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Geothermal Service of Canada

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ISOTOPE INVESTIGATIONS IN PERMAFROST REGIONS

F.A. Michel and P. Fritz
Waterloo Research Institute

Earth Physics Branch Open File Number 83-3

Ottawa, Canada, 1983

Price/Prix: $7.95

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UNIVERSITY OF WATERLOO
WATERLOO RESEARCH INSTITUTE

ISOTOPE INVESTIGATIONS IN PERMAFROST REGIONS

WRI PROJECT 205-17
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FINAL REPORT

Prepared for
Department of Energy, Mines and Resources
by
F.A. Michel, P. Fritz

FEBRUARY, 1983

Abstract

The results are reported of oxygen isotope measurements on core and massive ice samples collected along the Alaska and Dempster Highways in the Yukon and at Illisarvik Lake in the Mackenzie Delta. Analysis of the results reveals some interesting implications for past climate in the Yukon and the relationship to ground-water movement and the age and history of permafrost growth.

Résumé

Ce rapport présente les résultats de mesures d'isotopes d'oxygène sur des échantillons de carottes et de glace massive recueillis le long des autoroutes Alaska et Dempster dans le Yukon et au lac Illisarvik dans le Delta du Mackenzie. L'analyse des résultats révèle d'intéressantes implications pour l'étude paléoclimatique du Yukon et pour les rapports entre les isotopes et l'écoulement des eaux souterraines ainsi que l'âge et l'histoire de la croissance du pergélisol.

TABLE OF CONTENTS

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Isotope Investigations in Permafrost Regions

Chapter I

Introduction

1.1 Previous Studies

Initial investigations into the natural variations of stable isotopes in permafrost waters were undertaken by the authors in 1976 (Fritz and Michel 1977). That study, which involved an examination of cores from the Mackenzie Valley and central Keewatin, revealed the existence of oxygen-18 variations of up to 15‰ in the permafrost waters. Additional detailed field studies at Illisarvik in the Mackenzie Delta during 1979 and 1980 demonstrated that many small-scale variations of less than 3‰ are also preserved and that the isotopic profile can change dramatically over short distances. The preservation of small variations throughout the soil profile has been interpreted as an indication of negligible groundwater migration.

In an attempt to simulate the natural variations under controlled conditions, a series of laboratory experiments were conducted during the 1977 to 1982 period. These experiments have demonstrated that it is possible to generate small variations (less than 3‰) as a result of freezing. Futhermore, the experiments have shown that variations in excess of 3‰ (for oxygen-18) can be generated through fractionation under specialized conditions such as stationary freezing fronts and minor freeze-thaw cycles. Through the simultaneous study of deuterium isotopes it has also been possible to understand the significance of deuterium-oxygen-18 relationships which differ from the standard meteoric water line.

All results from field and experimental studies have been described in a series of annual reports and has been compiled and summarized by the senior author as a Ph.D. thesis (Michel 1982). In addition, portions of the work have been published at the Third International Permafrost Conference (Michel and Fritz 1978a) and the Fourth Canadian Permafrost Conference (Michel and Fritz 1982a).

More recently, work has been initiated on core material from the Dempster Highway pipeline route (Michel and Fritz 1982b) and the Alaska Highway pipeline route (Michel and Fritz 1982c). Although samples were scattered over a large number of cores, it was possible to determine that significant isotope variations do exist along portions of the Dempster Highway route. No such variations were visible along the Alaska Highway route.

1.2 Terms of Reference

As part of the ongoing investigations of groundwater in permafrost regions of Canada, this study was undertaken as a continuation of the previous research program. Specifically, the objectives of this study were:

1. to examine isotope variations in permafrost waters from unglaciated portions of the Dempster Highway pipeline route,
2. to examine isotope variations across a pingo at the Illisarvik test site in the Mackenzie Delta,
3. to complete a study of isotope variations in the drained lake bed and at surrounding sites, and
4. to examine the variation of 13C in the Illisarvik sediments.

1.3 Scope of This Report

This report describes the work completed and presents the data acquired during the contract period. Interpretation of the Dempster Highway data are discussed in relation to their significance in understanding the history of the permafrost waters along the Dempster Highway and the other regions of study. Data for massive ice from a single core along the Alaska Highway pipeline route are also presented.

At Illisarvik, the carbon-13 contents of samples from three cores within the lake basin were determined. Variations in the 13C contents are discussed in terms of their value in understanding the evolution of the lake basin since its inception. Finally, the report suggests a course along which further work could be pursued.

Chapter II

Yukon Pipeline Cores

2.1 Alaska Highway

During their 1982 drilling program along the proposed Alaska Highway route, Foothills Pipe Lines (Yukon) Limited collected a series of massive ice samples from a site (82-02-211(2)) located at kilometre 468.9 of the route for the authors. Since massive ice samples have normally been discarded, this core material provided a relatively unique opportunity to examine the oxygen-18 distribution in buried massive ice within the southern Yukon. Samples labelled C, represent the interval of 1.2 to 3.2 metres, and they consisted of stiff massive clay. Samples from the B series represent the interval of 4.1 to 7.5 metres and they consisted of massive ice. The oxygen-18 data are listed in Appendix 1.

As reported previously by Michel and Fritz (1982c), the oxygen-18 contents of groundwaters and surface waters along the Alaska Highway route are in the range of -19 to -23‰. Isotope data for permafrost waters examined for that report also were within the same range. On the basis of the similarity in values, it was concluded that all of the permafrost investigated was post-Hypsithermal in age.

Examination of the new data reveals several important features. The first point is that all of the δ180 values are within the previously determined range for post-Hypsithermal waters. The age of the waters examined is considered, therefore, to be younger than 4,000 years and the formation of the massive ice (approximately 4.4 metres) must have occurred within this time period. This suggestion is not unreasonable as it would involve a growth rate on the order of 1 mm/year.

The second feature to be noted is the similarity in δ180 values for the clay and the massive ice. This indicates that the clay was originally water saturated and that the ice formed by segregation. The possibility of the massive ice representing buried glacier ice can be readily discounted on the basis of the oxygen-18 contents. Glacier ice would have had much lower oxygen-18 contents than are present.

The third and perhaps most significant feature is the absence of any major isotope variation throughout the entire massive ice section. This lack of variation could be explained in two ways. Either the rate of freezing was so great (in excess of 2.5 cm/day) that no significant fractionation could occur, or the system was open, with sufficient groundwater migration to provide a source water with a constant isotopic composition.

The first possibility appears unreasonable since the rate of groundwater migration through the clay would have to be several orders of magnitude greater than would be expected. Alternatively, the second possibility is a reasonable mechanism for maintaining a uniform isotopic composition during relatively slow freezing. In this instance, the principal requirement is that the rate of freezing be less than the rate of groundwater migration or isotope diffusion. From the borehole log provided by Foothills Pipe Lines (Yukon) Ltd., the base of the permafrost occurs at a depth of 7.6 metres. Below the permafrost very wet, silty clay was encountered, thus providing support for the second hypothesis.

2.2 Dempster Highway

2.2.1 Introduction

The proposed route of the Dempster Highway pipeline closely follows the Dempster and Klondike Highways from Inuvik to Whitehorse. The major physiographic regions traversed by the pipeline include the Mackenzie Delta, Mackenzie Valley, Peel Plain, Richardson Mountains, Eagle Plain, Ogilvie Mountains, Tintina Trench and Pelly Mountains. Permafrost has been encountered along the entire route with the largest ice-rich sections located in the unglaciated Eagle Plain of the northern Yukon (Foothills 1978). A large number of core samples, from boreholes located along the entire route, were provided by Foothills Pipe Lines (Yukon) Ltd. from their 1978 drilling program.

During the 1981-82 period, Michel and Fritz (1982b) analysed a large number of samples collected from all portions of the route. It was found that the shallow permafrost waters contained oxygen-18 concentrations in the range of -20 to -22‰. These values were very similar to those of shallow groundwaters which have been sampled in the region. For the 1982-83 period, all available samples from boreholes 78-141, 78-142, 78-148, 78-165, 78-179 and 78-189 have been analysed for their oxygen-18 concentrations. The location of each borehole is shown in Figure 2.1.

2.2.2 Peel Plain Region

At the northern end of the route, boreholes 78-179 and 78-189 are located within the Peel Plain region of the North West Territories. Borehole 78-179 is situated in the centre of a broad east-west trending flat bottomed valley which is currently being downcut by several small streams. As can be seen in Figure 2.2, the stratigraphy of this valley is quite complex. The oxygen-18 profile for this core displays small 1.5‰ variations within the upper 8 metres, but is very uniform below this level. Most of the values are within the normal range for young groundwaters and precipitation (-20 to -22‰) and probably represent post-Hypsithermal-waters. The waters below 8 metres are slightly more positive (-19.5 to -20‰). This could be the result of slightly greater fluctuations in the normal range or could represent transitional waters from the Hypsithermal to post-Hypsithermal period. In either case, the waters represent an age of 4,000 years or less and indicate that since that time, permafrost has aggraded through the 15 metres of sediments examined.

The stratigraphy of borehole 78-189 is very simple in comparison to 78-179. As show in Figure 2.3, it consists of peat and organic silt overlying a fine grained clay and silt unit. This borehole is located on a broad flat plain stretching between the Peel and Mackenzie Rivers. The ground surface is described in the drill hole logs (Foothills 1978) as irregular with peat tussocks and frost mounds.

The oxygen-18 profile in Figure 2.3 displays fluctuations which are too large to be the result of fractionation during freezing. The major shift to more positive $\delta 18_O$ values at a depth of 2.1 metres corresponds perfectly with the organic silt/clay and silt boundary. The waters within the lower unit have oxygen-18 concentrations which are 2 to 3‰ greater than the average for shallow groundwaters in the area. These waters are isotopically similar to what should be expected for waters of the climatically warmer Hypsithermal. Since these waters are within a clay-silt unit which is located on a large flat plain, it is unlikely that the waters are part of a former regional groundwater flow system. It is more likely that these waters have infiltrated downward from the ground surface.

Within the organic-rich units, the isotopic contents of the waters decrease to almost -24‰. Isotopic compositions in this range are approximately 2-3‰ lower than the average for shallow groundwaters in the area. Although this size of variation could result from fractionation during freezing, the shape of the profile would not support such a conclusion. The experimental work conducted by Michel (1982) and other previously reported field evidence indicates that fluctuations resulting from fractionation are completely contained within 5 to 10 cm intervals. However, it is possible that the organic-rich sediments, which contain large quantities of water, could produce such a pattern during closed system freezing. As noted earlier, the area does contain frost mounds. The frost mounds at Bear Rock, N.W.T., which were previously described by Michel and Fritz (1978b) produced a similar isotopic distribution within the massive ice core. In this core no major ice-rich zones are reported. It is unlikely, therefore, that the pattern is the result of fractionation during freezing in a closed system.

If the isotopic composition of the water in the organic silts is not the result of fractionation, then the primary control must be temperature. Since the isotopic composition is lower than that of modern groundwater, it must be from a time period when temperatures were colder than at present. The major post-Hypsithermal cold period was the Little Ice Age. Such an interpretation would be consistent with an upward aggrading permafrost table.

2.2.3 Eagle Plain Region

The Eagle Plain, lying between the Richardson and Ogilvie Mountains, is a region which was not glaciated during the Wisconsinan. It is possible, therefore, to examine isotope profiles within this region without the complication of glacial waters. However, when examining cores from low lying areas such as valley floors, the possibility of glacial meltwaters from alpine glaciation and ponded lakes during the Hypsithermal must be remembered. Within this region four cores have been examined during the present study.

Borehole 78-165 is located adjacent to the Dempster Highway just south of where the highway crosses the Eagle River. The borehole was drilled approximately 10 metres from the edge of the bank along the Eagle River valley. This bank rises several tens of metres above the valley which served as a major glacial spillway during the late-Wisconsinan period. Work by Hughes et al. (1981) indicates that deglaciation of the Peel River - Bonnet Plume Basin area to the south was underway by 16,000 years ago.

The upper 10 metres of core recovered from borehole 78-165 contains laminated organic silts with thin interbedded peat layers. Although the age of these organic silts is unknown, they are probably mid-to late-Wisconsinan and pre-spillway. Although the organic silts are ice rich, a massive ice zone at a depth of 1.1 to 1.65 metres was the only one encountered in the section. Below the organic silt is a 1.3 metre interval of silt overlying 5 metres of silt and clay.

The oxygen-18 profile shown in Figure 2.4 reveals the presence of two distinct water masses. Within the silt and clay units below 10 metres, the oxygen-18 contents are slightly more positive than modern groundwater values (δ18O=-21.5‰) for the area. The waters are considered, therefore, to be representative of a slightly warmer time period. The oxygen-18 contents of water within the organic silts varies between -26 and -27.5‰ and are approximately 6‰ more negative than modern waters in the area. A temperature estimate based on these data would indicate that these waters were recharged during a period when the annual air temperature was as much as 9° C lower than today. If such an estimate is correct, then the waters would have to be late-Wisconsinan in age. This in turn would mean that the deeper permafrost waters must either be mid-Wisconsinan in age if they are older, or that they are part of an active Holocene groundwater flow system. Crampton (1979) reported the existence of a thick interpermafrost talik within the Eagle River valley near this site and water encountered in the talik was under pressure. Thus, it is possible that the deeper water could be Holocene in age, but it is impossible at present to determine which age is correct.

Further to the southwest, borehole 78-148 was drilled on gently sloping ground approximately 3 km. east of the Ogilvie River. The stratigraphy at this site consists of peat and organic silt to a depth of 2 metres underlain by 3.5 metres of silt which overlies at least 3.3 metres of gravel. Core samples available for study do not include the gravel unit at depth.

As can be seen in Figure 2.5, the oxygen-18 profile displays a shift from modern values near surface (-20 to -22‰) to more negative values (-26 to -27‰) at depth. The water from the uppermost peat sample is considered to be partially evaporated. The $\delta 18O$ values in the range of -26 to -27‰ are similar to those in the organic silts of borehole 78-165. These values would yield a temperature estimate similar to the one previously described for borehole 78-165 and these waters are assigned, therefore, to a late-Wisconsinan age. The gradual shift to more positive values toward the surface is representative of changing climatic conditions since the late-Wisconsinan.

The lowermost sample analysed in this borehole has a much higher oxygen-18 content than the sample immediately above and is several permil greater than modern water in the area. Examination of the oxygen-18 versus deuterium plot in Figure 2.6 reveals that this sample has not been altered by secondary processes. As was the case in borehole 78-165, the water from this sample must either be mid-Wisconsinan or Holocene in age. The thick gravel unit only 0.5 metres below this sample could represent a former interpermafrost talik through which isotopically heavier Hypsithermal waters have migrated. Exchange with such waters could result in the present isotopic composition. Unfortunately, it is impossible at present to determine if this was the case.

Boreholes 78-141 and 78-142 are located further upstream along the Ogilvie River (see Figure 2.1). Core material recovered from borehole 78-141 consists primarily of organic silt with some segregated massive ice zones. The borehole is located near the river on gently sloping ground; a mountain is located immediately to the north. It is not suprising, therefore, that the isotope profile (Figure 2.7) is devoid of any major shifts throughout the 6 metre section. Active groundwater systems, known to exist in the local area, have probably destroyed any previously existing isotopic variations. The minor fluctuations which do exist are characeristic of fractionations resulting from freezing.

Borehole 78-142 is located on a hillside sloping 3 degrees westward toward the Ogilvie River. During drilling, a total of 16.45 metres of massive segregated ice was encountered between a depth of 1.25 and 19.0 metres. Peat and organic silt overlie most of the massive ice (Figure 2.8). Between the two main ice sections, a 0.9 metre zone of silty sand was encountered. Drilling was terminated after 0.5 metres of silt was cored beneath the largest ice section. Unfortunately, no samples of the ice were retained during the drilling program. Therefore, all isotopic determinations reported are for waters from the sediment-rich horizons.

In Figure 2.8, the organic-rich sediments above the massive ice can be seen to have a relatively constant oxygen-18 composition similar to modern water. The silty sand layer at a depth of 5.2 to 6.1 metres contains ice with much lower oxygen-18 concentrations (approximately -29‰). The lowermost silt at a depth of 19.0 - 19.5 metres has a δ180 value of -14.7‰ which is much more positive than present day values.

Without the isotope data for the ice sections, it becomes very difficult to interpret these fluctuations with any degree of confidence. The lowermost silt sample is characteristic of a warmer climatic period than currently exists and is more positive than would be expected for water from the Hypsithermal. Examination of the oxygen-18 - deuterium relationship for this core in Figure 2.6 reveals that the deep sample lies to the right of the meteoric water line. If this is a result of evaporation during storage, the corrected δ180 value would be around - 18‰, which would then make a Hypsithermal age reasonable. However, since there was no evidence of evaporation when the core sample was examined during processing, it is doubtful whether such an adjustment can be legitimately made to the isotopic value. It is also possible that the offset from the normal trend could be due to a minor fractionation during freezing or to some other unrecognizable effect. Regardless of how the δ180 value is manipulated, the water still must be from a climatically warmer time period than currently exists in the area.

The low concentration of oxygen-18 in the silty sand samples could be due to two possible mechanisms. The first, would be that the water contained in the sand represents conditions during the glacial maximum of the late-Wisconsinan. It should be recognized that the oxygen-18 contents of these samples are approximately 2‰ less than the samples from boreholes 78-148 and 78-165. This might be explained by local variations in the average annual isotopic composition, but no data exists with which to examine such a hypothesis.

The second hypothesis is that the contact between the massive ice and the silty sand unit represents a former permafrost table; perhaps during the Hypsithermal. Organic-rich sediments above the contact were unfrozen and water saturated. During freezing from the surface downward, the silty sand layer would have acted as a confined aquifer feeding the system. In this situation, a closed system environment of freezing, similar to that for the formation of frost blisters, could develop. This could explain both the 3.3 metres of massive ice above the silty sand layer and the very low concentration of oxygen-18 in the water of the silty sand layer. To confirm such a hypothesis would require analysis of the massive ice above the silty sand unit.

2.2.4 Summary Discussion

In all of the cores examined which display evidence of climatic variations, water from a climatically warmer period than today exists and this period is most likely the Hypsithermal. The preservation of these waters at depth indicates that the rate of groundwater migration through the permafrost is generally very slow. The two cores which did not show any indication of climatic variation were both in areas of higher topographic relief where groundwater migration is conceivably more rapid.

The low concentrations of oxygen-18 found in cores 78-148 and 78-165 most likely reflect conditions during the late-Wisconsinan. Since both cores were collected in the unglaciated region of the north-central Yukon, the complication of glacial meltwaters has been eliminated. The preservation of climatic fluctuations from the late-Wisconsinan in these cores is important, therefore, in that it supports previous interpretations of isotopic variations found in cores from the Mackenzie Valley and Mackenzie Delta. Furthermore, the oxygen-18 composition of these waters suggest that temperatures during the late-Wisconsinan were possibly as much as 9°C lower than current average annual temperatures.

Within the upper section of core 78-189, the isotope profile contains δ180 values which are more negative than present day waters, but not as negative as the late-Wisconsinan δ180 values of waters found in the cores previously described from the north-central Yukon or the Mackenzie Valley. On the basis of the isotopic compositions, the site location and the stratigraphy, these waters have been interpreted as being indicative of the Little Ice Age period. This appears to be the first clear example where waters of this age have been recognized.

Together, the cores examined during the current contract period have provided clear evidence of the preservation of climatic variations related to the late-Wisconsinan, the Hypsithermal and the Little Ice Age periods as well as the present. Provided that conditions are favourable for preservation of these climatic variations, it is possible to determine the changes which have occurred in the vicinity of a specific site through the use of stable isotopes. The elimination of climatic variations either as a result of permafrost degradation or groundwater movement is also of importance for determining the permafrost stability of the specific site.

Chapter III

Illisarvik, N.W.T.

3.1 Background

Illisarvik is located on the northern tip of Richards Island in the Mackenzie Delta (Figure 3.1). The lake was drained via an artificial channel to the coast during August of 1978. This exposed the lake bed to the atmosphere and permitted the upper several metres of the lake bed to freeze for the first time during the winter of 1978.

In May of 1979 and 1980, drilling programs were undertaken in order to collect continuous core material from various locations within the lake bed and from the surrounding basin. A total of 15 boreholes and 2 ice wedges were drilled during the 1979 program, while a total of 8 cores were collected in 1980. The location of boreholes drilled within the grid area of Illisarvik are shown in Figure 3.2. All of the data compiled up to the end of 1981 are discussed by Michel (1982), while data acquired since 1981 are reported by Michel and Fritz (1982b).

3.2 Stratigraphy

Based on the observations of other workers (Hunter et al. 1979), and an examination of core material collected during the previous studies, the stratigraphy of the basin can be divided into three primary units, capped by modern peat, as shown in Figure 3.3.

The lowermost unit encountered during drilling consists of a clean, fine to medium sand, probably of deltaic origin, with finely laminated bedding sloping at 10 to 20 degrees in some cores, and containing scattered organic fragments. This sand grades upward into a series of interbedded sand and clay-silt layers.

Above these layers is a continuous clay-silt unit containing varying proportions of sand, minor organics, and numerous stones. These stones are up to 2 cm in diameter and vary in lithology from small red shale clasts (1 to 2mm thick) to sub-rounded quartz and granite pebbles. Rampton (1971) described "a till-like material up to 15 feet thick" overlying the sand unit on Richards Island, while Mackay (1963, p. 26) reported only "a small percentage of exposures" where a thin till could be found over the sands. Mackay suggested that "where stones are lacking, the field identification of till is hazardous." Although the limit of glaciation in this portion of the Mackenzie Delta is uncertain, it appears that the Illisarvik area was not glaciated during the late-Wisconsinan (Mackay et al. 1972). At Illisarvik, this clay-silt unit locally reaches a thickness of up to approximately 2 metres. This layer may represent solifluction debris, but the widespread nature of the unit and the preponderance of stones within it suggest to the authors that perhaps the unit represents flow till material as described by Boulton (1971).

Resting on this till is a sequence of organic-rich lake silts containing mollusc fragments near the base, that grade laterally into sands near the edges of the local Illisarvik basin. These lake silts are thickest in the central portions of the basin and thin outwards. A similar organic silt soil was found above the till layer in core 79-3 at an elevation of almost 7 metres above lake level.

Radiocarbon dating of organic material was undertaken in order to provide a time frame for the history of the lake and the sediments. A ^{14}C half-life of 5,568 years was used and the radiocarbon ages have been adjusted by standardization of their 13C contents to -25‰. Some of these data are plotted on the east-west cross-section shown in Figure 3.3.

In borehole 79-12, a 30 cm thick organic unit containing sticks and plant fragments was encountered at the boundary between the till layer and the overlying organic silts. Radiocarbon dating of a portion of this organic mat (WAT-803) provided an age of 11,240 years, which places an upper limit on the age of the till.

In borehole 79-4, radiocarbon dating of organic material from samples 44 and 53 (8,720 and 17,530 yrs. respectively) demonstrates the existence of an unconformity between the lake silts and the till. The boundary has been placed between samples 50 and 51, however there appears to have been some reworking or inwashing of till material as the lake formed which results in an apparent gradational contact. To better define this contact, sample 48 was submitted for radiocarbon dating. A radiocarbon age of 9,420±140 years was determined. This would suggest that the initial formation of the lake in the vicinity of borehole 79-4 occurred approximately 9,500 radiocarbon years ago.

The dating of lake organics from various intervals in cores 79-4, 79-6 and 79-9 indicates that the lake covered most of the lake basin by 7,000 years ago. The data also indicate that the water body has existed continuously since its formation, although fluctuations in the lake level have occurred as the basin evolved.

3.3 Carbon-13 Contents of Organic Lake Silts

On the basis of 13C contents, plants can be subdivided into two major categories (Smith and Epstein 1971). Most terrestrial plants have δ13C values in the range of -24 to -34‰, while those of aquatic plants vary from -6 to -19‰. The source of the carbon for terrestrial plants is atmospheric CO_2. Aquatic plants use CO2 dissolved in the water which can be derived from the atmosphere or from the dissolution of carbonates within the sediments or bedrock.

At Illisarvik small amounts of calcite have been noted by Michel (1982). During the current investigations, the lake silt samples were pretreated in cold HCl to remove any carbonate. All samples from the underlying till were pretreated in hot HCl to remove variable amounts of dolomite as well as the calcite. Spot checks on the lake silt samples confirmed that only trace amounts of dolomite were present and did not affect the reported δ13C values. The reported

$\delta^{13}C$ values, therefore, represent the 13C contents of the plant material. During this study samples from cores 79-4, 79-6 and 80-6 have been examined and the data are presented in Appendix 3. Error limits are ±0.2‰

As shown in Figure 3.3, boreholes 79-4 and 80-6 are located adjacent to one another. Borehole 80-6 was drilled one year later when the permafrost was thicker and therefore serves as a continuation of borehole 79-4. In Figure 3.4 the sample depths for 80-6 have been adjusted on the basis of stratigraphy to correlate with sample depths for 79-4. The boundary between the lake silts and the underlying till is located at a depth of 2.5 metres.

An examination of Figure 3.4 clerly shows that a dramatic shift in the 13C contents occurs at the boundary of till and lake silts. Within the till, δ13C values are very uniform in the range of -27 to -28‰; typical of terrestrial plant material. Immediately upon entering the lake silts, the 13C contents shift into the range of -22 to -24‰ and at a depth of 1.25 metres, the 13C contents begin to shift back to a range of -27 to -29‰ There is no detectable change in the stratigraphy or composition of the lake silts at this depth. Although a complete section through the lake silts is not available from core 79-6, the core recovery was sufficient to record a similar shift in the 13C contents (Figure 3.5). In borehole 79-6, this shift occurs at a depth of approximately 2.1 metres where once again no detectable change in the stratigraphy can be found.

Despite the difference in depth at which the shift occurs in the two cores, the radiocarbon ages are similar; approximately 6,000 years B.P. The recognition of a major 13C shift occurring contemporaneously across the basin signifies a dramatic change in the evolutionary history of the lake at this time. Since the 13C variations directly reflect upon the plants growing in the vicinity of Illisarvik, this event could be related to a change in the climatic conditions of the area.

By examining the relationship between 13C and 14C contents of various organic materials in the Illisarvik basin (Figure 3.6), it is obvious that all of the terrestrial plants (peat, fibrous organic, wood fragments) have constant 13C contents in the range of -26.5 to -29.5‰, regardless of age. Those lake silts which are younger than approximately 6,000 radiocarbon years contain organics with 13C contents which are similar to those of terrestrial plants. It is reasonable, therefore, to suggest that these organics are, composed of terrestrial plant fragments which have been washed into the lake or that the organics represent shallow water plants which use atmospheric C02 and were growing in situ.

The organics in lake silts older than 6,000 radiocarbon years have 13C contents of less than -25‰. As stated previously, aquatic plants have a characteristic range of 13C values which can be as negative as -19‰. Since the δ13C values of the organic silts lie midway between the values for terrestrial plants and aquatic plants (assuming a δ13C value of -18‰), it would appear that both sources are contributing roughly an equal amount of organic material to the sediment. This conclusion implies that the reason for the shift in 13C contents of the organic lake silts is because of the presence of aquatic plants. More specifically, it implies that the relative abundance of aquatic plants to terrestrial plants was considerably greater than during the period from 6,000 years to the present.

In examining cores 79-4 and 80-6, there is a 25 to 30 cm zone immediately above the organic silt till boundary which contains a higher percentage of non-organic material than higher in the section. This zone would correspond to the period of initial lake formation when sediments would be eroding into the newly-formed depression. The low percentage of organics and the δ13C value of -24.4‰ for sample 48 of core 79-4 indicate that aquatic plants were beginning to grow in the new lake and that both the aquatic and terrestrial plants were sparse.

As shown in Figure 3.7, the terrestrial plants had δ13C values of approximately -28.5‰ (star at 11,200 yrs.) prior to the initiation of the lake. The trend in 13C contents to values slightly less than -22‰ indicates that the aquatic plants flourished in the lake and provided an increasing percentage of the organic matter to the sediments. By 7,000 years ago the trend had reversed and land plants began to dominate. Around 6,000 years B.P., the aquatic plants were providing less than 25% of the organic matter.

To explain the changes in relative contributions one could assume that the abundance of one source remained constant while the other fluctuated with time. However, it is probably more realistic to assume that the abundance of both the terrestrial and aquatic plants have varied over the past 10,000 years. Following lake drainage there was little evidence of aquatic plants on the lake bed. The question which arises, therefore, is why did the aquatic plants flourish between 6,000 and 9,500 years ago, but diminish in abundance during the past 6,000 years. The answer must be related to climate and changing water tempertures. Since the lake appears to have formed very rapidly, probably as a result of thermokarst activity, the annual air temperature must have increased dramatically prior to lake formation. This would correspond to the beginning of the Hypsithermal interval. With warmer air temperatures than today, the lake water should also have been warmer. Aquatic plants flourished in the warmer water throughout the climatic maximum, but began to diminish as the climate deteriorated.

Additional evidence for the existence of warmer waters in the basin during the early stages of the lake can be found in the presence of mollusc shells in the lower lake silts. Michel (1982) has shown that the molluscs were living in waters which were isotopically more positive (δ180 = 16‰). In addition, it was noted by Michel (1982, p. 164) that for molluscs to reproduce, the water temperature must be at least 12°C; 2°C warmer than at the time the lake was drained.

3.4 Discussion of Radiocarbon Ages

In previous discussions of the radiocarbon data, it was suggested, since near surface sediments in cores 79-4 and 79-6 produced ages of 1,500 to 2,000 years, that there was possibly a hard water age effect of 1,500 to 2,000 years for the organic silts. After reviewing the stratigraphic correlations and examining the radiocarbon data for the various types of organic, Michel (1982) concluded that this was probably not the case. Instead, it was suggested that the anomaly could be due to changing circulation patterns causing lower sedimentation rates or even erosion as a result of a major lowering of the lake level approximately 2,000 years ago.

The possibility of a hard water effect can be further examined through the use of the 13C data. In Figure 3.7, the 13C data display a continuous evolution from early lake to present lake as a result of changing contributions from the aquatic and terrestrial plants. If hard water effects are present, they should have affected only the aquatic plants since these plants could have incorporated bicarbonate ions dissolved in the water during growth. Since the bicarbonate ions are formed by dissolution of inorganic carbonates, their ^{13}C contents should be near 0‰. Therefore, the δ13C value of the aquatic plants would be closer to -12‰ rather than the -18‰ assumed for discussion purposes in the previous section. This would then reduce the maximum contribution of the aquatic plants to the organic in the sediments from 50% to about 30%, which would in turn reduce the magnitude of any hard water effect that might exist.

The greatest possibility of a hard water effect would be in the 6,000 to 9,500 year period when aquatic plants were contributing a significant proportion of the total organic matter. During this interval the error in the radiocarbon ages could be up to 10% (600 to 1,000 years) based on the ^{13}C contents. This would mean that the lake could have formed only 8,500 years ago when the worst case scenario is used.

Returning to the original anomaly of the surficial sediment dates, it is obvious from Figure 3.7 that the organic material from which these dates were determined is composed almost entirely of terrestrial plant debris. It is impossible, therefore, that a hard water effect could be responsible for these dates. Thus, it must be concluded that the ages determined are correct and that the apparent anomaly is the result of lower sedimentation rates or erosion.

Chapter IV

Summary and Conclusions

4.1 Alaska Highway

Core material was provided by Foothills Pipe Lines (Yukon) Ltd. from a borehole which encountered massive ice and clay. The oxygen-18 contents of the water within the ice and the clay are similar to modern groundwater and precipitation. Therefore, the age of the water appears to be post-Hypsithermal and the ice is considered to be segregated ice as opposed to buried glacier ice. The lack of variation in the δ18O values suggests that the freezing front has migrated slowly downward through saturated sediments. Furthermore, the supply of water to the freezing front has been sufficient to maintain a constant isotopic composition.

4.2 Dempster Highway

During the current contract period, samples from six cores have been examined. Two of these cores are located within the Peel Plain and the remaining four cores are from the unglaciated interior. In all but two cores (78-141, 78-179) evidence of past climatic variations has been detected. Most of the cores containing these variations appear to have Hypsithermal waters present at depth. On the basis of oxygen-18 contents, the waters above the Hypsithermal sections have been interpreted as being from either the Little Ice Age period (core 78-189) or the late-Wisconsinan (core 78-148). Late-Wisconsinan water in core 78-165 overlies a zone containing modern water. The characteristic δ18O values for each period are as follows:

late-Wisconsinan	-26 to -28‰
Hypsithermal	-14 to -19‰
Little Ice Age	-23 to - 24‰
Modern	-19 to -23‰

It should be noted that these ranges are only approximate. Oxygen-18 contents of late-Wisconsinan water from the Mackenzie Valley and Delta have been reported as low as -31% (Michel and Fritz 1978a), but this may be due in part to the recharge of glacial meltwaters. One must also remember that intermediate oxygen-18 contents will exist for waters recharged during the transition from one period to another.

In areas of rugged topography, the existence of active groundwater systems will result in the destruction of past climatic variations. This may occur throughout the entire profile or it may be confined to specific horizons. Unless the groundwater systems in a region are understood first, it can be difficult to interpret the isotope profiles properly. Alternatively, the isotope profiles of permafrost cores can be of great assistance in estimating the importance of groundwater migration at a specific site.

Only a tentative interpretation of the isotope data for core 78-142 can be made because of the lack of massive ice samples. It appears that the lower ice has probably formed from waters of Hypsithermal age. The uppermost massive ice zone is thought to have formed by closed system freezing in a fashion similar to frost blisters. If this is not the case, then water in the underlying silty sand unit must be late-Wisconsinan in age. This would extend the range of oxygen-18 contents of waters in the Yukon from this period to -30‰, which is similar to the Mackenzie Valley waters.

4.3 Illisarvik, N.W.T.

At Illisarvik, work has been concentrated on the ^{13}C contents of the organic-rich lake silts. Profiles for cores 79-4, 79-6 and 80-6 reveal characteristic δ13C values for the various sediments examined. These include the lake silts, the till unit and various organic-rich horizons around the lake.

The till unit underlying the lake silts contains organic streaks with relatively uniform δ13C values in the range of -27 to -28‰. The similarity in values to those of peat, fibrous organic and wood fragments (-26.5 to -29.5‰) indicates that the organic material contained within the till was in equilibrium with atmospheric CO_2 during growth. There does not appear to be any major variation in the ^{13}C contents of the terrestrial plants since the late-Wisconsinan.

The organics within the lake silts display a systematic ^{13}C variation since the lake originally formed. The δ13C values shift from near -25‰ as the lake first formed, to -22‰ between 7,000 and 9,000 years ago. They then decrease to a range of -26.5 to -29.5‰ in sediments younger than 6,000 years. These variations in 13C content are the result of a change in relative contribution from different sources.

During the early stages of lake formation (9,500 years ago), the organic material in the sediments was derived from both terrestrial plants on shore and aquatic plants growing within the lake. The contribution of aquatic plants to the organic material increased to approximately 50% prior to 7,000 years B.P. By 7,000 years ago the trend had reversed and the land plants began to dominate. The contribution of the aquatic plants was less than 25% by 6,000 years ago. Since that time, the organics in the lake silts have been derived from the terrestrial plants.

The 13C contents have also been of assistance in examining the possibility of errors in the radiocarbon ages. The lake silts which were originally thought to have possibly yielded erroneous ages are the near surface sediments recovered from boreholes 79-4 and 79-6. If the reported ages are in error, it would be due to the incorporation of radiogenically dead carbon from bicarbonate ions in the water. Since the 13C contents of these samples are similar to the terrestrial plants which do not have this potential problem, the ages are considered to be correct. This would indicate, therefore, that the apparent anomaly of too old an age in the surficial sediments is the result of lower sedimentation rates or erosion.

4.4 Suggestions for Continued Work

The work conducted at Illisarvik has proven that variations in the 13C contents of the organics do exist. A continuation of this work to additional cores within and adjacent to the lake would provide a more detailed understanding of the history of the basin. When the history of the Illisarvik basin is fully understood, it will provide important information concerning the evolution of the outer Mackenzie Delta since the late-Wisconsinan. The Illisarvik basin can also serve as a comparison for work undertaken in other parts of the Mackenzie Delta.

Within the northern Yukon, the oxygen-18 data have shown that climatic variations have been preserved. Because of the wide spacing of samples within the stratigraphic sections and the distance between boreholes, it is suggested that a detailed program be undertaken at several sites. From the data contained in this report, it is recommended that two sites be investigated.

The first is the Eagle River area (core 78-165). This site provides the opportunity of examining late-Wisconsinan permafrost as well as the aggradation of permafrost in a meandering stream channel. This site would also provide an excellent opportunity to investigate the migration of water through interpermafrost taliks.

The second site is at the ice-rich location of borehole 78-142. This site would provide an opportunity to examine isotopic variations within a massive segregated ice body at depth. In addition, the possibility of forming massive ice as a result of freezing in a closed system could be investigated at the same location. A comparison of the two ice types would provide useful information for distinguishing the process of ice formation in other areas.

The Alaska Highway site of borehole 82-02-211(2) would also provide an excellent opportunity to investigate segregated ice which is currently forming. Detailed instrumentation of the site to measure the rate of freezing, rate of groundwater migration and the ground temperature distribution could be installed at the site for long term monitoring. An examination of this type would be beneficial for other geotechnical investigations of ground ice.

FIGURE CAPTIONS

Figure 2.1	Location map of borehole sites along the Dempster Highway.
Figure 2.2	Variation of ^{18}O contents with depth in porewater for core 78-179. Soil types are: 1-peat, 2-organic silt and clay, 3-silt, 4-gravel, 5-organic silt, peat and sand, 6-silt and clay.
Figure 2.3	Variation of ^{18}O contents with depth in porewater for core 78-189. Soil types are: 1-peat, 2-organic silt, 3-clay and silt.
Figure 2.4	Variation of ^{18}O contents with depth in porewater for core 78-165. Soil types are: 1-organic silt, 2-ice, 3-silt, 4-silt and clay, 5-shale.
Figure 2.5	Variation of ^{18}O contents with depth in porewater for core 78-148. Soil types are: 1-peat, 2-organic silt, 3-silt and stones.
Figure 2.6	Relationship between ^{2}H and ^{18}O contents for cores 78-142 and 78-148.
Figure 2.7	Variation in oxygen-18 content with depth for core 78-141. Soil types are: 1-organic silt and peat, 2-ice, 3-organic silt and clay.
Figure 2.8	Variation of ^{18}O contents with depth in porewater for core 78-142. Soil types are: 1-peat and organic silt, 2-ice, 3-sand, 4-silt.
Figure 3.1	Location of Illisarvik in the Mackenzie Delta.
Figure 3.2	Location of boreholes drilled within the grid area of Illisarvik in May of 1979 and 1980.
Figure 3.3	True east-west stratigraphic cross-section of Illisarvik and location of boreholes drilled along the section. Individual radiocarbon dates shown. Vertical exaggeration is 37.5 X.

Figure 3.4 Variation in ^{13}C content of organic fraction with depth for cores 79-4 and 80-6. Soil types are: 2b-organic silt, 3-clay silt with stones.

Figure 3.5 Variation in ^{13}C content of organic fraction with depth for core 79-6. Soil type is: 2b-organic silt.

Figure 3.6 Relationship between ^{13}C and ^{14}C contents for various types of organic material at Illisarvik.

Figure 3.7 Relationship between ^{13}C contents and time for organic fraction of lake silts in cores 79-4, 79-6 and 80-6. ^{14}C dated samples o, updated samples ·, basal organic mat in core 79-12 *.

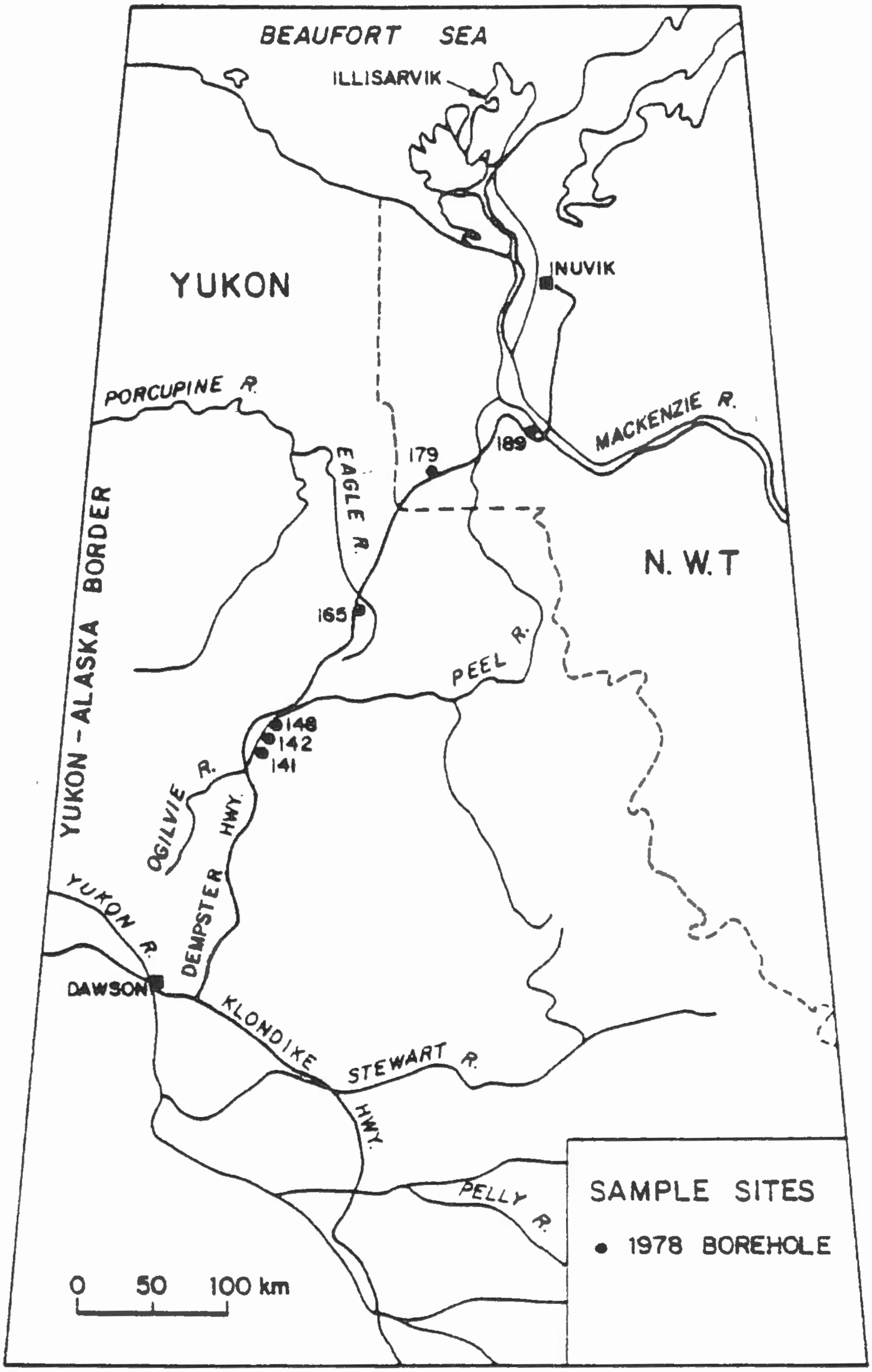


Figure 2.1 Location map of borehole sites along the Dempster Highway

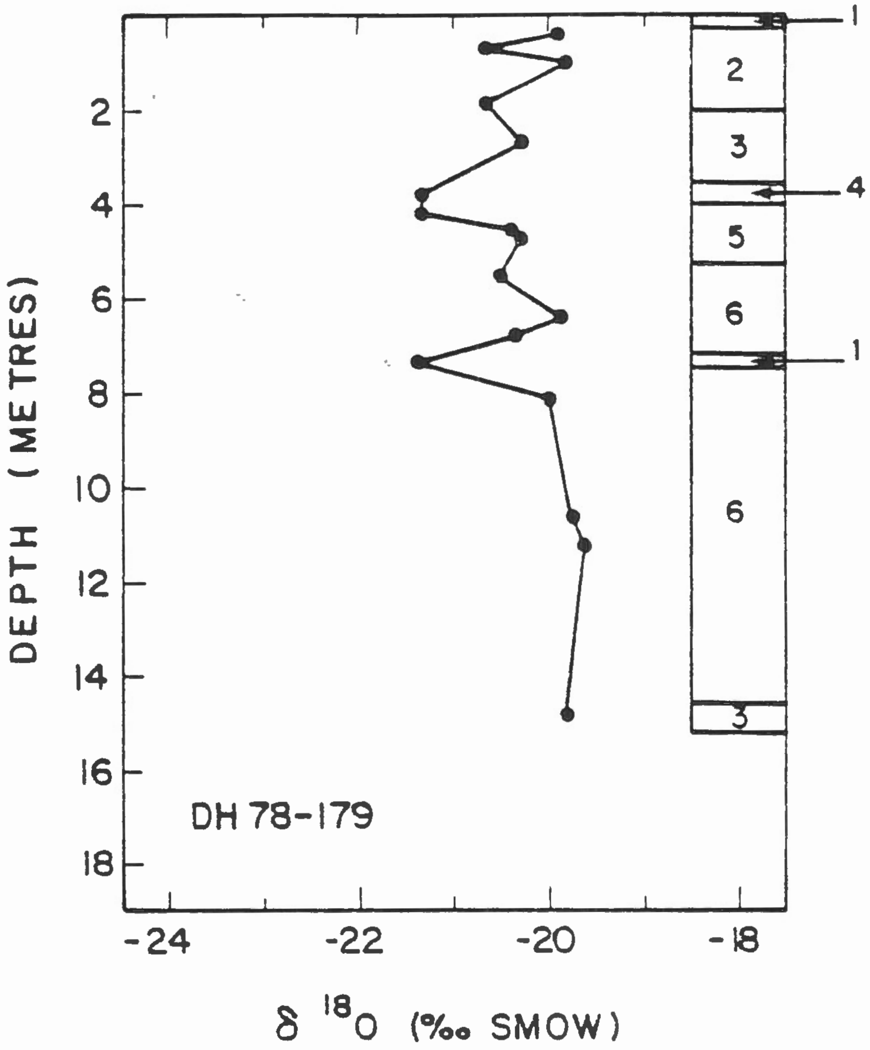


Figure 2.2 Variation of ^{18}O contents with depth in pore-water for core 78-179. Soil types are: 1-peat, 2-organic silt and clay, 3-silt, 4-gravel, 5-organic silt, peat and sand, 6-silt and clay.

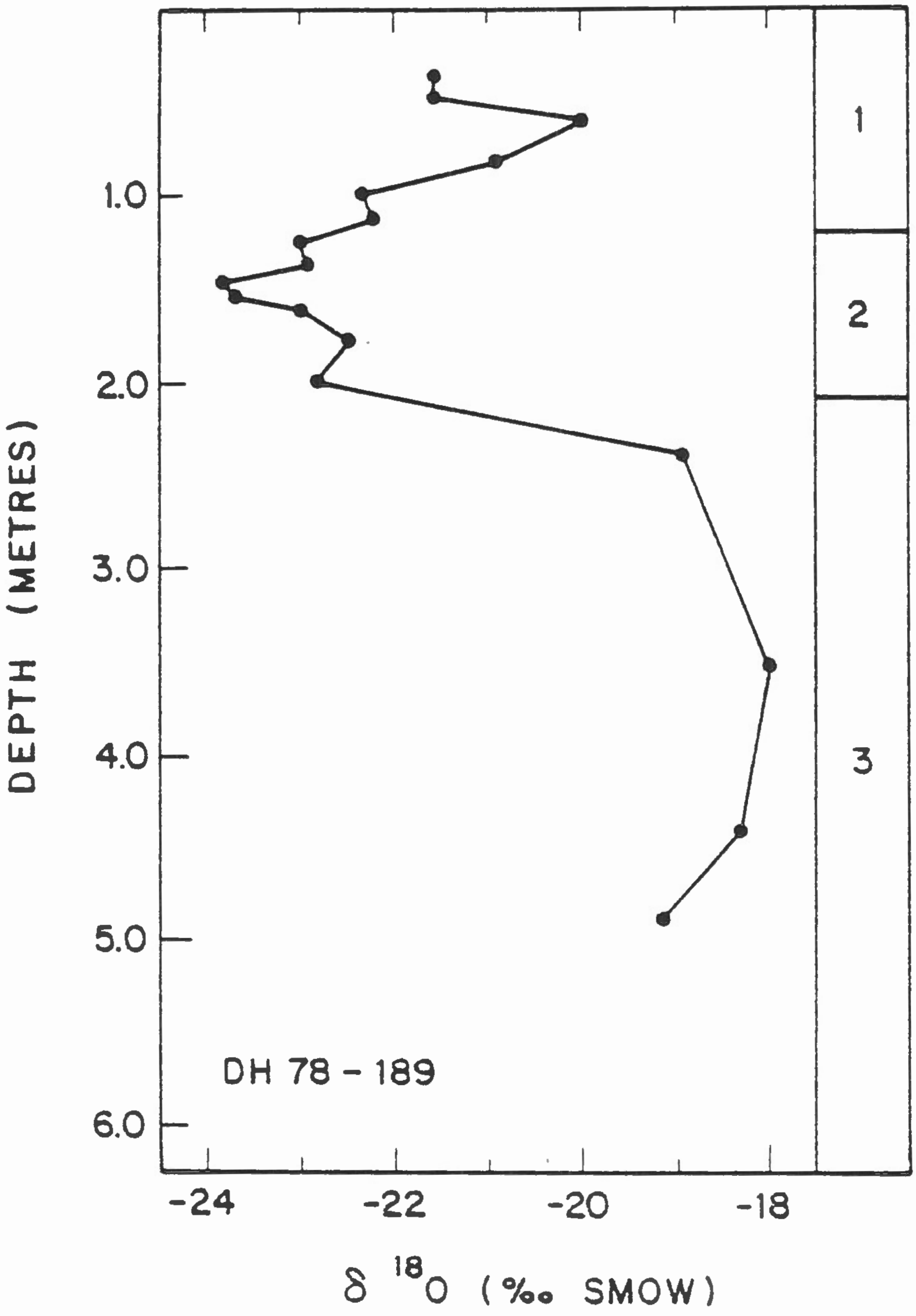


Figure 2.3 Variation of ^{18}O contents with depth in porewater for core 78-189. Soil types are: 1-peat, 2-organic silt, 3-clay and silt.

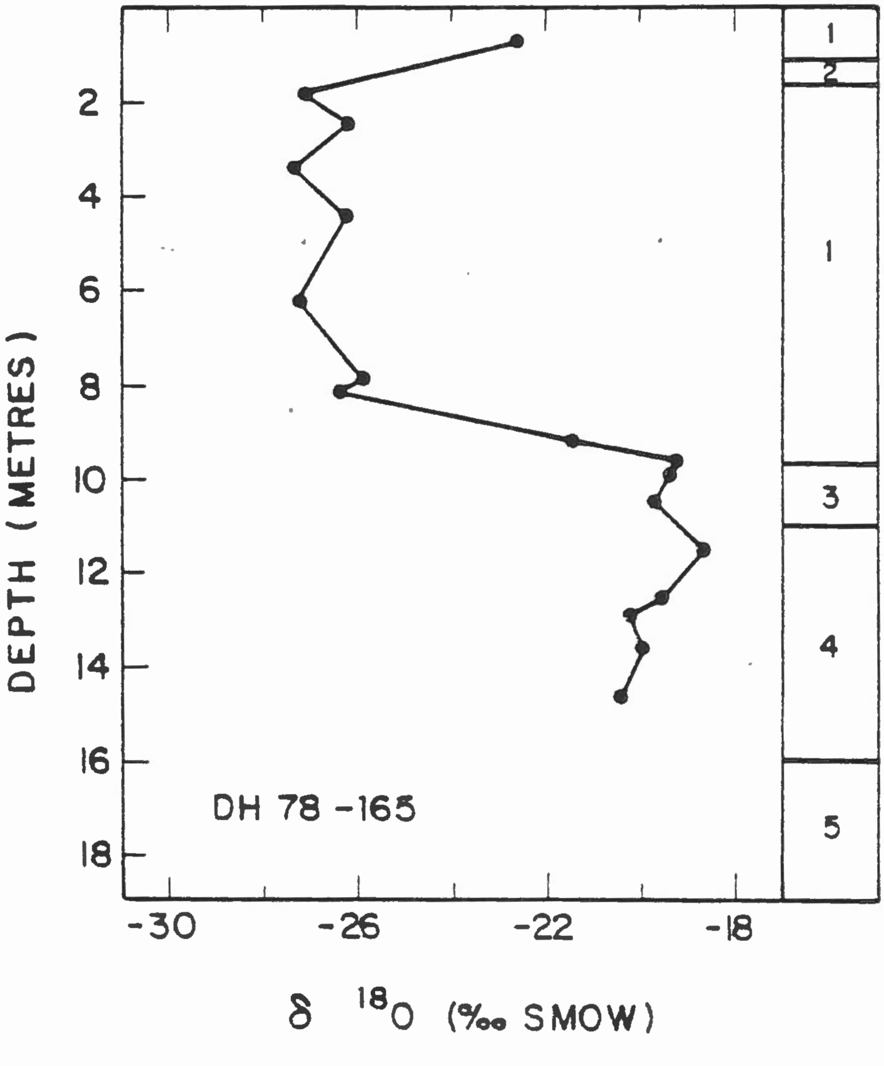


Figure 2.4 Variation of ^{18}O contents with depth in porewater for core 78-165. Soil types are: 1-organic silt, 2-ice, 3-silt, 4-silt and clay, 5-shale.

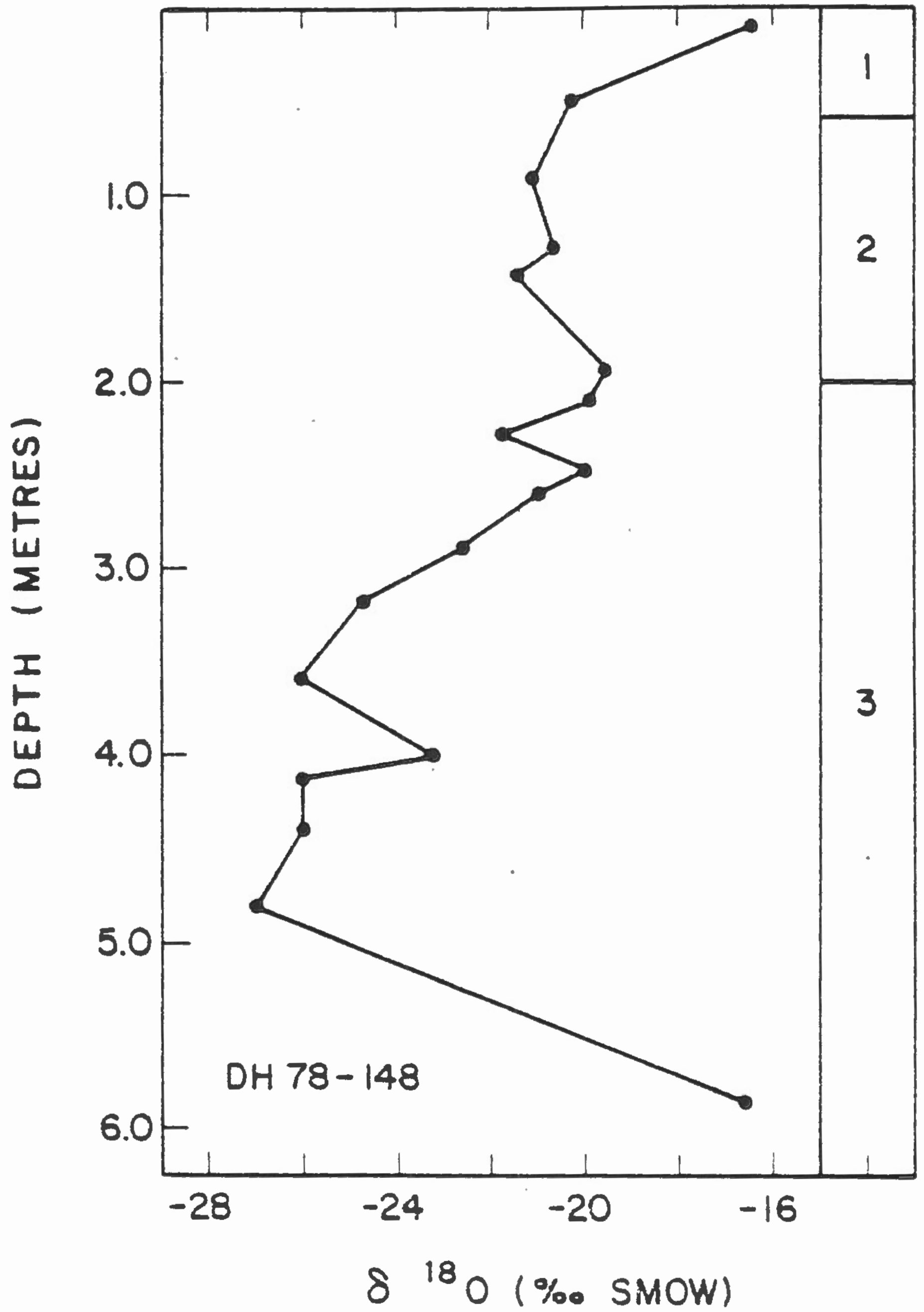


Figure 2.5 Variation of ^{18}O contents with depth in porewater for core 78-148. Soil types are: 1-peat, 2-organic silt, 3-silt and stones.

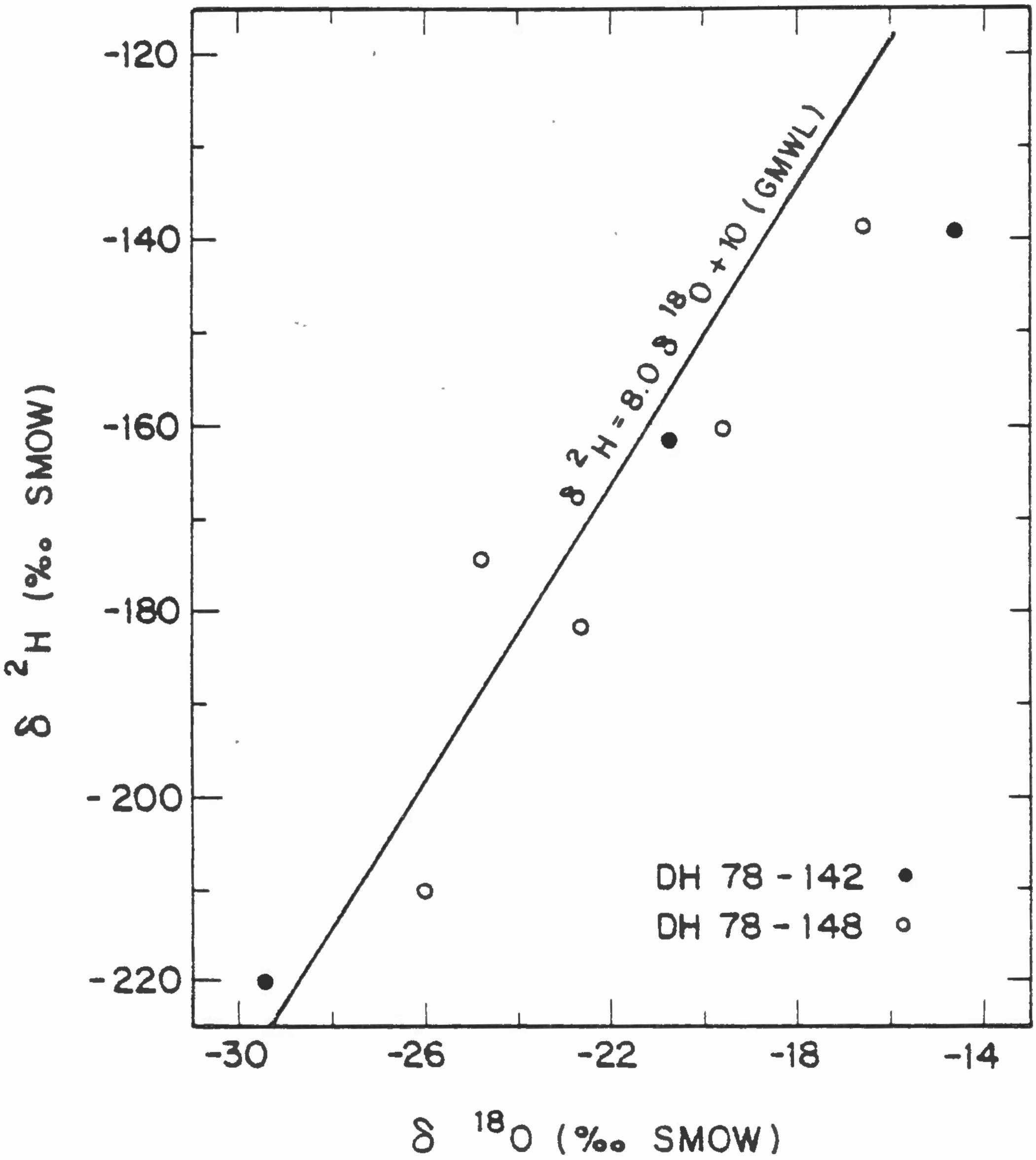


Figure 2.6 Relationship between ^{2}H and ^{18}O contents for cores 78-142 and 78-148.

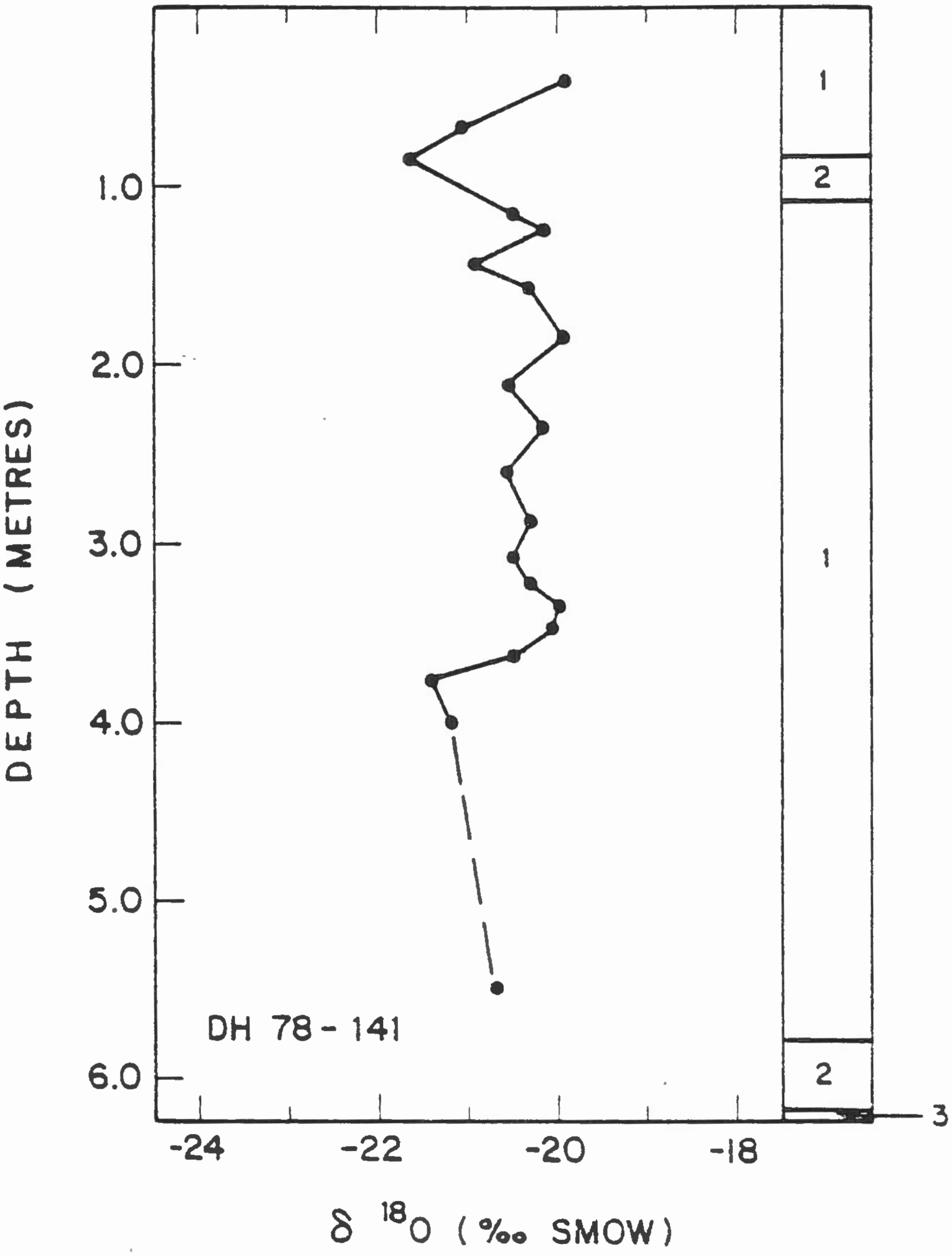


Figure 2.7 Variation of oxygen-18 content with depth for core 78-141. Soil types are: 1-organic silt and peat, 2-ice, 3-organic silt and clay.

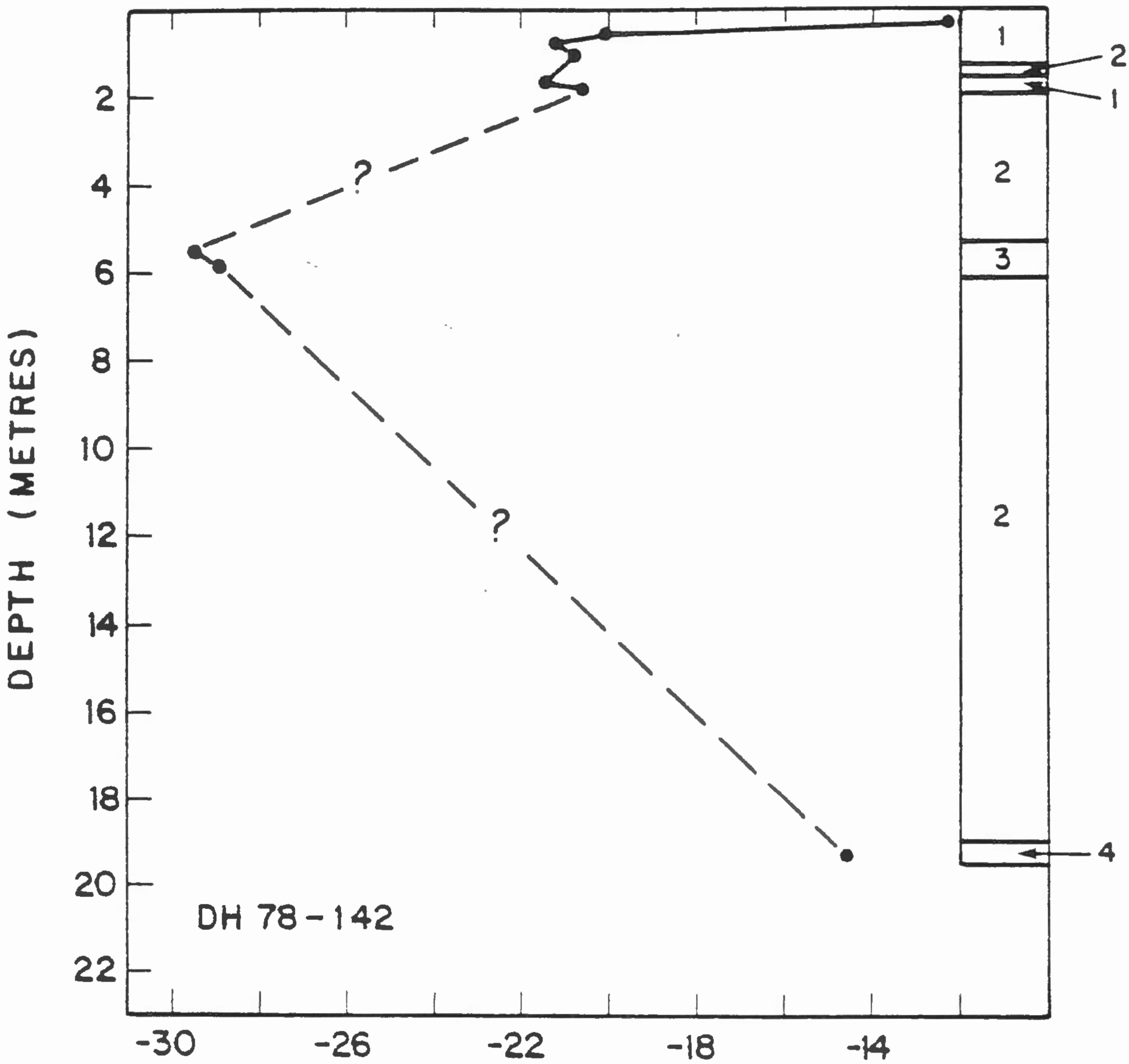


Figure 2.8 Variation of ^{18}O contents with depth in porewater for core 78-142. Soil types are: 1-peat and organic silt, 2-ice, 3-sand, 4-silt.

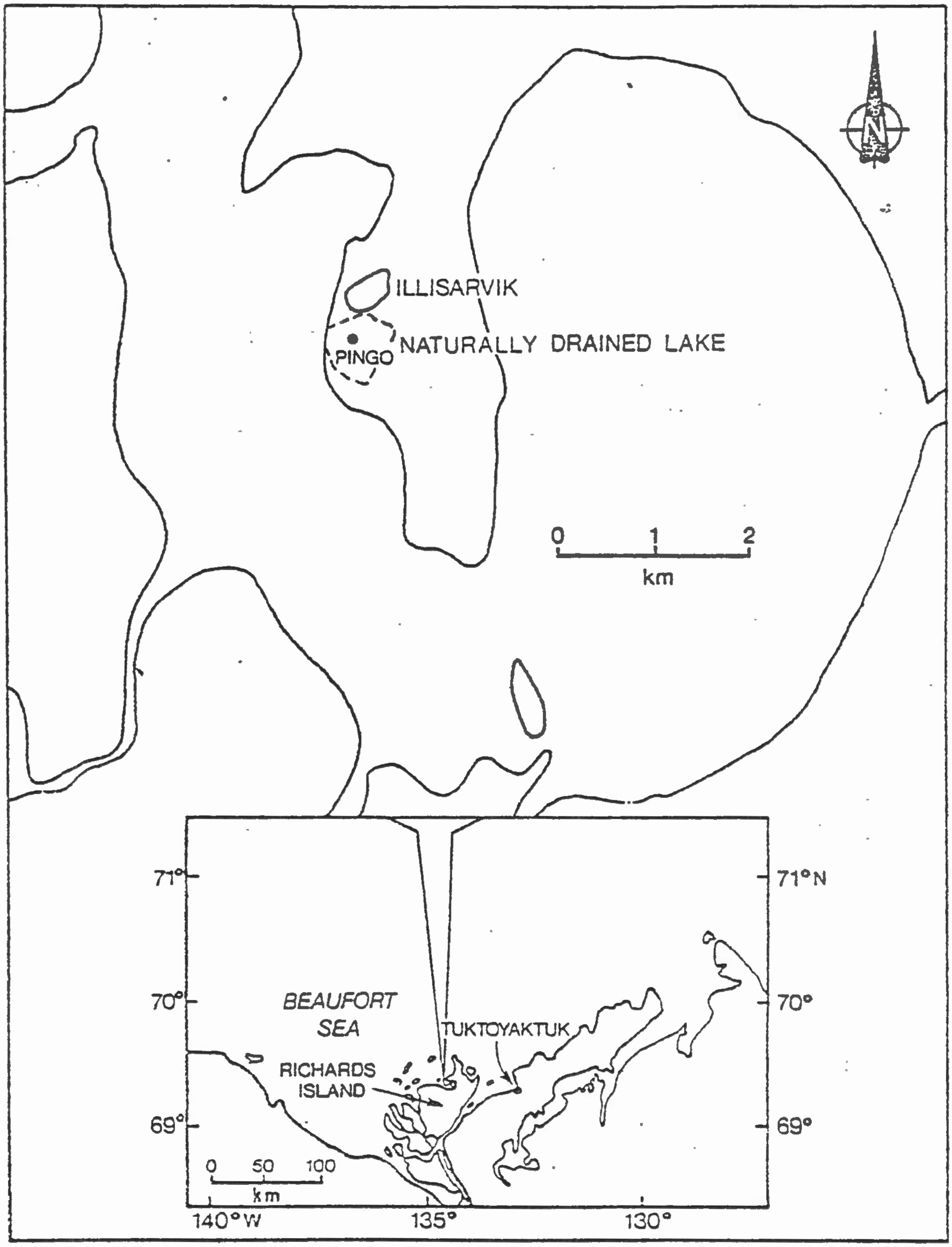


Figure 3.1 Location of Illisarvik in the Mackenzie Delta.

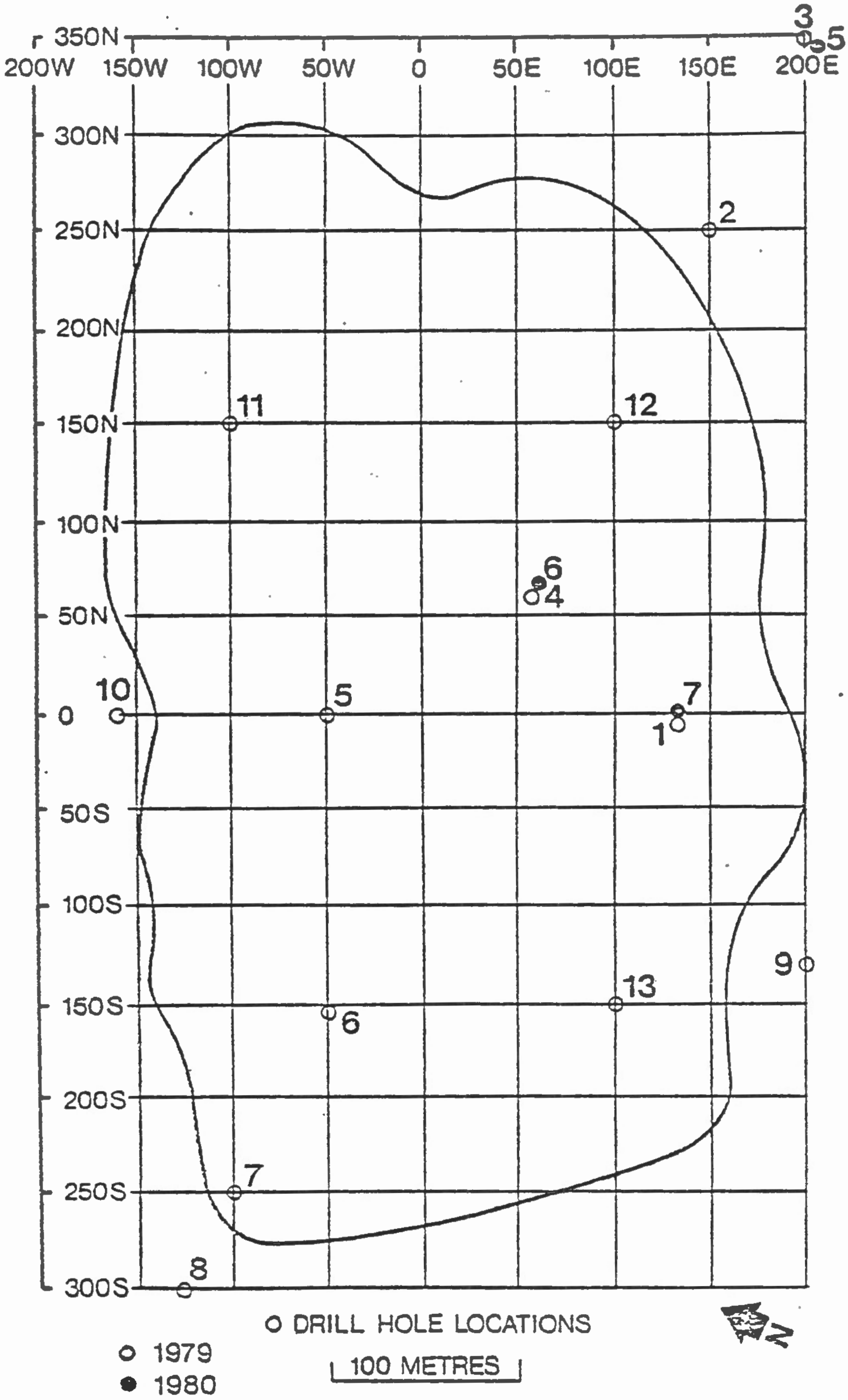


Figure 3.2 Location of boreholes drilled within the grid area of Illisarvik in May of 1979 and 1980.

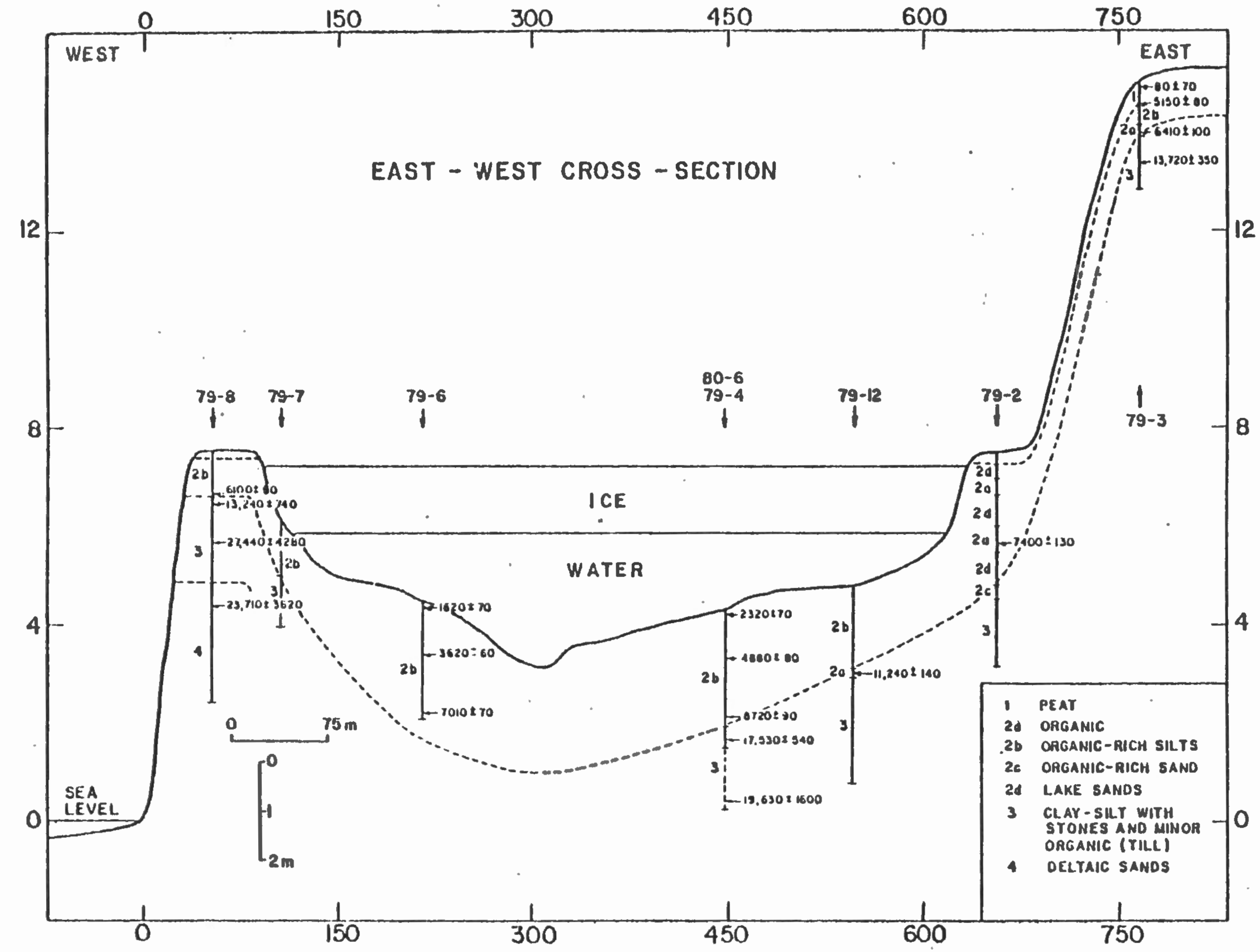
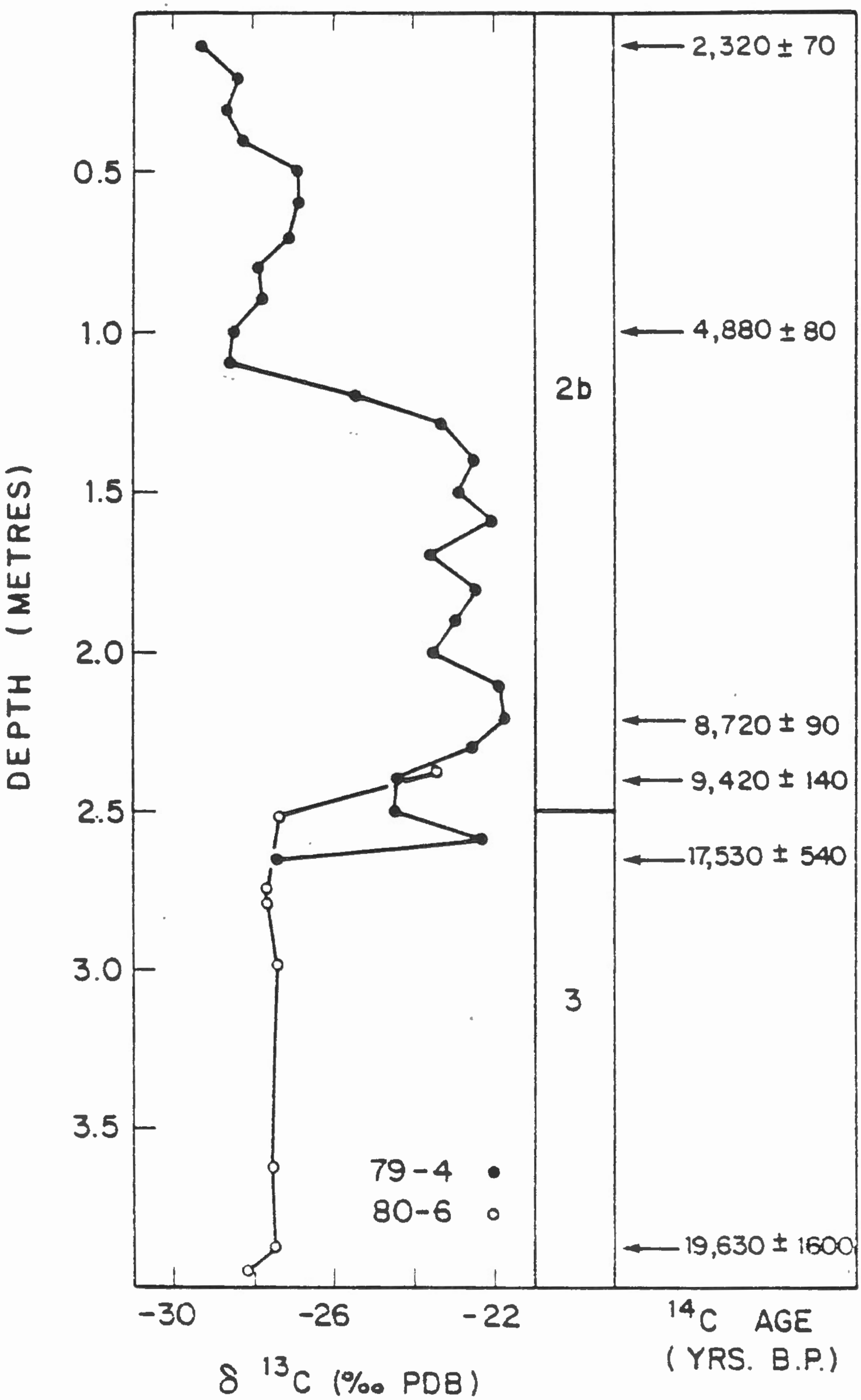


Figure 3.3 True east-west stratigraphic cross-section of Illisarvik and location of boreholes drilled along the section. Individual radiocarbon dates shown. Vertical exaggeration is 37.5x.



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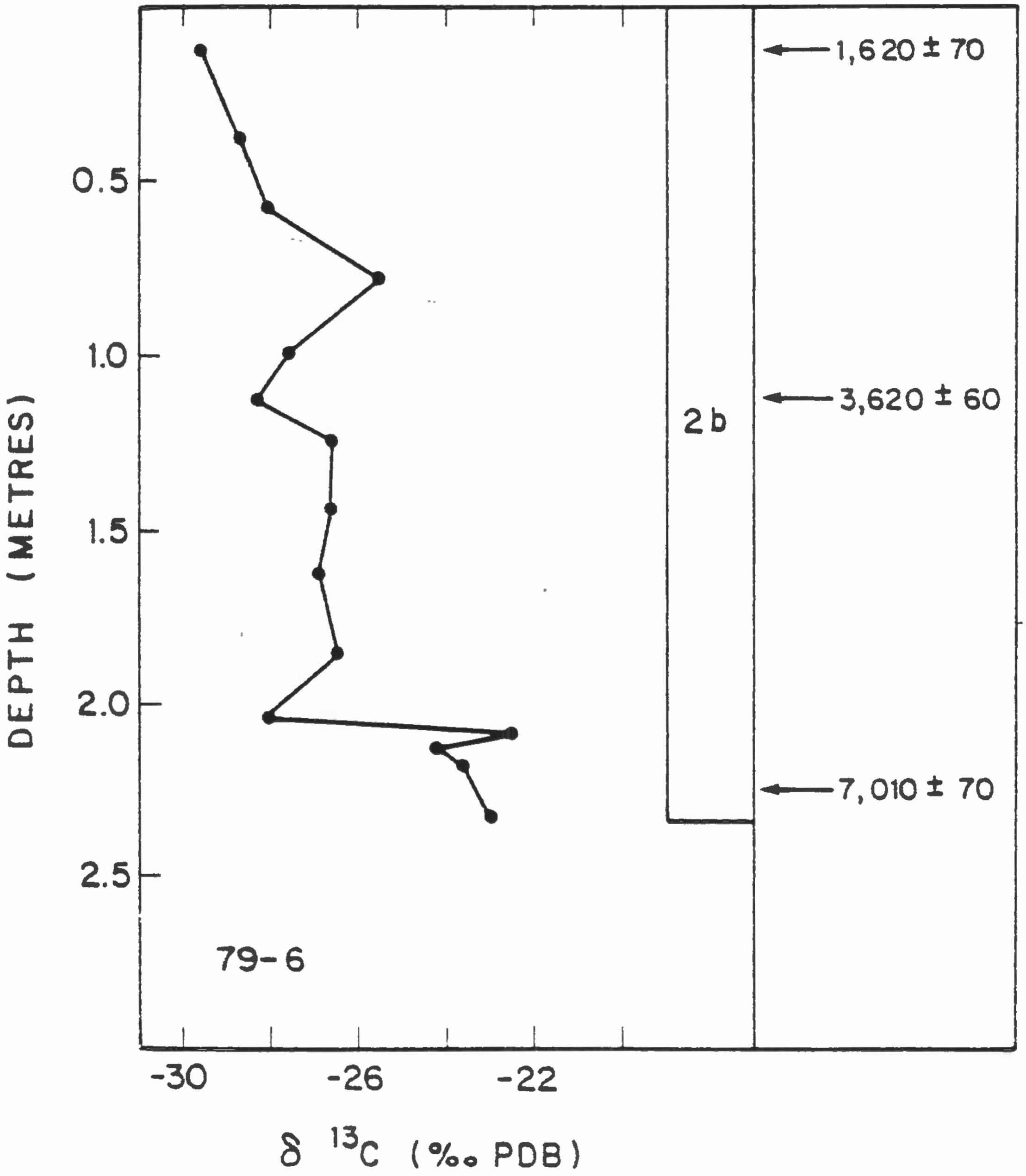

Figure 3.5 Variation in ^{13}C content of organic fraction with depth for core 79-6. Soil type is: 2b-organic silt.

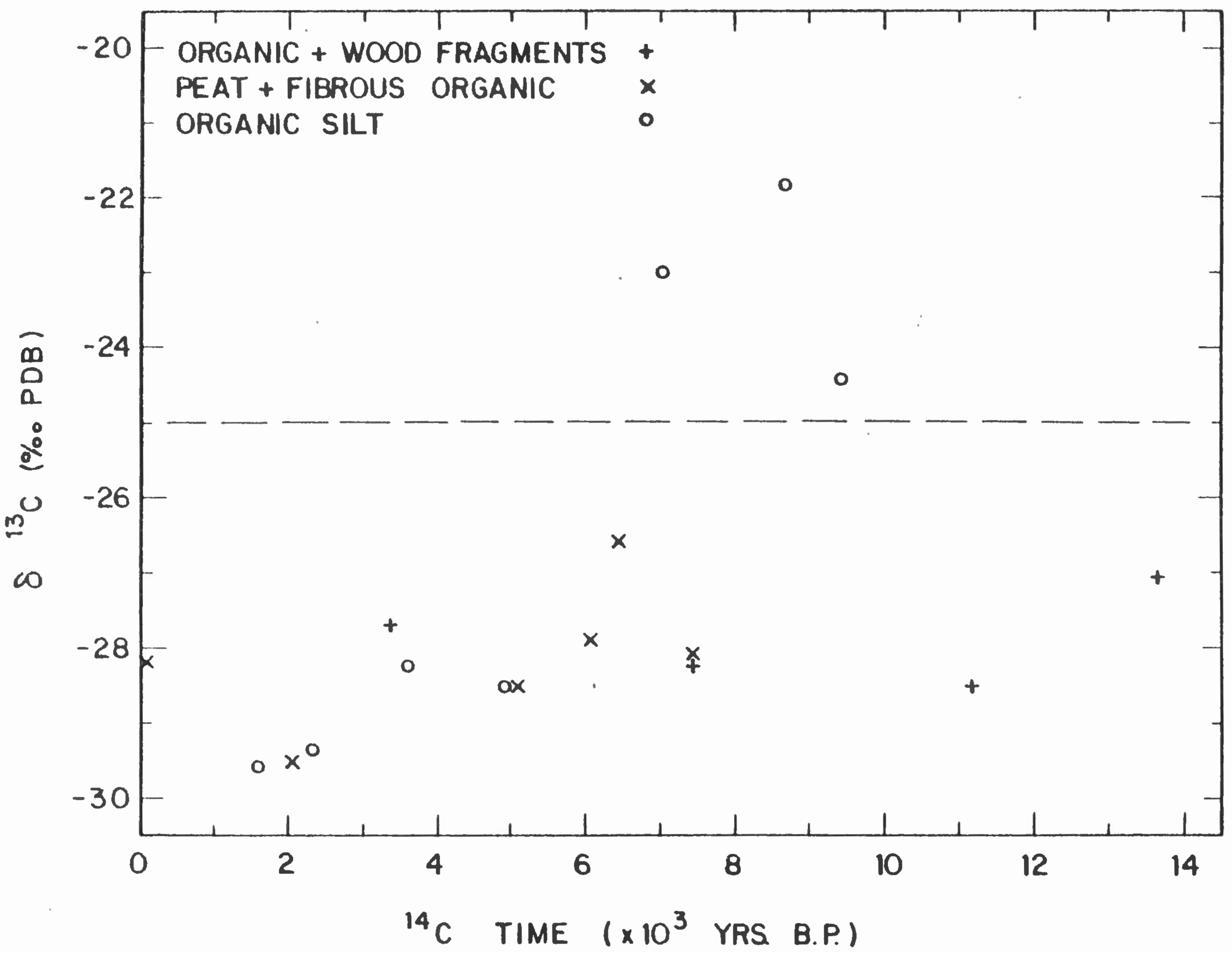

Figure 3.6 Relationship between ^{13}C and ^{14}C contents for various types of organic material at Illisarvik.

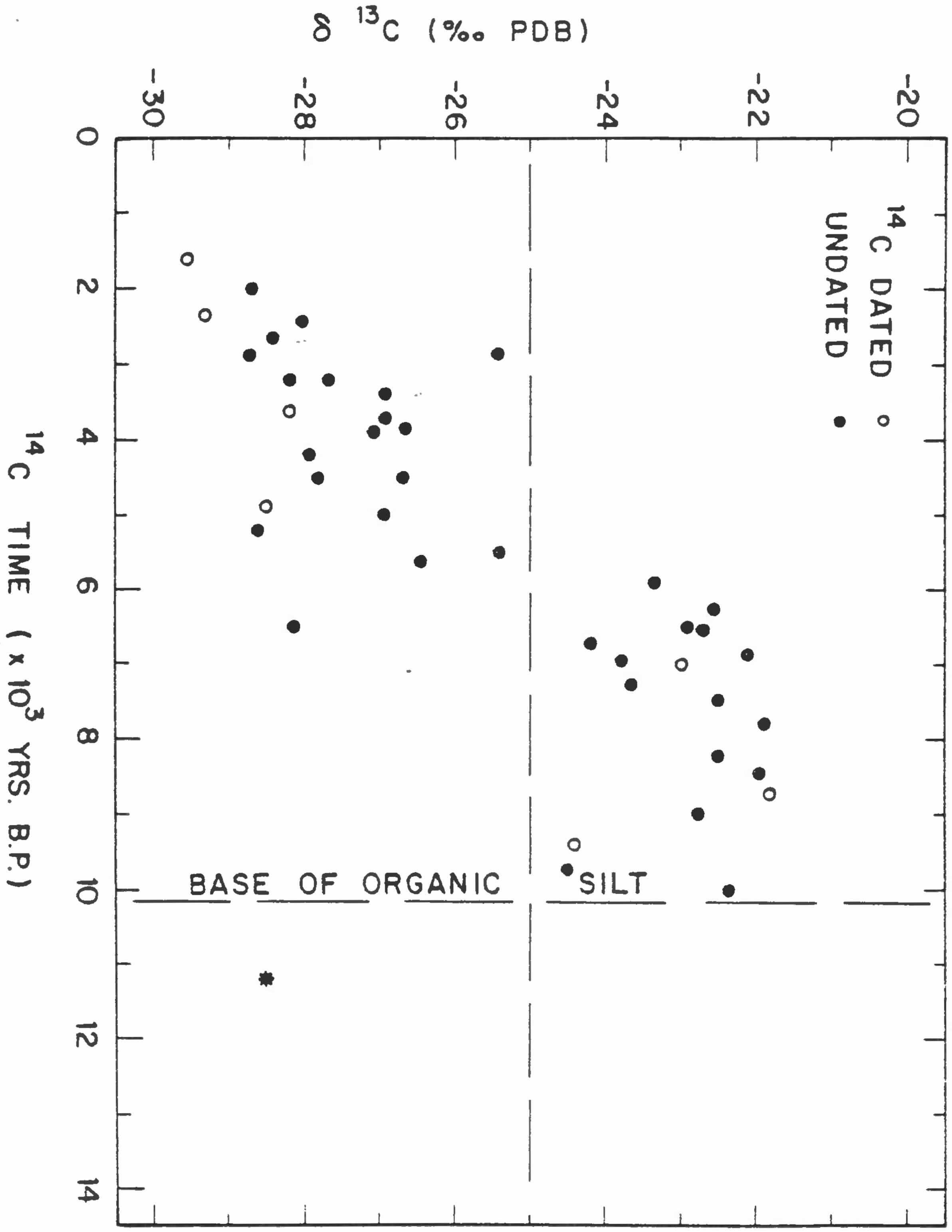

Figure 3.7 Relationship between ^{13}C contents and time for organic fraction of lake silts in cores 79-4, 79-6 and 80-6. ^{14}C dated samples o, updated samples · , basal organic mat in core 79-12 *.

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APPENDIX 1

^{18}O DATA FOR CORE 82-02-211(2)
FROM THE PROPOSED
ALASKA HIGHWAY PIPELINE ROUTE

82-02-211(2)

SAMPLE NO.	DEPTH(M)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
C-1-1	1.2 - 1.4	-22.6
C-3-1	3.0 - 3.1	-21.4
C-3-2	3.1 - 3.2	-21.5
B-2-1	4.1 - 4.45	-21.9/-21.9
2-2	4.1 - 4.45	-21.9
2-3	4.1 - 4.45	-21.0/-20.9
2-4a	4.1 - 4.45	-21.5
2-4b	4.1 - 4.45	-21.6
2-5	4.1 - 4.45	-21.5
2-6	4.1 - 4.45	-21.5
2-7a	4.1 - 4.45	-21.3/-21.4
2-7b	4.1 - 4.45	-21.5/-21.2
2-8a	4.1 - 4.45	-21.4
2-8b	4.1 - 4.45	-21.7
2-9a	4.1 - 4.45	-21.4
2-9b	4.1 - 4.45	-19.1
2-10a	4.1 - 4.45	-21.6
2-10b	4.1 - 4.45	-21.5
B-3-1	5.5 - 5.6	-21.2
3-2	5.5 - 5.6	-20.2
3-3	5.5 - 5.6	-21.2/-21.5
B-4-1	6.3 - 6.4	-22.0
4-2	6.3 - 6.4	-22.2
4-3	6.3 - 6.4	-22.1/-21.9
B-5-1	7.4 - 7.5	-21.9
5-2	7.4 - 7.5	-21.8
5-3	7.4 - 7.5	-21.8
5-4	7.4 - 7.5	-22.0

APPENDIX 2

^{18}O AND ^{2}H DATA FOR CORES FROM THE PROPOSED DEMPSTER HIGHWAY PIPELINE ROUTE

78-141

SAMPLE NO.	DEPTH (M)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
2	0.2 - 0.6	-19.9
3a	0.6 - 0.75	-21.1
3b	0.75 - 0.9	-21.7
4a	1.1 - 1.2	-20.5
4b	1.2 - 1.3	-20.2
5a	1.35 - 1.5	-20.9
5b	1.5 - 1.65	-20.3
6	1.65 - 1.9	-19.9
7	1.9 - 2.25	-20.6
8	2.25 - 2.45	-20.2
9	2.45 - 2.7	-20.6
10	2.7 - 3.05	-20.3
11a	3.05 - 3.2	-20.5
11b	3.2 - 3.3	-20.3
12a	3.3 - 3.4	-20.0
12b	3.4 - 3.55	-20.1
13a	3.55 - 3.7	-20.5
13b	3.7 - 3.85	-21.4
14	3.85 - 4.2	-21.2
15	5.45 - 5.65	-20.8/-20.6

78-142

SAMPLE NO.	DEPTH (M.)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
1	0.0 - 0.4	-12.2
2a	0.4 - 0.6	-20.3/-20.0
2b	0.6 - 0.8	-21.2
3	0.8 - 1.2	-20.8
4a	1.55 - 1.7	-21.5/-21.6
4b	1.7 - 1.8	-20.6
5	5.4 - 5.7	-29.5
6	5.7 - 5.9	-28.9
7	19.0 - 19.5	-14.5/-14.7

78-148

SAMPLE NO.	DEPTH (M.)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
1	0.0 - 0.2	-16.5
2	0.4 - 0.6	-20.3
3	0.8 - 1.0	-21.1
4a	1.2 - 1.35	-20.7
4b	1.35 - 1.5	-21.4
5	1.9 - 2.05	-19.6
6	2.05 - 2.2	-19.9/-19.8
7	2.2 - 2.35	-21.8
8	2.35 - 2.55	-20.0
9	2.55 - 2.7	-21.0
10	2.7 - 3.05	-22.7
11	3.05 - 3.4	-24.8
12	3.4 - 3.85	-26.0/-26.2
13	3.95 - 4.05	-23.2
14a	4.05 - 4.3	-26.1/-25.9
14b	4.3 - 4.5	-26.0
15	4.65 - 4.95	-26.5
16	5.75 - 5.95	-16.6

78-165

SAMPLE NO.	DEPTH (M.)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
2	0.65 - 1.0	-22.5/-22.8
3	1.75 - 2.1	-27.2/-27.0
4	2.3 - 2.6	-26.2
5	3.15 - 3.55	-27.3
6	4.15 - 4.45	-26.2
7	6.15 - 6.3	-27.2
8a	7.85 - 8.0	-25.9
8b	8.0 - 8.2	-26.4
9	9.1 - 9.3	-21.5
10a	9.5 - 9.65	-19.2
10b	9.65 - 9.8	-19.3
11	10.3 - 10.6	-19.7
12	11.35 - 11.6	-18.7
14	12.4 - 12.7	-19.6/-19.7
15	12.7 - 13.05	-20.2
16	13.45 - 13.8	-20.0
17	14.4 - 14.75	-20.4

78-179

SAMPLE NO.	DEPTH (M.)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
3	0.3 - 0.5	-19.9
4	0.5 - 0.8	-20.7
5	0.8 - 1.05	-19.8
6	1.8 - 2.0	-20.7
7	2.7 - 2.95	-20.3
9a	3.8 - 4.0	-21.3
9b	4.0 - 4.15	-21.4/-21.4
10a	4.45 - 4.6	-20.4
10b	4.6 - 4.7	-20.3
11	5.4 - 5.6	-20.4/-20.6
12	6.2 - 6.45	-19.8
13	6.75 - 6.95	-20.3
14	7.25 - 7.5	-21.4
15	8.05 - 8.25	-19.9/-20.0

78-179 Continued

SAMPLE NO.	DEPTH (M.)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
18	10.5 - 10.8	-19.7/-19.8
19	11.0 - 11.3	-19.6
21	14.7 - 15.15	-19.8

78-189

SAMPLE NO.	DEPTH (M.)	$\delta^{18}O$ ($^0/_{00}$ SMOW)
2a	0.3 - 0.4	-21.6
2b	0.4 - 0.5	-21.6
2c	0.5 - 0.7	-20.0
3a	0.7 - 0.9	-20.9
3b	0.9 - 1.1	-22.3
3c	1.1 - 1.2	-22.2
4a	1.2 - 1.3	-23.0/-22.9
4b	1.3 - 1.4	-22.9
4c	1.4 - 1.5	-23.8
4d	1.5 - 1.6	-23.7/-23.7
4e	1.6 - 1.65	-23.0
5a	1.65 - 1.9	-22.5
5b	1.9 - 2.1	-22.8
6	2.2 - 2.65	-18.9
7	3.45 - 3.65	-18.0
9	4.1 - 4.7	-18.3
10	4.7 - 5.1	-19.2

DEUTERIUM DATA

CORE NO./SAMPLE NO.	DEPTH (M.)	$\delta^{18}O$ ($^0/_{00}$ SMOW)	$\delta^{2}H$ ($^0/_{00}$ SMOW)
78-142-3	0.8 - 1.2	-20.8	-162
-5	5.4 - 5.7	-29.5	-220
-7	19.0 - 19.5	-14.5/-14.7	-139
78-148-5	1.9 - 2.05	-19.6	-161
-10	2.7 - 3.05	-22.7	-183
-11	3.05 - 3.4	-24.8	-174
-14b	4.3 - 4.5	-26.0	-210
-16	5.75 - 5.95	-16.6	-138
78-170-1	0.0 - 0.2	-15.2	-133
-2	-.25	-13.6	-104
-9	4.0 - 4.5	-12.1	-120

APPENDIX 3

^{13}C DATA FOR CORES FROM ILLISARVIK, N.W.T.

ORGANIC FRACTION

79-4

SAMPLE NO.	DEPTH (CM)	$\delta^{13}C$ ($^0/_{00}$ PDB)
2	5 - 10	-29.3
4	15 - 20	-28.4
6	25 - 30	-28.7
8	35 - 40	-28.2
10	45 - 50	-26.9
12	55 - 60	-26.9
14	65 - 70	-27.1
16	75 - 80	-27.9
18	85 - 90	-27.8
20	95 - 100	-28.5
22	105 - 110	-28.6
24	115 - 120	-25.4
26	125 - 130	-23.3
28	135 - 140	-22.6
30	145 - 150	-22.9
32	155 - 160	-22.1
34	165 - 170	-23.7
36	175 - 180	-22.5
38	185 - 190	-22.0/-21.7
40	195 - 200	-22.5
42	205 - 210	-21.9
44	215 - 220	-21.8
46	225 - 230	-22.7
48	235 - 240	-24.4
50	245 - 250	-24.5
52	255 - 260	-22.3
53	265 - 270	-27.4

79-6

SAMPLE NO.	DEPTH (CM)	$\delta^{13}C$ ($^0/_{00}$ PDB)
3	11 - 17	-29.6
7	35 - 40	-28.7
12	55 - 60	-28.1/-28.0
16	75 - 80	-25.4
20	95 - 100	-27.7
23	110 - 115	-28.2
25	120 - 125	-26.7
29	140 - 145	-26.7
33	160 - 165	-26.9
37	180 - 185	-26.4
41	200 - 205	-28.1
42	205 - 210	-22.7
43	210 - 215	-24.2
44	215 - 220	-23.8
45	230 - 235	-23.0

80-6

DEPTH (CM)	$\delta^{13}C$ ($^0/_{00}$ PDB)
204 - 208	-23.5
224 - 229	-27.4
245 - 250	-27.7
250 - 255	-27.7
270 - 275	-27.4
334 - 339	-27.4/-27.8
360 - 370	-28.1