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Tyuleniy Archipelago of the Northern Caspian: a testing ground for the study of ice-gouging processes

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ABSTRACT

The Northern Caspian is a well-known area of ice gouging. It is studying here form 1953. The seabed of the whole northern part of the Caspian Sea is affected by ice features: mobile ice ridges and immobile stamukhi. But on the most part of the bottom ice scours could not be preserved because of the waves' action and are hard-to-study. The bottom in enclosed bays and archipelagoes are rarely affected by waves, and sea ice occurs to be the most active agent of seabed topography change. At the Northern Caspian, Tyuleniy Archipelago (also known as Seal Islands) is the calmest zone, and ice scours are preserved here for a long time. It can become a testing ground for studying ice processes, the effect of ice on the seabed, and the morphology of ice scours. Using satellite imagery with the help of the field methods, we revealed many characteristics of the ice scours of Tyuleniy Archipelago. Monitoring of the ice processes and meteocan survey with the assistance of the study of the ice scours' morphology can provide unique information and associate the certain act of ice impact by known ice ridge with an individual ice scour. This leads us to predict characteristics of ice scours by a remote study of ice ridges and stamukhi.

KEY WORDS: Bottom topography; Ice ridges; Ice scours; Morphometry; Stamukhi.

INTRODUCTION

In the Caspian Sea, sea ice and ice features were studied since the end of the 19th century (Terziev, 1992). B.I. Koshechkin (1958) first considered the effects of ice on the seabed of the Northern Caspian. He found out the traces of the impact of moving ice "pile-ups" ("plowing scours") in the area of the Tyuleniy Archipelago (the Seal Islands, Figure 1). B.I. Koshechkin showed that an ice hummock with 35-40 cm sail and keel of about 3 m penetrate the seabed in that area. The analysis of the distribution of the main scours directions showed a similarity with the directions of the prevailing winds. B.I. Koshechkin proved that the movement of piled ice is subjected to the prevailing winds and currents.

Since the beginning of the 2000s, the exploration and development of oil deposits on the Caspian shelf caused detailed studies of the stamukhi parameters, grounding process, internal structure (Mironov, Porubaev, 2005) and their effect on the seabed (Nepomenko, Popova, 2018), modeling (Andreev, Ivanov, 2012) and detailed ice monitoring (Frolov et al., 2009). Later Ogorodov and Arkhipov (2010) detected the impact of stamukhi and ice ridges on the seabed at depths of up to 12 m a using slide-scan sonar survey. Stamukha pits (Parr et al., 2013) and ice scours (Fuglem et al., 2013) were studied concerning the assessment of loads on subsea pipelines. Ogorodov et al. (2019) estimated the main depths of the ice effects on the seabed.

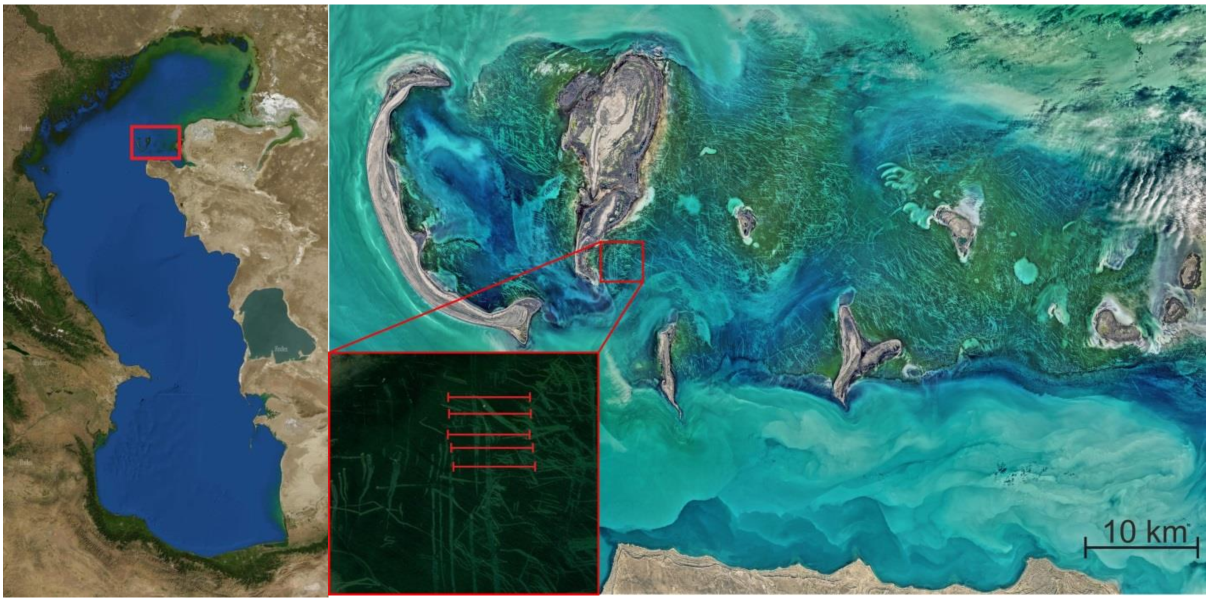

Figure 1. Fieldwork key sites in the Caspian Sea. On the right – the location of the echo sounder profiles in the Tyuleniy Islands area are marked with red lines, based on the WorldView-3 satellite imagery mosaic (spring 2016)

Comprehensive monitoring of the ice drift (Kadranov et al., 2019), stamukhi distribution, their parameters (Sigitov et al., 2019) and other ice cover characteristics started in 2013 by LLP ICEMAN.KZ. These studies throughout the Northern Caspian are based on continuous monitoring and hindcast of both formation and melting of stamukhi as well as provide a whole range of ice information for analysis (https://iceman.kz/).

We consider the Tuleniy Islands as a testing ground for studying the seabed gouging by ice features. In most parts of the Caspian seabed ice scours are destroyed by the first strong storm. The Tuleniy Islands are closed from wave influences, so the ice scours remain here for a long time. The depths in the area are less than 3 m, and under good conditions, we can see traces of ice impact on the bottom on satellite images. This allows us to perform a comprehensive study of ice conditions and ice scours. In this work, we performed a detailed study of ice scours. We are able to investigate the ice conditions, identify ice formations using satellite images and study the traces of their impact on the seabed.

METHODS

We selected two key sites in the area of the Tyuleniy Islands for ice scours deciphering. We downloaded the visible wavelength space imagery from open sources: Yandex.Maps (https://yandex.com/maps) and ESRI World Imagery (https://www.arcgis.com/home). We used the image taken in spring 2020. Then we carried out the visual interpretation of linear forms on a scale of 1 : 5000. For both single scours and their combs (systems), we created one polyline with a number of segments for the most correct estimation of the scour direction. For scour combs or systems of scours with different lengths, the most characteristic (average) length was chosen. After that, the width was determined manually for single scours. For combs and systems, we measured their width, the width of single scours in a comb, the number of scours in a comb. All the parameters were added to the attribute table. Since scours and combs often vary in width, the width entered in the attribute table was determined as average from several measurements.

Then, using the code developed for the Python console in QGIS 3.6.3, the length and direction of the lines were automatically determined. We determined two options for the direction of the lines. The first is a virtual line connecting the beginning and end of the line. The second is weighted average direction. It was calculated from the directions of each line segment weighted in proportion to the segment length. In some cases, these options for directions were significantly different; in most cases, they are practically the same. The obtained values of length and directions were automatically added to the attribute table. After determining the main morphometric characteristics, the attribute table was exported into an MS Excel document for further statistical processing.

We also performed fieldwork. The technique of the ice-gouging topography survey on the seabed does not generally differ from the survey of any other microtopography on the seabed but has its own specifics. At present, the method described by S. Ogorodov (Ogorodov, 2011; Ogorodov et al., 2013) is the most common. In this work, we used the materials of underwater shooting and echo sounder survey acquired in September 2019 (Figure 1).

The underwater shooting was carried out with an action camera GoPro Hero 7 in a waterproof box on a flexible clamp both when moving on a boat and when snorkeling. The echo sounding was made with a Lowrance Mark-5x echo sounder. Positioning was carried out using a GPS receiver Garmin GPSMAP 78S. A laptop with the installed Hypack 2016 software package recorded the results. A standard sampler was used to collect samples in plastic bags with a zip-lock.

Fieldwork was executed to the east of Morskoy and the west of Rybachy Islands in the area of deciphering (Figure 2). The depth of the sea (up to 1.5 m) allowed to carry out a complex of works on the survey of the seabed topography and bottom sediments. The echo sounding measurements were made at low speed with five traverses from west to east across the strike of the ice scours. Since the Tyuleniy Islands are closed from the wave activity and ice scours are preserved here for a long time, we identified not only scours of the 2018-2019 season. The last season before the fieldwork was mild but a number of stamukhi was formed in the study area (Figure 2).

RESULTS

A preliminary remote study in the Tyuleniy Islands area revealed the presence of ice-gouging landforms at depths of about 1 m. Near Rybachy Island depths do not exceed 1 m, which did not allow to perform an echo sounding survey. The average water layer is about 40-50 cm; 20-30 cm is occupied by plant mats, presumably represented by Charophyceae or Najas. As a result, the layer of free water is only about 20 cm, and movement in it by boat or swimming is difficult. The bottom sediments in this area are water-saturated silty soils, which prevent free movement by feet along the bottom. Reconnaissance work showed the chaotic disturbances in the bottom topography at the site with an absence of impressive scours.

Near Morskoy Island the sea depths (up to 1.5 m) allowed to carry out a complex work on the survey of the bottom topography and bottom sediments. We documented the bottom topography with the camera, sampled soil and completed the echo sounding survey. As a result, we recorded on the video the traces of ice impacts on the seabed impressed in the long furrows without vegetation cover with a width of 5 to 50 m, weakly expressed in the relief, with an amplitude up to 0.2 m (Figure 3). The echo sounding also showed that the scours are not very well impressed in the seabed topography.

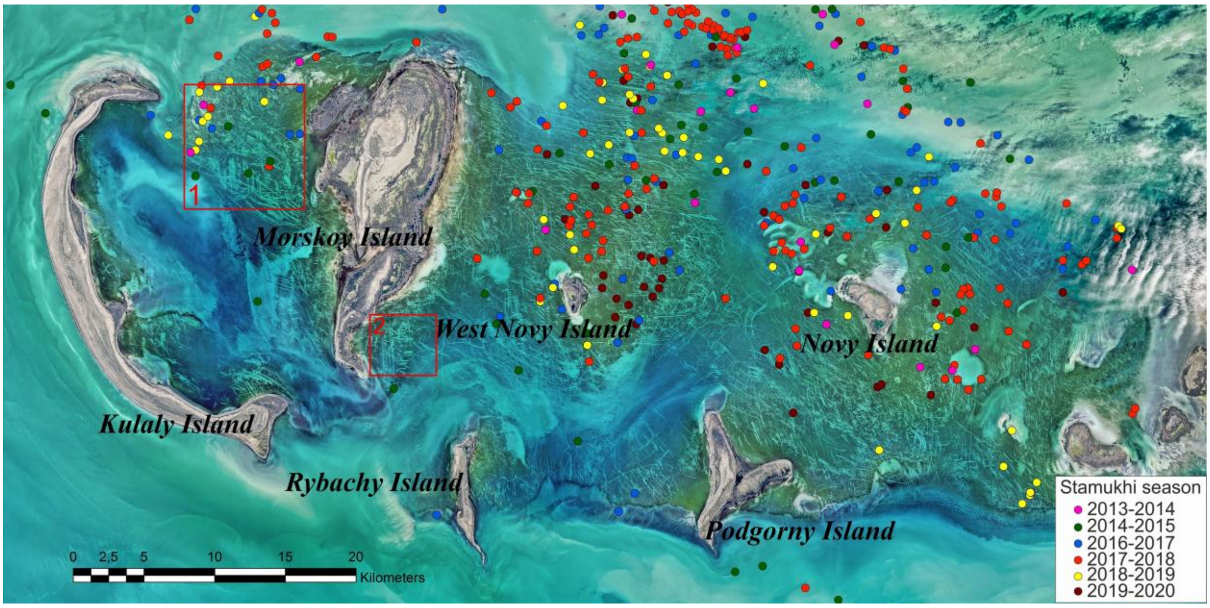

Figure 2. The location of the key sites of deciphering (in red boxes) and stamukhi of 2013-2020 seasons on WorldView-3 image (spring 2016)

The results of echo sounding show that the scours have a width of 50 to 150 m (on average – about 100 m), gently sloping sides, and a depth of 20-60 cm (on average – 30 cm). The height of the side berms is less than 0.2 m; their width is about 10 m. The scours have a complicated shape, mostly they are W-shaped, with several local ridges in the central part. In fact, such scours are merged combs with residual ridges in the central part. The pressure ridges are also expressed well, and composed of a mixture of algae and silty soils of the upper part of the sediments. The grain size analysis showed a sandy composition of bottom sediments with a significant part of silt and shells.

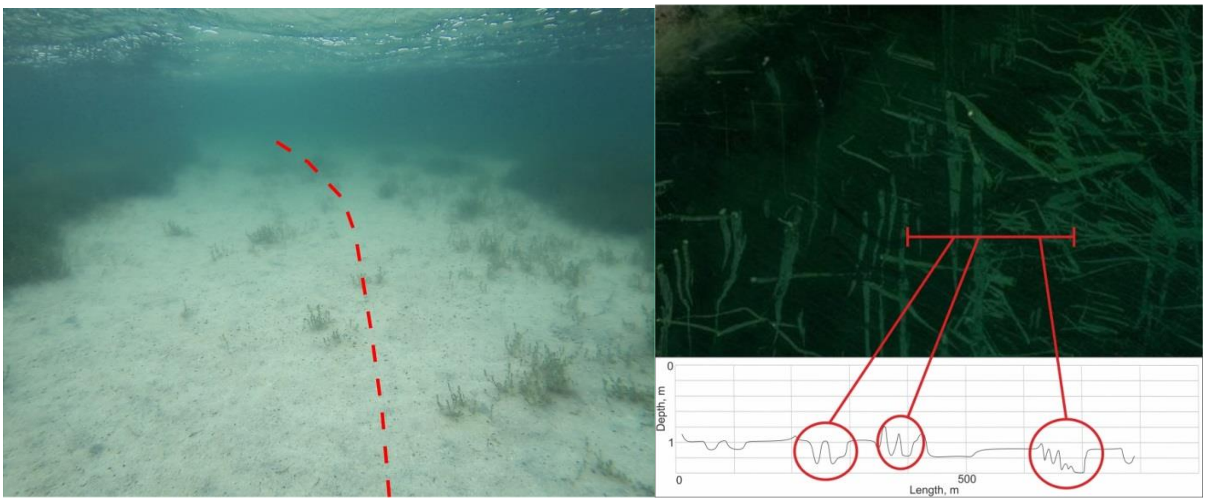

Figure 3. At the left: an underwater snapshot of ice scour (red line shows an axis) near Morskoy Island; at the right: an echo sounding profile on a WorldView-3 image mosaic (spring 2020)

We selected two key sites for deciphering: a site in the area of the maximum distribution of ice gouges and the highest visual density, and a site in the area of fieldwork (Figure 2).

The first site is located between Morskoy and Kulaly Islands. The site is characterized by the presence of well-defined large scours and scour combs with distinct pressure ridges, but not side ridges.

The width of the scours on the site ranges from 11 to 325 m, on average – 39 m (median 33 m). Scours are from 263 to 8846 m long, with an average of 1277 m (median 966 m). Combs consist of 3-4 scours and have an average width of 306 m, a median width of 163 m. In this case, the length and width of single scours are slightly larger than the length and width of scours from combs and systems. There are more single scours than combs (67% versus 33%). Scours generally have directions from WNW to ESE (Figure 4), which corresponds to the main directions of winds. Scours of medium length (49%) and medium width (63%) prevail on the site. The estimated coverage of the seabed by landforms of ice impact is 61%.

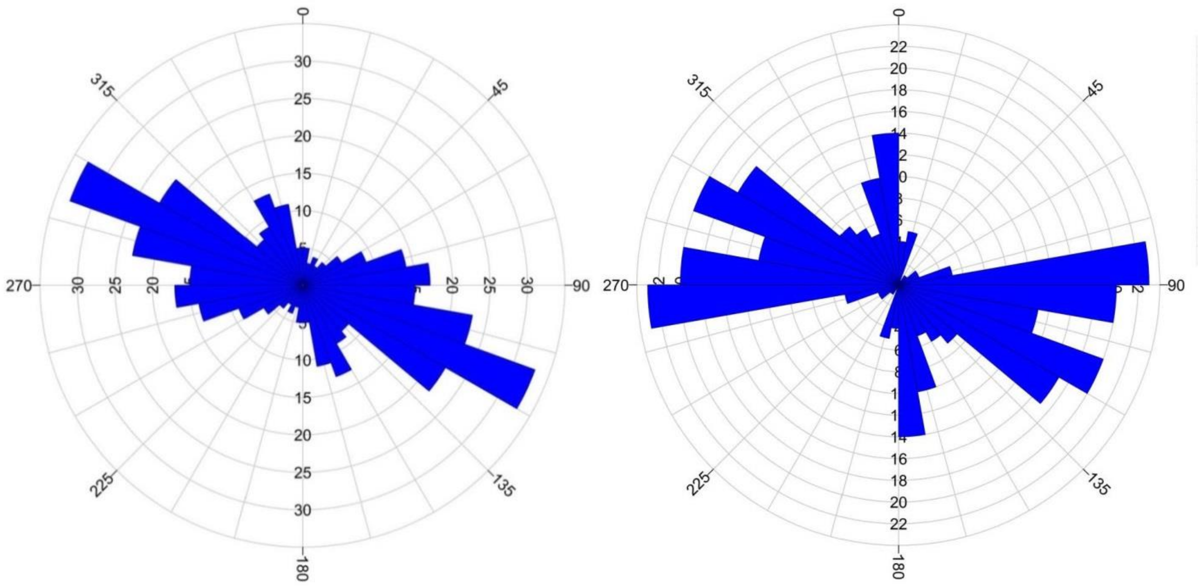

Figure 4. Rose diagrams of the directions of scours in sections 1 (left) and 2 (right)

The second site is located in the area of fieldwork. The ice scours are located east of the southern tip of Morskoy Island. The site is characterized by the presence of well-defined, oriented large and small scours and combs with expressed pressure ridges, but not side ridges.

The width of the scours on the site ranges from 5 to 79 m, on average – 21 m (median 18 m). Scours are from 64 to 4950 m long, with an average length of 691 m (median 508 m). Combs consist of 3-4 scours and have an average width of 144 m, median – 93 m. The width of single scours is slightly larger than the width of scours from combs and systems. The average length of the scours in the combs is longer than single ones, but the median is shorter. There are more single scours than combs (53% versus 47%). Scours generally have directions from W to E (Figure 4), which corresponds to the main directions of winds in the area. The site is dominated by short (77%) and narrow scours (82%). The estimated coverage of the seabed by landforms is 24%.

The data from the two sites were summarized (Table 1). The average width of the scours is 31 m; the median width is 27 m. The scours have an average length of 1024 m, the median length is 767 m. The combs consist of 3-4 scours and have an average width of 221 m, the median width is 127 m.

Table 1. The morphometry of the ice scours in the Tyuleniy Islands area

	Scour width, m	Scour length, m	Single scour width, m	Single scour length, m	Comb length, m	Comb width, m	Length of scours from comb, m	Number of scours in a comb
Number	359	359	219	219	140	140	140	140
Maximum	5	64	6	165	64	16	5	2
Minimum	325	8846	325	8846	4950	2208	95	17
Mean square deviation	26.6	959.0	31.7	1010.7	869.5	293.2	13.7	3.0
Variation	0.9	0.9	0.9	0.9	0.9	1.3	0.5	0.7
Mean	**31**	**1024**	**35**	**1075**	**945**	**221**	**25**	**4**
Median	27	767	31	812	711	127	23	3
Mode	32	--	32	--	--	62	25	2

DISCUSSION

Previous studies of the Caspian seabed showed some results for comparison. At depths from 3 to 12 m in the area of the Filanovskiy and Korchagin fields (with the center at 45.0 N, 48.5 E), the width of the ice scours is up to 5 m, the width of the systems of scours is up to 200 m, the length is more than several kilometers, and the depth was less than 1 m (Ogorodov and Arkhipov, 2010). B.I. Koshechkin (1958) showed the length of the plowing scours up to 2-3 km. He argued that their depth is only by 3-4 cm relative to the bottom surface, while the algal cover gives another 7-15 cm. At depths of up to 6 m in the area of the Kashagan field, the width of the scours is from 2 to 77 m, the maximum depth was 1.15 m taking into account the sediment filling (Fuglem et al., 2013). The greatest depth of stamukha pits in the same area is 1.2 m. The pit sizes depend on the stamukha size but reach at least 200 m (Parr et al., 2013). In the area of the Northern Caspian with depths of up to 3 m, ice scours are up to 10 cm deep and have side ridges up to 10 cm high. The landforms distribute in N-S and NW-SE directions (Nepomenko and Popova, 2018). The depth of the stamukha pits was 10-30 cm, on average a little more than 10 cm. In the western part of the Northern Caspian, the directions of the scours are nearly the same (Nepomenko et al., 2020).

We can see that ice scours in the Tyuleniy Islands area have lesser length due to limited water area between islands. At the same time, they are wider than scours in deep areas. We consider them to be created by rafted ice that is typical for that area (Bukharitsin, 1984). The real depth of ice gouging in the area is still unclear but we suppose that it is lesser than in deeper areas, where big ice ridges can form and reach the bottom.

We believe that the Tyuleniy Islands can become a testing ground for studying ice processes, the effect of ice on the seabed, and the morphology of ice scours. The Northern Caspian is a well-known area of ice gouging. On the most part of the Caspian seabed, ice scours could not be preserved because of the waves' action and are hard-to-study. The bottom in enclosed bays and archipelagoes are rarely affected by waves, and sea ice occurs to be the most active agent of seabed topography change. At the Northern Caspian, Tyuleniy Archipelago is the calmest zone, and ice scours are preserved here for a long time.

LLP ICEMAN.KZ performs stamukhi deciphering from satellite images, described in detail in (Sigitov et al., 2019 and Ogorodov et al., 2020). Visual investigation is carried out to spot identify ice features. Width of such features is then measured. The record also contains attributes of detection and erosion dates. Detection date is confirmed for each feature by backtracking. Sentinel-2 and Landsat high resolution images through the length of the season are thoroughly investigated to confirm the size of each object.

LLP ICEMAN.KZ generated stamukhi dataset for 2013-2020 in the Tyuleniy Islands area (Figure 2). Studying satellite images for every season, we can define the exact time of the scour formation, as well as identify the ice formation that created it. Nevertheless, we see traces of impact from moving ice, but stamukhi do not move and affect the bottom only locally. They form stamukha pits.

CONCLUSIONS

Based on the results of deciphering two sections of the Caspian seabed and fieldwork we obtained the morphometric characteristics of the ice scours in the area of the Tyuleniy Islands. Their average length is 1024 m, median – 767 m; average width is 31 m, median – 27 m; average depth is about 0.3 m.

Using multi-temporal imagery, we can study every ice formation that comes aground and estimate its motion before grounding. After melting, we can study the landforms that remain from specific stamukhi both in the field and by remote methods. The Tyuleniy Islands is a rare place with unique conditions where such remote sensing is possible. The development of the technology for the comprehensive study of ice gouging in the Tyuleniy Islands area can give new results and bring us closer to the understanding of ice gouging processes.

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