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PROBLEMS OF CONTINENTAL DUNE RESEARCH AND THEIR SOLUTION METHODS IN POLAND

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Introduction

Dunes cover a high percentage of Poland's territory where they occur as large continuous fields, small sets of dunes or single dunes scattered over nearly the entire surface area of the country. Their distribution in Poland is illustrated by sketch-maps and by the General Geomorphological Map of Poland (Starkel, 1980). As dunes and eolian sand covers are widespread in a large portion of Europe (including Poland), they have been the frequent object of study, resulting in hundreds of publications concerning these forms (Nowaczyk, 1986a) (Fig.1).

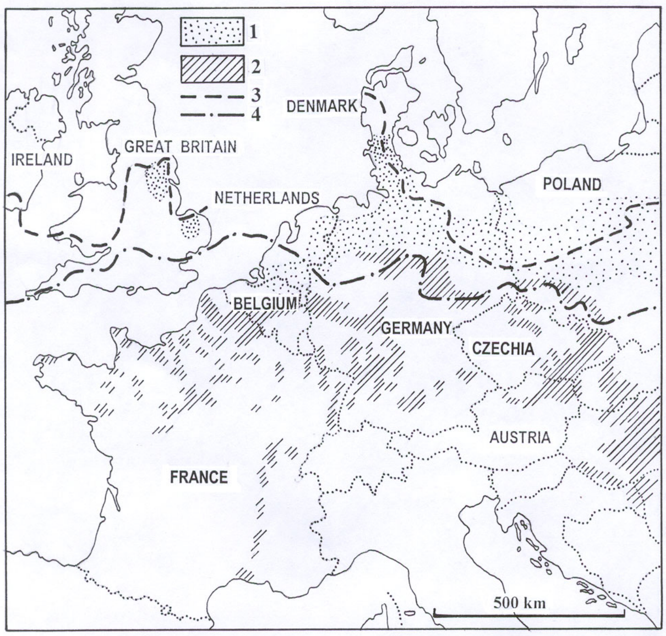

Fig. 1. Areal distribution of the European sandy–loess belt (compiled from various sources): 1 – eolian sand belt (inland and river dunes, cover and drift sands), 2 – sandy loess and loess deposits belt, 3 – the maximum extent of Weishelian (Devensian, Vistulian) ice sheet, 4 – the maximum extent of the continental Pleistocene ice sheet.

1 pav. *Teritorinis Europos smėlio-lioso juostos išsidėstymas (sudaryta remiantis skirtingais šaltiniais): 1 – eolinio smėlio juosta (žemyninės ir paupinės kopos, dengiamasis ir judrusis smėlis), 2 – smėlio–lioso ir lioso nuogulų juosta, 3 – Weishelio (Devensio, Vyslos) ledyno maksimalaus paplitimo riba.*

Eolian sands are known in such Lithuanian localities as the Curonian spit, Dzūkija Region, Kazlų Rūda, Rūdninkai, Viešvilė forest environs and some other places. They have been insufficiently investigated what becomes evident when one familiarizes with the scientific literature about dunes in Poland.

The aim of the present work is to overview the scope of problems analysed by Polish dune researchers (about 30 working in this field at present), compare the newest studies of eolian deposits with the previous works emphasizing the advance made and what is to be still done in the future, introduce the main methodical principles and most widespread methods, and to describe the method of determining the roundness of grain using a unique device.

1. The problems of investigation of Polish continental dunes

Some time ago (the 70ties–80ties of the 20th century) researchers – such as S. Kozarski, K. Tobolski (1968), B. Nowaczyk (1986 a,b), R. Borowka et al. (1986), R. Galon (1969), A. Okolowisz (1965), A. Dylikowa (1969), Z. Churska (1969), U. Urbaniak (1969) emphasized the importance of continental dune studies in Poland because the character of aeolian deposits reflects the climate changes in the past and even may be helpful for reconstruction of the landscape at the end of Pleistocene and in Holocene. Many literary works describe the distribution and spread area of continental dunes. The spread areas of their complexes in Poland are in the Silezian Lowlands, Lublin Upland, Torun–Bydgoszcz depression, Kampinos Forest, Sandomierz depression, and Leba environs. Many solitary dunes are scattered on the banks of such rivers as: Wkra, Pilica, Wisla, Odra, and Warta. As was mentioned above, the distribution of dunes is a sensitive indicator of geographical environment conditions that existed in different time frames of the past. Detailed studies of the problems raise the question whether dune formation was a continuous process or took place only at certain development phases. There are questions related with the dune age and dune formation conditions (whether they were uniform or bore zone character forming behind the melting glacier). Dunes are also investigated from the point of view of the mechanism of aeolian processes (dominance of accumulative or deflation processes). This mechanism can be comprehended analysing the microforms of coastal sandy relief. There are a lot of questions about the causes of uneven distribution of dunes (relief or hydrographic conditions), the extent to which the type of deposits predetermines the distribution pattern and the role of vegetation in stopping the dune movement. Basing on the dune structure (grain distribution according to their size) and texture (absence or presence of layers) A. Dylikowa (Dylikowa, 1969) distinguished four aeolian covers in the central Poland. Each recorded sand cover corresponds with the dune formation phase whereas the presence of orogenic material or buried horizon implies a pause between accumulation processes. The four distinguished dune covers are reflections of the four development phases of dunes: initial (Lower Driassic), main (Middle Driassic), reformation (Upper Driassic) and degeneration (Holocene after Preboreal) phases. There is an interesting question related with the position of dune forms. It is still not clear whether the reformation of dunes followed a regular pattern. Can we, for example, consider the parabolic dunes to be the initial form of longitudinal or transversal dune ridges or the other way round? Among investigation methods we can mention the comparison of morphological axes of different complexes with the structural axes. For example, a clear link between the morphological and structural axes in the upper part of dunes may serve as a proof of sand cover developed during the reformation phase.

Discrepancy between these axes implies that a thick aeolian cover previous to parabolic forms has developed from ridge-shaped forms. Not only the character of movement but also the topographic and hydrographic conditions may be mentioned among the causes of differences between the layers of various dune forms. W. Stankowski has determined (Stankowski, 1963) the link between the parabolic dunes and shallow till in the territory of Poland Major.

Among many scientific problems we can also mention ephemeral sand plants changing their arrangement and form depending on the wind direction. Psamophytes most actively participate in dune formation. They begin to grow vigorously when covered by sand containing humus and mineral salts. The long thin roots supply the plants with nutrients (partly coming with precipitation) and young sprouts and leaves shoot out from the sand.

Generalizing we must point out that the newest works of Polish continental dune researchers (Izmailow, 1975, Izmailow, 1984; Izmailow, Nalepka, 1994; Issmer, 1996; Dulias, 2002; Pelka–Gosciniak, 1996) are of descriptive and analytical character and based on abundant field material. Detailed morphological and structural analysis is the main research strength of recent years. It is expected to answer the global questions about dune formation. Examination of interesting wind–eroded boulders eglogliptolithes (Antczak–Gorka, 1996) suggests the absence of hypothetical 'Vrzesnia bay' in the eastern part of the Great Polish Lowlands. It is an attempt to characterize aeolian sands by the dendritic method, when investigation was carried out on the large crescentic dune (barkhan) (Szcypek, 1987). The Bukowino quarry in the Silesian Upland, where anthropogenic activity entailed aeolian processes forming deposits of the 'nebkcha' type has been the object of investigation for a few last years (Szcypek, Wach, 1993). It is characteristic that researchers of Poland have begun the international relationships and cooperation. A few common scientific products have been published (books, articles). One of them is "Aeolian processes in different landscape zones", which contains an article about aeolian phenomena in the south–western part of Spits Bergen in the Arctic (Kida, 2000) while the basic physical features of contemporarily blown aeolian sands in steppe zone of the Selenga–Chikoy interfluve in the Eastern Siberia are described in the paper by T. Szczypek and V. A. Snytko (Szczypek, Snytko, 2000).

2. Methodical principles and methods of eolian sand research

Polish experts study aeolian forms basing on cartographic material, field excavations (to the depth of 3 m), and microscopic analysis of textures and grains – rounded, frosted or transparent with different units – which provide information about movement in the wind and sand flow. They also use in their research a unique device – graniformameter.

The field studies involved mapping dunes in the study area, locating outcrops within them, and then detailed morphological–structural (textural) studies of dunes, which met the criteria required of such studies: were built of bedded sand, exposed over large areas in longitudinal and transversal sections crossing the central part of the dune. For each dune its conditions of occurrence, orientation, and shape as projected on a plane, shape of morphological axis, exposures and angles of slopes were described. The bedding of the sand was mostly studied in three planes: the horizontal plane, and vertical cross sections parallel and at right angles to the maximum dip of the laminar beds in different parts of the form. Particularly important are the measurements and dips of the laminar beds in lee–ward structures, made at 25 centimeters intervals in the vertical cross sections, marked at 1.5 m intervals along the lee-side slopes in several cases along the entire length of the form. They served to identify possible changes in the position of the morphological as well as the shape of the dunes during their development (Izmailow, 2001). Samples of sand from the dunes and substrate in several vertical profiles along the longitudinal cross sections of the form were taken for laboratory analysis.

The degree of deposit aeolization may be recorded in various features of deposits, such as composition of heavy minerals, proportion of quartz in the sandy fraction, the sorting degree, rounding and frosting degree of quartz grains.

The petrographic and mineralogical analysis of deposits is extremely valuable for inferring on the source and character of sedimentation, morphogenetic processes acting during deposit formation, and post–sedimentation processes. The petrographic composition varies according to the interval of the grain size. In order to determine the age and origin of deposits it is especially important to analyze heavy minerals. To define the age and origin of a deposit it is essential to divide heavy minerals occurring in it into minerals resistant and noon-resistant to chemical weathering.

According to the extreme limits of grain size in the analyzed sediments various methods of the measurement of granulometric composition are used. Analysis of sandy deposits (dustless, well washed) is usually made by dry way using a set of sieves of mesh size from 0.06 to 2.5 mm. To make further presentation of the results it is most advantageous to use in the sieve analysis as many sieves as possible in the tiniest fraction intervals. If the sieves are defined in phi units, it is recommended to use a set of sieves at the intervals every 0.5 phi unit.

Selected methods of analysis of the sand grain shape for palaegeographic and stratigraphic studies are used especially in Poland. Among four aspects of geometric methods, two of them are particularly useful for the above–mentioned purpose: 1. Surface texture and 2. Grain roundness. The former can be examined most precisely under electronic microscope (for example, SEM), and it permits an analysis of a large number of grain. It is advisable to complement observation from the optical microscope with the examination of selected grains under the electronic microscope. Unfortunately, there have so far been no widely accepted and fully satisfactory procedures of the analysis of roundness and texture of the grain surface. For the purpose of the history of grain abrasion, easiness of measurements and frequency of application the following methods were used: 1. Morphoscopy, 2. Measurement of roundness by comparing with standard charts, and 3. Mechanical graniformametry. Three main types of grains were distinguished according to morphoscopy method: 1. Unabraded, 2. Polished rounded, 3. Maximally rounded. In the case of sand grains the roundness is most often measured by comparing the grain shape with standards on chart of the Krumbeim scale, Power's scale and Gozdik scale. In Poland there are many well rounded grains and the arithmetic Krumbein scale differentiates them in a better way (Badania…, 1995). Mechanical graniformametry method is most frequently used in Poland.

3. The graniformametric method of the investigation of the sand grains

The shape of grains in the deposit regardless of their size depends on a number of factors, including the initial shape of the grain, its physical and chemical features, the duration of the process, character and environment of transport, as well as the type and intensity of weathering following the sedimentation. The two latter factors usually affect the grains most, especially the type and extent of its rounding and surface frosting. Thus the character of rounding and surface frosting of the grain is an indicator of the transport environment and of the subsequent diagenesis of deposits.

The form of grains is one of the most difficult properties of deposits to define. Methods used to examine the rounding of the grains depend on their size. Determination of the degree of abrasion of grains of the sandy fraction is attained using several methods. One of them is mechanical graniformametry (Fig.2).

Fig. 2. The view of uninique mechanical graniformameter used for determining the abrasion of eolian sand grains (photo by B. Izmailow), created in 1964 by B. Krygowski.
2 pav. *Unikalus mechaninis graniformametras naudojamas eolinio smėlio dalelių apzulinimo laipsniui nustatyti (B. Izmailov nuotr.), kurį sukūrė B Krygowskis 1964 m.*

It was introduced by B. Krygowski (1964), who adopted the behaviour of grains on inclined plane as the basis for their differentiation. He constructed a measuring device, which he called a graniformameter. The measure consists of the angle value at which the grain starts to roll down on the inclined plane of graniformameter.

Determination of the degree of abrasion of grains of the sandy fraction is usually based on the examination of quartz grains. Quartz is one of the most resistant mineral which very long preserve the features obtained in a definite sedimentary environment. Thus, before the analysis of the rounding is undertaken, this group of grains should be separated from the sample under investigation. They are cleaned from carbonate admixture by boiling in 10% hydrochloric acid. The graniformametric analysis consists of separation of 100 grains of a particular fraction (most frequently 0.75–1.02 mm in diameter, but we can take the grains 0.5–0.75 mm, 1.02–1.2 mm, 0.25–0.1 mm, 0.25–0.5 mm, 1.25–1.6 mm or 1.6–2.0 mm in diameter too) and then calculation of the proportion of grains in particular classes of rounding.

The measuring results were defined by Krygowski as indices of "abrasion". The term "abrasion" concerns both the grain shape and texture of its surface but the abrasion is

principally referred to roundness. This is reflected in defining three distinguishes types of grains:

1) those rolling down the plane inclined 0–8^o, defined as well-rounded grains – γ type;
2) grains rolling at an inclination interval 8–16^o, called medium-rounded grains – β type;
3) grains rolling down at an inclination of >16^o, described as non-abraded grains – α type.

The sedimentary environment and its dynamics are characterized by at least several parameters according to B. Krygowski formulas.
They are following:
1 parameter – W_o = 2400 - (Σnk * 100) : N - coefficient of abrasion
n - number of grains in angle classes
k - mean angle in given angle class
N - number of all the grains in a sample
2d parameter – coefficient of irregularity of abrasion – $N_m = Q_3 - Q_1$
Q_3 - angle in which 75% of the grains is rolled down
Q_1 - angle in which 25% of the grains are rolled down
3d parameter – the histogram type of grain abrasion

The first index W_o is ranging from 0 for non-abraded grains to 2400 for very well rounded grains. The coefficient N_m is the measure of sorting of the grain shape. Its large value implies selection ability of the grain shape in given sedimentary environment.

The histogram has been picked out since it provides the most comprehensive definition of the deposit as far as the dynamic conditions of its origin are concerned. It made it possible to arrange a classification for them. There are four principal types of histograms, illustrating a strong or weak tendency for shape selection or a total lack of it within a given environment. Another one comprises combinations produced by the superposition of two different histograms. This latter type illustrates some sort of pulsation of two tendencies within the environment: one towards shape selection, the other to aselection. The environment is not determined from one sample, but from the frequency with which samples occur showing definite parameters and coefficients. The conclusions as to the type of sedimentary environment in which samples from exposed deposits or from bore holes must have been deposited must obviously be based on a statistically satisfactory number of samples.

The analysis of quartz-grain rounding after Krygowski failed to discern the genetically different deposits. For example in the fluvial environment the grain is liable to slower abrasion than in the glacial or aeolian ones. Although the different sedimentary environments are more or less favourable for grain abrasion the investigation of rounding of the quartz grains has shown that this feature of the grains depends on the source of the deposits too. The degree of abrasion of quartz grains of the investigated deposits may not be considered separately but should always be compared with the abrasion of grains collected from the source deposits. This comparison displays the extent of transformation. The difference between the degree of abrasion of the grains of the investigated and source deposits may indicate the rank of time of the dynamics of environment of transport and sedimentation. Analysis of quartz-grain rounding enabled a variable degree of sediment transformation during saltation or rolling to be distinguished. A set of features was chosen in order to determine the degree of transportation of the substratum sediment into another forming one. The degree of transformation of source sediments into other ones may help to estimate the duration of active process that resulted in the formation of deposits. It may be a result of the processes of morphoselection during the transport. During the traction transport, the spherical grains are included in the movement at smaller velocities than the angular grains and they make a longer way. In saltation the angular grains being easier to carry, are preferred in the movement. Thus the character of morphoselection depends on the form of transport. Spatial variability of quartz-grain abrasion within the sediments of the same genesis is a result of variability of quartz-grain abrasion in the underlying deposits.

The results of the graniformametric analysis are largely used to estimate the actual dynamics of the sedimentary environment: to determine transport direction and velocity. In the case of palaeogeographic and stratigraphic investigations the analysis of the grain shape are made in the first place for reconstruction of the history of grains being subject to abrasion in the sedimentation cycle or cycles.

The analysis of the degree of rounding of the grain provided much data for the genetic interpretation of deposits, on dynamics and kind of processes, climatic conditions, and – indirectly – on the age of deposits. These results help to establish the boundary between the deposits, which have different genesis or age. For the purpose of interpretation - the described methods of investigation was used in studies on the Quaternary deposit. However it should be borne in mind that interpretation of the results must be considered in conjunction with the results of various other methods of investigation, which supplement each other.

The graniformametric method is one of the most frequently used in Poland, Hungary and Finland, most frequently in analysis of aeolian sands. By applying mechanical graniformametry a relatively rapid determination of grain abrasion from a great number of samples became possible. As regards the values and shortcomings of the above-mentioned method, it may be said that it is least the subjective then the morphoscopic one. However, in comparison with the microscopic method, the graniformametric one diminishes the number of well-rounded grains because the angle of rolling-down depends not only on corner line, but on the grain shape too. Some of the well-rounded grains for reason of their flatness are rolling down at a big inclination and are classified as β or α type. Therefore only the grains of γtype are of homogeneous roundness and seen to be the most valuable for later genetic inferences.

We have shown the results of work with graniformametry of Ūla (in Lithuanian Southern–Eastern plain) rivers outcrops aeolian sand (Fig.3), where are seen, may be, the little difference between glacio–fluvial or glaciolacustrine substratum in this area. So far the interpretation by results of these measurements is another theme.

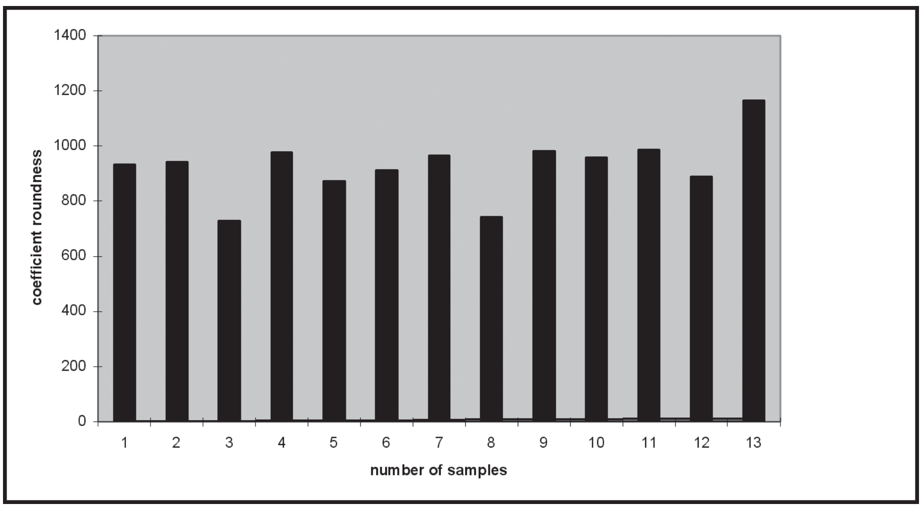

Fig. 3. The aeolian grain roundness data obtained by graniformametric method: samples from Ūla outcrops: 1– Paūliai, 2– Paūliai, 3–6– Mančiagirė, 7–8– Ūla-2, 9–11– Ūla-4, 12– Ūla-5, 13– Ūla-8.
3 pav. *Eolinio smėlio dalelių apzulinimo laipsnis, nustatytas graniformametru: pavyzdžiai iš Ūlos atodangų: 1– Paūliai, 2– Paūliai, 3–6– Mančiagirė, 7–8– Ūla-2, 9–11– Ūla-4, 12– Ūla-5, 13–Ūla-8.*

It should be noted that foreign researchers continue to seek more precise and more objective methods. Among the most promising ones are investigations based on Fourier harmonic analysis and on fractal analysis. So far, the results of measurements using this analysis, unfortunately, have not permitted to place them higher in practice than the methods used now and discussed above.

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Kontinentinių kopų tyrimų problematika ir metodai Lenkijoje

Santrauka

Darbe atskleista XX a. vidurio Lenkijos kontinentinių kopų tyrėjų (B. Nowaczyk, R. Borowka, R. Galon, A. Okolowisz, A. Dylikowa, Z. Churska, U. Urbaniak) darbų svarba, nes eolinių nuogulų tyrimai rodo klimato pokyčius praeityje ir pateikia duomenų apie pleistoceno pabaigos ir holoceno kraštovaizdį. Klausimų forma parodoma, kokios sprendžiamos problemos, pvz., kontinentinių kopų amžius ir formavimosi sąlygos, bei pobūdis (nuolatinis ar fazinis procesas), analizuojamas eolinių procesų mechanizmas, pavienių eolinių masyvų išsidėstymo priežastys, kopų formų padėtis, kopų tipų susidarymo pirmumo ar antrumo klausimas ir kt. Vėlesnių tyrėjų (B. Izmailow, D. Nalepka, J. Pelka-Gosciniak, B. Antczak-Gorka, R. Dulias, T. Sczypek) darbuose detaliau apžvelgiami atskiri regionai, pateikiamos daugiau analitinio pobūdžio kopodaros problemos, nes remiamasi gausia ekspedicijų ir tyrimų medžiaga.

Apžvelgus pažangą šioje srityje, pateikti eolinių nuogulų tyrimo metodiniai principai, būdingiausios metodikos: morfologiniai–struktūriniai kopų tyrimai ekspedicijos sąlygomis, sunkiųjų mineralų sudėties, kvarco kiekio, rūšiuotumo, granuliometrinės sudėties, dalelių apvalainumo ir paviršiaus tekstūros analizės. Paskutinei analizei naudojamas elektroninis mikroskopas, o dalelių apzulinimas nustatomas unikaliu mechaniniu graniformametru, kurį 1964 m. sukūrė B. Krygowskis.

Pateikiama detali darbo su unikaliu prietaisu – graniformametru metodika, apibūdinant pasirengimą darbui, skaičiavimo rezultatų pavaizdavimo būdus, tikslumo niuansus. Gautais grūdelių apzulinimo koeficientais galima tiksliau įvertinti skirtingos genezės ir amžiaus nuogulų paplitimo ribas. Paleogeografiniuose ir stratigrafiniuose tyrimuose smėlio dalelių formos analizė itin svarbi atkuriant neatsparių abrazijai dalelių dalyvavimą atskiruose sedimentacijos cikluose. Tyrimo šiuo metodu rezultatai aprobuoti kelių Ūlos atodangų eolinio smėlio mėginių apzulinimo koeficiento skaičiavimais, kurie pateikti histogramos pavidalu.

Darbe teigiama, kad graniformametrinis metodas yra dažniausiai naudojamas Lenkijoje, Vengrijoje ir Suomijoje ir yra vienas tiksliausių eolinio smėlio savybių tyrimų būdas. Prietaisas yra Jogailos universiteto mokslinėje bazėje, kurios tyrimų spektras gan platus: geomorfologiniai ir dirvožemio tyrimai, meteorologinis ir hidrologinis monitoringas, antropogeninių natūralios aplinkos deformacijų nustatymas.

Lenkijos kopų tyrinėtojų darbai, metodikų taikymo patirtis yra mums sektina, juolab kad artima valstybių kaimynystė ir analogiškos poledynmečio sąlygos savaime verčia neatsilikti šioje tyrinėjimų srityje.