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HYDRAULIC DETERMINATION AND PALAEOFLOW TRENDS OF TURBIDITE DEPOSITS IN KLEMATIA- PARAMYTHIA BASIN

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ABSTRACT

The Klematia-Paramythia basin consists of thick turbidite sequences that deposited as submarine fans during middle Eocene to late Miocene. The hydraulic statistical parameters show that these turbidites may have been deposited by two distinct in grain concentration, low-density flows. The mean palaeoflow velocity at the time of deposition ranged from 0.1-18cm/sec. Using lenticular lobes, sole marks, and channels the palaeoflow trends can be reconstructed. These palaeoflow indices suggest that during middle Eocene to late Oligocene the palaeoflow trends of the submarine fans were almost the same with the direction of progradation of Pindos foreland, ENE-WSW. During early Miocene to late Miocene the palaeoflow trends changed as both palaeoflow indices with NNW-SSE and ENE-WSW directions have been observed.

KEY WORDS: western Greece, turbidites, hydraulic patterns, palaeoflow regime.

1. INTRODUCTION

The grain size and the composition of sediments are related to the source material, the mode and the agent of transport. In submarine fans the transport of the sediments is made by turbulent and turbiditic currents. Fluid turbulence is the mechanism for the transport of sediments in suspension and the turbiditic currents are the way to describe this type of transport.

Turbiditic currents carry large volumes of sand into the deep ocean and deposit their load when velocity is reduced and the relief becomes gentle. The turbidite deposits are characterized by the Bouma sequence (Bouma, 1962) and are related to the submarine fan and fan facies models association (Mutti & Ricci-Lucchi, 1975). A complete Bouma sequence from the base upward consists of massive sand (Ta), laminated sand (Tb), cross - laminated sand or convolute bedding (Tc), laminated silt - sand (Td) and laminated mud (Te) (fig.1). The divisions of Bouma sequence represent the flow parameters of a waning current and the flow conditions at the time of deposition. According to Walker (1965) the massive unit indicates the upper flow regime, the laminated sand unit shows a shooting flow regime, the cross - laminated sand and the laminated silt - sand the lower part of the lower flow regime. Continuity to laminated silt - sand division is the laminated mud, which is settled from suspension.

A number of researchers have made hydraulic interpretations of turbidite deposits based on experiments using suspension or autosuspension criteria. There are attempts which evaluate the hydraulic conditions during the development of the turbidite current, from their grain size and their structures (Middleton, 1967; Lowe 1982; Komar 1985). All these attempts have been made in order to estimate the nature of the flow (water versus air) and evaluate the flow velocity and the bottom stresses at the time of deposition.

Another element for estimating the hydraulic conditions, is the direction where the flow develops. The palaeocurrent direction in an ancient submarine fan can be derived from erosional structures such as sole marks, slumps and channels. The *sole marks*, as erosional structures, are usually observed in the beginning of the Bouma sequence or generally in the bases of coarser beds in interbedded sequences. Slumps and channeled structures are recognized in vertical sections in the inner fan and lobes with lenticular geometry in the outer fan.

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The aim of the present paper is to estimate the hydraulic characteristics of turbidite deposits in Klematia-Paramythia basin and the palaeoflow directions of the submarine fans development. Moreover, calculated hydraulic parameters of this study will be compared to experimental results of other works.

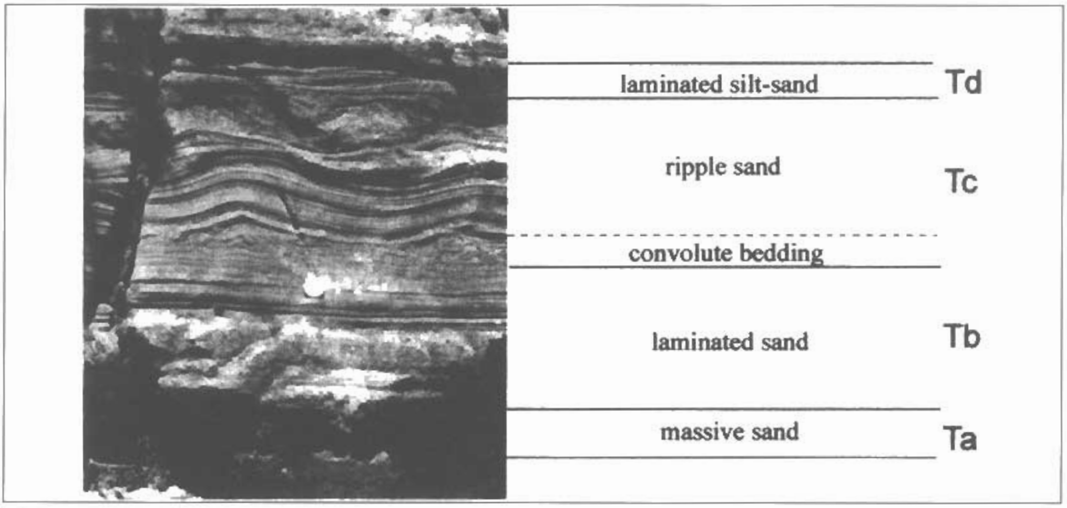

Figure 1: Turbidite unit showing the Bouma intervals Ta, Tb, Tc and Td, as it has been observed in Klematia - Paramythia basin.

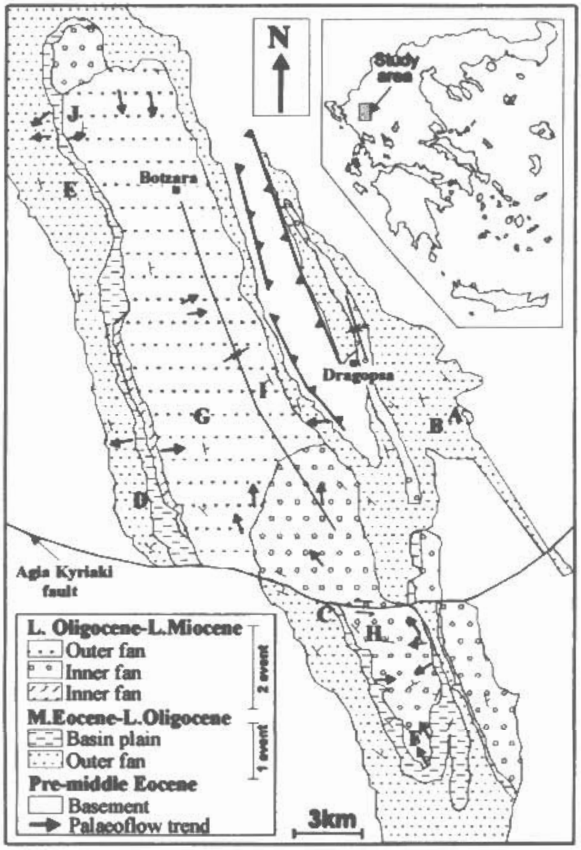

Figure 2: Sub-environme[illegible]in turbidite complex.

2. GEOLOGICAL SETTING

The Klematia - Paramythia basin belongs to the middle Ionian zone (I.G.S.R & I.F.P., 1966) and consists of, middle Eocene to late Miocene, thick turbidites, deposited as submarine fans. The studied basin is about 48km long and <15km wide with a NW-SE trend, parallel to the isopic zones of external Hellenides (Aubouin, 1965). During middle Eocene to early Miocene, Gavrovo and Ionian zone, were a foreland basin (Underhill, 1985), which was formed on the footwall of Pindos thrust. According to Avramidis et al. (1997) the configuration and the depositional environments of the studied basin were affected by two tectonic events. During the first tectonic event, middle Eocene to late Oligocene, Ionian zone was a foreland basin and in the studied area outer fan and basin plain deposits were accumulated up to 1050m thick. During the second tectonic event, late Oligocene to late Miocene, due to the Ionian zone subdivision, in the study basin both inner and outer fan deposits were formed, up to 2300m thick (fig.2).

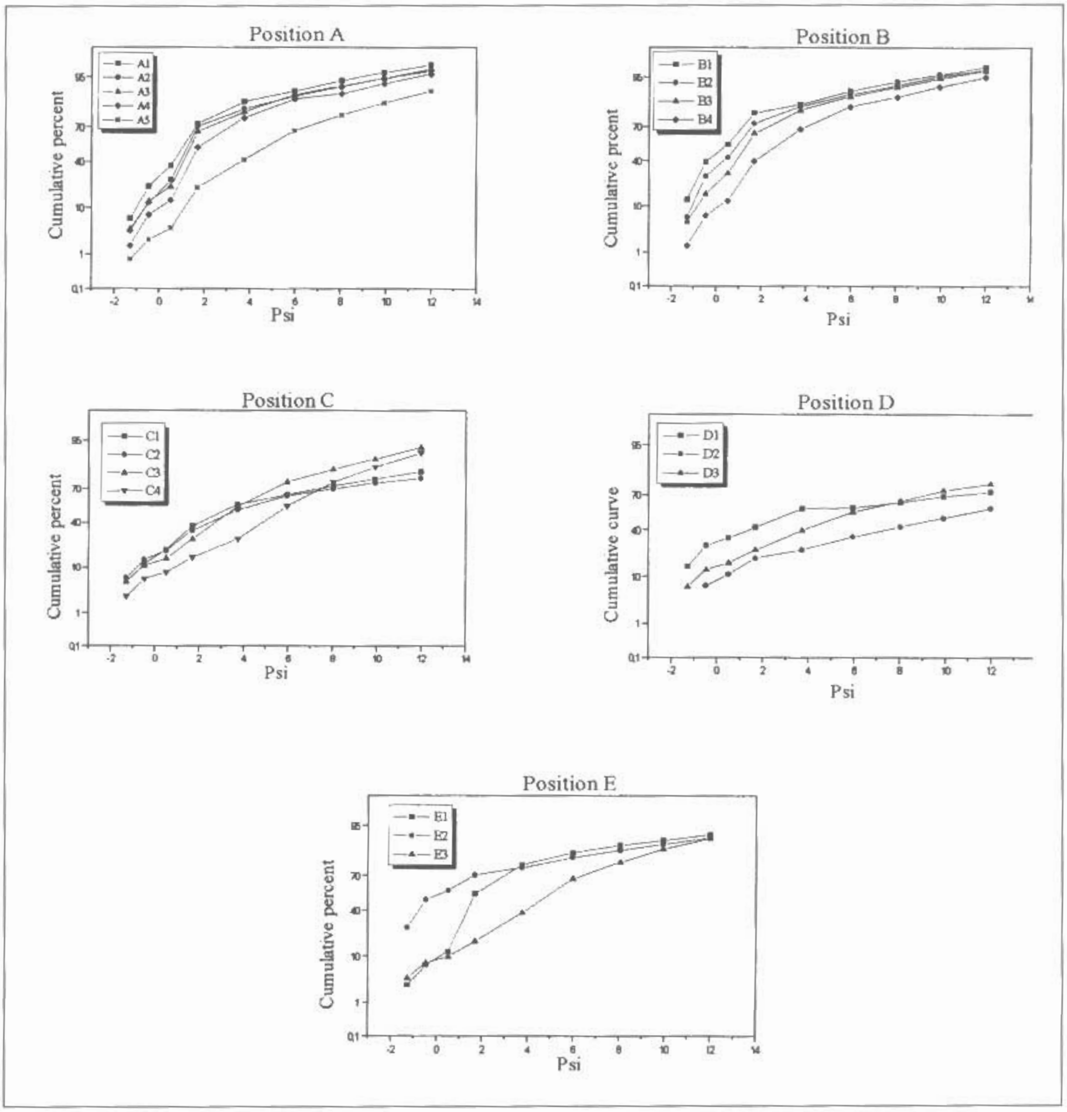

Figure 3: Cumulative curves of settling velocity (Psi) distributions through Bouma sequences of the middle Eocene to late Oligocene age.

Position A

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
A1	1,99	0,2	0,52	8,35	Ta	2
A2	2,17	0,4	0,44	7,02	Tb	13
A3	2,12	0,51	0,4	6,46	Tb	23
A4	2,26	0,56	0,32	5,14	Tc	32
A5	3,99	0,25	0,04	0,71	Td	39

Position B

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
B1	2,32	0,41	0,86	13,6	Ta	2
B2	2,32	0,33	0,58	9,2	Tb	27
B3	2,46	0,31	0,42	6,69	Tc	40
B4	2,76	0,37	0,18	2,93	Td	42

Position C

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
C1	6,05	0,53	0,12	1,92	Ta	2
C2	8,26	0.58	0.08	1.35	Tb	8
C3	4	0,35	0,09	1,57	Tc	14
C4	3,79	0,05	0,02	0,32	Td	19

Position D

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
D1	9,44	0,59	0,15	2,41	Ta	2
D2	8,28	-0,01	0,01	0,01	Tb	29
D3	7,01	0,32	0,02	0,43	Tc	35

Position E

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
E1	2,39	0,61	0,32	5,21	Ta	2
E2	4,17	0,66	1,22	19,33	Tb	22
E3	3,66	0,18	0,04	0,63	Tc	42

Figure 4: Statistical parameters of settling velocity distributions and hydraulic measurements of middle Eocene to late Oligocene turbidite samples.

3. METHOD

In order to estimate the hydraulic characteristics and the palaeocurrent conditions 10 positions have been selected from the whole basin, which are characterized by the Bouma sequence. These sequences include at least the Ta, Tb and Tc divisions. From each position 3-5 samples were collected, vertical to the Bouma sequence, and were analyzed for their grain size. The total thickness of the Bouma sequences ranged from 21cm up to 51cm with an average thickness of 40cm. The grains were separated using 20% solution of perydrol (H_2O_2) and trisodium phosphate. The boiling with these reagents had good results in grain separation, as this were tested by the microscopic examination of the samples. In 6 out of 10 selected positions only the Ta, Tb and Tc divisions were distinguished, as Td division was missing.

Using Rubey's (1933) general formula, for settling velocities, we converted diameters of grains (mm), in settling velocity values (W in cm/sec). The cumulative curves were constructed, based on the logarithmic Psi=-$\log_2(W_m)$scale where W_m is the measured settling velocity, a scale proposed by Middleton (1967) first. From the hydraulic cumulative curves the statistical parameters such as sorting and skewness were calculated, based on Inman (1952) equations. 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. According to this interpretation the mentioned mean flow velocity is given by the following equation:

$$\bar{u} = \frac{W_m}{\sqrt{C_f}}$$

where the u 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. Values of C_f in the range 0.0035-0.005 have been employed by Jonson, (1964), Bowen et al. (1984), and Komar (1985). In the calculations of mean flow velocity, we used C_f=0.004, as proposed by Komar (1985) first.

The palaeocurrent directions came from palaeoflow data such as sandstone lobes with lenticular geometry (from outer fan), channels (from inner fan) and erosional structures (sole marks) (from both outer and inner fan).

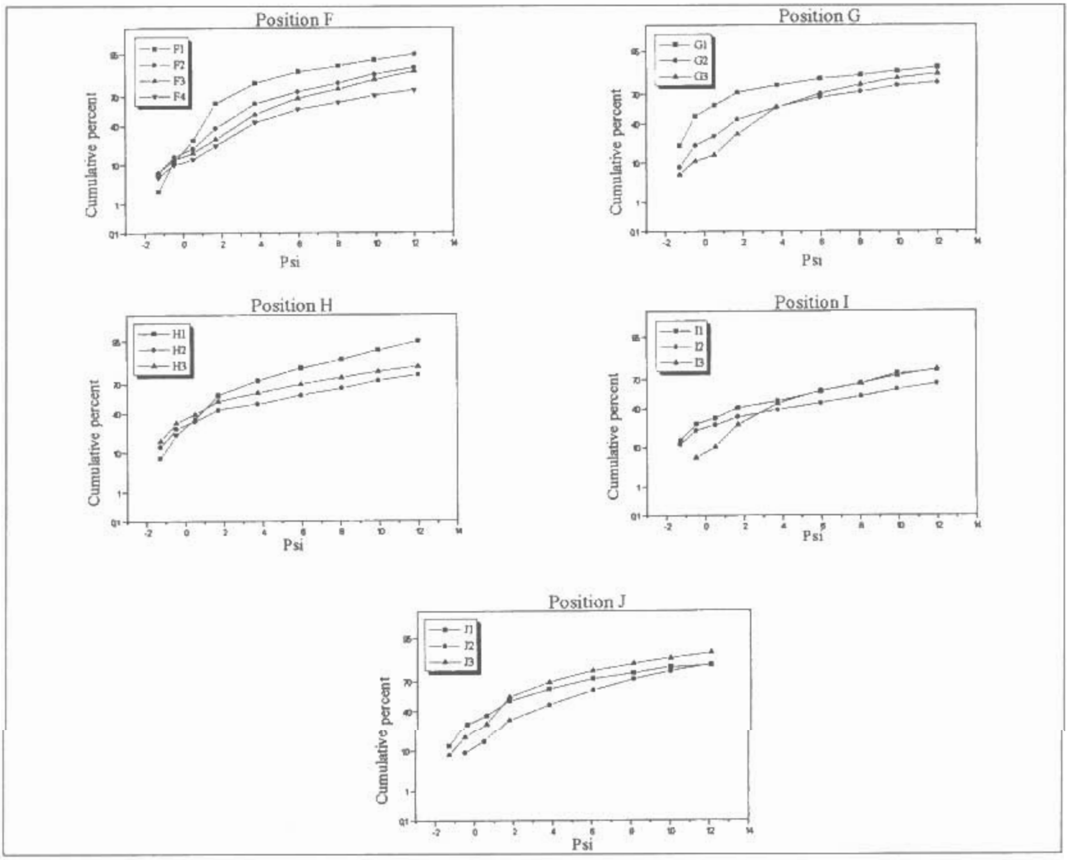

Figure 5: Cumulative curves of settling-velocity (Psi) distributions through the Bouma sequences of the early Miocene to late Miocene deposits.

Position F

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
F1	2,55	0,43	0,41	6,51	Ta	2
F2	4,69	0,41	0,15	2,39	Tb	18
F3	5	0,34	0,08	1,27	Tc	32
F4	6,98	0,44	0,03	0,52	Td	41

Position G

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
G1	4,63	0,73	1,19	18,93	Ta	2
G2	7,44	0,54	0,15	2,43	Tb	20
G3	5,46	0,5	01	1,58	Tc	38

Position H

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
H1	3,43	0,42	0,4	6,42	Ta	2
H2	8,58	0,45	0,07	1,25	Tb	16
H3	6,63	0,57	0,36	5,74	Tc	28

Position I

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
I1	8,65	0,38	0,05	0,86	Ta	2
I2	9,46	0,14	0.01	0,1	Tb	12
I3	6.91	0,48	0,04	0,64	Tc	26

Position J

Sample	Sorting	Skewness	Settling velocity	Mean flow velocity	Bouma division	Distance (cm)
J1	8,44	0,38	0,05	0,86	Ta	2
J2	5.86	0,14	0,01	0,1	Tb	16
J3	4,42	0,48	0,04	0,64	Tc	38
J4	4,5	0,42	0,01	0,1	Td	50

Figure 6: Statistical parameters of settling velocity distributions and hydraulic measurements of the early to late Miocene turbidite samples.

4. SAMPLING AND PRESENTATION OF RESULTS

Middle Miocene - late Oligocene turbidites

Samples have been collected from the turbidites which were accumulated during the first tectonic event(middle Eocene-late Oligocene). The localities of sampling are showed in figure 2. The positions A,B,C,D and E are referred to turbidite deposits of middle Eocene to late Oligocene age. The cumulative curves of settling velocity (Psi) distributions are presented in figure 3. The numeration of the samples has been made from the base to the top of Bouma sequences.

The results of the middle Eocene to late Oligocene Bouma sequences are given in figure 4. In this figure, we present the statistical and hydraulic parameters such as sorting, skewness, settling velocity, mean flow velocity, Bouma intervals and the distance from the base of Bouma sequence which the samples have been collected. The mean flow velocities for the samples of the first tectonic event, ranged from 0.01-19.33cm/sec and the mean value was 4.91cm/sec.

Early Miocene - late Miocene turbidites

Samples have been collected from the Bouma sequences which were formed during the second tectonic event(early-late Miocene). The positions where the sampling has been made are indicated in figure 2. These positions are F,G,H,I and J. The cumulative curves of settling velocity (Psi) distributions are presented in figure 5 and the statistical parameters and hydraulic measurements are presented in figure 6. The mean flow velocities for the second tectonic event ranged from 0.01-18.93cm/sec and the mean value was 2.96cm/sec.

5. PALAEOFLOW TRENDS

The palaeoflow trends during the first tectonic event (middle Eocene-late Oligocene), have been estimated from the sandstone lobes and the sole marks. The sandstone lobes suggests E-W and ENE-WSW trends (fig.2). These directions also are the directions of the submarine fan progradation, which were developed in return to the beginning of Pindos thrust activity. Moreover, the statistical analysis of 42 sole marks indicates a ENE-WSW palaeoflow direction(fig.7a). Both the sandstone lobes and the sole marks of middle Eocene to late Oligocene age suggests that the development of the submarine fans was almost parallel to the westward progradation of external Hellenides.

The palaeoflow trends, during the second tectonic event (early Miocene - late Miocene), have been estimated from channeled sandstones, observed in the inner fan, lenticular sandstone lobes, observed in the outer fan and from 41 sole marks. The channeled sandstones and the sandstone lobes indicate a NNW-SSE and a WSW-ENE development directions of the submarine fan (fig.2). The statistical analysis of the sole marks indicates two major palaeoflow directions which have already observed from channels and sandstone lobes (NNW-SSE and WSW-ENE)(fig. 7b).

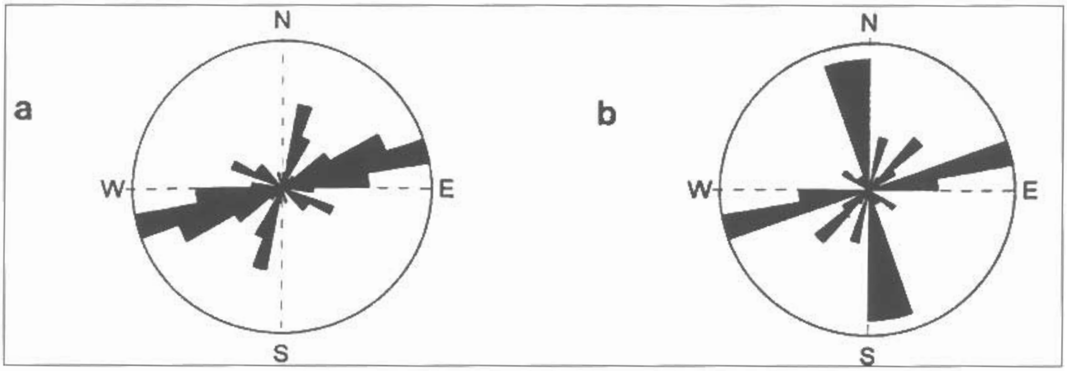

Figure 7: Rose diagrams of 42 sole marks of the first (a) and 41 sole marks of the second tectonic event (b).

6. CONCLUDING REMARKS

1. According to Lowe (1982) the studied turbidites are the product of the low-density turbidity currents as the identified grain size population is clay, silt and fine- to about medium-grained sand.

2. The basal samples (Ta) always show positive skewness. Moreover, the skewness reaches either a maximum in the Bouma sequences upwards and then decreases near the top (fig.4,6) (A,C,E,G,H) or a minimum upwards and then increases near the top(fig.4,6) (B,D,E,J,I). These trends in skewness are similar to those which have been noted earlier from experimental turbidites (Middleton, 1967). The trends are generally clearly developed suggesting that all the studied Bouma sequences came from the low concentration. The strong positive skewness has not been developed in experimental turbidites, as it was noted by Middleton, (1967). The median values of the Psi scale decreased upwards uniform through the

A,B,F and G Bouma sequences (fig.4,6). On the contrary the C,D,E,H,J and I Bouma sequences do not show so clear vertical decrease of this statistical parameter (fig.4,6). This result suggests that the A,B,F and G Bouma sequences came from lower 'low concentrations' rather than the C,D,E,H,J and I ones (Middleton, 1967).

3. The sorting generally increases upwards from the base of the A,B,E,F,G and H Bouma sequences (fig.4,6). Experimental studies of Middleton (1967) showed the same trends. The sorting of C,D,J and I Bouma sequences decreases upwards (fig.4,6). This trend suggests slow deposition Komar (1985) (flow velocities, in fig.4,6).

4. The mean flow velocity at the time of deposition decreased upwards uniform through the A,B,F and G Bouma sequences (fig.4,6). This trend is similar to this which has been noted by Komar (1985). On the contrary, the C,D,E,H,J, and I Bouma sequences do not show so clear vertical decrease of the flow velocity. The flow velocity trend may suggests that the A,B,F and G Bouma sequences are the result from a lower concentrations than the remaining Bouma sequences.

5. The mean flow velocity values are higher in the A and B Bouma sequences than in the C,D ones of middle Eocene-late Oligocene age. Also, the Tb interval of E Bouma sequence indicates an abnormal high flow velocity. The existence of higher velocity values at A and B than at C,D and E, Bouma sequences can be explained by the positions in which the Bouma sequences are situated in the basin. The A and B sequences are situated in the more proximal parts of the outer fan (fig.2), so the hydraulic interpretation indicates high flow velocities.

6. From the early to late Miocene Bouma sequences (F,G,H,I,J), the sequence G seems to have the higher flow velocities. The sequence G is situated near the inner fan of the western part of the basin. So the high flow velocities represent the more proximal part of the outer fan. Moreover the sequence I has the lowest flow velocities than the other sequences because the sequence I is situated far away from the feeding channels. During the mentioned period the feeding channels were restricted in Dragopsa syncline (fig.2). The other Bouma sequences F,H and J show intermediate flow velocities. Although these sequences are closed to inner fan, may be their slope gradient was gentler than this in the western part of Botzara syncline, where sequence G is situated.

7. The palaeoflow trends of the submarine fans development are related to the basin evolution. During middle Eocene to late Oligocene the palaeoflow directions were almost parallel to the direction of the external Hellinides progradation, ENE-WSW. During early to late Miocene, due to the Ionian zone subdivision, two major palaeoflow trends, the first ENE-WSW and the second NNW-SSE, were characterized palaeoflow development of the submarine fan.

REFERENCES

ABOUIN, J., 1965. Geosynclines. Elsevier, Amsterdam.

AVRAMIDIS, P., ZELILIDIS, A. & KONTOPOULOS N., 1997. Depositional environments and reservoir properties in Klematia - Paramythia basin, Western Greece. IAS Regional European Meeting of Sedimentology, GAEA heidelbergensis **3**, 51-52.

BOUMA, A.H., 1962. Sedimentology of some Flysch Deposits. Elsevier, Amsterdam, 162pp.

BOWEN, A.J., NORMARK, W.R. & PIPER, D.J.W., 1984. Modelling of turbidity currents on Navy submarine fan, California. Sedimentology **31**, 169-185.

INSTITUTE FOR GEOLOGY SUBSURFACE RESEARCH OF GREECE & INSTITUTE FRANCAIS DE PÉTROLE, 1966. Etude geologvque de l' Epire. Technip, Paris, France.

JONSON, M.A., 1964. Turbidity currents. Ann. Rev. Ocean. Org. Mar. Biol. **2**, 31-43.

LOWE, D.R., 1982. Sediment gravity flows: II Depositional models with special reference to the deposits of high-density turbidity currents. Journal of Sedimentary Petrology **52**, 1, 279-297.

KOMAR, P.D., 1985. The hydraulic interpretation of turbidites from their grain sizes and sedimentary structures. Sedimentology **32**, 295-407.

MIDDLETON, G.V., 1967. Experiments on density and turbidity currents, 3. The deposition of sediment.

Can. J. Earth Sci. **4**, 475-505.

MUTTI, E. & RICCI LUCCHI, F., 1975. Turbidite facies and facies associations. In: E. Mutti et al. (Editors), Examples of turbidite facies and associations from selected formations of the Northern Apennines. Field Trip Guidebook A-11, 9th International Association of Sedimentologists Congr., Nice, 21-36.

RUBEY, W.W., 1933. Settling velocity of gravel, sand, and silt particles. Am. Jour. Sci. **25**, 325-338.

UNDERHILL, J.R., 1985. Neogene and quaternary tectonics and sedimentation in Western Greece. PhD Thesis. University of Wales, Cardiff.

WALKER, R.G., 1965. The origin and significance of the internal sedimentary structures of turbidites. Proc. Yorkshire Deol.Soc. **35**, 1-32.