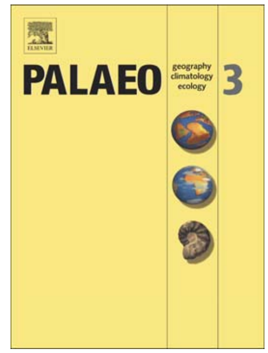

Facies architecture and palaeoenvironmental implications of the upper Cretaceous (Santonian) Csehbánya formation at the Iharkút vertebrate locality (Bakony Mountains, Northwestern Hungary)

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FACIES ARCHITECTURE AND PALAEOENVIRONMENTAL IMPLICATIONS OF THE UPPER CRETACEOUS (SANTONIAN) CSEHBÁNYA FORMATION AT THE IHARKÚT VERTEBRATE LOCALITY (BAKONY MOUNTAINS, NORTHWESTERN HUNGARY)

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Abstract

The Csehbánya Formation (Santonian), exposed in the Iharkút open-pit, Bakony Mountains, Hungary, is made up of a cyclic alternation of conglomerate, sandstone, and variegated siltstone and clay deposited in a fluviolacustrine environment. As a result of continuous excavation since 2002 it has yielded rich and diverse continental vertebrate and plant assemblages. A facies and architectural analysis of the Csehbánya Formation at this location identified four main lithofacies associations with eight subtypes consisting of (1) lenticular sandstones representing river channels, (2) conglomerates with sandstone (coarse grained likewise representing channel deposits), (3) heterolithic-channel fill (high density flash flow deposits) (4) splay sandstones produced by crevasse splays, (5) dark sandy siltstone (small-scale stagnant pool deposits with high organic content), (6) greenish-grey claystone (deposits of shallow lakes and ponds), (7) reddish (moderately drained) paleosols, (7) yellowish, mottled (hydromorphic) paleosols.

The sedimentological investigations revealed that the terrestrial deposits exposed by the Iharkút open-pit were formed in an anastomosing fluvial system because: (i) the alluvial architecture is characterized by large proportion of overbank deposits encasing the channel sandstone bodies, (ii) the ribbon shaped sandstone bodies are dominant, (iii) cross-bedding and lateral accretion are almost completely absent in the channel fill deposits and (iv) the sandstone bodies are clearly isolated from each other, embedded in floodplain sediments, suggesting multiple co-existing channels.

The most important vertebrate fossil site (SZ-6) was examined in special detail because it shows peculiar lithological features. The layers richest in fossils (Unit 1) of SZ-6 site is interpreted as a lag deposit formed during an episodic high density flash flood event representing a relatively short time interval, i.e., probably within a single rainy season.

1. INTRODUCTION

A significant part of continental vertebrate fossils is found in alluvial deposits thus the reconstruction of the depositional history of alluvial sequences is the main goal of any sedimentological, paleontological and taphonomical examination of vertebrate sites (Behrensmeyer, 1982, 1988; Retallack, 1984; Badgley, 1986a,b; Eberth and Miall, 1991; Nadon, 1993; Therrien, 2005; Roberts, 2007). One of the reasons for the accumulation of rich vertebrate fossil-bearing strata is that a relatively high number of animals are attracted to the floodplain due to abundant water and food supply (different plants or prey), which can result in a rich accumulation of bones (Behrensmeyer, 1988; Nadon, 1993; Andersson and Kaakinen, 2004). Furthermore, certain floodplain environments are favourable for bone preservation because of the relatively high depositional rate, post-mortem transportation, and reworking of animal remains by various fluvial processes (Behrensmeyer, 1988; Aslan and Behrensmeyer, 1996). Thus, a sedimentological investigation of fluvial deposits is indispensable in order to understand the physical and/or chemical processes responsible for the formation of fossiliferous horizons in alluvial sequences (Behrensmeyer, 1988; Csiki et al., 2010).

Iharkút is a Late Cretaceous (Santonian) vertebrate-bearing locality in the Bakony Mountains, western Hungary (Fig. 1A). The Csehbánya Formation, consisting of 30 to 50 m thick freshwater alluvial deposits (Kocsis et al., 2009), have yielded a rich and diverse assemblage of continental vertebrates including fish, amphibians, turtles, mosasaurs, lizards, pterosaurs, crocodilians and dinosaurs including birds (Ősi et al., 2012; Csiki et al., 2015). The Iharkút vertebrate assemblage is dominated by bones of aquatic and semi-aquatic animals while the number of bones of terrestrial animals is subordinate (Botfalvai et al., 2015).

The Iharkút locality yielded a rich and diverse fossil plant material with coalified woods being the most frequent macrofossils. Preliminary studies indicate that annual rings detected on these coalified woods refer to seasonality (Rákosi L. pers. com 2006, Ősi et al., 2016). The palynological assemblage described by Bodor and Baranyi (2012) is well preserved and dominated by the Normapolles group (40%). Other groups of angiosperms, gymnosperms (conifers, cycads, bennettitales), ferns and mosses formed 60% of the assemblages. The mesoflora of Iharkút sustaining less transport than sporomorphs (Friis et al., 2011), is important in providing more direct information on the flora. Study of more than 5000 plant mesofossils shows angiosperm dominated vegetation. The trees of the floodplain forests were Normapolles related forms represented mainly by the *Sphaeracostata barbackae* (Bodor and Baranyi, 2012). The Normapolles group is most likely related to Fagaceae (Friis et al., 2011).

In addition to the Normapolles related mesofossils, the Iharkút material includes a high number of Magnoliaceae, Hamamelidaceae, Urticaceae and Sabiaceae related fossils as well (Bodor et al., 2012). The Magnoliaceae is mainly represented by the *Padragkutia haasii* (Knobloch and Mai 1986a, b) having been less common element of the mixed forest (Bodor et al., 2014). In the underwood the locally abundant Urticaceae is an index of disturbed, moderately wet environment.

The macroflora is also angiosperm dominated. Some poorly preserved fern pinnules were found. Gymnosperms are represented by Araucariaceae related large trunks and branch fragments. Monocots are represented mainly by *Pandanites* leaves. The most common elements of the leaf fossils are dicots.

Based on these preliminary results Normapolles related forests with herbaceous angiosperm and fern dominated underwood can be reconstructed in the surroundings of the

Iharkút locality existed under tropical or subtropical climate (Siegl-Farkas and Wagreich, 1996, Bodor and Baranyi, 2012).

Taxonomical, palaeoecological, palaeobiogeographical, and taphonomical investigations of the Iharkút material arewell documented (Rabi et al., 2012; Makádi et al., 2012; Szentesi and Venczel 2012, Ősi et al., 2012; Botfalvai et al., 2014; Makádi and Nydam, 2014; Prondvai et al., 2014; Csiki et al., 2015; Rabi and Sebők, 2015), however, detailed description and interpretation of the Iharkút sedimentary basin and palaeoenvironment is still missing.

The aim of the present study is to give an insight into the sedimentological history of the bone-yielding Csehbánya Formation based on the exposures in the Iharkút open-pit. First, we give a brief description from the geological framework of the Iharkút area and the Csehbánya Formation. Based on the detailed description and interpretation of the identified facies associations the sedimentological and geological significances of the alluvial setting will be discussed and the identified depositional palaeoenvironments of the Csehbánya Formation in the Iharkút locality established. This study contributes to the increasing knowledge on ancient anastomosing fluvial systems, and improves our understanding of the geological and palaeoenvironment history of the Late Cretaceous European archipelago.

2 TECTONIC SETTING AND REGIONAL PALEOGEOGRAPHY

Rifting of the supercontinent Pangea during the Permian to Early Triassic was followed by the opening of the western arm of the Neotethys Ocean from the Middle Triassic (Haas et al., 1995). Then, in connection with the opening of the Atlantic Ocean, a new oceanic basin opened from the Early Jurassic onwards – the Penninic Ocean (“Alpine Tethys”). Closure of the Neotethys Ocean began in the Middle Jurassic and led to obduction of the oceanic basement onto the continental margins during the Late Jurassic–Early Cretaceous period. Southeast-directed subduction of the Penninic Ocean started in the early Late Cretaceous; an accretionary wedge came into existence and the development of the Austoalpine nappes commenced under a dextral transgressional regime (Faupl and Wagreich, 2000). The deformed Austroalpine domain uplifted and became subject to subaerial erosion in the Turonian. A transtensional regime formed pull-apart basins in the area of the Northern Calcareous Alps (NCA) where terrestrial and shallow marine sediments accumulated. These sediments were buried by deep-sea deposits during in the Santonian/Campanian in the NW part of the NCA (Faupl and Wagreich, 2000). These fundamental geodynamic events are reflected in the structural evolution of the Transdanubian Range Unit (TRU). Development of a flexural basin in the NE part of the TRU and appearance of ophiolite-derived clasts in the basin-filling siliciclastic formations record the obduction of the Neotethys oceanic basement (Császár and Árgyelán, 1994; Fodor et al., 2013). In the late Aptian to early Albian, roughly coeval with the onset of the evolution of the nappe-stack, accompanied by deformation, uplift, and subaerial exposure, the large synclinal structure of TRU formed. It was followed by a new depositional cycle initiated in the Middle Albian. Uplift and intense erosion took place again during the Turonian. Upper Triassic platform carbonates became exposed on the limbs of TRU syncline and were affected by intense karstification under tropical climatic conditions (Haas, 1983). Ferrallitic weathering products were transported to, and accumulated in, the karstic depressions. Diagenetic alteration of weathering products of variable origin led to the formation of bauxite deposits in the Northern Bakony and the western part of the Southern Bakony (Bárdossy, 1982; Mindszenty, 1985, Mindszenty et al., 2000). During the Coniacian(?) to Campanian a several hundred metres thick continental to deep marine succession was formed in the TRU. In spite of the intense pre-Eocene denudation, records of this succession are preserved in the Bakony Mountains and in the basement of the Little

Hungarian Plain and the Zala Basin to the west of the Transdanubian Range Unit (TRU), West Hungary (Fig. 1).

2.1 Local palaeogeographic setting and lithostratigraphy

As a result of the tectonic movements and the subaerial erosion, a dissected basin system came into being by the Coniacian(?)–Santonian with elongated highs and depressions between them, roughly parallel to the strike of the TRU syncline. Due to significant topographic differences, which strongly influenced the paleogeographic setting in the early stage of basin evolution, the stratigraphic successions of the depressions and the highs are significantly different (Haas, 1983) (Fig. 1B). In the eastern part of the depressions (Northern Bakony and northern foregrounds of the Southern Bakony) fluviatile and lacustrine deposits of the Csehbánya Formation were formed (Fig. 1B) with cyclic alternations of gravel, sandstone, siltstone, and variegated and/or dark grey claystone representing channel, flood plain, and swamp facies (Jocha-Edelényi, 1988), 50–200 m thick.

In some sub-basins in the southeastern part of the Late Cretaceous basin (in the Southern Bakony) lakes and freshwater swamps came into being and coal seams (the Ajka Coal Formation) began to form (Fig. 1B). As a result of a transgression the lacustrine coal seams are overlain by paralic ones (Góczán et al., 1986; Haas et al., 1992). The thickness of the coal-bearing formation may exceed 100 m. It is made up by alternating coal, limestone, marl, siltstone, and sandstone beds. The coal-rich intervals usually contain abundant brackish-water fossils (Czabalay 1983).

Continued transgression during the Late Santonian resulted in deposition of sediments recoding brackish-water and normal marine environments (Bodrogi et al., 1998; Fig. 1B). The brackish-water deposits are commonly dark grey, clays marls, generally with a rich, reworked bivalve, gastropod, and solitary coral fauna. The overlying normal salinity deposits consist of 50 to 100 m of grey marl with lenses and interlayers of *Pycnodonta* coquinas (Jákó Marl Formation) formed in the neritic zone. Rising sea-level eventually covered the tops of the ridges separating the sub-basins and led to the formation of carbonate platforms where the 100–400 m-thick rudist limestone of the Ugod Limestone Formation accumulated (Haas, 1979; Fig. 1B and C). Argillaceous wackestones and calcisilts were deposited in the relatively deep hemipelagic basins (lower part of the Polány Marl Formation; Fig. 1C) between the platforms. Drowning of the rudist platforms in the middle part of the Campanian (Haas, 1983) led to a significant decrease in the carbonate content of the basinal sediments and deposition of the upper part of the Polány Marl Formation. This unit consists of up to 600 m of marls with a rich planktonic foraminiferal assemblage deposited in a bathypelagic basin (Bodrogi et al., 1998) within which the carbonate content shows an upward decreasing trend.

The Late Cretaceous sedimentary cycle was followed by a long period of uplift and intense erosion in the early Palaeogene that resulted in the erosion of some of the Upper Cretaceous formations. Accordingly the maximum original extent of the Upper Cretaceous depositional basin is unknown. Since deep-sea conditions prevailed from the Late Campanian onward it is highly probable that the whole TRU was sea-covered at the climax of tectonically-controlled transgression–regression cycle (Haas, 1983).

2.2 The Csehbánya Formation

The Csehbánya Formation is made up by cyclic alternation of conglomerate, sandstone, and variegated siltstone, clay and marl layers with sporadic intercalations of thin coal seams (Fig. 2A) that are present in two NE–SW striking sub-basins separated by a slightly elevated ridge (Haas et al., 1992). In the eastern part of the southern sub-basin (Fig. 2B), the Csehbánya Formation was deposited directly onto the erosional surface of the pre-

Santonian formations or onto bauxite-filled karst depressions of the basement (Fig. 2A). In this area the thickness of the formation is 100–150 m (Fig. 2B). In the southern part of the southern sub-basin, conglomerates and grey sandstones are the most common lithologies although variegated clay and marl layers also occur, locally. The mean size of the moderately to well-rounded gravels is 5–8 cm Triassic dolomite prevails among the clasts. In the northern part of the southern sub-basin the formation is composed mostly of variegated clay, marl and siltstone with interbeds of conglomerate and sandstone. The clast composition is also more variegated with dolomite, limestone, quartz, quartzite, and sandstone being present (Jocha-Edelényi, 1988). Further to the southwest pre-Santonian formations are covered only by thin terrestrial deposits (claystones, sandstones) that pass upward into the coal-bearing Ajka Formation (60–80 m in thickness). The bulk of the Csehbánya Formation occurs above the coal-bearing unit and gradually thins and pinches out to the southwest. In this area variegated clayey marls, siltstones, and sandstones are the typical rock types (Jocha-Edelényi, 1988).

Limited borehole data indicate that the Csehbánya Formation in the northern sub-basin consists of 100–150 m of gravel and sandstone with subordinate amounts of variegated clayey marl and siltstone (Fig. 2B).

3 THE IHARKÚT OPEN-PIT

The oldest rocks in the Iharkút open-pit mine are Late Triassic shallow marine dolomites (Main Dolomite Formation) overlain by Late Cretaceous bauxite (Nagytárkány Bauxite Formation) filling deep karstic sinkholes (Fig. 2A). The bauxite and dolomite are unconformably overlain by the mudstones, siltstones, and sandstone of the Csehbánya Formation (Gellai et al., 1985; Figs. 2A and 3). Geochemical studies indicate that within the Iharkút open-pit the Csehbánya Formation was deposited in freshwater environments (Kocsis et al., 2009). Palynological studies show that sedimentation took place in the *Oculopollis zaklinskaiae - Brecolpites globosus* palynozones and *Oculopollis-Triatriopollenites* subzone which is correlated to CC16 Nannoplankton zone (Siegl-Farkas and Wagreich, 1996). This indicates a Late Santonian age of the formation in this outcrop (Bodor and Baranyi, 2012). The study interval is unconformably overlain by Middle Eocene (Lutetian) conglomerates and limestones. The youngest deposit exposed in the open-pit mine is Pleistocene loess which forms a discontinuous blanket over most of the area (Fig. 2A).

3.1 Sedimentology of the Iharkút open-pit

The sedimentology of the Csehbánya formation was analysed in detail at the Iharkút open-pit, where 12 stratigraphic sections were investigated in 15-20 m in length (7 sections are illustrated in Supplementary data 1). The EOV coordinates of the observed sections were measured by Javad Triumph-1 GNSS. Sediments were analysed in the field and hand specimens from some sections were cut, polished and examined with the stereomicroscope. The grain size of the sediments was established by using the Wentworth scale and the colour of paleosols with the Munsell Colour chart. Detailed facies and architectural analysis were performed, with particular attention devoted to channel morphology and paleontological data. The published palynological results of Baranyi were also taken into consideration (Bodor and Baranyi 2012). The studied mesofossils were extracted from the sediments by sieving. Sand or silt size quartz grains, often adhered to the surface of the seeds, were removed by hydrofluoric acid (40 %). Scanning electron microscopy was carried out at the Department of Plant Anatomy, Eötvös Loránd University, with a Hitachi S-2360N microscope and with S-2660N microscope at the Department of Botany, Hungarian Natural Historical Museum. The seeds and fruits were mounted on aluminium-stubs and sputter coated with gold-palladium using a Polaron SC7520 Mini Sputter Coater.

A total of 12 lithofacies were recognized using a classification based on grain size, bedding, palaeontology, and sedimentary structures (Miall, 1985; Roberts 2007). The abbreviation of the different lithofacies and their descriptions are listed in Table 1. The lithofacies were then grouped into four distinct lithofacies associations (fluvial channels, crevasse splay, shallow lakes and paleosols; Table 2).

3.1.1 Facies association 1: Fluvial Channels

Channel deposits are present as lenticular bodies (Figs. 3 and 4) with three subtypes based on the proportions of the different lithofacies and fossil content (Table 2).

3.1.1.1 Lenticular sandstones (included Gm, Se, St, Fr lithofacies; see Table 1)

Description: Lenticular sandstone bodies occur at various topographic levels in the open-pit (see Supplementary data 1). They are clearly isolated from each other, and are commonly encased in mudstones (Figs. 3 and 4A-B). This type of sandstone bodies is characterized by sharp scoured concave bases (Fig. 4 B) and abrupt flat tops. Thickness varies from 2 to 4 m and the width from 30 to 60 m. Their average width/thickness ratio is less than 15 in the Iharkút open-pit. The base of these lenticular bodies incises into the underlying mudstone (Facies Se). Incision produced mudstone intraclasts which often form a basal lag and include fragments of petrified wood, bones, teeth and sometimes well-rounded dolomite pebbles (1-3 cm in diameter; Facies Gm). The grain size varies from fine- to medium-grained sandstone near the base and siltstone, which may contain roots (Facies Fr), is often present at the very top of these sandstone bodies ("fining upward"). Point bar accretion is absent and cross-bedding (Facies St) is very rare in the channel fills.

Interpretation: The low width/thickness ratio (<15), the lenticular geometry, the absence of point bar accretion and the infrequent cross-bedding at this lenticular sandstone bodies suggest that lateral accretion was moderate, which is a characteristic feature of ribbon sandstone bodies (Gibling and Rust, 1990; Eberth and Miall, 1991; Kirschbaum and McCabe, 1992; Nadon, 1994; Roberts, 2007). The absence of point bar accretions in the channel fill deposits probably suggests that the active channels were laterally stable. These sandstone bodies are clearly isolated from each other, embedded in floodplain sediments suggesting multiple co-existing channels. The above mentioned characters are considered as diagnostic features of anastomosing river deposits (Eberth and Miall, 1991; Kirschbaum and McCabe, 1992; Nadon, 1993, 1994; Makaske, 2001; Horiuchi et al., 2012). The siltstone layers at the top of the lenticular bodies are interpreted as the results of decreasing flow energy as the channels were abandoned (Kirschbaum and McCabe, 1992). The bone and plant remains are rare in the sandstone filled channel ribbons supporting the hypothesis that instead of constant energy conditions, fossil accumulation was rather associated with fluctuating energy levels in the Iharkút quarry (see below).

3.1.1.2 Conglomerate with sandstone (Gcm, St, Se)

Description: Two channel fills in the uppermost part of the open-pit are characterized by alternation of sandstones and conglomerates (Fig. 4C). Unfortunately, these channel fills are very poorly preserved because of the recultivation of the open-pit obscuring the original shape and size of these channel fills. The sandstones are light brown or reddish brown, calcareous, medium- to coarse-grained, poorly sorted, and cross bedded (Facies St). The conglomerate layers, present at the base of the sandstone layers, are 0.3 m thick consisting of well rounded, poorly sorted dark to light coloured pebbles up to 15 cm in diameter with subordinate clayclasts (Facies Gcm). The pebbles are predominantly of dolomite and quartz with subordinate lidite (Gellai et al., 1985). The lower surface of these beds incises into the floodplain sediments (dark sandy siltstone or yellowish paleosols; Facies association 3 and 4) The sedimentary structures include trough cross-beds that range in thickness from 10 cm to 30 cm. Bones and plant debris are completely absent from these conglomeratic-sandy channel fills.

Interpretation: The marked cross-bedding and the coarse grain size of the sediment in this channel fills suggest that in this case the depositional environment and the energy conditions of sediment transport were probably different from the aforementioned ribbon sandstones bodies. The pebbly-sandstone channel fills occur in the uppermost part of the Iharkút open-pit representing separate sedimentary units above the ribbon and tabular sandstone bodies, a phenomenon possibly suggesting significant changes in the sedimentary conditions. However, neither the fluvial style nor the depositional environment could be properly established in this case because of the incompleteness of the record, as mentioned above.

3.1.1.3 *Heterolithic-channel fill (*Gm, Se, Sl, St, Fl, C)

Description: We examined this sequence (Fig.5) separately from the other channel fills, because it has different lithology and represents the most important fossiliferous horizon (site SZ-6; Botfalvai et al., 2015) in the Iharkút open-pit. Thus the interpretation of the sedimentology of this sequence is of primary importance for the vertebrate paleontological research a the Iharkút locality

These sediments fill an apparently asymmetric lenticular channel, the basal surface of which is clearly erosional, it cuts into the underlying massive greenish-bluish clay bed (Facies association 3). Its thickness shows up as 2.0 to 3 m and seems to have a lateral extension of approximately 90-100 m. The channel-fill forms a fining-upward sequence made up by coarse, pebbly sand and organic-rich silt/clay (Fig 4D and E). It can be divided into three different units (Unit 1-3; Fig. 5A).

The basal unit (Unit 1), containing most of the vertebrate fossils, is a grey-green (10GY 7/1), 10 to 50 cm thick layer (Figs. 4D-E and 5B) composed of clayclasts, sandstone, dolomite pebbles, siltstone, plant debris and complete or fragmentary bones (Facies Gm) bound by calcareous cement with trace amounts of pyrite. The intraclasts vary in size from 0.3 to 2 cm in diameter. The Unit 1 has a high bone concentration (23 bones or fragments/m^2) with the maximum dimension of the bones varying between 0.3 cm and 64 cm and being poorly sorted by shape (Botfalvai et al., 2015). The poorly sorted sandy breccia is interrupted by laminated siltstone/claystone horizons or few millimetre thick layers of coalified wood debris (Facies Fl, C). These coarse and fine grained horizons are repeated several times resulting in a stacked series of fining upward elementary units (Figs. 4D-E, 5 and 6). The siltstone horizons consist mainly of finely laminated dark grey silt (Facies Fl). Their thickness ranges from 3 to 5 cm and they can be laterally traced for several metres. Sedimentary structures are restricted to occasional, barely discernible cross-bedding (Facies Sl, St) in the coarser sandstone breccia horizon. Root traces and bioturbation were not observed in Unit 1.

Most bones and plant remnants (twigs, trunk fragments) are oriented with their long axes being near-horizontal, however, several bones and tree trunks were also observed with their long axes oriented sub-vertically (e.g. Fig. 7A-B) in Unit 1 (cf. with Bertini et al., 2006; Eberth et al., 2006). Several bones, such as the turtle plate fragment shown in Fig. 7, were observed with their long axes oriented sub-vertically, partially pressed into the siltstone layer, but mostly surrounded by coarser sandy sediments and intraclasts (Fig.7A-B). The palynorecord of Unit 1 shows that angiosperms *Oculopollis* and *Hungaropollis* are the most common, but ferns are also abundant in the record. More than 2000 seeds and fruits were found in Unit 1 (Bodor and Baranyi, 2012). The plant fossils are not charcoalified only carbonised, with the inner structures occasionally filled by pyrite. The most common size category is 0.5 to 3 mm. Leaf remnants are absent in this layers. The abundant wood fossils typically vary between 5 and 20 cm in diameter but larger-sized tree trunks (e.g., an 8 m long Araucariaceae trunk, Rákosy pers.comm.) were also found in the basal breccia layer. The bones extracted from this unit vary from those of fragile birds and pterosaurs to massive ankylosaurs. Vertebrate fossils are usually isolated with some associated bones, and one single articulated skeleton discovered and described by Botfalvai et al., 2015. Fragments of amber and a large number of pyritized mollusc shells were also found in this unit. Pyritic crusts are often well developed both outside and inside the bone and plant fossils. Pyrite concretions are also present in large quantities in both the finer and the coarser grained horizons (Tuba et al., 2006).

Unit 1 is covered by a firmly cemented grey-green (10GY 7/1), predominantly massive, sandstone bed 30 to 50 cm thick showing a poorly developed upward-fining trend. The grain size range of Unit 2 varies from fine- to medium-grained sandstone and both the lower and the upper contacts of this unit are typically gradational. Intraclasts (0.3-2 cm in diameter) and pebbles are rare but may be present in the basal part of this layer. Unit 2 also contains scarce remains of vertebrate fossils the state of preservation of which is, however, slightly different (more abraded and unweathered) from that of the rest. The vertebrate fossils are predominately isolated, but one associated incomplete skeleton (MTM V.152) was also recovered from Unit 2 (Botfalvai et al., 2015). Well preserved plant fossils (leaves) were also recovered. These are preserved as black carbonaceous films in the light grey, well-cemented sandstone. The lobes of the leaf-blades are not broken but the cuticles are very poorly preserved.

Unit 3 is a 50 to 150 cm thick (average 50 cm), laminated, greyish, brownish siltstone with large-scale, soft-sediment deformation containing plant debris, fewer bones than do the underlying units, and one incomplete skeleton of *Hungarosaurus* (MTM 2007.25; Botfalvai et al., 2015). Unit 3 is fining-upward and claystone laminae are present near its top (Facies Fl).

Plant debris, predominantly leaf fossils, is well preserved. The plant debris can be identified after maceration as dispersed cuticles (Bodor and Baranyi, 2012). In the palynological samples *Hungaropollis* and *Oculopollis* were the most abundant genera, while fern spores were very rare (Bodor and Baranyi, 2012). Bones and mollusc shells were also very rare. There was no evidence of plant roots, mottles or desiccation features.

Interpretation: The lenticular shape, the basal erosion surface and the clear tendency of fining upwards of the complete section (including Unit 1-3) suggest that this facies association was a channel fill deposit. The whole channel fill sequence of site Sz-6 resulted from depositional events which were characterized by a progressive decrease of flow energy. The presence of smaller or larger intraclasts of floodplain origin, the larger-sized tree trunks, and pebbles in Unit 1 indicate conditions associated with high energy flood events (c.f. Myers and Storrs, 2007), resulting in efficient reworking of the material of the interfluve areas (e.g. Retallack, 2005). Intraclasts are usually destroyed by transport over distances ranging from tens to hundreds of meters (Ryan et al., 2001). Thus the source of clayclasts must have been not very far from the depositional place and they were broken up by the same flooding event that collected also the bone fragments and skeletal parts (Ryan et al., 2001). The intraclasts were buried probably very quickly since these are physically fragile and chemically reactive particles when in direct contact with flowing water, so they never would have persisted at the surface for more than a single heavy rain (e.g. Retallack, 2005). The rarity of unidirectional sedimentary structures in the coarser part of Unit 1 and the presence of the laminated mudstones (Fig 5B) suggests that the massive appearance is a primary sedimentary structure indicating that bioturbation and other post-depositional destructive effects cannot have played a significant role after the accumulation of the “placer” (Rogers, 2005; Eberth et al., 2006, Lauters et al., 2008).

We suggest that the depositional environment was a high density flash flow based on the poor sorting, the lack of unidirectional sedimentary structures and the bone fragments observed with their long axes oriented sub-vertically (Behrensmeyer, 1988; Abdullatif, 1989; Eberth and Miall 1991; Miall 1996; Benvenuti and Martini, 2002; Rogers, 2005; Eberth et al., 2006; Myers and Storrs 2007; Lauters et al., 2008; Britt et al., 2009). Furthermore, there is no strong evidence for shape sorting in the vertebrate assemblage of this fossiliferous bed (Botfalvai et al., 2015) also suggesting that the Iharkút taphocoenose was not a typical fluvially transported assemblage but rather a density flow deposit (e.g. Eberth et al., 2006, Rogers 2005, Lauters et al., 2008; Britt et al., 2009). The high energy conditions were interrupted several times by quiet-water sediments (laminated siltstone, claystone; Figs 4D-E and 6) indicative of deposition from suspension in standing water following the flow events (e.g. Rogers, 2005; Eberth et al., 2006). Additional taphonomical and sedimentological characters of Unit 1 that are similar to other interpreted high density, flow-generated dinosaurs bonebeds described by Lauters et al. (2008) and Britt et al. (2009) are: (1) most of the bone fossils are isolated, the articulated and associated skeletal materials are limited; (2) most of the bones are broken; (3) the host sediments of Unit 1 comprise more stacked deposits; (4) the highest bone concentration occurs at the base of the site SZ-6 (Unit 1), and this fossiliferous deposits are incised into the underlying floodplain sediment (green clay). The absence of leaves and the high density of branches and wood fragments in Unit 1 also suggest a high energy transport. During this transport mechanical fragmentation and size reduction of plant debris did occur (Villalba-Breva et al., 2015). The small size seeds and fruits could better survive the transport or they may have originated from plants in the nearby floodplain, reasons, possibly explaining the so many well-preserved mesofossils found here. The most common form is *Sphaeracostata barbackae*, but, for instance, Magnoliaceae related forms also occur. The pollen grains refer to a closed-canopy forest with ferns in the underwood because the most common forms are related to the Normapolles group representing Fagaleaceae related trees (Friis et al., 2011) and fern spores occurring as additional elements. Wood fragments are mainly gymnosperms but since they are able to resist longer transportation they may be representatives of the non-flooded inland areas or some more distant upland territories.

Furthermore, several bones and fragments (such as the turtle plate fragment shown in Fig. 7) were observed with their long axes oriented sub-vertically, partially pressed into the siltstone layer but mostly surrounded by coarser sandy sediments and intraclasts (Fig.7A-B). This pattern suggests the following sequence of events: (1) the turtle plate was transported along with clayclasts and sand by a high energy flow; (2) the siltstone layer was still soft when the turtle plate intruded in it, as evidenced by the deformation of the sediment around the bone; (3) because the plate remained in an almost vertical position without tumbling over and there is no evidence for postburial deformation of the enclosing sediments (e.g. by trampling) that could have moved the plate vertically, it is most likely that the energy of the flow dropped suddenly after depositing the bone in this characteristic position (Fig. 7C). The orientation of this turtle bone and the arrangement of the laminated siltstone over the coarser sediments indicate that the depositional area of Unit 1 of site SZ-6 acted as a trap where current velocity suddenly decreased and the poorly sorted sand, intraclasts, pebbles, and bones accumulated (cf. with Bertini et al., 2006). Other taphonomic characteristics (abrasion, shape sorting, and skeletal completeness data) also suggest this depositional story rather than a slow fill up by a perennial stream (Botfalvai et al., 2015). Moreover, the associated and articulated skeletal remains of ankylosaurs demonstrate that the carcasses were buried shortly after the death of the animals (Botfalvai et al., 2015) supporting the trap (or “placer”) interpretation with a high sedimentation rate.

The grey-green, cemented sandstone bed (Unit 2) indicates reduction in flow velocity (either when the channels were abandoned or possibly at the end of the flooding events) when finer sediments (fine- to medium-grained sandstone) were deposited over the basal breccia layer. In Unit 2 angiosperm leaf remains are more abundant and more diverse than conifers. It may be litter deposited in the floodplain displaying an over-representation of deciduous plants and an under-representation of evergreens (Ferguson et al., 1999; Villalba-Breva et al., 2015). However in the case of Unit 2 the plant micro- and mesofossil material is also dominated by presumably deciduous angiosperms. So the dominance of angiosperm leaves is not simply the result of the fossilisation bias of the conifers. The leaf-blade lobes are not broken referring to short transport before burial. The lack of well-preserved cuticles in sandstone is common (Barbacka, 2011). Finer sediments are more likely to contain cuticles (Kerp, 1990).

The closing bed at site SZ-6 (Unit 3) is interpreted to represent open lacustrine conditions following the deposition of Unit 2 and resulting in the deposition of highly bioturbated siltstone. The large-scale, soft sediment deformation may be the result of trampling, which is common in most anastomosed fluvial deposits, because large herbivores inhabited seasonal wetlands dominated by marshes and lakes (e.g. Nadon, 1993, Gates, 2005, Britt et al., 2009). Furthermore, trampling-induced breakage (*in situ* breakage type) was detectable in the 2nd (holotype) skeleton of *Hungarosaurus* (MTM 2007.26) which was excavated from Unit 3 of site SZ-6 (Botfalvai et al., 2015). The fragmentation of cuticles in this layer can be also explained by bioturbation. Ferns are less abundant in the underwood (Bodor and Baranyi, 2012) but for example seeds of Urticaceae were found. Recent nettles are common in highly disturbed short-lived, moderately wet territories (Knobloch and Mai, 1986a,b). Their occurrence in Unit 3 confirms the disturbed environment.

3.1.2 Facies association 2: Crevasse splay

3.1.2.1 Splay sandstone (Sl, St, Sh)

Description: Tabular sandstone bodies that range in thickness from 0.5 to 1.5 m (average 0.5 m) and 50-100 m in width (width/ thickness ratio of >15) occurring within thick successions of mudstones (Fig. 3B and 4F). These sheet sandstones have flat, non-incised bases (Facies Sl). This sandstones are finer-grained than the ribbon sandstone bodies (predominantly fine grained sand) with rare intraclasts at the base and very rare recognizable sedimentary structures (Facies St, Sh). The beds fine upward to siltstones, which are commonly pedogenically modified (e.g. root mottles). Fossil material is restricted to scattered plant debris. The tabular sandstone bodies are less common in the open-pit than the lenticular sandstones (tabular- to lenticular sandstone ratio is approximately 1:3; see Supplement 1) and they are usually located in close association with hydromorphic paleosols and dark sandy siltstones.

Interpretation: The tabular sandstone bodies are interpreted as sheet splay deposits based on the high width/thickness ratio, the finer grain size, and the lack of incision. The scarcity of sedimentary structures may have been the result of post-depositional events, such as bioturbation (Nadon, 1994; Bristow et al., 1999; Roberts, 2007), because such environments quickly become colonized by vegetation after deposition (Smith et al., 1989; Nadon, 1994). Splay deposits usually formed during periods of overbank flooding (Nadon, 1994; Makaske, 2001; Roberts, 2007) when the transport capacity of the flow was drastically reduced after leaving a channel causing most of the sediment load to be deposited on the floodplain (van Gelder et al., 1994). Such sheet deposits are commonly associated with ribbon sandstones of anastomosing river systems (Smith et al., 1989; Eberth and Miall, 1991; Kirschbaum and McCabe, 1992; Miall, 1996; Nadon, 1993; Makaske, 2001; Makaske et al., 2002; Roberts, 2007) and suggest that flooding events must have been characteristic features of the palaeoenvironment at Iharkút (e.g. Bristow et al., 1999; Roberts, 2007; Horiuchi et al., 2012).

3.1.3 Facies association 3: Shallow lakes

The shallow lake or pond deposits are present as tabular beds containing siltstone and claystone (Fig. 8 A-C) with two subtypes based on the proportions of the different lithofacies, colour and fossil content (Table 2).

3.1.3.1 Dark sandy siltstone (Fl, Fc, Fcf, Fr, C)

Description: Dark sandy siltstones with a high organic content (Fig. 8A) are present in approximately 5% of the open-pit exposure. The beds vary from 0.3 to 1.5 m thick, are up to tens of meters wide and show a weak upward coarsening in grain size. The upwards increase in clastic content is accompanied by a decrease in the amount of organic material and a colour change from dark to light grey (Fig. 8B). The siltstone beds vary from massive with roots to laminated and occur either between two tabular sandstone bodies or interbedded within thick sequences of Facies Association 4. Pyrite concentrations are relatively high and form coatings around microfossils. The size of organic material varies from identifiable plant meso- and microfossils to unrecognizable plant debris, with rare small fragments of tree trunks and twigs (1 to 10 cm) also preserved (Facies Fcf, C). Besides the various *Oculopollis* species *Triatriopollenites* is the second most abundant palynomorph. In the mesoflora Normapolles-related forms are less dominant than at site SZ-6. The Sabiaceae, Hamamelidaceae and Magnoliaceae related fossils are frequent elements of this unit. The finer grained layers contain fragments of amber and egg shells (vary from 1 - 3 mm in size) as well as a large number of pyritized mollusc shells and a rich microvertebrate (generally less than 1 cm in diameter) assemblage (Botfalvai et al., 2015). The microvertebrate fossils are relatively frequent (site SZ-7-8 in Fig 5C) where the organic matter content is high and the grain size is coarser (fine-grained sandstone with siltstone). Bioclasts (i.e., bones and teeth) representing predominantly aquatic and semiaquatic species of fish, crocodiles, mosasaurs, and amphibians.

Interpretation: This facies association is interpreted as a product of deposition in a low-level (poorly drained) floodplain with elevated water table characterized by overall hydromorphy (Davies-Vollum and Wing, 1998; Kraus, 1999; Davies-Vollum and Kraus, 2001; Roberts, 2007). The preservation of laminations, the overall fine grain size, as well as the presence of pyrite indicate that these dark sandy siltstone beds were deposited in small poorly oxygenated pools of the floodplain (Retallack, 2008; Therrien et al., 2009). Root traces in the mudstone and the fossil plant material also indicate that the floodplain was vegetated (Therrien et al., 2009). The alternation of siltstones with the high-organic horizons (Fig. 8B) indicate that the deposition of organic matter was occasionally interrupted by the influx of clastic sediment deposited by low energy fluvial processes (e.g. Simit and Smith, 1980). Furthermore, the low abundance of high-organic mudstones and claystones in the Iharkút open-pit suggests that floodplain sedimentation was dominated by clastic sediment influx, which prevented the accumulation of substantial coal seams (Kirschbaum and McCabe, 1992; Davies-Vollum and Wing, 1998).

The *Triatriopollenites* discovered from these beds is attributed to Myricaceae (Akkiraz et al., 2008), which in the modern floras form shrub levels in swamps. The presence Sabiaceae family consists of trees, shrubs and lianas in modern subtropical-tropical wetland canopies, which is consistent with the previous interpretation of subtropical floodplain forest vegetation (Bodor et al., 2012). Hamamelidaceae were widely distributed in subtropical localities of the Northern hemisphere during the Late Cretaceous (Knobloch and Mai, 1991, Friis et al., 2011). The possible affinity of the amber drops in this type of sediment is most likely Cheirolepidiaceae (Kovács et al. 2015). Cheirolepidiaceae plants occasionally occur in highly watered areas (Barbacka, 2011).

3.1.3.2 *Greenish-grey* claystone (Fl, Fc, Fr)

Description: This subtype consists of tabular beds of generally massive or laminated green, light-grey or bluish grey claystones (Fig. 8C) that are laterally extensive (5-10 m) and 1,5 to 2 m thick. The massive horizons show abundant pervasive bioturbation, purple to red root-mottles (facies Fc, Fr) while the laminated claystones contain well preserved leaf fossils. The lower contacts of these beds are typically gradational, whereas the upper contacts are usually sharply truncated by the overlying cycle. Plant fossils are mainly represented by leaves in the laminated horizons. The leaves are preserved as impressions. They show the leaf shape, the primary and secondary venation but no carbonised material or cuticles were preserved. Attached pinnules of fern leaves were also found and even the petioles are preserved in many cases. In Iharkút the largest leaves were found in this facies association. The longest dicot leaf is 9 cm long, and the largest monocot (*Pandanites*) is more than 30 cm long.

Interpretation: This claystone facies association suggests deposition in shallow lakes and ponds (Miall 1996; Roberts, 2007) without significant coarse-grained sediment influx. The reason for the good preservation of the leaf fossils in the laminated horizons of this subtype was probably the lack of long distance transport and the low degree of bioturbation. The *Pandanites* could have been an important element of the immediate bank vegetation and might have tolerated the waterlogging of the root zone (Popa et al., 2014). The massive, colour mottling horizons are interpreted as the results of rooting, which implies periodic desiccation and subaerial exposure (Retallack 2008; Ghazi and Mountney, 2009).

3.1.4 Facies association 4: Paleosols

The pedogenically modified mudstones and claystone horizons with mottles and root traces are common in the study interval and represent two subtypes.

3.1.4.1 Reddish mudstones (Fr, P)

Description: These are reddish (2,5YR-5YR) 30 to 100 cm thick moderately to weakly calcareous mudstones with subordinate isolated sand grains and weakly developed ped structure (Fig. 8D). Drab haloed vertical root traces are present (Facies Fr, P, Fig. 8D) and so are a few microvertebrate fossils, including one crocodile tooth and one limb fragment of an anura found at the northwestern wall of the open-pit. Plant fossils were not detectable in the reddish mudstone. Such mudstones occur more frequently in the lower reaches of the section exposed in the open-pit (Fig. 2A), and show association with the sandstone bodies. Similar red mudstones with root traces are present in the upper levels of the open-pit too but there they are subordinate to the hydromorphic paleosols. This subtype accounts for about thirty percent of this facies association.

Interpretation: The reddish colour and the vertical root traces indicate that the mudstones of this facies association are paleosols. The red colour implies the abundance of ferric oxides and low organic content, indicating oxidizing conditions and a moderately- or well-drained environment during pedogenesis which is in accordance with the vertical root-traces as well. (e.g. Kraus, 1997, 1999; Davies-Vollume and Kraus, 2001; Therrien, 2005). The presence of sporadic burial-gley features (Fig 8D) indicate water-table fluctuations during or immediately after soil formation (Bown and Kraus, 1987; Retallack, 2008; Kraus, 1997, 1999; Davies-Vollume and Kraus, 2001; Therrien, 2005). The better-drainage, the reddish colour, and the coarser grain size also suggest that this soil was formed on a more elevated part of the floodplain (Bown and Kraus, 1987; Davies-Vollume and Kraus, 2001) probably close to a channel or on a slightly higher elevated alluvial ridge (Kraus, 1997; Davies-Vollume and Kraus, 2001).

3.1.4.2 Yellowish mudstones (Fr, P)

Description: This subtype is composed of massive, pale yellowish to grey (10YR-2,5YR), mudstones and sandstones with purple to violet coloured mottles (Fig. 8 E-F). The thickness can vary from 0.5 to 4 m and their lateral extent exposed by the quarry wall may reach ~25 m. Tiny irregular root traces (Facies Fr) are present as well as root mottles that vary in colour (red, green, strong brown and purplish) are sometimes very abundant. The mottles occupy 5-20% of the exposed surface. Vertical burrow fills, about 1 cm in diameter, infilled by the overlying sandstone (Fig. 8F-G) are present in limited numbers. The predominant particle size of this subtype is slightly smaller than that of the reddish paleosols described above. The yellowish mudstones are more predominant in the upper section of the open-pit and are closely associated with the tabular and ribbon-like sandstone bodies (Fig. 4B). Vertebrate fossils are very rare in this subtype and plant or invertebrate fossils are completely absent. The yellowish paleosols in the open-pit can be divided into two slightly different types. (1) fine to very fine grained yellowish, red to purple sandstone rich in tiny irregular drab-haloed root traces. It is, generally preserved immediately above or below the channel sandstone bodies, sometimes also in their lateral continuation. (2) predominantly silty or clayey pale yellowish to grey coloured mudstone with rather well-developed ped-structure

Interpretation: The mottled appearance, and the yellowish grey colour of these paleosols (Fig. 8E) indicate poorly drained conditions, where both oxidation and reduction were active, associated with a fluctuating watertable (Leckie et al., 1989; Therrien, 2005). The purple to violet coloured spots and the drab haloes around the root-traces are interpreted as gley features that indicate local/transient water-logging suggesting an intermediate redox (near neutral Eh) status (Retallack, 1984, 2008). These features of the yellowish paleosols in the Iharkút open-pit could be interpreted as signs of hydromorphism, indicative of prolonged saturation of the soil profile by groundwater (Leckie et al., 1989; Bown and Kraus, 1987, Kraus, 1999; Retallack, 2008; Therrien, 2005; Therrien et al., 2009). The poorly drained nature of the paleosols and their close association with the ribbon sandstones suggest that they formed in low-level flood-plain position. The high percentage of hydromorphic paleosols in the Iharkút open-pit mine indicates that the water table was high in most part of the year and it was characterized by seasonal or intermittent fluctuations (cf.with Sigleo and Reinhardt 1988). The yellowish red hydromorphic paleosol characterized by coarser grain size and tiny irregular root traces may have formed directly adjacent to the channel (e.g. levee deposits) under - at least intermittently - moderately-drained conditions (like those described by Bown and Kraus, 1987 and Kraus, 1999). On the other hand the yellowish grey paleosol with the root-mottles must have developed under conditions of permanent water-logging. It may be interpreted as the indicative of a low-level floodplain environment (Bown and Kraus, 1987; Kraus, 1997, 1999). The presence of the thick (2 to 4 m) and poorly developed paleosol sections (cumulate paleosols) in the upper reaches may be the result of rapid floodplain aggradation (Kraus, 1999).

4 DISCUSSION

4.1 Fluvial Style in the succession of the Iharkút mine

The type of fluvial system having deposited the alluvial sediments of Csehbánya Formation in the area of the Iharkút open-pit can be identified on the basis of the organization, grain size, and geometry of the channel bodies and the mudstone/sandstone ratio. A braided origin is unlikely because the width/thickness ratio of the channel bodies in Iharkút (most of them <15) is definitely lower than that of the modern braided rivers (> 40 or 50; Miall, 1977; Kirschbaum and McCabe, 1992). Furthermore, the predominance of floodplain mudstones in the studied area (Fig. 3B) is not typical of a high energy braided river system (Smith and Smith, 1980; Kirschbaum and McCabe, 1992; Makaske, 2001). The absence of point bar accretion within the channel fills and the lens-shaped geometry of the sandstones of facies association 1 is inconsistent with the meandering fluvial style (Eberth and Miall, 1991; Nadon, 1994; Roberts, 2007; Makaske, 2001; Horiuchi et al., 2012). The deposits exposed in the Iharkút open-pit are more typical of an anastomosed system (Fig. 9) based on the following features: (1) The abundance of lens-shaped channels (Gibling and Rust, 1990; Eberth and Miall, 1991; Kirschbaum and McCabe, 1992; Nadon, 1994, Makaske, 2001) and the isolation of the sandstone bodies (embedded in floodplain sediments) from each other, suggest multiple co-existing channels, (2) The large proportion of overbank fines, which encase the channel sandstone bodies (Smith and Smith, 1980; Kirschbaum and McCabe, 1992; Nadon, 1993, 1994; Makaske, 2001; Horiuchi et al., 2012). (3) The channel deposits consisting predominantly of fining upward sandstones (Makaske, 2001), (4) Point bar accretion is almost completely absent in the channel fill deposits (Eberth and Miall, 1991; Kirschbaum and McCabe, 1992; Makaske, 2001). The term “anastomosing” is identified here by the presence of multiple, vertically aggraded sandstone ribbons (Eberth and Miall, 1991), which can be interpreted as "interconnected channels that enclose floodbasins" (Makaske, 2001). These systems are characterized by relatively deep and narrow, usually straight (low sinuosity) channels with stable banks composed of fine-grained sediment (silt/clay) and vegetation (Smith and Smith 1980).

4.1.1 The channel fill and sheet splay deposits

Coarser grained sediments (mainly sandstone, subordinate clayclasts and gravel were deposited in the channels and the crevasse splays (Fig. 4). The most abundant channel fills are the ribbon sandstone bodies characterized by concave erosional base, low width/thickness ratio (<15) and they are relatively homogenous in texture (Fig. 4A-B). The grain size is predominantly medium to fine sandstone, but clayclasts, conglomerates and petrified woods or bones sometimes constitute a lag near the erosional base. They consist of multiple stories, separated by erosional surfaces. The lateral stability of these channels (absence of point bar accretion and limited cross-bedding and lenticular shape) in the Iharkút open-pit shows the typical characteristics of an anastomosing system (e.g. Smith, 1976; Smith and Smith, 1980; Gibling and Rust, 1990; Eberth and Miall, 1991; Kirschbaum and McCabe, 1992; Makaske, 2001; Gradźinski et al., 2003; Adams et al., 2004; Horiuchi et al., 2012). Such fluvial systems are generally characterised by lateral stability of the channels, which is due to the very low channel gradients (e.g. Makaske, 2001), the cohesive bank sediments (e.g. Nadon, 1994; Adams et al., 2004) and/or the vegetation controls (e.g. Smith, 1976; Smith and Smith, 1980; Gradźinski et al., 2003). The interchannel area must have been flat and highly vegetated in the Iharkút palaeoenvironment with a Normapolles dominated canopy and ferns in the underwood and this vegetation was rooted in the relatively wet ground (as shown by the gleyed hydromorphic paleosols) near the channel. The protective nature of riparian vegetation and the relatively low stream power may have been responsible for the negligible rate of lateral erosion of the channels at the Iharkút locality (e.g. Smith, 1976; Gradźinski et al., 2003). On the other hand, the resistant levee deposits also had important role in the lateral stability of the channel, because the levees aggrade faster than any other part of the anastomosed system due to their rapid depositional rates and coarser material (Nadon, 1994; Adams et al., 2004). However, the levee deposits (yellowish red, coarser particle sized paleosols with tiny irregular root traces) are subordinate in the Iharkút open-pit, which emphasizes the role of the vegetation in the lateral stability of the channels.

The other frequent sandstone bodies are splay sandstones interpreted as crevasse splay deposits having typically flat, non-erosional base (Fig 4F) and a width/ thickness ratio of >15. The grain size is usually medium to fine sandstone, coarser sediments are completely absent near the erosional surface. These channels and sheet splays had a significant role in the transportation of sediments and bones from the background area and they pumped finer sediments into the floodplains (e.g. Nadon, 1994).

The characters of the lenticular channels (stable banks, multiple-story bodies) and the abundant crevasse-splay deposits observed in the Iharkút open-pit might suggest that seasonal flooding and substantial vertical aggradation of the floodplain were common indicating high rate of sediment accumulation (i.e. high rate of subsidence; Roberts, 2007) for the Csehbánya Formation.

4.1.2 Sedimentology of vertebrate site SZ-6

The lenticular shape, the basal erosion surface and the clear tendency of fining upwards of the complete section of site Sz-6 (including Unit 1-3) suggest that this facies association represents a channel fill deposit where the highest bone concentration occurs at the base (in Unit 1). The basal breccia layer (Unit 1; Fig. 4D-E and 6) is interpreted as a lag deposit formed during an ephemeral high density flash flood. This interpretation is based on the observed sedimentary features (e.g. unsorted sediment, abundant clayclasts, and absence of unidirectional sedimentary structures). Furthermore, several bones were observed with long axes oriented sub-vertically, the bone material was not sorted by shape (Botfalvai et al., 2015), and the channel-fill comprises several stacked deposits.

Flash floods may occur during "high amounts of rainfall, combined with very efficient and rapid runoff on relatively small catchments" (Lóczy et al., 2012; 28). Other authors also emphasize the role of heavy rainfall inducing flash flow (e.g. Georgakakos, 1987; Malmon et al., 2004; Rogers, 2005; Billi, 2007). Anastomosing river systems often form in response to a strongly seasonal rainfall (Nadon, 1993, 1994). Furthermore, Nadon (1994) notes that anastomosing fluvial systems have been reported from various climatic zones, but always in regions of highly seasonal rainfall and flooding. The floral association (subtropical floodplain forest vegetation; Bodor et al., 2012) supports the idea that the climate was dominantly humid, but seasonal (so it must have been also at the time of the formation of the underlying bauxites). The seasonality in terms of humidity can be verified by the plant remains. The woods show annual rings and *Pandanites* is an important element of Iharkút as well as the Haţeg flora where strong seasonality is presumed, too (Popa et al., 2014). The Maastrichtian monsoonal environment could have provided also a highly diverse, angiosperm dominated vegetation and many groups are common between the two associations for instance the presumably Normapolles related unnamed form, "Taxon 1" of Lindfors et al. (2010) (Bodor and Baranyi, 2012). Along the river banks wetland habitat could have persisted even during the dry season. Most of the plants found in Iharkút required wet environment based on the ecological needs of their nearest living relatives. The water demand of the plants can be satisfied not only by frequent precipitation but also by high amounts of ground water. Leaf physiognomic data can provide more direct information about the moisture. In Iharkút the state of preservation does not make possible this kind of studies however based on this proxy more arid conditions are reconstructed in Europe than in North America (Wolfe and Upcurch, 1987). The high amount of Normapolles related fossils in Iharkút also do not exclude seasonal dry spells because the thick pollen wall of the group may have been an adaptation to an already rather drier climate (Friis et al., 2011). The large amount of clayclasts in Unit 1 and some ribbon sandstone bodies may also indicate seasonally hot and dry climatic conditions resulting in desiccation and surficial cracking of the clay rich alluvial sediments on the higher elevated interfluve areas. After the hot period, heavy seasonal rains in adjacent mountainous ranges, could trigger significant flooding events reaching the lowlands, transporting also broken up clay clasts from the previously dried up floodplain. Based on the above mentioned features, the exceptional rainfall events are suggested here as the most plausible explanation for the high density flash flood deposits of Unit 1 of site SZ-6.

4.1.3 Floodplain sediments

The interchannel areas the sediments of which are exposed in the open-pit, were situated topographically lower relative to the channel banks, as shown by the abundant hydromorphic paleosols and lacustrine and marsh sediments (Fig. 8). The interchannel areas are dominated by siltstones deposited from suspension during the flooding episodes. Fine-grained organic rich layers are interpreted as small-scale stagnant (poorly oxygenated water) pools of the floodplain filled up by organic-rich sediments (Fig. 8A-B), while the greenish-grey claystone (Fig. 8C) reflects deposition from shallow lakes and ponds without significant coarse-grained sediment influx. The paleosols developed mainly on the overbank deposits and were identified on the basis of root traces, mottling and colour banding. Most of the paleosols in the Iharkút open-pit are weakly developed aggradational or cumulate (sensu Kraus, 1999). Discrete well-drained paleosol horizons were encountered predominantly in the lower 20 meters of the exposed cover sequence only. The high percentage of hydromorphic paleosols in the interchannel areas indicates that the water table was high for at least part of the year. The paleosols have no diagnostic soil horizons and show weak pedogenic modification of the fine grained deposit (e.g. gleyzation or root traces) indicating that sedimentation was rapid (limited time of soil formation) and that the system was dominantly vertically aggrading with time (e.g. Besly and Fielding, 1989; Kraus, 1999; Davies-Vollum and Kraus, 2001; Therrien et al., 2009; Srivastava et al., 2013).

The lower part of the succession included more mature (moderately developed) paleosols than the upper part (poorly developed paleosols). This vertical change in the section probably indicates that the rate of sediment accumulation increased upward, because there is inverse relationship between soil maturity and sediment accumulation rate (Brown and Kraus, 1987). Initially the sediment accumulation rate probably was lower, thus more mature soils could develop. Later on as the accumulation rate increased (as shown by the accelerating aggradation) less mature paleosols developed in the upper part of the succession exposed by the open-pit.

Anastomosing fluvial systems typically occur in the lower reaches of rapidly aggrading alluvial basinal settings (Smith and Smith, 1980; Makaske, 2001). These conditions are supposed to have prevailed also at Iharkút. The rapidly aggrading basin setting and the development of an anastomosing fluvial system are often associated with sea-level rise (Smith and Smith, 1980; Makaske, 2001 and references there in). Similar channel bodies (ribbon channels) have been found also in the alluvial deposits of Iharkút. The Csehbánya Formation is coeval with the deposition of the Ajka Coal Formation, limnic at the base but clearly paralic in its upper reaches, reflecting the progress of the Late Cretaceous transgression as pointed out among others by Góczán and Siegl-Farkas (1990). The part of Csehbánya Formation exposed at Iharkút was formed during palynozone C of Góczán and Siegl-Farkas. By the time of zone C a freshwater marsh environment established in the wider surroundings and transgression proper has started. A major environmental change was detected during the time interval of zone D, when marine influence became more characteristic (lagoonal-paralic) based on ostracod and mollusk studies (Czabalay, 1988, Monostori 1988; Ősi et al., 2016). However, normal salinity marine microfossils are not found within the Ajka Coal Formation and the organic microfacies contains *Botryococcus braunii* freshwater green algae in the area of Káptalanfa even in the D zone (Siegl-Farkas 1988), indicating periodic presence of freshwater even at the time of the deposition of Zone D. The paleontological information (ostracod and mollusk; Czabalay, 1988, Monostori 1988; Haas et al., 1992; Ősi et al., 2016) of the Ajka Coal Formation indicates increasing marine influence in the D zone which can be explained by the sea level rise during the coal formation. The stratigraphic characters (the Csehbánya Formation and Ajka Coal Formation are coeval facies) and the detected environmental change in the Ajka Coal Formation (the marine influence show an upward increasing trend in the formation) suggest that the development of the anastomosing river system detected in the Csehbánya Formation at the Iharkút open-pit might have been related to the onset of rising sea-level (ie. the upward shift of the base-level of erosion).

5 ESTIMATION OF THE DURATION OF SEDIMENT AND BONE ACCUMULATION IN THE ALLUVIAL ENVIRONMENT OF THE CSEHBÁNYA FORMATION

To understand the evolution of the Iharkút continental vertebrate fauna and to estimate the duration of terrestrial sedimentation in the Bakony Mountains, it would be necessary to calculate the duration of the Late Cretaceous subaerial event in the Bakony Mts. According to the well-known Cretaceous stratigraphic record of the Bakony Mts., it is clear that the sedimentation of the alluvial deposits of the Csehbánya Formation and the establishment of the swamp of the Ajka Coal Formation were the closing events of the long lasting subaerial exposure phase.

5.1 Duration of the terrestrial environment in the Late Cretaceous Bakony Mts.

The Csehbánya Formation has a maximum thickness of ca. 150-200 m (Haas 1983, Jocha-Edelényi 1988; Fig. 2B) representing at most three palynozones (Siegl-Farkas and Wagreich, 1996). Chronostratigraphical correlation of palynological and nannoplankton data indicates a depositional age for the Csehbánya Formation not longer than one million year (Siegl-Farkas and Wagreich, 1996; Bodor and Baranyi, 2012). Stratigraphically the Csehbánya Formation is underlain by the terrestrial Nagytárkány Bauxite Formation and overlain by the marine Jákó Marl Formation (Fig. 1C). Since for the accumulation of high-grade bauxites (equivalents of oxisols) at least one million year (but often much more) is needed (Birkeland, 1984; Mindszenty et al., 1996, Retallack, 2008), the Iharkút bauxite, preserved in karstic sinkholes with a maximum thickness of 80 to 100 m, also needed at least several million years, or perhaps more. The youngest sedimentary unit of the Transdanubian Range known from the Bakony Mts. deposited before the Pre-Santonian subaerial event is the Albian-Cenomanian Pénzeskút Marl Formation (Szives et al., 2007). Being mostly eroded, its youngest preserved sequences are Cenomanian in age (Bodrogi, 1989). Therefore it can be suggested that its deposition might have continued until the end of the Cenomanian or even perhaps into the earliest Turonian. Fully aware of the uncertainties of this assumption we suggest that the minimum duration of the subaerial exposure event prior to the Santonian transgression in the Bakony Mountains may be estimated as about three to five million years but taking into consideration also the age of the last preserved marine sediments a five million years long time interval, as a maximum, is also possible.

5.1.1 Time average of the Late Cretaceous sediments of the Iharkút open-pit

Based on the investigations of Bodor and Baranyi (2012) the palynological assemblage of the Iharkút open-pit belongs to the *Oculopollis zaklinskaiae–Tetracolporopollenites* (*Brecolpites*) *globosus* Dominance Zone. According to the palynostratigraphic work of Góczán (1964), Góczán and Siegl-Farkas (1990) and Siegl-Farkas and Wagreich (1996) this zone indicates Late Santonian age. The correlation with other European localities is doubtful (Bodor and Baranyi, 2012). However in the regional stratigraphy it is well known and widely used (Siegl-Farkas, 1988; Góczán and Siegl-Farkas, 1990; Siegl-Farkas and Wagreich, 1996). This subzone was deposited during the CC16 nannoplankton zone (Siegl-Farkas and Wagreich, 1996). The duration of this zone was estimated as a few hundred thousand years by Siegl-Farkas and Wagreich (1996).

5.1.2 Time average of the bone assemblages in the Iharkút open-pit

The calculation of the time average of fluvial vertebrate remains is very problematic, because when the bones are found in a channel, they must be interpreted as an allochthonous assemblage transported prior to burial and probably representing a long accumulation time (e.g. Behrensmeyer, 1982; 1988; Aslan and Behrensmeyer, 1996; Kidwell and Flessa, 1996). The reworking of bones from overbank deposits and earlier channel fills can result in samples that have been averaged over as much as 10^3-10^5 years (Behrensmeyer 1982), therefore to properly estimate the duration of the time average in any fluvial vertebrate assemblage is of great importance for the accurate palaeoecological investigation (Behrensmeyer 1982, Kidwell and Flessa 1996, Martin 1999:22).

The vertebrate fossils in the Csehbánya Formation of the Iharkút open-pit occur primarily in the channel fill deposits (sandstones, siltstones). The bones are rare in the paleosols, because the hydromorphic paleosols dominant in the open-pit and representing conditions of water-logging, are not favourable for bone preservation, due to chemical and microbial destruction effects which are more significant in the periodically wet soils than in the dry ones (Retallack, 1984). In the overbank context, molluscs, plant and vertebrate fossils occur typically in pond deposits (claystone and siltstone). In the area of the Iharkút locality sediment reworking appears to have been restricted (absence of point bar accretion and the rarity of cross-bedding in the channel fills) as indicated by the limited lateral accretion of the channels. According to these palaeoenvironmental factors, there would have been minimal input of bones eroded from older overbank deposits so that the bone preservation in the channel fills represent a relatively short time interval (approximately 10^1–10^2 years), based on comparison with actual empirical observations (Aslan and Behrensmeyer, 1996).

Unit 1 of site SZ-6, the most important fossiliferous horizon of the Iharkút locality was formed by ephemeral high density flash flood events which deposited a stacked series of fining upward units (including sandstone with clayclasts (pebbles) and organic-rich siltstone and claystone). The coarser part of Unit 1 points to the deposition of a flash-flood sequence (high flow regime), while the siltstone layers indicate deposition from suspension in standing water, following each minor flow pulse. The basic unit with the poorly sorted coarse sandstone breccia overlain by finely laminated siltstone is repeated several times (Figs. 4F and 5) resulting in a stacked series of fining upward units. The coarser layers of Unit 1 were deposited probably under extremely short time intervals by ephemeral high density flash floods, because this kind of flood events are restricted in time, usually not exceeding a few hours (e.g. Gutiérrez et al., 1998; Malmon et al., 2007; Ortega and Heydt, 2009; Lóczy et al., 2012). The lack of evidence of soil formation (mottles, root trace, gleyzation) following the deposition of the laminated siltstone/claystone above the coarser sediments indicates that there was no intermittent subaerial exposure; i.e. the area remained submerged right throughout the accumulation of Unit 1 (e.g. Therrien et al., 2009). Furthermore, the frequent clayclasts (and rare paleosol-peds) in Unit 1 also indicate high depositional rate (without longer breaks), because the clayclasts do not withstand weathering for more than a few months and become decomposed rapidly during soil formation (Retallack, 2005). The apparent lack of bioturbation (indicated by the excellent lamination of the siltstone) suggests that the siltstone horizons between the coarser layers, represent short time intervals during the deposition of Unit 1. The laminated dark grey siltstone horizons indicate standing water conditions in the floodplain which were suitable environments for the development of low- to moderate diversity suites of invertebrates (Buatois and Mángano, 2004). Although this stagnant pool settings are of shorter lifespan than the perennial lakes, perhaps this difference may have been irrelevant from the point of view of opportunistic organisms able to rapidly colonize stagnant waters (Buatois and Mángano, 2004), between two successive flood events in the floodplain environment and destroy the original sedimentary structures (e.g. lamination). Rich ichnofauna was described from several Cretaceous fresh water (fluvial/lacustrine) environments, suggesting that bioturbation (e.g. invertebrate activity) could have been already abundant in this period (e.g., Kim et al., 2005; Fernandes and Carvalho, 2006 and references therein). In addition, some vertical burrow traces were also detected in the flood plain deposits of the Iharkút open-pit (Fig. 8G). The apparent lack of bioturbation and soil formation in Unit 1 at site SZ-6 suggest that relatively short time passed between two subsequent flood events that deposited the coarser sediment layers (e.g. Eberth et al., 2006).

6 CONCLUSIONS

1) The Upper Cretaceous (Santonian) Csehbánya Formation, Bakony Mountains, Hungary, consist of 100-150 m thick, cyclically alternating conglomerate, sandstone, and siltstone and claystone layers, formed in fluvio-lacustrine environment.
2) Four main lithofacies associations (with eight subtypes) were identified and interpreted in the vertebrate locality of Iharkút. Based on these results, the Csehbánya Formation in Iharkút open-pit is interpreted to have been deposited by an anastomosing fluvial system in a topographically low-level, wet, alluvial plain environment.
3) The floral association (subtropical floodplain forest vegetation) and the sedimentological investigations show that the climate was dominantly humid, but seasonal.
4) The stacked deposits of the most important vertebrate site (unit 1 of site SZ-6) exposed by the Iharkút open-pit were deposited by ephemeral high density flash-flood events probably triggered by episodic heavy rainfalls.
5) The unusual depositional mode (e.g. Fig. 7A) of several bones and the arrangement of the laminated siltstone above the coarser sediments at site SZ-6 indicate that the depositional area of Unit 1 of the bonebed was a trapping place where current velocity suddenly decreased and the poorly sorted sand, ripped-up clayclasts, pebbles, and bones accumulated.
6) Based on the statigraphical and sedimentological characters of the Csehbánya Formation, we suggest that: (a) the terrestrial environment in the Late Cretaceous Bakony Mts. lasted only for about 3 to 5 million years (b) the strata in Iharkút

developed during one palynological sub-zone thus representing few hundred thousand years (c) the bone assemblages from the channel fill deposits represent a very short time interval (approximately 10^1–10^2 years) (d) the stacked series of Unit 1 (and thus most of the vertebrate fossils in the Iharkút assemblage) was deposited in a relatively short time (e.g. single wet season) by successive flood events.

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Captions:

Figure 1. Map, palaeomorphological situations and simplified stratigraphy of Transdanubian Range Unit (TRU), during the Late Cretaceous A. Location map of the Iharkút vertebrate locality. B. Palaeomorphological situations and depositional environments of the TRU, during the Late Cretaceous (Late Coniacian – Middle Santonian) modified from Tari (1994). C. Time/space relations of the Late Cretaceous formations in the Bakony Mountains, western Hungary modified from Haas et al. (1992).

Figure 2. Section and thickness of Csehbánya Formation. A. Schematic section of the Iharkút open-pit mine. D. Thickness of the Csehbánya Formation (isopachs in meters) after Haas et al. (1992).

Figure 3. Sections and interpreted photograph of Northwest wall of Iharkút open-pit. A. Photograph of the Northwest wall, showing the sections (1-2) and the sandstone bodies. B. Sections are typical of the Csehbánya Formation in Iharkút locality, dominated by lenticular sandstone bodies within the fine grained floodplain sediments.

Figure 4. Channel fill sediment types of Iharkút open-pit. A. Ribbon sandstone body. B. Ribbon sandstone body with sharp scoured concave base. C. Pebbly-sandstone channel fill. D-E. Heterolithic strata of Unit 1 of site SZ-6. The basal breccia (including clayclast and sandstone) is interrupted by quite water sediment such as laminated siltstone (D) or plant debrish (E). F. Splay sandstone body interbedded within thick sequence of overbank sediments.

Figure 5. Schematic stratigraphic section of the site SZ-6 showing the main lithofacies (A) and picture of Unit 1 of site SZ-6 (B). Aerial photo of the Iharkút open-pit showing the position of different vertebrate sites (C). The site Sz-1 is the first exposure where vertebrate remains were found, site Sz-6 the richest fossil site (mentioned in the text) and the site SZ-7-8 is the microvertebrate site (see also Botfalvai et al., 2015).

Figure 6. Sediment sequence and petrographic features of Unit 1 of site SZ-6. A. Photograph of drill core of Unit 1. B. Drawing of drill core of Unit 1.

Figure 7. Turtle plate fragment with their long axes oriented sub-vertically at Unit 1 of site SZ-6, partially pressed into the siltstone layer but mostly surrounded by coarser sediments. Photograph (A) and drawing (B) of the turtle plate in original position at Unit 1 of site Sz-6. C. Flow chart of the transportation and depositional mode of the turtle plat fragment; (1) Turtle plate is transported with clayclast by turbulent, high energy flow. (2) The current velocity suddenly decreases and the poorly sorted ripped-up clayclasts and the turtle plate accumulate. (3) The final position of plate fragment as remained in an almost vertical position, partially pressed into the siltstone layer and surrounded by coarser sediments.

Figure 8. Floodplain sediment types of Iharkút open-pit. A. Dark sandy siltstone. B. High organic content siltstone and claystone alternate with lighter grey fine grained sandstone at SZ-7-8 microfossils site. C. Light-grey or bluish claystone. D. Reddish paleosol with burial-gley features. E. Pale yellowish paleosols with purple to violet coloured gleyed spots. F-G. Hydromorphic paleosol with vertical burrow fills.

Figure 9. Reconstruction of fluvial style in Csehbánya Formation of Iharkút open-pit. A different alluvial sub-environments in Csehbánya Formation of Iharkút open-pit (A) and reconstruction of fluvial style (B; modified from Nadon, 1994).

Table 1: Lithofacies types in the Csehbánya Formation of Iharkút open-pit, based upon Miall (1985) and Roberts (2007).

Table 2: Facies classification of Csehbánya Formation of Iharkút open-pit.

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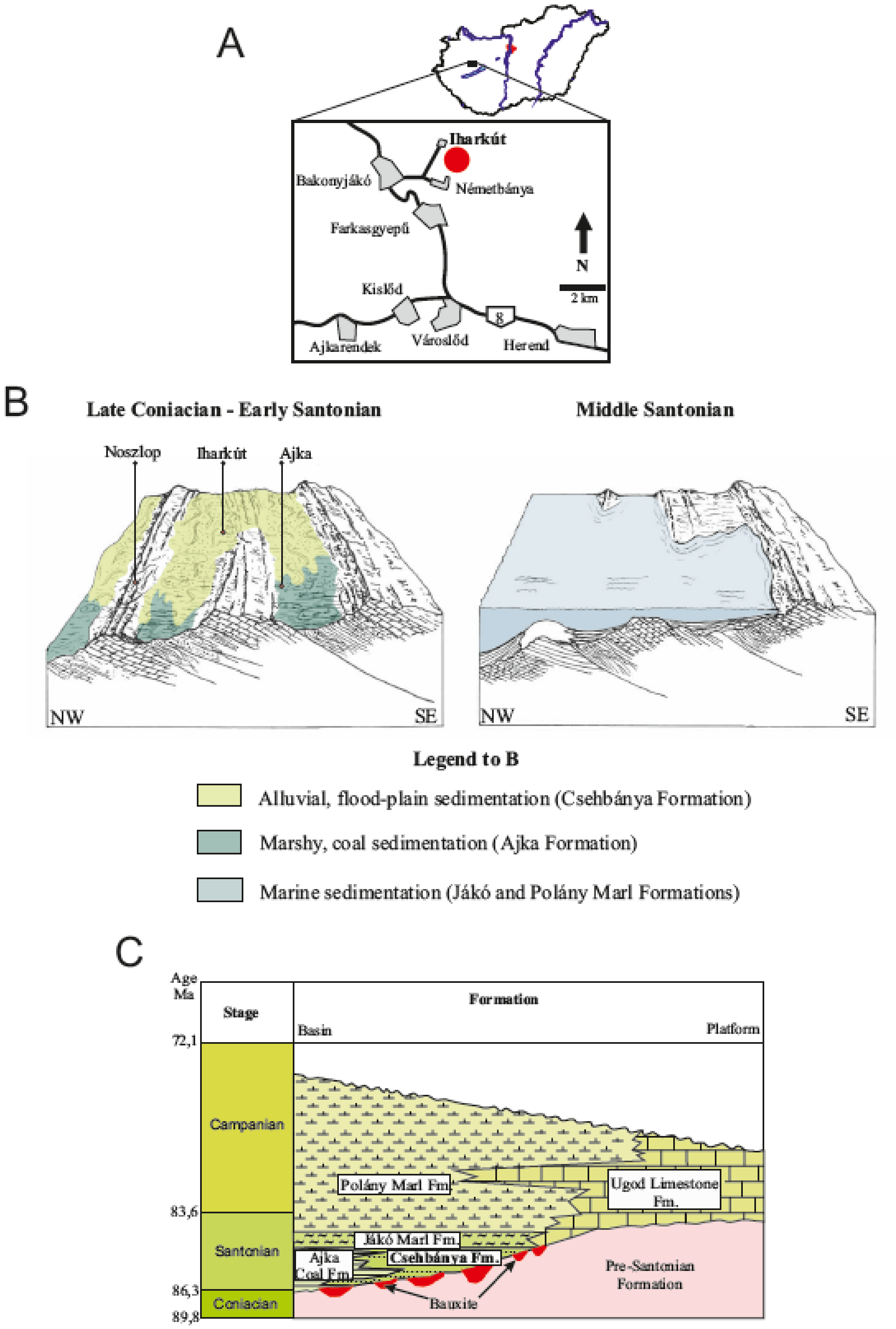

A
Iharkút
Bakonyjákó
Németbánya
Farkasgyepű
N
2 km
Kislőd
8
Ajkarendek
Városlőd
Herend
B
Late Coniacian - Early Santonian
Middle Santonian
Noszlop
Iharkút
Ajka
NW
SE
NW
SE
Legend to B
Alluvial, flood-plain sedimentation (Csehbánya Formation)
Marshy, coal sedimentation (Ajka Formation)
Marine sedimentation (Jákó and Polány Marl Formations)
C
Age Ma
Stage
Formation
Basin
Platform
72,1
Campanian
Polány Marl Fm
Ugod Limestone Fm.
83,6
Santonian
Jákó Marl Fm.
Ajka Coal Fm
Csehbánya Fm.
Pre-Santonian Formation
86,3
Coniacian
89,8
Bauxite

Figure 1

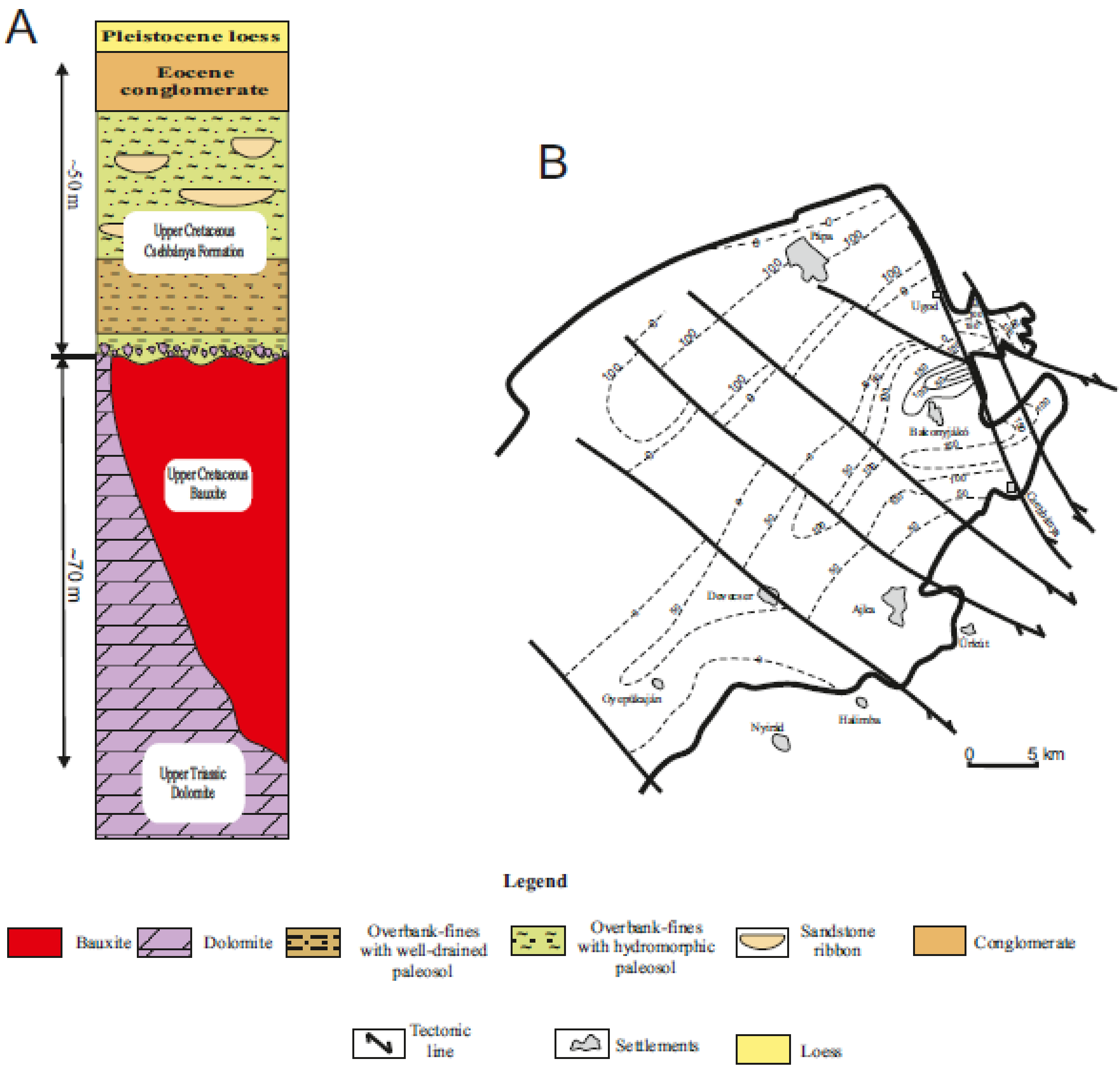
A
Pleistocene loess
Eocene conglomerate
Upper Cretaceous
~50 m
Upper Cretaceous Bauxite
~70 m
Upper Triassic Dolomite
B
0 5 km
Legend
Bauxite
Dolomite
Overbank-fines with well-drained paleosol
Overbank-fines with hydromorphic paleosol
Sandstone ribbon
Conglomerate
Tectonic line
Settlements
Loess

Figure 2

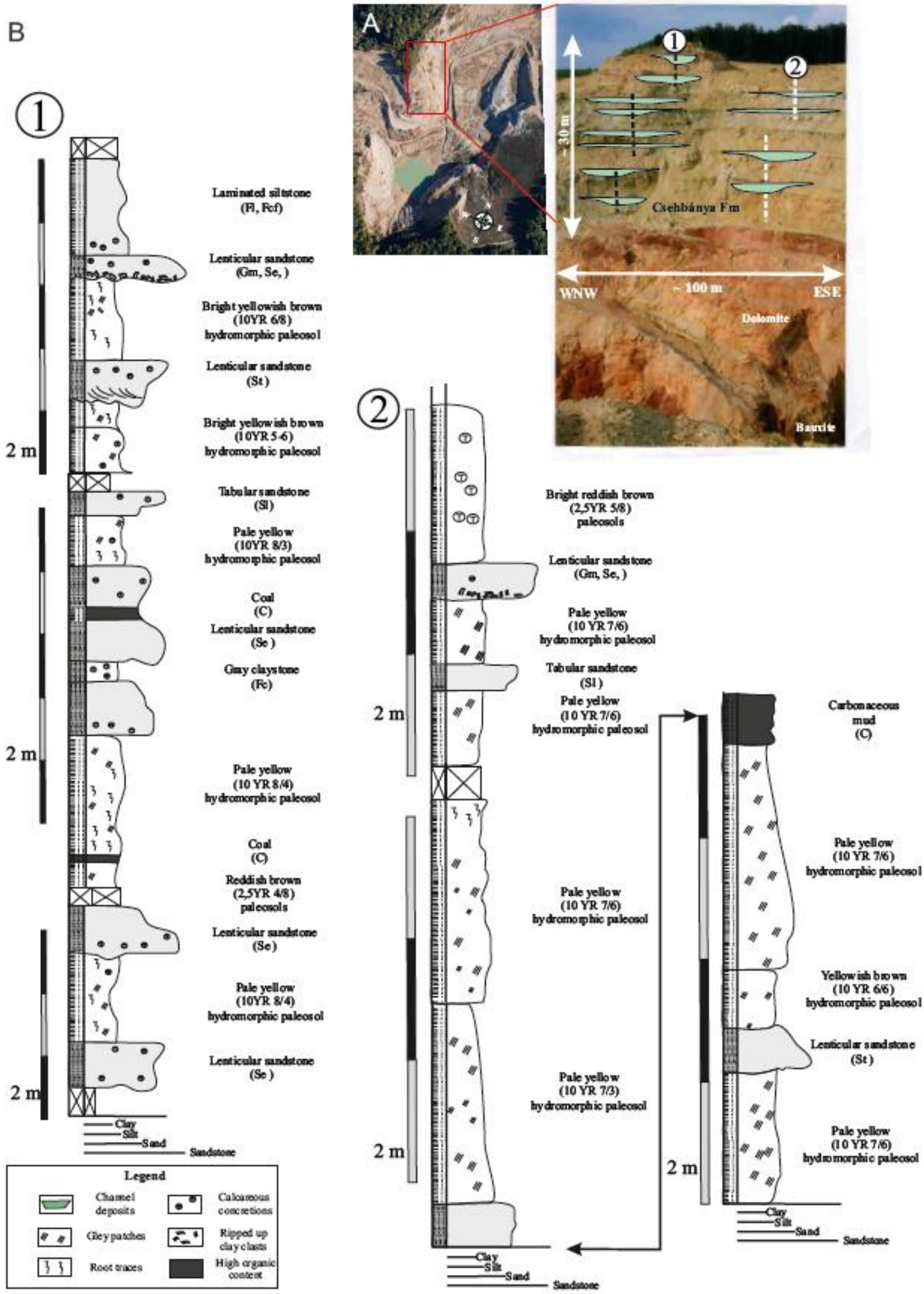
B
A
Cséhbánya Fm
~ 30 m
WNW
~ 100 m
ESE
Dolomite
Bauxite
Laminated siltstone (Fl, Fcf)
Lenticular sandstone (Gm, Se,)
Bright yellowish brown (10YR 6/8) hydromorphic paleosol
Lenticular sandstone (St)
Bright yellowish brown (10YR 5-6) hydromorphic paleosol
Tabular sandstone (Sl)
Pale yellow (10YR 8/3) hydromorphic paleosol
Coal (C)
Lenticular sandstone (Se)
Gray claystone (Fc)
Pale yellow (10 YR 8/4) hydromorphic paleosol
Coal (C)
Reddish brown (2,5YR 4/8) paleosols
Lenticular sandstone (Se)
Pale yellow (10YR 8/4) hydromorphic paleosol
Lenticular sandstone (Se)
2 m
Clay
Silt
Sand
Sandstone
Legend
Channel deposits
Calcareous concretions
Gley patches
Ripped up clay clasts
Root traces
High organic content
Bright reddish brown (2,5YR 5/8) paleosols
Lenticular sandstone (Gm, Se,)
Pale yellow (10 YR 7/6) hydromorphic paleosol
Tabular sandstone (Sl)
Pale yellow (10 YR 7/6) hydromorphic paleosol
Pale yellow (10 YR 7/6) hydromorphic paleosol
Pale yellow (10 YR 7/3) hydromorphic paleosol
Carbonaceous mud (C)
Pale yellow (10 YR 7/6) hydromorphic paleosol
Yellowish brown (10 YR 6/6) hydromorphic paleosol
Lenticular sandstone (St)
Pale yellow (10 YR 7/6) hydromorphic paleosol

Figure 3

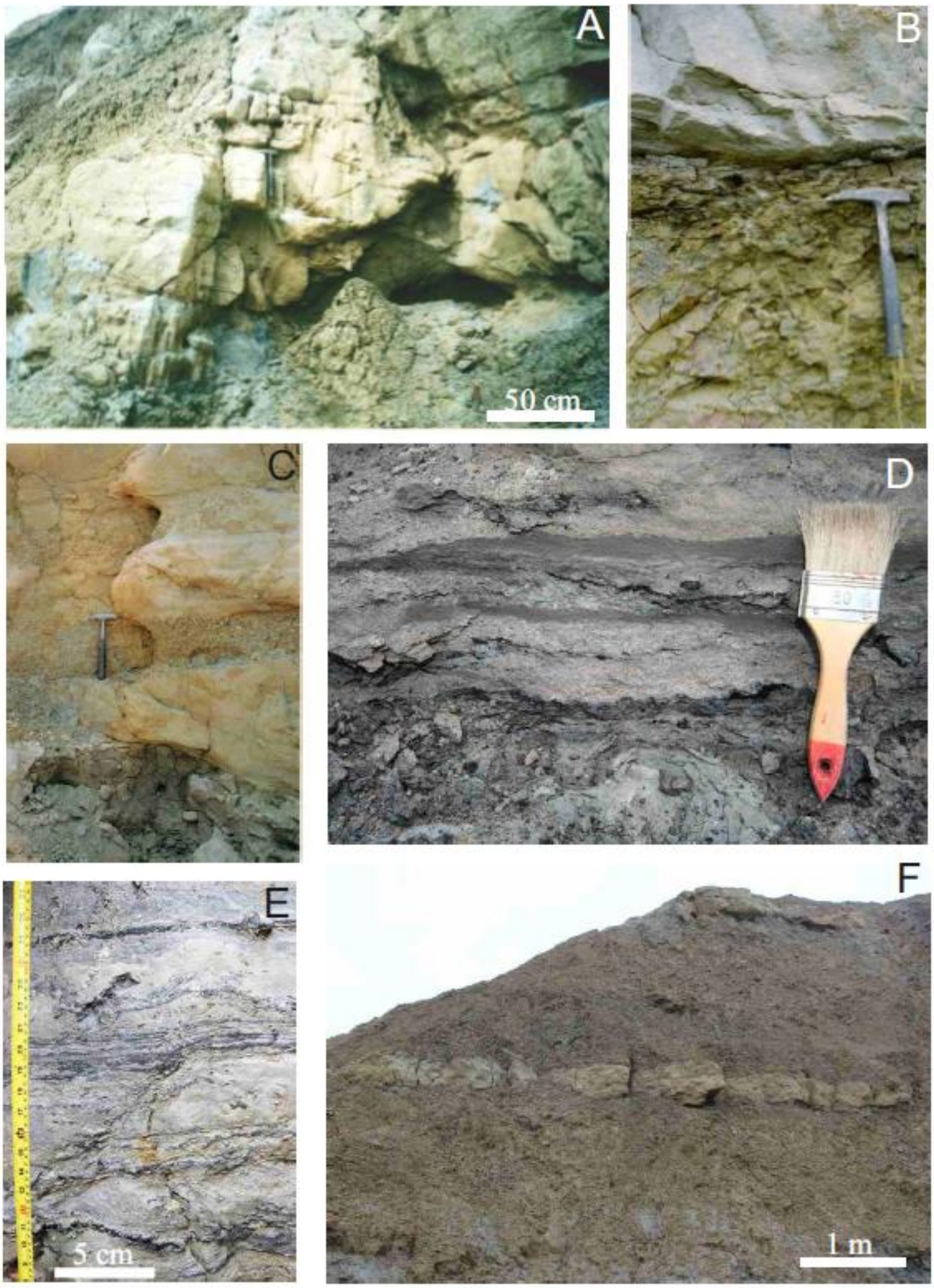

Figure 4

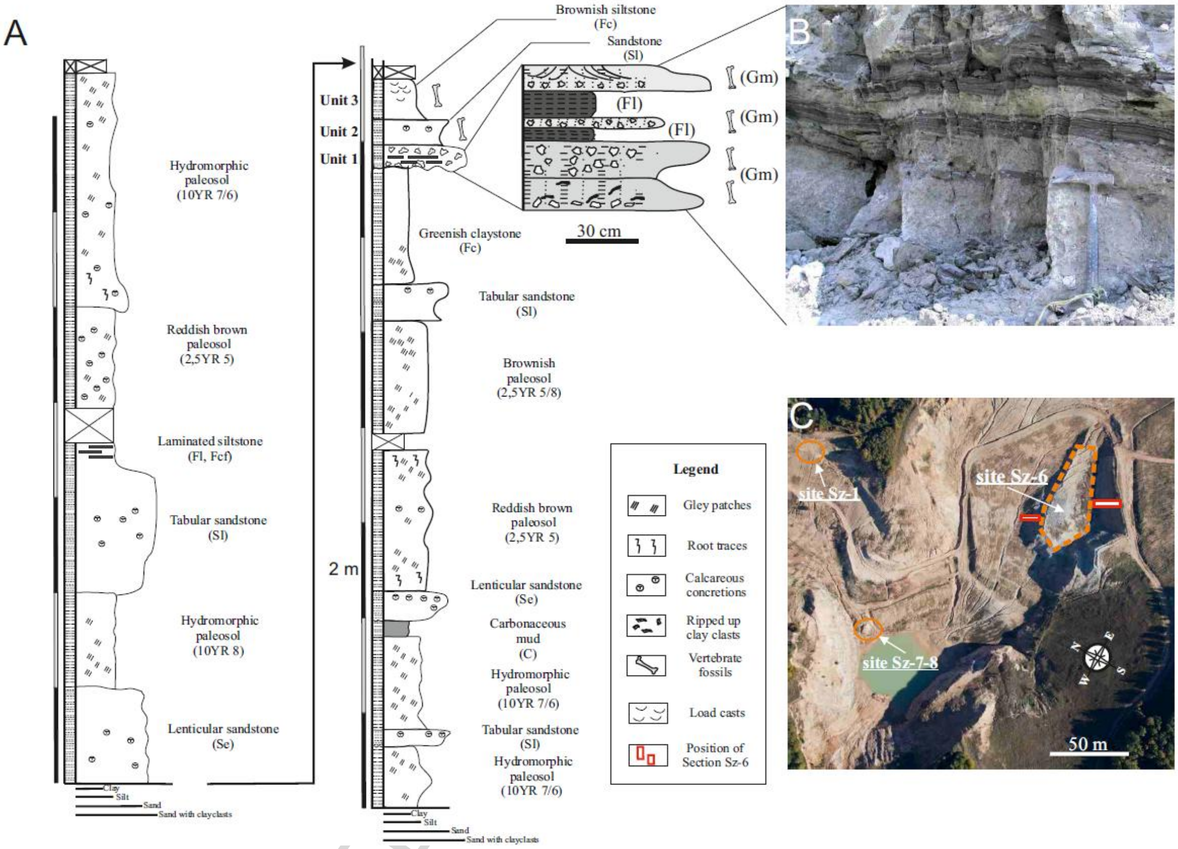
A
Hydromorphic paleosol (10YR 7/6)
Reddish brown paleosol (2,5YR 5)
Laminated siltstone (Fl, Fcf)
Tabular sandstone (Sl)
Hydromorphic paleosol (10YR 8)
Lenticular sandstone (Se)
Clay
Silt
Sand
Sand with clayclasts
Unit 3
Unit 2
Unit 1
2 m
Brownish siltstone (Fc)
Sandstone (Sl)
(Gm)
(Fl)
30 cm
Greenish claystone (Fc)
Tabular sandstone (Sl)
Brownish paleosol (2,5YR 5/8)
Reddish brown paleosol (2,5YR 5)
Lenticular sandstone (Se)
Carbonaceous mud (C)
Hydromorphic paleosol (10YR 7/6)
Tabular sandstone (Sl)
Hydromorphic paleosol (10YR 7/6)
Legend
Gley patches
Root traces
Calcareous concretions
Ripped up clay clasts
Vertebrate fossils
Load casts
Position of Section Sz-6
B
C
site Sz-1
site Sz-6
site Sz-7-8
50 m

Figure 5

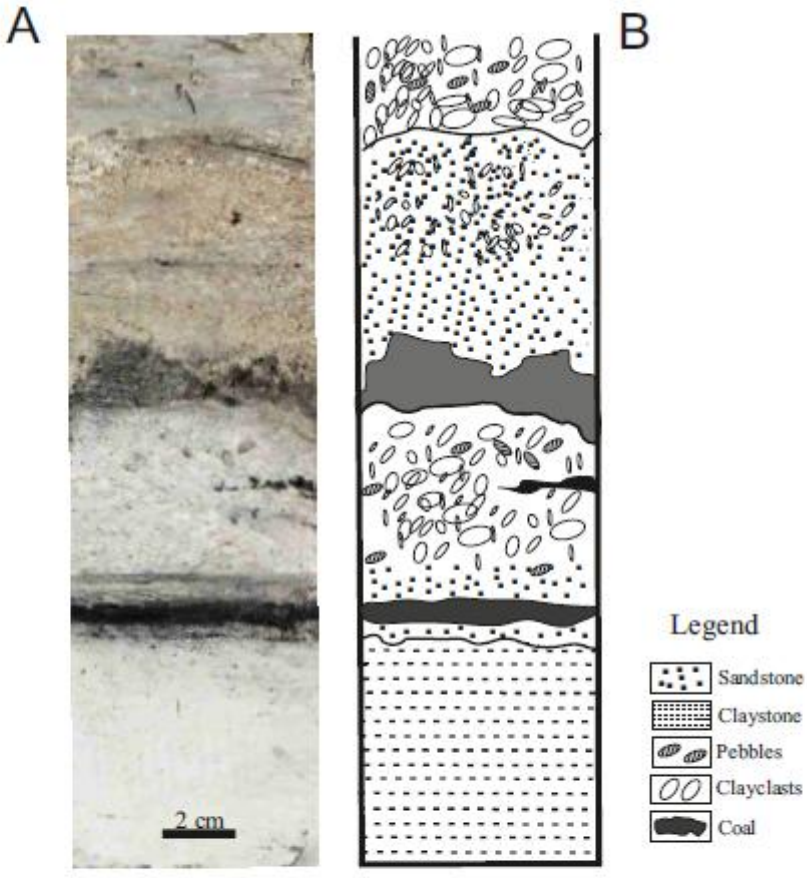
A
B
2 cm
Legend
Sandstone
Claystone
Pebbles
Clayclasts
Coal

Figure 6

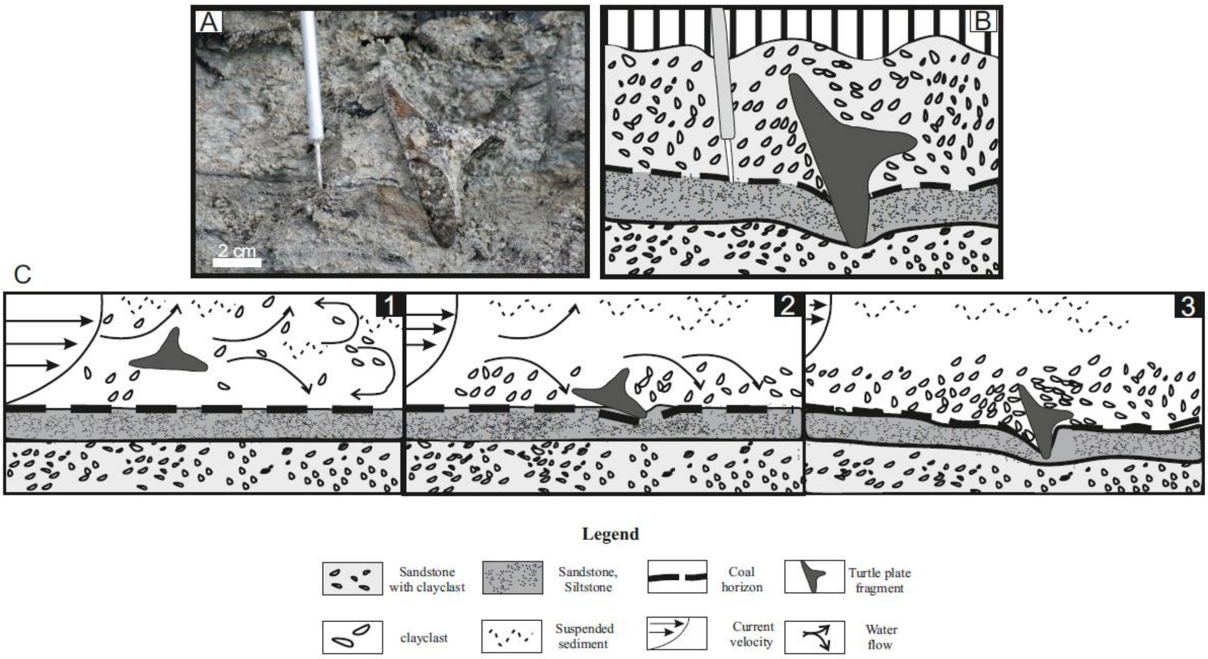
A
2 cm
B
C
1
2
3
Legend
Sandstone with clayclast
Sandstone, Siltstone
Coal horizon
Turtle plate fragment
clayclast
Suspended sediment
Current velocity
Water flow

Figure 7

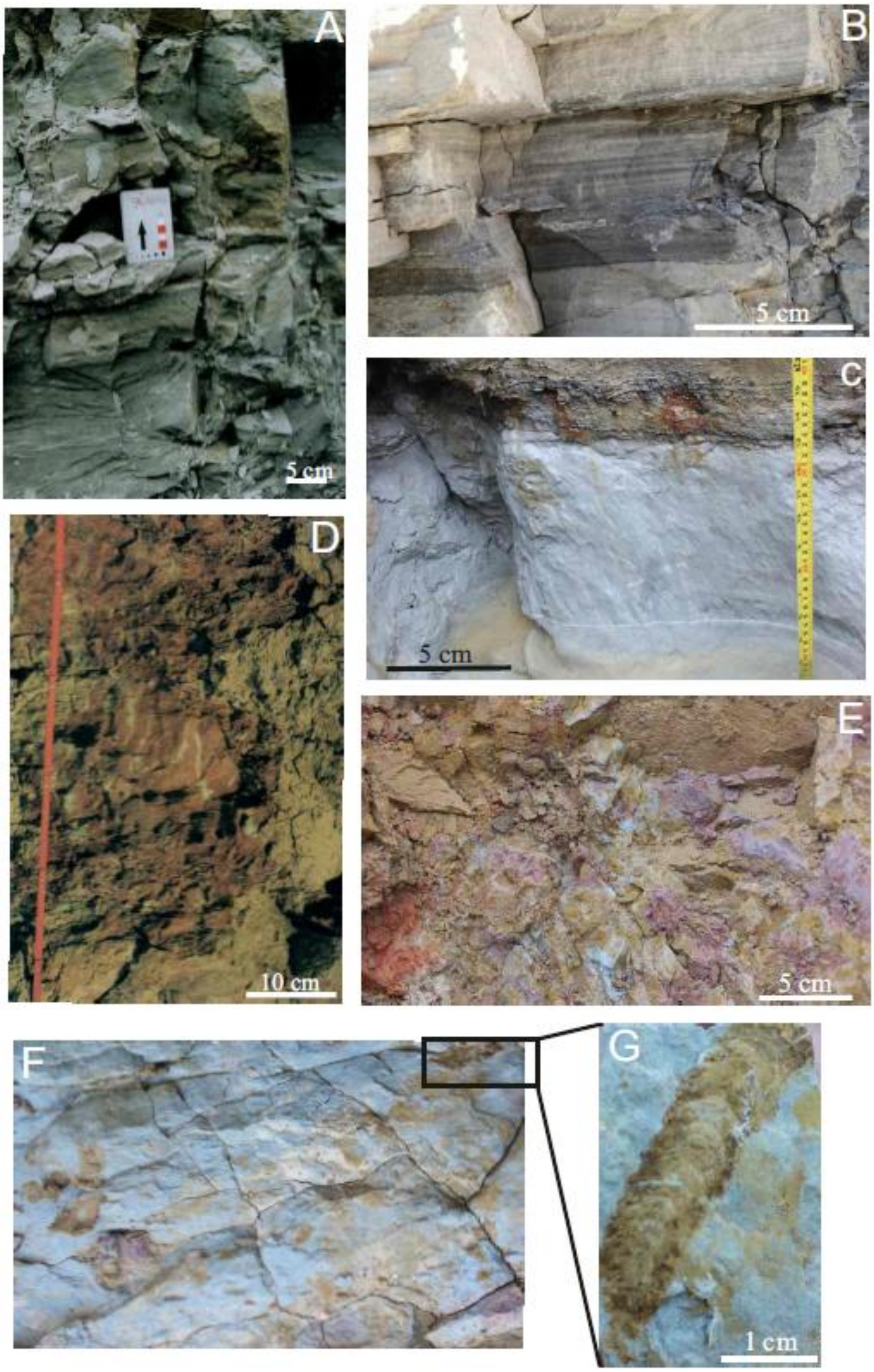

Figure 8

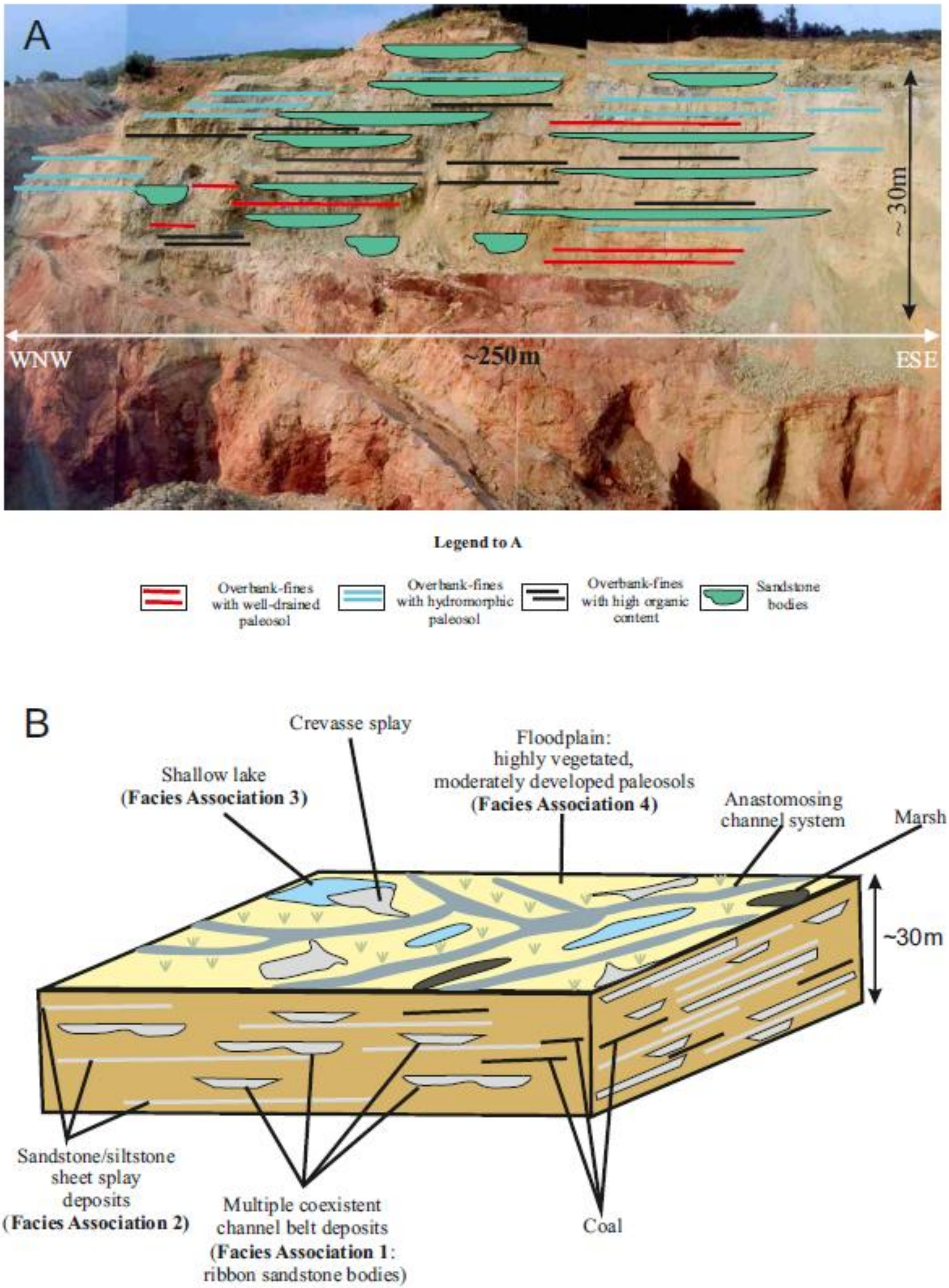
A
~ 30m
WNW
~250m
ESE
Legend to A
Overbank-fines with well-drained paleosol
Overbank-fines with hydromorphic paleosol
Overbank-fines with high organic content
Sandstone bodies
B
Crevasse splay
Shallow lake
(Facies Association 3)
Floodplain:
highly vegetated,
moderately developed paleosols
(Facies Association 4)
Anastomosing channel system
Marsh
~30m
Sandstone/siltstone sheet splay deposits
(Facies Association 2)
Multiple coexistent channel belt deposits
(Facies Association 1:
ribbon sandstone bodies)
Coal

Figure 9

Table 1.

Lithofacies identified in the Csehbánya Formation of Iharkút open-pit							
Coarse-grained lithofacies				**Fine-grained lithofacies**			
acies code	Lithof acies	Sedi mentary structures	Descriptions	acies code	Lithofacies	Se dimentary structures	Desc riptions
m	Limestone fragments and intraformational clayclasts	mass ive or crude stratification; clasts framework	*Colour:* Light green to light grey. *Matrix:* fine to medium-grained sand; poorly sorted. *Clasts:* typically granule to pebble-size; poorly sorted; dominantly intraformational clayclasts and rare extraformational dolomite pebbles; plant debris and complete or fragmentary bones and teeth also present	Fl	Finely laminated siltstone and claystone	la minated, large scale soft sediment deformation	*Colo ur*: greyish, brownish. Abundant to rare plant debrish, rare well preserved leaves and bone fossils.
cm	Clast-supported conglomerate	cros s-bedding	*Colour*: light brown or reddish brown. *Matrix*: medium to coarse grained, poorly sorted sand. *Clasts*: well rounded, poorly sorted, typically granule to pebble-sized, extraformational black to white pebbles and rare intraformational clayclasts.	c	Massive siltstone and claystone	ma ssive	*Colo ur*: green, light-grey or bluish grey. Slightly carbonaceous, plant debrish
e	Sands tone with erosional scours	mass ive, rarely cross-bedding	*Colour*: light grey. *Grain size*: fine to medium-grained sand with granule sized rip-up clasts.	cf	Massive siltstone and claystone	massive with fresh water	*Colo ur*: greyish, brownish. fresh

	and intraclasts					molluscs	water molluscs and carbonized plant material
l	Fine-grained sandstone	massive, low angle crossbeds	*Colour*: light green to light grey. *Grain size*: very fine- to fine-grained sand. Flat, non-erosive bases.	r	siltstone and claystone	root traces	Colour: green, light-grey or brownish grey. Vertical root traces
t	Trough cross-bedded sandstone	cross-bedding	*Colour*: light green to light grey. *Grain size*: fine- to medium-grained sand, sometimes coarse-grained.		Coal, carbonaceous mud	laminated or massive	Colour:black and dark grey. Carbonized plant material, fresh water molluscs, bones and teeth
h	Horizontally stratified sandstone	horizontal-bedded	*Colour*: light green to light grey. *Grain size*: fine- to medium-grained sand, rare parting lineation		Siltstone and claystone, subordinate sandstone.	pedogenic features: gleyed spots, root-mottles, tiny irregular root traces,	*Colour:* pale yellowish to grey (10YR-2,5YR) or reddish (2,5YR-5YR). The

	vertical, burrow fills	mottles vary in colour (red, green, strong brown and purplish). Absence of plant debris, rare fragmentary bones and teeth.

Table 2.

Facies associations in Csehbánya Formation of Iharkút open-pit

Lithofacies association	Subtype	Facies	Fossils	Interpretation of depositional environment
Fluvial channels	*Lenticular sandstone*	Gm, Se, St, Fr	Macro- and micro vertebrate fossils, plant debris.	Anastomosing fluvial channels (ribbon sandstone bodies)
	Conglomerate with sandstone	Gcm, St, Se,	The bones and plant debris are completely absent.	Coarse grained channel deposits
	Heterolithic-channel fill	Gm, Se, Sl, St, Fl, C,	Isolated, associated and articulated macrovertebrate material, plant debris, petrified wood, eggshell fragment, fresh water molluscs and microfossil remains (e.g. Botfalvai et al., 2015).	Emphemeral high density flash flood deposit
Crevasse splays	*Splay sandstone*	Sl, St, Sh	Scattered plant debris.	Crevasse splay deposits
Shallow lakes	*Dark sandy siltstone*	Fl, Fc, Fcf, Fr, C	Rich microvertebrate material, eggshell fragment, fresh water molluscs, carbonized plant fragments.	Small-scale stagnant pool deposits with high organic content
	Greenish-grey claystone	Fl, Fc, Fr,	Plant fossils (leaves).	Shallow lake and pond deposits
Paleosols	*Reddish mudstone*	Fr, P	Rare microvertebrate fossils, including crocodile tooth and one limb fragment of anura.	Well-drained paleosols

Yellowish mudstone	Fr, P	Vertebrate fossils are very rare.	Hydromorphic paleosols developed on water-logging or moderatly-drained conditions

Highlights to the reviewers

to the revised manuscript entitled

FACIES ARCHITECTURE AND PALAEOENVIRONMENTAL IMPLICATIONS OF THE UPPER CRETACEOUS (SANTONIAN) CSEHBÁNYA FORMATION AT THE IHARKÚT VERTEBRATE LOCALITY (BAKONY MOUNTAINS, NORTHWESTERN HUNGARY)

(MS No. PALAEO8537)

by

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- The Csehbánya Formation was deposited by an anastomosing fluvial system
- The depositional environment was a topographically low-level, wet, alluvial plain
- The climate was dominantly humid, but seasonal.
- The main fossiliferous horizon were deposited by high density flash-flood events