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AN EVALUATION OF FLYSCH-DERIVED FLUVIAL GRAVELS AS PROVENANCE INDICATORS

(3 Figs.)

O możliwościach błędnych rekonstrukcji paleogeograficznych opartych na żwirach pochodzących z niszczenia utworów fliszowych

(*3 fig.*)

Abstract: An analysis of Quaternary fluvial gravels in the Sandomierz Basin of southern Poland indicates that gravel assemblages derived from a heterogenous flysch sourceland are relatively unreliable indicators of provenance. Intrinsic attributes of the flysch facies render the derived gravels especially amenable to the acquisition of transport bias, resulting in the disproportionate concentration of durable and exotic lithologies. The final gravel assemblages are not only devoid of evidence reflecting their flysch affinities, but may also provide potentially misleading evidence indicating the presence of non-existant exotic lithologies within the inferred sourceland.

INTRODUCTION

The lithologic composition of fluvial gravels is frequently used to infer the composition of their sourcelands. Such evidence can provide a valid basis for provenance inferences. However, it must also be emphasized that fluvial gravel assemblages are frequently biased, and are potentially capable of providing totally misleading evidence.

As noted by Pettijohn (1957), the proportions of different lithic clasts in a gravel are not necessarily a direct reflection of the relative

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abundance of their respective source rocks within the sourceland. Assuming a constant tectonic and climatic framework, the lithologic composition of a particular fluvial gravel is largely a function of sourceland lithology, as well as the degree of lithologic bias acquired during transport. Transport bias is acquired by various processes such a differential abrasion, resulting in the preferential destruction of the more friable clasts, and the disproportionate concentration of the more durable components. Bias can also be acquired by selective sorting during transport, as a result of variations in size, shape, or density of component clasts. In addition, the continuous incorporation of clast admixtures derived from local bedrock sources during transport can also bias the fluvial gravel assemblage. The cumulative effect of these processes is frequently a progressive downstream variation in gravel composition. Consequently, the degree to which a fluvial gravel accurately reflects the lithology of its sourceland is largely reliant upon the amount of acquired bias, which is directly related to transport distance. The work of Plumley (1948) on fluvial gravels in the Black Hills of South Dakota indicates that substantial downstream compositional variations can occur within a short distance of only 10 miles. Plumley further notes that in a 30-mile transport distance, the quantity of limestone and sandstone pebbles present within the gravels experiences a tenfold percentage reduction. Similar observations have been made by Unrug (1957) and Nawara (1964) on recent gravels of the Dunajec river within the Carpathian Mountains.

Although bias resulting from the mechanics of fluvial transport can greatly influence the final composition of a gravel assemblage, sourceland lithology appears to be the predominant influential factor. Since the sourceland establishes the initial lithologic frequency distribution of a gravel (Plumley, 1948), the relative erosive resistance and gravel-producing capability of the individual source rocks, as influenced by tectonic and climatic factors, represent the ultimate determinants. The importance of climate in controlling sourceland gravel production is exemplified by a study of alluvial fan deposits, under arctic weathering conditions in the Northwest Territories of Canada (Legget et al., 1966). The alluvial fans were locally derived from Cretaceous sandstones, siltstones, and shales of the Richardson Mountains, but were devoid of any significant quantities of gravel-size detritus. Severe frost action resulted in extensive source rock disintegration, and inhibited the production of gravels.

Assuming constant climatic conditions which are favorable to the production of gravel, different sourcelands should produce fluvial gravel assemblages of varying reliability as provenance indicators. The most reliable gravel should be derived from sourcelands characterized by a relatively homogeneous lithology, since the resulting homogeneous gravel

would be less amenable to the acquisition of transport bias. Conversely, gravels derived from lithologically heterogeneous sourcelands which produce a wide spectrum of lithic clasts should be least reliable, since transport bias resulting from differential abrasion and selective sorting would be maximal.

In provenance studies, the degree of reliability of gravel assemblages in reflecting original sourceland lithology might comprise a complete continuum, ranging from totally reliable, to totally unreliable. The degree of reliability should be directly related to the degree of sourceland homogeneity, which in turn, largely influences the amount of acquired bias for a given transport distance. The objective of this paper is to analyze a fluvial gravel assemblage derived from a relatively heterogeneous flysch sourceland, and evaluate its reliability as a provenance indicator. This is accomplished by providing an illustrative example from the Sandomierz Basin of southern Poland.

GEOLOGIC SETTING

The Sandomierz Basin is located northeast of Cracow, and is situated adjacent to the northern margin of the Polish Carpathian Mountains (Fig. 1). Structurally, the basin is a foreland graben containing largely marine Miocene deposits, which border the outer nappes of the Cretaceous — Tertiary Carpathian Flysch. Following the Carpathian orogeny in late Miocene time, the Miocene fill of the Sandomierz Basin was subjected to several cycles of fluvial erosion and deposition. Early Quaternary (pre-Mindel) fluvial sediments deposited within the basin were derived exclusively from the Cretaceous and Tertiary flysch source rocks which comprise the outer Carpathian Mountains. The sediments were widely deposited throughout the basin by the ancestral northern Carpathian fluvial system, which drained eastward into the Black Sea (Dżułyński et. al., 1968; Laskowska-Wysoczańska, 1971). These fluvial deposits presently occur only as erosional remnants, overlain by Mindel glacial till. The best exposures occur near the village of Witów, approximately 30 km from the Carpathian margin, where gravels and sands attain a maximum aggregate thickness of approximately 100 meters. The Witów gravels and sands, which form the basis of this study, have been previously interpreted as Upper Miocene marine deposits (Łyczewska, 1948), and as fluvial deposits of Mindel age (Gradziński and Unrug, 1959). However, more recent studies by Kucia-Lubelska (1966) and Dżułyński et. al. (1968) have established the Witów sediments as Lower Quaternary fluvial deposits of pre-Mindel (Pre-Kansan) age. The gravels contain variable proportions of sandy matrix, and tend to occur as lenticular bodies dispersed throughout coarse sands and highly subordinate mud layers. The flysch sourceland of the

Witów deposits consisted of the ancestral Raba River drainage basin, which encompassed an area of approximately 1200 km² within the outer Carpathian nappes (Fig. 1).

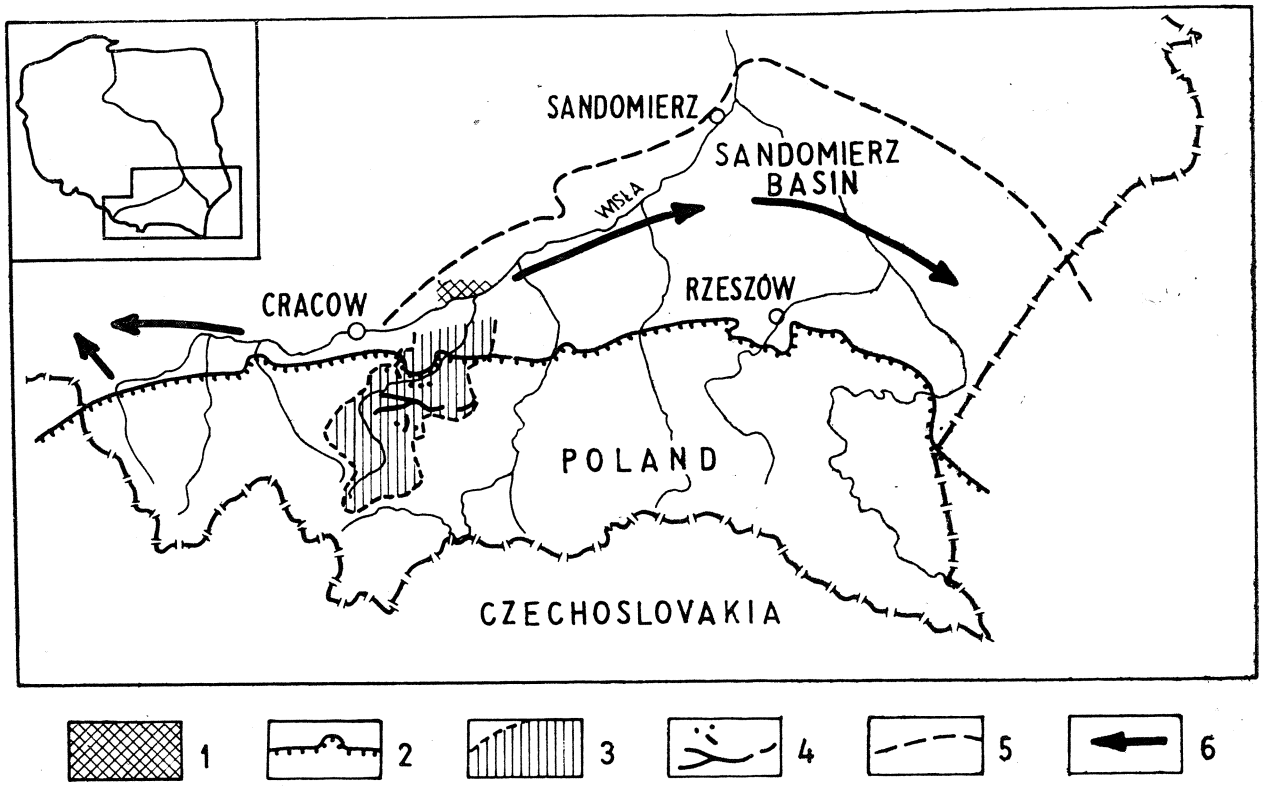

Fig. 1. Index map of study area: 1 — location of Witów gravels; 2 — Northern limit of the Carpathian Mountain flysch; 3 — ancestral Raba River drainage basin; 4 — exposures of the Lgota, Godula, and Grodzisk Beds; 5 — morphological boundary of the Sandomierz Basin; 6 — Early Quaternary drainage directions

Fig. 1. Występowanie żwirów witowskich: 1 — występowanie żwirów witowskich; 2 — północna granica Karpat fliszowych; 3 — dorzecze Raby; 4 — odsłonięcie warstw lgockich, grodziskich i godulskich; 5 — granice morfologiczne kotliny sandomierskiej; 6 — staroczwartorzędowe kierunki odwodnienia

DISCUSSION

Gravel Composition

The Witów gravels have been transported an average distance of approximately 60 km from their flysch sourceland, an amount presumably sufficient to result in the acquisition of substantial transport bias, as indicated by Plumley's (1948) study. The gravel assemblage is composed primarily of durable clasts derived from the more resistant flysch source rocks. The main components are siliceous subgreywacke clasts, derived from the Cretaceous Lgota and Godula Beds. Present in subordinate quantities are clasts of Cretaceous Grodzisk Sandstone, vein quartz, and chert derived from siliceous intercalations within the flysch facies. In addition, the gravels contain clasts of Paleozoic and Upper Jurassic limestones, as well as crystalline igneous and metamorphic rocks. These lime-

stone and crystalline clasts are of particular interest, since they occur exclusively as exotics in pebbly and bouldery mudstones locally intercalated within some flysch sequences which comprised the sourceland.

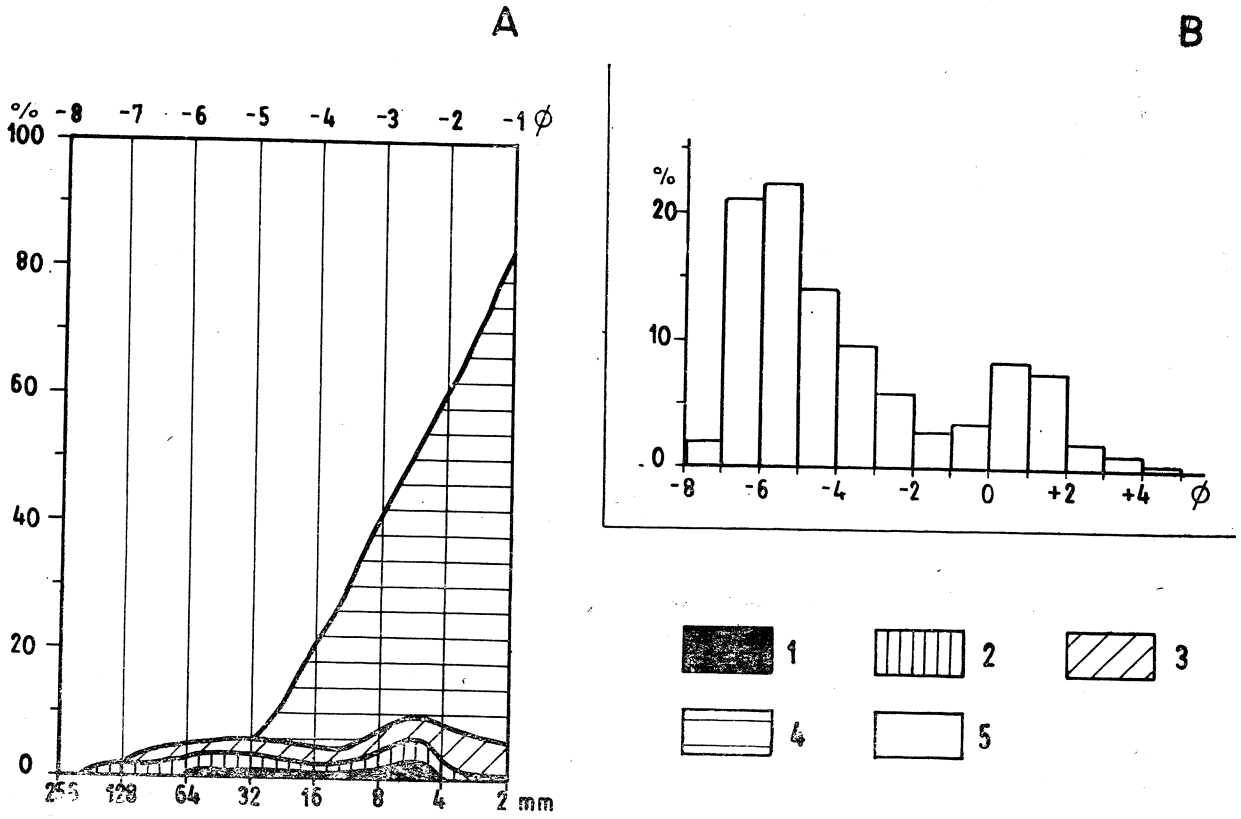

Fig. 2. A — Weight percentage variations in gravels composition as a function of size grade: 1 — igneous and metamorphic clasts; 2 — limestone clasts; 3 — chert clasts; 4 — quartz clasts; 5 — sandstone clasts. B — Histogram illustrating grains composition of gravels

Fig. 2. A — Zmienność składu petrograficznego żwirów w procentach wagowych w zależności od uziarnienia: 1 — skały magmowe i metamorficzne; 2 — wapienie; 3 — rogowce; 4 — kwarce; 5 — piaskowce. B — Skład ziarnowy żwirów.

A diagram illustrating relative percentages of each lithologic component comprising the Witów gravels is shown in Figure 2, with each size grade being treated separately. It should be noted that substantial compositional variations occur between size grades, a gravel characteristic also noted by other workers (e. g. Potter and Pettijohn, 1963). Although Figure 2 is based on weight percentages, it should be noted that similar results were also obtained using number percentages, a field measurement which is especially convenient when a large number of sample stations are involved. This compositional variability illustrates the necessity of utilizing all size grades in formulating sourceland inferences from gravel assemblages.

Sourceland Reconstruction

Employing the lithologic data provided by the Witów gravel assemblage, one might logically reconstruct the hypothetical sourceland as being composed primarily of siliceous sandstones, with subordinate amounts of cherts, limestones, and quartz-veined crystalline rocks. The fauna within the limestone clasts in the gravel would further indicate that the limestone strata present in the sourceland were of Devonian, Lower Carboniferous, and Upper Jurassic age.

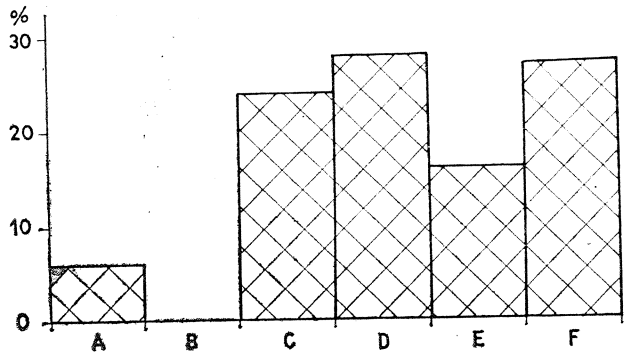

Fig. 3. Histogram illustrating areal percentages of source rocks within the ancestral Raba River drainage basin: A — Lgota, Godula, and Grodzisk beds (Cretaceous), B — Exotic — bearing beds; C — Istebna beds (Upper Cretaceous — Paleocene); D — Magura beds (Eocene); E — Krosno beds (Oligocene); F — other flysch units

Fig. 3. Histogram ilustrujący występowanie skał macierzystych otoczaków w dorzeczu Raby w % powierzchni: A — warstwy lgockie, godulskie i grodziskie; B — osady z egzotykami; C — warstwy istebniańskie; D — warstwy magurskie; E — warstwy krośnieńskie; F — inne utwory fliszowe

Although the foregoing sourceland reconstruction would be entirely reasonable for the evidence provided by the Witów gravels, it would be a highly erroneous interpretation. The actual extent of the true sourceland, which consisted of the ancestral Raba River drainage basin, can be delineated topographically on the basis of morphology (Fig. 1). Moreover, its lithologic composition can be accurately inferred from present geologic conditions, because no structural changes have occurred since early Quaternary time. The relative areal percentages of the various source rocks comprising the ancestral drainage basin are illustrated by the histogram in Figure 3. It is now possible to evaluate the erroneous sourceland interpretation. For example, no indigenous Devonian, Carboniferous, or Jurassic limestones exist within the ancestral drainage basin of the Raba River. In addition, crystalline igneous and metamorphic lithic units are equally non-existant. Gravel clasts composed of these limestone and crystalline materials are exotics derived from the weathering of rare pebbly and bouldery mudstones, and disproportionately represent an infinitesimally small percentage of the source materials which were available within the sourceland. The occurrence of such exotics in contemporary

Carpathian stream gravels is extremely rare, thus providing a true representation of their quantitative insignificance as source materials.

Another erroneous inference would be the importance attributed to the siliceous sandstone clasts which represent the bulk of the gravel assemblage, but which were derived from stratigraphic units that comprise less than 6 percent of the bedrock area within the drainage basin. It should also be noted that shales, which are volumetrically very important components of these flysch units (approximately 50 percent), are totally unrepresented in the gravels. Another significant feature of the Witów gravel assemblage is the absence or scarcity of clasts derived from prominent stratigraphic units whose areal distributions represent substantial percentages of the sourceland area. For example, no clasts derived from the Cretaceous-Paleocene Istebna Beds (24 percent), or from the Oligocene Krosno Beds (15 percent) have been noted. Both units are relatively friable, with the Istebna Beds consisting largely of arkosic sandstones, and the Krosno Beds consisting mainly of calcareous sandstones. Consequently, these prominent source rocks have completely disintegrated during transport, and are presently represented only by the sand layers and sandy matrix of the gravels.

CONCLUSIONS

An analysis of the Witów gravels indicates that gravel assemblages derived from relatively heterogeneous flysch sourcelands are highly unreliable as a basis for provenance studies. Such gravels, not only provide misleading evidence regarding source rock lithology, but also provide no indication of their original flysch affinities. The unreliability of flysch-derived gravels results largely from two biasing factors which are intrinsic to flysch sequences. One factor is the inherent stratigraphic nature of the flysch facies, being composed of heterogeneous sequences of alternating sandstones and shales. Gravels derived from such sequences are especially amenable to the acquisition of transport bias, with the shale clasts experiencing preferential disintegration and possible elimination over very short transport distances. In sourcelands characterized by a "normal flysch" facies (Dżułyński and Walton, 1965 p. 3), argillaceous units comprise approximately 50 percent of the sourceland volume; whereas, in a "shaly flysch" facies, they comprise a substantially higher percentage. Consequently, a flysch-derived gravel devoid of argillite clasts may volumetrically reflect the lithology of less than half of the original sourceland.

A second biasing factor inherent to the flysch facies is the occassional presence of exotic clasts incorporated within wildflysch or pebbly mudstone deposits. Although such clasts are volumetrically insignificant within the flysch facies, their durable nature relative to flysch shales and the

more friable sandstones, results in their disproportionate concentration within the gravel assemblage during transport. As a result, rocks which are non-existant as discrate stratigraphic units within the flysch source-land could be erroneously inferred from exotic materials.

These inherent attributes of the flysch facies indicate that flysch-derived fluvial gravels are especially amenable to transport bias, and are relatively unreliable indicators of provenance.

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STRESZCZENIE

Skład petrograficzny żwirów uzależniony jest między innymi od charakteru litologicznego obszaru źródłowego, jego tektoniki, warunków klimatycznych oraz sposobu transportu. W przypadku żwirów rzecznych w czasie transportu zachodzi selektywna abrazja związana z odmienną odpornością poszczególnych otoczaków oraz selektywne sortowanie materiału uwarunkowane różnicami w ich kształcie, wielkości i gęstości. W wyniku tych procesów skład petrograficzny żwirów często nie odzwierciedla budowy geologicznej obszarów źródłowych.

Niekiedy analiza składu petrograficznego otoczaków może prowadzić do wręcz błędnych rekonstrukcji, zwłaszcza, gdy wśród skał macierzystych występują odporne egzotyki. Przykładem tego są staroczwartorzędowe żwiry witowskie (starsze od zlodowacenia krakowskiego) pochodzące z niszczenia fliszu karpackiego w dorzeczu pra-Raby.

Głównym składnikiem żwirów są twarde i zwięzłe piaskowce z warstw lgockich i godulskich, a także grodziskich oraz otoczaki skał egzotykowych. Otoczaki piaskowców fliszowych pochodzą z najodporniejszych skał, które stanowią zaledwie około 6% współczesnego i które najprawdopodobniej w takim samym stosunku odsłaniały się w staroczwartorzędowym dorzeczu Raby. Pozostałe piaskowce fliszowe są albo w ogóle nie reprezentowane (np. piaskowce istebniańskie stanowiące około 24% dorzecza, czy też piaskowce krośnieńskie reprezentujące 15%), albo występują w nieznacznej ilości jak np. piaskowce magurskie. Ze zrozumiałych powodów nie ma zupełnie łupków stanowiących co najmniej połowę osadów macierzystych. Natomiast egzotyki występujące we fliszu w znikomo małych ilościach, i to wyłącznie pod postacią otoczaków i bloków, w żwirach witowskich uległy wielokrotnemu wzbogaceniu do ilości paru procent. Wśród egzotyków występują między innymi wapienie „typu

sztramberskiego", wapienie paleozoiczne oraz skały magmowe i metamorficzne.

Rekonstruując na podstawie składu petrograficznego żwirów witowskich budowę ich obszaru źródłowego, można by dojść do wniosku, że był on zbudowany między innymi ze skał magmowych i metamorficznych, z wapieni jurajskich i paleozoicznych, które jak wiadomo, nie odsłaniają się i nigdy nie odsłaniały się w dorzeczu Raby.

Możliwość występowania egzotyków na wtórnym złożu w żwirach rzecznych należy zatem brać pod uwagę przy wszelkich rekonstrukcjach obszarów źródłowych na podstawie kopalnych żwirów rzecznych.

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