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VARIATIONS OF  $\delta^{18}\text{O}$  AND Cl<sup>-</sup> IN THE ICE CORES OF SPITSBERGEN

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Résumé. Les recherches d'isotope-geochimiques dans l'archipel du Spitsbergen ont été faites pour déterminer les corrélations entre les compositions isotopiques et géochimiques du nêve et de la glace et les changements dans les conditions naturelles. Les cinq profils isotopiques des carottes de glace du Spitsbergen indiquent de grandes variations des conditions climatiques durant les 800-900 dernières années. Le mécanisme d'accumulation de Cl, Na et K est plus compliqué, ainsi que la concentration de ces éléments et leurs rapports sont différents; ils dépendent de la situation géographique des glaciers et de leur type d'alimentation.

Abstract. The isotope-geochemical investigations on the archipelago of Spitsbergen (Svalbard) were aimed at finding out correlations between the isotopic and geochemical compositions of firn and ice and changes in natural conditions. The isotopic curves by all the 5 Spitsbergen ice cores display great variations reflecting the changes in the climatic conditions during the last 800-900 years. The accumulation mechanism of Cl, Na and K is more complicated, as the concentration of these elements, as well as their ratios differ depending on the geographical location of the glaciers and their type of feeding.

## INTRODUCTION

Isotope-geochemical studies constitute an important part of the research program of the Spitsbergen aero-glaciological expedition on the Institute of Geography of the Academy of Sciences, USSR. They are aimed at reconstructing the glacio-climatic conditions during the last centuries. The task was set to study the formation mechanism of the oxygen isotope and chemical compositions of firn and ice masses in temperate glaciers under the conditions of strong melting and meltwater influence. The analyses of  $\delta^{18}\text{O}$  in atmospheric precipitation, carried out by us since 1975, revealed that though the correlation between  $\delta^{18}\text{O}$  and the condensation temperatures in single precipitation is often violated, the correlation coefficient for a longer line of data - 0,52 - still allows to use the isotopic curves in palaeoclimatic reconstructions. The primary information contained in seasonal sediments certainly undergoes definite changes in the processes of melting and metamorphism. Our investigations on the Grönfjord-Fridtjof ice divide and the Lomonosov plateau showed that the amplitude of  $\delta^{18}\text{O}$  variations in snow and firn deposits decreases in time, a shift of the mean  $\delta^{18}\text{O}$  value toward higher values is also marked. But, as a rule, these changes do not influence the general morphology of isotopic curves. The primary chemical composition is still better preserved. This is indicated by the sharp peaks on the  $\beta$ -activity curves and the seasonal rhythm in the variations of Na, K and Cl [1].

In order to determine the role of general climatic changes and local influences in the formation of the isotope-geochemical composition of ice we studied 5 glaciers situated in different geographical areas of the archipelago and belonging to different feeding types (fig. 1). Table 1 presents the main data of these glaciers together with the average values of the analysed components.

## SAMPLING AND METHODS

After the core's surface had carefully been cleaned by removing 3-5 mm of ice, even layers from fragments of the core, which had accumulated in 5-10 years on the

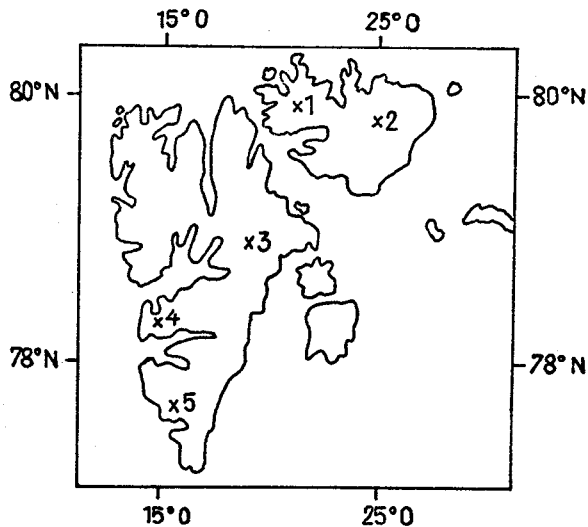


Fig. 1. Location of studied glaciers (see Table 1).

Table 1. Average  $\delta^{18}O$  and Cl values in the investigated ice cores.

No. on fig. 1	Glacier	Feeding type	Elevation, m	Length of core, m	Mean accumulation of ice, cm/yr	$\delta^{18}O$ , ‰	Cl <sup>-</sup> , mg/l
1	Westfonna (Nordaustlandet)	cold firn	580	208	88	-15,5	1,5
2	Austfonna (Nordaustlandet)	cold firn	700	202	97	-17,9	1,0
3	Lomonosov plateau (West-Spitsbergen)	cold firn	1000	201	85	-14,2	5,5
4	Grönfjord-Fridtjof ice divide (West-Spitsbergen)	firn-ice	450	201	62	-10,8	30-40
5	Amundsen glacier (West-Spitsbergen)	warm firn	700	368	?	-11,0	0,5

average were taken as samples. In order to investigate seasonal changes 1,5-2,5-meters long fragments of core were taken every 30-50 m, which in turn were sampled every 5-10 mm. Samples in the form of water were poured into clean vessels of glass and polyethylen and then hermetically closed. The  $\delta^{18}O$  values were determined on the MI - 1201 and "Delta-E" mass-spectrometers, Cl on a coulometric detector, Na and K by means of flame emission photometry. Various methods were used for stratifying the ice cores: the determination of reference layers, seasonal variations of  $\delta^{18}O$  and Cl, correlation of abrupt increases in sulphur concentration with volcanic eruptions [2], [3].

## DISCUSSION OF THE RESULTS

As all the studied ice cores cover approximately the same time span (800-900 years) and the number of analytical data is comparable, the average  $\delta^{18}\text{O}$  and Cl values of the ice cores characterize in general the formation processes of the isotope and chemical compositions of ice. Differences in the values are connected with differences in the geographical location and the elevation. Changes in the  $\delta^{18}\text{O}$  values first of all reflect variations in mean condensation temperatures together with the influence of the type of ice formation. For example, the isotope composition of the firn and ice masses in the cores from the Grönfjord-Fridtjof ice divide and the Amundsen plateau might have been influenced by the long stay (30-40 years) of precipitation in the infiltration zone with recurrent phasal transitions, thus causing the concentration of isotope  $^{18}\text{O}$ . As the course of yearly temperatures and, correspondingly, the  $\delta^{18}\text{O}$  variations in atmospheric precipitation are irregular there is no reason to presume strict seasonal variations of the  $\delta^{18}\text{O}$  values in firn and ice masses. Likewise, we did not succeed to determine seasonal layers on the basis of  $\delta^{18}\text{O}$  variations anywhere.

Seasonal changes in the concentration of Cl in atmospheric precipitation are better displayed. Much attention has been paid to the variation mechanism of chemical elements in atmospheric precipitation. Many reports on the symposium "Isotopes and impurities in snow and ice" were dedicated to these questions [4], [5]. The results are contradictory as yet - in Antarctica the investigators, as a rule, have found no seasonal variations [6], the concentrations of some elements in the ice cover of Greenland show regular fluctuations [4]. Investigating the distribution of elements in the seasonal snow cover, Y.T. Gjessing [7] came to the conclusion that the increased concentrations of Cl and Mg, as well as  $\text{NO}_3$  and  $\text{NH}_4$  in the layers of snow, accumulated in Nordaustlandet during the winter of 1974, were caused by storms which broke the ice cover on the surrounding aquatory. Our studies give support to the conclusions of Gjessing. In summer-autumn months the concentration of Cl in the samples of atmospheric precipitation collected at the meteorostation of Barentsburg exceeds the winter values by tens, sometimes hundreds of times. The concentration of Cl, an element of marine origin, sharply decreases at a greater distance from open sea or at a greater altitude (see also Table 1). For this reason it is evident, that only those glaciers which are located near enough to an open aquatory of changing ice conditions can reflect seasonal variations. Naturally, the process of metamorphic alterations can cause certain redistribution of primary concentrations, such as an increased concentration of Cl in interlayers of ice [7].

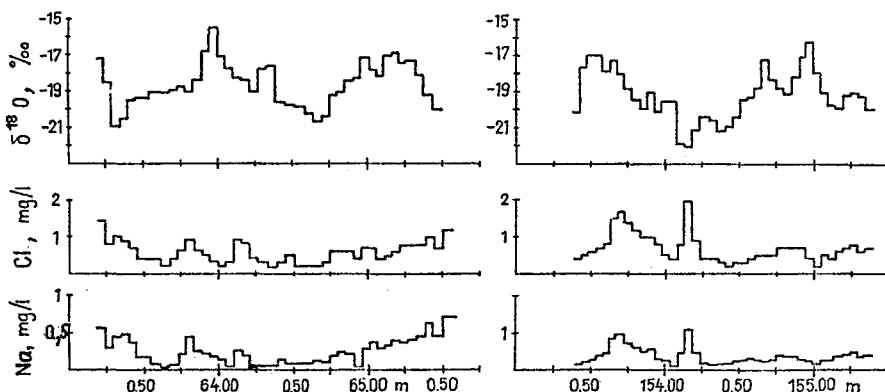


Fig. 2. Variations in the concentrations of Cl, Na and  $\delta^{18}\text{O}$  values in fragments of core from Austfonna.

At a greater distance from the open aquatory the atmosphere quickly loses the elements of marine origin and the determination of seasonal layers becomes complicated. On the basis of variations of C1 in this layers we succeeded in determining seasonal layers in the cores from Westfonna [2] and the Vavilov ice dome on Severnaya Zemiya archipelago [8], in Austfonna, situated farther off, seasonal rhythmicity could not be detected (fig. 2).

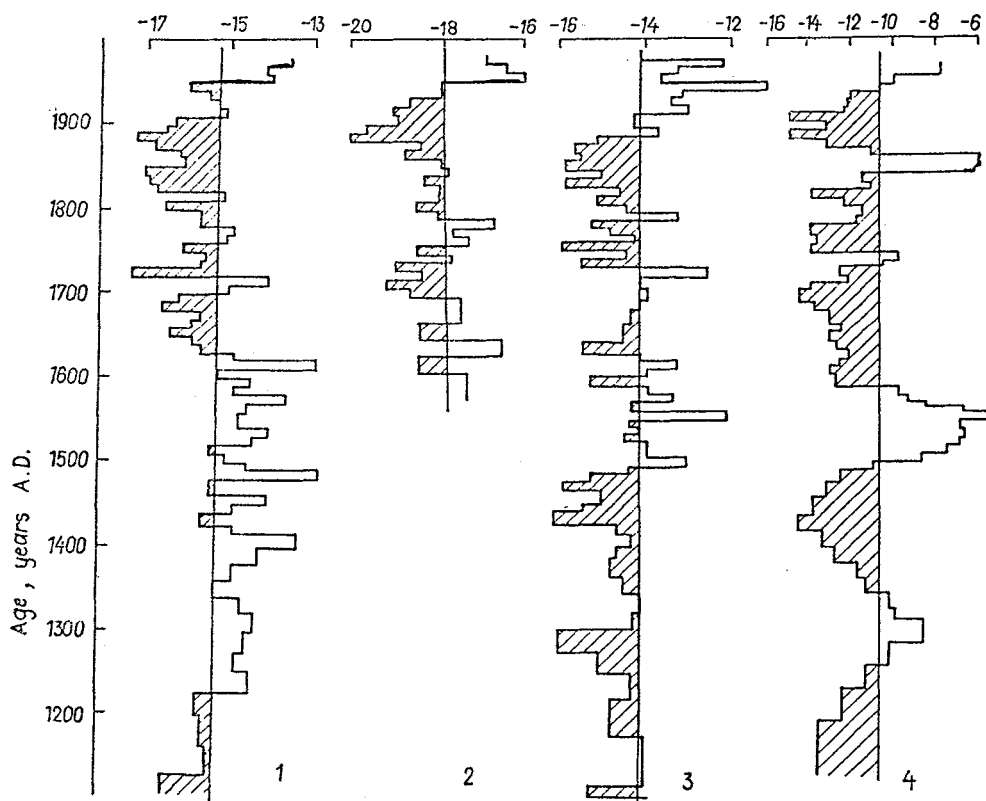


Fig. 3. Variations of  $\delta^{18}\text{O}$  (‰) in ice cores: 1) Westfonna, 2) Austfonna, 3) Lomonosov plateau, 4) Grönfjord-Fridtjof ice divide.

Distribution trends of chemical elements and the oxygen isotopic composition are of greatest interest in palaeogeographic reconstructions. Fig. 3 presents the  $\delta^{18}\text{O}$  curves for four Spitsbergen glaciers. The most characteristic feature of the oxygen-isotope curves is the presence of relatively negative  $\delta^{18}\text{O}$  values in the layers which accumulated from the first half of the XVII century to the beginning of the present one, at which the more significant decrease periods of  $\delta^{18}\text{O}$  in precipitation almost ideally coincide on all the curves. Hence, two conclusions: 1) climatic changes are well reflected on isotopic curves (after all, this is the s.c. Little Ice Age) and 2) the mechanism of formation and transportation of atmospheric moisture, as well as its general source had to be quite similar all over the archipelago. The central parts of the curves accumulated during a change from relatively warm to severe climatic conditions, differ a bit in morphology. In this time span the formation of the isotopic composition of firn and ice might greatly have been influenced by the unstable regime of atmospheric circulation and the feeding regime of glaciers.

After all, in altered external conditions many glaciers could have changed their type of feeding. It is also not excluded that short-term changes in meteorological conditions in various parts of Spitsbergen could have shown temporary shifts or proceeded in an opposite direction.

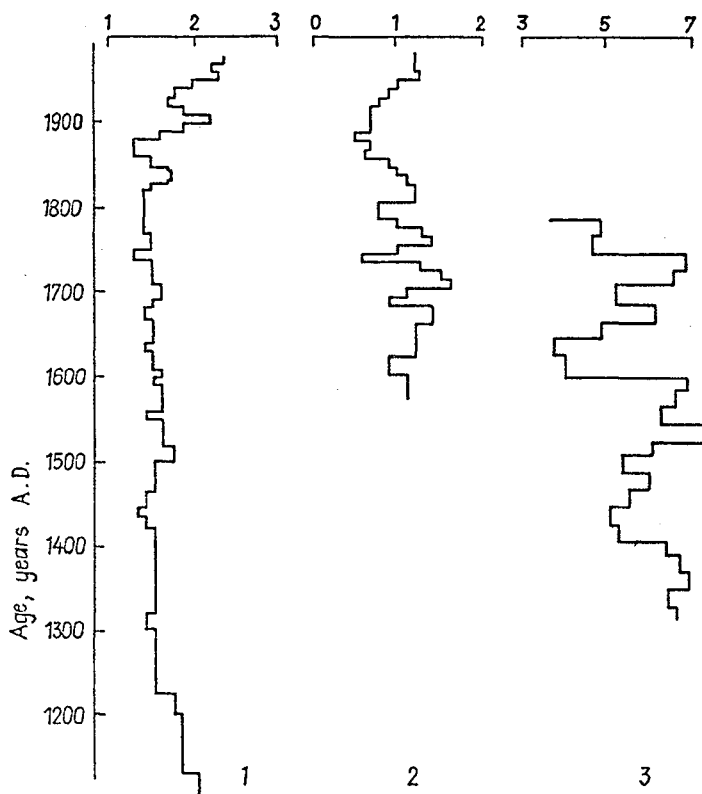


Fig. 4. Variations in the concentration of Cl (mg/l) in ice cores: 1) Westfonna, 2) Austfonna, 3) Lomonosov plateau.

Our investigations indicate that lasting changes in the concentration of Cl reflect the dynamics of pack ice cover on the aquatory surrounding the archipelago [9]. Satisfactory correlation of the concentration trends of Cl in the ice core from the Lomonosov plateau and the ice conditions on the surrounding aquatories (reconstructed on the basis of historical data as well as those from instrumental observations) stand as proof of this. The correlation coefficient between the variations of Cl and the dynamic of pack ice near the coast of Iceland 1500-1800 y.a. [10] is -0,78, and even -0,9 according to the data on the changes in ice distribution on the Sea of Greenland during the present century [11]. The effect of short-term meteorological conditions, having great influence on the seasonal course of the concentration of Cl in atmospheric precipitation, is smoothed in case of durable trends and becomes of secondary importance. Our conclusions are also supported by the satisfactory correlation between the curves of  $\delta^{18}O$  and Cl in the cores from the Lomonosov plateau and the Vavilov ice dome [1]. Variations of Cl in the cores from the ice domes of Nord-austlandet are considerably smaller, as the role of local influence decreases due to the bigger distance from the open sea (relative to the interval in the seasonal dynamics of the pack ice cover) (fig. 4).

Na and K were also determined in the core from Austfonna (Nord-austlandet). Table 2 presents the data and the correlation matrix according to 98 samples.

Table 2. Correlation matrix, mean concentrations of Cl, Na, K and mean  $\delta^{18}O$  values in the ice core from Austfonna.

	Cl	Na	K	$\delta^{18}O$	mg/l	% ( $\delta^{18}O$ )
Cl	1.000	0.892	0.526	0.049	1.0	
Na	0.892	1.000	0.567	-0.093	0.47	
K	0.526	0.567	1.000	0.040	0.05	
$\delta^{18}O$	0.049	-0.093	0.040	1.000		-17.86

The good correlation between Cl and Na, as well as the closeness of the Cl/Na ratio (2,13) in ice to that in sea water (1,8) speak of their common source - open sea aquatory. Instead, the weak correlation of Na and Cl with K and the relatively small ration of Na/K point to the partially continental origin of K.

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