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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

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THE VARIATION IN CLASTS ORIENTATION IN MID-MOUNTAIN RIVER CHANNELS UNDER THE INFLUENCE OF COARSE-GRAINED REGOLITH SUPPLY, POLISH FLYSCH CARPATHIANS

Abstract. The differences in the clasts orientation within the gravel bed rivers have been discussed in many papers. These clasts have been typically associated with the shape and the size of the gravels as well as with the position of clasts within the river channel and their location within channel mesoforms. This paper aims to demonstrate the changes in clast orientation caused by the supply of angular, coarse-grained regolith to the river channel from the valley slopes. The study was conducted in mid-mountain river channels (Mostysza, Koszarawa) of the Polish Flysch Carpathians. Slabby rock debris is supplied to the river channels in analyzed sites. The changes in azimuth distributions and thus the mean vector V of the angular and rounded imbricated clasts are correlated with these zones. In wide alluvial river channels (the Koszarawa–Jeleśnia site), a distinct difference can be observed between the mean vector V of angular clasts and the river bed axis direction. In narrow alluvial-rocky river channels (the Mostysza–Florynka site) the deviation is smaller, but still easily noticeable. Within the slope material supply zones and downstream of them, the resultant mean vector for angular clasts is directed towards the edges of the river channel. The research results presented in this paper clearly show that the degree of imbrication depends on the roundness of clasts. Rounded clasts are easier to reorient and they adopt an imbrication arrangement; their dip direction azimuth correlates with the direction of the valley axis. The angular, coarse-grained material supplied from the slope to the river channel is rougher and thus has more points of support, in that case are difficult to imbricate.
Key words: Polish Flysch Carpathians, regolith, gravel bed rivers, clasts orientation

INTRODUCTION

The Carpathian mountain range, around 1,500 km long, includes a large outer zone composed of flysch formations. Gravel bars, often large ones, constitute a characteristic relief feature of the valleys cutting across this zone and its immediate forefield. This is a result of the significant mobility of slope covers formed on flysch rock and changing precipitation and floods regimes, which are conducive to a pulsating supply of bed load into river channels.

The regolith supplied into river channels is transported as dissolved, suspended or dragged material. Coarse fractions are only set in motion during large floods. When the threshold velocity is exceeded, gravel and boulder fractions are reoriented and transported downstream the channel. When the flood-wave is falling and the current velocity is limited, gravel fractions are deposited, beginning with the coarsest ones (Unrug 1957; Johansson 1963; Bluck 1976). Long clast axes are then oriented parallel to the current direction and the largest cross-section planes dip upstream, which minimises their drag against running water. The imbrication of clasts is a common phenomenon in coarse-grained fluvial deposits (see Gradziński et al. 1986). The orientation of the A–B plane of imbricated clasts (the dip direction) indicates the direction of the current that deposited the single clasts (Church and Jones 1982; Baumgart-Kotarba 1985).

The differences in the orientation of clasts within the river bed have been discussed by many authors. Typically, they have been associated with the shape and the size of the pebble — imbrication was most pronounced in discoidal pebbles with large dimensions (Krumbein 1941; Unrug 1957; Byrne 1963; Johansson 1963). The position of clasts within the river channel and their location within channel mesoforms strongly influence their orientation (Klimek 1972; Baumgart-Kotarba 1985). B. J. Bluck (1976) lists three major causes for the differences in the orientation of directional structures in the case of gravel-bed rivers: 1) changes resulting from different current activity on the surface of gravel bars, 2) differences between the orientation of the long axis of the bar and the direction of the river bed, 3) the position of the pebbles in areas of steep bar face edges facing away from the current. The obstacles before which the gravel material are accumulated, usually perpendicular to the current direction, are another factor influencing the orientation of clasts (Elfström 1987). The measurements of clast orientation within pebble clusters show a large dispersion of the dip directions of the A–B plane. This is linked to perturbations occurring in the flow round an obstacle (Teisseyre 1975). B. J. Bluck (1971) and C. De Jong and P. Ergenzinger (1995) link the orientation of clasts in mountain gravel-bed rivers to the sinuosity of the river channel. The bouncing of flood-waves off rocky valley slopes transfers the current towards the opposite bank, which causes the orientation of clasts to deviate up to 90° from the river channel axis direction. The initial arrangement and position of coarse-grained material within the river channel also significantly influence its further movement and imbrication (Klingeman and Matin 1993; Pizzuto et al. 1999). In the case of shallow river channels, freezing during winter period, the movements of ice float also have an impact on clast orientation — they can transport and reorient even large rocks (Klimek 1989).

This paper aims to demonstrate the changes in clast orientation caused by the supply of angular, coarse-grained regolith from the valley slopes cutting across the outer zone of the Polish Flysch Carpathians (Fig. 1A, B). The relationship between the dip direction of clasts and their roundness has not been well enough

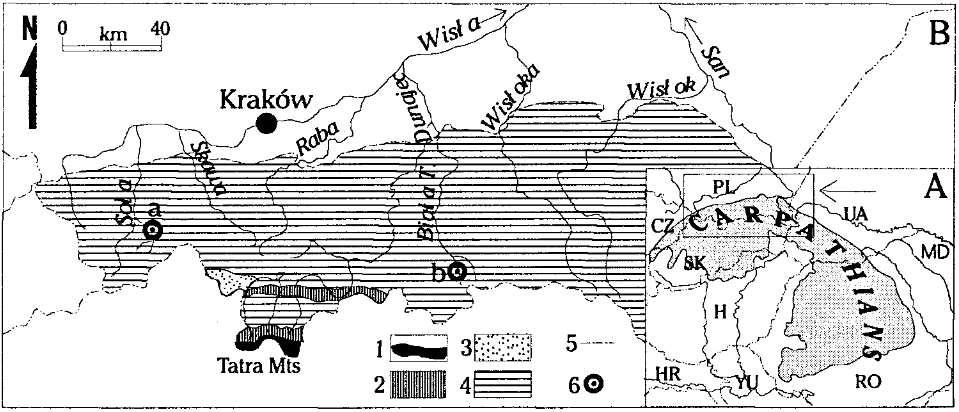

Fig. 1. A. Location of study area within Carpathians range, B. Location of the investigation sites. 1 — granites, gneisses (Paleozoic), 2 — carbonate rocks (Triase–Cretaceous), 3 — clays (Neogene), 4 — flysch sediments (Cretaceous–Tertiary), 5 — Carpathian frontal thrust, 6 — research sites, a — Koszarawa–Jeleśnia, b — Mostysza–Florynka

recognised. The measurements of the orientation of coarse-grained material within the river bed hitherto conducted have been mainly based on rounded material and the material researched has only been analysed according to the fraction it belonged to.

STUDY AREA

The study was carried out in an area of the Polish Flysch Carpathians (Klimaszewski and Starkel 1972), composed of folded Magura nappe flysch. Flysch series form alternating layers of sandstone and shale with slab texture. In the periglacial climate of the Pleistocene the sandstone beds supplied angular slabby rock debris, common in solifluction covers. Currently the regolith from these slope covers is introduced into the river channel system, influencing the development of new and the transformation of existing alluvial channel forms. The supply of this material into river channels takes place primarily through mass movements and erosion undercutting the slopes, while transport is limited exclusively to flood periods (Ziętara 1999). In the Western Polish Carpathians, which are composed of lithologically varied flysch nappes, the zones of pronounced presence of gravel river beds are typically located west of the Dunajec valley (Klimek 1979). The eastwards, where sand or dust are the primary products of flysch rock weathering, river channels are lacking of large gravel bars but numerous rocky steps instead.

Five sites located along the carpathian tributaries of the upper Vistula basin have been selected for detailed research. This paper presents the research results from two sites located in the Beskidy zone of the Western Polish Carpathians (Fig. 1B).

METHODS OF STUDY

A 1:400 scale morphological mapping of 1.2 km long river channel sections upstream and downstream of coarse-grained regolith supply zones was conducted during field research. The roundness of clasts was determined according to the six-category visual Powers index (Powers 1953) for each of the following fractions: 2–8, 8–16 and 16–30 cm (this article only discusses the roundness of the 16–30 cm fraction). The dip directions of the A–B planes and (in the case of strongly elongated clasts) A axes were measured for the 16-30 cm fraction. On each site the measurement results for angular clasts (the 1–2–3 ranges on the Powers scale) and rounded clasts (the 4–5–6 ranges on the Powers scale) were separately recorded. Attempts were made to maximise the number of measurements but because of the limitations of mountain river beds (i.a. small gravel bar areas and thus small quantities of clasts within each fraction) the maximum number was 35 measurements. Although the instructions concerning the methodology of directional structure measurements recommend at least 50 measurements (Johansson 1965; Rutkowski 1995), all distributions of directional data presented proved to be statistically reliable at the significance level of P = 0.05. The analysis of directional data for imbricated clasts was conducted according to J. R. Curray's (1956) method. Each data distribution was characterised by the mean vector parameter (current azimuth) V [°]. Its value was then compared to the azimuth of the river bed axis at a given point. The vector magnitude L [%] was used to determine the statistical significance, according to the following formula:

$$L = \frac{1}{N}\left[(\Sigma \sin v)^2 + (\Sigma \cos v)^2\right]^{1/2} \cdot 100\%$$

where: v — subsequent azimuths, N — the number of measurements.

The resulting values were tested using the graphic version of the Rayleigh test (Gradziński et al. 1986). The imbrication shown in all figures corresponds to the dip direction of clasts + 180°, i.e. the water flow direction.

SITE KOSZARAWA–JELEŚNIA

The Koszarawa, with a length of 30.4 km, is one of the largest tributaries of the Soła river (Fig. 1B.). Its basin cuts across the western part of the Polish Flysch Carpathians. The upper section of the Koszarawa drainage basin is located within the Beskid Żywiecki Mts (1,000–1,557 m a.s.l.). Downstream its confluence with the Kamienna river, the Koszarawa enters the Jeleśnia Basin (400–480 m a.s.l.), which is linked to the flat Żywiec Basin (350–400 m a.s.l.) via the Krzeszów Gate. The mouth of the Koszarawa is located within the Żywiec Basin. The location of the Koszarawa basin in the western part of the Beskidy Mts, exposed to rain-bearing winds, causes the basin to receive up to 1,200 mm of annual precipitation, 50–70%

thereof in the summer months. The rains cause violent floods (Dynowska 1971; Ziemońska 1973). Due to large vertical amplitude of the drainage basin, snow-melting floods are prolonged and smaller than summer floods. The mean discharge (at the Jeleśnia gauging station during the period 1977–1990) is 2.21 m^3/s. Maximum discharges exceed 100 m^3/s. Annual water level amplitudes reach 3.5 m.

The Koszarawa–Jeleśnia site is located in the northern part of the Jeleśnia Basin, 422 m a.s.l. Downstream of the mouth of the Pewlica tributary, the Koszarawa turns west, undercutting the right valley side (Fig. 2A). Colluvia from the un-

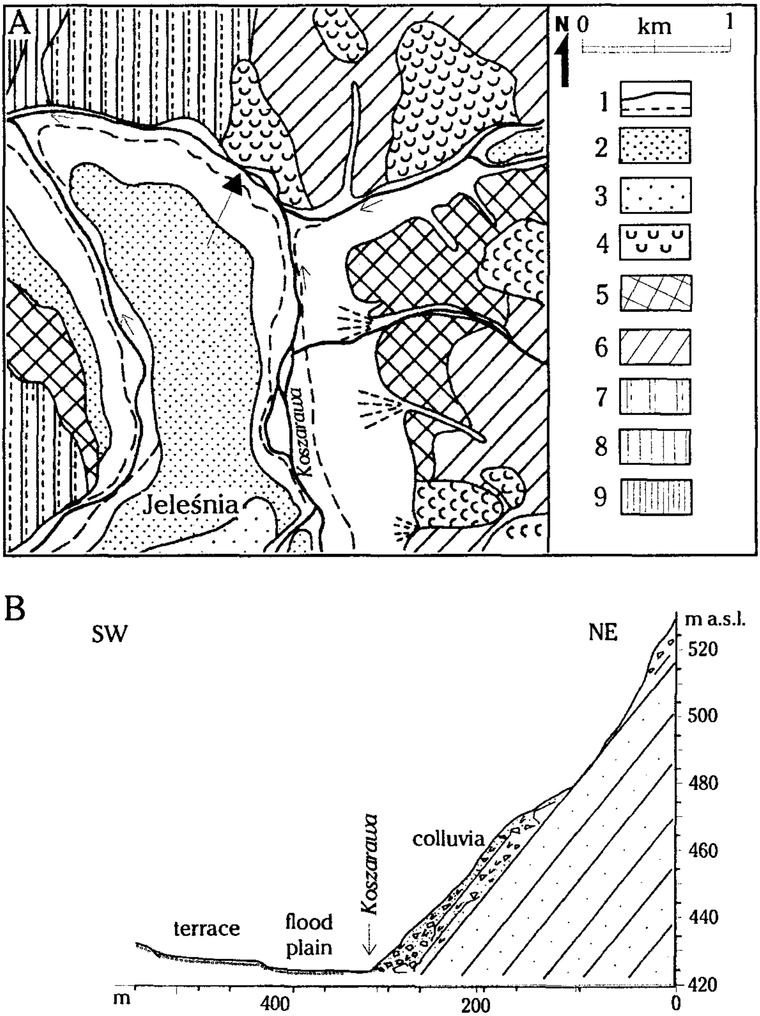

Fig. 2. Geological sketch of the nortern part of the Jelesnia Basin (A) with cross-section of the Koszarawa valley (B). 1 — river channel, floodplain, 2-3 — pleistocene terraces deposits, 4 — colluvia deposits, 5 — loam with rock debris (Holocene/Pleistocene), 6 — Magura sandstone, 7 — Zembrzyce shales (Middle Eocene), 8 — Mutne sandstones, 9 — biotite sandstones (Upper Cretaceous)

dercut landslide are supplied into the river channel (Fig. 2B). This is a consequent rock-waste landslide on the boundary of the Magura series and Zembrzyce shales (Golonka and Wójcik 1978). The line of slid is formed by marly shales and clay stones and the slide zone is formed by rock and regolith material and sandstone blocks with diameters exceeding 2.7 m.

The Koszarawa flows in a 50–80 m wide river bed cutting through coarse-grained alluvia embedded in older valley infill (Wójcik 1988). The morphology of this river bed is characterised by numerous chute channels and point and midchannel gravel bars (Fig. 3). The length of the supply zone of angular, coarse-grained colluvial material reach 80 m. The roundness of clasts within the 16–30 cm fraction was determined upstream and downstream of this zone, using the six-category Powers roundness index (Table 1). Rounded material dominates in locations upstream of the supply point of coarse-grained regolith. Within the supply zone and downstream, however, there is a marked increase in the quantity of angular material relative to the rounded one. Its percentage in debris bed load

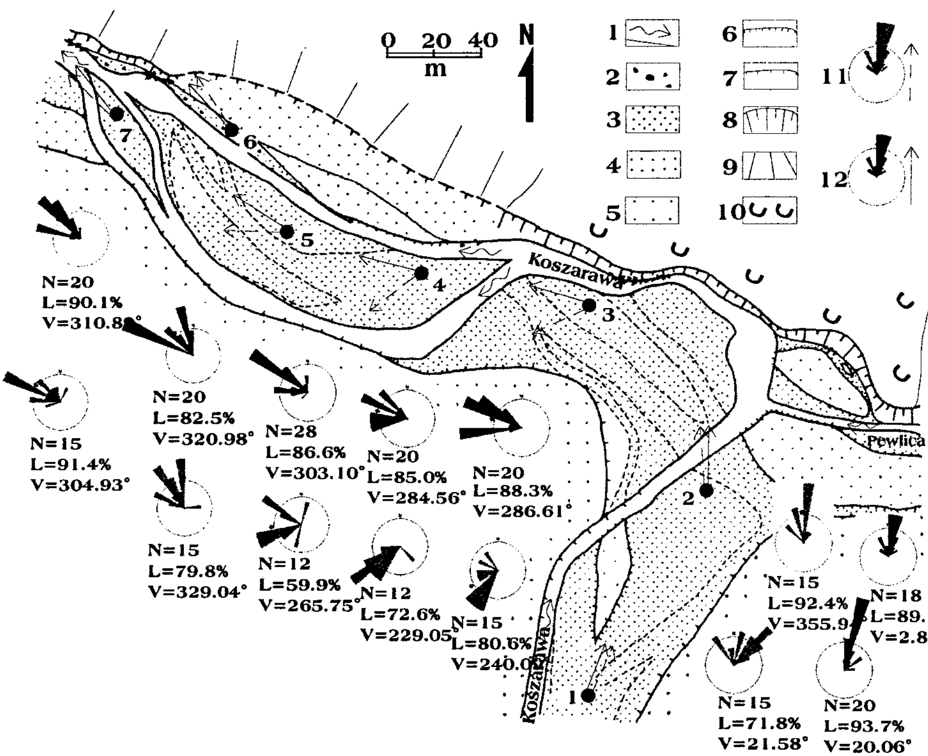

Fig. 3. Geomorphological sketch of river bed with diagrams of orientation of imbricated clasts in the site Koszarawa–Jelesnia. 1 — river channel, 2 — boulder and blocks above 1 m in diameter, 3 — gravel bars to 1 m high, 4 — gravel bars above 1 m high, 5 — terrace 2.0–2.5 m, 6 — erosional edge 1.0–2.0 m, 7 — erosional edge of terrace 2.0–2.5 m, 8 — erosional undercuts, 9 — slopes, 10 — landslides, 11 — directional distribution and mean vector for angular clasts (VA + A + SA), 12 — directional distribution and mean vector for rounded clasts (SR + R + WR)

reaches a maximum of 58.3% (Fig. 3; Table 1). Around 200 m downstream of the location where the tongue of the landslide is undercut, the quantity of angular clasts significantly decreases relative to the quantity of rounded ones, which dominate.

The changes in the distribution of imbricated clast directions within the researched site are correlated with their roundness, which indicates that they are linked to the zone of fresh supply of slope material (Fig. 3; Table 1). The mean vectors V for direction data distributions of angular and rounded clasts within sites 1 and 2 are convergent and correlated with the axis of the river bed. On sites 3 and 4, however, there is a marked dispersion of the dip directions of rounded and angular flat clasts. The orientation of the rounded material conforms to the direction of the river bed axis. The resultant dip direction vectors V for unrounded clasts are directed towards the opposite bank, however. The maximum deviation (53.95°) from the river bed axis has been measured for sample 4 (Fig. 3; Table 1). The dominating influence of other factors (e.g. the bouncing of the flood-wave current off the valley slope) on clast orientation can be excluded here because the observed differences pertain to the same fraction and the measurements were conducted within small bar areas. Together with the increase in the degree of bed load rounding downstream of the slope material supply zone, the angle between the dip direction of angular clasts and the river bed axis decreases. This angle is, however, still noticeable on sites 5 (36.25°) and 6 (18.04°). On site 7 the difference between the value of the mean vector V for angular material and the river bed direction reaches only 9.07° (Fig. 3; Table 1).

Table 1

Orientation and roundness of clasts in the research sites

Site		Direction of stream chanel [°]	VA + A + SA[1]		SR + R + WR[2]		% angular (VA + A + SA)
			Mean vector V [°]	Deviation from direction of stream channel	Mean vector V [°]	Deviation from direction of stream channel	
Koszarawa–Jeleśnia	1	23	21.58	1.41	20.63	2.31	49.0
	2	357	355.94	1.06	2.84	5.84	31.0
	3	285	240.09	44.91	286.61	1.61	55.1
	4	283	229.05	53.95	284.56	1.56	57.5
	5	302	265.75	36.25	303.10	1.1	58.3
	6	311	329.04	18.04	320.98	9.9	37.4
	7	314	304.93	9.07	310.89	4.88	47.2
Mostysza–Florynka	1	79	85.02	6.02	80.01	1.01	30.3
	2	58	64.50	6.50	61.54	3.54	55.2
	3	18	25.26	7.26	22.24	4.43	57.1
	4	34	30.76	3.24	32.09	1.91	60.0
	5	39	4.14	34.89	27.99	11.01	81.5
	6	7	353.48	13.52	11.15	4.15	71.9
	7	2	14.77	12.77	10.03	7.97	84.7

[1] — VA — very angular, A — angular, SA — subangular

[2] — SR — subrounded, R — rounded, WR — well-rounded

SITE MOSTYSZA–FLORYNKA

The Mostysza basin is located within the Beskid Niski Mts (700–850 m a.s.l.), within the range of the Magura nappe. The relief here is closely correlated to the geological structures. Resistant sandstone ridges are separated by depressions formed within shale and marly layers (Paul 1993). In its western part, the Beskid Niski Mts is dissected by the twin consequent longitudinal valleys of the Biała river and the Mostysza river (Fig. 1B). This area receive annually up to 850 mm of precipitations. Small vertical amplitude of drainage basin together with the simultaneous snow-melting period within the whole basin cause the snow-melting floods to be more violent than in the rivers in the western part of the Beskidy Mts. In the neighbouring of Biała valley (Brunary gauging station) the mean discharge in the 1976–1986 period was 1.08 m^3/s while maximum discharges exceed 70 m^3/s. Annual water stage amplitudes reach 3 m.

The site is located near Florynka village, 411 m a.s.l. (Fig. 4A). At this point the Mostysza river breaks through the Hańczowa Ridges (Klimaszewski and Starkel 1972; Paul 1993) flowing toward the depression formed in less resistant deposits. The Mostysza valley floor is dissected by alluvial-rocky channel with alternating erosion and accumulation sections (Fig. 5). Within the accumulation sections, narrow and long sided gravel bars are visible in the river bed and there are debris steps up to 0.5 m high in some places. Spurs and rock-ribs are visible within rocky channel sections, forming one metre high steps. The width of the river bed within the studied site varies from 12 to 25 m and the mean width of flowing water varies between 4 and 12 m.

South of Florynka, the Mostysza undercuts about 90 m long right valley slope (Fig. 4B), which is covered by up to 10 m thick coarse-grained regolith. These slopes are formed on coarse-bedded Magura sandstone and shales (Paul 1993), the formation of which is linked to the periglacial climate and their movement is caused by solifluction processes (Starkel 1960). Silty debris regolith, together with slabby rock debris with the diameter exceeding 0.8 m, are supplied to the river channel.

Just as in the case of the Koszarawa–Jeleśnia site, the roundness of clasts and their orientation within the colluvia supply zone and upstream and downstream of this zone have been investigated. In the undercut zone and downstream of this point, angular clasts significantly outnumber rounded ones (Fig. 5; Table 1). The maximum percentages of unrounded material within the 16–30 cm fraction relative to rounded reaches 81.5% and 84.7% in samples 5 and 7 respectively (Fig. 5; Table 1). Upstream of the undercut the mean dip direction vectors V for these two groups of clasts are correlated with the azimuth of the river bed axis, with only slight deviations (1.0–7.26°) (Table 1). In the debris supply zone and downstream, together with the decrease in the percentage of rounded material in the bed load, the orientation of angular clasts indicate a marked deviation from the axis of the river bed. In samples 5, 6 and 7 the mean dip direction azimuth vectors V are directed toward the edges of the river bed. The maximum deviation from the axis of the river channel (34.89°) was found on site 5. The orientation of the rounded material generally converges with the direction of the river bed axis, only the foot of the erosion undercut exhibits a deviation of vector V exceeding

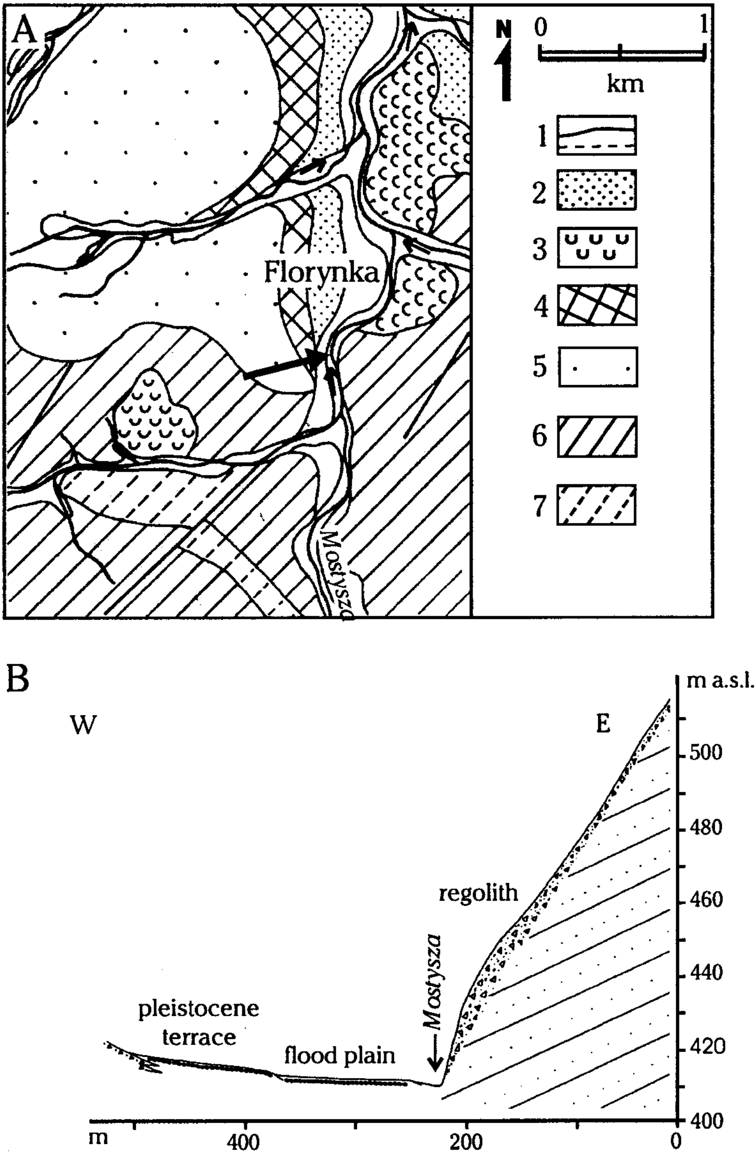

Fig. 4. Geological sketch of the lower part of the Mostysza catchment (A) with cross-section of the Mostysza valley (B). 1 — river channel, floodplain, 2 — pleistocene terraces deposits, 3 — colluvia deposits, 4 — loam with rock debris, 5 — silt and sands slope deposits (Pleistocene/Holocene), 6 — Magura sandstone, 7 — Hieroglypic beds (Middle Eocene)

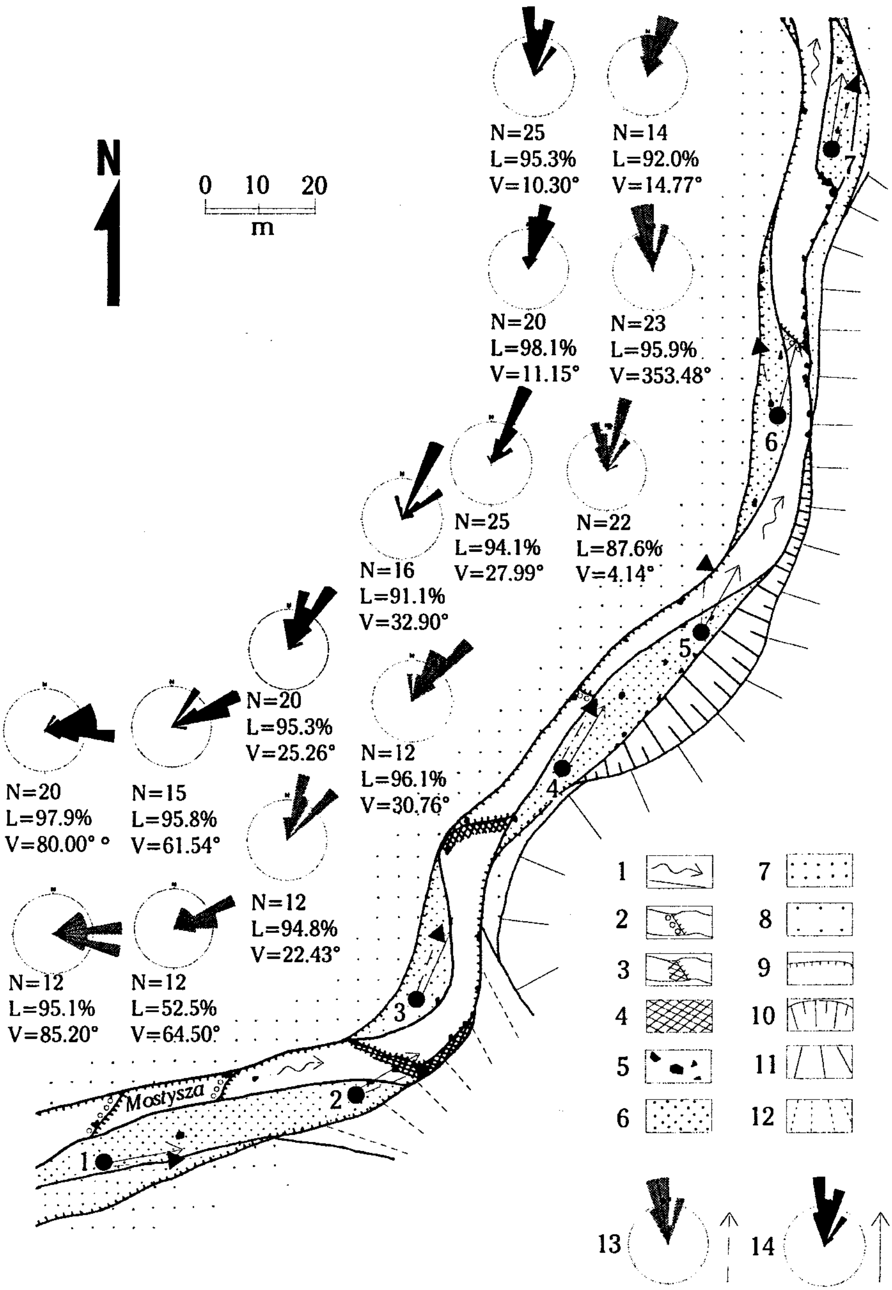

Fig. 5. Geomorphological sketch of flood channel with diagrams of orientation of imbricated clasts in the site Mostysza–Florynka. 1 — river channel, 2 — debris steps, 3 — rocky-steps, 4 — spurs and rock ribs, 5 — boulder and blocks above 1 m in diameter, 6 — gravel bars to 1 m high, 7 — gravel bars above 1 m high, 8 — terrace 2.0–2.5 m, 9 — erosional edge 1.0–2.0 m, 10 — erosional undercuts, 11 — slopes, 12 — colluvial fan, 13 — directional distribution and mean vector for angular clasts, 14 — directional distribution and mean vector for rounded clasts

10°. When moving away from the fresh slope debris supply zone, the dispersion of the orientation of clasts shows a steady decrease in the samples studied (Fig. 5; Table 1), despite the fact that angular material still prevails relative to rounded pebbles.

CONCLUSIONS

The Carpathian rivers which dissect areas composed of flysch rocks indicate changes in the size and roundness of river bed load within coarse-grained slope regolith supply zones and downstream of these zones. The changes in azimuth distributions and thus the mean vector V of the imbricated clasts are correlated with these zones. In wide alluvial river channels (the Koszarawa–Jeleśnia site), a distinct difference can be observed between the vector V of angular clasts and the river bed axis direction. In narrow alluvial or rocky river channels (the Mostysza–Florynka site) the deviation is smaller, but still easily noticeable. Within the slope material supply zones and downstream of them, the mean vector for angular clasts is directed towards the edges of the river channel.

The research results presented in this paper clearly show that the degree of imbrication depends on the roundness of clasts. Rounded clasts are easier to reorient and they adopt an imbrication; their dip direction azimuth correlates with the direction of the valley axis. The angular, coarse-grained material supplied from the slope is rougher and thus has more points of contact with adjacent clasts. The dominant mode of movement during floods is the rolling of clasts around their longest axes, which are orientated horizontally and perpendicular to the current direction (Unrug 1957; Johansson 1963). When the flood-wave decreases and traction transport stops, angular clasts are deposited in a way similar to the one in which they were transported. This explains the orientation of the A–B planes and A axes towards the channel edges.

The slab-like shape of the regolith supplied favours its reorientation during subsequent floods. Downstream of colluvia supply zones, its arrangement in the river channel soon correlates with the azimuth of the valley axis. This is linked to the fast abrasion of the edges of angular sandstone clasts, especially coarse-grained ones, which acquire the characteristics of discoidal or ellipsoidal pebbles (Malarz 2002).

It may be supposed that in crystalline areas, e.g. in the Tatra valleys, block material with a high roundness factor is supplied into the river channels, reflecting the character of weathering and the type of fissure network within the bedrock (Baumgart-Kotarba 1983). Clasts with such shapes are difficult to imbricate. The change of shape towards flatter pebbles is much slower, which is linked to their high resistance to abrasion (Drake 1970). Thus a point supply of regolith here will influence a longer section of the river channel than in flysch areas, where slabby rock debris is supplied from the slope.

The influence of regolith supply in mid-mountain river channels of the Flysch Carpathians should be considered one of the major causes, together with the size and shape of the material and the character of the river channel, of the changes of clast orientation within supply zones and downstream of them. This factor should be taken into account when determining the transport direction in mineral, coarse-grained fluvial deposits.

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STRESZCZENIE

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ZMIANY ORIENTACJI KLASTÓW W ŚREDNIOGÓRSKICH KORYTACH RZECZNYCH POD WPŁYWEM STOKOWEJ DOSTAWY GRUBOFRAKCYJNYCH ZWIETRZELIN, POLSKIE KARPATY FLISZOWE

Zróżnicowanie orientacji klastów w górskich rzekach żwirodennych było dyskutowane przez wielu badaczy. Łączono je głównie z kształtem i wielkością otoczaków oraz pozycją w korycie i w obrębie mezoform korytowych. Celem artykułu jest przedstawienie zmian orientacji klastów pod wpływem dostawy ostrokrawędzistych, grubofrakcyjnych zwietrzelin ze zboczy dolin. Badania prowadzono w średniogórskich korytach rzecznych Koszarawy i Mostyszy w Polskich Karpatach Fliszowych (ryc. 1). W analizowanych stanowiskach do koryt dostarczany jest płytowy rumosz skalny. W obrębie oraz poniżej stref dostawy materiału stokowego obserwuje się zmiany stopnia obtoczenia ładunku dennego rumowiska rzecznego. Wektor średni V dla rozkładów danych kierunkowych klastów ostrokrawędzistych i obtoczonych wyraźnie nawiązuje do tych stref. W szerokich korytach aluwialnych (stanowisko Koszarawa–Jeleśnia) obserwuje się wyraźny rozdział pomiędzy wektorem V

klastów ostrokrawędzistych a kierunkiem osi łożyska. W wąskich korytach skalno-aluwialnych (stanowisko Mostysza–Florynka) odchylenie osiąga mniejsze wartości, jednak jest dobrze widoczne (ryc. 3, 5). W punktach dostaw materiału stokowego wektor wypadkowy dla klastów ostrokrawędzistych jest skierowany ku brzegom koryta, natomiast orientacja materiału obtoczonego jest zgodna z przebiegiem osi łożyska. Przedstawione wyniki badań jasno wskazują, że stopień imbrykacji jest zależny od obtoczenia klastów. Klasty obtoczone łatwiej ulegają reorientacji i przyjmują dachówkowate ułożenie, a ich azymut upadu nawiązuje do kierunku osi doliny. Dostarczany ze zbocza ostrokrawędzisty, grubookruchowy materiał posiada większy stopień szorstkości, a tym samym więcej punktów podparcia wobec tego trudniej podlega imbrykacji.