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PATTERNS IN FORELAND FLUVIAL PROCESSES

Abstract: Foreland and mountain river channels differ markedly in terms of gradient, bedload composition and channel type as a result of differing geology and development processes in these two environments. To understand these differences, a comparison was made between the foreland rivers of the Northern Caucasus and the Western Ural Mountains. The foreland rivers selected represent the type of fluvial process characteristic for areas just below mountains, where the bedload is deposited and channels start branching out. The Western Ural rivers are peculiar in having developed flatland type channels while still within the mountains and meandering channels upon entering mid-mountain plains. This diversity of fluvial processes can be attributed to differences in geotectonic movements between the mountains and the foreland. Indeed, in the Caucasus, these have different directions and high amplitude, while in the Ural Mts. they are unidirectional and with small amplitude.

Key words: river pattern, river channel changes, fluvial processes.

1. Introduction

Within the relatively narrow transition zones separating mountains and flatlands all geographical and physico-geographical processes and phenomena change considerably (Baryshnikov 1992). This is particularly true about bedload transport, its dynamics and channel bed landforms. Practically all the factors affecting fluvial morphology and fluvial processes can be found within transition zones, i.e. valley lithology, past and present tectonic movements of adequate intensity and direction, soils and vegetation and to a lesser extent a changing water regimen. These influence such secondary factors as the highly diverse mountain relief giving way to flatland relief; erosion resistant sediments dominating in the mountains and being replaced by less resistant alluvial sediments in the transition zone; an increased erosion resistance of soils thanks to the density of vegetation cover (in wet zones); and a variability in discharge on a long-term and seasonal basis.

Such a diversity of external factors with an influence on the fluvial relief, which is typical for erosion channels, contributes to the transformation of the fluvial processes. Indeed, the reduction of the sediment erosion resistance leads to the replacement

of a regime of limited channel transformation by a regime of free channel migration. This is manifested by a morphological change from narrow valleys, often without a flood plain, to broad valleys with a well developed system of floodplains and terrace levels. The river gradient diminishes markedly, and so consequently does the current flow rate and bedload carrying capacity. The bedload composition also changes from boulder and gravel to gravel and sand, to sand alone.

Also the discharge regimen changes from the mountain type with turbulent current movement to the flatland type with calm water flow. These changes are accompanied by a transformation of the channel morphodynamic types and floodplain morphodynamic types, including their characteristics. These last include the rates of horizontal and vertical channel transformation, the structure and dynamics of channel accumulation features and the structure and relief of the floodplain. Incised mountain channels, which typically form under restricted conditions of channel transformation, quickly give way to landforms with broad floodplains that are typical of the zones of free development with their active horizontal channel transformations manifested in intensive bank erosion and therefore also in the rate of morphological change.

The foreland ends a succession of numerous vertical zones which are characteristic features of mountain rivers, each zone with its typical fluvial processes and morphodynamic types of channel. The reduction of valley gradient and increased quantity of water cause a change in channel type from the step-and-waterfall type to one with developed alluvial forms, corresponding to the morphodynamics of flatland rivers (Chalov 2002). These changes, reflected in the course of fluvial processes and in the channel and floodplain dynamics, are strictly linked to the local geology, rates of geotectonic movement and the orography of adjacent mountain areas (Nazarov et al. 1998). Such relationships are considered here using the examples of foreland rivers in the Northern Caucasus and in the Western Ural Mountains.

2. River channel development in the transition zone of the Northern Caucasus Mountains

In most cases the transformation of the North Caucasian rivers from the mountain type into the foreland type involves radical changes in the channel bed and water surface gradient and is accompanied by the development of accumulation landforms. Coming out of the mountains, large Northern Caucasian rivers, such as the Rivers Kuban, Urupa, Biala and Laba have gradients (7-8‰) maintaining their mountain channel type (Chalov 1979). This gradient, however, drops to just 0.6-7.0‰, i.e. a gradient typical of flatland rivers (up to 0.6‰), as soon as they enter the foreland. Such mountainous channels can reach 40 to 100 kilometres into the forelands (Figure 1A). Such a combination of a mountain river type and a foreland fluvial process in a foreland zone was also found in the case of the River Terek system (Chalov 2002).

The entry of a mountain type river into a foreland plain (or into a mid-mountain basin) is manifested by changes to its morphology, dynamics and floodplain. Immediately after entering a foreland flat the river channel changes from a mountain type with an incised channel into a broad floodplain type. (Only 2% of the valley length

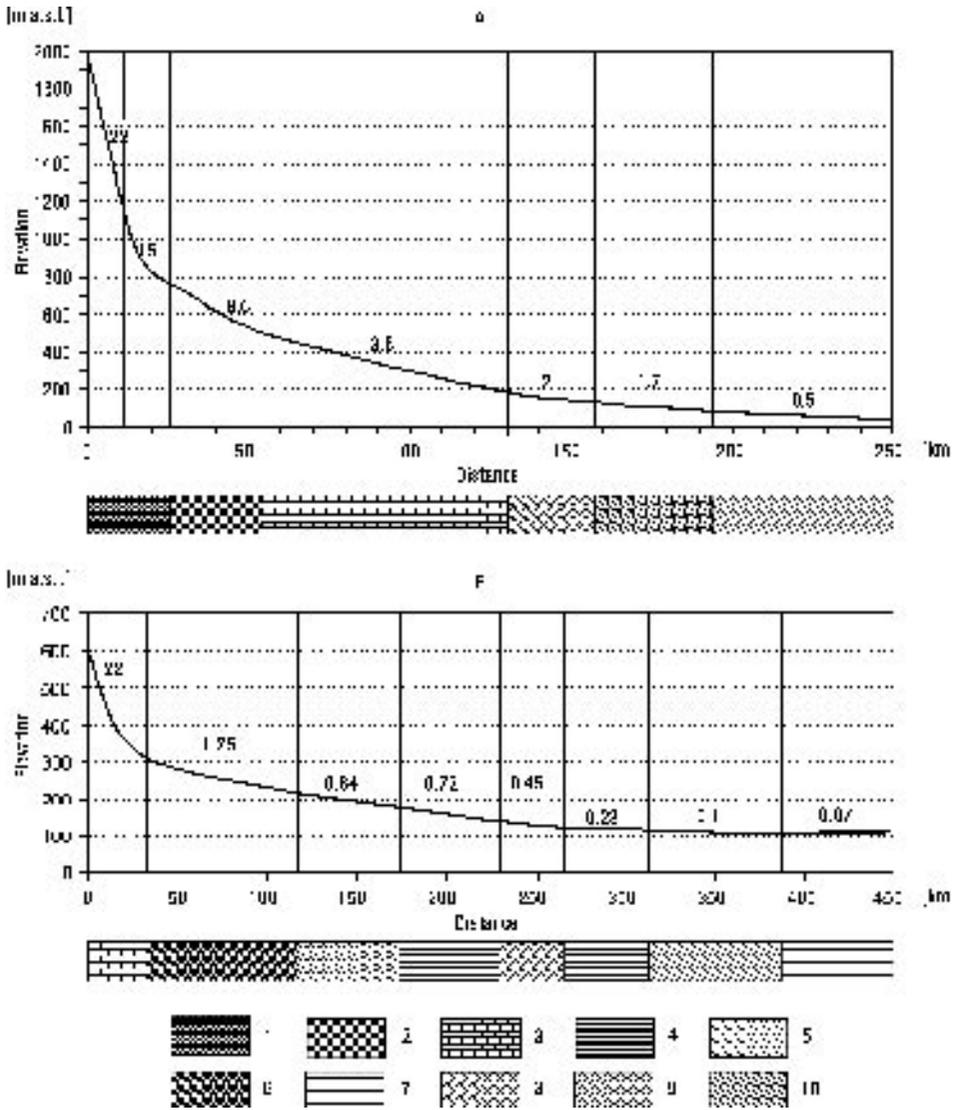


Figure 1. Typical longitudinal-profiles of transitional zone rivers in the Northern Caucasus (A) and the western slopes of the Ural Mts. (B)

Explanations: Morphodynamic channel types: 1 – with systems of thresholds, 2 – with undeveloped accumulation landforms, 3 – with developed accumulation landforms; foreland and flatland rivers: incised (erosion) channels, 4 – relatively straight-line, 5 – meandering, 6 – braided with broad floodplains, 7 – relatively straight-line, 8 – emerged meanders (emerged in the flood zone), 9 – free meander channels, 10 – forking (branches). Gaps on the channel type scale – lakes; vertical lines – morphological boundaries of uniform reaches; numbers on figures – channel reach gradients in %.

of the Northern Caucasian foreland rivers has incised channels). Most of these channels are of a braided-anastomosing character with numerous islands lined with gravel and boulder alluvia (Figure 2A). Such channels are extremely prone to erosion, as confirmed by the intensive erosion of the floodplain banks of up to 10 metres per year. Their side channels change location after every flood with some of the banks entirely washed away and new banks built up elsewhere.

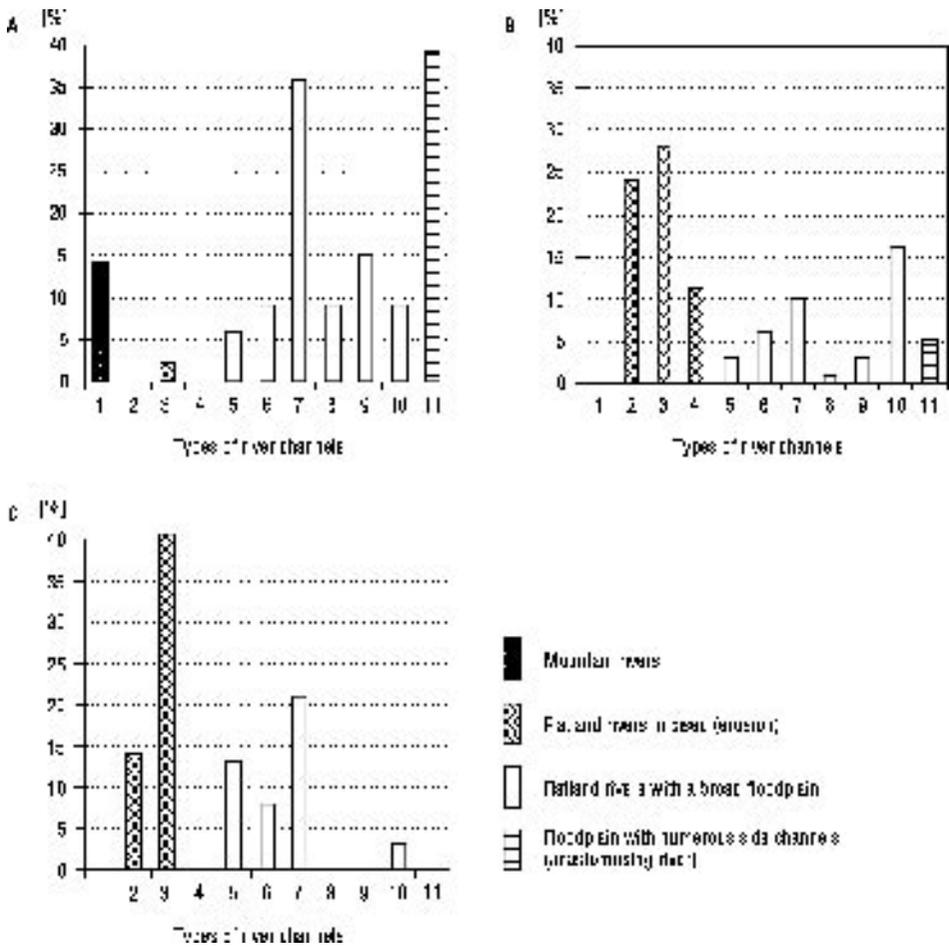


Figure 2. Distribution of morphodynamic types of medium river channels typical for the Northern Caucasus foreland (A) and the western slopes of the Northern and Central Ural Mts. (B) and western slopes of the Southern Ural Mts. (C)

Explanations: Channel types: 1 – mountain single channel; flatland incised: 2 – straight-line, 3 – meandering, 4 – accumulation branching; flatland with broad floodplain: 5 – straight-line, 6 – emerged and adapted meanders, 7 – free segmented meanders, 8 – free finger meanders, 9 – free broken meanders and branching channels, 10 – other braided; 11 – braided within a broad flood plain.

Further downstream from the mountains the channels gradually change from the braiding type into the meandering type as a result of the diminishing gradients and the replacement of mountain fluvial processes with foreland and flatland processes. However, the channels and floodplains remain prone to erosion until immediately below the transitional (foreland) zone of the North Caucasus. That is where valleys, such as that of the River Kuban, broaden and a freely meandering channel type becomes dominant. These have meanders which alternate with straight line reaches and the floodplain has a segmented structure.

Extensive bedload deposition at the foot of mountain ranges in transitional zones between mountain and flatland rivers has also been found in other river systems subject to active crustal uplifts (tectonics), such as the Western Carpathian Mts. (Krzemień 2003), Kopet-Dag (Khrisanov 1998), Tian-Shan (Borsuk et al. 1981, Kuznetsov, Chalov 1988), and the southern slopes of the eastern Great Caucasus Ridge. In this last case an increased accumulation in the foreland is often augmented by debris flows.

3. Development of river channels in the Western Ural transitional zone

The river channels of the Western Ural Mountains are completely different to those of the Northern Caucasus. The upper Ural Mts. consist of a number of parallel ranges separated by valleys running north-south. This parallel valley network changes as rivers leave the mountains and tend to break into neighbouring valleys, typically with antecedent river gaps. With this river network pattern, its prevailing steep gradients and the mountain nature of fluvial processes, the channels are deeply incised. However, as medium rivers, such as the Fishera, Yava, Ushva, Yulyuzan, Ay, Tzim and Belaya, enter the foreland their gradients drop to 1.5-0.5‰ and they quickly change their channels into the foreland or even flatland types (Figure 1B). When a river breaks through a mountain range, the gradients increase slightly along the gap reaches, but remain at a level corresponding to the type of fluvial process found in upstream rivers running between parallel ranges.

In the Western Caucasian foreland ca. 60% of the combined length of medium river channels runs through incised valleys, mostly with meandering channels but with some straight reaches. In the northern and central forelands of the Ural Mts., on the other hand, there are anastomosing rivers with floodplains of the island-and-branch type, where the floodplain consists of islands separated by side channels, and branching channels with many arms and a classically formed floodplain (Figure 2B). In these cases the branching reaches are normally no longer than 80 kilometres. In the western foreland of the southern Ural Mts. the channels with a broad floodplain tend to have a segmented pattern rather than emerged meanders connected by straight reaches. The latter only account for three percent of the total length of the medium rivers (Figure 2B). As has been mentioned above, the well developed floodplains of the Caucasus foreland rivers, dissected by side channels forming numerous islands, contrast with those of the Western Ural Mts. where they only constitute five percent of the total valley length. Also in the Ural Mountains there are some isolated cases of accumulation reaches.

Some of ponds that were constructed along the Western Ural rivers more than 200 years ago are still in use thus reducing bedload transport. This is a reason why the typical foreland river features, such as an evident reduction in the channel bed gradient, bedload

accumulation and the dominance of braided-anastomosing channels, are weak or non-existent. Instead of bedload accumulation there is downcutting accompanied by some bedload transport.

4. Causes of differences in the development of river channels in the Northern Caucasus and Western Ural Mts. forelands

The differences in the morphodynamics of the transitional (foreland) river channels in the Caucasus Mts. (also in the Carpathian, Koped-Dag and Tian-shan Mountains) on the one hand and in the Ural Mts. on the other stem from differences in the local geology and mountain development history. These manifest themselves in the differences in the course of geotectonic and structural processes. The Caucasus, Carpathian and Koped-Dag Mountains are young folded ranges of the Alpine orogenesis that are still active in terms of orogenetic uplifts. The *Map of the neotectonics of the USSR and adjacent areas* (Nikolayev et al. 1985) shows the upper parts of the Caucasus Mts. as an area of intensive crustal uplift. Indeed, the combined effect of this uplift since the Neogene period ranges from 1000 to 3000 m in various areas. Similarly, neotectonic movements are manifested in the Carpathian Mts. (the Eastern Tatras) producing an effect of exactly 1000 m and in the Koped-Dag Mts. of 3000-4000 m. These figures are confirmed by contemporary research by D.A. Lilienberg et al. (1972) in the Great Caucasian Ridge, which was found to be lifting at a rate of 10 mm per year. These movements are followed by river downcutting which is so typical in the Carpathian Mts. and Central Asian ranges (Nikonov 1973, Khakimov 1992).

The folded Tian-Shan Mts., despite their current temporary orogenetic phase, are located in an unstable continental tectonic belt which is conducive to crustal uplifts. This is confirmed by the fact that their northern part rose by 3000 m (Chatkalskiy Ridge) to 4000m (Altai Zailiyskiy) between the Neogene and the Quaternary periods.

On the other hand, the forelands of the mountain ranges in question have undergone crustal sinking. Between the Neogene and the Quaternary periods, the Caucasus Foreland was depressed by 6000 m, the Hertzian platform of the northern Koped-Dag Mts. by 1000-2000 m, the Zailiyskiy Altai foreland by 3000 m and the saddle of the northern Chatkalskiy Ridge by 600 m. Only the Podhale, separating the Alpine Tatras from the Beskidy Mountains, rose by 400-600 m, which however can be regarded as a relative crustal sinking in comparison with the dynamically lifting the Tatras.

The differing directions of the geotectonic movements, i.e. lifting in the mountains and sinking in the forelands, contributes to an intensive denudation of mountainous areas. The resulting rubble is carried away by rivers into the transitional zones and accumulates in the foreland. This is how large alluvial fans were deposited at the foot of the mountains during the Quaternary period.

Currently, braided channels develop in the forelands with floodplains acting as the site of accumulation. This process is assisted by the ongoing Alpine orogenesis contributing to the emergence of a mega anticlinorium, that so far has not been broken up into separate mountain ridges. A considerable number of rivers run through these structures along

the uplifting axis (antyclinorium), i.e. at the shortest distance between the high mountains and the foreland. This is the drainage pattern of, e.g., the northern Tian-Shan foreland.

These processes assume a different form in the Ural Mts. While the cross-platform orogenesis is also present here, it is particularly active in areas with contemporary uplifts. Between the Neogene and the Quaternary period, the upper parts of the Ural Mts. were lifted by 200-600 m, while the adjacent foreland to the west, tectonically linked to the East-European Platform, rose much more slowly, by 100-400 m, during the last 23 million years. It is due to this disparity that small rivers in the forelands of the Northern and Central Ural Mts. predominantly feature the mountain or foreland fluvial processes (Nazarov, Yegorkina 2004).

Meanwhile, the concurrent uplift of the Ural Mts., their forelands and adjacent plains is at a minor scale and has not caused any marked accumulation of river deposits. This is confirmed by a lack of evidence of rubble accumulation in the channels, i.e. a process that is typical in reaches featuring abrupt channel bed gradient reduction. The long-term tectonic uplifting of the Ural Mts. was accompanied by a matching incision along the entire length of river channel, regardless of whether in a mountain or foreland location. This has been helped by the number of the north-south running valleys along the Ural Mts. where the river gradients are reduced and the mountain fluvial processes are replaced by the foreland and flatland processes even before the rivers leave the forelands.

5. Conclusion

This analysis shows that during the last 23 million years the geological structure and tectonic movements in mountainous areas have had considerable impact on the fluvial processes of foreland rivers. This is also reflected in the bedload transport along those reaches and in the accumulation process. All of these processes must be taken into account when planning the use of the water and mineral resources of foreland rivers.

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