TRANSFORMATION OF THE CHANNEL PATTERN ON ALLUVIAL FANS – THE ČERNÁ OPAVA RIVER TRIBUTARIES, EASTERN SUDETES

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Małgorzata Wistuba: Transformation of the channel pattern on alluvial fans – The Černá Opava River tributaries, Eastern Sudetes. Geomorphologia Slovaca et Bohemica, 10, 2010, 2, 9 figs., 1 tab., 66 refs.

The comparative analysis of contemporary geomorphic maps and archival topographic maps (data from years: 1780, 1847, 1927, 1990 and 2003) shows that in the end of the 18th century channels of the Slučí, the Sokolí and the Rudná streams were sinuous and meandering, but in the turn of the 19th century they have straightened and deepened. In the period of 1780 – 1927 four cases of avulsion occurred on studied fans - channels lost their natural balance between sediment input and output. After 1927 only small changes in channel pattern occurred – streams were stabilized in a new state of slope-channel equilibrium. Described changes were caused by combination of two factors: anthropogenic deforestation and climate change during the Little Ice Age. Although, it is probable that human expansion was more important, it is not necessary for avulsion in the study area. It was proved by radiocarbon dating of the Sokolí stream channel abandonment to at least 7880 ± 120 BP (Ki-15288) – to the period devoid of human impact.

Key words: channel pattern, alluvial fan, human impact, deforestation, Little Ice Age, The Hrubý Jeseník Mts.

1 INTRODUCTION

During the last Pleistocene glaciation (Würm/Vistulian), the Hrubý Jeseník Mts. area was about 200 km away from the maximum extent of the Scandinavian ice sheet (STANKOWSKI 1996). In the periglacial environment – with a severe climate, lack of vegetation cover and with the presence of permafrost – colluvial and alluvial covers were deposited at the foot of mountain slopes. These deposits are up to 20 – 30 m thick (CZUDEK 1964 or CZUDEK 1997) and their character depends on: the substratum lithology, the local topography and the fluctuations of climate during the last glaciation (MIGOŃ and TRACZYK 1998). Among them there are alluvial fans in the valley mouths. The Holocene warming (development of forest vegetation) caused stabilisation of the covers. The reactivation of their downslope transfer was probably asso-ciated with:

a. human impact (mainly deforestation),
b. climate cooling and moistening (Little Ice Age).

The relation between influence of human and climatically induced geomorphic changes is a continuing source of debate. The problem is widely discussed for slope and fluvial environments in the Sudetes (e.g. MIGOŃ et al. 2002, KLIMEK et al. 2003b, KLIMEK and MALIK 2005, LATOCHA 2005, KLIMEK and LATOCHA 2007), in Poland (e.g. KOBOJEK 2003, KUKULAK 2004, STARKEL 2004) and in the whole Europe (e.g. BRAZIER et al. 1988, COULTHARD et al. 2002, CHIVERRELL et al. 2007, SCHNEIDER et al. 2007, DE MOOR et al. 2008, MACKLIN and LEWIN 2008).

The lowest sections of the Slučí, the Sokolí and the Rudná streams, studied in this paper, are cutting into the surface of Pleistocene alluvial fans. The main aim of presented study was:

a. to discover the direction of channel pattern transformation on the surface of fans, in the last 250 years
b. to identify factors probably responsible for channel shifting.

The human and climate impact on small alluvial fans and stream channel pattern was a subject of previous studies (e.g. WERRITTY and HARVEY 1997, DOTTERWEICH 2008 or ZYGMUNT 2009). Results from those researches often lead to conclusions:

a. that it is the human impact, which is crucial for relief transformation during the last centuries, or at least,

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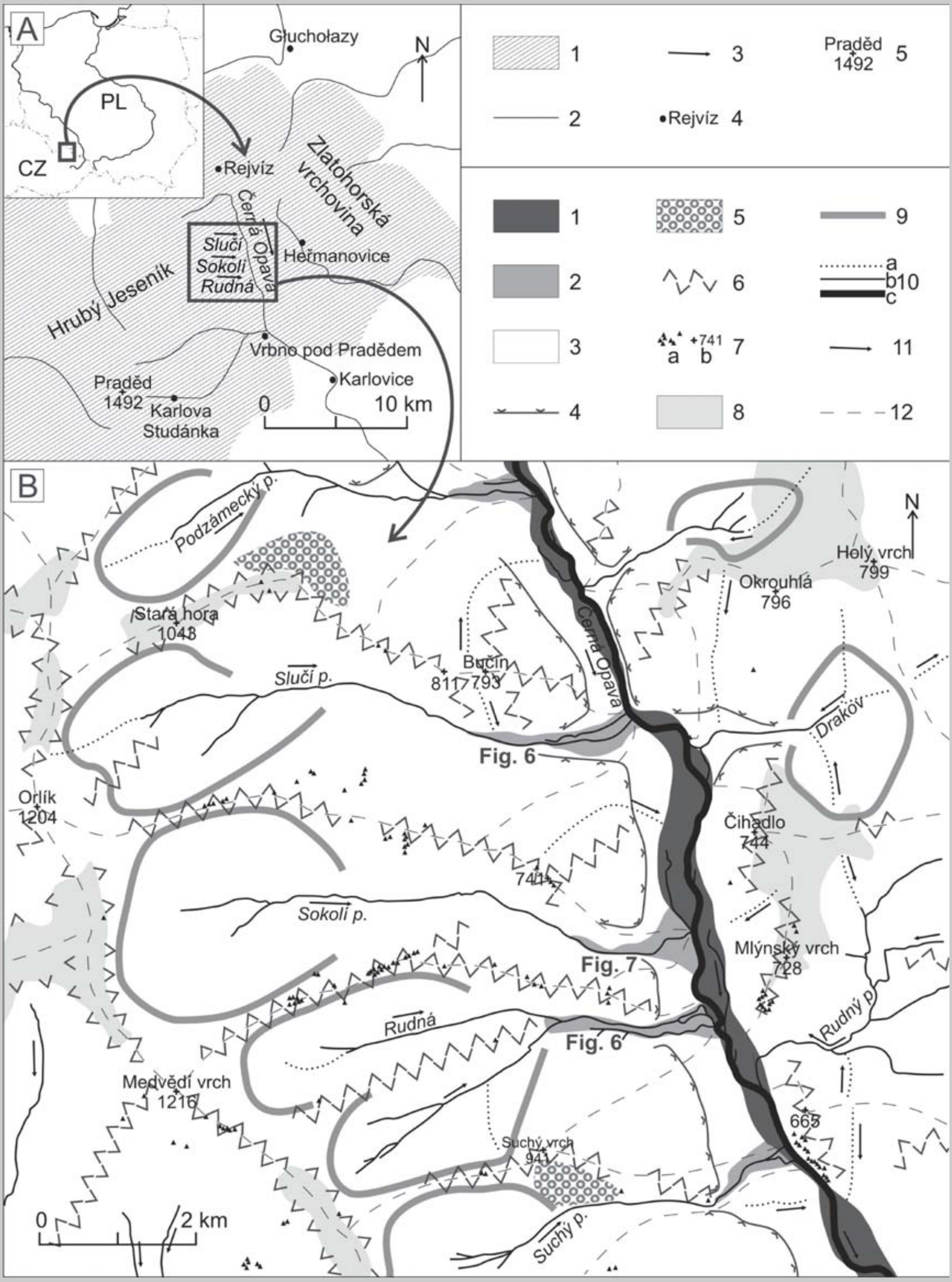

Fig. 1 – Location of the study area: the Černá Opava River and its tributaries: the Slučí, the Sokolí and the Rudná streams; B – Catchments of the Slučí, the Sokolí and the Rudná streams – a geomorphic sketch (based on: Základní mapa ČR 2004) with the location of Figures 6 and 7;

legend A: CZ – Czech Republic, PL – Poland, 1 – mid-mountain massifs of Eastern Sudetes, 2 – rivers, 3 – flow directions, 4 – towns and villages, 5 – mountain peaks (m a. s. l.);

legend B: 1 – the Černá Opava River valley floor, 2 – alluvial fans, 3 – slopes, 4 – major breaks of slopes, 5 – screes, 6 – mountain ridges, 7: a – rocks, b – mountain peaks (m a. s. l), 8 – flattened mountain ridges, 9 – valley heads, 10 – drainage lines: a – dry, b – streams, c –

b. that human and climate impacts are of equal importance and that they strengthened each other.

Some papers focus only on direct and indirect human impact on small mountain catchments and valleys (KOBOJEK 2003, KLIMEK and LATOCHA 2007 or LATOCHA 2009). There are very few studies which attribute most of recent relief transformation to the impact of climate changes.

2 STUDY AREA

The right-bank tributaries of the Černá Opava River, the Slučí, the Sokolí and the Rudná streams drain the eastern slopes of the Orlík massif (the Hrubý Jeseník Mts., Eastern Sudetes – **Fig. 1**). The highest peaks of the area are Medvědí Vrch (1216 m a. s. l.) and Orlík (1203 m a. s. l.). The most important characteristics of streams and their catchments are summarized in **Tab. 1**.

Catchments of small streams, like those studied, have small areas, so some factors important for the fluvial processes development (rainfall magnitude and duration, snow cover thickness and time of thaw) are identical over the entire area. Catchments of analysed streams have quite similar morphometric parameters. They are located in the mid-mountain area almost completely covered with spruce forest (uniform character of the vegetation cover). As a result, flood range and duration are also similar.

Geologically catchments of analysed streams belong to the Orlík and Vrbno units (part of the Eastern Sudetes Complex) – composed of Lower Devonian to Upper Proterozoic rocks (STUPNICKA 1989): blastomylonites, metagranites, quartzites, and phyllites (OTAVA et al. 1992, OPLETAL et al. 1998).

At the foot of the Orlík massif there are thick (up to 12 – 15 m) colluvial and alluvial covers. They are probably of Vistulian/Würm age. As in other parts of the Sudetes, older deposits were removed or integrated into younger covers (TRACZYK 2001). The studied fans are a part of those covers (**Fig. 1B**). They are small (area of 0.093 – 0.133 km^2) and steep (gradients over 100 ‰). Each of them is now dissected by (from one to three) active channels. On all fans there are also abandoned, dry channels clearly visible in the morphology (**Fig. 2, Fig. 3, Fig. 6** and **Fig. 7**).

The study area belongs to the temperate climatic zone with annual precipitation reaching 1500 mm. Intensive rainfalls of 220 mm per 24 hours or 260-300 mm per 5 – 12 hours are typical for the area. Such cases were observed during extreme floods (GÁBA and GÁBA 1997, ŠTEKL et al. 2001). In analysed catchments and streams there is no hydrological or meteorological gauging station. Below presented data come from the closest available locations. In Heřmanovice (village located 4 km north-east from the study area – **Fig. 1A**), average precipitation from the period 1961 – 2000 is 921.1 mm per year, and in Rejvíz (5 km north – **Fig. 1A**): 1025 mm per year (data: Český hydrometeorologický ústav, pobočka Ostrava). The greatest measured precipitation and water discharges in the study area and its surroundings occurred on:

a. 27 July – 3 August 1897: rainfall of 183 mm/1 day (GÁBA and GÁBA 1997),
b. 9 September 1903 : rainfall of 221 mm/1 day (GÁBA and GÁBA 1997),
c. August 1977: precipitation of 408 mm/month (Heřmanovice), 482.3 mm/month (Rejvíz), and discharges of max 76.1 m^3/s (Opava in Karlovice, 10 km downstream from the study area – **Fig. 1A**; data: Český hydrometeorologický ústav, pobočka Ostrava),
d. 5 – 8 July 1977: precipitation of 602.2 mm/month (Heřmanovice), 722.1 mm/month, 477 mm/4 days, 214 mm/1 day (Rejvíz), discharges of max 320 m^3/s (Karlovice; data: Český hydrometeorologický ústav, pobočka Ostrava),
e. 6 – 7 September 2007: precipitation of 304.2 mm/month (Heřmanovice), discharges of max 76.6 m^3/s (Karlovice; data: Český hydrometeorologický ústav, pobočka Ostrava).

morphometric parameters	Slučí	Sokolí	Rudná
catchment area (km^2)	4.3	4.1	3.6
avg. catchment width (km)	1.0	0.9	1.1
catchment relative altitude (m)	573.6	616.2	624.2
avg. catchment slope (‰)	275.9	305.2	330.5
stream length (km)	3.5	3.7	2.9
stream relative altitude (m)	388	406	384
avg. stream slope (‰)	109.6	108.9	133.1

Tab. 1 Morphometric parameters of the Slučí, the Sokolí and the Rudná streams and their catchments (author's calculation based on: Základní mapa ČR 2005)

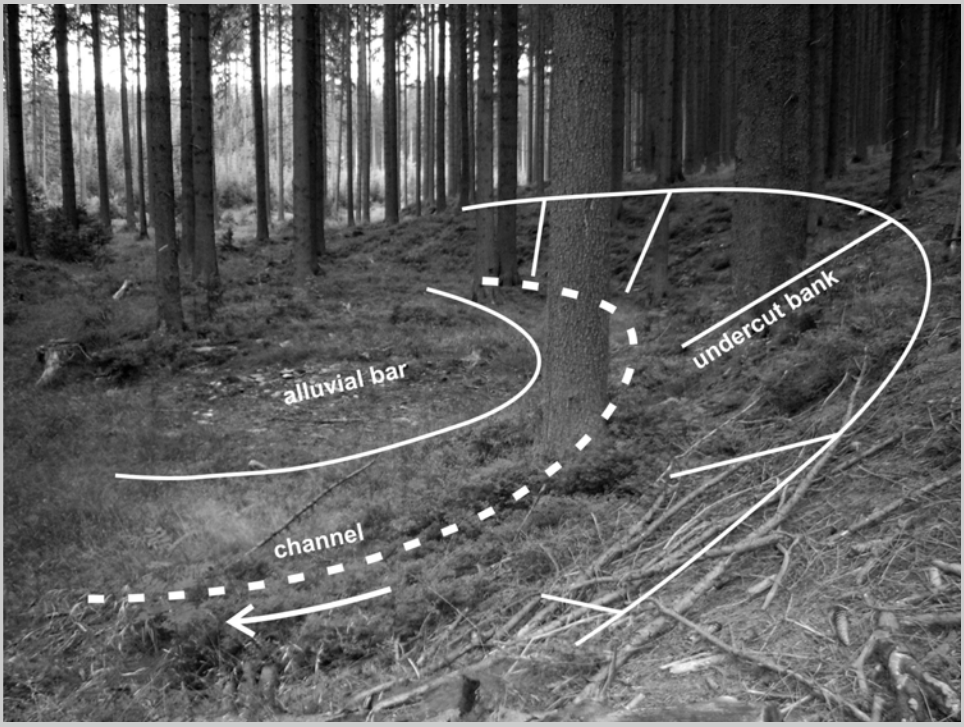

Fig. 2 Sinuous, semicircular undercut at the edge of the Slučí stream fan – remain of the former, meandering stream channel, probably active before the beginning of the 19th century (phot. by M. WISTUBA 2007)

location: see Fig. 6.

3 METHODOLOGY

The main study methods were geomorphic mapping and analysis of the archival maps. Comparison of historical maps with results of the geomorphic mapping was employed to reconstruct transformation of the channel pattern. The auxiliary method has been used for construction of longitudinal and cross profiles based on GPS survey. Also the result of radiocarbon dating of peat from abandoned Sokolí channel (WISTUBA 2009) was involved into discussion. The peat was taken from the depth of 107 – 108 cm, from the border of organic and mineral deposits. The peat is underlain by grey, horizontally laminated silts – probably of lacustrine origin (WISTUBA 2009).

About 1000 m long sections of the valley floors were mapped and selected profiles were measured with GPS. Undercut banks, channels (active and dry, main and abandoned), alluvial bars, debris flow lobes, boggy areas and artificial elements (roads, bridges, bridgeheads and dams) were considered during the field studies. The mapping and GPS survey took place in July 2007. Generalised results of the field studies are presented on **Fig. 6** and **7**.

Archival and contemporary maps used in the study were:

a. I. Rakouské vojenské mapování (1780), Josefské, 1:28 800, military map
b. II. Rakouské vojenské mapování (1847), Františkovo, 1:28 800, military map
c. Topographic map of the Czechoslovakia (1934), 1:75 000, state from year 1927,
d. Základní mapa ČR (2001), 1:25 000, state from year 1990, topographic map
e. Základní mapa ČR (2004), 1:10 000, state from year 2003, topographic map.

Fragments of listed archival maps with studied sections of streams are presented on **Fig. 5**.

There are some objections about using archival maps in general, and studied maps particularly. Disadvantages of the oldest ones are different methods of creation and different scales (LATOCHA 2006). Because of spatial inaccuracies of historical maps, some analyses focus only on the number of channels and location of outlets (SCHULTE et al. 2009). In case of older maps used (in studied case 1780 and 1847) accurate dates of field mapping are unknown, so channel dating based on them is approximate.

Despite disadvantages archival maps of different scales are considered as valuable sources of information (DEMEK et al. 2006) and are

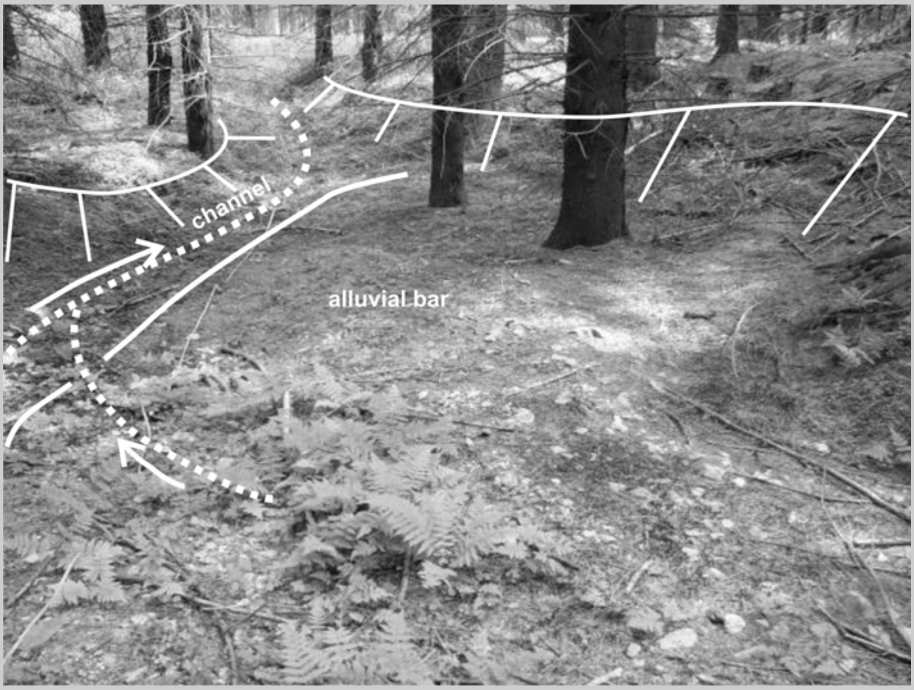

Fig. 3 Abandoned, braided channel of the Sokolí stream, probably active before the half of the 19th century (phot. by M. WISTUBA 2007)

location: see Fig. 7

the base of many environmental analyses. Research often include the last 100 – 150 years, only sometimes longer periods. Subjects of research are usually land use changes (DEMEK et al. 2006), forest area changes (WARCHOLIK 2006), changes of water reservoirs area (KLIMEK et al. 2003a), changes in settlement systems (PIETRZAK 2003) and in communication paths (WAŁDYKOWSKI 2006). In fluvial geomorphology archival maps are fre-

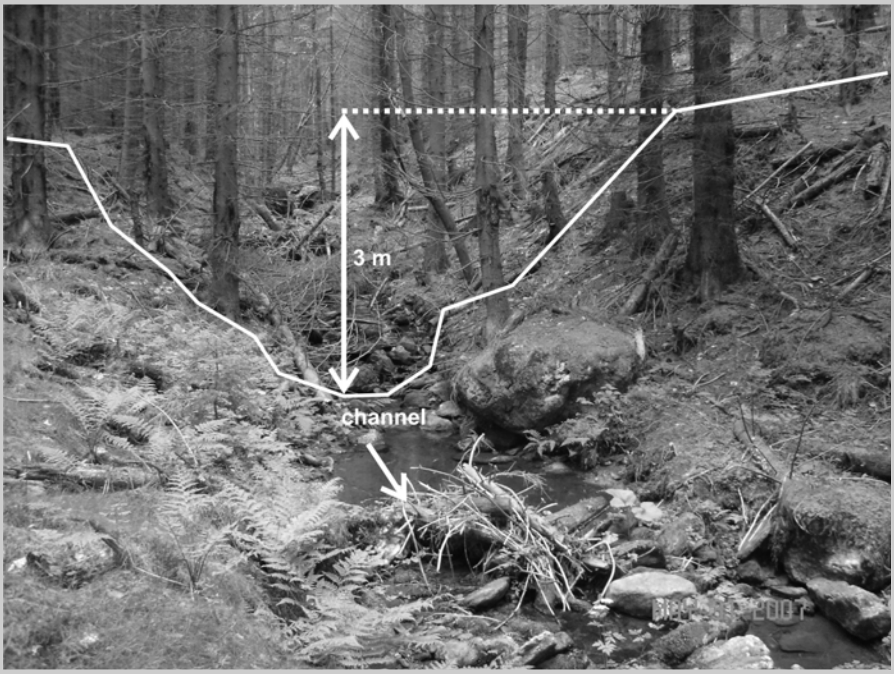

Fig. 4 Incised channel of the Rudná stream in the lowermost part of the fan (phot. by M. WISTUBA 2007)

location: see Fig. 6.

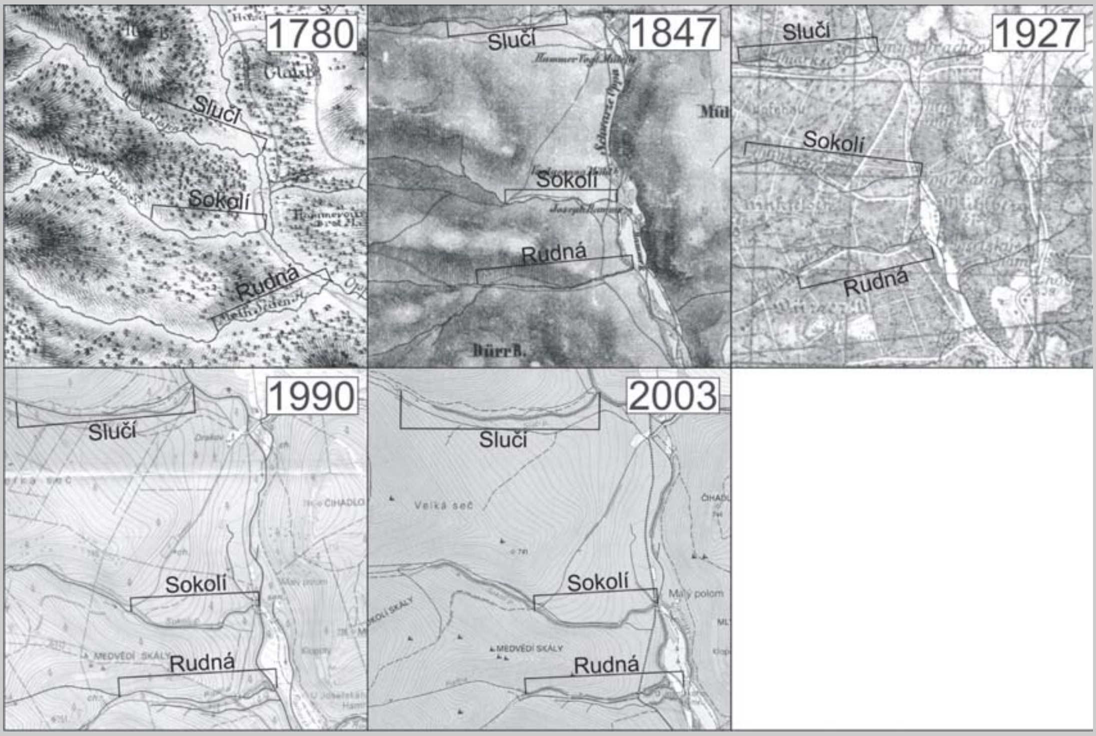

Fig. 5 Fragments of the archival maps with studied sections of the Slučí, the Sokolí and the Rudná streams (I. Rakouské vojenské mapování 1780, II. Rakouské vojenské mapování 1847, Topographic map of the Czechoslovakia 1934, Základní mapa ČR 2001, Základní mapa ČR 2004)

quently used for comparative analysis of channel pattern of medium and large rivers, usually meandering (HIGGS 1997, MCEWEN 1997, WERRITTY and MCEWEN 1997, FAJER 2003, KOCIUBA 2003, PLIT 2004, WOSKOWICZ-ŚLĘZAK 2005 or PIŠÚT 2007). Archival maps are also useful in analysis of river regulation (KOCIUBA and SUPERSON 2003, CISZEWSKI and DUBICKI 2008 or KISS et al. 2008). In the case of small rivers and streams – because of their size – using archival maps to analyse channel pattern is more difficult.

In studied case, small size of streams and poor accuracy of the oldest maps, do not allow to compare archival maps directly. Conclusions based on collected archival materials had to be limited and supported by field observations. Interpretations of channel pattern transformation should be treated carefully, as a model, which needs further research and improvements.

The base, for field identification of channels marked on archival maps, was their spatial relation with existing forest roads and bridges. The location of many trails did not change since 18th century. Some of the bridges were damaged, but their remains (abutments) still exist. The morphology of main and abandoned channels was also important. Channels vary in depth, width, sinuosity and complexity of relief. Sinuosity was the most helpful feature in comparing field observations with archival maps. On the base of GPS cross-profiles (**Fig. 7**), it was also assumed that channels with more complicated morphology are older. They are wide; they have systems of sinuous, semicircular undercuts (**Fig. 2**) and terraces (of different height – which proves their diverse age). Younger have simpler morphology – they are incised, straight and narrow. They usually have V-shaped cross-sections (**Fig. 4**) with maximum one, narrow terrace and no semicircular undercuts. Younger channels have not dissected the outcrops of solid bedrock yet. Bottoms of channels abandoned lately have fresh morphology: there are bars and boulder steps clearly visible. Channels abandoned long ago are filled with mineral and organic deposits.

4 RESULTS

4.1 MILITARY MAP: I. RAKOUSKÉ VOJENSKÉ MAPOVÁNÍ – ABOUT 1780

On the map from 1780 (**Fig. 5**) the sinuosity of the Černá Opava River, the Slučí, the Sokolí and the Rudná streams was generally high and

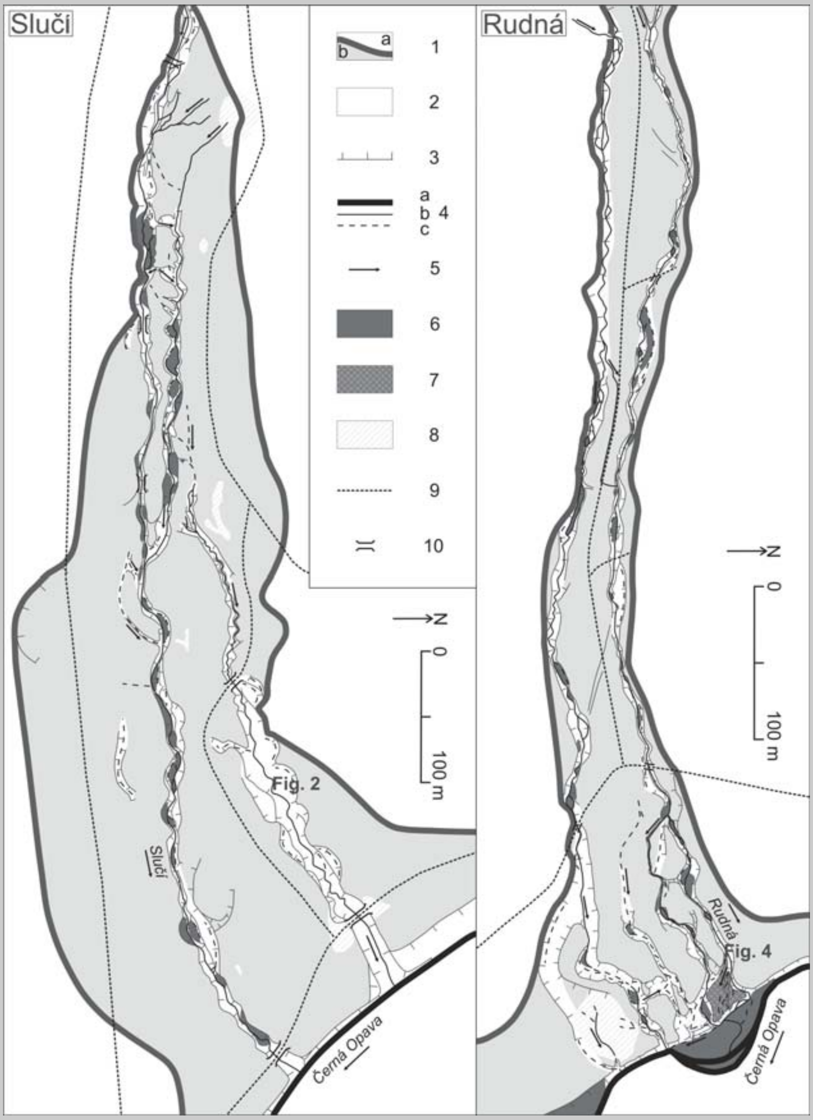

Fig. 6 Contemporary morphology of the Slučí and the Rudná streams alluvial fans (based on geomorphic mapping) with the location of Figures 2 and 4;

legend: 1 – borderlines between: a – slopes and b – alluvial fans with: 2 – zones of fluvial activity, 3 – bank undercuts, 4: a – the Černá Opava River channel, b – active (main and abandoned) stream channels, c – dry (abandoned) stream channels, 5 – flow directions, 6 – alluvial bars, 7 – debris flow lobes, 8 – peat hollows, 9 – roads, 10 – existing and damaged bridges

increased in their lowermost reaches. Locally channels could have been meandering. The streams had single main channels and single outlets to the Černá Opava River.

4.2 MILITARY MAP: II. RAKOUSKÉ VOJENSKÉ MAPOVÁNÍ – ABOUT 1847

On the map from 1847 (**Fig. 5**) the channel pattern was different than in 1780. The sinuosity was smaller. Streams still had single outlets. In its lower reaches the Slučí stream was divided into two channels, which were joined again just above the outlet.

4.3 TOPOGRAPHIC MAP OF CZECHOSLOVAKIA – 1927

In 1927 (**Fig. 5**) the Černá Opava River and studied streams had poor sinuosity. On the Slučí stream fan there was one channel, which was divided and joined again two times: in the

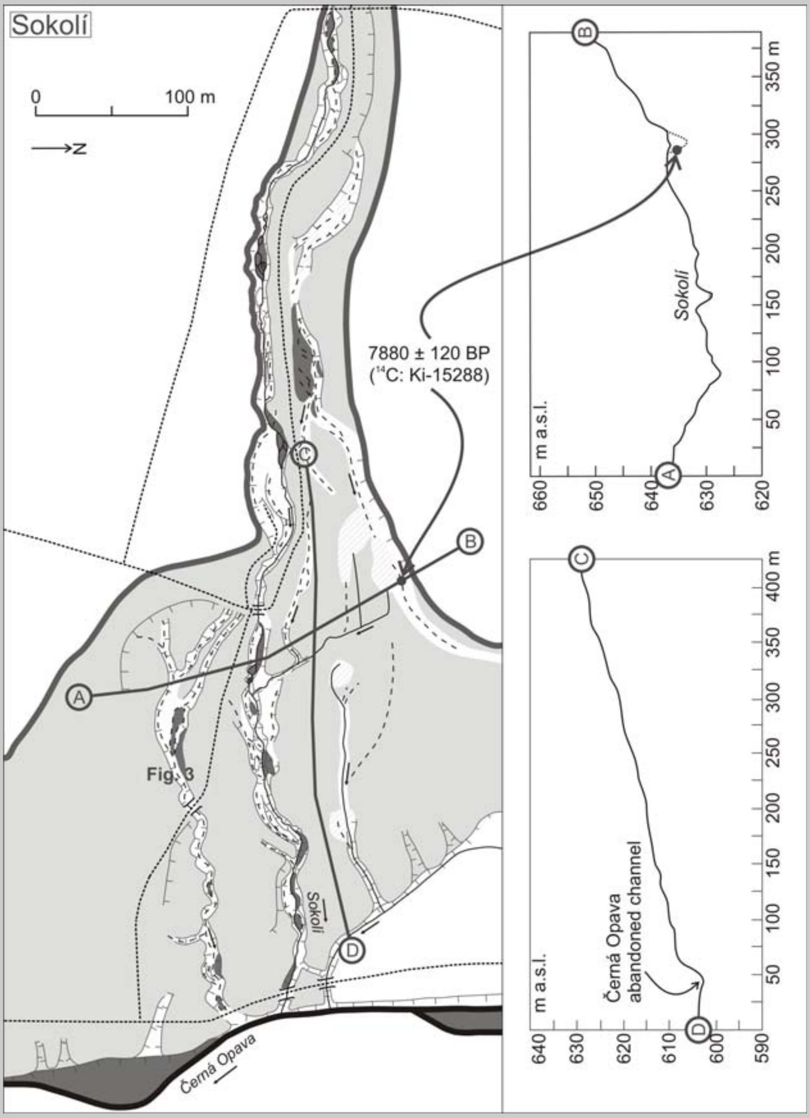

Fig. 7 Contemporary morphology, longitudinal and cross sections of the Sokolí stream alluvial fan (based on geomorphic mapping and GPS survey) with the location of Figure 3 and radiocarbon dating site (WISTUBA 2009)

legend: see Fig. 6

upper and lower part of the fan. The pattern of the Sokolí stream channel was the same as in 1847. In 1927 in the lowermost reaches of the Rudná stream, the channel was divided into two branches. Each branch had individual outlet to the Černá Opava River.

4.4 TOPOGRAPHIC MAP: ZÁKLADNÍ MAPA ČR – 1990

In 1990 (**Fig. 5**) the channel pattern on the Slučí, the Sokolí and the Rudná streams fans was very similar to contemporary. Streams had a poor sinuosity. On the Slučí stream fan there were two unconnected channels with separate outflows: main channel (right) and abandoned channel (left). The single channel of the Sokolí stream had new course. The Rudná stream had two separate channels with individual outflows: abandoned channel (right) and main channel (left). The main channel was divided and joined again just above the outlet. The abandoned channel had its own, separate outlet.

4.5 TOPOGRAPHIC MAP: ZÁKLADNÍ MAPA ČR – 2003

The only change which occurred between years 1990 and 2003 (**Fig. 5**) took place in the

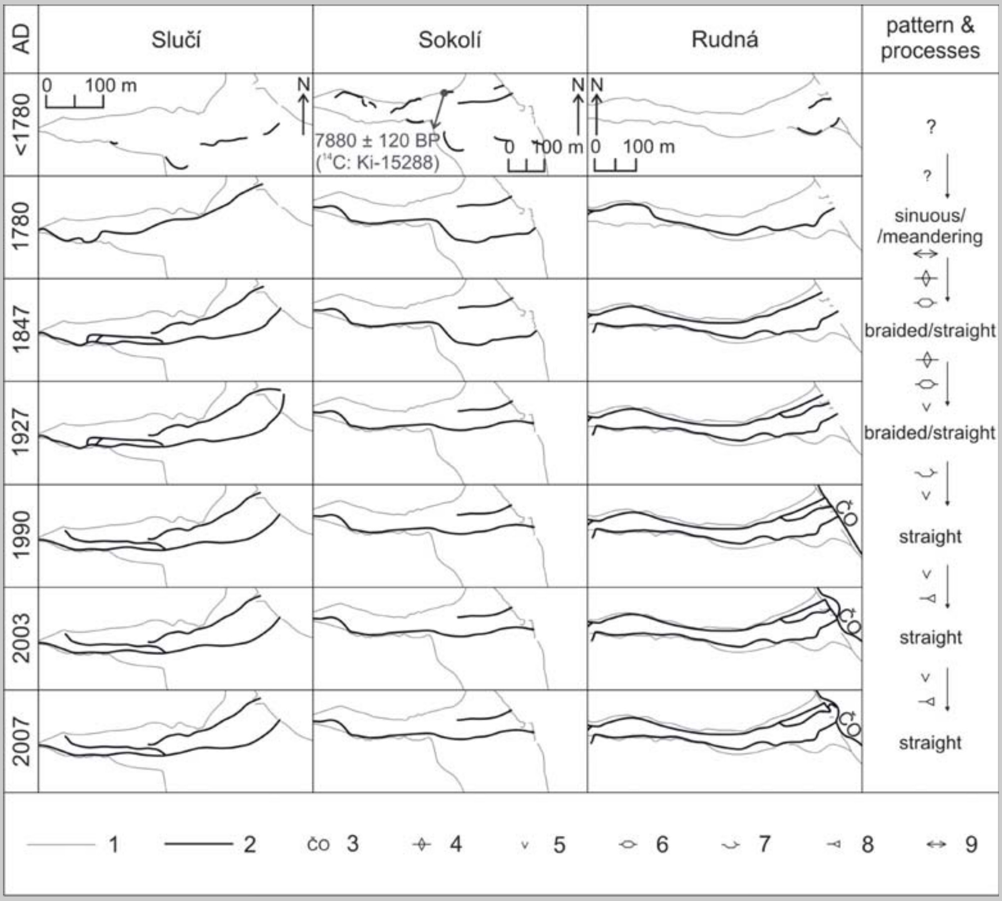

Fig. 8 Channel course changes of studied streams (columns: „Slučí", „Sokolí", „ Rudná") with the location of the radiocarbon dating site (WISTUBA 2009) and generalized channel pattern transformation (column: „pattern and processes") on the studied alluvial fans between 1780 and 2007;

legend „Slučí", „Sokolí", „Rudná": 1 – contemporary fan borderlines, 2 – active channels, 3 – the Černá Opava River channel;

legend „pattern and processes": 4 – avulsion, 5 – incision, 6 – channel branching, 7 – channel abandoning, 8 – changes of mouth location, 9 – channel straightening

Rudná stream mouth, where the Černá Opava River channel shifted and migrated towards east (a point bar was formed on the right bank of the river). The outlet of the Rudná stream main channel has moved as well. Both channels of the stream: active and abandoned had joint outflow.

4.6 Geomorphic mapping – 2007

Between years 2003 (**Fig. 5**) and 2007 (**Fig. 6** and **Fig. 7**) channel pattern and activity on the Slučí and the Sokolí streams fans did not change. In this period the outlet of Rudná stream moved. In the lowermost reaches, the main channel (joint two branches) has been cut into the point bar of the Černá Opava River. The former course (parallel to the edge of the Rudná stream fan) was dry. The outlet of the abandoned channel did not move and was separated from main channel outlet.

5 DISCUSSION

On the base of conducted research some similarities were noticed in the transformation of channel patterns on all studied fans:

a. before the end of the 18th century (before 1780) – there were some channels abandoned on all fans, one of them, on the Sokolí stream fan, before 7880 ± 120 BP (^{14}C: Ki-15288 – WISTUBA 2009),
b. the end of the 18th century (about 1780) – channels were sinuous, locally meandering,
c. the turn and the first half of the 19th century (1780 – 1847) – channels straightened, si-

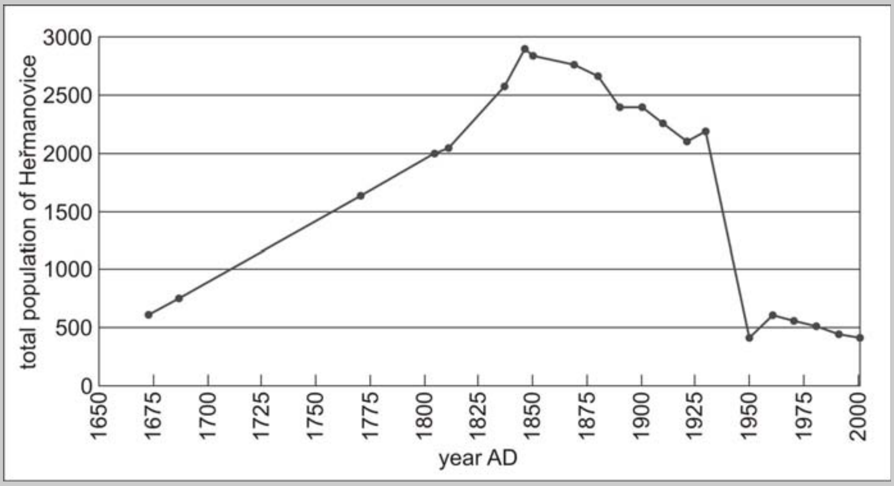

Fig. 9 Population changes in Heřmanovice – settlement near to the study area – in the last 350 years (location: see Fig. 1A; data after: ZEMAN 2001)

nuous undercuts were abandoned, the Slučí and the Rudná streams changed courses (pro-bably by avulsion),

d. the second half of the 19th and first decades of the 20th century (1847 – 1927) – the Slučí stream partially abandoned its left branch channel (according to results of dendrochronological studies: channel is inactive since at least 1880 – KLIMEK and ZIELIŃSKA 2006), the Sokolí and the Rudná streams changed courses (probably by avulsion), the Rudná stream channel divided into two branches,
e. 1927 – 1990 – the Slučí stream abandoned its left branch channel, changes occurred in the mouths of the Slučí and the Rudná streams,
f. 1990 – 2003 – 2007 – changes occurred in the mouth of the Rudná stream.

Considering mentioned trends a model of channel pattern transformation was constructed for the study area (**Fig. 8**).

The reasons for abandonment of stream channels (avulsion) in the period before human expansion (when catchments were completely forested) could have been:

a. extreme floods connected with climate fluctuations,
b. geomorphic factors, like creation of large woody debris dams in channels.

For the period between 8 ka BP and 1780 AD there is no evidence allowing to reconstruct channel pattern on studied fans. It can only be stated that susceptibility for avulsion decreased with incision and deepening of channels. On the longitudinal profile (**Fig. 7**) there can be seen that lower edge of the Sokolí stream fan is undercut by the Černá Opava River – local erosion base. While the river moved westward, the Sokolí stream shortened, which caused incision of stream channels. On the cross profile (**Fig. 7**) it is clear that contemporary active channel is much deeper than channel abandoned ~8 ka BP.

The sinuosity of streams in 1780 was an effect of balance between sediment input and output in the fluvial systems. The balance in catchments and channels developed under the cover of primeval forests – probably beech communities. Sinuosity and local meandering were an effect of the long relief evolution in the Holocene, in the natural environment, almost devoid of human impact. The sediment input to streams was probably limited to few bank undercuts. The discharges of the streams were balanced – because of big absorption capacity of catchments (with uniform deciduous forest cover). According to LATOCHA (2005) it was the period of week geomorphic connections between slopes and channels.

The most distinct sinuosity of the Slučí stream channel was probably an effect of the presence of quartzite vein on the edge of fan. The whole alluvial fan was supported by this outcrop. It still prevents fan from being dissected and maintains the low gradient of the surface.

Since the 16th century, an intensive logging was carried out in study area. First regulations for forest preservation in Heřmanovice – the nearest settlement – date back to 1588 (ZEMAN 2001). In the end of the 18th and in the first half of the 19th century population in the study area grew (**Fig. 9**) and, as a consequence, human exploitation intensified. In 1780 forests in the area of Vrbno and Heřmanovice were marked out as forests in a strategic protected zone, where logging was banned. Despite that from 1753 till the end of the 18th century their area was reduced almost by one fourth (ZEMAN 2001). Slopes clearance was caused by the need for timber:

a. to construct iron-ore mines on Holý vrch and Mlýnský vrch (**Fig. 1B**), iron and saw mills in the Černá Opava River valley,

b. to produce charcoal for blast furnaces, smithies in the Černá Opava River valley,

c. to produce wooden ash for flax bleaching (ZEMAN 2001).

It is often claimed that forest clearance changes water, nutrient and non-organic material fluxes in catchments (DOTTERWEICH 2008) and that it restores intense slope-channel coupling (LATOCHA 2005). In consequence of clearance anthropogenically driven systems, very vulnerable to catastrophic soil erosion with greatly accelerated processes, are created (DOTTERWEICH 2008).

Small catchments – like those studied – are considered especially sensitive to land-use changes in a high spatial scale, because of their low buffer capacity (DOTTERWEICH 2008). In studied case, deforestation exposed colluvial covers to the impact of rain water and surface wash. Forest clearance also changed water circulation: infiltration decreased and more water took part in surface wash. Extreme floods occurred more frequently. In consequence sediment supply to streams (from slopes and undercut banks) increased. All together – extreme floods and increased sediment supply – they forced incision of channels and their gradual transformation from sinuous to braided/straight pattern.

In the other part of Eastern Sudetes LATOCHA (2009) observed analogous situation. It led to conclusion that large scale land-use (and so vegetation) changes cause change in water and sediment delivery to streams and change in river-channel morphology. Intense erosion effects, resulting from deforestation, were observed by KLIMEK and MALIK (2005) in the Drakov headwater, near the study area (**Fig. 1B**). According to MIGOŃ et al. (2002), such great erosion and sediment transport, as observed in Sudetes in the last 200 years, do not occur on forested slopes.

Similar processes developed in the last 250 years, in Scotland, where the vegetation cover was removed by fires and pasturage. BRAZIER et al. (1988) noticed that many of Scottish alluvial fans were dissected, reworked and redeposited in consequence of anthropogenic disturbance of the vegetation cover. In England, in the Lake District, HATFIELD and MAHER (2009) attributed major erosional activity and increased (over 3 times) sediment flux "pulses" mostly to intensified agriculture, mining and deforestation in the 19th century, and less to pasturage and deforestation about 500 BP and 300 BP. In loess areas of central Germany and in Belgium sediment production, transfer and valley alluviation in Roman period and high Middle Ages were 40 times higher comparing with early and middle Holocene (DOTTERWEICH 2008).

Between years 1780, 1847 and 1927 the deforestation caused also abrupt avulsions of the Slučí, the Sokolí and the Rudná streams channels. Many channels could have been created and abandoned in that short period. Because of their immature morphology (**Fig. 3**), it is difficult to distinguish them at present. The channel avulsions probably took place during extreme floods, like those in: 1813, 1829, 1845, 1880, 1897, 1903 and 1921 (POLÁCH and GÁBA 1998 or ŠTEKL et al. 2001).

KLIMEK et al. (2002 and 2003b) connected the fossil braided pattern in the upper reaches of the Bílá Opava River (south-west form the study area) with the 19th century deforestation and extreme precipitation in 1903. The age of alluvial bars and channels was (dendrochronologically) estimated for the beginning of the 20th century. The great energy of the flood in 1921 was proved by CHROST (2006) by dendrochronological dating of sudden accumulation event in the Rudohorský stream headwater (west from the study area).

The direct reasons of old channel abandonment and new channel creation on studied fans could have been:

a. special susceptibility of the exposed fan surface to fluvial erosion,

b. availability of coarse mineral and woody debris – which during floods could create dams and force overflowing of water to new channels.

There are no sedimentary records of above described processes. It is possible that some colluvial deposits from the period of deforestation exist on catchment slopes, but they are indistinguishable from Pleistocene covers – in contrary to those accumulated on agricultural areas (LATOCHA 2009). In small valleys – like those studied – there are no traces of fine-grained anthropogenic alluvia deposition typical for bigger mountain rivers and mountain-foreland rivers (TEISSEYRE 1985, KUKULAK 2004 or LATOCHA 2009). In the period of deforestation analysed streams (because of their high gradients and narrow valleys) were located in the zone of erosion, not accumulation.

Population decline (**Fig. 9**) and decrease of human impact occurred in the study area after 1850. In such cases abandoned areas ultimately reach a new equilibrium and more or less naturally driven processes dominate (DOTTERWEICH 2008). The Slučí, the Sokolí and the Rudná streams catchments reforestation (artificial planting of the non-native spruce forest, minor secondary succession) and abandonment of forest roads stabilised colluvial covers, reduced surface wash, erosion and sediment flux. Despite that, archival maps younger than 1847 show, that straight stream pattern survived. It is not sure if:

a. it was a matter of, still, too short time given for catchment balance restoration, or,
b. it was preserved thanks to climate fluctuations at the end of Little Ice Age (see below), or,
c. it was preserved because instead of deciduous, coniferous trees were planted in the catchments.

According to the third explanation the crucial factor would be the decrease of general transpiration rate by 1.6 – 2.3 times associated with rebuilding of tree-species composition (KLIMEK and LATOCHA 2007). If so, the rate and speed of outflow remained bigger than in the primeval, natural conditions. But still, the reforestation caused slope-channel system decoupling (LATOCHA 2005).

The economic development of the Eastern Sudetes influenced the functioning of hillslope-valley systems – it accelerated erosion and accumulation processes on the slopes and in the valley bottoms (LATOCHA and MIGOŃ 2006 or LATOCHA 2009). But the channel pattern transformation on the studied fans in the last 250 year can not be wholly contributed to human activity – though it was probably crucial factor. On fan surfaces there are many abandoned channels, which are by now completely filled with mineral and organic deposits. They are probably older than 18th century. The radiocarbon date of ~8 ka BP for abandonment of the Sokolí stream palaeochannel (WISTUBA 2009) proves that human impact on vegetation cover is not necessary for avulsion in the study area. It may be caused by intrasystem factors – like natural tendency to creation dams of coarse woody debris in channels.

It is possible that in the last 250 years anthropogenic impact on the channel pattern was strengthened by climate fluctuations of the end of the Little Ice Age. In Bohemia LIA is dated to the period of 1570 – 1860 (BRÁZDIL 1992). According to BRÁZDIL (1992) in the northern Bohemia and Moravia from the second half of the 16th century there was a gradual increase in frequency of extreme events, among them floods. From the half of the 17th century climate was more continental. In the period 1776-1806 climate was getting cooler and wetter, mostly in the summer seasons (BRÁZDIL 1992, BRÁZDIL et al. 1994). The 19th century, particulary important for the study results, was characterized by increasing number of extreme events – floods (BRÁZDIL 1992).

The Little Ice Age, in general, was a period of increased fluvial and slope activity (KLIMEK and LATOCHA 2007). The impact of climate change on the susceptibility of a geomorphic system to anthropogenic deforestation was studied by COULTHARD et al. (2002). In the simulated catchment closed by a small alluvial fan they observed an increase of amount and amplitude of the transported sediment after deforestation. Maximum values occurred when the poor vegetation cover was accompanied by wetter climate. Alike there, in the studied case, smaller precipitation could have had the same effect on forested and deforested catchments. Only overlapping of increased precipitation and deforestation resulted in increased removing of sediment from catchments.

Similar situation was described by MARSTON et al. (2003) in the French Alps. Authors connected coarse bed load redeposition with interaction of Little Ice Age and anthropogenic deforestation. SCHULTE et al. (2009) attributed increased grain size in Alpine lake sediments to cooperation of human impact and cool pulses of the Little Ice Age. Yet, mentioned authors also claim that human impact masks the climate signal. LARUE (2002) stated that erosion in the French lowlands was triggered by human impact (major role) and climate – extreme precipitation (minor role).

The Little Ice Age could have, like introducing coniferous trees, preserved the straightened channel pattern. Under the conditions of increased outflow and increased amplitudes of discharge, the newly created branches of channels were easily preserved. The importance of the Little Ice Age is however denied by MIGOŃ et al. (2002). Mentioned authors stated that in the Sudetes it is not the climate change, but the human impact, that plays the main role in the course and effects of extreme geomorphic events.

The abandonment of the Slučí stream branch between 1927 and 1990 resulted from continuation of erosion and stabilisation of the new channel in changed hydrologic conditions. Changes in the lowermost reaches of analysed streams in the period 1927 – 2007 were probably connected with erosion and deposition (expansion of alluvial bars in the Černá Opava River channel) during extreme floods in 1938, 1948, 1977 1991, 1997, 1998 and 2001 (POLÁCH and GÁBA 1998 or ŠTEKL et al. 2001).

Between years 1990 and 2007 significant changes occurred in the location of the Rudná stream outlet. Changes were caused by expansion of alluvial bar in the Černá Opava River channel, on the edge of the fan, when the main river shifted eastern. The location of the bar suggests that it is built of material eroded from the Rudná stream fan. It is confirmed by the deep incision of the lowermost part of the fan (**Fig. 4**) and the presence of debris flow lobe in this area (**Fig. 6**). The bar was probably formed during four floods in 1991, 1997, 1998 and 2001 (POLÁCH and GÁBA 1998, ŠTEKL et al. 2001).

6 CONCLUSIONS

1. During the last 250 years several stages of the channel pattern transformation occurred on studied alluvial fans.
2. Before the end of the 18th century, in the Slučí, the Sokolí and the Rudná streams catchemnts the balance between sediment input and output in the fluvial system existed. It developed under the cover of primeval deciduous forests. In consequence of the balance channels of studied streams were sinuous, locally meandering.
3. Since the end of the 18th century channels of the Slučí, the Sokolí and the Rudná streams have straightened, shifted and divided into bran-ches. The main phase of slope and fluvial processes activation took place in the period of 1780-1927.
4. Changes were triggered by human activity (deforestation) and natural factor (climate change of the Little Ice Age), which both caused the change in hydrologic and geomorphic conditions.
5. In consequence of disordered hydro-geomorphic balance erosion and sediment flux increased, infiltration decreased and more water took part in the surface wash. Extreme floods occurred more frequently. Those processes forced incision and straightening of the channels.
6. The direct reasons of old channel abandonment and new channel creation on studied fans could have been:
   - special susceptibility of the exposed fan surface to fluvial erosion,
   - availability of coarse mineral and woody debris – which during floods could create dams and force overflowing of water to the new channels.
7. After the half of the 19th century, despite reforestation, new straightened channel pattern survived.
8. The importance of anthropogenic and natural factors and their proportion in impact on slope-channel system is hard to determine and distinguish, but it is probable, that the main role was played by deforestation.
9. The human impact is not necessary for the avulsion in the study area. It was proved by radiocarbon dating of the Sokolí stream avulsion to at least 7880 ± 120 BP (Ki-15288) – the period free from human impact.

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