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Upper Cenomanian – Lower Turonian (Cretaceous) calcareous algae from the Eastern Desert of Egypt: taxonomy and significance

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Abstract. An assemblage of calcareous algae (dasycladaleans and halimedaceans) is described from the Upper Cenomanian to Lower Turonian of the Galala and Maghra el Hadida formations (Wadi Araba, northern Eastern Desert, Egypt). The following taxa have been identified: *Dissocladella* sp., *Neomeris mokragorensis* RADOIČIĆ & SCHLAGINTWEIT, 2007, *Salpingoporella milovanovici* RADOIČIĆ, 1978, *Trinocladus divnae* RADOIČIĆ, 2006, *Trinocladus* cf. *radoicicae* ELLIOTT, 1968, and *Halimeda* cf. *elliotti* CONARD & RIOULT, 1977. Most of the species are recorded for the first time from Egypt. Three of the identified algae (*T. divnae*, *S. milovanovici* and *H. elliotti*) also occur in Cenomanian limestones of the Mirdita zone, Serbia, suggesting a trans-Tethyan distribution of these taxa during the early Late Cretaceous. The abundance and preservation of the algae suggest an autochthonous occurrence which can be used to characterize the depositional environment. The recorded calcareous algae as well as the sedimentologic and palaeontologic context of the Galala Formation support an open-lagoonal (non-restricted), warm-water setting. The Maghra el Hadida Formation was mainly deposited in a somewhat deeper, open shelf setting. Calcareous algae (*Halimeda* cf. *elliotti* CONARD & RIOULT) are restricted to one level in the uppermost Lower Turonian which indicates a brief return to shallow-water deposition after a significant deepening with maximum flooding during the early Early Turonian.

Keywords: Cretaceous, dasycladalean and halimedacean algae, palaeontological description, environmental significance, Egypt.

INTRODUCTION

Fossiliferous Upper Cretaceous successions are well exposed in the northeastern part of Egypt (Fig. 1). The strata are represented by marine siliciclastics, mixed with carbonates or interfingering with pure limestones at many localities in the northern Eastern Desert (Kuss, 1986a; Nagm, 2009) and Sinai (Kuss, 1989; Bauer et al., 2001, 2002, 2003).

In contrast to other fossil groups such as ammonoids which are fairly well studied (e.g., Luger and Gröschke, 1989; Kassab, 1991; Aly and Abdel-Gawad, 2001; Hewaidy et al., 2003; Nagm et al., *submitted*), few studies have been published on Upper Cretaceous calcareous algae of Egypt (Kuss, 1986b; Kuss and Conrad, 1991; Bauer et al., 2002). These works resulted in the identification of ca. 24 taxa of calcareous algae from different levels within the Cretaceous succession of the Eastern Desert and the Sinai Peninsula (Table 1).

In the present paper we describe for the first time calcareous algae from Upper Cenomanian – Lower Turonian strata of western Wadi Araba, specifically the East Wadi Ghonima section located in the western part of the north Eastern Desert (Fig. 1). The palaeoenvironmental and palaeobiogeographic significances of the records are briefly discussed.

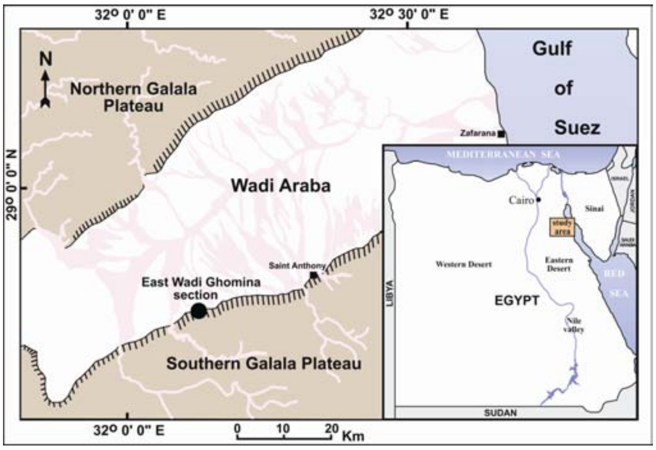

Fig. 1. *Locality map of the study area in Egypt, indicating the position of the East Wadi Ghonima section (see Fig. 2).*

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GEOLOGICAL SETTING

The Wadi Araba is bounded in the north and south by the Galala plateaux and in the east by the Gulf of Suez (Fig. 1). It is about 30 km wide and extends westward to the central Eocene limestone plateau of the Egyptian Eastern Desert. Wadi Araba has a NE–SW trend, following the direction of a regional Syrian Arc anticline structure, which is one of the best-kwon structural features in the north of Egypt (Said, 1990). The Syrian Arc can be traced from Syria to the central Western Desert of Egypt, via Sinai and the northern part of the Eastern Desert. The Galala plateaux, representing a major branch of the Syrian Arc in the Eastern Desert, are characterized by Late Cretaceous uplift in the north and subsidence further to the south. Folding and/or uplift of the Syrian Arc began in post-Cenomanian times (Aal and Lelek, 1994) and reached its acme during the Late Cretaceous (Kuss et al., 2000). Palaeogeographically, Egypt was situated at the southern margin of the Neotethys Ocean during the Cretaceous, at ca. 5° northern palaeo-latitude (Philip and Floquet, 2000) and deposition took place in tropical neritic settings. The early Late Cretaceous probably represents the most pronounced Cretaceous transgression in northern Egypt, with maximum flooding during the Early Turonian (e.g., Sharland et al., 2001; Nagm, 2009), and shallow marine Cenomanian – Turonian deposits are thus very widespread.

The East Wadi Ghonima section is located at the northern slope of the southern Galala Plateau (N 28^{o} 51` 34`` E 32$^{o}$ 09` 25``). At this locality, the most complete upper Middle Cenomanian – Turonian succession in the western Wadi Araba with a total thickness of 215 m is exposed (Fig. 2). It has a very good ammonoid record and serves as a standard section for the study area (Nagm, 2009). The succession commences with a non-marine sandstone unit (Malha Formation), followed unconformably by the Cenomanian Galala Formation. The Galala Formation reaches 95 m in thickness and is characterized by shallow-marine, open lagoonal deposits, comprising silty marls, marls, oyster shell beds and nodular fossiliferous limestones (Nagm, 2009; Fig. 2). The Galala Formation contains three horizons of calcareous algae (Fig. 2; 080217-3, 17-6, and 17-16), which can be dated as early Late Cenomanian (*Neolobites vibrayeanus* Zone; Nagm, 2009; Nagm et al., *submitted*). The upper limit of the Galala Formation is marked by a major unconformity at the base of the overlying Maghra El Hadida Formation. The measured thickness of the Maghra El Hadida Formation is about 118 m. This formation starts with the Wadi Ghonima Member, consisting of a brown, fine- to medium-grained calcareous sandstone unit (Nagm, 2009). The succeeding succession of the Maghra El Hadida Formation is characterized by an increase in carbonate content, represented by yellow, soft marls intercalated with fine-grained wacke- to packstones containing a highly diverse upper Upper Cenomanian to Lower Turonian ammonite assemblage. At the summit of the Lower Turonian, within the upper *Wrightoceras munieri* Zone (Nagm, 2009; Nagm et al., *submitted*), another horizon rich in calcareous algae was encountered (080217-29). The Middle Turonian part of the Maghra El Hadida Formation consists of poorly fossiliferous, thick-bedded, yellowish marls, punctuated by occasionally intercalated, medium- to coarse-grained, hummocky cross-stratified sandstone beds. The upper part of the Maghra El Hadida Formation consists of fossiliferous marly limestones with Upper Turonian ammonites (Nagm, 2009; Nagm et al., *submitted*).

The samples 080217-3, 17-6 and 17-16 from the Galala Formation are bioturbated skeletal wacke- to packstones. Recrystallized mollusc fragments (gastropods and bivalves) are most common, followed by dasycladalean and udoteacean algae as well as echinoderm debris, rare ostracod shells, serpulid tubes and small (?*Gavelinella*-like) foraminifera. Sample 17-16 contains rare foraminifera doubtfully ascribed to the genus *Pseudorhipidionina*. The fabric is inhomogeneous and the proportion of components is variable due to bioturbation.

Sample 080217-29 from the Maghra el Hadida Formation is a *Halimeda* wackestone. The udoteacean thalli are up to 5 mm long and float in a muddy–peloidal matrix. They are associated by fragments of gastropods, bivalves, echinoderms, worm tubes and ostracods (in decreasing importance). Foraminifera have not been observed. The inhomogenous fabric suggests bioturbation.

SHORT DESCRIPTION OF THE ALGAE

The first report of calcareous algae in Cretaceous deposits from Egypt was given by Kuss (1986b) who described dasycladaleans, udoteaceans and rhodophyceans from the Eastern Desert. Further records of calcareous algae from northeastern Egypt and southern Jordan have been published by Kuss and Conrad (1991) and Kuss (1994).

The calcareous algae described in this paper consist of the following taxa of dasycladalean and halimedacean green algae: *Dissocladella* sp., *Neomeris mokragorensis* RADOIČIĆ & SCHLAGINTWEIT, 2007, *Salpingoporella milovanovici* RADOIČIĆ, 1978, *Trinocladus divnae* RADOIČIĆ, 2006, *Trinocladus* cf. *radoicicae* ELLIOTT, 1968, and *Halimeda* cf. *elliotti* CONARD & RIOULT, 1977. Almost all of the taxa of this assemblage are reported for the first time from Egypt. Among the dasycladaleans, only *S. milovanovici* was doubtfully recorded (as *Salpingoporella* cf. *milanovici* RADOIČIĆ, 1978) by Kuss and Conrad, 1991, p. 875, Fig. 4.16).

Neomeris mokragorensis RADOIČIĆ & SCHLAGINTWEIT, 2007

Pl. I, Figs. 1-4.
?1986b – *Neomeris cretacea* – Kuss, p. 228, Fig. 5d.
2007 – *Neomeris mokragorensis* sp. nov. – Radoičić and Schlagintweit, 2007, p. 43, Pl. 1, Figs. 1-12; Pl. 2, Figs. 1-3; Pl. 3, Figs. 1-6. [Late Albian-Santonian, with synonymy].
Dimensions:
D (external diameter) = 1.1-1.65 mm
d (diameter of the axial cavity) = 0.8-1.05 mm
d/D = 0.64-0.73
w (number of ampullae per verticil) = 25
Diameter of ampullae = 0.10/0.12 to 0.17/0.20 mm
These dimensions fit well into the dimensional range given for the species by Radoičić and Schlagintweit (2007).
Discussion: *Neomeris mokragorensis* is characterized by calcification related mostly to the fertile, spheroidal ampullae. Plate I, Fig. 1 illustrates a strongly calcified specimen, but the subsphaerical ampullae indicate *N. mokragorensis*. The transverse and longitudinal-oblique sections in Plate I, Fig. 2 and 3, respectively

are more characteristic for the species. Figure 2 in Plate I shows a specimen with sparitic internal molds of the ampullae, while in Fig. 3 the ampullae have a thin sparitic sheath, the internal part being filled with micritic sediment.

Local occurrence: Lower Upper Cenomanian of the Galala Formation (sample 080217-3 and -17-6). Stratigraphical range: Late Albian-Santonian (Late Albian-Turonian of Serbia; Late Turonian-Late Santonian of the Northern Calcareous Alps; Radoičić and Schlagintweit, 2007).

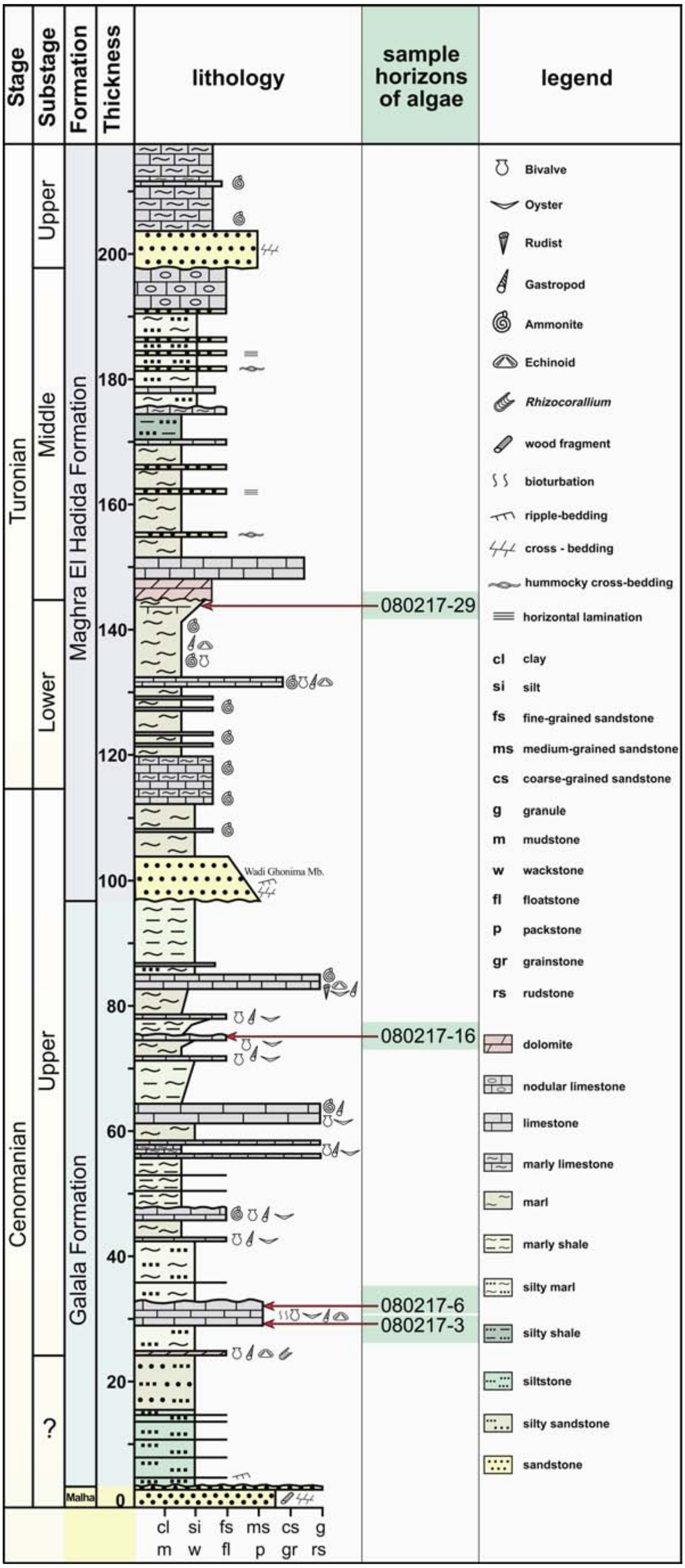

Fig. 2. *Stratigraphic log of the East Wadi Ghonima section, showing the sample horizons of the calcareous algae.*

Table 1. Previously identified Cretaceous calcareous algae from Egypt (Al. = Albian; Ce. = Cenomanian; T. = Turonian; Co. = Coniacian; S. = Santonian; Ca. = Campanian; Ma. = Maastrichtian; E.D. = Eastern Desert.

Calcarous algae	**Cretaceous Stages**							**locality**		**recorded by**
	Al.	Ce.	T.	Co.	S.	Ca.	M.	E. D.	Sinai	
Clypeina sp.	■	■							■	Kuss and Conrad, 1991
Cylindroporella aff. *C. barnesii*	■								■	
Cylindroporella parva		■						■		
Cylindroporella sugdeni	■								■	
Trinocladus tripolitanus		■	■					■		Kuss, 1986b; Kuss and Conrad, 1991
Dissocladella undulata		■	■	■		■		■		
Neomeris cretacea	■	■	■					■	■	Kuss and Conrad, 1991; Bauer et al., 2002
Praturlonella hammudai		■						■		Kuss and Conrad, 1991
Salpingoporella dinarica	■	■							■	
Salpingoporella cf. *milanovici* (sic!)		■							■	
Suppiluliumaella aff. *S. schroederi*		■							■	
Griphoporella sp.		■	■					■		Kuss, 1986b
Acicularia sp.		■	■					■	■	Kuss, 1986b; Bauer et al., 2002
Bouenia pygmaea		■	■			■	■	■	■	
Bouenia cf. *hochstetteri*			■						■	Bauer et al., 2002
Halimeda sp.		■	■					■	■	Kuss and Conrad, 1991
Permocalculus budaensis			■						■	
Permocalculus irenae		■							■	
Pseudochaetetes sp.		■	■					■		Kuss, 1986b
Parachaetetes asvapatii						■	■	■		Kuss, 1986b; Kuss and Conrad, 1991
Parachaetetes cf. *P. hadhramautensis*	■								■	Kuss and Conrad, 1991
Pseudolithothamnium album						■	■	■		Kuss, 1986b
Arabicodium aegagrapiloides			■						■	Bauer et al., 2002
Marinella lugeoni			■						■	

Trinocladus divnae RADOIČIĆ, 2006

Pl. I, Figs. 5, 7, 8, 10.
2006 – *Trinocladus divnae* sp. nov. – Radoičić, p. 66, text-Fig. 2, Pl. 1, Pl. 2, Figs. 1-8, Pl. 3, Figs. 1-6, 10-11.
Dimensions:
D = 0.66-1.2 mm
d = 0.18-0.21 mm
w (number of primary laterals per verticil) = aprox. 6-7
Discussion: The specimens from Egypt show the same general states of preservation as the specimens from Serbia. The outline of the main stem is visible in only one small specimen (Pl. I, Fig. 5, lower right corner). Other specimens (e.g., Pl. I, Fig. 7) show the characteristic calcification of cup-like units of laterals. Larger specimens have a calcification reduced to the distal part of secondaries, and to the tertiary laterals (Pl. I, Fig. 5, lower left and upper part; Pl. I, Fig. 10). Eventually, some specimens are almost completely recrystallized, displaying only the terminations of the tertiary laterals.
Local occurrence: Lower Upper Cenomanian of the Galala Formation (sample 080217-6 and 17-16).
Stratigraphic range: The type specimens are from the Albian-Cenomanian (Radoičić, 2006).

Trinocladus sp. cf. *T. radoicicae* ELLIOTT, 1968

Pl. II, Fig. 3.
A single specimen in sample 080217-16 shows characteristic features which are close to *Trinocladus radoicicae* (Elliott, 1968): small thallus (D = 0.65 mm; d = 0.25 mm) with primary laterals swelling out markedly before giving rise to thinner secondaries and tertiaries. The type specimens were described from Maastrichtian of Iraqi Kurdistan. The poor state of preservation of the Egyptian specimen from the lower Upper Cenomanian of the Galala Formation, as well as the different geological age, makes this attribution uncertain.

Dissocladella sp.

Pl. II, Fig. 4.
Small specimen (D = 0.40; d = 0.22) with pear-like primary laterals giving rise to a bush of small vesiculiform secondary laterals. It is recorded from the lower Upper Cenomanian of the Galala Formation (080217-16).

Salpingoporella milovanovici RADOIČIĆ, 1978

Pl. II, Figs. 1-2.
1978 – *Salpingoporella milovanovici* n. sp. – Radoičić, p. 379, Pl. 1-3, Cenomanian
?1991 - ? *Salpingoporella* cf. *Salpingoporella milanovici* Radoičić (sic!) – Kuss and Conrad, p. 876, Fig. 4.16.
1998 – *Salpingoporella milovanovici* RADOIČIĆ – Sgrosso et al., 1998, p. 113-115, Pl. 1, 2.
1999 – *Salpingoporella milovanovici* RADOIČIĆ – Masse and Arnaud-Vanneau, p. 63, Pl. 1, Figs. 13, 14.
Dimensions:
L (maximum observed length) = 3.10 mm
D = 0.26-0.28 mm
d = 0.08-0.09 mm
h (distance between consecutive verticils) = 0.07 mm
l (length of primary laterals) = 0.08-0.09 mm
p (diameter of primary laterals, distal part) = 0.06-0.08 mm
Discussion: A good longitudinal, slightly oblique section was found (Pl. 2, Fig. 1), together with another smaller fragment (Pl. 2, Fig. 2) in sample 080217-16. *Salpingoporella milovanovici* has small dimensions and this, together with an advanced recrystallization, could be why this species is frequently overlooked (Sgrosso et al., 1998), especially in thin sections having other larger dasycladaleans.

Local occurrence: Lower Upper Cenomanian of the Galala Formation.
Stratigraphical range: Cenomanian of the Dinarids (Serbia, Montenegro, Hercegovina) and the Apennines (Radoičić, 1978; Sgrosso et al., 1998); Albian of the West Pacific (Masse and Arnaud-Vanneau, 1999).

Halimeda sp. cf. *Halimeda elliotti* CONARD & RIOULT, 1977

Pl. II, Figs. 5-8.
Dimensions:
Length of segments (maximum) = 4.5 mm
External diameter of the segments = 0.25-0.65 mm
Diameter of the medullary zone – 0.09-0.20 mm
Diameter of the medullary filaments = 0.030-0.040 mm
Diameter of the cortical filaments – 0.015-0.018 mm
Discussion: Numerous fragments of a halimedacen alga were identified in thin section 080217-29. They resemble *Halimeda elliotti* by the less calcified (darker) medullary zone and the more calcified (sparitic) cortical zone. However, some characteristics differentiate these specimens from the type species: the medullary zone is thinner than to the cortical one, and the segments are longer than most segments illustrated by Conard and Rioult (1977). Thus, the taxon is kept in open nomenclature.
Local occurrence: Upper Lower Turonian of the Maghra el Hadida Formation.
Stratigraphical range: *Halimeda elliotti* is known from the Cenomanian-Turonian (Conard and Rioult, 1977; Radoičić, 2006).

CONCLUSION

An assemblage of calcareous algae (dasycladaleans and halimedaceans) is described from Upper Cenomanian to Lower Turonian limestones of the Galala and Maghra el Hadida formations from the western part of the Wadi Araba, northern Eastern Desert, Egypt. The following taxa have been identified: *Dissocladella* sp., *Neomeris mokragorensis* RADOIČIĆ & SCHLAGINTWEIT, 2007, *Salpingoporella milovanovici* RADOIČIĆ, 1978, *Trinocladus divnae* RADOIČIĆ, 2006, *Trinocladus* cf. *radoicicae* ELLIOTT, 1968, and *Halimeda* cf. *elliotii* CONARD & RIOULT, 1977. Most of the species are recorded for the first time from Egypt, and were only recently described in the literature (e.g., Radoičić, 2006; Radoičić and Schlagintweit, 2007). It is interesting to note that three of the identified algae (*T. divnae*, *S. milovanovici* and *H. elliotti*) have also been found to be associated in the Cenomanian limestones from the Mirdita zone, Serbia (Radoičić, 2006), indicating a trans-Tethyan distribution of these taxa during the early Late Cretaceous. However, in the Mirdita zone, Radoičić (2006) found, together with *Trinocladus divnae*, the following foraminifera: *Cuneolina, Nezzazatinella, Pseudolituonella reicheli, Chrysalidina gradata, Cisalveolina fraasi*. Of these taxa, only *P. reicheli* has been recorded from the Galala Formation of the Wadi Ghonima area (Nagm, 2009). Thus, similarities in biofacies of our samples and the Mirdita zone are mainly related to the occurrences of calcareous algae.

The abundance and preservation of dasycladaleans and halimedaceans in theese samples suggest that their occurrence is autochthonous. Thus, their presence can be used for the characterization of the depositional environment. Theese calcareous green algae indicate very shallow, light-saturated, warm-water settings (e.g., Wray 1977; Bucur and Săsăran, 2005).

The sedimentologic and palaeontologic context of the strata support an open-lagoonal (non-restricted) deposition for the Galala Formation (Nagm, 2009). The Maghra el Hadida Formation was mainly deposited in somewhat deeper, open shelf setting unsuitable for benthic algae dependent on light saturation. However, the occurrence of the *Halimeda* cf. *elliotti* is restricted to sediments that accumulated during the latest highstand of a Late Cenomanian – Early Turonian depositional sequence, just below a terminal emergence surface (Nagm, 2009). Thus, their presence in uppermost Lower Turonian strata indicates a brief return to shallow-water deposition after a significant deepening with maximum flooding during the early Early Turonian.

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PLATE I

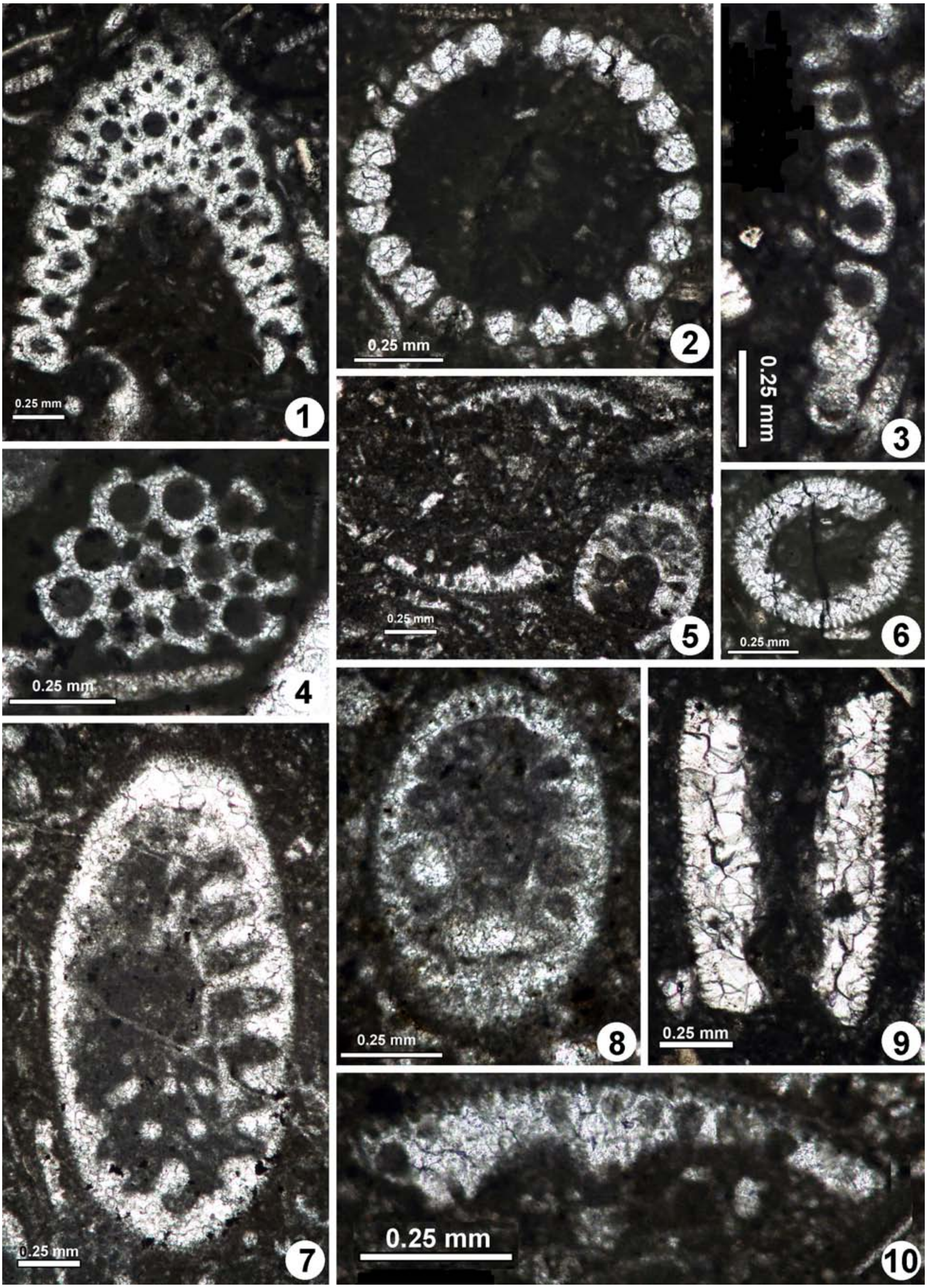

Plate 1. Dasycladalean algae from the lower Upper Cenomanian of the Galala Formation.
Figs. 1-4. *Neomeris mokragorensis* RADOIČIĆ & SCHLAGINTWEIT, 2007. Oblique (1), transverse (2), longitudinal-oblique (3), and tangential (4) sections. 1, 3, 4 – thin section 080217-3; 2 – thin section 80217-6.
Figs. 5, 7, 8, 10. *Trinocladus divnae* RADOIČIĆ, 2006. Oblique (5, 7, 8), and transverse (5) sections. 10 – close-up view of the specimen in Fig. 5 (lower left part). Thin section 80217-16.
Figs. 6, 9. ?*Trinocladus* sp. (strongly recystallized specimens). Thin section 80217-6.

PLATE II

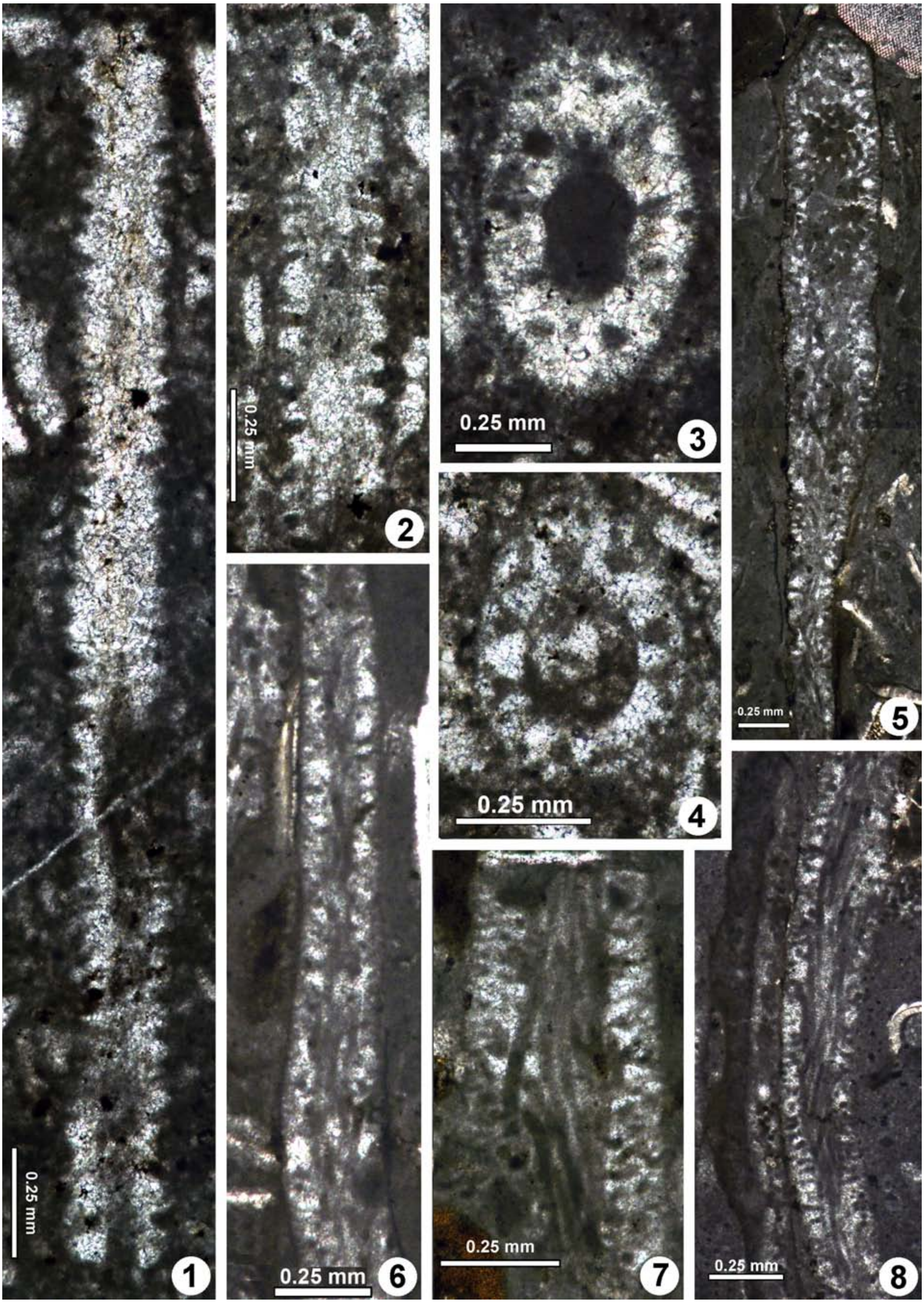

Plate 2. Dasycladalean and halimedacean algae from the lower Upper Cenomanian of the Galala Formation (Figs. 1-4) and upper Lower Turonian of the Magra el Hadida Formation (Figs. 5-8).
Figs. 1, 2. *Salpingoporella milovanovici* RADOIČIĆ, 1978. Longitudinal, slightly oblique sections. Thin section 80217-16.
Fig. 3. *Trinocladus* cf. *radoicicae* ELLIOTT, 1968. Oblique section. Thin section 80217-16.
Fig. 4. *Dissocladella* sp.. Transverse-oblique section. Thin section 80217-16.
Figs. 5-8. *Halimeda* cf. *elliotti* CONARD & RIOULT, 1977. Random longitudinal-oblique sections through segments. Thin section 80217-29.