Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, Τομ. XXXIV/2, 755-762, 2001
Πρακτικά 9ου Διεθνούς Συνεδρίου, Αθήνα, Σεπτέμβριος 2001

Bulletin of the Geological Society of Greece, Vol. XXXIV/2, 755-762, 2001
Proceedings of the 9th International Congress, Athens, September 2001

DEPOSITIONAL ENVIRONMENTS OF TERTIARY TURBIDITIC SEDIMENTS IN METSOVO BASIN, NW GREECE

G. ANANIADIS[1] & A. ZELILIDIS[1]

ABSTRACT

Tertiary sediments in Metsovo area consist of submarine fan turbidite deposits accumulated in the proximal part of the basin and represent mostly inner fan. The most proximal part of the inner fan could be related to a shelf environment. Palaeocurrent data indicate mainly two directions. The main direction is SW and results mainly from groove marks. The second direction represents an WNW trend which results mainly from flute marks. The Metsovo area seems to have multiple feeders from North and East. The total thickness of the turbiditic deposits in Metsovo area is approximately 6800 m due to tectonic stacking and folding.

KEY WORDS: Metsovo basin; submarine fan; turbidites; sole marks.

1.INTRODUCTION AND GEOLOGICAL SETTING

Submarine fans are constructional features on the see floor that develop seaward of a major sediment point source (Stow et al. 1996). According to Ricci Lucchi (1975) the development of a submarine fan is characterized by four major elements:(a)inner fan, (b) middle fan, (c)outer fan and (d)basin plain. The inner fan represents the proximal part of the submarine fan and consists of channel-fill, interchannel, levee and mouth bar deposits. The middle fan is characterized by both inner and outer fan features. The outer fan consists of lobes and lobe-fridge deposits. The basin plain represents the most distal parts of the fan and consists of mudstone and siltstone sediments. The transport of the sediment is made by turbidity currents. The sediment is sustained by fluid turbulence and deposited when velocity and gradient are reduced.

The sequence of sedimentary structure in turbidity beds are known as the Bouma sequence (Bouma, 1962). The ideal deposits of a turbidity current contains the complete (T_{a-e}) Bouma sequence which it consists from base to top of massive sand (T_a), laminated sand (T_b), rippled or convoluted sand (T_c), laminated silt-sand (T_d) and laminated mud (T_e).

The hydraulic conditions during the development of the turbidity currents are estimated from the grain size, structures and direction of flow. The palaeocurrent direction in a ancient submarine fan can be derived from erosional structures such as sole marks, ripple lamination and channels.

The Metsovo area is located in Northwestern Greece and belongs to the Pindos zone (Fig. 1). The area aligns parallel to the external Hellenides, that consist, from east to west, of the Pindos, Gavrovo, Ionian and the Pre-Apulian geotectonic zones (Aubouin, 1965). The external Hellinides represent parts of the Apulian plate which were separated from the Pelagonian microplate by the Pindos ocean (Robertson et al. 1991; Jones et al., 1992). The Pindos zone corresponds to the western marginal domain of the Pindos ocean. The terminal flysch deposition commenced in the Palaeocene and lasted until Oligocene times (Koch and Nicolaus, 1969; Fleury, 1980; Richter, 1993; Richter et al., 1993).

The Metsovo area is bounded from the Pindos Thust to the west and from the Pindos ophiolite to the east (Fig. 1). The Pindos flysch in Metsovo area according to Aubouin (1959, 1964) was deposited between Maestrichtian – Priabonian time. Lorsong (1977) referred to the area as Politses formation dividing the Pindos flysch (Metsovo area in this work) into members, based on outcrops in different places and not in detailed mapping. The four members from base to top are: the Chrisovitsa Member (red shales and limestones), the Ilias Member (turbidite conglomerates and sandstones), the Karakoli Member (thin bedded turbidites) and the Keramari Member (thick bedded turbidites).The succesion of sediments exist in at least 18 tectonic units bounded by high-angle thrust surfaces (Lorsong, 1977). Moreover Lorsong (1977), believes that the stratified part of the Pindos flysch in Metsovo is approximately 530 m, although Aubouin (1959) suggested thickness between 1000 m and 2000 m or more. According to Katsiavrias (1983), the base of the formation is not the red shales of Chrisovitsa Member but gray bluish massive non-bedded marls.

1. Department of Geology, University of Patras, 26500 Patras

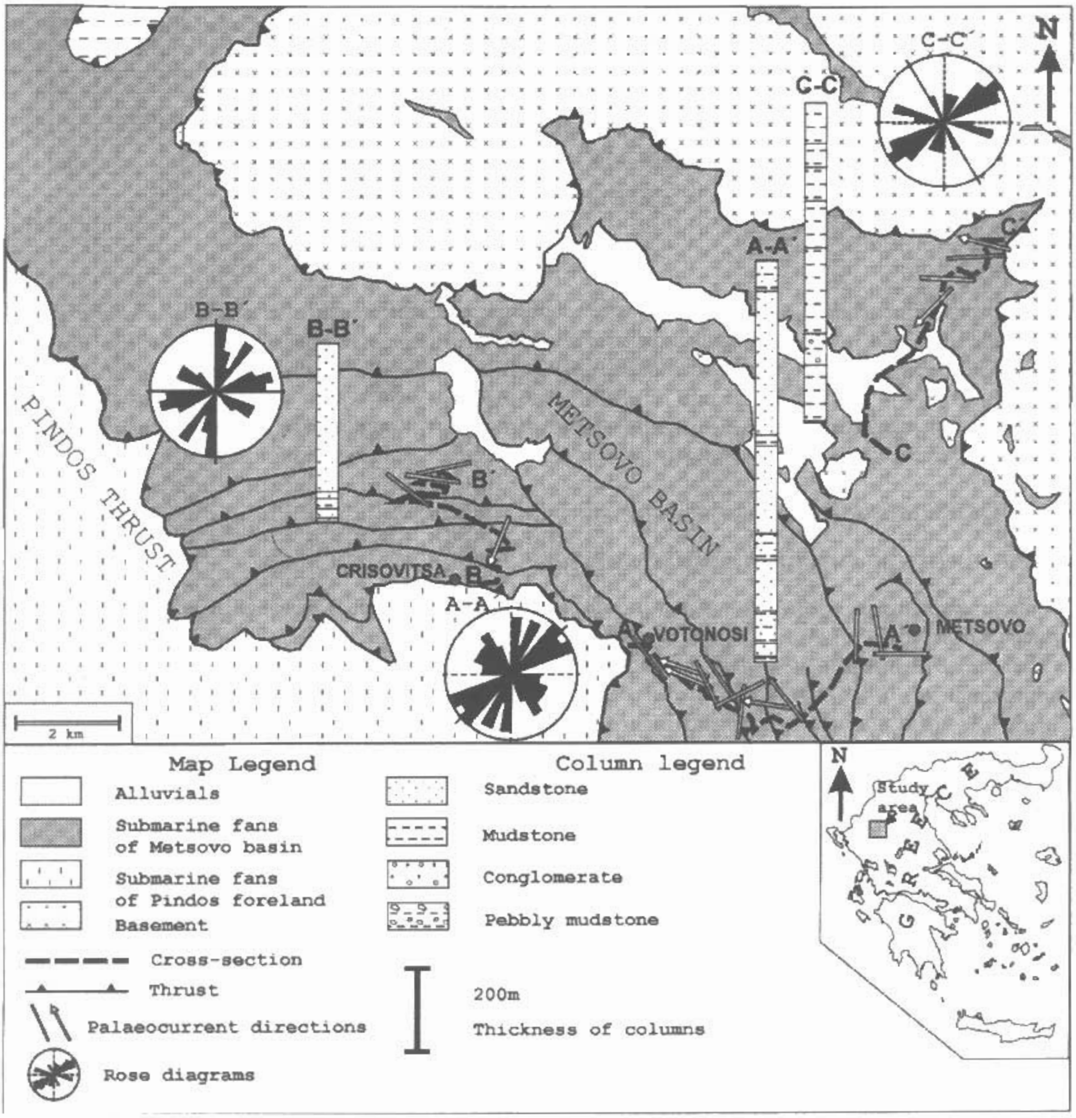
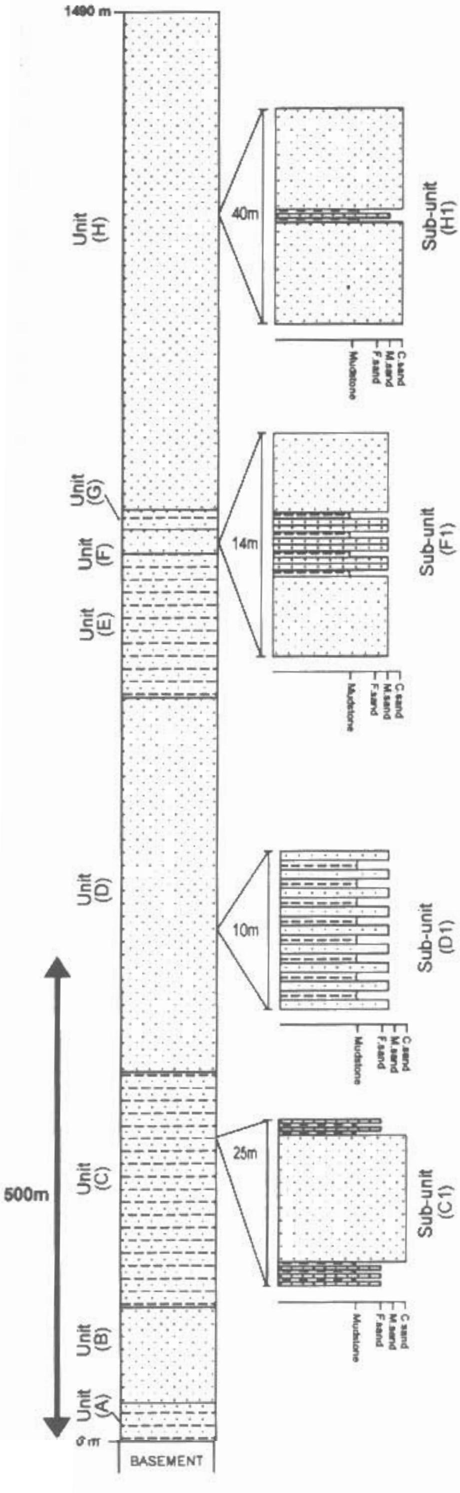


Fig.1 Geological map of the study area. Includes roses, palaeoflow trends and columns for each cross-section.

The aim of this paper is to study the sedimentary successions of the Tertiary turbiditic deposits in the Metsovo basin in order to understand and recognize the depositional conditions and depositional environments that formed in the Metsovo basin which is part of the Pindos zone. Moreover, palaeocurrent analysis will give informations about the feeding sources of the sediments.

2. DEPOSITIONAL ENVIRONMENTS

In order to better understand the depositional setting and stratigraphic architecture, the sediments in Metsovo area have been studied in three main cross-sections (fig.1). The first cross-section (A-A´) is situated in the central part of the area along the main road Votonosi-Metsovo (Fig. 2). The second cross- section (B-B´) is situated in the western part of the area (Fig. 3) and the third cross-section (C-C´) in the eastern part of the area (Fig.4).



Cross-section A-A΄(Votonosi-Metsovo)

H) Coarse brown sandstones with total thickness of 520 m and maximum bed thickness 5 m. The sandstones are characterized mostly by T_a intervals. A sub-unit of cyclic alternations up to 2 m thick consists of medium brown sandstone and greyish mudstone with s:m ratio 1:1 (H1).

G) Cyclic alternations with total thickness up to 20 m of brown greenish sandstones and grayish mudstones with s:m ratio 1:1. The maximum thickness of the sandstone bed is 20 cm. The sandstone is characterized mostly by Tc Bouma ripple lamination.

F) Medium brown sandstones with total thickness of 25 m and maximum bed thickness 2,5 m. Bouma interval T_a is mostly present. A sub-unit of cyclic alternations up to 5 m thick consist of medium brown sandstones and greyish mudstone with s:m ratio 2:1 (F1).

E) Cyclic alternations up to 150 m, of medium to fine brown greenish sandstones and grayish mudstones with s:m ratio 1:1. The maximum thickness of the sandstone bed is 20 cm. The sandstone is characterized mostly by T_c Bouma interval which represent ripple lamination.

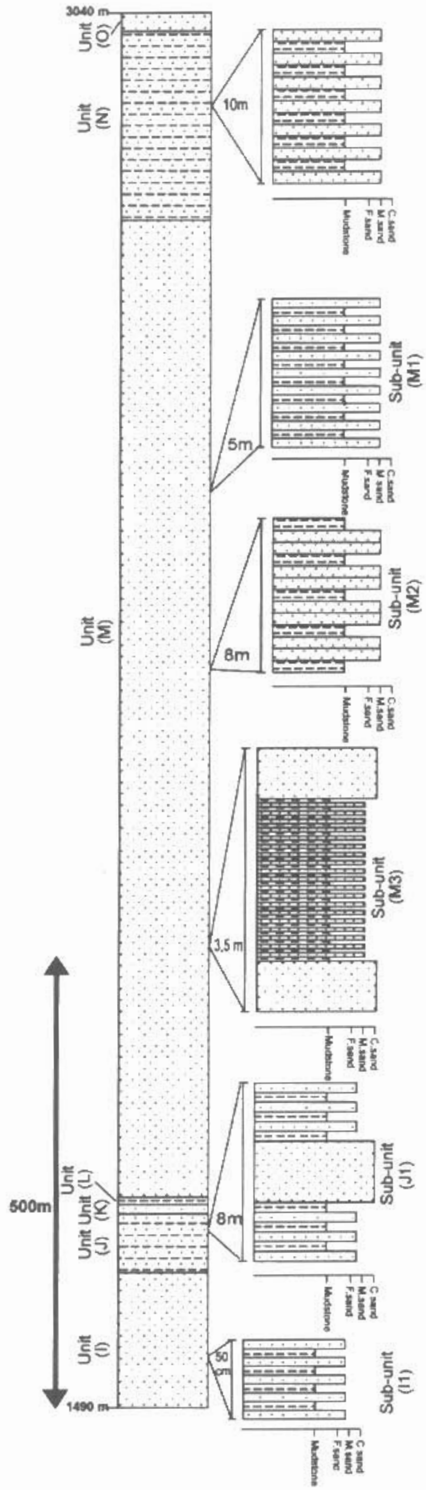
D) Coarse to medium grey sandstone with total thickness of 390 m and maximum bed thickness 1 m. Little black rounded clasts exist in the lower part of the sandstone beds. Bouma interval T_a is present. A sub-unit of cyclic alternations up to 10 m thick consists of medium to fine brown sandstones and mudstones with s:m ratio 1:1 (D1).

C) Cyclic alternations with total thickness up to 245 m of fine brown greenish sandstones and grayish mudstones with s:m ratio 1:1 . The maximum thickness of the sandstone bed is 60 cm. The sandstone is characterized by T_{bc} Bouma intervals. Tc represents ripple lamination. Two sub-units consist of coarse gray sandstones with maximum bed thickness 3 m and total thickness 20 m (C1) and 35 m each. They are characterized mostly by T_a Bouma interval.

B) Coarse to medium brown sandstones with total thickness 100 m and maximum bed thickness up to 5m. T_a Bouma interval is present.

A) Cyclic alternations, of thin-bedded fine gray sandstones and greyish mudstones with s:m ratio 1:1. Total thickness up to 40 m. The sandstones are characterized by T_{bc} Bouma intervals. Tc represents ripple lamination.

Continue..



O) Medium gray sandstones with thickness of 20 m and maximum bed thickness 1,5 m. They are characterized mostly T_{a-c} by Bouma intervals, groove casts and rills. The Tc Bouma interval represents ripple and convolute lamination.

N) Cyclic alternations with total thickness up to 210 m of medium greenish gray sandstones and grayish mudstones with s:m ratio 1:1. The sandstones are characterized by T_{bc} Bouma intervals. Tc Bouma interval is represented by ripple and convolute lamination.

M) Coarse gray mica sandstone beds with total thickness of 1085 m and maximum bed thickness 2,5 m. The sandstones are characterized by normal grading and mostly T_a Bouma interval. Small reddish rounded clasts are present in the lower part of the sandstone beds. In the upper part a sub-unit is intercalated up to 10 m thick, consisting of alternated medium gray sandstones and grayish mudstones with s:m ratio 1:1 with thickness of 10 m (M1). Bouma intervals T_{bc} are present. Ripple and convolute lamination represent the T_c Bouma interval. In the middle part a sub-unit is formed of cyclic alternated medium gray sandstones and grayish mudstones with s:m ratio 2:1 (M2) and thickness up to 10 m . The sandstones are characterized by T_{a-c} Bouma intervals with Tc to represent ripple and convolute lamination. Carbonate clasts within the laminated sandstone beds are present. In the lower part a sub-unit of cyclic alternations up to 2,5 m consists of medium gray sandstones and grayish mudstones with s:m ratio 1:1 and maximum bed thickness 5 cm (M3) are.

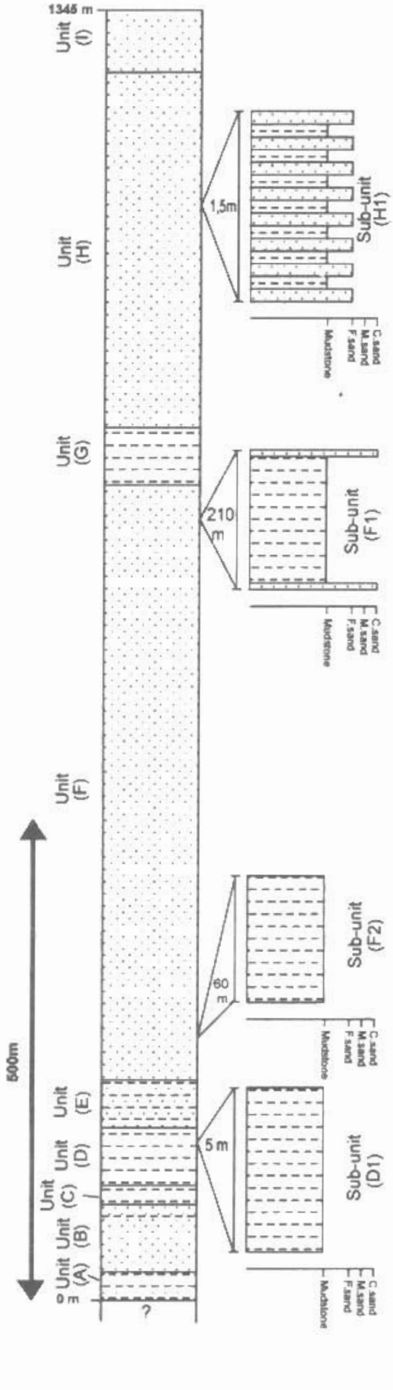
L) Grayish mudstone with total thickness of 10 m.

K) Medium gray sandstones, with total thickness of 10 m, are characterized by T_{bc} Bouma intervals. T_c corresponds to ripple lamination.

J) Cyclic alternations up to 65 m of medium to fine brown sandstones and grayish mudstones with s:m ratio 1:1. The maximum thickness of the sandstone bed is 40 cm. The sandstone is characterized by T_{bc} Bouma intervals. Carbonate clasts are aligned to the lamination. The Tc interval is represented by ripple lamination. A sub-unit consists of coarse grey sandstones with total thickness of 20 m (J1) and maximum bed thickness of 2,5 m.

I) Coarse gray sandstones with total thickness of 150 m and maximum bed thickness 2,5 m. Bouma intervals T_{a-c} are present.Tc refered to ripple and convolute lamination. A sub-unit of cyclic alternations up to 20 m which consists of thin-bedded fine to medium gray sandstones and grayish mudstone with s:m ratio 1:1 (I1) is also present.

Figure 2. Geological cross-section A-A΄, with a total stratigraphic thickness up to 3040 m, exposed in the central part of the area. This section could be divided in 15 units. For location and explanation of symbols see figure 1.



Cross-section B-B

I) Medium gray sandstone with maximum bed thickness 40 cm and total thickness 65 m. The sandstone is highly deformed and characterized by T_a Bouma interval.

H) Medium to fine brown grayish sandstones with total thickness of 370 m and maximum bed thickness of 75 cm. The sandstone is characterized by T_{a-c} Bouma intervals, water-escape structures and groove marks. T_c Bouma interval represents ripple and convolute lamination. Coal horizons are abundant. Several sub-units of total thickness up to 150 m consist of cyclic alternations of fine brown grayish sandstones and mudstones with s:m ratio 1:1 (H1). The maximum thickness of the sandstone bed is 10 cm. The sandstone is characterized by T_{a-c} Bouma intervals, slump horizons and groove marks. T_c Bouma interval represent ripple lamination.

G) Red and green mudstone with thickness of 60 m. In places a sub-unit with thin-bedded fine brown sandstones is present.

F) Coarse gray sandstones with total thickness up to 620 m and maximum bed thickness of 2 m. Bouma intervals T_{a-c} are present. T_c represents ripple lamination. In some places the sandstone is deformed. In the upper part a sub-unit of red and green mudstone with thickness of 190 m (F1) is present. In the lower part another sub-unit of highly tectonized bluish gray mudstone with thickness of approximately 80 m (F2) is present.

E) Cyclic alternations with total thickness 50m of highly deformed medium brown sandstones and brown mudstones with s:m ratio 1:1. The maximum thickness of the sandstone bed is 30 cm. The sandstone is characterized by T_{ac} Bouma intervals. T_c represents convolute lamination.

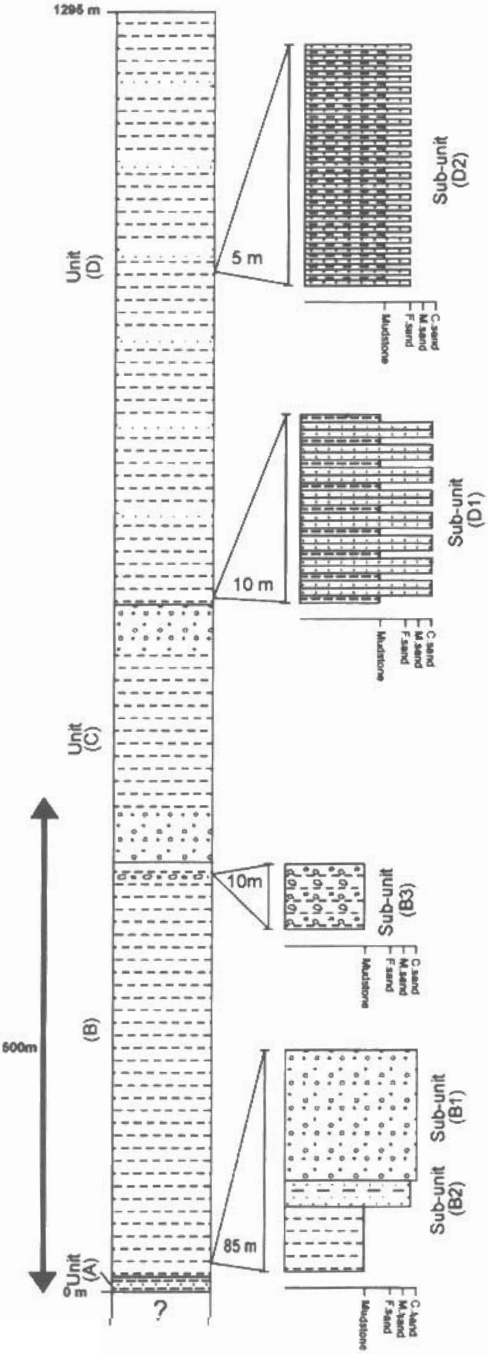
D) Cyclic alternations up to 60 m of medium to fine brown sandstones and greyish mudstones with s:m ratio 1:9. The sandstone bed maximum thickness is up to 90 cm. Bouma intervals T_{a-c} and flute casts are present in the sandstone beds. T_c Bouma interval represent ripple lamination. In the upper part a sub-unit which consists of gray mudstone with thickness of 5 m (D1) is present.

C) Brown greenish mudstone with thickness of approximately 20 m.

B) Cyclic alternations up to 70 m of medium brown sandstones and grayish mudstones with s:m ratio 9:1. The maximum thickness of the sandstone bed is 1 m. The sandstone is characterized by T_{a-c} Bouma intervals. Ripple and convolute lamination characterize T_c.

A) Cyclic alternations with total thickness up to 30 m of medium brown sandstones and brown mudstones with s:m ratio 1:1. The maximum thickness of the sandstone bed is 30 cm. The sandstone is characterized by T_{ac} Bouma intervals. T_c represents convolute lamination.

Figure 3. Geological cross-section B-B' with total stratigraphic thickness up to 1345 m thick, exposed in the western part of the area. This section could be divided in 9 units. For location and explanation of symbols see figure 1.



Cross-section C-C'

D) Alternated up to 600 m thick fine gray sandstones and bluish mudstones with s:m ratio between 1:9 and 1:1. The sandstone is characterized by many coal clasts. In the upper part of the unit a sub-unit up to 155 m thick with alternated coarse brown sandstones and mudstones with s:m ratio 2:1 (D1) was formed. The maximum thickness of the sandstone bed is 40 cm. The sandstone is deformed and characterized by T_a Bouma interval and abundant coal clasts. Small rounded clasts appear in the lower part of the sandstone bed. In the middle part of the unit a sub-unit consisting of alternated fine gray sandstones and grayish mudstones with s:m ratio 1:1 (D2) up to 20 m thick is present. The maximum thickness of the sandstone bed is 20 cm. The sandstone beds are characterized by many coal clasts, sole marks and Tbc Bouma intervals. The T_c Bouma interval is represented by ripple lamination.

C) Bluish mudstone with thickness of 260 m. In the upper and lower part of the unit intercalates a sub-unit which consists of conglomerate (B1) with total thickness of 100 m.

B) Greenish brown mudstone with total thickness of about 420 m. In some places a sub-unit consisting of thin-bedded brown sandstone with maximum bed thickness 4 cm was formed. The sandstone is characterized by T_a Bouma interval and coal clasts. In the top of this unit a sub-unit which consists of conglomerate with thickness of about 50 m (B1) is present. The conglomerate is coarse-grained, poorly sorted, clast-supported gravel lacking internal organization with sand matrix. Clasts are sandstone and limestone with Lmax 30 cm. In some places the conglomerate alternates with coarse to medium brown sandstones and brown mudstones with s:m ratio between 9:1 and 2:1 with total thickness up to 10 m (B2). The maximum thickness of the sandstone bed is 80 cm. In the bottom of the unit intercalates a sub-unit which consists of bluish pebbly mudstone with thickness of about 10 m (B3), is poorly sorted with no internal organization. The pebbles are sandstone with Lmax 20 cm.

A) Alternated thin-bedded fine reddish to brown sandstones and reddish mudstones with s:m ratio between 1:1 and 1:9 and total thickness up to approximately 15 m. The sandstone beds are characterized by T_{bc} Bouma intervals. T_c represents ripple lamination.

Continue..

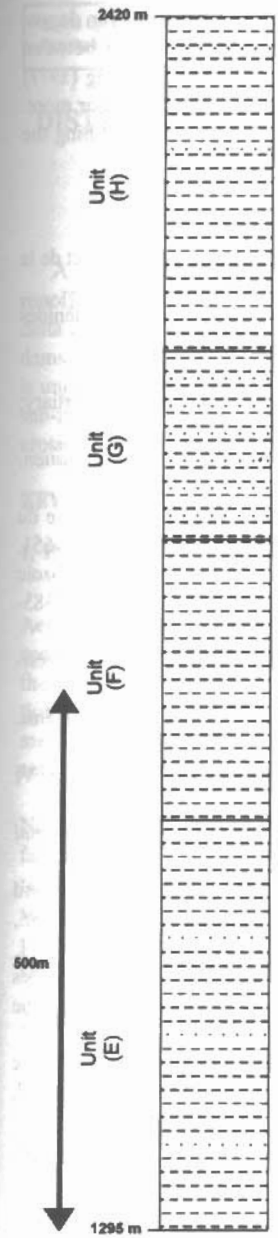


Figure 4. Geological cross-section C-C', with total stratigraphic thickness up to 2420 m thick, exposed in the Northwest part of the area. This section could be divided in 8 units.ll For location and explanation of symbols see figure 1.

H) Grayish mudstone with thickness of 310 m. In some places a sub-unit which consists of thin-bedded sandstones is present.

G) Cyclic alternations up to 175 m of thin-bedded coarse brown sandstones and grayish mudstones with s:m ratio between 2:1 and 1:1. The sandstone is characterized by T_{ab} Bouma intervals and groove marks. Coal horizons are abundant, aligned to the lamination of the sandstone beds.

F) Bluish mudstone, 260 m thick.

E) Cyclic alternations up to 380 m which consist of medium brown reddish sandstones and brown mudstones with s:m ratio between 1:6 and 1:9. The sandstones are characterized by $T_{a\text{-}c}$ Bouma intervals and sole marks. The T_c Bouma interval is represented by ripple lamination.

3. INTERPRETATION

Bouma sequence presence, within the studied sedimentary successions, indicates that submarine fans filled up the basin. The channelized geometry of the sandstones, the presence of conglomerates and slump horizons indicate that the whole studied deposits accumulated in the proximal part and mostly represent the inner fan sub-environment. The units of alternated thin bedded sandstones and mudstones with s:m ratio 1:1 (Figure 2, units: A, C, E, G, J, N, sub-units: D1, H1, I1, M1, M3 ; Figure 3, units: A, E, sub-units H1; Figure 4 , unit: G, sub-unit: D2) are interpreted as levees and interchannel deposits. The units of mudstones (Figure 2, unit: L; Figure 3, units: C, G, sub-units: D1, F1, F2; Figure 4, unit: H), and alternated cylces with sandstones and mudstones and s:m ratio 1:9 (Figure 3, unit: D; Figure 4, unit: E) are interpreted as levee mudstones. The thick mudstone units (Figure 4, units: B, C, F) may represent shelf deposits. Medium, coarse sandstone (Figure 2, units: B, D, F, H, I, K, M, O, sub-units: C1, J1; Figure 3, units: B, F, H, I; Figure 4, sub-units: B2) and conglomerate units (Figure 4, unit C, sub-unit: B1) are interpreted as channel deposits. The pebbly mudstone horizon (figure 4, sub-unit: B3) represents sediments that deposited in the slope area and formed due to slump and slide.4.

4. PALAEOCURRENT ANALYSIS

The palaeoflow trends have been estimated from the sole marks at the base of the sandstone beds. For sole marks which are hosted in beds with gradient greater than 25° the rose diagrams have been rotated. The projection of the mean palaeocurrent directions in the rose diagrams show two palaeoflow directions for cross- section A-A΄ (NE-SW and NW) and three direction for cross-sections B-B΄ (SWS, WNW-ESE and WSW-ENE) and C-C' (WNW, SW and E-W) (Fig. 1).

5. DISCUSSION AND CONCLUSIONS

The Metsovo area according to the interpretation of the three studied cross-sections indicates the proximal part of the submarine fan and represents the inner fan. The central and western parts of the Metsovo area represent the inner fan. The eastern part of the area represents the most proximal part of the inner fan and maybe a part of a shelf. The results from the palaeocurrent data indicate mainly two directions. The main direction is SW and the minor is WNW. The Metsovo basin seems to have multiple feeders from North and East, maybe the basement of Pindos. This hypothesis agrees in general with the palaeocurrent directions proposed by Richter (1993) and Bonorino (1996).

The total thickness of the flysch deposits in Metsovo area is approximately 6805 m. This thickness represents the total exposed thickness which includes possible increasement of the thickness due to tectonic stacking and folding of the submarine fan deposits. Although there are not many sedimentary horizons for correlation either in the same section or between adjacent sections researchers proposed different thickness of the flysch deposits in this area. Lorsong (1977) suggest 530 m, while Aubouin (1959) and Richter et al. (1993) proposed thickness of 1000 m to 2000 m or more. In order to estimate the exact stratigraphic thickness more detailed work is needed, dating and describing the exposed sediments. Our estimation is that the real thickness is more than 1000m but less than 6805m.

REFERENCES

AUBOUIN, J., 1959. Contribution à l´ étude géologique de la Grèce septentrionale: les confins de l´Epire et de la Thessalie: *Ann. Géol. des Pays Hell.*, 10, 1-184.

AUBOUIN, J., 1964. Reflection sur le problème des Flyschs et des Molasses: son aspect das les Hellènides (Grèce):*Eclogae Geolologicae Helvetiae*,57, 451-496.

AUBOUIN, J. 1965. *Geosynclines*. Amsterdam: Elsevier, 350 pp.

BONORINO, G. 1996, Foreland sedimentation and plate interaction during closure of the Tethys ocean (Tertiary; Hellenides; Western Continental Greece). *Journal of Sedimentary Research*, 66, 1148-1155.

BOUMA, A. H. 1962. *The sedimentology of some Flysch deposits: a graphic approach to facies interpretation.* Amsterdam: Elsevier, 168 pp.

FLEURY, J. 1980. Les zones de Gavrovo-Tripolitza et du Pinde-Olonus (Grece occidentale et Peloponnese du Nord): evolution d´une plateforme et d´une bassin dans leur cadre alpin. *Société Géologique du Nord* 4, 1-651.

JONES, G., DEWEVER, P. & ROBERTSON, A.H.F. 1992. Significance of radiolarian age data to the Mesozoic tectonic and sedimentary evolution of the nothern Pindos Mountains, Greece. *Geological Magazine*, 129, 385-400.

KATSIAVRIAS, N. 1983. The North Pindos Flysch : Flysch of the western part of the Gavrovo ridge . Northwestern Greece. Inst. Geol. Min. Expl., 126-139.

KOCH, K. E. & NICOLAUS, H. J., 1969, Zur Geologie des ostpindos flysch beckens und seiner umrandung. Inst. for. Geol. Subsurf. Reser. Athens, raport no 9.

LORSONG, J. A., 1977, Stratigraphy of the Pindos flysch in the Politses mountains, Northwestern Greece. VI Coll. Aegean region, II, 703-714.

RICCI LUCCHI, F. 1975.Depositional cycles in two turbidite formations of Nothern Apennines (Italy). *Journal of Sedimentary Petrology*, 45, 3-432.

RICHTER, D., 1993, Die Flyschzonen Griechenlands VII. Sedimentstrukturen, Ablagerungsart und Schüttungsrichtungen im Flysch der Pindos-Zone (Griechenland): *N. Jahrbuch für Geol. und Paläont., Monatshefte* 9, 513-544.

RICHTER,D., MULLER, C., AND MIHM. A., 1993, Die Flyschzonen Griechenlands V. Zur Stratigraphie des Flysches der Pindos –Zone im nordlichen Pindos-Gebirge zwischen der albanischen Grenze und der Querzone von Kastaniotikos (Griechenland):*N. Jahrbuch für Geol. Paläont., Monatshefte*, 5, 257-291.

ROBERTSON, A. H. F., CLIFT, P. D., DEGNAN, P. J. & JONES, G. 1991. Palaeogeographic and palaeotectonic evolution of the Eastern Mediterranean Neotethys. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 87, 289-343.

STOW, D. A. V., READING, H. G. & COLLINSON, J. D. 1996. Deep Seas. *In Sedimentary Environments* (ed. H. G. Reading), 395-453.