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The Holocene Alluvial Delta Relief Complex and Hydrological Regime of the Lena River Delta

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Summary: This study presents the geological-geomorphologic characteristics of the Holocene alluvial-delta relief complex of the Lena River delta and deposits comprising it. A complex of the Holocene alluvial-delta relief is represented by a set of channel forms and a low floodplain of modern age, a high floodplain forming from the end of the Early-Late Holocene and the first above- the floodplain terrace formed in the Early-Middle Holocene.

During the Early Middle Holocene, the main runoff of the Lena river was in the northwestern and northern direction along the Olenyokskaya and Malaya and Bolshaya Tumatskaya branches. At the end of the Middle-Late Holocene as a result of non-unidirectional tectonic development of the western and eastern delta sectors, a change of the main runoff in the Lena mouth area from northwest-north to northeast-east occurred.

The hydrological regime at the current stage plays a decisive role in the relief formation in the Lena River mouth area. The river factors (discharge of water and sediments to the delta, their distribution by delta arms, water level rise height in the branches during the flood and ice drift character) control completely the accumulation of alluvial deposits and the relief formation of the complex of channel forms and the low floodplain in the internal parts of the Lena River delta. They also influence the processes of destruction of the high floodplain shores, the first above-the floodplain terrace and more ancient terrace levels. The marine factors control the relief formation within the external delta margin. The most significant role in the relief formation in the group of marine factors belongs to surge sea level oscillations, whose influence spreads along the large arms over a distance of up to 56-90 km from the marine delta margin, influencing the relief development of a complex of channel forms and the low floodplain. The tidal phenomena play a noticeable relief-forming role only within the open external northern and northeastern margin of the Lena mouth area on the protrusion delta formation segments.

Zusammenfassung: Die vorliegende Arbeit beschäftigt sich mit der geologisch-geomorphologischen Charakteristik des holozänen, alluvialen Reliefs des Lena-Deltas. Das holozäne, alluviale Delta-Relief wird durch einen Komplex von Flussbettformen und die rezente untere "floodplain", die obere "floodplain" mittel- bis spät-holozänen Alters sowie die erste Terrasse oberhalb der "floodplains", die ein früh- bis mittel-holozänes Alter aufweist, gebildet.

Der Hauptteil des Lena-Ausstroms war während des Früh- bis Mittel-Holozäns nach NW und N entlang des Olenyok- sowie des kleinen und großen Tumatskaya-Kanals gerichtet. Infolge der unterschiedlichen tektonischen Entwicklung der westlichen und östlichen Lena-Delta-Sektoren verschob sich der Hauptausstrom der Lena am Ende des Mittel- bis Spät-Holozäns von N und NW in Richtung NO.

Die rezenten hydrologischen Bedingungen spielen die Hauptrolle bei der Reliefbildung des Lena-Mündungsgebietes. Die Flussparameter (Abflussvolumen, Sedimenttransport und deren Verteilung auf die unterschiedlichen Kanäle des Deltas, Anstieg des Pegels während des Frühjahrshochwassers, Eisgang) kontrollieren die Akkumulation der Alluvialablagerungen und die Bildung des Reliefs der Flussbettformen und des unteren "floodplains" im inneren Teil des Lena-Deltas. Auch die Ufererosion der oberen "floodplains", der ersten Terrasse oberhalb der "floodplains" und der älteren Terrassen wird durch diese Parameter gesteuert. Marine Einflussfaktoren dagegen kontrollieren die Reliefbildung am äußeren Delta-Rand. Die Hauptrolle spielen dabei Hochwasserereignisse, während derer das Meer über die großen Kanäle bis zu 56-90 km weit in das Delta vordringen kann und die Reliefentwicklung von Flussbettformen sowie der unteren "floodplain" beeinflusst. Die Gezeiten spielen lediglich im äußeren N- und NW-Randbereich, in dem sich das heutige Lena-Delta ins Meer vorschiebt, eine Rolle für die Reliefbildung.

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INTRODUCTION

During the last three years, new material was obtained during Russian-German "Lena-98", "Lena-99" and "Lena-2000" expeditions in the framework of the "Laptev Sea System" Project (RACHOLD & GRIGORIEV 1999, 2000, in press). It allows us to supplement and update the available information on the geological-geomorphologic structure and the history of development of the Lena River delta.

The Lena River delta presents a complicated feature, which is polygenetic by nature and formed at different times. Several geomorphologic levels differing in height and age with a different spatial distribution are identified in the Lena River delta (Fig. 1):
- low floodplain with a complex of modern channel features of the present age;
- high floodplain of Late Holocene age;
- first above-the floodplain accumulative terrace of Early-Middle Holocene age;
- second above-the floodplain erosion terrace of Late Pleistocene-Early Holocene age;
- third above-the floodplain erosion terrace of Late Pleistocene age;
- denudation relics worked out on the Paleozoic rock and pre-Pleistocene pebble-conglomerate rocks.

This study considers the geomorphologic levels whose formation occurred during the Holocene, i.e. the low terrace with a complex of modern channel features, the high floodplains and the first above-the floodplain terrace.

The main aim of the study is to give full geological and geomorphologic characteristics of the Holocene terrace levels of the Lena River delta, specify their formation time and establish their relationship with the hydrological regime of the Lena River mouth area.

METHODS

Field work

During the 1998-2000 expedition studies (Fig. 2) in the Malaya and Bolshaya Tumatskaya, Arynskaya, Olenyokskaya

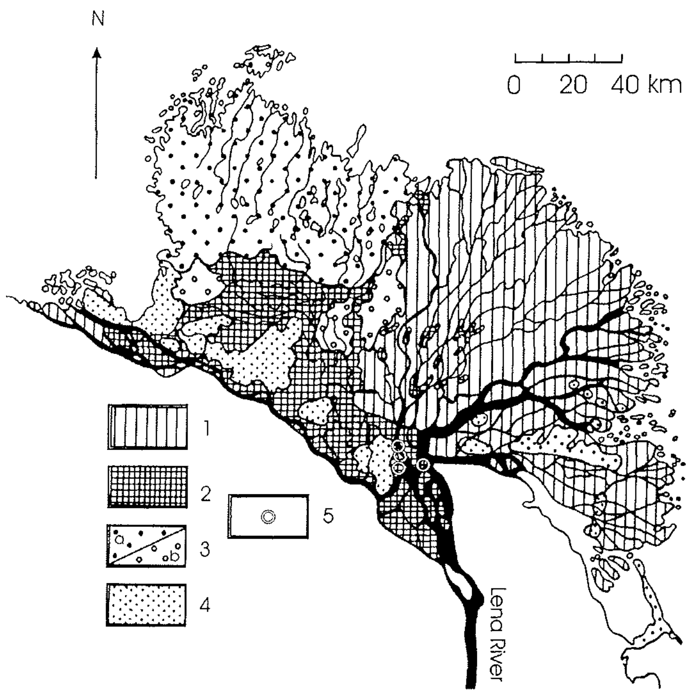

Fig. 1: Geomorphologic scheme of the Lena Delta (extended after GRIGORIEV 1993). (1) low floodplain with a complex of modern channel features of Recent age and high floodplain of Late Holocene age; (2) low and high floodplain and the first above the floodplain accumulative terrace of Early-Middle Holocene age; (3) second above the floodplain erosion terrace of Late Pleistocene-Early Holocene age ((a) most pronounced second above the floodplain terrace; (b) second terrace segments with most significant denudation reworking of the upper surface); (4) third above the floodplain erosion terrace of Late Pleistocene age; (5) denudation relics of Paleozoic rock and pre-Pleistocene pebble-conglomerate.

Abb. 1: Geomorphologisches Schema des Lena-Deltas (nach GRIGORIEV 1993). (1) unteres "floodplain" mit einem Komplex heutiger Flussbettformen und rezentem Alter, sowie oberes "floodplain" spät-holozänen Alters; (2) unteres und oberes "floodplain" und erste Akkumulationsterrasse oberhalb des "floodplain" mit mittel- bis früh-holozänem Alter; (3) zweite Terrasse oberhalb des "floodplain" mit spät-pleistozänem bis früh-holozänem Alter; (a) ausgebildete zweite Terrasse, (b) Segmente der zweiten Terrasse mit ausgeprägter Denudation); (4) dritte Terrasse oberhalb des "floodplain" mit spät-Pleistozänem Alter; (5) Verwitterungsrelikte paläozoischer Gesteine und vorpleistozäner Kiesel-Konglomerate.

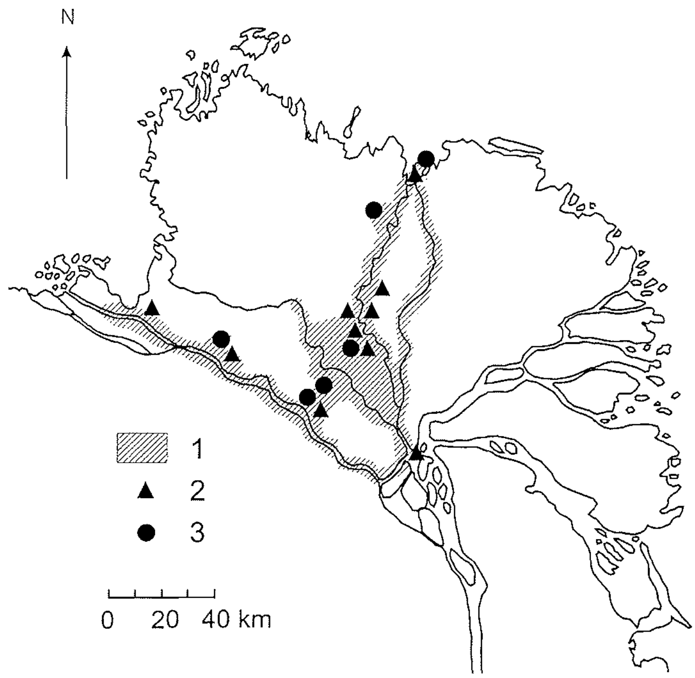

Fig. 2: Location map of the field geological-geomorphological investigations during the expeditions "LENA 98", "LENA 99" and "LENA 2000". (1) investigation area; (2) Holocene sections studied in detail; (3) lake sediment cores.

Abb. 2: Lagekarte der geologisch-geomorphologischen Untersuchungen während der Expeditionen "LENA 98", "LENA 99" und "LENA 2000". (1) Untersuchungsgebiet; (2) detailliert untersuchte holozäne Sequenzen; (3) Seesedimentbohrungen.

branches and in small branches based on the traverse geological-geomorphologic observations, the main terrace levels of the Lena delta were revealed and traced, shore outcrops of the branches and lakes were investigated with sampling for different analysis (including radiocarbon and AMS-dating) and bottom testing of lakes was performed (PAVLOVA & DOROZHKINA 1999, 2000, in press).

Laboratory studies

A large volume of published data on geology, geomorphologic structure, history of development of the Lena Delta in the Holocene and hydrological regime of the Lena mouth area were analyzed. The authors also used their own geological-geomorphologic data obtained in the course of the field surveys.

During the laboratory data processing, an analysis of topographic maps of different scale and aerial photographs of different years was performed. Based on these materials and using published data and results of the authors' own field observations, the geomorphologic maps at the scale of 1:200,000 were prepared for the key Lena Delta areas (PAVLOVA et al. 1999, PAVLOVA & DOROZHKINA 2000a).

Radiocarbon datings were carried out at the Laboratory of Geochronology of the Research Institute of Geography of St. Petersburg State University.

RESULTS AND DISCUSSION

Geological-geomorphologic characteristics of the Holocene alluvial relief complex of the Lena mouth area

A complex of current channel forms and the low floodplain actively form at the present stage and have a wide development by area within the Lena River delta (Fig. 1). KOROTAYEV (1984, 1991) and KOROTAYEV et al. (1990) referred to the low floodplain level within the delta, a young forming floodplain with heights of up to 3 m, which is mainly developed along the northern, north-eastern and eastern delta coasts as a 15-30 km wide band. The age of formation of the young floodplain was dated within the 400 to 1000 year interval. AGAPITOV (1962) and GRIGORIEV (1988, 1993) include to the low floodplain the segments with the heights of 1-3 m. Before this, a number of investigators (GUSEV 1953, 1959, 1961, LOMACHENKOV 1971) determined the low floodplain height as 6 m combining the low and high floodplains into the first above-the floodplain terrace of the Lena delta.

KOROTAYEV (1984, 1991) and KOROTAYEV et al. (1990) include the alluvial long-shore ridges, isles, spits and shoals to a complex of present channel features in the delta. The height of the present channel features in their data changes from the delta head towards its mouth from 4 to 1 m. The age of the features is determined as the last 100 years (KOROTAYEV et al. 1990, KOROTAYEV 1991).

A complex of current channel features is represented by channel bars, near-channel shoals and islets composed of alluvial wave-like-laminated sands with their surface being practically devoid of vegetation. In the areas of large scrolls near the convex shores of the branches, wide near-channel shoals, alluvial long-shore ridges and spits form. In the channel line of the branches, islets form, which can transform to the near-channel shoals with the inflow of sand material and channel migration.

The formation of the complex of current channel forms actively occurs during the flood period and its drop as a result of accumulating sand material of the channel and the near-channel alluvial facies. These deposits present obliquely- and sub-horizontally laminated fine-and close-grained sands of polymict composition. The deposits are characterized by a massive cryogenic texture and a low ice content not greater than several percent. In drained places in the coastal band, silty-clayey deposits are sometimes observed whose thickness comprises the first centimeters. Freezing of sediments of the near-channel alluvium facies occurs syngenetically with the formation of some frost clefts at the surface of near-channel shoals and central parts of the alluvial islets. The seasonal melting depth in sandy deposits of the near-channel alluvium facies comprises 0.55-0.7 m, on average (DANILOVA 1966). Relatively deep seasonal melting and a predominantly sandy composition of sediments ensures good surface drainage of the near-channel shoals and as a result a low volumetric ice content of deposits (ROSENBAUM 1983).

During the low-water period, the islets and near-channel shoals dry up. At this time, eolian processes actively occur at their surface with the formation of eolian relief features (sand ripples, hillocky sands and barkhans).

The low floodplain is traced in segments of a different width along the delta branches. The low floodplain deposits are represented by the floodplain alluvium facies: undulated-, horizontally laminated fine-grained sands of polymict composition and sandy-silty-clayey strata of alternation with plant detritus and autochthonous plant macro-remains. Active accumulative processes forming the strata of alternating sands and silty-clayey deposits with plant macro-remains occur at the time of the flood peak drop and wind surges at the periodic flooding of the low floodplain segments covered with vegetation (*Carex aquatilis, Eriophorum polystachion, E. vaginatum*). With distance from the water stream deep into the floodplain, the conditions of active accumulation of sand material are replaced by the conditions of swamping and peat accumulation. The deposits of the floodplain alluvium facies freeze syngenetically with the formation of frost clefts and ice veins of up to 1 m. Within the internal most remote low floodplain areas, a polygonal-ridge relief forms with predominantly quadrangular-shaped polygons. The low floodplain sediments are characterized by massive, thin lenticular and schlieren cryogenic textures. The volumetric ice content of the low floodplain increases to 30-50 %.

Mort lakes are widespread within the low floodplain being characterized by an elongated shape with a meandering coastline. The lake coefficient of the low floodplain comprises to 37 %.

At the seaside boundary with a subaerial delta, active formation of current delta features of different genetic types occurs. Extensive regional bay deltas form at the exit to the sea of Olenyoskaya and Bykovskaya branches. The estuary-delta (adopted from MIKHAILOV 1998) mouth segments of these branches are confined to the structurally governed depressions. Their geomorphologic boundaries are defined in the former case by the northern slopes of the Chekanovksy Range and the southern slopes of edoma, relics of the third erosion above-the floodplain terrace (Ebe-Basyn-Sis and Kyuryuel-yakh-Sis Islands) and in the latter case, by the northern slopes of the Primorsky Range and the southern edoma slope - Sobo-Sise-Island. The hydrographic network of the mouth segments of Olenyokskaya and Bykovskaya branches is complicated. Here, numerous mouth islands and alluvial islets separated by a dense network of cross-branches area form.

The Arynskaya branch "gripped" in its downstream reach between Kyuryuelyakh-Sis Island (relic of the third erosion above-the floodplain terrace) and Turakh-Sis Island (relic of the second erosion above-the floodplain terrace) forms a small estuary area at its exit to the sea (adopted from MIKHAILOV 1998) with the left- and right-hand mouth spits (Tumul-Kumaga sands and Cape Cherkannakh-Tumsa) and a mouth bar in the mouth bay.

At the northeastern and eastern external margin of the Lena mouth area between the mouths of the Bolshaya Tumatskaya branch and the Sardakhskaya branch, the protrusion deltas formed by the hydrographic network and geomorphologic structure are quite clearly subdivided into two parts (KOROTAYEV et al. 1990). Thus, at the marine margin from the Bolshaya Tumatskaya branch to the mouth of the Barchakh-Uesya branch, a multi-arm detrital cone forms on the shallow water seaside as a leveled rounded protrusion delta. On the Trofimovsky-Sardakhsky segment, a strongly dissected lobate protrusion delta is formed. Here within the mouth seaside, mouth bars protruding far to the sea develop in the continuation of the main branches.

In general, along the external margin of the Lena River delta, accumulation of the coastal-delta and coastal-marine deposits occurs, whose formation is governed by active interaction of river and marine factors with the leading role of the latter. Along the marine delta margin in the zone of tidal and surge phenomena, water-saturated, indistinctly laminated fine- and close-grained silty sands of the facies of beaches, tidal marshes, sand gentle obliquely laminated deposits of the facies of shore ridges form. At the mouth seaside as a result of active interaction of river and sea waters, the facies of mouth bars represented by silts and sands of different dimensionality are formed (MIKHAILOV et al. 1986).

The low floodplain and complex of current channel features height within the delta decreases from the delta head to its external margin. According to our data, the low floodplain is the highest in the near-head delta area. Here it is represented by extensive sandy islands and near-channel shoals 8-9 m high and 5-8 km wide (Sobol' sands of Taba-Bastakh-Belkee Island).

The low floodplain width along the Bykovskaya branch comprises 2-4 km at a height of 8 m at its beginning (left shore, Borogon-Kumaga sands) and 3-7 km at a height of 2 m in its middle current (Byrdakhtakh-Aryta Island). The low floodplain height decreases downstream up to 1 m at a width of up to 2-6.5 km (Chengya-Aryta Island, Taimylyr-Aryta Island). The width of mouth islets reaches 10 km at a height of 1 m.

The hydrographic network of the Trofimovskaya branch is extremely complicated. Extensive sand shoals (Yuryuge-Kumaga sands, Borogon-Kumaga sands) 5-8 m high and 3-10 km wide are developed along the left and right shores at the beginning of the Bolshaya Trofimovskaya branch. At the place of branching of the Bolshaya Trofimovskaya and Sardakhskaya branches, the low floodplain is represented by the narrow segments along the branches up to 200 m wide and sand islands with a width of up to 3 km and a height of 3-5 m. In the mouth area of the Trofimovskaya branch, the low floodplain is represented by a complex of extensive lowland islands and mouth islets 2-3.5 m high.

The upper segment of the Bolshaya Tumatskaya branch is also characterized by extensive sand shoals up to 5 km wide (Matvey-Aryta Island - Kuolay-Kumaga sands) with the height marks of the low floodplain of 7-8 m. The width of the low floodplain segments decreases downstream ranging from the first tens of meters in some places to 1.5 km. The low floodplain height also decreases to 4 m in the middle current and 1-1.5 m at the branch exiting to the sea. The marsh surface within the northern part of Sagastyr Island has a height of up to 1-1.5 m extending in a band up to 1.5-3 km wide.

Along the Malaya Tumatskaya branch, the low floodplain is represented by segments with a width between the first meters to 1-1.5 km, rarely up to 2 km (Chopporoy-Kumaga sands, Khoigulakh-Kumaga sands, Chutkuo-Kumaga sands). The low floodplain height decreases downstream from 4 to 1 m. Small islets are observed.

The Olenyokskaya branch is characterized by the development of extended segments of sand shoals along the entire branch whose width comprises 1.5-4 km (Butukan-Kumaga sands – Kuogastakh-Aryta Island, Belkey-Aryta Island, Diring-Ayan-Belkee Island). Large islets (Keltegey-Belkey Island) are formed nearly everywhere along the Olenyokskaya branch, which are joined to the branch shore by the input of sand material and channel migration transforming to the near-channel shoals (Kuogastakh-Kumaga sands). The low floodplain height downstream the branch decreases from 8 m in the upper portion to 1.5-2 m in the mouth region.

Along the small branches, the low floodplain height decreases from 6-4 m in the central part to 1-1.5 m towards the delta periphery with the width changing from the first meters to 0.5 km.

A complex of channel forms and the low floodplain of the Lena delta actively forming at the present time as a result of interaction of river and marine relief-forming factors have a current age. For the low floodplain, only one date is available for the deposits of Zayachiy Island, Olenyokskaya branch that has revealed the age of 667 ±250 yr BP (MGU-809) (KOROTAYEV 1984). The analysis of one of the dated sections of deposits comprising the high floodplain, has allowed us to determine the time of the beginning of formation of the current low floodplain of the Lena River as after 1300 yr BP.

The high floodplain (Fig.1) is developed everywhere throughout the entire length of the branches presenting a water-flooded surface during the flood period only in rare individual years. The different investigators determine the absolute marks of the high floodplain level and the time of its formation differently (Tab. 1).

The high floodplain along the Olenyokskaya and Malaya Tumatskaya branches is represented by segments of different width (of up to 2.5 km) jointed to the relics of the first above-the floodplain terrace. The high floodplain along the Arynskaya, Bolshaya Tumatskaya, Trofimovskaya and Bykovskaya branches is represented by a complex of large delta islands.

The height of the high floodplain surface decreases from the delta apex to its external margin. Whereas in the vicinity of Stolb Island, the high floodplain has 11 m marks, in the central

Author	total high floodplain height (m)	high floodplain height at delta head (m)	high floodplain height in marginal delta area (m)	high floodplain age (years)
GUSEV (1961)	8			
AGAPITOV (1962)		5.5	2	
GALABALA (1987)		6-7	1.5-2.5	
GRIGORIEV (1988)	3-6			
GRIGORIEV (1993)		4-7	1-3	Q^2_4
KOROTAYEV et al. (1990)	3-5			2000-3000
KOROTAYEV (1991)	3-5			1000-3000

Tab. 1: Absolute height of the high floodplain according to different authors.

Tab. 1: Angaben unterschiedlicher Autoren zur absoluten Höhe der oberen "floodplain".

delta sector along the Malaya and Bolshaya Tumatskaya branches and small delta branches, its surface height comprises only 6-8.5 m decreasing in the marginal delta area to 3-3.5 m. The high floodplain along the Olenyokskaya branch decreases from 9-10 m in the upper reach (for example, Samoilovsky Island, 9 m) to 5-6 m in the middle reach and to 3 m in the mouth area of the branch. The height of the high floodplain along the Trofimovskaya and Bykovskaya branches decreases from 10-11 m at the delta head to 4-5 m within the mouth area.

The high floodplain surface is characterized by a wide development of a polygonal and polygonal-ridge micro-relief with quadrangular-shaped polygons that reach 10-11 m in diameter. The widespread mort and thermokarst lakes are typical of the high floodplain. The mort lakes have an elongated shape with a meandering coastline reaching 1 km in length. The thermokarst lakes that formed from melting of ice-saturated deposits and ice veins, are characterized by round contours in the plan. AMS-dating of the lower portion of lacustrine deposits of the Ugyus-Dzhiye-Kyuele thermokarst lake located on the high floodplain in the central delta sector comprised 890 ±25 yr BP (PAVLOVA et al. 1999). The high floodplain lake coefficient is 12.5-17.2 %.

The high floodplain sediments are represented by laminated silty-sandy-peat deposits that have a high ice content (more than 50 %) with the development of ice interlayers and lenses. They are characterized by schlieren and reticulate cryogenic texture. The exposures of ice veins are observed everywhere in the high floodplain shore outcrops. The ice vein width reaches 2.5 m with a visible vertical thickness of up to 4 m. The spacing between the veins is 5-8 m. The seasonal melting depth of deposits of the high floodplain comprises 0.18-0.30 m (DANILOVA 1966, PAVLOVA & DOROZHKINA 1999).

The study of the high floodplain section in the shore scarp with an 8.5 m absolute height of the Dzheppiries-Tyubelege branch earlier (PAVLOVA & DOROZHKINA 1999), this section was erroneously referred to the level of the first-above-the floodplain terrace, due to the absence of radiocarbon dating and insufficient knowledge) and radiocarbon dating (PAVLOVA et al. 1999) allow a reconstrution of the conditions forming the alluvial deposits of this segment in the Late Holocene.

During the period preceding 2690 ±100 yr BP (LU-4193) (PAVLOVA et al. 1999), this segment presented a mort water body that had separated from the main branch channel. At this time interval, the material was deposited here under the calm environment conditions, i.e. the formation of the mort alluvium facies occurred, which was predominantly represented by silt with plant macro-remains. After 2690 ±100 yr BP, this area presented a low floodplain where under the annual flooding conditions, the floodplain alluvium facies formed represented by sedge lowland peat with silt interlayers, silt-peat and silt-sand-peat interbedding strata. During the period preceding 1320 ±80 yr BP (LU-4199) (PAVLOVA et al. 1999), a mort water body existed here again whose deposits reflect the stages of a gradual overgrowing of the water body. The lower portion of deposits is represented by silt with single plant macro-remains, which is replaced above by the peat-silty interbedding strata. After 1320 ±80 yr BP, this area entered finally the stage of the high floodplain development, which is only episodically flooded by river water. The formation of hypnum (*Drepanocladus, Calliergon, Tomenthipnum, Mnium, Scorpidium scorpioides, Thuidium, Aulacomnium*) and herbaceous-hypnum (with *Carex, Equisetum, Eriophorum)* silty peat occurs. Thus, the formation of the high floodplain deposits occurred in a complicated variable dynamic situation starting during the period earlier than 2690 ±100 yr BP. The dating of 1320 ±80 yr BP of the foot of the hypnum and herbaceous-hypnum peat from the upper section portion indicating the transfer of this delta portion to the high floodplain development stage allows a conclusion that after this age, the formation of the current low floodplain began here.

Datings of deposits comprising the high floodplain of the Lena Delta are few. At present, the following radiocarbon ages from the high floodplain deposits are available (Tab. 2). The radiocarbon dating of the high floodplain deposits using the authors' 1999 field data revealed the following age: Olenyokskaya branch 2850 ±200 yr BP (LU-4414), Arynskaya branch 3930 ±90 yr BP (LU-4413) (PAVLOVA & DOROZHKINA 2000). The analysis of the available radiocarbon dates shows that the formation of the deposits comprising the high floodplain began after 4000 yr BP, i.e. from the end of the Middle-Late Holocene.

The high floodplain formation during this time interval oc-

Site	Dating		Reference
Samoilovsky Island	2140±110	(IORAN-4101)	KUPTSOV & LISITSIN 1996
	3700±260	(IORAN-4167)	KUPTSOV & LISITSIN 1996
Sardakh-Aryta Island, Sardakhskaya branch	3250±119	(IM-871)	GRIGORIEV 1993
Right shore of Olenyokskya branch (Bulukurskaya branch mouth)	3480±500	(MGU-862)	KOROTAYEV 1984
Gagary Island, Olenyokskaya branch	4200±250	(MGU-808)	KOROTAYEV 1984
Lagutin Island, Bykovskaya branch	1400±100	(MGU-773)	KOROTAYEV 1984
	2530±200	(MGU-861)	KOROTAYEV 1984
Khardang-Sise Isl., Olenyokskaya branch	2850±200	(LU-4414)	PAVLOVA & DOROZHKINA 2000
Buor-Syr-Aryta Island, Arynskaya branch	3930 ±90	(LU-4413)	PAVLOVA & DOROZHKINA 2000

Tab. 2: Radiocarbon dates of the high floodplain deposits from published data.

Tab. 2: Publizierte ^{14}C-Datierungen des oberen "floodplain".

curred at a relative sea level close to the current one (ARE 1982) or higher by not more than 1-3 m (KAPLIN & SELIVANOV 1999). Data of current geochemical studies confirm the absence of a significant sea influence on the formation of the delta deposits in the Late Holocene (SCHWAMBORN et al. 2000).

The first above-the floodplain terrace (Fig.1) is spread in the southern delta head sector, in the southwestern delta sector along the Olenyokskaya branch, and in local segments along the submeridional Malaya and Bolshaya Tumatskaya branches in the central and northern delta sectors. The first above-the floodplain terrace is not practically spread in the northeastern and eastern delta sectors.

The first above-the floodplain terrace presents the ground surface areas comprised of alluvial deposits that are no longer under the river influence and are not flooded even during the high floods. According to data of GRIGORIEV (1993), the height of the first above-the floodplain terrace comprises 8-12 m in the delta head decreasing to 4-5 m in the margin area. The dating of a sample from the middle horizons of deposits of the first above-the floodplain terrace more than 8 m high (Bootulu-Sise Island) revealed the age of 4090 ±180 yr BP (IM-833) (GRIGORIEV 1993). GALABALA (1987) determines the level of the first above-the floodplain terrace as 8-12 m in the delta head and 3.5-4 m in the maritime sector. In the data of Galabala, the absolute age of sediments of the first above-the floodplain terrace does not exceed 8000-10000 years.

A polygonal and polygonal-ridge microrelief is developed at the flat hillocky surface of the first above-the floodplain terrace. The polygons often have a regular rectangular shape and a diameter of up to 12-15 m. The depth of the cracks between the polygons reaches 1.5-1.8 m. The central depressed polygon parts are swampy being occupied by small lakes. Bulgunyakhi whose height are up to 30 m are confined to the surface depressions of the first-above-the floodplain terrace. The terrace surface is characterized predominantly by thermokarst lakes of a rounded shape with smooth coastline contours and to a less extent by mort lakes. The lake coefficient of the first above-the floodplain terrace is 7.5-15.6 %.

The first above-the floodplain terrace in our data has a height of 13-14 m in the southern delta head area decreasing to the external delta margin. Thus, the height of the first above-the floodplain terrace decreases along the Olenyokskaya branch from 13.2 m on Samoilovsky Island to 12.5 m at the southwestern tip of Kurungnakh-Sise, to 11.5 m in the southern area of Byrrakan-Aryta Island and to 8-9 m in the vicinity of Nagym settlement. The height of the first above-the floodplain terrace along the Malaya and Bolshaya Tumatskaya branches decreases from 9.5-11 m in their upper reach to 3.5-4 m at the northern external delta margin (Skryabin-Aryta, Sagastyr Island).

In the central and northern delta sectors, one observes local linearly elongated predominantly northward and northeastward near-channel ridges 8-9 m high both along the large branches (Malaya and Bolshaya Tumatskaya branches) and currently small shallow water branches. They are comprised of fine- and medium-grained oblique- and wave-like laminated sands whose lamination is governed by alternating thin interlayers of silty fraction and sand interlayers.

The deposits of the first above-the floodplain terrace are similar by composition to the high floodplain sediments being represented by fine-, close-grained sands, silty-sandy peat deposits and peat. The permafrost deposits of the first above-the floodplain terrace are characterized by massive, lenticular and schlieren cryogenic textures. Ice veins are developed in the deposits. In the shore outcrops of the first above-the floodplain terrace, the ice veins are exposed. The vein width in the upper portion is 1.5-2.5 m with a visible vertical thickness of up to 3-6 m at the spacing between some veins of up to 11-13 m. The ice veins are often overlapped by laminated peat-silty deposits.

Dating of the alluvial deposits comprising the first above-the floodplain terrace developed along the Olenyokskaya branch shows the age of 5100 ±140 yr BP (LU-4411), 6530 ±160 yr BP (LU-4410) and 6870 ±230 yr BP (LU-4409) (PAVLOVA & DOROZHKINA in press). For the deposits of the first above-the floodplain terrace in the central delta area (Malaya Tumatskaya branch), the date of 8570 ±160 yr BP (LU-4191) was obtained (PAVLOVA & DOROZHKINA 2000a). Thus, the formation of alluvial deposits of the first-above-the floodplain terrace began as a minimum 8.5 kyr BP, i.e. in the Early Holocene rather than 4.5 kyr BP according to KOROTAYEV (1984, 1991). The formation of the first-above-the floodplain terrace occurred at the background of the second post-glacial transgression stage (ROMANOVSKII et al. 1997) that began 8-7 kyr BP being characterized by a slow rise of the global ocean level and climate warming.

Relation of relief formation and sedimentation to the hydrological regime

The hydrological regime plays a decisive role in the relief formation and sedimentation in the Lena mouth area. A complex of current channel forms, the low floodplain and the high floodplain actively form at the present stage under the influence of the water content of the Lena River (water runoff at the delta head), water runoff and sediment load distribution by the delta arms, water runoff and sediment load transformation along the length of the delta arms, marine factors.

The influence of each of the aforementioned factors is different in different parts of the Lena Delta. The formation and development of the current channel forms and floodplain levels within the delta apex and interior is completely determined by the water regime of the Lena Delta in its near-delta area. Within the external delta margin, the marine factors produce a significant influence on the relief formation in the mouths of the branches.

On average for a year, between 416-632 km^3 of water and 16.6-25.2 million tons of suspended sediments are discharged to the delta head (KOROTAYEV 1991). The main division of the water flow occurs in the vicinity of Stolb Island (Fig. 3). The observations of the water runoff distribution by the main delta branches over the period 1977-1998 revealed that on average for a year, the maximum runoff to the Laptev Sea is made by the Trofimovskaya (61.2 %) and Bykovskaya (25.5 %) branches, and the minimum runoff is made by the Olenyoks-

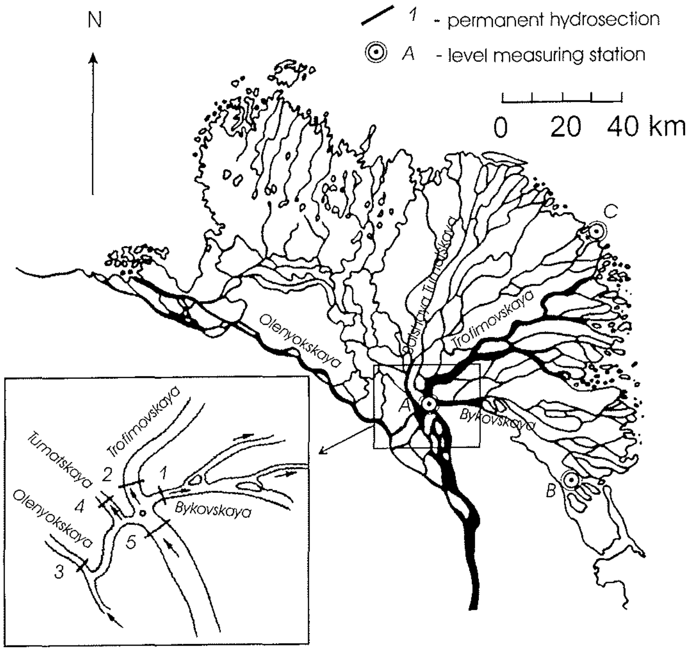

Fig. 3: Location of the hydrometric sections in the Lena Delta. Permanent hydrosections (by IVANOV & PISKUN 1995, 1999): (1) Bykovskaya branch; (2) Trofimovskaya branch; (3) Olenyokskaya branch; (4) Tumatskaya branch; (5) main Lena River. Gauging stations: (A) Stolb Island (Bykovskaya branch); (B) p/st. Maysheva (Ispolatova branch); (C) p/st. Sagyllakh-Ary (Antipinskaya branch).

Abb. 3: Lagekarte der hydrologischen Transekte im Lena-Delta. Permanente hydrologische Schnitte (nach IVANOV & PISKUN 1995, 1999): (1) Bykovskaya-Kanal; (2) Trofimovskaya-Kanal; (3) Olenyokskaya-Kanal; (4) Tumatskaya-Kanal; (5) Hauptstrom der Lena . Pegelmessstationen: (A) Insel Stolb (Bykovskaya-Kanal); (B) p/st. Maysheva (Ispolatova-Kanal); (C) p/st. Sagyllakh-Ary (Antipinskaya-Kanal).

kaya (6.8 %) and Tumatskaya (25.5 %) branches (Fig. 4). In general, the distribution of the runoff of suspended sediments by the delta arms repeats the water runoff distribution. (Fig. 4) (ANTONOV 1960, IVANOV 1964, IVANOV et al. 1983, IVANOV & PISKUN 1995, 1999, STATE WATER CADASTRE 1982-2000). The greatest annual runoff occurs during the ice-free period (June-September) with its maximum portion falling on the flood period.

The flood period in the Lena mouth area lasts for 70-80 days, on average (STATE WATER CADASTRE 1991). This time is a period of the most dynamic changes in the hydrological situation, sedimentation conditions and relief formation in the Lena delta.

The ice jams often forming at the initial flood stage in the Lena lower reaches present a short-term but powerful factor influencing both the distribution and redistribution of the water runoff and the heat sink at this time and sedimentation and relief formation. The process of jam formation in the near-apex and delta zones of the Lena mouth has a complicated character. The occurrence of jams in the Lena Delta branches is determined by the export of Lena ice from the area of Kyusyur - Tit-Ary Island, rather than by the ice breakup in the branches themselves (KOMOV 1968).

Powerful jams occurring near the delta apex in the main Lena channel from Sobol sands to the point located in 7-8 km upstream Stolb Island, make the enormous river ice masses in the Stolb Island area move in a continuous flow avoiding the main channel along parallel branches (Taba-Bastyakh-Tebyulege et al.). They fill the entire space of the left bank floodplain to the Bulukurskaya branch mouth and then the Olenekskaya branch floodplain in the vicinity of Vasily-Tabor Island (TASAKOV 1955). The development of jam phenomena directly in the delta depends on the water content of the spring flood in a specific year. If there is some drop of the flood level after the ice fills the left bank floodplain, the main mass of Lena ice deposits before it exits to the delta and jams even at the heads of the branches are unlikely. If the flood level still increases after the ice fills the left bank floodplain, a significant amount of ice is exported to the delta where strong local jams form (KOMOV 1968). The areas of jam spreading in the delta are determined by the boundary of spreading of the exported Lena ice along the branches (Fig. 5). In the Bykovskaya branch, the boundary of development of jams passes downstream Chai-Ary Island and in the Trofimovskaya branch, at the place where the Sardakhskaya branch separates from it. In the Olenyokskaya branch, the ice jams were regularly observed in the area of the Bulukurskaya branch flowing to it. The indications of jams at the head of the Bolshaya

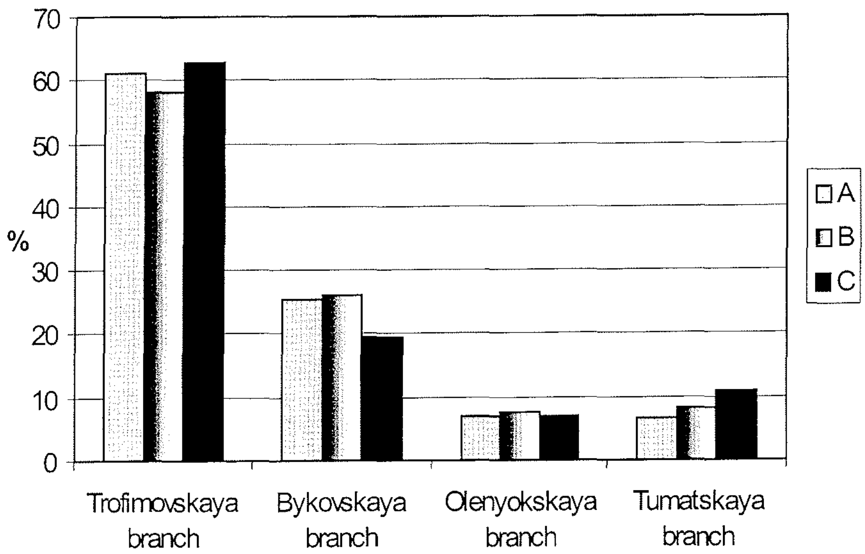

Fig. 4: Distribution of average annual water runoff (A), of water runoff during spring flood (B) and of average annual sediment discharge (C) of the main Lena Delta branches. (A) data from IVANOV & PISKUN (1995, 1999), STATE WATER CADASTRE (1992, 1995, 1997, 1999, 2000); (B) data from STATE WATER CADASTRE (1991). (C) data from IVANOV & PISKUN (1995, 1999).

Abb. 4: Verteilung des mittleren jährlichen Abflussvolumens (A). Abflussvolumen während des Frühjahrshochwassers (B) und des mittleren jährlichen Sedimenttransportes (C) in den Hauptkanälen des Lena-Deltas. (A) Daten von IVANOV & PISKUN (1995, 1999), STATE WATER CADASTRE (1992, 1995, 1997, 1999, 2000); (B) Daten von STATE WATER CADASTRE (1991). (C) Daten von IVANOV & PISKUN (1995, 1999).

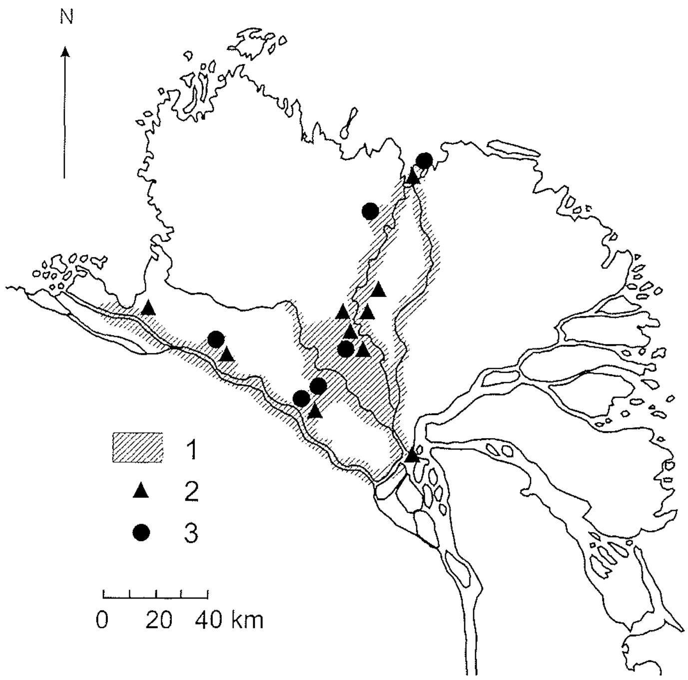

Fig. 5: Scheme of ice jam locations and of non-periodic (surge) sea level oscillations penetrating into the Lena delta (data from TASAKOV 1955, FEDOROV 1958, KOMOV 1968, IVANOV 1970 and this study). (1) ice jam locations; (2) boundary of Lena ice deposits; (3) fixed distance of non-periodic (surge) sea penetrations; (4) area of the delta which is exposed to the influence of surge phenomena.

Abb. 5: Position von Eisdämmen und marinen Überflutungen durch nicht-periodische Meeresspiegelschwankungen (Daten von TASAKOV 1955, FEDOROV 1958, KOMOV 1968, IVANOV 1970 und diese Arbeit). (1) Positionen von Eisdämmen; (2) Grenze von Lena-Eis-Ablagerungen; (3) nachgewiesene Grenze von nicht-periodischen Meeresvorstössen; (4) Fläche des Delta, die marinen Überflutungen ausgesetzt ist.

Tumatskaya branch were noted by TASAKOV (1955) and ANTONOV (1963).

Due to the local ice jams, the water level rises and a significant quantity of ice is scattered over the entire delta area, sand islands, alluvial isles, sandy shoals and in the low floodplain creating large multi-level ice piles in many places that present additional sources of water during melting (TASAKOV 1955, ANTONOV 1960, 1963). In some years, second-year river ice forms on the low delta islands and along the shores of the branches when the deposited large river ice concentrations do not have time to melt during the short Arctic summer remaining for the next year (TASAKOV 1955, ANTONOV 1960, KOMOV 1968). Thus, the main mass of Lena ice remains in the floodplain, on the islands and near-channel delta shoals serving as vast "ice settling tanks" (KOMOV 1968), where in the process of melting, the accumulation of material transferred by the ice occurs. Lena River ice does not practically reach the Laptev Sea (ANTONOV 1960, KOMOV 1968).

The local jams in the delta influence the runoff redistribution by the branches. The jams in the Olenyokskaya branch cause the increased runoff to the central and eastern parts of the delta, i.e. to the Bolshaya Tumatskaya, Malaya Tumatskaya, Trofimovskaya, Sardakhskaya and Bykovskaya branches. The export of a large quantity of Lena ice and the formation of jams in the Trofimovskaya and Bykovskaya branches causes temporary runoff redistribution directly between these branches. Due to the jam formation at the head of the Trofimovskaya branch, the discharge to the Bykovskaya branch increases and correspondingly, its breakup intensity also increases. At this time, the decay of the ice cover in the Tumatskaya and Trofimovskaya branches becomes slower (KOMOV 1968).

The spring ice drift influences significantly the formation of the delta relief (TASAKOV 1955). During the spring flood when ice is detached from the shoals at their flooding with water, loose soil frozen into the ice is taken away with ice. Ice has a scouring effect on the surface of shoals. Ice transports large blocks of peat deposits that have collapsed to the foot of precipitous shores during the preceding summer or in winter. As a result of the flood water rise covering vast delta areas, they are exported by ice during the ice drift to the lower floodplain and sandy shoals where they remain as peculiar "detached masses". Similar blocks can be observed in different delta zones. The concentrations of "detached" peat blocks are especially numerous on low islands of the delta apex area. The energy of the flood flow there is so great especially during the water bursting through jams, that it is capable to transfer large blocks over hundreds of meters deep into the islands. Such concentrations were observed in the delta apex area on Borogon-Kumaga sands, Ebe-Kumaga sands (right bank of the Olenyokskaya branch), Yrbalakh-Aryta Island and Kuolpi-Kumaga sands (right bank of the Bolshaya Tumatskaya branch). However, some blocks of peat deposits on sandy shoals were also observed at a significant distance from the delta apex on the sandy shoal of the southern tip of Dzhangylakh-Sis Island, Keltegey-Belkey Island (Olenyokskaya branch), Khoigulakh-Kumaga sands and Chutkuo-Kumaga sands (right and left banks of the Malaya Tumatskaya branch). Later, provided there is an intense influx of sandy material, the peat blocks can be partly buried forming lenses of allochthonous peat material in the deposits of the floodplain or near-channel alluvium facies. The detached peat blocks partly or completely being destroyed under the action of flowing water and other processes, become one of the sources of allochthonous detritus for alluvial sediments. During the ice drift due to ice piling up on sandy shoals and narrowing the effective cross-section of the branches, the hydrographic network of small branches changes. Some of them are covered and some are formed.

The energy of the spring ice drift decreases towards the external delta margin. Its duration in the mouth areas of the branches is small. The ice drift is of a more quiet character being restricted to the channel of the branches (BUNGE 1885, TASAKOV 1955) and not producing any significant effect on the relief formation.

During the flood within the Lena mouth area, extensive zones of the low floodplain, sandy shoals and alluvial islets are flooded where active processes of accumulation and redeposition of sediments occur. Flood waters export a vast quantity of driftwood to the delta, which is transported along the numerous delta branches and is deposited at the low and high floodplain surface either as individual trunks or as driftwood concentrations elongated along the channels of the branches marking the water level rise during the flood.

With water level rising during the flood, thermoerosion niches up to 3-5 m deep form in the precipitous shores of the high floodplain and the first above the high floodplain terrace at a height of 1.5-7 m from the branch waterline (depending on the distance from the delta apex) as a result of the flow's warming effect on deposits. Thus, on Samoilovsky Island (delta apex area), a thermoerosion niche was observed at a height of 6.5 m from the waterline. The thermoerosion niches were observed in the Malaya Tumatskaya branch in the central delta area at a height of 3.5 and 4 m from the waterline (Kyuedzhya-Aryta and Balagan-Aryta Islands). At the exit of the Malaya Tumatskaya branch to the sea, a thermoerosion niche was also observed in the shore scarp of the first terrace of Skryabin Aryta Island, however at a height of 1.7 m from the waterline. The height location of the thermoerosion niche is undeniable evidence of the annual water rise during the flood up to the marks recorded by the niche position itself. The thermoerosion niches are often filled with driftwood. The formation of thermoerosion niches contributes to a more active block destruction of the peat shores of the high floodplain and the first above the high floodplain terrace, which is most intense during the ice drift and in the summer months.

Among the main delta branches, the maximum runoff volume during the flood comprises on average, 58.2 % for the Trofimovskaya and 26 % for the Bykovskaya branches, and the minimum comprises 8.1 % for the Tumatskaya and 7.7 % for the Olenyokskaya branches (STATE WATER CADASTRE 1991) (Fig. 4).

During the flood period below the main delta branching node (Stolb Island), an intense spreading of the flood flow by the delta arms occurs (IVANOV 1961a). The plot of the annual water level oscillation in the Bykovskaya, Ispolatova and Antipinskaya branches clearly demonstrate the water level decrease from the delta head to its margin (STATE WATER CADASTRE 1987a) (Fig. 6). The low floodplain height also decreases in the same direction from the delta head to its external margin.

The low floodplain surface height is determined at present by the annual amplitude of the water level oscillations while the high floodplain surface height is controlled by the maximum water level values during the flood. (To some extent, the low and high floodplain surface height in the delta apex and its interior is controlled by ice jams). A similar tendency of the water level decrease from the apex to the external delta area appears to be also recorded at the earlier delta development stages in the Late Holocene during the period of high floodplain formation.

Thus, the river factors, namely, the water and sediment discharge to the delta, their distribution by arms, the water level rise height in the branches during the floods and the ice drift character play the main role in the relief formation of the channel forms and the low floodplain of the inner Lena Delta. They fully control the accumulation of alluvial deposits and as a result, the width and the height of the low floodplain areas and the near-channel shoals and the size of the alluvial islets in different parts of the delta. The river factors have a significant influence on the accumulation processes within the high floodplain and on the processes of destruction of the shores of the high floodplain and the first above the high floodplain terrace and more ancient terrace levels.

The external delta margin is located in the zone of impact of periodic (tidal) and non-periodic (surge) sea level (Fig. 5) oscillations whose significance in the relief formation of the delta has been insufficiently determined up to present.

The boundary of interaction of the marine and river factors in the Lena Delta moves up-or downstream of branches depending on the river runoff change by seasons and the sea level rise. During the spring flood, this boundary moves seaward, as the flood level rise due to the increased river runoff excludes completely the influence in the delta branches of tidal and surge level oscillations. The influence of marine factors becomes evident after the flood peak drop. During the winter low water period, the level oscillations in the mouths of the branches are determined by sea level oscillations (FEDOROV 1958, IVANOV 1961a).

The tidal oscillations in the delta are insignificant. The currently available data of systematic observations in the Bykovskaya branch allowed a conclusion that the distance of penetration of tidal phenomena to this branch is restricted by

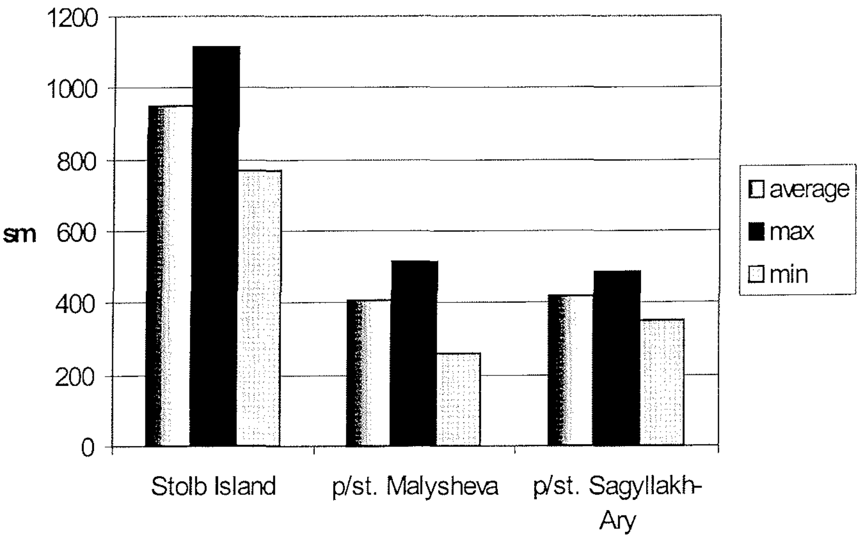

Fig. 6: Annual water level oscillations in the Bykovskaya branch (Stolb Island), Ispolatova branch (p/st. Maysheva) and Antipinskaya branch (p/st. Sagyllakh-Ary), data from STATE WATER CADASTRE 1987.

Abb. 6: Jährliche Pegelschwankungen im Bykovskaya-Kanal (Insel Stolb), Ispolatova-Kanal (p/st. Maysheva) und Antipinskaya-Kanal (p/st. Sagyllakh-Ary), Quelle: STATE WATER CADASTRE 1987.

the Dashka rift segment and comprises 25 km at the amplitude of 4-10 cm in the navigation period and 20-25 cm in the winter period. Upstream from the rift segment, the tidal phenomena are actually absent (IVANOV 1961, 1961a). Regretfully, there are no data on the distance of penetration of periodic oscillations to the other delta branches. Data on the amplitude of tidal phenomena are also practically absent. Thus, at the open coast of Olenyoksky Bay near Stannakh-Khocho settlement, the tidal amplitude comprises 70 cm decreasing to 20-30 cm in the Olenyokskaya branch mouth (FEDOROV 1958). Based on the water level observations at synoptic hours for two days in August 1999 of the sectional staff gauge in the Olenyokskaya branch mouth in 3 km downstream from Nagym settlement, the semi-diurnal tidal amplitude comprised 25-32 cm (PAVLOVA et al. 2000). Thus, in spite of extremely restricted data on the periodic water level oscillations, one can state that the tidal phenomena with an amplitude of the very first tens of centimeters do not have any significant influence on the relief formation in the mouth areas of the estuary-delta type branches such as Olenyokskaya and Bykovskaya branches. Obviously, at the open north and northeast coast of the delta, the tidal phenomena play a more significant role in the relief formation, which is manifested in the periodic drying and flooding of the coastal zone and in the formation of drained areas and marshes.

The role of non-periodic surge oscillations that penetrate the delta over a distance of up to 56 km, on average at the water level rise up to 185 cm at the marine delta margin is more pronounced (IVANOV 1970). Based on data of systematic water level observations on Malyshev Island (Bykovskaya branch, in 18 km from the mouth) in 1951-1955, the maximum amplitudes of non-periodic water level oscillations comprised +68 cm at the surge rise on 13.09.53 and -86 cm at the surge drop on 7.09.53. The minimum amplitudes comprised 1-4 cm (FEDOROV 1958). On average, the surge value here comprises ±50 cm from the navigation level (IVANOV 1961a). The range of surge penetration during the summer low water period along the Olenyokskaya branch can be up to 90 km from the sea due to the absence of rift zones in its lower reaches (FEDOROV 1958). In the Malaya Tumatskaya branch flowing northward, a surge was observed at a distance of 50 km from the mouth at the strong northerly wind resulting in the water rise by 50 cm in the branch.

In general, the relief-forming role of surge oscillations in the delta branches mainly affected the formation and reformation of the channel and near-channel relief forms (rifts, stretches, alluvial islets and near-channel shoals). At the time of the positive surge, the near-channel shoals and islets are flooded, the effective cross section of the branch channel increases and the current speed decreases and the accumulation of sediments occurs. At the time of a negative surge, an inverse process occurs compensating as a rule the sediment accumulation by the washout. The AARI expedition studies of the dynamics of sediments in the Bykovskaya branch channel in the Dashka rift area in 1955 have shown that the quantity of sediments accumulating at the time of a positive surge (around 3-5 cm/day) is comparable with the quantity of material washed out at a negative surge (c. 4 cm/day). The alternating positive and negative surges compensate sedimentation by the subsequent washout. A conclusion was made that the Dashka rift in the Bykovskaya branch is characterized by a practically stable state (FEDOROV 1958, IVANOV 1961). However, in some years with frequent and persisting storm surges, the sedimentation rate at the rift can be greater than their washout rate resulting in the water depth decrease at the rift (IVANOV 1961a).

The open coast zones are exposed to the greatest influence of non-periodic oscillations. Here, the largest amplitudes of the water level rise and drop are observed during surge phenomena, in particular near the Stannakh-Khocho settlement at a positive surge of 232 cm September 1955) and a negative surge of 164 cm (August 1954) (FEDOROV 1958). Under the effect of surge oscillations, mouth alluvial islets, spits, bars and tidal marshes actively form within the marine delta margin in the mouth areas of the branches.

Surge phenomena in the external delta margin zone, influence the formation of the hydrographic network. As a result of non-periodic water level oscillations, there is an alternating rapid and short flooding with sea and river waters of small branches drying during the low water period where the deposition of alluvial-delta sediments occurs in the course of transport of sediments of river and marine origin. Thus in August 1998, we observed a rapid short-term positive surge due to the strong southwesterly wind in the drying narrow Kondratiy-Tebyulege branch located in 25 km from the delta marine margin causing the level rise in the branch by 40 cm due to the river water inflow. At the time of surges from the sea, sea water is transported to this branch.

Thus, at the current stage, the relief formation in the Lena mouth area occurs under a complicated active interaction of river and marine factors.

CONCLUSIONS

The development of the Lena River mouth relief during the Holocene occurred under the complicated paleogeographical conditions of climate warming, post-glacial sea transgression and more active recent tectonic movements (PAVLOVA & DOROZHKINA in press).

The accumulation of the alluvial deposits proper in the Lena delta began at a minimum 8.5 kyr BP, i.e. in the Early Holocene rather than 4.5 kyr BP as was previously thought.

The formation of the first above the floodplain terrace occurred during the Early-Middle Holocene under the conditions of more active recent tectonic movements and at the background of the second post-glacial transgression stage that began 8-7 kyr BP, and was characterized by a slow rise of the World Ocean level and climate warming. The main Lena River runoff at this time was to the northwest and north, which is indicated by a wide development of the first above- the floodplain terrace along the Olenyokskaya branch and fragmentary development along the Malaya and Bolshaya Tumatskaya branches.

The formation of the high floodplain refers to the end of the Middle-Late Holocene and it occurred under the conditions of tectonic development of the western and eastern Lena Delta sectors in different directions. The development of the vault-block tectonic uplift of the western sector and the subsidence of the eastern one has caused a change in the main runoff in the Lena mouth area from the northwest-north to northeast-east governing widespread development of the high and low floodplains and a complex of current channel forms in the northeast-eastern sector. The relief development in the Late Holocene occurred at a relative sea level close to or exceeding the current one by not more than 1-3 m.

At the current stage, development of the complex of current channel forms and the low and high floodplains that have an area spreading within the Lena River delta is observed. The height and the area of their development are mainly determined by the hydrological regime of the Lena mouth area. A wide development of vast areas annually flooded during the flood period in the northeastern delta sector is determined by the maximum water runoff fractions and the suspended sediment discharge to the Trofimovskaya branch. The minimum of the water runoff fraction and of the suspended sediment discharge in the Olenyokskaya and Tumatskaya branches (western delta sector) determines a restricted development of the low floodplain area along the branches. The same tendency is preserved for the high floodplain.

The low and high floodplain height has a regular decrease from the delta apex towards its external margin, which is closely related to the hydrological delta regime and is primarily determined by the intense spreading of the flood flow below the main node of the delta branching by arms.

The river factors fully control the relief formation of a complex of channel forms and the low floodplain in the Lena Delta interior zones. In addition, they produce a significant influence on the relief formation within the high floodplain and the destruction processes along the shores of the branches.

The marine factors control the relief formation within the external margin of the Lena River delta. The width of the zone of their impact comprises 25-56 km, on average (IVANOV 1970). Among the group of marine factors, the most significant are surge sea level oscillations, whose influence depending on the morphological channel structure spreads by the large arms over a distance of up to 56-90 km from the marine delta margin and influences the relief development of a complex of channel forms and the low floodplain. Tidal phenomena play a noticeable relief-forming role only within the open external northern and northeastern margin of the Lena mouth area on the protrusion delta formation segments.

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