Annals of Glaciology 21 1995

Ion content of polygonal wedge ice on Bolshoi Lyakhov: a source of palaeoenvironmental information

Oksana S. Savoskul

Institute of Geography, Russian Academy of Sciences, Staromonetny 29, Moscow 109017, Russia

ABSTRACT. Bolshoi Lyakhov is one of the group of the New Siberian Islands in the Laptev Sea. The permafrost of the island is of an extremely low temperature regime, polygonal wedge ice being the most specific feature. The geomorphological level considered is a so-called edoma, presumably of late-Quaternary origin; polygonal ice wedges are more than 10 m wide and up to 25 m deep on this level, and about 1 m × 1.5 m on the peat bogs of Holocene age. Sixty-six samples of underground ice were taken on both surfaces. The macro-ion content was analyzed, i.e. Ca, Mg, Na, K, HCO_3, Cl, SO_4. A significant difference in ion content was found between the older and the younger ice. The late-Quaternary wedge ice is characterized by the predominance of Ca and HCO_3, while the Holocene ice contains considerably higher proportions of Na and Cl. This may be attributed to different environmental conditions during wedge-ice growth: more continental in the late Quaternary and more maritime in the Holocene.

INTRODUCTION

Polygonal wedge ice is the most specific feature of the permafrost of Bolshoi Lyakhov, New Siberian Islands, Russia. Only a few studies have been done in this vicinity on the chemistry of this type of underground ice (Volkova and Romanovskiy, 1974; Korzun, 1985). However, as was shown for western Siberia, the chemical content of underground ice could serve as an important source of palaeoenvironmental information when other data are not available (Danilov and others, 1980). The present paper considers the ion content of wedge ice of the late Quaternary and of the Holocene according to analyses of their macro-ion content, i.e. Ca, Mg, Na, K, HCO_3, Cl, SO_4.

STUDY AREA

Bolshoi Lyakhov is the most southerly of the New Siberian Islands in the Laptev Sea (Fig. 1). No detailed data exist on the cryolithological features here. On the geological evidence, the permafrost of Bolshoi Lyakhov is very similar to that of the Jana–Kolyma lowland. The latter is of an extremely low temperature regime, the mean annual temperature at the bottom of the active layer being estimated as below −10°C (Nekrasov, 1986). The Quaternary deposit of the Jana–Kolyma lowland, the so-called edoma complex, lying on Neogene marine strata, is a loose silt of loessial type with abundant plant remnants. Radiocarbon data indicate the late-Quaternary age (50 000–11 000 BP) of the edoma complex (Kaplina and others, 1980). Apart from the massive and segregation underground ice, this deposit contains polygonal wedge ice, with wedges 30–40 m deep. In some locations ice wedges up to 50–60 m deep have been described (Popov and others, 1985). Such extreme dimensions and other features of the ice wedges are explained by the hypothesis of syngenetic growth of ice wedges, i.e. an assumption of cryogenesis under conditions of continuous accumulation of the containing silt sediments, which are believed to be of alluvial origin

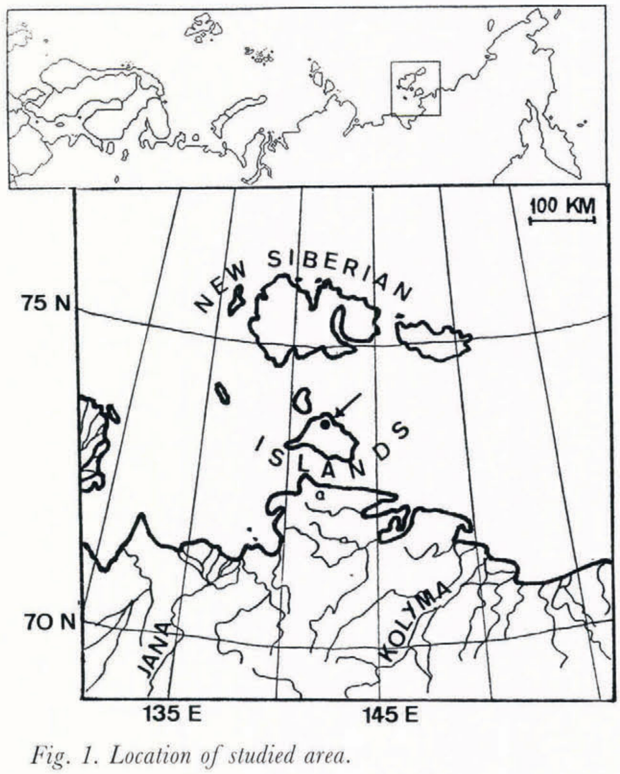

Fig. 1. Location of studied area.

https://doi.org/10.3189/S0260305500016128 Published online by Cambridge University Press

(Popov and others, 1985). However, there are other conceptions of the origin of these sediments, in particular that the edoma complex was deposited by wind (Tomirdiaro and Chernenkiy, 1984). According to another hypothesis, in the late Quaternary an Arctic-shelf glacial sheet covered this territory (Grosval'd, 1989).

The Holocene permafrost structures occur mostly on the river banks, where they take the form of syngenetic ice wedges 1–2 m deep (Popov and others, 1985). During the Holocene Optimum the edoma surfaces were eroded by thermokarst processes, which led to the widespread development of peat bogs in the thermokarst depressions (Kaplina and Gitterman, 1983). In the late Holocene, when climate turned colder, a period of ice-wedge formation occurred on the peat bogs. Thus, on the edoma surface, apart from gigantic ice wedges of late-Quaternary age, Holocene ice wedges of smaller dimensions occur.

STUDY SITES

The study sites are located in the northern part of Bolshoi Lyakhov (74° N, 142° E; Fig. 1). Based on geological drilling, the thickness of the late-Quaternary deposits at this location is 20–30 m (personal communication from P. S. Davidov, 1989). It is of the same pattern as the edoma complex of the Jana–Kolyma lowland, i.e. a light-brown silt stratum with abundant plant remnants, mostly grass and herb roots in situ and thin peat layers from several millimetres to 1–2 cm thick. The content of massive and segregation ice in the deposit is very high, up to 30–40%. The ice wedges are 5–10 m wide and up to 25–30 m deep. The length of polygons varies from 10 to 20 m. The late-Quaternary deposits lie on gravel-sand marine deposits of Neogene age with massive underground ice and numerous ice lenses. The scattered Holocene deposits take the form of a peat stratum up to 1–1.5 m deep with ice wedges up to 1 m wide. The polygons are seldom longer than 3–5 m.

The wedge ice was sampled in 11 outcrops (Fig. 2), which are located along a strip 5 km long, stretching in an east–west direction, about 7 km from the north coast of the island. Since absolute dating was not feasible, the ice age was estimated according to geomorphic evidence and ice-wedge dimensions. Later on we will refer to the large ice wedges of the edoma complex as late-Quaternary ice (following Popov and others (1985); an assumption of the same age for this ice and the containing deposit was adopted) and to small narrow wedges as Holocene ice. The wedge ice is of very specific texture. Mostly it is unclear due to the high content of mineral particles and air pores. The texture is characterized by numerous subparallel vertical layers, which often cross each other. However, some relatively clear zones occur within the wedges. These are most specific to the Holocene ice. In ice wedges 1–7 the late-Quaternary ice is exposed. No. 8 is a complicated ice wedge: the narrow upper part (8B) apparently grew after the formation of the wide lower part (8A). Thus the upper two samples are likely to be of Holocene age and the lower two of late-Quaternary age. Ice wedges 9–11 are of Holocene age. The locations of sampling points within the ice wedges are shown in Figure 2.

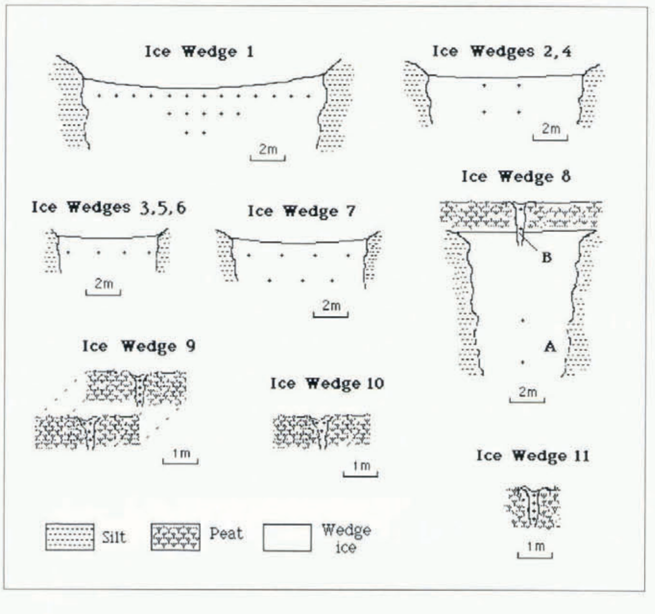

Fig. 2. Sketch of sampling points within the ice wedges.

METHODS

The samples were taken using axe and knife. Apart from the underground ice, snow and rain-water were sampled in the vicinity of the study sites, using plastic sheets and tools. The melted water was filtered and stored in 200 ml plastic bottles. The analyses were carried out in the chemical laboratory at the Geographical Department of Moscow State University. The concentrations of Ca, Mg, Na and K were measured using an atom-adsorption spectrometer with an accuracy of 0.01 mg l^{-1}. HCO_3 concentration was estimated by acid-alkaline titration using 0.01N solution of HCl with an accuracy of 0.05 mg l^{-1}; Cl concentration by titration using 0.02N solution of $AgNO_3$ with an accuracy of 0.01 mg l^{-1}; and concentration of SO_4 in solution of BaCl by spectrophotometer with an accuracy of 0.01 mg l^{-1}.

Concentrations of the ions, the Cl/Na index and the mineralization averaged for each ice wedge and the corresponding standard deviations are presented in Table 1. The concentrations are expressed for each ion as a percentage calculated from concentrations expressed in milliequivalent separately for cations and anions assuming that the sum of macro-ions is 100% in each case. Mineralization is computed as the sum of macro-ion concentrations and expressed in mg l^{-1}. In order to get easily comparable data the mean values of ion concentrations, the Cl/Na index and mineralization with standard deviations were computed separately for late-Quaternary ice, Holocene ice and samples of atmospheric water (Table 2).

RESULTS

Tables 1 and 2 and Figure 3 show that the late-Quaternary and Holocene ice differ considerably in values of mineralization. While the mineralization of the

https://doi.org/10.3189/S0260305500016128 Published online by Cambridge University Press

Table 1. Ion content of wedge ice and precipitation

Samples		*Ice wedges*												*Precipitation*	
Type		1	2	3	4	5	6	7	8A	8B	9	10	11	snow	rain
Number		20	4	4	4	4	4	7	2	2	8	3	4	5	5
Concentrations (%)															
HCO_3	mean	64	53	53	68	72	83	60	76	40	33	23	31	39	38
	s.d.	7	7	7	17	17	9	9	10	2	6	2	7	16	24
Cl	mean	29	39	39	26	23	13	33	16	50	64	71	58	54	54
	s.d.	8	9	5	13	12	7	7	5	2	7	3	12	9	20
SO_2	mean	6	8	8	6	4	4	6	7	10	3	6	12	7	7
	s.d.	6	5	7	5	5	4	3	6	3	2	1	8	8	7
Ca	mean	54	44	53	56	61	76	53	58	50	29	36	35	40	30
	s.d.	9	10	7	7	7	6	8	7	2	10	15	10	3	16
Mg	mean	24	21	24	23	23	19	23	18	25	23	20	18	19	15
	s.d.	5	3	2	1	2	4	2	1	3	15	5	3	8	13
Na	mean	19	30	21	18	14	5	21	23	19	45	40	38	38	50
	s.d.	7	8	8	7	8	2	9	6	4	16	18	14	8	25
K	mean	3	5	2	2	2	0	3	1	5	2	5	10	3	5
	s.d.	2	4	1	2	2	0	1	0	2	1	3	3	2	3
Cl/Na	mean	2.45	2.14	3.21	2.16	2.68	4.91	2.61	1.16	3.99	2.44	3.08	2.50	2.32	2.19
	s.d.	0.78	0.83	1.19	0.65	0.61	3.56	0.83	0.66	0.94	1.10	1.44	0.66	0.82	1.48
Mineralization (mg l^{-1})															
	mean	121.00	68.54	134.24	176.81	199.47	325.67	133.87	130.09	32.79	54.67	87.33	80.73	47.08	46.74
	s.d.	40.96	39.20	32.12	62.33	92.03	90.43	41.37	0.28	13.39	18.86	10.26	21.78	9.18	13.98

Holocene ice is very similar to the mineralization of present precipitation, that of late-Quaternary ice is approximately twice as great. The standard deviation of late-Quaternary ice indicates very high variability of the values of mineralization. However, mineralization of a few late-Quaternary samples is close to that of present precipitation.

Table 2. Averaged ion content of wedge ice and precipitation

		Late Quater-nary ice	*Holocene ice*	*Precipitation*
Concentrations (%)				
HCO_3	mean	65	31	39
	s.d.	12	7	19
Cl	mean	29	62	54
	s.d.	10	9	15
SO_2	mean	6	7	7
	s.d.	5	6	7
Ca	mean	56	34	35
	s.d.	10	11	12
Mg	mean	23	21	17
	s.d.	4	10	10
Na	mean	19	39	44
	s.d.	9	16	19
K	mean	3	5	4
	s.d.	2	3	2
Cl/Na	mean	2.72	2.58	2.25
	s.d.	1.38	1.03	1.13
Mineralization (mg l^{-1})				
	mean	147.68	63.99	46.91
	s.d.	78.30	24.62	11.15

The late-Quaternary ice is characterized by the predominance of Ca and HCO_3, while the Holocene ice contains higher proportions of Na+K and Cl, the most variable in both cases being the concentrations of SO_4 and Mg. The ion content of the Holocene ice is very similar to that of present precipitation, where concentrations of Na and Cl are also much higher than in the late-Quaternary ice. An interesting point is that the proportions of Ca and HCO_3 in late-Quaternary ice samples with low mineralization are also high. The variations of SO_4 and Mg concentrations are of an uncertain pattern.

The Cl/Na index is very variable, so it is not clear whether the differences between various types of samples should be attributed to genetical reasons or statistical variations.

The wedge ice is found to be chemically inhomogeneous in both the vertical and horizontal directions. However, no certain trend could be recognised in the variations of the ion content throughout the width of a wedge, as is clear from the comparison of 20 samples from ice wedge No. 1. Apparently there is a tendency for an increase of mineralization with depth in ice wedge No. 8, which could be explained by the complicated structure of the wedge, which contains ice of two different ages.

DISCUSSION AND CONCLUSIONS

The predominance of Ca and HCO_3 in late-Quaternary wedge ice was reported from the Lena river, Jana lowland

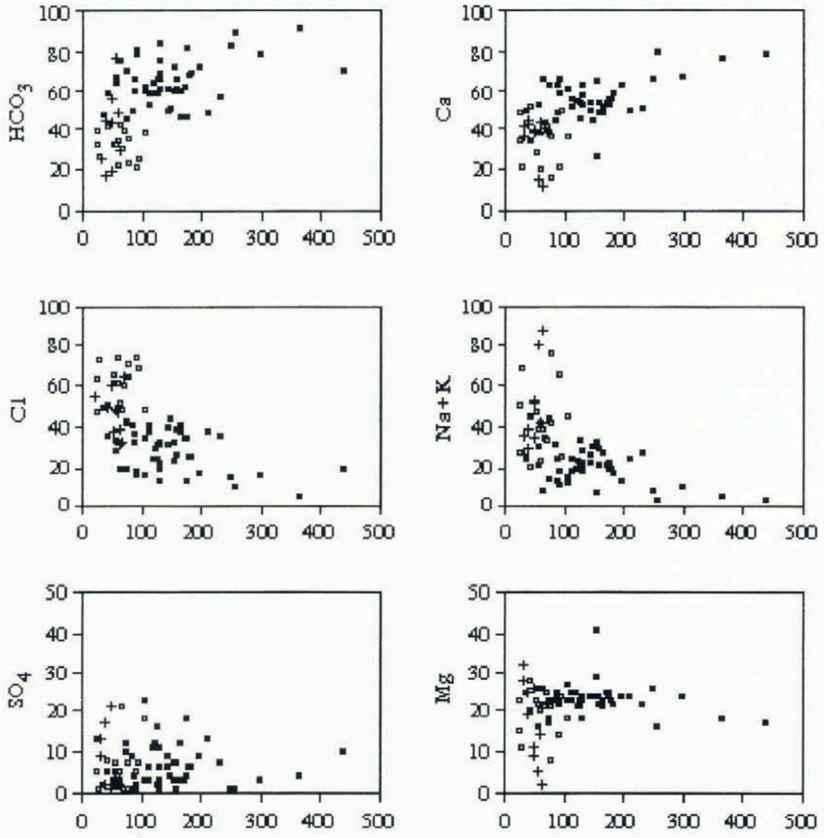

Fig. 3. Relations between the mineralization of the ice-wedge samples and the concentration of ions: x axis, mineralization ($mg\,l^{-1}$); y axis, concentrations (%); ■, Quaternary ice; □, Holocene ice; +, precipitation.

(Volkova and Romanovskiy, 1974) and Yenisei river terraces (Danilov and others, 1980). Higher content of Cl and Na and lower concentrations of Ca and HCO_3 in the Holocene wedge ice were reported from the Kolyma lowland (Korzun, 1985) and the Arctic zone of western Siberia (Vasilchuk and Trofimov, 1984). Volkova and Romanovskiy (1974) explain the differences between the ion content of late-Quaternary and Holocene ice by variations in the chemical content of precipitation. However, interpretation of these differences should be very careful, since the ion content of atmospheric precipitation and of underground ice are not as closely related as in the case of glacier ice.

Figure 3 shows the relations between the values of mineralization and concentrations of the macro-ions. As is clear from the graphs, with increasing mineralization the proportions of Ca and HCO_3 increase in late-Quaternary ice and those of Na and Cl decrease. Thus higher concentrations of Ca and HCO_3 in late-Quaternary ice having high mineralization could be ascribed to later alteration, for instance by the ion input from minerals. Nevertheless, it is important to stress that even samples with mineralization lower than 60 $mg\,l^{-1}$, very close to the mineralization of present precipitation and consequently insignificantly altered by ion exchange with minerals, also contain high proportions of Ca and HCO_3. This could mean that the late-Quaternary ice was initially formed from water of different chemical content to the Holocene ice. Presumably this ice-forming water was of atmospheric origin. The similarity of ion concentrations in present precipitation and Holocene ice, as well as low mineralization of the latest ice, show that the wedge ice could be used as a rough indicator of chemical content of precipitation. The samples with low mineralization from the late-Quaternary ice are likely to be acceptable for this purpose as well.

Thus an increase of $Ca + HCO_3$ and consequently a decrease of $Na + Cl$ in the precipitation during the late Quaternary as compared to the Holocene is likely. This may be attributed to different environmental conditions during wedge-ice growth: more continental in the late-Quaternary and more maritime in the Holocene. Other indicators of the palaeoenvironmental conditions in the region allow such a conclusion. For instance palynological data from the stratotypical sections in the Jana–Kolyma lowland give evidence of an extremely cold and dry climate during the major part of the late Quaternary between 50 000 and 11 000 BP which was replaced by a warmer, more humid climate in the Holocene (Kaplina and others, 1980; Kaplina and Gitterman, 1983; Tomirdiaro and Chernenkiy, 1984; Rybakova, 1990).

The similarity of the chemical content of late-Quaternary wedge ice in the studied sites and in the adjacent continental areas (Volkova and Romanovskiy, 1974) suggests a similarity in the palaeoenvironmental conditions of ice growth. It is likely that Bolshoi Lyakhov was part of the Indigirka delta during the late Quaternary and that the silt stratum containing the wedge ice was formed by accumulation of alluvial deposits. The existence of an ice-sheet cover on this territory, as stated by Grosval'd (1988), is therefore very unlikely. Perhaps considerably smaller glaciers covered northern islands of the New Siberian group at that time.

https://doi.org/10.3189/S0260305500016128 Published online by Cambridge University Press

REFERENCES

Danilov, I. D., V. I. Solomatin and N. A. Shmideberg. 1980. Khimicheskiy sostav podzemnykh l'dov kak pokazatel' uslovii ikh formirovaniya i genezisa vmeshchaiushchikh porod [Chemical composition of ground ice as an indication of ice formation conditions and origin of the enclosing rocks]. *In* Popov, A. I. and V. T. Trofimov, *eds. Prirodnyye usloviya Zapadnoy Sibiri. Vypusk 7 [Environment in western Siberia. Issue 7]*. Moscow, Izdatel'stvo Moskovskogo Universiteta, 119–126.

Grosval'd, M. G. 1988. Priznaki pokrovnogo oledeneniya Novosibirskikh Ostrovov i okruzhayushchego shel'fa [Evidence of ice-sheet glaciation of Novosibirskiye Ostrova and surrounding shelf]. *Dokl. Akad. Nauk SSSR*, **302**(3), 654–659.

Kaplina, T.N. and R. Ye. Giterman. 1983. Molotkovskiy Kamen' — opornyi razrez otlozheniy pozdnego pleystotsena Kolymskoy nizmennosti [Molotkovskiy Kamen' reference section of Late Pleistocene deposits in the Kolyma lowland.] *Izv. Akad. Nauk SSSR, Ser. Geol.*, **6**, 79–83.

Kaplina, T. N., G. N. Shilova and L. G. Pirumova. 1980. Shamanovskiy opornyi razrez pozdnepleystotsenovykh i golotsenovykh otlozheniy Indigirki [Shamanovskiy reference section of Late Pleistocene and Holocene deposits of the Indigirka area]. *Izv. Akad. Nauk SSSR, Ser. Geol.*, **9**, 74–81.

Korzun, A. V. 1985. Geokhimicheskie protsessy v lednikovykh i podsemnykh l'dakh severa Eurasii [The geochemical processes in glacial and underground ice in northern Eurasia]. (Ph.D. thesis, Moscow State University.)

Nekrasov, I. A. 1986. *Vechnaya merslota Yakutii [Permafrost of Yakutia]*. Yakutsk, Nauka, 37.

Popov, A. I., G. E. Rozenbaum and N. V. Tumel'. 1985. *Kriolitologiya [Cryolithology]*. Moskow, etc., Izdatel'stvo Moskovskogo Universiteta.

Rybakova, N. O. 1990. [Changes in the vegetation cover and climate in the Kolyma lowlands in Late-Quaternary time]. *Polar Geogr. Geol.*, **14**(*), 279–286. Translated from Skabichevskaya, N. A., *ed. Pleystotsen Sibiri i stratigrafiya i mezhregional'nyye korrelyatsii [The Pleistocene of Siberia: stratigraphic and interregional correlations]*. Novosibirsk, Nauka, 1989, 137–142. (Tr. Inst. Geol. Geophiz. 657.)

Tomirdiaro, S. V. and B. I. Chernenkiy. 1984. Osobennosti izucheniya pleystotsenovykh otlozheniy Yedomnoy serii Severo-Vostoka SSSR [Details of the Pleistocene sediments of the Edoma complex in northeastern USSR]. *In* Bespalyy, V. G., *ed. Pleystotsenovyye oledeneniya Vostoka Azii [The Pleistocene glaciation of eastern Asia]*. Magadan, Severo-Vostochnyy Kompleksnyy Nauchno — Issledovatel'skiy Institut, 159–173.

Vasil'chuk, Yu. K. and V. T. Trofimov. 1984. K voprosu o mineraliyatsii poligonal'nozhilnikh l'dov [On the mineralization of polygonal wedge ice]. *Izv. Akad. Nauk SSSR, Ser. Geol.*, **8**, 129–134.

Volkova, V. P. and N. N. Romanovskiy. 1974. O khimicheskom sostave podsemnykh l'dov v chetvertichnykh otlozheniiakh iuzhnoi chasti Iano-Indigirskoy nizmennosti [Chemical composition of ground ice in the Quaternary deposits in the southern part of the Iana–Indigirka lowland]. *In* Popov, A. I., *ed. Problemy kriolitologii. Vypusk 4 [Problems of cryolithology. Issue 4]*. Moscow, Izdatel'stvo Moskovskogo Universiteta, 112–135.

https://doi.org/10.3189/S0260305500016128 Published online by Cambridge University Press