NEW INSIGHTS ON MESOZOIC DEPOSITIONAL SEQUENCES AND HYDROCARBON SYSTEMS, FROM JIFFARAH ESCARPMENT TO LIBYAN OFFSHORE BASINS

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Abstract: This paper provides the results of outcrop data analyses across the Jiffarah Escarpment (JE). A new Mesozoic stratigraphic scheme and sequence stratigraphic framework are proposed which could be used both in the Libyan onshore and offshore. Chronostratigraphic chart has been constructed across the JE, in E-W direction. The chart demonstrates the way in which depositional sequences and sedimentation history vary across the JE via time. The exposed stratigraphic succession at JE ranges in age from Middle Triassic to Late Cretaceous. This Mesozoic succession represents two second-order sequences (Triassic to Middle Jurassic; and Cretaceous), both depositional sequences are bounded by major tectonic unconformities. The lower sequence (**SI**) is bounded by the Hercynian unconformity at the base of the Triassic and MFS of **SI** is placed in the Bathonian. The Cretaceous sequence (**SII**) is bounded by the Cimmerian-Austrian unconformities at the base and the Albine unconformity at the top. Deposition of the JE Mesozoic mega-sequences took place during several rifting phases effecting the Mediterranean basins, starting from Triassic and passing through the Jurassic and terminated during Early Cretaceous. The region witnessed compressional phases during the Albine Orogeny which lead to uplifting and erosion of wide areas along northern African margin. Stratigraphic correlations made on Mesozoic sequences reveal a complex sequential organization and also account for the impact of the Hercynian uplift and paleotopography on eastward truncations of Triassic-Middle Jurassic sequence. Post Albian deposits developed on a smoothed topography associated with a regional transgression and can be easily correlated over the JE. Reservoir and source rocks potential of the outcropping Triassic-Cretaceous sequences along JE reveal the importance of the deeper thermogenic petroleum systems located in the subsurface of the adjacent Gabes-Tripoli Basin. The exposed Miocene sequence along eastern JE represent good analogue to the proven biogeneic Neogene gas system in the adjacent Mediterranean basins and support the assumption of discovering similar plays in the Libyan offshore basins.

Keywords: Mesozoic Sequences, HC Systems, Jiffarah Escarpment (JE), Libyan Offshore Basins.

INTRODUCTION

The focal of this study encompasses new documentation of the stratigraphic scheme of the JE. The new stratigraphic scheme addresses the implementation of sequence stratigraphy approach in the subdivision of the outcropping rock units along JE (Figs. 1 and 2). Although the existence of valuable sedimentological and stratigraphic studies (Hinnawy & Cheshitev, 1975: Hammuda *et al*, 2000), no attempt has been made to upgrade the classical stratigraphy of the JE. This has contributed negatively on the correlation between the onshore sections and sub-cropping offshore sequences in adjacent basins. Hence, the outcomes are serious damage to the paleogeaographic reconstruction and augmented obstacles in the understanding of the geological history evolution of the region are persisted.

In this study, a review of previously published stratigraphic studies within these units is used to better constrain their dating. Stratigraphic correlations were based on studied outcrop sections along JE. Reconstruction of the temporal and spatial evolution illustrates a better constraint on the geologic history of the Jiffarah region.

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REGIONAL GEOLOGY AND TECTONIC SETTING

JE is a major topographic feature in the northwestern part of Libya (Fig.1). Jiffarah Uplift represents an arch between the Jiffarah Plain to the north and Ghadamis basin toward the south. In Libya, the JE is oriented in west-east direction and extends for about 350 km from Al Khumus to the Tunisian border. Towards Tunisia, the escarpment is known as the Dahar Plateau, and changes its orientation in a north-south trend. The JE delimits the Jiffarah Plain and rises above sea level to about 800m (Gharyan area).

The Mesozoic sequences exposed in the JE range in age from Triassic to Late Cretaceous. Sedimentation continued during Triassic-Early Cretaceous over a vast region in Jiffarah, however, a progressive truncation of Mesozoic sequences toward the east may be ascribed to both palaeotopgraphic and tectonic controls (Echikh, 1998; Bouaziz *et al*, 2002; Dardour *et al*, 2004 and Underdown *et al*, 2007). Prior to the Hercynian Orogeny, all western Libyan basins Jiffarah, Ghadmis and Murzug were forming single Paleozoic north-south trending basin. The Hercynian Orogeny inverted the northern Ghadamis basin into a prominent east-west arch which was extensively eroded during the Permian, exposing the Precambrian core of Pharusian rocks (Hallett, 2002).

In Triassic times the arch had been greatly reduced in elevation and Triassic-Jurassic and Early Cretaceous sediments were deposited over the rifted Mesozoic Jiffarah Arch and Ghadamis basin. The arch was also covered by the Late Albian-Turonian transgression and deposition of marine sediments continued probably, till the Late Eocene time. The Jiffarah Arch was reactivated during mid-Tertiary in response to the closing of the Tethys. It was subjected to uplifting accompanied by strike–slip faulting along the Al Azizyah Fault and Libyan coastal fault system.

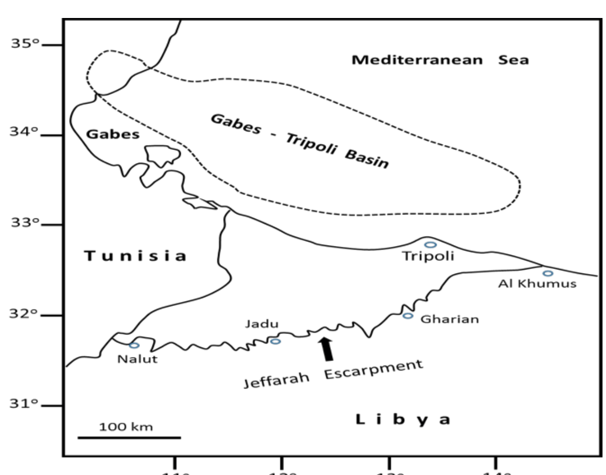

Fig. 1. Location map of the study area.

The current body and topography of the escarpment are the end result of the Alpine tectonic events (volcanic eruptions, uplifting and erosions). The Alpine orogenic event, the latest period of tectonism affecting the Jiffarah and western Libyan Palaeozoic basins, was caused by collision of the Africa-Arabia plate with Europe during latest Cretaceous-Eocene time (Boote *et al*, 1998; Guiraud *et al*, 2005). Exhumation related to this tectonic event is greatest over the uplifted basin margins to the south Gargaf and Tihemboka archs and east Nafusah Uplift (Underdown *et al*, 2007). Eocene tectonism also witnessed volcanic eruptions and lava flows near Gharyan region, and volcanism has continued till recent times. The advent of the Miocene, probably witnessed a major escarpment formation, and outcropping of Mesozoic rocks on the escarpment and in few places in the Jiffarah Plain. The formation of this escarpment has been considered as a retreating fault scarp, its shape and extension is controlled by the Al Aziziyah Fault (Lipparini, 1940 and Miller, 1971).

SEQUENCE STRATIGRAPHY OF THE MESOZOIC SEQUENCES

The exposed stratigraphic succession at JE ranges in age from Middle Triassic to Late Cretaceous (Fig. 2). This Mesozoic succession represents two second-order sequences (Triassic to Middle Jurassic; and Cretaceous), both depositional sequences are bounded by major tectonic unconformities. The older sequence boundary of SI is at the Hercynian unconformity at the base of the Triassic and MFS of SI is placed in the Bathonian. The base of younger sequence (SII) is at the Hauterivian-Cenomanian boundary, coincident with the Cimmerian-Austrian unconformities and MFS SII is placed in the Turonian (Fig. 2). The main tectonic unconformities or sequence boundaries bounding the second order sequences are defined below:

Sequence Boundaries

The lower and upper sequences are interrupted by two major tectonic unconformities along the JE.

They are known to geologist as Cimmerian and Austrian unconformities.

The Cimmerian Orogeny began 200–150Ma (Jurassic), when the Cimmerian plate collided with the North and South China blocks, closing the Paleo-Tethys Ocean between them and forming mountains. According to (Guiraud *et al*, 2005), tectonic deformations are recorded along most North African basins during the Jurassic-Cretaceous transition. This event is known as Cimmerian unconformity and probably occurred coevally with the tectonic activity in south-eastern Europe (Bodin *et al*, 2010).

The Austrian event, records a short-lived unconformity during the Early Cretaceous (Aptian) at the base of Kiklah Formation (Bodin *et al*, 2010) whereas, the Cimmerian unconformity has been applied at the base of Cabow Formation by the same authors. The Austrian tectonic event corresponds to the change of the relative motion and the initiation of the convergence of Africa relative to Europe (Dewey *et al*, 1989 and Rosenbaum *et al*, 2002).

The impact of Jurassic-Cretaceous unconformities on spanning of the sedimentary hiatus across JE can be summarized as follows:

In the western parts of the JE, the unconformity produces a sedimentary hiatus spanning the Oxfordian to Valanginian (164-134Ma & Fig. 2). In the central parts (Gharian area), the unconformity produces a sedimentary hiatus spanning the Sinemurian to Aptian (191-128Ma & Fig. 2). While, in the eastern parts of the region, the unconformity produces a sedimentary hiatus spanning the Rhaetian to Cenomanian (209-100Ma & Fig. 2). The impact of these tectonics on the sedimentary gab durations are varied widely across the JE. It records time duration of 30Ma, 63Ma and 109Ma at western, central and eastern parts of the JE respectively.

Stratigraphic correlations made on Mesozoic sequences reveal a complex sequential organization and also account for the impact of the Hercynian uplift and paleotopography on eastward truncations of Triassic-Middle Jurassic sequence. Post Early Cretaceous deposits developed on a smoothed

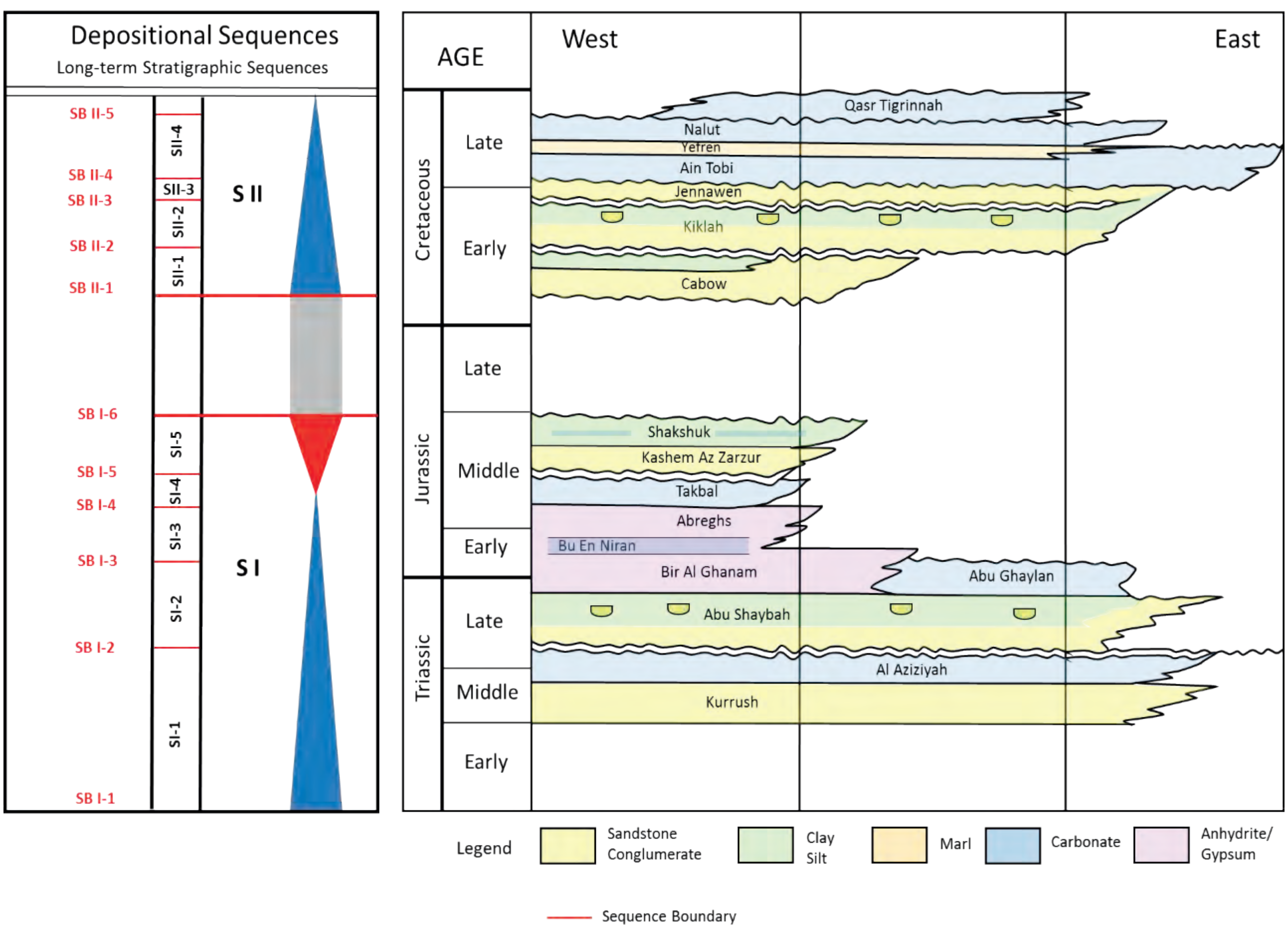

Fig. 2. A new stratigraphic scheme and sequence stratigraphic framework for the Mesozoic sequences outcropping along Jiffarah Escarpment.

topography associated with a regional transgression and can be easily correlated over the JE. The main second order sequences are defined as follows:

The Older Sequence

The lower sequence is essentially a second order transgressive–regressive (T/R) sequence and is comprised of mixed siliciclastics, carbonate and evaporite facies (Fig. 2). This sequence can be further subdivided into five T/R cycles and are developed during rifting phases of the Mediterranean Sea. Along the East-West transect of the JE, Sequences SI-1 and SI-2 are widely developed, whilst sequences SI-3, SI-4 and SI-5 are truncated toward the eastern flanks of the scarp (Fig. 2), indicating paleohigh control and significant erosion due to the tectonic unconformities (i.e. Cimmerian and Austrian). The exposed part of the lower sequence consists of marginal marine sisliciclastic and carbonate ramp facies of Middle Triassic (Anisian-Carnian) of Kurrush (Ras Hamia) and Al Aziziyah formations. This in turn grade upwards into the Late Triassic (Norian-early Rhaetian) fluvial facies of Abu Shaybah Formation which passes upwards into Late Triassic-Early Jurassic (Rhaetian-Sinemurian) shallow shelf carbonate facies of Abu Ghaylan Formation. This facies changes laterally to the west into the evaporites of the Bir Al Ghanam Formation. This unit is followed by the deposition of the Middle Jurassic (Bathonian) carbonate and shale facies of the Takbal Formation. The Bathonian Takbal facies marks the time of maximum flooding (TMF) of this sequence (Fig. 2). The first cycle is terminated by the deposition of the Middle Jurassic (Bathonian-Callovian) regressive sequence, showing an overall progradational stacking pattern and comprising of fluvial to marginal marine siliciclastic of Kashem Az Zarzur Formation that grade upward into mixed shallow marine siliciclastics and carbonates of the Shakshuk Formation (Fig.2).

The sequence is more than 1000m thick in Yefren-Jadu area, reflecting a period of relatively high accommodation. The older second-order sequence consists of fife sequences. They vary in thickness from 100 to 400m. They are defined as follows:

SI-1: The base of this sequence is taken in the lower part of the early Triassic (Scythian), Bir El Jaja Formation basal transgressive marine siliciclastic facies grading upwards into the Middle Triassic (Anisian-Ladinian) marginal marine, mixed siliciclastic and carbonate facies of Ouled Chebbi and Kurrush (Ras Hamia) formations. These in turn grade upwards into the Late Triassic (Late Ladinian-Carnian), shallow carbonate ramp facies of Al Aziziyah Formation. The transgressive to highstand parts of the sequence are represented by the Al Aziziyah Formation. The top of this sequence corresponds with the top of the Carnian Stage (Fig. 2).

SI-2: This sequence has a well-developed, lowstand-thick sandstone at the base of the Abu Shaybah Formation. The regionally identifiable floodplain shale represents the transgressive phase of the third-order sequence (Fig. 2). Locally, the Abu Shaybah Formation, overlain by few meters of marginal marine siliciclastics in the end of TST. Most of the highstand parts of the sequence are represented by the Bir Al Ghanam evaporites and its eastward equivalent Abu Ghaylan carbonates. The age of this sequence is likely Norian to Rhaetian, possibly as young as Sinemurian.

SI-3: The sequence extends from the Sinemurian through the Bajocian and comprises upper parts of the Bir Al Ghanam and whole section of the Bu En Niran and Abreghs formations (Fig. 2). There is a significant evaporate TST and HST components in this sequence, marking the change from siliciclastic to dominantly evaporate deposition in the western part of the study area. The Bu En Niran carbonate facies represents the TMF of this sequence. This sequence is more than 400m thick in the area, reflecting a period of relatively high accommodation. Toward the eastern parts i.e. in Gharyan area (e.g. only the carbonates of Abu Ghaylan Formation are present).

SI-4: This sequence is 22m thick in the Takbal village, comprising limestone and clay, and having retrogradational stacking pattern (i.e above the evaporite deposits of Abreghs Formation). The regionally identifiable Takbal carbonate and clay represents the transgressive phase of this third-order sequence and marking the TMF of the whole older sequence (Fig. 2). The sequence SI-4 is likely Bathonian in age.

SI-5: There is a significant siliciclastic regressive component in this sequence, showing an overall progradational stacking pattern and comprising of fluvial to marginal marine siliciclastic of Kashem Az Zarzur Formation that grades upward into mixed shallow marine siliciclastics and carbonates of the Shakshuk Formation (Fig. 2). Its age is likely Bathonian to Callovian, as defined by biostratigraphic data.

The Younger Sequence

The upper mega sequence is represented by the Cretaceous second-order incomplete transgressive sequence (Fig. 2). Within the Cretaceous sequence, four 3rd order T/R sequences were identified. The younger second-order depositional sequence extends from the Valanginian to Turonian, comprising Cabow, Kiklah, Jennawen, Ain Tobi, Yefren, Nalut and part of the Qasr Tigrinah formations (Fig. 2). The Qasr Tigrinnah shale represents the TMF of the sequence. The basal Cretaceous fluvial siliciclastic facies of Cabow and Kiklah formations are organized into two 3rd order sequences that form sequences SII-1 and SII-2.

A return to marine conditions by Late Albian resulted in deposition of sequence SII-3 of the Jennawen marginal marine siliciclastics facies (Fig. 2), lying unconformably on the Kiklah Formation and form an overall 3rd order transgressive trend where a maximum flooding surface occurs within the upper most deposits. Transgression continued during Late Cretaceous, as carbonates deposition become increasingly significant (Fig. 2). The overall sequence II-4 represents transgressive succession, forming backstepping shallow-marine carbonates and marl of Ain Tobi, Yefren, Nalut and Qasr Tigrinnah formations (Fig. 2). The TMF of this sequence coincides with the deposition of regional Turonian source rocks in G-T Basin and Tunisia.

In many parts of Jiffarah Scarp, above the Early Cretaceous regressive successions Cabow and Kiklah deposits, Both sequences II-3 & II-4 show backstepping character and are formed of marginal-marine Jennawen sediments and shallow-marine carbonates and marl of Ain Tobi, Yefren, Nalut and Qasr Tigrinnah formations.

SEQUENCES HC SOURCE POTENTIAL AND RESERVOIR ROCKS

The exposed Mesozoic sequences along JE provide clear vision on the HC potential for their subcropping analogue, encountered at greater depths in adjacent offshore basins (e.g. Gabes-Tripoli Basin). Selected examples explaining the case are illustrated in (Figs. 3-5).

Older sequence HC Source & Reservoirs

Deep-outer ramps Triassic (Carnian) shales of Al Aziziyah Formation are possible source rocks in the southern Gabes-Tripoli Basin (Mriheel, 2014). Triassic (Norian-Early Rhaetian) sandstones of

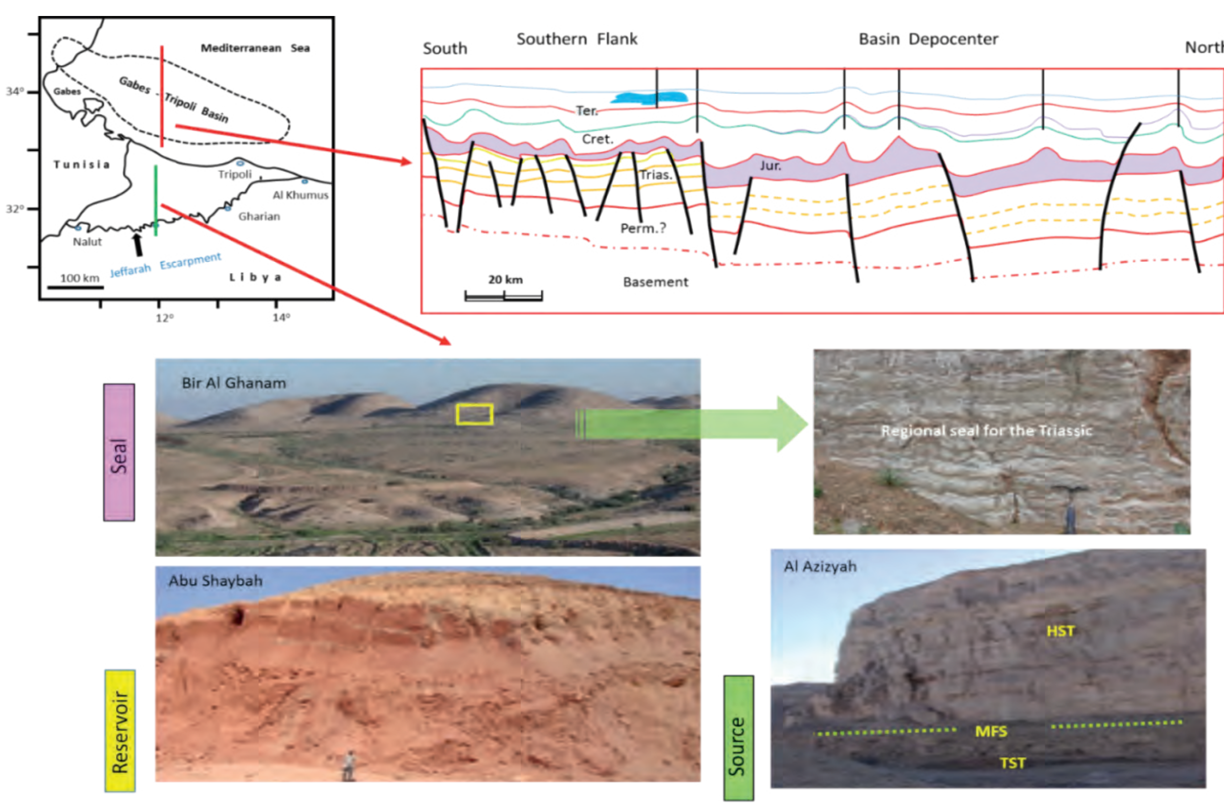

Fig. 3. Map, cross-section and field photos showing extension of Triassic petroleum play elements from outcrop to Libyan offshore.

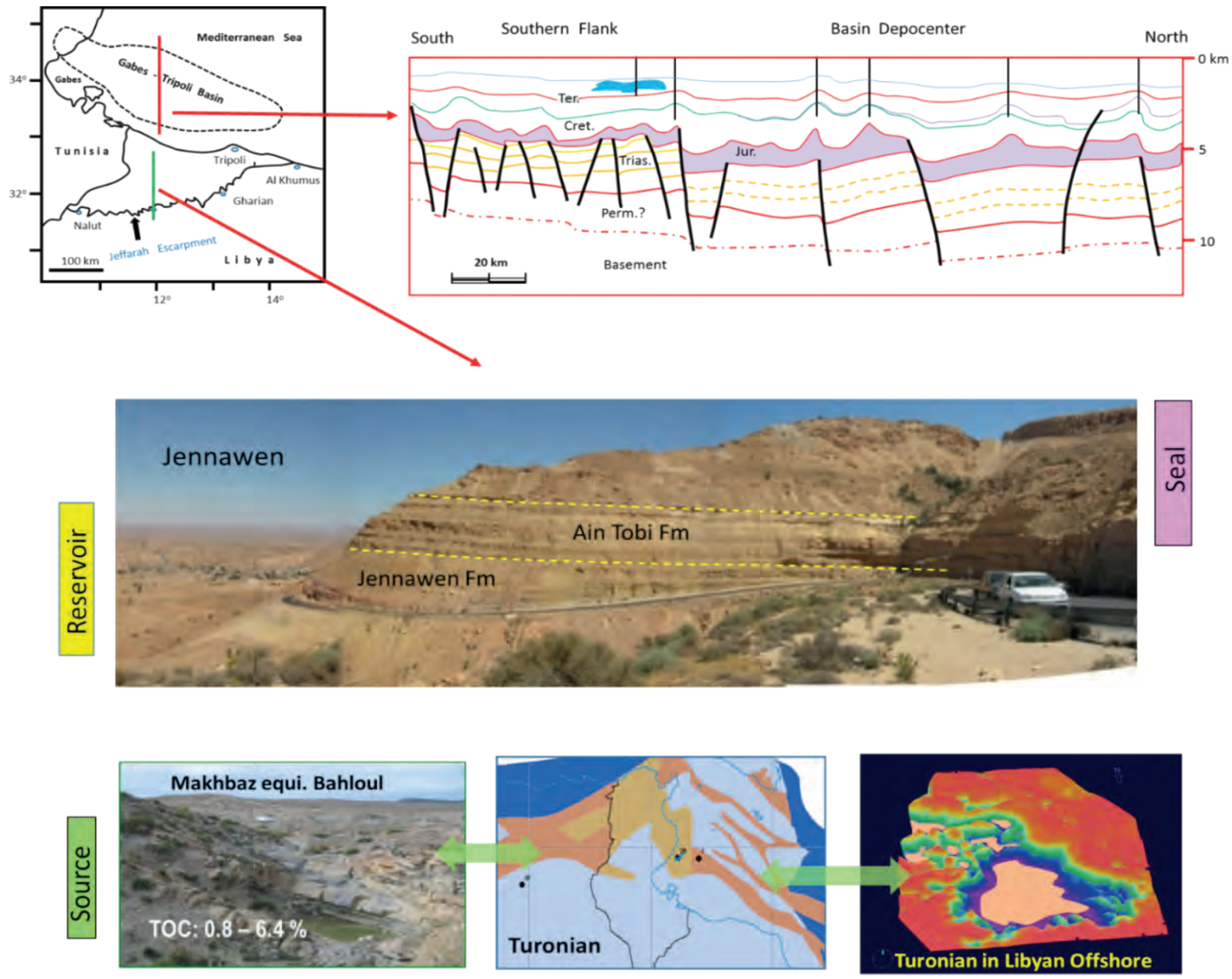

Fig. 4. Map, cross-section and Field photo showing extention of Cretaceous petroleum play elements from outcrop to Libyan offshore.

Abu Shaybah Formation are potential reservoirs both in Libyan and Tunisian offshores (Fig. 3). Triassic deposits are proven source rocks in eastern Sirt Basin. Middle Jurassic (Bathonian) shales and carbonates represent a time of significant maximum flooding and are considered as possible source rocks in the offshore basins. Equivalent Bathonian-early Callovian Khattaba Formation is source rock for oil in the Western Desert of Egypt (Keeley and Massoud, 1998). Triassic-Jurassic carbonate build-ups are principle reservoir in the Gulf of Gabes (Carr, 2003).

Younger Sequence HC Source and Reservoirs

Early Cretaceous (Aptian-Albian) Nubian lacustrine shales are source rocks in the eastern Sirt Basin. Early Cretaceous deposits are reservoirs in the eastern Sirte Basin and Gulf of Gabes. Important petroleum Late Cretaceous source rock in Gapes-Tripoli Basin is Makbaz Formation (equivalent to the Tunisian Bahloul Formation). Turonian marine deposits are source rocks in the eastern Sirt Basin. Late Cretaceous marine deposits are source rocks in Sirt Basin and in Gulf of Gabes. Late Cretaceous carbonates and siliciclastics are major reservoirs in Sirte Basin. Late Cretaceous sediments are reservoirs in Gulf of Gabes (Carr, 2003). The richness of the Late Cretaceous source rock section, availability of carbonate and clastic reservoirs and encouraging basin modelling (Fig. 4) results suggest that much more oil could be found in the transgressive Jennawen sandstones and Alalgah and Makbaz carbonate reservoirs (Mriheel, 2017).

Other Sequences HC Source and Reservoirs

The newly proposed biogenic gas system of the Oligocene-Early Miocene (Mriheel, 2017) reveals the existence of interesting accumulations in the

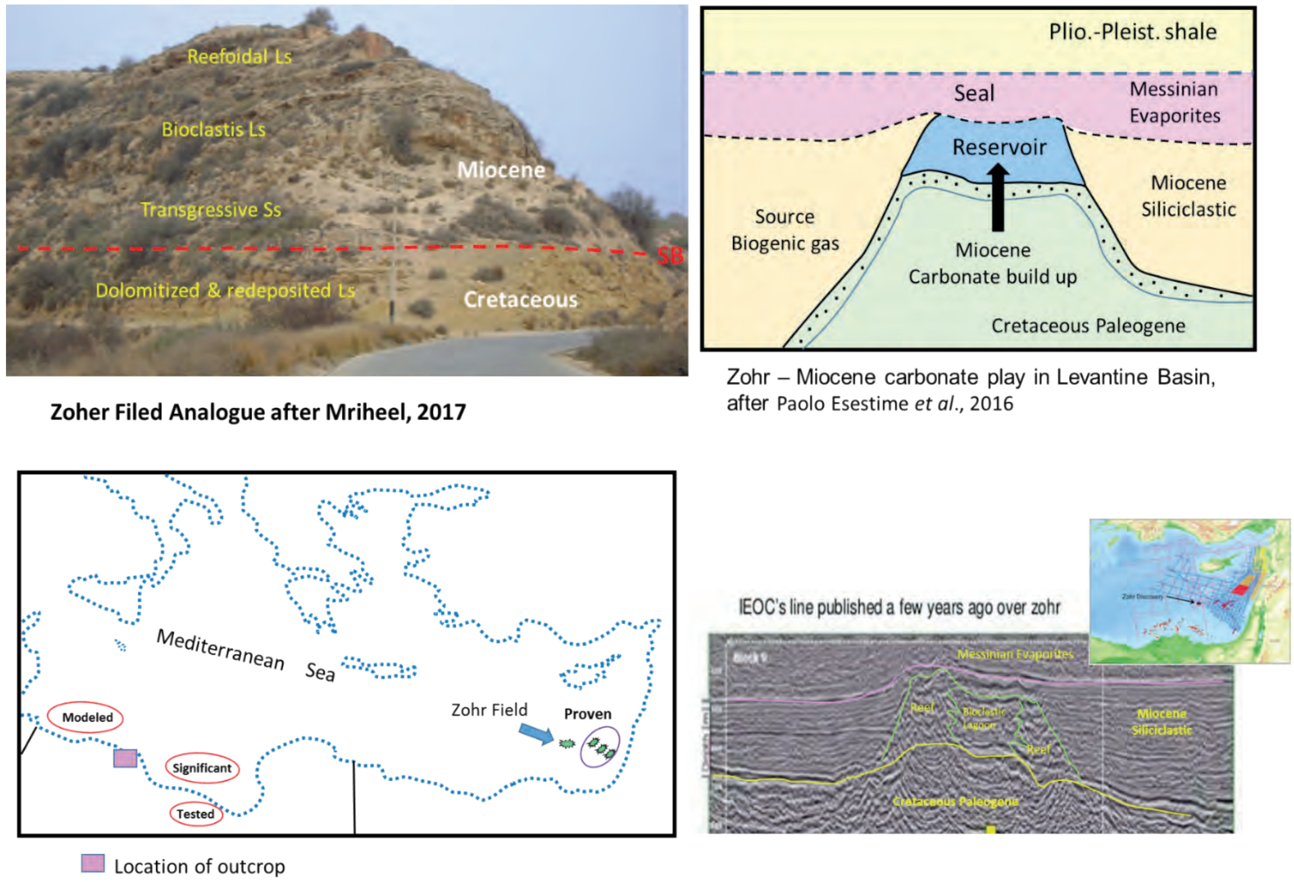

Fig. 5. Miocene biogenic gas play in Levantine and outcropping Miocene sequence above Cretaceous unconformity supports of similar plays in Libyan offshore.

Dirbal Formation sealed laterally and on top by the shales and marls of the Ras Abd Jalil Formation and Al Mayah Formation respectively. Future exploration must not neglect these spectacular carbonate build-ups both in the Gabes-Tripoli Basin and in the Sirt Basin offshore.

The Middle-Upper Miocene reefoidal carbonates of the Alkhums Formation (Fig.5) represent excellent analogue to the Zohar field at the Egyptian offshore where huge gas has recently been discovered. Furthermore, this newly proposed biogeneic gas system open new doors for gas exploration within the transgressive Oligocene sandstones in the onshore of the Sirt Basin.

CONCLUSIONS

A new stratigraphic framework for the Mesozoic succession in JE has been constructed. The stratigraphy is divided into two second-order sequences (older and younger) and key sequence stratigraphic surfaces for both sequences have been defined.

The older sequence boundary of SI is at the Hercynian unconformity at the base of the Triassic and MFS of SI is placed in the Bathonian. The base of younger sequence (SII) is at the Hauterivian-Cenomanian boundary, coincident with the Cimmerian-Austrian unconformities and MFS SII is placed in the Turonian. This sequence framework is intended to provide a basis for future in-depth analysis and further subdivisions of the succession. The outcomes of this framework synthesis will encourage younger geoscientists to carry out more detailed studies and consequently, help in recognition of the impacts of the global and relative sea level changes on sequences development of the region.

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