PRACE GEOGRAFICZNE, zeszyt 104

Instytut Geografii UJ
Kraków 1999

Wojciech Chełmicki, Kazimierz Krzemień

CHANNEL TYPOLOGY FOR THE RIVER FESHIE IN THE CAIRNGORM MTS, SCOTLAND

Abstract: The channel of the River Feshie was examined in order to identify and delimit the channel sections of different type, and explain the reasons for its high complexity developed in spite of almost uniform bedrock geology. The numerical taxonomy methods were applied. These were: the furthest neighbour, the median, the centroid, the mean and finally the nearest neighbour methods. Fourteen attributes of the channel and the transported material were taken into account. The taxonomy procedures were supplied with complementary, however subjective method based on the number of limits showing rapid change in characteristics describing succesive reaches of the river. The procedures resulted in four channel types identified. Their character and sequence result from the late-glacial and post-glacial history of the area, this is: the glacial erosion followed by the capture of todays upper part of the River Feshie, formation of glacial and fluvioglacial deposits being now the source of the bedload material, and finally the flushy hydrological regime of the river.

Key words: river chanels, fluvial processes, draynage basin, chanel typology.

1. Introduction

In the longitudinal profile of any river channel one can delimit different morphostatic and morphodynamic reaches. The degree of complexity of the river channel evidences its history. The more complex has been the channel evolution, the more morphodynamic reaches and their sequences can be recognized along its course.

It was widely documented, that the complexity of channel systems may result from spatial variations in the resistance of the bedrock. On the other hand one can point out the areas of almost uniform geology, and in spite of that highly differentiated and complex channel patterns. The studies on the internal complexity of river channels developed under different geologic and climatic conditions should lead to the better understanding of the role of changing environment in the river channel modelling.

The objective of this study is to identyfy different channel types within the whole channel of the mountain River Feshie in Scotland and explain its high complexity. Instead of the traditional descriptive methods of channel typology, we attempt to use for this purpose five methods of numerical taxonomy, that seem to be more objective than the traditional ones. Then the results are compared to these obtained by means of the simple method, which in detail will be explained later.

In different channel typologies (eg Mosley 1987) the whole river channels comprised types. Here we attempt to identify different channel types within a single river. The River Feshie seems to be very attractive for this purpose as its channel consists of many, highly differentiated reaches. On top of that the bedrock geology of the Glen Feshie is almost uniform, what makes the study more simple because the geological structure of the bedrock can be excluded as a factor of the channel modelling.

Some reaches of the River Feshie belong to the best examples of the braiding channels in Britain. Up to date channel studies were mainly focused on the evolution of braiding sections of this river (Werritty, Ferguson 1980; Ferguson, Werritty 1983). In this study we analyse the pattern of the whole channel of the river.

2. Research area

The River Feshie is situated in the Cairngorm Mts. of Scotland, which belong to the paleozoic system of the Grampians. The river is the right-bank tributary of the River Spey, which flows north-east to the North Sea (Fig. 1A).

The climate of the area is strongly oceanic. The annual totals of precipitation are high and air temperatures mild (Tab. 1).

Tab. 1. Main characteristics of the River Feshie and its drainage basin.

Characteristics	Value
DRAINAGE BASIN	
Area [km^2]	234.1
Maximum altitude [m asl]	1265
Minimum altitude [m asl]	218
Mean annual precipitation [mm]	
Kingussie [224 m asl]	830[1]
Cairngorm [1090 m asl]	2050[1]
Specific yield [l s^{-1} km^{-2}]	35
RIVER	
Length [km]	40.18
Mean slope [‰]	14.23
Discharge at Glenfeshie Lodge [m^{3}s^{-1}]	
mean	3.0[2]
maximum	c. 100[2]
Discharge at Feshiebridge [m^{3}s^{-1}]	
mean	8.0[3]
maximum	c. 200[3]

[1] in 1941-1970 (Mc Even 1985)
[2] in 1978-1990 (Fergusson, Werritty 1990)
[3] in 1951-1974 (Werritty, Fergusson 1980)

The bedrock geology of the drainage basin consists in 80 per cent of paleozoic metamorphic schists (Moinian schists). The rest is underlain by granite outcrops (Cairngorm granite) from the local batholits (Fig. 1B). These granites occur in marginal fragments of the basin and do not underlain the channel of the main river.

The River Feshie valley has been remodelled by Pleistocene glaciers. It cuts the high elevated Gaick Plateau (700-1000 m a.s.l.) and its north-western slope. Except the uppermost fragment which cuts the Gaick Plateau, the

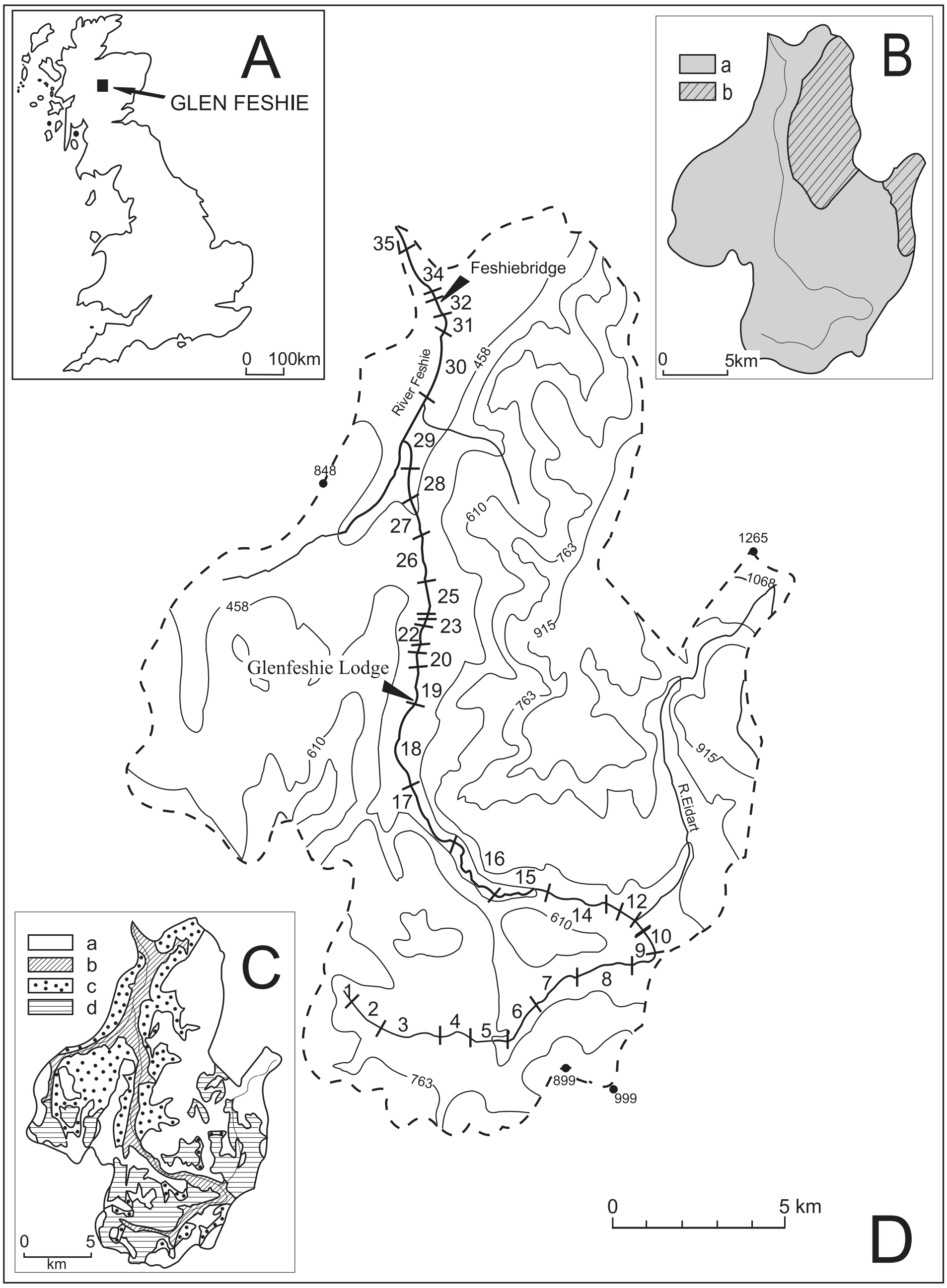

Fig. 1. Location and character of the research area. A - location of Glen Feshie; B - bedrock geology; a - granite, b - schist; C - superficial deposits: a - slope deposits, b - fluvioglacial and alluvial deposits, c - morainic deposits, d - blanket peat; D - location of reaches (1-35).

upper part of the valley is narrow and features a typical glacial trough. In the middle and the lower parts (below 400 m a.s.l.) the valley is getting wider. Its bottom is covered with alluvial deposits and flanked with morainic and fluvioglacial material which forms five, well expressed late-glacial and Holocene terraces (Young 1976). At the high elevations peat deposits dominate, and cover most of the area (Fig. 1C).

Before the late Pleistocene the upper part of today's Feshie valley belonged to the river system of Geldie. Then the low watershed between the two valleys was cut by transfluencing glacier and next by proglacial waters. As a result of this the upper part of the River Geldie was captured by the River Feshie (Linton 1949). This has caused the rapid growth of the drainage area of the River Feshie by about 30 per cent.

Glen Feshie is mostly deforested. Scots pine clusters (*Pinus silvestris*) being the remnants of the ancient Caledonian forest occupy the fragments of the valley bottom. Most of the area is covered by heath (*Calluna-Empetrum*). At the highest elevations the typical mountain meadow communities dominate.

Due to the steep valley slopes, poor bedrock permeability and well saturation of peat the infiltration of water is limited. This favours easy formation of overland flow, which results in rapid response of the river to rainfall events. Floods usually follow the intensive summer rainfalls of a convectional origin and autumn or winter ones of a frontal origin. The role of snowmelt in flood formation is minor (Werritty 1984). The lag between rainfall and flow peaks is short; thus the River Feshie is considered one of the flashiest rivers in Britain (Ferguson, Werritty 1983).

3. Method

The procedure leading to the final typology of the river channel was composed of three stages.

In the initial stage the whole channel of the River Feshie was divided into 35 reaches (Fig. 1D) according to general pattern of the channel's course and distribution of channel landforms recognizable on maps (1:25000 - Ordnance Survey) and air photos (1:10000 and 1:25000). Then this division was verified in field.

In the second stage the detailed survey of the channel and flood-plain landforms and material was made. Within each reach all the landforms were measured and put into the special form. The original method of channel surveying was described by M. Kamykowska et al. (1999) and applied for the the Polish Carpathian rivers by L. Kaszowski (1977), K. Krzemień (1981), and L. Kaszowski, K. Krzemień (1999).

However the channel reaches can be described by many different characteristics, only these attributes that could be easily measured in field or on maps, and expressed in quantitative values were taken into consideration. These were:

– Channel slope,
– Channel width,
– Flood-plain width,
– Maximum depth of channel at the banks,
– Percentage of channel's length cut in bedrock,
– Number of kettles,

– Number of bank undercuts,
– Number of steps,
– Number of bars,
– Area of bank undercuts,
– Area of bars,
– Braiding ratio; $b_r = \frac{q}{l_{ch}} 100$,
where q - number of islands and central bars,
l_{ch} - channel length,
– Sinusoity ratio; $sr = \frac{l_{ch}}{l_s}$,
l_{ch} - channel length,
l_s - length of the chord of the channel's bend,
– Maximum size (b-axis) of the transported clasts (mean of ten largest ones).

In the third stage, having the channel characteristics registered, five methods of numerical taxonomy were used to group the earlier distinguished reaches into typological units („regions" in the classical procedure of regionalization). These were:
– The furthest neighbour method,
– The median method,
– The centroid method,
– The mean method,
– The nearest neighbour method.

The first method (furthest neighbour) is the most demanding, this is the conditions that have to be be fulfilled in order to merge the two elements are the most difficult to achieve. According to it, the two different elements (reaches) merge, when the two most distant characteristics/attributes satisfy a condition of certain minimum similarity. On the other end of demand is the fifth method (nearest neighbour). In this case the two different elements merge when any two characteristics satisfying the condition of certain similarity just exist. In terms of demand the methods numbered *2* to 4 (median, centroid, mean) are somewhere between the first and the fifth one.

In the fourth stage the results were compared with these obtained by another method of reach clustering. Accordingly to that method all fourteen values of the particular characteristics were put into classes. Then, for each reach limit, the number of characteristics that change the class was calculated. We assumed, that the limits between the particular channel types should be established in these cases where the class change were most numerous. However the method is quite subjective, it is simple and easy to perform.

In the fifth stage the results were verified in field.

The taxonomy procedures were supplied with complementary, however subjective method based on the number of limits showing rapid change in characteristics describing succesive reaches of the river. The characteristics describing the river's channel were: slope, bedrock geology, channel width, channel pattern, alluvial plane width, shape of the cross-profile, number of bars, area of bars, number of undercuts, area of undercuts (last four characteristics per one kilometre), braiding ratio, maximum grain-size, mean grain-size and dominating process. All of the characteristics were put into the diagram. Taking each of the characteristics into consideration the similar reaches have formed the typological sections. Then taking all characteristics into account the number of limits between the sections was calculated. In places with the most numerous limits the borders of the types were established. Less numerous limits have shown the borders of the sub-types. In general four channel types and six channel sub-types were distinguished.

4. Channel characteristics

The River Feshie channel is highly differentiated. Its layout, long-profile, cross-profile and number and size of forms varies from place to place.

The course of the river channel within the upper part of the valley (up to the reach numbered 8) is of meandering character. This is that part of the valley, which before Pleistocene had belonged to the drainage basin of the River Geldie, and then the uppermost fragment of that river was captured by the River Feshie.

Below, up to the reach 16, the channel is of sinusoidal character. The river flows in the deep glacial trough. Further down the channel is alternatively of sinusoidal or braided character. Three sections of the river channel (reaches 17-18, 29-30 and 34-35) are typically braided ones. It has been documented that over at least two last centuries these three sections have undergone frequent changes of channel pattern. According to A. Werritty and R. I. Ferguson (1980) the lateral migration of the channel can be as large as 10 m a year, and the rate of erosion or deposition of the channel material can reach as much as 0,5 m as a result of a single flood event. In places where the river course is sinusoidal, the channel is not divided into separate branches and the rates of erosion or deposition are minor.

The long profile of the channel is irregular: concave-convex-concave (Fig. 2) and still far from the ideal profile of equilibrium. In the upper, concave part of the profile, the channel is cut in a blanket peat and sandy-gravelly fluvial and fluvioglacial deposits. Locally the channel cuts morainic deposits and the bedrock. In places the channel cuts just the blanket peat and the sandy-gravelly deposits emerging in the bottom. In the middle and lower course of the river, where the profile is convex-concave the channel cuts nlly the bedrock. There the numerous rocky steps (3-5.0 m high) occur.

The total length of the channel cut in the bedrock is 6.49 km what constitutes 16 per cent of the total length of the river. The rest of the channel is cut in fluvioglacial and alluvial deposits.

The gradient of the channel varies a lot. The slope of the steepest reaches (excluding the two uppermost ones) is as much as 0.025 in middle course, and 0.012 in the lower course of the river. The tributaries do not influence the gradient of the main river channel.

The shape of the cross-profile of any river channel results from hydrodynamic character of a river as well as characteristics of valley deposits and a bedrock. The cross-profile of the Feshie River is mostly parabolic or rectangular, scarcely trapezoidal or different from these shapes. The channel width varies extensively. In the braided sections the channel is wider than 50 m, while in the rocky ones the channel is very narrow (locally 2.5-4.0 m) and the bottom, especially below the rocky steps are overdeepen.

The bars and bank undercuts occur both in the braided and meandering sections of the river (Fig. 2). In the upper course (reaches 1-8) the number of bars and undercuts gradually lowers, and the area of these forms rises, as the river channel changes from meandering to sinusoidal type. In the braided sections, situated lower, both the number

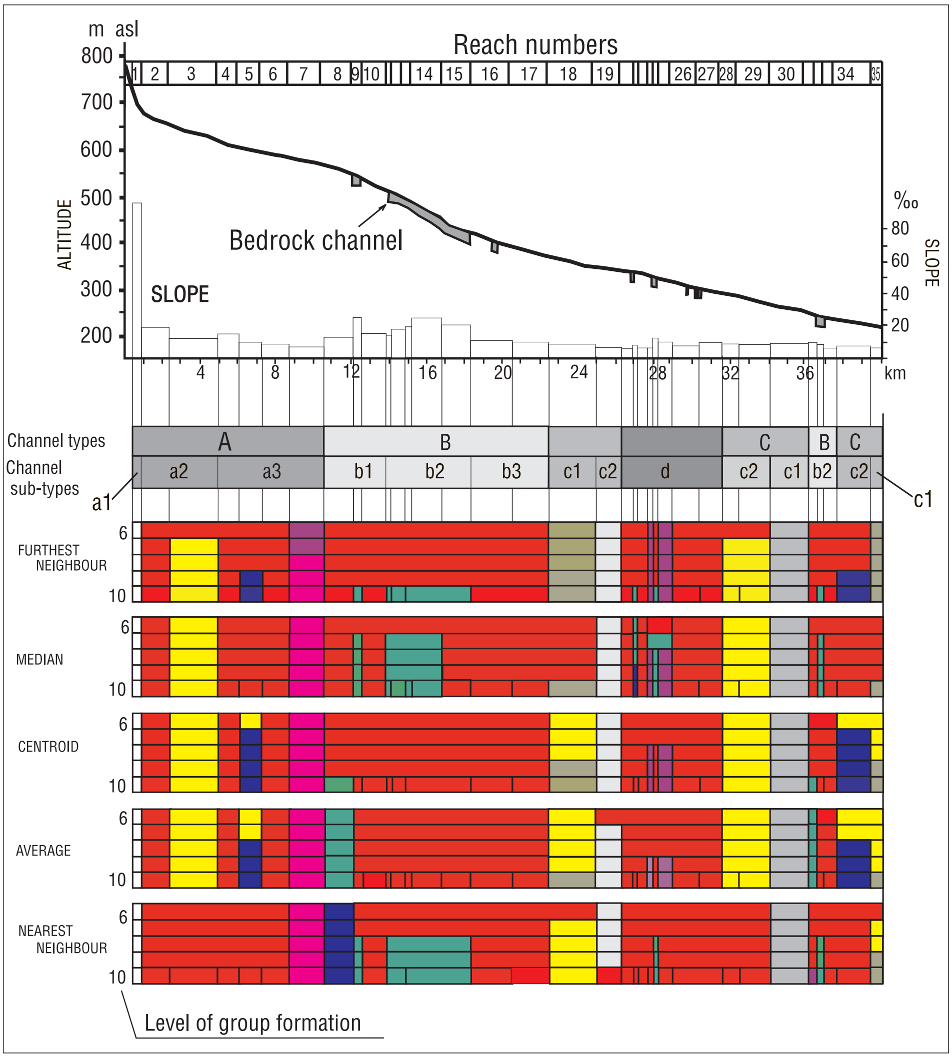

Fig. 2. The longitudinal profile of the River Feshie with the belt diagramms showing the formation of groups of reaches resulting in final channel typology.

and the area of the bars and undercuts rises in downstream direction. In the part of the rivers of mixed channel's pattern (reaches 20-28) the number and the area of individual forms rises and lowers alternatively.

There are no channel processes, that dominate along the whole course of the river; the particular fluvial processes dominate only locally and soon are replaced by other processes.

5. Channel typology

5.1. Taxonomy methods

Having 35 reaches distinguished and 14 attributes for each reach available, the taxonometric distances were calculated by means of each of the five methods listed above (see unit 3).

The dendrites (Fig. 3) show the way of cluster growth. The typological units start to emerge at the level 9-10. These units while transferred onto the long-profile of the river show the spatial distribution of the channel types (see Fig. 2). The differences in the position of type limits, that result from differences in methods applied are minor. The most contrasting results, were obtained by the use of the most liberal method, which was the method of nearest neighbour.

As the result of the typological procedure the following types of channels can be distinguished:

A. sinusoidal or meandering; cut in peat and fluvioglacial deposits;
B. straight or sinusoidal; cut in solid bedrock;
C. braided, cut in alluvial deposits;
D. sinusoidal, cut in bedrock and cover deposits, with high undercuts and vast gravel bars.

These types occur in different sequences.

The channel of type A follows the former channel of the River Geldie, captured in late Pleistocene. Within the whole channel system of the River Feshie this fragment is the most mature and most contrasting with the rest of the channel (Phot. 1.).

The channel of type B appears twice. The first fragment is a steep bedrock gorge resulted from the adjustment of the upper, captured part of the channel to the remaining, lower part. (Phot. 5.). The second fragment is also cut in the bedrock. In this case the gorge was formed in the late glacial period, when the melting water from local glacier was searching/looking for the shortest route to the River Spey, after glacier occupying of the Spey valley started to cease (Young 1976).

The channel of type C appears three times. (Phot. 2, 4, 6.). Two upper two sections are situated upstream of the zones of morainic accumulation, what is typical for the high mountain, formerly glaciated valleys. The third, lower section is developed on the alluvial fan of the River Feshie, just before it confluences with the River Spey.

The channel of type D is the most complicated. It is mostly of transportational character with typical high bank undercuts and vast gravel bars (Phot. 3.).

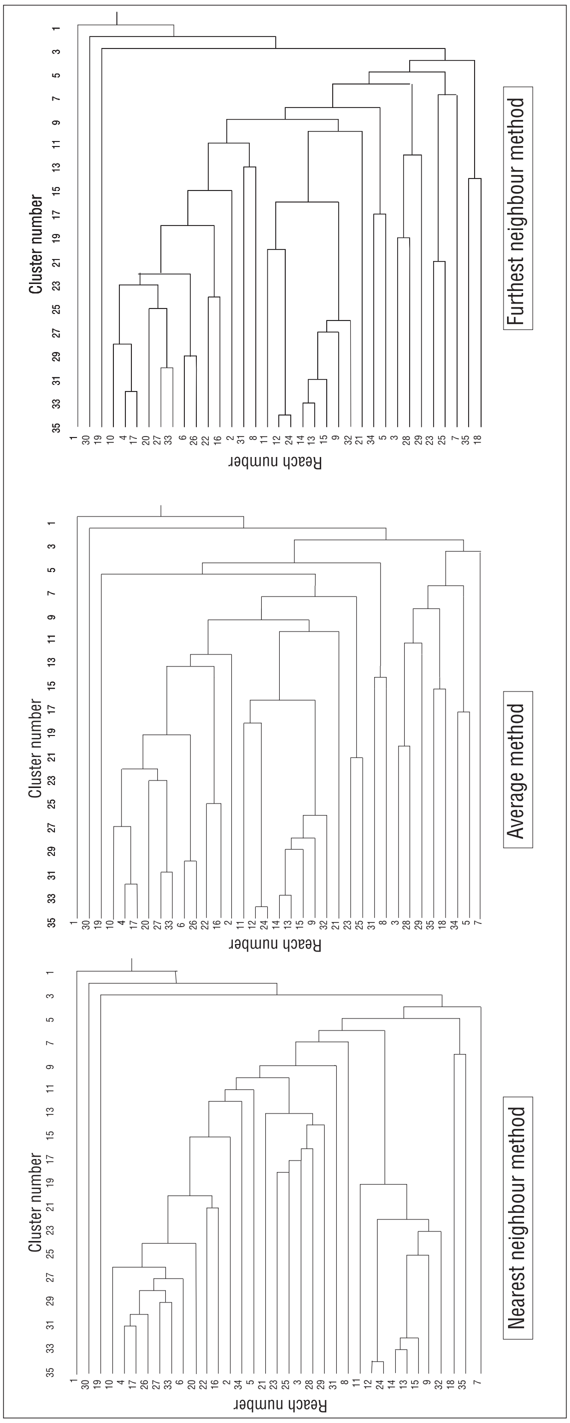

Fig. 3. Chosen dendrites showing reach clusters formation.

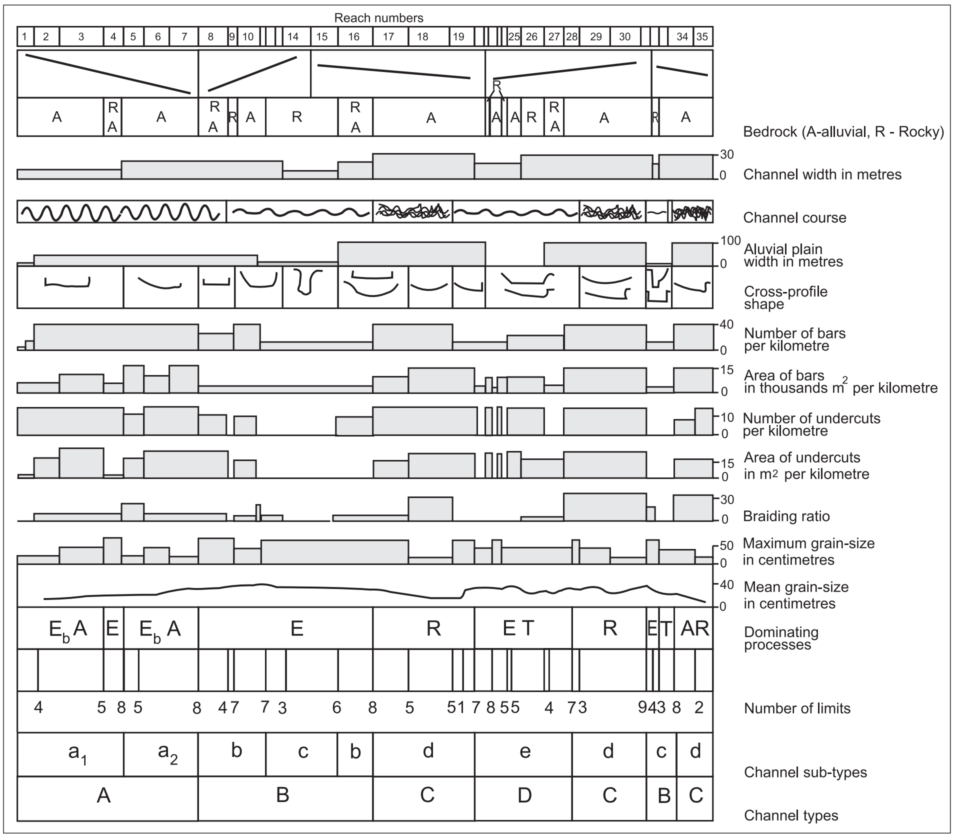

Fig. 4. Channel typology according to the method based on the number of limits showing rapid change in characteristics describing succesive reaches of the river.

On the whole the morphological structure of the River Feshie channel is quite sofisticated. The irregular shape of the channel as well as flushy regime of the river result in differentiated conditions of river transport along its course. Natural maturity of the channel shape is disturbed in many places, so that the shape of the river's long profile in different parts of its channel is being modelled in different way.

5.2. Method based on number of limits

The channel typology based on the method of limits is shown in Fig. 4. The final typology is similar to that resulted from the numerical taxonomy methods. The types are the same and the sub-types show only minor differences in length and internal differentiation.

6. Conclusions

Along the course of the River Feshie four basic channel types were distinguished. These types and their sequence reflect the complexity of the channel glacial and postglacial development. The glacial history of the area resulted in irregular long profile of the river and vast discharge of coarse morainic and fluvioglacial material from the bank undercuts. However the distinguished types of river channels occur in majority of Scottish highland rivers, their sequence varies and depend on the degree of maturity of particular channel system. In case of the River Feshie the adjustment of the channel long profile is not finished yet. The channel still adjust itself to the conditions developed in postglacial era.

The two different methods of channel typology were applied. As the second, less complicated and time consuming method, based on the analysis of the limits of the sections, gave very similar result to the more complicated method of numeraical taxonomy, the authors' suggestion for further studies is to use „limit" method rather than the numerical taxonomy.

Acknowledgements

The project was financially supported by the British Council, the Jagiellonian University and the Gibson-Sekura Trust of the University of St.Andrews, Scotland. We express our thanks to Alan Werritty for all arrangements, stimulating discussions and help while in field. We also acknowledge Mr. Dempster for the use of a private road and permission to conduct research in Glen Feshie.

References

Ferguson R.I., Werritty, A., 1983, *Bar development and channel changes in the gravelly River Feshie, Scotland*, Special Publ. of the Int. Ass. Sedim., 6.

Ferguson R.I., Werritty A., 1990, *Sedimentology and Channel Change in a Braided Gravel-bed river*, Unpubl. Report. to the Nat. Env. Council.

Kamykowska M., Kaszowski L., Krzemień K.,1999, *River-channel mapping instruction. Key to the river bed description*, Prace Geogr., 104, Inst. Geogr UJ.

Kaszowski, L., 1977, *Dynamiczna typologia koryt rzecznych w obszarze Karpat i ich przedpola*, Spraw. z pos. Kom. Nauk. PAN, Kraków, 21, 1.

Kaszowski L., Krzemień K., 1999, *River channel classification systems*, Prace Geogr., 104, Inst. Geogr UJ.

Krzemień, K., 1981, *Zmienność subsystemu korytowego Czarnego Dunajca*, Zesz. Nauk. UJ, Prace Geogr., 53.

Linton D. L., 1949, *Some Scottish river captures re-examined: I. The diversion of the upper Geldie*, Scott. Geogr. Mag., 65, 123-32.

McEven L.J., 1985, *River channel change in upland Scotland*, unpubl. PhD. thesis, St. Andrews Univ.

Mosley M.P., 1987, *The classification and characterization of rivers* [in:] K. Richards (ed.), *River channels, environment and process*, Inst. of Brit. Geogr., Special Publ. Series, Blackwell, Oxford.

Werritty A., Ferguson R.I., 1980, *Pattern changes in a Scottish braided river over 1, 30, and 200 years* [in:] R. A. Cullingford and J. Lewin (eds.), *Timescales in Geomorphology*, Wiley & Sons.

Werritty A., 1984, *Stream response to flash floods in upland Scotland* [in:] T.P. Bust and D.E. Walling (eds.), *Catchment experiments in fluvial geomorphology*, Geobooks, Norwich.

Young J.A.T., 1976, *The Terraces of Glen Feshie, Inverness-shire*, Trans. Roy. Soc. Edinburgh, 69.