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THE INFLUENCE OF SEA-LEVEL CHANGES ON RESERVOIR DEVELOPMENT ALONG PASSIVE MARGINS

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In passive margin settings the development of reservoirs is governed largely by the combination of sea-level changes and sediment supply. Three cases are compared, where the overall setting is similar, i.e. a thick sequence of seaward prograding sediments yet the development of the reservoirs is very different. The late Tertiary Nile Delta was exposed to subaerial erosion during the Messinian Salinity Crisis and a system of braided river channels developed on the delta front and its seaward extension. The sands filling these channels are important reservoirs today. In the Duala-basin, Cameroon, two periods of massive sea-level falls in the late Cretaceous and Oligocene initiated turbidites and the associated channel fills and fans act as resevoirs. In the offshore Tarfaya Basin, Marocco, during Jurassic times relatively stable sea levels resulted in a prograding sediment prism. A carbonate fringe developed along the outer margin of the shelf which acted as a reservoir trapping the hydrocarbons derived from Cretaceous sediments further offshore.

Keywords: sea-level, reservoirs, offshore, seismic surveys, Africa, hydrocarbons

1. Introduction

In the last two or three decades hydrocarbon exploration has shifted increasingly towards offshore areas, principally towards the margins of continents, or rather towards the accretionary sediment prisms that extend seawards from these margins . While the accepted plate tectonic classifica-

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tions are undoubtedly useful in recognizing and classifying hydrocarbon habitats it seems that sea level changes have a decisive influence on the development of reservoirs and the resulting plays. In essence we will be considering passive margins which are, on the whole, characterized by thick, seaward prograding sediment prisms, usually very little disturbed by tectonism, unless salt tectonics is involved. In this context deltas and shelves are very similar, the difference is in the concentration of the sediment supply and direction of growth. Along the west coast of Africa, for example, in many places it is possible to look at individual seismic sections extending seawards from the shore; these sections look exactly like a longitudinal section of a typical delta and yet sections on either side will show an identical picture for tens or hundreds of kilometres. Furthermore in some inland rift related basins, or other basinal depressions, similar accretionary sediment prisms can be seen and the similarity is not related to the nature of the plate margin (if any) underlying it, but to factors such as paleotopography, sediment supply, sea level changes, etc.

In this paper we will attempt to show the influence of sea level changes in the development of accretionary sediment prisms and their implications for hydrocarbon exploration. Since changes in sea level and sediment supply have a major influence on coarser detrital sediments, it is the development of reservoirs that will mainly be influenced by these factors. In the following pages three examples will be examined in some detail, in each case the behaviour of sea level relative to the seafloor is different.

2. Rapid sea-level drop — the Messinian of the Nile Delta

The Nile Delta is a large, northwards prograding sediment pile dating from the late Eocene; it is still actively depositing sediments along its rim in the Mediterranean (*Fig. 1*). The delta did not remain static during the Tertiary: it seems that in early Tertiary times it entered the Mediterranean far west of its present delta cone. In recent years gas has been discovered in significant quantities both on and offshore in the upper Miocene Abu Madi Formation and, consequently, this formation has received a lot of attention. In spite of this the interpretation of the formation both on the seismic and in the wells is fraught with problems.

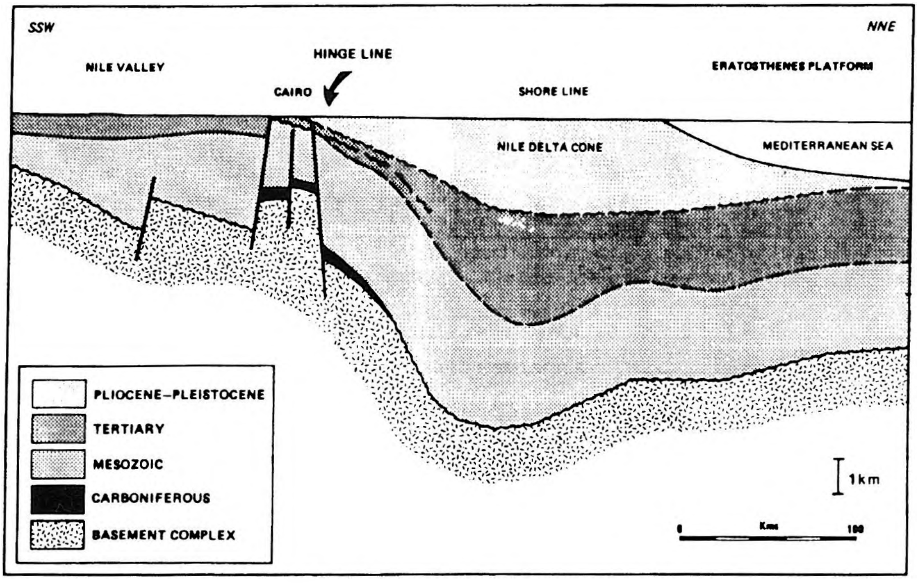

Fig. 1. Schematic longitudinal section along the Nile Delta
1. ábra. Vázlatos hosszanti szelvény a Nílus-delta mentén
Рис. 1. Схематический разрез вдоль дельты Нила

The late Tertiary (Miocene to recent) stratigraphy of the Nile Delta can be seen in *Fig.* 2. The Sidi Salim Formation (Middle Miocene) consists of marine shales and subordinate sandstones up to 1500 m thick; the shale is overpressured and produces intensive diapirs in places. The Upper Miocene Messinian rests with erosional unconformity on the underlying Sidi Salim shales. Three formations are recognized, the Girst being the Qawasim Formation at the base, up to 1200 m thick, consisting of a complex succession of sandstones, conglomerates and interbedded shales. The lithological characteristics point to an alluvial fan type of depositional environment. Next in the succession is the thin Rosetta Formation consisting of anhydrite and salt followed by the Abu Madi Formation, up to 460 m thick, but generally only half of this figure. Lithologically, sandstone and conglomerates dominate the Formation with some subordinate mudstones. The post-Miocene sequence is dominated by marine shales and sands. The Messinian section has been described as having been deposited either in a deep-sea turbidite/fan environment or in a sub-aerial sabkha type setting.

AGE		FORMATION	MAJOR LITHOLOGIES	DEPOSITIONAL ENVIRONMENT
PLEIST.		BILQAS	COARSE SAND	DELTAIC
PLIOCENE	UPPER	MIT GHAMR	SAND/SHALE	
		EL WASTANI	SAND/SHALE	
	MIDDLE TO LOWER	KAFR EL SHEIKH	SAND/SHALE	
MIOCENE	UPPER	ABU MADI	SAND/SHALE	ESTUARINE/ TURBIDITIC CHANNELS
		ROSETTA	ANHYDRITE/ SANDSTONE/SHALE	PLAYA/LAGOONAL
		QAWASIM	SANDSTONE/ SILTSTONE/SHALE	SHALLOW MARINE/DELTAIC
	MIDDLE	SIDI SALIM	PREDOMINANTLY SHALE WITH SIGNIFICANT SAND STRINGERS	SHALLOW TO DEEP MARINE (shale overpressured resulting in marked diapirism)
	LOWER	QANTARA	SANDSTONE/ SILTSTONE/SHALE	SHALLOW TO DEEP MARINE
OLIGOCENE		DABAA	SILTSTONE/SHALE OCC. LIMESTONE	

Fig. 2. The stratigraphy of the Nile Delta

2. ábra. A Nílus-delta sztratigráfiája

Рис. 2. Стратиграфия дельты Нила

We believe the seismic evidence supports the Sabkha type environment of deposition.

The three consistent formations of the Messinian are widely distributed over the Delta. Their contacts — either with each other, or with the underlying sequence — are erosive (*Fig. 3*). Channelling is very widespread in the Qawasim and Abu Madi formations but the amplitude (width) of the channels seems to be small and there are numerous, often parallel channels which are seen to be meandering, splitting and uniting when plotted on a map. Furthermore the channels can be grouped together according to their trend (*Fig.4*) and these groups of channels overlap each other indicating their different relative ages. Both the Qawasim and the Abu Madi Formations show this pattern.

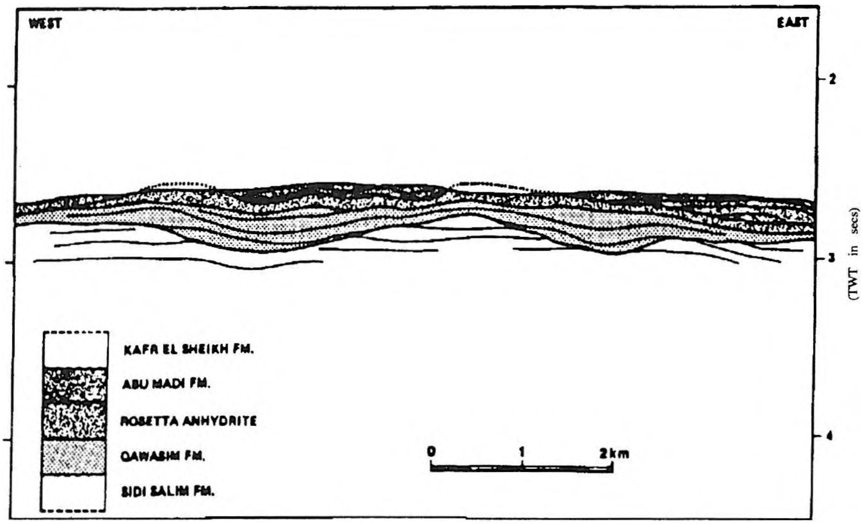

Fig. 3. Geoseismic section of the Messinian of the Nile Delta

3. ábra. A Nílus-delta messiniai emeletet képviselő szakaszának szeizmikus időszelvényét jellemző vázlat

Рис. 3. Геосейсмический разрез мессиния в дельте Нила

The environmental interpretation is, in our view, unequivocal. During the Messinian Salinity Crisis the Mediterranean became separated from its source of supply, the Atlantic Ocean, and the inland sea rapidly lost most of its water due to the high rate of evaporation. As a consequence a very deep depression developed, the floor of which contained hypersaline lakes, while alluvial fans and braided river systems supplied clastic sediments. The proto-Nile was probably the largest source of sediment of the Messinian Mediterranean depression and as a consequence a vast amount of coarse detrital sediments accumulated in this interval in the Nile delta area.

Similar sand rich deposits can therefore be expected in the Messinian not only in the Mediterranean, but also in the other associated inland sea remnants of Tethys, such as the Black Sea, the Caspian Sea, etc.

3. Moderate sea-level drop — Offshore Cameroon , West Africa

While in the previous example the drastic sea-level drop resulted in a complete change in the enviroment of deposition from relatively deep water

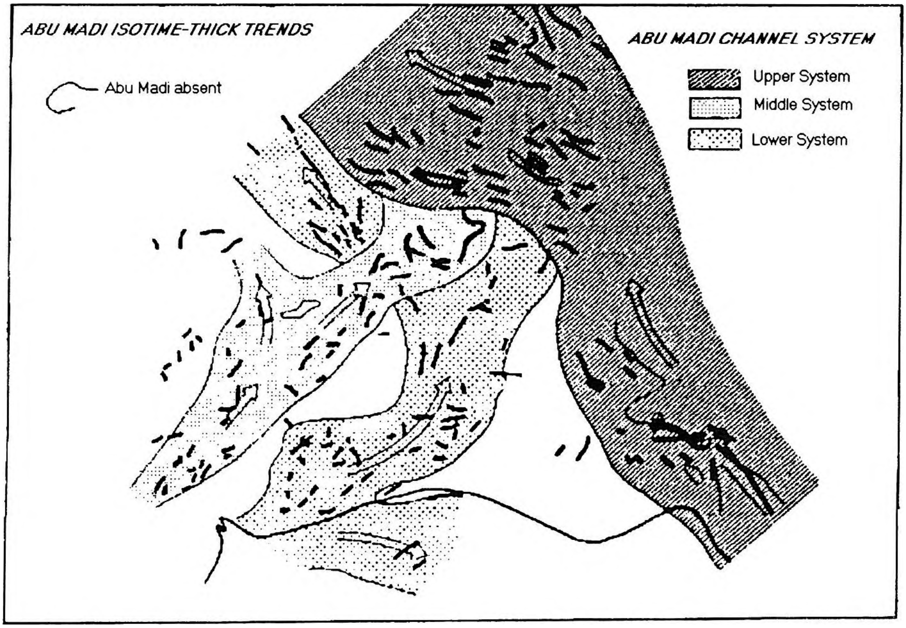

Fig. 4. Channel systems within the Abu Madi Formation, Messinian, Nile Delta

4. ábra. A messiniai Abu Madi formáción belüli csatorna-rendszer, Nílus-delta

Рис. 4. Система каналов в свите Абу Мади, мессиний, дельта Нила

marine to fluvial/sabkha type, in the following case the sea level drop did not result in a change to sub-aerial conditions, it simply rejuvenated the sediment supply in the area resulting in the development of turbidite channels and fans.

The offshore part of Cameroon (*Fig. 5.*) is the northern extension of the West African Salt Basin and is a typical marginal salt basin with up to 6000 m of Cretaceous and Tertiary sediment. The development of the westward prograding sediment prisms began in the early Cretaceous rifting phase with non-marine, lacustrine, fluvial and hypersaline deposits (Mundeck Formation, *Fig.6)*. With the beginning of the opening of the south Atlantic ocean drifting commenced in the Cenomanian and from this period to the present day a dominantly clastic sediment prism has gradually been prograding westwards. During the evolution of this sequence of sediments the combination of global sea-level changes and local subsidence rates resulted in two main periods of marked sea-level drops, one in the late

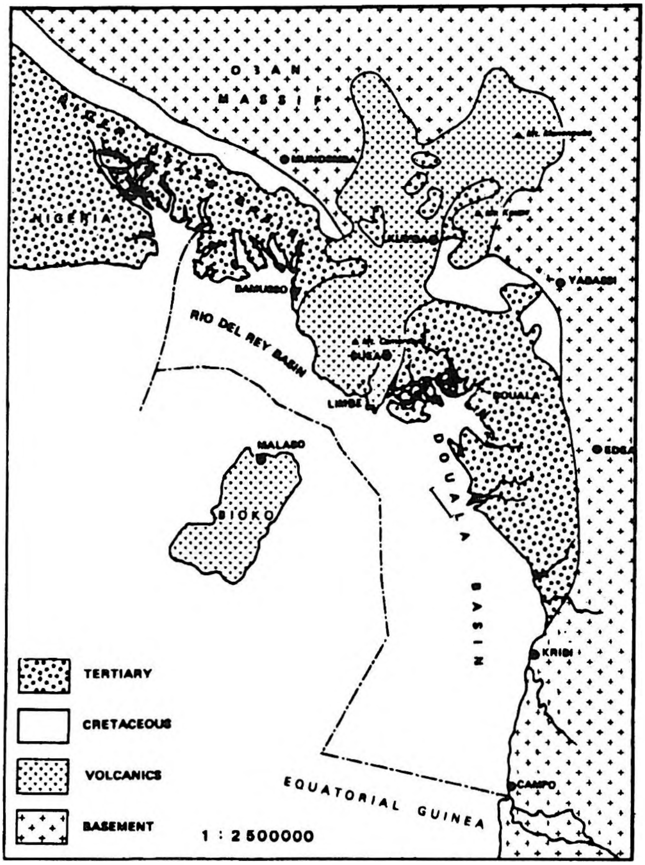

Fig. 5. Sketch map of the geology of the Douala Basin, Cameroon

5. ábra. A kameruni Douala-medence földtani felépítésének vázlata

Рис. 5. Схематическая карта геологии бассейна Дуала

Cretaceous (particulary in the Maastrichtian) and one in the Oligocene. As there are significant oil, gas and condensate accumulations associated with the sands accumulated during these sea-level low-stands it is important to discuss their origin.

Both the evidence of the seismic and wells suggest strong turbidite activity during these periods. This is seen on the seismic in a variety of ways: in the late Cretaceous Logbaba Formation a package of high amplitude reflectors marks the sand rich sequence within which obvious channelling and mounds can be seen *(Fig. 7.)*. Interpretation of the channel features presents no problem but the mound like features may be interpreted either as sand lobes, which are less compacted than the shale surrounding them, or the surface of the 'mounds' may be an erosion surface and one is,

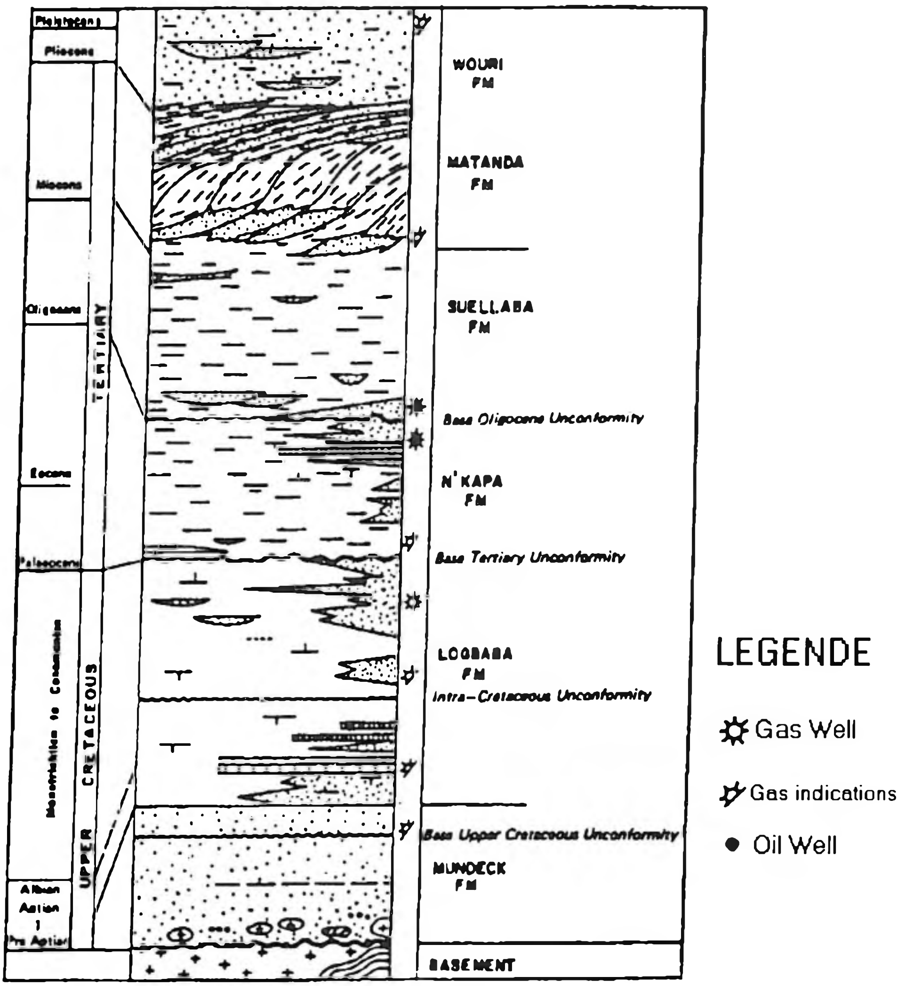

Fig. 6. The stratigraphy of the Douala Basin
6. ábra. A Douala-medence sztratigráfiája
Рис. 6. Стратиграфия бассейна Дуала

in fact, looking at a corrugated surface. We tend to favour the first explanation on the basis of seismic characteristics. During the Oligocene a second marked sea-level low stand occurred. The effect of this is seen in very deep channels cut into the shelf by the turbidity currents and further

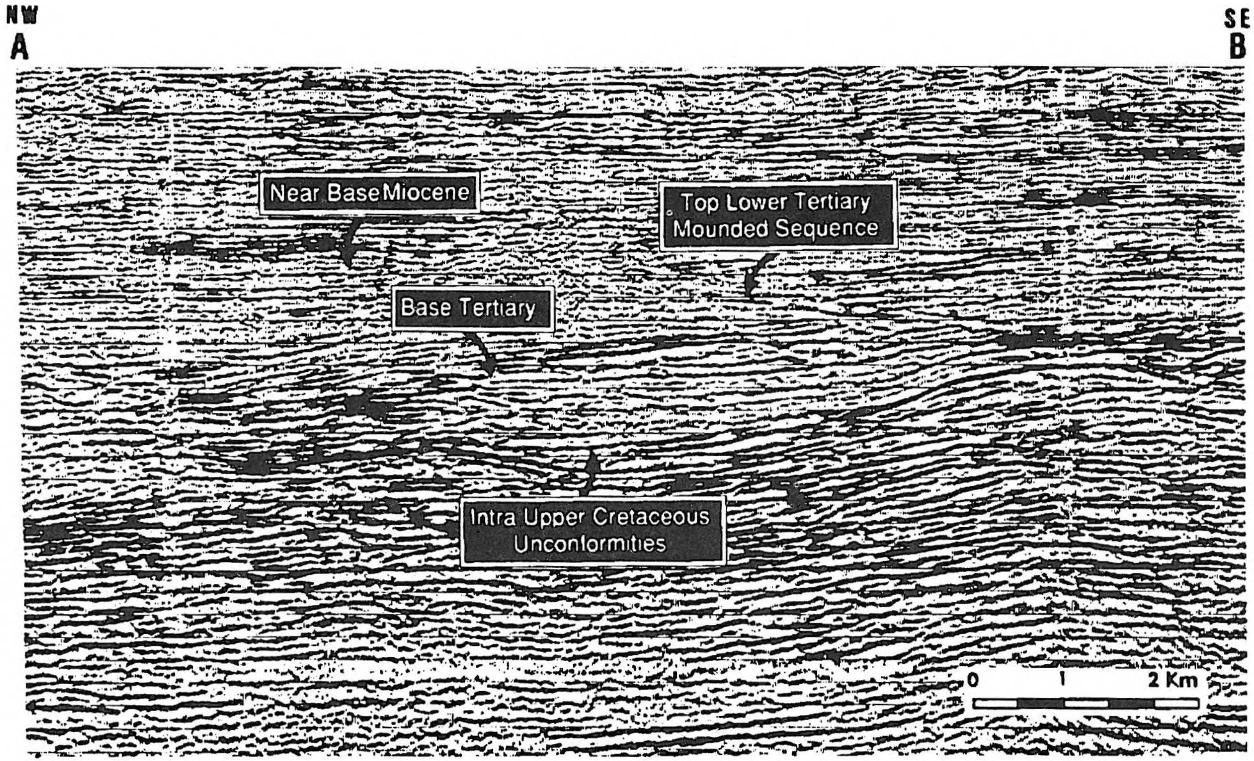

Fig. 7. Seismic section, offshore Douala Basin, showing late Cretaceous and early Tertiary mounded sequences

7. ábra. Szeizmikus szelvény a tengeri Douala-medencéből, felsőkréta és kora harmadkori "buckás" szekvenciával

Рис. 7. Сейсмический профиль, прибрежный бассейн Дуала, с волнистыми верхнемеловой и нижнетретичной толщами offshore sand lobes forming mounded sequences. It seems that the Oligocene sea-level drop was more drastic than the late Cretaceous one judging by the depth to which, in the case of the Oligocene channels, could reach several hundred metres. The axis of channels in both periods followed more or less the same lines, indicating that the main topography of the basin has remained more or less stable since Cretaceous times.

4. Stable sea-level — Offshore Tarfaya Basin, Morocco

In this particular example only the Jurassic shelf deposits are considered; from the early Cretaceous onwards continuous sea-level low stand produced deep cutting turbidity current channels, very similar to those described in the case of the offshore part of Cameroon.

During Jurassic times the sea level remained remarkably stable or perhaps it is more correct to say that subsidence, sediment accumulation and sea level changes stayed in the same relationship. As a consequence a thick, strongly seaward prograding sediment prism built up, the main accretion direction being lateral rather than vertical (*Fig. 8.*). Even so a total

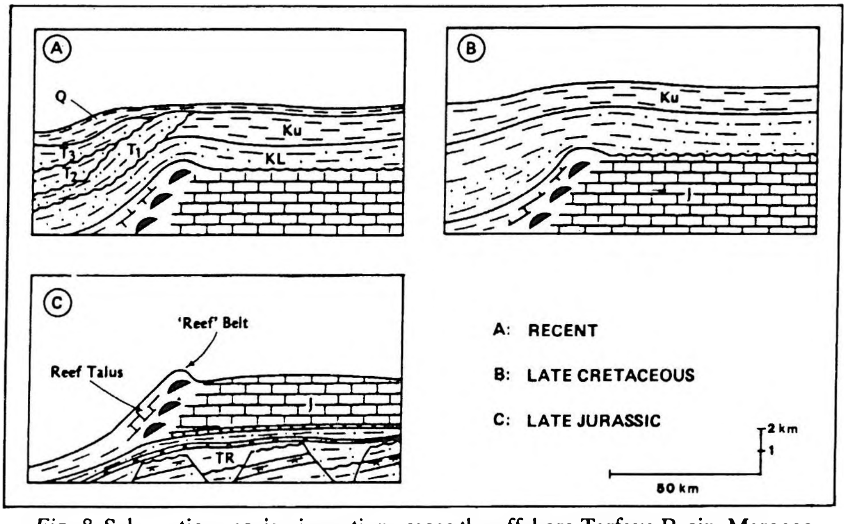

Fig. 8. Schematic geoseismic section across the offshore Tarfaya Basin, Marocco

8. ábra. A tengeri Tarfaya-medencét harántoló szeizmikus időszelvényt jellemző vázlat

Рис. 8. Схематический геосейсмический разрез через прибрежный бассейн Тарфайя, Марокко thickness of some 3000 metres of Jurassic sediments accumulated consisting of finer grained clastics and some carbonates.

Along the shelf edge a 'carbonate bank' developed which kept pace with both the seaward migration of the shelf edge and also with the vertical accretion of the shelf. On the landward side of the carbonate bank almost 'backreef' like conditions developed, i.e. very shallow water with perhaps increased salinity in which dolomites and occasional anhydrite layers were deposited. On the seaward side the very steeply sloping seafloor was covered with carbonate debris from the bank above. During the early Cretaceous sea level low-stand organic rich shales were deposited off the Jurassic shelf while on the shelf itself little or no sedimentation took place.

From the point of view of hydrocarbon exploration the carbonate banks provide the only acceptable reservoirs, the rest of the Jurassic (and later) sediments being mainly shales.

5. Conclusions

From the three examples given above it seems that relative sea-level movements during the evolution of prograding sediments prisms have a decisive influence on the development of reservoirs.

In the case of the Messinian of the Nile Delta (the first example discussed above) the drastic drop in sea level caused by the dessication of the Mediterranean, resulted in a complete change of the environment of deposition. Braided streams discharging into sabkha plains took the place of deep marine environments. The sands are largely channel fills although sheet sands and alluvial fans can also be expected.

The recognition of sand rich horizons on the seismic is not always easy, although the channel-like features are easy to see (Fig. 3); even so it is by no means certain that these are filled with sand. Sealing of the reservoir may be provided either by locally developed anhydrite or, more regionally, by the deep marine shales that follow the period of basin dessication. This type of situation has so far only been described for the Mediterranean but it could be expected to have occurred in other remnant Tethyan basins such as the Black and Caspian Seas.

The second example discussed in this paper concerned a much more common occurrence: turbidite channels and fans which developed in response to periodic sea-level low stands. The effect of these was a periodic rejuvenation of the area of sediment source and consequent increase in sediment supply. The course of the channels/fans tends to remain the same through time as the basic bathymetry of the Atlantic type marginal sag basins tends to remain unchanged. From a hydrocarbon exploration point of view these types of reservoirs are fairly easy to identify on seismic. The sands are either in channel fills or in large scale mounds, and show high amplitude reflections. The main problem seems to be the recognition of the trapping mechanism. If salt tectonics affects the reservoir the structural traps are easy to identify. In most case, however, the traps are stratigraphic and the updip sealing of channel fills or mounds is not easily ascertainable on seismic sections.

The third example, the carbonate bank shelf edge of the Tarfaya Basin, offshore Morocco, is also a widespread setting along passive continental margins. The high porosity carbonate banks could provide excellent reservoirs but there are a number of problems associated with this type of trapping situation. In the Tarfaya Basin the source of the hydrocarbons is the thick early Cretaceous shale sequence which was deposited downslope from the Jurassic shelf edge in deep water. Due to the rapid burial of these shales hydrocarbon generation started in late Cretaceous times and peak generation was reached in the early Tertiary. Strong turbidity flows started eroding into the Jurassic shelf soon after that and the carbonate shelf edge was bared of cover, left with very little seal or even completely eroded away. The trapped oil in many cases migrated away and the presence of heavy or dead oil in these reservoirs supports this view. Only in areas in which a thick cover of sealing shales remained in place can one hope for significant hydrocarbon discoveries.

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TENGERSZINT VÁLTOZÁSOK HATÁSA TÁROLÓK KIALAKULÁSÁRA PASSZÍV LEMEZPEREMEKEN

Tom I. KILÉNYI

Passzív lemezperemeken tárolók kialakulását elsősorban két tényező kombinációja határozza meg: a tengerszintváltozás és az üledék-utánpótlás. Három esetet hasonlítunk össze, ahol az alaphelyzet hasonló: a tenger felé progradáló vastag üledéksorozat, mégis a tárolók kifejlődése erősen eltérő. A fiatal harmadkori Nílus delta eróziónak volt kitéve a Földközi tenger messiniai kiszáradása alatt. Az ekkor, a delta fronton és ennek tenger felőli folytatásában kialakult meanderező folyócsatornákat kitöltő homokok fontos tárolók. A kameruni Douala-medencében két erős tengerszint-csökkenési időszak a felsőkrétában ill. az oligocénben turbiditek képződését idézte elő, és az azokkal kapcsolatos csatorna-kitöltések és törmelékkúpok képezik a tárolókat. A marokkói tengeri Tarfaya-medencében a Jurában relative állandó tengerszint mellett vastag üledékprizma alakult ki. A shelf külső szélén karbonát pad fejlődött ki, amely a szárazföldtől még távolabb leülepedett kréta üledékekben kialakult szénhidrogének csapdája lett.

ВЛИЯНИЕ КОЛЕБАНИЙ УРОВНЯ МОРЯ НА РАЗВИТИЕ РЕЗЕРВУАРОВ ВДОЛЬ ПАССИВНЫХ ОКРАИН

Т. И. Киленьи

В обстановке пассивных окраин развитие резервуаров контроллируется в основном сочетанием колебаний уровня моря и привноса осадков. Сопоставлены три случая, в которых общее положение сходно (имеется мощная, наступающая в сторону моря толща осадков), но резервуары тем не менее существенно отличны друг от друга.

В прибрежном бассейне Тарфайя (Марокко) сравнительно стабильный в юре уровень моря привел к возникновению наступающей призмы осадков. Вдоль внешнего края шельфа протягивается полоса карбонатов, образовавшая резервуар углеводородов, происходящих из меловых отложений, расположенных на большем удалении от береговой линии.

В бассейне Дуала (Камерун) в позднем мелу и олигоцене произошли два крупных спада уровня моря, которые привели к возникновению турбидитов и сопряженных с ними выполнений каналов и конусов, являющихся резервуарами.Позднетретичная дельта Нила размывалась во время мессинского солевого кризиса, и система ветвящихся речных русел развивалась на фронте дельты и на ее морском продолжении. Пески, выполняющие эти каналы, ныне представляют собой важные резервуары.