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HYDRAULIC AND STATISTICAL GRAIN–SIZE PARAMETERS OF PINDOS TURBIDITE DEPOSITS

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ABSTRACT

Final closure of the Pindos ocean, resulted in collision of Apulia with Pelagonian microplates, produced voluminous clastic sediments that flowed southwards as turbidity currents in the form of submarine fans, giving rise to Pindos flysch during early Tertiary. Samples coming from thin-bedded sandstones were collected from five cross-sections throughout Pindos flysch in order to determine the characteristics of the turbidity current between different areas. The hydraulic and grain-size statistical parameters showed that low energy turbidity currents deposited the analyzed sediments. Almost all samples show a positive skewness due to the competency of the unidirectional flow of the transporting media, where the coarse end of the size frequency curve is “chopped off”. The kurtosis values in combination with the sorting values are plotted to the turbidity filed. A correlation between the mean palaeoflow velocity and the grain size showed that the mean palaeoflow velocities related to sandy silt samples whereas the higher velocities with sandy samples.

1 INTRODUCTION

In order to estimate the statistical and hydraulic parameters of turbidites from Pindos flysch, sandstone samples were collected from five cross-sections selected throughout the study area (figure 1). In the northern part samples were selected from the cross-sections A-A´ (Votonosi-Metsovo) and B-B´ (Milia) in Metsovo area, in the northern and central part from the cross-section C-C´ in Kastanea area, in the central part samples were selected from cross-section D-D´ (Fournas) in Karpenisi-Fournas area and finally in the southern part cross-section E-E´ in Nafpaktos-Lidoriki area. Overall, 62 samples were collected.

2 METHOD

The collected sandstone samples had an average thickness of 15 cm in order to compare the results between different areas. In addition, all the samples were characterized by the presence of the subdivision Ta of Bouma sequence, while in small percentage (19%) subdivisions Tb and Tc were present. Firstly, the samples were crushed in small pieces (approximately 1cm long) and dissolved using acetic acid (30% p/v). Furthermore, at the dissolved samples were added Perydrol (30% p/v) and let to dry at 70^{o} C. After drying, sieve analysis of the samples was followed using the method of sieves and pipette where it was necessary. Using this methodology, 29 samples remained unbroken, with the majority of them coming from Lidoriki area (13 samples) and less from the other areas (Fournas: 8 samples, Kastanea: 6 sampes, Metsovo: 1 sample and Milea: 1 sample). This might be due to the great percentage of quartz in the matrix of the samples.

3 CLASSIFICATION OF SAMPLES

For the classification of the samples, we used the classification of Folk, Andrews and Lewis (1970) (fig. 2). Thus, the more fine-grained samples were those of Metsovo (sandy silt and silty sand), Milea (muddy sand and silty sand) and Lidoriki areas (silty sand). In contrast, the coarser samples were those of Kastanea and Fournas areas (sand and silty sand).

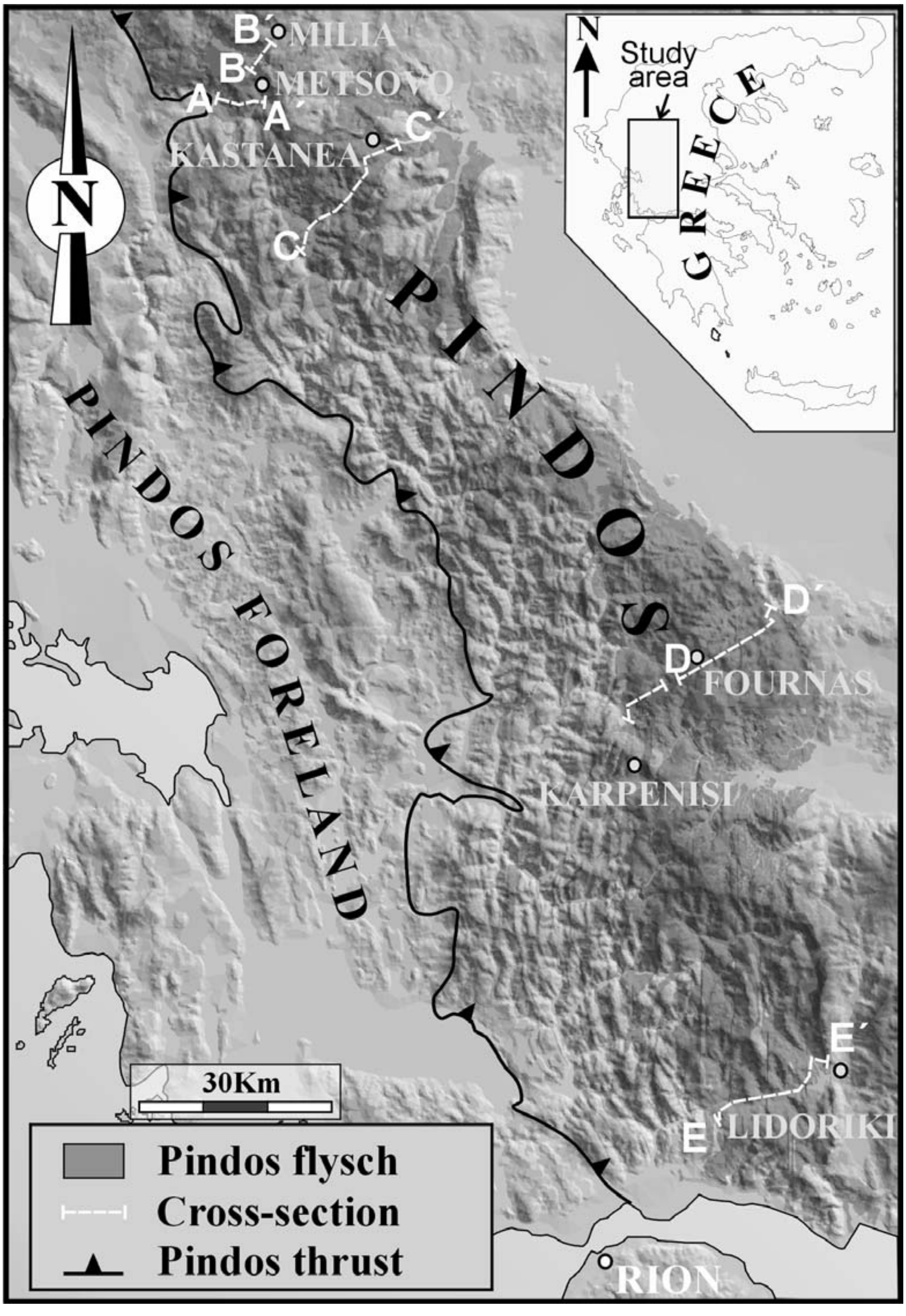

Figure 1. Simplified geological map showing the studied cross-sections.

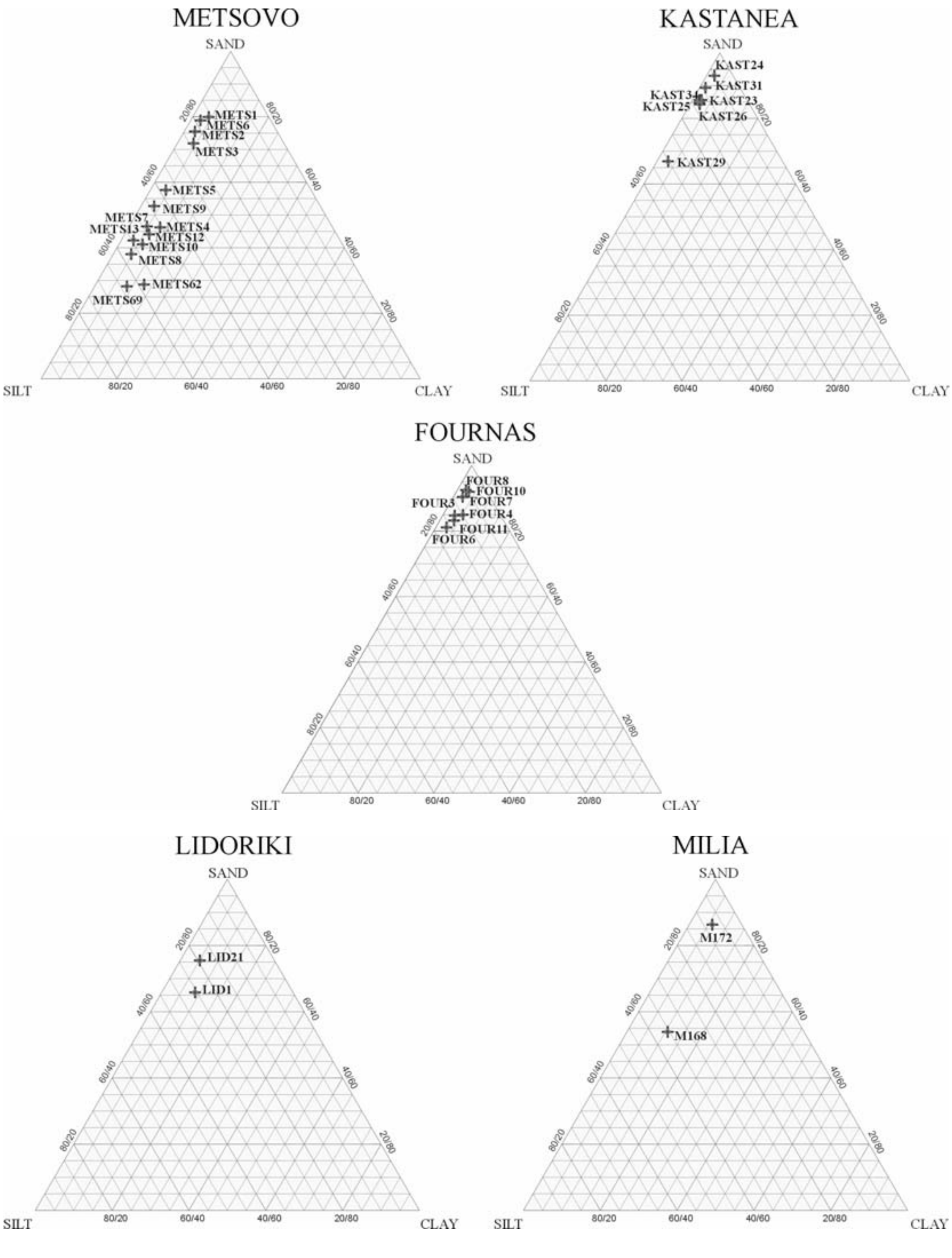

Figure 2. Projection of samples from the studied cross-sections in sand-silt-clay diagram.

4 STATISTICAL GRAIN-SIZE PARAMETERS

The estimation of the statistical grain-size parameters (tables 1-5) was accomplished using the mathematic formulas of Folk & Ward (1957). In detail the results for each area are:

Cross-section A-A´ (Votonosi-Metsovo)

Table 1. Grain-size statistical parameters of the samples from cross-section A-A´.

Sample	Median	Mean size	Sorting	Skewness	Kurtosis
METS1	3,62	3,47	1,35	0,00	2,00
METS2	2,91	3,12	1,32	0,30	0,99
METS3	3,27	3,45	1,45	0,26	1,15
METS62	4,63	5,04	2,21	0,46	1,92
METS4	4,17	4,31	1,65	0,27	1,30
METS5	3,83	3,93	1,44	0,17	1,04
METS6	2,95	3,10	1,29	0,24	1,13
METS7	4,11	4,19	1,33	0,17	1,21
METS 8	4,39	4,37	1,03	-0,05	0,92
METS9	3,92	3,81	1,46	-0,04	1,00
METS10	4,31	4,41	1,41	0,18	1,23
METS69	4,62	4,85	1,89	0,35	1,85
METS12	4,22	4,30	1,41	0,16	1,26
METS13	4,25	4,28	1,26	0,08	0,99

Cross-section B-B´ (Milea)

Table 2. Grain-size statistical parameters of the samples from cross-section B-B´.

Sample	Median	Mean size	Sorting	Skewness	Kurtosis
M168	3,93	4,32	2,28	0,46	1,92
M172	2,40	2,65	1,51	0,52	2,24

Cross-section C-C´ (Kastanea)

Table 3. Grain-size statistical parameters of the samples from cross-section C-C´.

Sample	Median	Mean size	Sorting	Skewness	Kurtosis
KAST34	2,46	2,66	1,21	0,33	1,11
KAST31	1,87	2,12	1,43	0,30	1,25
KAST29	3,35	3,60	1,49	0,33	1,03
KAST26	2,57	2,83	1,27	0,48	1,31
KAST25	2,40	2,66	1,28	0,44	1,21
KAST24	2,18	2,33	0,94	0,37	1,30

Cross-section D-D´ (Fournas)

Table 4. Grain-size statistical parameters of the samples from cross-section D-D´.

Sample	Median	Mean size	Sorting	Skewness	Kurtosis
FOUR3	2,97	3,06	1,21	0,26	1,25
FOUR4	2,94	3,05	1,42	0,37	1,69
FOUR6	2,85	3,09	1,50	0,46	1,60
FOUR7	3,54	3,31	0,72	-0,49	0,97
FOUR8	2,79	2,78	0,93	-0,05	0,76
FOUR10	2,81	2,83	0,86	0,00	0,85
FOUR11	3,16	3,27	1,13	0,29	1,42

Cross-section E-E´ (Lidoriki)

Table 5. Grain-size statistical parameters of the samples from cross-section E-E´.

Sample	Median	Mean size	Sorting	Skewness	Kurtosis
LID1	1,81	1,81	2,04	0,34	1,47
LID21	3,33	3,31	1,81	0,11	1,35

Afterwards, diagrams of the alternations in sorting, skewness and kurtosis are displayed in relation with the position of the samples on every cross-section.

According to these tables we are resulted in following:

Mean size: The Mz of the Votonosi-Metsovo samples ranges from 3,12 ϕ to 5,04 ϕ (on the average 4,05 ϕ). The Mz of the Milea samples varies between 2,65 ϕ and 4,32 ϕ (on the average 3,49 ϕ). The Mz of the Kastanea samples ranges from 2,12 to 3,60 ϕ (on the average 2,7 ϕ). The Mz of Fournas samples varies between 2,78 ϕ and 3,31 ϕ (on the average 3,06 ϕ). The Mz of the Lidoriki samples ranges from 1,81 to 3,31 ϕ (on the average 2,57 ϕ).

Standard deviation/sorting: The σ1 of Votonosi-Metsovo samples averages 1,46 ϕ (1,03 ϕ to 2,21 ϕ). The σ1 of Milea samples averages 1,90 ϕ (1,51 ϕ to 2,28 ϕ). The σ1 of Kastanea samples averages 1,11 ϕ (0,72 ϕ to 1,50 ϕ). The σ1 of Lidoriki samples averages 1,93 ϕ (1,81 ϕ to 2,04 ϕ). The Votonosi-Metsovo, Milea and Lidoriki sediments are characterized as poorly to very poorly sorted. Therefore, this result in combination with the presence of little clay suggests a submature texture of sediments (Folk, 1974). The Kastanea and Fournas sediments are characterized as moderately to poorly sorted and in combination to the presence of little clay they show a less submature character.

Skewness: The Sk_I of Votonosi-Metsovo samples ranges from –0,05 to 0,46 (on the average 0,18). The Sk_I of the Milea samples varies from 0,46 to 0,52 (on the average 0,49). The Sk_I of the Kastanea samples ranges from 0,30 to 0,48 (on the average 0,38). The Sk_I of the Fournas samples ranges from –0,49 to 0,46 (on the average 0,12). The Sk_I of the Lidoriki samples varies from 0,11 to 0,34 (on the average 0,23). The Votonosi-Metsovo sediments are near-symmetrical to strongly fine-skewed, the Milea and Kastanea sediments strongly fine-skewed, the Fournas sediments strongly coarse to strongly fine-skewed and the Lidoriki sediments fine to strongly fine-skewed.

Kurtosis: The K_G of the Votonosi-Metsovo sediments ranges from 0,92 to 2,00 (on the average 1,29). The K_G of the Milea sediments varies from 1,92 to 2,24 (on the average 2,08). The K_G of the Kastanea sediments ranges from 1,03 to 1,31 (on the average 1,20). The K_G of the Fournas sediments varies from 0,76 to 1,69 (on the average 1,22). The K_G of the Lidoriki samples ranges from 1,35 to 1,47 (on the average 1,41). The Votonosi-Metsovo sediments are mesokurtic to very leptokurtic, the Milea sediments very leptokurtic, the Kastanea sediments mesokurtic to leptokurtic, the Fournas sediments platykurtic to very leptokurtic and Lidoriki sediments leptokurtic.

5 SCATTER DIAGRAMS OF THE STATISTICAL GRAIN-SIZE PARAMETERS

Data of the statistical grain-size parameters plotted on scatter diagrams in order to evaluate their relationships and their effectiveness in differentiating of the sedimentological behavior between at the study sections (fig. 3).

Figure 3A is the plot of graphic mean grain size versus inclusive graphic standard deviation. Low standard deviation values (<1 ϕ) characterize the sand class (fig. 2), higher values (1 ϕ – 1,5 ϕ) are associated with the silty sand and sandy silt classes (fig. 2) while the highest values (>1,5 ϕ) belong in the muddy class (fig.2). Moreover, the scatter diagram of figure 3A does not demonstrate any relationship between mean size and sorting. This suggests a similar process as flood where the river sediment suspension lies down without sorting (Kukal, 1969). Similar character has the turbidity deposits. Turbidites have poor sorting because coarse and fine material gets carried together as mass flow. The plot of graphic mean grain size versus inclusive graphic skewness is displayed in figure 3B and gives information regarding the measure of asymmetry. It shows that 19% of the sediments are near-symmetrical, 39% are fine-skewed, 39% are strongly fine-skewed and 3% are strongly coarse-skewed. Moreover, the positive skewness (78% of samples) is due to the competency of the unidirectional flow of the transporting media where the coarse end of the size frequency curve is “chopped off” (Friedman, 1961, 1962, 1967). Analogous conditions prevail during the turbidite deposition.

The plot of inclusive graphic standard deviation versus inclusive graphic skewness (fig. 3C) illustrates that the very poorly sorted sediments (>2 ϕ) are strongly fine-skewed, the moderately sorted sediments are near-symmetrical or strongly coarse-skewed and the poorly sorted sediments are fine to strongly fine-skewed. The scatter plot shows a turbidite field according to Bjorlykke (1989).

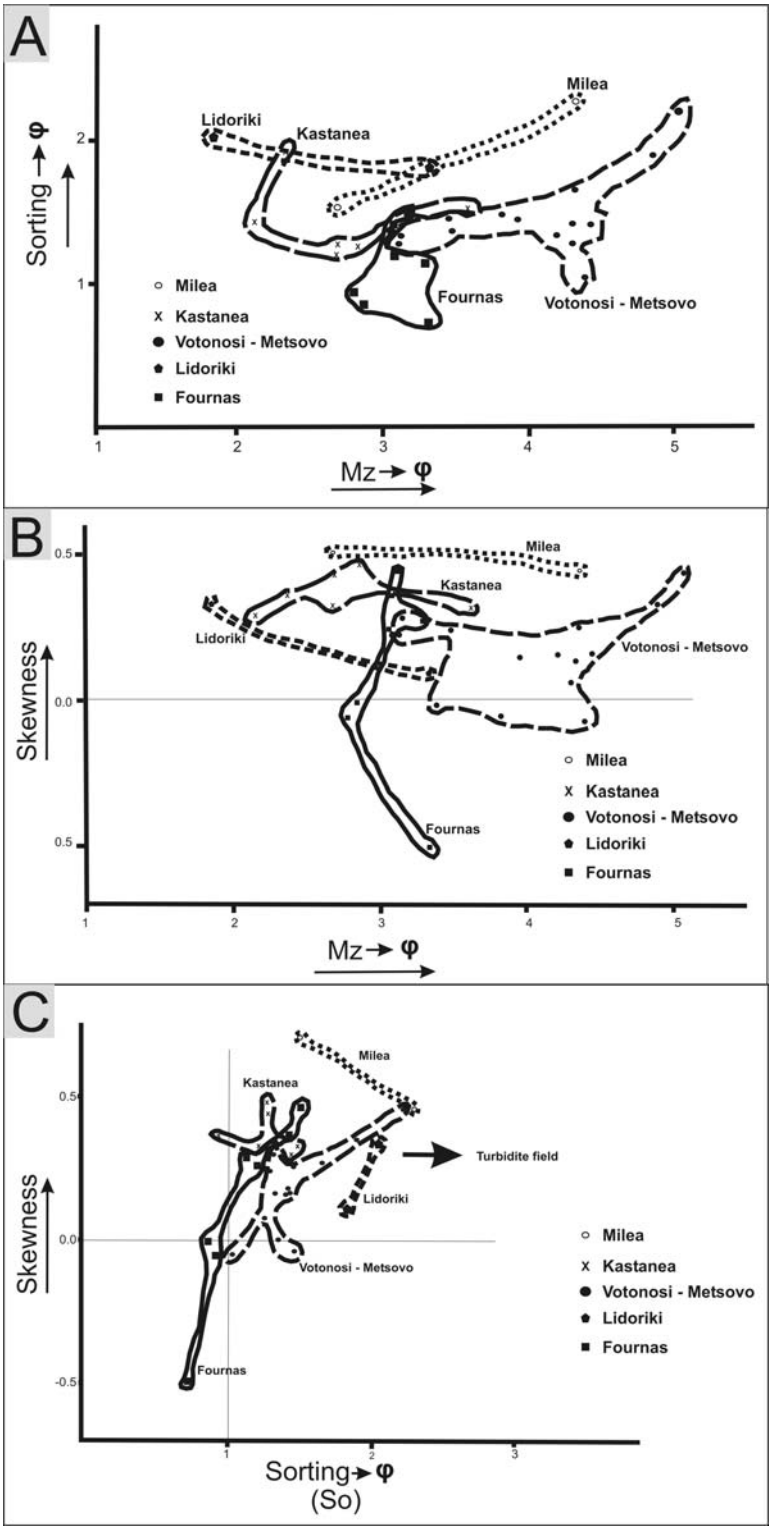

Figure 3: Scatter diagrams of the statistical grain-size parameters. A: Mean size in relation to sorting, B: Mean size in relation to Skewness, and C: Sorting in relation to Skewness.

6 HYDRAULIC PARAMETERS

Using Rubey's (1933) general formula, for settling velocities, we converted diameters of grains (mm), in settling velocity values (W in cm/sec). Furthermore, the cumulative curves were constructed, based on the logarithmic scale Psi=$-\log_2(W_m)$ of Middleton, (1967) (fig. 6). In order to estimate the mean palaeoflow velocity, at the time of deposition, the Psi_{50} values converted to settling velocities, from the cumulative hydraulic curves and using Middleton (1967) scale. The estimation of the mean flow velocity at the time of deposition, is based on Komar's (1985) hydraulic interpretation of turbidites and it is given by the following equation:

$$\bar{u} = {}^{Wm}\!\big/\!_{\sqrt{Cf}}$$

Where the ū is the mean flow velocity at the time of deposition, W_m is the settling velocity, which corresponds to 50-percentile, and C_f is a dimensionless drag coefficient. In the calculations of mean flow velocity, we used C_f=0.004, as proposed by Komar (1985) first.

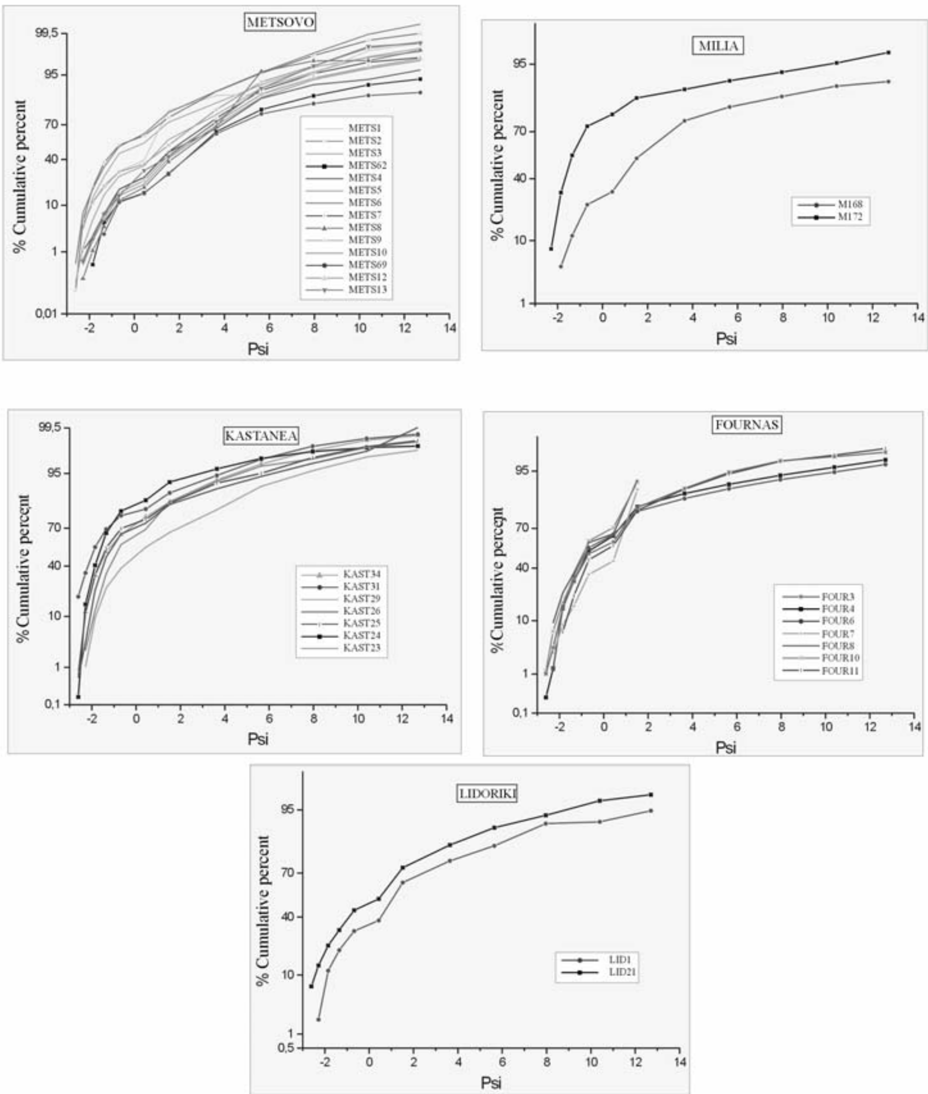

Figure 4. Cumulative curves of settling-velocity (Psi) distributions of samples from the studied cross-sections.

METSOVO

Table 6. Hydraulic and lithological parameters of samples from cross-section A-A´.

Sample	Bed thickness (cm)	Bouma sequence	Classification of sample	Mean flow velocity (cm/sec)
METS1	19	Ta	Silty sand	9,75
METS2	17	Ta	Silty sand	27,34
METS3	11	Ta	Silty sand	17,18
METS62	15	Ta	Sandy silt	2,16
METS4	30	Ta	Sandy silt	4,24
METS5	11	Ta	Silty sand	7,13
METS6	10	Tb, Tc	Silty sand	25,86
METS7	10	Ta	Sandy silt	4,7
METS8	14	Ta	Sandy silt	3,12
METS9	13	Tc	Silty sand	6,2
METS10	14	Ta	Sandy silt	3,49
METS69	15	Ta	Sandy silt	2,27
METS12	8,5	Ta	Sandy silt	3,98
METS13	10	Ta	Sandy silt	3,87

For samples from Metsovo area (table 6), the higher value of mean flow velocity was 27,34 cm/sec (METS2), instead the lower value was 2,27 cm/sec (METS69).

MILIA

Table 7. Hydraulic and lithological parameters of samples from cross-section B-B´.

Sample	Bed thickness (cm)	Bouma sequence	Classification of sample	Mean flow velocity (cm/sec)
M168	10	Ta	Muddy sand	6,22
M172	17	Ta	Silty sand	43,32

The average value for Milea samples was 24,77 cm/sec (table 7).

KASTANEA

Table 8. Hydraulic and lithological parameters of samples from cross-section C-C´.

Sample	Bed thickness (cm)	Bouma sequence	Classification of sample	Mean flow velocity (cm/sec)
KAST34	12	Ta	Silty sand	41,52
KAST31	11	Ta	Sand	61,52
KAST29	9	Ta	Silty sand	14,95
KAST26	16	Ta	Silty sand	37,35
KAST25	13	Ta	Silty sand	43,41
KAST24	11	Ta	Sand	50,23
KAST23	13	Ta	Silty sand	29,30

For samples from Kastanea area (table 8), the higher value of mean flow velocity was 61,52 cm/sec (KAST31), instead the lower value was 14,95 cm/sec (KAST29).

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Table 9. Hydraulic and lithological parameters of samples from cross-section D-D´.

Sample	Bed thickness (cm)	Bouma sequence	Classification of sample	Mean flow velocity (cm/sec)
FOUR3	13	Ta	Silty sand	25,69
FOUR4	15	Ta	Silty sand	26,59
FOUR6	15	Ta	Silty sand	28,5
FOUR7	16	Ta, Tb	Sand	10,65
FOUR8	17	Ta	Sand	30,55
FOUR10	8	Ta	Sand	29,92
FOUR11	16	Ta	Silty sand	19,74

For Fourna samples (table 9), the higher value of mean flow velocity was 30,55 cm/sec (FOUR8), while the lower value was 10,65 cm/sec (FOUR7).

LIDORIKI

Table 10. Hydraulic and lithological parameters of samples from cross-section E-E´.

Sample	Bed thickness (cm)	Bouma sequence	Classification of sample	Mean flow velocity (cm/sec)
LID1	17	Tb	Silty sand	8,23
LID21	19	Ta	Silty sand	15,06

The average value for lidoriki samples was 11,65 cm/sec (table 10).

7 CONCLUDING REMARKS

Samples from Metsovo (A-A´), Milia (B-B´), Kastanea (C-C´) and Lidoriki (E-E´) are characterized mainly as poorly sorted to very poorly sorted, while samples from Fournas area (D-D´) are characterized as moderately to poorly sorted. This sorting character confirms the presence of subdivition Ta of Bouma sequence and indicates that low energy turbidity currents deposited the analyzed sediments.

Almost all samples show a positive skewness. This value of skewness is due to the competency of the unidirectional flow of the transporting media where the coarse end of the size frequency curve is “chopped off”. Analogous conditions prevail during the turbidite deposition.

The most of the samples (68%) were characterized by leptokurtic to very leptokurtic curves. The remain samples are mesokurtic, except samples FOUR8 and FOUR10 which are platykurtic. The kurtosis values in combination with the sorting values are plotted in the turbidite field according to Bjorlykke (1989).

The mean flow velocity at the time of deposition from samples coming from areas except Kastanea (C-C´), ranged from 2.27 to 30 cm/sec, showing that these turbidites were deposited from sandy low-density turbidity currents (according to Nelson & Nilsen, 1984, low-density turbidity currents have mean flow velocities lower than 25 cm/sec). On the other hand, samples coming from Kastanea area showed slightly higher mean palaeoflow velocities at the time of deposition ranging from 14.95 to 61.51 cm/sec and deposition from higher density sandy turbidity currents than the other areas. Furthermore, a correlation between the mean palaeoflow velocity and the grain size was confirmed. Thus, the lower mean palaeoflow velocities were found on sandy silt samples (cross-section A-A´), while the higher on sand samples (cross-section C-C´).

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