Slovak Geol. Mag., 11, 2 – 3 (2005), 165 – 183

Deep-water sedimentary facies and depositional environments in the eastern part of the Lower Paleozoic Gelnica Group (Gemericum, Inner Western Carpathians)

MARTIN KOVÁČIK

Geological Survey of Slovak Republic, Jesenského 8, 040 01 Košice; kovacik@gssr-ke.sk

Abstract. Sedimentological investigation was focussed on psammitic horizon belonging to upward fining and thinning sequence, being a constituent part of sedimentary filling of Gelnica Group. The lithofacies of this horizon demonstrate their deep-water character. The coarse-grained sediments were transported to deposition place by concentrated density (gravity) flows, and the finer-grained lithofacies by turbidity flows. The finest pelitic lithofacies have the hemipelagic character. The lydites as an important lithofacies originated by pelagic deposition with contribution of siliceous solutions of submarine volcanic springs and low-density turbidity flows. Lydites together with alodapic carbonates and dark pelitic lithofacies represent a condensed horizon from the time of maximum height of sea level.

The psammitic horizon alone has a complex cyclic character. In its lower part (Tinesová dolina valley) the shallow distributary channels built by coarse-grained lithofacies are present. The channels are spatially connected with finer-grained lithofacies of levee and interchannel environments and together form the middle part of submarine fan. The upper, substatial part of psammitic horizon is formed by sediments of lobes and their margins (lobe fringes) of outer part of submarine fan (valleys Hutná dolina, Gelnická dolina and Zlatá dolina) with frequent compensation cycles.

Fining and thinning character of studied psammitic horizon, as well as whole sequence, to which it belongs, is a result of sea-level rising, attenuation of sedimentary material contribution into the basin and backstepping of deep-water sedimentary system towards continent.

Key words: deep-water facies, submarine depositional environments, Lower Paleozoic, Gelnica Group, Gemericum, Western Carpathians

Introduction

Metamorphosed and structurally complicated sedimentary successions seldom became an object of detail sedimentological investigation. Despite, in some cases the former composition, sedimentary structures and fabric are partially or fully preserved and it allows the sedimentological analysis.

Sedimentological investigation in the area of Lower Paleozoic sequences of Gemericum was done by several authors in the past. The sedimentological description and classification of deep-water depositional systems of this unit was presented by Snopko (1967) using terms by Vassojevič (1960). The thickness of lithofacies, uninterrupted sedimentary development, presence of lydites and alodapic carbonates, the relatively well developed Bouma intervals (Bouma, 1962) as well as the absence of large-scale cross-bedding were supposed to be the marks of deep-water sedimentation (Snopko and Ivanička, 1978). Later work by Vozárová and Ivanička (2000) determined seven principal lithofacies of Lower Paleozoic rocks of Gemericum using model defined by Mutti and Ricci-Lucchi (1972).

This work is aiming to present the lateral and vertical stratigraphic development of Lower Paleozoic Gelnica Group in its eastern part and to determine the lithofacies and sedimentary processes during their origin as well as to reconstruct the depositional environments of studied sedimentary system.

Methodology

The work integrates the data from two N-S trending profiles directed perpendicularly to course of lithological strips in eastern part of the Gelnica group of Gemericum (Fig. 1). First, western profile, was directed through Medzev town - Zlatá dolina valley - elevation points Zbojnícka skala and Kloptaň - Tinesova dolina valley - Hutná dolina valley and Helcmanovce village. Second, eastern profile, is coursing in the line Baňa Lucia settlement - Tri studne saddle - Gelnická dolina valley (respectively the Zimná voda valley) and Prakovce town.

The detail sedimentological investigation (Kováčik, 2004) was realized in 4 additional localities with numerous outcrops in the valleys Zlatá dolina, Tinesova dolina and Hutná dolina in western profile, and Gelnická dolina valley (resp. Zimná voda valley) in eastern profile (Figs. 1-3). Lithofacies were defined and interpreted using their thickness, geometry, sedimentary structures, fabric and petrography. The particular depositional environments

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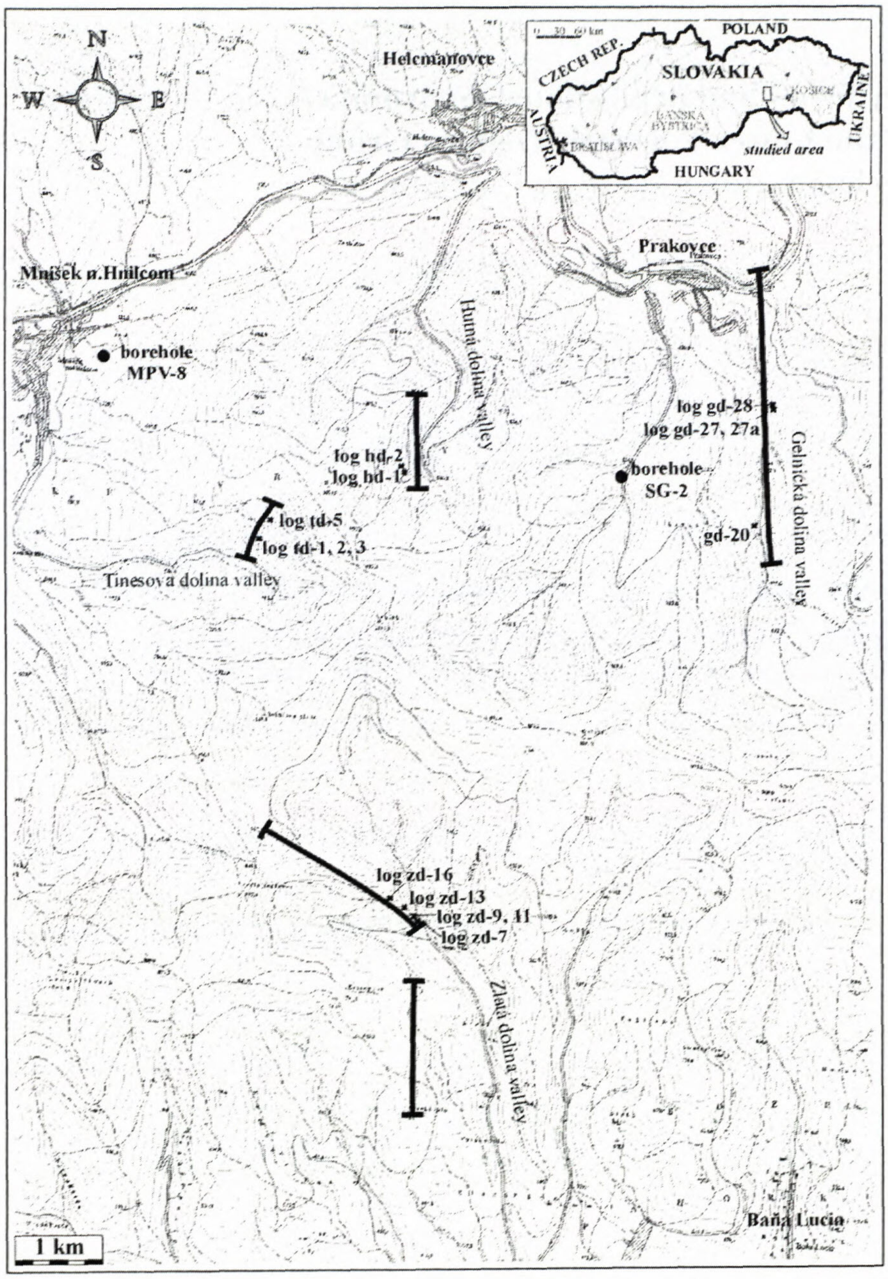


Fig. 1. Location of studied area, profiles, logs and drills

were distinguished by lithofacies and their characteristic associations, as well as vertical changes in bed thickness and grain size.

Sedimentological profiles (logs) from outcrops were supplemented by data from field mapping and geological maps (Kobulský et al., 2001) as well as older mining and drill works (e.g. Grecula et al., 1977; Kobulský et al., 1988) aiming to obtain the integrated profile through particular lithostratigraphic unit from its lowermost to uppermost parts.

Obtained data were elaborated in graphic form (logs from outcrops) and statistically (tables with principal statistic parameters, graphs of the trend of vertical changes of bed thickness from underlier to overlier – rhythmograms, where the thickness of the gravel-sand-silt fraction was plotted against the cumulative thickness of the total sediment, Fig. 10). Detail study of depositional conditions allowed to express lithostratigraphic conclusions and relative position of particular lithological units in vertical succession.

Geological setting and lithostratigraphy

The Lower Paleozoic Gelnica Group of Gemericum represents a volcano-sedimentary succession with regional metamorphic overprint in greenschists facies and deformation of at least in two orogenic cycles - Variscan and Alpine (e.g. Németh et al., 1997 and others). Paleozoic sedimentary successions were intruded by post-orogenic granite of Permian age (e.g. Kovách et al., 1986 and others).

Lithostratigraphic relations in Lower Paleozoic sequences of Gemericum were studied by numerous authors. Superposition of lithological units was and is evaluated by particular authors very differently, which causes also very differing lithostratigraphic division of this region (cf. Grecula, 1982; Ivanička et al., 1989b).

Ivanička et al. (1989b) supposes the Gelnica Group as a flysch formation 4500-8000 m thick with polygenetic and polycyclic development of mesorhythms. From its basal parts there were distinguished following formations: Vlachovo Formation (3 mesorhythms), Bystrý potok Formation (1 mesorhythm), Drnava Formation (2 mesorhythms). According to this interpretation the investigated area (Gelnica Group east of Smolnícky potok valley) has an anticline character with the Bystrý potok Fm. in its core and the northern as well as southern limb formed by Drnava Formation. The age of Bystrý potok Fm. was determined by microfossils as Upper Silurian. The Drnava Formation is Lower Devonian (Ivanička et al., 1989 a, b). The Vlachovo Fm., being present only in western part of Gelnica Group, is the oldest one. Its stratigraphic span was determined to Cambrium - Middle Silurian (Bajaník et al., 1984; Ivanička et al., 1989 b; Vozárová et al., 1998).

Recently in the eastern part of the Gelnica Group three sequences were distinguished (Seq 1, Seq 2, Seq 3, Kováčik, 2004, Figs. 2 and 3), but only the second one is completely preserved. Distinguished sequences are upward fining and thinning. Each sequence alone originated during one trangressive-regresive cycle (Vail et al., 1977; Haq, 1991). The sequence bases are built with volcanic horizon, upwards gradually passing to psammitic (sequence 2 – Seq 2, Figs. 2 and 3) or metapelitic horizons(sequence 1 – Seq 1). In the eastern part of Gelnica Group the sequence 1 is represented mainly by its upper lithological members belonging to the Bystrý potok Formation. They are built by dark-grey to black metapelites with small lenses of alodapic limestones and lydites, volcaniclastics are present less often. The substantial part of sequences 2 and 3 belongs to the Drnava Formation. The base of sequence 2 consists of acid metavolcaniclastics gradually passing to overlying psammitic horizon (so-called Kojšov metapsammites; Grecula, 1970), forming the

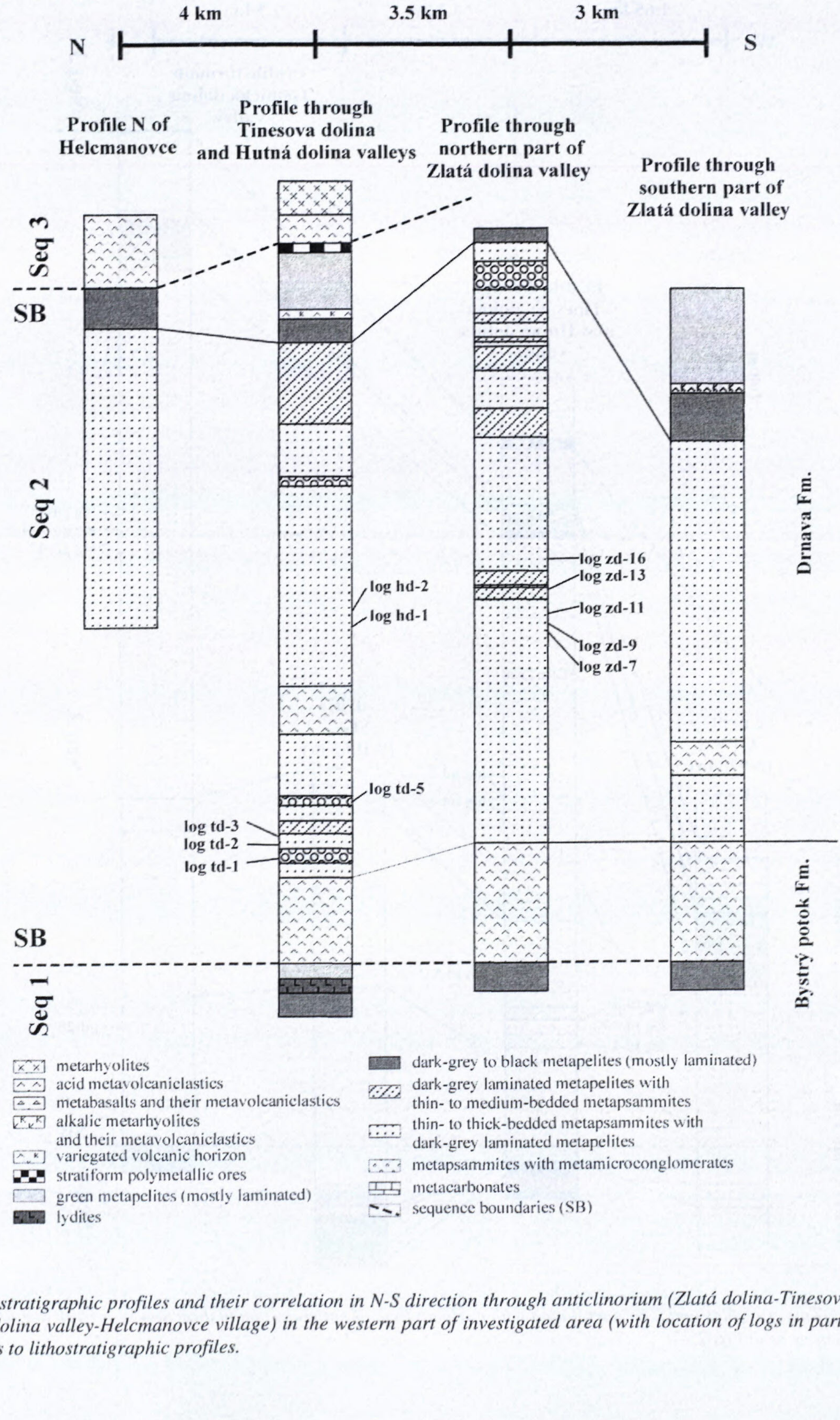


Fig. 2. Lithostratigraphic profiles and their correlation in N-S direction through anticlinorium (Zlatá dolina-Tinesova dolina valleys and Hutná dolina valley-Helcmanovce village) in the western part of investigated area (with location of logs in particular profiles). Explanations to lithostratigraphic profiles.

Slovak Geol. Mag., 11, 2 – 3 (2005), 165 – 183

prevailing part of basin-floor fan (Kováčik, 2003). This horizon gradually passes into dark, prevailingly laminated metapelites with lydite beds and sporadical metacarbonates (Smolník locality, e.g. Ilavský and Mrozek, 1960). This horizon has similar lithological content as upper part of the sequence 1 and represents the second phase of basin development with maximum value of sea level (Kováčik, 2004). Grecula (1982) assigned all Lower Paleozoic lydites and carbonates (from both sequences) of Gemericum into single Betliar Formation (Holec Beds), but our analysis did not confirm this opinion. In overlier of dark metapelites with lydites the horizon of green, pre-

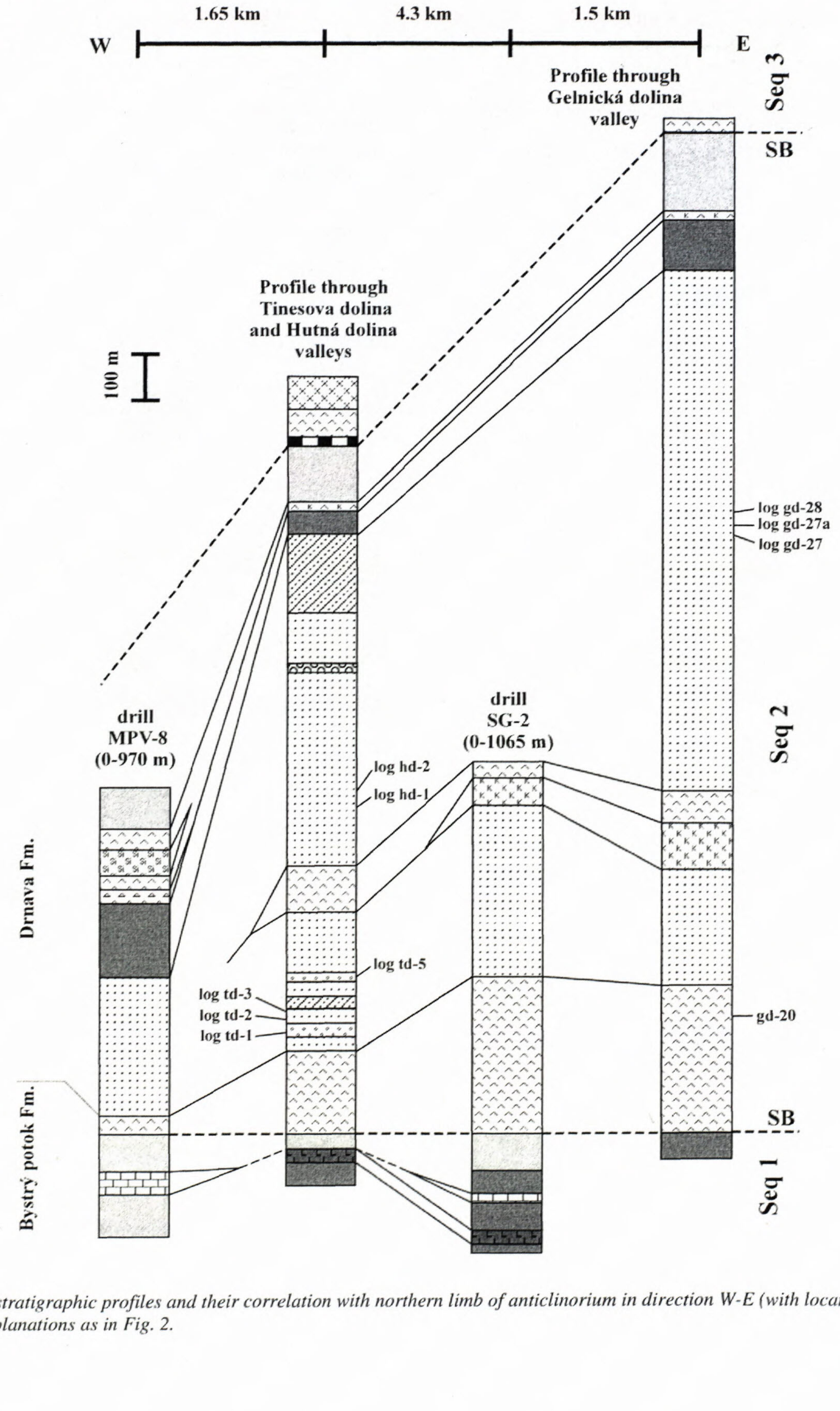


Fig. 3. Lithostratigraphic profiles and their correlation with northern limb of anticlinorium in direction W-E (with location of logs in profiles). Explanations as in Fig. 2.

vailingly laminated metapelites with small volcanite bodies in its lower part is developed (so-called lower variegated complex, Grecula, 1982). The horizon of green metapelites terminates the sequence 2 and in its overlier the main body of Gelnica Group volcanites is present. It is typically developed at Mníšek nad Hnilcom village and forms the base of sequence 3 (Figs. 2 and 3) and probably the highest part of lithostratigraphic succession of Gelnica Group.

Lithofacies – description and interpretation of depositional processes

The detail sedimentological analysis was focussed on metapsammite horizon (so-called Kojšov metapsammites, Grecula, 1970), forming the middle part of sequence 2 (Seq 2, Figs. 3 and 4). The lower part of the horizon is formed by metapsammites with pebbly psammite bodies, less of dark-grey laminated metapelites and volcaniclastics. In the upper part of horizon the metapelites gradually appear, and in the uppermost parts they prevail among further lithofacies. We have distinguished 11 lithofacies of siliciclastic sediments (Kováčik, 2004). Individual lithofacies are designated with codes with accompanied description and interpretation of depositional processes. Volcaniclastics and carbonates were not subjected to detail sedimentological investigation, but because they are the integral and important constituent of Gelnica Group, they will become a subject of the next evaluation.

Lithofacies Cs - stratified pebbly metapsammites

The lithofacies Cs was found in the Tinesova dolina valley (Fig. 5, log td-1, bed No. 66; Fig. 6, log td-5). Beds with stratified pebbly metapsammites are developed in medium to high thickness with typical parallel stratification (S_1 and S_2 interval, Lowe, 1982). Lithofacies Cs is characteristic with alternation of fine- and coarse-grained tabular layers in the frame of one bed (Fig. 4H). Finer-grained layers are formed with fine- to coarse-grained metapsammite, coarser-grained layers with very coarse-grained metapsammite to pebbly psammite. The thickness of individual layers varies between 5 to 25 cm. Their contacts are sharp or transitional, sometimes with inverse grading at the base of coarse-grained body. More coarse-grained intervals are matrix supported and the rafted clasts of dimensions 1-5 mm consist prevailingly from the fragments of quartz, quartzy rocks or dark metapelites. Quartzy-sericitic matrix has granularity 0.02-0.2 mm.

The lithofacies Cs correspond to lithofacies A2.5 according to Pickering et al. (1986) or lithofacies F4 according to Mutti (1992) and originates by deposition from concentrated density (gravity) flows. The particles in the flow are maintained by the grain-to-grain interactions making the dispersive pressure; the turbulence is suppressed (Mulder and Alexander, 2001). The individual coarser inverse graded units represent the traction carpets (sensu Dżułyński & Sanders, 1962; S_2 interval, sensu Lowe, 1982), originating from moving body of coarser-grained material in lower part of the flow.

Deposition of traction carpets can occur by continuous aggradation beneath a sustained steady or quasi-steady current, while the upper part of the current is supplying the sedimentary material (Lowe, 1982; Kneller & Branney, 1995). Traction carpets can reflect cyclically changing hydrodynamic conditions in unstable gravity flows (Hiscott, 1994) or changeable contribution and differing transport velocities of various granularity fractions in the current (Hand, 1997).

Lithofacies Cg - normally graded pebbly metapsammites

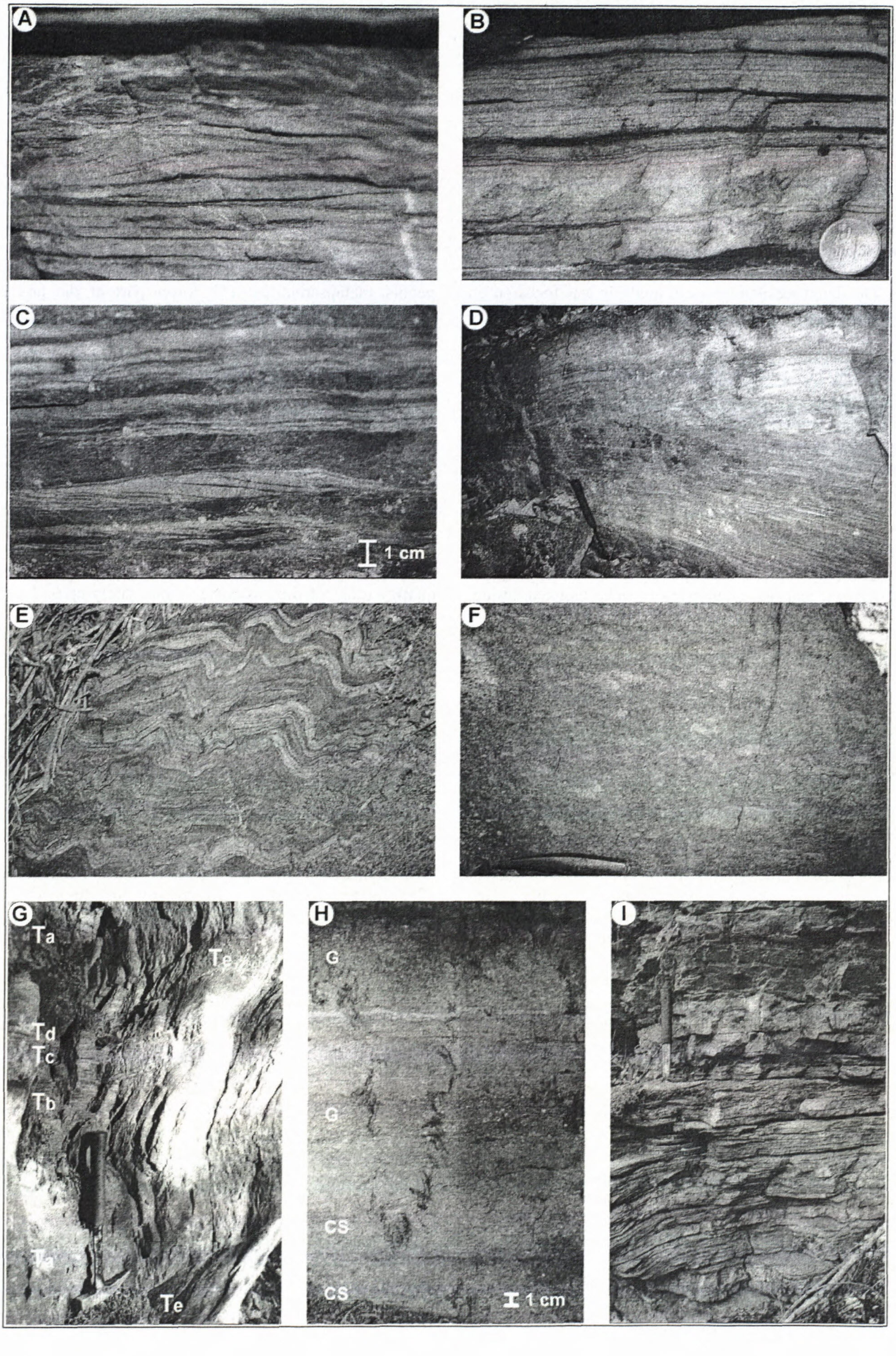
Lithofacies Cs is represented by normally graded pebbly metapsammites. The lower part of the bed is formed by massive pebbly psammite upward grading into the medium- to fine-grained metapsammite with preserved Bouma intervals (prevailingly T_a, T_b). Grading is manifested by gradual decrease of very coarse grains of psammite (1-2 mm) and granules (2-4 mm) in finer-grained matrix upwards (coarse-tail grading). Lithofacies Cg is developed together with lithofacies Cs in the Tinesova dolina valley (Fig. 5, log td-1; Fig. 6, log td-5). Beds thickness is usually more than 50 cm. Bases are sharp, flat, sometimes with preserved erosion structures. Similarly as at lithofacies Cs the pebbly psammites are matrix supported. Granularity has polymodal character. Very pourly sorted grains prevailingly of quartz or quartzy rocks of dimensions 1-4 mm, rarely up to 1 cm, are disseminated in fine-grained matrix. Matrix consists prevailingly from quartz (> 80 %), sericite, chlorite, sporadically there occur biotite, feldspar (prevalence of plagioclase), eventually carbonate. Lithofacies Cg originates by fast deposition from concentrated gravity flow in its lower part. In the upper less dense part it was formed from turbulent suspension, without more important traction transport of bed-load. Lithofacies Cs and Cg are typical mostly for channel sediments.

Lithofacies Pm - massive metapsammites

Lithofacies Pm (facies B1.1, sensu Pickering et al., 1986) is represented prevailingly by fine to medium-grained metapsammites with medium to very high thickness (e.g. Fig. 9, log gd-28). They are usually without sedimentary structures, with indications of undistinct gradation in the uppermost part of the beds. Lower as well as upper bedding planes are usually sharp, sometimes with preserved erosion structures at the base of the beds. Beds are usually amalmagated. Their former massive character, without any significant fabric, is often obscured by dense metamorphic schistosity. Granularity has polymodal character, though a part of finest fraction (0.01-0.05 mm) has a character of pseudomatrix. Its secondary enrichment in all lithofacies was found by post-sedimentary processes (diagenesis, metamorphism, deformation; Vozárová, 1993).

Lithofacies Pm originated probable by deposition of long-lasting quasi-steady concentrated density (Mulder & Alexander, 2001) or turbidity current (Kneller & Branney, 1995), in some cases from rapidly decelerating gravity flow (Lowe, 1982).

Slovak Geol. Mag., 11, 2 – 3 (2005), 165 – 183



Lithofacies Ps - cross-stratified metapsammites

Lithofacies Ps (lithofacies B2.2, sensu Pickering et al., 1986) represents cross-stratified metapsammites (Figs. 4D and 8, log hd-2, beds No. 65 to 74). They are fine to coarse-grained, bedding planes are moderately undulated or flat, sharply bordered, without grading. Beds are thick 15-70 cm, but their thickness can be laterally changed. Characteristic feature of internal setting of metapsammite is its planar or trough cross-lamination formed by migration of bedforms (e.g. dunes) or by reworking of deposited psammite by overriding concentrated density or turbidity flow, eventually by strong ocean bottom (contour) current (e.g. Pickering et al., 1986).

Sporadic climbing ripples indicate the high amount of sediment falling out from suspension in comparison to intensity of bed-load transport (Allen, 1982). At high angles of climbing the lamination has undulating character and originates as transitional form between horizontal lamination of upper flow regime and a ripple phase of lower flow regime.

Lithofacies Ph - thick- to very thick-bedded sand-mud couplets

The relatively well developed grading mainly in upper part of beds as well as sharp erosion bases are characteristic for this lithofacies. Beds are laterally unchangeable and can be correlable for distance of several hundreds to thousands metres. The monothonous alternation of psammitic and pelitic intervals in the frame of vertical succession is typical together with the relatively well preserved inner sedimentary structures of metapsammites being defined by Bouma (1962): T_a - massive (without structure) or graded fine to medium-grained metapsammite, T_b - horizontally laminated fine- to medium-grained metapsammite, T_c - obliquely laminated fine-grained metapsammite, locally bearing marks of convolution (strongly tectonically modified), T_d - very fine-grained metapsammite to metasiltstone with horizontal lamination (this interval is hardly recognizable in tectonized and weathered outcrops), T_e - dark grey to black metapelite, massive or with undistinct very fine lamination.

The Bouma sequence is a good base for hydrodynamic interpretation of deposition from turbidity flows, in which the upward component of fluid turbulence is a dominant supporting mechanism for particles carried by flow (e.g. Walker, 1965; Middleton & Hampton, 1976; Mulder & Alexander, 2001). The deposition of entire Bouma sequence progresses in three phases. First phase consists of a quick deposition of grains from suspension, during which the continuing friction of deposited grains by flow together with escaping water from intergranular spaces cause, that lowermost unit T_a is massive, eventually contains water escape structures. The second deposition phase is characteristic with traction of grains on ground, during which T_b originates in upper flow regime. Continuing decreasing of flow velocity causes the origin of ripples and their migration forms the ripple cross-bedding. In the case of strong addition of material the T_c has a character of climbing ripples. The last, third deposition phase is represented by intervals T_d and T_e originating by slow accummulation of finest suspended particles from the tail of the flow.

In the lithofacies Ph the T_a and T_b Bouma intervals are prevailing, quickly grading to T_c, T_d or T_e. These intervals are obscured by younger tectonic structures, which causes their difficult distinguishing. Together with lithofacies Pt and Fcl the lithofacies Ph forms the main part of deep-water deposition system of Gelnica Group in the middle part of sequence 2.

Lithofacies Pt – very thin to medium-bedded psammitic-pelitic beds

In comparison with lithofacies Ph they are thinner (1-10 cm), prevailingly fine-grained and with more distinctive gradation. They are formed with T_b, T_c, T_d and T_e Bouma intervals. They represent the more distal lithofacies and form a constituent part of less energetic environments (lobe fringes, levees, inter-channel sheets, basin plains), in minor amount they can occur also in other deep-water environments.

Lithofacies Fcl – dark-grey laminated metapelites

This lithofacies is formed by positive graded laminae of medium-grained metasiltstone to very fine-grained metapsammite having a character of ripple or regular laminae with cross- or horizontal internal lamination (T_0 interval, Stow & Shanmugam, 1980), or it is formed by regular laterally continuous or indistinct, very thin laminae of metasiltstone (T_3, T_4 interval, Stow & Shanmugam, 1980) alternating with lithofacies Fcm. Rarely the metasiltstone laminae are irregular and have a charac-

Fig. 4. Some lithofacies from documented logs. A) Lithofacies Pt, T_{bcde} turbidite thick 2.3 cm, log zd-13 (bed No. 14), Zlatá dolina valley. B) Lithofacies Pt, T_{bde} turbidite, log zd-16 (bed No. 3), Zlatá dolina valley (scale: coin with 2 cm diameter). C) Lithofacies Fcl, with preserved oblique ripple and horizontal lamination of metasiltstones, log td-3, beds Nos. 56-60, Tinesova dolina valley. D) Dark-grey laminated phyllites in lower part of outcrop - lithofacies Fcl, oblique laminated fine-grained metapsammites in overlier of phyllites - lithofacies Ps, log hd-2 (9.5-10.5 m), Hutná dolina valley. E) Disharmonically folded lamina and very thin beds of light-grey very fine-grained metapsammites and metasiltstones alternating with dark-grey metapelites, log gd-29a (0.5-0.8 m), Gelnická dolina valley. F) The base of bed of acid volcanoclastics – debris flows (lithofacies Vm), with preferred orientation of longer axes of clasts into the direction E-W, locality gd-20, Gelnická dolina valley. G) Completely preserved succession of Bouma intervals T_a – T_e, lithofacies Ph, log td-3 (bed No. 38), Tinesova dolina valley (scale: 30 cm hammer). H) Stratified microconglomerate (lithofacies Cs), in the scale of 1 bed the bodies of medium to coarse-grained psammites (CS) and pebbly psammite (G) are vertically alternating being deposited parallely to bed planes, log td-1 (Fig. 5, upper part of the bed No. 66), Tinesova dolina valley. I) Laminated thin to medium-thick fine-grained metapsammites (lithofacies Pt) with subsidiary intercalations of dark-grey laminated phyllites (lithofacies Fcl), lower part of the log zd-16, Zlatá dolina valley (scale: 30 cm hammer).

Slovak Geol. Mag., 11, 2 – 3 (2005), 165 – 183

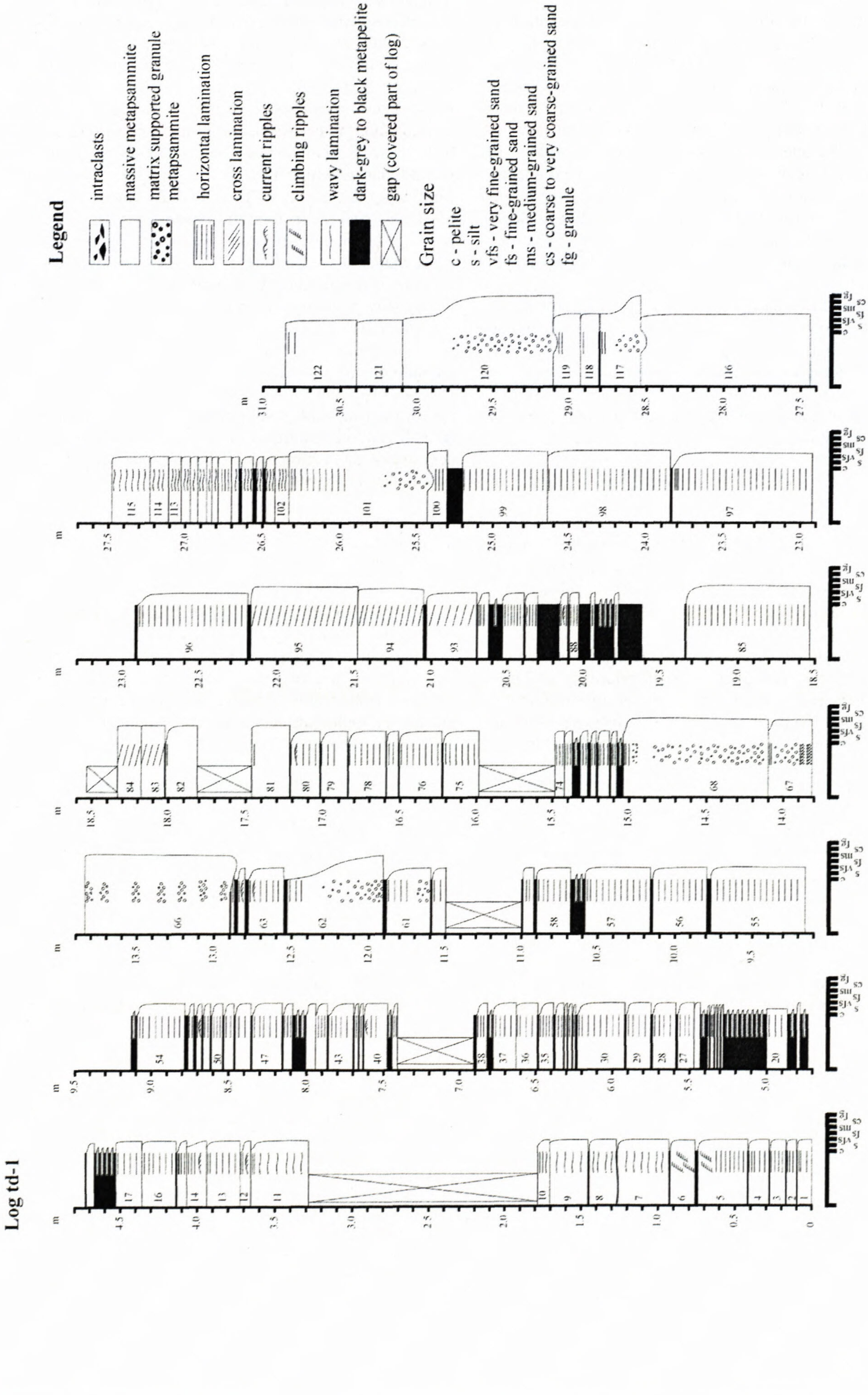


Fig. 5 Log td-1, Tinesova dolina valley. Explanations to logs.

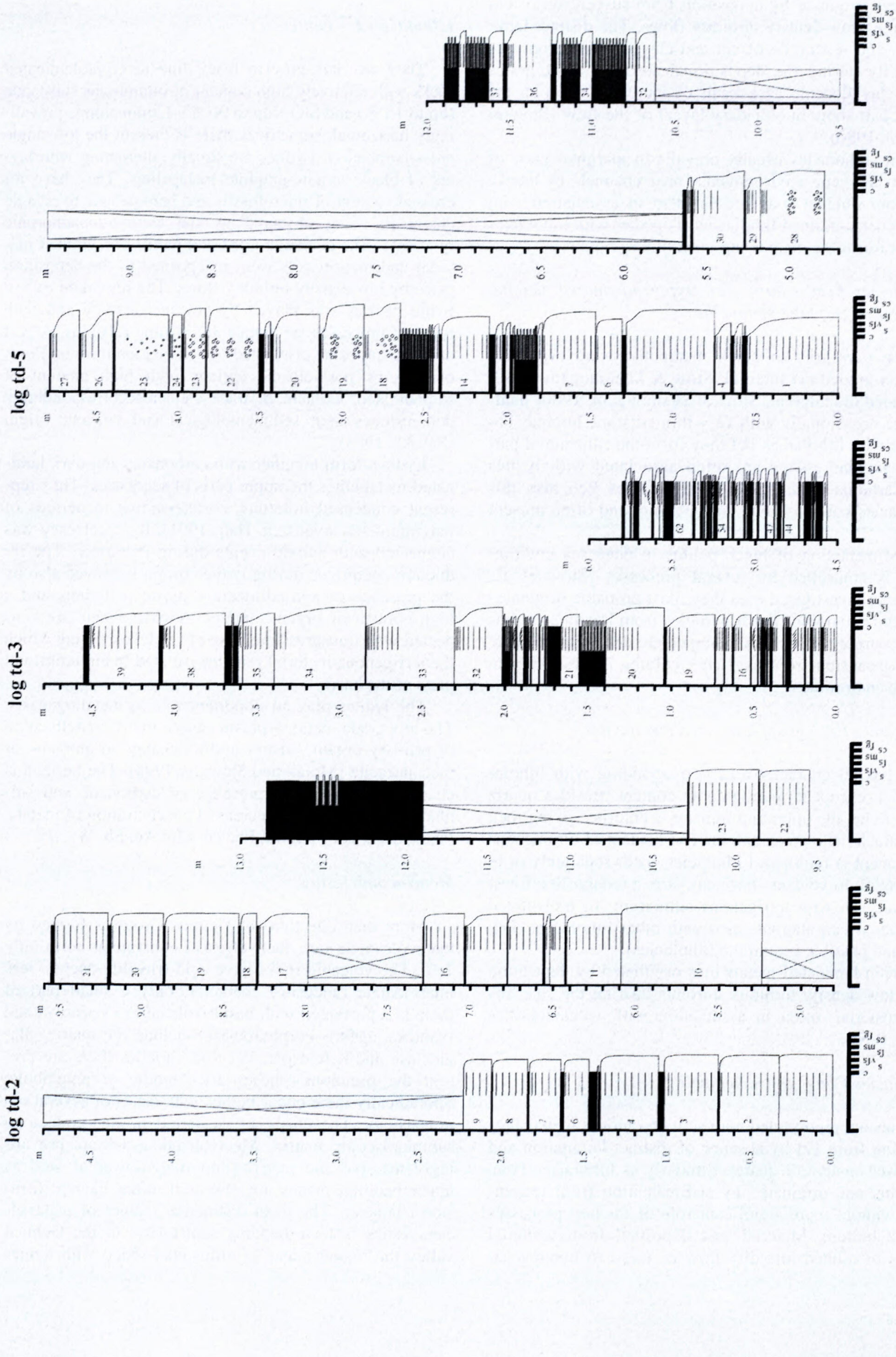


Fig. 6 Logs td-2, td-3 and td-5, Tinesova dolina valley. Explanations to logs are in Fig. 5.

ter of thin lenses. They contain abundant bitumen fraction and synsedimentary pyrite, which proves the reduction, anoxic conditions during deposition and diagenesis.

They originate by deposition from suspension of decelerating low-density turbidity flows. The distinct lamination and separation of silt and clay laminae originates primarily during the depositional sorting of silt grains from clay floccule as a result of increased shear in the lower part (bottom boundary layer) of the flow (Stow & Bowen, 1980).

This lithofacies usually prevails in marginal parts of higher energetic environments (near channels or lobes), in minor amount it is present also in association with more coarse-grained lithofacies. Together with lithofacies Fcm it forms the main component of basin plain.

Lithofacies Fcm – dark-grey cryptic laminated metapelites, black graphitic metapelites

The dark-grey to black metapelite were originally the non-graded (T_7 interval, Stow & Shanmugam, 1980) or graded (T_6 interval, Stow & Shanmugam, 1980) mudstones, occasionally with very thin siltstone lamina. Together with lithofacies Fcl they form the substantial part of basin plain. They are often associated with lydites and carbonates. Similarly as lithofacies Fcl, also this lithofacies contains abundant graphite and often present pyrite.

Sedimentation of black pelites in deep sea environment is controlled by several processes (Stow et al., 2001). In investigated area they most probable originated by sedimentation of finest particles from low-density turbidity current or by slow hemipelagic deposition of passive suspension from overlying column of sea water in anoxic environment.

Lithofacies Fzl – green laminated metapelites

It has all characteristics corresponding with lithofacies Fcl, except its petrographic content. Besides quartz and sericite, the important mineral is chlorite, giving rock its characteristic green colour. The content of bitumenous component is minimal. Lithofacies occur separately or in connection to volcanic horizons. It is a redeposited finest volcanic ash with terrigenous admixture. In transitional horizons it can alternate also with other lithofacies (Fcl, Fcm and possible psammitic lithofacies).

Green laminated metapelites originated by deposition from low density turbidity currents bearing the fine tuffitic material, often in association with volcaniclastics debris flows.

Lithofacies Fzm – green metapelites

They are represented with sericite-chlorite metapelites differing from Fzl by absence of distinct lamination and by lower content of quartz. Similarly as lithofacies Fcm, also this one originated by sedimentation from suspension, without more significant role of traction processes on the bottom. Material was deposited from scattered clouds of diluted turbidity flow or meso to hypopycnal flows transporting volcanic ash from the continental margin. Lithofacies is in tight association with lithofacies Fzl and Vm.

Lithofacies L – lydites

They are dark-grey to black fine to cryptolaminated rocks with relatively high content of bituminous substance (up to 15 %) and SiO_2 (up to 90 %). Lamination is prevailingly horizontal, sometimes there is present the low-angle cross-lamination. Lydites are usually alternating with layers of black sericite-graphite metapelites. They have increased content of microfossils and hemipelagic to pelagic character, being obscured by the tectono-metamorphic processes. The coarse-grained and partly fine-grained material and microfossils were redeposited to the deposition place by low density turbidity flows. The important role in lydite genesis was played by volcanic activity and both types of processes are frequently in time relations. A part of quartz probable originated by coagulation from outflows of syn- or postvolcanic springs with high amount of sulphur acid. Content of trace elements correspondingly demonstrates their sedimentological and volcanic origin (Ilavský, 1985).

Lydites form together with carbonates and dark laminated metapelites the upper parts of sequences. They represent condensed horizons, corresponding to periods of maximum sea-level (e.g. Haq, 1991). Its occurrence was connected with anoxic events during Paleozoic. The reduction conditions during lydites origin is proved also by the presence of synsedimentary pyrite in lydites and a high content of organic matter. Anoxic events are connected with transgressions, rise of sea level, during which the terrigenous material remains isolated in circumlittoral parts of the basin.

The lydites play an important role in metallogenesis. The low grade metamorphism caused the recrystallization of primary organic matter and its change to antracite or metaantracite (Molák and Slavkay, 1994). The horizon is characteristic with the presence of carbonatic and sulphidic deposits having increased concentration of metals: Fe, Mn, Ti, V, P, Ni, Co, Pb, Zn, Mo, Ag, Sb, W.

Metavolcaniclastics

More than one third of Gelnica Group is formed by metavolcaniclastics, their effusive equivalents form only 1 %. The volcanic rocks have acid (rhyolite-dacite), less intermediate (andesite) character, only a small part of them is represented with basalt volcanites (Vozárová and Ivanička, 1996). Porphyroclasts include the quartz, plagioclase and K-feldspar, in basic varieties there are present the pseudomorphoses after biotite or amphibole. Sporadically there occur bodies with clasts of several cm dimensions. The clasts are scattered in fine-grained to submicroscopic matrix. Metavolcaniclastics are prevailingly massive and matrix-supported. Lower as well as upper bedding planes are obscured, often having diffusion character. The most distinctive feature of metavolcaniclastics is their bedding schistosity. In the Gelnica valley the bigger clasts of ellipsoidal shape with longer

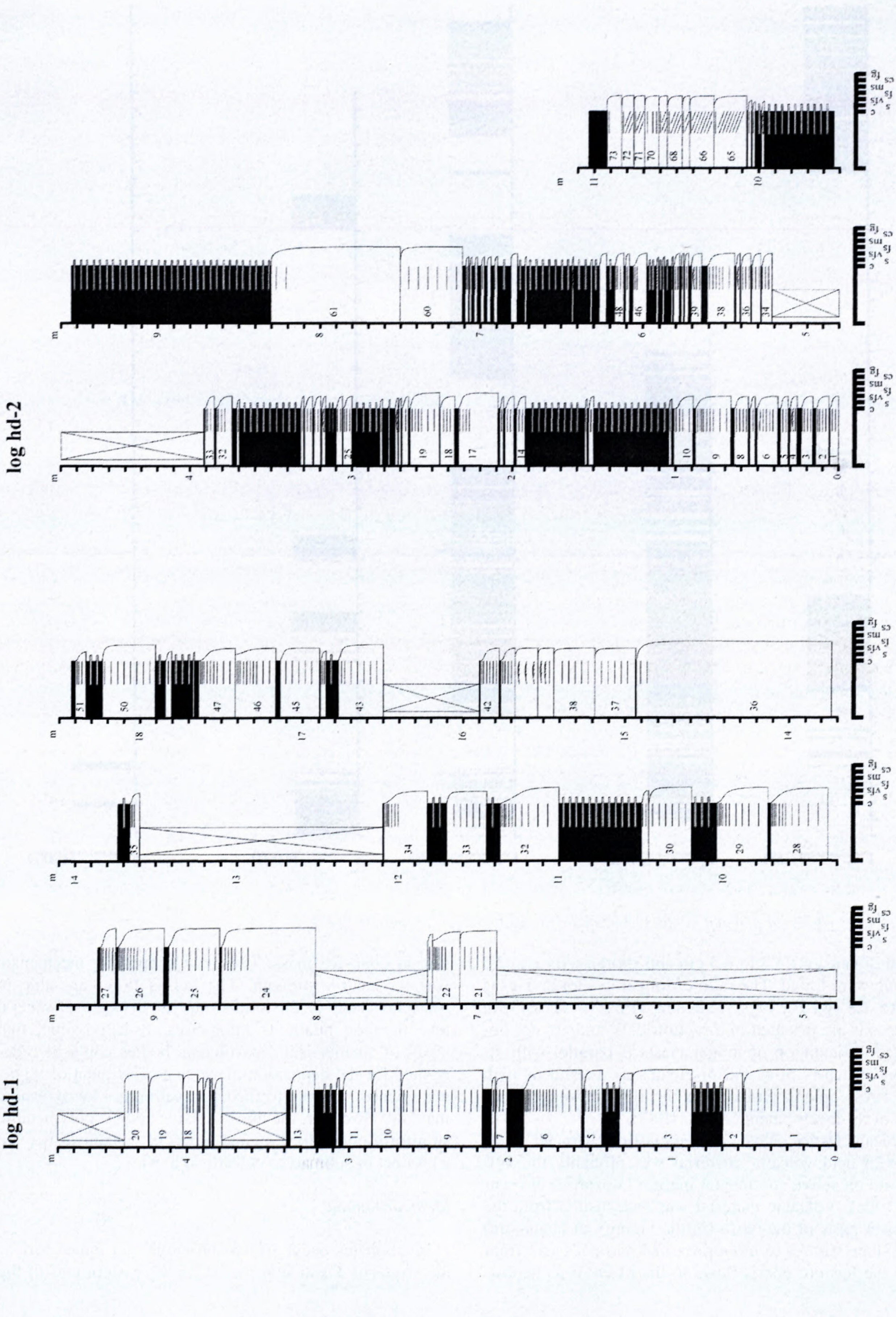


Fig. 7 Logs hd-1 and hd-2, Hutná dolina valley. Explanations to logs are in Fig. 5.

Slovak Geol. Mag., 11, 2 – 3 (2005), 165 – 183

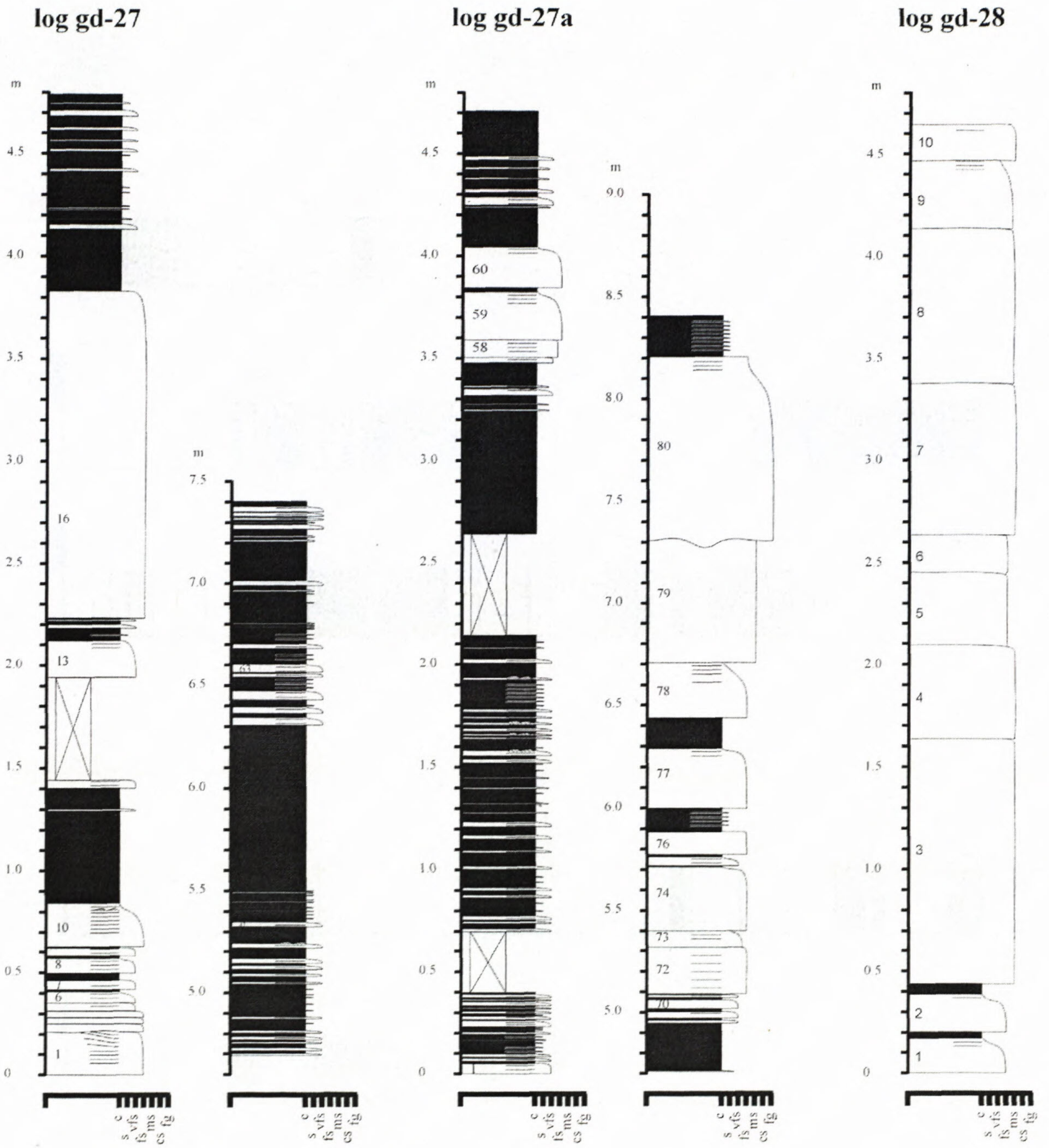


Fig. 8 Logs gd-27, gd-27a and gd-28, Gelnická dolina. Explanations to logs are in Fig. 5.

axis of dimensions 3.8 to 8.5 cm and shorter axis 1 to 2.5 cm long were found. The ratio of longer to shorter axes is 2.52 to 3.8 (gd-20, Figs. 1, 3 and 4F). The clasts with longer axis are oriented in direction E-W and are not imbricated. Orientation of longer clasts is parallel with direction of debris flow and originates as a result of high shear stress among particles in the flow during the last phase of its development (Allen, 1982).

Volcaniclastics have an epiclastic character. The source of acid volcanic material was probably the volcanic arc on active continental margin (Vozárová & Ivanička, 1996). Volcanic material was redeposited from the shallower parts of the basin (in the vicinity of island arc) to the slope base or to more proximal parts of basin-floor fan in the form of debris flows to the place of its deposition as cohesive mass. The main supporting mechanism was the matrix strength. The debris flows are able to transport clasts or olistoliths into the distance of several tens or even hundreds kilometres. It is possible, that a part of smaller isolated volcanic bodies could be redeposited for the deposition place as a constituent of vigorous debris flows formed prevailingly by volcanic material. However, the thick effusive bodies, polymetallic stratiform mineralization and a part of volcaniclastics are a product of submarine volcanism in situ.

Metacarbonates

Carbonates occur in two horizons - in upper part of the sequence 1 and sequence 2. In the eastern part of the

Gelnica Group directly in studied profiles this lithofacies superficially outcrops in the area of village Baňa Lucia, where the dark-grey fine-grained crystalline limestone was found together with lydites and black metapelites (Kováčik, 2004). They together form a condensed interval of the sequence 2 belonging to Lower Devonian Drnava Formation. Into this interval also carbonates from Smolník stratiform polymetallic deposit belong, being constrained on horizon of lava flow of paleodolerites to paleoandesites, chloritic metapelites and polymetallic ore with intercalations of graphitic and sericitic metapelites (Ilavský & Mrozek, 1960).

In eastern part of the Gelnica Group the carbonates are known from the surrounding of the Holec elevation point north of Smolnícka Huta, locally between Holec and Jedľovec elevation points and at Zlatá Idka village (Kobulský et al., 2001). They were penetrated by drills MPV-8 (Kobulský et al., 1988) and SG-2 (Grecula et al., 1977). This horizon is older (Upper Silurian, Bajaník et al. 1984) and allocated is in upper part of sequence 1.

The carbonates by their chemical composition correspond to limestone, dolomite, magnesite, ankerite and siderite. Their former composition (limestone, dolomite), sedimentary textures and structures are distinctly obscured by diagenetic-metamorphic and hydrothermal-metasomatic processes. Most often they are massive, crystalline or horizontally laminated, sporadically with cross-lamination. Carbonates in the eastern part of the Gelnica Group are alodapic (Vozárová & Ivanička, 1993). The sporadically preserved gradation and traction structures (Bouma intervals) indicate the resedimentation probable by turbidity currents.

In western part of the Gelnica Group the carbonatic bodies are more abundat. They are known from numerous places on the surface as well as from the drills in the surrounding of villages Vlachovo, Gočovo, Nižná Slaná, Dlhá dolina valley, Henclová village and another places. According to some authors they are of shallow-water origin (Grecula, 1982; Varga, 1970). It is proved neither sedimentological nor paleontological, though in distinctly laminated ankerite from Nižná Slaná Mišík found (in Turan & Turanová, 1993) the ostracode and stromatolite fragments, which can indicate the shallow water environment. These fossils were not more precisely systematically classified and there is also possible, that the fragments were resedimented.

Depositional environments

In recent studies of deep-water sedimentary systems the architectural element analysis is preferred (e.g. Clark & Pickering, 1996). It better indicates the spatial relations and variations in composition as well as geometry in individual depositional environments. The concept of "elements" in turbidite systems was established by Mutti & Normark (1987), correspondingly for recent as well as ancient settings.

The outcrop dimensions as well as complicated geological setting in our case do not allow the geometrical analysis of individual architectural elements and the direct observation of relations among them. This is the reason why we have determined individual elements by facies associations with characteristic vertical trend of change of bed thickness and granularity. We have applied the traditional vertical analysis on profiles. Asymmetric cycles in deep-water environments were supposed as one of key criteria for identification of individual subenvironments in submarine fan systems (e.g. Ricci-Lucchi, 1975), but statistic importance of these cycles was later disputed (Chen & Hiscott, 1999). Despite, we use in this study also the vertical variations of beds thickness visualized in rhythmograms (Fig. 10), because some vertical bed successions have evident asymmetric trend (e.g. rhythmogram of the log zd-13, Fig. 10) and the bed thickness is one of few values measured directly in the field. As a "bed" there is supposed the lower, coarse-grained (sandstone, sandstone-siltstone) part of deposit, originating from deposition of one density flow (e.g Lowe intervals S_1 to S_3, Bouma intervals T_a to T_d, besides the upper mudstone interval T_e).

Locality Tinesova dolina valley

Studied outcroups (logs td-1, td-2, td-3, td-5; Figs. 5 and 6) are located in termination of Tinesova dolina valley approximately 3 km to SE of the village Mníšek nad Hnilcom (Fig. 1). They are formed by prevailingly fine- to medium-grained metapsammites with intercalations of dark-grey laminated metapelites and pebbly metapsammites or coarse-grained metapsammites. They belong to lower part of the sequence 2 (Figs. 2 and 3). Metapsammites are relatively steeply dipping with inclination of bedding, resp. bedding schistosity to north in normal position. They are developed between two partial horizons of acid pyroclastics forming together the lower part of the sequence 2 in overlier of the sequence 1, which is demonstrated also by drill SG-2 (Fig. 3).

In this sedimentary succession the sandy horizons with prevalence of lithofacies Ph, Pm, Ps, Cg and Cs are alternating with horizons formed prevailingly by lithofacies Pt and Fcl (Figs. 5 and 6) being richer on pelitic (pre-metamorphic mud) component. Lithofacies Cg and Cs (Fig. 4H) represent together with volcaniclastics the coarsest-grained sediments of the Gelnica Group. They form elongated bodies of uncertain, probable lenslike shape with high length ratio (usually some tens m, maximum 200-300 m) in comparison with thickness (5-10 m). They are deposited correspondingly with surrounding finer-grained lithofacies, having frequent erosive contacts. They form probable the thalwegs of depositional distributary channels (Fig. 5 - log td-1: 11.6–15 m, 25.5 –31 m; Fig. 6 - log td-5: 2.6–5.2 m), in which the deposition from denser, concentrated gravity currents is prevailing (lithofacies Cg, Cs, Pm, Ph). The channel density flows are often stratified (for example the lithofacies Cs originated by their deposition), they are usually thick and towards both sides of the channel form wide overbank bodies. Bodies of coarse-grained facies associations are vertically stacked in sedimentary succession and probable originated by aggradation of sinuous submarine channels (Peakall et al., 2000). Thinning and fining of beds of channel fill indicate the gradual diminishing of currents,

Slovak Geol. Mag., 11, 2 – 3 (2005), 165 – 183

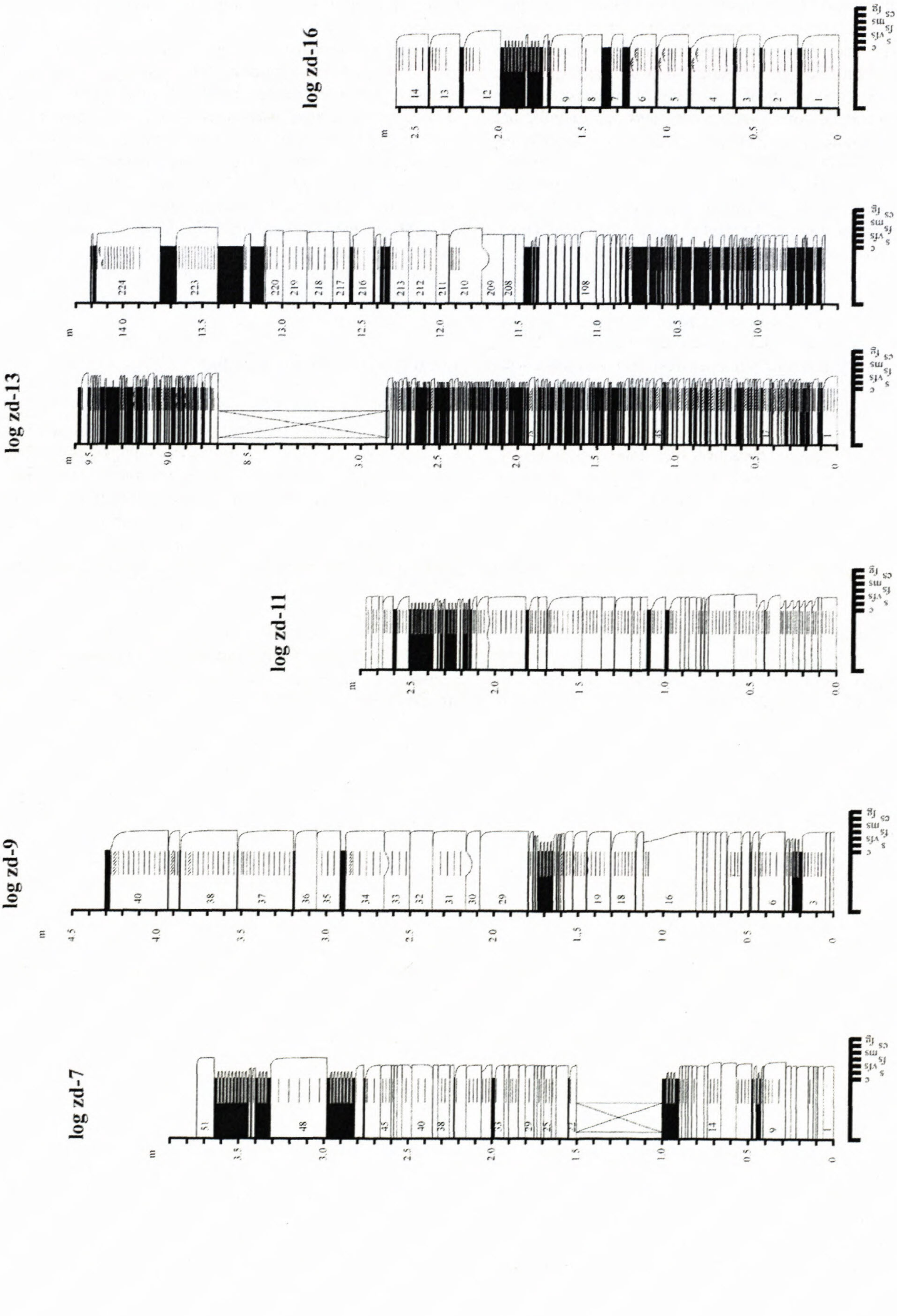


Fig. 9 Logs zd-7, zd-9, zd-11, zd-13 and zd-16, Zlatá dolina valley. Explanations to logs are in Fig. 5.

which backward infilled the channels. This trend is commonly supposed as typical for channel fills (Mutti & Ricci-Lucchi, 1972; Stow & Piper, 1984 and others). In some cases, when the lower part of channels is infilled with fine-grained thin beds from tails of flows and channels are consequently backward infilled with coarser beds, the channel infill has the upward thickening trend. This trend is usually observed in fine-grained sandstone deep-water systems, mainly in lower part of the slope, where the steeper gradient supports the bypass of the sediment into the basin (Gardner & Borer, 2000; M. Grecula et al., 2003). In the area of Tinesova dolina valley the fill & spill phases of the channels prevail as well as the high sand/mud ratio, which is typical rather for basin than for slope parts of deep-water depositional system. The phase of infilling of the channels originates due to base-level rise and lowering of the bottom gradient (Clark & Pickering, 1996).

The channel elements are in the space alternating with finer-grained and thinner levee facies (Fig. 6, log td-3). The shallow distributary channels caused, that density flows were not fully confined by the channel margins and so the coarse-grained lithofacies are present in levees and towards the inter-channel space they become finer-grained. The beds are laterally continual and have character of turbidites with well preserved Bouma intervals and positive grading. In the proximal parts of levees the cross- and wavy-laminated fine- to medium-grained metapsammites of the lithofacies Ps are often. Towards the distal parts the lithofacies Pt, Fcl and Fcm are gradually prevailing.

Distributary channels, levees and inter-channel sheets are a constituent of the middle part of submarine fan.

Localities Hutná dolina and Gelnická dolina valleys

Studied outcrops are located in the termination of Hutná dolina valley, approximately 1 km to east of the elevation point Hutná hoľa (1093.7 a.s.l.) and in Gelnická dolina valley south of Prakovce town (Fig. 1). They are formed prevailingly by fine to medium-grained metapsammites with bodies of dark-grey laminated metapelites. They are located in horizon belonging to middle part of the sequence 2 (Figs. 2 and 3). Metapsammites are, similarly as in the Tinesova dolina valley, in normal position and relatively steeply dipping to north. From the underlier they are gradually developed from basal volcaniclastics of the sequence 2 and towards overlier they are gradually exchanged by lithofacies of dark-grey laminated and crypto-laminated metapelites with intercalations of lydites. Contrary to lithofacies from the Tinesova dolina valley, their position in the bed succession is relatively higher (they are younger) and their lithofacies content is less variegated.

The bed succession (Fig. 7: logs hd-1 and hd-2; Fig. 8: logs gd-27, gd-27a and gd-28) has relatively monothonous lithofacies content with prevalence of metapsammites above metapelites. The metapsammites abundance ranges from 50 % up nearly to 100 % (Tab. 1). The conglomeratic lithofacies (Cs, Cg) are very rare (Figs. 2 and 3, upper part of the profile through Tinesova dolina and Hutná dolina valleys). The beds thickness is prevailingly several cm to 40 cm, maximum thickeness is 160 cm. The lithofacies Pt, Ph and Fcl are dominating, the lithofacies Pm and Ps are less often. Beds are parallel and have uniform thickness in lateral direction. The lower bed planes are sharp and flat, rarely with shallow erosion forms, while the upper bed planes are graded. Lithofacies have character prevailingly of T_{b-e} or T_{bde} turbidites, in thin-bedded turbidites the T_c interval is also present. Massive T_a interval is developed in lower parts of medium to thick-bedded lithofacies Ph and Pm. The upper cross lamination of metapsammites is in several cases dipping to NW (Fig. 4D and Fig. 7: log hd-2, beds 65 to 72), which indicates the direction of paleocurrent from SE to NW, corresponding with older data (Snopko, 1967; Snopko & Ivanička, 1979). Despite, cross-lamination and current ripples are commonly understood as a less reliable indicator of paleo-currents, therefore they must be controlled by measurements of sole marks on lower bed planes of turbidites. In some cases the difference towards the current direction determined by sole marks can be up to 90° (Kneller et al., 1991). The structures of lower bed planes are in metasediments of the Gelnica Group very poorly observable and their recognition can be subjective (some closures of mostly non-cylindrical folds of lower bed planes of metapsammites resemble the flute marks of parabolic shape) as a consequence of imperfect exposition of basal bed planes and tectonometamorphic overprint of former sedimentary facies, therefore the objective paleocurrent analysis in the studied region is impossible.

The vertical successions in Hutná dolina and Gelnická dolina valleys are characteristic with cyclic setting and changes of sand/mud ratios as well as the changes of beds thickness. Only small cycles (up to 5 m thick) are present, having simple or composite character with symmetric or asymmetric trends of the thickness changes of individual beds (Fig. 10: rhythmgram of the logs hd-2 and gd-27a). Often there are the thickening-upward compensation cycles (Mutti & Sonnino, 1981) originating as a consequence of progressive smoothing of subtle depositional relief produced during the upbuilding of individual lobe (Mutti & Normark, 1987). Their upward coarsening trend is usually connected with progradation of lobe and upward fining and thinning of beds indicate its regression. However, over the short time scales, most fans are built by aggradation, not progradation, so that lithofacies shift are controled mostly by channel avulsion and switching (Chen & Hiscott, 1999). In this case the vertical arrangement has no preferred trend reflecting irregular variations in the currents volume, particle concentrations and supplying paths of density flows. The marginal parts of lobes have larger abundance of fine-grained lithofacies Pt, Fcl and Fm and surround the proximal parts of lobes.

In the area of Gelnická dolina valley the several metres thick beds of massive amalgamated fine- to medium-grained metapsammites are sporadically present (Fig. 8: log gd-28, the lithofacies Pm and Ph predominate) forming the proximal parts of lobes, in which the sand/mud ratio is very high (> 90 %, Tab. 1). Erosion structures are in these facies more often. These lithofacies are from the

Slovak Geol. Mag., 11, 2 – 3 (2005), 165 – 183

Table 1 Principal statistic parameters for logs in Hutná dolina and Gelnická dolina valleys.

LOG	No. of beds	Ratio of psammitic component (%)	Ratio of pelitic component (%)	Minimum bed thickness (cm)	Maximum bed thickness (cm)
hd-1	57	83.3	16.7	1	119.5
hd-2	73	52.4	47.6	1	80
gd-27	79	51.9	48.1	0.2	160
gd-27a	79	56.4	43.6	0.3	90
gd-28	10	98.3	1.7	17	120

side of underlier and overlier bordered by lithofacies of lobe fringes. The distinguishing of particular beds became complicated by amalgamation. The beds amalgamation originates due to erosion and soft-sediment deformation or as a result of internal friction in concentrated gravity flows.

In the Hutná dolina and Gelnická dolina valleys the lithofacies associations of lobe fringes are prevailing over the proximal part of lobes, which indicates the competence of psammitic horizon to outer part of submarine fan. Though the pebbly psammitic bodies in upper parts of horizon indicate the sporadic progradation of higher energetic environments of distributary channels of middle fan among the lithofacies of the outer fan.

The vertical arrangement of lobes in the Hutná dolina and Gelnická dolina valleys has a character of type 1 (sensu Pickering, 1981). This lobe type originates directly after middle part of submarine fan.

Locality Zlatá dolina valley

Studied outcrops (logs zd-7, zd-9, zd-11, zd-13, zd-16, Fig. 7) are located on NW-SE mountain ridge approximately 1 km to south-east of the altitude point Zbojnícka skala (1147 m n.m., Fig. 1). They are formed prevailingly by fine- to medium-grained metapsammites with intercalations of dark-grey laminated metapelites. They belong to medium part of the sequence 2 (Fig. 3). Metapsammites are relatively shallowly inclined to SW in normal position. The underlier of metapsammites is probable formed by metavolcaniclastics forming the lowermost part of the sequence 2. Towards the overlier the transition of metapsammites to dark-grey laminated metapelites with lydite intercalations in upper part of the horizon occurs in surrounding of the Jedľovec altitude point (Grecula, 1970). Lydites are connected with variegated volcanic horizon, where the stratiform pyrite deposit at Smolník town is developed (e.g. Ilavský & Mrozek, 1960).

Lithological and sedimentological character of bedding successions in the area of Zlatá dolina valley strongly resembles that in the Hutná dolina and Gelnická dolina valleys. The beds are typical tabular (when not accounting the deformation of beds by tectonic processes) with few erosion structures and well developed Bouma intervals (prevailingly T_b to T_e intervals) in metapsammites. Beds are thick up to 50 cm and abundance of psammitic component in the range of whole succession is 60 to 90 %. The lithophacies Pt (Fig. 4A, B, I) and Fcl are prevailing, less common are the lithofacies Fcm and Ph. Similarly like in the Hutná dolina and Gelnická dolina valleys, also for facies successions in Zlatá dolina valley the cyclicity is characteristic (Fig. 10). The several metres thick asymmetric cycles are present, often with thickening-upward trend (Fig. 10: rhythmograms of logs zd-9 and zd-13). Symmetric or upward thinning as well as irregular cycles (Fig. 10: rhythmgram of log zd-7) are less often present. Therefore the lithofacies development in the area of Zlatá dolina valley belongs to outher part of the fan similarly as it is in northern development of studied horizon.

Conclusion

Studied psammitic horizon belongs to middle part of thinning-upward sequence 2, thick approximately 1500 m, forming the constituent part of sedimentary content in the eastern part of the Gelnica Group. The base of sequence 2 is formed by metavolcaniclastics sharply deposited on fine-grained lithofacies (Pt, Fcl, Fcm, Fzl, Fzm, lydites and carbonates) of the basin plain of sequence 1. The volcaniclastics were redeposited prevailingly by debris flows from the area of volcanic arc on active continental margin into the deeper part of the basin (Vozárová, 1993), or by influence of increased volcanic and tectonic activivy the submarine volcanoes supplied the pyroclastic material directly to sedimentation area. Psammitic horizon forms the middle part of the sequence and gradually passes into the finer facies of basin plain, being formed by the same lithofacies as in the sequence 1. The lydites, black metapelites (lithofacies Fcl and Fcm) and sporadic carbonate bodies (Smolník) of the sequence 2 form a condensed horizon, representing the second period when the sea level in the area of Gelnica Group reached its maximum level. In the basin there prevailed the hemipelagic and pelagic sedimentation with sporadical inputs of fine-grained clastics by low density turbidity currents. The coarser-grained clastic material was that time prevailingly deposited in shallow-marine environments. The volcanic phase of polymodal volcanism and related origin of stratiform sulphidic deposits (e.g. the Smolník deposit) is important in this period. In its overlier the horizon of green, prevailingly laminated metapelites is developed and it terminates the sequence 2.

The psammitic horizon is formed by 11 lithofacies of deep-water character. Clastics were redeposited by density flows from shallower parts of the sea on the slope to bottom of the basin and deposited in the environment of submarine fan during subsidence, low state as well as first phases of rise of sea level. More coarse-grained lithofacies (Cs, Cg, Pm) were transported by concentrated density flows, where the grain-to-grain interactions had

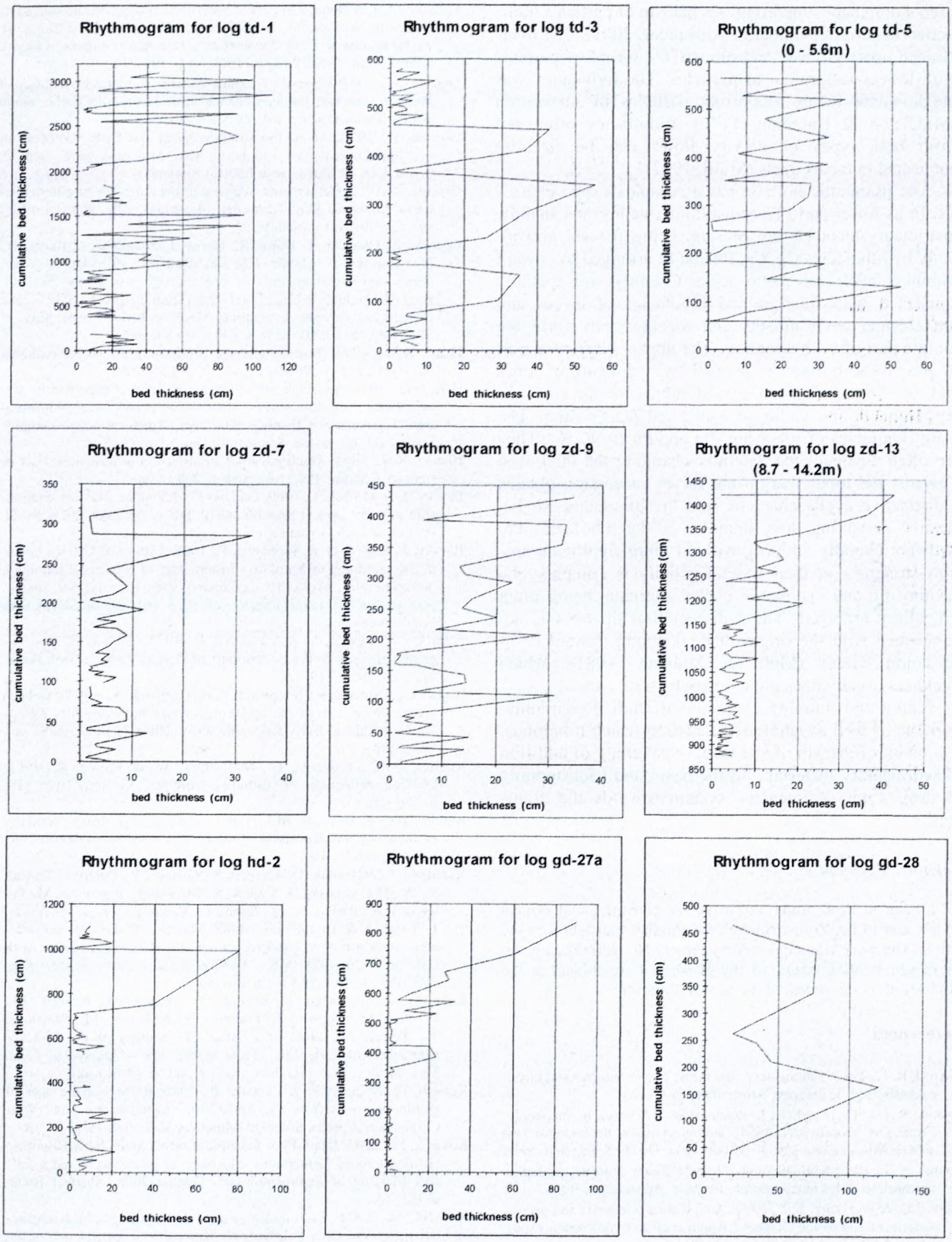


Fig. 10 Rhythmograms for logs td-1, td-3 and td-5 in Tinesova dolina valley, for logs zd-7, zd-9 and zd-13 in Zlatá dolina valley, for logs hd-2 in Hutná dolina valley and for logs gd-27a and gd-28 in Gelnická dolina valley.

been a dominant supporting mechanism of particles transported in current (Mulder & Alexander, 2001). The finer-grained material was transported by turbidity currents with low concentration of particles. The turbulency was the dominant factor supporting particles in suspension (Middleton & Hampton, 1976). Lithofacies originated from both types of gravity flows can be laterally connected in facies tracts (Mutti, 1992).

The psammitic horizon has a complex cyclic character. In its lower part (Tinesova dolina valley) the shallow distributary channels are present, being formed prevailingly by lithofacies Cg, Cs, Ph and Pt arranged to upward -thinning cycles of metre scale. Channels are spatially connected with finer-grained lithofacies of levees and interchannel environments and together they form the middle part of submarine fan. The upper, substantial part of psammitic horizon is formed by sediments of lobes and lobe fringes of outer part of submarine fan (the valleys Hutná dolina, Gelnická dolina and Zlatá dolina). The main lithofacies of lobes are Pm and Ph (> 90 %). They are often amalgamated, laterally changing the thickness. Towards the lobes margin the facies succession obtains a distinctive cyclic character and the lithofacies Pt, Fcl became prevailing, less abundant is the lithofacies Ph. Beds are laterally uniform, without more significant erosion structures at their base. Cyclicity is complex, the asymmetric and symmetric cycles alternate, being often irregullary arranged. The sedimentation in lobes is accompanied with the origin of thickenning upward compensation cycles (Mutti & Sonnino, 1981), which thickness usually does not overreach 10 m.

Fining and thinning character of studied psammitic horizon, as well as whole sequence, to which it belongs, is a result of growth of sea level, weakening of addition of sedimentary material into the basin and backstepping of deep-water sedimentary system towards the continent.

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