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APPLICATION OF BED THICKNESS DISTRIBUTIONS IN LATE EOCENE-OLIGOCENE TURBIDITE DEPOSITS OF GREECE: SOME PRELIMINARY RESULTS

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Abstract

A simple application of bed thickness distributions was attempted in outcrops of Late Eocene-Oligocene turbidites in three dispersed localities of Greece. The three studied sections are located at Evinohori area (West Greece), Karpathos Island (SE Greece) and Limnos Island (NE Greece). All outcrops show similar sedimentological characteristics. Three types of plots were used: log-log, log-probability and frequency curves. Bed thickness data indicate similarity between West-SE Greece turbidites and discrimination from NE Greece turbidites which is attributed to different basin morphology due to different tectonic processes.
Key words: *submarine fans, turbidites, bed thickness analysis.*

Περίληψη

Μια απλή εφαρμογή των κατανομών πάχους στρωμάτων επιχειρήθηκε σε φυσικές τομές τουρβιδιτών Άνω Ηωκαινικής – Ολιγοκαινικής ηλικίας σε τρεις διαφορετικές περιοχές της Ελλάδας. Οι τρεις τομές που μελετήθηκαν βρίσκονται στο Ευηνοχώρι Αιτ/νίας (Δυτική Ελλάδα), το νησί της Καρπάθου (ΝΑ Ελλάδα) και το νησί της Λήμνου (ΒΑ Ελλάδα). Όλες οι τομές παρουσιάζουν παρόμοια ιζηματολογικά χαρακτηριστικά. Τρία είδη διαγραμμάτων χρησιμοποιήθηκαν: διάγραμμα λογαρίθμου-λογαρίθμου, λογαρίθμου-κλίμακας πιθανότητας και καμπύλης συχνότητας. Οι κατανομές του πάχους των στρωμάτων και στα τρία είδη διαγραμμάτων δείχνουν ομοιότητα ανάμεσα στους τουρβιδίτες Δυτικής και ΝΑ Ελλάδας και διαφορά τους από αυτούς της ΒΑ Ελλάδας. Το γεγονός αυτό πιθανά οφείλεται σε διαφορετική μορφολογία των λεκανών ιζηματογένεσης των τουρβιδιτών, λόγω διαφορετικών τεκτονικών διεργασιών.
Λέξεις κλειδιά: *υποθαλάσσια ριπίδια, τουρβιδίτες, ανάλυση παχών στρωμάτων.*

1. Introduction-Geological Setting

A simple application of bed thickness statistical distributions was attempted in outcrops of late Eocene-Oligocene turbidites in three dispersed localities of Greece (Fig. 1). These localities represent similar depositional environments and cover most of the country's area. The three studied sections are located at Evinohori area (west Greece), Karpathos Island (SE Greece), and Limnos Island (NE Greece). West and SE Greece outcrops belong to Gavrovo and Ionian geotectonic zones respectively (External Hellenides units). Turbidite deposits of west Greece were deposited in a complex elongated foreland basin system formed by Pindos thrust fault from middle Eocene to late Oligocene (Vakalas 2003). A confined foreland basin model is proposed for Karpathos turbidites (Pantopoulos 2004). Limnos Island turbidites are considered a part of the molassic basins of the North Aegean Area (Internal Hellenides units) (Roussos 1993).

The aim of this work is the use of bed thickness distributions as a quantitative tool of turbidite research (combined with field observations), in order to provide information about sedimentation characteristics of turbidites.

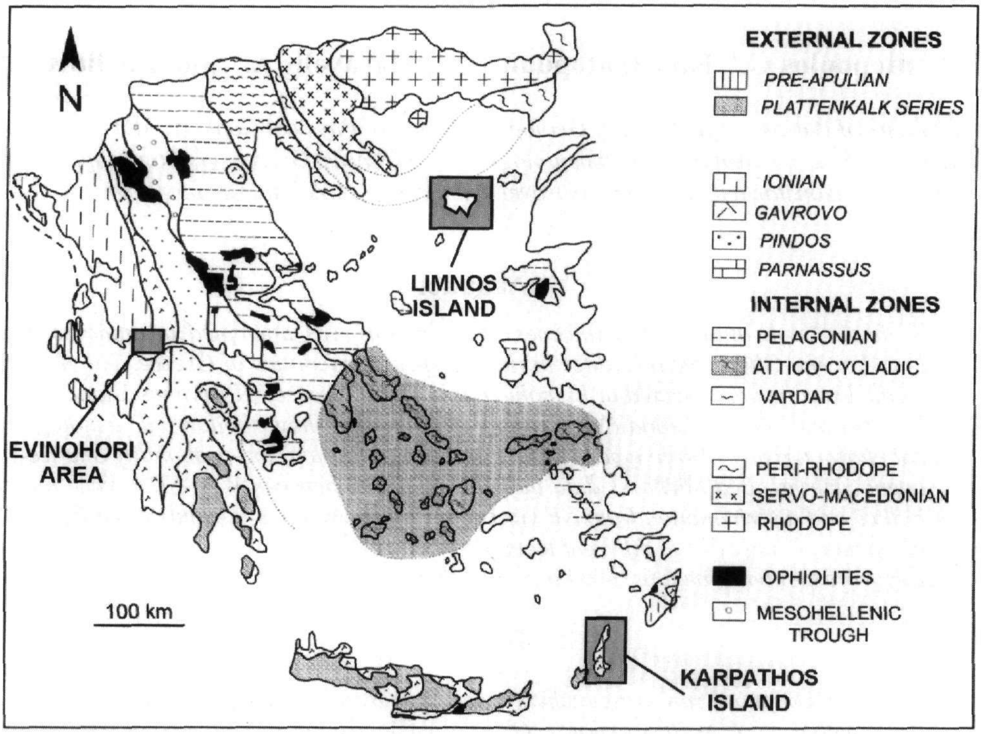

Figure 1 – Geotectonic map of Greece. The studied outcrop areas are shown in boxes

2. Methodology

In total, 470 sandstone beds were measured in the three studied sections. Three types of distribution plots were used for the bed thickness data: an exceedence probability plot in log-log axes, a logarithmic probability plot and a frequency curve plot (a histogram type) of bed thickness. The shape of bed thickness trend in each plot gives information about the type of statistical distribution that fits the data and shows similarities or differences between the data sets. Processing of results was based also on previous studies of turbidite bed thickness distributions made by Rothman and Grotzinger (1995), Carlson and Grotzinger (2001) and Talling (2001). The bed unit that was measured for the bed thickness distributions is the arenaceous component of the turbidite (Bouma divisions Ta-d) (Bouma 1962), which practically represent the sandstones of a turbidite outcrop. The measurement unit is centimetres (cm). A minimal cut-off thickness of 1 cm was established due to measuring difficulties below that thickness. In case of amalgamated or rippled beds, an average thickness was taken after several measures. The thickness of all the sandstone beds above 1 cm was measured in the three studied outcrops (Table 1), normal to bedding, using a tape measure.

3. Outcrop Characteristics

3.1. Limnos Island Outcrop

The studied outcrop (Fig. 2) is located at the southeast part of the island near Skandali settlement. Bed thickness ranges from 1 to 33 cm. The number of beds measured is 189. The outcrop represents a part of the lowest stratigraphic submarine fan unit in the island (Unit 1, Fig. 2). This unit, up to 100 m total thickness is characterized by fine to medium-grained sandstones grading upwards to very fine-grained sandstones interbedded with hemipelagic claystones. Sandstones often exhibit parallel lamination, cross- laminations and/or climbing ripples defining sequence Tb and Tc divisions of Bouma, (1962). The cross-lamination is commonly overlain by convolute lamination. The sandstone beds have flat bases and very good lateral continuity (at least a hundred meters). The claystone facies are brownwish and typically lack internal structure, although beds with silt lamina, with an upward decrease in lamina thickness have been recognized. The characteristic features of this unit demonstrate deposition from both low and high-density turbidity currents. The sandstone and claystones beds are classified as sedimentary facies C2.1, C2.2 and C2.3 and D2.2 in the Pickering *et al.* (1986) nomenclature, respectively. The common occurrence of convolute and climbing ripples clearly indicates rapid deposition of sediments from suspension. Such rapid deposition is related to the dilution of flow associated with the transition from confined, channelized conditions, with high gradients, to unconfined, lateral spreading across more gently sloping depositional lobe areas (Maravelis *et al.* 2007). Those characteristics classify the outcrop deposits as distal from the sediment source and probably outer fan deposits (Mutti and Ricci Lucchi 1972). Limnos Island turbidites have a late Eocene to early Oligocene age (Roussos 1993).

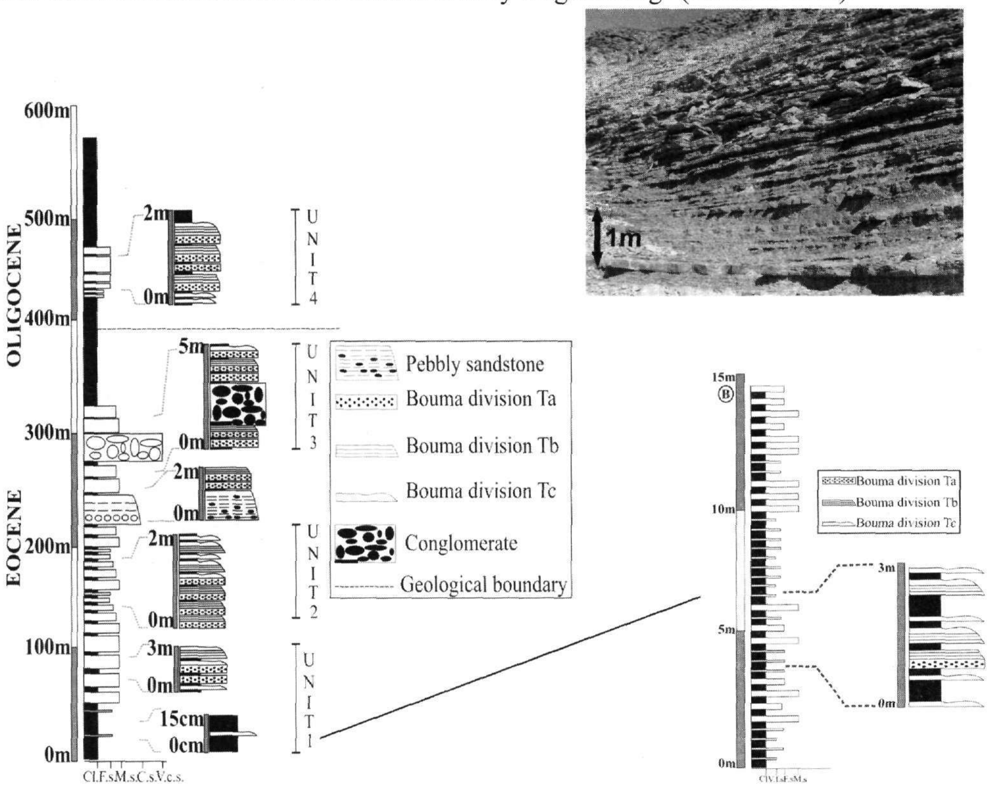

Figure 2 – General stratigraphic framework of submarine fan deposits at Limnos Island (left), with a log and photo of the studied section (right). Modification from Maravelis *et al.* (2007)

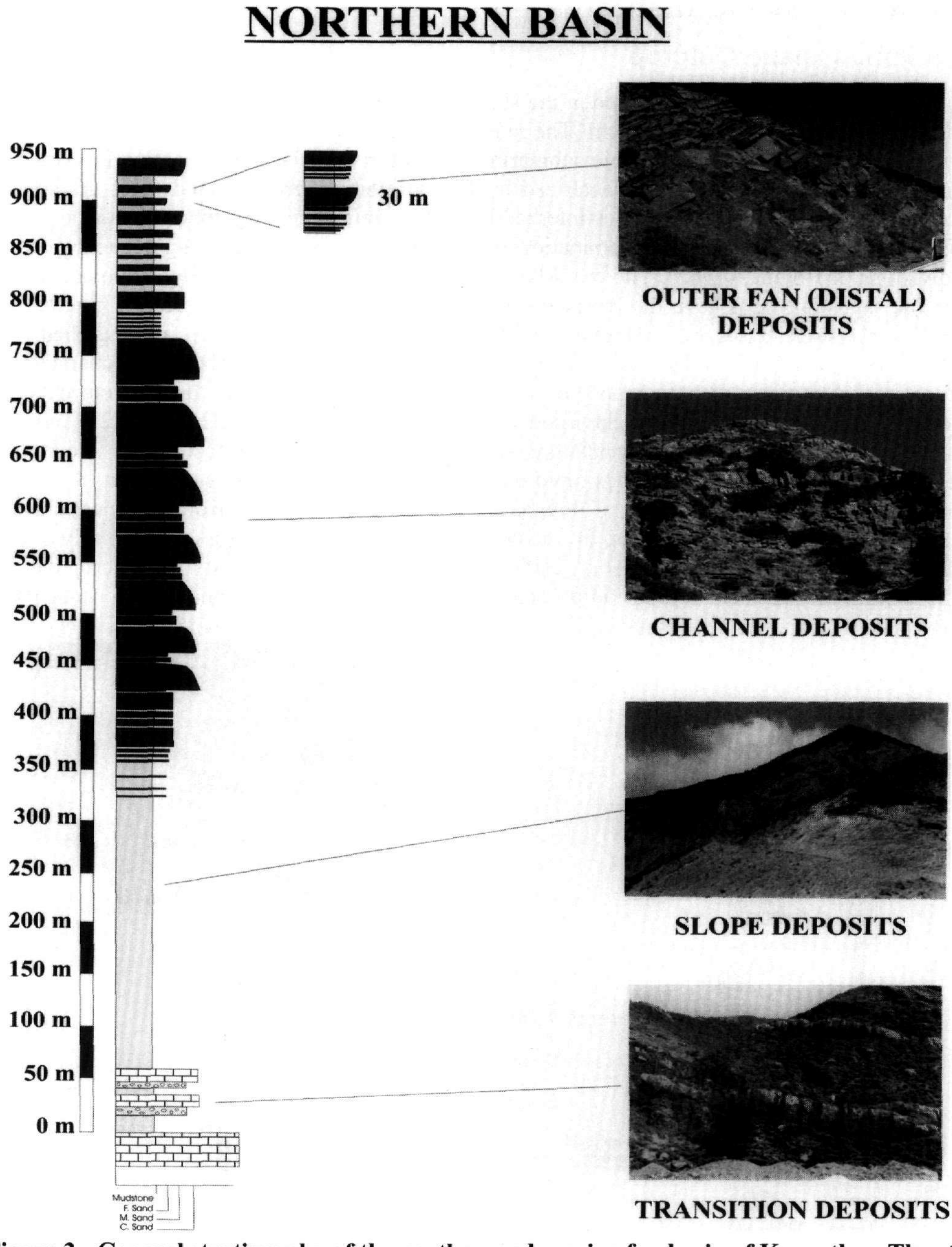

Figure 3 - General stratigraphy of the northern submarine fan basin of Karpathos. The studied section can be observed at the top photo and log. Modification from Pantopoulos (2004)

3.2. Karpathos Island Outcrop

136 beds were measured in the Karpathos Island outcrop (Fig. 3) that is located at the central part of the island, near Spoa settlement. Bed thickness ranges from 1 to 230 cm. The outcrop belongs to the upper stratigraphic units of the northern submarine fan basin of the island (Pantopoulos 2004) and consists of fine-grained sandstone-mudstone alternations which overlie a thick channel-conglomerate submarine fan system which shows evidence of confinement. These sediments

probably were deposited during abandonment of the channels due to the infilling of the topographically confined basin. Sandstone beds consist mainly of Bouma Tabc divisions, are fine-grained and have flat bases. Scarcity of amalgamation surfaces is also observed. These features suggest deposition from both low and high density turbidity currents (Lowe 1982) in a distal from the sediment source submarine fan environment. A late Eocene (Priabonian) to Oligocene age is proposed for Karpathos Island turbidites (Christodoulou 1967, Fytrolakis 1989).

3.3. Evinohori Outcrop

This outcrop (Fig. 4) is located at Antirrio-Agrinio national road, near Evinohori village. Bed thicknesses of the 145 measured beds range from 1 to 140 cm. The outcrop belongs to the lower stratigraphic submarine fan units of the area (southern Pindos foreland basin) and probably is a part of the Ellenika formation (Piper *et al.* 1978, Vakalas 2003). Previous workers give a distal submarine fan depositional setting for the turbidites of the Ellenika formation. Sandstone beds consist mainly of Bouma Tabc divisions, are fine to medium-grained and have flat bases. Amalgamation surfaces are rare. Also a thickening-upward sequence of bed thickness can be observed in the outcrop. These features suggest deposition from both low and high density turbidity currents (Lowe 1982) and classify the outcrop deposits as distal from the sediment source and probably outer fan deposits (Mutti and Ricci Lucchi 1972). A late Eocene to late Oligocene age is proposed for Evinohori area turbidites (Vakalas 2003, Vakalas *et al.* 2004).

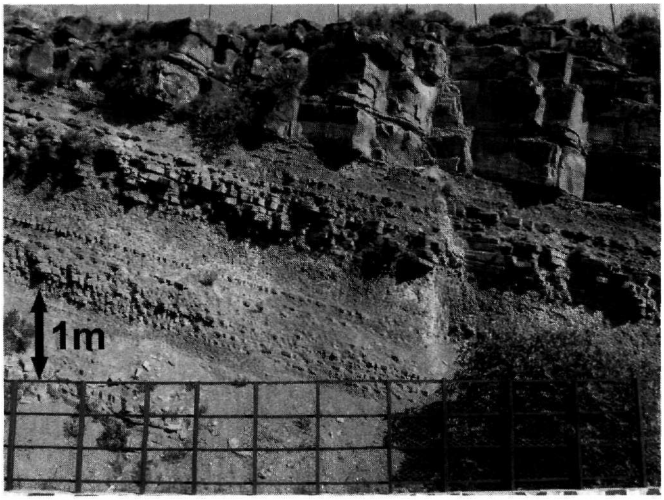

Figure 4 – Evinohori outcrop. A thickening-upward sequence can be observed

Table 1 - Summary of bed thickness data

Outcrop	Number Of Beds	Bed Thickness Range	Average	Standard Deviation
Limnos Island	189	1-33 cm	3.43 cm	3.86
Karpathos Island	136	1-230 cm	14.71 cm	30.31
Evinohori Area	145	1-140 cm	10.78 cm	19.89

4. Bed Thickness Plots

4.1. Log-Log Plot

An exceedence probability plot of sandstone bed thickness was created for each section in a plot with logarithmic values. Straight lines on these plots indicate power law frequency distributions which express scale invariance and self-similarity of a system. Bed thickness data from the three studied sections (Fig. 5) shows a high R^2 value to a linear fit ($R^2 > 0.9$) in the log-log plot. However, nonlinearity can be observed in the log-log plot especially for Evinohori and Karpathos data. A high R^2 value of a linear fit in a log-log plot does not always mean that all data follow a power law distribution but gives a good estimation of the possible power law exponent. Previous studies propose segmentation of the linear fits between thin and thick beds. The latter method gives better fitting and information about the three-dimensional arrangement of the beds (Malinverno 1997). This study attempts a simple fitting application to approximate the power law exponents taking into account the arguments of previous workers. The log-log plot indicates that there is a difference in the power law exponent (linear fit gradient) between the datasets. Turbidites of Evinohori and Karpathos have similar exponents less than unity (approximately 0.8), in contrast with Limnos turbidites which have an exponent more than 1 (approximately 1.3).

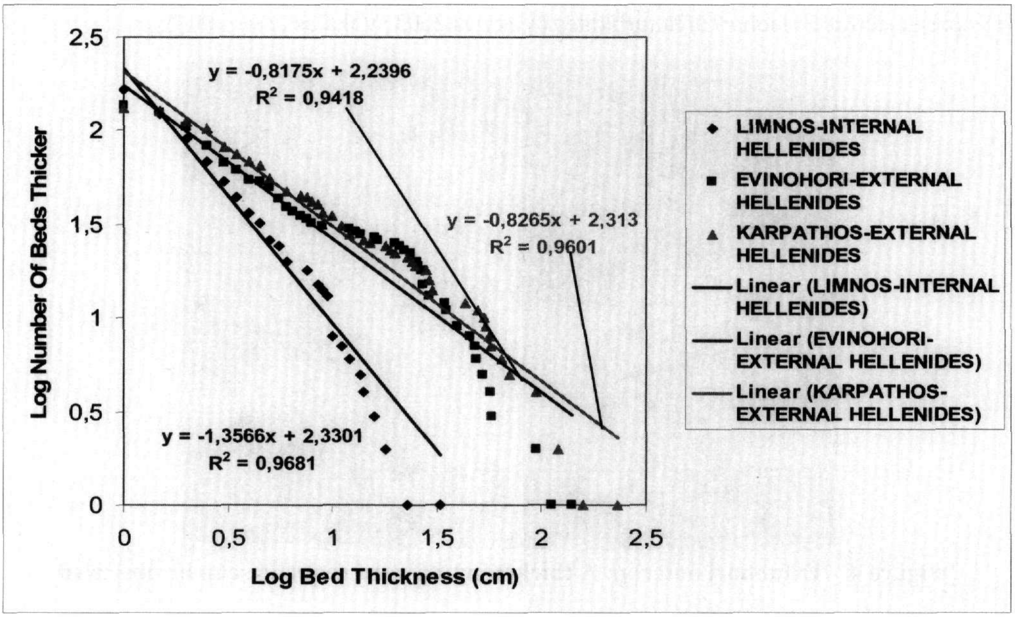

Figure 5 – Log-Log exceedence probability plot

4.2. Log-Probability Plot

A logarithmic probability plot of thickness was also created for each section. Straight lines on these plots indicate log-normal frequency distributions. The logarithmic probability plot (Fig. 6) shows similar segmented trends for west and SE Greece (Evinohori and Karpathos) and a different, more linear trend for NE Greece (Limnos). The stepped trends do not indicate a single log normal distribution but a mixture of log normal distributions (Talling 2001) is possible to be present.

4.3. Frequency Curves

Histograms of the bed thickness data were created, using a logarithmic axis and 5 cm bins. The line that passes from the histogram middle value of each bin forms the frequency curve. Symmetrical (Gaussian) bell-shaped curves on these plots indicate normal or log-normal frequency distributions, depending on the axis scale. In the frequency curve plot (Fig. 7), west and SE Greece data are again similar and show two symmetrical peaks that are suggestive of a lognormal mixture, in contrast with NE Greece which is showing only one mode, characteristic of a single lognormal population.

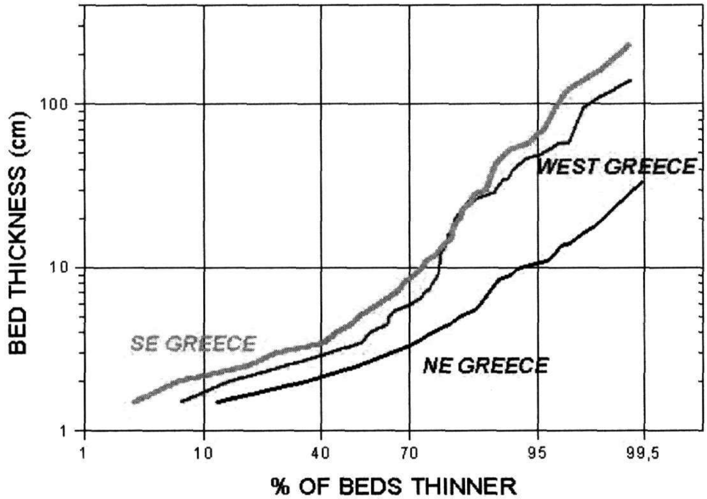

Figure 6 – Log-probability plot

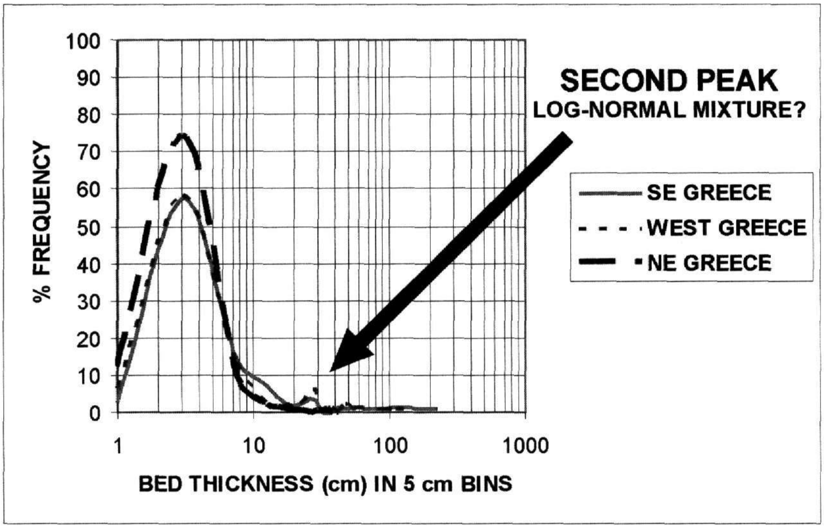

Figure 7 – Plot of frequency curves. West and SE Greece datasets seem to be bimodal

5. Discussion and Conclusions

5.1. Basin Morphology

Rothman and Grotzinger (1995) analyzed bed thickness datasets of turbidites and debris flow deposits of California and South Africa and proposed that variations in the scaling exponent of turbidite power law bed thickness distributions, regional or within the same deposit, are indicative of basin geometry and rheology of the sedimentary gravity flows. They introduced a spreading exponent relative to the bed thickness exponent and the bed volume scaling exponent. In general, deposits with low thickness scaling exponent seem to have lower spreadibility than deposits with higher scaling exponents. The log-log plot of the bed thickness dataset of this study shows two main scaling exponents for three cases of sedimentologically similar turbidites: approximately 0.8 for west and SE Greece turbidites (External Hellenides units), and 1.3 for NE Greece turbidites (Internal Hellenides units). The latter implies that basin geometry played a more important role than flow rheology in the exponent variation and also that west and SE Greece turbidites have a lower speadibility than NE Greece turbidites. This can be expained by the paleogeography of the area at late Eocene-Oligocene: Turbidites of west and SE Greece belong to the external Hellenides units and were deposited mainly in elongated foreland basins (typical in the area in late Eocene-Oligocene), forming thicker beds with low lateral extent. Limnos (NE Greece) turbidites belong to the Internal Hellenides units and were deposited in a tectonically different basin (forearc basin?) in which flows probably were free to spread in wider spaces with lack of topography, forming thinner, laterally extensive beds.

5.2. Type of Bed Thickness Distribution

The log-log plot of the three studied outcrops shows a high R^2 value to a linear fit ($R^2 > 0.9$) indicating a possible power law distribution of bed thicknesses and an agreement between Carlson and Grotzinger (2001) observations and sedimentary characteristics (distal submarine fan turbidites). The log-probability plot and the frequency curves show possible single log-normal or log-normal mixture distributions. The latter is in agreement with Talling (2001) observations. This thickness bimodality could be related with deposition from both dilute and dense flow parts (possibly low and high density turbidity currents) and this is also in agreement with the previous sedimentological results. Further research must be conducted because many types of statistical distributions (power law, log normal, log normal mixtures) can fit the data collected. The type of distribution that characterizes turbidite bed thickness and its relation with submarine fan depositional environments is still a controversial issue. However, depositional information can be extracted from the statistical analysis of turbidite bed thickness data combined with sedimentological observations.

5.3. Concluding Remarks

The observation of different power law bed thickness scaling exponents in sedimentologically similar turbidites of different localities of Greece is useful as a source of depositional information. West and SE Greece turbidite beds seem to have a lower speadibility than NE Greece turbidite beds. Generally, the three plot types used in this research indicate discrimination between west-SE and NE Greece turbidites which is probably due to different basin morphology related to different tectonic processes. Knowledge of differences in sandstone bed thickness and lateral extent is of great importance in hydrocarbon exploration.

6. Acknowledgements

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