Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, 2010
Πρακτικά 12ου Διεθνούς Συνεδρίου
Πάτρα, Μάιος 2010

Bulletin of the Geological Society of Greece, 2010
Proceedings of the 12th International Congress
Patras, May, 2010

# TECTONOSEDIMENTARY SIGNIFICANCE OF THE MESSINIA CONGLOMERATES (SW PELOPONNESE, GREECE)

**Pavlopoulos A.[1], Kamperis E.[2], Sotiropoulos S.[2] and Triantaphyllou M.[3]**

[1] *Agricultural University of Athens, Department of Sciences, Laboratory of Mineralogy-Geology, 11855 Athens, Greece, apvlo@aua.gr*

[2] *Hellenic Petroleum S.A., Kifissias 199, 15124 Maroussi Greece, EKamperis@helpe.gr, SSotiropoulos@helpe.gr*

[3] *National and Kapodistrian University of Athens (EKPA, Panepistimiopolis, 15784 Ilissia Greece, mtriant@geol.uoa.gr.*

## Abstract

*The marine fill of the Gavrovo-Tripolis foreland basin in the Messinia area (SW Peloponnese), includes facies and facies associations, deposited by sediment gravity flows in slope and inner fan settings. The above-mentioned gravity-driven sedimentary processes, resulted in the formation of thinning-upward sequences and fining fan facies associations, composed of impressive sheet-conglomerates at the base (Agia Mavra, Agia Varvara and Mali units), presenting mainly normal internal structure, while clay and sand-clay members predominate at the top. These conglomerates advocate a significant sediment supply and extended accommodation space, during periods of dramatic tectonic uplift, associated with the westward propagation of Pindos thrust front. In the prograding fan system, dominate paleo-currents with main flow direction to southwest. The finer fan facies associations show rapid lateral variations, both in lithology and thickness, indicating rapid changes in the inner, incised, part of the foredeep. Nannofossil analyses suggest that the sedimentation took place during Oligocene (NP22 to NP24 biozones). Three NNW-SSE trending thrust fault zones bound the above-mentioned units and they caused an important structural thickening of the fan facies associations. Biostratigraphic analyses date the end of the thrust activity in Gavrovo-Tripolis zone in Late Oligocene (biozone NP24).*

***Key words:*** *submarine-fan facies associations, conglomerate, thrust faults, Oligocene, Gavrovo-Tripolis foreland basin, External Hellenides.*

## 1. Introduction

Research on the origin and evolution of foreland basins has made strong advances, principally due to developments in understanding the mechanics of sedimentary basin formation. Geodynamic models proposed by Beaumont (1981), Stockmal et al. (1986) and others show the relations between the foreland subsidence and the resulting thickness of the foreland basin flysch-type clastic fill. There is a close relation between the nature, geometry and internal organization of clastic sediments and the evolution of the associated orogen. Furthermore, the eustatic movements play an important role, since they influence the accommodation space of the clastic sediments. In Mutti et al. (2003) there is an up today synthetic approach of the turbidites and the turbidity currents while Mutti et al. (2009) deal with the control of the fluvial regime on the turbidite sedimentation in deeper waters. Among the dif-

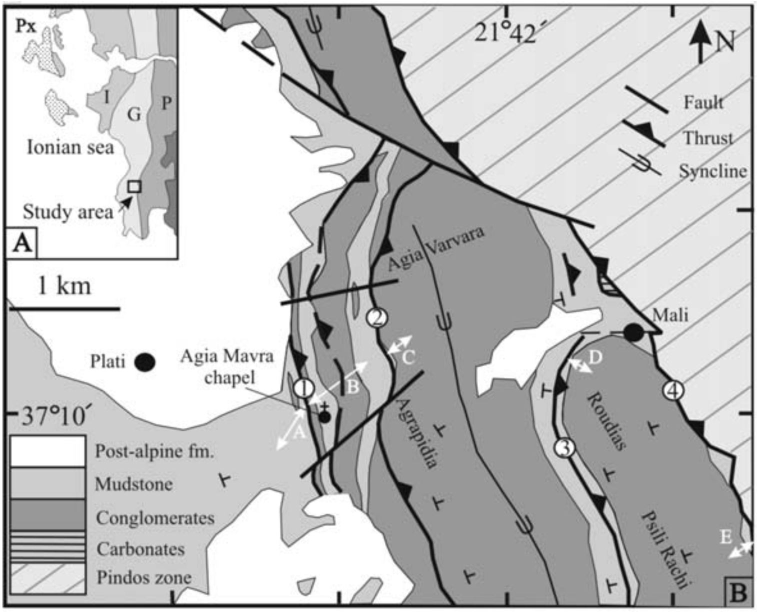

**Fig. 1:** A) Location map (Px: Pre-Apulian zone, I: Ionian zone, G: Gavrovo-Tripolis zone, P: Pindos zone). B) Geological map of the area studied, showing the location of stratigraphic cross-sections (A: Plati section, B: Agia Mavra section, C: Agia Varvara section, D: Mali west section, E: Mali east section), 1: Agia Mavra thrust fault (AMF), 2: Agia Varvara thrust fault (AVF), 3: Mali thrust fault (MF), 4: Pindos thrust fault (PT).

ferent kinds of the clastic sediments, the conglomerates are less abundant than other deep-water facies, but make up an important part of the deep-sea sedimentary record (Walker & James, 1992).

The Messinia region (SW Peloponnese, Greece) represents a very good study example, since thick conglomerate associations outcrop in the Gavrovo-Tripolis foreland basin near Pindos thrust (PT).

In this paper, we examine the ancient submarine fan-facies associations and the depositional systems that dominate this part of the Gavrovo-Tripolis foreland basin. Moreover, new structural and micropaleontological data are also presented towards a better understanding of the Gavrovo-Tripolis foreland basin evolution during Oligocene.

## 2. Geological setting

The fold-thrust belt of External Hellenides is the result of the collision between the Apulian plate (Adria Plate) and the Eurasian continent, which initiated in Late Cretaceous - Early Eocene times and continued during Tertiary (Dewey et al., 1973; Mountrakis, 1986; Doutsos et al., 1993; Karakitsios, 1995).

The pre-orogenic sequence of this fold-thrust belt consists, from east to west, of Mesozoic carbonates of Pindos, Gavrovo-Tripolis, Ionian and Paxos (Pre-Apulian) zones (Aubouin, 1959; Fleury, 1980; Karakitsios, 1995). In Late Eocene, the underlying Pindos zone detached from its basement and moved westwards along the Pindos thrust (Jacobshagen et al. 1978).

The tectonic load of the orogenic belt and the subsequent flexural subsidence have as result the formation of a foreland basin developed on the Ionian and Gavrovo-Tripolis zones. During the syn-orogenic period, thick turbidite sequences were deposited in the foreland basin, which progressively was involved during the orogenic process (Fleury, 1980).

In SW Peloponnesos, the foreland basin overlies Palaeocene to Eocene carbonates of Gavrovo-Tripolis zone (Fleury, 1980; Thiebault, 1982). According to these authors, the onset of the flysch sedimentation took place on the earliest Oligocene, whereas Fytrolakis (1971) considers that it took place in Late Eocene.

Based on our field observations, four flysch units have been distinguished in the study area, imprinting the conditions of the foreland basin fill during Oligocene. Plati, Agia Mavra, Agia Varvara and Mali unit are described in stratigraphic cross-sections A, B, C and D/E respectively based on the type and geometry of the sediments, and the internal structure of the beds (Fig. 1 & Fig. 2).

## 3. Structural data

The studied area is located west of the Pindos thrust (PT) which is trending NNW-SSE in this part of the fold-thrust belt. It is a mountainous area, that consists of two elongate ridges (Agia Varvara and Roudias), trending generally parallel to PT (Fig. 1B). The western flanks of these ridges are characterised by steep relief, while the eastern ones present a smoother relief. Conglomerates occupy the uppermost part of the ridges, while clay successions outcrop at the low relief areas. Fieldwork reveals new data concerning the structural deformation of flysch sediments.

The thrust fault activity controls the structural configuration of the foreland basin, imprinted in a series of ridges. In particular, three thrust faults zones, striking NNW-SSE and dipping to the east, have been recognized on clay successions, identifying three tectonosedimentary units, namely Agia Mavra, Agia Varvara and Mali.

The Agia Mavra's thrust fault zone (AMF), located on the lower part of the western flank of Agia Varvara ridge, influences both the upper part of Agia Mavra's clays and the lower part of Agia Mavra's conglomerates (Fig. 1B). On the footwall of AMF, the age of the uppermost members of Plati clays, based on nannofossil analyses, dated of late Oligocene (biozone NP24; cooccurrence of *Sphenolithus distentus* and *S. ciperoensis*) while the Agia Mavra's clays, above the AMF, dated of early Oligocene age (biozone NP23; detected by the cooccurrence of the nannofossil species *S. distentus* and *S. predistentus, Retculofenestra bisecta, Helicosphaera compacta*).

Further eastwards, Agia Varvara thrust fault (AVF) defines the tectonic contact between Agia Varvara and Agia Mavra units (Fig.1B). The base of Agia Varvara unit dated from early Oligocene age (NP 23), while the uppermost part which is situated on the footwall of AVF, dated from late Oligocene age (nannofossil biozone NP24).

The Mali thrust (MF), located in the lower part of Roudias ridge, is in line with the crest of this ridge (Fig. 1B). The low angle thrust fault plane dips to the east and strikes almost parallel to the mudstone stratification. Samples taken from mudstone indicates late Oligocene age (nannofossil biozone NP24) for the youngest sediments of the footwall and earliest Oligocene age (biozone NP22; detected by the co-occurrence of the species *Sphenolithus predistentus, Reticulofenestra umbilica* and *R. hillae* combined with the absence of *Sphenolithus distentus* and *S. ciperoensis*) for the hanging wall lowermost sediments. Furthermore, samples from the footwall of the Pindos thrust dates from late Oligocene age (nannofossil biozone NP24).

The frequent occurrence of nannofossil markers of biozone NP24 on the footwall of the above-mentioned thrust faults, as well as the Pindos thrust, suggests that the Pindos thrust emplacement and the main thrust activity in Gavrovo-Tripolis foreland basin, took place during the late Oligocene (nannofossil biozone NP24). These evidences are in accordance with other studies (Fleury, 1980; Sotiropoulos et al., 2003).

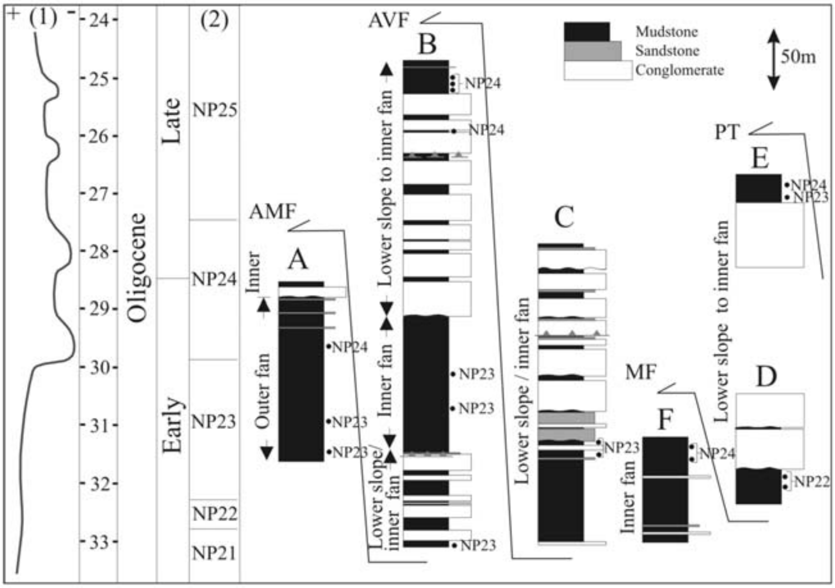

**Fig. 2:** Correlation of stratigraphic cross-sections during Oligocene (1): Eustatic short term curves, (Haq et al., 1987), (2): Biozones of calcareous nannoplankton (Martini, 1971), A: Plati section, B: Agia Mavra section, C: Agia Varvara section, D: Mali west section, E: Mali east section, F: Stavros section (out of the studied area). The location of all sections is presented in figure 1B.

Oblique normal faults are also recognized in the studied area. A representative case is the NE-SW trending oblique normal fault cutting across the AMF and AVF near the Agia Mavra chapel (Fig. 1B). Moreover, several ENE-WSW and ESE- WNW trending normal faults, affect the flysch deposits associated with the latest extensional stress field.

## 4. Sedimentary facies and depositional environments

### 4.1 Plati unit

It outcrops in the neighbourhood of Plati village (Fig. 1B) and it consists of silty mudstone / fine-grained sandstone alternations, presenting marked lateral continuity of at least 20 kilometres. They are characterised by sand /mud thickness ratios<1, more frequently with base-missing and / or rarely complete Bouma type-sequences (facies MS, Ghibaudo, 1992). The mudstones present laminated, parallel bedding, while the sandstones are thin-bedded and ‘plane-stratified’ (facies D, Mutti & Ricci Lucchi, 1972, D2, Mutti & Ricci Lucchi, 1975, facies MS of Ghibaudo, 1992). The depositional mechanisms are associated with low-density currents producing typical turbidites (outer fan associations).

The upper members of Plati unit outcrop west of Agia Mavra chapel (Fig.1 and Fig. 2, section A). They consist of fine-grained depositional intervals expose indistinct or poorly defined parallel bedding (subfacies TM / MT Ghibaudo, 1992). They present lateral variations in lithology (muddy or gravely sandstones) and include dispersed pebbles and gravels, locally concentrated in lenticular gravel or sand bodies (facies G, Mutti & Ricci Lucchi, 1972). Medium to fine-grained massive sandstones, up to 1 m. thick, are rarely enclosed in the silty mudstone which passes upwards to siltstone. These sandstone beds are bound by even, parallel, surfaces having rather good lateral continuity and are inferred to be equivalent to facies C (Mutti & Ricci Lucchi, 1972). The above-mentioned depositional system of facies is interpreted as indicative of an inner fan association.

At the top of Plati unit, 1.5 - 3 m thick, coarse-grained, poorly sorted disorganised conglomerate (facies A, Mutti & Ricci Lucchi, 1972, mG Ghibaudo, 1992, $A_{1\text{-}1}$ Pickering et al., 1986a, 1989) overlie the mudstones with a sharp contact. Conglomerates are irregular shaped, commonly amalgamated and characterised by an undulating, low-relief erosional lower surface and planar or slightly irregular upper one. They are clast-supported massive beds with limestone cobbles and boulders of Pindos zone origin, dispersed mainly at their basal part (facies A1, Mutti & Ricci Lucchi, 1978, subfacies, m Ghibaudo, 1992). Moreover, thin, sandy matrix-supported gravel depositional intervals are observed in the uppermost conglomerate beds, presenting ill-defined normal gradation (facies A, Mutti & Ricci Lucchi, 1972, subfacies GyS/ gGyS Ghibaudo, 1992). These facies type/group is related to highly erosive - debris flow - mechanisms and eventually rapid sedimentation in the lower slope to inner part of the submarine fan.

The presence of *Sphenolithus distentus, S. predistentus* and *Cyclicargolithus abisectus*, at the lower part of section A, suggests early Oligocene age (nannofossil biozone NP23), while the cooccurrence of *Sphenolithus predistentus* and *S. ciperoensis*, at the upper part, indicates late Oligocene age (nannofossil biozone NP24).

### 4.2 Agia Mavra unit

This unit consists of distinct depositional intervals made up of conglomerate and thin sandstone, at the base and siltstone/ silty mudstone couplets at the top (Fig. 2, section B). Sandstone beds are either absent or represent thin (up to 5 cm), very coarse-grained, parallel plane-laminated, depositional intervals. The finest constituents are upward increasing in thickness (2 m). This type of bed intervals is common between the lower members of Agia Mavra unit. The base of the gravel-bed intervals is characterized by a sharp contact generally expressed by a broadly undulating erosion surface and rarely by a sharp flat, while the upper boundary is almost planar and rarely undulated. The transition to the overlying sand-beds is either abrupt or gradual with an intermediate clast or sand-supported interval (subfacies gGS, Ghibaudo, 1992).

Considering the type of bed interval, the gravel part is coarse-grained, poorly to moderately well sorted, either well cemented with calcite, characterised by poorly defined normal grading, or loose, usually structureless (subfacies gGS and mG, Ghibaudo, 1992). Normal to inverse graded gravel beds are not very common. Amalgamated gravel beds are locally observed, presenting an irregular geometry due to either erosion or uneven depositional relief The dominating pebble size is 8 cm, ca. Some sand clasts were also observed at the lower part of the conglomerates. Conglomerate populations are dominated by light grey-coloured limestone, cherts and radiolarite from the Pindos zone, well to very well rounded pebbles and cobbles. These deposits suggest long-distance transport and rapid deposition by turbidity currents or debris flows (facies A1, Walker & Mutti, 1973, A1-1, Pickering, 1986, 1989, facies A1, Mutti & Ricci Lucchi, 1978, facies G/GS Ghibaudo, 1992).

The siltstone - mudstone depositional division is normally overlying the sand or the gravel bed intervals and it presents indistinct or poorly developed plane-parallel bedding. It includes dispersed gravels mainly in the muddy divisions. Thin lenticular bodies of sand and conglomerate are also enclosed in these intervals suggesting facies G/D (Mutti & Ricci Lucchi, 1972), probably subfacies ITM Ghibaudo, 1992). Lateral variations in thickness and local "discordant" contact with the underlying irregular shaped gravel-sand units are related to submarine erosion and channel fill geometry. The above-mentioned coarse and fine-grained intervals generally compose positive sedimentary sequences (Mutti & Ricci Lucchi 1974), deposited by debris flow and more dilute currents, respectively. They are interpreted as a slope – inner fan association.

A marly mudstone sequence, composed of laminated silt-mud depositional intervals with indistinct or poorly developed parallel bedding, predominate upwards, in the surrounding area of Agia Mavra chapel. This bed type comprises a silty lower division and a muddy upper one (facies lTM/IMT, Ghibaudo, 1992) and it is usually characterised by silt /mud thickness ratio<1. Very thin (few cm thick), discontinuous bedded sand layers, lenticular sand bodies and conglomerates are also rarely enclosed in this interval. At the base of this mudstone sequence, a conglomerate-sandstone facies association occurs, about 2 m thick suggesting facies S (Ghibaudo, 1992), C (Mutti & Ricci Lucchi, 1972). This sedimentary sequence, considered in a more extent sedimentary context, presents a channel-shaped irregular geometry, with significant lateral thickness changes. The individual bed intervals represent thinning-upward positive sequences (Mutti & Ricci Lucchi, 1974). The transport-depositional mechanism is inferred to be controlled mainly by dilute currents (inner fan association).

A thick conglomerate sequence, ca 190 m, overlies the above-mentioned marly mudstone sequence and it creates successive morphological steps as well as an impressive steep relief (Fig. 2, section B). A characteristic bed occurs at the base of this conglomerate-sequence, including white coloured, angular, medium to fine-grained, moderately sorted, pelagic limestone, silex and lydite gravels of Pindos origin. It is a coarse sand matrix-supported bed interval, (subfacies gG, Ghibaudo, 1992) with coarser-grained basal part, cemented with calcite. This sedimentary episode is related with a change in nature of the source rock in the feeding area.

The overlying conglomerates are either poorly to moderately sorted, medium-grained (8-10 cm) massive (facies mG, Ghibaudo, 1992), amalgamated, or graded occasionally with coarse-grained its basal part (facies gsG). Clast or sand supported beds are also recognised. The above types of bed intervals are associated with thin sand - muddy silt depositional divisions (<1 m locally up to 3 m). They consist of commonly thinning and fining-upward sequences (Walker & Mutti, 1973), including beds with parallel, almost even bounding surfaces (facies A2, Mutti & Ricci Lucchi, 1972). The entire sequence of conglomerate beds presents significant lateral thickness variation due to their channel geometry. The deposition took place in a lower slope to inner fan environment. The transport-depositional mechanism is mostly high-density turbulent "granular flow" or sandy "debris flow" when the sandy matrix content is high (Shanmugam, 2000; Mohrig and Marr, 2003).

Based on heavy mineral associations of the siliciclastic deposits of western Messinia, Faupl et al. (2002), state that the occurrence of coarse material in the structurally upper sequences of the Gavrovo-Tripolis flysch, witnesses a substantial erosion especially of the stratigraphic lower successions of Pindos flysch deposits.

The general feeding direction, based on imbricate structures, is from northeast to southwest. Some rare indications of flow direction towards WNW and N were also measured. The latter suggests flow parallel to the axis of the foreland basin. Kamperis et al. (2005) also report similar flow directions for the sedimentary flysch successions attributed to early Oligocene in the Gavrovo-Tripolis foreland basin, in the area of NW Peloponnese.

At the top of Agia Mavra unit, a mudstone-siltstone sequence overlies the above- mentioned conglomerate beds and it is characterised by significant thickness variations. It consists of couplets of parallel laminated silty division and muddy upper division (lTM facies, Ghibaudo, 1992). The sequence becomes coarser-upward, enclosing thin sandstone and conglomerate lenticular bodies. The depositional intervals are typical thin-bedded turbidites (facies D, Mutti & Ricci Lucchi, 1972), including also dispersed gravels. They are interpreted to be the product of dilute currents that acted in the inner part of the submarine fan.

The lower part of section B is inferred to be of early Oligocene age (NP23 nannofossil biozone) due to the presence of *S. distentus*, *S. predistentus* and *C. abisectus*, while the upper one is of late Oligocene age (NP24 nannofossil biozone) due to the cooccurrence of *S. ciperoensis*, and *S. predistentus* (Fig. 2).

### 4.3 Agia Varvara unit

This unit consists of two sequences, a thick upper one, made up of conglomerate and a lower one composed of silty mud-sand depositional intervals (Fig. 2, section C). The lower sequence consists of various combinations of mud-silt and mud-sand depositional intervals (facies MT to MS, Ghibaudo, 1992). Thicker muddy divisions are observed in the lower members (facies G, Mutti & Ricci Lucchi, 1972). The uppermost members also include fine-grained, plane-stratified, sand dominated (facies SM, Ghibaudo, 1992) depositional intervals (< 1 m thick). Individual sand beds are discontinuous, with wedging, commonly in sharp contact with the overlying siltstones and mudstones. Bed thickness ranges between 3 and 15 cm (facies E, Mutti & Ricci Lucchi, 1972, Walker, 1978). This type of bed interval is related to interchannel / overbank deposition and local grain flow processes. Thick channel fill deposits (40 m), are enclosed in the uppermost members. They consist of sandstones associated with thin siltstone and mudstone beds, characterised by almost planar, even and parallel bounding surfaces (facies C, Mutti & Ricci Lucchi, 1972). They are classified in thinning and fining-upward sequences. The bed intervals could include complete Ta-e Bouma sequences. The lower sequence facies association indicates deposition by dilute suspensions, including turbidity currents and grain flows in the lower slope to inner part of the submarine fan.

An uneven depositional relief separates the lower sequence and the overlying conglomerates (Fig. 2, upper part of section C). These conglomerates outcrop at Agia Varvara and Agrapidia ridges, creating an impressive steep relief which is the most prominent feature in the studied area (Fig. 1B). The individual beds of conglomerates are grey-coloured, poorly to moderately sorted, with the clast size ranging between 18 cm (lower beds) and 5 cm (upper beds). The clastic elements consist of platy to sub-spherical cobbles of grey sparitic limestones, lydites and rarely of dispersed sandstone clasts, classified in fining - upwards depositional intervals. This type of bed interval is well cemented with calcite and the grading is mainly normal and rarely inverse. They also present clast-supported or coarse-grained sand divisions in their upper part (subfacies gG, Ghibaudo, 1992). Some gravel beds consist of more depositional divisions, where their lower part is characterised by coarser-grained portion (subfacies gsG). Moreover, gravel beds with fining-upward depositional divisions occur, where sand predominates in the upper parts, locally associated with thin discontinuous beds of siltstone.

The Agia Varvara conglomerates commonly represent amalgamated beds, up to 8 m. thick, having an irregular geometry, due to channelling. The transport-depositional mechanism is mostly high-density turbulent “granular flow” or sandy “debris flow”. The deposition of these gravity flow beds took place in the lower slope to inner fan environment. These conglomerates correspond to facies A (Mutti & Ricci Lucchi, 1972), A2 (Walker & Mutti, 1973), A2-3 (Pickering et al. 1986).

Pebble imbrications are also observed indicating flow directions from SSW to NNE, almost parallel to the basin axis. At Foinikounda area, further south of the studied area, Konstantopoulos et al. (2007) and Konstantopoulos (2009) measured the same paleo-flow directions.

The uppermost members of conglomerate sequence outcrop on the eastern flank of Agrapidia ridge.

These conglomerates are loose, poorly sorted, characterised by angular coarse elements, (cobbles and boulders), mainly clast supported. They consist of thick, often amalgamated gravel beds with chaotic internal structure suggesting facies A1-1 (Pickering et al. 1986), formed at the lower slope.

Fine-grained sediments, which consists of thin-bedded silt-mud depositional intervals (facies TM and MT, Ghibaudo, 1992), outcrop eastwards, in the valley at the foot of Roudias and Psili Rachi ridges, referring probably to the uppermost members of Agia Varvara unit (Fig. 1B). This succession becomes thicker further to southeast, near Stavros village, including rare intercalations of thin conglomerate as well as thin, sand bed intervals (Fig. 2, section F), representing inner fan facies G (Mutti & Ricci Lucchi, 1972).

The base of Agia Varvara conglomerates (Fig. 2, section C), dated as early Oligocene age (NP23 biozone), while the uppermost members of this unit dated as late Oligocene age (NP24 biozone) due to occurrence of *S. predistentus* and *S. ciperoensis* (Fig. 2, section F).

## 4.4 Mali unit

The easternmost Mali unit outcrops on Roudias and Psili Rachi ridges, located on the hanging-wall of Mali thrust fault (Fig. 1B). The lowermost members of this unit consist of blue to grey-coloured, marly mudstones normally underlying a thick sheet-conglomerate that extends for many kilometres (Fig. 1B, Fig. 2, section D). These deposits consist of various ratios of mud/silt - sand depositional intervals (facies MT to MS, Ghibaudo, 1992) with the thicker muddy divisions observed at the base (facies G, Mutti & Ricci Lucchi, 1972). Rare thin conglomerate-lenses are also noticed in this sedimentary succession.

The overlying conglomerates are disorganized, thick-bedded and often amalgamated (Fig. 2, sections D and E). They are also loose, poorly sorted, characterised by angular coarse elements, pebble-cobbles and boulders, usually clast matrix-supported. The bedding surfaces are generally slightly undulate and sharp. The type of bed interval is mainly of A1-1 facies (Pickering et al. 1986). Rare depositional intervals made up of sandstone, less than 1m thick, are locally intercalated in the uppermost conglomerates of Mali unit. These sand bed intervals are discontinuous, characterised by wedging, indicating channel fill deposition (facies C, Mutti & Ricci Lucchi, 1972). Moreover, laminated, marly, silty mud-sand depositional divisions with few conglomerate-lenses (facies MT to MS, Ghibaudo, 1992) are developed on the top of Mali unit, underlying the Pindos thrust (Fig. 2, section E). They show common characters of the classic turbidites (facies D Mutti & Ricci Lucchi, 1972, Walker, 1978).

The Mali unit represents a submarine fan formed in the close proximity of the Pindos thrust by strong paleo-currents. The above-mentioned group of facies is inferred to be lower slope to inner fan association. The macroscopic sedimentary characters indicate that Mali unit represents the most proximal facies association of Gavrovo-Tripolis foreland basin in the studied area.

The nannofossil assemblage, contained in the lower members of Mali unit of the hanging wall of Mali thrust fault, suggests earliest Oligocene age (NP22 biozone) due to the occurrence of *Reticulofenestra umbilica, R. hillae, S. predistentus* and the absence of *S. distentus* and *S. ciperoensis* (Fig. 2, section D). The uppermost members of unit, located at the footwall of the Pindos thrust dated late Oligocene age (NP24 biozone) due to the occurrence of *S. ciperoensis*, *C. abisectus* and the absence of *S. predistentus* and S. distentus. The underlying mudstone beds are inferred to be of early Oligocene age (NP23 biozone) due to the occurrence of *S. predistentus, S. distentus, C. abisectus, R. bisecta, C. floridanus* and *H. recta* (Fig. 2, section E).

## 5. Foreland evolution

Previous studies suggest that the flysch sedimentation was widespread in the tectonically driven foreland basin, in front of Pindos thrust, during early Oligocene indicating significant subsidence rates in this interval (Fleury, 1980, Clews, 1989, Gonzales-Bonorino, 1996).

The limited presence of samples corresponding to NP21-NP22 biozones (base of Early Oligocene) in the study area indicates restricted flysch sedimentation during this period. The occurrence of the above samples close to the Pindos thrust (Fig. 2, section D) is related to the intensive thrust fault activity and was also recognized in similar parts of the same foreland basin northwards, east of Skolis mountain (Kamperis et al. 2005) and in Aetoloakarnania area (Sotiropoulos et al., 2003). Early Oligocene (NP23) is generally characterized by high eustatic sea levels (Haq et al., 1987; Fig. 2). Submarine fans formed in the foreland basin, which became wider and deeper (Avramidis et al, 2002, Sotiropoulos et al., 2003, Kamberis et al., 2005). A typical example of this interval in the area studied is Plati fan facies associations; deposited in the more distal parts of the basin, particularly in outer fan (Fig. 2, section A).

The onset of late Oligocene (the base of NP24 biozone) is marked by a dramatic sea level fall (Fig. 2). Coarse sediments were accumulated in foreland basin. This significant sea level change is generally portrayed in stratigraphic cross-sections, where conglomerate-successions overlie fine-grained sediments (Fig. 2). However, several parts of stratigraphic cross-sections are not related with the eustatic sea level changes. In particular, the uppermost mudstones of Plati unit deposited in outer fan during NP24 biozone (Fig. 2, section A), the lowermost conglomerates of Agia Mavra unit, deposited in NP23 biozone (Fig. 2, section B), the base of Agia Varvara conglomerates accumulated in NP23 biozone (Fig. 2, section C), as well as the base of Mali conglomerates were probably deposited during NP22-NP23 biozones (Fig. 2, section D).

Therefore, the thrust fault activity should be the primary factor that controls the depositional environment conditions, while the eustatic sea level changes play a secondary role. In addition, it is noteworthy, that the onset of the coarser-grained sediments accumulation took place progressively in the foreland basin, earlier in the more proximal part (during NP22 biozone in section D), later in section C (during NP23 biozone) and eventually during the NP24 biozone on the more distal section A (Fig. 2). This procedure seems to be less dependent of the sea level fluctuations and advocates to the significance of the thrust fault activity. The end of the flysch sedimentation in the Gavrovo-Tripolis foreland basin took place in late Oligocene (NP24 biozone), as the age of younger sediments on the thrust footwalls witnesses (Fig. 2). The same age has been determined northwards, in south Aitoloakarnania (Sotiropoulos et al., 2003, Sotiropoulos et al., 2008).

## 6. Conclusions

- Thrust faults activity influences the flysch sediments extensively, during Oligocene, resulting in the significant structural thickening of flysch.
- Conglomerate-successions were deposited by debris flows, acting in incised restricted continental slope, while the more fine-grained sequences deposited by limited muddy floods and turbidity currents in the inner channelized fan, near the feeder channel. The sedimentary facies of the conglomerate-successions suggest that the more eastward Mali unit deposited in the close proximity of Pindos thrust, whereas the western ones (Agia Varvara and Agia Mavra units) in a relatively more distal depositional environment.
- The onset of the conglomerate deposition took place progressively in the foreland basin, earlier, at the more proximal part (during NP22 biozone) and later, at the more distal part (during NP24 bio-

zone).

- The depositional conditions are mainly controlled by the thrust fault activity and less by the eustatic sea level fluctuations.

## 7. Acknowledgements

The authors wish to thank the reviewers Profs. B. Karakitsios and P.A. Ruiz-Ortiz for their constructive comments.

## 8. References

Aubouin, J., 1959. Contribution à l'étude géologique de la Grèce septentrionale: les confins de l'Epire et de la Théssalie. *Ann. Géol. Pays Hell.* 10, 1-483.

Avramidis, P., Zelilidis, A., Vakalas, I. & Kontopoulos, N., 2002. Interactions between tectonic activity and eustatic sea-level changes in the Pindos foreland and Mesohellenic piggy-back basins, NW Greece: Basin evolution and hydrocarbon potential. *Journal of Petroleum Geology* 25, 53-82.

Beaumont, C., 1981. Foreland basins. Geophys. *J. R. Astron. Soc.* 55, 291-329.

Clews, J. E., 1989. Structural controls on basin evolution: Neogene to Quaternary of the Ionian zone, Western Greece. *Journal of the Geological Society* 146, London, 447-57.

Dewey, J.P., Pitman, W.C.,, Ryan, W.B.F. & Bonnin, j. 1973. Plate tectonics and the evolution of the alpine system. *Geological Society of America Bulletin*, 84, 3137-80.

Doutsos, T., Piper, G., Boronkay, K. & Koukouvelas, I., 1993. Kinematics of the Central Hellenides. *Tectonics*, 12, 936-953.

Faupl, P., Pavlopoulos, A. & Migiros, G., 2002. Provenance of the Peloponnese (Greece) flysch based on heavy minerals. *Geol. Mag.* 139 (5), 513-24.

Fleury, J-J., 1980. Evolution d'une platforme et d'un bassin dans leur cadre alpin: les zones de Gavrovo-Tripolitza et du Pinde-Olonos: *Soc. Géol. Nord,* Spec. Publ. 4, 1-651.

Fytrolakis, N., 1971. Geological researches in Pylias county (Messinia). Ann. Géol. D. Pays Hellén., 23, *PhD. Thesis,* 57-122, Athens (in greek).

Ghibaudo, G., 1992. Subaqueous sediment gravity flow deposits: practical criteria for their field description and classification. *Sedimentology* 39, 423-454.

Gonzales-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.

Haq, B.U., Hardenbol, J. And Vail, P.R., 1987. Chronology of fluctuating sae levels since Triassic. *Science* 235, 1156-67.

Jacobshagen, V., Durr, S., Kockel, F., Kopp, KO., Kowalxzyk, G., Berckheimer, H. & Buttner, D., 1978. Structure and evolution of the Aegean Region. In: Closs, H., Roeder, D. & Schmidt, K. (Eds), *Alps Apennines Hellenides. Schweizerbart, Stuttgart,* 537-64.

Kamberis, E., Pavlopoulos A., Stella Tsaila - Monopolis, S. Sotiropoulos and C. Ioakim 2005. Paleogene deep-water sedimentation and paleogeography of foreland basins in the NW Peloponnese (Greece). *Geologica Carpathica* 56, 6, 503-15.

Karakitsios, V., 1995. The influence of pre-existing structure and halokinessis on organic matter preservation and thrust system evolution in the Ionian Basin, Northwest Greece. *AAPG Bull.* 79, 960-80.

Konstantopoulos, P., Maravelis, A., Pantopoulos, G. & Zelilidis, A., 2007. Sedimentology submarine fans paleocurrent analysis in Peloponnesus area of Pindos foreland basin. *Mineral Wealth* 143, 49-55.

Konstantopoulos, P., 2009. Sedimentological environments and stratigraphycal structure of the Peloponnese flysch-possibility of hydrocarbon genesis. *Ph.D. Thesis*, Patras University, 1-430.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. 2nd *International Conference on Planktonic Microfossils* 2, Roma, 739-785.

Mohrig, D. & Marr, J.G., 2003. Constraining the efficiency of turbidity current generation from submarine slides, slumps and debris flows and slides using laboratory experiments. In: *Turbidites: Models andProblems* (Eds E. Mutti, G.S. Steffens, C. Pirmez, M. Orlando and D. Roberts), *Mar. Petr. Geol.* 20, 883-99

Mountrakis, D., 1986. The Pelagonian zone in Greece. A polyphase-deformed fragment of the Cimmerian continent and its role in the geotectonic evolution of the eastern Mediterranean. *Journal of Geology* 94, 335-47.

Mutti, E. & Ricci Lucchi, F., 1972. Le torbiditi dell' Apenino ettentrionale: introduzione all' analisi di facies. *Mem. Soc. Geol. Ital.* 1-199.

Mutti, E. & Ricci Lucchi, F., 1974. La signification de certaines sequentielles dans les series a turbidites. *Bull. Soc. Geo., Fr.* 16, 577-82.

Mutti, E. & Ricci Lucchi, F., 1975. Turbidite facies and facies associations. In: *Examples of Turbidite Facies Associations from Selected Formation of Northern Appenines* (Eds E. Mutti, G.C. Parea, F. Ricci Lucchi, M. Sagri, Zanzucchi, G. Ghibaudo and S. Iaccarino), IX Int. Cong. IAS, Field Trip Guidebook, Nice, France., Nice, 21-36.

Mutti, E. & Ricci Lucchi, F., 1978. Turbidites of the northern Apennines; introduction to facies analysis (Transl. T.H. Nielsen), *Int. Geol. Rev,* 20, 125-166.

Mutti, E., Tinterr, R., Benevelli, G., Biase di, D. & Cavanna, G., 2003. Deltaic, mixed and turbidite sedimentation, of ancient foreland basins. *Mar. and Petr. Geol,* 20, 733-55.

Mutti, E., Bernoulli, D., Ricci Lucchi, F. & Tinterri, R., 2009. Turbidites and turbidity currents from alpine « flysch » to the exploration of continental margins. *Sedimentology* 56, 267-318.

Pickering, K., Stow, D., Watson, M. & Hiscott, R., 1986. Deep-Water Facies, Processes and Models: A Review and Classification Scheme for Modern and Ancient Sediments. *Earth-Science Reviews* 23, 75-174.

Pickering, K., Hiscott, R., & Hein, F., 1989. *Deep Marine Environments. Unwin Hyman, London,* 1-352.

Ricci Lucchi, F., 1975. Depositional cycles in two turbidite formations of northern Apennines (Italy). *Journal Sedimentary Petrology* 45, 3-43.

Shanmugam, G., 2000. 50 years of the turbodite paradigm (1950s-1990s): deep water processes and facies models. *Mar. Petrol. Geol.* 17, 285-342.

Sotiropoulos, S., Kamberis, E., Triantaphyllou, M. & Doutsos, T., 2003. Thrust sequences in the central part of the External Hellenides. *Geol. Mag,* 140 (6), 661-68.

Sotiropoulos, S., Triantaphyllou, M.V., Kamberis, E., Tsaila-Monopolis, S., 2008. Paleogene terrigenous (flysch) sequences in Etoloakarnania region (W. Greece). Plankton stratigraphy and paleoenvironmental implications. Geobios 41, 415-433.

Stockmal, G.S., Beaumont C. & Boutilier R., 1986. Geodynamic models of convergent margin tectonics: transition from rifted margin to overthrust belt and consequences for foreland basin development. *Bull. Am. Assoc. Petrol. Geol.* 70, 181-90.

Thiébault, E., 1982. Evolution géodynamique des Hellenides externes en Peloponnèse méridionale (Grèce). *Soc. Géol. Nord, Spec. Publ.* 6, 1-574.

Walker, R. G., 1978. Deep water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. Amer. *Bull. Assoc. of Petr. Geol.* 62, 932-966.

Walker & Mutti, E. 1973. Turbidite facies ana facies associations. In: G.V. Midleton and A.H. Bouma (Editors), Turbidites and Deep-Water Sedimentation. *Soc. Econ. Paleontol. Min. Pacific Section, Short Course,* Anaheim, 119-157.

Walker, R.G. & James, N.P., 1992. Facies Models: response to sea level change. *Geotext1, Geol. Ass. of Canada,* 1-454.