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Reconstruction of fluvial bars from the Lower Triassic "Buntsandstein Facies" (Lúžna Formation) in the Western Carpathians (Slovakia)

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Abstract: The 50–150 m thick Lower Triassic Lúžna Formation quartzose sandstones and conglomerates are widespread in the Tatricum, Northern Veporicum/Fatricum and Zemplinicum (Western Carpathians). Several braided fluvial facies are well developed in the vertical sections from the Tribeč Mountains, the Čierťaž Mountains and the Starohorské vrchy Hills. The channel lag and planar cross-bedded bar facies overlie major erosional surfaces and are characterized by complex interlayering of planar cross-beds 25–125 cm thick and trough cross-beds 15–50 cm thick. Paleocurrent data (both planar and trough cross-beds combined) indicate downcurrent, oblique or symmetrical accretion of the bars with respect to the local channel direction and are inferred to document lateral or mid-channel braid bar deposits. The thickness of the bar deposits suggests a shallow depth to the channels (~2 m). Paleohydrological data for mean and bankfull channel depth and width, mean annual discharge and mean annual bankfull discharge, paleoslope, drainage area and principal length of river are estimated. Paleoslope values estimated for the Lúžna Formation braid-channels lie between those generally found for alluvial fans and modern rivers (mean $S = 0.0099$). These higher paleoslopes, combined with shorter principal stream lengths, indicate a tectonically active, fault-segmented margin of the source area, from which were derived braided fluvial wedges of clastic sediments on the piedmont braid-plain.

Key words: Western Carpathians, Lower Triassic, braided river, channel bar, paleohydrological data.

Introduction

Reconstruction of fluvial bars in ancient fluvial deposits is crucial for interpreting channel pattern and paleohydraulics. Exposures of the Lower Triassic deposits of the Tatric and Northern Veporic Units of the Central Western Carpathians provide an opportunity for such a reconstruction (Fig. 1).

Bars are the principal depositional elements within rivers. Reconstruction of bars from ancient alluvium, therefore, serves as an important tool for paleoenvironmental analysis and paleochannel characteristics. A variety of bars, differing in scale and morphology, have been documented from ancient alluvium (Williams & Rust 1969; Rust 1972; Cant & Walker 1978; Haszeldine 1983; Kirk 1983; Miall 1985, 1994; Rust & Jones 1987; Wizevich 1992; Willis 1993; Fergusson 1993). This paper presents a detailed account of inferred bar deposits from the Lower Triassic alluvial strata of the West Carpathian Tatric and Veporic Units.

Previous authors considered the Scythian "quartzites" (defined as the Lúžna Formation by Fejdiová 1980), mostly as marine littoral sediments (Zoubek 1930; Matějka & Andrusov 1931; Andrusov 1959; Roniewicz 1966; Fejdiová 1980). Fluvial, lacustrine or deltaic environments were supposed by some authors (Limanowski 1903; Passendorfer 1951; Dzulinski & Gradzinski 1960). The only authors, who interpreted them as continental sediments of ephemeral braided streams on a piedmont plain were Mišík & Jablonský (1978, 2000).

The Scythian "quartzites" occur within the several Central Western Carpathians superunits. They developed from the beginning of the Mesozoic sedimentary cycle with an unconformable position to the underlying polymictic Permian sediments. The quartzites are conventionally attributed to the "Seis" (probably Griesbachian) without any paleontological or radiometric evidence. A continuous passage into overlying "Campilian" strata can be observed (Andrusov 1959; Biely et al. 1996).

Geological setting

The Western Carpathians have been traditionally divided into external (Outer Western Carpathians) and internal structural zones (Inner Western Carpathians) since the 19th century (Štúr 1860; Uhlig 1903; for summary Biely et al. 1996). Recently a concept of triple division into Outer (external zone), Central and Inner Western Carpathians (internal zone) has been widely accepted (Mišík et al. 1985). The internal part of the Western Carpathians orogenic range is divided into the pre-Gosau nappe system and an overlying post-nappe Upper Cretaceous to Neogene sedimentary and volcanic formations. The pre-Gosau nappe system comprises crystalline masses and Upper Paleozoic-Mesozoic envelope formations, as a part of a principal crustal-scale superunit and several cover nappe systems (Fig. 1). The Lúžna Formation sediments are a character-

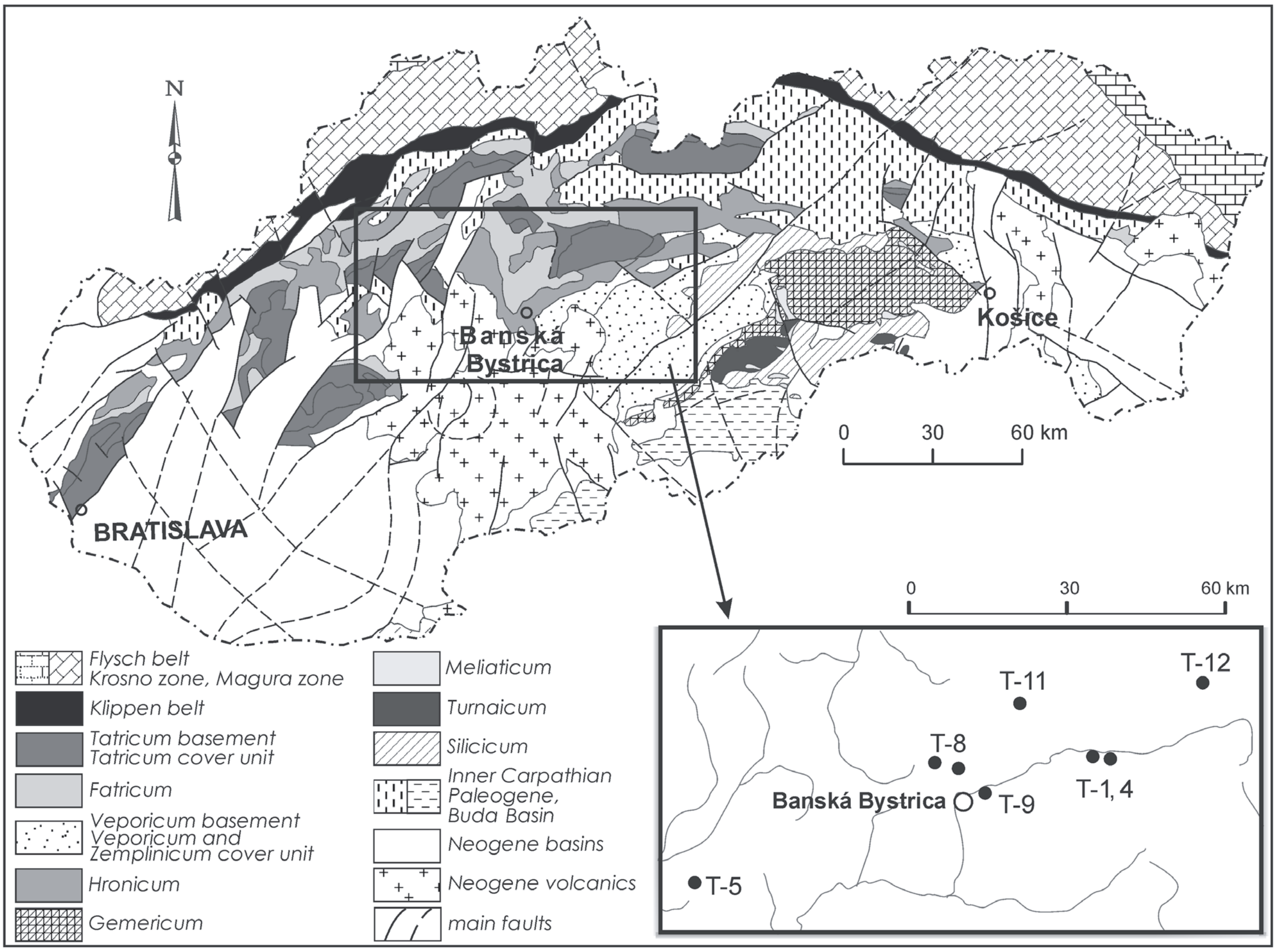

Fig. 1. Tectonic sketch of the Slovak part of the Western Carpathians and location of individual sections.

istic feature of the Mesozoic sequence within the Central Western Carpathians tectonic superunits (from N to S): the Tatricum, Veporicum and correlational Zemplinicum, as well the Fatricum and Hronicum cover nappe system (Fig. 2).

The Tatricum consists of crystalline cores and their Upper Paleozoic (Permian) and Mesozoic sedimentary cover (Lower Triassic to Lower Turonian). The Tatric crystalline basements have generally well preserved Variscan structures without a significant Alpine overprint. It is composed mainly of medium to high grade metamorphic rocks (mostly paragneisses, mica-schists, amphibolites) and several suites of Variscan granitoids. The Mesozoic sedimentary envelope unit is typical of the Carpathian Keuper Formation, various Lower Jurassic successions (crinoidal limestones and marlstones with cherty limestones) and Albian-Turonian flysch formations.

The Veporic Unit comprises: — crystalline massifs and overlying Upper Paleozoic-Mesozoic sequences, which form an indigenous sedimentary envelope of crystalline massifs; — a nappe system composed of Mesozoic sedimentary rocks (designated by Andrusov 1960 as the Lower Subtatricum or Krížna Nappe, and by Andrusov, Bystrický & Fusán 1973 as the Fatricum). The internal structure of the Veporic crystalline basement is complicated as it involves several lithotectonic units, which are different in lithology, the grade of Variscan metamorphism as well as its Alpine overprint and their Upper Paleozoic-Mesozoic sedimentary envelope. The character and evolution of the crystalline rocks in the Northern Veporicum is similar to that in the Tatricum (the Tatra Terrane acc. to Vozárová & Vozár 1996). In the Northern Veporicum, the Upper Paleozoic-Mesozoic sedimentary envelope constists of the mostly anchimetamorphosed Veľký Bok Group (Lower Triassic–Neocomian). Although different in detail, the Veľký Bok succesion is very similar to the Fatricum (Krížna Nappe) Mesozoic sediments. In this respect, the Veľký Bok suite was not detached from its original basement and it is compared with the Fatricum (Krížna Nappe) root zone. This sedimentary complex belongs to the Triassic facies area, characterized by the Carpathian Keuper facies. The low-grade metamorphic rocks and composite granitoids are common in the crystalline basement of the Southern Veporic Unit. Its sedimentary envelope is represented by the Stephanian-Permian continental sediments as well as Mesozoic rocks of the low-grade metamorphosed Foederata Group (Lower and Middle-Upper Triassic metacarbonates and rarely shales). The presence of the Stephanian clastics as well as the missing Keuper facies is an essential difference from the Northern Veporic zone.

The Zemplinicum consists of the high- to medium metamorphosed crystalline complexes and its Upper Carbonifer-

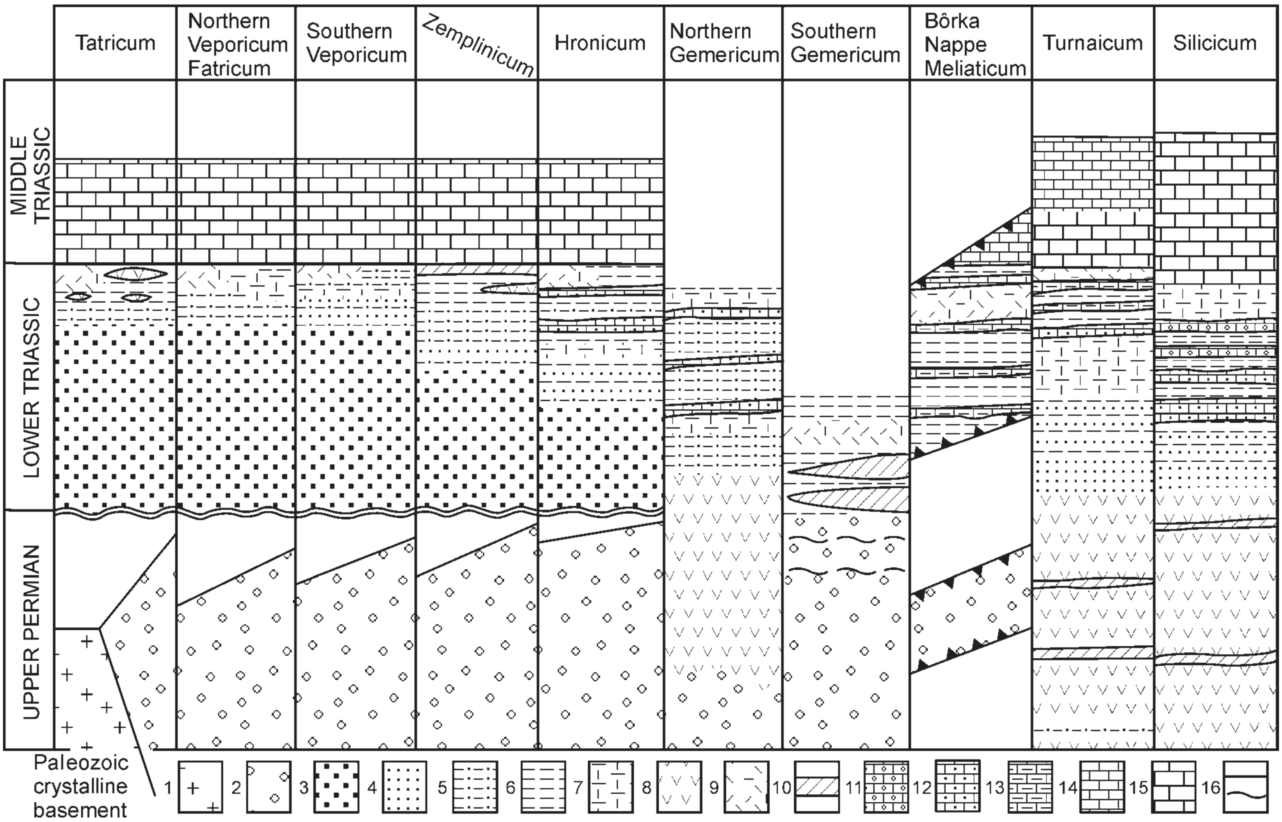

Fig. 2. Distribution of the Lower Triassic facies throughout the Western Carpathians. **1** — Paleozoic crystalline basement; **2** — Upper Permian continental "red-beds" facies; **3** — Lower Triassic continental gravel/sandy braidplain facies (the Lúžna Formation "Buntsandstein" facies); **4** — fine-grained sandstones; **5** — alternation of sandy/shaly sediments; **6** — silty shales; **7** — marls; **8** — evaporites; **9** — rauhwackes; **10** — dolomites; **11** — calcarenites, oolitic limestones; **12** — sandy limestones; **13** — alternation shales and limestones, marly limestones; **14** — slope- and deep-water limestones; **15** — epiplatform shallow-water limestones; **16** — thin lenses of lacustrine phosphorites and phosphatic sediments.

ous-Permian and Lower- to Middle Triassic sedimentary envelope. Dominant paragneisses, amphibolites and migmatites in the Zemplinic crystalline basement and the Upper Carboniferous to Middle Triassic sedimentary envelope correspond very well to the Tatric and Northern Veporic tectonic units.

The Scythian quartzose sediments are widespread within all three above mentioned tectonic superunits as the basal part of their Mesozoic envelope sequences. They are also an integral part of the Fatric and Hronic Lower Triassic sedimentary rocks (Fig. 2). The Scythian sediments transgressively overlie their substratum, either consisting of coarse-grained Permian clastic sediments or crystalline basement rocks.

General characteristics of the Lúžna Formation

The Lúžna Formation is a formal lithostratigraphic unit formerly defined by Fejdiová (1980) on the occurrences near Liptovská Lúžna village (Tatric Unit). A general feature is fining upward and graduate transition to fine-grained silty-shaly sediments of the Werfen Formation, occasionally with carbonatic pedogenic horizons or evaporites. The Lúžna Formation mostly consists of relatively monotonous sediments, mainly coarse- to fine-grained sandstones, with intercalation of conglomerates or gravelly sandstones and inferior thin layers of silty/sandy shales (Fig. 3). Conglomerates are mainly concentrated in the basal part of the Lúžna Formation as well as in the form of thin layers at the lower part of small alluvial cycles. The sandy sediments are cross-stratified, horizontal laminated or in some cases also massive or only crudely bedded. They are organized in multiplying smaller sedimentary cycles of alternating gravel-bearing and gravel-free finer sandstones, or thicker packages of multistorey sandstones. The boundaries between individual sedimentary units of different grain size are either erosional, sharp or gradual. Mudstone intercalations are very subordinate and are in the most cases limited to thin waning-flow drapes up to a few cm in thickness, whereas thicker mudstone beds or lenses are very rare exceptions. In the stratotype the Lúžna Formation consists of three members (Fejdiová 1980). The first member consists of coarse- to medium-grained sandstones interlayered with fine-grained conglomerates and gravelly sandstones. The sediments are light-pink and light-grey in colour, 10–20 m thickness in range. The second member (from 20 to 25 m in thickness) is characterized by the presence of green, occasionally red sandy shales.

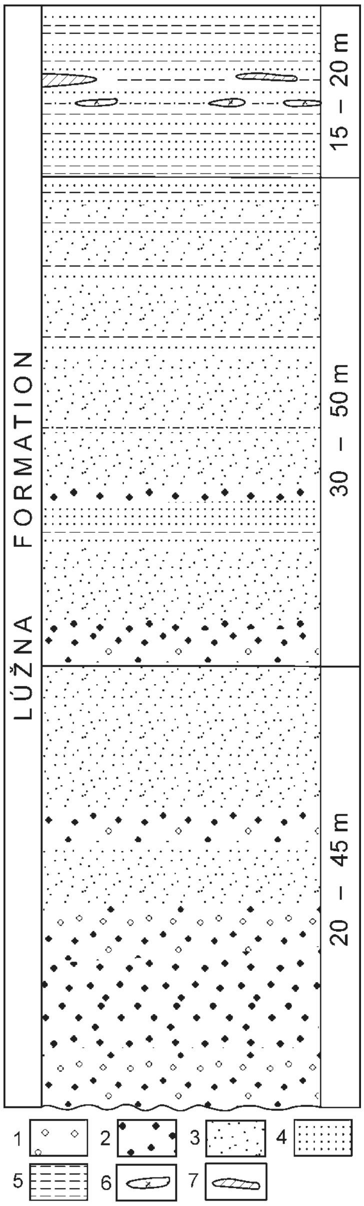

Fig. 3. Schematic lithostratigraphic section of the Lower Triassic "Buntsandstein" lithofacies. **1** — fine-grained conglomerates; **2** — very-coarse grained sandstones; **3** — coarse- to medium-grained sandstones; **4 — fine-grained sandstones; 5** — siltstones, mudstones, shales; **6** — calcretes and carbonatic nodules; **7** — thin layers/laminae of pink dolomites.

The lower part is composed of white to light-grey coarse- to medium-grained sandstones displaying cross-bedding and current lamination. Intercalations of shales range up to 5 cm in thickness. There is an upward increase only in their frequency and not in their thickness. The third member is violet and relatively finer-grained (from 10 to 30 m in thickness), and consists of medium- to fine-grained sandstones and silty/sandy shales.

Principally, these sediments manifested their relatively high grade of structural and mineralogical maturity. The dominant mineral is quartz (85–95 %, rarely 65 %), with less frequent K-feldspars (in general 5–10 %, rarely 20–25 %), fragments of acid volcanites, clastic micas and heavy minerals. Sandstones predominantly belong to the group of quartzose arenites and subarcoses, exceptional arcoses. Conglomerates are oligomictic, with dominant quartz pebbles. Only a few pebbles of black tourmalinites and acid volcanics were identified (for summary see Mišík & Jablonský 2000).

The depositional evolution of the Lúžna Formation reflects the trend of a highly to moderately-braided pebbly to sandy fluvial system whith transition to sandy/muddy coastal floodplain. The fluvial braidplain was associated with intervals of strong aeolian activity, documented by ventifacts, diagonally cross-bedded sandstones and high degree of structural maturity. Semi-arid and arid climatic conditions are inferred from horizons of pedogenic carbonate nodules as well as from tourmaline rich-laminae (former boron-rich clays or primary borates), genetically associated with small arid endorheic water reservoirs (Vozárová et al. 2003).

Reconstruction of bars in the Lúžna Formation quartzose sediments

The bars within braided streams include a hierarchy of individual bedforms, small bars, bar complexes and mature vegetated islands. In view of the morphological complexities involved and the difficulty of their recognition in the ancient record, Miall (1978) proposed a simple classification consisting of three categories: **1** — gravelly, planar or massive bedded bars; **2** — sandy, simple foreset bars; **3** — compound bars of sand and gravel. The bars inferred in the basal part of the Lúžna Formation are mostly of the compound type as defined above. Compared to this, sandy simple foreset bars are dominant in the upper part of the sequence.

The following lithofacies were recognized in the Lúžna Formation quartzose sediments:

1 — *Massive clast-supported pebble conglomerates (**Gm**):* Beds 23–100 cm thick show upward-fining trend; some clast-supported beds indicate crude horizontal stratification and clast imbrication; the mean size of pebbles reaches 1–3 cm; occasionally large imbricated pebbles attain 10 cm in size; they form flat beds with erosional bounding surfaces; imbrications in a few beds generally show N-S transport. *Interpretation:* longitudal bars, lag deposits, sieve deposits.

2 — *Trough-crossbed fine-grained pebble conglomerates and sandy conglomerates (**Gt**) with clast-supported structures:* Set thickness is 30–90 cm, 130–390 cm wide in bedding plane exposures; pebble size varies from 0.5–2 cm; occur seldom as coset up to 5 m thick; paleocurrent mean direction varies from NW–NE to SE–SW, occasionally SW–NE and E–W. *Interpretation:* minor channel fills.

3 — *Planar cross-bedded fine-grained pebble conglomerates and sandy conglomerates (**Gp**):* Beds 50–125 cm thick; 10–30 mm clasts dispersed throughout the cross-bedded units; angular, occasionally gentle sigmoidal foresets; paleocurrent mean direction generally varies from N-NW to S. *Interpretation:* rapid deposition from high velocity flow in shallow channel; linguoid bars.

4 — *Coarse- to very coarse-grained sandstones locally with granules and small (up 10 mm) pebbles (**St, Sp, Sc**):* Trough-or planar cross-bedded lenticular to tabular strata; solitary (theta or alpha) or grouped trough/planar cross-bedding; sandstone bodies 25–80 cm thick; cosets form sheet-like bodies bounded by sharp or erosive surfaces; paleocurrent mean direction varies from NE-SW. *Interpretation:* deposition from small three-dimensional dunes in shallow, wide channels (lower flow regime).

5 — *Medium- to coarse-grained tabular sandstones:* Massive ***(Sm)*** with clast-supported, occasionally matrix-supported, structure; very often with horizontal lamination, parting or streaming lineation ***(Sh)*** and graded bedding ***(Sg)***; 15–70 cm thick. *Interpretation:* planar bed flow.

6 — *Very fine- to medium-grained sandstones with low angle (<10°) or ripple lamination (**Sl, Sr**):* 15–30 cm thick; variable ripple orientation. *Interpretation:* deposition in pools/sluggish channels on bar tops or higher topographic levels of braided streams; crevasse splays.

7 — *Coarse-grained sandstones with pebbles:* Broad, shallow scours, occasionally including eta cross-stratification ***(Se)***. *Interpretation:* scour fills.

8 — *Very fine-grained sandstones and siltstones with fine lamination:* Occasionally asssociated with very small ripples ***(Fl)***. *Interpretation:* overbank or waning flood deposits.

9 — *Siltstones, mudstones with laminated to massive structures (**Fm, Fcf, Fsc**):* Horizons with pedogenic calcrete soils ***(P)*** or bioturbations ***(B)***.

The inferred bar succession of the Lúžna Formation sediments consists predominantly of cosets of massive/graded bedded or planar and trough cross-bedded conglomerates and medium- to coarse-grained sandstones, with minor amounts of very fine- to fine-grained sandstones, siltstones and mudstones (Figs. 4–11).

The fining upward succession is organized into several channel-fill successions. Each channel-fill succession is marked at its base by a major erosional surface that is flat to concave-up and can be traced laterally. The most prominent bounding surfaces are those marking the base of the channel-fill successions. These are designated as first-order bounding surfaces. The second-order bounding surfaces form the erosional bases of the larger, solitary or compound cross-sets (Fig. 7). These surfaces are irregular to flat and are subparallel or at a low-angle to the first-order bounding surfaces. Internal reactivation surfaces within the cross-sets or the intraset boundaries constitute the third-order bounding surfaces. The shape of the third-order surfaces (Fig. 7) is hardly variable and has been found to change from convex-up to concave-up within the same set.

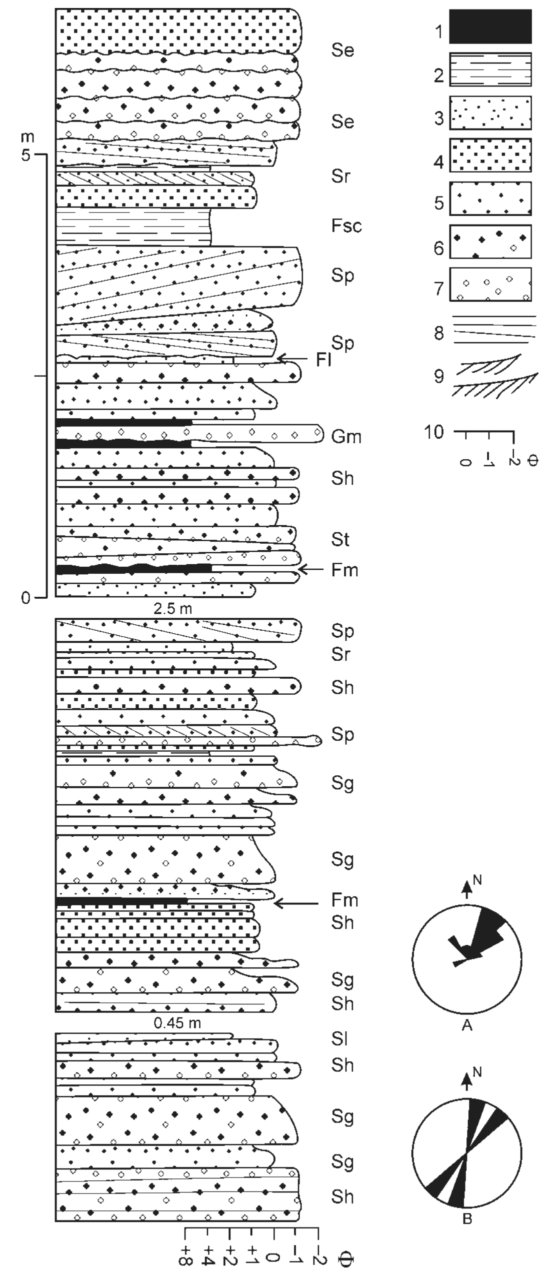

Fig. 4. Vertical section through profile T-11. Explanation: **1** — violet and green shale and mudrock; **2** — violet siltstone; **3** — fine-grained sandstone; **4** — medium-grained sandstone; **5** — coarse-grained sandstone; **6** — very coarse-grained sandstone; **7** — fine-grained conglomerate with grain supported structure; **8** — parting lamination and low-angle cross-bedding; **9** — ripple lamination; **10** — grain size in **Φ** units. The lithofacies symbols are from Miall (1978). The rose diagram (A) shows paleocurrent data from cross-beds and mean direction of channels (B) for both T-11 and T-12 sections.

Description of the sections

Tatric Unit

Section T-11

Loc. North of Baláže village, 580 m altitude, old abandoned quarry, the Nízke Tatry Mountains (Fig. 4).

Light-grey to pink coarse-grained to very coarse-grained siliciclastic sandstones are the main lithology. Single sandstones strata are 6–60 cm thick. Fine-grained channel lag conglomerates form only isolated irregular thin layers at the basal part of bar successions. White to pinkish fine-grained sandstones, siltstones as well as purple-red and green silty shales form highly eroded layers (2–7 cm to 15 cm thick) below first-order bounding surfaces. They represent fillings of abandoned channel sequences.

Active channel sediments mainly represented by the coarse- to very-coarse-grained massive and trough- or planar cross-bedded sandstones are dominant (lithofacies 4, 5 and 7 with **St**, **Sp, Sh**, **Sg**, **Sm**, **Se** type of sandstones). The massive sandstones have a clast supported structure, very often with parting or streaming lineation and graded bedding. Top part of individual bars is proved by lithofacies 6 with ripples and low angle crossbeds (**Sr**, **Sl**). The very scarce finer-grained sediments (lithofacies 8, 9 with **Fm**, **Fl** siltstones and mudstones) are interpreted as an ancient abandoned channel filling. Paleocurrent patterns (Fig. 4) indicate dominant accretion of the bars to the north-east direction along the channels. The smaller cross-beds show a more westerly flow direction.

The widths and depths of preserved channel fill structures in the section T-11 indicates very narrow and shallow channels (2 m wide and 0.2–0.3 m deep; Table 1). Comparing cross-beds calculating values and their bankfull equivalents varies significantly and their are noticeably greater (d_m = 0.49–3.12 m and w = 22–140 m; d_b = 1.91–5.58 m and w_b = 20–99 m; Table 2). Estimated paleoslopes for the section T-11 are relatively high, the average value for S = 0.0137 mm^{-1} (total = 13). Calculated mean annual bankfull discharge (Q_b = 353.4 m^{3}s^{-1} in average) and mean drainage area (A_d = 3249.7 km^2) are adequate to the calculated paleohydraulical data (Table 2).

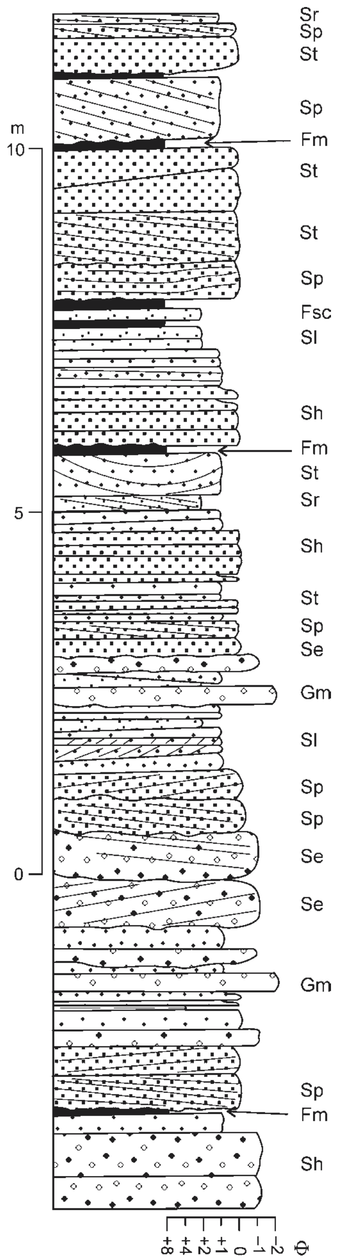

Fig. 5. Vertical section through profile T-12. Explanations as Fig. 4.

Table 1: Width and depth of preserved gravel and sandy channel-fill structures present in the Lúžna Formation.

Locality No.	Width (m)	Depth (m)
section T-1	3.5	0.9
	3.0	0.8
	2.0	0.5
	4.0	0.8
	6.0	1.9
section T-5	4.0	0.18
	2.0	0.11
	1.4	0.13
	1.5	0.09
section T-11	2.0	0.22
	2.0	0.30
section T-12	1.3	0.18
	5.0	0.70
	6.0	0.70
	3.0	0.23
	8.0	0.70
	5.0	0.45

Section T-12

Loc. Southwest from Nižná Boca village, northern slope of the Nízke Tatry Mountains (Fig. 5).

Fining-upward bars mostly consist of very coarse-grained to coarse-grained sandstones. Clast-supported fine-grained conglomerates form only two layers (each of 23 cm thick) of channel lag deposits at the basal part of the bar succession. The thickness of individual bars is from 1.5 m to 2 m, rarely up to 3–4 m. The massive conglomerates (lithofacies 1; **Gm**) show horizontal bedding or inconspicuous streaming lineation. They grade upward to lithofacies 4 (**St**, **Sp**), lithofacies 5 (**Sh**, **Sg**, **Sm**) or lithofacies 7 (**Se**). Sandy ripples occasionally occur at the upper part of bar successsions (**Sr**). Remnants of ancient abandoned channel sediments or overbank deposits are only seldom preserved. They are represented by lithofacies 6 (**Sl**) and lithofacies 8 (**Fm**, **Fsc**). The azimuth of the planar cross-beds shows a very consistent mean towards the north-east (Fig. 4), conforming with section T-11.

As is shown in Table 1 the widths and depths of the preserved sandy and gravel channel fill in the section T-12 are higher than those estimated for the section T-11. The real measurements change from 1.3 m to 8.0 m for width and from 0.18 m to 0.70 m for depth. The calculated equivalent paleohydrological values show approximately similar ranges (d_m = 0.41–3.12 m; w = 18.4–140.4 m; d_b = 1.72–5.58 m; w_b = 19.02–98.78 m; Table 2). This, however, probably reflects an inability to measure a greater amount of real channel-fill structures in the section T-11. The estimated paleoslope data for section T-12 are a bit lower than those for the section T-11 (S = 0.0103 mm^{-1}, total = 21; Table 2). In contrast to this, the mean annual bankfull water discharge value (Q_b=616.5 m^3s^{-1}; total=21) as well as the mean drainage area value (A_d=5939.3 km^2; total=21, Table 2) are higher.

Northern Veporic Unit

Section T-1

Loc. Upper part of the Kostolný potok Valley, about 200 m SE from heights 844 m, the Čierťaž Mountains (Fig. 6).

The basal part of the Lúžna Formation sequence in the Northern Veporic Unit, merely 6 m from the underlying Permian continental sediments. The surface exposures consist of coarse quartzose sediments, grading from fine-grained conglomerates to very-coarse and coarse-grained sandstones, very often with granules and pebbles (average size from 10 to 30 mm, locally at the basal part even 10 cm). Dominant are the lithofacies 1 (**Gm**), prograding upward to the lithofacies 2 (**Gt**) and 4 (**Sp**, **St**, **Sc**) with distinct planar- and trough cross-bedding. Relatively thick beds (from 50 to 80 cm, rarely up to 220 cm) are compound to the vertical succession of alternated active braided bars (Fig. 7). Mean direction of transport varies generally from NW to S in the planar cross-bedding and from N or NNW to S in the trough cross-bedding. In the whole vertical section the finer-grained sediments of abandoned channels are missing.

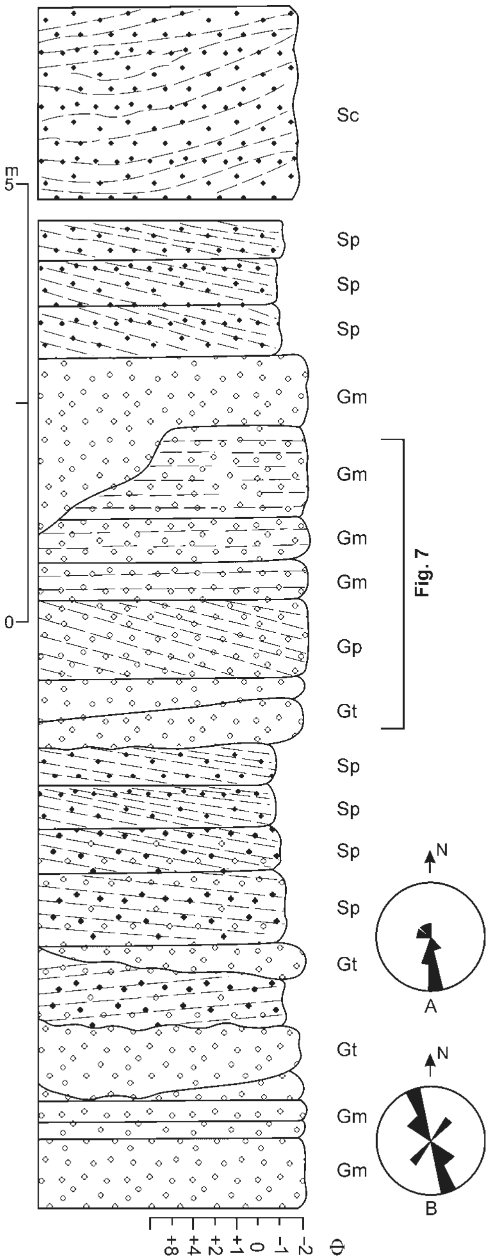

Fig. 6. Vertical section through profile T-1. Explanations as Fig. 4. The rose diagrams show mean flow direction from planar cross-beds (A) and mean directions of channels estimated from the T-1 and T-4 vertical sections.

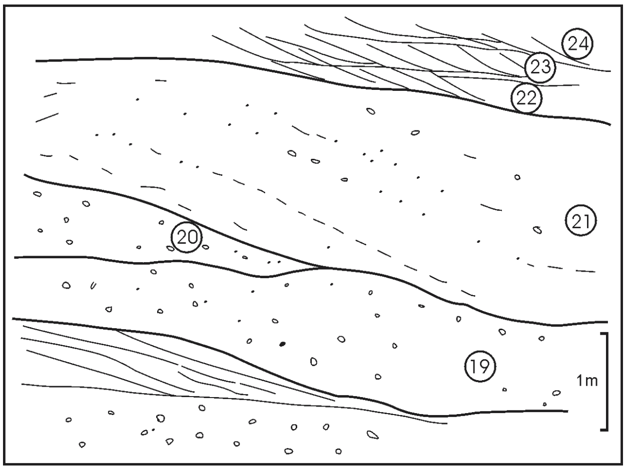

Fig. 7. Detailed outcrop diagram of section T-1 (Fig. 6). Note planar cross-beds alternating with massive fine-grained conglomerates and different order of bounding surfaces (e.g. second-order between 21 and 19 beds; third-order betwen 22, 23, 24 beds).

Azimuth of the planar and trough cross-beds in each of the exposures shows a very consistent mean NWN–SSE trend, which is very consistent with the dominant direction of channels (Fig. 6).

The preserved gravel channel-fill structures range from 2 m to 6 m in width and from 0.5 m to 0.9 m in depth (Table 1). The calculated widths and depths estimated from the cross-beds range from 1.35 m to 9.02 m for depth and from 60.7 m to 405.9 m for width (Table 2). The mean paleoslope value is lower than in the two sections above (S=0.007 mm^{-1}) and the mean annual discharge as well as mean drainage area are adequately higher (Q_b=2023.5 m^3s^{-1}, A_d=33401 km^2; total=8; Table 2).

Section T-4

Loc. The right slope of the Kostolný potok Valley, 680 m above sea level, 300 m SW from 844 heights, the Čierťaž Mountains (Fig. 8).

Fine cyclicity in the framework of small braided bars (up to 5 m thick) is dominant. Individual bars are underlain by erosive first-order bounding surfaces. Sediments are repeatedly coarse-grained. The fine-grained conglomerates create thick beds with low angle (up to 10°) streaming lineation and planar cross-bedding, occasionally with trough cross-bedding (litho-

Table 2: Estimations of paleohydraulic data from the Lúžna Formation on the basis of thickness of planar and trough cross-beds.

Locality	h (m)	d_m (m)	w (m)	Q_m (m^3s^{-1})	d_b (m)	w_b (m)	$Q_m(1)$ (m^3s^{-1})	S (mm^{-1})	$S(1)$ (mm^{-1})	Q_b (m^3s^{-1})	$Q_b(1)$ (m^3s^{-1})	A_d (km^2)	$A_d(1)$ (km^2)	L (km)	$L(1)$ (km)
T- 1	0.07	2.87	129.15	278.0	5.30	91.91	61.48	0.0053	0.0095	1647.8	1940.3	19462.5	24200.2	524.4	597.6
	0.04	1.64	73.8	90.8	3.84	58.54	28.43	0.0076	0.0165	795.1	858.5	6394.4	8540.5	268.9	319.9
	0.04	1.16	73.8	90.8	3.84	58.54	28.43	0.0076	0.0165	795.1	858.5	6394.4	8540.5	268.9	319.9
	0.04	1.64	73.8	90.8	3.84	58.54	28.43	0.0076	0.0165	795.1	858.5	6394.4	8540.5	268.9	319.9
	0.076	3.10	139.5	324.3	5.56	98.29	68.95	0.0051	0.0088	1873.5	2182.7	23096.2	28313.2	588.1	656.6
	0.033	1.35	60.7	61.5	3.34	48.15	20.35	0.0086	0.0199	493.6	623.3	3901.1	5336.0	199.9	241.2
	0.033	1.35	60.7	61.5	3.34	48.15	20.35	0.0086	0.0199	493.6	623.3	3901.1	5336.0	199.9	241.2
	0.22	9.02	405.9	2745.9	10.33	233.95	303.78	0.0026	0.0031	9374.6	9847.8	197668.3	211083.9	2107.1	2191.8
T- 4	0.06	2.46	110.7	204.2	4.86	81.40	49.95	0.0059	0.0110	1320.0	1571.6	14480.3	15716.0	439.1	461.3
	0.02	0.82	36.9	22.7	2.57	33.37	10.87	0.0119	0.0325	252.6	334.7	1597.0	2323.9	116.9	146.5
	0.025	1.02	45.9	35.1	2.92	39.90	14.76	0.0103	0.0262	351.5	456.5	2480.7	3515.3	152.4	187.8
T- 5	0.018	0.73	32.8	17.9	2.40	30.32	9.23	0.0129	0.0364	211.8	283.2	1262.7	1859.8	101.6	128.2
	0.04	1.64	73.8	90.8	3.84	58.54	28.43	0.0076	0.0164	715.1	886.9	6394.2	8521.2	268.9	319.5
	0.013	0.53	23.9	9.5	2.00	23.49	5.96	0.0158	0.0497	132.0	181.9	672.4	1031.3	69.6	90.0
T- 9	0.11	4.51	202.9	686.3	6.91	133.25	116.02	0.0040	0.0061	3290.4	3703.1	48940.7	57291.5	911.9	1002.3
	0.09	3.69	166.0	459.4	6.15	113.19	87.78	0.0046	0.0074	2424.4	2786.7	32569.3	39215.3	714.2	798.4
	0.36	14.76	664.2	7352.7	13.75	349.15	602.44	0.0019	0.0019	19701.6	19701.6	532111.1	532111.1	3817.1	3817.1
	0.13	5.33	239.8	958.6	7.62	152.80	146.63	0.0036	0.0052	4244.4	4704.3	78807.7	78824.5	1213.6	1213.6
	0.01	0.41	18.4	5.6	1.71	18.86	4.10	0.0186	0.0643	87.7	124.1	399.5	618.8	50.2	66.2
	0.025	1.02	45.9	35.1	2.92	39.90	14.76	0.0104	0.0262	352.5	456.5	2489.6	3515.3	152.7	187.8
	0.05	2.05	92.2	141.8	4.38	70.38	38.95	0.0066	0.0132	1007.2	1223.0	10096.5	13078.4	353.7	413.1
	0.02	0.82	36.9	22.7	2.57	33.37	10.87	0.0119	0.0325	252.6	334.7	1597.0	2323.9	117.0	146.5
	0.05	2.05	92.2	141.8	4.38	70.38	38.95	0.0066	0.0132	1007.2	1223.8	10096.5	13078.4	353.7	413.1
	0.07	2.87	129.1	277.9	5.32	92.40	62.04	0.0053	0.0095	1666.0	1961.7	19749.6	24557.6	529.0	602.9
	0.17	6.97	313.6	1639.3	8.98	192.30	217.25	0.0030	0.0040	6497.3	7042.3	121239.4	134985.2	1571.5	1653.6
	0.05	2.05	92.2	141.8	4.38	70.38	38.95	0.0066	0.0132	1007.2	1223.0	10096.1	13078.8	353.7	413.1
	0.05	2.05	92.2	141.8	4.38	70.38	38.95	0.0066	0.0132	1007.2	1223.0	10096.1	13078.8	353.7	413.1
	0.06	2.46	110.7	204.2	4.86	81.41	49.96	0.0059	0.0111	1320.2	1575.8	14482.8	18337.3	439.2	505.9
	0.02	0.82	36.9	22.7	2.57	33.37	10.87	0.0119	0.0325	252.6	334.7	1596.8	2323.8	117.0	146.5
	0.02	0.82	36.9	22.7	2.57	33.37	10.87	0.019	0.0325	252.6	334.7	1596.8	2323.8	117.0	146.5
	0.05	2.05	92.2	141.8	4.38	70.38	38.95	0.0066	0.0132	1007.2	1223.0	10096.1	13078.8	353.7	413.1
	0.025	1.02	45.9	35.1	2.92	39.90	14.76	0.0103	0.0262	351.5	456.5	2480.6	3514.9	152.3	187.8
	0.03	1.23	55.3	51.0	3.25	46.35	19.07	0.0092	0.0218	464.7	591.7	3599.4	4967.5	190.5	231.1
	0.02	0.82	36.9	22.7	2.57	33.37	10.87	0.0119	0.0325	252.6	334.7	1596.8	2323.8	117.0	146.5
	0.028	1.15	51.7	44.6	3.25	46.35	19.07	0.0096	0.0333	470.3	666.2	3657.3	5818.4	192.3	254.1
	0.016	0.66	29.7	14.7	2.27	28.04	8.07	0.0137	0.0402	183.2	247.6	1040.5	1554.7	90.5	115.1
	0.016	0.66	29.7	14.7	2.27	28.04	8.07	0.0137	0.0402	183.2	247.6	1040.5	1554.7	90.5	115.1
T- 11	0.046	1.88	84.6	119.3	4.16	65.48	34.43	0.0070	0.0144	881.6	1078.9	8453.3	11065.6	317.9	373.7
	0.012	0.49	22.0	8.1	1.91	20.02	5.34	0.0166	0.0539	117.3	162.8	572.9	889.9	63.2	82.3
	0.016	0.66	29.7	14.7	2.27	28.04	8.07	0.0137	0.0402	183.2	247.6	1040.5	1554.7	90.5	115.1
	0.015	0.61	27.4	12.5	2.16	26.16	7.17	0.0144	0.0435	160.8	219.2	874.4	1321.7	81.5	104.4
	0.01	0.41	18.4	5.7	1.72	19.02	4.16	0.0186	0.0643	89.2	126.2	398.5	633.0	50.9	67.1
	0.014	0.57	25.6	10.9	2.08	24.81	6.55	0.0151	0.0465	165.6	200.1	909.4	1170.4	83.4	97.1
	0.025	1.02	45.9	35.1	2.92	39.90	14.76	0.0104	0.0262	352.5	456.5	2490.1	3514.9	152.7	187.8
	0.076	3.12	140.4	328.5	5.58	98.78	69.54	0.0051	0.0088	1893.0	2205.4	23417.7	28706.7	585.9	662.1
	0.02	0.82	36.9	22.7	2.57	33.37	10.87	0.0119	0.0325	252.6	334.7	1596.8	2323.8	117.0	146.5
	0.013	0.53	23.8	9.5	2.00	23.49	5.96	0.0158	0.0500	132.0	182.3	672.1	1033.7	69.6	90.1
	0.012	0.49	22.0	8.1	1.91	22.02	5.34	0.0166	0.0540	117.1	162.9	572.9	889.7	63.2	82.3
	0.013	0.53	23.8	9.5	2.00	23.49	5.96	0.0158	0.0500	132.0	182.3	672.1	1033.7	69.6	90.1
	0.012	0.49	22.0	8.1	1.91	22.02	5.34	0.0166	0.0540	117.1	162.9	572.9	889.7	63.2	82.3
T- 12	0.04	1.64	73.8	90.8	3.84	58.54	28.43	0.0076	0.0165	715.1	988.9	6394.7	9852.3	268.9	348.5
	0.027	1.11	49.9	41.5	3.06	42.60	16.51	0.0098	0.0242	397.1	511.5	2918.8	4090.7	167.9	205.7
	0.01	0.41	18.4	5.7	1.72	19.02	4.16	0.0186	0.0643	89.2	126.2	398.5	633.0	50.9	67.1
	0.06	2.46	110.7	204.2	4.86	81.41	49.96	0.0059	0.0111	1320.2	1575.8	14482.0	18337.3	439.2	506.0
	0.06	2.46	110.7	204.7	4.86	81.41	49.96	0.0059	0.0111	1320.2	1575.8	14482.8	18337.3	439.2	506.0
	0.03	1.23	55.3	51.0	3.25	46.35	19.07	0.0092	0.0237	464.7	605.7	3599.4	5124.8	190.5	235.5
	0.025	1.02	45.9	35.1	2.92	39.90	14.76	0.0103	0.0341	351.5	491.5	2480.6	3878.8	152.3	199.2
	0.011	0.45	20.25	6.8	1.81	20.42	4.69	0.0175	0.1705	101.6	192.3	474.1	1109.9	56.4	94.0
	0.015	0.61	27.4	12.5	2.16	26.16	7.17	0.0144	0.0939	160.8	292.0	874.4	1937.2	81.5	131.3
	0.016	0.66	29.7	14.7	2.27	28.04	8.07	0.0137	0.0801	183.6	300.4	1040.5	2011.8	90.5	134.4
	0.013	0.53	23.8	9.5	2.00	23.49	5.96	0.0158	0.1229	132.0	234.5	672.1	1446.1	69.6	110.2
	0.045	1.84	82.8	114.3	4.11	64.38	37.08	0.0071	0.0107	854.6	958.6	8109.9	9451.8	310.1	340.0
	0.017	0.70	31.5	16.5	2.34	29.26	8.68	0.0132	0.0715	198.5	317.8	1154.0	2168.7	96.3	140.5
	0.037	1.52	68.4	78.0	3.68	55.15	25.67	0.0080	0.0156	641.0	772.8	5526.8	7091.8	246.4	286.1
	0.056	2.30	103.5	178.5	4.68	77.22	45.64	0.0062	0.0069	1199.7	1236.2	12747.6	13267.4	406.8	416.7
	0.047	1.93	86.85	125.6	4.22	66.81	35.63	0.0069	0.0098	915.4	1009.9	8888.2	10132.2	327.6	354.4
	0.047	1.93	86.85	125.6	4.22	66.81	35.63	0.0069	0.0098	915.4	1009.9	8888.2	10132.2	327.6	354.4
	0.028	1.15	51.7	44.6	3.13	43.97	17.42	0.0096	0.0270	421.6	563.2	3161.3	4651.0	176.2	222.1
	0.076	3.12	140.4	328.5	5.58	98.78	69.54	0.0051	0.0087	1893.0	2198.4	23417.2	28585.3	585.9	660.4
	0.033	1.35	60.7	61.5	3.43	49.98	21.69	0.0087	0.0197	539.0	672.6	4343.2	5893.1	213.2	256.0
	0.013	0.53	23.8	9.5	2.00	23.49	5.96	0.0158	0.1229	132.0	234.5	672.1	1446.1	69.6	110.2
x	**0.05**	**1.84**	**82.78**	**268.4**	**3.74**	**60.59**	**42.01**	**0.0099**	**0.0319**	**1180.7**	**1336.9**	**19444.1**	**21039.9**	**345**	**382**
Sx	**0.07**	**2.15**	**96.85**	**938.8**	**2.07**	**52.42**	**82.54**	**0.0045**	**0.0304**	**2653.9**	**2691.3**	**68069.7**	**68377.6**	**540**	**545**
n =	**71**														

facies 3, rarely 2). This coarse basal part of the bar progrades upward through very coarse to medium-grained sandstones (with parting lineation or low-angle cross-lamination) in its upper part (lithofacies 5). Abandoned channel or overbank facies are also absent.

The paleocurrent pattern is consistent with those in the section T-1. The calculated flow depth and width based on cross-beds range between 0.82 and 2.46 m (d_m) and from 45.9 to 110.7 m (w). Corresponding are values for bankfull channel depth and bankfull channel width (d_b = 2.57–4.86 m, w_b = 33.37–81.40 m; Table 2). The estimated paleoslope values (S = 0.006–0.012 mm^{-1}) as well as bankfull water discharge (Q_b) and drainage area (A_d) data are adequate to the others North Veporic sections (Table 2).

Vertical section T-5

Loc. The right slope of Drahožná Valley, 312 m above see level, the Tribeč Mountains (Fig. 9).

Sandy sediments with different size grades, from coarse-grained through medium- to fine-grained sandstones, prevail.

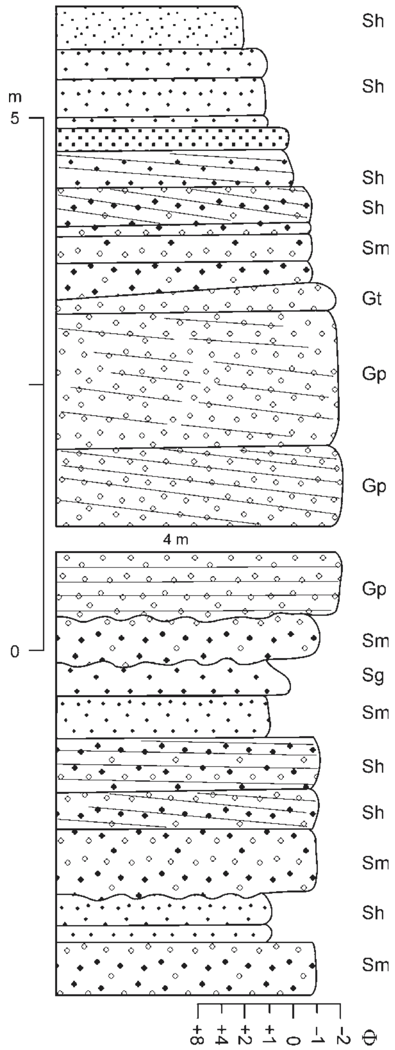

Fig. 8. Vertical section through profile T-4. Explanations as Fig. 4.

Explanations to Table 2: h — thickness of cross-beds (m); d_m — water depth (m); w — channel width; Q_m — maximum instantaneous water discharge; d_b — bankfull channel depth; w_b — bankfull channel width; $Q_m(1)$ — average daily discharge; S — stream paleoslope (eqn 8a); $S(1)$ — stream paleoslope (eqn 8b); Q_b — bankfull water discharge (using S values); $Q_b(1)$ — bankfull water discharge (using $S(1)$ values); A_d — drainage area (using Q_b values); $A_d(1)$ — drainage area (using $Q_b(1)$ values); L — principal stream length (using A_d) values; $L(1)$ — principal stream length (using $A_d(1)$ values).

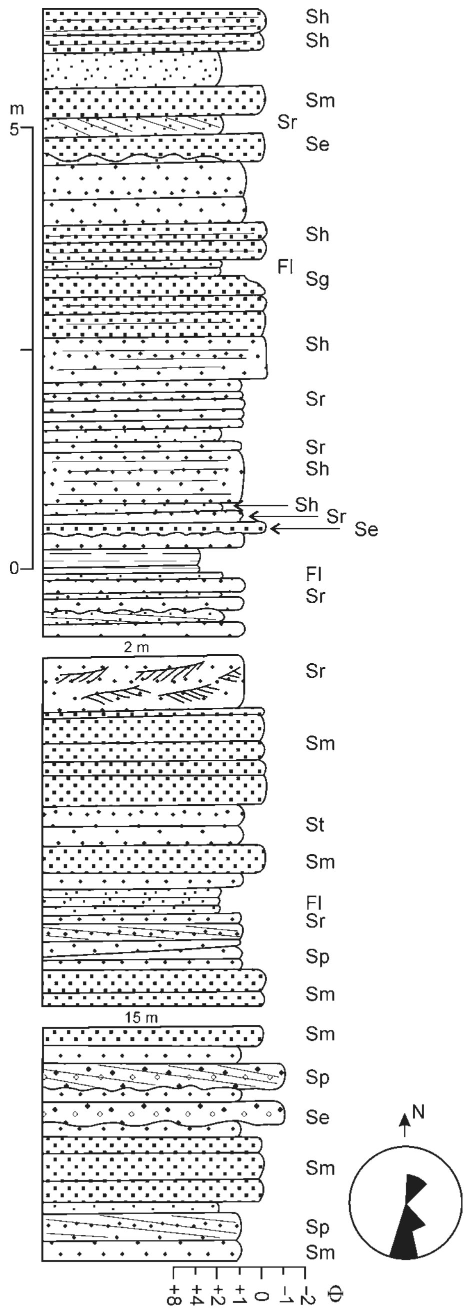

Fig. 9. Vertical section through profile T-5. Explanations as Fig. 4. The rose diagram indicates mean flow direction from planar cross-beds.

The first-order erosive bounding surfaces are overlain by relatively thin layers of pebble sandstones (up to 30 cm thick). They represent channel lag deposits and scour fills occasionally with intraclasts in basal part of braided bars. The whole sequence is well differentiated into small bars with distinct upward fining. Clast-supported massive or graded-bedded sandstones sometimes with streaming lineation are dominant (lithofacies 5; **Sm**, **Sg**, **Sh**). The lithofacies 5 progrades upward into the planar cross-beds, associated seldom with the wide and shallow trough cross-beds (lithofacies 4; **Sp**, **St**). Medium-grained rippled sandstones were locally identified in the upper part of bars (lithofacies 6; **Sr**). Purple to green-grey fine-grained sandstones, mudstone and silty shales are subordinate (lithofacies 9; **Fl**). They usually comprise fine horizontal lamination and occasionally small scale ripple marks. Paleocurrent patterns indicate dominant flow directions from the north to the south (Fig. 9).

The widths of the preserved sandy channel fill structure fluctuate between 1.4 and 4.0 m. The depth is very shallow, ranging from 0.09 to 0.18 m (Table 1). Compared to this the calculated values of depth and width and their bankfull equivalents are higher (d_m=0.53–1.64 m, w=23.9–73.8 m, d_b=2.0–3.84 m, w_b=23.49–58.54 m; Table 2). Paleoslope data indicate steeper slope (S=0.008-0.016 mm^{-1}) with adequate fluctuating bankfull water discharge (Q_b=132–715 m^{3}s^{-1}) and drainage area (A_d=672–6394 km^2; Table 2).

Section T-8

Loc. Haliar Valley, E of the Staré Hory village, the Starohorské vrchy Hills (Fig. 10).

This vertical section represents a fragment of fine-grained abandoned channel deposits or erosional remnants of backwaters or floodplain depression deposits. The prevailing sediments are purple siltstones intercalations of light-grey fine- and very fine sandstones and purple to green shales. The individual layers (2 to 10 cm thick) are uniform, with flat and sharp contacts between them. A very fine horizontal lamination is dominat, passing rarely into moderate oblique (lithofacies 8; **Fl**). Some laminated to massive siltstones, mudstones and shales (lithofacies 9; **Fm**, **Fcf**, **Fsc**) contain carbonate pedogenic (**P**) or bioturbation (**B**) horizons. The medium-grained sandstones form only two low angle cross-beds (up to 12 cm thick).

Vertical section T-9

Loc. The left slope of the Jelenská dolina Valley, SE from 700 m above sea level, the Starohorské vrchy Hills (Fig. 11).

Active braided channel deposits are dominant (up to 5 m thick, rarely more). They cyclically alternate one above the another in the whole vertical sequence. They are mostly represented by the fine-grained conglomerates of the lithofacies 1, 3 and rarely 2 (facies **Gm**, **Gp**, **Gt**) and very coarse to coarse-grained sandstones of the lithofacies 4 and 5 (facies **St**, **Sp**, **Sm**, **Sh**) with planar and small trough cross-bedding as well as parting lineation. Medium- to fine-grained sandstones with low angle planar or small trough cross-bedding were identified as bar-top finer sediments. Fine backwater or abandoned channel fill deposits form only scarce erosional remnants in the second half of the vertical section. The whole T-9 vertical

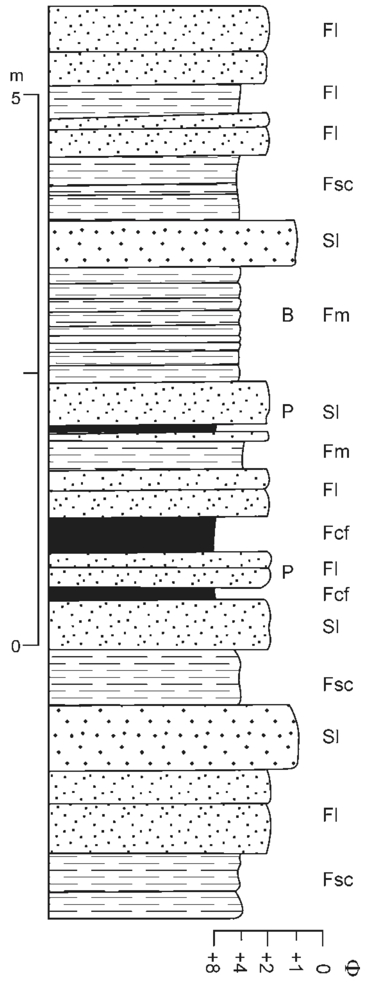

Fig. 10. Vertical section through profile T-8. Explanations as Fig. 4.

section shows a very moderate upward fining, similar to that within the individual bars.

The paleoflow directions of the smaller cross-beds show a divergent pattern (Fig. 11), to the NE and to the W. These measurements probably reflect flow divergence with respect to mean channel direction.

Estimated flow depths vary overall between 0.66 m and 6.97 m and width values range from 29.7 m to 313.6 m. Their bankfull equivalents indicate similar variability (Table 2). The mean paleslope value (S=0.009 mm^{-1}; total=23) is higher than the maximum known from the recent river (0.007; Blair & McPherson 1994). The bankfull water discharge fluctuates similarly to the drainage area in dependence of bankfull greatness and changes of paleoslope (Table 2). The relatively high mean bankfull water discharge is also reflected in the high mean drainage area (Q_b=2055.8 m^{3}s^{-1}, A_d=39977.2 km^2; Table 2).

Interpretation of the vertical sections and paleohydrological data

Planar cross-beds that dominate the bar succession were probably deposited by migrating dunes. Similar planar cross-

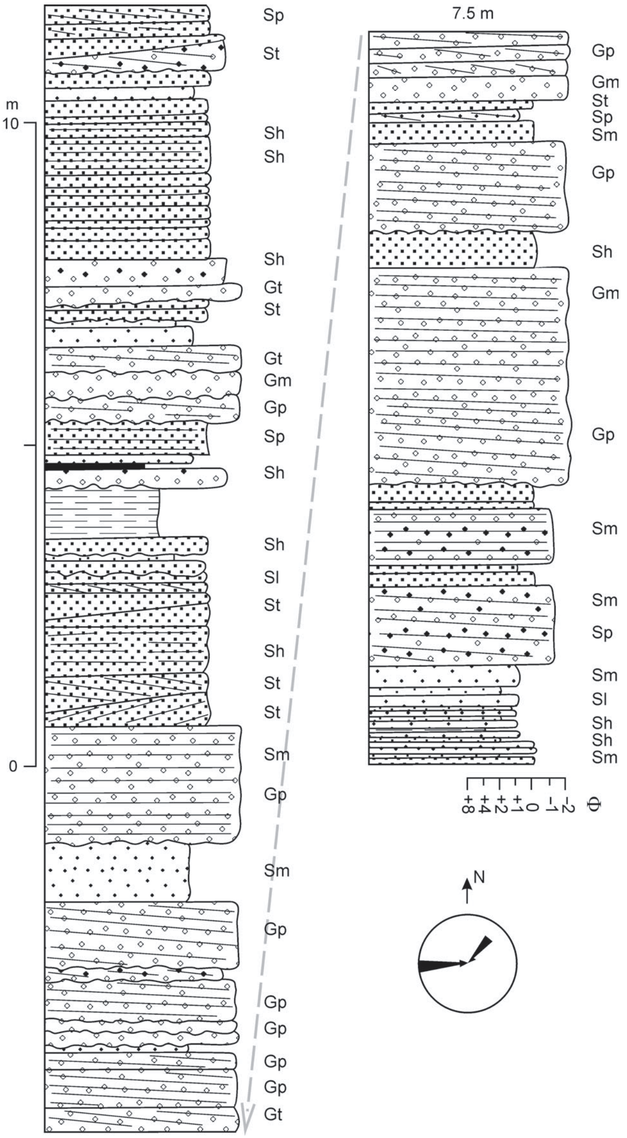

Fig. 11. Vertical section through profile T-9. Explanations as Fig. 4. The rose diagram shows divergent flow directions estimated from smaller cross-beds.

bedded successions were described in many modern and ancient braided fluvial deposits (Smith 1970; Rust 1972; Miall 1978, 1994; Ashley 1990; Selley 1996). Bedforms were both simple and compound types, the latter with superposed smaller bedforms. The paucity of fine-grained sediments and low directional variability of the planar cross-beds supports deposition in low-sinusoity bedload streams. Reactivation surfaces indicate frequent fluctuation of flow depth and velocity. Change in the shape of the reactivation surfaces from convex-up to concave-up probably represents a progressive lowering of the flow stage (Fig. 7). Erosional truncation of the planar cross-beds by lenticular, trough cross-bedded units is inferred to represent a shallow, low-stage channel which dissected the bar tops. The point bar within vertical sections T-11 and T-12 as well as T-5 (Figs. 4, 5 and 9) can be 3 to 5 m thick. The point bar sequence from the bottom to the top is made up of sandy and pebble sandy megaripples. Internally, cross-bedded units (10 to 50 thick) are present, laminae show high angles of dip (>30°). Horizontal bedding of the upper flow regime is also present. This type of sequence most probably represents the mid-bar facies (Levey 1978). The finer sediments of abandoned channel fills are present only in some erosive remnants.

The bars within sections T-1 and T-4 (Figs. 6 and 8) can be interpreted as gravelly stream deposits. Fine-grained conglomerates associated with pebble sandstones are the prevailing type of sediments. The bedding is often massive with clast-supported structure and often streaming lineation. The basal part of bars is made up of coarse channel lag deposits with erosive bounding surfaces. Those prograde to trough cross-bedded unit, made by migrating megaripples. This unit is overlain by the coset of planar cross-beds of transverse bars. This subfacies corresponds to the upper part of the point bar. The upper half of the section T-1 (Fig. 6) contains a very well preserved channel and bar sequence. This bar sequence is characterized by sinuous trend and steep foreset cross-stratification.

The vertical profile T-9 represents a fully developed braided bar sequence with gravel-sandy mixed sediments. Within the schematic vertical sequence, low-angle planar cross-bedded fine conglomerates alternate with trough cross-bedded ones. The bar top sediments are formed by massive or horizontal and rippled sandstones. In the upper part of the profile the coarse-grained sandstones are dominant. They are characterized by mainly horizontal bedding (parting lineation), low-angle planar cross-bedding (< 10°), and trough cross-bedding.

Paleohydrological data were estimated for the braided fluvial system of the Lúžna Formation using different formulas for the estimation of hydrological parameters in the ancient river system, proposed by various authors. The width and depth of the preserved channel-fill structure in the Lúžna Formation are presented in Table 1. A comparison of those results with calculated values (Table 2) indicates large and significant differences. Dimensions measured in the field are considerably smaller. This probably reflects an inability to recognize, and thus also measure, greater channel-fill structure in the field due to strongly forested surface area. Outcrops of the exposed Lúžna Formation sediments exceed several tens of meters in width and a few or tens of meters in height.

Table 2 provides various hydrological data parameters estimated in this study for the Lúžna Formation sediments (including mean and one standard deviation). The estimation of hydrological parameters was made on the basis of the thicknesses measured from cross-bed structures (e.g. Ethridge & Schumm 1978). Standard errors in their application are often significant and vary depending on the applied formula and the number of data points used to derive the equations (Miall 1976; Turner 1980; Van der Neut & Eriksson 1999). The set thickness of preserved cross-beds was used to obtain a mean water depth (d_m) in meters by applying the Allen's (1968) formula:

$$h = 0.086\,(d_m)^{1.19} \quad (1)$$

where h is the thickness of cross-beds in meters, and d_m is the mean water depth over the sedimentary structure, in meters. The ratio between channel width and depth (F) may be estimated by:

$F = 225\ M^{-1.08}$ (Schumm 1968) (2)

where M is the percentage of silt and clay in the channel perimeter. According to Schumm (1968), coarse bedload streams have M values of less than 5 %. The paleostreams of the Lúžna Formation drainage system generally fall into this category, as the sedimentary sequences have low matrix content, and M is, therefore, assumed to be 5 % in this study. Substituting this value in the equation (2) gives a channel width to depth ratio of $F = 45$. This value enables us to estimate of the width of channel, w (in meters), by calculating:

$w = 45\ d_m$ (Schumm 1968). (3)

From this equation is possible to assess the average daily discharge (approximation of mean annual discharge), Q_m (m^3s^{-1}), by calculating:

$Q_m = vA$ (4)

where A is the mean cross-sectional surface area of the channel (m^2), approximated by multiplying the water depth (d_m) by channel depth (w). The mean bankfull channel depth (d_b), in meters, can be calculated from:

$d_b = 0.6\ M^{0.34}\ Q^{0.29}$ (Schumm 1969) (5)

and then the bankfull channel width to calculate (w_b) from

$w_b = 8.9\ d_b^{1.40}$ (Leeder 1973). (6)

According to Van der Neut & Eriksson (1999), this value enables a more realistic estimation of an average daily discharge (Q_m) than eqn (4), when it is applied to the formula of Osterkamp & Hedman (1982):

$Q_m = 0.027 w_b^{1.71}$ (7)

as eqn (4) reflects the maximum instantaneous discharge and eqn (7) the average daily discharge. The gradient or slope of the river is one of the fundamental hydraulic parameters controlling channel morphology. The estimation of the stream paleoslope (S), in mm^{-1}, was calculated by formulas:

$S = 60\ M^{-0.38}\ Q_m^{-0.32}$ (Schumm 1968) (8a)

$S(1) = 30\ (F^{0.95}/w^{0.98})$ (Schumm 1972) (8b)

as the second estimation of Q_m (eqn 7) it is applied to eqn (8a). These two values provide an approximate range of possible paleoslope values for the Lúžna Formation braided channels. The boh S values enable to estimate two bankfull water discharge values, using:

$Q_b = 4.0\ A_b^{1.21} S^{2.28}$ (Williams 1978) (9)

where $A_b = d_b \times w_b$. Similar to this, Leopold et al. (1964) provide an estimation of the probable drainage area for river system by the formula:

$Q_b = (A_d)^b$ (10)

where A_d is drainage area (km^2). This value was used for calculation of supposed stream length. According to Leopold et al. (1964), the principal stream length has a stable and constant relationship to the drainage area and is approximated by the formula:

$L = 1.4\ (A_d)^{0.6}$ (11)

where L is the stream length (km).

The set of the above mentioned formulas was used by Turner (1980) for determination of the paleohydrological data of the Upper Triassic Molteno Formation as well as by Van der Neut & Eriksson (1999) for the fluvial river system of the Proterozoic Wilgerivier Formation. Both the Molteno and Wilgerivier Formations are inferred to reflect predominantly braided-river deposition systems (l.c.). Compared to the Lúžna Formation data (n = 71) the previous authors supported their results by the much greater set of paleohydrological data, for the Wilgerivier Formation of a total of 810 set thicknesses and for the Molteno Formation of a total of 137. Table 2 shows that all except two mean hydrological parameter estimated for the Lúžna Formation river deposits are a bit lower than their equivalent values derived from the Wilgerivier Formation (Table 3). The exceptions are the mean $S(1)$ value and both A_d parameters, which are relatively higher for the Lúžna Formation.

There is a strong dependence between the values of mean annual bankfull discharge (Q_b) as well as paleoslope (S) and drainage area (A_d) (Table 2). The paleoslope values (S) estimated for the Lúžna Formation braid-channels lie between those generally found for alluvial fans (>0.026) and for rivers (<0.007) (Blair & McPherson 1994), since the Lúžna Formation mean value are for $S = 0.0099$ and for $S(1) = 0.0319$ (Table 2). Blair & McPherson (1994) ascertained a distinct break in nature in the longitudinal slopes of fluvial distributary systems, between those found on alluvial fans (slopes ranging from 0.026 to 0.466) and those characteristic for river fluvial systems (maximum slope approx. 0.007). Paleoslopes estimated for the Lúžna Formation (in spite of a bit higher $S(1)$ value) fall mostly into the gap discussed above (Fig. 12), indicating

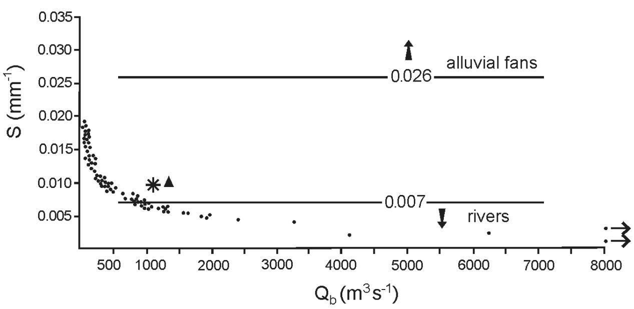

Fig. 12. Binary plot of paleoslopes (S) and mean annual bankfull discharge (Q_b) values estimated for the Lúžna Formation rivers. The maximum gradient (0.007) calculated for modern rivers and that associated with modern alluvial fans (0.026) are taken from Blair & McPherson (1994).

Table 3: Mean paleohydrological data estimated for the Wilgerivier Formation (Van de Neut & Eriksson 1999).

Wilgerivier Formation	h (m)	d_m (m)	w (m)	Q_m (m^3m^{-1})	d_b (m)	w_b (m)	$Q_m(1)$ (m^3m^{-1})	S (mm^{-1})	$S(1)$ (mm^{-1})	Q_b (m^3m^{-1})	$Q_b(1)$ (m^3m^{-1})	A_d (km^2)	$A_d(1)$ (km^2)	L (km)	$L(1)$ (km)
mean	0.23	2.23	100.57	198.32	4.50	74.19	45.44	0.01	0.02	1378.19	1564.77	16760.77	19624.53	440.42	489.29
stand. deviation	0.12	0.94	42.25	191.90	1.05	24.81	27.76	0.00	0.01	967.64	1015.29	17005.64	18250.84	237.56	244.96

braided channels different in character to either modern fans or bedload fluvial systems. The inferred values also correspond very well with paleoslope parameters estimated for the Wilgerivier ancient braided alluvia (Table 3). The direct dependence of discharge values on the size of the drainage area, applicable to river systems in general, is also reflected in the paleohydraulic estimates for the Lúžna Formation, as illustrated in the binary plot of Q_b again A_d (Fig. 13).

Evidence for a braided stream interpretation for the Lúžna Formation includes the predominance of cross-bedded (mainly planar) medium- to coarse-grained sheet sandstones, subordinate imbricated conglomerate beds, finer pebble and more common sandy channel-fill structure, consistently oriented N-S paleocurrent trends exhibiting only a small variation in direction and scarcity of mudrocks. The hydrological data from the Lúžna Formation reflect braided-river setting, with no evidence of significant suspended load or floodplain influences. Generally, the Lúžna Formation it thought to have been deposited within an active tectonic setting, following after a relatively short period of pre-Triassic tectonic stabilization linked with rapid weathering. The Lower Triassic mature sediments were deposited along a linear steep and faulted margin, bordered by a number of alluvial draining system. A predominant braidplain environment, with subordinate abandoned channels and small endorheic basins, proceeded to lagoonal and shallow water conditions in its distal part. An active tectonic faulting in the provenance area led to the origin of segmented depositional margins and thus, to a number of alluvial drainage areas of varying size. A semi-arid climate is inferred for the Lúžna Formation in general, owing to the presence of alluvial and aeolian deposits (e.g. presence of ventifacts, layers of sandstones with a high degree of sorting and mudrocks with carbonate nodules).

Concerning basin paleogeography, distributions of the Lúžna Formation facies give evidence of the development of a broader braidplain in the foreland of the erosional highlands (Fig. 14). The main reasons for the origin of this extensive braidplain were the frequency and intensity of ephemeral atmospheric precipitation to provide high-capacity discharge rates and volumes in the streams and tectonic rejuvenation of the relief in the provenance area to enable steep slopes. These factors together with aggressive weathering and a very rapid rate of erosion in the absence of land vegetation in the provenance area resulted in origin of an extensive braidplain, which was covered by a network of a highly- to moderately-braided river system. Thin aeolian sheet and dune sandstones represent separate intervals within the braided fluvial sediments. The Lúžna Formation upward fining is associated with decline in the sinusoity of watercourses. Moderately- to weakly braided sandy river system passed upward to sandy/muddy inland floodplain. Scarse bioturbation horizons were occasionally recognized in the upper part of shallow channels or thin sheet-flood sandy/silty sediments as well as the playa mudstone assemblage. These indicate low-energy or stagnant conditions which led to installation of endofauna and organogenic reworking of sediments. Upward decreasing of sedimentary supply and basin energy was connected with increasing of aridity. This is documented by the presence of pedogenic horizon with carbonate nodules, laminae of dolomites and lenses of evaporites in places.

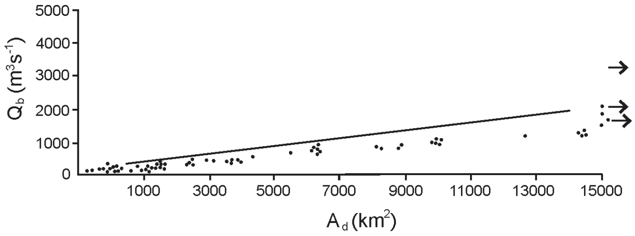

Fig. 13. Binary plot of mean annual bankfull discharge (Q_b) and drainage area values (A_d) estimated for the Lúžna Formation rivers.

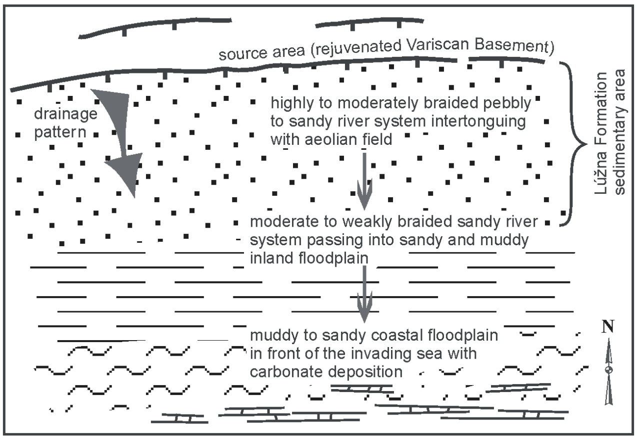

Fig. 14. Scheme of paleoenvironmental evolution of the Lúžna Formation sedimentary system.

In terms of general depositional modelling, the Lúžna Formation Buntsandstein facies sedimentary area passed through a broad braidplain river system and inland floodplain from the north to a coastal floodplain in front of the invading carbonatic sea to the south.

Conclusions

The common features that characterize the bar succession in the Lúžna Formation are:

1. the presence of succession of planar cross-beds above a major erosion surface and paucity of fine-grained sediments in the succession;

2. transition of the solitary planar cross-beds into compound cross-beds or into cosets of smaller trough cross-beds;

3. the presence of shallow channels that cut down into the top of large beds and are filled with small trough cross-beds;

4. the bar succession of the Lúžna Formation were formed during rapidly fluctuating flow conditions; bars were mostly of mid-channel type;

5. the channels had a low sinusoity;

6. the fluvial system was characterized by the contemporaneous existence of both shallow and deeper channels;

7. low dispersion of paleocurrents measured from large planar cross-beds.

The vertical profiles of the Lower Triassic Lúžna Formation sediments indicate a sand-dominant braided stream model. The basal, more proximal sequence contains mixed sandy-gravel material and no or a few mudrock layers. The upper part of the Lúžna Formation clastic succession is sand dominated, with some often thin mudrock intercalations and better developed fining upward cyclicity within bars. Inland floodplain facies with bioturbations and pedogenic horizons as well as playa evaporite intervals occur only in its uppermost part.

The paleohydrological data from the Lúžna Formation reflect a braided river setting, which is characterized by rapid and large fluctuations in river discharge (Q_m and Q_b variables; Table 2). Paleoslopes are close to the maximum known from modern rivers (0.007), but those estimated for the Lúžna Formation (0.0099) (Table 2) fall between this maximum and values corresponding to modern fans (>0.026). The faulted margins of the Lúžna Formation depositional area provided a number of smaller drainage areas and aggressive weathering and high erosion rates promoted formation of sandy detritus close to the former source area. High-gradient braided and intermittent torential storms played an important role on these braided floodplains.

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