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SOME NEW ASPECTS OF THE ANALYSIS OF HEAVY MINERALS IN RIVER TERRACES OF THE WEST CARPATHIANS

Les terrasses fluviales représentent dans les bassins des Karpates d'Ouest une suite la plus complète par leurs sédiments quaternaires. Pour cette raison, les questions de leur parallélisation réciproque et de leur datation sont d'une grande importance pour la solution des régularités de l'évolution quaternaire. D'une large échelle des méthodes appliquées aux recherches complexes des terrasses, l'auteur attache son attention à quelques nouveaux aspects de l'analyse des minéraux lourds. Une analyse quantitative des minéraux lourds ne peut être utile que très difficilement dans la parallélisation des terrasses fluviales dans les Karpates d'Ouest, des changements très rapides se produisant de place en place dans l'association des minéraux lourds, soit dans les cours récents, soit dans les sédiments pléistocènes. L'auteur renvoie à quelques possibilités de l'ètude de l'intensité de la destruction de l'hyperstène dans les terrasses de différent âge et il poursuit la dépendance entre l'intensité de la destruction et l'âge de l'accumulation des terrasses.

1. INTRODUCTION

Most of the water courses flowing through Central European middle mountains non-glaciated during the Quaternay, exhibit a more or less developed system of river terraces. The rives terraces of these middle mountain regions are one of the products of the relief-creating processes of the periglacial zone characterized by several generations of different morphological forms. Among the wide range of morphological forms typical for the periglacial zone in the field of non-glaciated middle mountains, river terraces constitute one of the most significant forms by which the laws of quaternary development can be assessed.

However, in spite of the indisputable importance of the river terraces, a whole complex of questions related particularly to their origin, correlation and dating remains to a great extent still unanswered. The solution of this problem is certainly hindered by the fact that the river terraces of middle mountains are considerably incoherent in the linear sense; in the vertical sense, the terrace grades are often incomplete and they display a great variablility in height.

The high importance of the river terraces of middle mountains as the forms most suitable for the determination of the quaternary development of the respective region on the one hand, and the marked incoherence and irregularity in the occurrence of terraces on the other, require an unceasing amplification and increasing thoroughness of the analythical methods utilised for the elucidation of the laws of their development.

Among the great number of methods utilised in complex geomorphological research work, we would like to point at least at one aspect, i. e. at the hitherto not fully exploited possibilities offered by the analysis of heavy minerals, investigating into the accumulation of Pleistocene river terraces with particular reference to the basin regions of the West Carpathians.

2. SOME SPECIFIC FEATURES OF THE WEST CARPATHIAN BASINS AND THEIR TERRACE SYSTEM

The relatively fast alternation of concave and convex forms of relief on a relatively small surface area gives the West Carpathians a characteristical shape, also described as a basin region (cf. L. Sawicki, 1909). The origin of basins, depressions inside of the mountain, having often even the character of graben, is very closely linked first of all with the vertical movements occurred during Neogene, particularly in the Pliocene. In dependence on the different intensity and mechanism of vertical movements the West Carpathians were divided into two regions differing by their tectonic regime. One of these regions can be described roughly as a territory with declining tendency (the near-Carpathian lowlands) while the other one as an ascending region (the mountain itself). This general picture of ascending mountains and declining lowlands was complicated by partial block movements (cf. E. Mazúr, 1964, 1965, T. Buday, I. Cícha, J. Seneš, 1965) which are reflected in the origin of the inner-Carpathian basins.

The development of quaternary form and their expansion in the West Carpathians is, to a great extent, just the reflection of this different tectonic regime in conditions of the intensive climatic oscillations in the Pleistocene.

On the one hand, in the elevated parts an intensive destruction was taking place in the Quaternary, and denudation processes were strongly predominant which is documented also by the relative absence of accumulative forms in the mountains; on the other hand, the lowland regions with a subsident character (at some places the thickness of the quaternary sediments amounting to more than 200 m) constituted during the Quaternary spaces of intensive sedimentation. Differently from the lowlands and mountains which in the Quaternary have in general constituted regions of intensive accumulation and destruction respectively, the quaternary development of the inner-Carpathian basins was markedly characterized by the alternating effects of erosive and accumulative processes in the medium of the changing climate of the glacial and interglacial periods. This fact is, in the inner-Carpathian basins, very markedly documented by the river terraces.

The incompleteness in the occurrence of river terraces, their considerable discontinuousness, linear incoherence and great variability of height mentioned already in the introduction as characteristical for regions of non-glaciated Central European middle mountains applies to a great extent also to the West Carpathian basins where the above described features appear to be almost as a regularity. In spite of the fact that accumulations of river terraces and terraced cones exhibit a considerably incomplete development in the West Carpathians, they provide the most complete sequence of quaternary deposits in basins.

The cognitions gained up to the present on basins of the West Carpathians are witnessing the fact that accumulations of Pleistocene river terraces have come into being in the cold Pleistocene periods (cf. E. Mazúr 1963, E. Mazúr, L. Kalaš, 1963, M. Klimaszewski, 1966). The origin of river terrace accumlations during the cold Pleistocene periods is proven by discoveries of psychrophilous malacofauna, syngenetic frost wedges and involutions, morphometric analyses of gravel, and finally by their relationship to other sediments and forms of basins. What we have in mind are accumulations of river terraces which reflect certain phases in the development of the entire valley accumulations which came into being during the cycles (cf. E. Mazúr, 1963) but not terraces of local significance and origin (described also as inner-cyclic, cf. A. I. Spiridonov, 1963) the origin of which, caused by tectonic or local lateral erosion, might be supposed to be linked also with the warm Pleistocene period.

3. QUESTIONS OF THE ANALYSIS OF HEAVY MINERALS IN THE RIVER TERRACES OF THE WEST CARPATHIANS

The great importance of river terraces for the cognition of the quaternary development of middle mountain regions causes a wide range of research methods being utilised in their examination. Most of these methods underwent a certain development in the course of the time and new aspects of their utilisation entered into consideration. Such possibilities are, in our view, also sedimentological analyses ,and — in this framework — also analyses of heavy minerals; among the sedimentological methods, the analysis of heavy minerals has achieved to occupy a principal place not only in the study of river terraces but also of fluvial sediments appearing in normal stratigraphic sequence (cf. J. I. S. Zonneveld, 1947, 1966, T. van Andel, 1950, R. Vinken, 1959, J. Frechen, G. van den Boom, 1959 and others).

Besides the relatively wide range of possibilities of the application of heavy mineral analysis, the principal task of this analysis in the study of river terrace accumulations of the West Carpathian basins consists in bringing about a parallelisation of the different terraces or groups of terraces which appear here rather incompletely, incoherently and with great height variability. In other words, the task of heavy mineral analysis is to reciprocally differentiate the different terraces or groups of terraces and to determine their relative age.

Of course, bringing into correlation the accumulations of river terraces of two neighbouring basins in the West Carpathians by means of the current methods of heavy mineral analysis is very difficult, in some places almost absolutely impossible. The great variety of the geological structure of the West Carpathians, and the thus resulting highly varegiated and fast changing minerological spectrum of the different water courses — either recent or their Pleistocene forerunners — causes that associations of heavy minerals in terraces of the same age exhibit — under the influence of tributaries — essential differences very often even in one and the same basin but almost regularly in neighbouring basins. Hence, one is allowed to state that in numerous instances the water courses do not conserve the characteristical association of heavy minerals even in the framework of one sole basin. This fact can be detected both in recent water courses and in Pleistocene terrace accumulations.

To illustrate conditions as described above we mention the example of the middle course of the Váh-river valley (from the two neighbouring basins, the Turiec and Žilina ones) where relatively great changes of heavy mineral associations can be observed in recent sediments. A similar example is that of the Hron-river in its section roughly between Banská Bystrica and Žiar nad Hronom.

The facts as described above, related to Pleistocene river terraces are to be illustrated by an endeavour of E. Mazúr (1963) who undertook to parallelize the river terraces in the middle course of the Váh-river by means of heavy mineral analysis. The results obtained by analysis of heavy minerals in the middle course of the Váh-river did not allow anything but to distinguish accumulations of terraces of the main river from its tributaries and to distinguish terrace accumulation from terraced alluvial cones. Only in the last place did they serve the purpose of bringing about an articulation of the terraces themselves (cf. E. Mazúr, 1963).

Heavy mineral associations appear for certain rivers to be more stabile and more or less characteristical only at their outlet from the mountainous Carpathian region into the lowland where they do not take up any tributaries of higher importance. Based on this fact, e. g. also M. Mišík (1956) distinguished in the Danube lowland two provinces on the base of typical associations of the Váh and the Danube on common flood plain.

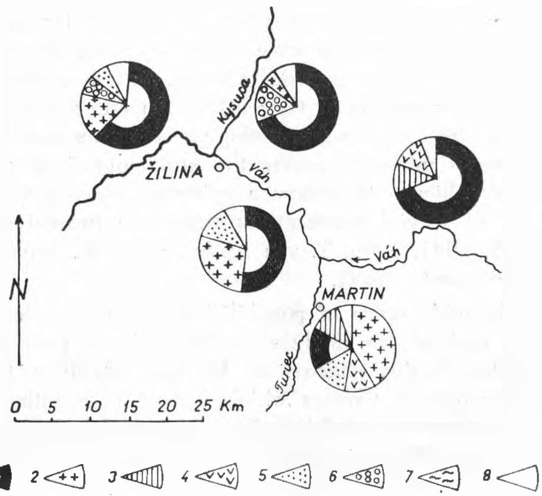

Fig. 1. Representation of heavy minerals in recent sediments of the Váh, Turiec and Kysuca rivers in the Turiec and Žilina basin 1 — opaque minerals, 2 — garnet, 3 — turbid minerals, 4 — amphibole, 5 — hypersthene, 6 — chlorite, 7 — biotite, 8 — others (particularly rutile, turmaline, epidote, zoizite, apatite and augite).

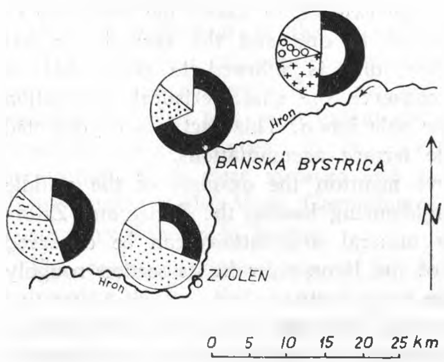

Fig. 2. Representation of heavy minerals in recent sediments of the Hron river. 1, 2, 3, 4, 5, 6, 7 cf. Fig. 1. — 8 — others (mainly turmaline, amphibole, epidote, zoizite, apatite, turbid).

Heavy mineral analysis carried out up to the present in river terrace accumulations of West Carpathian basins demonstrate that quantitative analyses of heavy minerals are — owing to the great variety of associations — only in a very limited measure suitable to resolve questions of terrace parallelisation and to determine the relative age of the terraces.

4. SOME NEW WAYS OF HEAVY MINERAL ANALYSIS IN THE TERRACES OF WEST CARPATHIAN BASINS

In our further research work concerned with heavy mineral associations in terrace accumulations of basins, lesser attention has been dedicated to quantitative relations which are strongly influenced by local conditions. However, increased attention was paid to the diferent signs and form of disintegration of heavy minerals.

The phenomena demonstrating disintegration of heavy minerals are generally known. Heavy mineral disintegration is proven e. g. by the different intensity of grain corrosion in amphiboles and pyroxenes, staurolite, apatite, by lobular corrosion of garnets and the like.

In F. J. Pettijohn's view, the greatest changes in rocks after their deposition are caused by the effect of intrastratal solution. N. G. Sudakova (1965), studying the disintegration of heavy minerals, attributes high importance to the physico-geographical medium and she states that mineral associations point at zonal bioclimatic discrepancies in the stage of sedimentation and their alterations in time.

The origin of corrosive formations on pyroxenes is ascribed by C. H. Edelmann and D. J. Doeglas (1932) to the action of intrastratal solution. According to M. Mišík (1956) the existence of disintegration forms alone does not yet disclose whether they have come into being in the stage of weathering of the mother rock during transport or in intrastratal solution.

In the river terrace accumulations examined in West Carpathian basins, forms of disintegration can be most frequently found in hypersthenes and augites, less frequently in amphiboles and only rarely in garnets. For this reason highest attention has been paid to pyroxenes, among them particularly to hypersthene which comes from young tertiary volcanites. It was found in the hypersthenes examined that the degree of disintegration of the grains is different in terraces of different ages. This finding leads us to the assessment of conditions in which disintegration forms have come into being in the different media.

A) *Origin of disintegration forms during weathering of the mother rock.* Studying the eluvia of young tertiary volcanites we have found that in the ortho-eluvium of pyroxenic andesites also corroded grains of hypersthene do appear besides integer grains. A similar conclusion has been attained at by J. Slávik (1955) in his study of other regions. To a certain extent unanswered remains the question of the influence exerted by hydrothermal processes on the origin of corroded grains. However, corroded hypersthene grains appear also in andesite eluvium not affected by hydrothermal alterations.

B) *Forms of disintegration coming into being during transport.* Well known is the appearance of corroded hypersthene grains and other less resistent minerals from several sediments of recent rivers draining young tertiary volcanites. Appearances of this kind have been pointed at by M. Mišík (1956) in his orientative study of heavy minerals of some recent rivers in Slovakia. However, despite corroded grains being

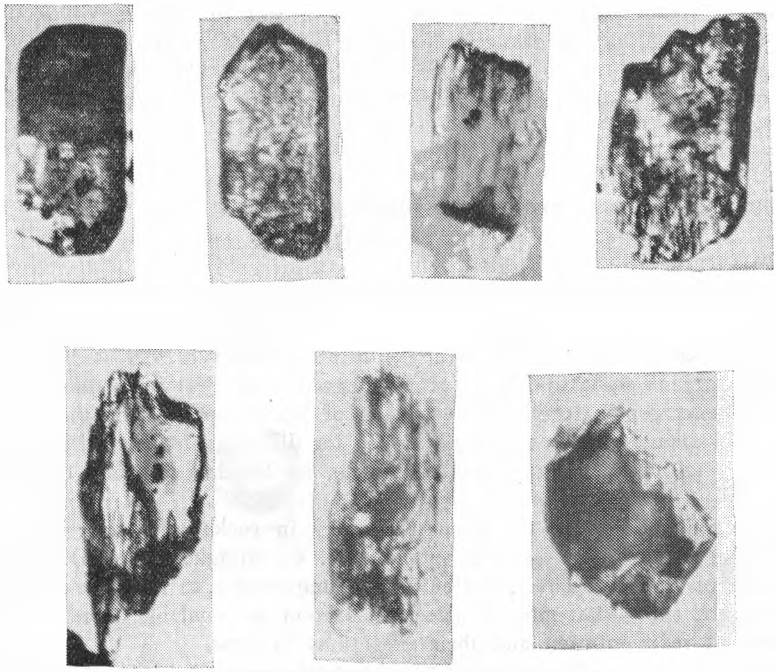

Photo 1. An example of the different intensity of hypersthene grain disintegration in river terrace accumulations.

found in recent rivers we assume that recent rivers do not constitute a medium suitable fo the formation of corrosive patterns in pyroxenes. Transport in a turbulent aqueous medium appears to be more suitable for the disintegration of fine edges than for their coming into being (cf. U. Wolff, H. Rothe, 1958). According to R. Vinken (1959), transport duration stands in no relationship to a stronger or lesser mineral disintegration. We assume that the corroded hypersthene grains have come into recent rivers by slope processes from older river terraces or deluvia.

C) *Forms of disintegration coming into being during intrastratal solution.* Changes occurred after elevation of the rock above ground water level do not belong any more to intrastratal solution, the latter being dependent in the first place on mineral resistance and duration of the solution process and also on the solubility of the rock (J. Petránek, 1963). These alterations can be ranged already to weathering processes though in many instances they are very like to changes caused by intrastratal solution.

Seen from this viewpoint, it appears to be necessary to assess hypersthene disintegration in quaternary river terraces where the accumulations were situated below ground water level roughly only in a stage in which they were forming the bottom of the basin and which later — owing to repeated waves of downcutting in their becoming independent in the shape of river terraces — emerged above ground water level. Hence, the fact that in accumulations of different ages we find grains of hypersthene and of other pyroxenes corroded with different intensity, can be ascribed mainly to weathering processes and to differences occurred during the time in which the material of the different river terrace accumulations was exposed to weathering processes. This fact urges us to endeavour to determine the dependence of the degree of disintegration of the hypersthene on the age of the respective accumulation, i. e. on the duration of the weathering process.

In order to avoid subjectivity in the assessment of the degree of disintegration of the hypersthene, the degree of disintegration of the different grains is expressed numerically. The degree of disintegration is expressed as the ratio of the corroded walls of the mineral to its entire circumference. Thus the possibility is given of expressing the percentuality of the disintegration degree with each grain. Based on 100 to 150 measurements in each sample with fractions from 0,25 to 0,09 mm the arithmetic average of the disintegration has been calculated for further assessments by means of methods of mathematical statistics.

Further, we have tested the statistical significance of the differences of the average values of hypersthene disintegration in accumulation the position of which in the quaternary chronological system is known by means of Student's test. In the Würm accumulations of the Turiec and Váh rivers the average values of the hypersthene disintegration degree amount to $x_1 = 3{,}30$, $x_2 = 4{,}01$, $t = 0{,}943 < t_{tab} = 2{,}101$ while in the Riss accumulations of the same rivers they are equal to $x_1 = 31{,}87$, $x_2 = 39{,}36$, $t = 2{,}062 < t_{tab} = 2{,}62$. The results obtained demonstrate that the difference between the averages of the hypersthene disintegration degree in accumulations of the same age in the region studied has no statistical significance, the level of significance being 0,05.

The average value of the hypersthene disintegration degree in Mindel accumulations is equal to $x = 52{,}10$. Terraces older than Mindel do not contain material in quantities sufficient enough for carrying out analysis in fractions from 0,25 to 0,09 mm. This fact is due to the circumstance that the hypersthene disintegration degree increases with the age of the accumulations and becomes apparently manifest by the phenomenon that hypersthene grains in older Pleistocene terraces appear to be corroded to such

Table 1

Values of hypersthene disintegration degree (in %) in Würm, Riss and Mindel river terraces

Würm	Riss	Mindel
1,0	34,5	47,9
1,5	34,7	50,6
2,3	36,5	50,7
2,5	37,0	52,4
2,8	38,5	53,7
2,9	39,0	53,8
3,2	39,3	54,0
3,7	40,2	—
3,9	40,3	—
4,3	41,2	—
4,4	—	—
4,7	—	—
5,1	—	—
6,1	—	—
6,5	—	—

an extent that they start to crumble away and break up, thus falling into granulation categories lower than 0,09 mm.

A fact known from numerous literature data is that with increasing age the associations of heavy minerals become pauperized. However, in this pauperization of heavy mineral associations the value of the independent variable (age) does not quite unambiguously correspond with only one value of the dependent variable (diminution of heavy minerals or the degree of disintegration) but with a certain quantity of values.

The well known chronological position of the different river terrace accumulations of the middle Váh-valley offers us the possibility of investigating into the dependence of the hypersthene disintegration degree on the age of the river terrace accumulations. In ranging the absolute age to the respective accumulation we have chosen always the lower boundary of the respective formation (Würm 73 000, Riss 125 000, Mindel 200 000 years, cf. H. and G. Termier, 1963). The examined relationship between the age of the accumulation and the degree of hypersthene disintegration in its material takes a non-linear parabolic course (cf. J. Činčura, 1967). This is due to the fact that the hypersthene disintegration degree increases at the beginning faster on surfaces oriented horizontally towards cleavage than in later stages where the walls situated parallely to cleavage are already in a state of corrosion.

The interrelationship in the case of non-linear correlation is expressed by the correlation index R_{xy}, in our case = 0,995 (J. Činčura, 1967) which is actually a very high dependence of the hypersthene disintegration degree on the age of the river terrace accumulations.

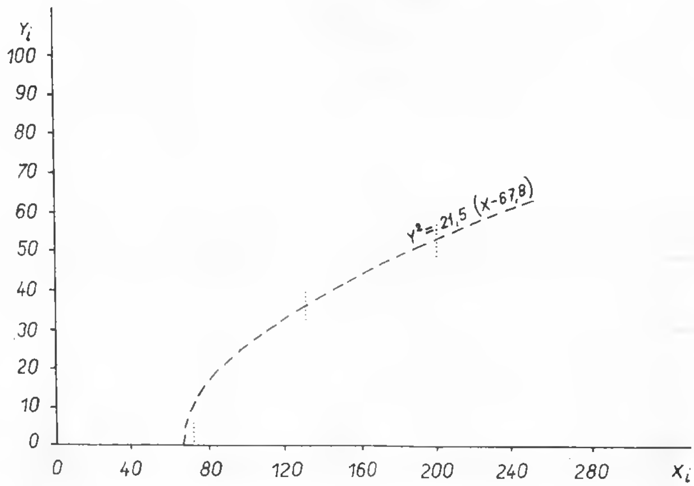

Fig. 3. Dependence of the degree of hypersthene disintegration (in %) on the age of river terrace accumulations (in 1000 years).

5. CONCLUSION

Concluding, one is bound to state that up to the present there is not one among the analythical methods utilised in the study of river terraces that would enable us to resolve satisfactorily the wide complex of questions related to river terraces without having its results supported by results obtained from other analyses. For this reason, our approach to resolving the problem of river terraces must be necessarily complex.

We consider some of the possibilities suggested by us for the study of the forms and intensity of disintegration of the different minerals in river terrace accumulations as one link in the chain of the ever expanding and intensifying complex analysis of river terraces.

From the Slovak translated by V. Heller

REFERENCES

1. Andel T. H. van, *Provenance, Transport and Deposition of Rhine Sediments.* Proefschrift Wiss. en Naturkunding Fak., Groningen 1950. — Buday T., Cicha I., Seneš J., *Miozän der Westkarpaten.* Bratislava 1965. — 3. Činčura J., *Abhängigkeit der Hypersthenzerstörung am Alter der Flussterrassen.* Geologický sborník XVIII, 1, Bratislava 1967. — 4. Edelman C. H., Doeglas D. J., *Reliktstrukturen detritischer Pyroxene und Amphibole.* Min. Petr. Mitt. 42, Wien 1932. — 5. Frechen J., Boom v. d. G., *Die sedimentpetrographische Horizontierung der pleistozänen Terrassenschotter im Mittelrheingebiet.* Fortschritte in der Geol. von Rheinland und Westfalen Bd. 4, Krefeld 1959. — 6. Klimaszewski M., *Views of the Geomorphological Development of the Polish Western Carpathians during the Quaternary.* Geomorphological Problems of Carpathians II., Geographia Polonica 10, Warszawa 1966. — 7. Mazúr E., *The Žilina Basin and the Adjacent Mountains (Geomorphology and Quaternary era).* Bratislava 1963 (English summary). — 8. Mazúr E., *Intermountain basins as a charakteristic element in the relief of Slovakia.* Geogrfický časopis XVI, 2, Bratislava 1964. — 9. Mazúr E., *Major features of the West Carpathians in Slovakia as a result of young tectonic movements.* Geomorphological Problems of Carpathians I., Bratislava 1965. — 10. Mazúr E., Kalaš L., *Die Entwicklung des mittleren Waagtales im Jungpleistozän.* Geografický časopis XV, 2, Bratislava 1963 (German summary).

11. Mišík M., *Anwendung der Schwerminerale in der paläogeographischen und stratigraphischen Forschung in bezug auf das Neogen und Quartär der Slowakei.* Geologické práce, zoš. 43, Bratislava 1956 (german summary). — 12. Petránek J., *Usazené horniny, jejich složení, vznik a ložiska.* Praha 1963. — 13. Sawicki L., *Z fizyografii Zachodnich Karpat.* Lvov 1909. — 14. Slávik J., *Sedimentologické poznámky k vývoji Košické a Trebišovské pánve a jejich okolí.* Rozpravy čs. akad. věd 65, 5, Praha 1955. — 15. Spiridonov A. I., *Osnovy obščej metodiky polevych geomorfologičeskich issledovanij,* 3, vyp. 2, MGU, Moskva 1963. — 16. Sudakova N. G., *Ustojčivosť mineralov.* Priroda, Moskva, Fabruar 1965. — 17. Termier H., Termier G., *Erosion and Sedimentation,* 1963. — 18. Vinken R., *Sedimentpetrographische Untersuchung der Rheinterrassen im östlichen Teil der Niederrheinischen Bucht.* Fortschritte in der Geol. von Rheinland und Westfalen, Bd. 4, Krefeld 1959. — 19. Weyl R., *Schwermineralverwitterung und ihr Einfluss auf die Mineralführung klastischer Sedimente.* Erdöl und Kohle 3, Hamburg 1950. — 20. Weyl R., *Terrassengliederung und Schwermineralführung von Schotterablagerungen des SW Schwarzwaldes.* Neues Jb. Geologie, monatsh. 1951.

21. Weyl R., *Zur Frage der Schwermineralwitterung in Sedimenten.* Erdöl und Kohle 5, Hamburg 1952. — 22. Wolff U., Rothe H., *Über die Umwandlung und Neubildung von Schwermineralien in Sedimentgesteinen.* Zeitschrift f. angewandte Geologie, Bd. 4, N. 8, 1958. — 23. Zonneveld J. I. S., *Het Kwartair van het Peel-Gebied en de naaste omgeving.* Mededel. van Geol. Stichting Serie C-VI-No. 3, Maastricht 1947. — 24. Zonneveld J. I. S., *Schwermineralgesellschaften in Niederrheinischen Terrassensedimenten.* Geol. en Mijnbouw N. S. 18, s' Gravenhage 1956.