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Depositional environments of loesses from the Sandomierz section, SE Poland, based on lithological and SEM studies

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The litology of the Sandomierz section deposits have been examined, with SEM analysis performed on 4 quartz grain-size classes. All of the Sandomierz deposits contain predominant quartz grains with signs of aeolian transport. This refers both to morainic till and muds underlying the loess section as well to loesses themselves along with soil complexes. A much smaller, although significant contribution comprises redeposited grains with features of a high energy beach environment. Their content increases up section. During sedimentation of the LMg (younger upper loess) deposits (later part of the Vistulian Glaciation) wind strength was increasing. This is indicated by the upwards increasing content of coarser fractions within the interval, with simultaneously improved sorting, as well as by the increased contribution of garnets and the greater content of zircon and rutile at the top. The increasing contribution of aeolian quartz grains, the considerable content of grains redeposited from a beach environment and the decreasing amount of post-sedimentary features all suggest increased wind speed. Low variability in the shape of the 1–0.5 mm quartz grains from the LMg horizon indicates short transport and a similar nearby source of material. Alimentary areas for this horizon were composed of young Pleistocene muds and tills. A change in depositional conditions is observed at the LMs/LMg boundary (upper part of the Vistulian Glaciation). During deposition of the LMs (younger middle loess) horizon, wind strength decreased, as shown by the content of heavy minerals and the smaller mean grain-size along with the reduced content of aeolized quartz grains.

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INTRODUCTION

The Sandomierz loess section (Fig. 1) is one of the most important in Poland because of the presence of the main stratigraphic sequences of loesses and soils in a relatively complete lithological profile and the occurrence of directly underlying deposits (muds and till). This section has long been investigated by using various methods (Konecka-Betley *et al*., 1987; Konecka-Betley and Czępińska-Kamińska, 1991; Kenig, 1991*a*; Rywocka-Kenig, 1997). It has also provided a good basis for applying a new sedimentological tool — quartz grain microtexture analysis by scanning electron microscope (SEM) in order to help define depositional enviroments.

The stratigraphy of the loess succession is adapted from the Maruszczak scheme (1991).

Examinations of quartz grain surface from aeolian deposits, including loess, have long been conducted in various regions of the world (Smalley, 1966; Smalley and Cabrera, 1970; Warnke, 1971; Vita-Finzi *et al*., 1973; Borsy *et al*., 1984; Derbyshire, 1984; Pye, 1984; Goudie *et al*., 1984, Pye and Tsoar, 1987; Coude-Gaussen and Balescu, 1987; Whalley *et al*., 1987; Mahaney and Andres, 1991; Gaozhong and Deming, 1991).

In Poland, the first results from scanning electron microscopy of silt fractions from the Głogówek and Zwierzyniec sections were published by Cegła *et al*. (1971). Their report was followed by a little-known paper by Pye (1983), dealing with the <0.063 mm quartz grain fraction from the Tyszowce and Komarów Górny sections. At the end of 1980s, comprehensive studies were performed by the present author, using different grain size intervals of sand and silt grades (Kenig, 1987, 1991*a*, 1997).

STUDY METHODS

An assortment of lithological features is a full background referred to by the results of microtexture analysis of quartz grains from loesses. Quartz grains contained within loess have

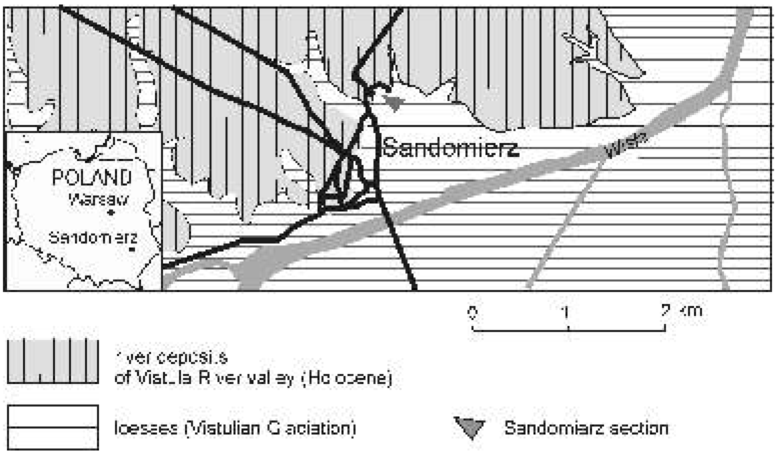

Fig. 1. Location of the Sandomierz section (generalized after Bielecka, 1964)

been subjected to the same environmental processes as those loesses and, in addition, they bear a record of features acquired in their earlier history. The tracing of these mutual relationships forms a basis for eventual interpretation.

Deposits from the Sandomierz section were examined in terms of their lithology, the following investigations being undertaken:

— grain-size analysis and calculations of graphic grain-size parameters according to Folk and Ward (1957) — Mz, σ, S_k and K_G (Kenig, 2006, Fig. 2);

— analysis of heavy minerals from the 0.25–0.1 mm and 0.1–0.05 mm fractions (only the finer fraction was interpreted for loesses);

— analysis of light minerals i.e. mineralogical-petrographical composition of the 1.0–0.5 and 0.5–0.25 mm grain fractions; results presented herein refer to the coarser fraction;

— calcium carbonate content determinations for the >0.1 mm fraction;

— pH measurements.

SEM analyses, enabled the identification of individual morphological patterns recorded on quartz grain surfaces, providing information on their history and that of the sediment.

The SEM investigations of quartz grain surfaces were performed for 4 grain-size classes (1.0–0.5, 0.5–0.25, 0.25–0.1 and 0.1–0.05 mm). A detailed description of the method used was earlier presented (Kenig, 2006). The classification of quartz grain morphology applied takes account of a range of diagnostic features which developed during grain transport, at a site of temporary or final deposition and in a source area (Rywocka-Kenig, 1997; Kenig, 2006). The classification also refers to the literature (Krinsley and Doornkamp, 1973; Le Ribault, 1977).

RESEARCH RESULTS

LITHOLOGICAL FEATURES OF THE SANDOMIERZ SECTION DEPOSITS

The lowest part of the section (Fig. 2) is composed of till (sample 12) representing the Odra Glaciation. The till shows a heterogenous grain-size distribution. The modal value is situated within the fine silt fraction. There is a considerable content of clay and a low content of sand grade material. The Mz value is 6.35 phi, being the highest within the entire section, representing the smallest value of the mean grain-size at nearly the worst sorting (σ = 1.64, Fig. 3), characteristic of a moderately dynamic environment. The negative skewness indicates a greater content of coarser fraction as compared to the fraction of maximum frequency.

The dominant element of the 0.1–0.05 mm fraction is the garnet-zircon association (33% each) with a distinct contribution of rutile (10.6%) and tourmaline (8.4%). It is characteristic that amphiboles are rare in this fraction. In the 0.25–0.1 mm fraction, the amount of amphiboles is higher, reaching 16%. This trend is the result of the fraction size and is also observed in tills of other regions (Kenig, 1991*b*). The amphibole grains are fresh with no signs of weathering (Fig. 4A). The dominant components are quartz (72%), feldspars and crystalline rocks (16%), and Palaeozoic limestones (12%) (Fig. 5). The tills contain merely 5% of calcium carbonate and show alkaline pH values which differentiate them from the overlying deposits.

The overlying muds (samples 9–11), locally of solifluction-delluvial origin, have been assigned to the Wartanian stage. They are relatively uniform in terms of their granulometry. The Mz parameter shows only a slight trend of upwards increasing mean grain size. As the grain-size increases, the sorting becomes poorer (Fig. 3). This is typical of a variable energy environment and increasing flow competence. The grain-size distribution curves are mesokurtic and positively skewed (Kenig, 2006) i.e. shifted towards finer fractions in relation to the content of fraction of maximum frequency. Mineralogically, the deposits represent a garnet–zircon–rutile association with tourmaline, so they show strong mineralogical affinity to the underlying till which may have been the source layer. Most of the mineral a habits are typical (Fig. 4B). The mineralogical-petrographical composition shows a considerable contribution of clay-calcareous aggregates and ferruginous concretions (Fig. 5), a typical feature of a still basinal environment. This sediment is low alkaline and low carbonate, with a tendency to an increasing $CaCO_3$ content towards the top where infiltration of carbonates has occurred.

The granulometry of the brown interglacial palaeosol (LSg, samples C) shows a modal value within the basic fraction (0.05–0.01 mm) corresponding to that of the loesses in this section. The especially high sand grade content indicates a local accumulation of insoluble aggregates. This is consistent with the mineralogical-petrographical composition with dominant limestones and clay-calcareous aggregates (Fig. 5). That is why the σ parameter indicates very poor sorting of the deposit. The grain-size distribution curve is leptokurtic and negatively skewed i.e. shifted towards the coarser fractions. The extreme position of point C in Figure 3 can be explained by varied dynamics of sedimentation and, perhaps primarily, by post-depositional processes resulting in winnowing of the finer fraction and the formation of insoluble calcareous aggregates. The

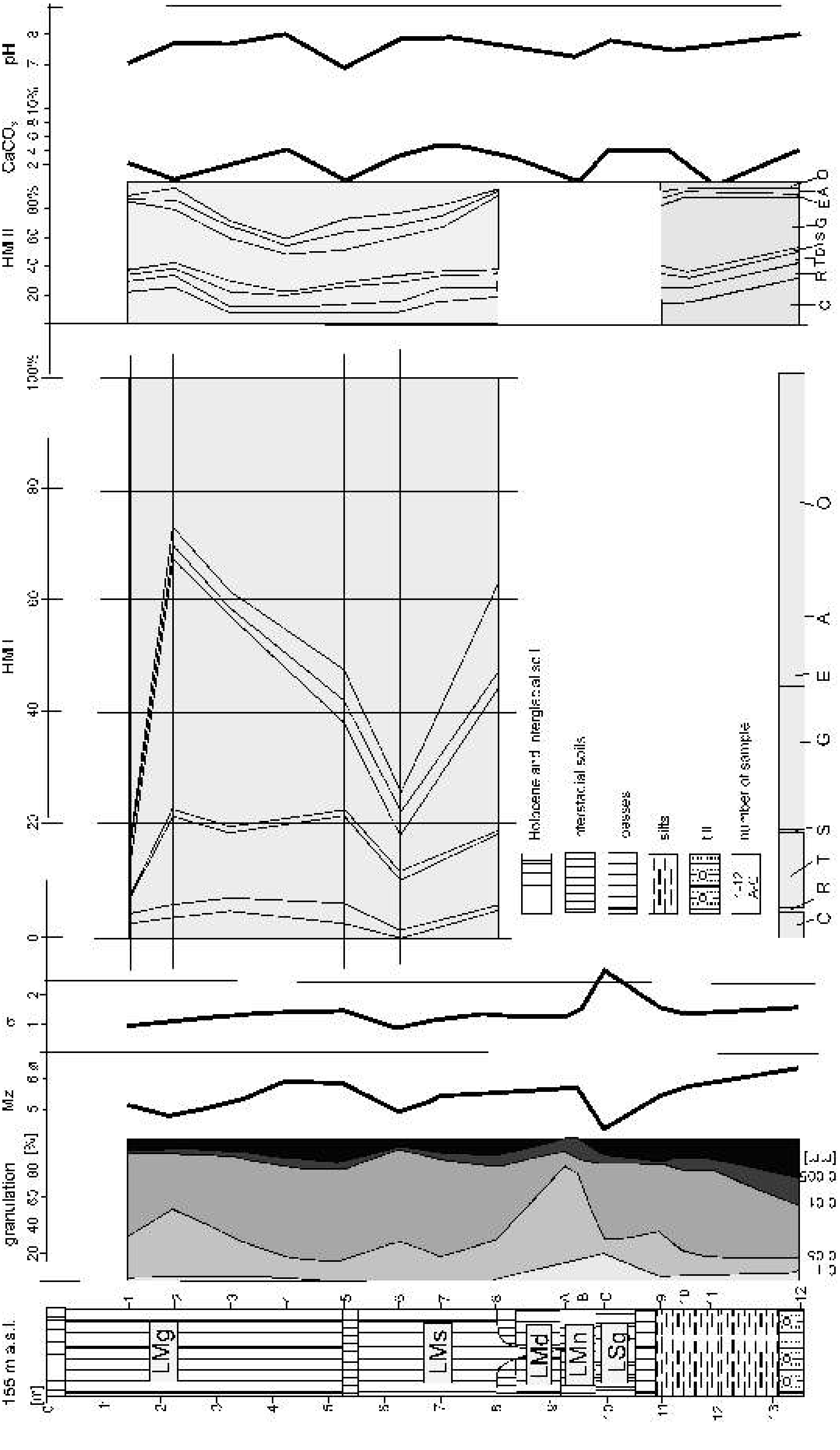

Fig. 2. Lithological features of the Sandomierz section deposits

Grain-size parameters: Mz — mean grain size, σ — sorting coefficient, HM I — heavy minerals 0.25–0.1 mm, HM II — heavy minerals 0.1–0.05 mm (C — zircon, R — rutile, T — tourmaline, D+S — disthene, staurolite, G — garnet, E — epidote, A — amphibole, O — others: mainly biotite, chlorite, staurolite), $CaCO_3$ — contents of carbonates, LSg — older upper loess, (Wartanian stage), LMn — younger lowest loess, LMd — younger lower loess, LMs — younger middle loess, LMg — younger upper loess (Vistulian Glaciation) (after Maruszczak, 1991)

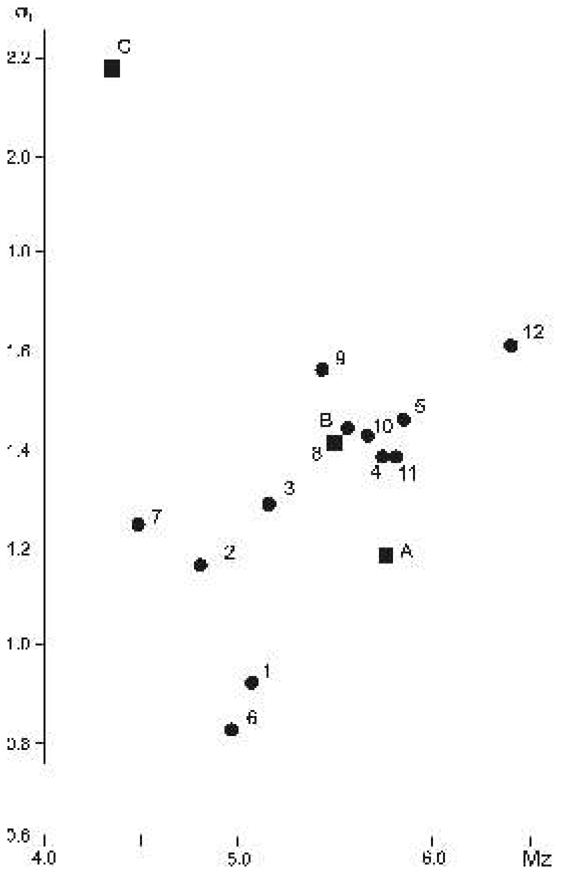

Fig. 3. The Mz/σ relationship

1–12, A–C — sample numbers

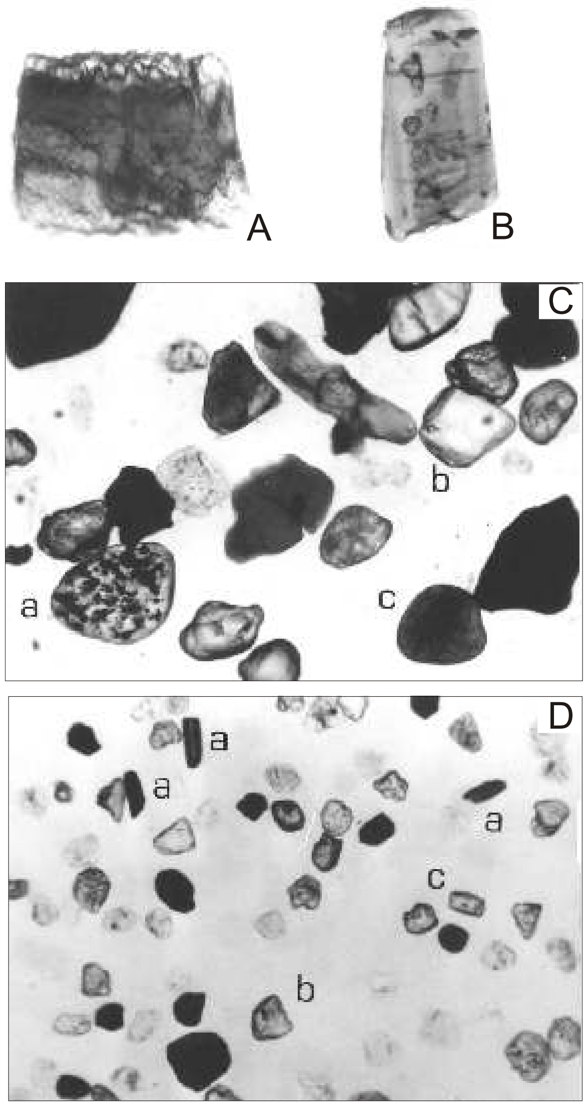

Fig. 4. Non-opaque minerals 0.25–0.1 mm

A — amphibole, sample 12; **B** — tourmaline with inclusions, sample 9; **C** — samples 9 (a — andalusite with inclusions, b — topaz, c — tourmaline); **D** — sample 1 (a — rutile, b — garnet, c — zircon)

calcium carbonate content of the deposits is 4.2%, pH is weakly alkaline.

In the LMn horizon (samples A and B) of the chernozem soil the mean grain-size decreases and the sorting becomes better, though remaining generally poor. This suggests a moderate-energy environment. It is likely that the fining trend is also the result of the presence of organic matter. The grain-size distribution curves are mesokurtic (moderately steep) and close to symmetrical (Kenig, 2006). The mineralogical-petrographic composition of the sand fraction shows qualitative variations between the C part of the section and the A and B parts, especially as regards the contents of ferruginous concretions and clay-calcareous aggregates. These components are very frequent in the chernozem layer, but they are absent in the brown horizon where calcareous aggregates, locally of a pseudomorph type, are predominant (Fig. 5). The deposits from samples A and B are non-calcareous with pH decreasing to neutral.

The LMs horizon (samples 6–8) is represented by a coarsing-upward loess. The Mz decreases from 5.51 to 4.97 phi and the sorting becomes better upwards. The grain-size characteristics of the LMs loesses are similar to those of the Nałęczów Plateau loesses (Harasimiuk, 1987). The content of opaques in the LMs is <30%. Garnet reaches the highest contribution and its content decreases upwards from 51.0 to 27.0%. Garnet occurs in association with tourmaline and zircon (8.0–16.0%). The sand fraction consists largely of clay-calcareous pseudomorph-type concretions and single quartz grains (Fig. 5). The relatively low calcium carbonate content (4–5%), dominant frequency of clay-calcareous concretions and lack of ferrous precipitates indicate a humid climate during deposition of the LMs horizon. The alkaline pH remains constant.

Lithologically, the LMg horizon (samples 1–5) is a silt-grade deposit (loess) with the modal value situated within the fine silt fraction. The contribution of coarse grains in this horizon increases upwards, as shown by the decreasing Mz parameter value from 5.95 at the base to 5.01 phi at the top. As deposition proceeded, the sorting consequently became better (from poor to moderate). This is clearly visible in Figure 3 (σ ranging from 1.45 to 0.95). The grain-size distribution curves (Sk) are positively skewed, mesokurtic (KG up to 1.3) and steep. In terms of grain-size characteristics, the loesses show

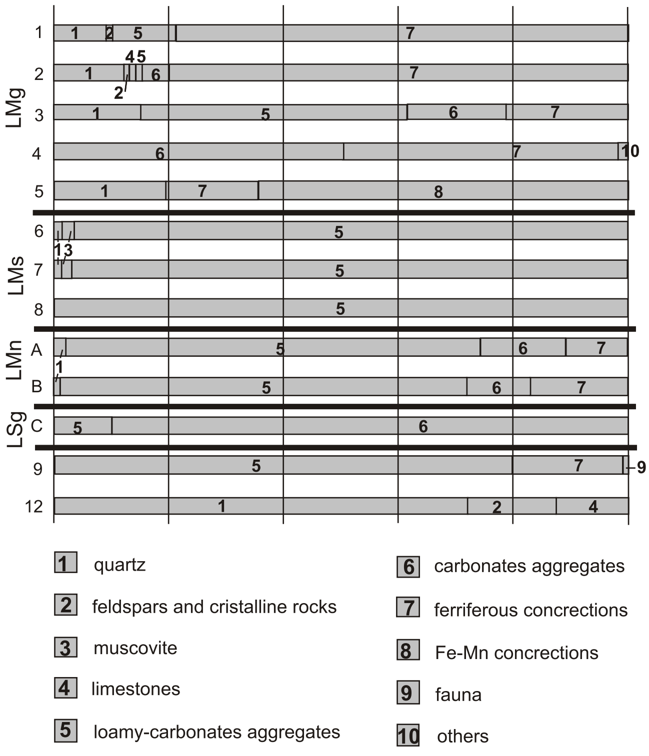

Fig. 5. Mineral and petrographical composition 1.0–0.5 mm of the Sandomierz section deposits

For other explanations see Figure 3

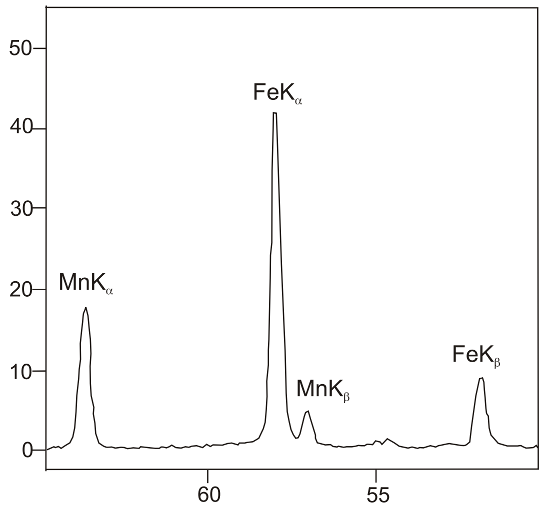

Fig. 6. Part of X-ray spectrum with Fe and Mn peaks, loess concretion from the Obrowiec section, sample 5

similarities to those of the LMg horizon from the eastern part of the Nałęczów Plateau (Harasimiuk, 1987) and the Horodło Grzęda Ridge (Dolecki, 1987).

The heavy mineral fraction is characterized by the upwards-increasing contribution of garnets from 22.3 to 45.2%, suggesting increasing wind strength, as confirmed also by the upwards-improving sorting. A record of lower transport energy at the bottom of the loess succession is also supported by the mineral composition of the 0.25–0.1 mm fraction in which a garnet content decrease and a chlorite content increase are observed. The tourmaline and zircon contents are irregularly variable. Heavy mineral grains from this horizon show no signs of destruction (Fig. 4C, D), hence it can be inferred that they were transported over a short distance and that their depositional environment was not chemically aggressive.

The dominant component of the sand fraction from the top part of the LMg interval comprises ferruginous concretions (Fig. 5). Clay-calcareous aggregates showing features of pseudomorphs after plant remains also occur there, but in smaller amounts. They have a characteristic tube-like shape, locally with bubble-like widening. Beneath a layer of decalcified sediments (3.0 m) there is a distinct increase in the amount of clay-calcareous aggregates (tubular) at the expense of brown Fe-Mn aggregates. X-ray analysis has shown a considerably higher contribution of amorphous Fe compounds than Mn compounds in a similar concretion taken from a loess sample of the Obrowiec section in the Lublin Upland (Fig. 6). The quartz content in this fraction is low and decreases up the section proportionally to the increase of other components. The increasing contribution of quartz in the finer fractions is a well-known feature related to fraction size. Concentrations of carbonates, observed in the upper portion of the section, are syngenetic to the deposit and form encrustations on the pseudomorph walls. The lower parts of the LMg interval also contain epigenetic concretions (so-called loess dolls). The pH is alkaline and only at the top of the horizon does the alkalinity decrease to neutral.

MICROTEXTURAL FEATURES OF QUARTZ GRAINS IN THE SANDOMIERZ SECTION

The till at the base of the Sandomierz section contains chiefly rounded (Fig. 7A) or subrounded (Fig. 7B), matt-frosted quartz grains of aeolian appearance, and rounded, glossy grains showing beach environment features (Fig. 7C). Subsequent chemical and hydrocryogenic processes are superimposed on all the features, resulting in grain corrosion (Fig. 7D).

Same of the grains bear signs of aeolian reworking that is especially typical of the Middle Polish Glaciation tills in central Poland (Goździk and Mycielska-Dowgiałło, 1988; Kenig, 1988). Young glacial deposits typically show few mechanical features, and their dominant features are diagenetic, e.g. in the moraines of Svalbard (Kenig, 1980).

The 0.1–0.05 mm fraction quartz grains are different in shape. Grains from the till are predominantly angular and mostly irregular in shape (Fig. 7E). Observations at higher magnifications enable recognition of irregular grains with variably rounded corners (Fig. 7F). Most of the grains show smooth surfaces with low relief, often encrusted in the form of flakes or minute etchings. Considering individual surface types, in particular the convex ones, there is no doubt that the surfaces show no fresh features of mechanical origin. The 0.1–0.05 mm fraction grains display records of chiefly chemical origin features rather than features caused by aerial or aqueous transport (this fraction is no longer capable of further rounding, being transported in suspension in air or water). These features developed within the source sediment in an arid climate. The grains were probably

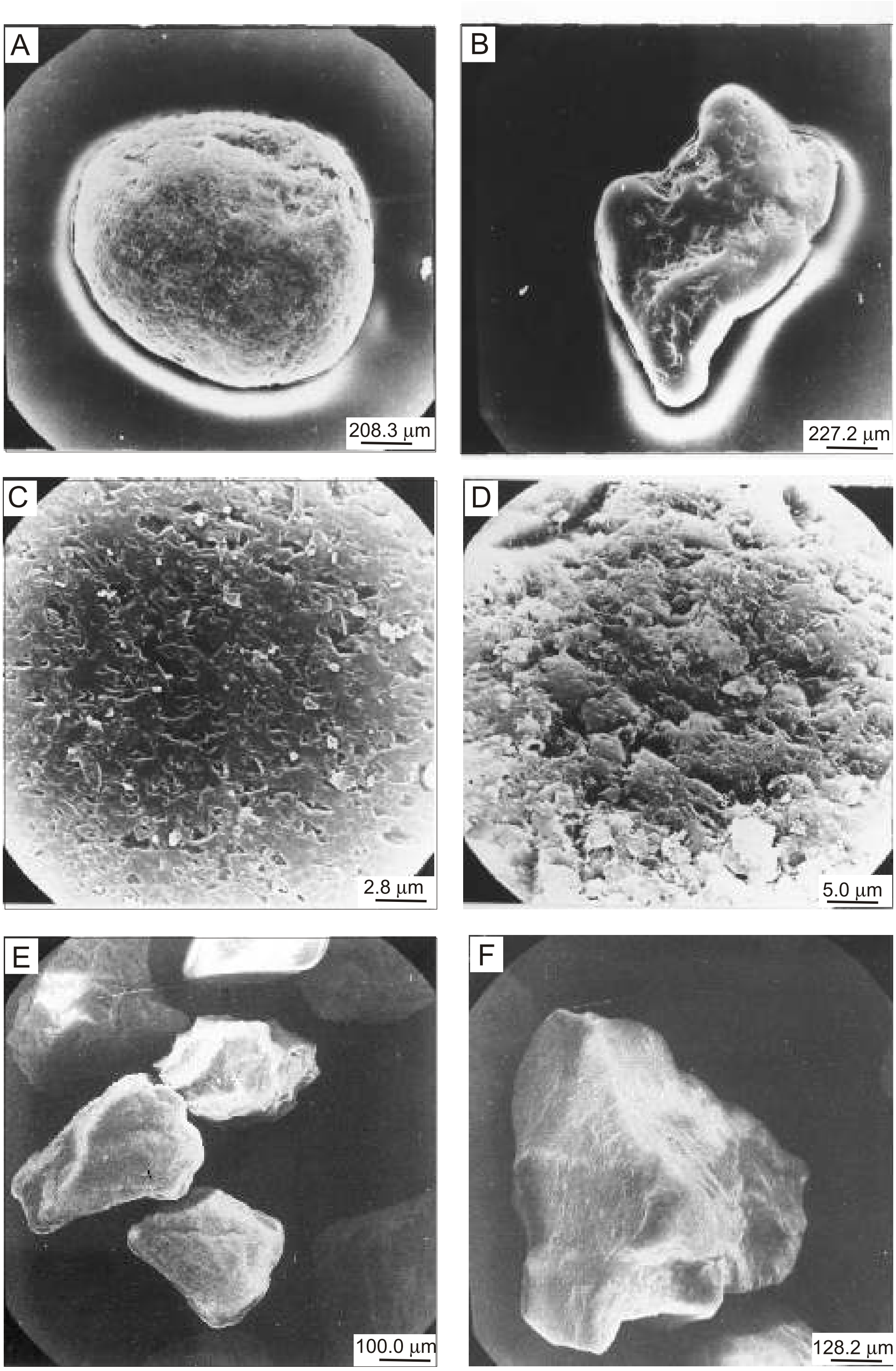

Fig. 7. Quartz grains from till

A — rounded and frosted grain; **B** — partly rounded, polished grain of irregular shape; **C** — v-shaped coastal pits deepened with chemical etching; **D** — abrasion v-shaped pits on abraded surface; **E** — general view of angular grains, fraction 0.1–0.05 mm; **F** — angular grain

blown in by the wind and incorporated into the till. As such, they would be a secondary deposit here.

The mud succession (samples 9–11) contains numerous rounded, frosted quartz grains with aeolian features (Fig. 8A). Their surfaces display aeolian pitting with a number of tiny incisions (Fig. 8B). In the middle part of the deposits there are sporadic grains showing features inherited from a high energy shoreline environment (Fig. 8E). The upper part of this interval also contains angular grains with fresh conchoidal fractures (Fig. 8C, D). Just after deposition, signs of final stages of surface destruction in the form of silica dissolution or precipitation (Fig. 8F) appeared on all the grains. Precipitation of secondary minerals and calcite also took place. Only one main

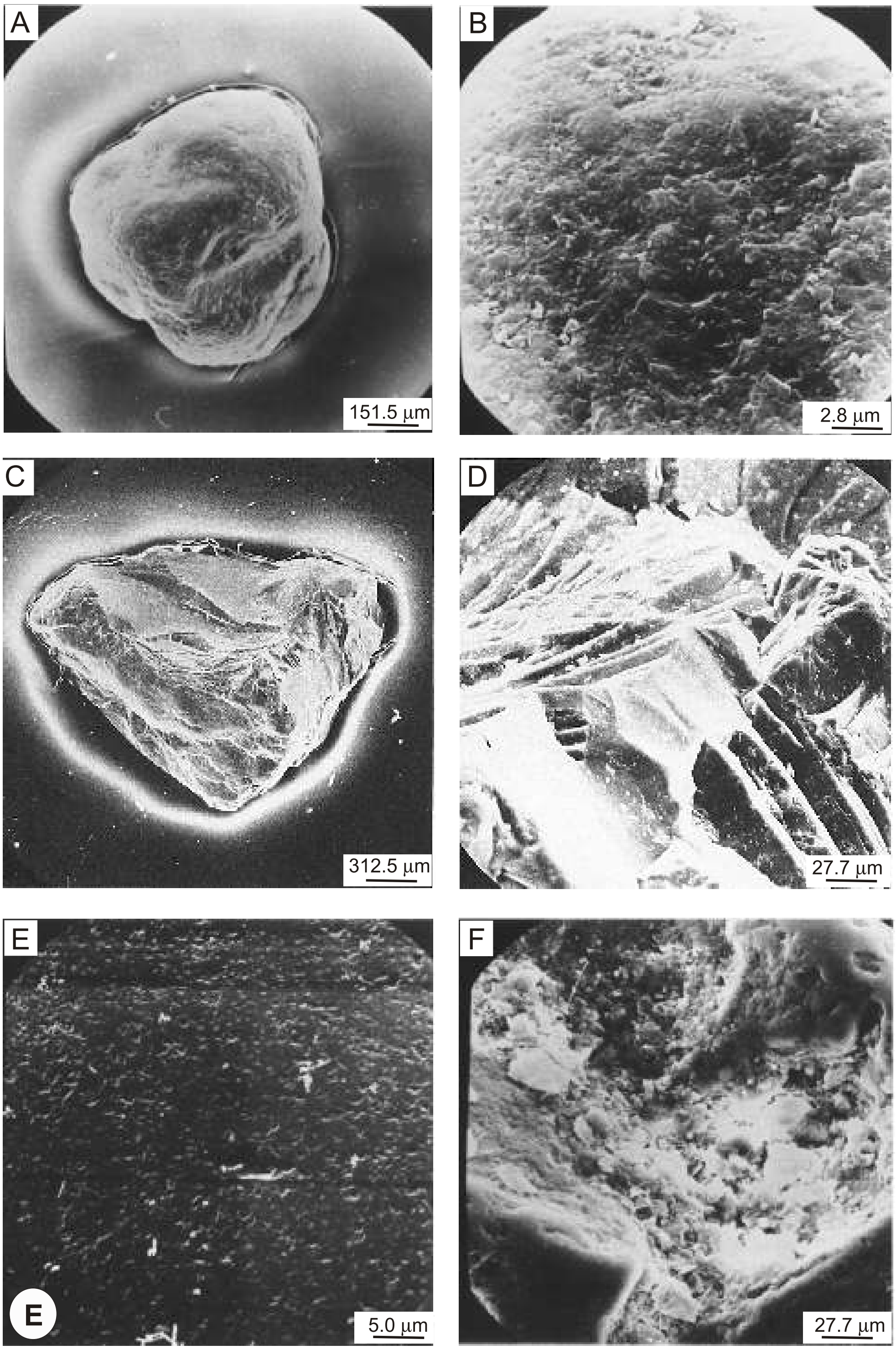

Fig. 8. Quartz grains from muds

A — rounded and frosted grain; **B** — aeolian pitting of a frosted grain with numerous fine pits; **C** — angular and polished grain; **D** — fresh conchoidal fractures on the grain from Figure 8B; **E** — fragment of polished grain with preserved v-shaped pits from a coastal environment; **F** — destruction in a cavern resulting in development of siliceous grains

source of grains is manifested here: aeolian or generally from long aerial transport.

The presence of grains displaying beach sediment features in these deposits (Fig. 8E) indicates the possibility that they could be derived from older Pleistocene deposits containing such material. At the top part of the mud succession, there is also a record of an additional, closer source area supplying fresh material containing angular quartz grains, possibly of glaciofluvial type (Fig. 8C).

Most quartz grains from the lower part of the soil succession (sample C) are subrounded, frequently irregular, and they usually have matt-frosted surfaces. There are also some broken

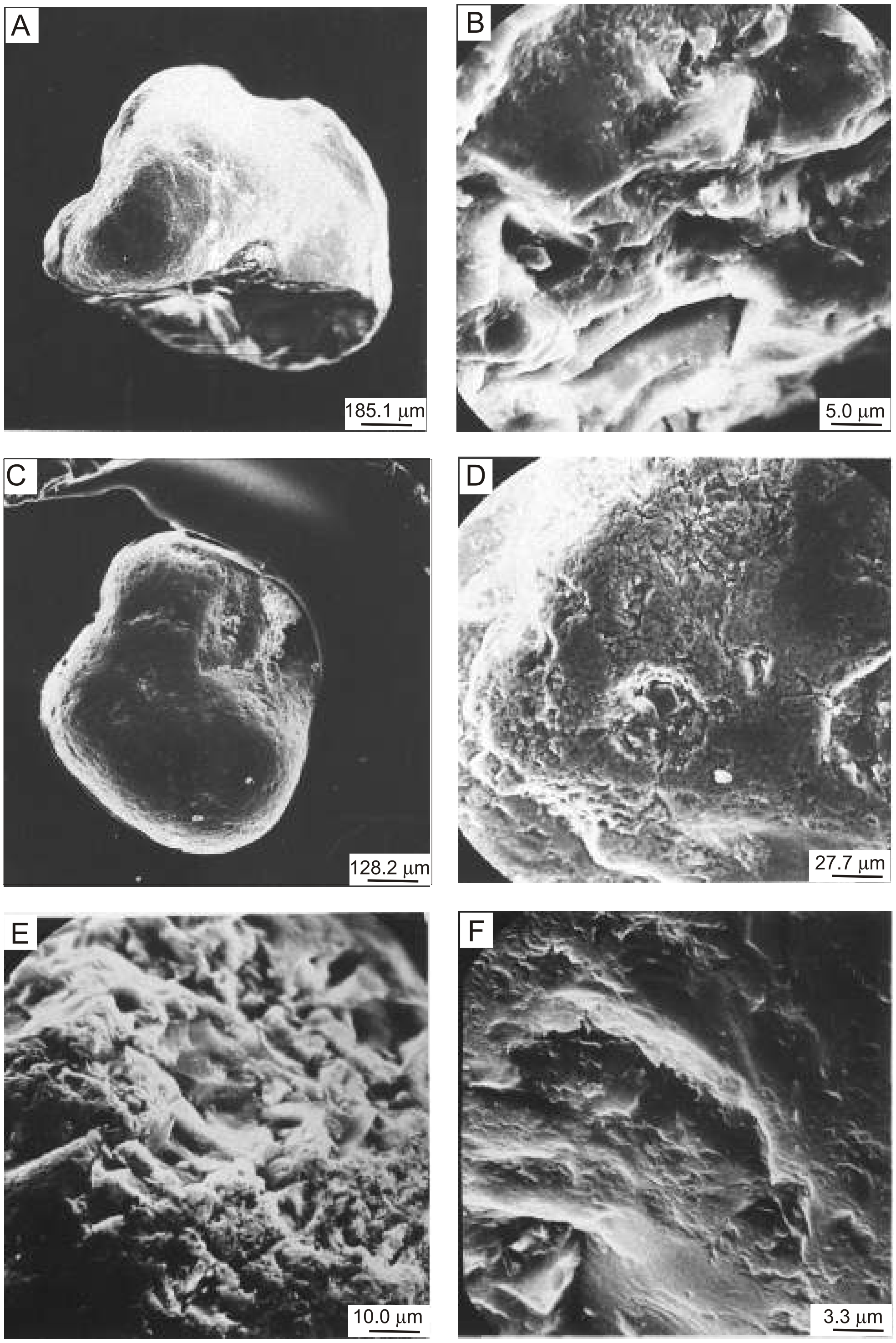

Fig. 9. Quartz grains from oil succession

A — fractured grain; **B** — abrasion v-shaped pits of varying intensity on aeolian-type surface; **C** — rounded grain, frosted with small fractures; **D** — aeolian-type surfaces; **E** — numerous fresh abrasion v-shaped pits on aeolian-type surface; **F** — ancient conchoidal fractures with traces of abrasion v-shaped and dissolution pits

grains (Fig. 9A). Aeolian processes are not strongly accentuated on the grain surfaces. However, there are variations in the intensity of abrasive features recorded as v-shaped incisions (Fig. 9B). Locally, the grain surfaces also have lichen-like patterns and oriented dissolution traces. Evidence cryogenic and chemical processes that resulted in rounding of grains was also observed. During accumulation of the loess followed by development of a brown soil, climatic conditions were more severe with more distinctly marked hydrocryogenic processes (freshly broken grains).

The upper part of the chernozem soil (samples A and B) contains subrounded quartz grains, locally with remarkable

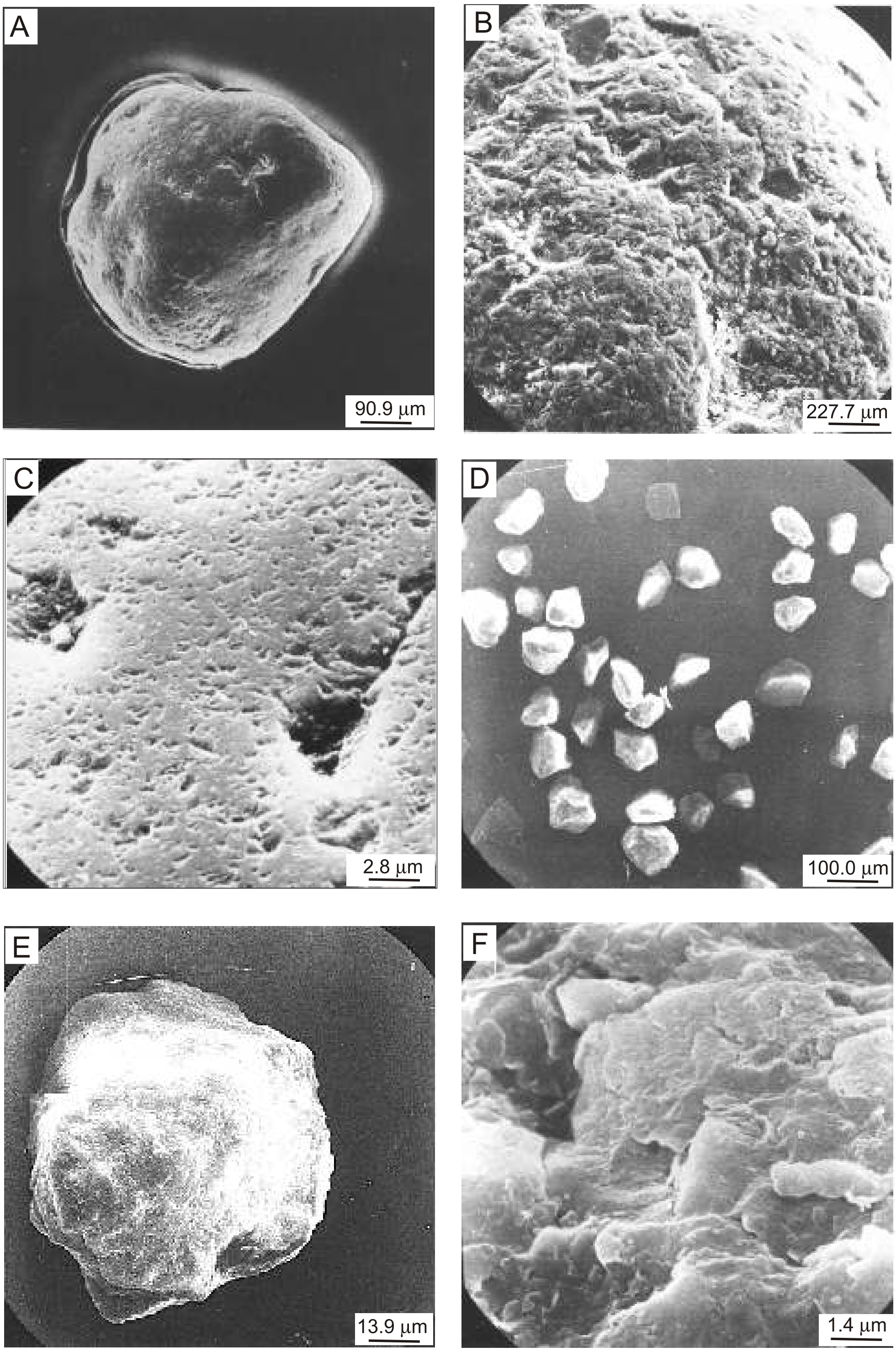

Fig. 10. Quartz grains from LMs

A — rounded and frosted grain; **B** — aeolian pitting; **C** — fragment of surface with v-shaped coastal incisions; **D** — sharp edged grains of the fraction 0.1–0.05 mm; **E** — grain of irregular shape encrusted with amorphous silica; **F** — exfoliated encrusted surface

scars (Fig. 9C) and the presence of infrequent angular grains especially in the lower portion of the soil. Well-rounded grains exhibit aeolian-type destroyed “worn” surfaces imparting a frosted appearance (Fig. 9D). Younger minute v-shaped impact indentations are observed on the surfaces (Fig. 9E). Aeolized grains with signs of later hydrocryogenic processes are predominant in this horizon. The amount of microtextural features of chemical origin decreases towards the younger portion of the soil. Rare angular grains show the presence of conchoidal fractures. Dissolution traces become visible on some broken grain surfaces (Fig. 9F).

In the LMs horizon (samples 6–8), rounded and frosted-surface grains were observed (Fig. 10A, B). However, it was also possible to recognize the morphology inherited from the

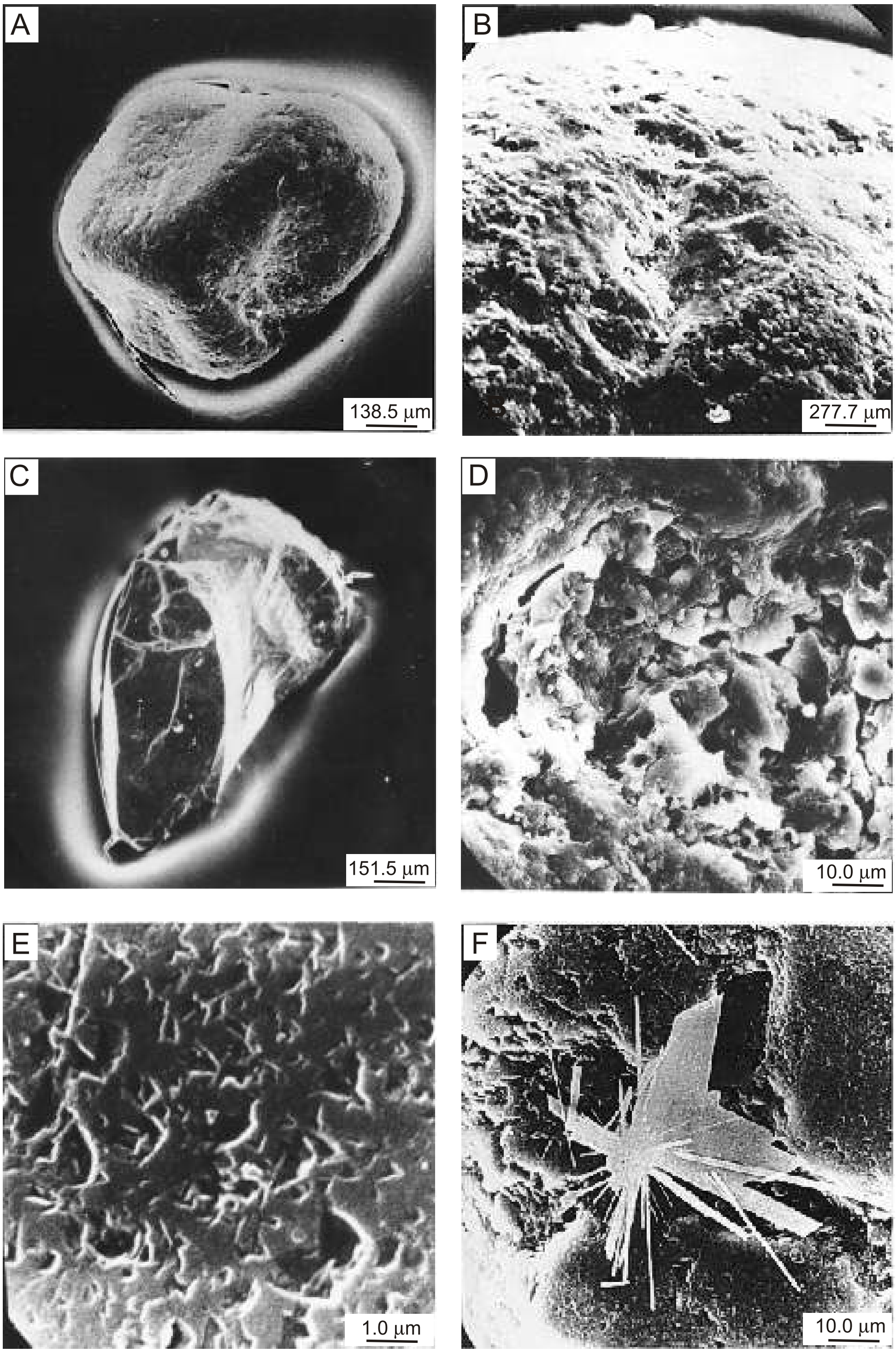

Fig. 11. Quartz grains from LMg

A — rounded and frosted grain; **B** — aeolian pitting; **C** — angular grain; **D** — cavern filled with exfoliation of silica; **E** — v-shaped incisions of coastal environment; **F** — secondary, rosette-type crystal of gypsum

previous high energy beach environment, represented by v-shaped incisions (Fig. 10C). The intensity of cryohydrogenic processes was stronger in this horizon than in the younger one. The transport of grains was consequently aeolian and only one source of material is marked.

Quartz grains of the finer fraction are most frequently angular and irregular in shape (Fig. 10D). Grains with smoother corners and edges were observed at high magnifications (Fig. 10E). The grains are covered by an amorphous silica layer. Locally, a flaked surface with cracks within the layer was observed (Fig. 10F).

In the LMg horizon (samples 1–5), rounded and frosted-surface grains are predominant (Fig. 11A). They are characterized by a pitted aeolian surface (Fig. 11B). Rare angular grains

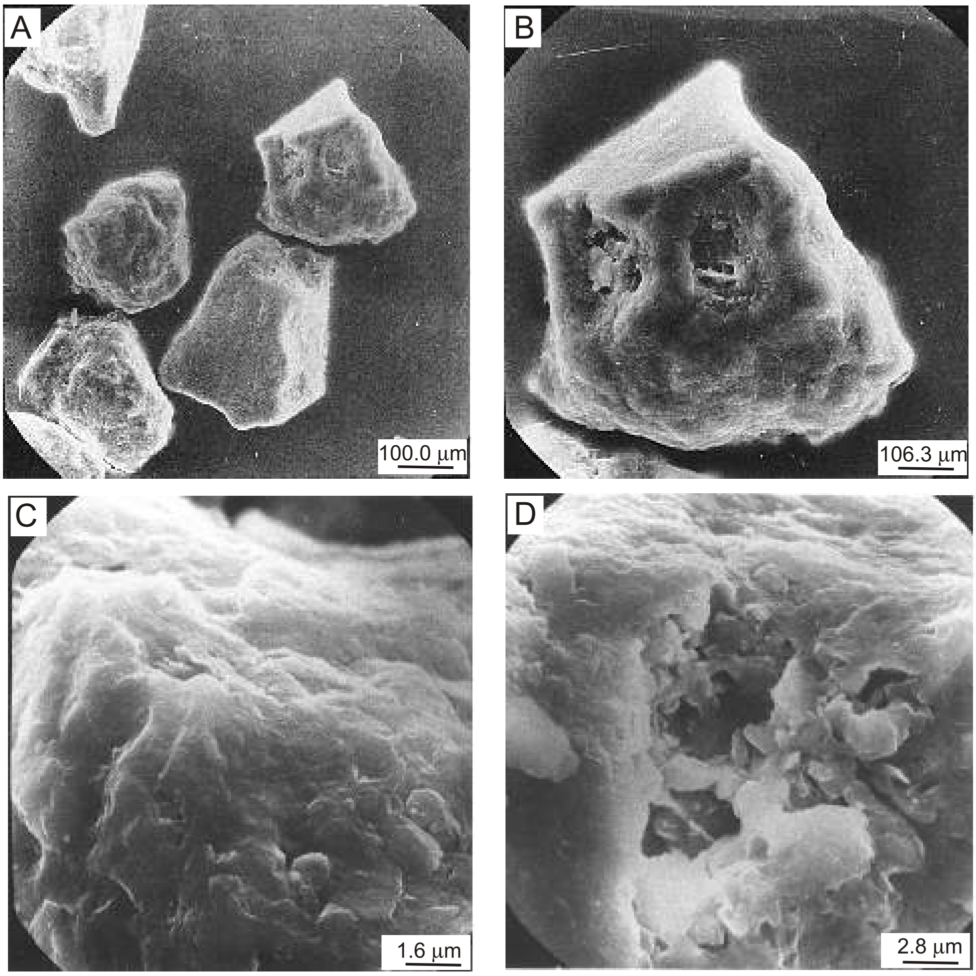

Fig. 12. 0.1–0.05 mm quartz grains from LMg

A — sharp-edged grains; **B** — grain with edges smoothed by encrustation of amorphous silica; **C** — fine exfoliation of encrusted surface; **D** — triangular shape of chemical etching masked with younger siliceous exfoliation

were observed in sample 2 only. Their habit is due to both fresh large-scale conchoidal fractures (Fig. 11C) and different micro-cracks. The grains were subsequently affected by chemical processes, silica dissolution and precipitation of silica encrustations. This resulted in the formation of flake and granular disintegration microtexture (Fig. 11D) and then in the detachment of silica silt from grain surfaces. The amount of glossy grains increases upwards. Their surface relief is inherited from a high energy beach environment (Fig. 11E). This horizon indicates conditions favouring development of secondary gypsum minerals in the form of small rosettes (Fig. 11F).

The 0.1–0.05 mm fraction of the LMg horizon contains very angular quartz grains (Fig. 12A). However, the corners and edges of the grains observed at higher magnifications are more rounded. Their angularity is blurred by a variably developed amorphous silica encrusting (Fig. 12B). Most of the grains have smooth convex areas even when observed at higher magnifications. Small flakes are visible on some grains (Fig. 12C). The silica layer was then subjected to corrosion, being dissolved and chemically etched to form a local triangular figure of chemical etchings. The subsequent processes forming numerous silica flakes led to a blurring of the original triangular shape (Fig. 12D). Mechanical features of fractures and indentations on the grain surfaces are rare.

Generally, the 0.1–0.05 mm fraction grains have smooth surfaces modelled by chemical processes, most probably within the source area. The observed shapes and surface textures of the quartz grains show similarities to those occurring in the LMs horizon, as shown by the presence of encrustiations formed in the source area under arid climate conditions.

DISCUSSION

Quartz grains with signs of aeolian transport are predominant in all the Sandomierz section deposits. This refers to the underlying till (Fig. 7A, D), mud deposits immediately underlying the loesses (Fig. 8A), and to the loesses themselves (Figs. 10A, B and 11A, B). The contribution of grains showing features of a high energy beach environment is significantly smaller (Figs. 7B, 8E and 11E). The amount of these grains increases upwards reaching the highest value in sample 1 (Fig. 13).

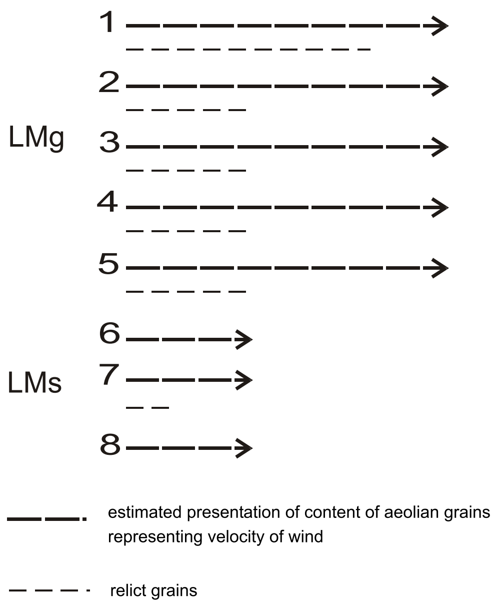

Fig. 13. Schematic diagram of wind strength in the LMs and LMg horizons of the Sandomierz section (after Kenig, 1997)

1–8 sample numbers

The intensity of cryohydrogenic processes was higher in the LMs horizon, as shown by the presence of numerous forms of granular and flake disintegration, that developed in cavities on quartz grain surfaces (Fig. 13). However, intense post-sedimentary processes did not destroy the entire original morphology represented on the grains from the middle part of the LMs horizon as v-shaped incisions inherited from the previous beach environment (Fig. 10C). Quartz grains from this horizon also show secondary calcite precipitations indicating that the deposits were saturated with respect to solutions rich in soluble carbonates (Rywocka-Kenig, 1997).

The LMg horizon quartz grains show fairly uniform microtexture characteristics (Fig. 14). An overall increase in the amount of grains with aeolian features was observed here (Fig. 11A, B). The contribution of redeposited beach grains (Fig. 11E) is considerably greater than in the underlying loesses. All the grain types display a distinct record of frost activity, enhanced by later processes of chemical dissolution (Fig. 11D). The processes, however, were less intense than in the LMs horizon. The upper part of the LMg horizon contains a larger amount of angular grains and beach environment grains (Fig. 13). This indicates short transport. However, on the other hand, the overall increase in the amount of aeolian grains in the LMg horizon suggests stronger winds at that time (Fig. 14).

Low variation in the 1.0–0.5 mm fraction grains of the LMg horizon indicates short transport and a similar source of material. A change is observed only in the upper, youngest portion of the horizon, where the greater contribution of angular grains suggests either an additional close source of deflation or a change in wind direction. Simultaneously, the increased contribution of rounded glossy grains originating from a high energy beach environment, observed towards the top of the horizon, reaching a maximum in sample 1 (Fig. 13), also indicates that they were transported over a short distance due to a change in wind strength or/and direction.

The latest investigations of anisotropy of magnetic susceptibility (AMS) more thoroughly show the westerly and south-westerly wind palaeocurrents during sedimentation of the youngest loess in Poland. However, the presence of many different local sources of aeolian material cannot be precluded (Nawrocki *et al*., 2006). Similarly, Chlebowski *et al*. (2003) see the possibility of nearby source areas for the loesses, supplying material from various directions and deposits.

The increased dynamics of the transporting force (wind) in the LMg horizon of the Sandomierz section is also indicated by the constant upwards increase in garnet (22.3–45.2%) as well as by the enrichment in zircon and rutile at the top (Fig. 2, HM II). Additional evidence is the increase in coarser fraction content and better sorting of the sediments during accumulation.

An increase in the contribution of quartz grains and redeposited grains with beach environment features, and a decrease in the amount of post-sedimentary corrosion features occur at that time.

In the 1.0–0.5, 0.5–0.25 and 1.25–0.1 mm fractions of the LMg horizon, there is close analogy in the quartz grain shape and surface microtexture. Grains with a pitted aeolian surface are dominant here. Grains showing features of a beach environment and angular grains are also present. All of these grains were subsequently modified by cryogenic chemical and physical processes in a humid climate. There was also an arid warm climate event that allowed precipitation of well-developed gypsum crystals.

Quartz grains with a relict microtexture inherited from a beach environment, indicating redeposition from nearby source areas, are present in many loess sections of various regions of Poland. They are well known from the Odonów section (Kraków region, Rywocka-Kenig, 1997), the Nieledew and Obrowiec sections (Lublin region, Kenig, 1993; Rywocka-Kenig, 1997) and the Orzechowce section (Carpathian foreland, Kenig, 1997; Rywocka-Kenig, 1997).

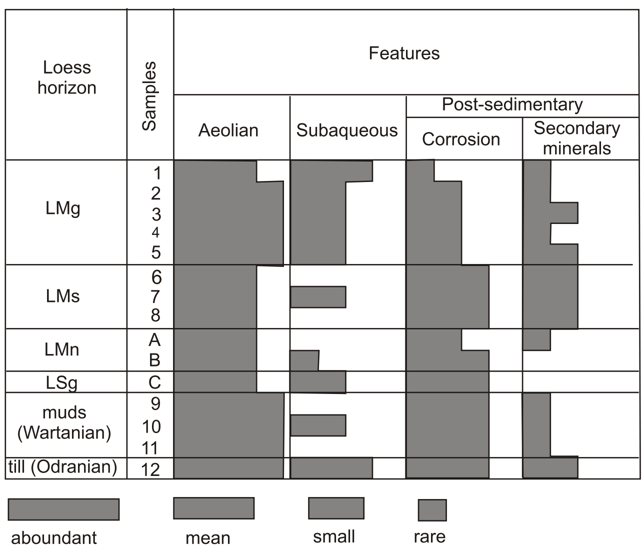

Fig. 14. Estimated contribution of major microtextural features of quartz grains from the Sandomierz section (Kenig, 2006)

Quartz grains from the loesses of Southern Poland show remarkable differences in the percentage contribution of grains displaying various shapes and microtextures, as compared to the loesses of Slovakia (Nove Mesto and Vyskovce) and the Hungarian Lowlands (Paks, Basaharc) (Rywocka-Kenig, 1997). Similar features of quartz grains from the Czech Republic area (rounded, matt-frosted, angular) were reported by Růžičková *et al*. (2001). They point out that the most abundant mechanical features due to aeolian transport are recorded on the 0.5–2.5 mm quartz grains. Angular grains of the finer fraction were carried in suspension.

The effects of chemical processes on quartz grains originating from soil horizons are visible in both the Sandomierz section and in other sections (Kenig, 1993). Similar features of chemical etching are also reported from soil successions of Russian loesses by Timireva and Velichko (2006). Those authors observed an increased contribution of chemical weathering features on quartz grains from interglacial soils in relation to those from loess horizons. It is worth adding that additional information on the changes in humidity conditions within soil horizons can be provided by thorough geochemical investigations of Mn-Fe concretions (Mahaney, 2002).

CONCLUSIONS

The lithological properties of loess horizons along with SEM observations enable characterisation of depositional environments.

The most significant differences within microtextural features of quartz grains from the Sandomierz section were observed at the LMs/LMg boundary. LMg contains a larger amount of aeolized grains, a smaller number of grains with post-sedimentary features and a considerable contribution of grains redeposited from a beach environment. These are related to the higher contribution of coarser fractions towards the top, improving sorting, and increasing content of garnets. These features suggest an increase in wind strength during deposition of the LMg horizon.

General conclusions from the lithological and sedimentological changes are consistent with the relationships illustrated in the graph of Pye (1987, fig. 9.16). This shows that the increase in mean grain size in the LMg horizon of the Sandomierz section coincides with a higher accumulation rate of the loesses, with a simultaneous decrease in the contribution of the clay fraction and a variable carbonates content. Therefore, it can be inferred that there was relatively low rainfall and poor vegetation cover over the loess accumulation areas.

It has been shown that both the loesses and the underlying deposits from the Sandomierz section (and also from other loess sections of Poland) contain quartz grains originating from a high energy beach environment. This is a regional feature related to the lithological structure of nearby deflation areas. Such grains are absent from other loess sections of Europe and elsewhere. The source area for the loesses was composed of Pleistocene deposits of different ages, which contained the quartz grains originating from older sediments. This could be neither Neogene marine deposits nor preglacial sediments of the Sandomierz Basin because they are represented by facies containing poorly rounded quartz sands (Mycielska-Dowgiałło, 1978).

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