*Depositional Environments and Structure Evolution of the Lower Akakus Formation, Area 47, North Hamada Field, Ghadames Basin, NW Libya

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Abstract

The lower member of Akakus Formation represents one of the main important hydrocarbon accumulations in the Area 47, North Hamada Field, Ghadames Basin, NW Libya. It consists interbedded sandstone and shale that was deposited during the Upper Silurian. High quality 3D seismic reflection data and well logs in the study area provide a good insight into the structure evolution and the depositional environment of the Lower Akakus Formation. The time structure map of Lower Member of the Akakus Formation indicated that the high structure in northwest of the study area and the Lower structure in the southwest of the study area. This structure was interpreted as the anticline that was caused by Pre-Devonian uplift.

The Lower member of the Akakus Formation was eroded by Pre-Devonian tectonic movement as a result the variation thickness of Lower Akakus Formation. The sigmoid progradatoinal pattern was identified by top lap angularity of seismic amplitude and instantaneous phase attribute across southern part of the Area 47. This pattern was interpreted as deltaic environment which was deposited during late Silurian. Integrating seismic reflection amplitude with well logs data interpretation were used to determine funnel shape. By using 3D seismic and well logging in Area 47, conclude that the high structure map and low structure map of the Lower Akakus was caused by Pre-Devonian uplift during Caledonian origin. In addition, the depositional environment of Lower Akakus interpreted as the progadational pattern (Deltaic Environment) by integrating log curve facies with the seismic sections. Meanwhile, this pattern is determined by the seismic configuration (sigmoid and oblique patterns).

Introduction

The Ghadamis Basin was a major site of frontier exploratory activity during the late 1950s, 1960s, and 1970s and the first significant oil in Libya was produced from Devonian sandstones reservoirs in this region. Interest in the area, however, diminished rapidly with discovery of the prolific giant oil fields in late Mesozoic and Tertiary deposits of the Sirte Basin which lies to the east in the north-central part of Libya. Production from this basin has underpinned the Libyan economy for the last thirty years. However, in recent years levelling off of significant finds in the Sirte Basin has seen a necessary renewed exploratory interest in the western province to discover new resources and maintain oil production as the country's economic basis.

This second exploration phase began during the mid-late 1980s (Fig. 1) with the effort focused mainly on already known Devonian (Tahara, Awaynat Ounien, Tadrart) and the Ordovician (Mamuniyat) reservoirs. More recently it has become clear that the Akakus Formation contains

both source and reservoir rocks and oil and gas shows are common. Geochemical analyses have demonstrated that some of the Akakus and Silurian Tannezuft Shale's (which both underlie and are laterally equivalent to the sandstones) are good source rocks, (Fello et al., 2006). At least two major fields are capable of production from these sandstones at present and many others wells with commercially significant flows of oil have been tested in recent years. Akakus-Tannezuft reservoirs were tested in the C.P.T.L Concessions 23 and 61, plus Concession 70 (Northern Flank of Ghadamis Basin), where the Akakus proved to be oil bearing. During the last year, in AGOCO Concessions NC7 and NC5, the Akakus-Tannezuft reservoirs produced a large amount of hydrocarbons. In the North-Western part of the Ghadamis, in BOCO Concession NC100 the Akakus reservoir showed good petroleum results from 14 wells drilled in the area from nine structures that are oil bearing. These recent exploratory works carried out in widely different parts of the Ghadamis Basin appear to confirm the regional potentiality of the Akakus-Tannezuft Formations as a major petroleum source and they are thus being increasingly targeted.

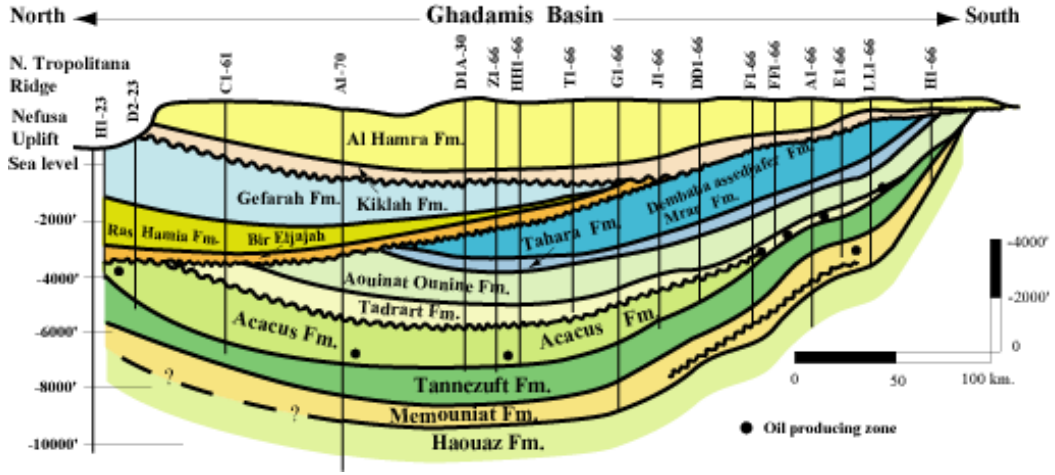

Figure 1. North-South cross-section showing Akakus Formation distribution along the Ghadamis Basin, where the Akakus proved to be oil bearing, modified from (Echikh, 2016).

Geographical Location of the Study Area

The Ghadamis Basin is one of a number of major sedimentary basins in Libya a country that occupies the north central region of Africa between Egypt and the Sudan to the east, Tunisia and Algeria to the west, with Niger and Chad situated directly to the south. Except for the northernmost parts, which have a Mediterranean climate, the country is substantially Saharan in aspect (Echikh, 2016). The site of the Ghadamis Basin is located in the western part of the country bordering directly on Algeria and southern Tunisia (Fig. 2).

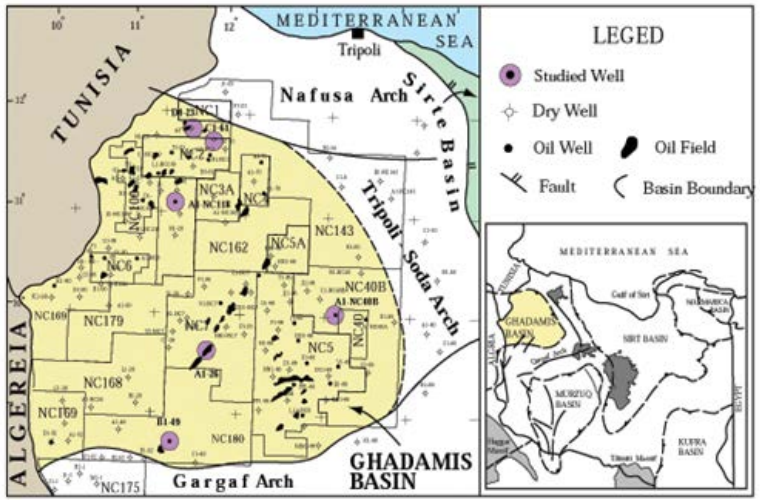

Figure 2. Geographical location map of Ghadamis Basin, western Libya. Modified from (Echikh, 2016).

Field Location and History

North Hamada field is located in the North Ghadames Basin, Libya, approximately 220 km South West of Tripoli. The field was discovered in 2005 by Verenex and MEDCO International Ventures Limited (MIVL) which was operating in Area-47 under Exploration and Production Sharing Agreement (EPSA). The field is divided into 4 Blocks with several structures (Oil & Gas) had been proved through exploration wells. The productive structures are mostly located in Block-2 and Block-4 as shown in (Fig. 3&4).

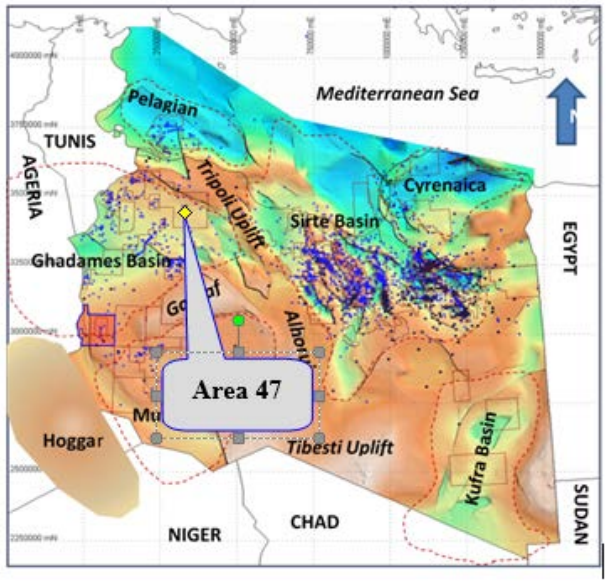

Figure 3: Location Map of Area 47 Showing the Regional Structure Elements.

The discovery well is A1-47/02 which penetrated the reservoir main producing sandstone of the Lower Akakus Formation (Upper Silurian). Until very recently, the majority of the exploration focus has been in Block 2 where thirteen (13) wells have been drilled in order to delineate and test the Akakus Formation. Six (6) proven structures designated AL, B, C, D, F and J already have commercial status through final appraisal report document (Fig 4). Those structures have been engaged in field development plan (FDP) and granted to deliver hydrocarbon from several multilayer from bottom to top (Sand 1 to Sand 5). Some of these drilled wells produce sand during the initial DST performed during the exploration phase (Fig. 5).

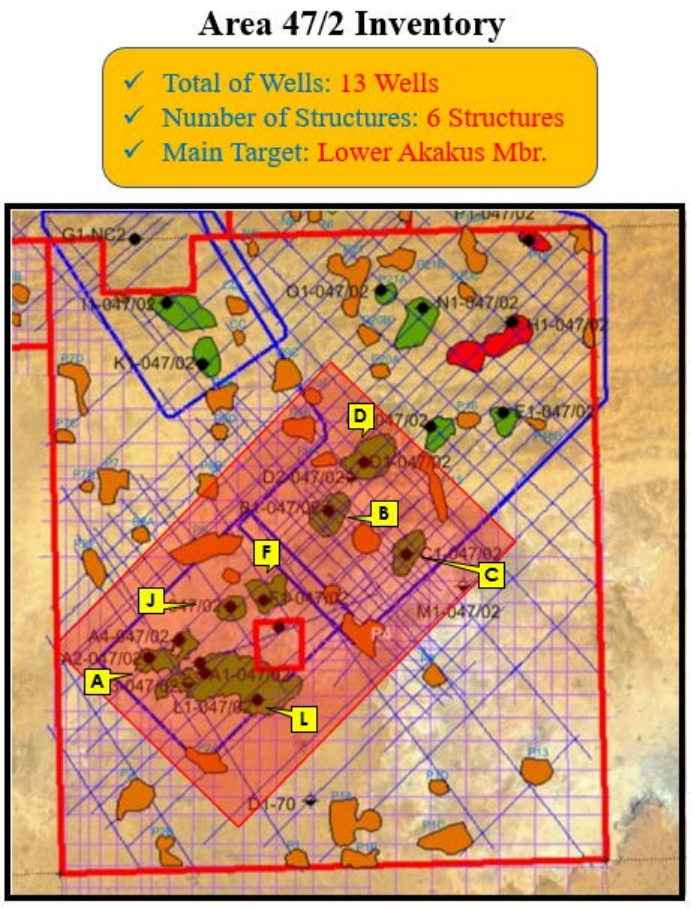

Figure 4: Location Map of Area 47 plus the drilled wells in Block 2

Tudy Synopsis

This study documentation of the Lower Akakus section in Area 47 of the Ghadames Basin, Libya. Nafusah Oil Operations Area 47 was commissioned to manage the project to perform supplementary desktop studies. The objectives of the study were to:

1. *Exploration* To develop depositional environmental models of the Silurian-age Lower Akakus section integrated with the well correlation framework; these models to be predictive of reservoir quality and stratigraphic trapping potential for use in the forward exploration programme.

2. *Development* To develop sandstone reservoir models at a field scale that predicts reservoir continuity and quality. Develop a sandstone diagenetic model. The models are to be calibrated with the current petrophysical analysis.

Specific specialist study deliverables included in the broad project scope included:

- Sedimentology – *describe all the core taken to date and new core as it is available. Prepare thin sections from core plugs and describe. In a report, correlate core to well logs and relate to thin section descriptions. Describe sedimentary facies with particular attention of relative fluvial, tidal, and wave processes. Develop possible depositional environment models.* All cores taken in the new wells have been described.

Sedimentology

The sedimentology portion of this study is fully described in a separate Nafusah report by Geoscences team entitled *Sedimentology of the Lower Akakuse Formation.* Synopses from this report appear below under the relevant sub-headings; for more detail on any item refer to the Nafusah report. The primary objectives of the sedimentology study in respect to the Lower Akakus section included:

- Determine the depositional environment of the Lower Akakus based on the sedimentological interpretation of newly acquired core and integrated with the concurrent palynology study. These models were to be predictive of reservoir quality and stratigraphic trapping potential for use in the forward exploration programme.
- To develop sandstone reservoir models at a field scale that predicts reservoir continuity and quality.

The objectives have been achieved and the results are significantly different than previously published models. During this report describes observations and analyses of the new and extensive Lower Akakus core data. Describes the proposed depositional environment model for the Lower Akakus and includes a discussion of depositional analogues, a synopsis of the high gamma ray sand sedimentology and mineralogy.

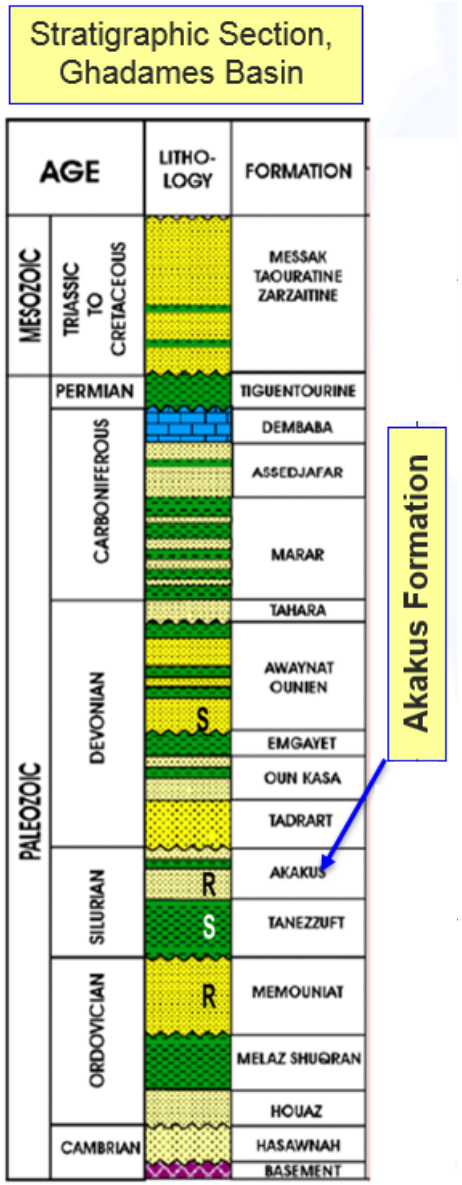

Figure 5 - Stratigraphy Column Section of Area 47

Core Sedimentology

The core database (946.5 ft), along with FMI borehole imagery and conventional wireline logs, has been used to define the sedimentological models for the Lower Akakus. The cores were described in a series of three visits to Corex's laboratory in Tripoli during 2008-2009. All cored sections are from Quadrant 2 wells (A3, A4, B1, C1, D1, D2, F1, G1, I1 and J1-47/02), with no coring attempted from any of the wells in Quadrant 4 (-47/04). The FMI tool was run on each of the ten Lower Akakus cored wells, and the interpretation from the FMI (carried out by Schlumberger) was used in the sedimentological interpretation of the cores, principally to add some direction to the migration of cross-bedded sandstones. The reader should note that the FMI interpretation reports were done soon after the well completions and without the benefit of the core logging.

Lower Akakus reservoir intervals tend to be fine to very fine grained and well sorted, forming at the top of m-scale coarsening upward parasequences. Much of the sandstone appears massively bedded, but cross-bedded intervals do occur, importantly forming herring-bone cross sets and defining tidal influence in places. Trace fossils are seen locally in the sandstones but are more notable in the intervening heterolithic deposits. *Rosselia*, *Asterosoma*, *Teichichnus*, *Thalassinoides*, *Planolites* and *Skolithos* burrows are all recognized, defining a *Cruziana* ichnofacies and suggesting a shoreface setting (Belhaj, 2000). The coexistence of *Rosselia* and *Asterosoma* in particular defines a lower shoreface setting. The sandstone is often notably porous and is friable in some cases. Core log montages have been completed for each of the cores and include FMI images, core GR, core plug analyses, petrography, and core photos; these documents will be filed with the final well reports.

Depositional Environment

Combining the wireline logs with knowledge gained from the core logging, it is evident that reservoir sands often appear at the top of coarsening (cleaning) upward parasequences. The more heterolithic facies form the lower parts of the parasequences. This relationship is typically associated with delta or shoreface progradation. The identification of intervals with *Cruziana* ichnofossil assemblages throughout the Lower Akakus Formation suggests the latter. Sand 2 in particular shows a number of parasequences with potentially up to six cycles of deposition recognized (e.g. H1-47/02). The lower cycles appear to prograde, while the upper cycles aggrade. These packages of sand are less easy to identify in wells to the SW implying a position closer to the shoreline where a thick sequence of sand accumulates, while offshore cycles separate and become more pronounced eventually shaling-out to the north. Similar characteristics are evident in the other sand units, but cycles are thinner and not as well developed (Massa, 1988).

The facies described in core, with the exception of herringbone cross-bedding, are by themselves not diagnostic of any one environment. However, trace fossil evidence in association with the tidal indicators suggests the Lower Akakus Formation was deposited on a shallow marine tidally-influenced platform (Fig. 5). Ichnofossils are common, with *Asterosoma, Skolithos, Rosselia, Planolites and Thalassinoides* found in sandy and heterolithic beds. These ichnogenera are typical of the *Cruziana* ichnofacies, which is considered to represent a shelf assemblage. *Rosselia* in particular is diagnostic of the lower shoreface environment. The presence of body fossils is by comparison relatively rare. Nevertheless, brachiopods are observed and support a marine setting (Whitbread and Kelling, 1982).

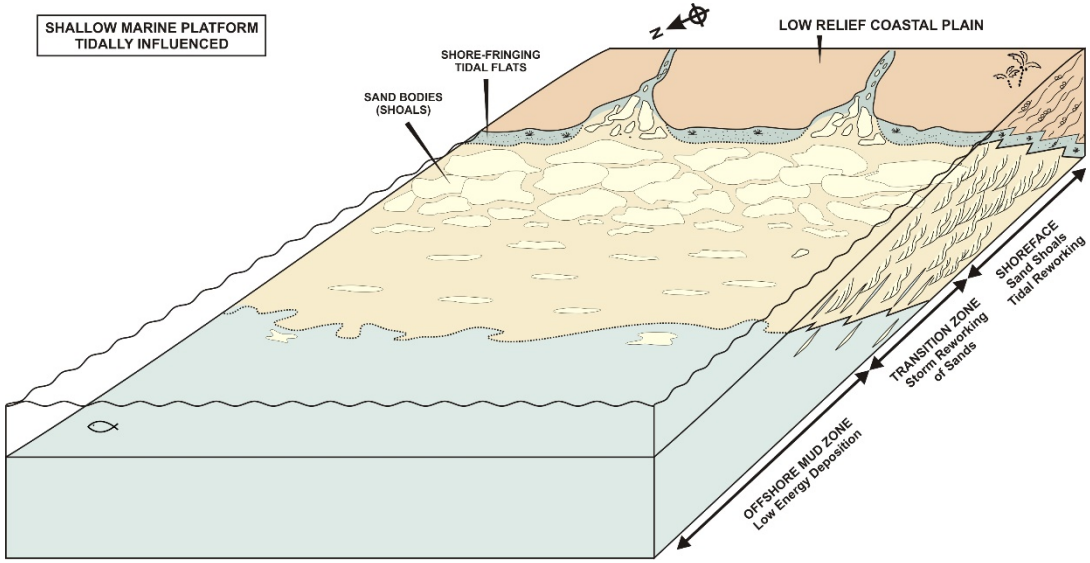

Figure 5 – Depositional Environment Model of the Lower Akakus Formation

Paleogeographic maps are constructed for each of the four main Lower Akakus reservoir sands and included in Nafusah Sedimentology Report; these maps are regional in nature, extrapolating beyond Area 47 using regional well control where possible. All the maps show a clear loss of sand content to the NNW, perpendicular to a shoreface orientated ENE-WSW. Beginning with Sand 3, an east-west embayment feature is developed with an eastern limb to the coastline located along the north-eastern boundary of Area 47. The embayment feature, oriented east-west through the G1-NC02 well, is an area of higher subsidence probably controlled by strike-slip faults that define the southern boundary of an ancestral Nefusah Arch. The parasequence sets for base Sand 2 to top Sand 3 thicken significantly from the south into this area (Boote, *et al*., 1998).

Depositional Analogues

The Lower Akakus Formation is interpreted to have been deposited on a tidally-influenced shallow rine platform. Perhaps the best modern analogue for such a setting is that defined by the distribution of sediment and bed forms on the NW European continental shelf, and specifically the Western Approaches and Celtic Sea. Small to medium sand waves are deposited across the shelf. These subaqueous dunes grade to sand patches as velocity decreases. Investigation of ancient models results in comparisons with shallow shelf seas which bordered the Iapetus Ocean in the late Precambrian to early Cambrian. Tidal shelf depositional models are proposed for the deposition of these laterally extensive sand-rich shelves. Recent papers of the Ordovician-age Hawaz Formation in Libya are also recognizing a primarily tidal shelf depositional environment for the sandstones preserved in outcrop and subsurface (Fello *et al*., 2006) (Ruth and Redfern 2006).

Conclusions & Recommendations

✓ Conclusions

- The study objectives have been achieved:
  - *Exploration* To develop depositional environmental models of the Silurian-age Lower Akakus section integrated with the Nafusah correlation framework; these models to be predictive of reservoir quality and stratigraphic trapping potential for use in the forward exploration programme.
  - *Development* To develop sandstone reservoir models at a field scale that predicts reservoir continuity and quality. Develop a sandstone diagenetic model. The models are to be calibrated with the current petrophysical analysis.

✓ Recommendations

- Obtain additional seismic, well log, and especially core data at the forced regression surface in wells to the south of Area 47 to test the forced regression model.
- A Petroleum System Study should be undertaken for exploration purposes. Reservoir, seal, and trap elements are all well constrained over Area 47. Understanding the oil migration timing and effective pathways remains work to be done.

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