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EVOLUTION OF ALLUVIAL CHANNEL FORMS UNDER THE INFLUENCE OF HILLSLOPE SEDIMENT DELIVERY (S POLAND)

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ABSTRACT

Coarse hillslope material affects the primary components of the mountain river channel ecosystem. The purpose of this paper is to describe the role that hillslope sediment delivery plays in the evolution of alluvial channel forms. The study was carried out in Southern Poland (Sudetes and Carpathian Mountains) along small tributaries of the Vistula and Odra drainage basins. Two types of primary sediment sources were identified: supply of angular coarse-grained material to streams from cut-bank sections and landslides. Within the supply zones and downstream there is a marked increase in the quantity of angular material relative to rounded and a distinct increase in sediment size. The development of new and the transformation of existing alluvial channel forms is observed in these sediment overload sections. The depositional zone created by coarse hillslope material consists of: lateral bars with a core of rock blocks or lunate bars, sandy eddy bars, debris bars, diffuse sheets of gravel debris and riffles.

Key words: Mid-mountain rivers, hillslope sediment supply, alluvial channel forms, Polish Carpathians, The Sudetes Mountains

INTRODUCTION

Mid-mountain river channels consist of alternating rocky and alluvial sections. Rocky channels are characteristic of erosion reaches, while alluvial channels are characteristic of accumulation ones. Sediment accumulates in a wide variety of types of gravel bars, which differ in morphology and growth pattern. They are a basic element of river channel deposition. The gravel bar is a significant feature of clastic sediment accumulation whose dimensions are comparable with the river channel (Miall 1996). However the term 'bar' often describes any exposed or slightly submerged major positive element of the river bed (Smith 1978). Bars are formed by complex successions of depositional and erosional events. The source of material for large scale alluvial bedforms are upper sections of the river, erosional undercuts of older terraces, erosional sections in river channels and individual subunits of small gravel bars (Bluck 1976, Carling and Reader 1982). The purpose of this paper is to describe the role that hillslope sediment delivery points play in evolution of alluvial channel forms in temperate mid-mountain river channels. Recent papers have been concerned with the regolith supply mechanism to upland and mountain streams (Harvey 1991, 2001; McEven and

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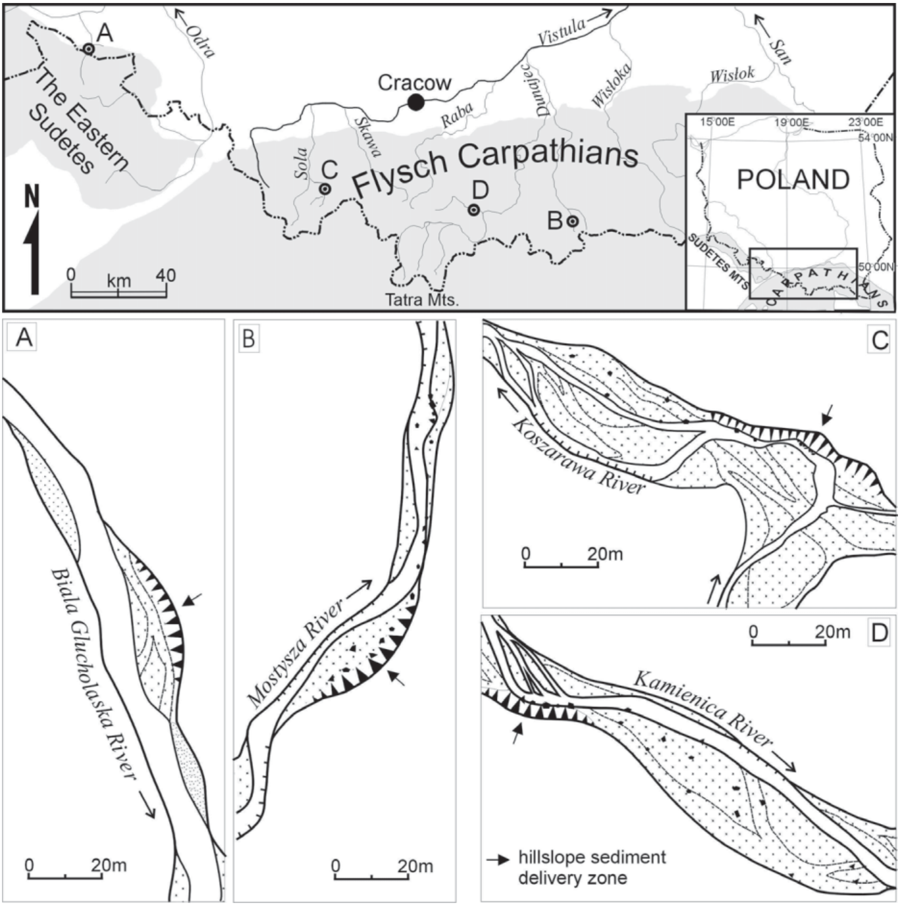

Fig1: Locations of the study areas. Maps of study reaches: A – the Biala Glucholaska River – Glucholazy (The Sudetes Mountains), B – the Mostysza River – Florynka, C – the Koszarawa River – Jelesnia, D – the Kamienica River – Legi (Carpathians)

Matthews 1998). Detailed sedimentological analysis of alluvial forms, which are connected with hillslope processes, were only carried out in mountain rivers in an arid and semi-arid zone (Leopold 1969; Gramis and Schmidt 1999; Webb et al. 1999).

STUDY AREA

This study was carried out in Southern Poland (Sudetes and Carpathian Mountains). The Sudetes are a mid-mountain range located in the temperate zone on the border between Poland and the Czech Republic (Fig. 1) whose massif is composed of a varied complex of Proterozoic and Paleozoic rocks. The research sites are located along the tributaries of the upper Odra river in the Eastern Sudetes (700-1491 m asl). Along the course of the Biala Glucholaska drainage basin analysed, the Eastern Sudetes primarily consist of Devonian quartzites, and, in its upper part, migmatites and paragneisses. The other research sites are situated in the northern part of the Carpathians (Fig. 1). This part of the range is occupied by mid-mountains (900-1725 m asl), densely forested, called the Flysch Carpathians or Beskidy Mountains. The Polish Flysch Carpathians are composed of lithologically varied folded flysch nappes, which form alternating layers of sandstone and shale with a slab texture. Sandstones are fairly resistant to mechanical erosion and form scarps and benches. The shales, interbedded with these harder deposits, are easily eroded and this leads to collapse of the unsupported sandstones as large angular clasts.

In the conditions of the periglacial climate of the last Pleistocene glaciation, the bedrocks of the Sudetes and Flysch Carpathians supplied angular rock debris, common in solifluction covers. The regolith from these slope covers is now being actively eroded and introduced into the river channel system. Colluvia originating from landslides are the secondary sediment source for the river channels.

The coarse hillslope material is only entrained during floods. The majority of precipitation in the western part of the Beskidy Mountains and the Eastern Sudetes falls in the summer months (50-70 %). For that reason rain fed summer flooding occurs each year. Snow-melt floods occur irregularly at intervals of a few years. Extreme flood events, which can entrain large blocks of rock, destabilize the river systems downstream of the supply points of coarse grained regolith.

Nine sites have been selected for detailed research. This paper presents the research results from four sites located along small tributaries of the Vistula and Odra drainage basins (Fig. 1). The research sites were selected to demonstrate erosional undercuts and slope processes that deliver coarse-grained regolith into the river channel.

DATA COLECTION

A 1:400 scale morphological mapping of the 1.2 km long river channel sections upstream and downstream of coarse-grained regolith supply zones was prepared during the field research. The mapping was repeated after flood events. Characteristics such as width and height of large scale alluvial forms, high-water marks and bank material were noted and surveyed at each site. The channel cross-section was measured to characterize the channel geometry at intervals upstream and downstream of the hillslope sediment delivery points. Channel-form sediments were sampled at approximately 50 m intervals along the length of the river channels being studied. The size of the largest clasts were surveyed in each of the sub-reaches. In addition, the roundness of the clasts (16-30 cm fraction) was determined according to the six-category Powers index (Powers 1953).

RESULTS

Sediment sources and river bed material

Two types of primary sediment source were identified: supplying angular coarse-grained material to streams from cut-bank sections and landslides. A simple tripartite division can be used to classify cut-bank sections depending on the composition of the slope material: rock, regolith and rocky-regolith cut-bank. Where the river undercuts the rock bank, coarse-grained material is mainly supplied by rock falls. In other types of cut-bank, the rock blocks and angular cobbles are being actively eroded from periglacial slope covers and, in the areas of immediate contact with the river channels, active landslides.

Hillslope sediment delivery points affect the sediment size and roundness of bed load. Mid-mountain streams, like the Mostysza, consist of alternating bedrock and sediment reaches making up a system in which sediment supply zones have specific effects on the bed sediment

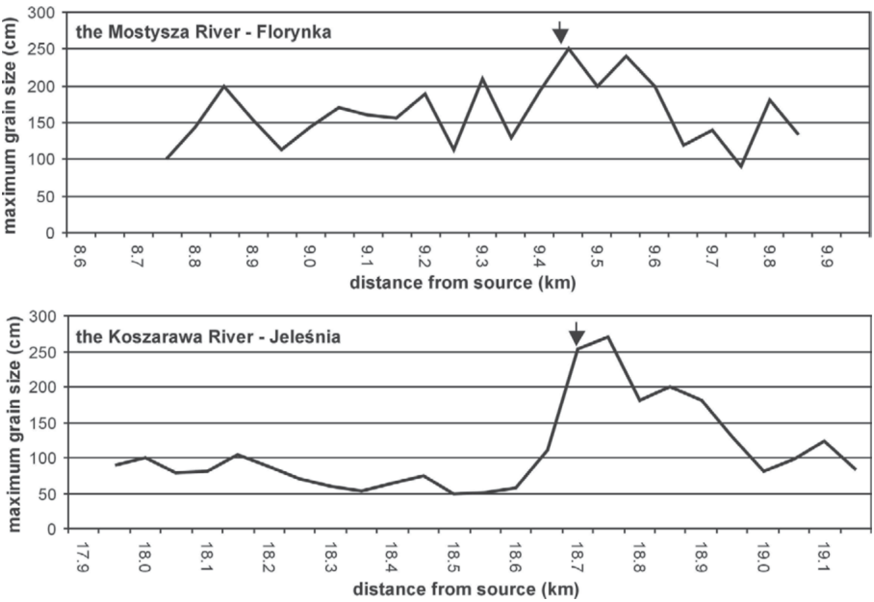

Fig2: Maximum grain-size in research sections of the Mostysza and the Koszarawa River

characteristics. The data gathered show no trend of downstream fining (Fig. 2). Coarse-grained material is delivered from hillslopes and also is eroded from bedrock reaches. A similar trend was observed by Billi (1993) on the Nant Tanllwyth River. In wide gravel-bed rivers like the Koszarawa the decline in sediment size is connected with abrasion and size sorting. In the research site analysed, a distinct increase in sediment size is observed due to fresh sediment delivery from an active landslide (Fig. 2).

The roundness of clasts within the 16-30 cm fraction was determined upstream and downstream of the sediment supply zones using the six-category Powers index. In all research sites rounded material dominates upstream of the supply points of coarse grained regolith. Within the supply zones and downstream, however, there is a marked increase in the quantity of angular material relative to rounded. The maximum percentages of unrounded clasts relative to rounded ones reaches 84.7 % in the Mostysza – Florynka site (Owczarek 2003).

Alluvial channel forms

Lateral bars with a core of rock blocks are located at the bottom of coarse-grained regolith supply points (Fig. 3). They are attached to the bank and occur in small rivers, like the Mostysza and also in large ones, like the Biala Glucholaska (Fig. 1A&B), where the input of illslope material is abundant. The core of the bar consists of rock blocks and angular cobbles which are mainly delivered by rock falls. This material affects the fluvial sediment accumulation. A steep depositional front of the bar progrades towards the channel axis influencing the lateral erosion of the opposite river bank. The bar surface is often scarred with abandoned channels and has other surface irregularities. There is a general decline in grain size from the upstream to the downstream region of the bar. In contrast to the bar head, which comprises comparatively coarse, imbricated gravels, the bar tail is composed of sand and pebbles. The large lateral bars with a core of rock blocks constrict streamflow, thereby

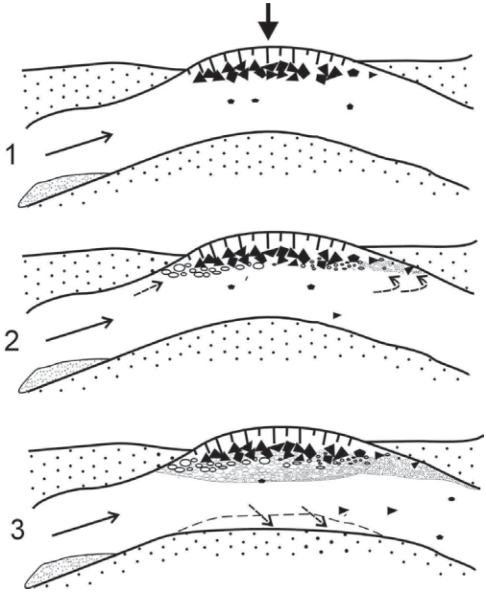

Fig3: The development of a lateral bar with a core of rock blocks. 1 – delivery of the coarse-grained hillslope material, 2 – fluvial sediment accumulation, 3 – progradation of the bar towards the channel axis

creating debris steps and riffle bars (Martini 1977). The riffle bars consist of a single string of large, angular clasts running approximately transverse to the axis of the river channel (Fig. 4). These riffle bars rarely move downstream and only for short distances under high flow conditions. Sandy eddy bars form downstream from the large side bars. These bars form along the channel margin in zones of separation flow called eddies (Andrews et al. 1999, Gramis and Schmidt 1999). Rapid deposition of the suspended sand and silt is observed in these recirculation zones during periods of high flow. They are exposed when the river flow rate declines. The thickness of fine-grained deposits ranges from a few centimetres to one metre. Sand and silt deposits contain a massive structure.

Different depositional system is observed in wide gravel bed rivers, like the lower courses of the Koszarawa and Kamienica Rivers (Fig. 1C&D). Gravelly debris lunate bars, which form downstream from hillslope sediment delivery points, are the most significant element of morphology of the river bed. They belong to the side bar group. Development of the lunate bars is connected with single large rock blocks delivered from the cut-bank (Fig. 5). The large particles entrained from the points of hillslope sediment delivery that were observed, were deposited a short distance downstream in the marginal zone of the river channel (Fig. 6). The immobilised rock blocks are influencing the deposition of gravels and sands. Lateral accretion of sediment in the channel form analysed is observed under conditions where sediment transport rates are high during subsequent high flows. The depositional front of the bar, like the lateral bars with a core of rock blocks, shifts towards the channel axis.

Debris ribbon bars are generally about

Fig4: Riffle bar (site: the Mostysza River – Florynka). The flow direction is from left to right

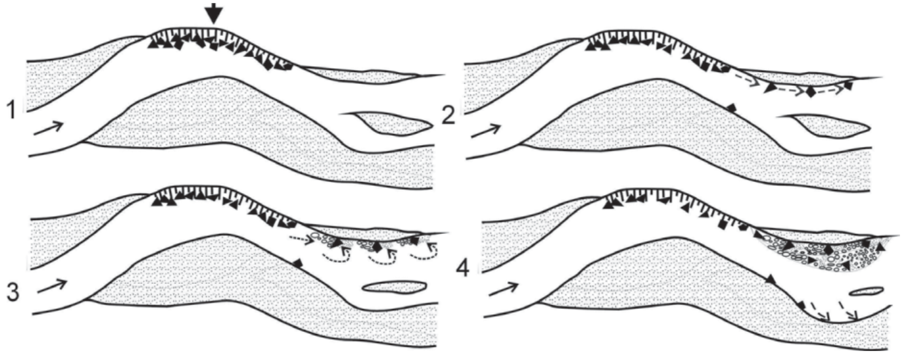

Fig5: The development of a gravelly debris lunate bar: 1 – delivery of the coarse-grained hillslope material, 2 – entrainment of boulders from cut bank, 3 – deposition of blocks and accumulation of fluvial sediment, 4 – progradation of the bar towards the channel axis

Fig6: Gravelly debris lunate bar on the Kamienica River. Note large block of rock deposited downstream the zone of hillslope sediment supply. View is downstream

two to four channel widths in length and form on the opposite side of the river. The debris bars are composed of angular cobbles. These alluvial forms are unstable during periods when there are small floods.

Diffuse gravel debris sheets are initial bar forms which form in mid-stream sections. These alluvial forms were observed in all those coarse sediment delivery zones. In contrast to the alluvial channel forms described above, these are submerged even during periods of low flow. The depositional fronts of the diffuse gravel debris sheets run transverse to the channel axis. They are lenticularly shaped and composed of angular to rounded imbricated clasts. Diffuse gravel debris sheets migrate downstream forming mid–channel bars.

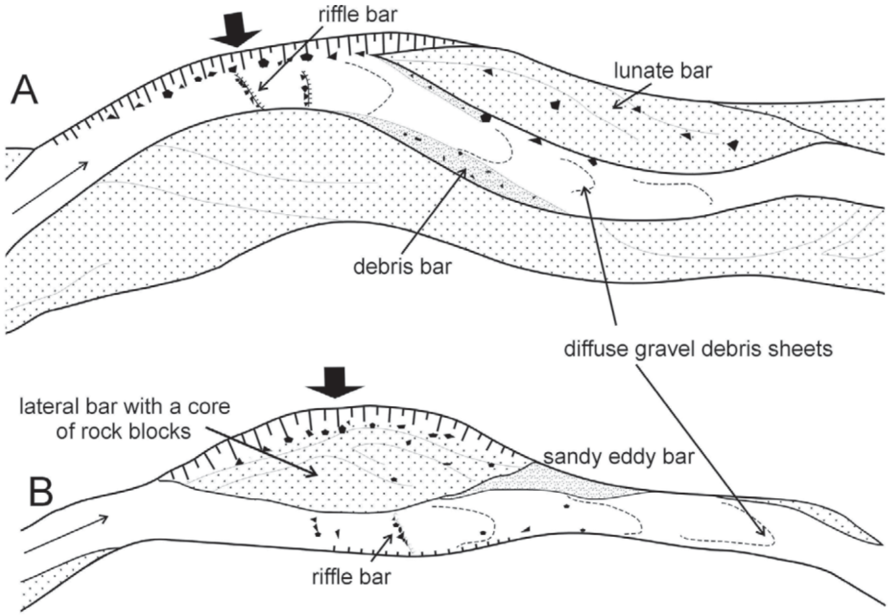

Fig7: Schematic diagrams showing the depositional zones created by coarse-grained hillslope material in wide gravel bed rivers (A) and narrow river channels (B)

FINAL REMARKS

For mid-mountain river channels where the sediment input from hillslope is abundant, patterns of sedimentation are determined by hillslope processes. The local control features, such as hillslope supply zones, influence sediment size, the roundness of bed load and the development of specific alluvial channel forms (Fig. 7). Coupling between hillslopes and river channels produces a unique association of process – sediment – channel form that distinguishes the channel sections analysed from those where available coarse grained hillslope sediment for fluvial processes is meagre. In river channels, where is a lack of fresh angular sediment supply, a decline in sediment size is observed and the occurence of alluvial channel forms is connected with hydrological processes, slope and the sinuosity of the alluvial channel. Sediment supply, and its accessibility for fluvial transport, is regulated by the frequency of floods as well as the type of cut-bank and hillslope process. In the temperate mid-mountain river channels analysed, annual summer floods affect entrainment and transport rock blocks. Input of coarse hillslope material is a main cause of development of large depositional forms but they are limited and do not migrate downstream. The roundness of clasts in these alluvial forms indicates that their source is a zone of hillslope sediment delivery immediately upstream. The depositional zone created by coarse hillslope material consists of: lateral bars with a core of rock blocks or lunate bars, sandy eddy bars, debris bars, diffuse gravel debris sheets and riffles. The width, pattern and type of the river channel affect the deposition and size of these forms.

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