



## Messinian ostracodes from the western Betic Strait (SW Spain)

**Verónica ROMERO** <sup>1, 2</sup>

**Francisco RUIZ** <sup>1, 3, 4</sup>

**María Luz GONZÁLEZ-REGALADO** <sup>1, 5</sup>

**Josep TOSQUELLA** <sup>1, 6</sup>

**Manuel ABAD** <sup>7, 8</sup>

**Tatiana IZQUIERDO** <sup>7, 9</sup>

**Antonio TOSCANO** <sup>1, 10</sup>

**Paula GÓMEZ** <sup>1, 3, 11</sup>

**Abstract:** During the Neogene, the Betic Strait was one of the gateways that connected the Atlantic Ocean and the Mediterranean Sea. In this paper, we have analyzed the ostracod faunas of samples collected from sediments crossed by a long borehole in southwestern Spain. These sediments were deposited in the Betic strait just before the Messinian Salinity Crisis. During the middle Messinian (6.8-6.0 Ma), the scarce and low diversified ostracod assemblages (*Krithe*, *Parakrithe*, *Henryhowella*) are typical of upper bathyal palaeoenvironments (200-400 m water depth). This period includes a short transition (6.26-6.25 Ma) to outer neritic palaeoenvironments, coinciding with a glaciation and characterized by the presence of *Acanthocythereis hystrix* (REUSS, 1850) and the disappearance of *Krithe* and *Parakrithe*. The most abundant species have a wide biostratigraphic distribution, most of them ranging from the Tortonian until the Holocene.

**Key-words:**

- Betic Strait;
- SW Spain;
- Messinian;
- upper bathyal-outer shelf ostracods;
- palaeoenvironmental evolution

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<sup>1</sup> Departamento de Ciencias de la Tierra, Universidad de Huelva, Avenida 3 de marzo, 21071 Huelva (Spain)

<sup>2</sup> [vero.ra93@gmail.com](mailto:vero.ra93@gmail.com)

<sup>3</sup> Research Center in Historical, Cultural and Natural Heritage

<sup>4</sup> Corresponding author;

[ruizmu@uhu.es](mailto:ruizmu@uhu.es)

<sup>5</sup> [montero@uhu.es](mailto:montero@uhu.es)

<sup>6</sup> [josep@uhu.es](mailto:josep@uhu.es)

<sup>7</sup> Departamento de Biología y Geología, Física y Química Inorgánica, ESCET, Universidad Rey Juan Carlos, c/Tulipán, s/n, 28933, Móstoles (Spain)

<sup>8</sup> [geosinergia@gmail.com](mailto:geosinergia@gmail.com)

<sup>9</sup> Instituto de Investigaciones Científicas y Tecnológicas (IDICTEC-UDA), Universidad de Atacama, Avenida Copayapu, 485, Copiapó (Chile)

[tatiana.izquierdo@uda.cl](mailto:tatiana.izquierdo@uda.cl)

<sup>10</sup> [toscano@dgyp.uhu.es](mailto:toscano@dgyp.uhu.es)

<sup>11</sup> [paula.gomezgutierrez@hotmail.com](mailto:paula.gomezgutierrez@hotmail.com)



**Résumé : Ostracodes messiniens du Déroit Bétique occidentale (Sud-Ouest de l'Espagne).-**

Au Néogène, le Déroit Bétique est l'un des passages entre l'Océan Atlantique et la Mer Méditerranée. Dans cet article, nous analysons les faunes d'ostracodes provenant d'un forage réalisé dans le sud-ouest de l'Espagne et, plus précisément, situé sur le trajet du déroit. Ce forage a traversé des sédiments déposés au cours de la période immédiatement antérieure à la crise de salinité messinienne. Au cours du Messinien moyen (6,8-6,0 Ma), les associations d'ostracodes, rares et peu diversifiés (*Krithe*, *Parakrithe*, *Henryhowella*), sont typiques de paléo-environnements bathaux supérieurs (de 200 à 400 m de profondeur). Cette période comprend une courte transition (6,26-6,25 Ma) jusqu'à des paléo-environnements néritiques externes. Elle coïncide avec un épisode de glaciation et l'association est caractérisée par la présence de *Acanthocythereis hystrix* (REUSS, 1850) et la disparition des genres *Krithe* et *Parakrithe*. Les espèces les plus fréquentes ont une large distribution biostratigraphique, la plupart étant présentes du Tortonien à l'Holocène.

**Mots-clefs :**

- Campanien supérieur ;
- événement paléo-océanographique ;
- paléo-climat ;
- fossiles de plante ;
- Plate-Forme Arabe ;
- Turquie du sud-est

## 1. Introduction

During the Tortonian and early Messinian, the Atlantic Ocean and the Mediterranean Sea were connected through the northern Betic Strait, which crossed the current Guadalquivir Basin (southern Spain), and the Rifian Corridor, located north of Morocco (Fig. 1.A; FLEKER *et al.*, 2015). These connections were closed during the so-called Messinian Salinity Crisis (MSC; HSÜ *et al.*, 1973, 1977), with an onset dated at 5.97 Ma and a later partial isolation of the Mediterranean Sea (5.59-5.33 Ma; KRIJGSMAN *et al.*, 1999). These closures have been attributed to eustatic changes, climatic events or tectonic processes (DUGGEN *et al.*, 2003; LEROUX *et al.*, 2018), although this discussion still persists (VAI, 2016; STERNAI *et al.*, 2017).

The timing of closure of the Betic Strait is still subject to debate. According to MARTÍN *et al.* (2009) and PÉREZ-ASENSIO *et al.* (2014), the Guadalhorce Corridor was the last seaway of the Betic Strait and it was closed during the early-middle Messinian (Fig. 1.A : ~6.18 Ma). Nevertheless, new research proposes that the Betic Strait was closed during the late Tortonian (SCHEE *et al.*, 2018). Other studies postulate that the Gibraltar Corridor was the sole Atlantic gateway during the Messinian (KRIJGSMAN *et al.*, 2018).

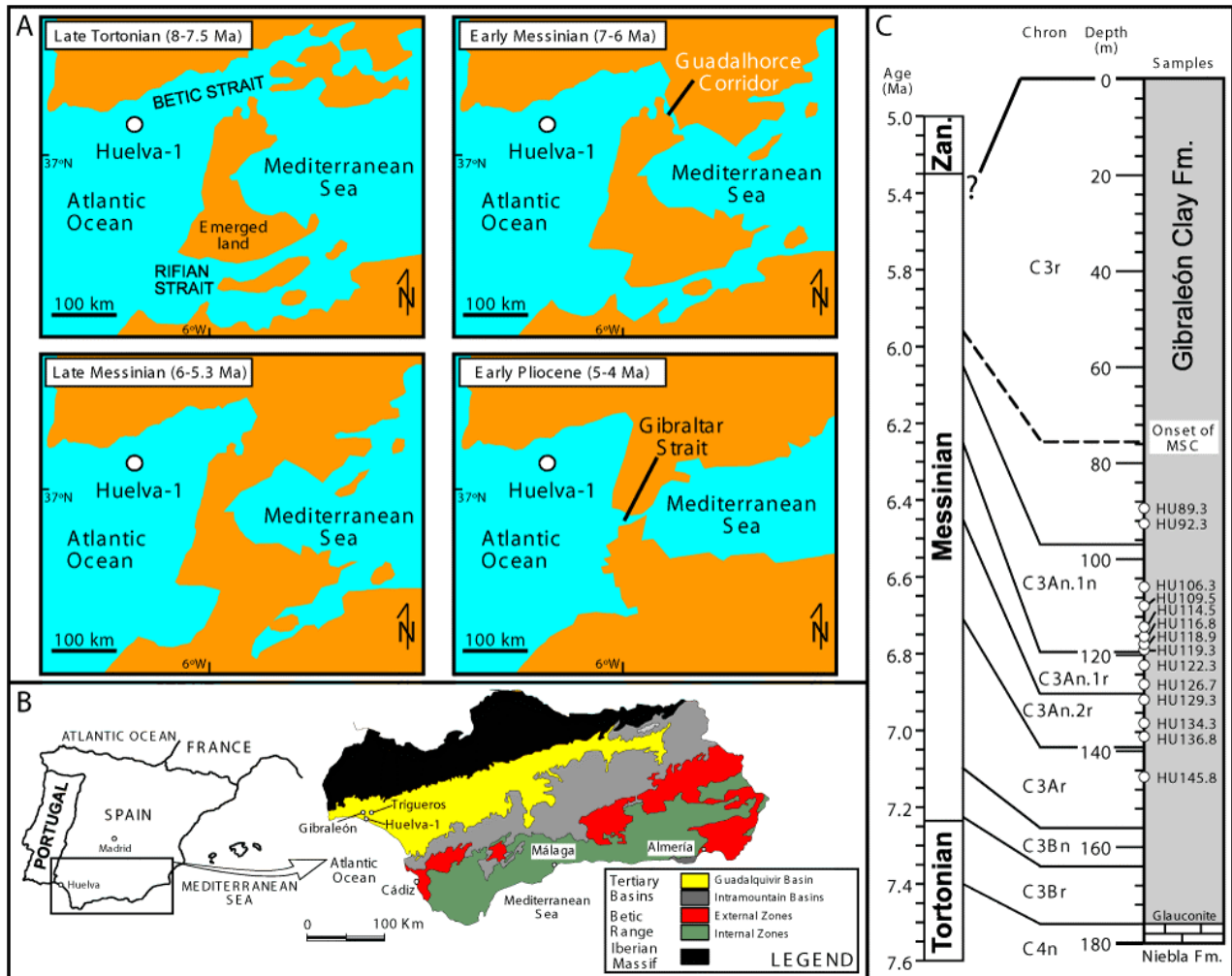
During the late Tortonian and early Messinian, these palaeogeographic, palaeoclimatic and/or palaeoceanographic changes affected the benthic faunas of the western Betic Strait. In a general overview, the analysis of the benthic foraminiferal assemblages indicates a progressive decrease in depth during this interval, together with remarkable variations in oxygen contents (GONZÁLEZ-REGALADO & RUIZ, 1996; GONZÁLEZ-REGALADO *et al.*, 2019).

In this paper, we study the ostracod fauna coming from samples of marine sediments crossed by the Huelva-1 borehole. These sediments constitute the Neogene infill of the Guadalquivir Basin (SW Spain). Results are compared with those obtained from the foraminiferal assemblages of the same core (GONZÁLEZ-REGALADO *et al.*, 2019) to recognize the main palaeoenvironmental changes that took place in this sector prior to the MSC.

## 2. Geological setting

In the southwestern sector of the Guadalquivir basin (Fig. 1.B), three main geological formations are exposed on a Palaeozoic-Mesozoic basement. The Upper Tortonian Niebla Formation (BACETA & PENDÓN, 1999) is composed of fluvial conglomerates, littoral sands and shallow marine calcarenites, this latter with a remarkable palaeontological record (echinoderms, nummulitids, red algae, bryozoans). The overlying Gibraleón Clay Formation (CIVIS *et al.*, 1987) consists of gray-blue marls and clays, with a condensed, silty glauconitic layer near the base. This unit presents a very rich micropalaeontological record (mainly foraminifera and calcareous nannoplankton). The planktonic foraminiferal fauna indicates a late Tortonian to Messinian age for these sediments (SIERRO, 1985), with Tortonian-Messinian boundary located just above the glauconitic level.

The Pliocene sedimentation of this area is represented by the Huelva Sand Formation (CIVIS *et al.*, 1987) consisting of massive, bioturbated sandy layers alternating with lumachellic layers attributed to storm action in an open bay palaeoenvironment (GONZÁLEZ-REGALADO *et al.*, 2009). These deposits include a new glauconitic layer with a rich fauna of selachians (RUIZ *et al.*, 1998). A broader regional analysis can be consulted in VIQUIER (1977).



**Figure 1:** **A.** palaeogeographical evolution of the Atlantic-Mediterranean connections during the Upper Neogene (modified from MARTÍN *et al.*, 2009); **B.** Main geological domains of southern Spain and location of the Huelva-1 borehole and some Messinian sections; **C.** Geochronology and sampling of the Huelva-1 borehole (modified from LARRASOÑA *et al.*, 2008, 2014). MSC: Messinian Salinity Crisis.

### 3. Material and methods

The Huelva-1 borehole (Fig. 1.C; UTM PB818265) was drilled by the IGME (Spanish Geological Survey) and it encompasses the upper part of the Niebla Formation (4 m) and most of the Gibraleón Clay Formation (Fig. 1.C : 172 m). The magnetostratigraphic datings indicate that this borehole spans from the latest Tortonian (C3Br.2r, ca. 7.4 Ma) to the latest Messinian (uppermost C3r, ca. 5.4 Ma) (LARRASOÑA *et al.*, 2008, 2014). Its geological record presents a cyclicity that started at 7.16 Ma, coinciding with the first sign of Mediterranean-Atlantic gateway restriction (BERG *et al.*, 2018).

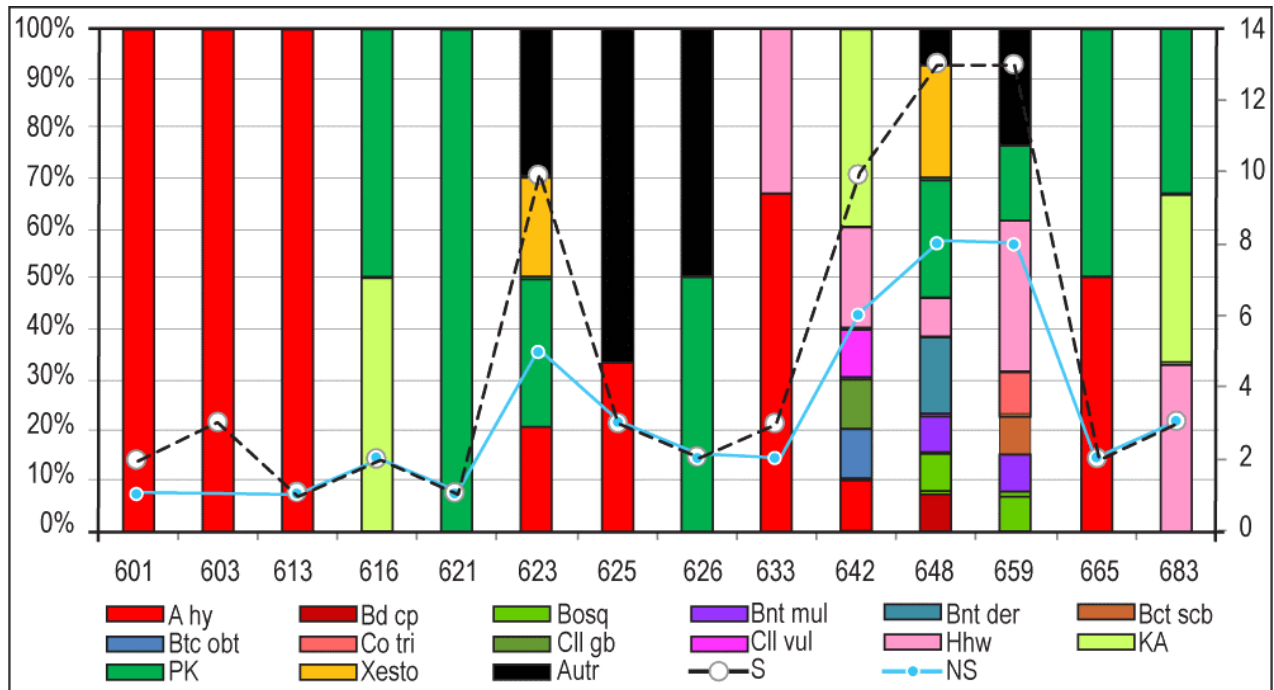
Fourteen samples (25 g) for micropalaeontological analysis were selected between 145.8 m and 89.3 m (Fig. 1.C : HU145.8 to HU89.3). These samples include the four chrons previous to the MSC and chron C3r, within which this crisis developed. The approximate time interval is included between 6.83 Ma (HU145.8) and 6.01 Ma (HU89.2) (Fig. 2). This time interval was calculated according to the magnetostratigraphy dedu-

ced by LARRASOÑA *et al.* (2008, 2014) for this borehole. These samples were wet sieved (63 µm mesh) and dried in an oven at 70°C. At the end all ostracodes were picked in each sample.

### 4. Results and discussion

#### A. Density and diversity: Comparisons with other nearby Messinian sections

The Huelva-1 borehole presents a badly-preserved and scarce ostracod fauna (Fig. 2). The total number of specimens is very low (69), with a maximum of thirteen specimens per sample in two samples (HU-134.3 and HU-129.3). On the contrary, sample HU-92.3 is barren (Figs. 1-2). The ostracod fauna is poorly diversified through the entire studied section of this core. A total of 21 taxa have been identified, including nine of them in open nomenclature. In a general overview, the ostracod fauna is dominated by *Acanthocythereis hystrix* (REUSS, 1850), *Henryhowella partenopaea* BONADUCE *et al.*, 1999, *Krithe* gr. *K. iniqua* ABATE *et al.*, 1993, and *Parakrithe* group *P. dactylomorpha* RUGGIERI, 1962 (Fig. 2).



**Figure 2:** Density (black dotted line), diversity (blue line) and abundance of the main species (in %). Horizontal axis: samples. Abbreviations: A hy: *Acanthocythereis hystrix*; Bd cp: *Bairdoppilata conformis*; Bosq: *Bosquetina carinella*; Bnt mul: *Buntonia multicostata*; Bnt der: *Buntonia dertonensis*; Bct scb: *Retibythere scaberrima*; Btc obt: *Bythocypris obtusata*; Co tri: *Costa tricostata*; Cll gb: *Cytherella gibba*; Cll vul: *Cytherella vulgata*; Hhw: *Henryhowella partenopaea*; K.A: *Krithe* gr. *K. iniqua*; Xesto: *Xestoleberis prognata*; Austr.: other species.

*Bosquetina carinella* (samples HU134.3 to HU129.3) and two species of *Buntonia* [*B. dertonensis* (RUGGIERI, 1954) and *B. multicostata* RUGGIERI, 1962]] have certain vertical continuity in some sections of the Huelva-1 borehole. Other species not included in Fig. 2 are *Cytheropteron* cf. *C. sulcatum* BONADUCE, CIAMPO & MASOLI, 1975 (sample HU129.3), *Loxoconcha* sp. (sample HU119.3), *Uroleberis* sp. (sample HU118.9), *Occultocythereis* cf. *O. scipionis* BONADUCE *et al.*, 1992 (sample HU118.9), *Propontocypris* sp. (sample HU116.8) and *Aglaioocypris?* sp. (sample HU116.8).

These low diversities and densities have also been verified in other Messinian sections of the Gibrleón Clay Formation, such as Gibrleón or Trigueros (Fig. 1.B; GONZÁLEZ-REGALADO & RUIZ, 1988, 1990). The ostracod assemblages of these sections are very similar to those of the Huelva-1 borehole, with *Cytherella*, *Krithe*, *Parakrithe*, *Henryhowella* and *Costa* as the most representative genera.

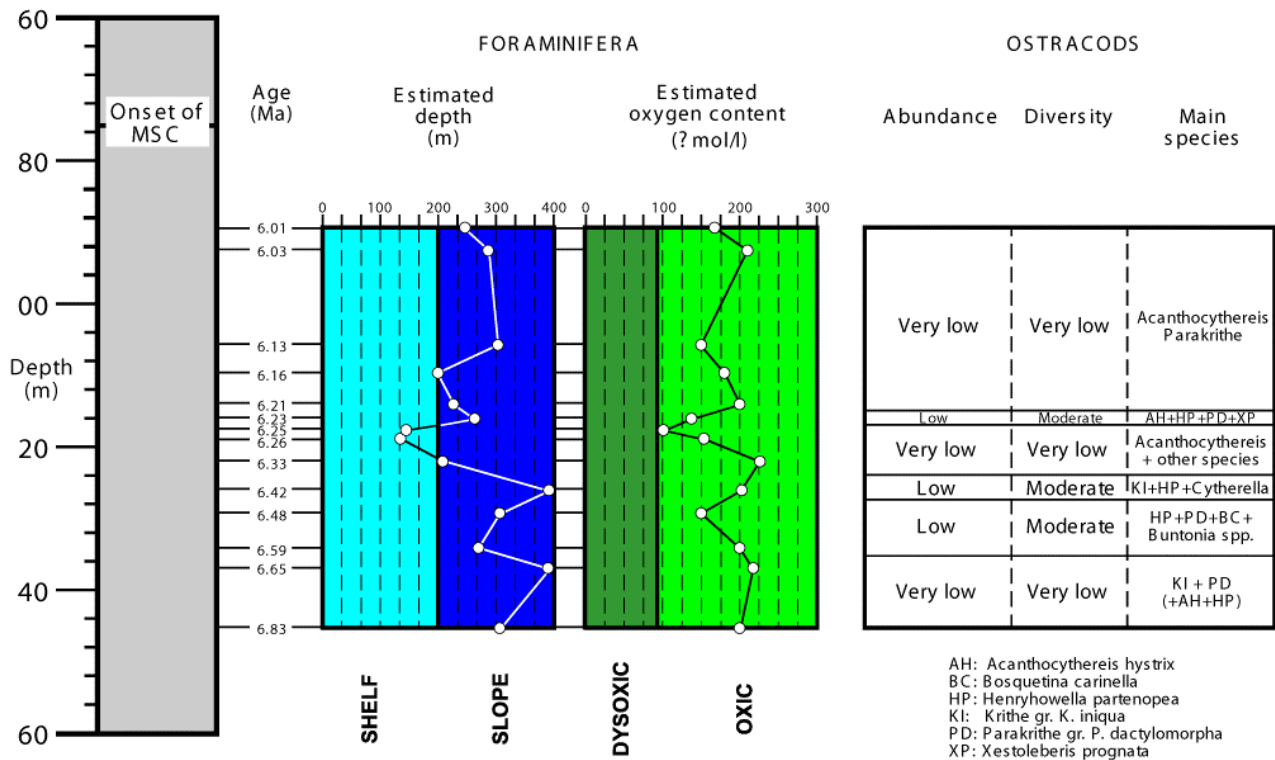
## B. Ostracod assemblages: Palaeoenvironmental reconstruction

As mentioned above, the main ostracod assemblage of the Huelva-1 borehole is composed of *Cytherella* spp., *Henryhowella partenopaea* BONADUCE *et al.*, 1999, *Krithe* spp. and *Parakrithe* spp. This assemblage characterizes Neogene to Recent upper slope environments of France, Morocco and the Mediterranean Sea (PURI *et al.*, 1969; PEYPOUQUET, 1979; LLANO, 1981; CARBONEL,

1985). This overall palaeoenvironment is confirmed by other key species with bathyal affinity, such as *Retibythere (Bathybythere) scaberrima* (BRADY, 1887), *Bythocythere obtusata* or *Costa tricostata* (REUSS, 1850) (SCIUTO, 2014, 2015). In addition, the estimated palaeodepth calculated on the basis of the recorded benthic foraminiferal assemblages agrees with an upper bathyal palaeoenvironment (Fig. 3: 200-400 m depth) for most samples (GONZÁLEZ-REGALADO *et al.*, 2019).

In these scenarios, there is usually a high variability in ostracod diversity (FANGET *et al.*, 2013), although the presence of low to moderately diversified ostracod assemblages (<15 species/sample in most cases) is frequent (BENSON, 1973a; SCIUTO, 2014; SCIUTO & ROSSO, 2015). The low ostracod diversity observed through the entire studied section of Huelva-1 borehole is comparable with those reported in other upper bathyal Messinian sections of the western Betic Strait (mean: <8 species/sample; GONZÁLEZ-REGALADO & RUIZ, 1990, 1991).

Both density (2-3 individuals/25 g) and diversity (2-3 species/sample) decrease significantly between samples HU122.3 and HU118.9 (Figs. 1-2: 6.33-6.25 Ma). *Acanthocythereis hystrix* (REUSS, 1850), an allocthonous outer neritic species in the remaining samples, is the most representative species of this interval, together with the presence of some individuals of the allocthonous genera *Uroleberis* and *Loxoconcha* should also be highlighted (HU119.3-HU118.9; 6.26-6.25 Ma).



**Figure 3:** Comparison between the palaeoenvironmental conditions deduced from the benthic foraminifera and the ostracod fauna of the Huelva-1 borehole.

Species of these two genera are generally collected together in recent and past shallow marine areas (ZAO & WANG, 1988; SAFAK *et al.*, 2015; EGLINGTON, 2019). These features would indicate a regression, with a transition from upper epibathyal to outer neritic palaeoenvironments, a process also detected in the foraminiferal assemblages (Fig. 3; 130-150 m water depth; GONZÁLEZ-REGALADO *et al.*, 2019). This period coincided with a Miocene glacial period deduced from the isotopic record of deep ODP cores in the North Atlantic (HODELL *et al.*, 2001).

In the remaining samples, the presence of these last species and others with shallower distributions [e.g., *Bosquetina carinella* (REUSS, 1850), *Loxoconcha* sp., *Cytheropteron* cf. *C. sulcatum* BONADUCE *et al.*, 1975] can be attributed to post-mortem transport (HASTRUP & THOMSEN, 2005; SALIHOGLU *et al.*, 2018). Neritic species are frequently found in upper bathyal palaeoenvironments because of downslope contamination by neritic sediments (e.g., GUERNET & FOURCADE, 1988).

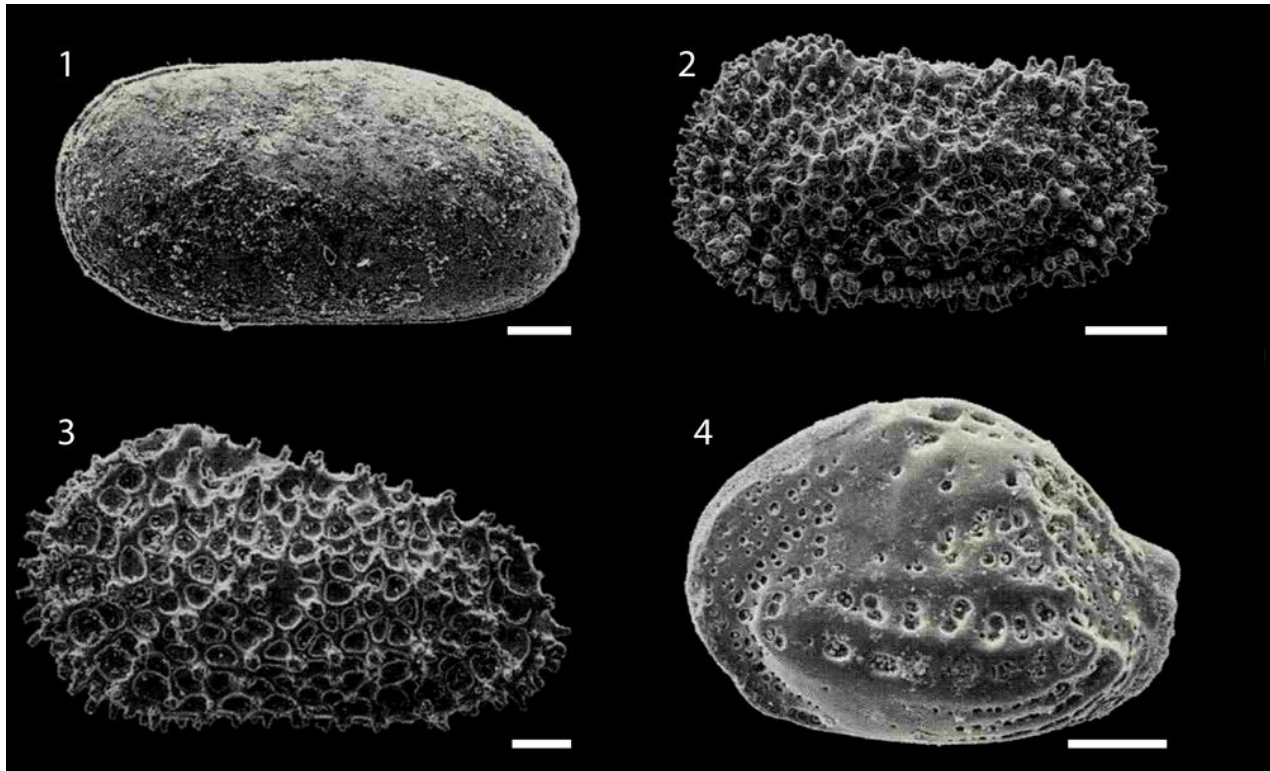
### C. Autoecology and biostratigraphy of some key species

Brief considerations about the most significant species, according to their palaeoenvironmental significance or biostratigraphic distribution. They are listed in alphabetical order in each section.

#### C.1. Autochthonous species

One specimen of *Bairdoppilata conformis* (TERQUEM, 1878) was found in sample HU129.3 (6.48 Ma). This species has a wide bathymetrical distribution in both the Mediterranean Sea (BONADUCE *et al.*, 1983; MONTENEGRO *et al.*, 1998) and the Atlantic Ocean (WHATLEY & COLES, 1987; YASUHARA & OKAHASHI, 2014), ranging from circalittoral to bathyal environments. It is a long-ranging species widely distributed within the Cenozoic, but this species has also been collected in recent sediments of the Mediterranean Sea (HARTEN & DROSTE, 1988; BOSSIO *et al.*, 2006; SCIUTO, 2012; SCIUTO & ROSSO, 2015).

Two specimens of *Buntonia dertonensis* (RUGGIERI, 1954) were extracted in sample HU129.3 (Figs. 1-2: 6.48 Ma). This species has been collected (also as *Buntonia sublatissima dertonensis* RUGGIERI, 1954) from Miocene to Recent marine sediments in Austria (SZCZECURA & AIELLO, 2003), Malta (BARRA & BONADUCE, 2001), Italy (SCIUTO, 2014), and Spain (GONZÁLEZ-DELGADO *et al.*, 1982). This species lives in lower circalittoral to epibathyal environments in the Mediterranean Sea (SCIUTO, 2014; see review in STOW *et al.*, 2013).



**Figure 4:** Main species of the Huelva-1 borehole. 1: *Cytherella vulgata* RUGGIERI, 1962 (sample HU126.7); 2: *Henryhowella partenopea* BONADUCE *et al.*, 1999 (sample 145.8); 3: *Acanthocythereis hystrix* (REUSS, 1850) (sample 136.8); 4: *Buntonia multicostata* RUGGIERI, 1962 (sample 134.3). Scale bar: 100  $\mu$ m.

*Buntonia multicostata* RUGGIERI, 1962 (Fig. 4.4), has been recovered (as *Buntonia sublatissima multicostata*) from Miocene to Pleistocene sediments in Spain (GONZÁLEZ-REGALADO & RUIZ, 1990; RUIZ *et al.*, 2008b), Italy (RUGGIERI, 1962; COLALONGO *et al.*, 1990), and Malta (BONADUCE & BARRA, 2002). It is an open-shelf/deep-water species (*sensu* RUSSO *et al.*, 2012), cited in lower circalittoral to bathyal palaeoenvironments of Algeria (>100 m depth; CARBONNEL & COURME-RAULT, 1997). This species is present in two consecutive samples (Figs. 1-2; HU134.3-HU129.3: 6.59-6.48 Ma).

One specimen of *Bythocypris obtusata* (SARS, 1866) has been collected in sample HU126.7 (6.42 Ma). It is mainly found in bathyal (palaeo-) environments, both in the Mediterranean Sea (300-2905 m depth; PURI *et al.*, 1964; BONADUCE & PUGLIESE, 1979; SCIUTO, 2014) and the Atlantic Ocean (BENSON *et al.*, 1983), although this species has been also observed in neritic areas of the North Atlantic (SARS, 1928). Specimens of this species have been collected from Miocene to Recent sediments in Italy (COLALONGO & PASINI, 1980; SCIUTO & ROSSO, 2015), Turkey (ERTEKIN & TUNOGLU, 2008), and Greece (SISSINGH, 1972).

*Costa tricostata* (REUSS, 1850) is a long-ranging species from palaeogene to Neogene sediments in France (DUCASSE & MONDAIN-MONVAL,

1984), Austria (ZORN, 2004), Italy (DALL'ANTONIA, 2002; SCIUTO, 2014), and Spain (RUIZ *et al.*, 2011). This species was typical of sediments referred to upper bathyal palaeoenvironments in Italy (RUGGIERI, 1992; BOSSIO *et al.*, 2006; SCIUTO, 2014) and Spain (ABAD *et al.*, 2005). One specimen of this species was found in sample HU134.3 (Figs. 1-2: 6.59 Ma).

*Cytherella gibba* AIELLO *et al.*, 1996, has been described from Tortonian to Pleistocene in Italy (AIELLO *et al.*, 1996; FARANDA *et al.*, 2007). This species inhabited at moderate water depths, exceeding 150 m, in upper Italian bathyal palaeoenvironments (FARANDA *et al.*, 2007; CIPOLLINARI *et al.*, 2009; BALDANZA *et al.*, 2013). One specimen of this species was collected in sample HU126.7 (Figs. 1-2: 6.42 Ma).

*Cytherella vulgata* RUGGIERI, 1962 (Fig. 4.1), is frequent from Miocene to Recent in the Mediterranean Sea (RUGGIERI, 1962; SISSINGH, 1972; CARBONNEL & COURME-RAULT, 1997) and adjacent Atlantic areas (ABAD *et al.*, 2011). This species inhabits in lower circalittoral to epibathyal environments, at water depths exceeding usually 125 m in the Mediterranean Sea (PURI *et al.*, 1969; BONADUCE *et al.*, 1975; ARANKI, 1987) and the Moroccan Atlantic shelf (LLANO, 1981). This species was only collected (1 specimen) in sample HU126.7 (Figs. 1-2: 6.42 Ma).



Eleven specimens of *Henryhowella partenopea* BONADUCE *et al.*, 1999 (Fig. 4.2), were collected in six basal samples of the Huelva-1 borehole (Figs. 1-2: HU145.8 to HU118.9, except two samples; 6.83-6.25 Ma). It is a common species [as *Henryhowella asperrima* (REUSS, 1850) in most cases] in Tortonian to Recent marine sediments from the Mediterranean Sea (BONADUCE *et al.*, 1999) and the adjacent Atlantic zones (RUIZ *et al.*, 2008a). This species has been found in recent shelf sediments of the Mediterranean Sea (40-170 m depth; BONADUCE *et al.*, 1999), although this species has been also found in Neogene upper slope palaeoenvironments of the Betic Strait (RUIZ & GONZÁLEZ-REGALADO, 1996).

*Krithe* gr. *K. iniqua* ABATE *et al.*, 1993, and *Parakrithe* gr. *P. dactylomorpha* RUGGIERI, 1962, are very similar to their reference-species, but the minimum differences are probably due to taphonomic processes. *Krithe iniqua* ABATE *et al.*, 1993, has been extracted from Tortonian to Pleistocene sediments in Italy (CIAMPO, 1980, 1986; ABATE *et al.*, 1993; AIELLO & BARRA, 2001) and Langhian-Serravalian limestones and clays in Malta (BONADUCE & BARRA, 2002). This species and others very similar have been collected in upper bathyal palaeoenvironments of Italy (SCIUTO & ROSO, 2008; SCIUTO & BALDANZA, 2020). Seven specimens of this species have been collected in four samples, ranging from 6.83 Ma (sample HU145.8) to 6.16 Ma (sample HU106.3).

*Parakrithe dactylomorpha* RUGGIERI, 1962, has been found in Miocene to Pleistocene sediments from Spain (GONZÁLEZ-REGALADO & RUIZ, 1990), Switzerland (BRINKMANN *et al.*, 2019), Italy (RUGGIERI, 1962), Croatia (HAJEK-TADESSE & PRTOĀLIAN, 2011), and Greece (SISSINGH, 1972; HASTRUP & THOMSEN, 2005). This species inhabited in lower circalittoral to epibathyal sediments both in the Betic Strait (BENSON, 1972; GONZÁLEZ-REGALADO & RUIZ, 1991) and the Mediterranean Sea (HASTRUP & THOMSEN, 2005). It is the most abundant species of the Huelva-1 borehole, with fourteen specimens extracted in nine samples distributed throughout the interval studied.

*Retibythere* (*Bathybythere*) *scaberrima* (BRADY, 1887) is a common species (as *Bythoceratina scaberrima*) in Mediterranean bathyal palaeoenvironments from Miocene to the early Pleistocene (review in SCIUTO, 2015). This species has even been described in Holocene sequences of the NE Atlantic Ocean (WHATLEY & AYRESS, 1988) and recent bathyal sediments of the Atlantic Ocean (see review in YASUHARA *et al.*, 2014). One specimen of this species was found in sample 134.3 (Figs. 1-2: 6.59 Ma)

*Xestoleberis prognata* BONADUCE & DANIELOPOL, 1988, has been collected in Tortonian to Pleistocene sediments from Italy (ABATE *et al.*, 1994)

and Spain (RUIZ *et al.*, 2004). In Italy, this species is frequent in bathyal palaeoenvironments (ABATE *et al.*, 1994; VIOLANTI *et al.*, 2009). Five specimens of this species were found in samples HU129.3 (6.48 Ma) and HU114.5 (6.23 Ma).

To sum up, the species found present a wide biostratigraphic range and indicate a Tortonian-Holocene age for the studied samples. This age is refined from the magnetostratigraphic analysis of Huelva-1 borehole. Ages of the fourteen studied samples ranges from 6.83 Ma (HU145.8) to 6.01 Ma (HU89.3) (LARRASOÑA *et al.*, 2008, 2014).

## C.2. Allocthonous species

Thirteen specimens of *Acanthocythereis hystrix* (REUSS, 1850) (Fig. 4.3) were collected in eight samples (Figs. 1-2: HU136.8 to HU89.3; 6.65-6.01 Ma). This species was previously known from the Middle Miocene of Austria (ZORN, 2004), Miocene-Pleistocene of Greece (HASTRUP & THOMSEN, 2005; FARANDA *et al.*, 2008) and Plio-Pleistocene of Tunisia (TEMANI *et al.*, 2016). This allocthonous species generally inhabits (or inhabited) shelf environments located between the external infralittoral to the inner circalittoral zones in the Eastern Mediterranean Sea (NAZIK, 2001; PARLAK & NAZIK, 2016) and Italy (BONADUCE & PUGLIESE, 1979; MONTENEGRO *et al.*, 1998).

*Bosquetina carinella* (REUSS, 1850). This species was found from Eocene to Holocene both in the Mediterranean Sea (PARLAK & NAZIK, 2016; TEMANI *et al.*, 2016; SALIHOGLU *et al.*, 2018) and the Atlantic Ocean (RUIZ & GONZÁLEZ-REGALADO, 1996). This species inhabited mostly circalittoral palaeoenvironments in Austria (ZORN, 2007) and Spain (RUIZ *et al.*, 2008b), although it has also been cited in infralittoral areas of Portugal (ANTUNES *et al.*, 1996).

## D. Other palaeoenvironmental variables

The mentioned autocthonous ostracod assemblage (*Retibythere*, *Krithe*, *Cytherella*, *Henryhowella*, *Bythocypris*) is typical of bathyal palaeoenvironments with low to very low temperatures (BENSON, 1973b; SCIUTO, 2015). Species of *Henryhowella* and *Krithe* were found at temperatures below 10°C (BENSON, 1973b; NAZEER *et al.*, 2019), whereas *Retibythere scaberrima* lives even in polar environments (YASUHARA *et al.*, 2014).

The foraminiferal assemblages indicate the presence of a well-oxygenated palaeoenvironment during the period studied (Messinian: 6.8-6.0 Ma; GONZÁLEZ-REGALADO *et al.*, 2019), with a small drop between 6.26-6.25 Ma. This interval coincides with a decrease in both the density and diversity of the ostracod fauna (Fig. 2). In addition, the frequent presence of *Parakrithe* is associated with high productivity (PEYPOUQUET, 1979; BASSETTI *et al.*, 2010).



## 5. Conclusions

During the middle Messinian (6.8-6.0 Ma), the western sector of the Betic Strait was occupied by upper bathyal palaeoenvironments (200-400 m depth), with a general decreasing depth trend during this period. These upper slope scenarios were dominated by *Henryhowella partenopaea* BONADUCE *et al.*, 1999, *Krithe* gr. *K. iniqua* ABATE *et al.*, 1993, and *Parakrithe* gr. *P. dactylomorpha* RUGGIERI, 1962, with minor contributions of the genera *Cytherella*, *Buntonia* and *Xestoleberis*. A timely transition to outer neritic palaeoenvironments is characterized by the presence of *Acanthocythereis hystrix* (REUSS, 1850), which is the main allochthonous species in most of samples. This general overview coincides with the results previously obtained from the benthic foraminiferal assemblages. The biostratigraphic distribution of the main species (mainly Tortonian-Holocene) agrees with the ages obtained by magnetostratigraphic studies (6.8-6.0 Ma). Small drops of the oxygen levels caused a decline in ostracod populations during a glaciation that occurred between 6.26-6.25 Ma.

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