Methane in water and bottom sediments of Onego Lake

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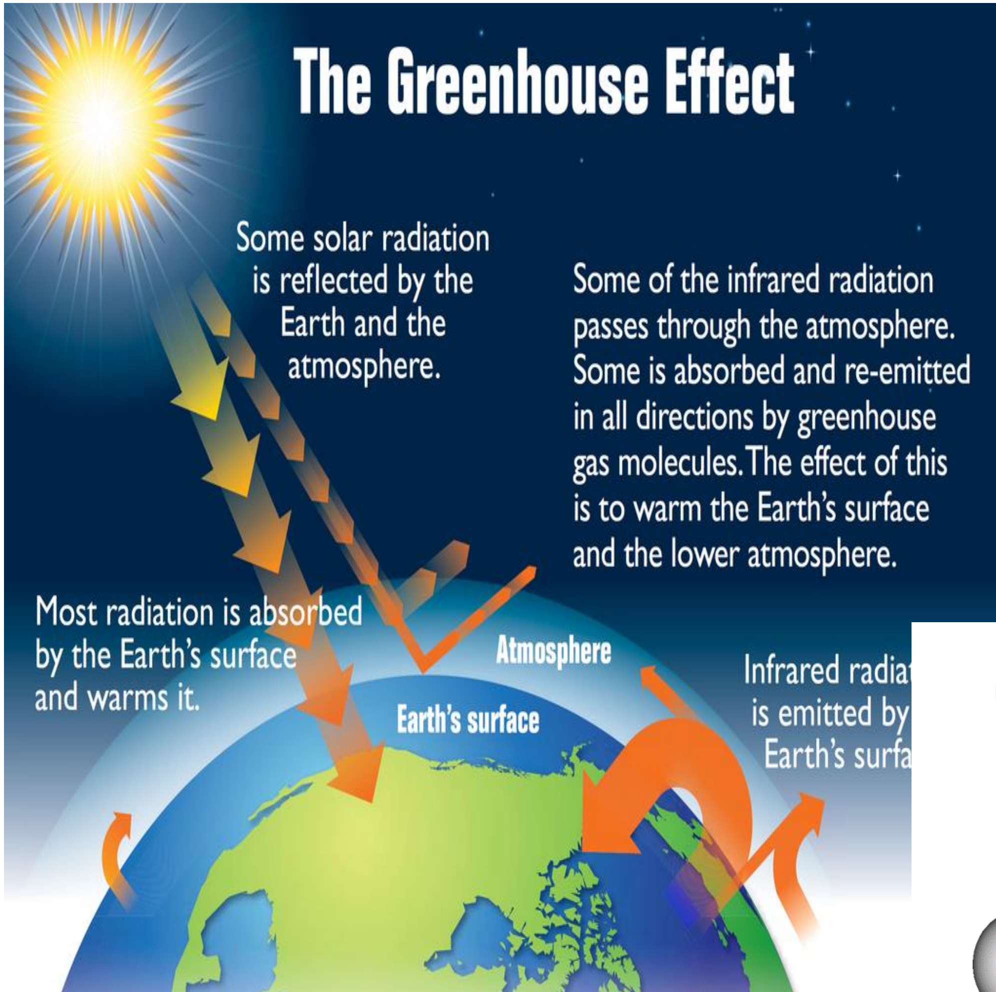
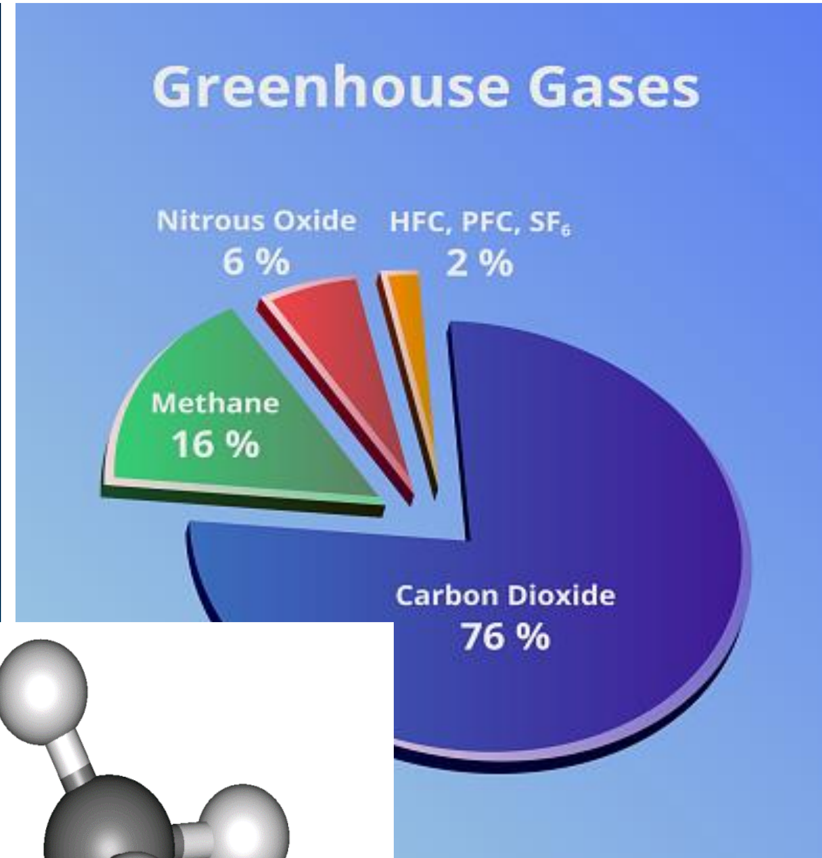
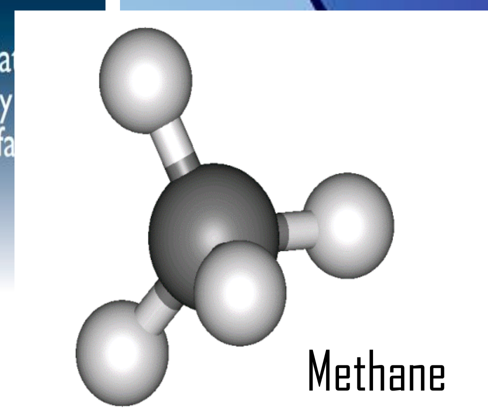
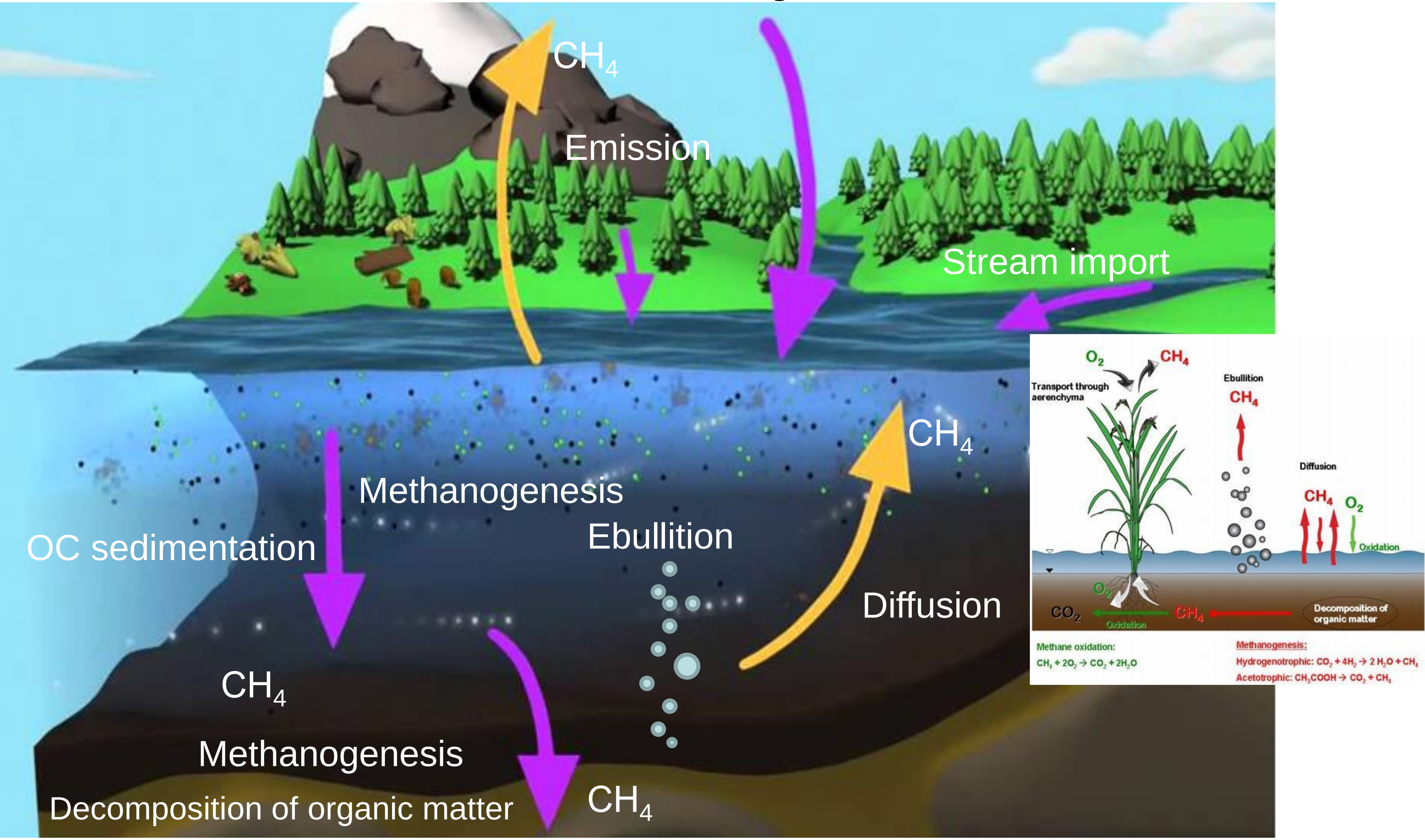






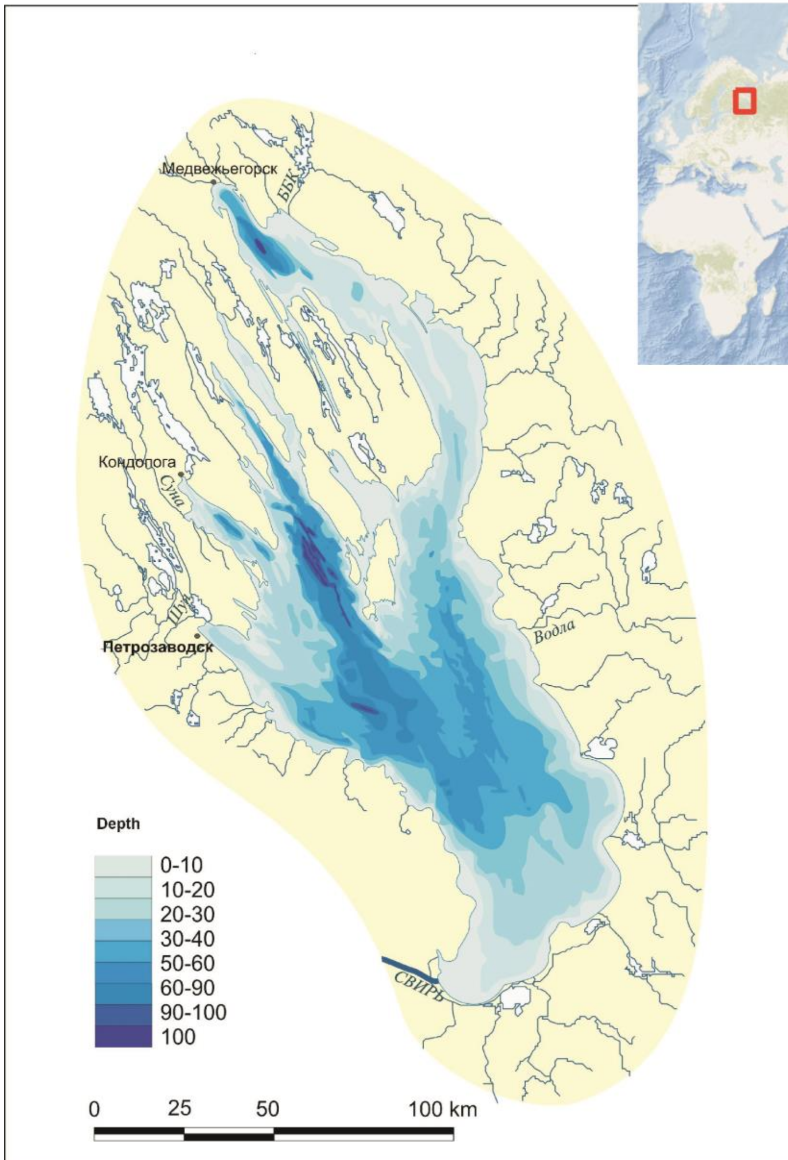
Methane is a greenhouse gas, accounting for about 20 percent of global emissions. Methane is more than 25 times as potent as carbon dioxide at trapping heat in the atmosphere. Over the last two centuries, methane concentrations in the atmosphere have more than doubled, largely due to human-related activities. Because methane is both a powerful greenhouse gas and short-lived compared to carbon dioxide, achieving significant reductions would have a rapid and significant effect on atmospheric warming pote

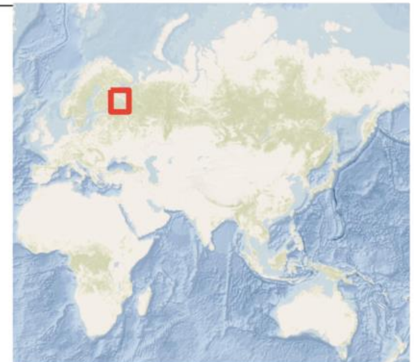
Methane cycle



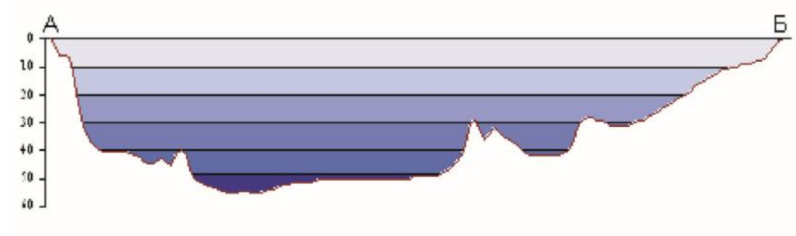
- The methane cycle is a geochemically important link in the global cycle carbon. The main processes of carbon transformation in this cycle are exclusively specific groups of microorganisms. Major pathways of CH4 emissions include: methanogenesis via efflux through plant aerenchyma, ebullition, and diffusion.

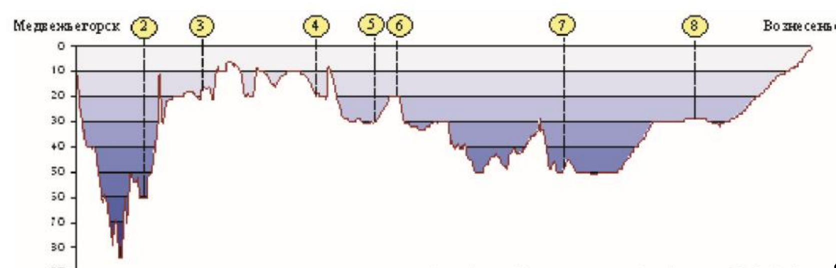
Onego Lake is the second-largest lake in Europe





Surface area, km^2		9720
Shoreline, km		1810
Volume, km^3		295
Length, km		290
Width, km	mean	33.5
	maximum	82
Depth, m	mean	30
	maximum	120





Lake Onego. Atlas, 2010

Methane in Petrozavodsk bay

The results of long-term observations of the methane content in water and bottom sediments of the coastal areas of the Petrozavodsk Bay of Onego Lake are presented. The influence of various natural and anthropogenic factors on the formation and distribution of methane concentrations is considered.

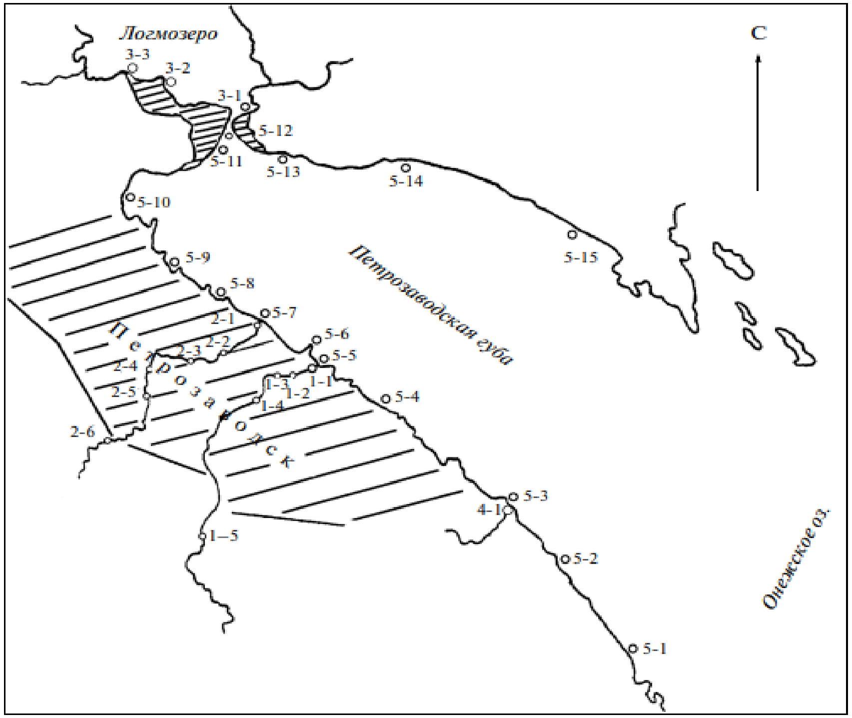


Рис. 1. Карта-схема расположения станций отбора проб воды и ДО в Петрозаводской губе Онежского оз. и в его притоках в июне–июле 2007–2010 гг.

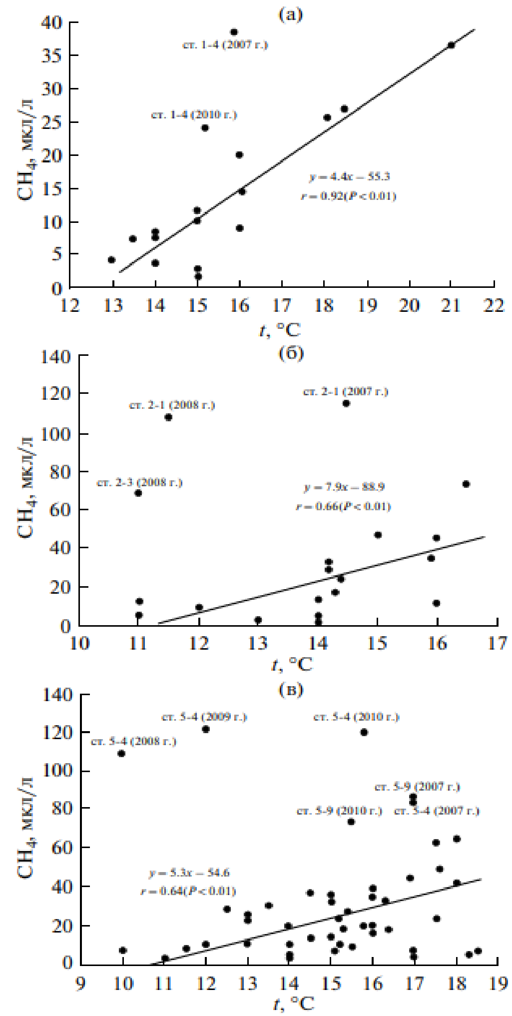
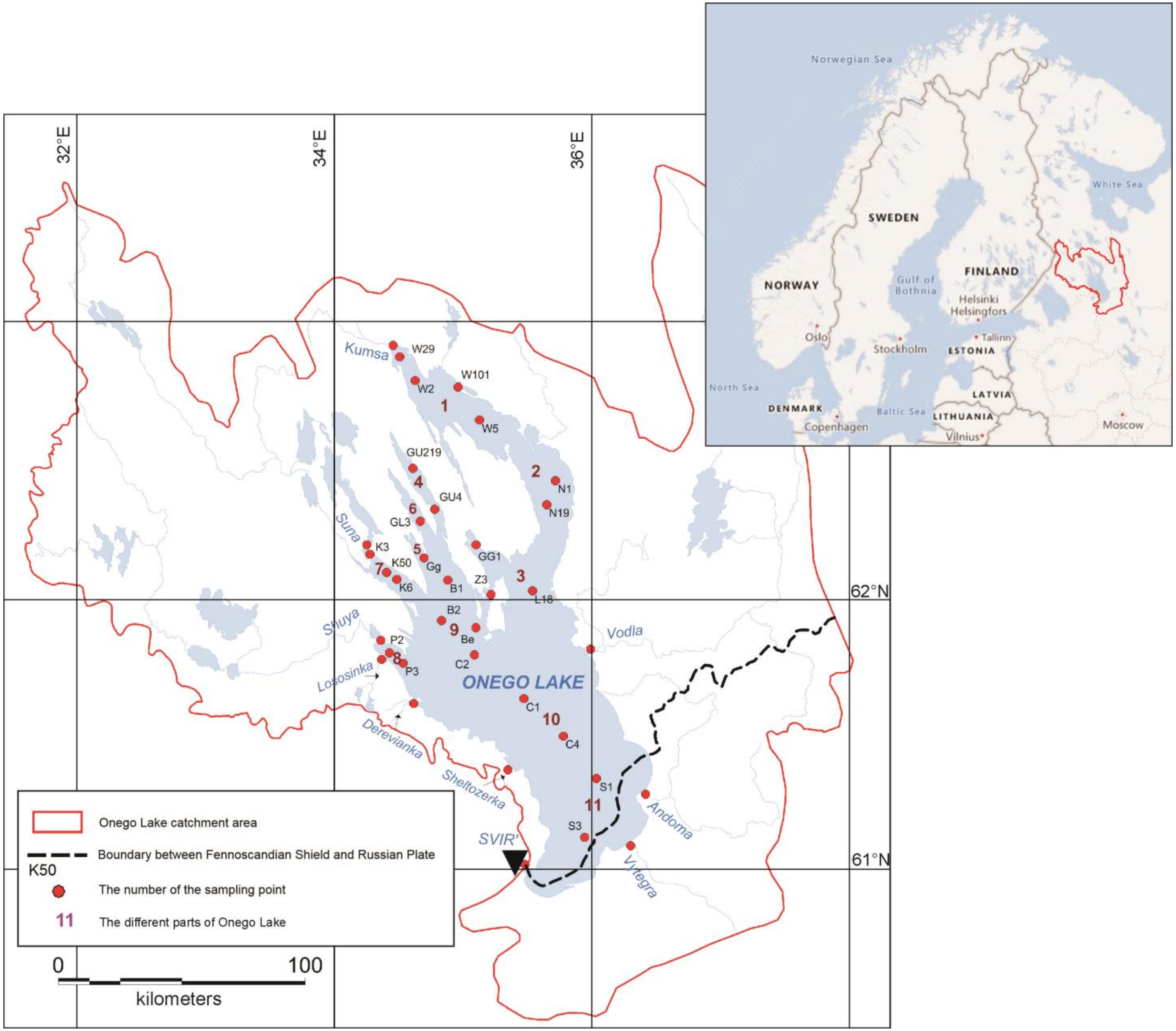


Рис. 3. Зависимости между содержанием метана и температурой воды, по данным 2007–2010 гг. а – р. Лососинка, б – р. Неглинка, в – Петрозаводская губа.

- Garkusha D.N., Fedorov Yu.A. Features of the distribution of methane content in the initiative areas of the Petrozavodsk Bay of Onego Lake // Water Resources, 2015. V. 42. No. 3. P. 331-339

The Lake Onego sampling scheme



Sampling equipment

Echosounder

Bathometer

Gravity corer
«LIMNOS»

Gravity corer
with a plastic tube 50 mm in diameter, 1 m long

Gravity corer 127 mm in diameter,
3 m long

Peterson grab
volume 0.025 m^2

Research methods

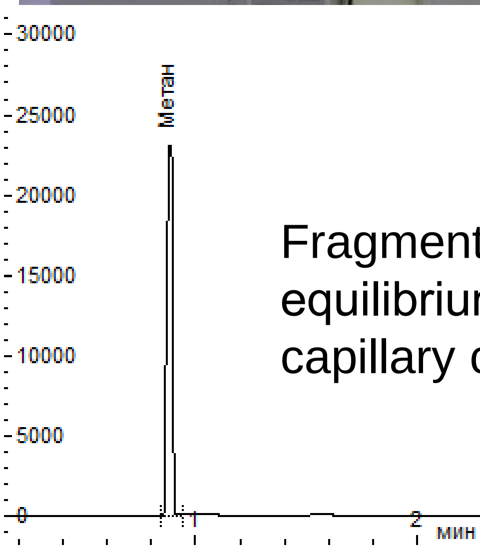
Methane analysis was carried out by the gas chromatographic method using the analysis of the equilibrium vapor of the mass fraction of methane in water and bottom sediments on a gas-liquid chromatograph Crystal 5000.1, Khromatek

Regression equation [Garkusha et al., 2016]

- $lgFCH_4 = 1{,}03891 lgCCH_4$ д. о. $+ 1{,}4631$ ($r = 0{,}84$; $n = 46$; $P < 0{,}01$),
- where $lgFCH_4$ is the logarithm of the methane flux from sediments to water, (nl/m^2)/day; $lgCCH_4$ – logarithm of methane concentration in sediments, nl/dm^3 of wet sediment

Fick’s law

- $J = -D*dc/dx$,
- where J is the amount of a substance passing perpendicularly through a unit of surface area per unit of time, m^2/s of a wet sample; D is the diffusion coefficient, m^2/s (the self-diffusion coefficient was used - 0.188 cm^2/s, Sherwood et al., 1975); dc/dx – concentration gradient



Fragment of the calibration chromatogram of the equilibrium vapor of methane 200 μl on a capillary column DB-WAX 30m, 0.32mm, 0.50u

Research methods

Bottom sediments

- Eh - Potentiometric method with Pt electrodes and mediator Trilon-B.
- Loss on ignition (LOI) - Gravimetric method T=550 ˚C
- Natural humidity (W20 °C) - Gravimetric method T=20 ˚C
- Porosity (Por), specific gravity (m_{sp}), absolute humidity (W150 °C) - Gravimetric method T=105 ˚C
- Ash content - Gravimetric method T=900 °C
- C_{org} - Direct combustion of solids, TOC-V Series Total Carbon Analyzer with SSM-5000A Attachment
- Consumption of O_2 by sludge - Exposure during the day, Winkler bottle method
- Plant pigments - Extraction with acetone, spectrophotometric method l=663, 645, 630, 750 nm
- Humic and fulvic acids - Photometric method after alkaline extraction, l=330, 360 nm
- $N\text{-}NH_4^+$ - Conway microdiffusion method, titrimetric termination (NaOH)
- N_{org} - Kjeldahl method, Conway method
- Phosphorus mineral (P_{lab}) - Boiling with 5N $H2SO_4$, photometric finish
- P_{total} - Kjeldahl Method
- Granulometric analysis - Mie and Fraunhofer laser diffraction combined with Polarized Light Differential Intensity Recording (PIDS)

TOC-V Series Total Carbon Analyzer with SSM-5000A Attachment, Shimadzu

Research methods

Water

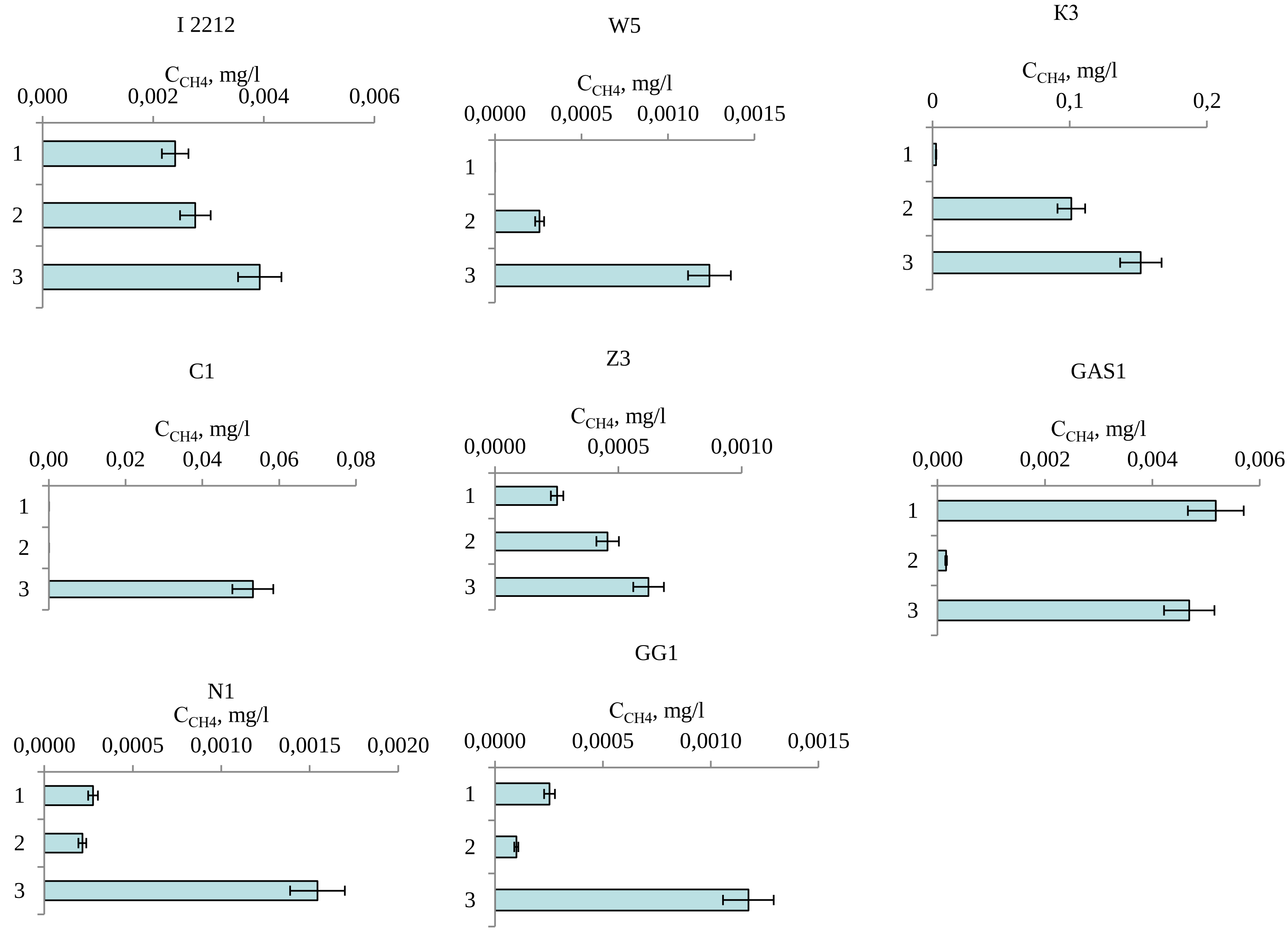
GFA-X7, Shimadzu

- CO_2 - Titrimetric method
- pH - Potentiometric method
- æ, T° - Conductometric method
- HCO_3 - Titrimetric method
- Cl^- -Photometric method with mercury thiocyanate in the presence of iron (III) nitrate
- SO_4^{2-} -Photometric method with sulfonazo (III)
- Na, K - Flame photometric method
- Ca, Mg - Atomic absorption spectrometry method
- O_2 - Titrimetric determination according to Winkler
- Biochemical oxygen demand (BOD_5) - Titrimetric bottle method
- Chemical oxygen demand (COD) - Titrimetric Method
- Permanganate oxidizability (PO) - Titrimetric method
- Chromaticity - Photometric method
- NH_4^+ - Photometric method as Indophenol Blue
- NO_2^- -Photometric method with sulfanilamide and N-(1naphthyl)ethylenediamine dihydrochloride
- NO_3 - Photometric method with sulfanilamide and N-(1-naphthyl)ethylenediamine dihydrochloride after reduction in a cadmium reducer
- N_{total} - Photometric method with sample mineralization in a thermoreactor
- P_{min}, PO_4^{3-} - Photometric determination with ammonium molybdate, λ= 882 nm

Oxygen regime of Onego Lake

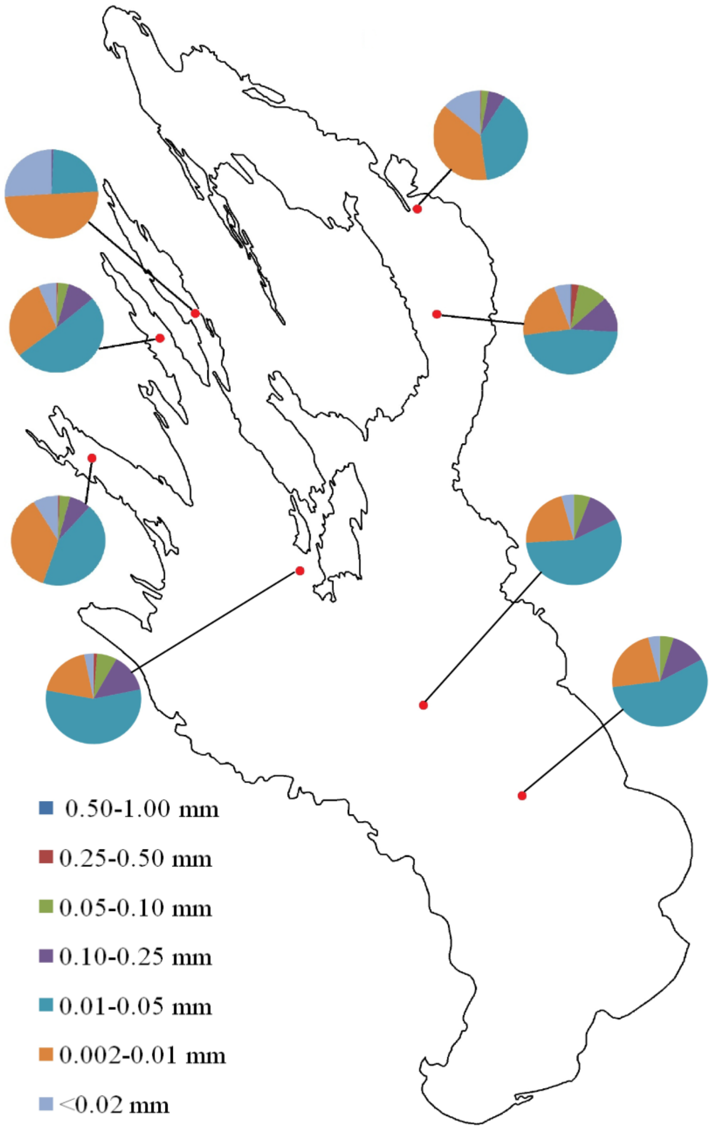
Date	Lake District	Surface horizon				Near-bottom horizon			
		T, ºC	O_2, mg/l	O_2, %	CO_2, mg/l	T, ºC	O_2, mg/l	O_2, %	CO_2, mg/l
May 2020-2021	Average for the Lake	2.6-6.0	9.68-13.14 (11.56)	89-105	1.98-2.75 (2.22) *PB 3.19-4.384 (3.74)	2.5-5.2	10.57-13.13 (12.01)	80-96	1.98-2.97 (2.44) *PB 4.51-5.94 (4.45)
August 2020-2021	Deep sea part	15-20	8.45-9.56 (9.29)	92-102	1.76-3.10 (2.38) *K6-2.3	4.0-6.8	9.68-13.14 (10.78)	67-100	2.86-5.28 (4.43) *K6-8.91
	Shallow Bays	15-20	7.31-9.42 8.78)	84-96	1.98-4.95 (3.40) *K3-4.6	10-17	7.28-11.54 (9.23)	72-94	2.75-8.25 (4.95) *K3-9.911

Results
Methane in water



Methane content in surface (1) and near-bottom water (2) - 100 cm, (3) - 30 cm at the bottom sediments of different stations of Onego Lake

Grain size of bottom sediments of Onego Lake



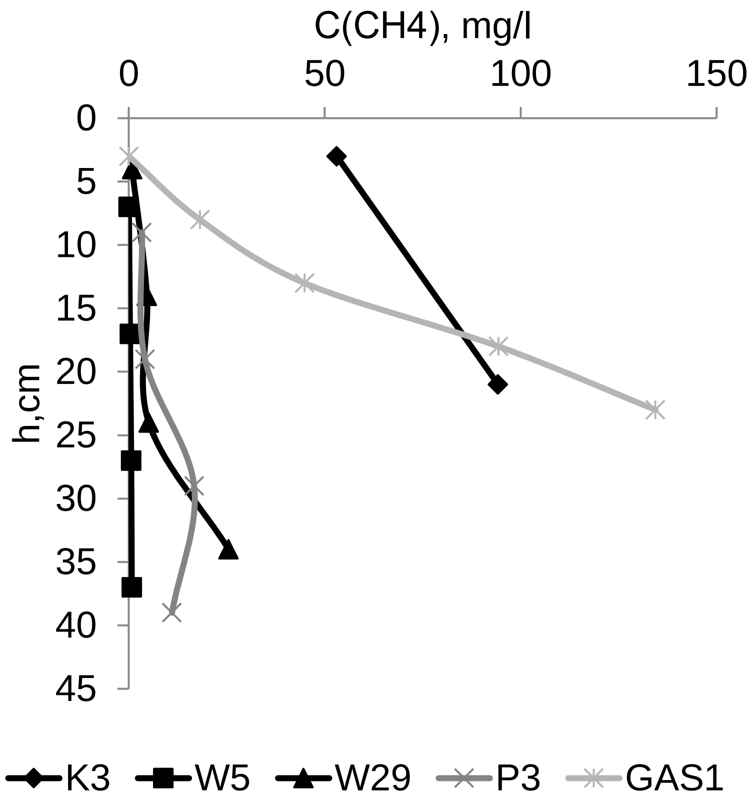
The grain size distribution of the study area is represented mainly by the fraction of dust particles (0.002-0.01 mm) from 53% to 86%.

Content of clay particles(<0.002 mm) varies from 3% to 36%.

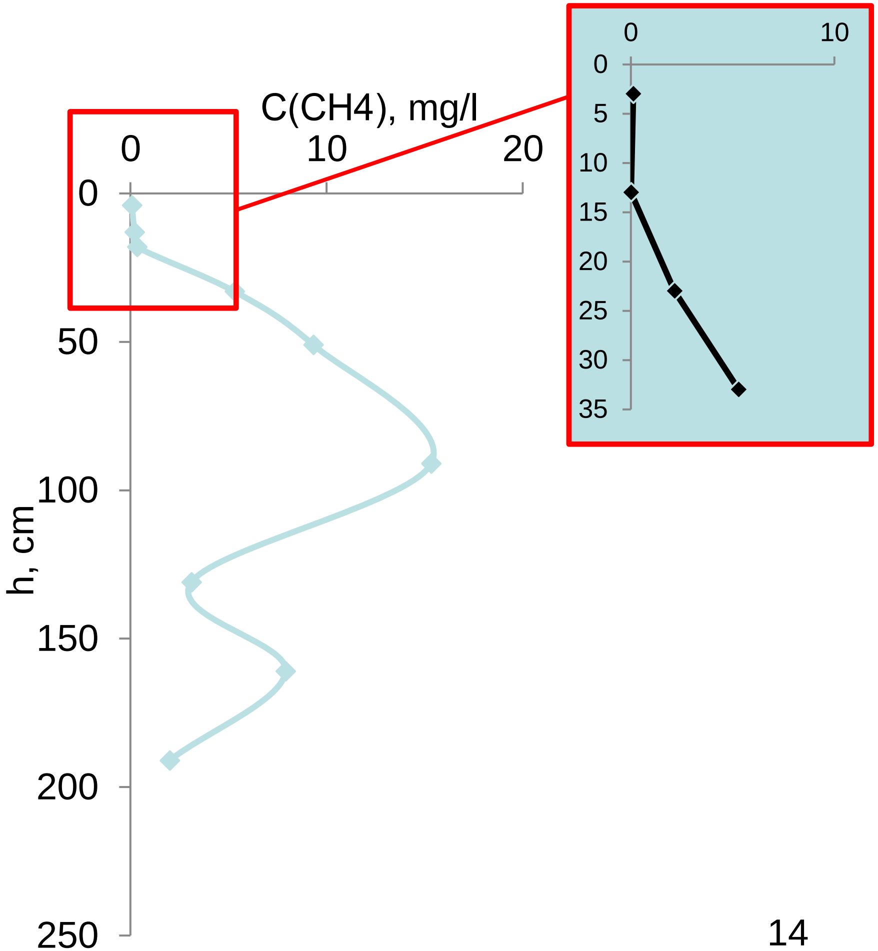
Fractions with the dimension of sand particles are not found in all bottom sediments and are mainly represented by fine particles (0.05-0.10 mm) from 0% to 24%.

Results
Methane in Onego Lake bottom sediments

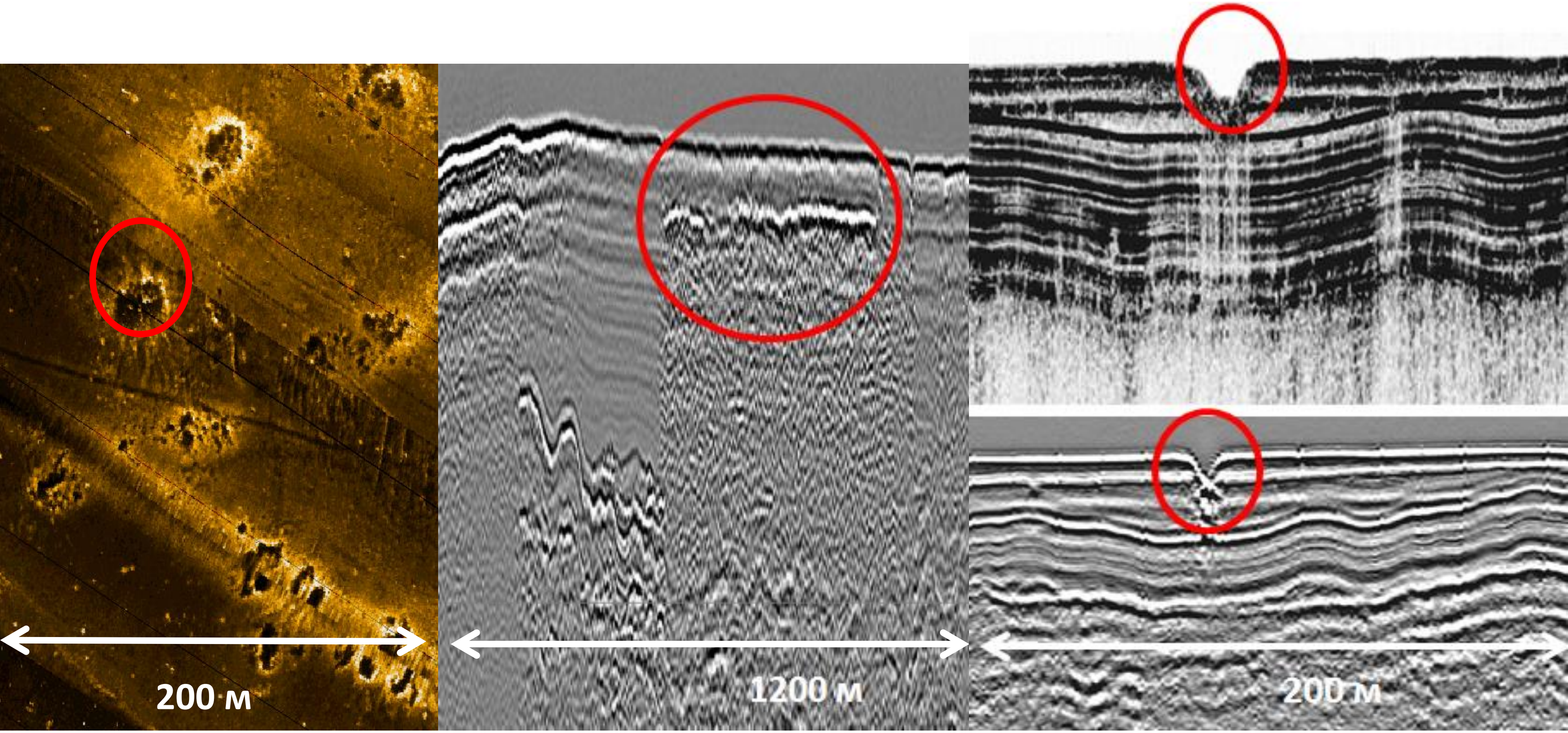
The concentration of methane in the bottom sediments of Onego Lake varied from 0.003 to 134.46 mg/l (average 13.14 mg/l)



Sampling with 3 m and 1 m samplers (station C1)



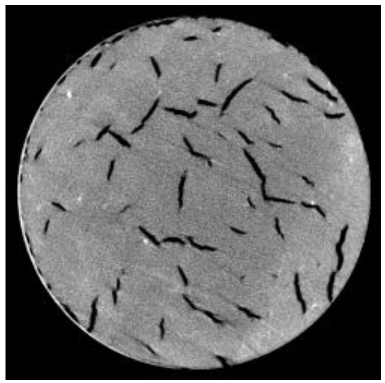
Geophysical research in the Petrozavodsk bay gas pockmarks



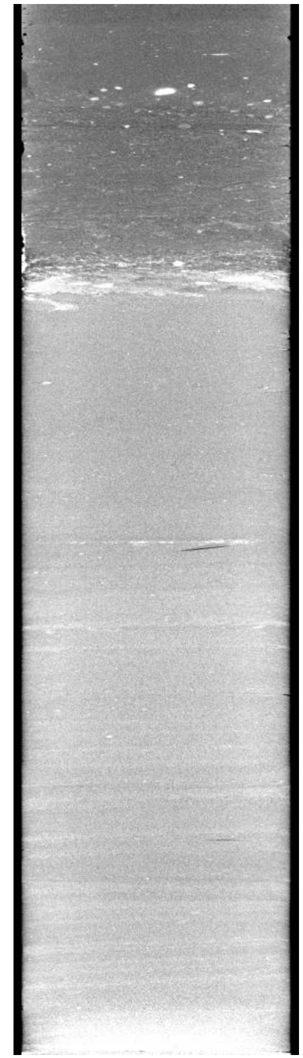
Subetto D., Rybalko A., Strakhovenko V., Belkina N., Tokarev M., Potakhin M., Aleshin M., Belyaev P., Dubois N., Kuznetzov V., Korost D., Loktev A., Shalaeva N., Kiskina A., Kostromina N., Kublitskiy Y., Orlov A. **Structure of Late Pleistocene and Holocene Sediments in the Petrozavodsk Bay, Lake Onego (NW Russia)** // Minerals, 2020. V. 10. P. 964
doi:10.3390/min10110964

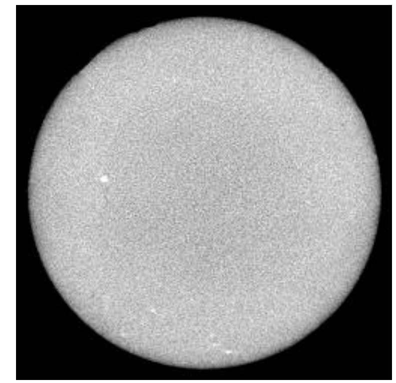
Tomography of bottom sediments columns
(vertical and horizontal sections)

Petrozavodsk Bay of Onego Lake (Rybalko et al. 2021)



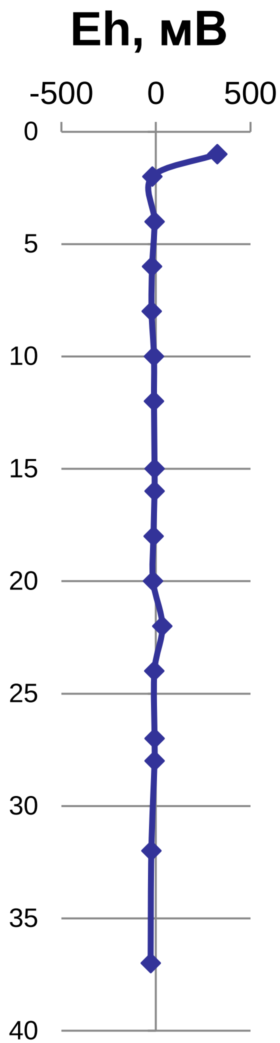
Porous structure of bottom sediments – as a result of gas emanation

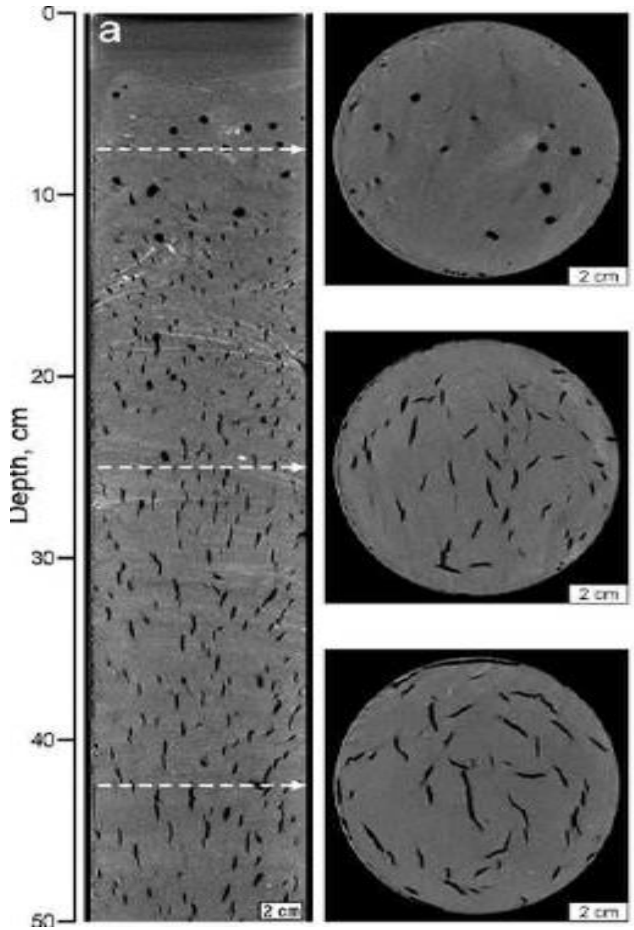


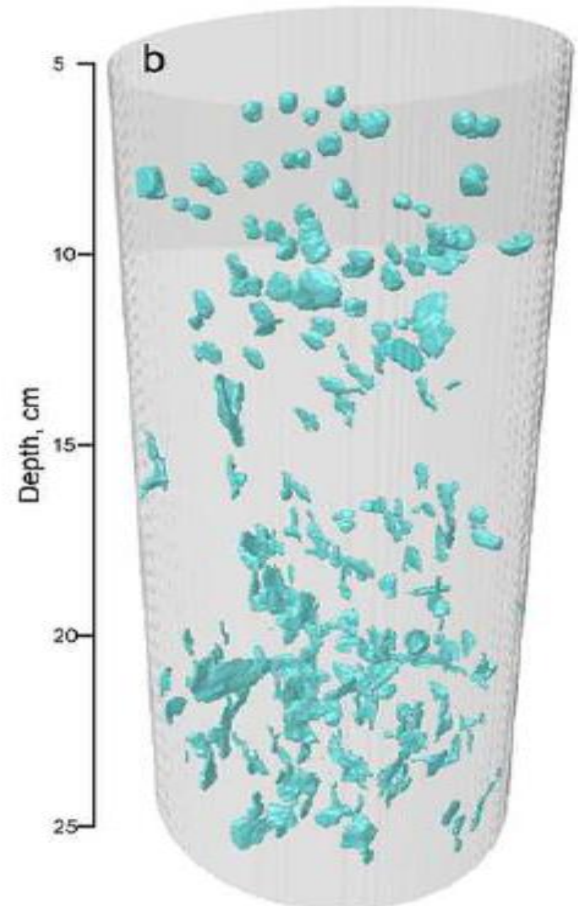


The usual structure of bottom sediments

Anomaly of CH_4 in the sediments of the Petrozavodsk Bay



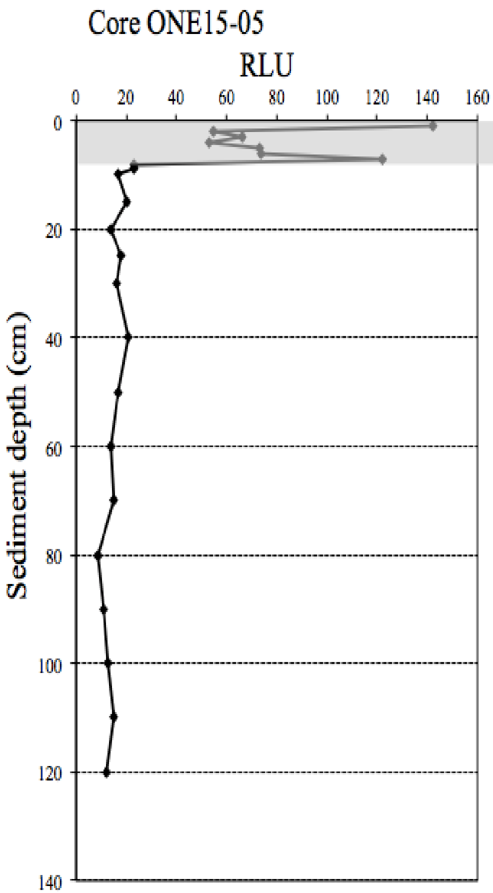


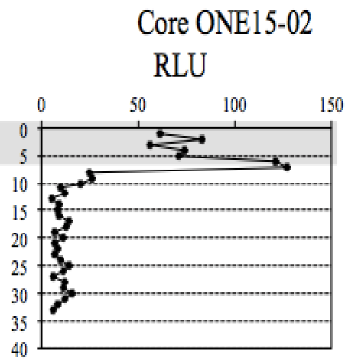


a - Vertical and separate horizontal radiographic contrast section views of the upper 50cm in core;

b – three-dimensional model of the cavity distribution (within the upper 25 cm) resulting from degassing of the sediments.

Microbial activity in the sediments of Onego Lake

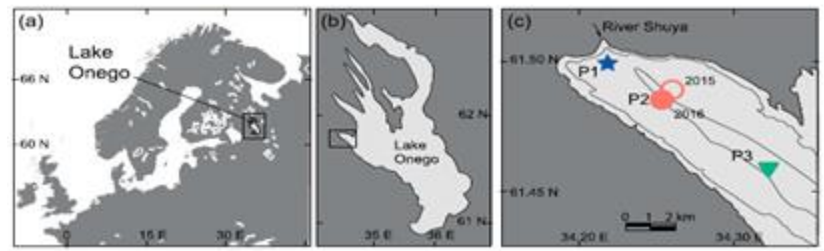




ATP
adenosine-5'-triphosphate
measurements as an indicator of
in situ bacterial activity

Downcore record of microbial activity (ATP) for Petrozavodsk bay sediments

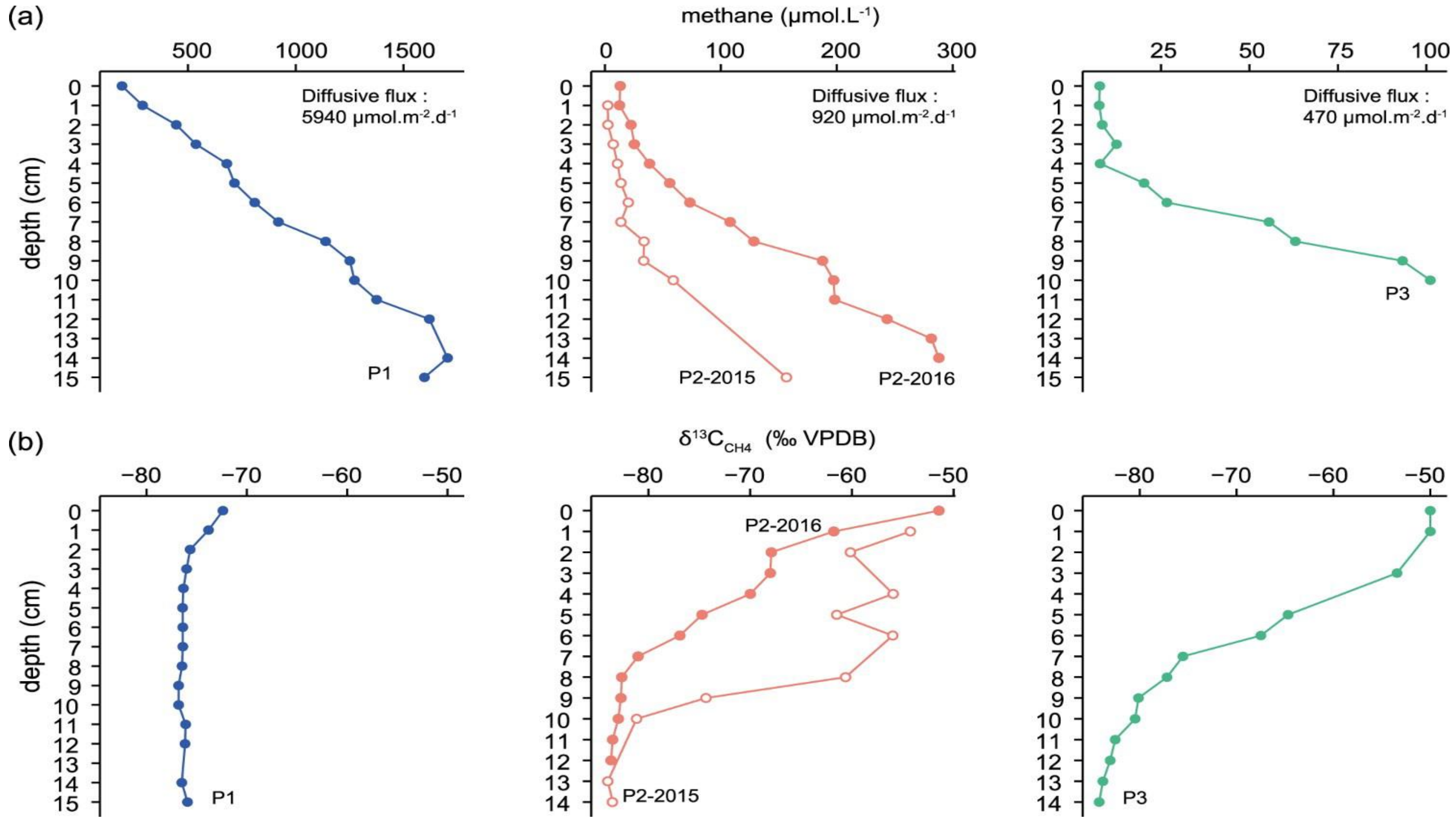
Thomas C., Frossard V., Perga M.-E., Tofield-Pasche N., Hofmann H., Dubois N., Belkina N., Zobkova M., Robert S., Lyautey E. Lateral variations and vertical structure of the microbial methane cycle in the sediment of Lake Onego (Russia) // Inland Waters, 2019. V. 9. I. 2: Life under Ice in Lake Onego (Russia) – An Interdisciplinary Winter Limnology Study. P. 205-226
doi.:10.1080/20442041.2018.1500227



Microbial methane cycle in the sediments of Onego Lake

Family	1 cm	2 cm	3 cm	4 cm	5 cm	6 cm	7 cm	8 cm	9 cm	10 cm	15 cm
Aerobic methane oxydation											
Methylobacteriaceae	0.21	0.18	0.19	0.18	0.04	0.19	0.09	0.10	0.07	0.07	0.15
Methylophilaceae	2.94	2.67	1.89	2.69	1.46	2.15	1.78	1.26	0.23	0.13	0.22
Methylococcales CABC2E06	—	—	—	—	0.16	—	—	—	—	—	—
Methylococcales *Crenothrix*	0.15	0.15	0.21	0.25	0.04	0.25	0.26	0.09	0.01	0.04	0.06
Methylococcales *Methylobacter*	0.17	0.12	0.11	0.12	2.49	0.39	0.18	0.16	0.02	0.01	0.03
Methylococcales Methylococcaceae unknown genus	—	—	—	—	0.01	—	—	—	—	—	—
Methylococcales pIW-20	0.01	—	—	—	0.01	—	—	0.01	—	—	—
All Methylococcales	0 . 33	0 . 27	0 . 32	0 . 38	2 . 70	0 . 64	0 . 44	0 . 26	0 . 03	0 . 05	0 . 09
Anaerobic methane oxidation											
Candidatus Methanoperedens	—	0.02	0.03	0.05	0.03	0.71	0.61	0.20	0.04	0.06	0.48
Candidatus Methylomirabilis	1.11	0.89	1.49	1.35	0.63	3.33	1.83	1.03	0.46	0.56	0.29
total reads per sample	12 969	8435	13 607	28 428	51 894	14 810	12 526	17 947	17 704	20 779	22 577

Methane in the sediments of Lake Onego



Sedimentary profiles of (a) methane concentrations and (b) ratio of carbon isotopes from methane in Petrozavodsk Bay. Calculated methane diffusive flux.

Conclusions

1. The distribution of methane content in water and BS in different parts of Lake Onega is uneven. An increased concentration of methane in water was found in the Kondopoga Bay of Lake Onego. This is due to the active influx of organic matter into the water column and BS and its subsequent decomposition to substrates (H_2, CO_2, acetate, etc.), causing methanogenic archaea, both in BS and in anaerobic microniches formed in organic matter suspended in water. mineral particles. A high concentration of gas in water and BS were found in the Petrozavodsk Bay, in the places of detection of gas-saturated deposits – pockmarks.
2. The nature of the distribution of methane in the aquatic environment mainly determines its concentration in the upper horizons of BS, as evidenced by the presence of a close correlation in these two media, due to the pattern of diffusion flows at the BS-water boundary.

The work was carried out within the RFBR project No. 18–45–100002.


Thank you for your attention !