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The role of pollen transport by wind in the formation of recent pollen spectra on Chernogora (Ukrainian Carpathians)*

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ABSTRACT. Pollen spectra of recent soils in the highest part of the Ukrainian Carpathians, Chernogora massif, are given, for two transects at altitudes from 1350 m to 1750 m a.s.l. and 1822 m to 2001 m a.s.l. Above the timberline and especially in the alpine belt pollen spectra consist mostly of transported arboreal pollen (up to 90%), among which *Fagus sylvatica* pollen is predominant (up to 58%).

KEY WORDS: Carpathians, transported pollen, wind direction, *Fagus*

INTRODUCTION

In palynological investigations the problems of both long- and short-distance wind transfer of pollen always receives great attention. In mountainous regions, where air-mass circulation is very complicated, the problem of wind transfer becomes of special importance. The transfer rate increases with elevation, for wind velocity and especially wind duration increase with altitude. At mid latitudes winds achieve maximum values above 2000 m a.s.l., or 3000 m a.s.l. on open summits and ridges. In high-latitude mountains with an arctic climate constant winds blow even at an altitude of 600–800 m (Barry 1984).

In earlier studies devoted to recent pollen spectra in surface samples of the Ukrainian Carpathians it was noted that above the timberline the role of transported pollen of arboreal species increases. For example, Środoń (1948), who carried out palynological investigations in the north-eastern part of the Ukrainian Carpathians, noted high amounts of lime, oak, elm, beech, and hazel pollen in the spectra of open landscapes of the subalpine belt at 1500–1700 m a.s.l. At 1630–1650 m in the Chernogora massif of the Ukrainian Carpathians Parishkura (1966) found high quantitites of pine and spruce pollen in recent surface pollen spectra. Here pollen of such arboreal species as alder, birch, beech, oak, hornbeam, lime, elm, and maple is recorded (Parishkura 1966).

Arap (1984) carried out more comprehensive investigations of pollen spectra in the Ukrainian Carpathians. However, these investigations, like those made by previous researchers, were restricted to the subalpine belt up to 1700 m, where long-distance pollen transport is not so important. Therefore, recently investigations have been carried out at altitudes from 1660 m to 2001 m, i.e. in places where the highest amount of transported arboreal pollen is observed (Kvavadze 1988, Kvavadze & Tretyak 1995). Especially pollen of beech and spruce is abundant, because these two trees are most important in the forests of the region under consideration (Fig. 1).

The aims of this study are: 1) to characterize in detail pollen spectra from the forest belt, the subalpine and alpine belts of the study region in the Ukrainian Carpathians;

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Fig. 1. Schematic map of the altitudinal vegetation belts in the Ukrainian Carpathians (after Golubets & Milkina 1988, emmended). A – localization of transect A; B – localization of transect B; **1** – premontane oak forest (100–220 m a.s.l.); **2** – beech forest (250–750 m a.s.l.); **3** – spruce forest (700–1450 m a.s.l.); **4** – subalpine belt (1300–1670 m a.s.l.); **5** – alpine belt (1700–2061 m a.s.l.)

2) to compare the contrasts in the alpine and forest pollen spectra in order to find exact criteria for their distinction.

MATERIAL AND METHODS

Surface samples of soils were collected in September 1986 on the basis of field investigations along two transects. Transect A (11 soil samples, Figs 1, 2) runs from the Prut valley (student's base at Zaroslyak, 1350 m a.s.l.) up to the mountain pass between Pozhizhevska and Breskul Mountains (1750 m a.s.l.). Samples 1–6 are from the alpine and subalpine belts and samples 7–11 from the upper forest zone with *Picea abies* in the lower part and *Pinus mugo*, *Alnus viridis*, and *Juniperus sibirica* thickets towards the tree limit. Transect B (20 soil samples (Figs 1, 3) 6 km long, runs meridionally from the south-east (Turkul) at the altitude 1822 m a.s.l. to the north-west, along the undulated ridge of the Chernogora range, through the lowest point 1660 m a.s.l. to the summit 2001 m a.s.l. at Rebra.

Laboratory treatment of samples was carried out using the Erdtman (1943) and Grichuk (Grichuk & Zaklinskaya 1948) methods. The samples contained abundant, well-preserved pollen and spores. The material studied is preserved at L. Davitashvili Institute of Palaeobiology, Academy of Sciences of Georgia, Tbilisi.

For the analysis and the construction of pollen diagrams, pollen and spore percentages were determined within three groups separately (arboreal pollen = trees and shrubs, herb pollen = herbaceous plants, and spores = ferns and others).

RESULTS

TRANSECT A: ZAROSLYAK–POZHIZHEVSKA (1350–1750 m a.s.l.)

As shown in the pollen diagram (Fig 2), pollen spectra from spruce–dominated forests (samples 10, 11) have the following characteristic features: 52–61% of total pollen and spores are areboreal pollen, 14–20% herb pollen, and 26–33% spores. Among arboreal pollen *Picea* is predominant (40–56%), *Fagus* (14–22%) and *Alnus* (14%) are sub-dominant, *Pinus*, *Carpinus*, and *Corylus* are rather abundant, and *Abies, Betula, Quercus, Tilia, Ulmus,* and *Juglans regia* are less important. Among shrubs *Juniperus* and *Rhododendron* occur as single pollen grains. In sample 8 however, taken directly under juniper shrubs, no juniper pollen was found.

Among herb pollen (not shown separately in Fig. 2) Poaceae (up to 45%) and Asteraceae (up to 44%) are predominant, Chenopodiaceae, *Plantago,* and Ranunculaceae are recorded in rather large quantities, and *Carex, Artemisia,* Silenaceae, Dipsacaceae, etc. are present in low amounts. Cerealia pollen is also found. Spores include mostly Polypodiaceae.

At the timberline sample 7 was seleceted in *Pinus mugo* scrub. However, *Pinus* accounts for only 23% of arboreal pollen, whereas *Alnus* prevails with 42%. *Fagus* pollen (11%) is recorded in high amounts, *Picea* (4%), *Corylus* (4%), *Carpinus* (3%), and *Quercus* (2%) and *Betula* are less important, *Tilia, Ulmus,* and *Abies* are present in single grains. Among herb pollen Asteraceae is predominant, Poaceae, *Artemisia,* and *Plantago* are present in smaller quantities, and Chenopodiaceae, Apiaceae, and Silenaceae are found in single grains. Spores include only ferns.

In lower subalpine meadows, at an altitude of 1600 m, sample 6 (1600 m a.s.l.) was taken 550 altitudinal m below the timberline. It has decreased arboreal pollen and increased herb pollen. Among arboreal species the transported pollen of *Picea* (20%), *Alnus* (18%), and *Fagus* (17%) is predominant, *Pinus* (15%), *Carpinus* (12%), and *Corylus* (10%) are abundant, and *Tilia, Betula, Abies,* and *Juglans* are less important. Herb pollen is mainly represented by Poaceae (up to 70%), Asteraceae have 21%, Chenopodiaceae and *Carex* are less important, and Fabaceae, *Artemisia,* and Silenaceae are present in single grains.

Among spores ferns (12%) are abundant, and several grains of *Huperzia selago* are found.

For pollen spectra of the upper subalpine belt (samples 1–5) a gradual increase in arboreal pollen (up to 80–91% of total pollen) is characteristic. Such high values are not ob-

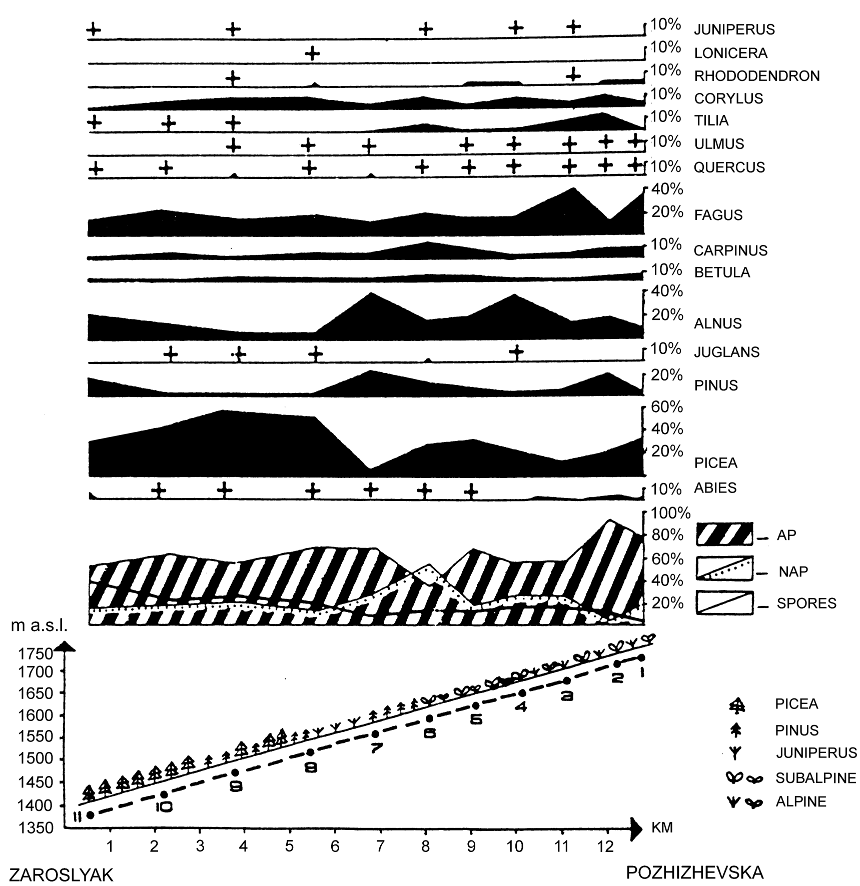

Fig. 2. Surface pollen spectra along the transect A (Zaroslyak – Pozhizhevska, Chernogora massif). 1–11 – sample numbers (after Kvavadze 1988)

served in the forest belt. It should be noted that nearer to the tree limit *Alnus* and *Pinus* pollen dominates, while in high-elevation sites farther from the tree limit *Fagus* and *Picea* pollen prevails. *Fagus* pollen reaches maximum values on the mountain ridge at 1700–1750 m a.s.l. (up to 40%). High *Tilia* pollen values (up to 10%) are also observed.

In the upper subalpine belt, among herb pollen Asteraceae and Poaceae prevail. The transported pollen of *Artemisia*, Chenopodiaceae, and Cerealia is recorded in lower quantities. Among spores ferns are abundant and *Lycopodium annotinum* is recorded in single spores.

TRANSECT B: TURKUL–REBRA (1822–2001 m a.s.l.)

Twenty samples along almost meridionally trending (from south-east to north-west) ridge of the Chernogora range were taken on a transect of 6 km. The results are characterized by a marked predominance of arboreal pollen over herb pollen (Fig. 3). The latter amount to only 20–35% (but 39% in sample 18). Similar to transect A, *Picea* pollen prevails at lower altitudes of about 1660 m (up to 41% in sample 12). However, with increasing altitude *Fagus* pollen sharply increases to 58% at 2001 m a.s.l. (sample 20). *Picea, Alnus,* and *Carpinus* pollen is subdominant, *Tilia,* and *Betula* abundant, whereas *Pinus, Quercus, Ulmus,* and *Abies* are less important and *Juglans regia* and *Salix* are even much lower. Among shrubs *Rhododendron* and *Corylus* are prevalent, and *Sorbus* is rare. Among herb pollen Poaceae is dominant in the entire transect, Asteraceae is subdominant, and the transported pollen of Chenopodiaceae and *Artemisia* is subdominant in some samples. Apiaceae, *Plantago*, Polygonaceae, and Ranunculaceae are constantly recorded in low quantities, and Brassicaceae, Campanulaceae, *Carex*, Cerealia, *Cichorium*, Dipsacaceae, Fabaceae, Geraniaceae, Lamiaceae, Plumbaginaceae, Silenaceae, *Valeriana*, etc. are sporadically. Spores are characterized by great diversity. Among them, *Pteridium, Huperzia selago, Lycopodium annotinum, Selaginella selaginoides,* and *Sphagnum* are found.

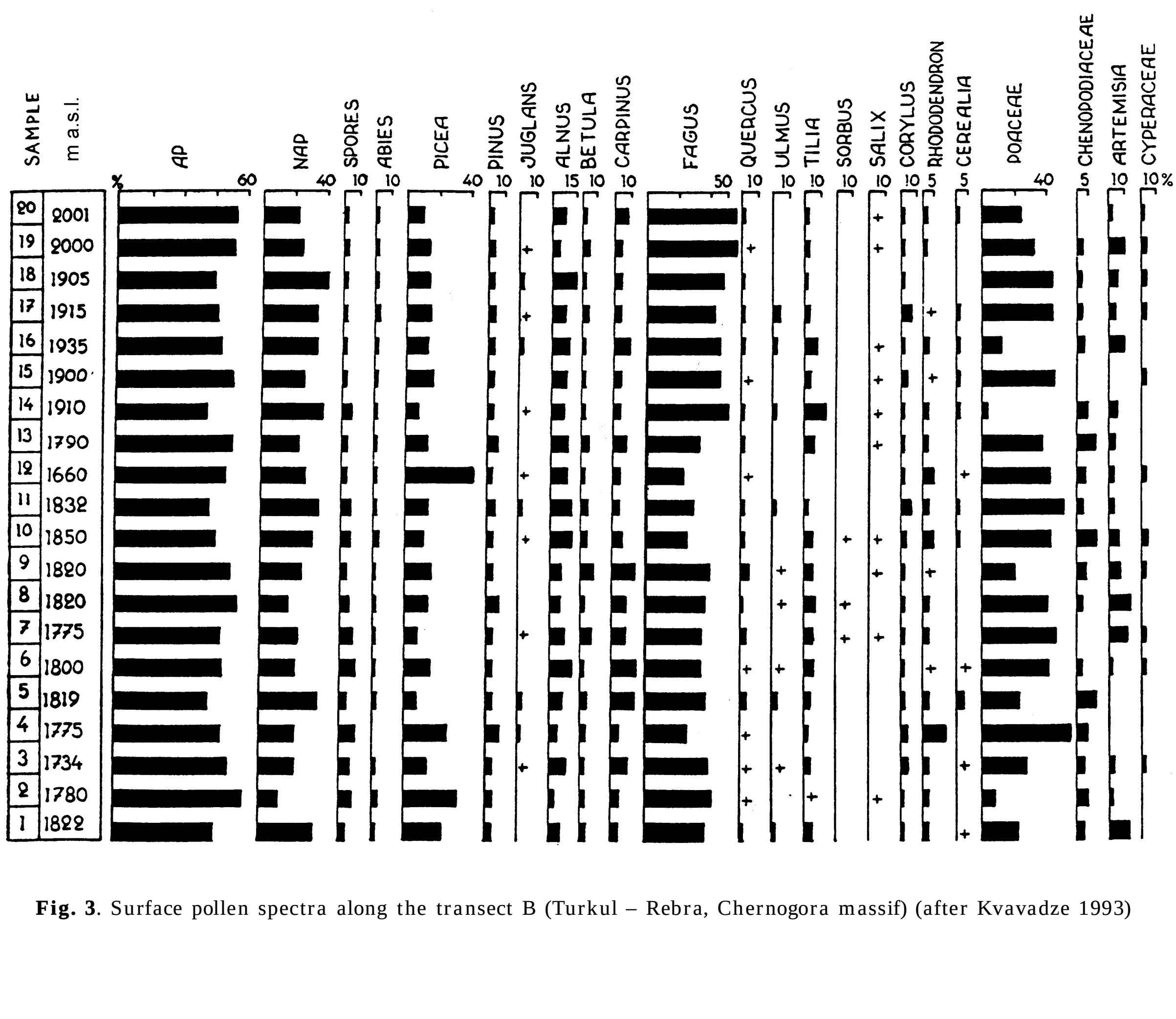

Fig. 3. Surface pollen spectra along the transect B (Turkul – Rebra, Chernogora massif) (after Kvavadze 1993)

DISCUSSION

Analysis of the pollen data shows that even in the belt of spruce forest at 1350 m – 1450 m a.s.l. the transported pollen reaches 30% (sample 10, 11), mainly beech. A similar situation is observed in the data reported by Środoń (1948, table 1). For comparison with his work, the pollen diagram in Fig. 4 shows that the first dominant in pollen samples from spruce forests is spruce, while the second dominant is beech transported from the underlying belt of beech forest. As seen on Fig. 2 in spruce-forest spectra a high proportion of spores (up to 26–33% of total pollen and spores) is characteristic, essentially ferns. Spores do not have such high values in the subalpine and alpine belts. This can be a good criterion for distinguishing between forest and unforested areas on the basis of pollen and spores. It should be noted that in spruce forests arboreal pollen reaches 52–61% of total pollen and spores and herbaceous plants 39–49% (Fig. 5).

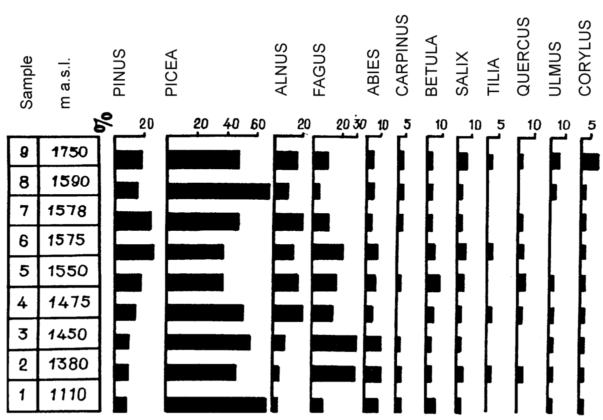

Fig. 4. Surface pollen spectra of Chernogora massif (after Środoń 1948)

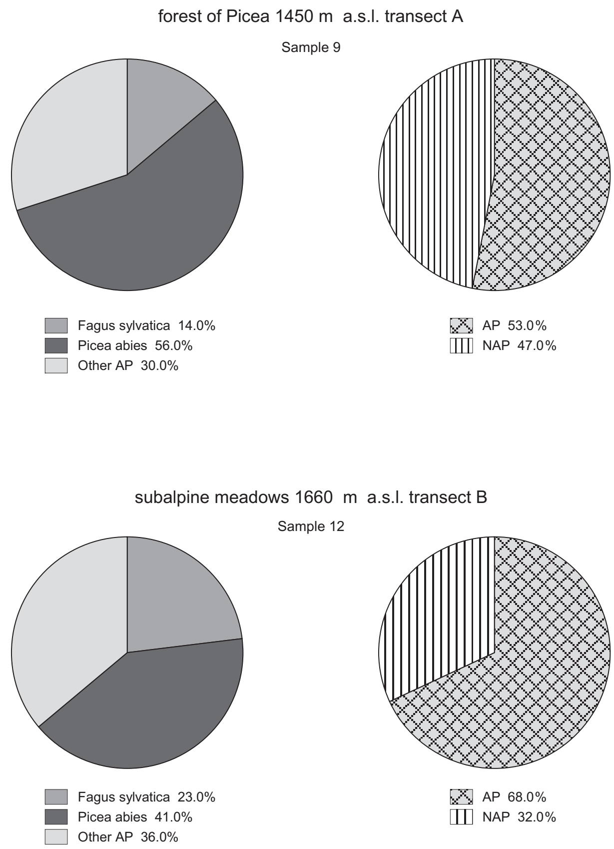

Fig. 5. Cyclograms of pollen spectra of spruce forest and subalpine meadow soils of Chernogora massif

Pollen spectra from the subalpine belt below the timberline are characterized by prevalence of spruce, alder, and pine within arboreal pollen. In *Pinus mugo* scrub alder pollen prevails (up to 42%), followed by pine, and then spruce. Arboreal pollen accounts for 60% of total pollen and spores and herb pollen reaches up to 34%, whereas spores are not very important (up to 7%). In open landscapes of lower subalpine meadows pollen of all three groups are present, with spruce pollen dominating, and a somewhat larger role of herb pollen (Fig. 2, samples 3, 4).

At 1700–1800 m, i.e. in the upper subalpine belt, the pollen spectra change drastically. Among arboreal pollen beech becomes prevalent (Fig. 3), and spruce pollen is usually the second dominant. Arboreal pollen averages 60% of total pollen and spores and herb pollen 40%.

In the alpine belt (1800–2001 m) beech pollen is more important. Arboreal pollen increases to 73% of total pollen and spores, in some cases even higher (Fig. 6).

A fossil pollen spectrum with similar characteristics (high arboreal pollen values with marked predominance of beech) might also be interpreted as derived from under the canopy of beech forest. However, the comparison of alpine pollen spectra in which beech pollen prevails with those, from under the beech-forest canopy in the Ukrainian Carpathians (Arap 1984) shows the following distinctive characteristics of beech-forest spectra (Fig. 6): 1) beech pollen is higher than in alpine meadows and reaches 78–84%; 2) among arboreal pollen

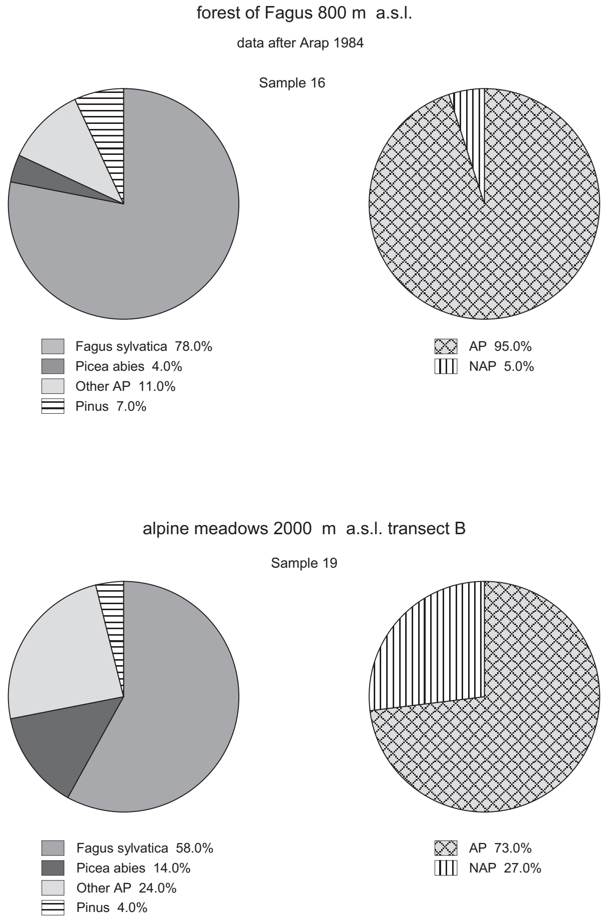

Fig. 6. Cyclograms of pollen spectra of beech forest and alpine meadow soils of Chernogora massif

pine rather than spruce is the second dominant; 3) herb pollen is very low (no more than 5%). Characteristic for alpine pollen spectra is the presence of high-mountain vegetation elements, such as *Selaginella selaginoides, Rhododendron kochii,* etc. Presence of absence of pollen taxa is one of the criteria to distinguish between unforested and forested areas in the region under consideration.

The results obtained in our earlier investigations caused astonishment and even perplexity, for such a massive pollen transport of broad-leaved species and especially of beech remained unclear (Kvavadze 1988, Kvavadze & Tretyak 1995). A similar situation was observed not only in the Caucasus (Kvavadze 1990, 1993), where abundant material for this problem was gathered, but also in the Polish Carpathians (Kvavadze & Stuchlik 1993, Stuchlik & Kvavadze 1995). Fifteen surface samples of soil were studied in the latter area, in Tatra Mts above the timberline, at altitudes of 1840–2013 m showing large quantities of transported arboreal pollen (Stuchlik & Kvavadze 1995). This was, however, mainly pine and spruce, whereas beech did not exceed 5–8%. The same picture is observed in surface sediments from the Tatra Mountains as reported by Obidowicz (1993, 1996).

Many researchers point to low transportation of *Fagus sylvatica* pollen in the European mountains. This question was discussed by Schneider (1984) and Jochimsen (1986). Therefore it becomes obvious that mass transport of beech pollen through the air, as observed in the Ukrainian Carpathians, is not an usual phenomenon. It might be connected with the almost meridional position of the Chernogora range toward the west and the predominance of air currents from the south-west. Beech forests in the western part of the Ukrainian Carpathians are as well-developed as over the rest of the area (Golubets & Milkina 1988). The other cause may be the fact that here the wind strength and duration reach high values (Mukha & Pritula 1994). These figures, for example, exceed significantly similar data for the Caucasus (Lominadze & Chirakadze 1971). But unfortunately in the literature no detailed seasonal windrose maps for the region under consideration are available. Maybe here west winds are stronger during beech flowering. The discussion of this problem should be left for the future. However, very important is the fact that we have revealed the phenomenon of mass pollen transport in the region of the Chernogora massif, and it should be taken into account in the interpretation of fossil pollen spectra from highlands.

CONCLUSION

The detailed study of recent pollen spectra from upper forest, subalpine, and alpine belts showed that in spite of mass pollen transport from one belt to another, spectra from each belt have a number of distinguishing features, as follows:

1) Spruce-forest pollen spectra are characterized by the prevalence of spruce and subdominance of beech as well as abundance of spores (up to 30%) among which ferns are prevalent.

2) Beech-forest pollen spectra in the region under consideration are characterized by the

high proportion of beech pollen, pine as the second dominant, and very low values (up to 5%) of herb pollen.

3) Pollen spectra from lower subalpine meadows with intensive transport of spruce pollen are characterized by the increased significance of alder and pine, which are subdominants. Spores and especially ferns are not very important.

4) Pollen spectra from the alpine belt are characterized by a high proportion of arboreal pollen with predominance of beech, spruce as the second dominant, herbs reaching 20–30% of total pollen and spores, and the presence of indicator pollen and spore taxa. The total amount of pollen of broad-leaved trees also reaches high values. Among herbs, Poaceae and Asteraceae are predominant. Among spores, only here *Huperzia selago, Selaginella selaginoides, Lycopodium annotinum,* and *Pteridium* are recorded.

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