Marine Geology 369 (2015) 52–66

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margeo

Early cementation and accommodation space dictate the evolution of an overstepping barrier system during the Holocene

Giovanni De Falco [a,*], Fabrizio Antonioli [b], Giorgio Fontolan [c], Valeria Lo Presti [d], Simone Simeone [a], Renato Tonielli [e]

[a] Istituto per l'Ambiente Marino Costiero CNR, Località Sa Mardini, 09170 Torregrande Oristano, Italy
[b] Enea — Unit for Environment and Energy Modeling, via Anguillarese 301, 00123 Roma, Italy
[c] Dipartimento di Matematica & Geoscienze, Università degli Studi di Trieste, via E. Weiss, 2-34128 Trieste, Italy
[d] Università degli Studi La Sapienza Roma, Piazzale Aldo Moro 5, 00185 Roma, Italy
[e] Istituto per l'Ambiente Marino Costiero CNR, Calata Porta di Massa Interno Porto, 80133 Napoli, Italy

ARTICLE INFO

Article history:
Received 11 March 2015
Received in revised form 15 July 2015
Accepted 1 August 2015
Available online 3 August 2015

Keywords:
Barrier
Beachrocks
Lagoon
Antecedent topography
Relative sea-level rise
Flooding

ABSTRACT

The morphology and stratigraphic features of a well-preserved drowned barrier system, located on the western coast of Sardinia (Mediterranean Sea), are presented here. The barriers were mapped using a multibeam echosounder. The Digital Terrain Model of the seabed revealed five sub-parallel barriers in a depth range of 18–37 m, with a distance of ~300 m between each single barrier. Direct inspection by scuba diving, revealed that the barriers consist of beachrocks, topped by seagrass meadows growing on a biogenic hardground. The inner-most barrier is limited landward by a steep cliff, 10 m high, bordering the back-barrier area. About 200 km of seismic lines were collected along the barrier system using a 0.4–1.0 kJ sparker source and a 3.5 kHz Chirp Subbottom profiler. The seismic data, calibrated with vibrocores, allowed us to recognize the subaerial topographic surface of the last glacial maximum as well as several seismic units interpreted as the Pliocene marine sediments, the pre-Holocene deposits and the Holocene barrier–lagoon complex composed of shoreface, barrier, lagoonal/deltaic and beach deposits.

Despite the relatively high seabed gradient (0.3°–0.4°) and the relatively low rate of sea-level rise (10–15 mm y^{-1}), the barriers were well preserved due to the early diagenetic processes which led to a rapid cementation with the formation of beachrocks, and the subsequent overstepping with the rise of the sea level. The development of the overstepping barrier system is strictly related to the antecedent subaerial topography which is, in turn, related to the tectonic setting of the area. The Pliocene seismic unit was lowered by a direct fault at the entrance of the gulf forming a depression filled by sediments. The overstepping barrier system developed following the increase of the seabed gradient and was limited landward by the above-mentioned depression which increased the accommodation space. Following the sea-level rise and the barrier formation, this depression was filled by lagoonal sediments, washover fans and sediments coming from the rivers.

The age model of barrier evolution, based on previous sea-level-rise curves during the Holocene, supported by radiocarbon data, highlighted that the whole system evolved over a time period of 1 ka; while the time elapsed from this formation to the drowning of single barriers was estimated to be in the order of magnitude of centuries. Scenarios of short-term evolution of modern barrier–lagoon systems of the adjacent coastal sector, under conditions of accelerated sea-level rise, according to Church et al. (2013) (2013 IPCC report) and Rahmstorf (2007) projections, were elaborated. The study of this ancient analogue suggests that the processes of adaptation of coastal systems to the rising sea level would require times evaluable from centuries to millennia.

1. Introduction

Late Quaternary barrier–lagoon systems that migrate landward as sea level rises have been found in several sites over clastic transgressive coasts (e.g., Swift, 1968; Belknap and Kraft, 1981; Nummedal and Swift, 1987). Understanding their dynamics is essential since they provide well-documented ancient analogues to possible future scenarios of coastal evolution under conditions of accelerated sea-level rise.

The term 'coastal barrier' for modern coastlines, has been used to refer to different geomorphological features from its early definitions to the recent scientific literature. Otvos (2012) reviewed the nomenclature and classification issues of coastal barriers considering two basic types: 1) barrier islands, a physiographic, hydrographic, sedimentary

* Corresponding author.
E-mail addresses: giovanni.defalco@cnr.it (G. De Falco), fabrizio.antonioli@enea.it (F. Antonioli), fontolan@units.it (G. Fontolan), valeria.lopresti@uniroma1.it (V. Lo Presti), simone.simeone@iamc.cnr.it (S. Simeone), renato.tonielli@cnr.it (R. Tonielli).

http://dx.doi.org/10.1016/j.margeo.2015.08.002
0025-3227/

and ecological boundary parallel to the shore which is located between the inshore and open marine environments, and 2) barrier spits, which are linked to the mainland shore at their updrift terminus, and may partially close the entrance of narrow, elongated lagoons parallel to the shore (Otvos, 2012). Modern barrier islands are extended worldwide along 20,783 km of coastline, 10% of all continental shorelines, mainly along wave-dominated coasts, which were subjected to a rising sea level in the late Holocene (5 ka BP to present) (Stutz and Pilkey, 2011).

Barrier–lagoon systems include the shoreface sector, the barrier and the back-barrier sector, where washover fans and lagoons develop (Mellett et al., 2012; Otvos, 2012).Their formation is related to the interplay between wave energy, sediment supply, accommodation space and rate of relative sea-level rise (Hesp and Short, 1999).

In particular, barriers and back-barrier–lagoons can develop when the substrate gradient ranges between 0.05° and 0.8° (Roy et al., 1994). The barrier development, type and stability depend on the amount of sediment available to build them and on the quality of sediment supplied to the system. Barrier islands receiving a surplus of sandy sediment may grow to considerable length and width, whereas barriers receiving mud-rich sediments tend to be narrow (Stutz and Pilkey, 2011).

Wave energy is essential for barrier formation. Most extensive barriers are formed along wave-exposed coasts, but they also exist in fetch-limited environments (Pilkey et al., 2009). The relative importance of storm waves on barrier islands may be predicted by the ration of the maximum storm wave height relative to the mean height (Stutz and Pilkey, 2011). Higher ratios (>5), typical of Arctic islands, are associated with storm-dominated barriers, while lower ratios (<3), typical of tropical islands, are associated with barriers evolved in response to fair-weather swells (Stutz and Pilkey, 2011). Intermediate ratios (3–5) are generally typical of temperate barrier systems. Overwash and inlet formation are frequent in storm-dominated settings, particularly along microtidal coasts (Hayes, 1979).

Sea-level rise is one of the main processes which led to the formation of present-day barriers (Swift, 1975) and rapid increases in the sea level may lead to barrier breakup and drowning (Carter et al., 1989; Storms and Swift, 2003; Lorenzo-Trueba and Ashton, 2014).

Another relevant factor which controls the barrier development is geological inheritance. This controls the accommodation space for sediments in terms of coastal geomorphological setting and topography of the transgressive surface (Belknap and Kraft, 1981; Evans et al., 1985). Barrier behavior is sensitive to changes in the back-barrier slope (Storms and Swift, 2003), and barrier drowning is more likely in flatter back-barrier surfaces (Lorenzo-Trueba and Ashton, 2014).

The preservation potential of drowned barriers and related transgressive deposits is considered relatively low in comparison to the deposits associated with regressive coasts (Storms and Swift, 2003). Two basic models of barrier retreat under transgressive conditions were proposed: (i) the rollover model is generally considered the dominant retreat process, and involves a continuous migration of the barrier systems following the shoreline retreat, with the reworking of shoreface and barrier deposits and the absence of deposit preservation offshore (Swift and Moslow, 1982; Leatherman et al., 1983); (ii) the barrier retreat through overstepping involves a partial preservation of transgressive deposits or barrier morphology following a fast rate of sea-level rise (Rampino and Sanders, 1980, 1982, 1983; Forbes et al., 1991; Storms et al., 2008; Mellett et al., 2012). In particular, gravel barriers are more likely to be preserved (Long et al., 2006; Mellett et al., 2012).

The acquisition of high resolution multibeam echosounder data during the last decades highlighted the occurrence of preserved morphology of overstepped barriers along some shelf sites, such as the Gulf of Mexico-North West Florida (Gardner et al., 2005, 2007), the Adriatic Sea (Storms et al., 2008), and the KwaZulu-Natal — Durban continental shelf, South Africa (Green et al., 2013; Salzmann et al., 2013). Meanwhile, the occurrence of barrier–lagoon transgressive deposits was revealed by seismic surveys and vibro-coring (Rampino and Sanders, 1980; Storms et al., 2008; Mellett et al., 2012), but there generally is a scarcity of examples of well-preserved drowned systems.

The cementation of beach deposits, forming the so-called beachrocks (Vousdoukas et al., 2007), may favor the preservation of barrier morphology and related transgressive deposits (Green et al., 2013; Salzmann et al., 2013). Beachrocks are currently found in tropical/subtropical and low temperate latitudes, and microtidal coasts (Vousdoukas et al., 2007). In the Mediterranean sea, their presence is only reported in the eastern basin. However, several examples of Late Pleistocene–Holocene beachrocks, used as markers of the last sea level rise, were also reported in the western basin (Demuro and Orrù, 1998; Mauz et al., 2015).

In this paper, we show a case study of a well-preserved transgressive barrier–lagoon system located in a high wave energy area (Cucco et al., 2006), the western Mediterranean, formed by overstepping barriers and back-barrier deposits. The coupling of geophysical data (multibeam and seismic), sediment (vibrocores, grab samples) and radiocarbon data, provided a detailed paleo-environmental reconstruction of the evolution of such a barrier–lagoon system.

The specific aims of the paper are (i) to show how barrier cementation and the topography of the pre-existing surface influenced the formation and retreat through overstepping of a transgressive barrier–lagoon system during early Holocene; (ii) to infer the time interval and the sea-level variation which occurred from the formation of the system up to their definitive drowning; and (iii) to infer possible future evolution scenarios of the adjacent coast under conditions of accelerated sea-level rise, based on this well-documented ancient analogue.

2. Regional setting

The study area is located along the inner shelf of western Sardinia (western Mediterranean Sea), at the entrance of the Gulf of Oristano (Fig. 1). The gulf has a surface area of approximately 150 km^2, and is bordered to the West by two rocky capes. The sandy shores are composed of barrier–lagoon systems, sandy spits, and attached barriers while the backshore is an alluvial plane with lagoons and dune systems. Several inlets allow for the connection between the lagoons and the sea. The Tirso river, whose mouth is located in the northeastern sector of the gulf, is the main source of sediments from the land. The inland plane was deeply modified during the past century by heavy drainage works and water channelization in order to promote the use of the land for agriculture.

The gulf represents the western boundary of the Campidano graben, a Pliocene–Quaternary structural depression which is oriented NW–SE. This basin is a half-graben with the main depocenter located in the Gulf of Oristano. It is bordered by an eastward dipping master fault located between the two capes of the gulf (Casula et al., 2001). The geological setting of the emerged land includes a Neogene sequence of marine sedimentary and volcanic formation outcropping in the Sinis Peninsula to the north and Cape Frasca to the south, overlying the Hercynian basement. Eastward, in the Campidano area, continental, brackish and marine Quaternary deposits occur.

The upper terms of the Neogene marine sequence, composed of Early Pliocene marine deposits, were found offshore the gulf entrance, below a thin layer of Quaternary sediments (Francolini et al., 1990; Lecca, 2000). Eastward, the Neogene marine sequence is tectonically dropped down and a thick succession of Pliocene–Quaternary deposits fills the gulf basin (Casula et al., 2001).

The gulf seafloor is colonized by two meadows of the seagrass *Posidonia oceanica* down to a depth of 15 m, separated by a barren channel running from the entrance of the gulf to the Tirso river mouth where deltaic river deposits are found (De Falco et al., 2006, 2008). The northern meadow is planted over a biogenic sedimentary substrate composed of carbonate sediments. The wider meadow is located in the central sector and is planted over coarse siliciclastic sediments derived from the wave winnowing of alluvial deposits (De Falco et al., 2008).