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ENVIRONMENTAL ISOTOPES IN PERMAFROST RELATED WATERS ALONG TWO PROPOSED PIPELINE ROUTES

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ABSTRACT

The report describes a preliminary study of oxygen and hydrogen isotope distribution with depth in five cores from the Mackenzie Valley and one from the Keewatin area.

RÉSUMÉ

Le rapport décrit une étude préliminaire de la distribution, en fonction de la profondeur, des isotopes d'oxygène et d'hydrogène dans cinq carottes de la Vallée du Mackenzie et une de la région de Keewatin.

Summary

Water from samples representing five cores, collected along the Mackenzie Valley Corridor, was analysed for its oxygen-18 and tritium contents. Sampling in these cores was done at one foot intervals near the surface and at five foot intervals at depth. The core from a sixth hole at Norman Wells was sectioned and analysed at 2 to 3 cm intervals. In all cases, tritium was found only at the surface and no measurable amounts were detected below about 3 meters. Similarily the ^{18}O contents decreased from about $\delta^{18}O$ = -23 ^{o}/oo SMOW at the surface to about $\delta^{18}O$ = -31 o/oo SMOW at depth. This change cannot be related to isotope fractionation effects and is interpreted as an age difference whereby the deep inactive permafrost is possibly as much as 7,000 to 10,000 years old. The tritium and ^{18}O data thus enable one to distinguish between active and inactive permafrost. The depth of the active permafrost appears to be roughly related to the grain size of the soil whereby the active zone tends to be deeper in soils with higher clay contents.

Résumé

L'eau provenant des échantillons de cinq carottes, obtenues le long du corridor de la valleé du Mackenzie, fut analyseé pour son contenu d'oxygène - 18 et de tritium. Les carottes furent échantilloneés par intervalles d'un pied, prés de la surface, et de cinq pieds, en profondeur. Un sixième carotte, venant d'un trou à Norman Wells, fut sectionneé et analyseé tous les 2 à 3 cm. Dans chaque cas le tritium ne fut repéré qu'en surface, n'ayant pas été décelé en quantité mesurable passé une profondeur de trois mètres. Le contenu d'^{18}O a également diminué d'une valeur de $\delta^{18}O$ = -23^{o}/oo SMOW en surface à une valeur de $\delta^{18}O$ = -31^{o}/oo SMOW en profondeur. Ce changement ne peut pas être attribué aux effets du fractionnement isotopique et on l'interprète comme étant le résultat d'une différence d'âge, le pergélisol inactif et profond étant âgé d'au moins 7,000 à 10,000 ans. Les valeurs de tritium et d'^{18}O permettent

ainsi de faire la distinction entre le pergélisol actif et inactif. L'épaisseur du pergélisol actif semble être relié à la granulométrie du sol, la zone active étant plus profonde dans les sols avec un plus haut pourcentage d'argile.

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ACKNOWLEDGEMENTS

Thanks are extended to Dr. F. C. Yip of Foothills Pipe Lines Ltd. and Mr. J. Roy of Klohn Leonoff Consultants Limited for making the core available for study and for providing the necessary geotechnical data. Mr. T. Normet of Polar Gas Limited gave permission to visit the field laboratory in Churchill. Mr. G. Miskin of EBA Engineering assisted in the sampling of the core in Churchill.

The assistance of Dr. R. O. Van Everdingen and Mr. J. A. Banner of Environment Canada during the drilling at Bear Rock and Norman Wells is greatly appreciated. The author is deeply indebted to Dr. R. Patterson and Mr. S. Frape of Queen's University who provided the equipment for squeezing the water from the cores. Thanks are also extended to Mr. R. Drimmie, Mrs. J. Catterall, Mr. D. Killion and Mr. M. Day for their assistance in running the isotope analyses.

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PART I

GENERAL BACKGROUND

Introduction

The recent interest in northern Canada as a result of the predicted energy shortage in the near future has led to the proposal of several pipeline routes throughout the Northwest Territories. Large sections of these pipeline corridors are situated in areas containing continuous or discontinuous permafrost.

The environmental studies conducted by the various pipeline consortiums to date have varied considerably. Geotechnical work has in general been restricted to drilling test holes along the proposed routes for the purpose of examining the properties of the various soils. These operations have been concentrated near the major river crossings. Hydrogeological studies by the consortiums are nearly non-existent. The sparse literature on hydrogeologic systems within the permafrost regions has been summarized by Williams and Van Everdingen (1973). Studies directly related to the permafrost conditions that will be encountered during construction have been restricted to theoretical calculations of frost heave and occassional down hole temperature profiling.

The present investigations were undertaken to examine the relationships between the permafrost and the groundwater. These relationships can be examined if water, either frozen or unfrozen, contained in the cores is analysed for its isotopic composition. An approach of this type was originally conducted by Mackay and Lavkulich (1975), who used oxygen isotopes to study the history of permafrost beneath a recently drained lake in the Mackenzie Delta. They demonstrated that isotopic differences reflecting the history of the permafrost do exist.

In this study, 387 samples were analysed for oxygen-18 and a representative number for tritium, with the aim of demonstrating that it is possible to deduce rather detailed information about the origin and history of the water in the permafrost. A paper on the perliminary results of this study was submitted earlier this year for presentation at the 3rd International Permafrost Conference to be held in Edmonton in July 1978.

Study Sites

An attempt was made to collect samples from various cores taken along the Foothills Pipe Lines Ltd. route through the Mackenzie Valley and from the Polar Gas Limited route along the western edge of Hudson Bay (Keewatin District, N.W.T.).

During the summer of 1975, a drilling program by Foothills Pipe Lines Ltd. resulted in the collection of a number of cores. These cores were sectioned in the field and maintained in a frozen state during transport to the laboratory facilities of Klohn Leonoff Consultants Limited in Calgary. The samples were then placed in freezers to retain this frozen state. All work conducted during testing of the soils was undertaken in a cold room on the premises.

In June of 1976, representative cores from the group were selected for study on the basis of their location, with respect to the existing permafrost conditions, proximity to rivers or lakes, grain size of the soils and quality of core preservation. Subsamples were taken from every available interval and each sample was double bagged in heavy plastic bags and placed within a third bag containing all of the samples from the individual core. The samples were stored in a refrigerated area at the University of Waterloo until the water was extracted for analysis. Unfortunately, samples that did not represent intervals within the zone of permafrost were not kept refrigerated since the time of drilling and therefore were not available for analysis. The location of the holes from which cores were sampled are shown in figure 1 and are from north to south, M.P. 23 (75-2-1), M.P. 176 (75-4-1), M.P. 313 (75-7-2), M.P. 423 (75-8-2), M.P. 488 (75-11-4), M.P. 505 (75-13-2), M.P. 536 (75-15-1), M.P. 582 (75-18-1), and M.P. 599 (75-19-3).

Also in June of 1976, two icing mounds at a spring discharge area on the south east flank of Bear Rock (at the junctions of Great Bear River and the Mackenzie River) were sampled in detail by Dr. R. O. Van Everdingen and Mr. F. Michel during a visit to the site. The first mound (BR-1) contained an exposed block of ice which was cut by means of a handsaw into 14 intervals, each of which was approximately 2.5 cm in thickness.

The second mound (BRD-1) was sampled using a portable power drill. The thawed soil was 60 cm thick and penetration of the frozen material (ice) was stopped at a depth of 71 cm below ground surface due to jamming of the drill rods by a rock in the upper portion of the hole. This mound was revisited in September 1976 when a second attempt at drilling was made (BRD-2). The original site was reoccupied and the ice was encountered at a depth of 79 cm, indicating 8 cm of thaw during the months of July and August. The ice-soil contact was encountered at a depth of 129 cm and the drilling was continued in the frozen soil for 18 cm giving

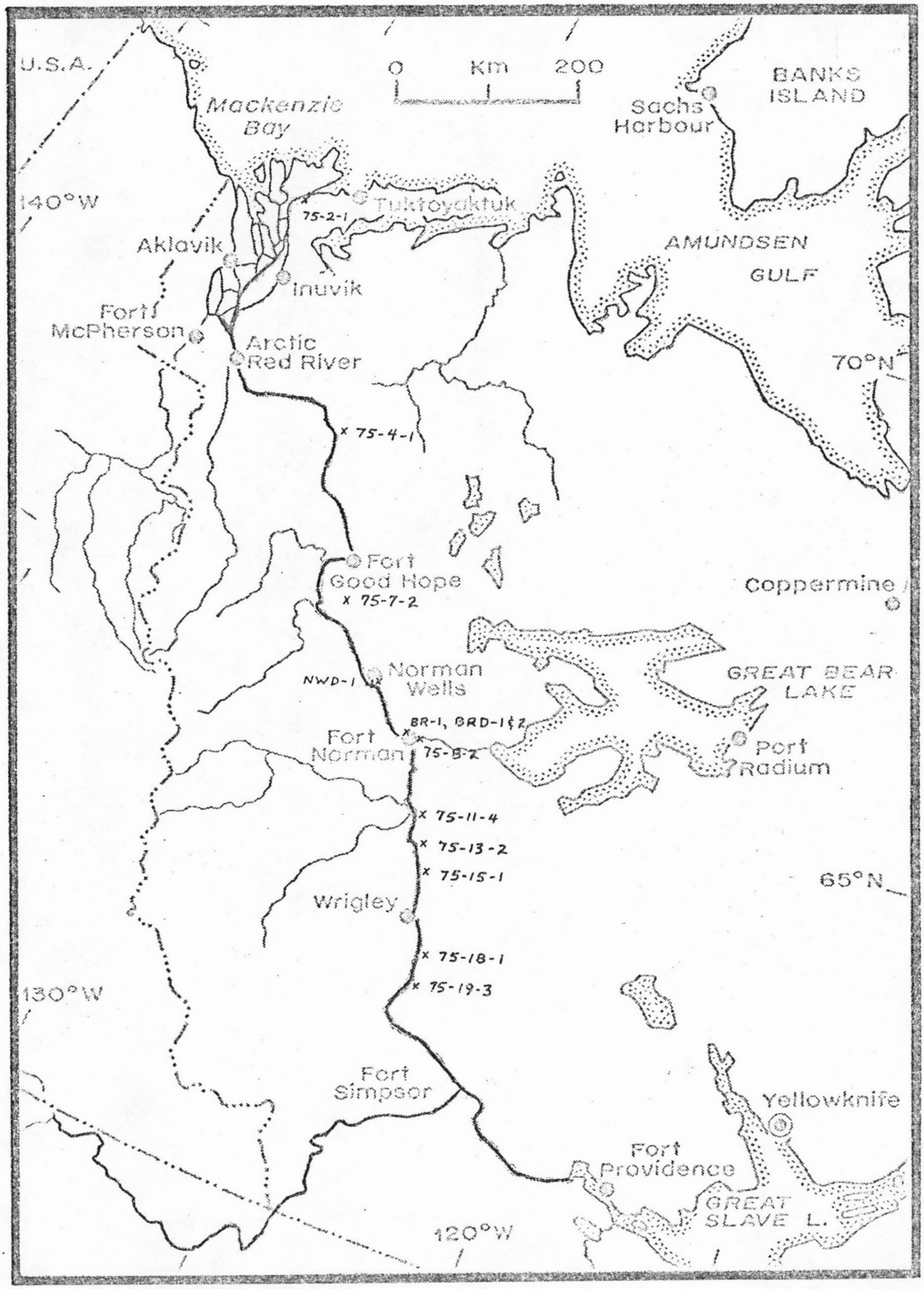

Figure 1: Location of cores studied from along the Foothills Pipe Lines route, Mackenzie Valley.

a total depth of penetration of 147 cm.

A core (NWD-1) also was obtained in September from drilling conducted along a test line to the south of Norman Wells. This core was divided into roughly 2.5 cm intervals in the field. Frozen material was encountered at a depth of 48 cm and the total depth of penetration was 185 cm.

During August 1976, a visit was made to the field laboratory set up in conjunction with the drilling program of the Polar Gas Limited route. Unfortunately, problems developed during the course of the visit and only two cores were collected. These cores are from south of Baker Lake but no exact location is available. An account of the problems encountered was sent to the Department of Supply and Services in the fall of 1976, a copy of which is attached as Appendix I.

Subsequent to that account, two pails of samples arrived from Churchill. The samples were in poor condition with one pail containing over 2 cm of water in the bottom. Many of the samples were from different cores so that a large number of the cores are represented by one or two samples only. It was decided to analyse the samples for oxygen-18 to fulfill the terms of the contract as originally outlined. The data must however be viewed with some reservations as to their actual meaning. No hole locations were provided with the samples and two samples have no identification at all.

The two pipeline routes will be discussed separately because of their vast differences in location, terrain, and the general background knowledge.

Experimental Procedure

To extract the water from the soil, the samples were first allowed to equilibrate in sealed bags to room temperature. Originally a simple distillation method was employed to separate the water and the soil. It was soon evident that the complete distillation of a clay sample required long periods of time. The slowness of this method, combined with the development of minor leaks in the evacuated system led to an early abandonment of this technique.

In place of the distillation method, a hydraulic jack apparatus developed and tested by Patterson et al (1977) for the extraction of water from sediment cores, was employed. Each sample was placed within a steel jacket and subjected to a controlled hydraulic pressure to squeeze the water from the soil. The water enters directly into a polypropalene syringe which can be sealed with wax until ready for analysis. Fractionation effects due to the high pressures are not known, but it appears from the reproducibility of $\delta^{18}O$ values that any effects are negligible below the 1500 p.s.i. maximum that was arbitrarily set.

Each sample, from which more than 3 ml of water could be obtained, was analysed for oxygen-18. The oxygen-18 contents are expressed as permil difference between the sample and Standard Mean Ocean Water ($\delta^{18}O$ °/oo SMOW). From an examination of the $\delta^{18}O$ values, samples were selected for tritium analyses. Interpretation of the isotope data has been accomplished with the aid of geotechnical data received from Foothills Pipe Lines Ltd., visual grain size classification of each sample during squeezing and hydrogeologic data collected by Dr. Van Everdingen and Mr. Michel.

The analytical error for oxygen-18 is less than ± 0.10 ‰. Tritium is done by direct liquid scintillation counting where the errors are relatively large and are dependent on counting times. Because of the small sample size, no enrichment was possible and therefore, the error is always given where tritium values are listed.

Contamination of the samples during drilling by air or the drilling fluid may affect the results, but a relatively uniform shift in the values would be anticipated. Tritium contamination is expected to be worse than the oxygen-18 contamination because of the large mass difference in $^{3}H : {}^{1}H$ as compared to $^{18}O : {}^{16}O$. Any tritium values in the range of 20 to 50 T.U. (tritium units, 1 T.U.= 10^{18} $^{3}H/^{1}H$) become difficult to interpret. Background for the tritium is approximately 10 T.U., below which the sample can be considered as being dead.

PART II

MACKENZIE VALLEY ROUTE

Introduction

The Mackenzie Valley contains terrain that is dissected by several major rivers flowing from low mountain ranges on the eastern edge towards the Mackenzie River. The banks of these rivers, near their confluence with the Mackenzie River, are generally composed of glacial sediments forming steep valley walls. These banks are considered to be the most problematic areas in terms of geotechnical considerations. All of the holes except for 75-7-2 and 75-15-1, are therefore located near major river crossings. Hole 75-7-2 is located in a level area within hummocky terrain. Spruce trees 15 to 20 feet tall are present but have been scorched by fire. Hole 75-15-1 is similarily located on level terrain which was previously the site of a forest fire. Permafrost is present in all of the holes to varying degrees. The northern delta region is underlain by continuous permafrost while the southern portions of the valley are underlain by discontinuous areas of permafrost.

Soils

During the last glaciation of North America (Wisconsin Glacial), the entire Mackenzie Valley was overriden at least twice from the east by the Laurentide ice sheet. The first advance was the most extensive and is recorded by the presence of a grey-black stony till. Retreat of this ice to the east resulted in the formation of glacial lakes within the Mackenzie Valley and tributary valleys to the west.

A second ice advance is recorded by the presence of a light grey-brown till generally near the surface. This ice sheet was not as extensive as the first advance and was controlled to a larger extent by the local topography. Tempoary halts in the retreat of the ice created hummocky terrain throughout the valley. With the retreat of this final advance, the valleys were again occupied by numerous glacial lakes which received large amounts of fine grained sediment from the meltwater streams. Down cutting by the Mackenzie River together with differential isostatic uplift drained the lakes. The soils present in the valley can be summarized as being composed of tills, glacial lacustrine and glacial fluvial deposits.

Rutter et al (1973) suggest that the ice had withdrawn from the southern Mackenzie Valley by 8280 years B.P. (G.S.C. 1837) on the basis of peat overlying the till, while Zoltai and Pettapiece (1973) also on the basis of radiocarbon dating consider the minimum date for deglaciation of the northern portion of the valley as 10,000 years B.P. More detailed descriptions of the terrain in the Mackenzie Valley are given in Zoltai and Pettapiece (1973), Hughes et al (1973), Rutter et al (1973) and Rampton (1974).

In post glacial time, permafrost has formed to some extent throughout the area, except under some ponds, lakes and streams.

The generalized stratigraphy for the cores is as follows:

75-2-1, sand and gravel to 1.7m, fine sand to bottom

75-4-1, clayey silt till throughout, except for gravel-sand till from 1.8m to 3.7m

75-7-2, clay and silt to 1.1m, clay to bottom

75-8-2, peat to 1.8m, sand to 2.7m, clay to bottom

75-11-4, peat to 0.6m, clay and silt to bottom

75-13-2, clay and silt throughout

75-15-1, peat to 0.9m, silt and clay to bottom

75-18-1, sand and silt to 0.9m, silt, sand and gravel till to bottom

75-19-3, silt and sand to 4.9m, silt and clay to bottom

Detailed descriptions of the soil type for each sample are available from Foothills Pipe Lines Ltd. The detailed descriptions for all of the other samples are listed in the tables with the isotope data. The grain size determinations are based on visual identification rather than by standard geotechnical analytical methods.

Hydrogeology

The Mackenzie Valley, from Willowlake River to Fort Good Hope, contains active hydrogeologic systems. The Franklin Mountains and Norman Range along the eastern edge of the valley form a major water divide and recharge area for regional flow systems. Numerous mineral springs discharge into low lying areas in the eastern plain and along the base of the mountains. Most of these mineral springs are cold and contain Na^+ and Ca^{++} as the major cations and $SO_4^=$, HCO_3^- and Cl^- as the major anions. The highest concentration of groundwater discharge is on the north side of Willowlake River close to the Mackenzie River. The predominant rock types in the area are limestones and dolomites with two evaporite units (Saline River and Bear Rock) also being present. Those waters which pass through the Saline River Formation during the course of their flow discharge as highly saline waters. Alternatively, waters passing in part through the Bear Rock Formation generally discharge as sulphate rich in composition, often containing hydrogen sulphide gas.

Thermal waters discharge on Old Fort Island just to the north of the junction of River Between Two Mountains with the Mackenzie River. Some of the water seeps are visible only during low flow periods in the Mackenzie River. This suggests that the permafrost free Mackenzie is the dividing line or sink into which waters from the eastern and western mountains ultimately discharge.

Roche qui trémpe à l'eau to the north of the community of Wrigley is the site of highly saline thermal water discharges from a thrust slice. The probable depths to which this water has been subjected suggests that a moderately high geothermal gradient exists in the area.

Groundwater systems are expected to be present within the permafrost, using taliks as the main conduits through which perennial flow is maintained. None of the perennial springs examined to date could be definitely associated with intrapermafrost waters.

Localized flow systems within the active layer above the permafrost are evident both as discrete spring discharges and more commonly as seepage along slopes. Relatively large areas of level terrain have resulted in the stagnation of these flow systems which now appear as numerous ponds and small lakes within the valley floor. Groundwater discharges in the form of base flow for many streams was noted during the fall to be of a significant quantity.

Carbon-14 dating of various spring waters indicates that the regional systems are presently discharging waters that were recharged in the order of 2,000 to 5,000 years B.P. Tritium analyses suggest that the regional groundwaters are being mixed with minor amounts of modern water in many cases.

Limited field data on the local recharge waters suggest that modern waters have values in the range of -20 $^{o}/oo$ to -24 $^{o}/oo$ $\delta^{18}O$ SMOW and tritium values of 150 to 180 T.U. Most of the water is recharged through karst systems and solution channelways.

Results and Discussion

The oxygen-18 and tritium data are listed in table 1 along with the soil type as mentioned earlier. Individual cores are plotted graphically whenever enough isotope data is available to describe the core. These cores are discussed in detail on an individual basis. It was felt that the other cores could not be discussed adequately with the small amount of data available.

Core 75-2-1 represents deltaic deposits near the mouth of the Mackenzie River which is in the region of continuous permafrost. Figure 2 depicts graphically the changes in $\delta^{18}O$ values with depth. The 6 $^{o}/oo$ shift to lighter oxygen-18 contents within the top two meters of the core is the most striking feature present. High tritium and relatively heavy oxygen-18 in the top sample clearly indicates that this water sample represents modern precipitation recharge. Low tritium values below this sample indicate older water that is probably pre-bomb (1954) in age.

The majority of the core, from 2.5m to 13m, shows a relatively

TABLE 1

Core No.	Sample No.	Depth (ft)	δ Oxygen-18 ($^{o}/oo$ SMOW)	Tritium (T.U.)	Soil
75-2-1	3	1.0-2.0	-22.3	250±6	
	4	2.0-3.0	-23.5	15±7	
	5	3.08-3.92	-23.8	17±6	
	6	3.92-4.25	-24.3		
	7	4.25-5.17	-24.2		
	8	5.17-6.17	I.S.		
	9	6.17-7.08	-24.7		
	10	7.08-8.17	-25.7	29±6	
	11	8.17-9.25	-29.1	24±5	
	12	9.25-10.13	-29.1		
	13	12.0-14.0	-29.0		
	14	15.17-15.63	I.S.		
	15	15.63-16.67	-29.9	39±6	
	16	18	-27.8		
	17	20.5-21.25	-30.3		
	18	21.25-22.0	-30.0		
	19	23.5-24.0	-28.7		
	20	24.0-24.67	-29.5		
	21	24.67-25.5	-29.7	30±8	
	22	30	-28.5		
	23	35.75-36.17	I.S.		
	24	36.17-37.5	-29.1	18±8	
	25	40.0-42.0	-29.5		
	26	45.17-46.0	I.S.		
	28	55.83-56.5	-27.6	25±9	
	29	56.5-57.25	-27.3		

I.S. Insufficient Sample
n.d. not detected

TABLE 1 CONT'D

Core No.	Sample No.	Depth (ft)	δ Oxygen-18 ($^{o}/oo$ SMOW)	Tritium (T.U.)	Soil
75-2-1	30	57.25-58.42	-27.3		
75-4-1	2	1.0-1.5	-23.0	258±6	
	3	1.5-2.5	-22.6		
	4	2.5-4.0	-22.2	95±10	
	5	4.0-6.0	-21.5		
	6	6.0-8.0	-23.1	66±17	
	7	11.0-12.0	-23.2		
	8	12.0-13.0	-23.1		
	9	13.0-15.0	-26.0		
	10a	15.0-16.0	-27.2	38±10	
	10b	16.0-16.5	I.S.		
	11	16.5-17.0	-27.3		
	12	20.0-22.0	-28.9		
	13	23.0-24.0	-29.2		
	15	28.0-29.0	-29.0		
	16	30.0-32.0	-30.9		
	17	38.5-39.0	-31.2	18±7	
	18	39.0-41.0	-31.5		
	19	45.0-47.0	-31.2		
	20a	47.0-48.0	-31.2		
	20b	48.0-49.0	I.S.		
	21	49.0-51.0	-30.9		
75-7-2	4	3.5-4.5	-22.1		
	5	6.0-6.5	-20.9		
	6	9.0-10.5	-20.6		
	7	12.0-13.0	-20.1		

TABLE 1 CONT'D

Core No.	Sample No.	Depth (ft)	δ Oxygen-18 (°/oo SMOW)	Tritium (T.U.)	Soil
75-7-2	9	17.0-18.0	-20.4		
	10	19.0-20.0	I.S.		
	11	20.0-21.0	-22.6		
75-8-2	2a	0.5-1.0	-23.4	166±11	
	2b	1.0-1.5	-23.0		
	3a	2.0-3.0	-23.2	n.d.	
	3b	3.0-4.0	-23.0	27±15	
	4a	4.0-5.0	-22.2	10±6	
	4b	5.0-6.0	-22.5	23±9	
	5	6.0-7.5	-22.7	30±7	
	6	7.5-9.0	-22.8	32±9	
	7a	9.0-10.0	-22.9		
	7b	10.0-11.0	-23.0	30±10	
	8	15.0	-24.0		
	9	19.0-20.0	I.S.		
	10a	20.0-21.0	-24.7		
	10b	21.0-22.0	-25.1		
	11a	25.0-26.0	-26.2		
	11b	26.0-27.25	-26.5	8±7	
	12a	30.0-31.5	-27.4		
	12b	31.5-33.0	-27.0		
	13	35.0-37.0	-27.5	n.d.	
	14	40.0-41.0	I.S.		
	15	44.0-45.0	I.S.		
75-11-4	4a	5.0-6.0	-23.2		
	4b	6.0-7.0	I.S.		

TABLE 1 CONT'D

Core No.	Sample No.	Depth (ft)	δ Oxygen-18 (°/oo SMOW)	Tritium (T.U.)	Soil
75-11-4	5a	7.0-8.0	-23.5		
	5b	8.0-9.0	-23.3		
	6a	9.0-10.0	-23.7		
	6b	10.0-11.0	-23.5		
	7	15.0-16.0	I.S.		
75-13-2	3a	5.0-6.0	-30.4		
	3b	6.0-7.0	I.S.		
	4a	7.0-8.0	-25.3		
	4b	8.0-9.0	-29.1		
	5	9.0-10.0	-30.0		
	6	15.0-16.0	-30.6		
	7	19.0-20.0	-30.0		
	8	20.0-21.0	-30.4		
	9	25.0-26.0	-30.1		
	10a	30.0-31.0	I.S.		
	10b	31.0-32.0	I.S.		
	11	35.0-36.0	I.S.		
	13	40.0-41.0	-30.2		
	14	41.5-42.5	I.S.		
75-15-1	3a	2.0-3.0	-21.8	25±6	
	3b	3.0-4.5	-21.8		
	4a	4.5-5.5	-22.4		
	4b	5.5-6.5	-22.3		
	5a	6.5-7.5	-22.1		
	5b	7.5-8.5	-22.1	34±6	
	6a	8.5-9.5	-22.3		

TABLE 1 CONT'D

Core No.	Sample No.	Depth (ft)	δ Oxygen-18 (°/oo SMOW)	Tritium (T.U.)	Soil
75-15-1	6b	9.5-10.5	-22.3		
	7a	15.0-16.0	-22.3	22±3	
	7b	16.0-17.0	-22.7		
	8a	19.0-20.0	-22.5		
	8b	20.0-21.0	I.S.		
	9a	23.0-24.0	-23.1	48±5	
	9b	24.0-25.0	-24.0		
75-18-1	3	4.0-5.0	-20.4		
	4	6.0-7.0	-20.2		
	5a	7.0-8.0	-19.5		
	5b	8.0-9.0	-20.2		
	6	9.0-10.0	-20.1		
	7	14.0-15.0	I.S.		
75-19-3	2a	1.0-2.0	-20.5	212±9	
	2b	2.0-3.0	-22.4		
	3a	3.0-4.0	-22.1		
	3b	4.0-5.0	-23.1		
	4a	6.0-7.0	-22.2	12±5	
	4b	7.0-8.0	-22.3		
	5	8.0-9.0	-22.0		
	6	9.0-10.0	-21.5		
	7	15.0-16.0	-22.1		
	8a	19.0-20.0	-23.3	15±9	
	8b	20.0-21.0	-23.3		
	9	25.0-26.0	-23.5	16±8	
	10	30.0-31.0	-22.1		

TABLE 1 CONT'D

Core No.	Sample No.	Depth (ft)	δ Oxygen-18 (°/oo SMOW)	Tritium (T.U.)	Soil
75-19-3	11	33.0-34.0	-21.3	32±6	
	12	40.0-41.0	-22.8	25±4	
	13	44.0-45.0	-22.4	26±10	

Core No.	Sample No.	Depth (cm)	δ Oxygen-18 (°/oo SMOW)	Tritium (T.U.)	Soil
NWD-1	A	10.0-20.0	-22.6		Peat
	B	20.0-40.0	-21.3		gry br clay
	C	40.0-48.0	-21.8		gry br clay
	1	48.0-51.0	-21.6		clay-silt
	2	51.0-55.0	-20.3		clay-silt
	3	55.0-58.0	-20.1		fine sand
	4	58.0-62.0	-20.9		"
	5	62.0-66.0	-21.6		"
	6	66.0-68.0	-21.0		"
	7	68.0-71.0	-21.2		"
	8	71.0-73.0	-21.7		"
	9	73.0-76.0	-21.3		"
	10	76.0-78.0	-21.3		"
	11	78.0-81.0	-21.5		clay-silt
	12	81.0-83.0	-22.0		"
	13	83.0-85.0	-22.3		"
	14	85.0-87.0	-22.9		fine sand
	15	87.0-89.0	-23.1	83±16	"
	16	89.0-92.0	-22.8		"
	17	92.0-94.0	-22.4		"

TABLE 1 CONT'D

Core No.	Sample No.	Depth (cm)	δ Oxygen-18 (o/oo SMOW)	Tritium (T.U.)	Soil
NWD-1	18	94.0-96.0	-22.2		sand-silt
	19	96.0-98.0	-22.2		"
	20	98.0-100.0	-22.2		"
	21	100.0-102.0	-22.2	30±13	"
	22	102.0-104.0	-22.1		"
	23	104.0-106.0	-22.0		"
	24	106.0-109.0	-21.8		"
	25	109.0-111.0	-21.6		"
	26	111.0-113.0	-21.8	14±16	"
	27	113.0-115.0	-22.1		"
	28	115.0-117.0	-22.3		"
	29	117.0-119.0	-22.4		"
	30	119.0-121.0	-22.3		"
	31	121.0-124.0	-22.2	14±13	"
	32	124.0-126.0	-22.3		clay-silt
	33	126.0-127.5	-22.2		"
	34	127.5-129.0	-22.1		"
	35	129.0-131.0	-22.2		silt-clay
	36	131.0-132.0	-22.9		silt-clay
	37	132.0-134.0	-23.6		clay-silt
	38	134.0-136.0	-23.6		silt-clay
	39	136.0-137.0	-22.2		"
	40	137.0-138.5	-21.3		"
	41	138.5-140.0	-21.3		"
	42	140.0-141.0	-23.4		clay-silt
	43	141.0-142.5	-23.5		"

TABLE 1 CONT'D

Core No.	Sample No.	Depth (cm)	δ Oxygen-18 (°/oo SMOW)	Tritium (T.U.)	Soil
NWD-1	44	142.5-144.0	-23.5		clay-silt
	45	144.0-146.0	-22.8		"
	46	146.0-148.0	-23.5		silt
	47	148.0-151.0	-23.1		"
	48	151.0-153.5	-23.3		clay-silt
	49	153.5-157.5	-23.5	9±14	"
	50	157.5-161.0	-23.6		"
	51	161.0-163.0	I.S.		"
	52	163.0-165.0	-23.3		silt
	53	165.0-167.0	-23.5		clay-silt
	54	167.0-169.0	-23.2		"
	55	169.0-171.0	-23.4		"
	56	171.0-173.0	-23.3		"
	57	173.0-175.0	-23.1		"
	58	175.0-177.5	-23.1		"
	59	177.5-180.0	-23.1		sand-silt
	60	180.0-182.5	-23.0		sand-silt
	61	182.5-185.0	-22.8		"
BR-1	1	20.0-24.0	-20.4		ice
	2	24.0-28.0	-20.6		"
	3	28.0-30.5	-20.5		"
	4	30.5-33.0	-20.7		"
	5	33.0-35.5	-20.7		"
	6	35.5-38.0	-20.7		"
	7	38.0-40.5	-20.7		"
	8	40.5-43.0	-20.7		"
	[illegible]	[illegible]	[illegible]		

TABLE 1 CONT'D

Core No.	Sample No.	Depth (cm)	δOxygen-18 (o/oo SMOW)	Tritium (T.U.)	Soil
BR-1	9	43.0-45.5	-20.2		ice
	10	45.5-48.0	-20.4		"
	11	48.0-50.5	-20.6		"
	12	50.5-53.0	-20.8		"
	13	53.0-55.5	-20.7		"
	14	55.5-58.0	-20.6		"
BRD-1	1	60.0-62.0	-18.3		"
	2	62.0-64.0	-20.9		"
	3	64.0-65.5	-20.8		"
	4	65.5-67.0	-21.7		"
	5	67.0-69.0	-21.3		"
	6	69.0-71.0	-21.5		"
BRD-2	1	79.0-80.5	-22.7		"
	2	80.5-83.0	-22.9		"
	3	83.0-85.0	-23.0		"
	4	85.0-86.5	-22.8		"
	5	86.5-88.0	-23.0		"
	6	88.0-89.5	-23.1		"
	7	89.5-91.0	-23.0		"
	8	91.0-93.0	-23.1		"
	9	93.0-94.5	-23.1		"
	10	94.5-96.0	-23.1		"
	11	96.0-98.0	-23.2		"
	12	98.0-100.0	-23.4		"
	13	100.0-101.5	-23.7		"
	14	101.5-103.0	-23.9		"

TABLE 1 CONT'D

Core No.	Sample No.	Depth (cm)	δ Oxygen-18 (o/oo SMOW)	Tritium (T.U.)	Soil
BRD-2	15	103.0-104.5	-23.7		ice
	16	104.5-106.0	-23.7		"
	17	106.0-108.0	-24.0		"
	18	108.0-111.0	-24.3		"
	19	111.0-114.0	-24.6		"
	19a	114.0-117.0	-25.0		"
	20	117.0-119.0	-25.6		"
	21	119.0-121.0	-25.7		"
	22	121.0-123.0	-26.2		"
	23	123.0-125.0	-26.1		"
	24	125.0-126.0	-25.4		"
	24a	126.0-129.0	-25.3		"
	25	129.0-131.0	-26.8, -26.5		silt-sand-ice
	26	131.0-133.0	-25.3		"
	27	133.0-135.0	-24.7		"
	28	135.0-137.0	-24.6		"
	29	137.0-139.0	-24.9		"
	30	139.0-141.0	-24.9		"
	31	141.0-143.0	-24.6		"
	32	143.0-145.0	-24.6		"
	33	145.0-147.0	-24.6		"
Norman Well's Freezer			-24.4		ice

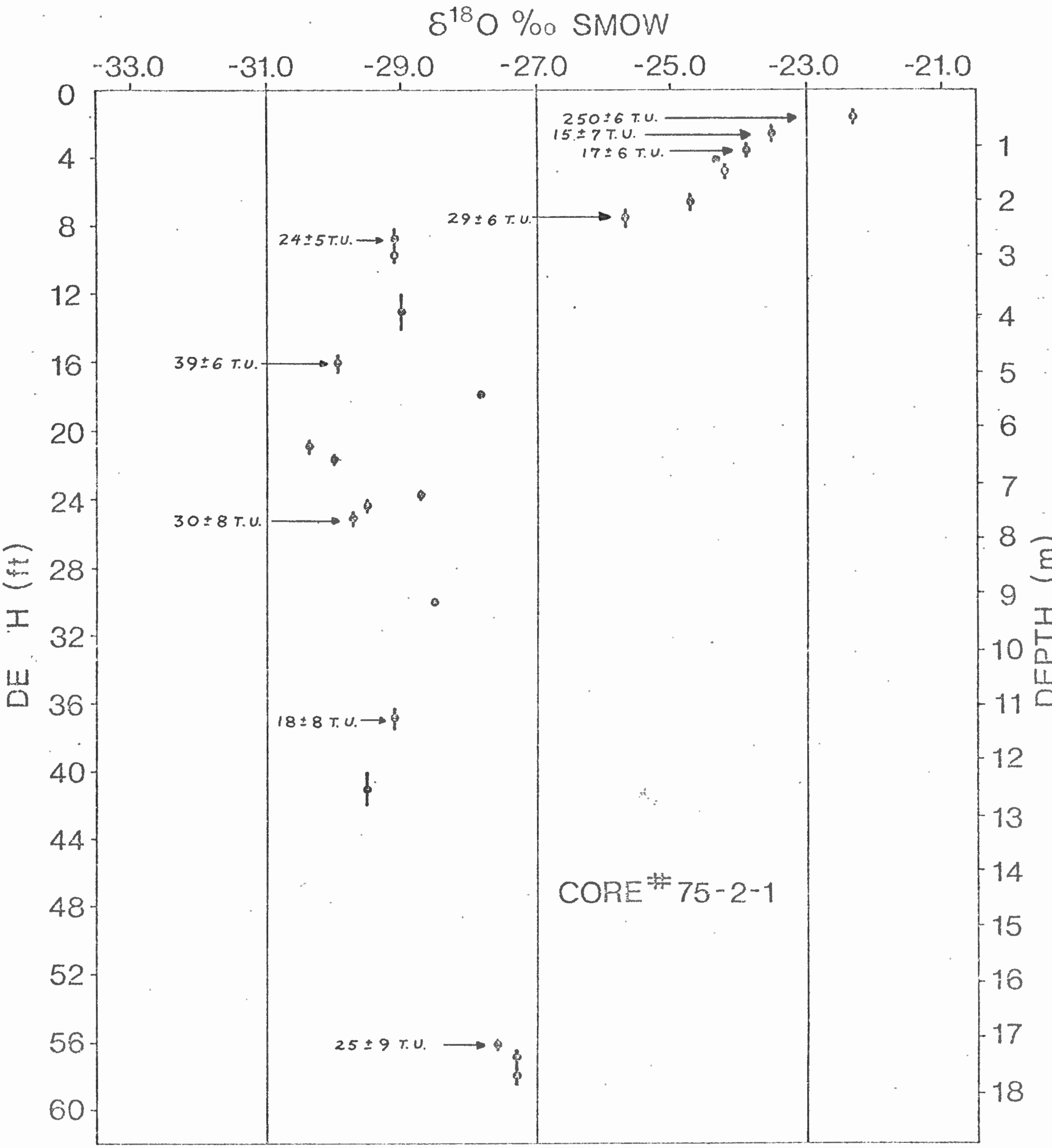

Figure 2: $\delta^{18}O$ ‰ SMOW versus depth for core no. 75-2-1.

steady trend in $\delta^{18}O$ values. The fluctuations or peaks on either side of the average value are not related to changes in the lithology. They may reflect actual variations in oxygen-18 contents during formation of the permafrost or may be the result of isotope effects created by fractionation of the isotopes during freezing. Suzoki and Kimura (1973) have shown that a 2 to 3 $^{o}/oo$ fractionation occurs between the solid and liquid water phases during freezing. The reverse trend in the lower part of the core can only be speculated about, but may reflect the proximity to the base of the permafrost.

The graph of core 75-4-1 (figure 3) duplicates the general trend developed in the previous core. High tritium values that slowly decrease with depth again suggest the presence of recent precipitation which has infiltrated through the upper part of the core. Water at the two meter depth can be roughly estimated as having been recharged around 1960.

The fluctuations in the lower portion of the previous core are not preserved in this core. The isotopically light water found in the lower portions of the two cores indicate colder climatic conditions during emplacement than are observed today.

The recognition of old and water within the core makes possible the delineation of three zones of groundwater activity within the permafrost of the two cores examined to this point. Figure 3 is used to define these zones. The upper zone, 0 to 4 m, represents water in isotopic equilibrium with modern waters and contains tritium. The lower zone, 6 m to bottom, represents older water which no longer contains tritium and is not in equilibrium with the modern waters. An

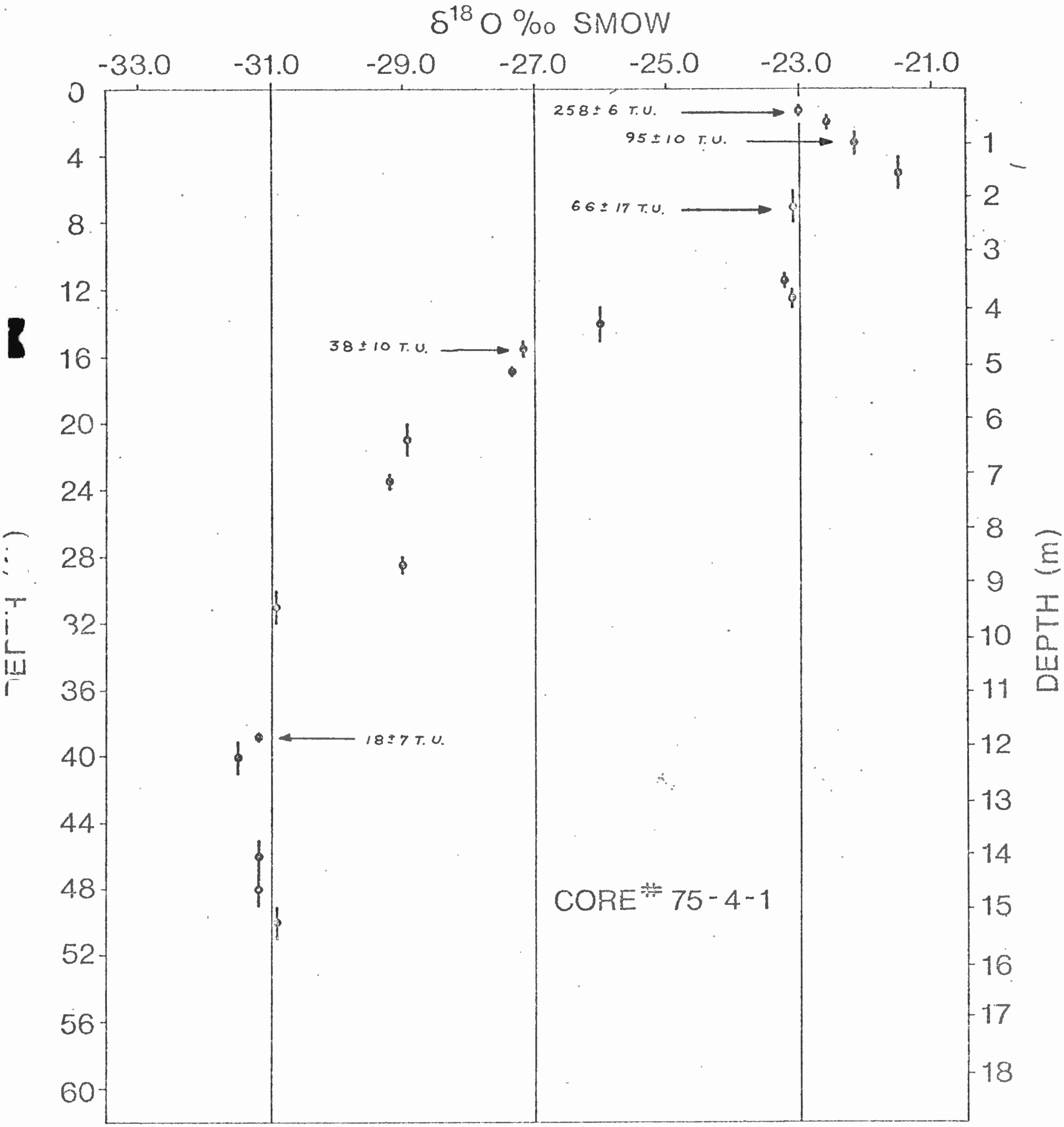

Figure 3: $\delta^{18}O$ °/oo SMOW versus depth for core no. 75-4-1.

intermediate zone, 4 to 6 m, may represent mixing of the waters from the upper and lower zones as the modern water migrates downwards. This interpretation differs from the one given by Mackay and Lavkulich (1975) who assumed that the oxygen-18 differences in their samples were due to isotope effects.

In figure 4, the upper and intermediate zones are again evident. The lower zone may be developing in the lowest three samples but it is not well defined. The same pattern of modern precipitation recharge at the surface appears in a thin surface sand, but is adjacent to a sample in which no tritium could be detected. This sample as described previously is a peaty material and contains over 400% water. Small amounts of contamination tritium emplaced during drilling could be diluted to below the detection limit while samples below the peat which contain lower water contents would maintain detectable low tritium values. The high water content in the peat would retard the downward migration of the recharging water for a sufficient period of time that the tritium decays within this unit.

Core 75-15-1 in figure 5 depicts, on the basis of oxygen-18 contents, the upper zone. A shift is present in the bottom sample but no trend can be determined. The low tritium values result from the presence of 0.9 m of peat which is water saturated to several hundred percent. The top sample contains water from the base of the peat unit. In both cores, 75-8-2 and 75-15-1, where a significant thickness of peat occurs, the tritium appears to have been blocked from a downward migration while the oxygen-18 has not been affected at all. This further supports the hypothesis that a long residence time for the water exists

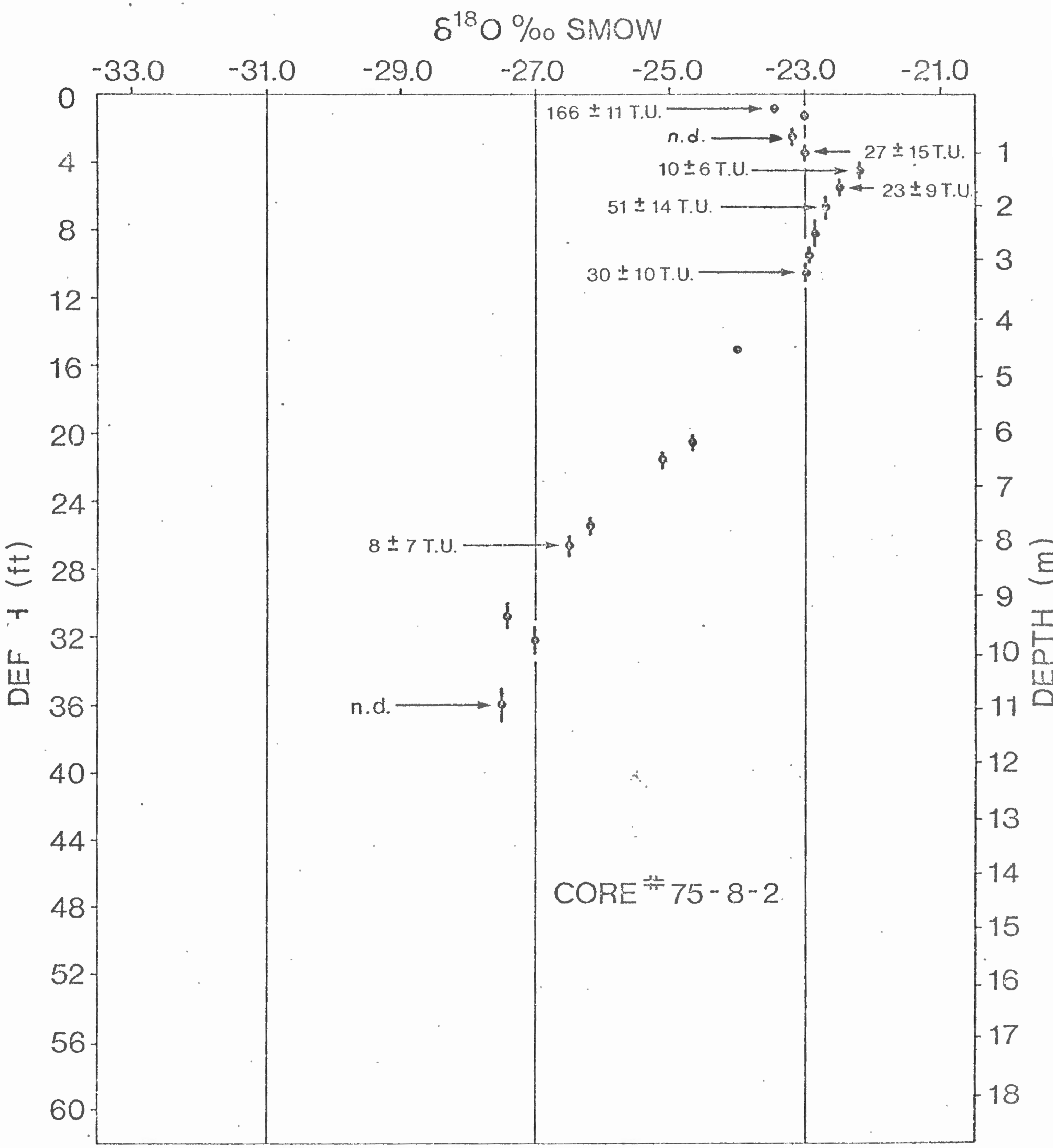

Figure 4: $\delta^{18}O$ ‰ SMOW versus depth for core no. 75-8-2.

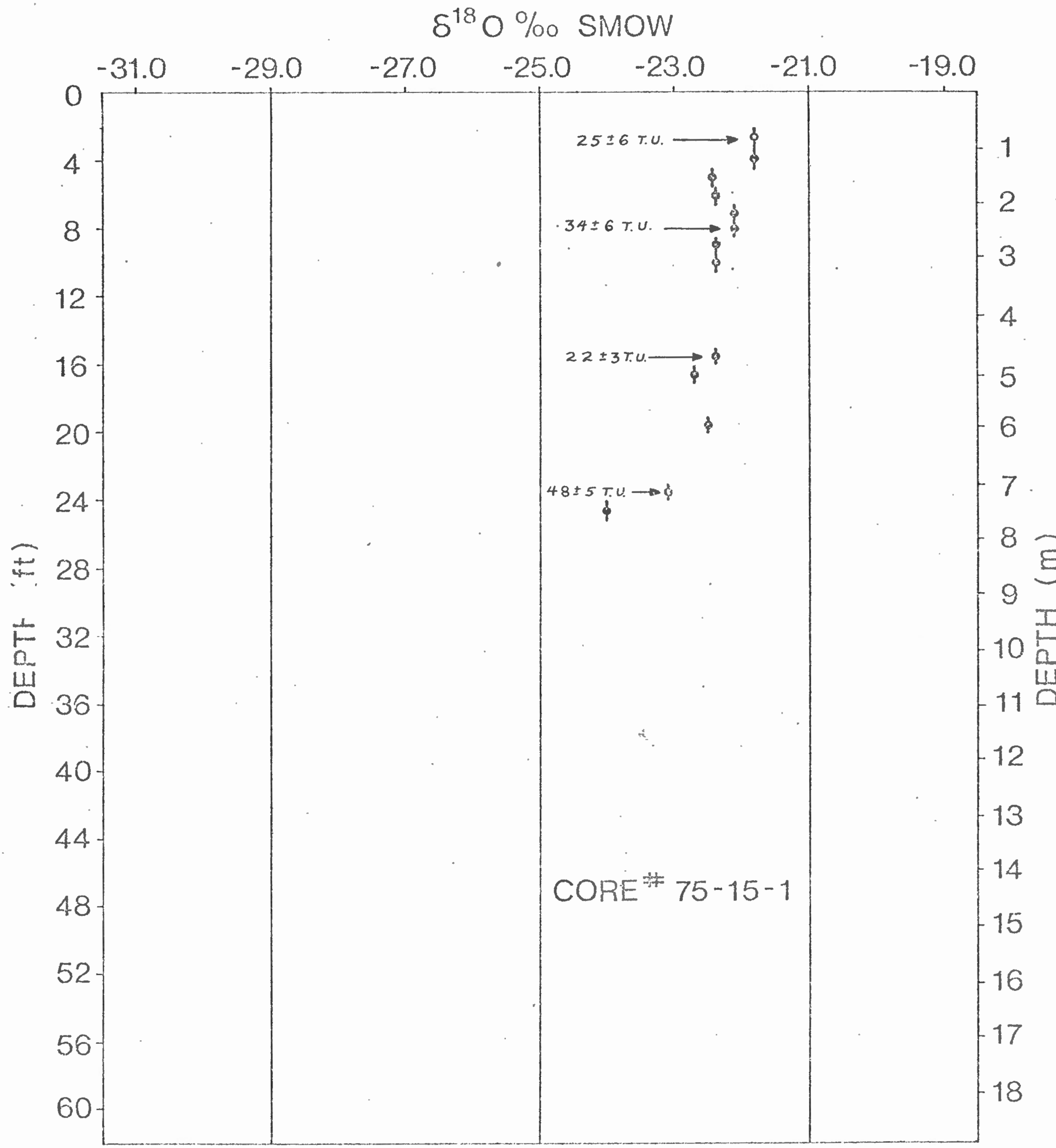

Figure 5: $\delta^{18}O$ °/oo SMOW versus depth for core no. 75-15-1.

in the peat horizon.

From the drill logs available, core 75-19-3 (figure 6) appears to most likely represent a ground condition where the temperature is near $0^{o}C$ throughout its entire length. Several systematic changes in the oxygen-18 contents are preserved within the core.

The lack of an oxygen-18 shift similar to the previous cores is explainable by the age of the water in the permafrost. The presence of active groundwater systems is expressed by the numerous spring discharges in the area. Corrected carbon-14 ages on these spring waters are in the order of 2,000 to 4,000 years B.P.

These spring waters have $\delta^{18}O$ values in the range of -21.9 $^{o}/oo$ to -23.4 $^{o}/oo$ and an average value of -22.9 $^{o}/oo$. The average $\delta^{18}O$ of the permafrost water is -22.5 $^{o}/oo$ and supports the assumption that this water is derived from the active groundwater system with some local precipitation recharge near the ground surface. The fluctuations throughout the core are possibly the result of isotope effects created during freezing.

Core 75-11-4 contains a narrow zone of permafrost, 1.5 m to 4.9 m, within its total length. The oxygen-18 contents reflect equilibrium with the adjacent groundwater.

The depth at which the boundaries between the various zones of groundwater activity occur is related to the grain size of the soil in the core. In core 75-2-1, where sands and gravels are present, the depth to the lower zone is only 2.5 m. Alternatively, in cores 75-8-2 and 75-15-1, where high clay contents are encountered, the depth to the lower zone is at least 9 m. This effect could be the result of capillary

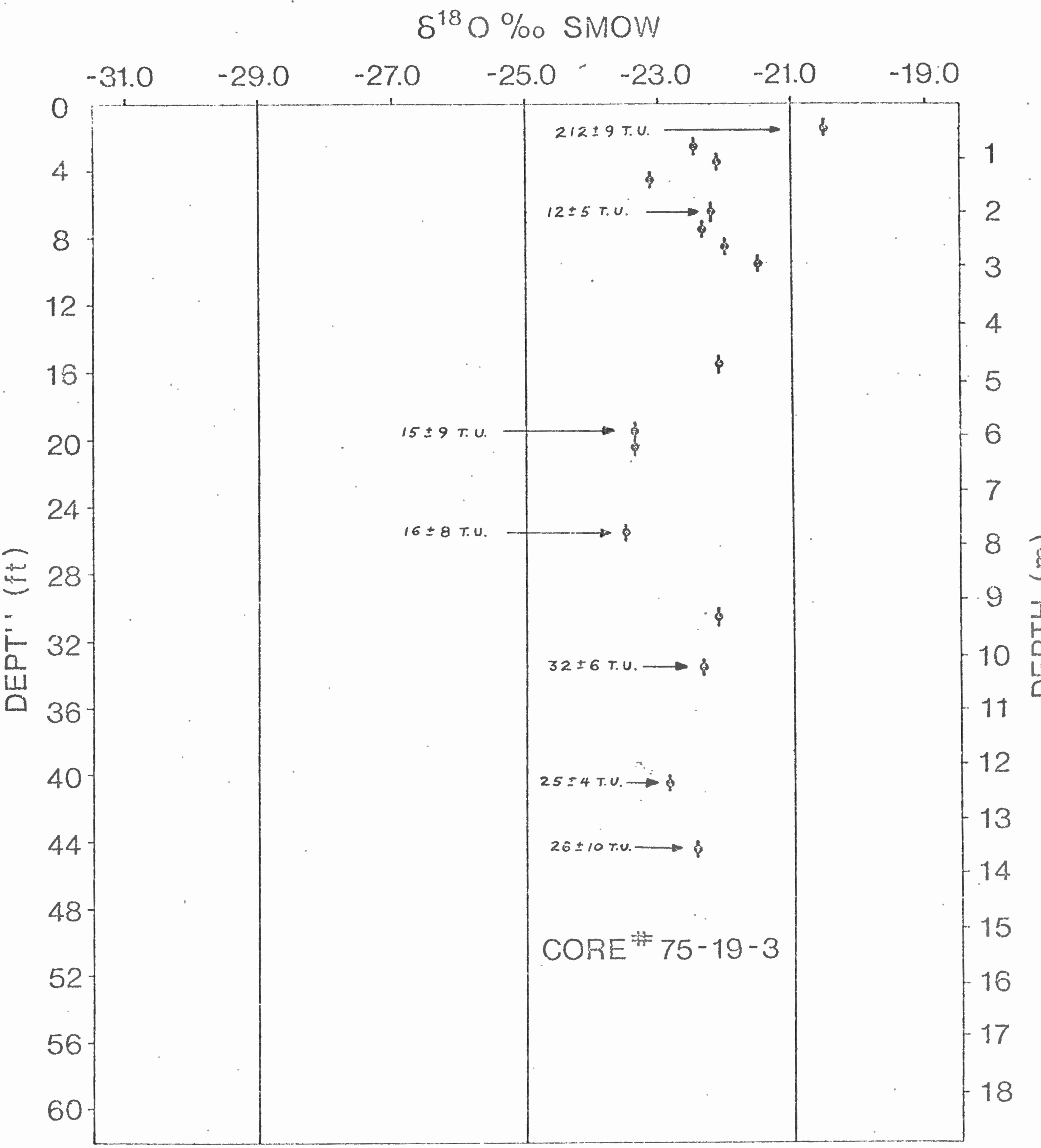

Figure 6: $\delta^{18}O$ °/oo SMOW versus depth for core no. 75-19-3.

action in which thin films of water within the finer grained soils are able to migrate downwards at a faster rate than in the coarser grained soils. With time, the thickness of the upper zone should increase in all areas regardless of the grain size.

Data from the detailed sampling undertaken at Norman Wells are graphically depicted in figure 7. The total depth of penetration of the core is 1.85 m and therefore represents only the very top of the permafrost in the area. Each sample was 2 to 3 cm in thickness. The detailed sampling illustrates the true complexity of the permafrost which is lost in all of the other cores.

The permafrost table on September 1st, 1976 was at 0.48 meters. Oxygen-18 contents in the top portion of the permafrost are highly irregular, probably indicating successive pulses of individual water masses migrating downwards. The overall trend, superimposed on cyclic variations, is towards more negative oxygen-18 contents with depth. At this time it is not known whether these cyclic variations are caused by isotope effects during freezing or whether they are due to the successive freezing of different water masses.

The small sample size has resulted in the lack of sufficient water to analyse for tritium. The few samples that were analysed indicate that the upper portion of the core represents modern recharge. The lower portions with tritium values at or below background, suggest older water is present below the 1 meter level.

The Bear Rock frost mounds do not relate directly to the groundwater - permafrost investigations which form the basis of the present study, but similar processes are involved with respect to the freezing

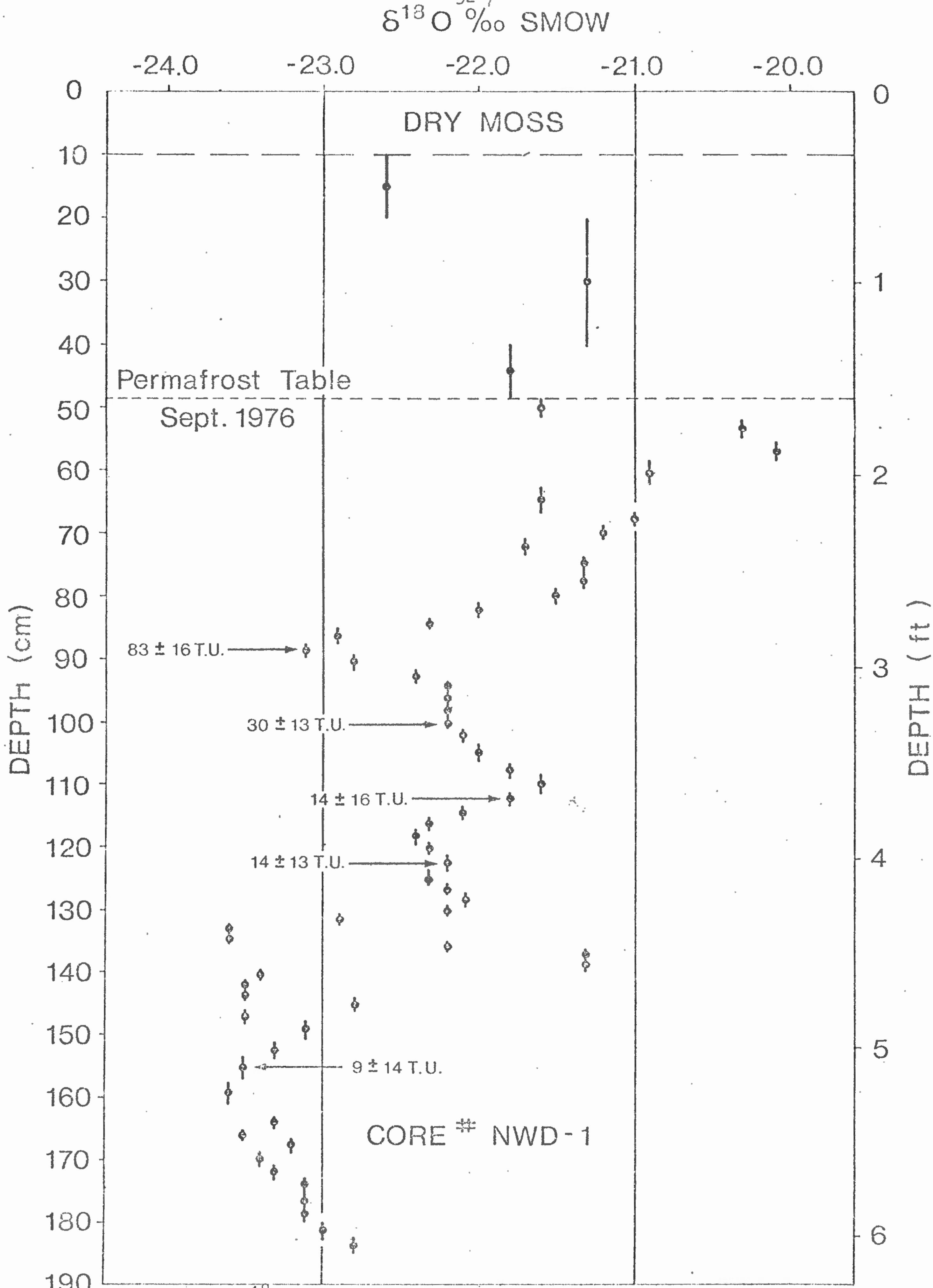

Figure 7: $\delta^{18}O$ ‰ SMOW versus depth for core no. NWD-1.

of the groundwater and the resulting fractionation.

In June 1976, the ice block encountered in the first mound (BR-1) was sliced into 14 sections. The soil on top of the ice had completely thawed with several small boulders partially sunk into the top of the ice. Below the ice was a hollow cavity which at one time during the winter is believed to have been filled with groundwater under a hydrostatic pressure. Sampling of the ice was achieved by cutting out a wedge from the block and using only the inner portion which had not been exposed to the atmosphere.

The oxygen-18 contents as shown graphically in figure 8 does not vary significantly throughout the ice. One major shift occurs at a depth of 42.5 cm. A shift was expected after visual examination of the ice revealed a variation in the colour of the ice which was a reflection of the amount of air trapped in the ice. The only significant feature that can be seen from figure 8 is the 2 $^{o}/oo$ shift of the ice away from the average spring water value. This is the type of shift that one would expect to see during fractionation in a closed system. Oxygen-18 molecules contain slightly less kinetic energy than oxygen-16 molecules resulting in a preferential freezing out of the oxygen-18 molecules as described by Suzuoki and Kimura (1973).

The information available from core BRD-1 and 2 in figure 9 also suggests fractionation during freezing. A large section of the ice contains $\delta^{18}O$ values similar to the average spring water. Above this section fractionation towards heavier oxygen-18 contents occurs, while below this section fractionation towards lighter oxygen-18 contents results. This trend towards the progressively lighter values represents

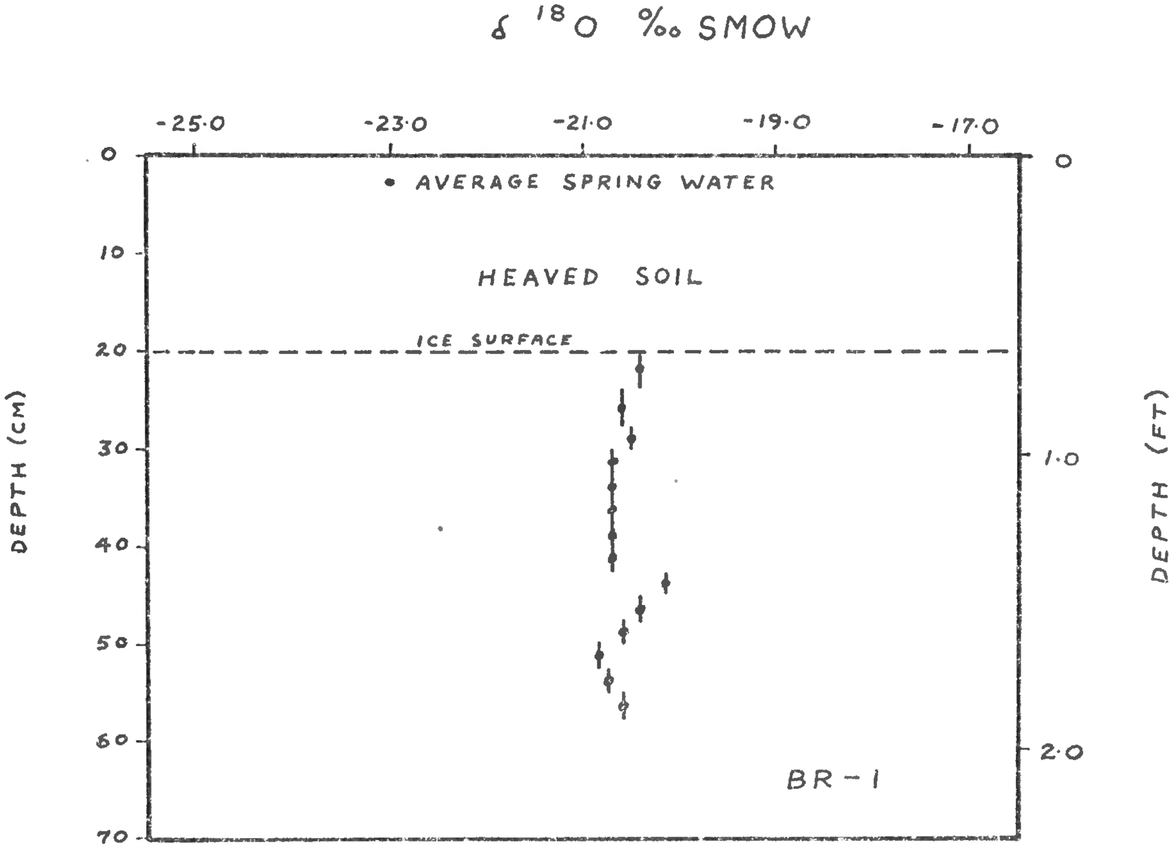

Figure 8: $\delta^{18}O$ $^{o}/oo$ SMOW versus depth for core no. BR-1.

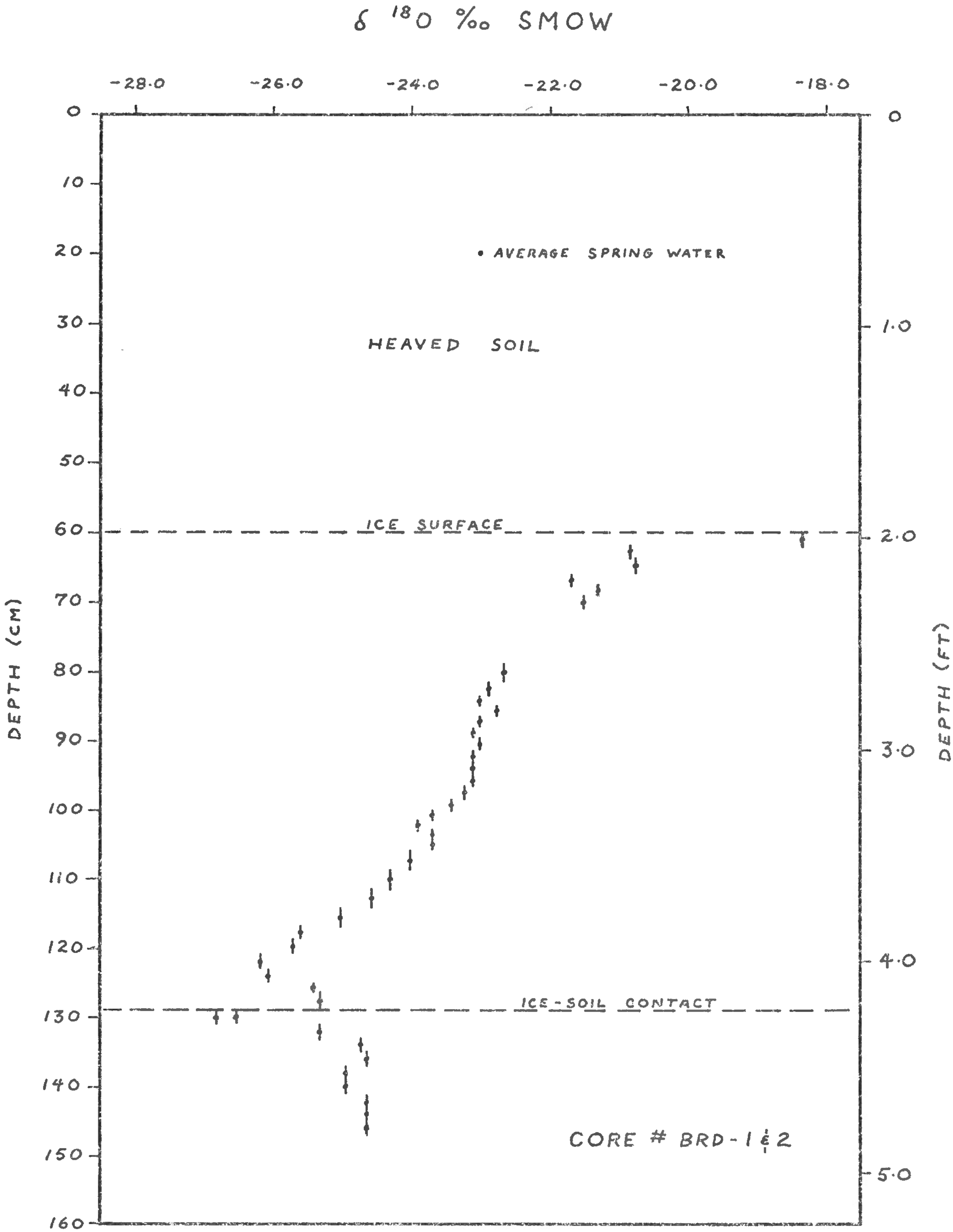

Figure 9: $\delta^{18}O$ °/oo SMOW versus depth for cores BRD-1 & 2.

continual fractionation within a residual pool which is not being continually renewed with outside water.

The fluctuations near the ice-soil interface are not understood at present. The $\delta^{18}O$ values of the water within the undisturbed soil is relatively uniform over the interval examined. A mixing of the isotopically light basal ice with the groundwater may be resulting in the values which are lighter than the average spring water.

It is speculated that the existence of permafrost beneath the ice sheet of the Wisconsin Glacial is unlikely (Mackay and Black, 1973). The growth of permafrost would then have occurred after the retreat of the ice. By 10,000 B.P. the Mackenzie Valley was completely ice free and the glacial lakes were draining. The water saturated sediments were subjected to extreme temperatures and permafrost aggradation locked this water in place. Corrected carbon-14 ages on the spring waters near the site of core 75-19-3 are in the order of 2,000 to 4,000 B.P. or late and post altithermal. The oxygen-18 contents associated with these springs add support to the suggestion that the water in the permafrost with lower $\delta^{18}O$ values is from before the altithermal period which began 7,000 to 8,000 B.P. and was recharged under colder climatic conditions.

PART III

POLAR GAS ROUTE - BAKER LAKE TO NELSON RIVER

Introduction

The Baker Lake to Nelson River portion of the Polar Gas route lies almost completely within the District of Keewatin, N.W.T. The entire section is underlain by continuous permafrost. Permafrost is absent beneath the larger lakes and rivers. The terrain in general is poorly drained with numerous lakes dotting the landscape as a result of the presence of the permafrost. As stated earlier no locations are available for the holes from which core was received. It is also impossible to state whether the samples received were recovered from frozen ground but this is most likely the case.

Soils

The central Keewatin near Baker Lake is believed to have been one center of spreading for the Laurentide ice sheet during the last glacial period. Several extensive till sheets cover the entire area. Hummocky moraines and eskers also occur in many parts of the District of Keewatin. From the examination of the soil received it appears that many of the present rivers flow through extensive glacial fluvial deposits.

Adjacent to Hudson Bay intrusion by the sea, before isostatic uplift, resulted in the deposition of thick marine silt and clay deposits. None of these deposits were encountered within the samples available for study.

Results and Discussion

Due to the low number of samples per core, only core 128A-1-3 has been graphically plotted. All analyses of oxygen-18 and tritium are listed in table 2 along with visual descriptions of the soil in each interval.

No precipitation data are available for determining the average oxygen-18 contents and tritium. A brief examination of table 2 reveals that the average $\delta^{18}O$ value for the precipitation is most likely in the range of -15 $^o/oo$ to -19 $^o/oo$. This interpretation is made on the assumption that the samples contain water from modern precipitation. Such an assumption is supported by the presence of high tritium contents in the uppermost samples. The low tritium value for the water in the bottom of can 1 indicates that this water has leaked from various samples contained within the can.

Core 128A-1-3 was the only core that was well represented by samples throughout its entire length. This was the only complete core available for sampling during the visit to the field laboratory in Churchill. The samples were frozen throughout the entire length of the core.

Figure 10 displays the isotope fluctuations present within core 128A-1-3. The uppermost sample contains large amounts of tritium which indicates that this water has infiltrated the ground recently. A rapid decrease in the tritium contents suggest slow percolation of the water downwards.

Oxygen-18, which is a conservative tracer, indicates downward penetration to the bottom of the core. Fluctuations throughout the length of the core are thought to result from isotope effects during freezing which have been retained since freezing originated. Towards the base of the core a shift in the $\delta^{18}O$ values is developing. This

TABLE 2

Core No.	Sample No.	Depth (m)	δ Oxygen-18 ($^{o}/oo$ SMOW)	Tritium (T.U.)	Soil
87-1-1	1	1.2-1.85	-16.6	13±8	org. fi sa si
	2	1.85-2.4	-14.1		fi sa si
	3	2.4-3.0	I.S.		fi sa si
	4	3.0-3.6	-16.4		fi sa si,stony
	5	3.6-4.1	I.S.		md-cor sa, fi grav.
	6	4.1-4.7	I.S.		cor sa, fi grav.
	7	4.7-5.3	I.S.		fi si sa
	8	5.8-6.4	I.S.		cor sa, fi grav.
	9	6.4-7.0	-16.5		fi si sa, stony
	10	7.0-7.6	I.S.		fi si sa, stony
	11	8.2-8.5	-15.7		fi si sa, stony
	12	8.5-9.1	-16.2		si fi-md sa
87-3-1	1	1.2-1.85	-17.4		peat
	2	1.85-2.4	-16.8		fi sa
	3	2.4-3.1	I.S.		fi sa
	4	3.1-3.6	-16.1		fi sa
	5	3.6-4.2	-15.9		fi sa, stony
	6	4.25-4.8	-16.6		fi si sa
	7	4.8-5.4	I.S.		stony till
	8	5.4-6.0	-16.0		stony till
	9	6.0-6.55	-16.1		stony till
88-3-3	1	1.0-1.3	-15.6		cl si, stony
	2	1.3-1.8	-14.9		cl si, stony
	3	1.8-2.4	-16.7		cl si
	4	3.0-3.6	-16.7		cl si
	5	3.6-4.2	-16.3		cl si

TABLE 2 CONT'D

Core No.	Sample No.	Depth (m)	δ Oxygen-18 ($^{o}/oo$ SMOW)	Tritium (T.U.)	Soil
88-3-3	6	4.2-5.0	-17.1		cl si
	7	5.0-5.6	-16.9		cl si
	8	5.6-6.2	-16.6		cl si, fi sa, stony
	9	6.2-6.7	-17.0		"
	10	6.7-7.3	-16.7		"
	11	7.3-7.9	I.S.		"
	12	7.9-8.5	I.S.		"
92-1-1	1	2.95-3.25	I.S.		fi-md sa, stony
	2	4.4-4.95	I.S.		si fi sa, stony
	3	4.95-5.45	I.S.		md sa, stony
92-1-2	1	2.1-2.95	I.S.		fi sa si
	2	2.95-3.05	I.S.		"
98-1-1	1	0.65-1.1	-15.3		fi sa
	2	1.1-1.95	I.S.		si fi-md sa
	3	1.95-2.55	-15.8		si fi sa, stony
	4	2.55-3.05	-16.9		"
	5	3.05-3.8	-16.8		"
	6	3.8-3.95	-16.8		"
	7	3.95-4.25	-17.2		"
	8	4.75-5.35	-17.5		"
	9	5.39-5.9	-16.0		"
	10	5.9-6.2	-17.8		"
102-1-1	1	0.3-1.0	-16.2	12±8	peat
	2	1.2-1.25	-16.0		si fi-md sa, stony
	3	1.75-2.0	-12.6		"
	4	2.0-2.4	-16.5		"

TABLE 2 CONT'D

Core No.	Sample No.	Depth (m)	δ Oxygen-18 (°/oo SMOW)	Tritium (T.U.)	Soil
102-1-1	5	3.9-4.4	-16.9		si fi-md sa, stony
	6	4.4-4.75	I.S.		"
	7	5.0-6.1	-17.1	14±9	"
107-2-1	1	0.61-1.3	-15.7		org, fi sa
	2	1.3-1.55	I.S.		fi-md sa
	3	2.1-2.6	I.S.		"
	4	2.6-3.2	I.S.		"
	5	4.75-5.0	I.S.		fi-md sa, stony
	6	5.15-6.1	I.S.		"
109-2-1	1	1.4-2.05	I.S.		si fi sa, stony
	2	2.05-2.65	-17.6		"
	3	3.8-4.4	-18.0		"
	4	4.9-5.45	-17.2		"
	5	5.45-6.0	-18.3		"
111-1-1	1	0.4-0.6	I.S.		fi sa
	2	0.7-1.2	I.S.		"
	3	1.2-1.9	I.S.		"
	4	1.9-2.15	I.S.		cor sa, fi grav.
	5	2.15-2.55	-15.3		md-cor sa
	6	2.55-2.9	I.S.		cor sa, fi grav.
	7	2.9-3.5	-14.5		cor sa
	8	3.55-3.9	I.S.		fi sa
	9	3.9-4.2	-12.3		fi-md sa
	10	4.25-4.5	-12.8		"
	11	4.5-4.8	-13.0		"
	12	5.3-6.0	-12.8		"

TABLE 2 CONT'D

Core No.	Sample No.	Depth (m)	δ Oxygen-18 ($^{o}/oo$ SMOW)	Tritium (T.U.)	Soil
111-4-1	1	3.1-3.45	-16.3		fi-md sa
113-1-2	1	2.65-3.0	I.S.		fi sa
113-2-2	1	0.6-0.8	I.S.		fi-md sa
	2	0.8-1.2	I.S.		"
	3	1.2-1.8	I.S.		"
	4	1.8-2.2	I.S.		si fi sa
	5	4.1-4.7	I.S.		"
115-1-1	1	3.6-3.8	-15.0		si cl
	2	4.2-4.8	-17.5		si fi sa, stony
	3	5.35-6.0	-14.9		"
116-3-1	1	3.2-3.7	I.S.		fi-md sa, stony
	2	3.7-4.25	I.S.		"
	3	4.85-5.1	I.S.		si fi-md sa, stony
	4	5.35-5.75	-16.2		"
117-4-1	1	1.7-2.4	-16.0		fi sa, stony
	2	3.45-4.15	I.S.		"
120-1-1	1	1.75-2.0	-18.8		cl si, fi sa, stony
	2	2.6-2.9	-17.6		"
124-1-1	1	2.3-2.7	-17.9		si fi sa, stony
	2	2.7-3.4	-21.5		"
	3	3.4-4.0	-20.1		"
	4	4.0-4.55	-20.2		"
	5	6.75-7.0	-21.0		"
	6	7.5-7.8	-19.0		"
124-1-2	1	2.7-3.3	-16.5		cl-si-sa, stony
	2	3.9-4.5	-16.5		"

TABLE 2 CONT'D

Core No.	Sample No.	Depth (m)	δ Oxygen-18 ($^{o}/oo$ SMOW)	Tritium (T.U.)	Soil
124-1-2	3	4.3-4.95	-15.2		cl-si-sa, stony
	4	4.95-5.55	-17.3		"
125-1-2	1	1.75-2.25	-16.5		si sa, stony
	2	3.9-4.25	-20.2		"
125A-1-1	1	1.9-2.3	-16.4		"
	2	2.3-2.8	-17.7		"
	3	2.85-3.45	-19.1		"
	4	3.45-3.9	-22.1		"
	5	4.0-4.5	-23.3		"
	6	4.5-4.7	-25.4		"
128A-1-3	1	0.3-0.65	-17.9	370±7	sa-si-cl, org.
	2	1.5-2.0	-18.0		si sa, stony
	3	2.0-2.55	-18.2	18±7	"
	4	2.55-2.8	-18.4	38±6	"
	5	3.0-3.55	-18.3	30±8	"
	6	3.55-3.9	-17.7		"
	7	3.95-4.25	-18.1	10±8	"
	8	4.25-4.3	I.S.		"
	9	4.3-4.6	-18.3		"
	10	4.6-5.0	-18.4		"
	11	5.0-5.65	-18.5		"
	12	5.65-6.2	-18.4		"
	13	6.2-6.75	-17.5		"
	14	6.75-7.0	-17.0		"
	15	7.0-7.35	-19.9		"
	16	7.35-7.85	-18.2		"

TABLE 2 CONT'D'

Core No.	Sample No.	Depth (m)	δ Oxygen-18 ($^{o}/oo$ SMOW)	Tritium (T.U.)	Soil
128A-1-3	17	7.85-8.45	-18.3		si sa, stony
	18	8.45-9.0	-19.9		"
	19	9.0-9.5	-20.3		"
Churchill Freezer			-20.2	124±13	ice
Bottom of can 1			-17.0	28±9	water, rusty
Unknown # 1			-16.7		cl si, stony
Unknown # 2			-15.4		si fi-md sa, stony

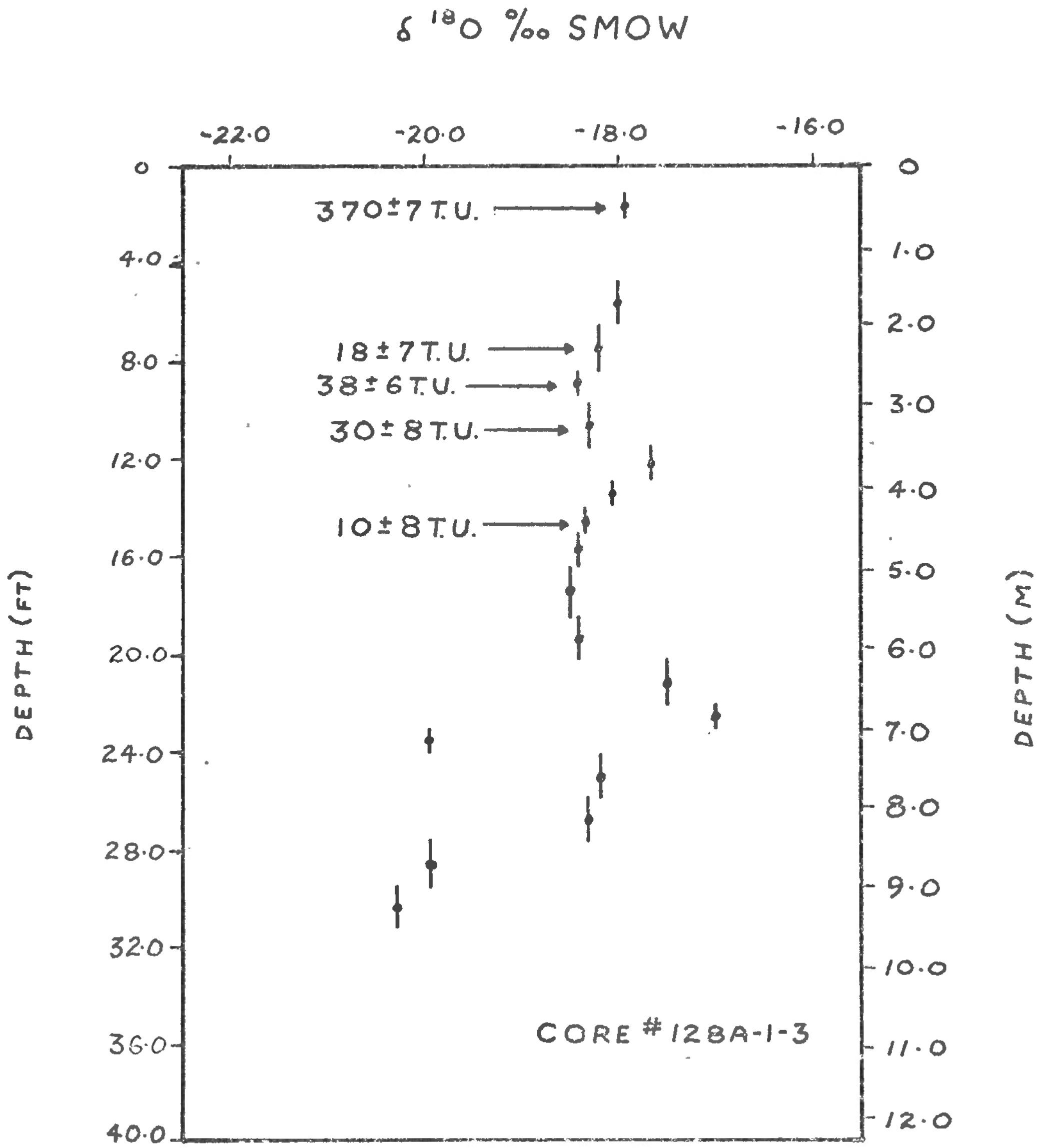

Figure 10: $\delta^{18}O$ $^o/oo$ SMOW versus depth for core no. 128A-1-3.

trend is similar to the zonation developed within the groundwater of the Mackenzie Valley cores. The soil in this core is generally a silty sand till. Development of the upper zone to depth is as extensive as the clay soils of the Mackenzie Valley. Each area must therefore be considered separately when examining the rates of downward infiltration.

PART IV

CONCLUSIONS

The usefulness of environmental isotopes in permafrost investigations has been documented through the present study. The following conclusions can be drawn as a result of this study.

1. Post bomb tritium is associated with high $\delta^{18}O$ values and is found only at the surface.

2. Three zones of groundwater activity can be defined within the permafrost as:

    a) An upper zone representative of modern precipitation recharge water. (active or contemporary permafrost)

    b) A lower zone representative of old post glacial water. (inactive or relic permafrost)

    c) An intermediate zone of mixing.

3. These zones are directly related to the thermal equilibrium of the subsoil with present day surface temperatures. The upper zone will increase in thickness as long as the present surface conditions exist. This zonation is present in both areas studied.

4. Active permafrost occurs to a greater depth in fine grained materials than in coarser gained aggregates. Rates of infiltration of modern waters can be directly correlated to grain size within regional areas of similar climate.

5. Comparison of the isotope data with similar data from springs in the Mackenzie Valley indicates that the water within the inactive, stable permafrost was emplaced some 7,000 to 10,000 years ago.

PART V

FUTURE RESEARCH

The present study has demonstrated the usefulness of environmental isotopes, particularily oxygen-18, in permafrost investigations. Continuous sampling of deep cores can aid in the interpretation of temperature profiling for delineating the thermal conditions in the permafrost. Oxygen-18 profiles of the cores obtained during installation of thermistor cables can provide the investigator with useful results in a short period of time. Detailed sampling provides more information than samples spaced throughout the core.

At this time, the major uncertainty in the interpretation of the present data concerns the small fluctuations in the oxygen-18 contents. These are very evident in core NWD-1 from the Norman Wells area. If the isotopes within the groundwater are diffusing downwards, one would expect a smoothing effect to be present. Any isotope effects created during the original freezing should now be obscured. This however does not appear to be the case.

A laboratory study of the isotope effects created during freezing should be undertaken in an attempt to resolve this problem. Columns packed with uniform grain size material can be subjected to regulated freezing conditions. Isotopically differnt water can then be introduced to the frozen material and allowed to diffuse downwards. The results of such a study should lead to a better understanding of the isotope profiles.

A detailed examination of a core,from a hole completely penetrating the permafrost, by oxygen-18 would significantly increase the understanding of the entire $\delta^{18}O$ profile. At present only the upper portion of the permafrost has been investigated using the environmental isotope tracers.

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APPENDIX I

PROBLEMS ENCOUNTERED DURING FIELD WORK

FOR WRI PROJECT 606-12

The project, as outlined in the proposal submitted, called for the collection of samples to be taken along the proposed routes of Foothills Pipelines Ltd. in the Mackenzie Valley and Polar Gas Ltd. along the west coast of Hudson Bay.

Samples for the Foothills route were collected in late June and early July from cores stored at Klohn Leonoff Consultants Ltd. in Calgary. The cores represented intervals varying from 0.5 to 1.0 feet in length. A total of 129 samples from a series of 9 holes representing the route from Swimming Point (south of Inuvik) to Willowlake River were collected.

Discussions with Mr. Normet of Polar Gas around the first of August resulted in a mutual decision in which I would collect the cores for this route at the portable laboratory in Baker Lake. This decision was due mainly to the lack of accomodation at the drill site and the wider variety of terrain types that would be available at the laboratory.

Because of drill and laboratory movement schedules, it was also decided that the period of August 10th to 19th would be the best time to visit the laboratory. I placed a call to Baker Lake from the University to ensure that these arrangements would be suitable for the laboratory personnel. At that time I was assured that everything would be alright.

Upon my arrival in Baker Lake on the 11th of August, I was met with the news that the schedule had been pushed forward and that the laboratory was packed and ready for shipment to Churchill. All of the core which was to have been saved for me had instead been discarded during packing.

The following day I returned to Churchill on one of the charter flights used to transport the laboratory. The laboratory was set up at the Churchill airport the following morning.

On the afternoon of Friday August 13th, I received word that the helicopter for the Arctic Island portion of the program had broken down. The helicopter from the drill that was to supply the core to the Churchill laboratory was in turn sent to the islands and we had to await the arrival of another helicopter from Toronto.

The replacement helicopter arrived in Churchill on August 16th and the first core arrived the evening of the 17th. The core maintained a frozen state overnight despite the freezer switch tripping off during the night. The core consisted of 26 samples from 2 holes with the represented intervals ranging from 0.2 to 0.55 meters in length.

Because of the prospect of obtaining core during the following few days, I remained in Churchill until Sunday August 22nd. By that time no further core had arrived because the aircraft used for transporting the core from the drill to the laboratory was sent to the islands to help close the camp. It was also necessary to leave at that time to continue my regular summer work with Environment Canada in Calgary.

The laboratory changed staff on August 23rd and on August 24th, I called the new technician in Churchill from Calgary. I told him of the previous two weeks and asked if he would collect samples for me. He agreed to do so and stated that there would be no problem. I also mentioned that I would route a later flight from Normal Wells, N.W.T. to Toronto via Churchill. After the conversation ended, I proceeded to write a letter explaining all the details again and sent it to the technician in Churchill.

For several days before leaving Norman Wells, I unsuccessfully attempted to call Churchill. On September 6th, the night before my departure, the Churchill Hotel staff informed me that the Polar Gas group had left that day and that there was no one left in Churchill.

Upon my return to Waterloo, I found that no samples had arrived from Churchill during my absence except for those that I personally had shipped.

While working for Environment Canada in Norman Wells, I proceeded with the help of Dr. Van Everdingen to collect samples from two locations.

The first area, known as Bear Rock, contains a series of frost mounds which are formed annually by spring discharge. During June of this year an oriented block of ice was cut from one of the mounds and sampled in 14 intervals. Two chip samples were also taken from a second mound and a short core consisting of 6 ice samples were collected from a third mound. During a return visit in September, the third mound was again drilled. This time a total of 34 continuous samples representing 75 cm of ice and frozen soil were recovered.

A second core was drilled beside a test line near Norman Wells. In this hole a total of 61 continuous samples of frozen soil were collected, representing a total length of 1.37 meters. Three samples of the unfrozen soil horizons above the core were also collected.

At the present time, the situation is as stated above. I have personally collected 120 samples from the Norman Wells area. An additional 129 samples representing the Foothills route have been collected from stored core and more is available if needed. The Polar Gas route has yielded only 26 samples of dubious quality and further core is not expected.

The proposal originally stated that 'approximately 400 samples' would be collected and was later changed to 'a minimum of 300 samples'. Due to the disasterous attempt to collect core from Polar Gas, this figure has not been achieved. At present a total of 275 samples of varying quality have been obtained.

Sept. 13/76 Frederick A. Michel