ISOTOPIC COMPOSITION OF ICE-WEDGE ICE IN NORTHWESTERN CANADA

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Abstract

The ^{18}O composition has been measured for over 50 modern ice wedges and several relict ice wedges in the Mackenzie Delta and Yukon Coastal Plain regions. $\delta^{18}O$ values for modern wedges range between -17 and -26‰ but 90% fall within a smaller range of -22 to -24.5‰. Several generations of old inactive wedges yielded $\delta^{18}O$ values between -26.7 and -33.2‰ and may provide information on paleoclimatic conditions. Detailed sampling of several wedges and their enclosing sediments indicates that isotopic homogenization has not occurred within the ice wedges, and that the ^{18}O composition of ice-wedge ice can be very different from ice in the enclosing sediments.

Résumé

La composition en ^{18}O a été mesurée dans plus de 50 coins de glace modernes et anciens situés dans le delta du Mackenzie et sur la plaine côtière du Yukon. Les valeurs de $\delta^{18}O$ de la glace des coins varient entre -17 et -26 ‰. Cependant, 90% de ces valeurs se situent entre -22 et -24,5 ‰. Plusieurs générations de coins de glace anciens et inactifs produisent des valeurs de $\delta^{18}O$ variant entre -26,7 et -32 ‰. Ces dernières peuvent fournir de l'information sur les conditions paléoclimatiques. L'échantillonnage détaillé de plusieurs coins de glace et des sédiments encaissants indique que l'homogénéisation isotopique n'a pas eu lieu à l'intérieur de la glace de fente en coin et que la composition en ^{18}O de la glace de coin peut être très différente de celle de la glace du pergélisol encaissant.

Introduction

Within the surficial sediments of the Mackenzie Delta and Yukon Coastal Plain regions, ice wedges represent one of the most common forms of ground ice and are a major component of the total near-surface ground ice volume (Pollard and French 1980, Rampton 1982, Harry *et al.* 1985). Mackay (1974) concluded that, on average, 40% of modern ice wedges at Garry Island, N.W.T. crack in any given year and that many of the active ice wedges have been rejuvenated, resulting in the development of multiple ice-wedge structures. Mackay (1983) has also concluded that "the source water for ice-wedge ice is derived mainly from snowmelt in May and June".

Isotopic investigations of ice-wedge ice have been undertaken by several researchers (Konjachin 1988, Mackay 1983, Michel 1985, Michel and Fritz 1981, 1982, Vasilchuk and Trofimov 1988). These studies have suggested that the isotopic composition of ice wedges can be related to variations in temperature conditions through time. The present paper examines isotope variations within ice wedges, and between ice wedges and the adjacent sediments at three sites on the western Arctic coast.

Sampling sites

Three ice wedge sites have been studied in detail. These sites are shown in figure 1 and are referred to as Illisarvik, King Point and Herschel Island.

Illisarvik is an artificially drained lake site located at the northern end of Richards Island, approximately 60 km west of Tuktoyaktuk. Relief in the area is low with the highest ground near the center of the peninsula. The sediments consist of a sequence of deltaic sands, diamicton and localized lacustrine silts (Michel *et al.* 1989). The two ice wedges examined in detail are part of a network of high center polygons that were exposed in the north wall of the drainage channel between the lake basin and coast. Both wedges were sampled horizontally at a depth of 2 m below surface, where they had true widths of 2.6 m and 0.32 m, respectively.

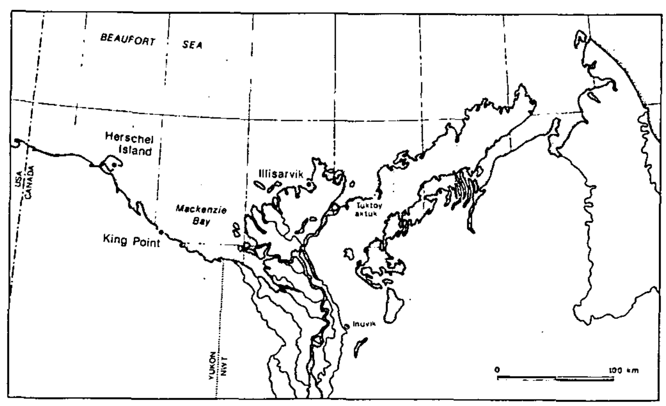

Figure 1. Location map of 3 detailed sites.

The King Point study site is located at a 1.2 km long retrogressive thaw slide approximately 3 km southeast of King Point and has been described by Harry *et al.* (1985). Along the headwall, an ice-wedge network of high center polygons is exposed in section. Harry *et al.* (1985) classified 80% of the wedges as modern and estimated the average true width of the wedges to be 2.3 m. Of over 50 ice wedges sampled for isotopic investigations at this site, 3 have been analysed in detail.

Field work on ice wedges at Herschel Island has been confined to a series of exposures in the headwalls of retrogressive thaw slides adjacent to Thetis Bay. The sediments, which have been described by Bouchard (1974), are highly deformed ice-rich sands, silts and clays. The work on Herschel Island has concentrated on examining the isotopic composition of ice wedges with varying ages and size.

Sampling and analytical procedures

All ice wedges examined during these investigations were exposed in sections and consequently, samples were collected from the exposed faces. Prior to sampling, the surficial ice was removed to a depth of at least 5 cm in order to prevent contamination from meltwater.

Two types of sampling were undertaken. The first type consisted of a single composite sample being collected from across the wedge. The second type involved continuous systematic sampling of a wedge in 10 cm intervals. The continuous sampling was generally taken as a vertical profile. Horizontal profiles were also collected from several wedges. At Illisarvik, both ice wedges were sampled horizontally using a Stihl drill with a CRREL core barrel.

Ice samples were individually double wrapped and sealed in plastic bags for shipment to the laboratory. After complete melting of the sample, the water was transferred to a sample bottle and submitted to the isotope laboratory for analysis where standard analytical procedures were employed. The error for the oxygen -18 analysis is ±0.2‰.

Isotope composition

Distribution of $\delta^{18}O$ values

The oxygen -18 composition of over 60 ice wedges from the three sites have been plotted in figure 2. Approximately 70% of the wedges are from the King Point site, and all of these are considered to be modern wedges as described by Harry *et al.* (1985). The distribution of $\delta^{18}O$ values for the King Point wedges is slightly negatively skewed. The range in $\delta^{18}O$ values from -20.5‰ to -25.5‰, agrees well with the -22‰ to -26‰ range suggested by Mackay (1983) for modern wedges in the Tuktoyaktuk Peninsula area. Almost 90% of the $\delta^{18}O$ values plot within the smaller range of -22.0‰ to -24.5‰. The two ice wedges sampled in the channel cut at Illisarvik also piot within this narrow range, while a third wedge plots within the larger range.

The ice wedge samples from Herschel Island display a wide range of $\delta^{18}O$ values, which are a reflection of the varying ages. Modern wedges with true widths greater than one metre plot in a range of -20.0‰ to -25.5‰; similar to the larger range noted previously. However, three small ice wedges (less than 0.5 m wide) yielded $\delta^{18}O$ values between -17.5‰ and -20.0‰.

Several generations of old inactive ice wedges from Herschel Island yielded $\delta^{18}O$ values between -26.7‰ and -33.2‰. The most negative ^{18}O compositions are similar to a relict ice wedge reported by Mackay (1983) from Hooper Island. At Herschel Island, even older ice wedges were encountered with $\delta^{18}O$ values between -27.9‰ and -28.7‰.

Internal isotope variations

Detailed isotope analyses have been completed on six modern ice wedges; three from King Point, two from Illisarvik, and one from Herschel Island. All six wedges have average $\delta^{18}O$ values of between -22‰ and -23‰. Due to the size of individual samples, each sample represents a composite of several discrete near vertical layers of wedge ice. Therefore, the $\delta^{18}O$ values reported are averages for the entire sample and may not reflect the full range of values which may be found in an analysis of each individual layer.

For all of the ice wedges sampled in detail, the individual $\delta^{18}O$ values fall within a range of -21.0‰ to -24.0‰. Vertical profiles for two ice wedges from the King Point site (fig. 3) display only small variations of less than 1.5‰ throughout the profiles. Ice wedge 10 is relatively constant at -23‰, while ice wedge 41B shows a gradual shift from -22‰ near the top of the wedge to -23.5‰ at depth.

Ice wedge 1 from Herschel Island (fig. 4) displays an average $\delta^{18}O$ value of -22‰ and an overall range of almost 2‰ in the vertical profile. In the horizontal profile the

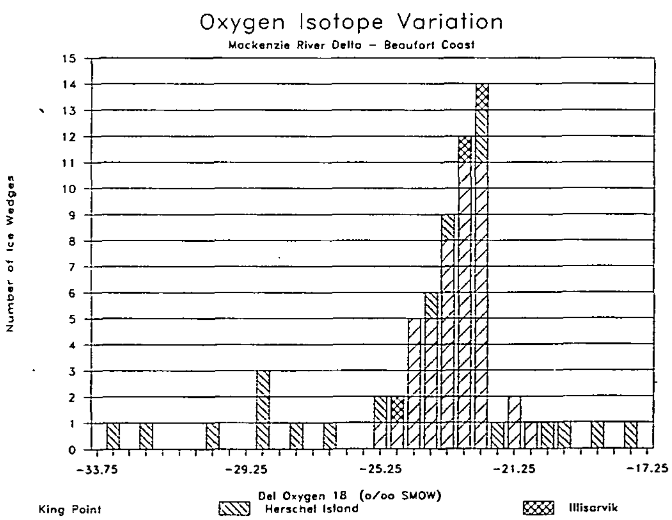

Figure 2. Histogram of $\delta^{18}O$ values (average) for ice wedges from the 3 sites. Increments are 0.5‰.

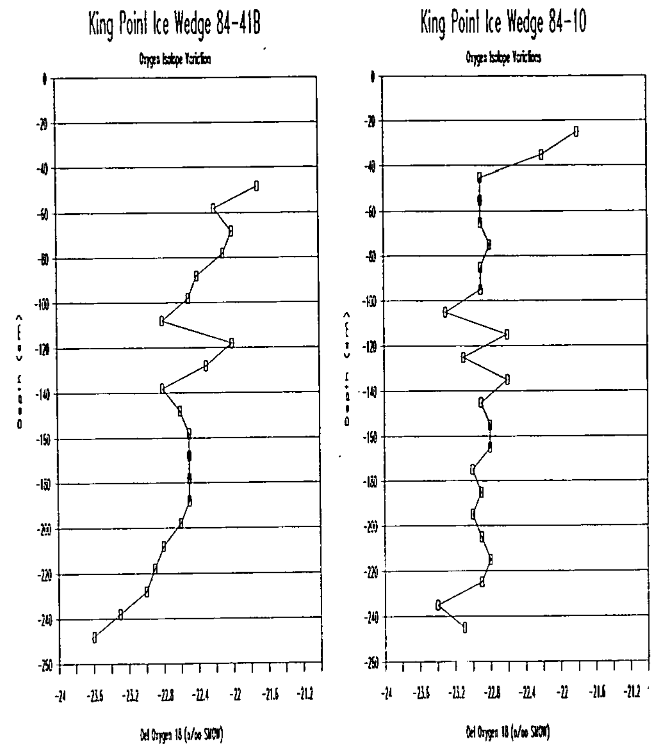

Figure 3. Vertical profiles of $\delta^{18}O$ versus depth for ice wedges 84- 41B and 84-10 at King Point.

average $\delta^{18}O$ value is also -22‰, however, the range is 3‰ and the variations are more pronounced.

This variability between samples is best illustrated in the horizontal profile of ice wedge 1 at Illisarvik (fig. 5). The range in $\delta^{18}O$ values is approximately 2.5‰, however, this can be measured in adjoining samples. Tritium analysis on 30% of the samples indicates that all sections of the wedge have been subjected to cracking during the past 30 years and that ice with the full range of $\delta^{18}O$ values has grown during this period.

Isotope Variations Between Ice Wedges and Enclosing Sediments

Ice wedges can develop whenever climatic conditions and ground conditions are suitable, regardless of the age of the enclosing sediment or pore ice. Thus, one should expect that the isotopic composition of the wedge ice may bear little relationship to that of the surrounding material. This is illustrated in figure 6, where $\delta^{18}O$ values for a horizontal profile through the enclosing sediment and ice wedge 2 at Illisarvik are shown. The ice wedge is clearly identified on the basis of a 9‰ shift in $\delta^{18}O$ values between the wedge ice and adjacent sediments. However, it should be noted that the isotopic composition of the pore ice in the sediments begins to change approximately 0.5 m away from the ice wedge. The gradual shift in isotopic composition toward that of the ice wedge and a corresponding increase in moisture content toward the wedge suggests that cracking is not confined solely to the ice wedge itself.

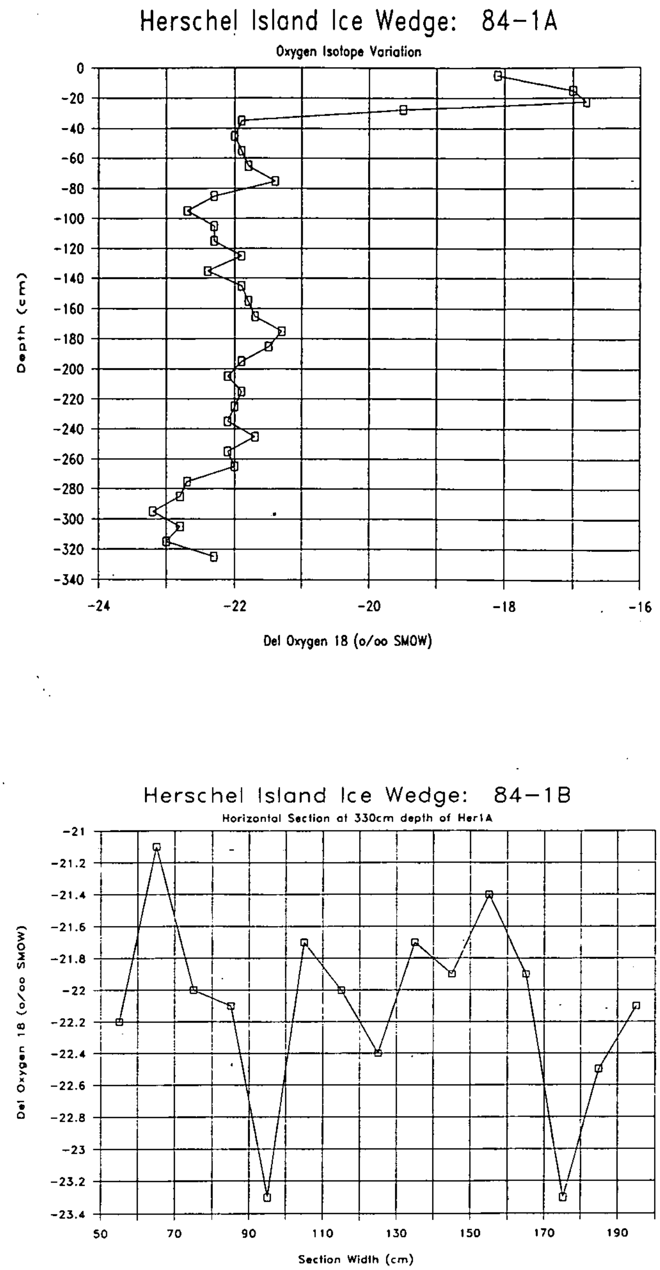

Figure 4. Vertical and horizontal profiles of $\delta^{18}O$ versus distance for ice wedge 84-1 at Herschel Island.

These sediments and pore ice were deposited during the hypsithermal (Michel *et al.* 1989) and, therefore, are isotopically heavier than present-day active layer waters which have an ^{18}O composition of -18‰ to -20‰ (Michel and Fritz 1982). In contrast, ice-rich, glacial-age sediments cut by ice wedge 1 on Herschel Island (fig. 4) have an average $\delta^{18}O$ value of -33.9‰, approximately 12‰ more negative than the wedge ice. Thus, while the enclosing sediments yield isotopic compositions corresponding to climatic conditions at the time of deposition and permafrost aggradation (a difference of 20‰ in the 2 examples), the isotopic composition of these two modern ice wedges (-22‰) reflect present-day climatic conditions.

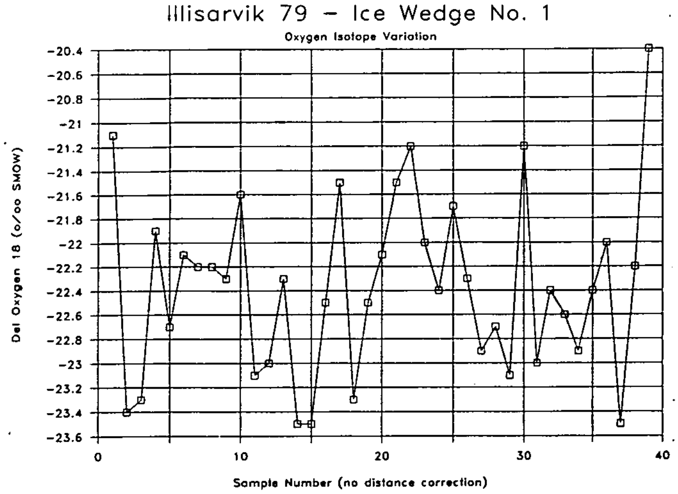

Figure 5. Variations in horizontal δ18O profile for ice wedge 79-1 at Illisarvik. Samples are 7.5 cm diameter and overlap with adjacent intervals. Total ice wedge width is 2.60 m.

Discussion

Isotope variations in the detailed profiling of modern wedges demonstrates that complete isotopic homogenization, through processes such as diffusion, has not occurred. The presence of tritium in samples covering the full range of isotopic compositions in ice wedge 1 at Illisarvik confirms that year to year variations of 2 to 3‰ do occur. This range is very small when compared to that of modern precipitation in the area (-16 to -33‰, unpublished data for Inuvik, 1984–86).

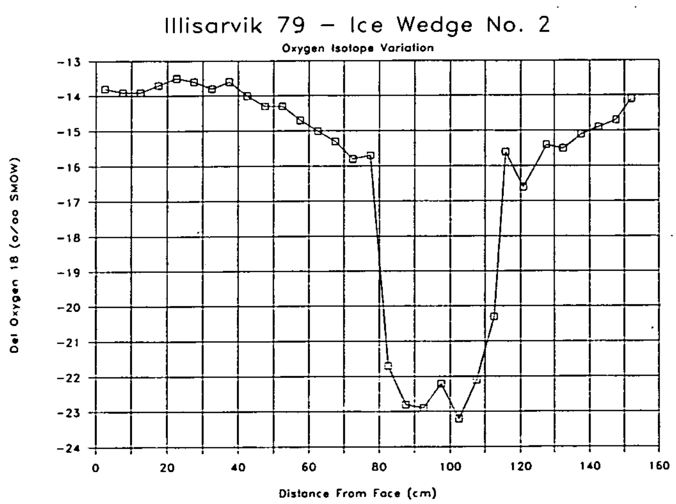

Figure 6. Variations in horizontal δ18O profile for ice wedge 79-2 and adjacent sediments at Illisarvik. The ice wedge is from 0.80 to 1.12 m.

As stated earlier, Mackay (1983) concluded that snowmelt in May and June is the primary source of water for the Mackenzie Delta ice wedges, while Konjachin (1988) has correlated the isotopic composition of ice wedges in Siberia to the mean winter temperature. The ^{18}O composition of winter precipitation in the Mackenzie Delta region averages approximately -30‰ (-26 to -33‰). Since simple melting of the snow or ice pack does not cause isotope fractionation, one would expect that the isotopic composition of modern ice wedges would be close to -30‰. This is clearly not the case. Therefore, the source water must represent either precipitation from a short time interval when the isotopic composition is near -22‰ (May or June), or an isotopically enriched snowpack, due to evaporation, sublimation and refreezing within the snowpack, or another source, such as active layer meltwater (from fall precipitation).

Each researcher also appears to have their own preferences in sampling. Konjachin (1988) suggests that only small ice wedges should be sampled since they represent a short discrete time period. Since the ice wedge is small, a single sample would be representative of the overall wedge. At Herschel Island, the small wedges are in fact isotopically different from the other modern wedges. Vasilchuk and Trofimov (1988) prefer vertical profiling in order to sample all generations of multiple complex wedges. Where several wedges of different ages exist, and this should be recognizable in section at the time of sampling, it is important to ensure that all generations are indeed sampled. However, as demonstrated in this paper, detailed profiling horizontally across an ice wedge provides excellent information on internal isotope variations with fewer samples than vertical profiling. If one required only an average isotopic composition for the ice wedge, then this can be accomplished by taking a composite sample across the face of the wedge.

For paleoclimatic work, ice wedges offer a potentially important source of isotope data. Since even the larger wedges have relatively uniform isotopic compositions, they should be included in any sampling program. It should be remembered, however, that they do represent a larger time period than small wedges and that samples must be truly representative of the whole wedge.

Conclusions

The detailed isotope investigations conducted to date in the Mackenzie Delta region have demonstrated that isotopic variations exist which may be related to fluctuations in climatic conditions. For paleoclimatic reconstructions, it is necessary that the age of the ice wedges be determined by placing them within the stratigraphic framework of the site. In most situations, representative composite samples are sufficient for determining the average isotopic composition of an ice wedge. For detailed work, horizontal profiling provides good resolution with fewer samples than vertical profiling. Further research is required on identifying the source water for ice-wedge ice.

Acknowledgements

The financial support of E.M.R. and NSERC for this research is greatfully acknowledged, as is the logistical support of PCSP and the Inuvik Research Centre. I would also like to thank the various field assistants for their dedication in sample collection, Dr. A. Judge for his personal support, and the 3 reviewers for their beneficial comments.

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