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# SEDIMENTOLOGIC ANALYSIS OF THICK DEPOSITS IN THE KARST PIT AT THE *N* BORDER OF THE HOLY CROSS MTS (POLAND)

While preparing the *Detailed Geological Map of Poland* on the scale of 1:50,0000, sheet "Wierzbica" (Barcicki, in press), a bore "Mirówek IG-1" was drilled to 68.0 m of depth; it records the deposits in a karst pit. The pit lies within the *N* Mesozoic border of the Holy Cross Mts, in the Iłża Foreland (Kondracki 1978), in a large monocline inclined to the North-East (Fig. 1). The karst pit was formed in the contact zone between Oxfordian limestones and marls (Malm) with frequently occurring flint, and Callovian sandstones (Dogger).

The southmost extent of pelagic deposits of the Lower Tertiary reaches some 20 km north of the investigated area (Areń 1957). At the same time, Lower Tertiary deposits can be found here in some places, in isolated karst depressions (Karaszewski 1966).

The Mirówek karst pit revealed by bores is filled with flint gravels in its bottom, higher-up with dusty sand and sandy silt, covered, in the top, with boulder clay. In order to determine the age and evolution of the karst form, a detailed analysis of the sediment infilling was performed. The results have been presented in a diagram (Fig.2).

At the depth of 68.0—57.3 m there occur flint and flinty sandstone gravels with an average diameter of 40 mm and a maximum of 100 mm (series I). The gravels have shapes of primary kidney stones. They are stuck in dark-grey waste clay.

From 57.3 to 31.0 m (series II) there occur light-grey or almost white decalcified dusty sands often containing much organic matter (with no pollen), rather compact in places. The whole series is distinguished by great differences of grain size indices in the following intervals $M_Z=4.3-2.5$ *phi*; $\delta=0.6-2.5$ *phi*; $SK_I=-0.15-+0.60$; $K'_G=0.45-0.75$ (after Folk and Ward 1957).

The grain abrasion was analysed using various methods: the morphoscopic method (Cailleux 1942) modified, the graniformametric method

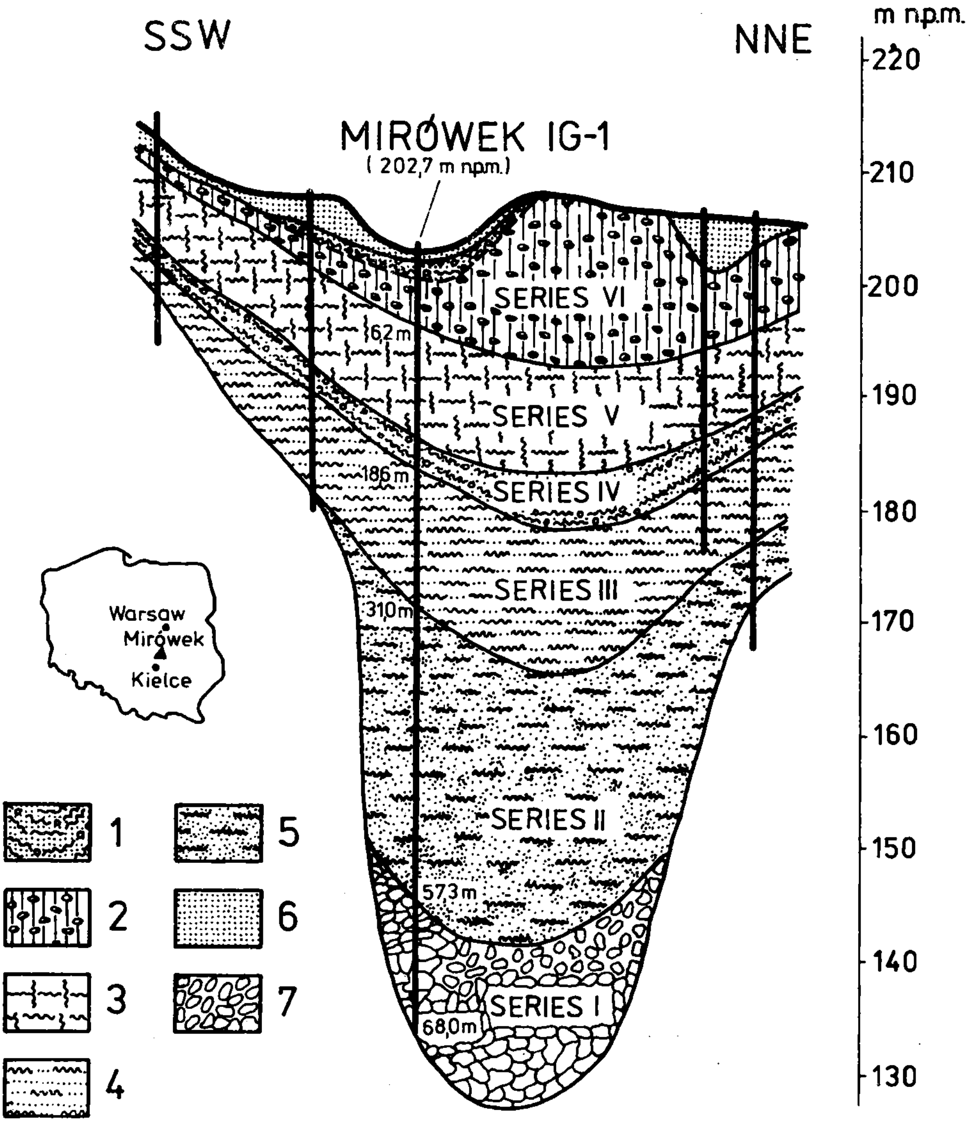

Fig. 1. Geological section of the karst pit at Mirówek: 1 flow clay, 2 boulder clay, 3 loess-like silt, 4 sandy silt, 5 silty sand, 6 sand, 7 gravel

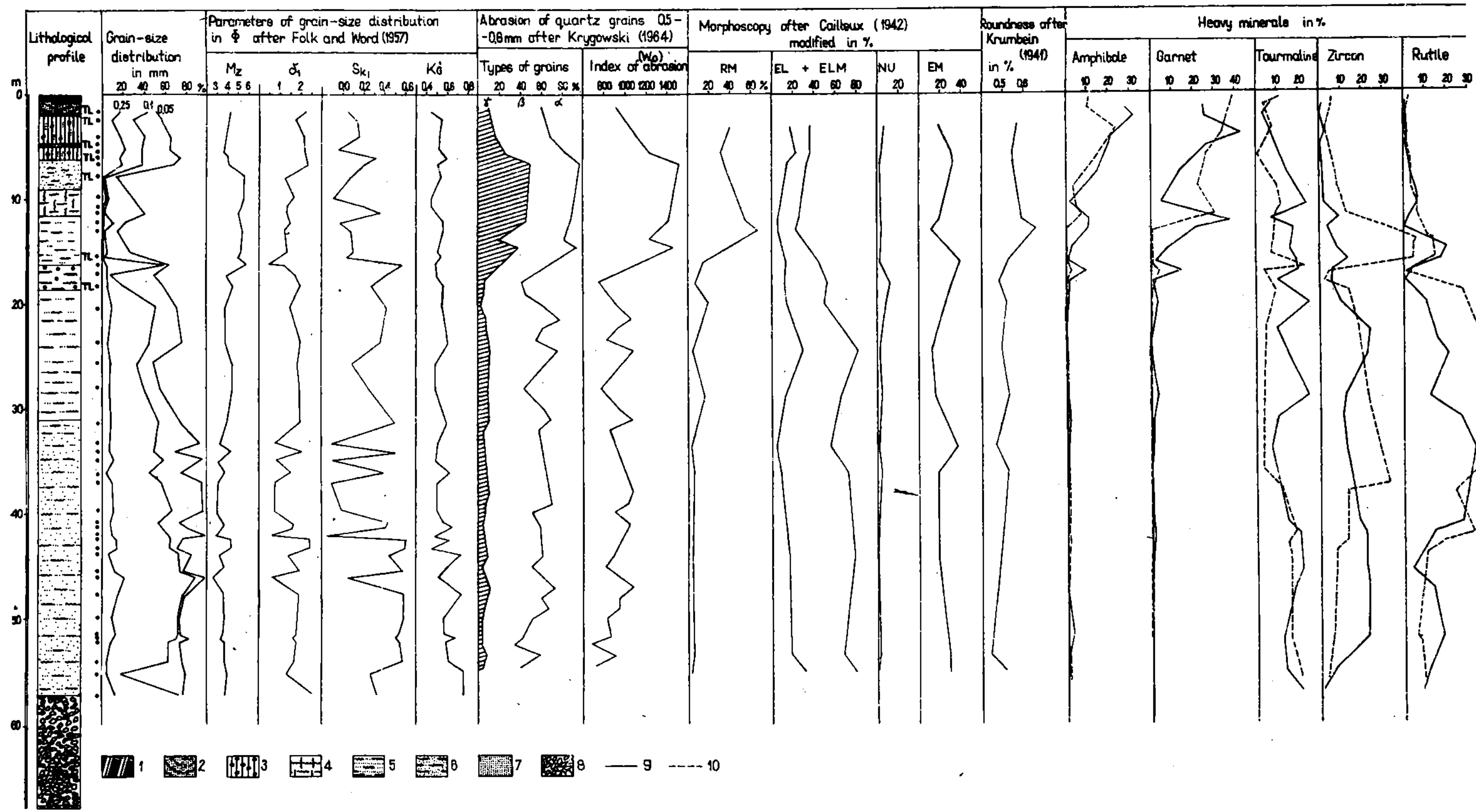

Fig. 2. Diagram of the lithologic composition, grain size distribution, rounding of quartz grains of the sandy fraction and heavy minerals content in the bore profile at Mirówek (JG—1). Explanations of the lithologic composition as in Fig. 1; α non-abraded quartz grains, β grains with medium rounding, γ well abraded grains; *RM* round mat grains, EL smoothened polished grains, ELM smoothened slightly frosted grains, NV non-worn grains, EM intermediate grains. 1 — soil, 2 — flow clay, 3 — boulder clay, 4 — loess-like silt, 5 — sandy silt, 6 — silty sand, 7 — sand, 8 — gravel, 9 — heavy mineral in 0.1—0.2 mm, 10 — heavy minerals in total sample.

(Krygowski 1964) and the determination of the rounding degree in Krumbein's scale (1941). The comparison shows (Fig. 2) that there are very small differences in the content of well abraded ($\gamma$), rounded mat (*RM*) and smoothened polished (*EL*) grains, according to rounding degrees in Krumbein's scale. The low content of $\gamma$-type grains (3 to 11%) and of *RM* grains — 6% — is characteristic. Instead, there are large quantities of *EL* grains and particularly of *EL*+*ELM* (rounded, slightly mat)[1] grains — 55 to 78%. In Krumbein's scale the rounding degree is average (0.4—0.5).

In order to examine the source of the deposit more closely two samples from series II (from 53.4 and 32.7 m of depth) were analysed in a scanning electron microscope (SEM) of the ISM-35 JEOL type[2] in respect of the quartz grain surface texture. Several hundred grains of 0.5—0.8 mm fraction were first examined in an optical microscope, then 12 of them were selected among charactristic groups of rounding and frosting for SEM examination. In the sample from the depth of 53.4 m most analysed grains have smoothened surfaces and rounded edges and corners. When magnified 40—72 × their general form resembles grains from present-day beach environment (Photo 1) and some have the same surface forms as quartz grains from hot climate beaches. When magnifield 300—800 × a distinct difference can be observed in the degree of abrasion of concave and convex fragments. In grains of beach origin convex fragments are strongly abraded while concave fragments often have smooth breakage surfaces. It proves that the mechanical abrasion was the main process forming the surface of those grains. The same magnification shows that convex surfaces, mechanically abraded, constitute favourable spots for processes of chemical weathering. In some grains the surface damaged by abrasion is chemically etched and forms deep grooves of a shape of semicircular bows and oblong cracks (Photo 2). The bow-form cuts are particularly characteristic in grains of present-day beach zones. V-shaped cuts, scattered disorderly, are also characteristic. They occur commonly on convex fragments of the investigated grains (Photo 3).

The analysis of the whole sample seems to show that it comes from littoral environment, from a coastal zone. At the same time the grains were formed, partly at least, by processes of chemical weathering. Hence it may be supposed that the then prevailing climate was warm and damp.

In the sample from 32.7 m of depth all the examined grains have smoothened surfaces and frosting characteristics of an environment of intensive chemical processes (Photo 4). The grain edges and corners are

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[1] They are grains with partly preserved features of a polished surface but undergoing frosting. The frosting was investigated by J. Goździk and E. Mycielska-Dowgiałło (1983 and in press). The authors found that the frosting was not due to aeolic abrasion but was the result of the chemical etching processes and abrasion in a strongly dynamic aquatic environment.

[2] The analyses were performed in the Institute of Geology, Warsaw. The authors thank M. Pawlik and Z. Piasecka who participated in the preparation of samples and of photos in the electron microscope.

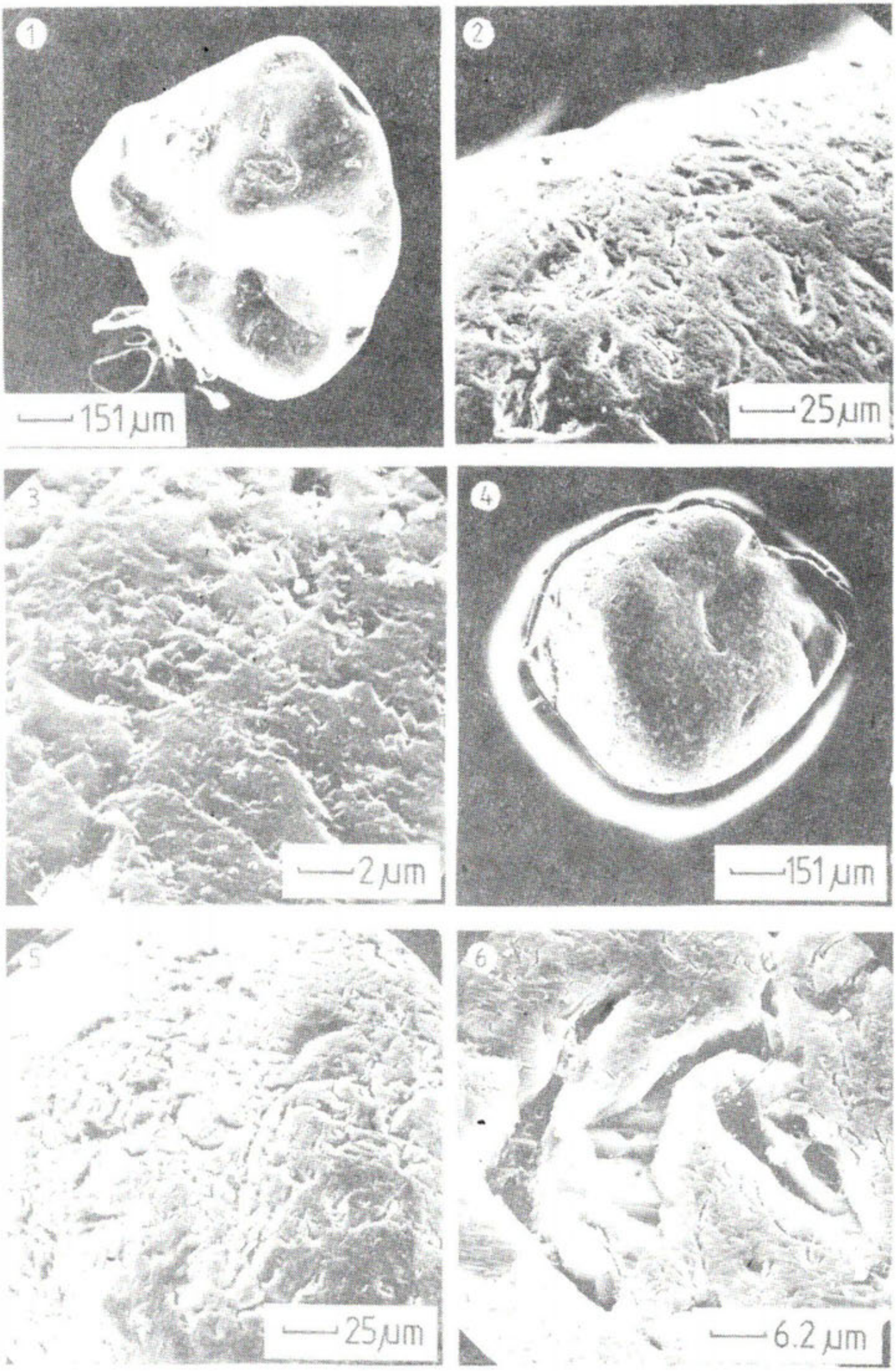

Plate I.
Photos 1—3 quartz grains and fragments of their surface; sample from 53.4 m of depth, SEM,
Photos 4—6 quartz grains and fragments of their surface; sample from 32.7 m of depth, SEM,
Explanations in the text

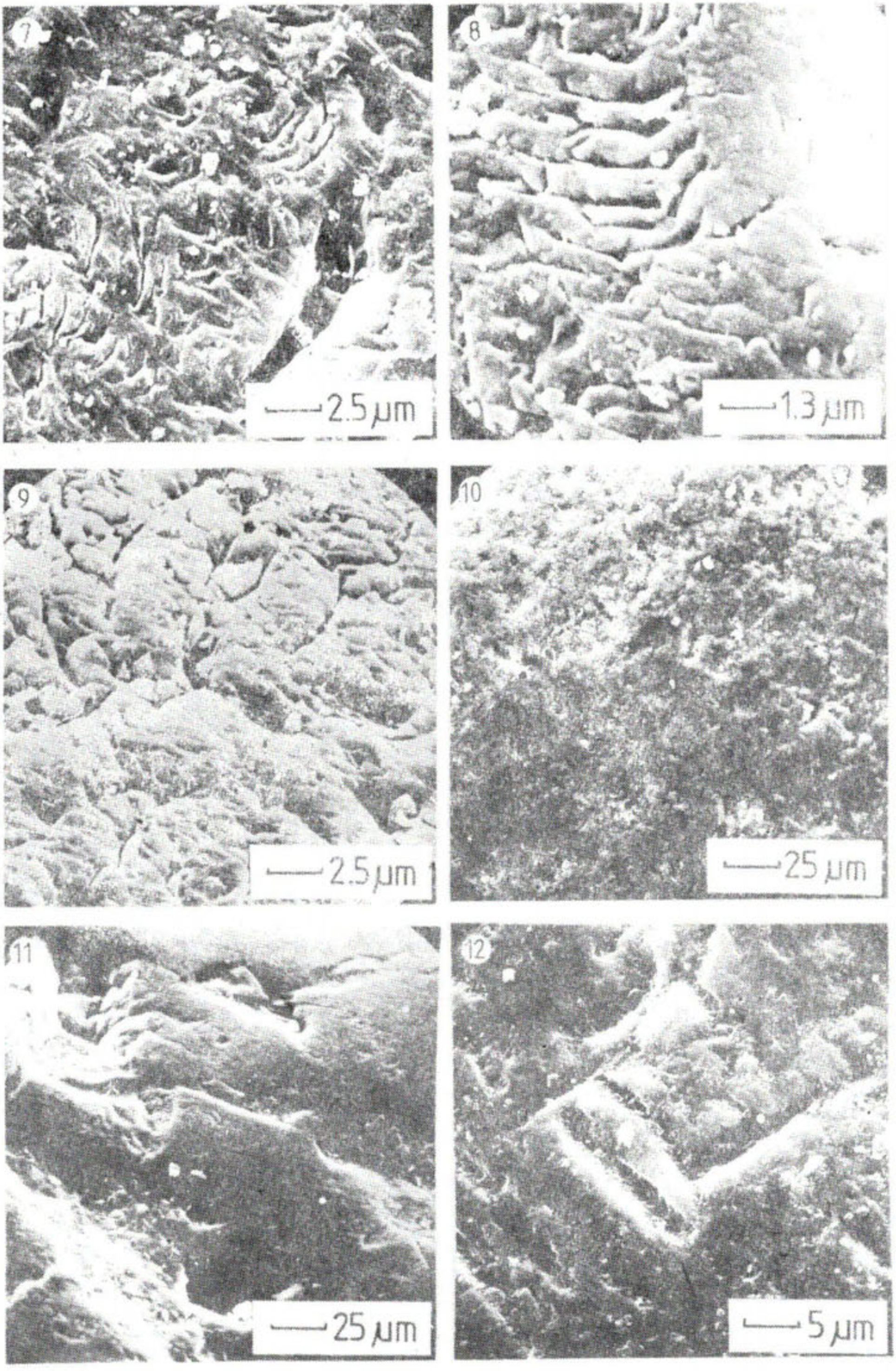

Plate II.
Photos 7—9 guartz grains and fragments of their surface; sample from 32.7 m of depth, SEM,
Photos 10—12 guartz grains and fragments of their surface; sample from 17.8 m of depth, SEM,
Explanations in the text

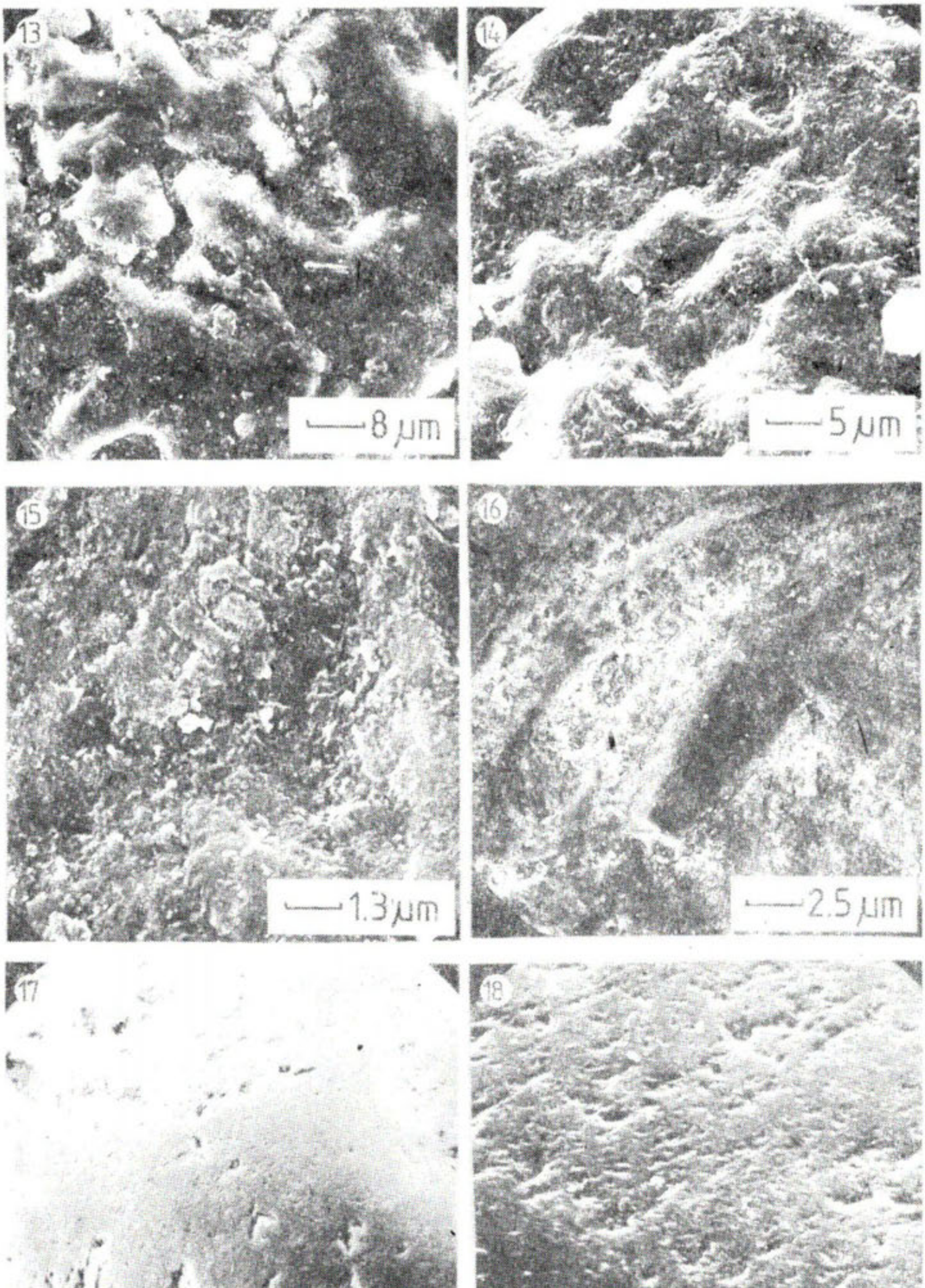

Plate III

Photos 13—15 guartz grains and fragments of their surface; sample from 17.8 m of depth, SEM, Photos 16—18 quartz grains and fragments of their surface; sample from 5.5 m of depth, SEM, Explanations in the text rounded. Larger magnification shows a grain texture typical in beach environment where processes of chemical weathering prevail over abrasion. Semicircular and oblong cuts transformed into deep "grooves" can be observed on the grain surface (Photo 5). Only some grains display nothing else but abrasive texture. When magnified 1600 × it can be seen that in the bottom of depressions deepened by chemical etching there occur crystallographically directed forms (Photos 6, 7). The forms of furrows within the grain surface are also visibly directed (Photo 8). Some fragments of the surface resemble lapiez-type texture (Photo 9). The analysis of the sample also seems to denote its littoral, coastal origin; it must have been formed by intensive processes of chemical etching the degree of which resembles that stated in Konin on grains of Miocene sands interbedding brown coal (Goździk, Mycielska-Dowgiałło 1983 and in press), as well as the weathering degree stated on grains of the present-day beaches of Congo and Puria in the Bengal Bay (Mycielska-Dowgiałło, in press).

In order to define the feeding region of this area and the conditions of its sedimentation 27 analyses of heavy minerals (fraction 0.2 – 0.1 mm) were performed and additional 23 analyses in fraction 0.25 mm. Beside the quantitative composition also grains in the particular mineral groups — garnets, zircons, amphiboles and pyroxenes — were examined.

In series II (57.3—31.0 m) a characteristic feature is the almost exclusive occurrence of minerals resistant to chemical weathering. It can be observed, too, that upwards from a depth of 40 m the content of rutile and zircon increases while the quantity of tourmaline and disthene decreases. Amphiboles, pyroxenes and garnets occur in the whole series in trace quantities only.

The next sedimentary series (series III — 31.0—18.6 m) is developed as light-grey sandy silt with a large content of decomposed organic matter (without pollen). A characteristic feature of this series is a greater homogeneity in respect of grain size distribution as compared with the underlying series. The grain size indices range within relatively narrow limits: $M_Z = 3.8 - 4.4$ *phi;* $\delta_1 = 1.5 - 2.0$ *phi,* $SK_1 = 0.09 - 0.41$; $K'_G = 0.49 - 0.60$. As for features of quartz grain abrasion, this series differs from the underlying ones in a variable and generally higher content of rounded mat grains ranging from 4 to 19%. Instead, there are no changes in the degree of abrasion according to Krygowski's index or in rounding after Krumbein's scale.

The analysis of heavy minerals in two samples of this series (19.0—28.7 m and 20.3—20.0 m) has revealed not only resistant minerals (disthene, staurolite, epidote, tourmaline and rutile) which prevail in quantity, but also an increased content of pyroxenes, epidotes and garnets, especially as compared with the underlying series (II). A detailed analysis of the mineralogic properties of pyroxenes from horizons where they occur in larger quantities has permitted an exact determination of this mineral group. Those pyroxenes belong to the group of simple and basaltic augites.

The next horizon (series IV — 18.6—16.2 m) is composed of clay (probably flow clay); it is compact, of a rusty or grey colour. The streaks of laminas occurring in the drill core slant at an angle of 25°. It proves that the bore-hole is placed in the slope of the karst form. The grain size distribution is as follows: $M_Z = 5.3-4.7$ *phi*; $\delta = 1.7-2.0$ *phi*; $SK_I = 0.27-0.40$; $K'_G = 0.50-0.56$. The flow clay has the same values of quartz grain abrasion as the underlying series; similarly, Krygowski's rounding coefficients and Krumbein's rounding indices are the same as in the underlying silts. Instead, a feature different from the underlying series is the lower content of abraded polished (*EL*) and slightly frosted (*ELM*) grains.

The surface texture of quartz grains from a sample collected at 17.8 m of depth was analysed in the electron microscope. A great diversity of abrasion can be observed. There occur grains with beach or aeolic abrasion, with their surface texture changed by chemical weathering, by etching or crusting. The texture is more distinct when magnified 400×. The granular type of the aeolic texture indicates a cold climate in which it was formed (Photo 10). The second type of grains comes from a beach environment (Photo 11). The third type comprises grains with surfaces considerably transformed by chemical weathering. The forms here are visibly directed (Photo 12). Larger magnification shows that the progress of weathering leads to the formation of the lapiez-type texture (Photo 13) and of monadnock texture (Photo 14). On a number of grains, surface exfoliation can be observed; it may be the effect of the mechanical weathering (Photo 15).

The analysis of the whole sample indicates a great genetic diversity of the grains.

The analysis of heavy minerals in the flow clay has revealed, in its middle part, a slightly higher content of amphiboles, pyroxenes and garnets than in the underlying and overlying horizons. The same as in the underlying series pyroxenes have the form of colourless, grey-green or green grains. There is a distinct difference in the content of brown jagged grains. In the lower horizons it amounted to 7% of the total of all pyroxenes while in the analysed flow clay it rises to 33%.

The next horizon (series V, 16.2—6.2 m) is formed of sandy or clayey silts, resembling loess, decalcified, rather compact, with infiltrations of iron oxides, cream-coloured or light-grey. The grain size distribution is as follows: $M_Z = 3.8-5.8$ *phi*; $\delta_1 = 1.0-2.3$ *phi*; $SK_1 = -0.09- +0.56$; $K'_G = 0.45-0.56$.

In respect of quartz grain abrasion this series is different from all the underlying sedimentary series. The content of round mat grains (RM) increases violently and reaches 66%. It is also much higher than in the overlying boulder clay. At the same time, the content of smoothened polished grains (EL) and of rounded slightly frosted grains (ELM) is visibly lower in this series. At the depth of 13 m this content is the lowest within the whole investigated profile (21%). A similarly high degree of quartz abrasion is indicated by the Krygowski's $W_0$ index. It ranges from 1226 to 1514, and the content of grains of group $\gamma$ is high: 18—49%. Those values are then the highest within the whole profile. The Krumbein's rounding coefficient is also the highest: 0.53—0.66.

The analysis of heavy minerals has shown a large content of epidotes, garnets and tourmaline, less amphiboles and pyroxenes. The content of amphiboles, reaching, in this series, 15.2% at most, is much higher than in the underlying flow clay (containing a maximum of 9.4%). A characteristic feature of this horizon is the growing content of amphiboles and epidotes proceeding from the bottom to the top of the series. At the same, time, a visible increase in the content of zircon and rutile can be observed in its bottom (13.8—15.8 m).

The highest and last of the analysed series (series VI, 6.2—0.6 m) is a complex of dark brown boulder clays with detritus of local and northern rocks, of 5 mm of diameter. In its upper part the clay, when dry, is cloddish, strongly weathered, olive-yellow and with features of flow clay. The grain size distribution is as follows: $M_Z = 3.8-4.3$ *phi*; $\delta_1 = 1.8-2.3$ *phi*; $SK_1 = -0.03- +0.31$; $K'_G = 0.45-0.59$. The rounding of quartz grains is visibly lower as compared to the underlying loess-like silts. The content of round mat grains ranges from 30 to 40%, that of group $\gamma$ — 10—26%, and the rounding index $W_0$ is 914—1240. Krumbein's rounding coefficient is also lower: from 0.55 to 0.57.

A sample from 5.5 m of depth was analysed in the electron microscope. It has revealed great diversity in grain abrasion. When magnified 54—60× grains of beach zones, aeolic as well as grains not visibly abraded can be distinguished. By higher magnification the grain polygenism is visible. Grains where the previous texture is abraded by processes of mechanical weathering (Photo 16) occur most frequently. Another process which also effaces traces of previous processes is the aeolic process. The third group consists of grains with beach abrasion but, differently from the grains in the previously analysed samples, no effect of chemical weathering can be found here. Their texture resembles that of grains from beaches of moderate climates (Photo 17). When 3000—4000× magnified their convex surfaces are uniformly cut with *V*-shaped forms (Photo 18).

The analysis of the whole sample allows to state that forms connected with mechanical weathering of the surface prevail here, while no traces of chemical weathering can be observed. Besides, the type of abrasion of littoral deposits indicates glacial transportation of those grains from the North, i.e. from the Baltic Sea basin.

The analysis of heavy minerals has shown the prevalence of non-resistant minerals. An essential role is played here by amphiboles, garnets and epidotes. Instead, pyroxenes, zircon, tourmaline and rutile occur in small quantities. A visible increase of pyroxene content occurs in horizon 2.2—2.0 m. Irregular, brown rugged grains prevail (45.5%). In the upper series of boulder clay, which seems to occur on a secondary position, the amount of amphibole and epidote decreases while the rounding of amphiboles is decidedly higher.

According to the results of the analyses presented above it may be concluded that series I respresents the initial stage of formation of the karst dip filled with weathering residuum (flint) after removed carbonate deposits. The already existing form was gradually filled with sandy and silty reservoir deposits (series II). The considerable diversity of grain size coefficients as well as an admixture of decomposed organic matter seem to indicate a coastal zone where the transporting force depended on weather conditions and changed with time. This zone is also indicated by the surface texture type of quartz grains (*SEM*) and the high content of smoothened polished grains (*EL*) characteristic in reservoir deposits. Both the high content of grains with surfaces formed by intensive processes of chemical weathering (especially in the upper part of series II), and the almost total absence of aeolically abraded grains prove that the climate was warm and damp. The series comes undoubtedly from the Tertiary, a proof of which is, among others, the almost excllusive content of minerals well resistant to chemical weathering. It may be supposed, by comparison with the mineral composition of deposits filling other karst pits in the neighbourhood, that the filling of the investigated pit began in the Lower Tertiary. Series III is a deposit of an inland reservoir of quiet sedimentation which is evidenced by the relatively small variety of grain size coefficients. The occurrence of grains with subsynchronic aeolic abrasion in the deposit as well as an admixture, among heavy minerals, of non-resistant minerals, alien in relation to the basment and the underlying deposits, shows that aeolic processes might have brought the sediment from a remote source. The considerable thickness of the series (12 m) denotes the successive deepening of the karst form. Adopting the stratigraphical classification (Lindner 1984) the accumulation of series III is connected with the Eopleistocene by comparison with similar deposits (Kosmowska-Ceranowicz 1966).

The further development of the karst pit is documented by clayey flow deposits (series IV). A fine-grained poorly sorted fraction prevails here. SEM investigations have shown a great genetic variety of the deposits. Here appear the first grains with a texture characteristic of mechanical weathering. The great content of ragged brown pyroxenes indicates other sources of alimentation than in the underlying series III. In spite of the slightly higher content of amphiboles, pyroxenes and garnet than in the underlying layers there is no proof of the immediate presence of glacial deposits in this area. The petrographic analysis of the gravel fraction isolated from the flow clay has not shown any detritus of crystalline rocks. There prevail grains of quartz and flint with surfaces considerably changed by weathering processes. The thermoluminescence dating of a sample from 17.8—18.0 m has revealed its age of$\geqslant$900 thousand years. Thus series IV should also be connected with the Eopleistocene.

The successive deepening of the karst pit must have also occurred during the accumulation of the ten-meter thick series of loess-like silts (series V). Most probably this accumulation took place in aquatic environment with a varying supply from outside. A proof of it, among others, is the considerable range of grain size indices. At the same time, the high coefficients of grain abrasion prove that aeolic processes occurred at the time in the neighbourhood of the pit. The content of non-resistant minerals growing towards the top of the series means that the accessibility of the deposits of glacial accumulation to aeolic deflation grew in the same direction. Thermoluminescence dating was done in two samples, from the depth of 15.1 – 15.2 m and of 8.0 m. The age of the lower sample was $\geqslant$830 thousand years, that of the upper one was$\geqslant$670 thousand years. These results mean that the investigated deposit was accumulated during the first transgressions of the continental glacier over Poland.

Before the continental glacier of the Riss glaciation invaded the investigated area, the karst pit was in the course of development. It can be concluded from the depression in the bottom of series VI (boulder clay) visible in the cross-section (Fig. 1). The bottom horizon of the boulder clay (ca 4 m of thickness) filled the existing karst form. The age of the clay, according to thermoluminescence dating of two samples (6.2—6.0 m and 4.5 m of depth) is 247—231 thousand (Odra glaciation). The grain size distribution, the features of the quartz grains abrasion and of their surface texture (SEM), as well as the composition of heavy minerals, confirm the glacial origin of the deposit.

The upper part of series VI has distinct features of a waste sediment occurring on a secondary position. The quantity of amphiboles and epidotes decreases while the rounding degree of amphibole grains is higher. The flow origin of this clay during the last glaciation is confirmed by the results of thermoluminescence dating of two samples (2.2—2.3 m and 1.5—1.6 m of depth). Their age ranged from 117 to 105 thousand years means the early Vistulian (early Würm). As follows from Fig. 1 the Vistulian flow clay in the roof of the profile was occurred on the slope of the valley without a clear connection with the karst form. The presented profile proves that the karst pit described here was developing at least until the Odra glaciation.

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