Palynoindication of the environment of industrial cities in the Far North

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Abstract. Data of palynological analysis of pollen of Pinus sylvestris L. under the conditions of technogenic pollution of the cities of Monchegorsk and Murmansk are presented. A high level of polymorphism of pine pollen is revealed, 11 teratomorphs are described. In samples from Murmansk, the proportion of abnormal pollen is higher than that in Monchegorsk. On the basis of the scale of ecological zoning of territories according to the content of normal pollen by N.A. Kalashnik, districts with different levels of environmental pollution are identified in the cities under investigation.

1. Introduction
The Arctic is the "climatic pantry of the world", and, probably, the richest region in fossil resources (mainly hydrocarbons). The Murmansk region is the most diversified one in the Russian sector of the Arctic, with developed mining industry, metallurgy and electric power industry [1]. Despite the fact, that in modern industrial centers control over pollution of the atmospheric air, water, soil is carried out, these analyzes are not sufficient to compile a complete picture of the ecological situation within the urbanized territory [2]. One of the new directions of environmental monitoring is palynoindication, where quality of the environment is assessed by the ratio of normally developed and teratomorphic pollen of indicator plants. Traditionally, results of palynological studies have been used in carrying out paleogeographic and paleogeoeological reconstructions. More recently, palynomorphology has begun to be used for quality assessment of the environment [3]. Palynoindication studies of cities in the Arctic zone started in recent years [4], [5], [6], [7], [8]. The purpose of the study is palynoindication and assessment of the quality of the environment of industrial cities of the Far North.

Studies were carried out in the cities of Monchegorsk (67° 56' N, 32° 52' E) and Murmansk (68° 58' N; 33° 05' E). The cities are located in the Atlantic-Arctic zone of temperate climate. Monchegorsk – in the zone of extreme northern taiga, Murmansk – in the subzone of the subarctic tundra and forest tundra. The Monchegorsk industrial-territorial complex includes a number of copper-nickel deposits, a quarry, the Severonikel metallurgical plant with a sump and a sludge storage. Pollution of the atmospheric air and the natural environment in Monchegorsk occurs due to gas and smoke emissions from the Severonikel Plant, blasting operations in mining, transportation and mechanical processing of ores, semi-finished products, natural stone, production of building materials, and fuel oil burning [9]. Calculations showed that the Severonikel plant is characterized by high aerosol pollution of the environment (specific load 13.3 t/km²). This is due to the presence in the plant’s processing procedure of the discharge of hot slag into open slag storage, accompanied by the formation of a significant amount...
of aerosols. The Khibiny region, where the mining and metallurgical complex is located, is an area of extremely dangerous and highly dangerous levels of environmental pollution with heavy metals (Cr, Co, Ni, Cu, Zn, Cd, Hg, Pb) [10].

Murmansk is the largest ice-free port in Russia beyond the Arctic Circle, and is the principal support base for the transportation of cargoes to the regions of the Far North and to far-abroad countries. The main sources of air pollution in Murmansk are: Murmansk Commercial Sea Port, the plant for thermal treatment of solid waste, Murmansk boiler houses (South, Central and East boiler houses), the 35th shipyard «Zvezdochka» and the Atomflot base. The city's soils are heavily contaminated with heavy metals (Cu, Zn, Ni, V) [11].

2. Materials and methods
Scots pine (*Pinus sylvestris* L.) is often used as a test object for the state of the environment thanks to the high sensitivity of this species to pollution. A decrease of pollen viability is observed under conditions of technogenic load as a result of increased production of abnormal pollen grains. In parks and mini-parks of the city of Monchegorsk, 9 test sites were laid for carrying out palynoindication studies. The area near the Holy Ascension Cathedral, situated most distant from the Severonikel plant, was selected as the control area. In Murmansk, in different districts of the city, 5 test sites have been laid. Control samples were collected at the 39th km of Serebryanskoye highway north of the city. The collection of samples was carried out during the period of mass dusting of pine, in the second half of June – early July. Pollen research was carried out by the aceticarmine method using light microscopy. In each field of view of the microscope, the presence of normal and teratomorphic pollen was recorded (N=400), their number was counted, and developmental anomalies were analyzed. Palynoindication of the environment of the cities of Monchegorsk and Murmansk was carried out on the basis of the content of normally developed pine pollen in the samples, according to the classification of N. A. Kalashnik [12]. According to this scale of ecological zoning of territories, pollen samples of conditionally clean territories contain more than 90% of normally developed pollen, moderately polluted – 89.4–82.9%, heavily polluted – 82.3–75.2%, critically polluted – 68.6–62%.

3. Results and discussion
Testing of pine pollen samples from Monchegorsk and Murmansk revealed normal and teratomorphic pollen. Typical (normally developed) pollen grains of *P. sylvestris* are two-sacci, heteropolar, bilaterally symmetric, and distally monoleptic [13]. Pollen sacci are oblong-elliptical in shape, sharply separated from the pollen grain and shifted to the distal side (figure 1).

During the analysis of samples from the city of Monchegorsk, it was revealed that the largest amount of normally developed pollen is contained in the samples of: control (90%), Kirova Avenue (87%) and Ecopark (86%) (figure 2). Among the rest of the samples, the range of variation of the typical pollen is very wide. In the sites of the Revolution and Five Corners squares, Fersman Street, its share is from 71 to 76%, in the City Park from 60 to 64%, on Metallurgov Avenue 45%. Abnormal (atypical) pine pollen grains differ from normal by size, shape and number of sacci. 11 teratomorphs of pollen of *P. sylvestris* are distinguished: without sacci, with a single saccus, two dissimilar sacci, with three sacci, with four sacci, with exine fissures, polyads, giant, dwarf, with reduced body, without content (figure 1).
Figure 1. Normal and teratomorphic Scots pine pollen grains from Murmansk and Monchegorsk. Legend: 1 – normal, 2 – without content, 3 - unevenly colored with reduced content, 4 - hypertrophied pollen with three air sacci, 5 – with reduced body, 6 – without sacci, 7 – with a single saccus, 8 – two dissimilar sacci, 9 – giant, 10 – dwarf, 11 – with exine fissures, 12 – dwarf with outgrowths on the exine. The scale line in the micrographs corresponds to 20 μm.

The ratio of teratomorphic pollen in the samples from Monchegorsk varies from 10 to 55%. The highest amount of the pollen grains with anomalies of development is detected in the samples from Metallurgov Avenue (55%) and three sample sites of the City Park (36–41%). In the Revolution and Five Corners squares - 27%, Kirova Avenue and Ecopark – 13–14%, in the control area – 10% (figure 2).

Figure 2. The ratio of normal and teratomorphic pine pollen in Monchegorsk (in %).

In the city of Murmansk, it was revealed that the largest amount of normally developed pollen of P. sylvestris is contained in the samples of the control site (84.4%) located at the 39th km of the Serebryanskoje highway, north of the city. In samples of pine pollen from the test sites of Murmansk, the share of normal pollen is much lower: Shabalina Str. – 46%, Lobova Str. – 35%, Domostroitelnaya Str. – 32%, Lomonosova Str. and Maklakova Str. – 30% (figure 3). At the same time, the amount of
teratomorphic pollen grains at all test sites of the city is very high, from 54 to 70% (16% in the control). The largest number of developmental anomalies was found in the pollen samples from pine trees growing on Maklakova Str. and Lomonosova Str. (70%), Lobova Str. (65%) (figure 3). The samples revealed 11 pollen teratomorphs, mostly similar to those found in Monchegorsk. The peculiarity of palynoteratic complex of *P. sylvestris* in Murmansk is hypertrophied pollen with three sacci, found in the samples from four test sites and dwarf pollen with symmetrical outgrowths on the exine in the area of pollen sacci, found in the samples from Lobova Str. in the vicinity of the «Zvezdochka» shipyard (figure 1).

Studies have shown that despite the fact, that in the vicinity of Monchegorsk the Severonikel copper-nickel plant is located, pollen of pine trees in this city are less prone to teratogenesis than in Murmansk. The content of typical and anomalous pollen of *P. sylvestris* in the samples differs significantly in the various districts of Monchegorsk. Several districts of the city can be distinguished where a high proportion of normal pine pollen (86 – 90%) in the samples was revealed: the territory of the Holy Ascension Cathedral, Ecopark, Kiroy Avenue. According to the palynological scale of ecological zoning by N. A. Kalashnik [12], these territories can be classified as moderately polluted. Fersmana Str., Revolution Square and Five Corners Square are heavily polluted. Metallurgov Avenue and the City Park, where the lowest content of normal pollen (45 – 64%) was found, are areas with a critical level of pollution. Studies carried out in Murmansk revealed a low content of typical *P. sylvestris* pollen (30 – 46%) in all districts of the city. According to the palynological scale of ecological zoning by N. A. Kalashnik [12], all of these studied areas can be classified as critically polluted.

![Figure 3. The ratio of normal and teratomorphic pine pollen in Murmansk (in %).](image)

4. Conclusion

Palynomorphological studies of *P. sylvestris* in Murmansk and Monchegorsk revealed a high level of pollen teratomorphism in the Arctic climate and industrial pollution of the urban environment. M. Surso [14] notes that usually the amount of abnormal pollen grains in the total pollen pool of conifers is small and does not exceed 2 – 5%. Scots pine pollen can be widely used for bioindication studies of industrial cities, since the number of developmental anomalies and the total proportion of teratomorphic pollen grains increase in *P. sylvestris* under environmental stress.

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