MISCELLANEA GEOGRAPHICA
WARSZAWA 1998 Vol. 8

Ewa Smolska, Piotr Szwarczewski,
Dorota Giriat, Krzysztof Borkowski

TEXTURE CHARACTERIZATION OF THE CONTEMPORARY COARSE CLASTIC OUTWASH SEDIMENTS OF FLÁAJÖKULL AND FALLJÖKULL IN SOUTH-EASTERN ICELAND

INTRODUCTION

The study of the sediments of proglacial rivers, and first of all the detailed analysis of the deposition processes in the areas of contemporary glaciation, provide information on the dynamics of the sedimentation outwash environment (Klimek, 1972; Smith, 1985; Maizels, 1997). The gravel outwash deposits are linked with the environment of the high energy proximal braided rivers, while the sandy sediments — with the distal rivers of lower dynamics (Boothroyd and Ashley, 1975; Boothroyd and Nummedal, 1978). The lithofacial models (Miall, 1985) facilitate the sedimentological analysis of the fossil outwash sediments (Casshyap and Tewari, 1982; Zieliński, 1993). The studies mentioned, though, refer to a too limited degree to the texture properties of the sediments.

The purpose of the study reported here was to determine the texture properties of the contemporary outwash sediments in terms of expression of the transport conditions. The properties analysed included maximum grain magnitude, orientation, treatment and shape of grains of the stony fraction in the proximal, middle and distal zones of the outwashes.

Two small outwash tracks being formed in the contemporary period, located in the foreground of the Fláajökull and Falljökull glaciers on Iceland were selected for the study (Fig. 1). These glaciers are the tongues flowing down from the ice cap of Vatnajökull in its south-eastern part. The proglacial rivers analysed have the braided setting of the beds.

The field study was carried out during the research voyage to Iceland in August 1997, organized by the Sedimentological Laboratory of the Faculty of Geography and Regional Studies of the University of Warsaw.

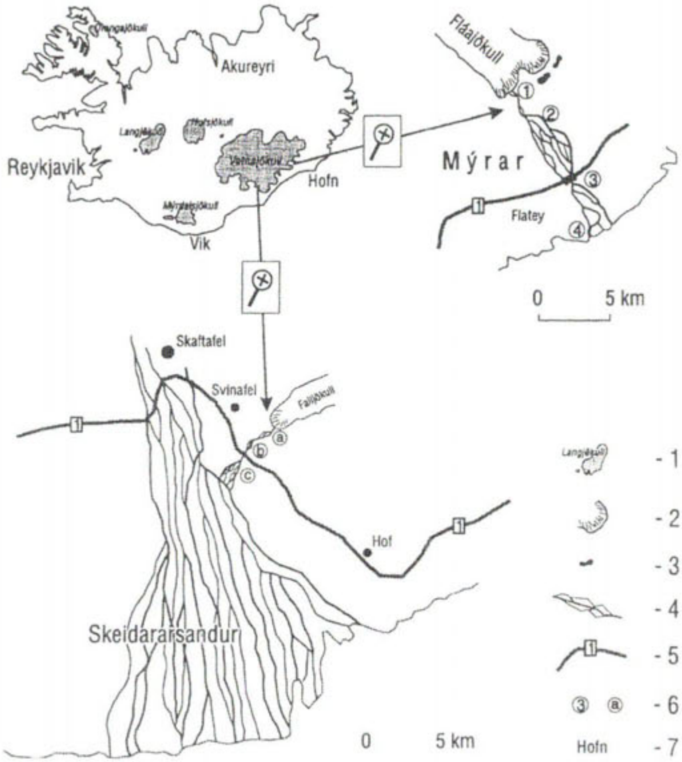

Fig. 1. Location of the study area: 1 — glaciers, 2 — glacier fronts, 3 — proglacial lakes, 4 — outwash courses, 5 — more important roads, 6 — sampling points, 7 — important localities.

METHODS OF INQUIRY

The measurements of the coarse clastic material was performed in four fractions: 3–5 cms, 5–7 cms, 10–15 cms and 20–25 cms, fifty grains from each of them. The rounding of the material was assessed with the method of Olszewski (1974), consisting of the classification on the poorly, medium and well treated grains, as well as the broken ones. Orientation of the coarse clastic material was analysed in the fractions of 5–7 cms and 10–15 cms, 30 grains in each of them. Direction of the longer axis of the grain was measured and the inclination of the two basic axes of the grain. The shape of the grain was assessed with the method of Zingg (1935) according to the fractions of 3–5 cms and 5–7 cms, 50 grains in each. The fractions of grains for analysis were selected taking into account the methods of inquiry into the texture of sediments (Gradziński et al., 1986, Mycielska-Dowgiałło, 1995), as well as the maximum diameters of the material forming the bars along the two outwash tracks. The maximum diameters of the matter deposited in the longitudinal bars in the zone of active river bed were measured. The outline of river beds was established and the bed mesoforms appearing within the outwash segments studied were mapped.

THE AREA OF STUDY

The geological structure of the area under study is determined by the location of Iceland in the rift zone. The areas surrounding the Fláa glacier are formed of the volcanic effusive rocks (alcaline and neutral lavas) primarily originating from the upper pliocene and older pleistocene. Within the foreground of the glacier one can also find the outcrops of the older volcanic rocks of similar origins — basalts and liparite intrusions (upper tertiary, older than 3.1 million years). Somewhat further from the glacier front one finds the holocene sediments accumulated by the outwash rivers, and originated by the destruction of the bedding of the glacier tongue in question and of the whole Vatnajökull cap. The lithology of the vicinity of the Fall glacier is genetically little differentiated. The areas adjacent to the glacier are formed of the volcanic, effusive, upper tertiary rocks (of more than 3.1 million years of age), as well as the ones originating from the younger pleistocene (younger than 0.7 million years). Some rocks, mainly the little resistant ones and very porous lavas, appeared due to the eruptions of the volcanoes active until nowadays and located under the Vatnajökull glacier (Bárdarbunga, Kverkfjöl, Esjufjöll, Öraefa or Grímsvötn).

Annual precipitation values range between some 1700 mm in the vicinity of the Fláa glacier and 2000 mm near to the Falljökull tongue. The number of days in a year with precipitation displays a similar distribution and ranges between 192 (34 days with snowfall) for the south-eastern part of Vatnajökull and 220 (37 with snowfall) for the western part. The monthly average temperatures of the air in the areas of the two glaciers are similar, with the Fláa glacier being somewhat cooler, and they range between –6 and 2°C in January, and between 6 and 10°C in July (Wójcik, 1976).

The hydrological regime of the proglacial rivers selected for the analysis is primarily conditioned by ablation of glaciers. In the period between November and April very low discharges occur here or even periodical disappearance of water flow (Wójcik, 1976). Concentration of the annual throughflow over a relatively short time period constitutes the characteristic feature. The maximum discharge occurs in July and August. During the summer season there are usually between one and 3–4 spates with very high flow intensity, involving changes in the course of particular river beds (Klimek, 1972; Wójcik, 1976). Side by side with the yearly cycle the proglacial rivers feature also the daily rythm with the maximum flow in the afternoon hours and the minimum discharge in the morning. In August

1997 the daily fluctuations of water levels amounted to 10–30 cms and entailed only local modifications in the course of secondary beds.

The proglacial rivers selected for the study are characterized by the typical braided setting, with domination of the alternating joining and branching river beds (Fig. 1). Both of the proglacial rivers originate from the ice gates and are only periodically additionally supplied by small flows from the marginal zone. They drain the fragments of glacier tongues. The analysed outwash course of Fláajökull drains the western marginal zone of the glacier. The second outwash course drains the eastern part of the Falljökull glacier. In the upper stretches there are usually 1–2 main river beds and several secondary ones. A characteristic feature of these rivers is alternating appearance of the wide segments of the river beds with longitudinal bars and smaller gradients, and the narrower, steeper stretches, with domination of rapids. The longest segments of the straight river bed occur in the zones of gorges cut through the walls of the frontal moraines, and especially so in the case of the third, the most pronounced and the tallest wall (Dąbski, Fabiszewski, Pękalska, in this volume). The width of both of the contemporary outwash courses clearly increases in the direction of the distal zone, and simultaneously the number of beds, both the primary and the secondary ones, increases. The outwash course originating from Fláajökull is approximately 11.4 km long and ends up in the ocean, while the Falljökull outwash course joins the Skiejdarárjökull course after having reached the length of some 8.5 kms.

The detailed measurements of the texture of the stony fraction were performed on the surfaces of the emerging longitudinal bars located in lateral sections of the proglacial beds in the direct vicinity of the secondary beds. The study encompassed the proximal, middle and upper zones of the Fláajökull and Falljökull outwashes (Fig. 1). In the lower part of the distal outwash of Fláajökull the inquiry was not conducted, because it is formed by sand and gravel. As indicated before, the proglacial outflow of Falljökull joins in its lower distal part the outwash outflows of Skiejdarárjökull.

RESULTS OF THE STUDY

There is a significant difference in the grain rounding between the moraine and outwash sediments (Fig. 2). With exception of the finest fraction (3–5 cms) the moraine sediments contain in the coarser fractions more grains with higher degree of rounding. Fractions with diameter exceeding 5 cms are well smoothed in the glacial transport. On the other hand medium and poor smoothing of the stony matter, irrespective of the grain magnitude, dominates in the sediments of the outwashes analysed. The distance on which the grains are transported within the outwash courses studied seems to be too short for the grains to acquire a distinct increase of rounding. The treatment of the finer fraction (3–7 cms) is somewhat feebler than in the case of the coarser fractions (10–15 cms and 20–25 cms). In all the fractions of the Fláajökull outwash a significant share of the broken grains (up from 20% to more than 40%) is observed. On the other hand, in the Falljökull outwash the share of the cracked grains does not exceed a

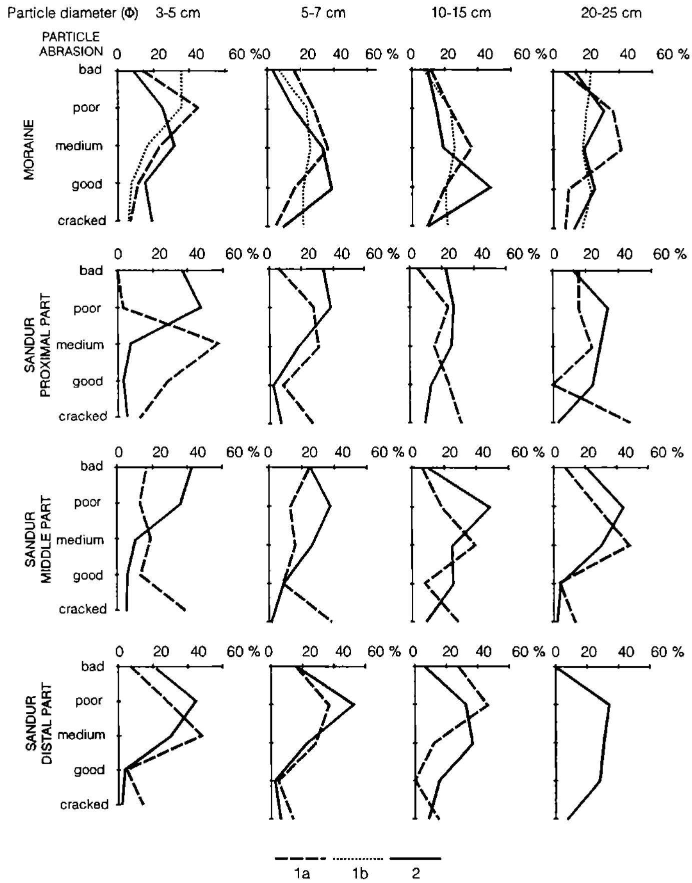

Fig. 2. Degree of rounding of the moraine and outwash deposit grains of selected glaciers: 1a — positions within the Fláajökull moraine and outwash, 1b — an additional position within the Fláajökull moraine, 2 — positions within the Falljökull moraine.

couple of per cent. Such a high difference between the sediments of the two outwashes analysed demonstrates that it cannot be the result of the climate. The reason may therefore lie in the difference of flow dynamics or in differences in lithology of the clastic material and its resistance to cracking. The question remains open for the time being.

In the upper proximal segments of the outwashes produced by the glaciers of Fláa and Fall the weakly and medium rounded grains of the fractions of 3–5 cms and 5–7 cms constitute up from 30% to more than 50% of all the grains analysed. In the middle part of the Fláajökull outwash attention is attracted by the increase of the share of poorly rounded and cracked grains. Within the same zone of the Falljökull outwash there is an increase of share of the poorly treated grains in the finest fraction. In the distal part of both of the outwashes, as well as in the middle zone of the Falljökull outwash the grains of the 5–7 cm fraction are somewhat better rounded — the share of the weakly and medium rounded grains increases (to 37–50%). The situation in which the middle part of the outwashes features the finer stony fraction characterized by a poorer rounding (with special emphasis on the increased share of broken grains) may be an evidence of destruction of these fractions during transport. The destructive role of transport could appear in saltation, during which grains collide with each other. It can be supposed on this basis that the grains of the diameter of 3–7 cms (in case of Falljökull outwash only the grains of 3–5 cms of diameter) are often transported in the middle stretches of outwashes through saltation. Periodically, during high discharges, transport of this fraction takes place in suspension, and then the grains are weakly treated. The increase of the degree of rounding of the material in the beds of both of the outwash rivers in their distal zones — although differently marked in the two sandurs — may indicate that transport of the fraction of 3–7 cms takes place through dragging or rolling only in this particular zone.

In case of grains of 10–15 cms of diameter the gradual increase of rounding of the material from the proximal to the distal zone was observed, expressed through the increased share of medium and well rounded grains. This phenomenon is more distinct along the Falljökull outwash. The rounding of the stony material of 20–25 cms of diameter takes a similar pattern in this outwash. In conditions of a persistent domination of the share of poorly rounded grains the shares of the medium and well rounded grains increase. On the other hand, in the upper part of the distal zone of Fláajökull outwash the decline of the smoothing of the grains having 10–15 cms of diameter is observed (Fig. 2), indicating a lower energetic transport environment in this zone. Besides this, in the distal zone of the Fláajökull outwash the share of grains with more than 20 cms of diameter decreases in the sediments, and so the respective diagram is absent from Fig. 2.

The process of watership sorting influences first of all the shape of the coarse clastic material. Generally, the spherical grains roll easier, and so are brought further, while disk-shaped grains remain on place (Mycielska-Dowgiałło, 1995). The fusiform or cylindrical grains are also relatively easily transported by rolling. The analysis of the shape of grains belonging to 5–7 cm fraction indicates that the spherical grains constitute in the proximal zone of both outwashes quite a small share of all grains (10–14%) and there is less of them than in the material forming the ice-moraine walls (Table 1). In the Falljökull outwash, below the outflow from the ice gate, the disk-shaped grains dominate in an obvious way (48%), and their share gradually decreases in the direction of the distal zone, along with the increase of the share of spherical and fusiform grains. This is a typical change of the average grain shape along the transport route (Mycielska-Dowgiałło, 1995). The shape of the analysed grains presents a somewhat different picture in the case of the Fláajökull outwash: the observed decrease of share of spherical and spindle-form grains, and the well pronounced increase (up to 70%) of the share of ellipsoidal (blade-shaped) grains. At the current stage of research this phenomenon can hardly be explained. A potential explanation lies in the lithology of the bedding of the zone analysed.

Table 1

Percentage shares of grains of various shape in moraine and outwash sediments of Fláajökull and Falljökull glaciers, after Zingg (1953)

Study items	Grain shape			
	spherical	fusiform	ellipsoidal	disk-like
Flájökull fraction 3–5 cms				
moraine	42	20	12	26
outwash — proximal zone	18	22	18	42
outwash — middle zone	14	26	18	42
outwash — distal zone	18	22	28	32
fraction 5–7 cms				
moraine	16	34	30	20
outwash — proximal zone	10	44	18	28
outwash — middle zone	5.5	34.5	47.3	12.7
outwash — distal zone	0	20	70	10
Falljökull fraction 3–5 cms				
moraine	42	24	10	24
outwash — proximal zone	52	18	6	24
outwash — middle zone	34	28	2	36
outwash — distal zone	52	18	6	24
fraction 5–7 cms				
moraine	48	18	6	28
outwash — proximal zone	14	26	12	48
outwash — middle zone	38	30	4	28
outwash — distal zone	32	30	16	22

The finer fraction, with the diameters of 3–5 cms, is characterized by a very differentiated shape of grains. It can be supposed that this is linked to their transport in suspension or periodically in saltation. In the highly energetic, but variable transport environments of both outwashes considered the deposition took place in the central and side bars, along with the whole suspended material, during the abatement of the spate waves. Then, the rate of grains rounding has been much slowlier (Mycielska-Dowgiałło, 1980). This manner of transport of the fraction of 3–5 cm of diameter is confirmed by the chaotic orientation of the longer axis of the pebbles (Gradziński et al., 1986).

It can generally be stated that over such a short distance of the outwashes considered (8–11 kms altogether) there is an increase of the share of the blade-shaped grains having more than 5 cms of diameter while the disk-shaped ones are impoverished. The high number of disk-shaped grains in the proximal zone constitutes also the evidence of the segregating activity of water flow. The grains of this form are less susceptible to being transported.

The subsequent category of measurements concerned the orientation and inclination of the grains along their two basic axes. The orientation of the grains of the more than 5 cm fraction displays an ordering and is usually transversal — the longer axes of grains are oriented perpendicularly to the direction of the flow forming the bars (Fig. 3). Only in the proximal zone of the Falljökull outwash both of the considered fractions of grains (5–7 cms and 10–15 cms of diameter) do not display any ordering. This is the cause of the lack of respective measurements. In the proximal zone of Fláajökull certain degree of ordering can be observed. The grains of both the finer and the coarser of the fractions analysed are oriented transversally to the direction of water flow. The transversal orientation of the elongated grains indicates that they had been transported by rolling and that the strength of the water current quickly decreased, so that it turned out impossible to change their position to the one of least resistance (longitudinal with imbrication). The transport position was preserved. Simultaneously, it is characteristic for this zone that both the middle and the longer of the grain axes are inclined conform to the direction of the water current shaping the bar. This phenomenon is typical for the fluvial environment in which the coarse clastic material is being transported. It can be caused by the pressure from the moving medium exerted on the surface layers of the loose sediments. As a consequence of the abrupt deposition of the sediments the inclination of the grains takes places and it is conform to the direction of the water flow (Fig. 3). This kind of orientation is displayed by almost all grains of the diameter of 5–7 cms and by 75% of those with 10–15 cms of diameter. Only some 17% of larger grains are oriented against the current with their middle axis (imbrication).

The characteristic feature of the middle stretches of both outwash courses is constituted by the imbrication of the pebbles, that is — orientation against the current, in the direction opposite to the flow forming the given bar. Here also, the transversal orientation of the pebbles dominates. This is a distinctly more stable position of the sediments here considered, deposited on the bars, and a proof of a certain dynamic equilibrium of this zone. A part of grains, some 23%, display imbrication along the longer axis. These are the most stably positioned grains.

The distal zone of the outwashes is characterized by a similar positioning of the grains to the one observed in the middle stretches. A bit less of grains are imbricated (between 10% and 16%). There is a distinct orientation of the longer axis of the pebbles, although with a greater dispersion

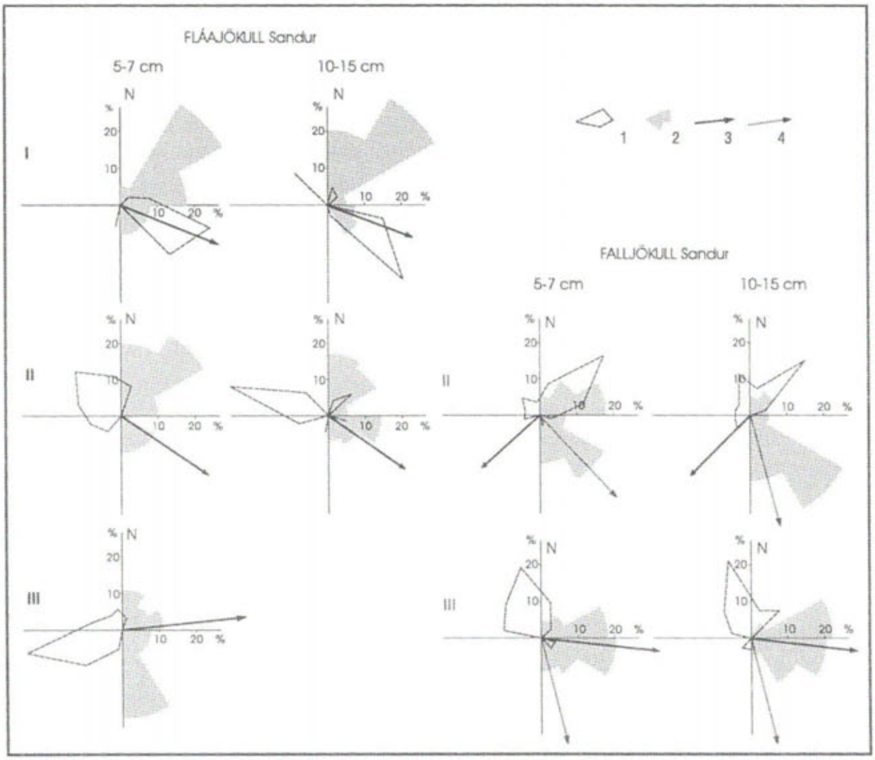

Fig. 3. Measurements of orientation directions of the coarse clastic sediments within selected outwash deposits: 1 — inclination of the pebbles, 2 — orientation of the longer axis of the pebbles, 3 — bar orientation, 4 — main direction of water flow (determined on the basis of imbrication).

(some 60 degrees); this orientation is conform to the longer axis of the respective bars.

Both of the fractions observed in the middle stretch of the Falljökull outwash and the 10–15 cm fraction in the case of the distal zone contain a part of grains displaying inclination (imbrication), which can be used to determine the secondary direction of water flow, oblique with respect to the longer axis of the bars. In the distal zone the main direction of the water current determined on the basis of imbrication of the grains of 5–7 cms diameter indicates, as well, the water flow that is oblique with respect to the longer axis of the bar. At the present stage of research it is difficult to unambiguously determine the cause for such a positioning of a part of the grains. This particular direction seems to be of a later origin and is linked with a less energetic environment. This may be indicated by a greater share of the finer grains, whose orientation underwent a change with respect to the longer axis of the bar.

CONCLUSIONS

The analysis of the texture properties of the gravel fraction along the outwash courses indicates that the transversal position of the grains dominates, along with poor or weak smoothing of the material. The observed differences in the texture properties of the sediments forming central bars in the individual zones of the outwash courses considered reflect the characteristics of transport and deposition of the sediments. The rounding of the stony material, the shape of grains and their orientation may be helpful in the analysis of the palaeo-environments of the pleistocene outwashes.

The analysis of grain positioning is of special importance. The direction of flow of outwash waters can be reconstructed on the basis of orientation of the longer axes of the grains having more than 5 cms of diameter. Their dominating part has the transversal (perpendicular) position with respect to the current shaping the respective bar. The second indicator of the flow of outwash waters, in terms of its significance, is the inclination of pebbles, usually displaying imbrication. This kind of layout can be disturbed only in the dynamic waters and by the abrupt accumulation conditions (proximal parts of the outwash).

REFERENCES

Boothroyd J.C., Ashley G.M., 1975, Processes, bar morphology, and sedimentary structures on braided outwash fans, *NE Gulf of Alaska*, in: A.V. Jopling, B.C. McDonald, eds. *Glaciofluvial and glaciolacustrine sedimentation*, SEPM Spec.Publ., 23, pp.193–222.

Boothroyd J.C., Nummedal D., 1978, Proglacial braided outwash: a model for humid alluvial-fan deposits, in: A.D. Miall, ed. *Fluvial sedimentology*, Can. Soc. Petrol Geol., Mem., 5, pp.641–648.

Casshyap S.M., Tewari R.C., 1982, Facies analysis and palaeogeographic implications of a Late Palaeozoic glacial outwash deposit, Bihar, India, *J. Sediment. Petrol.*, 52, pp.1243–1256.

Gradziński R., Kostecka A., Radomski A., Unrug R., 1986, *Zarys Sedymentologii* (An Outline of Sedimentology; in Polish), Wyd. Geologiczne, Warszawa.

Johannesson H., Saemundsson K., 1989, *Geological map of Iceland 1:500,000*, Icelandic Museum of Natural History and Icelandic Geodetic Survey.

Klimek J., 1972, Współczesne procesy fluwialne i rzeźba równiny Skeidararsandur (Islandia) [Contemporary fluvial processes and the relief of Skeidararsandur plain (Iceland); in Polish], *Pr. Geogr IG PAN*, 94.

Maizels J., 1997, Jökulhlaup deposits in proglacial areas, *Quaternary Science Reviews*, 16, pp.793–819.

Miall A.D., 1985, Facies architecture in clastic sedimentary basins, in: C. Paola, eds., *New Perspectives in Basin Analysis*, Kleispehn, Springer Verlag, pp.67–81.

Mycielska-Dowgiałło E., 1980, *Wstęp do sedymentologii* (An Introduction to Sedimentology; in Polish), WSP, Kielce.

Mycielska-Dowgiałło E., 1995, Wybrane cechy teksturalne osadów i ich wartoć interpretacyjna (Selected texture properties of deposits and their interpretative value; in Polish), in: E.Mycielska-Dowgiałło, J.Rutkowski, eds, *Badania osadów czwartorzędowych. Wybrane metody i interpretacja wyników*, Wyd. WGiSR UW, Warszawa.

Olszewski A., 1974, Jednostki litofacjalne glin subglacjalnych nad dolną Wisłą w wietle analizy ich makrostruktur i makrotekstur (Lithofacial units of subglacial clays on lower Vistula river in the light of analysis of their macrostructures and macrotextures; in Polish), *Studia Soc. Sci., Geografia*, 8(2), Toruń.
Smith N.D., 1995, Proglacial fluvial environment, in: G.M. Ashley, J. Shaw, N.D. Smith, eds. *Glacial Sedimentary Environments*, SEPM Short Notes, 16, pp.85–134.
Wójcik G., 1976, Zagadnienia klimatologiczne i glacjologiczne Islandii (Climatological and glaciological problems of Iceland; in Polish), *Rozprawy UMK*, Toruń.
Zieliński T., 1993, Sandry Polski północno-wschodniej — osady i warunki sedymentacji (Outwashes of the north-eastern Poland — deposits and the conditions of sedimentation; in Polish, *Prace Naukowe Uniw.Śl.*, 1938, pp.1–97.
Zingg T.,1935, Beiträge zur Schottenanalyse, Schweiz, *Min. Petr. Mitt.*, 15.