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GEOMORPHIC RESEARCH ON THE PRESENT-DAY PROCESSES AND LANDFORMS IN THE WESTERN CARPATHIANS IN THE CZECH REPUBLIC

INVESTIGATIONS INTO WIND EROSION AND AEOLIAN LANDFORMS

Referring to the basic division of the Western Carpathians presented in the paper of Ivan and Kirchner in this volume, the system of the Outer Carpathian Depressions in Moravia and Silesia consists of widely opened, meridionally oriented depressions, starting from the Ostrava Basin and passing through the lowlands of Upper Morava (Hornomoravský úval), Dyje and Svratka (Dyjsko-Svratecký úval), to that of Lower Morava (Dolnomoravský úval) as a northern projection of the Vienna Basin and the adjacent Carpathian mountain range piedmonts. The continuous system of depressions and piedmont foothills is opened for moving air and is thus subjected to a destructive activity of wind more intensively than the Bohemian Massif.

In the 1960s and the 1970s was formulated the basic knowledge on the distribution of wind erosion, its magnitude/frequency in Moravia and Silesia, and harmful effects on agricultural production (Švehlík 1972, 1985; Hrádek et al. 1997, Pasák 1970). In the following years this knowledge has been broadened. Attention has been paid to the distribution of dust storms and their causes, the magnitude and frequency of wind erosion and to investigations of aeolian landforms. Areas of the strongest activity have been delimited and, in addition, more detail features recorded (Hrádek and Švehlík 1993, 1995; Hrádek et al. 1995).

DUST STORMS AREAS

The centrally positioned belt of Moravia and Silesia, situated between blocks of the levelled border of the Bohemian Massif and that of Carpathian–Pannonian blocks belonging to the Alpine–Carpathian orogenic belt, brings about a topographical diversity of the surface favourable for dust storms and wind erosion. The dissection and roughness of the surface influenced the direction of winds, their magnitude and climatic conditions in this territory such as temperature, humidity, precipitation, evaporation, solar radiation increasing to the south, etc., which also conditioned the soil quality and the vegetation cover. Man-made impacts, namely the intense agricultural activities, support the origin of dust storms. Typical landforms of the lowlands that are the most affected by dust storms are flat watersheds formed by loess covers, river terrace plateaux as well as the planation surfaces, and broad floodplains of rivers (Hrádek and Švehlík 1995).

Dust storm regions coincide with areas of the Outer Carpathian Lowlands, i.e. in the Dyje and Svratka Lowland between Znojmo and Brno, the Lower Morava Lowland, the Vyškov Gate, the Upper Morava Lowland, and the Silesian Lowland. Intentionally is mentioned here the area of the piedmont of the Bílé Karpaty Mts in its section between Strážnice, Uherské Hradiště and Bojkovice in the valley of Olšava (Fig. 1).

Directions of winds in individual regions are different. In the Svratka and Dyje Lowland these are north-western and south-eastern winds, in the Vyškov Gate these are northern winds featuring both the western and the eastern components, the Upper Morava Lowlands linked to the Moravian Gate and the Ostrava Basin are affected by winds coming from the north up to north-eastern sector and also by those from the south-west or south-east. In the Silesian Lowland there are harmful effects of south-eastern winds which get there dynamically warmed up in consequence of their having crossed the ranges of the Western Carpathians and dried out due to their subsequent descent to the lowland. In the Lower Morava at the foot of the Middle Moravian Carpathians (Středomoravské Karpaty) the harmful southern and eastern winds prevail as well as north-western ones, yet in its northern part also the north-eastern winds. There is also situated the oldest known area of the so called "Moravian Sahara" with dust storms and moving dunes of blown sands situated between the towns of Bzenec and Hodonin. The leeward sides of the highest dunes, inclined 7–15°, are exposed to the south-east while the windward ones, inclined only 4–5°, have an opposite exposition. The first dunes in this now stabilised area were formed as early as the mid 1st century BC.

MAGNITUDE AND FREQUENCY OF WIND EROSION

The more detailed data regarding the magnitude and frequency of wind erosion were obtained in the area of the Bílé Karpaty Mts piedmont, in the surroundings of the village of Bánov. The Bílé Karpaty Mts (White Carpathians) constitute a mountain range that separates the territory of the northern part of the Vienna Basin in south-eastern Moravia from the Pannonian Basin. During south-eastern cyclonal situations occurs the phenomenon of the south-eastern wind ascending the windward slopes of the Bílé Karpaty Mts, then falling föhnwise over their ridges to finally descend, with a moderately warming up and desiccating effect, on the Moravian side causing dust storms.

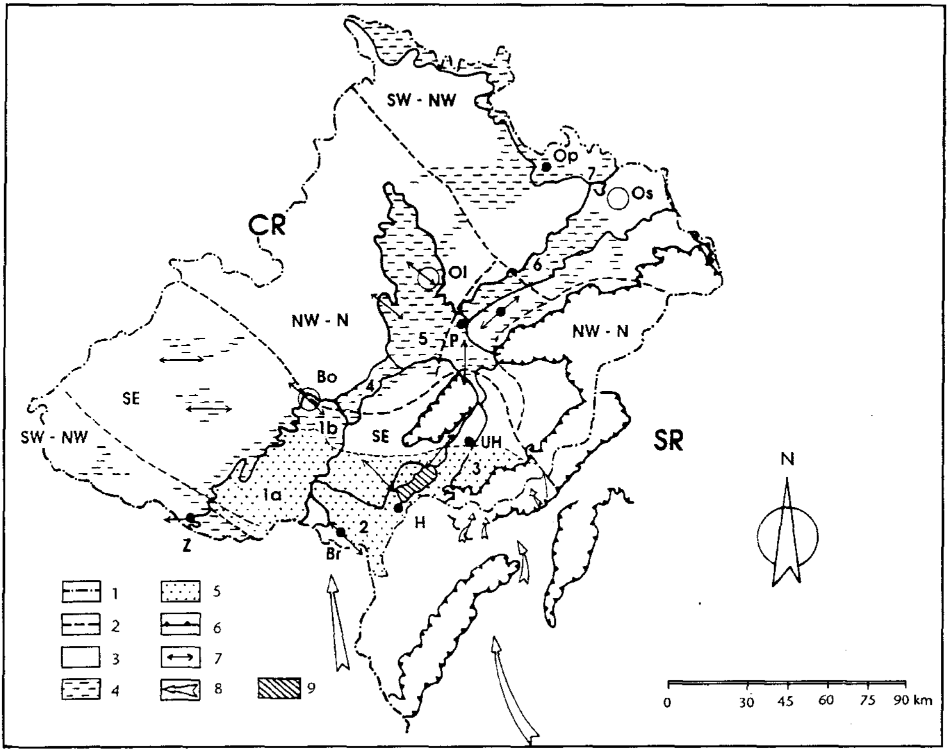

Fig. 1. Distribution of dust storms in the West Carpathians in Moravia and Silesia. 1 — Boundary of Moravia and Silesia, 2 — Boundary of sectors and prevailing wind directions, 3 — Areas unaffected by dust storms, 4 — Areas occasionally affected by dust storms, 5 — Areas regularly affected by dust storms, 6 — Fronts of the West Carpathian mountain chains, 7 — Directions of winds triggerring dust storms, 8 — Directions of important regional winds of the föhn type, 9 — Areas with dunes of wind blown sands. Numbers: 1 — Dyje and Svratka Lowlands, 1a — Znojmo and Mikulov area, 1b — Brno area, 2 — Lower Morava Lowland, 3 —The piedmont of the Bílé Karpaty Mts, 4 — Vyškov Gate, 5 — Upper Morava Lowland, 6 — Moravian Gate, 7 — Silesian Lowland. Abbreviations: CR — Czech Republic, SR — Slovak Republic, Bo — Brno, Br — Břeclav, H — Hodonin, Ol — Olomouc, Op — Opava, Os — Ostrava, P — Přerov, UH — Uherské Hradiště, Z — Znojmo

Ryc. 1. Rozmieszczenie burz pyłowych w Karpatach Zachodnich, na Morawach i Śląsku. 1 — granice Moraw i Śląska, 2 — granice sektorów z przeważajcymi kierunkami wiatrów, 3 — obszary nie objęte burzami pyłowymi, 4 — obszary objęte burzami pyłowymi tylko okazjonalnie, 5 — obszary regularnie objęte burzami pyłowymi, 6 — czoło Karpat Zachodnich, 7 — kierunki wiatrów wywołujących burze pyłowe, 8 — kierunki ważnych wiatrów regionalnych typu fenowego, 9 — obszary z wydmami piaszczystymi. Numery oznaczają: 1 — nizina Dyji i Svratki, 1a — obszar Znojma i Mikułowa, 1b — obszar Brna, 2 — nizina dolnej Morawy, 3 — piedmont Białych Karpat, 4 — Brama Vyškova, 5 — nizina górnej Morawy, 6 — Brama Morawska, 7 — Nizina Śląska. Skróty: CR — Republika Czeska, SR — Republika Słowacka, Bo — Brno, Br — Břeclav, H — Hodonín, Ol — Ołomuniec, Op — Opawa, Os — Ostrawa, P — Přerov, Uh — Uhreské Hradiště, Z — Znojmo

In its peaks the wind speed reaches values as high as 29 $m \cdot s^{-1}$ (11 Bf). There is a foreshadow of the dust storm in the form of a föhn wall rising above the ridges of the Bílé Karpaty Mts (Švehlík 1978, 1985; Hrádek and Švehlík 1993).

The Bílé Karpaty Mts piedmont is a part of a moderately warm and moderately humid climatic region, with a mild winter. The average yearly temperature is 8.4° C, the yearly precipitation total is 725 mm in 330–380 m a.s.l. Since the end of the first half of the last century there is a number of written documents on strong dust storms which caused much damage to agriculture and traffic. In spring of 1972 the piedmont area of the Bílé Karpaty Mts was stricken by a series of dust storms in which almost 200 m^3 of soil were carried away by wind from some fields near the village of Bánov. This value represents the highest measured magnitude of a disastrous wind erosion in the Czech territory so far. During dust storms the majority of particles are carried away in a layer up to 0.05 m above the ground surface (Table 1).

Table 1 — Tabela 1

Quantity of the soil dust carried away by wind changing with the height above the ground surface picked up during the dust storm in the deflameter (Švehlík 1985)
Ilość pyłu glebowego usuniętego przez wiatr, rejestrowanego w deflametrach

Height above the surface [m]	0.00–0.05	0.05–0.10	0.10–0.15	0.15–0.96
Amount of soil [%]	57.0	18.5	8.0	16.0

In places deprived of fine-grained material that has been carried away by wind remained rather coarse, the so called loosened sediments, with characteristic stone pavements and ventifacts lying among them, tilted in the direction of the wind. In front of the obstacles and behind them are formed characteristic accumulation landforms (vast aeolian sheets of dust with ripples, horizontally bedded flat drifts).

Based on the long-term observations, a frequency of dust storms has been found out in relation to other climatic characteristics, above all to temperature and precipitation. Dust storms occur mostly in winter and at the beginning of spring. The largest number of days with wind erosion in a year is in March (25.17%), followed by February (21.4%), then January (20.75%) and April (20.13%). In May the fields are already covered with vegetation and the frequency of dust storms decreases to c. 3.77%. On the contrary, there are nearly no dust storms in summer (Švehlík 1985). Dust storms occur in the period with the smallest precipitation and with the lowest temperature at the beginning of a year and at the beginning of spring (Hrádek and Švehlík 1993). In this period the surface of soil is subjected to freeze-thaw cycles, its structure gets disrupted and soil aggregates (pellets) become loose. In snowstorms (blizzards) soil is carried away along with snow. Drifts of snow are then usually mixed with layers of arable soil.

The length of periods during which intensive aeolian activity occurs (i.e. the period between the first and last storm during one year) differs in the period of 1957–1990. The mean onset of wind erosion falls on 12 February and mean end on 7 April. Mean length of the deflation period is 54 days (Švehlík 1985). Fluctuations in a number of days with dust storms in individual years plays an important role in the investigation into time correlation of aeolian processes. The most frequent daily dust storms occurred in 1960, 1962 and 1964. In other years, the number of days with dust storms was lower. For example, in 1977 and 1979 there was only one day and in 1956 no dust storm occurred. Also, some short-time cyclic fluctuation in the occurrence of a large number of days with aeolian activity can be observed. These cycles always followed a 4- to 5-year interval. The periods with a higher intensity of wind erosion repeat after 4 to 5 years (Hrádek and Švehlík 1993). The frequency of south-eastern situations with gust winds reached approximately 21% in the period between 1946 and 1965.

The magnitude of wind erosion expresses the quantity of soil carried by wind out of an area of a known extent (mostly given in hectares) during a certain time span (mostly in one year). In the Bílé Karpaty Mts piedmont volumetric and vegetation methods, as well as deflameter were used for measuring the magnitude of wind erosion (Švehlík 1985).

The volumetric method involves direct measurements of the volume of soil blown away in places affected by corrasion and deflation as well as the volume of soil accumulated, using precise geodetic levelling. In the vegetation method, using the naked parts of culture plants (roots, necks), is measured the so called erosion height, i.e. the thickness of the layer of arable soil blown out by wind. In the foci of a dust storm this erosion height can reach 1–2 cm. The deflametric method of measuring is relatively most precise as the soil that is carried by wind is directly caught in a special device — the deflameter.

For all the above mentioned methods have been derived mathematical and graphical relations with the purpose of calculation and expression of the magnitude of a wind erosion (Švehlík 1989) (Fig. 2). The research has shown that in the area of the Bílé Karpaty Mts piedmont 0.4 mm of arable soil is removed on the average. Wind erosion causes threat to 40,000 hectares of arable soil. According to the calculations, the wind raises into atmosphere c. 60,000–80,000 m^3 of dust yearly. The average yearly intensity is 37.8 m^3 ha^{-1} $year^{-1}$. The maximum magnitude was reached in 1972 in the village of Bánov where out of a plot of 3 hectares a record of 579 m^3, i.e. 193 m^3 ha^{-1} $year^{-1}$, have been carried away in a series of dust storms.

The removal of soil by wind in the area of the Bílé Karpaty Mts is also controlled by specific soil conditions. Flysch sandstones are featured by heavy clayey soils which are seemingly quite resistant to wind erosion. In reality the matter is different and soil removal here, as already mentioned above, is among the strongest in Czech. Grain size distribution analyses on sieves have shown that the heavy soils here decompose into soil aggregates (pellets) sized more than 0.8 mm (but also larger than 2–3 mm) which has not been supposed so far, based on the results of experiments and calculations by Chepil (1955, 1956). On the contrary, Van Doren's opinions (Pasak 1970) have been con-

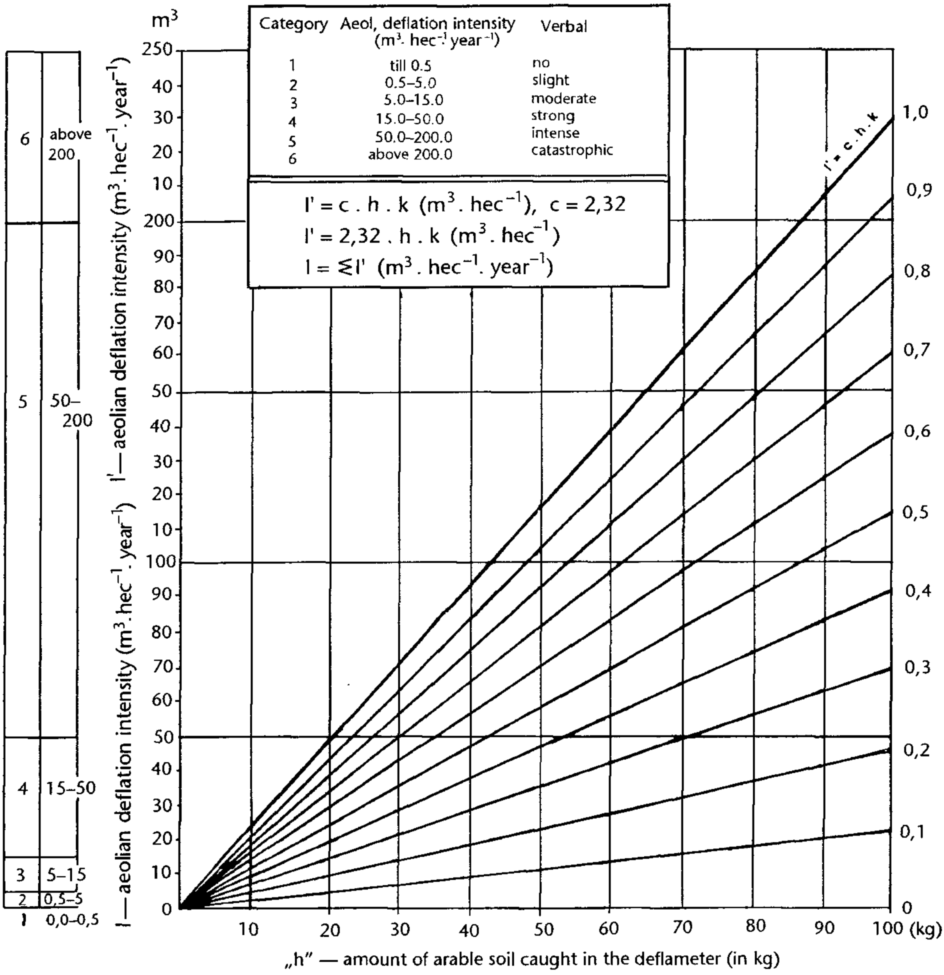

Fig. 2. Linear relation between amount of arable soil (h) caught during the dust storm in the deflameter [kg] and magnitude of wind erosion (I) [$m^3 \cdot hectar^{-1}$]

Ryc. 2. Liniowe zależności pomiędzy ilością gleby chwytanej w deflametrze na polach ornych (h) podczas burz pyłowych [kg] i wielkością erozji wietrzenej (I) w m^3 ha^{-1}

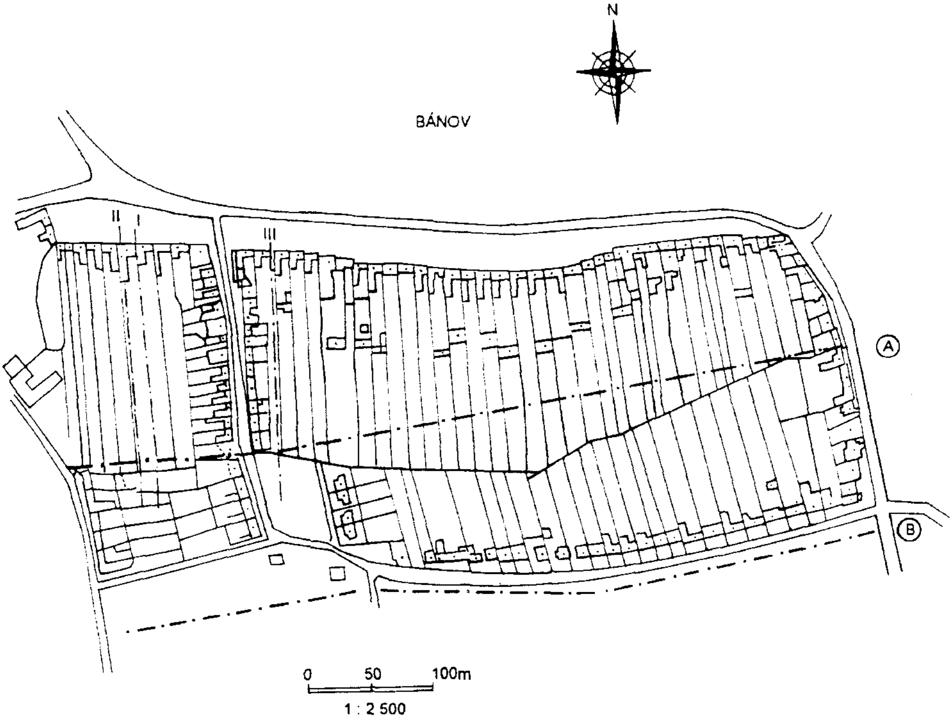

Fig. 3. Ground-plan of the part of the village of Bánov with position of axes of the transverse dust dunes crests (A, B) and longitudinal transects (I, II, III). Dust dune A, in front of the row of the older houses, is older than dune B, in front of the the younger houses developed in consequence of the village growing

Ryc. 3. Plan części wsi Bánov z zaznczonymi osiami podłużnymi grzebietów wydmowych (A, B) i przekrojami podłużnymi (I, II, III). Wydma A przed szeregiem starszych domów jest starsza niż wydma B przed młodszymi domami

firmed, according to whom the critical average of soil particles subject to wind removal is 2 mm, which is on the boundary of fine-grained earth. The erodibility limit of heavy soils is more than 0.8 mm. Air is closed in the pores of soil aggregates, and this is why they are light, capable of air transport.

RESEARCH ON AEOLIAN LANDFORMS

In the piedmont of the Bílé Karpaty Mts in the villages of Bánov and Suchá Loz as well as near the Volenov yard, have been found typical aeolian landforms presented here as flat drifts of dust with crests. These drifts could also be interpreted as stabilised transverse dust dunes, in our older works called aeolian ridges (Hrádek and Švehlík 1993; Hrádek et al. 1995). Crests of these grass-covered dust drifts are roughly oriented in the E–W direction in relation to the ground-plan of villages (Fig. 3) and to the position of obstacles. The dune crest near the Volenov yard was formed in front of a brick wall which constitutes an obstacle to the eastern winds. After some years with intensive wind activity the 2.5 m high wall almost disappeared under aeolian cover. The largest is the dust dune in Bánov (Fig. 4) which is as much as 500 m long, about 120 m wide and the height of its crest reaches up to 2.5 m. Its longitudinal axis lies parallel to a row of houses at the end of gardens (Fig. 4).

The grain size analyses of the aeolian material from the Volenov yard dust dune have shown some differences in comparison with the composition of the fresh wind-blown, material deposited during dust storms. The densified material of the stabilised dust dunes contains less clay and more silt particles (Fig. 5). The original horizontal bedding is not clear.

The origin of dust dunes is associated with accumulation of material blown away from fields in the course of dust storms. The investigation followed two objectives. The first was the dating of the origin and a further development of dust dunes based on pollen analysis of samples taken from aeolian material. The other objective was the establishment of historical relations between dust storm occurrences and the respective weather situations in which they are originated. Formation of the dunes was possible in historical times as a response to development of houses and the gardens in the villages of this region which were the obstacle obstructing the wind (Fig. 3) (Hrádek et al. 1995). Aeolian dust dunes arose as a response to man-induced changes in the landscape ecosystem. The development of the villages since the 13th century, as well as the frequency of south-eastern winds, in which dust storms originate, played an important role here. Based on the analysis of samples of loamy-clayey soil material taken from the aeolian sheet so far we arrive at the conclusion that the dunes developed under the influence of man's economic activities, above all in the period following the first land reform (i.e. starting from 1919) and after the communist collectivisation (after 1948). These periods were featured by deforestation, re-parcelling of agricultural land and formation of vast tracts of land. It is most likely that the pollen grains in the dunes characterise the period of the last 60–70 years of this century. The period after the collectivisation is featured by the occurrence of the overseas plant species *Ambrosia sp.* and, at the same time, the absence of *Centaurea cyanus* and *Agrostemma githago*. It can be seen that the environment of stabilised dust dunes is not too favourable for a long preservation of pollen grains.

New investigations confirmed that regions with contemporary aeolian landforms in the piedmont of the Bílé Karpaty Mts present areas of the maximum magnitude of wind erosion. The global cause of the origin of dust storms and of dust dunes can be stated with certainty as the last stage of the manifold response of dynamic Earth systems, both global and regional, to outer impacts, both natural and man-induced (man's interventions within the environment

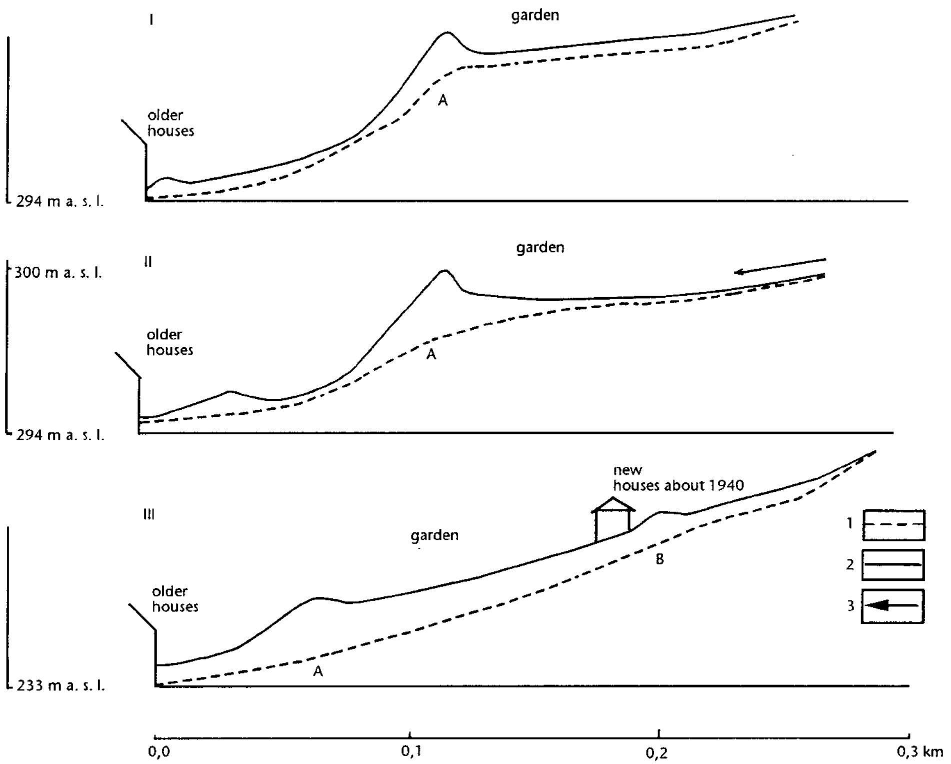

Fig. 4. Longitudinal transects through the transverse dust dune A (see Fig. 3). 1 — original surface, 2 — surface after deposition of aeolian material, 3 — direction of wind

Ryc. 4. Profile podłużne przez poprzeczną wydmę A (por. ryc. 3). 1 — powierzchnia pierwotna, 2 — powierzchnia po złożeniu materiału eolitycznego, 3 — kierunek wiatru

that are of economic character, growth of settlements, turning of pastures into arable land, and the everincreasing extent of agricultural cultivation of land) in the piedmont of the Bílé Karpaty Mts (Hrádek and Švehlík 1993). The conversion of pastures into fields has brought about wind erosion; obstacles to wind in forms of village houses and other facilities have led to formation of flat dust dunes. The winds themselves, mostly of the south-eastern direction, are a part of the global atmospheric circulation. The descending wind, the föhn, is a response to the adiabatic process brought about by the passing of more humid air masses over the barrier of the mountain range of the Bílé Karpaty Mts (Hrádek and Švehlík 1993). Dust storms represent a rapid response of the dynamic system of wind circulation to man's economic activities, above all to deforestation and intensive agricultural cultivation especially in the areas which are the most prone to destructive wind action due to their exposition and a kind of soil.

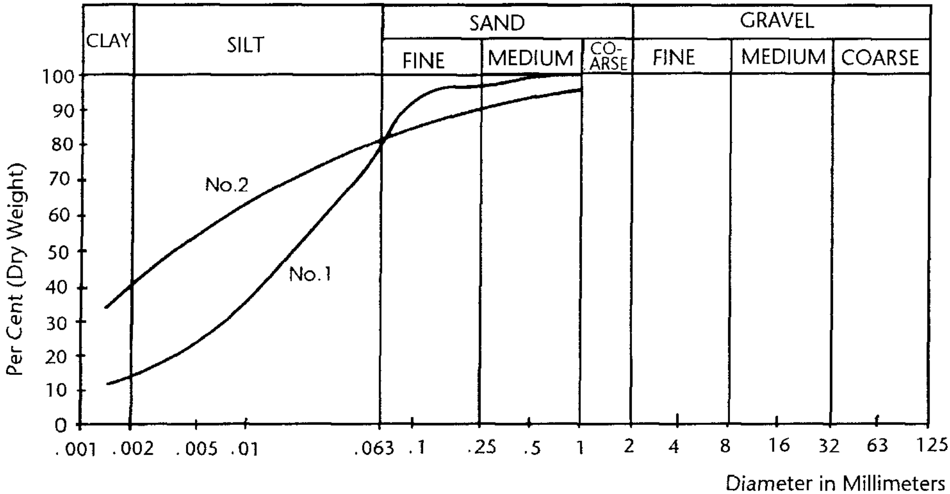

Fig. 5. Comparison of grain size composition of densified aeolian material from Volenov farm transverse dune (No 1) and fresh, aeolian dust at Volenov (No 2) deposited during a dust storm

Ryc. 5. Porównanie krzywych uziarniena zagęszczonego materiału eolicznego z wydmy poprzecznej w gospodarstwie rolnym Volenov (nr 1) oraz świeżej depozycji materiału eolitycznego podczas burzy piaskowej w miejscowości Volenov (nr 2)

SLOPE PROCESSES AND EROSION BY RUNNING WATER

Gravitational slope processes and their manifestations are generally observed in the Outer Western Carpathians. As early as in the 1960s their extent and their impact upon economic activities have led to the formation of a central register that has subsequently been supplemented by research performed for the purpose of file-keeping and of detailed geological and geomorphological mapping. Within the limits of the former Czechoslovakia a brief overview of the problems in question is presented in the paper by Hrádek et al. (1997).

In 1997, in connection with the very intensive summer rainfall, many old landslides became activated and vast new ones were triggered, moreover in conjunction with massive flooding. In many places the slope masses still continue sliding. At various locations the slide movements of slopes and the floods acquired the character of local disasters and caused sizeable economic losses as well as ecological damage of the order of thousands of millions crowns. In consequence of this event there were about 450 significant landslides monitored in the Moravian part of the Carpathian flysch so far, which number is likely to increase. Investigations on the consequences of these processes are still going on.

Concerning the processes of water erosion a new contribution to the knowledge is presented in the paper by Buzek (1996) who summed up the fifteen years of observations and of measurements in the drainage basin of the upper reaches of the Ostravice River in the Moravskoslezske Beskydy Mts. The intensive soil erosion in the area is primarily conditioned by a character of the bedrock (Buzek 1997) and by duration of daily precipitation of 10–30 mm. Much more soil is carried away if the forestry machinery operates in a wet terrain. From Buzek's observations it results that 76 t/km^2 on the average are carried away from the upper Ostravice drainage basin (72.96 km^2) per year, which is the value representing 0.04 mm of soil profile.

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STRESZCZENIE

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BADANIA GEOMORFOLOGICZNE PROCESÓW I FORM W KARPATACH ZACHODNICH NA OBSZARZE REPUBLIKI CZESKIEJ

W pracy przedstawiono wybrane wyniki badań przebiegu i natężenia współczesnych procesów morfogenetycznych w karpackiej części Czech. Skoncentrowano się na zagadnieniach dotyczących erozji wietrznej i form wydmowych. Po wydzieleniu obszarów, na których występują burze pyłowe scharakteryzowano wielkość i częstotliwość procesów eolicznych, częściowo w ujęciu ilościowym. Było to możliwe dzięki zastosowaniu deflametrów. Przedstawiono zależności matematyczne i graficzne pozwalające na obliczenie wielkości erozji wietrznej oraz zwrócono uwagę na wpływ typu użytkowania ziemi na tempo i sposób współczesnego modelowania obszaru przez procesy eoliczne. Wspomniano również o potrzebie prowadzenia badań nad erozją wodną.