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PETROGRAPHIC COMPOSITION OF THE QUATERNARY GRAVELS OF THE CARPATHIANS AND THEIR FORELAND

INTRODUCTION

The subject of the paper is quantitative petrographic composition of the Quaternary gravels of the Carpathian origin which occur in the Carpathians and at their Foreland (Fig. 1). This gravel is an interesting study material due to differences in geological structure of the drainage basin, and, in the northern part, due to the presence of the extra-Carpathian material carried by the continental ice sheet from Scandinavia and southern and central Poland.

PARENT MATERIAL

A parent material of the Quaternary gravels of the Carpathians are flysch deposits usually represented by clay shales and mudstones, sandstones interbedded with shales, less frequently by sandstones alone and only exclusively by limestones (Cieszyn region). Crystalline rocks (granites and gneisses) as well as quartzites of the lower Trias (Seis) occupy only a small area in the Tatras. It refers to limestones and dolomites known of the Tatras and the Pieniny Mts as well. The clayey-muddy Miocene deposits building a vast part of the Carpathian foreland and filling the intra-mountain basins do not supply clasts for gravels.

During gravel formation the unresistant components are selectively degraded and the most resistant ones are becoming relatively more significant. The first to be degraded are shales and clays which do not practically occur in gravels. Among sandstone the easiest to disintegrate and to loose sand is sandstone of a fluxoturbidity type (Istebna, Ciężkowice Beds). The most resistant are sandstones of a strong silica, silica-limy or limy cement of the Lgota, lower Godula and Grodziszcze Beds. Particularly resistant are hornstones derived from the Lgota Beds (in the western part of the Carpathians) and hornstones derived from the Menilite Beds (in the eastern part). The

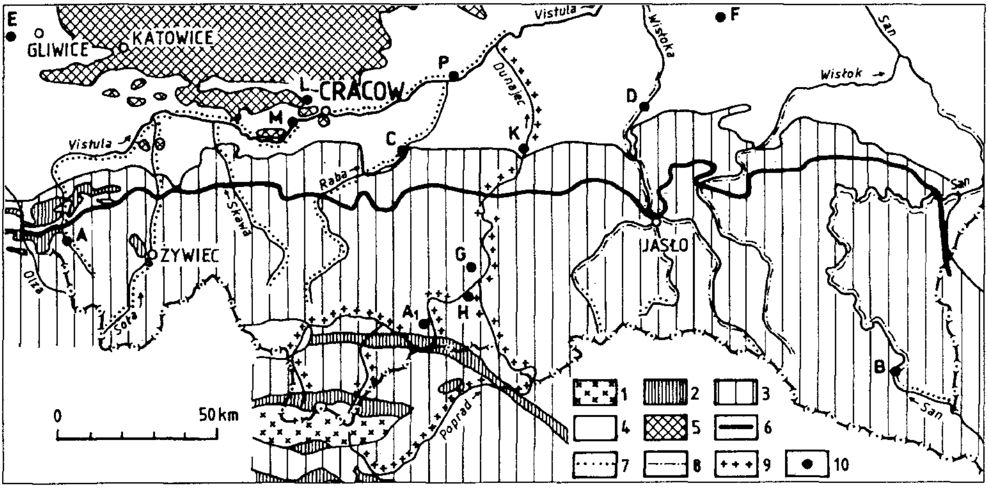

Fig. 1. Gravel distribution in the Polish Carpathian Mts and at their Foreland. Carpathian. 1 — magmatic and metamorphic rocks (Paleozoic) and quartzites (Trias), 2 — carbonate rocks (Trias-Cretaceous), 3 — shales and sandstones (Jurassic-Tertiary), Carpathian Foreland; 4 — clays (Miocene), 5 — limestones, sandstones (Devonian-Cretaceous), 6 — maximum limit of the Mindel glactaition, 7 — sandstone gravels, 8 — sandstone gravels with admixture of menilitic hornstones, 9 — sandstone-granite-quartzite gravels, 10 — sampling points, A–R — samples labelling according to Fig. 3 and the text

Ryc. 1. Rozmieszczenie żwirów w Karpatach i na ich przedpolu. Karpaty. 1 — skały magmowe i metamorficzne (paleozoik) oraz kwarcyty (trias), 2 — skały węglanowe (trias-kreda), 3 — łupki i piaskowce (kreda-trzeciorzęd), Przedpole Karpat: 4 — iły (miocen), 5 — wapienie, piaskowce (dewon-kreda), 6 — zasięg maksymalny zlodowacenia południowo polskiego, 7 — żwiry piaskowcowe, 8 — żwiry piaskowcowe z domieszką rogowców menilitowych, 9 — żwiry piaskowcowo-granitowo-kwarcytowe, 10 — punkty pobrania prób. A–R — oznaczenia prób zgodne z Ryc. 3 i tekstem

most resistant component is quartz which is usually accompanied by lydites. Very resistant clasts built of quartz, magmatic and metamorphic rocks, and sometimes of limestones are worth to be noticed. They are “exotics”, i.e. they originate from gravel contained in the flysch deposits.

Gravel material currently filling the Carpathian river valleys has mainly been formed during glaciation, when solifluction processes acted on vegetation barren slopes in a cold climate. Channel erosion and tributaries presently supply insignificant amounts of material.

In the northern part of the Carpathians and at their Foreland, within the limit of the Scandinavian glaciation is an admixture of magmatic and metamorphic rocks as well as of quartzites and quartz of the Scandinavian origin. They are accompanied by rocks derived from the southern and central Poland (mainly cherts derived from the Mesozoic rocks, quartz originating from the Carboniferous Upper Silesian sediment, and less frequently by quartzites or limestones).

GRAIN SIZE DISTRIBUTION

Determination of grain size composition of gravel-sandy deposits filling the river valleys based on the samples taken from the bars (Unrug 1957, Nawara 1964) is currently not possible. This is due to the ongoing exploitation of river channels, selective removal of larger clasts out of the deposits, channelization and functioning of water dams. Therefore, grain size composition has been based on samples obtained from drillings which have gone through the whole gravel-sandy series. The results are the weighted average calculated for the gravels and sands (Fig. 2, Rutkowski 1982). The material obtained in this way is much finer than that obtained from bar surfaces.

Amount of sand (grains smaller than 2 mm, –1 phi) in the valleys located in the extent of the Carpathians is usually larger then 30% (Fig. 2A). It particularly refers to the valley of the Soła, Skawa and Dunajec rivers at the direct foreland of the Carpathians. In the lower reach of the Wisłoka and San, and also in the Vistula reach down of Cracow the amount of sand increases locally to 70%.

The opposite is the case of the grains coarser then 32 mm (–5 phi, Fig. 2B). The largest amounts of this grain class, exceeding 60%, are found in the intra-mountain basins of Żywiec, Nowy Targ and Nowy Sącz. The largest amounts of cobbles (clasts larger than 64 mm, –6 phi), reaching 48%, have been observed in the last of the mentioned basins.

PETROGRAPHIC COMPOSITION

Petrographic composition has been studied according to the author's method (Rutkowski 1977, Rutkowski in press). The samples were taken from the bar surfaces, river bottom, outcrops and gravel-pits. They were sieved according to the phi scale, and each fraction was accepted as 100% (Fig. 3). This approach allows to eliminate grain size effect on petrographic composition. Results have been given in percent of clasts. This is the fastest method and in the case of clasts of similar bulk density the results obtained do not significantly differ from the results obtained by weighing method (for details see Rutkowski and Zuchiewicz 1987). In each grain size class 300 clasts have been calculated. In the case of a smaller number of clasts, or if the clasts had partly crumbled when taking the sample, the results have been considered as approximated and areas in the diagrams have been separated by a dashed line.

The percentage of various components in the grain size class chosen for the analysis is the background for interpretation of spatial differentiation. It should occur in the whole study area. In addition, it should be sufficiently large to allow for determination of all the petrographic components present in it as well as it should be sufficiently small to be manageable to take it easily to a laboratory. In the

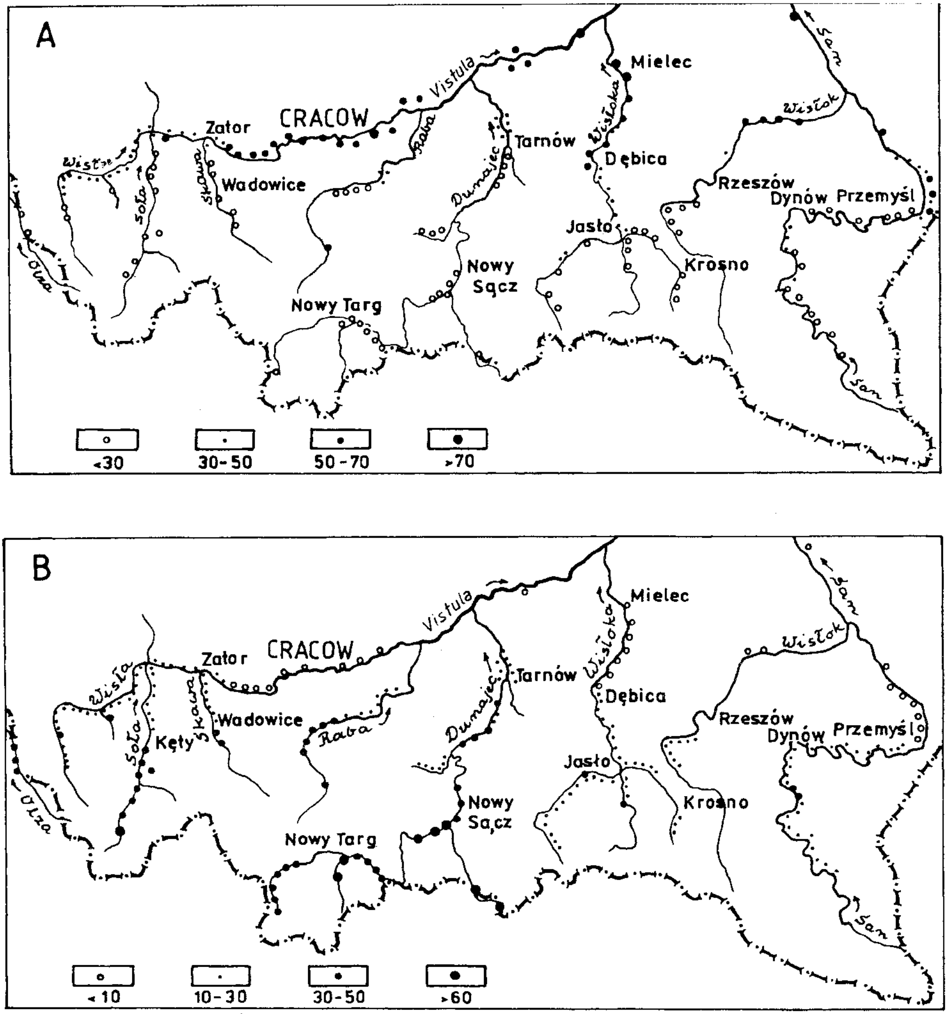

Fig. 2. Grain size composition of the Holocene Carpathian gravels (after Rutkowski 1982, partly modified): A — sand contents (less than 2 mm), B — contents of grains larger than 32 mm

Ryc. 2. Uziarnienie holoceńskich żwirów Karpat i ich przedpola (wg Rutkowski 1982, nieco zmienione): A — zawartość piasku (pon. 2 mm), B — zawartość ziarn grubszych od 32 mm

Carpathians where very coarse grain rocks are lacking the above conditions are best fulfilled by the grain size class of 16–32 mm (–4 to –5 phi).

Three types of gravel can be distinguished in the Carpathian river valleys according to the petrographic composition. These are: 1 — sandstone gravels characteristic of majority of the valleys, 2 — sandstone-granite-quartzite gravels with some limestone typical of the Dunajec and Poprad valleys and 3 — mixed gravels containing some clasts originating from Scandinavia and from the central and southern Poland and which occur at the foreland of the Carpathians.

The most wide-spread in the Polish Carpathians are gravels formed from sandstones which have been treated together with sporadically occurring conglomerates (type 1, Rutkowski 1977, 1982, 1990, Rutkowski and Sokołowski 1983). Rocky material has been supplied to them along the whole valley. They contain some quartz which can vary from a few to several percent (Fig. 3A, B). The amount of quartz increases as grains become finer. Sometimes admixtures of magmatic and metamorphic rocks, quartzites and limestones of exotic origin are stated here (Fig. 3A). In the western part (the Vistula, Soła, Skawa and Raba valleys) the admixture of bluish hornstones derived from Mikuszowice Beds is sometimes observed. Limestones of Flysch origin are found in gravels in places, e.g. in the San valley or Wiar valley (Malarz 1992) while in the Cieszyn region they occur only sporadically.

This type of gravels is also represented by Eopleistocene gravels from Witów (Fig. 6P) which are characterized by a large contents of quartz. In opposite to Holocene gravels of the valleys discussed above, they contain only sandstones most resistant to degradation (Dżułyński *et al.* 1974). A very interesting feature here is the admixture of clasts of exotic origin (crystalline rocks, limestone and quartzites). The Pliocene gravels of Sośnicowice (Smoleńska 1975), formed due to selective degradation in warm Pliocene climate and due to a longer transportation route (above 60 km from the margin of the Carpathians), are also rich in quartz (Fig. 3D).

In the eastern part of the Polish Carpathians, in the valleys of the Wisłoka, Wisłok, San, Biała and Uszwica, in the middle reaches of the valleys sandstone gravels always contain some laminated brown hornstones derived from the Menilite Beds what is illustrated by the sample from Międzybrodzie (Fig. 3B).

Gravels of the Kolbuszowa region, at the foreland of the eastern part of the Polish Carpathians, are of the same character. These gravels are formed of resistant sandstones and they are enriched in quartz and hornstones from the Menilite Beds (Fig. 3F, Rutkowski 1987). They are assumed to be the Eopleistocene deposits (Dżułyński *et al.* 1968, Laskowska-Wysoczańska 1971) of the same age as the gravels of Witów. It is highly probable, however, that they have been reworked to a large degree during the Scandinavian glaciations. Thus, they are sometimes considered to be glacial (e.g. Buraczyński and Wojtanowicz 1967 / 1968).

The gravels of the Dunajec valley (type 2) are of a different character. They have been best recognised (Unrug 1957, Nawara 1964, Kucharska-Słupikowa 1964, Rutkowski and Zuchiewicz 1987). They are built of flysch sandstones, granites and quartzites originating from the Tatras (Fig. 4, 5G, H, K). These gravels are accompanied by the Tatric limestones and dolomites as well as by the Pieniny limestones. In the fine grain size classes quartz is observed. Sporadically, crystalline rocks of exotic origin are found. Quartzites are the most resistant material in the Dunajec valley. Their contents increases as the material becomes coarser. It is related to weaker

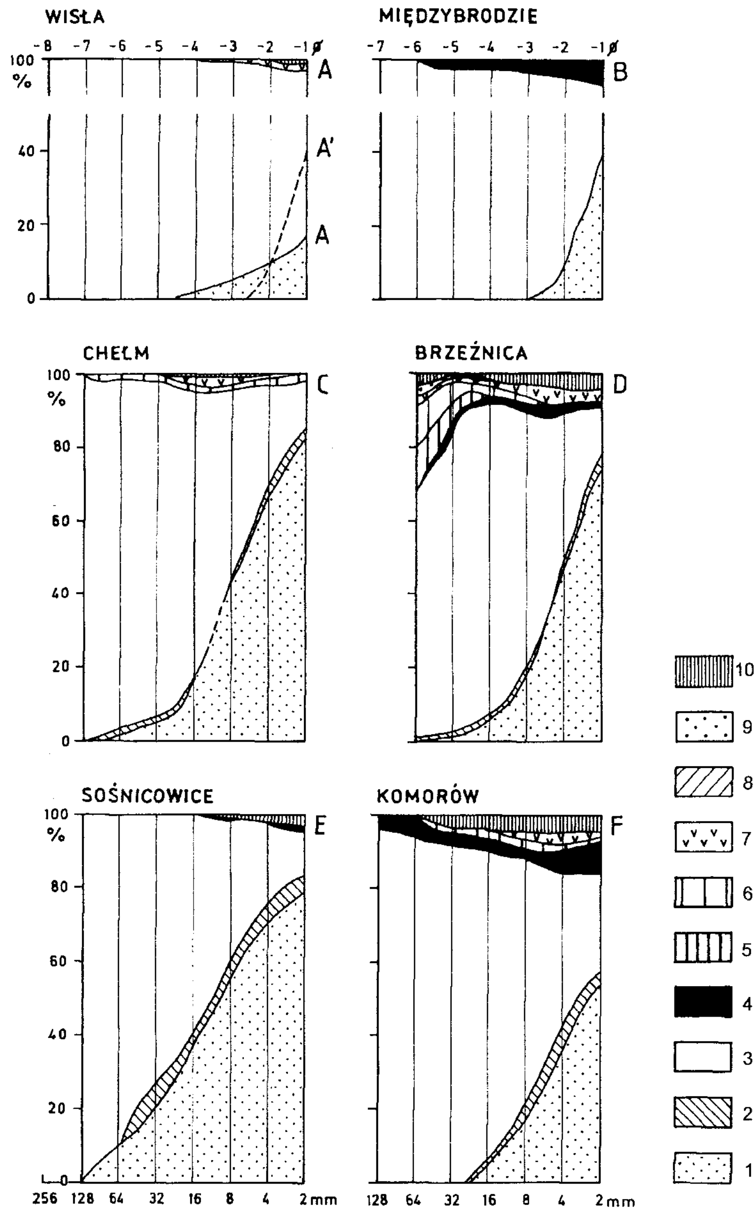

Fig. 3. Petrographic composition of some sandstone gravels from Carpathian and the Foreland in percent of number of grains: 1 — quartz, 2 — lidytes, 3 — flysh sandstones, 4 — Carpathian hornstones, 5 — Tatric quartzites, 6 — others quartzites, 7 — magmatic and metamorphic rocks, 8 — limestones, 9 — cherts, 10 — others, (E — after Smoleńska 1975)

Ryc. 3. Skład petrograficzny niektórych żwirów z Karpat i ich przedpola w procentach ilości ziarn: 1 — kwarc, 2 — lidyty, 3 — piaskowce fliszowe, 4 — rogowce karpackie, 5 — kwarcyty tatrzańskie, 6 — inne kwarcyty, 7 — skały magmowe i metamorficzne, 8 — wapienie, 9 — krzemienie, 10 — różne. (E — wg Smoleńska 1975)

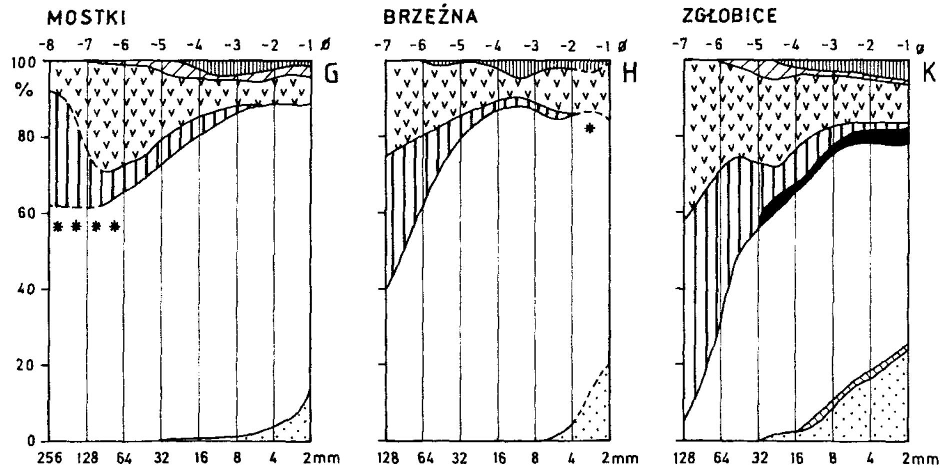

Fig. 4. Petrographic composition of some Dunajec gravels in percent of number of grains: Explanations as in Fig. 3 (G, H — after Rutkowski and Zuchiewicz 1987, K — after Sokołowski 1987). Composition changed due to: ** — selective exploitation, * — crumbling during the sieving process

Ryc. 4. Skład petrograficzny żwirów z doliny Dunajca w procentach ilości ziarn: Objaśnienia na Ryc. 3. (G, H wg Rutkowski i Zuchiewicz 1987, K — wg Sokołowski 1987). Skład zmieniony na skutek: ** — selektywnej eksploatacji, * — rozkruszania przy przesiewaniu

fracturing of quartzites than granites or flysch sandstones. Improportionally large percentage of quartzites in gravels when compared with the area of their outcrops in the Tatra territory (c. 13 km^2) is related to a very large resistance.

There is linear supply of the sandstone material to the Dunajec valley along its almost total length (Fig. 4), i.e. similarly as in the case of sandstone gravels (type 1). On the other hand, the Tatras built of crystalline, calcareous and quartzite rocks as well as the Pieniny built of limestones can be treated as areally limited sources. Petrographic distribution of the Dunajec gravels is very diversified (Fig. 4). Currently, the material filling the channel is suitable only for limited quantitative studies. Granite clasts of the size of 64–256 mm are removed from the channel on a mass scale and are used for ornamental plastering. Therefore, petrographic composition has been presented based on the studies of Nawara (1964).

In the Czarny Dunajec valley at the outlet of the Tatras calcareous rocks with a dash of crystalline rocks predominate. The more to the north these rocks are degraded and crystalline ones are becoming the major components. Granites predominate at the outlet of the Białka river from the Tatras. Due to an intensive supply of flysch material, sandstones sometimes predominate in the middle reach of this river. However, they are quickly eliminated and in the vicinity of the Białka mouth, the gravel contains mainly granites again. Downstream of the gorge in the Pieniny the contents of limestones, making almost a half of the material, increases.

In the subsequent gorge through the Beskid Sądecki the amount of sandstones increases. Just in the lower reach of the river are observed the increase in the content of granites and quartzites, and the decrease in the amount of sandstones which is related to their degradation. The composition of gravels sampled in the vicinity of the Dunajec mouth is non-typical.

In the region of Nowy Sącz petrographic composition of the Dunajec gravels is alike (Rutkowski and Zuchiewicz 1987) from the Mindel stage to the Holocene (Fig. 5G, H). The differences mainly consist in the lack of limestones in the gravels older than the last Glacial. Crystalline rocks and quartzites occur also in the covers of the stages: Biber, Donau and Günz. The situation is opposite at the outlet of the Dunajec river from the Carpathians, where gravels seem to contain more quartzites (Fig. 5C) while those of the older levels are slightly enriched (Sokołowski 1987).

At the Carpathian foreland mixing of the Carpathian material with that originating from the Silesian-Cracow Upland and from Scandinavia (Type 3) is observed. The gravels from Bielany near Cracow (Fig. 6M) contains a significant addition of cherts originating from the Jurassic limestones. They play the largest role in the class of the coarsest grains which is typical of the gravels of this region (Rutkowski and Sokołowski 1983). The mixing of the material is illustrated by the gravel from Chełm on the Raba river (Fig. 3C), where the Carpathian sandstones are accompanied by much smaller amounts of quartz and there is also a dash of quartzites and crystalline rocks. A significant content of crystalline rocks, quartzites and cherts feature the gravels of Szczyglice (Fig. 6L) and mixed gravels of Witów (Fig. $6P^1$), originating from the stage Mindel (Sanian). The Holocene gravels of Brzeźnica on the Wisłoka river (Fig. 3D) containing the addition of the northern and Tatric material are of a different character.

The gravels contain anthropogenic components as well. These are chunks of bricks, concrete, slag, slag-concrete, china, faience and glass or pieces of plastic. Clasts of coal occurring in all grain size classes, from the finest to 32 mm, and larger sporadically (Fig. $6M^1$), should also be noted. That coal originates from mines but also from lighters and barges, on which it was transported in the past. This coal dates the deposits as not being older than of the beginning of the 18th century. This coal has been described from the present-day Vistula channel deposits (Kociszewska-Musiał 1969, Rutkowski 1986). This coal occurs in the old meanders of the Vistula which were active in the 19th century.

The Carpathians sandstones and hornstones can be observed far from the margin of the Carpathians. The farther from the Carpathian margin the smaller their contents and the larger the amount of glacial material (Rutkowski 1990). In Brzeźnica, over 15 km from the margin of the Carpathians 78% of sandstones and hornstones (Fig. 3D) are observed in the grain size class 16–32 mm. In Nagnajów, 75 km from the margin there is ca 45%, in Warsaw

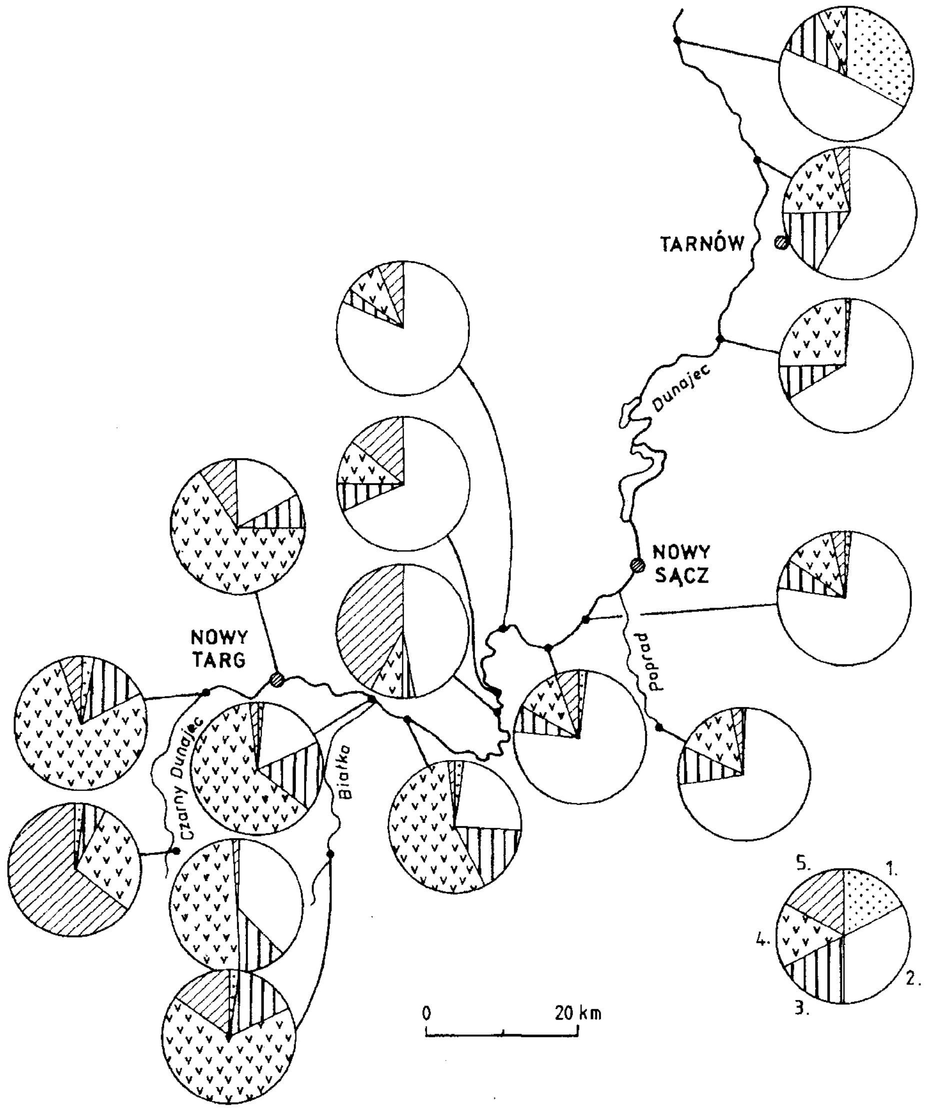

Fig. 5. Variability of the petrographic composition of the Dunajec gravels (grain size 16–32 mm) in percent of number of grains (after Nawara 1964 data, partly suplementted): 1 — quartz, 2 — sandstones, 3 — quartzites, 4 — magmatic and metamorphic rocks, 5 — carbonate rocks

Ryc. 5. Zmienność składu petrograficznego żwirów Dunajca (frakcja 16–32) w procentach ilości ziarn (wg Nawara 1964, uzupełnione): 1 — kwarc, 2 — piaskowce, 3 — kwarcyty, 4 — skały magmowe i metamorficzne, 5 — skały węglanowe

(345 km, Fig. 1) — 10% and in Płock (465 km) — 2%. A similar situation has been described from the Odra river valley (Magiera 1974) where, c. 25 km from the Carpathian margin, their amount is 60% and decreases to 20% over the distance of 65 km.

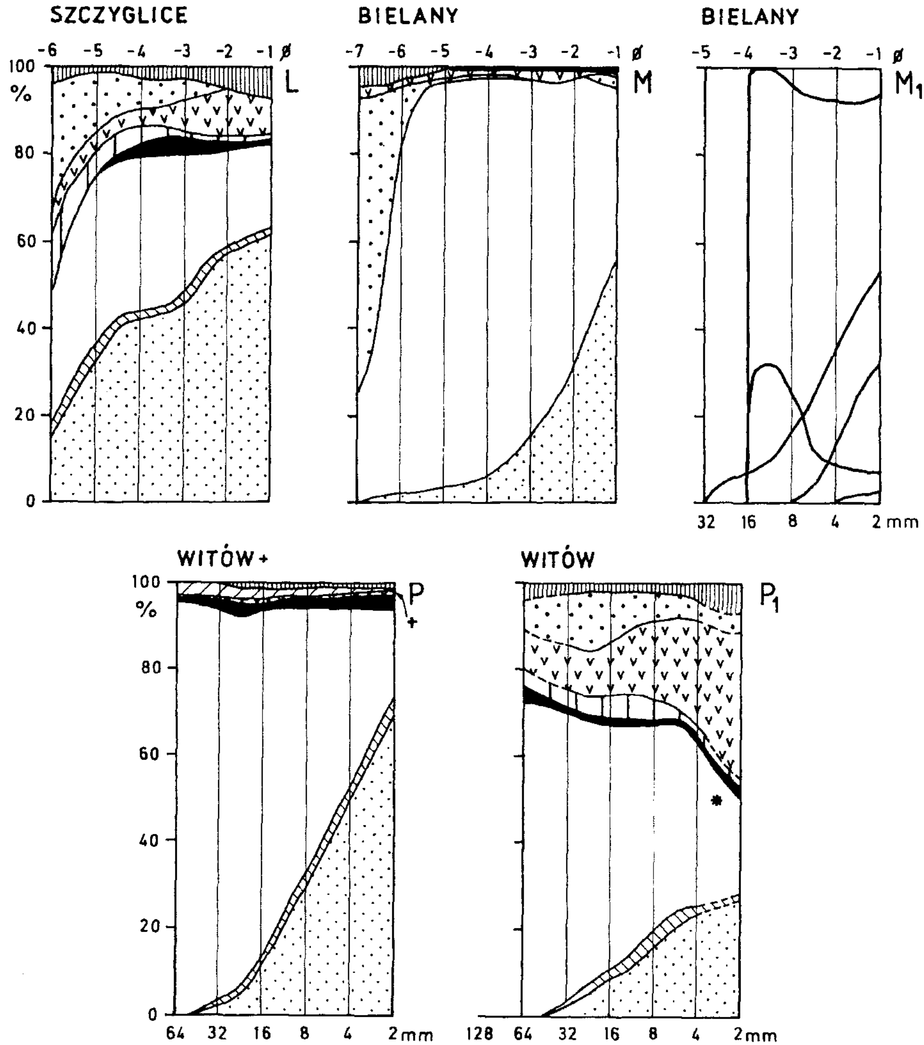

Fig. 6. Petrographic composition of some Carpathians gravels with the admixture of the outside material and Witow gravels in percent of number of grains: Explanations as in Fig. 3; * — composition changed due to crumbling during the sieving process, + — quartzites and crystalline rocks together

Ryc. 6. Skład petrograficzny niektórych mieszanych żwirów karpackich oraz żwirów z Witowa, w procentach ilości ziarn. Objaśnienia na Ryc. 3; * — skład zmieniony na skutek rozkruszania przy przesiewaniu. + — kwarcyty i skały krystaliczne łącznie

The Tatric material (mainly quartzites but also granites) occurs along the margin of the Carpathians, to the east of the Dunajec outlet from the Carpathians (Laskowska-Wysoczańska 1971) over the distance of 120 km. It is related to the old flow of the Dunajec which was active during the Eopleistocene and during the retreat of the Mindel glaciation.

CONCLUSIONS

In the light of the performed studies one can state that the petrographic composition of the Carpathian gravels remains generally in agreement with the lithology of the drainage basin. The distinguished types of gravels preserve their character in their long transportation routes. Therefore, it is possible to distinguish the Carpathian material in the Vistula valley in the distance of several hundreds kilometers from the Carpathian margin. Indicators of the presence of the material brought by a glacier or rivers are mainly cherts originating from the Mesozoic deposits of the southern and Middle Poland as well as some Scandinavian porphyries or quartzites not occurring in Poland. The petrographic composition of gravels in these zones is most diversified.

The shape of graphs allows also for the genetic interpretation. The gravel being mainly formed due to mechanical disintegration of parent rocks are characterized by a similar composition of particular grain size classes (Fig. 3A). If the gravel had been subjected to selective degradation during its formation and transportation then a relative enrichment of it in quartz or quartzites whose amounts seem to increase in the lower reach of the Dunajec took place (Fig. 3G, H, K). In the Carpathian foreland the addition of quartz, which is accompanied by the rocks derived from the north seems to indicate the age of the gravels to be older than the last Glacial. Dating of the present-day deposits can be based on the anthropogenic chunks admixed.

The factors decisive about the presence of given rocks in gravels, besides their lithology which controls vulnerability to destruction, are their fracturing and interlayering. Morphology of the source areas plays an important role. Thus, the high mountain, of which the Tatras are the example, with large height differences, glaciarized several times in the Quaternary, supplied large amounts of the granite and quartzite material and smaller amounts of the calcareous one. Large amounts of limestones originate from the Pieniny, which, although being medium-high mountains, have very steep slopes at the gorge of the Dunajec river. On the other hand, the Cieszyn Upland built of limestones which occupy a comparable area (Fig. 1) supplies the material only sporadically.

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STRESZCZENIE

J. Rutkowski

SKŁAD PETROGRAFICZNY CZWARTORZĘDOWYCH ŻWIRÓW KARPAT I ICH PRZEDPOLA

Skład petrograficzny żwirów Karpat badano na próbach rozsianych zgodnie ze skalą phi, traktując każdą frakcję jako 100%, co pozwala porównywać żwiry o zróżnicowanym uziarnieniu (Ryc. 2). Wyniki podano w procentach ilości ziarn (Rutkowski 1977, Rutkowski w druku). Z punktu widzenia składu petrograficznego wyróżniono 3 typy żwirów (Ryc. 1). Najpospolitsze są żwiry utworzone głównie z piaskowców (Rutkowski 1977, 1987a, 1990) zawierające w drobniejszych frakcjach kwarc (Ryc. 3 A, B). W części zachodniej Karpat stwierdza się na ogół domieszkę rogowców mikuszowickich, a we wschodniej rogowców menilitowych. Niekiedy obserwuje się klasty skał magmowych i metamorficznych oraz wapieni pochodzenia egzotykowego (Ryc. 3A, F, 6P, Dżułyński *et al.* 1968). Szczególnie wzbogacone w kwarc są staroczwartorzędowe żwiry z Witowa i plioceńskie z Sośnicowic (Ryc. 6P i 3E, Smoleńska 1975).

Odrębny charakter mają żwiry doliny Dunajca. Budują je piaskowce fliszowe, granity i kwarcyty seisu pochodzące z Tatr oraz wapienie tatrzańskie i pienińskie. Ich skład petrograficzny jest bardzo zmienny (Ryc. 1, 4, 5, Nawara 1964, Kucharska-Słupikowa 1964, Rutkowski i Zuchiewicz 1987). Najodporniejszym składnikiem żwirów są kwarcyty seisu, których udział jest nieproporcjonalnie duży w stosunku do powierzchni wychodni na terenie Tatr, a ich ilość rośnie ku frakcjom najgrubszym (Ryc. 5).

Na przedpolu Karpat materiał karpacki miesza się w różnym stosunku z materiałem pochodzącym z Wyżyn Środkowopolskich i Skandynawii (Ryc. 3C, D, 6). Z wyżyn pochodzą głównie krzemienie, których ilość wzrasta ku frakcjom najgrubszym (Ryc. 6M, L, P_1) i część kwarcytów. Materiał skandynawski to głównie skały magmowe i metamorficzne oraz różowe i czerwone kwarcyty.

Materiał karpacki można obserwować daleko od brzegu Karpat (Rutkowski 1990). Przykładowo w Płocku (465 km) we frakcji 16–32 mm jest go ok. 2%. Stwierdza się to także w dolinie Odry (Magiera 1974). Żwiry przerabiane w czasach historycznych zawierają domieszkę antropogeniczną, np. węgla kamiennego (Ryc. $6M_1$, Rutkowski 1986). O obecności danych skał w żwirach decyduje odporność na niszczenie, spękanie i uławicenie skał macierzystych oraz morfologia obszarów źródłowych.