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Posted Date: 4 August 2023

doi: [10.20944/preprints202308.0421.v1](https://doi.org/10.20944/preprints202308.0421.v1)

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Article

Gravelly Beach Deposits as a Proxy for Relative Sea-Level Changes in Microtidal Wave-Dominated Shoreline Systems: Examples from the Hinterland of the Taranto Gulf (Middle Pleistocene, Basilicata, Southern Italy)

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Abstract: The hinterland of the Taranto Gulf in Basilicata (southern Italy) provides a great opportunity for the study of coarse-grained coastal systems belonging to a staircase of Quaternary terraced marine-deposits. Among gravelly successions, beach deposits abound in the stratigraphic record, offering exceptional outcrops useful to allow detailed information on their facies features. In this paper, we describe sedimentary facies, textural variations and depositional architecture of these deposits in order to:

- demonstrate that the area is an excellent training ground for the study of gravelly beaches in microtidal settings;
- discuss about the use of beach deposits as proxy of even small relative sea level variation.

Keywords: gravelly beach deposits; relative sea-level changes; Metaponto Coastal Plain

1. Introduction

The hinterland of the Taranto Gulf in Basilicata, i.e., the Metaponto Coastal Plain and its inland (southern Italy) (Figures 1 and 2), is characterized by the occurrence of coarse-grained coastal deposits located in the uppermost part of exposed successions; the latter have been interpreted to be linked to a flight of marine terraces developed during Quaternary because the interference between regional uplift and eustatic sea-level changes [1]. Despite the large number of geomorphological studies, of either regional or local significance, and the production of several local chronostratigraphic data, authors working in the area disagree each other about the number of these marine terraces, whose proposed surfaces span from 7 [2,3], to 11, [4,5], up to 18 [6]. A detailed sedimentological and stratigraphic study performed in a selected part of the area, between the Cavone and Basento Rivers, highlighted the presence of a very complex succession related to several high- to very high-frequency relative sea-level changes with more than one vertically-stacked coastal sequence, even in the subsurface of the present day coastal plain [7–10]. As a consequence: i) each terrace-surface cannot be simply linked to a cycle of relative sea-level change but, eventually, to the last of those ones recorded in the local sedimentary succession.; ii) coastal or alluvial coarse-grained deposits, often located in the uppermost part of the section, just below a terraced surface, could be not genetically related to some of the underlying (possibly datable) sandy deposits, whose sedimentation could be linked to a previous (older) and different relative sea-level/base-level position. This means that, before to date outcropping deposits, it is necessary to perform a detailed facies analysis of the selected succession, in order to collocate the sample both in the right palaeoenvironment (i.e., its hypothetical paleodepth) and in the local history of sea-level changes.

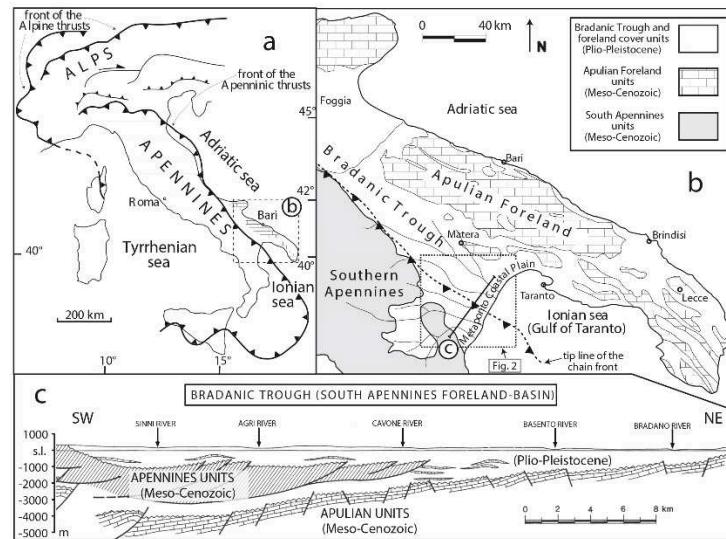


Figure 1. (a) Schematic structural map of Italy; (b) schematic structural map of southern Italy; (c) geological cross-section of the Bradanic Trough (after [11] modified). After [10], modified.

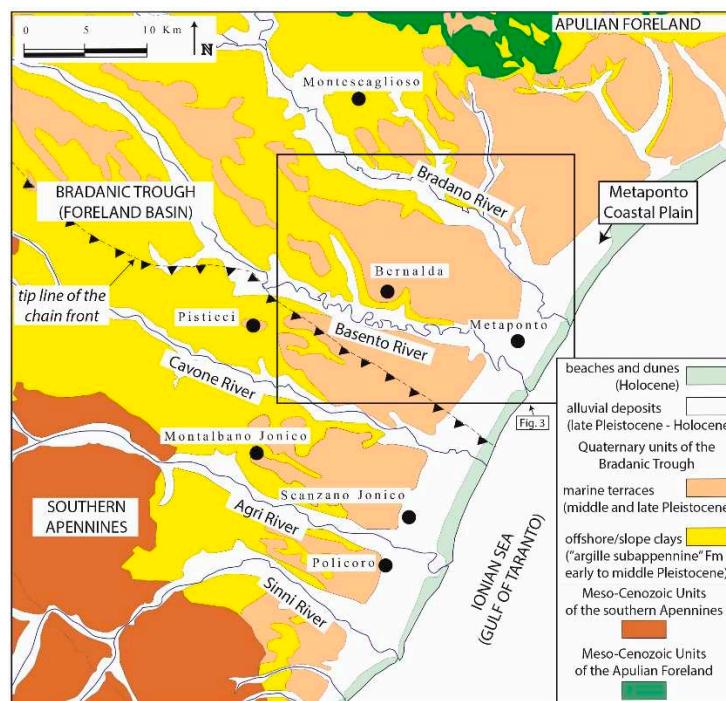


Figure 2. Schematic geological map of the region comprising the study area (see Fig. 1 for location). The study area is located between the Bradano River and the Basento one (see also Figure 3). After [12] and [13,14], modified.

In coastal settings, the most sensitive environment to even the smallest relative sea-level change is the beachface, that, during its development, represents also the best record (with a small error range) of the relative position of the sea level. In order to develop future age-dating of uplifted Quaternary successions in the hinterland of the Taranto Gulf, the recognition of beachface facies (and adjacent ones), even not directly linked to a terraced surface, represent one of the main tools to constrain deposits to the relative sea-level to which they were genetically related.

After this premise, this work has a double purpose:

- (1) demonstrate that the area is an excellent training ground for the study of gravelly beaches in microtidal settings;
- (2) be a basis for following studies about the complex evolution of vertically-stacked multistory paralic-deposits topped by a terrace, considering that beachface deposits (and genetically adjacent ones) represent a proxy of the relative sea level variation in the analyzed successions.

2. Gravelly beach: a brief overview

Present-day gravelly coastal systems are made up of coarse-grained particles of various shape and size as a result of redistribution induced by waves on sediments transported towards the shore by rivers or glaciers or fallen down at the foot of seacliffs [15]. Prograding gravelly coastal systems mainly consist of sigmoidal to prismatic longshore-elongated sedimentary bodies, and, since inclination of clinobeds is linked to grain size of particles [16,17], basically gravelly systems show a more inclined slope than sandy ones and are part of reflective beaches rather than dissipative ones (*sensu* [18]).

The depositional profile is conventionally divided into three sectors on the basis of its morphology and of hydrodynamics and sedimentary processes occurring in the area [19–21]. Accordingly, proceeding from the submerged coastal area to the exposed one, the three sectors are represented by: i) the shoreface, corresponding to the submerged gently sloping coastal belt affected by oscillatory shoaling waves and unidirectional longshore currents; ii) the beachface (often indicated as synonym of foreshore, i.e., the intertidal zone of these coasts), corresponding to the seaward inclined narrow coastal belt straddling the shoreline and affected by surging or just-broken waves that infiltrate or flow down the slope; iii) the backshore, corresponding to the exposed and most elevated part of the beach affected by seasonal different wave-front action (run-up); it typically shows a sub-horizontal to gently landward-sloping surface.

Commonly, in coarse-grained systems, the beachface and the backshore together are referred as “the beach”, and the transition from beachface to shoreface is often marked by a morphological step (plunge step) [22–28].

In macrotidal examples, gravelly beaches were subdivided into shore-parallel zones (facies belts), with discoidal elements generally deposited in the middle-upper part of the beach (backshore) and spherical-shaped ones accumulated in the lower part (beachface) [29–37]. The gravelly beach zoning is caused by both marine swash and undertow, since these processes are induced by waves whose energy has not been dissipated in the surf zone, a narrow or not developed zone in gravelly systems [38,39]. Therefore, discoidal clasts are brought up on the backshore, while spherical ones tend to avalanche, rolling down along slope and accumulating at the foot, as a consequence of the deceleration of the undertow. Furthermore, since the transport takes place on a gravelly surface that acts as a sieve, the larger elements are transported seaward (overpassing), while smaller ones get trapped upwards; this process allows to the development of gravelly berms, corresponding to thin wedge-shaped bodies mainly made up of flat clasts.

Examples of gravelly beach in microtidal setting differ from meso- and macro-tidal ones since the beachface, i.e., the sloping sector of the system corresponding to the intertidal zone of “classic” (meso- macro-tidal) beaches, extends below the low-tide level. Indeed, the term beachface, commonly accepted as a synonym for foreshore, has acquired a different meaning, and has been used by [40] and [35] to indicate the whole sloping face of the beach, from the highest berm to the landward boundary of the shoreface (breaker zone). Accordingly, the beachface shows two subzones: the lower beachface, corresponding to the subtidal part of the zone, and the upper beachface, corresponding to the Intertidal one.

3. Geological setting

The study area is located close to the town of Bernalda, in the hinterland of the Taranto Gulf (Basilicata, southern Italy) (Fig. 3). It corresponds to the southernmost sector of the Bradanic Trough (the south Apennines foredeep) (Figures 1 and 2), where middle and upper Pleistocene terraced marine-deposits crop out due to a regional uplift [41,42]. The uplift and the consequent deepening of

the drainage network led to the exposure of the upper part of the basin-fill deposits, showing a regressive succession made up of offshore silty clay deposits (Argille subappennine Fm), followed by sandy and gravelly coastal and continental deposits (terraced marine-deposits) which become younger and younger moving from NW to SE, up to the Metaponto Coastal Plain [2,3,43]. These coarse-grained coastal deposits are mainly made up of sands and gravels [2] where it is possible to distinguish either progradational beaches or Gilbert-type deltas [40,44].

After a detailed facies analysis of tens of natural sections outcropping close to studied area, whose coarse-grained successions have thickness ranging from a few meters up to 40 m and more, [7] proposed a composite ideal vertical suite of facies ranging from shallow-marine to alluvial ones, developed during a depositional regression. Comparing this ideal suite of facies with the complex facies stacking observed in the measured sections, [7] concluded that these terraced marine-deposits record more than a single relative sea-level changes in the succession located below each terraced surface.

4. Methods

The present work concerns the sedimentological and stratigraphic studies of beach deposits that are part of Middle Pleistocene terraced marine-deposits outcropping in the studied area. Classical methods of sedimentology have been adopted, such as facies analysis, performed along different sections which were aided by the realization of sedimentological-stratigraphic logs as well as the collection of images through photographic shots. Sedimentary facies were distinguished based on their macroscopic characteristics as such bed thickness, lithology, grain size and sedimentary structures. Terminology for gravel-sized clasts follows the classification proposed by [45]. Location of measured logs was georeferenced using a GPS, and subsequently placed on a map showing the different main interpretations proposed by different Authors about number and distribution of terraced surfaces (Figure 3).

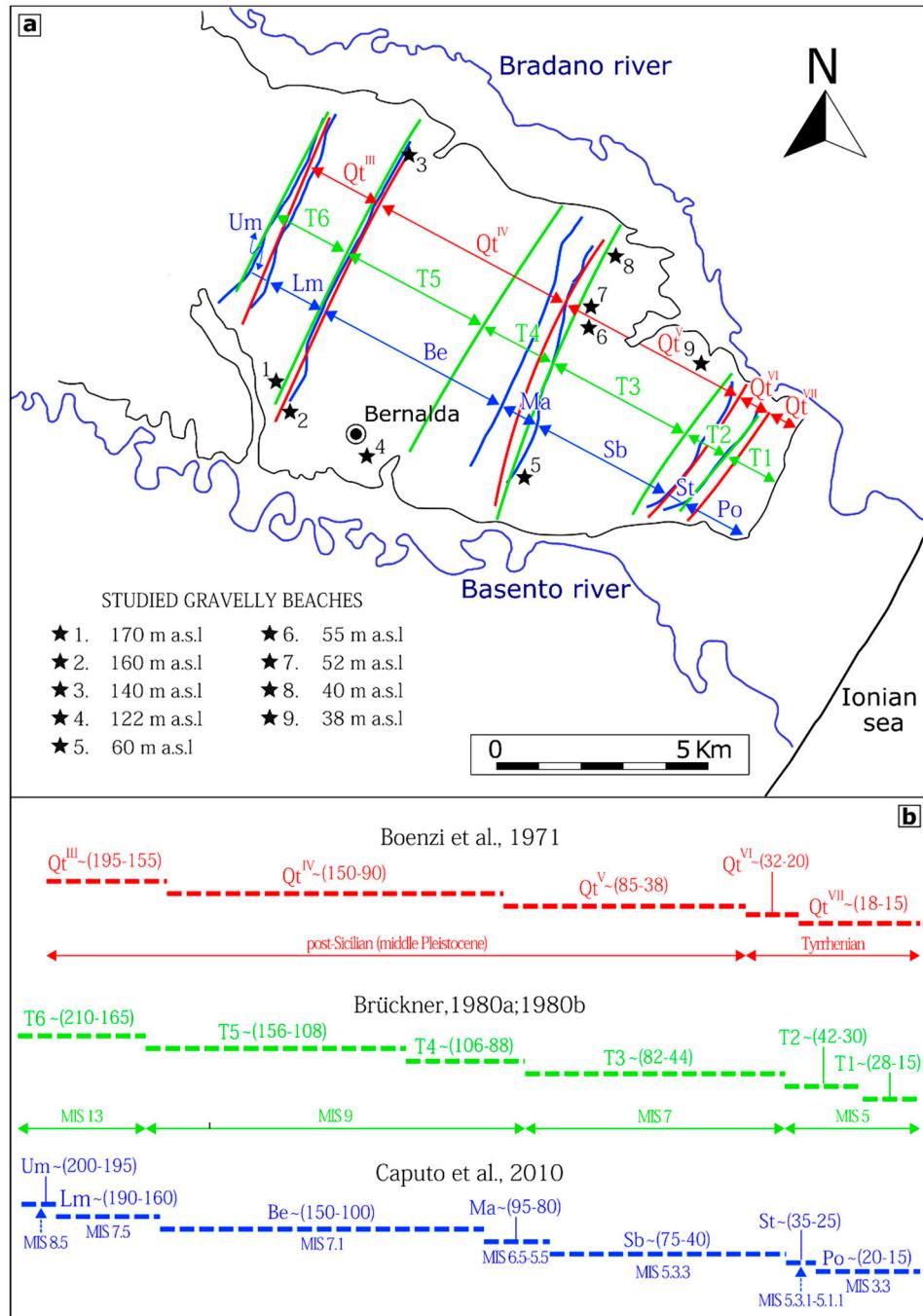


Figure 3. (a) Location of studied beach sections. Note number and location of marine terraces according to [3] (Qt^{III}- Qt^{VII} - boundaries in red), to [4,5] (T6-T1 - boundaries in green), and to [6] (Um-Po - boundaries in blue). (b) schematic altitudinal distribution and ages of marine terraces according to the same Authors.

5. Facies analysis

In order to analyze the main sedimentological features of gravelly beach deposits outcropping in the study area, a facies analysis has been carried out. Five facies have been recognized and labeled by a code formed by one or more capital letters, indicating grain size, followed by lowercase letters, indicating main sedimentary structures, and finally by subscript letters, indicating the main shape of clasts.

5.1. Clinostratified gravel with spherical clasts (Gcs)

Facies Gcs (Figure 4) consists of clast-supported gravelly beds with low to absent sandy-gravelly matrix content. The beds generally range in thicknesses from 10 to 30 cm, and form clinoforms with slopes that can reach 25°. The gravel is composed of well-rounded clasts varying in size from pebbles to coarse cobbles; the latter tend to accumulate downslope in the terminal portions of gravelly layers.



Figure 4. Spherical clasts in the facies Gcs.

Although several forms are present, spherical clasts predominate, and these are basically associated with the larger elements, while discoidal, rod and blade ones are present in a smaller percentage, the latter two often characterizing the matrix that fills the pores of these deposits.

5.1.1. Interpretation

Sedimentological features of the Gcs facies allow it to be interpreted as the result of mass-transport mechanisms, rheologically comparable to a debris fall avalanches [46]. After deposition, the deposits could be partially reworked by wave motion. This gravelly facies seems to correspond with the "infill zone" of [29], also described in microtidal beach systems by [35].

5.2. Massive gravel with discoidal clasts (G_{md})

This facies (Figure 5) is made up of massive and clast-supported sub-horizontal up to 20 cm thick gravelly layers, sometimes with sandy matrix content. The clasts are well rounded and predominantly discoidal in shape, and ranging in size from pebble to coarse cobble. They generally lack sedimentary structures except for occasional seaward-imbrications.



Figure 5. Detail of massive gravel with discoidal clasts (facies: G_{md}).

5.2.1. Interpretation

Facies G_{ma} is the result of storm phases capable of selecting and accumulating discoidal clasts along beaches. It corresponds to: the “large-disc zone” *sensu* [29], the “higher berm” *sensu* [40] and the “high storm berm” *sensu* [35].

5.3. Clinostabilized gravel with imbricated clasts (G_{ci})

Facies G_{ci} is represented by clinostabilized gravelly beds, forming gently inclined foreset (from 5° to 8°) showing a lenticular geometry. The gravel is basically arranged in well segregated from 10 to 20 cm thick clast-supported layers, with little or no sandy matrix content; layers are often separated by erosive surfaces along which cobbles-sized elements accumulate. Clasts show mainly flattened shapes such as discoidal and/or blade-like and they vary in size from pebbles to fine cobbles. The flattened elements also exhibit a well-developed SE-dipping imbrication. Discoidal clasts are mainly found in layers with a thickness ranging from 10 to 20 cm (Figure 6a) while the blade-like ones are mainly found in thin pebbly layers with a thickness not exceeding 10 cm (Figure 6b); the former, compared to the previous ones, show a lower degree of selection both for size and shape, in fact rod-like clasts were found in smaller quantities. Spherical elements are generally scarce, and represent a small fraction of the clasts content.



Figure 6. Clinostratified gravel with imbricated clasts (facies: Gci) (yellow arrows). (a) pebbles to cobbles discoidal clasts exhibiting a well-developed seaward-dipping imbrication (to the right in the photo); (b) gravelly layers composed of blade-like imbricated pebbles.

5.3.1. Interpretation

This facies is the result of highly selective processes that act preferentially on shape and size of the clasts and lead to the development of a clear seaward imbrication. Facies of this type can be traced to the traction transport produced by the combination of marine swash and backwash [29,47,48], which leads to the formation of very well-segregated gravelly layers. The presence of numerous erosive surfaces (Figure 6), suggest how selective processes alternate with higher-energy phases, capable of eroding and resedimenting clasts of variable size.

5.4. Planar cross - laminated gravel and sand (GSp)

Facies GSp consists of thin and slightly inclined lenticular gravelly and sandy layers (Figure 7), up to 15 cm thick, with low angle cross lamination (not exceeding 12°) mainly dipping landward. The gravelly component consists of well-rounded elements ranging in size from granules to fine pebbles.

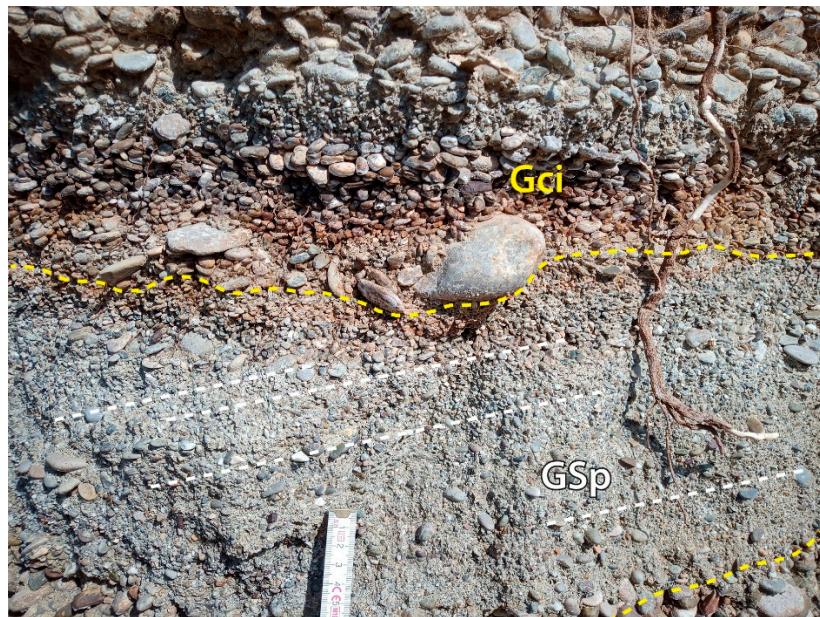


Figure 7. From the bottom to the top: planar cross - laminated gravel and sand (facies: GSp) erosional overlie by a cobbles-sized lag in turn passing to clinostratified gravel with imbricated clasts (facies: Gci).

5.4.1. Interpretation

Facies Gsp can be interpreted as the result of the combined action of marine swash and backwash along the emerged beach.

5.5. Horizontal laminated sand and gravel (SGh)

This facies consists of fine- to coarse-grained sandy and gravelly (mainly granules in size) up to 15 cm thick layers, showing a slight inclination, with a slope that varies from a few degrees to no more than 6°-7°. The examined deposits show a clear horizontal planar lamination (Figure 8).

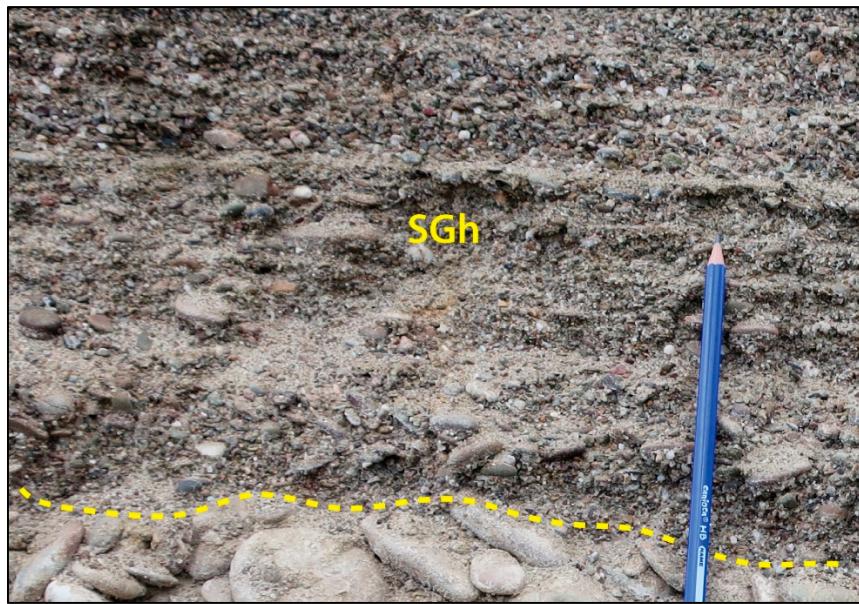


Figure 8. Fine- to coarse-grained sand and gravel with horizontal lamination (facies: SGh).

5.5.1. Interpretation

The dense horizontal plane-parallel lamination allows us to interpret the facies as the result of a traction transport by an upper flow regime, capable of organizing sands and granules, allowing the development of flat laminae essentially linked to marine swash. The facies was defined by [29] as "sund run".

6. Facies associations

The performed facies analysis allowed to group the five recognized facies into three facies associations referred to the following environments: lower beachface, upper beachface, and backshore.

The above-mentioned environments occupy the middle-upper portions of the beach-system and, as a whole mainly consist of clinostratified sigmoidal to wedge-shaped gravelly-sandy bodies. Slope of the lower beachface varies from 10° to 25°; slope of the upper beachface dips of about 8°; backshore form sub-horizontal to no more than 5° dipping layers.

6.1. Lower beachface

This facies association consists of up to 30 cm thick seaward SE-dipping gravelly layers belonging to Gcs facies which accumulate for a total thickness (clinoform height) that rarely reach 1 m; the overlapping of different layers leads to an "apparent" coarsening upward trend, as described by [46]. The inclination of these deposits varies from 10° to 25°; those associated with minor slopes generally outcrop close to a deltaic feeding area; on the contrary, deposits related to steeper slope are found far from delta mouths, and often show a higher degree of size and shape selection, with major content of spherical clasts and with lower or no matrix content. These deposits pinch out downward wedging into sandy-gravelly upper shoreface deposits.

This facies association identifies a beach environment not directly affected by the swash-backwash and located below the intertidal zone (*sensu* [35]) where predominantly spheroidal elements accumulate at the foot of the slope thanks to gravity processes triggered in the upper portion of the slope.

6.2. Upper beachface

This facies association consists of slightly inclined (no more than 8°), seaward dipping stratified gravelly and gravelly-sandy bodies. They are composed of decimetric layers which rarely exceed 20

cm in thickness. This facies association mainly consists of horizontal laminated sandy and gravelly layers (SGh) and up to 8°clinostratified gravelly layers with imbricated clasts (Gci). The latter exhibit both blade and rod-like shaped pebbles and cobbles with seaward imbrication, as well as spheroidal clasts no larger than pebbles in size. This facies association can be related to beach environments directly affected by marine swash, in particular referable to foreshore environment *sensu* [35], where ephemeral berms could also develop. In the studied microtidal example, this facies association is relatively thin and corresponds to the seaward extent of the swash zone.

6.3. Backshore

This facies association consists of sub-horizontal to slightly inclined (no more than 5°), mainly seaward-dipping beds comprising clinostratified gravel with imbricated clasts (Gci), massive gravel with discoidal clasts (Gmd) and sometimes planar cross-laminated gravel and sand (GSp). The facies Gci, which in these deposits completely lacks both sandy matrix and spheroidal clasts, often alternates with the facies Gsp producing an up to 40 cm thick vertical repetition of sediments. Facies Gmd forms gravelly layers no more than 20 cm thick. The main facies features of the described deposits reflect the internal zoning observed in present-day beaches as a result of the highly selective processes triggered by marine swash and backwash that lead to the development of the main forms found on gravelly beaches, such as ordinary and storm berms [29,35,47].

7. Discussion

7.1. Why are beach deposits so important for constraining relative sea-level changes?

A very wide literature deals with wave-dominated clastic coastal systems (mainly sandy rather than gravelly) and their response to: i) the alternation of the seasons; ii) the variable amount of sediment supply; and iii) relative sea-level changes.

- i) To start, it is important to highlight that a seasonal beach-cycle characterizes these depositional coastal systems, with the alternance of a swell (fairweather) profile, when the beachface grows, and a storm profile, when the beachface is eroded and the sediment is redistributed to the shoreface [49] (Figure 9a and 9b). Assuming a stable sea level in a stable region (no changes in base level) and assuming that inputs and outputs of sediment (sources and sinks) to- and from- the coast are equivalent, the alternance of beach profiles does not produce a long term progradation or retrogradation of the coastal system as well as its aggradation.
- ii) The described “stable” dynamic conditions are very difficult to realize and, more easily, a landward or a seaward shoreline migration can be recorded. During a still-stand of the sea-level, in clastic coastal systems where source rate is greater than sink rate a seaward shoreline migration is recorded, leading to the progradation of the depositional system with the sedimentation of a coarsening and shallowing upward sequence (a regressive sequence), accompanied by the creation of subaerial accommodation space potentially filled by aggrading alluvial deposits [50] (Figure 9c). On contrast, where source rate is lesser than sink rate, a landward shoreline migration is recorded, accompanied by the erosion of older sediments and by the carving of a seacliff (Figure 9d).
- iii) Since beaches are the most sensitive environments to relative sea-level changes over time, they, during their development, must be considered an excellent proxy of the sea-level position. After [51], it has been widely accepted that a coastal regressive sequence can be recorded not only during a sea-level still stand, when, seasonally, sediment inputs exceed sediment outputs (normal regression with constant relative sea-level, *sensu* [50] (Figure 9c), but even during a relative sea-level rise, when the long-term rate of sediment supply exceeds the rate of accommodation space created at the basin margin (normal regression with rising relative sea-level, *sensu* [50]) (Figure 10). As a consequence of a normal regression with constant relative sea-level, thickness of the shallowing upward sequence approximates the water depth existing at the beginning of the seaward shoreline migration (Figure 9c); moreover, the vertical distance of each facies from that of the (upper) beachface represents the original depth (or altitude) of that environment respect to the constant relative sea level [52]. Anyway, rarely this simple scenery

develops, and single beach sequences can be thicker than expected, recording high sediment supply during relative sea-level rise (Figure 10).

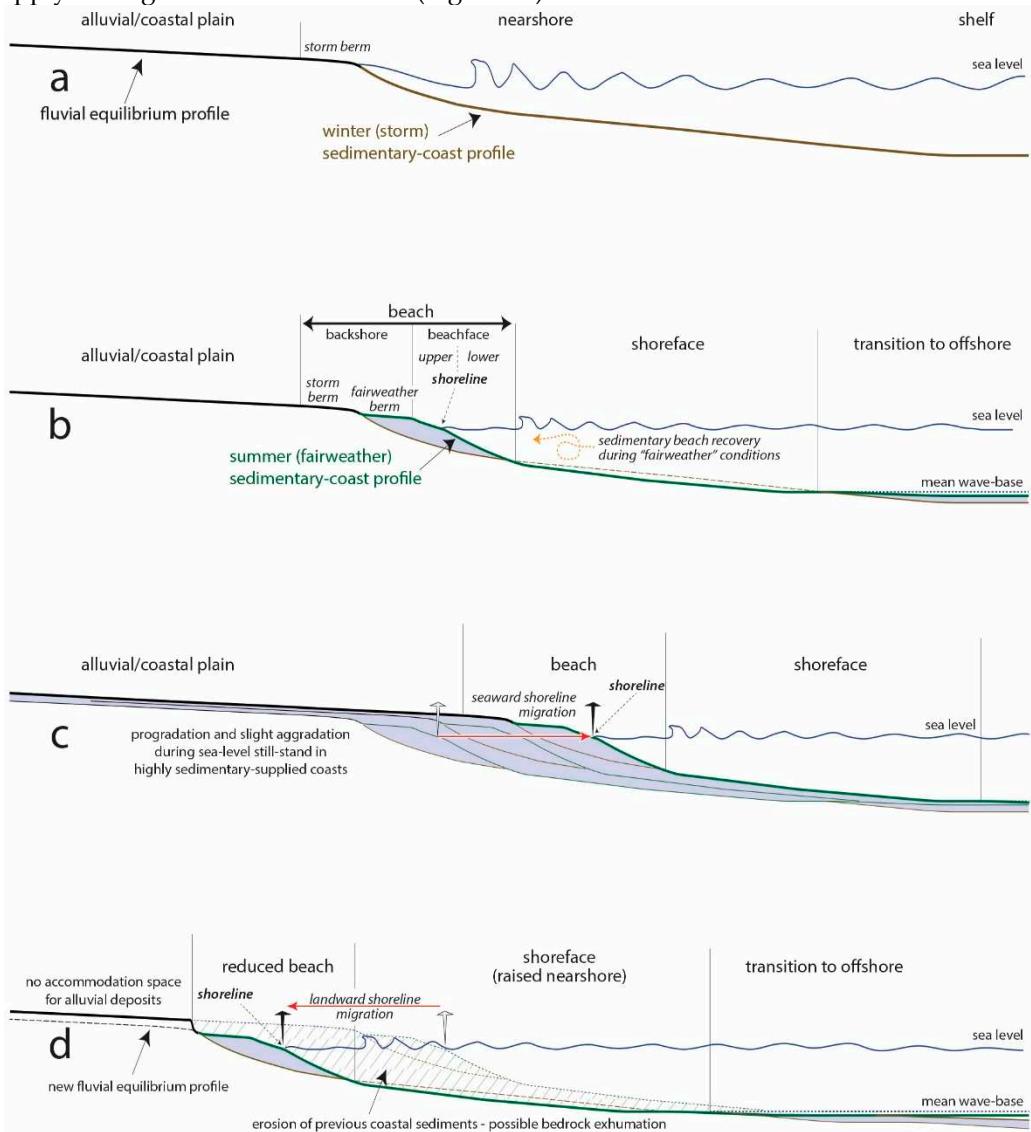


Figure 9. Behavior of a beach system during a relative still stand of the sea level: (a) and (b) seasonal response of the beach system to waves. (c) and (d) response of the beach system respectively in high- and low- supplied sedimentary coasts. Note in (c) the small aggradation potential respect to the amount of progradation potential.

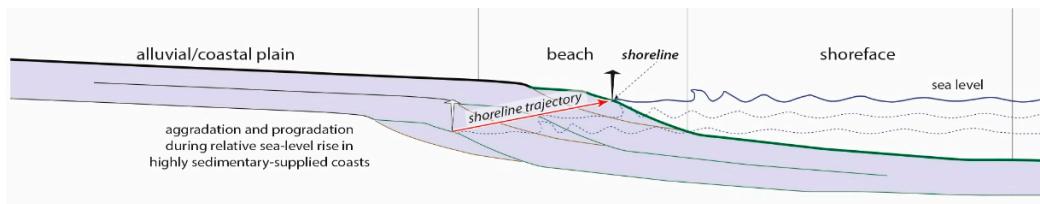


Figure 10. Behavior of a beach system during a relative sea level rise on highly-supplied sedimentary coasts. Note the high potential of aggradation during progradation. Compare with Figure 9c.

7.2. Remarks on terraced marine-deposits of the hinterland of Taranto Gulf

All the quoted works regarding the terraced marine-deposits of the hinterland of Taranto Gulf interpreted the terraced surfaces as related to past relative sea-levels high-stands. Regrettably, number of surfaces and age of underlying deposits differ from Author to Author; moreover, rarely

the genetical link of each surface to the “anatomy” of the underlying succession was proposed, assuming that each surface represents the top of a single transgressive-regressive coastal cycle. By contrast, and without enter in the definition of how many terraced surfaces could have been detected in the area, a detailed sedimentologic and stratigraphic study performed between the Cavone and Basento Rivers (adjacent to the area of the present study – see Figure 2 for the location of quoted rivers), highlighted the presence of different and very complex successions below the topographic surface since each measured log records several high- to very high-frequency relative sea-level changes [7].

The Authors concluded that each terraced surface cannot be simply linked to a cycle of relative sea-level changes but, eventually, to the last of those ones vertically recorded in the local sedimentary succession. Since more sea-level oscillations are locally recorded below the topographic surface (Figure 11a), and since photointerpretation seems not useful to distinguish how many different marine-terraced surfaces developed in the area (Figure 3b) studies exclusively based on geomorphological methods are unable to describe the complex interaction between regional uplift and relative sea-level changes. Therefore, age of samples not well constrained to a detailed measured and sedimentological interpreted succession cannot be simply and confidently used to relatively date the top of the sampled terraced succession (Figure 11b). This means that, before to date outcropping deposits, it is necessary to perform a detailed facies analysis of the selected succession, in order to collocate the sample both in the right palaeoenvironment (i.e., its hypothetical paleodepth) and in the local history of relative sea-level changes.

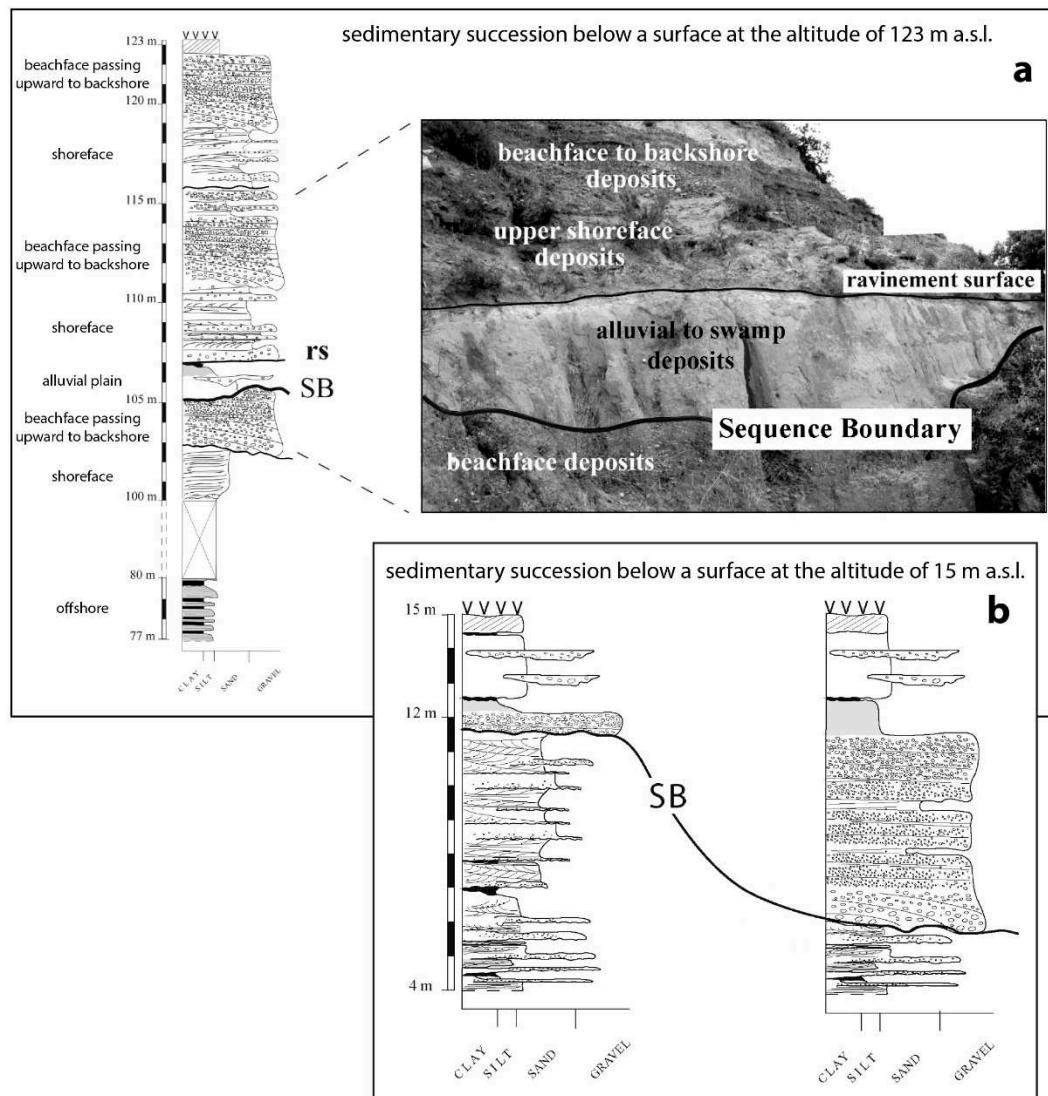


Figure 11. Marine terraced successions of the hinterland of Taranto Gulf measured in detail by [7] in the vicinity of the area of the present study. (a) A log showing the stacking of 3 beach sequences (from shoreface to backshore) and the presence of alluvial deposits encased in marine ones. Alluvial deposits were interpreted to be related to a late lowstand of the relative sea-level. Since these deposits are the finest ones of a coarse-grained “marine” terraced succession ending in a beach sequence, they could have been the best candidate for dating the terrace. Unfortunately, the topmost surface is genetically related only to the uppermost beach sequence (far away from the fine sediments) and, moreover, alluvial deposits didn’t develop during a relative high-stand of the sea-level. (b) From the correlation of 2 close sections, the presence of a beach sequence erosively lying (and pinching) on shoreface deposits was observed. The stratigraphic architecture suggests that shoreface deposits are related to a previous position of the relative sea-level, that dropped and led the formation of the gravelly beach only during a following relative rise and high-stand of the sea-level. Also in this case, age of finer deposits doesn’t correspond to the age of the terraced surface.

7.3. Applying these concepts to two studied examples

To apply these concepts to concrete examples, two of the studied beach sections showing deposits on top of the marine terraced succession have been selected (sections 6 and 8 in Figure 3). Section 6 shows a beach sequence erosively developed onto the sloping surface of a gravelly delta (Figure 12a). Section 8 shows the stacking of three gravelly beach sequences (Figure 13).

In the locality Spineto-Bernalda, a stratigraphic section elongated along dip respect to the palaeocoastline has been studied. The section cut a succession lying below a topographic surface considered a single marine terrace by all the previous Authors. The outcropping succession shows a beach sequence pinching out on the slope of a gravelly delta (not studied in detail) (Figure 12a). The architecture of the outcropping deposits can be explained only assuming that the succession developed during a cycle of relative sea-level change. Therefore the “terraced surface” cannot be attributed to a single episode of relative still stand of the sea-level. Locally the top of the gravelly delta has an elevation of about 55 m a.s.l. and approximatively can be assumed as the record of the relative sea-level during the delta progradation (Figure 12b – T1). To explain the presence of an erosional surface on which backshore deposits could aggrade it is necessary to invoke a relative sea-level fall (whose entity cannot be determined) followed by a quick rise of the relative sea-level (Figure 12 – T2 and T3). Note that a slow rise would determinate the aggradation of alluvial deposits (see Figure 10) while the first record of the return of the sea on the flank of the delta are backshore deposits, suggesting a sedimentation rate unable to match with creation of new accommodation space (imagine the scheme in Figure 9d applied during relative sea-level rise). Since the backshore zone is very narrow (Figure 9b), the possibility that the related facies could stack for meters is only allowed during a relative stationarity of the shoreline (Figure 12 – T4), i.e., if the shoreline lies in the same place during the rise of the sea level. The topmost layer of the beach sequence has an elevation of about 53 m a.s.l. and approximatively can be assumed as the record of the maximum relative sea-level rise during the beach aggradation.

In the locality Serra Marina-Bernalda, an about 3 meters thick stratigraphic log was measured in detail (Figure 13). Even in this case, the stacking of backshore deposits should indicate a certain stationarity of the shoreline during a slow relative sea-level rise. Actually, the succession records three episodes of slight drowning of the sedimentary coast (landward migration of the shoreline), since, for three times, lower beachface facies sharply covers backshore ones. This feature records three episodes of moderate transgression that could be explained in two ways:

- the sea-level was characterized by three slight accelerations in the rate of relative rise, leading the overlap of relatively deeper environments on shallower ones;
- during a constant rate of relative sea-level rise, the supply rate was not constant, and, during time-spans of reduced supply, the beach systems migrated landward. This process could be related to the cyclical switch of a delta mouth located in the vicinity of the studied beach system.

In both cases, the top of the succession indicates the topmost relative rise of the sea-level recorded in the locality and related to the development of that sedimentary coastal system.

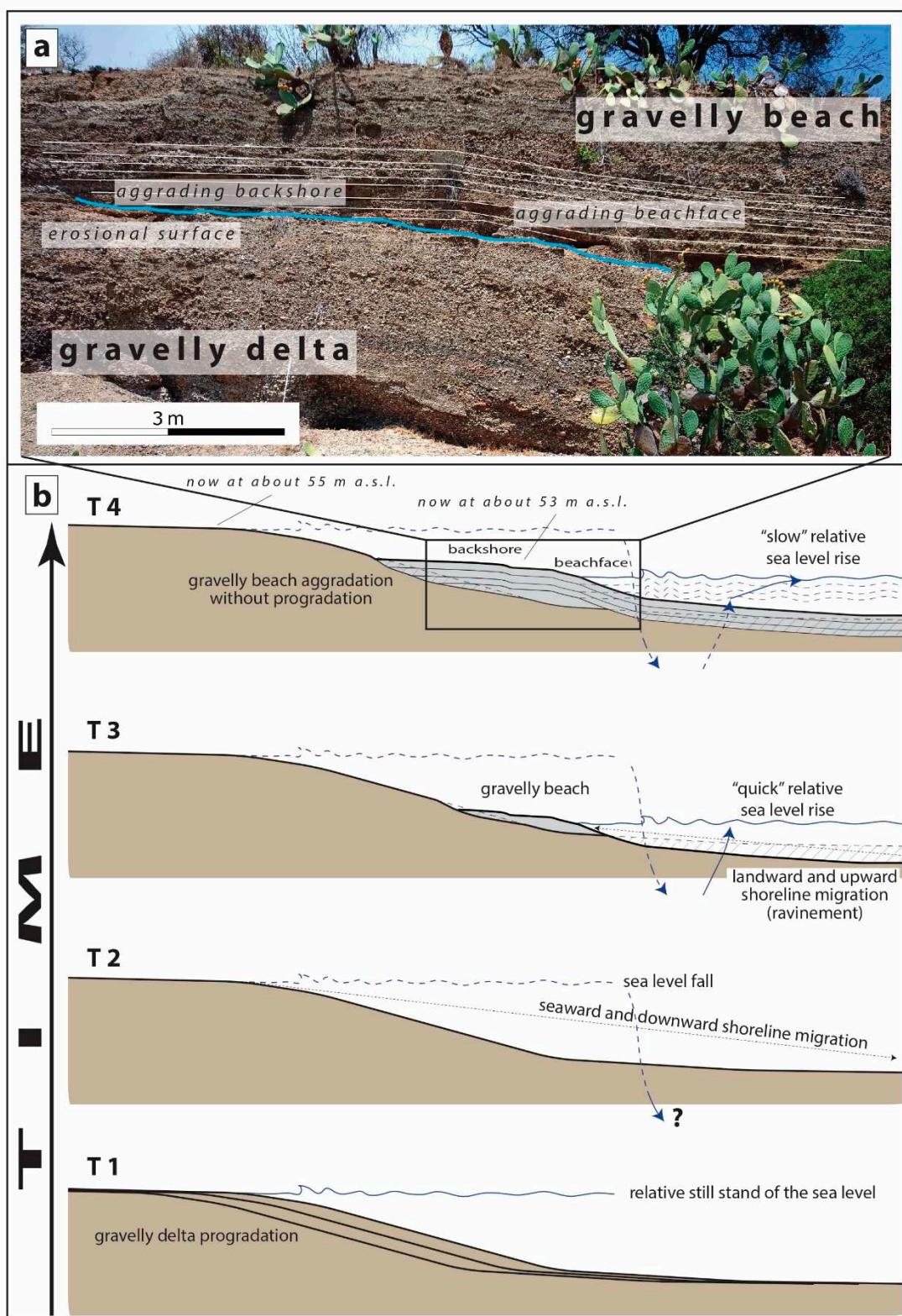


Figure 12. (a) a gravelly beach sequence erosively lying on previous (older) gravelly delta deposits. (b) to explain the amount of aggrading beach deposits it is necessary to invoke a relative sea-level rise (compare with Figure 10) after a relative sea-level fall. To explain the aggradation of backshore facies it is necessary to invoke the development of a "stationary" shoreline during relative sea-level rise. The delta must be attributed to a previous (higher) position of the relative sea level. Note the small difference in altitude of the top of the delta and of the topmost layer of the beach.

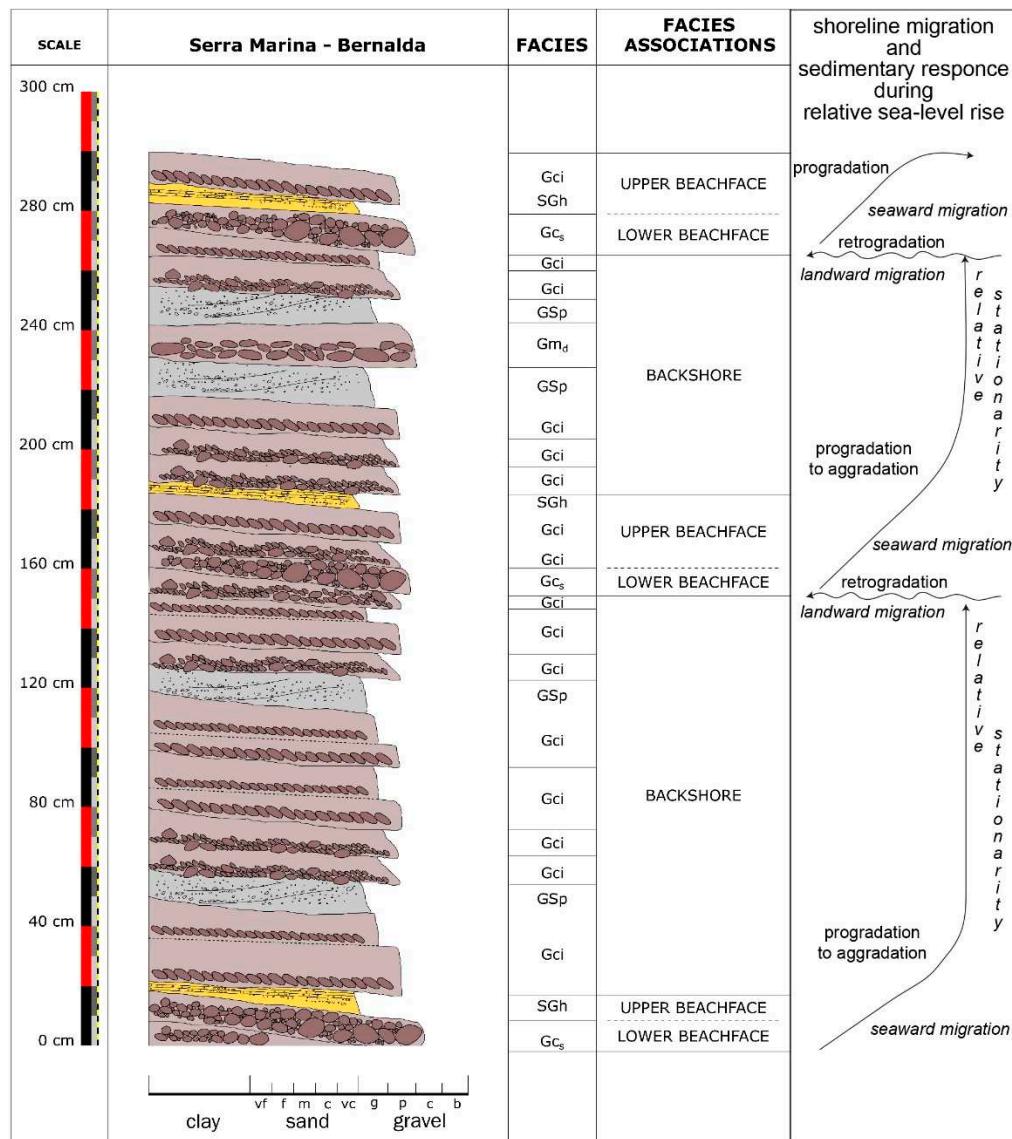


Figure 13. Sedimentological-stratigraphic log performed in contrada Serra Marina-Bernalda (MT), showing the different facies and facies associations that identify the environments of the gravelly studied beach. Also shoreline migration and sedimentary response during relative sea-level rise are indicated.

8. Concluding remarks

In wave-dominated coastal settings, the most sensitive environment to even the smallest relative sea-level changes is the beachface, that, during its development, represents also the best record (with a small error range) of the relative position of the sea level. Therefore, in order to obtain better constrained age-dating of uplifted Quaternary successions, the beachface recognition represents one of the main tools to correlate deposits to the relative sea-level during their formation, especially in microtidal settings.

The Quaternary terraced marine-successions extensively outcropping in the hinterland of Taranto Gulf, offer a good opportunity to apply these concepts, since gravelly beach deposits abound in the stratigraphic record. The area, besides to be an excellent training ground for the study of gravelly beaches in microtidal settings, represent a region where terraced surfaces and marine successions still are not unanimously attributed to global curves proposed for the Quaternary the sea-level changes.

The reported examples demonstrate that beach deposits can be used as proxies to highlight even small relative sea-level variation.

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