ORIGIN AND EVOLUTION OF RIVER SYSTEMS

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Summary

The origin of rivers at Earth has a long history. It is related to the appearance and development of the continents and islands as a result of tectonic-magmatic processes as well as to the formation of the Earth's hydrosphere in the process of juvenile water inflow to the Earth's surface. A large role in its formation belonged to the processes of complicating global water exchange and erosion development as well as changing climatic conditions. In the processes of their development, rivers changed the direction of their currents and had different water content during the different geological epochs. Their development was influenced by the repeatedly occurring inland water bodies of lagoon type and inland seas, level oscillations of the basins as well as land glaciation events, especially significant in the Northern Hemisphere.

The processes of erosion, transport and deposition of sediments occurring with a different intensity during the geological epochs in the past and at present, as well as economic activity (creation of water reservoirs, water withdrawal for irrigation and numerous economic needs) determined the evolution of rivers and a modern look of the river network.

1. Introduction

Water at the planet Earth (in the oceans, on the continents and in the atmosphere) appeared during the Archean epoch. According to the most widespread standpoint, the

Earth's hydrosphere appeared as a result of gravity differentiation and degassing of the mantle substance. Due to water bonding at the Earth's surface and its burying in sedimentary deposits, this process was characterized by a gradual slowing. At the beginning of the Paleozoic (570 million years BP), the hydrosphere volume comprised more than 90 % of its current value. Many geological data confirm that 1.5 – 2 billion years BP, the average ocean depth comprised 2 – 3 km; the present depths were achieved not later than in the Late Pre-Cambrian (1.6 billions years BP). It is however, not excluded that as early as the end of the Cretaceous (100 – 70 million years BP), there was land in place of the present oceanic basins, or more probably, shallow epi-continental seas.

The significant water volumes in some past epochs were concentrated in addition to the oceans and the glacial sheets, in vast sea basins, lakes and swamps, in the water-bearing layers and at the continents.

In addition to drain and drainless lakes of the current type, the Earth's history knows vast lakes of lagoon type and inland seas, where the connection with the ocean was periodically interrupted or made difficult as a result of tectonic motions and significant ocean level changes. Such lakes–seas that occupied in some epochs tens of millions of square kilometers of the area were not only the giant accumulators of sea salts but also powerful moisture evaporators.

The formation of land hydrography in the past and, especially, generation and evolution of the river systems was predominantly determined by the occurrence and development of the continents as a result of tectonic-magmatic processes. It is related to the formation of the Earth's hydrosphere in the process of juvenile water coming to the Earth's surface as well as to the development of the processes of water exchange and soil-ground erosion under the action of incoming solar radiation to the Earth's surface.

There are comparatively few direct data on the development of the river network at the Earth's continents in the geological past. That is why the corresponding estimates for the individual epochs in the past, especially for the Pleistocene, were obtained from paleoclimatic reconstructions. The majority of such estimates were obtained for Eurasia. The development of the river network and the formation of lakes and swamps during the Pleistocene are inseparable from the glaciation events. The most complete data on the hydrography of rivers and the river runoff are available only for the periods of Valdai glaciation and the Holocene.

Thus, the formation of the river network throughout the entire Earth's history was and is still naturally influenced by the tectonic, climatic and astronomical factors. These factors govern the distribution at out planet of the seas and the oceans, solar radiation, corresponding orography and lithological structure of the locality, soil-ground and vegetation as well as erosion activity and action of flowing waters.

2. Primary stage of the occurrence of river systems

Around four billion years BP, due to the occurrence of separate land massifs – protoplatforms, active erosion activity of surface waters began. This fact contributed to the accumulation of ancient sedimentary deposits, whose fragments were found in different land areas. Most traces of primary watercourses and water bodies in the territory of initial continents were destroyed in the process of erosion, tectonic deformations and repeated marine transgressions. The most clear traces of the surface water activity on land are detected from the Proterozoic (table 1), about 1 – 2 billion years BP, in the form of fragments of ancient river rills as well as different forms of such deposits as continental pebble-beds and sands of proluvial, lacustrine and river origin.

Eras	Periods	Beginning, million years ago	Duration, million years
	Phanerozoic		
Cenozoic	Quarternary	1.5	1.5
	Neogene	25	23.5
	Paleogene	67	42
Mesozoic	Cretaceous	137	70
	Jurassic	195	58
	Triassic	230	35
Paleozoic	Permian	285	55
	Carboniferous	350	65
	Devonian	410	60
	Silurian	440	30
	Ordovician	500	60
	Cambrian	570	70
	Precambrian		
Proterozoic	Upper(Riphean)	1600	1030
	Middle	1900	300
	Zower	2600	700
Archean		>3500	>900

Table 1. Geochronologic scale of Phanerozoic and Precambrian.

We shall consider the occurrence of primary river systems by the example of the Russian platform. It was established that the initial stage of the river systems at the Russian Platform belongs to the Late Riphean (around 1 billion years BP), when its surface began to form as a result of consolidation around the Baltic and Sarmatian shields with accumulation of sedimentary material. It is suggested that rivers of the Late Proterozoic – Early Phanerozoic flowed southeastward from the Baltic shield and then along the Baltic-Moscow depression to the west-southwest. It was established that the main large river flowed along the Finnish-Neva basin where now the Gulf of Finland, Lakes Ladoga and Onega and the Neva, Svir' and Onega Rivers are located. The meridional inflows of the main river were confined to the Luga-Narva and Il'men-Ladoga depressions.

The Near-Caspian syneclise formed almost simultaneously, which was probably more mobile than the Moscow one. It is assumed that at the Riphean time (800 – 900 million years BP) the drainage from the central part of the Russian platform towards its southeastern margin begins. The Don and Voronezh Rivers originate. At the same time a pra-river corresponding to the modern Dnestr originates. The Russian platform was repeatedly subjected to the advance of the sea either from the west in the Ordovician (ca. 500 millions years BP) during strong ocean transgressions to the land or from the east in the Devonian (ca. 400 million years BP) as a result of submergence of the Urals geosyncline and the Moscow syneclise. Similar processes governing the initial stage of the river systems also occurred at the other Earth's continents.

3. Development of rivers in the Paleozoic

In place of West Europe in the Cambrian period (550 million years BP), there was an uplift – the Franco – Cheshsky massif, which turned sometimes to an archipelago of islands. Then, the accumulation of lacustrine and river sediments occurred in this region. Gradually with time, there was a massif rise and appearance of some mountain ranges, from which the watercourses removed an enormous quantity of coarse detrital material. In the Devonian (400 million years BP), temporary, periodically drying lakes existed in the central part of the basins whose traces are preserved in the form of clayey and clayey-calcareous silts. The rivers flowing from the territory of expanding land to marine basins as a result of export of a large quantity of sedimentary material formed powerful deltas.

In the Earth's history, inland water bodies of lagoon type and inland seas appeared repeatedly. Their connection with the ocean was periodically interrupted or made difficult as a result of positive tectonic movements and large ocean level changes. Such lakes-seas that occupied in some epochs tens of millions of km^2 of land were not only giant accumulators of sea salts but also powerful moisture evaporators. They could have a significant influence on the global water exchange processes. The Caspian and the Aral Seas are relicts of such features in the present epoch.

The lagoon and lacustrine sediments are encountered in different regions of Eurasia in the deposits of all geological periods of the Phanerozoic. Their greatest development is typical of the Early Cambrian, Ordovician, Middle and Late Devonian (400 million years BP), Triassic (200 million years BP), Middle Jurassic (160 million years BP) and Late Cretaceous (70 million years BP), i.e., the epochs following the periods of development of epi-continental seas. The epochs of the development of lakes and increased water content of rivers usually corresponded to the periods of general humidization of climate in the territory of the continents.

In the Silurian (440 million years BP), climate aridization gradually developed achieving its maximum in the Devonian (about 400 million years BP). It is supposed that these were the most pronounced arid conditions in the Earth's history, which is indicated by large areas and volumes of spreading of the Devonian deposits corresponding to arid conditions (red bed, dolomites, gypsum and salts).

At the Late Devonian time (ca.350 million years BP), desiccation of the territory at the Russian platform occurs in the area of the Vyatka basin and Oksko-Tsninsky and Zhigulevsky uplands. The rivers during this period discharged their waters to the areas of the Moscow and Near-Caspian syneclises. The rivers flowing along the Dnieper-

Donetsk basin also made their way here.

It is supposed that in the Devonian, the southeastward runoff from the Russian platform has finally formed. As a result of a complicated development of tectonic processes causing both a rise and a subsidence of large Earth's crust segments, a continuous river network reformation occurred. In the Paleozoic and the Mesozoic (200 – 400 million years BP), meridional elongated marine straits appeared connecting the seas of the Moscow and the near-Caspian syneclises. With the development of continental conditions when seawater retreated, rivers flowing northward and southward originated.

The river systems of North Eurasia achieved their greatest development in the first half of the Carboniferous, Late Triassic, Early Jurassic and first half of the Cretaceous periods and in the Paleogene and Neogene, i.e. predominantly in the epochs of relative climate humidization and start of decreasing tectonic-magmatic activity and damping positive tectonic movements. During the same stages of geological history or slightly earlier, the areas of lakes of North Eurasia increased. In the inland parts of Asia, the "river" stages probably replaced the "lake" ones under the conditions of developing aridization of climate.

During the Early and Middle Carboniferous periods (ca. 325 million years BP), the upper Volga basin starts forming in the axial zone of the Moscow syneclise. At this time, a wide water flow is formed directed to the east. It ended flowing to the sea of the Urals geosyncline. From the Carboniferous period, segments of the ancient channels are traced corresponding to the Middle Volga and Lower Kama. It is assumed that already in the Early Carboniferous period, the Lower Kama was a tributary of the Middle Volga. Slightly later in the Mesozoic, the Middle Kama intercepted the runoff of the Ural River from the Upper Volga (Figure 1). A delta of the river draining the Ryazan-Saratov depression was established in the Saratov area at the northwestern side of the Near-Caspian syneclise. During the Visean Stage (ca. 340 million years BP), the river corresponding to the Upper Volga, Kama-Kinel and Ryazan-Saratov Rivers flowed from the Timano-Valdai-Donbas water divides to one marine basin of the Urals geosyncline, Near-Caspian syneclise and the Pre-Caucasian geosynclinal basin.

Beginning from the Cambrian, a gradual formation of the structural modification of the Russian platform and generation of the main river water divides occurred. During this period, the main water divide of the Russian platform originated with drainage predominantly in the southwestern, northeastern and southeastern directions. The Upper Volga runoff was directed to the Moscow syneclise basin, while waters of the Lower Kama, Middle Volga and runoff from the Ryazan-Saratov depression and the Dnieper-Donetsk Basin were directed to the Near-Caspian Sea.

At this time, a river existed whose remains are followed in the form of a buried main Pre-Jurassic Moscow trough. This river continued from the Shatsk town along the Ryazan-Saratov depression towards the Near-Caspian syneclise in whose northwestern area, it merged with the Donetsk River. The Moskva River and the Ryazan segment of the Oka correspond to the Mesozoic trough. In the west of the Russian platform, a river flowed along the Dnieper-Donetsk depression until the Late Triassic (200 million years BP) from the middle reach of the Dnieper to a closed sea of the Near-Caspian syneclise that formed extensive alluvial plains.

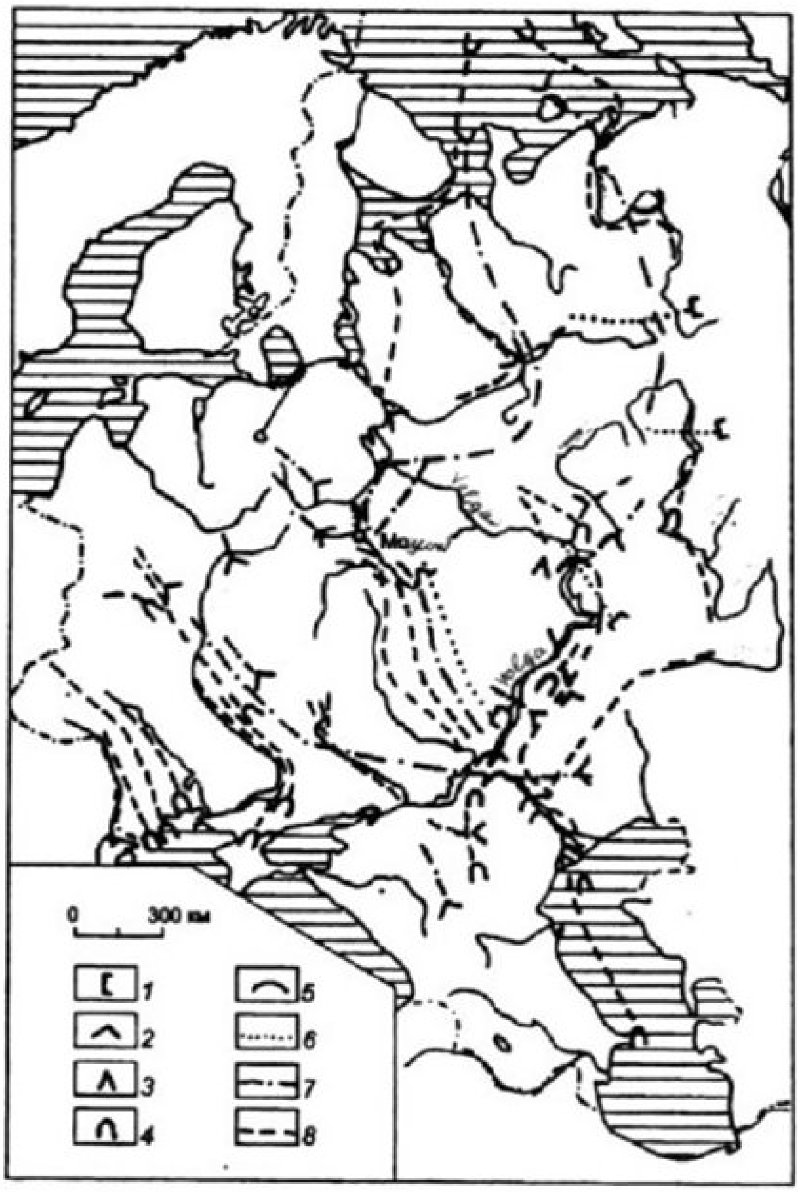

Figure 1. Mouths and channels of the largest paleo-rivers of the Russian platform
Mouths: 1 – Paleozoic, 2 – Mesozoic, 3 – Paleocene, 4 – Neogene, 5 Quaternary
Channels: 6 - Paleozoic, 7 – Mesozoic, 8 – Tertiary

In the Late Paleozoic (ca. 300 million years BP), the rivers of the Middle Urals flowed to the Moscow syneclise. The Lower Kama channel in the upper Permian (200 million years BP) was directed southward, while a meridional segment of the Middle Kama and Chusovaya and Belaya Rivers formed in the area of the Pre-Urals marginal depression. As a result of the subsequent interception of the Urals rivers, the Kama runoff increased. It is probable, that the runoff at the Mesozoic time was divided between the Volga and the Kama.

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Biographical Sketch

Vladimir Ivanovitch Babkin was born in 1941. In 1965, he graduated from the Voronrzh State University. Since 1969 he has worked at the State Hydrological Institute. In 1970, Babkin defended theses for the degree of candidate of geographical– sciences, and in 1984 – doctor theses of geography.

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V.I. Babkin is the author of 130 scientific papers including seven monographs on hydrology, hydrophysics, and water balance and water resources. Most of his studies deal with hydrological cycle processes (evaporation, runoff, precipitation, and infiltration), developing methods for their estimation, as well as discovering global mechanisms of land moisturizing on the continents.