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Basic regularities of the process of sedimentation of suspended organic matter in the shallow-water zones of the seas at middle latitudes*

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Abstract — On the basis of analysis of literature data, we consider the regularities of sedimentation of suspended organic matter in shallow waters. The seasonal variability in sedimentation is demonstrated, and its scheme is constructed involving such classes of organic compounds as suspended amino acids, fatty acids, and hydrocarbons.

For a long time, it was assumed that organic matter, phytoplankton, and zooplankton have a similar chemical composition in various regions of the ocean. In fact, the compositions of organic matter in the deep-water and shallow-water zones have considerable differences. For dissolved organic matter in brackish waters and seawater, these differences are described in [1].

In the present work, we consider the specific features of the composition and sedimentation of suspended organic matter in river waters and in contact and shallow-water zones of the sea.

The amount of dissolved and suspended organic matter discharged by rivers into the ocean constitutes about 0.5% of its primary production [2]. In river waters, the ratio of suspended organic matter to dissolved organic matter is equal to 0.8.

According to the data of [3], a part of organic matter of the river suspension has the form of organic compounds enriched with nitrogen (C/N = 10–13) and bound with mineral grains due to specific interactions such as ion exchange, acid–base interactions, and adsorption. After the removal of organic covering from the surface of particles, their specific surface increases.

The suspended organic matter in rivers mostly consists of lignin, cellulose, mono- and polysaccharides, and polycyclic aromatic hydrocarbons and is characterized by a significant fraction of humic substances. In the course mixing of river waters and seawater in the shallow-water zone, the major part of particles suspended in river waters coagulates and precipitates. The organic matter of estuaries and the shallow-water zone of the sea has a different composition, namely, 50% proteins, 30% carbohydrates, 10% lipids, and 10% nucleotides [2].

As is known, the processes of roiling, redistribution of sedimentary matter, and horizontal transfer under the conditions of surface stratification affect the sedimentation of the total suspended matter. For the investigation of the sedimentation rate of the total suspended matter, one needs information on its seasonal dynamics. The specific features of this dynamics manifest themselves not only in different sedimen-

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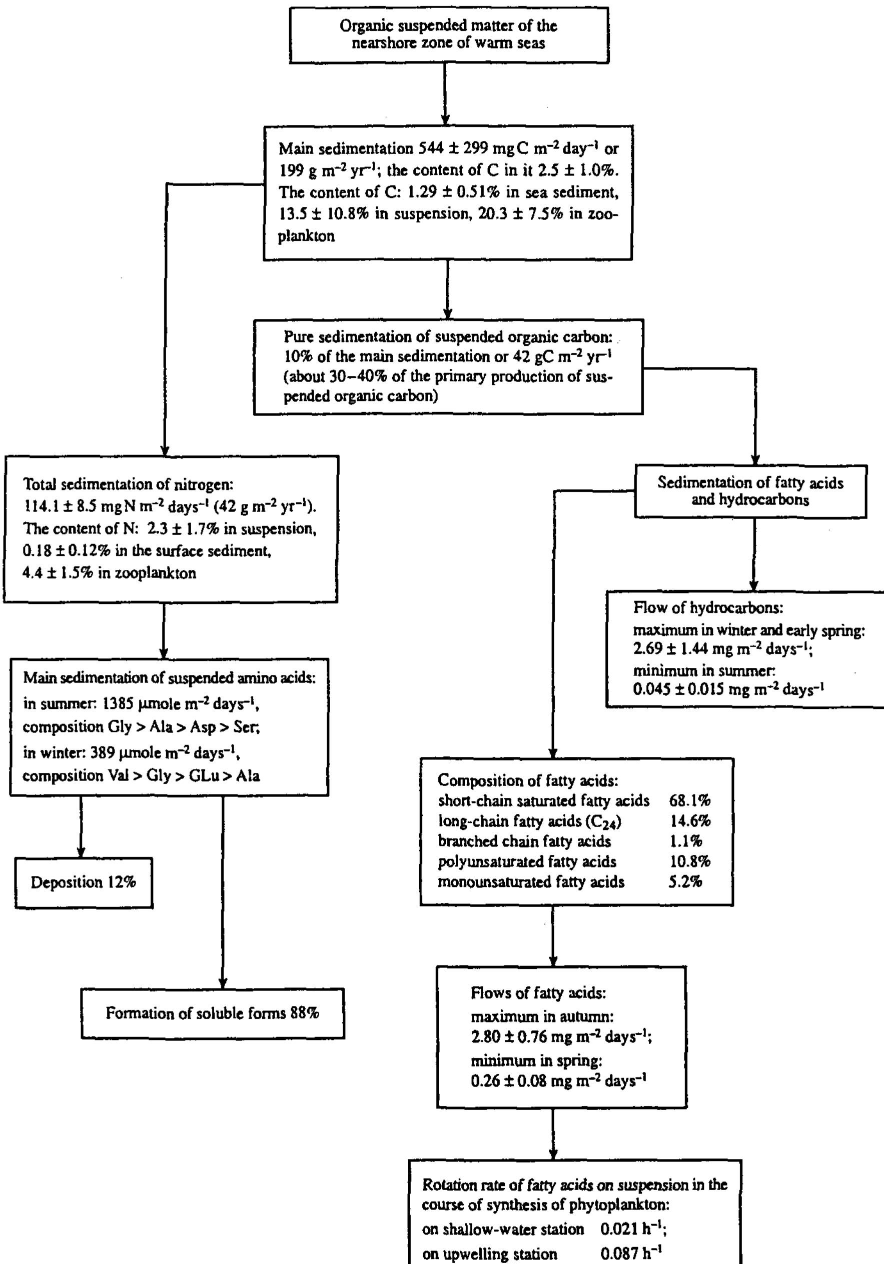
tation rates but also in the seasonal variation in the composition of organic substances. The sedimentation rate of suspensions is maximum in winter and early spring because of roiling of a benthonic sediments by storms in winter and early spring. The maximum total sedimentation of organic carbon, nitrogen, and total nitrogen is observed during the bloom of phytoplankton. The content of organic carbon and organic nitrogen increases in the following sequence: zooplankton → surface sediment → deposited suspension. In the case of high total sedimentation of carbon (544 + 299 mg C m^{-2} per day), its pure sedimentation constitutes 10% of the total value. The behaviour of carbon in amino acids is similar. Analysis of the literature data allows us to conclude that, among all lipids of suspended organic matter, fatty acids are investigated most adequately [4]. The minimum sedimentation of fatty acids is observed from the midwinter to the middle of spring at the maximum rate of sedimentation of suspensions; in autumn, one observes the inverse dependence. The autumn intermixing increases the salinity of shallow-water zones, which promotes the removal of long-chain fatty acids from these zones. The bloom of algae is characterized by an increase in the concentration of monounsaturated fatty acids $C_{16:1}$ and $C_{18:1}$ and polyunsaturated acid $C_{20:5}$. The formation of mucous aggregates is accompanied by an increase in the fraction of monounsaturated and short-chain saturated fatty acids. It should be noted that fatty acids can play the role of certain biomarkers. Thus, the polyunsaturated fatty acid $C_{20:5}$ is a biomarker of diatomic algae, fatty acids with branched chain are biomarkers of bacterial biomass, and fatty acids whose chain is longer than C_{24} are biomarkers of land higher plants [4]. In what follows, we present a general scheme of sedimentation of suspended organic matter in the nearshore zones of warm seas. As follows from this scheme, the winter–spring intensification of physical processes such as roiling and redistribution of sediment matter mostly affects the sedimentation of hydrocarbons (maximum sedimentation takes place in winter and early spring, and minimum sedimentation is observed in summer). For the sedimentation of fatty acids, the inverse dependence is observed, namely, the minimum sedimentation of fatty acids takes place in winter and early spring when the maximum sedimentation of the total suspended matter is observed, and the maximum sedimentation of fatty acids is observed in autumn. This is explained by the biological processes of bloom and destruction of phytoplankton and the physical process of sharp increase in salinity in estuaries in this period of the year. The sedimentation of amino acids and proteins depends on biological processes, namely, on phytoplankton bloom and the growth and destruction of zooplankton. For these classes of organic compounds, the maximum sedimentation is also observed in summer, and the minimum sedimentation in winter.

It should also be noted that, as a result of the elevated sedimentation of long-chain fatty acids, a large amount of higher fatty acids is detected in the substances of a trap due to the decomposition of unsaturated and short-chain homologs [4].

The average ratio C/N in the rapidly depositing total suspended matter is equal to 8.1–4.2 (in the total suspended matter, this ratio is equal to 8.5–7.1, and, in the surface sediment, it is equal to 13.1–10.7). The value of the ratio C/N in the sediment is determined by the decomposition of nitrogen-containing compounds in the course of sedimentation and by the influence of the river total suspended matter.

Scheme of sedimentation of suspended organic matter in the nearshore zones of warm seas according to [4, 5]



The amino acid composition of suspended organic matter within the water column is intermediate between the compositions on the sea surface and on the surface of the sediment. The qualitative composition of amino acids in the depositing suspended organic matter varies from season to season. For example, in summer, the concentrations of certain amino acids decrease in the course of sedimentation of suspended organic matter in the following sequence: Gly > Ala > Asp > Ser. In winter, they decrease as follows: Val > Gly > Glu > Ala [5]. It is known [5] that more than 50% of colloidal amino acids are associated with materials whose molecular weight is 5000. These colloids consist of carbohydrates and peptides and are similar in composition to phytoplankton: 50% protein, 30% carbohydrates, 10% lipids, and 10% nucleotides [2].

In the investigation of sedimentation of suspended organic matter, the size of suspended particles plays an important role.

In [6], the physical characteristics of suspended particles were investigated for the bays of the northern part of the Adriatic Sea. The suspended particles were classified into the following three groups: organic matter (alive, detrital), inorganic (colloids of elements), and clay (aluminosilicates).

Alive organic matter includes small bacteria and viruses. They have low electron densities and are amorphous. These particles have submicron sizes and constitute the major part of the mass of suspended particles.

Particles with a size of 100–500 nm consist of $Fe(OH)_3$, crystalline aggregates of elliptic form. Occasionally, $Ti(OH)_4$ and $Si(OH)_4$ were also detected among these particles.

Particles with a size of 200–1000 nm also include aluminosilicates. In the range of 40–100 nm, for all types of particles the integral volume increases as the size of particles decreases, and the integrated mass is 0.05–0.09 mg $litre^{-1}$.

Organic submicron particles may originate from larger suspended substances being a result of the microbial decomposition of the metabolic wastes of protozooplankton and large-size zooplankton or substances of the surface of cells from marine viruses.

Depending on their origin, particles can belong to two groups: small particles (8–10 μm) of the river origin, and large particles (70 μm) of the marine origin [7]. In [7], it was established that particles with hydrophilic surfaces (sugars, amino acids, cellulose, bacteria, and their metabolites) have higher sorption activity than other organic particles. In one of the estuaries, the content of particles characterized by the presence of organic covering and detritus varied from 8% at a freshwater station to 67% at a sea station [7]. In the same estuary, small particles (<20 μm) were detected, 80% of which were particles of size <2 μm. The major part of these particles were cyanobacteria.

The suspended organic matter of the shallow-water zones of the Black Sea is inadequately investigated. In [8], the seasonal dynamics and spatial variability of the suspended organic matter in the northwest part of the Black Sea were described, and the role of phytoplankton in the formation of suspended organic matter was investigated.

Depending on the class of organic compounds of suspended organic matter, its sedimentation can be largely determined by physical processes (hydrocarbons), combined action of biological and physical processes (fatty acids), or by biological processes in the planktonic and detrital fractions of suspended organic matter (amino acids and proteins).

Thus, the analysis of the literature data carried out in this work showed that the seasonal variation in sedimentation of suspended organic matter is determined by the class of organic compounds, surface properties and size of suspended particles, and by physical, biological, and geochemical processes taking place in shallow waters.

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