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TORTONIAN *CLYPEASTER* FAUNA (ECHINOIDEA: CLYPEASTEROIDA) FROM GAVDOS ISLAND (GREECE)

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Abstract

The Tortonian sediments of Gavdos Island (Greece) contain a rich and diverse echinoid fauna. Clypeasteroid (sand dollars) echinoids are an important component of this fauna and sixteen taxa are recognized. Of these, eleven species are new records for Gavdos Island. The present paper is an annotated species list along with notes on certain aspects of the ecology of the determined echinoderms.

Key words: *Tortonian, Clypeaster, Gavdos, taxonomy.*

Περίληψη

Τα ιζήματα ηλικίας Τορτονίου, της νήσου Γαύδου (Ελλάδα) περιέχουν μια πλούσια και ποικιλόμορφη πανίδα εχίνων με κύριο αντιπρόσωπο το γένος Clypeaster. Από το σύνολο των δεκαέξι ειδών που έχουν αναγνωρισθεί, τα έντεκα αποτελούν καινούριες ανφορές για τη νήσο Γαύδο. Η παρούσα εργασία αποτελεί αναφορά στη συστηματική ταξινόμηση και στην οικολογία των έντεκα αυτών ειδών.

Λέξεις Κλειδιά: *Τορτόνιο, Clypeaster, Γαύδος, Συστηματική ταξινόμηση.*

1. Introduction

Clypeasteroids can be very common in Recent, shallow water environments in a variety of biogeographic settings and represent important members of benthic invertebrate communities. Mass deposits of fossil clypeasteroids are also common and characteristic of many Cenozoic shallow water deposits. Their distribution and formation, however, has received much less attention than molluscan counterparts, although fossil examples are found within all three of the clypeasteroid suborders.

The Neogene deposits of Gavdos Island cover almost half of the island area and have been divided by Anastasakis *et al.* (1995), into two formations: Potamos and Metochia. A good reconnaissance map and description of the formations is given by Anastasakis *et al.* (1995), Drinia *et al.* (2004) and Tsaparas (2005) and need not be repeated here. Antonarakou (2001) and Antonarakou *et al.* (in press) consider that these formations are late Middle and Late Miocene in age respectively, basing their conclusions on the faunas of planktonic foraminifera.

A number of systematic works have been published on the corals, foraminifera and molluscs of the Gavdos Miocene, but until now there has been no work devoted particularly to the echinoids of the island. The most important work is that by Marcopoulou-Diakantoni (1970) who characterized the skeletal elements of about five genera of echinoids. It is therefore significant to report a second Miocene echinoid fauna from Gavdos Island. This differs from that of Marcopoulou-Diakantoni (1970) in including eleven more taxa. These fossils are preserved in a conspicuous thick marker bed of Middle Toronian age which is characterized by the predominance of the large benthic foraminifer *Heterostegina.*

The present paper is an annotated species list along with notes on certain aspects of the ecology of echinoderms. It supplements the information on echinoderms provided by Marcopoulou-Diakantoni (1970).

2. Material and Methods

The specimens documented herein were collected from throughout a fossiliferous βεδ which provides an excellent marker bed that can be traced almost throughout the basin. Its lithology consists of medium-sized partially cemented sandstone with mottled structure and no visible stratification. In an outcrop scale, endobenthic and epibenthic bivalves, bryozoans, irregular echinoids (including large *Clypeaster*) and large benthic foraminifers (*Heterostegina*) predominate, with minor proportions of gastropods. Because of its typifying large foraminifer fauna and lateral continuity, this bed represents an excellent stratigraphic marker bed. The skeletal content implies a fully marine shelf setting. Skeletal biota are well preserved which points to a rather quiet depositional setting below wave abrasion depth (WAD), (Brachert *et al.* 2003). Large benthic foraminifers have a broad depth range, and their presence fits a depositional environment in the lower segment of the photic zone (e.g. James *et al.* 2001). Their presence implies warm-temperate surface temperatures (Betzler *et al.* 1997).

An adequate number of individuals, from the genus *Clypeaster*, was collected from the above mentioned sandstone marker bed. Most of the specimens' test is covered by attached colonies of membraniporiform type Bryozoans. Taxa were defined almost entirely on the basis of skeletal characteristics, meaning that the same criteria can be used for fossil as for recent echinoderms. Quantitative characters, notably the size of echinoderms were used in order to distinguish between species belonging to the same genus. All given dimensions of specimens are in millimetres. The following abbreviations have been used: Lo= Length, la=width, h=height. Scanning electron microscopy was considered a crucial technique in echinoid taxonomy as small-scale characters are being increasingly applied to differentiate otherwise similar species.

Field observations and material analyses are completed by a more general bibliographic review of the distribution of Late Neogene Mediterranean echinoids. The bibliographic data used are those given by Philippe (1998) for Tortonian echinoids from southeast France; by Montenat and Roman (1970), Roman and Soudet (1990), Néraudeau *et al.* (1999), Lacour and Néraudeau (2000), Saint-Martin *et al.* (2000) for Tortonian to Pliocene echinoids from Spain; by Borghi (1995a, b) and Néraudeau *et al.* (1998) for Pliocene and Pleistocene echinoids from Italy; by Boggild and Rose (1985) for Neogene echinoids from the Maltese islands; by Marcopoulou-Diakantoni (1967, 1972, 1974, 1977); and Heimann and Marcopoulou-Diacantoni (1977) for Late Miocene and Plio–Pleistocene echinoids from Eastern Mediterranean; and by Ragaini (1996) for Pliocene echinoids from Switzerland. Although selective rather than comprehensive in regional coverage, we believe that these most recent accounts of local faunas are taxonomically and stratigraphically more appropriate for our purpose than the sometimes extensive but imprecise older literature.

Because of the important variations in the species concept of the genus *Clypeaster*, we have grouped as much as possible the various species under some great names, such as *C. scillae, C. altus, C .campanulatus* and *C. ventiensis* according to the classification scheme of Marcopoulou-Diakantoni (1985).

3. Results

Even though the preservation state of certain of the studied specimens was not good enough, the following species were determined: *Clypeaster altus, C. calabrus, C. campanulatus, C. crassus, C.* cf. *di-Stefanoi, C. intermedius, C. intermedius* (form *crassicostatus*), *C. lamberti, C. portentosus, C. tauricus, Clypeaster* cf. *ventiensis*. From these species, the following are characteristic for the Miocene of the Mediterranean basin: *C. altus, C. calabrus, C. campanulatus, C.* cf. *ventiensis, C. lamberti.*

3.1. Systematic Paleontology

Phylum: Echinodermata Klein 1734
Subphylum: Echinozoa Haeckel in Zittel 1895
Class: Echinoidea Leske 1778
Subclass: Euechinoidea Bronn 1860
Superorder: Gnathostomata Zittel 1879
Order: Clypeasteroida Agassiz 1872
Suborder: Clypeasterina Agassiz 1872
Family: Clypeasteridae Agassiz 1835
Genus: *Clypeaster* Lamarck 1801

Clypeaster altus **(Klein, 1734)**

1734. *Scutum angulare altus* Klein, p. 29.
1778. *Echinanthus altus* Leske, p. 189, pl. LIII, fig. 4.
1816. *Clypeaster altus* Lamarck, p. 14, tav. III.
1958. *Clypeaster altus* (Klein).- Imbesi, vol. LIII (n. ser. vol. XXIII), p. 28, tav. X, fig. 1, 1a, 2, 2a, 2b.
1967. *Clypeaster altus* (Klein).- Marcopoulou-Diacantoni, p. 359, Pl. III, fig. 1, 1a, Pl. IV, fig. 2.
1969. *Clypeaster altus* (Klein).-Mitrovic-Petrovic, p. 126, tav. V, fig. 2, 2a.
1985. *Clypeaster altus* (Klein).- Marcopoulou-Diacantoni, p. 103, 105, 108, 159, Pl. I-III.
1998. *Clypeaster altus* (Klein).- Philippe, p. 122
2000. *Clypeaster altus* (Klein).- Marcopoulou-Diacantoni, p. 177.

Specimens: 1 individual ; *Dimensions:* 2004 / P8 :Lo: 135, la: 115, h: 61,,l/L: 0,85, h/L: 0,45

Remarks: Oral face with large infudibulum belonging to the group of *Clypeaster altus.* Ambulacral petals form petaloid open with elevated intermediate region. Ambitus rounded.

Stratigraphical and Geographical distribution. Burdigalian (Algeria, Malta, Italy); Middle Miocene (Algeria, Malta, Sicily, Sardinia, Turkey, France, Greece); Tortonian (Hungary, Greece); Middle Tortonian (Gavdos).

Clypeaster calabrus **(Seguenza, 1880)**

1880. *Clypeaster intermedius* var. *calabra* Seguenza, Tav. V, fig. 3, 3a, 3b.
1925. *Clypeaster novaresei* Checchia – Rispoli, Tav. IX, fig. 1,1a,1b,1c,2b, Tav. X, Tav. XIII, fig. 1, 1a, 1b, 2.
1925. *Clypeaster calabrus* Seguenza.- Checchia – Rispoli, vol. IX, parte III, p. 18, tav. VII, fig. 2.
1958. *Clypeaster calabrus* Seguenza.- Imbesi, vol. LIII (n. ser. vol. XXIII), p. 17, tav. II, fig. 1,1a, 1b, 2, 2a, tav. III, fig. 1.
1967. *Clypeaster calabrus* Seguenza.- Marcopoulou-Diacantoni, p. 365, Pl. XVI, fig. 1, Pl. XVIII.
1985. *Clypeaster calabrus* Seguenza.- Marcopoulou-Diacantoni, p. 128, 134, 162.

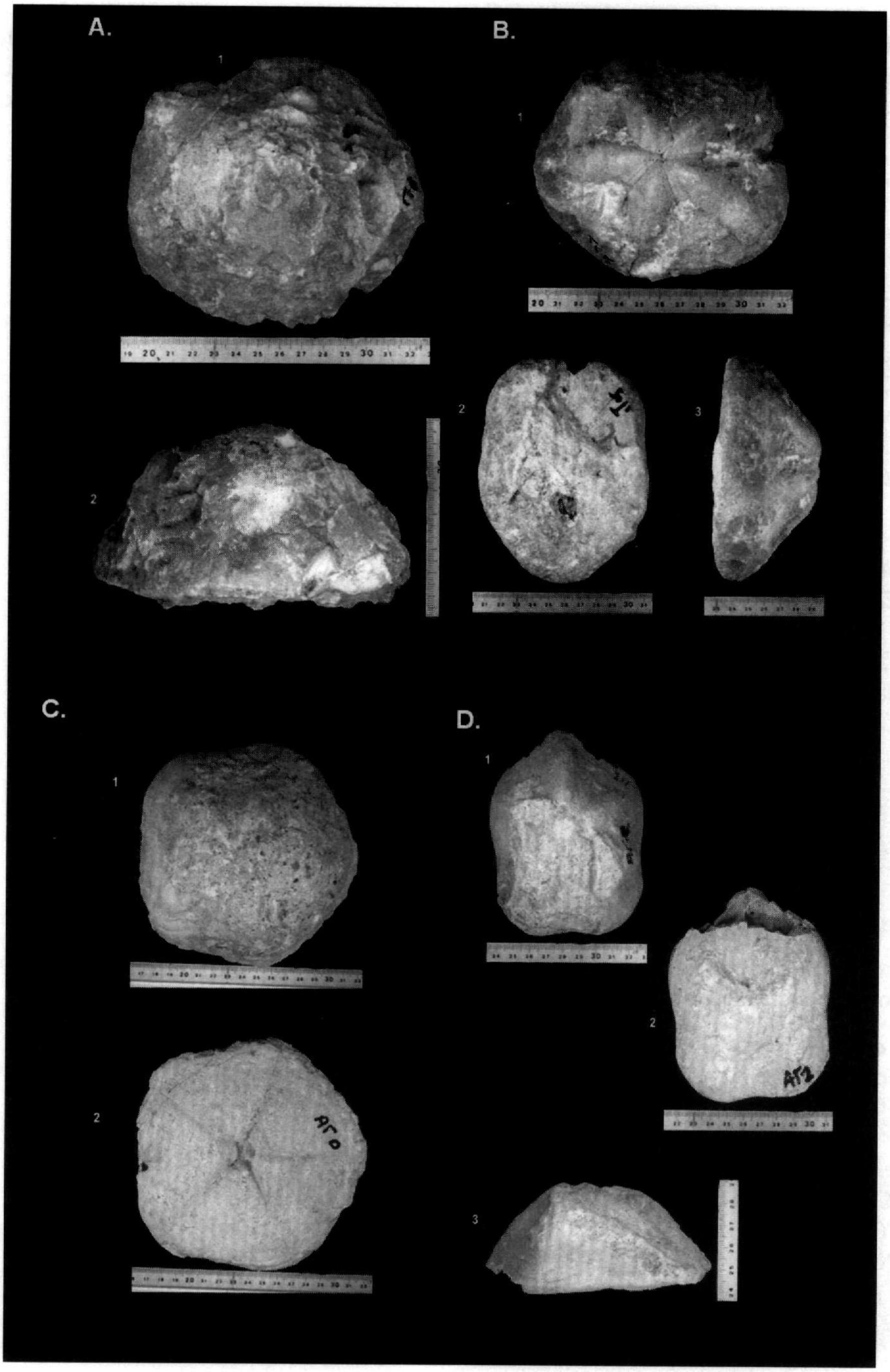

Plate 1 - A. *C. altus*, B. *C. calabrus*, C. *C. campanulatus*, D. *C. crassus*

Specimens: 3; *Dimensions:* 2004 / P5 : Lo:124, la:107, h:56, l / L :0,86, h / L :0,45
2004/G5 : Lo:143, la:122, h:65, l / L :0,85, h / L :0,45
2004/AG3 : Lo:111, la:96, h:44, l / L :0,86, h / L :0,39

Stratigraphical and Geographical distribution. Aquitanian (Italy); Middle Miocene (Italy, Sicily); Middle-Late Miocene (Greece); Middle Tortonian (Gavdos).

Clypeaster campanulatus Schlotheim, 1820

1906. *Clypeaster campanulatus* Schlotheim.- Lambert, p. 14.
1913. *Clypeaster campanulatus* Schlotheim.- Lambert, vol. XXXIX, 3e partie, p. 117.
1967. *Clypeaster campanulatus* Schlotheim.- Marcopoulou-Diacantoni, p. 367, Pl. XII.
1985. *Clypeaster campanulatus* Schlotheim.- Marcopoulou-Diacantoni, p. 104, 116, 118, 119, 162.
1998. *Clypeaster campanulatus* Schlotheim.- Philippe, p. 123.
2000. *Clypeaster campanulatus* Schlotheim.- Marcopoulou-Diacantoni, p. 177, Pl. I, fig. 3a,b, Pl. II, fig. 2a,b, Pl. III, fig. 2a,b.

*Specimens:*3 ; *Dimensions*: 2004/AG0 : Lo:152, la:140, h:47, l / L:0,92, h / L:0,30
2004/P9 : Lo:153, la:135, h:60, l / L:0,88, h / L:0,39
2004 / P11 : Lo:156, la:142, h:62, l / L:0,91, h / L:0,39
Remarks: Test pyramidal with large infudibulum and oral face flat belonging to the group of *Clypeaster campanulatus* (Marcopoulou-Diakantoni, 1985). Ambulacral petals form petaloid open with elevated intermediate region. Ambitus rounded.

Stratigraphical and Geographical distribution: Middle Miocene (France, Austria, Spain, Corsica, Valearides, Sardinia, Greece, Turkey); Tortonian (Hungary, Cilice, Syria, Greece); Middle Tortonian (Gavdos).

Cypeaster crassus Agassiz, 1861

1963. *Clypeaster crassus* Agassiz.- Kier, vol. 145, p. 30, Pl. 11, fig. 1-3.
1985. *Clypeaster crassus* Agassiz.- Marcopoulou-Diacantoni, p. 129,132, 166, Pl. XIII,XV,XVI.

Specimens: 1 ; *Dimensions:* 2004 / AG2 : Lo: 109, la : 93, h: 29, l / L: 0,85, h / L: 0,26

Stratigraphical and Geographical distribution: Early Miocece (France, Sardinia, Algeria, Corsica, Egypt); Middle Miocene (France, Turkey); Late Miocece (Florida USA); Tortonian (Hungary); Middle Tortonian (Gavdos).

Clypeaster cf _di–Stefanoi_ Checchia – Rispoli, 1916

1916. *Clypeaster di-Stefanoi* Checchia – Rispoli, vol. XXII, p. 238, tav. XXVIII, fig. 2.
1967. *Clypeaster di-Stefanoi* Checchia – Rispoli.- Marcopoulou-Diacantoni, p. 368, Pl. XVI, fig. 2.
1985. *Clypeaster di-Stefanoi* Checchia – Rispoli.- Marcopoulou-Diacantoni, p. 169

Specimens : 1 ; *Dimensions:* 2004 / G2 : Lo: 133, la: 123, h: 50, l / L: 0,92, h / L: 0,37

Stratigraphical and Geographical distribution. Middle Tortonian (Gavdos); Pliocene (Italy, Greece)

Clypeaster intermedius Desmoulins, 1837

1778. *Echinanthus humilis* Leske, pl. XL, fig. 1, pl. XLI, fig. 1.
1837. *Clypeaster intermedius* Desmoulins, p. 73, moules r. 11, r. 12.
1928. *Clypeaster intermedius* Desmoulins.- Lambert, vol. 1, No 2, II partie, p. 13.
1967. *Clypeaster intermedius* Desmoulins.- Marcopoulou-Diacantoni, p. 370, Pl. VI.
1985. *Clypeaster intermedius* Desmoulins. –Marcopoulou-Diacantoni, p. 128, 134, 159, 176, Pl. X-XII.

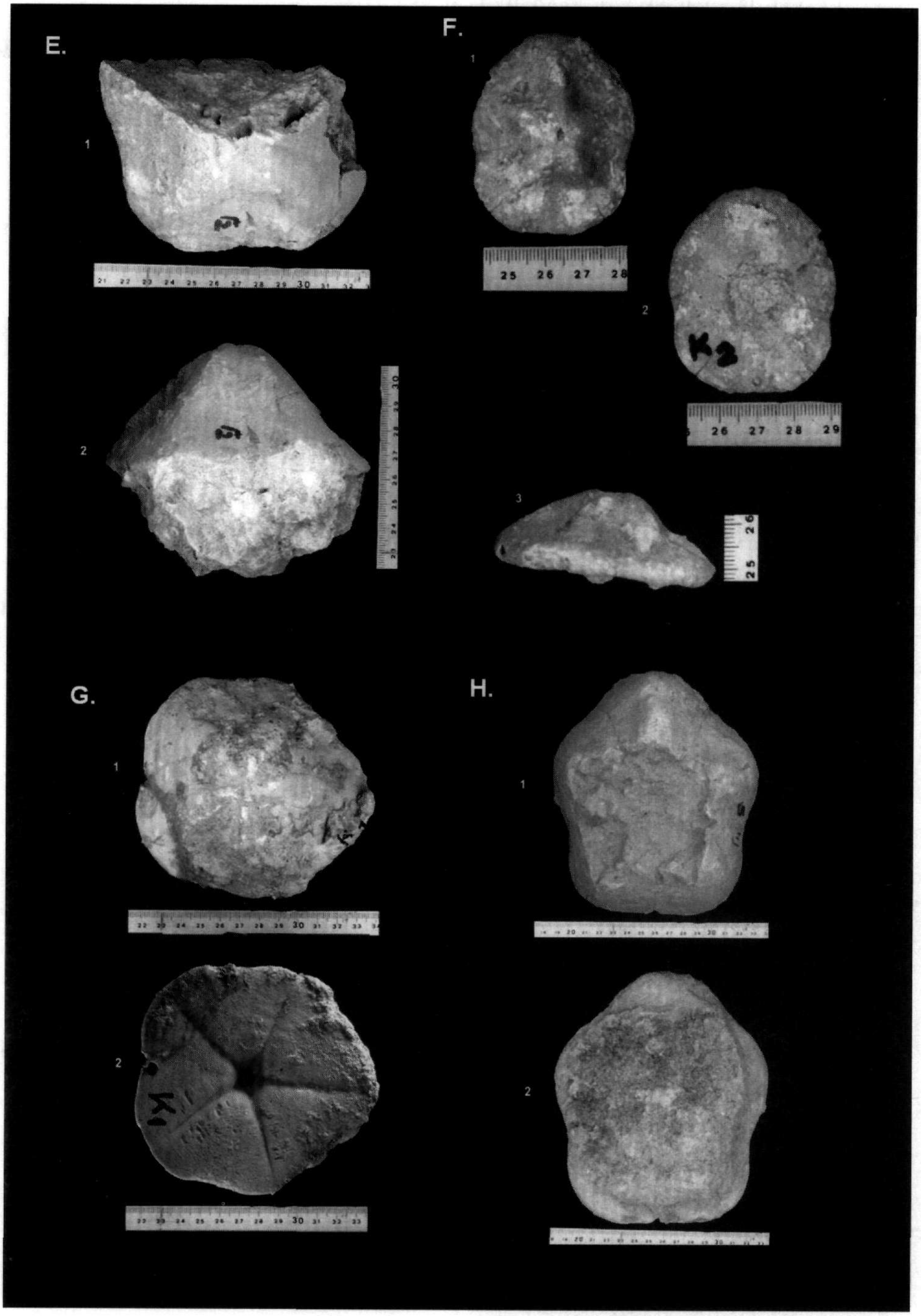

Plate 2 - E. *C.* cf. *di Stefanoi*, F. *C. intermedius* (form *crassicostatus*), G. *C. intermedius*, H. *C. lambert*

1998. *Clypeaster intermedius* Desmoulins. – Philippe, p. 302, pl. 11, fig. 4-6, pl. 12, fig. 1-4.
2000. *Clypeaster intermedius* Desmoulins. – Marcopoulou-Diacantoni, p. 178, Pl. III, fig. 1a,b, Pl. V, fig. 3a,b, Pl. VI, fig. 1.

Specimens : 1 ; *Dimensions:* 2004 / K1 :Lo: 120, la: 103, h: 39, l / L: 0,85, h / L: 0,32

Remarks: In the typical form of this species the impair ambulacral anterior zone is more narrow and elevated than in our specimen. The species belongs to the group of *Clypeaster scillae* (Marcopoulou-Diakantoni, 1985).

Stratigraphical and Geographical distribution: Early-Late Neogene (France, Spain, Corsica, Valearides, Egypt, Algeria, Italy, Middle East); Middle-Late Miocene (Greece); Middle Tortonian (Gavdos).

Clypeaster intermedius (form *crassicostatus*) Desmoulins, 1837

1985. *Clypeaster intermedius* (de la forme crassicostatus) Desmoulins.- Marcopoulou-Diacantoni, pl. XIV, XIX.
1998. *Clypeaster intermedius* (form *crassicostatus*) Desmoulins.- Philippe, p. 117, pl. 12, fig. 4.
2000. *Clypeaster intermedius* (form *crassicostatus*) Desmoulins.- Marcopoulou-Diacantoni, p. 178, Pl. V, fig. 2.

Specimens: 1 juvenile ; *Dimensions:* 2004 / K2 :Lo:51, la:46, h:18, l/L:0,90, h/L:0,35

Remarks: The species belongs to the group of *Clypeaster scillae* (Marcopoulou-Diakantoni, 1985).

Stratigraphical and Geographical distribution: Middle-Late Miocene (Europe, North Africa, Middle East); Middle Tortonian (Gavdos).

Clypeaster lamberti Lovisato, 1905

1905. *Clypeaster lamberti* Lovisato, p. 17.
1907. *Clypeaster lamberti* Lovisato.- Lambert, vol. XXXIV, p. 49, pl. III, fig. 7, pl. IV, fig. 1, 2.
1960. *Clypeaster lamberti* Lovisato.- Roman, No 55, p. 80, pl. IV, fig. 2, 2a.
1967. *Clypeaster lamberti* Lovisato. - Marcopoulou-Diacantoni, p. 372, pl. IV, fig. 1, pl. V, fig. 1, 1a.
1972. *Clypeaster lamberti* Lovisato. -Marcopoulou-Diacantoni, p. 150.
1985. *Clypeaster lamberti* Lovisato. -Marcopoulou-Diacantoni, p. 116, 178, pl. VII.
2000. *Clypeaster lamberti* Lovisato. -Marcopoulou-Diacantoni, p. 179, Pl. I, fig. 1a,b.

Specimens : 4 ; *Dimensions:* 2004 / G1 :Lo:143, la:126, h:58, l / L :0,88, h / L:0,40
2004/G4 :Lo:161, la:142, h:51, l / L :0,88, h / L:0,31
Remarks: The species belongs to the group of Clypeaster campanulatus (Marcopoulou-Diacantoni, 1985).

Stratigraphical and Geographical distribution: Oligocene (Cuba); Miocene (Sardinia); Early-Middle Miocene (Hungary, Sardinia, Turkey); Middle-Late Miocene (Greece); Middle Tortonian (Gavdos).

Clypeaster portentosus Desmoulins, 1837

1837. *Clypeaster portentosus* Desmoulins, p. 218, N° 14.
1843. *Clypeaster agassizi* E. Sismonda, p. 48, pl. II, fig. 5-7.
1861. *Clypeaster portentosus* Desmoulins.- Michelin, 2e serie, tom. VII, p. 125, pl. XXVIII, fig. A-e.
1948. *Clypeaster portentosus* Desmoulins.- Mortensen, Text, p. 7, fig.3.
1958. *Clypeaster portentosus* Desmoulins.- Imbesi, vol. LIII (n.ser.vol. XXIII), p. 21, tav. IV, fig. 2, 2a, 2b, tav. V, fig. 1, 1a, 2, 2a, 3, 4.
1967. *Clypeaster portentosus* Desmoulins. - Marcopoulou-Diacantoni, p. 373, pl. VIII, IX, XIV.

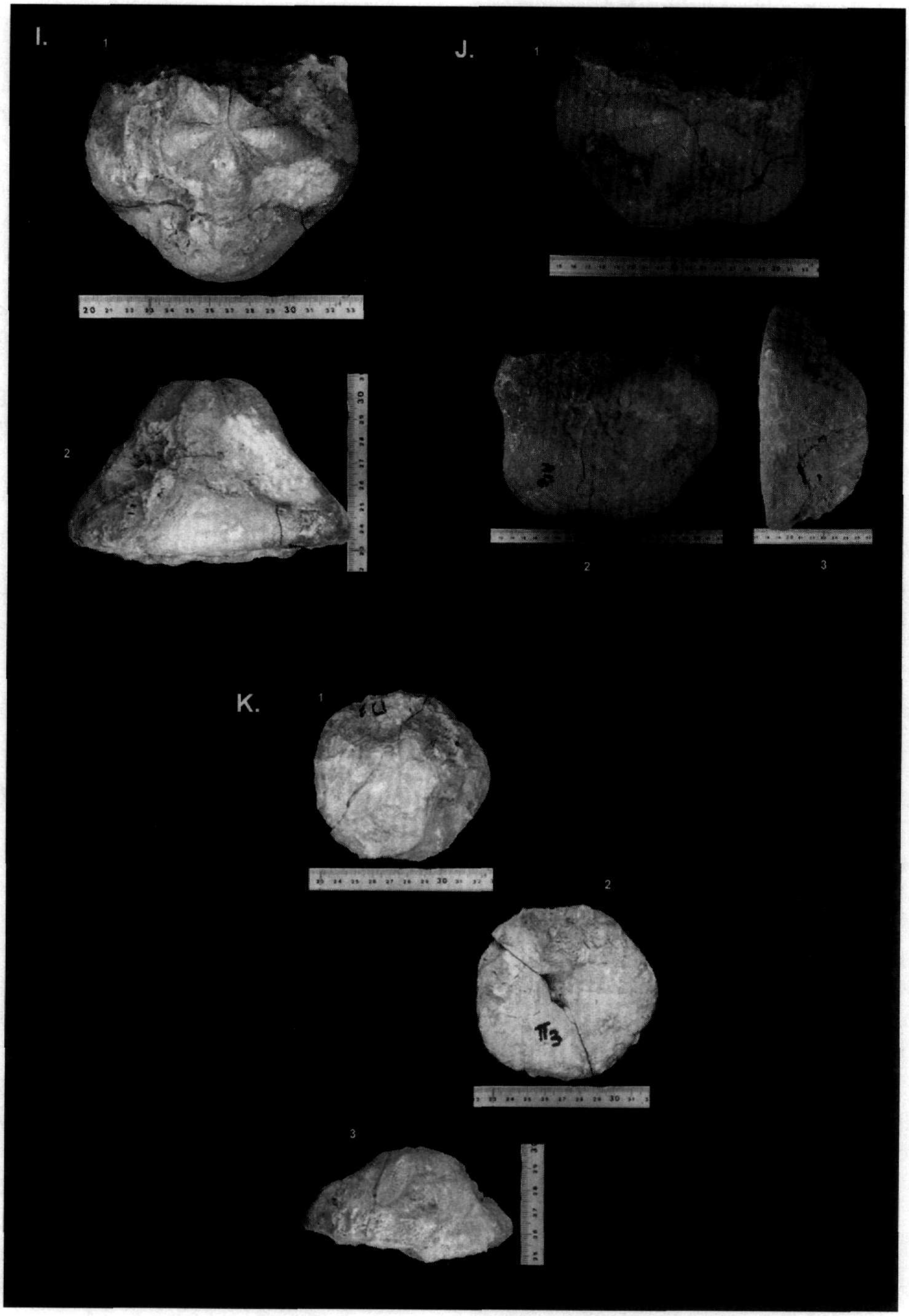

Plate 3 - I. *C. ponterosus*, J. *C. tauricus*, L. *C.* cf. *ventiensis*

1985. *Clypeaster portentosus* Desmoulins. - Marcopoulou-Diacantoni, p. 108,112, 190, pl. IV-VI.

Specimens : 5 ; *Dimensions:* 2004/P4 :Lo:148, la:120, h:86, l / L:0,81, h / L:0,58
2004 / P10 :Lo:142, la:122, h:63, l / L:0,85, h / L:0,44
2004/AG4 :Lo:152, la:131, h:84, l / L:0,86, h / L:0,55
Stratigraphical and Geographical distribution: Middle Neogene (Corsica, Kalavria, Balearics, Malta, Hungary, South France, Algeria, Cyprus); Miocene (Italy); Middle Tortonian (Gavdos).

***Clypeaster tauricus* Desor, 1859**

1861. *Clypeaster tauricus* Desor.- Michelin, p. 108, tav. X, XI, fig. a-e.
1895. *Clypeaster tauricus* Desor.- Cotteau, p. 23.
1958. *Clypeaster tauricus* Desor.- Imbesi, vol. XIII, fig. 2a, 2b.
1967. *Clypeaster tauricus* Desor.- Marcopoulou-Diacantoni, p. 377, pl. XIII.

Specimens : 1 ; *Dimensions:* 2004/AG4 : Lo: 180, la: 152, h: 78, l / L: 0,84, h / L:0,43

Stratigraphical and Geographical distribution: Middle Neogene (Portugal); Middle Miocene (Sardinia, Corsica, Malta, Spain, Syria, Crete); Middle Tortonian (Gavdos).

***Clypeaster* cf. *ventiensis* Tournouer, 1878**

1912. *Clypeaster* cf. *ventiensis* Tournouer. - Lampert
1985. *Clypeaster* cf. *ventiensis* Tournouer. - Marcopouloy-Diacantoni, p. 136, 138, 139, 201, pl. XXIV.

Specimens : 1 ; *Dimensions:* 2004/P3 : Lo: 100, la: 90, h: 35, l / L: 0,90, h / L: 0,35

Stratigraphical and Geographical distribution: Miocene (Sardinia, Katalonia); Middle Tortonian (Gavdos).

4. The irregular echinoid *Clypeaster* as potential paleoenvironmental tool

The irregular echinoid *Clypeaster* is locally common in Oligocene to Quaternary sedimentary deposits in the Mediterranean region, particularly in marine limestones of shallow-water origin. According to Kier and Grant (1965) the major factor influencing echinoid distribution is water depth/shore distance. Other factors (such as light penetration, wave agitation, current direction and food supply) are either functions of these or factors difficult to evaluate. However, Smith (1984) concluded that nine factors affect the distribution patterns of echinoid species: nature of the substratum, hydrodynamic regime, predation, salinity, temperature, food availability, water depth, behaviour and chance.

Paleoenvironments represented by Miocene echinoid assemblages may be interpreted using Recent analogues (e.g. Kier 1972). The significance of such interpretations is that they may be helpfully precise. For example, *Clypeaster altus* is closely similar to Recent species of *Clypeaster* with thick test margins in the Red Sea, such as *Clypeaster fervens*, and *Clypeaster marginatus* is convergent with Recent *Clypeaster* with thin margin from the Red Sea such as *Clypeaster humilis*. The ecological affinities of the Recent representatives of these taxa can therefore be used to interpret quite closely, by morpho-functional analogies, the palaeoenvironmental adaptations of the Miocene species, especially their bathymetrical adaptations

In the present-day Mediterranean and the surrounding marine areas (Red Sea, Atlantic Ocean), the bathymetric range of irregular echinoids can be defined according to the nomenclature proposed by Peres and Picard (1964). These authors define, in the Mediterranean, the infralittoral zone as the inner shelf with photophile seagrass, the circalittoral zone as the outer shelf with sciaphile seagrass and the bathyal zone as the topographical transition to the slope.

Recent *Clypeaster*, with hypermorphic petals, are typical of shallow, high-energy environments in the infralittoral zone thus defined, generally in water depths of about 1–50 m (George and George 1980, Dollfus and Roman 1981, Nebelsick 1992, Roman and Lachkhem 1993). The high subconical *Clypeaster altus*, with a thick test margin, settled in the shallowest environments with high energy, with coarse sediments and lived often epifaunally near coral patches or along the coast (Boggild and Rose 1985, Nebelsick 1992, Roman and Lachkhem 1993).

Thus by analogy with the bathymetric distribution of Recent Mediterranean irregular echinoids, and taking into account the stratigraphical succession of their Miocene representatives, the studied clypeasteroid fauna is indicative of an upper infralittoral environment. Furthermore, the presence of attached colonies of membraniporiform type Bryozoans on the tests of the studied specimens strongly supports the above mentioned conclusion (e.g. Moissette 1988).

5. Acknowledgements

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