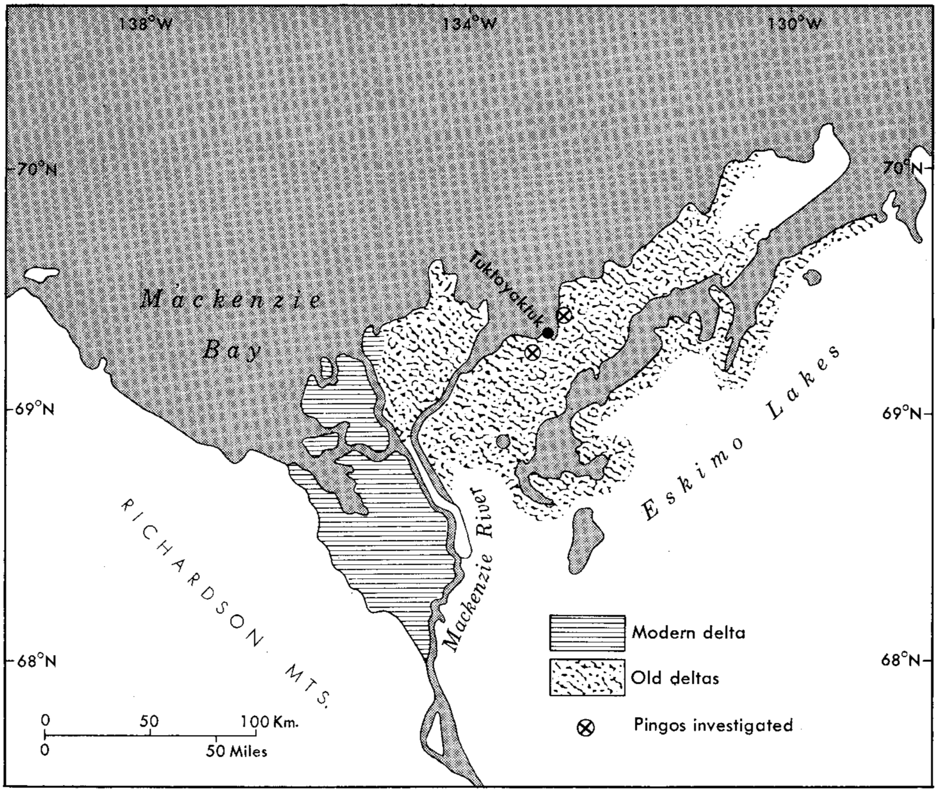

Fig. 1. The Mackenzie Delta area, Northwest Territories.

ANALYSIS OF SOME STRATIGRAPHIC OBSERVATIONS AND RADIOCARBON DATES FROM TWO PINGOS IN THE MACKENZIE DELTA AREA, N.W.T.

Fritz Müller*

Introduction

PINGOS are the most striking relief feature of the northeastern lowlands of the Mackenzie Delta area. Stager (1956, p. 16) counted 1380 of these conical hills in the area of the old deltas, east of the present delta and north of the Eskimo Lakes, 10 per cent having a height of more than 25 m. (80 ft.). Practically all these pingos occur in the centre of shallow, rounded, or elongated lakes or former lake basins, which are abundant in and typical of this gently rolling landscape. There are also some pingos to the south and to the east of the Eskimo Lakes, and several of a rather different nature in the present Mackenzie Delta.

A thorough investigation was made of two typical pingos in the vicinity of the Eskimo village of Tuktoyaktuk (69°27'N. 133°04'W.) between May and July 1955 (Figs. 1 and 2), and they were compared with similar features studied in Northeast Greenland. An account of the detailed examinations and a morphogenetic explanation of these pingos were given in an earlier paper (Müller 1959, pp. 73-103).

Samples of organic material were collected from both the Tuktoyaktuk pingos for radiocarbon dating. The results of these tests have become available only recently. Before discussing the significance of the radiocarbon dates, a brief description will be given of the two pingos and of the stratigraphic situation of the organic material.

THE IBYUK PINGO

The Ibyuk Pingo (Fig. 3) was called "Crater Summit Pingo" on the hydrographic chart "Approaches to Port Brabant, 1950" and in Müller (1959, pp. 76ff.), but the name has been changed to "Ibyuk Pingo" by the Canadian Board on Geographical Names (*see* Arctic 12:125). It is situated in the geometric centre of a former lake that covered an area of 1.5 km.^{2} (more than half a square mile). A creek meanders through the shallow basin, draining the patterned-ground marshland toward the sea, whose level is only about 1 m. lower than the base of the pingo. At times of high tide and westerly storms the sea invades the basin, leaving after its retreat huge stacks of driftwood at the foot of the pingo and along the surrounding low

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hills. Rising abruptly from the plain, the characteristically ruptured cone overtops the landscape. This pingo has a height of 42 m. above sea-level (136 ft.). The circumference at the base measures approximately 900 m. (2800 ft.). The large crater in the summit contains a small lake.

From an intensive programme of digging and drilling in the Ibyuk Pingo it was learned that its main constituent features are (1) a large internal ice body with a thickness of about 40 m., overlain by (2) a cover of 15 m. (50 ft.) of frozen sediments, which cracked open as the internal ice body grew.

The sediments covering the ice core

The stratigraphic profile of the covering sediments (Fig. 4) was found to be more complex than expected and it would appear that the sediments are not of one simple origin. Only section A, about one quarter of the total

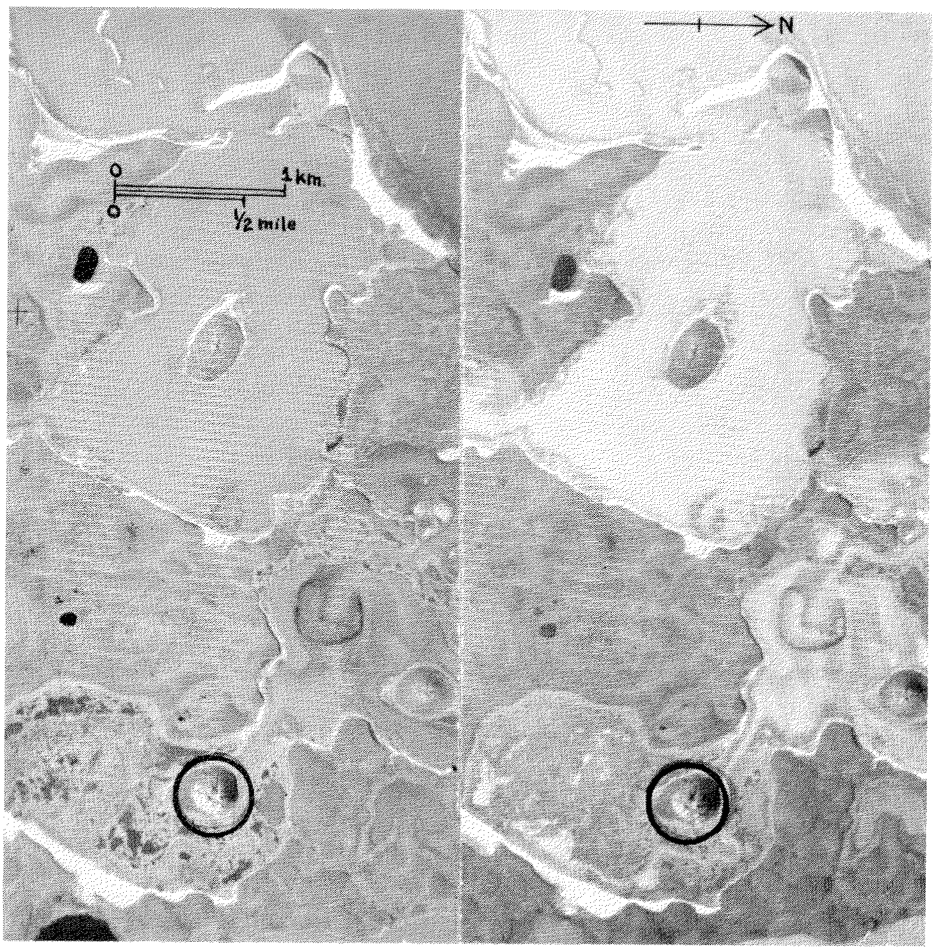


Photo courtesy of R.C.A.F.

Fig. 2. Stereo-pair of airphotographs of the Ibyuk area (circled: Ibyuk Pingo).

thickness of the covering material, appeared to originate from a post-glacial infilling process into a lake. Section B consists of material clearly associated with a glacierization of the area. Section C represents deltaic and fluvial material of a period prior to the glacierization.

If the updomed layers of this pingo were to be returned to their original horizontal position, the zero-level of the stratigraphic profile (Fig. 4) would be at least 3 m. (10 ft.) below present sea-level.

Fig. 3. Ibyuk Pingo seen from the north-northeast. Height approximately 41 m. (133 ft.) above surrounding snow-covered marshland (May 1955).

Section A

The interbedded, rust-red layers near the top of section A, also noted by Porsild (1938, p. 54), are coloured by a very large content of iron-hydroxide due to the prevailing swamp conditions of the final stages of sedimentation. The extraordinary blue colour of the next lower layers (from 1 to 3 m. profile depth) is the result of the presence of phosphorus.

The high content of organic matter in section A is striking. At a depth of about 1.5 m. (5 ft.) a first layer of small pieces of driftwood occurs, with another marked concentration at 2.2 m. (7 ft.) below the surface. The radiocarbon age of a sample of organic matter from the 2.2-metre level, containing driftwood, rootlets, and some shells of snails, has been given as 12,000±300 years (C-14 sample No. S-69). The presence of driftwood indicates the existence of a connection with the sea or with a channel of the Mackenzie River at that particular time. Shells of various molluscs occur throughout section A, reaching a maximum concentration at a depth of 3.1 m. (10 ft.).

The sediments of section A result from a slow infilling process into the "Ibyuk Bay" or "Ibyuk Lake", which gradually became a marsh.

Section B

Several characteristics usually accepted as proof of the former presence of glaciers appear in this section of the stratigraphic profile: (1) a large number of angular rocks with an average size of 5 cm. (2 in.); (2) a few large crystalline erratics, up to 50 cm. (20 in.) in size, with well-polished surfaces and marked striae, and (3) no sign of bedding in the matrix, which consists of sandy silt with a relatively high content of clay. A peculiar feature, however, is that the glaciated rocks were mixed with organic matter, particularly with fragments of driftwood.

Washburn (1950, p. 43, and Pl. 13, Fig. 2) found "bedded fines with relatively few stones and a lower part consisting of a *silty till*" in the covering sediments of a pingo on Wollaston Peninsula, Victoria Island, and explained them as products of a glacierization that was perhaps contemporaneous with a submergence.

The general appearance of the till of the Ibyuk Pingo suggests that these glacial sediments were deposited subaqueously. The intermingling of organic matter, particularly of driftwood, would however indicate that the submergence at that time was only very slight. It is unlikely that the submergence was sufficient to allow the ice to float.

Transitional zone between sections B and C

The cryoturbation forms observed in the contact zone of sections B and C (Fig. 4) at a depth of 6 m. (19 ft.) have two possible explanations, (a) they may be periglacial features associated with the last glaciation, or (b) they may result from over-thrusting by glacier ice, as suggested by Mackay (1956b) for similar features.

Section C

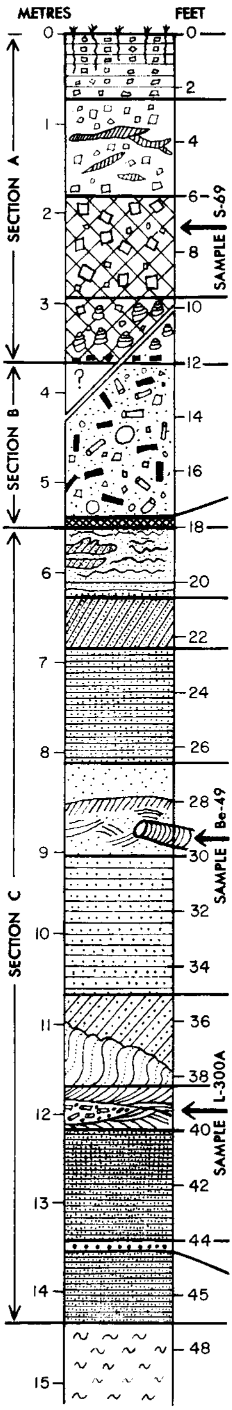
The well-bedded, clean sands of section C show frequent alternation between local foreset and topset bedding. This complex is of the nature of a fluvial plain sediment that accumulated near sea-level. Though not necessarily a sea-level delta deposit, it was probably graded to sea-level with deposition taking place only a few metres above it. The sorting and the grain size of these sands would support this assumption.

The radiocarbon dating of the driftwood from the 12-metre level (sample Be-49) gave an age of $28{,}000 \pm 2{,}000$ years and the age of the 15-metre sample (L-300A) was determined as $>33{,}000$ years.

THE SITIYOK PINGO

Situated about 4 km. north-northeast of Tuktoyaktuk and not more than 300 m. from the shore of the sea, this small pingo rises only 10 m. (32 ft.) above the level of its surrounding lake and has a circumference at the base of 210 m. (680 ft.). The basin contributing to this pingo, of which about a third remains as lake, is only about an eighth of the size of that in which the Ibyuk Pingo stands. The nearby marshland, the floor of the shallow

Altitude of exploration surface 37 m. (120 ft.) above sea-level.



grey silty clay (44% clay, 42% silt, 14% sand, unfrozen dry flakes (May 30, 1955); interbedded red layers; high content of organic matter (roots and branches of willow)

blue clayey silt (38% clay, 48% silt, 14% sand), high degree of ice saturation (moisture content 96%), ice lenses; some small pieces of driftwood

flakes of blue sandy silt (21% clay, 42% silt, 37% sand) in a matrix of clear ice (moisture content 110%); varied organic matter: snails, small pieces of driftwood and rootlets; radiocarbon age 12,000 ± 300 years (sample S-69)

blue clayey silt (31% clay, 41% silt, 28% sand); ice coating the flakes of mineralic material as well as the numerous shells of molluscs (moisture content 62%)

grey mixture of clay, silt, sand, and gravel (30% clay, 35% silt, 35% sand) containing both angular and polished striated boulders, and much organic matter, mainly small pieces of driftwood; ice segregation

layer of almost pure organic material

brown sand, bedded, probably cryoturbation, ice occupies only pore spaces; no organic matter

deltaic foreset-bedding in brown sand (100% sand)

clean sand, very well bedded, very little ice (moisture content 19%)

sand and some gravel, cross-bedding; including a log of driftwood (diameter 14 cm. (6 inches); radiocarbon age 28,000 ± 2,000 years (sample Be-49)

clean sand, excellent bedding, red layers interbedded

complicated disturbance in delta-bedded sand

small pieces of driftwood enclosed in cross-bedded sand and gravel; radiocarbon age $>$ 33,000 years (sample L-300A)

fine-grained sand, very well bedded, no ice segregation

layer of coarse-grained sand with a few pebbles

well-bedded, fine-grained sand

pingo ice.

Grain size classification: clay diameter $<$ 0.002 mm.
silt diameter 0.002 — 0.060 mm.
sand diameter 0.060 — 1.200 mm.
gravel diameter $>$ 1.200 mm.

Moisture content: percentage of water equivalent of ice to dry soil, on basis of weight.

Fig. 4. Stratigraphic profile of the sediments covering the Ibyuk Pingo.

lake, and even the pingo itself are covered by an almost rectangular pattern of large ditches of ice-wedge polygons of up to 2 m. (7 ft.) width, which form a system concentric to the pingo.

Extensive digging revealed pingo ice at a depth of 5.5 m. below the top of the pingo. The profile of the covering sediments of this pingo shows similarity to section A of Ibyuk Pingo, but there is no parallel to section B, for no evidence of glacierization was found in the Sitiyok Pingo.

The upper complex consists of 4 m. (12 ft.) of silt (first sample 20 per cent clay, 64 per cent silt, 16 per cent sand; second sample 21 per cent clay, 62 per cent silt, 17 per cent sand), which is characterized by a very high content of ice and organic material. The organic matter occurs in a distinct layer just below the surface, varying in thickness between 20 cm. and 60 cm. (8 to 24 in.), and also in numerous pockets and lenses below this first layer to a depth of 3 m. (9 ft.). In the subsurface organic layer plant remains, including pieces of wood and willow roots, are dominant. Below about 20 cm. there are increasing amounts of shells of various lacustrine snails and other molluscs mixed with the vegetable material. The results from the investigation of these shells by Dr. Lubinsky, Montreal, indicate a rather warmer climate at the time of sedimentation than at present and prove that the infilling process took place in a freshwater lake.

A sample for radiocarbon age determination was taken from 30 cm. (1 ft.) below the surface. It consisted of plant remains with small pieces of wood and various mollusc shells. The age of this sample (S-57) was given as 6,800±200 years.

Conclusions

Age of the pingos

The **Ibyuk Pingo** is certainly considerably younger than the glacierization that produced the glacial deposits (section B) in its cover of sediments. This is proved by the sedimentation continuing long after the glacial material had been deposited. Sedimentation ceased less than 12,000 years ago (sample S-60); this fixes the earliest possible time for the commencement of the updoming. It is estimated that this pingo is at the most 7,000 to 10,000 years old, i.e., of late Wisconsin age. Only after the radiocarbon dates for the youngest layers included in this pingo have been obtained can the onset of the upheaval be more accurately dated. It is presumed that conditions during the Hypsithermal permitted the continuance of aggradation of permafrost and thereby the growth of pingos.

The youngest layers of the covering sediments of the **Sitiyok Pingo** were deposited in a lake or swamp about 6,000 years ago (sample S-57), that is, during the Hypsithermal. The formation of the Sitiyok Pingo is therefore likely to have started with the marked general cooling of the climate that followed the Hypsithermal time, i.e., about 4,000 years ago. Thus the Sitiyok Pingo would be of an age similar to that of the pingo in the Thelon Valley described by Craig (1959, 510).

Extent and time of glacierization

There is ample evidence for a glacierization of the Ibyuk area and the environs of Tuktoyaktuk, but so far no such evidence has been found around the Sitiyok Pingo. In a brief reconnaissance to the northeast of Tuktoyaktuk no glacial remnants were observed except for one huge boulder near Toker Point, 20 km. to the north of Sitiyok.

The glacial material contained in the sediment cover of the Ibyuk Pingo is certainly younger than 28,000±2,000 years and older than 12,000±300 years. It is estimated that the glacierization of the Mackenzie Delta area that produced the Ibyuk till lasted from 25,000 B.P. to 15,000 B.P., being therefore late Wisconsin.

Net submergence

The occurrence of driftwood at various levels in the stratigraphic profile of the covering sediments of the Ibyuk Pingo indicates that during the deposition of this material the land surface was frequently more or less at, or only slightly above, sea-level. This conclusion is based on the observation that water-logged driftwood does not sink in brackish water or sea-water.

Since the three layers with dated tree remnants in this pingo would, if returned to their original position, now lie below sea-level proves that net submergence of the Mackenzie Delta area has occurred, at least in its eastern part. The term net submergence simply denotes the difference in height of the shoreline between two dates. For example, the driftwood L-300A, situated at the bottom of the sediments constituting the Ibyuk Pingo cover, proves a net submergence of 15 m. since its deposition more than 33,000 years ago. During the last 28,000 years the net submergence amounted to 12 m. (40 ft.). Between 28,000 and 12,000 years ago the net submergence was 6.5 m. (22 ft.). Various signs of shore-line recession along the coast of the Juk Peninsula indicate that there is a submergence of this area taking place now.

By superposition of the net submergence (—) or net emergence (+) and the net eustatic change of sea-level, the net isostatic movement can be calculated (Table 1). The curves for the eustatic sea-level changes (Hopkins 1959, Fairbridge 1961) are considered as fairly accurate for the last 12,000 years. The accuracy of the second sample of Table 1 is, however, very much less.

The net isostatic movement over the last 12,000 years has resulted in a land rise of about 40 m. During the last 6,000 years the mean sea-level was stable with only minor oscillations (Fairbridge 1961, p. 156). Any major submergence during this period would therefore be a true subsidence of the land. The increasing load of the accumulating delta deposits has been held responsible for the submergence of the Mackenzie Delta area (Richards 1950). However, Table 1 indicates the existence of a post-glacial isostatic land-rise in the area that is much greater than the depression by delta sediments. The balance between the two forces (possibly there are more

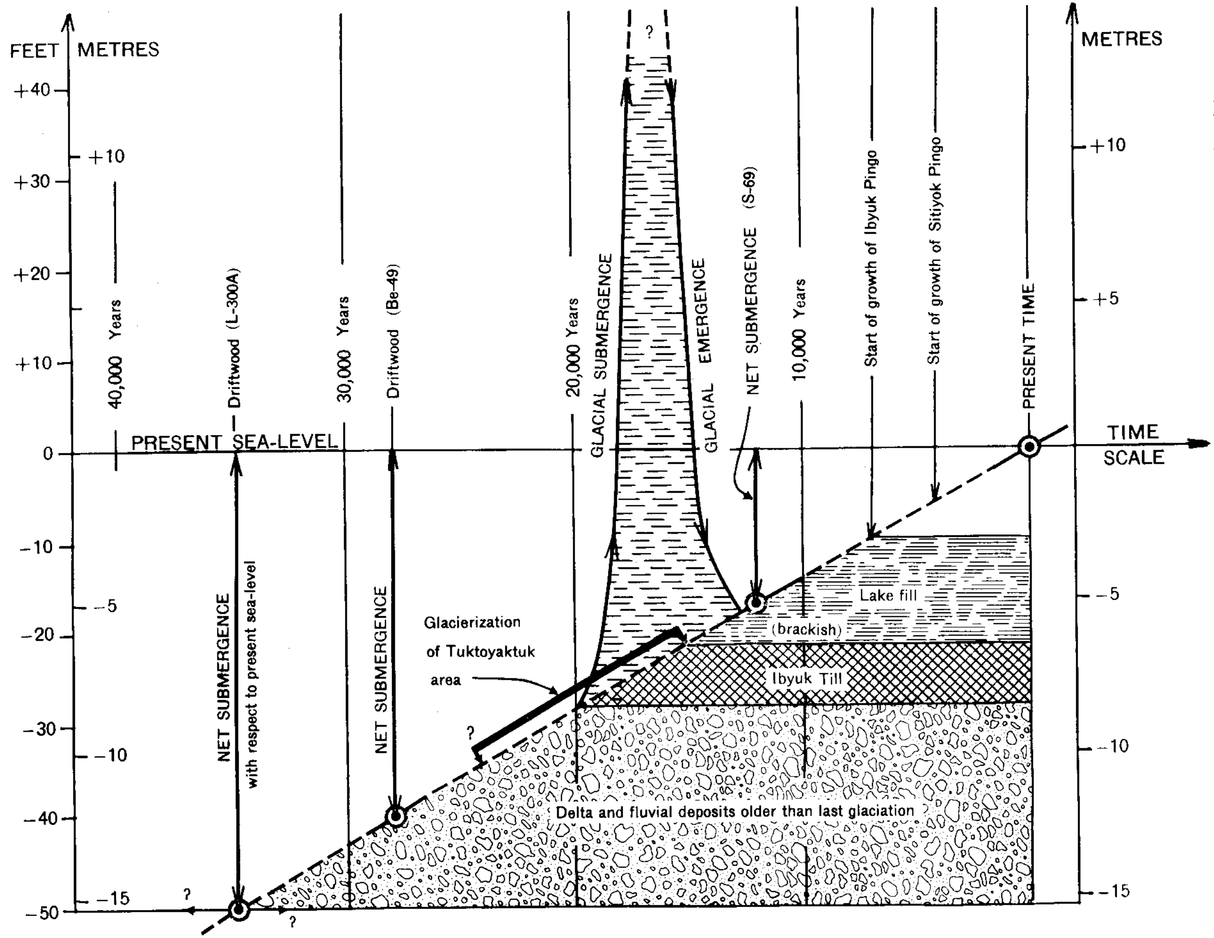


Fig. 5. The glacierization, the submergences, and the initiation of two pingos in the northeastern Mackenzie Delta area shown diagrammatically in chronological sequence.

than two involved) results in the 40-m. land-rise of the last 12,000 years mentioned above.

Glacial submergence

Superimposed on the absolute and relative changes in the height of the sea and land discussed above, the glacierization has initiated a short but very effective submergence followed by an emergence of roughly the same amount. Several authors have mentioned such glacial submergence of the Mackenzie Delta area (O'Neil 1924, pp. 11A, 30A, 33A; Hattersley-Smith 1951, p. 12; Mackay 1956a, p. 10). Only Richards (1950, p. 37) is of another opinion, holding that the Mackenzie Delta area was not flooded during late glacial time. The amount of this submergence has undoubtedly been considerably less than that in other places along the northern coast of the mainland. Evidence points to a post-glacial emergence of approximately 30 m. (100 ft.) (Mackay 1956a, p. 10 and personal communication).

The chronological relationship of the events discussed in this paper are depicted in Fig. 5.

Table 1. Two examples of the calculation of the net isostatic movement in the Mackenzie Delta area.

Sample No.	*Radiocarbon age (years)*	*Net submergence* a	*Net eustatic change of sea-level since deposition of sample* b	*Net isostatic movement since deposition of sample* $c = a + b$
S-69 driftwood	12,000 ± 300	− 6 m.	+46 m.*†	+40 m.
Be-49 driftwood	28,000 ± 2,000	−12 m.	+ 42m.†	+30 m.

* From Fairbridge (1961, p. 156)
† From Hopkins (1959, p. 1524)

Acknowledgements

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