Libyan Journal of Science & Technology 9:1 (2019) 31–37
The 2nd International Conference on Geosciences of Libya-GeoLibya 2 (2017), 14-16 October 2017, Benghazi-Libya

Faculty of Science - University of Benghazi
Libyan Journal of Science & Technology
journal home page: www.sc.uob.edu.ly/pages/page/77

Classification of hydrocarbons trapping systems of the Ghadames and Murzuq Basins in relation to Gargaf high, West Libya.

Al Fasatwi Yahya Ahmed.

Libyan Academy, Tripoli, Libya,

E-mail address: Alfasatwi@yahoo.com

Highlights

- **This paper provides comprehensive synthesis of the hydrocarbon trapping systems of the Ghadames and Murzuq Basins, Western Libya.**
- **The influence of the intervening Gargaf Arch on the trapping systems of the Ghadames and Murzuq basins has also been investigated in this paper.**
- **The paper provide an idea on the influence of the combination of tectonic, sedimentation, oil migration on forming trends of hydrocarbon accumulations in the Ghadames and Murzuq Basins. The resulted maps can be used for hydrocarbon exploration in the two basins.**

ARTICLE INFO

Article history:
Received 01 February 2018
Revised 22 March 2018
Accepted 29 March 2018
Available online 31 March 2019

Keywords:
Gargaf high, Ghadames, Murzuq, hydrocarbons, trapping systems, basin

ABSTRACT

The Ghadames and Murzuq Basins, West Libya, are major producers of hydrocarbons in Libya. The producing-bearing horizons of the two basins range in age from Cambro-Ordovician to Triassic. Reservoirs of Devonian and Silurian age are major producing horizons in the Ghadames Basin. In the Murzuq Basin, the main reservoirs are Cambro-Ordovician in age. The Silurian Tanezzuft shales are the main source rock of the hydrocarbons in the Ghadames and Murzuq Basins. The reservoir characteristics indicate that the hydrocarbons of the Ghadames basin have mainly accumulated mainly in combination and stratigraphic traps in areas close to Gargaf high, and in structural anticline traps in areas close to the centre of the basin. In the Murzuq Basin, hydrocarbons are trapped mainly in structural faulted traps.

The distribution of oil fields in the Ghadames and Murzuq Basins appears to be confined to a regional trend, which reflects the close relationship between tectonics, sedimentation, oil migration and accumulation.

1. Introduction

Recent oil discoveries within the Ghadames and Murzuq Basins indicate the necessity for a renewed examination of the tectonic and stratigraphical framework of both basins. This study provides an analysis of the hydrocarbon systems of the Ghadames and Murzuq Basins (Fig. 1). More than 150 exploratory wells have been drilled in these basins, resulting in the discovery of some 50 oil pools in the Ghadames Basin and some 20 in the Murzuq Basin. Fig. 1 illustrates the distribution of major known hydrocarbon resources across the region. Most of the hydrocarbon exploration carried out in the Ghadames and Murzuq Basins have been within their major depocentres. The primary objectives of this study are to compile a reliable data set of oil and gas fields in the Ghadames and Murzuq Basins and to develop criteria for subdividing these areas into zones or trends. It is believed that recognition of such processes is essential for a better understanding of the tectonic and stratigraphical framework of the region, and it is hoped that this regional approach will help to gain an insight in:

1. *Facies development (source rocks, reservoir rocks, cap rocks, etc.),*
2. *Structural development (migration, traps, etc.),*
3. *Establishing a tentative correlation between regional structural patterns and hydrocarbon accumulations.*
4. *Predicting possible hydrocarbon trends.*
5. *Comparing the Murzuq and Ghadames Basins.*

This understanding will be transferred to less explored and currently unproductive areas within the region, in an attempt to highlight areas and fairways of remaining exploration potential.

Hydrocarbons in the Ghadames and Murzuq Basin have been produced from several Paleozoic sandstone pay-zones (Fig. 2). The source rock is mainly Silurian shales of the Tanezzuft Formation, supplemented by Devonian and Cambro-Ordovician shales. The main producing horizons in the Ghadames Basin are the Silurian Acacus Formation in the northern and central parts of the basin and the Devonian Tadrart Formation in the southern and central parts of the basin. Other intervals with minor production are found in several parts of the basin. In the Murzuq Basin, the Ordovician Memouniat Formation is the main producing horizon; other Devonian formations are also producing. Structural traps are the most common types of trap in the Murzuq Basin; traps in the Ghadames Basin range from combination traps in the southern and northern parts of the basin (close to the rims of the basin) to structural traps in the central part of the basin. Minor discoveries are found in stratigraphical traps in the western part of the basin. All discovered oils are naphthenic crude.

2. Comparison of the hydrocarbon systems in the Ghadames and Murzuq Basins

2. 1 Introduction

Stratigraphy and hydrocarbon occurrence relationships within the Ghadames and Murzuq Basins are summarized in Fig. 2. Comparison of the hydrocarbon systems in the two basins indicates that there are some points of similarity and also some differences.

 ISSN 2663-1407; National Library of Libya, Legal number: 390/2018

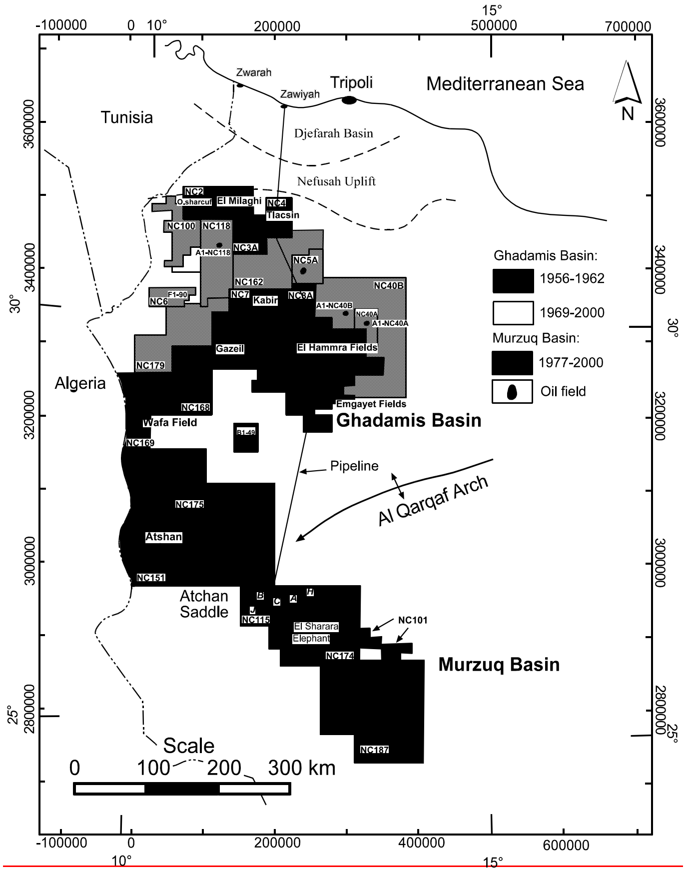

Fig. 1. Index map of the study area showing concessions, names and locations of main hydrocarbon-producing fields in the Ghadames and Murzuq Basins.

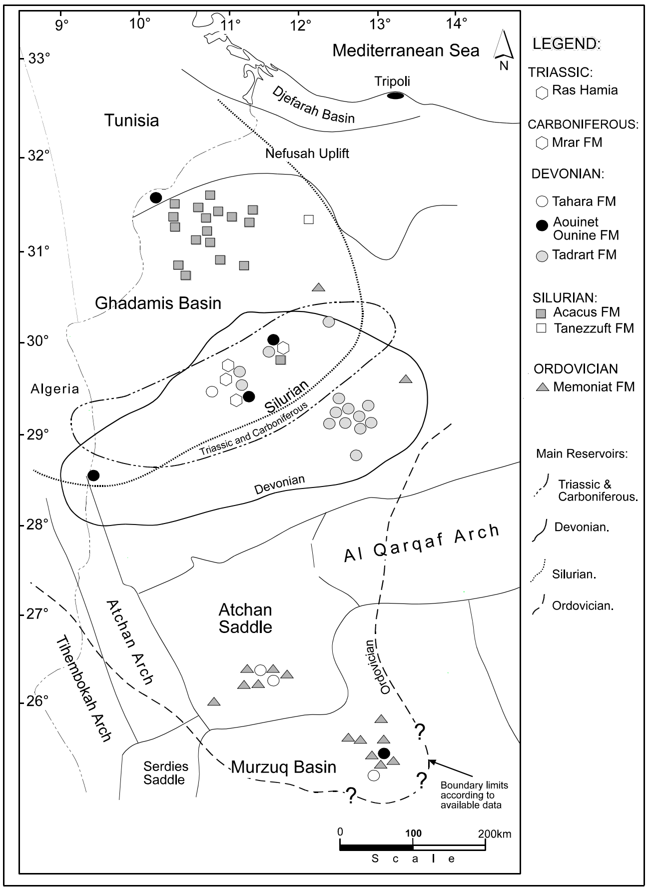

Fig. 2. Map showing regional distribution of reservoirs in the Ghadames and Murzuq Basins.

2. 2. Distributions of reservoirs in the Ghadames and Murzuq Basins

2.2.1 Spatial and stratigraphical distribution:

Fig. 2 presents the regional distribution of the reservoirs in the Ghadames and Murzuq Basins. In the north part of the Libyan part of the Ghadames Basin, the Upper Silurian Acacus Formation is the most productive horizon, and in the southeast of the basin the Lower Devonian Tadrart Formation. In the central part of the basin, there is a combination of different reservoirs, ranging from the Acacus Formation to the Lower Carboniferous Mrar Formation. The reason for this, according to Alvares (1956), is apparently to be sought in the source-cap relationship. The middle Acacus shale units have apparently acted as a cap, confining oil generated in the Tanezzuft shale to Lower Acacus sands, and preventing it from reaching the reservoirs of the Upper Acacus/Tadrart. As the Middle Acacus shale dies out to the southeast, the lack of barriers permits Tanezzuft oil to reach the Tadrart reservoirs.In the Murzuq Basin, the Cambro-Ordovician Memouniat Formation is the most important producing horizon. Two clusters of reservoirs are producing in the basin, the first one located in the central part of the basin, and the other one located in the area of the Atchan Saddle.

2.2.2 Depth distribution

Fig. 3 shows N-S cross sections with the reservoirs in the area. Most of the discovered hydrocarbon fields in the Ghadames and Murzuq Basins are almost similar in depth, ranging from 600 to 2200 m in both basins. The correlation with the depth to the top of basement map indicates that the discovered hydrocarbon fields are located in areas where the depth of the basement ranges from 1220 to 2740 m subsea in the Ghadames Basin and from 610 to 2440 m subsea in the Murzuq Basin.

2.2.3 Field size distribution

Fig. 4 represents the distribution of trap types and the initial recoverable reserves. The fields of the two basins have been subdivided into four groups, with less than 50, 50 to 100, 100 to 150, and more than 150×10^{6} barrels of initial recoverable reserves. In the north and central Ghadames Basin, the discovered hydrocarbon fields range in size between 50 and 100 MMBO. In the northern part of the Ghadames Basin, the traps are mainly a combination of structural and stratigraphical traps. The size of the fields increases to the south, where fields reach more than 150 MMBO close to Al Qarqaf Arch. Most of the traps in the south are combination traps. Mixed types of traps also characterize the central part of the Ghadames Basin. All the traps of the Murzuq Basin are structural, with two groups of reservoirs. The first is located in the area of the Atchan Saddle and is characterized by fields that have recoverable reserves of between 50 and more than 150 MMBO. The other group is located in the northeastern part of the Murzuq Basin and is characterized by fields of smaller size, generally less than 100 MMBO.

2.2.4 Play type distribution (classification of traps)

Analysis of well and seismic data over the Ghadames and Murzuq Basins indicates the existence of a wide variety of structural and stratigraphical trap types of different age. Three main classes of traps have been identified in the area (Figs. 4 and 5). In the Ghadames Basin, we indeed find structural traps in the centre of the basin and combination to stratigraphical traps towards the flanks. Most of the productive structures in the Ghadames Basin have an SW-NE orientation, especially in the southern parts of the basin where the influence of Al Qarqaf Arch is strong. In the Ghadames Basin, all Acacus Formation oil has been found in structural traps. Trap development in the Ghadames Basin has been assumed to be related to tectonism in the latter part of the Silurian (Caledonian) and in the Carboniferous and Permian (Hercynian). In the case of the Murzuq Basin, the story is different because all of the traps identified are structural and most of the faults trend NW-SE (almost perpendicular to the direction of Al Qarqaf Arch).

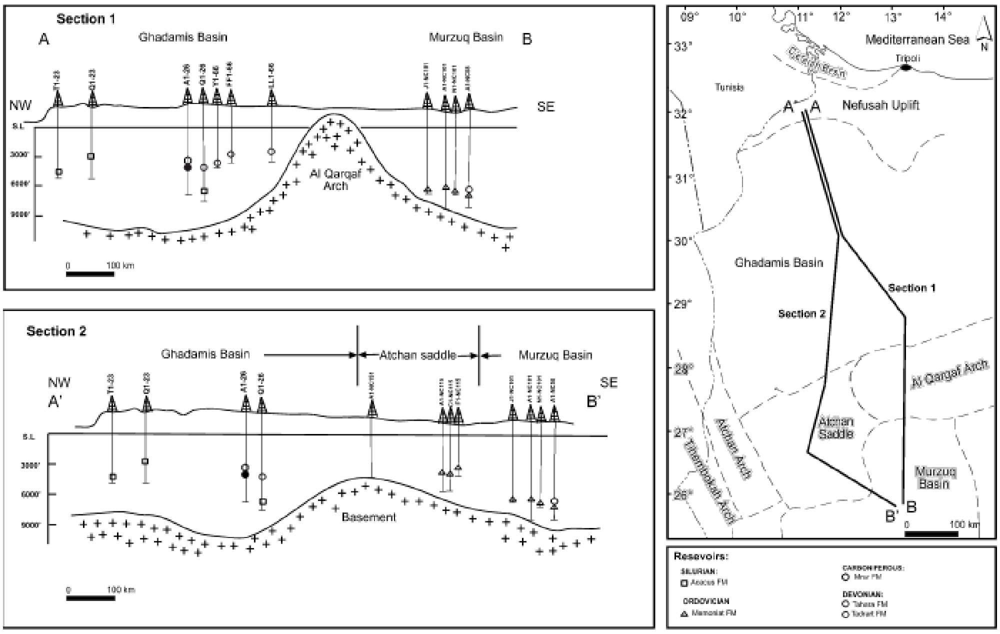

Fig. 3. Cross sections showing the depths of reservoirs in the Ghadames and Murzuq Basins.

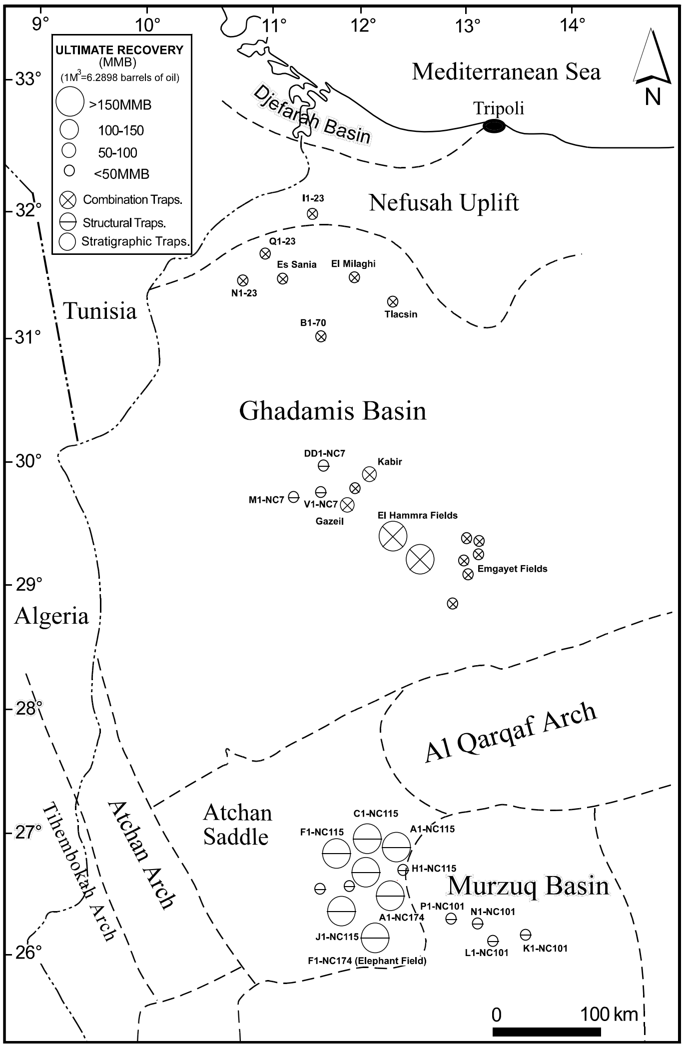

Fig. 4. Trap styles and ultimate oil recovery of hydrocarbon occurrences in the Ghadames and Murzuq Basins.

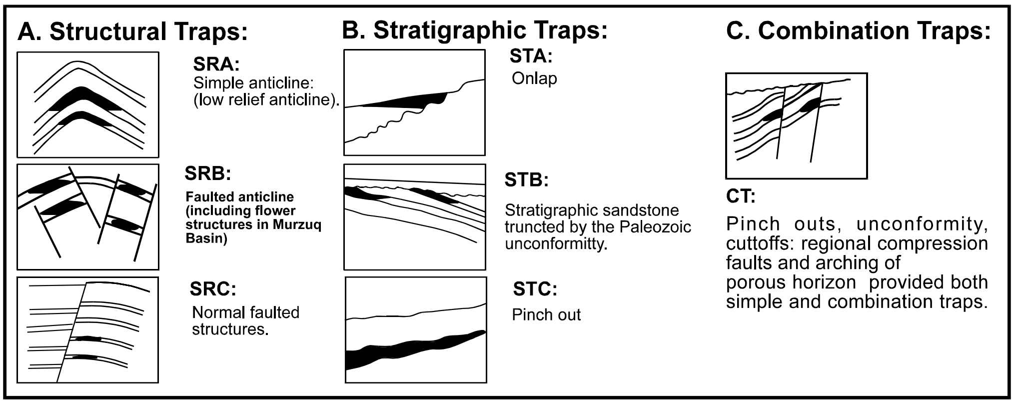

Fig. 5. Types of traps in the Ghadames and Murzuq Basins.

A. Structural traps

Most of the large hydrocarbon accumulations discovered in the Ghadames and Murzuq Basins occur in structural traps. In the Murzuq Basin, most structural traps of the Murzuq Basin were probably formed before or coincident with the first phase of oil generation in the Late Paleozoic. Fig. 7 shows a TWT structural map (Middle Devonian Unconformity) showing N-S en-échelon fault blocks. The fault system is part of the 10° wrench fault. The seismic windows A and B of Fig. 7 show flower structures associated with the wrench fault. The figure shows that the oil in the area of the Elephant oil field is trapped in a reverse faulted anticline over basement uplift. The structural history of the area of both basins has produced a wide variety of structural traps of different ages.

A.1 Simple low relief anticline (SRA)

This trap type is present mainly in central and northern parts of the Ghadames Basin (Figs. 6 and 7). These anticlines are generally broad low-relief structures and were formed during the Silurian and Devonian (Echikh, 1998).

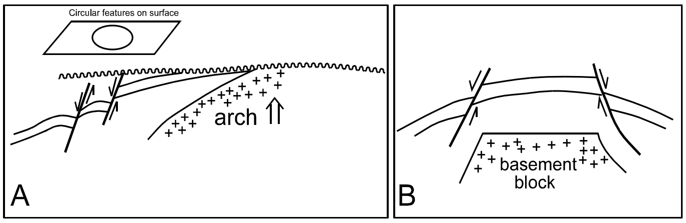

Fig. 6. Schematic sections illustrating the mechanism of faulted anticlines and normal faulted structures associated with arch structures and basement blocks.

A.2 Faulted anticline (SRB)

This type of faulting corresponds to the model of traps associated with the near surface arch. In this form of trap, entrapment was achieved by the faulting of anticlines (Fig. 5). This type of structure is found in the southern part of the Ghadames Basin, close to Al Qarqaf Arch. In this area, the beds have a regional NNW dip and are arranged in large tilted fault blocks, bounded to the south by major ENE trending faults, which are downthrown to the south. Oil and gas have accumulated in anticlines on the footwall side of the faults, the accumulations being locally sealed by these faults.

These fields are made up of several pools, some of which are divided into "sub-pools" separated by saddles or faults. In many cases. The faulted anticlines appear on the surface as circular and semi-circular features, which are interpreted from remote sensing images and are located in the southern part of the Ghadames Basin. It is likely that these semi-circular features are a result of the subsurface tectonics and are thus of practical interest in hydrocarbon prospecting. Two types of circular features appear from the interpretation of remote sensing images. They are located in the southern part of the basin and range from 5 to 35 km in diameter. These features coincide with the location of El Hammra and Emgayet oil fields and are located on the aeromagnetic map in an area of high magnetic anomalies.

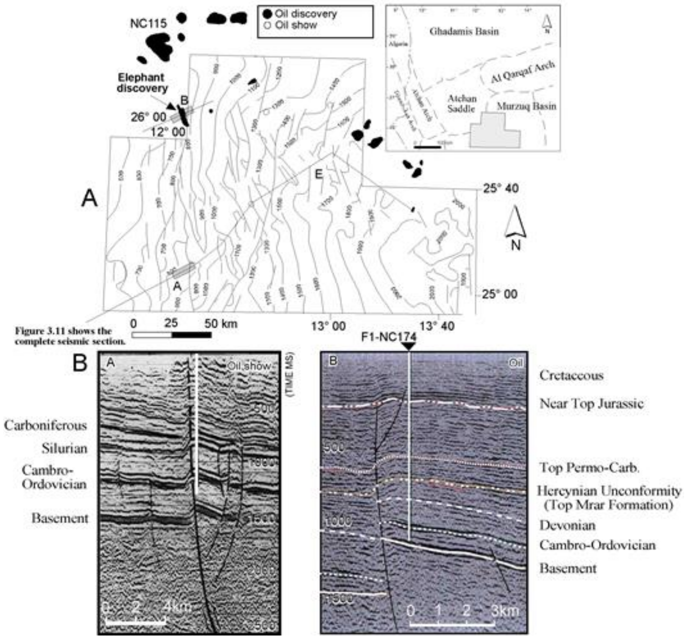

Fig. 7. A) TWT structural map (Middle Devonian unconformity), C.I.20 msec, showing N-S en-échelon fault blocks. The fault system is part of the 10° wrench zone. B) Seismic windows, the seismic sections showing flower structure in concession NC58 (window A) and reverse faulted anticline formed over a basement uplift (window B). Well F1-NC174 is a well in the giant Elephant field, while the other well is a dry hole in a smaller but well-defined closure to the south.

A.3 Normal faulted structures (SRC)

This type of trap is mainly related to the faulting of layers due to basement uplifting. In the Ghadames Basin, this type was formed during the Hercynian events. To date, available data indicate the presence of this type in the central and northern parts of the Ghadames Basin (Fig. 6). This type is mostly expected in flanks of Al Qarqaf Arch.

B. Stratigraphical traps

The traps formed by a lateral change in the reservoir. Two types of stratigraphical traps have been observed, namely:

B.1 Stratigraphical truncation on unconformity (STB)

This type consists of sandstone reservoirs that are truncated by the Paleozoic unconformity. It is present in the central and northwestern parts of the Ghadames Basin. According to Echikh (1998), in this type, hydrocarbons are trapped against the subcrop of the Silurian Acacus reservoirs against Triassic shales.

B.2 Permeability pinchout traps (STC)

In the Ghadames Basin, this type of trap is present in the western part of the basin, close to the Tihembokah Arch (Fig. 5). The sandstone bodies of the Aouinet Ouenine Formation are considered as the main target in this area, where they pinch out into shale. The extensive shale layers within the formation provide the seals. No information has been released on the reservoir characteristics.

C. Combination traps (structural-stratigraphical traps)(CT)

This is a combination of any two or more of the above. This type of trapping includes pinchouts, unconformity, fault-bounded closures, regional compressional faults and arching.

2.2.5 Seals:

In the Ghadames and Murzuq Basins, stratigraphical units possessing seal rock properties are like the reservoir rock and source rocks to be found at various levels within the Paleozoic succession. The Early to Late Silurian (Ludlovian) Tanezzuft shales are the regional seal deposited across the Murzuq Basin. Fig. 8 shows the model of the relationship between source rock, reservoir rock and sealing in the central and southern parts of the Ghadames Basin. Some layers of the Acacus Formation serve as a good seal for the hydrocarbons of the formation in the central and northern parts of the Ghadames Basin. The Tadrart reservoirs in the Ghadames Basin have as their top seal the shales that occur at the base of the overlying Early Devonian Ouan Kasa Formation. The extensive shales of the Early Carboniferous Mrar Formation provide seals for the Tahara reservoir.

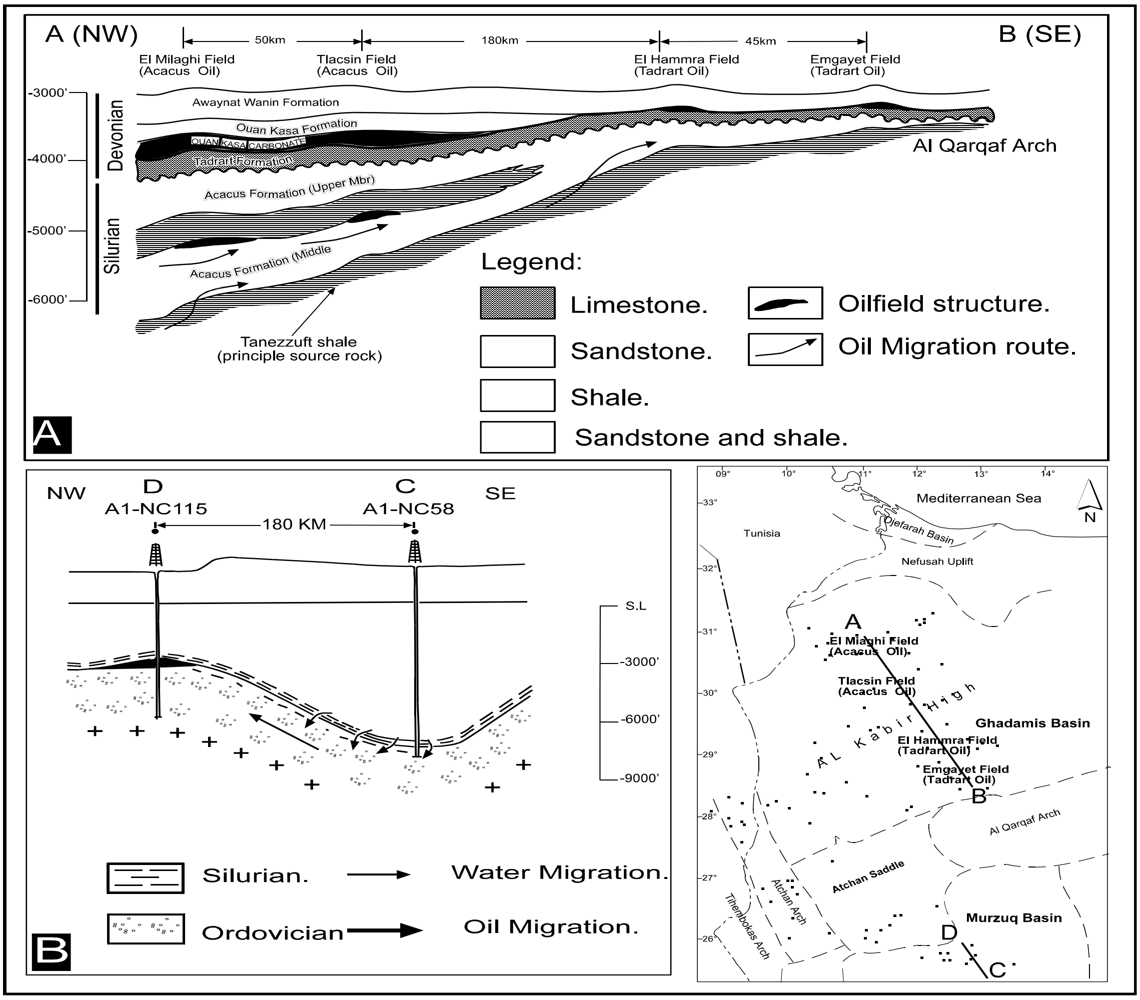

Fig. 8. Schematic cross sections showing hydrocarbon migration routes and trapping in (A) the Ghadames Basin (after Alvares, 1956) and (B) the Murzuq Basin (after Meister *et al.*, 1991).

2.2.6 Hydrocarbon generation, migration and trapping

The generation and expulsion of hydrocarbons of varying thermal maturation can be explained with reference to a source rock's thermal history (Fig. 8). Burial history curves of three wells in the Murzuq Basin show important geological horizons and key Time-Temperature Index (TTI) lines. These curves were used to estimate theoretical maturity and to determine the likely time of hydrocarbon generation. The Time-Temperature Index has been computed using Lopatin's method (Waples, 1980). This method is applied to three wells in the Murzuq Basin. The calculations and graphics indicate that the base of the Silurian sediments reached a Time Temperature Index of 15 at respectively 50, 107 and 112 million years before present for wells A, B and C. This means that Silurian rocks would have attained sufficient thermal maturity to start generating oil only since Cretaceous to Early Tertiary times. Peak generation was probably in Late Mesozoic (Early Cretaceous) time. Generation in source rock units younger than the Silurian was somewhat later. The Devonian may not have produced hydrocarbon until Cretaceous time. In general, traps older than Jurassic would be expected to be most favourable for oil accumulation (Massa *et al.*, 1994). Migration distance for the discovered fields in the Murzuq Basin, according to Meister *et al.* (1981), must have been in the order of 150 to 200 km. It is generally assumed that lateral migration played an important role since much of the shale underneath the producing areas is insufficiently mature to have provided hydrocarbon to the overlying reservoir zones.

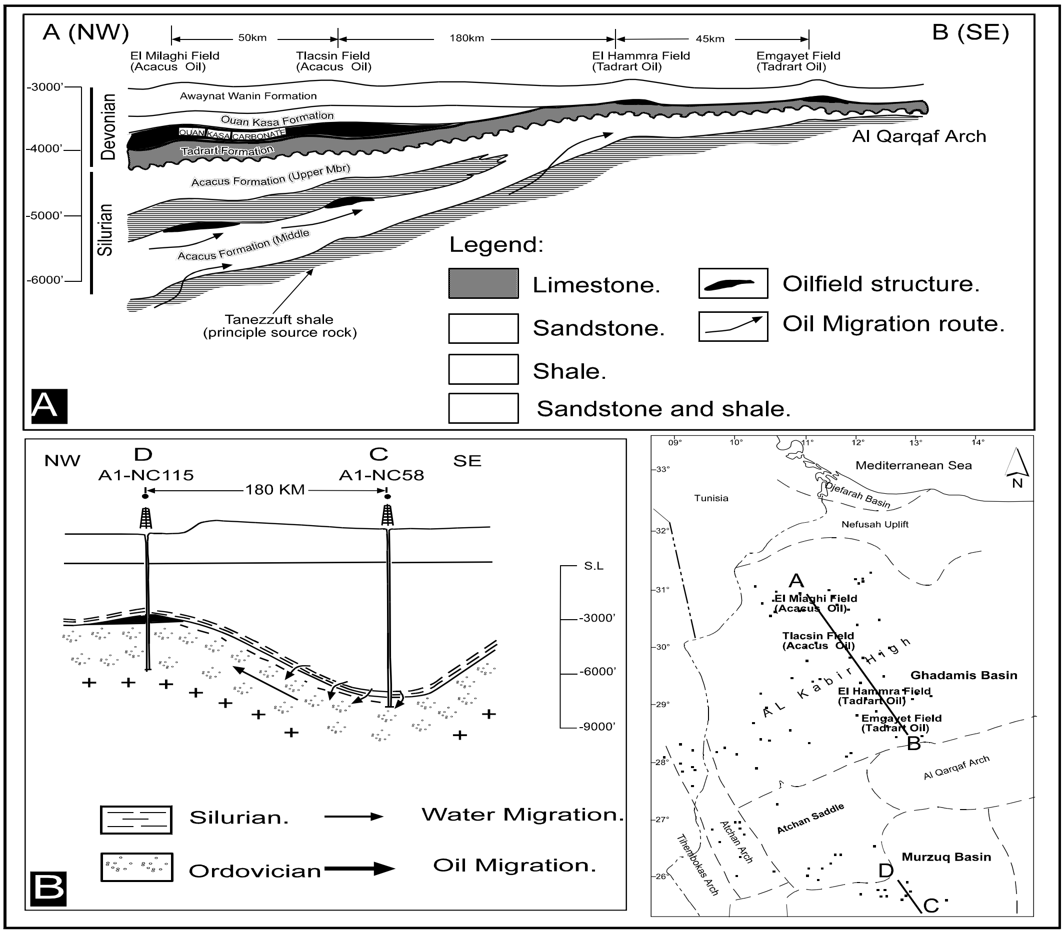

Fig. 8. Schematic cross sections showing hydrocarbon migration routes and trapping in (A) the Ghadames Basin (after Alvares, 1956) and (B) the Murzuq Basin (after Meister *et al.*, 1991).

3. Future trends:

Hydrocarbon prospectivity increases towards the basin margins, where traps tend to be structural and structural/stratigraphical. The structures tend to be low-amplitude anticlinal closures, and hydrocarbon columns are small. Most stratigraphical traps found so far are associated with the regional Hercynian Unconformity, which facilitates the overstep of dipping Paleozoic reservoirs by basal Mesozoic seals.

In the Murzuq Basin, the Late Ordovician Memouniat Formation is the primary prospective horizon. The Murzuq Basin is bounded by two major wrench zones. This type of faulting will produce flower structures, which are potential traps.

The hydrocarbons of the recently discovered giant Elephant oil field are trapped in a reverse faulted anticline formed over a basement uplift of compressional origin, with dip closure to the north, east and south. The structure resulted from several pulses of uplifts (Compton *et al.*, 1999). It can be concluded that the western and northern parts of the Murzuq Basin are highly prospective for hydrocarbon exploration. The eastern parts of the basin are less prospective due to the lack of source rock. As we have seen before, the structural and the hydrocarbon systems of the Ghadames and Murzuq Basins are quite different with respect to the influence of Al Qarqaf Arch. The influence of Al Qarqaf Arch on the structural and trapping systems in the Ghadames Basin is stronger than that in the Murzuq Basin.

Therefore, potential oil and gas plays are expected to be present in both basins include the following:

1. Pinchout of the reservoir units of the Late Silurian Acacus Formation could occur as the section thins against the Al Qarqaf Arch axis at the southern edge of the Ghadames Basin. The same could occur in the northern parts of the Murzuq Basin with the Cambro-Ordovician Memouniat Formation.
2. Structural doming of porous horizons along wrench faults on the western and central parts of the Murzuq Basin.

A sketch summary of the play concepts of the two basins is shown in Fig. 9, in which one can see the distribution of the major resources and source rocks and the principle migration routes.

4. Recommendations

1. A study of the distribution and maturity of all possible source rocks, and source rock-cap rock relationships, in particular around Gargaf high.
2. Investigation of the formation water salinities in the two basins, which may give clues to the nature and age relationships between oil emplacement, erosional stripping and fresh-water flushing. In some areas, oil may be emplaced after the erosional stripping and fresh-water flushing of the reservoir rocks. In such cases, anomalous salinity values are expected.
3. There are not enough data available to establish the pattern of diagenesis for the reservoir rocks occurring in the area, so further analysis is recommended.
4. Detailed work on the role of faults in migration in both basins is highly recommended.
5. The role of wrench faults in the trapping of oil in the Murzuq Basin should be investigated in more detail by integrated interpretation of seismic data over a large area.

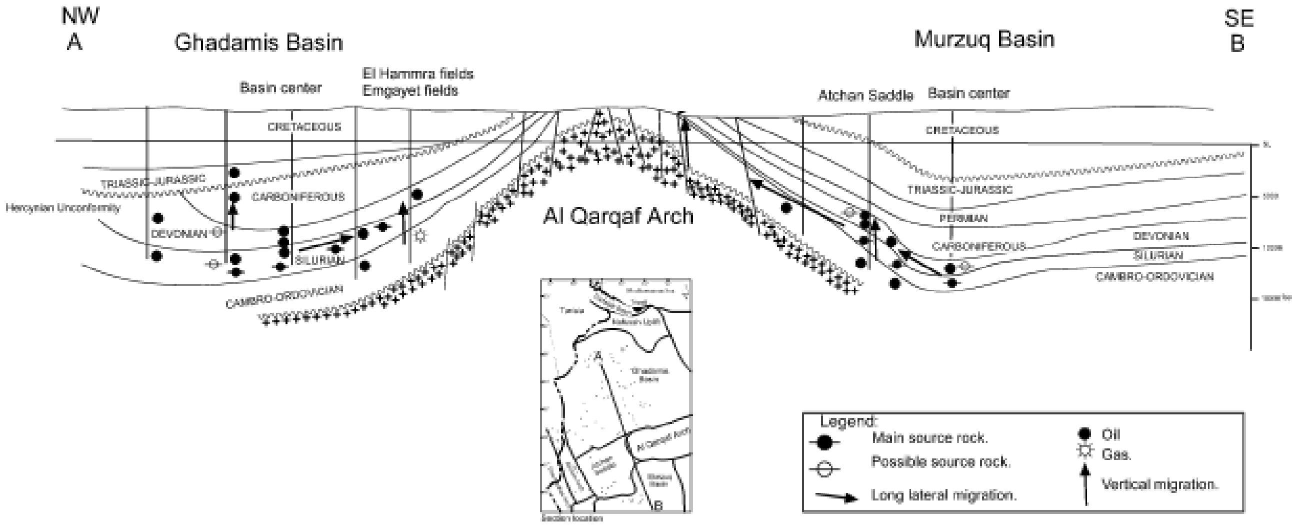

Fig. 9. Sketch summary of play concepts of the Ghadames and Murzuq Basins.

References

Alvares, W. (1956) The Upper Silurian-Lower Devonian (Sinawan Group) in Northwestern Libya. National Oil Corporation, Open File Report, 21p.

Compton, P., Hammali., A. and Walker, R. (1999) AAPG International Conference, Birmingham, England, Sept. 12-15, 132p.

Echikh, K. (1998) Geology and Hydrocarbon Occurrences in the Ghadames Basin, Algeria, Tunisia, Libya. In: (eds Macgregor, D. S., Moody, R.T.J. and Clark-Lowes, D.D.) Petroleum Geology of North Africa. Geological-Society Special Publication, pp. 109-129.

Massa, D., Oesterle, H. and Kirmanik, K. (1994) African Exploration Opportunities: Ghadames, Murzuq-Djado and Kufra-Edri Basins. Petroconsultant, 372p.

Meister, E. M., Ortiz E.F., Pierobon, E. S. T., Arruda, A.A. and Oliveira, A.M. (1991) The Origin and Migration Fairways of Petroleum in the Murzuq Basin, Libya: An Alternative Exploration Model. In: (eds Salem, M.J. and Busrewil, M.T.) The Geology of Libya. Academic Press, London, 2725-2741.

Waples, D.W. (1980) 'Time and Temperature in Petroleum Formation: Application of Lopatin's Method to Petroleum Exploration', *AAPG Bulletin*, 64(4), pp. 91