https://jssr.ui.ac.ir/?lang=en
Journal of Stratigraphy and Sedimentology Researches
E-ISSN: 2423-8007
Vol. 40, Issue 4, No. 97, Winter 2024, pp 1-22
Received: 06.05.2024 Accepted: 03.07.2024

Research Paper

The development of mixed sequences in a marginal setting: example of the Late Albian–Cenomanian in Central Tunisia

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Abstract
The sequence stratigraphy of mixed succession with evaporitic intercalations has already reported in several works around the world. The present work aims to study the sequence stratigraphy of the mixed succession of the Zebbag Formation (Albian–Cenomanian) in Central Tunisia. This study is based on the measuring of a 140 m-thick section of the Zebbag Formation with a tight sampling of the carbonate rocks, completed by the microscopic observation of thin sections and the analysis of the chemical composition of the carbonate rocks. According to the vertical changes of the depositional facies notably the carbonate facies on one hand, and the vertical variation of the chemical composition of the carbonate levels on another hand, the Zebbag Formation can be subdivided into 22 mixed depositional sequences that developed in a marginal setting at the southern Tethyan border. The depositional sequences were controlled by the fluctuation of sea level and recorded the alternating marine regression and transgression and the resulting continental and marine influences, respectively. All the depositional sequences show at the base an evaporite succession representing the lowstand system tract, whereas the transgressive and the highstand system tracts are occurred by different deposits according to the depositional environment. Indeed, in the inner part of the platform these system tracts are represented by bedded limestones, whereas in the outer parts are indicated by marls. In the middle part of the platform, the transgressive and highstand system tract are recorded by interbedded marls and limestones.
Keywords: Depositional facies, Mixed sequences, Late Albian–Cenomanian, Zebbag Formation, Khanguet Zebbag, Central Tunisia

Introduction

The Zebbag Formation is a Late Albian–Cenomanian sedimentary series (Burollet 1956; Gargouri-Razgallah 1983; Fournie 1978; Abdallah 1987; Ben Ferjani et al. 1990; Touir et al. 2017) that developed in the most of central and southern Tunisia and overlying the Aptian carbonate platform that emerged during the Late Aptian–early Albian interval. (Chihaoui et al. 2010; Masse 1984; M'rabet 1987; Khessibi 1978; Memmi 1999; Bismuth et al. 1982; M´Rabet 1987; Touir et al. 2015 ; Trabelsi et al. 2010; Latil 2021). The Zebbag Formation generally consists of interbedding limestones, marls and evaporites. It developed in a restricted marginal-littoral evaporitic environment under fairly arid conditions (Burollet 1956; Marie et al. 1984; Gargouri-Razgallah 1983; Abdallah 1987; Ben Ferjani et al. 1990).

Towards north Tunisia, this marginal environment passes gradually into an open marine outer ramp where a predominantly marly interval with limestone intercalations called the Fahdene Formation occurred (Bismuth 1973; Dali-Ressot 1987; Ben Ferjani et al. 1990; Marie et al. 1984; Bismuth et al. 1973; Ben Ferjani et al. 1990; Chihaoui et al. 2010). In the middle of this ramp a rudist-bearing reef complex occurred, it corresponds to the called Isis Formation (Gargouri-Razgallah 1983; Marie et al. 1984). Towards South Tunisia, the marginal evaporitic environment extended while being more restricted and evaporitic and passes gradually into the continental environment called the Saharan Platform (Bodin et al. 2010).
In the study area (Khanguet Zebbag), the Zebbag Formation includes three distinct lithostratigraphic units: a lower unit dominated by limestones, a middle unit represented by

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Haj Ali H. Bouaziz S. and Touir J. (2024). (2024). The development of mixed sequences in a marginal setting: example of the Late Albian–Cenomanian in Central Tunisia. Journal of Stratigraphy and Sedimentology Researches, 40(4):1-22. https://doi.org/10.22108/jssr.2024.141331.1285

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https://doi.org/10.22108/jssr.2024.141331.1285

limestones, marls as well as interbedded evaporites, and an upper unit dominated by marls.

In terms of sequence stratigraphy, the mixed carbonate-evaporite sedimentary successions with intercalations of evaporites have already reported by several workers (Beigi et al. 2017; Husinec et Harvey 2021; Xiao et al. 2021; Sarg 2001; Tucker 1991). According to these studies such mixed successions are regarded as constituting depositional sequences called carbonate-evaporite mixed sequences linked to 3rd-order sea-level fluctuation. These researchers consider the evaporitic intercalations due to the lowstand system tracts, while the carbonate levels represent the transgressive and the highstand system tracts. The same workers assert that evaporites can also be developed at the top of the highstand system tracts (late highstand system tracts) in an inner part of the platform.

As for the Zebbag Formation, the evaporitic intercalations are alternating not only with carbonate levels, as in the examples reported by Sarg (2001) and Tucker (1991) in particular, but also with marls layers. These marls are considered by earlier studies as marine lagoonal deposits (Burollet 1956; Gargouri-Razgallah 1983; Abdallah 1987; Newport et al. 2017).

The present work aims for the first time to conduct a thorough study of depositional facies of this mixed carbonate-evaporite succession, particularly the carbonate microfacies, and reconstruct the depositional environments of the Zebbag Formation in its type section (Khanguet Zebbag).

This work aims in addition for the first time establish the sequence stratigraphy of this mixed carbonate-evaporite succession. Furthermore, the presence of marls intercalations in the studied sequences compared with the depositional sequences already reported in particular by Tucker (1991) and Sarg (2001) will be as well discussed.

Geological background

The study area corresponds to the Khanguet Zebbag, a pass crossing Jebel Meloussi from north to south (Fig. 1). This area is located in the low steppes region (Sidi Bouzid, Central Tunisia) between longitudes 34°45'39" and 34°46'32" and latitudes 9°27' 27" and 9°27' 00". The Jebel Meloussi located approximately 30 km south of Sidi Bouzid city corresponds to a NE-SW oriented anticline with a core formed by the Berriasian successions and covered with the Aptian successions; in addition, the Turonian series occur on the NW flank.

The Zebbag Formation is well exposed on the NW flank of the Jebel Meloussi (Fig. 2). The Zebbag Formation is unconformably underlain by the Serdj Formation (Aptian) at the base and passes gradually to the Gattar Formation (Uppermost Cenomanian–Lowermost Turonian) at the top (Fig. 3) (Touir et al. 2017). The Zebbag Formation is attributed to the Late Albian–Cenomanian interval (Fournié 1978; Gargouri-Razgallah 1983; Abdallah 1987; Ben Ferjani et al. 1990).

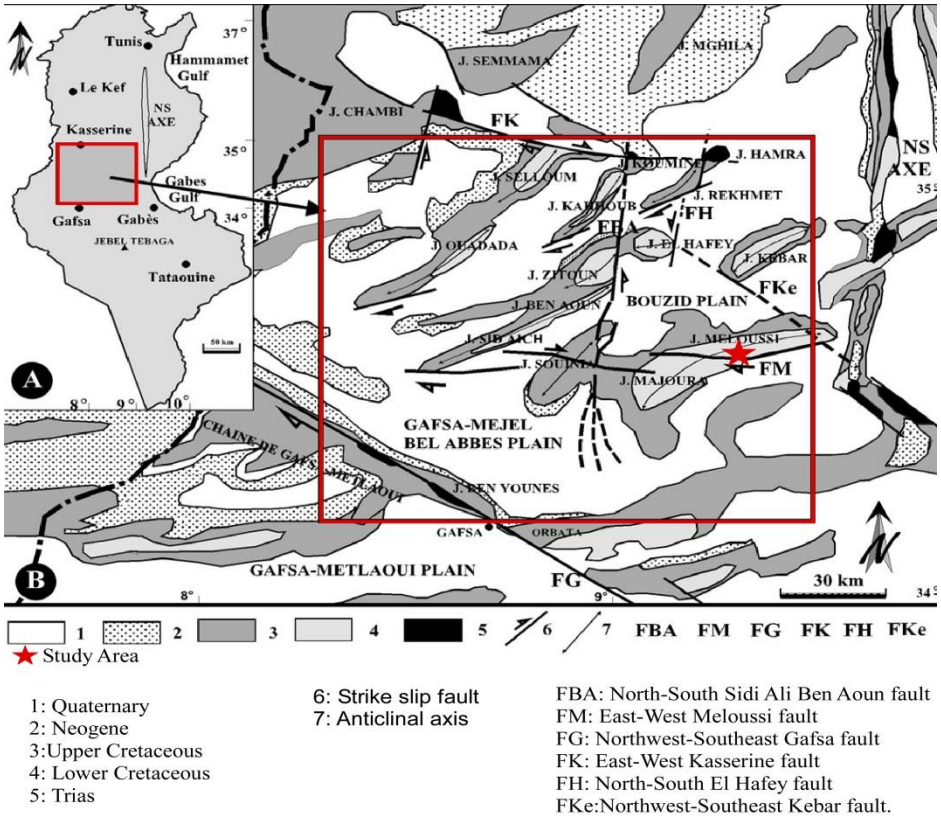

Fig 1- Location map of the study area (modified from Bouaziz et al. 2002).

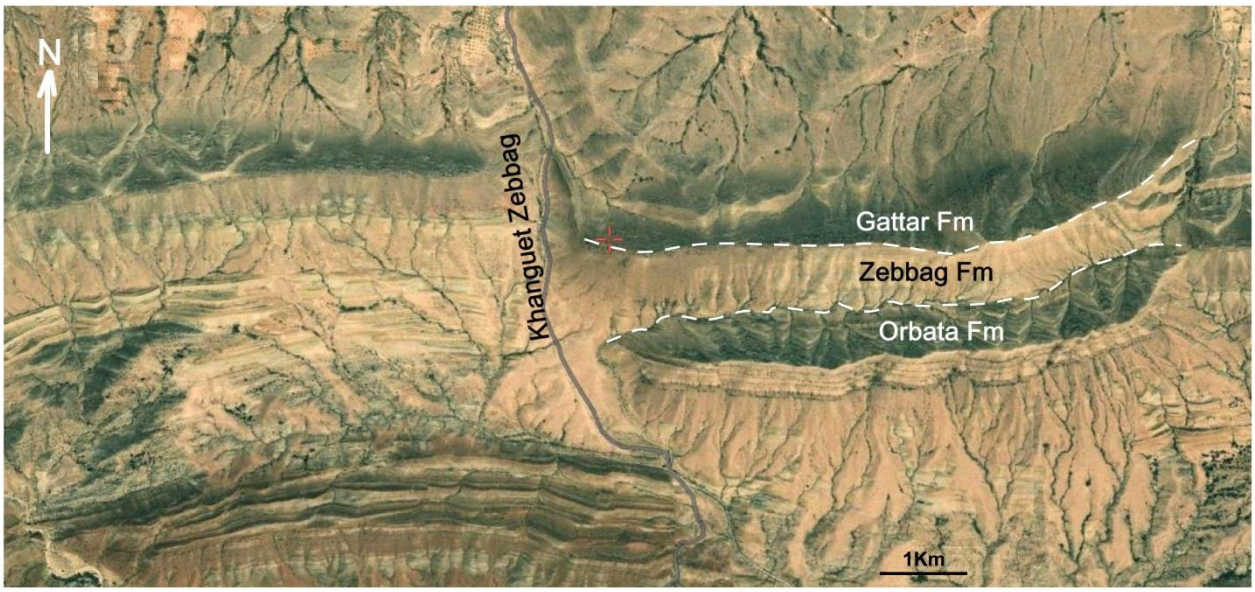

Fig 2 - Satellite image of the Jebel Meloussi showing the Khanguet Zebbag and the stratigraphy of Zebbag Formation between the Orbata Formation (Aptian) and the Gattar Formation (Early Turonian).

Fig 3 - Field view of the Khanguet Zebbag section showing the Zebbag Formation

Methods

The study of the mixed carbonate-evaporite-marls succession of the Zebbag Formation is based on the field examination of the outcropping succession at the Khanguet Zebbag, complemented by the survey of a geological section 144 m thick with a tight sampling of all the carbonate intercalations. In this study, a total of 49 samples were collected every 20 cm through the carbonate beds. The thicknesses of the intercalations are measured, and the vertical lithofacies change, the surfaces of unconformities and the sedimentary structures are recorded. The carbonate samples were the subject of thin sections microscopic of observation with the aim of the identification of the carbonate microfacies, while considering Dunham´s classification (1962) as well as the works of Purser (1973) and Flügel (2010). The depositional environments were reconstructed taking into account the

classification of Wilson (1975, 2012) and the works of Flügel (2010) and Milliman et al. (2012). Nineteen carbonate samples representing the different carbonate microfacies were selected for a chemical analysis on rock powder by X-ray fluorescence spectrometry using the "Thermo Scientific Niton FXL FM-XRF Analyzer" model in the Laboratory of Mineralogy at the Faculty of Sciences of the Sfax University. Such analysis allowed us to determine the concentrations of some chemical elements (Ca Mg, Si, Al, Fe, K, S, Ti, Mn).

The results of observation and analyses are used first to interpret the depositional environments and reconstruct their change over time, then to establish their sequence stratigraphy framework based on the principles of Vail et al (1977, 1991), while taking into account the model of the sequence stratigraphy of mixed successions as already established in particular by Tucker (1991) on the Upper Permian NE of England in the North Sea. The work of Sarg (2001) on mixed carbonate-evaporite deposits was also considered with the aim of interpreting the mixed sequences of the Zebbag Formation according to the 3rd-order sea-level fluctuation. On another hand, the analysis of the vertical variation of the depositional facies and environments considers Walther's law (1894).

Results

Depositional facies and environments

The study of the outcrop section of the Zebbag Formation (144m) (Fig.4a, 4b et 4c) measured at the Khanguet Zebbag locality made it possible to subdivide this formation into three distinct lithostratigraphic units: interbedding limestone dominated and accessory evaporites (lower unit) (Fig.5), interbedding marls, limestones and evaporites (middle unit) (Fig.6) and interbedding marls and limestone (upper unit) (Fig.7). The Zebbag Formation is thus characterized by three interbedding types of lithofacies: carbonates, marls and evaporites.

Carbonate lithofacies

These lithofacies are represented by centimetric to metric intercalations of limestone beds. Based on the field examination and the microscopic observation of thin sections, while considering the classifications of Dunham (1962) and Flügel (2010), six distinct carbonate microfacies (F1 to F6) have been identified. According to the sedimentological analysis taking into account the works of Wilson (1975, 2012) and Flügel (2010), these carbonate microfacies indicate different depositional environments.

Microfacies F1: bioclastic mudstone-wackestone with debris of various benthic fossils (lamellibranchs, foraminifera, ostracods) (Fig. 8a-b). This facies corresponds to a shallow marine subtidal environment with medium to low hydrodynamic energy. It is a fairly open marine environment as evidenced by the presence of various benthic microfossils and bioclasts.

Microfacies F2: mudstone–wackestone rich in pellets associated with rare debris of echinoderms and phantoms of dissolved ostracods and fine detrital quartz grains (Fig. 8c). The limestone beds generally show at the surface desiccation cracks (mud-cracks and sheet-cracks) which are sealed by silica cement. These cracks are observed both in the field (Fig. 7b) and in the thin sections (Fig. 8d). The surfaces show local desiccation breccias (Fig. 7b). Such a microfacies rich in pellets and poor in microfossils and bioclasts against the presence of desiccation cracks and breccias suggests to a lagoonal environment exposed to tidal currents, with alternating episodes of low hydrodynamic energy giving rise to pellet-rich limestone and episodes of relatively high hydrodynamic energy reworking this material into desiccation breccias (Bathurst 1973; Flügel 2004). The brecciation of the limestone was necessarily preceded by episodes of temporary emersion of the sedimentary environment followed by transgressive episodes. On another hand, this depositional environment should have been exposed to continental influences as evidenced by the presence of terrigenous detrital quartz in this limestone (Razgallah et al. 1994).

Microfacies F3: wackestone rich in coarse debris of oysters with subordinate debris of lamellibranchs and ostracods and scarce phosphatic pellets (Fig. 8e-f). The dominance of oyster debris in this limestone associated with phosphatic grains generally characterizes more or less restricted subtidal marine environments, likely a lagoon (Beji-Sassi 1984; Jarvis et al. 1994).

Microfacies F4: oolithic grainstone, the ooids in this microfacies are small and well sorted (Fig. 9a-b) with a diameter of 100 to 150 µm. The ooids are dominated by the type β of Bathurst (1973). The core of the ooids often consists of a bioclast, particularly foraminifera. The oolithic limestones generally characterize warm and shallow coastal waters for example in the Bahamas or in the Persian Gulf (Purser 1973; Sipos et al. 2018). Furthermore, the grainstone texture and the good sorting of the ooids indicate a sedimentary environment located above the lower limit of wave action, with fairly high hydrodynamic energy linked to waves and tidal currents.

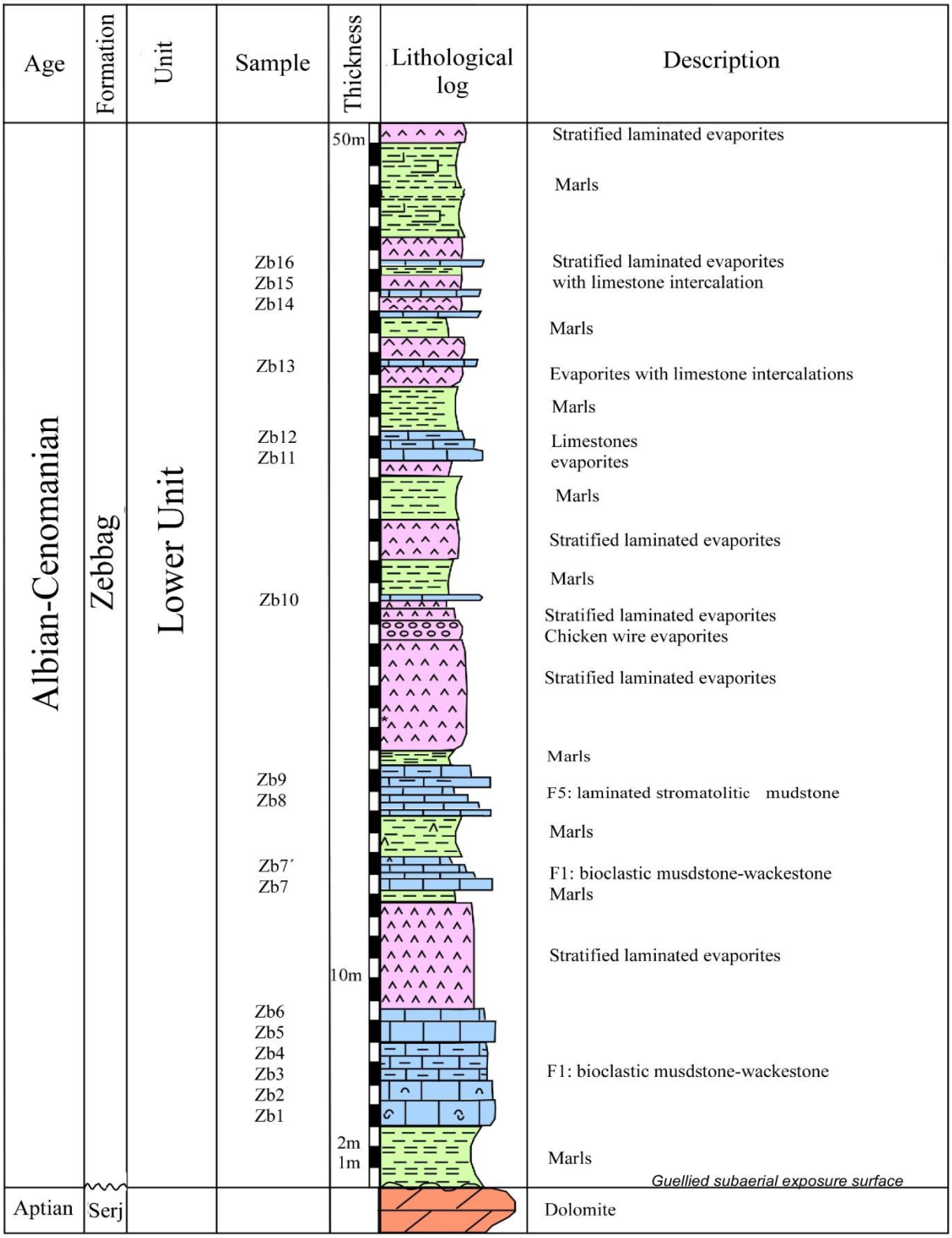

Fig 4a - Lithostratigraphy and depositional facies of the Lower Unit of the Zebbag Formation (Khanguet Zebbag).

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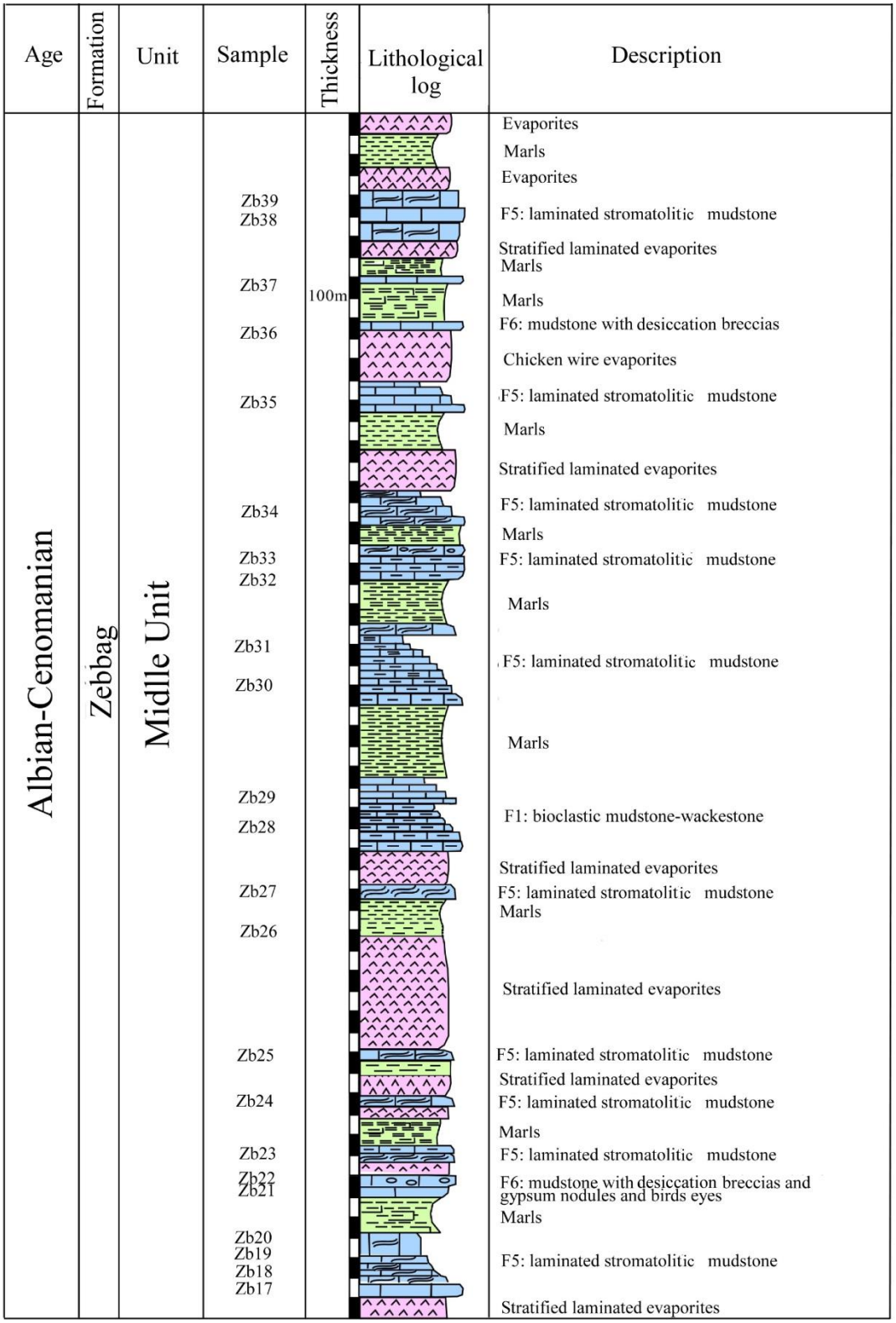

Fig 4b- Lithostratigraphy and depositional facies of the Middle Unit of the Zebbag Formation (Khanguet Zebbag).

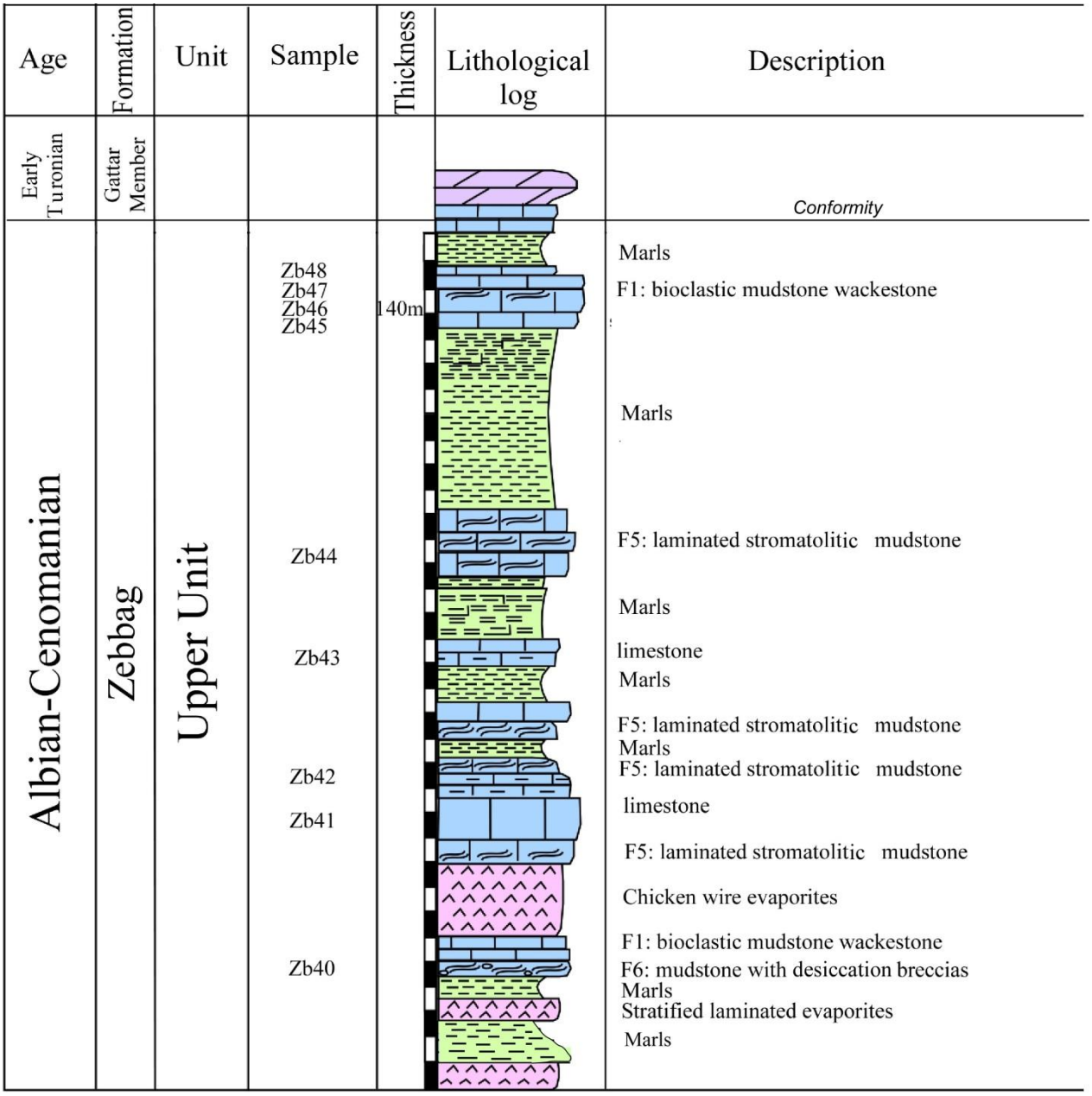

Fig 4c- Lithostratigraphy and depositional facies of the Upper Unit of the Zebbag Formation (Khanguet Zebbag).

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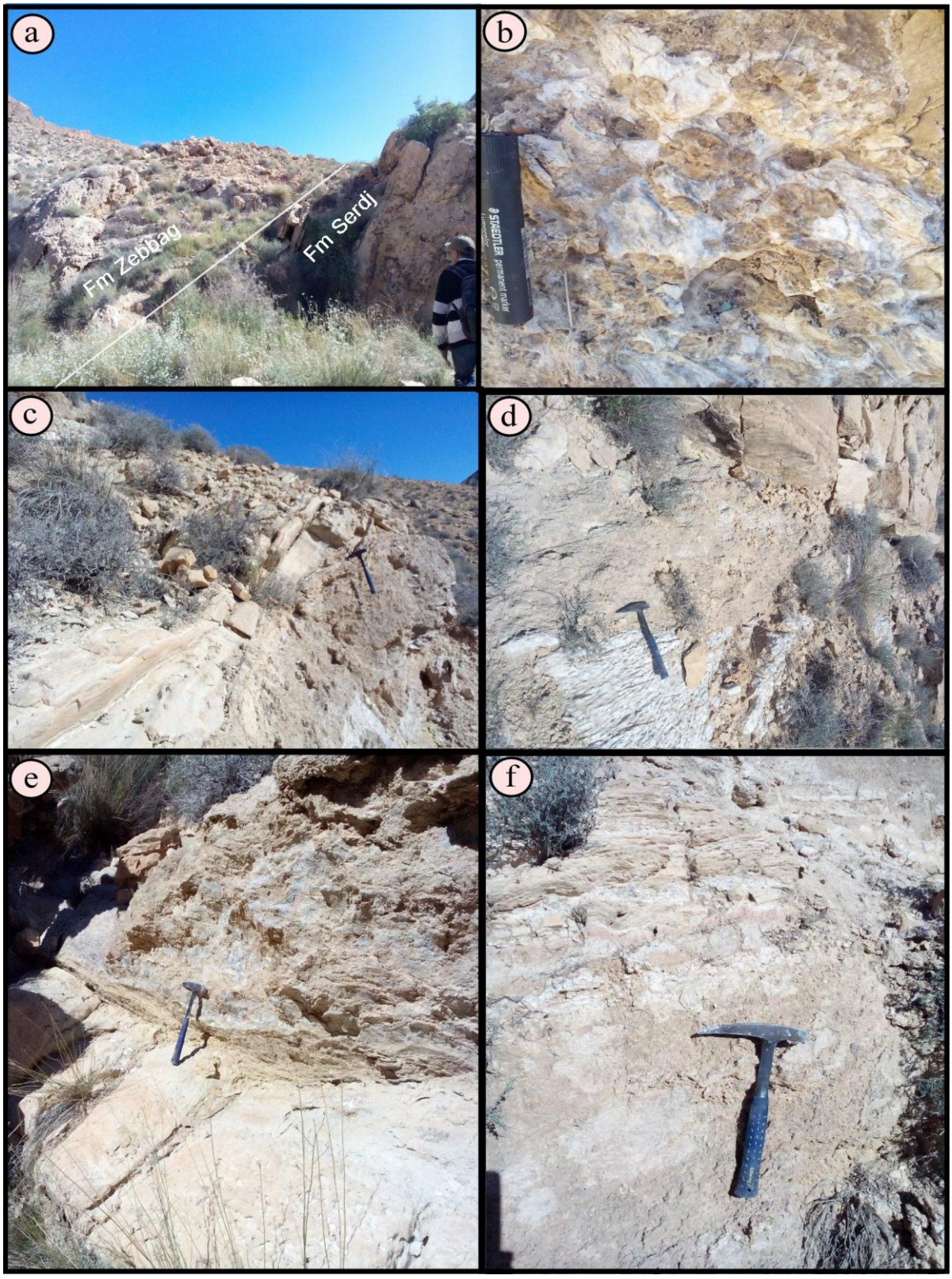

Fig 5- Field view of the Lower Unit of Zebbag Formation: a: Serdj-Zebbag boundary formations, b: chicken wire evaporites structure, c: limestone-evaporites alternation, d: stromatolitic limestone, e: stromatolitic limestone-evaporites alternations, f: stromatolitic limestone with desiccation cracks.

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Fig 6- Field photograph of the Middle Unit of Zebbag Formation: a :clayey limestone with oblique stromatolites, b: massive and bioturbated limestone.

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Fig 7 - Field photograph of the Upper Unit of Zebbag Formation: a :evaporites at the bottom of the photo and stromatolite at the top, b : laminated limestone with desiccation breccias.

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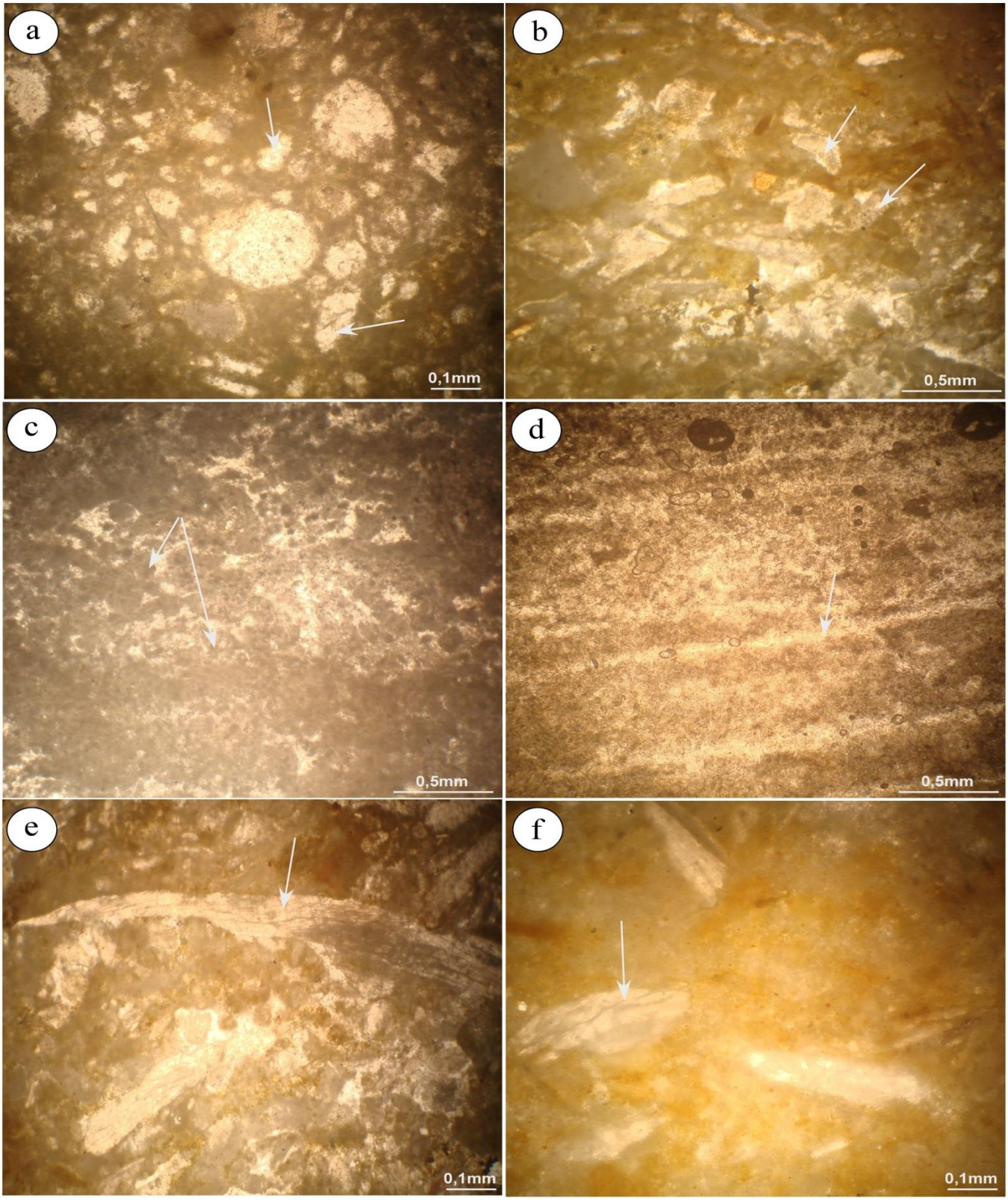

Fig 8- Microphotographs of the carbonates microfacies (F1–3): a and b: bioclastic mudstone-wackestone with debris of benthic fossils (F1), c: pellets-rich mudstone-wackestone (F2), d: desiccation cracks (F2), e and f: oysters debris-rich wackestone (F3).

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Microfacies F5: stromatolitic mudstone, showing laminated structure with undulating thick clear sedimentary laminations alternating with thin dark organic laminations (Fig. 9c). In addition, this microfacies shows numerous birdseye currently enlarged by later meteoric dissolution (Fig. 9d). This limestone is visibly poor in bioclasts and microfossils. The depositional environment relating to this microfacies is the shallow-water intertidal environment that was intermittently exposed to aerial conditions (Perkins 1963; Laporte 1967). Birdseyes and laminated stromatolitestructures are largely described in recent dolomitic sedimentation (Shinn et al. 1965) and are considered to indicate supratidal to intertidal zones that experience arid conditions (Shinn 1969, Reineck et al. 1990).

Microfacies F6: mudstone with birdseye, desiccation breccias and dissolved gypsum nodules. This microfacies is almost devoid of bioclasts and microfossils (Fig. 9f). At the top limestone beds show laminated levels crossed by desiccation cracks which are frequently sealed by iron oxides and hydroxide residues. The limestone levels crossed by desiccation cracks are locally transformed into desiccation breccias (Fig. 9e). This birds-eyes-rich mudstone with desiccation cracks and breccias and abundant dissolved gypsum modules indicates a supratidal to upper intertidal zone (Purser 1980; Flügel 2004, Wilson 2012).

Evaporitic lithofacies

The evaporite intercalations in the Zebbag Formation consist of centimetric to metric thick layers of anhydrite currently transformed into stratified laminated gypsum. These evaporite layers are interbedded with marl and limestone beds. In some layers, the gypsum is organized into chicken-wire disseminated within carbonate beds. The relatively thickbedded and laminated evaporite layers are indicative of evaporitic sedimentary environments that developed under arid to semi-arid conditions (Purser 1975; Wilson 1967; Flügel 2004). Such an assumption is consistent with Hallam's (1985) climate chart according to which the Cenomanian interval was marked by an arid climate. The fairly significant thickness of the evaporitic intercalations suggests on another hand a relatively subsiding marginal environment which could have been a semi-closed evaporitic basin. Furthermore, the possibility of arid conditions is compatible with the paleogeography of Tunisia during the Cenomanian according to which the study area corresponds during the Cenomanian to a restricted evaporitic margin (Burollet 1956; Marie et al. 1984; Gargouri-Razgallah 1983; Abdallah 1987; Ben Ferjani et al. 1990).

Marls lithofacies

In the Zebbag Formation, the marls are arranged into centimetric to metric intercalations formed with dark greyish detrital clays generally poor in fossils, and contain some fossil organic matter. Given the marginal-littoral palaeogeographical setting of the study area during the Cenomanian, and according to the analysis of the associated carbonate microfacies, such clays would have been transported from the continent before being deposited in a fairly restricted lagoonal environment during regressive episodes. In addition, the presence of fossil organic matter in these marls confirms the assessment of restricted conditions and refers to suboxic marine waters (Noffke et al. 2001; Zink et al. 2004; Lakhdar et al. 2006).

Geochemistry

The results of the chemical analysis of the carbonate intercalations of the Zebbag Formation are presented in Table 1. According to this table, the concentrations of the analyzed chemical elements vary vertically from bottom to top of the Zebbag Formation depending on the depositional facies (Fig. 10).

According to several works (Pearce and Jarvis 1992; Banner 1995; Sageman and Lyons 2003; Algeo and Maynard 2004; Harris et al. 2013; Turner et al. 2015) the chemical composition of the sedimentary rocks can be used to interpret the sedimentary environments; such as in the marginal settings in particular some chemical elements are considered as indicating dominant marine influences (Mg, Ca) against others that are rather indicating dominant continental influences (Si, Al, Fe, Ti). It is worth noting that in the present study, the chemical composition of the analyzed carbonates varies with the depositional microfacies which confirms and enhances the interpretation of the sedimentary environments.

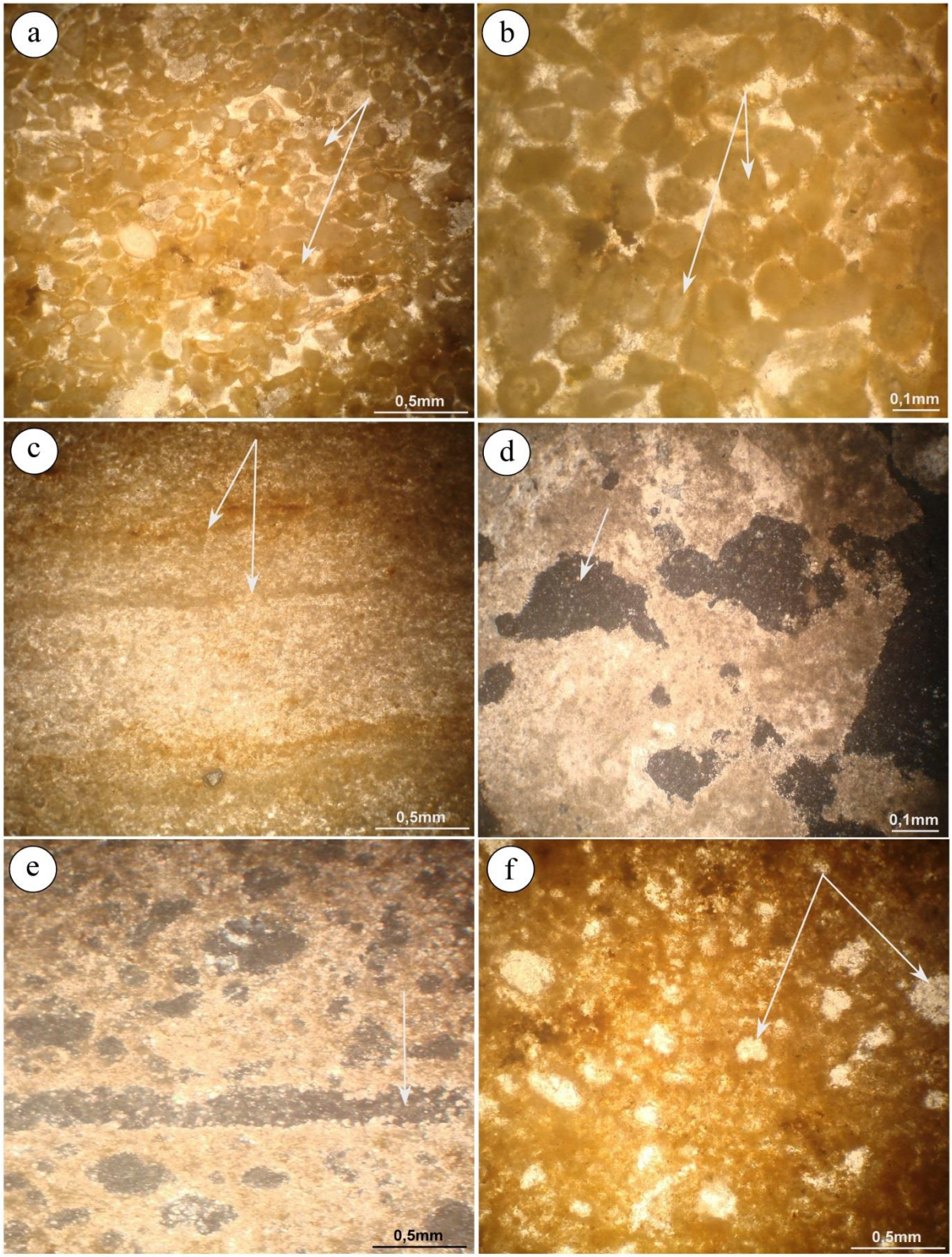

Fig 9- Microphotographs of the carbonates microfacies (F4-6): a and b: oolithic grainstone in that the ooids are affected by micritization (F4), c: laminated stromatolitic mudstone (F5), d: birds eyes enlarged by dissolution (F5), e: mudstone with desiccation breccias (F6), f: birds eyes associated with gypsum nodules.

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Table 1- Major and minor oxides (in wt%) compositions of the carbonates of the Zebbag Formation, Tunisia.

Deposit facies	Samples	Chemical elements								
		%SiO2	%Al2O3	%Fe2O3	%TiO2	%MnO	%MgO	%CaO	%K2O	%SO3
Bioclastic mudstone-wackestone (F1)	**Zb1**	1.71	0.53	0.88	0.02	0.03	11.47	39.9	0.19	1.32
	Zb14	0.72	0.2	0.42	0.01	0.03	13.6	33.89	0.1	9.29
	Zb48	1.21	0.28	0.11	0.01	0.02	0.41	60.47	0.2	0.34
Pellets-rich mudstone-wackestone with desiccation cracks (F2)	**Zb7**	3.15	0.87	0.9	0.04	0.06	4.48	32.86	0,49	32,14
	Zb8	4.14	1.54	0.95	0.05	0.06	9.28	32.51	0.48	14.28
	Zb11	3.6	0.82	0.57	0.05	0.06	0.9	58.37	0.6	0.4
	Zb25	0.92	0.4	0.54	0.01	0.02	6.23	31.2	0.1	37.15
	Zb31	4.4	1.63	1.11	0.06	0.03	12.9	36.14	0.51	0.23
	Zb35	1.33	0.43	1.73	0,01	0.03	13.57	37.85	0.17	0.34
	Zb39	1.94	0.53	0.54	0.02	0.02	9.2	34.54	0.29	13.38
	Zb44	1.73	0.41	0.75	0.01	0.03	0.6	37.78	0.22	0.39
	Zb45	1.75	0.57	2.76	0.02	0.05	0.6	34.43	0.15	0.13
Oysters debris-rich Wackestone (F3)	**Zb6**	1.9	0.52	0.55	0,02	0.04	15.54	35.9	0.27	0.13
Oolithic grainstone (F4)	**Zb29**	4.8	0.74	1.22	0.06	0.15	1.8	28.52	0.54	0.23
Laminated stromatolitic mudstone with birds eyes (F5)	**Zb19**	0.83	0.3	0.3	0.01	0.03	7.6	34.83	0.05	20.56
	Zb40	1.7	0.43	1.64	0.02	0.07	6.98	44.1	0.22	2.83
	Zb41	7.48	2.43	0.66	0.1	0.01	14.43	32.66	1.07	0.7
	Zb43	1.71	0.48	1.22	0.02	0.05	0.63	34.25	0.21	0.29
Musdstone with desiccation breccias and gypsum nodules (F6)	**Zb10**	3.62	1.06	0.95	0.03	0.04	7.29	33.24	0.41	14.28

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Depositional microfacies with dominant Mg, K and Ca

They include the microfacies F1 (bioclastic limestone) and F3 (limestone with oyster debris) where the concentrations of Mg, K and Ca are fairly higher compared with the other microfacies (Fig. 10).

In the F1 microfacies, the Mg values vary from 0.41% to 13.6% and Ca values from 34% to 60.5%. It is the same for microfacies F3 with Mg 15.54% and Ca approximately 86%. On the contrary, the group of chemical elements (Si, Al, Fe, Ti) is characterized by relatively low values. Indeed, the microfacies F1 shows averages of 1.2% for Si, 0.33% for Al, 0.45% for Fe and 0.013% for Ti. It is the same for the microfacies F3 with 1.9% for Si, 0.52% for Al, 0.55% for Fe and 0.02% for Ti.

Such a chemical composition dominated by Mg, Ca and K characterizing the depositional microfacies F1 and F3 are considered as rather indicate the dominance of marine influences in the depositional environment (Pearce and Jarvis 1992; Banner 1995; Sageman and Lyons 2003; Algeo and Maynard 2004; Harris et al. 2013; Turner et al. 2015), and confirms therefore the marine subtidal conditions already indicated by the limestones with various marine microfossils and bioclasts.

Depositional microfacies with dominant Si, Al, Fe and Ti

This association of chemical elements is considered to indicate rather the dominance of continental influences in the depositional environment (Pearce and Jarvis 1992; Banner 1995; Sageman and Lyons 2003; Algeo and Maynard 2004; Harris et al. 2013; Turner et al. 2015) characterizes the microfacies F2 (limestone with pellets and desiccation breccias), F4 (oolithic limestones), F5 (Stromatoliticlimestones with birds eyes) and F6 (limestones with desiccation breccias and gypsum nodules) (Fig. 10).

Compared with the previous microfacies F1 and F3, the carbonates of microfacies F2, F4-6 are relatively richer in Si, Al, Fe and Ti and poorer in Ca and Mg. Indeed, in these limestones the Si varies from 0.83% to 7.48%, the Al between 0.3% and 2.43%, the Fe between 0.3% and 2.76 %, and Ti vary from 0.03% to 0.1%. On the contrary, the concentrations of Mg and Ca in these carbonates are relatively low and vary between 0.6% and 14.4% for Mg and between 31.2% and 58.37% for Ca.

Such chemical compositions of limestones dominated by Si, Al, Fe and Ti characterizing the depositional microfacies F1 and F4–6 are compatible with and support the sedimentological interpretation according to which the depositional environment relative to these microfacies corresponds to a marginal peritidal lagoonal environment which was episodically subject to continental detrital inputs. Indeed, the presence of detrital quartz particles, added to the presence of stromatolites, desiccation breccias, birds eyes and gypsum nodules support the assumption of a marginal sedimentary environment exposed to continental influences.

Sequence stratigraphy

Based on the vertical variation of the depositional facies from bottom to the top of the Zebbag Formation and their corresponding depositional environments on one hand, while taking into account the principles of the sequence stratigraphy of mixed "carbonate-evaporitic" deposits according to Tucker et al. (1991) and Sarg (2001) on the other hand, it was possible to distinguish 22 mixed depositional sequences in this formation which can be regrouped into three distinct types (i) "evaporites-carbonate sequences", (ii) "evaporites-carbonate-marls sequences" and (iii) "evaporites-marls sequences".

Evaporites-carbonate sequences

This type is represented by the sequences S5, S7, S12 and S18 (Fig.11). A sequence occurred above an unconformity generally characterized by a subaerial exposure surface. This surface is overlain by a stratified laminated gypsum layer which developed in a marginal restricted evaporitic environment; it represents the lowstand system tract. The sequence continues with a bedded limestone succession characterized by different carbonate microfacies; this limestone which is directly overlained by the evaporites of the overlying depositional sequence should correspond to the transgressive and the highstand system tracts. The vertical change of the carbonate microfacies allows sometimes identifying the boundary between these two system tracts. Indeed, in the sequences S5 and S7, the transgressive interval consists of bioclastic and oo-bioclastic packstone, indicating a subtidal to intertidal environment with medium to high hydrodynamic energy, whereas in the sequences S12 and S18 the transgressive system tracts are characterized by oolithic packstone indicating an intertidal environment with warm and shallow coastal waters. The highstand system tracts are generally marked by stromatolitcmudstone showing birdseyes and gypsum nodules. The identified depositional sequence shows at the top desiccation cracks and breccias indicating the temporary subaerial exposure of the sedimentary environment and the end of the sequence.

Evaporites-marls-carbonate sequences

This type of depositional sequence is represented by S1, S2, S4, S6, S8, S10, S11, S13, S15, S16, S17, S21 and S22 (Fig.11). A sequence is generally unconformably overlying a subaerial exposure surface which supports a relatively thick evaporitic layer with stratified laminated gypsum greyish in color due to the presence of clay particles. These thick evaporites that developed in a subsided evaporitic marginal zone correspond to the lowstand system tract. The evaporites are overlain by interbedded thick-bedded limestones and thin- to medium-bedded marl levels which represent the transgressive system tracts. The marls include scarce benthic foraminifera and display a relatively dark color due to the presence of organic matter; it refers to a restricted lagoonal condition. The limestone intercalations show bioclastic wackestone indicating episodes of relatively open marine subtidal environments. The maximum flooding surface is recorded within the limestone level the richest in marine fossils (foraminifers, oysters, echinoderms). The uppermost limestone levels which consist of wackestone poor in fossils but rich in pellets with desiccationdesiccation breccias at the top indicate a shallowing-up and represent therefore the highstand system tract.

These depositional sequences never end with a subaerial exposure surface like the first type of sequences described above; their upper boundary is marked by a brutal change from shallow- to deep-water depositional facies.

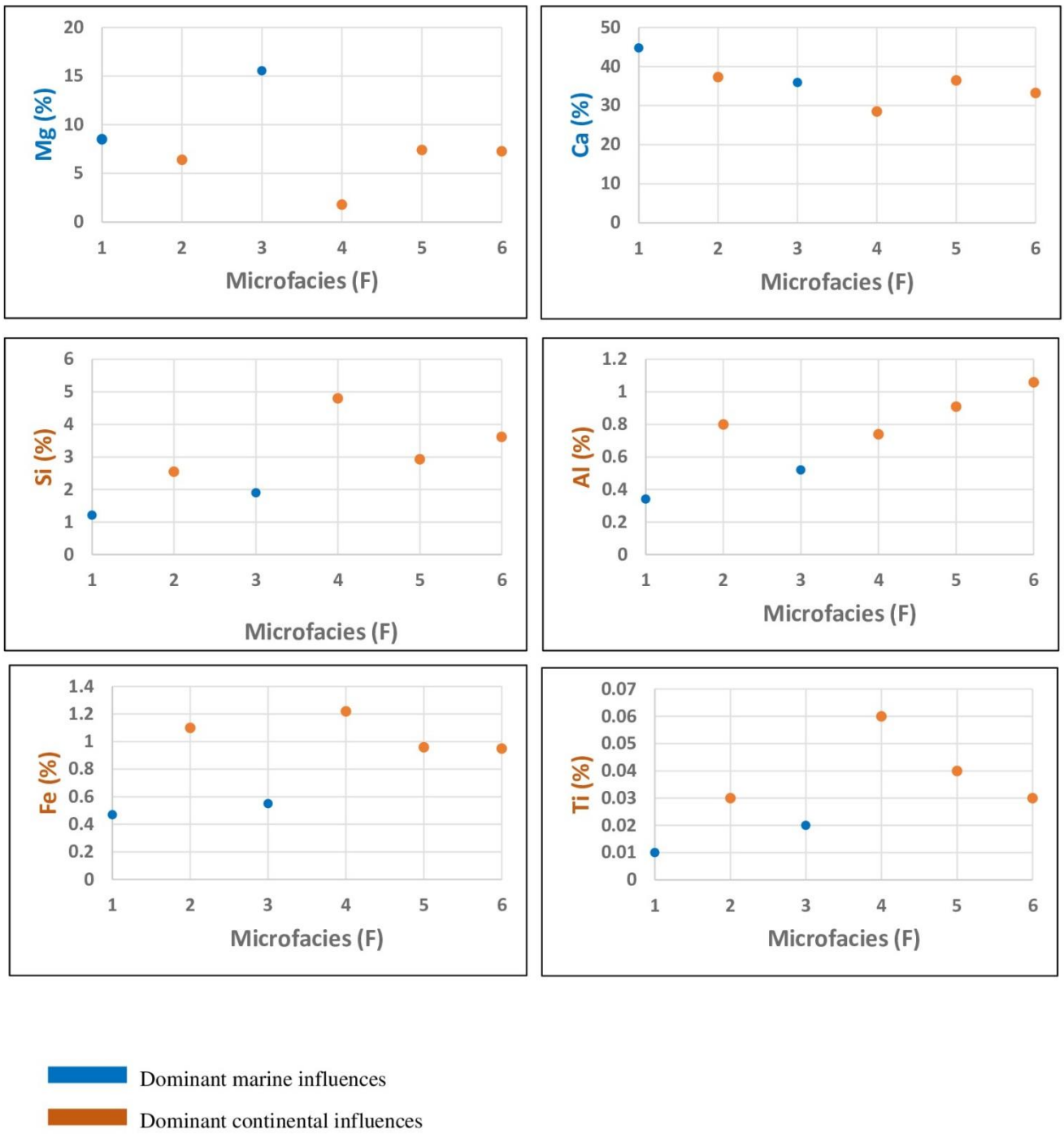

Fig 10- Diagrams of the distribution of chemical element concentrations with the different carbonate microfacies of the Zebbag Formation.

Evaporites-marls sequences

This type of depositional sequence is represented by S3, S9, S14, S19 and S20 (Fig.11). The lower sequence boundary is generally characterized by a subaerial exposure surface above which a relatively thick stratified laminated gypsum layer occurs; it represents the lowstand system tracts. The marls overlying the evaporites represent the transgressive and the highstand system tracts. At the base, the marls show scarce marine fossils (oysters) and display a dark greyish color due to the presence of organic matter content; these marls represent the transgressive system tract, and the maximum flooding surface can be placed at the level the poorest in fossils and the darkest in color. To the top, the marls become less dark and less poor in marine fossils with the presence of

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benthic foraminifera, lamellibranches and oysters, these marls should correspond therefore to the highstand system tract. According to such features, while taking into account the sedimentological study, it seems that both the transgressive and highstand system tracts developed in a lagoonal environment which became less restricted with the end of the depositional sequence.

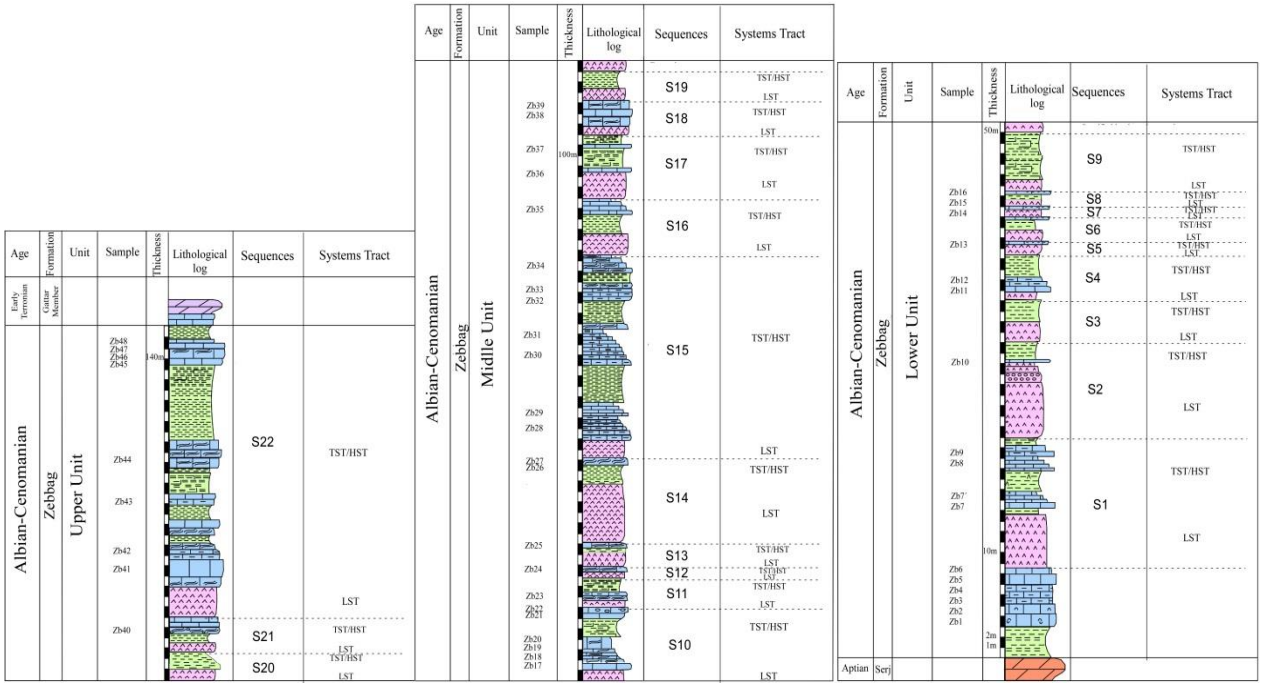

Fig 11- Depositional mixed sequences of the Zebbag Formation at Khanguet Zebbag, Central Tunisia

Discussion

Based on the field examination of lithofacies, and according to previous works, the Zebbag Formation can be primarily attributed to a marginal-littoral evaporitic environment (Burollet 1956; Fournier 1973; Gargouri-Razgallah 1983; Marie et al. 1984). The presence of thick intercalations of stratified laminated evaporites in this formation supports such an assumption. The fairly significant thickness and the bedding of the evaporitic intercalations in this formation suggest on another hand a fairly subsided sedimentary basin which is compatible with an evaporitic lagoonal environment developed in a passive margin and suggests abrupt eustatic sea-level changes (Zamannejed et al. 2013).

Considering the palaeogeography of Tunisia during the Late Albian–Cenomanian interval, the formation of a restricted lagoonal evaporitic environment can be linked to the presence of the rudist-bearing reef complex called the Isis Formation that occurred at the NE of Central Tunisia; it displayed a barrier reef within the Cenomanian carbonate mid ramp (Gargouri-Razgallah 1983; Marie et al. 1984).

The presence of fossils poor limestones and marls, which are commonly interbedded with the evaporitic layers of the Zebbag Formation, supports the assumption of a restricted lagoonal sedimentary environment in the study area. In addition, the relatively dark greyish color of the marl intercalations refers to the conservation of organic carbon within an oxygen-poor (hypoxic) environment.

According to several workers (Gargouri-Razgallah 1983; Marie et al. 1984; Abdallah 1987 and Ben Ferjani et al. 1990), the interbedded evaporites-limestone-marls of the Zebbag Formation correspond to a marginal-littoral evaporitic environment. Indeed, the stratified evaporites which are alternating with fossil-poor limestone are already considered by these workers as a shallow-water inner ramp with lagoonal restricted conditions. This lagoonal environment passes towards South Tunisia into a more evaporitic environment, while towards North Tunisia it passes into a deep-water open marine outer ramp (Marie et al. 1984; Ben Ferjani et al. 1990).

In terms of palaeoclimate, the development of fairly thick evaporitic layers in the Zebbag Formation indicates a relatively arid climate. Such an assumption is compatible with the climate chart of Hallam (1985) according to which, on a global scale, the Cenomanian is marked by an arid climate. This is also supported by the works of Newport et al. (2017) on the Zebbag Formation in south Tunisia, according to whom the Cenomanian–Turonian interval was marked by equatorial conditions that resulted in sufficient evaporation of sea water leading to a mesohaline reflux dolomitization of the carbonate intercalations of Zebbag Formation in South Tunisia.

The interpretation of the depositional environment is furthermore clearly supported by the results of the carbonate microfacies analysis. Indeed, both the mudstone-wackestone with pellets and rare bioclasts, as well as the oolithic packstone are compatible with a marginal-littoral environment. Accordingly, the limestone with pellets and poor in fossils and bioclasts refers to a restricted subtidal lagoonal environment, while the oolithic limestone is

characteristic of warm and shallow coastal waters (Purser 1973; Sipos et al. 2018). The marginal-littoral setting can also be testified by the frequent presence of desiccation cracks and breccias associated with gypsum nodules (Purser 1973; Wilson 1975; M Rabet 1987; Flügel 2010).

According to Tucker (1992), the marginal-littoral setting is the most sensitive to sea-level fluctuation, and it therefore, best records the variation of continental influences and marine influences linked respectively to marine regression and transgression. Accordingly, the fluctuation of sea level and its impact on the variation of depositional facies are rather more sensitive in the marginal-littoral environment than in the infralittoral to basin environment.

In the Zebbag Formation, the alternating marine influences and continental influences recorded in the depositional environment can be highlighted by the vertical variation not only of the depositional facies but also of the chemical composition of the carbonate intercalations. Indeed, in microfacies F1 and F3 which refer to subtidal open marine environments, the limestone is marked chiefly by Mg, K and Ca which are rather known as indicating dominant marine conditions. On the contrary, the limestones rich in ooids associated with desiccation breccias and detritic quartz particles representing the microfacies F2 and F4–6 are basically marked by Si, Al, Fe and Ti known as indicating dominant continental conditions (Pearce and Jarvis 1992; Banner 1995; Sageman and Lyons 2003; Algeo and Maynard 2004; Harris et al. 2013; Turner et al. 2015). It is then clear that the sedimentological features of the studied succession are compatible with the chemical analytical results, which confirms the interpretation of the sedimentary environment.

The vertical changes in both depositional facies and chemical composition through the Zebbag Formation are controlled by the fluctuation of sea level that controlled the change of the depositional environment. Consequently, the environment was episodically subject to dominant continental influences during the regressive stages and to dominant marine influences during the transgressive ones. As a result, the Zebbag Formation was arranged into a succession of depositional sequences that were controlled by the variation of sea level in a marginal-littoral setting. It consists of mixed sequences with evaporitic intercalations.

According to the vertical variation of the depositional facies, taking into account Walther's law (1894), the mixed sequences of the Zebbag Formation occurred in different environments and are therefore composed of different system tracts.

Compared with the mixed sequences with evaporitic intercalations as already described by Tucker (1991) and Sarg (2001), those identified in the Zebbag Formation begin as well with evaporites at the base which represent the lowstand system tract, but they never end with limestone as for the transgressive and highstand system tracts; they end in addition either with interbedded limestone and marls or by marls. Several other authors, working on mixed sequences, identified only interbedded evaporites-carbonate succession, as for example Xiao et al. (2021) working on mixed sequences in the Ordos Basin of China during the Ordovician, Husinec and Harvey (2021) working on Late Ordovician in a mixed carbonate-siliciclastic-evaporite lithofacies in Williston Basin (USA); all these workers attribute the evaporitic intercalations to the lowstand system tract of third-order depositional sequences and the carbonate levels to the transgressive and highstand system tracts.

In fact, the Zebbag Formation includes three types of mixed sequences that developed in three distinct settings formed along the marginal-littoral environment in Central Tunisia (Fig.12). Indeed, the evaporites-carbonate sequences should have been developed in the shallow water inner part of the margin, while the evaporites-marls sequences seem to have been occurring in the deeper water outer part of the margin. Accordingly, it seems plausible that the evaporites-carbonate-marls sequences represent a transitional zone between the two previous zones.

Considering Walther's law (1894) the three marginal zones cited above are alternating vertically depending on the alternating marine regression and transgression. Indeed, during the lowstand of sea level and resulting marine regression, the evaporites developed in a shallow water evaporitic lagoonal environment under arid conditions. During the beginning of sea-level rise, the sedimentary environment received and accumulated detrital clayey inputs. During the transgressive stage, the sedimentary environment became deep enough to allow the carbonate precipitation. Such a spatial distribution of the sedimentary environments determines the spatial distribution of the three types of mixed sequences as shown in Figure 11.

Although the models of the sequence stratigraphy of mixed successions as established by Tucker (1991) and Sarg (2001) are applicable to the studied formation, the mixed sequences already identified in this formation are basically different from those reported by the previous workers by the presence of marl intercalations interbedded with limestones and evaporites. According to the present study while considering the previous works (Burollet 1956; Gargouri-Razgallah 1983), the clays forming these marls have been transported from the neighboring continent before being deposited in a restricted marginal lagoonal environment.

Furthermore, the presence of terrigenous detrital clays is generally interpreted as indicating a significant continental weathering linked to rather humid conditions (Millot 1964; Bougeault et al. 2017; Zhong et al. 2018; Liu et al. 2020). Then the presence of marl intercalations in the studied mixed sequences can be linked with a climatic fluctuation during the Cenomanian, with not particularly prolonged episodes during which the humid episodes generated clays and the arid episodes generated evaporites. In this regard, the absence of clayey intercalations in the Permian mixed sequences of Tucker (1991) and Sarg (2001) can be explained by a rather arid climate that prevailed during the Permian in the area studied respectively in North England and Michigan (USA) as well as in the Gulf of Mexico.

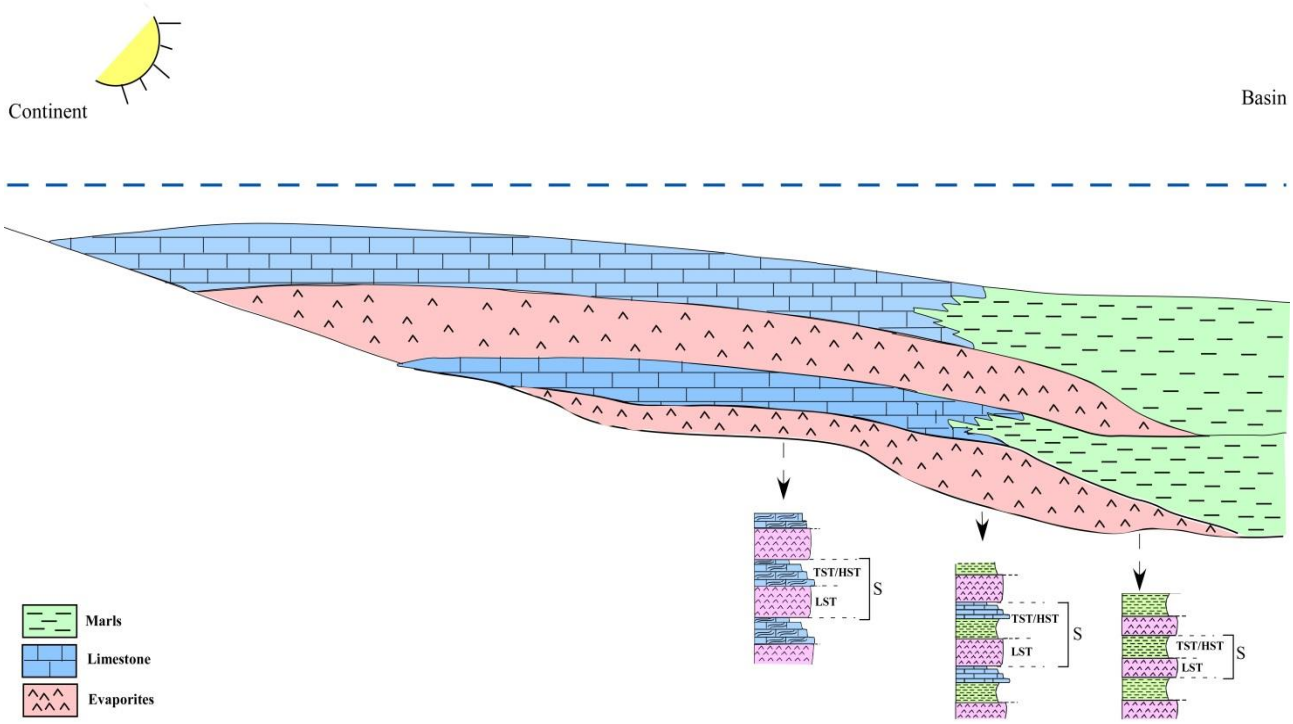

Fig 12-Types of mixed sequences forming the Zebbag Formation in Central Tunisia

Conclusions

The Late Albian–Cenomanian interval is represented in Central Tunisia by a mixed succession called the Zebbag Formation. It consists of interbedded stratified evaporites, oolithic and bioclastic carbonates, and fossils-poor marls.

The Zebbag Formation occurred within a margino-littoral setting at the southern border of Tethys. The carbonate intercalations include different depositional microfacies that developed in different depositional environments, varying between the open marine subtidal and the restricted inter- to supratidal environments. The evaporite intercalations occurred within an evaporitic environment, while the marls refer to a restricted lagoonal environment.

The carbonate depositional environments as already interpreted based on the identified microfacies are confirmed by the chemical composition of the carbonates. The vertical variation of both depositional microfacies and chemical composition from the bottom to the top of the Zebbag Formation records the role of the sea-level fluctuation and the influences of the marine transgressions and regressions on the depositional environment.

According to the vertical distribution of the depositional facies and chemical composition, while taking into account the presented models for mixed depositional sequences1, the Zebbag Formation includes three types of mixed sequences: evaporites-carbonate sequences developed within the inner part of the margin, evaporites-marls sequences in the outer part of the margin, and the evaporites-carbonate-marls sequences in the middle part of the margin.

In comparison to the proposed mixed depositional sequences model elsewhere, those of the Zebbag Formation include in addition marl interclations, which suggests a fluctuating climate with humid episodes giving rise to marls and arid episodes generating evaporites and carbonates.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Acknowledgments

The authors would like to thank the Department of Earth Sciences, Faculty of Sciences, University of Sfax, for their technical support, especially the Laboratory of Mineralogy. We are also grateful to the anonymous reviewers for their constructive comments, which helped to improve this paper. The authors are grateful to the editor for significantly improving and clarifying the manuscript.

References

Abdallah H. 1987. Le Crétacé supérieur de la chaine nord des Chotts (Sud tunisien): biostratigraphie, sédimentologie, diagenèse (Doctoral dissertation, Dijon), 225p.

Algeo T. J. and Maynard J. B. 2004. Trace-element behavior and redox facies in core shales of Upper Pennsylvanian Kansas-type cyclothems. Chemical Geology, 206(3-4): 289-318. https://doi.org/10.1016/j.chemgeo.2003.12.009

Banner J. L. 1995. Application of the trace element and isotope geochemistry of strontium to studies of carbonate diagenesis. Sedimentology, 42(5): 805-824. https://doi.org/10.1111/j.1365-3091.1995.tb00410.x

Bathurst R. G. 1973. Problèmes généraux posés par la diagenèse des sédiments carbonatés, BULL. CENTRE RECH. PAU; FR. 7(0001): 99 A 110.

Beigi M. Jafarian A. Javanbakht M. Wanas H. A. Mattern F.

and Tabatabaei A. 2017. Facies analysis, diagenesis and sequence stratigraphy of the carbonate-evaporite succession of the Upper Jurassic Surmeh Formation: Impacts on reservoir quality (Salman Oil Field, Persian Gulf, Iran). Journal of African Earth Sciences, 129 : 179-194. https://doi.org/10.1016/j.jafrearsci.2017.01.005

Béji Sassi A. 1984. Pétrologie, Minéralogie et Géochimie des sédiments phosphatés de la bordure orientale de l'île de Kasserine (Tunisie). Thèse Doct. 3 ème Cycle, Univ. El Manar.

Ben Ferjani A. Burollet P. F. and Mejri F. (1990). Petroleum Geology of Tunisia: Entreprise Tunisienne d'Activités Pétrolières. ETAP, Tunis, Tunisia (194 p).

Bismuth H. Boltenhagen C. Donze P. Le Fevere J.et and Saint –Marc P. 1982. Etude sédimentologique et biostratigraphique du Crétacé moyen et supérieur du Jebel Semmama (Tunisie du centre Nord). Cretaceous Research, 3 (1 & 2): 171-185. https://doi.org/10.1016/0195-6671(82)90018-0

Bismuth H. 1973. Réflexions stratigraphiques sur l'Albo-Aptien dans la région des Djebels Douleb et Semmama et son environnement (Tunisie du Centre-Nord). Ann. Mines Géol, 26: 179-212.

Bodin S. Petitpierre L. Wood J. Elkanouni I. and Redfern J. 2010. Timing of early to mid-Cretaceous tectonic phases along North Africa: New insights from the Jeffara escarpment (Libya–Tunisia). Journal of African Earth Sciences, 58(3): 489-506. https://doi.org/10.1016/j.jafrearsci.2010.04.010

Bouaziz S. Barrier E. Soussi M. Turki M. M. and Zouari H. 2002. Tectonic evolution of the northern African margin in Tunisia from paleostress data and sedimentary record. Tectonophysics, 357(1-4): 227-253. https://doi.org/10.1016/S0040-1951(02)00370-0

Bougeault C. Pellenard P. Deconinck J. F. Hesselbo S. P. Dommergues J. L. Bruneau L. and Thibault N. 2017. Climatic and palaeoceanographic changes during the Pliensbachian (Early Jurassic) inferred from clay mineralogy and stable isotope (CO) geochemistry (NW Europe). Global and Planetary Change, 149: 139-152. https://doi.org/10.1016/j.gloplacha.2017.01.005

Burollet P. F. 1956. Contribution à l'étude stratigraphique de la Tunisie centrale. Ann. Mines Géol., 18: 350.

Chihaoui A. Jaillard E. Latil J. L. Zghal I. Susperregui A. S. Touir J. and Ouali J. 2010. Stratigraphy of the Hameima and lower Fahdene formations in the Tadjerouine area (Northern Tunisia). Journal of African Earth Sciences, 58(2): 387-399. https://doi.org/10.1016/j.jafrearsci.2010.02.008

Dali-Ressot M.D. 1987. Les Calcisphaerulidae des terrains albiens à maestrichtiens de Tunisie centrale (J. Bireno et J. Bou el Ahneche). Intérêts systématique, stratigraphique et paléogéographique. Thèse 3e cycle.

Dunham R. J. 1962. Classification of Carbonate Rocks According to Depositional Textures, in Ham W.E., Ed., Classification of carbonate rocks. Am. Assoc. Petroleum Geologists Memoir, 1: 108-121.

Ferjani A. B. Burollet P. F. and Mejri F. 1990. Petroleum Geology of Tunisia. Memoir Enterprise Tunisienne d'Activités Pétrolières, Tunis, 1: 194 p..

Flügel E. 2010. Microfacies of Carbonate Rocks: Analysis, Interpretation and Application, Microfacies data, p. 177-242.

Fournié D. 1978. Nomenclature lithostratigraphique des séries du Crétacé supérieur au Tertiaire de Tunisie. Bull. cent. Rech. Explor. Prod. Elf. Aquitaine, 2(1): 97-148.

Gargouri – Razgallah S. 1983. Le Cénomanien de Tunisie centrale. Etude paléoecologique, stratigraphique, micropaloéontologique et paléogéographique thèse doctorat d'état, Univ. Lyon, 215 p.

Hallam A. 1985. A review of Mesozoic climates. Journal of the Geological Society, 142(3): 433-445.

Harris N. B. Mnich C. A. Selby D. and Korn D. 2013. Minor and trace element and Re–Os chemistry of the Upper Devonian Woodford Shale, Permian Basin, west Texas: Insights into metal abundance and basin processes. Chemical Geology, 356: 76-93. https://doi.org/10.1016/j.chemgeo.2013.07.018

Husinec A. and Harvey L. A. 2021. Late Ordovician climate and sea-level record in a mixed carbonate-siliciclastic-evaporite lithofacies, Williston Basin, USA. Palaeogeography, Palaeoclimatology, Palaeoecology, 561: 110054. https://doi.org/10.1016/j.palaeo.2020.110054

Jarvis I. Burnett W. C. Nathan Y. Almbaydin F. S. M. Attia A. K. M. Castro L. N. ... and Zanin Y. N. 1994. Phosphorite geochemistry: state-of-the-art and environmental concerns. Eclogae Geologicae Helvetiae, 87(3): 643-700.

Khessibi M. 1978. Etudes géologiques du secteur de Maknassy-Mezzouna et du Djebel Kebar (Tunisie Centrale). Thèse Doctorat Université, Lyon, 175 p.

Lakhdar R. Soussi M. Ismail M. H. B. and M'Rabet A. 2006. A Mediterranean Holocene restricted coastal lagoon under arid climate: case of the sedimentary record of Sabkha Boujmel (SE Tunisia). Palaeogeography, Palaeoclimatology, Palaeoecology, 241(2): 177-191. https://doi.org/10.1016/j.palaeo.2006.02.014

Laporte L. F. 1967. Carbonate deposition near mean sea-level and resultant facies mosaic: Manlius Formation (Lower Devonian) of New York State. AAPG Bulletin, 51(1): 73-101.

Latil J. L. Jaillard E. Bardet N. Raisossadat N. and Vincent P. 2021. The Albian-Cenomanian transition in a shelf-basin transect: Biostratigraphy, sedimentology and paleontology of Jebel Mghila, Central Tunisia. Cretaceous Research, 124: 104809. https://doi.org/10.1016/j.cretres.2021.104809

Liu Y. Song C. Meng Q. He P. Yang R. Huang R. ... and Xing Z. 2020. Paleoclimate change since the Miocene inferred from clay-mineral records of the Jiuquan Basin, NW China. Palaeogeography, Palaeoclimatology, Palaeoecology, 550: 109730. https://doi.org/10.1016/j.palaeo.2020.109730

Marie J. Trouvé P. Desforges J. and Dufaure P. 1984. Nouveaux éléments de paléogéographie du Crétacé de Tunisie. Total Compagnie Française de Pétrole, Notes et Mémoires, 1: 38 p.

Masse J. P. 1984. Données nouvelles sur la stratigraphie de l'Aptien carbonaté de la Tunisie centrale, conséquences

paléogéographiques. Bull. Soc. Géol. France, S7-XXVI(6): 1077-1086. https://doi.org/10.2113/gssgfbull.S7-XXVI.6.1077

Memmi L. 1999. L'Aptien et l'Albien de Tunisie biostratigraphie à partir des ammonites. Bulletin de la Société géologique de France, 170(3): 303-309.

Milliman J. D. Müller G. and Förstner F. 2012. Recent sedimentary carbonates: Part 1 marine carbonates. Springer Science & Business Media, p. 138-147.

Millot G. 1964. Géologie des argiles, Masson édit., Paris, 499 p.

M'Rabet A. 1987. Stratigraphie, sédimentation et diagenèse carbonatée des séries du Crétacé inférieur de Tunisie centrale. Annale Min. Geol., 30: 412 p.

Newport R. Hollis C. Bodin S. and Redfern J. 2017. Examining the interplay of climate and low amplitude sea-level change on the distribution and volume of massive dolomitization: Zebbag Formation, Cretaceous, Southern Tunisia. The Depositional Record, 3(1): 38-59. https://doi.org/10.1002/dep2.25

Noffke N. Gerdes G. Klenke T. and Krumbein W. E. 2001. Microbially induced sedimentary structures: a new category within the classification of primary sedimentary structures. Journal of Sedimentary Research, 71(5) : 649-656. DOI:10.1306/2DC4095D-0E47-11D7-8643000102C1865D

Pearce T. H. and Jarvis I. 1992. Applications of geochemical data to modelling sediment dispersal patterns in distal turbidites; Late Quaternary of the Madeira abyssal plain. Journal of Sedimentary Research, 62(6) : 1112-1129. https://doi.org/10.1306/D4267A64-2B26-11D7-8648000102C1865D

Perkins R. D. 1963. Petrology of the Jeffersonville limestone (Middle Devonian) of southeastern Indiana. Geological Society of America Bulletin, 74(11) : 1335-1354. https://doi.org/10.1130/0016-7606(1963)74[1335:POTJLM]2.0.CO;2

Purser B. H. and Evans G.. 1973. Regional sedimentation along the Trucial coast, SE Persian Gulf. In The Persian Gulf: Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. Springer Berlin Heidelberg, 211-231.

Purser, B. H. 1975. Tidal sediments and their evolution in the Bathonian carbonates of Burgundy, France. In Tidal deposits: a casebook of recent examples and fossil counterparts (pp. 335-343). Berlin, Heidelberg: Springer Berlin Heidelberg.

Purser B. H. 1980. Sédimentation et diagenèse des carbonates néritiques recents, T.1, Tecnip. éd., Paris, 366 p.

Razgallah S. G. 1983. Le Cénomanien de Tunisie centrale: étude paléoecologique, stratigraphique, micropaléontologique et paléogeographique (Doctoral dissertation, Université Claude Bernard-Lyon I).

Razgallah, S., Philip, J., Thomel, G., Zaghbib-Turki, D., Chaabani, F., Ali, N. B. H., & M'rabet, A. 1994. La limite Cénomanien-Turonien en Tunisie centrale et méridionale: biostratigraphie et paléoenvironnements. Cretaceous research, 15(5), 507-533. https://doi.org/10.1006/cres.1994.1031

Reineck H. E. Gerdes G. Claes M. Dunajtschik K. Riege H. and Krumbein W. E. 1990. Microbial modification of sedimentary surface structures. Sediments and Environmental Geochemistry: Selected Aspects and Case Histories, 254-276.

Sarg J. F. 2001. The sequence stratigraphy, sedimentology, and economic importance of evaporite–carbonate transitions: a review. Sedimentary Geology, 140(1-2) : 9-34. https://doi.org/10.1016/S0037-0738(00)00170-6

Sageman B. B. and Lyons T. W. 2003. Geochemistry of fine-grained sediments and sedimentary rocks. Treatise on Geochemistry, 7: 115-158. https://doi.org/10.1016/B0-08-043751-6/07157-7

Shinn E. A. Ginsburg R. N. and Lloyd R. M. 1965. Recent supratidal dolomite from Andros Island, Bahamas. In : Dolomitization and limestone diagenesis. Soc. Econ. Paleont. Mineral., spec. Publ., °13:112-123. https://doi.org/10.2110/pec.65.07.0112

Shinn E. A. 1969. Submarine lithification of. Holocene carbonate sediments in the Persian Gulf. Sedimentology, 12, 109-144. https://doi.org/10.1111/j.1365-3091.1969.tb00166.x

Sipos A. A. Domokos G. and Jerolmack D. J. 2018. Shape evolution of ooids: a geometric model. Scientific Reports, 8(1) : 1758.

Touir J. Ali H. H. Mahjoubi F. and Ouali J. 2015. Microstratigraphy and interpretation of the karst sedimentary fillings associated to the Aptian–Albian unconformity in Jebel Semmama (Central Tunisia). Journal of African Earth Sciences, 112: 186-198. https://doi.org/10.1016/j.jafrearsci.2015.09.003

Touir J. Mechi C. and Ali H. H. 2017. Changes in carbonate sedimentation and faunal assemblages in the Tunisian carbonate platform around the Cenomanian-Turonian boundary. Journal of African Earth Sciences, 129 : 527-541. https://doi.org/10.1016/j.jafrearsci.2017.01.025

Trabelsi K. Touir J. Soulié-Märsche I. Martín-Closas C. Soussi M. and Colin J. P. 2010. Découverte de charophytes de l'Albien dans la Formation Kebar (Tunisie centrale): implications paléoécologiques et paléobiogéographiques. In Annales de Paléontologie, 96 (3) : 117-133. https://doi.org/10.1016/j.annpal.2011.04.001

Tucker M. E. 1991. Sequence stratigraphy of carbonate-evaporite basins: models and application to the Upper Permian (Zechstein) of northeast England and adjoining North Sea. Journal of the Geological Society, 148(6): 1019-1036. DOI:10.1144/gsjgs.148.6.1019

Tucker M. E. 1992. The Precambrian–Cambrian boundary: seawater chemistry, ocean circulation and nutrient supply in metazoan evolution, extinction and biomineralization. Journal of the Geological Society, 149(4) : 655-668. https://doi.org/10.1144/gsjgs.149.4.0655

Turner B. W. Tréanton J. A. and Slatt R. M. 2015. The use of chemostratigraphy to refine ambiguous sequence stratigraphic correlations in marine shales: An Example from the Woodford Shale, Oklahoma. In SPE/AAPG/SEG Unconventional Resources Technology Conference (pp. URTEC-2154166). URTeC.

Vail P. R. 1977. Seismic stratigraphy and global changes of

sea level. Memoir of the American Association of Petroleum Geologists, 26 : 49-50.

Vail P.R. Mitchum R.M. and Thompson S. 1977. Seismic stratigraphy and global changes of sea level, part 3 : Relative changes of sea level from coastal onlap, In: Payton C.W. (Ed.) , Seismic stratigraphy - Applications to Hydrocarbon Exploration : American Association of Petroleum Geologists Mem, 26 : 83-97.

Vail P. R. and Wornardt W. W. 1991. Well log-seismic sequence stratigraphy: an integrated tool for the 90's, 41, p. 630-650.

Walther, J. 1894. Einleitung in die Geologie als historische Wissenschaft. In Lithogenesis derGegenwart. Jena: G. Fischer, Bd. 3, pp. 535-1055

Wilson, J. L. 1967. Carbonate-evaporite cycles in lower Duperow Formation of Williston Basin. Bulletin of Canadian Petroleum Geology, 15(3), 230-312. https://doi.org/10.35767/gscpgbull.15.3.230

Wilson J. L. and Wilson J. L. 1975. Principles of Carbonate Sedimentation. Carbonate Facies in Geologic History, p. 1-19.

Wilson J. L. 2012. Carbonate facies in geologic history. Springer Science & Business Media, p. 20-55.

Xiao D. Cao J. Tan X. Xiong Y. Zhang D. Dong G. and Lu Z. 2021. Marine carbonate reservoirs formed in evaporite sequences in sedimentary basins: A review and new model of epeiric basin-scale moldic reservoirs. Earth-Science Reviews, 223: 103860. https://doi.org/10.1016/j.earscirev.2021.103860

Zamannejad A. Jahani D. Lotfpour M. and Movahed B. 2013. Mixed evaporite/carbonate characteristics of the Triassic Kangan Formation, offshore area, Persian Gulf. Revista Mexicana de Ciencias Geológicas, 30(3): 540-551.

Zhong Z. Chen Z. Xu Y. Ren C. Yang G. Han X. ... and Feng, Y. 2018. Relationship between soil organic carbon stocks and clay content under different climatic conditions in Central China. Forests, 9(10): 598. **https://doi.org/10.3390/f9100598**

Zink K. G. Furtado A. L. Casper P. and Schwark L. 2004. Organic matter composition in the sediment of three Brazilian coastal lagoons: district of Macaé, Rio de Janeiro (Brazil). Anais da Academia Brasileira de Ciências, 76: 29-47. DOI:10.1590/S0001-37652004000100004