

Assemblages of recent benthic foraminifera from the northeastern gulf of Cadiz.

Asociaciones de foraminíferos bentónicos recientes en el noreste del golfo de Cádiz.

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RESUMEN

La distribución de foraminíferos bentónicos recientes de un sector del Noreste del Golfo de Cádiz se ha realizado a partir de 50 muestras superficiales, se han enumerado las principales especies encontradas en tres áreas distintas y se han identificado 5 asociaciones que parecen estar relacionadas con las características hidrodinámicas y sedimentológicas de la zona. La asociación de la plataforma continental externa y comienzo del talud viene caracterizada por *Cassidulina laevigata*, afectada principalmente por la corriente Atlántica entrante, ocupa profundidades de 100 a 500 metros. La asociación de la plataforma interna caracterizada por *Ammonia beccarii* y afectada por corrientes atlánticas costeras ocupa profundidades inferiores a 50 metros. La asociación de la plataforma continental media caracterizada por *Valvulineria bradyana* y relacionada con el fango progradante procedente de la desembocadura del Guadalquivir, ocupa profundidades entre los 50 y 100 metros. La asociación del talud caracterizada por *Bulimina marginata* y afectada por el flujo Mediterráneo de salida y la asociación del sur de la plataforma caracterizada por *Nonion asterizans* ocupa profundidades entre 30 y 70 metros.

Key words: Recent benthic foraminifera, assemblages, northeastern Gulf of Cadiz, SW Spain.

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Introduction

The main purpose of this study is to expand on the knowledge of the recent benthic foraminifera distribution in the Spanish coast of the Gulf of Cadiz, the zone is a hydrodynamical and sedimentological extraordinary complexity, the hydrodynamic is affected by the orientation of the coast with a linear trend NNW-SSE and several steps E-W, by the littoral currents and by the exchange of water masses between the Atlantic and Mediterranean through the Gibraltar Strait, there is North Atlantic Surface Water to about 140 meters depth, some North Atlantic Central Water has been detected and the presence of outflow Mediterranean Water flows below 500 meters in this area (Zenk, 1975).

Recent nonconsolidated sediments in this area are siliciclastic with quartz as the most abundant mineral in the sandy sediments. In the infralittoral domain, in the northern sector prevails the fluvial-deltaic depositional processes in relation with the Guadalquivir river mouth (Fig. 1). Moreover in the central and southern sector prevail

the infralittoral depositional processes and the development of discontinuous sandwaves fields. In front of the Bay of Cadiz coexist the depositional processes of sediment input from the inner Bay and the erosional processes due to strong tidal stream. In the continental shelf domain there is a northern sector where the fluvio-deltaic depositional processes predominate in relation with the Guadalquivir river input determining a sedimentary dynamics towards the SE, a central sector with the presence of large sands bodies over a shallow abrasion shelf at 25-30 meters depth and a southern sector where coexistent the fluvio-deltaic depositional processes in relation with the Barbate river input and the erosive processes due to the water flow towards the N-NW. In the shelf break prevails the progradational depositional processes in the north and central sectors and the neotectonic and depositional processes in the southern sector. In the upper slope predominates the depositional processes producing the slope aggradation and progradation, gravitational processes, and erosive processes due to the interaction of a Superficial Atlantic Water Flow. In the

middle slope prevails the erosion processes related with the Mediterranean Outflow, and the combined processes in relation with trough and submarine canyons occurrence (Lobo, 1995).

Materials and methods

This study is only based on more representative and abundant species taken from 50 samples collected from shoreline to slope using a Shipek bottom sampler. Each sample was washed over the 125 mm sieve, the residue was split to a fraction containing more than 300 specimens of benthic foraminifera all of which were picked and identified a total number of 170 benthic foraminiferal species under a binocular microscope (Loeblich and Tappan, 1988). The samples were not stained, the assemblages may thus represent both living specimens and empty shells. In general the foraminifera are well preserved and little affected by dissolution.

The following environmental parameters have been used for the multifactorial correlation analysis: depth, temperature, salinity, clay, silt, sand,

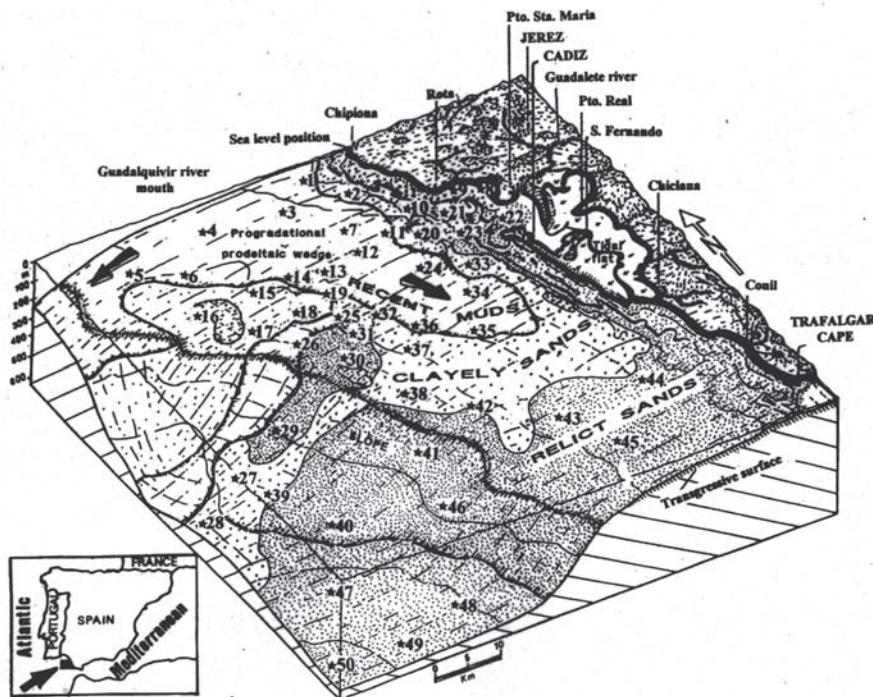


Fig. 1.- Sedimentological features (Geogaceta 14, p.34) and samples location.

Fig. 1.- Características sedimentológicas (Geogaceta 14, p.34) y localización de las muestras.

gravel, carbonate, organic matter, and mineralogy.

Results and discussion

The depth as reflect of biotic and abiotic environmental factors that control the distribution of foraminiferal (Horton *et al.* 2007) has been used with the aim to recognize and enumerate the main existing abundant species in three areas: Outer Bay, Continental shelf and Slope:

Outer Bay: A large semiclosed bay, with a characteristic low-cost morphology, the materials of sedimentary origin fundamentally, with deposits and some conglomerate levels date of Plio-Quaternary (Zazo *et al.*, 1983), the hydrodynamic system is controlled by tides. The dominant species according to the abundance order are: *Ammonia beccarii*, *Criboelphidium vadescens*, *Ammonia beccarii inflata*, *Rosalina globularis*, *Cassidulina laevigata*, *Elphidium crispum*, *Eponides concameratus*, *Quinqueloculina auberiana*, *Elphidium complanatum*, *Cibicides refulgens*, *Nonion asterizans*, *Elphidium macellum*, *Quinqueloculina seminulum*, *Quinqueloculina longirostra*, *Elphidium advenum*, *Adelosina cliarensis*, *Miliolinella subrotunda*, *Criboelphidium cuvilleri*, *Bolivina dilatata*, *Quinqueloculina lamarckiana*, *Nonionella*

turgida.

Continental shelf (10-200 m). There is a complex distribution facies pattern, the southern part is characterized by the presence of rock outcrops, the overlying sediments are mainly composed of sand, gravel and with a high content of bioclastic remains. In the northeastern sector sediments are predominantly fine-grained muds which correspond to the prodelta of the Guadalquivir river. Among them, a delimited transitional area characterized by the mixture of fine-grained advected from more distal areas mixed with sands, there is a Holocene sandy and gravel coastal facies that extends along the coast (Lopez Galindo *et al.*, 1999). The dominant species according to the abundance order are: *Valvulineria bradyana*, *Ammonia beccarii*, *Cassidulina laevigata*, *Hanzawaia boueana*, *Hyalinea balthica*, *Criboelphidium vadescens*, *Elphidium advenum*, *Nonion asterizans*, *Bulimina aculeata*, *Ammonia beccarii inflata*, *Bulimina marginata*, *Uvigerina peregrina*, *Quinqueloculina seminulum*, *Cibicides refulgens*, *Rectobolivina raphana*, *Rectuvigerina phlegeri*, *Textularia flintii*.

Slope: (200-600m). This area contains a large variety of sediment facies that include muddy sands, sand and gravel, and marls, with a general distribution

characterized by a westward in grain size increasing (Lopez Galindo op cit.). The dominant species according to the abundance order are: *Cassidulina laevigata*, *Hyalinea balthica*, *Uvigerina peregrina*, *Bulimina marginata*, *Hanzawaia boueana*, *Uvigerina mediterranea*, *Cassidulina reniforme*, *Bolivina dilatata*, *Bulimina costata*, *Quinqueloculina seminulum*, *Valvulineria bradyana*, *Bulimina buchiana*, *Lagena sulcata*, *Nonion asterizans*.

Assemblages

Benthic foraminiferal assemblages in close areas have been determined by Gonzalez-Regalado *et al.* (2001), Schönfeld (2002) and Mendes *et al.* (2004).

The definition of the various assemblages existing in the zone has been carried out by Q-Mode Factorial analysis using the BMPQ statistical program.

The 47 highest ranked species were selected on the basis of relative abundance of 3% or more at least in one of the samples and occurrence in at least three samples. Factor analysis with Varimax rotation produces 5 factor assemblages which account for an accumulative total of 93,8 % of the variance. The geographical distribution representing values for factor loadings of greater than 0,75 is summarized in figure 2. The factor assemblage names used here indicate the species with the highest factor score in each factor.

1. *Cassidulina laevigata* assemblage.

Middle shelf to upper slope assemblage (100-500 m). Accounts for the 45% of variance observed and this assemblage includes the following species with positive factor scores: *Cassidulina laevigata* (6,62). *Hyalinea balthica* (0,48). *Uvigerina peregrina* (0,23). *Hanzawaia boueana* (0,21).

Cassidulina laevigata assemblage had been related in the Atlantic seaboard of Europe and Africa in T-S margins of 34,9-35,11 ‰ and -1 to 17 °C in substrates sand and mud, between 100 and 2500 m depths (Murray, 1991) with *Hyalinea balthica* in Morocco coast (Mathieu, 1971) and with *Uvigerina peregrina* in NW of Africa (Debenay and Basov, 1993). This assemblage has been located in middle shelf to upper slope (100-500 m) with a large variety of sediments facies, there are muddy sands that probably represent a variety of coastal and estuarine deposits recording a complex transgressive and southeastward progradation along shelf to the Atlantic

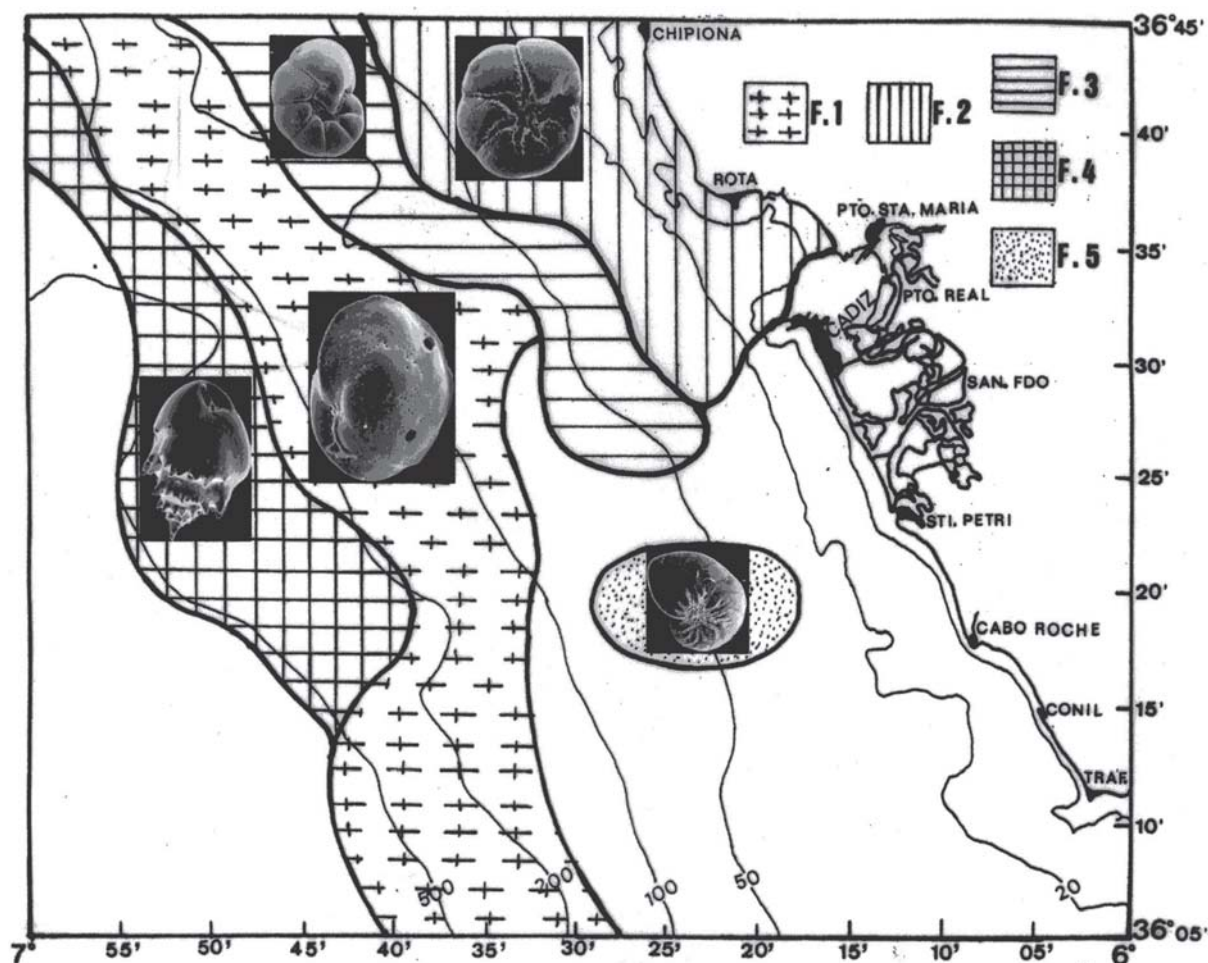


Fig. 2.- Distribution of benthic foraminiferal assemblages. F1.-*Cassidulina laevigata*; F2.- *Ammonia beccarii*; F3.- *Valvulineria bradyana*; F4.-*Bulimina marginata*; F5.- *Nonion asterizans*

Fig. 2.- Distribución de las asociaciones de foraminíferos bentónicos. F1.-*Cassidulina laevigata*; F2.- *Ammonia beccarii*; F3.- *Valvulineria bradyana*; F4.-*Bulimina marginata*; F5.- *Nonion asterizans*

inflow current system, in the southern shelf edge, interaction of the Atlantic inflow and Mediterranean outflow currents advect and prevent deposition of fine grained sediments. (Nelson *et al.*, 1999). *Cassidulina* is a cosmopolitan taxon that has been reported from a variety of environments. Fluctuations of *Hyalinea balthica* have been used for related interglacial-glacial oscillations, although in a complex manner and in general the presence of *Uvigerina peregrina* has been used as an indicator of bathyal depths low-oxygen content of the water and high organic carbon content of the sediment (Hermelin and Shimmield, 1990). This assemblage present only positive significance correlation (0,52) with the water depth and negative with the gravel in the studied zone. This could reflect a sustained flux of organic matter and high surface productivity resulting from an upwelling in this area.

2. *Ammonia beccarii* assemblage. Inner shelf assemblage (shallower than 50 m).

Accounts for the 28 % of variance observed and this assemblage includes the following species with positive factor scores: *Ammonia beccarii* (5,95). *Ammonia beccarii inflata* (1,64). *Criboelphidium vadescens* (1,62). *Quinqueloculina seminulum* (0,36). *Elphidium crispum* (0,20).

Ammonia beccarii assemblage had been related in the Atlantic seaboard of Europe and Africa in a T-S margins of 22-35 ‰ and 0,7 to 29 °C in muddy-sand substrate and between 0 and 60 m depths (Murray, 1991), similar assemblage is described by Mendes *et al.* (2004) on the Guadiana shelf, in water depths of up to 12 m influenced by fair-weather waves, and correspond to the shoreface or foreshore domains.

Ammonia is a very conspicuous taxon that has been related in diverse but principally shallow environments. Modern species of *Elphidium* are found in shelf and littoral environments and *Quinqueloculina* species are dominantly

shallow neritic taxa. In the studied zone, the relative depth range of this shelf assemblage (10-100 m) is a reflection of its occurrence. It is predominant throughout the northeast of the studied area and is restricted to inner shelf region. Its southern limit is bounded by the northern edge of Bay. The inner shelf contains a complex variety of sediment lithologies of consolidated bedrock outcrops, beach rock, shoreface sand and gravel deposits, and mud patches. Sporadic local gravel deposits, typically of shells are associated with the beach rocks deposits throughout innermost shelf areas. The southeast gravel are associated with both shells deposits and bedrock outcrops, sand is the predominant sediment texture in the inner shelf except gravel-rich deposits.

Southeastward Atlantic inflow and south to southwestward veering flow down appears to control the development of bedforms (Nelson *et al.*, 1999). The correlation coefficients of this

assemblage are remarkable a negative with water depth (-0,74) and positive with the gravel (0,31). Corresponding to a typical North-Atlantic nearshore assemblage.

3. *Valvulineria bradyana* assemblage. Middle shelf assemblage (50-100 m).

Accounts for the 9% of variance observed and this assemblage includes the following species with positive factor scores: *Valvulineria bradyana* (5,88). *Annonia beccarii* (1,54). *Nonion asterizans* (0,93). *Elphidium advenum* (0,74). *Bulimina aculeata* (0,66).

The factor assemblage dominated by *Valvulineria bradyana*, was described in the Mediterranean Rhone river mouth as *Valvulineria complanata* in depths between 30 and 100 m and muddy sand substrate (Bizon and Bizon, 1984).

Valvulineria bradyana is related to clayey substrata with a high content of organic matter and *Bulimina aculeata* itself is a cosmopolitan species and in the Western Mediterranean is considered as a good shallow water indicator (De Rijk *et al.*, 1999).

Species constituting this assemblage are controlled mainly by factors directly linked to the fine-grained substrata. This area occupies the middle shelf and delineates a southeastward trending lobe. The sediments are predominantly fine-grained muds that correspond to the submerged prodelta of Guadalquivir river, fine grained sediments from the river mouth are advected by geostrophic currents toward distal areas resulting in southward progradation of the mud over the sand layers, the sediment is distributed by the surface Atlantic water flowing southeastward (Lopez Galindo *et al.*, op. cit.)

The correlation analysis shows a high positive coefficient (0,70) with the mud and negative with the sand (-0,76) and quartz (-0,74).

4. *Bulimina marginata* assemblage. Slope assemblage.

Accounts for the 9% of variance observed and this assemblage includes the following species with positive factor scores: *Bulimina marginata* (3,86). *Uvigerina mediterranea* (2,73). *Uvigerina peregrina* (2,37). *Hyalinea balthica* (1,83). *Cibicides refulgens* (0,99). *Angulogerina angulosa* (0,85). *Cassidulina reniforme* (0,75). *Trifarina fornasini* (0,73).

Bulimina marginata assemblage had been related in the Atlantic seaboard of Europe and Africa in a T-S margins of 25-35 ‰ and 5,5 to 13° C in muddy-sand substrate and great variety of depths (Murray op. cit.)

Bulimina marginata abounds in deeper Mediterranean environments (De Rijk *et al.*, 1999). *Uvigerina mediterranea* seems to be linked to the Mediterranean outflow (Caralp, 1988). *Angulogerina angulosa* is a foraminifer of sandy substrates and relatively high bottom current velocities, independent of conservative water mass characteristics as temperature and salinity (Mackensen *et al.*, 1990).

This assemblage distribution corresponds to water depths greater than 500 m and to depths characterized by a strongest hydrographic gradients and affected by the Mediterranean outflow water. The facies include muddy sands, sand, gravel and marls, with a general distribution characterized by a westward increase of grain size, although most of the coarse-grained facies on the slope represent palimpsest and relict deposits, the presence of gullies and canyons on the slope and the strong Mediterranean undercurrent facilitate the development of gravity and contour flows that are influencing the present sediment distribution patterns (Lopez Galindo *et al.*, op. cit.). This assemblage has a strong positive correlation with the depth (0,74)

5. *Nonion asterizans* assemblage. South shelf assemblage.

Accounts for the 6% of variance observed and this assemblage includes the following species with positive factor scores: *Nonion asterizans* (6,15). *Hanzawaia boueana* (0,94). *Annonia beccarii* (0,93). *Planorbulina mediterraneensis* (0,90). *Cibicides refulgens* (0,62).

Very close assemblage is described by Schönfeld (2002) as assemblage 2a from the shelf and uppermost slope at depths of 103-272 m in the Gulf of Cadiz.

In this area the sands although have been reworked, caused by the Atlantic inflow inshore and Mediterranean outflow currents offshore. Because of the combination of modern and ancient processes, they are categorized as a palimpsest sand dune facies that extend across the middle shelf from south, beach rock and bedrock outcrops increasingly disrupt the dune facies (Nelson *et al.*, 1999).

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M^a Angeles and Iago.

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