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Notes

Biostratigraphy, palaeoecology and palaeogeography of the Middle Cenomanian–Early Turonian Levant Platform in Central Jordan based on ostracods

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Abstract: Study of a Cenomanian–Turonian sequence, including the oceanic anoxic event 2 (OAE2) in Central Jordan, yielded 22 ostracod species from the Middle–Late Cenomanian interval; no ostracods were found in the Early Turonian. The majority of the taxa have a wide geographical distribution along the southern shores of the Tethys; from Morocco in the west to the Arabian Gulf region in the east. Biogeographical homogeneity of the ostracod associations in North Africa and the Middle East reflects facilitated communication along the whole expanse of the southern Tethys margin during the Cenomanian, and suggests similar living conditions and absence of important geographical barriers that could hinder marine faunal exchange. Biostratigraphically, the investigated fauna revealed five informal ostracod biozones (I to V from older to younger). The recorded assemblages are characterized by ostracod faunas of typical marine shelf setting in biozone I, shelf lagoonal setting with fresh-water influence in biozone II, marine shelf setting with intervals of fresh-water supply in biozones III and IV, and reduced oxygen levels in the interval of biozone V. This sequence of biozones provides palaeontological evidence for the occurrence of an interval of enhanced fresh-water influence in Levant platform lagoons preceeding OAE2. A combined biostratigraphic and chemostratigraphic time scale based on stable carbon isotopes reveals the first appearance of *Reticulicosta kenaanensis*, previously described as an Early Turonian indicator species already in the Late Cenomanian. Absence of ostracods throughout the Early Turonian indicates environmental conditions adverse to ostracods during most of OAE2 and its aftermath interpreted to reflect strong water column stratification.

Sediments rich in organic matter reflect a significant disturbance in the global carbon cycle related to an oceanic anoxic event (OAE) at the Cenomanian–Turonian (C–T) transition interval (OAE2). Deposits of this global phenomenon are characterized by major biotic changes in microfaunas (e.g. Leckie *et al.* 2002). Increased deposition of organic carbon in the oceans and shelf seas has been explained by both enhanced bio-productivity and unusual preservation of the total organic carbon (TOC) (Arthur *et al.* 1987; Kuypers *et al.* 2002). While the effects of OAEs in pelagic to hemipelagic deposits have been studied intensively, the palaeoenvironmental conditions related to these significant events in the near-shore environments still need to be investigated in more detail. OAE2 was preceeded by a significant sea-level drop, followed by a rapid transgression in conjunction with the onset of a positive $\delta^{13}C$ isotopic excursion, which reflects a disturbance in the global carbon cycle (e.g. Schlanger *et al.* 1987; Voigt *et al.* 2006; Elrick *et al.* 2009; Wendler *et al.* 2010). While being defined as an oceanic event, this anomaly in the life system of Earth also involves the shallow marine and terrestrial environments (e.g. Hasegawa 1997; Davey & Jenkyns 1999). Regarding shallow marine environments, OAE2 is well-developed in North African shelf–sea deposits, including the Levant carbonate platform of the southern rim of the Tethys.

The aim of this paper is to study the ostracod record in the Cenomanian–Turonian section of Ghawr Al-Mazar (GM3) in order to enhance the biostratigraphical framework of the study area, and reconstruct the mid-Cenomanian through Early Turonian palaeo-environmental conditions related to OAE2. The ostracod data are being integrated into a biostratigraphical scheme based on calcareous nannoplankton and ammonites. Biostratigraphy is supported here by a high-resolution stable carbon isotope stratigraphy as an independent chemostratigraphical tool. The ostracod assemblages discussed

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in the present paper represent the prime palaeontological tool for reconstruction of the palaeoecology of the study area because other fossils are scarce and fail to provide continuous records over the section. Previous studies of Cenomanian–Turonian ostracods of Jordan comprise Babinot & Basha (1985), Powell (1989), Basha (1997), and Schulze *et al.* (2004).

Location and stratigraphic setting

The studied section (GM3) is situated at Ghawr Al-Mazar (31°15′34″N; 35°35′41″E) in central Jordan. It crops out in the Wadi system cutting east–west into an extended plateau area east of the Dead Sea (Fig. 1). The Karak Limestone Member is not well-exposed in the studied section. Therefore, a section representing this member at Mujib Dam (MD5), NNE of Ghawr Al-Mazar, was logged into the profile (see Fig. 2). The investigated interval comprises the Middle Cenomanian–Lower Turonian, which incorporates the Fuheis, Hummar, and Shueib Formations (Masri 1963), being subdivisions of the Ajlun Group (Quennel 1951).

Biostratigraphy

The multi-biostratigraphical framework of Schulze *et al.* (2003), using nannofossils and ammonites supported partly by larger benthic foraminifera, forms the base of the stratigraphy presented here (Fig. 2). The section comprises the calcareous nannoplankton zones CC-9 to CC-11. For details on indicative species see Schulze *et al.* (2003). The ammonite occurrences in the Cenomanian–Turonian of Jordan (Schulze *et al.* 2004) provide a relatively detailed biostratigraphy correlated with ammonite zone schemes of southern Europe (Hardenbol *et al.* 1998) and Israel (Lewy 1989, 1990). In conjunction with the isotope record presented here it enables an excellent time control. The Fuheis and Hummar formations (0–56 m) contain abundant *Neolobites vibrayeanus* indicating a Middle to Late Cenomanian age (Fig. 2). In section part 38–43 m, it co-occurs with the larger benthic foraminifer *Praealveolina cretacea* marking the basal Late Cenomanian. *Vascoceras cauvini*, *Metoicoceras geslinianum* and *Burroceras transitorium* indicate ammonite zone T1 for the basal Shueib Formation, correlating with the *M. geslinianum* and *N. juddi* zones of Europe. Ammonite zones T2–4 correlate to the basal CC-11 and can be detected only by scarce and poorly preserved not *in situ* findings of *Choffaticeras pavillieri* and *Ch. quaasi* in section part 67–74 m. The limestone in the top of the section represents the Wala Limestone Member, which is the ammonite marker bed 3 of Schulze *et al.* (2003, 2004). It is characterized at the base by an ammonite assemblage with *Vascoceras durandi*, *Thomasites rollandi*, *Fagesia lenticularis*, *Choffaticeras quaasi* and *Ch. luciae* indicative of zones T5–6a. Transition into zone 6b (*M. nodosoides*/*C. woolgari* zone boundary, base Middle Turonian) was detected by Schulze *et al.* (2003, 2004) in the middle Wala Limestone.

Material and methods

A total of 255 samples from the GM3 (Ghawr Al-Mazar) section were collected at 15–25 cm sample spacing, attaining an 83 metre-thick Middle Cenomanian–Lower Turonian profile. The section exhibits the following lithological units:

0–9 m nodular limestone rich in oysters;

9–18 m dark grey clay with grey nodular limestone beds;

18–40 m (Karak Limestone) laminated limestone alternating with nodular and massive platform limestone and marl beds (recorded at section MD5 (Mujib Dam 5; see Fig. 2; 79 samples);

40–43 m (Hummar Limestone) massive limestone with larger benthic foraminifera;

43–54.8 m green clays and marls;

54.8–57.3 m dolomitic limestone;

57.3–64.8 m platy, bituminuous limestone bed/brown marly clay alternation;

64.8–74 m brown calcareous clays;

74–80 m grey marls;

80–83 m (Wala Limestone) massive platform limestone.

The section presented here (Fig. 2) is a composit with the section part MD5 inserted into section GM3. MD5 represents the most complete record of the Karak Limestone and the Hummar Limestone, which vary considerably in thickness owing to lateral facies shifts. The latter is especially significant for the Hummar Limestone Member, which is replaced in the GM3 section by clays. This lateral facies change is plausible from field observation, mapping (Powell 1989) and the repetitive isotope record at that position (Fig. 2). A gap in the ostracod record in the MD5 section part is due to the fact that this limestone succession is unsuitable for disaggregational processing and isolation of ostracod tests. Abundant ostracods can be observed in thin sections of this material; however, a determination of these specimens on a species level is impossible.

100 g of sample were disaggregated by repeated freezing and thawing in saturated sodium sulphate (Glauber's salt) solution, and washed through sieves at mesh sizes of 20, 63, 100 and 630 μm. The sieved fractions were cleaned by applying 0.5–2 min ultrasonic treatment with parallel microscopic controlling to avoid fossil specimen destruction. Additional cleaning with

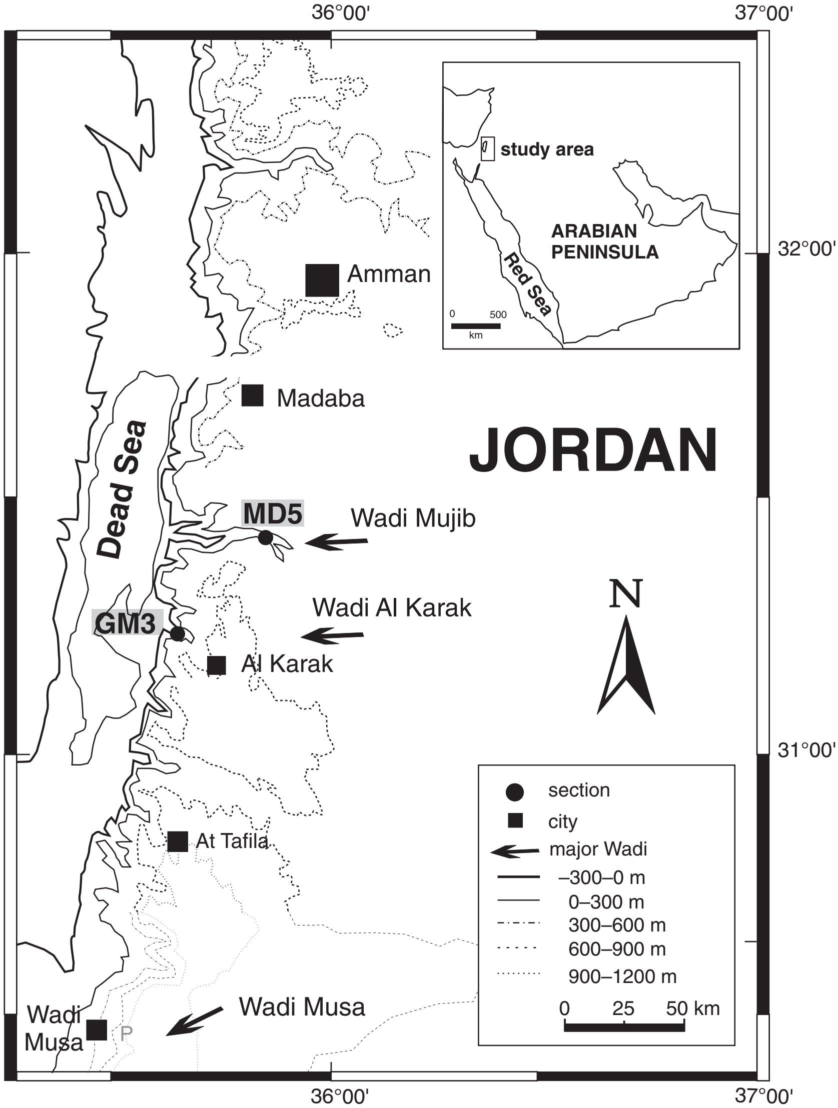

Fig. 1. Location map of the Ghwar Al-Mazar (GM3) section (modified after Schulze *et al.* 2004).

REWOQUAT-tenside was applied when high amounts of clay were present. For intervals with very high amounts of fine fraction up to 500 g of sample were prepared in a second processing in order to obtain more corse fraction and micropalaeontological specimens therin. The 100–630 μm size range was then dry-sieved into fractions 100–250, 250–400 and >400 μm for systematic assessment of ostracods. Systematic subsamples of the 100–250 μm fraction were prepared using a micro splitter. Ostracods were picked at a binocular microscope at 50× magnification. All samples were analysed, but only the samples indicated in Figure 2 yielded ostracods. For taxonomic purpose and documentation, selected specimens of the ostracod faunas were analysed and photographed using a *Cam Scan* SEM at Bremen University, Germany. Samples are stored at the Geology Department, Faculty of Science, Ain Shams University (Cairo, Egypt). Reference numbers (JC-01 to JC-57) are given only to the illustrated specimens. Stable carbon isotopes of bulk carbonate (complete sample set) were measured at the isotope laboratory of Bremen University, Germany, using a Finigan MAT 251 mass spectrometer. The results are reported relative to the PDB-standard.

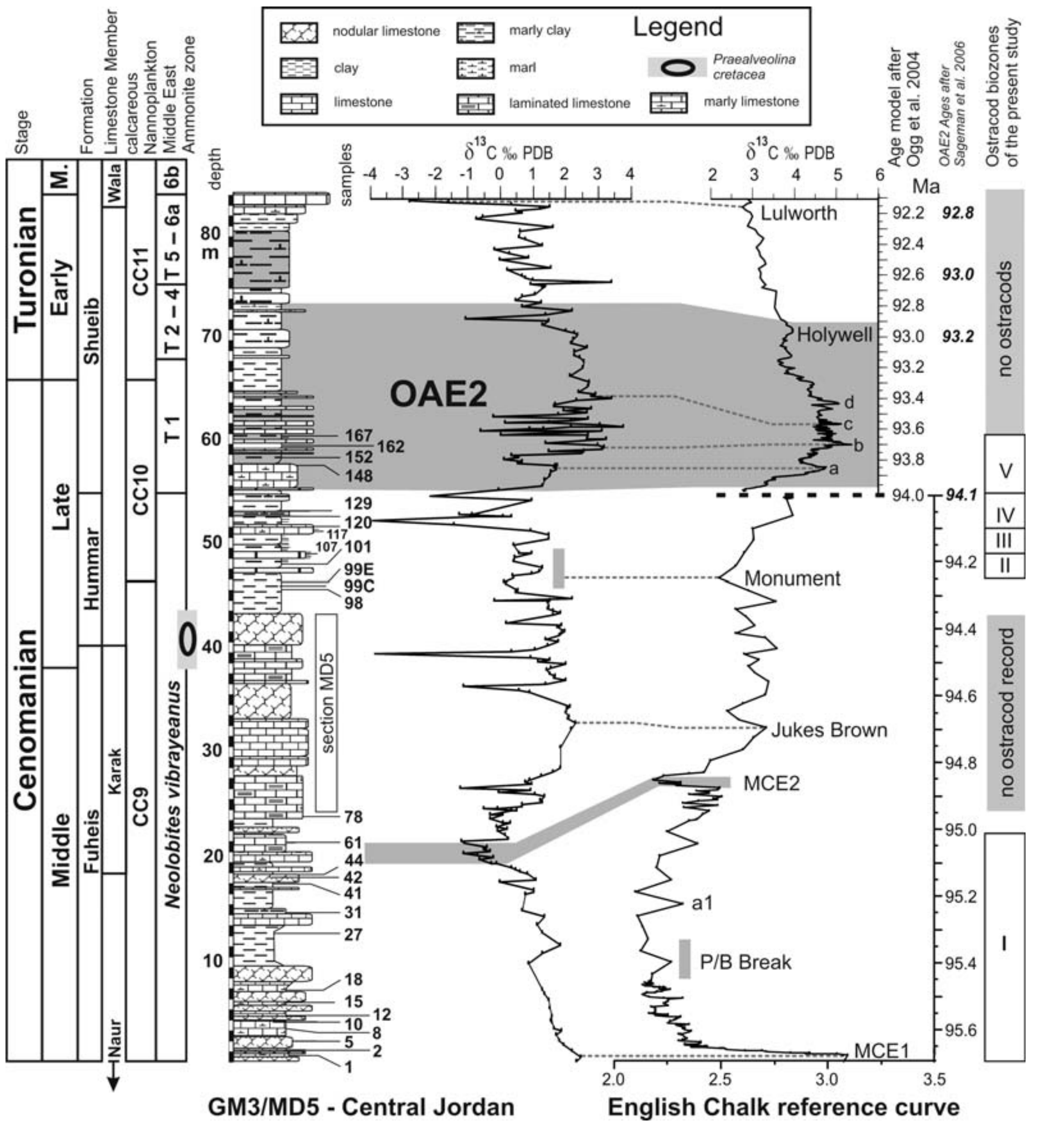

Fig. 2. Middle Cenomanian–Early Turonian section (GM3) showing formations, members, calcareous nannoplankton zones, ammonite zones, and stable carbon isotope record. English chalk reference curve from Jarvis *et al.* (2006), note change in scale (carbon isotopes and age) below OAE2 for enlargement of the Middle–Late Cenomanian part of the record. Indicated isotope events and intervals mark long-term inflection points. For details in section interval 47–83 m (OAE2) see Wendler *et al.* (2010). Sample numbers indicate samples with ostracods. Shaded lithological intervals are black shales. Right panel: ostracod assemblages.

Isotope stratigraphy

Stable carbon isotopes of bulk carbonate are in the range of −4 to +4‰. Compared to deeper marine records the present data reveal a relatively noisy signal with an enhanced amplitude range. The record contains some significant negative excursions, the most significant one occurring just below OAE2. Major positive excursions of the record are distinctive and can be used by correlation for a chemostratigraphic subdivision of the Middle Cenomanian through Early Turonian. Correlation of stable carbon isotope events recorded in the Jordan data with the English Chalk reference record of Jarvis *et al.* (2006) is given in Figure 2. From the bottom to the top of the investigated section, these δ^{13}C-excursions can be correlated to the major global isotope events mid-Cenomanian event 1 (MCE1), Jukes-Brown Event, and OAE2, as well as some minor peaks (Fig. 2). The record is embedded in the multi-biostratigraphical framework given above, and supported by the detailed analysis of the OAE2 (see Wendler *et al.* 2010). The timescale of Ogg *et al.* (2004) that was applied to the English Chalk reference δ^{13}C-record and the orbital timescale established for the GSSP stratotype (Sageman *et al.* 2006) can be transferred by this correlation to the Jordan record for age control. The isotope record is used here mostly for stratigraphical control. An in-depth discussion, being beyond the scope of this paper, is given in a separate publication (Wendler *et al.* 2010).

Systematic descriptions

The studied fauna yielded 22 ostracod species (Fig. 3) that are assigned to 16 genera belonging to 10 families. The classification has been made following Horne *et al.* (2002). Species synonymies are abbreviated; synonymy lists include the first naming of species and the names other than those utilized herein. Complete records of the species are given in Figure 4. Morphological and taxonomic comments are given wherever necessary.

Subclass PODOCOPA Müller, 1894
Order PLATYCOPIDA Sars, 1866
Suborder PLATYCOPINA Sars, 1866
Superfamily CYTHERELLOIDEA Sars, 1866
Family CYTHERELLIDAE Sars, 1866
Genus *Cytherella* Jones, 1849

Cytherella aegyptiensis Colin & El Dakkak, 1975
Figure 5, figs 1–3

1974 *Cytherella* gr. *ovata* (Roemer); Rosenfeld & Raab, p. 3, pl. 1, figs 3–5.
1975 *Cytherella aegyptiensis*, Colin & El Dakkak, p. 50, pl. 1, figs 2–3.
1991 *Cytherella* cf. *eosulcata*, Colin; Shahin (1991) p. 133, pl. 1, figs 3–4.
1994 *Cytherella ahmadiensis*, Al-Abdul-Razzaq; Shahin *et al.* (1994) p. 36, pl. 1, figs 1–2.

Material: 384 specimens.
Dimensions: Length: 0.76–0.82 mm; height: 0.51–0.54 mm; width: 0.37–0.39 mm.
Stratigraphical and geographical distribution: This species is known in the Cenomanian of Egypt (Colin & El Dakkak 1975; Shahin *et al.* 1994; Morsi & Bauer 2001; Szczechura *et al.* 1991) and Morocco (Andreu-Boussut 1991), Cenomanian–Turonian of Israel (Rosenfeld & Raab 1974) and Middle Cenomanian of Jordan (Schulze *et al.* 2004).
Occurrence in the studied section: Middle–Upper Cenomanian.

Cytherella dhalalensis Morsi & Bauer, 2001
Figure 5, figs 4–5

1991 *Cytherella* sp. 5, Andreu-Boussut, p. 450, pl. 5, figs 5–10.
2001 *Cytherella dhalalensis*, Morsi & Bauer, p. 383, pl. 1, figs 3–5.

Material: 20 specimens.
Dimensions: Length: 0.63–0.68 mm; height: 0.38–0.42 mm; width: 0.29–0.31 mm.
Stratigraphical and geographical distribution: Middle Cenomanian of Morocco (Andreu-Boussut 1991) and Upper Cenomanian of Egypt (Morsi & Bauer 2001) and Jordan (present section).

Cytherella cf. *gambiensis* Apostolescu, 1963
Figure 5, figs 6–7

cf. 1963 *Cytherella gambiensis*, Apostolescu, p. 1680, pl. 1, figs 1–3.
2002 *Cytherella* cf. *gambiensis*, Apostolescu; Bassiouni, p. 91, pl. 22, figs 13–15.

Material: 28 specimens.
Dimensions: Length: 0.63–0.69 mm; height: 0.42–0.51 mm; width: 0.30–0.31 mm.
Stratigraphical and geographical distribution: This species was recorded in the Lower Turonian of Egypt (Bassiouni 2002) and Middle–Upper Cenomanian of Jordan (Schulze *et al.* 2004).
Occurrence in the studied section: Middle Cenomanian.

Cytherella sp.
Figure 5, figs 8–9
Material: 11 specimens.
Dimensions: Length: 0.64 mm; height 0.41 mm; width: 0.31 mm.
Description: Carapace subrectangular in lateral outline. Dorsal margin of right valve slightly convex; dorsal margin of left valve straight. Ventral margin slightly concave. End margins rounded, smoothly joined to anteriorly converging longitudinal margins. Right valve larger than left valve; maximum overlap at mid-dorsum and mid-ventrum. Maximum length central; maximum height behind middle, at posterior one third of length. Lateral surface smooth, with pronounced mediodorsal shallow sulcus. Anterior margin occupied by a marginal rim. In dorsal view, carapace elongated ovate with greatest width at posterior one third of length. Sexual dimorphism pronounced, males are thinner than females.
Remarks: *Cytherella dhalalensis* Morsi & Bauer (2001), which originally comes from the Late

Stage		Sample No. \ Species	Calcareous nannoplankton zones	*Bairdia youssefi*	*Veeniacythereis maghrebensis*	*Cytherella aegyptiensis*	*Cythereis namousensis*	*Bythocypris* sp.1 Rosenfeld & Raab	*Parakrithe andreui*	*Cytherella* cf. *gambiensis*	*Metacytheropteron berbericum*	*Paracypris dubertreti*	*Dolocytheridea atlasica*	*Veeniacythereis streblolophata schista*	*Peloriops aegyptiaca*	*Neocyprideis vandenboldi*	*Perissocytheridea istriana*	*Cytherella dhalalensis*	*Schuleridea houneensis*	*Monoceratina ? trituberculata*	*Reticulocosta kenaanensis*	*Cytherella* sp.	*Bairdia* sp.	*Paracypris mdaourensis*	*Brachycythere* gr. *sapucariensis*	Ostracod biozones
Cenomanian	Upper	GM3-167	CC10																		68				1	V
		GM3-166																			26	5	5	5		
		GM3-162																			128		3	3		
		GM3-152																			37	6				
		GM3-148																			69					
		GM3-129					13						1	3												IV
		GM3-122												1				2								
		GM3-121																1								
		GM3-120			5	23										71										
		GM3-118			2							1				16	21									
		GM3-117				1					1		1			6										
		GM3-115											1					1								
		GM3-114				3							2	2				4								
		GM3-113			33	33	41				73	2	158						10							III
		GM3-112			36	5	91				171	4	249			28		2	17							
		GM3-111			11	3	9				65		68			112	5			2						
		GM3-110			24	26	12				28		94					10	1							
		GM3-109			59	99	52				51	1	102													
		GM3-108			4		10									349										II
		GM3-107			18	34	5				1		45			46										
		GM3-!05											4			18	1									
		GM3-104														8										
		GM3-103					1									7										
		GM3-102														1										
		GM3-101									2					4										
		GM3-99E			5		13				3		19			448										
		GM3-99C			1																					
		GM3-98			2	13					4		14	4												
	Middle	GM3-78	CC9		1																					I
		GM3-61			4	3				4																
		GM3-44			1	3			5	2	1		4		1											
		GM3-42		1		11	2		2				2		1											
		GM3-41			14	11	3		4		5		4													
		GM3-31			5	52			48	13	4	4	5													
		GM3-27			1	7								6												
		GM3-18			9	13			6		1															
		GM3-15		2	3	7	1		1	2	7		1													
		GM3-12				15	1		3	2	4		4													
		GM3-10			5	5																				
		GM3-08			1	2				1	2															
		GM3-05		4	10	13	1	5	9	4	1	2	4													
		GM3-02				1	1																			
		GM3-01		1	1	1																				

Early OAE2 interval

Middle–Upper Cenomanian boundary

Fig. 3. Stratigraphical distribution of ostracods in the studied section.

	Portugal	Jugoslavia	West Africa	Morocco	Algeria	Tunisia	Egypt	Israel	Jordan	Lebanon	Arabian Gulf
Cytherella aegyptiensis				Cenomanian			Cenomanian	Cenom.–Turon.	m.–u.Cenom.		
Cytherella dhalalensis				m. Cenom.			u. Cenom.		u. Cenom.		
Cytherella cf. *gambiensis*							l. Turonian		m. Cenom.		
Cytherella sp.									u. Cenom.		
Bairdia youssefi				m. Cenom.			l. Cenom.		m. Cenom.		
Bairdia sp.									u. Cenom.		
Bythocybris sp.1 Rosenfeld & Raab							u. Cenom.	u. Cenom.	m. Cenom.		
Paracypris dubertreti				m. Cenom.	Cenom.–l.Turon.		Apt.–Cenom.	Apt.–u. Cenom.	m.–u.Cenom.	m.–u. Cenom.	
Paracypris mdaourensis				Vranc.–l.Turon.	l. Turon.		Alb.–Turon.	l.Cenom.–l.Turon.	u. Cenom.		
Monoceratina? *trituberculata*			Cenomanian	m.–u.Cenom.	u. Cenom.	Cenomanian	u. Cenom.	u. Cenom.	u. Cenom.		
Dolocytheridea atlasica					l.–u. Cenoman.	Cenomanian	?Alb.–Turon.	l.–u. Cenoman.	m.–u.Cenom.		Alb.–Cenom.
Neocyprideis vandenboldi							u.Cenom.l.Turon.	u.Cenom.l.Turon.	u. Cenom.		
Perissocytheridea istriana		Cenomanian		u. Cenom.			Cenomanian		u. Cenom.		
Schuleridea houneensis								l. Cenoman.	u. Cenom.	Albian	
Metacytheropteron berbericum	Cenomanian			Cenomanian	Cenomanian	u.Alb.–Cenom.	?Alb.–Cenom.	Cenomanian	m.–u.Cenom.		Cenomanian
Parakrithe andreui	Cenomanian						Cenomanian		m.–u.Cenom.		
Cythereis namousensis					Cenomanian	Cenomanian	Cenomanian		m.–u.Cenom.		
Peloriops aegyptiaca							u. Cenom.		m. Cenom.		
Veeniacythereis maghrebensis							l. Turon.	l. Turon.	u. Cenom.		
Veeniacythereis streblolophata schista					u. Cenom.	u. Cenom.	?Alb.–Cenoman.	Cenomanian	m.–u.Cenom.		Cenomanian
Reticulocosta kenaanensis				Cenomanian	l. Cenom.	Cenomanian	?Alb.–Cenoman.		m.–u.Cenom.		Alb.–Cenom.
Brachycythere gr. *sapucariensis*			m. Cenom.	Cenomanian					u. Cenom.		

Fig. 4. Geographical distribution of ostracod taxa. Vranc., Vranconian; Apt., Atian; Cenom., Cenomanian; Turon., Turonian; l., lower; m., middle; u., upper.

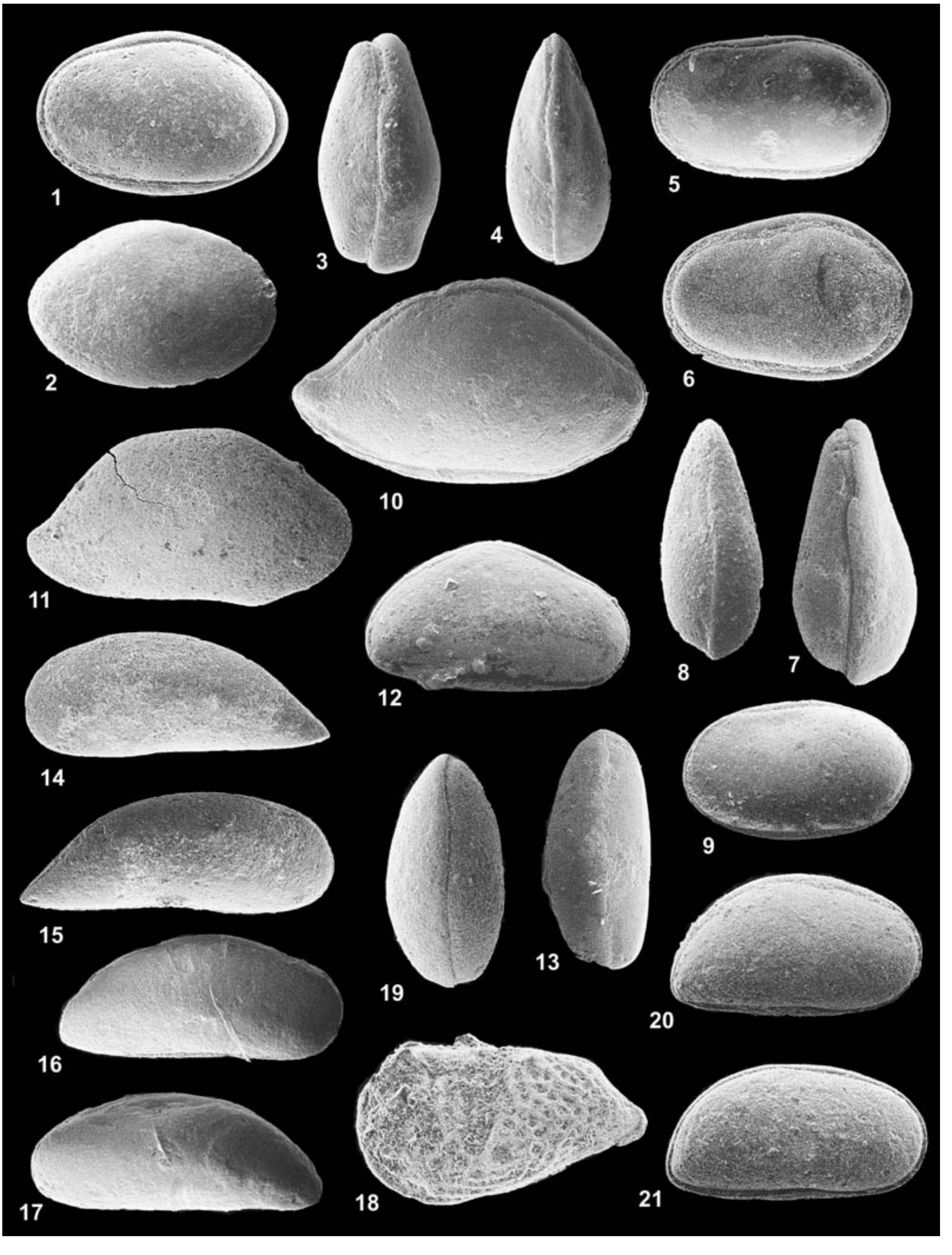

Fig. 5. **1–3**: *Cytherella aegyptiensis* Colin & El Dakkak (1975). Hummar Formation, sample GM3-109, 1, JC-01, L 0.78 mm, LVC; 2, JC-02, L 0.77 mm, RVC; 3, JC-03, W 0.39 mm, DVC; **4–5**: *Cytherella dhalalensis* Morsi & Bauer (2001). Hummar Formation, sample GM3-114, 4, JC-04, W 0.29 mm, DVC; 5, JC-05, L 0.63 mm, LVC; **6–7**: *Cytherella* cf. *gambiensis* Apostolescu (1963). Fuheis Formation, sample GM3-31, 6, JC-06, L 0.63 mm, LVC; 7, JC-07, W 0.30 mm, DVC; **8–9**: *Cytherella* sp. Shueib Formation, sample GM3-152, 8, JC-08, W 0.31 mm, DVC; 9, JC-09, L 0.64 mm, LVC; **10**: *Bairdia youssefi* Bassiouni (2002). Fuheis Formation, sample GM3-05, JC-10, L 0.88 mm, RVC; **11**: *Bairdia* sp. Shueib Formation, sample GM3-162, JC-11, L 0.83 mm, RVV; **12–13**: *Bythocypris* sp. 1

Cenomanian of Egypt, is similar to the present species. However, it deviates by its more symmetrical posterior margin and having the dorsal margin joined to pthe osterior margin at posterior one fifth of length; in the present species, the posterior margin is asymmetrical and the dorsal margin joins the posterior margin at posterior one third of length. *Cytherella* sp. 11 Andreu-Boussut (1991) from the Late Cenomanian of Morocco also resembles the present species. However, it differs in having a straight ventral margin, unlike the present species which has a concave ventral margin.
Stratigraphical and geographical distribution: Upper Cenomanian.

Order PODOCOPIDA Müller, 1894
SuborderBAIRDIOCOPINA Sars, 1968
Superfamily BAIRDIOIDEA Sars, 1968
Family BAIRDIIDAE Sars, 1888
Genus *Bairdia* McCoy, 1844

Bairdia youssefi Bassiouni, 2002
Figure 5, fig. 10

1991 *Bairdia* sp. 1, Andreu-Boussut, p. 470, pl. 11, figs 1–6.
2002 *Bairdia youssefi*, Bassiouni, p. 15, pl. 1, figs 1–4.

Material: 8 specimens.
Dimensions: Length: 0.88 mm; height: 0.51 mm; width: 0.47 mm.
Stratigraphical and geographical distribution: This species was previously recorded from the Lower Cenomanian of Egypt (Bassiouni 2002) and Middle Cenomanian of Morocco (Andreu-Boussut 1991).
Occurrence in the studied section: Middle Cenomanian.

Bairdia sp.
Figure 5, fig. 11

Material: 8 specimens.
Dimensions: Length: 0.83 mm; height: 0.50 mm.
Remarks: The present species is represented only by separate valves. They differ from *Bairdia youssefi* Bassiouni (2002) in having a broader anterior margin and shorter caudal process.
Stratigraphical and geographical distribution: Upper Cenomanian.

Family BYTHOCYPRIDIDAE Maddocks, 1969
Genus *Bythocypris* Brady, 1880

Bythocypris sp.1, Rosenfeld & Raab, 1974
Figure 5, figs 12–13

1974 *Bythocypris* sp.1, Rosenfeld & Raab, p. 6, pl. 1, figs 17–18.

Material: 5 specimens.
Dimensions: Length: 0.85 mm; height: 0.45 mm; width: 0.38 mm.
Stratigraphical and geographical distribution: This species was recorded from the Upper Cenomanian of Israel (Rosenfeld & Raab 1974) and Egypt (Morsi & Bauer 2001).
Occurrence in the studied section: Middle Cenomanian.

Suborder CYPRIDOCOPINA Jones, 1901
Superfamily CYPRIDOIDEA Baird, 1845
Family CANDONIDAE Kaufmann, 1900
Subfamily PARACYPRIDINAE Sars, 1923
Genus *Paracypris* Sars, 1923

Paracypris dubertreti, Damotte & Saint-Marc, 1972
Figure 5, figs 14–15

1972 *Paracypris dubertreti*, Damotte & Saint-Marc, p. 276, pl. 1, fig. 1.
1974 *Paracypris acutocaudata*, Rosenfeld; *in* Rosenfeld & Raab, p. 8, pl. 1, figs 22–24.
1991 *Paracypris* cf. *dubertreti*, Damotte & Saint-Marc; Andreu-Boussut, p. 485, pl. 18, fig. 9.
1999 *Paracypris acuta* (Cornuel); Ismail, p. 309, pl. 3, figs 14–15.

Material: 14 specimens.
Dimensions: Length: 0.76–0.78 mm; height: 0.30–0.31 mm.
Remark: complete synonymy and arguments for placing *P. acutocaudata* Rosenfeld as a junior synonym for *P. dubertreti* are found in Bassiouni (2002).
Stratigraphical and geographical distribution: This species was first described from the Middle and

Fig. 5. (*Continued*) Rosenfeld & Raab (1974). Fuheis Formation, sample GM3-05, 12, JC-012, L 0.85 mm, RVC; 13, JC-13, W 0.38 mm, DVC; **14–15**: *Paracypris dubertreti* Damotte & Saint-Marc (1972). 14, Fuheis Formation, sample GM3-31, JC-14, L 0.76 mm, LVC; 15, Hummar Formation, sample GM3-100, JC-15, L 0.78 mm, RVC; **16–17**: *Paracypris mdaourensis* Bassoullet & Damotte (1969). Shueib Formation, sample GM3-162, 16, JC-16, L 0.85 mm, RVC; 17, JC-17, L 0.85 mm, LVC; **18**: *Monoceratina? trituberculata* Rosenfeld (1974). Hummar Formation, sample GM3-111, JC-18, L 0.53 mm, LVC; **19–21**: *Dolocytheridea atlasica* Bassoulet & Damotte (1969). Hummar Formation, sample GM3-110, 19, JC-19, female, W 0.25 mm, DVC; 20, JC-20, female, L 0.50 mm, RVC; 21, JC-21, male, L 0.52 mm, RVC. *Abbreviations*: RVC, right view carapace; LVC, left view carapace; DVC, dorsal view carapace; LVV, left view valve; RVV, right view valve; L, length; W, width.

Upper Cenomanian of Lebanon (Damotte & Saint-Marc 1972), and subsequently from the Aptian to Upper Cenomanian of Israel (Rosenfeld & Raab 1974, 1984), Middle Cenomanian of Morroco (Andreu-Boussut 1991), Cenomanian–Lower Turonian of Algeria (Viviere 1985, Majoran 1989) and Aptian–Albian and Cenomanian of Egypt (Boukhary *et al.* 1977; Shahin *et al.* 1994; Ismail 1999; Morsi & Bauer 2001; Hewaidy & Morsi 2001; Bassiouni 2002).
Occurrence in the studied section: Upper Cenomanian.

Paracypris mdaourensis Bassoullet & Damotte, 1969
Figure 5, figs 16–17

1969 *Paracypris mdaourensis*, Bassoullet & Damotte, p. 140, pl. 1, fig. 10a–d.

Material: 8 specimens.
Dimensions: Length: 0.85 mm; height: 0.32 mm; width: 0.31 mm.
Stratigraphical and geographical distribution: The present species was recorded in the Lower Turonian of Algeria (Bassoullet & Damotte 1969; Viviere 1985). It was also reported from the Vraconian to Upper Cenomanian of Morocco (Andreu-Boussut 1991), Lower Cenomanian to Lower Turonian of Israel (Rosenfeld & Raab 1974; Lipson-Benitah *et al.* 1985), Albian–Turonian of Egypt (Shahin 1991; Ismail 1999; Morsi & Bauer 2001; Bassiouni 2002) and Middle Cenomanian of Jordan (Schulze *et al.* 2004).
Occurrence in the studied section: Upper Cenomanian.

Suborder CYTHEROCOPINA Jones, 1901
Superfamily CYTHEROIDEA Baird, 1850
Family BYTHOCYTHERIDAE Sars, 1926
Genus *Monoceratina* Roth, 1928

Monoceratina? *trituberculata* Rosenfeld, 1974
Figure 5, fig. 18

1974 *Monoceratina*? *Trituberculata*, Rosenfeld, *in* Rosenfeld & Raab, p. 11, pl. 2, figs 10–11; pl. 4, fig. 6.
1979 *Exophthalmocythere*? *Bituberculata*, Al-Abdul-Razzaq; Grosdidier, pl. 9, figs 52a–d.
1985 *Perissocytheridea*? *Trituberculata*, (Rosenfeld); Viviere, p. 150, pl. 5, figs 1–3.

Material: 2 specimens.
Dimensions: Length: 0.53 mm; height: 0.31 mm.
Stratigraphical and geographical distribution: This species is widely known from the Upper Cenomanian of Israel (Rosenfeld & Raab 1974), Algeria (Viviere 1985); Cenomanian of Gabon (Grosdidier 1979); Middle and Upper Cenomanian of Morocco (Andreu-Boussut 1991); Cenomanian of Tunisia (Bismuth *et al.* 1981*a*; Ben Youssef 1980; Gargouri-Razgallah 1983) and Upper Cenomanian of Egypt (Shahin *et al.* 1994; Morsi & Bauer 2001; Bassiouni 2002).
Occurrence in the studied section: Upper Cenomanian.

Family CYTHERIDEIDAE Sars, 1925
Subfamily CYTHERIDEINAE Sars, 1925
Genus *Dolocytheridea* Triebel, 1938

Dolocytheridea atlasica Bassoullet & Damotte 1969
Figure 5, figs 19–21

1969 *Dolocytheridea atlasica*, Bassoullet & Damotte, p. 139, pl. 2, fig. 9a–d.
1973 *Dolocytheridea* cf. *atlasica*, Bassoullet & Damotte; Grosdidier (1973), pl. 3, fig. 22.
1985 *Dolocytheridea* aff. *Atlasica*, Bassoullet & Damotte; Viviere (1985), p. 154, pl. 4, figs 1–2.

Material: 782 specimens.
Dimensions: Length: 0.50 mm; height: 0.29 mm; width: 0.25 mm (female).
Length: 0.52 mm; height: 0.28 mm (male).
Stratigraphical and geographical distribution: *Dolocytheridea atlasica* is widely known from the Lower and Upper Cenomanian of Algeria (Bassoullet & Damotte 1969; Viviere 1985) and Israel (Rosenfeld & Raab 1974), Cenomanian of Tunisia (Ben Youssef 1980), Upper Albian–Cenomanian of Oman (Babinot & Bourdillon de Grissac 1989; Colin *et al.* 2001), Upper Albian and Cenomanian of Iran (Grosdidier 1973) and (?)Upper Albian–Turonian of Egypt (Shahin *et al.* 1994; Colin & El Dakkak 1975; Boukhary *et al.* 1977; Szczechura *et al.* 1991; Ismail 2001; Morsi & Bauer 2001; Bassiouni 2002). In Jordan, it was recorded in the Middle Cenomanian (Schulze *et al.* 2004).
Occurrence in the studied section: Middle and Upper Cenomanian.

Genus *Neocyprideis* Apostolescu, 1956

Neocyprideis vandenboldi Gerry & Rosenfeld, 1973
Figure 6, figs 2–3

1964 *Fabanella*?, sp. A, Bold, p. 120, pl. 14, fig. 5a–d.
1973 *Neocyprideis vandenboldi*, Gerry & Rosenfeld, p. 103, pl. 1, figs 1–9; pl. 2, figs 1–6.

Material: 1114 specimens.
Dimensions: Length: 0.81–0.83 mm; height: 0.47–0.50 mm; width: 0.35–0.40 mm.

Stratigraphical and geographical distribution: The present species was previously recorded in the Upper Cenomanian and Lower Turonian of Israel (Gerry & Rosenfeld 1973; Rosenfeld & Raab 1974; Lipson-Benitah *et al.* 1985) and Egypt (Bold 1964; Shahin 1991; Bassiouni 2002). In Jordan, it was reported from the Middle Cenomanian (Schulze *et al.* 2004).
Occurrence in the studied section: Upper Cenomanian.

Genus *Perissocytheridea* Stephenson, 1938

Perissocytheridea istriana Babinot, 1988
Figure 6, figs 4–7

1988 *Perissocytheridea istriana;* Babinot, p. 8, pl. 2, figs 1–7.
1991 *Pterygocythere*? sp. 1, Andreu-Boussut, p. 612, pl. 42, figs 12–16.
pars 1991 *Perissocytheridea ignota*, Szczechura *et al.*, p. 18, pl. 6, figs 8–11; non fig. 7.
1994 *Looneyella sohni*, Rosenfeld; Shahin *et al.* (1994), p. 54, pl. 3, figs 11–12.
1999 *Cytheropteron* cf. *navarroense*, Alexander; Ismail (1999), p. 307, pl. 3, figs 2–3.

Material: 27 specimens.
Dimensions: Length: 0.59–0.62 mm; height: 0.34–0.38 mm; width: 0.33 mm (female).
Length: 0.63 mm; height: 0.31 mm; width: 0.31 mm (male).
Stratigraphical and geographical distribution: This species was first recorded in the Cenomanian of Prementura, south Istria, Croatia (Babinot 1988). It was also illustrated from the Cenomanian of Egypt (Szczechura *et al.* 1991; Shahin *et al.* 1994; Ismail 1999; Morsi & Bauer 2001; Bassiouni 2002) and Upper Cenomanian of Morocco (Andreu-Boussut 1991).
Occurrence in the studied section: Upper Cenomanian.

Subfamily SCHULERIDEINAE Mandelstam, 1959
Genus *Schuleridea* Swartz & Swain, 1946

Schuleridea houneensis Bischoff, 1990
Figure 6, fig. 1

pars 1974 *Dordoniella*? *D. baidarensis*, Damotte & Saint-Marc; Rosenfeld & Raab (1974), p. 12, pl. 2, fig. 20; non 21–22; non pl. 4, fig. 11.
1990 *Schuleridea* (*Schuleridea*) *houneensis*, Bischoff, p. 109, pl. 9, fig. 121; pl. 10, figs 122–137.

Material: 28 specimens.
Dimensions: Length: 0.47 mm; height: 0.30 mm.
Remarks: The present species differs from *Schuleridea baidarensis* (Damotte & Saint-Marc 1972) in having a narrower posterior end and less steeply downward sloping posterior outline.
Stratigraphical and geographical distribution: This species was previously recorded from the Albian of Lebanon (Bischoff 1990) and Lower Cenomanian of Israel (Rosenfeld & Raab 1974).
Occurrence in the studied section: Upper Cenomanian.

Family CYTHERURIDAE Müller, 1894
Genus *Metacytheropteron* Oertli, 1957

Metacytheropteron berbericum (Bassoullet & Damotte 1969)
Figure 6, figs 8–13

1969 *Cytheropteron berbericus*, Bassoullet & Damotte, p. 137, pl. 2, fig. 7a–d.
1973 *Metacytheropteron parnesi*, Sohn; Grosdidier (1973), p. 150, pl. 6, fig. 54a–d.
1974 *Metacytheropteron berbericum* (Bassoullet & Damotte); Rosenfeld & Raab (1974), p. 12, pl. 2, figs 26–28; pl. 5, figs 2–4.
1983 *Metacytheropteron pleura* Al-Furaih, p. 2, pl. 1, figs 1–2.
1991 *Metacytheropteron* gr. *parnesi* Sohn; Andreu-Boussut (1991), p. 563, pl. 31, figs 7–10.
1991 *Metacytheropteron* cf. *berbericus* (Bassoullet & Damotte); Szczechura *et al.*, p. 23, pl. 4, fig. 15; pl. 10, fig. 1.

Material: 424 specimens.
Dimensions: Length: 0.52–0.57 mm; height: 0.29–0.34 mm; width: 0.33 mm (females).
Length: 0.56–0.59 mm; height: 0.29–0.32 mm; width: 0.33 mm (males).
Stratigraphical and geographical distribution: This species has a wide distribution in North Africa and the Middle East. In Algeria, where it was first described, it was recorded throughout the Cenomanian (Bassoullet & Damotte 1969; Viviere 1985; Majoran 1989). It was also found in the Upper Albian–Cenomanian of Tunisia (Ben Youssef 1980; Bismuth *et al.* 1981*a*; Gargouri-Razgallah 1983; Abdallah *et al.* 1995), Cenomanian of Morocco (Andreu-Boussut 1991), Israel (Rosenfeld & Raab 1974; Majoran 1989), Saudi Arabia (Al-Furaih 1983), Oman (Athersuch 1988, 1994), Iran (Grosdidier 1973) and Egypt, the (?)Albian–Cenomanian of Egypt (Colin & El Dakkak 1975; Boukhary *et al.* 1977; Shahin 1991; Shahin & Kora 1991; Szczechura *et al.* 1991; Shahin *et al.* 1994; Ismail & Soliman 1997; Ismail 1999, 2001; Morsi & Bauer 2001; Bassiouni 2002). In Jordan, it was also reported from the Middle Cenomanian (Schulze *et al.* 2004). In southern Europe, the

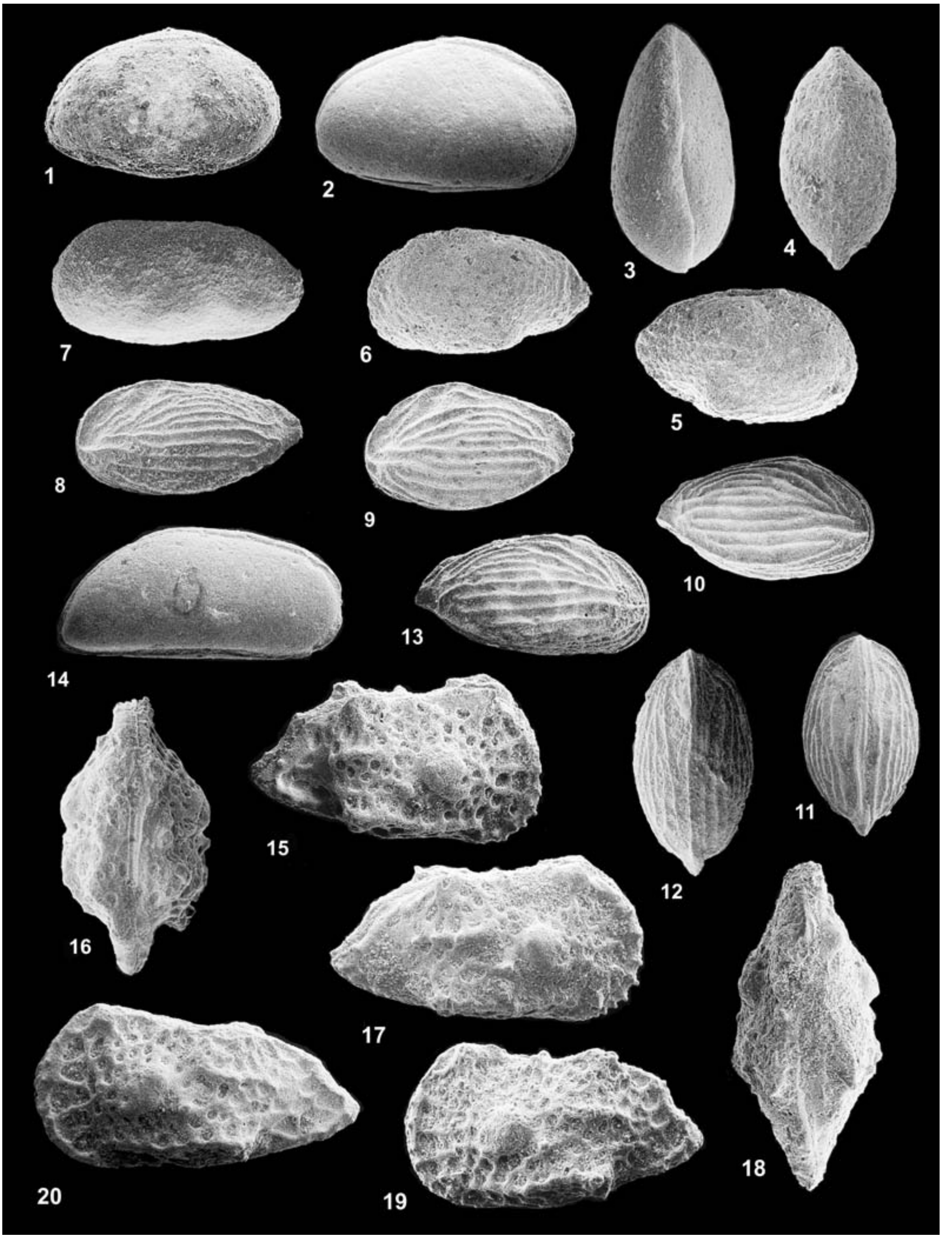

Fig. 6. **1**: *Schuleridea houneensis* Bischoff (1990). Hummar Formation, sample GM3-112, JC-22, L 0.47 mm, RVC; **2–3**: *Neocyprideis vandenboldi* Gerry & Rosenfeld (1973). Hummar Formation, sample GM3-112, 2, JC-23, L 0.83 mm, RVC; 3, JC-24, W 0.40 mm, DVC; **4–7**: *Perissocytheridea istriana* Babinot (1988). Hummar Formation, sample GM3-118, 4-6 female, 4, JC-25, W 0.33 mm, DVC; 5, JC-26, L 0.62 mm, RVC; 6, JC-27, L. 0.59 mm, LVC; 7, male, JC-28, L 0.63 mm, LVC; **8–13**: *Metacytheropteron berbericum* Bassoullet & Damotte (1969). Hummar Formation, sample GM3-111, 8, 12, 13 male, 9-11, female: 8, JC-29, L 0.58 mm, LVC; 9, JC-30, L 0.52 mm, LVC; 10, JC-31, L 0.55 mm, RVC; 11, JC-32, W 0.33 mm, DVC; 12, JC-33, W 0.33 mm, DVC; 13, JC-34, L 0.56 mm, RVC;

present species was recorded in the Cenomanian of the western Portugese Basin (Babinot *et al.* 1978).
Occurrence in the studied section: Middle and Upper Cenomanian.

Family KRITHIDAE Mandelstam, 1958
Subfamily KRITHINAE Mandelstam, 1958
Genus *Pararithe* van den Bold, 1958

Parakrithe andreui Bassiouni, 2002
Pl. 2, fig. 14

?1978 *Pontocyprella*? sp. 14, Andreu, p. 275, pl. 39, figs 8, 10–11.
2001. *Parakrithe* sp.2, Morsi & Bauer, p. 390, pl. 3, figs 12–13.
2002 *Parakrithe andreui* Bassiouni, p. 35, pl. 8, figs 4–11.

Material: 78 specimens.
Remarks: *Pontocyprella*? sp. 14, Andreu (Andreu 1978) from the Lower Cenomanian of Portugal fits externally well into the present species. However, it is placed with question mark in the synonymy since its internal features were not described.
Dimensions: Length: 0.67–0.75 mm; height: 0.34–0.35 mm.
Stratigraphical and geographical distribution: This species was previously recorded in the Lower and Upper Cenomanian of Egypt (Morsi & Bauer 2001; Bassiouni 2002) and Middle Cenomanian of Jordan (Schulze *et al.* 2004).
Occurrence in the studied section: Middle Cenomanian.

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948
Subfamily TRACHYLEBERIDINAE Sylvester-Bradley, 1948
Genus *Cythereis* Jones, 1849

Cythereis namousensis Bassoullet & Damotte 1969
Figure 6, figs 15–20

1969 *Cythereis namousensis*, Bassoullet & Damotte, p. 134, pl. 1, fig. 3a–d.

Material: 256 specimens.
Dimensions: Length: 0.66–0.70 mm; height: 0.37–0.38 mm; width: 0.36 mm (females).
Length: 0.74–0.83 mm; height: 0.38–0.43 mm; width: 0.33 mm (males).
Stratigraphical and geographical distribution: The present species is common in the Cenomanian rocks in Algeria (Bassoullet & Damotte 1969; Majoran 1989), Israel (Rosenfeld & Raab 1974; Majoran 1989), Tunisia (Ben Youssef 1980; Bismuth *et al.* 1981*a*; Gargouri-Razgallah 1983; Abdallah *et al.* 1995), Egypt (Boukhary *et al.* 1977; Shahin *et al.* 1994; Shahin 1991; Ismail 2001; Morsi & Bauer 2001; Bassiouni 2002) and Jordan (Schulze *et al.* 2004).
Occurrence in the studied section: Middle and Upper Cenomanian.

Genus *Peloriops* Al-Abdul-Razzaq, 1979

Peloriops aegyptiaca Morsi & Bauer, 2001
Figure 7, figs 1–2
2001 *Peloriops aegyptiaca*, Morsi & Bauer, p. 394, pl. 5, figs 4, 5, 8.

Material: 2 specimens.
Dimensions: Length: 0.58–60 mm; height: 0.32–0.33 mm.
Stratigraphical and geographical distribution: This species was first described from the Upper Cenomanian of Egypt (Morsi & Bauer 2001).
Occurrence in the studied section: Middle Cenomanian.

Genus *Reticulocosta* Gründel, 1974

Reticulocosta kenaanensis (Rosenfeld 1974, in Rosenfeld & Raab 1974)
Figure 7, figs 3–8

1974 *Cythereis rawashensis kenaanensis* Rosenfeld, n. ssp., *in* Rosenfeld & Raab, p. 17, pl. 3, figs 23–25; pl. 6, figs 5–6.
2002 *Reticulicosta kenaanensis* (Rosenfeld), Bassiouni, p. 77, pl. 18, figs 9, 10.

Material: 328 specimens.
Dimensions: Length: 0.81–0.84 mm; height: 0.44–0.46 mm; width: 0.35–0.36 mm (females).
Length: 1.00 mm; height: 0.51 mm; width: 0.36 mm (males).
Stratigraphical and geographical distribution: This species was previously recorded from levels assigned to the Lower Turonian in Israel (Rosenfeld & Raab 1974), Egypt (Bassiouni 2002) and Jordan (Schulze *et al.* 2004).
Occurrence in the studied section: Upper Cenomanian.

Fig. 6. (*Continued*) **14**: *Parakrithe andreui* Bassiouni (2002). Fuheis Formation, sample GM3-05, JC-35, L 0.75 mm, RVC; **15–20**: *Cythereis namousensis* Bassoullet & Damotte (1969). Hummar Formation, sample GM3-111, 15, 16, 19, female, 17, 18, 20, male: 15, JC-36, L 0.66 mm, RVC; 16, JC-37, W 0.36 mm, DVC; 17, JC-38, L 0.83 mm, RVC; 18, JC-39, 0.33 mm, DVC; 19, JC-40, L 0.74 mm, LVC; 20, JC-41, L 0.79 mm, LVC.

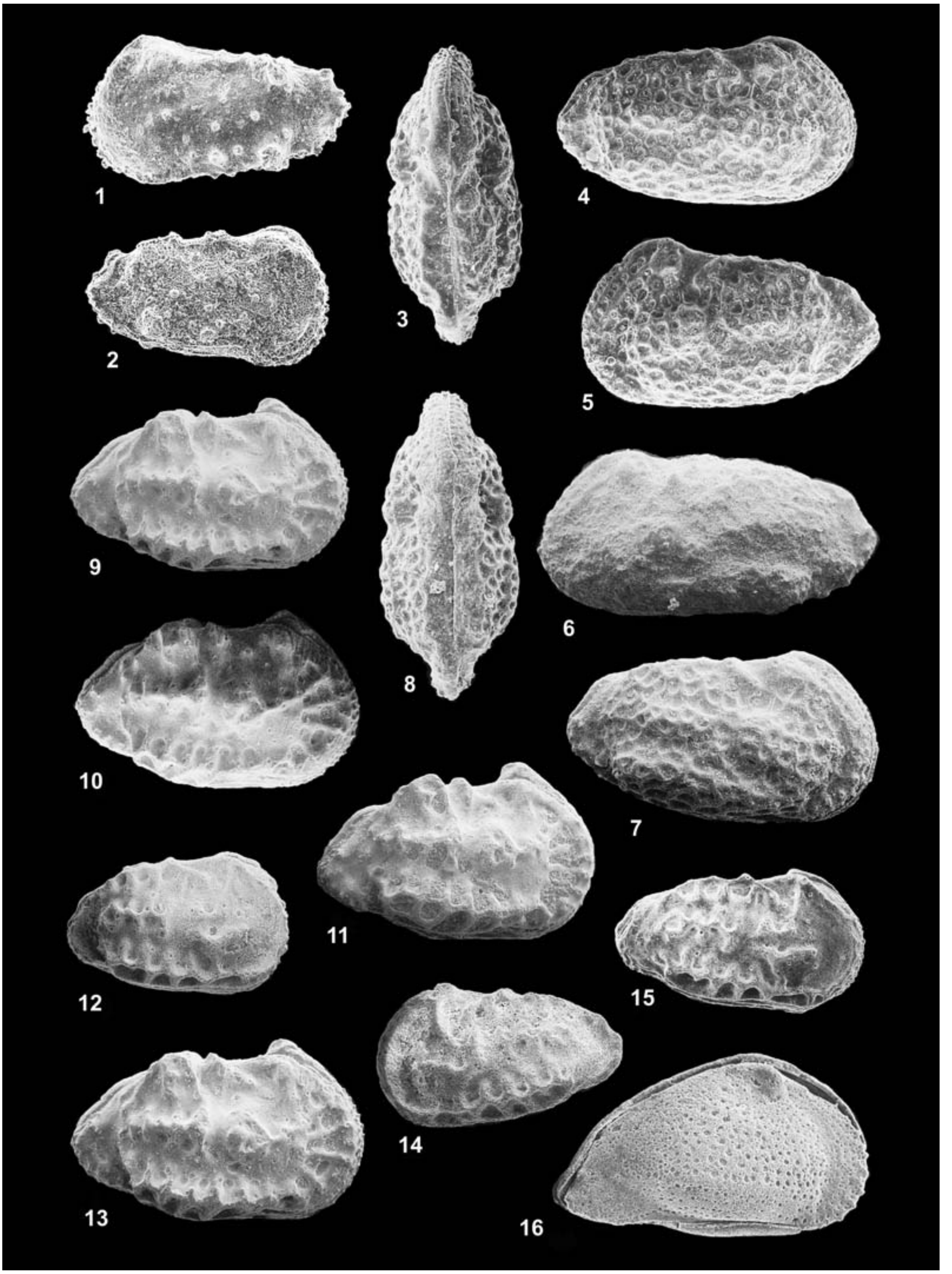

Fig. 7. **1**, **2**: *Peloriops aegyptiaca* Morsi & Bauer (2001). Fuheis Formation, 1, sample GM3-42, JC-42, L 0.54 mm, LVC; 2, sample G3-44, JC-43, L 0.56 mm, RVC; **3–8**: *Reticulocosta kenaanensis* Rosenfeld & Raab (1974). Shueib Formation, sample GM3-167, 3-5, 7, 8, female, 6, male: 3, JC-44, W 0.35 mm, DVC; 4, JC-45, L 0.84 mm, RVC; 5, JC-46, L 0.81 mm, LVC; 6, JC-47, L 1.00 mm, LVC; 7, JC-48, L 0.82 mm, RVC; 8, JC-49, W 0.35 mm, DVC; **9–11**, **13**: *Veeniacythereis maghrebensis* Bassoullet & Damotte (1969). Fuheis Formation, sample GM3-10, 9-11,

Genus *Veeniacythereis* Gründel, 1973

Veeniacythereis maghrebensis (Bassoullet & Damotte, 1969)
Figure 7, figs 9–11, 13

1969 *Cythereis maghrebensis*, Bassoullet & Damotte, p. 133, pl.1, fig. 2a–e.
pars 1974 *Veeniacythereis jezzineensis* (Bischoff); Rosenfeld & Raab, p. 21, pl. 3, fig. 30, non figs 28–29, 31–33.
pars 1975 *Veeniacythereis jezzineensis* (Bischoff); Colin & El-Dakkak, p. 56, pl.1, figs 11–12; pl. 2, fig. 2, non pl. 2, fig. 1.
pars 1985 *Veeniacythereis* gr. *jezzineensis* (Bischoff); Viviere, p. 185, pl. 11, fig. 7, non pl. 11, figs 5–6, 8–11.
1991 *Veeniacythereis jezzineensis* (Bischoff); Szczechura *et al.* p. 28, pl. 7, figs 4, 9–11; pl. 10, fig. 5.

Material: 255 specimens.
Dimensions: Length: 0.82–0.84 mm; height: 0.53–0.54 mm; width: 0.48 mm (females).
Length: 0.87 mm; height: 0.54 mm; width: 0.48 mm (male).
Stratigraphical and geographical distribution: This species is widely known from the Upper Cenomanian of Algeria (Bassoullet & Damotte 1969; Viviere 1985), Tunisia (Bismuth *et al.* 1981*a*; Gargouri-Razgallah 1983) and Kuwait (Al-Abdul-Razzaq & Grosdidier 1981); Cenomanian of Oman (Athersuch 1988, 1994) and Israel (Rosenfeld & Raab 1974), (?) Albian–Cenomanian of Egypt (Colin & El Dakkak 1975; Boukhary *et al.* 1977; Shahin 1991; Szczechura *et al.* 1991; Shahin *et al.* 1994; Ismail & Soliman 1997; Morsi & Bauer 2001; Bassiouni 2002). In Jordan, it was reported from the Middle Cenomanian (Schulze *et al.* 2004).
Occurrence in the studied section: Middle and Upper Cenomanian.

Veeniacythereis streblolophata schista Al-Abdul-Razzaq & Grosdidier, 1981
Figure 7, figs 12, 14, 15

1973 *Cythereis* IR C 4, Grosdidier, pl. 8, fig. 66a–d.
pars 1975 *Veeniacythereis jezzineensis* (Bischoff); Colin & El Dakkak, p. 56, pl. 2, fig. 1, non pl. 1, figs 11–12; non pl. 2, fig. 2.
pars 1981*a* *Veeniacythereis streblolophata*, Al-Abdul-Razzaq; Bismuth *et al.* (1981*a*), p. 233, pl. 10, figs 5–7, non figs 3–4.
1981. *Veeniacythereis streblolophata schista*, Al-Abdul-Razzaq & Grosdidier, 185, pl. 2, figs 1–5.
pars 1985 *Veeniacythereis* gr. *jezzineensis* (Bischoff); Viviere, p. 185, pl. 11, fig. 5, non pl. 11, figs 6–11.
1991 *Veeniacythereis* ex. gr. *streblolophata* Al-Abdul-Razzaq & Grosdidier; Szczechura *et al.* (1991), p. 29, pl. 7, figs 1–3, 5–8.
1991 *Veeniacythereis* gr. *jezzineensis* (Bischoff); Andreu-Boussut, p. 659, pl. 67, fig. 5.
1991 *Veeniacythereis jezzinensis* (Bischoff); Shahin, p. 144, pl. 3, figs 8–9.
1997 *Cythereis* cf. *canteriolata* (Crane); Ismail & Soliman, p. 178, pl. 3, figs 19, 20.
1997 *Cythereis gapensis* (Alexander); Ismail & Soliman, p. 180, pl. 3, figs 21, 22.
1997 *Veeniacythereis jezzinensis* (Bischoff); Ismail & Soliman, p. 182, pl. 3, figs 14, 15.

Material: 16 specimens.
Dimensions: Length: 0.60–0.62 mm; height: 0.36–0.39 mm (females).
Length: 0.67 mm; height: 0.38 mm (male).
Stratigraphical and geographical distribution: The present subspecies was previously found in the Arabian Gulf region from the Albian–Lower Cenomanian of Iran (Grosdidier 1973), Cenomanian of Oman (Athersuch 1988, 1994) and Upper Cenomanian of Kuwait (Al-Abdul-Razzaq & Grosdidier 1981). In North Africa, it was recorded in the Cenomanian of Morroco (Andreu-Boussut 1991) and Tunisia (Bismuth *et al.* 1981*a*; Garghouri-Razgallah 1983), Lower Cenomanian of Algeria (Viviere 1985) and (?) Albian–Cenomanian of Egypt (Colin & El Dakkak 1975; Shahin 1991; Szczechura *et al.* 1991; Shahin *et al.* 1994; Ismail & Soliman 1997; Morsi & Bauer 2001; Bassiouni 2002). In Jordan, it was reported from the Middle Cenomanian (Schulze *et al.* 2004).
Occurrence in the studied section: Middle and Upper Cenomanian.

Subfamily BRACHYCYTHERINAE Puri, 1954
Genus *Brachcythere* Alexander, 1933

Fig. 7. (*Continued*) female, 9, JC-50, L 0.83 mm, RVC; 10, JC-51, L 0.84 mm, RVC; 11, JC-52, L 0.82 mmRVC; 13, male, JC-53, L 0.87 mm, RVC; **12**, **14**, **15**: *Veeniacythereis streblolophata schista* Al-Abdul-Razzaq and Grosdidier (1981). Fuheis Formation, sample GM3-37, 12, female, JC-54, L 0.60 mm, RVC; 14, female, JC-55, L 0.62 mm, LVC; 15, male, JC-56, L 0.67 mm, RVC; **16**: *Brachycythere* gr. *sapucariensis* Krömmelbein (1964). Shueib Formation, sample GM3-167, JC-57, L 0.71 mm, RVC.

Brachycythere gr. *sapucariensis* Krömmelbein, 1964

Figure 7, fig. 16

gr. 1964 *Brachycythere sapucariensis*, Krömmelbein, p. 490, pl. 44, figs 1–5.

1991 *Brachycythere* gr. *sapucariensis*, Krömmelbein; Andreu-Boussut (1991), p. 602, pl. 44, figs 1–11.

Material: A single specimen.
Dimensions: Length: 0.71 mm; height: 0.51 mm.
Stratigraphical and geographical distribution: *Brachycythere sapucariensis* s.s. was originally described by Krömmelbein (1964) from the Coniacian–Santonian of NE Brazil. It was subsequently recorded in the interval from the Early Cenomanian–Early Coniacian in Brazil and West Africa (e.g. Krömmelbein 1996; Neufville 1973, 1979; Grosdidier 1979; Andreu-Boussut 1991; Viviers *et al.* 2000). In North Africa and the Middle East, related forms were found in the Early Turonian–Early Coniacian of Tunisia (Bismuth *et al.* 1981*a*, *b*), Algeria (Viviere 1985), Egypt (Shahin 1991; Shahin *et al.* 1994) and Oman (Athersuch 1988).
Occurrence in the studied section: Upper Cenomanian.

Ostracod biostratigraphy

Ostracod biozonations were suggested by Rosenfeld & Raab (1974) in Israel; Bismuth *et al.* (1981*a*) in Tunisia; Athersuch (1988, 1994) in the Arabian Gulf area; Hataba & Ammar (1990), Shahin *et al.* (1994) and Ismail (2001) in Egypt; Andreu (2002) in Morocco; and Damotte (1995) for North Africa. In the present section, ostracods are significant contributors to the microfauna in the Middle and Late Cenomanian (Schulze *et al.* 2003, 2004), where several horizons yield a variably diversified ostracod fauna (Fig. 3). On the contrary, no ostracods have been retrieved from the Lower Turonian. Most of the elements recorded in the present section were previously utilized by the above mentioned authors to characterize different parts of the Cenomanian. However, some elements were also recorded in other regions from the Albian and some also extend higher into the Turonian (Fig. 4). Based on relative age dating in previous records, the species making up the associations found herein can be differentiated into: Aptian/Albian–Cenomanian taxa, which include species ranging from the Aptian/Albian to the Cenomanian, represented by *Bairdia youssefi*, *Paracypris dubertreti*, *Schuleridea houneensis* and *Metacytheropteron berbericum*; Cenomanian taxa, consisting of species known only for the Cenomanian, represented by *C. dhalalensis, Bythocypris* sp. 1 Rosenfeld & Raab, *Parakrithe andreui*, *Monoceratina*? *trituberculata*, *Perissocytheridea istriana*, *Cythereis namousensis*, *Peloriops aegyptiaca*, *Veeniacythereis maghrebensis* (questionable in the Albian) and *V. streblolophata schista* (questionable in the Albian); and Cenomanian–Early Turonian taxa, including species crossing the C–T boundary such as *Cytherella aegyptiensis*, *Cytherella* cf. *gambiensis*, *Neocyprideis vandenboldi*, *Reticulocosta kenaanensis* and *Brachycythere* gr. *Sapucariensis*, and besides those, *Paracypris mdaourensis* and *Dolocytheridea atlasica*, which were recorded since the Albian, extending up to the Lower Turonian.

In terms of biostratigraphical zonation, the following informal ostracod biozones I to V are recognizable in the section of Ghawr Al-Mazar (GM3) from base to top (Figs 2 & 3). These biozones are correlated with the different biozones established in other North African and Middle East regions (Fig. 8). The ostracod biozones established in these regions differ, not only in faunal composition, but also in their stratigraphical ranges and could not be followed in the studied section with a satisfactory exactness. More differentiation was needed owing to distinct palaeo-environmental variability of at least local significance for the time interval preceding OAE2. Owing to the different resolution, creation of an additional formal zonation in the present study has been seen inconvenient, and only an informal biozonation with an attempt to correlate with the previously established ostracod biozones, has been made (Fig. 8).

1-Ostracod biozone I

This biozone occurs in the lower part of the section incorporating the lower part of the Fuheis Formation, which is assigned to the Middle Cenomanian. It is an assemblage zone characterized by common to abundant occurrence of *Bairdia youssefi*, *Bythocypris* sp.1 Rosenfeld & Raab, *Parakrithe andreui*, *Cythereis namousensis*, *Cytherella aegyptiensis*, *C.* cf. *gambiensis*, *Dolocytheridea atlasica*, *Metacytheropteron berbericum*, *Paracypris dubertreti*, *Peloriops aegyptiaca*, *Veeniacythereis maghrebensis* and *V. streblolophata schista*. Of these taxa *Bairdia youssefi*, *Bythocypris* sp. 1 Rosenfeld & Raab, *Cytherella* cf. *gambiensis*, *Parakrithe andreui*, and *Peloriops aegyptiaca* are restricted to this zone. The taxa making up this zone are predominantly shelf taxa, reflecting normal shallow marine environmental settings.

2-Ostracod biozone II

This ostracod biozone is separated from the underlying biozone by the Karak and Hummar Limestone Members that are unsuitable for ostracod sampling.

Age		(Morocco) Andreu (2002)	(Tunisia) Bismuth *et al.* (1981)	(Egypt) Shahin (1991)	(Egypt) Shahin *et al.* (1994)	(Egypt) Ismail (2001)	(Northern Israel) Rosenfeld & Raab (1974)	(Southern Israel) Rosenfeld & Raab (1974)	(Central Jordan) Present Study
Turonian	Early	*Spinoleberis yotvataensis* Assemblage Zone	*Cythereis mdaouerensis* Zone	*Asciocythere polita* - *Neocyprideis vandenboldi* Assemblage Zone barren interzone	*Neocyprideis vandenboldi* Taxon Range Zone	*Spinoleberis yotvataensis* Assemblage Zone	*Neocyprideis vandenboldi* Assemblage Zone (UC-5) *Reticulocosta kenaanensis* Assemblage Zone (UC-6) *Neocyprideis vandenboldi* Assemblage Zone (UC-5)	*Neocyprideis vandenboldi* Assemblage Zone (UC-5) *Reticulocosta kenaanensis* Assemblage Zone (UC-6)	Barren
Cenomanian	Late	*Reticulocosta boulhafensis* Assemblage Zone	*Veeniacytheries maghrebensis* Zone *Cythereis algeriana* Zone	*Cythereis* spp. Assemblage Zone Barren interzone *Cytherella* - *Veeniacythereis* - *Metacytheropteron* Assemblage Zone	*Amphicytherura distincta* Interval Zone Barren interzone *Veeniacythereis* - *Metacytheropteron* Oppel Zone	*Cythereis algeriana* - *Metacytheropteron berbericum* Assemblage Zone	*Amphicytherura distincta* Assemblage Zone (UC-2)	*Neocyprideis vandenboldi* Assemblage Zone (UC- 5) *Metacytheropteron berbericum* Acme Zone (UC-4)	Ostracod Biozone V Ostracod Biozone IV Ostracod Biozone III Ostracod Biozone II
	Middle		*Protobuntonia semmamaensis* Zone		*Cytherella sulcata* Partial Range Zone			*Veeniacytheries jezzineensis* Acme Zone (UC-3)	Ostracode Biozone I
	Early		*Veeniacytheries streblolophata schista* Zone		*Neocythere bisulcata* Taxon Range Zone	*Cytherella ovata* Assemblage Zone		*Neocythere ? bisulcata* Assemblage Zone (UC-1)	

Fig. 8. Correlation of Cenomanian–Early Turonian ostracod zonal schemes in North Africa and Middle East regions.

This section part yields only a single specimen of *Veeniacythereis maghrebensis* at the base, and an ostracod fauna in common with the underlying zone 1 represented by *Cytherella aegyptiensis*, *Metacytheropteron berbericum*, *Dolocytheridea atlasica*, *Veeniacythereis maghrebensis* and *Veeniacythereis streblolophata schista.* Zone II is located in the lower part of the Hummar Formation and is distinguished from Zone I by the first occurrence of *Neocyprideis vandenboldi* in the section. This species dominates the assemblage throughout most of Zone II. *Cytherella aegyptiensis*, *Dolocytheridea atlasica*, *Metacytheropteron berbericum*, *Perissocytheridea istriana*, *Cythereis namousensis* and *Veeniacythereis maghrebensis* are also found. The dominance of *Neocyprideis vandenboldi* and a scarce presence of *Perissocytheridea istriana* together with marine faunal elements indicate a shelf lagoonal environmental setting with fresh-water influence (Bartov *et al.* 1980; Rosenfeld *et al.* 1988; Flexer *et al.* 1989; Bauer *et al.* 2003).

3-Ostracod biozone III

This biozone is distinguished by a significantly abundant occurrence of *Dolocytheridea atlasica*, *Metacytheropteron berbericum*, *Cythereis namousensis*, *Veeniacythereis maghrebensis* and *Cytherella aegyptiensis* and represents the peak interval for these taxa. It lies in the middle part of the Hummar Formation. Representatives of *Cytherella dhalalensis*, *Paracypris dubertreti*, *Schuleridea houneensis* and *Monoceratina*? *trituberculata* also co-occur. The assemblage making up this zone indicates a shallow marine environmental setting. In the middle of this zone, two samples (GM3-111 and GM3-112) yield abundant *Neocyprideis vandenboldi* and *Perissocytheridea istriana*, thus indicating a significant fresh-water influx in this level.

4-Ostracod biozone IV

This biozone is characterized by an ostracod assemblage with rare *Dolocytheridea atlasica*, *Metacytheropteron berbericum*, and *Veeniacythereis maghrebensis* that were significantly abundant in the underlying zone. *Cytherella aegyptiensis*, *C. dhalalensis*, *Paracypris dubertreti*, *Cythereis namousensis* and *Veeniacythereis streblolophata schista* also co-occur. This biozone is located in the upper part of the Hummar Formation, and is immediately followed by the OAE2 level. It is probable that the scarcity of the marine ostracod fauna in this zone was generally a response to the Late Cenomanian global regression and decreasing oxygen levels related to this event (e.g. Babinot & Crumiere-Airaud 1990). The interval in the middle of the zone is a marly limestone (samples GM3-117 to 120) which yields *Neocyprideis vandenboldi* and *Perissocytheridea istreana* in the assemblage, indicating fresh-water influence in this level.

5-Ostracod biozone V

This biozone occurs in the lower part of the Shueib Formation, which is assigned as Late Cenomanian. It is an acme zone characterized by a highly abundant occurrence of *Reticulocosta kenaanensis*. This taxon, which dominates the assemblage throughout biozone V, occurs together with rare *Cytherella* sp., *Bairdia* sp., *Paracypris mdaourensis* and *Brachycythere* gr. *sapucariensis*. The species found in this zone indicate a shallow marine setting. The base of ostracod biozone V corresponds to a latest Cenomanian major transgression at the onset of OAE2 (Wendler *et al.* 2010), and this zone comprises the lower part of OAE2 in the studied section. At the peak level of the OAE2 interval, just below the Cenomanian–Turonian boundary, and higher up in the Early Turonian part of the section, no ostracod fauna has been found. The *Cythereis rawashensis kenaanensis* zone of Rosenfeld & Raab (1974) probably represents the continuation of the present *R. kenaanensis* zone into the Early Turonian. This assumption cannot be proved here owing to the lack of ostracods in the Lower Turonian of the studied section. However, findings of *R. kenaanensis* in other Central Jordan sections in the Lower Turonian have been reported by Schulze *et al.* (2003), together with ostracod species belonging to the *Cythereis rawashensis kenaanensis* zone (UC-6) of Rosenfeld & Raab (1974).

Discussion

In a previous study carried out by Schulze *et al.* (2004) in west-central Jordan, ostracod faunas were recorded in the Lower–Middle Cenomanian interval represented by the Naur Formation, and higher up in the Fuheis Formation. Of the taxa they recorded in this interval, *Cytherella aegyptiensis*, *C.* cf. *gambiensis*, *Dolocytheridea atlasica*, *Metacytheropteron berbericum*, *Parakrithe andreui*, *Cythereis namouseni*s, *Veeniacythereis maghrebensis* and *V. streblolophata schista* are in common with the fauna recorded in the present study in the Middle Cenomanian, which is assigned to the ostracod biozone I. A similar assemblage was also recorded from this interval in Jordan by Babinot & Basha (1985) and Powell (1989). Schulze *et al.* (2004) also recorded ostracods in the uppermost Cenomanian–Lower Turonian interval represented by the upper part of the Shueib Formation at the OAE 2 level. Their Turonian assemblage (ostracod assemblage 2 'OA2') is devided from the lower assemblage (OA1) by a lag in ostracod presence similar to our study. The association they found has *Reticulocosta kenaanensis* in common with the present record, therefore, belonging to the ostracod biozone V. However, if it is assumed that the gap in ostracod occurrence in Schulze *et al.* (2004) and the one shown here are time-equivalent, then the assemblage 'OA2' of these authors would represent the continuation of the *R. Kenaanensis* zone in the late Early Turonian. In the interval between ostracod biozones I and V, they only recorded *Cytherella* sp., which already begins in the Lower–Middle Cenomanian. Comparison with ostracod faunas from other North African and Middle East regions reveal similarities in faunal compositions. However, variations are observed in the stratigraphical ranges of the species, most likely owing to environmental variability. These variations resulted in establishing several local zonal schemes in these regions to which bio-correlation of the present record is attempted in Figure 8.

Palaeoecology

The studied ostracod assemblages of the Middle Cenomanian and lowermost part of the Upper Cenomanian are dominated by open marine shelf taxa. Marine associations are mainly comprised of different species of *Cytherella*, *Bairdia*, *Paracypris*, *Metacytheropteron*, (?)*Monoceratina*, *Cythereis*, *Peloriops* and *Veeniacythereis*, which are widely distributed in the marine Cenomanian sediments along the Southern Tethys. In contrast, *Neocyprideis vandenboldi* is quite common in the Hummar Formation at 49 m and 51–52 m, accompanied in sample GM3-118 by *Perissocytheridea istriana*. Both species have been interpreted as reflecting fresh-water influence (Bartov *et al.* 1980; Rosenfeld *et al.* 1988; Flexer *et al.* 1989; Bauer *et al.* 2003). Recent species of the genus *Perissocytheridea* have been associated with sandy mud substrates in a euryhaline environment, favouring the mesohaline zone with large and quick salinity changes (Keyser 1977). The benthic foraminifera assemblage found in samples that yield *Neocyprideis vandenboldi* are dominated by the genera *Haplophragmoides*, *Ammobaculites*, *Cyclammina* and *Trochammina*. *Haplophragmoides* spp. in particular indicate variable salinity and are interpreted as typical inhabitants of brackish marsh environments (e.g. Murray 1991; Fatela *et al.* 2009). These species are recorded in co-occurrence with marine species, indicating that coastal marine environmental settings, with rapidly varying conditions including repeated periods of significant fresh-water influx, prevailed during the time of this interval that spans a period of about 300 ka prior to OAE2 (Fig. 2). Alternatively, a temporal restriction of marine-water influx owing to strong sea-level fall could have led to brackish conditions, under a humid climate. The co-occurrence of brackish and fully marine species is suggestive of time-averaged sampling underpinning the rapidity of salinity fluctuations during this phase. The strong negative $\delta^{13}C$ excursions in this interval (section metre 51–54) may support both interpretations since, apart from possible late diagenetic effects, it could be interpreted as representing; a) isotopically light CO_2, most probably derived from soil formation during sea-level fall (Allan & Matthews 1982), or b) isotopically light marine carbonates precipitated under fresh-water influence (Elrick *et al.* 2009). A very similar signal has been recently reported by the latter authors from Mexico so it seems that such features in the $\delta^{13}C$ record of Cenomanian–Turonian shallow-water sections below OAE2 has a global extend. The uppermost ostracod-yielding levels in the section contain a marine fauna dominated by abundant *Reticulocosta kenaanensis*. Correlation of these levels, with calcareous nannoplankton and ammonite zonations as well as the stable carbon isotope record (Fig. 2, Wendler *et al.* 2010), dates them as latest Cenomanian. *Reticulocosta* avoids strong food pulses and is probably better than other genera adapted to longer but still temporary periods of oxygen depletion-dominating during the transition to permanent oxygen deficiency (Gebhardt & Zorn 2008). Therefore, the occurrence of *Reticulocosta kenaanensis* in high abundance within a low diversity assemblage could represent a response to environmental stress, which resulted from the early phase of oxygen depletion associated with OAE2. The other Late Cenomanian taxa were seemingly unable to tolerate these conditions, therefore became scarce or even extinct at this level. On the other hand, the ability of *R. kennanensis* to tolerate oxygen deficiency and excessive nutrients, together with a lack of effective competition from other taxa, allowed for the increased abundance of this species compared with other co-occurring taxa.

Many of the south Tethyan marine ostracod species and whole genera of the Cenomanian became extinct below the C–T boundary (see, Bassoullet & Damotte 1969; Rosenfeld & Raab 1974; Babinot & Colin 1988; Damotte 1985, 1995; Ismail 1999; Bassiouni 2002). Owing to the magnitude and global extent of the OAE2, it is possible that only the taxa, which were capable of surviving bottom water oxygen deficiency, could persist into the Early Turonian. *Reticulocosta kanaanensis*, being such a potentially opportunistic species, was reported in North Africa and Middle East areas as an Early Turonian newcomer indicating the base of the Turonian (Rosenfeld & Raab 1974; Bassiouni

2002; *Cythereis rawashensis kenaanensis* Assemblage zone of Rosenfeld & Raab 1974). The appearance of this species in the present material is well below the Cenomanian–Turonian boundary (by 0.5 Ma, Fig. 2). This suggests that *Reticulocosta kanaanensis* probably represents a taxon, which came into existence along with an event of environmental stress caused by anoxic conditions related to the onset of OAE2 in the Late Cenomanian. Therefore, its use as a marker for the stratigraphic boundary is problematic. Absence of any ostracods higher up in the section merits further discussion. Contrary to this lack of ostracods, the presense of well-preserved calcareous remains of benthic and planktic foraminifera, echinoderms, coccoliths, and calcareous dinoflagellates indicates that diagenesis has not induced a solution of carbonate in this interval. Hence, unless the unlikely case of selective ostracod dissolution, the disappearance of ostracods can be interpreted to reflect palaeoenvironmental conditions adverse to ostracods. A biomarker investigation of the studied section parallel to the present study (Sepúlveda *et al.* 2009) showed that water coloumn stratification increased to extreme levels throughout OAE2 and after. As a result of this density stratification, bottom waters were highly saline and depleted in oxygen, which could explain the observed absence of ostracods.

Palaeobiogeography

During the Cenomanian, the Levant platform area of today's Jordan was part of the South Tethyan bioprovince. The largest assembly of palaeobiogeographical aspects dealing with the Cenomanian ostracod faunas from this province and a comparison with the Northern Tethys bioprovince was carried out by Babinot & Colin (1988), Andreu (1993), Gebhardt (1999), Grékoff (1969) and Luger (2003). Significant contributions have also been added by Babinot *et al.* (1978), Damotte (1985, 1995), Viviere (1985), Athersuch (1988), Andreu (1993), Majoran (1988, 1989) and Morsi & Bauer (2001). Very similar ostracod assemblages, characterized by representatives of *Veeniacythereis*, *Peloriops* and *Reticulicosta*, dominate this province, which extended from the Atlantic coast of Morocco in the west to the Arabian Gulf region in the east. Many of the elements recorded in Jordan are also known from the different North African and Middle East countries (Fig. 4). *Cytherella aegyptiensis*, *Paracypris dubertreti*, *Paracypris mdaourensis*, *Monoceratina*? *trituberculata*, *Dolocytheridea atlasica*, *Metacytheropteron berbericum*, *Cythereis namousensis*, *Veeniacythereis maghrebensis* and *V. streblolophata schista* show the widest occurrence in North Africa, as well as in the Middle East. *C. dhalalensis*, *C.* cf. *gambiensis*, *Bairdia youssefi*, *Bythocypris* sp. 1 Rosenfeld & Raab, *Schuleridea houneensis*, *Peloriops aegyptiaca* and *Reticulicosta kenaanensis* are also found in Egypt, Israel and Lebanon. The biogeographical homogeneity of the ostracod associations in North Africa and the Middle East reflects communication along the whole expanse of the Southern Tethys margin during the Cenomanian and suggests, as also indicated by Babinot & Colin (1988), Andreu (1993) and Morsi & Bauer (2001), similar living conditions and the absence of important geographical barriers that could hinder marine faunal exchange. North–south exchange with the northern rim of the Tethys is not clearly pronounced. Only a few species represented by *Perissocytheridea istriana* and *Metacytheropteron berbericum* have occurrences in common with the northern Tethys province. *Perissocytheridea istriana* was previously recorded in Portugal (Babinot *et al.* 1978) and *Metacytheropteron berbericum* from Yugoslavia (Babinot 1988). Ostracods are mostly benthic organisms lacking pelagic larvae and having poor dispersal properties. Babinot & Colin (1988) put forward the interpretation that a too-deep central Tethys ocean, and also unfavourable currents, could be probable causes of reduced north–south migrations between the northern and southern Tethys rims. *Monoceratina*? *trituberculata* and *Brachycythere* gr. *sapucariensis* occur together within basins of West Africa, for example, Gabon (Grosdidier 1979). Probable affinities between the southern Tethys bioprovince and the coastal basins of West Africa during the Cenomanian were indicated by many authors (Grosdidier 1979; Viviere 1985; Athersuch 1988; Babinot & Colin 1988). *Brachycythere sapucariensis*, found as a single specimen in the studied material, was originally described from Brazil (Krömmelbein 1964) and represents one of the taxa reflecting affinities between South America and West Africa during the Cenomanian.

Conclusions

Twenty two ostracod species were found in the investigated section. The assemblages can be grouped into five informal ostracod biozones that reflect considerable palaeoecological variations. Most significantly, brackish water species are recorded in co-occurrence with marine species, indicating that coastal marine environmental settings with rapidly fluctuating salinity conditions, including repeated periods of significant fresh-water influx, prevailed during a period of a few 100 ka prior to OAE2. A flourishing of the opportunist *Reticulocosta kanaanensis* during the major transgression at the base of OAE2 is replaced soon after by the absence of any ostracod throughout the remaining OAE2 and Early Turonian period of time. The investigated mid- to Late Cenomanian ostracod association has much in common with ostracod associations in North Africa and other areas of the Middle East reflecting communication along the whole expanse of the southern Tethys margin during the Cenomanian.

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