Study of ice core chemical composition in polar regions of the Earth (by the example of Vostok station, Antarctic)

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The results of complex study of the ice core at Vostok station (Antarctic Continent, the drilling hole 5G) are presented. The chemical analysis has shown a correlation between the ion composition of the ice core water and paleoclimatic signals. Maximal concentration of the dissolved matters (up to 600 μg/l) in ice corresponds to the last maximal glacial period (the ice age is 22 000 years). During "warm" periods (MIS 1; 7500 years) and (MIS 5e; 126 600 years), a minimum of dissolved matter is observed (200–400 μg/l). Comparative analysis of the results with available data of international investigations has shown a possibility of formulation and successive solution of problems of the complex analysis of ice cores in the polar regions of the Earth.

Introduction

It is well known that many climate changes took place on the Earth for years. At present, the scales and times of these events are under discussion. One of the markers of the paleoclimate is the chemical composition of the ice core in the polar regions, which study is of particular importance in investigation of the atmosphere composition, volcano processes, and other events on the Earth for the last hundreds of thousand years.

Russian Antarctic station Vostok is situated in the center of the East Antarctic Continent (78°28′S, 106°48′E) at a height of 3488 m. Geophysical researches conducted near the station have revealed a lake under ice, which was called Lake Vostok. The ice thickness above the lake level varies between 3750 and 4150 m. The lake is meant the largest subglacial lake in the Antarctic.[1]

The drilling of ice at the station started since the end of 1960s. The drilling of the fifth bore had started in 1989, the depth of which to the moment is 3650 m. Studies of isotope composition, crystal sizes, and other ice parameters has shown that at a level higher 3538 m the ice is of meteor origin, lower – of the lake one.[2,3] It is planned to reach the Lake surface during the 52-nd Russian Antarctic expedition. The study of the 440 000 year paleorecord obtained from the ice core has revealed four macroclimatic cycles of cooling and warming, characterized by periodicity caused by changes in parameters of the Earth orbital. A close connection of the climate with variations of greenhouse gases (CO_2 and CH_4) in the atmosphere was noted.[4–6] The study of the ice-core chemical composition has shown the sea, soil, and secondary aerosols to be the sources of the dissolved particles.[7] However, at present, there is insufficient amount of data on the ice chemistry, which could give a valuable information on accumulation markers, dust particle identification, and paleoclimatic signals of the Earth.

This paper present results of chemical analysis of ice cores, which describe a history of the climate in five key bores for the last 126 000 years.

Materials and methods

Ice cores of the station Vostok (drilling hole 5G, 17 sections, a general length of 689 cm) were taken from the station archives. To the age attachment, an average depth-age model[8] was used. The cores, chosen for analysis, corresponded to periods 7 500 years (marine isotope stage MIS 1, holocoen); 22 000 years (MIS 2, the last glacial maximum); 55 600 years (MIS 3 pastpleistocen interstage); 111 600 years (MIS 5d, the first pastpleistocen glacial period); 126 600 years (MIS 5e, the last interglacial period).

Accounting for the unique properties of the object under study, the specificity of the ice drilling,[9] the authors, based on the literature data and the experience of their own,[10] have conducted a careful preparation in order to solve the methodical problems and analyze the core chemical composition.

The ice core was washed by deionized water, free of bacteria, inside a sterile microbiologic chamber, where all rules of "clean room" were maintained, including a special cloth of researchers. The ice core was cut with a step of 2.5 cm. The obtained samples were put into a refrigerating chamber with a temperature of –20°C for further analyses. Then the samples, taken from the chamber, were again carefully washed by the deionized water, melted up to the stage when their volume changed approximately by 1/3, and put into a polypropylene

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box with a tight cup. The samples were melting at 25°C; the pH was immediately determined in the melted water. The rest of the sample was filtered through the membrane filter with pore diameters of 0.2 μm for further analysis of ions. The chemical analysis of the water composition was conducted by the present day methods, using both the available standardized attested methods and specially worked out at the Limnological Institute (LIN) SB RAS for ultra-fresh water.[11,12]

To identify the accumulation markers, dust particles, volcanic traces, the basic ions (HCO^{3-}, SO_4^{2-}, Cl^-, NO_3^-) were analyzed by the method of high-performance liquid chromatography (Milichrom A-02); (Ca^{2+}, Mg^{2+}, NA^+, K^+) – by atom adsorption (AAS-30), and mass-spectrometry with plasma ionization of matters (ICP-MS Agilent 7500). The divergence from the ion balance therewith was on the average less than 8% and did not exceed 15% at a summarized ion concentration lower 30 μg/l.

Results and discussion

As the results of chemical analysis of the melted water have shown, the ion sum varied between 10 and 1500 μg/l (Fig. 1). The pH solutions had a weakly acid reaction varying between 5.05 (MIS 3) and 6.4 (MIS 2). Basic ions in water of the ice in all sections of ice cores under study were NA^+, SO_4^{2-}, Cl^-. The same ions are basic in water of the meteor ice (which agrees with results of other authors), despite the choice of results for comparison was conducted for different depths.[7,13]

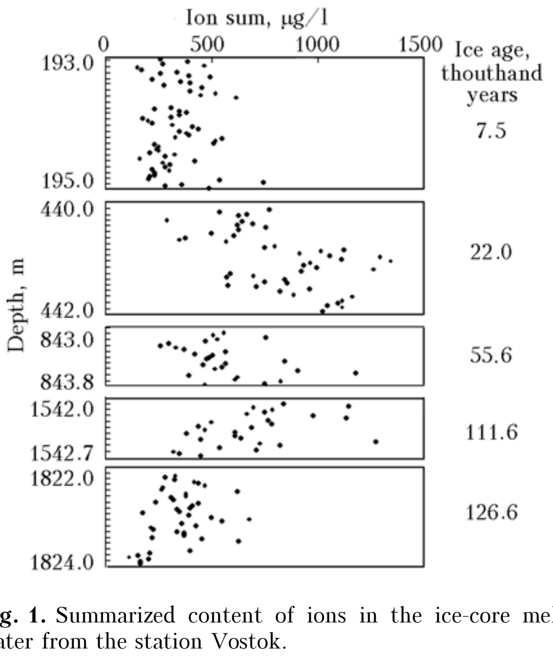

Fig. 1. Summarized content of ions in the ice-core melted water from the station Vostok.

In ice cores, related to periods of global cooling (MIS 2, ≈ 22000 years and MIS 5d, ≈ 111600 years), maximal concentrations of the dissolved matters were determined (400–600 μg/l on the average). In the epochs of cooling, caused by inter-latitude contrasts, more strong winds are observed and ice covers are formed.[1] Decreasing of see level results in the shelf drainage, precipitation decreases, and increases of the amount of the suspended matter in the atmosphere. The increased dust content of the atmosphere is reflected in the increased concentration of ions NA^+, K^+, SO_4^{2-}, Cl^- in the melted water of ice cores; and of ions Na+, Ca^{2+}, Mg^{2+}, K^+, SO_4^{2-}, Cl^-, and NO_3^- in the last glacial maximum.

In the first case, possibly, a great role in atmospheric pollution was played also by the volcano activity followed by the growth of such ions as K^+ and SO_4^{2-}. In the maximal glacier period (22000 years) mineral particles accumulated in ice, what is evidenced by the increased ion concentration of Ca^{2+}, Mg^{2+} relative other cations in ice-cores of that period. The influence of continents on the mineral matter chemical composition in the epoch of the last maximum glacier is also supported by increased concentrations of aluminum, one of the basic elements of the Earth crust.[7]

In the intervals corresponding to ice age of 7500 and 126600 years (the periods of global warming), a minimum of dissolved matters was observed (200–400 μg/l). The basic ions in the ice cores of the “warm” period (Na^+, K^+, SO_4^{2-}, Cl^-) reached polar regions from the ocean surfaces and due to volcano activity.

The chemical analysis of the melted water has shown that the highest concentrations among basic ions have the anion SO_4^{2-} (from 44 to 550 μg/l) at an average value of 190 μg/l. The mean concentration of the same ions given by Legrand et al. [Ref. 7] is 180 μg/l (Fig. 2). The highest concentration of sulfates in water is found in ice cores aged 22000 years (MIS 2), the lowest one refers to 126600 year (MIS 5e). Among cations, that evident domination of Na^+ in maximum paleoclimatic periods (MIS 1; MIS 2; MIS 5d; and MIS 5e), the Ca^{2+} concentration increases.

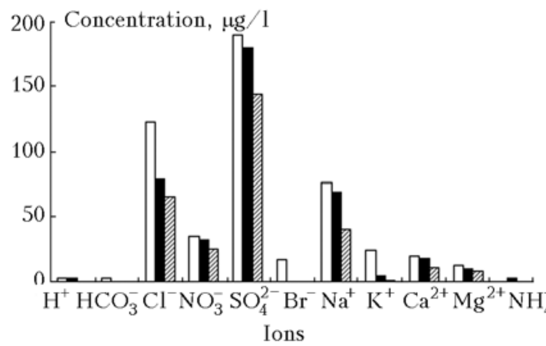

Fig. 2. Mean concentrations of basic ions in the ice-core water from station Vostok (Antarctic). (Light squares present data of the LIN, 2006; the mean ice thickness is 17 sections; dark squares are from Ref. 7; the mean for ice thickness is 125–2080 m; dashed squares are from Ref. 10; the mean is 3350–3535 m).

Data on dynamics of the summarized concentration of ions in ice-cores, as well as individual ions, obtained by us well agree with data of other authors (Fig. 3). High concentrations of ions in ice-core water[7] correspond to periods of global cooling, low ones – to periods of warming.

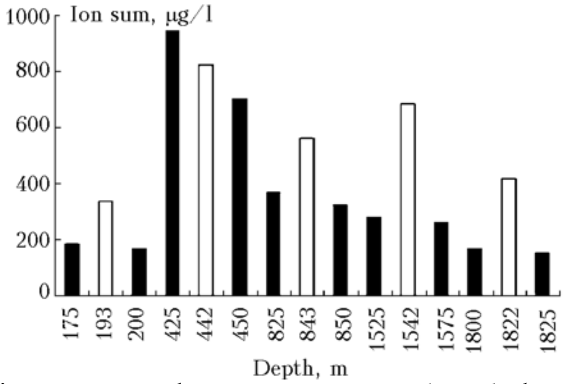

Fig. 3. Summarized ion concentration in the melted water of ice-cores from station Vostok (light squares – LIN SB RAS; dark squares – Ref. 7).

Conclusion

Results of chemical analysis have revealed a connection between the ion composition of ice cores (Vostok, Antarctic) with global changes of climate. Maximal concentrations of dissolved matters (up to 600 μg/l) correspond to periods of global cooling MIS 2 (22000 years) and MIS 5d 111600 years. In “warm” periods MIS 1 (7 500 years) and MIS 5e (126600 years) their minima have been determined (200–400 μg/l). These investigations favor the experience accumulation for future chemical analysis of water from the unique ultrafresh subglacial Lake Vostok.

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