Late Messinian coastal barrier and washover fan sedimentation in Sorbas (SE Spain)

Sedimentación en islas barrera y abanicos de washover en el Messiniense Superior de Sorbas (S.E. España)

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ABSTRACT

Deposition of washover fans in coastal settings are related to accommodation space, slope of the basin margin, and coeval changes of sea level. Some preliminary models of development and stacking of sand bodies are presented.

Key words: *Controls of sedimentation, coastal deposits, beach barrier, washover fan*

RESUMEN

El depósito de washover fans en áreas costeras está relacionado con el espacio de acomodación disponible, la pendiente del margen de cuenca y los cambios coetáneos de nivel del mar. Se ofrecen modelos preliminares del desarrollo y apilamiento de cuerpos arenosos.

Palabras clave: *Controles sedimentarios, depósitos costeros, islas barrera, abanicos de washover.*

Geogaceta, 21 (1997), 89-92
ISSN: 0213683X

Introduction

Beach-barrier sediments are easily recognised in the fossil record by the usually well-preserved, gently inclined swash lamination. But barrier islands include a wider variety of sedimentary environments, each producing definite sedimentary structures and vertical sequences of sedimentary facies that include erosional surfaces. Towards the sea, coastal sedimentary units interfinger with muddy shelf deposits; landward they end abruptly, or change facies in short distances to tidal, lagoonal, swash and fluviatile deposits producing complex stacking patterns of coastal facies.

Back barrier environments and sediments are well known in present day examples, but are less precisely considered in fossil examples, where they are usually referred to as backbarrier or washover-fan facies, and supposed to interfinger with tidal or fluvial deposits.

A detailed knowledge of the 3-D arrangement and lateral facies relationships of the stacking patterns in coastal deposits are essential to approach many geological problems such as precise tracing of sea level changes, particularly when small scale fluctuations are involved, modelling of sand

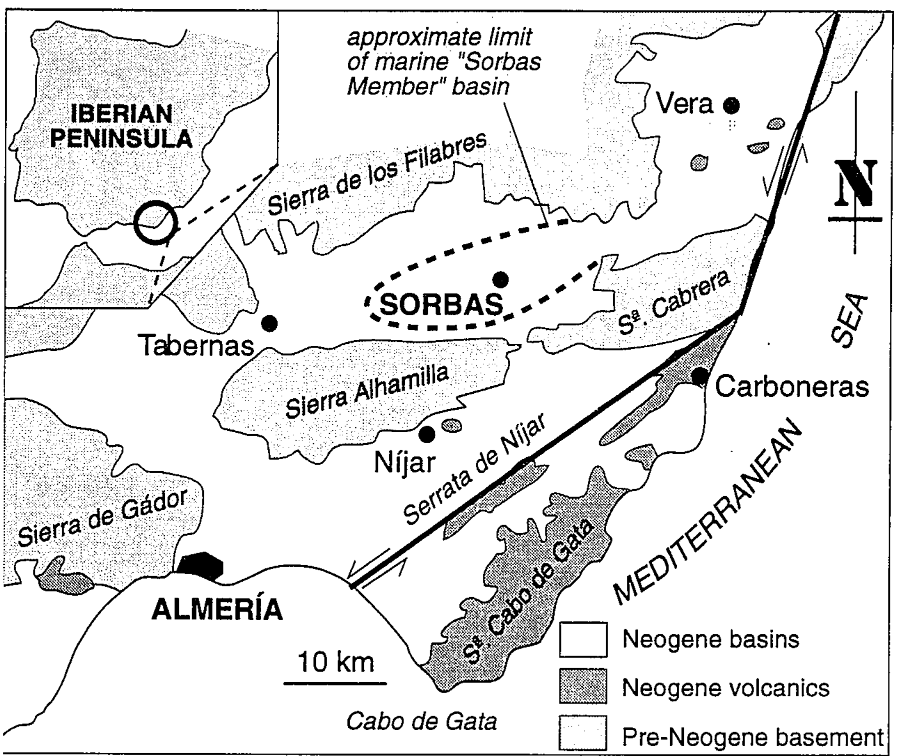

Fig. 1.- Location map.

Fig. 1.- Mapa de localización.

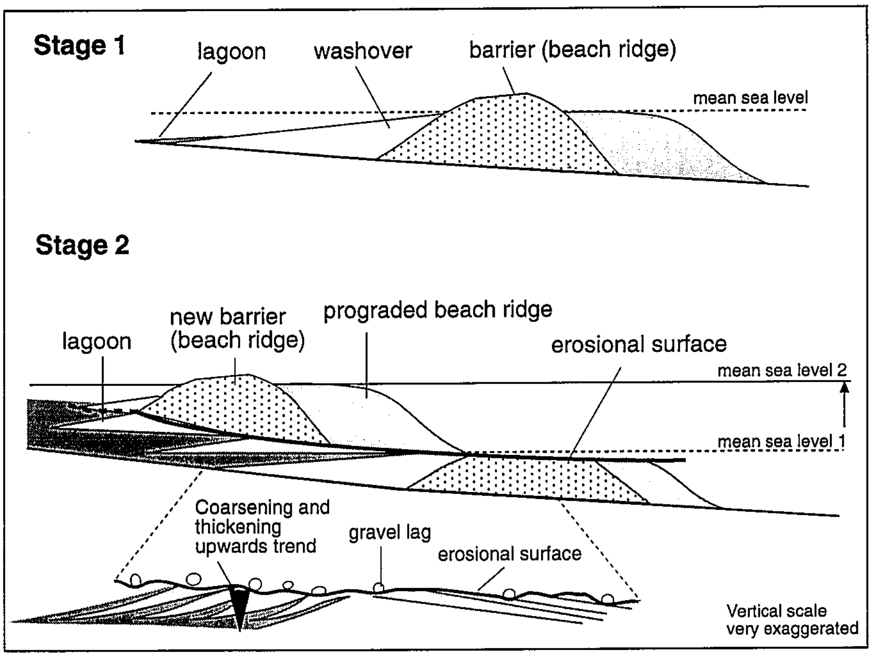

Fig. 2.- Sketch of facies relationships resulting from a rise of sea level in beach barrier environments, with generation of washover fans and erosional surfaces (vertical scale exaggerated).

Fig. 2.- Esquema de las relaciones de facies producidas por una subida del nivel del mar en un ambiente de playa barrera, con generación de abanicos de washover y superficies erosivas.

bodies acting as migration pathways and seals, or having potential interest as reservoir.

It is well known that the highly-variable architecture of sedimentary bodies deposited in coastal settings is governed by sediment supply, wave-and tidal processes, coastal morphology, and accommodation space. But these parameters change with time, and erosional surfaces may play a prominent role in areas located towards land, once a given topographical position above base level is reached. Besides, lateral shift of erosional or depositional loci very often results in destruction of large parts of the sediment record.

We studied washover fans in coastal deposits and related them to accommodation space, slope of the basin margin, and coeval changes of sea level changes, offering a few preliminary models of sand-body development and stacking. The study is based on the upper part (informally called Unit III) of the late Messinian Sorbas Member in southern Spain, because of the magnificent outcrop allows detailed three-dimensional observation.

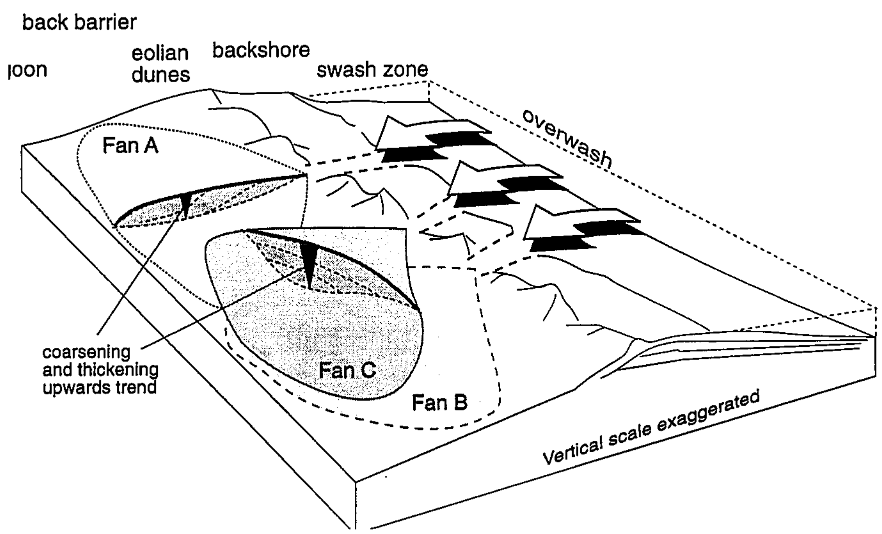

Fig. 3.- Repeated overwash that produces laterally and vertically stacked washover fans. Schematic longitudinal and transversal sections illustrate internal structure (vertical scale exaggerated).

Fig. 3.- Overwash repetido que produce abanicos de washover apilados lateral y verticalmente. Las secciones esquemáticas longitudinal y transversal ilustran la estructura interna.

Geological setting

Following the fall of sea level that favoured the deposition of Messinian gypsum in western Mediterranean basins, a minor transgression occurred during which the coastal deposits of Sorbas were deposited.

These deposits consist of a stack, up to 70m thick in total, of three units with roughly coarsening-upward vertical trends, informally called I, II, and III, formed during temporary seaward progradation to the east (Roep *et al.*, 1979).

Beach progradation took place in the western termination of the relatively narrow, east-west oriented embayment that formed the basin at that time (Fig. 1). We assume that the repeated progradations and outbuilding of the coast that generated Units I, II and III are tied to relative changes of sea level in the order of tens of meters. By contrast, the vertical stacking of lagoon, washover, and barrier deposits, algal stromatolites and erosional surfaces in Unit III point to minor, meter sized, fluctuations of sea level that rose hardly enough to cover the topographical irregularities of the coastal zone and allowed little accommodation space.

A large part of the calcarenite Unit III observed around Sorbas was generated during transgressive events, as landward up-stepping washover fans, interfingering with lagoonal muds. Due to further transgression, coastal erosion removed a part of these washover fans, and barriers with active swash zones facing the sea (to the east) accumulated upon the erosional surface. Subsequent sea-level drops forced the coastline to jump seaward and barriers were left behind as "stranded" ridges, whereas renewed transgressions moved new girdles of washover fans towards land overstepping previous barriers. Progradation occurred in the most seaward part of Unit III.

Paleomagnetic data (Gautier *et al.*, 1993; Hilgen *et al.*, 1995) allow us to

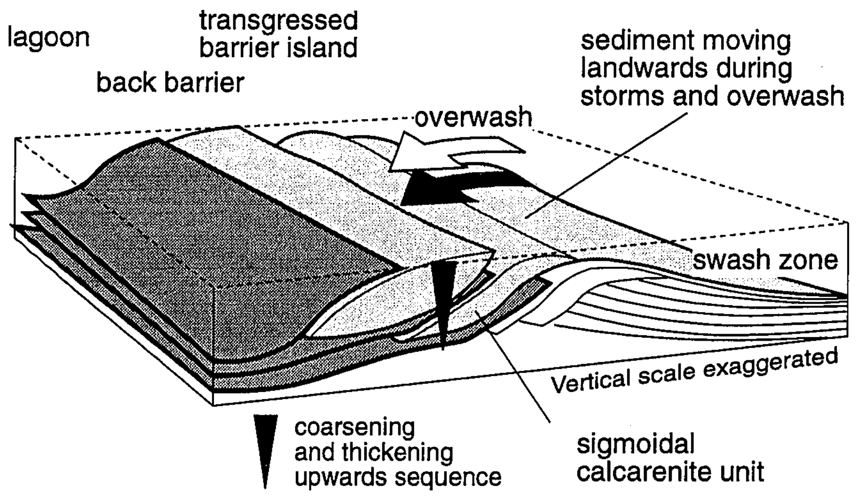

Fig. 4.- Overwash of the whole beach barrier and generation of sigmoidal units of beach derived sediments that interfinger with lagoonal mudstone (vertical scale exaggerated).

Fig. 4.- Overwash de toda la isla barrera y generación de unidades sigmoidales de sedimentos derivados de la playa que se interdigitan con las lutitas del lagoon.

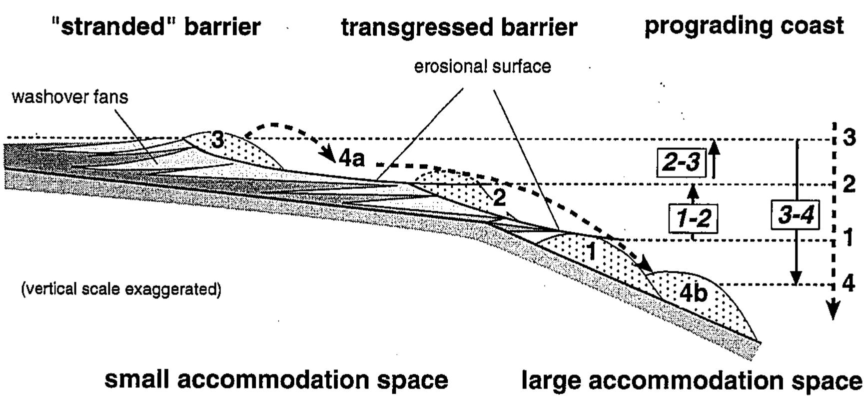

Fig. 5.- Influence of the available accommodation space in the generation of coastal units. 1 to 4 are ideal steps during a fluctuation (rise followed by fall) of sea level.

Fig. 5.- Influencia del espacio de acomodación disponible en la generación de unidades costeras. 1 a 4 son pasos ideales durante una fluctuación (subida-descenso) del nivel del mar.

estimate that many of the smaller jumping episodes of Unit III studied here are probably related to fluctuations with periodicity of about 2,5 Ka.

Coastal deposits

Shelf to basin sediments are mostly grey siliciclastic micaceous sandstones, silt and clay. Beach deposits are calcarenites that include coated grains, and oolites, coexisting with gravels partly derived from local erosion of the barrier during beach retreat.

Lagoon deposits are yellowish to white parallel laminated silt and clay, with mud cracks, raindrop imprints, salt pseudomorphs, insects, rootlets and plant remains and imprints of diverse animals (Roep *et al.*, 1979; Roep and Beets, 1977; Kenter, pers. com.). Thin (1 to 3 cm thick) layers of fining upward, siliciclastic sandstone that occur interbedded are interpreted as deposited during floods from fluvial systems feeding the coastal lowlands.

Sediments of washover-fan facies are wedge-shaped layers of calcarenite that occur stacked vertically and tend to diverge from the beach barrier, thinning distally until they end between lagoonal muds. Sediment forming these layers derive from the barrier island with minor contribution from the shoreface/shelf. Vertically, such successions linked to transgression may be thought to have thickening upward character, because of the transgressive advancing coastline.

Lithological differences in shelf, barrier island, lagoon, and washover-fan deposits reveal the diversity of source areas and coastal transport:

(a) Rivers bringing in siliciclastics with variable grain size.

(b) In situ precipitation of carbonate as oolites, coated grains, stromatolites and thrombolites, probably under a warm climate.

(c) Littoral drift (longshore currents) moving sediment into the barrier from sources of sediment located to the north as deduced from dominant lithology.

Sequences in washover fan

Lagoonal and related deposits are limited upwards by erosional surfaces overlain by layers of beach-rock breccia generated during ensuing transgressions, which implies that sea moved landward at the cost of the washovers. Then occur the prograding beach facies marking a new regression (Fig. 2). This is repeated upwards and, mostly, laterally around Sorbas.

Coastal facies models usually assume the well-known picture of girdles of washover fans moving towards land and shifting laterally with transgressions and regressions according to the position of the coastline. Landward progradation of washover fans generates thickening and coarsening upwards sequences, often truncated during the ongoing transgression (Fig. 2).

However, such a simple scheme can not be maintained because of the facies relationships resulting from landwards and seawards shift of sedimentary environments induced by sea-level fluctuations are further complicated by simultaneous displacements alongshore of overwash and their related washover fans, tidal inlets and deltas, eolian ridges, etc. forced by littoral drift, prevailing winds, and other causes (Fig. 3). As a result, what we see are compensation cycles that resemble the type described by Mutti and Sonnino (1981) for submarine fan lobes.

We found thickening upward, thinning upward and irregular sequences, for which we infer the following scenario: at places were a barrier is pierced during storm relatively thick stacks of washover fans accumulate, but (owing to their fan shape) they thin away from the breech towards

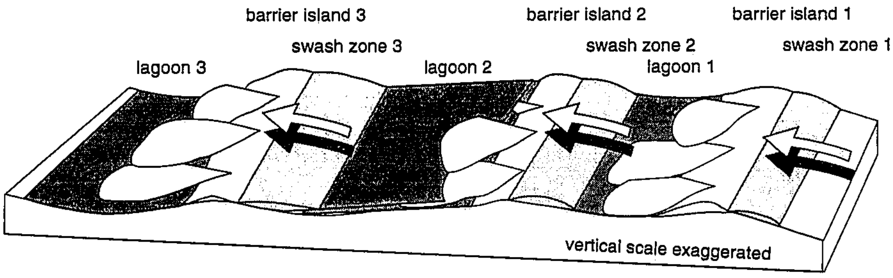

Fig. 6.- Influence of irregularities in the substratum on the location of beach ridges and lagoons: Topographically-higher areas act as nucleation (root) areas for accumulation of barrier island, whereas lower areas serve as swales that evolve into lagoons.

Fig. 6.- Influencia de las irregularidades del substrato en la generación de crestas de playa y lagoones: las zonas topográficamente más elevadas actúan como zonas de nucleación de islas barrera mientras que las deprimidas son ocupadas por lagoones.

both land and any other places close to the coastline where it was not pierced. Later the reverse may occur, as the barrier islands is broken or surpassed in different places. This, coupled with variable rates of sea-level rise may produce diverse types of large-scale cross bedding in the landward-migrating backbarrier.

In other cases, generalised overwash of the barrier produces coarse-grained sigmoidal units that interfinger down-wards and landwards with lagoonal muds (Fig. 4).

Sedimentary controls and synthetic models

Transgression after deposition of calcarenite unit II created a wedge-shaped accommodation space to the east ("sea") that changed to a more box-shaped space towards the west ("land") (Fig. 5). As the accommodation space available for deposition of unit III was neatly different in these two places, it occurs with distinctive geometry and facies distribution. Thus, unit III displays a complex arrangement of facies, associated with extensive deposition of washover-fan sand and lagoonal mud in back-barrier settings, seaward and landward step of coastlines, and progradation in the deeper (eastern) part of the unit. This is interpreted as the result of a jumpy behaviour of the coastline.

Taking the thickness of Unit III as an indicator of water depth and magnitude of sea-level fluctuations involved in the changes of coastlines, a water depth of ca. 10m was deduced. This is further supported by the position that occupy in the vertical sequence certain sedimentary features indicative of the coastline such as bird-foot tracks, swash zones, and beach-rock levels.

There are three types of barrier deposits and swash zones in unit III (Fig. 5): (1) "stranded" coastal barriers left behind after seaward jump of the coastline during regression; (2) swash zones connected with erosional parts of the coastline at the cost of landward-lying washover sediments; and (3) prograding coastal sequences.

The reason for this complex behaviour lies in the limited depositional space (accommodation), where minor fluctuations of sea level have great influence, and usually result in dramatic regressions and transgressions. Slight regressions, for example, may cause an offshore bar to build up quickly near or above sea level, after which the coastline jumps seaward. Thus, the three types can be related laterally to the variable accommodation space during a fluctuation of sea level (Fig. 5).

Besides the available accommodation space, there is still one more factor that controlled the generation and preservation or destruction of washover fans in the Sorbas Member: The bottom (top of Unit II) was not perfectly plane and horizontal: Instead, gentle north-south directed, synsedimentary topographic irregularities, 3 to 4m high, further restricted the already limited vertical space available for sedimentation. Interference of these irregularities with the oscillating sea level contributed to the jumpy trend of the coastline. This effect added to the angle of incidence of waves under E-W prevailing winds. The origin of irregularities is related to gentle folding.

Topographically-higher areas acted as nucleation (root) areas for accumulation of barrier island, whereas lower areas acted as swales that evolved into lagoons (Fig. 6). One of the zones preferred for lagoon and washover-fan development is located just under Sorbas town.

Acknowledgements

CJD and MDP received financial support from European Union Project EV5V-CT94-0445 and Spanish DGICYT Project AMB95-1005-CE. It is a part of INQUA Shorelines Commission and IGCP Project 367.

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