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WÜRMIAN PERIGLACIAL PROCESSES ON THE KOLNO PLATEAU IN THE LIGHT OF SEDIMENTOLOGIC INVESTIGATIONS WITH THE USE OF THE SCANNING ELECTRON MICROSCOPE

Abstract

In the course of geomorphological investigations carried out on the Kolno Plateau, Poland, systems of periglacial fissure forms were distinguished within the top parts of glacial forms. Most of them may be reckoned among fissure forms of primary filling. In order to interpret the processes which have formed the deposits filling the distinguished structures a number of detailed sedimentologic analyses were made of the fluvioglacial material underlying those forms and of the material filling the fissures. The lithological type of the deposits and the relief characteristics of the sandy fraction quartz grains examined in the electron microscope show that the main process which formed the deposits filling the fissure structures was mechanical weathering with the cooperation of washing processes. The lack of any prevailing influence of aeolian processes was also stated. The high degree of quartz grain matting observed in periglacial deposits is the result of mechanical weathering which have formed highly exfoliated surfaces. The differentiated surface relief of quartz grains of fluvioglacial environment, which were the source of periglacial deposits, has thus obtained a common feature which has overlain all the previous ones

During geomorphological investigations carried out in the central part of the Kolno Plateau, an attempt was taken up to evaluate the significance of periglacial processes in the transformation of the glacial relief of the region. First of all an analysis was made of the transformation degree of the deposits filling frost fissures by comparing them with the original deposit. Seven profiles were investigated (KOROTAJ, 1977) three of which have been discussed below (Fig. 1, 2, 3). Samples were collected in the vertical profile, every 20—30 cm, so as to make it possible to compare structureless transformed material with the unchanged, stratified deposit of fluvioglacial origin. By means of the sieving analysis, using a set of 23 sieves with mesh diameter from 20 mm to 0.06 mm, the granulometric composition of the studied deposits was determined. For each sample a cumulative curve was drafted in the probability scale. On this base indices of granulation were calculated according to FOLK and WARD's formulas (1957) and the type of the deposit was determined according to DOEGLAS's rule (1968). In Table I the results concerning the granulometric features of deposits from the particular profiles have been jointly presented. Frequency curves were also plotted for all samples (Fig. 4, 5, 6); they are the best illustration of the grain-size distribution.

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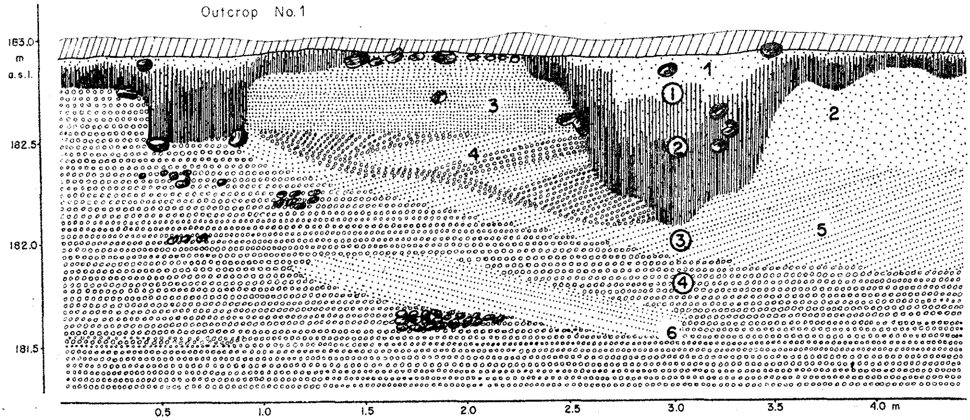


Fig. 1. Olszewo Małe. Outcrop No. 1, in a dead-ice moraine hill

1. medium-grained sand with pebbles of 3 cm diameter; 2. medium-grained unstratified sand with pebbles of 3 cm diameter; 3. stratified, fine-grained sand; 4. stratified gravel, interbedded with sand; 5. medium-grained, stratified sand; 6. stratified gravel with pebbles of 5 cm diameter interbedded with white stratified sand; numbers in circles — number and place of sample collecting

Characteristics of grain-size distribution

No. of sample	Sampl-ing depth (m)	Grain-size distribution indices according to FOLK and WARD (1957)			Roundnes index according to KRYGOWSKI (1964)		Roundness index according to MIHALTZ § UNGAR (MYCIELSKA-DOWGIAŁŁO, 1963)
		M_z	δ_1	Sk_1	W_0	Nm	K_1
Outcrop No. 1							
Sample No. 1	0.3	−0.837	2.49	−0.446	1062	6	2.52
Sample No. 2	0.5	0.483	1.54	0.02	967	6	2.50
Sample No. 3	0.7	1.33	1.16	−0.435	1133	5	2.41
Sample No. 4	0.9	−0.253	2.77	0.284	1404	4	2.31
Outcrop No. 2							
Sample No. 5	0.3	−0.333	1.50	0.461	614	9	2.72
Sample No. 6	0.6	−0.777	1.18	−0.197	1228	4.5	2.81
Sample No. 7	0.9	−2.249	2.55	−0.239	1267	5	
Sample No. 8	1.2	1.077	0.97	0.159	760	8	
Outcrop No. 3							
Sample No. 9	0.5	−0.07	3.25	−0.047	806	7	2.64
Sample No. 10	0.8	−0.613	1.13	−0.389	782	7	2.29
Sample No. 11	1.5	−2.15	2.38	0.026	628	12	2.64

Further laboratory investigations included an analysis of the re-working degree of quartz grains. Two different methods were used. All samples were examined in the graniformameter according to KRYGOWSKI' s (1964) assumptions. Quartz grains of the 0.5—0.8 mm fraction were analysed. At the same time the fraction was analysed in a binocular and, according to MIHALTZ and UNGAR's assumptions (MYCIELSKA-DOWGIAŁŁO, 1963), its roundness degree was determined (K_1). Indices of re-working and roundness calculated by the above mentioned methods are listed in Table I. Basing on the results concerning the degree of re-working, obtained from the graniformameter, re-working histograms were drafted for each sample (Fig. 7, 8, 9).

For a detailed study of the relief type of the quartz grain surface in fraction 0.5—0.8 mm samples from outcrop No. 1 were additionally examined with the use of the scanning electron microscope.

In the same samples the petrographic composition of the coarse sand fraction (0.5—0.8 mm) and, in the 0.1—0.2 mm interval, the composition of the heavy fraction were determined (Tab. II).

Table I

and of quartz-grains roundness and matting

% of grains in 3 matting classes			Qualification of grain-size distruibution according to DOEGLÄS (1968) modified by MYCIELSKA-DOWGIAŁŁO (1978)	
mat	semi-mat	lustreons	numerical	descriptive
61	16	23	101	very fine gravel to coarse sand
39	20	41	012	very coarse sand to medium sand
36	18	46	123	corase sand to fine sand
51	24	25	012	very coarse sand to medium sand
42	28	30	101	very fine gravel to coarse sand
50	20	30	100	very coarse sand with admixed very fine gravel
			201	coarse sand with admixed fine gravel
			112	coarse sand with admixed medium sand
53	24	23	122	medium sand with admixed very fine fravel
40	34	26	100	very coarse sand with admixed very fine gravel
41	30	29	310	very coarse sand with admixed medium gravel

The relief of the Kolno Plateau is connected with the Mława substage of the Central Poland glaciation (Fig. 10, 11). Forms prevailing here arose in the zone of dead ice during the recession of this substage. Those forms are mainly eminences not exceeding 10 m of relative height; their base diameter reaches 500 m and their slopes, in the average, have 3—6°.

The samples analysed below were collected in periglacial fissures formed in the top of dead ice moraine hills.

In the investigated areas of the Kolno Plateau (middle part) Pleistocene forms of the dead ice zone display a differentiated structure. Because of this great variety of deposits forming dead ice moraines several zones of their occurrence have been distinguished. And so: outcrop No. 1 (Fig. 2) presents characteristic forms of the south-west zone which extends from the locality Milczki Sucholaszczki to the village of Jurzec. Here dead ice moraines of a sand-and-gravel structure prevail. Outcrop No. 3 (Fig. 3) shows a form found in the central-east zone (from the village Obrytki to the village Stryjaki). The hills in this zone do not show any order. They are built mainly of structureless sand and gravel. We can also observe here the greatest differentiation in the structure of particular hills as well as great variety of material within a single form. The type of stratification preserved in the deposits shows that fluvioglacial waters played an important part in the construction of the mentioned forms.

The relief of the studied area was considerably transformed in the periglacial climate of the latest glaciation. During that period the area was uninterruptedly covered with permafrost. Climate changes then occurring caused only oscillations of the permafrost top. It is assumed (Dylik, 1963) that there exist three distinct climatic periods, connected with the transgression and the recession of the latest glaciation: the waxing phase (cold and humid), the climax phase (frosty, dry, continental) and the cold and humid waning phase. Definite morphogenetic processes occurred in each phase (Dylik, Dylikowa, 1964). In the waxing phase the development of ground ice and permafrost prevailed; those processes were accompanied by the disturbance of the original structure of rock material caused by thermic contraction and by the development of permafrost. In the climax phase strong frost weathering prevailed and in the waning phase there was a seasonal, thermally conditioned water outflow and an intensive wind activity.

Basing on the results of a wide range of analyses the present authors made it their aim to find out which phase had a most distinct influence on the transformation of the deposits filling periglacial fissures and what processes were decisive. Transformation occurred in the top material which did not exceed 1.6 m of thickness.

Periglacial conditions in the Kolno Plateau left traces in the relief as slope covers and autochthonous covers of periglacial weathering. The present paper deals only with the latter of the distinguished cover types. It occurs within the flat and the undulated moraine plateau, on surfaces where slopes do not exceed 2°. The thickness of the covers is poorly differentiated, it ranges from 0.5 to 0.8 m. They are mainly built of sand and gravel.

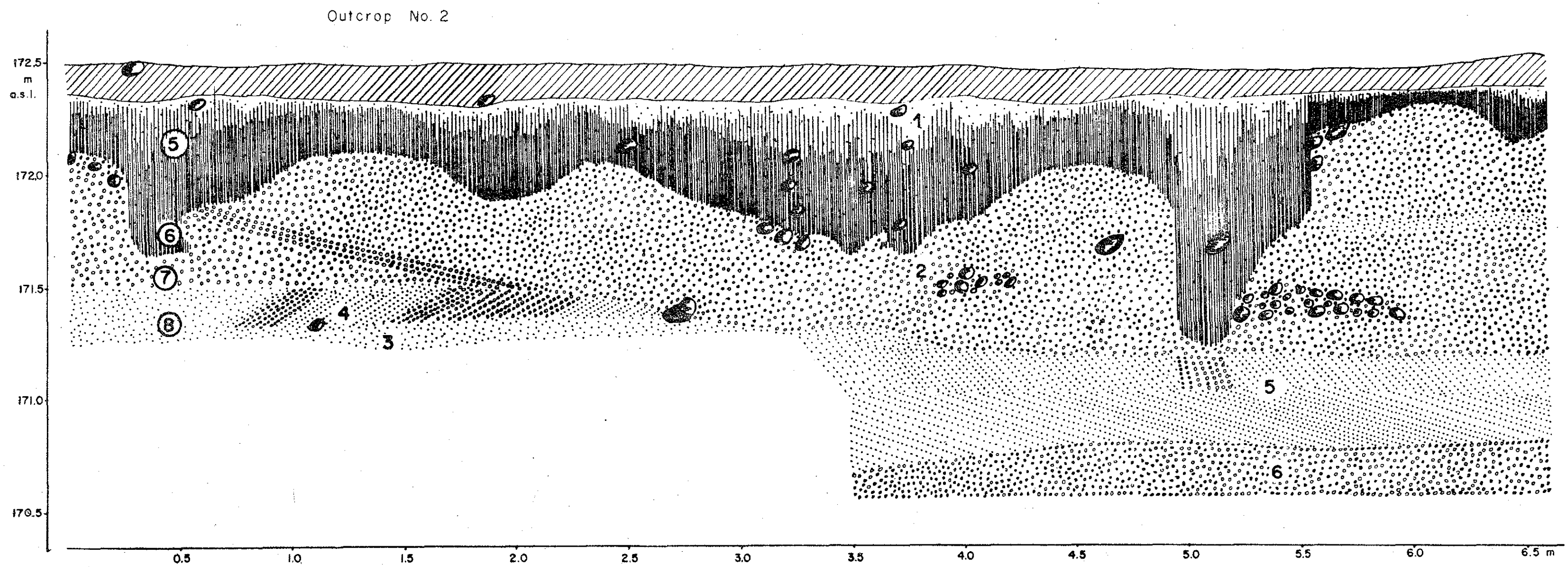


Fig. 2. Jurzec. Outcrop No. 2, in a dead-ice moraine hill

1. various-grained, structureless, slightly clayey sand with pebbles of 5 cm diameter; 2. structureless gravel with pebbles of 7 cm diameter, traces of stratification visible in some places; 3. unstratified, structureless white sand; 4. interstratified sand and gravel with single pebbles; 5. medium-grained, stratified sand; 6. stratified gravel with pebbles of 5 cm diameter interbedded with white stratified sand; numbers in circles — number and place of sample collecting

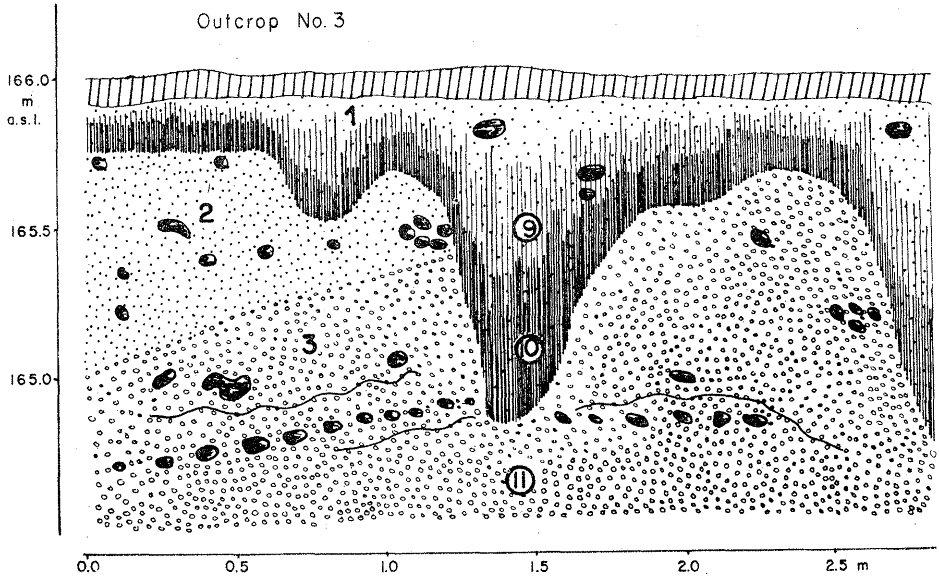


Fig. 3. Obrytki. Outcrop No. 3, in a dead-ice moraine hill

1. various -grained sand with iron pans, structureless, pebbles of 6 cm diameter; 2. coarse-grained sand with large amounts of pebbles (3—4 cm diameter); 3. structureless gravel interbedded with pebbles; numbers in circles — number and place of sample collecting

Periglacial structures occur within those covers and they frequently form their bottom. They are well visible in the deposit owing to iron layers (Fig. 1, 2, 3). The periglacial structures were formed into the shape of pockets and wedges filled with material coming from their walls or shifted down from the surface.

Structures occurring over the whole investigated area (fig. 11) are formed on surfaces of varying absolute altitude (143—183 m) and of varying slope. They occur as well in flat areas, of a slope below 1°, as in considerably sloping terrain (above 8°). No connection between the type of relief and the occurrence of periglacial structures has been observed. They are most frequently found in the moraine hills of dead ice but they also occur in kames and kame terraces. Instead, a distinct correlation of the frost structures occurrence and the kind of material building the given glacial form has been stated. A considerable percentage of recorded periglacial forms (over 80%) have been developed in gravels, while only few of them are found in medium-grained sands. Fine-grained and dusty sands do not contain any frost structures. Thus coarse-grained deposits, most frequently gravels and pebbles, are most favourable to the formation of periglacial structures.

According to some authors (Goździk, 1973) the kind of the substratum is of essential importance for the width of fissures and the size of polygons. In coarse-grained material, as a result of the drop of temperature which causes an increase of stress, large fissures are formed. It may be observed both in present--day zones of periglacial climate (Kaplina, 1960) and in the periglacial zone of the latest glaciation (DYLIK, 1963; JAHN, 1970). In the neighbourhood of Łódź the largest polygons occur in coarse-grained material (GOŹDZIK, 1973).

In the investigated area both fissures and frost pockets occur; the latter are probably records of fissure systems. This statement is based on horizontal intersection. The size of pockets varies greatly (Fig. 1, 2, 3). Structures of 0.8--1.0 m prevail, but also smaller ones frequently occur (0.3—0.6 m). The width of the pockets is about the same in their lower and upper part. The depth they reach ranges from 0.5 to 1.2 m. Most frequently it is 0.5—0.8 m. Also the size of the frost fissures varies greatly. Their depth is usually greater than that of the pockets and reaches an average of 0.8—1.6 m. The shapes of the fissures, in their vertical section, differ from one another. Generally their upper part is widened and the lower part is narrow. The width of the upper part ranges from 0.25 to 1.0 m and most frequently equals 0.6—0.8 m.

As early as during preliminary field investigations of deposits filling the distinguished periglacial structures it was noticed that the upper parts of the fissures differ from the lower ones. That is why two samples were collected, for further investigations, from each of the fissures and — for comparison — another sample from deposits with an unchanged structure of the primary stratification. A full analysis of deposits, based on all the methods mentioned above, was applied to samples from outcrop No. 1. The results obtained will be presented in the first place; they will be completed with results of chosen analyses of samples from the two other outcrops.

ANALYSES OF DEPOSITS IN OUTCROP NO. 1

GRAIN-SIZE ANALYSIS

The investigated deposits, both the glacial ones and those filling the fissure are poorly and very poorly sorted (Tab. I). The frequency curves of those deposits have a multimodal scheme where only one of the subordinate maxima occurs in all the samples analysed (Fig. 4, 5, 6). It ranges between 0.74 and 1.0 φ (0.6—0.5 mm). The frequency curve illustrating the deposits which fill the top of the pocket form clearly differs from the others by a high maximum in fraction, from —0.58 to —0.26 φ (1.5—1.2 mm). It may be supposed that the accumulation, in that horizon, of coarse-grained deposits is the result of frost segregation and of coarser grains shifting upwards.

PETROGRAPHIC ANALYSIS

Fraction 0.5—0.8 mm was chosen for petrographic analysis. An analysis of powdered samples and additional thin-sections of samples sealed in an epoxide resin were done. This made it possible to classify the examined minerals and detritus more closely.

been found three fragments where carbonates form the cement. As a rule, the degree of carbonates rounding is high, the grains are egg-shaped, oval or ideally spherical.

The content of quartz is the highest in all the samples but it varies in the particular samples. It is lowest in stratified gravel deposits (sample 4—76.3%). In higher lying stratified sands, also of fluvioglacial origin, the quartz content increases (sample 3—84.9%) but it slightly drops in deposits filling the bottom part of the pocket structure (sample 2—80.5%). The highest quartz percentage was found in deposits filling the top of fissures (sample 1—89.4%).

Feldspars are the third component as regards their percent content. They occur in two groups: plagioclases and potassium feldspars.

Within stratified gravels (sample 4) the total content of feldspars equals 10.5% (plagioclases — 4.6%, potassium feldspars — 5.9%). The higher lying stratified sands (sample 3) have a similar feldspar content which equals 10.9% (plagioclases — 7.1%, potassium feldspars — 3.8%) and it is about the same in deposits filling the bottom of pocket structures (sample 2) : 10.5% (plagioclases — 5.5%, potassium feldspars — 5.0%). This content changes in top deposits filling the fissure form (sample 1). Here the total feldspar content amounts to 7.4% (plagioclases — 1.6%, potassium feldspars — 5.8%).

Crystalline rock detritus is the next component as regards quantity. Detritus of magmatic and metamorphic rocks were distinguished. They will be considered jointly in further considerations. The highest content of crystalline rock detritus has been observed in stratified gravels (sample 4) — 5.0%; it decreases in the

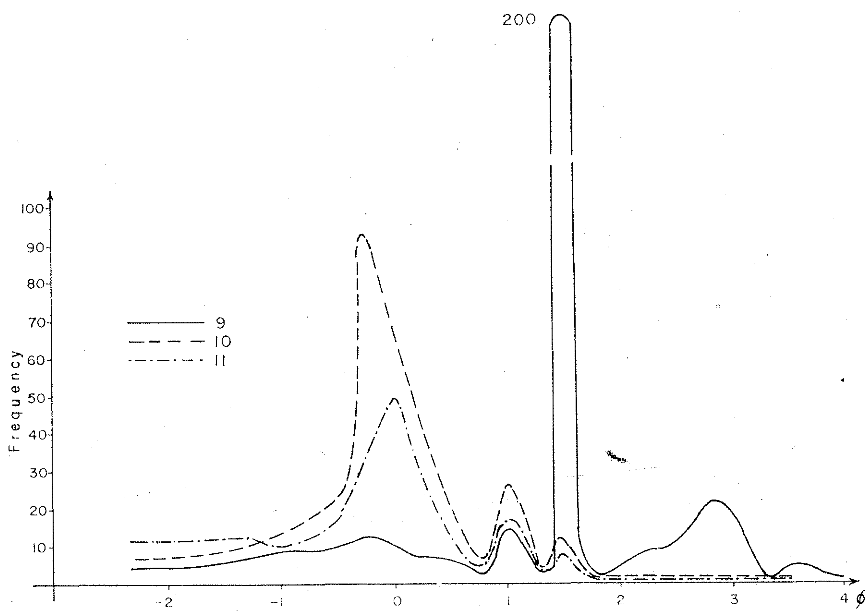


Fig. 6. Grain-size frequency curves of samples taken from outcrop No. 3
Samples: 9 — depth 0.5 m; 10 — depth 0.8 m; 11 — depth 1.5 m

next two samples. In stratified sand (sample 3) and in bottom deposits of the pocket structures (sample 2) it amounts to 3.2%. In the top deposits which fill the fissure form (sample 1) the content of crystalline rock detritus is quite small and it amounts to only 1.6%.

Beside the above named components detritus of quartzites, clay rock, siliceous rock and carbonate-cemented sandstones have been distinguished in the examined samples. Their content is relatively small (ca 1%) and about the same in all the samples.

The above presented petrographic composition, however similar — in a general way — in all the samples, is somewhat differentiated. The lowest lying deposits (stratified fluvioglacial gravels) have the smallest percentage of quartz and the largest content of crystalline rock detritus. In the above lying stratified fluvioglacial sands the quartz content increases while the percentage of crystalline rock detritus decreases. It seems that a disintegration process of crystalline rocks into their mineral components has occurred as well as a certain selection of the material according to its resistance.

In the initial phase the deposit filling the pocket structure was strictly connected with the immediate surroundings of the fissure. This can be seen in the percentage both of quartz and crystalline rock detritus and feldspars. Only the uppermost series differs from the lower one displaying some influence of weathering transformation. In the investigated fraction (0.5—0.8 mm) the quartz content increases, while the content of crystalline rock detritus and of feldspars decreases considerably. Among the latter the most visible decrease is that of plagioclases as less resistant to weathering processes than potassium feldspars.

ANALYSIS OF HEAVY MINERALS

The heavy fraction was analysed in powder samples prepared in Canada balsam, based on 0.1—0.2 mm fractions. The most numerous minerals identified by means of the microscope are amphiboles and non-transparent minerals.

Non-transparent minerals have been treated as one group. They show a varying degree of mechanical re-working, from rugged grains to spherical, ideally rounded ones. Rounded grains decidedly prevail in this group. The number of fresh grains is small.

Two groups have been distinguished among amphiboles — green and brown hornblende. Green hornblende visibly prevails. The brown kind was found in two samples only (sample 2 and 3). Green hornblende forms short stakes which are mainly broken fragments of larger grains. The re-working degree is small. In the analysed samples only a few spherical grains have been found. The analysed hornblende grains seem to be quite fresh, having no visible traces of secondary processes such as chloritization; grains with ferric oxide on their surface have not been found, either. There were no more than 2—3 grains per sample with slightly marked secondary processes.

Tourmalines form short stakes with distinct lateral faces and a pyramid-

-shaped point, with only slightly smoothed edges. The decided majority of grains shows paleochroism from green to brown. Single yellow and blue grains were found; they have a much higher degree of mechanical re-working. All the grains contained numerous endomorphs of non-transparent minerals as well as gas inclusions.

Two groups of garnets were distinguished: pink and colourless garnets. The latter form grains of a varying degree of re-working, from ideally rounded grains to those of a sharp outline. The sharp-shaped grains are smaller and it is not excluded that they come directly from the disintegration of larger grains. Some of them have certain angles which are ideally rounded while other edges have a very fresh outline. The grains of pink garnets are usually smaller and less worn.

Pyroxene occurs in relatively small quantities in the investigated samples. It forms angular grains, usually of brown pleochroic colours.

Epidotes have been treated as one group (Tab. II) because of the decided prevalence of ordinary epidote. Beside ordinary epidote single grains of zoisite

Table II

Mineral composition of heavy fraction in sands (volume percent) *

Minerals	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
Non-transparent minerals	21.0	30.1	15.6	37.3
Biotite	0.7 (0.9)	1.5 (2.1)	0.7 (0.9)	2.0 (3.2)
Muscovite	0.3 (0.5)	—	1.0 (1.1)	—
Chlorite	—	1.0 (1.4)	0.3 (0.4)	—
Green amphiboles	54.3 (68.7)	32.4 (46.0)	48.7 (57.7)	13.3 (21.1)
Brown amphiboles	—	0.4 (0.65)	2.7 (3.2)	—
Pyroxenes	—	3.7 (5.2)	1.0 (1.1)	2.5 (4.0)
Epidotes	4.7 (5.7)	5.2 (7.4)	11.3 (13.4)	3.8 (6.3)
Pink garnets	—	1.9 (2.8)	—	8.2 (13.0)
Colorless garnets	13.0 (16.5)	16.9 (24.1)	12.7 (14.9)	24.9 (39.7)
Tourmaline	2.7 (3.4)	2.4 (3.5)	3.7 (4.4)	1.3 (2.1)
Rutile	0.3 (0.4)	0.7 (1.1)	—	—
Zircon	1.0 (1.3)	1.0 (1.5)	0.3 (0.4)	1.3 (2.1)
Disthene	0.7 (0.9)	—	—	—
Staurolite	0.3 (0.4)	1.0 (1.5)	0.3 (0.4)	2.5 (4.0)
Andalusite	0.7 (0.9)	0.4 (0.7)	0.7 (0.9)	0.7 (1.1)
Titanite	0.3 (0.4)	0.3 (0.4)	0.3 (0.4)	—
Sillimanite	0.3 (0.4)	0.3 (0.4)	0.7 (0.9)	—
Aggregate (clayey) minerals	—	0.6 (0.9)	—	2.5 (4.0)

* Numbers without brackets mean percent values of the particular minerals in relation to the total; numbers in brackets concern percent calculation only of transparent minerals.

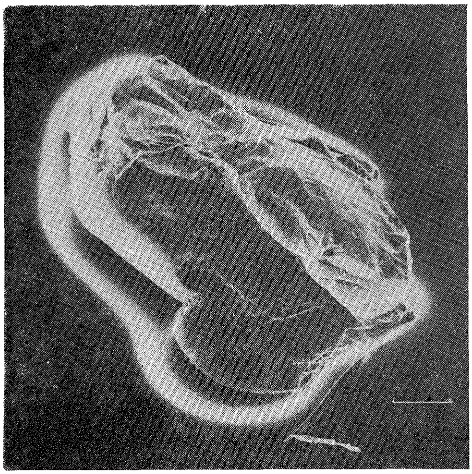
and pistacite have been noticed. They form short stakes with no marks of mechanical re-working.

The remaining minerals constitute a small admixture and their grains are generally poorly rounded. It should be noticed, in the presented percent content of heavy minerals, that the content of amphiboles is twice increased (from sample 4 to 3 and from sample 2 to 1), while the garnet content decreases simultaneously. It is well-known that amphiboles belong to the group of minerals the least resistant to chemical weathering and of medium resistance to mechanical working (RACINOWSKI and RZECHOWSKI, 1969; TURNAU-MORAWSKA, 1955; MYCIELSKA-DOWGIAŁŁO, 1978). Instead, garnets are reckoned among minerals of great resistance to mechanical erosion and of medium resistance to chemical weathering (MORAWSKI, 1955). These changing tendencies appearing in the described profile seem to indicate a lack of any distinct activity both of chemical and mechanical weathering processes. In the series of stratified deposits the passage from a relatively small content of amphiboles and a large content of garnets in fluvioglacial gravels (sample 4) to a large content of amphiboles and a small part of garnets in the higher lying fluvioglacial sands reveals the dynamics and the character of transport and sedimentation. Amphiboles are minerals (in the heavy minerals group) of a relatively small specific gravity and this is why they are carried out of broken rock material rather easily and deposited in sites of calmer sedimentation. On the contrary, garnets have a considerable specific gravity and they are characteristic in deposits formed by a greater transporting force (RACINOWSKI, 1973). The rather poor rounding of heavy mineral grains also indicates short-distance transportation and a close connection with the disintegrated parent rock.

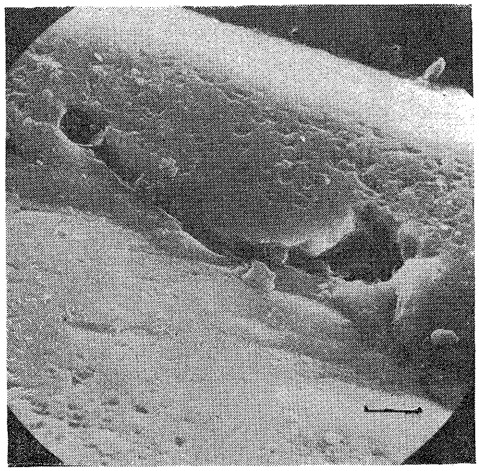
Deposits filling the pocket structures seem to present a similar situation. More garnets and less amphiboles occur in the bottom. In the top of the distinguished form an inverse disposition occurs. The process observed seems to be that of material selection according mainly to the different specific gravity of the minerals. In the deepest part of the fissure minerals of greater specific gravity (garnet, biotite) are accumulated, while the lightest minerals (amphibole) prevail in its top part.

RE-WORKING, ROUNDNESS AND SURFACE RELIEF CHARACTER OF QUARTZ GRAINS

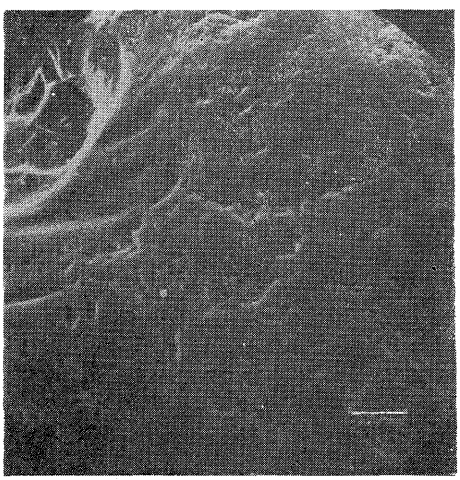
The character of grain re-working and roundness has been determined by various methods basing on 0.5—0.8 mm fraction. Two hundred quartz grains of the 0.5—0.8 mm fraction were selected and their re-working degree was determined with the use of KRYGOWSKI's graniformameter (KRYGOWSKI, 1964) and by MIHALTZ and UNGAR's binocular method (MYCIELSKA-DOWGIAŁŁO, 1963). A dozen or so quartz grains, typical of the given sample (in the same fraction), were selected by means of a microscope for observation in the scanning electron microscope. The preparation of samples was performed according to



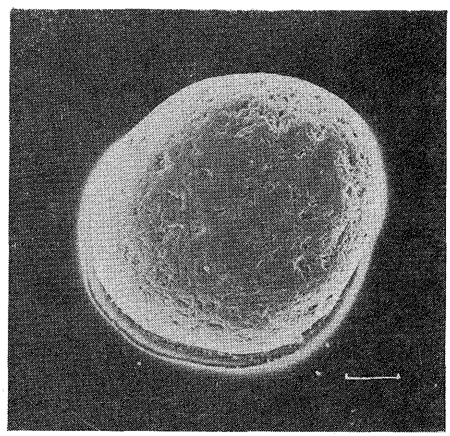
Pl. 1. Grain of fresh form with clearly outlined, unchanged edges and relatively smooth fracture surfaces. The marked section = 140 μm



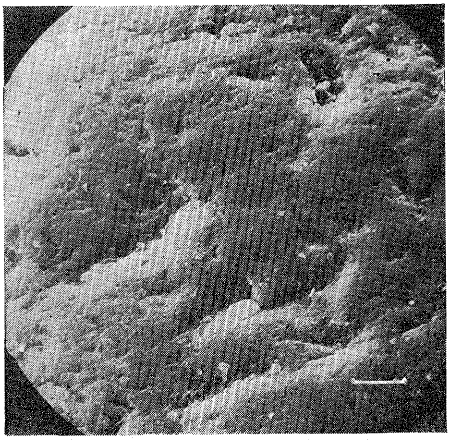
Pl. 2. Small V-shaped cuts on convex grain fragments. The marked section = 4 μm



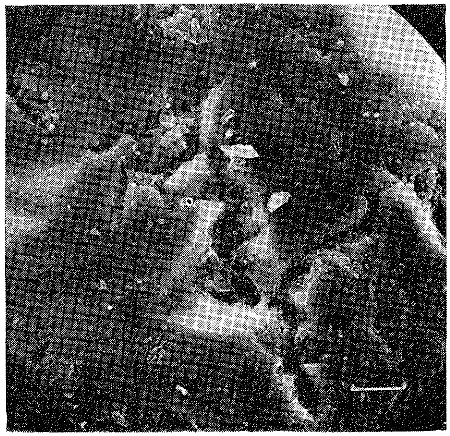
Pl. 3. Mosaic system of grooves on the grain surface as the evidence of chemical corrosion processes. The marked section = 28 μm



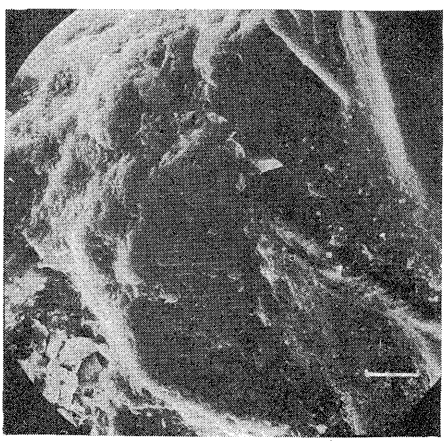
Pl. 4. Grain with wind-worn relief. The marked section = 100 μm



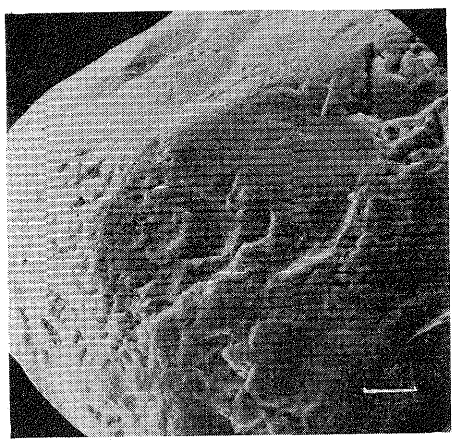
Pl. 5. V-shaped cuts of various sizes. Grain surface worn by aeolian activity. The marked section = 8 μm



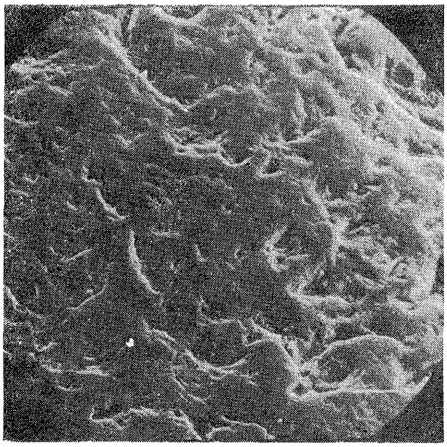
Pl. 6. Deep grooves of chemical corrosion of the grain surface. They are marked within the crust of amorphous silica. The marked section = 7.5 μm



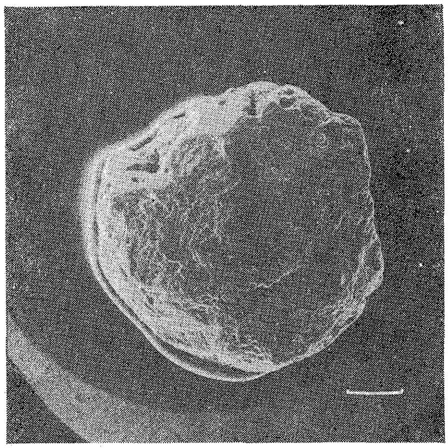
Pl. 7. On the right, smooth fracture surfaces occur next to nodular precipitation of amorphous silica. The latter are visible on the left. The marked section = 10 μm



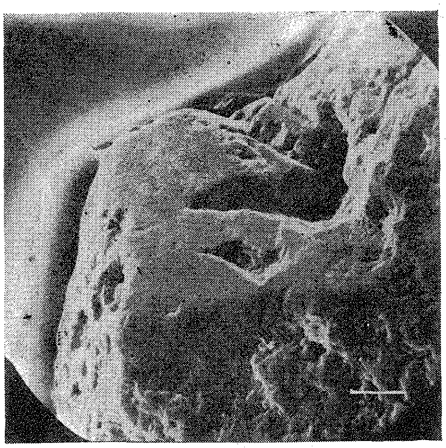
Pl. 8. Smooth, large surface immediately neighbouring with small conchoidal fractures indicating mechanical wearing. The marked section = 25 μm



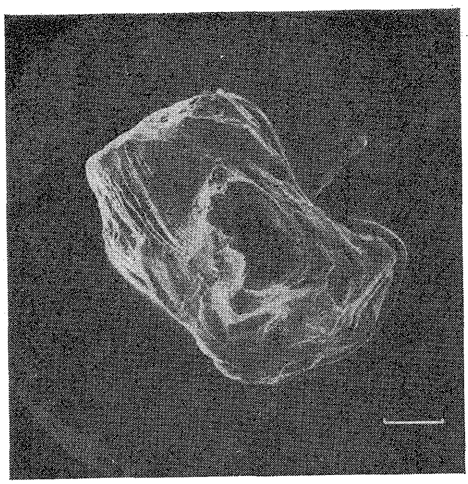
Pl. 9. V-shaped cuts, chaotically arranged, indicating mechanical wearing. The marked section = 25 μm



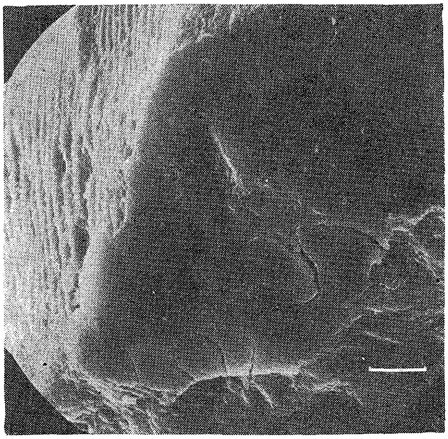
Pl. 10. Grain of differentiated surface relief. The greater part of the surface is covered with V-shaped cuts. Only a frgament has a smooth surface. The marked section=150μm



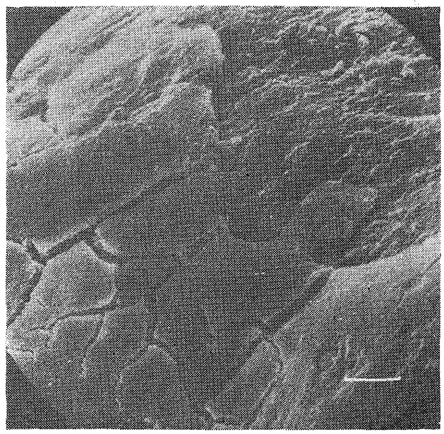
Pl. 11. Magnification of Pl. 10. The smooth surface, formed throught the off-chipping of a grain fragment, has recorded strong mechanical wearing which has formed deep, V-shaped cuts. The marked section = 29 μm



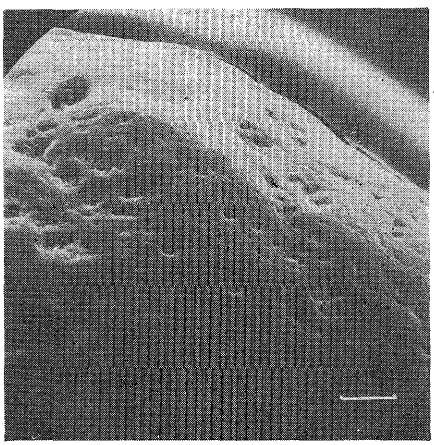
Pl. 12. Grain of a generally poor roundness with chemically isolated clevage planes. The marked section = 167 μm



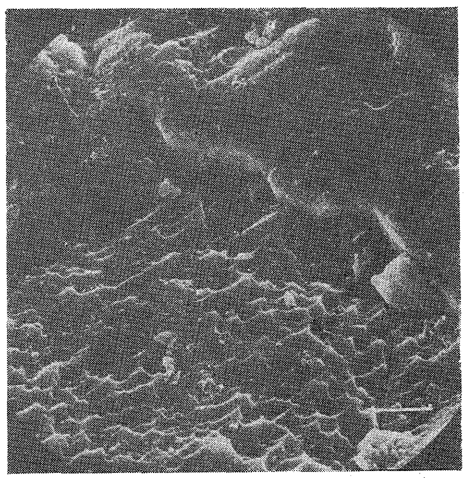
Pl. 13. Magnified fragment of Pl. 12. Clevage planes in the form of isolated steps and a thick cover of amorphous silica greatly cracked in some places. A record of intensive, multi-directional chemical processes. The marked section = 4 μm



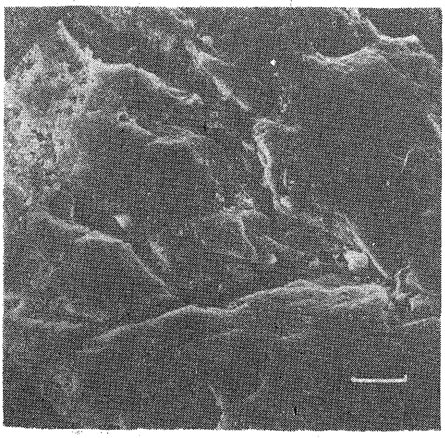
Pl. 14. Strongly exfoliated cover of amorphous silica. The marked section = 2.3 μm



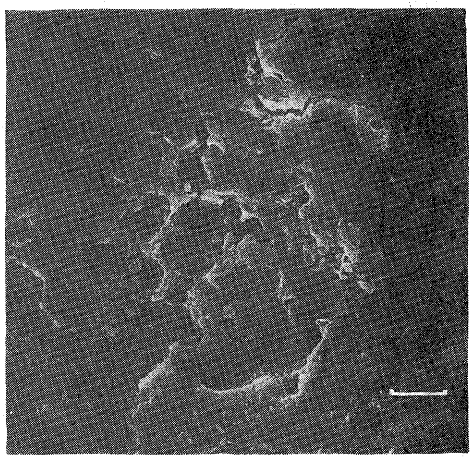
Pl. 15. Wind-worn grains. The marked section = 25 μm



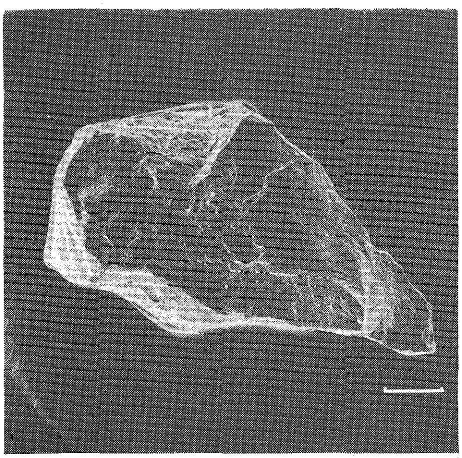
Pl. 16. The upper part of the grain shows a cover of amorphous silica, under which a relief indicating intensive processes of chemical corrosion can be seen. All the forms are directed according to crystallographic lines. The marked section = 7 μm



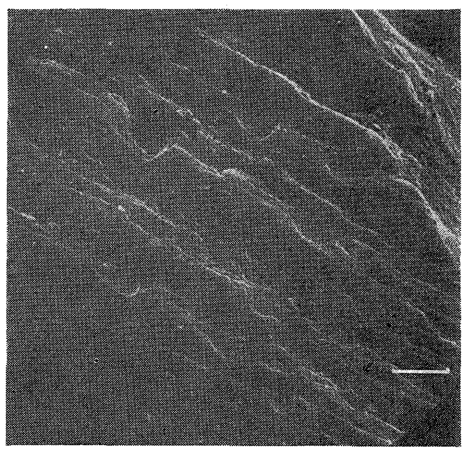
Pl. 17. Surface of amorphous silica cover strongly carved by chemical corrosion. A network of deep furrows can be seen. The marked section = 15 μm



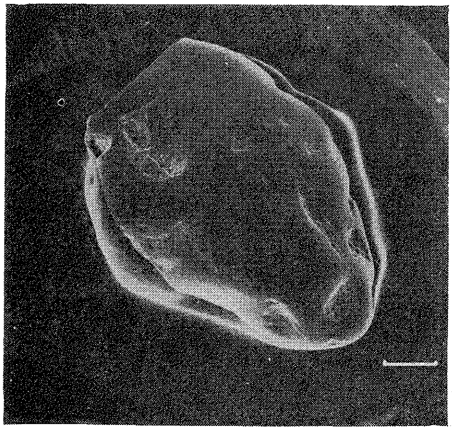
Pl. 18. Strongly exfoliated surface. The marked section = 12.5 μm



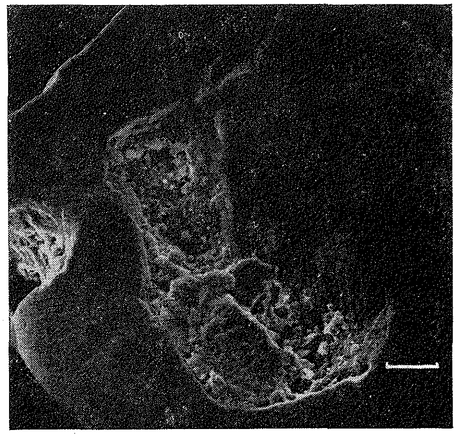
Pl. 19. A grain with fresh outline, visible exfoliation on surface fragments. The marked section = 116 μm



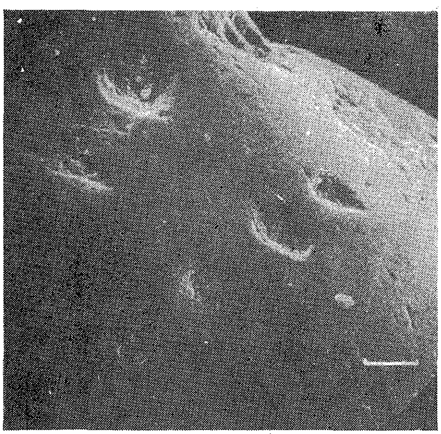
Pl. 20. Edges of fracture steps ravaged by V-shaped cuts. The marked section = 3.3 μm



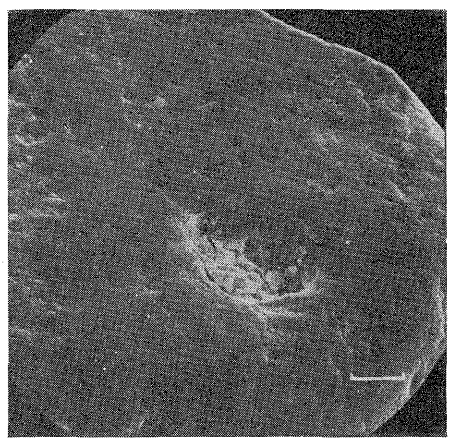
Pl. 21. Smooth grain surface with deep cuts of all shapes and sizes. The marked section = = 140 μm



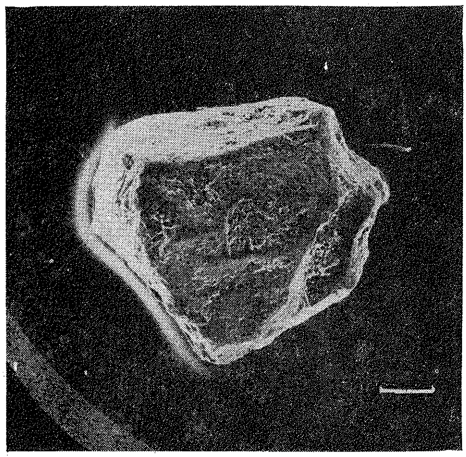
Pl. 22. Magnified fragment of Pl. 21. Deep erosion cut on smooth grain surface; within the cut traces of exfoliation processes are visible. The marked section = 29 μm



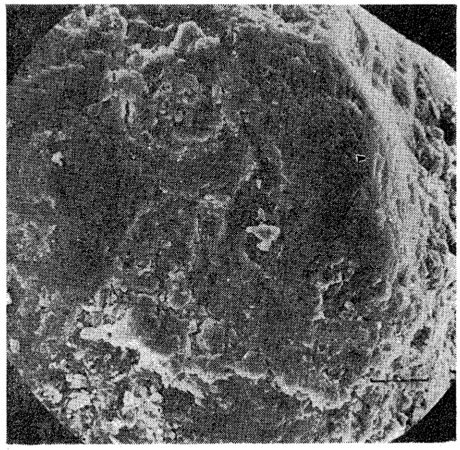
Pl. 23. Smooth grain surface with deep erosion cuts. The marked section = 25 μm



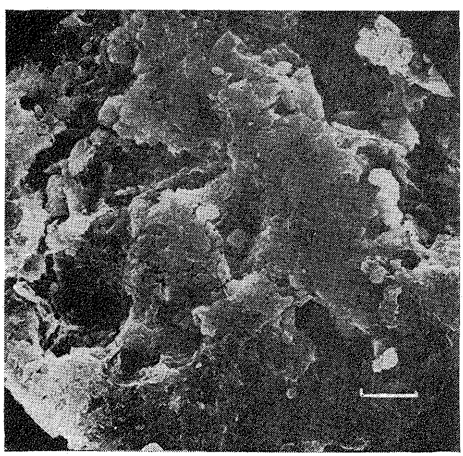
Pl. 24. Grain with aeolian relief. In an isolated pit traces of exfoliation can be seen. The marked section = 23 μm



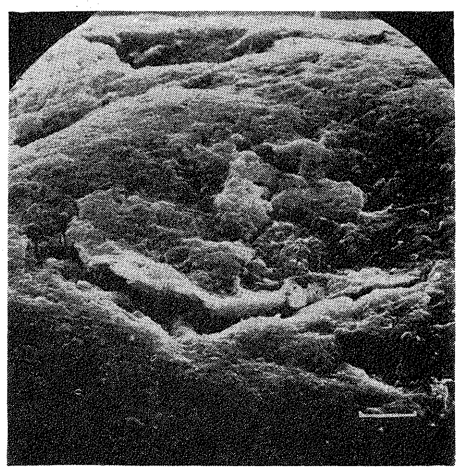
Pl. 25. Grain of sharp-edged outline and surfaces covered with exfoliation spots. The marked section = 140 μm



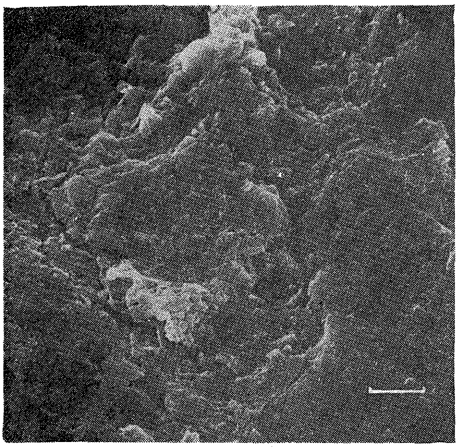
Pl. 26. Strongly exfoliated and cracked grain surface. The marked section = 33 μm



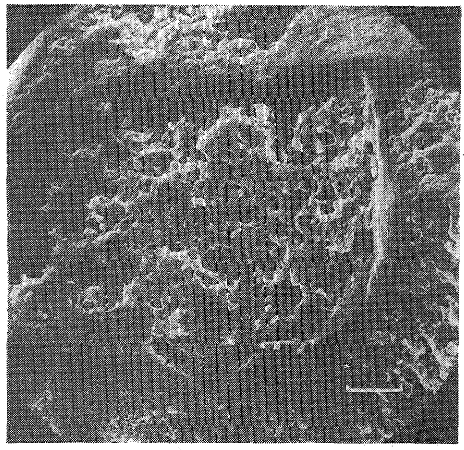
Pl. 27. „Lichen" type surface exfoliation. The marked section = 5 μm



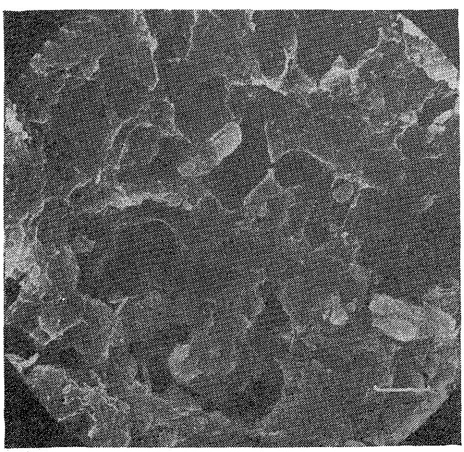
Pl. 28. Chipped-off grain fragment in a local pit of surface. The marked section = 5.5 μm



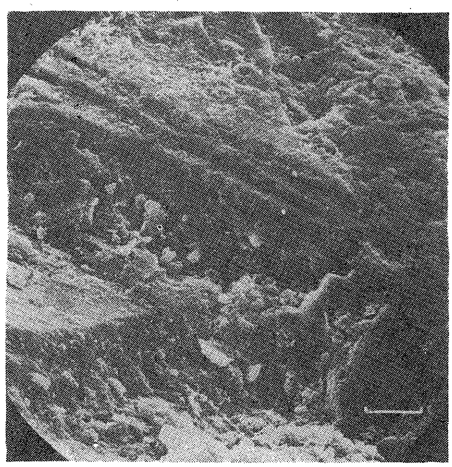
Pl. 29. Lines of cracks preceeding the off--chipping of large grain fragments. The marked section = 6 μm



Pl. 30. Surface pits filled with amorphous silica of a „pitted" structure, strongly exfoliated. The marked section = 28 μm



Pl. 31. Magnified fragment of Pl. 30. The „pitted" structure of siliceous precipitation and a simultaneously marked process of exfoliation. The marked section = 5 μm



Pl. 32. Traces of exfoliation of the siliceous cover visible on its edge. The marked section = 14 μm

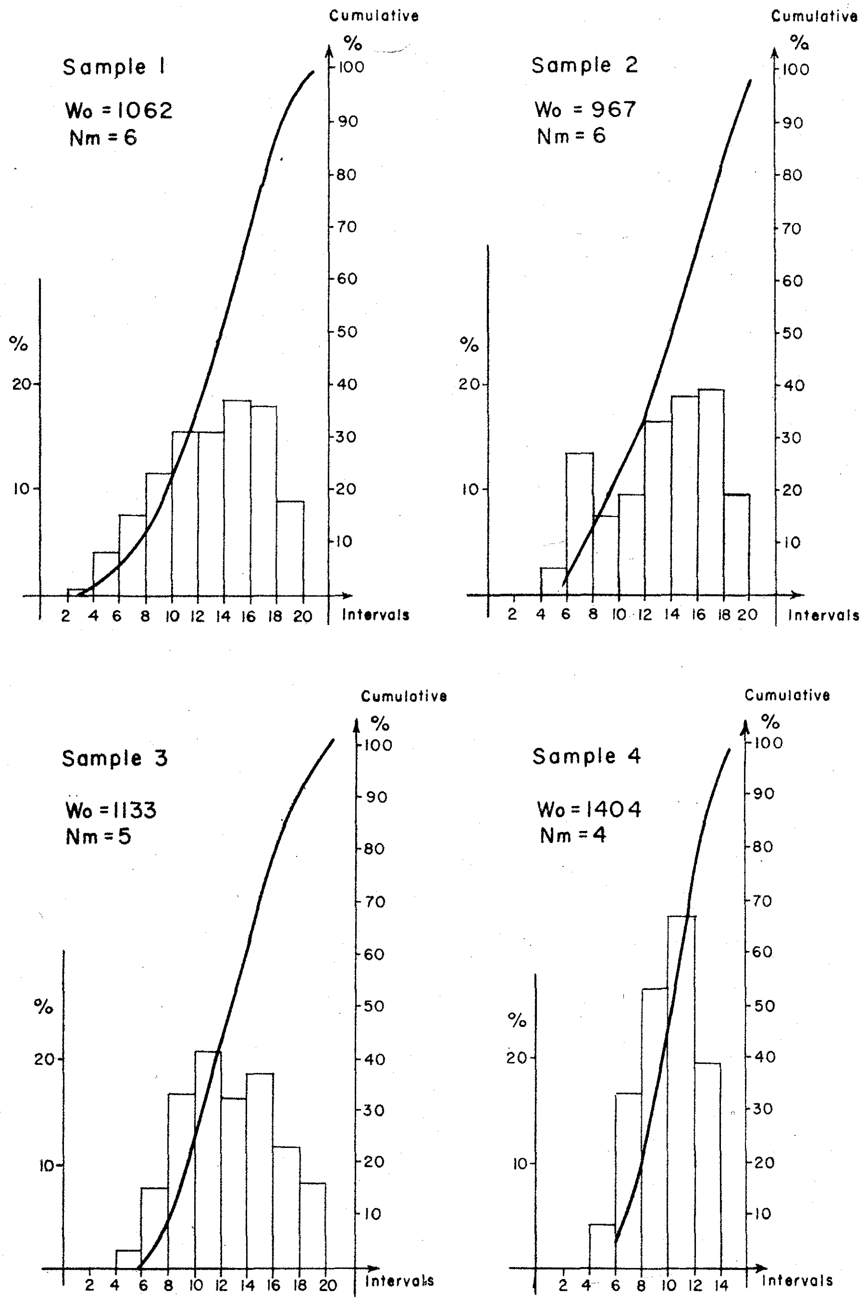


Fig. 7. Histograms of quartz grain re-working from sediments of outcrop No. 1

the method described earlier (Mycielska-Dowgiałło and Krzywobłocka--Laurow, 1976).

The results of all the measurements will be presented together since they are, in an essential way, complementary to one another.

Sample No. 4

The histogram of quartz grain re-working (fraction 0.5—0.8 mm) shows that 79.5% of grains come in the medium re-working group (type β according to Krygowski, 1964) with a distinct maximum at 12° of plate inclination, and 20.5% of grains display high re-working (type γ). The great homogeneity of quartz grains re-working causes the relatively low value of the Nm index (Nm = 4) and the high value of the Wo index (Wo = 1402) which, if not accompanied by other measurements, could suggest, a large content of well-rounded grains. However, this result is complemented with that of the measurement of quartz

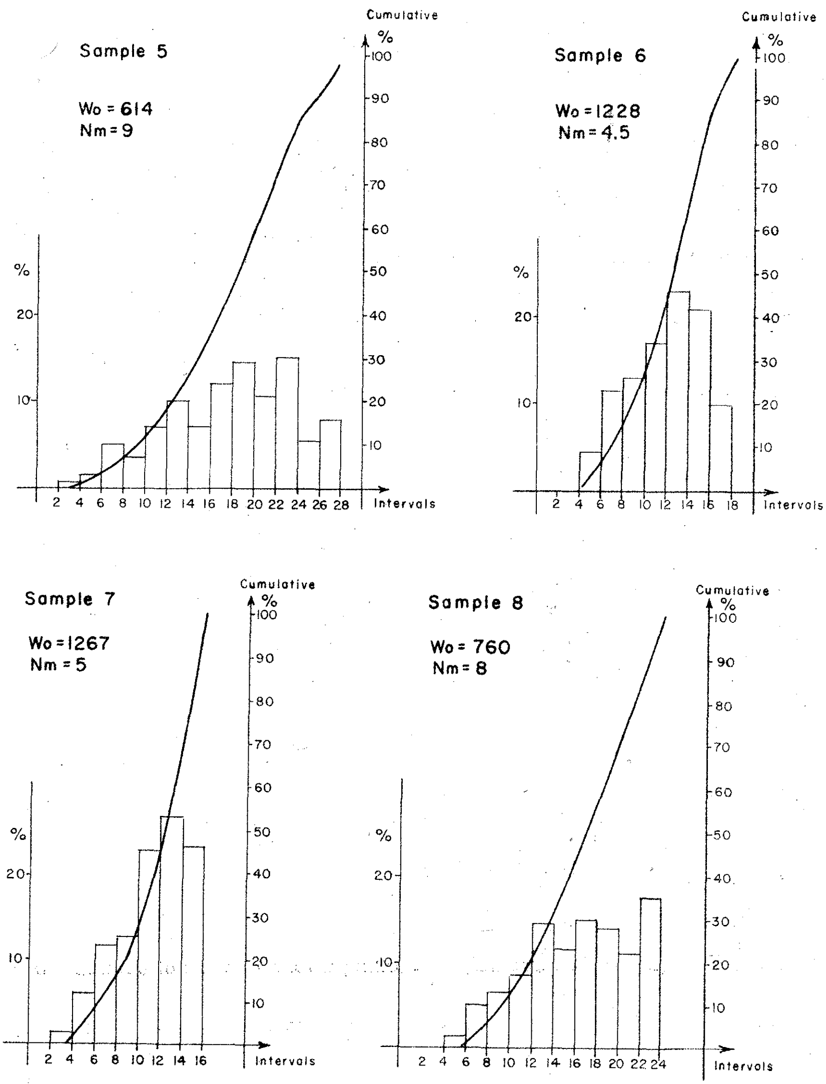


Fig. 8. Histograms of quartz grain re-working from sediments of outcrop No. 2

grain re-working carried out by the binocular method and it is the lowest result of all samples analysed ($K_1 = 2.31$).

The analysis of the 0.5—0.8 mm fraction quartz grains in the electron microscope has shown a decided predominance of grains which have already passed through earlier varied re-working or other deformation before getting into the running water environment where they were finally deposited. Grains of a fresh form constitute only a small group (clearly outlined, non-worn edges and relatively smooth fracture surfaces — Pl. 1). On the convex fragments of those grains small V-shaped cuts may be observed (Pl. 2) which have been noticed in the environment of very dynamically running water (Krinsley and Doorkamp, 1973). Probably, they are the record of the polishing activity of the latest environment (of running water) on the grain surface.

The second group distinguished in the electron microscope, also rather small, consists of grains with a fresh outline but carrying records, on fragments of their surface, of earlier weathering or polishing processes. It seems that the recorded processes occurred in the following order: chemical processes transformed the grain surface by precipitating on them covers of uncrystallized silica or they slightly corroded them forming a mosaic system of grooves (Pl. 3). The grains then underwent mechanical re-working of considerable strength (probably in a glacial environment) and the earlier-formed surfaces remained as relicts.

The last and largest group consists of grains with good or medium roundness and strongly transformed surfaces. Aeolian relief has been found here of a characteristic, slightly undulating, smooth surface with irregular cuts, similar to the „erosive texture" distinguished by Klatkowa (1976) (Pl. 4, 5) as well as the relief formed in the grain encrusting process, which masks all protruding edges and corners. Traces of intense corrosion may also be seen within the crust (Pl. 6). In the surface pits of those grains clayey minerals can be found.

The classification of grains from sample 4 as regards the matting degree of the surface has shown a visible content prevalence of mat grains (51%) and a much smaller part of lustreous ones (25%, Tab. I).

Sample No. 3

The histogram of quartz grain wearing (fraction 0.5—0.8 mm) shows that 71.5% of grains have a medium type of polishing (type β), 19.5% — weak polishing type α) and 9% of grains are well rounded (type γ). The same as in sample 4 the maximum roundness frequency of grains occur at 12° of the graniformameter plate inclination.

The roundness index (Wo) for this sample is lower than for the formerly analyzed. It is 1133. A higher content of poorly rounded grains is in accordance with a larger content of lustreous grains (46%).

The analysis of 0.5—0.8 mm fraction quartz grains in the electron microscope has revealed the occurrence of a relief of quartz grains generally resembling that observed on grains of sample 4. Here, too, grains of highly differen-

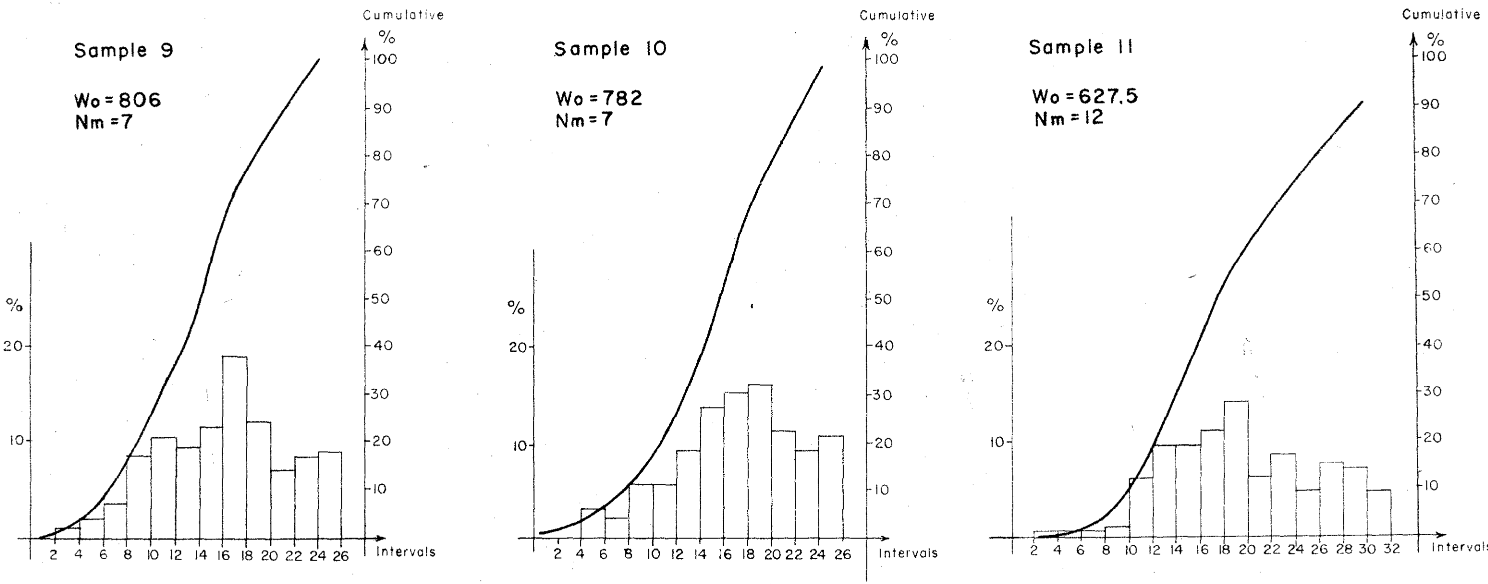


Fig. 9. Histograms of quartz grain re-working from sediments of outcrop No. 3

tiated relief can be seen. There are only few fresh grains with little worn surfaces but they generally have cuts of different size on their edges. The edges do not form a straight line but they are very much rugged and resemble forms occurring in the fluvial environment.

The second group of poorly rounded grains (the most numerous group in the investigated sample) contains grains of a differentiated surface relief. Smooth surfaces of fractures or crystalline surfaces of grains occur next to forms resulting from the sedimentation of amorphous silica (Pl. 7) or from mechanical re-working of the grain (Pl. 8). The grains the surface fragments of which are smooth while the whole grains are mostly marked by strong re-working (Pl. 9, 10, 11) may also be reckoned among this group, as well as grains the general outline of which is characterized by poor roundness and where the semicircular steps of the fractures occur in immediate neighbourhood of surfaces thickly covered with silica (Pl. 12, 13). The relief of conchoidal fracture and semicircular steps appears from under the silica cover. The latter underwent strong exfoliation in the final process which formed the grain (Pl. 14) [1].

In the group of well-rounded grains great genetic differentiation may be observed. A part of the grains have an aeolian origin (Pl. 15), another part has recorded considerable chemical transformation (Pl. 16, 17). Covers of amorphous silica surrounding the grain can be found (Pl. 16, 17) as well as strongly chemically corroded surfaces appearing from under the above mentioned cover (Pl. 16). Some grains show coatings which are also strongly marked by chemical corrosion (Pl. 17) [2].

Sample No. 2

The histogram of quartz grain wearing (fraction 0.5—0.8 mm) shows a bimodal system. The group of well-rounded grains (type γ contains 16% of grains while the group of poor polishing (type α) — 31.5%. The third group consists of grains of medium polishing (type ß) and contains 52.5% of grains.

Two observed frequency maxima of grain roundness occur at 8° and 18° inclination of the graniformameter plate.

The relatively large part of α and ß polishing types and the small admixture of type γ results in a low value of the re-working index (Wo = 967). The percentage of grains with a various matting degree is about the same as in the two samples described above. There are 41% of lustreous grains and 39% of mat grains.

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[1] It is difficult, in this group, to follow the succession of processes acting on the grains. Some of them, though, have left distinct marks on the grains and they are legible in spite of the effect of later processes. Hence on some grains the processes of mechanical re-working in beach zone can be seen (Pl. 9), on others — glacial wearing (Pl. 8) or chemical weathering owing to which crusts of amorphous silica were formed (Pl 7, 12, 13, 14).

[2] None of the observed features of relief occurs on all the grains examined. It is a collection of grains of various genesis and age, on which the latest environment of transportation and sedimentation has not left any visible mark.

The analysis of quartz grains (0.5—0.8 mm fraction) in the electron microscope has shown grains of much varying origin, the same as in the previous two samples. A half of grains magnified 50—100 times have a sharp-edged, non-rounded outline. But the same grains, if still more magnified, show surface fragments of various origin and age. At the same time many grains have traces of intense exfoliation which — judging by their relation to other forms — were the last stage of transformations (Pl. 18, 19). In the described grain group, on the fracture edges marked by steps, magnified 3000 times, V-shaped cuts can be seen indicating mechanical re-working. The character of wearing suggests the influence of fluvial environment (Pl. 20). The exfoliation marked on most grains of this group, as the result of the final modelling process, seems to testify the occurrence of a mechanical weathering.

On a number of grains crusts destroyed by progressing exfoliation may be observed.

The second group, as regards numbers, consists of grains having a smoothed surface with deep cuts of various shapes (Pl. 21, 22, 23). This type of relief is found in Pleistocene deposits in different parts of Poland. They probably occur there on a secondary place and come from the Tertiary pelagic deposits. When magnified ca 6000 times the smooth surfaces display numerous, small V-shaped cuts.

In the second group of grain just discussed exfoliation processes also occur. They are mainly observed in the cuts and depressions of the surface. This is probably due to better conditions for the concentration of moisture (Pl. 22).

The same as in the previous samples, grains with aeolian erosion are found here. Within larger wearing pits traces of chips can be seen (Pl. 24).

Exfoliation processes seem to have played a leading role on the grain surface of the examined sample though the percentage of exfoliated surfaces is rather low. They have been marked on grains of various origin as the latest processes modelling their surface.

Sample No. 1

The histogram of quartz grain polishing (0.5—0.8 mm fraction) shows that 12% of the grains are highly polished (type γ) and 31.5% — weakly polished (type α). The medium type of polishing (type ß) comprises 56.5% of grains.

Both the percentage of grains of different polishing kinds and the values of the roundness indices determined by the binocular method show a great resemblance with the above analysed sample 2. Instead there is a great difference in the matting degree of the grain surface. Sample 1 contains nearly twice as many mat grains as sample 2, that is 61% of grains.

The analysis of quartz grains (fraction 0.5—0.8 mm) in the electron microscope has shown that the percentage of exfoliated surfaces greatly prevails over surfaces of a different relief. In spite of a great number of grains with a generally sharp-edged outline the character of their surfaces visibly differs from that of the grain surfaces in sample 2. The greater part of the grain surfaces is covered with spots of exfoliation. This can be noticed in grains magnified even less than 100 times (Pl. 25). In greater magnification it may be seen that the exfoliation is of various charcter. Sometimes a network of small cracks covers large fragments of grains, whether those are convex or concave fragments of the surface, forming a fine-grained „lichen" (Pl. 26, 27). In other cases the surface fragments are chipped off which is particularly frequent in local pits of the surface (Pl. 28. 29). This process of chipping of usually accentuates negative forms within the surface and causes the formation of convex monadnocks.

Sometimes the type of exfoliation in the grain surface pits suggests the interaction of mechanical and chemical weathering processes. The latter lead to the precipitaition of amorphous silica which forms a pitted structure which is strongly exfoliated (Pl. 30, 31).

In the exfoliation process the previous grain surfaces, of various origin and age, underwent considerable obliteration (Pl. 26, 32).

The analysis of the quartz grain surfaces (sample 1) in the electron microscope has shown that the exfoliation of the surface was the prevailing and undoubtedly the latest process; it has considerably transformed the earlier relief of the grain. It can be also seen that the large percentage of mat grains is not connected here with the predominance of the aeolian process but with grain surface exfoliation due to frost weathering and to some extent — to chemical weathering.

THE RESULTS OF GRAIN-SIZE COMPOSITION AND RE-WORKING ANALYSES OF QUARTZ GRAINS FROM OUTCROP NO. 2 AND NO. 3

For fuller documentation of the presented results the grainsize composition and re-working of grains from other two profiles were additionally analysed (Fig. 2, 3).

All the investigated deposits, both moraine and periglacial, are poorly or very poorly segregated. In the deposits filling frost structures it decreases towards the top. This is due to the occurrence, within that horizon, of both coarse- and fine-grained deposits. It is well illustrated by the frequency curves (Fig. 4, 5, 6).

In periglacial deposits the skewness (Sk_1) has generally negative values. This means that coarse grains are more numerous in relation to the fraction of maximum frequency. Also DOEGLAS's determination and the value of the grains mean diameter (M_z) shows that those are coarse-grained deposits (Tab. I).

The values of re-working indices of 0.5—0.8 mm fraction quartz grains (W_0), calculated according to graniformameter measurements, are highly differentiated both in moraine deposits and in periglacial structures. The grain-worn degree, determined for the same fraction in the binocular, is high. It is generally higher in frost structures than in the unchanged substratum. It is possible that the microrelief of the grain surface plays a role here by influencing the rolling capacity of the grains in the graniformameter. Grains with exfoliated surface may have

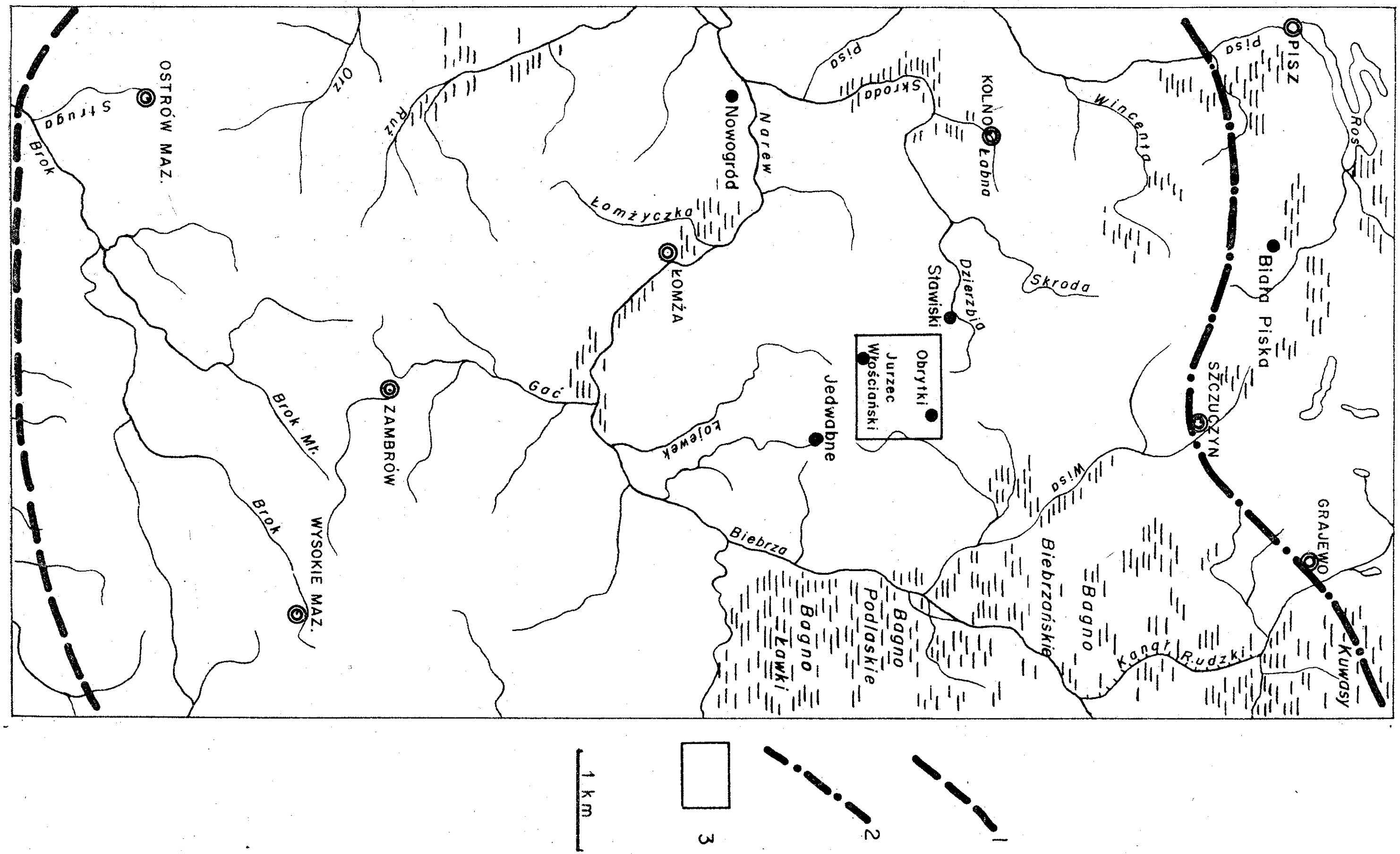

Fig. 10. Location of the investigated area against the map of the extent of glaciations on the Kolno Plateau (according to S. Z. Różycki)

1. extent of the Mława substage of the Central Poland glaciation; 2. extent of the Leszno phase of the Baltic glaciation; 3. investigated area

a lower rolling capacity in the graniformameter than grains of similar form but with a smooth surface.

The above mentioned feature is connected with the matting of the grain surface. Periglacial deposits can be well distinguished from the moraine lying beneath by the degree of grain matting. In outcrop No. 3, the same as in outcrop No. 1, a visible increase of quartz grain matting may be observed in the top layer of deposits filling the investigated periglacial structure. There are no complete data for outcrop No.2.

RECAPITULATION OF RESULTS

The analysis of periglacial structures carried out according to GOŹDZIK'S recommendations (1973) (vertical and horizontal sections) proved their fissure character. The examined structures most resemble forms determined by GOŹDZIK (1973) as fissure structures of primary filling. There are no major disturbances in the neighbouring layers, and the deposit, macroscopically examined, seems to be alien in relation to that surrounding the structure.

However, a detailed analysis of the deposits has shown that the material filling the structures is directly connected with the substratum and changed only by weathering. The character of the outer boundaries of the structures and the mineral composition of the deposits filling those forms seem to suggest that processes of washing away have also played here an important role. Water displaced the deposits within the active zone of permafrost. It is, probably, the record of climatic conditions in the waxing phase of the latest glaciation. A sample collected from the bottom of a pocket form (outcrop 1, sample 2) for examination in the electron microscope still resembles the source deposit very much, but it differs from the latter by the occurrence of exfoliation on the grain surface fragmenst. This testifies the action of frost weathering on the grain.

The next sample, collected from the upper part of the pocket form is characterized by the prevalence of grains with their previous relief obliterated by all kinds of exfoliation and off-chippings. The visible predominance of exfoliation processes observed on the grains of this sample indicates the prevalance of mechanical weathering in the final formation of the grain surface. The high percentage of mat grains is also undoubtedly due to the strong exfoliation of the grain surface. It is probable that those deposits were mostly formed in the climax of the latest glaciation under the influence of intensive processes of mechanical weathering.

The small number or the lack of wind-worn grains in the deposits filling periglacial structures means that aeolian processes did not prevail in the investigated area during the formation of the structures. On the other hand, the frequent occurrence of exfoliation and off-chipping on the grain surfaces seems to prove that those grains obtained their final form, frequently of considerable roundness, as the effect of an intensive exfoliation.

Weathering processes of the waning phase of the latest glaciation and of the

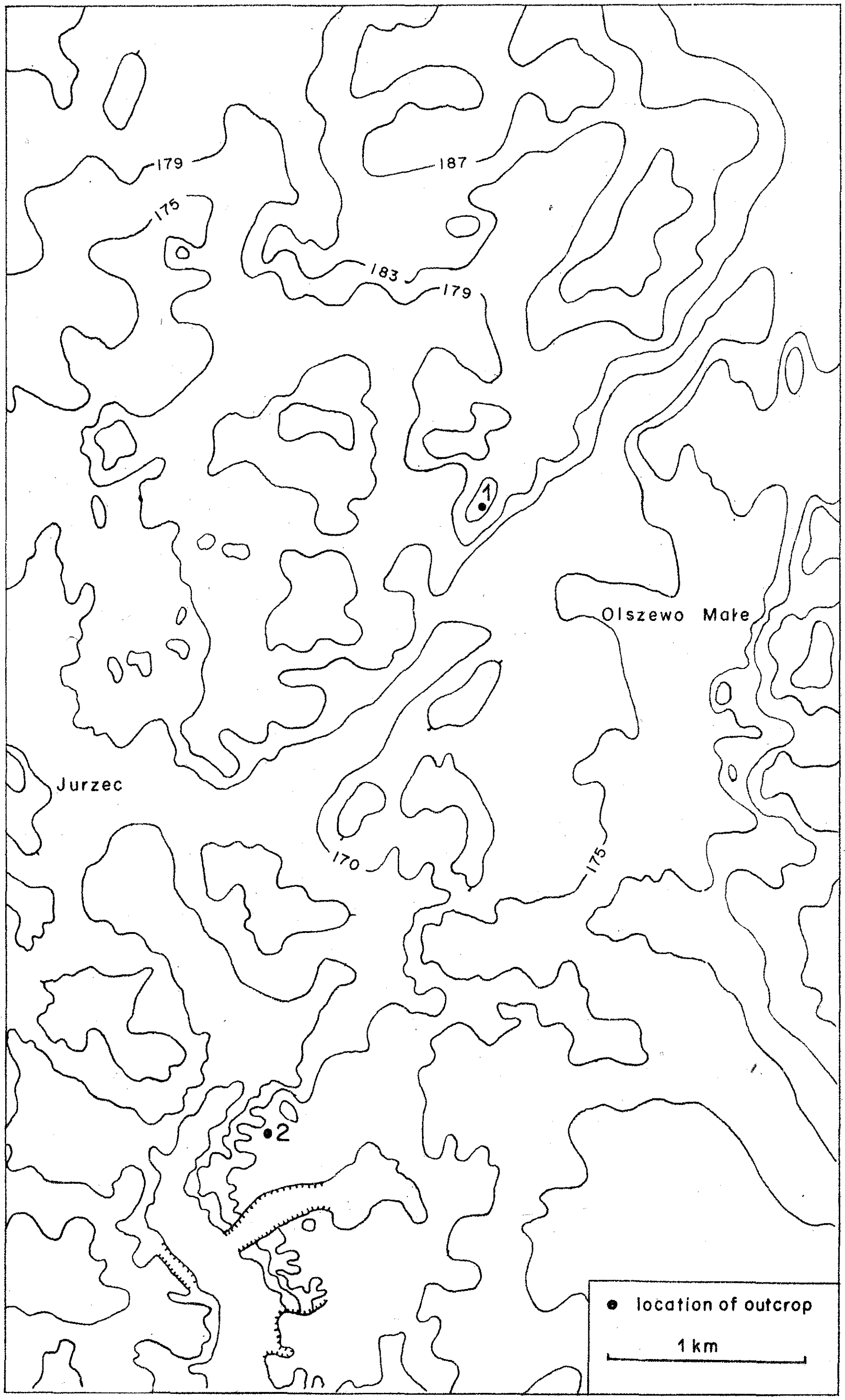

Fig. 11. The glacigenic relief of the investigated area

Holocene cannot be easily distinguished on the grain surfaces. Probably, the blurred traces of chemical weathering, sporadically observed on the grains, are connected with this transformation phase.

ACKNOWLEDGEMENT

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