ENVIRONMENTAL INTERPRETATION USING RECENT EPIPHYTIC FORAMINIFERA OF WESTERN CRETE, GREECE.

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ABSTRACT

The determination and evaluation of studied Recent epiphytic foraminiferal associations furnished important information which allow us to consider their utility in ecological analyses and reconstructions of the coastal marine environment of western Crete. Semiquantitative frequency distributions of the observed epiphytic foraminifera show a high participation of some very significant species like *Miniacina miniacea*, *Peneroplis*, *Quinqueloculina* and *Sorites* which are present in great abundance. Contrary, *Cyclocibicides, Elphidium, Planorbulina* and *Rosalina* have a lower diversity. High diversity assemblages with annual or perennial life-spans were found on phytal substrates. Different lithological substrates proved to significantly affect both distribution and specific diversity patterns. Factors controlling the diversity of epiphytic foraminifera are shown to include both temporal and spatial components.

KEY WORDS: Recent, Epiphytic Foraminifera, Ecology, Marine Environment, Shallow-water, Western Crete island.

INTRODUCTION

Recent epiphytic Foraminifera, building living marine ecosystems along the coasts of Crete island, were chosen for this study (fig. 1a). By definition, epiphytes are organisms which live and rely on plants. Phytal "substrates" offer a wide variety of foraminiferal microhabitats, depending each time on the overall shape and structure of the host (LANGER, 1993). It has been suggested that three factors additionally affect the specific diversities and distributional pattern of the benthic populations developed on the coastal or infra-littoral environments: 1) the substrate-type competition with other groups of colonizing organisms, 2) water -turbulence and -temperature changes and 3) salinity regimes (RIBES et al., 1998; REINHARDT et al., 2001). In conjunction to them, but to a much lesser extent, a variety of other ecological factors such as pH, nutrients, food requirements and light are considered to affect these benthic communities as well (REISS & HOTTINGER, 1984).

Present sampling was carried out at three locations: a) at two natural bays, namely the Gramvousa and Livadhia, located to the North and to the central-west of the island respectively and b) at Elafonissos island to the southwest. All three localities represent the most beautiful and well-known swimming coasts and bays of W. Crete. Aim of the study was firstly the identification of the living species and further to try approaching their living habitat and diversity in conjunction to literature data of other regions, where similar environmental conditions prevail. Additionally, it is tried to pinpoint species which allow us to identify the environment in a high temporal resolution. This attempt was made in order to facilitate monitoring the state of the natural shallow-marine environment and ecosystems of western Crete and to apply in the future this information on the interpretation of paleoenvironments.

MATERIAL-METHODS

The samples were collected in the summer of 1997, from the soft sea-bottom as well as from the sea-coast of the present-day lagoon by Balos, located to the western coast of the island (co. figs. 1b,c,d). The study was based on the SEM. Sampling took place at three localities, where assemblages of epiphytic Foraminifera from five samples are presently discussed: A) Two samples come from the Gramvousa bay (GR1 & GR2). GR1 was taken at the western coast-line of Gramvousa Peninsula, south of Balos bay, at an altimeter of the present SL of ±0m and GR2 at ca. -2m depth and is located ca. 200m to the west of GR1. B) Another two samples come from the Livadhia bay and are coded FA1 and FA2 respectively (to the south of the GR series). They are both situated at the northern part of the bay, in the neighbourhood of Cape Koutri and Falasarna village. Horizontal

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distance between them is 500m approximately. C) The third locality is situated on the southern coast-line of Elafonisos island. Periodically, depending on weather conditions, wind direction, wave height and intensity, this part of southwestern Crete island is isolated and becomes an island, while temporarily a sand-bar, which operates like a barrier-bridge, is built thus connecting Elafonisos and Crete. Under the same process is temporarily developed the Balos semi-lagoon as well.

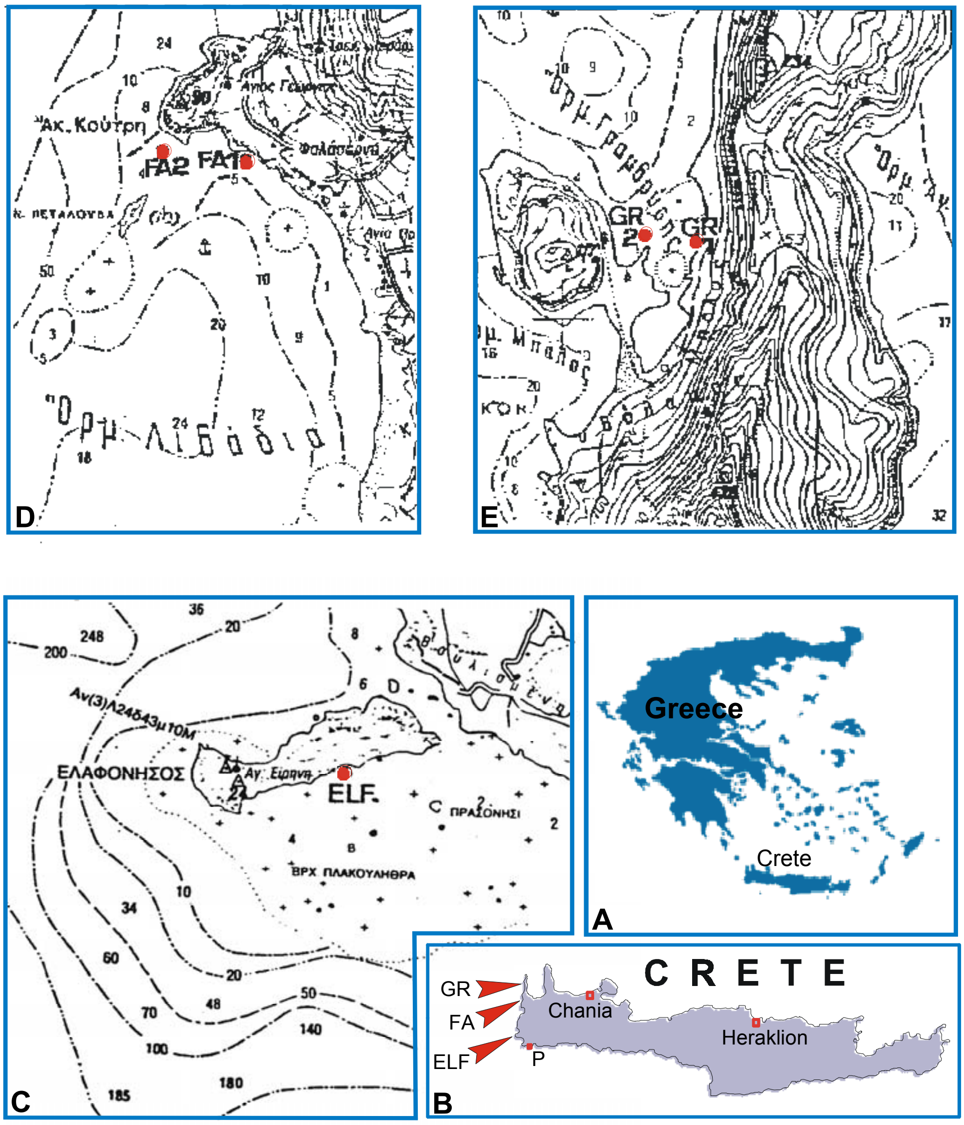

Fig. 1. Location of sampling sites for epiphytic foraminifera, on the western part of Crete island, Greece (see arrows in inlet 1B). The abbreviations are as follows below:
1B: GR=Gramvousa, FA= Falasarna and ELF= Elafonisos.
1C:The sampling site along the Elafonisos coastal zone, ELF,
1D:The two sampling sites in the Livadhia bay, FA1 and FA2 and
1E:The two sampling sites in the Gramvousa bay, GR1 & Gr2.
P : Paleochora National Meteorological Station

BRIEF DESCRIPTION OF THE SUBSTRATES

There are mainly two substrate types of sea-bottom in the study area. Both of them can be classified as moderate to hard. The first type (**1**) is partly characterized by late Holocene Aeolianites (**Ae**, samples FA1 & FA2), while the second one (**2**) is represented by dark in colour massive limestones (**Li**) which belong to the Tripolitza nappe of Crete, with an age ranging from Jurassic to Eocene (samples GR1 & GR2). According to KELLETAT (1994), the Aeolianite is lithologically a cemented dune-sand, which also occurs in Israel and on the Bermuda islands. On top of these two substrates there are locally developed either a) extensive buildups of Recent *Vermetus* gastropods and Peyssoneliaceae red algal reefs, which particularly in Livadhi Bay reach up to the present sea level (PSL), and/or b) fine-layered loose sands owing their origin probably to the erosion of the widespread Neogene strata presently uplifted (SCHRÖDER, 1994) in western Crete.

FOSSIL AND RECENT EQUIVALENTS - ENVIRONMENTAL DEMAND

Most previous work which has focused on epiphytic foraminifera mainly concerned on the description of associations and the study of cultivated, living species (ALTENBACH et al., 1993; BLANC-VERNET et al., 1979; BRASIER, 1975a-d; BRÖNNIMANN, 1949; LANGER, 1988, 1993; MURRAY, 1965; PAWLOWSKI & LEE, 1991; VENEC-PEYRE & CALVEZ, 1988). Following authors in turn, reported on the *Peneroplis* and the wide, discoidal *Sorites*, which live in association with seagrass (GUDMUNDSSON, 1994; SEVERIN, 1983; REISS & HOTTINGER, 1984; FABER, 1991). CHERIF (1973) studied the *Quinqueloqulina* species from shallow-water sands of two bays located at the western coast of Naxos island. Accounts on the paleontology and stratigraphy of algae and their recent analogues are given among others by WRAY (1977) and VAN DEN HOEK (1984), respectively.

A description of fossil Vermetidae reefal buildups, similar to the presently studied ones, is given by KEUPP et al. (1994). They represent a littoral facies of late Miocene age. The outcrop is located in Gramvousa/NW Crete, ca. 80m easterly and ca. 120m above the occurrence of the living Vermetids. The fossil littoral facies is characterized by the development of reefs consisting of Vermetidae, Peyssoneliaceae, red algae and balanidae, which found to co-occur with diverse benthic foraminifera.

The presently studied foraminifera as mentioned above, were sampled from the Recent Vermetidae reefs as well as from the coastal-line. The latter zone is marked by a red-coloured "sand". The colour is caused by the domination of the red epiphytic foraminifer *Miniacina miniacea* (Pallas) which is present both as whole individual-shells and as test-fragments. Differences in the distribution and abundances of the epiphytic foraminifera between these two habitats and substrates are shown in Table 1.

Physical parameters and major factors controlling the diversity and distribution of the epiphytic foraminifera are shown to include both temporal and spatial components. For example, the late Holocene coseismic coastal uplift (from ca. 1530 yrs BP to Present), significantly affects western Crete. The uplift gradient increases from North to South, from ca. 6.5m above PSL at Gramvousa/Falasarna to ca. 8m at Elafonisos. This process might have affected in turn the shallow-water benthic foraminifera and algal communities by changing their habitat-area. Similar observations concerning on benthic foraminifera distributions were also made in Lechaion, a harbour of ancient Corinth by REINHARDT et al. (2001).

Coastal environments particularly, are dependant and very sensitive to climatological changes. The latter could directly affect the salinity, the turbulence, the nutrient availability of the sea-water and consequently the development of phytal hosts for the epiphytics. Such data are given below for the study area for the period between 1981 and 1994, provided by the National Meteorological Service (E.M.Y.) of Greece for Paleochora Station (southwestern Crete, located ca. 18km east of Elafonissos sample site, 35.15°N latitude /23.41°E longitude). Surface-water temperature ranged between 27.7°C and 12.7°C in July and January respectively, though, given the latitude of the area, extremely lower temperatures have been registered as well (i.e. 9.6°C to 10.0°C during January/February period of 1981 to 1985). Relative humidity varied between 52.5% and 70.8% in July and January respectively.

INTERPRETATION OF THE ENVIRONMENT

Following the model by LANGER (1993) concerning the association as well as the life-style of epiphytic foraminifera, two groups of them were distinguished in the studied samples:

a) Permanently sessile species

Miniacina miniacea (Pallas) is the most prominent sessile species of this group. It is an arborescent, epiphytic foraminifer, which belongs to the Family Homotrematidae and dominates all studied assemblages and samples (see D in Table 1). During its ca. one-year life-time, *M. miniacea* was observed to be mainly attached on small buildups constructed by vermetid gastropods and/or peysso-neliaceaen red algae using its flat or slightly concave, bowlshaped lower side (Plate 1:2). After its death, empty tests are massively transported by wave energy onto the beach, where they are presently found, thus giving this very characteristic red colour in the sand.

Both, *Cibicides lobatulus* (Walker & Jacob) and *Planorbulina mediterranensis* d'Orbigny belong as well to the permanent sessile species. The latter species is present in few to rare frequencies only in the FA1 and FA2 samples of Livadhi bay, while *C. lobatulus* is common in the whole set of studied samples. According to LANGER (1993) and RIBES et al. (1998), both species prefer as microhabitats the Mediterranean seagrass *Posidonia oceanica* and the brown algae *Sargassum hornschuchi*.

b) Permanently vagile (motile) species

In this group were placed species like the *Peneroplis planatus* (Fichtel & Moll) bearing a sieve-form of aperture openings and the discoidal *Sorites marginalis* (Lamarck) both of the Family Soritidae. They were observed in high abundances in our samples (A to D in Table 1). Another foraminifer of this group, *Spirolina cylindracea* Lamarck, was also observed in common frequency, but it was only present in the Gramvousa bay (samples GR1 and GR2). All previous epiphytic species prefer the leaves and rhizomes of seegrass, but also the smaller *Dasycladus* algae as their microhabitat. The *S. marginalis* additionally, relies on the coralline algae *Pseudolithophyllum* as well (LANGER, 1993).

In all samples, the Family Miliolidae is well-represented by numerous individuals belonging to 24 different species of the subfamily Quinqueloqulinae. Four of these species (*Q. bicornis*, *Q. bicostata, Q. flavescens* and *Q. peregrina -striata*) are only found occasionally and in low frequency (R in Table 1). Quinqueloqulins are porcellaneous shell foraminifera and bear narrow to bottle-neck like apertures. In order to be well-developed, they need special environ-ment conditions, mainly concerning to the salinity and water -temperature and -clearness. Moreover, due to their short life-span, they can be important recorders of environmental changes. Therefore, and given their great abundance, the Quinqueloqulinids are presently considered as ideal ecologic indicators giving valuable information on the above mentioned physicochemical parameters of the sea-water and their fluctuation. The Quinqueloqulinids show also frequency maxima or preferences to certain plant microhabitats in flat and arborescent phytal substrates (LANGER, 1993). The Vermetid- and Peyssoneliaceae- reefs of the studied bays offer therefore an ideal microhabitat for the *Quinqueloqulina* taxa.

Among other vagile species in our material, *Elphidium crispum* (Linné) and *Rosalina globularis* d'Orbigny were recorded, the former in rare to few frequencies, relying upon *P. oceanica* rhizomes and green algae, while the latter was only occasionally and in rare frequency observed along the coastal-line of Falasarna (FA1) and Elafonissos (ELF). *E. crispum* bears multiple aperture-openings and has a short life-time, ranging between 3 and 4 months. *R. globularis* with a broader aperture has also a short life-time, but somewhat longer than *E. crispum* ranging between 2 and 5 months.

Table 1	**Samples**				
Epiphytic Foraminifera Species	**GR1 (Li)** ±0,00m	**GR2 (Li)** -2,00m	**FA1 (Ae)** ±0,00m	**FA2 (Ae)** -2,00m	**ELF (Ae)** ±0,00m
Asterigerina planorbis d’Orbigny			F	R	
Cibicides lobatulus (Walker & Jacob)	C	C	C	C	C
Cruciloculina triangularis d’Orbigny	C	C	C	C	C
Dendritina arbuscula d’Orbigny	A	A	C	C	C
Elphidium crispum (Linne)	F	R	F	R	F
Miniacina miniacea (Pallas)	D	D	D	D	D
Peneroplis planatus (Fichtel & Moll)	D	D	D	D	D
Planorbulina mediterranensis d’Orbigny			F	R	
Quinqueloculina akneriana d’Orbigny	F	F	C	C	C
Q. anguina Terquem	F	F			
Q. anguste-oralis (Wiesner)	C	C	C	C	C
Q. auberiana d’Orbigny	A	C	A	C	A
Q. bicornis Walker & Jacob			R		
Q. bicostata d’Orbigny			R		
Q. elongata (d’Orbigny)	F	F	F	F	
Q. flavescens d’Orbigny			R		
Q. gualtieriana (d’Orbigny)	F	F	F	F	F
Q. hauerina d’Orbigny			F	R	
Q. inflata (d’Orbigny)	C	C	C	C	C

Q. laevigata (d'Orbigny)	C	C	C	C	F
Q. (*Pseudoschlumbergerina*) *ovata* (Sidebottom)	F	F	F	F	
Q. peregrina-striata (Wiesner)			R		
Q. plana d'Orbigny	C	C	C	C	C
Q. (*Pseudotriloculiana*) *planciana* d'Orbigny			C	C	C
Q. pseudoreticulata Parr			F	F	
Q. (*Pseudotriloculiana*) *reticulata* (Soldani)			F	F	F
Q. rotunda d'Orbigny	F	F	F	C	C
Q. schreibersii d'Orbigny	F	F	F	F	
Q. seminulum (Linne)	C	C	C	C	C
Q. subcarinata d'Orbigny	F	R	F	R	
Q. suborbicularis d'Orbigny	C	F	F	R	F
Q. vulgaris d'Orbigny	C	C	C	C	C
Rosalina globularis d'Orbigny			R		R
Sorites marginalis (Lamarck)	A	A	D	D	A
Spirolina cylindracea d'Orbigny	C	C			
Spirolina sp. (?)	C	C			
Spiroloculina depressa d'Orbigny	F	F	C	C	C
Triloculina trigonula (Lamarck)	C	C	C	C	C
Valvulineria complanata (d'Orbigny)	F	R	F	R	

Tab. 1. Relative frequency distribution of benthic Foraminifera in samples from W.Crete/S.Greece. Their Systematic is based on the Taxonomy of Loeblich & Tappan (1978). Species are here alphabetically organized. Abbreviations are as follows: **D**= Dominant, **A**= Abundant, **C**= Common, **F**= Few and **R**= Rare.
Samples abbreviations (top line) are referred to locations of figure 1: **GR**= Gramvousa, **FA**= Falasarna and **ELF**= Elafonisos island. Substrate: **Li=** Limestone, **Ae=** Aeolianite. Elevation is in meters above (positive) or below (negative numbers) the present sea-level which is considered to be at ± 0,00m.

CONCLUSIONS

1. Summarizing, two groups (associations) of epiphytic Foraminifera could be clearly distinguished in W. Crete, due to different habitats following the model of Langer (1993); a) the permanent sessile and b) the permanent vagile taxa.
2. Substrate-type differences on assemblages are delineated by variation of *Quinqueloqulina* representatives. *Q.* (*Pseudotriloculiana*) *planciana*, *Q. pseudoreticulata* and *Q.* (*Pseudotriloculiana*) *reticulata* (F to C) found to prefer Aeolianites, while *Spirolina* (C) seems to prefer harder substratum such as limestones (Table 1).
3. *Quinqueloqulina* taxa belonging to the second group, appear to be very well represented with 24 different species. A further study will be required to reconstruct the temporal development of this taxon and trace the anthropogenic impact and its consequences in the environment as it has also been highlighted by Reinhardt et al. (2001).
4. Monitoring stations of the environmental parameters are sparsely distributed in the eastern Mediterranean. Additional data is provided by satellites. Currently, their spatial resolution is limited. For studying changes in small-scale habitats (i.e. small bays or coastal-areas, like in Greece) and keeping low the cost, the study of distribution of selected epiphytic Foraminifera such as the *Quinqueloqulina* species is considered a useful tool for palaeoecological and paleoenvironmental studies.
5. The present state of the environment represents one time slice in the geohistory. It is controlled among other by long term geological processes. The latter can only be derived from the stratigraphic record (compare Pirazzoli et al., 1991). Understanding of these processes will allow us to extrapolate (predict) future changes in the environment.

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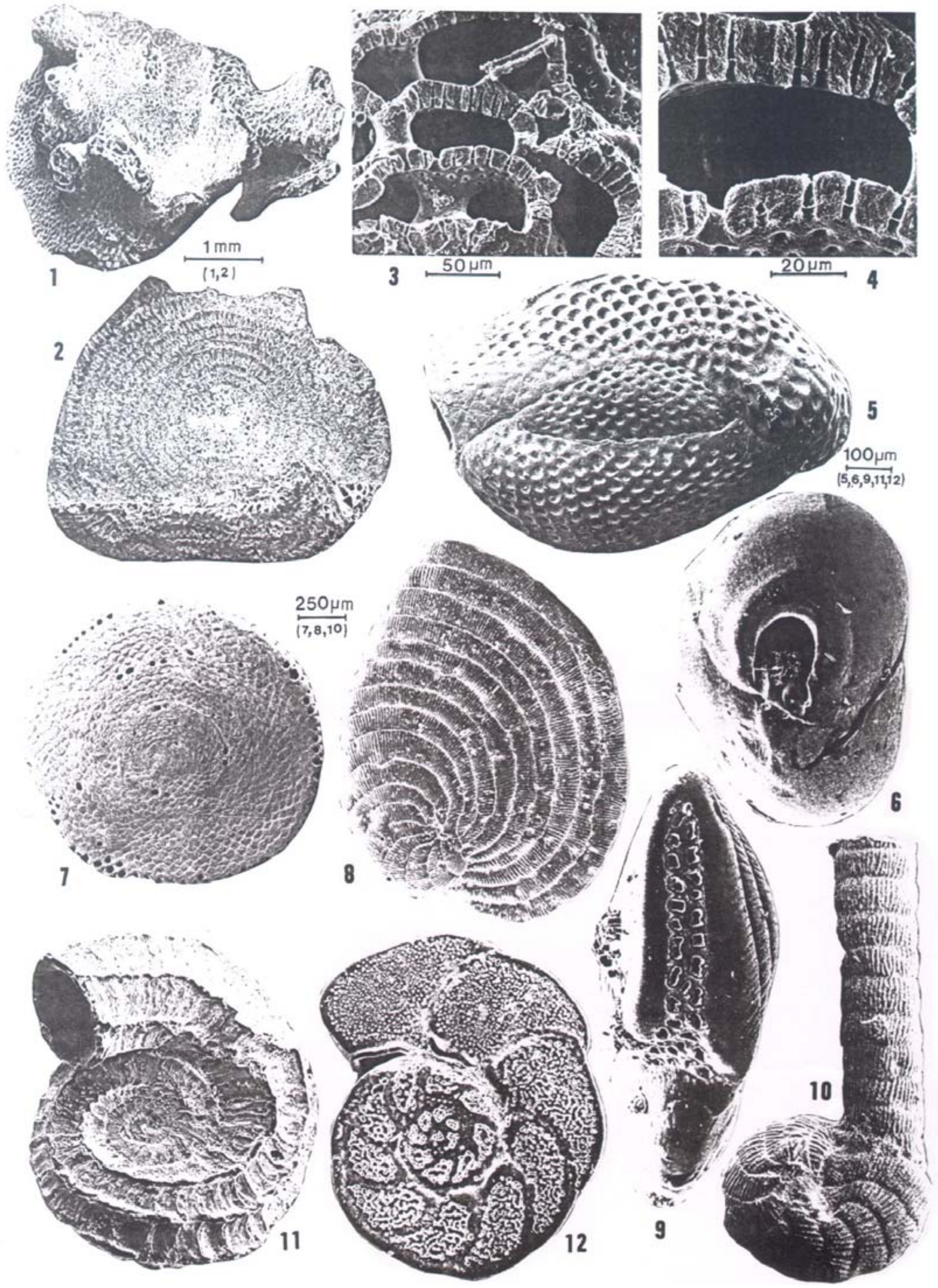
Plate 1

Scanning Electron Microscopy (SEM) photographs of epiphytic Foraminifera species from W. Crete island, southern Greece.

1-4: *Miniacina miniacea* (PALLAS) test. Large, adult, epiphytic foraminifer, which lives sessile, using its bowlshaped lower-side, attached on various algal reefs of Gramvousa, Falasarna and Elafonissos bays of the western coasts of Crete island. Black-bars are for scale.
1: Face-view of *M. miniacea*. Its tree-like upper-surface, presents a fine perforation with a number of thin, net-like branches. Magnification x17.
2: Lower-side view of *M. miniacea*. The spiral-form order of chambers shows a "Beer"-like structure of the test. Magnification x17.
3: View of the upper-surface of *M. miniacea* and **4**: Detail of the previous micro-photo. There are to be observed the foramina or pores connecting the chambers as well as a distint doublicate wall-structure of the shell, which is cut by the so-called "Arrow-pores". Magnifications are for fig. **3**: x125 and for fig. **4**: x300.
5: *Quinqueloqulina* (*Pseudotriloculina*) *reticulata* (SOLDANI). Dorsal side-view. Magnification x100.
6: Apertural view of *Quinqueloqulina plana* d'ORBIGNY. Magnification x100.
7: *Sorites marginalis* (LAMARCK). Magnification x40.
8, 9: *Peneroplis planatus* (FICHTEL & MOLL). **8**: Spiral- and **9**: Apertural- views. Magnifications x40 and x100 for figures 8 and 9 respectively.
10: *Spirolina cylindracea* d'ORBIGNY. It was observed only in samples from the Gramvousa bay. Magnification x40.
11: *Spirorbis* sp. It has a polychaetic microhabitat. A lot of marine, segmented worms live temporarily or permanent in the tubes. Magnification x100.
12: *Cibicides lobatulus* (WALKER & JACOB). Spiral-side view. Magnification x100.

PLATE 1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