New Horizons Journal of Basic and Applied Sciences, 2025, Vol. X, Iss. X, 1-14

DOI: 10.62184/nhjbas.jnh10020251

Research Article

SCIENCE PARK PUBLISHER

New Horizons Journal of Basic and Applied Sciences

Biostratigraphy and sequence stratigraphy of the Upper Cenomanian-Turonian successions at Southern Galala Plateau, North Eastern Desert, Egypt

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Received: 22, 03, 2025; Accepted: 08, 04, 2025; Published: 01, 06, 2025

Abstract

The Upper Cenomanian-Turonian strata are well studied at two sections; the first is Wadi (W.) El Dakhl section towards the north and the second is W. Um-Artah section towards the south, which is introduced for the first time in the manuscript. This study aims to provide stratigraphic, biostratigraphic, and sequence stratigraphic data, and correlate its depositional sequence with local and international ones. The studied successions represent the initial major sea level transgression, mainly consisting of siliciclastic/carbonate facies rich in macrofaunal contents. Five ammonite zones covering the Late Cenomanian-Turonian interval are identified. The integrated field, lithologic, and biostratigraphic criteria led to define four 3rd depositional sequences (DS1-DS4) during this interval. These depositional sequences are bounded by five sedimentary unconformity surfaces (Ce4, Ce5, Tu1, Tu2, and Tu3 sequence boundaries), which correlate with others in Tethyan regions. This correlation indicates that the sequence boundaries of the latest Cenomanian-Turonian (Ce5, Tu1, Tu2, and Tu3) match with those of the Middle East, North Africa, and Europe regions. While the early-Late Cenomanian sequence boundary (SB Ce4) mismatch at the same regions.

Keywords: Upper Cenomanian; Turonian; Ammonites biostratigraphy; Sequence stratigraphy; Eastern Desert, Egypt

1. Introduction

The Upper Cenomanian-Turonian successions covered large provinces in north Egypt. These successions are represented by siliciclastic and carbonate marine facies which rich with diverse macrofaunal assemblages. Several biostratigraphic and palaeoecological studies have been carried out on these faunal assemblages [1-11]. However, some localities in the North Eastern Desert are still uninvestigated until now; one of these localities is the Um-Artah area (Figure 1). So, the most important goal of the present study is to fill the gap in information on the Um-Artah section, whereas there is no information about this area. Therefore, this study firstly introduced details stratigraphic studies about the Upper Cenomanian-Turonian transition at the Um-Artah area. At the same time, it aims to establish a detailed biostratigraphic and sequence stratigraphic framework for the Upper Cenomanian-Turonian successions of the Southern Galala Plateau, and hence, correlated its depositional sequence with local and international ones.

2. Materials and methods

Two stratigraphic sections were described, measured in detail in the Upper Cenomanian-Turonian strata at the Southern Galala area (Figure 2) with a focus on their macrofossil content (especially ammonites). The first outcrop is located in the southern part of W. El Dakhl section (at latitude 28° 39' 48'' N

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and longitude 32° 24' 58" E) and the second section is at W. Um-Artah section (at latitude 28° 34' 58" N and longitude 32° 23' 01" E). These sections were described in detail. The stratigraphic ranges of the macrofossil content were identified and traced, and therefore, biostratigraphy records were established. These macrofossils were photographed. The integrated stratigraphic data were interpreted in the sequence stratigraphic framework.

3. Lithostratigraphy

Two rock units are analyzed: Galala (at the base) and Maghra El-Hadida (at the top) formations. These two formations represent the Upper Cenomanian-Lower Turonian transition. They are unconformably underlain by the Malha formation and overlain by Matulla formation. Due to the vertical lithologic variations between Malha/Galala and Maghra El-Hadida/Matulla formational boundaries, these formational contacts are easily detected in the field. The unfossiliferous cross-bedded sandstones of the Malha formation vertically change to fossiliferous shale of the Galala Formation (Figures 2-4). At the same time, there is a vertical facies change between the uppermost part of Maghra El-Hadida formation (carbonate facies) and the Matulla formation (clastic facies). These formational contacts are characterized by unconformity surfaces (Figures 2-4).

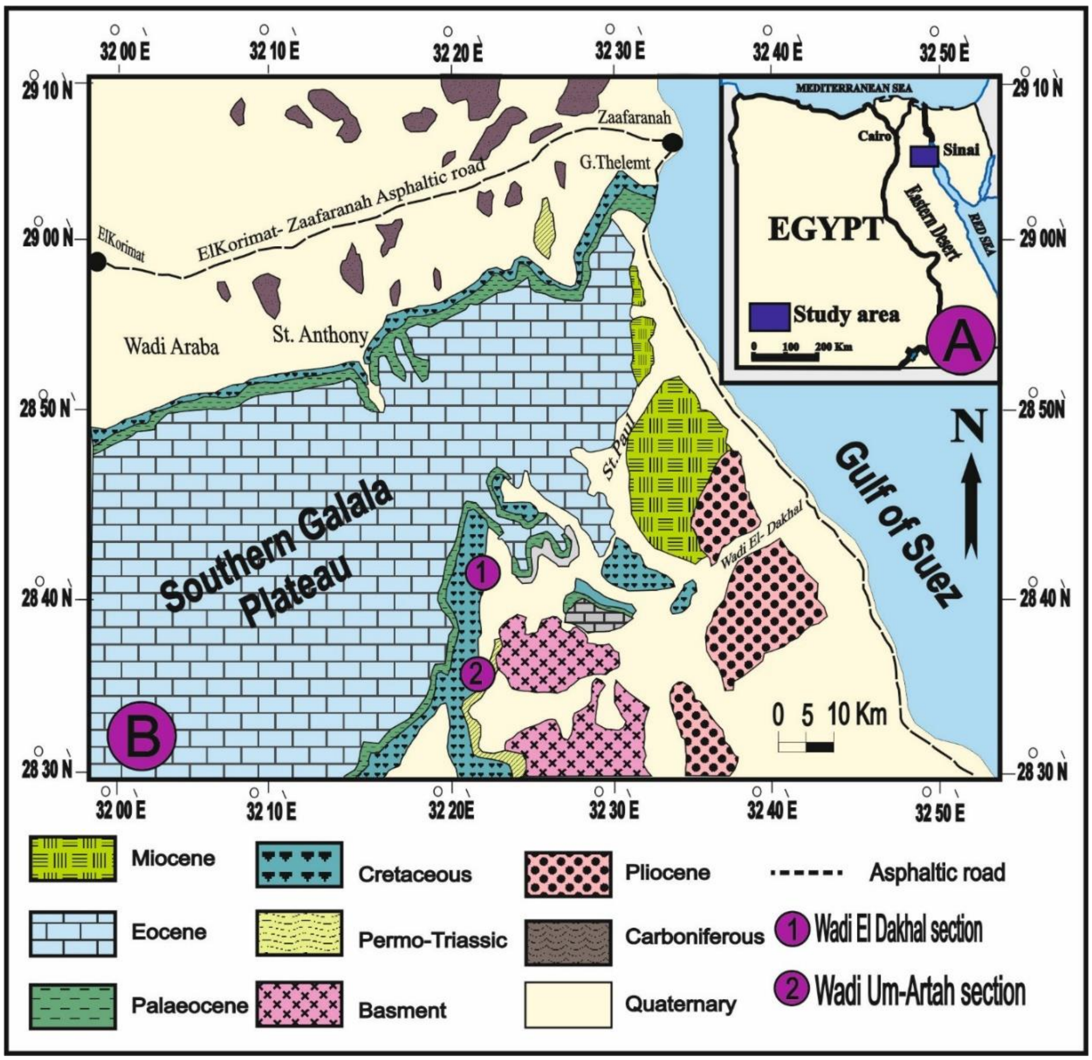

Figure 1. (A) Location map shows the studied area **(B)** Geological map shows the distribution of the rock units at the studied area and the location of the study sections (modified after [12]).

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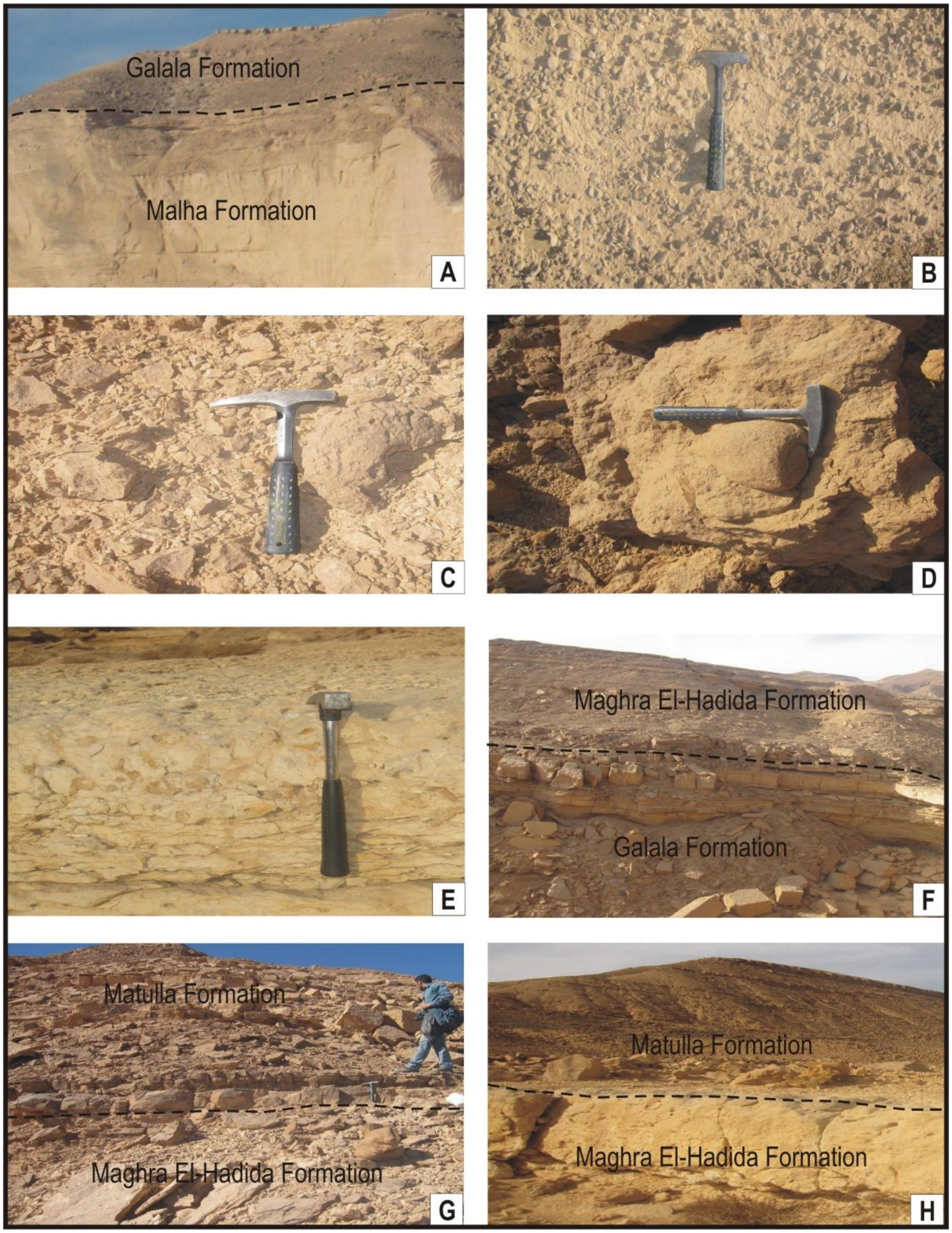

Figure 2. Field photographs showing: A. Malha/Galala formational boundary (SB Ce 4), W. Um-Artah section. B. Oysrer bank in Galala Formation, W. Um-Artah section. C. Vascoceras cauvini horizon within the uppermost part of Galala Formation, W. Um-Artah section. D. Pteroceras incerta (D'orbigny) within Galala Formation, W. Um-Artah section. E. Thalassinoides within Galala Formation, W. El Dakhl section. F. Galala/Maghra El-Hadida formational boundary, W. El Dakhl section. G. Maghra El-Hadida/Matulla formational boundary, W. Um-Artah section. H. Maghra El-Hadida/Matulla formational boundary, W. El Dakhl section.

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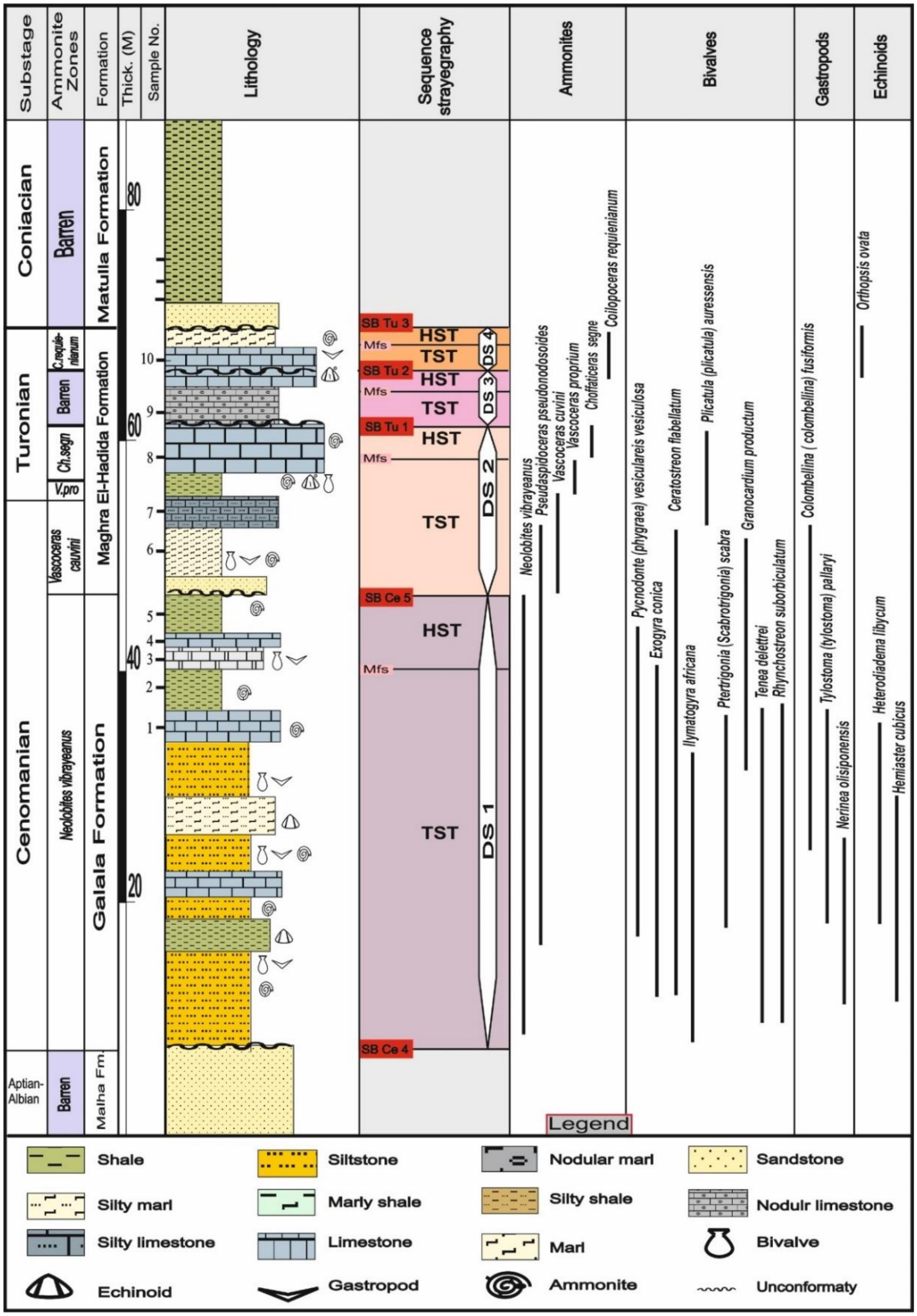

Figure 3. Litho-biostratigraphic subdivisions, vertical distribution of various macroinvertebrate faunal species, and sequence stratigraphic interpretations at W. El Dakhl section.

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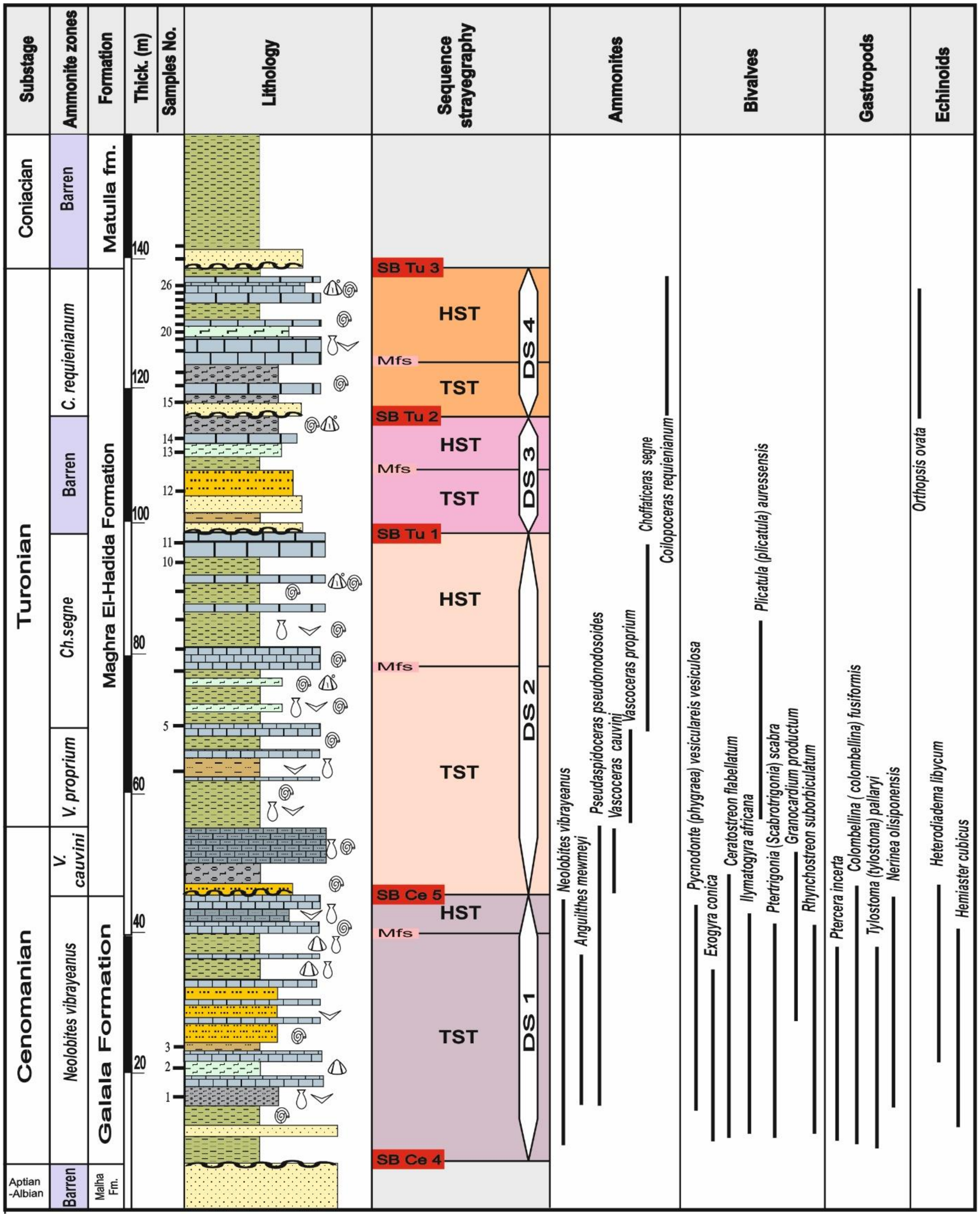

Figure 4. Litho-biostratigraphic subdivisions, vertical distribution of various macroinvertebrate faunal species, and sequence stratigraphic interpretations at W. Um-Artah section.

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3.1. Galala formation

It attains about 40 m at W. El Dakhl section and about 43m at Um-Artah section. It covers the Late Cenomanian time interval. At W. El Dakhl, it is composed of shallow-marine deposits of siltstone and silty marl with limestone intercalations, followed by thick green shale intercalated with hard limestone. On the other hand, at the W. Um-Artah section, it is composed of shales, limestones, siltstones, and nodular marl with oyster limestone intercalations in the lower part; change upward within the upper part into hard silty limestone. It is unconformably overlain by Maghra El-Hadida formation. This formational contact is marked by vertical facies variation from carbonate facies (uppermost part of Galala) to clastic facies (lowermost part of Maghra El-Hadida) [13].

3.2. Maghra El-Hadida formation

It attains about 26m and 89m thick at W. El Dakhl and W. Um-Artah sections respectively. It represents the latest Cenomanian-Turonian time interval. At W. El Dakhl section, it is composed of sandstone, shale, and limestone interbedded, followed by nodular bioturbated limestone and marl. At W. Um-Artah section, Maghra El-Hadida formation consists of siltstone, nodular marl, shales with thin, well-bedded limestone intercalations, while the upper part is composed of sandstone and nodular marl intercalated with limestone and sandy dolomitic limestones [14].

4. Biostratigraphy

These sediments of the early-Late Cenomanian (Galala formation in the present study) are deposited during a major sea-level transgression [15]. Therefore, the Upper Cenomanian Galala formation represents the initial marine transgression over the study area, and hence it is marked by abundant of macrofaunal (cephalopods, bivalves, gastropods, and echinoids) contents. The identified index ammonite species led to the establishment of a biostratigraphic framework for the study area (Figure 3-4), which is used for regional and inter-regional chronostratigraphic correlations [16-21] (Figure 5). The distribution charts of the identified macrofossils are illustrated in Figures 3 and 4 and photographed and shown in Figures 6-7. Based on the index ammonite taxa, five ammonite zones of the Upper Cenomanian-Turonian interval are identified, which are stratigraphically arranged from older to younger and described as follows:

4.1. *Neolobites vibrayeanus* zone (Late Cenomanian)

D'Orbigny [22] defined this zone as the total range of it's nominate taxon. *Neolobites vibrayeanus* Zone is represented by the Galala formation. It attains ~43m at W. Um-Artah section and ~40m at W. El Dakhl section. Neolobites vibrayeanus Zone includes the cephalopods: Pseudaspidoceras pseudonodosoides (Choffat) and Angulithes mermeti (Coquand); the bivalves: Exogyra conica (Sowerby), Pycnodonte (Phygraea) vesiculosa (Sowerby), Ilymatogyra africana (Lamarck), Granocardium productum (J.Sowerby), Rhynchostreon suborbiculatum (Lamarck), Ceratostreon flabellatum (Goldfuss) and Pterotrigonia (Scabrotrigonia) scabra (Lamarck); the gastropods: Pterocera incerta (Sowerby), Tylostoma pallaryi (Peron and Fourtau), Colombellina (Colombellina) fusiformis (Douville) and Nerinea olisiponensis (Sharpe); the echinoids: Heterodiadema libycum (Agassiz and Desor) and Hemiaster cubicus (Conrad). The same zone is recorded in Eastern Desert [21] and in Sinai [23]. In the Tethyan region (Figure 5), this zone as herein defined corresponds partly to the *N. vibrayeanus* Zone recorded in Tunisia [24] and Algeria [25].

4.2. *Vascoceras cauvini* zone (Latest Cenomanian)

Chudeau [26] defined this zone as the total range of Vascoceras cauvini. It is represented by ~6m and ~8m of the lowermost part of the Maghra El-Hadida formation at W. Um-Artah and W. El Dakhl sections respectively. Vascoceras cauvini Chudeau is associated with the cephalopods: Pseudaspidoceras pseudonodosoides (Choffat); bivalves: Ceratostreon flabellatum (Goldfuss) and Granocardium productum (Sowerby). The same zone is recorded in the Eastern Desert [3, 21] and Sinai [5]. Also, this zone is recorded from western Tethys, where this species is widespread during the latest Cenomanian in Niger [27] and Nigeria [28].

4.3. *Vascoceras proprium* zone (Early Turonian)

Reyment [29] defines this zone as the total range of its nominate taxon. The lowest occurrence of the Vascoceras proprium is represented the biomarker for the Turonian base. This zone is conformably overlain by the Early Turonian Choffaticeras (Choffaticeras) segne Zone. It attains about 11m and 2m of the lower part of the Maghra El-Hadida formation at W. Um-Artah and W. El Dakhl sections, respectively. It corresponds to Vascoceras proprium Zone recorded in Sinai [18]

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DOI: 10.62184/nhjbas.jnh10020251

and in the Eastern Desert [30] and Pseudaspidoceras flexuosum Zone recorded in Tunisia [31]. The Vascoceras proprium is used as the biomarker for the Turonian base instead of Pseudaspidoceras flexuosum, depending on the wide spreading of Vascoceratidae (this is recommended by [32]), which is widely distributed from Africa, South America, and Boreal Europe. The lowest occurrence of *Vascoceras proprium* is equivalent to the lowest occurrence of *Watinoceras devonense* (in Egypt, [33]; in Jordan, [17]). So, this species is the reliable bioevent marking the Turonian base.

4.4. *Choffaticeras (Choffaticeras) segne* zone (Early Turonian)

Solger [34] defines it as the total range zone. It is overlain by a barren interval. It is recorded within the middle part of Maghra El-Hadida formation and covers ~34m at W. Um-Artah section and ~5m at W. El Dakhl section. This zone is recorded by Abdel-Gawad et al. [3] in the north Eastern Desert. Also, it is equivalent to Choffaticeras securiforme-Choffaticeras quaasi and Choffaticeras segne zones in the Eastern Desert [6]. In Sinai, it is equivalent to Choffaticeras segne, Choffaticeras securiforme and Choffaticeras luciae zones [5] and Choffaticeras segne Zone [35]. Inter-regional scale, this zone is equivalent to Choffaticeras interval (or Choffaticeras spp. Interval zone) in Tunisia [31].

4.5. Barran interval

The upper part of the Maghra El-Hadida formation is barren of macrofossils including ammonites. This interval is represented by ~13m at W. Um-Artah section and ~7m thick at W. El Dakhl section. This interval is underlain by Choffaticeras (Choffaticeras) segne Zone of the Early Turonian age and overlain by Coilopoceras requienianum Zone of the Late Turonian age. Therefore, it belongs to the Middle Turonian age.

Substage	Standard ammonite zonations of tethyan [16]	Jordan [17]	Sinai		North Eastern Desert		
			[18]	[19]	[20]	[21]	Study area
Upper Turonian	*Subprionocyclus neptuni*		*Coilopoceras requienianum*	*Coilopoceras requienianum*	*Coilopoceras requienianum*	*Coilopoceras requienianum*	*Coilopoceras requienianum*
Middle Turonian	*Romaniceras deverianum*				*Hoplitoides ingens*		
	R.ornatissimum						
	R. kallesi						
	Kamerunoceras turoniense						
Lower Turonian	*Mammites nodosoides*	*Ch.(ch) Segne*	*Ch.Segne*	*Ch.Sinaticum*	*Ch.Luciae*	*P. Nigerinsis*	*Ch.(ch) Segne*
	Watinoceras coloradoensel				*Ch.Segne*	*Choffaticeras ssp.*	
	Watinoceras devonense	*Vascoceras proprium*	*Vascoceras proprium/v obesum*	*Ch.Segne*	*Vascoceras proprium/v pioti*	*Vascoceras proprium*	*Vascoceras proprium*
Upper Cenomanian	*Neocardioceras juddii*	*Vascoceras cauvini*	*Vascoceras cauvini*	*Vascoceras cauvini*		*Vascoceras cauvini*	*Vascoceras cauvini*
	Metoicoceras geslinianum	*Neolobites vibrayeanus*	*Neolobites vibrayeanus*	*P.Pseudunidosoides/ R.alatum*	*Neolobites vibrayeanus*	*Metoicoceres geslinianum*	*Neolobites vibrayeanus*
	Claycoceras naviculare			*Neolobites vibrayeanus*		*Neolobites vibrayeanus*	

Figure 5. Comparison of the ammonite zones during the Late Cenomanian-Turonian interval of the present study with local and inter-regional ones (Tethyan regions).

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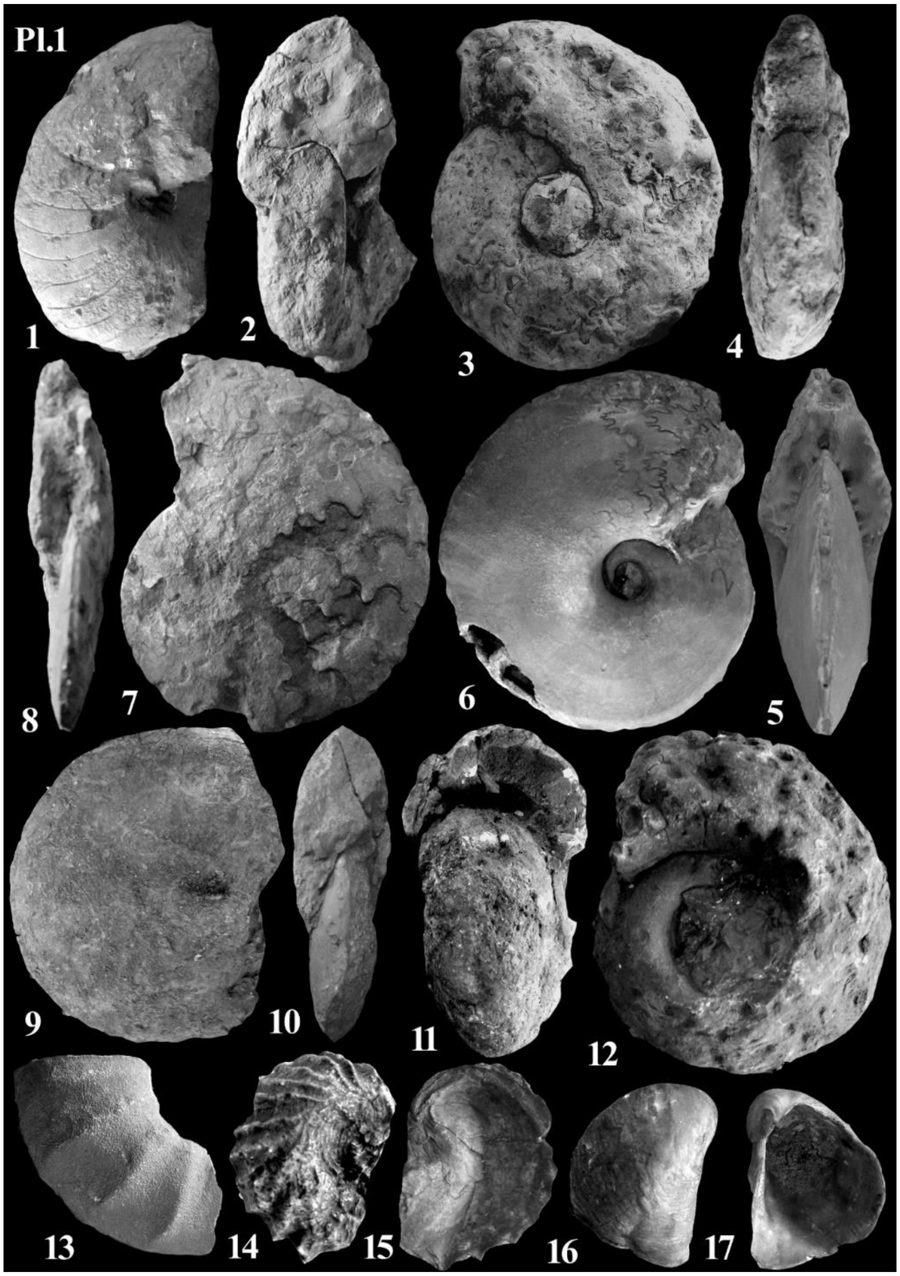

Figure 6. 1-2. Angulithes mermeti (Coquand), X0.5, 1: umbilical view, 2: apertural view, Upper Cenomanian, Galala Formation, W. Um-Artah section; 3-4. Vascoceras cauvini Chudeau, X0.3, 3: umbilical view, 4: apertural view, Late Upper Cenomanian, Galala Formation, W. Um-Artah section; 5-6. Choffaticeras (Choffaticeras) segne (Solger), X0.3, 5: apertural view, 6: umbilical view, Lower Turonian, Maghra El-Hadida Formation, W. Um-Artah section; 7-8. Neolobites vibrayeanus (D'Orbigny), X0.5, 7: umbilical view, 8 apertural view, W. El Dakhl section; 9-10. Coilopoceras requienianum (D'Orbigny), X0.3, 9: umbilical view, 10: apertural view, Upper Turonian, Maghra El-Hadida Formation, W. El Dakhl section; 11-12. Vascoceras proprium (Reyment), X0.4, 11: apertural view, 12: umbilical view, Early Lower Turonian, Maghra El-Hadida Formation, W. Um-Artah section; 13. Pseudaspidoceras pseudonodosoides (Choffat), X0.6, umbilical view, Upper Cenomanian, Galala Formation, W. El Dakhl section; 14-15. Ceratostreon flabellatum (Goldfuss), X1, 14: external view of left valve, 15: internal view of left valve. Cenomanian, Galala Formation, W. El Dakhl section; 16-17. Pycnodonte (Phygraea) vesicularis (Lamarck) vesiculosa (Sowerby), X1, 16: external view of left valve, 17: internal view of left valve, Cenomanian, Galala Formation, W. El Dakhl section.

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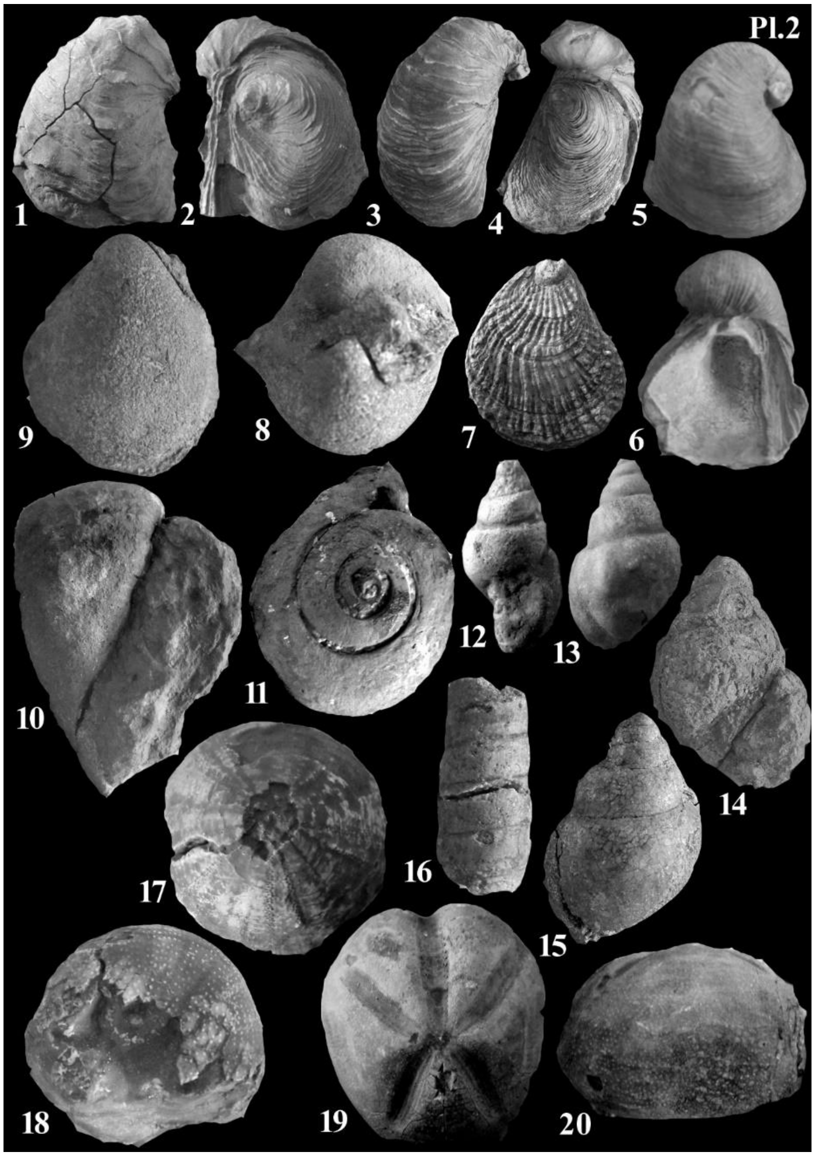

Figure 7. 1-2. *Exogyra conica* (Sowerby), X1, 1: external view of left valve, 2: internal view of right valve, Cenomanian, Galala Formation, W. Um-Artah section; 3-4. *Ilymatogyra africana* (Lamarck), X1, 3: external view of left valve, 4: external view of right valve, Cenomanian, Galala Formation, W. Um-Artah section; 5-6. *Rhynchostreon suborbiculatum* (Lamarck), X1, 5: external view of left valve, 6: external view of right valve, Cenomanian, Galala Formation, W. Um-Artah section; 7. *Plicatula auressensis* Coquand, X1, external view of right valve, Turonian, Maghra El-Hadida Formation, W. El Dakhl section; 8-9. *Granocardium productum* (Sowerby), X1, 8: dorsal view, 9: external view of left valve, Cenomanian, Galala Formation, W. Um-Artah section; 10-11. *Pterocera incerta* (D'orbigny), X0.5, 10: apertural view, 11: adapical view, Cenomanian, Galala Formation, W. Um-Artah section; 12-13. *Colombellina* (*Colombellina*) *fusiformis* (Douville), X1, 12: apertural view, 13: abapertural view, Cenomanian, Galala Formation, W. El Dakhl section; 14-15. *Tylostoma pallaryi* (Peron and Fourtau), X1, 14: apertural view, 15: abapertural view, Cenomanian, Galala Formation, W. El Dakhl section; 16. *Nerinea olisiponensis* (Sharpe), X1.3, Side view, Cenomanian, Galala Formation, W. Um-Artah section; 17-18. *Orthopsis ovata* (Coquand), X1, 17: adapical view, 18: dorsal view, Upper Turonian, W. El Dakhl section; 19-20. *Hemiaster cubicus* (Conrad), X0.7, 19: adapical view, 20: side view, Cenomanian Galala Formation, W. Um-Artah section.

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4.6. *Coilopoceras requienianum* zone (Late Turonian)

D'Orbigny [22] defines this zone as the total range zone. It is represented by the uppermost part of the Maghra El-Hadida formation, covering ~25m at W. Um-Artah section and ~4m at W. El Dakhl section. The same zone is recorded in the Eastern Desert [36] and in Sinai [37-38].

5. Sequence stratigraphy

The sequence stratigraphy of the Upper Cenomanian-Turonian strata has been attempted by many authors, such as Bachmann and Kuss [39] and Wilmsen and Nagm [40]. Four 3rd depositional sequences are recorded in the study area, based on the integrations of the field observations, lithologic and macrofaunal analyses (Figures 3 and 4). The calibration of the depositional sequences using the biostartigraphic zones is helpful for correlating the stratigraphic surfaces with those in other regions (Figure 8). These depositional sequences and its stratigraphic surface are described as follows:

5.1. Depositional sequence 1 (DS1)

The first DS1 comprises ~43m and 40m of Galala formation at W. Um-Artah and W. El Dakhl, respectively (Figures 3 and 4). It is of Late Cenomanian age.

The Galala/Malha formational boundary represents the lower sequence boundary (SB Ce 4). This SB Ce 4 is an unconformity surface which is easy to identify in the field by vertical facies variation of Malha (non-marine deposit)/Galala (marine deposit) contact. The SB Ce 4 is herein placed at the base of Neolobites vibrayeanus Zone, which is equivalent to Calycoceras (Proeucalycoceras) guerangeri Zone at European basins. So, the SB Ce4 in the present study is mismatching with Ce 4 at the European basins [41] due to the absence of Acanthoceras jukesbronei Zone (or its equivalent zone in this region). Also, it is nearly coincidence with the SB Ce 4 at the North Eastern Desert of Nagm and Wilmsen [21]. The SB Ce 4 (the base of DS 1) coincides with the transgressive surface (TS).

The transgressive systems tract (TST) of this sequence attains about 37m thick of shales, siltstones, and silty marl with limestone intercalations at W. Um-Artah section. The TST at W. El Dakhl section attains about 32m thick of siltstone and silty marl with limestone intercalations. The high density and diversity of oysters, gastropods and echinoids with bioturbated limestone reflect a shallow open lagoon environment within the TST. A thick limestone bed that contains abundant of ammonite Neolobites vibrayeanus and nautiloid Angulithes mermeti associated with abundant macro-faunal content is marked the maximum flooding surface (MFS).

The highstand systems tract (HST) of this sequence attains ~5m of silty limestone with limestone intercalations at W. Um-Artah section and ~8m of shale and limestone at W. El Dakhl section (Figures 3 and 4).

5.2. Depositional sequence 2 (DS2)

DS2 covers the upper Cenomanian-lower Turonian transition. The SB Ce 5 (base of the DS2) is recorded at the notable lithological variations from fossiliferous limestone and green shale of the uppermost part of the *Neolobites vibrayeanus* Zone to siltstone and sandstone of the lowermost part of the *Vascoceras cauvini* Zone. This SB Ce5 is equivalent to the SB Ce5 at North Eastern Desert [21], Ce 5 at European basins [41], SB at Tunisia [44] (Tunisia) and SB at Anglo-Paris basin [43] (Figure 8). The absence of *Metoicoceras geslinianum* zone documented this unconformity surface (SB Ce5).

The depositional sequence (DS2) is represented by ~51m at W. Um-Artah and ~15m at W. El Dakhl sections. The TST of DS 2 is ~29m of siltstone, nodular marl, shale, marl and limestone intercalations at W. Um-Artah and ~11m of sandstone, shale, silty limestone and topped by limestone at W. El Dakhl section with abundant of the fossil content in the upper TST marking the MFS, which overlain by the HST.

This HST is ~ 22m of shale with limestone intercalations at W. Um-Artah and ~4m of limestone at W. El Dakhl sections (Figures 3 and 4). The HST includes the latest Cenomanian ammonite Vascoceras cauvini and the Early Turonian Vascoceras proprium and Choffaticeras (Ch.) segne zones. The Vascoceras cauvini Zone rests over the SB Ce 5, indicating a stratigraphic gap due to the missing of Metoicoceras geslinianum Zone of middle-Late Cenomanian at the study area. Nagm et al. [7] noted that this zone is mostly missing in Egypt.

5.3. Depositional sequence 3 (DS3)

The DS3 covers the Middle Turonian interval and represented by the upper part of the Maghra El-Hadida formation at the two studied sections. This DS3 is barren of any ammonites. It belongs to the Middle Turonian age based on its stratigraphic

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position. The DS3 attains ~16m at W. Um-Artah and ~7m at W. El Dakhl sections.

The DS3 is bounded at the base by SB Tu 1 and topped by SB Tu 2. According to the zones comparison, the SB Tu 1 matches with Tu 1 at European basins [41], while this SB Tu 1 is mismatch with that of North Eastern Desert [21], due to missing of *Watinoceras munieri*/*Mammites nigeriense* zone at this study. The TST of the DS3 attains ~9m at W. Um-Artah and ~4m at W. El Dakhl sections. This TST is composed of sandstones, silty shale, and siltstone at W. Um-Artah and nodular marl at W. El Dakhl sections.

The HST of the DS3 is composed of shale, marly shale and nodular marl in W. Um-Artah and nodular marl with limestone in the W. El Dakhl sections. It attains ~7m at W. Um-Artah and ~3m at W. El Dakhl sections (Figures 3, 4).

5.4. Depositional sequence 4 (DS4)

The fourth depositional sequence (DS4) is represented by Upper Turonian sediments of the uppermost part of the Maghra El-Hadida formation. This depositional sequence attains ~22m and ~4m at W. Um-Artah and W. El Dakhl sections, respectively.

The DS4 is bounded at base by sequence boundary SB Tu 2 and topped by sequence boundary SB Tu 3. The SB Tu 2 in the study area is equivalent to Tu3 at European basins [41] and SB Tu 3 at the North Eastern Desert [21]. The boundary between DS 3 and DS 4 is marked by the vertical facies change from carbonate facies of the uppermost DS 3 to clastic facies of the lowermost DS 4. Also, the SB Tu 3 matches with Tu4 in the European basins [41] and SB Tu 4 at the North Eastern Desert [21].

The TST consists of ~8m of sandstone, nodular marl with limestone intercalations at W. Um-Artah section, and ~2m of limestone at W. El Dakhl section. It is topped by MFS which is marked by frequent occurrence of the ammonite *Coilopoceras requienianum*. The HST is composed of hard fossiliferous limestone and shale with limestone intercalations in W. Um-Artah section and limestone in the W. El Dakhl section. It attains ~14m at W. Um-Artah and ~2m at W. El Dakhl sections. The DS4 is topped by the SB Tu 3 which is marked by vertical facies change from marl or shale of the uppermost part of the Maghra El-Hadida formation (DS 4) to sandstones of the lowermost part of the Matulla formation.

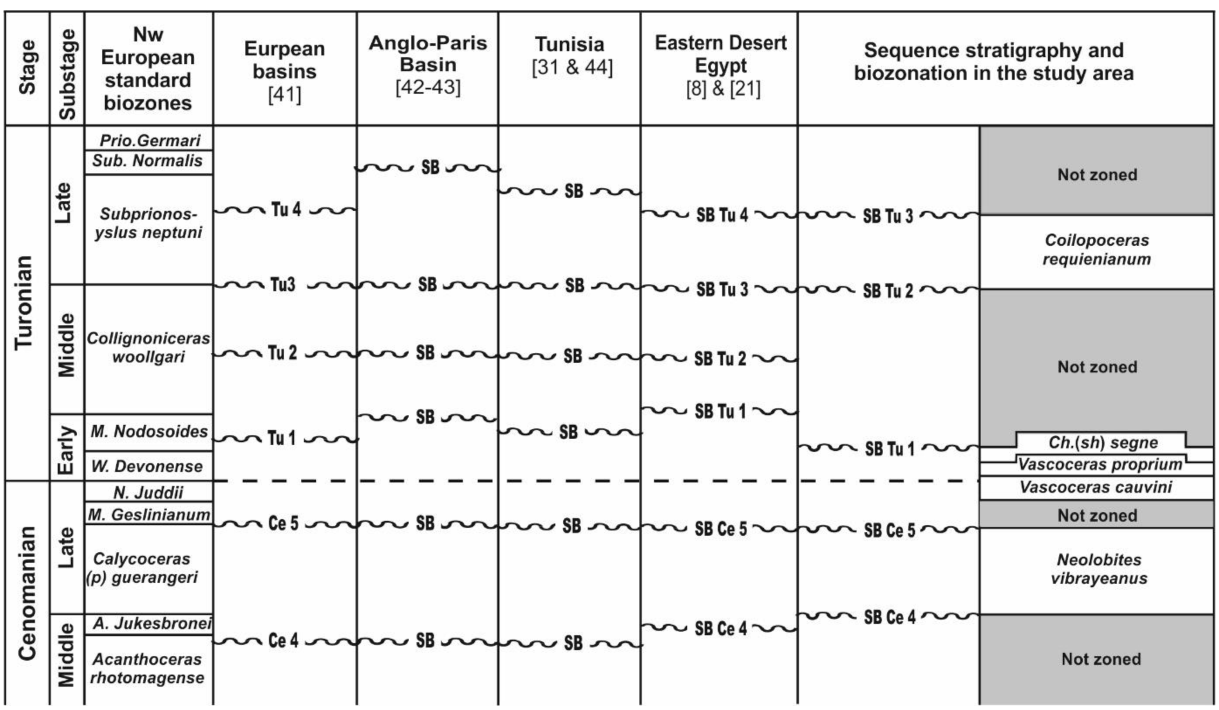

Figure 8. Diagram showing the different sequence boundaries correlation in the study area with those in the Middle East, North Africa, and Europe; DS, depositional sequence; SB, sequence boundary; Ce, Cenomanian; Tu, Turonian.

6. Conclusions

- The Upper Cenomanian-Turonian successions at Southern Galala Plateau, Eastern Desert, Egypt, have been studied in two exposures, namely: W. El Dakhl (northward) and W. Um-Artah (southward). Lithostratigraphically, these successions are subdivided into: Galala (Late Cenomanian) and Maghra El-Hadida (latest Cenomanian-Turonian).
- These successions are unconformably underlain by the Malha Formation of Lower Cretaceous-Middle Cenomanian age and unconformably overlain by the Matulla Formation of Coniacian-Santonian age. The shallow marine Galala Formation represents the first marine transgression over the study area, which consists of siltstone and silty marl with limestone intercalations topped by thick green shale intercalated with hard limestone at W. El Dakhl section and shales, limestone, siltstone and nodular marl with oyster limestone intercalations topped by hard silty limestone at W. Um-Artah section.
- Biostratigraphically, five ammonite zones are defined throughout the Upper Cenomanian- Turonian; Neolobites vibrayeanus and Vascoceras cauvini zones of Late Cenomanian; Vascoceras proprium and Choffaticeras (Ch.) segne zones of Early Turonian and Coilopoceras requienianum Zone of Late Turonian, while the middle Turonian is barren of ammonites.
- Five sedimentary unconformity surfaces (Ce4, Ce5, Tu1, Tu2 and Tu3 sequence boundaries) have been recognized. These sequence boundaries outlined four third order depositional sequences (DS 1-4).
- These sequence boundaries are correlated with others in the Middle East, North Africa, and Europe regions. In comparison with the sequence boundaries at the European basins for example, the sequence boundary SB Ce 4 is mismatching with Ce 4 at the European basins. On the other hand, The SB Ce 5 matches with the SB Ce 5 at European basins. During the Turonian, the SB Tu 1 matches with Tu 1 at European basins. At the same time, The SB Tu 2-3 in the study area is equivalent to Tu 3-4 at European basins.

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References

[1] Kassab, A. S. (1996). Cenomanian - Turonian boundary in the Gulf of Suez region, Egypt: towards an inter-regional correlation, based on ammonites. Geological Society of Egypt, Special Publication, 2, 61-98.
[2] Zakhera, M. S., & Kassab, A. S. (2002). Integrated macrobiostratigraphy of the Cenomaniane Turonian transition, Wadi El-Siq, west central Sinai, Egypt. Egyptian Journal of Paleontology, 2, 219-233.
[3] Abdel-Gawad, G. I., El Qot, G. M., & Mekawy, M. S. (2007). Macrobiostratigraphy of the Upper Cretaceous succession from southern Galala, Eastern Desert, Egypt. 2th international conference of the Tethys, Cairo University, 329-349.
[4] El Qot, G. M. (2008). Upper Cenomanian-Lower Santonian ammonites from Galala Plateau, North Eastern Desert, Egypt: A systematic Paleontology. Egyptian Journal of Paleontology, 8, 247-289.
[5] El Qot, G. M., & Afify, A. M. (2010). Macrobiostratigraphy of the Um Horeiba - El Giddi Upper Cretaceous succession, westcentral Sinai, Egypt. Egyptian Journal of Paleontology, 10, 123-144.
[6] El Sheikh, H., El-Beshtawy, M., Qot, G. M., & Shaker, F. (2010). High resolution biostratigraphy of the Upper Cretaceous - Lower Tertiary sequence of Saint Paul and Sudr El-Hitan on both sides of the Gulf of Suez, Egypt. Egyptian Journal of Paleontology, 10, 179-225.
[7] Nagm, E., Wilmsen, M., Aly, M. F., & Hewaidy, A. (2010). Upper Cenomanian-Turonian (Upper Cretaceous) ammonoids from the western Wadi Araba, Eastern Desert, Egypt. - Cretaceous Research, 31, 473-499. https://doi.org/10.1016/j.cretres.2010.05.008
[8] Nagm, E., Wilmsen, M., Aly, M. F., & Hewaidy, A. (2010). Biostratigraphy of the Upper Cenomanian - Turonian (lower Upper Cretaceous) successions of the western Wadi Araba, Eastern Desert, Egypt. Newsletter on Stratigraphy, 44 (1), 17-35. https://doi.org/10.1127/0078-0421/2010/0002
[9] Nagm, E. (2015). Stratigraphic significance of rapid faunal change across the Cenomanian-Turonian boundary in the Eastern Desert, Egypt. Cretaceous Research, 52, 9-24. https://doi.org/10.1016/j.cretres.2014.07.005

[10] Nagm, E. (2019). The late Cenomanian maximum flooding *Neolobites* bioevent: A case study from the Cretaceous of northeast Egypt. Marine and Petroleum Geology, 102, 740-750. https://doi.org/10.1016/j.marpetgeo.2019.01.037

[11] Darwish, M., Abdel-Maksoud, N., Zakhera, M., & Obaidala, N. (2023). Paleoecology and paleogeography of the Cenomanian-Turonian macrofossils, north Eastern desert and Sinai, Egypt. New Valley University Journal of Basic and Applied Sciences, 1(1), 45-64. https://doi.org/10.21608/nujbas.2022.117895.1001

[12] Mahfouz, K. H., Hewaidy, A. A., Mostafa, A., & El-Sheikh, I. (2018). Resolution enhancement of foraminiferal biostratigraphy of the Campanian-Maastrichtian interval: A case study from the Eastern Desert, Egypt. Journal of African Earth Science, 145, 215-226. https://doi.org/10.1016/j.jafrearsci.2018.06.003

[13] Abdallah, A. M., & Adindani, A. (1963). Notes on the Cenomanian-Turonian contact in the Galala Plateau, Eastern Desert, Egypt. Egypt. -Egyptian Journal of Geology, United Arab Republic, 7 (1), 67-70.

[14] El Akkad, S. E., & Abdallah, A. M. (1971). Contribution to the geology of Gebel Ataqa area. Annals of the Geological Survey of Egypt, 1, 21-42.

[15] Wilmsen, M., Niebuhr, B., & Hiss, M. (2005). The Cenomanian of northern Germany: facies analysis of a transgressivebio sedimentary system. Facies, 51, 242-263. https://doi.org/10.1007/s10347-005-0058-5

[16] Gradstein, F. M., Ogg, J. G., & Smith, A. G. (2004). A geologic time scale. Cambridge University Press, New York, 2004, P 589.

[17] Aly, M. F., Samadi, A., & Abu Azzam. H. (2008). Late Cenomanian-Early Turonian ammonites of Jordan. Revue de Paleobiologie, 27, 43-71.

[18] Kassab, A. S., & Obaidalla, N. A. (2001). Integrated biostratigraphy and inter-regional correlation of the Cenomanian-Turonian deposits of Wadi Feiran, Sinai, Egypt. Cretaceous Research, 22, 105-114. https://doi.org/10.1006/cres.2000.0240

[19] Abdel-Gawad, G. L., El-Sheikh, H. A., Abdelhamid, M. A., El-Beshtawy, M. K., Abed, M. M., Fursich, F. T., & El Qot, G. M. (2004). Stratigraphic studies on some Upper Cretaceous successions in Sinai, Egypt. Egyptian Journal of Paleontology, 4, 263-303.

[20] Hewaidy, A. A., Azab, M. M., & Farouk, S. (2003). Ammonite biostratigraphy of the Upper Cretaceous succession in the area west of Wadi Araba, north Eastern Desert, Egypt. Egyptian Journal of Paleontology, 3, 331-359.

[21] Nagm, E., & Wilmsen, M. (2012). Late Cenomanian-Turonian (Cretaceous) ammonites from Wadi Qena, central Eastern Desert, Egypt: taxonomy, biostratigraphy and palaeobiogeographic implications. Acta Geologica Polonica, 62 (1), 63-89. https://doi.org/10.2478/v10263-012-0003-1

[22] Orbigny, A. d. (1840-1842). Paléontologie francaise: Terrains crétacés. 1. Céphalopodes. - Masson, Paris.120 (1840), 121-430 (1841), 431-662 (1842).

[23] Abdel-Gawad, G. I., El Qot, G. M., & Mekawy. M. S. (2006). Cenomanian-Turonian macrobiostratigraphy of Abu Darag area, Northern Galala, Eastern Desert, Egypt. 8th International Conference on the Geology of the Arab World, Cairo University, 2, 553-568.

[24] Abdallah, H., Sassi, S., Meister, C., & Souissi, R. (2000). Stratigraphie séquentielle et paléogéographie a la limite Cénomanien- Turonien dans la région de Gafsa-Chott area (Tunisie centrale). Cretaceous Research, 21, 35-106. https://doi.org/10.1006/cres.2000.0200

[25] Amard, B., Collignon, M., & Roman, J. (1981). Etude stratigraphique et paleontologique du Cretace superieur et Paleocene du Tinhert-W et Tademait- E (Sahara Algerien). Documents des Labor. de Geolog. Lyon, Hors Serie, 6, 15-173.

[26] Chudeau, R. (1909). Ammonites du Damergou (Sahara meridional). Bulletin de la Société Géologique de France, 9 (4), 67-71.

[27] Meister, C., Alzouma, K., Lang, J., & Mathey, B. (1992). Les ammonites du Niger (Afrique occidentale) et la transgression transsaharienne au cours du Cénomanien-Turonien. Geobios, 25, 55-100. https://doi.org/10.1016/S0016-6995(09)90038-9

[28] Courville, P., & Thierry, J. (1993). Nouvelles données biostratigraphiques sur les dépôts cénomano-turoniens du Nord-Est du fossé de la Bénoué. - Cretaceous Research, 14, 385-396. https://doi.org/10.1006/cres.1993.1027

[29] Reyment, R. A. (1954). Some new Upper Cretaceous Ammonites from Nigeria. – Colonal Geological Mineral Resources, 4(3), 248-270.

[30] Hewaidy, A. A., Awad, M. H., Farouk, S., & El Balkeimy, A. (2012). Cenomanian biostratigraphy and sequence

stratigraphy of southern Galala plateau, north Eastern Desert, Egypt. Egyptian Journal of Paleontology, 12, 143-172.

[31] Robaszynski, F., Caron, M., Dupuis, C., Amédro, F., González Donoso, J. M., Linares, D., Hardenbol, J., Gartner, S., Calandra, F., & Deloffre, R. (1990). A tentative integrated stratigraphy in the Turonian of central Tunisia: formations, zones and sequential stratigraphy in the Kalaat Senan area. Bulletin des Centres de Recherches Exploration- Production, Elf-Aquitaine, 14, 213-384.

[32] Birkelund, T., Hancock, J. M., Hart, M. B., Rawson, P. F., Remane, J., Robaszynski, F., Schmid, F., & Surlyk, F. (1984). Cretaceous stage boundaries- Proposals. Bulletin of the Geological Society of Denmark, 33, 3-20.

[33] Aly, M. F., & Abdel Gawad, G. I. (2001). Upper Cenomanian- Lower Turonian ammonites from north and central Sinai, Egypt. - El-Minia Science Bulletin, 13 (2) - 14 (1), 17-60.

[34] Solger, F. (1903). Über die Jugendentwicklung von Sphenodiscus lenticularis Owen und seine Beziehungen zur Gruppe der Tissotien. Zeitschrift der Deutschen Geologischen Gesellschaft, 55. 69-84.

[35] Hanna, W. (2011). Taxonomy and palaeoecology of the Cenomanian-Turonian macroinvertebrates from eastern Sinai, Egypt. Ph.D Thesis, Würzburg University, 1412.

[36] Nagm, E. (2009). Integrated stratigraphy, palaeontology and facies analysis of the Cenomanian-Turonian (Upper Cretaceous) Galala and Maghra El-Hadida formations of the western Wadi Araba, Eastern Desert, Egypt. PhD thesis, Würzburg University (Germany), 1-213.

[37] El Qot, G. M. (2006). Late Cretaceous macrofossils from Sinai, Egypt. Beringeria, 36, 3-163.

[38] Khalil, H. M. (2007). Macrobiostratigraphical, paleoecological and paleobiographical studies of the Cenomanian-Turonian transition of Wadi Watir (El Sheikh Attia), Sinai. Egypt. Egyptian Journal of Paleontology, 7, 245-267.

[39] Bachmann, M., & Kuss, J. (1998). The Middle Cretaceous carbonate ramp of the northern Sinai: sequence stratigraphy and facies distribution. Geological Society Special Publication, 149, 253-280.

[40] Wilmsen, M., & Nagm, E. (2013). Sequence stratigraphy of the lower Upper Cretaceous (Upper Cenomanian-Turonian) of the Eastern Desert, Egypt. Newsletter on Stratigraphy, 46 (1), 23-46. https://doi.org/10.1127/0078-0421/2013/0030

[41] Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., De Graciansky, P.C., Vail, P.R., 1998. Cretaceous sequence stratigraphy, Chart 4. In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T., Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins, 60. SEPM (Society for Sedimentary Geology) Special Publication, pp. 3-13.

[42] Gale, A. S. (1996). Turonian correlation and sequence stratigraphy of the Chalk in southern England. In: Hesselbo, S. P., & Parkinson, D. N. (Eds.): Sequence Stratigraphy in British Geology. Geological Society London, Special Publication, 103, 177-195.

[43] Robaszynski, F., Gale, A. S., Juignet, P., Amédro, F., & Hardenbol, J. (1998). Sequence stratigraphy in the Cretaceous series of the Anglo-Paris Basin: exemplified by the Cenomanian stage. In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T., & Vail, P. R. (Eds.), Mesozoic and Cenozoic sequence stratigraphy of European basins. SEPM (Society for Sedimentary Geology) Special Publication, 60, 363-386.

[44] Robaszynski, F., Hardenbol, J., Caron, M., Amédro, F., Dupuis, C., González Donoso, J. M., Linares, D., & Gartner, S. (1993). Sequence stratigraphy in a distal environment: the Cenomanian of the Kalaat Senan region (Central Tunisia). Bulletin des Centres de Recherches Exploration- Production, Elf-Aquitaine, 17, 395-433.