Revista de la Sociedad Geológica de España 29 (1)

ISSN (versión impresa): 0214-2708
ISSN (Internet): 2255-1379

COMPARATIVE ANALYSIS OF THE DEPOSITS LEFT BY THE TSUNAMI THAT FOLLOWED TO THE LISBON EARTHQUAKE (1755 AD), ON THE CASTILNOVO BEACH AND THE OLD TUNA FACTORY OF LA CHANÇA (CONIL DE LA FRONTERA, SW SPAIN)

Análisis comparativo de los depósitos dejados por el tsunami que siguió al terremoto de Lisboa (1755 DC), en la playa de Castilnovo y la antigua fábrica de salazón de atún de La Chança *(Conil de la Frontera, SW de España).*

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Abstract*: On coasts of tectonically active areas, where old tsunami deposits are in a fragmentary state, the study of paleo-tsunamis provides data for interpreting facies and processes. In order to recognize facies, a study has been carried out on a sector of the SW coast of Spain, where some historical tsunamis are documented, such as that caused by the Lisbon earthquake (November 1, 1755 AD). This study is focused on a sector between the Salado River Mouth and Castilnovo Beach (Conil de la Frontera), where depositional morphologies attributed to this event can still be observed. It includes a comparative analysis with well-preserved deposits found inside an old tuna salting factory,* La Chança *which, albeit severely damaged, survived the tsunami. The sediments deposited by the 1755 AD tsunami record a mixture of older coastal deposits, including sands and muddy-sands, pebbles, mollusc shells, foraminifers, terrestrial gastropods, root features, and archaeological remains. After the tsunami, a part of the deposits were remobilized and mixed with normal coastal sediments, becaming unrecognizable as tsunamites. Several stratigraphic units have been distinguished, corresponding to different sedimentary stages. The results suggest that some depositional features were caused not by this event, but rather are a consequence of the interaction of other factors. Shelly beds intercalated within the deposits have provided a* ^{14}C *age older than 1755 AD, which have been interpreted as records of other older events or erosion of older deposits followed by deposition during the tsunami event.*

Keywords*: Paleo-tsunami, Lisbon earthquake, Tsunami 1755, Gulf of Cadiz,* La Chança, *Conil de la Frontera.*

Resumen: *En costas de regiones tectónicamente activas, donde depósitos de antiguos tsunamis se encuentran en estado fragmentario, el estudio de paleo-tsunamis proporciona datos para la interpretación de facies y la reconstrucción de los procesos. Con objeto de reconocer las facies y los procesos involucrados, se ha realizado un estudio sedimentológico en un sector de la costa SO de España, donde están documentados varios tsunamis históricos, como el causado por el terremoto de Lisboa del 1 de Noviembre de 1755. El estudio se centra en un sector comprendido entre la desembocadura del río Salado y la Playa de Castilnovo (Conil de la Frontera), donde aún se pueden observar morfologías y depósitos atribuidos a este evento. El estudio incluye el análisis comparativo con los sedimentos depositados en la antigua factoría de salazón de* La Chança *que, aunque seriamente dañada, sobrevivió al tsunami.*

Los sedimentos depositados por el tsunami de 1755 se combinaron con depósitos costeros más antiguos, resultando una mezcla de arenas, fango, clastos, conchas de moluscos, foraminíferos, gasterópodos terrestres, raíces y restos arqueológicos de la época. Tras el evento, estos sedimentos fueron redepositados en medios costeros, resultando unos depósitos irreconocibles, aunque algunos han sido interpretados como tsunamitas. Se *han diferenciado varias unidades sedimentarias correspondientes a diferentes etapas, incluyendo la acción de este evento. Los resultados sugieren que algunos rasgos deposicionales presentes en los depósitos no fueron totalmente causados por el tsunami de 1755, sino que son una consecuencia de la interacción de varios factores. Además, algunas capas bioclásticas intercaladas en los depósitos han proporcionado una edad ^{14}C mayor de 1.755 dC, lo que ha sido interpretado como el registro de eventos más antiguos.*

***Palabras clave**: Paleo-tsunami, Terremoto de Lisboa, 1755 AD Tsunami, Golfo de Cádiz,* La Chança*, Conil de la Frontera.*

Gutiérrez-Mas, J.M., Gómez Fernández, V., García-López, S., Morales, J.A. y Ibáñez Ageitos, J.M. (2016): Comparative analysis of the deposits left by the tsunami that followed to the Lisbon Earthquake (1755 AD), on the Castilnovo beach and the Old Tuna Factory of La Chança (Conil de la Frontera, SW Spain). *Revista de la Sociedad Geológica de España*, 29(1): 21-33.

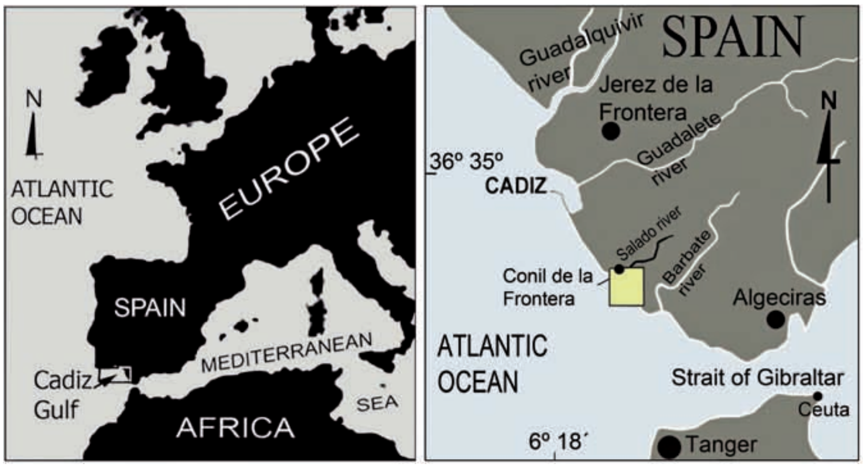


Fig. 1.- Geographical location of the study zone.

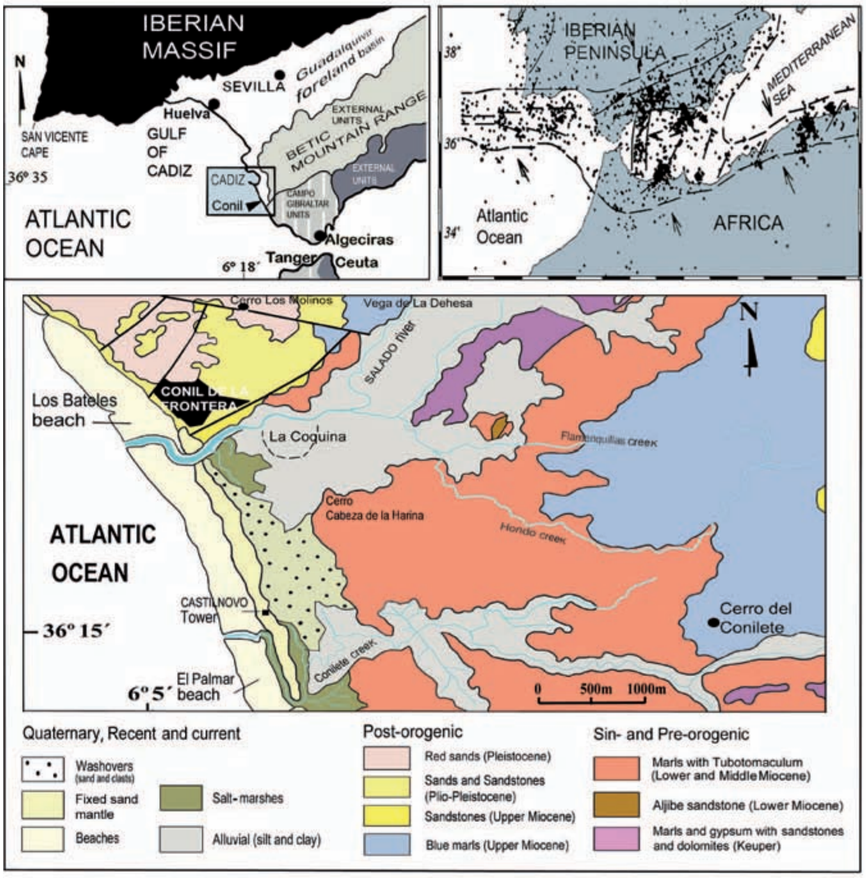


Fig. 2.- Upper: Geological and tectonic setting. Lower: Geological map of the study area.

The onshore sedimentary record provides a promising key for reconstructing the impacts of the tsunami waves, and to identify the deposits, helping to increase the knowledge of the magnitude and frequency of the events (Goff et al., 2001). Because many scientific studies on tsunamis are currently being carried out on depositional imprints left behind by past tsunamis, it is important to know how the paleo-tsunami deposits have changed over time, especially in areas where these are fragmented and the historical tsunamis only cover a short time period.

Along the SW coast of the Iberian Peninsula, there are historical evidences of major earthquakes and tsunamis, such as the Lisbon earthquake (November 1, 1755), which had a severe effect on the Atlantic coast of Andalusia (Galbis, 1940; Campos, 1991; Andrade et al., 1994; Ribeiro, 1995; Dawson et al., 1995; Baptista et al., 1998; Dabrio et al., 1998; 2000; Hindson and Andrade, 1999; Luque et al., 2001, 2004; Martinez and Arroyo, 2004; Whelan and Kelletat, 2005; Silva et al., 2005; Ruiz et al., 2005; Lima et al., 2010; Gutierrez-Mas et al., 2009a and b; Cunha et al., 2010: Gutierrez-Mas, 2011). Other older deposits are attributed to events occurred in the 1st and 3rd centuries BC (Rodriguez-Ramirez et al., 2014). Paleo-tsunamis deposits considered as ranging in age from the Pliocene to Pleistocene are observed in outcrops on the Cádiz coast (Luque et al., 2002; Gutiérrez-Mas and Mas, 2013).

In order to establish the factors that conditioned the evolution of deposits left by the 1755 tsunami, a study was carried out in a coastal sector between the Salado River mouth and the El Palmar Beach in

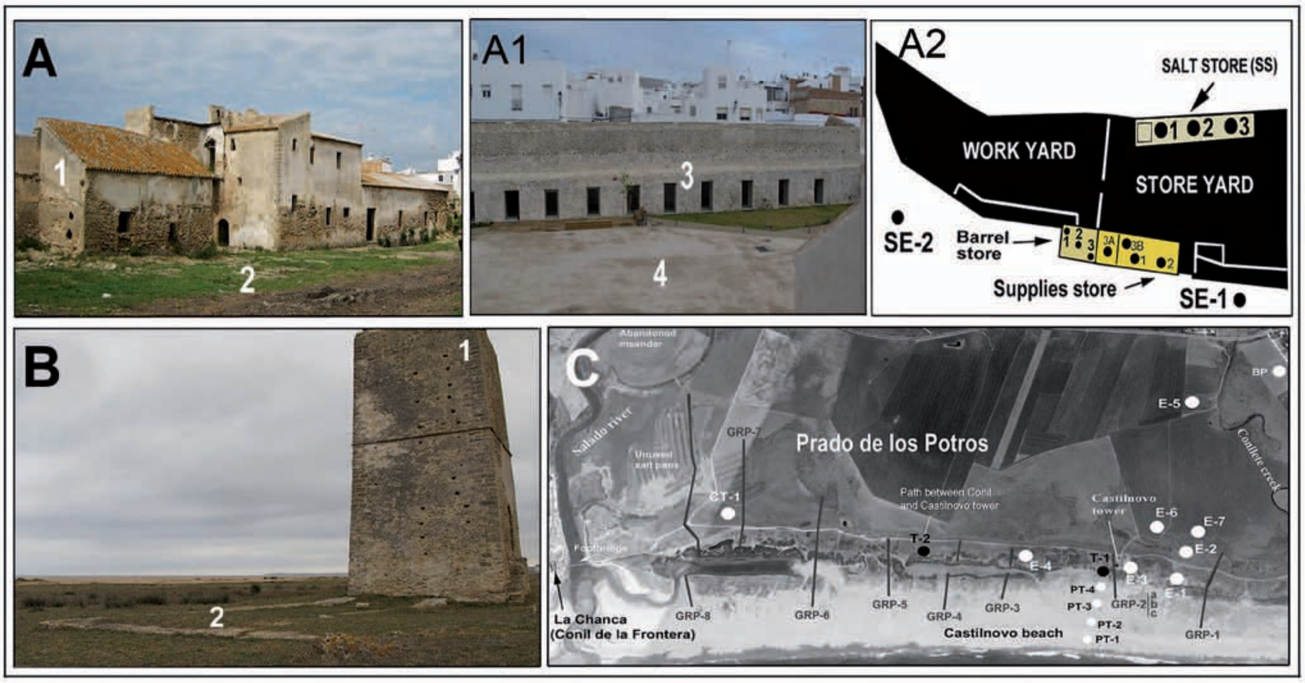


Fig. 3.- A) Photography of the old tuna factory of *La Chança* before its restoration: 1 Main building, 2 Work yard covered by debris; A1: 3 Salt store, 4 Work yard after restoration; A2: Location of sampling stations. B) 1 Castilnovo tower, 2 Tsunami deposits covering the tower wall. C) Location of the sampling stations.

Conil de la Frontera (SW Spain). In this area there are abundant morphologies and depositional features attributed to the cited 1755 event, which can be still observed. The study also includes the analysis of deposits found inside an old tuna salting factory, *La Chança* which, was severely damaged by the 1755 tsunami (Figs. 1, 2, 3A).

Geological and tectonic setting

The study area is located on the Atlantic coast of Andalusia (SW Spain). It is part of three geological realms (Figs. 1, 2): a) Betic Mountain Range, with pre-orogenic materials from Triassic to Early Miocene; b) Guadalquivir Tecto-Sedimentary Complex, with syn-orogenic marls from the Early–Middle Miocene, and c) Guadalquivir Basin, with post-orogenic materials from the Late Miocene to the present day, made up by marls, sands, sandstones and conglomerates. The outcrops show evidence of neotectonic activity, with faults and folds oriented according to known structural directions, NW-SE and ENE-WSW (Figs. 2, 4), while the coastline and fluvial network show abrupt changes in direction (Rehault et al**.**, 1985; Sanz de Galdeano et al., 1993; Gutscher et al., 2006).

The neotectonic activity is a consequence of the proximity to the Azores-Gibraltar fault zone, the boundary between the Euroasiatic and African plates, whose displacement cause a substantial seismic activity in the region, such as the earthquake occurred on November 1, 1755 AD, known as the Lisbon earthquake (Udias et al., 1976; Grimison and Chen, 1986; Campos 1991; Dawson et al., 1995; Borja et al., 1999; Solares and Arroyo, 2004; Gutscher et al., 2006).

Based on the reported wave height, the tsunami reached a level of 4.5 on the Japanese Scale devised for the Pacific Ocean, which indicates a tsunami of exceptional magnitude (Campos, 1991), and an earthquake of great intensity (8.5 to 9). However, if allowance is made for the combined effects of coast and seabed configuration and high-tide time, the tsunami could have been less intense, about 3.5 on the Japanese Scale. The epicentre location is also discussed. Backward ray-tracing tsunami modelling suggests an "L" shaped double break at 100 km to the west of Cape Saint Vincent, while others author consider that the seismic focus was related to subduction processes in the Gorringe Bank, or on the Western Iberian Continental Shelf near Lisbon (Udías et al., 1976; Ribeiro, 1995, Baptista et al., 1998).

The tsunami waves reached Cadiz at 11.10 a.m., one hour after the earthquake. The waves from the West and North broke through the walled enclosure of Cádiz, cut the barrier-island, and opened a channel between the lagoon and the open sea (Campos, 1991, Rodríguez de la Torre, 2005). In Conil de la Frontera, about 30 km to the south of Cádiz, the tsunami arrived at 10.30 a.m., starting with a sea retreated, followed of great waves crashed onto the beach. The Conilete settlement, close to the seashore, was destroyed, while the walls that surrounded the Castilnovo tower were buried (Fig. 3). Waves dragged fishing boats and equipment out to sea, and smashed the old tuna factory of *La Chança*, where several persons died. The river courses overflowed, and seawater reached several kilometres inland (Martínez Solares, 2001; Luque et al., 2004; Campese Gallego et al., 2009).

Methods

The paleo-tsunami research requires a detailed study, in order to determine if the deposit are really from a tsunami and not from another kind of event such as a major storm (Bourgeois, 2009; Engel and Brückner, 2011). Sedimentological methods were utilized to recognize facies, detect depositional anomalies, and to obtain criteria to differentiate and interpret processes. The studies were carried out on the coast of Conil, between the Salado river mouth and the beach of El Palmar (Figs. 1 and 3).

Systematic sampling and drilling work was carried out at 30 representative stations. Stratigraphic sections were obtained from cores and field observations (Fig. 3). Sedimentary lithologies and structures, but also fossil content were used to identify depositional features and environments. The outcrops were analysed *in situ* and photographed for subsequent interpretation. Several sectors were differentiated: a) current coastal environments; b) old coastal deposits, which are currently fixed by continental vegetation; and c) coastal industrial buildings that were operating in 1755 AD. The study includes the analysis of an old tuna factory, *La Chança*. The work consisted of the excavations and ground movements, in order to identify archaeological remains, essential to establish their contemporaneity with the 1755 AD tsunami.

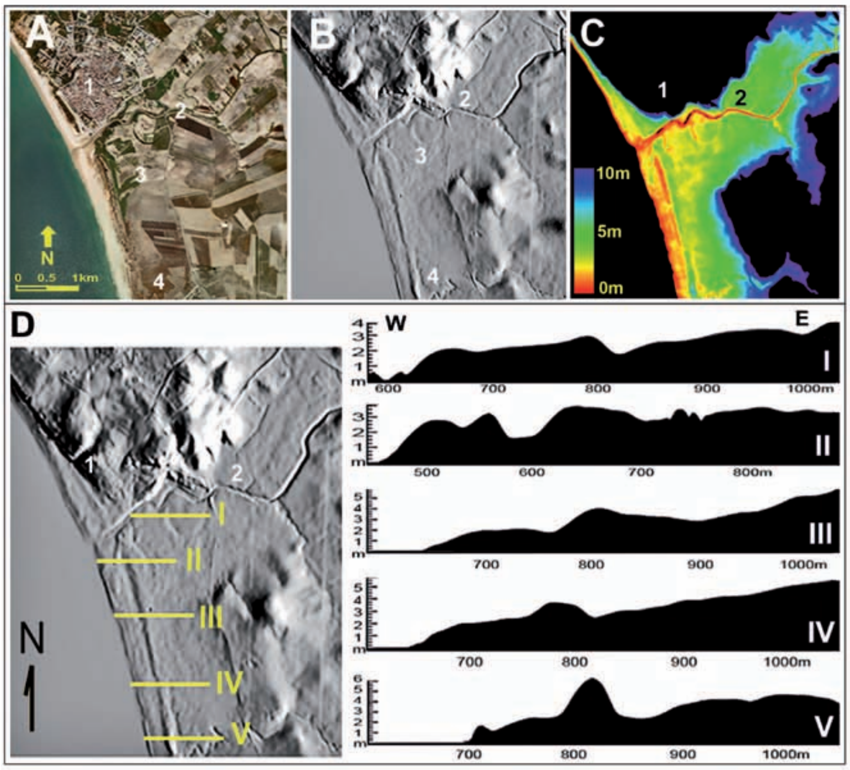
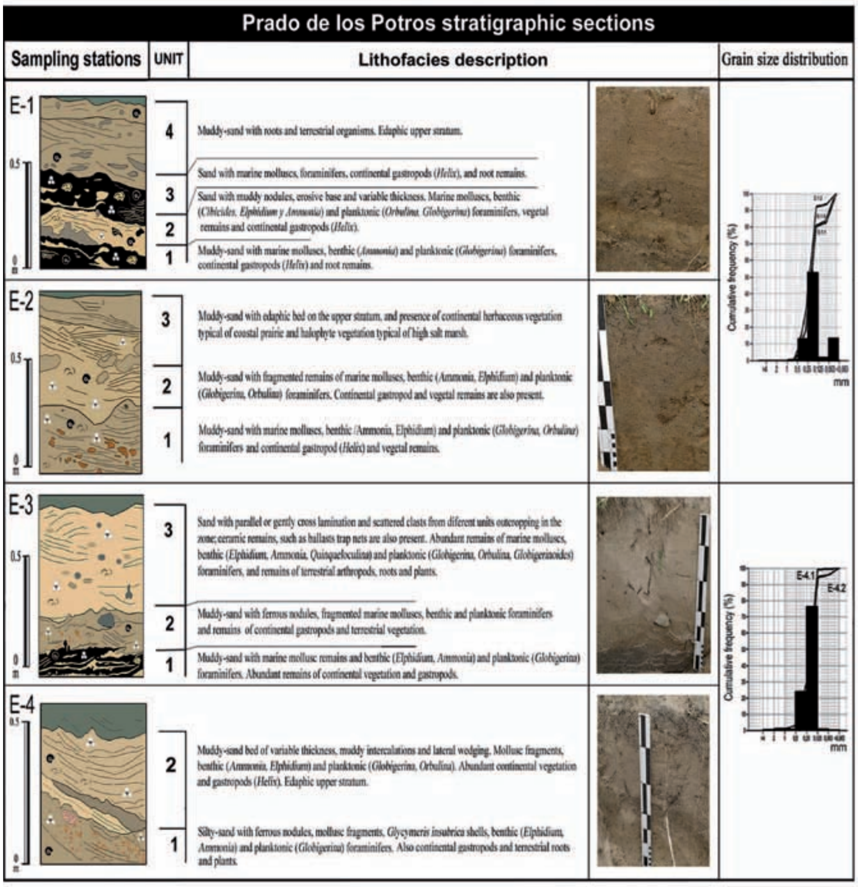


Fig. 4.- A) Photographic analysis on image of 2008 AD year; B) Digital Terrain Model (DTM) black/white shading: 1 Conil de la Frontera, 2 Salado river, 3 Prado de los Potros, 4 Conilete creek. C) Colored DTM image; altitude range: 0 to 10 meters. D) Topographic profiles of five locations indicated in DTM image.



Prado de los Potros stratigraphic sections

Sampling stations	UNIT	Lithofacies description
E-1	4	Muddy-sand with roots and terrestrial organisms. Edaphic upper stratum.
	3	Sand with marine molluscs, foraminifers, continental gastropods (*Helix*), and root remains.
	2	Sand with muddy nodules, erosive base and variable thickness. Marine molluscs, benthic (*Cibicides, Elphidium y Ammonia*) and planktonic (*Orbulina, Globigerina*) foraminifers, vegetal remains and continental gastropods (*Helix*).
	1	Muddy-sand with marine molluscs, benthic (*Ammonia*) and planktonic (*Globigerina*) foraminifers, continental gastropods (*Helix*) and root remains.
E-2	3	Muddy-sand with edaphic bed on the upper stratum, and presence of continental herbaceous vegetation typical of coastal prairie and halophyte vegetation typical of high salt marsh.
	2	Muddy-sand with fragmented remains of marine molluscs, benthic (*Ammonia, Elphidium*) and planktonic (*Globigerina, Orbulina*) foraminifers. Continental gastropod and vegetal remains are also present.
	1	Muddy-sand with marine molluscs, benthic (Ammonia, Elphidium) and planktonic (*Globigerina, Orbulina*) foraminifers and continental gastropod (*Helix*) and vegetal remains.
E-3	3	Sand with parallel or gently cross lamination and scattered clasts from diferent units outcropping in the zone; ceramic remains, such as ballasts trap nets are also present. Abundant remains of marine molluscs, benthic (*Elphidium, Ammonia, Quinqueloculina*) and planktonic (*Globigerina, Orbulina, Globigerinoides*) foraminifers, and remains of terrestrial arthropods, roots and plants.
	2	Muddy-sand with ferrous nodules, fragmented marine molluscs, benthic and planktonic foraminifers and remains of continental gastropods and terrestrial vegetation.
	1	Muddy-sand with marine mollusc remains and benthic (*Elphidium, Ammonia*) and planktonic (*Globigerina*) foraminifers. Abundant remains of continental vegetation and gastropods.
E-4	2	Muddy-sand bed of variable thickness, muddy intercalations and lateral wedging. Mollusc fragments, benthic (*Ammonia, Elphidium*) and planktonic (*Globigerina, Orbulina*). Abundant continental vegetation and gastropods (*Helix*). Edaphic upper stratum.
	1	Silty-sand with ferrous nodules, mollusc fragments, *Glycymeris insubrica* shells, benthic (*Elphidium, Ammonia*) and planktonic (*Globigerina*) foraminifers. Also continental gastropods and terrestrial roots and plants.

Fig. 5.- Stratigraphic sections and lithofacies of deposits from the Prado de los Potros (Location in Figure 3C).

Finally, a comparative analysis of the sediments found in outdoor areas and the deposits from *La Chança* was also carried out. Archaeological objects were reconstructed and studied according to the available documentary sources.

The laboratory work consisted of textural analysis of sedimentary samples by mean of mechanical sieving, using the size scale established by Udden and Wentworth, and statistical grain size parameters were calculated. Determination of the sand fraction constituents and microfossils was determined by mean of binocular magnifying glass. The grain-size distribution analysis was used to describe sediments and the processes involved, and to establish differences between deposits and recognize depositional features.

Sample age was established by mean of ^{14}C method at the National Accelerator Centre (Seville University). Calibration was carried out using the Washington University CALIB software 5.01 (Stuiver and Reimer, 1993; Stuiver and Braziunas, 1993; Stuiver et al., 1998; Reimer et al., 2002) and Marine Curve 04. Data were corrected

Sample	Place	Environment	^{14}C age	(ΔR)*	Calibrated ^{14}C age	Calendar ^{14}C age
1s *Glycymeris*	Core CT-1	Marine	2276± 32 BP	-135±20	2411±38 BP	199 BC–22 AD
1i *Glycymeris*	Core CT-1	Marine	2807±32 BP	-135±20	2942±38 BP	869-698 BC
Tuna vertebra	La Chanca	Marine	_	_	_	Not collagen
Current *Helix*	Prado de los Potros	Terrestrial	1000±31BP	_	1151–983 AD	Fragmentation of ^{14}C Cdating by "diet effect"
M1 (*Helix*)	Core CT-1	Terrestrial	3836±34 BP	_	2155–2457B	
M4 (*Helix*)	Core CT-1	Terrestrial	2581±35 BP	_	565–816BC	
M6 (*Helix*)	Core CT-1	Terrestrial	2197±33 BP	_	3658–181BC	

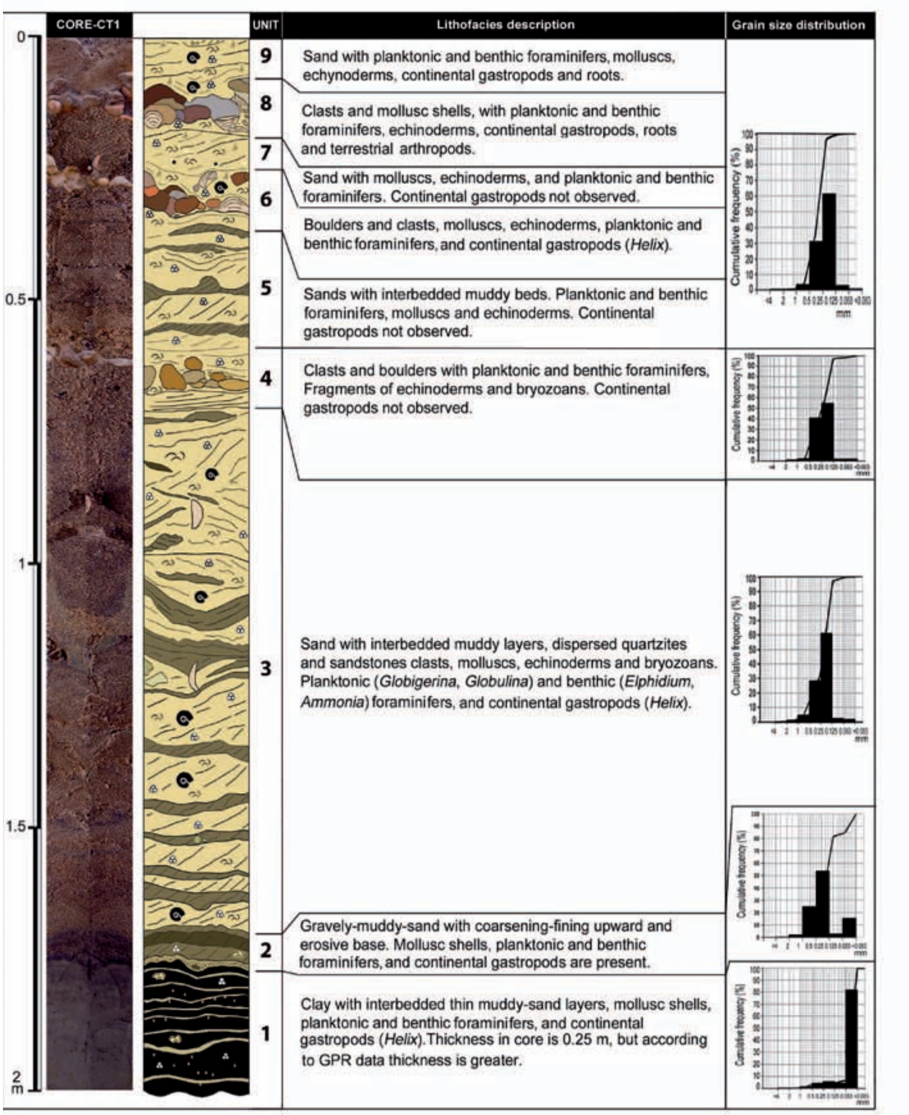
* Δ*R* Reservoid Effect According Monge Soares and Matos Martins (2009)

Table. 1.- Samples dating of sedimentary deposits from the Prado de los Potros and the old tuna factory of *La Chança* (Conil de la Frontera).

applying the Local Reservoir Effect (Δ*R* = -135 ± 20) according to Monge Soares and Matos Martins (2009) (Table 1).

Terrestrial gastropods (*Helix*), included in deposits interpreted as caused by the 1755 AD tsunami, provided ages older than the event. A standard current gastropod sample provided an anomalous ^{14}C age of 1000 years BP caused by the *diet effect* (Glenn, 1987; Pigati et al., 2010). Therefore the ^{14}C ages obtained for terrestrial gastropods were rejected (Table 1). Other samples, such as tuna vertebrae, also failed to provide an age for the deposits, due to the absence of sufficient collagen for their dating.

Photogrammetric analysis was used to obtain data from the terrain and to identify depositional anomalies (Fig. 4). It consisted of analysing orthophotographs of 0.5 to 1 m resolution (REDIAM, Junta de Andalucía). Two Digital Terrain Models (DTM), with mesh size of 5 m (Instituto Geográfico Nacional, 2009): a) automatic photogrammetric stereo-correlation, with resolution of 25-50 cm/pixel, and RMS in Z of 1-2 m (National Plan of Aerial Orthophotography, PNOA); b) interpolation of ground type from the point cloud Laser imaging Detection and Ranging (LiDAR), with density of 0.5 points/m^2 and RMS in Z of 0.5-1 m. The processing consisted of a re-sampling cell size of 2.5 m, to match the grid of both models, which had been averaged, obtaining a DTM that includes identifiable features of the two models. Finally, a mask was established to isolate values between 0 and 10 m, and a colour scale to differentiate heights (Fig. 4).



9 Sand with planktonic and benthic foraminifers, molluscs, echynoderms, continental gastropods and roots.

8 Clasts and mollusc shells, with planktonic and benthic foraminifers, echinoderms, continental gastropods, roots and terrestrial arthropods.

7 Sand with molluscs, echinoderms, and planktonic and benthic foraminifers. Continental gastropods not observed.

6 Boulders and clasts, molluscs, echinoderms, planktonic and benthic foraminifers, and continental gastropods (*Helix*).

5 Sands with interbedded muddy beds. Planktonic and benthic foraminifers, molluscs and echinoderms. Continental gastropods not observed.

4 Clasts and boulders with planktonic and benthic foraminifers, Fragments of echinoderms and bryozoans. Continental gastropods not observed.

3 Sand with interbedded muddy layers, dispersed quartzites and sandstones clasts, molluscs, echinoderms and bryozoans. Planktonic (*Globigerina*, *Globulina*) and benthic (*Elphidium*, *Ammonia*) foraminifers, and continental gastropods (*Helix*).

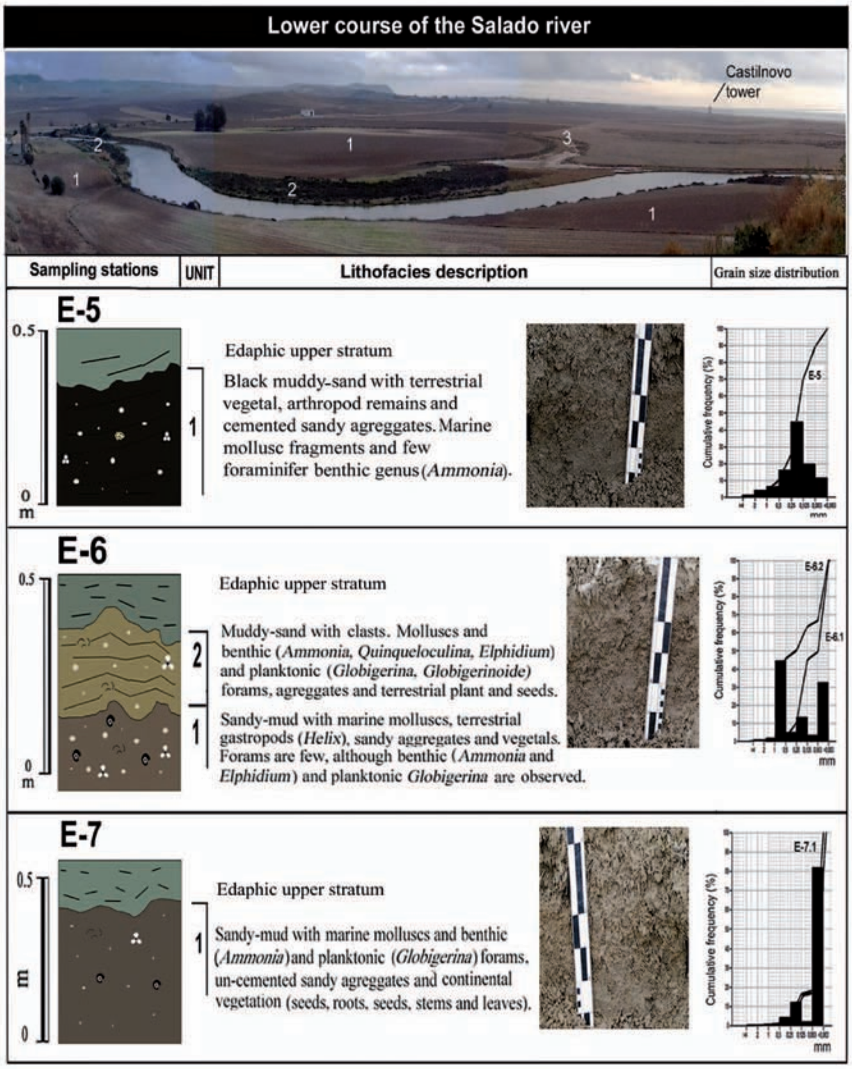
2 Gravely-muddy-sand with coarsening-fining upward and erosive base. Mollusc shells, planktonic and benthic foraminifers, and continental gastropods are present.

1 Clay with interbedded thin muddy-sand layers, mollusc shells, planktonic and benthic foraminifers, and continental gastropods (*Helix*). Thickness in core is 0.25 m, but according to GPR data thickness is greater.

Fig. 6.- Stratigraphic section and lithofacies vertical association in the core CT-1 from the Prado de los Potros. (Location in Figure 3C).

Results

Morphological data indicate a strong structural control, evidenced by a coastline and fluvial network of rectilinear sections and abrupt changes in direction (Figs. 2, 4). The photographic analysis indicate that on the upper part of the current beach, there is a sandy mantle of elongated morphology and orientation parallel to the current coastline. This sandy mantle is fixed by te-



E-5
Edaphic upper stratum
1 Black muddy-sand with terrestrial vegetal, arthropod remains and cemented sandy agreggates. Marine mollusc fragments and few foraminifer benthic genus (*Ammonia*).

E-6
Edaphic upper stratum
2 Muddy-sand with clasts. Molluscs and benthic (*Ammonia, Quinqueloculina, Elphidium*) and planktonic (*Globigerina, Globigerinoide*) forams, agreggates and terrestrial plant and seeds.
1 Sandy-mud with marine molluscs, terrestrial gastropods (*Helix*), sandy aggregates and vegetals. Forams are few, although benthic (*Ammonia* and *Elphidium*) and planktonic *Globigerina* are observed.

E-7
Edaphic upper stratum
1 Sandy-mud with marine molluscs and benthic (*Ammonia*) and planktonic (*Globigerina*) forams, un-cemented sandy agreggates and continental vegetation (seeds, roots, seeds, stems and leaves).

Fig. 7.- Upper: Fluvial plain from the Salado river. Photograph taken near the river mouth zone: 1) Old alluvial deposits; 2) Current alluvial deposits; 3) Abandoned meander. Lower: Stratigraphic sections and lithofacies of deposits from the plain flood near to the Salado river mouth. (Location in Figure 3C).

rrestrial vegetation, and its maximum height is 7.5 m on the *datum* (Fig. 4B, D).

This fixed sandy mantle separates two tidal channels parallel to the coast, which are fed with seawater from the Salado river mouth and Conilete creek during high-tides. The tidal channels are separated from the intertidal zone by an incipient aeolian mantle, consisting of *sand shadows* transversely cut by *washovers*.

From its particular geographical situation, *La Chança* was an important witness of the 1755 tsunami. The building is only 100 m from the seashore, with an altitude of 4 m above the *datum* and 1.5 m above the spring-tide level. Due to the absence of obstacles that might have prevented the advance of the waves, *La Chança* received the full impact of the waves.

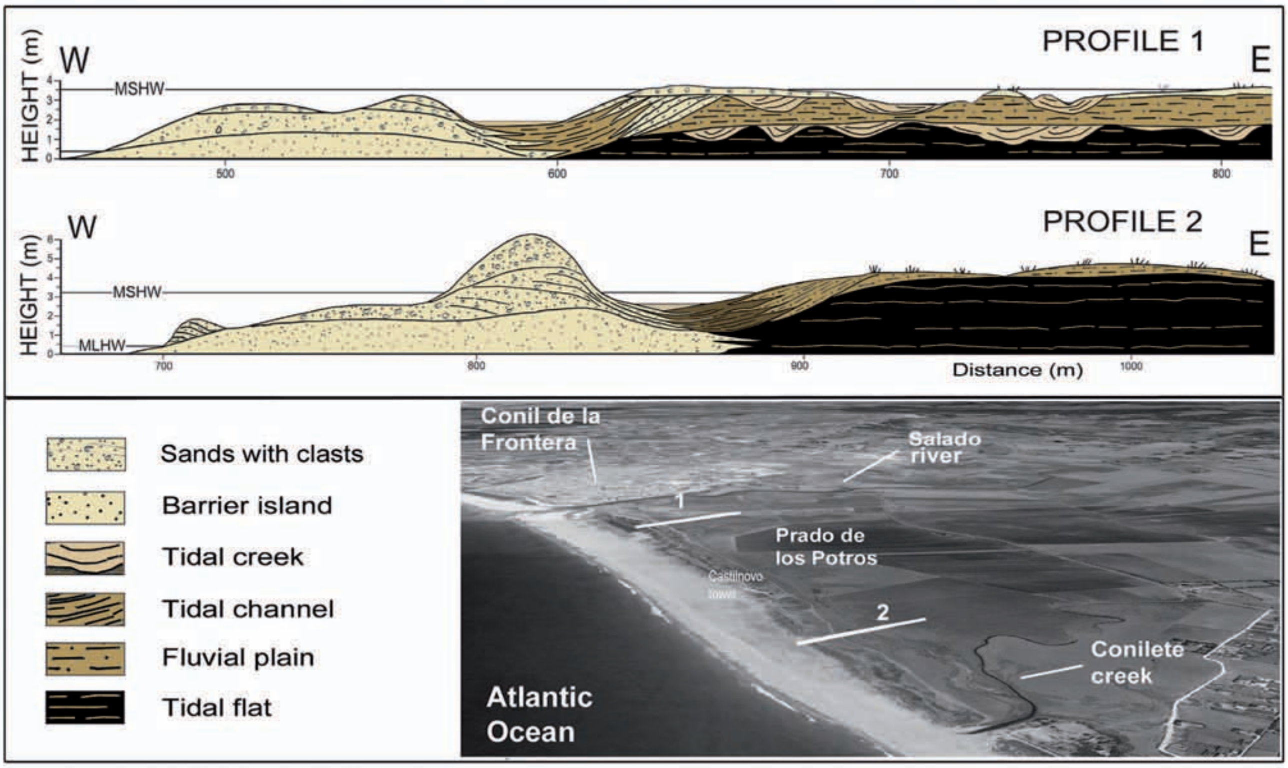


Fig. 8.- Upper: Geological profiles representative of the lithofacies associations observed in the deposits from the Prado de los Potros. Lower: Legend and profile location.

Sediments and facies

The deposits show significant lateral changes of facies, thickness variations, and deposits relatively bad stratified and poorly sorted. Sand is the dominant sediment, with grain-size mode in fine sand fraction. The gravel fraction is constituted of rounded and angular pebbles, boulders and shells, especially disarticulated valves of *Glycymeris insubrica*. The main sedimentary structures present in the deposits are: parallel and cross-lamination, oriented and imbricate shells and pebbles, and roots. The most abundant microfossils are benthic and planktonic foraminifers, fragments of molluscs, echinoderms and bryozoans, terrestrial gastropods, arthropods, plants and roots.

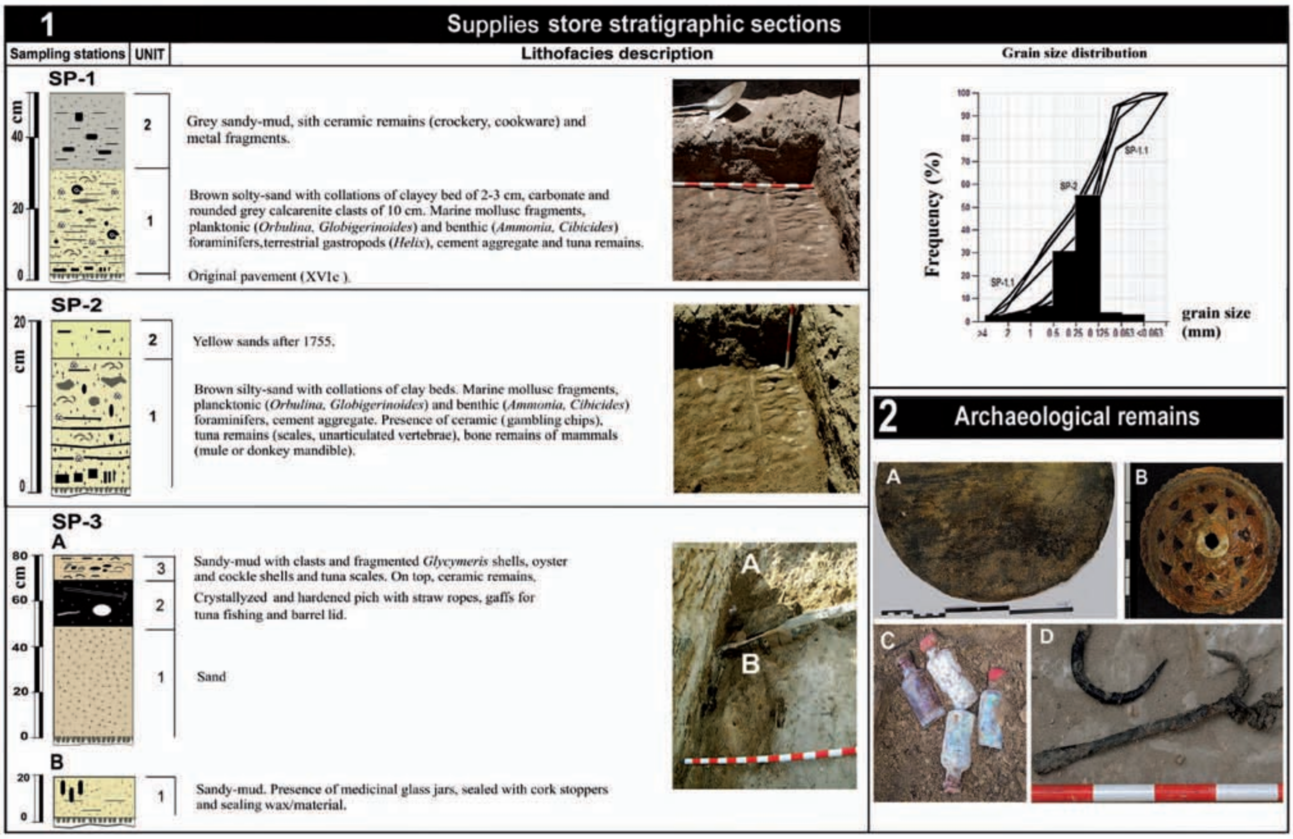
In the current intertidal zone (station PT-1), the sediment is 100% sand, with molluscs, echinoderms, and benthic and planktonic foraminifers. In the backshore (PT-2), sand is predominant, with fragments of molluscs, and benthic and planktonic foraminifers. The aeolian zone (PT-4) is underdeveloped, and it is constituted by some fields of *sand shadows*, fields, which consist of well-sorted fine sand (Figs. 3C).

In the Prado de los Potros (Figs. 3C and 5), the predominant sediment is sand, with intercalations of muddy-sand, pebbles, mollusc shells and terrestrial gastropods, plants and roots. Also, mortar granules and isolated ceramic fragments were observed. Microfossils are benthic and planktonic foraminifers. The stations E-3 and E-4, show silty-sand with pebbles, *Glycymeris* valves and isolated ceramic remains (Figs. 3C, 5).

On the beach at south of the Salado river mouth, several washover fans are observed, which penetrate hundreds of meters inland (Figs. 3C, 5). The deposits are made up of sand with pebbles of different size and lithology, as well as disarticulated valves of *Glycymeris*, which show impact and dissolution prints. A representative stratigraphic section is the core CT-1 (Figs. 3C, 6), whose base is constituted of clay with muddy-sand intercalations and fauna and flora from salt marsh, terrestrial gastropods, arthropods and plants. The deposit also contains molluscs, and benthic and planktonic foraminifers. Above there is an alternation of sand and muddy-sand, with mollusc fragments, benthic and planktonic foraminifers, and continental gastropods. At top there is sand with bioclastic intercalations and muddy-sand beds (Fig. 6).

Clasts and boulders are abundant, being the ratio in the deposits of 400 clasts per 1 m^3 of sediments. Their lithology is similar to those rocks that constitute the nearby sea cliffs and outcrops, such as sandstones from the Upper Miocene, Pliocene and Pleistocene (Fig. 2). Other pebbles have quartzite nature, such as those from Aljibe sandstone outcrops (Campo del Gibraltar Units).

In a small salt marsh zone, located at east of the Castilnovo tower (stations E-2 and E-6), the deposits consist of muddy-sand with pebbles (Figs. 3C, 7 and 8). At station E-7 there are sandy-mud with mollusc fragments, benthic and planktonic foraminifers, seeds, roots, stems, leaves, and uncemented aggregates. At south of the Salado river mouth (station E-5), on the fluvial plain, the sediments consist of muddy-sand, with molluscs and foraminifers



SP-1, 2: Grey sandy-mud, sith ceramic remains (crockery, cookware) and metal fragments.

SP-1, 1: Brown solty-sand with collations of clayey bed of 2-3 cm, carbonate and rounded grey calcarenite clasts of 10 cm. Marine mollusc fragments, planktonic (*Orbulina, Globigerinoides*) and benthic (*Ammonia, Cibicides*) foraminifers,terrestrial gastropods (*Helix*), cement aggregate and tuna remains.

Original pavement (XVIc).

SP-2, 2: Yellow sands after 1755.

SP-2, 1: Brown silty-sand with collations of clay beds. Marine mollusc fragments, plancktonic (*Orbulina, Globigerinoides*) and benthic (*Ammonia, Cibicides*) foraminifers, cement aggregate. Presence of ceramic (gambling chips), tuna remains (scales, unarticulated vertebrae), bone remains of mammals (mule or donkey mandible).

SP-3 A, 3: Sandy-mud with clasts and fragmented *Glycymeris* shells, oyster and cockle shells and tuna scales. On top, ceramic remains.

SP-3 A, 2: Crystallyzed and hardened pich with straw ropes, gaffs for tuna fishing and barrel lid.

SP-3 A, 1: Sand

SP-3 B, 1: Sandy-mud. Presence of medicinal glass jars, sealed with cork stoppers and sealing wax/material.

Fig. 9.- Stratigraphic sections and lithofacies of deposits from the Supplies store (*La Chança*): 1) Lithofacies and grain-size distribution; 2) Archaeological objects: A. Barrel top, B. Perfume/incense burner, C. Sealed medicinal vials, D. Boathooks.

With respect to the deposit age, the only available data are those provided by the *Glycymeris* valves, which have provided ages from 199 BC to 22 AD for the upper bioclastic layer (Table 1), and from 869 to 698 BC for the lower bioclastic layer. Both ages are older than the 1755 AD tsunami age, being conceivable that those shells were remobilized by the waves.

From base to top, five distinctive sedimentary units can be differentiated:

Unit I comprises clay with sandy intercalations. Its thickness is in excess of 2 m (Figs. 8), and its top presents an erosive surface, with the presence of paleochannels of variable size, from 0.5 to 1 m thick; these are interpreted as transverse sections of tidal channels of 4-8 m width, and with longitudinal axes parallel to the coast.

Unit II comprises two sub-units: IIa and IIb (Figs. 8). The unit IIa represents the sedimentary filling of the furrows excavated on the top of unit I. The deposits are of muddy-sand with clayey intercalations. The unit IIb consists of a sandy deposit, 0.5-0.8 m thick, with muddy intercalations.

Unit III comprises sand with dispersed pebbles and muddy intercalations. At the top of the unit there are paleochannels filled of sandy-mud, similar to those of unit IIa; these furrows are interpreted as the filling of tidal paleochannels, from 2 to 3 m wide, with longitudinal axes parallel to the coast.

Unit IV is about 0.3 to 0.5 m thick, (Figs. 8). It consists of fine and medium sand, with abundant clasts and shells of different origin and ages, which produce anomalies of hyperbolic morphology in the reflections.

Unit V comprises sand and muddy-sand, with dispersed clasts and shells. Its thickness is variable, and it corresponds to current deposits of beach, aeolian zone, and fillings of tidal channels and saltmarshes.

Deposits from La Chança

During the 1755 event the building of *La Chança* was flooded and partially buried under the sediments. The deposits have variable thickness and are mainly constituted of sand, muddy-sand, and gravelly-sand, with parallel and cross lamination, rounded clasts, disarticulated shells, and archaeological remains (Fig. 3). Microfossils are essentially benthic and planktonic foraminifers, terrestrial gastropods and plant remains.

In the *Supply store* (Figs. 3A and 9), muddy-sand and gravel rests on a pavement from the 16th Century, made of similar pebbles to those found in the Prado de los Potros. At stations SP-1 and SP-2, on the pavement there is muddy-sand with pebbles and tuna remains. The sand contains bioclasts of molluscs, echinoderms, bryozoans, benthic and planktonic foraminifers, and terrestrial gastropods (*Helix*). Above this there are sandy-mud with vessels, ceramic bowls, gambling chips and metal objects. At station SP-3, there is sand and a hard tar bed with archaeological remains (string, barrel top and boathooks). Above this, there is muddy-sand, pebbles, G*lycymeris* valves and oyster shells, tuna scales, and ceramic objects; outside, there is muddy-sand with archaeological remains (sealed medicinal vials).

In the *Barrel store* (Figs. 3A and 10), the dominant sediment is sand. At station SB-1, the base is constituted of gravelly-sand with ceramic weights used for the old fishing nets, tuna bones, molluscs, foraminifers and terrestrial mosses; above there is muddy-sandwith mortar fragments, roots, fish bones, ceramic fragments, glass, metal buttons and nails. At station SB-2, the base comprises sand with tile and brick fragments, followed by clayey-sands, yellow and brown sands and silty-sand. At station SB-3, the base is silty-sand with

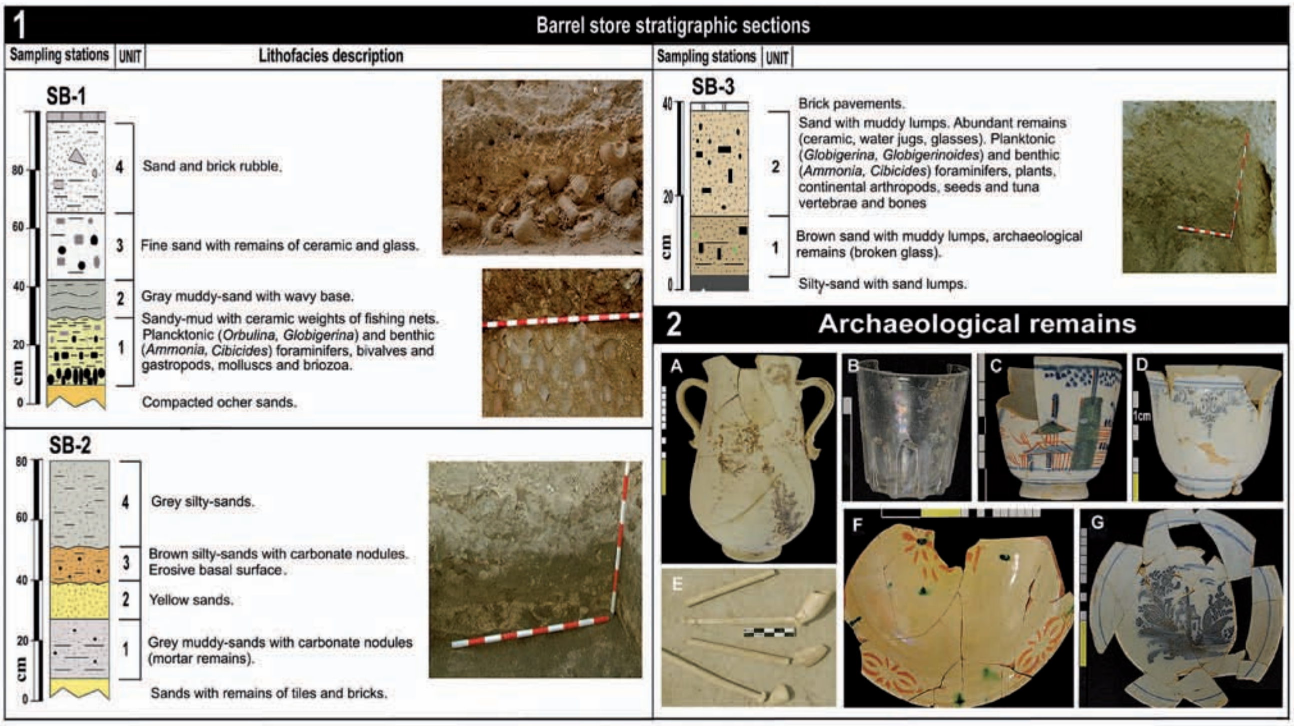


Fig. 10.- Stratigraphic sections and lithofacies of deposits from the Barrel store (*La Chança*): 1) Lithofacies; 2) Archaeological objects: A. Ceramic vessel, B. Glass cup, C. Ceramic cup, D. Tea cup, E. Kaolin smoking pipes, F. Ceramic bowl, G. Ceramic basin.

granule, followed of sands with mud nodules and ceramic and glass remains. The sands contain benthic and planktonic foraminifers, tuna bones, terrestrial arthropods, plants, seeds and ceramic jars, glass bottles, urinals and spittoons.

In the *Salt store* (Figs. 3A and 11), the sediments are homogeneous, with mud and calcareous nodules; above there is muddy-sand. In the centre of the room there is muddy-sand, with plant and archaeological remains.

Outside *La Chança* (stations SE-1 and SE-2), on a clay base, there is sand with pebbles, archaeological remains, and tuna and mammal bones (Fig. 11).

The ^{14}C ages provided by *Glycymeris* shells present in the sediments from *La Chança* have provided an older age than 1755 AD year, with an age range from 869 BC to 22 AD. Neither did the ^{14}C analysis of tuna bones provide credible ages, due to insufficient collagen for dating analysis. Moreover, the ^{14}C analysis of terrestrial gastropods present in the deposits, provided anomalous values, which exceed 1000 years (Table 1). Therefore the age of the tsunami deposits within *La Chança* was provided from the presence of archaeological remains corresponding to the time when this event occurred.

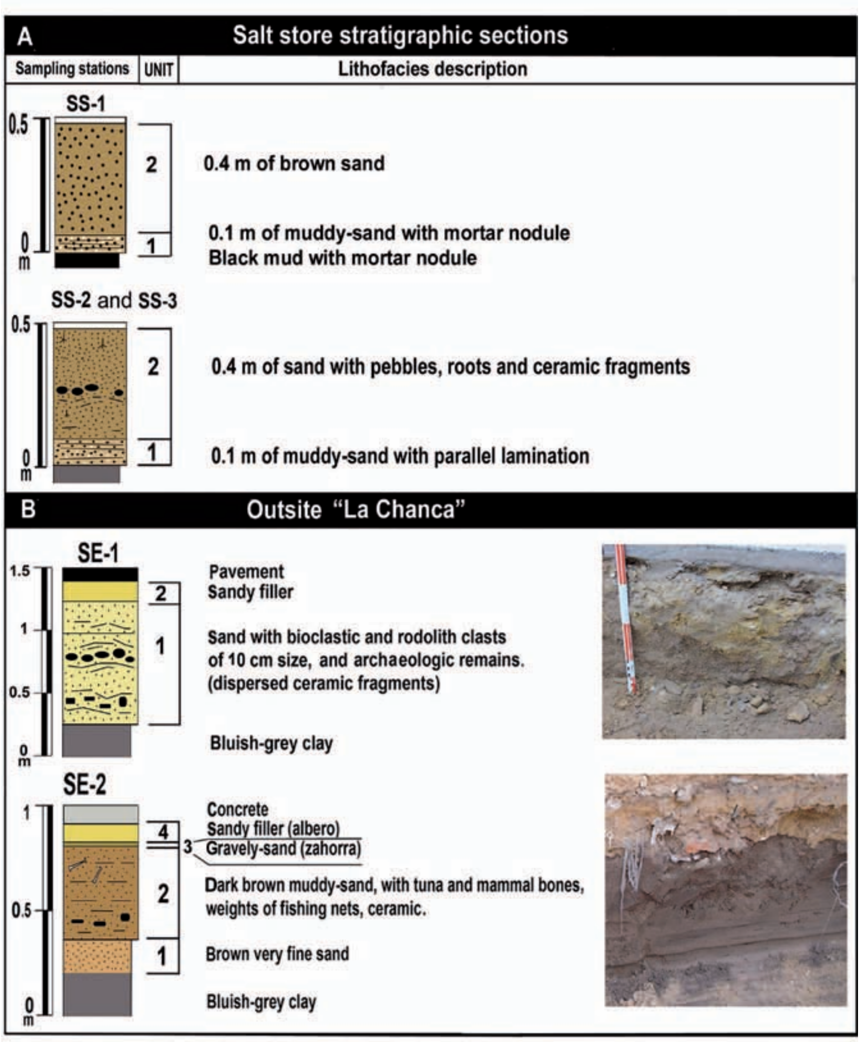


Fig. 11.- A) Stratigraphic sections and lithofacies of deposits from the Salt store (*La Chança*); B) Stratigraphic sections and lithofacies of deposits from sample stations outside of *La Chança*.

Discussion

In coastal environments from tectonically-active zones, there are deposits caused by old tsunamis, whose facies represent depositional anomalies, respect to the sediment deposited by normal coastal processes. When paleo-tsunami deposits are in zones of low preservation potential, post-depositional process cause sediment mixing, in such a way that, their study requires a wide knowledge of the environment and the processes that have taken place, both before and after the tsunami. In this sense, some authors have examined the compositional and textural features to distinguish them, while others have found no differences, concluding that only a combination of data may allow a proper distinction (Kortekaas and Dawson, 2007; Bourgeois, 2009).

Previous deposit to the 1755 AD tsunami are included in the units I, II and III. Over these there is clayey-sand (unit IIa), interpreted as filling of tidal creeks, which laterally changes to sands (unit IIb), interpreted as remains of an old sandy bar. Sands with benthic and planktonic foraminifers (unit III) are interpreted as remains of another sandy bar, while the sandy-mud-filled grooves on top of the bar are interpreted as tidal creeks. As a whole, the sedimentary accumulation from the unit I to unit III, is interpreted as a result of a regressive sequence.

Depositional action of the 1755 AD Tsunami

With respect to the depositional effects of the 1755 AD tsunami on the study zone, when the tsunami waves reached the shore, eroded and dismantled the beach deposits. The tsunami run up eroded the foreshore, backshore and dune zone, dragging sand, pebbles and shells inland. The waters reached 8 m in height, ruining crops and damaging buildings, such as the Conilete settlement and Castilnovo tower, whose walls were destroyed and buried under the sediments (Fig. 12) (Rodríguez de la Torre, 2005; Campese Gallego et al., 2009). Tidal zones near to shore were filled by tsunami sediments, and the old saltworks were ruined.

The deposits left by the tsunami run-up are included in the unit IV, and they are extended from the shore to hundreds of metres inland (Figs. 6, 8). The sediments show variable thicknes, facies lateral changes, poorly sorted and stratified sediments, and parallel and cross lamination. The fossil content is made up of *Glycymeris* valves, pebbles, roots, and marine microfossils (benthic and planktonic foraminifers), terrestrial gastropods and arthropods. Other depositional features are: parallel and cross lamination, oriented and imbricate fossils and pebbles, and roots.

In the coastal plain close to the current seashore, the deposits contain abundant pebbles and *Glycymeris* valves, whose ^{14}C age is older than 1755 AD. This age range is consistent with the ages provided by a similar shelly deposits observed in the Bay of Cadiz, which have been interpreted as event deposits that occurred several hundred years before the 1755 tsunami (Gutierrez-Mas, 2011)

Several *washovers* caused by the waves of this tsunami are visible between the Salado River and Conilete creek (Figs. 6, 7, 8). These show various features: 1) erosive furrows that cut transversally into old sandy bars located on the upper part of the beach; and 2) sedimentary wedges deposited on fixed sands, salt marshes, tidal creeks, and alluvial deposits.

Other tsunami deposits were caused by overflow and flooding of rivers and creeks, due to the rising influx of seawater up the fluvial courses. Significant quantities of marine and coastal sediments were transported by the tsunami, reaching a landward penetration of about 8 km (Campese Gallego et al., 2009), being deposited on previous deposits from salt marshes, tidal creeks, and alluvial soils.

In zones distant from the seashore, the tsunami deposits are thinner, being characterized by a mixing of marine fine sands with benthic and planktonic foraminifers, molluscs, and fluvial silt and clay with terrestrial gastropods. These deposits are completely altered by remobilization and sediment mixing, as well as by herbaceous vegetation and crops, being now practically unrecognizable. The only tsunami trace is the presence of benthic and planktonic foraminifers and terrestrial gastropods.

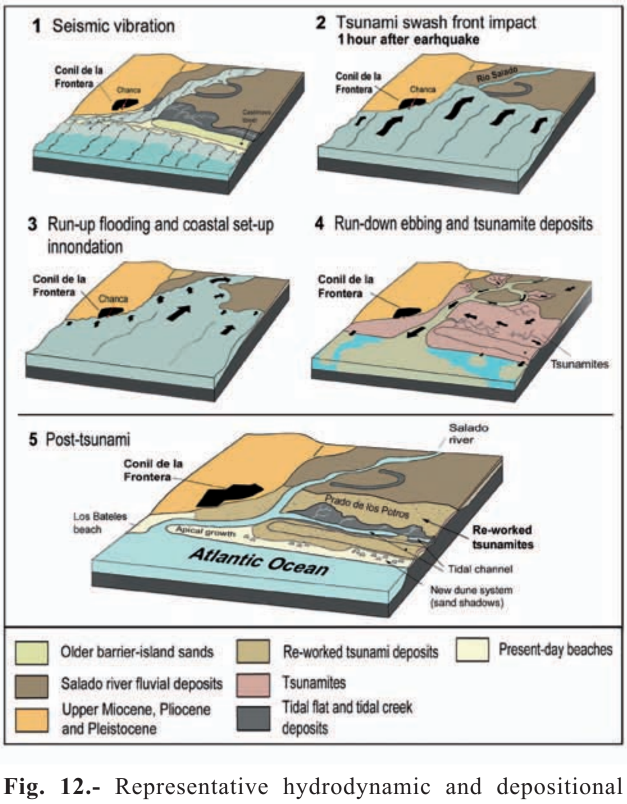


Fig. 12.- Representative hydrodynamic and depositional stages of the 1755 AD tsunami in the area of Conil de la Frontera (SW Spain).

With respect to *La Chança*, because its proximity to the seashore and absence of obstacles that reduced the effects of the waves, this received the direct impact of the waves, which destroyed doors and roofs, flooded the rooms and deposited sediments inside (Gómez Fernández, 2011). However, the sediments deposited by the tsunami waves are well-preserved, since they suffered no post-depositional changes. The deposits are better differentiated than those from the Prado de los Potros, since the sediment mixing only occurred during the tsunami. The sediments that remained inside *La Chança* were protected and non-altered by post-depositional processes. The worst-affected zone was that located on the side facing the sea, especially the supply and barrel stores (Figs. 9, 10 and 11), with deposits consisting of sands, silt and clay, with parallel and cross lamination, pebbles from the erosion of flooring, disarticulated shells, and mortar fragments from erosion of the walls.

There are similarities between the *La Chança* deposits and those from the coastal plain and the Prado de los Potros, especially an identical content of marine and terrestrial fossils, while the main differentiating feature is the presence in the *La Chança* deposits of archaeological objects such as, perfume burners, medicinal vials, ceramic vessels, glass, ceramic caps, and kaolin smoking pipes (Figs. 9 and 10). Once they had been restored they were sufficiently recognizable as belonging to the 18th Century.

Post-depositional evolution and stratigraphic layout of the deposits

Although some features caused by the 1755 AD tsunami are still observable on the terrain, the post-depositional processes caused changes and mixing of sediment and fossil, such as the disappearance of some original features caused by the tsunami (Luque et al., 2004; Gutiérrez Mas and García-López, 2015) (Fig. 13). After the event, the tsunami deposits were eroded by normal coastal agents, and the sediments transferred to the shore, where they contributed to rebuilding the previously destroyed backshore and foreshore zones. The aeolian zone was rebuilt, and several fields of *sand shadow* are observed on the floor of the washovers.

The presence of fossils from underlying layers in deposits interpreted as caused by 1755 AD tsunami, indicate that the post-depositional processes reached a deeper than the thickness of the original tsunami deposits, thereby achieving a complete depositional alteration of those. However, given the proximity to the shore of these deposits, it can be thought that the sediment mixing could be caused by the remobilized action of the tsunami waves.

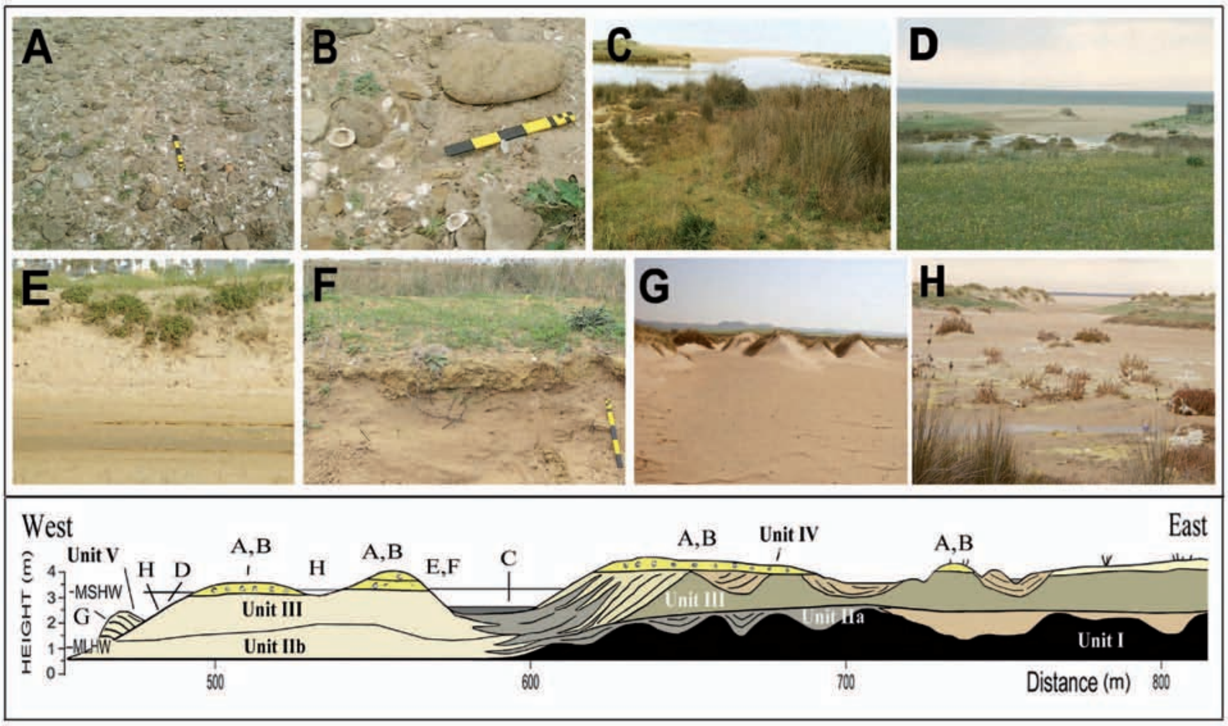


Fig. 13.- A and B) Pebbles and boulders deposited by the 1755 tsunami waves; C and D) Washover caused by the 1755 tsunami; E and F) Scarps excavated on older tsunami deposits; G) Current sand-shadows on washover floor; H) Salt marsh developed on washover floor. In this sector is observed that an algal pavement difficult the growth of halophyte plants. Below: Geological profile showing the different sedimentary environments and facies equivalents represented in the previous photographic images from A to H.

Other difficulty to interpret the lithofacies are the sediment sources, which are constituted by deposits from old coastal environments, reason why these provide a sediments of similar texture, although belonging to different depositional cycles. Considering these facts, it is possible to deduce that some depositional features attributed to the 1755 AD tsunami are really consequence of different processes occurred before and after the known event of 1755 AD.

The best preserved deposits are those of greater thickness and located near to seashore, such as sands with pebbles and shells from the Prado de los Potros. Sediments farthest from seashore are thinner than those, such as those deposited on fluvial soils. These sediments are covered by vegetation or crops. Under such conditions, and although the deposits still retained some of their original depositional characteristics, the data indicate that there is a notable absence of reliable features to define these deposits as tsunamites s.s.

Although most of the depositional changes were clearly caused by natural processes, alterations due to human activity cannot be ruled out. Works to clear debris, the preparation of the beach zone for tuna fishery activities and agricultural works on the coastal plain all altered the original layout of the deposits.

Conclusions

On the SW coast of the Iberian Peninsula, there is historical evidence of earthquakes and tsunamis, such as the tsunami that followed the Lisbon earthquake (November 1, 1755). In order to identify the lithofacies and depositional processes, a study has been carried out in a sector from the Cadiz coast, between the Salado river mouth and the El Palmar beach.

The deposits have been compared with other deposited inside an old tuna factory, *La Chança*. The results indicate that both deposits are similar, with abundant marine microfossils, pebbles and shells. The main difference is the presence in the deposits from *La Chança* of archaeological remains from the18th Century.

Several sedimentary units have been differentiated. The basal units are interpreted as result of a forced regression that caused the abandonment of the coastal deposits, which deposits are nowadays a main sediment source to the coastal environments.

The deposits considered as caused by the 1755 tsunami contain elements from older events. The presence of shelly layers with ages older than 1755 AD, indicates that the zone was probably affected by events happened between 869 BC and 22 AD, an age range coincident with the ages provided by a similar deposits observed in the Bay of Cadiz, which are interpreted as event deposits occurred several hundred years before the 1755 tsunami.

Post-depositional processes that affected to the 1755 AD tsunami deposits, caused mixing of sediments and fossils, and eliminated some of the original features caused by the tsunami. The best-preserved deposits are those of greater thickness, such as sands with pebbles and shells. The sediments deposited on fluvial soils and far of the seashore are thinner, and are poorly preserved, being almost unrecognizable. The human activity cannot be ruled out. Works to clear debris and prepare the beach zone for tuna fishery activities, and agricultural works on the coastal plain, have altered the original layout of the deposits, although these still retain many original features.

Acknowledgements

This paper has been supported by the Research Project GL2010-16878 of the Ministry of Science and Innovation of Spain (FEDER). Our thanks to the Journal Editor and to the reviewers Dr Pedro P. Cunha and Dr German Flor, for their corrections and suggestions.

References

Andrade, C., Hindson R., Freitas, C. and Dawson, A. (1994): Sedimentary evidence of tsunami flooding in Algarve coastal lowlands. In: *Congress. Littoral*, 94: 26-29.

Baptista, M.A., Heitor, S., Miranda, J.M., Miranda, P. and Mendes Victor, L. (1998): The 1755 Lisbon Tsunami: Evaluation of the Tsunami parameters. *Journal of Geodynamic*, 25 (2): 143-157.

Borja, F., Zazo, C., Dabrio, C.J., Díaz del Olmo, F., Goy, J.L. and Lario, J. (1999): Holocene aeolian phases and human settlements along the Atlantic coast of southern Spain. *Holocene*, 9(3): 333-339.

Bourgeois, J. (2009): Geologic effects and records of tsunamis. In: *The Sea*, *Volume 15: Tsunamis* (A.R. Robinson and E.N. Bernard, Eds). Harvard University Press, 53-91.

Campese Gallego, F., Gamero Rojas, M., González Polvillo, A., Hidalgo Lerdo de Tejada, F., Pérez García, R.M. and Pezzi, P. (2009): Los efectos del maremoto de 1755 sobre las costas andaluzas. IX Reunión Científica de la FEHM-UMA. In: *Población y grupos sociales en el Antiguo Régimen* (J.J. Bueno Cano and J. Sanz Sampelayo, Eds). Vol. I. Málaga, 63-377.

Campos, M.L. (1991): Tsunami hazard on the Spanish coasts of the Iberian Peninsula. *Science of Tsunami Hazard*, 9 (1): 83-90.

Cunha, T.A., Matias, L.M., Terrinha, P., Negredo, A., Rosas, F., Fernandes, R.M.S., Pinheiro, L.M. (2012): Neotectonics of the SW Iberia margin, Gulf of Cadiz and Alboran Sea: a reassessment including recent structural, seismic and geodetic data. *Geophysical Journal International*, 188: 850-872.

Cuven, S., Paris, R., Falvard, S., Miot-Noirault, E., Benbakkar, M., Schneider, J.-L., Billy, I. (2013): High-resolution analysis of a tsunami deposit: Casestudy from the 1755 Lisbon tsunami in southwestern Spain. *Marine Geology,* 337: 98-111.

Dabrio, C.J., Goy, J.L. and Zazo, C. (1998): The record of the tsunami produced by the 1755 Lisbon Earthquake in Valdelagrana spit (Gulf of Cadiz, Southern Spain). *Geogaceta,* 23: 31-34.

Dabrio, C.J., Zazo, C., Goy, J.L., Sierro, F.J., Borja, F., Lario, J., González, J.A. and Flores, J.A. (2000): Depositional history of estuarine infill during the last postglacial transgression (Gulf of Cádiz, southern Spain). *Marine Geology,* 162: 381-404.

Dawson, A.G., Hindson, R., Andrade, C., Freitas, C., Parish, R. and Bateman, M. (1995): Tsunami sedimentation associated with the Lisbon earthquake of 1 November AD 1755: Boca do Rio, Algarve, Portugal. *The Holocene*, 5(2): 209-215.

Engel, M. and Brückner, H. (2011): The identification of palaeotsunami deposits –a major challenge in coastal sedimentary research. In: *Dynamische Küsten-Prozesse, Zusammenhänge und Auswirkungen* (V. Karius, H. Hadler, M. Deicke, H.v. Eynatten, H. Brückner and A. Vött, Eds.). Coastlin, Reports, 17: 65-80.

Galbis, R.J. (1940): *Catálogo sísmico de la zona comprendida entre los meridianos 58 E y 208 W de Greenwich y los paralelos 458 y 258 N.* Instituto Geográfico y Catastral, Madrid, 277 pp.

Glenn, A.G. (1987): Radiocarbon age anomalies in shell carbonate of land snails from semi-arid areas. *Radiocarbon*, 29 (2): 159-167.

Gómez Fernández, V. (2011): La Chanca de Conil de la Frontera. Recientes excavaciones arqueológicas. In: *Pescar con Arte. Fenicios y romanos en el origen de los aparejos andaluces* (D. Bernal Cassasola, Eds). Monografías del Proyecto Sagena. Servicio Publicaciones Universidad de Cádiz. 319-334

Goff, J, Chagué-Goff, C. and Nichol, S. (2001): Palaeotsunami deposits; a New Zealand perspective. *Sedimentary Geology*, 143: 1-6.

Grimison, N.L. and Chen, W.P. (1986): The Azores-Gibraltar Plate Boundary: focal mechanisms, depths of earthquakes, and their tectonic implications. *Journal of Geophysical Research*, 91: 2029-2047.

Gutierrez-Mas, J.M., Juan, C. and Morales, J.A. (2009a): Evidence of high-energy events in shelly layers interbedded in coastal Holocene sands in Cadiz Bay (south-west Spain). *Earth Surface Processes and Landforms*, 34: 810-823.

Gutierrez-Mas, J.M., López-Arroyo, J. and Morales, J.A. (2009b): Recent marine lithofacies in the Cadiz Bay (SW Spain). Sequences, processes and control factors. *Sedimentary Geology*, 218: 31-47.

Gutierrez Mas, J.M. (2011): Glycymeris shell accumulations as indicators of recent sea-level changes and high-energy events in Cadiz Bay (SW Spain). *Estuarine, Coastal and Shelf Science*, 92 (4): 546-554.

Gutierrez-Mas, J.M. and Mas, R. (2013): Record of very high energy events in Plio-Pleistocene marine deposits of the Gulf of Cadiz (SW Spain): facies and processes. *Facies*, 59: 679-701.

Gutierrez-Mas, J.M. and García-López, S. (2015): Recent evolution of the river mouth intertidal zone at the Río San Pedro tidal channel (Cádiz Bay, SW Spain): controlling factors of geomorphologic and depositional changes. *Geologica Acta,* 13(2): 123-136.

Gutscher, M.A., Baptista, M.A. and Miranda, J.M.(2006): The Gibraltar Arc seismogenic zone (part 2): Constraints on a shallow east dipping fault plane source for the 1755 Lisbon earthquake provided by tsunami modelling and seismic intensity. *Tectonophysics,* 426: 153-166.

Hindson, R.A. and Andrade, C. (1999): Sedimentation and hydrodynamic processes associated with the tsunami generated by the 1755 Lisbon earthquake. *Quaternary International*, 56: 27-38.

Kortekaas, S. and Dawson, A.G. (2007): Distinguishing tsunami and storm deposits: an example from Martinhal, SW Portugal. *Sedimentary Geololgy,* 200: 208-221.

Lima, V.V., Miranda, J.M., Baptista, M.A., Catalao, J., González, M., Otero, L., Olabarrieta, M., Alvarez-Gómez, J.A., and Carreño, E. (2010): Impact of a 1755-like tsunami in Huelva, Spain. *Natural Hazards Earth System,* 10: 139-148.

Luque, L., Lario, J., Zazo, C., Goy, J.L., Dabrio, C.J., and Silva, P.G. (2001): Tsunami deposits as paleoseismic indicators: examples from the Spanish coast. *Acta Geologica Hispanica*, 36(3–4): 197-221.

Luque, L., Lario, J., Civis, J., Silva,.PG., Zazo, C., Goy, J.L., Dabrio, C.J. (2002): Sedimentary record of a tsunami during Roman times, Bay of Cadiz, Spain. *Journal of Quaternary Science*, 17(5–6): 623–631.

Luque, L., Zazo, C., Lario, J., Goy, J.L., Civis, J., González-

Hernández F.M., Silva .PG. and Dabrio C.J. (2004): El efecto del tsunami del año 1755 en el litoral de Conil de la Frontera (Cádiz). *Zona Arqueologica*, 4: 73–82.

Martínez Solares, J.M. (2001): *Los efectos en España del terremoto de Lisboa (1 de Noviembre de 1755). Apéndice II. Transcripción de los Documentos del Archivo Histórico Nacional*, Ministerio de Fomento, Instituto Geográfico Nacional. Subdirección General de Producción Cartográfica. Servicio de Edición y Trazado. Madrid. 296-297.

Martinez, S. and Arroyo, L. (2004): The great historical 1755 earthquake. Effects and damage in Spain. *Journal of Seismology*, 8: 275–294

Monge Soares, A. and Martos Martins, J.M. (2009): Radiocarbon dating of marine samples from Gulf of Cadiz: the reservoir effect. *Quaternary International*, 221(1-2): 9-12.

Pigati, J.S., Rech, J.A. and Nekola, J.C. (2010): Radiocarbon dating of small terrestrial gastropod shells in North America. *Quaternary Geochronology*, 5: 519-532

Red Información Ambiental de Andalucía (REDIAM) (2012): *Ortofotografía Digital*. Hoja 1061-4-4 (Last overview: February, 2016).

Rehault, J.P. Boillot, G.Y. and Mauffret, A. (1985): The western Mediterranean basin. In: *Geological evolution of the Mediterranean Basin* (D.J. Stanley and F.Z. Wezel, Eds). Springer, Berlin. 101-129.

Reimer, P.J., Hughen, K.A., Guilderson, T.P, McCormac, F.G., Baillie, M.G.L., Bard, E., Barratt, P., Beck, J.W., Brown, D.M., Buck, C.E., Damon, P.E., Friedrich, M., Kromer,.B, Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., and van der Plicht, J. (2002): Preliminary report of the first workshop of the IntCal04 Radiocarbon Calibration/Comparison Working Group. *Radiocarbon*, 44(3): 653-661

Ribeiro, A. (1995): Deformable plate tectonics of the Azores-Gibraltar boundary–where the next 1755 earthquake will strike again? In: *1er Simpósio sobre a margen continental Ibérica Atlântica*. Lisbon, 46-47.

Rodríguez de la Torre, F. (2005): *Documentos en el Archivo Histórico Nacional (Madrid) sobre el terremoto del 1 de Noviembre de 1755*. Ediciones Universidad de Salamanca. *Cuadernos Dieciochistas*, 6: 79-116.

Ruiz, F., Rodríguez-Ramírez, A., Cáceres, L.M., Rodriguez-Vidal, J., Carretero, M.I., Abad, M., Olías, M. and Pozo, M. (2005): Evidence of high-energy events in the geological record: Mid-Holocene evolution of the southwestern Doñana National Park (SW Spain). *Palaeogeography, Palaeoclimatology, Palaeocology*, 229: 212–229.

Sanz de Galdeano, C., Martin, A., and Rivas, P. (1993): Comments on structure and palaeogeography of the External Betic Cordillera, southern Spain. *Marine and Petroleum Geology*, 10: 518-521.

Silva, P.G., Borja, F., Zazo, C.J.L., Bardají, T., Luque, L., Lario, J. and Dabrio, C.J. (2005): Archaeoseismic record at the ancient Roman City of Baelo Claudia (Cadiz, South Spain). *Tectonophysics,* 408: 129–146.

Solares, J.M. and Arroyo, A.L. (2004): The great historical 1755 earthquake. Effects and damage in Spain. *Journal of Seismology*, 8(2): 275-294.

Stuiver, M., and Braziunas, T.F. (1993): Sun, ocean, climate and atmospheric $^{14}CO_2$, an evaluation of causal and spectral relationships. *Holocene*, 3: 289–305.

Stuiver, M. and Reimer, P.J. (1993): Extended ^{14}C database and revised CALIB3.0 14C age calibration program. *Radiocarbon*, 35: 215–230.

Stuiver, M, Reimer, P.J. and Braziunas, T.F. (1998): *Radiocarbon*, 90: 1127–1151.

Udias, A., López Arroyo, A. and Mezcua, J. (1976): Seismotectonics of the Azores–Gibraltar region. *Tectonophysics*, 31: 259–289.

Whelan, F. and Kelletat, D. (2005): Boulder deposits on the southern Spanish Atlantic coast: possible evidence for the 1755 AD Lisbon tsunami? *Science of Tsunami Hazards*, 23 (3): 25-38.

MANUSCRITO RECIBIDO EL 13-10-2015
RECIBIDA LA REVISIÓN EL 20-03-2016
ACEPTADO EL MANUSCRITO REVISADO EL 23-03-2016