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MOHAMED S. ZAKHERA

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Distribution and Abundance of Rudist Bivalves in the Cretaceous Platform Sequences in Egypt: Time and Space

MOHAMED S. ZAKHERA

Geology Department, Aswan Faculty of Science, South Valley University,
Aswan 81528, Egypt (E-mail: zakhera40@yahoo.com)

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Abstract: As the rudist bivalves represent important organic buildups in the Cretaceous platform sequences, this study emphasizes vertical and spatial distribution of this group of bivalves in the geographic divisions of Egypt, including Western Desert, Eastern Desert and Sinai. Rudists are encountered in different rock facies ranging from mudstones to carbonates. About sixty eight species belong to twenty one genera are reported from Egypt. They belong to six families: Requieniidae, Monopleuridae, Caprotinidae, Caprinidae, Hippuritidae, and Radiolitidae. The Radiolitidae is the most diverse family, comprising eleven genera and fifty-one species, dominated by species of *Radiolites, Eoradiolites* and *Durania*. The elevator morphotype of the Radiolitidae became the dominant species in the Turonian sequences. The diversity (richness) peaks in the Turonian (36 species) Cenomanian (26 species) and Albian (9 species), with few records in Aptian, Coniacian, Campanian and Maastrichtian (totally 5 species). As yet rudists are not recorded from Santonian rocks. Geographically, rudists are highly represented in Sinai (60 species) concentrated in the Cenomanian (23 species) and Turonian (32 species), followed by Western Desert (19 species) and Eastern Desert (8 species). Regarding abundance so far, the relatively highly abundant species in Egypt are *Eoradiolites liratus* (19 sites), followed by *Praeradiolite biskraensis* and *Eoradiolites sinaiticus* (7 sites for each), *Praeradiolites ponsianus, Durania humei, Radiolites sauvagesi* (6 sites for each), *Durania gaensis* and *Radiolites lusitanicus* (5 sites for each). The rare occurrence during the Campanian and Maastrichtian may be attributed to stagnant conditions related to deposition of black shales and phosphatic deposits and the change to deep inner shelf setting respectively. The disappearance of rudists from some segments of the sequence is attributed oceanic anoxia or related to shelf drowning especially at the basal Turonian, which may related to global warming.

Key Words: Rudist bivalves, species richness, Cretaceous, Egypt

Mısır'da Kretase Platform İstiflerinde Rudist Bivalviaların Dağılımı ve Bolluğu: Zaman ve Mekan

Özet: Bu çalışma, rudist bivalviaların Kretase platform istiflerinde önemli organik yığışımlar oluşturmaları nedeniyle, bunların Western Desert, Eastern Desert ve Sinai'yi de içine alan Mısır'ın coğrafik bölgelerinde düşey ve yatay dağılımını konu alır. Rudistler çamurtaşlarından kireçtaşlarına kadar farklı fasiyeslerde gözlenir. Mısır'da yirmibir cinse ait altmışsekiz tür tanımlanmıştır. Bunlar altı aileye aittir: Requieniidae, Monopleuridae, Caprotinidae, Caprinidae, Hippuritidae ve Radiolitidae. Baskın olarak *Radiolites, Eoradiolites* ve *Durania*'ya ait türler ile temsil edilen ve onbir cins ve ellibir tür içeren Radiolitidae ailesi en çeşitli aileyi oluşturur. Radiolitidae'nin düşey büyüyen morfotipleri Turoniyen istiflerinde baskın türleri oluşturur. Çeşitlilik (zenginlik) Turoniyen'de (36 tür), Senomaniyen'de (26 tür) ve Albiyen'de (9 tür) maksimuma ulaşır, Apsiyen, Koniasiyen, Kampaniyen ve Mastrihtiyen'de ise birkaç tür bulunur (toplam 5 tür). Bugüne değin Santoniyen kayalarında rudist saptanmamıştır. Coğrafik olarak rudistler Sinai'de yaygın olarak bulunur (60 tür); bunlar sırasıyla Senomaniyen'de (23 tür) ve Turoniyen'de (32 tür) yoğunlaşırlar. Sinai'yi Western Desert (19 tür) ve Eastern Desert (18 tür) takip eder. Bolluk sözkonusu olduğunda, Mısırdaki en yaygın türler sırasıyla şöyledir; *Eoradiolites liratus* (19 lokalite), *Praeradiolite biskraensis* and *Eoradiolites sinaiticus* (her biri için 7 lokalite), *Praeradiolites ponsianus, Durania humei, Radiolites sauvagesi* (her biri için 6 lokalite), *Durania gaensis* ve *Radiolites lusitanicus* (her biri için 5 lokalite). Rudistlerin Kampaniyen ve Mastrihtiyen'de seyrek bulunuşu, bu dönemde siyah şeyllerin ve fosfatlı tortulların çökelimine bağlı olarak durgun koşulların hüküm sürmesi ve iç şelf ortamının derinleşmesi ile ilgili olabilir. Bazı istif bölümlerinde rudistlerin yokluğu, okyanusal anoksiya veya özellikle küresel ısınmayla ilişkili olabilecek Erken Turoniyen şelf gömülmesine bağlı olabilir.

Anahtar Sözcükler: Rudist bivalviaları, tür zenginliği, Kretase, Mısır

Introduction

Rudists were a group of bivalves that evolved in Late Jurassic times and dominated the carbonate shelves on the Tethys margins during the Cretaceous Period. They extinguished at the end of the Cretaceous. The distribution of rudists is of considerable economic importance, as the most rudist-bearing sediments form hydrocarbon resources worldwide, in particular in the Middle East and around the Gulf of Mexico (Scott *et al.* 1993; Steuber & Löser 2000). Through Late Cretaceous times their diversity climbed to a peak and then entered a period of rapid decline (Swinburne 1990). Most of the exposed mid-Cretaceous strata in the Middle East were deposited on a very broad, shallow shelf platform and they contain benthic fossils, especially rudists and oysters (Lewy & Raab 1976). In Egypt, rudists were first recorded in the early twentieth century (Fourtau 1900, 1903; Dacqué 1903; Douvillé 1910, 1913).

Bauer *et al.* (2004) mentioned that endemism of the Cenomanian and Turonian faunas of Sinai is largely expressed on subspecies level.

The rudists of the Eastern Desert were dealt by Douvillé (1913), Klinghardt (1929), Metwally & Abd El-Azeam (1997); El-Hedeny & El-Sabbagh (2004); El- El-Hedeny & El-Sabbagh (2005) and Abdel Gawad *et al.* (2006). Rudists of Sinai were treated in more works (Douvillé 1913, 1915, 1916; Youssef & Shinnawi 1954; Shata 1959; Bartov *et al.* 1980; Parnes 1987; Cherif *et al.* 1989; Kora & Genedi 1995; Bachmann & Kuss 1998; Steuber *et al.* 1999; Bauer *et al.* 2001, 2004; Steuber & Bachmann 2002; Abdel Gawad *et al.* 2004a, b; Aly *et al.* 2005; Zakhera 2005, 2008; Saber *et al.* 2009). While others (Dacqué 1903; Douvillé 1910, 1913; Hamza 1993; De Castro & Sirna 1996; El-Sabbagh & El-Hedeny 2003; El-Hedeny 2007) studied the rudists of the Western Desert. Only some of these works dealt with palaeontological details of rudists in Egypt. Other works dealt with rudists from different viewpoints which may be sedimentological, stratigraphical or palaeoecological angles. Platform development started at the northern shelf-margin at north east Egypt at Late Aptian with rising sea-level during Albian causing deposition of shallow water carbonates, punctuated by episodes of paralic to deltaic clastic deposits (Kuss 1992; Scott 2003). The marine transgressed southward from north Sinai since Cenomanian (Bachmann & Kuss 1998). Major transgression over shallow shelf started at middle Campanian, and the sea advanced during Maastrichtian depositing pelagic chalks in the north Egypt and fine-grained siliciclastics southward. Cretaceous platform ecosystem responded to global environmental controls by dramatic change in species composition, diversity and abundance (Scott 2003).

Because rudists represent important organic buildups in Cretaceous platforms, this study emphasizes vertical and spatial distribution of this group of bivalves in the geographic divisions of Egypt, including Western Desert, Eastern Desert and Sinai (Figure 1). Data have been compiled from Aptian to Maastrichtian. The results of this study are based on the author work besides the published data concerning with rudists in Egypt.

Distribution and Species Richness (Diversity) During the Cretaceous

Rudists in Sinai

About sixty rudist species are reported from the Cretaceous rocks in Sinai as a whole, representing 69% of the all recorded rudists from Egypt. The species richness (diversity) peaks in the Turonian (32 species), followed by Cenomanian (23 species) (Figure 2). Three of the Cenomanian species are reported also from Albian, including *Eoradiolites liratus* (Conrad), *Eoradiolites davidsoni* (Hill) and *Ichthyosarcolites* sp. (Table 1). Also *Eoradiolites plicatus* (Conrad) is reported in the Aptian and extended to Albian according to Steuber & Bachmann (2002). *Radiolites lusitanicus* (Bayle) is reported from both Cenomanian and Turonian. No record of rudist from Coniacian through Maastrichtian from Sinai so far. Aly *et al.* (2005) and Saber *et al.* (2009), included *Bournonia fourtaui* Douville within the Cenomanian sequence in Sinai, although the genus *Bournonia* started in Turonian according to Dechaseaux & Coogan (1969).

Rudists in Eastern Desert

A total of eight rudist species are reported from the Eastern Desert, representing 9.2% of the all recorded

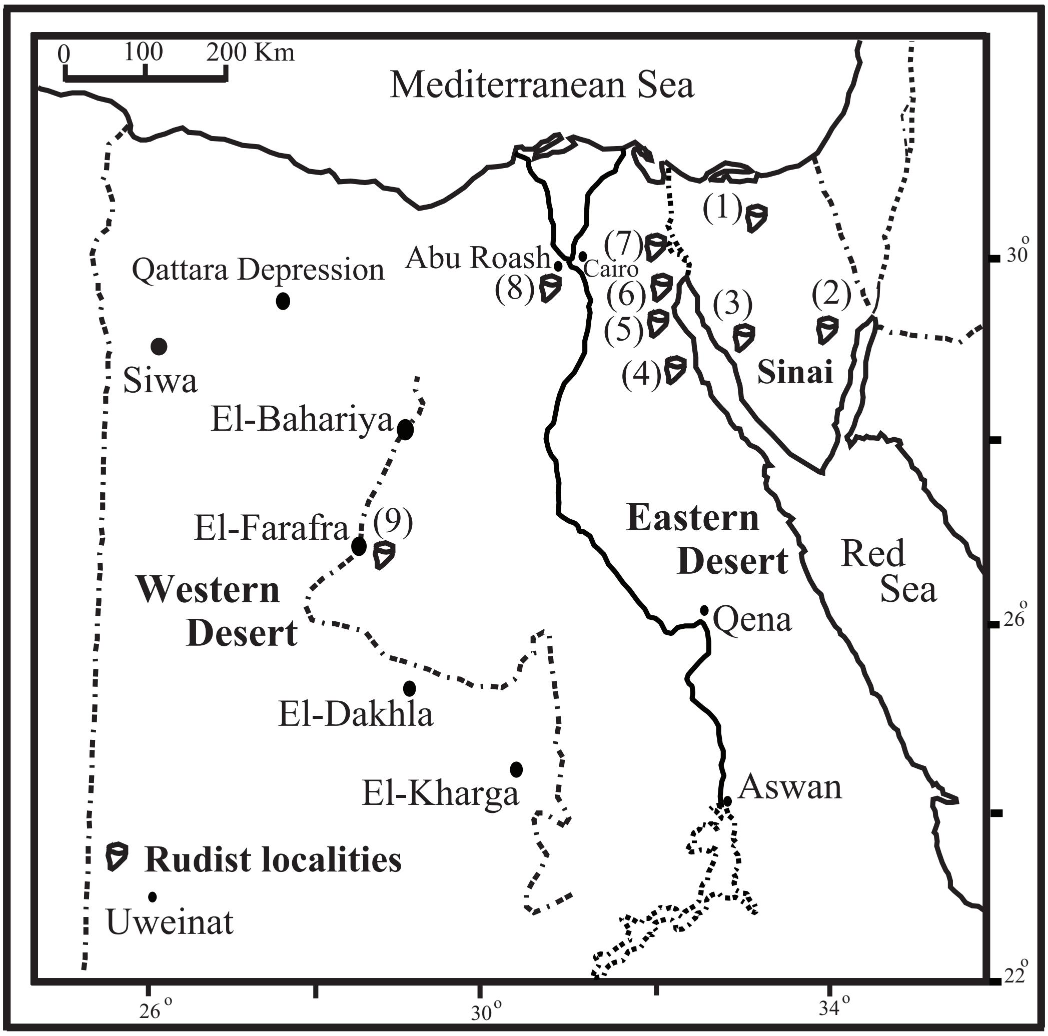

Figure 1. Rudist occurrences in Egypt. 1– North Sinai, 2– East central Sinai, 3– West central Sinai, 4– Southern Galala, 5– Northern Galala, 6– Gebel Ataqa, 7– Gebel Shabraweet, 8– Abu Roash, 9– El-Farafra Oasis.

rudists from Egypt. The species richness (diversity) peaks in the Cenomanian (7 species), followed by Campanian (1 species). Yet, no record of rudist from Aptian, Albian, Turonian, Coniacian, Santonian and Maastrichtian of the Eastern Desert (Figure 3).

Rudists in Western Desert

A total of nineteen rudist species are reported from the Western Desert (Figure 4), representing 21.8% of the all recorded rudists from Egypt. The species richness (diversity) peaks in the Turonian (14 species), followed by Cenomanian (2 species), one

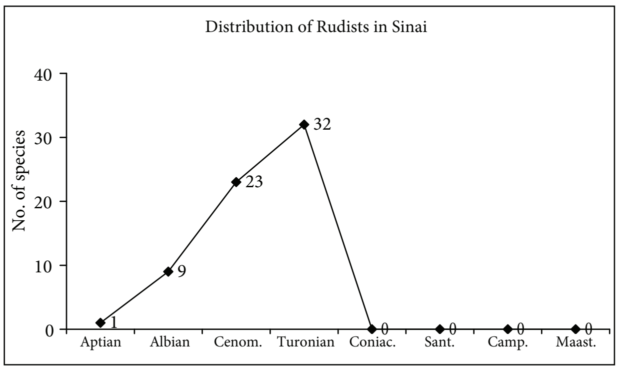

Figure 2. Species richness of rudists in the Cretaceous rocks of Sinai.

Table 1. Biostratigraphic (vertical) distribution of the Cretaceous rudists in Egypt.

Maast.	Camp.	Sant.	Conia.	Turon.	Cenom.	Albian	Aptian	Species
					■	■		*Eoradiolites liratus*
	■							*Vaccinites vesiculosus*
				■	■			*Radiolites lusitanicus*
					■			*Sauvagesia villei*
				■				*Bournonia fourtaui*
				■				*Durania gaensis*
				■				*Bournonia roachensis*
				■				*Durania arnaudi*
			■	■	■			*Distefanella lombricalis*
	■							*Durania farafrahensis*
				■				*Durania austinensis*
					■			*Eoraiolites sinaiticus*
					■			*Ichthyosarcolites triangularis*
					■			*Toucasia carinata*
				■				*Hippurites requieni*
					■			*Praeradiolites biskraensis*
				■				*Radiolites peroni sinaitica*
				■				*Durania* sp.
				■				*Radiolites expansus*
				■				*Radiolites lewyi*
				■				*Radiolites minor*
				■				*Radiolites obtusus*
				■				*Radiolites rishensis*
				■				*Radiolites sauvagesi*
				■				*Radiolites validus*
					■	■		*Eoradiolites davidsoni*
				■				*Hippurites resectus*
				■				*Durania humei*
				■				*Sauvagesia sanfilippoi*
				■				*Durania inermis*
				■				*Vaccinites rousseli*
				■				*Durania runaensis*
					■			*Durania sinaitica*
				■				*Praeradiolites ponsianus*
					■			*Distefanella zumoffeni*

Table 1. Continued.

				■			*Caprinula* sp.
				■	■		*Ichthyosarcolites* sp.
			■				*Durania*
			■				*Lapeirousella aumalensis*
			■	■			*Sauvagesia nicaisiei*
			■				*Sauvagesia sharpie*
			■				*Sauvagesia toucasi*
				■			*Monopleura sp.*
			■				*Praeradiolites irregularis*
			■				*Radiolites radiosus*
			■				*Biradiolites angulosus*
			■				*Bournonia judaica*
			■				*Vaccinites* sp.
			■				*Apricardia* sp.
				■			*Praeradiolites cf. fleuriaui*
				■			*Requienia tortuosi*
				■			*Apricardia carentonenis*
				■			*Eoradiolites syriacus*
				■			*Sphaerulites agariciformis*
				■			*Sphaerulites depressus*
			■				*Vaccinites grossouvrei*
				■			*Eoradiolites cf. davidsoni*
					■		*Neocaprina raghawiensis*
					■		*Neocaprina?* sp.
					■		*Sellaea* sp.
					■		*Agriopleura? darderi*
					■		*Eoradiolites murgensis*
					■	■	*Eoradiolites plicatus*
					■		*Praeradiolites cf. irregularis*
					■		*Praeradiolites* sp.
					■		*Radiolites* sp.
					■		*Distefanella* sp.
■							*Radiolites* sp.

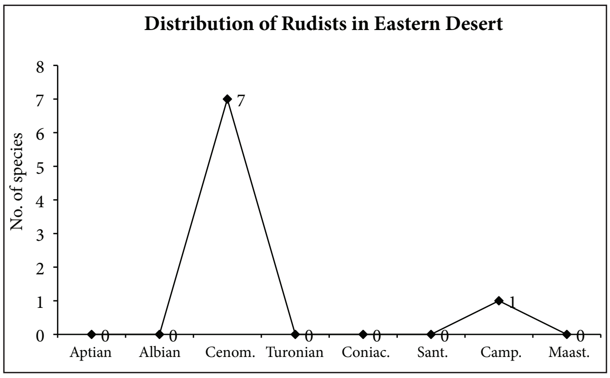

Figure 3. Species richness of rudists in the Cretaceous rocks of Eastern Desert.

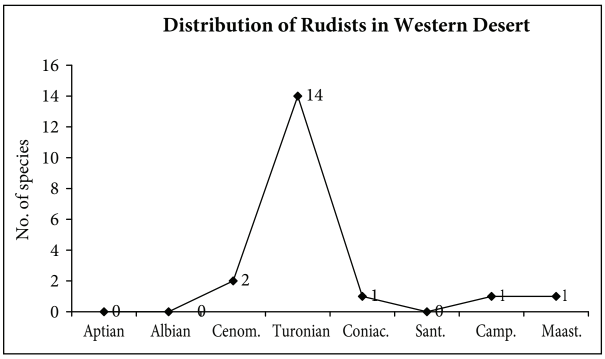

Figure 4. Species richness of rudists in the Cretaceous rocks of Western Desert.

species from each of the Coniacian, Campanian and Maastrichtian. So far, no record of rudist from Aptian, Albian, Santonian of the Western Desert.

Total Species Richness and Abundance of Rudists in the Egyptian Districts

The term 'Abundance' is taken in the sense of Steuber & Löser (2000), meaning the number of species records. Regarding species richness in the geographic divisions of Egypt, it is found that rudists are highly represented in Sinai (60 species) concentrated in the Cenomanian and Turonian. In the Western Desert 19 species are reported mainly from Turonian. While only 8 rudist species are found in the Eastern Desert, mainly in Cenomanian (Figure 5).

Regarding the total species richness in Egypt through the Cretaceous, the diversity (richness)

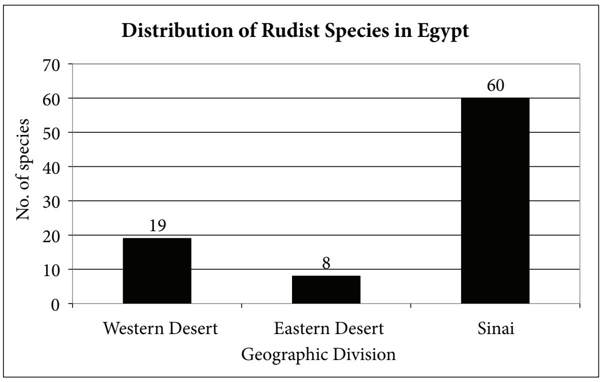

Figure 5. Total distribution of rudist species in the Egyptian geographic divisions.

peaks in the Turonian (36 species) and Cenomanian (26 species), then followed by Albian (9 species) with few records in Aptian, Coniacioan, Campanian and Maastrichtian (totally 5 species) (Figure 6).

Regarding abundance of the rudist species so far, the relatively highly abundant species in Egypt are *Eoradiolites liratus* as it is reported from 19 sites, followed by *Eoradiolites sinaiticus*, *Praeradiolites biskraensis* (7 sites for each); *Praeradiolites ponsianus*, *Durania humei*, *Radiolites sauvagesi* (6 sites for each), and *Durania gaensis, Distefanella lombricalis* and *Radiolites lusitanicus* (5 sites for each) (Figure 7). The other species are reported between one to four times in the Egyptian geographic divisions. Some rudist species are sharing between two geographic divisions for example in the Turonian of Western Desert and Sinai and in the Cenomanian of Eastern Desert and Sinai. Also some species are extending within two

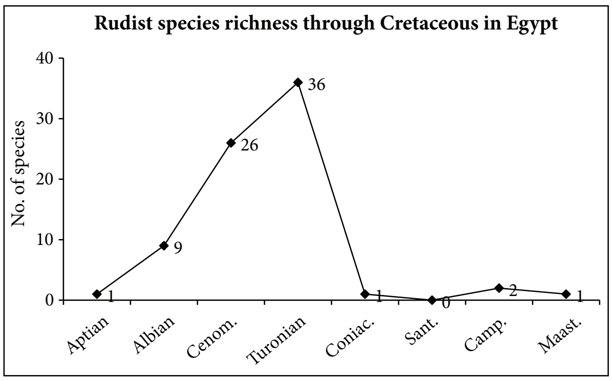

Figure 6. Distribution and total species richness of rudists through the Cretaceous in Egypt.

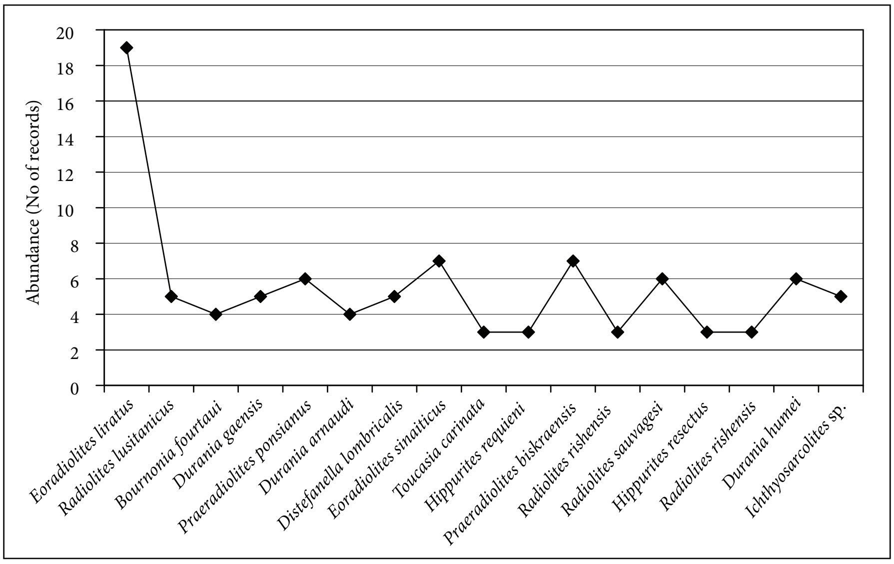

Figure 7. The most abundant rudist species in the Cretaceous rocks of Egypt.

stratigraphic levels such as Aptian and Albian or Cenomanian and Turonian (Table 1). As a consequence to this repetition, the total number of species found in Egypt in general is less than the total collective species in the three geographic regions.

Although rudists are very rare during Campanian and Maastrichtian of Egypt, many rudist species were reported from the Campanian–Maastrichtian of Turkey (Özer & Fenerci 1993; Özer 2005a, b; Steuber *et al.* 2008; Özer *et al.* 2009), Croatia (Moro *et al.* 2002), Italy (Schlüter *et al.* 2008), Peru (Philip & Jaillard 2004), Jamaica (Mitchell 2003; Mitchell & Gunter 2006), Syria, Saudi Arabia, Iran, United Arab Emirates and Oman (Steuber & Löser 2000). Also Rudists are particularly abundant in Santonian–Campanian limestones of Boeotia, central Greece (Steuber 1999).

Discussion and Conclusions

The Aptian through Maastrichtian successions in Egypt were deposited under oscillating sea level. Different rock units are given to these sequences due to lateral facies changes or basin characteristics. About sixty eight species belong to twenty one genera are reported from Egypt. They belong to six families: Requieniidae, Monopleuridae, Caprotinidae, Caprinidae, Hippuritidae, and Radiolitidae (Figure 8). The Radiolitidae is the most diverse family, comprising eleven genera and fifty-one species, dominated by species of *Radiolites, Eoradiolites* and *Durania*. The Caprinidae, Requieniidae and Hippuritidae are less diverse families in Egypt, while the Monopleuridae, Caprotinidae are weakly diverse. The elevator morphotype of the Radiolitidae became the dominant species since the Turonian time. The average number of specimens for each species range between 1 to 3 in Aptian, Albian, Coniacian, Campanian and Maastrichtian. Exceptional high

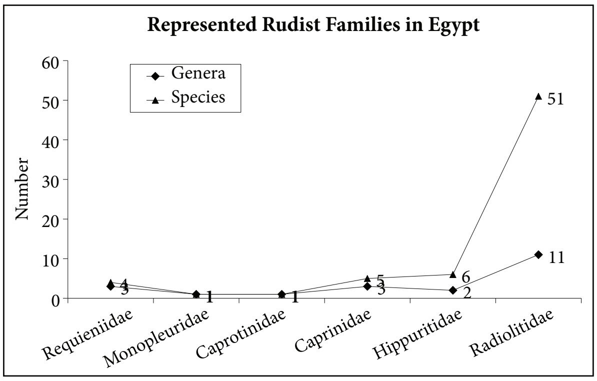

Figure 8. The represented rudist families, genera and species in the Cretaceous rock of Egypt.

specimens density in Albian of north Sinai is achieved by *Sellaea* sp., and *Agriopleura? darderi* (Astre) of Steuber & Bachmann (2002), where as the density of species was higher in Cenomanian and Turonian (4 to 20 specimens for each species in average, sometimes 50 to 120). *Eoradiolites liratus* (Conrad) is found in considerable density as it managed to adapt shelf conditions in both Albian in north Sinai and Cenomanian of central Sinai.

Authentication of some species that reported in different ages (i.e. Aptian to Albian or Cenomanian to Turonian or Turonian to Coniacian) needs further morphological investigations. For example *Distafanella lombricalis* (D'Orbigny) was reported as Coniacian species from Abu Roash (Douvillé 1913); as Turonian species from Sinai and Abu Roash (Bauer *et al.* 2004; Aly *et al.* 2005; Abdel Gawad *et al.* 2008), and as Late Cenomanian species from Saint Paul of Eastern Desert (El-Hedeny & El-Sabbagh 2004). Regionally, the species was reported from Turonian rocks of Guatemala by Scott (1995).

Also *Radiolites lusitanicus* (Bayle 1857) is reported from Late Cenomanian of Southern Galala and western Sinai (Metwally & Abd El-Azeam 1997; El-Hedeny & El- Sabbagh 2004; Zakhera 2008). It is also reported from Turonian rocks of eastern Sinai and Abu Roash (Kora & Genedi 1995; El-Hedeny 2007 respectively).

Biradiolites zumoffeni Douvillé, 1910 was mentioned by Douvillé (1910); Aly *et al.* (2005) and Saber *et al.* (2009) as Cenomanian species from Cenomanian sequence. It was modified as *Distefanella zumoffeni* (Douvillé 1910) by Steuber (2002). Although the stratigraphic range of Biradiolitinae rudist extends from Turonian to Maastrichtian according to the Treatise on Invertebrate Palaeontology by Dechaseaux & Coogan (1969). *Praeradiolites aegyptiaca* Douvillé is considered a synonym of *Praeradiolites ponsianus* (D'Archiac) according to Steuber (1999) and Zakhera (2008), so the number of the species richness is reduced by one and the number of record sites of *Praeradiolites ponsianus* is increased. *Hippurites resectus* Defrance is used instead of the name *Hippuritella resecta* (Defrance) according to Zakhera (2008). *Durania* sp. is reported two times from Gebel Er-Risha and Wadi Sudr (Sinai), so they are probably one species or they could be two separate species according the further taxonomic studies. The same also for *Ichthyosarcolites* sp.

The Lower Cretaceous (Aptian–Albian) rocks with rudist species are reported only from north Sinai where the shelf characteristic is suitable for some rudist rather than the conditions in Western Desert and Eastern Desert (fluviomarine to fluvial). The Aptian–Albian rudists are more represented in the European Tethyan margin according to Fenerci-Masse *et al.* (2006).

The species richness peaks in the Cenomanian and Turonian and the post-Cenomanian associations are predominantly elevator morphotype of the family Radiolitidae. The Turonian was a period of tectonic activity and eustatic sea level changes along southern Tethys (Lüning *et al.* 1998), these tectonic is considered as an echo to Laramide orogeny associated with an opening stage of the Atlantic Ocean and elevation of many areas northern Egypt (Kerdany & Cherief 1990). This condition resulted in creation of appropriate environment for dominance of elevator rudist morphotypes in Egypt. The Cenomanian–Turonian rudist species are highly represented in north and central Sinai, the environment was fully marine and the shallow platform favoured for rudist growth. Some Cenomanian rudists like *Ichthyosarcolites triangularis* and *Hippurites resectus* are cosmopolitan species as they are reported also from south west Turkey by Sarı & Özer (2009).

Crises in species richness and abundance during Early and Middle Cretaceous can be attributed to regional environmental perturbation, induced by either oceanic anoxia or tectonic movements (Steuber & Löser 2000).

The disappearance of rudists from the middle part of the Cenomanian–Turonian sequence is related to deeper setting resulted from sea level rise or floor subsidence (shelf drowning) (Steuber & Löser 2000; Zakhera 2008), which may related to global warming.

The rudists are rarely occurred and low diversified during Coniacian, Campanian and Maastrichtian. In Coniacian, only one rudist record from Western Desert, as a siliciclastic input from southerly exposed hinterland increased in Sinai and Eastern Desert (Bauer *et al.* 2003). No record of rudists from Santonian rocks in Egypt so far. The rudists are scarce in Egypt during Campanian as they are reported from two isolated areas in El-Farafra Oasis and Gebel Ataqa within partially phosphatic sediments, which leading to stagnant conditions and effect on rudist growth.

The Cretaceous carbonate platform was locally exposed above sea-level during Coniacian–Santonian and covered with continental strata of mixed origins (Kuss 1992), this may relate to Syrian Arc tectonics and led to rarity of rudists at these times.

Wanner (1902) reported one specimen of *Radiolites* sp. from the top white chalk from north of El-Farafra. The species is of Maastrichtian age according to its association with *'Pecten'* Zittle and other Maastrichtian molluscan fossils just below beds with Tertiary fauna. Also the upper part of the white chalk of Khoman Formation is of Maastrichtian age (Abdel-Kireem 1986; Tawadros 2001).

The rare occurrence during Maastrichtian may also be attributed to stagnant conditions related to deposition of black shales and fine-grained siliciclastics with phosphatic intercalations (Dakhla Formation) in south and central Egypt and dominance of outer shelf pelagic marine chalks and chalky limestones (Khoman and Sudr formations) in northern Egypt.

At the same time, the considerable occurrence of Campanian and Maastrichtian rudist species along Tethyan margins of Afro-Arabian, South Europe and Caribbean regions may be attributed to platform characteristics controlled by regional tectonics. The rudist fauna in Egypt shows Tethyan affinity with close relationship with southern Europe, North America, North Africa and Middle East.

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