The dispersed spatial structure of the loess Khanka lake ecosystem

P.V. Postnikova, V.S. Filimonov, A.D. Aponasenko, V.N. Lopatin, and L.A. Shchur

Institute of Computational Modeling, Siberian Branch of the Russian Academy of Sciences, Krasnoyarsk

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The possibilities of using optical methods for estimating the parameters of disperse and spatial structures of water ecosystem of loess water bodies are considered using the Khanka lake as an example. It was shown that proximate optical methods could be used to estimate the average size of organo-mineral chorions, their boundary surface, the concentration of mineral suspension particles, the average distance between particles, and total content of the organic matter. The methods of instrumental valuation of contact boundary characteristics, which were used, allow proceeding to direct investigation of quantitative characteristics in studying the processes in the boundary zones. The evaluation of number of bacterio- and phytoplankton, carried out with the help of standard hydrobiological methods, has allowed estimating a structure of their distribution over the lake. The data on spatial distribution of bacterioplankton, phytoplankton and particles of a mineral suspension enable one to more precisely determine the energy losses of bacteriocells at their passage from free to an attached state and those of the phytoplankton cells at their vertical migration.

In recent years the structural-functional approach has been actively developed in the investigation of water ecosystems. Its idea is in connecting the integrated fluxes of matter and energy with the disperse components of ecosystems.[1–5] Disperse components have huge surfaces of the suspension–water boundary and form a special structure of boundary layers, zones of active transformation of matter and energy.[6–7] The quantitative expressions of activation of biogeochemical processes in the boundary zones, inaccessible for direct observation, cannot be obtained without knowledge of quantities of the boundary area and volume of the impact zone formed by this boundary. First of all, this is true for the chorion of a single particle (a particle+boundary zone). It is known that the primary production of water ecosystems correlates closely with the detritus content.

The discovery of a mechanism of transformation of dissolved organic matter (DOM) into a trophically valuable suspension[8–9] has resulted in the revision of the concepts on the regularities of functioning of water ecosystems. Methods of transformation of DOM into suspension are different and can be realized both due to microbial activity and using abiotic mechanisms when a leading role belongs to physicochemical processes. Owing to the adsorption of DOM on the boundary surfaces of suspended mineral particles and the formation of organic-mineral detritus (OMD) considerable reserves of matter and energy, accumulated in it, can be considered as a supplementary link in the system of trophic relations of the food chain.[5]

In ecological hydrobiology the biophysical methods of investigations based on the research of optical, bioluminescent and fluorescent fields have gained wide application. The investigation of physical processes, which reflect the interaction among the organisms and surrounding medium, has made it possible to assess many parameters of water ecosystems. This provided the basis for estimating a possibility of using optical methods for obtaining characteristics of the disperse structure of suspensions, a comparison of those with some characteristics of disperse structure of phytoplankton and bacterioplankton as well as for the assessment of spatial structure of these links of ecosystem in the reservoir of loess type. In such reservoirs, characterized by high content of mineral suspension, these processes must be clearly defined, and the observation of processes is essentially simplified.

Object and methods of research

The object for the research was the Khanka lake, the greatest lake in the Far East. The lake area is 4070 km^2, the maximum depth is 6.5 m. The lake is a typical representative of the loess system, which peculiarity is in the fact that their ecosystems function under conditions of the presence in water of great quantity of finely divided terrigenous particles, which strongly scatter light. In this case they remain highly efficient, enduring considerable anthropogenic loadings.

To characterize the disperse structure the sampling was made at 150 stations over the entire lake area during 4 seasons in 1992, and over a period of 1995–1997. The samples were collected at several coastal and lake stations for investigating the processes of adsorption of mineral suspension. The content of suspended mineral particles, their effective

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mean size were estimated and the interface of suspended particles–water system was determined as well as DOM content based on the primary hydrooptical characteristics (spectral coefficients of absorption, extinction, scattering of light for the spectral range from 400 to 800 nm) and the integral light scattering phase functions using the methods described in the literature.[10] The contribution of the adsorbed organic matter (AOM) was evaluated based on the ratio between the difference of absorption coefficients of unfiltered and filtered samples to the absorption coefficient of unfiltered sample and as the ratio between the AOM concentration and the total concentration of organic matter adsorbed on particles and dissolved in water (AOM+DOM). True dissolved organic matter is considered to be the dissolved organic matter, which passes through the filter with pores of 0.17 μm size, because the part of AOM, adsorbed by small particles, was no more than 2–5%.

Samples of phytoplankton were taken in the surface layer using a bathometric method the probe concentration was made using the filtration method. To calculate the quantity of algae a counter chamber of volume 36.5 mm^3 was used. The biomass and boundary surface were calculated using the mean volume by equating the shape of cells to a close geometric body. The account of bacterial cells, including those attached to detritus and inorganic particles, was made using the epiflorescent microscopy. As fluorochromium we used fluorescamin. Bacteria were deposited on polynuclear filters with pores of 0.17 μm diameter. The natural fluorescence of the filters was removed by processing those by sudan black-B.[11]

Results and discussion

One of the problems of the present work is in the investigation of OMD and, first of all, reserves of OM accumulated by mineral particles from the dissolved phase to suspension, its volume concentration, thickness and volume of an adsorbed layer. For this purpose the adsorption isotherms for lake waters were obtained (Fig. 1). To take into account different degree of dispersion in the test samples the concentration of adsorbed and dissolved OM was calculated not per unit mass of adsorbent but per its unit surface.

The obtained adsorption isotherms were approximated by the Langmuir model typical for adsorption from water solutions:

$$q = kC_d/(1 + kC_d), \quad C_a = C_{a\,max}\, q,$$

where C_a and C_d are the concentrations of adsorbed and dissolved OM per unit surface of OMD, respectively, $C_{a\,max}$ is the maximum possible concentration of AOM, k is the constant of adsorption equilibrium, q is the degree of coating of particle surface (part of occupied adsorption centers).

Parameters of the Langmuir model are: the multiple correlation coefficient – 0.95; the relative reduced error – 18%; the number of observations – 27; the maximum possible concentration of AOM – (310 ± 25) mg/m^2; the constant of adsorption interaction – 0.035 m^2/mg.

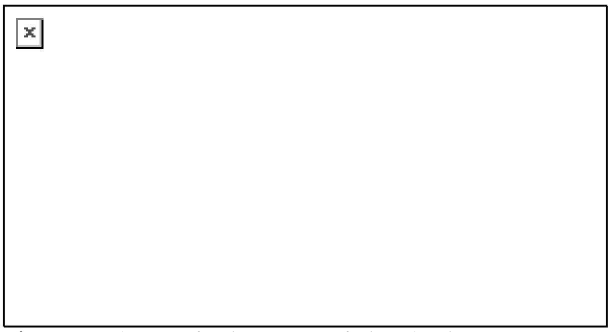

Fig. 1. Isotherm of adsorption of dissolved organic matter (DOM) on mineral suspension for water areas of the Khanka lake.

In the previous model experiment[12] the dependence was determined of the adsorbed layer thickness on the surface concentration of AOM. Because the dependences of the relations C_a/C_d on the DOM concentration (Fig. 2) and C_a concentrations on the value of the suspension surface area (Fig. 3) are the same for the lake water, one can find from them the thicknesses of the OMD adsorbed layer.

Thicknesses of adsorbed layer for the Khanka lake mainly varied from 0.18 to 0.50 μm. Maximum thickness (at $C_{a\,max}$) was 0.60 μm. The volume of the adsorbed layer was from 0.3 to 0.8 volumes of chorion depending on the ratio between the concentrations of the organic matter and suspension. Calculations of the volume density of adsorbed organic matter (g) have shown that it linearly depends on C_a. In the Khanka lake water area the value g varied from 150 to 400 kg/m^3. Thus the mineral suspension concentrates the dissolved organic matter by tens and hundreds thousand times.

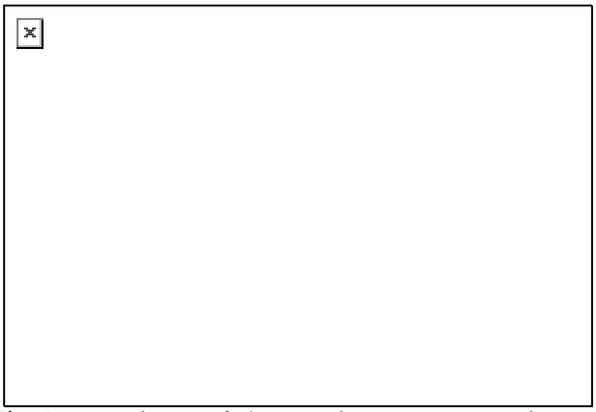

Fig. 2. Dependences of the ratio between AOM and DOM on the DOM concentration per unit particle surface area: the Khanka lake (*1*); model experiments (*2*).

The plots show that the Khanka lake suspension is characterized by higher adsorptivity relative to that of the suspension in model systems. Probably, this is related to the difference of the component composition of organic substance and various nature of adsorbent, but in this case the dependence behavior is retained.

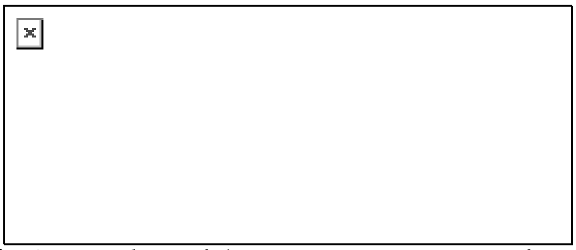

Fig. 3. Dependence of the AOM content per unit surface on the size of suspension surface per unit DOM mass. Designation as in Fig. 2.

The numerical calculations have shown that with the growth of the suspension surface area the ratio between AOM and DOM for water area of the Khanka lake varies from 1.7 (at the suspension concentration of 8.8 mg/l) to 23 (at the suspension concentration of 128 mg/l) that is indicative of the presence of organic matter in the adsorbed state in the natural reservoir. It is therefore concluded that the main peculiarity of natural disperse systems can be determined as the presence in water of not a pure disperse terrigenous suspension but chiefly organic-mineral complexes, including organic compounds of both allochthonous and autochthonous origin.

Consequently, in using the proposed optical methods of investigating the structure of water ecosystems based on the interfaces of suspension–water phases and in estimating dimensions of particles and their boundary surfaces, one should take into account the assessment of the quantity of dissolved organic matter. In the regions where the DOM content is insignificant, and, thus, its lesser amount is adsorbed on the suspension particles the size estimations will be closer to the true size of the adsorbent, and in the regions rich in DOM the optical data will characterize the size of chorions. These results suggest that it is necessary to study in detail the disperse structure of mineral suspension in the surface waters to determine their role in the functioning of the ecosystem of the specific reservoir. Such investigations of the disperse structure of mineral suspension were performed at the Khanka lake.

During winter period the distribution of suspension over the lake is rather homogeneous. The increased concentration is observed at the lake areas adjacent to river mouths carrying during this period larger amount of suspension than in the lake. During spring period the amount of mineral suspension in the lake water increased sharply up to 154 mg/l, and the areas with decreased concentration are adjacent to the separate river mouths. High suspension concentrations (45–85 mg/l) are observed over the entire central part of the lake. In summer and autumn the suspension distribution over the lake area becomes more homogeneous. On a significant part of the territory of central part of the lake the suspension concentration remains high – 65–85 mg/l.

The mean effective sizes of suspensions were also determined. In different seasons the mean particle size in the lake varied from 0.17 to 1.59 μm. Considerable seasonal variation of the particle size have been observed. In winter the mean particle size is 0.66 ± 0.16 μm, in spring – 1.24 ± 0.13 μm, in summer – 1.15 ± 0.17 μm and in autumn – 1.07 ± 0.17 μm. As would be expected in winter season, when water mixing slows down, the mean size of particles ought to be well below than that in the periods of open water. At the same time it has been found that the mean quantity of particles in the lake in different seasons varied within the limits from $24 \cdot 10^9$ to $49 \cdot 10^9$ part/l, and the boundary surface – from 30 to 130 m^2/m^3.

The data obtained on the suspension concentration and mean size of particles have made it possible to assess the particle concentration, the total value of the boundary surface per unit volume, the ratio between the surface and the volume, and the distance between particles. All these characteristics are given in a more detail in Table 1. At the same time at high quantity of phytoplankton and bacterioplankton these components of seston can affect the estimation of the population and determined size characteristics of the mineral suspension in the surface waters. For this purpose the population of these components on the lake area was determined.

The most intensive growth of phytoplankton was observed in spring period. In this case the overall population of phytoplankton varied from 1.5 to 35 mln cell/m^3, at mean value about 8.6 mln cell/m^3. In summer period the population of phytoplankton remained sufficiently high, but somewhat below than in spring period. In the autumn samples the mean population decreased down to 3.1 mln cell/m^3, and in winter period to 2.7 mln cell/m^3. In this case the mean size of the boundary surface of phytoplankton cells in spring season at its maximum growth was 0.91 m^2/m^3, when the variations at separate stations were from 0.07 to 5.7 m^2/m^3. Thus even with minimum concentration of suspended mineral particles recorded in the lake, which was $2 \cdot 10^9$ part/l, the phytoplankton cannot contribute significantly to the assessment of the particle concentration and their boundary surface in the loess reservoir.

The number of bacteria in the lake reservoir during winter period varies within the limits from 0.5 to 4.2 mln cell/ml at mean value about 1.3 mln cell/ml. The limits of variation of the number of bacterioplankton cells over the lake water surface area in spring at mean value of the number of 1.7 mln cell/ml were less than in winter. The mean number of bacteria in summer period was 1.5 mln cell/ml, and in autumn – 1.4 mln cell/ml. For the spring season characterized by the greatest mean number of bacteria, the mean area of the boundary surface of cells was 3.3 m^2/m^3 at variation over the lake surface area from 1.0 to 5.8 m^2/m^3.

Table 1. Characteristics of suspension, DOM, bacterio- and phytoplankton of the Khanka lake

Month	Size	DOM content, mg/l	Content of suspension, mg/l	Mean particle diameter, μm	Spacing between particles, μm	Number of particles per unit volume $\cdot 10^9$, part/l	Area of boundary suspension surface per unit volume, m^2/l	Number of bacteria per unit volume $\cdot 10^9$, cell/l	Spacing between bacteria, μm	Number of phyto-plankton per unit volume $\cdot 10^3$, cell/l	Spacing between phyto-plankton cells, mm
February–March	medium	5.9	7.5	0.72	41	49	0.03	1.3	91	2.7	7.1
	minimal	1.8	2.3	0.17	9	2	0.01	0.5	126	–	–
	maximal	21.2	31.3	1.51	81	1100	0.11	4.2	62	–	–
May	medium	7.2	62.5	1.24	35	24	0.12	1.7	84	8.6	4.9
	minimal	2.5	12.8	0.91	25	4	0.03	0.5	126	1.5	8.7
	maximal	13.2	154.0	1.56	63	53	0.27	9.0	48	35.0	3.1
July	medium	4.4	64.0	1.15	31	34	0.13	1.5	87	–	–
	minimal	1.8	20.2	0.83	22	7	0.04	0.5	126	–	–
	maximal	18.5	130.6	1.57	52	80	0.25	3.3	67	–	–
October	medium	3.9	50.8	1.06	32	35	0.12	1.4	89	3.1	6.9
	minimal	2.5	8.9	0.69	21	4	0.02	0.8	108	–	–
	maximal	8.3	128.4	1.51	64	96	0.23	2.2	77	–	–

Comparing these results, we can note that in the loess reservoirs the mean concentration of suspended inorganic particles exceeds the bacterioplankton concentration by more than one order of magnitude. Consequently, we may claim that in the loess reservoir neither phytoplankton nor bacterioplankton have an essential effect on the variation of the scattering properties. The assessments of seston particle dimensions obtained using optical techniques present the proper estimation of mean dimensions of particles of organic-mineral suspension.

The assessments of mean dimensions of particles and concentrations of mineral suspension, phytoplankton and bacterioplankton enabled us to begin the consideration of parameters of spatial organization of water ecosystem of the lake. The mean spacing between the mineral particles in various seasons varies from 31 to 41 μm, the mean lake boundary surface of suspension varies from 30 to 130 m^2/m^3. The mean spacing between bacterial cells in various seasons is from 84 to 91 μm, and between the phytoplankton cells – from 4.9 to 7.1 mm. These data make it possible to present the volume structure of disposition of these components. Using as the parameter the integrated areas of boundary surfaces of ecosystem components, their disperse structure can be represented in the form of generalized structure formulae. Such formulae can be derived for different areas of the reservoir averaged for the whole water object and the mean over the season can be studied. Averaged formulae of the Khanka lake disperse structure (summer season) for a series: phyto-plankton–bacteria–detritus–organomineral detritus are presented in the form: 1:3:6:140.

The previously obtained high values of boundary surface of suspension for the loess reservoir suggest that it is necessary to attentively tackle the problem of evaluating the significance of OMD in the functioning of the reservoir at the cost of physicochemical and biological processes occurring in the boundary layers, as well as in estimating the bioproductivity, biotic cycle and formation of water quality.

Conclusion

The quick test optical methods used in this study have made it possible to detect the structure and to investigate the parameters of organic-mineral detritus (to evaluate the mean dimensions of organic-mineral chorions, their boundary surface, particle concentration, spacing between particles) for the loess reservoir. We have made an estimate of the number of cells of phyto- and bacterioplankton as well as of the cell spacings. These data enabled us to present the spatial structure of these components of biocenosis, to assess the total amount of dissolved organic matter, accessible for each cell, and the energy expenditure necessary for a cell for its consumption. We have found out that in the loess reservoir the vast majority of dissolved organic matters is distributed not freely in water medium but is in the absorbed state on the mineral particles suspended in water. In this case the boundary of a disperse phase is from several tens to hundreds square meters per cubic meter of the lake water that points to the necessity of taking into account and place special significance on the processes in the adsorbed layers for loess ecosystems.

The solution of a series of problems has been made possible related to the fundamental scientific problem of revealing and studying the spatial structure of water ecosystems based on a unified system principle – boundaries of division (contact) that enabled us to come to the investigation of the processes occurring in the boundary areas on particle chorions in reservoirs.

References

1. K.M. Khailov, *Ecological Metabolism in the Sea* (Kiev, 1971), 252 pp.

2. A.F. Alimov, Ecology, No. 3, 45–51 (1982).
3. A.F. Alimov, *Elements of Theory of the Functioning of Water Ecosystems*, (Nauka, St. Petersburg, 2000), 147 pp.
4. B.L. Gutelmacher, *Metabolism of Plankton as an Integral* (Nauka, Leningrad, 1986), 156 pp.
5. A.P. Ostapenya, "*Seston and detritus as structural and functional components of water ecosystems,*" Doct. Biol. Sci. Dissert., Minsk (1988), 530 pp.
6. T.A. Aizatullin, V.L. Lebedev, and K.M. Khailov, *Ocean Fronts, Dispersions, Life* (Gidrometeoizdat, Leningrad, 1984), 192 pp.
7. V.L. Lebedev, *Boundary Surfaces in the Ocean* (MSU, Moscow, 1986), 150 pp.
8. E.R. Baylor and W.H. Sutcliffe, Limnol. Oceanogr. **8**, No. 4, 369–371 (1963).
9. G.A. Riley, Limnol. Oceanogr. **8**, No. 1, 372–386 (1963).
10. A.D. Aponasenko, V.N. Lopatin, V.S. Filimonov, and L.A. Shchur, Izv. Akad. Nauk, Fiz. Atmos. Okeana **34**, No. 5, 721–726 (1998).
11. M.N. Poglazova and I.N. Mitskevich, Microbiology **53**, No. 5, 850–858 (1984).
12. P.V. Pozhilenkova, A.D. Aponasenko, and V.S. Filimonov, Proc. SPIE **5397**, 102–108 (2003).