Bol. Inst. Esp. Oceanogr. 15 (1-4). 1999: 181-190 **BOLETÍN** INSTITUTO ESPAÑOL DE OCEANOGRAFÍA
ISSN: 0074-0195

Distribution of Planorbulinacea (benthic foraminifera) assemblages in surface sediments on the northern margin of the Gulf of Cadiz

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Received September 1997. Accepted February 1998.

ABSTRACT

The distributional patterns and related environmental parameters for four species of benthic foraminifera of the Superfamily Planorbulinacea occurring in surface sediments from the northeast Gulf of Cadiz are discussed. Their distribution is related to bathymetry, in the case of *Hyalinea balthica* (Schröter, 1783), and to the texture of the sediments in the area for the other three, *Cibicides refulgens* (Montfort, 1808), *Lobatula lobatula* (Walter and Jacob, 1798) and *Planorbulina mediterranensis* (d´Orbigny 1826). Two characteristic assemblages were differentiated with Q-mode analysis: F1 (*H. balthica),* affected mainly by water depth; and F2 (*C. refulgens* and *L. lobatula*), related to the substrate, typical of high-energy/low sedimentation rate environments.

Key words: Planorbulinacea, benthic foraminifera, northeast Gulf of Cadiz, Spain.

RESUMEN

Distribución de Planorbulinacea (foraminíferos bentónicos) en los sedimentos superficiales del margen norte del golfo de Cádiz

Se ha determinado el área de distribución de las cuatro especies de foraminíferos bentónicos de la superfamilia Planorbulinacea encontrados en los sedimentos superficiales del margen septentrional del golfo de Cádiz. Su distribución está relacionada, en el caso de Hyalinea balthica *(Schröter, 1783), con la batimetría, y las otras tres,* Cibicides refulgens *(Montfort 1808),* Lobatula lobatula *(Walter and Jacob, 1798) y* Planorbulina mediterranensis *(d'Orbigny, 1826) con las características texturales del sedimento. Hay dos asociaciones características: F1 (*H. balthica*) afectada principalmente por la profundidad en el dominio del agua noratlántica central y F2 (*C. refulgens *y* L. lobatula*) relacionada con el substrato, propia de ambientes de alta energía y baja tasa de sedimentación.*

Palabras clave: *Planorbulinacea, foraminíferos bentónicos, noreste del golfo de Cádiz, España.*

INTRODUCTION

Foraminifers are shelled protozoans, usually less than 1 mm in diameter, displaying a great deal of morphological variety. Benthic foraminifera are distributed in all marine environments, from bays to abyssal depths; since they are sensitive environmental indicators, they have been widely used to describe modern as well as ancient marine environments. Usually a few millilitres of sediment con-

tain hundreds of individuals and several species. When they reproduce or die, their shells, called test, become part of the sediment and, subsequently, the fossil record. Foraminifera test provides a worldwide historic record from the Cambrian to the present day: several thousand species still live in the Earth's oceans, and therefore they constitute an ideal group for examining the distribution of species in space and time (Buzas and Culver, 1991). The Superfamily Planorbulinacea Schwager, 1877 is one of the 65 superfamilies of the Loeblich and Tappan classification (1988), and defined as: Test free or attached, trochospiral, at least in early stage, late may be uncoiled and rectilinear or biserial or may have many chambers per whorl or chambers added irregularly, wall coarsely perforate, apertural face may be imperforate; aperture interiomarginal and extraumbilical-umbilical to nearly equatorial, subterminal in coiled forms, additional equatorial or umbilical apertures may be present at the opposite edge of the chambers' (p. 579).

The present study is part of a wider one (Villanueva Guimerans, 1994), and its main objectives are to give the spatial distribution of the Superfamily Planorbulinacea species located in surface sediments from the continental margin of the Gulf of Cadiz, as well as their relationship with environmental parameters and characteristic assemblages. Benthic foraminifers on the Iberian coast have been studied by different authors, principally on the Spanish littoral (Mateu, 1970; Sánchez Ariza, 1979; for a summary, see Colom, 1974) and on the Portuguese coast Levi *et al.*, 1995; Schönfeld, 1997).

General Setting

The study zone is shown in figure 1a. Recent nonconsolidated sediments in this area are siliciclastic, with quartz as the most abundant mineral in the sandy sediments. On the continental shelf domain there is a northern sector, where the fluviodeltaic depositional processes related to the Guadalquivir River input prevail, a central sector, with the presence of large sand bodies over a shallow abrasion and a southern sector where the depositional processes related to the Barbate river input co-exists with erosive processes (Lobo, 1995; Lobo *et al.,* 1997 (figure 1b). Its hydrodynamics are affected by North Atlantic Surface Water, North Atlantic Central Water and outflow Mediterranean Water below 500 m (figure 1c) (Melières, 1974). (For more details see Villanueva Guimerans and Cervera Currado, in this volume.)

MATERIALS AND METHODS

The present study is based on selected species of 50 samples from the northern part of the Gulf of Cadiz (figure 1a), collected using a Shipek grab sampler. Each sample was washed over a 125-µm sieve, and the residue was split into a fraction containing more than 300 specimens of benthic foraminifera (Buzas, 1990), all of which were sorted and identified. Selected specimens were coated with gold using Blazer sputtering equipment, and photographed with a Jeol 820 in the SEM Unit at the University of Cadiz. The grain-size analysis was carried out using the standard sieve-and-pipette method (Folk, 1965; Villanueva Guimerans and Cervera Currado, in this volume). The correlation and factor analysis was carried out using a BMDP statistical program.

RESULTS

Four species were identified from the samples studied and assigned to Families and genera, mainly according to the Loeblich and Tappan (1988) classification.

Family Planulinidae Bermúdez, 1952

Hyalinea balthica (Schröter, 1783) (figure 2.1a,b,c). Test essentially very low trochospiral, coiled and strongly compressed, flat, semievolute. There are 8-12 subtriangular chambers in the outer whorl. Sutures curved, limbate, merge with the peripheral imperforate keel. Aperture in a low equatorial arch bordered by a rim continuing into a spiral aperture with lib. Secondary apertures open beneath umbilical flaps on both sides of the test. Wall with circular pores of 0.5 microns in diameter. Dimensions: 0.5-0.7 mm. In the study zone (figure 3), it is abundant and widespread. Its upper-depth boundary occurs at about 20 m in the north, increasing to the south, where it occurs in excess of 100 m in variable frequencies, the highest being about 20 % of total assemblages, having a

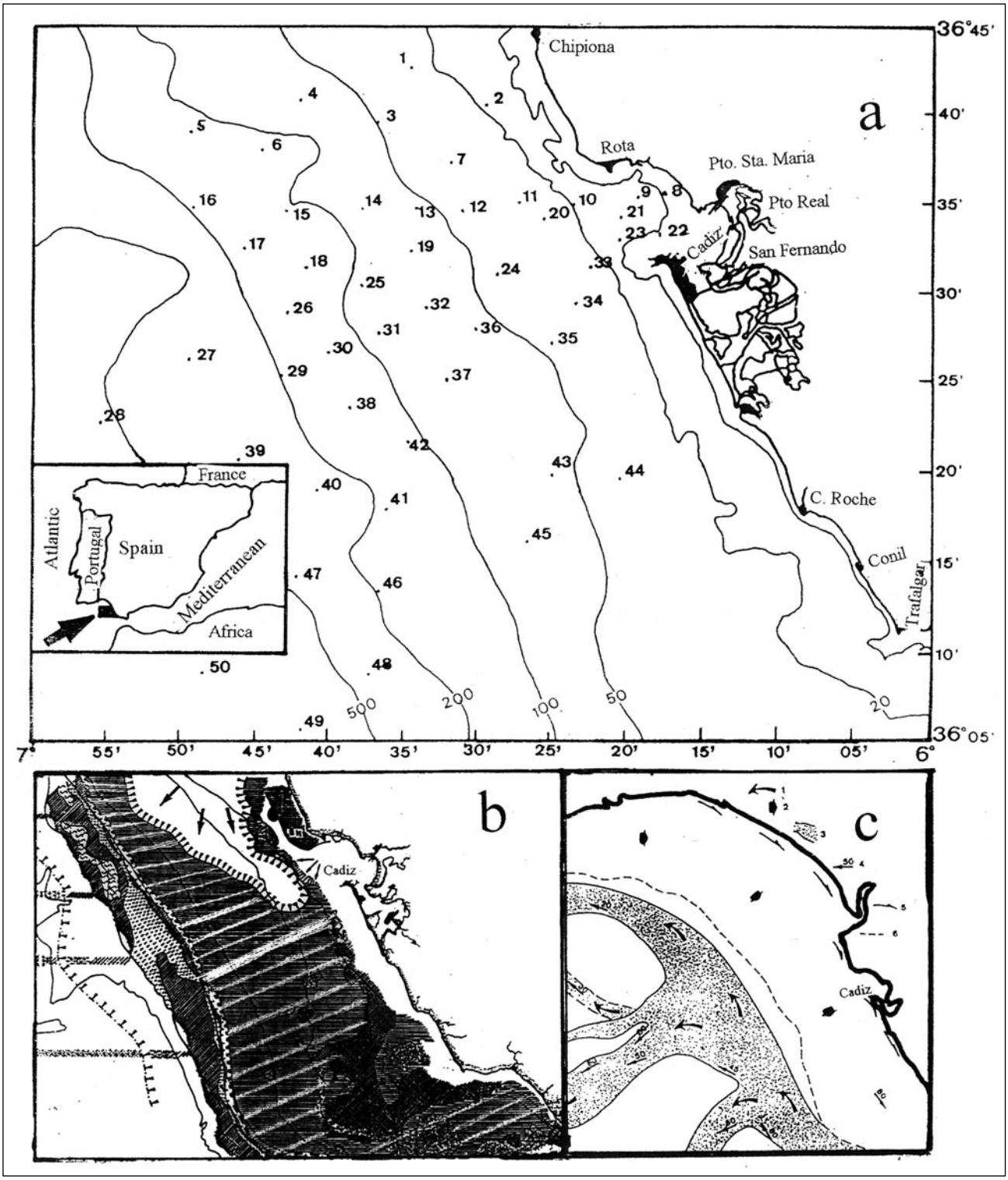

Figure 1. (a): geographic location of the study area and sample locations; (b): morphological features (Lobo *et al.*, 1997); (c): hydrodynamic circulation model (Mélières, 1974)

positive correlation with water depth (0.63) and, of course, with distance from the coast (0.66), on a substrate of finer-grained sediments; it is also located scattered in the external bay, probably drifted. In the modern ocean, *H. balthica* has been described as a cool-to-cold-water indicator species by

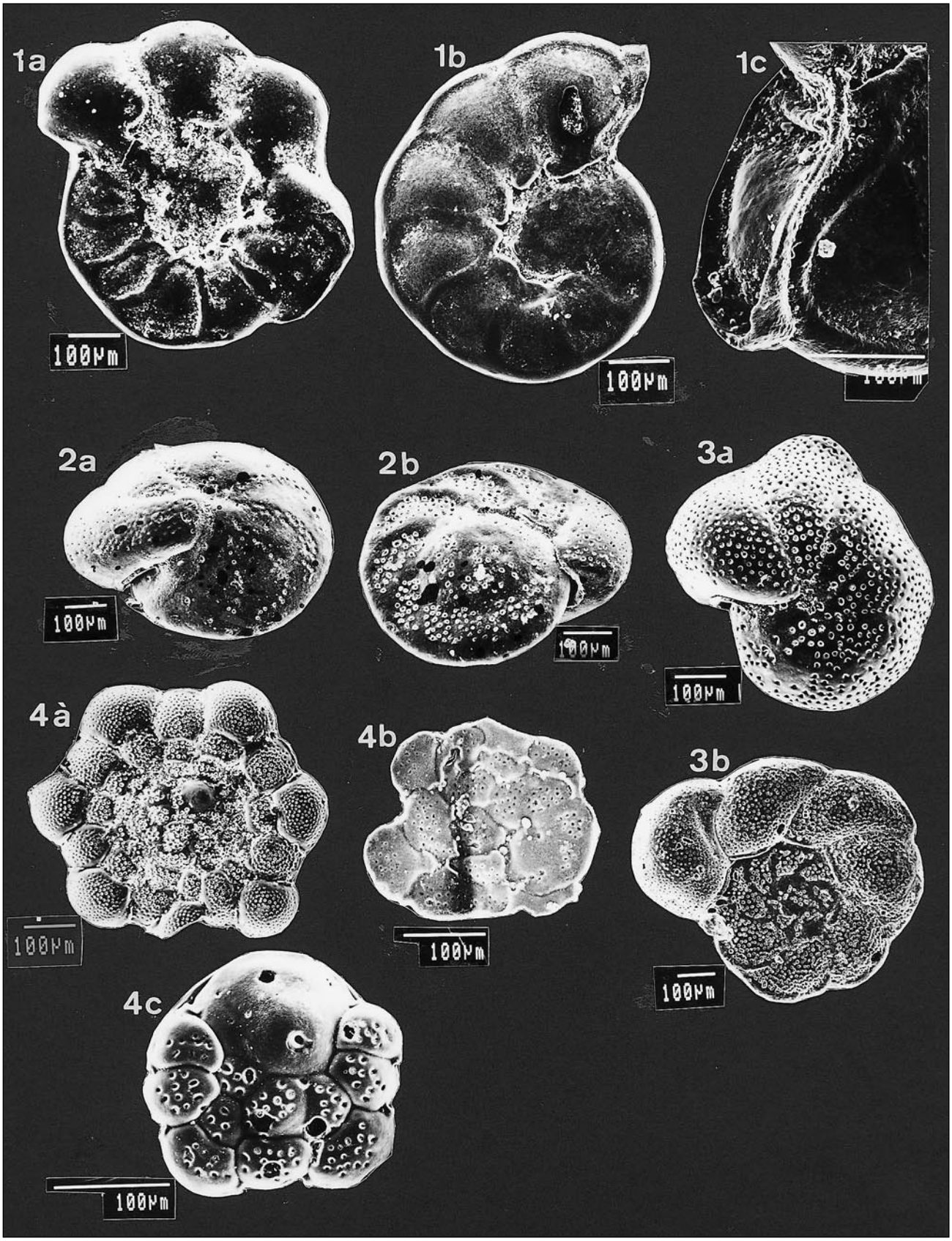

Figure 2. Species collected. (1a,b,c): *Hyalinea balthica*; (2a,b): *Cibicides refulgens*; (3a,b): *Lobatula lobatula*; (4a,b): *Planorbulina mediterranensis*

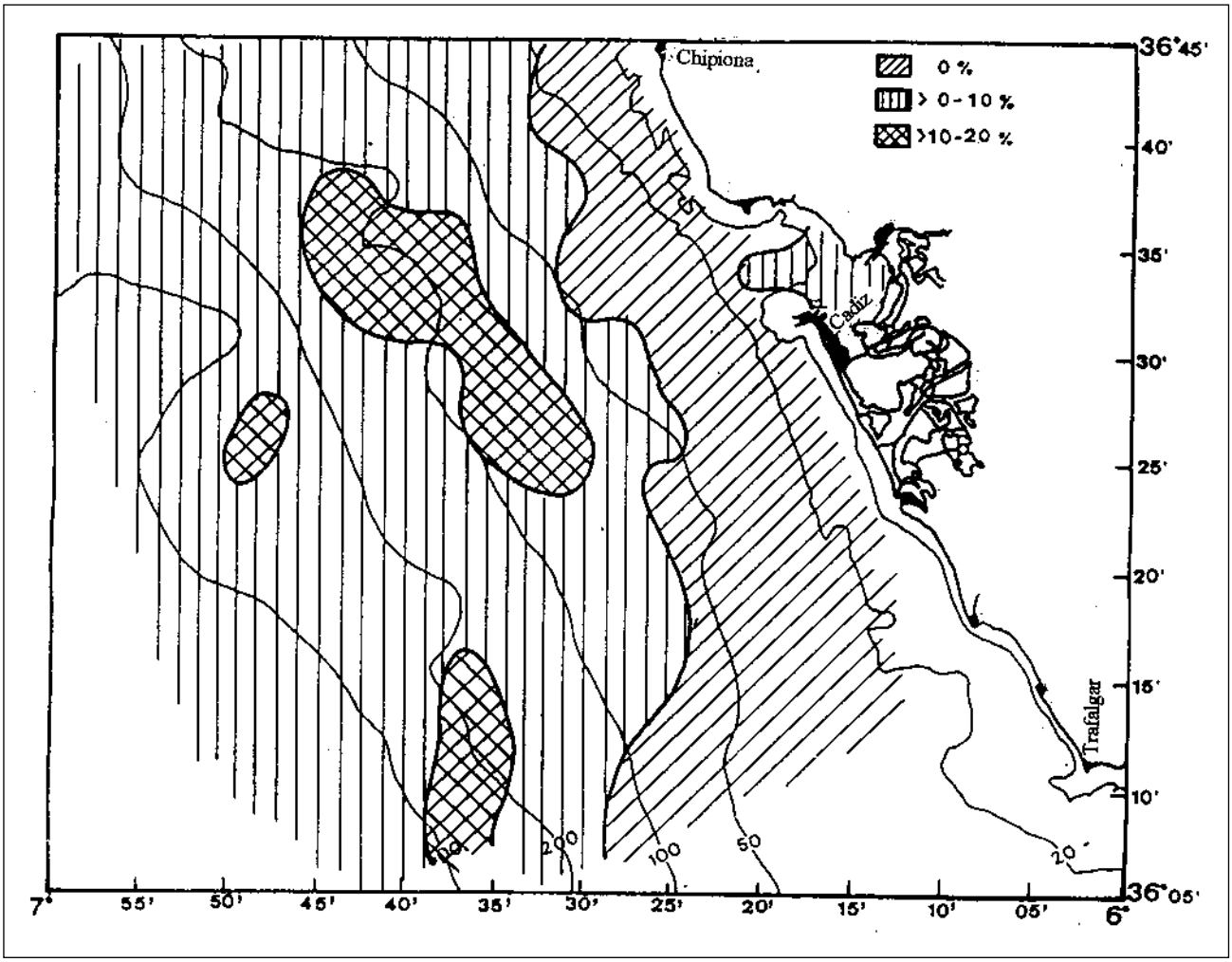

Figure 3. Distribution of *Hyalinea balthica*

Bock (1971), and as cool-to-temperate species by Murray (1973). Highest frequencies are recorded at high latitudes of the North Atlantic. According to Cita *et al.* (1977), its present range in the Mediterranean Sea and the Atlantic Ocean is about 60-1 000 m, being absent in the deeper eastern and western basins. On the Iberian coast it has been reported both in Cantabria and Galicia (Colom, 1974), on the Portuguese continental shelf (Levi *et al.,* 1995) and in the Alborán Sea, in the depth-range from 200-1 000 m (Mateu, 1992).

Family Cibicididae Cushman, 1927

Cibicides refulgens de Monfort 1808 (figure 2.2a,b). Test outline subcircular, trochospiral, strongly planoconvex, spiral side flat and evolute, umbilical side strongly convex and involute with a depressed and backwards curved sutures, periphery angular with a thin imperforate keel, chambers numerous, 9-12 in the final whorl, all chambers visible from attached spiral side, increasing fairly in size as added, last few inflated ventrally, sutures slightly depressed on the umbilical side and curved on spiral side, flush with a surface slightly curved, about 2.5 whorls. Wall smooth, finely perforate, perforations large, widely spaced and few on the spiral side. Aperture interiomarginal extraumbilical-equatorial, bordered by a protruding rim, continuing into a spiral supplementary aperture. Dimensions: 0.4-0.6 mm. In the study zone (figure 4) it is widespread from the south, in the depth-range from 20-600 m, mainly in gravel and sand sediments, with maximum frequencies of about 18 % of total assemblage. On the Iberian coast, it is reported mostly from the north (Colom, 1974); on the

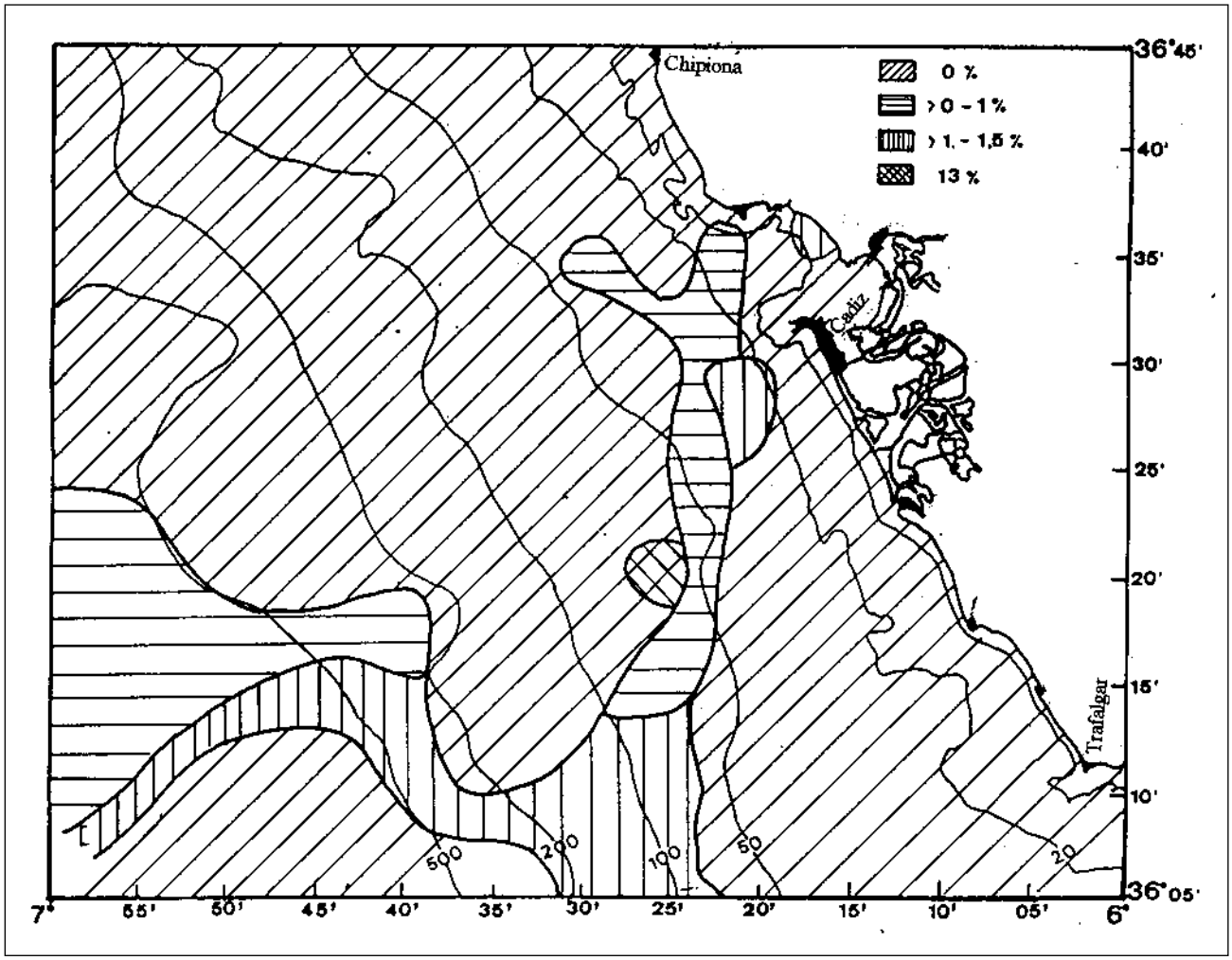

Figure. 4. Distribution of *Cibicides refulgens*

Portuguese continental shelf, it is sporadic and especially abundant between Nazaret and Lisbon (Levi *et al.*, 1995); in the Mediterranean it is rare in the neritic zone of Motril-Nerja (Sánchez-Ariza, 1979) and more frequent in the Alborán Sea (Mateu, 1992).

Lobatula lobatula (Walter & Jacob, 1798) (figure 2.3a,b.). The test is trochospirally coiled, ovate in outline, periphery acute, carinate, the spiral side is flat or irregular, the umbilical side is convex. Chambers inflated, 7-8 in final whorl, gradually increasing in size as added, sutures on spiral side slightly raised and imperforate, depressed and slightly backwards curved on the umbilical side. Wall in umbilical side coarsely perforate or lacking pores (about 5 microns in diameter), on the spiral side pores intermediate in size (2 microns) and uniformly distributed. Aperture interiomarginal, extraumbilical-equatorial and bordered by a protruding rim continuing into a spiral supplementary aperture, open in the last 1-3 chambers. Dimensions: 0.4-0.8 mm. Many authors have lumped this species with others, such as *C. refulgens.* McLean (1956) went so far as to write: 'Unfortunately, so many different forms have been ascribed to Walter and Jacobs's species that assigning the name *lobatulus* to a *Cibicides* is tantamount to giving the form a status more truthfully described by the term *incertae sedis.'* However, we regard these views as extreme, and found *L. lobatula* to be an abundant and easily distinguishable species on the Cadiz coast, closely comparable with populations occurring elsewhere off the Iberian coast. In the study zone (figure 5), its distribution is similar to that of *C. refulgens,* but with low frequencies. The species is very widespread in the south, with a frequency range of 2-16 % of the total assemblage, principally on sandy bottoms (correlation with sand = 0.67). It occurred in two

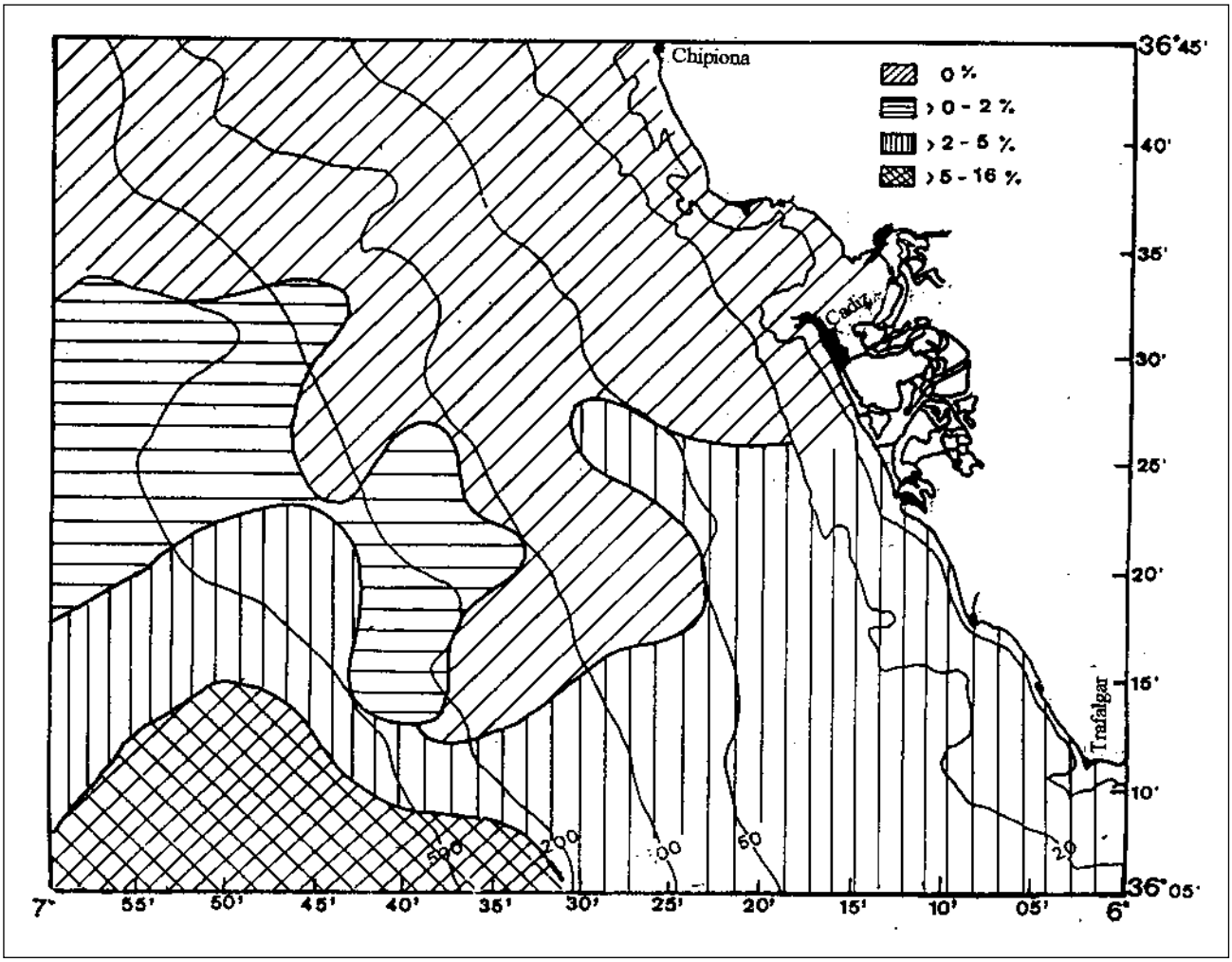

Figure 5. Distribution of *Lobatula lobatula*

samples, one from the outer bay, and another in the infralittoral zone from Rota. This species has been described from every latitude in both hemispheres, but many of the records are suspect and many others indicate, generally, a shallow water distribution in environments where shelter can be found in weeds. On the Iberian coast, it is abundant in Galicia (Colom, 1952), and it is also a dominant species on the Portuguese continental shelf (Levi *et al.*, 1995). In the Mediterranean it is very widespread species, mostly reported from the infralittoral zone, especially on *Posidonia* prairies, where it generally occurs attached to the leaves.

Family Planorbulinidae Schwager, 1877

Planorbulina mediterranensis d'Orbigny 1826 (figure 2.4a,b,c). The early part of the test is trochospiral, with a single arched aperture in each chamber, but later chambers are added in a cyclical pattern with two interiomarginal apertures, each bordered by a protruding peristomal rim. The test is variable in outline. Spiral side planar or concave, 2-6 whorls, chambers on umbilical side globose, acute-to-irregular in shape, on spiral side flat, embracing. Wall thin, coarsely perforate (pores of about 1-4 microns in diameter), sutures depressed on the spiral side, thickened and imperforate on the attached side. Dimensions: 0.6-0.8 mm. In the study zone (figure 6), it is mainly found in the southern infralittoral in the depth-range of 80-600 m in sandy sediments; relatively higher frequencies (13 % of total assemblage) occur in the parallel of Sancti Petri at a depth of 55 m. As its specific name implies, this species was first described from the Mediterranean Sea. Thereafter, it has been reported widely in the Atlantic regions, as well. It lives clinging by its spiral side to substrates,

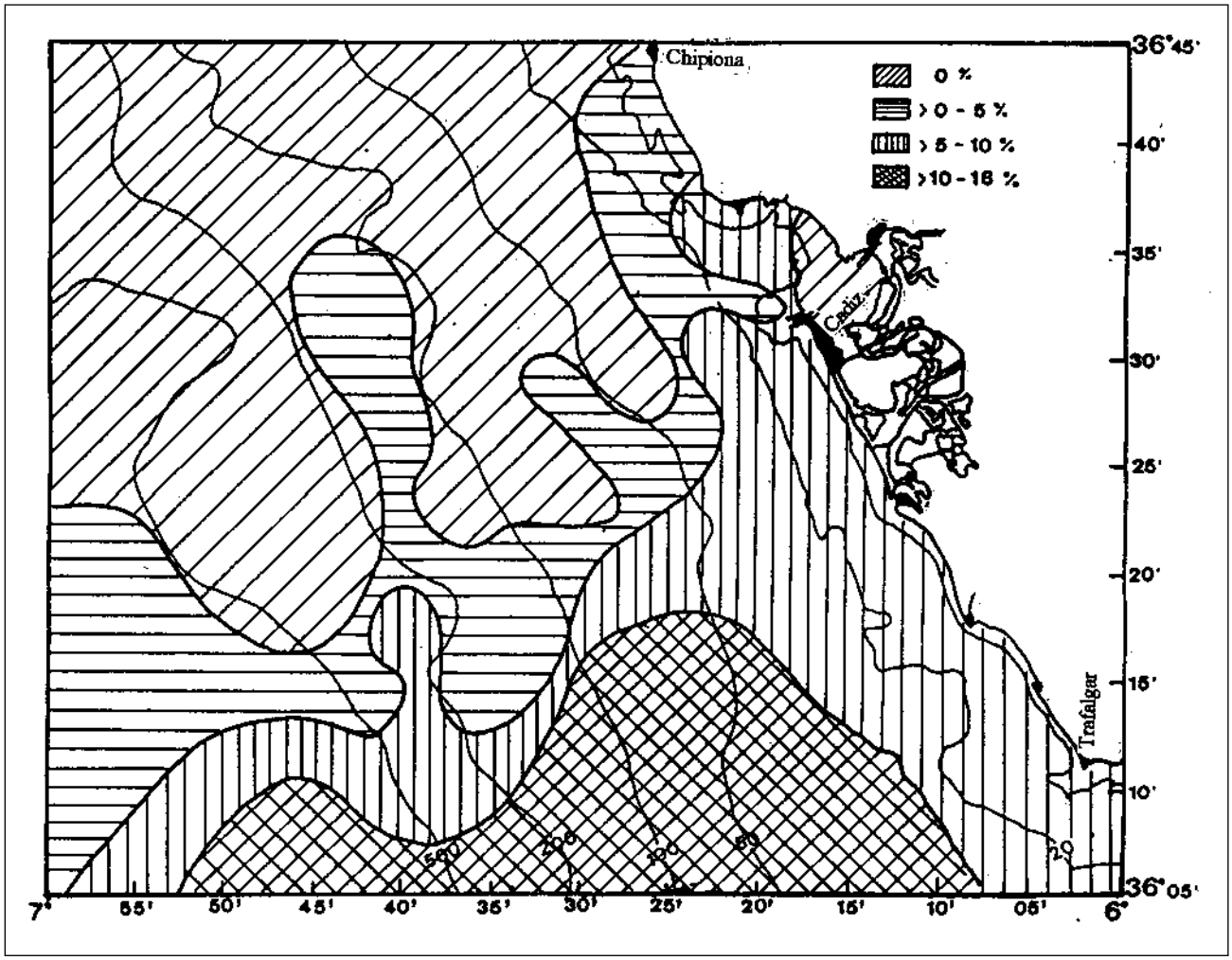

Figure 6. Distribution of *Planorbulina mediterranensis*

e.g. seaweeds and rocks, in areas of current-swept sea floors; the dead are more abundant and widespread than the living representatives. On the Iberian coast, it has been reported from the Galician infralittoral zone (Colom, 1974), and it is frequent on the Portuguese continental shelf at 75 m (Levi *et al.*, 1995); in the Mediterranean this very widespread species occurs on the infralittoral bottom with vegetation cover, and it is frequent in the muddy sediments off the Catalan coast (Mateu, 1970), but rare in the Motril-Nerja neritic zone (Sánchez-Ariza, 1979).

Data analysis

A thanatocoenosis may be defined as an assemblage of dead organisms which are repeatedly found together, and which are typical of certain kinds of environmental conditions; for their determination, the mathematical method described by Jöreskog, Klovan and Reyment (1976) was ysed. The numerical method gives a Varimax solution to Q-mode factor analysis, reducing the large matrix of foraminiferal abundance data into two smaller matrices. The matrix of Varimax factor loadings describes the importance of each factor (assemblage) at each locality; the factor score matrix reveals the relative importance of each species within each factor. The reduction of the data to this form allows easier determination of main faunal assemblages and facilitates mapping of foraminiferal assemblage distribution in the study zone.

The Q-mode factor analysis of 29 stations determines two factor assemblages accounting for 91 % of the variance with high communalities. In each assemblage, the factor loadings of greater than 0.75 are included (Williamson, Keen and Mudie, 1984) (tables I and II).

Table I. Varimax rotation factor matrix of the factor loadings (Factor 1 and Factor 2) for the stations (Sta) with the communalities (COM)

Sta	COM	Fact. 1	Fact. 2
4	0.95	0.989	–0.148
5	0.93	0.991	–0.135
6	0.95	0.989	–0.148
14	0.95	0.989	–0.148
15	0.93	0.991	–0.135
16	0.95	0.989	–0.148
17	0.91	0.868	–0.076
18	0.93	0.991	–0.135
19	0.95	0.989	–0.148
25	0.95	0.989	–0.148
26	0.98	0.996	0.061
27	0.94	0.986	–0.118
28	0.93	0.991	–0.135
30	0.89	0.921	0.331
31	0.95	0.989	–0.148
32	0.93	0.991	–0.135
37	0.95	0.989	–0.148
38	0.95	0.989	–0.148
41	0.92	0.988	–0.128
42	0.93	0.998	–0.041
45	0.89	–0.316	0.795
46	0.95	0.989	–0.148
47	0.98	0.998	–0.050
49	0.89	–0.455	0.875
50	0.89	–0.360	0.911

Table II. Varimax factor scores for each factor loading

	Fact. 1	Fact. 2
H. balthica	1.483	–0.222
C. refulgens	–0.332	1.51
L. lobatula	–0.460	0.660
P. mediterranensis	–0.692	–1.281

The distribution of the factors (assemblages) is plotted in figure 7.

The Factor 1 assemblage determines the principal thanatocoenosis, which accounts for 68% of total variance; it is mainly composed of *H. balthica* (factor score 1.48), and its main distribution corresponds to water depths greater than 55 m in the central and northern area. The substrate is fine-grained and has relativity high organic matter content.

The Factor 2 assemblage determines the second thanatocoenosis, which accounts for 23 % of total variance; it is principally composed of *C. refulgens* (factor score 1.05), *L. lobatula* (factor score 0.66) and *P. mediterranensis* (factor score –1.28). It comprises only a few stations, and its distribution is re-

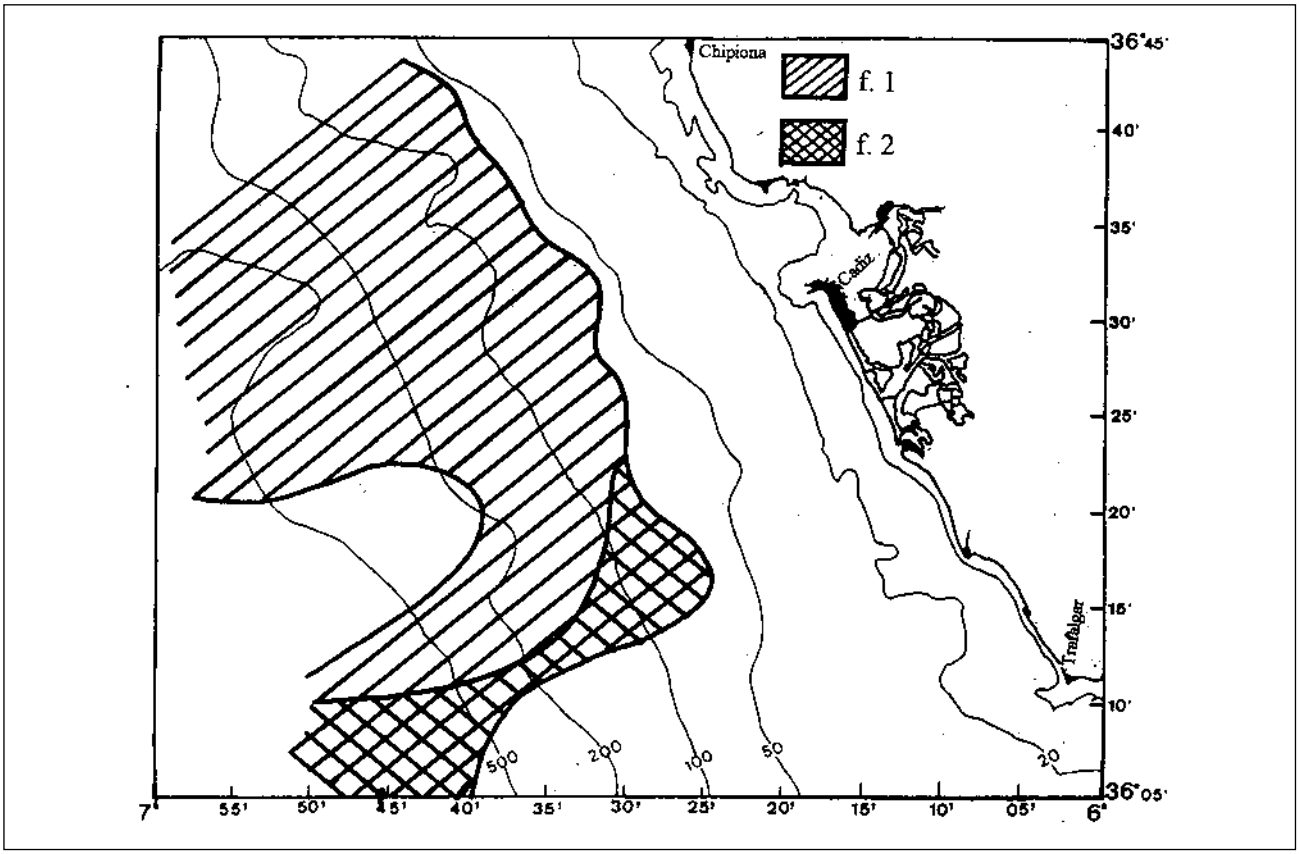

Figure 7. Distribution of the thanatofacies, from the factor loadings

stricted to the southern part of the zone, down to 75 m, in sand and quartziferous muddy sand with reworked bioclastic sediments. This assemblage is typical of high-energy/low sedimentation rate environments (Williamson *et al.,* 1984) and has a cosmopolitan distribution.

DISCUSSION

Quantitatively, total benthic foraminifera reported in the study zone represents about 9.7 % (Villanueva Guimerans, 1994), and in their distribution it related to different variables. The overall distribution of *H. balthica* shows a temperate range of adaptatibility, as in medium latitudes, increasing towards the open shelf zone and with a gradual decrease of depth-range to the south. *C. refulgens*, *L. lobatula* and *P. mediterranensis* mainly occupy the southern zone, in areas associated with sand, gravelly sand and sandy gravel substrates.

The F1 cold temperate assemblage accounting for 68 % of the variance is related to water depth on the North Atlantic Central Water influence.

The F2 assemblage accounted for 23 % of the variance. This calcareous assemblage was marked by a patchy distribution in the southern zone. The restriction of this assemblage to coarse sands supports previous studies, which suggested a correlation between the substrate and absence or slow rate of sedimentation.

ACKNOWLEDGEMENTS

Thanks to Agustín Santos for the SEM photographs. This research is part of the IGCP Project 396, 'Continental Shelves in the Quaternary'.

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