The record of the tsunami produced by the 1755 Lisbon earthquake in Valdelagrana spit (Gulf of Cádiz, southern Spain)

El registro del Tsunami producido por el terremoto de Lisboa de 1755 en la flecha de Valdelagrana (Golfo de Cádiz, sur de España)

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ABSTRACT

Several washover fans breaking through the spit of Valdelagrana existing in middle 18th Century in the Guadalete estuary (Bay of Cadiz) are interpreted as the trace of the exceptional tsunami generated by the AD 1755 Lisbon earthquake, based on geological, morphological and historical arguments.

Key words: *tsunami deposits, Lisbon earthquake, Bay of Cadiz, recent coastal evolution.*

RESUMEN

A partir de pruebas geológicas, morfológicas e históricas interpretamos varios abanicos de sobrepaso (washover) que cortan la flecha de Valdelagrana activa a mediados del siglo XVIII en el estuario del Guadalete (Bahía de Cádiz) como la huella del excepcional tsunami producido por el terremoto de Lisboa de 1755.

Introduction

The so-called 1755 Lisbon earthquake, with Richter magnitude 8.5-9, produced devastation and triggered an extremely large tsunami that struck the western and southern shores of the Iberian Peninsula causing loss of lives and properties.

Much interest has arisen in recent times directed to find out the deposits associated to the exceptional tsunami as the remarkably high waves must have left a recognisable signal.

However, no record of the deposits generated by the tsunami has been found in southern Spain so far, not even in cores drilled in the Guadalete estuary, a few hundreds of metres inland of the Valdelagrana spit (Dabrio et al., 1998). The only references to tsunamigenic deposits assumed to be coeval of the 1755 event have been cited in southern Portugal near Tavira (Andrade et al., 1994) and Boca del Rio (Dawson et al., 1995).

In the Spanish littoral the only reference to deposits or effects of the tsunami upon changes of coastal morphology have been briefly suggested by Dabrio et al., (1998) in the Valdelagrana spit that partly closes the Guadalete estuary in the northern extremity of the Bay of Cádiz (Fig. 1). Written reports cited the destruction of the beaches connecting Cadiz with the mainland (Campos, 1992), but no durable effects or modifications have been studied.

Geological setting

The Guadalete estuary underwent tectonic subsidence during the Quaternary due to movements of faults such as the Puerto de Santa María (Fig. 1) and Cádiz. The last with NNE–SSW direction, and it limits the City of Cadiz to the east. These movements favoured the occurrence of the Guadalete river valley opening to the west. River incision took place during the Last Glacial period. During the postglacial rise of sea level, the seaward reaches of the valley were inundated and acted as a wave-dominated estuary separated from the sea by the complex spit barrier of Valdelagrana.

From detail mapping and morphosedimentary analysis coupled with ^{14}C dating in spit barriers of southern Iberian Peninsula it is possible to deduce that the first spit began to grow immediately after the maximum of the Present Interglacial (ca. 6.500 yrBP) in the most complete case preserved (Almería). Beach systems are composed of four spits (H_1 to H_4) that represent two major phases of coastal progradation: The first one between 6,500 and 2,700 yrBP, with a sedimentary gap at ca. 4,000 yrBP; and the second one from 2,400 yrBP up to present, with an intervening gap at ca. 900-800 yrBP (Dabrio et al., 1998). These progradational phases develop during still stands followed by relative sea-level fall, whilst the sedimentary gaps represent relative high sea level. In the Mediterranean areas with higher uplifting trend, marine terraces coeval to those gaps occur (Zazo et al., 1994; Goy et al., 1996).

No subaerial H_1 deposits have been found in the estuaries of the Gulf of Cadiz regardless of their dynamic regime (wave- or tide-dominated). This is the case even in estuary mouths with well-developed spit systems. Dabrio et al., (1998) suggested that the absence of H_1 is due to a combination of unfavourable factors. H_1
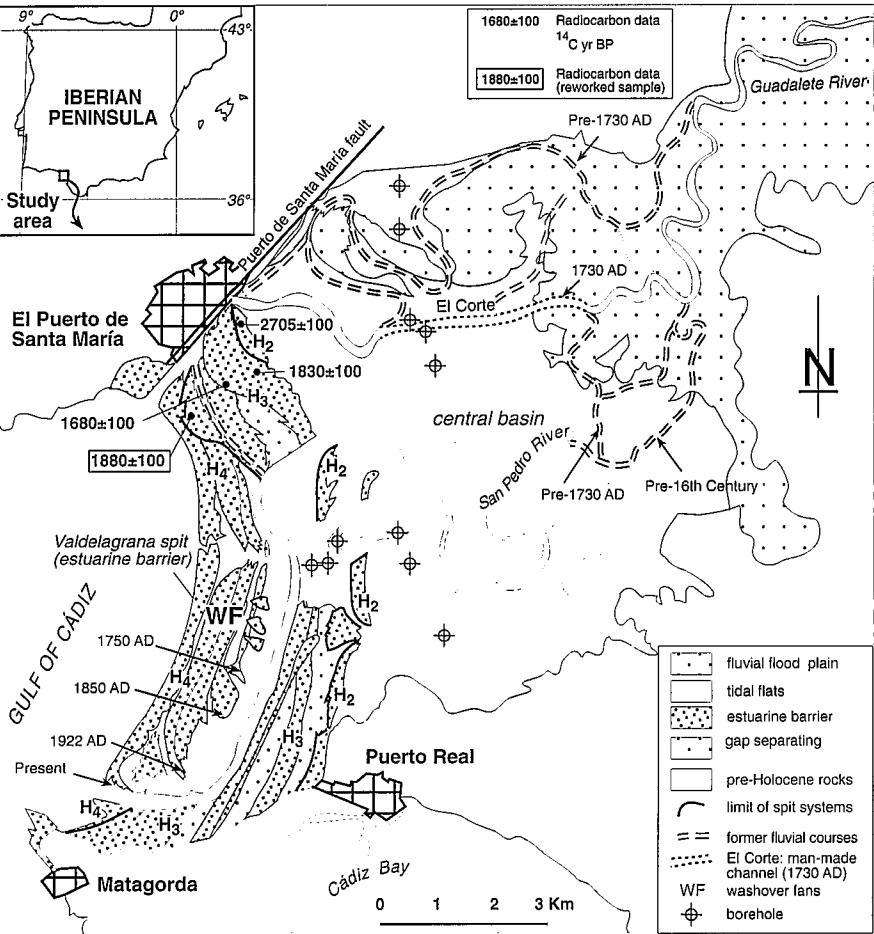
Fig. 1.- The Guadalete estuary and Valdelagrana spit system. Note breaching of the Valdelagrana spit active in the second half of the 18th Century and washover fans ca. 3 km NNE from Puerto real interpreted as the trace of the 1755 Lisbon earthquake. After Dabrio et al. (1998) and modified after Zazo et al. (1994).

Fig. 1.- El estuario del Guadalete y el sistema de flechas de Valdelagrana. Se aprecia la ruptura de la flecha de Valdelagrana activa en la segunda mitad del siglo XVIII y los abanicos de sobrepaso (washovers) unos 3 km al NNE de Puerto Real que se interpretan como la huella del terremoto de Lisboa de 1755. Según Dabrio et al. (1978) y modificado de Zazo et al. (1994).

was deposited in a period immediately after the maximum flooding, when a large part of the river input was retained inside the bay-head delta and did not reach the estuarine barrier. This probably means that the estuarine barrier during H_1 was not particularly large, and most of it was eroded before (or even during) the time of deposition of H_1 by tidal-inlet shift.

H_4 (800 yrBP-Present) records very rapid progradation of beaches and spits.

Coastal dynamics in the bay of Cádiz– its role in the record of Tsunamis

The coast of the Gulf of Cadiz can be described as a semidiurnal mesotidal coast with mean tidal ranges of 2.1 m. Wave energy is medium, because 75% of waves do not exceed 0.5 m in height. These conditions favour the development of broad littoral lowlands, usually sheltered by spit barriers. Washover fans are present in some places but they are not particularly abundant along the coast.

The relatively low energy of the coast may help to identify processes connected to normal or major storms from those of larger catastrophic events such as tsunamis.

As the gulf opens towards the south-west, the morphology of the coasts of southern Europe and north-western Africa imposes severe constraints to the propagation and greatly reduces the effectiveness of wave trains generated in the Atlantic Ocean. This was the case of the 1755 tsunami, and it is presently the case of Atlantic gales, and also of the daily and prevailing winds. Only wave fronts and surges moving towards the north-east are able to reach the shore. The oblique incidence of wave fronts induces in a large part of the shore longshore transport and littoral drift demonstrated by direct observation, measurements of sand transport, and the occurrence of active spit barriers along the coast. The maximum effect of Atlantic-generated waves must be expected in the eastern seashores of the Gulf, just around the City of Cádiz. As the Cádiz bay and its connected Guadalete estuary face the opening of the Gulf of Cádiz, it is likely to have received a major stroke from the sea during the tsunami.

Effects of the tsunami (Fig. 2)

Traditionally the source area of the earthquake is considered to be at the Gorringe Bank (SW from San Vicente Cape), that is a part of the complex Azores-Gibraltar plate boundary (Ribeiro, 1994). However, the precise location of the source area of this exceptional event is unclear; according to Ribeiro (1994), there are three possibilities: in the Gorringe Bank, along the western margin of Iberia, or in both places simultaneously.

Written reports indicate that the tsunami caused flooding and damages in public works in many places of the Gulf of Cádiz. The tsunami moved eastwards affecting the shores of Algarve (Southern Portugal) where damages varied from place to place depending on local morphology of the shore. Low-tide conditions greatly reduced the effects in many places such as Faro (Pereira da Sousa, 1919). Some kilometres eastwards, three waves overwashed the estuarine barrier of the Odiel-Tinto estuary (Huelva, southern Spain) during ebb tide flooding some parts of the city and causing damage (Camacho et al., 1997).

In contrast, the bay of Cádiz (southern Iberian Peninsula) was severely affected by the tsunami (Campos, 1992) owing to an unfortunate coincidence of factors: (a) The local funnel-shaped morphology of the shore, with the opening facing the west, i.e. the tsunami that, according to witnesses, came from the north-west; (b) The gradient of the continental shelf (shoreface) in the area (Fig. 2); (c) The high-tide conditions that magnified the tsunami waves which reached three metres above mean sea-level. A pole near the lighthouse of Chipiona (a
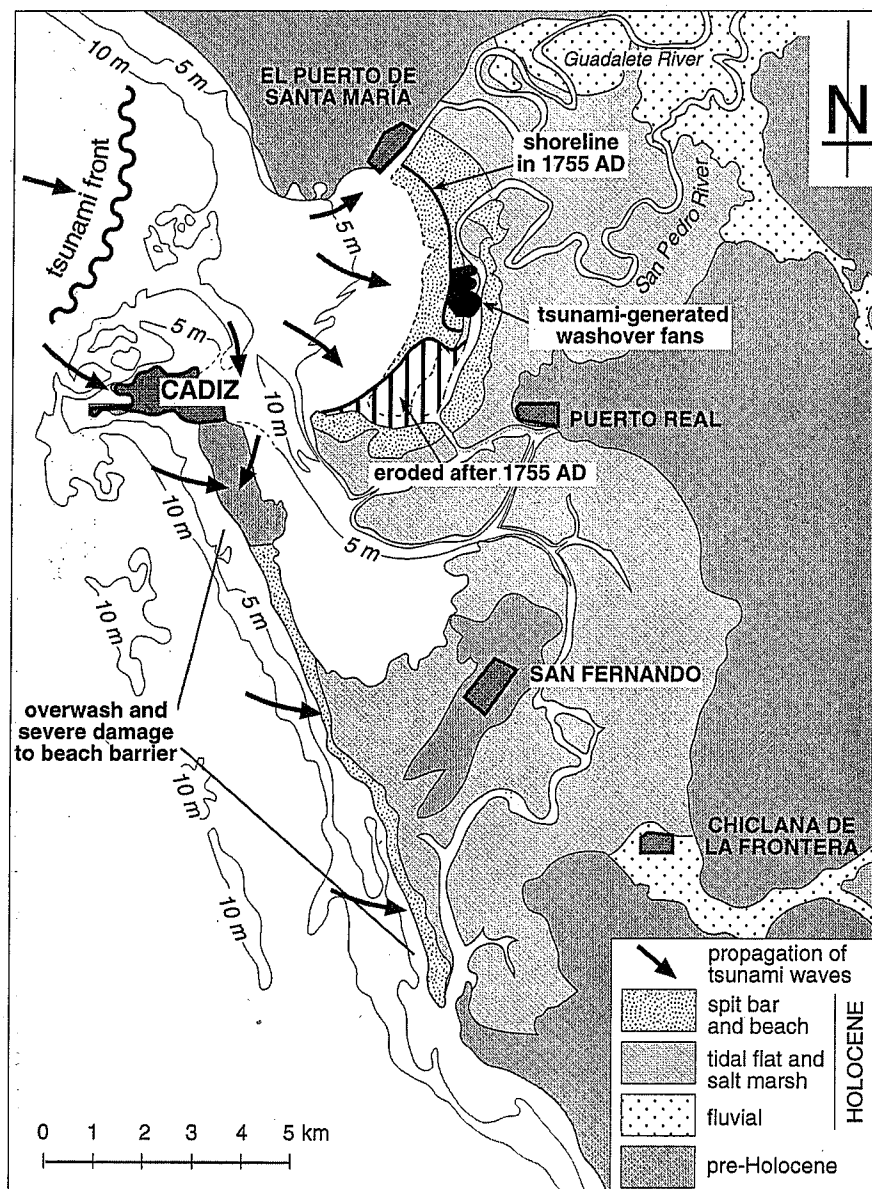
Fig. 2.- Map of the Bay of Cádiz and river courses about 1755. Note that villages have been represented smaller than to-day. Constructed with maps of an Anonymous Author (1740--1750), Barnola (1743), Rodolphe (1750), Coello (1842--1858), Tofiño de San Miguel (1789), and Rambaud (1996).

Fig. 2.- Mapa de la Bahía de Cádiz y los cursos fluviales alrededor de 1755. Nótese que las ciudades se han representado más pequeñas que en la actualidad. Elaborado a partir de mapas de un Autor Anónimo (1740--1750), Barnola (1743), Rodolphe (1750), Coello (1842--1858), Tofiño de San Miguel (1789) y Rambaud (1996).

San Pedro rivers, as late as the 18th Century. These channels supplied sand to the coastal areas as demonstrated by radiometric ages of shells collected from the channel fill facies (Dabrio *et al.*, 1998). There is morphological evidence that the spits did not completely close the bay.

The relative importance of the northern distributary of the river (Guadalete) as a supplier of sand to the coastal zone increased after public works in 1730 AD (H_4). Renewed input of sand to the northern extremity of the estuarine barrier favoured the rapid growth of a spit (largely, the present Valdelagrana spit) towards the south (Rambaud 1996), sheltering, in the process, the mouth of the axial channel. Eventually the abandoned and almost-filled former active channel became the residual meandering tidal channel, known as the San Pedro river, which is no longer fed by the main river, but ends aimlessly in the intricate supratidal flats.

The washover fans considered in this paper dissect only the spit barrier active in 1755 AD (Fig. 3).

There are only two isolated washover fans crossing the beach crests of the spit barrier deposited after 1755 AD (Fig. 3). Moreover, they did not deposit much sand, although one of them is relatively large. This means that the studied washover fans record an exceptional event which took place shortly after the only available map (1750) depicted the barrier active in middle 18th century.

It is not easy to date with the required accuracy the precise age of washover-fan generation but this is the most likely explanation for these remarkable coastal features. No suitable fossil remains have been found so far.

Acknowledgements

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few kilometres NW from Cadiz) marked the topographic height reached by the waves. In the early 1980s, the present authors observed it to be more than 3 m above mean sea level.

A set of three washover fans dissecting the spit existing at ca. 1750 AD (Figs. 1 and 3) may be the result of the 1755 Lisbon earthquake.

As the area immediately to the south of the spit has been eroded after 1755 due to the migration of the channel (San Pedro River) it is not possible to find preserved deposits in this sector. This area must have undergone severe damages as it protected the village of Puerto Real from direct wave damage.

Geological proofs (Figs. 2, and 3)

Morpho-sedimentary analysis of spits and tidal inlets indicates that there were two main estuarine channels, roughly coincident with the present Guadalete and
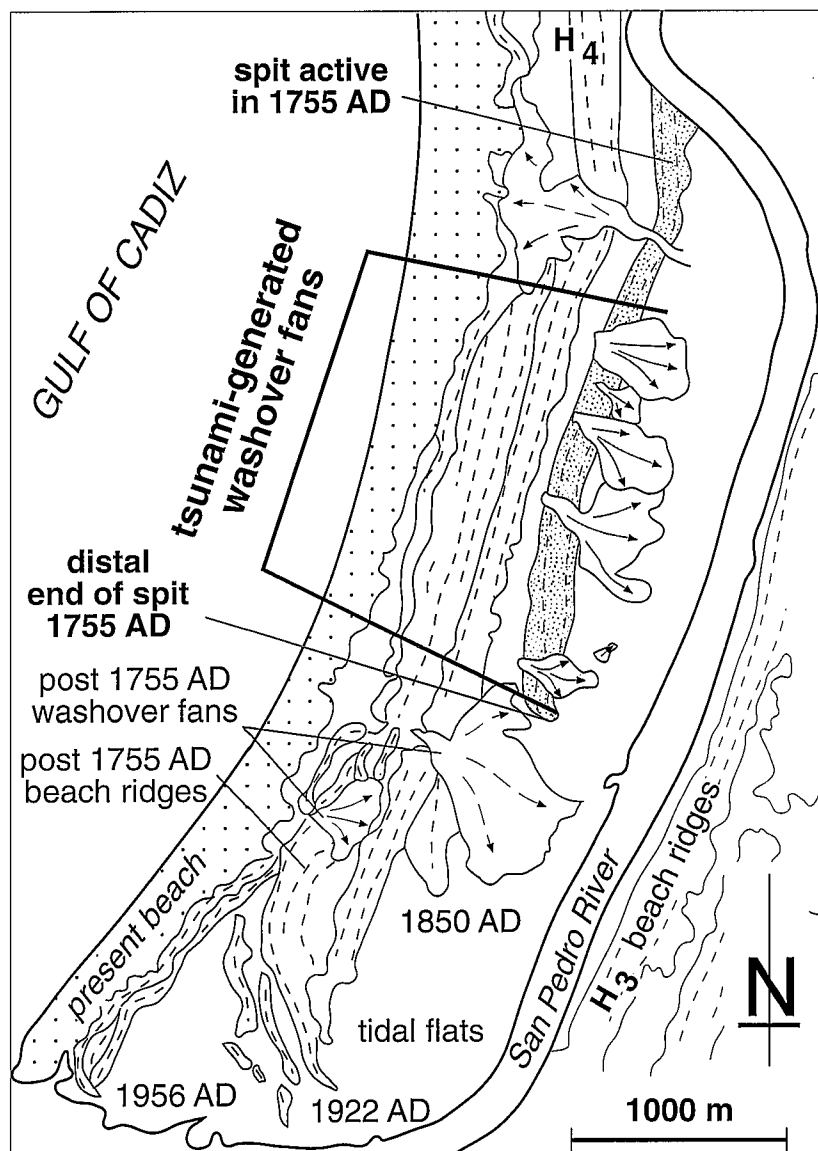
Fig. 3.- Detail map of the Valdelagrana spit barrier sowing the spit active in 1755 and the generalised washover-fan generation. Younger spit units have been represented in a sketchy way. Note that only one washover fan has been formed after 1755. Drawn from air photograph taken in 1956.

Fig. 3.- Mapa detallado de la flecha de Valdelagrana mostrando la flecha activa en 1755 y la formación de muchos abanicos de sobrepaso (washover). Las unidades más recientes de la flecha se han representado de una forma más esquemática. Obsérvese que sólo se ha formado un abanico de sobrepaso (washover) desde 1755. Dibujado a partir de una fotografía aérea tomada en 1956.

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