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Slope-Channel Coupling as a Factor in the Evolution of Mountains

The Western Carpathians and Sudetes

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Slope-Channel Coupling as a Factor in the Evolution of Mountains

The Western Carpathians and Sudetes

Doctoral Thesis accepted by
University of Silesia in Katowice, Sosnowiec, Poland

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Supervisor's Foreword

Numerous works have been published on the mechanisms of relief evolution in mountain areas but new questions and research problems still arise during field observations. One of these is the issue of determining the importance of coupling between geomorphic processes on slopes and fluvial erosion and deposition in valley bottoms for the evolution of montane relief at a general scale.

This thesis undertakes a comprehensive analysis of the links between slope and channel subsystems in small mid-mountain catchments so as to propose on that basis some generalisations and conclusions of broader importance, which would lead to the development of a schema for relief evolution in mid-altitude mountains. This objective was accomplished through studies in ten stream catchments located in the Western Carpathians and Sudetes in the Czech Republic.

The studies conducted have shown that mass movements on slopes, in particular landsliding, and fluvial erosion on valley floors of small, forested, mid-mountain catchments are coupled. When slope material is transported into valley floors, it enters river channels and causes feedback bringing on erosion at the foots of slopes. On the other hand, fluvial erosion occurring at the boundary between slopes and valley floors causes disturbance of the slope equilibrium and another generation of mass movements. Repeating cycles of landsliding and erosion cause the gradual transformation of V-shaped cross profiles of valleys into flat-bottomed ones and a gradual retreat and lowering of slopes.

The thesis contains an extensive and a diverse range of documentation on field and laboratory studies which were the basis for the generalisations later presented which frequently go beyond the previously recognised facts concerning the evolution of relief in forested mid-mountain areas of the temperate climatic zone. The thesis represents a new perspective in understanding relief, particularly within the study areas of the Western Carpathians and Sudetes.

The thesis is also of potential interest to all researchers dealing with the problem of geomorphic coupling because the results were obtained through the use of an original approach, never before applied in analyses on slope-channel feedback.

The occurrence, length and frequency of the cycles of slope-channel coupling were determined by means of dendrochronological dating. This results from the rapid recent development of dendrogeomorphological methods. In the thesis, the precise dating of erosion was applied through the analysis of wood anatomy in roots. An original method, developed for the needs of the thesis, was also applied and described. The method allows the dating of mass movement activity on slopes using the eccentric growth of trees tilted by ground instability. Comparison of temporal patterns of mass movement on slopes and fluvial erosion on valley floors was key to proving the great importance of positive feedback between slopes and channels in the evolution of mid-altitude mountain landscapes. At the same time, the method of eccentricity analysis developed proved its value in landslide studies and shows great promise in scientific analyses of, e.g. triggering factors and the spatial pattern of landsliding, but also in practical applications, e.g. estimating landslide hazard and risk. Hence, the thesis presented is also a good example of scientific work in which a purely research problem was to be solved, but the tools developed for that purpose can also have practical application.

Sosnowiec, Poland, June 2014 Prof. Ireneusz Malik

Abstract

Coupling between hillslopes and river channels is often considered to be a fundamental aspect of the functioning of geomorphic systems. In this thesis, coupling between the delivery of slope material into valley floors and river erosion was considered to be a factor in the evolution of mid-altitude forested mountains, where the connectivity between slope and fluvial subsystems is, so far, poorly recognised.

The thesis describes geomorphological and dendrochronological investigations carried out in mid-altitude areas of the Sudeten Mts and Carpathian Mts to analyse temporal and spatial relations between slope and fluvial processes (landsliding and erosion in particular). Landsliding and erosion occurrence were dated using the annual rings of Norway spruce. Using an original dendrogeomorphic approach it was possible to determine the cyclic occurrence of landsliding and erosion in the catchments studied during recent decades. The results show that the processes studied are strongly interdependent. Fluvial erosion can trigger landsliding by undermining slope bases. Landsliding can intensify erosion by delivering slope material into valley floors.

The results of dendrochronological studies have permitted a better understanding of the relief observed in areas where landslides and erosion are coupled. A schema was established which describes the evolution of mid-mountain landscape. This was discussed taking into account the influence of geological setting, human impact, climate change and tectonic activity. Using the results obtained from the ten catchments analysed and data obtained from the literature review, a proposition was made that the established model may describe a general rule for the evolution of mid-mountain landscape.

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In 2011–2012, I received a postgraduate scholarship from the UPGOW project during thesis preparation (financed from the EU European Social Fund, Operational Programme—Human Capital).

Contents

Chapter 1
Introduction

1.1 Outline of the Research Problem

The relationship between slopes and river channels is a fundamental aspect of the functioning of geomorphic systems [50]. The zones, where they are in direct contact, are places where the products of weathering and slope processes are delivered to the fluvial subsystem [106] and included in further transfer of debris by flowing water. One-directional transfer of material occurs between slopes and channels (downwards, through gravitation from slopes to channels). This is represented by the delivery of regolith into valley floors and stream channels and also by the results of the delivery for valley relief and the course of fluvial processes (e.g. [13, 25, 48, 49, 68, 69, 94, 99, 106, 108, 113]).

In contrast with the one-directional transfer of debris, the influences of channel and slope processes are mutual. There are examples of the impact of delivery from slopes on fluvial processes and examples of the fluvial processes influencing the balance and stability of slopes (e.g. [2, 21, 69, 83, 104]). The mutual and straightforward merging of those influences at the boundary between a slope and valley floor results in the occurrence of a coupled slope-fluvial system [9, 48].

The spatial scale of slope-fluvial coupling is represented by, among other factors, the length of valley floor sections with a direct, active link between slopes and channels. The strength of coupling between the two geomorphic subsystems, slope and fluvial, is influenced by external factors from outside the catchment system, such as the tectonic activity of the bedrock (e.g. [18, 24, 25, 60, 67, 84]), climatic conditions (e.g. [15, 16, 95, 127]), human impact (e.g. [16, 23, 26, 31, 52, 80]) and internal features of the system, such as slope relief, valley floor relief and catchment size. Considering the latter group of factors it can be stated that:

- the larger the relative height of a catchment,
- the more dissected the catchment surface,
- the more branched the relief,
- the narrower the valley floor, and
- the smaller the size of the catchment,

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the closer is the connection between slope and fluvial processes [23, 58]. With an increase in spatial scale—increases in basin area, valley floor width, order of a channel—the coupling of slopes and channels becomes weaker. In extreme cases one can observe the occurrence of decoupled, buffered geomorphic systems, devoid of links between slope and channel subsystems [8, 9, 49], e.g. due to their separation by an alluvial plain [95, 106].

Taking the above considerations in the area studied (Western Carpathians and Sudetes) as an object of research on the course of the delivery of slope material into valley floors and the impact of the delivery on relief evolution in mid-altitude mountains, I have chosen the catchments and valleys of small streams which are areas with the strongest potential for coupling between slope and fluvial subsystems, high energy and strong dynamics of geomorphic processes.

The hillslope-valley topography of mid-altitude ranges of the Western Carpathians and Sudetes is widely perceived as: (1) determined by geological structure (e.g. [4, 6, 55, 56, 86, 115, 128, 141, 144, 165]), (2) inherited from the periglacial conditions of the Pleistocene (e.g. [19, 20, 47, 129]), (3) transformed by human activity (e.g.: [63, 65, 66, 78, 80, 143, 154]) the effects of which were probably increased by the climate fluctuations during the Little Ice Age (e.g. [66]).

The delivery of slope material into valley floors and stream channels, occurring now and previously in the Holocene period and the possible interaction of slope and fluvial subsystems are rarely considered in discussions on the evolution of relief in the mid-altitude parts of the Carpathians and Sudetes. The importance of slope-channel coupling is considered mainly in the palaeogeographic context, identifying it with the past impact of the periglacial climate of the Pleistocene or, since the Middle Ages, the strong human impact on geomorphic systems of mid-altitude mountains now belonging to the temperate climatic zone. At the same time it is recognised that the impact of both periglacial conditions and human disturbance is now ending and we observe a system relaxation after the end of periods with intensified slope-channel interaction. The material delivered earlier is now being removed and layers of periglacial and anthropogenic deposits are being dissected and redeposited (e.g. [78, 80, 97, 140, 160, 161]). The slope-fluvial system which exists under the forest cover (both now and before human disturbance) in the mid-altitude parts of the Carpathians and Sudetes during the Holocene period, is described as a system which became decoupled [80, 135] and due to the change in environmental conditions developed into a buffered or dormant system (active only periodically).

According to the above-mentioned opinions, in research on geomorphic processes, slopes and channels in the mid-altitude parts of the Western Carpathians and Sudetes were for a long time discussed as parts of relief which are independent of one another (e.g. [35]). The regional literature, Carpathian and Sudetic, related to processes such as landsliding, debris flows, and lateral erosion is wide-ranging. The published work, however, relates mostly to the triggering factors, the conditions and frequency of their occurrence and the spatial distribution of the processes. Publications on coupling between slope and fluvial processes are relatively rare within this body of work despite the fact that the above-mentioned phenomena are sources of slope material delivery into valley floors potentially common in forested mid-altitude mountains of the temperate climatic zone. The state of research thus described results from investigating slopes and channels as two separate geomorphic systems. Only a few authors have described examples of: (1) the impact of erosion on the stability of landslides in the Western Carpathians [21, 36, 42, 72, 131, 162–164], and rarely in the Sudetes [104, 166], (2) the importance of landslides in moulding valley floors, mostly due to the damming of stream channels by colluvia when lakes are formed upstream [78, 89, 102, 103, 105, 106, 112], (3) the delivery of slope material into channels by debris flows [96, 88] (4) the importance of the delivery of periglacial regolith from eroded banks in determining the relief of river channels and alluvial structure [106, 107].

At the same time studies conducted in mountain areas other than the Carpathians and Sudetes widely prove the substantial impact of slope-channel coupling on: (1) the regime of sediment transport in river channels (e.g. [25, 57, 113]), (2) channel avulsion (e.g. [68]), (3) changes in valley cross-sections (e.g. [68, 69]), (4) changes in the longitudinal profiles of channels (e.g. [113]), (5) the formation of landslide-dammed lakes and associated backwater lacustrine, deltaic, and alluvial deposits, meandering channels and river gorges (e.g. [25, 53, 69, 71]), (6) the formation of subsequent generations of landslips or rotational landslides under the impact of lateral channel erosion (e.g. [2, 69, 83, 146]).

The most numerous and spectacular examples of coupling come from high mountain areas (e.g. [5, 25, 53, 68–71, 122]). There are many examples of the impact of coupling between slope and fluvial subsystems on the evolution of relief at different scales—from single channels, channel systems, through valley floors and sides, to whole catchments. Particularly in case of coupling between channels and landslides there are opinions on its great importance in the evolution of the relief of whole mountain ranges [17, 70].

Studies on coupling in non-alpine areas are less frequent [2, 50, 51, 57, 82, 83], especially those conducted in forested mid-mountains of the temperate climatic zone—similar to the ones studied in this thesis. In the case of the Western Carpathians only single authors consider the coupling of landslides and channel processes as a factor locally modelling the mid-mountain relief, leading to, e.g. the deepening and widening of valley floors, increase in the inclination of valley sides [36] or the formation of river gorges [72]. Despite the above mentioned examples from the regional and international literature the importance of slope-channel interaction in the development of relief in the mid-altitude ranges of the Western Carpathians and Sudetes is probably underestimated.

Both the study areas are/were potentially characterised by strong coupling between slope and channel processes:

- in the Pleistocene period—due to the periglacial climate and character of geomorphic processes,
- in the Holocene period, in conditions of strong human pressure on the environment—due to increased denudation of deforested slopes,

but also:

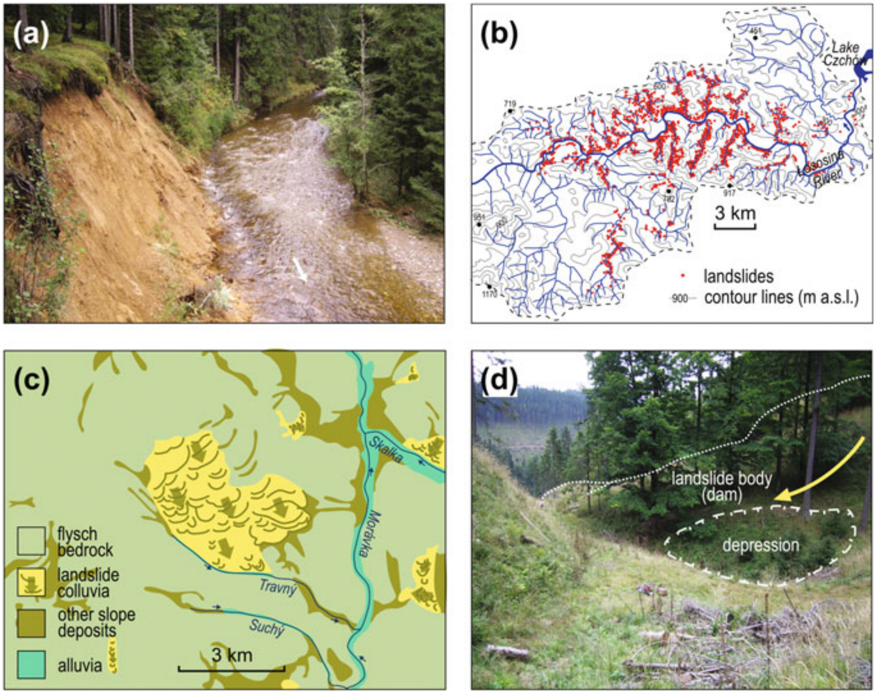

Fig. 1.1 Evidences of delivery of slope material into valley floors in mid-altitude mountain ranges of the Western Carpathians and Sudetes: **a**—One of the numerous undercut banks exposing slope deposits developed as a result of lateral erosion of the Černá Opava river, Hrubý Jeseník Mts, Eastern Sudetes, Czech Republic (picture taken during flood in September 2007), **b**—landslides active in 1997–2000 (*marked in red*) in the Łososina river basin, Western Carpathians, Poland (after [43], modified). Note clusters of small landslides along the edges of valley floors and river channels, **c**—landslide originating high on the slope descending down to the floor of the valley of the Travný Stream, Moravian-Silesian Beskid Mts, Western Carpathians, Czech Republic (after [54], modified), **d**—colluvia delivered from the slope of Włostowa (Kamienne Mts, Central Sudetes, Poland) dam up the valley floor. Note depression above the dam (*yellow arrow* shows the direction of landslide movement)

- in the Holocene period, under forest cover, before anthropogenic disturbance, and in contemporary times when human impact is limited. The coupling of channel and slope processes is potentially strong due to the: (1) occurrence of thick, loose covers of regolith (partially inherited from periglacial conditions) on slopes and at the foot of slopes where they are available for lateral channel erosion (Fig. 1.1a), (2) widespread occurrence of active landslips at the boundary between slope and valley floor (channel) in the Flysch Carpathians (Fig. 1.1b), (3) widespread occurrence of landslides which originate high on the slopes but reach the valley floors in the Flysch Carpathians (Fig. 1.1c), (4) increasing number of reported landslides in different parts of the Sudetes

Table 1.1 Relationship between distance from the drainage network and area of landslides in a selected part of the Carpathian Piedmont, Poland (data after [153])

Distance from drainage network (m)	Area of landslides	
	(km^2)	(%)
0–100	6.114	35.9
100–200	4.992	29.3
200–300	3.151	18.5
300–400	1.470	8.6
400–500	0.754	4.5
500–600	0.277	1.7
600–700	0.181	1.1
700–800	0.065	0.4
>800	0.001	0.0
Total	17.005	100.0

[1, 96, 98, 104, 117, 118, 120, 121, 133, 166], among them also landslides with toes reaching the valley floors ([96, 98]; Fig. 1.1d).

The evidence for large-scale coupling between slopes and channels in the Flysch Carpathians is the fact that in some areas of the Carpathian foothills over 80 % of the landslide surface is located between 0 and 300 m from the drainage network ([153]; Table 1.1). According to [153] only 38 (7.27 %) of 523 landslides located in selected part of the Carpathian Piedmont were completely disconnected from streams or valley floors. Another 54 (10.33 %) landslides occured in the heads of valleys, and the other 82.4 % were landslides and landslips directly neighbouring channels and valley floors. Similarly, according to [155], in the Koszarawa river basin in the Polish Western Carpathians, 62.3 % of landslides occur in contact with valley floors and another 23.4 % occur in valley heads.

1.2 The Subject of the Study: Delivery of Slope Material into Valley Floors in the Slope-Fluvial System of Mid-Altitude Mountain Ranges of the Western Carpathians and Sudetes

1.2.1 Basic Terminology Used in the Thesis

The title of the thesis and subject of the study require the definition of several basic terms used whose interpretation can be ambiguous; and also due to them formerly being used by other authors in different meanings.

Relief evolution in its simplest meaning is the *mode of change of landform or geomorphic system over time* [125]. The change can be described using qualitative theories (e.g. [22, 61, 114]) or quantitative models (e.g. [62, 145]).

Term *slope material* is used as a term describing all the material that can be the subject of geomorphic slope processes: soil with forest litter, regolith with slope deposits and in situ decomposed, disintegrated rocks, unweathered rock substratum forming mountain massifs. The term *material* was used with this meaning (including both loose and solid matter) by Selby [106] and Owczarek [124].

Delivery of slope material into valley floors is a phenomenon occurring through: (1) the movement of the material downslope under the impact of gravity, often with the presence of groundwater [7] or (2) under the impact of erosion [108]. As a result of the phenomenon slope material is delivered directly or in stages into valley floors where it becomes available for fluvial processes.

The delivery of slope material is dependent on geomorphic processes of different mechanisms, distribution and triggering conditions. For the needs of the thesis a group of processes was distinguished as *lateral delivery of slope material*. This was defined as a transfer of material which occurs perpendicular to the valley axis, directly from the slopes to the valley floor omitting erosional gullies and tributary streams. Examples of processes delivering slope material laterally from valley sides are: bank erosion, debris flows and landslides. The term *lateral delivery* distinguishes the geomorphic processes mentioned above from the delivery of debris along the axes of valleys or erosional gullies, e.g. fluvial delivery through channels from the upper parts of catchments, delivery by surface wash concentrated in initial dissections, gullies or roads, and from landsliding which occurs in valley heads in a direction parallel to the axis of valley below.

The thesis concerns *mid-altitude mountains* (or *mid-mountains*) which can be described here as mountains covering more than one climatic/vegetation belt, but only occasionally exceeding the upper treeline [73, 126]. Contemporary mid-altitude mountains of the temperate climatic zone are not glaciated, there are no active glacial or periglacial processes, and most of them were not glaciated during the Pleistocene period [73, 106].

The slope-fluvial geomorphic system of mid-altitude mountains which developed in the Holocene and now occurs in the Western Carpathians and Eastern Sudetes is, according to the literature, distinguished by the following diagnostic features [73, 106]: (1) occurrence of a thick loamy-debris cover of regolith retained under the forest, (2) availability of the material for fluvial processes in zones with direct contact between the valley sides and channels, (3) pulsating delivery from slopes and mobilisation of debris in channels during extreme rainfall (mostly during summer seasons) and floods (caused by precipitation in summer and connected with thaw in spring), (4) intermittent connectivity of slope and fluvial subsystems, which occurs during extreme events and over periods with high human activity in the environment.

The sediment flux system on slopes and in channels in mid-altitude mountains of the temperate climatic zone is considered to be much less efficient and complex than in high mountains. However, as mentioned above in Sect. 1.1, it is also much less recognised in comparison with high mountains [73].

In the thesis studies on the delivery of slope material into valley floors in mid-altitude mountain ranges of the Western Carpathians and Sudetes focused on *small valleys* and *small catchments*. The strongest coupling between slopes and channels was expected to occur within them. Valleys and catchments of order 1–3 according to the stream-ordering system by [132] applied to the drainage network from 1:25,000 topographical maps (33) were treated as small.

In order to emphasise the subject of the study: a potentially strong geomorphic coupling between slopes and channels (as subsystems within small catchments), I ceased using the terms *fluvial system* [106] or *morphogenetic system*, *system of sediment flux*, *denudation system* [73], which all appear in the literature, and instead used the term *slope-fluvial system*.

1.2.2 The Structure of the Slope-Fluvial System

Analysis of the mode and results of the delivery of slope material into valley floors in the mid-mountain slope-fluvial system of the temperate climatic zone was based on the division of the fluvial system by [123]. He distinguished three zones in the longitudinal profile of the system (Fig. 1.2): the production zone (I), transfer zone (II), and deposition zone (III). The division could well be mainly concerned with extensive, large scale systems of valleys and catchments of the order of e.g. Vistula, Oder—main rivers entering directly to the Baltic Sea or their principal tributaries.

The division established by Schumm is not well suited to the specific features of mountain river catchments where the production and delivery of slope material to channels is widespread and can occur both in the uppermost zone (I) and further downstream [106]. The division requires modification, in order to be applied for the description of mountain catchments. For the needs of a study conducted in mid-altitude mountains Schumm's division was modified by [106] who in catchments of mid-mountain rivers (having sources in mountain areas but outlets within vast intra-montane basins, piedmonts or lowlands), has distinguished (Fig. 1.2):

- the uppermost zone, production zone—valley heads, deep valley sections with V-shaped cross-sections (equivalent to zone I in Schumm's division),
- the middle, transitional zone—flat-bottomed sections of valleys where slope material supply to channels is local and occurs in short sections where there is direct contact with the valley sides (a combination of zones I and II according to Schumm),
- the lowermost zone—terminal sections of rivers where sediment transport and deposition/redeposition occur (processes typical of zone II according to Schumm), river sections often flowing through fans (relief typical of zone III according to Schumm).

In small mid-mountain catchments which are the subject of this thesis, contact between slopes and stream channels is even more frequent than in the valleys of larger mountain rivers and active delivery of slope material to channels can probably occur from valley head to stream outlet. Because of this, the divisions of [106, 123] presented above should be adapted for the slope-fluvial system of small mid-mountain catchments in the eastern Carpathians and Sudetes (Fig. 1.2). This was done on the basis of studies of the regional literature (the following Sect. 1.2.3).

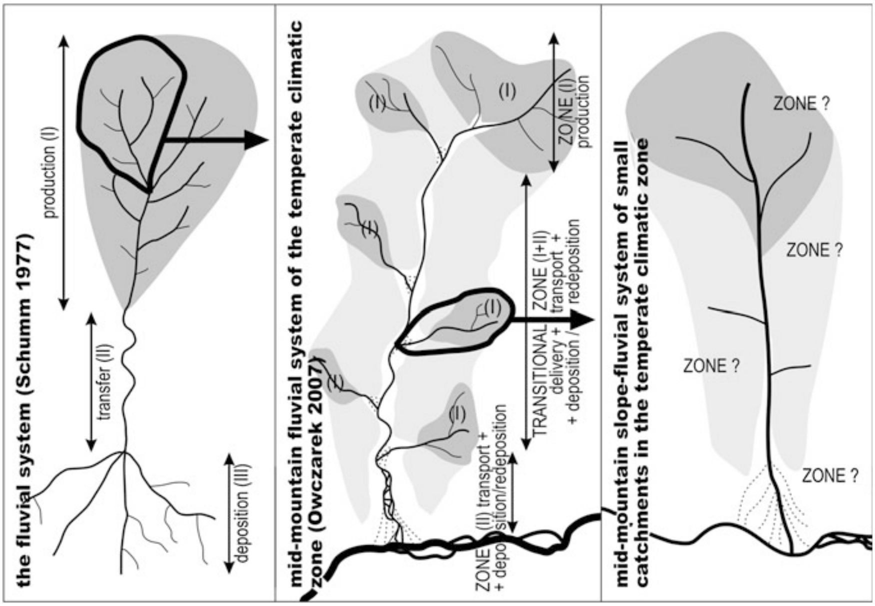

Fig. 1.2 The division of the fluvial system by Schumm [123] and the division of the mid-mountain fluvial system of the temperate climatic zone by Owczarek [106]—a basis for the division of small mid-mountain catchments of the temperate climatic zone in the Western Carpathians and Sudetes

1.2.3 The Delivery of Slope Material to Valley Floors in Small Mid-Mountain Catchments in the Carpathians and Sudetes: The Current State-of-the-Art as a Basis for the Division of the Slope-Fluvial System

The number of papers concerning the delivery of slope material to valley floors in small Carpathian and Sudeten catchments—similar in size to those analysed in this thesis—is small. They are mostly papers published in the last 20 years when interest in the topic of small catchments gradually increased in geomorphic studies. Moreover, most of the papers relate more to the conditions and mode of specific geomorphic processes than to their importance in the delivery of slope material into valley floors and importance as a manifestation of coupling between slope and fluvial subsystems.

Information obtained from literature studies suggests that the mode of slope material delivery to valley floors of small catchments changes along the stream courses from source to mouth. In the upper parts of catchments, in valley heads, debris flows (Fig. 1.3) and rarely mud flows (e.g. [164]) were described. Papers mostly relate to flows initiated above the upper tree line, with tracks, gullies, levees and toes entering into the forest belt [32, 88, 97, 116], and rarely to those occurring wholly under the forest cover [164]. Numerous works concern the occurrence of debris flows in massifs transitional between mid-mountains and high mountains such as Mt Babia Góra (e.g. [85, 93]) and Karkonosze (on glacially transformed slopes; e.g. [97, 109, 134, 142]). Connectivity between debris flows and the channel subsystem was only described in a small proportion of the papers (e.g. [87, 88, 164]).

Landslides occurring in valley heads in the Flysch Carpathians are rarely described from the point of view of their impact on drainage network evolution and the mode of occurrence of fluvial processes. Detailed studies mostly concern the susceptibility of slopes to mass movements (e.g. [119]), their relations with extreme rainfall (e.g. [40, 42]) and the geological conditions for landslide development [3, 6]. Landslides with their associated peatbogs were also treated as sources of palaeogeographical information (e.g. [91]). Only individual papers consider their role in forming the drainage network through the initiation of the development of valley heads, their deepening and dissection (e.g. [110, 157, 159]). Surface wash and linear erosion are rarely studied processes in the forested valley heads of small Carpathian and Sudeten catchments (e.g. [12, 27, 34, 44, 158]; Fig. 1.3). Studies on surface and linear erosion connected with surface wash were mostly conducted on the arable slopes of foothills and low mountains (e.g. [29, 30, 37–39, 41, 130, 135, 136]).

Among the numerous routes for the delivery of slope material onto sections of the floors of small valleys below the valley heads, the most frequently described are linked to problems of lateral bank erosion (Fig. 1.3). There is however, a lack of papers which analyse the impact of delivery from undercut banks on channel morphology—similar to the paper prepared for larger channels and river valleys by [106]. The works available concern, above all, the hydrological conditions of erosion, its mode and the dating of erosional events (e.g. [28, 45, 74, 75, 87, 100, 101, 149]). Lateral erosion in streams (of a size similar to those analysed in this thesis) is rarely considered as a source of slope material for the fluvial subsystem (e.g. [27]). In the literature there are only rare descriptions of lateral delivery of slope material from landslides reaching valley floors between valley heads and outlet fans (Fig. 1.3). Previous papers mostly concern the role of landslide toes in damming channels and creating backwater reservoirs (e.g. [78]) and sediments filling up those lakes as sources of palaeogeographic data (e.g. [112]). The development of numerous shallow landslides and landslips was also described in the middle zones of catchments due to the occurrence of extreme rainfall events and high water levels [45]. Single papers describe the occurrence of debris and mud flows within channels in the middle parts of small Carpathian catchments [137, 138, 164]. Flows are triggered by increased delivery of slope material from stream banks eroded during floods.

The lowest parts of small mid-mountain catchments in the Flysch Carpathians and Sudetes are those that are least studied. This is probably because the alluvial fans occurring there enter wide valley floors of main rivers and are currently developed and strongly transformed by human activity. The possibility of studying the processes which now occur there is limited and the record (geomorphic,

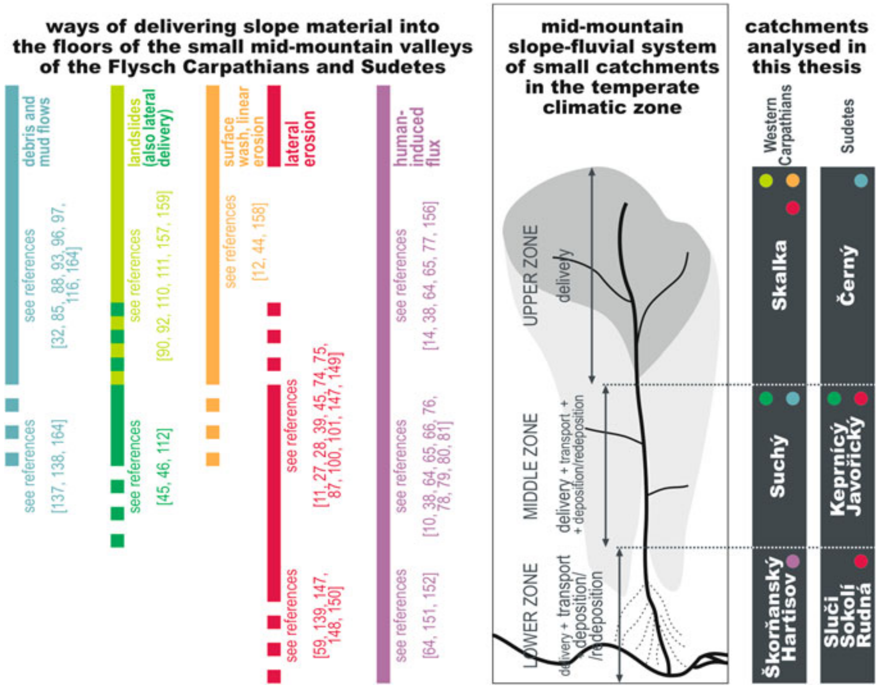

Fig. 1.3 Ways of delivering slope material into the floors of the small mid-mountain valleys of the Flysch Carpathians and Sudetes—examples of previous publications with regard to the location of studies within catchments. Small catchments are divided into three zones with the locations of valley sections analysed in the thesis (*font size* relate to the relative importance of the processes) with indication to catchments studied in the thesis (*coloured dots* relate to the paths for the delivery of slope material into valley floors as observed during the field studies)

sedimentary, palaeobotanic) of older events is often destroyed. For the lowest parts of catchments only a few papers exist considering lateral erosion of stream channels (e.g. [59, 139, 148, 150]; Fig. 1.3).

Compared to the avenues for the delivery of slope material to valley floors by gravitational mass movements and fluvial erosion described above, human induced phenomena (among them sediment flux from slopes) and the human impact in shaping the relief of small mid-mountain catchments in the Western Carpathians and Sudetes (Fig. 1.3) is much more frequently described. There are numerous works relating to particular parts of those systems—valley heads or outlet alluvial fans (e.g. [14, 65, 77, 80, 152]), but there are also papers considering small catchments as a whole (e.g. [10, 78, 80, 81]).

Because the routes for the delivery of slope material to valley floors vary within the areas of small mid-mountain catchments in the Western Carpathians and Sudetes, their spatial distribution is uneven and shows a distinct pattern (Fig. 1.3). These systems were classified, in a similar manner to larger ones, by distinguishing the following zones:

- the upper zone (valley heads) where the delivery of slope material to channels occurs, where there is an occasional lateral delivery,
- the middle zone (valley sections with V-shaped cross-sections and flat-bottomed valleys) which was distinguished on the basis of the dominance of lateral delivery as a specific diagnostic group of processes (this is the reason why the names 'transitional' and 'transfer' were abandoned); debris is also delivered through the channel from the upper parts of the catchment, and transport and deposition/redeposition occur,
- the lower zone (outlet fans) where debris is delivered through channels from the upper parts of catchments, occasionally lateral delivery from slopes occurs and transport and deposition/redeposition occur.

Each zone covers the area of the valley floor with the stream channel, valley sides and slopes as far as the watershed.

1.3 Research Objectives

A. To determine the temporal and spatial scale of coupling between the slope and channel subsystems of small mid-mountain catchments of the Western Carpathians and Sudetes—using examples of selected stream catchments.
B. To determine the importance of coupling between slope and channel subsystems in small catchments for the evolution of relief in mid-mountains of the temperate climatic zone.

The detailed objectives of the research were:

A-1 To determine the diversity of geomorphic processes delivering slope material into valley floors in the upper zones (valley heads), middle zones and lower zones (outlet fans) of selected small mid-mountain catchments.
A-2 To determine the scale of contemporary coupling between slope and channel subsystems and its impact on the relief of slopes and valley floors in selected small mid-mountain catchments, in particular:
A-2-1 To determine the level of contemporary activity of geomorphic processes delivering slope material into valley floors and the frequency of their occurrence during recent decades and centuries.
A-2-2 To determine the impact of the delivery of slope material into valley floors on:

- the morphology of valley floors and channels,
- features of alluvial deposits,
- the mode of erosion and accumulation in channels,
- the development of the valley network.

A-2-3 To determine the impact of fluvial processes on the activity and mode of slope processes.