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

3. INTERPRETATION IN LIGHT OF HEAVY-MINERAL DATA

(9 Figs.)

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

3. *Interpretacja w oparciu o minerały ciężkie*

(9 fig.)

Abstract. Heavy-mineral assemblages in the upper shallow-marine portion of the Weissliegendes sandstones differ from those of the underlying aeolian sandstones in: (1) higher heavy-mineral concentration, (2) enrichment in heavy constituents and, (3) lack of hydraulic equilibrium among the mineral populations. Such differences are explained by concentrating processes which reworked the primary aeolian sands during marine transgression. The nature of concentrating mechanism and heavy mineral provenance, are discussed in detail.

INTRODUCTION

The heavy mineralogy of the Permian sandstone samples is examined as part of a comprehensive study to define and explain the origin of the Weissliegendes sandstones. The sandstones investigated lie in the Permian clastic sequence (Fig. 1) of the Fore-Sudetic Monocline (SW Poland), the sedimentary sequence being known mainly from bore-hole records in the region (Fig. 2). In parts 1 and 2 of this paper (Nemec and Porębski, 1977a, b) the sedimentary environment of the Weissliegendes sandstones and the origin of their colouration are examined in detail. The results obtained show that the Weissliegendes sandstones are of complex origin. Their upper portion consists of shallow-marine deposits, while their lower portion represents an uppermost, non-reddened, part of the underlying thick aeolian sandstones. In the present part of the paper an attempt is made to examine and interpret, on the basis of heavy-mineral data, the sources and processes which have determined the Weissliegendes sandstones.

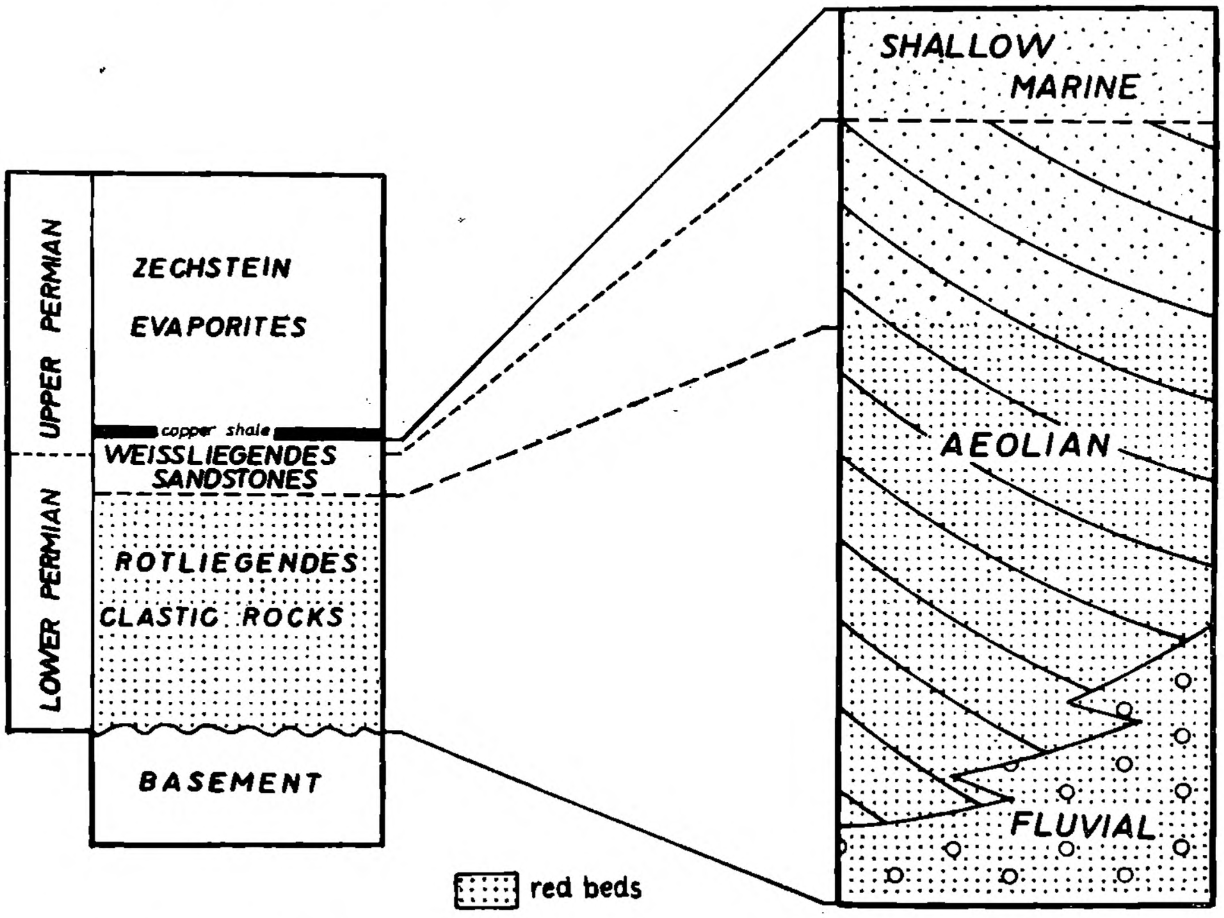

Fig. 1. General stratigraphy of the Permian, Fore-Sudetic Monocline; no scale

Fig. 1. Zgeneralizowany profil stratygraficzny utworów permskich monokliny przedsudeckiej; bez skali

Heavy mineralogy of the Permian Weissliegendes sandstones was examined petrographically, in various areas of the Fore-Sudetic Monocline, by several authors (e. g. Krasoń and Grodzicki, 1964, 1965; Grodzicki et al., 1967; Przybyłowicz, 1968; Jerzykiewicz et al., 1976), but only few attempts were made to interpret the data from environmental point of view. The present study mainly concerns the heavy mineralogy of the Weissliegendes sandstones and reviews some of the conclusions reached in the previous parts of the paper. The primary purpose of this study is to provide supplemental data concerning the sedimentary environment of these sandstones. The data obtained appear to confirm the concept of complex origin of the Weissliegendes sandstones and fit well the environmental model previously developed, on independent grounds (Nemec and Porębski, 1977, 1977a). Aeolian mechanism of deposition of the large-scale cross-stratified sandstones (including the lower portion of the Weissliegendes sandstones) is supported,

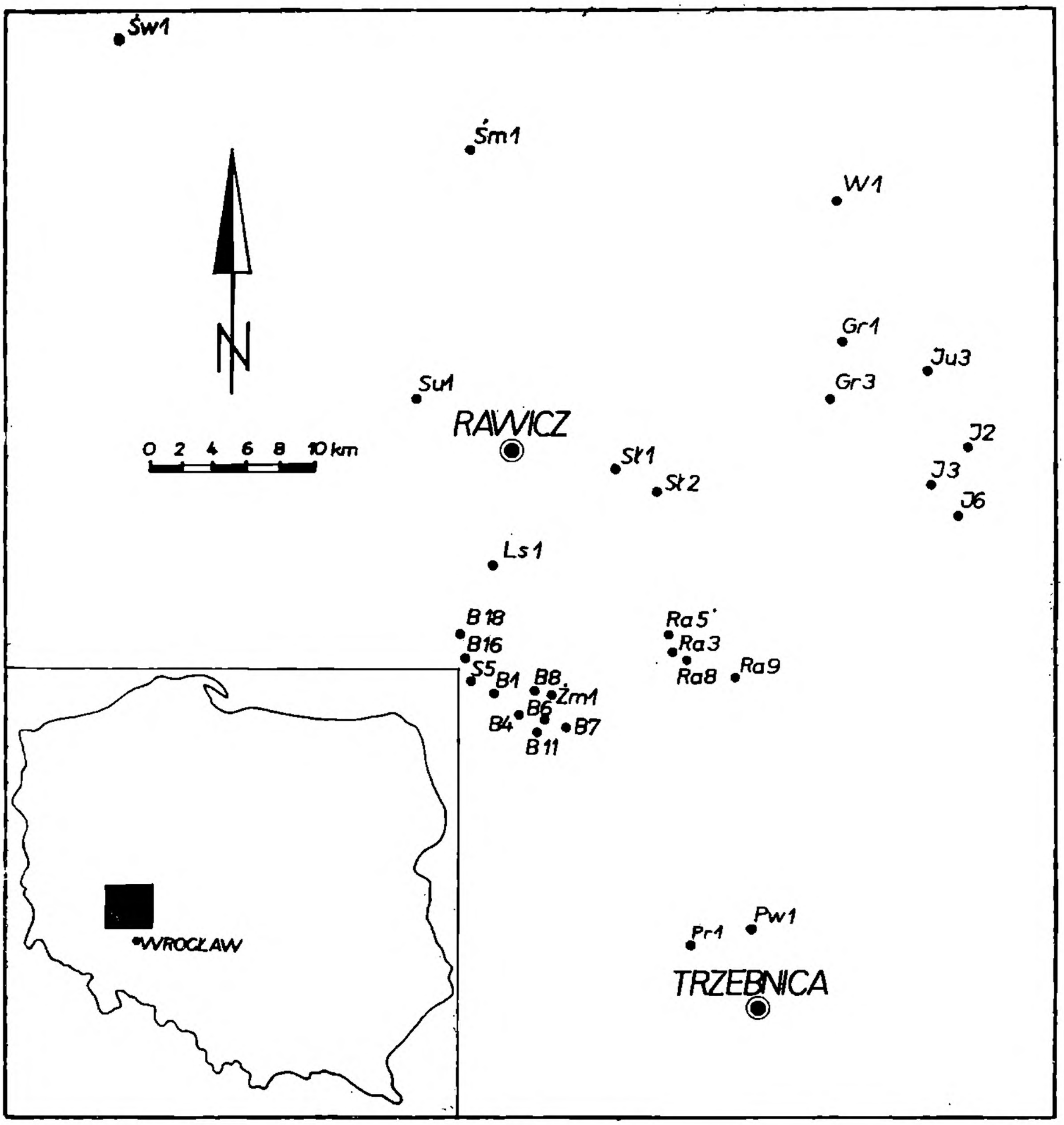

Fig. 2. Index map showing location of bore-holes

Fig. 2. Mapa sytuacyjna otworów wiertniczych

while an environment of wave-dominated shoreline is confirmed with respect to the upper (shallow-marine) portion of the Weissliegendes sandstones. This study has also led to an dentification of the main source rocks, and their relative contribution for the Permian clastic sediments in the area.

METHODS

Samples were collected from the three intervals of the Permian sandstones: reddened aeolian sandstones, non-reddened aeolian sandstones, and shallow-marine sandstones (see Fig. 1). Disaggregated sandstone samples, having an initial minimum weight of about 100 grams, were split and small subsamples, each of 20 grams, were used for further analysis. The heavy fraction was extracted from bulk of the subsample. In total the heavy-mineral composition of 72 samples was analysed.

In order to reduce errors, the analyses were not restricted to certain size fraction(s). This is because many authors (e. g. Arps and Kluyver, 1969) suggested 0.5 mm as an upper limit of the fraction analysed and no Permian samples studied were coarser. Every sample was separated using bromoform (S. G. = 2.89) into a light and a heavy fraction. The heavies were mounted in clearax (R. I. = 1.66) and the slides were counted by line-counting. The percentage and size distribution of the detrital heavy minerals (except mica and chlorite) have been determined by identification and registration of 100 mineral grains; grain's shorter axis was consequently measured for size analysis (see e. g. Griffiths, 1967, p. 64). Heavy mineral grains are usually counted in sets of 200 to 300 grains, to minimize counting errors. In order to control the potentially higher error in our 100 grain counts, we have counted in subsets of 25 grains using an automatic point counter (see e. g. Swift et al., 1971). Griffiths (1967, pp. 209—213) has shown that, assuming a binomial frequency distribution of a given mineral species on the slide, such a nested sampling procedure will reduce the absolute counting error by a factor of 0.4. The difficulty in this apporently more efficient counting system lies in insuring that no sorting of the heavy fraction occurs during separation and mounting, so that each species will truly have a binomial frequency distribution on the slide. In our study, the inefficiency in the number of grain counts was also tentatively compensated by the two factors: (1) the extraction of the heavy fraction from bulk of the sample, and (2) a fairly dense sampling that allowed a better control of the distribution of heavy minerals in the vertical profile of the sandstones, in relation to the strong variability tested among nearby samples.

The above method was adopted in order to reduce the factors that disturb heavy-mineral correlations (see also Van Andel, 1959; Gazzi, 1965; Rosen, 1969; De Jong and Poortman, 1970; Rizzini, 1974). McIntyre (1959), Cordes (1966) and Friis (1974) also microscopically differentiated and sized their samples, obtaining satisfactory results.

HEAVY-MINERAL COMPONENTS

Heavy minerals generally show a very low concentration in the Permian sandstones and their weight percentages range from 0.05 to 1.1%, being usually less than 0.6%. Although showing rather poor and/or irregular vertical variations in the sandstone sequence, the heavy-mineral content appears to be relatively higher in the upper (i. e., shallow-marine) portion of the Weissliegendes sandstones. In the latter portion of the sandstones also some thin (1—3 mm) dark heavy mineral-rich laminae have been sporadically observed, these having a concentration of the heavies as high as several per cent.

Zircon is the most abundant non-opaque heavy mineral in the Permian sandstones and its amount averages 20.65 number per cent of the heavy fraction (standard deviation, S. D., of 21.29%), but it can constitute up to 70%. Zircon occurs as colourless waterclear, sometimes brownish, grains. These are well to very well-rounded, while euhedral and subhedral, usually zoned, forms are very rare. Many zircon grains, particularly the well-preserved micro-crystals, show inclusions of fluid, glassy blebs, and crystaline minerals which include apatite, rutile and smaller zircon crystals. The well-rounded colourless, non-zoned, grains are relatively free from inclusions. This suggests different primary source rocks of contrasting age and composition (see e. g. Baker, 1962).

Tourmaline is the next abundant transparent heavy constituent and its amount widely ranges from 0 to 50% of the heavy fraction, averaging 7.71% (S. D. = 10.41%). Tourmaline occurs as well-rounded grains and its pleochroism varies greatly: from pale yellow and pale olive to brownish and brownish green, and from pale pink to dark brown. The grains are well abraded and frequently have a frosted appearance and minutely pitted surfaces. As zircons, the tourmalines also show small inclusions of other crystaline minerals.

Apatite averages 1.87% of the heavy fraction (S. D. = 3.50 %), being sometimes absent in the sample. It occurs as white or yellowish green grains which are either very well-rounded („egg-shaped" to almost spherical) forms or poorly rounded, short euhedral (stumpy) prisms. This is also an indication of two, at least, different source rocks.

Garnet is present in some of the samples, averaging 0.39% of the heavy fraction (S. D. = 1.81 %) and only sporadically exceeding several per cent. It occurs colourless or pinkish grains. These are relatively well-rounded but often reveal such features as surficial etch-pitting and grooving.

In several samples also well-rounded grains of amphibole, mainly hornblende, are present in small amounts (mean content, M. C., equals 7.7 % of the heavy fraction; S. D. = 1.47 %). Small percentages of well-rounded staurolite grains (M. C. = 0.18 %; S. D. — 0.64%), showing pale („straw") yellow to dark yellow pleochroism, and sub--rounded grains of epidote (M. C. = 0.94 %; S. D. = 3.47 %) have been noted in many samples. More sporadically occur the grains of kyanite and rutile.

Detrital opaques are often the most abundant heavy minerals present in the sandstone samples, averaging as much as 66.94 % of the heavy fraction (S. D. = 32.02 %). These include well-rounded grains of magnetite and (sub-)rounded grains of leucoxene and ilmenite, and also, in places, rounded earthy grains of hematite. It is often difficult to identify, optically, all of the opaque grains present in the Permian sandstones; some of the grains seem to be iron sulfides and amorphous ferric hydrates.

HEAVY-MINERAL ASSOCIATIONS AND PROVENANCE

Heavy-mineral associations of the Permian sandstones were tested by the means of principal component analysis. The heavy mineral composition of each sandstone sample was arranged in a rectangular array with samples down the columns and the heavy minerals in the rows. The data matrix was reduced to a symmetric correlation matrix of the order 8 by the product-moment method with unities in the diagonal cells. Although the use of communalities in the diagonal cells would have been more appropriate to achieve the aim of reducing the rank of correlation matrix, keeping unities is the only practicable proposition (Cooley and Lohnes, 1962) in view of the facts that communalities are neither known nor easily estimated a priori, and also that the goal of reducing the order of correlation matrix is not missed, because some of the components which prove to be negligible (e. g. Cattell, 1965, p. 198; Patro and Sahu, 1974, p. 62) can be disregarded.

A principal-component analysis was performed on the R-mode, using slightly modified technique of Hotelling (1933). Due to the criterion of Rao (1965), Kendall (1965) and Sahu (1973), the extraction of factors was stopped when the extracted factors constituting a matrix accounted for 85—90% of the variance of the system where the minimum variance of cumulated eigenvalues also occurred. An initial factor matrix was rotated to simple structure using a minimum entropy criterion (Nemec and Peroń, 1977). On this basis the rotated principal-factor matrix (Table 1) consisting of five retained factors, with their eigenvalues and percent of variance explained, was obtained for the Permian sandstone samples. The rotated eigenvalue associated with a rotated factor was evaluated by summation of squares of its rotated loadings in the rotated factor matrix. All statistical computations were performed on an ODRA 1204 computer using a program written in ALGOL 60 for the R-mode principal component analysis.

A factor in factor analysis signifies the existence of a causal phenomenon in the real physical world. The variable(s) on which a rotated factor is significantly loaded in the rotated factor matrix reveal(s) the rotated factor's identity with a causal process. A study of the rotated loadings of the different heavy minerals on different factors in Table 1 reveals the heavy mineral assemblages extracted. The present knowledge of the basement rocks in the region helped considerably in making possible the correlations between the mineral assemblages extracted and their potential source rocks.

Factor I is highly loaded on nearly all of the heavy constituents, except only for the low positive loading on epidote and the negative loading on heavy opaques. This highly composite association suggests a complex of older sedimentary rocks as a major source for the detrital heavies, particularly for zircon and tourmaline, in the Permian sandstones. Variance explained by this factor equals about 41%. This heavy-mineral province can be easily related to the folded and erodded Lower Carboniferous clastic rocks which form the basement of the Permian sequence in most of the study area (see also Oberc, 1972; Nemec, 1973; Malik, 1974).

Factor II is heavily positively loaded on apatite, epidote, amphibole, zircon and tourmaline, while showing negative loadings on the other heavies. This heavy-mineral association seems to be characteristic, in general, for acid igneous rocks; the Lower Permian volcanic rocks, well-known from many adjacent areas (see e.g. Nemec, 1973, 1976; Przybyłowicz, 1973), are very likely here. This volcanic rock-complex represents, probably, the next important source for the heavy minerals present in the Permian sandstones and its relative contribution to the basin can be estimated, quasi-quantitatively, as 20% (see Table 1).

Factor III is highly positively saturated with epidote, amphibole, garnet, apatite, staurolite and opaques, and this mineral assemblage is usually typical for high-rank metamorphic rocks (see e.g. Baker, 1962, p. 90). Regionally, this factor can be generally related to the metamorphic rocks of the Fore-Sudetic Block area, i.e., to the originally main southern hinterland adjacent to the discussed part of the Permian sedimentary basin (see also Oberc, 1972). These rocks contributed to the Lower Permian basin in slightly more than 12%, being also the third important source for heavy minerals and the major source for detrital opaques.

Factor IV affected the heavy-mineral composition of the Permian sandstones in a manner similar to the factor II. This can be approximately interpreted as older, acid crystalline rocks and directly related to the granitoides which have been recorded, in a number of boreholes, in the basement of the region (e.g. Oberc, 1972; Pinkosz, 1973; Sachanbiński, 1977). These rocks contributed as a source for detrital heavies and determined the heavy fraction in probably slightly more than 10%, being also the third important source for detrital opaques.

Factor V is positively loaded on amphiboles, tourmaline and opaques. The lack of significant loadings on the remaining heavies indicates that this factor may be interpreted as a complex of schists, most prabably mica schists (cf. Baker, 1962). Such a rock complex is known, from borehole records, to be present in the basement of the Permian sequence and is represented by folded Early Paleozoic rock sequence (see Oberc, 1972; Nemec and Porębski, 1977 a). These rocks contributed in probably about 10% (see Table 1) to the composition of the heavy fraction and were the second important source for detrital opaques.

Principal component matrix with five rotated factors Table 1

Macierz składowych głównych z pięcioma zrotowanymi czynnikami Tabela 1

Variables:	Factors:				
	I	II	III	IV	V
Zircon	.8200	.2404	-.3603	.0540	-.2414
Tourmaline	.7037	.1183	-.2423	-.4302	.3237
Apatite	.4990	.4233	.2733	.5977	-.2090
Garnet	.5486	-.7620	.2373	-.0325	-.0375
Amphibole	.5579	.1020	.3808	.2025	.6645
Staurolite	.5981	-.7183	.1332	.0339	-.2211
Epidote	.1530	.4285	.6787	-.5011	-.2788
Opaques	-.9256	-.2522	.2124	.0849	.1089
Per cent Sums of squares:	40.83	20.07	12.34	10.59	9.85
Cumulative per cent Sums of squares:	40.83	60.90	73.24	83.83	93.68

The above five factors (I—V) account for about 94% of the variation in heavy mineral composition of the Permian sandstones. The remaining 6% may be discarded as ambient noise of the system. This high degree of explanation clearly suggests that a satisfactory description has been obtained. The relative importance of the factors is judged on the basis of the rotated eigenvalues of the rotated matrix and the variance percent explained by the factors. The relative importance of the five mineral provinces considered may be estimated as a ratio 4 : 2 : 1 : : 1 : 1. This outcome of factor analysis seems to be environmentally and regionally sensitive and in keeping with the original heavy-mineral provinces and supply relations. This study demonstrates the utility of factor analysis in the interpretation of sediment provenance from relatively uniform heavy-mineral data.

STABILITY OF HEAVY MINERALS

It is clear from the above section that differences in petrographical composition within the source area caused the main variations in the petrographic composition of the sediments, including their heavy mineralogy. But there are several additional physical factors which may inflict great variations on a heavy-mineral suite. For example, all minerals are not equally affected by abrasion during transportation, because the rate of mechanical wear of different minerals is controlled largely by their hardness, cleavage, and tenacity (see e.g. Baker, 1962). By selective abrasion, softer, more cleavable minerals tend to be progressively eliminated, leading to enrichment in more durable harder species. From recent publications the heavy minerals may be approximately listed according to their abrasion resistance (order of resistance; see Friese, 1931; Baker, 1962, p. 13, Tab. 2). The relationships between heavy-mineral percentage, order of abrasion resistance and grain roundness in the Permian sandstones are illustrated on Fig. 3. From the diagrams is seen that no clear, or regular, relations exist between the above characteristics of the heavy fraction. The data strongly suggest a complex source area with high differences in its petrographic composition, time of erosion and rate of contribution as a source for detritus; distance of transport was, perhaps, also a factor. This is in full agreement with the results of factor analysis (see previous section).

The order of persistence, i.e., stability to weathering, of heavy minerals is related to their chemical stability, and is not directly related to their order of resistance to abrasion. The relationships between the heavy mineral percentages and their generally accepted (see Baker, 1962, p. 12, Tab. 1; Friis, 1974, p. 207, Tab. II) order of persistence are shown in Fig. 4. From the histograms, one striking feature seen is the high percentage of stable minerals, such as zircon and tourmaline, when compared with the very low percentages of less stable constituents. Significant content of apatite, the least stable heavy constituent, in some of the samples is explained by the presence of two, at least, different „generations" of this detrital mineral in the Permian sandstones. These apatite generations are attributed to different source rocks which were erodded, and contributed to the basin as independent sources for detritus, in different and widely separated time periods. The apatite percentages now observed are thought to be mainly due to the presence of relatively younger, first-cycle detritus which was transported, probably, on a relatively short distance. This interpretation is in full agreement with the microscopic obervations and results of factor analysis.

In many samples of the white, both aeolian and shallow-marine, sandstones also the extremely unstable amphiboles (e.g. hornblende) and unstable epidote and garnet are present in small amounts. The general paucity of these minerals in the underlying sediments may be directly related to, and well-explained by, the processes of post-depositional weathering of the sediments (see Nemec and Porębski, 1977 a). As previously evidenced by the authors, biotite and chlorite were also

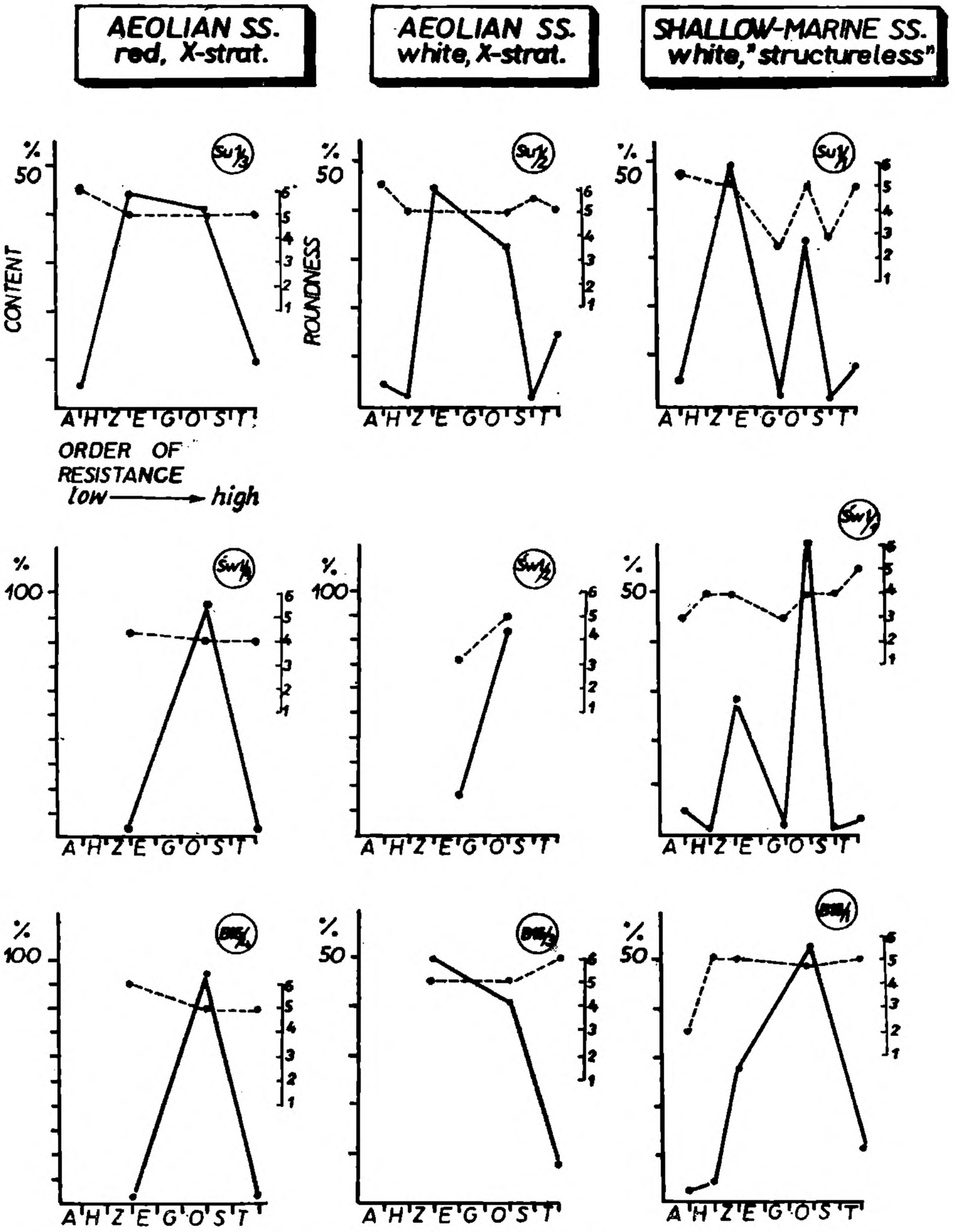

Fig. 3. Percentages of heavy minerals related to their roundness and order of resistance to abrasion. Heavy minerals: A — apatite; H — amphibole (mainly hornblende); Z — zircon; E — epidote; G — garnet; O — opaques (mainly magnetite); S — staurolite; T — tourmaline

Fig. 3. Procentowa zawartość minerałów ciężkich w stosunku do ich obtoczenia i względnej odporności na abrazję. Minerały ciężkie: A — apatyt, H — amfibol (głównie hornblenda); Z — cyrkon; E — epidot; G — granat; O — minerały rudne (głównie magnetyt); S — staurolit; T — turmalin

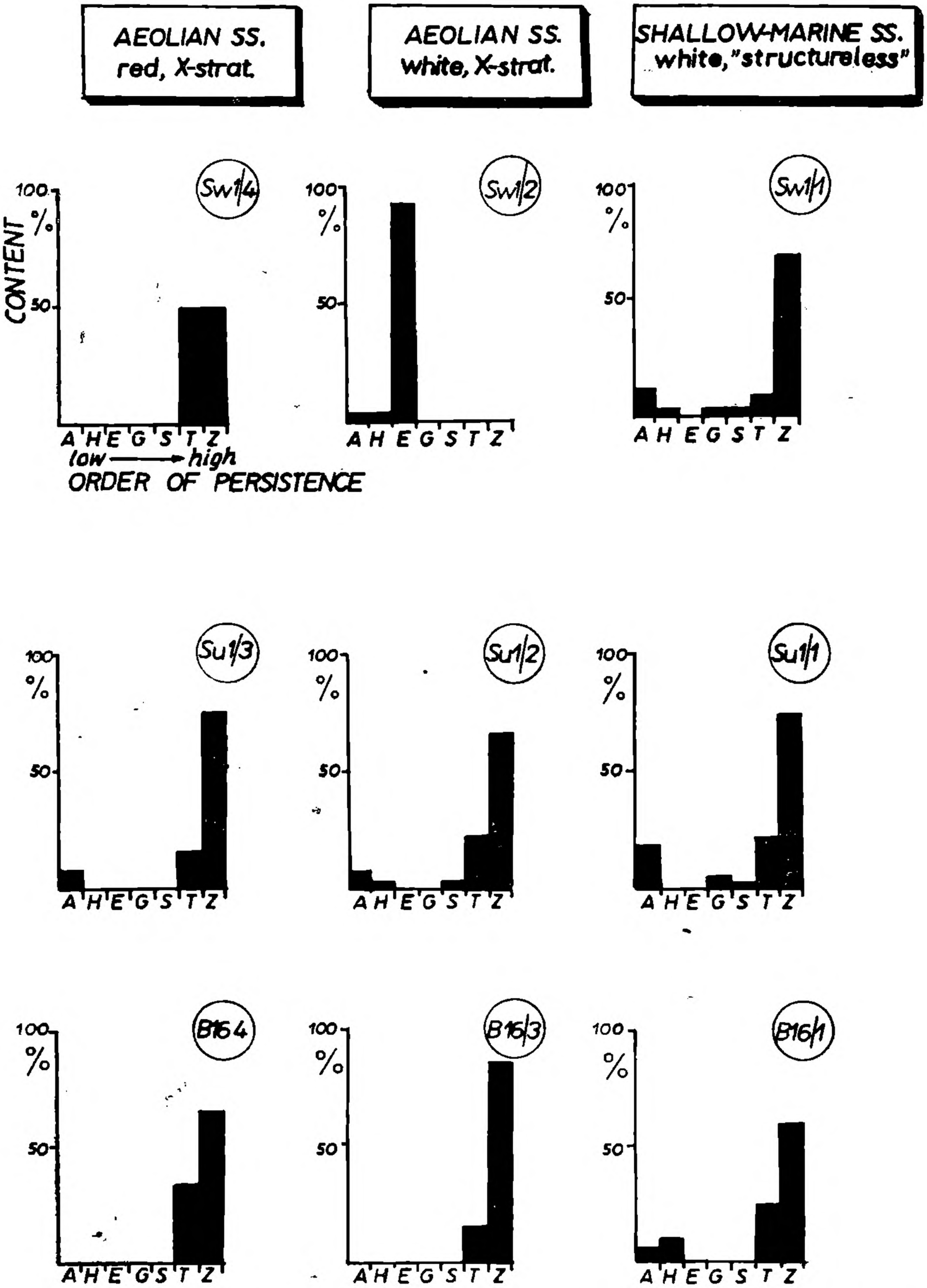

Fig. 4. Percentages of heavy minerals related to their order of persistence (stability to weathering). Letter symbols as in Fig. 3

Fig. 4. Procentowa zawartość minerałów ciężkich w stosunku do ich względnej odporności na wietrzenie. Symbole literowe jak na fig. 3

largely destroyed, in now red sediments, by these post-depositional processes. It is thought that the post-depositional weathering played an important role and was closely connected to the process of reddening of the Permian sediments. There are indications that this weathering occurred, in a significant rate, shortly after deposition of the sediments, possibly syn-depositional. From the available data, a late weathering seems not to be an important controlling factor.

The early post-depositional weathering partly reduced the original heavy-mineral association of the now red sandstones to a more stable association. The difference in the degree of postdepositional weathering between the reddened and the non-reddened deposit, although not very distinct and manifested by a relatively few heavy species, can be still observed in the sequence. More striking is the difference between the lower and the upper portion of the Weissliegendes sandstones. For many reasons, however, this difference in heavy-mineral suites cannot be satisfactorily explained by the post-depositional weathering and it seems to be determinated mainly, if not only, by the transporting/depositional processes. The problem is discussed, in detail, in the next section.

COMPARISON OF HEAVY-MINERAL SUITES

The data obtained show that the heavy-mineral suites of the Permian sandstones, although generally similar in their mineral composition, show a fairly clear differentiation as regards the relative amounts of the individual components and the total content of the heavies in the sandstones (Figs. 5 and 6; see also Nemec et al., 1977). From the diagrams (Fig. 6) is seen that the upper (i.e., shallow-marine) portion of the Weissliegendes sandstones differs from the underlying (aeolian) portion by: (1) a relatively large number of the heavy-mineral species present in significant amounts, and (2) a slightly higher weight percent of the heavies. These data clearly suggest that the deposition of the sandstone shallow-marine member was accompanied by a sort of processes which resulted in a fairly significant concentration of the heavy minerals in this transgressive deposit. Przybyłowicz (1968, pp. 811—812) also noted that the Weissliegendes sandstones differ from the underlying sediments by the proportions among the heavy species (mainly zircon, tourmaline and rutile). Although the data obtained by this author did not yield out any sufficiently clear results (because were collected and analysed with a traditional assumption that the Weissliegendes sandstones are environmentally uniform and entirely represent a marine deposit) she made also a suggestion about an effect of concentrating processes. This is in full agreement with the present results.

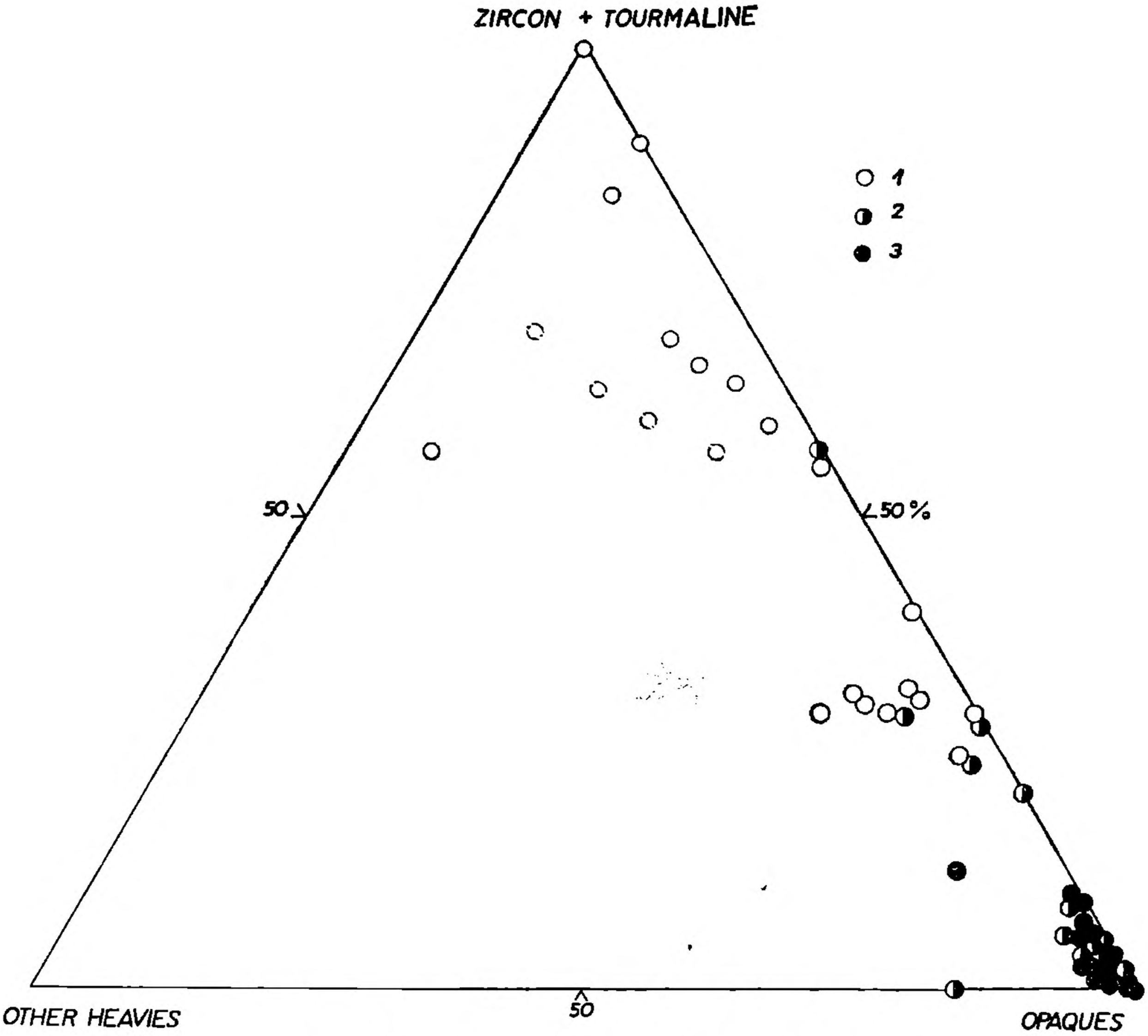

Fig. 5. Modal composition of heavy fraction, Permian sandstones. 1 — white „structureless" ss., 2 — white cross-stratified ss., 3 — red cross-stratified ss.

Fig. 5. Modalny skład frakcji ciężkiej w piaskowcach permskich. 1 — białe piaskowce „bezstrukturowe"; 2 — białe piaskowce przekątnie warstwowane; 3 — czerwone piaskowce przekątnie warstwowane

Recognition of the nature of the concentrating mechanism, as indicated by the granulometry of the initial and resultant deposit, is one of the purposes of this study. The subject, itself, is important because it may throw some light on the problem of processes which laid down the shallow-marine, transgressive, portion of the Weissliegendes sandstones.

Size distributions of heavy constituents were analysed in order to study the problem of density /grain size hydrodynamic equivalence in the polymineralic Permian sandstones. Quartz was chosen to be the basis for settling equivalence comparisons. It can be argued, however weakly, that as deposition is an inverse analogue of entrainment, all grains hydrodynamically equivalent to the basic grain population (quartz) be-

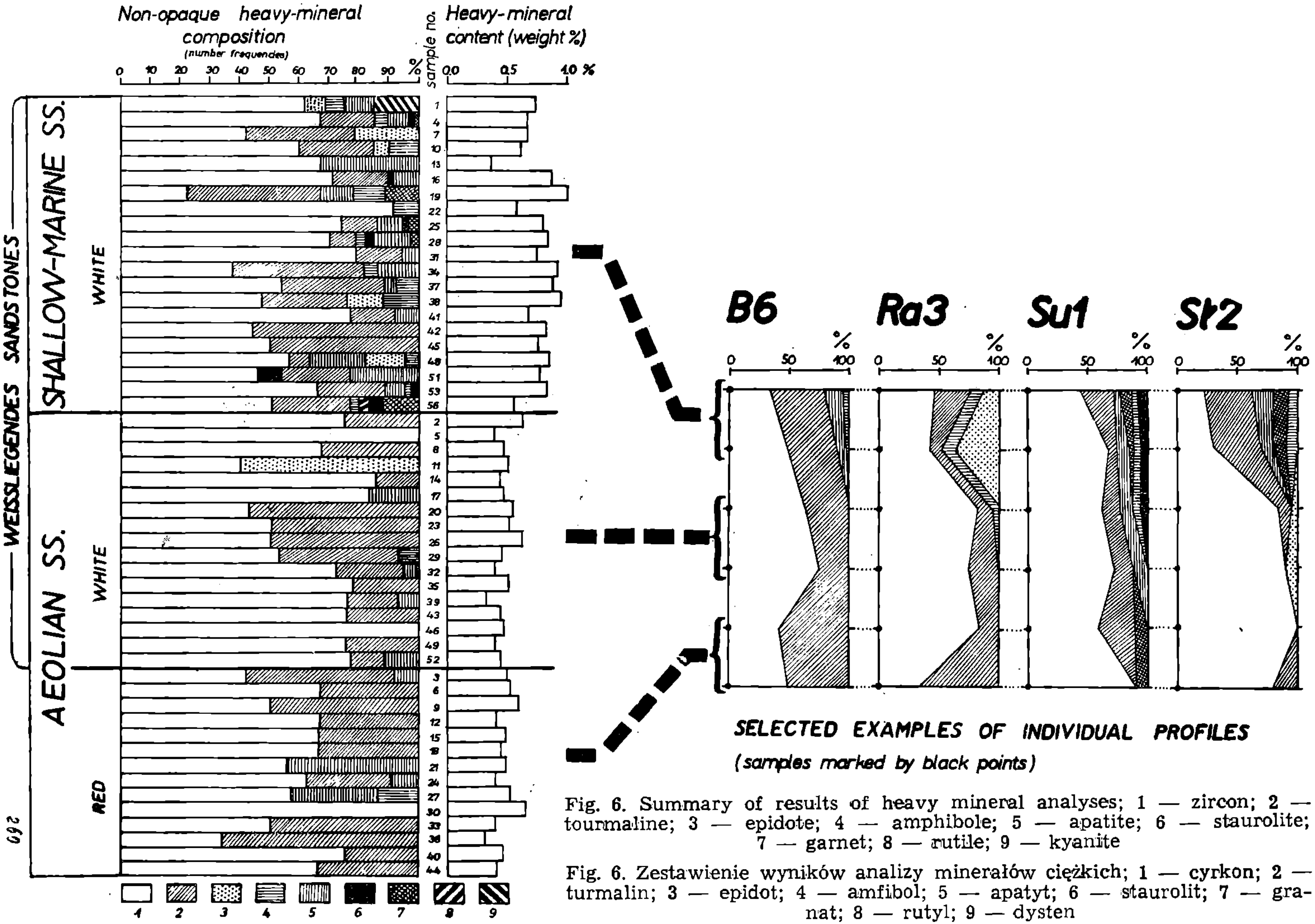

Fig. 6. Summary of results of heavy mineral analyses; 1 — zircon; 2 — tourmaline; 3 — epidote; 4 — amphibole; 5 — apatite; 6 — staurolite; 7 — garnet; 8 — rutile; 9 — kyanite

Fig. 6. Zestawienie wyników analizy minerałów ciężkich; 1 — cyrkon; 2 — turmalin; 3 — epidot; 4 — amfibol; 5 — apatyt; 6 — staurolit; 7 — granat; 8 — rutyl; 9 — dysten

ing entrained should also be entrained if they are available. The matter of concentration was approached from the standpoint of changes in the heavy-mineral populations. Settling equivalence comparisons were made using McIntyre's (1959) formula. A sample mean grain size was computed for each of the heavy species in eight measured sandstone samples and an overall (total) mean grain size was also determined (optically) for quartz. The quartz mean (± standard deviation) was used to generate, theoretically, equivalent mean sizes for each analysed mineral. The results are presented in Figs. 7 and 8.

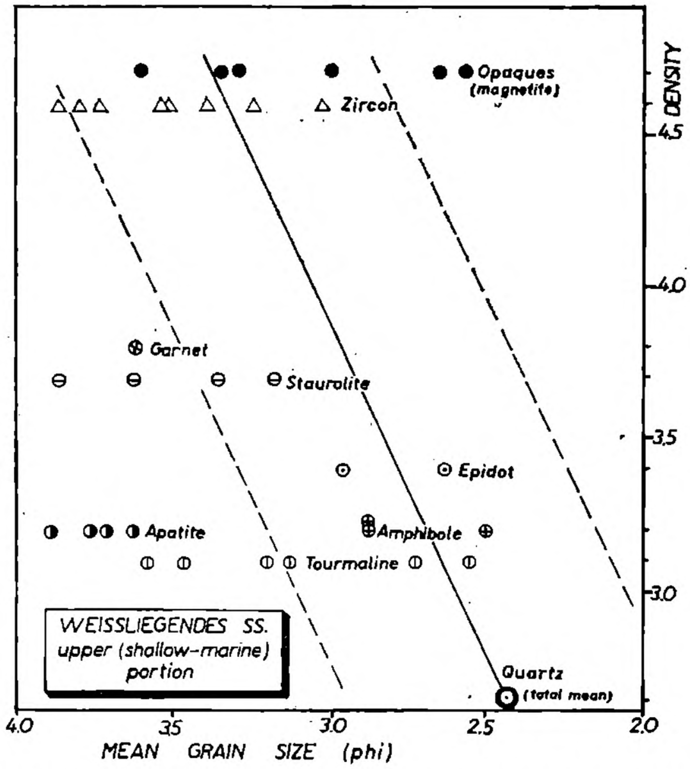

Fig. 7. Plot of density versus mean grain size for the aeolian portion of the Weissliegendes sandstones. The slant line is the settling equilibrium line (± standard deviation of quartz mean) theoretically constructed on the mineral data from 8 samples

Fig. 7. Wykres zależności między masą właściwą a średnią średnicą ziarna dla eolicznego członu piaskowców białego spągowca. Linia ukośna jest teoretycznym wykresem równowagi sedymentacyjnej (± standardowe odchylenie średniej średnicy kwarcu) ustalonym dla danych z 8 przykładowych prób

From the diagram in Fig. 7 is seen that, relative to quartz, there is a settling equilibrium among most of the heavy mineral populations present. Apatite population, as the only, is too small and this „too small" nature is, probably, a function of the primary grain-size availability. The data for incompletely identified heavy opaques (mainly magnetite) have been plotted for comparison only.

Comparison of the diagrams presented in Figs. 7 and 8 suggests that the shallow-marine sandstones are enriched in finer grained heavy minerals. This is also visible in Fig. 9 which shows the grain-size distributions of the heavy constituents. Moreover, the quartz mean remains almost the same in both the diagrams. This „too small" nature of the shallow-marine heavy-mineral suites is not a results of the grain-size availability and reflects rather an effect of the transporting/depositional mechanisms.

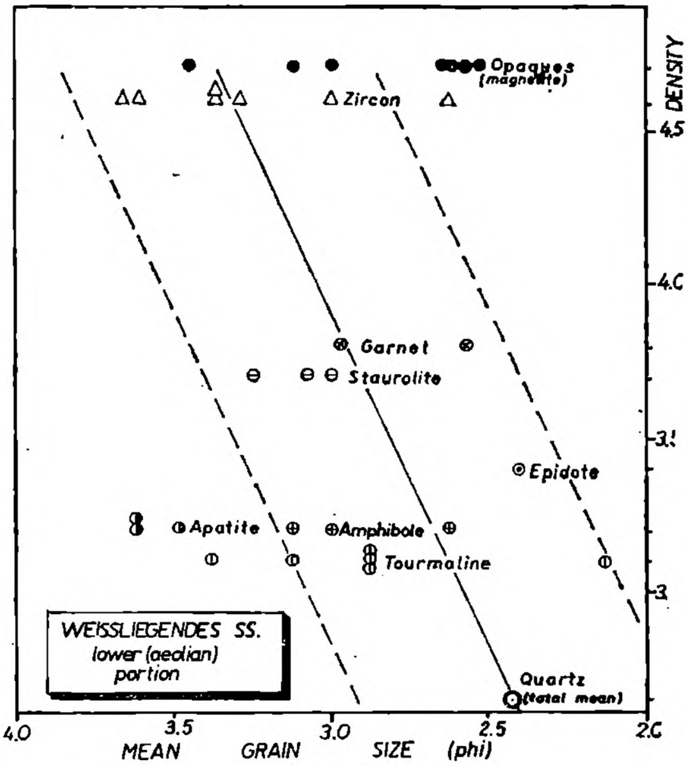

Fig. 8. The same plot as in Fig. 7 constructed for the shallow-marine portion of the Weissliegendes sandstones

Fig. 8. Wykres analogiczny do przedstawionego na fig. 7 skonstruowany dla płytkomorskiego członu piaskowców białego spągowca

As demonstrated by recently published data, the heavy minerals are concentrated primarily in one of two places: either on the beach face, or offshore with subsequent delivery to the beach face as a slug of heavy mineral-rich sand. The paucity of heavy mineral-rich layers and the very low concentration of heavy minerals in the shallow-marine member of the sandstones argue against a concentrating mechanism operating typically offshore (of Stapor, 1973). The generally low concentration of heavy minerals in the aeolian and shallow-marine sandstones may suggest swash zone concentration of incoming sands as being important to the origin of the transgressive sandstone member. Swash-zone concentration, although may sometimes dominate, is, however only a part of a more complex concentrating mechanism.

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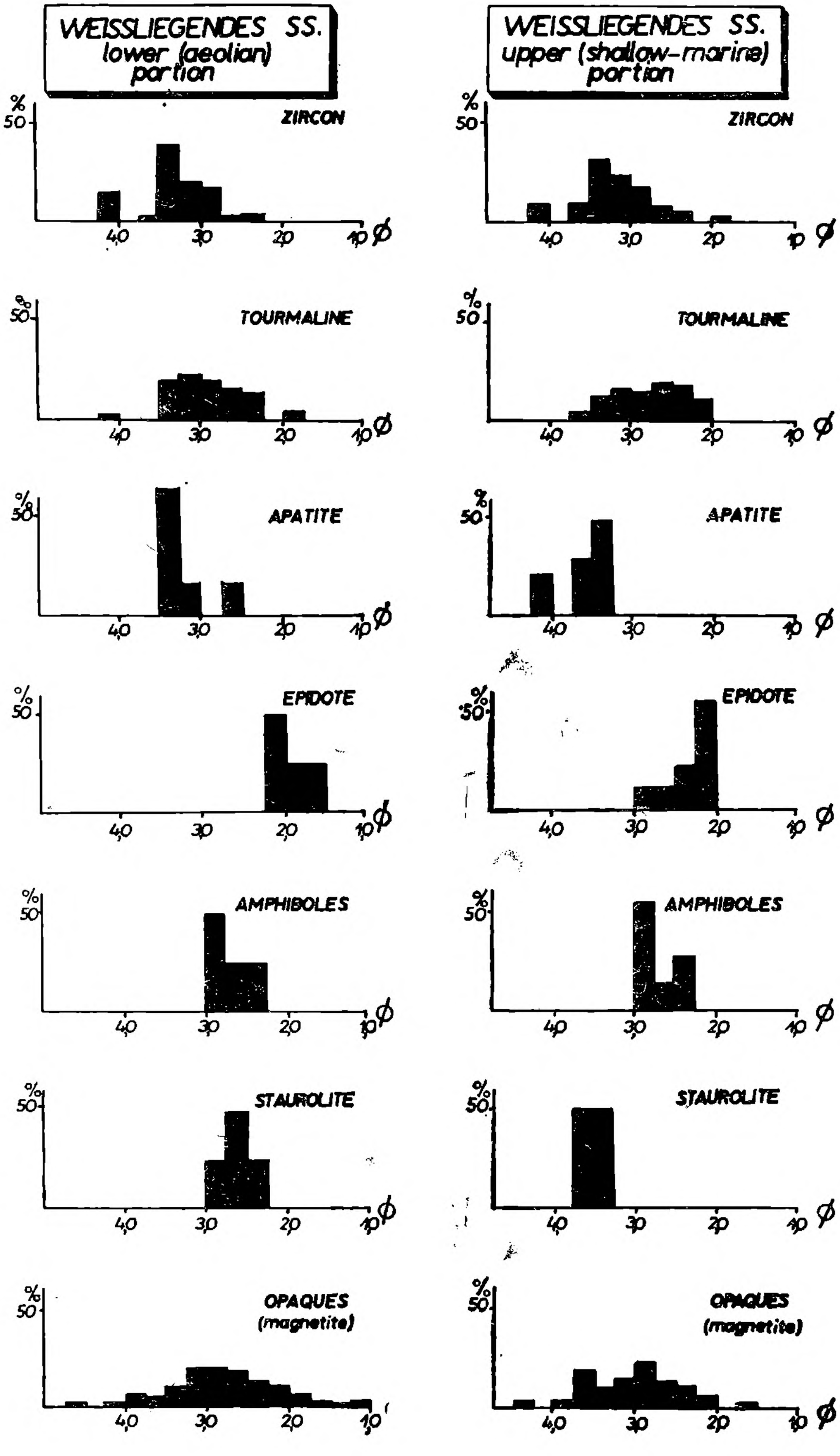
Fig. 9. Size distributions of the heavy minerals, Weissliegendes sandstones

Fig. 9. Histogramy uziarnienia dla poszczególnych minerałów ciężkich w piaskowcach białego spągowca


WEISSLIEGENDES SS.
lower (aeolian) portion
WEISSLIEGENDES SS.
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Based on the available data, the nature of this concentrating process can be explained by appealing to a differential in the entrainment capability between the landward and seaward strokes generated by shoaling waves (May, 1973). One may add to the landward-versus-seaward stroke differential some other mechanism allowing better explanation of the system. Perhaps a dispersive stress analogous to the one described by Bagnold (1954) would allow the coarser heavy-mineral grains to be preferentially elevated and moved more readily by the seaward stroke. This might result in the finer grains having a more rapid net landward movement than the coarser grains, with a potentially maximum effectiveness at the breaker zone where the greatest difference between absolute shoreward and seaward velocities occurs. The heavy minerals will experience a more or less effective net shoreward transport relative to the light minerals and will, therefore, be delivered to the beach at an above-average concentration. A combination of this process with the swash-zone concentration is thought to be responsible for the deposition of the shallow-marine member of the Weissliegendes sandstones.

Hand (1967) argued that as the quartz is much larger in grain size it should tend to shield the smaller heavy mineral grains during entrainment. Hence, the heavy minerals entrained with the quartz should be somewhat smaller than equilibrium settling requires (see Fig. 8). This shelter process would probably be most effective in quartz-rich sands and/or during the initial functioning of a heavy mineral concentrating process (see also Stapor, 1973, p. 405). The coastal dune data presented by Hand (1967) show the main heavy species coarser in the aeolian dunes than in the beaches, while quartz remained the same. Furthermore, in the dunes many heavy species were in settling equilibrium with quartz population. Similar relations are observed in the Permian sandstones. These are not puzzling if one assumes that the (coastal) dunes have not been derived from the beach sediment but were formed by offshore winds, as also previously hypothesized by the authors (Nemec and Porębski, 1977a; cf Brongersma-Sanders, 1969, 1971).

The hypothesis presented above cannot be tested adequately on the basis of the present data and it is also difficult to consider, clearly, the relation between the two types of marine concentrating processes discussed above. It is, however, probably a valid assumption that only wave activity (i.e., fluid motions resulting directly from waves) is important in the transport of heavy minerals and other particles to the beach (see e.g. May, 1973; Stapor, 1973). Important currents not directly associated with waves, such as wave-induced longshore currents and tidal currents, move more or less parallel with the shore. Moreover, their energy level is usually too high to produce selective transport of different mineral populations, particularly those being in hydrodynamic equilibrium in the initial sediment. Normal current energy of the offshore region should rework and mix primary dune sediment and prevent progressive concentration. Thus, the mechanisms of wave activity on a moderate energy shoreline seem to be most likely here. Although wave velocities greater than normal are usually required to transport, in a significant rate, the heavy mineral fraction of the sediment population and the higher energy regime of incident waves the finer heavy mineral concentrates, May (1973, p. 211) emphasized the lack of selective transport at extreme energy levels. From the present data the shoreline energy regime is estimated as slightly higher than moderate.

CONCLUDING REMARKS

Heavy minerals of the Permian sandstones have been studied in the central Fore-Sudetic Monocline. The primary purpose of the study was to provide supplemental data concerning the sources and processes which have determined the Weissliegendes sandstones.

Most important mineral species from the investigated area are zircon, tourmaline, apatite and opaques; as less common occur the grains of garnet, amphibole, staurolite, epidote and kyanite. The mineral associations, extracted with the use of principal component analysis, reflect the metamorphic, igneous and older sedimentary rocks. Five heavy-mineral provinces have been outlined and their relative contribution as sources for the heavies were estimated quasi-quantitatively.

It is suggested, on the basis of available data, that postdepositional weathering is reduced in the Weissliegendes sandstones and some mineral species appear to be protected against chemical attack. The persistence/resistance relations in the heavy-mineral suites suggest a complex source area with high differences in its petrographic composition, age, time of erosion and rate of contribution as a source for detritus.

Heavy-mineral weight percentages are very low and usually less than 0.6% in the sandstone samples examined. In general, heavy-mineral percentages are relatively higher in the upper (shallow-marine) portion of the Weissliegendes sandstones when compared with the underlying aeolian sandstones. The heavy mineral suites of the shallow-marine sandstones differ from those of the aeolian sandstones by the proportions in the amount of individual components; the former contain more mineral species present in significant amounts and less opaque heavies. Thus, the bipartition of the Weissliegendes sandstones and their compound origin are supported by the results of heavy-mineral analyses.

The data point into an effect of concentrating process being associated with the deposition of the transgressive, shallow-marine sand-

Principal features of Permian sandstones, Fore-Sudetic Monocline — Table 2

Główne cechy sedymentologiczne piaskowców permskich monokliny przedsudeckiej — Tabela 2

General stratigraphy		Lower Permian		Upper Permian.
		Rotliegendes sandstones	Weissliegendes sandstones	
			alpha-type ss./x	beta-type ss./x
		Association II		Association III
Rock colour		Dark reddish-brown to very pale-orange	Yellowish-gray to light-gray	Light-gray
Thickness		90 - 210 m	0 - 30 m	0 - 18 m
Lower contact		Transition from underlying fluvial deposits observed as gradual change in lithology and grain size	Transitional, observed as gradual change in rock colour	Usually erosive
Textures	Grain size	Mostly fine and very fine-grained; occasionally medium to coarse-grained ss. in the lowermost portion. Very fine-skewed distributions, with three or two modes within saltation population. Percentage of silt-clay averages : 6.4 %,	Fine-grained ss. Fine-skewed distributions, with two or three modes within saltation population. 4.6 %,	Fine-grained ss. Nearly symmetrical distributions, with unimodally distributed saltation population 2.3 %
	Roundness	Subrounded, on average : 0.43,	0.42,	0.38

	Surface microtextures	Solution features, upturned cleavage plates	Solution features, upturned cleavage plates	Solution features and upturned cleavage plates with superimposed V-shaped pits
Sedimentary structures		High-angle, large-scale cross-bedding; structureless portions with mudflakes and/or beds of adhesion ripples present in places	High-angle, large-scale cross-bedding; structureless portions present. Deformed siltstone drapes occasionally preserved on the foresets	Mostly structureless sediment interbedded with horizontally laminated or low-angle cross-stratified thin units. Soft-sediment deformations common; bioturbations at top
Petrography	Modal composition	Lithic to quartzose arenites	Quartzose arenites	Quartzose arenites
	Detrital heavy minerals	Heavy-mineral populations almost in settling equilibrium in relation to quartz	Heavy-mineral populations almost in settling equilibrium in relation to quartz	Heavy-mineral populations, not in settling equilibrium; non-opaque heavies concentrated
	Clay minerals	Illite, kaolinite	Illite, kaolinite	Illite, kaolinite, often chlorite
	Origin of rock colour	Post-depositionally reddened /intrastratal weathering of iron-rich silicates	Non-reddened	Non-reddened
Interpretation		Desert-dune sediments with minor amount of water-laid deposits	Coastal/?/-dune sands	Transgressive beach-and-shoreface sands

/x Division proposed by Jerzykiewicz et al. /1976/

stone member. The relations observed seem to be well-explained by a model of shoaling waves, probably associated with swash-zone regime, operating on a moderate energy, wave-dominated shoreline. As a whole the results support the environmental interpretation previously presented by the authors (Nemec and Porębski, 1977, 1977 a).

SUMMARY

The validity of the proposed model for the origin of the Permian Weissliegendes sandstones, Fore-Sudetic Monocline, is supported by a large group of sedimentary features of the sequence. The most important characteristics are summarized in Table 2. Further corroboration of the model must await additional studies of the Weissliegendes sandstones, involving larger areas and various regions of the Central Europe. In future investigations there lies main expectation to prove or disprove regional significance of the data obtained in the present study. This will decide whether the model proposed by the present authors is of regional, or only local significance.

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STRESZCZENIE

Praca niniejsza, będąca częścią obszerniejszego studium sedymentologicznego, ma na celu dostarczenie dodatkowych danych odnośnie do procesów, które uformowały piaskowce białego spągowca na obszarze monokliny przedsudeckiej (fig. 1 i 2). Przedstawiono w niej wyniki szczegółowej analizy frakcji ciężkiej zawartej we wspomnianych piaskowcach oraz w niżejległych piaskowcach czerwonego spągowca. Wyniki te wskazują, że górny (płytkomorski) człon piaskowców białego spągowca różni się na badanym obszarze stosunkowo wyraźnie od członu dolnego (włączając niżejległe, eoliczne piaskowce czerwonego spągowca) takimi cechami frakcji ciężkiej, jak jej nieco wyższa zawartość oraz urozmaicenie pod względem składników mineralnych występujących w istotnych ilościach (fig. 3—9). Różnica ta wskazuje na wynik działania procesów sedymentacyjnych prowadzących w warunkach płytkomorskich do koncentracji minerałów ciężkich. Uzyskane wyniki analizy uziarnienia i równowagi hydraulicznej w obrębie frakcji ciężkiej wskazują na sedymentację w warunkach wybrzeża zdominowanego przez reżim fal, a ściślej — mechanizmem fal płyciznowych współdziałającym z mechanizmem strefy zmywu (May, 1973; Stapor, 1973). Dane te potwierdzają złożoność genetyczną piaskowców białego spągowca i są w pełni zgodne z modelem przedstawionym wcześniej (Nemec i Porębski, 1977, 1977 a).

Innymi problemami rozpatrzonymi w aspekcie analizy frakcji ciężkiej są: ustalenie stref alimentacyjnych dla opisywanej sekwencji klastyków permskich oraz rola procesów wietrzeniowych w osadzie. W zakończeniu podsumowano całość uzyskanych wyników dotyczących genezy piaskowców białego spągowca na obszarze monokliny przedsudeckiej.