S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
VOL. XXXVII KRAKÓW 2003 PL ISSN 0081-6434
L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

ROMAN MALARZ (KRAKÓW)

DOWNSTREAM CHANGES OF FLUVIAL GRAVELS, THE PRUT RIVER, UKRAINE

Abstract. Characteristics of modern alluvial gravels were studied in the valley of the Prut river, which crosses the Ukrainian East Carpathians and their foreland. The Prut is one of the few large Carpathian rivers not barred with any dams or barrages, so that its discharge and transport of debris are shaped entirely by natural processes. Petrographical composition, roundness and shapes of pebbles were studied at nine sites located in the river channel between Worochta and Chernivtsi. The rate of abrasion was determined by comparing the sizes of 20 largest specimens from each site.

Pebbles of fine-grained sandstones dominate at all localities. Their content does not fall below 60 percent in any of the studied fractions. A characteristic feature of the Prut gravels is exceptionally low, as for the Carpathians, content of quartz clasts. Quite frequent are cherts which are even more frequent than quartz at some sites. The values of roundness increase downstream and the pebble size decreases in the same direction. The values of the Sternberg size reduction coefficient ranges from 0.0121 in the foreland reach to 0.0335 in the mountain reach. The proportion of rod-like pebbles increases systematically downstream.

Key words: gravels, fluvial sediments, Prut River, East Carpathians

INTRODUCTION

The Prut is one of the biggest left tributaries of the Danube. The river is 953 km long and the surface area of its drainage basin is 27,000 km^2. The sources of the Prut lie on the eastern slopes of the Hoverla, the highest montain in the East Carpathians (2,060 m a.s.l.). The river flows initially to the north, diagonally cutting through the lithostratigraphic units belonging to the Chernogora nappe, Krosno zone, Skole nappe and Borislav–Pokutie Folds (Fig. 1). Near the village of Delatyn, downstream of Yaremcha, the Prut leaves the Carpathians and flows over the Neogene, mainly Sarmatian, sediments. Beginning from Yaremcha, the river takes an easterly course, and then, more or less from Śniatyn, a more and more southerly one. The nature of the valley is controlled by geological structure

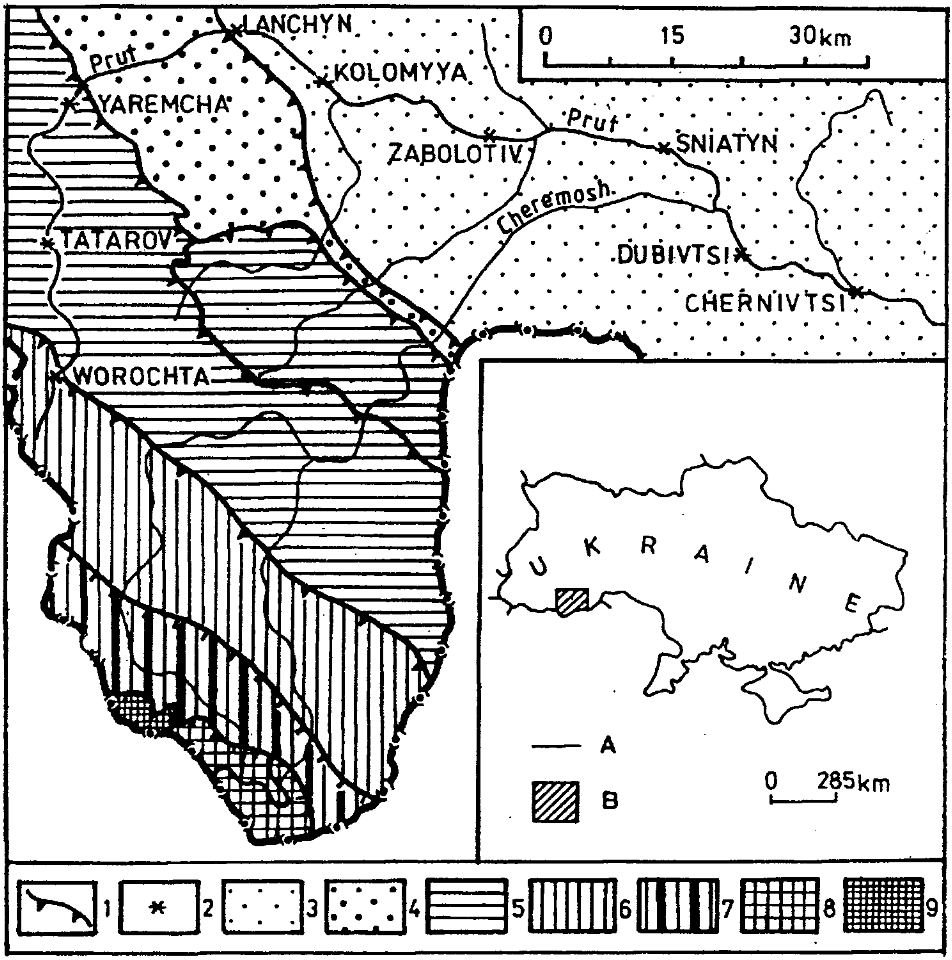

Fig. 1. Schematic geological map of the upper Prut river basin. 1 — major overthrusts, 2 — studied sites, 3 — Neogne, 4 — Skole nappe, 5 — Krosno zone, 6 — Chernogoraora nappe, 7 — Suchow zone, 8 — Marmarosz zone, 9 — Rachow zone

of the bedrock. In more resistant rocks, mainly thick-bedded sandstones, the valley has a narrow bottom, steep and locally precipitous slopes (Photo 1), high longitudinal gradient, and cascades appear in the river channel between Yamna and Yaremcha (Teisseyre 1938). A high waterfall on the Prut was blown up in the 19th century in order to facilitate log rafting (Grodziski 1998). In the zones built of less resistant rocks, where shales are abundant in bedrock, the valley is wider and its slopes are gentle. In the upper course of the river, near Worochta, such a zone gives rise to a wide intramontane depression. The Prut gap extends between Tatarov and Yaremcha. Crags and cliffs appear on the steep slopes, of which best known is the Dobosz Stone near Yamna. The river has a much lower gradient and is braided in the foreland zone.

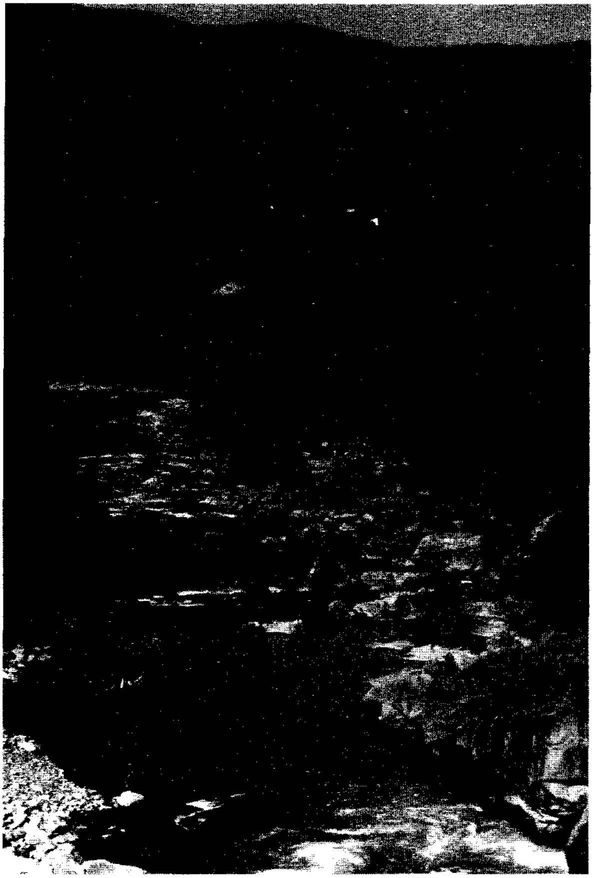

Photo 1. The Prut River near Yamna

The Prut, similarly as other Carpathian rivers, has a very variable discharge. High water stages occurs frequently, and there is a devastating flood once in 10 to 20 years. Springtime highwaters are due to snow melting, and those during the summer due to heavy rainfalls. Annual rainfall in the upper part of the Prut drainage basin exceeds 1,800 mm (*Atlas*... 1990). Heavy or prolonged rainfalls in summer result in large floods which cause great changes in the river channel and great damage to infrastruture (Photo 2). Between ten and twenty large floods occured in the Prut valley in the 20^{th} century. The most devastating one was on June 8, 1969. The water level in Yaremcha rose to 760 cm (Fig. 2). The mean annual water stage at this place is 233 cm. An earlier flood of this size was on August 31, 1927. The water level was then more than one metre lower and attained 609 cm. Increased erosion, transport stage are taking place during such devastating flods, followed by accumulation at the waning stage. It also during such floods when the coarsest debris is transported and abraded. The result of these processes is a downstream change in some characteristics of the Prut gravels.

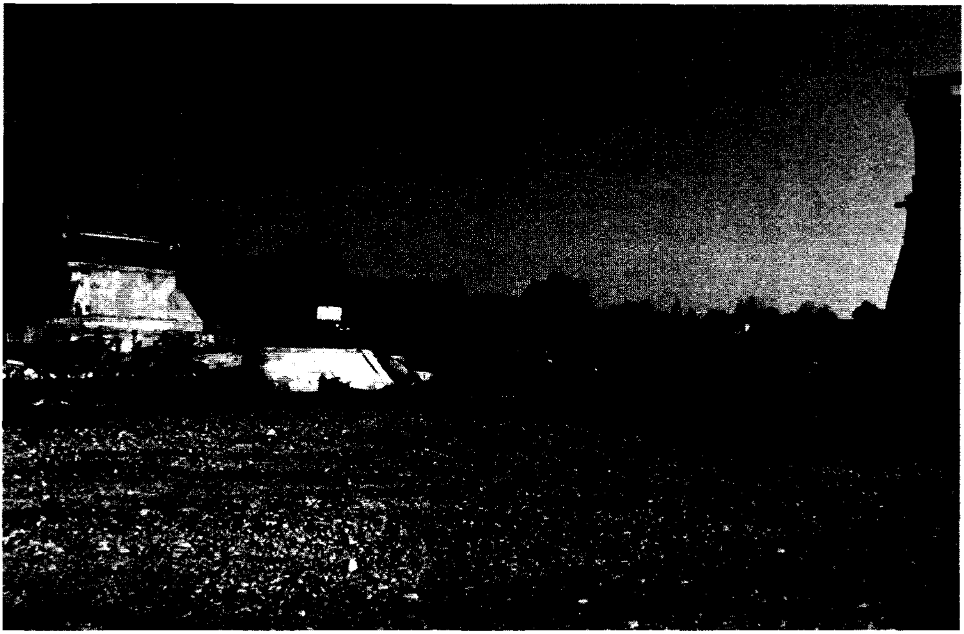

Photo 2. Collapsed bridge in Kolomyya

The aim of the field work was a preliminary characterization of the Prut alluvium between Worochta and Chernivtsi (154 km). Nine sites were selected for the study (Table 1). Three of them (Worochta, Tatarov, Yaremcha) are located within the Pokutie–Bukovina Carpathians and the other six in a wide foreland depression narrowing southwards towards the Prut Gate near Chernivtsi. Studied were the gravel bars directly adjacent to the channel, bearing no traces of exploi-

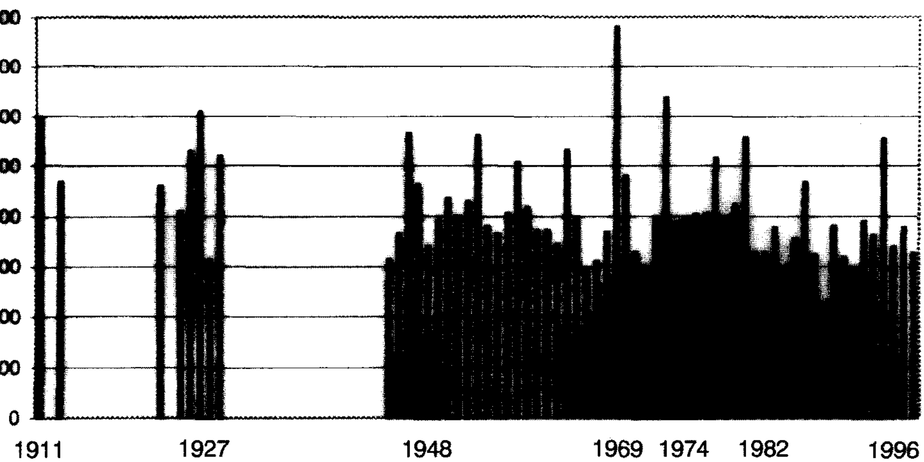

Fig. 2. High water stages on the Prut river at Yaremcha (based on unpublished data of the Hydrological Station in Yaremcha)

tation or other form of human activity. Field conditions and time limitations caused some reduction in the amount of the data collected in the field. The data collection at each site was limited to measurement and mezoscopic investigation (roundness and petrographic composition) of 20 largest pebbles at each site and taking a sample of the 2–64 mm size-class for analyses of granulometric and petrographic composition. Moreover, roundness and shapes were studied for the 17–32 mm fraction, accepted as the inex class.

Table 1

Location of studied sites in the Prut valley

Site	Distance from spring [km]	Altitude in m	Type of bedrock
Spring	0	1,750	Carpathians
Worochta	13.5	825	Carpathians
Tatarov	31.5	645	Carpathians
Yeremcha	46.5	501	Carpathians
Lanchyn	67.0	368	Foreland
Kolomyya	87.5	285	Foreland
Zabolotiv	99.5	230	Foreland
Śniatyn	130.5	202	Foreland
Dubivtsi	152.0	178	Foreland
Chernivtsi	167.5	161	Foreland

GEOLOGICAL SETTING

The Chernogora Nappe includes a sequence of rock series from the Upper Cretaceous through the Oligocene. B. Świderski et al. (1934) includes the Oligocene sandstones that make up the Koźmierska-Mariszewska range to the most resistant rock series. The highest part of the Chernogora — the Howerla–Pop Iwan range — is carved in steeply dipping and tightly folded Oligocene sandstones, shales and conglomerates. The marginal range of the Chernogora Nappe — the Kukula–Kostrzyca range — is built of resistant, anticlinally uplifted Inoceramian Beds. It is within this series where the Prut valley for the first time has the features of a gap.

The Krosno Zone occupies the broad depression of Worochta–Żabie where the valley widens to 1,000 m. The bedrock consists of non-resistant, tightly folded Oligocene Krosno Beds (Świderski et al. 1934).

The dominant lithological element of the Skole nappe in the Prut drainage basin are the Incoeramian Beds. The Lower Inoceramian Beds consist mostly of argillaceous and calcareous shales, fine-grained and medium-grained platy sandstones and subordinate hard marls and conglomerates (Wdowiarz 1948). Sandstones predominate (70–90%) in the Upper Inoceramian Beds. The main lithological variety in this unit are medium- and thick-bedded grey calcareous sandstones. Individual sandstone beds are up to 2 m thick. The three youngest members of the Skole Nappe are the Yamna Sandstone, Hieroglyphic Beds and Menilite Shales. The Yamna Sandstone consists of thick-bedded sandstones and thin-bedded sandstones alternating with variegated shales. Extensive boulder sheets in the Prut channel near Dora are built of the Yamna Sandstone (Photo 1). Siliceous varieties of the Yamna Sandstone form block and scree fields on mountain crests and slopes, known mainly from the Gorgany (the Chomiak–Hrebla range). The Yamna Sandstone is overlain by the shales and sandstones of the Hieroglyphic Beds. The uppermost stratigraphic member of the Skole Nappe are Menilite Shales and Menilite Cherts. The cherts make up to several percent in the Prut gravels, especially in the finest fractions.

The Skiba Folds zone is widest in the central part of the Ukrainian Carpathians and towards the Romanian frontier it narrows to 11 km. The sequence of strata which makes up this unit attains 1.5 km in thickness. The exposures of this unit appear in the Prut valley in Delatyn. The unit consists here of two anticlines with Hieroglyphic and Menilite Beds in their cores (in one of them also the Yamna Sandstone is exposed — see Świderski et al. 1934).

The Miocene sediments that appear at the front of the Carpathians are folded together with the flysch and thrust to the north for at least 12 km. Outcrops of salt-bearing clays that appear at the margin of the Carpathians in the Prut valley form an embayment which indents the mountainfront by 1 km. Downstream of the salt-bearing clays appear masses of the Sloboda Conglomerate and the Stebnik Beds. Somewhat farther to the east the salt-bearing formation lies at the depth of ca 1,300 m (Wyszyński et al. 1939). The salt-bearing clays are overlain by clays with sandstone intercalations. These include deltaic sediments laid down by an unknown river flowing from the Carpathians. The capacity of this river is attested by pebbles exceeding 0.5 m in size, laid down in the delta. The delta wedges out towards the northeast and the gravels are being replaced by sands and then clays. The molasse sediments in Pokucie include: 1) gravels and conglomerates, 2) sands and calcareous sadnstones, 3) clays — often marly or sandy (Wyszyński et al. 1939).

CHARACTERISTIC OF THE PRUT GRAVELS

PETROGRAPHIC COMPOSITION

The analysis of the petrographic composition was limited to four size classes: 2–4 mm, 5–8 mm, 9–16 mm and 17–32 mm. Only these fractions could be transported to the lodging place in quantities that permitted a correct evaluation of their composition. The frequencies of specimens in separate fractions varied from 100 in the coarsest fraction (16–32 mm) to more than 500 for the finest pebbles (2–4 mm). The samples were separated into size fractions by sieving. Three varieties of sandstones were separated within each size fraction: fine- (S1), medium- (S2) and coarse-grained (S3), as well as conglomerates (C), quartz (Q) and cherts (Ch). The exotic rocks varieties and pebbles of athropogenic origin were classified as "others" (O). Clasts of fine-grained sandstones predominate in all size classes at all sites. They make up more than 80% in the finer classes. They are somewhat less numerous in the coarser size-classes (9–16 mm and 17–32 mm) though nowehere is their content lower than 60%. The content of the fine-grained sandstones higher than 95% was found in the 2–4 mm class at the farthest upstream sites (Lanchyn, Yaremcha, Tatarov, Worochta). Medium-grained sandstones are practically absent in the finest size-class. Only at four sites they appear in statistically recordable amounts (0.6–1.1%). The proportion of the medium-grained sandstones increases with increasing size of clasts. Their amount is marked already in the 17–32 mm class (5–29%). Coarse grained sandstones and conglomerates are absent in the finest size-class and rare — usually below 10% — in the 17–32 class (Table 2).

Table 2

Petrographic composition of the Prut gravels (percentages), 2–4 mm size-class

	Worochta	Tatarov	Yaremcha	Lanchyn	Kolomyya	Zabolotiv	Śniatyn	Dubivtsi	Chernivtsi
S1	96.0	96.6	96.1	95.4	91.5	85.6	81.7	90.0	88.0
S2	0	0	0.6	0	1.1	0	1.0	0	0.9
S3	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0
Q	2.2	1.0	0.9	2.3	1.9	4.8	7.0	6.9	3.9
Ch	1.8	2.2	2.4	2.2	5.3	8.8	9.6	2.7	6.4
O	0	0.2	0	0.1	0.2	0.8	0.7	0.4	0.8

S1 — fine grained sanstone, S2 — medium grained sanstone, S3 — coarse grained sandstone, C — conglomerates, Q — quartz, Ch — cherts, O — others

A characteristic feature of the Prut gravels is their low content of quartz clasts, unusual in the Carpathians. Even in the finest size class their content does not exceed a few percent, the maximum content, at Śniatyn — is 7.0%. At most sites even cherts are more numerous than quarts. This feature clearly distinguishes the Prut gravels from the gravels of the West Carpathian rivers, which have several tens percent of quartz pebbles in the finest size classes (Rutkowski 1987, 1995; Malarz 1992). The high content of cherts is related to the extensive outcrops of the Menilite Krosno Series in the Prut drainage basin. Cherts are frequent in this lithostratigraphical unit.

An analysis of downstream variations in petrographical composition of the gravels is a separate topic. Though the dominant position of the fine-grained sandstones disturbs the graphic representation of these variations (Fig. 2), a rule observed earlier in the Carpathians emerges here clearly, namely the alluvium becomes enriched downstream in the most resistant components — quartz and chert. The proportion of fine-grained sandstones gradually decreases between Worochta and Śniatyn. The content of this lithological variety rapidly increases at Dubivtsi. There is only one explanation for this. The site lies downstream of the Cheremosh confluence with the Prut (Fig. 1) and the petrographical composition and other characteristics of the gravels (see below) represent alluvium of the Cheremosh rather than of the Prut. This is due to the higher dynamics, gradient and often higher discharge of this largest right affluent of the Prut.

The taking of the measurements of the largest 20 pebbles at each site was accompanied by determination of their petrographical composition. Though their frequency is too small to calculate percentages and to draw detailed conclusions, the data in Table 3 may suplement the earlier analyses. The greatest pebbles in the studied sites include all the three varieties of sandstones and conglomerates. The latter are most frequent in the farthest upstream sites. The highest content of these varieties was found at Worochta (four specimens). Nevertheless, the fine- and medium-grained sandstones predominate. The share of the former is dominant at the three lowest downstream sites (11 specimens at each site).

Table 3

Petrographical composition of the largest pebbles in the Prut gravels (> 128 mm size class)

	Worochta	Tatarov	Yaremcha	Lanchyn	Kolomyya	Zabolotiv	śniatyn	Dubivtsi
S1	5	4	11	10	7	4	11	11
S2	6	9	7	9	13	9	3	7
S3	5	4	1	1	0	6	4	2
C	4	3	1	0	0	1	2	0
Q	0	0	0	0	0	0	0	0
Ch	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0

S1 — fine grained sanstone, S2 — medium grained sanstone, S3 — coarse grained sandstone, C — conglomerates, Q — quartz, Ch — cherts, O — others

PEBBLE SIZE

The size of pebbles in gravel-bed Carpathian rivers depends on local conditions. Where the bedrock is built of flysch, the size of the largest boulders depends on the thickness of the sandstone or conglomerate layers. The largest pebbles appear where thick-bedded sandstone or conglomerate series occur in the bedrock. The greatest boulders in the Prut valley appear on the outcrops of the Yamna Sandstones. At the Tatarov (Fig. 3) and Yaremcha sites their dimensions exceed 2 m (Table 4). At the higher upstream site Worochta, located on the outcrops of thin-bedded Krosno Beds, the dimensions of the largest specimens are three times smaller than at the two earlier mentioned sites. As

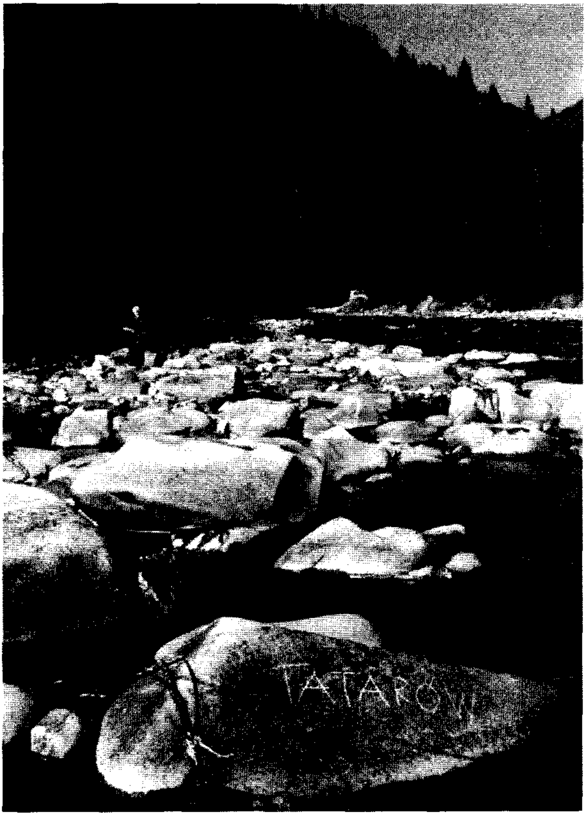

Photo 3. The Prut river gravel-bed at Tatarov

a result, we observe a downstream increase rather than a decrease in the pebble size along the Worochta–Tatarov reach. This fact is not surprising. Large oscillations of pebble size in mountain river gravels were earlier found by A. D. Knighton (1982), Y. Kodama (1994) and M. Mikoš (1993). Similar in pebble size the present author observed in gravel bars of the Soła and Skawa (Malarz 2002). The supply of flysch material to the Prut channel ceases where the river crosses the front of the Carpathians at Lanchyn (Photo 4) and the Miocene strata appear in the bedrock. From this place on, a regular reduction in pebble-size is taking place, disturbed only by the supply of coarser fractions from the right Carpathian affluents of the Prut: the Rybnica and the Cheremosh. Pebbles of Sarmatian sandstones appear in larger amounts at the site Chernivtsi. The Prut river enters there the Prut Gate and mass movements supply Sarmatian material rich in flat concretions of light medium-grained sandstones. For this reason this site was omitted from the discussion on the rate of size reduction of the Carpathian pebbles.

The rate of pebble size reduction is described by the Sternberg law (Sternberg 1875):

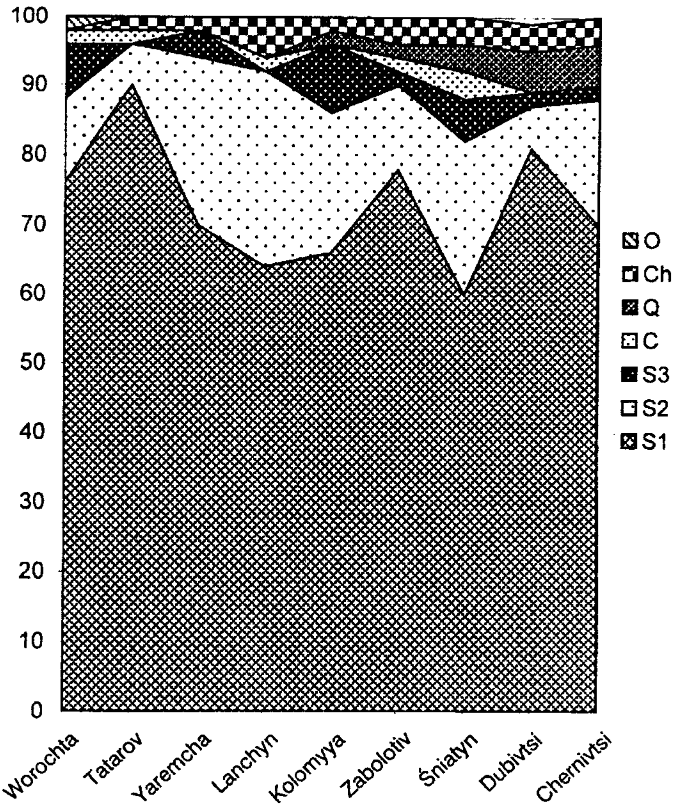

Fig. 3. Petrographical composition of the Prut gravels between Worochta and Chernivtsi (17–32 mm size class). S1 — fine grained sanstone, S2 — medium grained sanstone, S3 — coarse grained sandstone, C — conglomerates, Q — quartz, Ch — cherts, O — others

$$S = S_0 e^{-kx}$$

where: S — the pebble size after transport (in mm), S_0 — the initial size (in mm), e — the base of natural logarithm, x — the lenth of transport route (in km), k — coefficient of reduction for given rock type.

The index is variable for the Prut. Its values are higher in the mountain reach, and lower in the foreland reach (Table 4). Within the Pokutie–Bukovina Carpathians reach of the Prut the rate of size reduction of rock particles is nearly three times higher than within the foreland reach. The reason should be sought in higher dynamics of the river, manifest in its steeper gradient, the presence of bedrock obstacles in the channel and higher flow velocities. Also the role of resistance selection of the transprted bedload should be taken into account (Knighton 1982).

Photo 4. The Prut gravels at Lanchyn. Scale bar — 10 cm

Table 4

Sternberg indices for the Prut gravels

	Mean of 20 greatest specimens			The greatest specimen		
	a	b	c	a	b	c
Mountainous reach (Tatarov–Lanchyn)	0.0335	0.0337	0.0248	0.0349	0.0376	0.0276
Foreland reach (Lanchyn–Dubivtsi)	0.0121	0.0147	0.0124	0.0113	0.0078	0.0210

Table 4 presents indices representing mean values of the a, b and c axes of the 20 largest pebbles in the extreme sites and identical parametres of the greatest particles. In the mountain reach, the b axis (pebble width) is reduced fastest. The rate of reduction is lowest for the c axis (thickness). It seems to be the result of rolling along the bottom during which this axis is most susceptible to collisions. The relations are somewhat different in the foreland reach where quite high value of *c* axis (thickness) reduction may indicate another mechanism of bedload transport.

The above indices may be used to determine the length of the transport route after which the greatest particles in the river will be reduced do the size below 2 mm, i.e. to the point where gravel fraction will disappear from the river channel. This should occur in the Prut 446 km downstream from the place where it leaves the Carpathians.

ROUNDNESS

Fluvial transport of rock fragments results in the increase in their roundness. Roundness is here determined using the scale of W. C. Krumbein and L. L. Sloss (1963). The value of roundness depends mainly on the resistance to abrasion and resistance to compression. For the gravels consisting of flysch rocks a major, if not decisive role, is played by the kind of cement. Sandstones with siliceous cement endure fluvial transport much better and they are abraded at a much lower rate. The specimens with calcareous and clayey cement become rounded at a much higher rate (Dżułyński et al. 1974). The degree of roundeness is also controlled by the length of transport (Marshal 1927; Unrug 1957). In the Prut valley, important is also the supply of material, mainly from the right, Carpathian affluents. Roundness at any given site is also influenced by the amount and and quality of the gravel supplied from older alluvial terraces. There are more than ten of them in the Prut valley (Klamczuk 1994).

Average roundness in the size class 17–32 mm in the Prut gravel oscillates between 0.51 at Tatarov to 0.73 at Kolomyya and Zabolotiv. Somewhat greater is the variation in roundness of the greatest clasts at the same localities. The average values for the 20 greatest clasts range from 0.43 at Yaremcha to 0.83 at Zabolotiv. The tendency to downstream increase in roundness is clear (Fig. 5). Average roundness of 100 specimens in the 17–32 mm size class is 0.54 and in the most downstream site it is as high as 0.72. Figure 4 shows how great is the importance of the lateral supply for the values of this parametre. The tributaries shorter than the main river supply less rounded material and this is immedi-

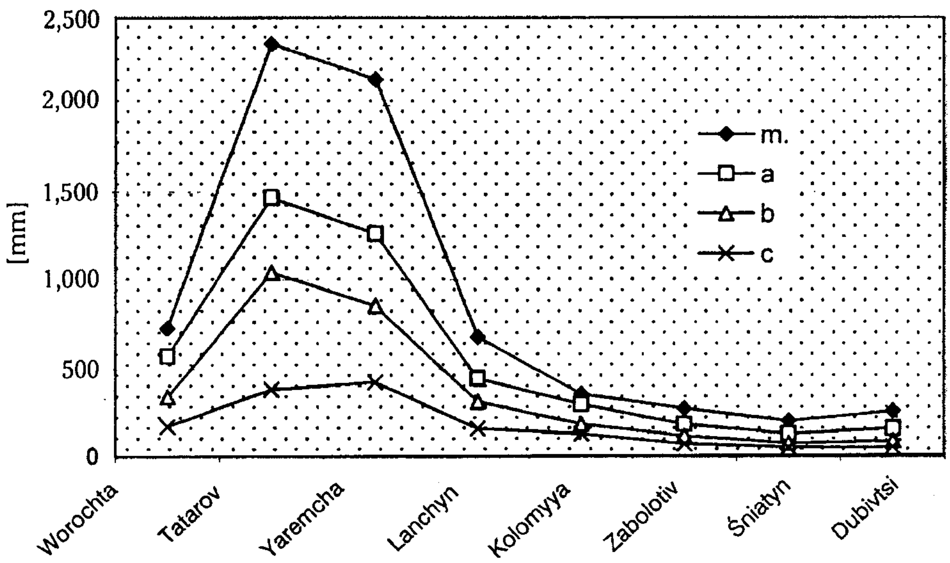

Fig. 4. The sizes of the greatest clasts in the Prut gravel bars (in mm); m — the greatest specimen, a, b, c — mean sizes of 20 greatest specimens

ately reflected in the value of roundness. So the bend in the curve at Tatarov is the result of supply of gravel by the Jabłonicki stream whose sources lie in the area of the Tatarska Pass. The Tatarov site lies downstream of the confluence of the Jabłonicki stream with the Prut. The decreases in the values of roundness of the Prut gravels at Sniatyn (Photo 5) and Dubivtsi can be exlained in a similar way. The former site lies below the confluence with the Rybnica and the latter below the confluence with the Cheremosh. The roundness of the same size class of the Cheremosh gravels at Chartoryya, 4.5 km upstream of the confluence is 0.69 (Malarz et al. 2001). Relatively smaller is the influence of tributaries on the roundness of the greatest specimens. Such a pattern could not be found in the Carpathian sites. Only in the foreland roundness becomes nearly identical as in the finer size classes.

An important information on the internal variation within the samples is provided by the value of standard deviation. Its value is greatest in the samples from the uppermost site — Worochta (Table 5). There the average value of roundness is largely influenced by the extreme values. At the foreland sites, the standard deviation decreases, twofold in some cases. There is a relation of inverse proportionality between the value of roundness and the standard deviation. It is expressed in correlation coefficients of $r = -0.623$ for the 16–64 mm size class and $r = -0.599$ for the >128 mm size class.

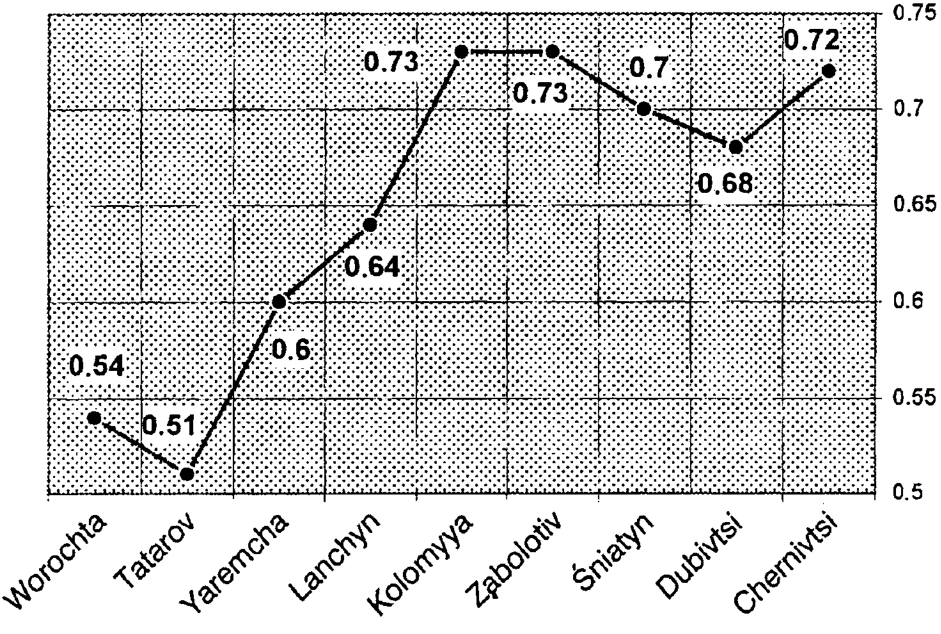

Fig. 5. Roundness of the Prut gravels (17–32 mm size class)

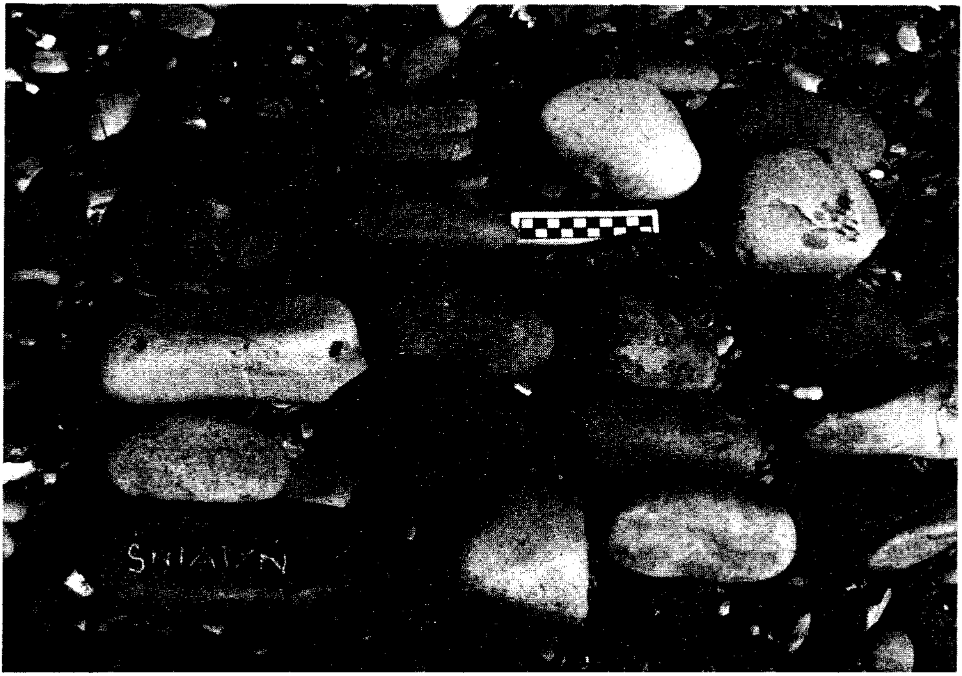

Photo 5. The biggest clasts of the Prut river at Śniatyn. Scale bar — 10 cm

Table 5

Degree of roundness of the Prut gravels and standard deviation

	Distance from spring (in km)	17–32 mm	Standard deviation	> 128 mm	Standard deviation
Worochta	13.5	0.54	0.201	0.59	0.246
Tatarov	31.5	0.51	0.197	0.64	0.131
Yaremcha	46.5	0.60	0.194	0.43	0.175
Lanchyn	67.0	0.64	0.199	0.79	0.165
Kolomyya	87.5	0.73	0.145	0.82	0.101
Zabolotiv	99.5	0.73	0.181	0.83	0.117
Śniatyn	130.5	0.70	0.204	0.78	0.136
Dubivtsi	152.0	0.68	0.155	0.73	0.149
Chernivtsi	167.5	0.72	0.171		

The various lithological varieties differ in the rate of abrasion and hence in the values of the roundness index of the gravels. The values of roundness are lowest for cherts. None of the examined specimens had better roundness than 0.5. Somewhat better rounded than chert clasts are quartz clasts. Of the three varieties of sandstones the coarse-grained ones have the highest values of roundness (0.71–0.80). Somewhat lower are the values for medium-grained sandstones (0.71–0.76). The least rounded of sandstones is the fine-grained variety (0.46–0.72). A clear relationship is visible here: the coarser the grains in the sandstones, the higher is the value of roundness (Fig. 6). A clear proof of this is the value of roundness of conglomerate grains (0.70–0.90).

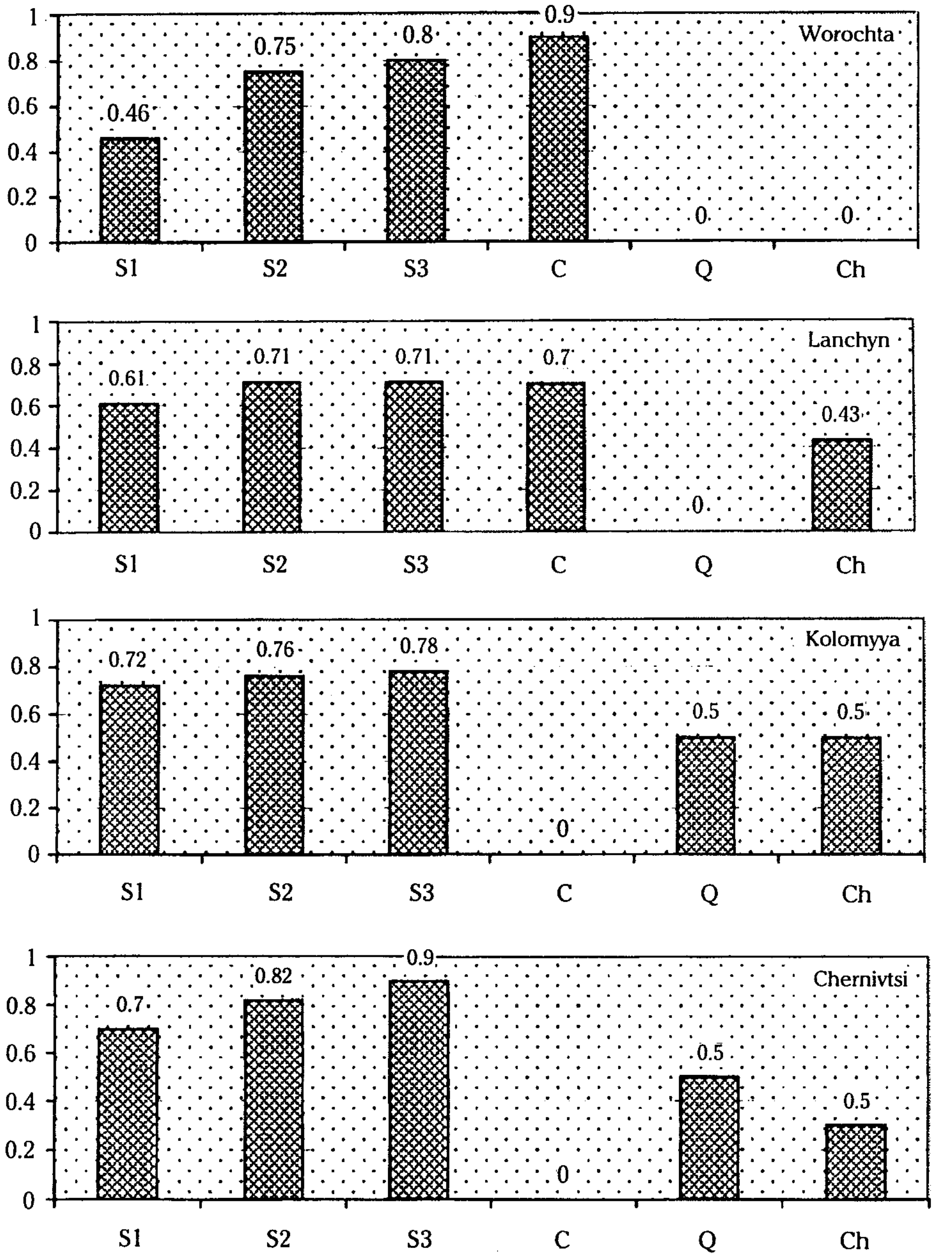

Fig. 6. Values of roundness in petrographic classes. S1 — fine grained sanstone, S2 — medium grained

SHAPES

Shapes of pebbles were studied using the T. Zingg's (1935) method. Because of the limited possibilities of sampling and sample transport, the investigation of this parametre was limited to the 17–32 size class. This class has been considered representative for the analyses of the Carpathian gravels (Mycielska-Dowgiałło and Rutkowski 1995). Three axes of at least 100 specimens were measured from each site. Discoidal pebbles predominated at all nine sites. Their share varied from 27.5% at Dubivtsi to 61.5% at Worochta and Lanchyn (Table 6). The second most frequent class is that of rod-like (four sites) or bladed clasts (five sites). The least frequent group is usually that of spherical clasts. Only at three sites; Yaremcha, Lanchyn (Fig. 6) and Zabolotiv they are somewhat more frequent, third in the order of frequence. At the farthest downstream site Chernivtsi the numer of spherical pebbles exceeds the numbers of the rod-like and bladed ones. The proportion of the spherical and rod-like pebbles increases downstream. At the farthest upstream site Worochta the sum of both classes was 18%. At the sites situated farthest downstream — Dubivtsi and Chernivtsi — these two classes had much higher frequencies — 42.5% and 37.5%, respectively. However, the increase is not uniform. At some sites the proportions were different and sudden increases or decreases in proportions of rod-like and discoidal pebbles were observed. Smaller are the variations in the proportions of the ellipsoidal and spherical clasts. Their proportion in the studied populations is not subject to such sudden variations (Fig. 7).

Table 6

Percentages of four shape classes in the Prut gravels (size classes: A — 16–32 mm, B — >128 mm)

Site	Distance (in km)	Discoidal		Bladed		Spherical		Rod-like	
		A	B	A	B	A	B	A	B
Worochta	13.5	61.5	30	20.5	35	7.5	30	10.5	5
Tatarov	31.5	33.0	65	23.5	30	15.5	—	28.0	5
Yaremcha	46.5	32.0	55	12.5	15	25.5	15	30.0	15
Lanchyn	67.0	61.5	70	18.5	10	12.0	5	8.0	15
Kolomyya	87.5	33.0	10	19.5	25	16.5	25	32.0	40
Zabolotiv	99.5	54.0	50	24.5	5	19.5	—	2.0	45
śniatyn	130.5	44.5	20	23.5	25	8.0	20	24.0	35
Dubivtsi	152.0	27.5	20	30.0	20	20.5	10	22.0	50
Chernivtsi	167.5	44.0		16.5		21.5		16.0	

The measurements of the three axes of the largest specimens in the studied gravel bars were used to establish the shapes of the thickest size-classes. The

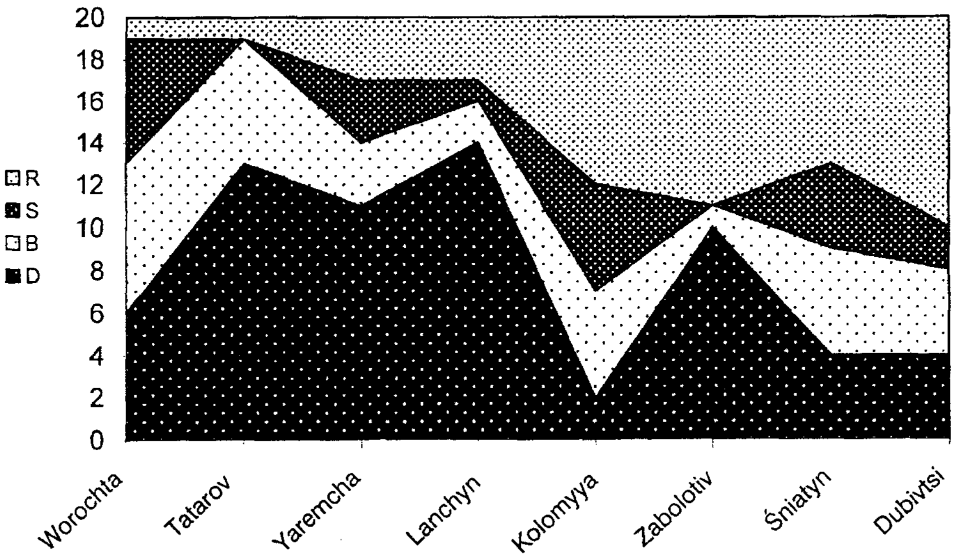

Fig. 7. Shapes of the greatest clasts of the Prut river (> 128 mm). D — discoidal, B — bladed, S — spherical, R — rod-like

comparison is difficult as the largest boulders at the mountain sites exceed 1.5 m in diametre, and those in the foreland are much below 0.5 m. Discoidal boulders predominate among the largest specimens in the Carpathian part of the valley. Their proportion varies from 65% at Tatarov to 30% at Worochta. Rod-like forms are the most common at the foreland sites, and they increase in proportion downstream. Their proportion attained 40% at Kolomyya and as much as 50% at Dubivtsi. Their proportion at the mountain sites does not exceed 15% (Photo 4).

There is also another clear relationship. The smaller the diametre the more numerous become spherical pebbles at the cost of the rod-like ones. This relationship was found at several sites. It is most clear at Dubowce and Śniatyń. The coarser-grained are the sandstones the lower is the proportion of discoidal pebbles.

CONCLUDING REMARKS

The Prut is one the few large Carpathian rivers not barred with dams or weirs. The discharges and water levels in the river are shaped by natural processes. The same regards the processes of transport and accumulation of debris. The only human intervention in the natural channel processes on the Prut river occurred in the 19th century when a waterfall upstream of Yaremcha was blown up to facilitate log rafting. There is no trace left of the engineering works that facilitated log rafting. The Prut may be thus considered a good natural laboratory for studies on geomorphological processes which are especially intense during high water stages and floods. Transport, abrasion and sedimentation of fluvial gravels occur during the spring and summer high water stages, whose sizes are strongly variable. The greatest boulder fields in the river channel were observed at Tatarov. Still greater boulders were found by the author in the Prut gap near Yamna. Their sizes attained 3 m. From this place downstream the pebble size decreases and at Delatyn, the second farthest downstream site, the greatest pebble was only 26 cm in size. The distance over which the coarsest size class in the channel will fall down below 2 mm is 446 km downstream from the site Lanchyn at the margin of the Carpathians.

Fine-grained sandstones clearly predominate in the petrographic composition of the gravels. Their proportion increases with the fining diametres of pebbles. While their content in the 17–32 mm size class is above 60%, in the 2–4 mm granules it is higher than 80%. Medium-grained sandstones are practically absent in the finest size-class. Only at four sites they appear in statistically recordable amounts (0.6–1.1%). The proportion of medium-grained varieties increases with increasing pebble diametres. They occur already in considerable amount (5–29%) in the 17–32 mm size class. Coarse-grained sandstones and conglomerates are absent in the finest class and rare in the 17–32 mm class, always below 10% (Table 2). A characteristic feature of the Prut gravel bars is the low content of the quartz clasts. Their proportion does not exceed several percent even in the finest size class (maximum at Śniatyn — 7.0%). At most sites even chert clasts are more frequent than those of quartz. This feature clearly differentiates the Prut gravels from the gravels of the West Carpathian rivers which have several tens percent of quartz pebbles in the finest size classes.

The shapes of pebbles also change along the course of the Prut. The proportion of spheroidal and rod-like pebbles increases at the lowermost sites at the coast of the discoidal and bladed ones. At the highest upstream site at Worochta, the combined share of the two classes was 18%. At the lowermost sites, at Dubivtsi and Chernivtsi their share was 42.5% and 37.5%, respectively. The above statements regard the 17–32 mm size class. An increase in proportion of the rod-like clasts at the expense of each of the other three groups is clearly discernible among the largest clasts.

The values of roundness clearly increase downstream, both in the index size-class and among the twenty largest specimens. Only at the site situated below the confluences with the right tributaries from the Carpathians, the average values of roundness decrease. The standard deviation from this mean clearly decreases downstream as a result of pebble selection.

The results of the study of gravel bars in the Prut provide a valuable material for comparison with similar analyses conducted by the author for the West Carpathian rivers.

ACKNOWLEDGMENTS

I express my cordial thanks to my colleagues Dr Władysław A. Nowak of the Institute of Geography, Cracow Pedagogical University, Professor Wiaczesław Andreychouk of the Silesian University and Docent Mirosław Proskurniak of the

Institute of Geography, Chernivtse State University for their assistance in the preparation and in the fieldwork. Special thanks go to my collegue Dr Grzegorz Haczewski of the Institute of Geography, Cracow Pedagogical University for his many useful suggestions and the translation of this text to English.

Institute of Geography
Cracow Pedagogical University
ul. Podchorążych 2, 30-147 Kraków, Poland
e-mail: rmalarz@ultra.wsp.krakow.pl

REFERENCES

Atlas Iwano-frankowskoj obłasti. 1990, Moskwa, 32 pp.

Dżułyński S., Rutkowski J., Shideler G. L., 1974. *An evaluation of flysch-derived fluvial gravels as provenance indicators.* Rocznik Polskiego Towarzystwa Geologicznego 2–3, 171–180.

Grodziski S., 1998. *Wzdłuż Wisły, Dniestru i Zbrucza.* Wydawnictwo Grell, Kraków, 426 pp.

Klamczuk B. M., 1994. *Etapi razwitki riczkowych dolin basejnu wierchnogo Prutu.* Biuletyn Akademii Nauk Ukrainy, Instytut Geografii, Kijw, 3–22.

Knighton A. D., 1982. *Longitudinal changes in the size and shape of stream material: evidence of variable transport conditions.* Catena 9, 25–34.

Kodama Y., 1994. *Downstream changes in the lithology and grain size of fluvial gravels, the Watarase River, Japan: evidence of the role of abrasion in downstream fining.* Journal of Sedimentary Research, ser. A, 64, 68–75.

Krumbein W. C., Sloss L. L., 1963. *Stratigraphy and sedimentation.* Freeman and Company, San Francisco, 660 pp.

Malarz R., 1992. *Etap denudacyjny w polskich Karpatach fliszowych.* Prace Monograficzne, Wyższa Szkoła Pedagogiczna, Kraków, 150, 136 pp.

Malarz R., 2002. *Powodziowa transformacja gruboklastycznych aluwiów w żwirodennych rzekach Zachodnich Karpat fliszowych.* Prace Monograficzne AP w Krakowie 335, 147 pp.

Маляж Р., Новьак В., Проскурняк М., Андрейчук В., 2001. *Русловий алювій Черемошу.* Гідрологія, гідрохімія і гідроекологія, том 2, Київський національний університет, Київ, 253–262.

Marshall P., 1927. *The wearing of gravels.* New Zeland Inst. Treat. 58, 28–36.

Mikoš M., 1993. *Fluvial Abrasion of Gravel Sediments.* Mitteilungen 123, 321 pp.

Mycielska-Dowgiałło E., Rutkowski J. (eds), 1995. *Badania osadów czwartorzędowych.* Wydział Geografii i Studiów Regionalnych UW, Państwowy Instytut Geologiczny, Komisja Litologii i Genezy Osadów Czwartorzędowych Komitetu Badań Czwartorzędu PAN, 356 pp.

Rutkowski J., 1987. *Żwiry rzek karpackich o dorzeczach zbudowanych wyłącznie z osadów fliszowych,* [in:] *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej,* Materiały sympozjum, Kraków, 87–92.

Rutkowski J., 1995. *Petrographic composition of the quartenary gravels of the Carpathians and their foreland.* Studia Geomorphologica Carpatho-Balcanica 29, 78–89.

Sternberg H., 1875. *Untersuchungen uber Langen und Querprofil geschiebefuhrender Flusse.* Zeitschrift für Bauwesen 25, 483–506.

Świderski B., Bujalski B., Teisseyre H., 1934. *Przekrój odwodowej niecki oligoceńskiej nasunięcia grupy średniej (nasunięcia skolskiego), przekrój płaszczowiny czarnohorskiej, zlodowacenie pasma Czarnohory,* [in:] *Przewodnik wycieczek Zjazdu PTG we Wschodnich Karpatach,* Lwów, 1–4.

Teisseyre J., 1938. *Etude des profils longitudinaux des riviéres des Karpates Orientales Polonaises.* Rocznik Polskiego Towarzystwa Geologicznego 14, 81–112.

Unrug R., 1957. *Recent transport and sedimentation of gravels in the Dunajec valley (Western Carpathians).* Acta Geologica Polonica 7, 217–250.

Wdowiarz J., 1948. *The Skole nappe in the region of the Czeremosz.* Rocznik Polskiego Towarzystwa Geologicznego 17, 153–186.

Wyszyński O., Teisseyre H., Obtułowicz J., 1939. *Le levé geologique de l'avant-pays des Karpates sur la feuille de Kuty.* Rocznik Polskiego Towarzystwa Geologicznego 15, 1-14.

Zingg T., 1935. *Beitrag zur Schotteranalyse.* Schweitzerische Mineralogische-Petrographische Mitteilungen 15, 39–140.

STRESZCZENIE

R. Malarz

ZMIANY CECH ŻWIRÓW PRUTU (UKRAINA)

Celem badań przeprowadzonych w dolinie Prutu na odcinku od Worochty do Czerniowiec była charakterystyka współczesnych żwirów tej rzeki. Do badań wyznaczono 9 stanowisk. Trzy z nich (Worochta, Tatarów, Jaremcze) zlokalizowane były w obrębie Karpat. Pozostałe w obrębie szerokiego obniżenia przedgórskiego zwężającego się ku południowi, aż do Bramy Prutu w okolicach Czerniowiec. Badano skład petrograficzny żwirów frakcji 2–4 mm, 5–8 mm, 9–16 mm i 17–32 mm. Dla najgrubszej frakcji określono obtoczenie i kształty otoczaków. Na każdym ze stanowisk zmierzono 20 największych otoczaków i określono ich skład petrograficzny, kształty i obtoczenie.

W petrograficznym składzie żwirowisk Prutu wydzielono 3 odmiany piaskowców (drobno-, średnio- i gruboziarniste), zlepieńce, kwarce, rogowce i inne. We wszystkich przebadanych frakcjach dominują otoczaki piaskowców drobnoziarnistych. We frakcji 2–4 mm stanowią one ponad 80% zbiorowości. We frakcjach grubszych (9–16 mm i 17–32 mm) jest ich nieco mniej, nigdzie jednak ich udział nie spada poniżej 60%. Cechą charakterystyczną żwirowisk Prutu jest niezwykłe ubóstwo żwirów kwarcowych. Nawet we frakcji najdrobniejszej ich udział nie przekracza 7% (Śniatyń).

Rozmiary otoczaków Prutu są bardzo zróżnicowane. Największe głazy w korycie pojawiają się w miejscu występowania piaskowców jamneńskich. Na stanowiskach w Tatarowie i Jaremczy ich średnice przekraczaja 2 m. Od Łanczyna, gdzie ustaje dostawa materiału fliszowego z podłoża, obserwuje się regularny spadek wielkości otoczaków zaburzany jedynie dostawą grubszych frakcji przez prawobrzeżne dopływy: Rybnicę i Czeremosz. Tempo redukcji rozmiarów otoczaków określono współczynnikiem Sternberga. Współczynnik ten jest dość zróżnicowany. Wysoki dla odcinka karpackiego (0,0349), niski dla przedgórskiego (0,0113).

Badaniem obtoczenia objęto frakcję 17–32 mm i 20 największych okazów na żwirowisku. Stopień obtoczenia określano według wizualnej skali Krumbeina i Slossa. Dla frakcji 17–32 mm średnie obtoczenie jest zróżnicowane od 0,51 na stanowisku w Tatarowie do 0,73 w Kołomyji i Zabłotowie. Nieco większe zróżnicowanie obtoczenia wykazują największe okazy badane na tych samych żwirowiskach Prutu. Tu średnie wartości obtoczenia są zróżnicowane i wzrastają od 0,43 w Jaremczy do 0,83 w Zabłotowie. Najniższymi wskaźnikami obtoczenia charakteryzują się rogowce. Nieco lepiej od rogowców obtoczone są kwarce. Wśród trzech odmian piaskowca najwyższymi wskaźnikami obtoczenia charakteryzują się piaskowce gruboziarniste (0,71–0,80).

Kształty otoczaków określano metodą Zingga wydzielając w obrębie frakcji 17–32 mm okazy dyskoidalne, elipsoidalne, kuliste i wrzecionowate. Na każdym z 9 stanowisk dominowały otoczaki dyskoidalne. Ich udział wahał się od 27,5% na stanowisku Dubowce do 61,5% na stanowiskach w Worochcie i Łanczynie. Najmniej liczebną grupę stanowiły otoczaki kuliste. Z biegiem rzeki rośnie udział otoczaków kulistych i wrzecionowatych. Szczególnie wyraźnie jest to widoczne wsród okazów największych.