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Sedimentological evolution of the F3 sandy bar of the western Alrar field (Eifelian - Givetian), Illizi basin, Algeria

Rabah CHAOUCHI*, Mohand Said MALLA and Fatiha KICHOU****
* *Institut National des Hydrocarbures et de la Chimie - Boumerdès, Algérie*
** *Sonatrach - Division Exploration - Hussein Dey, Alger - Algérie*

Abstract : Commercial accumulation of hydrocarbons depend on several factors, among which sedimentological conditions are of prime importance. Effects of such conditions have been observed on a mainly sandy reservoir of Givetian- Eifelian (Middle Devonian) age, within the western part of the Alrar field. Frequent variations of the reservoir characteristics are present within the area. Previous studies have failed to produce a coherent model capable of explaining observed patterns of hydrocarbon distribution and entrapment within the West Alrar field. A previous sedimentological model incorporates new well data and helps explain these patterns, though the southern limit of the F3 remains largely hypothetical. We believe that, in Alrar, the reservoir was deposited as tidally influenced littoral bars. These are elongated in a NW-SE direction with an interbar area in the vicinity of well DZ-1.

Based on this model, four possible sedimentological interpretations of the extention of the F3 reservoir to the south and west have now been developed. The pinch out also seems to be related to the rapid thinning out of the section in this direction and to active faulting and uplifts at the time of deposit.

Key words : Alrar - Devonian - Reservoir - Evolution of the bars.

Evolution sédimentologique de la barre gréseuse du F3 d'Alrar Ouest (Eifélien - Givétien) - bassin d'Illizi - Sahara oriental - Algérie

Résumé : Les conditions de sédimentation sont un facteur important de l'accumulation des hydrocarbures.

Le réservoir gréseux F3 d'ALRAR OUEST fait partie de la série détritique paléozoïque (Dévonien moyen) d'âge Eifélien et Givétien, constitué par par un ensemble gréso-argileux présentant des variations de caractéristiques réservoir très variables.

Les études faites jusqu'à ce jour en sédimentologie, diagenèse, géochimie et analyse structurale ont permis d'expliquer l'accumulation des fluides dans la structure d'Alrar Ouest. C'est pourquoi le modèle sédimentologique de F. Sommer a été revu et modifié grâce aux données recueillies par le biais des forages récents (AL28 jusqu'à AL36). En effet la limite d'extension du F3, au Sud, tracée par F. Sommer est une limite hypothétique. En réalité on est en présence à Alrar de deux barres tidales, allongées suivant une direction NW-SE avec une inter-barre au niveau du puit DZ.1.

De même il a pu être établis 4 hypothèses sédimentologiques sur l'extension du F3 à l'Ouest.

1ère hypothèse : Passage latéral de faciès.
2ème hypothèse : Passage latéral brutal.
3ème hypothèse : Passage latéral brusque avec contrôle.
4ème hypothèse : Présence d'un haut fond qui arrête la sédimentation de la couche réservoir.

En particulier l'évolution du F3 d'Alrar Ouest s'établit dans un milieu de dépôt de barre littorale à influence tidale et le biseautage vers le Sud et l'Ouest semble être lié à des amincissement rapides et parfois à des accidents et soulèvements brutaux du fond.

Mots-clés : Alrar - Dévonien - Réservoir - Evolution des Barres Sableuses.

INTRODUCTION

The Alrar field is located in the South Eastern part of the Algerian Sahara within the Illizi Basin (fig. 1). The field lies 230 km North of the town of In Amenas, this area corresponds to the Tinhert Hamada, South of Ghadames basin, limited Eastward by the Algerian-Libyan boundary and Westward by the Ahara high (fig. 2). In contrast to most other major fields in this region, trapping at the Alrar field is highly dependant on facies changes, and the field is basically a stratigraphic trap. In addition to the influence of sedimentological conditions on the extent of the field, there are also large variations observed over the field in reservoir quality and thickness. Despite the drilling of a large number of development wells, the distribution of the main Eifelian-Givetian (F3) clastic reservoir over the Alrar field is still poorly understood. The objective of this paper is to update and revise existing sedimentological models for the field in the light of most recent data, and consider the implications of various models for the areal extent and pinchout of the main reservoir unit.

The area studied covers the entire Algerian sector of the field, with an emphasis on the changes in sedimentary model resulting from the recent, development of the western structural segment of the field (West Alrar).

HISTORY OF THE FIELD

The Alrar field was discovered in August 1961 by drilling the Well AL-1. The discovery underscored the existence of gas condensate in the F3 reservoir. During the same year, the well AL-2 proved these results. Two years later (1963 - 1964) seven (07) other wells were drilled and all proved gas condensate except the well ALE-102 which fell in the water bearing reservoir part. The well ALB-1, drilled in the western part, discovered gas condensate in the F3 reservoir too. Up to 1970, seven other wells were drilled (AL-5; AL-6; AL-7; AL-8; AL-103; AL-106 and AL-107). During this period of development, the well AL-103 discovered a gaz / oil contact at -1948.5m and proved the existence of a ten meter thick oil ring in Alrar East (oil / water contact at -1958.5m) (fig. 4).

The other discovery of the Stah oil field in 1971 resulted in the cessation of activity on the Alrar field as the AL-9 was drilled later on in 1976. In 1978, drilling resumed for the field development and production of gas condensate in the eastern Alrar part. In the western Alrar part, 26 wells were drilled, of which 23 during the period 1982 - 1993. All these wells discovered gas condensate except the wells AL-37 (absence of F3 reservoir), AL-39 (water bearing F3 reservoir) and ALC-1 (F3 reservoir very reduced and of poor quality).

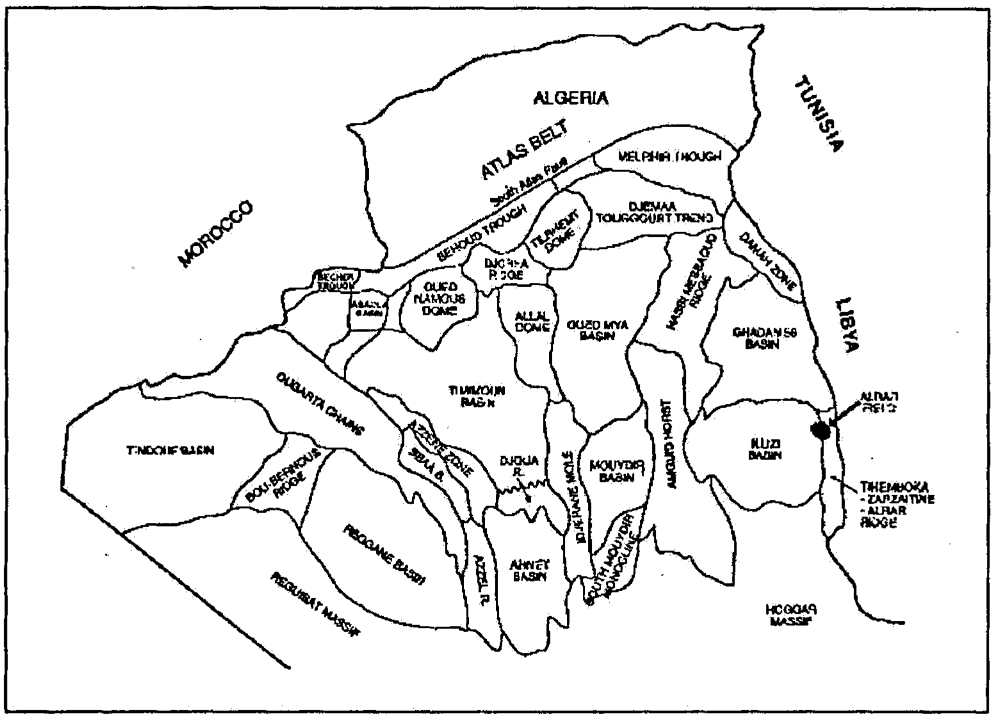


Fig.1- Principal structural elements of the Sahara platform, showing majors ridges and domes separating major basins (from Sonatrach,1991)
Principaux éléments structuraux de la plate-forme saharienne

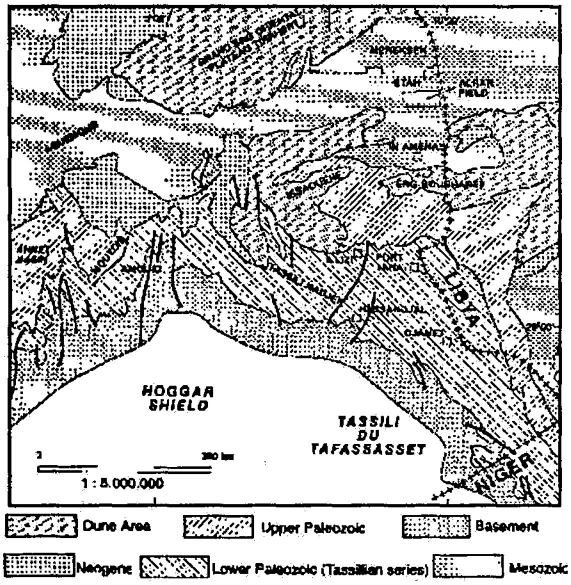


Fig. 2 - Geological map
Carte géologique

All these wells drilled in the western Alrar part did not prove the presence of oil within the F3 reservoir; which resulted in the assumption that an oil ring did not occur in this western part as was the case for the eastern part. Following the drilling of AL-49 in 1994, the above assumption was rejected on account of drill stem results in this well which underscored oil in the lower part of the F3 reservoir with a very weak flow rate, and proved the existence of an oil ring in the western Alrar. So, the gas / water contact is recognized at - 1448 in the block bearing DZ-1, DZ-2 and DZS.1 in the Northern part of West Alrar (fig. 10a), (Sonatrach, 1970; 1992 and 1996). The west Alrar hydrocarbon reserves are 55.10^9 $M^3$of gas and $12.2\ .10^6$ T of condensate (Chaouchi *and al.*, 1996). In this, the western Alrar compartment proves to be an important petroleum play.

STRATIGRAPHY

The lithostratigraphical column (fig. 3) is constituted by two important cycles : Paleozoic and Mesozoic. This series ranges from Cambrian to Cretaceous times and separated by the following unconformities: Taconic, Caledonian, Frasnian, Hercynian and Austrian.

During Paleozoic times thick series of sandstones, interbedded shales and sands and shaly limestone, aged from Cambrian to Carboniferous (mainly middle Devonian) deposited. The hercynian orogenesis ends the sedimentation and is followed by the erosion of the outcrops. In Mesozoic times begins a transgression, characterized by the lower clastic complex of triassic sequences. All of the Paleozoic sandstones are potential reservoirs, Silurian and Devonian shales are the primary source rock (Attar, 1987 and Sommer, 1979).

LOCAL STRUCTURAL FEATURES

The studied area looks like a dipping Northward monocline (fig. 4). Numerous faults or flexures having a sub meridian orientation complicate the studied area (fig. 5). From West to Est there is an increase of the F3 total thickness, with a minimum in KAR-1 well (6 meters) and a maximum in AL.32 well (48 meters) (fig. 9 and 6).

LITHOFACIES AND ENVIRONMENT

Based on log interpretations (fig. 14, 15 and 16), core observations, petrographic analysis and earlier works by F. Sommer 1979, Beicip 1975 and 1987, the F3 can be subdivided into three (03) large lithofacies units; whence from base up we record (fig.7, 10a, 10b and13) :

- a set of sandy bars;

- a shale and sandstone complex;

- a set of alternating bioturbated shale and sandstone designated as the progradation sequence according to F. Sommer;

These units so designated by F. Sommer correspond to their Beicip equivalents as follows (Beicip, 1987; Sommer, 1979) :

(Sommer, 1979)		(Beicip, 1987)
- Sandy bars	⇒	Littoral barrier facies
- Shale and sandstone complex - Progradation sequence	} ⇒	Subtidal facies

The schematic section of F3 reservoir in Alrar area (fig. 7, 15 and 16) comprises the following, from the base upward :

Lower part

The lowermost part of the section begins above the *Supra F4 Pteropode shales*, with bioclastic black shale, passing upward to bioturbated shaly sandstones with numerous shells. Each one of the interbedded sandstone and shale layer shows a characteristic upward grading passing from sharp based sandstone into shales. Laminations are horizontal at the base becoming more wavy upward. Bioturbation is common in the upper finer grained part of the sandy or shaly sequences. The black shale represents very low energy deposits, with only weak influences of storm activity as indicated by bioclastic lags Shale and sandstone interbeds show an upward grading, formed by alternating storm and quite water deposit. Bioturbation mainly occurs during the quite water periods. The sandstone beds could correspond to fluvial channel deposits.

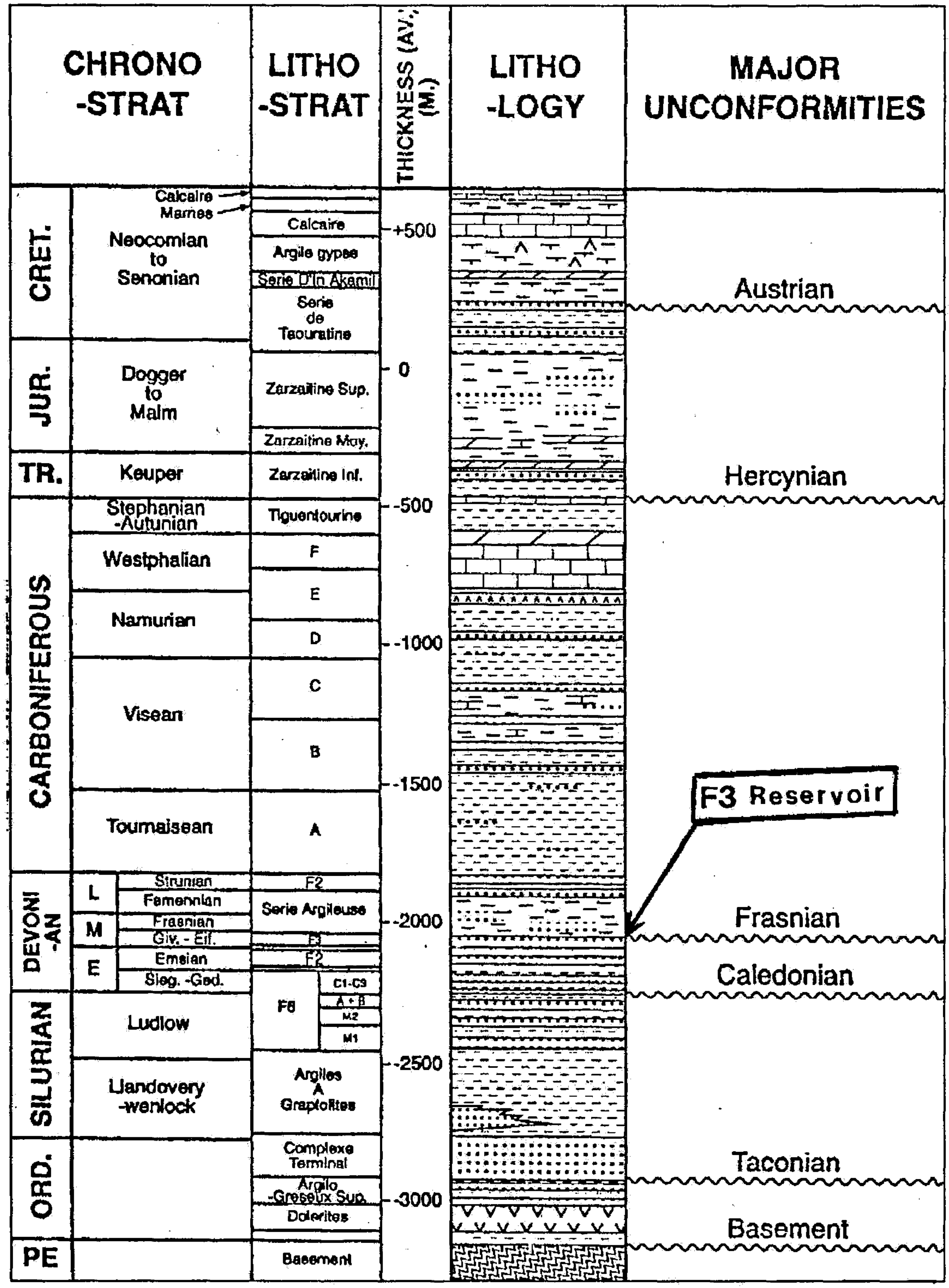


Fig. 3 - Lithological column :North-East of Illizi Basin
Colonne stratigraphique : Nord-Est du Bassin d'Illizi

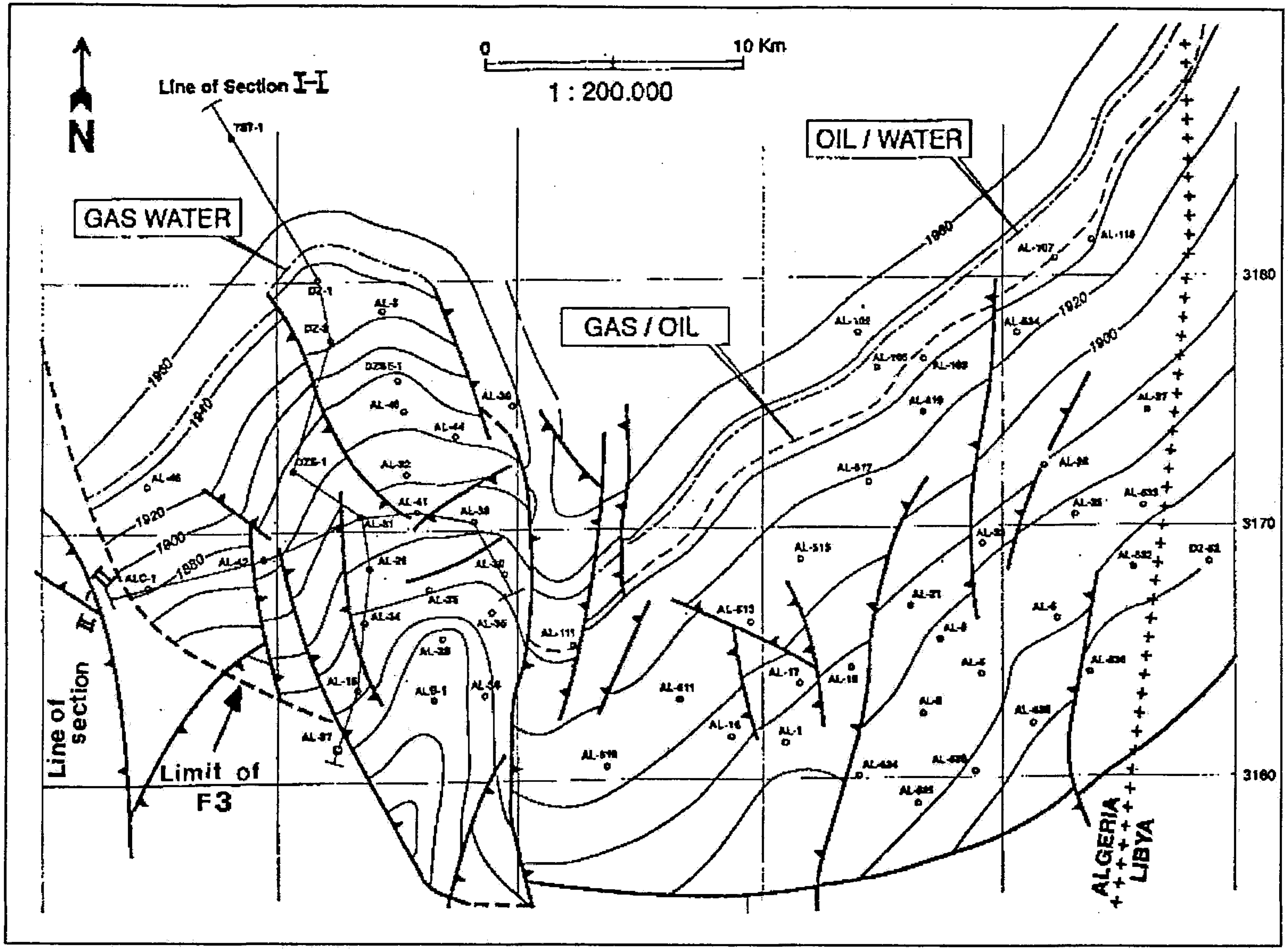


Fig. 4 - Top F3 Isobath Contour map of Alrar field
Carte en isobathe au toit du F3 champs d'Alrar

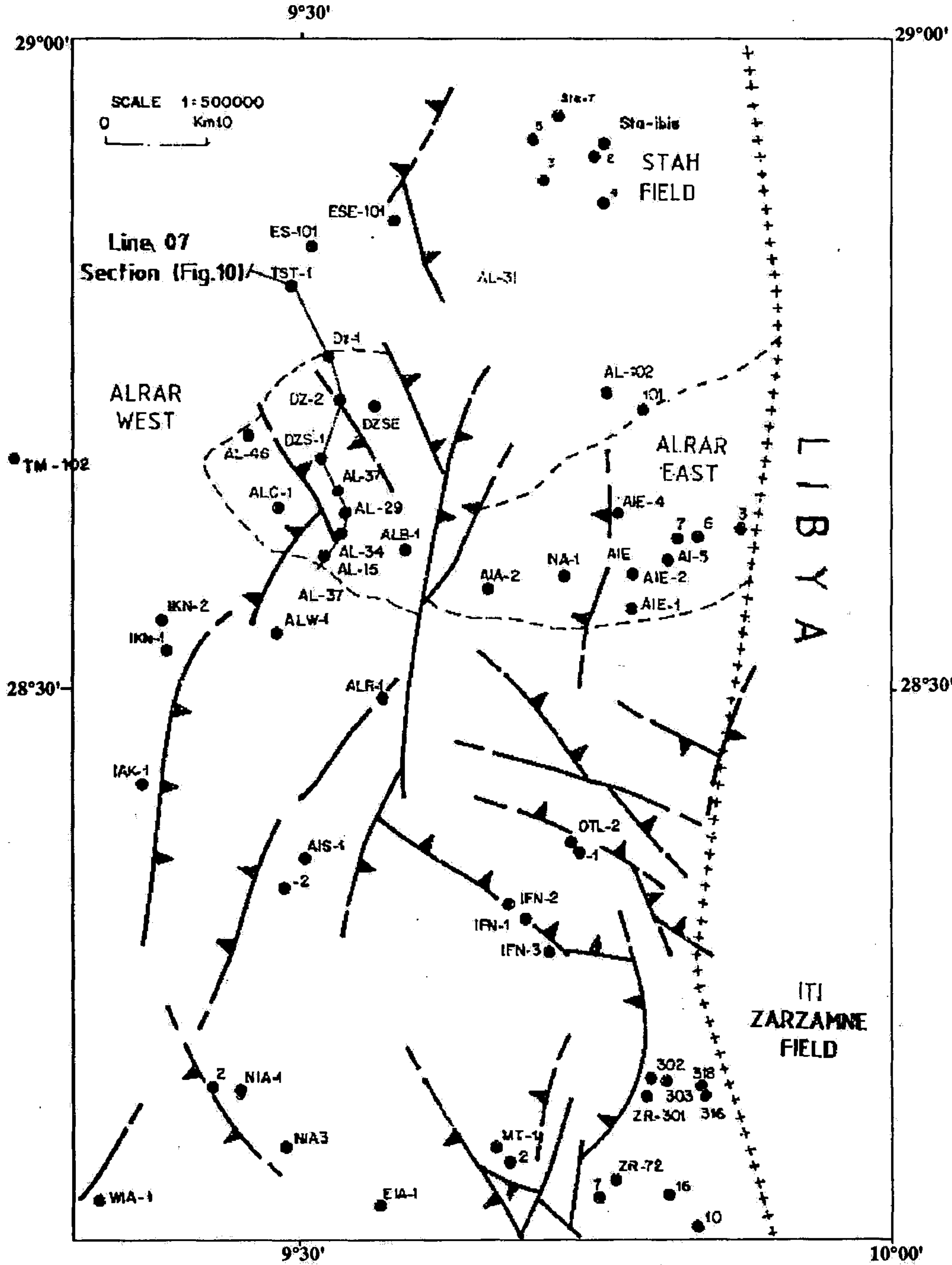


Fig. 5 - Structural framework of the eastern part of the Illizi Basin
Schéma structural de la partie orientale du Bassin d'Illizi

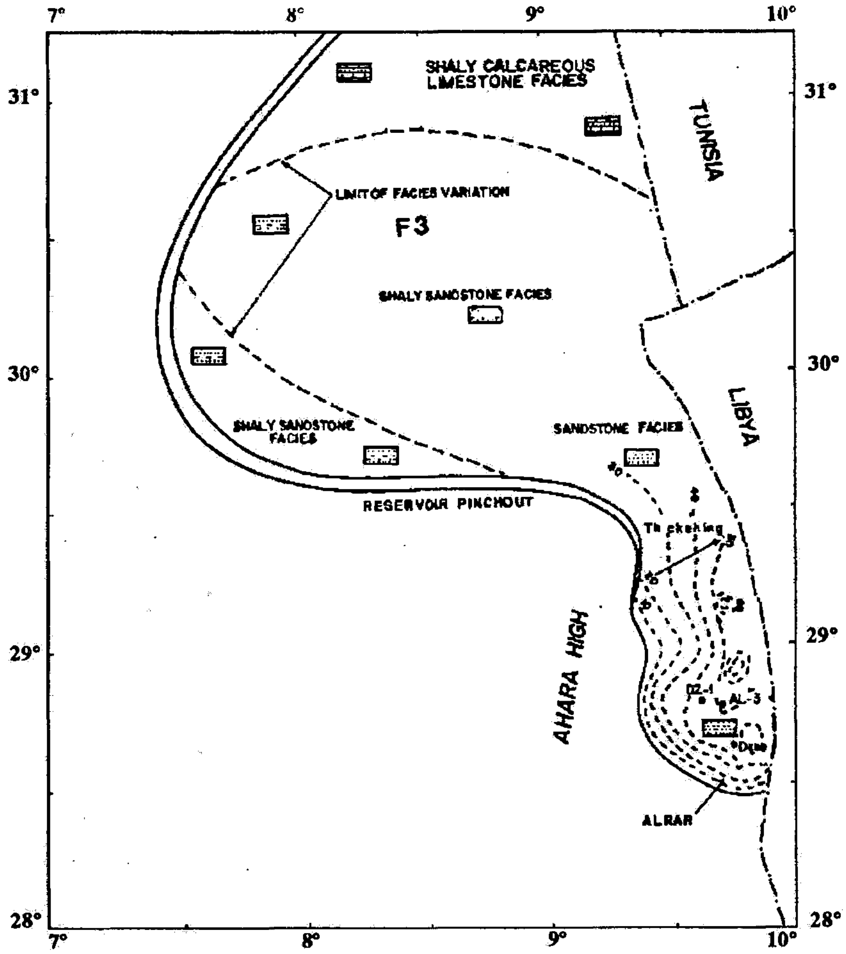


Fig. 6 - F3 reservoir isopach map « North-East of Illizi Basin »
Carte isopaque du réservoir F3 « Nord-Est du Bassin d'Illizi »

The middle part

The middle part of the sequence consists of a *shaly sandstone complex* which begins with coarse grained sandstone with high angle cross stratifications and shale pebbles at the bottom, passing upward into quartzitic and fine grained sandstones : above there is a medium grained sandstone with low angle cross stratifications interbedded with black shale, lenticular sandstone, shaly fine grained sandstone, and numerous flasers are present in this interval.

The coarse grained sandstone represents a channel deposit with a basal lag made up of clays chips; above sub-marine dune facies are characterized by low angle cross stratification and a decreasing of grain size.

The uppermost part

Consists of very thick coarse grained sandstone beds with high angle cross stratification, interbedded with finer grained intervals with stylolites and rare flasers.

The coarsenting upward sequence is interpreted as sandy bars representing a high energy deposit.

Thus the origin of the sandstone beds represent a prograding coastline sequence.

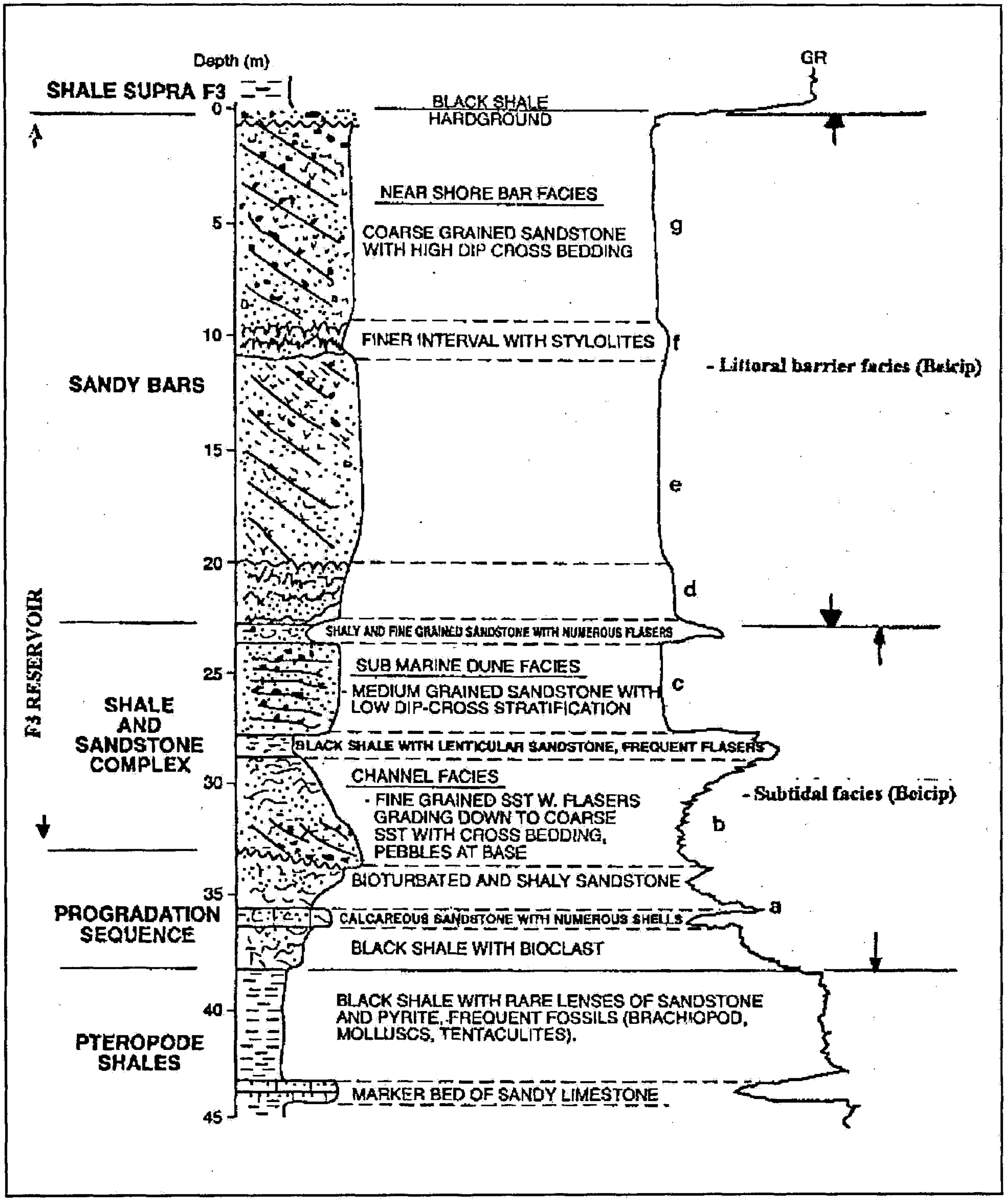


Fig. 7 - Schematic section of F3 reservoir in Alrar area (Sommer, 1979)
Coupe schématique du réservoir F3 de la zone d'Alrar (Sommer, 1979)

SEDIMENTOLOGICAL MODELS

Sedimentological hypotheses of the Westward F3 extention (BEICIP 1987)

Due to the lack of any data about wells 30 km Westward it is according to Beicip, possible to discuss only about several hypothesis on the process leading to the change of F3 from type 1 to 2 (fig. 8).

- **1st hypothesis** : A progradation from West to East of the distal bar. However, there is no sedimentological arguments to prove that.

- **2sd hypothesis** : Sharp lateral facies change. In fact, it is possible to notice that the type 1 reservoir facies is suddenly interrupted.

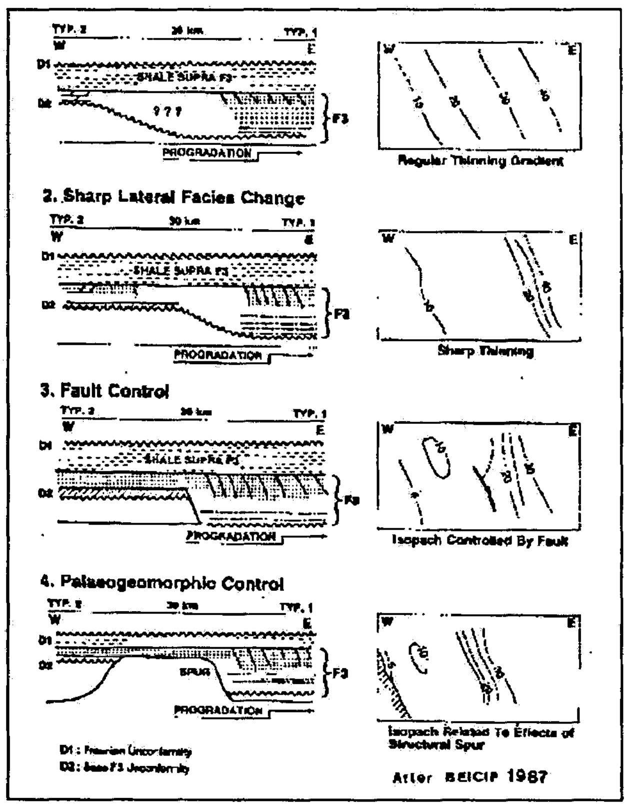


Fig. 8 - Extension hypotheses (Beicip, 1987)
Hypothèses d'extensions du F3 (Beicip, 1987)

- **3rd hypothesis** : Sharp lateral facies change due to structural control. This case existe between AL-37 and AL-34 . The thickness variation is also sharp however it also is controlled by the ancient scarp fault.

- **4th hypothesis** : The non deposition of the F3 is related to the presence of a high spur, stopping the reservoir layer sedimentation.

SOMMER Sedimentological Model

In this study it is the sedimentological interpretation results from F. Sommer (TOTAL Algérie, 1979) on behalf of Sonatrach, the data from wells drilled up to june 1979 (wells reported on fig. 9) and all the works carried out on the area that have been used. These interpretation results are summarised in figure 9; the main morphological and geodynamic characters that control the

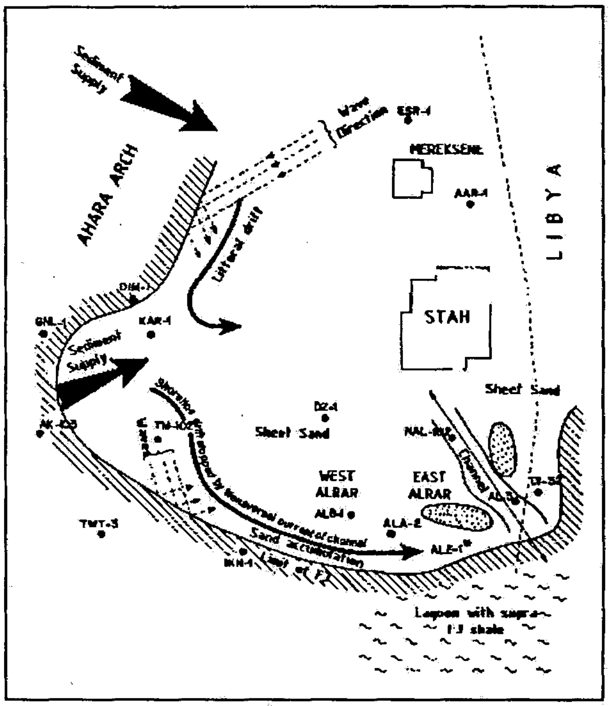


Fig. 9 - Sedimentary Model of F3 Alrar
(Model of F. Sommer, 1979)
Modèle sédimentologique du F3 du champ d'Alrar (F. Sommer, 1979)

sedimentological model are the following :

- Existence of a gulf whose shape merges with the F3 's;

- Deposits sourced from the West; from erosion of older terranes (F6 reservoir deposits on the Ahara high);

- Existence of a littoral drift obliquely abutting against the sea shore;

- Existence of a channel setting the communication between the F3 gulf and the continentally influenced lagoonal supra F3 shales.

The marine currents flowing through the channel break the littoral drift, which produces sand accumulation and submarine dunes . We can thus account for the preponderance of fine material and the scarcity of reservoir sandstone in the wells with the channel facies.

This framework had been working with a remarkable constancy all along the F3 deposition, and we can assume that it repeated itself with likely modifications owing to different paleomorphologies for Stah and Merksene following the progressive infill of the gulf from South to North (Sonatrach, 1992).

Modified Sommer Model

On account of well data from DZ.1, F. Sommer considers that all the B compartment (West Alrar) is made up of sheet sandstone characterizing the type 2 formations which are lithologically different from the Eastern part formations. Whereas newly drilled wells as AL.28 and AL.36 have penetrated a type 1 F3 similar to that penetrated at Eastern Alrar. This allows to conclude that the F3 of Western Alrar is made up of two (02) types:

- A type 1 F3 characterizing a regressive sequence, thikening and coarsening upwards indicating an increase in the energy from base up, varying in thickness from 29m to 48m and comprised of three distinct facies.

- A type 2 F3 (located to the West of study area) with a thickness ranging from 2m to 11m, comprised a 3m thick dolomite bed at the base and an alternation of fine sandstone and sandy shale with carbonate nodules at the top.

Whence a question arises; how does the passage from the type 1 to the type 2 F3 occur and how far does it take to occur, this insofar as correlations are possible between AL.28 and TM.101 (to the extreme West of stady area) fig: 5 we do not know the depositional pattern of the type 2 F3 nor do we know how the passage between these two types of facies occurs.

The well data enable us to modify the Sommer model. In fact, due to poor available data, SOMMER had considered that the whole West Alrar compartiment were composed of sand sheet: however recent wells (DZS-1, DZ-2, AL-28 and AL 36), all show the same section as East Alrar (fig. 10a).

Following the currents direction (bimodal) taken from dipmeter data (F3 type 1) it is possible to notice (fig. 11) :

- In AL-28, there is a main current of East - West direction on the top, whereeas, on the bottom, a bimodal one with a dominant direction SW-NE and another of WSW-ENE occurs.

- In DZS-1, on the top there is a bimodal current SW-NE and NW-SE, whereas, on the bottom we have a main direction SW-NE and another of SE-NW.

- In DZ-02, on the top there is also a bimodal current, the main one being SW-NE and the second SE-NW. The above data provide information

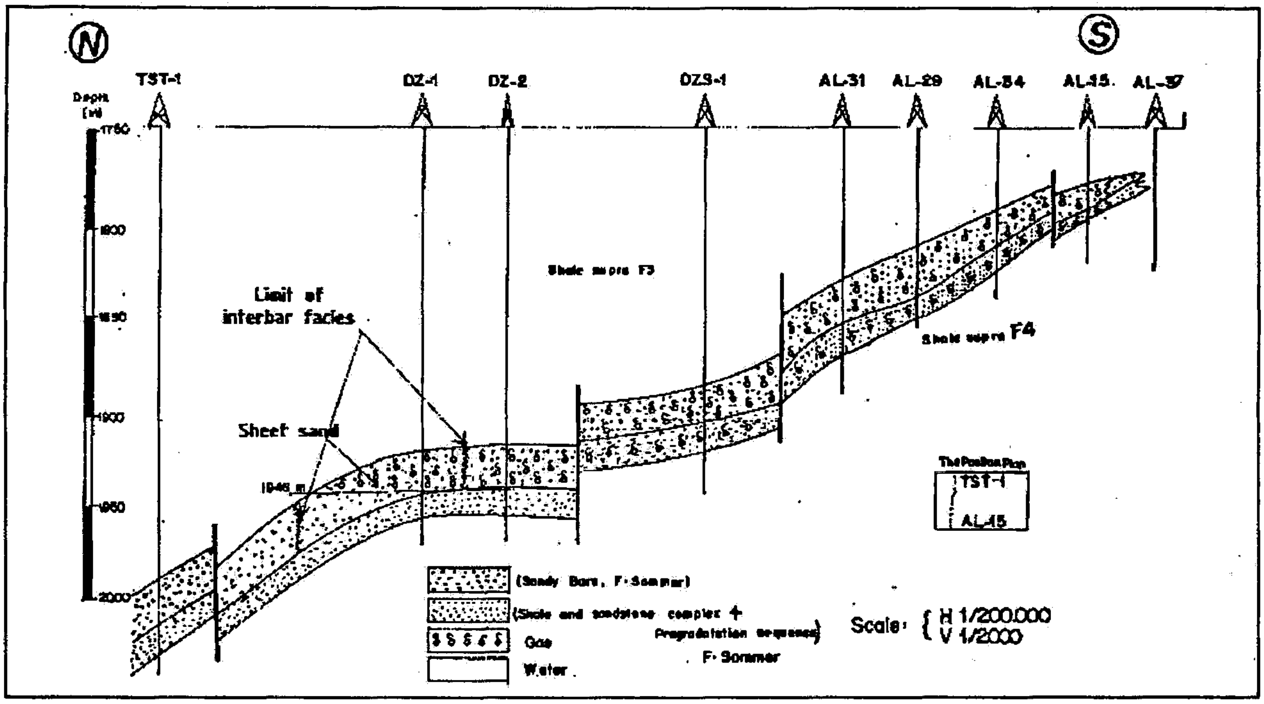


Fig. 10a - Cross section of F3 between TST-1, DZ-1, DZ-2, ...and AL-37 (West Alrar)
Coupe géologique du réservoir F3 à travers TST-1, DZ-1, DZ-2, ...et AL-37 (Alrar Ouest)

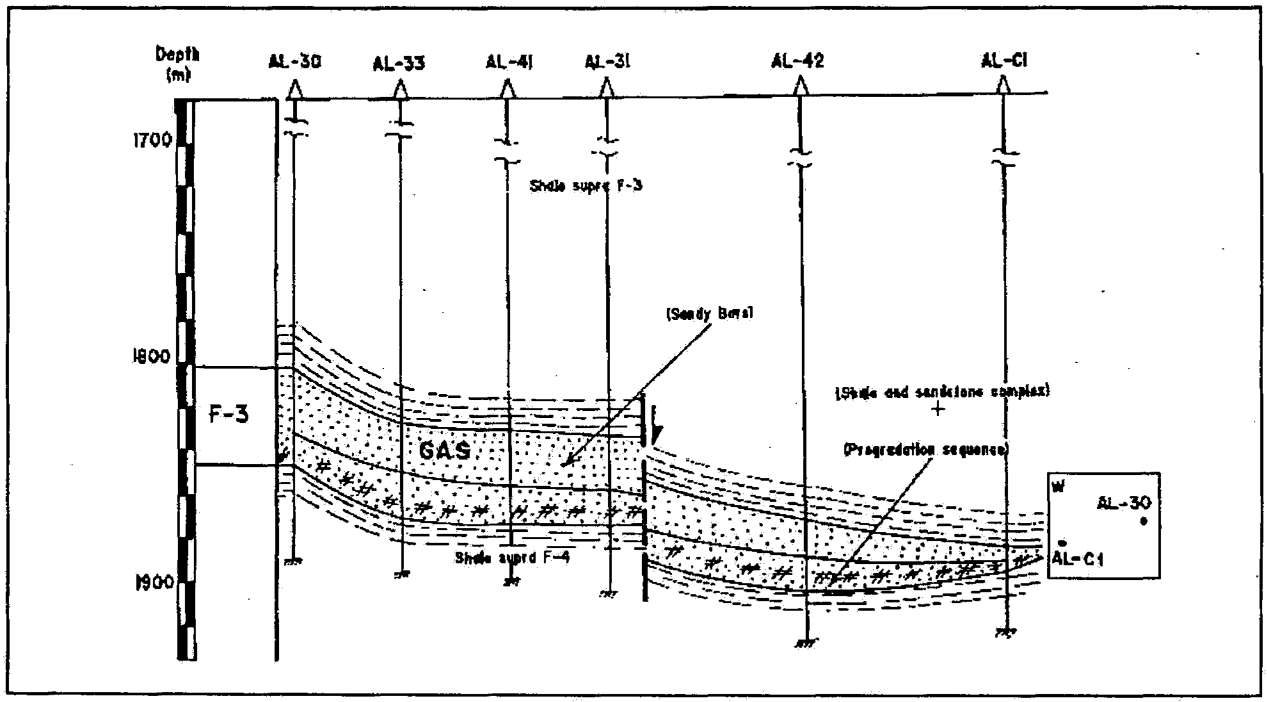


Fig. 10b - Cross section of F3 between AL-30, AL-33, AL-41,...and ALC-1 (West Alrar)
Coupe géologique du réservoir F3 passant à travers AL-30, AL-33, AL-41,...et ALC-1 (Alrar Ouest)

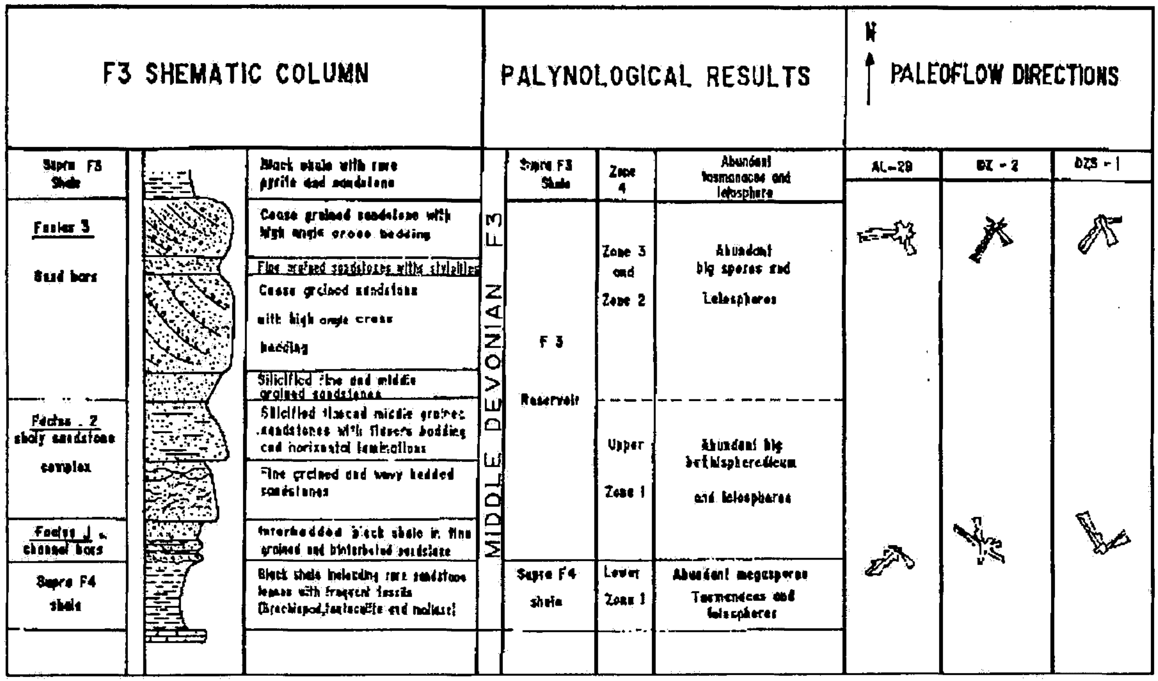


Fig. 11 - Paleoflow directions
Direction des paléo-courants

about two tidal bars spreading along NW-SE direction, with an interbar at DZ-1. (fig 12).

Critic of the proposed model

The new well data do not permit detailing the sedimentological model of F3. The ALC.1 - DZS.1 section (Fig. 13), provides information about facies disappearing (thinning out), toward the south-west. The DZS-1's F3 is represented by the classical Alrar's F3 formation : 15 metres of clean medium grained sandstones in the top which is a good reservoir interpreted as littoral barrier deposits. In the lower part, there are 20 metres of shaly fine grained sandstone with bioturbations typical of shoreface environment which are a bad reservoir.

At ALC-1, only the bottom of the F3 reservoir is present : the good reservoir facies made of littoral barriers is missing and replaced by lagoonal

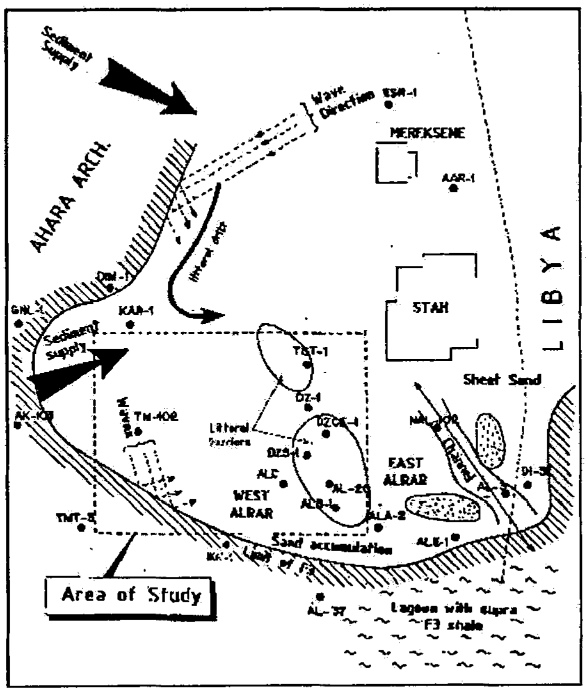


Fig. 12 - Modified sedimentary model of F. Sommer
Modèle sédimentologique de F. Sommer, modifié

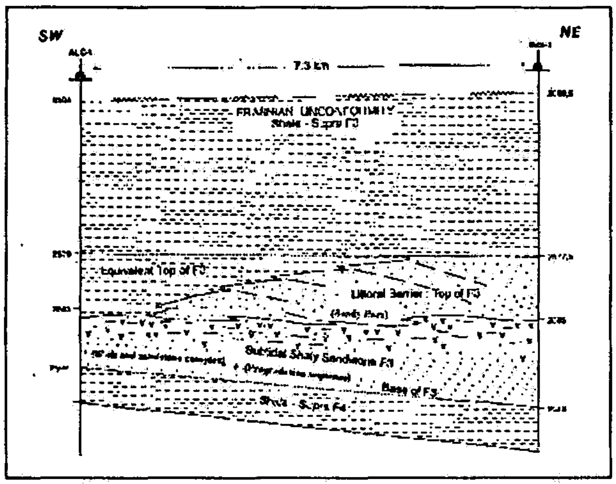


Fig. 13 - Sedimentary model of F3 between ALC-1 and DZS-1
Modèle sédimentologique du F3 établi entre ALC-1 et DZS-1

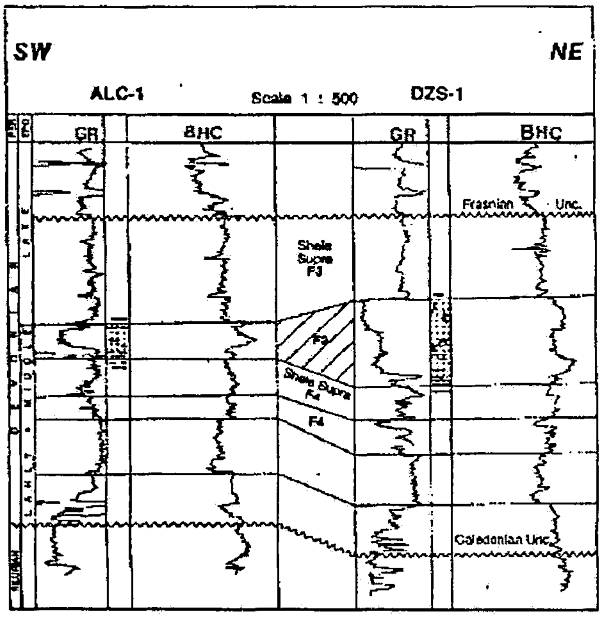


Fig. 14 - Diagraphic correlation between ALC-1 and DZS-1 (F3 reservoir)
Corrélation diagraphique passant à travers ALC-1 et DZS-1 (réservoir F3)

shales (13 meters), representing a lateral equivalent.

Thus, the westward pinch out of reservoir facies results from a lateral facies variation between a littoral barrier and lagunal deposits located backward of this barrier on the gulf floor.

In this case, the reservoir disparition seems to be progressive whithout any structural relationship, as probably the case south of AL-37 area.

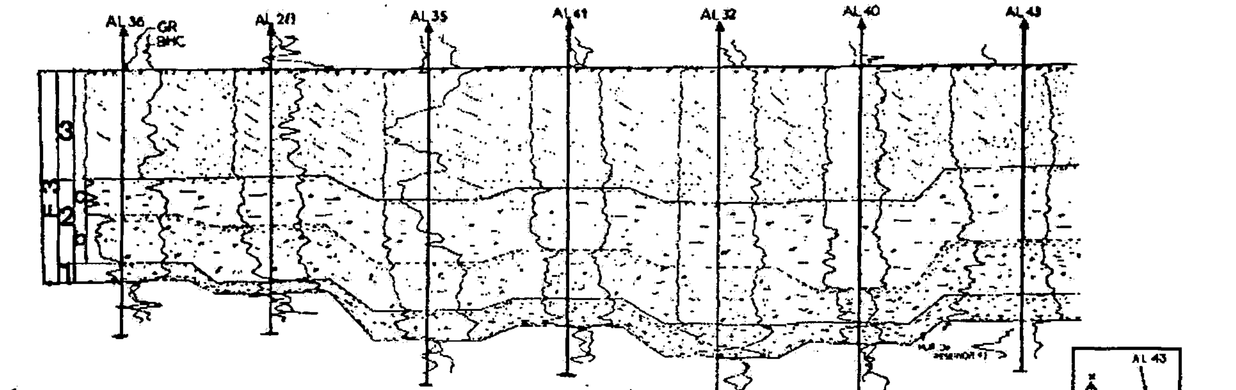
The excellent diagraphic correlations between ALC-1 and DZS-1 show the absence of the frasnian unconformity major effects (Fig.14).

This confirms the idea concerning our proposed model.

CONCLUSION

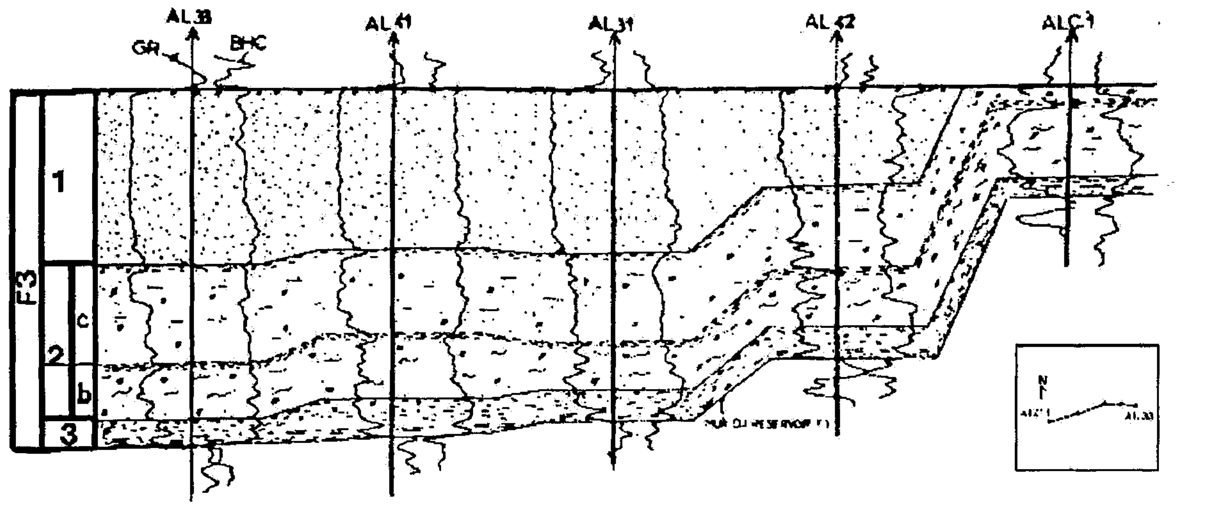
The F3 reservoir in the Alrar field was deposited as a coastal deposit, with the main and highest quality reservoir unit corresponding to a series of tidally influenced barrier bars. In West Alrar, two such tidal bars are present, which follow a NW-SE elongation as interpreted from dipmeter data. A poorer quality sheet sand was deposited in an interbar area in the early DZ-1 well. Understanding the distribution of the tidal bars is critical to locating development wells on the field.

The nature of the shale-out of the F3 reservoir to the south and west, which provides the trapping mechanism to the field, is still poorly understood. Recent well control indicates that the shale-out is controlled by different mechanisms in different areas. In some regions, a gradual loss in reservoir thickness related to gradual progradation is suggested, while in other areas a structural control is evident. The latter appears to be related to a rapid thickening, sometimes lined to faulting or structural uplifts.



1 Progradation sequence (F. Sommer)
\+
2 Shale and sandstone complex (F. Sommer)
} = Subtidal facies (Beicip)
3 Sandy Bars (F. Sommer) [litoral barrier facies (Beicip)]

Fig. 15 - Diagraphic correlation between AL-36, 28, 35, 41, 32, 40 and AL-43 (F3 Reservoir)
Corrélation diagraphique passant par les sondages AL-36, 28, 35, 41, 32, 40 et AL-43
(Reservoir F3 Reservoir)



1 Sandy Bars (F. Sommer) [litoral barrier facies (Beicip)]
2 Shale and sandstone complex (F. Sommer)
\+
3 Progradation sequence (F. Sommer)
} = Subtidal facies (Beicip)

Fig. 16 - Diagraphic correlation between AL-33, 41, 31, 42 and ALC-1 (F3 Reservoir)
Corrélation diagraphique passant par les sondages AL-33, 41, 31, 42 et ALC-1
(Reservoir F3)

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