Dr. Naum Oberman
Head of the Centre for the Monitoring of the Subsoil Conditions
MIREKO Company,
Republic of Komi. Russia

Degradation of Permafrost in the Condition of Global Warming and its Impact on Infrastructure in the Eastern Part of The Barents Region

In the eastern part of the Barents region there are 13 geocryologic stations with long-term observations; half of those stations are functioning now. And besides, there are numerous reference thermometric boreholes dispersed on the whole area and shown on Figure 1.

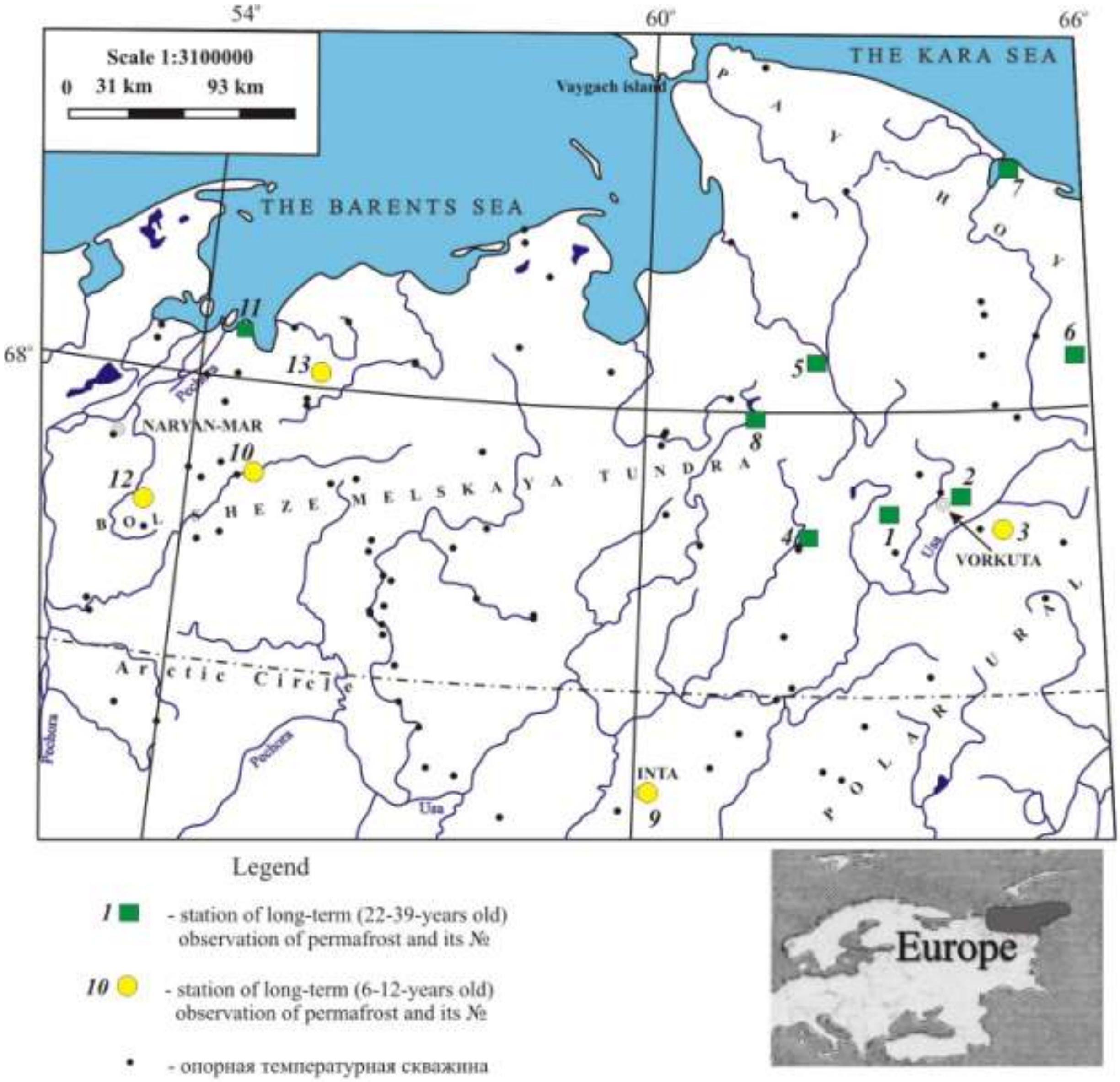


Figure 1. Survey Map of the Region

Results of all these observations allow characterizing consequences of climate warming for the permafrost of region. The tendency of rise in air temperature on this territory is marked everywhere and, generally, since 1970 (Figure 2).

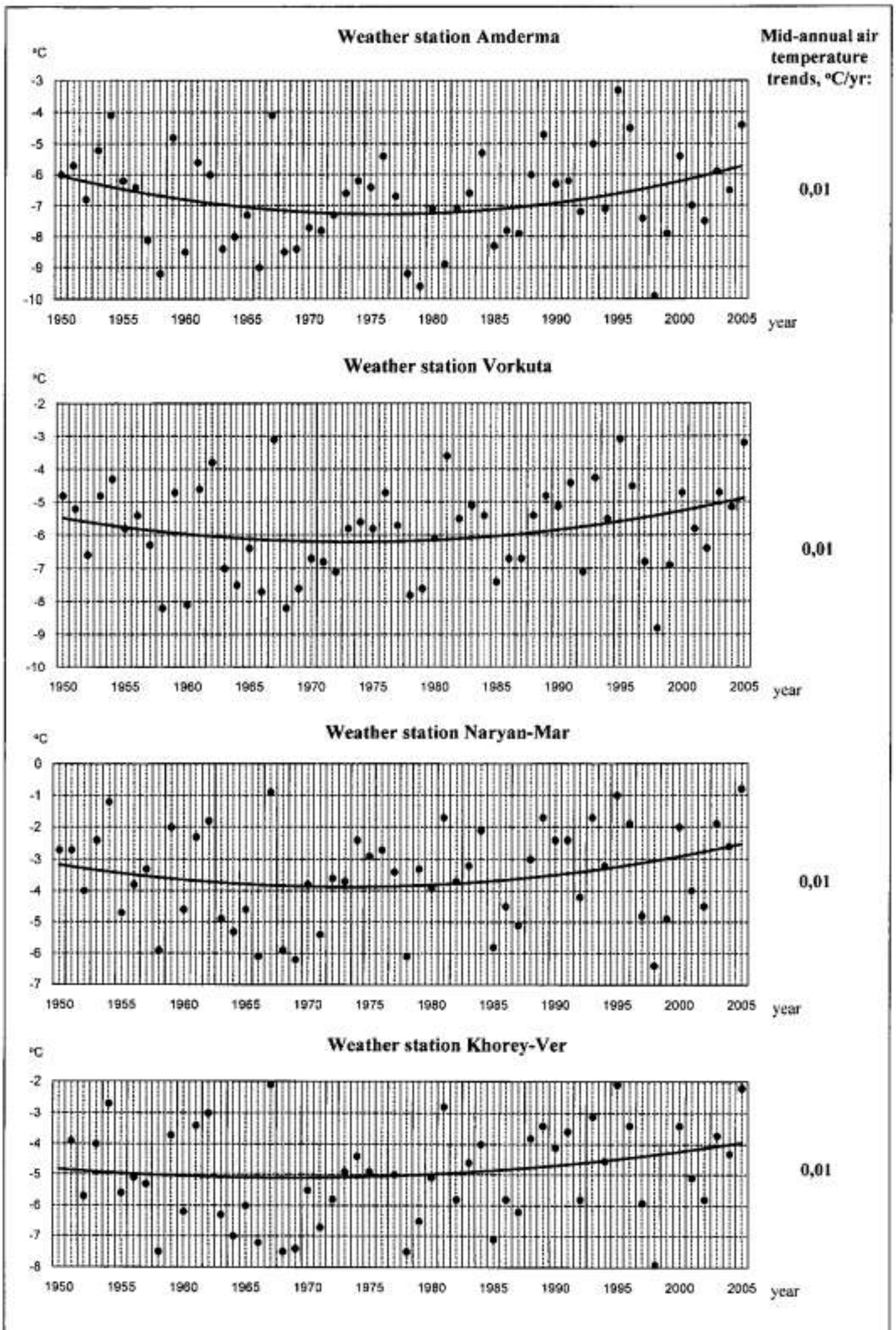


Figure 2. Mid-annual air temperature trends in the region for 1950-2005

As follows from this Figure, the value of trend of air temperatures, according to characteristic meteorological stations of considered territory, as a whole, is identical. It would seem that the reaction of permafrost to climate warming should be identical. But here the most diverse uneven-aged landscapes are widespread: glacial-marine, lacustrine-alluvial, marine, socle plains and landscapes of Urals and Pay-Khoy Mountains (Figure 3).

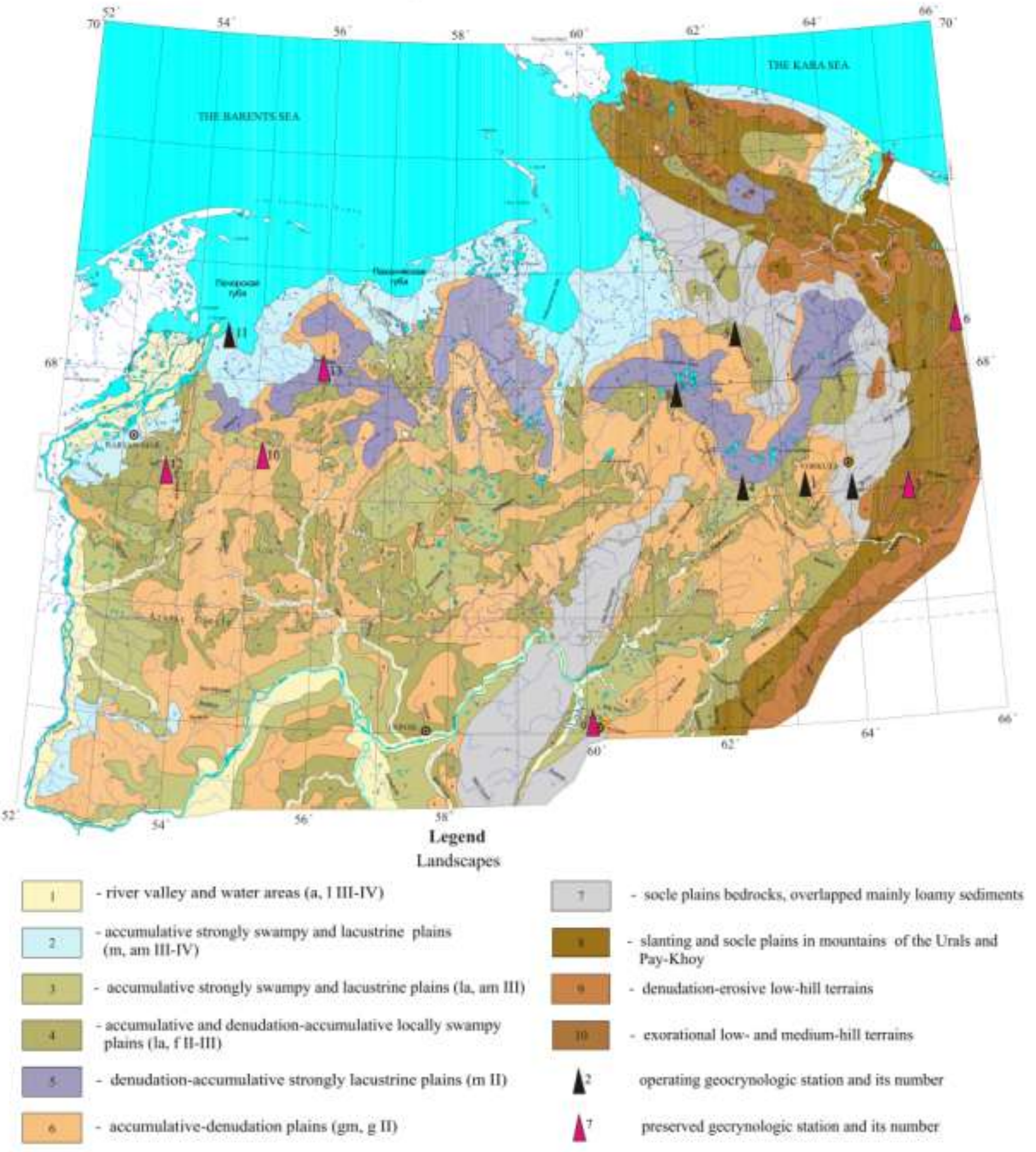


Figure 3. Landscape map of the region
Scale 1:1500000

It is obvious that sands, peats, loams, bedrocks composing these landscapes, should react differently even to identical changes of air temperature. And data of long-term observations, in particular, of temperature of permafrost at depths of 10-15 m confirm this statement. For example, amplitudes of rise in permafrost temperature for the long-term period vary within 0,2 to 1,6 °C, and the long-term average rate of permafrost warming differs on different landscapes in 3-8 times, that is, almost at an order (look at the last 2 columns in table 1).

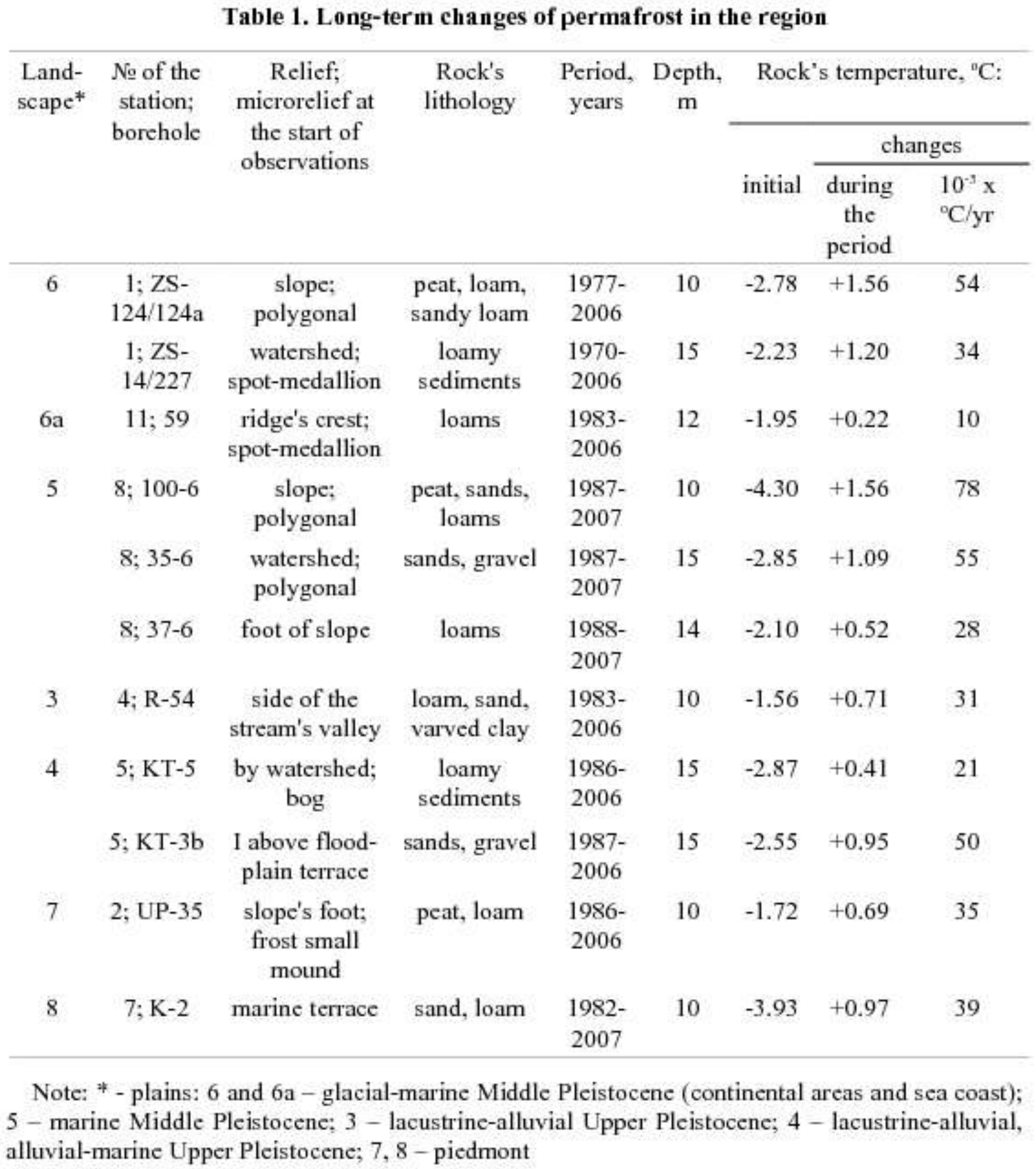


Table 1. Long-term changes of permafrost in the region

Land-scape*	№ of the station; borehole	Relief; microrelief at the start of observations	Rock's lithology	Period, years	Depth, m	Rock's temperature, °C:		
							changes	
						initial	during the period	10^{-3} x °C/yr
6	1; ZS-124/124a	slope; polygonal	peat, loam, sandy loam	1977-2006	10	-2.78	+1.56	54
	1; ZS-14/227	watershed; spot-medallion	loamy sediments	1970-2006	15	-2.23	+1.20	34
6a	11; 59	ridge's crest; spot-medallion	loams	1983-2006	12	-1.95	+0.22	10
5	8; 100-6	slope; polygonal	peat, sands, loams	1987-2007	10	-4.30	+1.56	78
	8; 35-6	watershed; polygonal	sands, gravel	1987-2007	15	-2.85	+1.09	55
	8; 37-6	foot of slope	loams	1988-2007	14	-2.10	+0.52	28
3	4; R-54	side of the stream's valley	loam, sand, varved clay	1983-2006	10	-1.56	+0.71	31
4	5; KT-5	by watershed; bog	loamy sediments	1986-2006	15	-2.87	+0.41	21
	5; KT-3b	I above flood-plain terrace	sands, gravel	1987-2006	15	-2.55	+0.95	50
7	2; UP-35	slope's foot; frost small mound	peat, loam	1986-2006	10	-1.72	+0.69	35
8	7; K-2	marine terrace	sand, loam	1982-2007	10	-3.93	+0.97	39

Note: * - plains: 6 and 6a – glacial-marine Middle Pleistocene (continental areas and sea coast); 5 – marine Middle Pleistocene; 3 – lacustrine-alluvial Upper Pleistocene; 4 – lacustrine-alluvial, alluvial-marine Upper Pleistocene; 7, 8 – piedmont

Dynamics of thickness of closed taliks depending on their genesis and landscape conditions is no less contrast. The increase of talik thickness for 2-3 decades made from less 1 to almost 16 m in permafrost Quaternary sediments and to 25 m in bedrocks (Table 2).

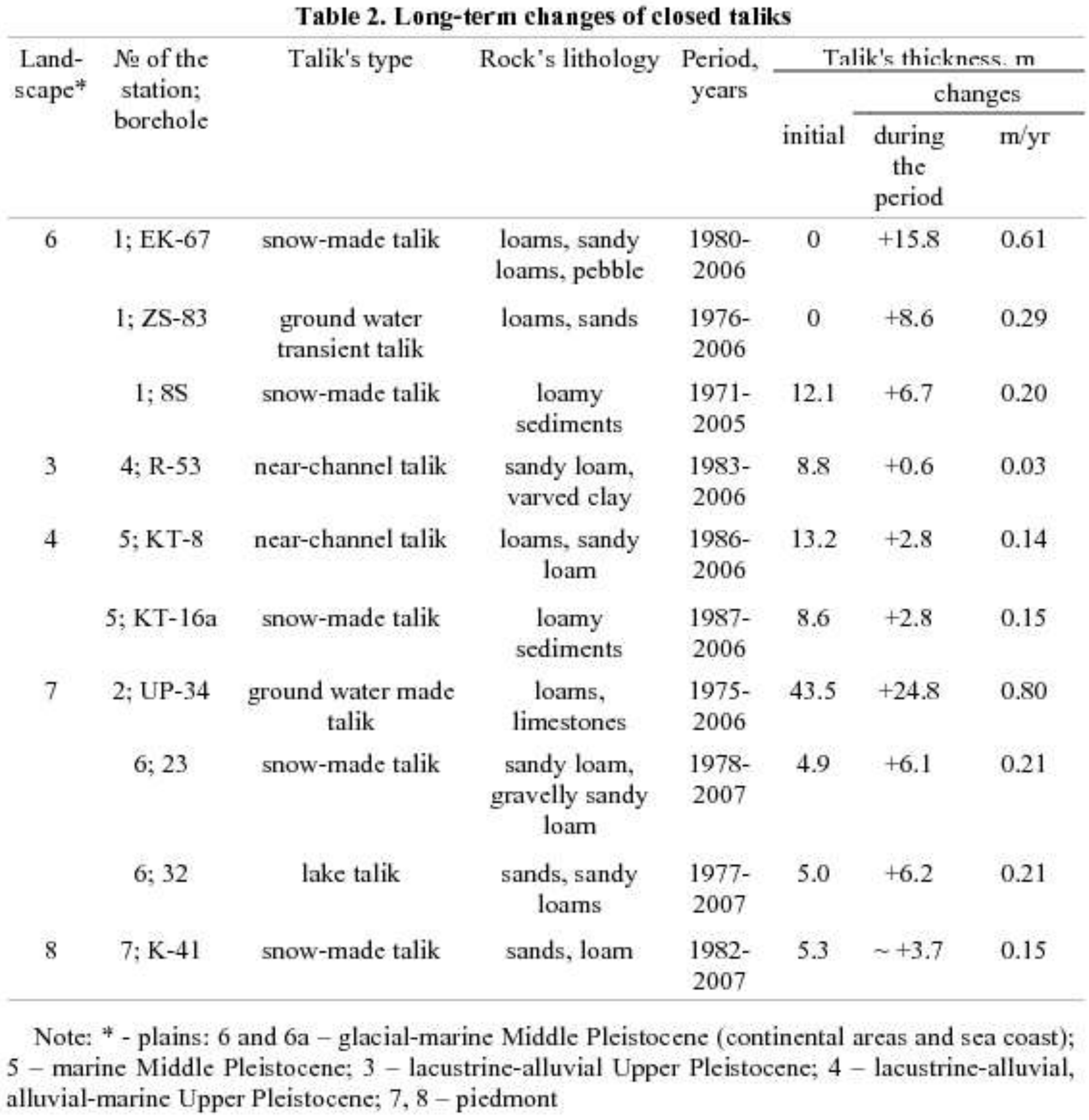
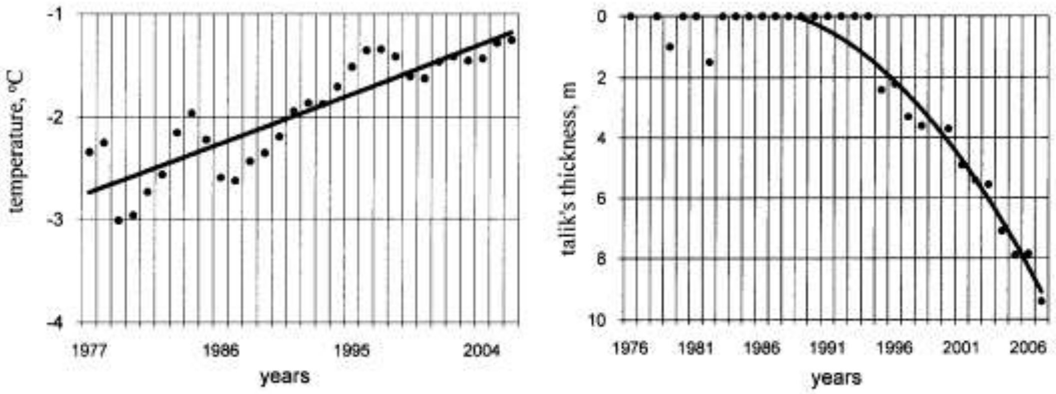


Table 2. Long-term changes of closed taliks

Land-scape*	№ of the station; borehole	Talik's type	Rock's lithology	Period, years	Talik's thickness, m		
						changes	
					initial	during the period	m/yr
6	1; EK-67	snow-made talik	loams, sandy loams, pebble	1980-2006	0	+15.8	0.61
	1; ZS-83	ground water transient talik	loams, sands	1976-2006	0	+8.6	0.29
	1; 8S	snow-made talik	loamy sediments	1971-2005	12.1	+6.7	0.20
3	4; R-53	near-channel talik	sandy loam, varved clay	1983-2006	8.8	+0.6	0.03
4	5; KT-8	near-channel talik	loams, sandy loam	1986-2006	13.2	+2.8	0.14
	5; KT-16a	snow-made talik	loamy sediments	1987-2006	8.6	+2.8	0.15
7	2; UP-34	ground water made talik	loams, limestones	1975-2006	43.5	+24.8	0.80
	6; 23	snow-made talik	sandy loam, gravelly sandy loam	1978-2007	4.9	+6.1	0.21
	6; 32	lake talik	sands, sandy loams	1977-2007	5.0	+6.2	0.21
8	7; K-41	snow-made talik	sands, loam	1982-2007	5.3	~ +3.7	0.15

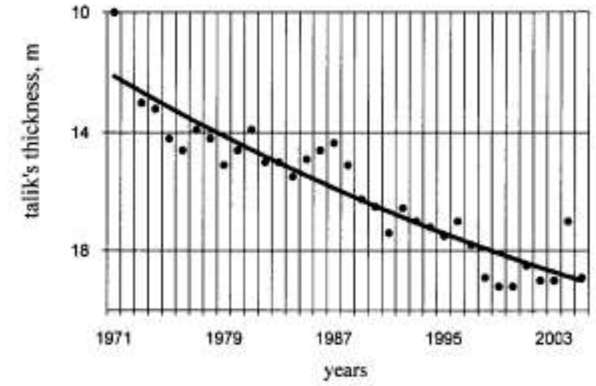
Note: * - plains: 6 and 6a – glacial-marine Middle Pleistocene (continental areas and sea coast); 5 – marine Middle Pleistocene; 3 – lacustrine-alluvial Upper Pleistocene; 4 – lacustrine-alluvial, alluvial-marine Upper Pleistocene; 7, 8 – piedmont

Clear representation about features of dynamics of the mentioned and some other parameters of degradation of modern permafrost is given in Figure 4.

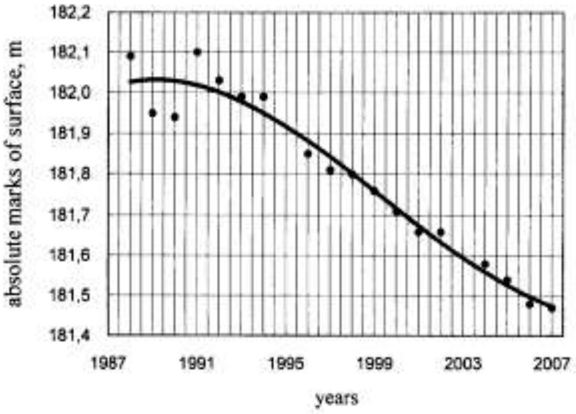


A. Increasing permafrost temperature

B. New formation of closed taliks



C. Increasing thickness of taliks existed before 1970



D. Thermokarst settling of a soil surface, m

Figure 4. The some indices of modern permafrost degradation in European North-East

On the diagram A of this Figure you can see short-term fluctuations of permafrost temperature against the background of longer trend of its increase. The diagram C illustrates the process of permafrost thawing in the base of closed taliks existed prior to the beginning of modern climate warming, and increase of talik thickness as a result of permafrost thawing. The diagram B shows as rapidly, only within one decade, a closed talik 10 meters thickness aroused on a site with former discharged permafrost composed of sandy loam-loamy sediments with low ice content. Diagrams C and B are at the same time indirect exponents of reduction rates permafrost thickness and change of its structure in vertical section. Simultaneously chronological diagram of new growth of closed taliks testifies to reduction of distribution of permafrost on the area. Diagram D shows thermokarst settling of terrestrial surface at permafrost thawing. Decreasing of its mid-annual absolute marks, extremely irregular even at small distances, can reach, as seen on the diagram, 0,6 m in all for 20 years.

Regional display of some of the listed parameters of transformation of permafrost is reflected in the map of its degradation on the area of the European Northeast for the period 1970-2005 (Figure 5).

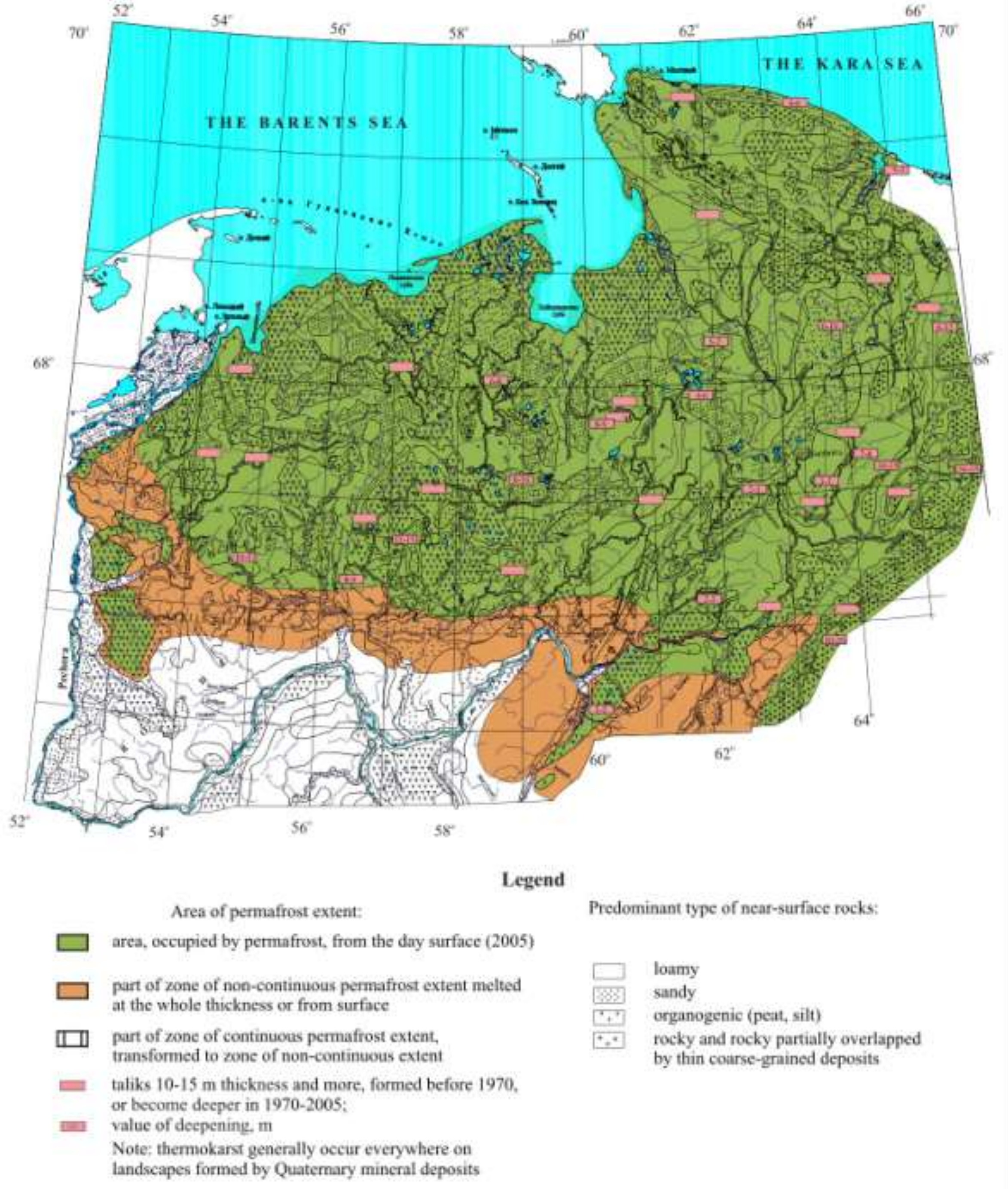


FIGURE 5. MAP OF PERMAFROST DEGRADATION IN EUROPEAN NORTH-EAST FOR 1970-2005

(Compiled by: Oberman N.G., Shesler I.G. 2008 Computerized support: Makov R.B., Melnichuk E.B.)

Green color on the map shows the area occupied by permafrost widespread from the day time surface, as of 2005. Brown color covers a part of zone of non-continuous permafrost thawed out for the whole thickness or from the surface. That is, it is a territory from which the southern border of distribution of permafrost receded to the north for the specified 35-years period. The value of such receding on the areas composed of mineral deposits made, generally 30-40 km on the Pechora lowland and up to 70-100 km in the

Pre-Urals. Pink rectangles display fixed closed taliks and increases of their thickness for the considered period. Taliks appeared not only in the coastal strip of rivers and lakes, but also on watersheds and their slopes. This fact combined with the rise of temperature of permafrost warmer than minus 2-2,5^{o}C is interpreted as partial transformation of the zone of continuous permafrost to the zone of non-continuous permafrost. This territory is pick out on the map by vertical shading. The map is accompanied by the note in which it is marked that thermokarst settlements are practical everywhere on the areas composed of Quaternary mineral deposits.

All the stated shows how significant the degradation transformations of permafrost, which were enveloped it in conditions of global warming. Therefore no wonder that perceptible negative influence of permafrost degradation on various infrastructure of region is reveal itself already now. To estimate this influence on the multi-storey building in the city of Vorkuta we used such a parameter as deforming coefficient suggested by G. Belotserkovskaya. It represents the ratio of degree of actual wear of a building to its normative wear. It is well known that in process of increase in time of exploitation of buildings and erections their settling are gradually stabilized. Therefore the value of the mentioned coefficient should come nearer to one in due course. Such situation is marked in Vorkuta for the buildings erected on taliks not reacting on climate warming (Figure 6, pink lines 5, 6).

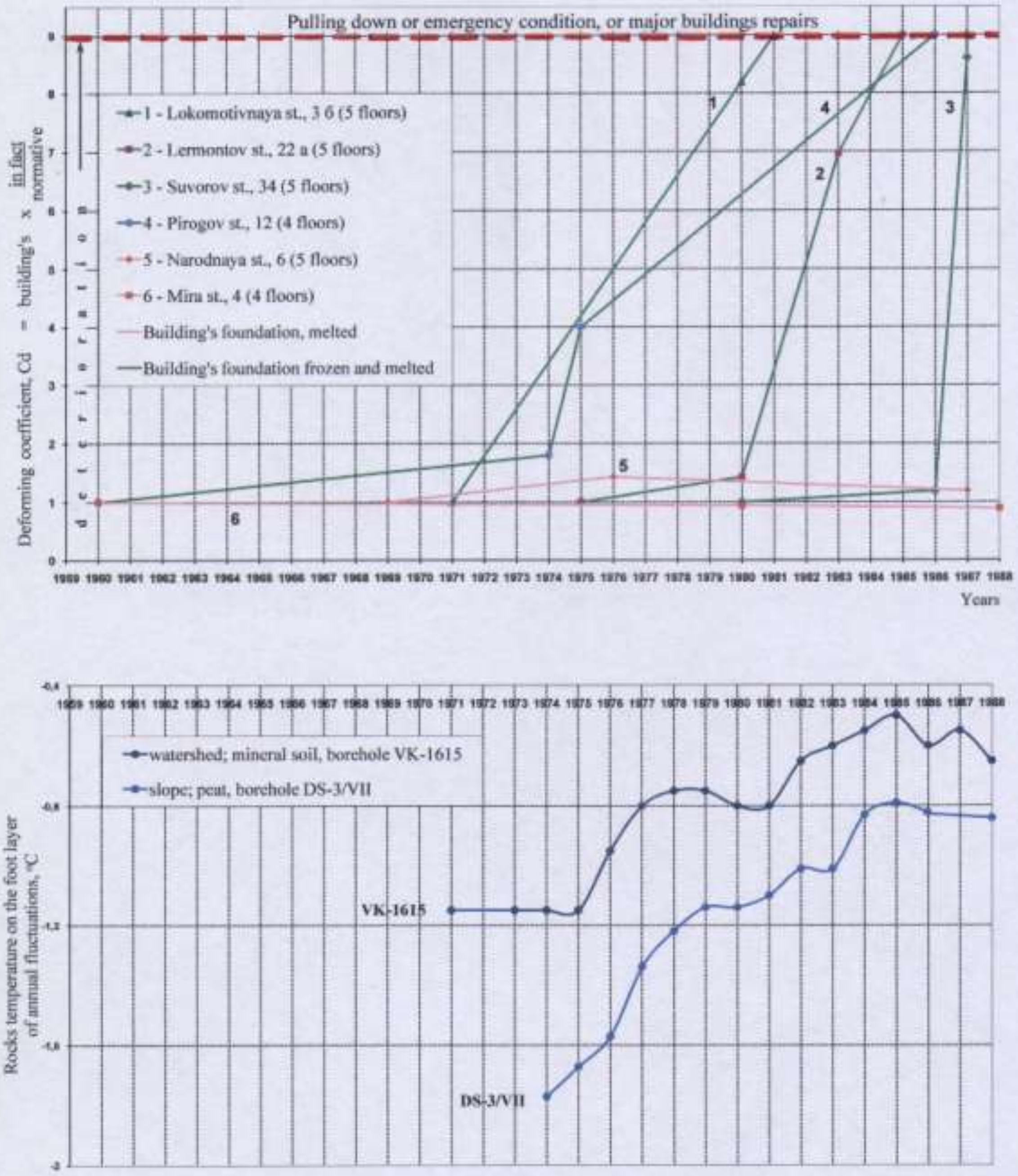


Figure 6. Permafrost temperature regime and accident rate in Vorkuta

Absolutely opposite picture we observing for the buildings erected mainly on permafrost. There are numerous examples of increase of value of this coefficient up to 4-6 and even 9 units. In such cases buildings are deformed, come to emergency state and are subject to demolition, at the best - their overhaul is necessary. On photo 1 you can see a house, which inhabitants are settled out, and the house is subject to demolition. And it quite often occurs just in 6-10 years of exploitation, at normative term - 50 years.

Photo 1. General view of the house №14 on Vorgashor street in Vorkuta. Resident were resettled and the house will be destroyed

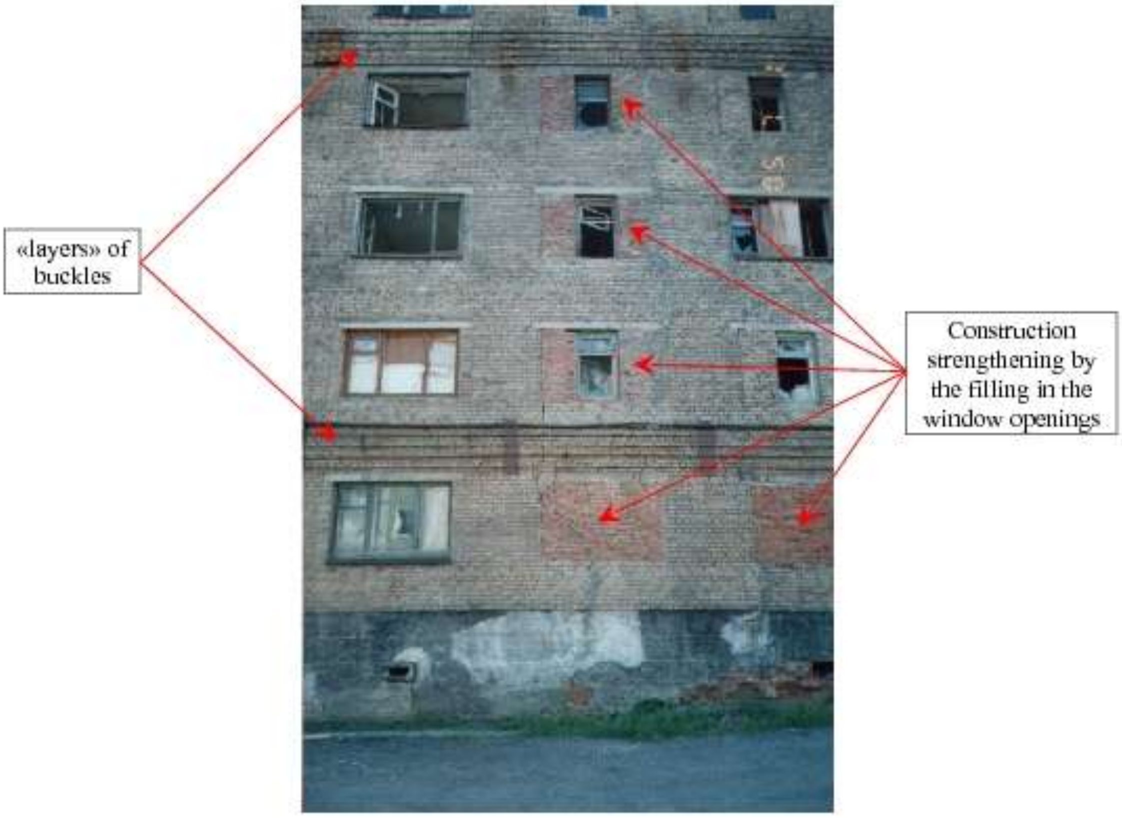


Photo 2. Emergency house №13 (fragment) on Lermontov street in Vorkuta

On photo 2 you can see another house strengthened by “layers” of buckles and partial filling of window apertures. It should be noticed that catastrophic deformations of buildings are remarkably confined to only one of three decades, to 1980s. That is, to the years, characterized by the greatest increase of temperatures of permafrost composed of mineral Quaternary deposits and peat. Figure 6 illustrates the aforesaid. At increase to 6-7 years of the period between the date of putting of a building to exploitation from the time of preceded engineering-geological researches, the deforming coefficient of buildings increases according to G. Belotserkovskaya, in several times. It testifies, in our opinion, to the discrepancy of changed recently engineering-geocryologic conditions to initial design decisions. The reason of such changes in conditions of absence of technogenic loading could be only natural degradation of permafrost.

There are ground to approve that natural uneven thermokarst settlings of terrestrial surface resulted to the world's largest damage on the oil pipeline Vosey-Head Erections. As a result of breaks of the pipe 160 thousand tons of oil-containing liquid has overflowed. Gas pipe-line Vasilkovo-Naryan Mar was forced to be reconstructed in some years of its exploitation. And again designers considered only the influence of the gas pipeline on permafrost, but not the influence of changing climatic conditions. The monitoring of the test unexploited 45 kilometers overground pipeline executed by Institute PechorNIPIneft, showed that even seasonal uneven thermokarst settling offer numerous emergency situations.

The upper part of Figure 7 reflects increase of depths of annual thermokarst settlings of embankments in process of warming of mid-annual temperature of air in the same site of permanent way of Northern railway. The bottom part of this figure illustrates increase the length of sites of the permanent way with annual spring thermokarst settlings at increase of mid-annual temperature of air.

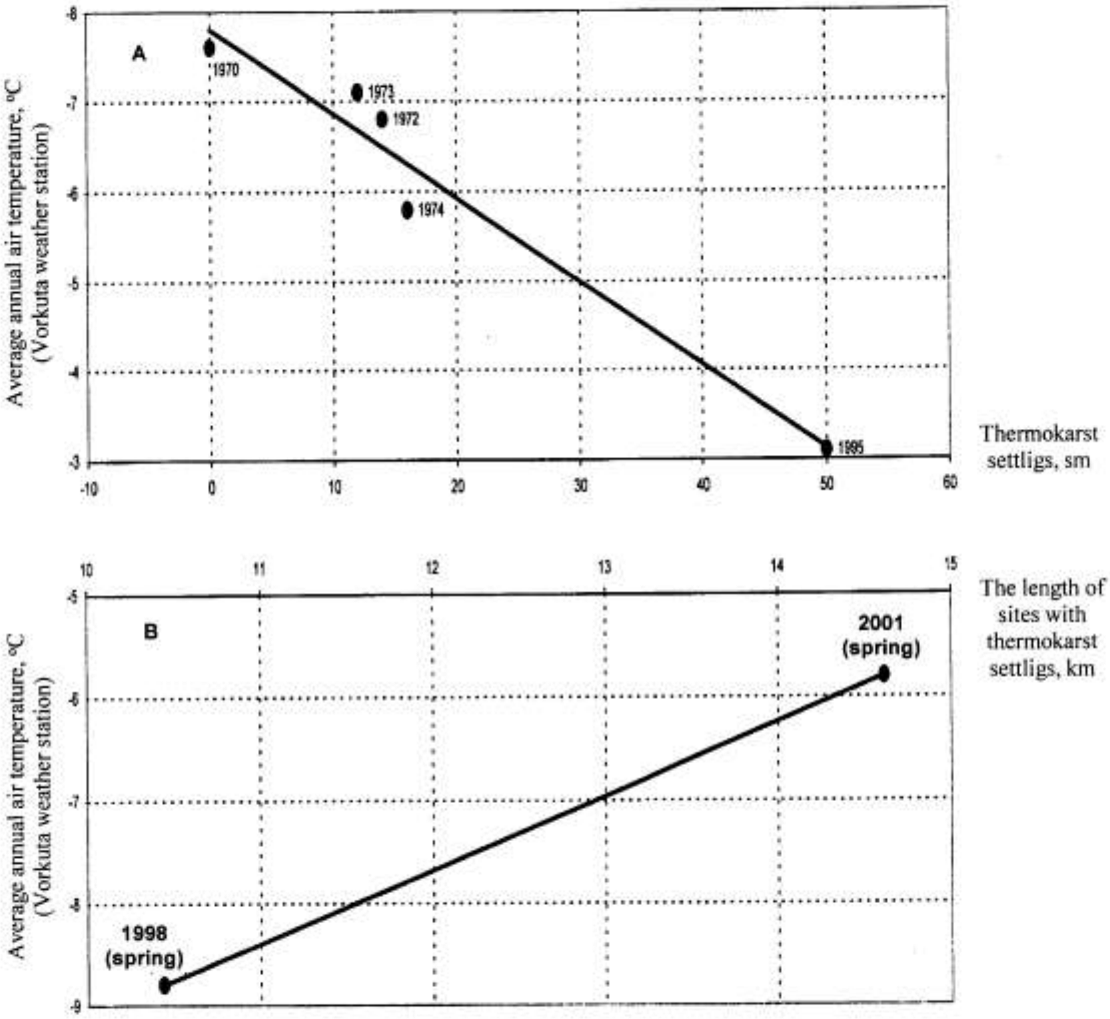


Figure 7. Dependence of thermokarst settlings (A) from average annual air temperature and the lendth of this sites on the Northern of railway road-bed (B); stage Seyda-Vorkuta

The considered materials allow formulating some recommendations to minimize or even to prevent negative consequences of natural degradation of permafrost for the infrastructure.

1. At designing civil and industrial buildings and erections it is necessary to take into account natural dynamics of permafrost for the period of their construction and exploitation.

2. Impossibility in most cases of successful struggle against natural degradation of high-temperature permafrost demands more careful approach to design decisions on erection and exploitation of buildings and constructions with preservation of permafrost in their foundation.

3. Necessary condition of objective forecasting for the near future of dynamics of key parameters of permafrost, including dangerous exogenic processes, is the widening of network of permafrost and meteorological observations on landscapes, which have been yet not enveloped by such monitoring. To solve such problems is possible only at union of efforts and possibilities of the countries of the Barents Euro-Arctic Region.

4. For the decision of problems of geocryologic mappings and monitoring it is recommended to use, besides, electric and electromagnetic methods successfully developed by Geological service of Finland together with Mining Geological company MIREKO with effective assistance of the Ministry of natural resources and preservation of environment of Komi Republic.