PLIOCENE LITHOFACIES WITHIN THE MARINE GEOLOGIC RECORD FROM THE CADIZ BAY (SW SPAIN): ENVIRONMENTS AND PROCESSES

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Abstract: Depositional trend that characterized the post-orogenic sedimentary fill in the southern sector of the Guadalquivir Basin has been established by means of sedimentological analysis of Pliocene marine deposits from the Cadiz coast (SW Spain). Lithofacies indicate important variations of depositional regime, alternating calms and storm periods with occasional oceanographic events, which are characterized by the deposition of bioclastic and boulder deposits. According to the features and fossil content, several lithofacies types have been identified, from muddy sands to sandstones, calcarenites, bioclastic accumulations, and large boulder accumulations. Sands, sandstones and calcarenites show features which indicate a seasonal depositional regime, while bioclastic and large boulder beds show different features respect to the over and underlying beds, having been classified as event deposits. The origin of the event deposits and the involved depositional processes is also discussed. Both, lithofacies and tectonic setting are coherent with historical data, and indicate that these deposits were generated by very-high energy oceanographic events, such as major storms or tsunamis.

Key words: Pliocene, high-energy deposits, boulders, tempestites, tsunamites, Cadiz Gulf.

Resumen: Mediante el estudio sedimentológico de los afloramientos Pliocenos de la costa de Cádiz (SO de España), se ha establecido la tendencia deposicional que caracteriza el relleno sedimentario post-orogénico en el sector sur de la cuenca del Guadalquivir. Las facies indican variaciones importantes del régimen deposicional, alternando períodos estacionales de calma y tormenta con eventos ocasionales de muy alta energía, caracterizados por el depósito de materiales clásticos y bioclásticos de mayor tamaño. De acuerdo con las características sedimentarias y el contenido fósil, varios tipos de litofacies han sido identificados. Las arenas, areniscas y calcarenitas muestran características que indican un régimen estacional, mientras que las capas bioclásticas y los depósitos de bloques muestran características completely distintas a los depósitos infra y suprayacentes, habiendo sido clasificados como depósitos de eventos. También se ha discutido el origen de estos depósitos y los mecanismos deposicionales involucrados en su formación. Tanto las litofacies como el marco tectónico y el registro histórico, indican que estos depósitos fueron generados por eventos oceanográficos de muy alta energía, tales como grandes olas generadas por importantes temporales o tsunamis.

Palabras clave: Plioceno, depósitos de alta energía, Golfo de Cádiz.
The Pliocene shallow marine records from Cadiz coast (SW Spain) were studied with the aim of establishing the depositional conditions that characterized the sedimentary evolution in the south-western sector of the Guadalquivir Basin (Figs. 1 and 2). This basin is result of the flexural subsidence of the Iberian Foreland during the formation of the Betic Mountain Range (García-Castellanos et al., 2002; González-Delgado et al., 2004). Several high-energy deposits were identified, whose analysis provided information on the effects of sedimentary processes. There has been controversy regarding the interpretation of these accumulations, specifically with respect to the provenance of the boulders and the involved processes.

Relevant bibliography:


- Sanz de Galdeano and Lopez Garrido, 1991; Aguirre, 1995). Two neo-tectonic stages are distinguished: a) a Pliocene extensional stage, evidenced by normal faults oriented N 110º E and E-W, and an angular unconformity between the late Miocene and Pliocene, and b) a compressive stage from Late Pliocene to Holocene, which reacted older fractures, and gave way to dextral tear faults oriented NE-SW and E-W.

**Stratigraphy**

The study of the post-orogenic deposits from Cadiz coast early starts by the geologist MacPherson (1873) in the late of 19th century, and somewhat later, in the first half of the 20th century by Gavala and Laborde (1959 y 1992, who focus their studies from a stratigraphic and cartographic point of view (Gutierrez Mas et al., 1991). During the second half of 20th century, Viguier (1974) carried out detailed studies about the Neogene from lower Guadalquivir basin, including the Cadiz province. Almost simultaneously, Benkhelil (1976) studied of post-orogenic tectonic deformation in this area, coming to identify two major neo-tectonic stages.

Zazo (1979, 1980), studied the Pliocene-Quaternary boundary on the Cadiz, considering that the Pliocene to Quaternary step is represented by an erosive unconformity and a karstic surface that separates the Pliocene materials of the “red sands”, which represent the first Quaternary de-
unit II is conformably on the previous one and consists of cemented calcarenite with abundant remains of *Ostrea edulis* and *Pecten sp*. Finally, the unit III consists of a conglomeratic set, on which appears a well-marked erosive surface fossilized by Quaternary “red sands”. More recently, Rico-García *et al.* (2008), studies the Pliocene pectinids from Vejer de la Frontera outcrops, and Rico-Garcia and Aguirre (2008), study the taphonomic features of the fossil associations from Pliocene deposits of this basin. These define three taphofacies types: a) taphofacies from inner shelf, b) taphofacies from shallow lagoon, and c) taphofacies from storm deposits.

**Methods**

Field work consisted of outcrop studies, sedimentological and stratigraphic analyses and sampling (rocks and fossils) of eleven stratigraphic sections along the Cadiz coast (Figs. 3, 4, 5 and 6). The sedimentological study included the analysis of the lithofacies and petrographic samples. The textural, petrographic and mineralogical analyses were carried out in order to characterize the deposits, whereas the microscopic analyses of different types of boulders and clasts aimed at determining their petrographic features and similarities, provenance, transport distance and sedimentary evolution.

The $\text{Sr}^{87}/\text{Sr}^{86}$ Isotopic Relation Analysis Method was used to determine the absolute age of 12 calcareous samples (Table 1). Strontium isotope analysis is based on the variation of the average $\text{Sr}^{87}/\text{Sr}^{86}$ ratio in seawater (McArthur *et al.*, 2001). The samples were analysed in the Geochronology and Isotope Geochemistry Laboratory of the Universidad Complutense de Madrid. The Sr measurements were corrected for possible $\text{Sr}^{87}/\text{Rb}$ interferences, and normalized to $\text{Sr}^{87}/\text{Sr}^{88} = 0.1194$, due to possible mass fractionation during the analysis. Age was determined using the relation $\text{Sr}^{87}/\text{Sr}^{86}$ and the marine Sr-Isotope Curve for 509 Ma (millions of years) (Table 1). The standard seawater marine curve given by McArthur *et al.* (2001) was used. The chronostratigraphic position of the units was based on Scale of the International Stratigraphic Commission (Gradstein *et al.*, 2004) (Table 1).

**Results**

The oldest deposits are Miocene marls from Guadalquivir Olistostrome Complex, located at base from section 6 (Fig. 5). These are composed of white marls with olistoliths with a variable lithology, such as, blocks of sandstones, limestones, gypsiums, etc., belonging to different units from the Betic Mountain Range. Blue marls from Upper Miocene are also present at the section 6 (Fig. 5), while Upper Miocene calcarenites are present to the south of the study zone, near the town of Conil (Figs. 3 and 6).

Pliocene deposits are mostly represented by silty sands, bioclastic sands, and calcarenites (Figs. 3 to 7). An exceptional case is the presence of a group of spherical blocks of quartzarenite, which are interbedded in Pliocene sands and...
PLIOCENE LITHOFACIES WITHIN THE MARINE GEOLOGIC RECORD FROM THE CADIZ BAY (SW SPAIN): ENVIRONMENTS AND PROCESSES

Table 1.- Samples Age from $^{87}$Sr/$^{86}$Sr Isotopic Analysis

<table>
<thead>
<tr>
<th>Samples</th>
<th>$^{87}$Sr/$^{86}$Sr</th>
<th>Error</th>
<th>Age (Ma BP)</th>
<th>Deposit age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuente del Gallo (section 10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Unit 2a Oyster</td>
<td>0.709092</td>
<td>5</td>
<td>1.9</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>11 Unit 2 Pecten</td>
<td>0.709070</td>
<td>4</td>
<td>2.6</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>10 Unit 2 Cardin</td>
<td>0.709043</td>
<td>6</td>
<td>4.8</td>
<td>Upper Pliocene</td>
</tr>
<tr>
<td>9 Unit 2 Oyster</td>
<td>0.709153</td>
<td>5</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>La Barrosa (section 4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Unit 4 shell from boulder</td>
<td>0.709139</td>
<td>5</td>
<td>1</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>6 Unit 5 Pecten (upper conglomerate)</td>
<td>0.709094</td>
<td>5</td>
<td>1.7</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>8 Unit 5 Oyster (upper conglomerate)</td>
<td>0.709083</td>
<td>5</td>
<td>2.1</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>5 Calcarenites</td>
<td>0.709049</td>
<td>6</td>
<td>4.4</td>
<td>Lower Pliocene</td>
</tr>
<tr>
<td>4 Unit 2 Pecten</td>
<td>0.709019</td>
<td>5</td>
<td>5.1</td>
<td>Lower Pliocene</td>
</tr>
<tr>
<td>3 Pecten (lower conglomerate)</td>
<td>0.709025</td>
<td>5</td>
<td>5.3</td>
<td>Lower Pliocene-Late Miocene</td>
</tr>
<tr>
<td>2 Oyster (lower conglomerate)</td>
<td>0.709025</td>
<td>6</td>
<td>5.3</td>
<td>Lower Pliocene-Late Miocene</td>
</tr>
<tr>
<td>4 Unit 2 Pecten</td>
<td>0.708964</td>
<td>5</td>
<td>5.7</td>
<td>Late Miocene</td>
</tr>
<tr>
<td>Roman oven (section 3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Unit 6 Shell in sands</td>
<td>0.709053</td>
<td>5</td>
<td>4.5</td>
<td>Lower Pliocene</td>
</tr>
</tbody>
</table>

▲ Trusted samples; ● Unreliable samples; ** Allochthonous fossils; * In situ samples

Fig. 3.- A) Geological map of the study zone; B) Geological map of the study zone, and stratigraphic section location (modified from Gutierrez-Mas et al., 1991).

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calcarenites, which are present in the section 10 (Figs. 6 and 7). The macrofauna is mainly represented by bivalve mollusks, primarily oysters and pectinid shells. In general, the shells are disarticulated, with biofouling, bioerosion, fragmentation and abrasion signs. Also gastropods, brachiopods, rhodoliths, corals and scaphopods are present.

Pectinids are the most represented family. Genus *Aequipecten* is represented by three species: *Aequipecten escabrellus*, *Aequipecten opercularis* and *Aequipecten radians*. Genus *Pecten* is represented by the species: *Pecten jacobaeus*, *Pecten maximus* and *Pecten benedictus*. Genus *Chlamys* is represented by: *Chlamys multistriata* and *Chlamys varies*. Other identified fossils are: *Hinnites crispus*, *Ostrea edulis*, *Flexopecten flesuoxus*, *Balanus* and *Mytilus sp*. Some fossils are in mold state, as *Glycymeris sp* and *Panopea sp*. Bryozoans are present in several bioclastic levels, while Brachiopods, although not abundant, are also present.

Regarding the age of the bioclastic deposits and sands, isotopic analysis results (87Sr/86Sr ratio) of 12 shelly samples, indicate ages between 5.7 Ma and 1.5 Ma, that is, from the Upper Miocene (late Messinian) to the Pleistocene (Table 1). In the section 5 (Fig. 5), an *Amusium cristatum* shell provided an age of 4.25 Ma (early Pliocene) (Table 1), while in section 4 (Fig. 5), fossils from bioclastic sands have yielded an age of 4.4 Ma (Zanclean, early Pliocene).

**Lithofacies types**

In the Pliocene deposits have been distinguished five lithofacies types (Figs. 7 and 8, Table 2).

(I). Muddy sands with pectinids: Yellowish silty sands containing pectinid shells, graded bedding, cross-bedding and burrows (Fig. 8A). Hydroplastic structures (fluid escapes and convolute-beding) are also present. Sandstone and calcarenite with hummocky cross-stratification (HCS) are interbedded in the sands.

(II). Calcarenites: Sandy bioclastic grainstone with HCS, which are interbedded in the bioclastic sands (Fig. 8B), with erosive base and intense burrowing.

(III). Bioturbated fine sands with pectinids: Sandy-bioclastic grainstones with pectinid and oysters, interbedded with calcarenites (Figs. 8C).

(IV). Shelly conglomerates: Well-cemented or no-cementated layers of sandy-gravelly-bioclastic-rudstone, with shells of oysters, pectinids, gastropods, bryozoans, echinoderms and benthic foraminifera (Fig. 8D).

(V). Aljibe sandstone blocks: Discrete group of sub-spherical and rounded boulders of quartzarenite from the Aljibe For-
Fig. 5- Stratigraphic sections from 3 to 6 (Legend in Fig. 4, Location in Fig. 3).
Fig. 6.- Stratigraphic sections from 7 to 10 (Legend in Fig. 4, Location in Fig. 3).
mation (Unit of Campo de Gibraltar, from Betic Mountain Range) (Fig. 8E), which are interstratified with sands and calcarenites.

**Petrography of boulders and clasts**

From their petrographic characteristics, different types of clasts have been distinguished:

**Quartzarenite boulders:** These are sub-spherical and rounded blocks of 0.3 to 0.7 m in size, which are present in the upper part of section 10 (Figs. 6, 8 and 9). Those are bioclastic to feldspathic litharenite. The microfacies show a 60-65% content of quartz, 10-15% of feldspars and 30-35% of calcareous fragments and cement (Fig. 9D). The calcareous fragments include fragments of bryozoans, echinoderms, bivalves, foraminifers, calcispheres, ferruginous cemented fine-grained sandstone and muscovite. Their petrographic features are similar to the Aljibe sandstones (Campo de Gibraltar Units), which must be the source rock. The outcrops have local character, since they depend on the proximity of Aljibe sandstone outcrops (Figs. 2, 6 and 8).

**Pliocene calcarenitic clasts:** They are pebbles of 10 to 20 cm in size, with greyish white to blue colours, ellipsoidal shape, well-rounded surfaces, and bioturbation marks (Fig. 9). Two types are distinguished: 1) clasts with microfacies of intraclastic grainstone-packstone, quartz grains, ferruginous sandstone, glauconite grains, foraminifers and calcispheres (Figs. 9A and 9B); 2) clasts with microfacies of sandy bioclastic-intraclastic rudstone-grainstone, recrystallized bivalve fragments, bryozoans, foraminifers, ostracodes, quartz and glauconite (Fig. 9E). Both types of clasts have microfacies similar to the calcarenitic layers interbedded in Pliocene sands.

**Discussion**

**Depositional processes**

The results suggest that the entire Pliocene deposits were deposited in shallow marine and coastal environments. The fossil content and the variety of species present in the deposits, indicate a conditions of waters warmer than the Present day and Pleistocene (Monegatti and Raffi, 2007). According to the energy and the involved hydrodynamic processes, the lithofacies are grouped into three types (Table 2):

**Low-energy facies:** The deposits show lithofacies of sandy mud, muddy sand and fine sand. Structures such as graded bedding, parallel lamination, planar cross-bedding and bioturbation marks are also present. The lithofacies type I is representative, being present in the lower part of the sections (Figs. 4, 5 and 6). The facies indicate low-energy environments (Table 2), where the prevalent calm conditions favour the settling of silt and clay. In spite of the dominance of fine sediments, the sedimentary structures indicate that a part of the sediment was also transported as bed load (fine and medium sand). Later the sediments were deposited and bioturbated by vertical burrows in subtidal environments.

**High-energy facies:** These deposits have siliciclastic or bioclastic nature, coarse grain size, erosional base, and wealth of sedimentary structures, such as, upper flow-regime, parallel lamination, imbricated clasts, graded bedding, cross-stratification, trough cross-stratification, HCS, and reactivation surfaces (Fig. 8B and Table 2). The most representative lithofacies are the types II and III (calcarenites).

**Very high-energy deposits:** These are represented by siliciclastic or bioclastic gravel accumulations. They have erosional base, with irregular top, graded bedding, cross-bedding, minor inner erosional surfaces, and imbricated clasts and shells (Fig. 6). Most of the mollusc shells are fragmented, while others are intact, and occasionally with articulated valves. The most representative lithofacies is the type IV (Pliocene shelly conglomerate) (Fig. 8E and Table 2).

A special deposit are the Aljibe sandstone boulders (lithofacies V), which are inter-stratified in the Pliocene fine sands (Figs. 8E and Table 2). They are allochthonous boulders originating from the Betic Mountains, whose shape and size is controlled by the thickness of the original beds and fracture directions. The high sphericity and round-
ness of the boulders indicate that they were alternately eroded by successive fluvial, littoral and marine processes. The boulders were re-mobilized and transported seaward by return currents generated by very high-energy oceanographic or meteorologic processes, and deposited in shallow marine environments, such as the inner continental shelf (Fig. 10).

**Environments and hydrodynamic agents**

The fossil content and the lithofacies suggest that the Pliocene materials were deposited between the inner continental shelf and the foreshore, under warm climatic conditions, such as indicates the presence of abundant fauna (Monegatti and Raffi, 2007). The highest biodiversity in the study area was reached between the upper Messinian and the early Pliocene, between 5.6 and 5.3 Ma (Monegatti and Raffi, 2007), which is the time interval in which a greater number of genera and species appears. These data are largely consistent with the models of climatic distribution and diversity from Monegatti and Raffi (2007) and Marques da Silva et al. (2010). According to this information, in the latitude areas such as the present Gulf of Cadiz, the biodiversity gradient was increased at the end of the Miocene, when the boundary between the subtropical and tropical zones was located at higher latitudes than at present, with more penetration of warm water northward, and a greater extension of the subtropical faunas along the North Atlantic coasts (Monegatti and Raffi; 2007; Williams, 2012). 3 Ma ago, an Earth cooling caused significant climatic and oceanographic changes that led to the migration to the South of the boundary between subtropical and tropical areas, reaching latitudes of the southern Portugal, with the subsequent decrease in biodiversity in these areas. This situation remained until 2.7 Ma ago, i.e. until the beginning of the Pleistocene (Monegatti and Raffi, 2007; Marques da Silva et al., 2010).

Under a depositional viewpoint, the facies features show important flow regime fluctuations, from low-energy environments, represented by very bioturbated muddy sands, to medium and high-energy environments, represented by

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**Table 2.** Pliocene lithofacies.

<table>
<thead>
<tr>
<th>Lithofacies</th>
<th>Energy</th>
<th>Processes</th>
<th>Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Yellow muddy fine sands</td>
<td>L</td>
<td>Fair-weather and tidal</td>
<td>Off-shore (neritic) and distal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>currents</td>
<td>estuarine</td>
</tr>
<tr>
<td>II Calcarenites</td>
<td>H</td>
<td>Storm-weather and rip-currents</td>
<td>Subtidal-shoreface (litoral)</td>
</tr>
<tr>
<td>III Bioturbated fine sands</td>
<td>H</td>
<td>Storm-weather and rip-currents</td>
<td>Off-shore (neritic) or shoreface</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(litoral)</td>
</tr>
<tr>
<td>IV Shelly conglomerate</td>
<td>VH</td>
<td>Major storm or tsunami</td>
<td>Shoreface (litoral)</td>
</tr>
<tr>
<td>V Aljibe sandstone boulders</td>
<td>VH</td>
<td>Major storms or tsunami</td>
<td>Shoreface (litoral)</td>
</tr>
</tbody>
</table>

L. - Low-energy  H. - High-energy;  VH. - Very high-energy
PLIOCENE LITHOFACIES WITHIN THE MARINE GEOLOGIC RECORD FROM THE CADIZ BAY (SW SPAIN):
ENVIRONMENTS AND PROCESSES

Fig. 8.- Pliocene lithofacies: A) Yellow muddy sands with pectinid shells and bioturbated silty fine sands; B) Calcarenites; Alternation of bioturbated silty sands and calcarenite beds with HCS; C) Bioturbated yellow muddy sands; D) Shelly conglomerates; E) Aljibe sandstone boulders interstratified in Pliocene sands and calcarenites.
bioclastic sands and calcarenites. Three types of environments and depositional processes are differentiated: a) Protected shallow environments, b) Inner continental shelf, c) Storm layers (tempestites), and d) Event layers.

a) Protected shallow environments: Low and moderate-energy sediments, mostly represented by bioclastic silty-fine sands. The calm conditions favored the deposition processes from the suspension. The calm stages were interrupted by storm episodes, represented by thin calcarenite layers. During the calm periods, both sands and tempestites were subjected to an intense bioturbation by action of subtidal marine organisms.

b) Inner continental shelf: These are bioclastic and siliciclastic sands with cross-lamination, and interbedded sandstone and calcarenite with HCS. The materials were deposited in open coastal environments, from the foreshore to the shoreface, and they are constituted of massive accumulations of bivalve mollusk shell fragments.

c) Storm layers (tempestites): These are high-energy deposits, being represented by calcarenites interbedded in the...
Pliocene sands. These layers show progradational character, being more frequent and thicker towards the top of the sections, consequence of their deposition in a full time shallow environment. This shallowing process was probably caused by an elevation of the Betic Mountain Range, which resulted in marine regression during the late Pliocene (Benkhelil, 1976; Estevez and Sanz de Galdeano, 1980).

d) Event deposits: These represent an important part of the Pliocene record. They are deposits of very high-energy, which show important differences with the seasonal deposits. The interbedding of these deposits into the bioclastic sands and calcarenites, suggests that they are event deposits, very different from the characteristic storm-layers (Shanmugam, 2006, 2008; Gutierrez-Mas et al., 2009a and b; Gutierrez-Mas and Mas, 2010). They are a consequence of the action of very energetic oceanographic processes, which developed their maximum effectiveness in shallow marine environments (Aigner, 1985).

But, which agent was able of producing such deposits? The depositional features indicate the action of strong flows and a high conservation potential of the deposits, due to its deposition in depths greater than the wave base level (Fujino et al., 2006; Massari et al., 2009). They are represented by massive accumulations of bivalve mollusk shells and large boulders, which can only be generated by greater waves of major storms and tsunamis. Both processes are able to generate deposits similar, sometimes difficult to differentiate, especially in wave dominated shallow environments (Shanmugam, 2006, 2008; Gutierrez-Mas et al., 2009a and b; Kortekaas and Dawson, 2007; Kennedy et al., 2007, Morton et al., 2007). This problem is especially pronounced when we study older deposits, which have lost some depositional features, while the historical records and meteorological data are not available. If the lithofacies are not enough to differentiate them, other additional criteria should also be taken into consideration (Dawson, 2004; Dawson and Stewart, 2007; Dott, 1996; Nanayama et al., 2000; Goff et al., 2001; Bryant and Nott, 2001; Nott, 1997, 2003). In this sense, the study area is located near the Eurasian and African plates boundary, where most recent historical earthquakes and tsunamis are documented (Udías et al., 1976; Campos, 1991; Ribeiro, 1995, Luque et al., 2001, 2002, Gutscher et al., 2006, Silva et al., 2005, Gracia et al., 2006, Morales et al., 2008), while meteorologic data points to the possibility that these depositional events may have been generated both by the action of tsunamis as major storms, such that either can totally be discarded (Gutierrez-Mas et al., 2009a and b).

Conclusions

The Pliocene marine records from Cadiz Bay (SW Spain) have been studied with the aim of establishing the depositional trends that characterized the sedimentary filling in this sector of the Guadalquivir basin. During the Pliocene the zone was occupied by a sea whose shoreline would be similar to the present, but shifted to the NE, so that the depth of the Pliocene Sea would increase toward SW. During the Pliocene there was great faunistic diversity, represented by abundant fossil remains of marine organisms typical of tropical and subtropical waters, mainly bivalve molluscs. The maximum Pliocene biodiversity was acquired in the Gulf of Cadiz 5.5 Ma ago, time when the boundary between tropical and subtropical zones was farther north than the present-day. The decline in biodiversity, evidenced by the disappearance of many species and the migration to southern boundary of the limit of the tropical and subtropical areas, happened 3 Ma ago, indicating the onset of a cold period that points out the beginning of the Pleistocene.

The Pliocene lithofacies indicate shallow marine environments, mainly neritic and littoral. According to the sedimentary features, several lithofacies types are differentiated, which indicate important variations in the depositional regime, a consequence of the alternation of seasonal deposits, calms and normal storms, and very high-energy events. The sedimentary features reflect the action of very high-energy flows. The event deposits show anomalous depositional features with respect to the over- and underlying sedimentary beds, with abrupt facies changes, erosional bases, internal erosion surfaces, and allochthonous fossils.

The repetition in the stratigraphic sections of massive bioclastic accumulations and large boulder deposits, which interrupt the seasonal deposits, suggests the action of very-high energy processes, such as major storms or tsunamis. The proximity of the area to the Eurasian plate boundary and Africa, and the historical record of earthquakes and tsunamis that occurred in the Gulf of Cadiz, to suggest that the option tsunamigenic to explain these bioclastic accumulations should not be discarded.

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