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A new Hydromorphological Typification of the Russian Arctic River Mouths

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Abstract: This review article provides a detailed in-depth investigation of the different river mouth types in the Russian Arctic. Polar river mouths are still one of the least studied geographical objects. They have a lot of peculiar features – including features of their location and the processes of delta formation, the geological and geomorphological structure of the territory, the short period of functioning of the rivers, and the noticeable susceptibility from sea tides, storm surges and ice formations. This leads to the presence of a wide range of forms and outlines and the features of the hydrological regime of the Arctic river mouths that do not fall within one of the hydrological, morphological and genetic mouth types used by the international classification scheme due to prevalence of the small-sized objects (whereas most classification adopted for large rivers). Therefore, this article shows the adaptation of existing classifications for Arctic river mouths, which consists of five types with eleven subgroups. The new data of remote sensing and the instruments of their processing, field researches, the new maps, the open archives of the past expeditions allow this new complex classification.

Zusammenfassung: Dieser Übersichtsartikel enthält eine detaillierte Untersuchung der verschiedenen Typen von Flussmündungen in der Russischen Arktis. Flussmündungen in den Polargebieten sind nach wie vor die mit am wenigsten untersuchen geografischen Objekte. Sie zeigen eine Menge von Merkmalen und Eigenschaften – einschließlich ihrer örtlichen Lage und den Prozessen der Deltabildung, der geologischen und geomorphologischen Strukturen, der nur kurzzeitigen Aktivität der Flüsse, ihrer unterschiedlichen Größe und ihrer auffälligen Abhängigkeit von den Meeresgezeiten, Sturmfluten und spezifischen Eisbildungen. Das führt zum Auftreten einer großen Auswahl von Merkmalen, Mustern und Besonderheiten des hydrologischen Regimes der arktischen Flussmündungen, die nicht einem hydrologischen, morphologischen und genetischen Mündungstypus des international genutzten Klassifikationsschemas zugeordnet werden können – dies allein wegen ihrer geringen Größe (während die meisten Schemata für große Flüsse eingeführt worden sind).
Deshalb versucht dieser Beitrag die bestehende Klassifikation auf die Mündungen der arktischen Flüsse mit der Beschreibung von fünf Typen und elf Untertypen zu übertragen. Neue Daten der Fernerkundung und der Datenauswertung, der Feldforschung, sowie neue Karten und die Öffnung der Archive früherer Expeditionen erlauben diese komplexe Typisierung der arktischen Flussmündungen.

INTRODUCTION

In general, a mouth area consists of a mouth site and a mouth coastal area (marine offshore). A mouth coastal area is a part of the coastal water area of the reception reservoir exposed to the desalting, heating and other influence of the river waters. A mouth site is the lower part of the river exposed to the influence of sea surges and tides. The river mouth may have a delta or be without a delta. The largest river mouths are belonging to the large and the greatest Arctic rivers. The mouth areas of the Arctic rivers considerably differ from one another by size, by the morphological, hydrographic and landscape structure, by the morphological type, by the origin of separate parts of the mouths.

The major factors influencing the mouth processes and the types of river mouths can be divided into two parts: natural and anthropogenous ones. Three groups of subtypes which can be assigned to the natural factors are riverine factors (river water level, heat flux, water runoff, river ice phenomena, hydrochemical and physical properties of water, desalting, river biota); marine factors (sea water level, tidal height, sea ice regime, contraflows, wind-induced waves, intrusion of sea waters, sea biota); local physiographic factors (in particular, the features of alongshore redistribution of material and its main source). Landscape-related factors indirectly influence the water object, such as climatic, soil and geological ones. Two subtypes are regarded to be the anthropogenous factors: direct and indirect anthropogenic influence, which tends to minimum in the Arctic regions. The anthropogenous factors include harbour infrastructure with concomitant dredging of waterways, icebreaking vessels activities, pollution etc., timber drifting with further anchoring on the river mouth banks (Fig. 2) and many other local types of influence.

The main processes influencing the mouth areas in the Russian Arctic – besides the dynamic interaction of the river waters with the sea waters and the transformations of a river runoff – are alongshore currents and corresponding sediment fluxes, tidal effects and ice processes – for example, exaration, debacle and ice jams formation–, vertical movements of Earth's crust – from 0 to 9 mm/year in observed regions –, the washout and erosion of the coasts – including those caused by thermo-abrasion.

Hydrographic conditions

The Arctic Ocean differs from other oceans being the smalllest but having a significant catchment area. The relation of the catchment area to the actual area of the ocean is 1.38 – as a comparison, this indicator for the Atlantic Ocean having the largest catchment area is 0.76, for the Pacific Ocean 0.12, and for the Indian Ocean 0.26. More than 2/3 of the catchment area of the Arctic Ocean is the share of the rivers flowing in from the territory of the Russian Federation (Dobrovolsky & Zalogin 1982).

Over 1,500 continental rivers more than 10 km long, including about 110 medium-sized – with drainage basin areas from 2,000 to 50,000 km^2 – and 19 large rivers with drainage basin areas of >50,000 km^2, flow into the seas of the Arctic zone of

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Fig. 1: Geographic map of the Russian Arctic and shelf seas indicating referenced locations of rivers and settlements.

Abb. 1: Geografische Übersicht über die Russische Arktis und die angrenzenden Schelfmeere mit Lage und Kennzeichnung der zitierten Flüsse und Siedlungen.

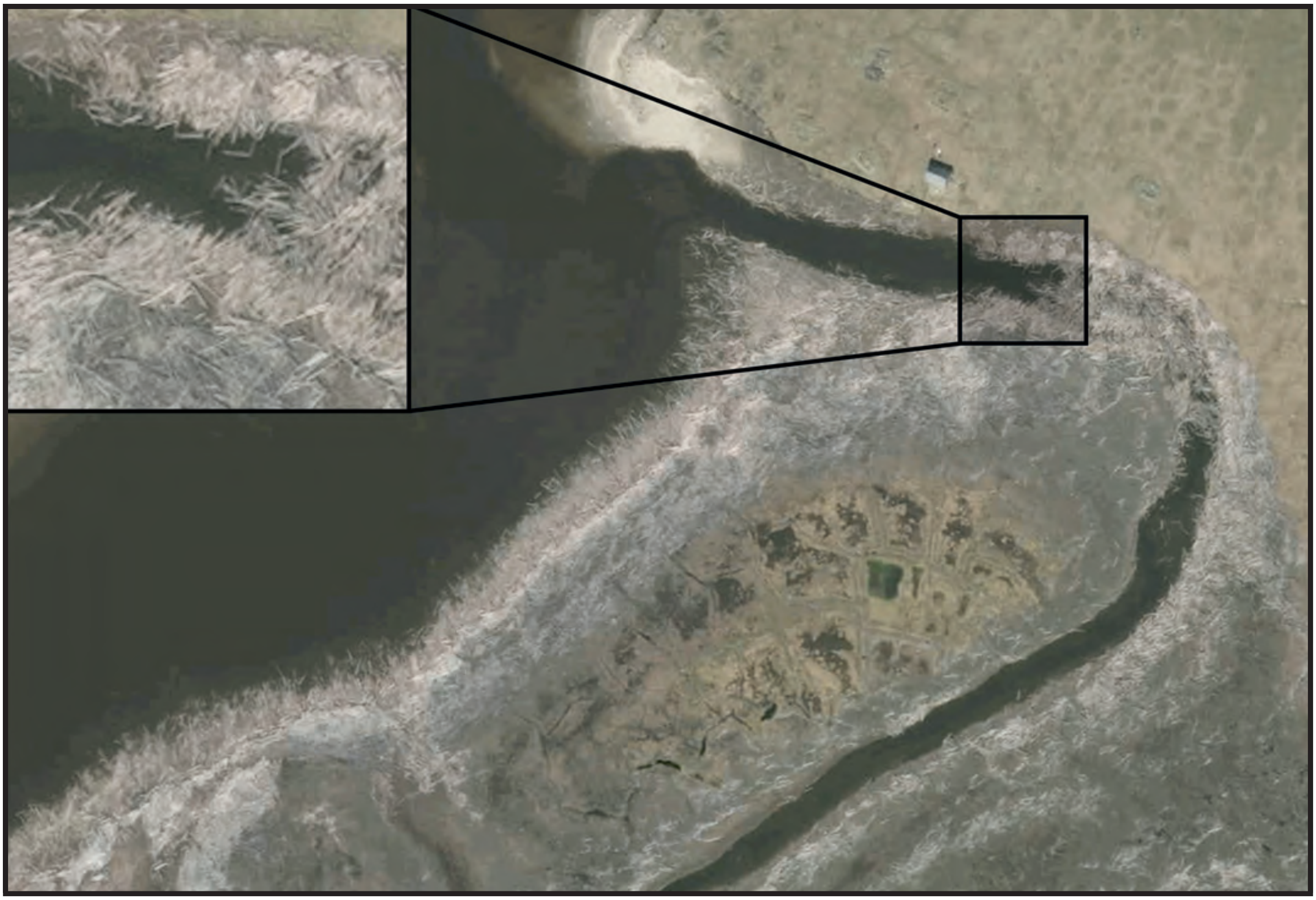

Fig. 2: Uncontrolled timber logjam on the shores of Northern Yenisei Guba (Mongocheyakha River delta) caused by heavy commercial wood drifting in past years and storm surges (<https://here.com/maps>).

Abb. 2: Unkontrollierte Holzwirtschaft im Bereich des nördlichen Yenisei (Mongocheyakha Flussdelta); durch intensive Flößerei und Sturmereignisse kann es an kritischen Stellen des Flusses zur Verstopfung kommen (<https://here.com/maps>).

Russia. About 400 more rivers flow in from the Arctic islands. A lot of rivers of the Russian Arctic are regarded as the world's largest ones, in particular, seven of them are among the fifty largest rivers of the world by their basin area (except catchments of the individual tributaries), nine of them, in particular the Yenisei, the Lena, the Ob, the Pechora, the Kolyma, the Northern Dvina, the Khatanga, the Olenyok and the Taz are among the 50 largest rivers by the average annual water discharge (Fig. 1).

The total average annual runoff volume of the rivers of the Russian Arctic is about 2,800 km^3 (Tab. 1). Besides the fresh water inflow into the Ocean, the rivers of the Arctic zone make a significant contribution to the thermal balance of the peripheral seas and also bring in considerable volumes of solid material and dissolved chemicals (Lein et al 2013). The hydrographical regime and circulation within the peripheral seas result in the considerable dependence of their regime on the runoff of the rivers (Alekseevskiy 2007). Also, there are a large number of mining enterprises in the basins of the studied rivers (including open placer works). Together with high natural turbidity values (Karaushev 1977) it leads to an increase of the solid flow of the rivers and an influx of heavy metals in the marine reception reservoirs (Alekseevskiy et al 1992).

	Length of shoreline (km) Wessel & Smith (1996)		Annual runoff volume (km^3) Alekseevskiy (2007)
	continental	insular	
Barents Sea	4,472	14,524	199 (210 total)
White Sea	4,432	2,283	205
Kara Sea	12,090	17,114	1271
Laptev Sea	8,982	9,045	726
East Siberian Sea	4,392	5,248	206
Chukchi Sea	1,571	1,392	18 (72 total)

Tab. 1: Characteristics of the Russian Arctic Seas (Wessel & Smith 1996, Alekseevskiy 2007).

Tab. 1: Grunddaten der russischen Arktischen Schelfmeere (Wessel & Smith 1996, Alekseevskiy 2007).

In the place of their influx into the seas the rivers form unique geographical objects – the mouth areas having incredibly important ecological, social and economic values for the Arctic region. The mouths of the rivers carry out a role of a marginal filter (Lisitsyn 1994) at the sites of interaction of the river and seawaters, detaining and transforming the load of the river sediments and pollutants flowing in from the river catchment. It is here that the result of large-scale hydroclimatic processes and formation of a geodrain in the basins of the Arctic rivers, the final manifestation of which are mouth processes, including the hazardous ones, is clearly visible. Many mouths of the rivers of the Arctic zone of Russia contain deltaic forms – the plains and lowlands penetrated by a network of distributaries put by alluvial, lacustrine and sea deposits. The Lena River in its mouth has created the largest delta of the country and of the whole Arctic (~30,000 km^2), which is unique in its structure and morphological type. The deltas of the Ob (~3,930 km^2), the Yenisei (~7,100 km^2), the Yana (~8,200 km^2), the Indigirka (~7,650 km^2), the Kolyma (~3,250 km^2) and the Olenyok (~700 km^2) are large deltas as well. Over 10 % of the total extent of continental coasts of the seas of the Russian Arctic are the share of the so-called deltaic coasts (Alekseevskiy 2007). The abundance of natural waters and nutrients different in structure and origin, the heating influence of river waters, the variety of waterbodies in the mouth areas and the uniqueness of location make the mouths of the rivers and especially river deltas incredibly biologically productive under conditions of a severe Arctic climate (Alekseevskiy 2007). In the mouths of the rivers there are places of spawning, feeding and migration of a lot of fish breeds, wintering, feeding and rest of migratory birds. The mouths of the rivers Niva, Northern Dvina, Pechora, Ob, Yenisei, the Lower Taymyra, Pyasina, Lena and Kolyma are included – in whole or in part – in the structure of especially protected natural territories: reserves, wildlife areas, national parks and Ramsar wetlands.

The mouth areas of the rivers are regarded as the most developed sites of the Arctic coast of the country. The geographical location, natural resources – biological, water, water transport and mineral ones – and conditions, and the historical prerequisites have determined the modern social and economic development of the Arctic mouths. But in the course of use of the natural resources of mouths of the Arctic rivers there are complex environmental and hydro-economic problems. The mouth of the Northern Dvina is among the most developed and occupied ones – including that in the country – unlike other areas of the Russian Arctic. Arkhangelsk and Severodvinsk with the total number of inhabitants of ~550 thousand people are located here; wood processing, the chemical, light and food industry, shipbuilding and ship repair, mechanical engineering, fish processing, marine and river transport have been developed. In the mouths of many other large Arctic rivers the water transport, fishery and fish processing, logging, traditional crafts and occupations of the indigenous people have been the most developed. There are water transport ways of the region across the majority of the mouths. The Arctic navigation (in the system of the Northern Sea Route), is supported and served by numerous mouth ports (Fig. 1), including such large as that in Murmansk, Kem, Belomorsk, Arkhangelsk, Naryan-Mar, Salekhard, Dudinka, Tiksi and Zelenyy Mys (Green Cape, Cherskiy).

In the deltas of the Pechora and the Taz and in the adjoining areas fields of natural gas and gas condensate have been found. Gas pipelines are laid from there to settlements and ports. Tidally influenced river mouths have very big hydropower potential that is used only by the experimental low power Kislogubskaya tidal power station. The project of a huge Mezenskaya tidal power station is completely ready (Fig. 1).

Geological control mechanisms

The Arctic coast and its shelf are a complex conglomerate of uneven-age geological structures of the North Asian continental margin and their underwater continuations in the deep basin of the Arctic Ocean (Aksenov 1987). A considerable impact on the relief was exerted by the Pleistocene glaciations that caused late and postglacial glacioisostatic raising of the territory. Only a rough estimate can be given for the vertical movements of the Earth crust in the Arctic region as the northern coasts have multidirectional tectonic movements; areas of late Pleistocene glaciers after a glacioisostatic raising (the modern melting of a glacier and thereof the reduction of its weight, Baranskaya 2015) are also located here. The raising of the Baltic Shield, Franz Josef Land and Novaya Zemlya can reach 8 mm/year, considerably exceeding the effect of the eustatic sea level. The average rates of the newest vertical movements of platform areas of the central Arctic (among which Severnaya Zemlya archipelago is) are, in general, close and weakly positive – on average, 1-2 mm/year during the Holocene. The formation of fjords and lagoons in mouth sites can be a characteristic sign of the crust raising.

The complex formation of the Arctic coasts, including the coasts of river mouth areas, provides a complex combination of the factors influencing the forms of mouth and the processes of delta formation.

To the eastern edge of the Taimyr Peninsula, within the seaside plains of Yakutia, flat and shallow steeply sloping plains of limnic and marine origin put in the form of the so-called "ice", or "yedoma" complex – aleurites and sandy loams with huge (up to 4-6 m) buried polygonal ice wedges. These complexes are widespread. Entirely on the coast of this site of the territory permafrost processes are widespread (Kaplin et al 1991). An important role in the reduction of the coasts and land area plays by thermo-abrasion (Aré 1988).

The cryogenic thickness of the sea coast is a dynamic system, which sensitively reacts to the changes of climate. The modern rate of thermo-abrasive destruction of the Russian Arctic coast vary from 0.2 for primary rocky shores (Kaplin et al 1991) to 40 to 50 m/year on the sandy and clay complexes of valley gulfs of the Kara Sea (Grigoryev & Ermakov 1984). Considerable destructions can be observed along all the perimeter of islands of the Novosibirsk archipelago where the interception of the top links of the channel network is a result of the systematic reduction of the area of islands (Sisko 1971). It has been noted by Ivanov & Yashin (1959) that the maximum speed of destruction is due to the mouth section of the rivers. In general, the average annual speed of erosion of 0.4-2.0 m/year is characteristic for the coasts of the east sector of the Arctic (Grigoryev et al 2006).

Marine control mechanisms

The tidal phenomena in the Arctic seas are generally determined by the tidal wave extending from the Atlantic Ocean. The tidal wave flows into the Laptev Sea, the East Siberian Sea and the Chukchi Sea from the north, through the Arctic basin, and flows into the Barents Sea and the Kara Sea from the west from the Norwegian Sea (Dobrovolsky & Zalogin 1982). Tides and tidal currents have the correct semidiurnal character prevail, two periods of phase inequality are definite within a month (depending on the phases of the Moon), there is one maximum (spring) and one minimum (neap tide) in each of them. Spring tides occur in 2-3 days after a new moon or a full moon, neap tides are of the same period.

The height of spring tides, which is usually accepted to judge the intensity of participation of tides in the hydrodynamics of the coastal zone by, considerably changes from place to the place. A considerable height of tides – more than 1.5 m – is noted in the North European basin, in the southern part of the Barents Sea and in the northeast part of the White Sea. The maximum is confined to the Mezen gulf where the height of spring tide reaches 10 m; further to the east the tide height quickly decreases, and it is less than 0.5 m along the most part of the extent of the Siberian coast (National Atlas 2007).

On the most part of the coasts of the Arctic Ocean the scope of storm surges is considerably higher than that of tides. An exception is the Barents Sea where storm surges generate lower than the tidal oscillations level. The largest heights of the surge, reaching 2 m and more, characterize the Laptev Sea and the East Siberian Sea. In the east part of the Laptev Sea, for example near Vankina Guba (Fig. 1), the extreme height of a surge can reach 5 to 6 m judging by the level of material thrown out by modern storms above the sea level (Popov & Sovershaev 1979). On the coasts of Svalbard, Franz Josef Land and Severnaya Zemlya archipelagos surges are much weaker due to both the relative depth of these coasts and their orientation, relative to dominating winds, adverse for the formation of large surges. Maximum storm surge height can reach 1 m along coastal areas of the Kara Sea, and in the gulfs of the Ob and the Yenisei they are close to 2 m. In the Chukchi Sea, the heights of the surge are still higher than the tidal ones, and Wrangel Island is the only place where tides and surges impacts are approximately identical (Dobrovolsky & Zalogin 1982).

The accumulative wind and wave foreshores are characteristic for the Arctic coast of Russia. They are very shallow (slopes of 0.001-0.004 ‰) and are developing under the frequent and almost regular repeatability of surge cycles and the influx of a large amount of loose fine-grained material from the coastal land. They are developing under conditions of the high amplitude of tidal phenomena and the existence of a large amount of the material flowing into the coastal zone as a result of thermos-abrasion. In the Laptev Sea and the East Siberian Sea, the formation of such elements of relief is also provided by a large amount of the material taken out by the rivers. The surge activity considerably influences the regime of separate mouth. In particular, low bedrock coasts of Khroma Bay having a complex configuration become covered with water during very strong surges, turning the bay and the surrounding territories into a large shallow sea gulf (Popov & Sovershaev 1979). Due to the fact that most of the time these low inclined surfaces develop under subaerial conditions, continuations of valleys of the small and middle rivers flowing in on this site of the coast are formed as large tidal creeks. The length of the similar tidal creeks on some rivers of the Kotelny Island and the coast of Yana Bay can reach 15 km. The detailed development mechanisms of such mouths are still poorly studied.

MATERIALS AND METHODS

Typification of mouth areas: terminology and concepts

Mouths of rivers play an important role in the formation of hydrological and geomorphological interactions between a river and a reception object. In Russian the concept "mouth" (*ust'je, устье*) means "opening" and originates from the word "lips". In Russian hydrology I.V. Samoylov was the first person who introduced the concept "mouth area of the river" (Samoylov 1952). One of the first definitions of mouth area of the river was introduced by S.S. Baydin and developed by V. N. Mikhailov: *"The mouth area of the river (the mouth of the river) is an unique geographical object covering the region of the river inflow into the reception reservoir having a specific structure, landscape and regime and which is formed as a result of mouth processes (the dynamic interaction and mixture of waters of the river and the reception reservoir, the deposition and redeposition of river and partially sea sediments), providing the formation of both an mouth debris cone, and frequently delta"* (Baydin 1971, Mikhailov 1971). Every river has its mouth; the part of the river adjoining the river inflow into the reception reservoir (waterway) can form an estuary, a delta, a coastal lake, a lagoon, etc.

Mikhailov (1998) allocates four types of the mouth:
I – simple,
II – estuarial,
III – estuarial-deltaic,
IV – deltaic.
The main typification of mouth areas of the rivers in Russian science (Tab. 2) is based on a complex of the classification attributes relating to the structure and the regime of the mouth section of the river and the mouth coastal area (Fig. 3). As for morphological features, all mouth areas are subdivided into deltaic ones and those without a delta, and mouth coastal area into open and half-closed ones.

Estuarial site	Estuarial coastal area	Estuarial area of the river
With one distributary (without a delta)	Open	I. Simple
	without a blocking bar	Ia without a blocking bar
	with a blocking bar	Ib with a blocking bar
	Half-closed	II. Estuarial
	without a blocking bar	IIa without a blocking bar
	with a blocking bar	IIb with a blocking bar
With a few or numerous distributaries (deltaic)	Half-closed	III. Estuarial and deltaic (with a bay delta)
	without a blocking bar	IIIa without a blocking bar
	with a blocking bar	IIIb – with a blocking bar

Tab. 2: Classification of estuarial areas of the rivers and their parts by morphological features (Mikhailov 1998).

Tab. 2: Klassifizierung des Mündungsbereichs von Flüssen unter Berücksichtigung ihrer morphologischen Formen, nach Mikhailov (1998).

As additional classification attributes the following terms are also used for the deltaic site:

- a quantity of distributaries;
- the degree of unevenness and protrusion of shoreline, and
- also, the intensity of protrusion or reliction of the sea edge of the delta, and for the mouth in the coastal area the prevailing character of water depth.

Mikhailov & Gorin (2012) put forward a new scheme of typification of the mouth area of the river by the existence and interaction of the delta and the estuary. According to this classification (Tab. 3), estuaries due to the specificity of their hydrological regime, morphological structure and ecological conditions, are admitted to be special geographical objects which are not assigned either to the mouth section of the river or the mouth coastal area of the reception reservoir respecttively. The river "ends" either in the delta top or in the top of the estuary.

Type of estuarial area of the river and its index	Main signs of estuarial area of the river.
I Simple (S)	Both the delta and the estuary are absent.
II Estuarial (E)	The main element of estuarial area of the river is an estuary, the delta is absent.
III Estuarial-deltaic (ED)	The main element of estuarial area of the river is an estuary, a bay delta adjoins it or is within it.
IV Deltaic-estuarial (DE)	The main element of estuarial area of the river is a protruding delta some distributaries and water-bodies of which periodically have inflow of the salted waters.
V Deltaic (D)	The main element of estuarial area of the river is a protruding delta, the estuary is absent.

Tab. 3: Hydrological and morphological typification of estuarial areas of the rivers (Mikhailov & Gorin 2012).

Tab. 3: Hydrologische und morphologische Bezeichnung der Mündungsgebiete von Flüssen (Mikhailov & Gorin 2012).

Together with the typification of mouth area of the river the mentioned authors have also introduced a separate typification of estuaries. The allocation of groups of estuaries by several interconnected properties is the basis for this typification. The next properties are considered: the morphological structure of estuaries and by their origin; the place of estuaries in the mouth area of the river; the nature of circulation of waters, etc. The following types and subtypes of estuaries are allocated (Mikhailov & Gorin 2012):

1) coastal lake estuaries, including those which are not blocked (Estuarial E or Estuarial-deltaic ED; Tab. 3) and partially blocked estuaries (E, ED);
2) channel estuaries without estuarial widening, including the lower parts of beds of the rivers (E, ED) and the lower parts of distributaries of deltas (Deltaic-estuarial DE);
3) channel estuaries with estuarial widening, including the lower parts of beds of the rivers (E) and the lower parts of distributaries of deltas (DE);
4) lagoon estuaries, actually including lagoon estuaries (E, ED, DE), lagoon and lake estuaries (E, ED) and lagoon and channel estuaries (E, ED);
5) sea estuaries, actually including sea (E, ED), fjord estuaries (E, ED) and ria estuaries (E, ED).

It should be noted that all the above-mentioned classifications and typifications of mouth areas adhere to the hydrological and morphological approach to the definition of "delta" term. According to such an approach, the place of the first division of the river bed into deltaic distributaries is considered the top of the delta. The lower boundary of the delta is along its outer edge. Only the top surface part of mouth fan and the hydrographic network formed as a result of modern processes of delta formation are considered by a river delta.

There is an essentially other approach to the classification of mouths when performing it from the point of view of the geological and geomorphological features of their formation. From the point of view of geologists and geomorphologists, mouths are regarded as relatively closed forms of shore relief with solid boundaries (Safyanov 1987). Thus, hydrological and mixing processes are a consequence of and depend on the features of the formation of a particular object, and the rate of sediments deposition in river mouths are highest among the World Ocean. The concept of the delta from this point is much wider as in that case the delta includes not only the forms of surface relief and the thickness of modern deposits, but also all the complex of the alluvial, deltaic, coastal and sea deposits accumulated within the mouth alluvial cone i.e. all the thickness of terrigenous material within the mouth alluvial cone is meant by a delta: a surface (a subaerial delta) and an underwater (a subaqueous delta, or a foreset) delta. Korotayev (2008) gave the following definition of a river delta: *"A river delta is a complex of subaerial and subaqueous deltaic bodies consisting of alluvial-deltaic and marine-coastal accumulative and erosive forms of relief, the deposits composing them and the systems of the interconnected watercourses with the*

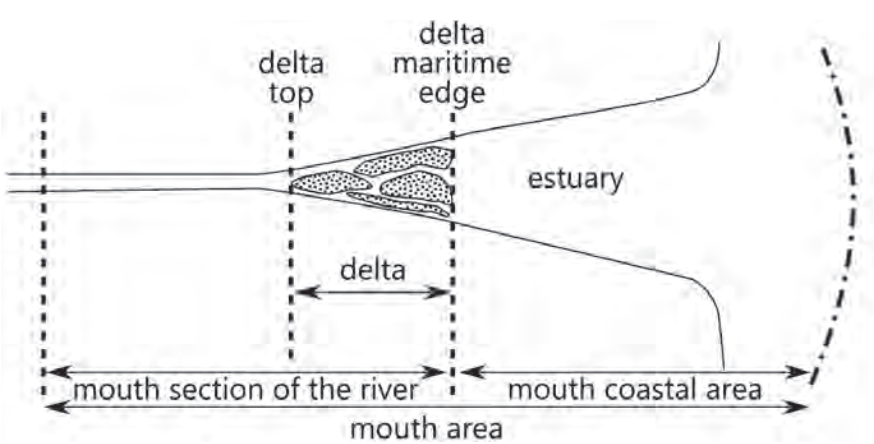

Fig. 3: Structure of the mouth area according to (Mikhailov 1998).

Abb. 3: Modellhafte Struktur einer Flussmündung nach Mikhailov (1998).

general branching junction (the delta top) formed by the river and the sea within the mouth alluvial cone for a definite historical time interval" (Tab. 4).

The morphogenetic modifications of river deltas within the group of gulfs filling are extremely different and depend on a combination of the natural factors influencing delta formation (a river runoff, wave activity, etc.). The group of filling deltas includes tidal deltas of estuaries (with a few distributaries and a primary surface delta); lobate deltas (of partial and full filling of long valley gulfs (*guba* in Russian). The second group of river deltas connected with the formation of an alluvial mouth cone on an open sea or oceanic coast, refers to protruding deltas. This small group of deltas owes its origin to the features of the geological structure of the coastal plain when the rivers crossed the mountain massif at the outflow.

International science classifications of mouths and estuaries based on water balance, geomorphology, vertical structure of salinity, hydrodynamics (Valle-Levinson 2010, de Miranda et al. 2017, etc.). The international approach to similar typifications is given in the work (Pritchard 1952). In this work estuaries can be classified according to their geomorphology as coastal plain, fjord, bar-built and tectonic. Another approach (Savenije 2012) has generalized the features of distribution of salinity and impact of tides on the mouths of middle and large rivers. When the river flows into the reception reservoir, the stream stops being limited to its bed and extends in width. According to this classification the main types of river mouths are grouped according to the main natural process influencing their formation. Groups of river mouths are allocated by the dominant factor – the influence of a river runoff, tidal influence and wave influence. At the same time the different processes in river mouths characterize their different types. For example, where the river runoff factor prevails, the delta of the river is more extended; where the wave processes prevail, the delta is bowl-shaped (i.e. the liman and lagoon forms of relief separated from the reception reservoir are formed); in the places of domination of tidal processes the mouths of the rivers are presented by estuarial (funnelled) forms with some or another stage of filling them with the deposits. Processes of accumulation or erosion of these deposits depends on the ratio between the tide height and the runoff of the river. This typification of deltas is as follows:

• River mouths with the prevalence of fluvial processes. As a rule, they have a multi-lobate shape which results from the repeating flooding of the delta with pre-flood waters and the accumulation of deposits.
• River mouths with the prevalence of wave processes. The wave erosion controls a delta form, limiting its growth and/or creating the blocking forms which provide the partial or full closure of the mouth area.
• River mouths with the prevalence of tidal processes. In these mouths' the features and the distance of penetration of a tidal wave into mouths influence both the bedrock coasts and the processes of accumulation of deposits.
• Estuaries. In this type of classification only the relief forms having a geological history of formation are regarded as estuaries (Pritchard 1952). As a mouth is a transition from the river to the sea, the form of the mouth is a consequence of geological processes, and the processes of delta formation in the top of estuary have the type and speeds depending on the modern landscape and geological conditions.
• "Gilbert deltas". This type of delta called in honour of the American geologist Grove Karl Gilbert (Bates 1953) is a special type of delta formed by coarse-grained deposits (pebble and boulders) and having a considerable slope unlike the classical flat deltas formed mainly by sandy material.
• Internal deltas. The river delta is located in a large valley and is called an inverse river delta. Sometimes the river is divided into several branches in the internal area just to return and continue its movement towards the sea. These deltas can be formed both owing to the geological reasons and to the century cycles of change of the ocean level.

After the short review of the main classifications and typifications which are available in literature, a typification of river mouths of the Russian Arctic which includes both the hydrological features of rivers – still poorly studied due to the lack of gauging stations and its poor spatial distribution, especially on the small rivers –, the geological features of formation and location of mouth areas, and a set of the wave and tidal effects considerably influencing the mouth areas of the small and middle rivers typical for the Arctic has been created. The final classification describes all the types of river mouths, which are presented on the shore of the Russian Arctic.

The morphological analysis of 89 mouth areas has been made using the Gosgistsentr topographic maps (Federal science and technology centre of geodesy, cartography and infrastructure of spatial data of Russian Federation), edited in 2001, at scales of 1:50,000 and 1:200,000, and the high spatial resolution satellite images of different date of survey which are

Main morphogenetic groups of estuarial and deltaic systems			
Filling			Protruding
estuarial-deltaic	liman and deltaic	lagoon and deltaic	deltaic
Geomorphological phase of development of estuarial and deltaic systems			
• With a few distributaries, full filling with a bar and a subdelta on an open coastal area. • With a lot of distributaries, a lobate delta of partial filling with an estuarial bar. • With one distributary, a beak-shaped delta of partial filling with an estuarial bar. • With one distributary, with an active delta front.			• With a lot of distributaries with a smooth sea edge, with an active delta front and a deep-water alluvial cone. • With a lot of distributaries, a lobate delta bordered with coastal bars. • With one distributary, a beak-shaped delta with an estuarial bar. • With one distributary, an alluvial ledge.

Tab. 4: Flowchart of typification and evolution of estuarial and deltaic systems (Korotayev 2008).

Tab. 4: Flussdiagramm der Typisierung und Entwicklung von Mündungs- und Deltasystemen nach Korotayev (2008).

freely available from various sources e.g., (KH-9, Quickbird, Geoeye, Spot, Landsat, etc.). The photographic material with geographical reference collected both from open sources in the Internet and from the participants of various expeditions have also been used.

Authors applied both hydrological and morphological approaches characterizing the features of interaction of river and sea water masses and the geomorphological approach describing the processes of formation of deltas and other specific fluvial and sea forms of relief in the coastal zone. Mixed approach was used owing to lack of data for most mouths on the river runoff, the geological structure of coast and coastal area, the bathymetry and processes of mixing.

The small areas of river catchments and lack of the data about mixing processes of sea and river waters prevent direct application of the classification suggested by Mikhailov & Gorin (2012).

RESULTS AND DISCUSSION

Typification of mouth areas and deltas of the rivers of the Russian Arctic

Owing to the mouth processes, which are multidirectional and various in their volumes, a unique hydrological regime, landscape shape and diverse habitat of each mouth area, regardless of their size, are created. The complex analysis has been made for the rivers of all of the Arctic for the first time (Tab. 5, Tab. 6). As a result of typification five types of river mouths – simple, estuarial, estuarial-deltaic, lagoon-deltaic, and deltaic – and eleven of their subtypes have been allocated (Fig.4). The highest variety of mouth forms is observed for the small rivers, the azonal factors for which can cardinally influence the type and form of mouth area.

Type of the estuarial area	Subtype	Type of the mouth and delta
1. Simple	including the mouths developing on the foreshores	Open, without a delta
2. Estuarial	2.1 Fjord, with one distributary 2.2 Estuarial, with one distributary	Half-closed, without a delta
3. Estuarial-deltaic	3.1 Fjord, with a lot of distributaries 3.2 Estuarial, with a lot of distributaries	Half-closed, with a filling type of delta (of a valley gulf / fjord)
4. Lagoon-deltaic		Closed, with a filling type of delta (an estuarial lagoon / liman)
5. Deltaic	5.1 Deltaic, with a lot of distributaries	Opened, with a protruding delta
	5.2 With a lot of distributaries and an estuarial bar on the coastal area	Opened, with a filling type of delta of estuarial lagoon
	5.3 With a lot of distributaries and an estuarial bar on the coastal area	Opened, with a filling type of delta of valley gulf

Tab. 5: Types of mouths and deltas of the rivers of the Russian Arctic.

Tab. 5: Mündungstypen und Deltatypen der Flüsse in der Russischen Arktis.

Type of the estuarial area		Number	Observed rivers (see Fig.4)
1. Simple		8	Strelna, Varzuga, Umba, Tivtey-Yaha, Venuyyeuo, Seyakha, Alazeya, Chegitun
2. Estuarial	2.1 Fjord	4	Tuloma, Kharlovka, Iokanga, Ponoy
	2.2 Estuarial	14	Kem’, Onega, Kuloy, Mezen, Oma, Pesha, Savina, Yesyayakha, Neizvestnaya, Vezdekhodnaya, Sellyakh, Sanga-Yuryakh*, Khroma*, Sundrun
3. Estuarial-deltaic		16	Varzina, Niva, Korotaikha, Ob’, Pur, Taz, Yenisei, Pyasina, Lenivaya, Taymyr River, Leningradskaya, Khatanga, Popigay, Anabar, Uele, Bolshaya Chukochya
4. Lagoon-deltaic		23	Voron’ya, Northern Dvina, Indiga, Neruta, Pechora, Kara*, Nadoyakha, Gyda, Klyuyevka, Podkamennaya, Novaya, *Balyktakh*, Omoloy, Chondon, Pegtymel, Kuekvun, Ekviatap, Amguema, Vankarem, Kem’yneyveem, Linatkhyrvuvaam, Ulyuveem*, *Mamontovaya*
5. Deltaic	5.1 Protruding delta	8	*Romantikov*, Chirakina, Yada-Yakhody-Yakha, Messoyakha, *Posadochnaya*, Olenyok, Lena, *Nadëzhnaya*
	5.2 Filling of estuarial lagoon	3	Chernaya, Yana, Indigirka
	5.3 Filling of valley gulf	13	Yuribey (Yamal Penins.), Mordyyakha, Yakhodyyakha, Nadym, Nyda, Yuribey (Gydan Penins.), Mongocheyakha, *Truba*, Bolshaya Balakhnya*, Kolyma, Rauchua, Lelyuveyem*, Chaun-Palyavaam*

Tab. 6: Distribution of types of estuarial areas in the Russian Arctic (for the large and average rivers). * the estuarial areas relating to more than one river are marked (the largest is specified). The rivers of islands are *italicized*. Transliteration of toponyms was made using operational navigation charts by US Defence mapping agency.

Tab. 6: Verteilung der Typen von Mündungsgebieten in der Russischen Arktis (nur die großen und mittelgroßen Flüsse). * markiert sind die Mündungsgebiete, die zu mehr als einem Fluss gehören (der größte ist jeweils markiert). Die isländischen Flüsse sind *kursiv* gedruckt. Die Transliteration von Toponymen folgt den Seekarten der „US Defence Mapping Agency“.

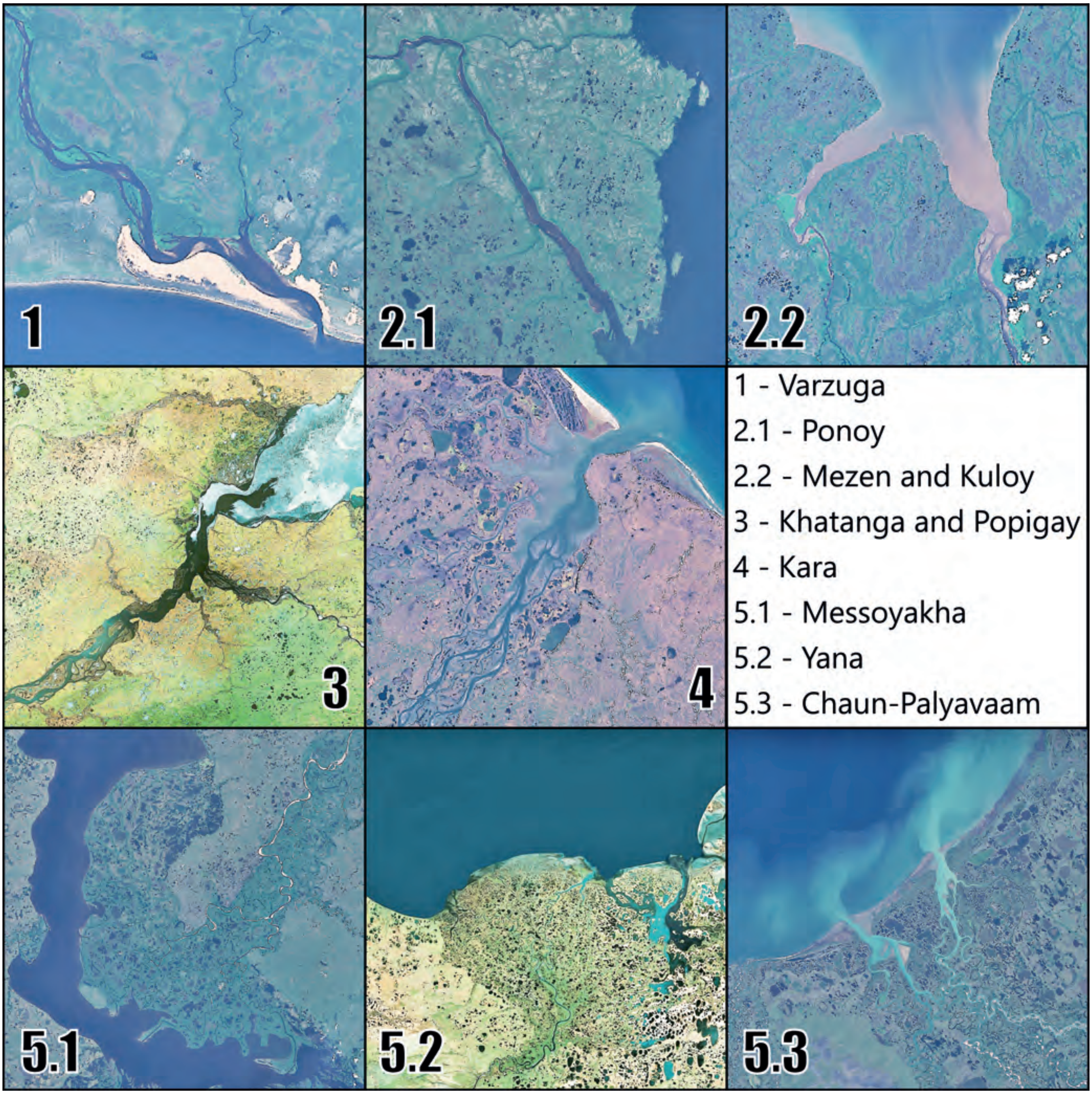

Fig. 4: Satellite images (Sentinel 2 L1C) of the typical mouth areas for each classification type (see Tab. 5). For locations see Fig.1.

Abb. 4: Satellitenbilder (Sentinel 2 LIC) charakteristischer Mündungsbereiche entsprechend der Klassifikation Typ 1 bis Typ 5 (vgl. Tab. 5); für Lokationen siehe Abb. 1.

Type (1) Simple river mouths

This type is spread everywhere in the Arctic zone and is characterized by an open type of mouth, one tributary and having no delta. In the Arctic Region, the mouths of this type are formed in the following conditions:
- the small streams and rivers having the minimal volume of water runoff and, therefore, an insignificant erosion potential and volume of the sediment load;
- the watercourses whose runoff is regulated by lakes, therefore the water level changes are not so great, and the most part of deposits of basin origin is intercepted;
- the watercourses, the mouths of which are located on the sites of the coastal area with the active currents alongshore which provides the redistribution of the taken-out material along the coast and the formation of coastal accumulative forms (beaches, beach ridges, etc.);
- the watercourses having the high stream gradients and often a rapids and waterfall type of the riverbed processes, flowing along the rocks, which are resistant to erosion due to the stratification of geological meso-structures. As a result, the corrosive potential of a stream is insufficient for the formation of a sufficient volume of deposits of bed origin.

This type of mouths can be attributed to the Kola Peninsula region where the runoff of rivers is regulated by the lakes, and the crystalline basement rocks provide low background values of a sediment load. Small rivers with simple mouths can also be seen everywhere in the tundra zone. The largest river having a simple mouth is Alazeya two channels of which flow into the sea. However, the reason for bifurcation here is the geological structure of the valley, and the main processes in the mouth area are wind and wave and thermos-karst ones.

There are also mouths with a continuation in tidal creeks which are difficult to assign to a certain type because of an extremely flat coastal area and the existence of a large foreshore area in its limits in which the channel forms meanders and is branching. The similar mouths are characteristic of the rivers of the New Siberian Islands having an extremely low average height and a mean slope of the catchment against the background of the modern raising of the territory of their basins and mouth sites. There are still not enough data on these mouths, therefore they can not be assigned to a separate subclass.

Type (2) Estuarial river mouths

The second type of mouths is form by estuarial river mouths. Morphologically, the Arctic estuaries differ in their form which depends on the conditions of their formation and development. Unlike the simple ones, the mouths of estuarial type are half-closed, having an available link with the open sea, but at the same time considerably diluted with the arriving flow of the rivers. The reason why the delta is not formed in the mouths of this type may be the following:
i) the insufficient water runoff of the river;
ii) the low erosion potential of the watershed – characteristic for the flat tundra landscapes of the Arctic;
iii) the geological features of formation of the mouth;
iv) the considerable scale of tidal influence which prevents formation of the delta even in large rivers. The mouths of this type are widespread in the east sector of the Russian Arctic in the small rivers of non-tidal and micro-tidal regions of the coast where the influence of the sea is limited to the surge phenomena – the rivers of the Taimyr Peninsula, the Khroma River, etc.

In middle and small rivers as a result of the mutually directed action of a water runoff and tidal currents, channel estuaries (with the width several times greater then, the width of the inflowing river) can be formed. The estuarial widenings which are funnelled gulfs are characteristic of the mouths with a considerable tide height (to 10 m on the Mezen River) confined in the Arctic to the coasts of the White and Barents seas. In the rivers of the Kola Peninsula and on the Novaya Zemlya archipelago fjord estuaries which are the flooded valleys developed by glacial erosion during the freezing periods are widespread.

Type (3) Estuarial-deltaic mouth

This mouth Type is characterized by a high variety of forms of interaction of the reception reservoir and the actual mouth of the river. Such mouths have a half-closed mouth coastal area owing to which the influence of sea factors is weakened (the Taimyra River).

Owing to the high variety of geographical features of the Arctic the mouths of this type have the estuaries, which are quite different in form, sizes and features. The largest of them are valley gulfs in the tops of which deltas are formed – the rivers Yenisei, Ob, Pur and Taz). In general, owing to the territory scales, the sizes of deltas and mouths of the rivers are often incomparable to the sizes of estuaries – gulfs and bays, and the form of these parts of reception reservoir can be extremely various as well. In general, the mouths can be assigned to this type only if there are certain geological prerequisites – it may be absurd to assign the gulfs and bays which are often incomparable in size even with the catchment area of this waterway, or that which do not belong to the waterway by origin (e.g. Gafner-Fjord Bay, the Leningradskaya River), to the estuarial areas of such rivers. In the mouth areas of the larger rivers transferring considerable volumes of material accumulative forms are formed, and the mouth becomes closed. Owing to the closeness of mouth the deltaic complex is often a developing braided floodplain with a lot of branches.

The review of mouths of the rivers of the Arctic islands (Shkolnyi & Aybulatov 2016) has allowed to allocate in addition fjord mouths with a lot of tributaries as a separate subtype (Type 3a). The similar mouths are formed on the islands with a significant area of the territory covered with glaciers during the melting and reliction of which narrow and deep valleys of fjord type have been created by exaration and gravitational processes. The formation of this type depends on the geological age of the valley and the geomorphological features of the site. The active melting of a glacier provides the formation of the streams carrying a significant amount of sediments. Depending on the current state of glaciation on some sites the glacier tongue is located at a considerable distance from the sea, therefore the developed lengthwise profile of the river created during reliction provides a transfer of the most part of deposits towards the sea edge of the delta and its accumulation there. Such estuarial areas are the narrow and deep gulfs in the top of which there is a filled flat deltaic plain of various sizes. In separate waterways, the distance from the delta top to its sea edge can reach several tens of kilometres, making more than 50 % of the total length of the river (the Stepovoy River (Fig. 5) and the Mityushikha River on the Novaya Zemlya). The comparison of cartographic materials and satellite images shows the modern prominence of the sea edge of such deltas or, at least, a significant increase of tidal foreshore area (that is an increase in the foreset massif of a deltaic form). At the same time, in the tops of some fjords there are still tongues of outlet glaciers presented.

In that case either an unstable and fast developing delta which consists of the products of rewashing of end moraine is formed, or material is depositing along the sides of the retreating glacier between its body and the boards of the valley. It should be noted that the review of fjord regions of the globe has shown the lack of similar objects on the tops of fjords. Single objects of this type can be found in Iceland however, the average annual module of a water runoff and deposits of the rivers is much higher due to volcanic genesis and activities (Tomasson 1990).

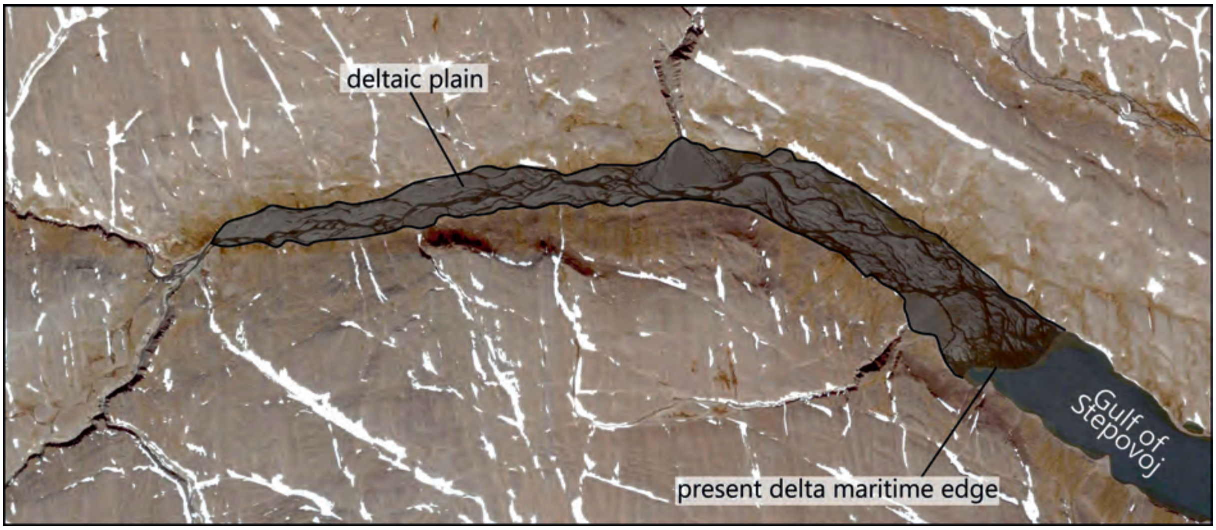

Fig. 5: Fjord delta of Stepovoy River, Southern Island of Novaya Zemlya (<https://bing.com/maps>).

Abb. 5: Delta des Stepovoy Flusses in einem Fjord auf der Südinsel von Nowaja Semlja; Typ 3 der Klassifikation (<https://bing.com/maps>).

Type (4) Lagoon-deltaic type of mouths

This type is regarded as the closed type of mouths and is widely seen on the studied area which is due to a large number of the factors providing its formation in the Arctic zone – first of all, the vertical earth movements and the cycles of oscillation of sea level (Brovko 1990). As a result of the centuries-old action of these processes and also the influence of the wave factor and the alongshore transfer of the river sediments and products of shore erosion, the accumulative forms which separate them off are formed in a lot of the shallow gulfs intruding deep into the land. Depending on the waterway size, both the small parts of valleys flooded during the ingression of the sea and the clusters of the sea up to several hundred km^2 limited by large accumulative sand-and-shingle forms can act as lagoons. Under conditions of the limited influence of tides on the internal parts of these lagoons deltas of various sizes are formed in them, with gradual filling of lagoons by the material carried in. The extent of filling can fluctuate from the first percent (e.g., the Indiga River) up to almost the full filling of the lagoon or pro-estuary (e.g., the rivers Northern Dvina and Omoloy). The Pechora River, having filled a pro-estuarial part of the lagoon (the present Korovinskaya Guba [Korovin Bay]), now is protruding into the Pechora Bay which is a lagoon of another genesis, separated from the sea by the blocking forms (the Gulyaevskie Koshki Islands [the Gulyaev Cats Islands]) created by the alongshore sediment flux (Fig. 6).

Occasionally lagoons are presented by the narrow, extended reservoirs separated by an offshore bar. This type of mouths

Fig. 6: Satellite image (Sentinel 2 L1C) of the Pechora river mouth area.

Abb. 6: Satellitenbild (Sentinel 2 LIC) des Mündungsgebiets des Pechora Flusses; Typ 4 der Klassifikation.

is wide-spread most of all in Chukotka where owing to the specificity of sea and coastal processes the formation of the alongshore blocking bars is a typical characteristic (Fig. 7). That bars are stretched practically along all the coast of the peninsula to the east from Cape Yakan and separate the coastal shallow sites of the water areas turning into separate lagoons or chains of lagoons.

Also, a type of "lake" deltas can be allocated as a subtype of lagoon-deltaic mouths. Such deltas located on the mouths with a quite complex geometry of connection to the sea. The largest of such mouths consist of the chains of hollows connected by large channels and having a narrow and long entrance. Owing to the originality of their form the sea water can not go deep into these reservoirs even during tides and surges, and their filling with the sea water occurs at best only during the period of the minimal flow or its absence. During the warm season these water volums are probably considerably desalinated. As it has been noted in numerous papers, the formation of deltas in the desalinated waterways occurs under different conditions compared to the deltas at the open coast, which contributes to the appearance of the unique objects. For example, there are 35 km between the delta of the Goltsovaya River (the Southern Island of Novaya Zemlya) and the entrance of its estuary which is a gulf of complex configuration. This gulf has a length, which length is comparable to the length of the river.

Type (5) River mouths with deltas

This type represents one of the complex objects of own study as with a certain visual similarity of the considered objects, some characteristics are appeared to be different due to differences in the object genesis. A feature of deltaic mouths is caused by open coast position of the mouth, however not always deltas are formed directly at the sea coast. The formation of protruding deltas has been noted in the gulfs and fjords which are, on the one hand, half-closed water areas, and, on the other hand, each of these deltas has its own bottom-set and fore-set massif. The size of a deltaic form does not almost depend on the area of the river catchment and depends also on a combination of local factors – in particular on the configuration of a river mouth coastal area. Thus, deltaic forms can be seen even in the small streams and rivers of the Arctic archipelagos. An important factor for the formation of deltas is a

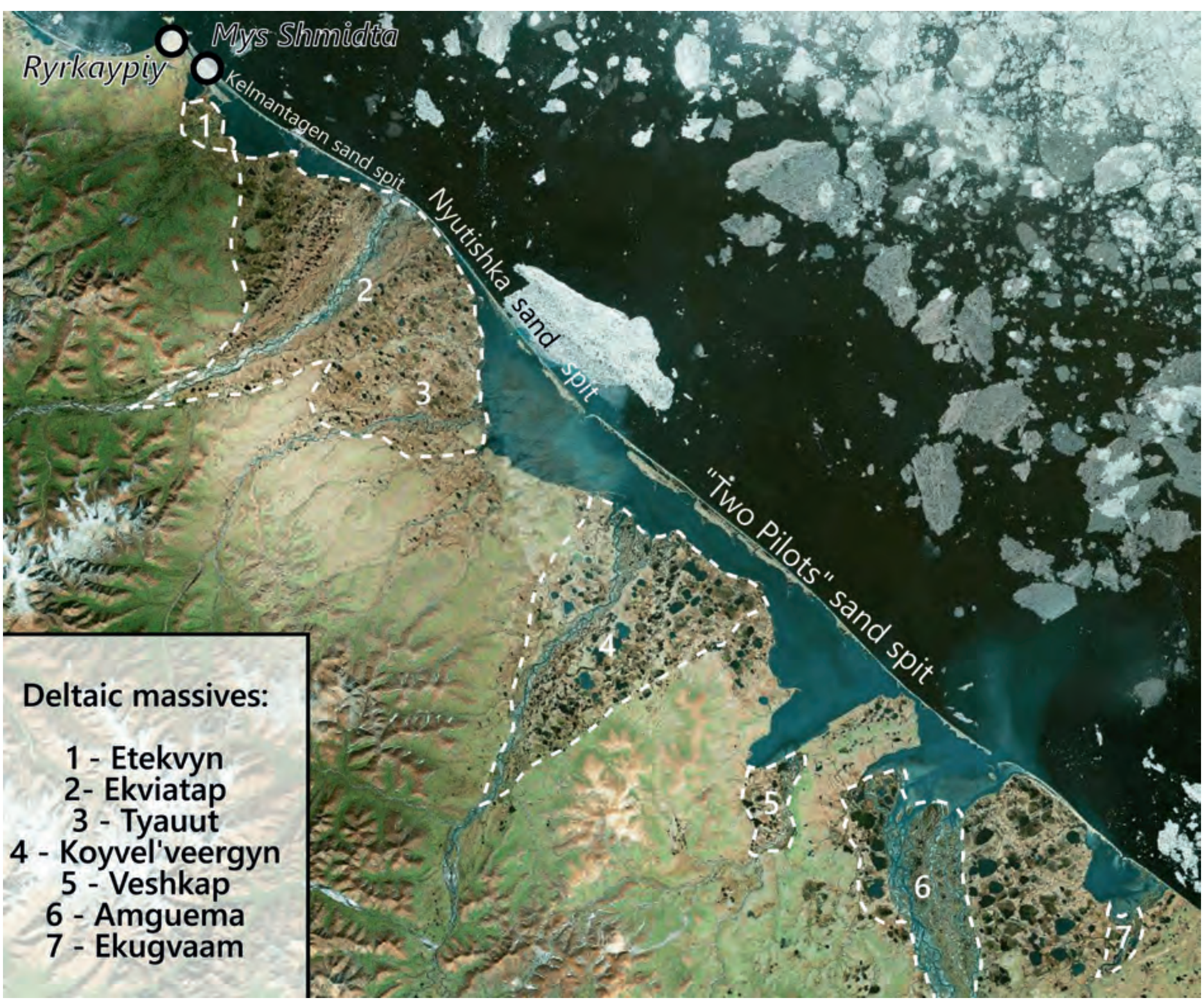

Fig. 7: Tenkergynpil'gyn lagoon of surge and wave genesis, typical on the coast of Chukchi Sea, derived from the sea by long and thin sand spits and partially filled by income river deltas <(https//vandex.ru/maps/>.

Abb. 7: Die Lagune Tenkergynpil'gyn, durch Brandung und Wellen geformt, ist typisch für die gesamte Küste der Tschuktschensee, charakterisiert durch lange, schmale Sandzungen vor sich vorbauenden Flussdeltas <(https//vandex.ru/maps/>.

lack of the considerable tidal influence due to which the largest deltas (the Lena, the Olenyok and the Yana) are confined to the micro-tidal coasts of the Laptev Sea.

This study allocates three subtypes. Classical protruding deltas (Type 5a) with a lot of distributaries are generally confined to large rivers (the rivers Lena, Olenyok and Messoyakha), however their formation has also been noted for the small rivers in severe climatic conditions where, despite a short period of the open channel, the quantity of deposits surpasses the transporting ability of alongshore streams and is accumulated on the coastal area, going beyond the general line of the coast. For example, some amount of developed protruding deltas can be found in extreme latitudes (81° N) on the Severnaya Zemlya archipelago (e.g., Posadochnaya River on Komsomolets Island) and Franz Josef Land (e.g., Romantikov River on Heiss Island). On the New Siberian Islands where the rising of the land is at its maximum, the body of protruding deltas is often a foreset massif of the delta (foreset bed) brought from subaerial to the day surface becoming the continuation of its valley. The separate protruding deltas which are formed on the sides of fjords have a considerably lower growth rate than the deltas which are filling the fjords in the axial direction. In course of time their bodies become a part of a bay delta, and the process of delta formation stops, and waterways become the tributaries of the main river.

Deltas of full filling (Types 5b and 5c) which are mouths with a lot of distributaries with an estuarial bar on the coastal area arise in case of the full filling of the estuarial lagoon or the valley gulf with the existence of the limiting factor inhibiting their further development. In case of the proceeding accumulation of deposits these deltas form a complex of estuarial bars within which a further formation of the body of prominence may occur in future.

Most deltas of the Russian sector of the Arctic have a lobate shape, the network of their water currents is extremely rare in relation to the area of the delta, and the slopes of the deltaic body are most likely high. This is due to the peak discharges of material during the short summer period with an increased runoff, therefore separate alluvion plumes are formed on the surface of the delta. The washout and re-deposition of the brought material are just the mechanisms that define the quantitative and structural features of the network of deltaic water currents. However, the separate deltas which are the continuation of wide valleys of the rivers with glacial supply and an unstable and often shifting river bed with a lot of distributaries, have a dense network of water currents, concentrated however mainly in one of the sectors of the deltaic body.

CONCLUSION

Despite a large variety of forms, the Arctic river mouths can be classified on the basis of the hydrological and morphological approach (e.g., Mikhailov 1971, 1998, Mikhailov & Gorin 2012) characterizing the features of interaction of river- and sea-water masses, and the geomorphological approach describing the processes of formation of deltas and other specific fluvial and sea forms of relief in the coastal zone (Korotayev et al. 2016, Korotayev 2006, 2008). As a result of our new typification adapted to Arctic river mouths five types of mouths – (1) simple, (2) estuarial, (3) estuarial-deltaic, (4) lagoon-deltaic and (5) deltaic ones and their 11 subtypes have been allocated (Tab. 5, Tab. 6, Fig. 8). The greatest variety of river mouths is observed for the small rivers on which the local factors can cardinally influence the type, form and regime of mouth area.

Simple river mouths (Type 1) are widespread everywhere in the Arctic zone, but are generally inherent in small rivers. The larger rivers with this type of mouths can be seen on the Kola Peninsula where the runoff of rivers is regulated by lakes, and the crystalline basement results in the low background values of turbidity of river waters.

Estuarial river mouths (Type 2) include the half-closed estuarial coastal areas (estuaries), having an open connection with the open sea, but at the same time considerably desalinated by the arriving river runoff, sometimes with the water surface gradients and essential flow velocities in the uppermost layer, especially during a high-water season. Morphologically, estuaries differ in the conditions of their formation and development. The estuarial expansions which are the funnelled gulfs passing (towards the sea) into typical sea gulfs, for example, Onega Bay, Dvina Bay and Mezen Bay, are characteristic of the mouths with a considerable tide height – to 10 m in the mouth of the Mezen River – relating to the coasts of the White and Barents seas.

The fjord estuaries which are the flooded valleys developped in the beginning by glacial erosion during the periods of freezing, and subsequently – by the water erosion amplified by the raising of sea coasts here are widespread in the mouths of the rivers of the Kola Peninsula and the Novaya Zemlya Archipelago. On the flat sea coasts the postglacial rising of sea level of the Arctic Ocean provided the flooding of the lower parts of valleys of both small and very large rivers and the formation of shallow estuaries here. As a result of transfer, accumulation and re-deposition of river and sea deposits a part of sea coastal water area was separated from the seas by sand bars, islands and coastal bars, therefore lagoon estuaries were created in the mouths of the rivers flowing in them. This type of river mouth is wide-spread most of all in Chukotka.

Owing to the reduced influence of marine mechanisms and quite a large sediment load of some of the rivers flowing into the estuaries, deltas of various sizes, shape and configurations have been formed in a lot of them. These are bay deltas or estuarial-deltaic mouths (Type 3). The age of these deltas is about 5 to 7 thousand years (Korotayev 2008). Such estuarial and deltaic mouths are characteristic of several large and two largest rivers of the Arctic (the Ob and the Yenisei) and a lot of other rivers the mouths of which are the valley gulfs deeply intruded into the dry land gradually filled with deposits.

In a lot of deltas which have stopped or extremely slowed down their development within the mouth area a half-closed system of water currents and reservoirs is formed. Such mouths are regarded as a lagoon and deltaic type (Type 4).

River mouths with deltas (Type 5) have two subtypes. Depending on the interaction with a reception reservoir in the

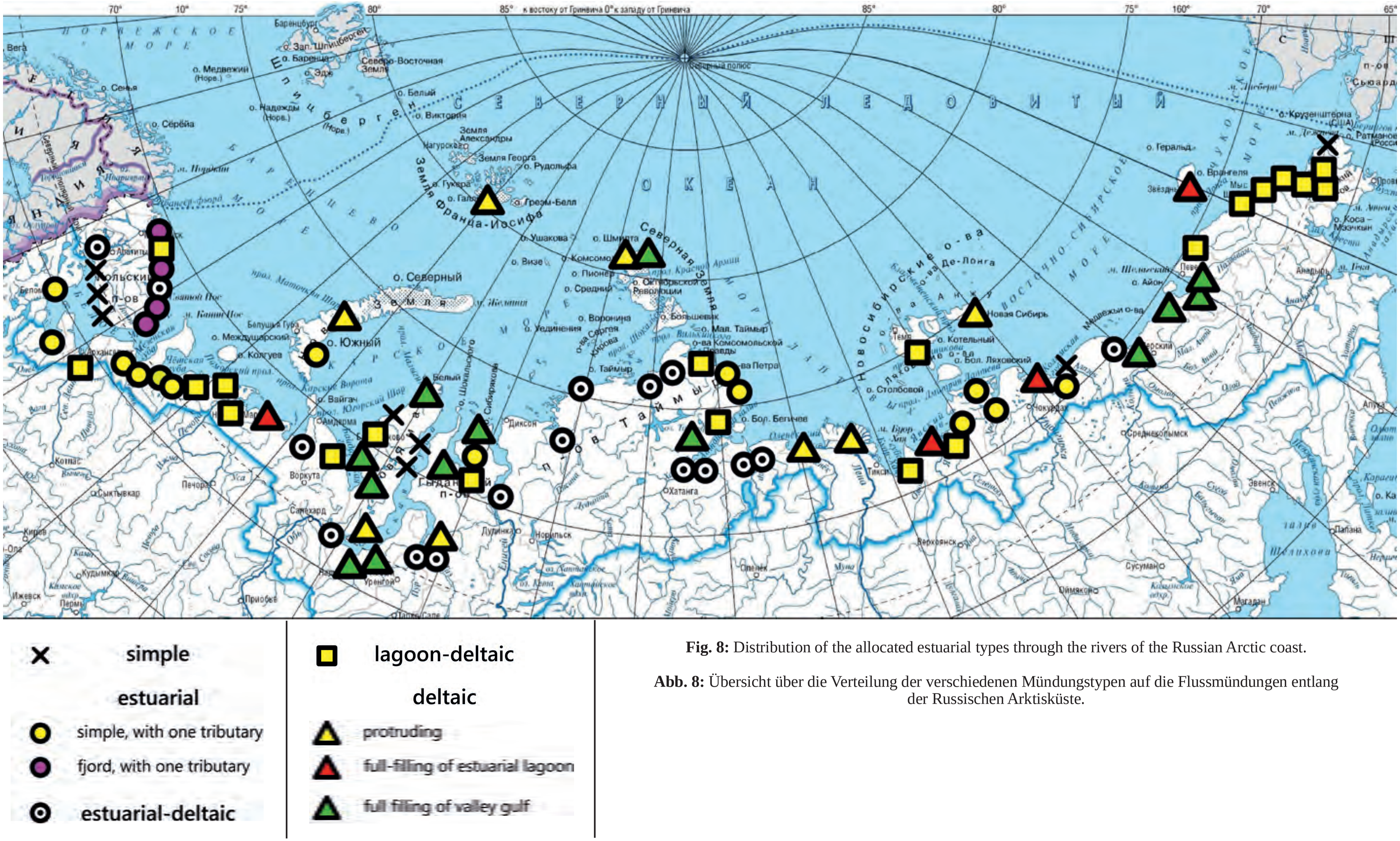

Fig. 8: Distribution of the allocated estuarial types through the rivers of the Russian Arctic coast.

Abb. 8: Übersicht über die Verteilung der verschiedenen Mündungstypen auf die Flussmündungen entlang der Russischen Arktisküste.

place where a river flows out onto an open coastal area, either a delta of full filling with an estuarial bar on the coastal area (a shallow with a small depth on the crest created both of river and of sea deposits) and separate deltaic lobes, or the protruding delta the size of which does not almost depend on the area of the river catchment and depends on a combination of local factors (in particular on the configuration of the river coastal area) is formed. Thus, the large deltas or deltaic (alluvial) ledges with the soil and vegetable cover that is not developed yet can be seen even in the small streams and rivers of the Arctic archipelagos. Low tide influence on the coasts of the Laptev Sea allows forming most of protruding deltas (including largest ones) here.

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