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Quantitative approach in environmental interpretations of deep-marine sediments (Dukla Unit, Western Carpathian Flysch Zone)

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Abstract: In structurally complicated terranes with outcrops limited in number and extent, additional methods for interpreting depositional environments are required. Statistical analysis of bed thicknesses, in addition to conventional sedimentological analysis, is a quantitative way to refine environmental interpretations, interpretations that can be useful in predicting reservoir architecture. We analysed Paleogene deep-water sediments belonging to the Cisna, Sub-Menilite, and Menilite Formations of the Dukla Unit, Outer Carpathian Flysch Zone and, using two independent quantitative methods, tried to define their depositional environments. As a first approach we used Carlson & Grotzinger's model (2001), which suggests power law distribution of turbidite bed thicknesses. The second one is the lognormal mixture model of Talling (2001). Based on a quantitative approach, we suggest deposition of the lowermost Cisna Formation in the channel-levee environment. The overlying sediments of the Sub-Menilite Formation were deposited in a more distal, probably outer lobe environment. The uppermost Menilite Formation is interpreted as deposits from an outer lobe/basin plain environment.

Key words: Western Carpathian Flysch Zone, Dukla Unit, statistics, depositional environment, turbidites.

Introduction

Knowledge of reservoir architecture is one of the basic requirements for hydrocarbon development and production. The common methodology used during the initial phase of such prospection is lithofacies analysis of sediments exposed on the surface followed by interpretation and modelling of depositional environments. However, this attempt is often hampered by poor rock exposures and/or dense vegetation resulting in a discontinuous record of sedimentary successions.

One of the methods used as an aid for interpretation of depositional deep-water environments, is statistical evaluation of bed thickness. Because the thickness of a turbidite bed is determined by the shape of the bed and the distance from the source, initial sediment volume, grain size and flow type (Talling 2001), the statistical evaluation may provide information on processes controlling turbidite feeding, depositional processes, distribution and geometry (e.g. Rothman et al. 1995; Malinverno 1997; Carlson & Grotzinger 2001). Moreover, the data may serve as an specifying factor for interpretation when "classical" facies analysis cannot be fully developed due to the scarcity of exposures.

The problem of frequency distribution of turbidite bed thicknesses, has been the object of study since the 1960's. Generally, four types of distribution — truncated Gaussian, exponential, lognormal and power law distributions were applied to bed thickness distributions in turbidite deposits (e.g. Ricchi Lucchi & Valmori 1980; Muto 1995; Drummond & Wilkinson 1996; Malinverno 1997; Talling 2001; Sinclair & Cowie 2003). Among these, lognormal and power law distribution seem to be most appropriate for describing the turbidite bed thickness variation (see discussion in Sylvester 2007).

The power law distribution is often interpreted as a sign of the tendency of large dissipative systems to develop a state of criticality and generate events of all sizes (Sylvester 2007). For example, it has been linked to self-organization of continental slopes to a critical state or to generation of slope failures by earthquakes (Rothman & Grotzinger 1996; Talling 2001). The distribution of the turbidite beds is often ascribed to the so-called segmented power law distribution that is characterized by several straight-segment intervals on an exceedence probability plot (Winkler & Gawenda 1999; Carlson & Grotzinger 2001; Sinclair 2003). However, Sylvester (2007) argues that the segmented power law trend is not a simple mixture of the power law population. Carlson & Grotzinger (2001) assume that power law distribution may be the primary input signal for some systems. Departure of the measured distributions from the power law model is indicative of different processes such as erosion and amalgamation, and thus it can help in determining depositional environment. The proximal part of the turbidite system represents areas with increased erosion and amalgamation and frequency distributions of turbidite beds have considerably curved course. Basinward, in more distal areas of the turbidite system, the effects of erosion and amalgamation are moderate and the turbidite beds distribution displays a linear trend with departures at the ends of the distribution. In the most distal areas of the system (outer fan, basin plain), the flows are unconfined, the effects of erosion and amalgamation are minimal, and thus the distribution is expressed by a line segment typical for the power law distribution (see Table 2 in Carlson & Grotzinger 2001).

The lognormal distribution applies to many geological processes and has been found useful in bed thickness analysis of turbidites elsewhere (e.g. Ricchi Lucchi & Valmori 1980). Talling (2001) points out that frequency distribution of turbidite thickness comprises the sum of a series of lognormal frequency distributions, associated with a basal Bouma division. If only thin- or thick-bedded turbidites are present, the frequency distribution follows a lognormal distribution. Combination of lognormal distributions produces a stepped trend on the probability plot for the entire bed population. This stepped trend is equivalent to the segmented power law trend seen in cumulative plots of bed thickness. Sylvester (2007) also prefers description of turbidite bed thickness data by a lognormal mixture model and emphasizes the importance of variability of bed thicknesses (thin and thicker beds) for interpretation of deposition setting.

The main objective of this study is to apply two different statistical approaches for interpreting depositional environments, and based on comparison with the sedimentological interpretation to discuss how these approaches may contribute to the environmental analysis.

The analysed sediments occur in extensive outcrops flanking the water-dam Starina in Eastern Slovakia, Western Carpathians (Figs. 1, 2). After brief characterization of the geological structure, we describe the sedimentary successions, based on measured sections. Finally, the obtained data are used to interpret the depositional environments.

Geological setting

The Outer Carpathians (Fig. 1) record the development of an orogenic wedge from a remnant ocean basin to a collision-related foreland basin (e.g. Oszczypko 1999). The closure of the Alpine Tethys during the Late Cretaceous and collision of the Carpathian orogenic wedge with the European passive margin at the transition from Eocene to Oligocene caused the transformation of remnant ocean basin to foreland basin with dominant turbiditic and pelagic sedimentation. The modern configuration of the Outer Carpathian Flysch Zone is a conse-

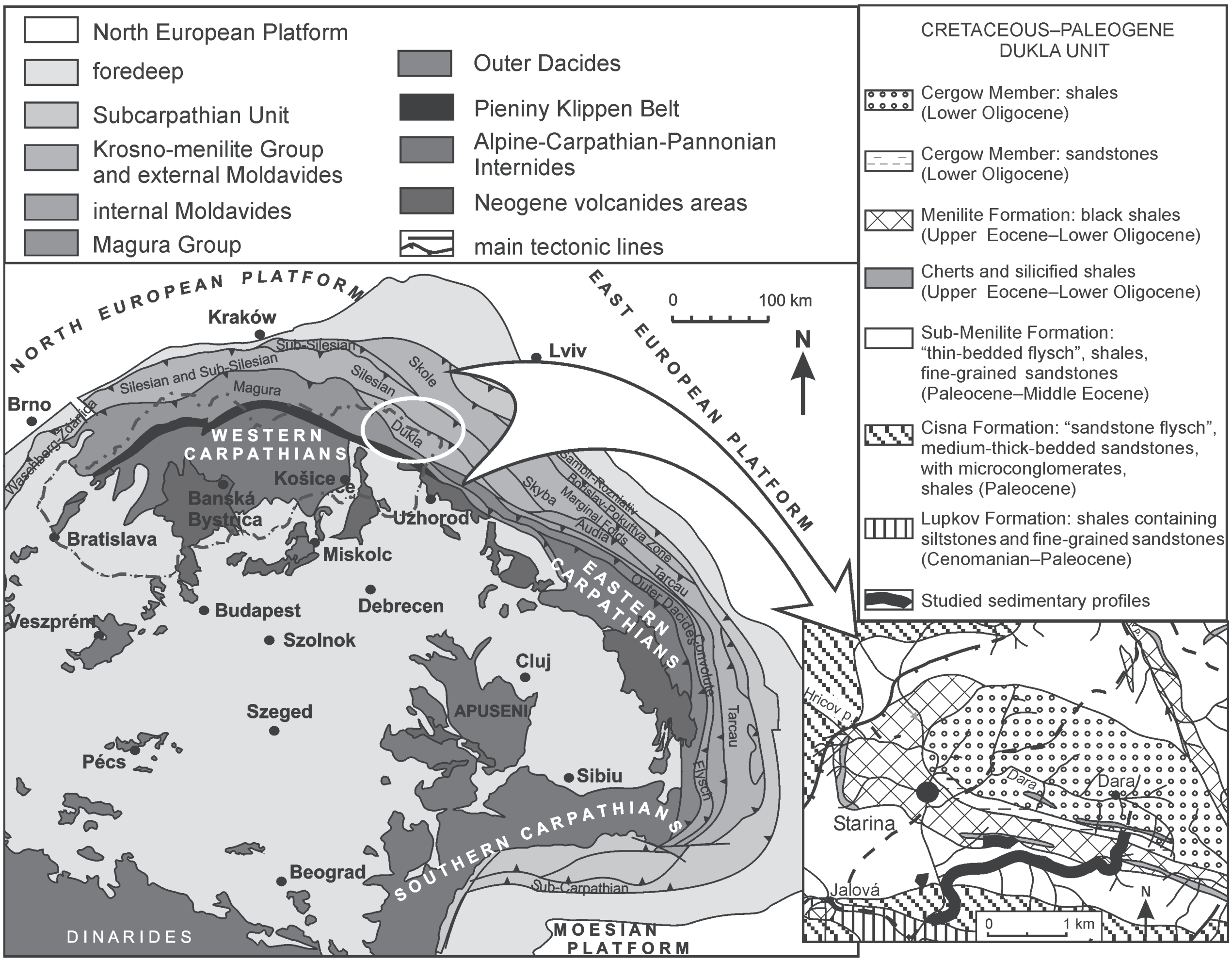

Fig. 1. Location of the study area in the Carpathian mountain system, and individual nappes of the Outer Carpathian Flysch Zone. The studied outcrops of Paleogene flysch sediments are marked by a heavy line in the close-up map (after Kováč et al. 1998 and Koráb & Ďurkovič 1978, modified).

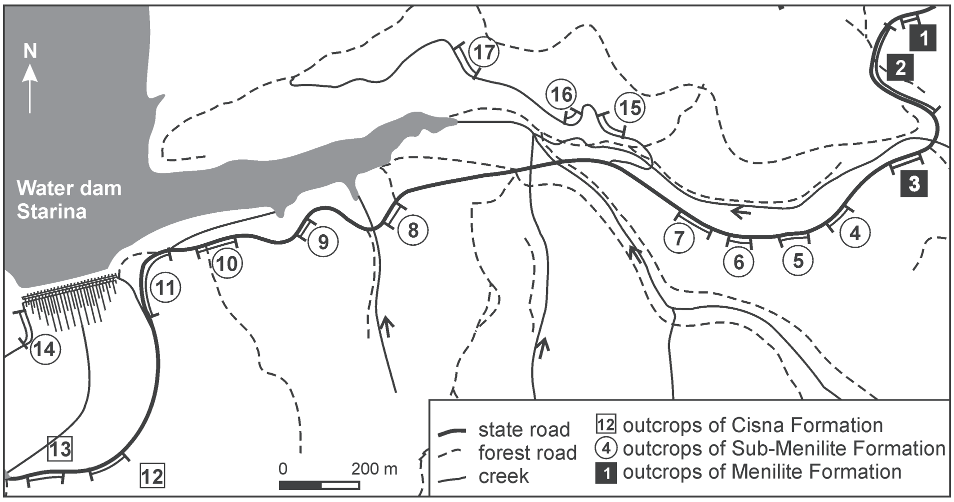

Fig. 2. Detailed location of studied sedimentary profiles in the Dukla Unit.

quence of complex tectonic processes including folding, thrusting and rotation (e.g. Janočko & Flečko 2002; Golonka 2003; Oszczypko 2006).

The study area lies in the Dukla Unit that extends from SE Poland to NE Slovakia and adjacent parts of Ukraine (Fig. 1). The Dukla Unit, sandwiched between the Silesian Nappe in the north and Magura Nappe in the south, contains Cretaceous and Paleogene flysch sediments (mostly rhythmically interbedded shales and sandstones) and has a complicated fold-and-thrust structure. The interpretation of the paleogeographical position of the Dukla Basin is still ambiguous and subject to debate (e.g. Koráb & Ďurkovič 1978; Slaczka & Walton 1992; Malata 2006). The paleoflow direction reflects changing source areas and topography at the active plate margin. While the prevailing paleoflow during the Paleocene and Eocene was from the E, NE and SE (e.g. Bąk & Wolska 2005), the paleoflow changed to the opposite direction during the Oligocene, probably as a result of emerging new source areas formed during subduction.

The sediments in the study area are affiliated to the Cisna, Sub-Menilite and Menilite Formations. The entire succession is capped by the Cergow Sandstone that is a lithologically contrasting member of the Menilite Formation (Figs. 2 and 3). The Paleocene Cisna Formation contains medium- to thick-bedded sandstones alternating with shales. The Paleocene to Middle Eocene Sub-Menilite Formation is represented by thin-bedded fine-grained sandstones rhythmically alternating

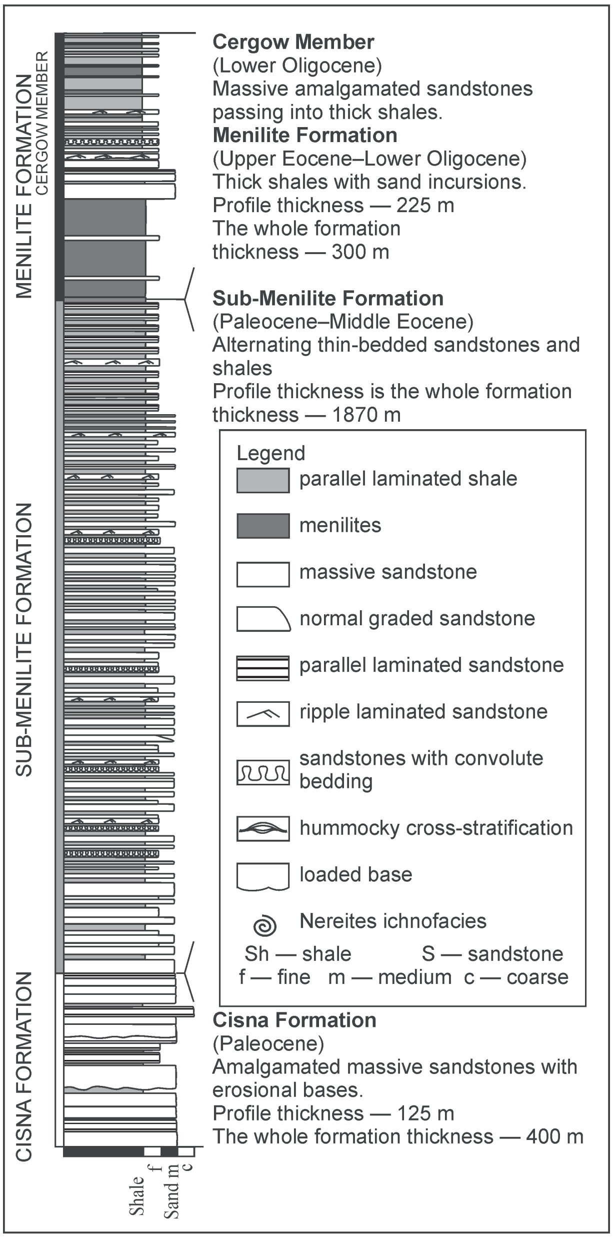

Fig. 3. Composite sedimentary profile showing stratigraphy of sediments in the studied outcrops. The lowermost Cisna Formation (Paleocene) contains medium- to thick-bedded sandstones alternating with shales. The overlying Sub-Menilite Formation (Paleocene to Middle Eocene) is represented by thin-bedded fine-grained sandstones rhythmically alternating with shales. The uppermost Menilite Formation (Upper Eocene–Lower Oligocene) consists of thin-bedded shales siltier or sandier at the base, occasionally alternating with thin-bedded, fine-grained sandstones. The entire succession is capped by the Cergow Sandstone (Lower Oligocene) representing a member of the Menilite Formation. This is composed of medium- to thick-bedded sandstones interlayered with alternating, thin-bedded shales and sandstones and/or typical menilite shales.

with shales. The Menilite Formation of Oligocene age may be divided into two superimposed subunits in the studied area: the lower one consists of thin-bedded shales with silty or sandy bases occasionally alternating with thin-bedded, fine-grained sandstones. The overlying Cergow Sandstone, defined as a member of the Menilite Formation, is composed of medium- to thick-bedded sandstones alternating with thin-bedded rhythmical flysch and/or typical menilite shales (Fig. 3).

Methods

Vertical bed thickness measurements were carried out in 17 profiles (Fig. 2) and combined into 3 composite vertical sections. The profiles were measured bed by bed and graphically displayed in logs. The first section is reconstructed from 13 sedimentary profiles with a total thickness of 412 m. Three sedimentary profiles with a total length of 41 m combine in the second vertical section, while the third section consists of one 79 m long sedimentary profile (Figs. 2 and 3). Each sandstone bed was measured from its base to the overlying mudstone or sandstone bed. Every bed thicker than 1 cm was measured. In the case of amalgamated beds, if the sandstone beds were distinguishable, each bed was measured separately. Individual Bouma divisions were measured separately. Sandstone thickness data were also displayed in histograms.

The type of thickness distribution can be recognized using diagrams with different scales on the horizontal axis. In the first type of diagram, the sandstone bed thickness (h) is displayed linearly on the horizontal axis (LN plot) while in the second type the logarithms of bed thicknesses (log h) are depicted (LL plot). The vertical axis is the same for both types of diagrams: the logarithm of the number of beds thicker than the measured bed ($N \geq h$). The resulting frequency distribution exhibits the characteristics of one of the three possible distributions — lognormal, exponential, or power law distribution (Fig. 4).

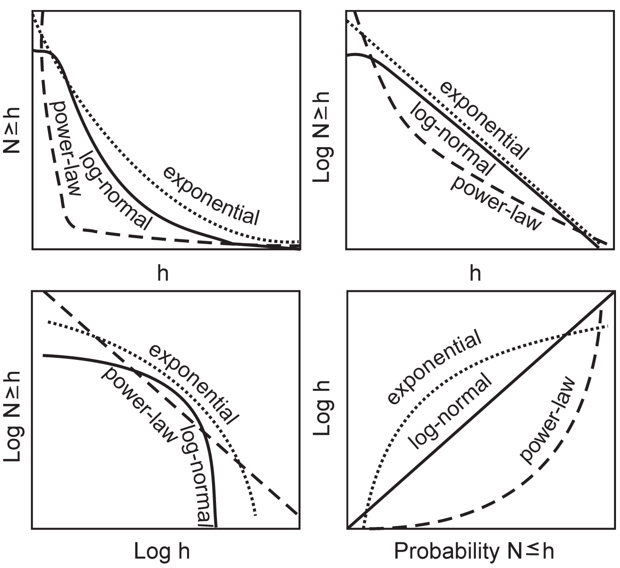

Fig. 4. Various turbidite bed-thickness distributions (after Sinclair & Cowie 2003, modified).

After displaying turbidite thicknesses either on LL or on LN plot it is not always clear what type of distribution is representative for the given dataset. Therefore we also constructed logarithmic probability plots with bed thickness h (cm) on the horizontal axis and with percentages of beds thinner than h (%) presented on vertical axes.

The Kolmogorov-Smirnov test and quantile-quantile plot were used for testing the lognormal distribution of our data.

Description of sedimentary profiles and bed statistics

440 m of sediments, encompassing 17 logs and divided into three sections were measured bed-by-bed. The sediments of the Cisna Formation reach 400 m in thickness in the studied area; only 125 m could be measured because of discontinuity of outcrops. The total of the measured beds of the Sub-Menilite Formation is 1870 m. The sedimentary log of the Menilite Formation encompasses 225 m of sediments (Fig. 3).

For the statistical analysis 11 logs were used. The remaining 6 logs belonging to the Sub-Menilite Formation were left out either because they are dominated by shales with minor thin sandstone beds or they are too short for statistical analysis. However, these logs still provide important data for the overall picture of the sedimentological evolution of the area. In the following section, we describe the analysed sedimentary successions from base to top (see Fig. 3).

Cisna Formation (Fig. 5)

The Early Paleocene Cisna Formation is represented by logs 13 and 12, with a total thickness of 125 m (Fig. 5). The sedimentary profile is dominated by intervals of thick-bedded, amalgamated sandstones alternating with intervals of thin- to medium-bedded sandstones with shales. The sandstone/shale ratio of the entire succession is 8 : 1. The medium-grained grey sandstones are predominantly massive and occasionally parallel laminated and the dark grey shales are parallel laminated. The sandstones are arranged in sharply-based beds. Locally, shallow erosive channels are developed.

The bed thicknesses of 156 sedimentary beds vary from 1 to 300 cm, with a mean shale thickness of 11 cm and mean sandstone thickness of 26 cm (Fig. 5). The prevalence of thicker beds is demonstrated in the frequency histogram of sandstone bed thickness showing 72 % of beds thicker or equal to 10 cm. Beds of 10 cm thickness are the most frequent.

The thick-bedded, amalgamated, massive, and medium-grained sandstones may represent deposits of concentrated flows (Mulder & Alexander 2001) in the channelized part of the turbidite system. As these flows develop, progressive fluid entrainment and dilution increase their turbulence and cause them to transform into turbidity flows, driving the deposition of the thin-bedded massive or parallel laminated sandstones capped by shales.

The cumulative distribution of turbidite sandstone beds expressed by diagram with logarithmic scales on both horizontal and vertical axes (LL plot) and logarithmic values only on the vertical axis (LN plot) is displayed in Fig. 5. The LL plot

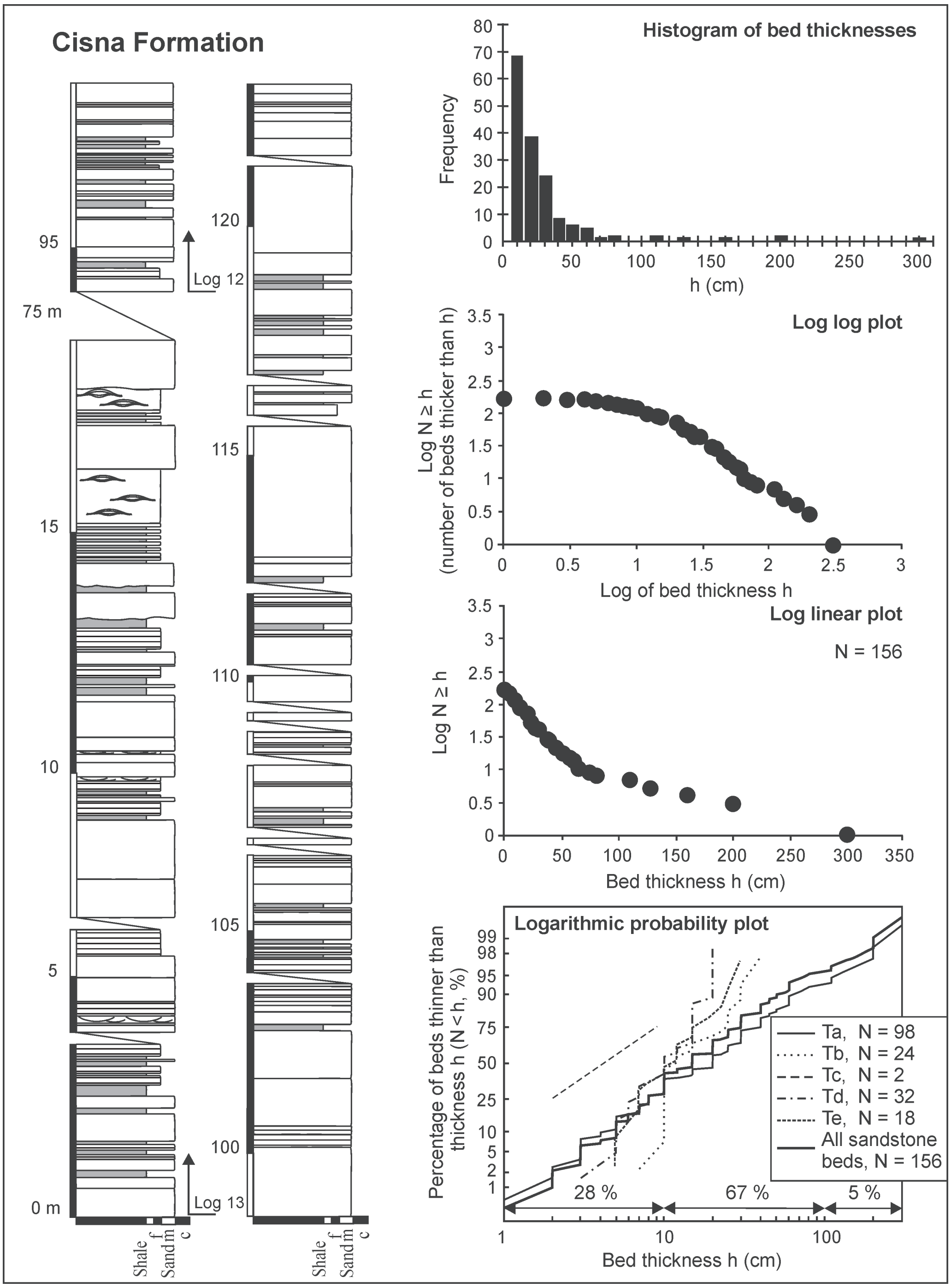

Fig. 5. Sedimentary profile of the Cisna Formation and histogram of bed thicknesses. The cumulative distribution of turbidite sandstone beds in the LL and LN plots shows deviations from the power law distribution at both ends of the curve. The distribution of bed thickness of all sandstones is expressed by linear trend line on logarithmic probability plot, thus indicating lognormal distribution of our data.

shows a concave curve while LN plot follows a convex curve. For a more complete evaluation, we also display the data as a logarithmic probability plot where the distribution of bed thickness of all measured sandstones is expressed by a linear trend. The Ta, Tb and Td divisions display a straight line as well.

After displaying our data on the LL, LN and logarithmic probability plots we suggest a lognormal distribution of turbidite thickness for the Cisna Formation as confirmed by Kolmogorov-Smirnov test (KS test), and quantile-quantile plot (q-q plot, Fig. 8). From the Bouma divisions, the Ta division has high variability similarly to all sandstone bed lines. Curves representing Tb, Tc, Td and Te divisions show markedly lower bed thickness variability.

Comparing similarly distributed bed thicknesses from the Tarcu Sandstone (Eastern Carpathians), which is interpreted as channel-and-levee complex (Sylvester 2007), we think that the lower variability of Tb, Tc, Td, Te may suggest levee deposits above channelized sandstone characterized by Ta division with higher variability. This interpretation is supported by our results based on facies analysis.

According to Carlson & Grotzinger's (2001) methodology, which argues for power law distribution of turbidites, the absence or faint linear segment may indicate segmented power law distribution. In this case the shape of the analysed distribution in LL and LN plots implies deposition of sediments in environment characterized by higher influence of erosion and amalgamation — such as upper fan, channelized part of depositional lobe or channel-lobe transition.

Sub-Menilite Formation (Fig. 6)

The Paleocene to Middle Eocene Sub-Menilite Formation overlies the Cisna Formation and consists of rhythmically alternating, sharply based medium- to thin-bedded sandstones and shales at the base of the formation overlain by an interval of thick-bedded sandstones with a thinning-upward trend (log 11, Figs. 2 and 6). The sandstone is fine- and medium-grained, with sporadic coarse-grained intervals. The most frequent thickness of beds is 6 cm but amalgamated sandstones are up to 140 cm thick. Massive structure and occasional normal grading prevail in the coarse- and medium-grained sandstones, while the fine-grained sandstones are mostly ripple-cross laminated and parallel laminated with rare convolute bedding (Fig. 6). Upward the whole succession becomes finer grained with mean thicknesses of both sandstone or mudstone decreasing to ca. 2–4 cm. Sharp bed soles exhibit traces characteristic of the *Nereites* ichnofacies.

The main difference between the Sub-Menilite and Cisna Formations is the increase in shale content resulting in lower sandstone/mudstone ratio 2:1 in the whole succession and even less than 1:1 in the section above the basal thick sandstones (Fig. 6). In contrast to the Cisna Formation, the percentage of beds thinner than 10 cm increases to 89 %, while 10 cm and thicker beds represent only 11 % of the whole bed population. The most frequent are beds with thicknesses of about 1 cm.

The vertical trend of the sediments (Fig. 6) suggests shift of the depocentre during their deposition to areas less affected by erosion (e.g. distal part of lobes). The trend may also be interpreted as representing overbank deposits (typical rhythmically alternating thin beds of sandstones and shales); however, lack of associated channel sediments and erosion features favour the outer lobe interpretation.

The frequency distribution of bed thickness on the LL plot exhibits linear segment bounded with rollover on the both ends. Departure is more significant at the thin bed end and it occurs in beds thinner than 3 cm and thicker than 130 cm. On the LN plot, the distribution has a convex shape (Fig. 6). The distribution of bed thicknesses of all sandstones on the logarithmic probability plot displays a slight deviation from a linear trend. Plotted individual Bouma divisions show a similarity between the distributions of Ta division and all sandstone beds.

The distribution of bed thickness data based on the LL, LN and logarithmic probability plots cannot be interpreted unequivocally. The goodness-of-fit of the data using KS test did not confirm lognormal distribution and the data also markedly deviate from the modelled distibution on q-q plot (Fig. 8) The higher variability of Tc, Td and Te divisions (Fig. 6) compared to that in the Cisna Formation may indicate a more distal depositional environment, probably lobe fringe. Similar relationships are found in data from the Marnoso-Arenacea Formation (Sylvester 2007) and it is also in accordance with the interpretation based on facies analysis.

Assuming Carlson & Grotzinger's (2001) hypothesis that turbidites without signs of erosion and amalgamation have power law distribution, the data from the Sub-Menilite Formation would suggest deposition in lower fan, lobe fringe or basin plain environments.

Menilite Formation (Fig. 7)

The Menilite Formation mainly consists of brown, grey and black, laminated shales and occasional sandstones. The shales often contain "menilites" — black, silicious shales with the origin related to decreased supply of terrigenous material and anoxic regime caused by major paleogeographical changes during the Eocene-Oligocene boundary (e.g. Puglisi 2006). The formation is deposited above the Globigerina marl horizon that is typical for the Eocene-Oligocene boundary (Leszczyński 1996). A part of the formation, defined as a member, is called the Cergow Sandstone and is composed of thick sandstone beds separated by dark grey and black, "menilitic" shales (Fig. 7).

In the study area the formation is represented by a 60 m thick interval of grey, brown and black shales overlain by the 129 m thick Cergow Sandstone (Fig. 7). The monotonous shale succession is interrupted by several beds of massive sandstone that indicate rare incursions of flows with high competence. The lowermost part of the Cergow Sandstone is characterized by thick-bedded, amalgamated sandstones separated by thin, parallel laminated and massive dark shales. The bases of the sandstones are sharp and loaded and the sandstones occasionally contain rip-up clasts in the higher part of the beds. Frequent flute and rill marks indicate main paleoflow direction from WWN to EES. Upsection, several upward-thinning cycles in the medium to thick sandstone beds alternating with shales are developed. The sandstones are predominantly fine- and medium-grained, massive, planar parallel and ripple cross-laminated, occasionally convoluted. The cycles are separated by 3 to 6 m thick intervals of typical black "menilitic" shales.

The entire Menilite Formation contains 509 sandstone beds of which the 1 cm thick beds are the most frequent. Although this compares well with the Sub-Menilite Formation, the beds thicker or equal to 10 cm increase to 21 % and beds thinner than 10 cm decrease to 79 % here (Fig. 7). Thick accumulation of dark and black shales with menilites suggests quiet depositional conditions with restricted circulation. Prevailing suspension sedimentation was abruptly changed to turbidite deposition resulting in sedimentation of the thick Cergow Sandstone.

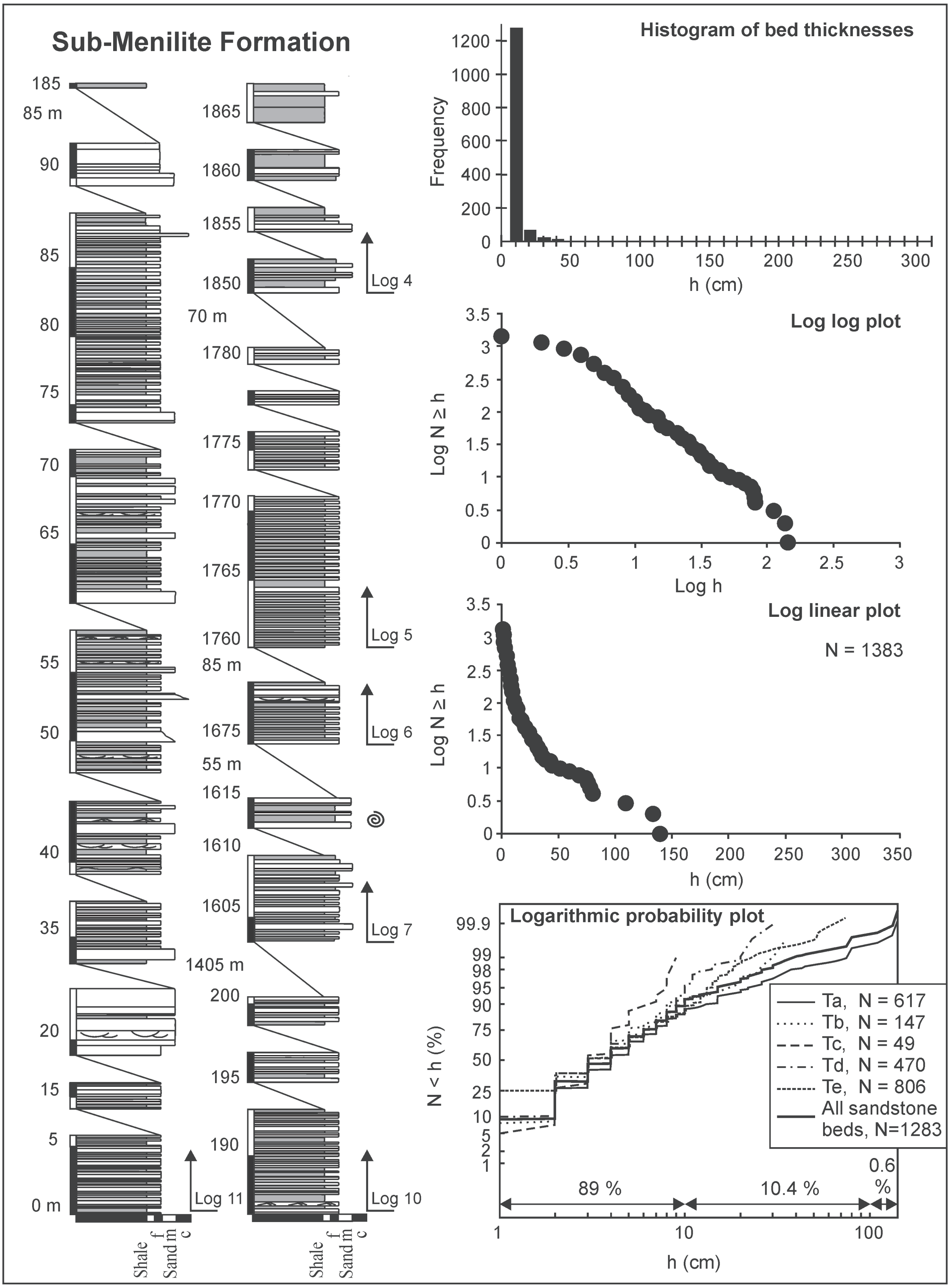

Fig. 6. Sedimentary profile showing the sediments of the Sub-Menilite Formation. The bed-thickness histogram strongly suggests dominance of thin-bedded beds. The frequency distribution of the bed thickness in LL plot shows slight deviation from power law distribution. The distribution on the LN plot displays a convex form that may indicate both power law and lognormal distributions. The logarithmic probability plot of turbidite thickness of the Sub-Menilite Formation differs from the probability plot of the Cisna Formation (see Fig. 5). The distribution of bed thickness of all sandstones displays slight deviation from lognormal distribution. Note the resemblance between distributions of Ta division and all sandstone beds.

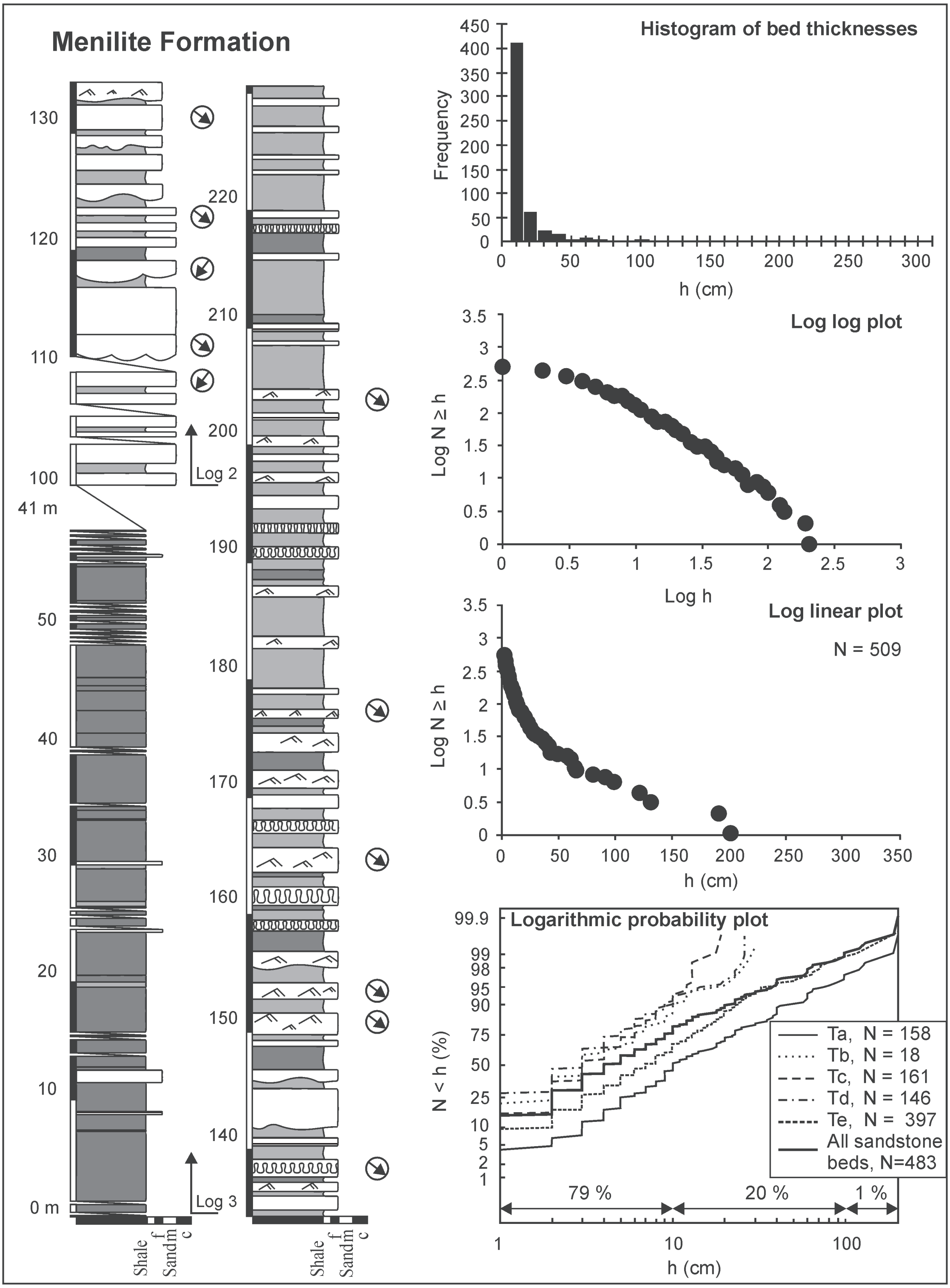

Fig. 7. The uppermost Menilite Formation topped with the Cergow Sandstone Member in its upper part. The bed-thickness frequency distribution on the LL plot and LN plots indicates either power law or lognormal distributions. The logarithmic probability plot of the Menilite Formation resembles the probability plot of the Sub-Menilite Formation (see Fig. 6). The linear trend of distribution of all sandstone divisions again indicates a lognormal distribution of turbidite thicknesses.

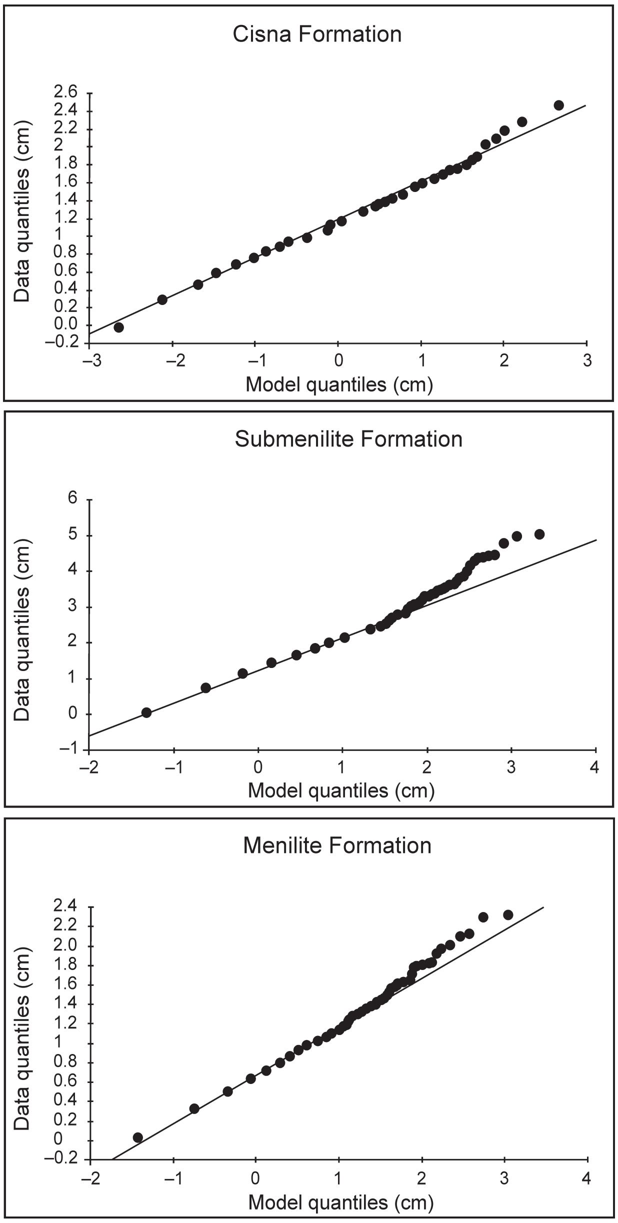

Fig. 8. Quantile-quantile plots of all studied formations showing the fit of the distributions to the assuming lognormal model.

The LL plot of bed thickness implies power law distribution contrary to the logarithmic probability plot that rather shows lognormal distribution. However, the lognormal distribution did not pass the KS test. The analysed bed thickness distribution also slightly deviates from the theoretical lognormal distribution on q-q plot (Fig. 8).

The variability of Tb, Tc, Td and Te Bouma divisions closely resembles divisions from the Sub-Menilite Formation. However, higher variability of Te divisions indicates occurrence of thicker fines thus suggesting weaker erosion. This may be represented by the outer fan/basin floor environment. The cumulative distribution of beds displayed on the LL plot has a slightly concave shape (Fig. 7). The rollover begins at the thin beds end with the beds thinner than 4 cm, and at the thick beds end with beds thicker than 120 cm. The curve in the LN plot shows a convex shape. The logarithmic probability plot has a linear trend.

Application of Carlson and Grotzinger's approach to bed thicknesses having power law distribution, results in interpretation of a depositional environment typical of weak erosion. Such an environment may be represented by the distal parts of a turbidite system.

Discussion and conclusions

More than 440 m of Paleocene to Oligocene sediments assigned to the Cisna, Sub-Menilite and Menilite Formations of the Dukla Unit were measured bed-by-bed in order to obtain data for statistical analysis, which should serve as an additional tool for interpretation of the sedimentary environment. The entire analysed sedimentary succession consists of thick-bedded massive sandstones alternating with shales (Cisna Formation) overlain by thin-bedded sandstones and shales (Sub-Menilite Formation). The succession passes upward to thick shales capped by massive sandstones of the Menilite Formation. Based on the facies analysis we interpreted deposition of the Cisna Formation in a proximal fan (channelized section) while the sediments of the Sub-Menilite Formation were deposited in the outer lobe. The uppermost deposits — the Menilite Formation are interpreted as outer fan/basin floor and lobe deposits, respectively.

The obtained bed thickness data were used for construction of histograms, LL, LN and logarithmic probability plots. For evaluation of our data we used interpretational methods assuming a) lognormal distribution and b) power law distribution of turbidite bed thicknesses.

Bed thickness distribution for the Cisna Formation shows lognormal distribution with Ta division having high and Tb, Tc, Td, Te divisions having much smaller variabilities (Fig. 5). According to our interpretation based on facies analysis, these bed thickness characteristics reflect deposition in a channel and levee environment. Similar variability of Bouma divisions was identified in the Tarcău Sandstone (Sylvester 2007) and also interpreted as a channel-levee complex. The distributions of the Sub-Menilite and Menilite Formations show only slight divergence from the lognormal distribution. The bed thickness distribution of the Sub-Menilite Formation, facially interpreted as outer lobe sediments, suggests that for this environment higher variability of Tb, Tc, Td and Te divisions (Fig. 6) is typical. The variability of these divisions from the Menilite Formation, deposited in an outer fan/basin plain environment, is similar (Fig. 7). The only difference is considerably higher variability of Te division. The high thickness of Te division probably reflects an environment with negligible erosion that is in accord with our sedimentological interpretation.

If we assume power law distribution of bed thicknesses (Carlson & Grotzinger 2001), the deviation of our data from power law distributions on LL and LN plots indicates erosion and amalgamation. The greatest deviation is observed on the plots of the Cisna Formation suggesting its deposition in the proximal part of the turbiditic system. The distribution of the Sub-Menilite Formation sediments slightly deviates from the power law distribution implying a more distal environment with lesser erosion. The uppermost sediments of the Menilite Formation only depict a slight deviation on both sides of the bed thickness distribution curve with the best approximation to the power law distribution with regard to the older formations. This indicates deposition in an environment with minimum erosion and corroborates outer fan/basin floor environments inferred from the sedimentological analysis.

The lognormal distribution of bed thicknesses from individual formations were tested by the Kolmogorov-Smirnov test, which only confirmed this distribution for the Cisna Formation. The data from this formation also show the best approximation to the modelled lognormal distribution on the quantile-quantile plot in contrast to the data from the Sub-Menilite and Menilite Formations. However, the step-like trend visible in the all sandstone curve on logarithmic probability plots of these two formations (Figs. 6 and 7) may suggest a polymodal bed thickness population. Thus, testing of individual populations for lognormal distribution, which may form components of lognormal mixture model should be a subject of the next study.

The applied methodology may represent an important part of depositional environment analysis in the areas with limited outcrops or subsurface data, such as the Outer Flysch Zone of the Carpathians. Our interpretation was made on the basis of comparison with similar analyses elsewhere (Tarcău Sandstones, Eastern Carpathians; Marnoso-Arenacea Formation, Apennines; Cloridorme Formation, Quebec, etc.) and was confirmed by the results of facies analysis. It is interesting that the interpretations from both the applied methods yielded similar results proposing the need for more case studies in order to select the most reliable method. We agree with Sylvester (2007) who pointed out that it is unlikely that a few numbers or curves derived from bed thickness data alone can give general guidance about depositional setting, degrees of confinement, erosion, bypass and other important characteristics of the turbidite thickness. However, even if the interpretation based on quantitative methods is not always unambiguous, together with other sedimentological methods it contributes to more reliable interpretations.

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