DAY 2
Tectonics and Depositional Systems of a Shallow-Marine, Intra-Continental Strike-Slip Basin: Exposures of the Český Ráj Region, Bohemian Cretaceous Basin

David ULIČNÝ, Stanislav ČECH and Radomír GRYGAR

[1] *Geophysical Institute, Academy of Sciences of the Czech republic, Boční II/1401, 141 31 Praha 4, Czech Republic*
[2] *Czech Geological Survey, Klárov 3, 118 21 Praha 1, Czech Republic*
[3] *Insitute of Geological Engineering, VŠB– Technical University Ostrava, 17. listopadu, 708 33 Ostrava, Czech Republic*

Introduction: focus of the field trip

The aim of this field trip is to demonstrate the relationships between tectonic evolution and sedimentary infill of the Bohemian Cretaceous Basin, an intracontinental strike-slip basin system which formed by reactivation of Palaeozoic basement fault zones of the Bohemian Massif. Although the basin system was short-lived (<11 My) and the thickness of its preserved infill is mostly less than 1 km, good exposures and abundant borehole data allow to study in detail the record of tectonic events and other processes in depositional systems. The Český Ráj area of northeastern Bohemia is famous for its "rock cities", areas of excellent exposure of late Turonian-Coniacian deltaic sandstone bodies (Uličný, 2001). These coarse-grained deltas represent the most typical basin-fill style developed during the lifetime of the Bohemian Cretaceous Basin. Outcrop features examined during the trip provide insights into the hydraulic processes that operated in the depositional setting, as well as into the genetic sequence-stratigraphic aspects of the deltaic systems. This information is combined with regional correlation, based on well logs and cores, which allows to appreciation the relationships between longer-term geological processes that operated at the basinal scale: basin-floor subsidence, sediment supply, and eustasy. The trip also demonstrates the post-depositional deformation at the northern basin margin, related to widespread inversion of Central European intra-continental basins during Late Cretaceous-Paleogene times.

Tectonic and palaeogeographic framework

The Bohemian Cretaceous Basin and its source areas formed during the mid-Cretaceous, within an anastomosed system of strike-slip faults inherited from the structural pattern of the Variscan basement of the Bohemian Massif (Fig. 1; Uličný, 1997, 2001; Voigt, 1996). There is a general agreement that the basin system of the Bohemian Cretaceous formed in response to far-field stresses transmitted through the Alpine-Carpathian foreland during the early phase of eo-Alpine collision (e.g. Malkovský 1987; Ziegler 1990, Pfiffner 1992, Faupl and Wagreich, 2000), which led to reactivation of the pre-existing basement shear zones at upper crustal levels. Individual pull-apart sub-basins and adjacent source areas formed at WNW to NW-trending, principal displacement zones having a dextral sense of slip. These overlapping fault zones belong to the Elbe Zone as interpreted by Arthaud and Matte (1977), Matte et al. (1990) and other authors, or to the southern part of the Elbe Fault System sensu Scheck et al. (2002), which includes also the Sudetic Fault system (e.g. Aleksandrowski et al., 1997). Numerous subordinate NW-NNW-directed faults (Fig. 1B) probably functioned as Riedel shears related to the principal Elbe Zone faults. Several NNE-directed fault zones, such as the Rodl Line (Brandmayr et al., 1995) were reactivated as conjugate, antithetic fault zones and locally significantly influenced the basin palaeotopography.

Because of the number of sub-basins and intrabasinal uplifts active during the basin lifetime, the Bohemian Cretaceous Basin should not be seen as a single basin, and it is more useful to refer to it as a "basin system". For instance, in the "Police Basin", a Cretaceous successor to the Palaeozoic Intra-Sudetic Basin, as well as in the Kraliky Graben (Nysa Trough), many features in stratigraphic evolution and palaeogeography show that these Sudetic sub-basins were closely linked to the larger sub-basins formed within the Elbe Zone proper.

The tectono-sedimentary history of the Bohemian Cretaceous basin system was divided into three principal parts by Uličný (1997): initial Phase I (middle-late Cenomanian), mature Phase II (late Cenomanian-early Coniacian), and terminal Phase III (mid-Coniacian through Santonian; Fig. 2). The depositional patterns of the early Phase I, reflecting the filling of pre-Cenomanian topography and early movements of reactivated structures, are described e.g. by Uličný and Špičáková (1996) and Špičáková and Uličný (2002). The tectonic-driven transition from the early fluvial-estuarine deposition of Phase I, with dominant role of NNE-directed fault systems of the Rodl Line, to the mature Phase II characterized by dominance of dextral displacement on the NW-directed Lužice and Labe Fault Zones is described by Uličný et al. (2003, this volume). This field trip focuses on the depositional patterns of Phase II which was characterized by progradation of coarse-grained deltaic systems basinwards from the marginal strike-slip faults (Fig. 3A,B). The early Coniacian deposits of the Český Ráj region probably recorded an increase in subsidence rates which later culminated during the Phase III (Fig. 2A).

During the mature phase (Phase II) of basin evolution, the structurally deepest depocentres were situated along the most active marginal strike-slip faults: the Lužice (Lausitz)

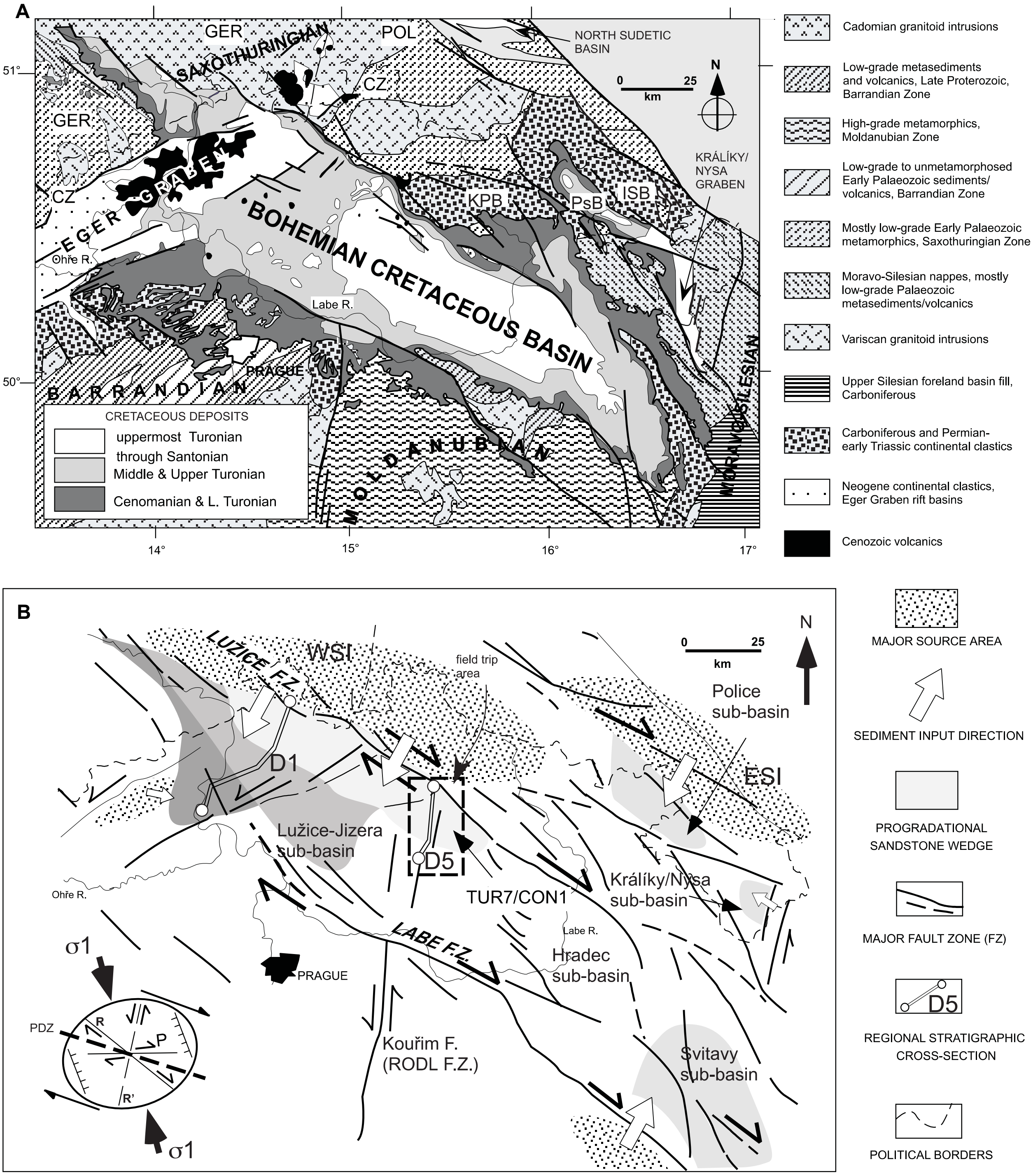


Fig. 1. (A) Schematic geological map of the Bohemian Cretaceous Basin and its surroundings showing the major tectonostratigraphic units of the Bohemian Massif. KPB – Krkonoše Piedmont Basin; ISB – Intra-Sudetic Basin; PsB: Police sub-basin. Compiled from various sources. (B) Schematic map of the tectonic and palaeogeographic setting of the Turonian-early Coniacian sandy deltaic systems of the Bohemian Cretaceous Basin. The overall shape of the sandstone bodies is highly simplified: each lobe in the drawing represents an area of numerous subordinate foreset packages. For chronostratigraphic significance of genetic sequences TUR 1-7/CON1 see Fig. 2. WSI, ESI – Western and Eastern Sudetic Islands, respectively. Inset: kinematic scheme of the main structural elements active during the Cretaceous deposition and corresponding prevailing orientation of ?1 – principal horizontal stress. PDZ – principal displacement zone; R, R', P – Riedel shear terminology, after Christie-Blick and Biddle, 1985.

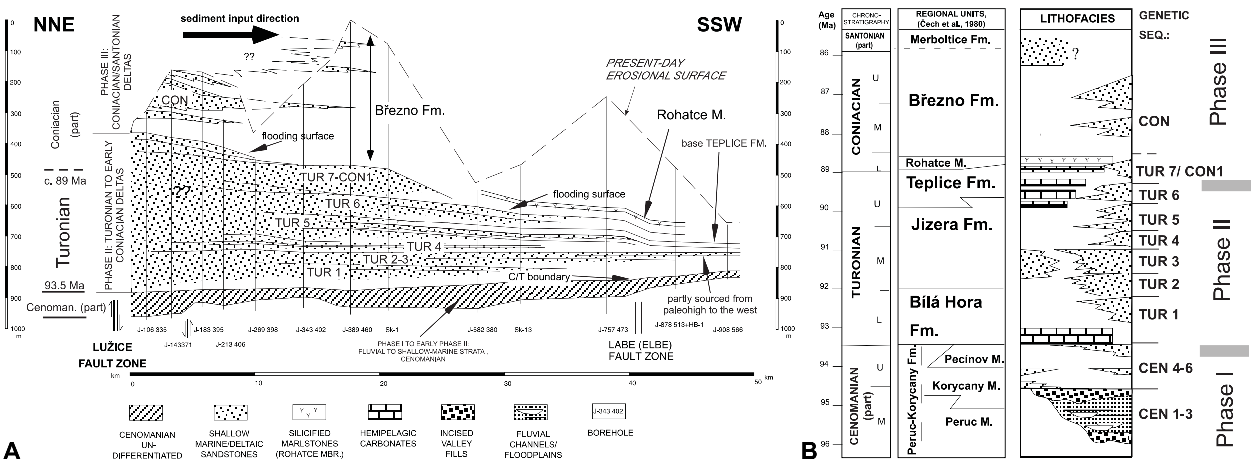


Fig. 2. (A) Basin-scale stacking patterns of coarse-grained deltaic bodies of Turonian-early Coniacian age in the western part of the Bohemian Cretaceous Basin, stratigraphic cross-section D1 in Fig. 1b. Genetic sequences TUR1-7 etc. after Uličný and Laurin (2001) and Laurin and Uličný (in review). Correlation panel based on well-log and core data; see Uličný (2001) for details and regional context. Correlation lines are flooding surfaces. 25× vertical exaggeration. Geochronologic dates from Hardenbol et al. (1998). (B) Synoptic stratigraphic table showing the chronostratigraphic positions of genetic sequences CEN1-6, TUR1-7/ CON1. Younger sequences in the Coniacian not resolved.

Fault Zone and southwest of the Intra-Sudetic Fault Zone. The regional subsidence rate gradients, however, were relatively gentle and the cross-section of the basin (Fig. 2) shows a geometry similar to the box-grabens typical of most pull-apart basins (Dooley and McClay, 1997). The Cenomanian through late Turonian / early Coniacian subsidence regime was characterized by relatively low subsidence rates (c. 70–100 m/Ma maximum; Uličný, 1997). Such rates, unusually low for a strike-slip basin system (cf. Christie-Blick and Biddle, 1985), are attributed to strain distribution in the broad, anastomosed fracture zone and the resulting small net displacement along the principal strike-slip faults (Uličný, 1997).

The largest depocentre during this stage of basin evolution was the Lužice-Jizera sub-basin located south of the Lužice Fault Zone (Fig. 1, 2). There, the sandstone bodies of the Bílá Hora, Jizera, and Teplice Formations, representing prograding deltaic shoreface depositional systems, are spectacularly exposed in the so-called "rock cities" of North Bohemia and Saxony. The siliciclastic source was an uplifted block north of the Lužice Fault (the Western Sudetic Island, cf. Skoček and Valečka, 1983). Regions devoid of direct siliciclastic input were characterized by deposition of offshore muds and marls, and, under specific circumstances, even hemipelagic limestone-marl facies (Čech et al., 1996; Svobodová et al., 2002; Laurin and Waltham, 2003, this volume)

The youngest preserved deposits are of Santonian age, and their small areal extent precludes speculations about the palaeogeography and tectonic regime at that stage of basin evolution; it is not known whether the Late Cretaceous deposition continued beyond the Santonian (cf. Valečka and Skoček, 1991). The basin-fill succession experienced uplift and deformation during the Cenozoic, notably during the Paleogene transpressional episode (e.g.Coubal, 1990). The history of Cenozoic deformation, exhumation and erosion of the basin system has not been thoroughly studied yet. The preservation of a thick successions of Late Turonian through Santonian strata in the downthrown blocks of the Oligo-Miocene Eger Graben clearly show, however, that the Cenozoic uplift, especially in the central part of the basin, led to erosion of at least 500 m of Cretaceous strata.

Controls on evolution of the český ráj deltaic systems (field trip stops 1 and 2)

Throughout the Lužice-Jizera sub-basin, deltaic bodies show a variety of internal geometries, ranging from stacks of very thin (3–15 m) deltaic packages with low-angle foresets to thick (50–75 m) packages of high-angle foresets (10-30°). The former, named descriptively Type-L packages, were recently interpreted as record of progradation of shallow-water deltas, whereas the latter (Type-H) correspond to deep-water deltas (Fig. 3; Uličný 2001). This interpretation is, in fact, close to the intuitive notion by Zahálka (1918) that the sandstone bodies near basin margins were deposited by deltas; see Uličný (2001) for extensive discussion of the "non-deltaic" sedimentological interpretations by Skoček and Valečka (1983), Jerzykiewicz and Wojewoda (1986), and Adamovič (1994).

The first two stops of the trip will be devoted to the analysis of depositional geometries, bounding surfaces, and lithofacies of the deltaic succession belonging to the TUR 7 / CON 1 genetic sequence (Fig. 2) exposed in the Český Ráj rock cities. Several key points are summarized below, as a basis for discussions at the individual field trip stops.

Bounding surfaces

Individual foreset packages are separated from one another by various types of unconformity surfaces (Fig. 4A, B). Surfaces which truncate the upper parts of underlying foreset packages can be correlated for many kilometres in well-logs and outcrops (Fig. 3). They are commonly intensely burrowed and/or overlain by gravel lags, and commonly downlapped by an overlying foreset package. Lithofacies above each of these surfaces indicate an increase in water depth and therefore they a readily interpreted as flooding surfaces in the sequence-stratigraphic terminology. The history of many of these surfaces is probably more complicated, however, involving one or more periods of subaerial erosion prior to the flooding (Fig. 5B).

Foreset facies

The grain size of the foreset facies varies from fine-grained to very coarse-grained and pebbly sandstones. The main facies, summarized in Fig. 4, are as follows:

1. Cross-bedded sandstone and conglomerate facies assemblage. Trough cross-bedding is the dominant internal structure in most of the foreset packages. Soft-sediment deformation is common in the cross-strata in the type-H packages. Palaeocurrent data (Figs. 3, 6) indicate that the Český Ráj deltas (as well as other, older deltas of the Lužice-Jizera subbasin) were strongly affected by dominantly SE-directed currents, interpreted as tidal by Uličný (2001), which caused the formation and migration of dunes on the foreset slopes.
2. Backset facies (sensu Jopling and Richardson, 1966 and Nemec, 1990) are sets of upslope-dipping cross-lamination, typically developed in distinctly coarser sandstone than the surrounding facies. The backsets are recognized as an individual facies if they rest on foresets without distinct erosion at the base of the backset. Elsewhere, backsets form a part of the chute-fill facies assemblage (below). Caution must be applied in distinguishing between true upslope-migrating backsets and cross-strata formed by obliquely migrating bedforms.
3. Chute-fill facies assemblage. The term "chute-fill" describes sandstones which rest on undulating, concave-upward erosional surfaces or fill narrow gullies, in places over 7 m deep, cut into the foresets (or, into an underlying chute fill, causing amalgamation of the chute-fill bodies). The upper surface is normally conformable with the overlying foreset geometry. This topography is analogous to erosional troughs – chutes – described e.g. by Prior and Bornhold (1990) from modern coarse-grained deltas. The basal parts of the chute

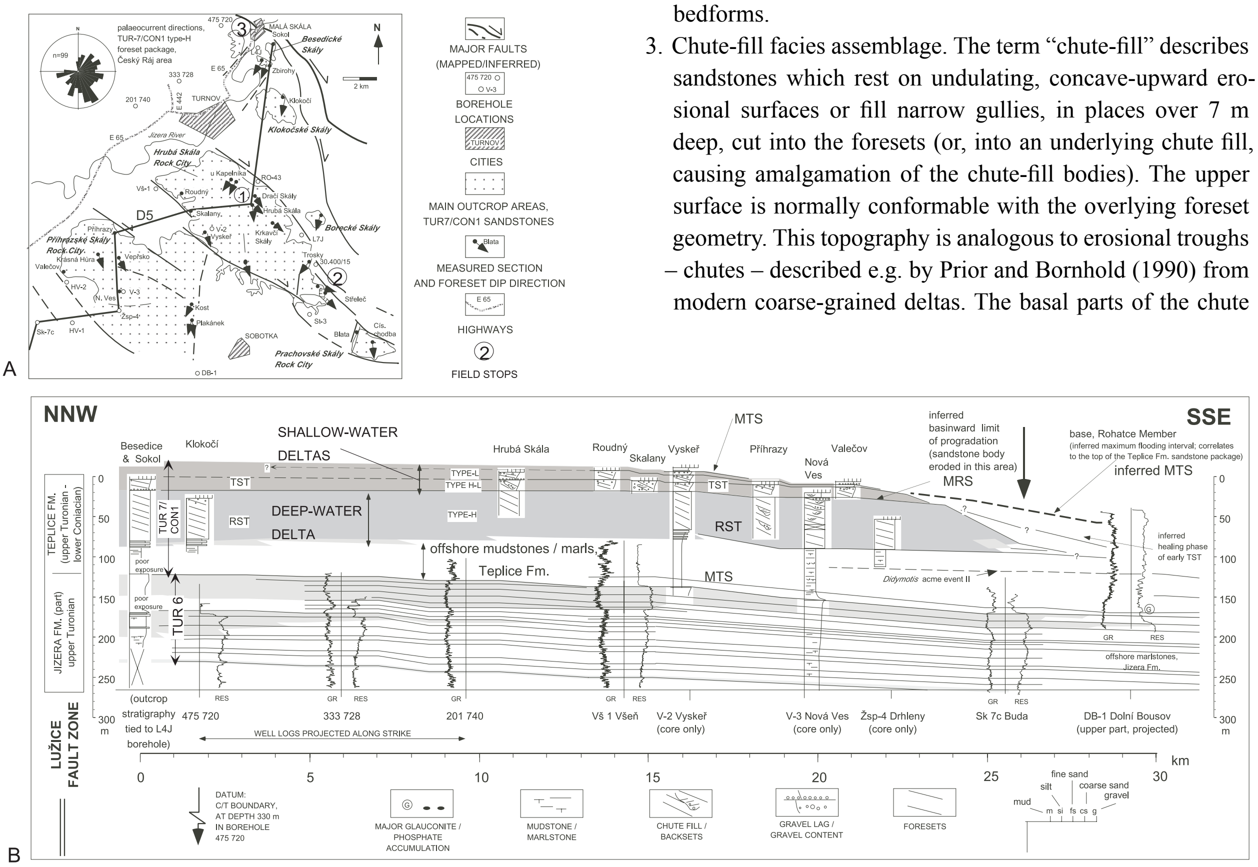


Fig. 3. (A) Simplified location map for the field trip area in Český Ráj, including palaeocurrent data from the cross-bedded sandstone lithofacies within the foreset packages (rose diagram) and foreset dip directions of the main type-H foreset package (arrows). Bold line denotes the position of the regional cross-section D5 (see Fig. 1B). (B) Detail of cross section D5 showing genetic sequence stratigraphic interpretation of the Teplice Formation (TUR7/CON1) sandstone packages approximately along depositional dip (sediment input from the NNW). Based on combined well-log, core, and outcrop correlation. Topmost parts of the Jizera Formation are shown for stratigraphic context. Datum of the cross-section (Cenomanian/Turonian boundary) is beyond the area of the figure. The Didymotis acme event II approximately corresponds to the Turonian/Coniacian boundary. TS – transgressive surface, MTS – maximum transgressive surface, MRS – maximum regressive surface; TST- transgressive systemts tract. RST – regressive systems tract comprising the highstand, falling stage and lowstand systems tracts; quality of stratigraphic control does not allow to precisely locate the sequence boundary separating the falling stage from lowstand).

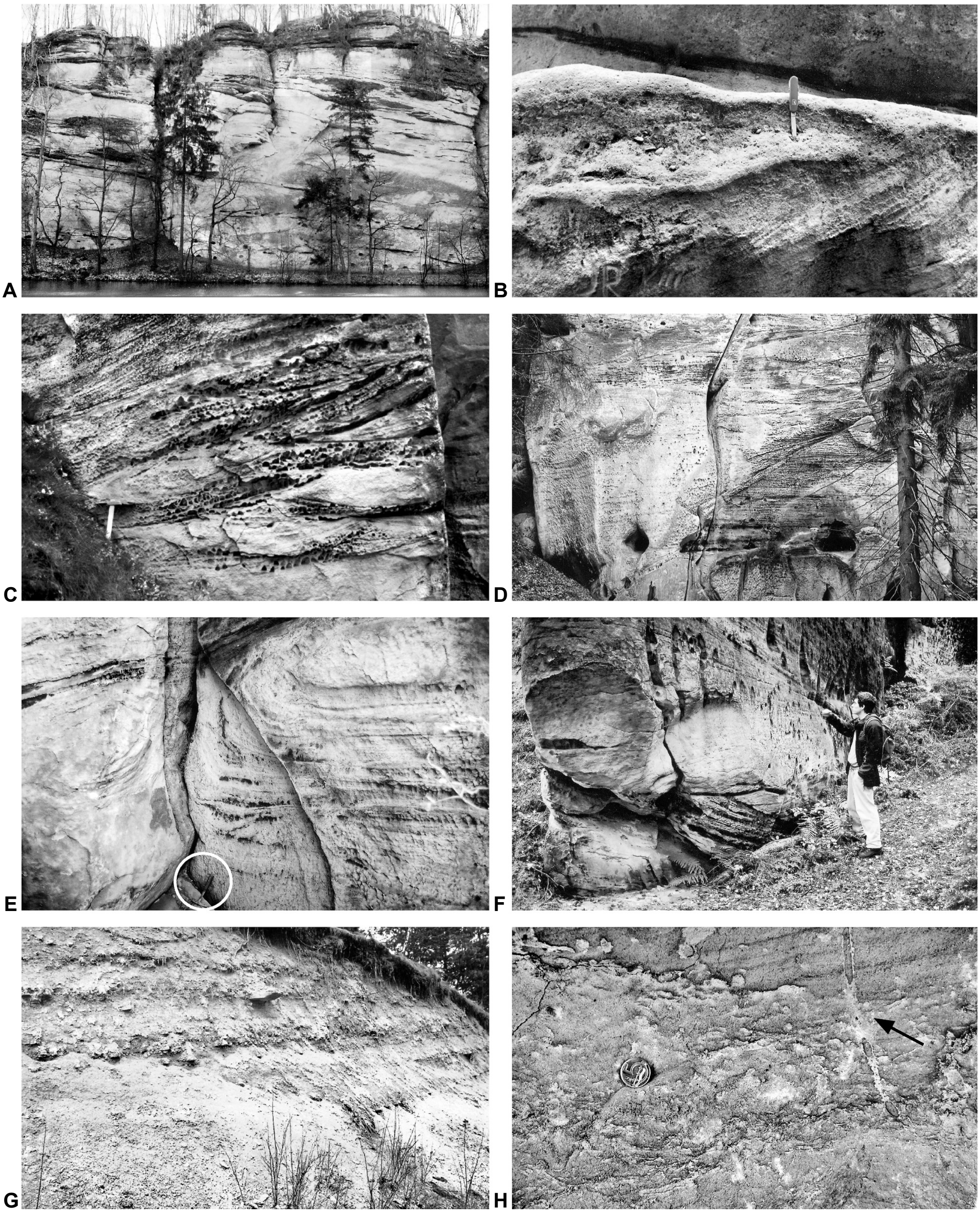


Fig. 4. (A) High-angle foresets of the deep-water, Gilbert-type delta that forms the lower part of the Teplice Fm. sandstones (TUR7/CON1 sequence) in Český Ráj, truncated by a ravinement surface and overlain by a shallow-water delta, Plakánek Valley near Sobotka. Exposure is 35 m tall. (B) Pebbles up to 4 cm in diameter, concentrated on the ravinement surface that truncates the foresets of the underlying type-H package, Sokol section, near Malá Skála. (C) Trough cross-stratification in medium to coarse-grained sandstones forming the foresets of the main deep-water delta body, Klokočské skály. (D) base of a chute incised into foreset strata of the main deep-water delta body. View direction up the foreset slope, depth of incision 7 m. Hrubá Skála rock city, near Adamovo lože. (E) large water-escape structure in the uppemost part of a chute-fill succession, Hrubá Skála – Mountaneers' Monument (c. 7 m above the base of section in Fig. 6). Hammer (circled) for scale. (F) Backsets within a chute-fill succession, overlain by high-angle foresets. Hrubá Skála – Mountaneers' Monument, 14 m above base of section in Fig. 6. (G) heterolithic bottomsets of the type-H package, near Střeleč quarry; larger blocks of sandstone weathering out of the outcrop face are "pot casts" – see text; exposure is c. 4 m high; (H) example of bioturbated sandy bottomsets with well-pronounced Ophiomorpha isp. burrows, Střeleč quarry, c. 15 m below top of section in Fig. 7. Arrow shows a prominent sub-vertical burrow with typical nodular lining.

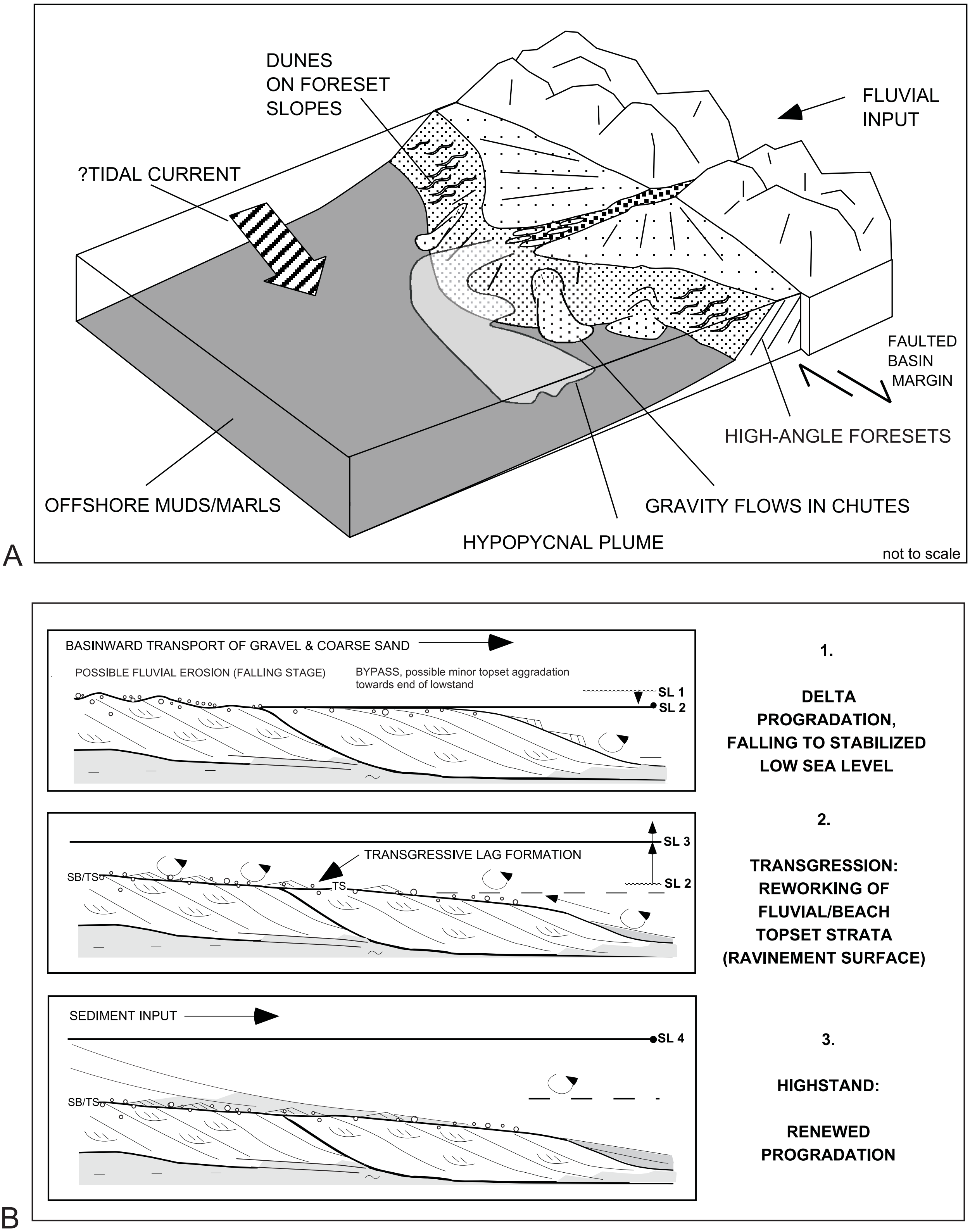


Fig. 5. (A) A schematic depositional model of a Gilbert-type, deep-water delta, based on the examples of deep-water deltas from the Bohemian Cretaceous Basin. The presumed main controls on the depositional style are indicated. (B) a schematic succession of events that led to destruction of topset strata during transgression and formation of a transgressive lag. SL – relative sea level; G – glauconite; SB – sequence boundary (Exxon-type); TS – transgressive surface.

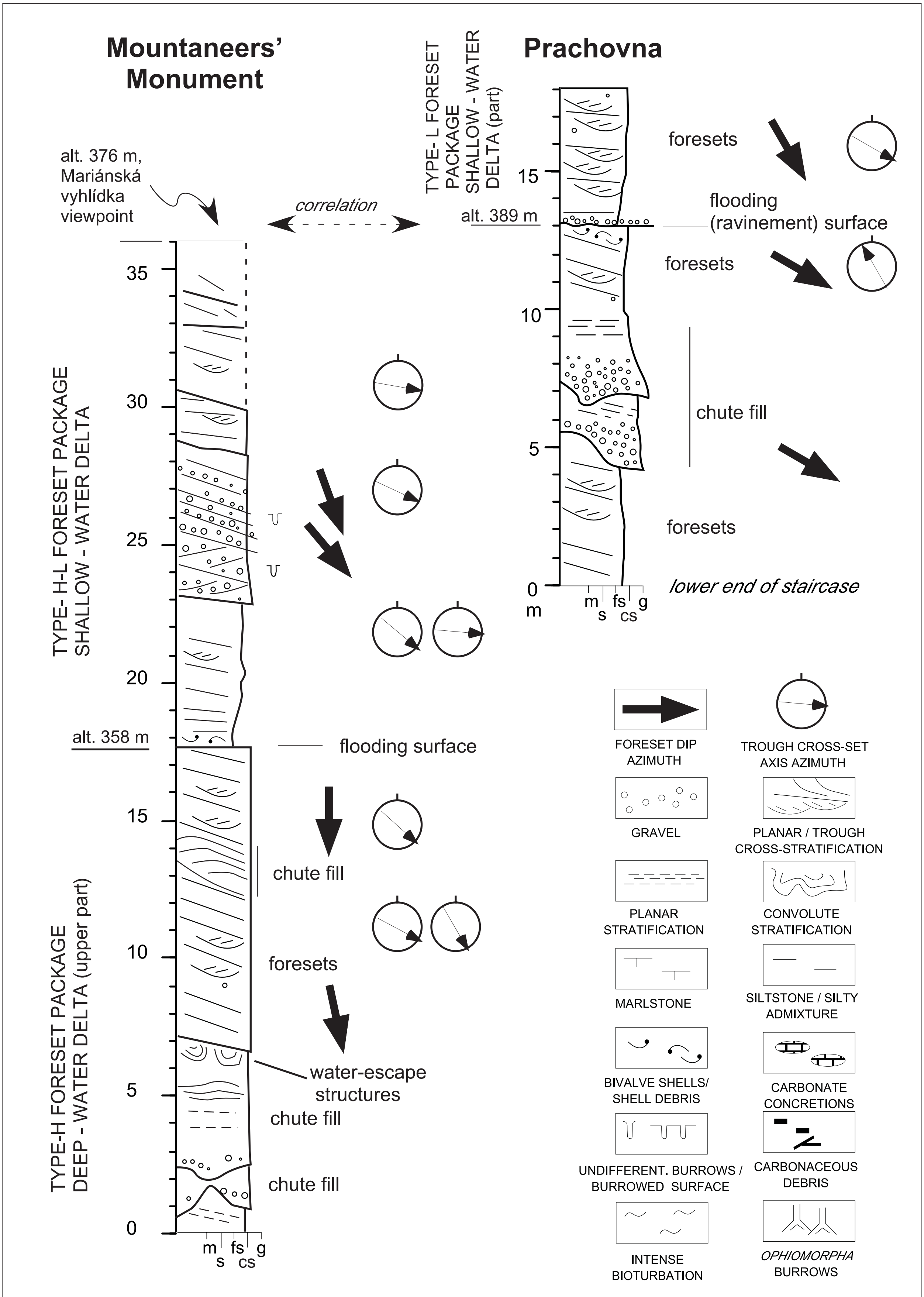
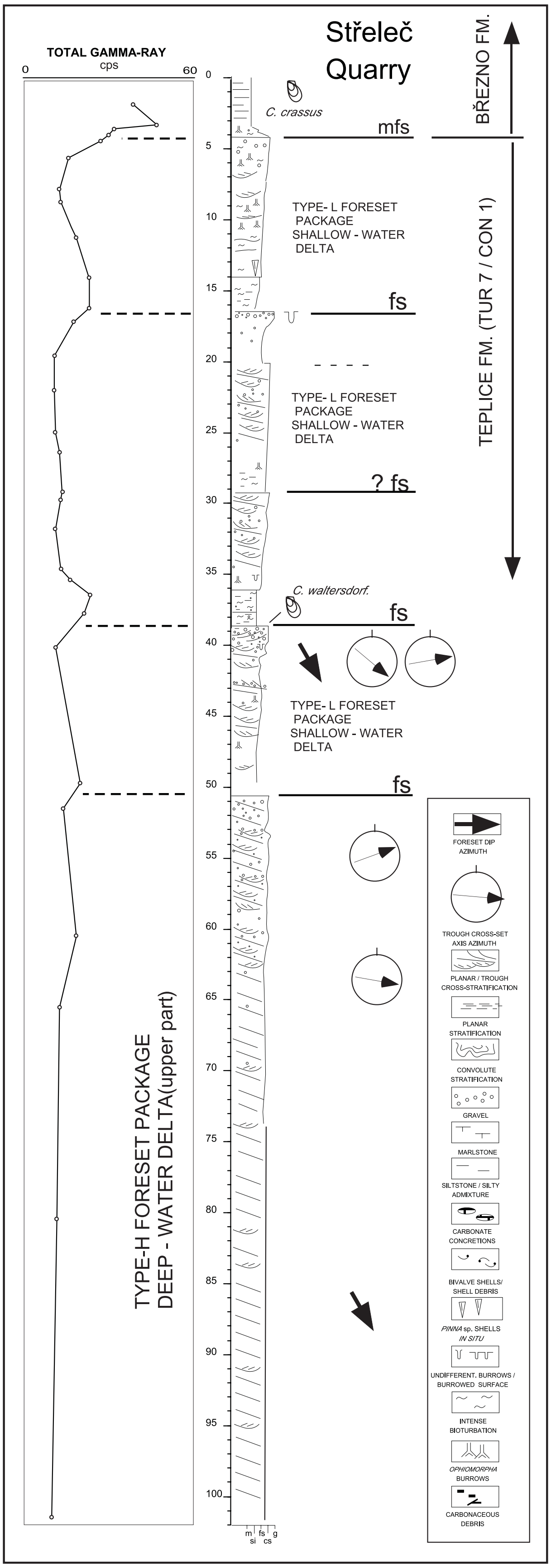


Fig. 6. Measured sections of the exposures near the Hrubá Skála chateau, stop 1b. Comments on lithofacies and sequence-stratigraphic aspects in text and Fig. 5b.

fills may or may not include concentrations of pebbles and coarse sand, locally with bivalve shells, at their base. In the upper parts of some chute fills, sub-parallel, slightly undulating laminae occur, and pass upslope into backsets. In many most chute-fill bodies, cross-sections parallel to the foreset dip reveal poorly-defined backset stratification throughout the most of the chute-fill thickness. Locally,water-escape structures occur near the top of the chute-fill bodies or in the overlying foresets (see Field Stop 1b).



The formation of chutes and their infills in steep-slope deltas is interpreted as a result of liquefaction of the upper part of the unstable foreset slope and downslope movement of liquefied sand behaving essentially as a cohesionless debris flow. The internal structures of the chute fills, particularly the backsets, are interpreted as caused by the supercritical nature of the gravity flows that were prone to development of hydraulic or granular jumps at topographic breaks (e.g., base of foreset slope, irregularities of chute-fill topography; cf. Nemec, 1990 and references therein; Massari, 1996). Various types of backset and parallel lamination found in the chute fills may have been formed by upslope migration of such jumps. The lack of such phenomena in shallow-water deltas with low-angle foresets may be due to the lower potential for foreset failure as well as to the higher potential of reworking of sand by processes such as currents and waves in shallow water.

Bottomset facies

Bottomsets of the deltaic bodies are commonly poorly exposed, but where accessible, they fall into two groups:

1. Bioturbated sandy bottomset facies, typical of type-L packages comprises very fine-grained, intensely bioturbated, sandstones with some proportion of mud, characterized mostly by a dense ichnofabric dominated by Ophiomorpha, Thalassinoides, and Planolites ichnogenera (Fig. 4H).
2. Heterolithic bottomset facies. In outcrop, this facies shows alternation of silty mudstones with upward-thickening beds of ripple-laminated sands and abundant "pot casts" sensu Aigner and Futterer (1978); it is found associated with type-H foreset packages of deep-water deltas (Fig. 4G). This facies is interpreted as sandy turbidites, triggered by delta front collapse, and deposited in the offshore area where they interfinger with mudstone representing the "background" deposition.

General absence of topset strata

In most cases the foreset packages are truncated by erosional bounding surfaces. Topset facies which are generally indicative of aggradational conditions in a delta plain, are not preserved

Fig. 7. Composite measured section of the Střeleč Quarry. fs – flooding surface, mfs – maximum flooding surface. Middle Coniacian bivalve Cremnoceramus crassus occurs in the basal Březno Fm. mudstones. Early Coniacian species C. waltersdorfensis and Didymotis costatus occur in the heterolithic facies below the sandstone body. C. waltersdorfensis was also found within the succession of shallow-water delta bodies in the quarry.

in outcrops. Therefore, it has been difficult to interpret in detail the physiography and processes governing the sediment transport on the upper part of the delta plain, as well as the nature of transition between the topset and foreset areas. However, the characteristics of sediment delivered to the foresets as well as the lag deposits on some of the bounding surfaces suggest that the delta-plain environment was characterized by shallow, bedload-dominated fluvial channels and probably by partial redistribution of sand and gravel by waves. The absence of fluvial topset strata led some earlier workers (Skoček and Valečka, 1983; Jerzykiewicz and Wojewoda, 1986; Adamovič, 1994) to reject the deltaic origin of the Bohemian Cretaceous sandstones and therefore it is important to understand the deposition/preservation potential of topset strata within a sequence-stratigraphic context of long-term evolution of stratigraphic geometries; this will be discussed at Stop 1c.

Depositional model

A simplified depositional model, shown in Fig. 5A, combines the main processes that operated during deposition of a typical Gilbert-type, deep-water sandy delta in the Bohemian Cretaceous. According to Uličný (2001), the most important depositional processes on the foreset slopes were (i) migration of sandy bedforms driven by mostly unidirectional currents, and (ii) gravity flows of mobilized sand interpreted to be responsible for the formation and filling of the chutes (cf. Fig. 6). These gravitational processes represent a link to the heterolithic bottomset facies interpreted as sandy turbidites interbedded with offshore muds. It is, however, the marine current activity what makes the Bohemian Cretaceous deltas slightly different from many cases of Gilbert-type deltas which typically are dominated by gravitational processes and commonly contain poorly sorted debris-flow deposits in their foresets (e.g. Nemec, 1990; Ori et al., 1991).

Palaeocurrent data from the cross-bedded sandstones (Figs. 3, 6, 7) indicate that the Český Ráj deltas (as well as other, older deltas of the Lužice-Jizera sub-basin) were strongly affected by predominantly SE-directed currents which caused the formation and migration of dunes on the foreset slopes. Sustained tidal circulation resulting in unidirectional currents along the NW margin of the open seaway was suggested by Uličný (2001) as the cause of the significant current activity affecting the foresets of the sandy deltas in the Bohemian Cretaceous. The persistent current activity also helps to explain another feature of the Bohemian Cretaceous deltas: why the sandstones are so "clean" – that is, why there is the lack of fine-grained clastic material in the foreset facies, especially given the dominance of muddy to marly facies in the offshore. The strong segregation of grain sizes between the sandy deltaic bodies and muddy offshore can be explained as due to the density contrast between seawater and the suspension-laden freshwater brought to the shore by river channels. Due to the lower density of freshwater, mud-grade suspended load was carried away from the delta front as hypopycnal plumes near the sea surface by the same basinal currents that caused the dune migration along delta slopes (Fig. 5A; cf. Nemec, 1995). Evidence from basin-scale geometries of muddy clinoforms for the transport of fine-grained sediment along the basin axis is also demonstrated by Uličný (2001).

Stop 1a: Hrubá Skála, Mariánská Vyhlídka Viewpoint, (near the Hrubá Skála Chateau)

This stop is an introduction to both the general setting of the Bohemian Cretaceous Basin and the local sedimentological features of the Teplice Formation sandstones. On the northern horizon, the Lužice Fault Zone is marked by a topographic ridge formed by Cenomanian sandstones tilted and partly overturned during the Palaeogene transpressional deformation (Adamovič and Coubal, 1999). The Kozákov Hill (744 m), preserving also relicts of a Pliocene-age volcano (nepheline basanite of 4–6.6 Ma, Ulrych et al., 1999; Christensen et al., 2001), marks a major bend in the trace of the Lužice FZ, accompanied by a flexure of Cretaceous deposits SW of Kozákov. Faults roughly parallel to the Lužice Fault Zone were active also post-depositionally and are prominent in the present-day geomorphology – the Libuňka Fault marks the abrupt NE limit of the Hrubá Skála outcrop area, well visible in the foreground. The block SW of this fault was relatively downthrown by several tens of meters at this part of the fault which runs across most of the Český Ráj region.

Further north, beyond the basin margin, we can see hills formed by metamorphic units of the Krkonoše-Jizera Crystalline Complex and by intensely deformed Permian and Upper Carboniferous clastic sediments. Other geological sights include Tertiary volcanics which intruded the Cretaceous deposits during an episode of Oligo-Miocene rifting in North Bohemia.

During the mid-Cretaceous, the source areas north of the Lužice Fault Zone supplied clastic material to coarse-grained deltas which prograded generally southward. At Mariánská Vyhlídka we are surrounded by isolated sandstone towers of the "rock city" which provide good exposures of the internal architecture of the deltaic bodies. From the viewpoint we can estimate the general S-SE dip direction of the foresets visible in some of the towers.

Stop 1b: Hrubá Skála, Mountaineers Monument

This stop introduces the main geometric features and lithofacies of the deltaic system. The high-angle foreset package exposed in the lower part of the exposure belongs to the main deep-water delta body that constitutes the lowermost 60-80 m of the Český Ráj sandstones, and is overlain by a thinner body belonging to a shallow-water delta, but locally displaying also steep foreset angles (a transitional Type H-L package sensu Uličný, 2001) probably due to high sediment input rates. The two packages are separated by a pronounced, subhorizontal flooding surface, marked by an abrupt decrease in grain size at the base of the upper sandstone body. Overlying foresets downlap tangentially on this surface that truncates the foresets of the underlying sandstone body (Fig. 6). The lowermost part of the outcrop shows a prominent chute-fill with backsets at the base and large-scale water-escape structures near its top. In the upper foreset package, some of the upslope-dipping strata resemble the backset stratification, but in cases where a three-dimensional control is possible, a more complex stratification pattern is revealed, related probably to oblique migration of large bedforms along the delta slope.

Stop 1c: Hrubá Skála, Prachovna

This outcrop above the Hrubá Skála Chateau shows the boundary between two shallow-water delta bodies, marked by a sharp surface overlain by a pebble lag with quartz clasts up to 4 cm in diameter (visible also from a distance). The underlying foresets are correlated to the transitional type H-L foreset package of the upper part of Stop 1b (Fig. 6).

The formation of the pebble lag is interpreted by Uličný (2001) as due to transgressive erosion and reworking of the uppermost part of a delta body submerged by a relative sea-level rise (Fig. 5B). The presence of outsize clasts concentrated at the unconformity surface indicates a former presence of very coarse-grained lithofacies in the uppermost part of the delta, most probably fluvial and beachface deposits. Therefore, the prominent surface which truncates the foresets is interpreted as a ravinement surface, i.e., transgressive surfaces of marine erosion reworking an originally subaerially exposed surface. The formation of widespread ravinement surfaces was the most common process during transgression in the Bohemian Cretaceous deltas, partly due to low subsidence rates, and was a significant factor in the wholesale removal of topsets, including fluvial strata. This transgressive reworking is also the reason why Exxon-type sequence boundaries (e.g. Van Wagoner et al. 1990) cannot be recognized in the Bohemian Cretaceous deltas, and the flooding / ravinement surfaces are used in regional correlation.

Stop 2: Střeleč Quarry (Eximos Sklopísek Střeleč, a.s.)

The Střeleč Quarry exposes the Český Ráj delta system in a nearly complete thickness (Fig. 7), tilted between 6 and c. 12° and faulted during the Cenozoic tectonic deformation. The lowermost part of the main deep-water delta is not exposed, but a small railway cut near the quarry (Fig. 4G) shows the heterolithic bottomset facies belonging to this delta body. Because of the quarrying, the stratal geometries are not well visible, but the exposures allow to examine the sedimentological features of shallow-water deltas of the upper part of the TUR7/CON1 sequence, and the terminal flooding of the deltas (onset of deposition of the Březno Fm. mudstones), not well exposed elsewhere in the region. Other points of interest include the syn- and post-depositional activity of the faults exposed in the quarry and their role in the ascent of Neogene volcanics, currently also exposed in the quarry.

The Střeleč exposures (Fig. 7) show very clearly the distinct stacking pattern of the deltaic packages belonging to the TUR7-CON1 genetic sequence in the Český Ráj area: a thick, deep-water delta body (type-H foreset package, up to 80 m thick) in the lower part of succession, overlain by a vertically stacked pile of much thinner, shallow-water delta bodies which show a long-term retrogradation terminated by flooding and deposition of offshore muds (the lower part of the Březno Fm., Figs. 3, 7). A similar geometry exists, for instance, in the Late Turonian Jizera Fm. in the Broumov Cliffs as well as in the Coniacian-age deltaic bodies of the Adršpach and Teplice

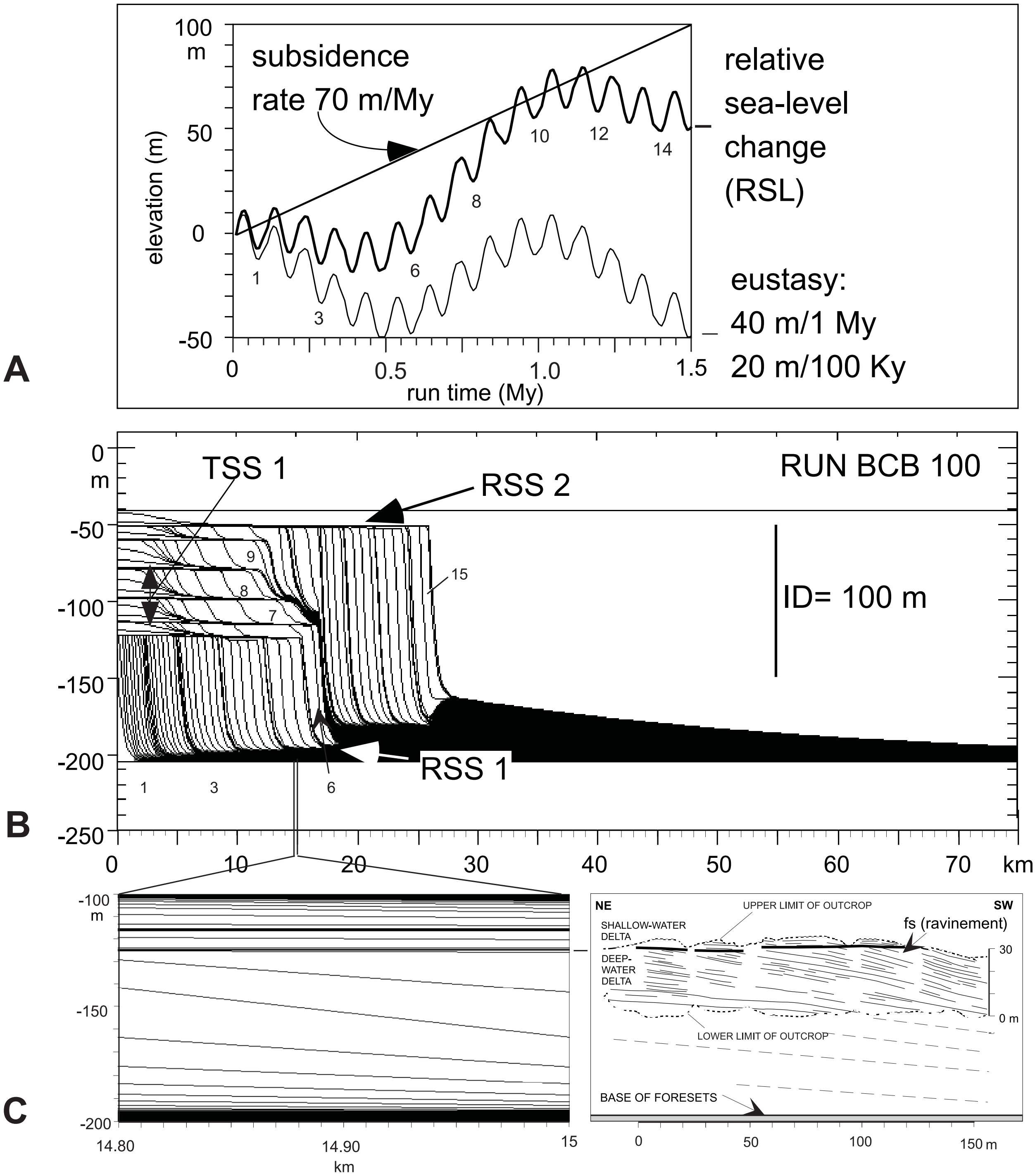


Fig. 8. (A) Parameters of a conceptual model used to simulate the stacking pattern of the Český Ráj deltaic succession, after Uličný et al. (2002). Relative sea-level change produced by combining the subsidence rate of 70 m.Ma-1 with an arbitrary, composite sea -level change curve. Numbers 1-14 denote the lowstands of the short-term sea-level cycles superimosed on the long-term sea-level curve. (B) A forward stratigraphic model run simulating a simplified geometry of the TUR7/CON1 and younger deposits in the Český Ráj area. Initial depth (ID) before onset of deposition was 100 m. RSS, TSS – regressive and transgressive sequence sets, respectively. RSS 1 and TSS 1 correspond to the TUR7/CON1 sandstone bodies. Strata equivalent to thy modelled RSS 2 are not preserved in the Český Ráj region. 127x vertical exaggeration, time line interval 10ky. (C) A closeup view, without vertical exaggeration, of the architectures of high-frequency sequences generated by the run BCB 100, in a location along depositional dip that approximately coresponds to that of the Plakánek Valley outcrop (see Fig. 4). A drawing of the outcrop section is shown for comparison, with the subsurface part interpreted from borehole data (see Uličný 2001 for details), and underlying mudstones shown in grey colour. Time line interval 2 ky.

Rock Cities, in the Police sub-basin (Uličný 2001). This poses a question of what governed this sort of a stacking pattern, where the shallow-water deltas in the upper part strongly suggest a presence of a high-frequency cyclic control on the transgressive-regressive history (such as relative sea level or sediment input fluctuations), which is not clearly recognizable in the architecture of the underlying deep-water delta.

Uličný et al. (2002) focused on modelling the effects of the interplay between a cyclical relative sea-level change of two frequency orders and the basin-margin topography (Fig. 8). They concluded that the above stratal geometry is tied to initial (pre-depositional) depth at the faulted basin margin, which results from a delay in the onset of sedimentation during fault-related subsidence. This "initial depth" (ID) controls the geometry of the first stratal units deposited at the basin margin and thus modifies the response of the depositional system to subsequent, syndepositional changes in accommodation. In systems with a sharp break in the depositional profile, such as the topset edge in coarse-grained deltas, the initial depth controls the foreset height and therefore the progradational distance of the topset edge (topset length, L in Fig. 9A). The topset length, in turn, influences topset accommodation during cyclical relative sea-level (RSL) variations and therefore is reflected in the resulting stacking patterns at both long- and short-term time scales (Fig. 9). In the simplified cases modelled by Uličný et al. (2002), it is the relationship between the initial depth and the net increase in depth over the interval of a relative sea level cycle (ΔH) that governs long and short term stacking patterns. In situations where the initial depth is significantly larger than ΔH, the topset accommodation of the first delta is insufficient to contain the volume of sediment of younger sequences formed during subsequent relative sea-level cycles, due to short topset length, L. Therefore, the depositional system tends to prograde over a number of relative sea level cycles before the topset length increases so that the long-term stacking pattern can change to aggradation upon reaching an "equilibrium" value of L (Fig. 9A). Stacking patterns of high-frequency sequences are influenced by a combination of the topset accommodation available and position of the short-term relative sea-level cycles on the rising or falling limb of a long-term sea level curve. This determines whether deposits of short-term cycles are accommodated in delta topsets or foresets, or in both (Fig. 9). Note that during the long-term RSL fall or stillstand, the short-term cycles in RSL or sediment input are recorded only in the foresets of the deep-water delta, and therefore are difficult to identify in the field.Variations in stacking pattern caused by different initial depths could be misinterpreted as due to relative sea level or sediment supply changes and it is necessary to consider initial bathymetry in modelling and interpretation of stacking patterns, especially in fault-bounded basins.

The modelling results in Fig. 8 suggest that (1) a period of subsidence that preceded deposition occurred during the latest Turonian along the Lužice Fault Zone, (2) it is likely that the main deep-water delta of the TUR7/CON1 sequence prograded into large initial depth during a minor long-term relative sea-level fall or stillstand, and that the retrogradational stack of shallow-water deltas records several short-term RSL cycles

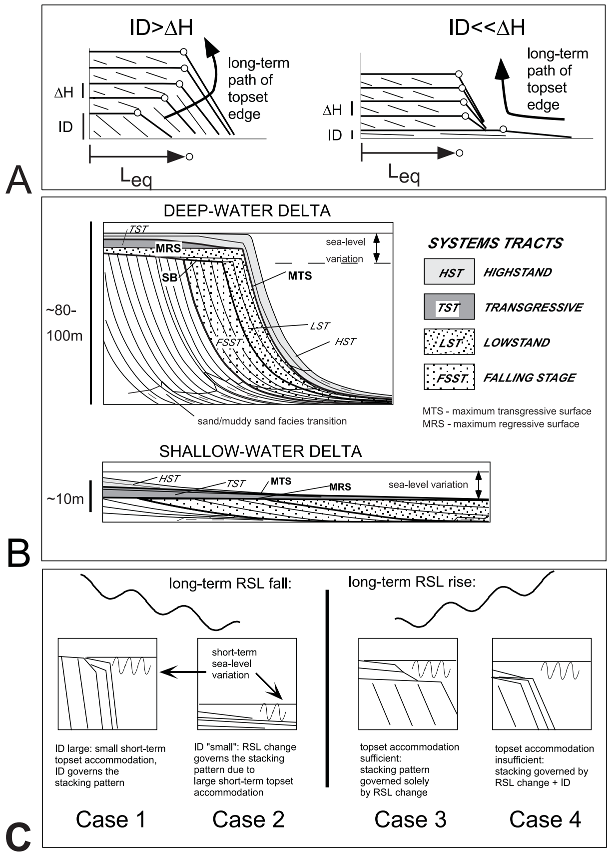


Fig. 9. (A) A schematic drawing (not to scale) showing the general long-term stacking patterns defined by the paths of topset edge (circled) for different relationships between the initial depth (ID) and the net increase in depth over a relative sea-level cycle (ΔH). The thickness of the lowermost sequence is governed by the ID whereas that of the younger sequences reflects ΔH. L_{eq} is the „equilibrium topset length", an approximate progradation distance of topset edge that leads to a long-term aggradational stacking pattern for a given sediment input rate and a given relative sea-level cyclicity. (B) Simplified examples of internal geometries of a high-frequency sequence, formed in response to a short-term cycle of relative sea level in a deep-water (Gilbert-type, above) and shallow-water (below) coarse-grained delta, incorporating some of the features of the model runs in Uličný et al. (2002). The sequence in the deep-water delta is part of a long-term regressive sequence set (RSS); note that the deposits in the topset area are largely prone to destruction due to long-term RSL fall. The boundary between FSST (falling stage) and LST (lowstand) systems tracts in the foresets corresponds to the correlative conformity of a sequence boundary, formed during the lowest sea level. SB – sequence boundary (Exxon-type), MRS – maximum regressive surface, MTS – maximum transgressive surface. (C) Four schematic drawings (not to scale) illustrating the variations in stacking patterns of high-frequency sequences resulting from the combination of short-term sea-level fluctuations with long-term relative sea-level fall (left) or rise (right). After Uličný et al. (2002).

superimposed on a long-term RSL rise. Similar geometries are produced by modelling short-term cycles in sediment supply superimposed on the long-term RSL trend.

Although younger Coniacian deposits than the basal Březno Fm. mudstones are not exposed in the Český Ráj area, the model predicts that a continuing long-term RSL cycle should result in formation of a major, deep-water delta, with foresets over 100 m tall. We hypothesize that the flat-lying sandstone bodies of the Coniacian "Chloumek sandstone" and "flyschoid facies", exposed in the Markvartice region and Chloumek Ridge south of Český Ráj, represent gravity-flow deposits of the bottomset area of such delta, triggered by instability of the steep delta slope.

Deformation of Cretaceous Sediments in the Lužice Fault Zone, Malá Skála (Field Trip Stop 3)

Introduction

This stop combines overview of basin-scale tectonic and geomorphologic features with observations of outcrop-scale brittle deformation developed in shallow-marine sandstones of Late Cenomanian age (Fig. 10). The reason why the northern margin of the basin exposes the oldest sedimentary units of the basin fill (and also the underlying Late Palaeozoic clastics) is that it recorded a period of mostly transpressional deformation along the Lužice Fault Zone during the Cenozoic inversion – part of a process that affected a vast area of Central Europe in the Alpine-Carpathian foreland (cf. Ziegler, 1990; Peterek et al., 1997; Scheck et al., 2002; Krzywiec 2002, among many others).

During the Cretaceous, the Lužice Fault Zone sensu lato (LFZ) formed the northern margin of the Lužice-Jizera sub-basin of the Bohemian Cretaceous basin system, separating it from the adjoining source area – the Western Sudetic Island (Fig. 1; cf. Skoček and Valečka, 1983; Voigt ,1996, and references therein). Together with the Labe-Železné Hory Fault Zone (Fig. 1), the LFZ defined the overlapping zone of strike-slip deformation which led to formation of Cretaceous strike-slip sub-basins (Uličný 2001). Their origin as ductile shear zones can be traced at least into the Devonian (e.g. Edel and Weber 1995). The LFZ, together with the Bavarian Fault Zone, the Sudetic fault system, and other major, NW-directed weakness zones of central Europe, approximately parallel to the Teissseyre-Törnquist Zone, acted as a dominatly dextral shear zone during most of the Variscan collision (Arthaud and Matte 1977; Aleksandrowski, et al., 1997; Peterek et al., 1997). Based on gravity data and on petrological and structural data from the Krkonoše-Jizera Crystalline unit (e.g. Mazur and Aleksandrowski, 2001; Franke and Zelazniewicz, 1997), the southeastern boundary of the Saxothuringian domain has undergone polyphase dextral translation along the Elbe Zone. Out of the total 50–60 km of total dextral displacement since the Devonian, a significant portion was accommodated at or near the LFZ.

The most prominent phases of activity in the evolution of the LFZ, documented by sedimentary record and deformation, fall into the Late Carboniferous-Permian, Mid-Cretaceous, and latest Cretaceous-Paleogene (Coubal, 1990;Uličný, 2001; Uličný et al., 2002). Several kilometres of dextral displacement along the LFZ are hypothesized by Uličný et al. (2002) to have occurred during the Saxonian (Late Permian), and the same authors estimate the dextral displacement during the Bohemian Cretaceous Basin lifetime as about 10 km. Significant sediment yield from the relatively small area of the Western Sudetic Island (generally, the Lusatian Block) suggests a relatively rapid mid-Cretaceous uplift, but no quantitative data on possible uplift rates and total magnitude are available.

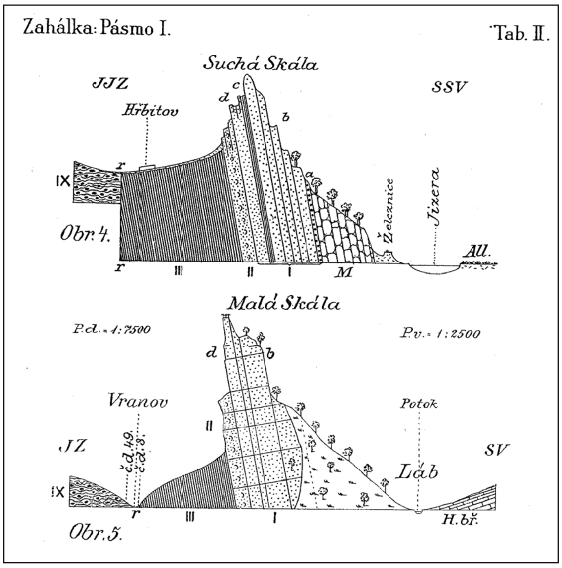
Post-Cretaceous deformation at the Lužice Fault Zone, Malá Skála area

The LFZ s.l. in the area of the field trip represents a major zone of brittle deformation, typically several hundred meters to over 1 km wide, oriented WNW-ESE, and separating the northern margin of the Cretaceous deposits, together with underlying clastics and volcanics of Late Palaeozoic age (the Mnichovo Hradiště Basin, Tásler 2001), from the Krkonoše-Jizera Crystalline Complex and other basement units belonging to the Saxothuringian Domain, as well as of the Carboniferous-Permian Krkonoše Piedmont basin, to the north of the margin of the Cretaceous deposits.

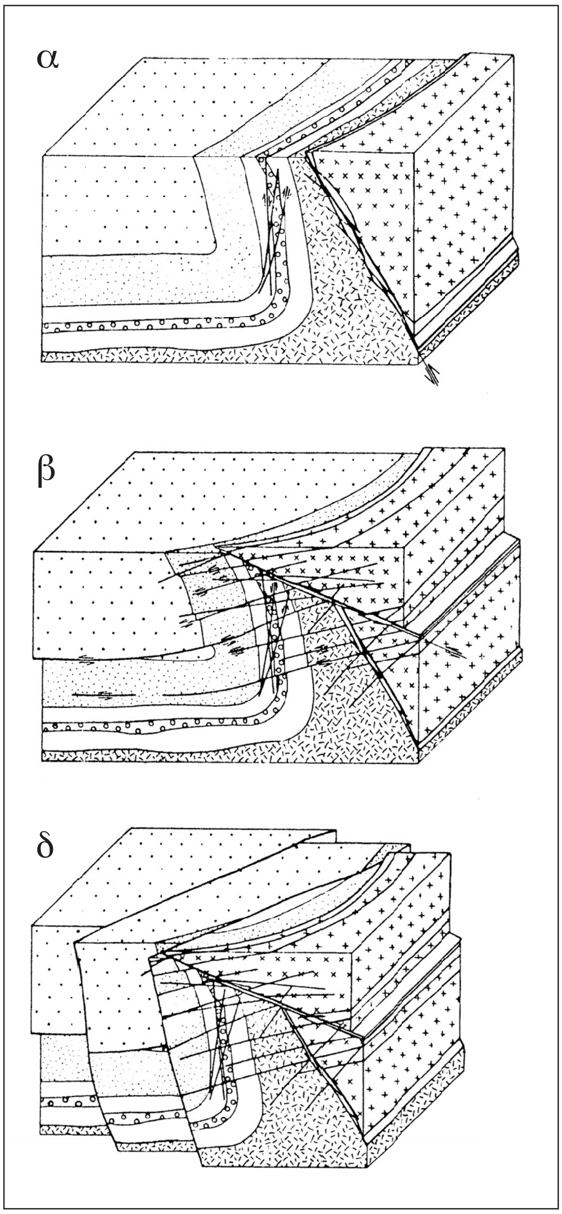
The Lužice Fault s.s. is located by Coubal et al. (1999) mostly at the boundary between the crystalline blocks and Late Palaeozoic-Cretaceous clastics. The Lužice Fault s.s. near the region of the trip has a thrust geometry, with a northward dip varying between c. 15 –60° ; it should be borne in mind that the traditional term "Lužice thrust" or "Lausitz thrust" (e.g. Seifert, 1932) relates only to this part of the broader LFZ.

A number of subordinate structures accompany faults of large vertical and strike-slip displacement in the LFZ. A notable feature is the prominent array of en-echélon, NW-SE oriented, short fault segments spanning the whole LFZ area from Saxony to the Malá Skála area, developed as R (Riedel) shears synthetic to the main dextral displacement zone (Fig. 1). A minor displacement of the Suché Skály Ridge on the eastern bank of the Jizera River in Malá Skála towards the north relative to the western bank, is tentatively interpreted as a sinistral reactivation of a NNE-directed strike-slip fault conjugate to the main trace of the LFZ (R' shear).

Analysis of brittle deformation (Coubal 1990, Coubal et al. 1999) shows that blocks of sedimentary infill were displaced along strike as rigid blocks with very little ductile deformation (in various parts of the LFZ, including the Malá Skála area, upturned to overturned strata occur in the immediate vicinity of subhorizontal or gently inclined strata in situ). Local flexural deformation is related to drag folding. Meso-scale deformation features, well exposed in the Cenomanian shallow-marine sandstones in the marginal part of the LFZ, include silicified fracture systems and mylonite zones, slickensides, tectonic polishes and conjugate shear joints. Palaeostress interpretations by Coubal (1990) and Adamovič and Coubal (1999) suggest two phases of compression of latest Cretaceous-Paleogene age. An initial compressional phase, with the maximum horizontal stress oriented NNE-SSW, is hypothesized to be responsible for thrusting at the Lužice Fault s.s., and was followed by NW-SE – oriented compressional phase of probably Eocene age which resulted in a more transpressional nature of deformation of the whole LFZ (cf. Fig. 10). Although more precise dating is difficult, the timing of the initial deformation phase can be constrained by the c. 50–70 Ma ages of intrusive bodies in N Bohemia whose geometries conform with this palaeostress orientation (Adamovič and Coubal, 1999), and the Late Eocene onset of deposition in the Zittau Basin, situated north of the LFZ. According to Coubal et al. (1999), the magnitude of Cenozoic uplift of crystalline blocks to the north of the LFZ reached over 1000 m. A younger phase of extensional deformation, probably of Miocene age (Adamovič and Coubal, 1999), cannot be demonstrated in the Malá Skála area.



A



B

Fig. 10. (A) Historical geological cross-sections of the upturned Cenomanian (I, II) and Early Turonian (III) strata in the Malá Skála and Suché Skály region. From Č. Zahálka (1902). Note the juxtaposition of early Turonian (III) against late Turonian deposits (IX) across a vertical fault. (B) main phases of brittle deformation of Cretaceous strata in the Malá Skála-Suché Skály area, Lužice FZ, according to Coubal (1990). Phase α – main phase of subhorizontal N-S compression, δ -terminal phase involving cross-cutting of earlier fracture systems by NNW-trending strike-slip faults, induced by NW-oriented.

Acknowledgements

This field guide presents parts of research accomplished with support of GAČR grant 205/01/0629 to DU. The authors are grateful to the company Sklopísek Střeleč for permission to enter the Střeleč quarry, and Mr. Ciprýn is thanked for personal assistance. L. Špičáková provided valuable feedback on earlier version of the manuscript and M. Svojtka is thanked for patient editorial work.

References

ADAMOVIČ J. and COUBAL M., 1999. Intrusive geometries and Cenozoic stress history of the northern part of the Bohemian Massif. In: J. ULRYCH and J. ADAMOVIČ (Editors), Magmatism and Rift Basin Evolution. Proceedings of IGCP 369 Final Session, Sept. 7-11, 1998, Liblice. *Geolines*, 9: 5-14.

ADAMOVIČ J., 1994. Paleogeography of the Jizera Formation, Late Cretaceous sandstones., Kokořín area, central Bohemia. Sborník geol. Věd – G, 46: 103-123.

AIGNER T. and FUTTERER E., (1978) Kolk-Töpfe und -Rinnen (pot and gutter casts) im Muschelkalk – Anzeiger für Wattenmeer? *N. Jb. Geol. Paläont. Abh.*, 156: 285-304.

ALEKSANDROWSKI P., KRYZA R., MAZUR S. and ŹABA, J. , 1997. Kinematic data on major Variscan strike-slip faults and shear zones in the Polish Sudetes, northeast Bohemian Massif. *Geological Magazine*, 134: 727-739.

ARTHAUD F. and MATTE P., 1977. Late Paleozoic strike-slip faulting in southern Europe and northern Africa: Result of a right-lateral shear zone between the Appalachians and the Urals. *GSA Bulletin*, 88: 1305-1320.

BERGERAT F. , 1987. Stress field in the European platform at the time of Africa-Eurasia collision. *Tectonics*, 6, 99-132.

BRANDMAYR M., DALLMEYER R.D., HANDLER R. and WALLBRECHER E., 1995. Conjugate shear zones in the Southern Bohemian Massif, Austria.: implications for Variscan and Alpine tectonothermal activity. *Tectonophysics*, 248: 97-116.

COUBAL M. , 1990. Compression along faults: example from the Bohemian Cretaceous Basin. *Mineralia Slovaca*, 22: 139-144.

COUBAL M., ČECH S., MÁLEK J. and PROUZA V., 1999. Lužický zlom. Závěrečná zpráva grantového projektu GAČR č. 205/96/1754. Archiv Českého geologického ústavu, Praha.

CHRISTENSEN N.I., MEDARIS L.G., WANG H.F. and JELINEK E., 2001. Depth variation of seismic anisotroppy and petrology in central European lithosphere: A tenconothermal synthesis from spinel lherzolite. *Journal of Geophysical Research-Solid Earth*, 106 (B1): 645-664.

CHRISTIE-BLICK N. and BIDDLE K. T., 1985. Deformation and basin formation along strike-slip faults. In: Strike-slip Deformation, Basin Formation, and Sedimentation, Ed. by K. T. Biddle and N. Christie-Blick., *SEPM Spec. Publ.*, 37: 1-34.

ČECH S., KLEIN V., KŘÍŽ J. and VALEČKA J., 1980. Revision of the Upper Cretaceous stratigraphy of the Bohemian Cretaceous Basin. Věstník Ústředního Ústavu geologického, 55: 277-296.

ČECH S., HRADECKÁ L., LAURIN J., ŠTAFFEN Z., ŠVÁBENICKÁ L. and ULIČNÝ D., 1996. Úpohlavy quarry: record of late Turonian sea-level oscillations and synsedimentary tectonic activity. In: Stratigraphy and Facies of the Bohemian-Saxonian Cretaceous Basin. Field Trip Guide, 5th International Cretaceous Symposium, Freiberg, 32-42.

ČECH S. and ULIČNÝ D., 1996. Bohemian-Saxonian Cretaceous Basin – Overview, in Stratigraphy and facial development of the Bohemian-Saxonian Cretaceous Basin: Field Trip Guide B1, 5th International Cretaceous Symposium, Freiberg, p. 1-8.

DOOLEY T. and MCCLAY K., 1997. Analog modeling of pull-apart basins: AAPG Bulletin, 81: 1804-1826.

EDEL J. B. and WEBER K., 1995. Cadomian terranes, wrench faulting and thrusting in the Central Europe Variscides: geophysical and geological evidence: *Geologische Rundschau*, 84: 412-432.

FAUPL P. and WAGREICH M., 1999. Late Jurassic to Eocene Palaeogeography and Geodynamic Evolutiíon of the Eastern Alps. *Mitt. Oesterr. geol. Ges.*, 92: 79-94.

FRANKE W. and ZELAZNIEWIZ A., 1997. The Sudetes seen from the West: terrane correlation across the Elbe Zone. *Terra Nostra*, 97/11: 46-50.

HARDENBOL J., THIERRY J., FARLEY M.B., JACQUIN T., DE GRACIANSKY P.-C. and VAIL P.R., 1998. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins, In: De GRACIANSKY P.-C., HARDENBOL J., JACQUIN T., and VAIL P.R., (Editors), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins, SEPM Special Publication 60, chart 5.

HELLAND-HANSEN W. and MARTINSEN O.J., 1996. Shoreline trajectories and sequences: description of variable depositional-dip scenarios. *Journal of Sedimentary Research*, 66/4: 670-688.

JERZYKIEWICZ T. and WOJEWODA J., 1986. The Radków and Szczeliniec Sandstones: an example of giant foresets on a tectonically controlled shelf of the Bohemian Cretaceous Basin , Central Europe.. In: Shelf Sands and Sandstones, Eds J. R. Knight and J. R. McLean., *Can. Soc. Petrol. Geol. Mem.*, 11: 1-15.

JOPLING A.V. and RICHARDSON E.V., 1966. Backset bedding developed in shooting flow in laboratory experiments. *J. Sed. Petrol.*, 36: 821-825.

KRZYWIEC P., 2002. Mid-Polish Trough inversion – seismic examples, main mechanisms, and its relationships to the Alpine-Carpathian collision. In: EGS Stephan Mueller Special Publication Series, Vol. 1, 233-258.

LAURIN J. and WALTHAM D., 2003. Climatic vs. Tectonic Controls on a Shallow-Water Hemipelagic Carbonate System (Turonian of Western Bohemia). This volume

MASSARI F., 1996. Upper flow-regime stratification types on steep-face, coarse-grained, Gilbert-type progradational wedges (Pleistocene, southern Italy). *J. Sed. Res.*, B 66: 364-375.

MATTE P., MALUSKI H., RAJLICH P. and FRANKE W., 1990. Terrane boundaries in the Bohemian Massif: Result of large-scale Variscan shearing: *Tectonophysics*, v. 177: 151-170.

MAZUR S. and ALEKSANDROWSKI P., 2001. The Tepla, ?./ Saxothuringian suture in the Karkonosze-Izera massif, wetern Sudetes, central European Variscides. *Int. J. Earth Sciences*, 90: 341-360.

NEMEC W., 1990. Aspects of sediment movement on steep delta slopes. In: Coarse-Grained Deltas , Eds A. Colella and D. B. Prior., *Int. Assoc. Sedimentol. Spec. Publ.*, 10: 29-74.

NEMEC W., 1995. The dynamics of deltaic suspension plumes. In: Geology of Deltas, M.N. OTI and G. POSTMA (Editors), 31-93, A.A. Balkema, Rotterdam.

ORI G.G., ROVERI M. and NICHOLS G., 1991. Architectural patterns in large-scale Gilbert-type delta complexes, Pleistocene, Gulf of Corinth, Greece. In: The Three-Dimensional Facies Architecure of Terrigenous Clastic Sediments and Its Implications for Hydrocarbon Discovery and Recovery, A.D. MIALL and N. TYLER (Editors), SEPM Concepts in Sedimentology and Paleontology, 3, 207-216.

PETEREK A., RAUCHE H., SCHRÖDER B., FRANZKE H.-J., BANKWITZ P. and BANKWITZ E., 1997. The late- and post-Variscan tectonic evolution of the Western Border fault zone of the Bohemian massif, WBZ. *Geologische Rundschau*, 86: 191-202.

PFIFFNER A., 1992. Alpine orogeny, In: BLUNDELL D., FREEMAN R. and MUELLER S., (Editors), A Continent Revealed: The European Geotraverse: Cambridge University Press, Cambridge, p. 180-190.

PRIOR D.B. and BORNHOLD B.D., 1990. The underwater development of Holocene fan deltas. In: Coarse-Grained Deltas (Eds A. Colella and D. B. Prior), *Int. Assoc. Sedimentol. Spec. Publ.*, 10: 75-90.

SCHECK M., BAYER U., OTTO V., LAMARCHE J., BANKA D. and PHARAOH T., 2002. The Elbe Fault System in North Central Europe – a basment controlled zone of crustal weakness. *Tectonophysics*, 360: 281-299.

SEIFERT A., 1932. Horizontalverschiebungen im sächsischen Turon-Quader rechts der Elbe als Auswirkungen der Lausitzer Überschiebung. *Neu. Jb. Miner. Beil.*, Stuttgart., 69B: 35-62.

SKOČEK V. and VALEČKA J., 1983. Paleogeography of the Late Cretaceous Quadersandstein of Central Europe. Palaeogeogr. *Palaeoclimatol. Palaeoecol.*, 44: 71-92.

SVOBODOVÁ M., LAURIN J. and ULIČNÝ D., 2002. Palynomorph assemblages in a hemipelagic succession as indicators of transgressive-regressive cycles: Example from the Upper Turonian of the Bohemian Cretaceous Basin, Czech Republic. In: M. WAGREICH (Editors), Aspects of Cretaceous Stratigraphy and Palaeobiogeography. Oesterr. Akad. Wiss., Schriftenr. Erdwiss. Komm. 15, 249-267.Vienna.

TÁSLER R., 2001. Mnichovohradišťská pánev. In: J. PEŠEK et al.: Geologie a ložiska svrchnopaleozoických limnických pánví České republiky, 167-186. Český geologický ústav, Praha.

ULIČNÝ D., 1997. Sedimentation in a reactivated, intra-continental strike-slip fault zone: the Bohemian Cretaceous Basin, Central Europe. Gaea heidelbergensis , 3, Abstracts, 18th IAS Regional European Meeting, Heidelberg, 347.

ULIČNÝ D., 2001. Depositional systems and sequence stratigraphy of coarse-grained deltas in a shallow-marine, strike-slip setting: the Bohemian Cretaceous Basin, Czech Republic. *Sedimentology*, 48: 599-628.

ULIČNÝ D. and LAURIN J., 2001. Well-log – based correlation of Turonian – Lower Coniacian depositional systems in the western part of the Bohemian Cretaceous Basin: New Basis for reconstructing the basin history. Proceedings of the 6th Meeting of the Czech Tectonic Studies Group, Donovaly, May 3-6, 2001. *Geolines*, 13: 121.

ULIČNÝ D., NICHOLS G. and WALTHAM D., 2002. Role of initial depth at basin margins in sequence architecture: field examples and computer models. *Basin Research*, 14: 347-360.

ULIČNÝ D. and ŠPIČÁKOVÁ L., 1996. Response to high-frequency sea-level change in a fluvial to estuarine succession: Cenomanian paleovalley fill, Bohemian Cretaceous Basin. In: J.A. HOWELL and J.F. AITKEN (Editors), High-resolution Sequence Stratigraphy: Innovations and Applications. Geological Society Special Publication 104, 247-268. The Geological Society, London.

ULIČNÝ D., ŠPIČÁKOVÁ L. and ČECH S., 2003.: Changes in depositional style of an intra-continental strike-slip basin in response to shifting activity of basement fault zones: Cenomanian of the Bohemian Cretaceous Basin. This volume.

ULRYCH J., PIVEC E., LANG M., BALOGH K. and KROPÁČEK V., 1999. Cenozoic intraplate volcanic rock series of the Bohemian Massif: a review. In: J. ULRYCH, V. CAJZ and ADAMOVIČ J. (Editors), Magmatism and Rift Evolution. proceedings of Final Session of IGCP 369 Project. *Geolines*, 9, 123-129.

VAN WAGONER J.C., MITCHUM R.M., CAMPION K.M. and RAHMANIAN V.D., 1990. Siliciclastic sequence stratigraphy in well logs, cores, and outcrops. *AAPG Methods in Exploration Series*, 7: 1-55.

VALEČKA J. and SKOČEK V., 1991. Late Cretaceous lithoevents in the Bohemian Cretaceous Basin, Czechoslovakia. *Cretaceous Research*, 12: 561-577.

VOIGT T., 1995. Faziesentwicklungen und Ablagerungssequenzen am Rand eines Epikontinentalmeeres – Die Sedimentazionsgeschichte der Sächsischen Kreide: PhD Thesis, Bergakademie Freiberg, 130 pp.

ZIEGLER P. A., 1990. Geological Atlas of Western and Central Europe: Shell Internationale Petroleum Maatschappij, The Hague, 239 p.

ZAHÁLKA Č., 1902. Pásmo I. a II. křidového útvaru v Pojizeří. Věstník Královské české společnosti nauk, Tř. math.-přídoprověd., Praha.

ZAHÁLKA Č., 1918.Východočeský útvar křidový. Královská česká společnost nauk, Roudnice, 1-155.