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GEOLOGY

Sedimentation System of the Angara River after Regulation of Its Flow

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Construction of reservoirs changes natural features of channel processes and depositional conditions in rivers. Based on the variation degree of these processes within reservoirs, we can distinguish the regressive accumulation, alternating backwater, and permanent backwater zones (areas) [1]. Zones of alternating backwater represent reservoir areas with river to lake-reservoir transitional conditions and are regarded as areas of the regulated river mouth, where mechanical deposition of most suspended material and active accumulation of sedimentary material take place due to a decrease in the transport capacity of water flow [2]. According to Lisitsyn [3, 4], the combination of interrelated processes in river mouths and accumulation of enormous masses of sediments with specific composition and properties can be qualified as a marginal filter phenomenon.

This work discusses for the first time the formation of the Angara sedimentation system after regulation of its flow. The system is located 1650 km upstream of the natural river mouth. The flow of the Angara River running out of Lake Baikal was regulated by the Angara cascade of hydroelectric power stations (HPS), one of the largest in the world, coupled with the Irkutsk, Bratsk, and Ust-Ilim reservoirs (Fig. 1). The Irkutsk Reservoir, the first in the cascade, is of high strength. Therefore, the small amount of suspended material delivered from Baikal is efficiently transferred through the reservoir.

To study water mass transformation and peculiarities of sedimentation in reservoirs of the Angara cascade, the author carried out hydrological, hydrochemical, and lithogeochemical investigations in the years 1972–2002. We also performed laboratory analytical works, including the determination of the granulometric, mineralogical, and chemical compositions of water and bottom sediments. It has been established that construction of reservoirs provoked the offset of a segment of the Angara River mouth toward the river head. This segment with features of a marginal filter began to form 160 km away from Lake Baikal in the alternating backwater area and the upper Angara region of the Bratsk Reservoir. The new sedimentation system extends for 90 km and covers an area of 135 km^2. The suspended material concentration in Angara water is low. Nevertheless, due to the great volume of the water mass, the annual sediment load transported by the Angara River into the area of alternating backwater makes up 1.398 Mt. One-half of this load remains in the alternating backwater area and the upper Angara region. The water flow velocity decreases along the length of the alternating backwater area, but regularities in the vertical distribu-

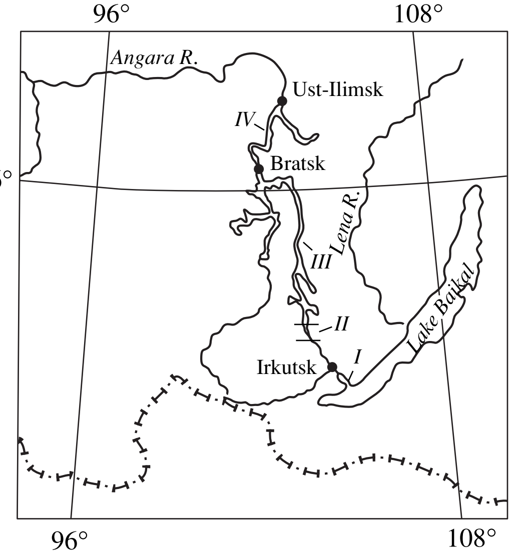

Fig. 1. Schematic map of the Angara River and reservoirs of the Angara cascade. (*I*) Irkutsk Reservoir; (*II*) alternating backwater area and the Upper Angara area of the Bratsk Reservoir; (*III*) Bratsk Reservoir; (*IV*) Ust-Ilim Reservoir.

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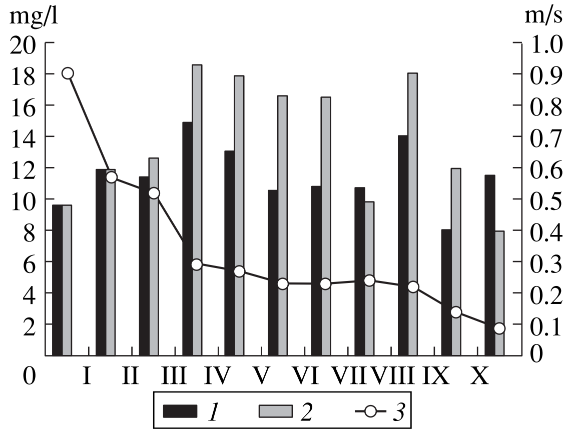

Fig. 2. Distribution of flow velocity and concentration of suspended material in the Angara marginal filter. Observation areas: (0) Usol'e-Sibirskoe; (I) 110 km; (II) Kulakovo; (III) Buret; (IV) 125 km; (V) 130 km; (VI) 135 km; (VII) Svirsk; (VIII) Kamenka; (IX) Kazach'e; (X) Seredkino. (*1*) Surface layer; (*2*) near-bottom layer; (*3*) stream.

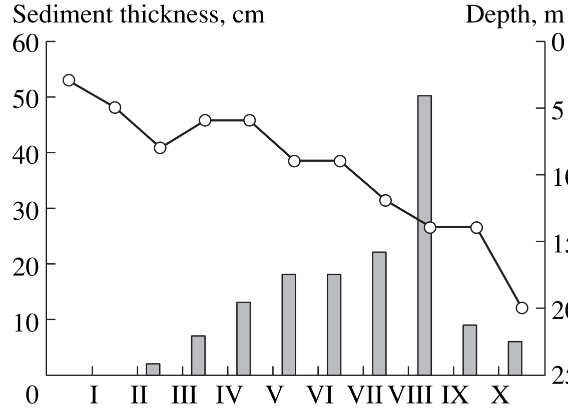

Fig. 3. Thickness of fine-dispersed bottom sediments in the Angara sedimentation system. See Fig. 2 for observation areas.

tion of the suspended material, which are characteristic of the natural river mouth, are not clearly expressed in the region because of the unsteady flow regime and possible inflow of particles from fresh bottom deposits.

The upper part of the alternating backwater area, in which flow velocities in the summer period vary within 0.29–0.52 m/s, represents a section of steady sedimentation of fine-grained sandy material transported in suspension. Fraction 0.25–0.05 mm is abundant in sands, making up 63% on average. The sum of <0.01 mm particles makes up 5.1% [5]. According to our calculations, the critical noneroding velocity is 0.2–0.3 m/c. Particles of fraction 0.05–0.01 mm are intensely deposited at lower values of this parameter [6]. The main transportation mode for particles of such size is transfer in the suspension state. Therefore, with decreasing water flow velocity, the particles are deposited in the lower segment of the alternating backwater area and in the upper Angara region, where water velocity does not exceed 0.29 m/c (Fig. 2). The main lithological types of bottom deposits are represented by the prevalent coarse silt and the subordinate fine mud. In coarse silts, the sand fraction makes up 1.1%, the fraction 0.25–0.05 mm amounts to 39.8%, and the share of the leading fraction 0.05–0.01 mm is as much as 46.2%.

Investigations carried out in river mouths showed that sediment load in marginal filters of the Ob and Yenisei rivers makes up 1321 and 22 156 mg · m^{-2} · day^{-1}, respectively [3]. It was established that the intensity of sedimentation at the gravitational stage of the Angara marginal filter makes up 14 034 mg · m^{-2} · day^{-1}. At the gravitational/sorption transition stage, the sediment load reaches 93 145 mg · m^{-2} · day^{-1}. At the sorption stage, the sediment load decreases to 11 177 mg · m^{-2} · day^{-1}. Hence, the hydrological system is characterized by an ultrafast vertical flow of sedimentary material in the marginal filter of the Angara River due to its regulation not far from the river head.

The thickness of deposited sediments increases along the length of the alternating backwater area, i.e., at the gravitational stage, and reaches its maximum at the area of transition to the sorption stage (Fig. 3), where basic types of bottom sediments are represented by fine and silty–clayey mud. The mud thickness at the sorption stage decreases toward the reservoir, making up 4–20 cm at the Kazach'e area and 3–18 cm at the Seredkino area. Sediment grading deteriorates due to decrease in flow velocity and a mass accumulation of fine terrigenous material. A small thickness of sediments at the river/alternating backwater boundary is related not to a low sedimentation rate but to the regime of the reservoir exploitation. The reservoir drawdown by 7–10 m and low water level over several years promote a shift of the backwater boundary down to the reservoir and an increase in the flow velocity along the alternating backwater area. Fine-dispersed sediments are washed out, transferred into the suspension state, transported, and deposited on lower areas. For instance, coarse silts deposited at the low backwater level are completely washed out and only sands remain in the Kulakovo–Buret area.

Calculations based on the thickness of bottom deposits and the timing of their accumulation show that the sand sedimentation rate in the Angara marginal filter may be as high as 186 m/ka. The sedimentation rate for coarse and fine particles is estimated at 220–500 m/ka. As is evident, flows of sedimentary material in the alternating backwaters of reservoirs are comparable with flows in natural river mouths. Based on the inferences in [7], such high rates can be attributed to processes of avalanche sedimentation.

Thus, after regulating the Angara flow by the cascade of reservoirs, the sedimentation system of the river mouth area with characteristic features of the marginal filter shifted to the alternating backwater area and the upper Angara region of the Bratsk Reservoir. When passing through a newly formed marginal filter, half of the terrigenous material brought by the Angara River is lost, resulting in the formation of the new sedimentation system of the Angara River with ultrafast avalanche-type sedimentation.

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