RESEARCH OF THE LAND FORMING ACTIVITY OF WIND AND PROTECTION AGAINST WIND EROSION IN HUNGARY

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ABSTRACT. Research of the land forming activity of wind and protection against wind erosion in Hungary. Descriptions regarding the land forming activity of wind – primarily its harmful effects and the importance of protection against it were published in Hungary as early as the 18th century. Geographers, however, started researching them only slightly more than a century ago. At the beginning morphology and land development was the most interesting to researchers. Researching the physical laws of wind erosion and possibilities of protection against wind erosion were only started at the beginning of the second half of the last century. Hungarian research of aeolian processes can be dissected into well-defined sections. The present paper aims primarily to present research ways and the most important results achieved so far.

Key words: research, wind, erosion, activity, Hungary

1. Introduction

Extended areas of wind-blown sand can be found in Hungary. Almost 25% of the crop land in Hungary is covered by wind-blown sand, sandy loess and loessy sand. Wind-blown sand covers large areas primarily in the Danube-Tisza Interfluve, Nyírség and in Inner Somogy, however, this type of sand occurs in numerous places in small spots or larger areas (Figure 1).

Studying the surface of wind-blown sand dates back almost for two hundred years. First significant results were obtained by Cholnoky J. (1902), who dealt with studying the forms and classifying them according to genesis. Later (1940) he studied the wind erosion a form of movement and extension of wind blown sand.

New results were gained by the researches of Kádár L. (1930, 1934, 1935, 1938) related to the forms of national wind-blown sand areas. Still at that time the research of Sümeghy J. (1944) gave useful data for the development of wind-blons sand areas. The statement still relevant today can be associated with his name that

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the source material of wind-blown sand is the fluvial sand of alluvial fans of former rivers.

From the early 1950s Borsy Z. (1961, 1965, 1968, 1971), Bulla B. (1951, 1953), Erdélyi M. (1960), Franyó F. (1961), Góczán L. (1955), Kádár L. (1951, 1954, 1956, 1957, 1966), Láng S. (1954, 1958, 1960), Marosi S. (1955, 1958, 1962, 1965, 1966, 1967, 1970), Miháltz I. (1952, 1953, 1954), Molnár B. (1961, 1964), Pécsi M. (1957, 1960), Sümeghy J. (1951, 1953, 1955), Szilárd J. (1955), Urbancsek J. (1955, 1963) wrote valuable publications that contributed significantly to our knowledge considering the development and morphology of areas of wind blown sand.

Figure 1. Areas of wind-blown sand in Hungary (1:Inner-Somogy, 2:Danube-Tisza Interfluve, 3:Nyírség)

From the early 1970 studying the characteristics of wind-blown sand movement has been possible in Hungary as well as the wind tunnel of the University of Debrecen was installed. Most important results of this field were achieved by Borsy Z. (1974). Recent results of wind tunnel experiments have been also published (Lóki J. 1995, Lóki J. – Szabó J. 1996, 1997).

Among labor atory analyses, grain-size distribution of sand layers, roundedness of quartz particles (Borsy Z. 1965, Lóki J. 1975) and electron microscope imaging of quartz grains (Borsy Z.- Félszerfalvi J. - Lóki J. 1982, 1983, 1985) were the most important ones. Analysing the sand sediments of drilling cores by electron microscope made the separation of fluvial and aeolian sand more accurate yielding new data for clearing the development of alluvial fans (Borsy Z.- Félszerfalvi J. - Franyó F. - Lóki J. 1987).

Recent years saw the continuing field surveys besides laboratory measurements that focused on the one hand on wind erosion and protection against it (Borsy Z. 1974; Lóki J. 1985, 1995) and on the other hand on the development of land covered by wind-blown sand.

2. Land development of wind-blown sand areas and the age of wind-blown sand layers

Explaining the formation of Hungarian sand areas was first attempted by Sümeghy (1944) who based on borehole data explained the filling of the basin by alluvial fan development. In the course of the formation and development of Pleistocene alluvial fans wind-blown sand could have developed under appropriate climatic conditions – where sandy sediments of suitable grain-size were deposited – in several time periods. Following the recognition of the alluvial fan character of the Kiskunság in the Danube-Tisza Interfluve, the idea of Cholnoky (1910) that the wind-blown sand of the Kiskunság was originated from sand blown from the Danube and carried to the Tisza was rejected. Finding the place of origin of the wind-blown sand was not a problem any more, as Marosi (1967) wrote "distribution of the wind-blown sand is identical to the area of the prior fluvial land formation, its origin is fluvial sediments".

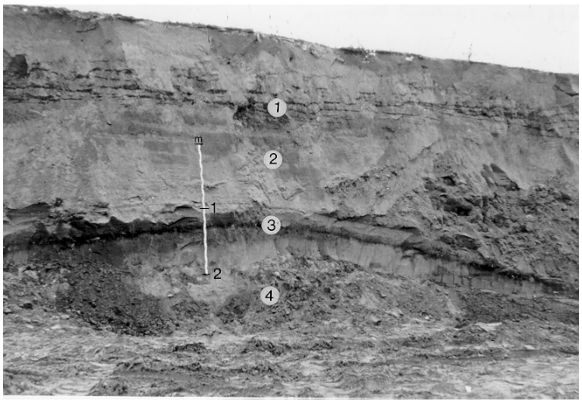

Figure 2. Fossil soil in the sand quarry at Kenézlő 1. kovárvány containing sand layers; 2. Old wind-blown sand formed in the Dryas; 3. Bölling interstadial fossil soil; 4. Upper Pleniglacial wind-blown sand. Age of the soil is 12400±360 B.P.

Studying the shape of sand grains of different origin has more than seven decades of history (Szádeczky−Kardoss 1933; Miháltz 1952; Miháltz–Ungár 1954; Borsy 1965, 1974; Lóki 1975). Examination of sand particle includes small, intermediate and coarse grains as well. Initially stereomicroscopic images were interpreted using national and foreign methods. Separation of fluvial and aeolian sands was helped by the investigations of Borsy (1965) applying Krygowski method and by the interpretation of stereomicroscopic images of the grains. He called attention to that knowing roundedness alone is not enough to identify wind-blown sands as fluvial sand grains may become more rounded than wind-blown sand particles. When determining the age of surface wind-blown sand the time when the form was developed had to be defined. In this case, apparently the time of the formation of the alluvial fan has to be considered primarily. Marosi explained the roundedness of the particles in the wind-blown sands of the Belső-Somogy by that the development of alluvial fans was ceased there first providing the longest time for wind to form the land. In his opinion wind was the dominant land forming factor in the dry periods of the entire Würm in the sand areas of the Belső-Somogy. Pleistocene age of the forms is also proved by the periglacial features in their surface like frost wedges filled by kovárvány containing sand and fossil soil (Marosi 1966, 1967, 1970). In the Holocene sand was moved only in smaller areas and primarily as the result of anthropogene activity. Borsy (1961) assumed Holocene sand movement based on the studying of the larger and more intact forms of the Nyírség. In outcrops he recognised fossil soils dissecting the dunes and also identified loess layers occurring at places. He placed the formation of the wind-blown sand above the loess layer into the boreal phase when the climate was drier than today. He changed his opinion on Holocene sand movement when ^{14}C age determinations enabled the more accurate determination of the movement periods of wind-blown sand. In dune outcrops in the wind-blown sand areas of the northeastern part of the Great Hungarian Plain fossil soils were found at several places (Figure 2) that contained charcoal remnants. By the radiocarbon analysis of these the age of formation of wind-blown sand can be determined accurately. Studying the stratification of the dune outcrops and the results of the radiocarbon determinations (Table 1) it was verified that largest sand movement took place in the Upper Pleniglacial in the northeastern part of the Great Hungarian Plain (Borsy et al. 1985, Lóki et al. 1993, Borsy és Lóki 1994, Lóki 2003).

Table 1. Radiocarbon data of samples from the wind-blown sand areas

Number in laboratory	Sampling site	Radiocarbon age (B.P.)
Deb- 123	Vajdácska I.	12330±320
Deb- 135	Vajdácska II.	12230±400
Deb- 237	Bodroghalom I.	11600±500
Deb- 228	Bodroghalom II.	11460±500
Deb- 311	Bodroghalom III.	11240±500
Deb- 329	Kisrozvágy	12680±400
Deb- 330	Kenézlő	12400±360
Deb- 196	Aranyosapáti	12900±360
Deb- 199	Székely	11350±360
Deb- 155	Nyírmihálydi I.	11930±340
Deb- 157	Nyírmihálydi II.	11250±340
Deb-3050	Debrecen SSE I.	11795±118
Deb-3053	Debrecen SSE II.	11572±107
Deb-1092	Lakitelek	11700±250
Deb-1080	Tiszaalpár	15310±350
Deb-1079	Hay-tanya	11770±300

In the first part of the Upper Pleniglacial – 27000–22000 (B.P.) – climate became cooler and drier than before. At the time of maximum cooling annual mean temperatures decreased below oC and the annual precipitation could have been 200–250 mm. In cold and dry climate the sandy sediments on the surface of the alluvial fan were protected only by a sparse vegetation characteristic for cold steppe and wooded steppe that was proved to be not enough against strong northern winds. Then on the unprotected or slightly sheltered areas wind-blown sand formation was started together with wind-blown sand forms characteristic for semi-bound areas. Sand movement changed the morphology of the alluvial fan significantly. Larger or smaller deflation flats and to the south of them dunes were developed. Sand movement was not active at the slightly warmer and wetter climate between 22000 and 20000 B.P., however, only to be continued in the second, again colder and drier period of the Upper Pleniglacial to the Bölling interstadial. At that time under the wetter and warmer climate, steppe and wooded steppe was formed stopping the movement of sand. Soils developed under climatic conditions and vegetation cover of that time were exposed at several places.

Thin soil cover (< 20 cm) suggests that its formation was not taking a long time. Vegetation again retreated under the more severe climatic conditions of the Dryas (12400–10200 B.P.) and sand started to move again at several places. occasionally a sand cover of 2-5 m occurred on the soil.

During the research in the northern part of the Danube-Tisza Interfluve fossil soil was present in the outcrops only at a few places. In the small number of fossil soils, charcoal in quantity enough for measure is found only in outcrops at Lakitelek and Tiszaalpár (Sümegi and Lóki 1988-89, Sümegi et al. 1992). Studying the stratification of outcrops and boreholes it was revealed at several places that the wind-blown sand was deposited onto fluvial sediments containing large amount of snail shell. Therefore the malacological and stratigraphic survey and interpretation of the strata was started. By this time we had the chance for age determinations in this way, the ages determined in the northern part of the Danube-Tisza Intefluve (Lóki and Sümegi 199192). At that time age determination from mollusc shell was possible. Age data from the northern part of the Danube-Tisza Interfluve are the same as in the Nyírség and Bodrogköz. In this way we can state that the sand movements in Hungary at the end of the Pleistocene took place in the Upper Pleniglacial and in the Dryas periods.

Fossil soil is found only at a few places in the wind-blown sand areas of the Belső-Somogy as well. Thickness of the wind-blown sand exceeds not 10-12 m even in accumulation areas (Marosi 1970, Lóki 1975, 1981). More precipitation fell on the alluvial fan in the Belső-Somogy in the wetter periods of the late glacial than in the central or in the eastern parts of the country therefore closer vegetation cover developed in the Bölling following the sand movement of the Upper Pleniglacial that provided enough shelter at most places in the Dryas as well. In this way, the sand land of the Belső-Somogy has to be regarded the oldest among Hungarian wind-blown sand areas.

The question arose whether wind erosion appeared before and whether wind transformed the already developed forms or not. To answer these questions we have to analyse the sand sediments of deeper strata in more detail on the one hand and on the other hand, when studying young Holocene surface changes ecological factors have to be considered besides climatic changes. By the electron microscope analysis of the sand layers of cores from deep boreholes in the Great Hungarian Plain stored in the Geological Institute of Hungary (Borsy et al. 1987) it was verified clearly that wind-blown sand was formed in several time periods in the Pleistocene prior to the upper Pleniglacial. These wind-blown sand layers are dissected by fluvial strata according to the formation of alluvial fan and are located deep at places as a result of tectonic movements.

In the Holocene, warmer and wetter climate enabled the development of a vegetation cover protecting the surface more than before. By studying near-surface sand layers, archaeological findings, OSL measurements and ^{14}C data, however, sand movements – primarily as a result of anthropogenic effects – were identified at various time periods in the Holocene.

Considering Holocene climatic changes former research presumed sand movement in the Preboreal and Boreal phases and in the drier periods of the Atlantic phase (Kádár 1956, Marosi 1967, Borsy 1974, 1977ab, 1980, 1987, 1991, Borsy et al. 1991, Lóki 2003, 2004b, Gábris 2003, Nyári és Kiss 2005a, Ujházi et al. 2003).

Research carried out in the Nyírség and in the Danube-Tisza Interfluve suggests that sand moved even several times in the Danube-Tisza Interfluve. This can be explained by that this area belonged to the driest places of the Karpathian Basin in the last millennia therefore wind erosion was more frequent on the wind-blown sand surfaces there. This is why developed soil in the sand areas in the Danube-Tisza Interfluve could not have evolved.

Recent studies (Félegyházi and Lóki 2006, Kiss et al. 2008) that in the Nyírség the first Holocene sand movement took place in the Preporeal. This corresponds to the former suggestions of Borsy (Borsy 1961) who assumed Boreal sand movements in the middle of the last century, however, he rejected this idea following the accurate determination of the age of the buried soil layers of the dunes. Age data of the newest studies (Kiss 2000, Kiss and Sipos 2006, Kiss et al. 2008) indicate again Boreal sand movement as a result of climatic change.

Atlantic sand movement was first suggested by Borsy (1980). Based on recent research, Ujházi (2002) determined Upper Atlantic sand movement above the older Dryas in the outcrop at Dunavarsány. Kiss and his colleagues detected Atlantic and Subboreal wind erosion in the model areas at Bagamér and Erdőspuszta (Kiss– Sipos 2006, Kiss et al. 2008). Research based on archaeological and OSL data (Gábris2003, Ujházi et al. 2003, Nyári and Kiss 2005b, Kiss et al. 2006, Sipos et al. 2006, Nyári et. al 2006ab, 2007ab) prove that sand was moved in several time periods at the beginning of the Subatlantic phase, in the iron age and at the time of the great migrations as well. Bronz Age and Sarmata findings in the blanket sand in the southern margin of the Nyírség suggest wind erosion as a result of anthropogenic effects (Félegyházi and Lóki 2006). Bronz Age sand movement was caused by overgrazing (Lóki and Schweitzer 2001, Gábris 2003, Nyári and Kiss 2005b, Félegyházi and Lóki 2006). Several scientists (Marosi 1967, Borsy 1977a, b, 1980, 1987, 1991, Borsy and Lóki 1982, Lóki 2003) referred to the sand movements of historical times (18th and 19th centuries) that were associated to deforestation and land cultivation.

At the current climatic conditions the threat of wind erosion in Hungary has to be considered only in dry areas not protected adequately by vegetation. It can be expected primarily on parcels ploughed in spring or autumn, however, it may occur in winter as well on surfaces void of snow cover (Lóki 1985).

3. Studying the principles of wind erosion

In the drier periods of the middle of the last century wind erosion damage was increased due to large parcel cultivation and inappropriate agricultural technologies. Research trying to establish protection procedure with studying the conditions of wind erosion was started at that time. Regarding soil scientists the works of Bodolayné (1965, 1966) have to be noted who, on the one hand, started the examination of the quantity of wind load and on the other hand, worked out various procedures on experimental parcels for decreasing deflation of wind. Sand traps used at the start of the measurements, however, could not enable the accurate identification of load transport.

In order to know wind erosion more accurate, Borsy held experiments at the University of Debrecen from 1962 with various type horizontal and vertical load traps. In the Nyírség and in the Danube-Tisza Interfluve he carried out vast number of field measurements throughout the year (Borsy 1972) on the basis of which he determined that if the value of W* reached 20–21 (equalling 5.5–6.0 m/sec wind speed at 100 cm) the magnitude of sand movement became surprisingly high.

Obtaining information regarding the conditions of wind erosion was helped greatly by the wind-tunnel built (1970) in the University of Debrecen (Figure 3). Experiments were held in the wind-tunnel parallel to field measurements. Experiments were carried out initially using wind-blown sand from the Nyírség. Critical triggering velocity, wind profile, quantity and grain-size of moved material were determined. Obtained results were compared to the values of field measurements and to international data published in the scientific literature. High number of wind-tunnel and field measurements enabled us to determine wind erosion conditions for Hungarian wind-blown sand (Borsy 1974).

Deflation activity of wind unfortunately appears on more bound soils apart from our loose wind-blown sand areas and wetland and mull surfaces. Therefore from the middle of the 1980s studying the erodability of different physical soil types was started. Using wind-tunnel experiments on different soil types wind erosion conditions were determined for non wind-blown sand surfaces as well and a wind erosion information system was constructed (Lóki 1994, 2003).

The new modern instruments enable us to make measurements more accurate. At the University of Szeged load transport measurements have been carried out on experimental parcels using Saltiphon for ages and based on the obtained data they are working out a wind erosion model (Mezősi és Szatmári 1996, Szatmári 2006).

In recent years colleagues of the University of Debrecen and the University of Szeged have been comparing wind-tunnel and field measurement data. Comparison of these values contributes to our knowledge on the conditions of wind erosion.

4. Studying protection against wind erosion

Traces of wind erosion can be detected in Hungarian arable lands in almost every year. Numerous textbooks and publications have discussed methods of bonding sand Traces of wind erosion can be detected in Hungarian arable lands in almost. Areas covered by loose wind-blown sand giving recommendations for planting forests. Binding wind-blown sand by woodland and orchards got momentum in the second part of the 19th century. In this time period wind-blown sand over extended areas was bond and utilized agriculturally by planting orchards and acacia groves.

Works of Westsik (1951 and Egerszegi (1961) have to be mentioned who made huge efforts for a long time to improve the production rate of sand soils and to reduce deflation damage. Possibilities of protection against deflation in irrigated sand areas were investigated by Bodolayné (1965). She called attention to that soil cultivation has significant role in wind erosion. She also studied the erosion reducing effect of the crust developing on the surface of soils. Gál (1974) suggested the plantation of shelterbelts and woodlands in order to protect against deflation and air pollution.

In the second half of the 1970s a national collaboration among agricultural professionals was developed in research aiming to protect against wind erosion. New papers were published discussing the wind erosion of Hungarian sand soils and the protection of soils (Fekete and Király 1973).

Considering geographers, primarily the works of Borsy have to be highlighted as he pointed out knowing the conditions of wind erosion is essential for protection against it (Borsy 1974).

From the beginning of the 1980s, experiments were extended over different soil types in Hungary. Critical triggering velocity and erodability of various physical soil types were determined (Lóki 2000, 2002, 2007, Lóki and Négyesi 2003, Lóki et. al 2005, Négyesi 2009).

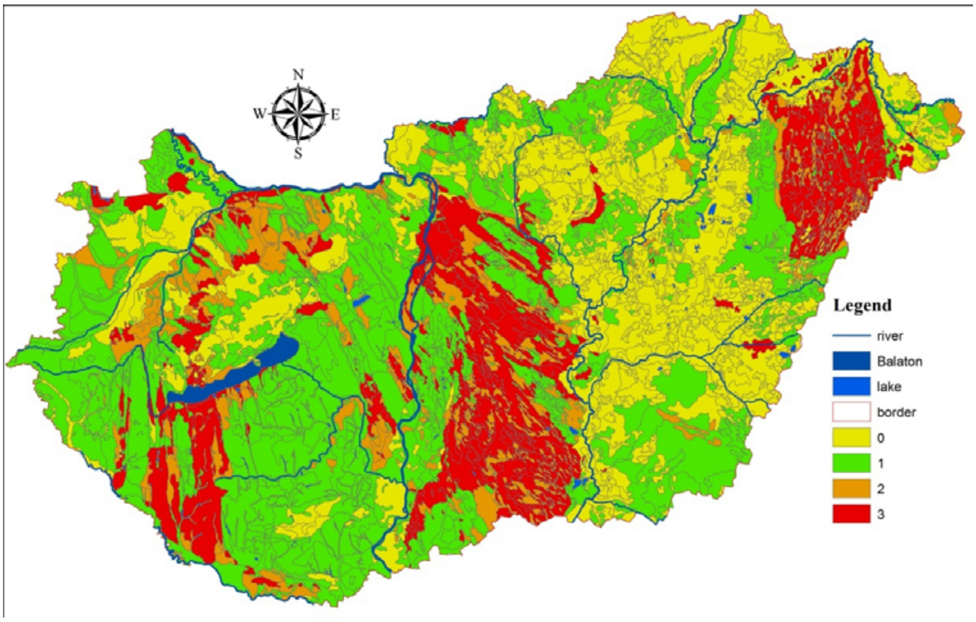

Figure 3. Potential wind erosion map of Hungary
(0: insignificant, 1: slight, 2: moderate, 3: severe)

Development of wind erosion and the grade of its damage depend on numerous factors (e.g. soil texture, climate, vegetation, anthropogenic effects, etc.). When constructing the potential wind erosion map the critical triggering wind velocity and the erodability of soils (amount of material transported for 5 minutes at 14 m/s) with different texture were considered. Soils were classified into different risk categories regarding wind tunnel measurement mean results according to the following:

- *Insignificant (0)* wind erosion is characteristic for silty, clayey adobe, silty clay and clay soils. Wind velocities exceeding 10.5 m/s are required in order to move these soils and the amount of eroded material reached not 1 kg.

- *Slight (1)* wind erosion is regarded when the critical triggering velocity of soils is between 8.6 and 10.5 m/s and the amount of transported material was double the amount above. Adobe and silty adobe soils belong to this category.

- *Moderate (2)* is the risk on sandy adobe soils. Wind erosion in areas with such soil starts at wind velocities between 6.5 and 8.5 m/s and the amount of transported material was three times that of the first category.

- *Severe (3)* category includes sand and adobe sand soils together with mull and peat containing high amount of organic material. These soils can be moved by wind velocities smaller than 6.5 m/s and the quantity of transported material is more than three times that of the first category.

Estimated ratio of lands threatened by wind erosion of various severity considering the above is presented in Table two while their spatial distribution is given in Figure 3.

Regarding protection procedures various degree of irrigation, protective effects of vegetation, application of agrotechnical methods (annulate and plain cylindrical) and the wind erosion reducing effects of different crust forming chemical have been studied (Lóki and Szabó 1997, Lóki 1994, 2003, Lóki and Négyesi 2003, Négyesi 2009). Great emphasis was put on finding environmentally sound methods giving appropriate protection (Lóki 2004a). Regarding this both laboratory and field experiments verified that applying appropriate amount of molasses of appropriate concentration has beneficial results (Lóki 1994).

Table 2. Potential wind erosion risk in Hungary based on soil texture

Risk category	ha	%
Insignificant (0)	2804168	30.2
Slight (1)	4039407	43.3
Moderate (2)	873898	9.4
Severe (3)	1589026	17.1
Total	9306499	100

As a result of global climatic change, climate became more extreme. This is indicated in recent years by that days of great precipitation falling in short time periods are followed by longer water deficient periods when the risk of wind erosion increases. Therefore we consider further research on environmental friendly methods of protection against deflation very important.

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