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*MAPPING OF GROUND ICE IN CENTRAL YAMAL**

SUMMARY. The Map of tabular ground ice depth was compiled as a result of the analysis of borehole and published data. The Map is based on a landscape features-indicators method. It is established that tabular ground ice occurs closer to the surface within outliers of marine plains, and deeper at the lowered surfaces subjected to thermokarst.

KEY WORDS. Tabular ground ice, landscape indication, cryogenic landsliding, thermokarst, mapping technique.

The distribution and occurrence of tabular ices in the cut is rather well studied. The peninsula of Yamal is known as the brightest representative of areas with tabular ices [1]. In numerous publications [2-9] it is noted that in Central Yamal (in the interfluves area of the rivers Muzzle-Yaha, Se-Yaha and Naduy-Yaha) the tabular ice covers the area of tens of square kilometers; it is distributed on all levels, from high geomorphological marine plains to floodplains. Vertically stratified ice is represented by one or several layers. Typically, the ice reservoir is found at depth of several meters to tens of meters, and it has a capacity of tens of centimeters to tens of meters [4], [5], [8]. Ice is often identified by specific cryogenic processes on the surface [2], [7]. The analyzed data suggests that the power and distribution of tabular ice is diminishing to the north (from Bovanenkovo to Kharasavey — the two most fully-characterized drilling areas). The data received in the outcrops of Neytinskiye lakes provides information of ice height of 20 m at depths of 5-26 m [5], and according to some sources, the height can reach 40-50 m [3]. The area of separate ice deposits can be up to 5.7 km^2, the height of 30-45 m, and the volume of 150-300 million m^3 [6].

The basic information on the ice occurrence is in columns of numerous wells drilled with the prospect of erecting linear structures [9].The district of Bovanenkovo field is selected as the major one due to the wide expansion of tabular ice occurrence near the surface and due to the large amount of research in this sphere.

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The signs of ice embedded close to the surface are the following:

- As for space-and air photos, it is landslide circuses with hanging thermokarst lakes on the slopes (Fig. 1a) and deep thermokarst lake, near which there is tabular ice reservoir opened in the wells (Fig. 1b);
- As for the maps, it is landslide circuses (Fig. 1c) and wavy horizontals (Fig. 1d).

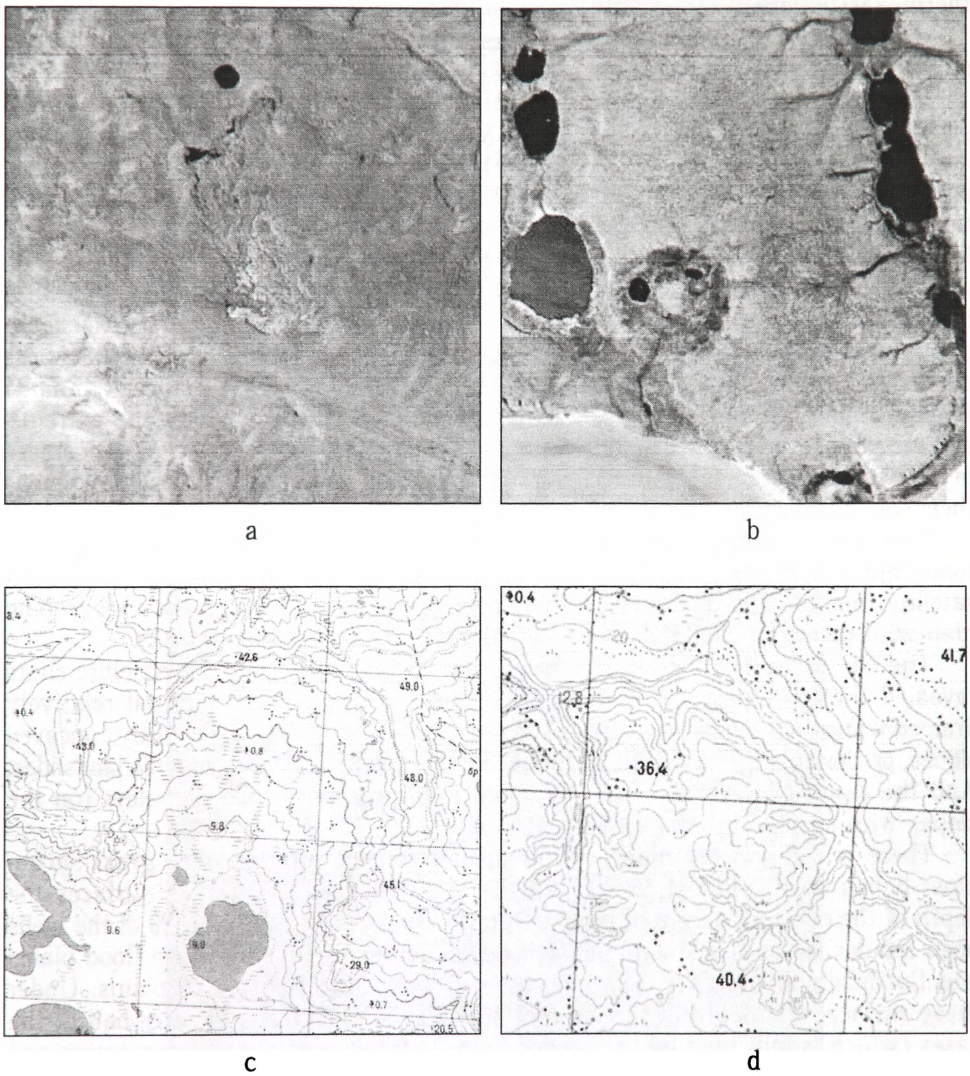

Fig. 1. Fragments of air photos (a, b) and topographic maps (c, d) with the signs of tabular ice embedded close to the surface

The distribution of tabular ice in the Central Yamal (and in generally bare territories) can be identified in the following way. Tabular ice is found:

- in contours of interfluvial areas, where ice is found in lakes and rivers with coastal breaks, and in wells.
- in contours of the interfluvial areas, complicated by landslide circuses and concave slopes.
- in contours of interfluvial areas, where there are slopes with small perched thermokarstic lakes.
- at the base of khasyrey of small lakes and wide inundated spaces with narrow strongly migrating courses.

A considerable amount of factual material was obtained by perennial geocryological surveys and drilling by All-Russian Research Institute of Hydrogeology and Engineering Geology — (ARRIHEG). The processing of this material gives an opportunity to check the thoretical laws in the areas, the photos of which were taken by ARRIHEG under the direction of E.S. Melnikov in Bovanenkovo gas field in 1987-1991. According to the data gathered from 76 wells, the height distribution statistics of tabular ice is as follows: in 15% of cases it exceeds 15 m; in the 38% it ranges from 15 to 5 m, and in 47% it is less than 5 m. The change in the thickness of a reservoir is connected with the local geomorphological conditions: the thickness decreases in the sequence: marine terrace remnants III > alluvial terraces remnants II > floodplains of major rivers. This tendency can be seen for both the extreme, and for average variables. The thickness of ice decreases generally owing to decrease in absolute marks of the roof of layers (that is, thermokarstic processes), whereas their sole has smaller hesitations.

The tables, compiled as a result of the analysis of ARRIHEG drilling data, topographic maps and images (Table 1), are used to interpret the high resolution satellite images. Fig. 2 shows the overlapping of the image and the topographic map with marked ARRIHEG wells (a fragment of the key area 04-87).

The comparison of the location of opened up tabular ice and the satellite shots revealed that the majority of wells are drilled on either sub-horizontal relatively drained watershed shrub-grass-moss surfaces (20%), or on the flat/slightly concaved slopes, predominantly with shrubs (19%), and often with ancient cryogenic landslides. And the depth of the roof of the ice there is mostly more than 3 meters (on the slopes with shrubs it rarely exceeds 10 meters).

There is a high percentage of rolling and convex surfaces with grass-shrub-moss-lichen cover (almost 18% of all the analyzed wells). On such surfaces the depth of the embedded ice roof ranges from 1-3 meters. More than 15% of the wells open tabular ice on flat low marsh surface, characteristic of I, II above-flood plains and floodplain of the river Seyakha, as well as extended low lake plains. Under these surfaces the depth of the ice roof strata is 5-10 meters in nearly half of the cases (which is indicated by the predominance of sphagnum moss, vegetation and surface polygonal character)

In other cases, where the depth of the ice roof is less than 5 meters, there are flat, marshy places, with sedge-moss or shrubs (mainly willow forests in the transition zone between a little more drained elevated surfaces and low minimum drained surfaces).

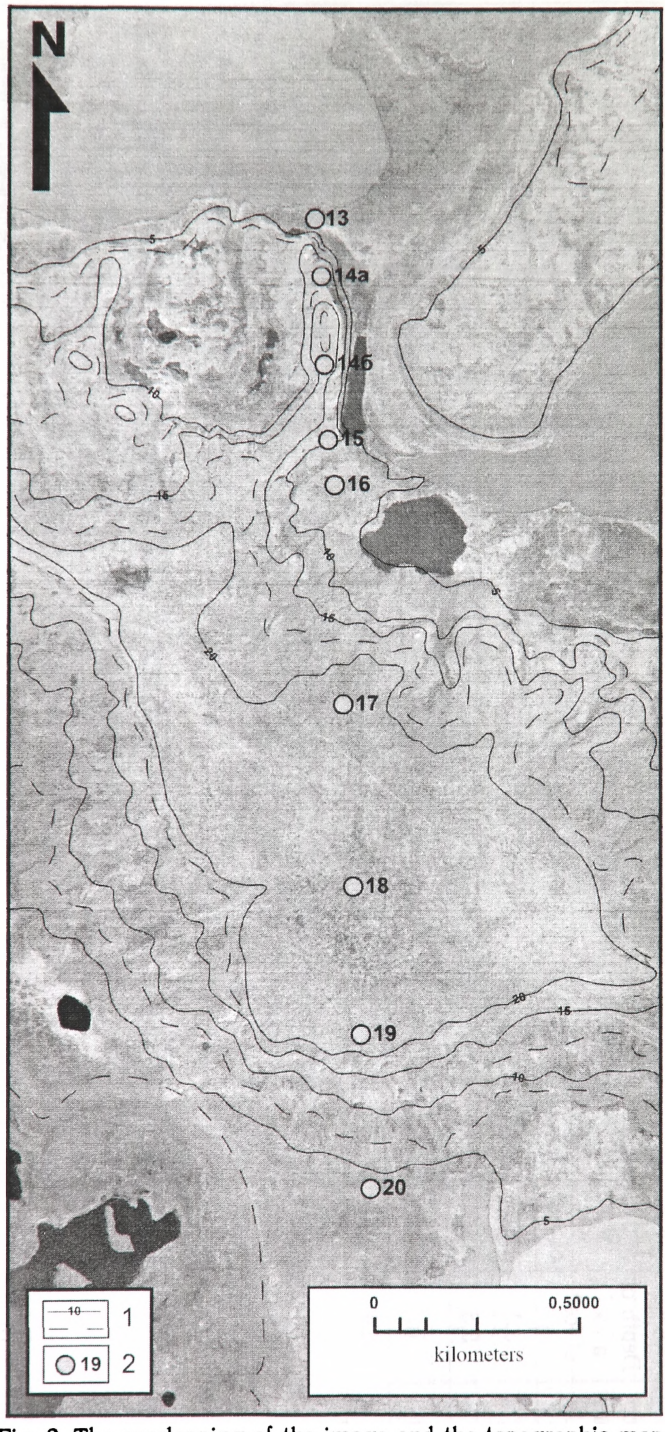

Fig. 2. The overlapping of the image and the topographic map with marked ARRIHEG wells

Table 1

Tabular ice indicators in the wells at the key site 04-87 (according to the data processing of VSEGINGEO shots carried out by E.S. Melnikov Group in 1987-1991

hard currency No.	Depth of a roof of ice*	Depth of a sole of ice*	Ice capacity	Geol. index	Character of a relief	Absolute height (by topographical map), m	Comment
13	3,4	3,5	0,1	a IV	Flat boggy surface	4-5	Slopes and an outlier of the second above the flood plain terrace of river of the Seyakh dismembered by lakes, a board and the bottom hasyreya. Sole of a layer of ice below a well face (except for thin pro-layers and PzhL)
	5,8	6,0	0,2				
14a	1,1	3,5	2,4	a III	Convex top (peripheral part)	9-10	
14б	0,9	2,7	1,8	a III	Convex top	15-17	
	5,8	-	-				
15	5,5	-	-	a III	Convex top (peripheral part)	10-12	
16	1,3	1,4	0,1	b IV	Flat boggy surface	7-8	
	2,4	2,5	0,1				
17	19,7	-	-	a IV	Flat surface of a watershed	20-21	Surface of the III alluvial and sea plain surrounded with podzol slopes and dismembered by lakes. A sole of a layer of ice below a well face
18	12,3	-	-	am III	Polygonal surface of a peatland	21	
19	12	-	-	am III		20-21	

The end of Table 1

20	4,3	-	-	s IV	Lower part of an ancient podzol slope	4	Slope of the III alluvial and sea plain surrounded with podzol slopes and dismembered by lakes. Sole of a layer of ice below a well face
22	3,1	-	-	m III	Surface of an ancient podzol slope	8	Outlier III of the sea terrace surrounded with podzol slopes and dismembered by lakes. On podzol slopes small trailing lakes. A sole of a layer of ice below a well face (except for thin pro-layers and PZhL)
4	14,8	-	-	m III	Flat surface of an outlier	23	
2	9,2	11,6	2,4	m III	Surface of an ancient podzol slope	7-8	
23	4,8	4,9	0,1	m III(2-3)	Convex surface of a slope	19-20	
	5,1	5,2	0,1				
	12,8	-	-				
25	3,1	9,6	6,5	m III	Gentle slope	12-13	Slopes and an outlier of the III sea and alluvial and sea plain surrounded with podzol slopes and dismembered by lakes. Capacity of a layer of ice from 1,8 to 6,9 m (an average of 4,5 m)
26	18,5	25,4	6,9	am III	Convex top	24-25	
27	3,7	6,5	2,8	m III	Surface of an ancient podzol slope	8-10	
28	5,8	7,6	1,8	m III	Lower part of an ancient podzol slope	5-6	

* data of shooting ARRIHEG

Almost a tenth of all the analyzed wells are on the surface or sliding thermocircuses, where outcrop formations of ice are found. These surfaces are characterized by the development of thermoerosion and by the overgrowing vegetation after a massive deconstruction due to the thawing of tabular ice and after cryogenic landslides. The depth of ice roof in this case changes from 1 to 10 meters (the height of the ice reservoir may reach up to 15 meters), and there is no clear predominance of a particular depth range. Most likely this is due to the fact that different modern thermocircuses or landslide cirques carved into the surface of different origin, in which massive ice initially occurred at different depths. Besides, the reason the diversity of depths of ice reservoirs may be the differences in the degree of activity of thermoerosion processes and the rate of restoring the damaged surfaces of thermocircus/landslide circus. Due to this, there is no clear dominance of a particular range of depths of the ice roof strata under the concave slopes, occupied by willow forests (7.1% of the analyzed wells). The only difference is that the minimum depth at which the ice occurs is 1 m. This is owing to the fact that slopes with tall willows are surfaces of ancient landslides, which at the time of drilling were not subject to thermoerosion and were characterized by a seasonally formed layer of more than 1 m. This is confirmed by the fact that 3 of the 4 wells that fall subject to the ancient creep gentle slopes with willows, reveal massive ice at depths of 3 to 5 meters. The remaining wells were distributed at 1-2 holes on different surfaces, and it is not enough to talk about the signs of the depth of ice formations.

According to the research results, the index features build up a map of the roof depth of the ice formation (Fig. 3.) based on the landscape map of the key area, the method of construction for the area was developed [10]. In constructing the depth map of the tabular ice roof the percentage of wells belonging to a variety of environmental systems was taken into account.

The depth range of the ice roof strata "from 1 to 5 m" is characteristic of rolling surfaces — remnants II of floodplains and rolling slopes mostly with bushes, treated by cryogenic slumping process. The depth of the roof strata of ice, "from 5 to 10 m", dominates the flat and poorly drained wetland surfaces with moss. For most of the other surfaces characterized by the absence of tabular ice deposits, cut by drilling, so these surfaces refer to a range of depth of ice formation of "more than 10 meters".

The survey has revealed that the ice deposits are least deep in remnants of higher surfaces. Relatively deep dislocation of ice is in rather extensive watersheds, less processed by denudation. These watersheds are large storage pools of tabular ice. A deeper location of ice formations is in valley bottoms and lake basins, the reason for what is melting of ice in the Holocene optimum thermal period, and the warm influence of water masses (migrating river channels and lakes) and the anthropogenic factor. Thus, it was found out that the characteristics of the relief can be considered as one of the most important components of the landscape when exploring the depth of the ice formation.

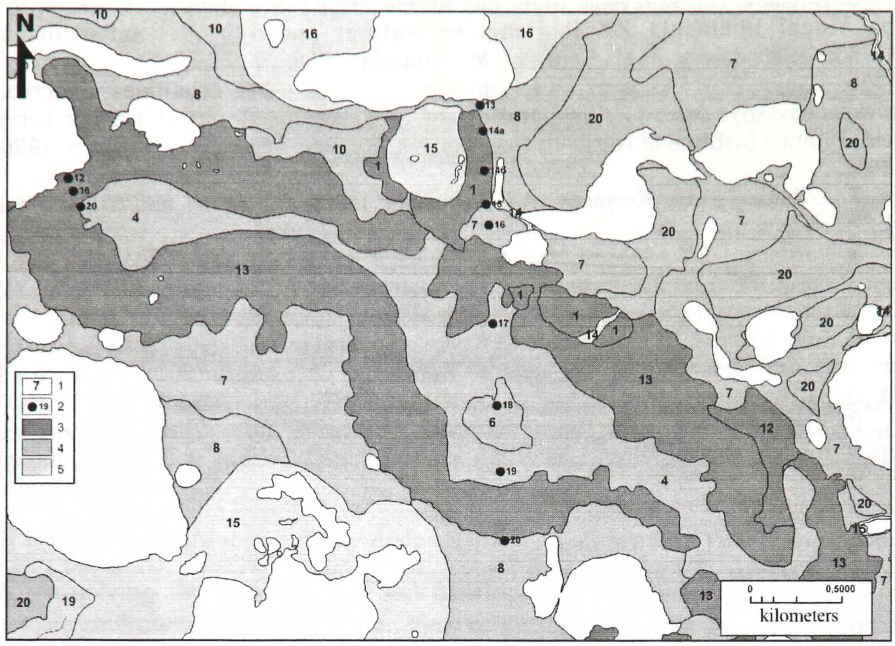

Fig. 3. The fragment of the key area 04-87 and 01-88 with the depth map section of the ice roof strata

1 — CPT codes (for A.V. Khomutov, 2010) [10]

2 — wells drilled during ARRIHEG shooting; the depth of formation of the ice roof

3 — from 1 to 5 m, 4 — from 5 to 10 m, 5 — 10 m

The analysis of ice layers in the cut found that the highest ice of the top 20-meter rock strata lie at depths of 5-7 m below the surface. The upper limit of the ice is not noticed to exceed 12 m, while deep wells are characterized by this. This suggests the existence of two ice layers different in age in Central Yamal Peninsula, which is consistent with our observations of the double-layered structure of tabular ice in outcrops Yugra Peninsula and outcrops of Yamal and Taimyr.

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