A SIMPLE METHOD TO DEMONSTRATE THAT ICE FORMATION CREATES STRATIFICATION IN SALT MEROMICTIC LAKES

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ABSTRACT

One of the possible factors determining the vertical stratification of the water column in the coastal meromictic Arctic lakes is the ice formation. When seawater is freezing, the salt brine concentrates in the ice pores and is later released under the ice. The aim of this research was to verify the hypothesis that ice formation is an important mechanism explaining water stratification in salty meromictic lakes of the Arctic coast.

Seawater samples were frozen at a temperature of -10°C for 12-24 hours, and then slowly thawed at room temperature during 1–2 days. Freezing/thawing was performed in 1.5 l and 2 l plastic bottles. In all bottles with initial salinity of 30 psu, a diluted layer with salinities between 3 and 15 psu (average 7 psu) was formed at the surface. Close to the ice/water interface, the salinity varied between 6 and 14 psu. At the bottom a thin layer with a salinity of 40-50 psu was created. These vertical salinity differences were preserved after a period of 24 h. Additional experiments showed that similar water stratification occurred for samples with initial salinities of 27, 24, 20, 15, 10, 6 and 1 psu. The observed phenomena resemble the formation of brine fingers in Antarctic waters.

INTRODUCTION

Vertical stratification is a very important characteristic of the lakes separated from the White Sea. Water density differences have a major impact on environmental parameters including biological communities. The aim of this research was to examine the influence of ice formation on the vertical water stratification of White Sea lagoons by simple lab experiments with freezing and melting of samples having variable salinity.

METHODS

The research was carried out on the N.A.Pertzov White Sea Biological Station of Moscow State University in January 2012 and 2013. Seawater samples from the White Sea with a salinity of 30 psu were obtained in plastic bottles (1.5 - 2 L) that were later frozen (partially at the surface or total volume) at -10°C during 12–24 hours. Subsequent ice melting was done at room temperature. After melting, liquid samples were obtained every 5 cm of depth using a long thin pipette.

Water salinity was measured using a refractometer with an accuracy of 1 psu. This measure was repeated 24 h later. The same was repeated for different saline solutions: 27, 24, 20, 15, 10, 6 and 1 psu. In the next experiment, we melted natural ice from the White Sea and measured water salinity after melting. Also, we measured the salinity of water from pores in icicles formed at the lower surface of the littoral ice and at different air temperatures (57 icicles at -1°C and 14 at -12°C). In the last experiments, the salt concentration was very high and beyond the range of the refractometer, thus, samples were diluted 10-fold with distilled water using a 0.5 ml syringe.

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RESULTS

The most important findings during the ice melting experiments were:

1) in bottles where the initial salinity of samples was 30 psu, the surface layer was desalted down to 5-8 psu,
2) the salinity increased gradually with depth if the total volume of the bottle was completely frozen (Figure 1, Tables 1 and 2),
3) the salinity increased toward the bottom of the bottle, if ice was formed only in the upper layer.

In 2) and 3), brine with a salinity of 40-50 psu was formed at the bottom. These stratification patterns were conserved after 24 h as demonstrated by the refractometer measurements.

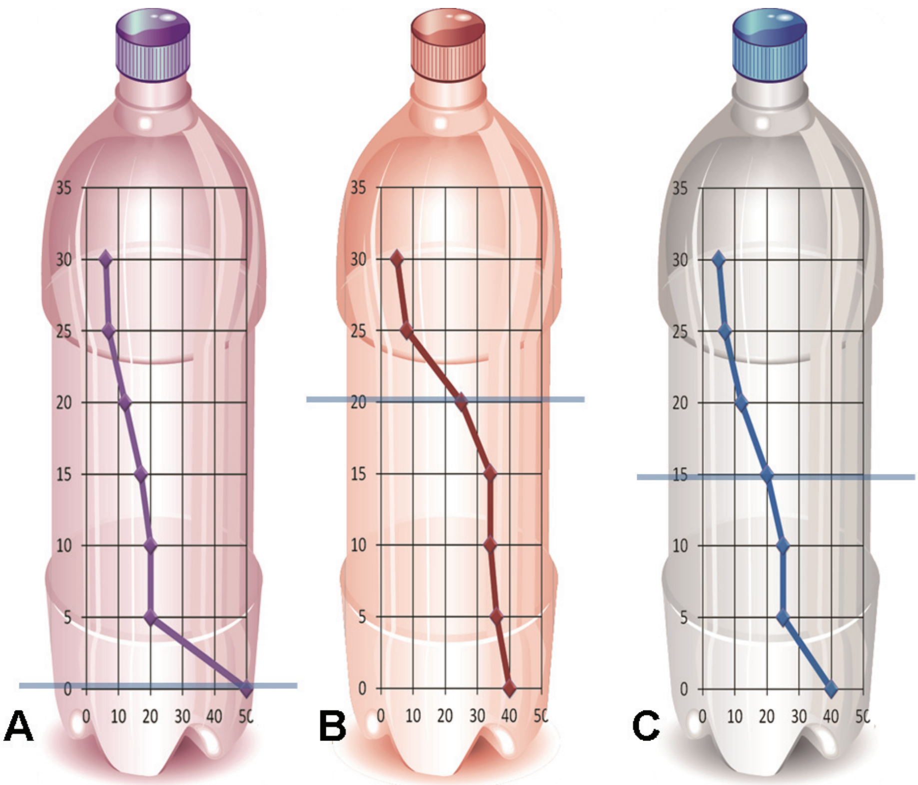

Figure 1: Vertical salinity profiles during the experiments using seawater with 30 psu. A: the sample was totally frozen; B: ice was formed from the surface to a depth of 20 cm; C:) upper 15 cm were frozen. Depth with respect to the bottom of the bottle in cm (vertical scale), salinity in psu (horizontal scale).

Table1: Salinity of water in different layers after freezing.

Depth*	Salinity (psu)	
	First sampling	After 24 hours
Surface	5	4
25 cm	8	5
20 cm	25	8
15 cm	34	23
10 cm	34	not measured
5 cm	36	36
Bottom	40	40

* - Depth is counted upwards from the bottom.

Table 2: Salinity (psu) of water in different layers after freezing and melting.

Ice thickness of 14 cm		**Ice thickness of 16 cm**		**Ice thickness of 13 cm**		**Frozen totally**		**Almost no ice formed**	
Surface	10	Surface	3	Surface	5	Surface	7	Surface	27
25 cm	15	20 cm	10	20 cm	7	20 cm	21	25 cm	27
20 cm	16	15 cm	11	15 cm	12	15 cm	25	20 cm	27
16 cm	30	14 cm	17	12 cm	20	10 cm	29	15 cm	27
15 cm	30	10 cm	28	10 cm	25	5 cm	34	10 cm	27
10 cm	31	5 cm	29	5 cm	25	Bottom	34	5 cm	27
5 cm	32	Bottom	40	Bottom	40			Bottom	30
Bottom									

The next experiment showed that the same process occurs in dilute solutions. Weak stratification effect appeared even if salinity was 1 psu: the upper layer was completely freshened as the salinity of the bottom layer increased up to 2 psu (Table 3).

Table 3: Salinity of different layers after freezing of sea water in different dilutions.

Salinity in psu before freezing	27	24	20	15	10	6	1
Layer:	Salinity after freezing and melting						
Surface	10	15	11	5	5	3	0
20 cm	20	25	17		8	5	1
15 cm	23	25	19	13	11	5	1
10 cm	23	26	20	15	12	5	2
5 cm	28		20	19	12	6	
Bottom	30		20				

The last experiment was the melting of natural White Sea ice. Vertical salinity difference also appeared (Table 4) suggesting brine released by melting ice.

Table 4. Salinity (psu) of water from melted naturel sea ice.

Layer	**Salinity**	**Layer**	**Salinity**
Surface	1	Surface	4
15 cm	4	15 cm	14
10 cm	12	10 cm	15
5 cm	15	5 cm	15
Bottom	18	Bottom	23

In January 2014, the ice conditions along the coast of the White Sea were unusual. Indeed, due to the anomalous warm weather the ice was washed away leaving only ice floes on the littoral. At the bottom of the ice floes, we found tube-like icicles. The salinity of water drained by these structures varied depending on the air temperature. The lower the temperature, the more concentrated was the brine. Thus, if temperature was -1°C the brine salinity ranged from 30 to 35 psu while the salinity at sea was 28 psu. However, when the temperature was -12°C the salinity increased to 120 or even 156 psu.

CONCLUSIONS

Our experiments can be regarded as a water stratification model occurring in real lakes. As ice formation creates vertical stratification in the bottle, a comparable phenomenon may be present in a lake. This is in agreement with the salinity profiles obtained in coastal meromictic lakes near the White Sea Biological Station (1). Indeed, after melting of the ice cover, the surface water salinity in these lakes is minimal for the full year (7-9 psu). In the lakes where surface salinity is comparable to that in the White Sea, the near bottom salinity can be substantially higher than in the sea.

On the Karelian coast, there are two separated lakes evolving with increased salinity: the lagoon on the Cape Zeleny and the lake on the Island Tonisoar. In both water bodies, the process of brine release is assumed to be the cause of the aforementioned hydrological changes associated with ice freezing and melting (2,3). A comparable process has been described in Antarctic as brinicles (4), and is responsible for the hypersalinity in some coastal lakes located in the Canadian Arctic (5). Observations in the Biofiltry Bay not far from the White Sea Biological Station show that brinicle-like structures are quite common in this region. It seems that brine draining is an ubiquitous natural result of the formation of sea ice and the lower the temperature the more concentrated is the brine.

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REFERENCES

1 Krasnova E D, D A Voronov, N L Frolova, A N Pantyulin & T E Samsonov, 2015. Salt lakes separated from the White Sea. EARSeL eProceedings, 14(S1): 8-22

2 Krasnova E D, D A Voronov & A D Voronova, 2013. Effect of ice formation on the appearance of vertical stratification in saline lagoons separated from the White Sea. In: The Study, Rational Use and Protection of Natural Resources of the White Sea. XII International Conference with the elements of a school for young scientists and graduate students. Collection of materials. (Petrozavodsk: Karelian Research Centre, Russian Academy of Sciences, Petrozavodsk, Russia) 168-170 [in Russian: Краснова Е.Д., А.Д. Воронова, Д.А. Воронов, 2013. Влияние образования льда на формирование вертикальной стратификации в соленых лагунах, отделяющихся от Белого моря. В сб.: Проблемы изучения, рационального использования и охраны природных ресурсов Белого моря. XII Международная конференция с элементами школы для молодых ученых и аспирантов. Сборник материалов. Петрозаводск, Россия. Петрозаводск: Карельский научный центр РАН: 168-170]

3 Krasnova E D, D A Voronov & A D Voronova, 2013. The role of sea ice brine in the formation of vertical stratification in reservoirs, separated from the White Sea. In: Geology of Seas and Oceans: Proceedings of XX International Conference (school) on Marine Geology. V. III (GEOS, Moscow) 201-205 [in Russian: Краснова Е.Д., Д.А. Воронов, А.Д. Воронова, 2013.

Роль вымораживания рассола из морского льда в формировании вертикальной стратификации в водоемах, отделяющихся от Белого моря. В сб.: Геология морей и океанов: Материалы XX Международной научной конференции (школы) по морской геологии. Т. III. М.: ГЕОС: 201-205]

4 Cartwright J HE, B Escribano, D L González, C I Sainz-Díaz & I Tuval, 2013. Brinicles as a case of inverse chemical gardens. Langmuir, 130403173604005. DOI: 10.1021/la4009703

5 Dugan H A & S F Lamoureux, 2011. The chemical development of a hypersaline coastal basin in the High Arctic. Limnology and Oceanography, 56(2): 495-507