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Facies and architectural analysis of fluvial deposits of the Nýřany Member and the Týnec Formation (Westphalian D – Barruelian) in the Kladno-Rakovník and Pilsen basins

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Abstract. The fluvial strata of the Nýřany Member (Westphalian D – Cantabrian) and of the lower part of the Týnec Formation (Cantabrian – Barruelian) have been the subjects of systematic sedimentological studies. Detailed analyses of the facies, paleocurrents, and sedimentary architecture were performed on the exposures. The cumulative stratigraphical thickness of the studied successions reaches about 100 m. Six sedimentary facies were distinguished: siltstone with plant material content (Fsm), fine-grained horizontal laminated sandstone (Sh), medium- to coarse-grained cross stratified sandstone (Sc), fine- to medium-grained massive conglomerate (Gm), fine- to medium-grained cross stratified conglomerate (Gcm), and coarse-grained cross stratified conglomerate (Gcc). Five architectural elements were identified: channels (CH), sand bed forms (SB), gravel bars and bed forms (GB), sediment gravity-flow deposits (SG), and downstream accretion macroforms (DA).
All of these sediments represent braided river systems, though the type or behaviour of these systems differs at individual localities. Most of them were high energy, braided rivers of low sinuosity. Laterally migrating braided streams of low sinuosity, possibly forming braidplain fluvial environments, were distinguished at the Hostibejk Cliff deposits and in the lower part of the Pecínov quarry succession. Deposits indicative of vertically aggrading streams of higher sinuosity and lower energy fluvial environments were recognized in the Lobeč Cliff deposits and in the upper part of Pecínov quarry. Radčice Cliff is dominated by laterally migrating channels, though multi-storey channel fills also occur.

Key words: Pennsylvanian, Pilsen and Kladno-Rakovník Basins, fluvial architecture, facies analysis, sedimentary processes

Introduction

The sedimentary infill of continental basins presents a record of tectonic processes, erosion, and of climatic character. The interplay of varying subsidence rates and sediment supplies results in the development of different sedimentary environments, ranging from alluvial and fluvial to a variety of lacustrine settings. In most of these basins, fluvial sediments form often a substantial part of the basin fill. Consequently, a number of case studies and review papers have appeared in the literature during the past few decades. These studies have been focused mainly on the analysis of facies and architecture of the fluvial strata of ancient and modern rivers, towards interpreting sedimentary processes and environments, and recognizing the main depositional factors (Bridge and Mackey 1993, Ramos and Sopena 1983, Sánchez-Moya et al. 1996, Smith 1990, Shanley and McCabe 1993, 1994, Capuzzo and Wetzel 2004). In continental basins in which the sedimentary record was affected by eustatically driven base level changes, the application of sequence stratigraphy is very common (Martinsen et al. 1999, Hampson et al. 1999). Despite all the above-described trends, sedimentological studies on this topic are very rare for Late Paleozoic continental basins in the Bohemian Massif. These basins have received much attention since the beginning of the nineteenth century when systematic coal-mining was started in most of them. Intensive borehole exploration after the Second World War further improved our knowledge of the basin-wide lithostratigraphy and of local lithostratigraphic peculiarities. The current knowledge of the lithostratigraphic subdivision of the basin fill, the thickness of particular units, the biostratigraphy, and coal reserves have been summarized in several papers, especially by Havlena and Pešek (1980), Pešek (1994, 1996) and Pešek et al. (2001). However, information on the facies and architecture of the fluvial strata, as well as the interpretation of sedimentary processes and the character of sedimentary environments, are either lacking or are discussed only generally for the central and western Bohemian basins. The study of a lacustrine and lacustrine-delta system of Stephanian B age (Skoček 1990) is an exception. The fluvial sediments that comprise most of the basin fill were studied mostly in terms of cyclic analysis and basic facies description (Spudil et al. 1980, Spudil 1982, Bosák 1991, Pešek 1994). The present study was performed on outcrops of fluvial deposits of the Nýřany Member (Westphalian D – Cantabrian) in the Kladno-Rakovník Basin, and in the Týnec Formation (Cantabrian – Barruelian) of the Pilsen Basin. The sediments of these units provide one of the best opportunities for sedimentological study in central and western Bohemia. The goal of this study is to describe and interpret the sedimentary facies and their origins, and to examine their architectural elements toward reaching a better understanding of the Nýřany Member and Týnec Formation depositional environments in the Kladno-Rakovník and Pilsen basins.

Geological setting and stratigraphy

The Late Paleozoic continental basins of the Czech Republic are situated on different terranes of the Bohemian Massif,

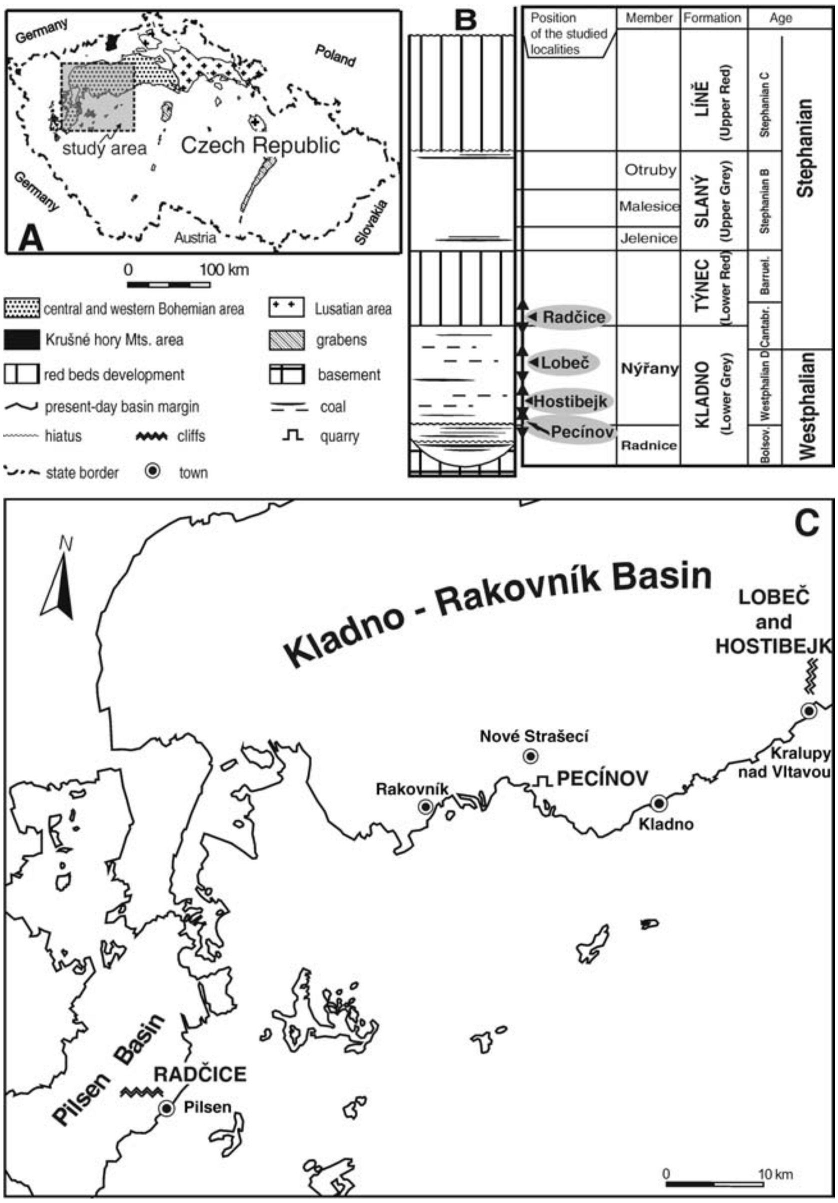

Figure 1. A – Late Paleozoic continental basins of the Czech Republic and their regional subdivision.
B – Lithostratigraphic units in the basins of central and western Bohemia. The approximate stratigraphic position of the studied localities is indicated by arrows.
C – Detailed map of the central and western Bohemian area, with the locations of the studied outcrops

the tectonic histories of which are generally independent of each other. Based on the distinct stratigraphical ranges of these basins, they are divided into the following four regions (Pešek 1994): 1. Central and Western Bohemian Upper Paleozoic basins, 2. Lusatian Upper Paleozoic basins, 3. Krušné hory (Erzgebirge) Upper Paleozoic, and 4. grabens (Fig. 1A). These regions are further subdivided into particular basins whose borders are mostly formal, as they usually represent only part of a larger depocenter.

The Pilsen and Kladno-Rakovník basins belong to the region of Central and Western Bohemian Upper Paleozoic basins. Their sedimentary history began around the Duckmantian/Bolsovian boundary. Deposition, interrupted by several hiatuses, lasted at least until the end of the Carboniferous (Fig. 1B). The basin fill is divided into four lithostratigraphic formations based on the alternation of reddish coal-barren, and greyish coal-bearing deposits (Weithofer 1896, 1902, Havlena and Pešek 1980, Pešek 1994). The formations of grey sediments are further subdivided into members (Fig. 1B).

Only a few papers describe the formation and tectonic evolution of these basins. Havlena (1982) characterized these basins as a simple asymmetric mega-graben formed on the Teplá-Barrandian block, subsiding along the WSW-ENE striking faults (the Central Bohemian Fault in the south and the Litoměřice Fault in the north). This opinion is contrary to that of Pašek and Urban (1990), who emphasized the role of the NW-SE striking wrench faults related to the oblique collision between Gondwana and Baltica. Their conclusions are based on an analysis of brittle structures and the migration of depocenters of particular lithostratigraphic units that indicate three periods of tectonic evolution corresponding to the main sedimentary cycles separated by prominent basin-wide hiatuses: 1. Lower Bolsovian (the Radnice Member), 2. Upper Westphalian D – Stephanian B (the Nýřany Member, the Týnec and Slaný Formations), 3. Stephanian C – Autunian (the Líně Formation).

The Nýřany Member and the Týnec Formation

The Nýřany Member consists of the upper part of the Kladno (Lower Grey) Formation, the oldest unit of sedimentary fill in the central and western Bohemian basins. Its predominantly fluvial strata span the interval of the Upper Westphalian D to Cantabrian. It is separated from the underlying Radnice Member by a basin-wide hiatus related to the Leonian phase of the Variscan Orogeny (Opluštil and Pešek 1998). This separation is marked not only by an unconformity, but also by an apparent lithological contrast (Fig. 3a). However, where sediments of the Radnice Member consist of fluvial facies (Pešek 1994), the precise identification of erosional surfaces between these two units is problematic without paleontological evidence (especially in borehole samples). The Nýřany Member is overlain by the Týnec (Lower Red) Formation of similar facies and structure, indicating the continuous deposition of both units. The boundary between them is marked by the prominent red colour of the fine-grained sediments and the absence of coal seams in the Týnec Formation. This boundary is interpreted as a response to climatic change from humid to drier conditions (Pešek 1994, Opluštil and Pešek 1998).

The thickness of the Nýřany Member varies on a basin-wide scale from 0 to more than 500 m in the central part of the Kladno-Rakovník Basin. However, the average thickness of this unit in the Pilsen Basin is 288 m, whereas in the Kladno-Rakovník Basin it is 336 m (Pešek 1994). Northwestward and eastward, the thickness decreases as sediments of this unit wedge out toward the former basin margin.

The Nýřany Member is characterized by the presence of coarse-grained fluvial sediments, especially in the southern part of the Kladno-Rakovník Basin and most parts of the Pilsen Basin, where medium to coarse-grained arkoses with pebbly admixture predominate. Conglomerates are common at the base of the unit. Fine-grained floodplain, palustrine, or even lacustrine facies are more common in the N and NE parts of the Kladno-Rakovník Basin outside the study area. Coal seams are usually only several tens of centimetres thick, and thicknesses over 1 m are rare. Pešek (1994) distinguished three facies in the Nýřany Member: 1. fluvial facies, 2. phytogenic-volcanic facies, and 3. alluvial fan facies which represents facies associations rather than individual facies. The fluvial facies consist of coarse- to medium-grained arkose with pebbly admixtures, which predominates over fine-grained sandstone and mudstone. The sediments are arranged into upward fining cycles. The mudstones at the top are often rooted. Thin coal may be locally present at or near the top any cycle. The thicknesses of the cycles vary from less than 10 m to more than 25 m, being about 10 m on average. It is generally higher along the basin margins, where the content of floodplain sediments is low. Phytogenic-volcanic facies are characterized by the predominance of mudstones that often contain fossil roots, carbonaceous shale, and coal with subordinate arkoses. This facies is developed mostly in the central and NE part of the Kladno-Rakovník Basin. In the western part of the Pilsen Basin, coal seams up to 3 m thick are present in the surroundings of the town of Nýřany. Alluvial fan facies were recognized by Pešek (1968, 1994) in the western part of the Pilsen Basin, where the so-called Komberk Horizon occurs. It is a fan-like body, reaching up to 60 m in thickness, comprised of reddish or mottled mudstones and subordinate arkoses located along the basin margin, which wedges out toward the basin centre.

The Týnec Formation overlies the sediments of the Nýřany Member. Its thickness in the Pilsen Basin varies between 92–132 m, with an average of 116 m, whereas in the eastern part of the Kladno-Rakovník Basin it is between 94 and 245 m thick, with an average of 172 m. Their lithological character generally resembles the sediments of the Nýřany Member. They are also arranged into cycles dominated by basal, coarse-grained members. The most apparent difference is the absence of any coal seams and red coloured mudstones, which are typical for the Týnec Formation. Moreover, in the Pilsen Basin, sediments of the Týnec Formation are generally coarser and richer in conglomerates than the underlying Nýřany Member sediments (Pešek, pers. com.).

The paleogeography of the Nýřany Member and the Týnec Formation has been described by many authors, including Havlena and Pešek (1980), Holub et al. (1975), Pešek (1994), Pešek et al. (1998), and Opluštil and Pešek (1998). The sediments of this unit were deposited within a large alluvial plain exceeding the size of the currently preserved area of the basins in western and central Bohemia. The main sediment input came from the Central Bohemian Pluton located south of the basins (Pešek 1994). Local sources, however, surrounded nearly all the basin margins.

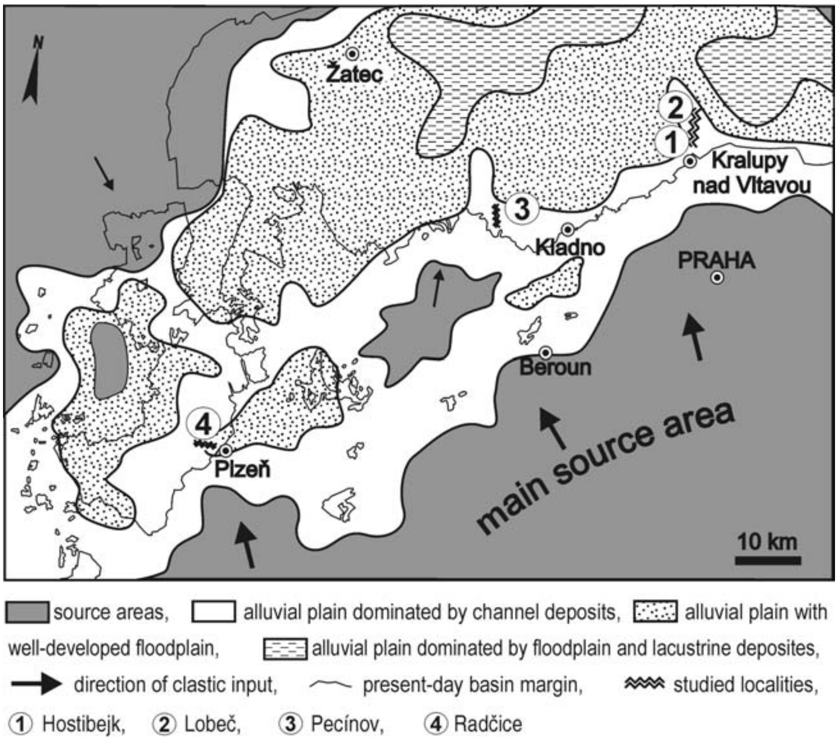

Figure 2. Paleogeographic map of central and western Bohemia during the deposition of the Nýřany Member and the Týnec Formation in the Late Westphalian and Early Stephanian (based on Pešek et al. 1998). Note the position of studied localities and source areas.

Methods

The presently flat and densely vegetated surface of the study area provides only limited opportunities for studying the facies and architectural elements of the sedimentary record of the Nýřany Member and the Týnec Formation. Outcrops of these sediments are located only along the southern margin of the Kladno-Rakovník Basin, and along the

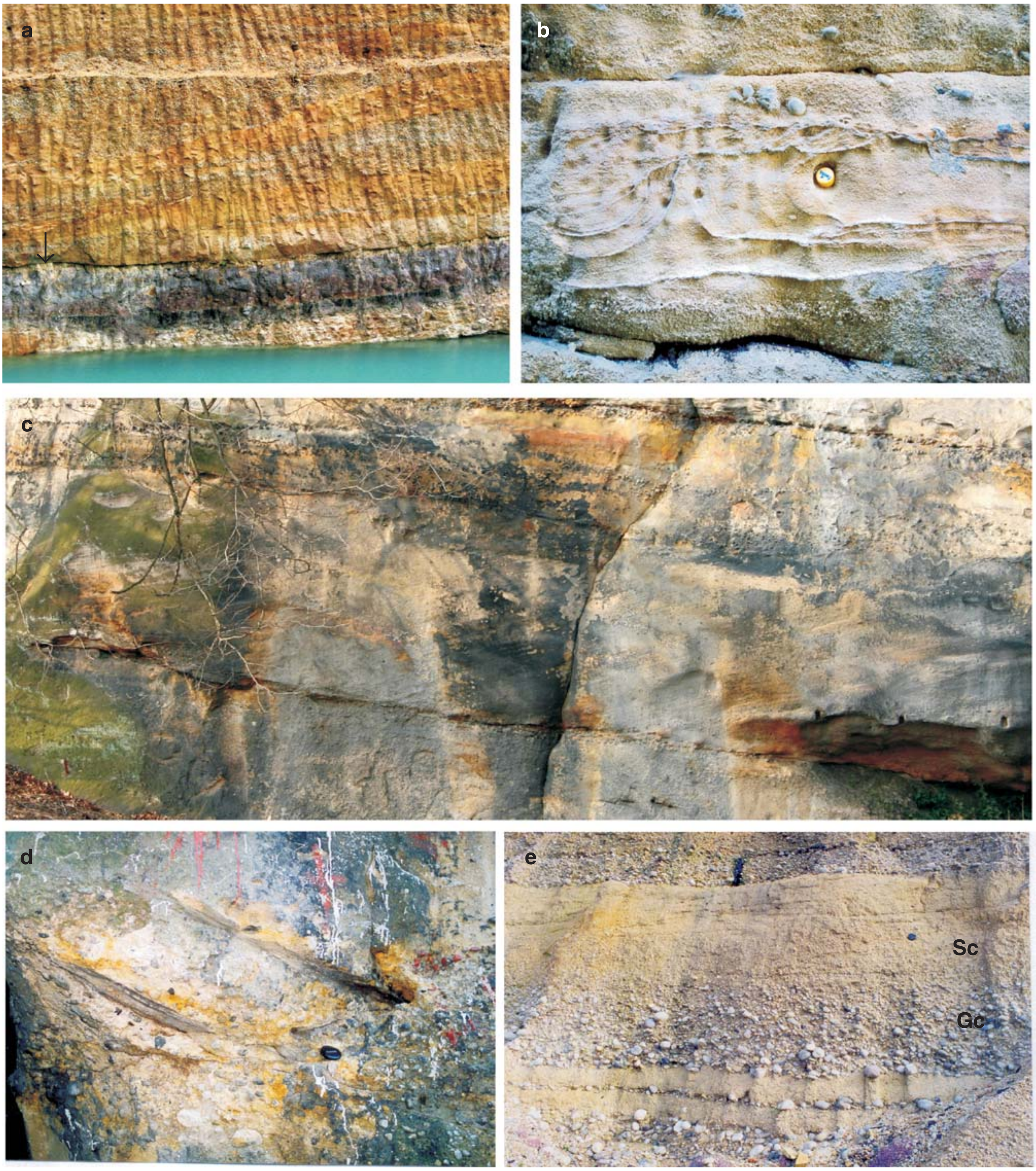

Figure 3. a – base of the Nýřany Member just above the contact with the underlying strata of the Radnice Member in the western quarry at Pecínov. The contact of both lithostratigraphic units is interpreted as a 6th order bounding surface (Miall 1996). The longer side of the photograph is about 7 m. b – water-escape structure in sediments of the Sc facies in the Hostibejk I Cliff. c – planar cross-bedding (Sc facies) in the Hostibejk II Cliff. The longer side of the photograph is about 2 m. d – planar cross-bedded conglomerates of the Gcm facies in the upper part of the Hostibejk II Cliff. Cross-bedding is marked by tree trunks. The longer side of the photograph is 1 m. e – fining upward of grain size within the cross-bedded conglomerates (humpback dune of Miall, 1996) of the Gc facies, terminated by a reactivation surface followed by diagonally cross-bedded sandstone of the Sc facies. Pecínov quarry. The longer side of the photograph is about 1 m.

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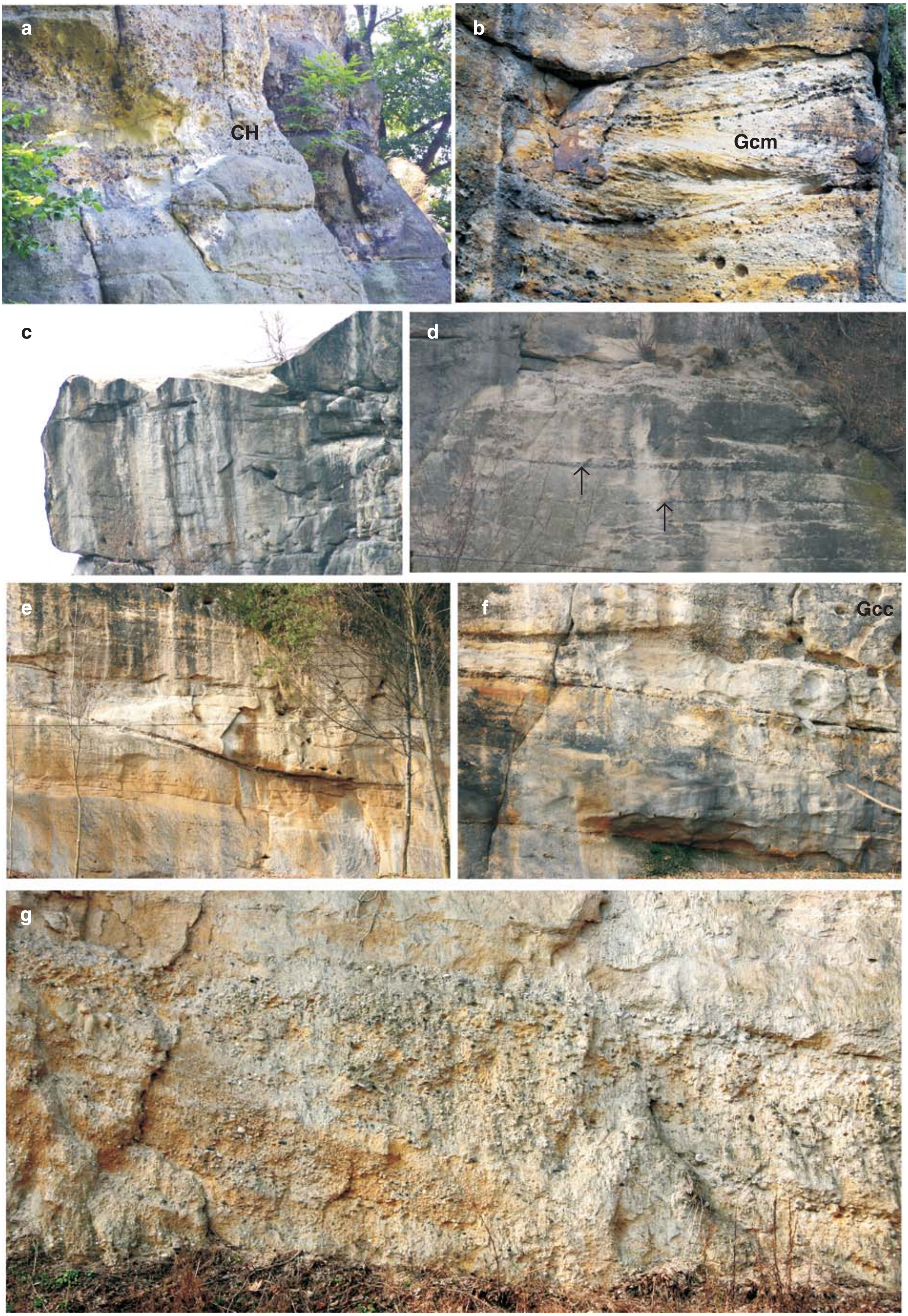
Figure 4. a – high erosional relief at the base of conglomeratic channels (CH), Gcm facies. Radčice near Plzeň. The longer side of the photograph is 5 m on outcrop (oblique view). b – through-cross-bedding in Gcm facies. Pebble admixture in sandstone is present as scattered pebbles and residual lags at the bases of channels or reactivation surfaces. Note the high erosional relief at the base of the channel (top). Radčice near Plzeň. The longer side of the photograph is 4 m. c – through-cross-bedded sandstone of Sc facies. Lobeč near Kralupy nad Vltavou. The longer side of the photograph is 4 m. d – residual pebble lags at the bases of the channels can be seen, as well as the vertical stacking pattern of individual channels. Lobeč near Kralupy nad Vltavou. The longer side of the photograph is 12 m. e – example of small channel approximately perpendicular to outcrop strike. Hostibejk near Kralupy nad Vltavou. The longer side of the photograph is 10 m. f – cross-bedded conglomerates of Gcc facies at the bases of the channels (top). Hostibejk near Kralupy nad



Vltavou. The longer side of the photograph is 4 m. g – diagonally bedded conglomerate of Gcm facies. Northern part of the Hostibejk Cliff near Kralupy. The longer side of the photograph is about 1 m.

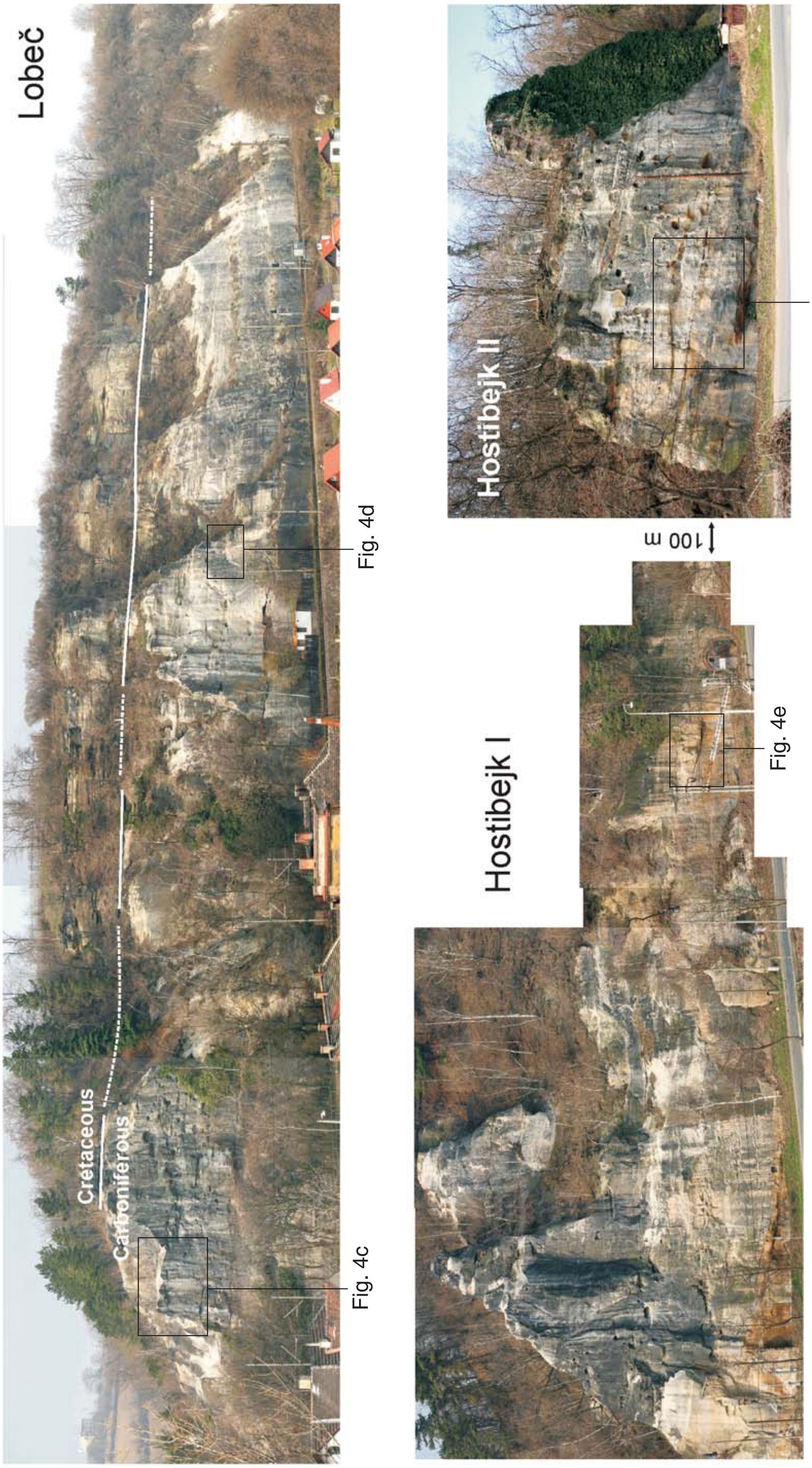


Figure 5. Overview of the studied cliffs at the Lobeč and Hostibejk localities.

eastern margin of the Pilsen Basin. The most extensive and continuous outcrops of fluvial sediments occur at the localities of Radčice (3 km NW of Pilsen), Pecínov (2 km south of Nové Strašecí and Lobeč), and Hostibejk (between Kralupy nad Vltavou and Nelahozeves). These exposures were studied using the methods of facies, architectural, and paleocurrent analysis toward interpreting the sedimentary processes and environment.

The main criteria used for defining the facies follow those of Miall (1978, 1996), which have been adopted by many authors. These criteria principally concern grain sizes and sedimentary structures, the geometry of sedimentary bodies, and presence or absence of identifiable plant remains. The codes used for facies also agree with those used by Miall (1996).

Axes of cross beddings, flute casts, and tool marks were used as the main paleocurrent indicators. In poorly exposed parts, the planar features and foreset dip directions of cross beddings were also considered.

Our analysis of the sedimentary architecture generally follows the approach of Miall (1985, 1996), but outcrop-scale features are described more simply for clarity (see Bridge 1993). They were identified from studied outcrops and are indicated in photomosaics. These photomosaics were prepared as montages of partly overlapping photographs taken from a distance of several tens of metres to avoid distortion. The facies and structural elements are indicated in the photomosaics. Widths and thicknesses of the architectural elements were measured on the photomosaics, and ratios of these dimensions are given. The relation of the actual width of an object to that measured on the photomosaic, which are in some cases oblique to paleoflow, is discussed below.

Characteristics of the studied outcrops

Kralupy nad Vltavou

Two large sets of cliffs are located along the left bank of the Vltava River (Moldau), between the towns of Kralupy nad Vltavou and Nelahozeves. The strike of all the cliffs is approximately to the north. The part located in Kralupy nad Vltavou is called Hostibejk and consists of about three continuous, partly vegetated cliffs, the heights of which vary between 24 and 36 m. However, only two of them were accessible for study (Fig. 5) during the field seasons of 2002 and 2003. The main Hostibejk Cliff (Hostibejk I, Fig. 5) is about 80 m long, whereas the length of Hostibejk Cliff II is only about 20 m.

The Lobeč Cliff is situated further north, and is separated from the Hostibejk Cliffs by a tectonically bounded valley about 150 m wide (Obrhel 1960). Lobeč Cliff is located between the northern margin of Kralupy nad Vltavou and the southern margin of Nelahozeves. It is more than 1 km long. However, only 150 m of its southern part was suitable for photographic documentation, and was studied in detail using the above-mentioned methods (Figs 5, 8).

The strata of the Hostibejk and Lobeč cliffs gently dip to the north at an angle of up to 5°. The stratigraphically oldest strata are exposed along the southern margin of Hostibejk Cliff I, whereas the stratigraphically youngest sediments crop out in the northern part of Lobeč Cliff near Nelahozeves. The cumulative thickness of the studied part of the stratigraphic succession exposed in the Hostibejk Cliffs is estimated to be about 35 m, while that of Lobeč Cliff about 45 m. However, when the non-studied part of the Lobeč exposure is included, its stratigraphic range is seen to be much larger, probably up to a few hundred metres.

The stratigraphic position of the exposed sections is based on biostratigraphy, the lithological character of the exposed strata, and correlations made by using old mining data. Coarse-grained, fluvial-dominated, floodplain-poor sediment successions exposed in the studied cliffs are typical of the Nýřany Member and the Týnec Formation. This is consistent with biostratigraphical and old mining data. Historical exploration of the Upper Radnice Coal at Červená Hůrka Hill (Obrhel 1960, Šetlík 1968), now part of Kralupy nad Vltavou (called “Hůrka”) occurred several tens of metres south of Hostibejk Cliff I. This data indicates that sediments exposed at the base of Hostibejk Cliff I form the close overburden of the coal-bearing strata of the Radnice Member and, therefore, represent the lowermost part of the Nýřany Member. Flora of the Westphalian D character collected by Obrhel (1960) at the top of the southern edge of Lobeč Cliff still refers to the position in the lower to middle part of the Nýřany Member succession. However, the presence of *Sphenophyllum oblongifolium*, the reliable Stephanian element, found by Šetlík (1968) in a roof mudstone of a thin coal seam in a northern part of Lobeč Cliff, approximately 500 m behind the area considered here, clearly indicates a stratigraphic position in the upper part of the Nýřany Member. Thus, all the cliffs between Kralupy nad Vltavou and Hostibejk expose fluvial sediments that range stratigraphically from the lower (both Hostibejk Cliffs) to the upper part of the Nýřany Member (behind the studied sector of the Lobeč Cliff), and possibly up to the Týnec Formation.

Pecínov

The Pecínov locality, about 2 km south of Nové Strašecí, consists of two quarries in which the company ČLUZ j.s. extracts refractory claystone of the Radnice Member (middle Westphalian). This claystone directly underlies the Nýřany Member. Because of weathering and accessibility, only one of these quarries (the western one) was subjected to detailed sedimentological study. Exploration activity is less dynamic in this quarry, and the exposed walls were studied in two successive field seasons in the years 2002 and 2003. The western quarry is about 150 m long and up to 45 m high at its central part. Sediments of the Nýřany Member comprise most of the succession, the thickness of which attains a maximum of 35 m. It is underlain by sediments of the Radnice Member, separated by an erosional surface and overlain by Cretaceous strata. The azimuth of wall is approximately 190°. Strata exposed in the western quarry gently dip to the NNE at an angle of 3 to 5° (Fig. 10).

Radčice

The Radčice locality, about 3 km NW of Plzeň (Pilsen), consists of a discontinuous series of outcrops about 1 km long, east of the village of Radčice, located along the left bank of the Mže River and a road cut. The strata dip gently to the ENE. The stratigraphical position of the exposed strata ranges from the uppermost part of the Nýřany Member in the western part of the outcrops, to the lower part of the Týnec Formation in its eastern part. The boundary between these lithostratigraphic units is marked by several metres of conglomerate at the base of the Týnec Formation. Because of discontinuity and the presence of dense vegetation along most of the exposure, which prevented the taking of photographs for the photomosaic, detailed sedimentological study was performed only on the easternmost cliff, about 100 m long and up to 12 m high. The cumulative thickness of the exposed succession in this part of the Radčice locality is about 16 m, and stratigraphically represents sediments from the lower part of the Týnec Formation.

Sedimentary facies analysis

Six facies (Table 1) were recognized in the studied outcrops of the Nýřany Member (Hostibejk and Lobeč cliffs in the Kralupy nad Vltavou, and the Pecínov quarries near Nové Strašecí) and the Týnec Formation (eastern part of Radčice Cliff). Most of them are sandstone- to conglomerate-dominated. Mudstone-dominated facies are less common or even absent in individual outcrops.

Table 1. Facies recognized at individual localities

Facies	Localities			
	Hostibejk	Lobeč	Pecínov	Radčice
Fsm	–	+	+	–
Sh	+	+	+	–
Sc	+	+	+	+
Gcm	+	+	+	+
Gcc	+	+	+	+
Gm	–	+	+	–

Mudstone-dominated facies

Fsm: Laminated sandstone and mudstone

This facies consists of interlaminations of mud, silt, and very fine-grained sand. The thickness of particular sharp-based bodies varies from 0.1 m (Hostibejk) to more than 1 m (Pecínov). They often rest on an erosional surface or on medium- to coarse-grained sandstone. They pass upward into fine-grained, ripple bedded sandstone, or can be overlain by medium- to coarse-grained sandstone. Lamination can be prominent. Plant remains are locally present either as detritus or identifiable plant remains. Lobeč Cliff provides the best example at the well known locality of the "Nýřany flora" (Obrhel 1960). In the Pecínov quarry, only cordaite leaves were found. Roots are infrequent but are occasionally observed at the Pecínov locality.

Interpretation: Sediments of this facies were deposited mostly from suspension, but also by low velocity unidirectional currents. They most probably represent an abandoned channel fill, as indicated by the erosional surface at the base or by the presence of medium- to coarse-grained sandstone.

Sandstone-dominated facies

Sh: Horizontally stratified, fine-grained sandstone

Fine-grained sandstone forms bodies that are up to 0.95 m thick, with sharp bases underlain by fine- and/or coarse-grained gravel of facies Gp and Gt, and overlain by medium-grained sandstone (facies Sp, St) and fine- and/or coarse-grained gravel (Gp, Gt). The fine-grained sandstone is well sorted with subrounded grains. Sedimentary structures include flat lamination and current ripple lamination. The sandstone often contains plant remains and is rarely interbeded with siltstone.

Interpretation: Sandstone Sh was deposited from traction by a low-energy, unidirectional current. Current ripple lamination, flat lamination, and silt interbeds indicate changes in velocity and sediment load within the channel.

Sc: Cross-stratified sandstone

(Figs 3c, 4c)

Medium- to coarse-grained, cross-stratified, arkosic sandstone dominates these sections of the outcrops. Their base is sharp and erosional, with up to 0.4 m deep cuts into the underlying deposits, though some channels in the Radčice Cliff have erosional relief up to 1.2 m. Pebble lag a few centimetres thick can be present at the base. These facies are usually underlain by fine- or coarse-grained gravel, and are rarely underlain by fine-grained sandstone or medium-grained gravel. Overlying deposits consist of fine- or coarse-grained sandstone. Sandstone Sc is well to moderately sorted with subrounded grains. In most cases this sandstone has a pebbly admixture (maximum pebble size observed is 10 cm). Quartz pebbles are usually better rounded than quartzite, Proterozoic greywacke, and siltstone pebbles, which can even be angular. A feldspar content of up to 30 to 40 % was observed locally. Coalified stems may be present. Rare silt interbeds, silt intraclasts, and pebbles are present either as scattered deposits or as layers within the sandstone bed. The pebbles are usually between 0.5 and 3 cm, with maximum size of 5 cm in diameter. Sedimentary structures include planar and trough-cross bedding. Current ripple bedding is very rare. Sedimentary structures have been locally destroyed by soft sediment deformation, water escape structures, and bed slumping (Figure 2b). This sandstone can appear massive in places of stronger diagenesis and weathering.

Interpretation: Sandstone Sc was deposited from traction by a unidirectional current. Tabular and trough cross stratification record the migration of channel bed forms. High pebble contents indicate the high energy of the depositional current. Pebble lag preserved on base of the sandstone suggests the cessation of a rolling gravel bed load, which could mean a fall in the initial energy of the depositional current. This interpretation is further supported by the fining upwards of several beds terminated locally by current-ripple-bedded sandstone. Soft sediment deformation and slumping reflect channel bank instability.

Gravel-dominated facies

Gm: Massive conglomerate
This facies was observed only in the Lobeč and Pecínov sections. It consists of fine- to medium-grained conglomerate. Pebbles are usually of size between 0.5 and 2 cm. Individual beds are up to 1.3 m thick, with sharp bases. This facies is underlain by coarse-grained gravel and/or coarse-grained sandstone. Overlying deposits are comprised of coarse-, medium-, and fine-grained gravel. Gm conglomerates are poorly sorted, matrix supported, and contain subrounded pebbles. This facies appears massive, occasionally with preserved coarser pebble layers enclosed within finer beds, which marks changes in hydrodynamic conditions and the multi-phase nature of the deposition. The matrix of the conglomerate is mainly composed of moderately sorted, coarse-grained sandstone to fine-grained conglomerate.

Interpretation: The absence of sedimentary structures, and the poor sorting and mixing of fine and coarse material suggest that conglomerate Gm was deposited by gravity flow, probably of a debris flow nature.

Gcm: Cross-stratified, matrix supported conglomerate
(Figs 3d, 4b, g)
These fine- to medium-grained, clast-supported conglomerates are well to moderately sorted, with subrounded pebbles. Coarse-grained conglomerates are less common but not rare. The latter are well sorted, clast supported, and contain subrounded pebbles. Average pebble size is between 0.5 and 4 cm, with a maximum of 20 cm. The conglomerate matrix is formed by medium- to coarse-grained sand and/or fine-grained gravel, occasionally with some amount of compressed plant material. Sandstone rip-up clasts derived from underlying strata rarely occur close to the conglomerate base. Spheroidal limonitic nodules are common. The most common sedimentary structures are trough and tabular cross-bedding with ordered imbricated fabric. Fining upwards into coarse-grained sandstone is observed only occasionally.

The sediments of these facies form erosionally based bodies, with relief between 0.5 and 1.2 m. The base is characterised by a pebble lag a few centimetres in thickness. These facies alternate with cross-bedded sandstone facies.

Interpretation: The conglomerates of these facies were deposited from traction by a unidirectional current. Trough and tabular cross-bedding indicate high discharge and depositional energy, causing the migration of dunes and bars.

Gcc: Cross-stratified, clast supported conglomerate
(Fig. 3e)
This coarse-grained conglomerate is well sorted, clast supported, and contains sub-rounded pebbles. Sedimentary structures include trough and tabular cross bedding, with ordered imbricated fabric. Fining upwards into coarse--grained sandstone was observed in one case. This conglomerate's matrix is composed of coarse-grained sand and/or fine-grained gravel, occasionally with some amount of plant fragments. Rip-up sandstone clasts derived from underlying sediments rarely occur at the base of the conglomerate. Spheroidal limonitic nodules are common.

The conglomerate's base is sharp and erosional, with up to 0.5 m deep cuts into the underlying deposits. This facies is underlain by coarse-grained sandstone in most cases, and rarely by fine-grained sandstone and/or fine- and medium-grained gravel. Overlying deposits consist of coarse-grained sandstone, fine- and medium-grained gravel, and rarely of fine-grained sandstone.

Interpretation: The conglomerate Gcc was deposited from traction by a unidirectional current. The coarse grain size reflects high discharge and higher energy of the depositional current than the Gcm facies.

Analysis of the sedimentary architectural elements

Five architectural elements were recognized: channels, sand bed forms, gravel bar and bed forms, sediment gravity-flow deposits, and downstream accretion macroforms. Not all of these features were observed at each outcrop (Table 2). These elements, defined by their geometries and bounding surfaces (Miall 1996), form the basis for interpreting depositional environments. Individual elements represent different levels in terms of classification; for example, sand and gravel beds form channels, channels form downstream accretion macroforms, while some gravel bars do not represent channel fill but are evaluated as inter-channel elements.

CH: Channels, CH(F): Abandoned channel fills

Channel deposits comprise lithofacies Sc, Gcm, and Gcc. Few abandoned channels in the Pecínov quarry are filled

Table 2. Architectural elements of individual localities

Architectural elements	Facies	Localities			
		Hostibejk	Lobeč	Pecínov	Radčice
CH CH(F)	Sc, Gcm, Gcc, Fsm, Sh	+ +	+ +	+ +	+ –
SB	Sh, Sc	+	+	+	+
GB	Gcm, Gcc	+	+	+	+
SG	Gm	–	+	+	–
DA	Sc, Gcc, Gcm	+	+	+	–


Hostibejk 1
NNW
SSE
SSE
5 m
10 m
Vegetation
Vegetation
Vegetation
SB
GB
CH
CH?
DA?
facies:
Sc
Gcc
Gcm
c si sa gr
0 m

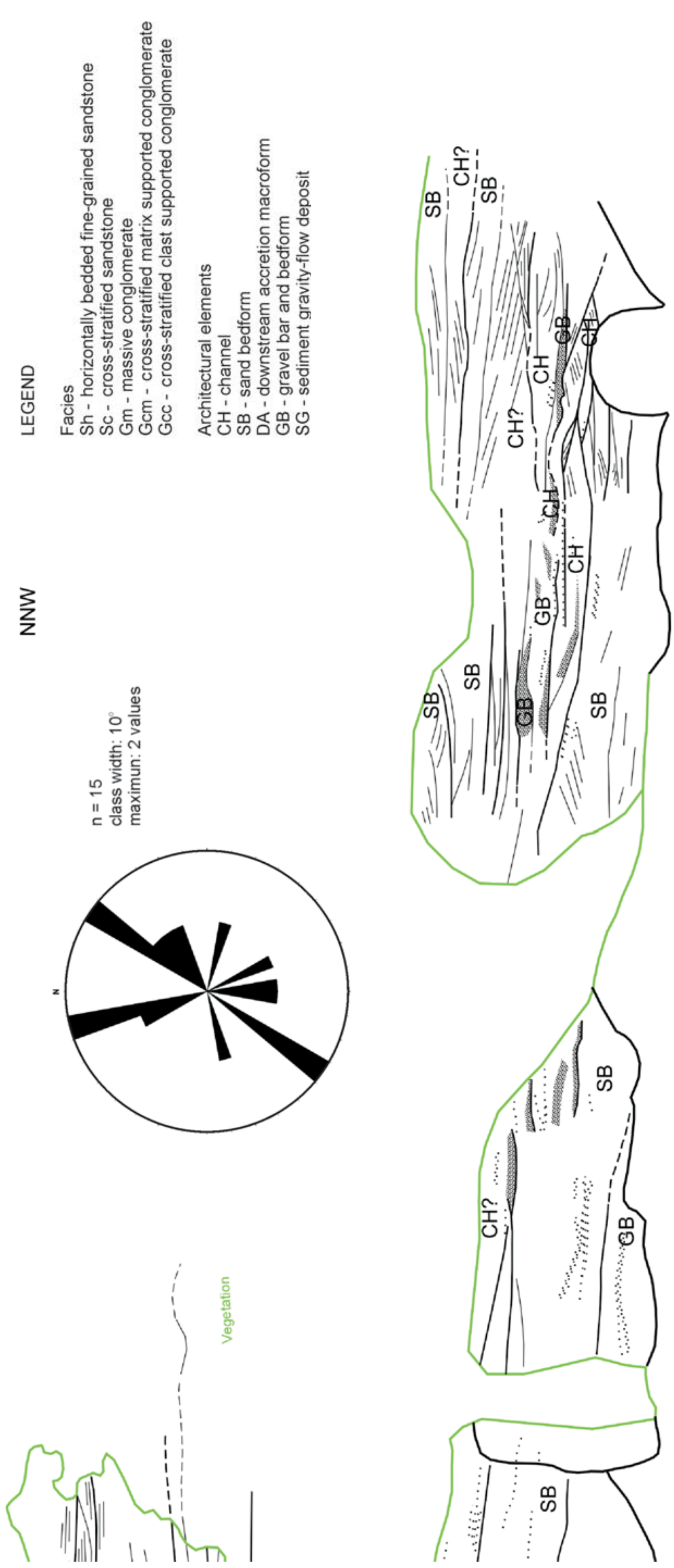


Figure 6. Interpretation of the photomosaic of the Hostibejk I Cliff near Kralupy nad Vltavou, depicted in Figure 5. Paleocurrents are measured on the foreset dip direction on cross-bedding, which explains the large spread of paleocurrent vectors. The limited exposure did not allow the measurement of axes of trough cross-bedding.

with Fsm and Sh lithofacies. Channel deposits have sharp erosional bases with relief of about 4 m at the Pecínov and Kralupy nad Vltavou cliffs, but only 1.5 m at the Radčice locality. They often erode sand bed forms and other channels. Their geometry is of the concave-up channel shape, occasionally forming a multi-storey channel geometry. Channel thicknesses are up to 2 m in most cases, and rarely up to 3.5 m. Channel widths vary between 5 m and 25 m. The average width/thickness ratio is 14.6 within the whole studied area, 17.3 at Hostibejk I Cliff, 13.3 at Hostibejk II Cliff, and 12.6 at Lobeč Cliff (Figs 6–8).

At the Radčice Cliff (Fig. 11) the channel widths vary between 6 m and more than 50 m, but the determination of width is complicated by limited outcrop length and the nearly parallel direction of the channels to the cliff wall.

Interpretation: Channels comprising facies Sc, Gcm, and Gcc record channel deposition. The presence of coarse-grained conglomerates may indicate a sudden increase in the velocity of the depositional current. High lateral migration of channels are a typical feature. Most channels have a multi-storey and multi-lateral nature. Single channels with simple fill were found rarely, e.g. in the upper part of the section cropping out in the Pecínov quarry.

The channel geometry probably represents channels with nearly E-W paleocurrent directions; the SSE-NNW orientations of all exposures display the channels in transverse cross sections, e.g. almost at a right angle to the direction of paleoflow. The channels can be divided into three groups based on their width/thickness ratios: 1. channels with ratios up to 7, 2. channels with ratios between 7 and 16, and 3. channels with ratios between 16 and 40. The first group is represented by only one channel exposed at Lobeč Cliff, the second group includes most of the channels within the studied area, while the

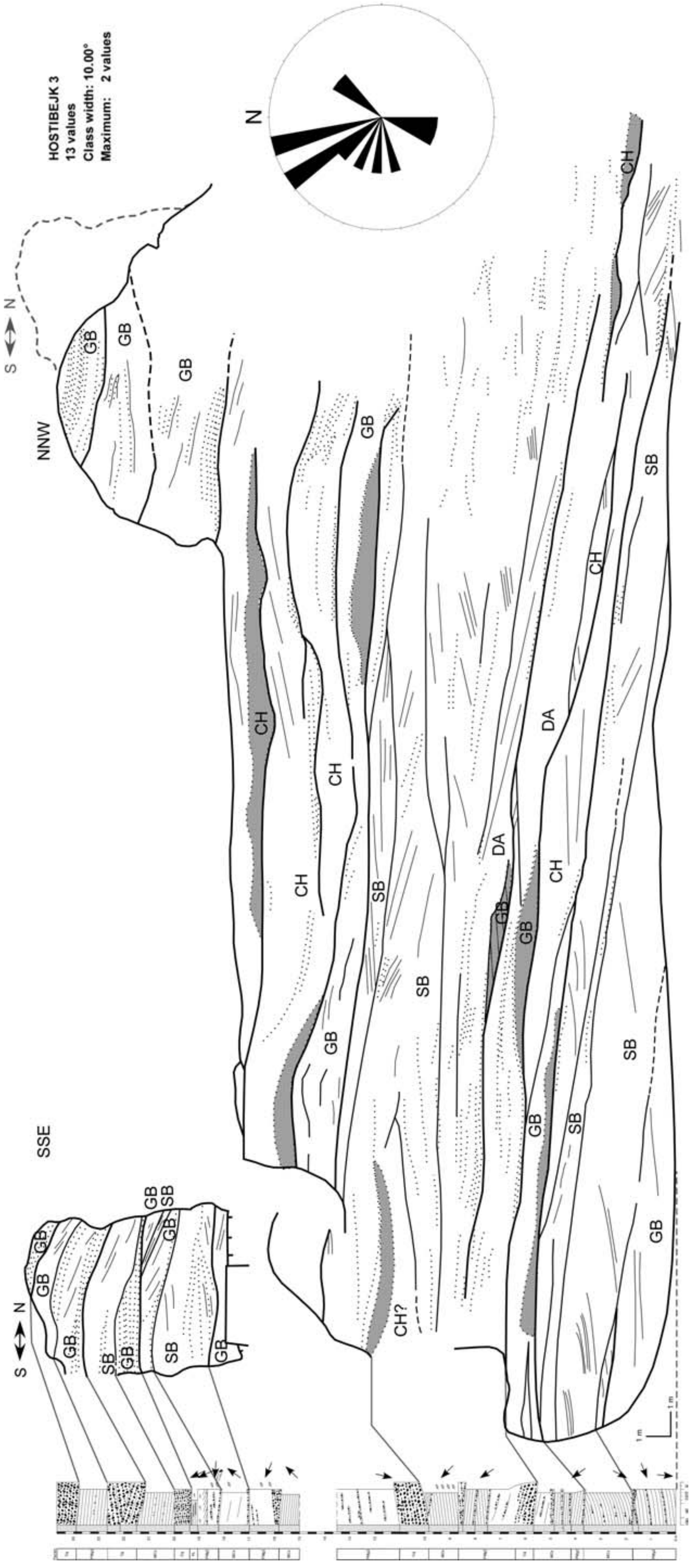


Figure 7. Interpretation of the photomosaic of the Hostibejk II Cliff near Kralupy nad Vltavou. For the photomosaic of the cliff see Figure 5.

third group is represented by the Hostibejk Cliff I channels. Decreasing width/thickness ratios from the Hostibejk to the Lobeč cliffs is a function of exposure orientation. The channels at Hostibejk Cliff are exposed at angles closer to the paleocurrent directions than are those at Lobeč Cliff, which are exposed almost at a right angle to the paleocurrent directions. Thus channels at Hostibejk Cliff display higher widths than channels at Lobeč Cliff.

SB: Sand bars and bed forms

Sheet-like bodies of sand bed deposits comprise facies Sh and Sc. They have sharp bases and are often eroded by channels. The erosional relief of the sand bed forms can be up to 2 m, though at Radčice Cliff it is only between 0.1 and 0.6 m. Sand bed forms are usually about 1.5 m thick, but occasionally reach the thicknesses up to 3 m (at Hostibejk and Lobeč). Their widths vary between 20 m and 40 m in most cases at the Kralupy nad Vltavou cliffs and Pecínov quarry, whereas at the Radčice locality it is only between 10 m and 15 m in most cases. The average width/thickness ratio is 19.3 within the studied area, 21.8 at Hostibejk Cliff I, 21.2 at Hostibejk Cliff II, and 20 at Lobeč Cliff (Figs 6–8).

Interpretation: Sand bed forms record intra-channel deposition. They were probably produced by migrating dunes within the channel. This is supported by paleocurrent measurements, which show paleoflow directions to the NNW, NE. Because of the SSE-NNW orientations of all exposures, where channel geometry is displayed close to the longitudinal cross section (subparallel to paleoflow direction), the channel geometry appears sheet-like. Sand bed forms were probably deposited by migrating dunes within the channel.

GB: Gravel bars and bed forms

Gravel bar and bed deposits comprise facies Gcc and Gcm. They have sharp erosional bases and often erode sand bed forms and channels. Their geometry is lobate or sheet-like. The average width/thickness ratio of the gravel bar and bed forms is 30.6 within the studied area, 24.6 at Hostibejk Cliff I, 15 at Hostibejk Cliff II, and 47.7 at Lobeč Cliff (Figs 5–7). The thicknesses of the gravel bar and bed forms are up to 2 m in most cases, and rarely up to 4 m. Gravel bar and bed form widths are up to 40 m at the Hostibejk Cliffs, but at Lobeč Cliff they reach 135 m. The erosional relief of the gravel bar and bed forms varies between 0.5 m and 4 m.

A flat based gravel bar was observed only at Radčice Cliff. This sheet-like body with a sharp flat base is overlain by sand bed forms and channels. The gravel bar's thickness varies from 0.3 to 1.5 m. Its width is 15 m and erosional relief only 0.2 m.

Interpretation: Gravel bar and bed form deposits, comprising facies Gcm and Gcc, record intra-channel deposition. These gravel bar and bed form deposits can be divided into two groups based on their width/thickness ratios: 1. with ratios up to 15, and 2. with ratios higher than 20.

Gravel bed forms with width/thickness ratios up to 15 display an erosional relief between 1.5 to 4 m. They consist of fine- to coarse-grained conglomerates of the Gcm and Gcc facies. Gravel bed forms record either migrating channel bed loads when comprised of coarse-grained conglomerates (Gcm), or migrating channel bed forms when comprised of facies Gcc. Gravel bed forms with width/thickness ratios higher than 20 record fluvial bar deposition when they are comprised of coarse-grained conglomerate facies and have erosional relief of 0.5 m, or the migration of large channel bed forms when comprised of facies Gcc and Gcm.

If a gravel bed form a few centimetres thick is present within the channel just above the erosional base, we can suggest that gravel bar erosion and subsequent deposition within the channel occurred. This indicates a sudden increase in the velocity of the depositional current.

SG: Sediment gravity-flow deposits

Sediment gravity-flow deposits consist of matrix supported, massive gravels. They have sharp erosional bases and the geometry of elongate lobes. They are underlain by gravel or sand bed forms, and they occur also within channel deposits. These deposits occur rarely at Lobeč Cliff and in the Pecínov quarry. Sediment gravity-flow deposit thicknesses are up to 1 m in most cases. The widths of these sediment gravity-flow deposit vary between 5 m and 7 m. The average width/thickness ratio of sediment gravity-flow deposits is up to 10 within the studied area, while their erosional relief is 0.3 m.

Interpretation: Sediment gravity-flow deposits indicate non-cohesive gravity-flow deposition. Their presence within the channel fills probably records channel bank instability and slumping.

DA: Downstream accretion macroforms

Downstream accretion macroforms comprise facies Sc, Gcc, and Gcm (sand and gravel bed form deposits). Their geometry is sheet-like. Their average width/thickness ratio is of 13.8 within the studied area, 16.3 at Hostibejk Cliff I, and 8.6 at Hostibejk Cliff II (Figs 5–7). Downstream accretion macroforms were not recognized at Lobeč Cliff (Fig. 8). Downstream accretion macroform thicknesses are up to 4.5 m, and widths vary between 20 m and 40 m.

Interpretation: Downstream accretion macroforms record channel deposition. Accretion surface interpretation is based on knowledge of the paleocurrent direction. In cases where paleocurrent directions are sub parallel to the accretion surfaces, they are considered as downstream accretion.

Summary and interpretation of the studied outcrops

Kralupy nad Vltavou

In all, 37 paleocurrent measurements were taken from both cliffs, 28 of which were measured at the Hostibejk Cliffs (Figs 6, 7), and 9 at Lobeč Cliff (Fig. 8). In most cases, they represent measurements of cross bedding and laminae, and only rarely of the true paleoflow indicators such as ridges of current ripples, axes of trough cross bedding, and tool marks. Paleocurrent indicators from the Hostibejk Cliffs show two major trends: to the NNW and to the NE. Only minor components of paleoflow directions are to the S and to the SW. Measurements of Lobeč Cliff also display two dominating directions striking W and E. Measurements taken from the Hostibejk Cliffs agree with the expected position of the source area to the south (Pešek 1994) and the direction of the main drainage approximately to the north.

Hostibejk Cliff

The presence at Hostibejk Cliff of vertically stacked channels forming multi-storey channel fill, downstream accretion, abundant occurrence of gravel bars, and an absence of overbank fine deposits (alluvial plain and/or floodplain deposits), indicate that the depositional environment of the Hostibejk Cliff could be interpreted as a fluvial stream complex of low sinuosity. This depositional environment could be described as a system of probably braided channels, which cut and eroded themselves and accreted downstream. Some channels are bounded by gravel bars. High dynamics and current velocity are reflected in the grain sizes of the deposits (coarse-grained sandstones and conglomerates), in sedimentary structures (very rare preservation of current ripples, abundant cross stratification), and in the geometry of the deposits (multi-storey channels, channel bed forms bounded by erosive surfaces, erosional relief of deposits up to 4 m). The absence of alluvial plain deposits could be explained either by their subsequent erosion by braided channels, or that fine alluvial plain deposits did not occur due to sudden the development and deposition of the complex braidplain. Plant and wood material in the Hostibejk Cliff deposits undoubtedly originated in an alluvial plain; and though the Hostibejk Cliff streams were erosive, we should see some relicts of alluvial plain deposits exposed there. Thus the interpretation is that a distant allu-

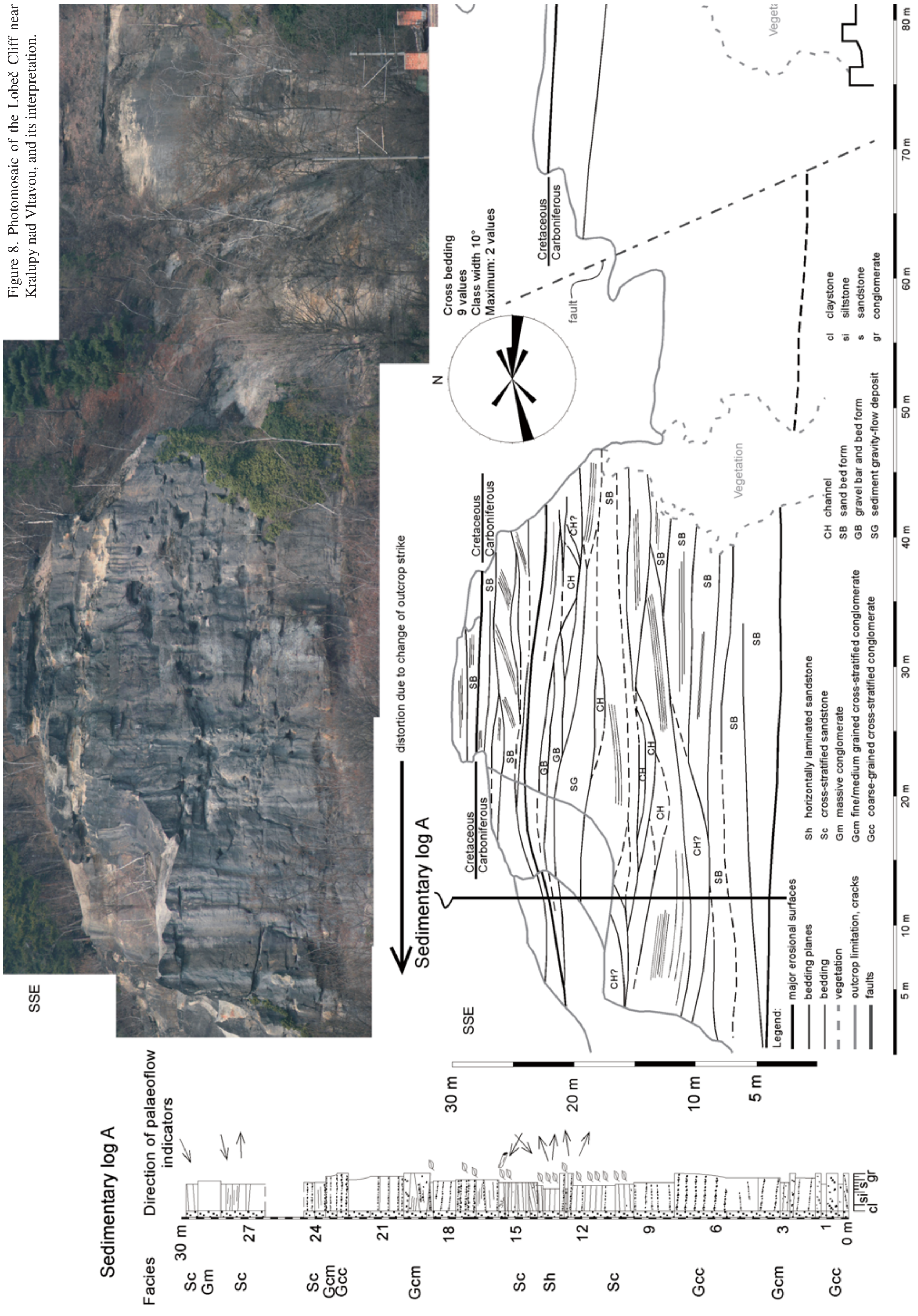


Figure 8. Photomosaic of the Lobeč Cliff near Kralupy nad Vltavou, and its interpretation.

Figure 8, continued

vial plain existed, from which plant and wood material was transported by braided streams, and which evolved into the braidplain. It must be noted that this interpretation is influenced by the limited exposures in the Kralupy nad Vltavou area.

The paleocurrent analysis shows a relatively low spread of paleocurrent vectors, which is characteristic of low sinuosity streams. The major paleoflow trends are to the NNW and to the NE, with only minor directions to the S and to the SW. Therefore, we propose that the main sediment supply was from the SSE and SW generally toward the N-NE.

Lobeč Cliff

Lobeč Cliff (see Fig. 7) represents a different depositional environment than that recorded in the Hostibejk Cliffs. Rare occurrences of gravel bars and the generally finer grain size of the deposits, especially in the upper part of Lobeč Cliff, indicate that the depositional environment was a complex of fluvial streams with higher sinuosity than those of the Hostibejk Cliffs. The depositional environment could be described as a complex of vertically aggrading channels that partly cut into the underlying ones. The dynamics and velocity of the paleocurrents probably decreased in time as indicated by the fining upwards in grain size within the sequence (fine- and medium- to coarse-grained sandstones), by sedimentary structures (current ripple and horizontal lamination), and by the geometry of the deposits (erosional relief of deposits up to 2 m). However, the Lobeč Cliff channels should not be interpreted as representing high sinuosity or meandering streams, as there is an absence of lateral accretion macroforms (e.g., point bars), while coarse-gravel channels and rare gravel bars occur only at the lower part of Lobeč Cliff.

In addition to a Carboniferous/Cretaceous unconformity recognized at the upper part of the outcrop, a significant intra-Carboniferous unconformity was recognized also near the bottom of the cliff. A succession of relatively thin, typically 1 to 2 m thick channels, bars, and bedforms occurring above the unconformity, is described in detail above. The underlying succession is poorly exposed, but beds of crudely stratified fine-grained pebble conglomerates up to 4 m thick can be seen. The latter succession represents very a different fluvial system not observed at the other localities.

Several subvertical faults were interpreted in the central part of Lobeč Cliff. A large southern fault zone shows significant reduction of the upper Carboniferous succession on the hangingwall between the unconformities. This seems to indicate predominant horizontal displacement, which is further supported by the occurrence of a smaller negative flower structure north of main fault zone (see Fig. 8).

Comparison of the fluvial styles of the Hostibejk and Lobeč cliffs

The sedimentary record preserved at Lobeč Cliff is interpreted as a product of deposition in streams of higher sinuosity and lower dynamics than at the Hostibejk Cliffs (Fig. 9). This is indicated by a higher spread of paleocurrent vectors, which is characteristic of high sinuosity streams, and by generally finer-grained nature of the fluvial sediments.

The transition from a low sinuosity, highly dynamic, braided river system (Hostibejk Cliffs) to the higher sinuosity and less dynamic braided system of the Lobeč Cliff may be explained as a gradual change from one fluvial style to another. Deposits exposed at Hostibejk Cliff II display a more distinct vertical stacking pattern than those of the lower part of Hostibejk Cliff I, where the architecture of the sedimentary record indicates the lateral migration of channels and the presence of multi-storey channels. The overlying Lobeč Cliff deposits, representing the final depositional environment of higher sinuosity and lower dynamic streams flowing to the E, could record a gradual change from the vertically stacked channels of Hostibejk Cliff II to the aggrading channels of Lobeč Cliff. Thus the Kralupy nad Vltavou successions represent a gradual cessation of the initial high energy depositional conditions (Hostibejk Cliffs) to the final lower energy depositional conditions (Lobeč Cliff). The change in paleocurrent directions could be explained by the gradual change in dip of the basin floor, which could be the primary cause of the gradual change of the depositional environments. A gradual change in the dip of the basin floor could be related to gradual infilling of the basin with sediments or by changes in tectonic activity.

An alternative explanation relates the existence of two different sedimentary environments to a short-term hiatus between the deposition of sediments exposed in Hostibejk and Lobeč cliffs, which could be responsible for changes in the tectonic settings and consequently for the re-configuration of local paleogeography/paleotopography. The possible existence of such short-term hiatuses within the Nýřany Member has been mentioned by Wagner (1997), who studied the floral succession within this unit. Additionally, such a change in sedimentary environment can also be related to the different stratigraphic positions of sediments exposed in cliffs that are separated by a fault-bounded valley (Obrhel 1960). Such a fault could be responsible for the juxtaposing of stratigraphically higher parts of the Nýřany Member, exposed at Lobeč Cliff, against the basal part of this unit at the Hostibejk Cliffs.

Pecínov

The main sedimentological studies were carried out in the western quarry, where up to 35 m of the basal Nýřany Member strata are exposed in a wall about 150 m long. The conglomerate-dominated basal sediments of the Nýřany Member are separated from the underlying Radnice Member by a hiatus marked by a prominent erosional surface (6th order sensu Miall 1996), with only minor relief of about 2 m over the distance of the whole quarry (Fig. 10). The exposed part of the Nýřany Member is dominated by conglomerate (Gcc, Gcm) and sandstone (Sc) lithofacies, with only a minor occurrence of mudstone lithofacies. Conglomerate lithofacies predominate the lower part (approximately the lower third) of the exposed section. The remaining upper part is dominated by sandstone lithofacies with erosional relics of mudstone and fine grained sandstone (lithofacies Fsm and Sh).

The most common architectural elements are channels, gravel bars, and sand bedforms. Down stream accretion macroforms were rarely observed. Channels are mostly filled by conglomerate or sandstone facies with planar or through cross bedding. Pebble admixture is common in the sandstones. Minor erosional surfaces are also frequent, indicating a multi-storey pattern of channel fill. Channels in the middle part of the section, bounded at the base by up to 4 m of erosional surface, are filled by mudstone and fine grained sandstone lithofacies (Fsm, Sh). The bounding surfaces are of several hierarchies. Except for the most prominent discordances separating the Nýřany Member from the Radnice Member at the base, and from the Cretaceous sediments at the top of the wall (basin-wide surfaces of the 6th and 7th order, sensu Miall 1996), there are bounding surfaces of the 5th order within the Nýřany Member which are generally traceable over the whole exposure. They show erosional relief between 1 and 2 m which locally reach up to 4 m. The distance of adjacent surfaces is between 2 and 8 m, being about 5 m in average. They are interpreted as a base of major channels with multi-storey fill patterns, as indicated by the presence of bounding surfaces of lower hierarchies. The generation of the main bounding surfaces of the 5th order is a response to base level changes.

Paleocurrent data were measurable only in the upper half of the section, and are derived from cross-bedding and partly from axes of through cross bedding. They indicate a NNE direction for the main clastic transport. This trend is consistent with the assumed position of the main source area to the south, and the basin centre to the north (Pešek 1994).

As a whole, the succession exposed in the Pecínov quarry is characterized by a fining upward trend indicating the increasing thickness of the channel elements. Also the presence of mudstone-dominated facies is typical for the upper part of the succession. This change in grain size and in stacking pattern is interpreted as a transition from a highly dynamic, shallow gravel bed, braided, fluvial system to an apparently less dynamic, sandy, braided fluvial system. Paleocurrent data for the low sinuosity fluvial systems in the Pecínov area indicate NNE directions for the main clastic transport.

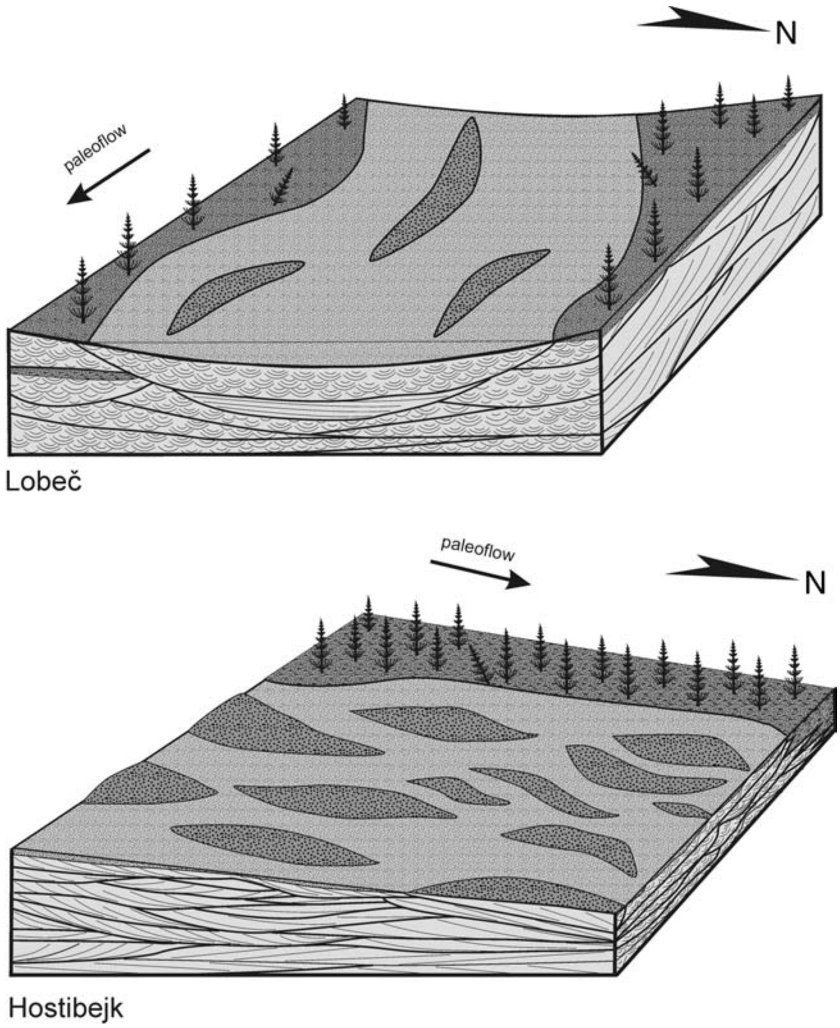
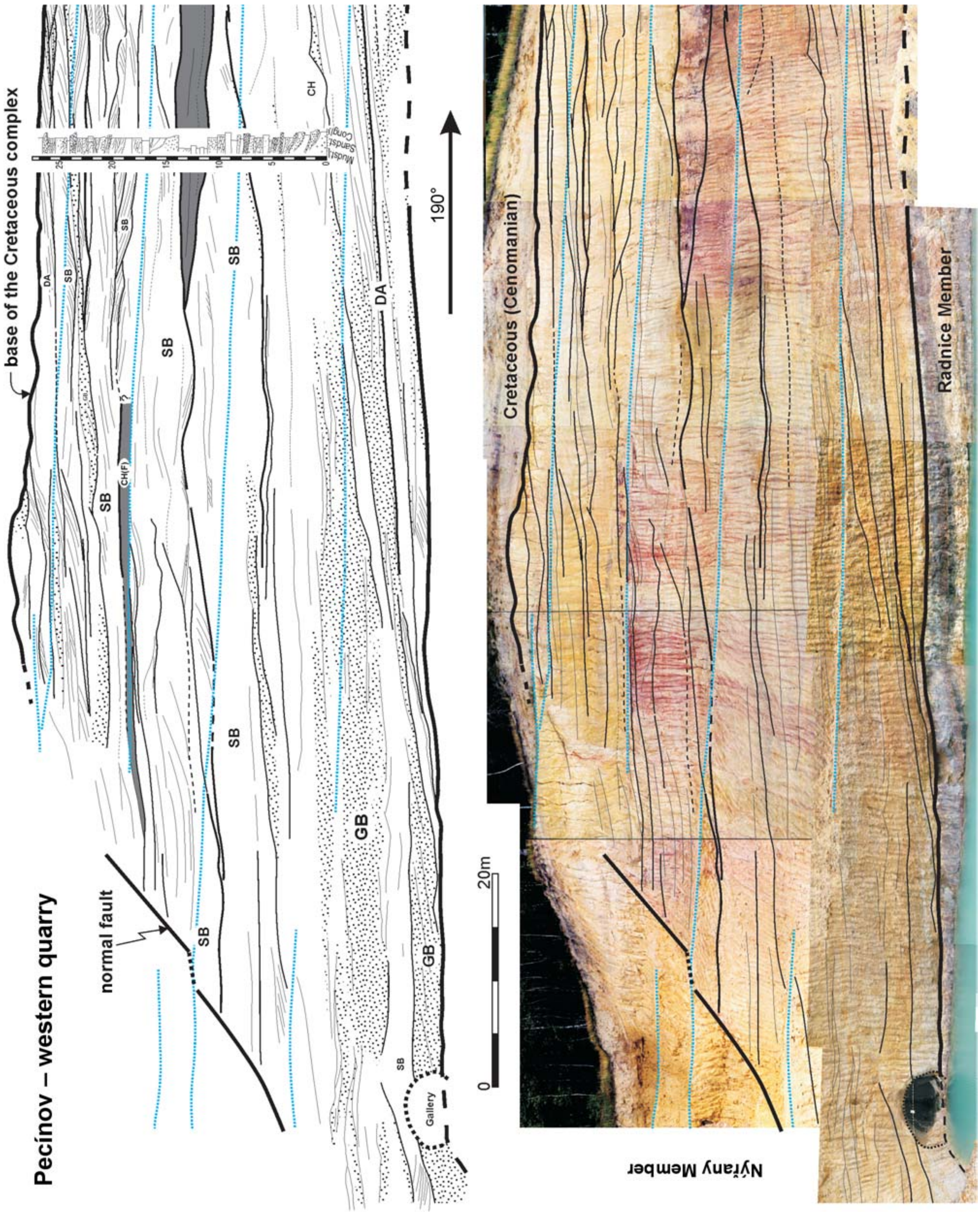


Figure 9. Depositional models of the Nýřany Member of the Hostibejk and Lobeč cliffs.

Radčice

Our interpretation of the Týnec Formation fluvial system, exposed on the eastern part of Radčice, is based mainly on measured sections and photomontage of a 70 m long and 12 m high rock cliff situated on the road to Radčice north of Plzeň. Facies analysis reveals that this outcrop is dominated by the Sc and Gcm lithofacies. Cross bedding and erosional bases are the most common features in sandstones of the Sc facies, and matrix supported conglomerates of the Gm facies. Clast supported conglomerates of the Gcc facies occur locally. Low angle cross bedding was also observed locally, ripples are absent (see Fig. 11).

This outcrop is dominated by channel architectural element CH, with higher erosional relief (up to 2 m). Channel fill is vertically stacked in a multi-storey pattern, but a lateral migration forming a multi-lateral pattern prevails in most of the outcrop. Width/depth ratios range approximately between 5 and 20. Finer grained sandy bedforms (architectural element SB) occur less frequently. They form the top of the channel fill, and are often eroded by channels (CH). Low-angle, cross bedded gravel and sand bars of the GB architectural element occur rarely (see Fig. 11).



Paleocurrent indicators show a low spread of vectors; the axes of trough cross bedding and foresets of planar cross bedding range between 55° and 180° , but are mostly between 120° and 180° (Fig. 11).

The features mentioned above lead to the interpretation of the Nýřany Member fluvial system in the Radčice area as a high energy, higher gradient system with low sinuosity. The considerable lateral migration of channels indicates unstable banks. No substantial changes in grain size were observed in vertical sections, though lateral variation in grain size can be observed within individual channels, which is mostly a function of hydraulic factors. These features can be

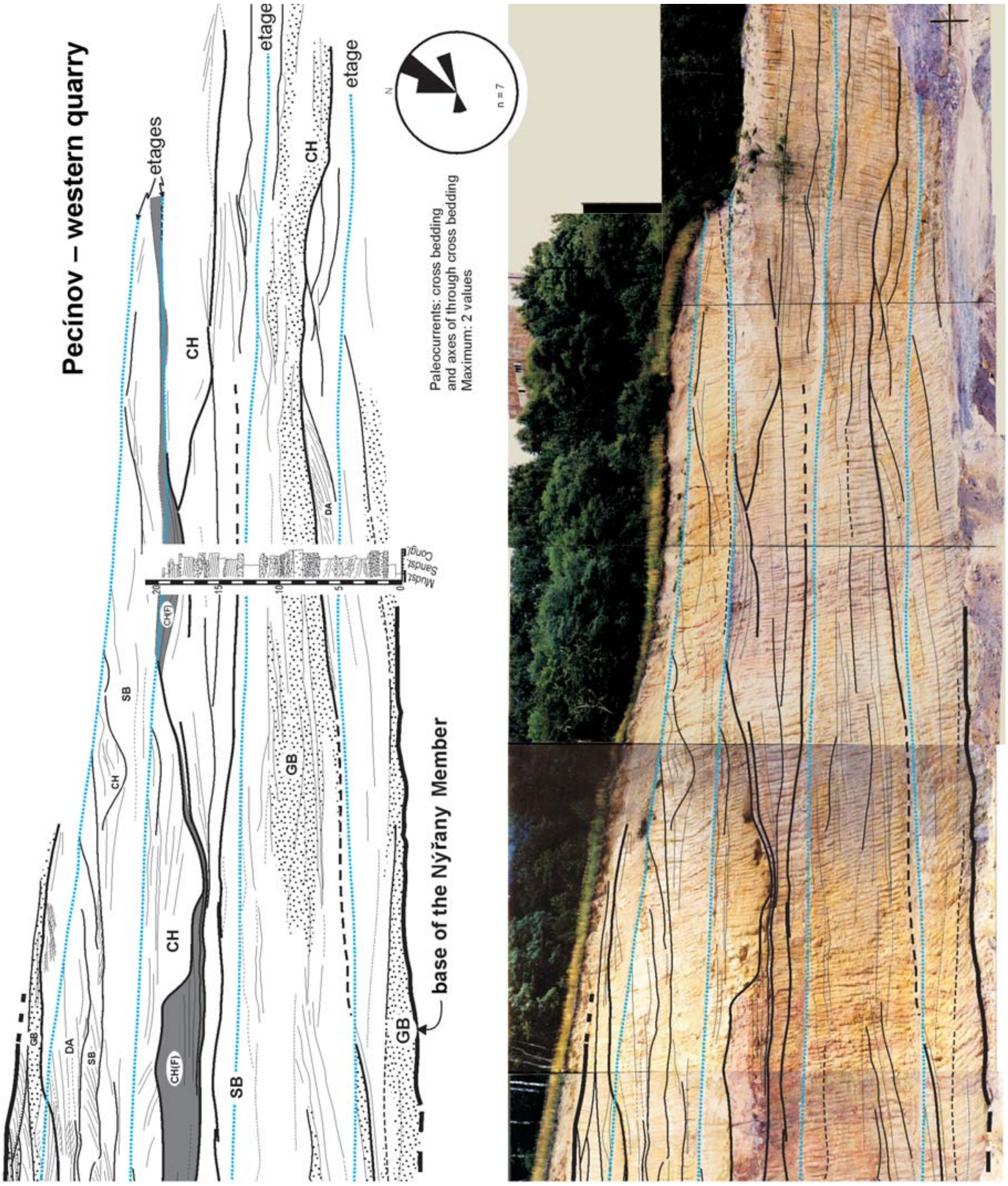


Figure 10. Photomosaic of the western Pecínov quarry near Nové Strašecí, and its interpretation.

interpreted as a fluvial system with relatively high and uniform discharge. The climatic setting was generally humid, though some minor climatic variations could occur (such as seasonal variations in rainfall). This interpretation is supported by the occurrence of residual lags at the base of many erosionally-based channels. This can be evidence of higher energy/discharge during channel incision.

Discussion, conclusions and recommendations

Sedimentological studies of fluvial strata at the above-mentioned localities indicate that the fluvial conditions of the Nýřany Member and the Týnec Formation changed with time. Generally, sediments exposed at all of the studied localities are interpreted as a record of a braided fluvial system. However, differences in stacking patterns and variability in grain size and the presence/absence of fine-grained facies indicate the existence of different types of braided rivers.

The basal part of the Nýřany Member exposed at Hostibejk Cliff I and the lower part of the Pecínov quarry was interpreted as a high energy braided fluvial system with low sinuosity channels. Here, the sediments are characterized by increased conglomerate facies and the absence of fine grained facies deposited from suspension. Paleocurrent data show a typically narrow range of directions striking to

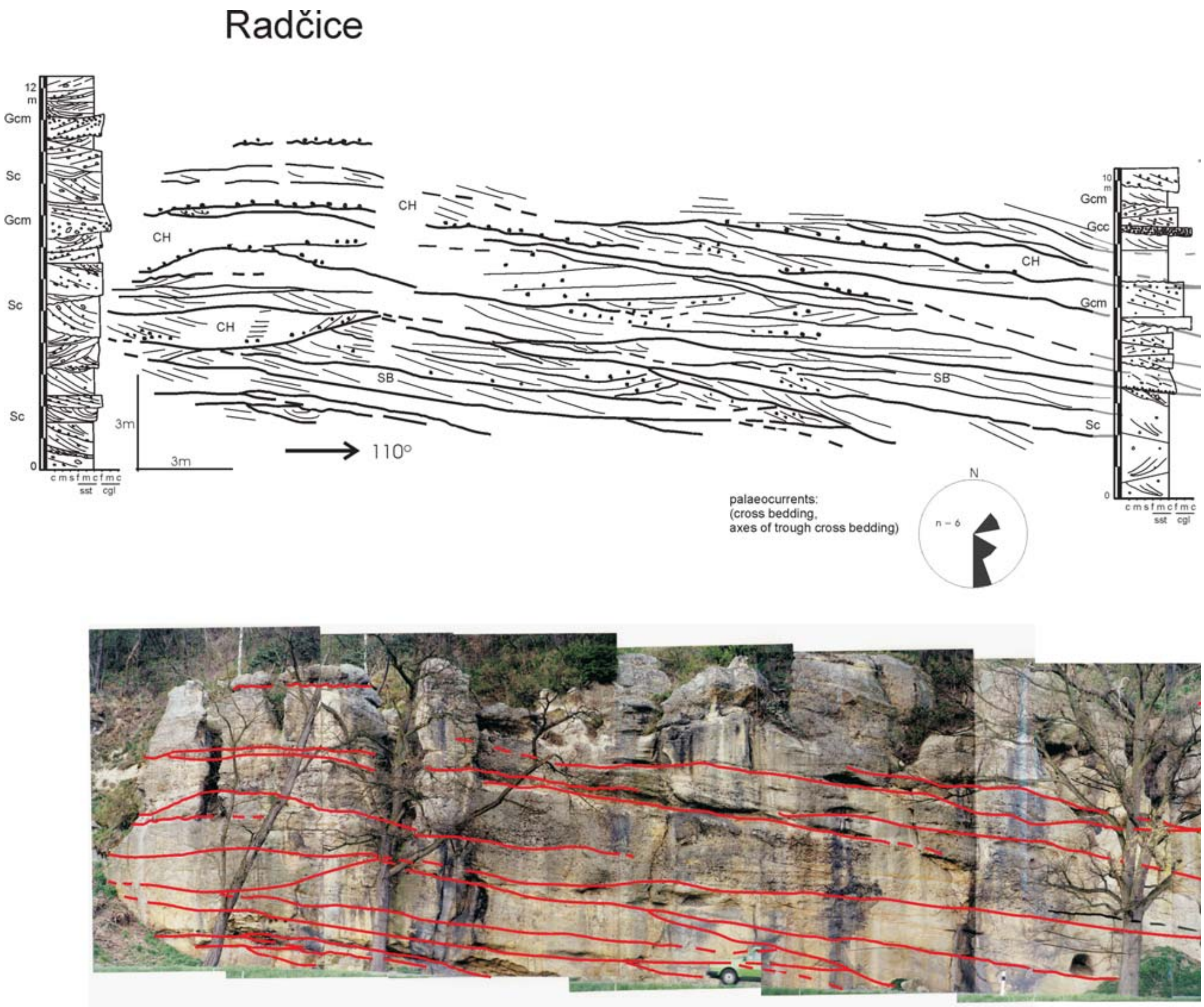


Figure 11. Photomosaic of the eastern part of the Radčice Cliff near Pilsen. Týnec Formation, Cantabrian-Barruelian.

the north. This is consistent with the assumed location of the main source area to the south and the basin centre to the north (Fig. 9), as already stated by Havlena and Pešek (1980), Pešek (1994), and Pešek et al. (1998). This type of braided river deposition seems to have gradually passed upward into a less dynamic braided river system of higher sinuosity, exposed at localities in Lobeč and probably also in the upper part of the Pecínov quarry. It is marked by a generally finer grain size of sediments, by the presence of fine-grained facies (Fsm, Sh) interpreted as that fill of an abandoned channel or possibly as the preserved remains of floodplain sediments. This system is also characterized by a wide range of paleocurrent data. Unfortunately, the paleocurrent indicators in the Pecínov quarry are not as prominent as those from Lobeč Cliff. A high-energy, low sinuosity, braided river system prone to lateral migration was also interpreted in the eastern part of the Radčice locality in the lower part of the Týnec Formation. Facies deposited from suspension or low velocity currents are absent in the studied part of the succession. Paleocurrent data indicate a prevailing SE to S direction for the main clastic transport. Thus, the Radčice fluvial system is partly similar to that of Hostibejk Cliff I and the lower part of the Pecínov quarry. The extent of the present study, however, does not allow us to decide whether these changes in the character of the braided rivers were basin-wide or only local, or whether they were related to local tectonic or paleogeographic conditions. Answering these questions will require further studies of other localities, and their correlation to borehole samples from the central parts of the basins.

The thickness of the studied succession, which ranges stratigraphically from the base of the Nýřany Member to the lower part of the Týnec Formation, is estimated to be about 320–350 m, whereas the cumulative thickness of the stratigraphic succession exposed in the studied cliffs is about 100 m (including the partial stratigraphic overlap of the Hostibejk and Pecínov sections). These localities represent the approximately 50 m thick basal part of the Nýřany Member succession. The part of Lobeč Cliff studied here represents a further 40 to 45 m of stratigraphic interval of the Nýřany Member located below the middle part of the succession of this unit. Con-

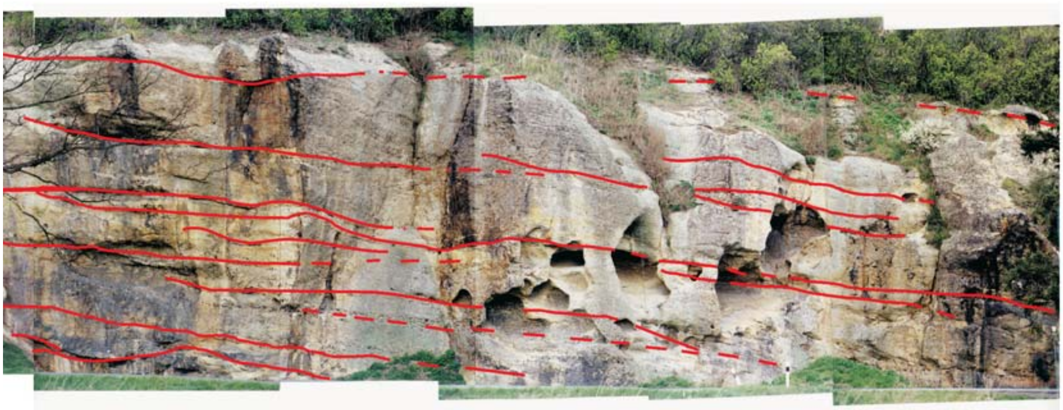


Figure 11, continued.

cerning Radčice Cliff, only an approximately 20 m thick succession, located along its eastern and most continuous part of its outcrops, was studied. It comprises the youngest strata that belong to the lower part of the Týnec Formation.

Future work, therefore, should focus on the detailed sedimentological study of the other outcrops, and the correlation of exposed strata to wireline log and core data derived from boreholes in the vicinity of studied localities. This will clarify the lateral relations of these deposits. Gamma ray field measurements should be undertaken in the future toward correlating distant successions more precisely. Such data could allow more thorough and rigorous climatic/tectonic interpretations.

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