Geological Quarterly, 2012, **56** (1): 67–84

Eustatic and tectonic control on late Eocene fan delta development (Orava Basin, Central Western Carpathians)

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Starek D., Sliva Ľ. and Vojtko R. (2012) – Eustatic and tectonic control on late Eocene fan delta development (Orava Basin, Central Western Carpathians). Geol. Quart., **56** (1): 67–84.

The evolution of the Central Carpathian Paleogene Basin (CCPB) reflects an important role of relative sea level changes on a tectonically active basin margin. After the initial upper Lutetian/Bartonian transgression, the next regressive-transgressive cycle played a key role in a formation of the late Eocene fan delta facies associations in the southern Orava region of Northern Slovakia. Detailed sedimentary analysis allowed the separation of the following three facies associations which represent distinct depositional environments: alluvial fan (subaerial fan delta; Unit 1); subaqueous fan delta (Unit 2); and prodelta/slope and basin (Unit 3). The first stage of delta development is connected with eustatic sea level fall at the Bartonian/Priabonian boundary, accompanied by subaerial exposure, fluvial incision and deposition of alluvial fan sediments. Subaerial deposition was characterized by a variety of mass flow conglomerates with a red muddy matrix, interfingering with stream or sheetflood deposits. The next stage of the delta corresponds to high-amplitude transgression related to rapid tectonic subsidence along the CCPB margins during the Priabonian. The vertical arrangement of facies suggests retrograde delta development that shows rapid submergence of the subaerial parts and onlap of subaqueous mass flow conglomerates, often reworked by waves or wave-induced shallow-marine currents. Continuous deepening of the depositional environment during the late Priabonian/early Rupelian led to the relatively rapid superposition of prodelta/slope and basin facies associations by slowly accumulated hemipelagic deposis.

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Key words: Paleogene, Orava, Western Carpathians, fan delta, mass flow deposits, coarse-grained delta.

INTRODUCTION

Facies associations of alluvial fan deltas (*sensu* Nemec, 1990*a*) can preserve detailed stratigraphic records and processes at basin margins. The term "fan delta" denotes coarse-grained deltas, typically fed by alluvial fan feeders, developed along steep topographic gradients where alluvial fans have prograded directly into a standing body of water (McPherson *et al*., 1987; Nemec, 1990*b*). Fan deltas therefore represent the interaction between sediment-laden alluvial fans and marine or lacustrine processes (Nemec and Steel, 1988). Delta styles and architecture are mainly controlled by tectonic movement (e.g., Gordon and Bridge, 1987; Dabrio, 1990; Frostick and Steel, 1993); sea level fluctuation (e.g., Posamentier and Vail, 1988; Galloway, 1989; van Wagoner *et al*., 1990; Bardaji *et al*., 1990; Dart *et al*., 1994; Postma, 1995), and climate change (Monecke *et al*., 2001; Postma, 2001; Deb and Chaudhuri, 2007).

This paper describes sedimentological studies of the coarse-grained sequences which are well-known from outcrops in the southern Orava region of Slovakia and which form part of the Central Carpathian Paleogene Basin fill. These sequences which were named the Pucov conglomerates (Gross *et al*., 1982), and later categorized as the Pucov Member (Gross *et al*., 1984); they have been studied by several authors (Bieda, 1957; Maheľ *et al*., 1964; Andrusov, 1965; Gross *et al*., 1982). The latest, generally accepted interpretation of the Pucov Member is connected with deep marine canyons and fans (Gross *et al*., 1982, 1993). The aim of this paper is the sedimentological reinterpretation of the Pucov Member based on new field observations. Herein, we present a new alluvial and fan delta depositional model, where the deposition was controlled by both eustatic changes and tectonics. Sedimentation was mainly influenced by a regressive-transgressive cycle in the late

Bartonian to early Priabonian period. The sedimentary facies suggests deltaic subaerial to subaqueous mass-flow deposition, wave-reworking, and deposition by hyperpycnal and hypopycnal flows on the delta slope and in the prodelta and basinal environments.

GEOLOGICAL SETTING

The CCPB lies within the Western Carpathian Mountain chain (Fig. 1A) and it developed in the basinal system of the Peri- and Paratethys. The basin accommodated a forearc position on the destructive Alpine–Carpathian–Panonnian (ALCAPA) microplate margin and at the hinterland of the Outer Western Carpathian accretionary prism (Soták *et al.*, 2001). The basin is mainly filled with flysch-like deposits with a thickness of up to a thousand metres and they overlap the Palaeoalpine, pre-Senonian nappe structure. The age of the sedimentary fill ranges from Bartonian (e.g., Samuel and Fusán, 1992; Gross *et al.*, 1993) to latest Oligocene (*cf.* Soták *et al.*, 1996, 2001, 2007; Soták, 1998; Olszewska and Wieczorek, 1998; Gedl, 2000).

The deposits of the CCPB are preserved in many structural sub-basins (Fig. 1B), including the Žilina, Rajec, Turiec, Orava, Liptov, Podhale, Poprad and Hornád depressions. The

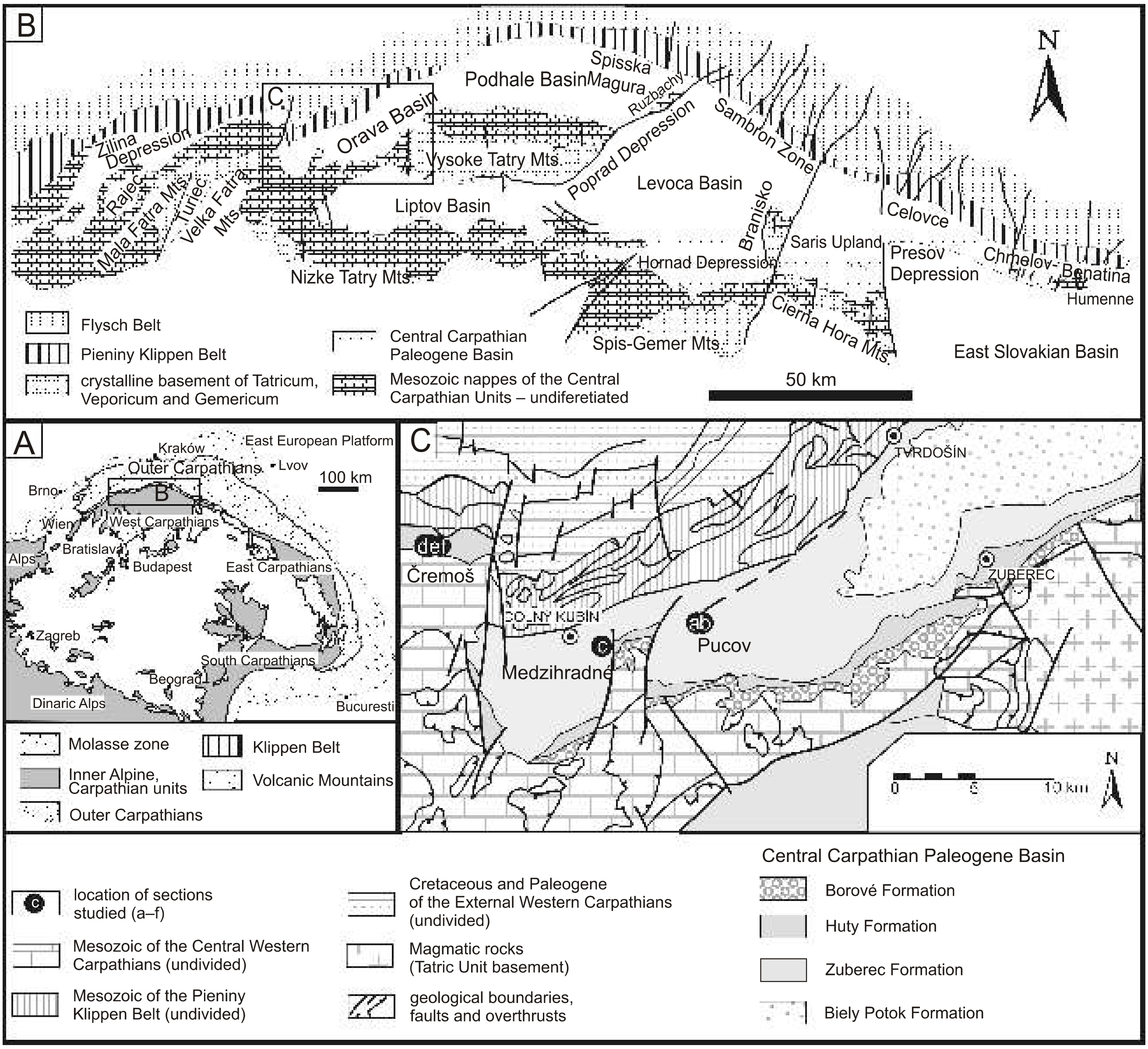


Fig. 1A – location of study area within the Alpine-Carpathian orogen; B – Central Carpathian Paleogene Basin system with structural sub-basins, basement and surrounding units; C – geological sketch of the Orava region (after Gross *et al.*, 1993; Biely *et al.*, 1996, modified)

C – location of studied sections: a – N 49°13’14’’, E 19°22’17’’; b – N 49°13’5’’, E 19°21’18’’; c – N 49°12’8’’, E 19°19’9’’; d – N 49°15’14’’, E 19°9’43’’; e – N 49°15’12’’, E 19°9’57’’; f – N 49°15’12’’, E 19°10’11’’

CCPB sediments in the study area are bounded by the Palaeoalpine late Paleozoic to Mesozoic units in the south, while the northern boundary is represented by the Pieniny Klippen Belt (Fig. 1) which represents a transpressional strike-slip shear zone related to a plate boundary (Csontos *et al*., 1992; Ratschbacher *et al*., 1993; Csontos, 1995; Potfaj, 1998). The CCPB was formed on the upper plate above the subducting oceanic slab attached to the European Platform (e.g., Royden and Baldi, 1988).

The CCPB deposits are commonly divided into four lithostratigraphic formations (Gross *et al*., 1984; Fig. 2A). The lowermost, Borové Formation consists of basal terrestrial deposits linked to alluvial fan and fluvial systems (Marshalko, 1970; Baráth and Kováč, 1995; Filo and Siráňová, 1998) and shallow-marine transgressive deposits (Kulka, 1985; Gross *et al*., 1993; Filo and Siráňová, 1996; Bartholdy *et al*., 1999). This formation is overlain by the Huty Formation, which mainly embraces various mud-rich, deep marine deposits (e.g., Janočko and Jacko, 1999; Soták *et al*., 2001; Starek *et al*., 2004). The overlying Zuberec and Biely Potok formations are composed of facies associations of sand-rich submarine fans (Soták, 1998; Janočko *et al*., 1998; Starek *et al*., 2000; Starek, 2001;

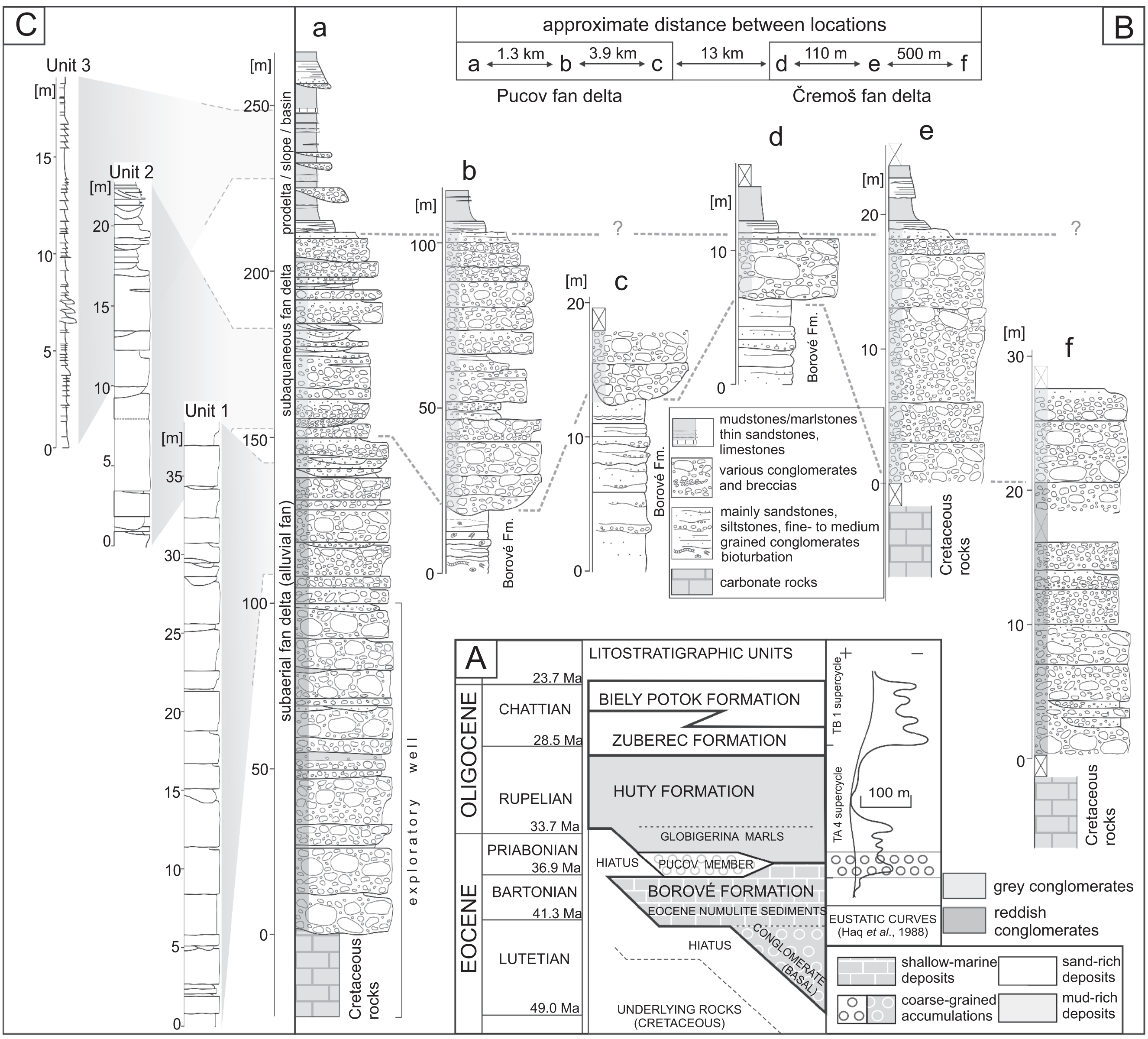


Fig. 2A – descriptive lithostratigraphy of the CCPB; nomenclature of the formations according to Gross *et al.* (1984, adapted); biostratigraphy is based on the data published by Olszewska and Wieczorek (1998), Starek *et al.* (2000), Starek (2001), and Soták *et al.* (2001, 2007); B – representative logs of alluvial fan delta deposits (a, b – Pucov sites; c – Medzihradné site; d–f – Čremoš sites); for map location and GPS position data see Figure 1C; C – representative fragment of the individual facies associations

For more details see Figures 3, 4, 7

Soták *et al*., 2001). The Pucov Member in the Orava Basin is generally incised into the Borové Formation and Mesozoic basement. It is overlain by the Huty Formation and eventually its deposition disappears in the lowermost part of Huty Formation (Gross *et al*., 1982). Nevertheless, the definition of the Pucov Member deposits (*sensu* Gross *et al*., 1984) is understood to be a lithotype representing coarse-grained input to the deeper parts of the basin and occurring in all lithostratigraphic formations. It exists in almost all regions of the CCPB.

The conglomerates of the Pucov Member have their main outcrops near the village of Pucov and these have been interpreted in several ways. Originally, they were regarded as "basal" transgressive lithofacies (Bieda, 1957; Maheľ *et al*., 1964; Andrusov, 1965), but Gross *et al*. (1982) later showed that this coarse-grained sequence is not a basal component of the transgressive succession – the Borové Formation (*cf*., Gross *et al*., 1984). They were considered to be conglomerates transported by canyons of submarine valleys 5–10 km towards the north where the sediments formed a 210–270 m thick submarine fan (Gross *et al*., 1982, 1993).

The conglomerates studied occur at several sites in the Orava Basin. However, only six exposures were applicable to this study because of the poor exposure (Fig. 1C). The most complex data are derived from a more than 250 m thick sedimentary succession near Pucov. The conglomerates are exposed in cliffs 150 m high. The lowermost part of the succession was documented by an exploration borehole (Gross, 1979). The sedimentary sequence at the bottom begins with reddish massive boulder-size conglomerates which are the most abundant deposits at the Pucov section (Fig. 2B, section a). The reddish colour disappears gradually at higher levels, where sandstone and finer conglomeratic beds start to occur. The uppermost part of the Pucov section mainly consists of siltstone, marlstone, and sandstones with scarce, isolated conglomeratic beds. This is referred to as the Huty Formation (*sensu* Gross *et al*., 1993), and more precisely to the Globigerina and Submenilite beds (*cf*. Soták *et al*., 2007).

No biostratigraphical data could be obtained from the massive conglomerates. However, the late Bartonian to early Priabonian time span of the deposition has been determined from their position above the Bartonian Nummulitic limestones of the Borové Formation (Bieda, 1957; Samuel and Salaj, 1968; Gross *et al*., 1984, 1993) and from the first occurrence of the lower Priabonian (Zone P 15) fossiliferous marls in the uppermost part of the conglomeratic succession (Soták *et al*., 2007; Soták, 2010).

RESULTS

SEDIMENTARY FACIES

The classification is mainly based on descriptive parameters such as grain-size, rounding, sorting and grain fabric, supplemented by other parameters including sedimentary structures, shape, occurrence of biogenic remains and bioturbation structures. Herein, grain-size and textural classification was used according to Blair and McPherson (1999). The coarse-grained facies evaluated show wide variation in their roundness and here the standard index of Powers (1953) was applied. The deposits that comprise exclusively, or mostly, very angular to subangular clasts are termed breccias (Facies B1, B2). Those that consist of subrounded to well-rounded clasts are referred to as conglomerates (Facies C). The sandstones are referred to as Facies S and mudstones/marlstones as Facies M. Although the facies are also evaluated by matrix colour, as in reddish and grey conglomerates, differences between matrix colours are not used as parameters to divide the separate facies. Herein, 13 individual facies with their possible hydrodynamic interpretation were distinguished, as depicted in Table 1.

The occurrence and arrangement of facies defined in vertical succession allowed as to separate the following three main units (Fig. 2C) that represent facies associations, specific of distinct depositional environments.

FACIES ASSOCIATION OF UNIT 1

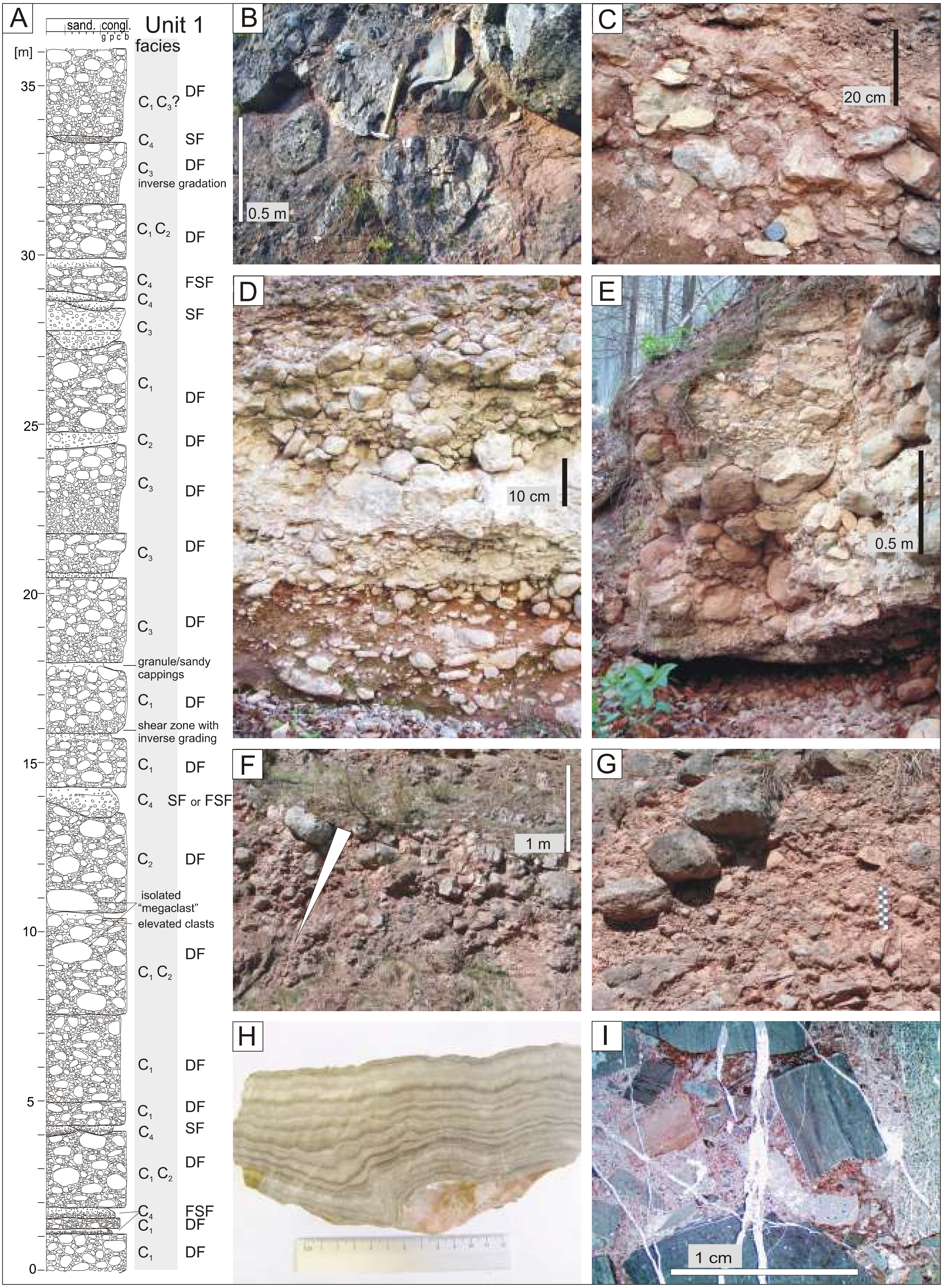
Description: the deposits of Unit 1 are generally thick-bedded, massive, unsorted or poorly sorted matrix- to clast-supported conglomerates of Facies C (Fig. 3B, D–G) or rarely breccias of Facies B, mainly at the Čremoš locality (Fig. 3C). The beds are sheetlike, non-erosive or with insignificant basal erosion. The thickness of individual beds is variable but it mainly ranges from less than 1 m to 2.5 m. Conglomerates range from texturally polymodal to bimodal, with clast size ranging from pebbles to large boulders. The maximum size of the boulders is often more than 1 m in long axis and locally isolated "oversized clasts" up to 2.5 m across can occur. These are evidently larger than the common large boulder size in the beds and they often equal the bed thickness. Although clasts are randomly arranged, subhorizontal and flow-parallel clasts are relatively common. There is wide variation in the character of matrix but, generally, it comprises poorly sorted gravelly, reddish sandy mud (Fig. 3I). Some conglomerates have a predominantly sandy matrix, while others are more muddy (Fig. 3D). Marked size differences in clast roundness are observable in Facies $C_{1–3}$ at the Pucov locality. The larger, cobble- to boulder-size clasts are often subrounded or rounded, while the smaller clasts are generally less rounded and more subangular or angular. The inverse grading in the conglomerates (Facies C_3, Fig. 3F) is marked by a gradual increase in larger cobbles and boulders which occur mainly in the uppermost part of the bed leaving the bulk of the pebble/cobble-size conglomerate vertically unchanged. Less frequently, there is a progressive increase in the size of all clasts throughout the bed. The thick-bedded conglomerates are occasionally interbedded with massive, reddish sandy mudstones with sporadic scattered clasts (Facies M_1).

Some deposits of Unit 1 generally form thinner beds, from a few decimetres to a metre thick, and they usually have an erosive base. They are often lenticular and pinch out over a distance of a few metres (Fig. 3A). Clasts size here range from granules to cobbles, typically with clast-supported fabric and crude gradation (Facies C_4). However, they occasionally show signs of crudely developed stratification in the upper parts of beds (Facies C_6). The clasts usually show horizontal orientation and signs of imbrication. The sorting and roundness of these

Table 1

Description and interpretation of dominant sedimentary facies in the late Eocene alluvial fan delta sequence (the Pucov Member) of the southern Orava region

Facies	Occurrence	Characteristics	Interpretation
Facies B_1 – massive, clast supported breccia	subordinate	clast-supported fabric, ungraded, very angular to subangular, poorly to very poorly sorted, coarse pebble to medium boulder-size clasts, sandy muddy matrix, slightly organized – parallel-oriented large clasts, some vertical clasts, sheet-like laterally continuous beds, bed thickness from decimetres to several metres	laminar shear flow, cohesion less debris flow, hyperconcentrated flow (Allen, 1981; Lowe, 1982; Shultz, 1984; Postma, 1986)
Facies B_2 – massive to crudely stratified, matrix supported breccia	subordinate	matrix-supported fabric, very angular to subangular, poorly sorted, very coarse pebble to coarse cobble-size clasts occasionally with some isolated "outsized" clasts (medium boulders), gravely (fine pebble), sandy muddy matrix, disorganized to slightly organized – clasts arrangement shows parallel-orientation to bedding but many of clasts are randomly oriented (much more than in facies B_1); usually sheet-like beds generally not exceed 1 m in the thickness; sporadic thin inverse grading at the base	debris flow, (laminar shear to plug flow) (Naylor, 1980; Nemec and Postma, 1993)
Facies C_1 – massive, clast supported conglomerates	main	clast-supported fabric, subrounded to rounded (rare also well-rounded), poorly to moderately sorted, ungraded (sometimes thin inverse grading at the base), pebble to medium boulder-size clasts (usually not exceed 70–80 cm in long axis); sand/fine gravel matrix with the local marked increasing of mud portion, disorganized to slightly organized (parallel-oriented large clasts, some vertical clasts); laterally continuous beds, non-erosive base, beds thickness from decimetres to several metres	cohesionless debris flow (Nemec *et al.*, 1980; Lowe, 1982; Massari, 1984)
Facies C_2 – massive, matrix supported conglomerates	main	matrix-supported fabric, subrounded to rounded (rare also well-rounded), poorly sorted, ungraded (sporadic thin inverse grading at the base), very coarse pebble to coarse boulder-size clasts, the isolated "outsized" clasts can reach very coarse boulder size (up to 2.5 m in long axis), variable granule/sand-muddy to sandy fine pebble gravelly matrix; disorganized to slightly organized (randomly- to parallel-oriented large clasts), usually sheet-like beds, from decimetres to several metres in thickness, non-erosive base	debris flow, dominant cohesive strength support, disperse pressure at clast interactions can occur (Johnson, 1970; Hampton, 1979; ;Lowe, 1979, 1982)
Facies C_3 – inversely graded conglomerates	subordinate to rare	variably clast- to matrix-supported (clast-supported fabric prevail), subrounded to rounded, poorly sorted, graded (the inversely gradation is often less-distinctive and may form all the bed or just part of the bed), pebble to fine boulder-size clasts, sandy muddy matrix, beds thickness are approximately 50–250 cm, the lower boundaries are usually flat; the upward coarsening clast-supported granule to cobble conglomerates, sometimes with erosive base, usually up to 80 cm thick beds	debris flows (Lowe, 1982; Nemec and Steel, 1984; Postma, 1986;) channel bar deposits (Nemec and Postma, 1993)
Facies C_4 – normally graded conglomerates	subordinate to rare	clast-supported fabric, subrounded to rounded, poorly to moderately sorted, graded, granule to fine boulder-size clasts, sandy muddy to sandy matrix, variable bed thickness from 20–100 cm, usually erosional lower boundary, occasionally with the coarse to very coarse grained poorly sorted sandstones in the uppermost part of the facies	gravely high-density turbidite; fluidal sediment flow, water-laid deposits/stream flow, debris fall deposits (Lowe 1979, 1982; Nemec, 1990; Nemecand Postma, 1993)
Facies C_5 – inversely-to-normally graded conglomerates	rare	variably clast- to matrix-supported, subrounded to rounded, poorly to moderately sorted, pebble to fine boulder-size clasts, graded (lower inversely graded part is usually matrix-supported, normally graded part tend to be clast-supported), poorly to well-sorted predominantly sandy matrix, beds thickness up to 250 cm, the lower boundaries are usually flat and sharp	debris flow, high-density turbidity current (Lowe, 1982; Nemec and Steel, 1984; Kim *et al.*, 1995)
Facies C_6 – stratified conglomerates and sandstones	subordinate	clast-supported fabric, subrounded to well-rounded, moderately to well-sorted pebble to cobble-size conglomerates ("outsize" fine boulder-size clasts are present) interstratified with coarse to very coarse grained pebble sandstones and granule-size conglomerates with occurence of cross-bedding and parallel lamination, commonly bimodal or polymodal textures, beds thickness are about 20–150 cm, distinctive lower boundaries, occasionally erosive	deposition in the shoreface zone under wave action (Reineck and Singh, 1980; stream flow (Rust, 1978; Nemec and Steel, 1984)
Facies C_7 – well-sorted, imbricated conglomerates	subordinate	massive, close-packed, well-sorted, well-rounded, rod/spherical to disc/blade shaped pebble-size (rare cobble-size) clasts, well-sorted sandy matrix, up to 1 m thick laterally discontinuous beds with erosive bases	shoreface or beachface with rip channels (Bluck, 1967; Gruszczyński *et al.*, 1993; Hart and Plint, 1995; Davis and Fitzgerald, 2004)
Facies S_1 – massive to graded sandstones	subordinate	medium to very coarse sandstones, few centimetres to several decimetres in thickness, can form isolated beds or can be part of larger succession, normal grading usually in the basal part; well to poorly sorted, sometimes with dispersed granule to pebble-size clasts; strong variability in grain shaping (from angular to rounded); occasionally large amount of well to moderately preserved fossil remains (mainly large foraminifers) – dispersed or concentrated at the base; rare bioturbation	turbidity currents, waning traction currents, return storm flows (Lowe, 1982; Brenchley, 1985; Myrow and Southard, 1996)
Facies S_2 – laminated sandstones and siltstones	subordinate	medium sandstones to fine siltstones, variable in thickness from several centimetres to few metres; sometimes continuing from facies S_1 or facies C_4; mainly thick beds show fining – upward tendency in grain size (from sandstones to very fine siltstones); possible current ripples; commonly overlain by facies M_2	hyperpycnal flows, suspension settling (hypopycnal flows); low-density turbidity currents (Bouma, 1962; Middleton and Hampton, 1976)
Facies M_1 – massive, reddish mudstones	rare	unstructuralised mudstones, poorly sorted, occasionally with scattered clasts and varied content of sand; decimetres to maximal 2 m thick interbeds	the result of settling of fines after flooding (Bardaji *et al.*, 1990), mudflow
Facies M_2 – homogeneous mudstones/marlstones	main	variable content of a silty compound; random bioturbation, rich on microfossils (foraminifers, dinoflagellates, calcareous nannoplankton), rare occurrence of thin tuffite horizons and laminated limestones; thin to very thick (few centimetres to several metres)	hemipelagic settling (Pickering *et al.*, 1986)


A
sand. congl.
g p c b
Unit 1
facies
[m]
35
30
25
20
15
10
5
0
C1 C3? DF
C4 SF
C3 DF
inverse gradation
C1 C2 DF
C4 FSF
C4 SF
C3
C1 DF
C2 DF
C3 DF
C3 DF
C3 DF
granule/sandy cappings
C1 DF
shear zone with inverse grading
C1 DF
C4 SF or FSF
C2 DF
isolated "megaclast"
elevated clasts
C1 C2 DF
C1 DF
C1 DF
C4 SF
C1 C2 DF
C4 FSF
C1 DF
C1 DF
B
0.5 m
C
20 cm
D
10 cm
E
0.5 m
F
1 m
G
H
I
1 cm

deposits vary considerably from being well-sorted and having relative textural maturity to poorly sorted conglomerates and breccias with an unsorted reddish matrix. The conglomerates locally exhibit textural bimodality with openwork gravels filled with fines of – clay and fine silt/sand (*cf*. Frostick *et al*., 1984).

No fossil remains were found within Unit 1 and the clast composition reflects the source areas formed by the Choč and Krížna nappes (*cf*. Gross *et al*., 1984). Occasionally, at the Čremoš locality, flowstone clasts (Fig. 3H) were found.

Interpretation: the internal characteristics of the facies of the Unit 1 indicates that deposition could range from slow-moving, high-strength/viscosity debris flows to more water-rich fluidal flows with intense shearing and possibly turbulence.

Ungraded, poorly sorted beds with random fabric may indicate high shear-strength or high viscosity, and these can be interpreted as "cohesive debris flows" with the development of a "semi-rigid plug" (Johnson, 1970; Naylor, 1980). This semi-rigid plug usually forms in the thicker, upper part of the bed overlying the basal high-shear layer (e.g., Hubert and Filipov, 1989), and it can form almost the entire bed thickness, often with thin inverse grading restricted to the basal few centimetres (shear zone; Fig. 3E). The larger boulders tend to move upwards in the flow and out of the shearing layer, thus producing the inverse grading seen at the base of the beds (Hubert and Filipov, 1989). Although inverse grading throughout the bed has been explained by dispersive pressure in the flow, so that the larger clasts move upwards through the flow to equalize the stress gradient (e.g., Bagnold, 1954; Nemec and Steel, 1984), later laboratory experiments proposed a mechanism known as kinetic sieving. This process involves small grains passing through the interstices between the larger particles through agitation, thus displacing the larger particles upwards (Middleton, 1970; Naylor, 1980; Gray and Thornton, 2005).

The trend of size differences in clast roundness can be observed almost exclusively in those facies with a reddish matrix (Unit 1). This may be a result of more effective abrasive processes for large clasts over a short transport distance, or alternatively it may indicate redeposition of older fluvio-alluvial deposits.

The normal grading in conglomerates (Facies C_4) with signs of basal erosion most likely occurred as a result of deposition from more watery fluidal sediment flows (e.g., Lawson, 1982). A transverse clast alignment (Fig. 3G) suggests development from more fluidal flow with a significant tractional component (Pierson, 1981; Lawson, 1982).

Massive, reddish, sandy mudstone interbeds (Facies M_1) are rare, and these may reflect the settling of fines following flooding (Bardaji *et al*., 1990) or a redeposition of fine-grained material reworked from debris flow deposits or bedload-dominated deposits.

Water-laid deposits (Bull, 1972), are represented by stream and sheetflood deposits. They represent fluid-gravity flows, with fluid turbulence supporting clasts in Newtonian fluids, and they are characterized by a lack of shear or yield strength (Costa, 1988). The thinner erosive conglomerate beds may represent channel-fill deposits or broad shallow scour fills, the largest clasts at the base likely being bed-load material deposited after erosion in the maximum stage of flooding as channel-floor lags.

The sporadic upward coarsening character of the clast-supported conglomerates (Fig. 3A) occurs in association with channel-floor lags and these can most likely be interpreted as channel bar deposits (Nemec and Postma, 1993).

The presence of the upward-fining sandy capping (Facies S_1), locally with an erosive base, and signs of stratification, may result from turbulent fluid flow or alternatively from heavily sediment-laden stream flow followed by debris flow (Nemec and Steel, 1984). Some beds are more laterally extensive with slight stratification and they can represent sheetfloods deposits. Sheetflood conglomerates can be deposited from extremely heavy but short-lived floods (Blair and McPherson, 1994). In contrast to streams, these form shallow, unconfined flows covering a large surface.

The facies association of Unit 1 comprises sedimentary facies which are predominantly involved in mass flow deposits interfingering with fluid-gravity flow deposits (Fig. 3A).

Massive, disorganized to slightly organized conglomerates (Facies C_1, C_2) including massive to crudely stratified breccias (Facies B_1, B_2) are the most frequent facies in Unit 1. These facies commonly show strong vertical variations, and clast-supported conglomerates often pass to or are interbedded with matrix-supported conglomerates (Fig. 3D). However, some beds exhibit better organization with inversely graded conglomerates being relatively abundant (Facies C_3) and, in a few isolated cases, normally graded conglomerates (Facies C_4) with an erosional base occur. The debris flow-type conglomerates in the lower parts of Unit 1 are occasionally interbedded with massive, reddish mudstones (Facies M_1). This facies has been doc-

Fig. 3A – detailed section of the alluvial fan facies association (Unit 1) specific in mass-flow deposits interfingering with stream deposits; B – matrix-supported, well-rounded boulder conglomerates with reddish sand-clayey matrix (Facies C_2, Pucov site); C – clast-supported reddish breccias (Facies B_1, Čremoš site); D – surging debris flow deposits with vertical variation in character of the matrix from reddish muddy matrix of the matrix-supported conglomerates (Facies C_2, lower part) to the sandy matrix of the clast-supported conglomerates (Facies C_1, upper parts); E – ungraded, poorly sorted, debris flow conglomerates (Facies C_1) with slightly organized to random fabric ("semi-rigid plug" flow deposition) with thin inverse grading restricted to the basal few centimetres (shear zone); F – inversely graded conglomerates (Facies C_3); G – transverse alignment of clasts in more fluidal flow with a significant tractional component; H – rare flowstone clasts in debris flow conglomerates at the Čremoš site indicate karstification the source area; I – breccia with poorly sorted sand-clayey reddish matrix (Čremoš site, microscopic view)

A: DF – debris flow, SF – stream flow, FSF – fluidal sediment flow, g – granule, p – pebble, c – cobble, b – boulder umented only by borehole investigation (Gross, 1979). Stream and sheetfloods deposits occur in far fewer portions as mass flow deposits.

The facies association of Unit 1 represents the subaerial portion of a coarse-grained fan delta. Subaerial mass-flow deposits are noteworthy for their reddish colour and they form the vertically most extensive succession with a maximum thickness of approximately 150 m (Gross, 1979; Fig. 2B, section a).

FACIES ASSOCIATION OF UNIT 2

Description: the deposits of Unit 2 are generally thick-bedded, massive, matrix- to clast-supported conglomerates (Facies C; Fig. 4A) with a greyish-to-yellowish poorly to moderately sorted gravelly/sand to sandy matrix (Fig. 4D). The beds are usually sheet-like, non-erosive, with bed thicknesses ranging from less than 1 m to several metres. Although the bed boundaries are locally indistinct and amalgamated, they are generally much better defined than those in Unit 1. These conglomerates are ungraded, with some beds exhibiting better organization with inverse grading of Facies C_3 (Fig. 4G). Normal grading (Facies C_4, Facies S_1 – in the case of sandy cappings) or rare inverse-to-normal grading (Facies C_5) occasionally occurs. The clasts vary from granule- to boulder-size up to 80 cm.

Some laterally discontinuous beds have an erosive base (Fig. 5A), and they are formed by close-packed, well-sorted, often imbricated, rod/spherical (Fig. 5A1) to disc/blade (Fig. 5A2) shaped pebbles (Facies C_7). A bedset of well- to moderately sorted, well-stratified coarse-grained pebbly sandstones and pebble- to cobble-size conglomerates (Facies C_6; Fig. 4A – upper part) occur within Unit 2. These beds have distinctive and occasionally erosive lower boundaries and laterally they show significant persistance.

The clast composition is almost identical to that of the Unit 1 deposits, but in the uppermost parts of Unit 2 some pebbles of middle Eocene carbonate sandstones from the Borové Fm. also occur (Gross *et al.*, 1982, 1993).

Interpretation: the characteristics of the deposits of Unit 2 (Fig. 4F) are generally similar to those of Unit 1, and they indicate deposition within high shear-strength or high viscosity flows ("rigid plug" flow deposition – with random fabric and some clasts projected above the bed), strongly sheared, laminar flows with preferred clast orientation fabric, and more water-rich fluidal flows (normal grading, signs of basal erosion). The scarce inverse-to-normal grading of Facies C_5 may reflect the tendency of subaqueous debris flows to reduce flow density and frictional/viscous resistance and to evolve into high-density turbidity currents (Lowe, 1982; Nemec and Steel, 1984).

Good sorting and lack of intergranular mud within Facies C_7 reveal that the depositional processes were effective in washing and sorting the sediment (Clifton, 1973; Bluck, 1999). Close-packed, well-sorted, well-rounded conglomerates often represent wave-reworked tops of debris-flow conglomerates and they can be attributed to a wave ravinement surface. Sharply bounded tabular gravel beds may be interpreted as wave lag deposits with storm-related erosional surfaces. Small channels and cross-lamination (Fig. 5B, C) may have been formed by either waves or alongshore currents (Hart and Plint, 1995). The channels and scours can represent both alongshore troughs and rip channels (Gruszczyński *et al.*, 1993). However, the clast imbrication shown in Figure 6A is similar to the imbrication in the underlying debris flow deposits in Figure 6B, and this points rather to rip channel features.

As for the deposits of the Unit 1, those of Unit 2 were predominantly supplied as mass-flow deposits (Fig. 4A) and subordinately as wave-reworked deposits that form lateral discontinuous interbeds ranging from a few decimetres up to a metre thick inside debris-flow deposits, or they form bedsets up to 6 m thick sporadically alternating with thinner debris-flow conglomerates.

However, there are generally some textural and structural differences between the mass flow deposits in Units 1 and 2. Unlike in Unit 1, the maximum clast size here is considerably smaller and the mass flow deposits generally exhibit better rounding of all particles (Fig. 4D, E); better sorting; an absence of intergranular mud; a more frequent occurrence of granule/sandy cappings, and more beds that show an upwards increase in their matrix content.

Fossil remains occur in Unit 2 (Fig. 4B) together with rare bioturbation (Fig. 4C), wave-reworked deposits (Fig. 5), and sporadic thin mudstone interbeds rich in microfossils (Soták *et al.*, 2007). These characters suggest that the facies association of Unit 2 reflects deposition in the subaqueous part of a coarse-grained fan delta. Subaqueous coarse-grained fan delta deposits occur at Pucov, Čremoš, and most likely also at Medzihradné. The limited outcrop and monotonous, grey massive conglomerates at this latter locality do not allow unambiguous interpretation of the depositional setting.

FACIES ASSOCIATION OF UNIT 3

Description: the deposits of Unit 3 are well-documented as an approximately 50 m thick sequence at the Pucov section (Fig. 2B, section a). The sequence is characterized by decreasing conglomerate volume, while sandstones and siltstones (Facies S_1, S_2) are dominant and the mudstone proportion (Facies M_2) is markedly higher (Fig. 7B).

The bed thickness ranges from a few cm to more than 1.5 m. Thinner beds of up to 20 cm in the lower parts of Unit 3 form isolated granulites to sandstones with distinct bottoms and tops (Facies S_1). Most of the sandstones contain a relatively large number of redeposited fossil remains, predominantly those of large foraminifers (Fig. 7C), and these sandstones are separated by decimetre-thick mudstones.

Infrequent, well-defined, isolated, and non-continuous beds up to 1 m in thickness occur here (Fig. 7D). These are formed by normally graded fine boulder- to pebble-size conglomerates (Facies C_4) passing upwards to very coarse pebbly sandstones (Facies S_1) and to a thin interval of laminated fine sandstones and siltstones (Facies S_2).

Occasionally, there are also composite beds more than 1 m thick (Fig. 7F) with massive, clast-supported conglomerates at the base (Facies C_1). These conglomerates are overlain by normally-graded beds (from base upward Facies C_4, S_1, and S_2) and also by homogenous mudstones (Facies M_2).

The upper portion of Unit 3 is mainly represented by fine-grained marlstones rich in microfossils (Facies M_2), and interbedded with thin sandstones (Facies S_2) as well as with

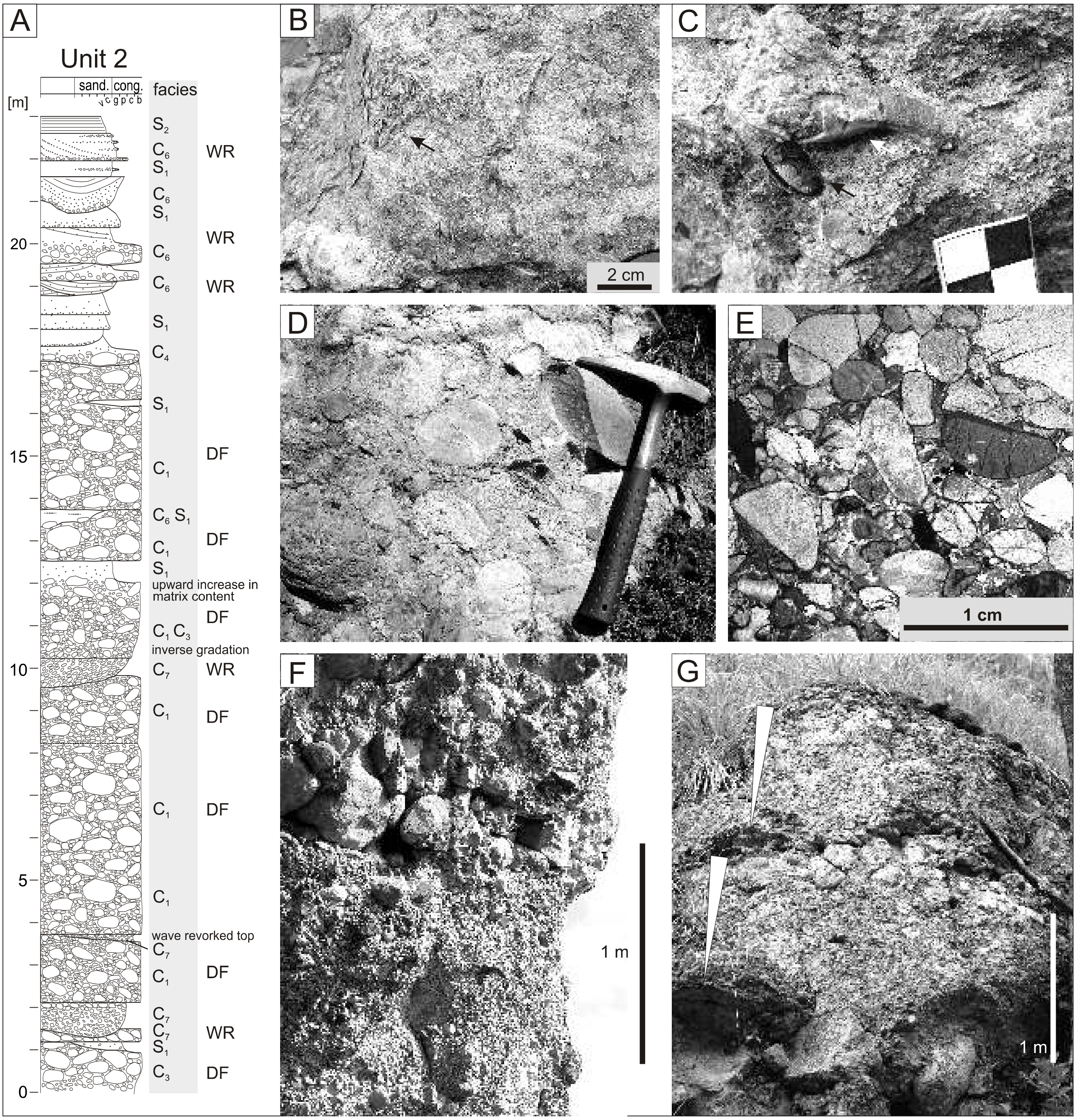


Fig. 4A – detailed section of the subaqueous fan delta facies association (Unit 2) specific in mass-flow deposits interfingering with wave-reworked deposits; occurrence of fossil remains (B – large foraminifers) and bioturbation (C) in the subaqueous fan delta deposits; matrix-supported conglomerates (Facies C_2) (D) and clast-supported conglomerates (E) with relatively well-sorted and rounded particles (Facies C_6); F – mass-flow conglomerates (Pucov); G – inversely graded beds (Facies C_3)

DF – debris flow, WR – wave reworked; v c – v. coarse, for other explanations see Figure 3

laminated limestones (Fig. 7G) and thin ocherous brown tuffite horizons (Fig. 7H). The uppermost part of Unit 3 at the Pucov and Čremoš sections shows occurrences of a thick isolated sandstone bed.

Interpretation: a relatively thick pebble to boulder size, usually normally graded conglomerate can be interpreted as the deposit of a hyperconcentrated flow (Costa, 1988) or debris-fall avalanche (Nemec, 1990*b*). The medium pebble size conglomerates to sandstones facies of S_1 and S_2 in the top of these beds may reflect deposition ranging from gravelly high-density turbidity currents (Lowe, 1982) to low-density turbidity currents (Bouma, 1962). The coarse-grained isolated

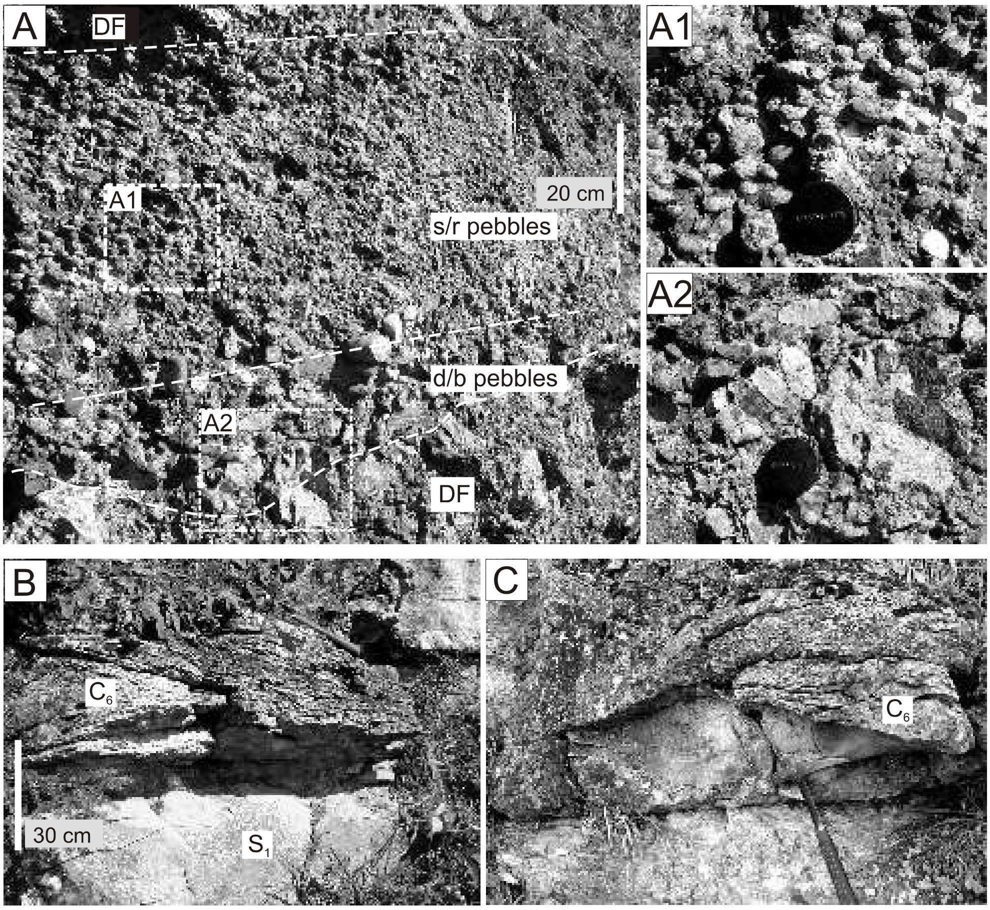


Fig. 5A – wave-reworked top of debris-flow conglomerates (Facies C_7); A1 – close-packed, well-sorted, imbricated, rod/spherical shaped pebbles; A2 – imbricated pebbles behind the large boulder (relict of debris-flow deposition); B, C – cross-laminated fine-grained conglomerates and sandstones formed by waves or shallow-marine (wave induced) currents (Facies C_6, S_1)

DF – debris flow, d/b – disc/blade, s/r – rod/spherical

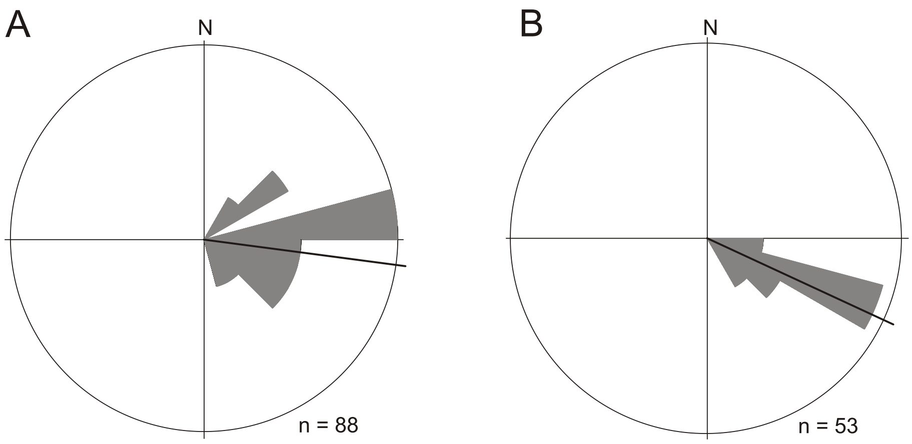


Fig. 6. Measurements of inclined clasts from debris-flow conglomerates of Unit 1 (A) and rip channels of Unit 2 (B) presented by Rose diagram of dip direction

Data is rotated to original position; general palaeotransport is toward the NW to W; n – number of measurements granulites to sandstones with distinct tops suggest incomplete turbidites ("top cut-out" beds) that may reflect the downslope bypassing of most of the fine-grained suspended load (Nemec, 1990*b*). The fine-grained, usually laminated sandstones and siltstones (Fig. 7E) may reflect discharge from a flood-stage stream with a high concentration of sediment deposited by hyperpycnal flows (Bates, 1953; Wright *et al*., 1988; Mulder and Syvitski, 1995) or by flows of hyperconcentrated bedload (Prior and Bornhold, 1989) that reached the prodelta and slope. The fine-sediment fractions may also be derived from intense fallout from the suspension plume blanketing large subaqueous areas with a dense, mobile suspension which could evolve into a sheet-like underflow (*cf*. Hay *et al*., 1982; Wright *et al*., 1986; Syvitski and Farrow, 1989).

The facies association in the lower parts of Unit 3 suggests deposition in a prodelta and slope environment and forms the uppermost part of the delta fan succession. An increasing trend in the proportion of complete medium- to fine-grained turbidites (low-density turbidity currents; *cf*. Bouma, 1962; Middleton and Hampton, 1976), the contribution of hemipelagic mudstones/marlstones facies (M_2), and an occurrence of laminated limestones are mainly evident in the higher parts of Unit 3. These components may reflect distal prodelta/slope deposition and a basinal facies (Fig. 7A).

DISCUSSION

BOUNDARY BETWEEN SUBAERIAL AND SUBAQUEOUS FAN DELTA ENVIRONMENTS

The subaerial and subaqueous deposits of the Pucov section are relatively similar and it difficult to precisely distinguish their interface because of their mass flow coarse-grained character (*cf*. Nemec and Steel, 1984). However, in addition to the presence of fossil remains, rare bioturbation and wave reworking in the upper part of Unit 2, there are other differences among the mass flow deposits in these units. In Unit 2, a large number of greyish conglomeratic beds tend to be better organized and sandy cappings being are more common. This may reflect the tendency of the subaqueous debris flows to evolve towards high-density turbidity currents (Lowe, 1982). However, beds with an upwards increase in their matrix content are more frequent. A reddish muddy matrix, common in Unit 1, is completely missing in the Unit 2 conglomerates, which also exhibit better sorting and rounding of particles and an absence of conglomerate interstitial mud. This may suggest a redeposition of sediments which were reworked on the seashore as well as cannibalism of the shallow-marine units of previous cycles (Borové Formation). The coarse-grained facies analysed show a positive correlation between bed thickness and maximum clast size (Fig. 8). This could be used to support the idea of mass-flow deposition of the conglomerates (e.g., Larsen and Steel, 1978; Porębski, 1981; Nemec and Steel, 1984; Nemec, 1990*b*). Although boulder-size clasts are frequent in Unit 2, the maximum average size is less than those in Unit 1. This distinction is also expressed in the different regression line gradient of the MPS/BTh diagram in Unit 2 (Fig. 8), which may reflect a relative decrease in debris-flow competency after passing into water, due to admixing of water into the flow, which reduces their density, viscosity and concentration (Larsen and Steel, 1978; Nemec and Steel, 1984). However, the MPS/BTh diagram shows a relatively wide dispersion of data and a low correlation coefficient. This may have been due to the small number of beds analysed and to the impossibility of determining bed interfaces between the massively textured sediments. Additionally, even if it were possible to define such interfaces, they may represent breaks between sediments deposited by multiple discrete flows rather than breaks between individual flows (Mayor, 1997). Other factors influencing MPS/BTh correlation include (*cf*. Nemec, 1990*b*):

– inaccurate definition of flow competence due to the redeposition of pre-sorted debris (seemingly lower competence),
– erosion of the uppermost parts of debris flow deposits,
– the addition of large clasts to freezing debris flows by debris-fall processes (seemingly higher competence).

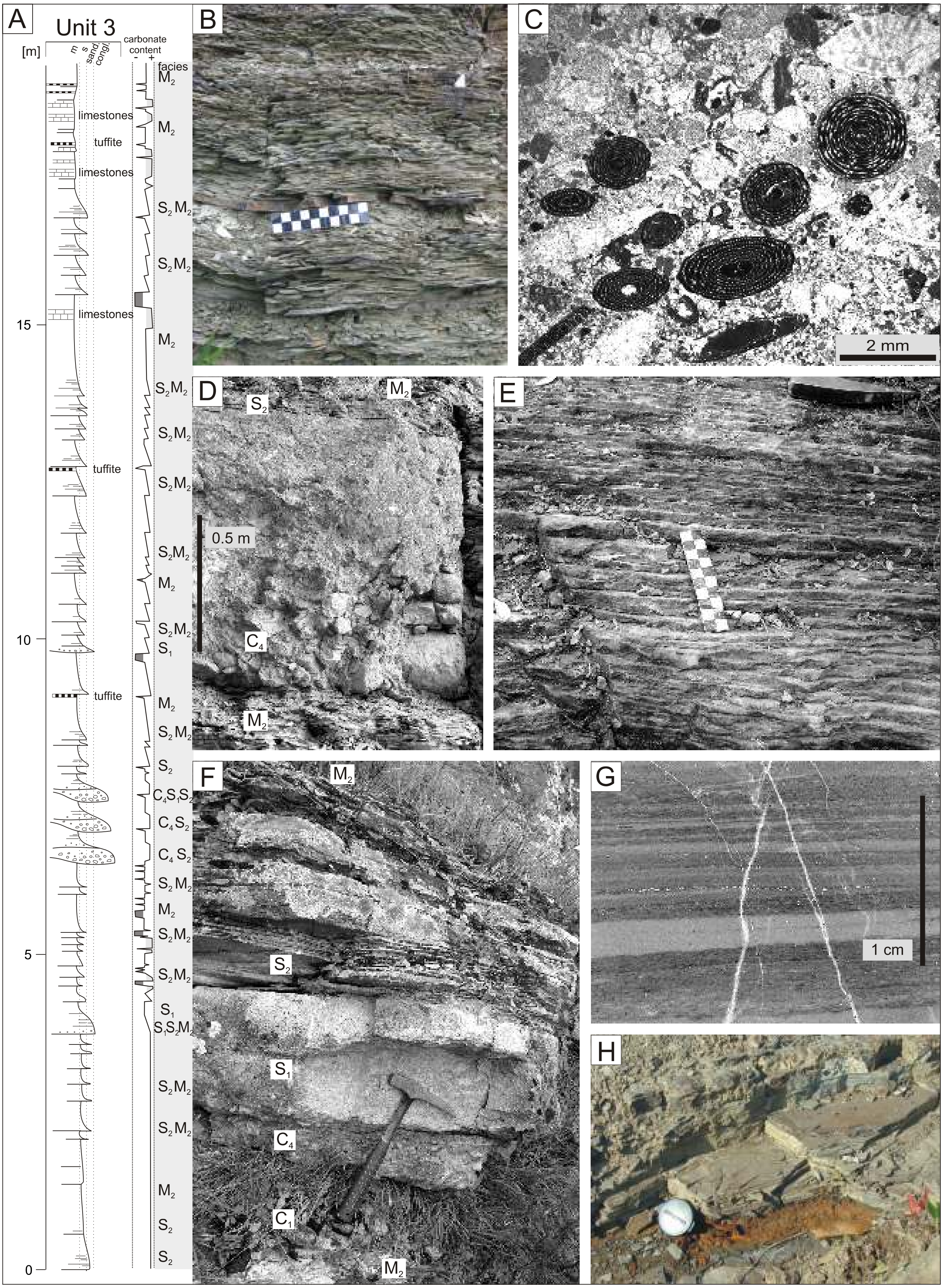
Moreover, later studies on experimental debris flows by Mayor (1997) and Inverson (2003) cast doubt on the suitability of the MPS/BTh analytical method. These experiments revealed that massively textured, unsorted debris-flow deposits can often result from progressive incremental deposition which can accumulate without obvious stratigraphic contact. This can particularly occur where there is a short time interval between events, or similar source materials, or small travel distances. Vertical accretion of sediment from surges can produce beds that appear to "support" oversized particles which were emplaced rather than being tractional bedloads (Mayor, 1997). Since the above mentioned problems adversely affect the estimation of flow properties emanating solely from MPS/BTh analysis, this correlation was utilized herein only as additional support in distinguishing the Unit 1 and Unit 2 deposits.

The border line between Units 1 and 2 was defined as that partition in the sedimentary section where the reddish muddy matrix disappears from the deposits and the greyish conglomerates bearing the above mentioned signs appear.

TECTONIC AND EUSTATIC CONTROLS ON SEDIMENTATION

Tectonics and eustasy played an important role in the formation of the upper Eocene alluvial fan delta facies associations in the southern Orava region.

After the initial transgression of the CCPB (TA 3.5–3.6 third-order Exxon cycles), deposition changed from subaerial to subaqueous (Baráth and Kováč, 1995), with the deposition of the shallow marine Bartonian facies of the Borové Fm. During the highstand, most of the coarse sediments of the fan deltas were stored adjacent to hinterland, thus restricting the areal extent of the subaerial fans. The marked eustatic lowering of sea level in the early Priabonian, at the beginning of the TA4 supercycle, led to regression accompanied by subaerial exposure and the erosion of deposits of previous sedimentary cycles. Rare flowstone clasts (Fig. 3H) in the debris flow conglomerates can indicate karstification in the source area. The exposed shelf was prone to developing incised valleys as a result of fluvial incision (e.g., Vail *et al*., 1984; Porębski and Steel, 2003). Consequently, the reddish nonfossiliferous mass-flow domi-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nant conglomerates (alluvial fan deposits/subaerial fan delta; Unit 1) filled the incised valleys. The fluvial incision into the underlying deposits of the Borové Formation and the Mesozoic basement units is well-marked at the Čremoš locality and it corresponds to a sequence-stratigraphy boundary (SB1). This incision increased from the margin towards the central part of the Pucov conglomerates, with only the central part of this valley incised into the Mesozoic basement being overlain by the Unit 1 and 2 deposits. The incision at the marginal areas terminated in deposits of the Borové Formation. Valley flanks here are overlain by more wide-spread deposits of Unit 2 as a consequence of backstepping of fan deltas.

The conglomerates of Unit 1 are notable for their reddish matrix. We assume that this red pigment is hematite formed by mature hydrated ferric oxides entering the alluvial sediments as finely divided soil-weathering products (Taylor, 1982), following their transport and deposition by rivers (e.g., McPherson, 1980). The red pigmentation may also have been increased by disintegration of red and violet sedimentary rocks of the Mesozoic units (Gross *et al*., 1982). A subsequent rise in the relative sea level accompanied by relatively rapid tectonic subsidence (Soták *et al*., 2001) along the CCPB margins during the Priabonian led to extensive transgression and the gradual overlying of subaerial alluvial deposits by the subaqueous fan delta facies association of Unit 2. The onset of transgression is marked by wave-reworked conglomerates and by the onlap of deposits of Unit 2 onto the incised valley walls, where the transgressive surface coincides with the SB1 sequence boundary. Erosive features filled by wave-worked conglomerates may represent ravinement surfaces. The subaqueous environment of delta fans shows a relatively high coarse-grained input which is mainly due to mass flow movement. However, this environment is characterized by heterogeneity of the facies sequences, which can reflect interplay between processes. These include varying discharges of sediment during individual flood events or the effects of wave, tide and current processes. Wave-reworked segments in the Unit 2 may indicate a "transition zone" (Wescott and Ethridge, 1982) where coarse-grained deltas are influenced by wave and tides (Postma, 1984; Colella, 1988).

A subsequent continual relative sea level rise resulted in a deepening depositional environment which is documented by the generally upwards-fining trend in particle size between Unit 2 and 3. This reflects the relatively rapid transition from a shallower-water facies to a prodelta/slope and basinal facies with slow hemipelagic settling. Maximum flooding occurred in Unit 3 abreast of deposition of the Globigerina Marls (Soták *et al*., 2007).

However, it is difficult to estimate the individual contributions of eustatic fluctuations and tectonic effects to the relative sea level changes (e.g., Schlager, 1993; Massari *et al*., 1999). While regression at the Bartonian/Priabonian boundary appears to be coupled rather with a eustatic sea level fall, the influence of tectonic activity at the sources cannot be excluded. This is due to the very coarse-grained sediments which indicate a steep gradient in the depositional area which is typical of tectonically controlled basin margins. Additionally, the following transgression and relatively rapid deepening of the depositional environment suggest a significant effect of tectonic subsidence in the Orava region of the CCPB. The continuous relative sea level rise may have influenced the delta front to retreat towards the land. Abandonment of the delta slope and the prodelta resulted in a hemipelagic drape on the subsiding fan delta lobes in Unit 2.

The relatively small lateral extent of individual deltaic bodies, the variable discharge competence, and the limited transport distance as indicated by the scarceness of stable constituents and the dominance of immature debris; all suggest a small fan delta system with a small drainage basin and a short feeder system. The formation of such deltas reflects a rapid response to climatic and tectonic changes (Postma, 1990). The architecture of the Pucov succession corresponds to a shallow-water coarse-grained alluvial delta, generally dominated by gravel, with a steep gradient of the A-feeder type system (*sensu* Postma, 1990). It is characterized by ephemeral, unconfined streams involving mass flows. Due to rapid tectonic subsidence along the CCPB margins, this initial shoal-water delta stage changed during the Priabonian and deposition reflects the deepening environment affecting the fan deltas' architecture. This caused the landward shifting of coarse-grained facies with clasts trapped on the shore, while distal parts of the fan delta were deactivated by the superposition of basinal marlstones, limestones and thin turbidites.

SEDIMENTOLOGICAL INTERPRETATION AND SPATIAL OCCURRENCE OF THE PUCOV MEMBER

The interpretation of the Pucov Member presented in this paper differs from that provide by Gross *et al*. (1982, 1993). From a sedimentological viewpoint, there are at least three reasons for this different interpretation.

Fig. 7A – detailed section of the distal prodelta/slope and basin facies association (upper part of Unit 3) showing mainly its fine-grained hemipelagic deposition and turbidites (Pucov); B – rhythmic deposition of siltstones and mudstones with thin turbiditic sandstones in prodelta (Facies M_2, S_2); C – microscopic view of carbonate sandstones (Facies S_1) with common redeposited fossil remains (mainly large foraminifers: *Nummulites* sp., *Alveolina* sp.); D – isolated, thick bed of normally-graded conglomerates (Facies C_4) underbeded with Facies M_2 and overlapped by thin interval of Facies S_2 with Facies M_2 (prodelta/slope enviroment); E – fine-grained, laminated sandstones and siltstones (Facies S_2) deposited by hyperpycnal flows; F – thick complex bed formed (bottom upwards) by pebble to fine cobble debris-flow conglomerates at the base (Facies C_1), overlain by a turbidite unit of massive to normally-graded coarse pebble conglomerates with erosive base (Facies C_4), coarse pebble sandstone (Facies S_1) and planar-stratified sandstones to siltstones (Facies S_2) continuous passing into mudstones (Facies M_2); G – laminated limestones; H – thin tuffite horizon

m – mudstone, s – siltstone, sand. – sandstone

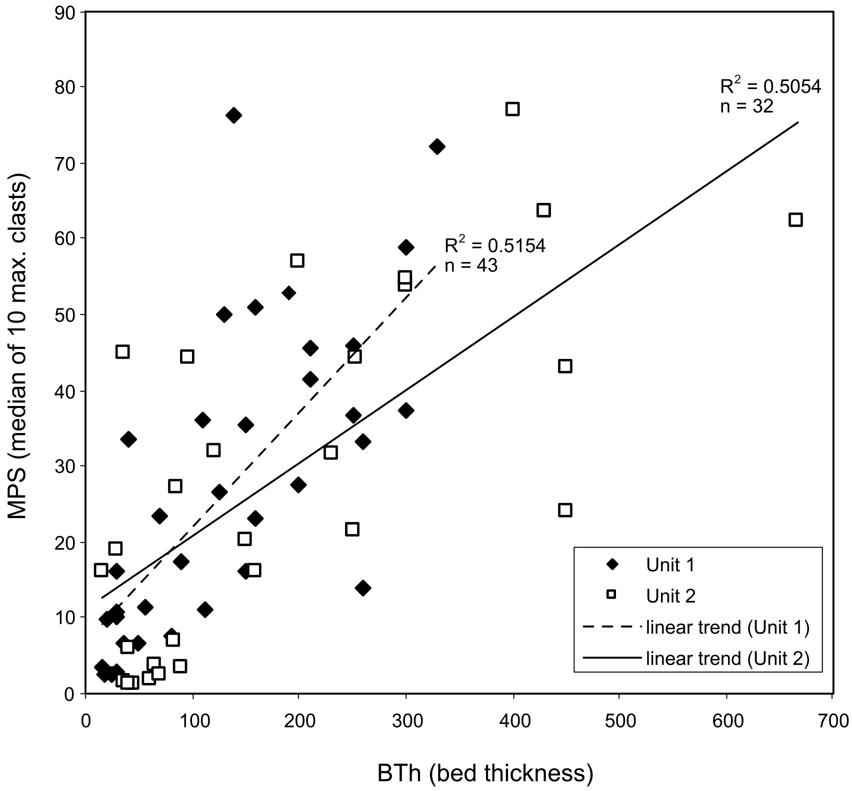

Fig. 8. MPS/BTh relationship in debris flows from subaerial (Unit 1) and subaqueous (Unit 2) deposits of the alluvial fan and fan delta

Firstly, if the Pucov conglomerates form a deep-water depositional fan in the lower part of the Huty Formation, the presence of an underlying Eocene basinal/deep-water facies can be presumed. However, such a basinal/deep-water facies was not confirmed by field mapping and by an exploration well. It was established that only other shallow-water deposits of the Borové Formation or the Cretaceous sedimentary basement of the Krížna Nappe are preserved in the studied sections.

Secondly, sedimentary features, such as the colour and composition of the matrix, the absence and upwards increase of fossil remnants, and the occurrence of wave reworked segments, all suggest deposition changing from a subaerial to a shallow marine environment rather than a deep marine one (e.g., Dabrio, 1990).

Thirdly, the total absence of fossils in the rare fine-grained facies associated with the red conglomerates is more in keeping with alluvial fan models rather than with deep-water canyons or terminal fan models, where interbedding with hemipelagic mudstone drapes which are often rich in microfossil content, and also more sandy horizons, are typical (e.g., Wright *et al*., 1988; Prior and Bornhold, 1990; Gardner *et al*., 2003).

With regard to criteria such as facies associations, depositional palaeoenvironment, and stratigraphic position, the Pucov Member can be defined as the fan delta facies association which reflects the change from subaerial to subaqueous depositional environments during the late Bartonian to early Priabonian regressive-transgressive cycle. The sedimentary record for the separate locations in the Orava Basin (Fig. 2B) represents coeval equivalents within the fan delta system that changed during evolution of the basin.

However, conglomerate deposits marked as the Pucov Member are documented in different stratigraphical levels in various parts of CCPB (*sensu* Gross *et al*., 1984). These are often connected with unrelated events and depositional palaeoenvironments during evolution of the CCPB (e.g., Tokáreň conglomerates on the eastern slope of the High Tatra Mts.; Janočko and Jacko, 1999; Janočko *et al*., 2000). That they share the name the Pucov Member is confusing (*cf*. Sliva *et al*., 2004; Soták *et al*., 2007).

Sedimentary facies, similar to the Pucov Member with red to grey coarse clastic deposits of terrestrial to shallow marine origin, are preserved at different stratigraphic levels in several CCPB outcrops. The most distinct of these are on the northern flanks of the High Tatra Mts. (Hruby Regiel), where pre-transgressive deposits of red to grey conglomerates and breccias are overlain by the shallow marine strata comprising sandstones and limestones of the Borové Formation (Sokołowski, 1959). A partly similar situation occurs at the eastern part of the CCPB, in the Hornád Member as described by Filo and Siráňová (1998). Pre-transgressive deposits near Markušovce village have been interpreted as a terrestrial fluvial valley fill to the fan delta (Marschalko, 1970; Baráth and Kováč, 1995; Prekopová and Janočko, 2005). The facies association of the Pucov conglomerates is also similar to the Vajsková conglomerates in the Lopejská kotlina Depression (Biely and Samuel, 1982), but despite this similarity, their stratigraphical position remains unclear because of poor exposure area.

Renewal of a succession of pre-transgressive character (developed on the base of the Borové Formation) in the terminal part of the Borové Formation (Pucov Member) suggests a new regressive cycle at the boundary between the Bartonian and Priabonian. Identification of this regressive event in other parts of the CCPB is unclear.

This may be established by the presence of strata rich in plant fragments in the terminal part of the Borové Formation (Nummulitic Eocene in Poland; Sokołowski, 1959; Głazek and Zastawniak, 1999). Soták *et al*. (2007) suggested that the Pucov conglomerates could be indirectly correlated with alluvial and fluviolimnic deposits such as the freshwater Odorín limestones in the Spiš area or with the freshwater and brackish clays at the top of the Paleogene coral horizon of the Buda Basin (Seneš, 1964). These were deposited during regression and subaerial erosion at the end of the mid Eocene and preceded the new marine transgression at the beginning of the late Eocene.

However, in accordance with the stratigraphical position and facies features of the Pucov Member, it currently appears that its occurrence is limited to the Orava region.

CONCLUSION

The Central Carpathian Paleogene Basin evolution reflects the important role of relative sea level changes on a tectonically active basin margin. After the initial upper Lutetian/Bartonian transgression with shallow-marine deposition, the next regressive-transgressive cycle played a key role in the formation of late Eocene alluvial fan delta facies associations in the southern Orava region.

The first stage of delta development is connected with the regression which corresponds well with the marked global eustatic lowering of sea level at the Bartonian/Priabonian boundary. This sea level lowering was most likely the main reason for subaerial exposure and incision of previous sedimentary successions and also for the consistent deposition of coarse-grained alluvial fans. The subaerial deposition, accompanied mainly by thick boulder-rich conglomerates with a reddish clayey matrix, suggests a mass-flow-dominated alluvial delta with a variety of deposits reflecting a range of slow-moving, high strength/high-viscosity debris flows to more water-rich fluidal flows, likely showing a transition to sediment-laden stream flows. The alluvial fans adjoin the subaqueous environment distally where the mass flow deposits were often subject to reworking by waves or wave-induced shallow-marine currents and they were also subject to further resedimentation.

However, the vertical arrangement of the facies associations shows a retrograding delta system which suggests that high-amplitude transgression resulted in a relatively rapid submergence of the subaerial and shallow water parts of the the coarse-grained alluvial delta with accompanying superposition of prodelta/slope and basinal facies associations. During the rapid increase in sea level, the areal extent of the subaerial fans was restricted and the distal parts of the fan delta became inactive. Although this transgression responded to the gradual eustatic sea level rise during the Priabonian and at the beginning of the Rupelian, we propose that rapid tectonic subsidence (Soták *et al*., 2001) along the CCPB margins during the Priabonian was the main agent leading to this transgression and to the marked deepening of the depositional environment.

Acknowledgements. This work was supported by the scientific grant agency of the Slovak Republic (Vega 0140) and Slovak Research and Development Agency under the contract No. APVV-0465-06. We thank D. Ventra and anonymous reviewer for the detailed review of this paper and constructive comments.

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