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LITHOFACIES AND ORIGIN OF A DEPOSIT OF LARGE BOULDERS IN THE COAST OF CADIZ (SW SPAIN). EVIDENCE OF AN EVENT OF HIGH ENERGY DURING THE PLEISTOCENE

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Abstract: A deposit of large boulders, interstratified in Pliocene and Pleistocene sediments has been studied in the coast of Cádiz (SW Spain). The deposit is constituted by conchiferous large boulders, medium and small size clasts and shell fragments. The facies indicate a marine origin of the deposit, and the re-worked character of the sediments and fossils, which were deposited in a high energy marine environment, previously to that they were mobilized and re-deposited by action of a high energy directional flow.

The most appropriate depositional mechanism to explain the formation of this deposit, is the action of big waves, generated by a great energy marine event, probably a very strong storm or a tsunami. The tsunami action is probable since the area is located in a seismically active area, near to the limit of the African and Euro-Asian plates, at the same that several earthquakes and tsunamis are historically documented in the Cadiz coast. The event should happen during the early Pleistocene, coincident with a *highstand* stage. The isotopic analysis by means of the Method 87Sr/86Sr carried out, has established an age interval from 1.35 to 1.1 million years, corresponding to the Calabriense (Lower Pleistocene).

Key words: Cadiz Gulf, Large boulders, High Energy Deposit, Pleistocene

Resumen: Se ha estudiado un depósito de grandes bloques conchíferos, que se encuentra interestratificado en formaciones Plioceno-Pleistocenas del litoral de Cádiz. El depósito está constituido por grandes bloques conchíferos, clastos de mediano y pequeño tamaño y fragmentos de conchas. Las facies indican el origen marino del depósito y el carácter retrabajado de los sedimentos y fósiles, los cuales se depositaron en un medio marino de alta energía, antes de que éstos fueran removilizados y redepositados por la acción de flujos direccionales de alta energía.

El mecanismo más adecuado para explicar la formación de este depósito de grandes bloques, es la acción de grandes olas, generadas por un evento marino de gran energía, probablemente un fortísimo temporal o un tsunami. La acción tsunamigénica es probable, desde el momento en que la zona se encuentra en un área sísmicamente activa, cercana al límite de las placas africana y euroasiática, mientras que, varios sismos y tsunamis están históricamente documentados en la costa de Cádiz. El evento debió de suceder al inicio del Pleistoceno, durante una etapa de alto nivel del mar. El análisis isotopico mediante el Método $^{87}Sr/^{86}Sr$, ha establecido un intervalo de edad para el evento de 1.35 a 1.1 millones de años, correspondiente al Calabriense (Pleistoceno inferior).

Palabras clave: Golfo de Cadiz, Grandes bloques, Depósitos de alta energía, Pleistocene

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A deposit of large boulders within Plio-Pleistocene units has been studied in coastal outcrops close to the Cadiz Bay (SW Spain) (Figs. 1 and 2). It is a singular sedimentary body composed of clasts, shells and large shelly boulders, which show important differences regarding to the underlying and overlying deposits (Figs. 3, 5 and 8A). Similar deposits have been described in the coasts of Chile (Paskoff, 1991), Scotland (Dawson *et al*., 1988), Caribe (Hearty, 1997 and 2007 McMurtry et al., 2007), Cadiz (Luque *et al*., 2001 and 2002; Whelan and Kelletat, 2005; Gracia *et al*., 2006; Gutierrez-Mas et al, 2009 a and b), Japan (Nanayama *et al*., 2000; Fujiwara and Kamataki, 2007; Goto *et al*, 2010a and b), and Mediterranean (Kelletat and Schellmann, 2002; Morhange et al., 2006; Vött, et al., 2006; Maouche *et al*., 2009).

The study and interpretation of these coastal boulder accumulations presents some questions concerning the involved depositional mechanisms (Hearty, 1997; Bryant and Nott, 2001; Clifton, 2002). Nevertheless, many of these deposits are attributed to the action of great waves generated by meteorological or geological causes, just as, cyclones or tsunamis respectively (Paskoff, 1991; 1988, 1996; Hearty, 1997; Castle, 2000; Satake *et al*., 2002; Lorang, 2000; Goff *et al*., 2001; Bryant and Nott, 2001), although other hydrodynamic processes could also are involved. On the other hand, the studied boulder deposit is situated in the lower section of a transgressive sequence, hence that they can be also considered as a basal conglomerate, representative of a transgresive lag (Clifton, 2002). Neverthrless, the facies indicates the action of strong directional flows. In this sense, at the moment it is broadly accepted that deposits of high energy events, just as tsunamites, tempestites or turbidites, are also part of the stratigraphic record (Einsele *et al*., 1991; Aigner, 1985).

A similar deposit was described by MacPherson (1872), in a Plio-Pleistocene outcrop to the Southwest of Cadiz located, which is on a well cemented shelly layer 0.5 m thick with similar lithology to the overlying boulders. This author considered that the boulder deposit was a consequence of great geologic diastrophisms, without to specify the processes. Gutierrez-Mas *et al*. (1991), considered that the boulder deposit was the result of the boulder downfall from a coastal cliff, in a geologic setting controlled by normal faults.

In spite of the previous interpretations, the deposit fabric indicates other process, just as, the action of strong directional flows. In this work the lithofacies has been analyzed and interpreted, the sediments dated, and the depositional mechanism, environment and age established.

Geological setting

The study zone is located in the SW margin of the Guadalquivir Basin, and to the West of the Betic Mountain Range (Figs. 1 and 2). Several units are differentiated (Viguier, 1974): 1) A lower unit of pre-orogenic materials from the External Zones of the Betic Mountain; 2) Above, syn-orogenic materials are deposited, they represented by calcarenites and marls with olistolithic boulders; 3) post-orogenic deposits are represented by two formations separated by an unconformity (Viguier, 1974): a lower one of Upper Miocene marls and calcarenites, and an upper one of

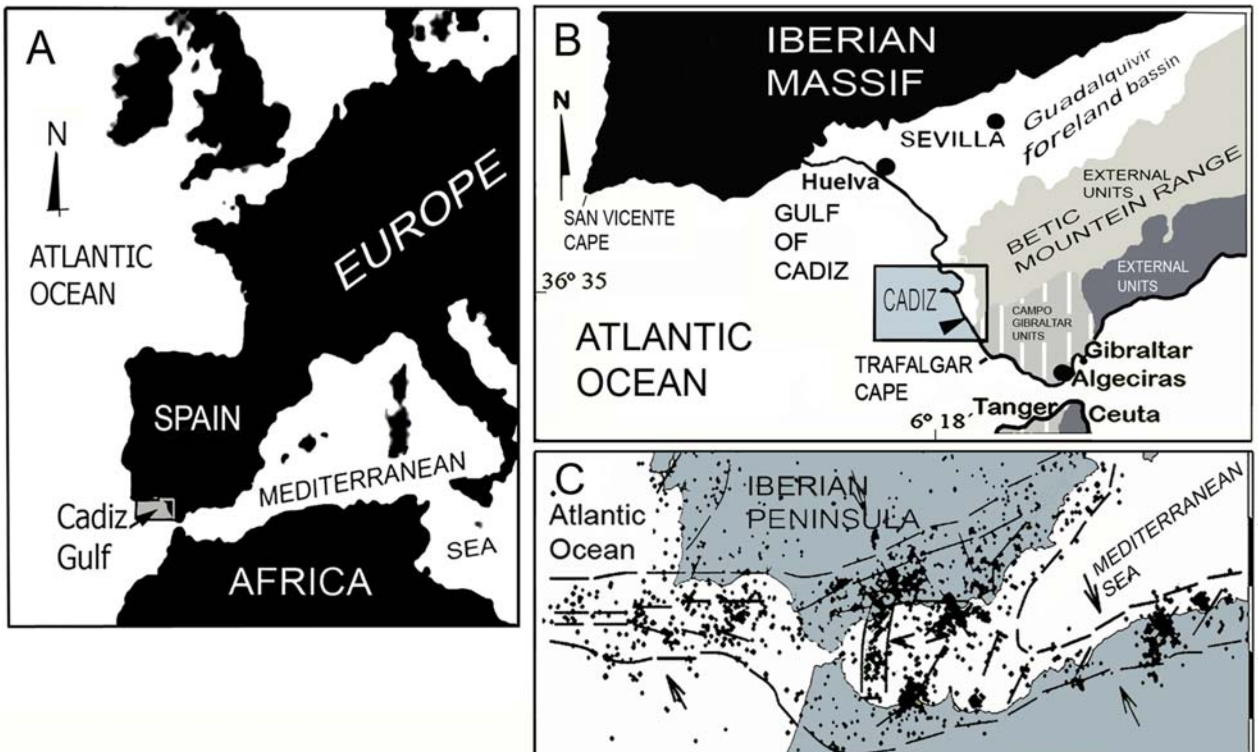

Figure 1.- A) Geographic location; **B)** Geological setting (modified from Udías *et al*., 1976; Mezcua *et al*., 1983; Campos, 1992 and Gutierrez-Mas *et al*, 2003).

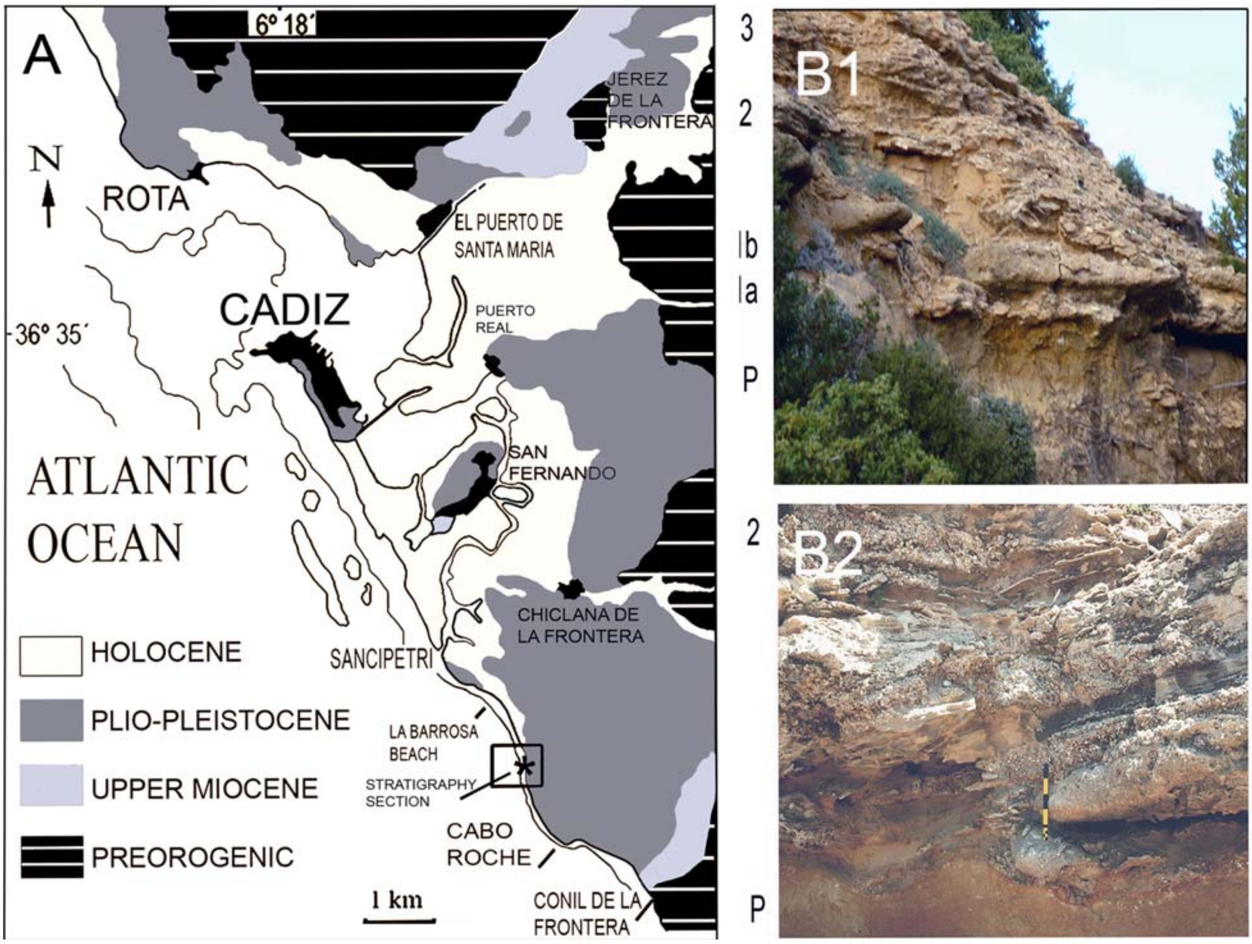

Figure 2.- **A)** Geological map and outcrop location (modified from Gutierrez-Mas *et al.*, 1991); **B1** and **B2)** View of the outcrop (P: Pliocene; 1a: clasts; 1b: boulders and clasts; 2: sand and sandstone with hummocky cross-stratification; 3: sand and sandstone with *Thalassinoides.*

Pliocene to Pleistocene calcarenites and bioclastic conglomerates.

Two tectono-stratigraphic stages are recognized: an extensional phase from Upper Miocene to Lower Pliocene and a compressive from Upper Pliocene to Pleistocene (Viguier, 1974; Benkhelil, 1976; Estevez and Sanz de Galdeano, 1980; Sanz de Galdeano and Lopez Garrido, 1991; Cloething *et al*., 1992).

Methods

The field work consisted of the exploration of outcrops, stratigraphic studies, facies analysis and sediment sampling. The sedimentological analysis consisted of the identification and description of facies and determination of specific sedimentary features. The structures were classified and measured to deduce the deposit environment and the involved dynamic agents.

Microscopic analysis of boulders and clasts were carried out, to determine the petrographic features of the deposits and lithological similarities with units present in near outcrops, with the goal of to establish the provenance of the boulders and clasts.

The method of the $^{87}Sr/^{86}Sr$ Isotopic Relation Analysis was used to determine the absolute age of the carbonated samples. The analysis is based in the variation of the average $^{87/86}Sr$ ratio in the seawater (Farrell *et al*., 1995; McArthurey *et al*., 2001; Kuhlmann *et al*., 2006). Samples were analysed in the Geochronology and Isotope Geochemistry Laboratory of the *Complutense University of Madrid*. The measures were corrected of possible ^{87}RB interferences, and normalized to the $^{87}Sr/^{86}Sr = 0.1194$, regard to possible masses fractionation during the analysis.

To establish the sample age, the standard seawater curve marine from McArthurey *et al*. (2001), was used. The cronostratigraphic position was established from the International Stratigraphic Chart 2004 (Gradstein *et al*., 2004). Finally, a reliability test was carried to correct unit age deviations, caused by presence of allochthonous and recrystallized fossils (Table I and Fig. 8).

Results

The stratigraphic sections show a succession of detritic and bioclastic units, deposited in neritic and littoral environments. The best outcrop is located in a coastal creek at south of the *La Barrosa* beach (Chiclana de la Frontera) (Figs. 1, 2 and 3). It is to a distance of 300 m from the current sea-shore, and 15 m height on the average sea level. The outcrop dips 10º northward, and it is affected by several joint families. From base to top, a progressive rotation of the joint orientations is observed, prevailing the N–S and NNW–

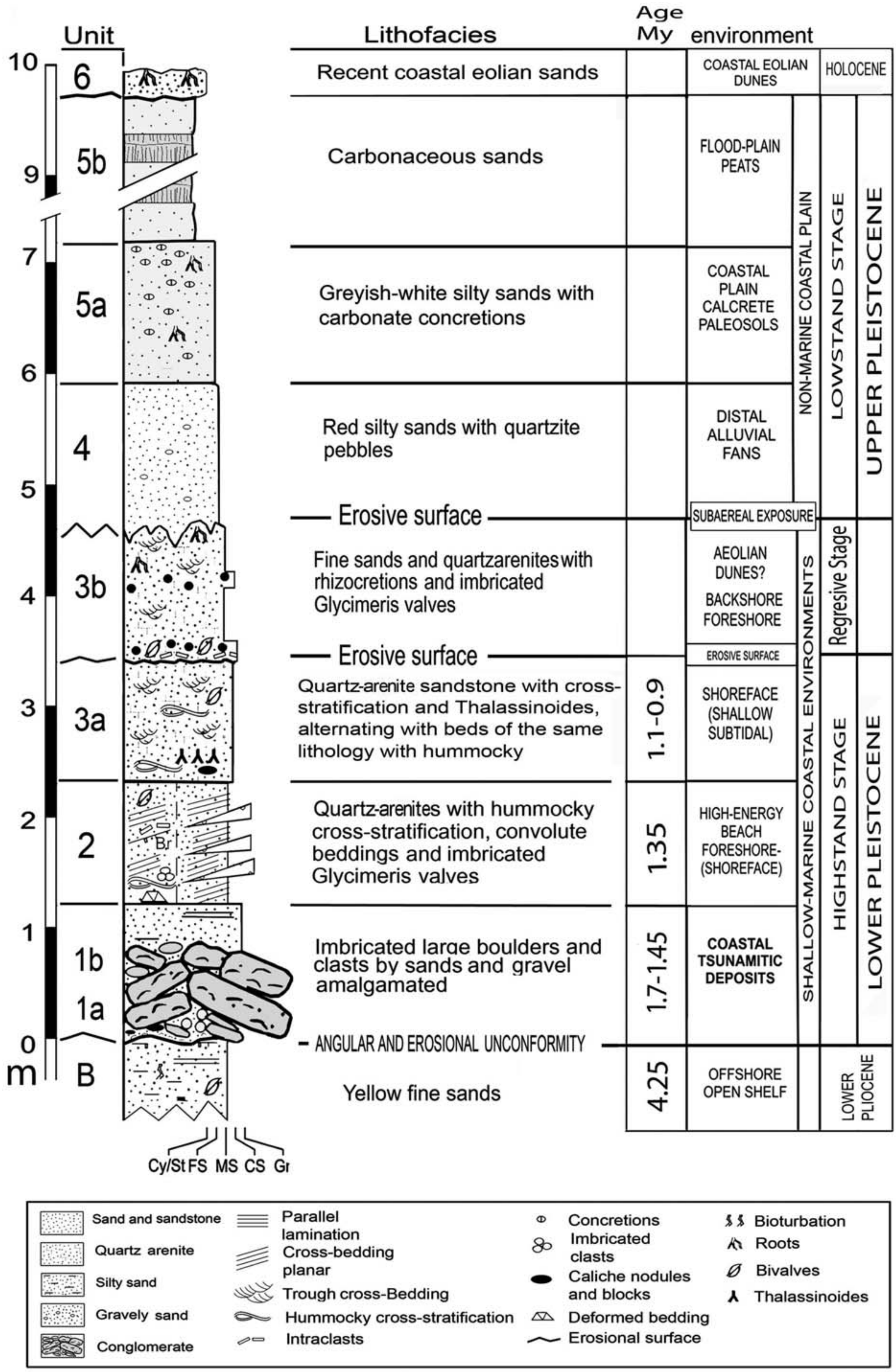

Figure 3.- Detailed stratigraphic section (Location in Fig. 2).

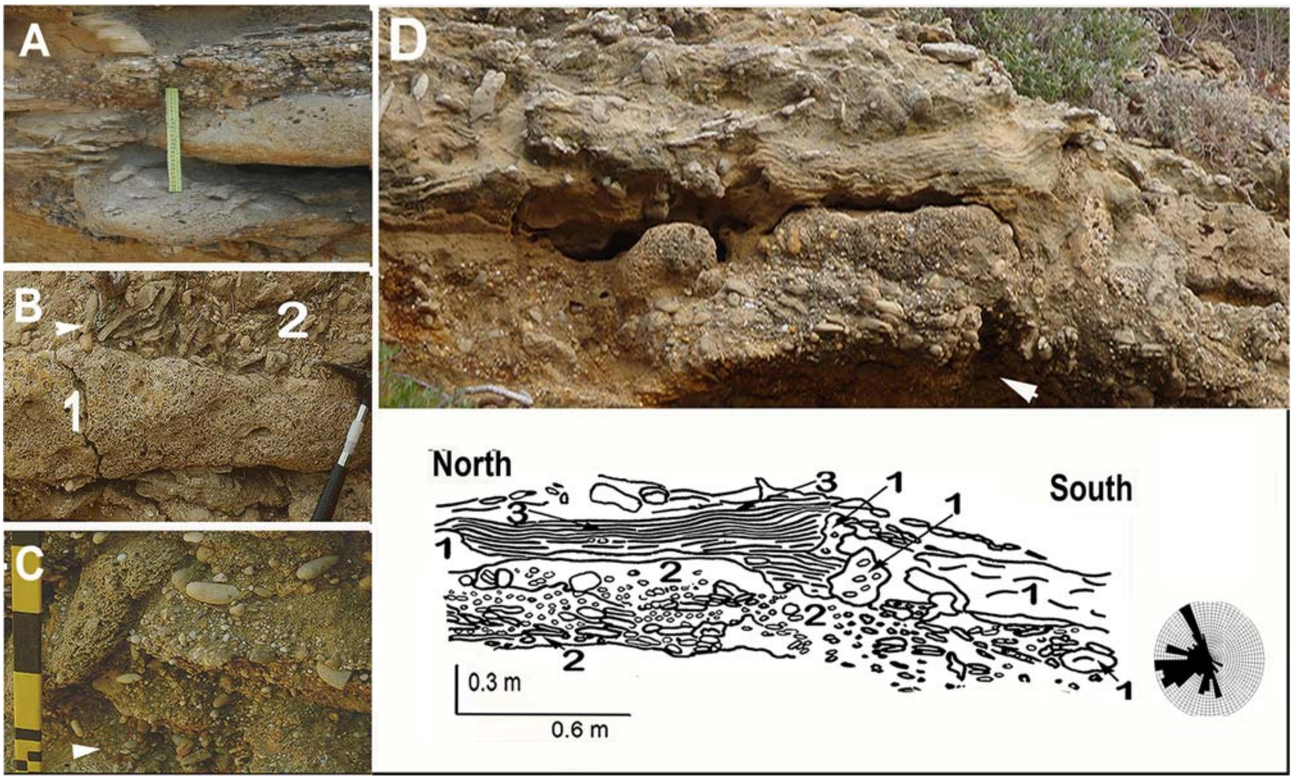

Figure 4.- View of the clasts from the basal unit. Arrows indicate the flow direction. **A)** imbricate medium clasts; **B** y **C)** 1- large boulder, 2. imbricate small and medium clasts; **D)** 1. imbricate small clasts, 2. large boulders, sands and sandstones with hummocky cross-stratification.

SSE orientations, although NE-SW, E–W and ESE–WNW directions are also present.

Stratigraphic section and lithofacies

The base is constituted of yellow fine sands with pectinid shells and well preserved shells of *Amusium cristatum*. On the basal sands, a well remarkable erosive surface appears, it is recovered by clasts and mollusc shells (Figs. 3 and 4). On the erosional surface, several units are differentiated:

Unit 1. From 0.8 to 1.6 m of a conglomerate of large boulders, gravelly-sandy matrix and erosional base. Two sub-units are distinguished (Figs. 4 and 5):

1a. 0.7 m of gravelly-sands, mollusc shells and imbricate clasts with cross lamination, convolute bedding and erosional base. Small and medium clasts show strong imbrication, with slopes oriented towards the NNW and SW.

1b. 0.9 m of a heterolithic conglomerate with overlapped boulders and very imbricated clasts. The boulder size is from 0.1 to 0.6 m, although some are bigger than 5 m. The largest boulders are bioclastic (calcirrudite), while the smallest are calcarenitic. Quartzite pebbles are also present.

Unit 2. 1.2 m of cemented and uncement sands with imbricate glycimeris shells, hummocky cross-stratification, convolute bedding, parting lineation, beachrocks and angular intraclasts (Figs. 3, 4 and 5). The sand layers present parallel lamination and hummocky cross-stratification. On the hummocks surface, parting lineations appear with orientation NE–SW and E–W. The unit ends with a layer of cross-laminated gravel. Southwards, sandstones and sands are laterally truncated by an alternating of conglomerates and sands of 0.8 m thick.

Unit 3. Sands and sandstones with *Thalassinoides*. Above a bed of caliche of 5 cm thick, and an alternating of quartz sand and sandstone with trough cross-stratification. Two sub-units are distinguished (Figs. 3 and 4):

3a. 1.1 m of a quartz-arenite sandstone bed, with quartzite pebbles and rough cross-stratification with *Thalassinoides*, alternating with beds of the same lithology with hummocky crossstratification (Fig. 4).

3b. 1.2 m of a fine uncemented sand with cross-stratification, which alternates with quartz-arenite sandstone with root traces. The unit finishes with a visible and irregular erosional surface.

Unit 4. Above, fossilizing the paleorelief developed on the previous unit, red silty sands with quartzite pebbles appear (Fig. 3).

Unit 5. 1.4 m of greyish-white muddy-sands, with carbonate concretions. Above, 2.5 m thick of a greyish-black carbonaceous silty-sands.

Unit 6. Holocene and recent eolian sands.

Lithology of boulders and clasts

Boulders and the other clasts have detrital nature, they are fragments of pre-existing sedimentary rocks, generated in littoral and neritic environments. From their petrography and morphology, different types are differentiated.

a) The largest and characteristic boulders have shelly nature, angular or rounded ellipsoidal shape, yellowish-brown colour, surface, and

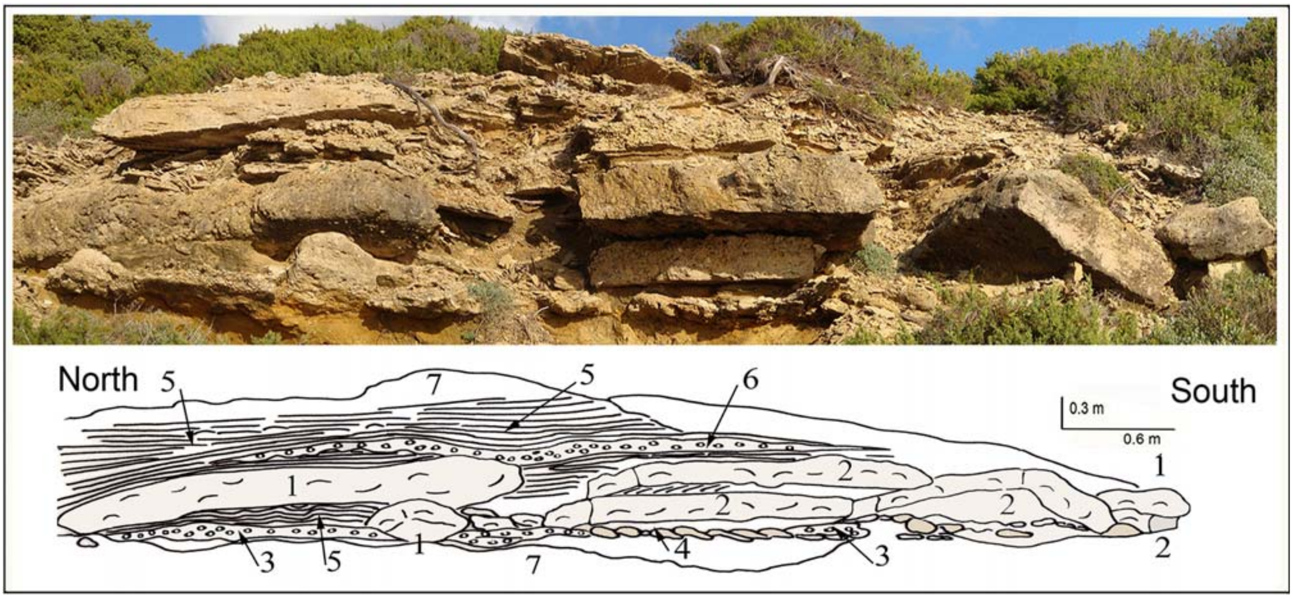

Figure 5.- General view of the large boulders deposit. **1)** rounded large boulders; **2)** angular large boulders; **3)** basal erosive surface; **4)** basal Imbricate mediun and small clasts; **5)** sand and sandstone with hummocky cross-stratification; **6)** alternance of conglomerates and sands; **7)** basal Pliocene sands.

bioturbation superficial marks. They are composed of a well-cemented mixture of sand, pebbles and shells of oysters, pectens, chlamys, glycimeris and rhodolites (Figs. 3, 5 and 10). Northward, the rhodolite contents decreases, in favour of an increase of detrital and bioclastic elements, while southward the rhodolitic boulders are predominant (Fig. 6B and C). Microfacies consist of sandy-gravelly bioclastic rudstone composed of oyster and pectinids fragments, bryozoans, echinoderms, benthic foraminifers and quartz and glauconitic grains (Fig. 7A).

b) Calcarenitic clasts are smaller, from 10 to 20 cm, with ellipsoidal shape, greyish-white to blue colour, well rounded surface and bioturbation marks. The clasts show two microfacies types: one consists of very sandy, small-sized intraclastic grainstone-packstone with quartz pebbles and ferruginious sandstone. Quartz and glauconite grains, foraminifers and calcispheres are also frequent (Fig. 11C).

c) Other small clasts are porous limestone fragments of brown colour, and size from 1 to 10 cm (Fig. 10). The microfacies is compound of sandy-gravelly bioclastic-intraclastic rudstone-grainstone, fragments of oyster and pectinid shells and benthic foraminifers, bryozoans, echinoid, serpulids and glauconitic rhodolites, quartz and glauconite.

Material age

The $^{87}Sr/^{86}Sr$ isotopic analysis indicates an age to the basal fine sands with *Amusium* of 4.25 My BP (Lower Pliocene) (Table I and Figs. 3 and 8).

Shelly fragments included in well cemented large boulders (unit 1b), provided a $^{87}Sr/^{86}Sr$ isotopic age rank from 1.7 to 1.45 My (Lower Pleistocene).

Glycimeris shells interbedded in sands and sandstones from unit 2, immediately on the large boulder unit (1b), provided a age of 1.35 My (Lower Pleistocene) (Table I and Fig. 7).

Shells in sands and sandstone from the unit 3, provide an isotopic ages from 1.1 to 0.9 My BP (Lower Pleistocene).

Provenance of boulders and clasts

Boulders and clasts have different lithology and age, consequence of their provenance from several source rocks, present in near Plio-Pleistocene outcrops. The large calcirruditic boulders coming from the erosion of a thin and well-cemented shelly conglomerate present in some outcrops, which show microfacies coincident with the boulders (Figs. 9 and 10). This conglomerate layer is not easily visible, due to the previous erosion processes, which caused its fragmentation and dispersion around of the outcrops, with similar layout to those that actually appears in the current coastal areas close to Cadiz (Figs. 9 and 10).

The small calcarenitic clasts have petrographic similarity with the calcarenitic storm layers interbedded in the basal Pliocene sands (Fig. 6A). The shape and size of these clasts are controlled by the layer thickness, from 10 to 20 cm, and vertical and lateral incisions caused by bioturbation (Fig. 6B). Other small porous calcarenitic clasts show petrographic and textural similarities to a Lower Pleistocene unit present in outcrops located an unit present in outcrops from Lower Pleistocene located to the south of the zone, from the Roche Cape lighthouse to Conil (Fig. 10).

Depositional mechanisms

The deposit shows a chaotic inner structure, with sandy-gravelly matrix, imbricate clasts, and overlapped large boulders, which indicate a high energy littoral

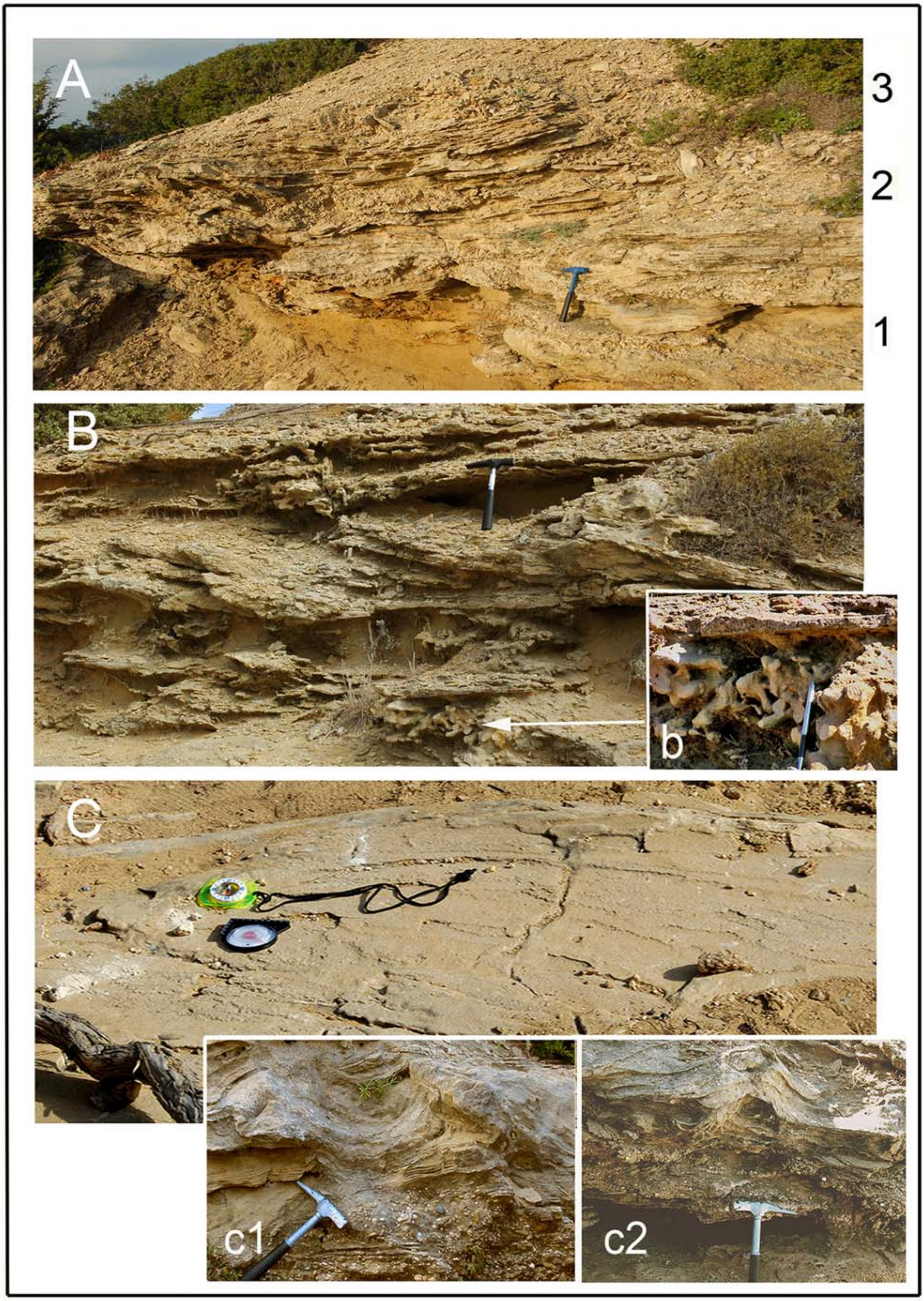

Figure 6.- **A)** Fine sands interbedded with crossbedded quartz-arenite sandstones (unit 3b). **B)** quartz-arenite sandstone with quartzite pebbles, rough cross-stratification and *Thalassinoides* (b) (unit 3a); **C)** Sands and sandstone with hummocky cross-stratification (C1 and C2, fluid escape structures on the hummock surface).

	Samples	$^{87}Sr/^{86}Sr$ ratio	Error	Millions years (My)	Stages	Reliability Test
9	*Cardium* in gravely sands	0.709162	5	0.4	Upper Pleistocene	** ●
8	*Pecten* in gravelly sands	0.709143	5	0.9	Lower Pleistocene	** ●
7	*Oyster* in gravelly sands	0.709129	6	1.1	Lower Pleistocene	** ●
6	*Glycimeris* in sandstones	0.709135	5	1.1	Lower Pleistocene	▲
5	*Glycimeris* sands and sandtone	0.709112	5	1.35	Lower Pleistocene	▲
4	Shell in calcirudite boulder	0.709106	6	1.45	Lower Pleistocene	▲
3	Shell in calcirudite boulder	0.709106	5	1.45	Lowe Pleistocene	▲
2	Shell in calcirrudite boulder	0.709095	5	1.7	Lower Pleistocene	** ●
1	*Amusiun cristatum* basal fine sands	0.709052	6	4.25	Lower Pliocene	▲

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

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

environment, where the continuous wave action could give rise to the formation of graded deposits and to erode the boulders and clasts. Nevertheless, the facies analysis also indicates the action of very energetic directional flows.

The only agents capable to mobilize these boulders are great waves generated by storms or tsunamis (Dawson *et al*., 1988; 1996; Nott, 2003; Bryant and Nott, 2001; Goff *et al*., 2001; Kennedy *et al*., 2007; Kortekaas and Dawson, 2007). But, due to the facies similarity, both deposit types, tempestites and tsunamites, can be sometimes muddled (Bryant and Nott, 2001; Shanmugam, 2006). Nevertheless, some differences can be established (Nanayama *et al*., 2000; Dawson *et al*., 1988, 1996; Dawson, 2004; Kortekaas and Dawson, 2007). Tsunamites extend much further inland than storm deposits, have an erosional base, are worse-classified and often contain soil and vegetable remains (Paskoff, 1991; Dawson et al., 1988, 1996; Nanayama et al., 2000; Dawson, 2004). In the studied case, those features are not sufficient to establish the depositional mechanis, and other criteria can be necessary to distinguish it (Cita and Aloisi, 2000; Shanmugam, 2006).

From a hydrodynamic perspective, the movilization and transport of large boulders require a specific wave height and energy-level thresholds (Nott, 2003; Maouche *et al*., 2009). Recent studies demonstrate that the impact of extreme storm waves is less effective than tsunami waves in the detachment and transport of large boulders (Maouche *et al*., 2009). To mobilize boulders of 20 Ton weight, storm waves of 16 m high are required, while these same boulders could be mobilized by tsunami waves of 4-10 m height. The tsunami waves only need to be a quarter the size of a storm wave to transport the same size boulder (Nott, 1997; Maouche *et al*, 2009). Tsunami waves of 12 m height can move boulders of up to 67 Ton weight (Nott, 2003; Whelan and Kelletat, 2005).

Thus, it is difficult to justify the formation of the studied large boulder deposit by the only action of storm waves, since many boulders exceed 10 Ton weight, and some reach up 25 Ton (Figs. 5, 6 and 9). A most energetic agent is required. From the previous data, that the tsunami waves are a most effective mechanism to transport large boulders that the storm waves is deduced, since they have a longer wavelength and energy quantity than the storm waves (Nott, 2003).

Other criteria in favour of the intervention of a tsunami are the geologic tectonic setting and the tsunami and earthquake historical record. In this sense, the zone is near to an active tectonic area, located at SW of the San Vicente Cape (Fig. 2), where recent geophysics study show the existence of active faults (Udias et al., 1976; Ribeiro, 1995, Baptista et al., 1996; Gutsher, 2005 and 2006), which could be the focus of several well documented earthquakes and tsunamis (Galbis, 1940; Udias *et al*., 1976; Ribeiro, 1995; Dawson *et al*., 1996; Luque *et al*., 2001; 2002; Silva *et al*., 2005; Gutierrez-Mas *et al*., 2009a and b). The most known, the tsunami that continued to the Lisbon earthquake (1st November 1755 AD), which razed the SW coast of the Iberian Peninsula (Udias *et al*., 1976; Campos, 1992; Ribeiro, 1995; Luque *et al*., 2001 y 2002).

Finally, we can conclude that the facies indicate the action of high energy flows, while the boulder size pointer to the tsunami wave as the best hydrodynamic option and a adequate depositional mechanism to explain the formation of the deposit. Moreover, the tectonic setting and the historical data, coincide to consider the tsunami action as the most likely agent.

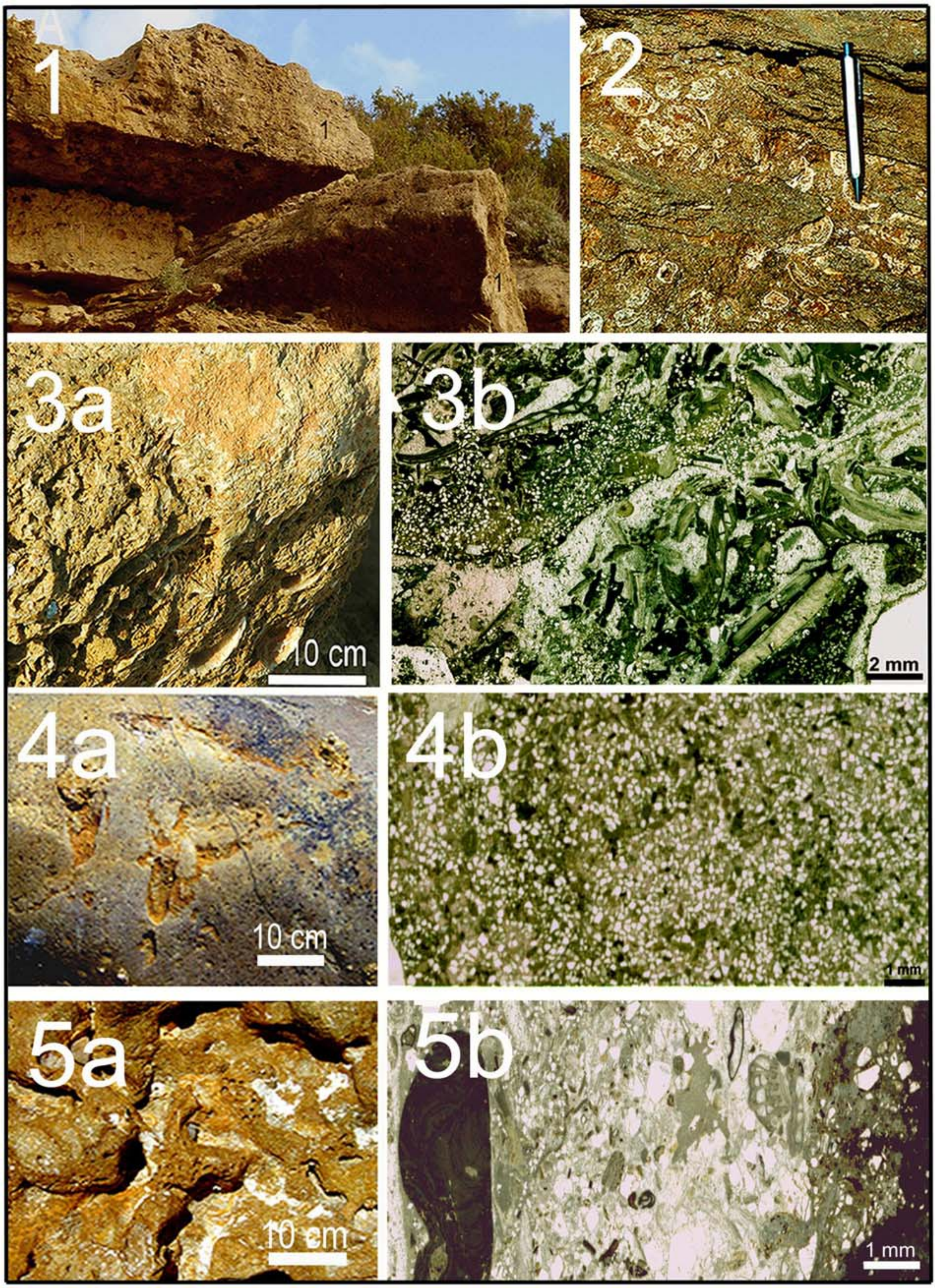

Figure 7.- **1)** Calcirruditic large boulders; **2)** Rhodolitic large boulder; **3a)** Detail of a calcirruditic boulder, and **3b)** Microfacies: sandy rudstone with oysters, bryozoans, echinoderms, forams, quartz and glauconitic crusts (bar=2mm); **4a)** Calcarenitic clast with bioturbartion marks, and **4b)** Microfacies: sandy intraclastic grainstone with ferruginous sandstone, forams, calcispheres, quartz and glauconitic grains (bar=1mm); **5a)** Porous calcarenitic clast, and **5b)** Microfacies of a Pleistocene calcarenitic: sandy-gravelly bioclastic rudstone with bryozoans, bivalves, coralline red-algae, echinoids spines, forams, quartz, glauconite and sandstone grains (bar=5mm).

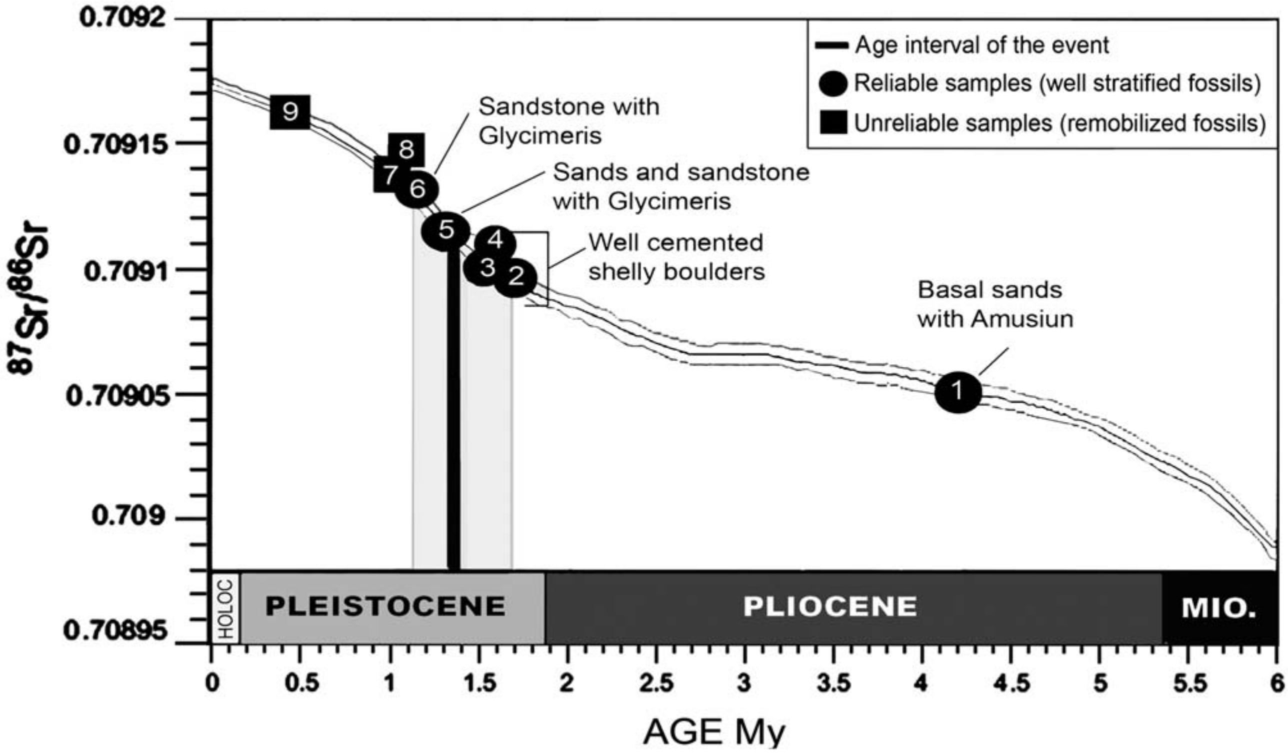

Figure 8.- Evolution curve of $^{87}Sr/^{86}Sr$ isotopic ratio values in seawater (modified from McArthur, *et al*. 2001), and carbonate sample ages from different units.

However, the storm wave action should not be totally discarded, because the meteorological waves were decisive agents that contributed to the erosion and transport of pre-existent sediments.

Deposit environment

The presence of fine sands with hummocky cross-stratification and imbricate mollusc shells, indicates a shallow marine environment affected by storm waves (Fig. 10). Large boulders of tabular shape and superficial bioturbation signs indicate previous erosive processes and presence of eroded pre-existing coastal cliffs is indicated by the composition of other clasts. The event should have occurred during a *highstand* stage, coincident with an interglaciar period or a coastal downlift, which facilitated the sedimentary deposition in this marginal sector of the Atlantic Ocean. The event altered the depositional regime of the affected environments, being the boulders, cobles and sands remobilized and redeposited. The flow direction can be deduced through the imbrication slope orientation of the clasts. The results indicate flows from the NW, W and SW, all them corresponding to open Atlantic water. The appeared variations could be caused by direction changes of the paleo-coast and continental margin, which caused changes in the propagation direction of the wave fronts.

After the event, the usual depositional regime was recovered, being the event deposit buried by fine sands with hummocky cross-stratification, which denote a shallow marine environment affected by waves, probably, the shoreface zone orthe inner continental shelf. More, the presence of *Thalassinoides* in an upper sedimentary layer, indicates a low energy stage, perhaps caused by a slight sea level rising. Later on, a still-stand stage followed by a sea level lowering gave place to a prograding stage and to the deposition of a regressive littoral sequence, represented by beach and coastal dunes facies with root traces, which concluded with the sub-aerial exposure of the zone.

Event age

The isotopic ages obtained from the $^{87}Sr/^{88}Sr$ ratios analysis, are concordant with the crono-stratigraphic ages provided by other authors to the Miocene and Pliocene units (Viguier, 1974; Aguirre, 1995) (Table 1 and Fig. 7). Nevertheless, to the Pleistocene, substantial differences are observed (Zazo, 1979; Lario, 1995), since the $^{87}Sr/^{88}Sr$ isotopic method provided oldest ages. These differences could be caused by presence of recrystallizated fossils, distinct sampled outcrops, or the different used isotopic method.

Respecting to the effectiveness of the $^{87}Sr/^{88}Sr$ isotopic method, some authors consider that the changes of $^{87}Sr/^{86}Sr$ ratio and age values could be caused by entrance in the depositional system of water masses of different temperature (Palmer and Edmond, 1989; Kuhlmann, 2004; Kuhlmann *et al*., 2006). In this sense, some questions concerning to the studied zone can be outlined. From the Messinian salinity crisis ending, with the sudden invasion by the Atlantic waters of the Mediterranean, the marine basin of the Gult of Cadiz has been affected by two important water masses, which have different salinity and temperature: the Surficial Atlantic Water Flow and the Mediterranean Out Flow (Villanueva and Gutierrez-Mas, 1994). Moreover, a seaward decrement of $^{87}Sr/$

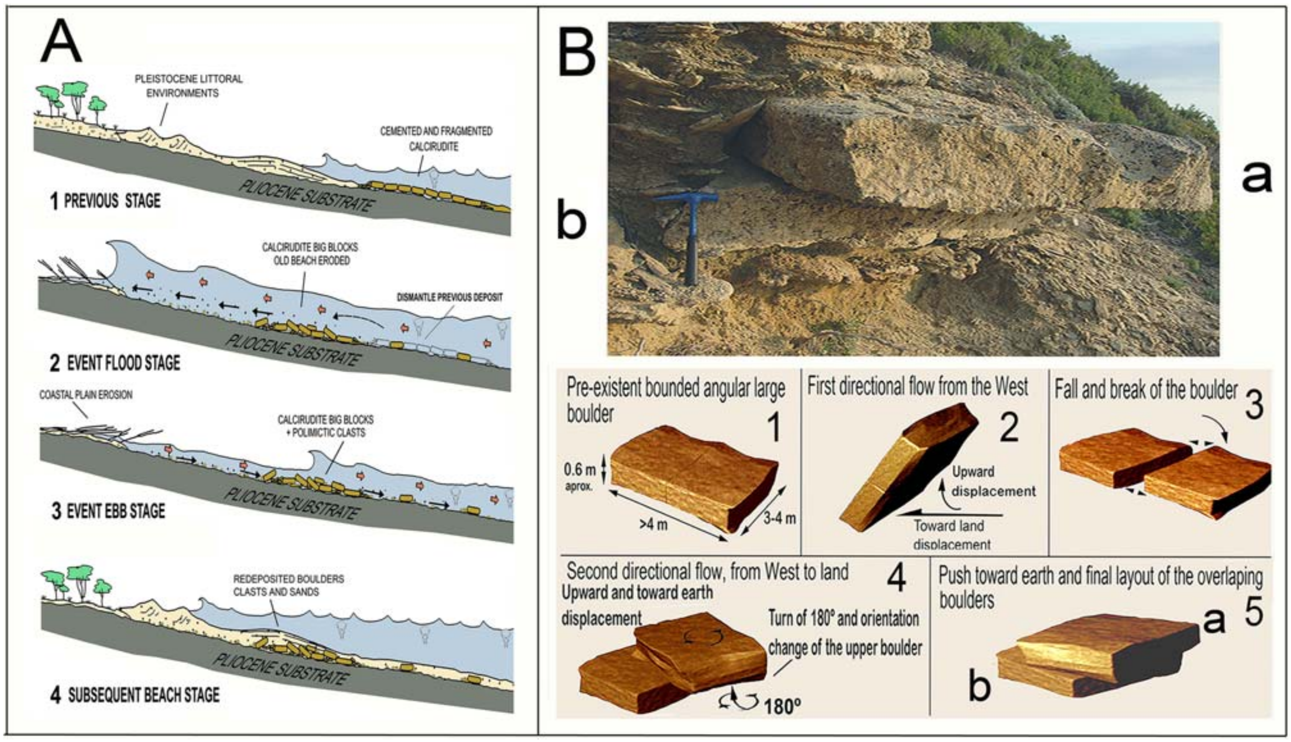

Figure 9.- **A)** Stages of the re-mobilization and transport of large boulders and clasts during the event. **B)** Displacement phases of an overlapped large boulders.

^{86}Sr isotopic ratio is observed in deep mud volcanoes aligned across the present-day continental margin (Scholz *et al*., 2009).

Nevertheless, although these factors should be considered, it doesn't mean that the ^{87}Sr/^{86}Sr isotopic ratio values obtained for the analyzed Plio-Pleistocene marine sediments do not correspond to the standard values established in the sea water curve from McArthur *et al*. (2001). An approximate age interval of the event can be established, from 1.35 to 1.1 My, during the Calabrian, one of the oldest stages of the Pleistocene (Gradstein, 2004; Cita and Pillans, 2009).

Conclusions

Sedimentary evidences indicate the action of a very high energetic event in the Cadiz Gulf during the Pleistocene, probably a great tsunami. The event is recorded as a deposit of large calciruditic boulders and

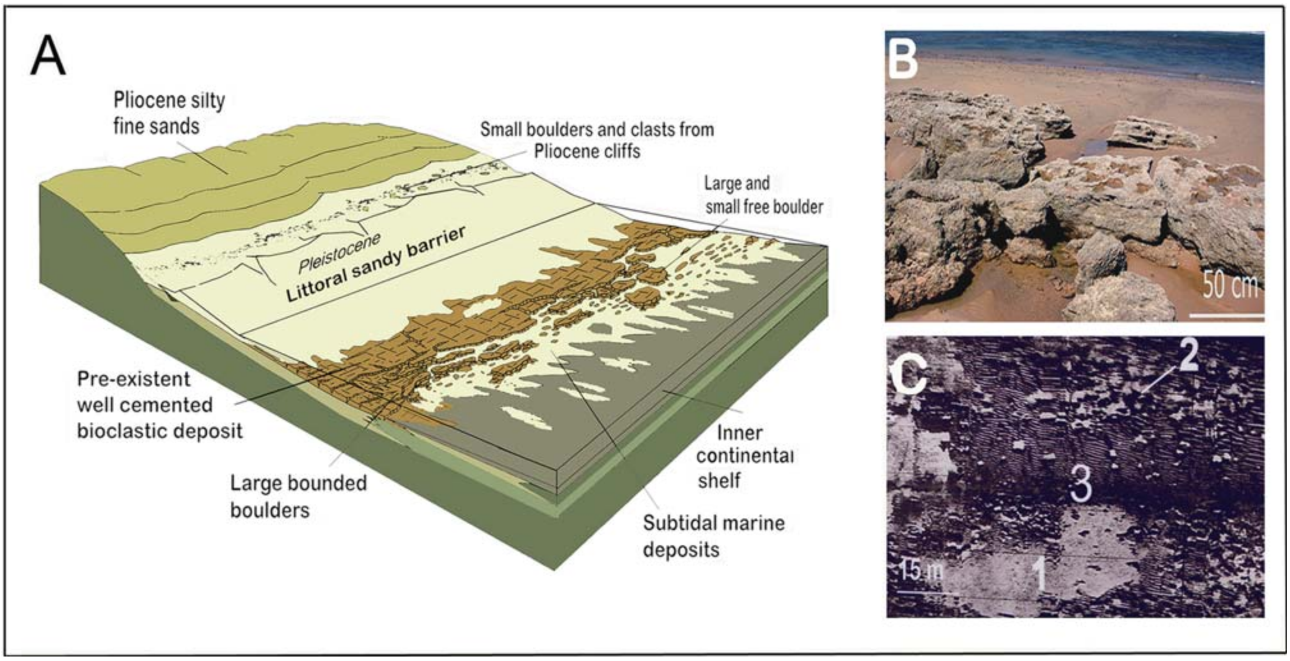

Figure 10.- **A)** Paleographic situation previous to the event. **B)** Pleistocene outcrop in the intertidal zone (Cadiz Bay). **C)** Side scan sonar image of a submarine Plio-Pleistocene outcrop: 1. rocky outcrop; 2. Boulders and clasts; 3. Current ripples and megarripples.

calcarenitic clasts interstratified in Plio-Pleistocene units. The mobilization and deposition of the boulders took place in a shallow marine environment.

The sources of the calciruditic large boulders are sedimentary units included in Pliocene or Lower Pleistocene outcrops. They are constituted of a well-cemented mixture of sand and bioclastics, whose age is coincident with the boulder age. The sources of calcarenitic clasts are well cemented storm layers interstratified in the Pliocene fine sands present in the coastal outcrops and cliffs. After the event, the deposit was buried and amalgamated by fine sands with hummocky and *Glycimeris* shells, which denote a shallow environment affected by storm waves, just as, the transition zone with the inner continental shelf.

The event could be induced by an strong earthquake, followed by tsunami big waves. The focus could be located in near areas, just as the Southwest of San Vicente Cape. Regarding to the event age, the data allow establishing an age interval from 1.35 to 1.1 My, during the Calabrian (early Pleistocene).

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