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TWO DIFFERENT SUBMARINE FAN LOBE TYPES AND THEIR RELATIONSHIP TO BASIN EVOLUTION; IMPLICATION TO HYDROCARBON RESERVOIRS, WESTERN GREECE

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ABSTRACT

In the Klematia - Paramythia basin turbidite complex, two different depositional lobe types have been distinguished. The first depositional lobe type, up to 8m thick, was deposited during middle Eocene to late Oligocene. It consists of thickening and coarsening upward sandstone beds, is interpreted as attached sandstone lobes and corresponds to type II turbidite system. The second depositional lobe type, up to 9.5m thick, was deposited during early Miocene to late Miocene. It consists of thickening and coarsening upward sandstone beds, is interpreted as detached sandstone lobes and corresponds to type I turbidite system. These different lobe types reflect different hydrocarbon reservoir conditions. The porosity and permeability values of 10 collected sandstone samples, of the middle Eocene to late Oligocene deposits, suggest fair to excellent reservoir conditions.

KEY WORDS: submarine fan, turbidites, sandstone lobes, reservoir, western Greece.

1. INTRODUCTION

Nowadays, the interest in oil exploration has been based on submarine fan lobes, as lobes are major hydrocarbon reservoirs throughout the world. The geometry, the vertical and lateral communication of the sandstone lobes comprise the major elements for the interpretation of turbidite sub-environments. The first researchers who applied the term lobe were Normark (1970) and Mutti & Ricci Lucchi (1972). Shanmugam & Moiola (1991) based on previous workers, distinguished four types of submarine fan lobes: 1) suprafan lobe with excellent reservoir quality, 2) depositional lobe with good reservoir quality, 3) fan lobe with moderate reservoir quality and 4) ponded lobe with poor reservoir quality. Moreover, Nelson et al. (1985) used the term lobe to explain the occurrence of facies C in the upper part of the Ebro fan as evidence for the existence of channelized lobes. Normark & Gutmacher (1985) applied the term levee-valley lobe to describe upper fan sediments of the Delgada fan and Thornburg & Kulm (1987)used the term lobe to describe erosional segments of the fan.

Although the term lobe has been used with different concepts the main characteristics of the submarine fan lobe deposits after Shanmugam & Moiola (1988)are: common thickness fluctuated from 1-50m, the mass transport process is made by turbidity currents, the lithology of the lobes is sandstone/mudstone, the sedimentary features such as complete or partial Bouma sequence and continuing sand bodies. According to Mutti & Ricci Lucchi (1972) facies, lobes are characterized by facies C & D and their main features are the coarsening upwards grain size and the thickening upwards of the sandstone beds.

Mutti's (1985) depositional lobe model suggests that sheet-like sand bodies can be either detached or attached from their feeder channels. Detached and attached depositional lobes have been related to type I

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and type II turbidite systems, respectively. The existence of detached lobes is related to hydrodynamic readjustment zone of turbidity flows (Mutti, 1979), although Shanmugam & Moiola (1985) suggests that the bypassing zone may be developed by tectonic activity such as growing anticlines, shale diapirs or salt domes. Detached lobes are characterized by shale intervals and can be significant elements in evaluating the hydrocarbon potential and producibility, because shale could act as an impermeable barrier.

The aim of this paper is to correlate the different types of sandstone lobes, which have been observed in the middle Eocene to late Miocene turbidite deposits in Klematia - Paramythia basin, to the basin evolution. Moreover, measurements of permeability and porosity will be compared to lobe types, in order to estimate the reservoir potential.

2. GEOLOGICAL SETTING

The Ionian zone is subdivided from east to west in internal, middle and external Ionian zone (I.G.S.R & I.F.P., 1966). The studied area is an elongated basin with a northwest - southeast trend and belongs to the middle Ionian zone.

As the deformation of the external Hellinides migrated westward, in the footwall of Pindos thrust, flysch deposits were accumulated from the Pindos mountains. The Gavrovo and the Ionian zone during this migration of the external Hellenides, were acting as a foreland basin, as first proposed by Underhill (1985).

The flysch of the Ionian zone has been interpreted first by Piper et al., (1978) as parts of a submarine fan (turbidite deposits). Sedimentological data indicate that the turbidites were derived from the east and the source area of these submarine fans was the Pindos front.

The division of the Ionian zone in internal, middle and external occurred during late Oligocene to early Miocene. The Klematia - Paramythia basin, as part of the middle Ionian zone, consists of thick turbidite sequences, which tectonically deposited during the westward progradation of external Hellinides and are extended longitudinal to the axes of the Botzara syncline (fig.1). These turbidites have been interpreted by Avramidis et al.(1997) as submarine fan deposits and classified with the main facies types and facies association of turbidite depositional environments (Mutti & Ricci Lucchi, 1972; Walker, 1978). In the Klematia - Paramythia basin, during the middle Eocene to late Oligocene, turbidite units were deposited, which represent the distal parts of a submarine fan (lobe, lobe-fringe and basin plain), while during early Miocene to late Miocene, due to differential tectonic evolution of the basin, the turbidite units represent both proximal and distal depositional environments, of inner and outer submarine fans. According to Avramidis et al. (1997) the middle Eocene to late Oligocene turbidites are up to 1050m thick and were deposited before the division of the Ionian zone. The early Miocene to late Miocene turbidites were deposited after the division of the Ionian zone, in a restricted basin and are up to 2300m thick. According to King et al. (1993) the Klematia - Paramythia basin configuration has been affected by a strike-slip fault (Agia Kyriaki fault) and by a strike-slip transpressional fault (Kourenton fault) which seperated the Dragopsia and Botzara syncline (fig.1).

3. TYPES OF SANDSTONE LOBES

Middle Eocene - late Oligocene lobes

Description

In the middle Eocene to late Oligocene turbidite deposits two thickening and coarsening upward cycle types have been distinguished:

The first cycle type is up to 5.5-8m thick and consists of medium to thick interbedded yellowish gray calcareous sandstone and grayish mudstone beds (12-50cm) (fig.2A). At the lower two meters of the cycle the s:m ratio is 1:2, passing upwards to 5:1 while the sandstone beds achieve a maximum thickness up to 0.5m. Complete Bouma sequence (Tabcde intervals) is present, where Ta is observed at the thickest sandstone beds. In the upper parts, at the base of sandstone beds, erosional features such as sole marks are present.

The second cycle type is up to 6-8m thick. It consists of medium to thick interbedded yellowish gray sandstone (15-75cm) and blue to grayish mudstone beds (15-60cm) (fig.2B). At the lower 3m the s:m ratio is 1:4 passing upwards to 6:1 while the sandstone beds reach their maximum thickness up to 60cm. The complete Bouma sequence (Tabcde) is present. Sandstone beds, thickening and coarsening upwards with their grain size ranging from medium to coarse grained sand. In sandstone beds water escape and normal grading structures are observed.

Interpretation

These type cycles are equivalent to the lobes which were initially proposed by Mutti & Ricci Lucchi (1972) in their submarine fan model, where the depositional lobes were attached to the feeder channels. According to Mutti (1985) turbidite types and Shanmugam & Moiola (1991) types of submarine fan lobes, the interpreted as lobes cycles correspond to type II turbidite system and are equivalent to the attached submarine fan lobes.

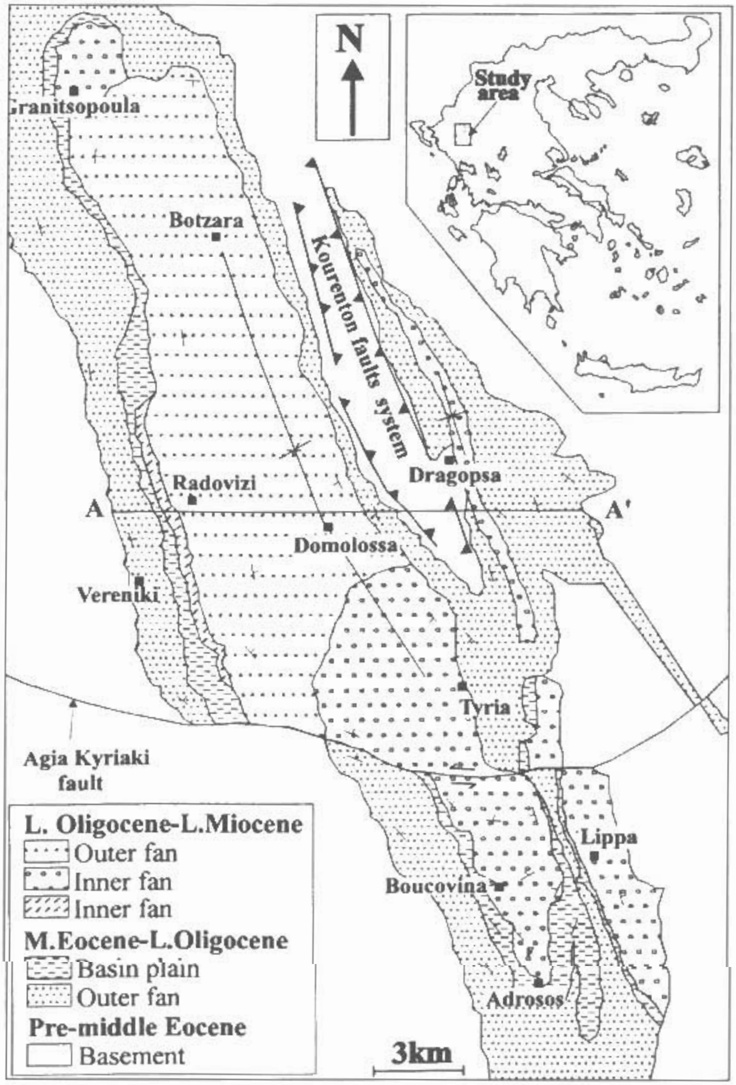

Figure 1: Map showing the sub-environments distribution in Klematia - Paramythia turbidite complex.

Early Miocene - late Miocene lobes

Description

In the early Miocene to late Miocene turbidite deposits three different thickening and coarsening upward cycle types have been distinguished:

The first cycle type, is up to 9m thick and consists of interbedded medium to very thick grayish yellow sandstone and thin blue-gray mudstone beds (fig.3A). The thicker 1.1-3.5m sandstone beds are characterized by amalgamated Tbc Bouma intervals and by flute marks, at their bases. The Tc Bouma interval presented as convolute lamination. This cycle indicate a thickening and coarsening upwards of sandstone beds with the grain size of sandstone beds ranging from fine to coarse grained sand and the thickness of the thicker beds between 1.1-3.5m. The s:m ratio at the lower 4m is 1:5 passing upward to 8:1. Complete Bouma intervals are present.

The second cycle type, is up to 9.5m thick, consists of thin to very thick interbedded pale yellowish calcareous sandstone and blue gray mudstone beds with the grain size of sandstone beds ranging from fine to coarse grained sand (fig.3B). This cycle indicates a thickening and coarsening upwards of sandstone beds and the s:m ratio is ranged from 1:5, at the lower 3.5m, 1:2 to 1:1, at the next 2.5m, and 5:1 to 9:1 at the upper 3.5m. The thickest sandstone beds, locally, are amalgamated and characterized by Tbc Bouma intervals.

The third cycle type is up to 6m thick, consists of interbedded medium to thick calcareous sandstone beds and thin bedded mudstones. The ratio of s:m change from 1:4 at the lower 3m to 1:1 and 3:1 at the upper 3m (fig.3C). At the thickest sandstone beds lenticular features are observed. Bouma internals, Tabce are also present in this cycle.

At the base of these three thickening and coarsening upward cycles, mud/shale intervals with few thin bedded sandstone intercalations are presented (fig.3A,B,C). Bioturbation is common at the three cycle types and is observed at the lower 2m of each cycle, within the mudstone beds. Burrows are 1.5-15cm long and the burrow fill material is sand or silt.

Interpretation

In some cases there are detachment lobes from their associated channel-mouth as the result of sediment bypassing. These kind of lobes have been described in Mutti & Ricci Lucchi (1975) model. As a result of the existence of the bypassing zone for a long period of time, is the development of mud/shales. Also, these mud/shale intervals are observed at the base of the early to late Miocene sandstone lobes and according to Shanmugam & Moiola (1991) interpreted as detached lobes. These detached lobes correspond to type I turbidite systems which according to Mutti (1985) are best observed in large and elongated flysch basins of thrust belts.

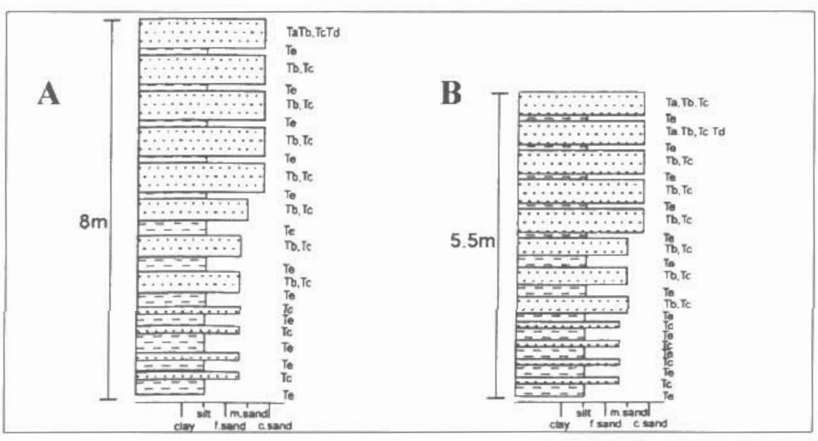

Figure 2: Coarsening and thickening upward cycles, representing sandstone lobes deposited during middle Eocene to late Oligocene.

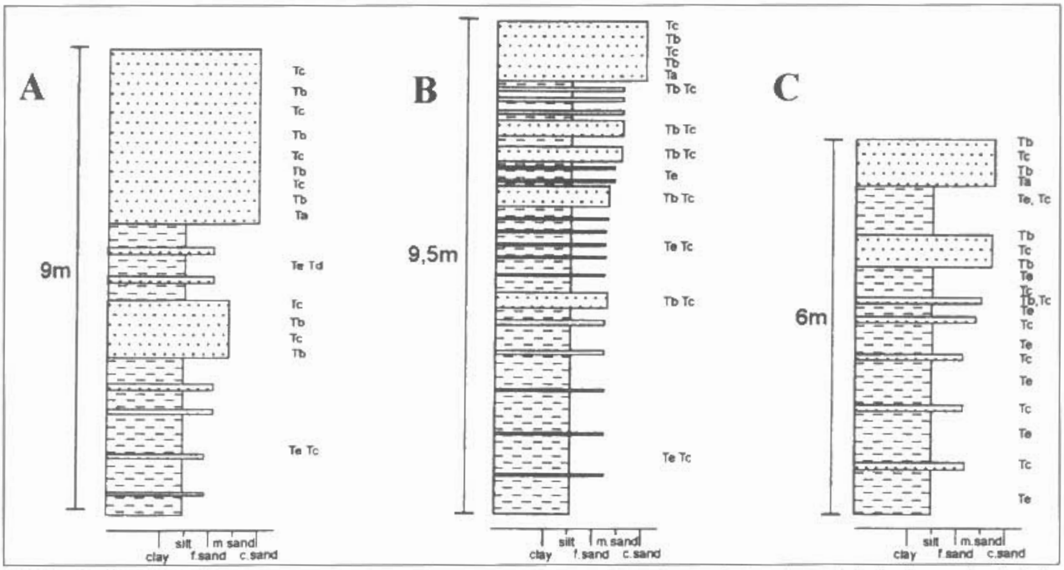

Figure 3: Coarsening and thickening upward cycles, representing sandstone lobes deposited during early to late Miocene.

4. RESERVOIR PROPERTIES-POTENTIAL

Porosity - Permeability

A total number of 10 samples have been collected from the middle Eocene to late Oligocene sandstone lobes and were analyzed for their porosity and permeability. The values of porosity (using saturation and buoyancy technique) and permeability (using falling head technique with Wykeham Farrance equipment) ranged from 4-18.7% and 113-295milidarcy, respectively (table 1).

Sample	Porosity %	Permeability (milidarcy)	Sample	Porosity %	Permeability (milidarcy)
S1	4	120	S6	18,7	295
S2	8,5	218	S7	16,5	175
S3	16,5	210	S8	9,5	113
S4	5,5	183	S9	10	194
S5	12,6	144	S10	6	124

Table 1: Porosity and permeability values of the 10 collected sandstone samples of the middle Eocene to late Oligocene lobes.

These results indicate that the sandstone lobe samples of the middle Eocene to late Oligocene deposits of the Klematia - Paramythia basin, have fair to good porosity and excellent permeability values. These features of the sandstone lobes constitute excellent hydrocarbon reservoir conditions.

Petrological data

The classification of the samples based on the Folk's (1980) sandstone classification, utilizing only the framework grains. The components which are used for this classification are a) quartz, b) feldspar and c) rock fragments. The samples are also analyzed for their grain size, roundness and sphericity of grains.

Among the collected samples appears no significant difference in grain size, as the results of the microscope examination indicated that all the sandstone samples range from fine to medium grained sand. Samples appear to be poorly sorted. The grain types comprise a mixture of angular to sub-rounded grains with very low sphericity. The exception to this result is the sample S10 which appears to has a high sphericity type of grains. Fraser, (1935) and later Beard & Weyl, (1973) indicate that sandstones with high sphericity grains have lower porosities than sandstones with grains of low sphericity. This seem to hold good for the sample S10 which with high sphericity type of grains has lower values of porosity and permeability relatively to the other samples.

From the three main components which observed from the microscope analysis quartz forms the 50-76% of the detrital minerals, rock fragments 16-40% and feldspars 10-20% (fig.4). The sandstones classification utilizing framework grains (Folk, 1980) shows that the clan name of the samples ranged between feldsphatic litharenite and litharenite sandstone (fig.4). Also glauconite is usually presented in small amounts indicating that the sand grains derived from a shelf area. Moreover fossils and fossil fragments were observed. Calcite is common to all samples and it may reduced significantly the primary porosity of sandstone bodies as it is also presented such as matrix material. Almost all the samples appear to have heavy minerals, such as titanite, muschovite and hematite.

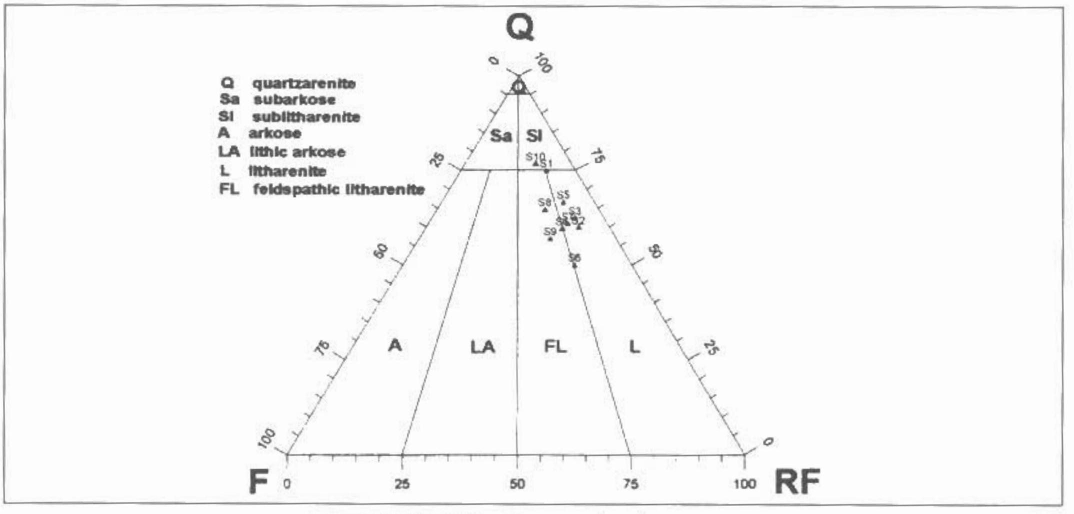

Figure 4: Folk's (1980) sandstone classification utilizing framework grains quartz (Q), feldspars (F) and rock fragments (RF).

Reservoir Potential

The interpretation of the Klematia-Paramythia basin sandstone lobes suggests that they correspond to depositional lobes (Mutti, 1977). Regarding the fact that depositional lobes have good reservoir quality, after Shanmugam & Moiola (1991), the existence of depositional lobes in the studied basin, is a good indices for reservoir potential. The existence of detached depositional lobes, in the early to late Miocene turbidite deposits, indicates better conditions for the depositional lobes to be hydrocarbon reservoirs, as the mud/shale intervals at their bases could act as topseals.

The porosity and permeability measurements of the collected sandstone samples indicate that the values of porosity are fair to good (4-18.7%) and the values of permeability are excellent (113-295milidarcy). Moreover, the petrological results, where the samples seem to be poorly sorted and with very low sphericity grains, suggest good reservoir conditions, although calcite is common to all the samples as matrix material and reduces the primary porosity.

5. BASIN EVOLUTION AND SANDSTONE LOBES DEVELOPMENT

During middle Eocene to late Oligocene the Ionian zone was a foreland basin and in the studied area outer fan and basin plain deposits were accumulated. During late Oligocene to late Miocene, in the studied area inner and outer fan deposits were formed (fig.1). The description and the interpretation of sandstone lobes suggests that during middle Eocene to late Oligocene attached depositional lobes were formed and during early to late Miocene detached depositional lobes were formed in Klematia - Paramythia basin.

The development of attached lobes was made when the Ionian zone was acting as a foreland basin.

During this period in the studied basin the relief was gentle and for this reason the feeder channels were attached to the sandstone lobes. The explanation of the detached lobes existence has been reviewed by Shanmungam & Moiola (1988) (fig.5). According to this work the formation of detached lobes could be occurred either by hydrodynamic parameters or by tectonic activity (fig.5).

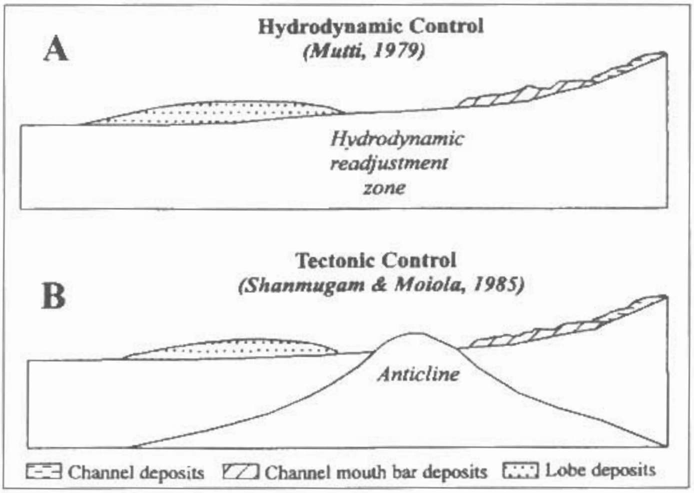

Figure 5: Explanation for the existence of detached lobes, A. by hydrodynamic readjustment, B. by tectonic activity.

In the Klematia - Paramythia basin the existence of detached depositional lobes can be explained both by tectonic activity and by hydrodynamic readjustment zone (fig.6). After the Ionian zone subdivision the source material for the Klematia - Paramythia basin submarine fans was the middle Eocene to late Oligocene turbidite deposits, and the source material was from east and west. The eastern source of the submarine fans produced detached depositional lobes as it was influenced by tectonic activity caused by a strike-slip transpressional fault (Kourenton fault system) (fig.6). Also, the absence of inner fan deposits in the eastern parts of Botzara syncline supports the concept of detached lobes, produced by tectonic activity. For the western feeder of the fan there is not any evidence of tectonic activity to explain the existence of detached lobes. However, in the western part of the Botzara syncline the existence of inner fan deposits (slumps with chaotic bedding), indicates a slope area (fig.1). The existence of both slump horizons and detached depositional lobes, supports the assumption that the bypassing zone of the detached lobes, from the western feeder, can be explained by a sudden downward increase in slope, as Komar (1983) proposed.

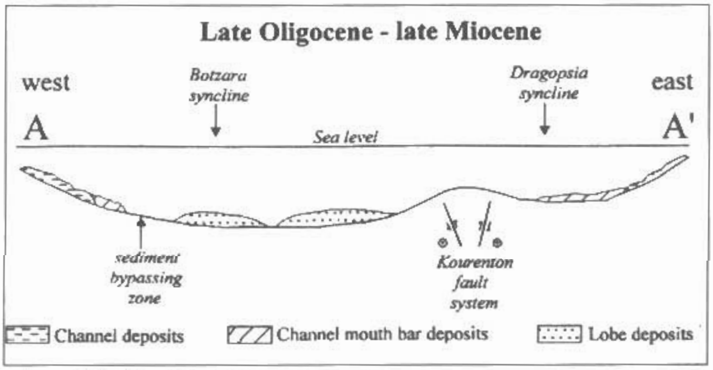

Figure 6: Depositional model for the detached lobes, that have been observed in Botzara syncline (cross section AA' is indicated in figure 1).

6. CONCLUSIONS

Two different submarine fan depositional lobe types have been distinguished in Klematia - Paramythia basin turbidite deposits. During middle Eocene to late Oligocene in the studied area attached depositional lobes were formed corresponding to type II turbidite system. During early Miocene to late Miocene detached depositional lobes were formed corresponding to type I turbidite system. The existence of depositional lobes and the values of porosity and permeability, indicate that Klematia-Paramythia basin turbidite deposits could act as hydrocarbon reservoir rocks.

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