The use of deuterium to trace the origin of drifting sea ice

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ABSTRACT

Ice formed under equilibrium conditions contains about 20‰ more deuterium than the mother liquid. Therefore, in principle, it should be possible to distinguish between drift ice formed in the Arctic region, with δ-value of the surface waters, ranging from −20‰ to −30‰, and ice formed in the region between Iceland and Spitsbergen, with δ-value of the surface water close to zero.

Measurements of sea ice that drifted into the Húnaflói region north of Iceland in 1969 showed a rather uniform deuterium concentration, δ = −10‰ to δ = −17‰. It is concluded that this ice must have been formed somewhere in the Arctic Ocean.

INTRODUCTION

Studies of the stable isotope content of sea ice might give information about the region of formation and the drifting of the ice.

When formed at sea under equilibrium conditions, sea ice will contain 20‰ more deuterium and 3‰ more oxygen-18 than the mother liquid (Friedman et al. 1964, Craig and Hom 1968, Árnason 1969). In nature these conditions are not likely to be exactly realized because of the inclusion of brine in the ice. However, measurements reported by Friedman et al. (1964) have shown that the actual values obtained for deuterium content of sea ice, when corrected for brine entrapment, are not far from those expected from theoretical considerations. Ice samples collected at Woods Hole, Massachusetts and Hopedale Bay, Labrador, and analyzed by Friedman, contained approximately 20‰ more deuterium than the sea water from which it was formed, when corrections had been made for entrapped brine on the basis of the salt content of the ice.

Since the isotope content of ice depends on that of the mother liquid, from which the ice is formed, it should be possible to distinguish between ice masses frozen out from sea water with different isotope content.

THE DEUTERIUM CONTENT OF THE NORTH ATLANTIC AND THE ARCTIC OCEAN

The isotopic composition of sea water is relatively uniform throughout the oceans of the world. Exceptions are the polar regions where the content of deuterium and oxygen-18 in the surface or near-surface water is exceptionally low due to mixing with melted snow and glacial ice.

Figure 1 shows some values obtained for deuterium in surface waters of the Arctic Ocean and in the region north of Iceland. The results are given as δ-values, where δ denotes ‰ deuterium enrichment (depletion negative) relative to Standard Mean Ocean Water (SMOW). The deuterium results have an error of ±1‰ or less.

All deuterium values shown for the Arctic Ocean are taken from Redfield and Fried-

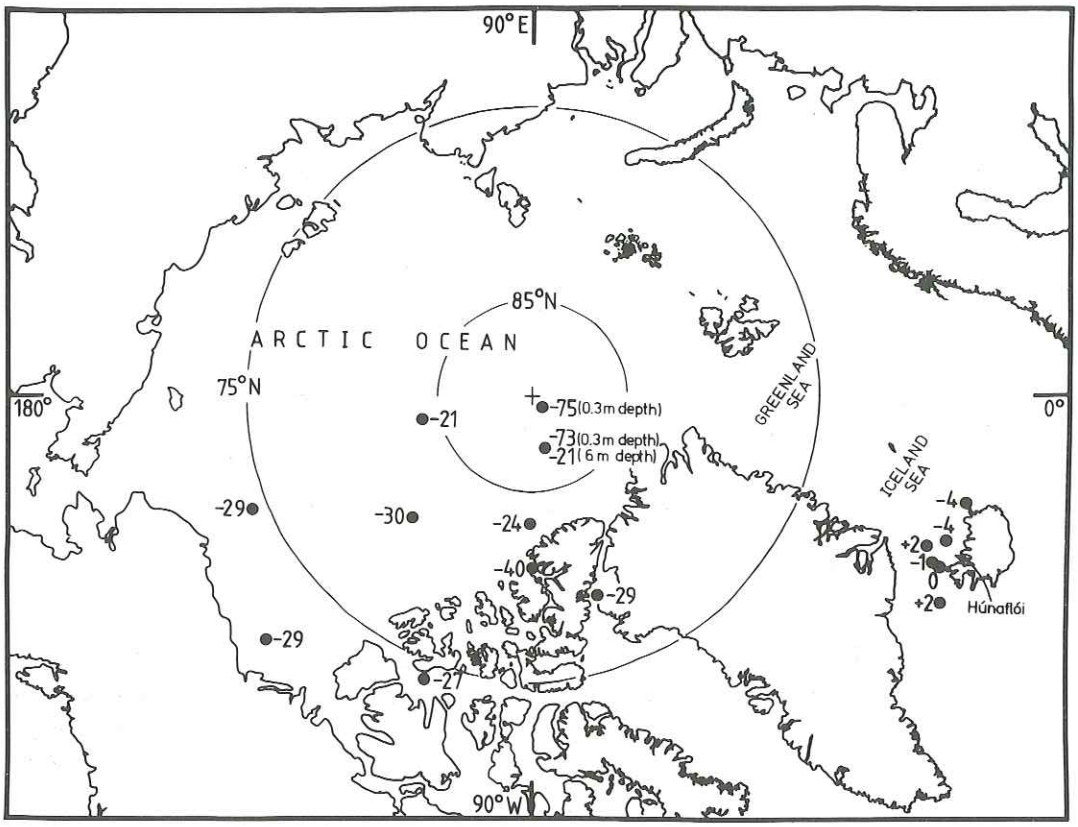

Fig. 1. Deuterium concentrations of surface waters in the Arctic Ocean and in the ocean north of Iceland. The deuterium results are expressed as ‰ deuterium enrichment (depletion negative) relative to SMOW. All values shown for the Arctic Ocean are taken from Friedman et al. (1961) and from Redfield and Friedman (1969). All samples from Icelandic waters were collected from Icelandic research vessels.

man (1969) and Friedman et al. (1961). Two sampling stations at latitudes higher than 85°N are shown in Figure 1. At these stations water with exceptionally low deuterium content was found, $\delta = -73‰$ and $\delta = -75‰$, respectively. According to Friedman et al. (1961) this deuterium depleted water is formed by summer melting of surface snow and is found in a very thin surface layer only in parts of the Arctic Ocean during summer. We therefore believe that the value $\delta = -21‰$ found in a sample collected at 6 m depth at one of these two localities, is more representative of surface or near-surface water in this region.

The deuterium content of the Arctic Ocean surface water should therefore vary between $\delta = -20‰$ and $\delta = -30‰$ (Fig. 1) and sea ice formed in this region should have a deuterium concentration not far from $\delta = 0‰$ to $\delta = -10‰$.

The δ-values shown for the stations north of Iceland are all close to zero, and according to Redfield and Friedman (1965) similar δ-values are to be expected in the whole area between Iceland and Spitsbergen. Sea ice formed in this area should therefore have a deuterium concentration of approximately $\delta = +20‰$.

Thus it should in principle be possible to

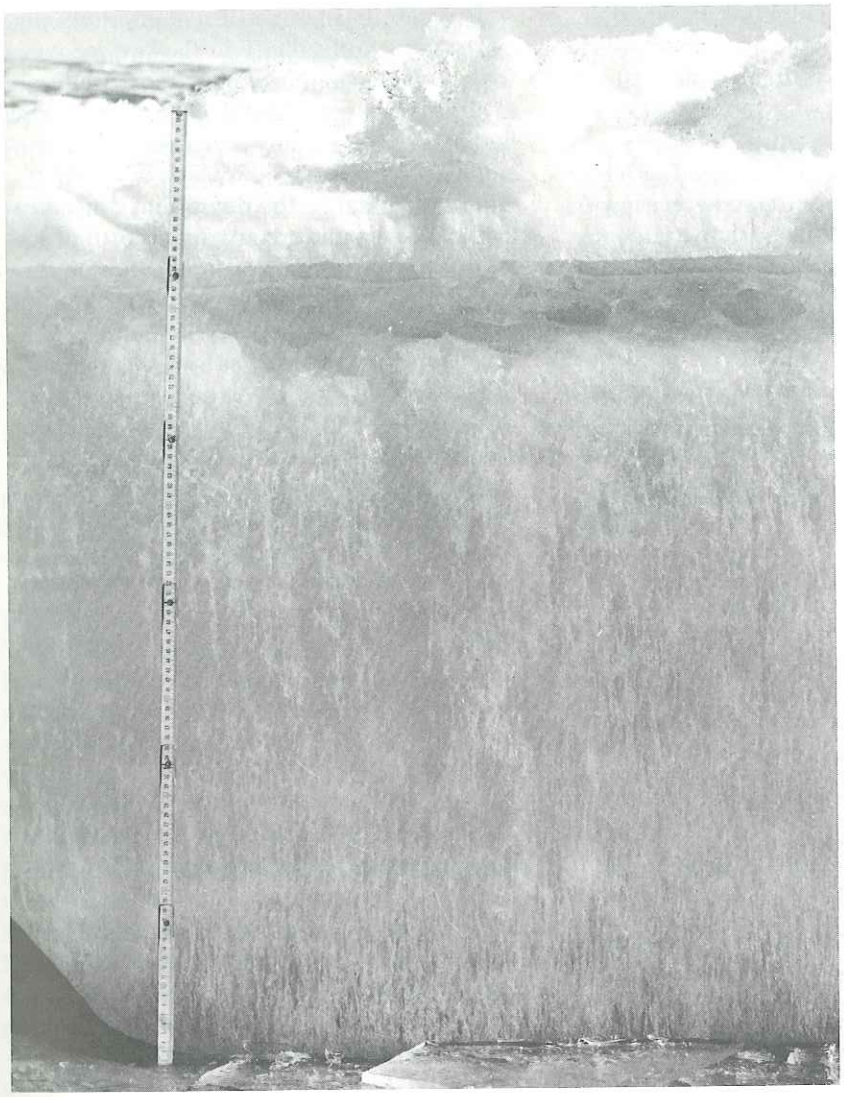

Fig. 2. A typical profile of ice that drifted into Húnaflói, North Iceland, in May 1969.

distinguish between sea ice formed in the Arctic Ocean and sea ice formed in the Greenland and the Iceland Seas.

THE DEUTERIUM CONTENT OF SEA ICE DRIFTED TO ICELAND

In May 1969 sea ice drifted into the bay Húnaflói north of Iceland. Ice cores were collected from two floes and some samples taken from these ice cores were measured for their deuterium concentration and salinity. The thickness of the ice ranged from one to three meters, but since the floes examined were all aground, the deepest part of them could already have been reduced by friction at the sea floor.

Figure 2 shows the profile of one of the ice floes from which a core was collected, and can be taken as a typical example of the

ice that drifted into Húnaflói at this time. The uppermost part of the ice was obviously winter snow, usually of the thickness 20–50 cm. Below the winter snow an almost transparent ice layer 5–15 cm in thickness was frequently observed, and below this clear transitional layer the ice looked greyish with brine inclusions that obviously were percolating through the ice.

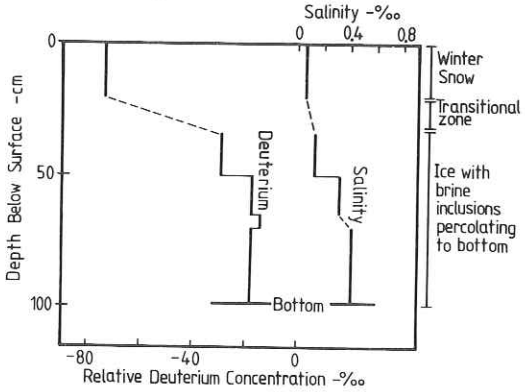

Fig. 3. Deuterium concentration and salinity of an ice core from 100 cm thick drift ice collected near Kirkjuból, Steingrímsfjörður, Húnaflói, Iceland, in May 1969. The solid lines indicate weighted averages for the corresponding depth intervals. The dotted lines serve only to guide the eye.

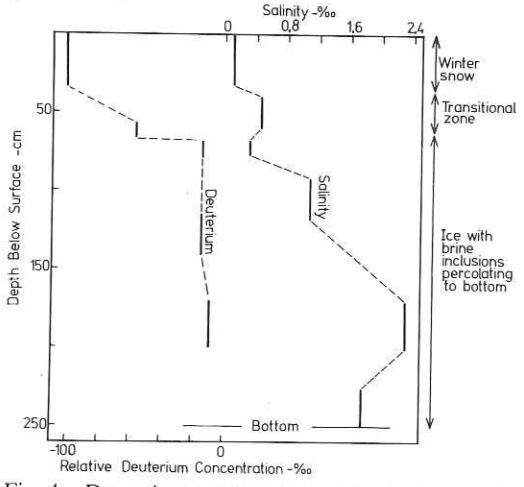

Fig. 4. Deuterium concentration and salinity of an ice core from 250 cm thick drift ice collected near Kirkjuból, Steingrímsfjörður, Húnaflói, Iceland, in May 1969. The solid lines indicate weighted averages for the corresponding depth intervals. The dotted lines serve only to guide the eye.

The results obtained for deuterium concentrations and salinity in the two ice cores from which samples were measured, are given in Figures 3 and 4. The winter snow had a very low salinity and a deuterium concentration from $\delta = -75‰$ to $\delta = -100‰$, which is similar to the deuterium concentration of the winter precipitation north of Iceland. Below the winter snow the ice became rather uniform in deuterium concentration with δ-values between $-10‰$ and $-17‰$. The salinity of the ice was low, but increased downwards as would be expected as a result of the percolation of brine inclusions downwards in the ice.

The average deuterium concentration of the sea ice collected in the Húnaflói is similar to that which would be expected if the ice were formed from water with deuterium concentration of approximately $\delta = -30‰$. Such ice can hardly have been formed in the area between Iceland and Spitsbergen, since ice formed in this region should have deuterium concentration of approximately $\delta = +20‰$.

Thus we conclude that the ice that drifted into the Húnaflói in May 1969 must have been formed somewhere in the Arctic Ocean.

At the end of May 1975 two discrete samples of sea ice were collected from a research vessel near the ice border about 60 naut. miles north of Iceland. One of these ice floes had a muddy surface, suggesting that it might have been formed near shore, possibly off the Siberian coast. Both samples gave a δ-values similar to those found for the ice in Húnaflói 1969.

DISCUSSION

Friedman et al. (1961) reported results of deuterium measurements of three ice cores collected from sea ice in the Arcic Ocean. In two of the cores the deuterium content was almost uniform and approximately 20‰ higher than the deuterium content of the sea

water in the same region. In one of the cores three minima of deuterium concentration were observed. These minima are interpreted as being due to the formation in summer, and freezing in early winter, of a thin surface layer of water of low deuterium concentration. The sea ice floats in this deuterium-poor layer, which is the first material to be added to the bottom of the ice floe when freezing begins in early winter. Such deuterium minima, if found in sea ice profiles, might be of help in distinguishing between annual layers and thus in determining the age of the sea ice.

For detecting such deuterium minima, if present, in the ice cores collected in the Húnaflói, much more detailed analyses would have been necessary.

As mentioned before, Friedman et al. (1964) used the salinity of the ice formed at Woods Hole, Massachusetts and Hopedale Bay, Labrador to make a correction for the amount of brine entrapped in the ice when it was formed. The average salinity of this ice was found to be about 7‰, indicating 20% of sea water entrapped in the ice. An ice floe containing such an amount of entrapped sea water is expected to have a deuterium concentration approximately 16‰ higher than the mother liquid, instead of 20‰ higher, if the ice had been formed under equilibrium conditions, free of any entrapped sea water.

The very low salinity of the ice that drifted into the Húnaflói, on the average 1.5‰, suggests that a significant part of the brine inclusions entrapped in the ice when formed, had percolated downwards through the ice.

It seems likely that as the brine inclusions move down through the ice they remain almost in isotopic equilibrium with the solid ice, and when leaving the ice, they will have a deuterium concentration similar to that of the initially entrapped brine. Thus, as the salinity of a sea ice decreases, the deuterium concentration of the remaining ice can be expected to approach a δ-value 20‰ higher than that of the sea water from which the ice was formed. This is supported by the earlier mentioned results of Friedman et al. (1961), where the sea ice collected in the Arctic Ocean, with only 2‰ salinity was found to have a δ-value nearly 20‰ higher than the δ-value of the ambient sea water.

The studies here discussed indicate that stable isotope measurements on drift ice could give information about its origin and even about its age. Such studies have, however, been given rather little attention in the past and much more detailed measurements are necessary to prove the validity of the method.

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