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THE ROLE OF BEACH RIDGES, SPITS OR BARRIERS ~~(SO-CALLED *GIVONI*)~~ IN UNDERSTANDING ~~THE FORMATION AND EVOLUTION~~MARINE TERRACES PROCESSES ~~OF MARINE TERRACES~~ ON LOOSE OR SEMI-CONSOLIDATED SUBSTRATES: INSIGHTS FROM THE "*GIVONI*" OF THE GULF OF TARANTO (SOUTHERN ITALY).

Vincenzo De Santis [a,*], Massimo Caldara [a], Trinidad Torres [b], José E. Ortiz [b], Yolanda Sánchez-Palencia [b]

[a] Dipartimento di Scienze della Terra e Geoambientali, Via Orabona 4,
Università degli Studi di Bari "Aldo Moro", 70125 Bari, Italy;
[b] Biomolecular Stratigraphy Laboratory, Madrid School of Mines, C/Rios
Rosas 21,
E-28003 Madrid, Spain.

[*] *Corresponding author. Tel.: 0039 080 5442471; Fax: 0039 080 5442625*
E-mail addresses: vincenzo.desantis@uniba.it (V. De Santis), massimoangelo.caldara@uniba.it (M. Caldara), trinidad.torres@upm.es (T. Torres), joseeugenio.ortiz@upm.es (J.E. Ortiz), yolanda.sanchezpalencia@upm.es (Y. Sánchez-Palencia)

Abstract

This paper presents a detailed geological and geomorphological analysis of the so-called *givoni* ~~,~~ ~~which are~~(low-relief, mainly gravelly landforms subparallel to the coastline)~~,~~ associated with ~~of~~ the MIS 5 terrace in the northern Gulf of Taranto (southern Italy). These landforms can be interpreted as former beach ridges, swash/drift-aligned spits or swash/drift-aligned barriers (BSBs); thus, *givoni* are palaeoshoreline indicators. In the study area, recognising the classic landforms ~~present~~ associated with ~~in the~~ marine terraces, that is, surfaces and scarps, is difficult as the *givoni* are often associated and variably combined with surfaces and scarps. Thus, we reconstruct the formation and evolution processes of the MIS 5 marine terrace, ~~that~~ including~~e~~ the formation of surfaces, scarps and BSBs (and the resulting composite landforms), in an overall evolutionary framework based on eustatic oscillations. Then, we reconstruct a complete set of ~~cases that lead to the formation of BSB in relation~~ situations in which BSBs form on loose or semi-consolidated substrates in response to eustatic oscillations~~ on loose or semi-consolidated substrates~~: 1) BSBs can form during a highstand of a warm stage on previously consolidated sediment; 2) BSBs may represent coastlines formed during sea-level ~~still-~~standstills in the context of a general regressive phase ~~that~~ following~~ed~~ the highstand peak that created ~~the~~ a relict sea cliff; 3) BSBs may represent coastlines formed during a new relative highstand ~~of~~ in a warm substage on previously unconsolidated deposits formed during the same stage; and 4) BSBs may be formed by a process similar to that of the previous case, except that the sea level stopped~~s~~ rising against a pre-existing BSB.

Keywords: composite landforms, *givoni*, Gulf of Taranto, marine terrace deposits, ~~*givoni*,~~ terracing on soft substrates, ~~composite landforms,~~ MIS 5, MIS 7.~~;~~ ~~Gulf of Taranto.~~

1. INTRODUCTION

The Apulia Region of southern Italy is characterised by the widespread presence of raised marine terraces that are typically underlain by marine, transitional or continental deposits. In the Gulf of Taranto, these deposits are characterised by the presence of ~~so-called *givoni* (singular: *givone*), which are~~ low-relief landforms that are subparallel to the coastline and several kilometres long (Boenzi, Palmentola & Valduga~~ *et al.*~~, 1977),~~.~~ locally termed *givoni* (singular: *givone*). The evolutionary models for rocky coasts developed by various authors indicate that the evolution of a marine terrace begins with coastal marine erosion, which leads to the formation of a wave-cut platform bounded by a ~~slope~~ cliff on the landward side (Bradley ~~and~~ & Griggs, 1976; ~~Sunamura 1992;~~ Stephenson ~~and~~ & Kirk, 2000a,b; Sunamura 1992; Threnhaile 2000, 2001, 2002a). However, literature regarding the processes responsible for forming marine terraces on substrates composed of loose or semi-consolidated sediments is sparse (Brückner, 1980; 1982).

A~~n~~ ~~emerged~~ succession of raised marine terraces is represented by earlier wave-cut or shore platforms, ~~whose~~ that ~~ages~~ decrease in age in the seaward direction; a terrace is preserved if the interaction between eustatic oscillations and tectonic ~~movements~~ uplift is such that the terrace is protected from later ~~new~~ sea-level rises (Bosi, Carobene & Sposato, 1996; ~~Lajoie, 1986;~~ Cinque, De Pippo & Romano~~ *et al.*~~, 1995; Lajoie, 1986; ~~Bosi *et al.*, 1996;~~ Threnaile, 2002b). Consequently, a constantly uplifting coast preserves many marine terraces. During phases of tectonic stability, different sea-level highstands may settle at similar levels, and records of ~~many~~ earlier highstands can be obliterated by later subsequent highstands (Dumas, Guérémy & Raffy, 2005).

There is ~~a~~ general agreement that marine terraces are generated mainly during sea-level highstands and that their inner edges, which are located at the foot of the slope along the inland border of the terrace, represent a palaeoshoreline and indicate the maximum sea level during ~~a~~ the highstand (Brückner, 1983; Lajoie, 1986).

The conceptual models proposed for the formation of marine terraces commonly assume that the longer a highstand persists, the wider the terrace surface. However, Anderson, Densmore and Ellis ~~et al.~~ (1999) clearly showed that the closer in time and elevation subsequent highstands are and the longer their durations are, the more the older uplifted surface decreases in width as ~~it is eroded at~~ its base is eroded.

Carobene (1980) and Brückner (1983) addressed the nomenclature and origins of various elements of marine terraces and focused on the distinction between an abrasion platform and a terrace deposit. Moreover, this work differentiated the bottom surface of a terrace deposit, which coincides with the abrasion platform, from the upper surface of the terrace deposit, which can be erosional or depositional. In theory, a marine terrace deposit consists of transgressive sediments in its lower parts and regressive sediments in its upper part; however, in some cases, only the transgressive or regressive sediments are preserved. The top of the marine terrace deposit can also comprise continental deposits contemporaneous with the regressive phase or deposits that post-date the marine deposition. Consequently, the true palaeoshoreline ~~dating of~~corresponding to the highstand peak during which the abrasion platform formed coincides with the knickpoint between the wave-cut platform and the slope (both ~~incised~~ involving erosion~~in~~ of the substrate underlying the terrace deposit) and can often be masked by continental deposits.

Often, terraced deposits are characterised by the presence of relict beach ridges, spits or barriers.

Beach ridges are ubiquitous landforms developed on progradational~~ed~~ coasts with beach shorelines. Beach ridges are ~~are~~ formed~~ed~~ adjacent to the beach by a range of processes and are subsequently isolated from the active nearshore processes as ~~further~~ additional beach progradation occurs (Timmons, Rodriguez, Mattheus & DeWitt,~~ et al.,~~ 2010).~~,~~ ~~a~~At ~~which~~ this point, these~~y~~ isolated beach ridges are preserved as relict elongate mounds parallel to subparallel to the shoreline. Beach ridges and their subsurface deposits thus record past coastal processes and are indicators of past shoreline positions and shapes (Tamura, 2012). The architecture of beach ridges primarily comprises ~~by~~ seaward-dipping beds, ~~and~~while landward-dipping beds are less common (Billy, Robin, Hein, FitzGerald & Certain, 2014; Tamura, 2012). Most of the ~~literature~~ authors agree~~s~~ that high-energy waves during onshore storms are the most common mechanism~~s~~ responsible for beach ridge initiation and ~~building~~ development (~~Nott *et al.*, 2009, 2013;~~ Bendixen, Clemmensen & Kroon~~*et al.*~~, 2013; Goslin ~~and~~ & Clemmersen, 2017; Nott, Smithers, Walsh & Rhodes 2009; Chague-Goff, Goff, Sloss &, Riggs, 2013).

Barrier islands are shore-parallel, wave-constructed nearshore landforms surrounded by water and often capped by aeolian sand (Otvos, 2018). Attached to the mainland shore ~~by~~ at one end, spits are also elongated landforms. ~~The b~~Barrier islands and spits protect low-energy, brackish, nutrient-rich mud-dominated lagoonal or bay-like conditions behind them. Otvos (2018) ~~has~~ summarised four basic barrier island formation categories: 1) island aggradation from seafloor sand shoals or bars, 2) spit detachment or segmentation by wave and tidal erosion, 3) detachment of unconsolidated foredune sets ~~by the~~ during a marine transgression~~g sea~~, and 4) composite islands,~~;~~ –in which prograding beach ridges surround well-consolidated, wave-resistant relict older island cores.

Aggradational, transgressive, and regressive styles of barrier evolution have been recognised (Galloway ~~and~~ & Hobday, 1983; Timmons *et al.*, 2010). Aggradational barriers form when the rate of sediment accumulation equals the rate of creation of ~~sediment~~ accommodation space; in this case, both ~~inner and ocean~~ seaward and back-barrier shorelines remain stationary.

Transgressive barriers form when the rate of sediment accumulation is less than the rate of creation of ~~sediment~~ accommodation space; thus, both seaward and back-barrier ~~the inner and ocean~~ shorelines migrate landward by wave erosion and overwashing. Landward-dipping reflectors are dominant in transgressive barriers, and they can be interpreted as former flood-tidal deltas and washover fans, which generally overlie sandy-mud deposits that formed in a back-barrier environment (Billy *et al.*, 2018; Timmons *et al.*, 2010; Tillman & Wunderlich, 2013). Regressive barriers form when the rate of sediment accumulation exceeds the rate of creation of ~~sediment~~ accommodation space; in this case, the ~~ocean~~ shoreline progrades seaward. Seaward-dipping parallel to oblique reflectors are very common in regressive barriers, and these reflectors are interpreted to be clinoforms that indicate progradation (Billy *et al.*, 2018; Timmons *et al.*, 2010; Tillman & Wunderlich, 2013). In the upper part of a barrier, the inner structure commonly exhibits seismic facies identified as aeolian sand dunes.

This study presents two terraces in the northern part of the Gulf of Taranto along a segment of the coast from the city of Taranto to the Bradano River, and it focuses on the study of the *givoni* present on the lower of these two terraces, which are interpreted as relict beach ridges, spits or barriers. Our main goal is to describe a set of cases for the formation and evolution of scarps, beach ridges, spits or barriers on loose or semi-consolidated substrates with the aim of providing a comprehensive picture of the relationship between eustatic oscillations and the creation of composite coastal landforms generated by ~~the~~ a ~~fusion~~combination of erosive forms (surfaces or scarps) and depositional forms (beach ridges, spits or barriers).

2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

During the Neogene, the geologic history of the southern Italian peninsula was characterised by the formation of a mountain chain–foredeep–foreland system (~~Fig.~~Figure 1). The foredeep, named the Bradanic Trough, started to form in the middle Pleistocene and has undergone an uplift phase that continues today (~~Ricchetti *et al.*, 1992;~~ Doglioni, Mongelli & Pieri~~ *et al.*~~, 1994, Doglioni, Tropeano, Mongelli & Pieri, 1996; Ricchetti, Ciaranfi, Luperto Sinni, Mongelli & Pieri, 1992). Glacio-eustatic sea-level oscillations occurred ~~with~~ during this uplift, complicating the ~~mechanism of~~ regression signal. During this phase, several marine terraces formed (Brückner, 1980; Ciaranfi~~ *et al.*~~, Pieri & Ricchetti, 1992). These terraces consist of a wave-cut platform incised ~~on~~ into a substrate ~~constituted~~composed of, in most cases, ~~by~~ the A~~a~~rgille S~~s~~ubappennine unit (ASP) belonging to the Bradanic Trough sedimentary cycle (~~Ricchetti, 1967;~~ Azzaroli, Perno & Radina~~*et al.*~~, 1968; Ricchetti, 1967; 1981; Ricchetti *et al.*, 1992) and, in some cases, ~~by~~ deposits of an older terrace. Above these platforms, terraced deposits can occur.

The sequence of the Ionian Sea marine terraces and palaeoshorelines along the Gulf of Taranto has been studied by several authors. The works by Vezzani (1967) and Boenzi *et al.* (1977) represent the first attempts to describe and characterise ~~wide~~ large portions of the terrace succession. These works were followed by those of Amato, Belluomini, Cinque, Manolio & Ravera (1997), Bianca and Caputo (2003), Dai Pra and Hearty (1992), Parea (1986), Sauer *et al.* (2010) and ~~Dai Pra and Hearty (1992), Amato *et al.* (1997), Bianca and Caputo (2003), and~~ Zander, Fülling, Brückner & Mastronuzzi, ~~*et al.*~~ (2006). The works by Brückner (1980a,b, 1982) represent the first detailed regional investigations of the entire terrace sequence along the Gulf of Taranto.

Some authors focused on ~~descriptions of~~ single outcrops, some of which are located in our study area. Boenzi, Caldara & Pennetta ~~*et al.*~~ (1985) and Caldara (1987) described the Ponte del Re section (at elevations between ca. 20 and 30 m a.s.l. at the inland Castellaneta Marina location), where they found specimens of *Strombus bubonius* (now *Persististrombus latus*), which ~~that~~ they assigned to MIS 5.5. Laviano and Pennetta (1980) described in detail the Fontana del Fico section at elevations between ca. 30 and 40 m a.s.l., ca. 4 km west of the town of Palagiano, and ~~dated~~ attributed the likely timing of the formation of this section ~~(probably)~~ to the Mindel-Riss interval ~~interglacial (MIS 7)~~.

~~Caputo *et al.* (2010) performed a detailed morphotectonic analysis of terraces along the Ionian coast of southern Italy. A major result of their research was a reconstruction of the geometry of the marine surfaces that documents the presence of 18 palaeoshorelines and provides evidence of strong regional uplift.~~

Most authors have interpreted the terrace sequence along the Gulf of Taranto as having resulted from interactions between regional Quaternary land uplift and glacio-eustatic sea-level fluctuations. In contrast, Bentivenga, Coltorti, Prosser & Tavarnelli ~~*et al.*~~ (2004a,b) interpreted the entire terrace sequence as ~~resulting from~~ a single middle Pleistocene terrace ~~under the assumption~~ that was later offset by normal faults related to large-scale gravitational processes ~~have offset the single terrace~~, shifting ~~its~~ the fragments to different elevations.

According to many authors (Brückner, 1983, Pieri, Sabato & Tropeano~~ *et al.*~~, 1996; Sabato, 1996; Tropeano, Sabato & Pieri~~ *et al.*~~, 2002), the sequence of the marine terrace deposits along the Gulf of Taranto is a regressive and generally coarsening-upward sedimentary body consisting of sand and conglomerate beds unconformably overlying the ASP unit. Detailed sedimentological analyses performed in three key areas (Taranto, Pisticci, and Nova Siri) based on the principles of sequence stratigraphy (Cilumbriello *et al.*, 2008) clearly indicate that each terrace is characterised by a sedimentary sequence consisting of paralic and beach deposits.

Caputo *et al.* (2010) performed a detailed morphotectonic analysis of terraces along the Ionian coast of southern Italy. A major result of their research was a reconstruction of the geometry of the marine surfaces. Furthermore, their work documents the presence of 18 palaeoshorelines and provides evidence of strong regional uplift.

More recently, in the study area, De Santis, Caldara, Torres, Ortiz & Sánchez-Palencia (2018) recognised and mapped three terrace deposits that date to MIS 7.3, MIS 7.1 and MIS 5 along the coastal area from the city of Taranto to the Bradano River in the northern Gulf of Taranto (southern Italy). They also provided uplift estimates for the inner edge of the MIS 5.5 deposits in the western, central and eastern sectors of ca. 0.39, ca. 0.35, and ca. 0.26 mm/y, respectively.

D~~A d~~istinctive elements of the terraces ~~of~~ along the Gulf of Taranto ~~is~~ are the so-called *givoni*. These landforms have been poorly studied and have been interpreted in different ways. Bentivenga *et al.* (2004b) and Boenzi *et al.* (1977) ~~and Bentivenga *et al.* (2004b) have~~ described the *givoni* as low-relief landforms that are subparallel to the coastline and several kilometres long with seaward slopes that are steeper than the~~ose~~ ~~of their~~ landward ~~sides~~slopes. According to Boenzi *et al.* (1977), the internal structure seems to vary ~~from place to place~~spatially. ~~In s~~Some outcrops exhibit~~,~~ a clinostratified structure with sloping beds of gravels and sands, dipping approximately 30° towards the sea~~, appears~~. Above this structure lies a thin layer of fine sediments, which reaches a thickness of 10 m in the intervening depressions~~ between two givoni~~.

Figure 1

3. METHODS

This study focused on ~~the~~ two lower marine terrace deposits, ~~which can be observed~~ that are above the present coastal plain, ~~and in~~with particular emphasis on ~~a~~ peculiar landforms present on one of the two terraces, the ~~the so-called~~ *givoni*~~*e* (plural: *givoni*)~~. We started by collecting all previous literature and published maps of the terraces. A fundamental assumption that we accepted is the correlation between the inner edge of each terrace and the interglacial or -interstadial peaks ~~of~~ in~~the~~ sea level. Then, a remote sensing analysis was performed using various sets of aerial photos (taken in 1954-55, 1972, 1996, and 2003), and satellite images (collected ~~with~~in the last decade) to map outcrops, and a digital terrain model was developed based on a 1:5,000-scale topographic regional map. In the second phase of the work, all data obtained from the remote sensing analysis were verified with intensive field surveys, which consisted of visiting approximately 43 sites (the most significant ~~sites~~ ones are shown in ~~Fig.~~Figure 1), generating approximately 24 stratigraphic sections and ~~dating~~ 57 samples for dating~~; these data have been partly published in De Santis *et al.*, (2018) and partly in this study for the first time (see Tab. 1 caption)~~.

~~When mapping the inner edges of the terraces, we evaluated the amount of the continental wedge that had accumulated at the base of the scarp and partially masked the original knickpoint.~~

~~We considered the definitions given by Carobene (1980) and then I) characterised and dated the marine terrace deposits but not the wave-cut abrasion platforms; II) surveyed the upper surfaces of the terrace deposits, the results of which are shown in Fig. 1; and III) distinguished the true inner edges and edges masked by continental deposits wherever possible.~~

The dating was performed by applying amino acid racemisation (AAR) to ostracod valves and *Glycymeris* shells following the methods applied in our previous works on the marine and alluvial terrace deposits in the Apulia r~~R~~egion (De Santis, Caldara, Pennetta, Torres, Ortiz & Arribas, 2013;~~De Santis *et al*., 2010;~~ ~~Caldara *et al*., 2013;~~ De Santis Caldara, Torres & Ortiz~~*et al*.~~, 2010; ~~2013;~~ De Santis, Caldara & Pennetta, 2014 a,; De Santis, Caldara, Torres & Ortiz, 2014b). In Table 1, only ages obtained from the sites described for the first time in this study (4 stratigraphic sections and 10 samples) with their inferred MIS are reported. In Table 2, a concise description of the most significant stratigraphic sections cropping out in the study area is reported: most sections are those previously described in more detail in De Santis *et al*. (2018); the remainder are published in this study for the first time.

Table 1

After dating the terrace deposits, we used the dates to determine the timing of the entire development of the terrace from the formation of the wave-cut abrasion platform to the regression phase and the associated final deposition.

Table~~.~~ ~~1~~2

When mapping the inner edges of the terraces, we evaluated the amount of the continental wedge that had accumulated at the base of the scarp and partially masked the original knickpoint.

We considered the definitions given by Carobene (1980) and then I) characterised and dated the marine terrace deposits but not the wave-cut abrasion platforms; II) surveyed the upper surfaces of the terrace deposits, the results of which are shown in Figure 1; and III) distinguished the true inner edges and edges masked by continental deposits wherever possible.

4. DATA AND RESULTS

4.1 General framework

The combination of the geological field surveys, remote sensing images and ~~absolute~~ dating with amino acid racemization (AAR) method allowed us to identify some terrace deposits in the Apulian sector of the Gulf of Taranto (De Santis *et al.*, 2018).~~, and t~~ Two of these deposits ~~that~~ dated~~ back~~ to MIS 7.1 and MIS 5 are considered and mapped in this paper (~~Fig.~~Figure 1).

~~Fig.~~Figure 1

The older deposit underlies a more or less triangular surface that is likely ~~the~~ what remains of a wider surface that was partly obliterated by erosion. This marine terrace is approximately 7 km long and up to ca. 1.7 km wide (~~Fig.~~Figure 1), and the elevation of its inner edge (masked~~ by younger continental/colluvial deposits~~ by younger continental/colluvial deposits) ranges between ca. 66 and ca. 62 m a.s.l. (De Santis *et al.*, 2018).~~.~~

The upper surface of the younger deposit ~~underlies a~~is a wide, continuous surface that is approximately 30 km long and up to ca. 6 km wide (~~Fig.~~Figure 1). The elevation of the inner edge of this deposit varies: in the western sector, the inner edge is masked by younger continental/colluvial deposits and has an elevation of ca. 55 m. a.s.l.; in the central sector, it coincides with the MIS 5.5 palaeoshoreline and has an elevation of ca. 50 m. a.s.l.; and in the eastern sector, it is possible to distinguish the inner edge masked by younger continental/colluvial deposits (45 m a.s.l.) from the MIS 5.5 paleoshoreline (38 m a.s.l; De Santis *et al.*, 2018). The new dates presented in this study (TM6/9, TM6/10, TM6/15 and TM6/17 in ~~Tab.~~Table 1) allow us to update the division of substages in the MIS 5 deposit (De Santis *et al.*, 2018). In fact, the whole set of ~~absolute dates~~ages obtained highlights the existence of at least two deposits in the MIS 5 terraces, one ~~of~~ corresponding to MIS 5.5 and another corresponding to ~~of~~ MIS 5.3, both of which are characterised by the presence of *givoni*~~BSB~~.~~;~~ ~~w~~We consider the existence of ~~deposits of~~ MIS 5.1 deposits to be ~~as~~ highly probable, but at present, there are no sufficient ~~dates~~ ages estimates to distinguish the deposits of MIS 5.3 from those of MIS 5.1. A possible limit between the MIS 5.5

and MIS 5.3 terraces is reported in ~~Fig.~~Figure 1; this limit has been updated compared to that hypothesised by De Santis *et al.* (2018) in light of the new dates available in this study. It is important to emphasise that this limit is not an evident scarp;~~:~~ if a scarp exists, it is masked by *givoni* according to the set of cases that will be described in sections 5.2~~1~~ and 5.3~~2~~.

Both terrace deposits are part of two depositional terraces: calcareous to siliciclastic sandy and gravelly sediments accumulated to thicknesses of up to 12-15 m above a wave-cut platform incised into the substrate (the ASP unit and, ~~subordinately~~less commonly, previous terrace deposits). In ~~Tab.~~Table 2~~1~~, the principal features of the main locations surveyed are summarised. For a more complete description of the stratigraphy, fossiliferous content, palaeoenvironments, and absolute ages obtained for each unit, please refer to De Santis *et al.* (2018).

In the schematic description of the units reported in ~~Tab.~~Table ~~1~~2, we distinguish that the gravel fraction ~~origin~~ i~~a~~s ~~being~~ derived from ~~Apenninic and Murgian: the first source is~~ the Apennine chain, which yields mostly siliciclastic detritus, and the ~~second source is the~~ Murge highland (exposed Mesozoic carbonate foreland), which yields carbonate detritus.

Both terraces generally display subplanar and slightly seaward-~~-~~sloping geometries (3–5°) and are incised by the main rivers and secondary tributaries that form the stream network ~~of~~ in the area.

The collected data allow the reconstruction of the stratigraphic relationships between the two terraces and the lateral and vertical variations in their deposits (~~Fig.~~Figure 2). The MIS 7.1 terrace deposits are found ~~A~~above a wave-cut platform incised into the substrate (ASP)~~, the terrace deposits of MIS 7.1 are found~~. These deposits are mainly calcareous in the area of the Masseria Stoccatarda high (locations TM5/10-14 and TM5/17 ~~locations~~ in ~~Fig.~~Figure 1). On the southern edge of the high, there is a scarp characterised by the presence of *Lithodomus* holes (~~Fig.~~Figure 2; ~~Tab.~~Table ~~1~~2); we interpret this scarp as the inner edge of the MIS 5 terrace, and therefore, that the scarp coincides with the palaeoshoreline of the MIS 5.5 interglacial peak.

~~Fig.~~Figure 2

The terrace deposit of MIS 5.5 lies unconformably ~~discordantly~~ on both the MIS 7.1 deposits and the ASP unit. At the Ponte del Re location, the MIS 5.5 terrace deposit ~~of MIS 5.5~~ (~~Fig.~~Figure 2, ~~Tab.~~Table ~~1~~2) starts with a basal unit consisting of transgressive conglomerates; this unit is overlain by bioconstructed biostromal-biohermal limestone with *Cladocora caespitosa* and scattered centimetre-scale Apenninic ~~centimetric~~ pebbles. This limestone grades upwards into clayey sands, then into fine sands with flute casts and flute marks and~~,~~ finally~~,~~ into a gravelly unit that constitutes the real Ponte del Re *givone* (~~Fig.~~Figure 2).~~;~~ T~~t~~he MIS 5.5 deposits of the Ponte del Re section shows a continuous, transgressive-regressive sequence ~~all referable to MIS 5.5~~ (De Santis *et al.*, 2018).

At the Stornara location (TM6/9 of ~~Fig.~~Figure 1; ~~Fig.~~Figure 3), the deposit inland of the Stornara *givone* (~~Fig.~~Figure 1) can be observed along the walls of a reclamation canal that cuts perpendicularly through ~~cuts~~ the area: ~~heterometric~~ poorly sorted conglomerate of Apenninic origin transitions ~~passing~~ northward into silt and clayey silt ~~can be observed~~. Notably, the silty ~~-~~clay unit is rich in freshwater fauna (i.e., *Planorbis planorbis*), thus suggesting that this deposit ~~was~~ formed in a back-barrier environment with a substantial freshwater supply. We attribute the succession at the Stornara location to MIS 5.5 due to the obtained ~~absolute~~ age estimate ~~obtained~~ (~~Fig.~~Figure 3; ~~Tab.~~Table 1).

~~Fig.~~Figure 3

Near Crossodromo Fox Valley ~~motocross track~~ (TM6/15 and TM6/17 in ~~Fig.~~Figure 1), two other artificial sections ~~can~~ have been ~~observed that~~ cut through the Stornara *givone* no~~t~~ more than 300 metres apart. At the TM6/15 section (~~Fig.~~Figure 4a, d; ~~Tab.~~Table 1), the succession starts with massive beige fine sands passing upwards into beige fine sands with cemented sub-horizontal layers ~~with~~ and abundant flute marks and flute casts. Upwards,~~;~~ gravel layers become increasingly numerous, thicker and coarser~~ upwards~~. Marine fauna ~~are ~~is present. We attribute this lower part of the succession to MIS 6.5 (Scholz, Mangini & Maischner, 2006; Thompson & Goldstein, 2005) due to the ~~absolute age ~~obtained age estimate~~d~~ (~~Fig.~~Figure 4; ~~Tab.~~Table 1); thus, this part can be considered a remnant of a previous marine deposit ~~that ~~constituting~~es~~ the local substrate of the subsequent terrace deposit. The latter unconformably overlies on the substrate and is ~~made up~~composed of ~~heterometric ~~poorly sorted conglomerate of Apenninic origin with lenses of beige sands~~,~~ and bedding planes that dip southward, containing rare specimens of marine fauna ~~southward, with southward dip direction of bedding planes;~~. ~~t~~This unit is interpretable as a beach deposit. We attribute this upper part of the TM6/15 succession to MIS 5.5 due to the ~~absolute age~~ obtained age estimate (~~Fig.~~Figure 4; ~~Tab.~~Table 1)

At the TM6/17 section (~~Fig.~~Figure 4a, b, c; ~~Tab.~~Table 1), the succession starts with massive beige/reddish fine sands with no faunal content. The succession continues with a clayey unit rich in *Cerastoderma glaucum*, indicative of a lagoonal environment. The last unit ~~lies ~~is in abrupt contact ~~above ~~with the lagoonal unit and consists of a moderately ~~heterometric ~~sorted conglomerate of Apenninic origin with a northward~~-~~dipping ~~direction of ~~bedding planes, and this unit constitutes~~ing~~ the ~~real ~~true Stornara *givone*. In ~~the ~~its lowermost centimetres, the gravel clasts ~~s ~~are smaller than those in the ~~rest ~~remaining part of the unit, and some specimens of *Cerastoderma glaucum* in living position ~~are ~~can be observed (~~Fig.~~Figure 4c). ~~,~~The presence of these specimens among the small gravel clasts indicates an aborted attempt to adapt to new environmental conditions. These observations suggest~~s~~ that the ~~-~~Stornara *givone* is stratigraphically conformable with ~~overlies ~~the lagoonal unit~~ in stratigraphic continuity~~.

~~Fig.~~Figure 4

4.2 Focus on the ~~*so-called*~~ *givoni*

We studied in detail the *givoni* of the ~~terrace of~~ MIS 5 terrace. These *givoni* can reach heights of ca. 10 m above the surrounding surface, and their maximum widths are approximately 400 m ~~ca~~. Some *givoni* are isolated, ~~and~~ whereas others are present in groups of two, ~~or~~ three or four (conjugate~~d~~) separated by shallow depressions. The most distinct conjugate *givoni* are Miraglio's *givoni* (~~Fig.~~Figure 1).

Based on cross-sectional views, the *givoni* ~~consist, in general, of~~ mainly consist of conglomeratic deposits and display lateral variations in grain size and a dominant seaward dip direction of bedding planes. The observed exposures reveal the following patterns in the bedding planes, which may be present within the same *givone*:

1) In some cases, the two sides of a *givone* exhibit ~~an~~ opposing~~te~~ dip directions~~ is observed at different angles between the two sides of the *givone*~~. Although ~~the~~ *givoni* exhibits both landward and seaward dip directions, the latter is dominant (~~Fig.~~Figure 5a), except for the Stornara *givone* at the TM6/17 section (~~Fig.~~Figure 4a, b), where only a landward (northward) dip direction is present. The sequence of the seaward-dipping planes appears to be interrupted by erosion surfaces, which ~~are~~ probably formed during erosive high-energy events or periods of reduced sediment supply. Each of the sedimentary units bounded by erosion surfaces corresponds to a period of beach ridge accretion.

2) In other cases, a component of the dip direction is parallel to the *givone* elongation direction (~~Fig.~~Figure 6) and adds to or completely replaces the opposite dip direction, and longshore sediment sorting is observed.

~~Fig.~~Figure 5

From a textural point of view, the *givoni* observed in the study area consist of the following two grain-size facies, which may be present within a single *givone*:

~~1)~~ mixed gravelly-sandy type (GS) and

~~2)~~ mainly gravelly type (G).

GS type: ~~a c~~Clear cross-shore sediment sorting is observed. From the landward slope, sandy layers that alternate with arenaceous layers, all of which show low-angle landward dips, can be observed. Towards the centre of the body, the sandy/~~-~~sandstone layers tend to become sub-horizontal, and gravelly layers with centimetric pebbles appear. Then, from the centre of the body towards the seaward slope, the pebbles become larger, and the gravelly layers become more abundant until they constitute the entire deposit.~~, – which here consists of a~~This ~~–~~set of high-angle seaward-dipping gravelly layers ~~that~~ constitutes the majority of ~~the~~ a *givon~~i~~e*. Furthermore, t~~T~~he gravelly layers fine upwards (~~Fig.~~Figure 5a, b). Disarticulated valves are present, and the most common belong to *Glycymeris* sp. or *Cerastoderma glaucum*.

G type: T~~t~~he internal structure (arrangement of bedding planes) is similar to that of the GS type, although the texture is mainly gravelly in the landward portion, at the centre of the body and in the seaward portion. However, G-~~-~~type *givoni* can have a dip direction parallel or subparallel to the *givone* elongation direction, ~~that~~ partially modifying~~ies~~ the opposing dip direction of the landward and seaward sides typical of the GS-~~-~~type *givoni*. In this case, longshore sediment sorting can be observed (~~Fig.~~Figure 6).

~~Fig.~~Figure 6

In some ~~sections~~ observed sections, the *givoni* constitute the final ~~term~~ deposit of regressive sequences (~~Fig.~~Figure 7). From the bottom up, the sequences are as follows:

1) generally fine sands with horizontal lamination~~, eventually with~~and cemented bioturbation~~s that are~~ grouped in sub-horizontal layers that become increasingly numerous and thicker upwards; the faunal content (De Santis *et al.*, 2018) consists of species characteristic both of heterogeneous associations (PE *sensu* Picard, 1965) and circalittoral environments (terrigenous mud biocoenosis; VTC *sensu* Pérès, 1967);

2) coarser sands with widespread cross~~-~~ bedding, cemented layers, flute marks and flute casts; towards the top, lenses and layers of gravels/conglomerates appear;~~–~~ ~~and~~ ~~. T~~the faunal content consists of species characteristic of an infralittoral environment (well-sorted fine sand biocoenosis; SFBC *sensu* Pérès, 1967);

3) gravels and conglomerates that constitute the ~~real~~ actual *givone*, whose bedding plane arrangements and internal texture have been previously described;~~.~~ ~~T~~the faunal content consists of transported specimens characteristic of a nearshore-beach environment and, in some cases, a lagoonal environment (De Santis *et al.*, 2018).

~~Fig.~~Figure 7

An exception is constituted by the Stornara *givone*. Where section~~al~~s ~~views~~ are available (i.e., TM6/9, TM6/15 and TM6/17; Figs. 3 and~~,~~ 4), it is not possible to recognise this *givone* as the final ~~term~~ deposit of a regressive sequence. Around the Crossodromo Fox Valley ~~motocross track~~ (TM6/15 and TM6/17; ~~Fig.~~Figure 4), the *givone* appears to be associated with gravelly beach deposits that abruptly cut the substrate constituted by older marine deposits. In this location, the beach deposits are seaward dipping, while those of the *givone*, cropping out slightly fa~~u~~rther south, are landward dipping and conformably overlie the lagoonal deposits. At the Stornara location (~~Fig.~~Figure 3), the sediments below the *givone* do not crop out, so it is impossible to recognise any regressive trend; ~~on the other hand,~~ however, a silty-clayey freshwater deposit has been recognised ~~at the back~~landward of the Stornara *givone*.

5. DISCUSSION

In ~~our~~ the described study area, recognising the classic features ~~present in the~~of marine terraces, that is, surfaces and scarps, is difficult. Thi~~e~~s~~e~~ difficulty~~ies~~ ~~are~~is derived from the fact that the *givoni* are often associated and variously combined with surfaces and scarps. In particular, our field survey and digital terrain model analysis highlighted that one of the ~~reasons for greater~~sources of confusion in the identification of the inner edge of the terraces is the misinterpretation ~~between~~ of the ~~real~~ true inner edge and the seaward slope of the *givoni*. Such misinterpretations have ~~These difficulties~~ resulted in ~~the~~ different results for the locations of the scarps and the number of terraces ~~identified~~ by authors ~~who studyng~~studying~~ied~~ this area. Thus, we have first interpreted the *givoni* and then reconstructed a set of cases involving ~~that includes~~ the formation of surfaces, scarps and *givoni*~~,~~ ~~with~~ (and resulting composite landforms)~~,~~ on loose or semi-consolidated substrates in an overall evolutionary framework and in relation to eustatic oscillations~~ on loose or semi-consolidated substrates~~.

5.1. Interpretation of the *givoni*

The interpretation of the *givoni* is controversial because few authors have described and interpreted these landforms (Bentivenga *et al.*, 2004a,b; Boenzi *et al.*, 1977~~; Bentivenga *et al.*, 2004a,b~~). In addition, the internal structure described in this paper differs from those reported in the literature, in which only the seaward-dipping beds are described. Our observations of coastal dynamics at various beaches along the Gulf of Taranto, where sandy-gravelly beach deposits are observed, and at other mostly gravelly coastal stretches allow us to identify the landforms that are most similar to ~~the~~ *givoni*, including the following:

1) beach ridges (Anthony, 2009; Hesp *et al.*, 2005; Otvos, 2000; ~~Hesp *et al.*, 2005; Anthony, 2009;~~ Tamura, 2012), which are also present on beaches along the Gulf of Taranto (~~Fig.~~Figure 5c, d) and are composed of ~~have~~ sandy-gravelly deposits and

2) spits or barriers (Otvos, 2018, Otvos ~~and~~ & Carter, 2013;~~ Otvos, 2018~~ Roy, Cowell, Ferland & Thom, 1994). We imagine that ~~our~~the described *givoni* may be relicts of landforms similar to those depicted in the figure 8a (New Zealand: Hart, 2007; 2009; Paterson, Hume & Healy, 2001;) and figure 8b (southern coast of England: Cope, 2004; Stripling, Bradbury, Cope & Brampton, 2008).

Figure 8a, in particular, clearly illustrates the whole framework in which many of ~~our~~the *givoni* could have formed. ~~such as those in New Zealand (Paterson *et al.*, 2001; Hart, 2007, 2009; Fig. 8a) or along the southern coast of England (Cope, 2004; Stripling *et al.*, 2008; Fig. 8b).~~

~~Fig.~~Figure 8

The *givoni* are similar to the modern beach ridges present along ~~of~~ the Calabrian ~~Gulf of Taranto~~Ionian coast (~~Fig.~~Figure 5) ~~with regard to their~~in terms of shape~~s~~, ~~the~~ different inclinations of the~~ir~~ seaward and landward slopes ~~(Goslin and Clemmersen, 2017)~~, and ~~the~~ distributions of their sandy and gravelly components (if any), where the gravelly components become increasingly dominant and coarsen seaward until fine-grained components are not observed.

However, the narrow elongated shape of the *givoni* and their arrangement subparallel to the ~~current~~ present coastline lead us to hypothesise that they could also be relict spits or barriers similar to those depicted in figures 8a and 8b ~~(Cope, 2004; Stripling *et al.*, 2008; Otvos and Carter, 2013; Otvos, 2018)~~.

Ther~~s~~efore, we ~~observations lead us to~~ hypothesise that the *givoni* were formed by ~~both~~ longshore and/or cross-shore processes; thus, according to the classification of Cope (2004), the *givoni* may represent former beach ridges, swash/drift-aligned spits, or swash/drift-aligned barriers (here~~in~~after BSBs), and they generally display a regressive style (Galloway ~~and~~ & Hobday, 1983; Timmons *et al.*, 2010) due to the dominance of the seaward-dipping layers. The relationship between gravelly and sandy components varies along the coast as a function of the ~~fluvial~~ distance from the sediment ~~input~~source; thus, ~~beach ridges, spits and barriers~~BSBs can be composed exclusively of sand, shingle~~s~~ (shingle beach ridges, shingle barriers, and shingle spits), ~~and~~ or combinations thereof. Additionally, lateral variations in grain sizes can be observed ~~with~~in the same body.

These characteristics are evident within the *givoni* in the MIS 5 terrace deposit. For example, the *givone* exposed in ~~S~~section TM5/9 (~~Fig.~~Figure 5), is the~~for example, exposes a~~ GS type~~ of *givone*~~, whereas the same *givone* exposed in section TM5/15 (~~Fig.~~Figure 6) ~~exposes the same *givone*, but here, it~~ is primarily the G type.

Our sedimentological data do not permit us to determine with certainty ~~whether~~ ~~what~~which ~~of the~~ *givoni* of the MIS 5 terrace represent~~s~~ ~~a~~ relicts of ~~a~~ beach ridges~~s~~, wh~~at~~ich of ~~a~~ barriers~~s,~~ and ~~what~~which of ~~a~~ ~~or~~ spits~~s~~. ~~Such a distinction would require the identification of possible connections to the mainland (Cope, 2004; Stripling *et al.*, 2008), which is currently impossible. Regardless, this distinction is mostly contrived, and transitional or intermediate landforms between these endmembers are common (Cope, 2004).~~

It is important to emphasise that when we assume that the *givoni* ~~may be previous~~derived from spits or barriers, the spits or barriers are thought to have been ~~we think that these were~~ narrow landforms (Roy *et al.*, 1994)~~relatively small landforms~~, often without the whole series of sub-environments ~~typical of the~~associated with most large barriers or spits~~. Furthermore, we imagine that the spits or barriers that we observe today in the form of *givoni* should~~ and not ~~be~~ very different, in terms of their size (especially in ~~reference~~ terms of~~to the~~ width, and to a lesser degree ~~to the~~ length)~~, and variety of subenvironments,~~ from the spit that formed in 2003 at the mouth of the Bradano River (~~Fig.~~Figure 9).

In any case, since the *givoni* are interpreted as landforms associated with coastline processes, they can be effectively used as indicators of palaeoshorelines.

~~Fig.~~Figure 9

5.2. Process of formation and evolution of the MIS 5 terrace

In this section, we reconstruct the process of the formation and evolution of the MIS 5 marine terrace that includes the formation of surfaces, scarps and BSBs (and the resulting landforms) in an overall evolutionary framework based on eustatic oscillations. This reconstruction is based on the following elements: 1) ~~absolute~~ dating (~~Tab.~~Table ~~1~~2), which highlights the existence of two ~~deposits of~~ MIS 5 deposits, one of MIS 5.5 and another of MIS 5.3, both characterised by the presence of BSBs; in addition, we believe that it is highly probable that a deposit dating ~~back~~ to MIS 5.1 exists, although at present, there are ~~no~~ insufficient dates to substantiate this hypothesis; 2) stratigraphic data (cfr. section 4.2); and 3) interpretation of *givoni* as palaeoshoreline indicators.

This process is characterised by the following steps:

1) During the transgressive phase towards the MIS 5.5 peak, carbonate sediments with *Cladocora caespitosa* bioherm were deposited in shallow waters (~~Fig.~~Figure 10a) above a thin basal gravelly layer (Ponte del Re; ~~Tab.~~Table ~~1~~2). The marine transgression culminated at the Masseria Stoccatarda locations during MIS 5.5 and created the inner edge of the terrace, which is the scarp that currently limits the Masseria Stoccatarda high to the south and coincides with the palaeoshoreline. This finding is ~~demonstrated~~ supported by numerous *Lithodomus* holes in the scarp (~~Fig.~~Figure 10a).

2) During the remainder of the MIS 5.5 highstand peak and the early stage of the subsequent regression, the coastal sedimentary wedge, which is composed mostly of siliciclastic sands, formed and continued to develop. The coastline advanced because of the terrigenous contributions from inland that buried the transgressive deposits containing *Cladocora caespitosa*. In this phase, the three Miraglio's *givoni* formed (~~Fig.~~Figure 10b).

3) During a short sea-level ~~still-stand~~standstill that interrupted the regression from the MIS 5.5 highstand peak, another BSB formed (*givone* of Ponte del Re; ~~Fig.~~Figure 10c) in the context of the general post-MIS 5.5 sea-level fall; in this case, the Ponte del Re *givone* is part of a continuous transgressive-regressive sequence ~~all referable~~related to MIS 5.5, and there are no evident traces of the formation of sea cliffs ~~and~~ or platforms linked to the short sea-level ~~still-stand~~standstill that gave rise to this BSB.

4) During another sea-level ~~still-stand~~standstill, longer than that of the previous ~~point~~standstill event, the Stornara *givone* formed (~~Fig.~~Figure 10d).~~;~~ ~~t~~The formation and evolution of the Stornara *givone* deserves a short in-depth analysis. The section observed at the Stornara location (TM6/9; ~~Fig.~~Figure 3) suggests the permanence of this BSB in the stationary regime (*sensu* Galloway ~~and~~ & Hobday, 1983; Timmons *et al.,* 2010). In contrast~~stead~~, the sections observed around the Crossodromo Fox Valley ~~motocross track~~ (TM5/15 and TM6/17; ~~Fig.~~Figure 4) suggest the following evolution (~~Fig.~~Figure 11): 1~~1~~) prolonged sea-level ~~still-stand~~standstill with formation of a beach in erosive contact with the substrate (Figure 11a); 2~~2~~) formation of a BSB just off the beach and coeval~~ntextual~~ formation~~identification~~ of a lagoon between the beach and the BSB (Figure 11b); and 3~~3~~) establishment of a transgressive regime (sensu Galloway ~~and~~ & Hobday, 1983; Timmons *et al*., 2010) with landward migration of the BSB by rollover processes driven by overwashing (Figure 11c-e), ~~exemplified~~ evidenced by the layers dipping landward in the back-barrier environment (Montes ~~*et al*~~, Bujalesky & Paredes~~.~~, 2018).~~;~~ ~~i~~In fact, overwashing is the main process in landward migration of gravel barriers (Timmons *et al*., 2010; Montes *et al*., 2018).

~~This~~ These ~~apparent~~ discrepancies between ~~these~~the two sites ~~contradiction~~ can be explained by a probable difference~~t~~ in the sediment budget of the same BSB at the two sites. A~~: a~~t the Stornara location, the sediment budget was balanced; conversely, at the Crossodromo Fox Valley ~~motocross track~~, the occurrence of overwashing was associated with ~~the scarcity of available~~limited sediment availability, as described by Orford and Carter (1982) and Orford, Carter & Jennings ~~*et al.*~~ (1996), Orford, Forbes & Jennings (2002).

The possibility that the same barrier ~~is~~ can be stationary, transgressive or regressive from place to place depending on different sediment budgets has been widely documented (Billy, Robin, Certain, Hein & Berné, 2013;Timmons et al., 2010). We believe that these different behaviours of the same BSB were in some way influenced by the different distances from the river mouth that ~~constituted~~ acted as the source of sediments, probably the mouth of the Bradano River.

5) During the relative MIS 5.4 lowstand, emersion occurred, likely along with subaerial erosion (~~Fig.~~Figure 10e).

6) During the new highstand of MIS 5.3, an abrasion platform and associated inland scarp ~~were~~ formed and then it were ~~then~~ masked by the subsequent formation of the SS.106 *givone* and its inland depression (~~Fig.~~Figure 10f).

Other BSBs most likely formed during the highstand of MIS 5.1.

~~Fig.~~Figure 10

~~Fig.~~Figure 11

Our reconstruction~~s~~ of the formation and evolution processes of the MIS 5 marine terrace showed the possibility of the formation of several landforms during terracing phases in the Gulf of Taranto~~,~~ and that these landforms were generated from various combinations of the formation of platforms and sea cliffs and the formation of coastal wedges with associated BSBs and ~~their~~ back-~~-~~barrier environments~~s~~. The reconstructed cases are as follows: 1) an abrasion platform and a ~~relict~~ sea cliff formed and then they were ~~then; the former~~ totally and ~~the latter~~ partly covered, respectively, by a ~~subsequent~~ coastal sedimentary wedge (including BSBs and ~~their~~ associates back-~~-~~barrier~~s~~ deposits) and partly obliterated by subaerial erosion.~~:~~ ~~t~~The resulting landform appears as a small, residual scarp with one or more BSBs at a certain distance seaward (i.e., the Stoccatarda high and Miraglio's *givoni*); 2) an abrasion platform and a ~~relict~~ sea cliff formed; the former was then totally covered by a subsequent coastal wedge (including BSBs and ~~their~~ associated back-~~-~~barrier deposits~~s~~), and the latter was totally obliterated by ~~covering of~~ the wedge and subaerial erosion.~~:~~ ~~t~~The resulting landform ~~was~~ is only the BSBs and ~~their~~ associated back-~~-~~barrier~~s~~ deposits.~~; this process is the case,~~ The Stornara *givone,* for example, formed via this process ~~the Stornara *givone*~~; 3) the same process as in cases 1) or 2) occurred but with the difference that ~~the~~ a ~~relict~~ sea cliff was generated ~~from~~ by wave erosion ~~of~~ in the seaward slope of a pre-existing BSB, when the sea level stopped~~s~~ rising.

~~against it;~~ ~~t~~This process~~ is~~, for example, occurred in the case of the contact between the Stornara *givone* and the SS106 *givone*; and 4) no abrasion platform ~~and~~ or sea cliff ~~were~~ formed, but the BSBs and associated~~their~~ back-~~-~~barrier deposits~~s~~ formed conformably on ~~overlie~~ the coastal marine deposits belonging to the same stage of the ~~the same stage of the~~ BSB.~~;~~ ~~for example, t~~This process is the case of the Ponte del Re *givone*.

5.~~2~~3 Formation context of the BSB and resulting landforms in relation to sea-level oscillations

In this section, we reconstruct the ~~following~~ set of cases that lead to the formation of BSBs and associated landforms.~~;~~ T~~t~~his set of cases could be applied ~~a~~to all the coastal stretches affected by terracing phases with characteristics similar to the Gulf of Taranto: eustatic oscillations affecting loose or semi-consolidated substrates, high amounts of sedimentary inputs, and repeated formation of BSBs.

1) BSBs can form during a highstand of a new warm stage on previously consolidated sediment (typically deposited during a highstand of a previous stage). In this case, the relict sea cliff of the terrace is generally evident as a scarp, and the BSB, located more seaward, may represent a new coastline coeval with the same highstand peak that generated the relict sea cliff due to the accumulation of the coastal sedimentary wedge, which can create one (~~Fig.~~Figure 12c) or more BSBs (~~Fig.~~Figure 12d), depending on the continental sediment input and the coastal progradation rate;

2) BSBs may represent coastlines formed during sea-level ~~still-stands~~ standstills in the context of a general regressive phase ~~that~~ follow~~ed~~ing a~~the~~ highstand peak that created ~~the~~ a relict sea cliff (~~Fig.~~Figure 12e, f).~~;~~ ~~s~~Similar to the previous case, the BSBs are typically located more seaward. In this case, the sea-level ~~still-stand~~standstill operates on unconsolidated sediments; thus, if it is quite long, a platform and a sea cliff can form (~~Fig.~~Figure 12e), but they are not evident at ~~the~~ present because they can be totally or partially obliterated by the subsequent formation of BSBs and/or

subaerial erosion. If the ~~still-stand~~standstill is short, ~~the~~ no platform ~~and~~ or~~the~~ sea cliff ~~do not~~ forms, and BSBs conformably overlie older deposits of the same stage (~~Fig.~~Figure 12f);

3) BSBs may represent coastlines formed during a new relative highstand of a warm substage on previously unconsolidated deposits formed during the same stage (~~Fig.~~Figure 12g). The return of a high sea level leads to the formation of a platform and a sea cliff, but they are not evident because they can be totally or partially obliterated by the subsequent formation of BSBs and/or subaerial erosion; ~~and~~

4) BSBs may form by a process similar to that ~~of~~ in the previous case, except that the sea level stops rising against a pre-existing BSB. In this case, the result is a landform ~~due~~ related to the wave erosion of the seaward slope of the pre-existing BSB, which can also be partially or fully covered by later deposits (~~Fig.~~Figure 12h).

~~Fig.~~Figure 12

5.~~3~~4 Comparison between *givoni* and other present barriers and spits: palaeoclimatic considerations

The features of the *givoni* on the MIS 5 terrace can be compared ~~allow other considerations and comparisons~~ with those of spits and barriers in other locations around the world, ~~and~~ allowing us to draw some conclusions regarding some aspects of the palaeoclimatic conditions in which they are formed. The observations published by Neal, Richards & Pye, ~~*et al.*~~ (2003) and Hart (2009) appear to be particularly useful for interpreting *givoni*.

Neal *et al.* (2003) distinguished the internal structures of progradation and retrogradation i~~o~~n the sand- and gravel-rich barrier-spit beach ridges of the northern Essex coast, England. In the retrogradation deposits, these authors identified washover-sheet deposits with gentle landward-dipping (up to 4°) and subparallel stratification, which conforms with crosscutting surfaces that bound individual sedimentation events. In progradational barriers and spits, two additional deposits can be recognised. One deposit type is characterised by gently seaward-dipping stratification~~a~~ (ca. 5°) that are concordant with overlying and underlying bounding surfaces, resulting from the seaward growth of the entire upper beachface. The other deposit type features ~~latter show~~ seaward-dipping stratifications that progressively flattens upward and eventually become gently landward-dipping (ca. 1–2°); these structures are berm -ridge~~-~~ ~~welding~~ deposits.

Similarly, in Clemmensen and Nielsen (2010) the internal architecture of an individual beach ridge is composed mainly of seaward-dipping beachface deposits and subordinately of landward-dipping washover deposits; the beachface deposits downlap onto the underlying shoreface deposits. Additionally, in Billy *et al.* (2014), the internal structure of individual beach ridges is characterised by sigmoidal configurations with seaward-dipping beds with steeper dips along the exposed coast.

Hart (2009) described eleven temperate non-estuarine river-mouth lagoons in New Zealand. These lagoons are sheltered by mixed sand and gravel barriers facing wave-dominated and microtidal coasts. These lagoon-barrier systems are located at the mouths of large braided rivers fed by catchments originating in tectonically active areas.

The conditions and features described by these authors appear to be very similar to those of the *givoni* in our study area: their internal structures appear to be comparable to those of the prograding sand- and gravel-rich barrier-spit beach ridges described by Neal *et al.* (2003), and the context in which the *givoni* formed appears to be similar to that described by Hart (2009). The high gravel contents of the *givoni* and the similarly in the rivers fed by catchments originating in tectonically active or rapidly uplifting areas (the Apennine chain and the Bradanic Trough in our case) led us to hypothesise a palaeogeography with braided rivers capable of transporting gravel to the sea. In such an environment, reworked by waves and currents, the gravel formed the *givoni*.

According to many authors (Cope 2004; Forbes, Orford, Carter, Shaw & Jennings, 1995a; Forbes, Shaw & Taylor, 1995b; Orford, Carter & Jennings~~ *et al.*~~, 1991; Shulmeister ~~and~~ & Kirk, 1993~~;~~ ~~Forbes *et al.*, 1995a,b; Cope 2004~~), shingle barriers and spits are especially common in formerly glaciated areas at mid- to high latitudes, whereas fine clastic barriers are located in ~~the~~ low to mid-latitudes. This difference is caused by two main factors:

1) The supply of fine-grained suspended sediment is low along mid- to high-latitude coasts because these areas have few large rivers and low rates of weathering. Short (1999) noted that passive coasts in the low to mid-latitudes are characterised by long, fine- to medium-grained quartz-rich sand barriers and spits. In these environments, however, barriers are widespread because sediment inputs are large and are supplied by some of the world's largest rivers, which often include a contribution of autochthonous carbonate material;

2) Paraglacial coarse sediments are most common ~~on~~ along mid- to high-latitude coasts (Billy, Robin, Hein, Certain & FitzGerald, 2015; Billy, Robin, Hein, FitzGerald & Certain, 2018; Forbes *et al.,* 1995a; Hein *et al.*, 2012) within the limits of past ice ~~cap~~ sheet advances. In fact, these sediments ~~were derived from~~formed during glacial periods~~, which include~~ in marine glacial, fluvio-glacial, and periglacial ~~conditions~~environments.

Cope (2004) concluded that fine clastic barriers and spits are mainly formed ~~by~~ from river sediments (with a contribution from offshore sources), whereas coarse clastic barriers and spits are formed mainly ~~by~~ from paraglacial sediment from offshore sources that were integrated into the barrier system during the Holocene transgression. As a result, barriers in the low to mid-latitudes are typically finer grained, larger and longer than those in the mid- to high latitudes.

The *givoni* in our study area do not seem to fall into this bipartite division. From a dimensional perspective, these landforms belong to the category of mid- to high-latitude barriers and spits, with dimensions comparable to those of their British counterparts, i.e., generally ranging from a few to approximately 30~~two or three tens of~~ kilometres in length (i.e., from the 1-km length of the East Head spit to the 28-km length of Chesil beach; Stripling *et al.*, 2008); however, the same is not true for the grain sizes. In fact, the *givoni* in ~~our~~ the described study area are generally dominated by gravel~~coarse sediments~~, although they are not in a periglacial area. In southern Italy, periglacial conditions were confined to restricted areas; thus, a periglacial origin for the ~~high~~ large amount of coarse-grained sediment can be excluded. Instead, as described in section 4.3, the sediment is predominantly Apenninic, which suggests a mainland source of sediment ~~source~~ that was later transported by rivers to the sea and then ~~-~~by littoral drift.

In addition, we ~~can~~ exclude ~~that idea~~ that the continentally derived sediments that constitute the *givoni* ~~can~~ are actually ~~be~~ marine~~-~~-derived ~~even though they originated from the land, as they may have been stored in the nearshore during lowstands~~ and ~~then~~ recycled during the transgression. In fact, the regressional and progradational context in *givone* formation implies a continental origin of the sediments that form the coastal wedge and ~~its~~ the associated *givon~~e/~~i*.

Regardless of the origin of the coarse-grained sediments, the fact remains that, although catchment areas have not changed between the rivers of MIS 5 and their modern counterparts (Boenzi *et al*., 1977), the latter are incapable of carrying significant amounts of coarse sediment to the sea (unlike their MIS 5 counterparts). In fact, the ~~whole~~ Holocene coastal plain is mostly sandy (Tropeano *et al*., 2013) and characterised by a large sandy dune field (Figure 1).

To the best of our knowledge, no certain information exists on the origin of the large amounts of gravelly sediments. However, we consider it very likely that the formation of this gravel was promoted by semi-arid conditions that enhanced the physical weathering process and reduced the vegetation cover on slopes. In our opinion, these semi-arid conditions may be those of MIS 5. In fact, a series of multi-centennial intra-interglacial arid events in southern Europe are documented (Tzedakis *et al*. 2016) and correspond to cold water-mass expansions in the North Atlantic. Nevertheless, a high production of gravelly sediment in alluvial plains has also been documented in southern Italy during MIS 6 (De Santis *et. al*., 2010); thus we cannot exclude the possibility that the production of the gravelly sediment occurred entirely or in part during MIS 6.

~~Thus, modern beaches are almost entirely sandy (Tropeano *et al*., 2013).~~

~~We hypothesise that the high availability of coarse sediments during *givone* formation was caused by climatic factors.~~ Furthermore, we hypothesise that during the interstadial peaks of MIS 5 when the *givoni* were deposited, some phases occurred during which rainfall was sufficiently abundant for the rivers to transport gravel to the sea. This conclusion is consistent with the findings presented by several authors regarding precipitation in the Mediterranean area during MIS 5. This period was generally wet (Bar-Matthews, Ayalon, Gilmou, Matthews & Hawkesworth~~et al.~~, 2003; Hodge *et al.*, 2008) or presented alternating wet and dry phases (Bardají *et al.*, 2009; ~~Mauz et al., 2012;~~ Zucca *et al.* 2014; Mauz, Fanelli, Elmejdoub & Barbieri, 2012).

In addition, Kallel *et al.* (2000) suggested that the Mediterranean sapropel S5, which dates to MIS 5.5, formed when precipitation and runoff were high and almost equal to or greater than evaporation. In particular, sapropel S5 occurred after the deglaciation instead of during the glacial to interglacial transition. This timing indicates that sapropel S5 was caused by increased rainfall instead of glacial meltwater discharge. Rohling, Marino & Grant~~ et al.~~ (2015) concluded that these wetter conditions were due to increased winter moisture, which likely reflected enhanced Mediterranean depression activity.

Thus, our observations confirm the hypothesis that the MIS 5.5 interstadial peak~~s~~ was~~ere~~ characterised by a climate that was wetter than that of MIS 1; thus, the rivers in the northern Gulf of Taranto were capable of carrying gravel to the sea, which is no longer observed.

6. CONCLUSIONS

The Gulf of Taranto is the ideal place to study marine terracing processes occurring in particular conditions, such as in the presence of loose or semi-consolidated substrates and high amounts of available sediments. In these conditions, the classic erosive forms linked to marine terraces, such as platforms and scarps, ~~can~~ are often ~~be~~ variously masked by accretionary~~umulation~~ forms such as relict beach ridges, spits or barriers (BSBs, locally called *givoni*). Starting from ~~what we~~our observation~~ed~~s of ~~in~~ the marine terraces ~~on~~ along a large stretch of the Gulf of Taranto, we have summarised a set of cases that describe the different landforms generated by the combination of erosive and depositional forms, each in relation to the~~a~~ ~~precise~~ behaviour of the sea level during its eustatic oscillations.

In general, a succession of relict ~~beach ridges, spits or barrier~~BSBs do not necessarily indicates~~s~~ a simple progradational~~ed~~ coast~~,~~ but can ~~testify~~ indicate a complex history of sea level ~~still-stands~~ standstills and oscillations.

A sea-level ~~still-stand~~standstill above an unconsolidated coastal wedge deposited during a previous highstand does not necessarily form a classic abrasion platform with an adjoining cliff but can form a series of composite landforms, including ~~beach ridges, spits or barrier~~BSBs. Eventually, a narrow abrasion platform and cliff can form, which can ~~subsequently~~ later be totally or partially obliterated by the growth of BSBs.

For the first time, this work refutes the concept that all~~an arcuate morphology of the~~ inner edges of terraces are arcuate, at least in the Apulian sector of the Gulf of Taranto, where~~ich has to date been~~ the inner terrace edges are observed to be more or less subparallel to the current shoreline. The palaeoshoreline of the MIS 5.5 terrace at the Masseria Stoccatarda high provides strong support for this argument. Additionally, this palaeoshoreline configuration was most likely due to the particular lithology of the substrate, which is carbonate cemented and, therefore, more resistant.

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Table Captions

Table 1 - Aspartic acid (Asp) and glutamic acid (Glu) D/L values in ostracod valves of the sites described in this study with their corresponding ages and inferred MIS; for the provenance of the samples, see the geological map (Figure 1) and/or sections (Figs. 3 and 4). For a ~~complete~~ description of the AAR dating method applied, refer~~s~~ to De Santis *et al.* (2010, 2013, 2014b, 2018).

~~Tab~~Table~~le~~ 2~~1~~ - Schematic description of the terraced deposits cropping out in the study area. For each location, the outcropping units are reported from the bottom up. All d~~D~~ata ~~The reported parameters (~~from De Santis *et al.*~~,~~ (2018), except for the TM5/7, TM6/9, TM6/15 and TM6/17 locations, first published in this study. ~~) are as follows: the geographic coordinates, the e~~Elevation refers to ~~of~~ the base of the section above the present sea level. Age range includes ~~, the approximate maximum thicknesses, synthetic descriptions, significant fauna, palaeoenvironment, m~~maximum and minimum ages obtained with the AAR dating method applied to ostracod shells ~~or (*)~~ and the Alle/Ile values (indicated by a star) obtained by applying the isoleucine epimerisation method to *Glycymeris* sp., and associated substages (according to Belluomini *et al.*, 2002; Caldara *et al.*, 2003; Torres *et al.*, 2013 for the Alle/Ile values). The thick continuous line indicates an erosive/transgressive surface; the thick ~~dotted~~ dashed line indicates an erosive/transgressive surface marked by *L~~l~~ithodom~~o~~us* holes.

SFBC = well-sorted fine sand biocoenosis (*sensu* Pérès, 1967)

VTC = terrigenous mud biocoenosis (*sensu* Pérès, 1967)

PE = heterogeneous associations (*sensu* Picard, 1965)

AP = photophilous algae biocoenosis (*sensu* Pérès, 1967)

LEE = eury~~i~~aline and eury~~i~~therm lagoon biocoenosis (*sensu* Pérès, 1967)

ASP = argille subappenine unit

Figure Captions

~~Fig.~~Figure 1 - Location of the study area and schematic geomorphological map. The terrace deposits, *givoni*, and literature sites are reported.

~~Fig.~~Figure 2 - S~~chematic s~~ketch of the ~~reciprocal~~ stratigraphic relation between the MIS 7.1 and MIS 5 terrace deposits. The light grey background shows the MIS 7.1 terrace deposit; the white background shows the MIS 5 terrace deposit. The numbers refer to elevations (m a.s.l.) ~~refer to~~in the central sector of the study area.

~~Fig.~~Figure 3 - Section of the Stornara location (TM6/9 in ~~Fig.~~Figure 1). Below the section, the AAR ages of the dated samples are reported. The legend is referenced by~~refers to~~ all the following figures.

~~Fig.~~Figure 4 - a) Correlation scheme of the Crossodromo Fox Valley ~~motocross track~~ area; the observed and analysed outcrops are also highlighted, indicated with the abbreviations TM6/15 and TM6/17; these outcrops are artificial scarps of two agricultural land terraces; b) detail of the TM6/17 location, with the *givone*, characterised by landward (northward)-dipping gravelly layers that cover lagoonal clays; c) detail of photo b showing the contact between the gravels of the *givone* and the lagoonal clays: *Cerastoderma glaucum* specimens are observed in living~~fe~~ position ~~inside~~ among the small gravel~~s~~ clasts; d) detail of ~~stop~~ site TM6/15 in which ~~the~~ an abrupt and erosive contact between the sands of a previous marine deposit (MIS 6) and the sandy-gravelly unit of the MIS 5.5 is evident. Below the section, the AAR ages of the dated samples are reported. For symbols, see the legend of ~~Fig.~~Figure 3.

~~Fig.~~Figure 5 - Comparison between a *givone*, observable in a section at the TM5/9 site (a, b), and ~~the~~ a ~~current~~ present beach ridge ~~present at a beach of the Gulf of Taranto~~~~in~~from the central Ionian Calabrian coast, where there is a mixed gravelly_-sandy component (c, d). For symbols, see the legend of ~~Fig.~~Figure 3.

~~Fig.~~Figure 6 ~~-~~- G-~~-~~type *givone* cropping out at the TM5/15 site. A component of the inclination of the gravelly beds, parallel to *givone* elongation, can be observed.

~~Fig.~~Figure 7 - Sections near Masseria Difesella, where a succession culminating with one of the Miraglio’s *givoni* is observable (TM5/7 in ~~Fig.~~Figure 1):~~.~~ a) ~~S~~sectional view normal to the *givone* elongation direction ~~(a)~~ and its interpretation (S = seaward side; L =landward side) ~~(a’)~~; b) seaward side ~~of the *givone* (b)~~ and its interpretation~~ (b')~~; c) particular of the coarser sands with cemented layers, flute marks and flute casts; the position is reported in the box b; d) landward side ~~of the *givone* (c)~~ and its interpretation~~ (c'); d) landward side view~~; e) particular of the dominant gravelly seaward bedding plane inclinations in the *givone*; the position is reported in the box d; f)~~showing~~ particular of another point of the landward side of the *givone* showing the dominant seaward bedding plane inclinations (indicated by the thick white arrows) and the minor landward bedding plane inclinations (indicated by the thin white arrows), most likely due to overwashing events.~~ The numbered photos 1 and 2 are the enlargement of the corresponding numbered boxes.~~ For symbols, see the legend of ~~Fig.~~Figure 3.

~~Fig.~~Figure 8 - Shingle barriers of the Rakaia River mouth (New Zealand; a) and Chesil Beach (England; b). According to our reconstruction, the *givoni* of the study area ~~were able to~~ formed in a context very similar to those~~at~~ represented in these photos.

a: Creative Commons Attribution 2.0 Generic license; https://creativecommons.org/licenses/by/2.0/deed.en

b: Source: Plymouth Coastal Observatory http://southwest.coastalmonitoring.org/wp-ontent/uploads/2016/04/241894.jpg http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

~~Fig.~~Figure 9 - A sand spit formed in October 2003 at the Bradano River mouth. The *givoni* of the MIS 5 terrace were possibly generated as spits or barriers by similar processes as those occurring today but under conditions of mixed gravelly sandy or exclusively gravelly inputs from inland sources.

~~Fig.~~Figure 10 - Reconstruction of the formation and evolution processes of the MIS 5 terrace deposits. For each phase described, the sea level from Waelbroeck *et al.* (2002) is reported. In

~~Fig.~~Figure 10b, the mechanism of *givone* formation is the same as that reported in ~~Fig.~~Figure 12d; in ~~Fig.~~Figure 10c, the mechanism of *givone* formation is the same as that reported in ~~Fig.~~Figure 12f. In ~~Fig.~~Figure 10d, the mechanism of *givone* formation is the same as that reported in ~~Fig.~~Figure 12e. In ~~Fig.~~Figure 10f, the mechanism of *givone* formation is the same as that reported in ~~Fig.~~Figure 12h. For the symbol legend, see ~~Fig.~~Figure 2.

~~Fig.~~Figure 11 - Reconstruction of the evolution of the Stornara *givone* ~~as deducible from~~based on two sections near the Crossodromo Fox Valley~~ motocross track~~: the evolution is characterised by the landward migration of the *givone* by rollover processes driven by overwashing.

~~Fig.~~Figure 12 - Schematic sketch showing different scenarios leading to *givon~~e~~i* formation:~~. See the text for details.~~a-b-c) formation, during the highstand peak, of a platform and cliff on a consolidated substrate (b) and accumulation of the coastal sedimentary wedge which can create one BSB (c). From this point different scenarios can occur: d) accumulation of the coastal sedimentary wedge which can create more BSBs during the highstand; e) sea-level standstills in the context of a regressive phase can create a series of BSBs with the formation of platforms and sea cliffs; f) the same of (e) but no formation of platforms and sea cliffs occurs; g) a new relative highstand of a warm substage on unconsolidated substrate formed during the same stage can create one or more BSB; h) the same of (e), except that the sea level stops rising against a pre-existing BSB. In all these cases, the sea cliff and abrasion platform can later be totally or partially obliterated by the growth of BSBs and/or by subaerial erosion.

Sample	**Location**	**Analytical samples**		**D/L Asp**	**D/L Glu**	**Age (ky)**	**MIS**
TM6/9b	Stornara	5	*Cyprideis torosa*	0.362±0.020	0.128±0.024	126±30	5.5
TM6/9b bis	Stornara	5	*Cyprideis torosa*	0.312±0.021	0.138±0.024	116±38	5.5
TM6/9c	Stornara	5	*Cyprideis torosa*	0.328±0.030	0.126±0.031	120±25	5.5
TM6/9d	Stornara	5	*Cyprideis torosa*	0.343±0.009	0.137±0.021	127±22	5.5
TM6/15b	Crossodromo Fox Valley	5	*Cyprideis torosa,*	0.413±0.019	0.153±0.010	168±19	6.5
TM6/15d	Crossodromo Fox Valley	3	*Cyprideis torosa, Leptocythere*	0.394±0.025	0.109±0.023	131±25	5.5
TM6/17b1	Crossodromo Fox Valley	5	*Cyprideis torosa,*	0.378±0.019	0.128±0.010	130±18	5.5
TM6/17b2	Crossodromo Fox Valley	5	*Cyprideis torosa,*	0.379±0.021	0.132±0.009	135±21	5.5
TM6/17b3	Crossodromo Fox Valley	5	*Cyprideis torosa,*	0.389±0.011	0.128±0.011	137±17	5.5
TM6/17b4	Crossodromo Fox Valley	5	*Cyprideis torosa,*	0.361±0.027	0.129±0.003	137±9	5.5

Study location	Geographic coordinates	Elevation m a.s.l.	Max thickness (*ca.* m)	Synthetic description	Significant fauna	Palaeoenvironment	Age range (ky)	MIS	
TM5/17 Masseria Stoccatarda high	40°30'47"N 16°53'56"E	45	0.5	greyish brown laminated siliciclastic sandstones alternating with loose sands that fill erosion marks and *Lithodomus* holes in the surface of the underlying limestone unit				5	De Santis *et al.* (2018)
			4	massive biostromal-biohermal limestone	*Cladocora caespitosa* marine molluscs bryozoans, serpulids, echinoids, calcareous algae	marine infralittoral	174.3±29.2 179.3±8.7	7.1	
			1	fining upward sand with clayey and arenaceous beds; lenses of fine bioclastic sands are present in the upper part	*Pecten* sp.	marine		?	
TM5/10,11,13, 14 Masseria Stoccatarda high	Between 40°30'42"N 16°53'25"E And 40°31'33"N 16°55'46"E	52	0-5	brown siliciclastic sands		continental		5	De Santis *et al.* (2018)
			0.3-3	massive biostromal-biohermal limestone	*Cladocora caespitosa* marine molluscs bryozoans, serpulids, echinoids, calcareous algae	marine	190.3±30.7 (TM5/14)	7.1	
TM5/12 Masseria Stoccatarda high	40°30'51"N 16°53'22"E	53	2	massive biostromal-biohermal limestone	*Cladocora caespitosa* marine molluscs bryozoans, serpulids, echinoids, calcareous algae	marine	196.6±18.5 229.7±42.8	7.1	De Santis *et al.* (2018)
TM5/5 Canale Palagiano	40°35'00"N 17° 3'21"E	36.5	1	light beige calcareous-siliciclastic fine sands passing upwards into a thin layer of pink silt	*Planorbis planorbis*, Hydrobidae *Cerastoderma glaucum*, *Abra segmentum*	lagoonal and freshwater	80.8±20.0 128.6±27.1	5	De Santis *et al.* (2018)
			2	massive body composed of medium-coarse mixed calcareous-siliciclastic sand with scattered centimetric to decimetric pebbles of Apenninic origin	*Pecten* sp. (transported)	beach-backshore		5	
TM5/2-4 Canale Palagiano	Between 40°34'39"N 17° 3'12"E and 40°34'39"N 17°03'12"E	31	5	medium-coarse, beige to brownish, partially cemented, mixed calcareous-siliciclastic sands gentle dipping to the south, high- to low-angle cross bedding	*Pecten* sp.	marine infralittoral	80.8±20.2 126.9±25.8	5	De Santis *et al.* (2018)
TM5/6 Fontana del Fico	40°34'27"N 16°59'29"E	ca. 31	2	polygenetic poorly sorted pebbles in a reddish clay matrix; lenses and beds of reddish clay are also present		floodplain		5	De Santis *et al.* (2018)
			3	whitish sand grading rapidly upwards into light grey to whitish silt	*Theodoxus fluviatilis*, *Melanoides tuberculata*, *Planorbis planorbis*	freshwater/ continental	65.7±12.6 96.6±22.9	5	

			3	thin layers of clayey silt, silty clays and clays that are dark brown to light beige and containing scattered pebbles at the base	*Lymnaes* spp. *Bithynia* spp., Characeae *Cerastoderma glaucum, Abra segmentum,* Hydrobiidae	LEE alternating to continental with running or stagnant freshwater	127.1±29.0 148.7±29.1	5	
			2.5	poorly sorted gravels of both Murgian and Apenninic origin. Upward fining is evident: first, the sandy matrix increases and the pebbles gradually grade smaller; then, the deposit grades into reddish clays	pulmonate gastropods	floodplain		5	
			0.5	tawny fine bioturbated sands overlain by a level of calcareous algae in a matrix of sand and small pebbles	*Pecten* sp., *Ostrea* sp.	marine circalittoral		?	
TM5/1 Masseria D’Anela	40°31'57"N 16°55'17"E	ca. 28	4.5	inclined-bedded calcarenite that grades upwards into fine, cross- or inclined-bedded siliciclastic sand with polygenetic poorly sorted pebbles at the base and bioturbation	thalassinoides	marine infralittoral SFBC	131.9±4.6	5	De Santis *et al.* (2018)
			4	fine-grained, brown-grey, cross-laminated siliciclastic sands with flute casts passing upwards to calcarenite layers alternating with siliciclastic sand layers	*Aequipecten opercularis*	marine infralittoral SFBC	144.9±29.6	5	
			3	greyish silt with light and dark intervals	*Teodoxus fluviatilis, Valvata piscinalis* *Cerastoderma glaucum*	lagoonal with freshwater inputs		5	
			1.5	ASP				Middle Pleistocene	
TM5/7 Near Mass. Difesella	40°32'18"N 16°57'19"E	33	3	southward inclined-bedded, poorly sorted conglomerate of Apenninic origin	*Glycymeris* sp.	beach shore one of Miraglio’s *givoni*		5.5?	This study
			3	beige fine sands with cemented sub-horizontal layers containing abundant flute marks; gravel layers that become increasingly numerous, thicker and coarser upwards	*Glycymeris* sp.	marine infralittoral		5.5?	
			5	massive beige fine sands with some thin cemented layers	*Glycymeris* sp.	marine circalittoral		5.5?	
TM5/8 Near Mass. Sant’Andrea Grande	40°30'48"N 16°55'43"E	27	4	yellowish-brown siliciclastic sands	*Glycymeris* sp.	marine infralittoral SFBC	0.462±0.032 *	5.5	De Santis *et al.* (2018)
TM5/15 Near Mass D’Anela	40°31'33"N 16°55'46"E	40	2	poorly sorted Apenninic gravel with SE-dipping laminae	*Glycymeris* sp.	beach	0.490±0.026 *	5.5	De Santis *et al.* (2018)
TM6/1 Ponte del Re	40°30'54"N 16°56'20"E	21	0.8	gravelly unit composed of poorly sorted Apenninic pebbles	*Cerastoderma* sp.	beach shore (Ponte del Re *givone*)		5.5	De Santis *et al.* (2018)
			7	clayey sand passing upwards into fine sand with flute casts and flute marks	*Glycymeris* sp.	marine infralittoral SFBC	123.7±24.8 0.480±0.056 *	5.5	

			0.5	biostromal-biohermal limestone with scattered centimetric Apenninic pebbles	*Cladocora caespitosa, Pecten* sp.	marine infralittoral AP		5.5	
			0.5	conglomerate composed of marly pluridecimetric pebbles in a matrix of centimetric Apenninic pebbles		marine		5.5	
			0.5	ASP				Middle Pleistocene	
TM6/2 and TM6/8 Masseria Perrone	40°30'18"N 16°56'33"E 40°30'18"N 16°56'12"E	5	5	poorly sorted gravels of Apenninic origin	*Glycymeris* sp., *Cerastoderma* sp.	beach shore (SS.106 *givone*)		5.3	De Santis *et al.* (2018)
			2	grey-beige fine clayey sand with calcareous nodules and lenses and layers of gravel/conglomerate	*Glycymeris* sp.	marine infralittoral SFBC		5.3	
			4	massive beige fine sand	*Glycymeris* sp. *Corbula gibba, Ditrupa cornea, Turritella communis*	marine circalittoral (PE – VTC) passing upwards into infralittoral	97.3±18.9 0.436±0.048 * 0.427±0.026	5.3	
			4	beige fine sand with cemented bioturbation grouped in sub-horizontal layers that become increasingly numerous and thicker upwards	*Turritella communis, Corbula gibba, Ditrupa cornea*	marine circalittoral VTC - PE		5	
TM6/6 and TM6/7 Cave Sarim	40°28'52"N 16°49'02"E 40°28'46"N 16°49'09"E	26	6	Sub-horizontal to gently sloping beds show a fining-upward trend: the gravel beds decrease in number, thickness and grain size toward the top until they are replaced by fine sand and clay	*Cyprideis torosa*	continental environments with freshwater episodes	102±16 ka	5.5	De Santis *et al.* (2018)
			>14	large prograding sedimentary body with mainly gravelly seaward sloping clinoforms,		coastal prograding wedge with beach and nearshore environments		5.5	
TM6/9 Stornara	40°27'06"N 16°50'30"E	ca. 16	2	southwestward inclined-bedded, poorly sorted conglomerate of Apenninic origin passing northward into silt and clayey silt	*Planorbis planorbis* (within silt and clayey silt)	freshwater (back barrier of Stornara *givone*)	116±38 127±22	5.5	This study
TM6/15 Crossodromo Fox Valley	40°32'05"N 17°01'05"E	14	4	southwestward inclined-bedded, poorly sorted conglomerate of Apenninic origin with lenses of beige sands	*Chlamys opercularis, Ditrupa cornea*	beach shore (Stornara *givone*)	131±25	5.5	This study
			1.5	beige fine sand with cemented sub-horizontal layers with abundant flute marks; gravel layers that become increasingly numerous, thicker and coarser upwards	*Mactra stultorum, Spisula subtruncata*	marine infralittoral SFBC		6.5	
			1.5	massive beige fine sand	*Pecten* sp., *Anomia* sp., *Echinoids*	marine	168±19	6.5	
TM6/17 Crossodromo Fox Valley	40°32'02"N 17°01'14"E	15	2	northward inclined-bedded, poorly sorted conglomerate of Apenninic origin		beach shore (Stornara *givone*)		5.5	This study
			0.70	clay	*Cerastoderma glaucum*	LEE	137±17 130±18	5.5	
			3.0	massive beige/reddish fine sand		marine (?)		5.5	

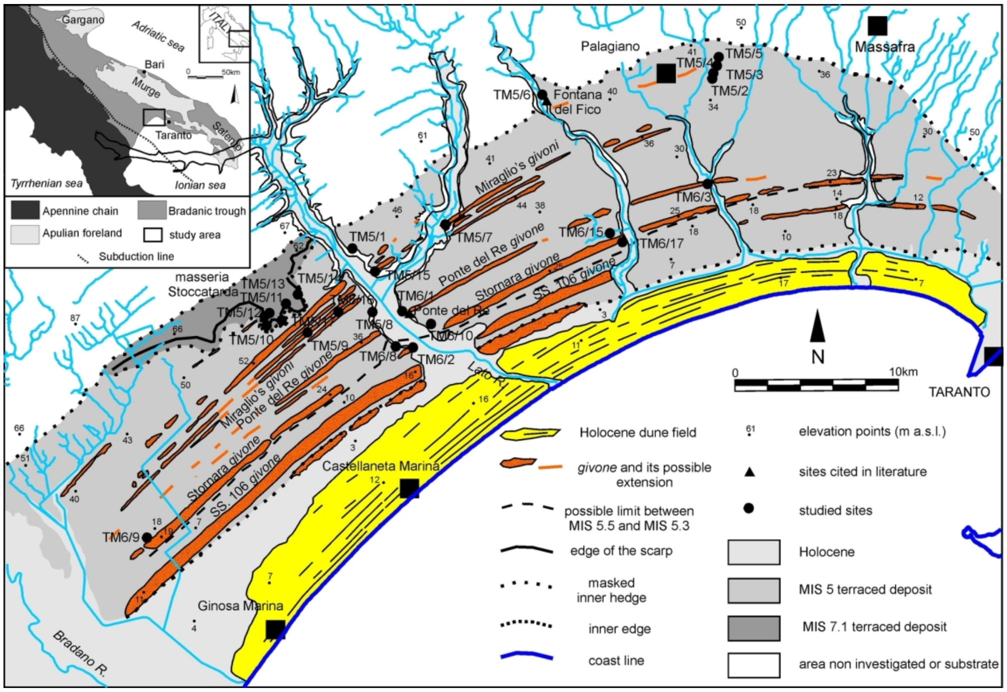

Figure 1 - Location of the study area and schematic geomorphological map. The terrace deposits, givoni, and literature sites are reported.

160x109mm (300 x 300 DPI)

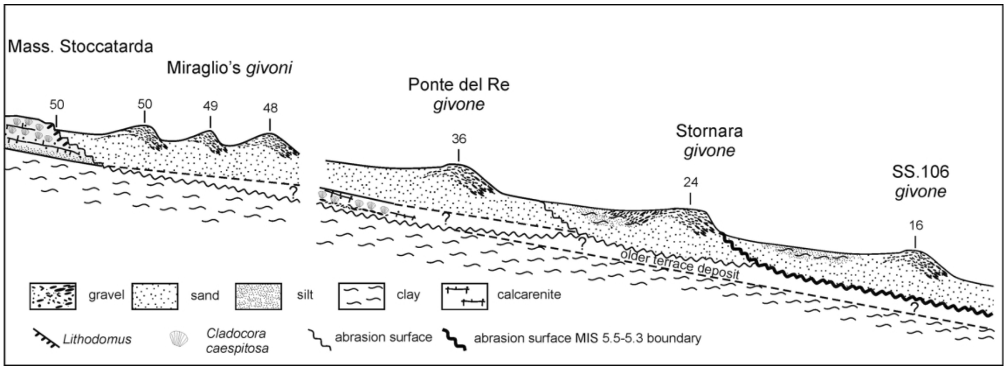

Fig. 2 - Schematic sketch of the reciprocal stratigraphic relation between the MIS 7.1 and MIS 5 terrace deposits. The light grey background shows the MIS 7.1 terrace deposit; the white background shows the MIS 5 terrace deposit. The elevations (m a.s.l.) refer to the central sector of the study area.

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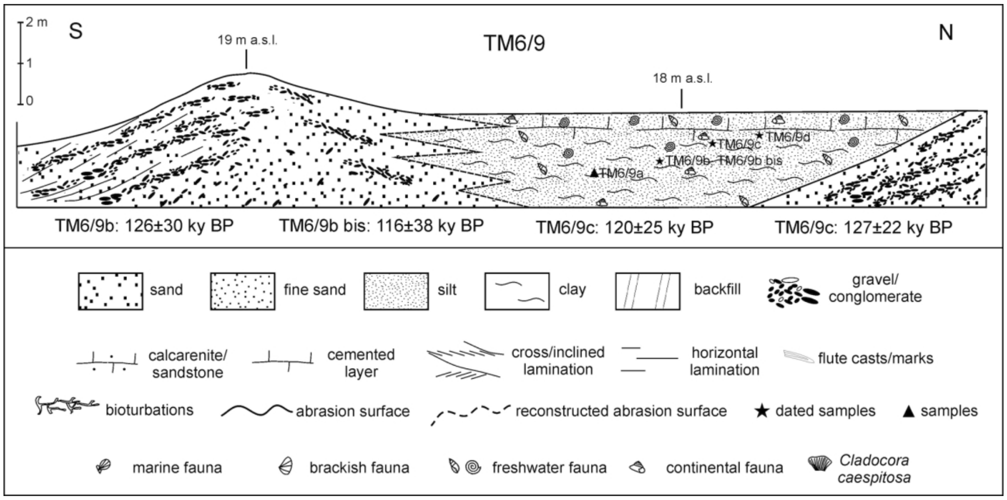

Fig. 3 - Section of the Stornara location (TM6/9 in Fig. 1). Below the section, the AAR ages of the dated samples are reported. The legend is referenced by all the following figures.

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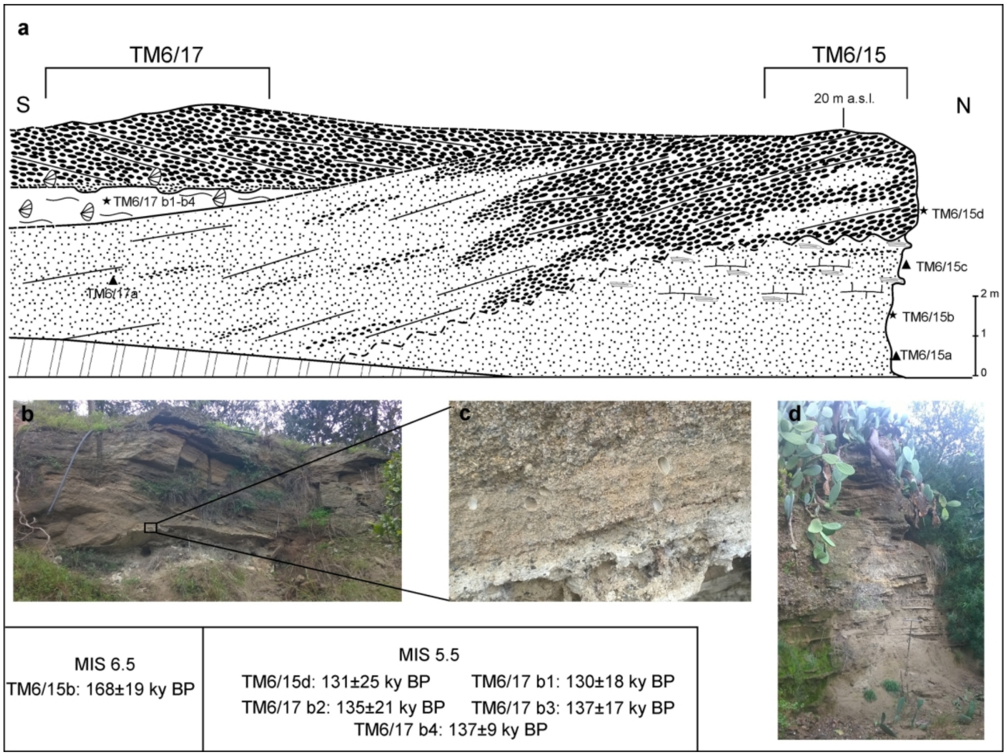

Fig. 4 - a) Correlation scheme of the Crossodromo Fox Valley area; the observed and analysed outcrops are also highlighted, indicated with the abbreviations TM6/15 and TM6/17; these outcrops are artificial scarps of two agricultural land terraces; b) detail of the TM6/17 location, with the givone, characterised by landward (northward)-dipping gravelly layers that cover lagoonal clays; c) detail of photo b showing the contact between the gravels of the givone and the lagoonal clays: Cerastoderma glaucum specimens are observed in living position among the small gravel clasts; d) detail of site TM6/15 in which an abrupt and erosive contact between the sands of a previous marine deposit (MIS 6) and the sandy-gravelly unit of the MIS 5.5 is evident. Below the section, the AAR ages of the dated samples are reported. For symbols, see the legend of Fig. 3.

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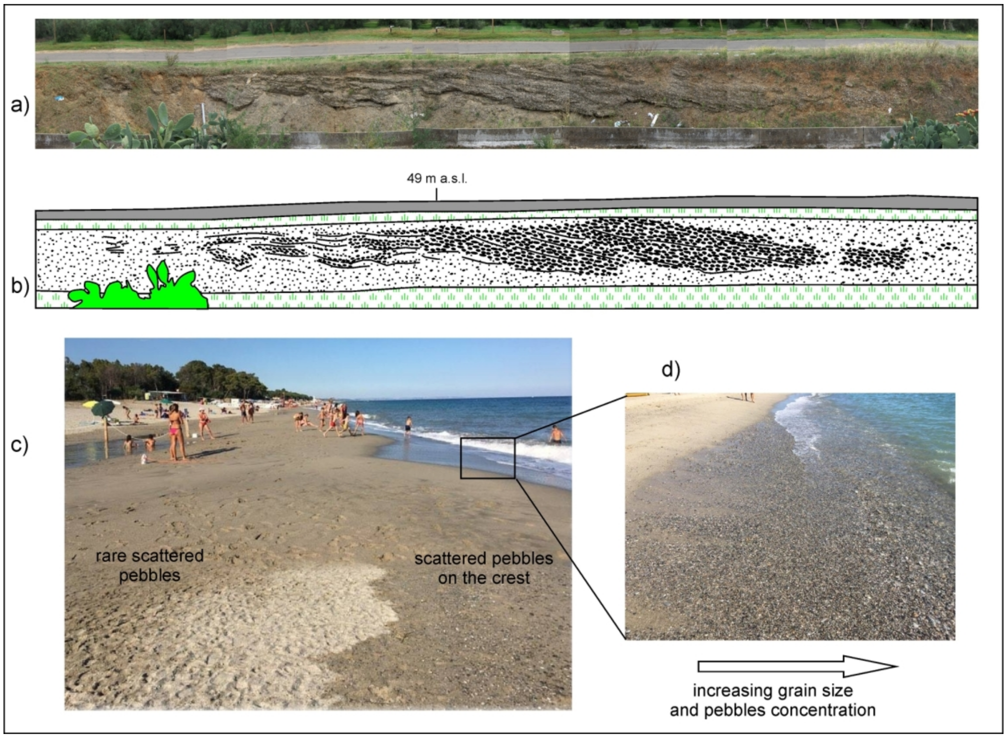

Fig. 5 - Comparison between a givone, observable in a section at the TM5/9 site (a, b), and a current beach ridge present in the central Ionian Calabrian coast, where there is a mixed gravelly sandy component (c, d). For symbols, see the legend of Fig. 3.

160x117mm (300 x 300 DPI)

Fig. 6 - G-type givone cropping out at the TM5/15 site. A component of the inclination of the gravelly beds, parallel to givone elongation, can be observed.

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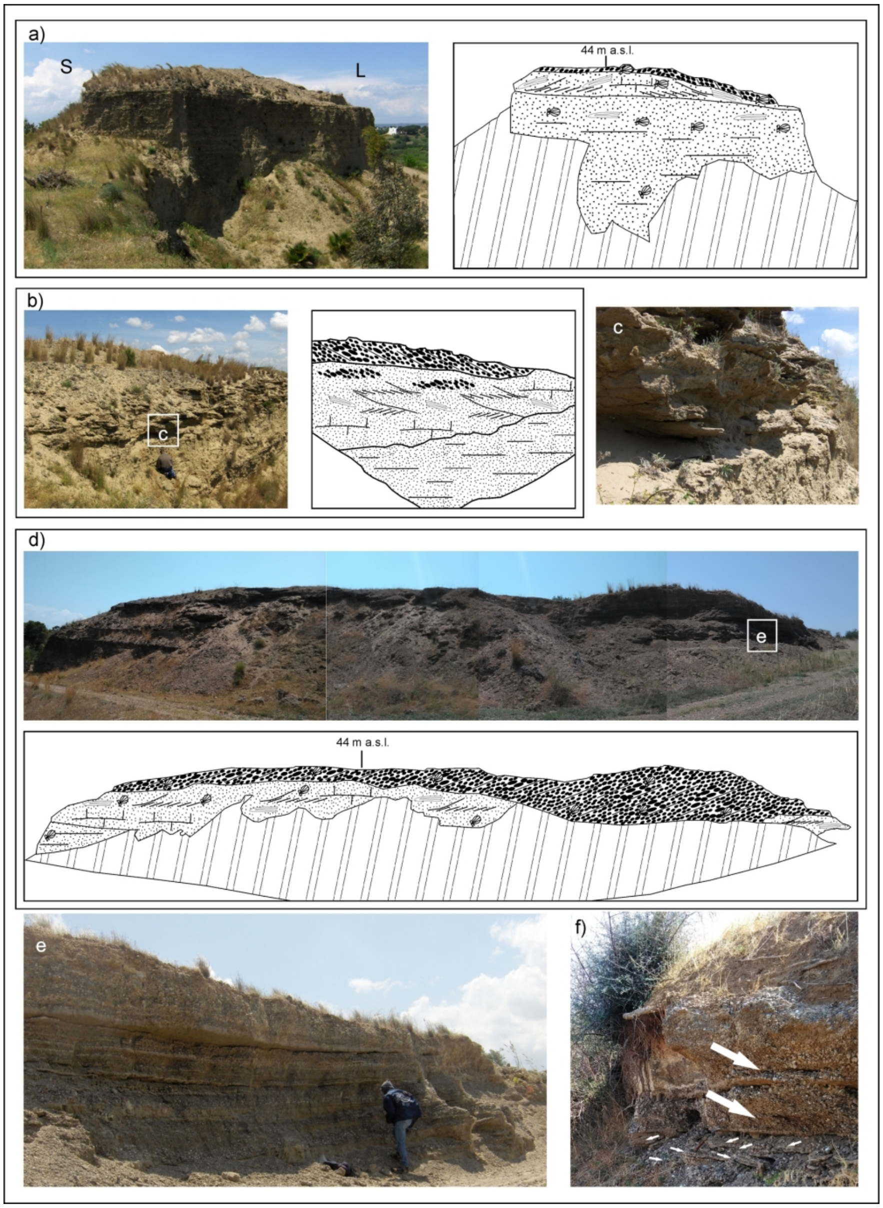

Figure 7 - Sections near Masseria Difesella, where a succession culminating with one of the Miraglio's givoni is observable (TM5/7 in Figure 1): a) sectional view normal to the givone elongation direction and its interpretation (S = seaward side; L =landward side); b) seaward side and its interpretation; c) particular of the coarser sands with cemented layers, flute marks and flute casts; the position is reported in the box b; d) landward side and its interpretation; e) particular of the dominant gravelly seaward bedding plane inclinations in the givone; the position is reported in the box d; f) particular of another point of the landward side of the givone showing the dominant seaward bedding plane inclinations (indicated by the thick white arrows) and the minor landward bedding plane inclinations (indicated by the thin white arrows), most likely due to overwashing events. For symbols, see the legend of Figure 3

160x218mm (300 x 300 DPI)

Fig. 8 - Shingle barriers of the Rakaia River mouth (New Zealand; a) and Chesil Beach (England; b). According to our reconstruction, the givoni of the study area formed in a context very similar to those represented in these photos.
a: Creative Commons Attribution 2.0 Generic license; https://creativecommons.org/licenses/by/2.0/deed.en
b: Source: Plymouth Coastal Observatory http://southwest.coastalmonitoring.org/wp-ontent/uploads/2016/04/241894.jpg http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

159x53mm (300 x 300 DPI)

Fig. 9 - A sand spit formed in October 2003 at the Bradano River mouth. The givoni of the MIS 5 terrace were possibly generated as spits or barriers by similar processes as those occurring today but under conditions of mixed gravelly sandy or exclusively gravelly inputs from inland sources.

79x53mm (300 x 300 DPI)

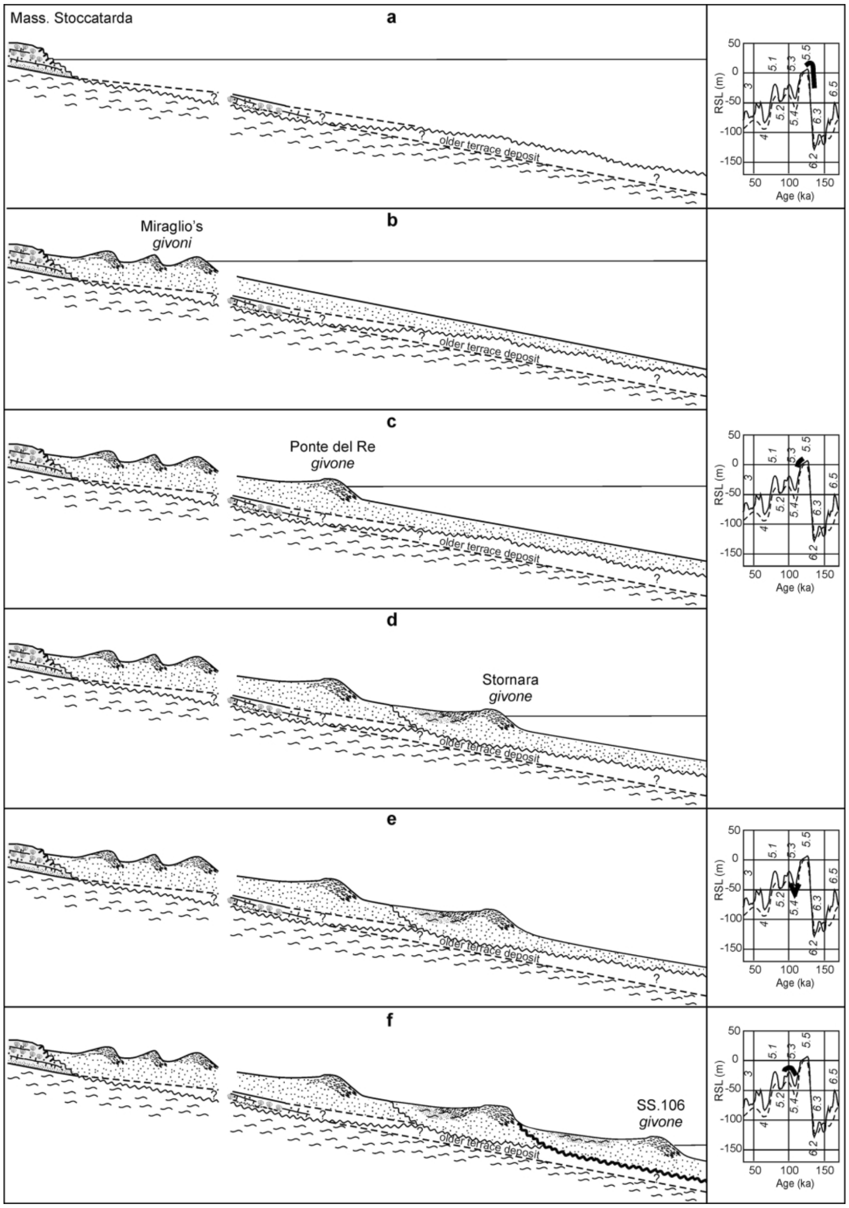

Fig. 10 - Reconstruction of the formation and evolution processes of the MIS 5 terrace deposits. For each phase described, the sea level from Waelbroeck et al. (2002) is reported. In Fig. 10b, the mechanism of givone formation is the same as that reported in Fig. 12d; in Fig. 10c, the mechanism of givone formation is the same as that reported in Fig. 12f. In Fig. 10d, the mechanism of givone formation is the same as that reported in Fig. 12e. In Fig. 10f, the mechanism of givone formation is the same as that reported in Fig. 12h. For the symbol legend, see Fig. 2.

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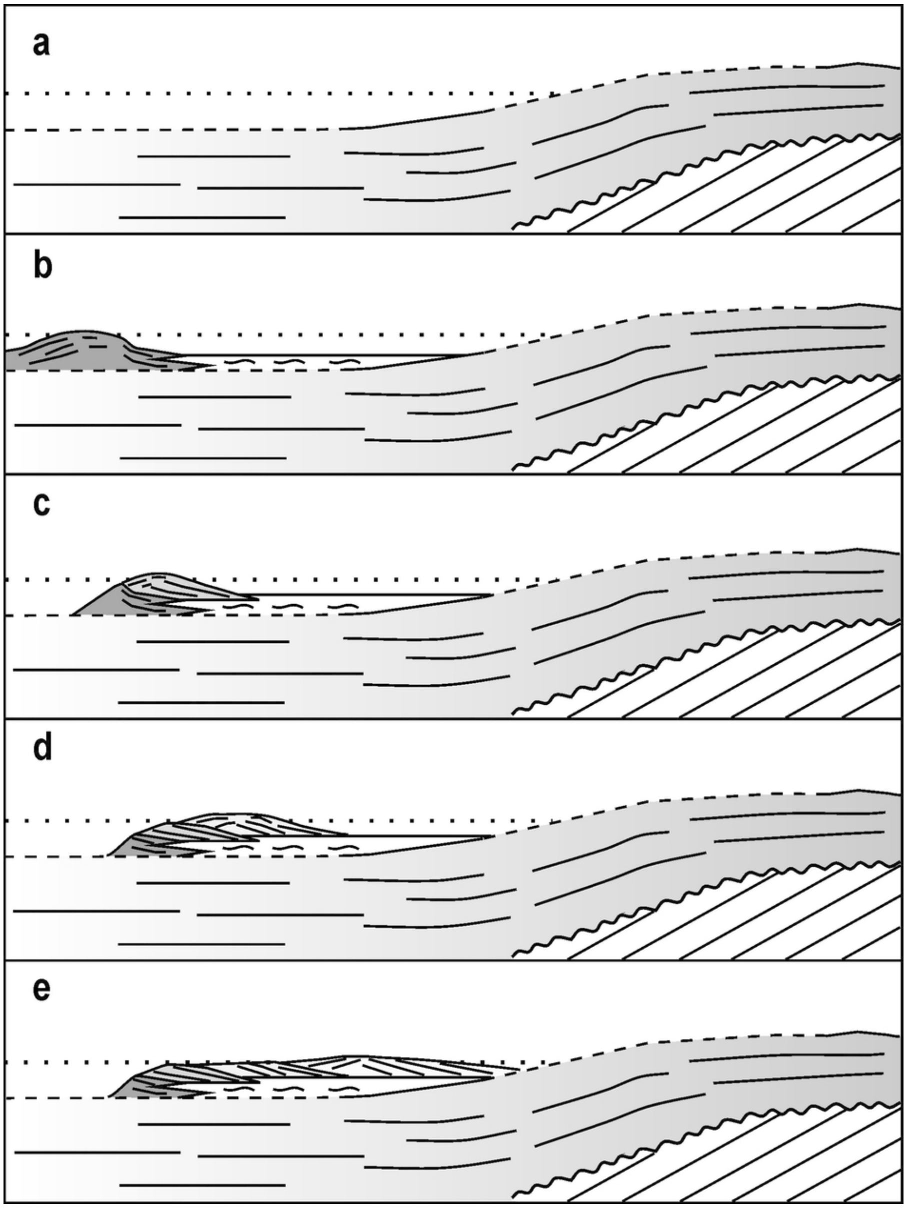

Fig. 11 - Reconstruction of the evolution of the Stornara givone based on two sections near the Crossodromo Fox Valley: the evolution is characterised by the landward migration of the givone by rollover processes driven by overwashing.

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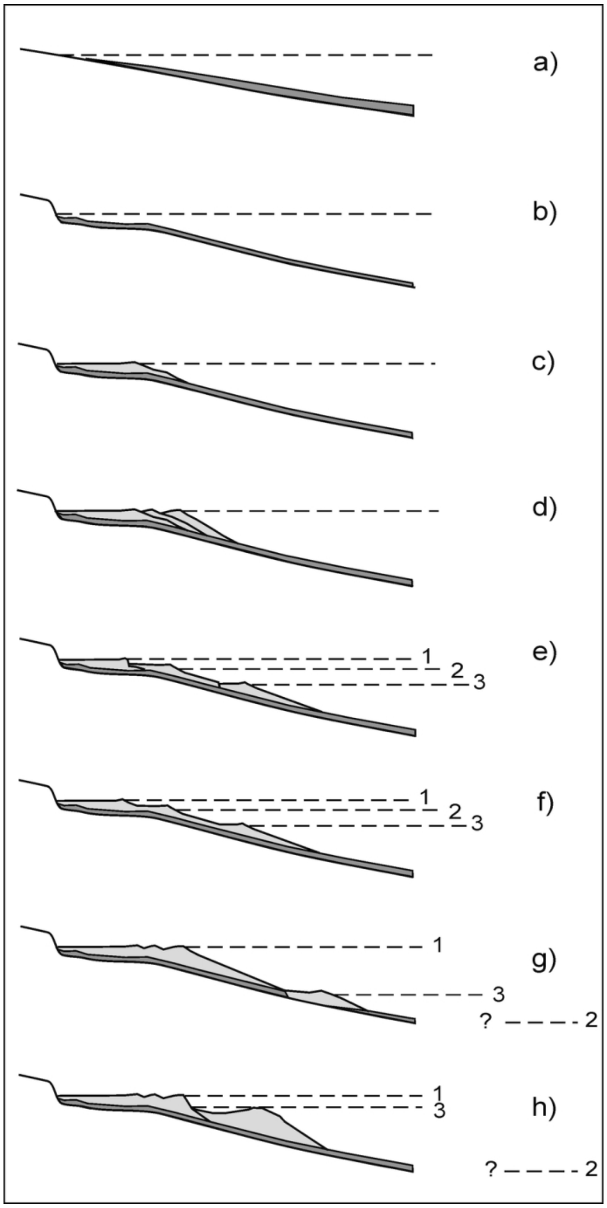

Figure 12 - Schematic sketch showing different scenarios leading to givoni formation: a-b-c) formation, during the highstand peak, of a platform and cliff on a consolidated substrate (b) and accumulation of the coastal sedimentary wedge which can create one BSB (c). From this point different scenarios can occur: d) accumulation of the coastal sedimentary wedge which can create more BSBs during the highstand; e) sea-level standstills in the context of a regressive phase can create a series of BSBs with the formation of platforms and sea cliffs; f) the same of (e) but no formation of platforms and sea cliffs occurs; g) a new relative highstand of a warm substage on unconsolidated substrate formed during the same stage can create one or more BSB; h) the same of (e), except that the sea level stops rising against a pre-existing BSB. In all these cases, the sea cliff and abrasion platform can later be totally or partially obliterated by the growth of BSBs and/or by subaerial erosion.

80x160mm (300 x 300 DPI)