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Salt Domes Influence on Ice Formation Processes in the North Caspian Sea

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ABSTRACT

During the longstanding ice air-reconnaissance, the observers notice the polynyas in those shallow areas of the North Caspian, where they expect the thick stationary ice (shore-fast ice). Attempts to explain its formation by dynamic factors only (under-ice currents, ice drifting) did not produce any good result. With artificial satellites emerge the data on the Caspian ice increased drastically. Analysis of ice cover state and dynamics data allowed to make a conclusion, that some polynyas form annually in the same locations of the North Caspian Sea. Brusilovsky (1986) supposed, that the polynyas locations may be related to salt domes presence in the water areas of the North Caspian. The Caspian waters dissolve salt domes peaks, leading to local water salinity growth, which in a cold season results in delay in ice forming above the salt domes. Consequently, there form the polynyas. In summer months, local focuses of higher water salinity can hardly be disclosed due to winds, waves and currents. The research should be continued to receive a more detailed hydro-chemical description of the coastal area marine waters in the Caspian Sea (above the salt domes) during a winter season.

KEY WORDS**:** North Caspian; Ice Cover; Salt Domes; High Salinity; Polynyas.

SATELLITE ICE DATA

Thanks to space technologies development during the 1970-s, radically new and promising methods for hydrological conditions study were developed, including ice processes in seas and oceans. This was facilitated by creation of the satellite information autonomous receivers network. In 1975, such receiver site was created in Astrakhan on the basis of the Astrakhan Zonal Hydro-meteorological Observatory (AZHMO). In winter 1976, for the first time ice cover television pictures were used for precise determination of ice edges and boundaries location acquired from ice air reconnaissance at the Caspian Sea. A simple optical-graphical method was employed for decrypting the satellite television pictures and mapping the ice situation. Informative value and accuracy of these ice maps received was successfully augmented by synchronous shooting. A comparative evaluation between the ice maps accuracy, which were acquired from the Meteor spacecraft, NOAA satellites, etc. and maps of synchronous ice air reconnaissance revealed a satisfactory coincidence of shore-fast ice boundaries, margins of drifting compacted ice, as well as dimensions and location of flaw polynyas, which were averagely 3 miles (5.5 km) across. While the satellite information receiving and processing took a minimum of time (20 to 30 minutes), it sufficiently increased the ice maps operativeness and quality. This offered using the satellite information as a basis for ice reconnaissance pre-flight briefing, coordinating routes for the next air reconnaissance with flight crews, correcting and accurate determining the ice situation in those sea regions, where the air reconnaissance was not carried out due to various reasons, as well, as their fast supplying for scientific purposes and for sea industries of domestic economy [2-5, 9].

REMOTE STUDY OF FLAW POLYNYAS

Satellite data provided an opportunity for monitoring formation, development and extinction process in one of the most important and changeable hydro-meteorological condition elements during winter in the North Caspian - the flaw polynya. The ice air-reconnaissance did not provide such opportunity because of insufficient monitoring frequency and data incompleteness. It was thought, that locations, where polynyas appear as well, as their development processes are determined by wind's speed, direction and duration effect, coupled by under-ice currents' speed and direction. The satellite data helped to reveal that with sustained and offshore winds blowing in the northern Caspian, between the shore-fast ice and the drifting ice, there appear polynyas several hundred metres to 10 miles and more in width, sometimes up to 100 miles or even more (Fig. 1). Formation of these giant polynyas is facilitated by wind-drift currents, which result from wind effect blowing on sea surface free from ice. Ice situation may change rapidly with wind change. Drifting ice will close the existing polynyas, while new ones will form at the windward side [7, 8].

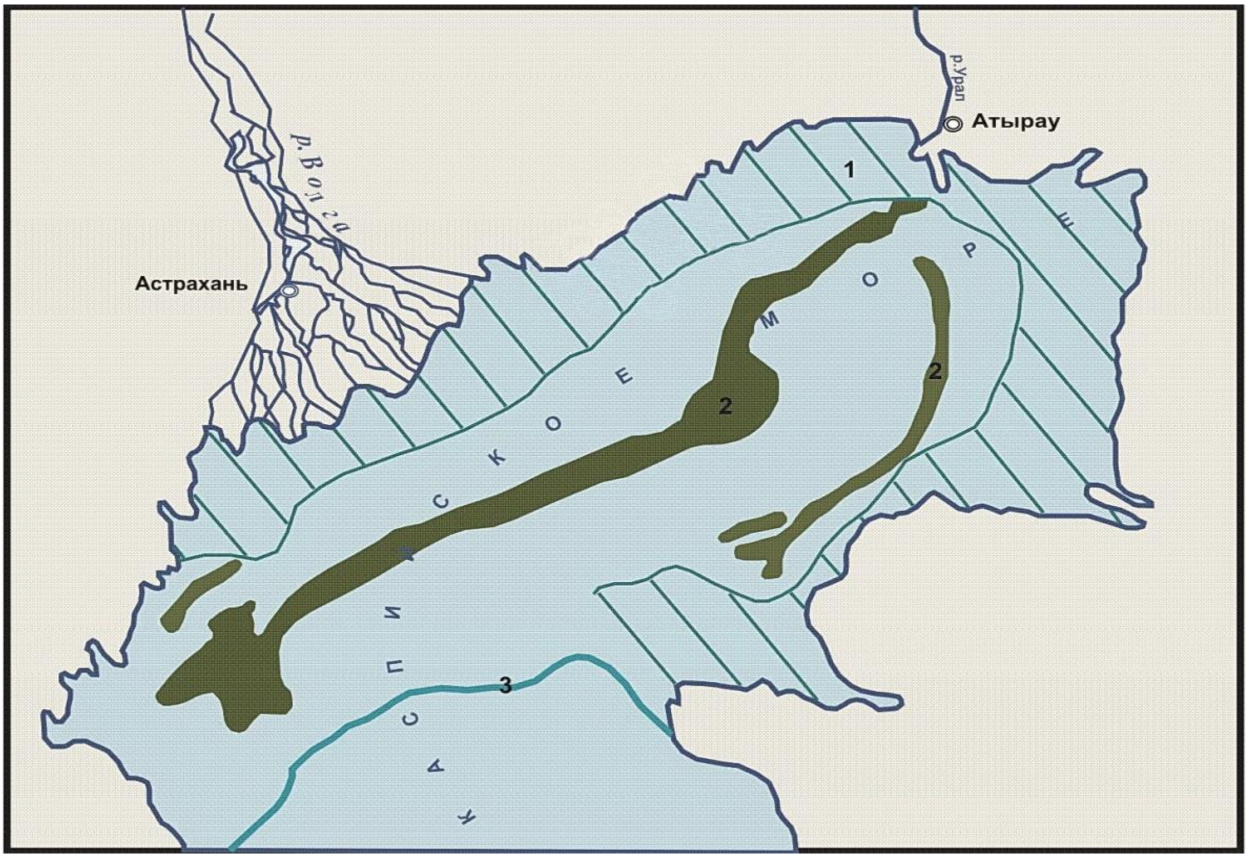

Figure 1. The North Caspian areas, where the polynyas form regularly, are marked in grey-brown

A compiled map shows vast flaw polynyas in shore-fast ice edge, shot by the satellites during 1980-90-s, provided determining the North Caspian areas with a sustained shore-fast ice, i. e. sea areas, where stationary ice remains during the whole ice season from its formation moment to fracturing in spring.

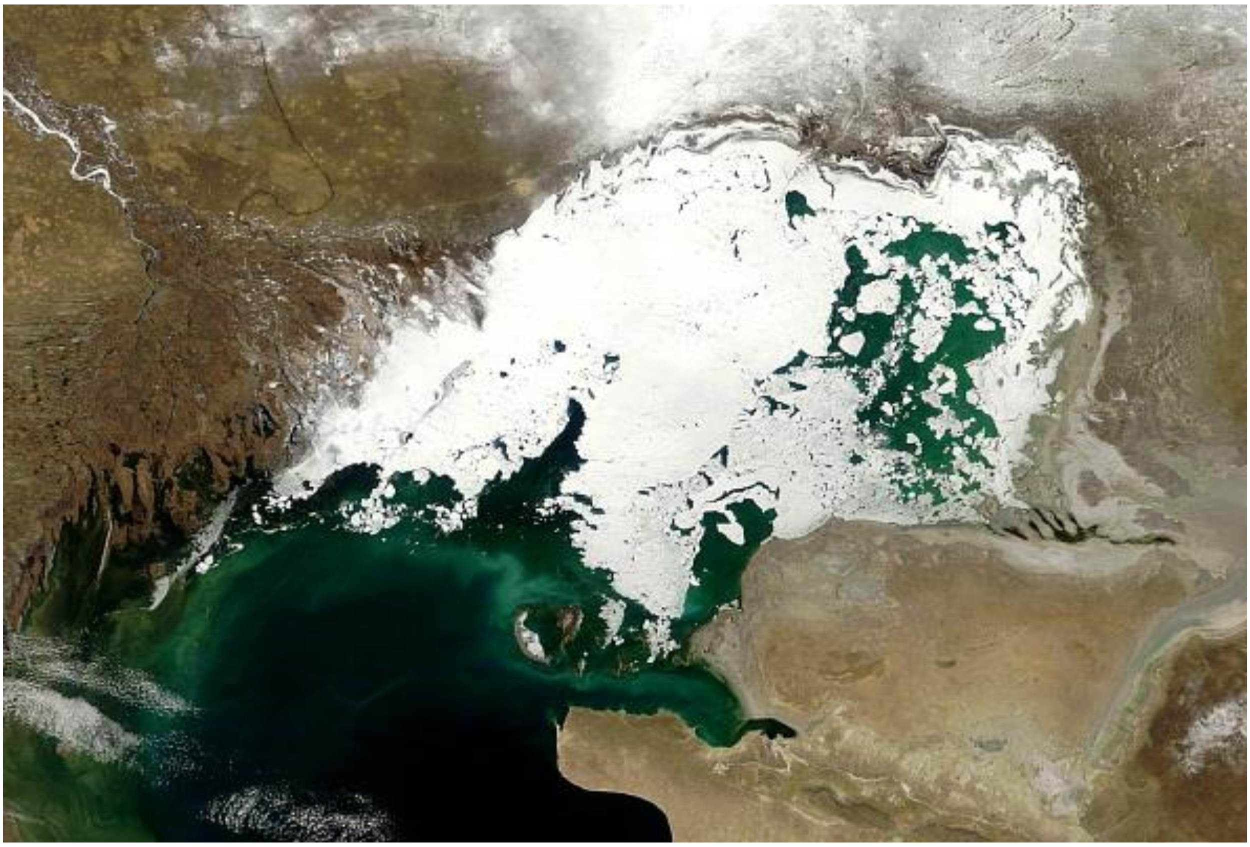

Figure 2. Polynyas in the northern Caspian ice cover
(this photo was found on the Internet df67c592)

It was revealed that during the ice cover formation period, the shore-fast ice movement to the south is not gradual, as it had been thought before, but leaping. Boundaries between older and newer shore-fast ice are often marked by hummock ice, several kilometres in size, which is similar to those forming in drift divides of arctic seas. They may be seen well on satellite pictures and decrypted easily. Thanks to aircraft and satellite data, we managed to trace gradual daily changes in ice distribution on the entire area of the North Caspian, which was not possible with any previously existing traditional methods. As a result, appearance, location and dynamics of ice leads and flaw polynyas in relation to wind direction, speed and duration effect was revealed. A sequence of shore-fast ice fracturing process in spring time was traced as well [6].

Although, for many years during ice air reconnaissance carried out in depth of winter, oceanologists have been noticing vast polynyas in shallow areas of the North Caspian, where, according to their calculations, they could not have been, but there should be a thick stationary ice (shore-fast ice) instead. Attempts to explain its formation by dynamic factors only (under-ice currents, ice drifting) did not produce any good result [1]. There should be some unknown reason, due to which they form (Fig. 2).

NORTHERN CASPIAN SALT DOMES

Brusilovsky (1986) was the first to suppose, that the polynyas locations may be related to salt domes presence in the water areas of the North Caspian (Fig. 3).

In 2002, a Russian book "Regional geology and oil-and-gas-bearing capacity of the Caspian Sea" by Glumov, et al., was published [11]. In this book, the authors draw a conclusion for many years of marine geological and geophysical research conducted by methods of seismic, electrical, magnetic, gravity and geothermal survey, drilling, geochemistry, seismology, etc., which was executed mainly by the VNIIMORGEO (All-Russia Scientific-Research Institute of Marine Geology and Geophysics) in the city of Gelendzhik. This is the former all-Soviet leading scientific institute (renamed many times), which set out hundreds of expeditions across the Caspian Sea, including those under supervision of B.N. Golubov. In their work scientist present a detailed diagram of salt tectonics and adjacent dry land in the North Caspian according to drilling, seismic survey and gravimetric data (Fig. 4). Unfortunately, the authors did not make any mention in their book of the salt domes relation to ice processes in the northern Caspian, nor to the polynyas, in particular.

Marine hydrochemistry results, acquired by Gursky (2003, 2007), are also of an informational value. They are published in his Doctor of Sciences dissertation research, comprising 2 volumes. The diagrams acquired by him resemble much in details salt dome rise contours in the North Caspian.

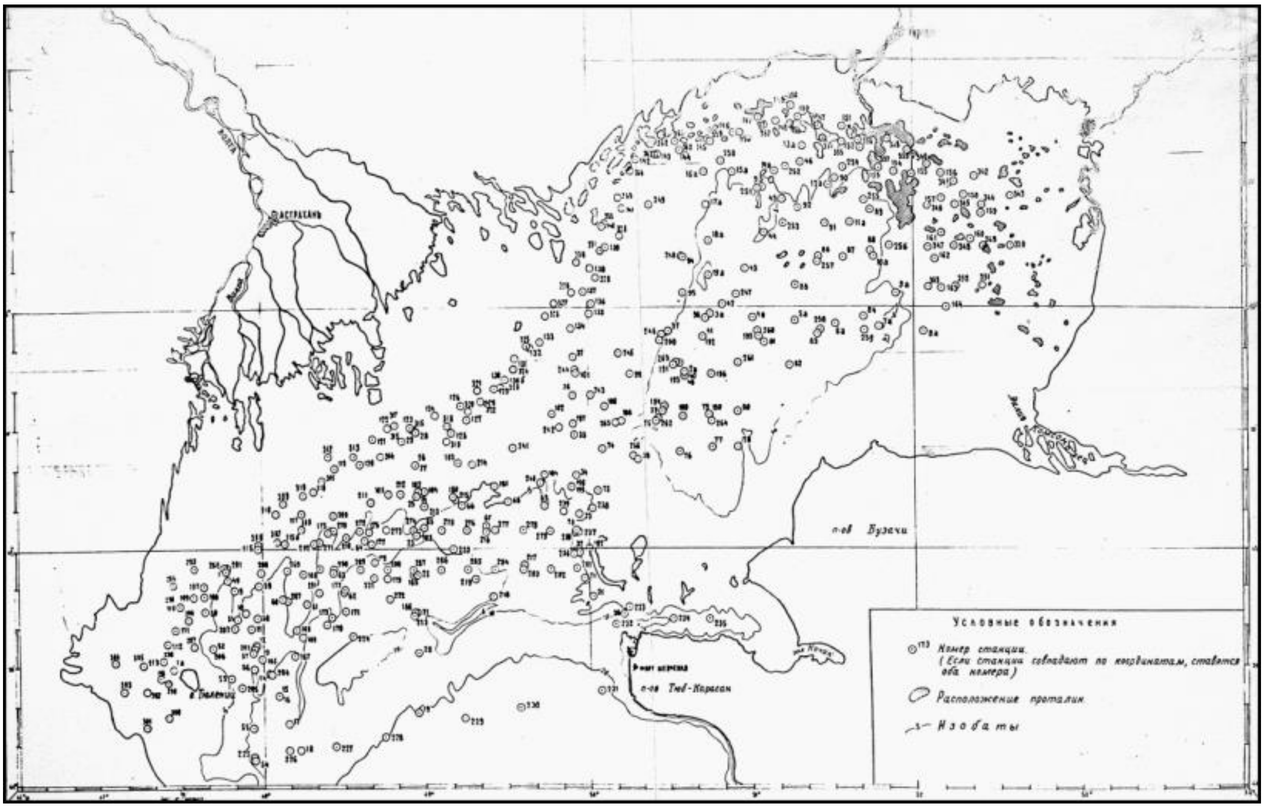

Figure 3. The diagram of salt tectonics and adjacent dry land in the North Caspian (Brusilovsky, 1978)

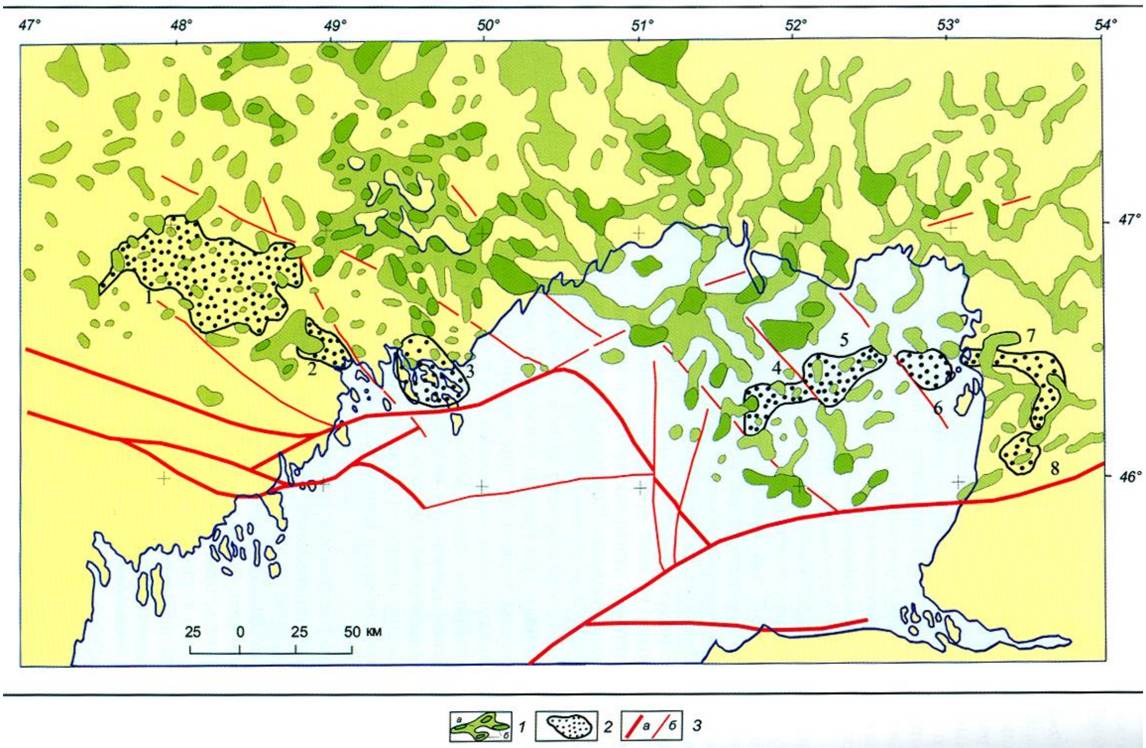

Figure 4. The diagram of salt tectonics and adjacent dry land in the North Caspian (according to drilling, seismic survey and gravimetric data) [11]. Map symbols: 1 - salt beds and masses (a) and local salt cores (b); 2 - subsalt bed protrusions; 3 - subsalt bed fractures: primary (a) and secondary (b). Map figures: subsalt bed protrusions 1 - Astrakhansky, 2 - Imashevsky, 3 - Zhambaisky, 4 - Kerogly-Nubar (western Kashagan), 5 - Kashagan (eastern Kashagan), 6 - Kairan, 7 - Tazhigali-Karaton. 8 - Tengiz.

The author analyses data acquired from many years of observations and proves the supposition made by Brusilovsky: stationary polynyas location practically coincides with salt domes outcropping in the northern Caspian Sea bed (Fig. 5).

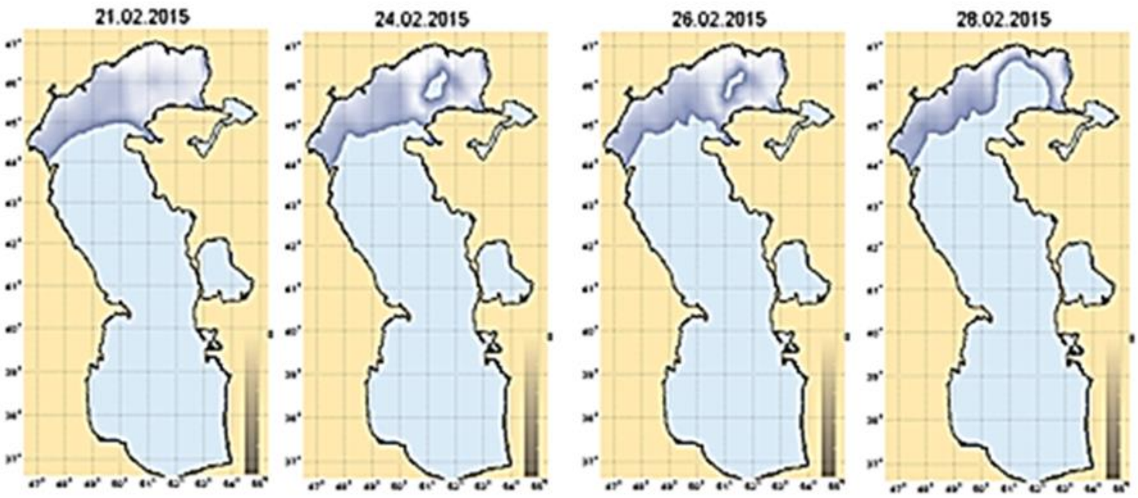

Figure 5. Diagram of the salt domes and polynyas in the North Caspian

The Caspian waters dissolve salt domes peaks, leading to local water salinity growth, which in a cold season results in delay in ice forming above the salt domes. Consequently, there form the polynyas. In summer time, waves and currents hinder findings of local focuses of higher water salinity.

FIELD RESEARCH ON THE CASPIAN ICE STRENGTH PROFILE

Many factors influencing ice strength lead to a large range of strength value, which is described in dedicated literature. Using the same devices and studying methods by the same researchers provided grounds to hope for better results accuracy and a much homogeneous data on the strength, which depends only on objective characteristics of the ice cover. The diagram resulting from many years of study is given in Fig. 6 [10]. Systematic research on the ice strength profile in the eastern part of the North Caspian using a helicopter was conducted in winter season 1970-71. Ice structure and strength study was conducted on open cut of Gurievskaya borozdina - Ukatny isle - Karakaisky bank site on 6th and 9th March, 1971. The ice thickness in the cut ranged from 27 to 42 cm. Tests of plates, obtained from cutting cylinder-shaped ice cores, revealed ice destructive stress value at compression related to its salinity (chlorinity). In all plate samples, its average value was 10-16 kg/cm.

On 29 January, 1972 a helicopter-assisted work was carried out to select the ice cores during the Caspian ice strength study in: Gogolskaya spit, its continental slope, Balashovsky, Suendykovsky, Kolkhozny sand islands, totally at 5 locations in the extreme east of the North Caspian. At the time of the study, the temperature was -19°C, snow cover on ice 0-5 cm, sea depth in three locations was 60-70 cm, in two locations the ice lay on the ground 32-38 cm in thickness. The ice was slightly structured, homogeneous across its strata and matted, as a turbid water had been frozen. Lower strata had air bubbles. Snow temperature was -14.5°, under-ice temperature showed -0.4° - (-0.3°). It was found that the temperature in the ice cores increases from surface towards the sea depth. Thus, on the surface it showed - 13° - (-14°), while in the bottom part only - 5°, with the ice temperature growing faster from the surface. Difference between first 10 cm of the core was 3°, then 2°, 1.5°and, in the lowest strata 1.0 - 0.5°.

The ice chlorinity (salinity) in the considered samples increased along its depth. At the ice surface it was 700-900 mg/l and in lower strata - 1300-1500 mg/l. Destructive load for 100 ice plate samples, as tested by application-interpreted model was: 40-50 kg - for upper strata, 30 kg - for lower strata. The ice strength value varies from 7 to 3-4 kg/cm.

In January, 1973 the aircraft-assisted work for the ice strength study in the eastern part of the North Caspian was continued. Photography shooting was carried out on January 27 at nearly the same locations, as were in January, 1972. At the time of the study, air temperature was -7°, snow cover on ice 4–5 cm, the ice temperature -5.5°, upper ice stratum temperature -4.8°, ice temperature in near-water stratum was -1.5°, water temperature -0.2°. Thus, the temperature distribution in the ice strata measured in January, 1973 differed significantly from that of the previous year. Ice temperature increasing gradient did not exceed 1.0° (in 1972 it reached 3.0°) across all the ice strata.

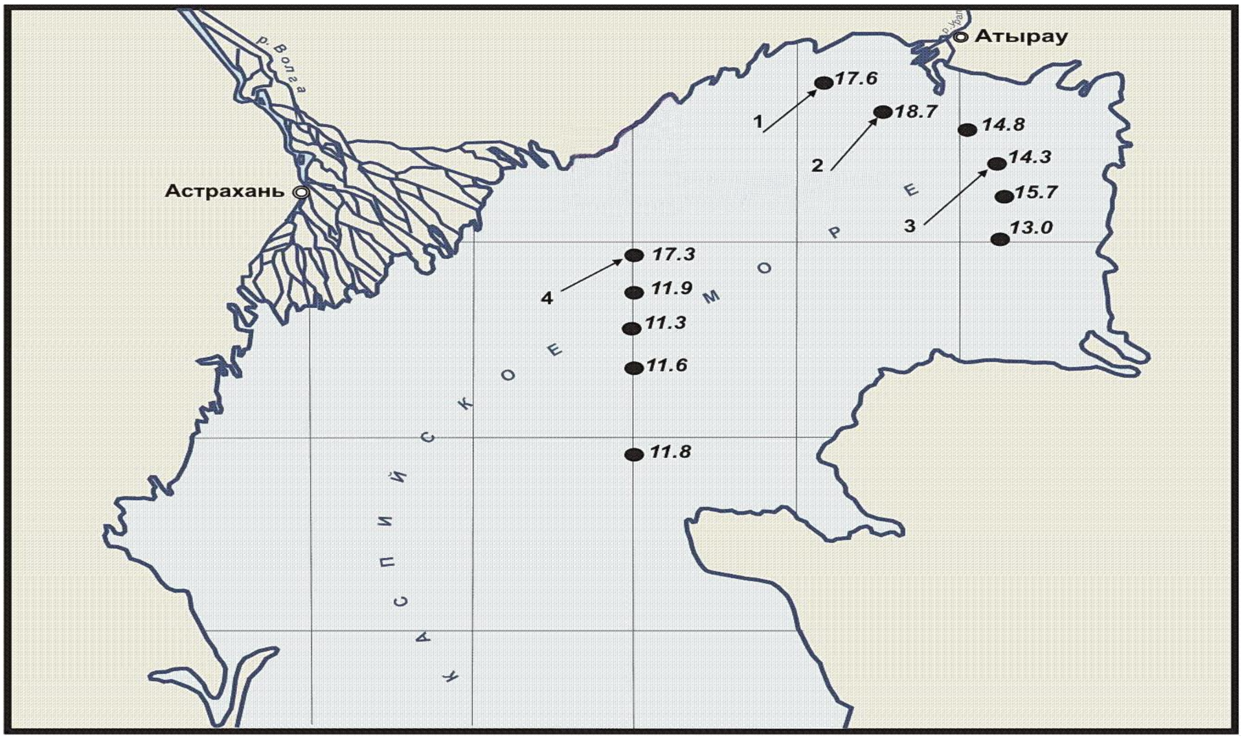

Figure. 6. The ice core sampling points in the east of the North Caspian.
Figures near the points stand for ice average strength in core, kg/cm².
Arrows show the points, data from which was used to draw the ice strength curves.

The chlorinity (salinity) in different ice strata varied from 320 to 1,540 mg/l (Table 1).

Table 1. Comparison of ice chlorinity in eastern areas of the North Caspian
in 1972 and 1973, mg/l

Average	Years		Average for 2 years
	1972	1973	
From surface ice samples	826	585	665
From bottom ice samples	1405	890	1062
From all samples	1085	685	835

Such difference in the ice chlorinity (salinity) value for the years given may be explaine d by ice formation peculiarities. So, during the winter seasons 1971-72 ice formation ran quickly. Freezing water captured many salts, which, forming salt brine cells, filled in sp ace between the fresh-water ice crystals, thus increasing the chlorinity (salinity) of the ic e. While in winter 1972-73 decrease in temperature occurred slowly. The ice formation p assed gradually, with the salt brine leaking down into the water and increasing salinity o f the under-ice water, at the same time, the ice chlorinity (salinity) was decreasing.

Like the chlorinity (salinity), average ice strength in 1973 proved to be sufficiently highe r than in 1972 - 14.4 kg/cm. Near the same was an average strength in upper and lower strata.

For the two years (1972-1973), average value of the ice strength in all horizons was 10. 7 kg/cm, and surface stratum average strength was 12.1 kg/cm [10].

The next stage of the ice study was measuring ice maximum strength in different areas of the North Caspian. This work was conducted from December 27, 1973 to February 3, 1974 at 30 equidistant points in the North Caspian water area. Air temperature at the c ore sampling points ranged from -1.5° to -18.1°, ice thickness was 11 to 43 cm, snow c over on the ice was 0 to 4 cm and water temperature under the ice was 0.85° to -0.26°. Water salinity at the surface (under the ice) varied greatly: from almost fresh at estuary seashores of the Volga and the Ural rivers to 20.52 ‰ in coastal area at the extreme eas t of the sea (Fig. 6 and 7) [10].

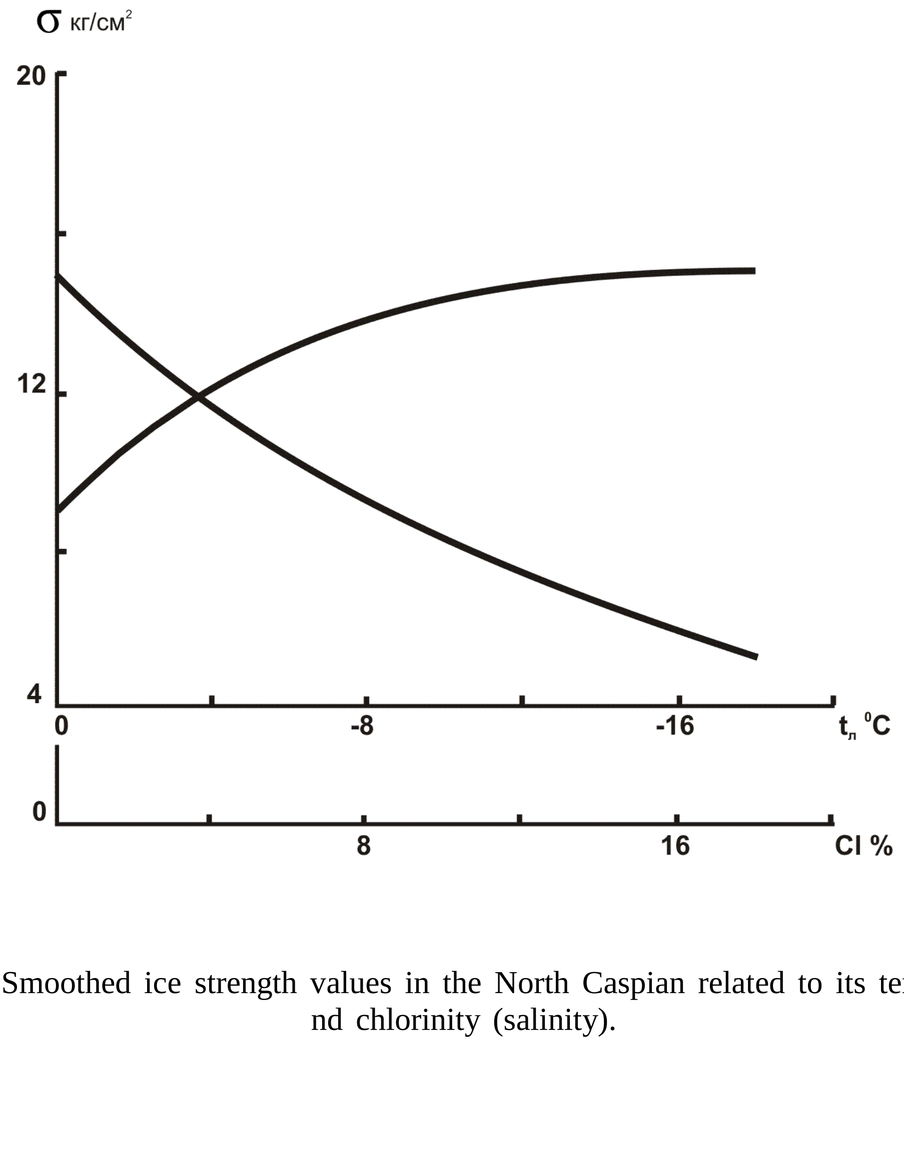

Figure 7. Smoothed ice strength values in the North Caspian related to its temperature a nd chlorinity (salinity).

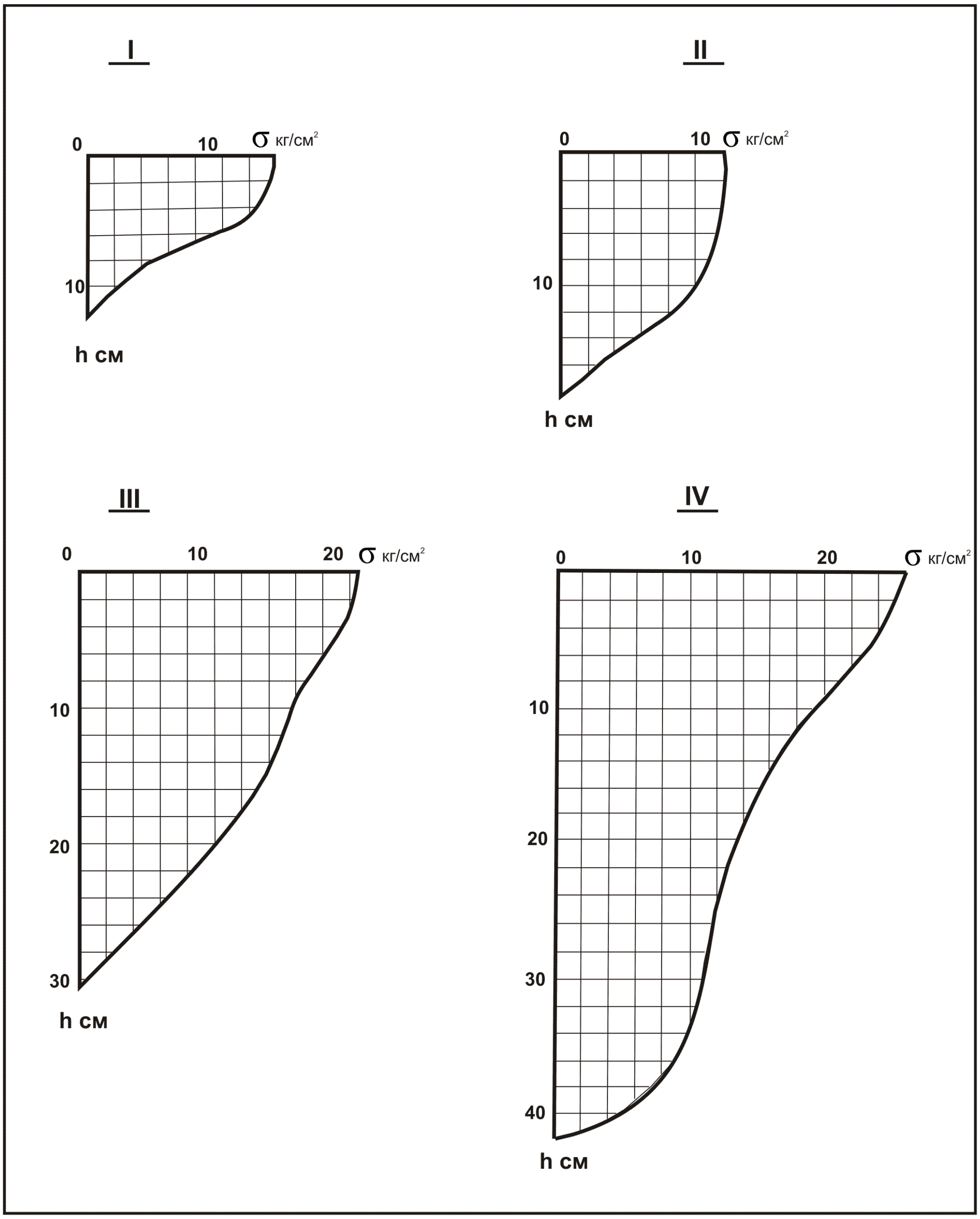

Figure 8. The curves of the ice strength at points located in the eastern part of the North Caspian:

1 - 27. XII.1973; **2** - 05.01.1974; **3** - 10.1.1974; **4** - 20.01.1974.

CONCLUSIONS

Analysis of the gathered aircraft and satellite data proved Brusilovsky's supposition, that some polynyas in freezing shallow areas of the North Caspian Sea form annually in the same locations.

The most probable factor facilitating their local formation is the least strong and thick ice, which forms above the salt domes, and with wind and currents, it is destructed easier than a stronger ice formed from almost fresh water of the Volga and the Ural rivers falling into the northern part of the Caspian. The field research results obtained during wintertime studies 1970-73 prove this supposition completely.

The research should be continued to receive a more detailed hydro-chemical description of the coastal area marine waters in the Caspian Sea (above the salt domes) during a winter season.

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