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WEISSLIEGENDES SANDSTONES: A TRANSITION FROM FLUVIAL-AEOLIAN TO SHALLOW-MARINE SEDIMENTATION (LOWER PERMIAN OF THE FORE-SUDETIC MONOCLINE)

1. SEDIMENTARY STRUCTURES AND TEXTURAL DIFFERENTIATION

(Pls. I—III and 7 Figs.)

Przejście od sedymentacji kontynentalnej do płytkomorskiej w obrębie białego spągowca (dolny perm monokliny przedsudeckiej)

1. Struktury sedymentacyjne i zróżnicowanie teksturalne
(tabl. I—III i 7 fig.)

Abstract. In the Permian clastics, the following major environmental associations have been distinguished in ascending order: (I) fluvial, (II) aeolian and (III) shallow-marine. Based on structural-textural data, the Weissliegendes sandstones are interpreted here as aeolian dune deposits (possibly coastal dunes). The uppermost part of the Weissliegendes has been redeposited in shallow-marine waters during the Zechstein transgression. The Weissliegendes sandstones are of complex origin. They represent a transition from the continental Rotliegendes to marine Zechstein deposits.

INTRODUCTION

The Weissliegendes sandstones, underlying copper-bearing shales (Kupferschiefer) and thick Zechstein evaporites, have been extensively studied in Central Europe, largely because of their copper-ore deposits. The sedimentary environment of the Weissliegendes sandstones has been much discussed and still remains controversial. The main reason for this are lack of paleontological evidence through most of the sequence and some difficulty in defining the base of the sequence.

The three main hypotheses concerning the origin of the Weissliegendes sandstones are:

(1) fluvial-estuarine deposits (Herrmann, 1956);

(2) aeolian dune sediments developed along the margins of the Zechstein sea (Brandes, 1912; Richter, 1942; Richter-Bernburg, 1953; Falke, 1972, and others) and (in the uppermost part) redeposited shallow-marine sediments (Oberc, Tomaszewski, 1963; Porębski, 1974);

(3) shallow-marine deposits (cf. Zwierzycki, 1951; Wyżykowski, 1964; Pryor, 1971a; Jerzykiewicz, Kijewski, Mroczkowski, Teisseyre, 1976).

The environmental interpretation has an additional significance because marine or non-marine origin might place the sequence either with the Zechstein or with Rotliegendes sequences respectively.

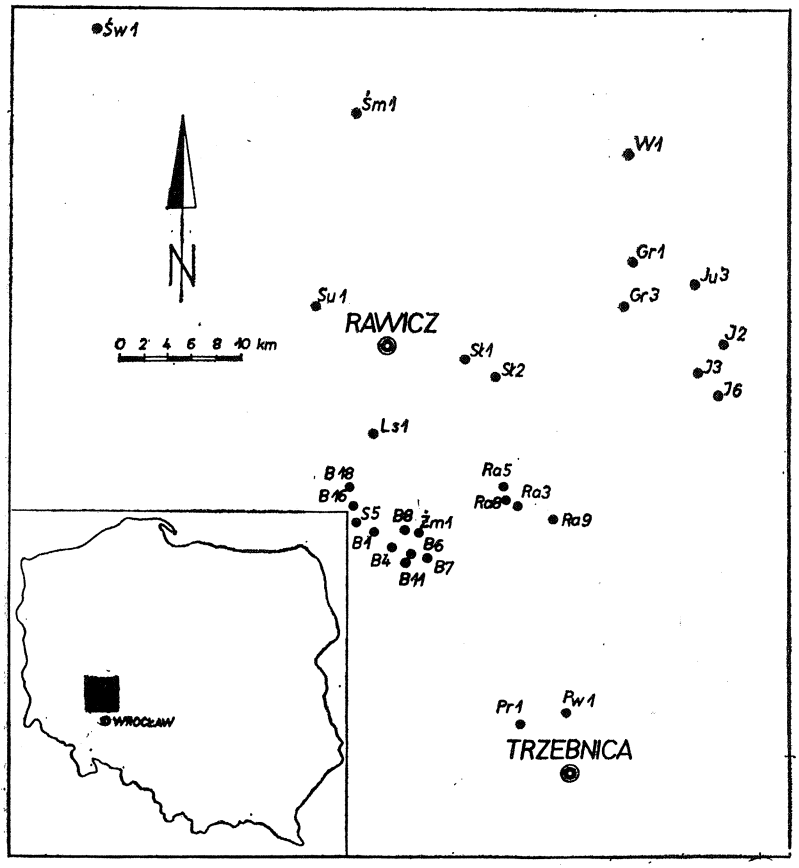

Fig. 1. Index map showing location of bore-holes

Fig. 1. Mapa sytuacyjna otworów wiertniczych

The present study is an attempt to interpret the Weissliegendes sandstones within the context of the underlying Rotliegendes succesion. For the purpose of the present paper 28 borehole profiles were examined (Fig. 1) and a special note was made of vertical changes in textural-structural attributes, in order to detect the horizons representing transition from Rotliegendes aeolian deposits to Zechstein marine deposits. The results suggest that the Weissliegendes sandstones are mostly aeolian deposits, merely a continuation of Rotliegendes sedimentation, but that there is a transition to shallow marine condition in the uppermost horizons.

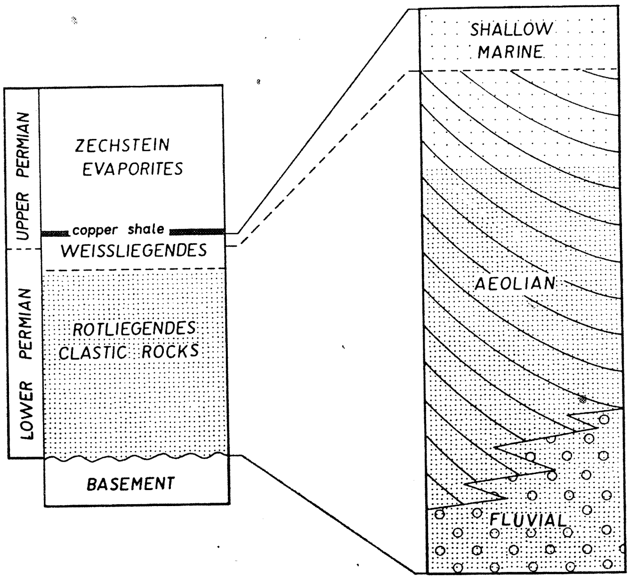

Fig. 2. General stratigraphy of the Permian, Fore-Sudetic Monocline; no scale

Fig. 2. Zgeneralizowany profil stratygraficzny utworów permskich monokliny przedsudeckiej; bez skali

In the studied area of the Fore-Sudetic Monocline the Lower Permian rocks rest directly on a tectonically deformed basement of Paleozoic rocks (Silurian, Lower Devonian, Carboniferous) and of Eocambrian rocks in the northwestern vicinity (see O b e r c, 1972). The Permian sediments are overlain by Mesozoic (Lower Triassic, Lower Cretaceous) and Cenozoic rocks.

In the Permian deposits described here, three major environmental associations (Fig. 2) are distinguished on the basis of structures and textures. These associations are introduced as fluvial, aeolian and shallow-marine respectively, for easier reading, although facts and interpretation are clearly separated in the text. The other two parts of the present paper, to be published in the following issues, will examine in detail some other sedimentological aspects of the problem (W. N e m e c, P o r ę b s k i, 1977; H. N e m e c et al., 1977).

FLUVIAL DEPOSITS

Description

The basal 60 m of the Rotliegendes succesion differ from the remainder in being dominated by fine conglomerates (average median 7,6 mm), pebbly sandstones and sandstones. The lowest 45—50 m consist of a number of fining-upward cyclothemes, each of them tens of centimeters to several meters thick (cf. W. N e m e c, 1975). A typical cyclothem consists of an erosively based, clast - supported conglomerate bed, overalain by medium to coarse-grained, often cross-stratified, pebbly sandstone which in turn passes up. either gradationally or by an interbedding, to fine grained sandstones. Each unit is capped by silty, micaceous fine sandstone which may (especially in the uppermost cycles) contain adhesion ripples or may be overlain by a thin mud layer with dessication cracks and occasional sandstone dykes. Most of the conglomerates and the uppermost sandstones are structureless, but occasionally the former have a pebble alignment parallel to the bedding, while the latter exibit a lenticular, wavy or flat lamination or may contain thin intraformational (mudflake) conglomerates.

The deposits of the overlying 10 to 15 m are not cyclically organized but consist mainly of clast-supported conglomerates and thin interbedded sandstones. These conglomerate-sandstone couplets are interbedded in the lower part, by occasional matrix-supported, massive conglomerates and, in the upper part, by thin units of fine sandstones and siltstones with adhesion ripples.

Interpretation

It is suggested that the lowest 60 m of the Rotliegendes succesion are mainly fluvial deposits. These deposits accumulated in the marginal part of the alluvial fan system which extended north and north-eastwards from the Fore-Sudetic Block area (cf. P o k o r s k i, 1976).

The fining-upwards cyclothems are similar to, but somewhat coarser than the classic alluvial cyclothems (A l l e n, 1970a) deposited by channel and overbank processes in streams of medium to high sinusoity. The large amount of conglomerates in the cyclothems disccused suggests dominantly bed load channels, probably in streams of medium to low sinusoity (cf. S t e e l, 1974). The uppermost 10 to 15 m of the succesion the clast-supported dominate. Sandstones are present only in minor amount.

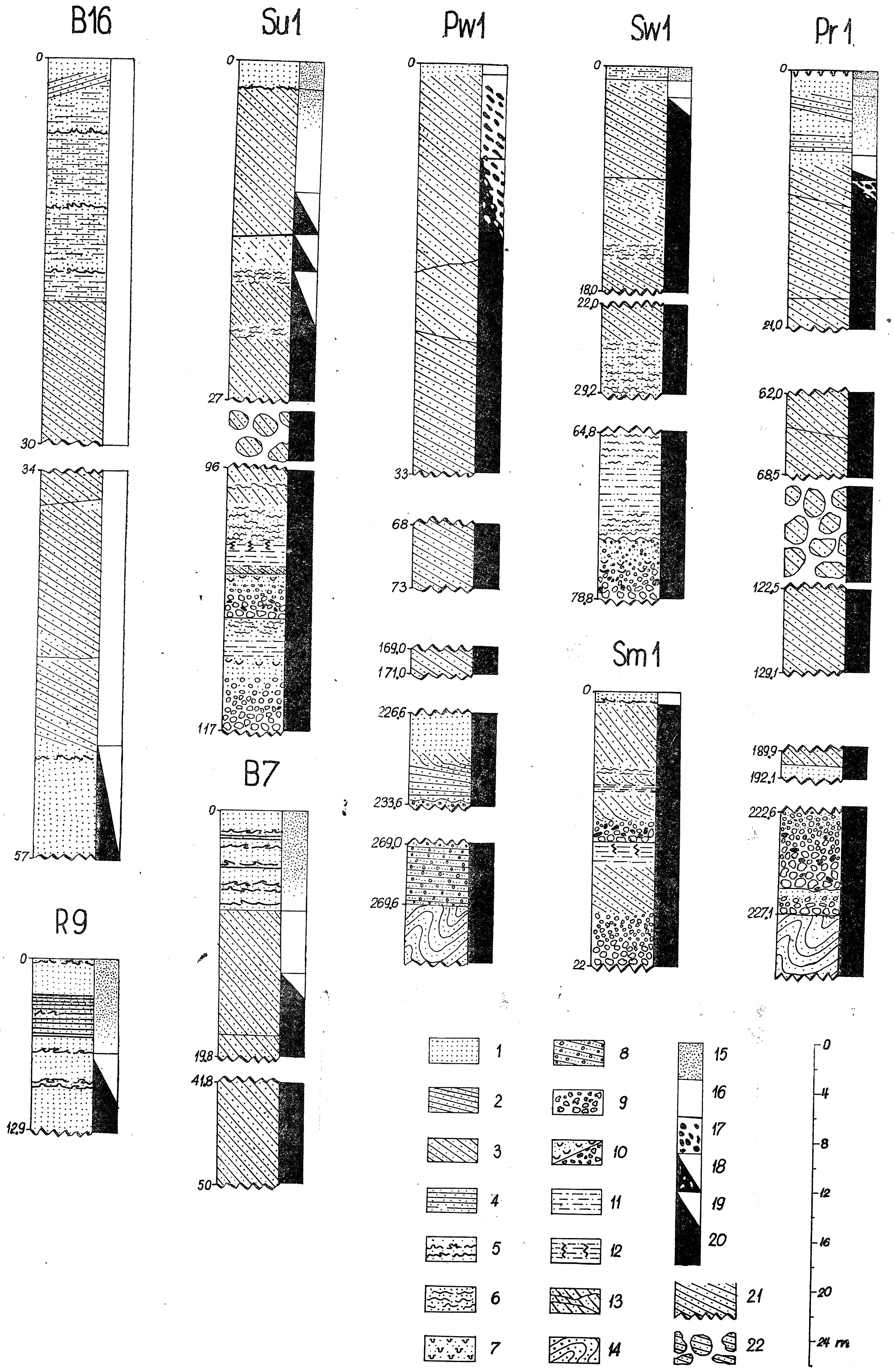

Fig. 3. Lithology and sedimentary structures in selected profiles (for bore-hole location see Fig. 1). 1 — sandstone devoid of internal structure ("structureless" ss.); 2 — low-angle cross-stratified sandstone; 3 — high-angle cross-stratified sandstone; 4 — sandstone with parallel mud lamination; 5 — soft-sediment deformation; 6 — sandstone with indistinct horizontal bedding and/or adhesion ripples; 7 — bioturbations; 8 — fine pebbly sandstone; 9 — massive conglomerate; 10 — mudflake conglomerate; 11 — mudstone; 12 — mudcracks and sand-dykes; 13 — erosional surface; 14 — basement. Rock colour: 15 — medium light grey (N 6); 16 — very light grey (N 8) to very pale orange (10 YR 8/2); 17 — red-mottled pink; 18 — purple-red mottled reddish brown; 19 — uniformly pink; 20 — red to reddish brown. Other explanations: 21 — core samples; 22 — bit samples

Fig. 3. Wybrane profile przedstawiające litologię i struktury sedymentacyjne badanych utworów. 1 — piaskowce masywne („bezstrukturowe"); 2 — piaskowce z nieznacznie nachyloną laminacją przekątną; 3 — piaskowce ze stromo nachyloną laminacją przekątną; 4 — piaskowce z płaską, równoległą laminacją mułowcową; 5 — struktury deformacyjne; 6 — piaskowce z niewyraźnym warstwowaniem poziomym i riplemarkami adhezyjnymi; 7 — struktury bioturbacyjne; 8 — piaskowce zlepieńcowate; 9 — zlepieńce masywne; 10 — zlepieńce śródformacyjne; 11 — mułowce; 12 — szczeliny z wysychania i dajki piaszczyste; 13 — powierzchnie erozyjne; 14 — podłoże. Barwa osadu: 15 — jasnoszara; 16 — bladoszara do bladopomarańczowej; 17 — różowa z czerwonymi plamami; 18 — czerwonobrunatna z purpurowymi plamami; 19 — różowa; 20 — czerwona do czerwonobrunatnej. Inne oznaczenia: 21 — próby rdzeniowe; 22 — próby okruchowe

Accordingly, it is suggested that this part of the section represents a more proximal alluvium probably deposited by ephemeral braided stream processes. The sediments are similar to the wadi deposits of G l e n n i e (1979, 1972), and the interbedded sandstone units probably represent the quieter, waning stages of individual, short-lived flood events (cf. M i a l l, 1970). The matrix-supported conglomerates that interbed with the clast-supported ones are texturally similar to the debris flow deposits of modern alluvial fans (cf. B u l l, 1972) and probably represent occasional discharges of higher sediment concentration on the fan. The gradual appearance of adhesion-rippled interbeds in the uppermost parts of the profile suggests longer pauses between flooding, when aeolian processes could proceed.

The overall time-trend of sedimentation in the lowest 60 m of the Permian succesion, coarsening-upwards together with an increased aeolian contribution, suggests an alluvial fan progradation and a change to wards more arid climatic conditions.

AEOLIAN DEPOSITS

Overlying the fluvial deposits are 240 m mainly of large-scale cross-stratified, well sorted fine to medium-grained sandstones which lack any conglomeratic or siltsone interbeds. This part of the section was studied in detail since it contains the Rotliegendes (Weissliegendes sediments boundary and other authors suggest that a significant environmental change accompanies the change from red to white coloured sediments.

D e s c r i p t i o n

Large-scale cross-stratified sandstones

Large-scale cross-stratified sandstones (Pl. I, figs. 1—3, Pl. II, figs. 3 and 5) occupy about 90% of the vertical interval of association II.

The sequence is dominantly red-coloured but it is important to note that it varies from dark reddish-brown (10 R 3/4) and moderate orange-pink (10 R 7/4) in the lower and middle portions, to greyish orange-pink (5 YR 7/2), very pale orange (10 YR 8/2) and light-grey (N 8) in the upper parts. The uppermost light-grey sediments are usually referred to as „white" and correspond to the alpha-type sandstones of Jerzykiewicz et al. (1976) in the Lublin mining district. It is also worth nothing that some rare, thin (4 — 10 cm), cross-laminated and deformed beds of light-grey colour (N 8) also occasionally occur within a sequence of dark-pink sandstones. These beds are located some distances below the main pink light-grey transition (Fig. 3).

The grain size in the sandstone sequence is dominantly fine (M_z lies between 2.02 and 2.77 phi), although a range from coarse (mainly in the lower parts) to very fine is also found there. Silt-sized grains, usually concentrated along stratification planes, are rarely scattered through beds and reach a maximum of 7% in some beds. The grain sorting ranges from 0.19 to 0.72 phi, although most samples are sorted within the range 0.40 — 0.70 phi (well to moderately well sorted). In addition to a slight fining-upwards of the grain size in the succesion, sediments also become better sorted.

Observations of bedding planes were often limited because of incomplete core records. In general, however the cross-stratified units vary in thickness from 0.7 to 10 m. These units are separated by inclined erosion surfaces or by thin sets of horizontal lamination and adhesion ripples, particularly in lower part of the sequence. In the uppermost parts of the sequence, there are often structureless portions although the boundary between the cross-stratified sequence and the overlying marine sediments is often erosional (Pl. II, fig. 2). The individual laminae within cross-stratified sets are delineated by variation in texture and colour. Laminae of medium sand, 0.1 to 0.5 cm thick and sometimes with scattered coarse grains, commonly alternate with very fine sand and silt with thickness up to 0.3 cm. Even in finer-grained sediments lamination is still distinct because laminae rich in silt or clay-sized grains usually have a higher content of ferric-iron. Cross-laminated sets usually have erosional tops, and foresets have a relatively uniform angle of dip (15° to 25°), although instances of tangential toe-sets have been recorded. Considering the great thickness of overlying sediments in this region, it is likely that the pre-compaction angle of foreset lamination has been significantly greater than the maximum 25° now observed (cf. Walker, Harms, 1972).

Homogenized (structureless) sandstones

Units of dark reddish-brown (10 R 3/4) to moderate reddish-orange (10 R 6/6) sediment devoid of visible structure, from 1 to 8 m thickness, occur particularly in the lowermost and uppermost portions of the sequence. The rare occurrences of such units within the cross-stratified portions are usully associated with sets of adhesion ripples.

The structureless sandstones, immediately overlying the fluvial deposits, are coarse-grained and very poorly sorted with silt fraction content up to 25%. They often contain mudflakes up to 4 cm in diameter. There sometimes occur closely associated units of medium sandstones which contain flattish lenses of granule sandstone.

The structureless sandstones in the uppermost parts of the succesion are fine-grained well to moderately well sorted and have a silt content of less than 4%.

Sandstones with indistinct horizontal bedding and/or adhesion ripples

Within the cross-stratified sandstones there occur units of fine to very fine-grained, moderately to poorly sorted (3 — 15% silt content) sandstones which exhibit indistinct horizontal stratification and well developed adhesion ripples (Pl. I, figs. 4 and 5). Such units, of tens of centimeters up to 1 m in thickness occur only in red-coloured sediments. The adhesion ripples consist of very fine sand and silt and in section appear as wavy lamination with strongly asymmetrical crests (amplitude 1 — 4 mm, chord length 0.3 — 3 cm).

Interpretation

The characteristics of the there groups of sandstones described above suggest that they represent mostly aeolian deposits (cf. criteria of Allen, 1970b; Glennie, 1970), despite the colour change, observed in sediments from red to white. The following features are considered important in this interpretation:

(1) There is a great thickness of sand-sized sediments (about 240 m) without gravel or significant siltstone interbeds.
(2) The sediments are texturally and mineralogically mature (see further text and also W. Nemec, Porębski, 1977).
(3) More than 90% of the sandstones are large-scale cross-stratified, with relatively high (without correction for compaction) and constant angles of the foreset dip.
(4) There is a low silt-clay content (less than 7%) in the cross-stratified sandstones and this figure was probably lower prior to diagenesis.
(5) There are sharp differences in grain size between the sediments in adjacent laminae in cross-stratified sets.
(6) General lack of flaky minerals and a scarcity of detrital clay in particular can be observed (cf. Jerzykiewicz et al., 1976).
(7) The fine grains of sand are relatively rounded and frosted, suggesting transport and abrasion by aeolian processes; (cf. Porębski, 1974; Jerzykiewicz et al., 1976). The examination of quartz grains by scanning electron microscopy revealed typical aeolian features, i. e. upturned fracture plates which are aligned along traces of cleavage planes.
(8) Units of adhesion ripples, which are formed when sand and silt grains are blown over moist surfaces (Van Straaten, 1953), are relatively common. These structures are known from modern tidal flats (Reineck, 1955) and various desert subenvironments, as well as from ancient sediments, including Rotliegendes (Hunter, 1969; Glennie, 1970, 1972).
(9) There is no marine fauna.

(10) A study of the nature and origin of the red colour in these sediments has suggested that they are very likely to be continental (W. N e m e c, P o r ę b s k i, 1977).

On the basis of the above features it is suggested here that the very thick suquence of cross-stratified sandstones, whether white or red, accumulated as aeolian dunes in a relatively continuously subsiding basin area. The interbeds of indistinct, horizontally laminated or adhesion-rippled sandstones probably represent interdune areas (cf. G l e n n i e, 1972). As regards the structureless sandstones, these poorly sorted with a high silt-clay content and clay drapes were probably deposited by sediment-laden water (cf. G r a d z i ń s k i, J e r z y k i e w i c z, 1974, p. 139), while those which are better sorted, with a lower silt content may represent dune sediment reworked either by wind or by flowing water. Soft sediment deformations occurring within pink sandstones (see profile B 16, Fig. 3) may have originated from sliding of the water-saturated aeolian sand on the dune slip face, or from redeposition dune sediments by ephemeral (wadi) water flows. Similar bed types that originated in such way are found in modern deserts (G l e n n i e, pers. comm.).

The presence of ephemeral water in the dune field area is obvious, but its origin, whether from rain storms or from brief sea-water influxes (e. g. as in Lower Permian of NW Europe; G l e n n i e, 1972), is still problematic. The undulating bottom morphology might have been suitable for an easy influx of sea-water but on the other hand, various occurrences of water-laid deposits in the area appear to be of a local importance only.

As noted above, the white coloured, uppermost part of the cross-stratified sandstone sequence in the Lubin mining district has been termed alpha-type sandstones and interpreted by J e r z y k i e w i c z et al. (1976) as subaqueous sand ridges (cf. P r y o r, 1971 a,b). The basis of this interpretation was the presence of a regular cross-stratification, occasionally with deformed siltstone drapes on the foresets, and the mineralogical-textural similarity between these sandstones and the overlying ones, undoubtedly of shallow-marine origin.

In the present study the uppermost white, large-scale crossbedded sandstones are interpreted as an integral part of the aeolian sequence (cf. S m i t h, 1971), the bulk of which happens to be red coloured. Siltstone laminae, also uncommon in aeolian dunes, have been described from both ancient and modern dune sand (C o r n i s h, 1897; L u t z, 1941; G l e n n i e, 1970) and may originated from clouds of clay and silt which were partly trapped by sieve-like processes in the sandy dune surface (S o k o ł o w, 1894; F o l k, 1971). Moreover, a study of silt and clay-sized material in the present paper has strongly suggested that it may be partly authigenic. Plate II, fig. 1 shows a light-grey, cross-laminated sandstone with alternating fine sand (light laminae) and very fine sand

and silt (dark laminae) in which the silt content is 7% (data from sieve analysis). The microscopic examination of the same specimen has shown that up to 3% of the finest material is authigenic clay. Small deformation structures, similar to those described by Jerzykiewicz et al. (1976) are quite common in modern coastal dune sands (Bigarella, 1972; McKee, Bigarella, 1972). An additional aspect of the white, cross-stratified sandstones is that they lack both marine fauna and any trace of bioturbation. Although littoral sand bars are not environmentally suitable for the preservation of benthonic fauna, a common feature of both modern and ancient shallow-marine bars is either concentrations of redeposited fauna or abundant traces of biogenic activity.

Summing up, the authors suggest that it is not possible to distinguish the large-scale cross-stratified, red sandstones from the overlying white ones on a basis other than colouration, and that colouration cannot be used as an environmental criterion because of its post-depositional origin (W. Nemec, Porębski, 1977). The sedimentary characteristics of the succesion overlying fluvial deposits and overlain, often erosively, by marine sediments (considered below), strongly indicate an aeolian origin. Its uppermost portion may represent a coastal dune field.

SHALLOW-MARINE DEPOSITS

The studied profiles show a clear bipartition of the Weissliegendes sandstones into a lower portion of large scale cross-stratified sandstones, included in the aeolian association discussed above, and an upper part consisting of structureless sandstones interbedded with horizontal, cross-laminated and penecontemporaneously deformed sandstones (cf. Jerzykiewicz et al., 1976). The latter part averages several meters in thickness (sporadically tens of centimeters and up to 20 m); it is equiva lent to the beta-type sandstones of Jerzykiewicz et al. (1976) in the Lublin mining district and often rests erosively on the underlying aeolian sandstones.

Description

The sandstones of this association are light-grey (N 6) to very-light (N 8), although in some thinly bedded sandstones there are single laminae with a large admixture of silt-sized grains and authigenic clay, which are greyish-black (N 2). The sandstones are fine to very fine-grained (M_z between 2.22 and 3.10 phi), with rare medium sandstones (M_z from 1.25 to 2.00 phi). The grain size of siltstone interbeds averages 4.60 phi, while the silt fraction content of the structureless sandstones ranges from 0.04 to 2%, and up to 5% in silt-laminated sandstone beds. The sandstones are well to moderately well sorted (0.39 to 0.75 phi).

The horizontal stratification consists of alternating parallel sandy laminae, 0.3 — 1.0 cm thick and sometimes normally graded, with siltstone laminae, 0.3 cm thick. Laminae sets are 20 to 100 cm thick and sometimes show low-angle cross-lamination. Trough cross-laminated sets usually do not exceed 7 cm in thickness but occasionally reach 50 cm with dip angles in the range 10° — 15°. In some instances the cross-strata appear to have been a part of an originally larger bed form or they have a progradational hollow-filling character.

Small-scale (cm) soft-sediment deformations occur in horizontal or cross-laminated units (Pl. III), where there are alternating sand and mud layers, or individual thick (2 — 3 cm) mud laminae. The lower surfaces of sandy beds exhibit flame structures sometimes with preferred orientation. Superimposed load-casted ripples, oversteepened cross-lamine, and varietes of distortion consisting of small folds, generally asymmetrical, with axial planes in an almost horizontal position (Pl. II, fig. 1; Pl. III), are also observed in places. The origin of these structures is probably connected with differential loading and shearing stresses imposed on the bottom sediment by the overlying mass of sediment. Silt laminae show deformations which probably formed during early stages of sediment consolidation and which are connected with an explosive escape of water along vertical planes. They are various forms of small intrusions cutting the primary lamination and are usually internally structureless.

Bioturbation structures were noticed in one of the profiles (Fig. 3, Pw 1), where a 10 cm thick dolomitic sandstone bed with a large admixture of silt and clay material (24%) occurs and which shows traces of animal activity (Pl. II, fig. 4). The bioturbations appear to be cause of the absence of a well developed lamination. In the cases where primary silt laminae are disrupted, broken, partly curved downward and upward, some vertical and horizontal burrows are also visible; the latter are filled with silt material sometimes showing a significant concentration of copper substance. There is no evidence of soft-sediment deformations in this bed and it appears to be equivalent to the so-called „bioturbation layer" of the Lublin mining district (cf. J a r o s z, 1979; J e r z y k i e w i c z et al., 1976).

The bulk of sandstones in this association lacks organic fossils and only in the uppermost part (tens of centimeters) in some adjacent areas of the Fore-Sudetic Monocline examples of marine fauna have been found. The most abundant form is *Lingula credneri* G e i n i t z (W y ż y k o w s k i, 1964; T o k a r s k i, 1967; J a r o s z, 1970; A l e x a n d r o w i c z, S ł u p c z y ń s k i, 1970; the others forms reported are *Schizodus obscurus* S o w e r b y, *Cleidophorus hollebeni* G e i n i t z (B ł a s z c z y k, P r y m k a, 1973) and foraminifers, ostracods, fragments of bryozoans and crinoids (P e r y t, 1976).

Interpretation

The above features support the opinion of Jerzykiewicz et al. (1976) that this association is water-deposited. The marine fauna, bioturbations, sedimentary structures and stratigraphic position suggest that this association represents a transgressive deposits of the Zechstein sea. The sandstones might have originated from reworking and redeposition of dune sediments in the environment of a wave-dominated shore (cf. H. Nemec, 1976).

Incomplete core records often limited sedimentological observations, so it is difficult to present a more detailed environmental interpretation of the sandstones. The structureless sandstones, which form most of this association, might have originated in a surf zone, where the primary dune stratification was destroyed and silt-clay particles were winnowed out; the latter may also explain the low content of silt fraction in this sandstones. Beds with a low-angle cross-stratification, composed mainly of sand, may be considered a product of swash-backwash regime. The sandstones with thick, often deformed, silt laminae originated probably in low, protected areas of beach or backshore i. e. on the lee-side of ridges or runnels (cf. Howard, 1971; Wunderlich, 1972). The deposition of dolomitic sandstones with a significant content of silt-sized material might have taken place in separated, temporarily flooded by sea water portions of the basin. Such lagoons, protected from the immediate action of currents and waves, might have been suitable for growth and preservation of the Lingula fauna (Porębski, 1974).

TEXTURAL DIFFERENTIATION

Grain-Size analysis

A general conclusion from the evidence presented above is a complex origin of the Weissliegendes sandstones. The question rising here is whether there is any traceable differentiation in the sandstone grain-size distribution which may be explained in terms of the two different depositional factors: aeolian and marine. To solve this question, the grain size distribution of 58 sandstone samples was studied in 10 selected profiles, the sampling being closely related to the sandstone structure and colour. The aeolian sandstones (here referred to as association II) were divided into a number of subassociations. Within the largescale cross-stratified sandstones there were distinguished light-grey (IIb), intermediate (IIc) and red-coloured (II d). The other subassociations considered are represented by red sandstones with an indistinct horizontal bedding and/ or adhesion ripples (IIe), and orange-red structureless sandstones (IIa) which are present in the upper part of aeolian sequence and are sometimes overlain by marine sediments. The latter shallow-marine sandstones were considered as a separate association (III).

Method

Sieve analysis

Sieving was accomplished using a combination of the Polish standard and German DIN—1171 sieves which, in the mesh-size, closely approximate 1/3 phi intervals (from 0 to 4 phi). Although the use of 1/4 phi intervals has been recommended by many authors, limited laboratory facilities made the adoption of this approach impossible.

Treatment of size data

Graphical statistics (mean size, standard deviation, skewness, and kurtosis) were calculated using the formulas of Folk and Ward. The σ_I/M_z and Sk_I/M_z relationships are shown graphically in Fig. 4. The range and average value of the parameters calculated for the (sub-) associations are shown in Tables 1 and 3.

Q-mode factor analysis was accomplished to obtain an objective classification of samples on the basis of their grain-size distributions. The same Q-mode approach was used by many authors to classify recent sediment samples (e.g. Klovan, 1966; Stubblefield et al., 1975) and the principal factors extracted were claimed to reflect different types of depositional energy.

The input for the analysis was a grain-size distribution (14 size-ranges) of 58 samples. Only three variamax rotated factors were extracted routinely from the data in this study, since experiments in extracting more indicated that reasonable physical interpretation was possible only for the first three common factors. The three corresponding eigenvalues were found to represent 94%; the remaining 6% may be discarded as ambient noise. All samples, except four, have the communality above 0.90, and the majority exceed 0.95, which suggests that a satisfactory grouping description is obtained for the bulk of samples. The normalized factor loadings were plotted on a ternary diagram (Fig. 5). The ODRA 1204 computer facilities of the University of Wrocław were used for all computations.

Graphical dissection of grain-size distributions is the other approach discussed in this study. In the grain-size distributions of many modern and ancient sands the presence of distinct, log-normally distributed grain populations was reported by many authors. Since the classic works by Moss (1962) and Visher (1969), the analysis of these populations has been thought a useful tool for environmental studies. In order to deduce the populations from size distributions, several authors have attempted to dissect frequency and cumulative curves on the basis of natural breaks or by comparison of curve-shape parameters (Visher 1969; McKinney, Fiedman, 1970;

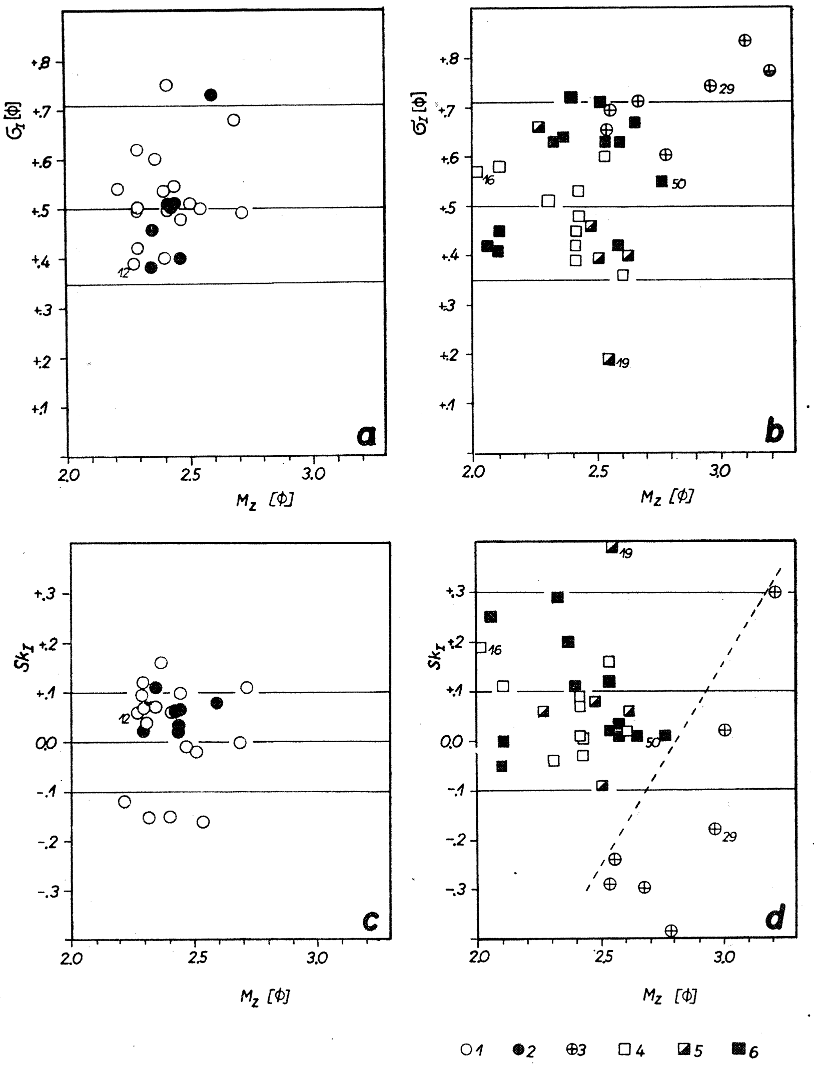

Fig. 4. Plots of mean size (M_z) vs. standard deviation (σ_I) or skewness (Sk_I) for sandstone associations III (plots a and c) and II (plots b and d). 1 — sandstones of association III; 2 — pink „structureless" sandstones (subassociation IIa); 3 — red sandstones with indistinct horizontal bedding and/or adhesion ripples (IIe); 4 — white cross-stratified sandstones (IIb); 5 — pink and mottled cross-stratified sandstones (IIc); 6 — red cross-stratified sandstones (IId). Note that only sandstone subassociation IIe is separated from the others

Fig. 4. Wykresy zależności pomiędzy standardowym odchyleniem (σ_I), średnią średnicą (M_z) i asymetrią (Sk_I) rozkładów uziarnienia piaskowców asocjacji III (wykresy a i c) i II (wykresy b i d). 1 — piaskowce asocjacji III; 2 — różowe piaskowce „bezstrukturowe" (subasocjacja IIa); 3 — czerwone piaskowce o niewyraźnym warstwowaniu poziomym i z riplemarkami adhezyjnymi (IIe); 4 — białe piaskowce przekątnie warstwowane (IIb); różowe i plamiste piaskowce przekątnie warstwowane (IIc); 6 — czerwone piaskowce przekątnie warstwowane (IId). Jedynie piaskowce subasocjacji IIe wykazują wyraźniej zaznaczoną odrębność

Table 1

Summary of grain-size variations in sandstone association II and III

Zróżnicowanie w uziarnieniu piaskowców asocjacji II i III

Sandstone /sub-/association			No of samples	Mean size M_z/phi/		Sorting σ_I /phi/		Skewness/x Sk_I		Kurtosis/x K_G		Fines % /> 4 phi/	
				Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
III		Light-grey structureless sandstones with silt laminae and deformation structures	17	2.22 - 2.71	2.43	0.38 - 0.75	0.52	-0.16 - +0.15	+0.006	0.82 - 1.72	1.09	0.04 - 4.83	2.33
II	a	Red-to-pink structureless sandstones	7	2.28 - 2.60	2.42	0.39 - 0.73	0.50	+0.02 - +0.13	+0.06	1.83 - 1.30	1.04	0.50 - 7.00	2.73
	b	**Light-gray** large-scale cross-stratified sandstones	10	2.02 - 2.60	2.42	0.36 - 0.60	0.49	-0.04 - +0.18	+0.07	0.80 - 1.65	1.20	0.70 - 7.00	4.58
	c	Pink and/or red-mottled large-scale cross-stratified sandstones	5	2.27 - 2.62	2.40	0.19 - 0.66	0.42	-0.10 - +0.39	+0.04	0.78 - 1.64	1.17	0.60 - 6.02	4.40
	d	Red, large-scale cross-stratified sandstones	12	2.06 - 2.77	2.40	0.41 - 0.72	0.56	-0.05 - +0.29	+0.10	0.84 - 1.57	1.22	0.00 - 6.39	4,03
	e	Red sandstones with indistinct horizontal bedding and/or adhesion ripples	7	2.54 - 3.01	2.83	0.60- 0.83	0.72	-0.39 - +0.30	+0.13	0.94 - 1.57	1.15	2.70 - 16.0	10.77

/x In most of the samples /50/ the amount of unanalysed fraction /finer than 4 phi/ was no greater than 5 %; for the remaining samples /8/ the percentile ϕ_{95} was approximated with assumption that the suspension population is log-normally distributed.

also discussed by Stubblefield et al., 1975, p. 349). The cumulative curves of the studied Permian sandstones show the presence of a saltation population in the grain-size range from 1 to 3 phi. It is often divided into two or three subpopulations which are referred to as A_1, A_2, and A_3 respectively due to the increase in their phi mean size. Grains smaller than 1 phi in size are scarce so the traction population is usually not developed in the studied curves. Table 2 gives a quantitative summary of the population analysis.

Results and discussion

Bivariate plots

The plots of M_z/σ_I and M_z/Sk_I (Fig. 4), considered to be most effective in differentiating beach and inland-dune sands from coastal-dune ones (Moiola, Weiser, 1968), show no clear textural differentiation in the considered sandstone (sub-) associations. Only sandstones with an indistinct horizontal bedding and/or adhesion ripples (IIe) are separated from remainder. They are very fine to fine-grained, moderately sorted, coarse to fine skewed, with large percentage of fines (Tab. I). The difference between the association III and the large-scale cross-stratified sandstones (IIb, IIc, IId) is not significant. It is noteworthy, however, that the distributions of sandstones of association III are more or less symmetrical (average $Sk_I = + 0.006$ while those of cross — stratified sandstones are more positively skewed (see Tab. 1).

Application of the factor analysis

The relationships between samples are clearer in the ternary diagrams (Figs. 5 and 6) which show the connection between the samples, representing sandstone (sub-) associations and the first three pricipal components of the factor analysis (see also Tab. 2).

Sandstones of association II. Seven of the samples show a particularly high connection (above 80%) with factor F_2 (Fig. 6), and these are only sandstones with an indistinct horizontal stratification and/or adhesion ripples (IIe). Their cumulative curves show the presence of three well-separated saltation subpopulations and relatively high contribution (average 17%) of a poorly sorted and well separated suspension population. These features are also reflected in the relatively poorer sorting and significant asymmetry of their size distribution. Their σ_I and Sk_I parameters are almost identical with those reported by Folk (1971, Figs. 8 and 11) from deflationary flats (reg) of the Simpson Desert, Australia.

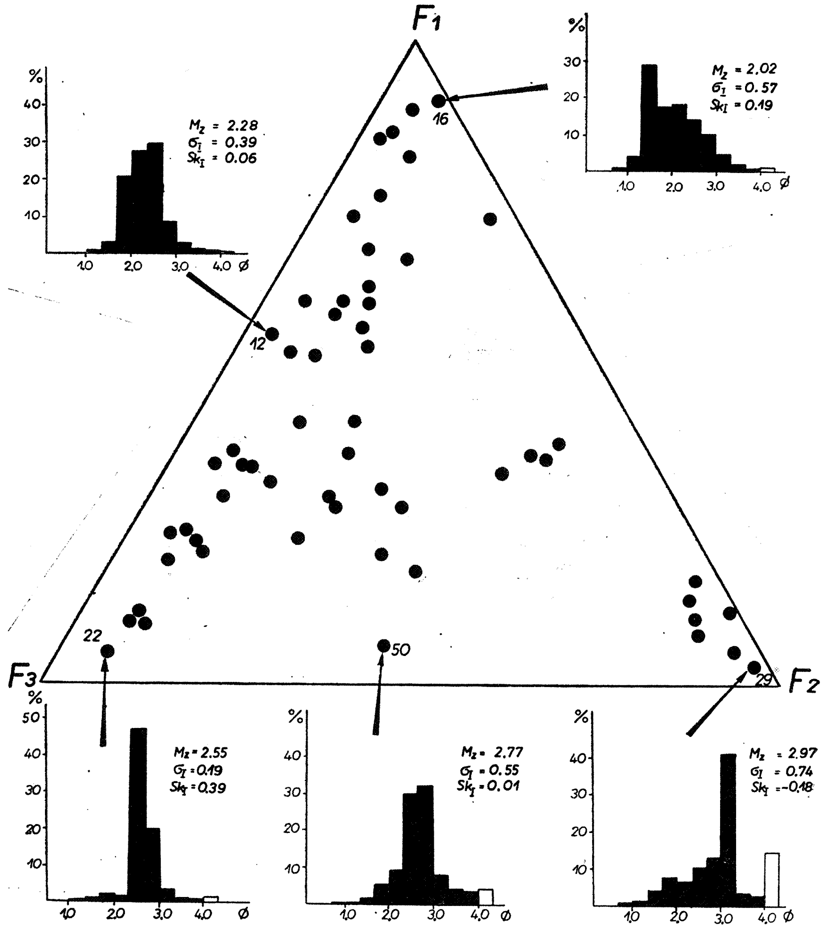

Fig. 5. Normalized factor components of 58 sandstone samples and associated histograms of representative samples. Factors F_1 and F_2 denote the eigenvalues of great influence on all the samples, whereas factor F_2 represents that of least influence. The histograms display the mean grain size (M_z), standard deviation (σ_I), and skewness (Sk_I) in addition to the size distribution; undshadowed areas represent percentage of unanalysed fines

Fig. 5. Znormalizowane ładunki czynnikowe 58 prób piaskowców i histogramy uziarnienia reprezentatywnych prób. Próby wykazują przede wszystkim powiązanie z czynnikami F_1 i F_3. Dla histogramów podano wartości średniej średnicy ziarna (M_z), standardowego odchylenia (σ_I) i asymetrii (Sk_I); nie zaciemnione pola histogramu odpowiadają nie analizowanej frakcji najdrobniejszej

The samples of cross-stratified sandstones are concentrated along the F_1 — F_3 side of the ternary diagram (Fig. 6). Following the samples found along the sides F_3 — F_2 and F_3 — F_1 respectively, a general increase in their grain-size and sorting are easily traceable, this being also reflected in the decreasing suspension population and the declining subpopulation A_3. The saltation population shows two subpopulations, A_1

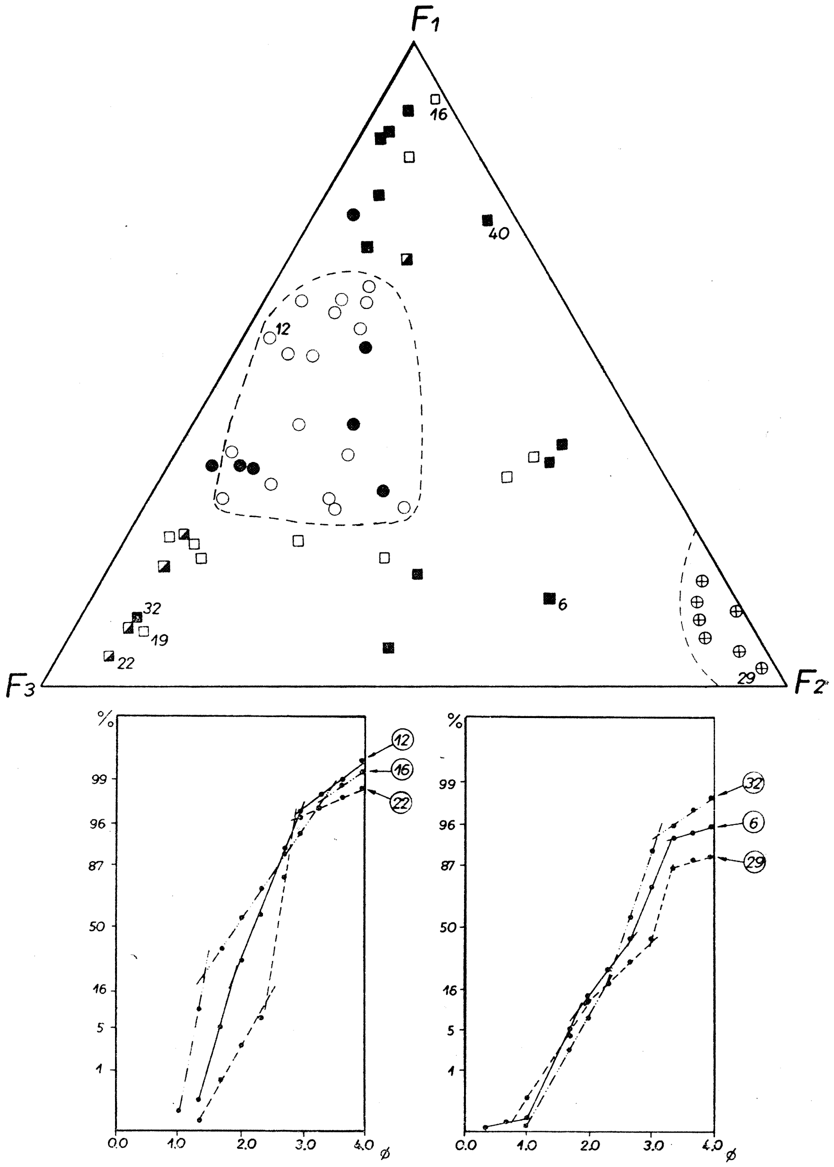

Fig. 6. Normalized factor components and associated cumulative probability curves of representative samples. The samples are symbolized (as in Fig. 4) to indicate the sandstone (sub-)associations

Fig. 6. Znormalizowane ładunki czynnikowe i kumulacyjne krzywe rozkładu uziarnienia prób reprezentatynych. Próby reprezentujące wydzielone (sub-)asocjacje piaskowców oznaczono odrębnymi symbolami (jak na fig. 4)

and A_2, with the varying degree of sorting, percentage of contribution and location of intrasaltational „breaks".

Samples closely connected with the first principal factor show the relatively highest mean size values, they are moderately well sorted (0.57

Table 2

Range in percentage composition of phi-normal components and truncation points of cumulative frequencies related to principal components of factor analysis

Charakterystyka populacji ziarnowych w próbach o określonym związku z głównymi składowymi analizy czynnikowej

Connection with principal factors /F/, in percent	Sandstone /sub-/association	SALTATION POPULATION /A/									F.T. /phi/	SUSPENSION POPULATION /B/		
		A_1		I.T.	A_2		I.T.	A_3		Mixing of subpopulations		Contribution /%/	Sorting	Mixing with saltation population
		Contribution /%/	Sorting	/phi/	Contribution /%/	Sorting	/phi/	Contribution /%/	Sorting					
$> 80\%$ F_1	IIb, IId	15.0-30.0	good to fair	1.45-1.65	57.0-81.0	good	--	--	--	poor to fair	3.00-3.30	4.0 - 4.5	good	good to fair
40-60 % F_1 40-60 % F_3 $< 10\%$ F_2	III, IIa	16.0-30.0	good to excell.	2.00	65.0-79.0	good	--	--	--	very good	3.10-3.20	21 - 40	good	good to fair
		96.0-98.0	good to fair	--	--	--	--	--	--	complete	3.10-3.20	21 - 40	good	good to fair
$> 80\%$ F_3	IIb,IIc,IId	8.0-20.0	fair to good	2.30-2.40	72.0-84.0	good to excell.	--	--	--	fair to poor	2.80-3.15	6.0 - 8.0	good to fair	fair to good
$> 80\%$ F_2	IIe	3.0-16.5	good	1.5-2.0	16.0-42.0	poor	1.6-3.0	30.0-55.0	excellent	poor	3.20-3.30	7.0-26.0	fair to poor	poor to medium

Explanation of letter symbols:

A_1, A_2, A_3 - log-normally distributed grain subpopulations within saltation population /see also text/;

F.T. - fine truncation points;

I. T. - intrasaltational "breaks"

phi on the average), positively skewed, and have silt-clay content not exceeding 2%. Their log-probability curves show the presence of two saltational subpopulations, excellently to well sorted A_1, and well sorted A_2, both truncated and joined of about 1.50 phi. The contribution of a poorly separated, well to fairly sorted suspension population does not exceed 4%.

Samples showing the strongest connection with the third principal factor have the mean size values intermediate for the studied samples. They are very well sorted (from 0.19 to 0.35 phi), positively skewed (+ 0.09 to + 0.39) with the silt-clay content not larger than 4%. Their cumulative curves show the presence of a well to fairly sorted subpopulation A_1 and a well to excellently sorted subpopulation A_2, both being truncated and joined at a point of about 2.20 phi; the contribution of a fairly to well sorted suspension population does not exceed 8%.

A characteristic feature of the cross-stratified sandstones (both red and white), interpreted here as aeolian, is that there is no connection between their grain-size distributions and rock colour (see Fig. 6). Their cumulative curves show the presence of two or even three well separated saltation subpopulations, as well as sometimes a significant contribution of a fairly well separated suspension population (Tab. 2). These features, however, are not thought in the literature to be generally typical of aeolian dune sands. The intra-saltational „breaks" are known to occur also in the sediments of beach and tidal-estuarine environments. The occurrence of these „breaks" was explained as a result of removal or mixing of the sediment by periodic changes in the type of the hydrodynamic transport associated with the swash-backwash regime and/or flood-ebb currents (V i s h e r, 1969; K o l m e r, 1973).

Recent works on the aeolian sediments throw, however, some light on the problem. It is known from the studies of modern desert sands that they exhibit a significant variation in their size distributions. Their curves often show two, three or even more distinct grain populations with widely separated size modes (C h a k r a b a r t i, 1968, Figs. 2 and 3; F o l k, 1971, Fig. 7 and 15; S k o č e k, S a a d a l l a h, 1972, Fig. 3; V o s s m e r b ä u m e r, 1974, Fig. 9). Their grain-size distributions differ significantly from those of coastal dune which have steep cumulative curves, with well mixed grain populations, and are often incorrectly thought to be typical of the aeolian environment as a whole.

The shape of the grain-size curve of aeolian sand is determined by several factors, such as the competence of wind, the type of dune, the nature of source material and also the intensity and character of diagenetic processes.

The competence of the eroding and transporting action of the wind varies significantly, due to fluctuating velocity of the latter. In consequence, the resulting sediment deposited under varying conditions may be a mixture of log-normally distributed populations, sometimes with widely separated size modes (cf. Folk, 1971, pp. 40 — 42), the latter being manifested by the strong polimodality and skewness of distributions. For example, a vertical alternation of laminae of different grain sizes is reported by Skoček and Saadallah (1972) as a common feature of stabilized sands of the Southern Desert, Iraq, (cf. Glennie, 1970, Figs. 125 and 126). Relationships between the mixing of grain populations and dune morphology are also reported and discussed in detail by Folk (1971). It is also well known that many inland-dune sands are derived from reworking of poorly sorted fluvial sediments which contain a significant proportion of the finest particles. Thus, the primary availability of fines in the desert sandes results in their generally strong, positive asymmetry (cf. Moiola, Weiser, 1969). Moreover, the amount of fines may increase during the diagenetic processes, due to the decomposition of unstable detrital grains (feldspars unstable rock fragments) by chemical weathering, resulting in the formation of authigenic clay minerals. The latter process is particularly intense in stabilized sands, i.e. those exposed to exodiagenesis for a long period (Skoček, Saadallah, 1972; cf. Friedman, 1962). Thin-section data suggest that a significant contribution of the well-separated suspension population in the studied Permian sandstones is closely related to the admixture of authigenic clay in the sediments. It should be also remembered that a certain amount of fines may come from the mechanical desintegration and preparation of sandstone samples for sieving; in any case, such a possibility cannot be excluded.

Sandstones of association III. Samples of these sandstones are not significantly connected with a single principal factor (Fig. 6), since they are concentrated mainly near the middle of the F_1 — F_3 side of the ternary diagram. Their connection with the component F_2 generally does not exceed 20%. Starting from the end-members F_1 and F_3 respectively, then going towards the middle of this side of the diagram (Fig. 6), it is observed that the samples show an increasing mixing of the grain subpopulations A_1 and A_2 with the maximum maximum placed almost exactly at a point 50%. Only very few samples show the presence of a poorly separated subpopulation A_3, and these are better connected (23 — 35%) with the component F_2.

As a whole, the sandstones of association III differ from those of association II (including both red and white cross-stratified sandstones) in the following features: (1) good to excellent mixing of saltational subpopulations; (2) consistent location of intrasaltational „breaks" (at 2 phi, if present); and also, to some degree, in (3) lesser amount of suspension population (Tab. 1). These are the features typical of beach and coastal-dune sands (Visher, 1969; Moiola, Spencer, 1973, Fig. 4; and and others), although the values of σ_1 (0.52 phi, on the average) and the amount of fines (2.33%, on the average) are somewhat greater than those observed in the recent foreshore and backshore sands.

In general, the difference between the grain-size distributions of association II an III is not very distinct but it appears to be transitional in character. It is assumed that source material was the main cause of the grain-size relations now observed. As suggested Folk and Robles (1964), the limits of variability for sediment size and sorting may be inherited from source material, whereas variation within the inherited limit can result from environmental processes. Sediment derived from the homogenous policyclic source material display a tendency to be less amenable to textural differentiation in the final environment than heterogenous material (Hails, 1967; Shideler, 1974).

The sedimentary features and stratigraphic position of the sandstone association III suggest that it represent a basal, transgressive marine deposits. The transgressive sands might have originated from the redeposition of aeolin dune sediments inheriting from them the limits of grain size and general sorting. Thus, the action of littoral currents is thought to be the main cause of log-normal distributions of the sandstone association III.

Recent studies of modern beach and coastal-dune sands associated in the genetic couplets, have shown that dune sands are often better sorted and more positively skewed than the beach sands (Mason, Folk, 1958; Greenwood, 1972; and many others). A generally more negative skewness of the beach sands results from the permanent winnowing of fines under the swash-backwash regime. In the studied Permian samples, the sandstones of association III are less skewed (average asymmetry + 0.006), while the underlying white cross-stratified sandstones (IIb) show an asymmetry of about + 0.07. Their sorting averages 0.52 phi and 0.49 phi and the content of fines is 2.33% and 4.58%, respectively. A significant contribution of a relatively well-separated suspension population in the sandstones of association III might have probably resulted from continuous supply of fines by offshore winds. In such conditions a relatively low energy of the wave-zone would favour formation and preservation of the grain-size distributions now observed. A generally poorer sorting of the sandstones of association III, when compared with modern beaches and coastal dunes, seems to be the result of inheriting sediment features from source material, perhaps additionally combined with diagenetic changes in sediment.

In conclusion of the above discussion it should be observed that there are features of the studied sanstones which are need to be stressed here. The sandstones of association II are similar in their polymodal size distributions (Figs. 6 and 7) and size parameters (Tab. 3), to many modern desert-dune sands. It is assumed that the polymodality of their distributions resulted from the primary availability of fines in source ma-

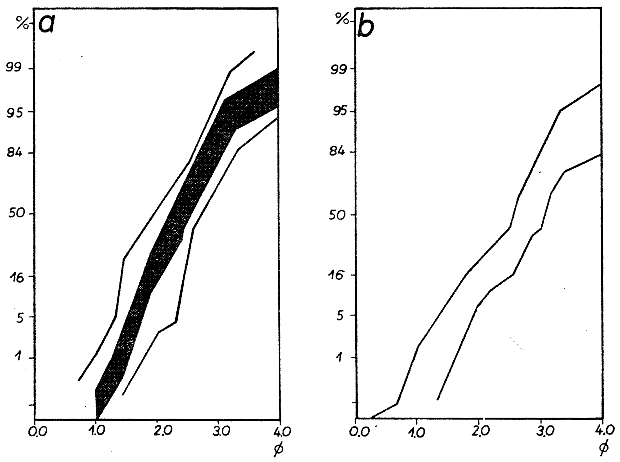

Fig. 7. Fields representing the sum of cumulative probability curves; a — samples of sandstone association III (shadowed field) and samples of all cross-stratified sandstones (unshadowed field); b — samples of sandstones with indisfinct horizontal bedding and/or adhesion ripples

Fig. 7. Sumaryczny zakres kumulacyjnych krzywych rozkładu uziarnienia; a — próby reprezentujące piaskowce asocjacji III (pole zaciemnione) i całość piaskowców przekątnie warstwowanych (pole nie zaciemnione); b — próby piaskowców o niewyraźnym warstwowaniu poziomym i z riplemarkami adhezyjnymi

Summary of grain-size parameters Table 3

/compared with an example of recently published data/

Porównanie średnich wartości parametrów uziarnienia z danymi ze współczesnych osadów wydmowych

Parameters	Present study Sandstone subassociations IIb, IIc, IId interpreted as dune sediments	IIe interpreted as reg	Folk /1971/ dune	reg
Mean size, M_z	2.42	2.83	2.70	2.85
Sorting, σ_I	0.52	0.72	0.53	0.95
Skewness, Sk_I	+0.08	+0.13	+0.09	+0.04
Kurtosis, K_G	1.19	1.15	1.04	0.90

terial (i.e. fluvial sediments of association I), as well as from mechanism of aeolian sedimentation itself (cf. Mason, Folk, 1958; „quantum theory" of aeolian deposition — Folk, 1971); postdepositional modification of the sediment might have also contributed, to some degree to this fact. Upwards in the profiles these sandstones show an increase in their textural maturity, which is manifested by an increasing degree of sorting and a decreasing positive asymmetry. The white cross-stratified sandstones (IIb), which correspond to the alpha-type sandstones of the Lubin mining district, are similar in their grain-size features to the remaining cross-stratified sandstones of the association II. They do not show, however, textural features typical of recent coastal-dune sands which are derived from wind acting on excellently-sorted beach sand source. On the other hand, it seems very likely that their textures are due to the activity of predominant offshore winds. Moreover, such conditions are suggested for the Zechstein coastline by some authors, the evidence being reviewed and discussed in detail by Brongersma-Sanders (1969). The sandstones of association III originated from redeposition of the above mentioned dune sands having inherited from them the range of grain-size and sorting. A poor separation of grain populations in the inherited size distributions is interpreted as a result of littoral mixing during marine transgression. The relative decrease in the amount of fines in the sandstone association III may be attributed to the swash-backwash phase of sediment reworking.

ROUNDNESS

The roundness of detrital quartz grains was tested in 30 sandstone samples in order to detect its possible differentiation in the stratigraphic profile. Five samples were selected from association III and subassociations IIa, IIb, IIc, IId and IIe respectively. Roundness value were determined within a range from 0.125 — 0.062 mm of sieve fraction, using the method proposed by Beal and Shepard (1956). Average roundness values obtained for the (sub-) associations are presented in Table 4.

The relatively high values obtained for the finest sand grains are comparable with those reported by Beal and Shepard from recent coastal dunes, which strongly indicate a prolonged wind abrasion. It is also noteworthy that there is no significant differentiation in the grain roundness between the sandstones within association II. The sandstone association III, interpreted as a beach sediment, shows somewhat smaller roundness values when compared with association II (Tab. 4). This fact is in agreement with some recent observations of other authors; the

Summary of roundness data

Table 4

Zestawienie wartości obtoczenia

Sandstone /sub-/association	Mean roundness value
Association III	0.38
Association II /total/	0.43
subassociation IIa	0.42
subassociation IIb	0.43
subassociation IIc	0.44
subassociation IId	0.45
subassociation IIe	0.41

roundness of dune sand is usually better than that of beach sand associated with it. This difference may be explained as being due to selective sorting in the swash-backwash zone. Such an explanation, however, would not be conformable to recent opinions on the mechanism of sorting in the latter zone. Therefore, it is difficult to explain clearly the results obtained in this study. In spite of the fact that, according to Krumbein (1942), the roundness itself is not the factor in selective sorting, yet because of the correlation between sphericity and roundness the selective sorting to sphericity also results in roundness sorting. In the present study the problem has not been studied in detail, so is difficult to explain the observed roundness differentiation. The difference, however seems to be environmentally sensitive.

Detrital quartz grains form the selected sandstone samples were examined by means of scanning electron microscopy to help the interpretation of sedimentary environments. In the present paper, however, some general conclusion have been presented only. The environmental interpretation of the quartz grain textures is complex, due to the presence of layers of precipitated silica and/or of solution features, either of them tending to obscure the previously formed mechanical textures. A common feature of almost all sandstones is a series of thin, parallel plates (upturned cleavage plates), either continuous or discontinuous, usually oriented at some angle to the grain surface. These are textural characteristics of an aeolin abrasion and, particularly, of the „hot" desert conditions (cf. Margolis, Krinsley, 1974). They are usually modified or obliterated by a chemical action (patina or coating of precipitated silica). In shallow-marine sandstones (association III) several larger quartz grains have been observed to exhibit „V" shaped impact pits which are superimposed and cut across the pattern of upturned plates. These V-shaped depressions are characteristic of a subaqueous abrasion (Margolis, Krinsley, 1974).

DISCUSSION

Summing up the results presented above, it should be stated that the characteristics bipartition of the Weissliegendes sandstones, recently, reported from the Lublin mining district (Jerzykiewicz et al., 1976), is also traceable in the central part of the Fore-Sudetic Monocline.

The present results show that the Wessliegendes sandstones are of a complex origin. Their lower part consists of aeolian sediments, while the upper one is represented by shallow-marine deposits. The latter, transgressive Zechstein sands resulted mainly from the redeposition of aeolian-dune sediments and probably in places, of fluvial deposits (Zechstein Conglomerate of some adjacent areas). The redeposition itself is marked by the presence of: (1) local erosional surfaces, (2) sedimentary structures of water origin, (3) grain-size distributions with well-mixed grain populations and (4) marine fauna and common traces of biogenic activity in the uppermost horizon. Some other features, including rock colouration and heavy minerals, are discussed by the authors in separate papers, to be published latter (W. Nemec, Porębski, 1977; H. Nemec et al., 1978.)

The basement of the transgressive Zechstein clastics consists of a thick sequence of aeolian sandstones (association II) which are underlain by a sequence of fluvial deposits (association I). The aeolian sandstones represent mainly desert-dune sediments, while their uppermost, white portion may represent coastal-dune sediments formed by the predominant offshore winds. The latter suggestions are in agreement with those presented by Brongersma-Sanders (1969, and others) as to the origin of the Zechstein copper-bearing shales, copper ores, and evaporatic sequence in the southern margins of the Zechstein sea in Europe. As a whole, the model presented is simple.

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STRESZCZENIE

Niniejsza praca stanowi próbę interpretacji genetycznej piaskowców białego spągowca w kontekście podścielających je miąższych osadów klastycznych dolnego permu. Ogółem zbadano zmienność litologiczną, cechy teksturalne i struktury sedymentacyjne w profilach 28 otworów wiertniczych, których lokalizację przedstawia fig. 1. W obrębie utworów permskich leżących pomiędzy sfałdowanym podłożem a poziomem łupków miedzionośnych wyróżniono trzy asocjacje litologiczne interpretowane jako osady trzech środowisk sedymentacyjnych: rzecznego (I), eolicznego (II) i płytkomorskiego (III). Występują one w sekwencji transgresywnej.

Utwory rzeczne mają miąższość około 60 m. Składają się one z brunatnoczerwonych: drobno- i średnioziarnistych zlepieńców, piaskowców zlepieńcowatych, przekątnie warstwowanych i masywnych piaskowców, którym towarzyszą na ogół nieliczne przewarstwienia pyłowców i mułowców z pospolitymi szczelinami spękań błotnych. Charakterystyczną cechą tych osadów jest występowanie frakcjonowanych cyklotemów prostych o erozyjnych powierzchniach spągowych i ze słabo rozwiniętym lub zerodowanym członem pelitycznym. Utwory te interpretowane są jako osady rzek roztokowych rozwinięte w peryferycznych partiach stożków napływowych (por. Pokorski, 1976).

Osady rzeczne przechodzą stopniowo w górze w miąższą (około 240 m), monotonną sekwencję czerwonych, w stropie jasnoszarych piaskowców, które pozbawione są praktycznie przewarstwień żwirkowych i pelitycznych. Wśród nich zdecydowanie przeważają (około 90%) drobno- i średnioziarniste piaskowce z wielkoskalowym warstwowaniem przekątnym. Osady te przewarstwione są drobno- i bardzo drobnoziarnistymi piaskowcami z poziomami riplemarków adhezyjnych, rzadziej „bezstrukturowymi". Asocjacja ta reprezentuje głównie utwory wydm pustynnych z niewielkim udziałem osadów o wodnej genezie.

Stropową część badanej sekwencji stanowią piaskowce białego spągowca. W budowie ich zaznacza się charakterystyczna dwudzielność opisana już wcześniej z obszaru Lubińskiego Zagłębie Miedziowego (Jerzykiewicz et al., 1976). Dolna część białego spągowca reprezentowana jest przez jasnoszare, drobnoziarniste, dobrze wysortowane piaskowce z wielkoskalowym warstwowaniem prząkątnym. Łączą się one w spągu

na ogół stopniowymi przejściami w barwie osadu z analogicznie wykształconymi, czerwonymi piaskowcami o niewątpliwie eolicznej genezie. Górna część białego spągowca o miąższości od kilkudziesięciu centymetrów do maksymalnie 20 m wykazuje wiele cech osadu powstałego w wodnym ośrodku depozycyjnym. Wśród nich na uwagę zasługują ciemnoszare, mułowcowe przewarstnienia o grubości od kilku milimetrów do 3 cm wykazujące często deformacje charakterystyczne dla osadu w stanie hydroplastycznym. Występują tu również, choć niezbyt często drobne zestawy lamin płaskich i przekątnych oraz struktury bioturbacyjne.

Zdaniem autorów piaskowce białego spągowca stanowią osad poligeniczny. Ich górna część reprezentuje transgresywne piaski cechsztyńskie powstałe głównie z redepozycji osadów wydmowych, dziedzicząc po nich zasadnicze cechy teksturalne. Obok obecności struktur o wodnej genezie, bioturbacji i fauny morskiej wpływ transgresji morskiej uwidocznił się powstaniem lokalnych powierzchni erozyjnych oraz w nieznacznych zmianach cech teksturalnych osadu (m. in. w drobnym wymieszaniu populacji ziarnowych w rozkładach uziarnienia, obecności V-kształtnych zagłębień na powierzchniach ziarn). Dolna część białego spągowca reprezentowana przez piaskowce z wielkoskalowym warstwowaniem przekątnym stanowi kontynuację dolnopermskiej sedymentacji eolicznej. Biorąc pod uwagę cechy teksturalne oraz pozycję stratygraficzną tej części piaskowców białego spągowca można sądzić, że stanowią one osady wydm nadmorskich.

Czerwona barwa podścielających utworów związana jest z obecnością w nich hematytowego pigmentu, którego powstanie wiąże się z postdepozycyjnymi zmianami składu mineralogicznego osadu (W. Nemec, Porębski, 1977). Biała barwa piaskowców białego spągowca tylko w małej części (lokalnie) może wiązać się z procesami odbarwienia w czasie transgresji cechsztyńskiej lub późniejszej infiltracji wód morskich o redukcyjnym charakterze. Zdaniem autorów brak jest dowodów na to, że zasadnicza część tych piaskowców była kiedykolwiek czerwona.

Na koniec odnotować należy duże podobieństwo w wykształceniu badanej sekwencji osadów dolnego permu do jej odpowiedników w północno-zachodniej Europie i na obszarze Morza Północnego (cf. Glennie, 1972).

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EXPLANATION OF PLATES
OBJAŚNIENIA TABLIC

Plate I — Tablica I

Figs. 1—3. Aeolian cross-stratified sandstones. Note gradual change in rock colour upwards (from fig. 3 to fig. 1) in an interval of about 14 m; bore-hole Pw1
Piaskowce eoliczne z wielkoskalowym warstwowaniem przekątnym. W interwale około 14 m zaznacza się stopniowa zmiana barwy od czerwonej (fig. 3) w dolnej części profilu do jasnoszarej z brunatnymi plamami (fig. 1) w części górnej; otwór Pw1

Figs. 4—5. Adhesion ripples in very fine (fig. 4) and medium-grained sandstone (fig. 5); bore-hole Sw1
Riplemarki adhezyjne w piaskowcach: bardzo drobnoziarnistym (fig. 4) i średnioziarnistym: otwór Sw1

Scale in centimeters
Skala w centymetrach

Plate II — Tablica II

Figs. 1—3. Transition from the white, large-scale cross-stratified sandstone to the sandstone association III; bore-hole Su1. White, well sorted cross-stratified sandstone (fig. 3) is erosionally truncated at the top (fig. 2), and overlain by structureless sandstone with occasional mud laminae (fig. 1). In the center of the last figure, soft-sediment deformation consisting of small folds is visible
Przejście od białych, przekątnie warstwowanych piaskowców do piaskowców asocjacji III; otwór Su1. Przekątnie warstwowany piaskowiec (fig. 3), erozyjnie ścięty w stropie (fig. 2) przykryty przez „bezstrukturowe" piaskowce ze sporadycznymi wkładkami mułowymi. Laminy mułowcowe wykazują deformacje typu małych, odkorzenionych fałdów (fig. 1)

Fig. 4. Bioturbations in very fine, dolomitized sandstone; bore-hole Pr1
Struktura bioturbacyjna w zdolomityzowanym, drobnoziarnistym piaskowcu; otwór Pr1

Fig. 5. An example of silt-enriched laminae in the white, cross-stratified sandstone; bore-hole B7
Piaskowiec biały z laminacją przekątną podkreśloną ciemnymi smugami wzbogaconymi w materiał pylasty; otwór B7

Scale in centimeters
Skala w centymetrach

Plate III — Tablica III

Examples of soft-sediment deformation in sandstones of association III
Przykłady struktur deformacyjnych w piaskowcach asocjacji III

Fig. 1. Over-steepened, partly discontinuous and disrupted cross-laminae; bore-hole R9
Zestromione, częściowo poprzerywane laminy przekątne; otwór R9

Fig. 2. Mud flame in very fine grained, structureless sand; bore-hole B7
W obrębie bardzo drobnoziarnistego, „bezstrukturowego" piaskowca lamina mułowcowa zdeformowana w kształcie płomienia; otwór B7

Fig. 3. Superimposed, partly loaded ripples (top), horizontal mud lamina disrupted by a small sandy injection (middle), and a poorly visible flame structure (bottom); bore-hore R9

U góry widoczne nasunięte, częściowo pogrzężnięte riplemarki; w środku płaska lamina mułowcowa przerwana małym diapirem piaszczystym; u dołu słabo widoczna struktura płomieniowa; otwór R9

Fig. 4. Convolute-like continuous deformation; bore-hole Ls1

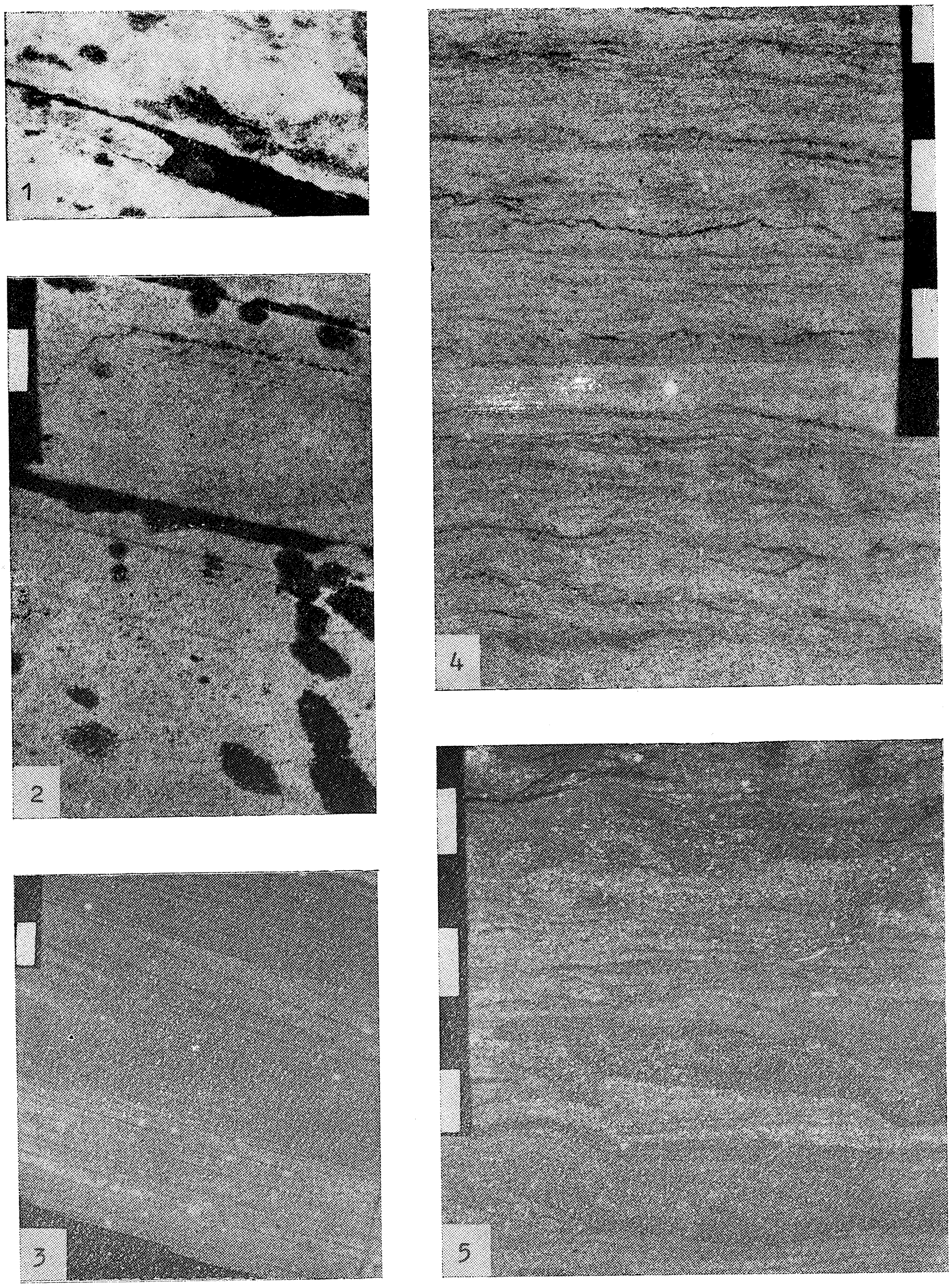
Przykład deformacji, w wyniku której sfałdowane laminy piaszczysto mułowcowe nie tracą ciągłości: otwór Ls1

Fig. 5. Discontinuously deformed mud laminae; in the center a sandy intrusion is visible; bore-hole B16

Przykład deformacji nieciągłej; w środku słabo widoczna intruzja piaszczysta; otwór B16

Scale in centimeters

Skala w centymetrach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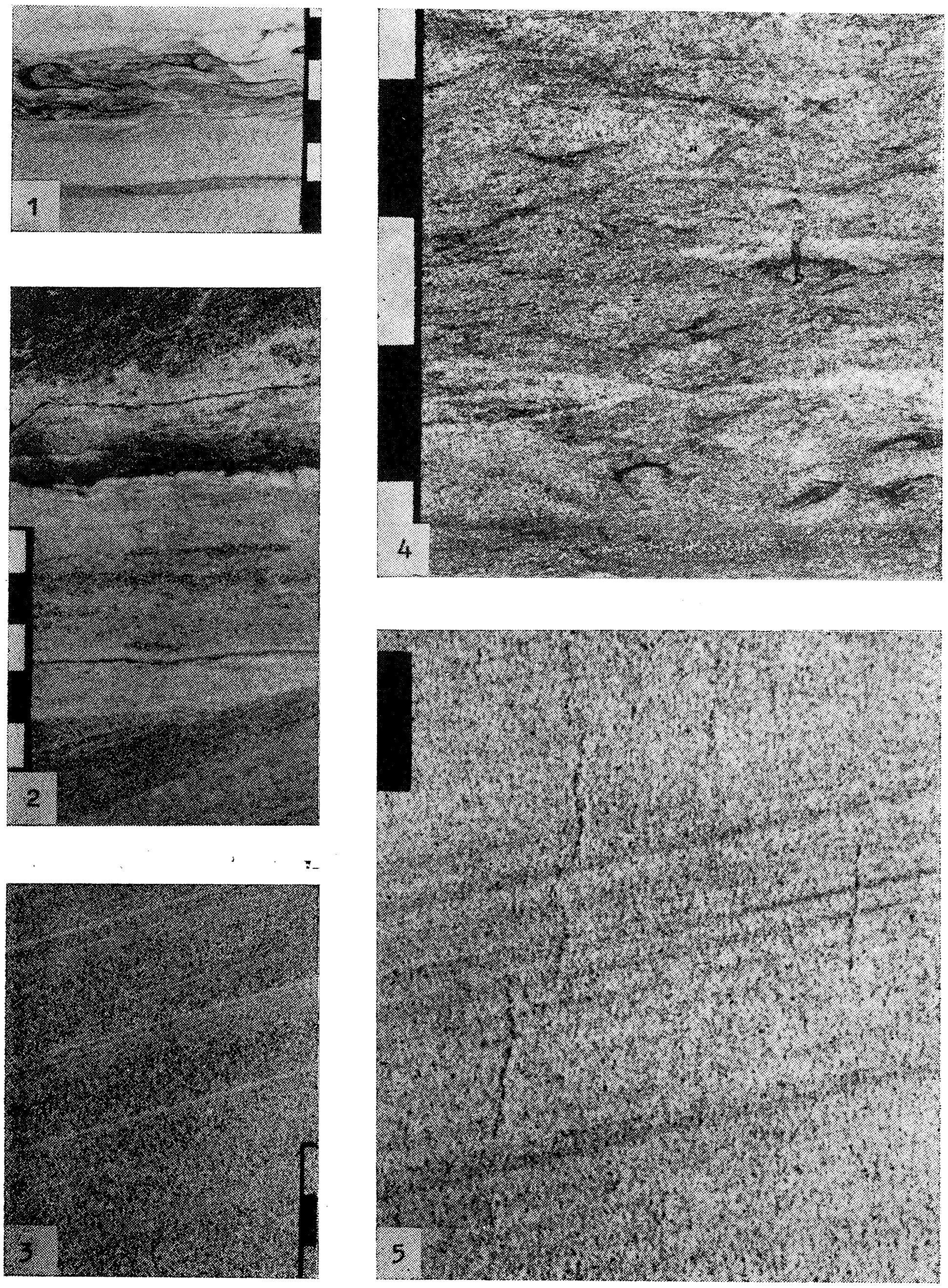
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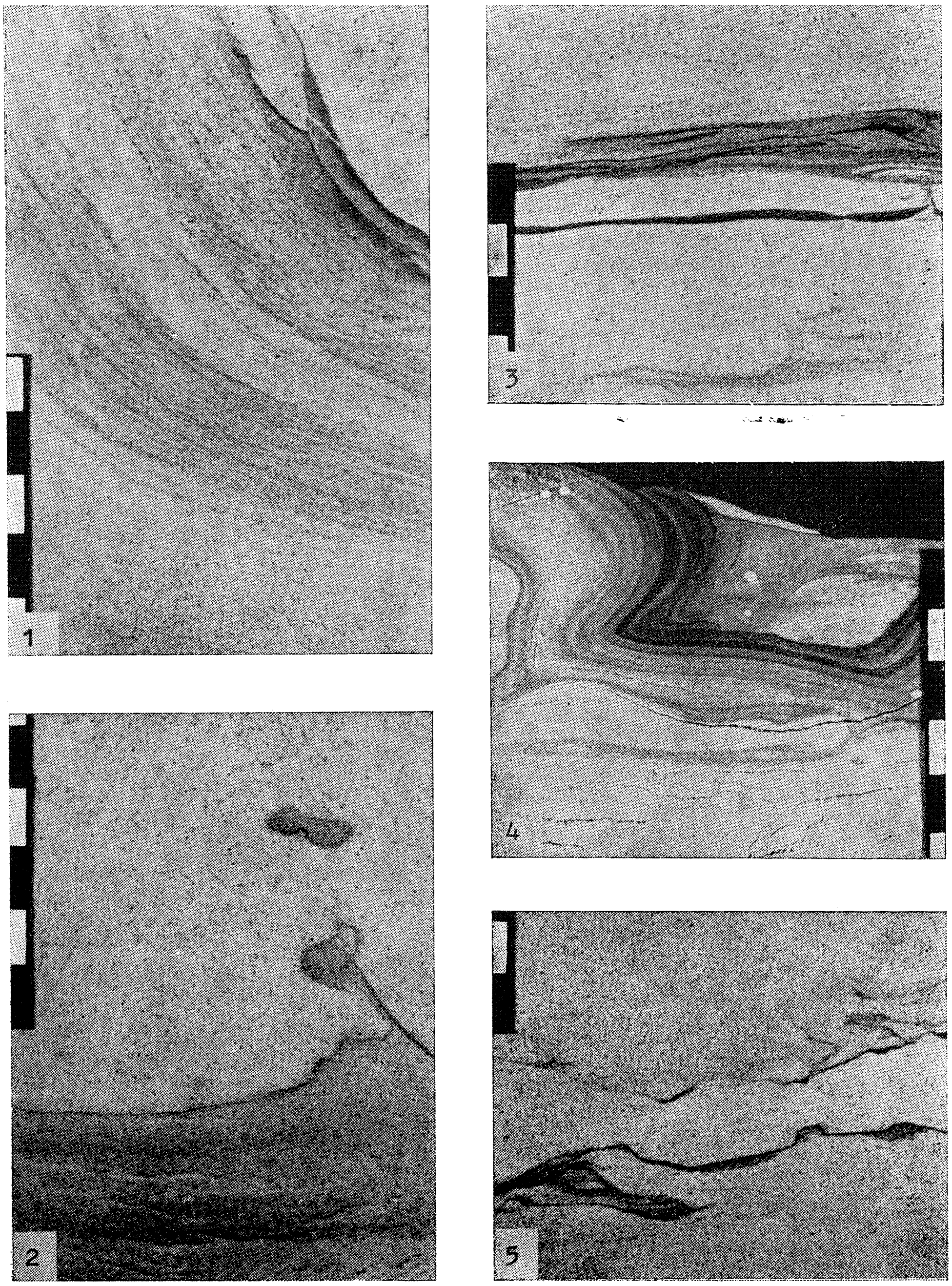
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