible variations in initial activity and the 32 percent probability that the age of any given sample does not fall within its limits of error (see Part I of this paper).

However, evidence of another sort is available regarding this sample. A layer of limnic peat in a 127 cm long core of lake sediments collected by A. Häggblom of our expedition has been dated at  $5160 \pm 400$  years B.P. (Olsson, 1960, p. 121). The basal part of the sediment in the core contains marine diatoms, followed in turn by brackish water forms, but the peat layer lies within a zone of fresh-water diatoms extending to the top of the core (priv. comm. from Häggblom). The outlet of the lake is now only 5.2 m above sea level. Even though the outlet may have been cut down a few meters during the last 5000 years, it is still difficult to reconcile the evidence from the core with the presence of the log at 9.8 m only 3 km away. If an eustatic transgression 4000 years ago lifted this log to its present position and persisted long enough to bury the log under a cover of shingle, the same transgression should have brought in marine diatoms to the lake investigated by Häggblom.

One possible explanation is that this sample and that from 2.0 m (U-33,  $6780 \pm 100$  years old) at the same locality have been reversed. These two samples, and only these two, were collected on the same day and dried at the same time in an electric oven. Of course the presence of the lower log may easily be explained also by redeposition from a higher level or another locality, but mixing of the samples, though not proved, must be considered as a possible way of accounting for both these anomalous dates.

Obviously no conclusions can be drawn from the 4000 year old log, but the other dates indicate that this prominent beach was forming during *part* of the time represented by the Hypsithermal Interval (see Deevey and Flint, 1957, pp. 182-184). It also seems certain to the writer that this strandline corresponds to one or more of the *Tapes* levels in Norway, where similar pumice is found and where Marthinussen (1960, p. 424) has found driftwood of similar age.

It is naturally better to have several dates from the same strandline, but since organic material was scarcer at higher levels on the beaches, the curve has been drawn through the three isolated driftwood samples.

The bones may also have been redeposited at lower levels, but because of the age differences between the organic and inorganic fractions the bone dates are unreliable and must be regarded as minimum values; the dates plotted in Fig. 9 are those of the organic fractions after total com-



bustion. Nevertheless, it is interesting to note that the age of sample U-110 ( $6380 \pm 150$  years) is very close to that of U-107 ( $6200 \pm 100$  years), a driftwood sample collected from the same locality at the same elevation.

It must also be emphasized that no corrections for eustatic changes of sea level, particularly the rapid rise of sea level between 14 000 and 5500 years B.P. (Godwin *et al.* 1958, pp. 1518-1519), have been made. Nor has allowance been made for the greater apparent ages for samples of marine origin; i.e., as noted in Part I, recently living shells collected from the present-day beach average about 400 years in age. Subtracting 400 years from the shell dates would not affect the curve except in the case of the highest sample (U-166 at 44 m), where such a shift would make the upper part of the curve even steeper. If this correction should also be applied to whale bones, subtracting 400 years would have a greater effect, but because of the unreliability in these dates no corrections have been applied.

Even though additional age determinations are needed to provide more details about land uplift in Nordaustlandet, this preliminary and uncorrected curve gives an approximate outline of the sequence of events. As expected, land uplift was rapid at first, but the rate of uplift became increasingly slower with time. The presence of a Russian hunting hut known to be at least 100 years old, but which is now only 1.1 m above high tide level and 8 m from a tidal lagoon, indicates that little or no uplift is now occurring (Blake, 1961 a, pp. 108-109). The curve is strikingly similar to that presented by Feyling-Hanssen and Olsson (1959-1960, p. 123) for the Billefjorden area of Vestspitsbergen, which was based purely on shells collected from excavated beach strata.

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