

# Sedimentary and Tectonic Control of the Eocene/ Lower Miocene Hydrocarbon Systems of the Gulf of Gabes Basin-Ggb in Tunisia



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## Introduction

In the Gulf of Gabes Basin (GGB), limestones in the El Garia (Ypresian) and Ketatna (Rupelian-Burdigalien) formations are gas and oil prone [1-5]. They are comprised of carbonate platforms on which sedimentation, eustasy, tectonics and inter-related subsidence have exerted important controls. They were deposited in a lithotectonic setting dominated by two major orogenic phases, the Pyrenean and the Alpine. The former enabled collision of the North African plate margin against its Apulian counterpart [6-9] the initiation of the Tethys closure, the erection of the so-called box-folds and subsequent emersion of the Saharan Atlas [10].

The benthic El Garia and Ketatna Formations and the respectively coeval but pelagic Boudabbous and Salammbô Formations extend in a broad area covering the gulf of Hammamet, gulf of Gabes and Pelagian Block in the Southeast Tunisia [1,2,5,11]. Detailed petrographic and petrophysical studies of the limestones building the El Garia Formation have shown these series form commercial reservoir in the Asstart, Cercina, Chergui, oil fields.

Furthermore, the study of petroleum system series in the GGB help decipher a stratigraphical scenario of repetitive benthic carbonate platforms stacked in the sequence of stratigraphic ages, fitting laterally and upwards into pelagic counterparts. The Eocene El Garia reservoir settled in a broad area in the southwest of the GGB in continuity with the NW-SE directed Nummulitic ridge, passes laterally to the northwest into the Boudabbous Formation, a source rock dominated by marly limestones and black shales highly enriched in marine kerogen. This complex is sealed by a thick shaly Cherahil Formation, which in turn is transgressed over by a repetitive benthic but moderately to highly thick limestone packages in the Ketatna Formation. The latter broadly covers the proximal areas in the GGB, Pelagian Block and gulf of Hammamet, and fits laterally into its pelagic counterpart the Salammbô Formation which consists of rather marly

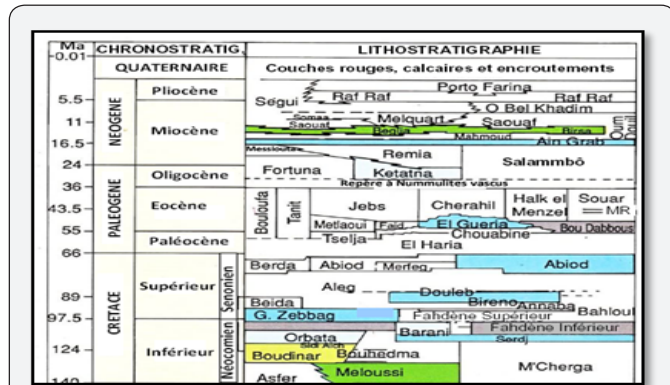
deposits interceded with limestone beds. Moreover it is likely that increasing tectonic subsidence which might have dominated in the study area during the Lower Miocene has caused the marls and black shale deposits in the Salammbô Formation prograde over and seal the Ketatna limestone reservoirs.

Based on recent fieldwork, stratigraphic data, well results and wire line log details, and seismic data, the main aim of this study is to demonstrate the close time/palaeogeographic relationships and configurations of these two major and superposed petroleum systems in the GGB covering a time span from the Eocene to the Lower-Middle Langhian times. The major constraints on the lithotectonic evolution, differentiation of sedimentary deposits and basin geometry are also examined in the light of sismostratigraphical and sismotectonic interpretations. The modeling approach help decipher benthic carbonate platform- and pelagic depositions, paleoeustatic changes in sea level, tectonics and inter-related subsidence, and as a consequence reservoir quality and source rock formation and maturation in the study time interval. This help us better contribute to the knowledge of the economic potential of the Eocene to Langhian series in the GGB.

## Results and Discussion

According to previous works, the Atlassic domain [12-14] and Sahel area [15-17] as well as the entire study area [4,11] were subjected to a dominant transpressive tectonic period beginning in the Santonian and ending in the early Paleogene with local East-verging reverse faulting identified in Santonian series of the Sahel area [17] During this period, transpressional move southeastwards exerted on transverse regional faults (E-W, S-N and NW-SE), has created rhomb-shaped and rotating blocks [18] with dominant low stand follows by a transgressive (TST) benthic carbonate sedimentation deposited in peritidal to infratidal milieu as indicated by frequent hummocky cross stratifications. These series have formed during the entire

Senonian and have covered broad anticline structures and fault-bend folds. However, the latter were trimmed by depressions and remarkably subsiding tectonic troughs which have been in filled by the Upper Maastrichtian-Paleocene marls of the El Haria Formation.



**Figure 1:** Lithostratigraphic Chart of study area in Central eastern part of Tunisia (based on the work of Burolet [12], Comte et Dufore [38], Fournié [1], Vernet [41], Bismuth et Bonnefous [35], Blondel [37], Bonnefous et Bismuth [26], [34] et Ben Ferjani et al. [2].

The Ypresian to Lower Lutetian was a period of intense tectonic activity with dominant transpression directed NW-SE. In the Atlassic domain and Sahel area, tectonic deformation caused local uplift and erosion, continental/lacustrine sedimentation on emerged blocks and has initiated the Atlassic box and salt-cored folds directed majorly NE-SW [11,12,19]. In contrast, no clear folding features have been observed in the study area. Instead, the tectonic framework includes a dominant tilted morphology with ramp-shaped and uplifted blocks superimposed to a network of normal faults directed majorly NW-SE and faced NE, but conjugated with additional regional sutures, S-N and particularly E-W in strike. This paleogeographic style has closely controlled the Lower Eocene sedimentation. Indeed, during the Ypresian and Lower Lutetian, the ramp-shaped blocks were the sites of benthic carbonate deposition and enrichments in coarsened foraminifera (Figure 1).

The Ypresian to Lower Lutetian platforms include carbonate sequences deposited in a Transgressive Systems Tract during a period of sea level rise. These deposits may rest disconformably over the older El Haria and Abiod Fms sequences. Towards the Jeffara mole, the Eocene Group (Chouabine and El Garia Fms) fits laterally into the Tanit Formation which comprises shales and dolomites deposited in a shallow, presumably lagoonal environment, whereas, to the northeast, in the deeper basin parts, this Group passes laterally to thick pelagic series of bituminous black shales and lime mudstones enriched in Globigerinids in the Boudabbous Fm.

The Ypresian to Lower Lutetian transpression was followed by a period of dominant subsidence and basin fill by remarkably thick, shaly and carbonate series of the Cherahil Fm which may rest disconformably over older deposits of the El Garia, El Haria

and Abiod Fms. The Cherahil Fm are shales and siliciclastics poor in faunal content, interceded by mollusk bearing limestones. In field outcrops, these are forth to fifth order sequences with dominant shaly strata at the base shallowing upward into Bryozan, Mollusk and Ostrea- rich limestones. The Cherahil/Souar shaly series provide seals for the oil prone El Garia Fm reservoirs and subdivide into three main Members: the so-called lower Cheral/Souar A and Upper Cherahil. Souar B separated by the middle Reineche Member formed by lime mud to wackestone containing mainly Nummulites. The latter horizon, picked in seismic limes, could represent a Lutetian TST even if tectonic transpression, folding and uplift would be accompanied by bottom elevation and subsequent carbonate deposition in the photic zone. Indeed, tectonics is thought to have intervened and enabled the Cherahil Fm present local gaps and rest disconformably over the Maastrichtian Abiod, El Garia and EL Haria Fms.

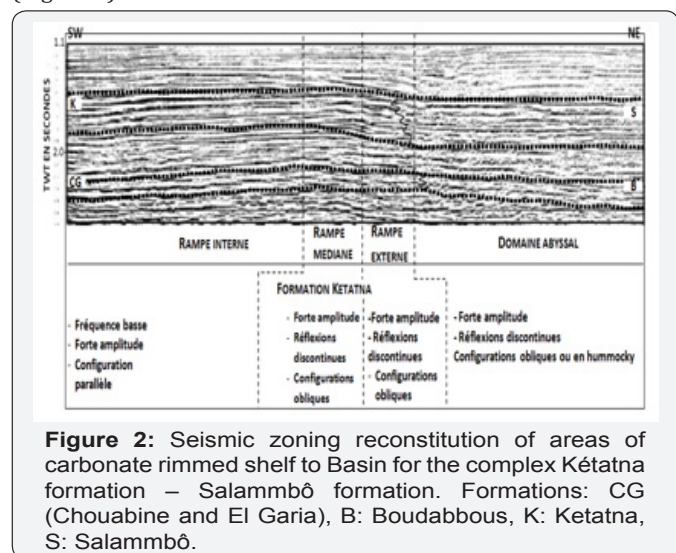
During the Rupelian to Burdigalian period, carbonates and marls prevailed with a clear disparity between platform and basin deposits. In the carbonate platforms, a basal Rupelian Horizon, 2 to 20m thick is easily picked in seismic lines in the Sahel, Pelagian Block and study area and is described as the lime wacke/packstones enriched in Nummulites vascus. It retraces a retrograding TST during the Early Oligocene, and passes upward to a highly thick carbonate series the strato type of which was described by Fournié in the Ketatna well. The series include lime mudstones and wacke/packstones enriched in coarse grained foraminifera, Nummulites, Bryozoans, Echinoids, Mollusks and Corals, dolomite beds and clay intervals. At the Jebel Abderrahman, Lower Oligocene limestone packages appear stratified, admit marl intercalations and display a similar faunal content [20,21]. In study area, the Ketatna Fm deposited to the west on a broad platform rimming a local basin centered on the gulf of Gabes.

The geometry of the Rupelian-Burdigalian deposits was dictated by deep-seated and reactivating shear faults directed NW-SE, S-N and SW-NE, with antithetic branches. Due to prevalently trans tensional move of these flower-faults almost NW-SE in azimuth and with dominant vertical offsets, polygonal blocks organized in stacked ramps have formed, among which the most uplifted were the sites for benthic carbonate facies of the Ketatna Fm with clear shallowing up features on paleohighs. In contrast, subsiding blocks have formed graben and half graben basins always in filled by pelagic shales, marls and embedded lime mudstones of the Salammbô Fm. The latter may disconformably overlie the Boudabbous, the Abiod and the Doubled Formations. Also, in the Oil wells, the Ketatna Fm transgresses the El Garia and Double Fms respectively.

Thus, the basin framework during the Rupelian-Burdigalian times, responds to those continuously reactivating shear zones inter-related with the older Upper Cretaceous-Lower Paleocene and Upper Eocene tectonic phases. This is clearly evidenced by the lateral variations in facies and total thicknesses of the

Ketatna and Salammbô Fms, but also by the facies inversions and interpenetrations thus forming a transition zone between these formations. The transitional lithofacies are dominated by an admixture of marls and carbonate deposits as observed in wells and in seismic lines cutting across the Ashtart oilfield, with flower faults and discontinuous hummocky cross-stratified seismic facies.

The seismic facies reconstruction and extension of the platforms of El Garia and Ketatna are complex. In the internal ramp area of the two platforms of El Garia and Ketatna, seismic reflections are continuous, high amplitude and concordant; this can be explained by stacking carbonate seismic reflectors; however, the frequency is often low, so that reflections are sub-parallel configurations resulting spatiotemporal continuity of carbonate sedimentation. The seismic facies of the middle ramp variables are generally characterized by discontinuous reflections are strong amplitudes and sometimes clearly arranged in parallel or sometimes chaotic. The external ramp is cut by seismic reflections that offer high amplitude, discontinuous, sometimes heckled with an oblique configuration or hummocky (Figure 2).



The findings of the study based on the well to well correlations enhanced by logging analyzes, information obtained from the 3D seismic picking of seismic horizons and conversion in depth from Oil well data, stratigraphically well defined, and delineation of facies by discontinuities and sequences hiatus, gives Fms El Garia and Ketatna form of carbonate platforms. The respective periods of lithofacies genesis, these platforms have recognized regional extension and were dislocated by regional dominant accidents NW-SE direction which was originally transpressive paleostress movements especially during the Maastrichtian, the Late Eocene, middle Miocene and Miocene-upper.

These carbonate platforms seem to have been built in favorable photic conditions. The sedimentary floor may be relatively steady incline imposed on blocks cut by branched flowers faults that appear in the seismic profiles. Trends in

bioaccumulations large foraminifera, including the Eocene and richness of carbonate productivity are indicatives of dominance of an environment beaten by the currents, well ventilated and oxygenated with absence of turbidity and away from detrital input. This type of environment supports Nummulites accumulations installed on the platform depth sloping shaped carbonate ramp built during the lower Eocene, then later repeated with the same intensity of productivity carbonates and explosion biological diversity in marine shallow during the Oligocene-Miocene.

Successive sedimentation periods, was also conditioned by two factors: tectonics and eustasy. The tectonic factor contributes to the fragmentation of the blocks, their tilt; and in the distal area, subsidence basin with a marked change in the sedimentation represented by the micrite and pelagic deposits nature. Thus, by collapse of blocks of El Garia Formation is relayed by the facies of the Boudabbous Formation, and Formation Ketatna by pelagic deposits Salammbô Formation. Similarly, the above figures show that it is practically the same rooted accidents that have structured the Eocene sedimentary floor and controlled spatial and temporal distribution of deposits, by replaying the Oligocene- lower Miocene to impose similar palaeogeographical limits and almost at the same place of transition between Fm Ketatna and Salammbô Formation.

Tracking facies described using cuttings and cores from boreholes clarifies the facies distribution and to recognize the characteristics of three distinct environments facies usually described for carbonate platforms ramp shaped [22-24]: internal ramp facies (inner ramp), the middle ramp facies low bathymetry (mid-ramp) and outer ramp facies (outer-ramp) depth seaward up the talus [18,23,25-27].

Finally, eustatisme also involved in instauration of retrograde transgressive deposits like those of Reinèche, Ain Ghrab and Melqart marking a remarkable extension of carbonate platforms in response to accelerated in the average level of sea rising.

In the major parts of the basin of GGB faulting and subsidence controls on sedimentation. We found the deep effects of tectonics in the heightening blocks, deformation and sealing unconformable. The most common events were those Maastrichtian-Paleocene transition with the creation of bald areas in the NW part of the field of study and particularly in the Sahel of Sfax [16]. Dynamic events largely affected the series were also identified through the well data to higher-Priabonian Eocene to Langhian-Serravallian, then the passage of the Group Oum Douil Fm Soma preceding the transgression of the limestone Fm Melqart and continentalization corresponding to laguno-lacustrine deposits Fm Oued Belkhédim.

Carbonated systems associated with the development of a carbonate sedimentation on rhombic blocks which can be controlled by the eustatisme; but such carbonate sedimentation with an environmental dimming internal platform type to

external platform environments. The deposits are thick and have lateral facies transitions with equivalent formations formed in the pelagic environment in abyssal conditions.

We also noted the repetition over time of this type of sedimentation especially the Ypresian time (Fms El Garia/Boudabbous) and later during the Oligocene-Burdigalian (Fms-Ketatna Salammbô). When comparing the zonal distribution of one and the other of these formations, and taking into consideration the well data and literature information, we realize in the study area, it is the same tectonic lineaments that have worked at successive periods to score quite deeply lithology series along paléogéographique transition lines passing between paleogeographic areas kind of training and different environment.

The results of the seismic analysis enhanced by well logging allowed to recognize the architecture of the sedimentary cover at different times and to establish the relationship between litho stratigraphic formations (lateral facies passages), but also amongst tectonics and sedimentation.

The major tectonic style is the continuity amongst a deep tectonic affecting the basement, which witnesses have been described by the authors in Medenine and Jeffara area [28,29]. We demonstrate that old tectonic dating to the Paleozoic and early Mesozoic is transmitted into the sediment cover. These manifestations are ramified to flowers faults that reactivated at different epoch. The major trending faults NW-SE to NS most often play slide ably with escarpments often looks NE, dislocated and raised of blocks and basins in grabens and half-grabens, very similar of what is commonly described by the authors on the continent in Central of Tunisia and in the chain of Chotts.

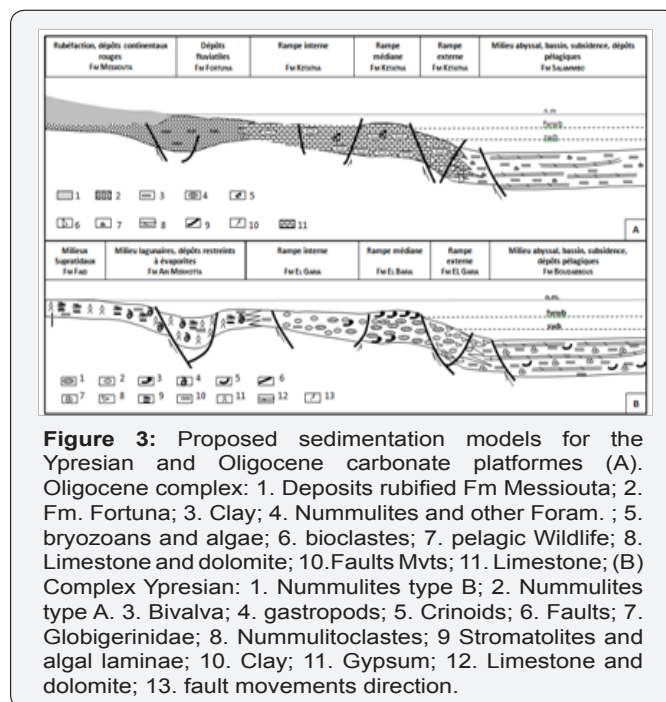
The research of the discontinuities amongst sequences linked to the main geodynamic events that have controlled the basin sedimentation helps to clarify the geometry and the Seismic-sequences cutting series. Thus, it is possible to correlate the seismic super sequences to what is known in regions in central Tunisia as sedimentary megacycles identified by the authors regionally.

In previous work [30,31], we found a great similarity in the distribution of deposits platforms and those pelagic equivalent, but at different ages as the Ypresian and Oligocene-Miocene epoch. We also showed the precise controls of eustatisme, reactivation of tectonic deep accidents, and morphology of the basins (platform, abyssal areas, shoals, emerged edges of blocks) in the differentiation of carbonate sedimentary environments [32-35].

Thus, it clearly shows by geophysical profiles in Asstart province, on the vast field of the Pelagian block, the range of platforms (internal, intermediate and external shelf) and transitions to pelagic abyssal domains (basins) at the Ypresian (Formations Jebbs, Metlaoui, El Garia, Boudabbous) and Miocene-Oligocene (Formations Messiouta/Fortuna, Ketatna Salammbô)

are controlled by the same tectonic lineaments reactivated by ramified faults (flower structure) and sliding at different epochs [36-38].

Cutting blocks, the heightening local, also the subsidence allows the installation of carbonates platforms ramps environments in which carbonates productivity is provided by large foraminifera as Nummulites the Operculines the Discocyclines for Ypresian strata but also by Nummulites, the Amphistégines lepidocyclines and in the case of deposits of Oligocene-Miocene. These carbonate platforms ramps often isolated because of dislocated tectonic blocks. These ramps are distally deepened (distally steepened) and rarely bordered (rimmed shelves) (Figure 3) [39-41].



**Figure 3:** Proposed sedimentation models for the Ypresian and Oligocene carbonate platforms (A). Oligocene complex: 1. Deposits rubified Fm Messiouta; 2. Fm. Fortuna; 3. Clay; 4. Nummulites and other Foram. ; 5. bryozoans and algae; 6. bioclastes; 7. pelagic Wildlife; 8. Limestone and dolomite; 10. Faults Mvts; 11. Limestone; (B) Complex Ypresian: 1. Nummulites type B; 2. Nummulites type A. 3. Bivalva; 4. gastropods; 5. Crinoids; 6. Faults; 7. Globigerinidae; 8. Nummulitoclastes; 9. Stromatolites and algal laminae; 10. Clay; 11. Gypsum; 12. Limestone and dolomite; 13. fault movements direction.

### Conclusion

As we mentioned in the case of the Permian, this architecture division of the Southeast margin of Tunisia during the Permian, Triassic, Jurassic, Cretaceous and as demonstrated in this work for the Cenozoic, is controlled by ancient tectonic directions affecting the basement [29], has always supported the development of carbonate platforms and bio constructions. It is therefore the same environmental control factors and sedimentation at different periods, produce the same effects. However, more NE and north, block subsidence allows the establishment of a frank pelagic sedimentation, where the lateral transitions in bathymetry conditions contrast between El Garia Fms/Boudabbous and Ketatna/ Salammbô. The interest and petroleum implications of these formations is the tectonic dynamic controlled the genesis of carbonate facies platforms ramp, but also their subsequent deformation: the El Garia Fm was distorted by tectoniques Pyrenean deep reactivated movements during the Lutétien -to Priabonian, and Fm Kétatna

by Alpine movements dating from Langhian-Serravallian. The deformation of the blocks and their emersion promotes the effects of the diagenesis dolomitizante enhances the porosity and permeability of such reservoirs; while the tectonic enhances fracture porosity and permeability. Moreover, reservoirs in contact with older source rocks (Bahloul, Fahdène, Aleg, El Haria, Tselja, Chouabine), but also with contemporary source rocks (Fms Boudabbous/El Garia and Salamambo/Ketatna) and the existence of thick clay layers forming impermeable seal against of oils migration (Fms Souar, Fm higher Salamambo; Oum DOUIL Group), offer a real opportunity for improving national reserves on hydrocarbons.

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