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# Quaternary Evolution of Coastal Plain in Response to Sea-Level Changes: Example from South-East Sicily (Southern Italy)

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**Abstract:** During a cycle of sea-level variation, coastal environments develop in different position of the continental shelf following seaward and landward shift of the coastline. They vary widely in character, reflecting the wide range of process-regimes that are brought about during the different stages of sea-level variations. Within this scenario, the morphology of continental shelves, mainly resulting from the combined effect of tectonic activity and eustatism, plays an important role in controlling the features and the preservation of coastal environments. Coastal deposits formed along continental shelves in the past, during different stages of sea-level changes, consist of discontinuous and thin depositional bodies, thus their reconstruction can be best carried out through the interpretation of high-resolution seismic data. Such a research approach is adopted in the present study to investigate a portion of the continental shelf of the southernmost sector of SE Sicily, in the offshore of Marzamemi village (Syracuse). The interpretation of high-resolution "Sparker" profiles allowed us to reconstruct the evolution of alluvial and lagoonal environments, established on a substratum of Pliocene or more ancient marine deposits, with the detection of several seismic units and unconformity surfaces, which have been related to alternating sedimentation and erosional processes, depicting the sea-level change framework of glacial-interglacial phases, from the late Pleistocene onward.

**Keywords:** hyblean plateau; seismic stratigraphy; continental shelf; transgressive and highstand system tracts



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## 1. Introduction

The evolution of transitional environment is strictly connected to the sea-level changes, which reflect the combined action of tectonic activity and eustatism [1–3]. In general, erosional surfaces incise the continental shelf during the falling and lowstand of sea-level and are followed by discontinuous transgressive deposits that accumulate during the successive landward shift of the coastline during rising sea-level [4,5]. After the maximum sea ingression, marked by a maximum flooding surface, the high stand deposits often correspond with a progradational wedge that progressively extends seaward.

The reconstruction of the details and the sedimentary record of these different phases of sea-level variations are best accomplished through the interpretation of high-resolution seismic profiles. The latter are the only tool with the resolution needed to unravel the facies and geometry of the thin sediment packages that mark the process-regime changes associated with sea-level variations. In particular, during transgressive phases, sediment are generally trapped in the alluvial and coastal plain environments and offshore sediment export is in general reduced. The resulting deposits can be fully marine or can include continental/transitional facies such as estuarine/lagoonal, fluvial and aeolian deposits, characterized by higher variability in response to the changes in the sea-level rise rate [5].

However, transgressive deposits are often subject to successive reworking and erosion resulting in cannibalization (through ravinement) and thus have a poor preservation potential. In some settings, however, favourable conditions, resulting from the interplay of basinal oceanographic processes and continental shelf morphology, allow the preservation of Transgressive System Tract (TST) deposits. In these cases, TST deposits offer a record that can be used to reconstruct the evolution of past coastal environments [5,6].

The focal point of this work is to reconstruct the position of transgressive bodies within the Marzamemi offshore coastal plain, which provide unique information on Holocene variations of the sea-level. We investigate, through the analysis of Sparker seismic data, the offshore of the southernmost Sicilian Ionian coast (Figure 1), in the neighborhoods of Marzamemi village (Syracuse).


**Figure 1.** Geographic map (WGS 84) of the south-eastern Sicily and the offshore sector investigated in the present study (Marzamemi area). In yellow are the main bathymetric contours; in white are the locations of all seismic profiles.

Development, variability and arrangement of this part of Ionian coast are strongly influenced by different geological factors, such as regional tectonics, sea-level fluctuations, according to the geomorphological features or the area, karst processes.

The high-resolution seismic data, imaging the details of the sedimentary elements developed during the last cycle of sea-level variation, have been interpreted for the reconstruction of the succession of depositional environments in the Late Quaternary. Based on a seismo-stratigraphic interpretation of the succession, tied to the on-land stratigraphy and geology, our work aims at showing how the morphology created during the emersion of the continental shelf determine the development and the arrangement of successive coastal and transitional environments.

## 2. Study Area

### 2.1. Structural and Stratigraphic Features

The study area is part of the southernmost Hyblean Plateau (Figure 2), one of the main morpho-structural elements of the Sicilian Orogen [7] and reference therein. The Hyblean Plateau is part of the relatively tectonically undisturbed northern margin of the African Plate [8] and represents the emerged portion of the NE-SW-oriented bulge of the African foreland [9], formed in the frame of the post-Tortonian NW-SE-oriented

Africa-Europe convergence [10–13]. It is bounded to the northwest by a system of NE-SW-trending, NW-dipping normal faults [7,14]. The Hyblean Plateau is flanked NW-ward by the Gela Foredeep [15–18], a Plio-Pleistocene subsiding area associated to the convergent geodynamic context responsible for the progressive advancement of the chain units, filled by huge volumes of terrigenous sediments, resting on the most advanced front of the Sicilian orogenic belt (Gela Nappe) [19,20]. To the east, the Hyblean Plateau is bounded in the offshore by the Hyblean–Malta Escarpment, one of the most prominent physiographic features of the Central Mediterranean. This escarpment represents a regional system of extensional faults, NW-SE/NNW-SSE oriented [8,21], which control the tectonic evolution of the eastern Sicilian offshore and, consequently, also the accommodation space of the study area [22].

The geological setting of the study area is significantly conditioned by the presence of these trending fault systems, responsible of a general uplift of the area which played a fundamental role also in the estimation of sea-level variations [14,23–27]. These authors, even with different approaches (e.g., seismic analysis or soil deformations), report an average uplift of the area of about 0.2 mm/a since Tyrrhenian time.

The Hyblean Plateau stratigraphic succession consists of carbonate sediments of Triassic to Quaternary age, with volcanic units due to intermittent volcanic activity, whose stratigraphic features have been widely described [8,19,28]. The carbonate facies reflect distribution in two distinct paleogeographic domains: the strongly subsiding basin of the "Siracusa Sector" to the east, and the persistent carbonate shelf of the "Ragusa Sector" to the west. An intermediate carbonate ramp developed between the two paleogeographic domains [8,18,29]. At present the two domains are separated by the Tellaro River Valley interpreted as a left transtensive fault, active also during the Early Pliocene [30,31].

The study area is part of the Siracusa domain, with some features that are more pertinent to a transitional domain. The stratigraphic succession (Figure 3) starts with Upper Cretaceous massive limestones with Rudist remnants (Priolo Fm. Auct.) associated with the products of subaerial volcanic events, described in detail by [32,33]. The overlying sedimentary succession [32–36] is represented by white-pinkish Nummulitic calcirudites of the Paleocene-Eocene age and blue-gray marls of the Tellaro Formation of the middle to late Miocene age.

The Pliocene units are represented by the Trubi Fm. (Early Pliocene) and white-yellowish marls of the Piacenzian age. Polygenic conglomerates of probable Pliocene age outcrops west and south-west of the Pachino village [34]. The Quaternary deposits (see detailed logs in Figure 3) cropping out in the coastal area are represented by Tyrrhenian reddish organogen calcarenites (Marzamemi Formation, Figure 4a), Holocene alluvial and lagoon sediments and the present-day beach deposits [32–36].

### 2.2. Geomorphological Features

From a geomorphological point of view, the study area is part of "the Pantani area", a coastal stretch characterized by a series of lagoons, elongated parallel to the actual coastline and separated by the open sea by elevated ridges (maximum 10 m above sea level) of Tyrrhenian calcarenites and/or by coastal sand barriers and bars [37].

The geomorphological features are controlled by the development of local hydrographic basins. The rivers communicate with the sea through the coastal lacustrine-palustrine system and, therefore, recent/actual deposits are represented by palustrine and lacustrine sediments with sandy barrier beaches and an extensive coastal dune system. In this sector are also evidenceds of erosional forms cut into carbonate units such as cliffs, cave and shore platforms and mainly karts depressions incised in carbonate-cemented marine and aeolian sandstones [38].

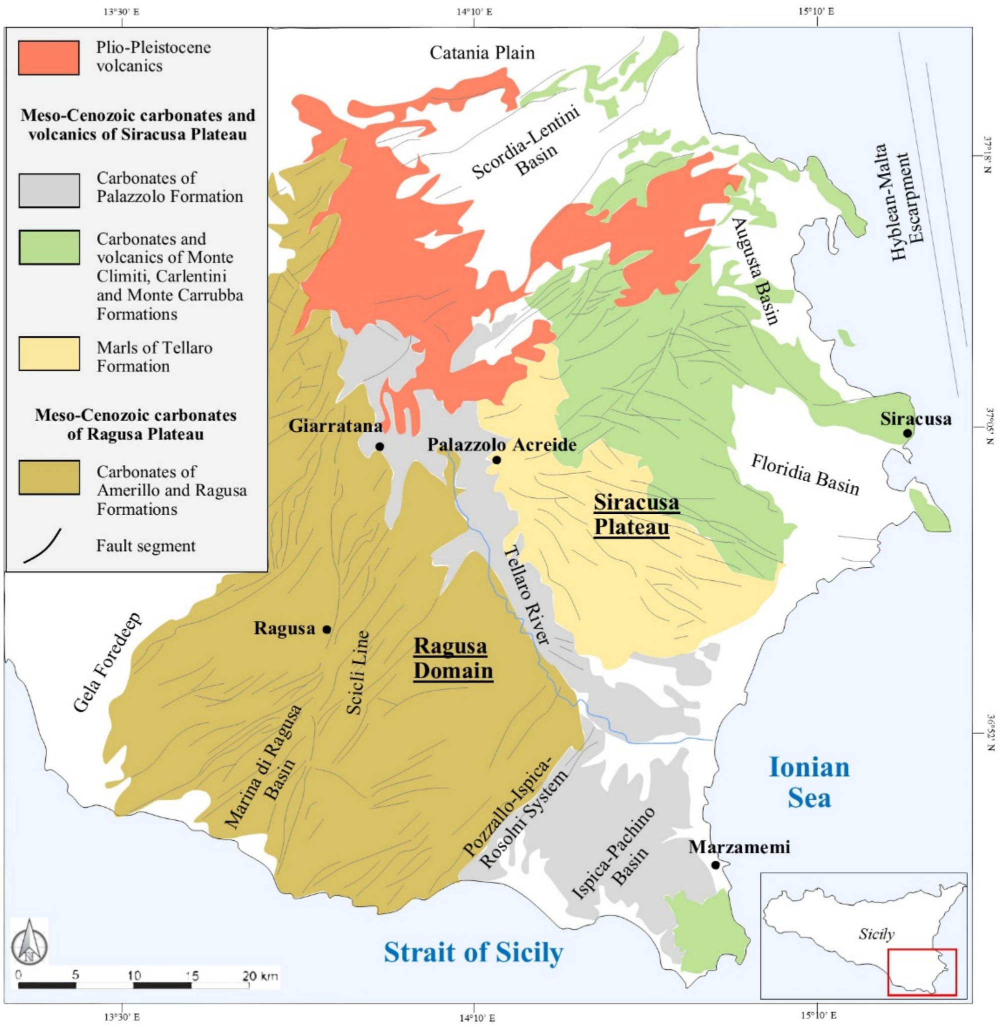


**Figure 2.** Schematic geological and structural map (WGS 84) of the Hyblean region (modified from [31]).

The submerged morphology of the sublittoral and inner shelf zones draws a complex closed depression with a flat bottom limited by carbonate outcrops, levelled at roughly constant depths. These characteristics are quite similar to those of karst depressions, named "poljes" and commonly developed along the Mediterranean karst regions [39–41]. The genesis of "poljes" is related to corrosional lowering of the land surface, commonly beneath a loose, permeable and non-karst cover, usually alluvial or soil cover [38]. The subaerial corrosion surfaces (Figure 4b) in this area are an indicator of the height reached by relative sea-level during the Late Quaternary. In this sense, the regional highest altitude reached by the Tyrrhenian marine terraces is +15 m above the sea level [42]. Subsequently, postglacial sea-level/base-level rise produced sedimentary deposition and transformation of river valleys into a progressively infilling estuary.

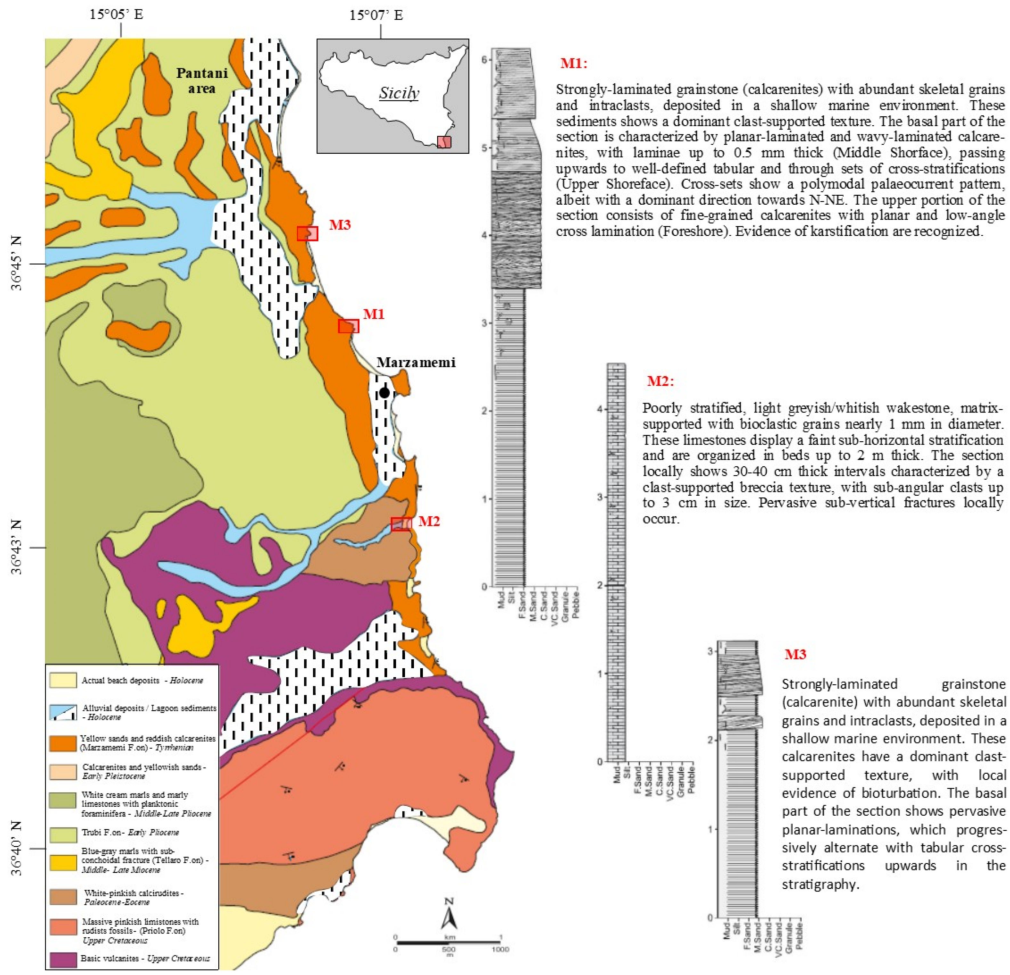


**Figure 3.** Geological sketch-map (WGS 84) of the Marzamemi area and short description of three (M1, M2, M3) stratigraphic logs.

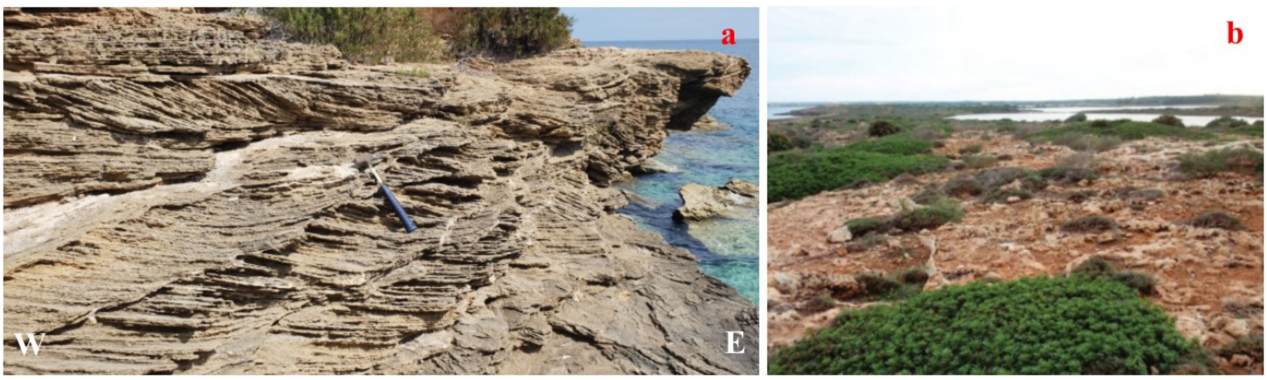


**Figure 4.** (**a**) Calcarenites of the Marzamemi Formation (Tyrrhenian), outcropping in the littoral stripe N of the Marzamemi village. (**b**) Subaerial corrosion surfaces nearby the study area [40].

## 3. Methodology

Our study is based on the interpretation of about 100 km of seismic Sparker lines (Geo-Spark 1000 Pulsed Power Supply system), acquired in May 2019 and forming a grid of eighteen profiles, in the Marzamemi offshore (Figure 1).

The seismic profiles, acquired in SEG-Y format, were processed and interpreted using the Geo-Suite software (2020R2 version). Initially, a standard processing sequence was applied to all seismic profiles. The Debias operator was used to remove the DC (Digital

Circuit) component, which usually affects the seismic data. The Infinite Impulse Response (IIR) filter module was employed to attenuate undesired frequency content of the signal spectrum (e.g., electrical low frequency noise). The trace equalization was applied to compensate amplitude variations across the profile. Finally, a constant Gain (50 dB) was applied, increasing the amplitude of the acoustic signals. The seismic profiles (about 150 ms TWT) have high resolution (<1 m), allowing to imagining the upper part of the sedimentary succession of the Marzamemi offshore.

The recorded seismic profiles highlight a crustal portion whose thickness ranges from a minimum of 5 m, in proximity of the coastline, to a maximum of 120 m seaward. All the seismic profiles are affected by a multiple reflector ("echo" of reflectors with the highest impedance acoustic) of the seabed that represents the lower boundary of the interpretable data. In particular, the multiple is especially shallow approaching the coastal where only a very thin portion of the sedimentary succession is correctly imaged.

The analysis of all the available profiles was first aimed at recognizing the main seismic reflectors that permit to subdivide different seismo-stratigraphic units. They were digitalized by mean of the "horizon-picking" phase. The oldest units were correlated with those known on land, to which they can be confidently tied because of our line end very close to the emerged areas. With a sequence stratigraphic approach, the more recent units, on the basis of their reciprocal geometric relationships, were assigned to different stages of the last cycle of sea-level, allowing to individuate the boundary surfaces of the Lowstand System Tract (LST), Transgressive System Tract (TST) and Highstand System Tract (HST). Successively, the analysis of the seismic facies of the component of the various system tracts was carried out to unravel the depositional environment of the various depositional bodies.

In order to calibrate the available seismic lines with a realistic velocity model, an analysis of deep well-logs located in the study area has been carried out. The ViDEPI project allows free on-line consultation (http://www.videpi.com (accessed on 15 March 2021)), as well as related documents concerning Italian oil exploration. Very few ViDEPI well-logs are located in the southeastern Sicily offshore and only one (Marzamemi_001) rests in proximity of the study area, namely the on-land sector of the northern Marzamemi coastline. The Marzamemi_001 well log shows the stratigraphic feature of a succession developed from 10 m down to about 130 m, consisting of massive clays and gray-green marls, passing downward to a conglomerate level about 15 m thick, referable to the Ribera Formation of the Pliocene age. The stratigraphic succession continues downwards with gray-green marls attributed to the Tellaro Formation (Middle-Late Miocene).

In addition, the available ViDEPI seismic profiles located in the neighbourhood of the study area were consulted, aimed at evaluating the possibility of reconstructing a more exhaustive framework of the considered zone. They afford a deep penetration (up to 5.0 sec twt) but furnish a low vertical resolution, estimated in about 25 m (frequency of the seismic source of 20 Hz). Thus, they are not particularly relevant for the study of the morpho-stratigraphic setting of the first tens of meters of the Hyblean sedimentary succession.

## 4. Results and Interpretation

### *4.1. Land–Sea Correlation*

Lacking useful well data, the main seismic horizons and units have been calibrated (Figure 5) through the comparison with the outcropping successions [32,34,35,43,44]. In fact, all the dip seismic profiles terminate very close to the coastline (sometimes <10 m) and, therefore, represent the natural offshore prosecution of the sedimentary deposits outcropping on land. In particular, the on-land stratigraphic features of the eastern part of the Marzamemi peninsula have been compared with the western termination of seismic line Orto 4 (Figure 5).

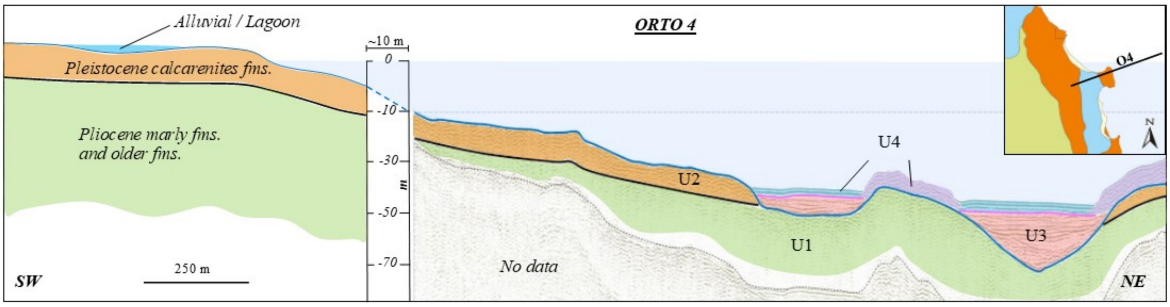


**Figure 5.** Correspondence between the recognized seismic facies and the equivalent onshore litho-stratigraphic units.

The Pliocene marls formations of the hinterland continue in the oldest seismo- stratigraphic units (named U1 unit) detected within all seismic profiles. The Calcarenites of Marzamemi Formation outcropping along the Marzamemi coastline (Tyrrhenian age) [34] consist of yellow sand and reddish organogenic calcarenites, with the basal part characterized by planar-laminated and wavy stratification that passes upwards to well-defined tabular setting and sets of cross-stratifications (Figure 4a). In the offshore, they correlate with U2 unit (named U2) consisting of packages of reflectors with high-to-medium amplitude and variable continuity often arranged in cross-stratified wedges. The development of the U2 within the seismic profiles occurs only in proximity of the coastline, up to a maximum depth of 30 m.

### 4.2. Acoustic Facies Analysis

In this section we present the analysis of the seismic units detected within the seismic profiles, separated by main reflectors, as illustrated in Figure 6.

As mentioned in the previous paragraph, the U1 unit is associated with the Pliocene marls deposits and makes up the deeper part of the profiles. It consists of low-to-medium-amplitude reflectors with variable lateral continuity (Figures 7–12). Due to the increase depth of the multiple reflectors, the imaged thickness of U1 considerably increases seaward, reaching also 70 m. Besides the Pliocene unit, the U1 could also include older units, such as the Tellaro Formation, outcropping on land in the southern portion of the study area. Especially in proximity of the coastline and in general along all seismic profiles, the reflectors of U1 appear poorly marked or indistinguishable, conferring locally a semi-transparent character to the unit, probably an artifact due to a reduced penetration of the acoustic energy in the shallower areas.

Reflector 1 (named R1) represents the top of U1, and has medium-to-low amplitude and variable lateral continuity. It corresponds on land with the unconformity between the Pliocene unit and the Calcarenites of Marzamemi Formation and its extension occurs only in the western portion of the study area (Figures 7–11). Above R1, the orthogonal seismic profiles show that U2 unit has a regular development, with a thickness that varies between 5 m and 10 m.

Reflector 2 (named R2) corresponds with the top of U2 and is a very high amplitude horizon with excellent lateral continuity. Within the study area the trend of the R2 is very variable in terms of morphological features and bathymetric development. In proximity of the coastline, the R2 represents often the seabed surface keeping a trend that is regular enough; instead, seawards, in the northern and central portion of the study area, R2 tends to deepen up to 50 m and shows a rough surface emphasizing a marked erosional character (Figures 7–9, 11 and 12). Here, the trend of R2 shows numerous depressions and V-shaped incisions, whose horizontal extensions are very variable (between 20 m and 300 m). They are interpreted as fluvial valleys. In the northeastern and southern portion of the study area, the R2 displays again a regular and weakly wavy trend and further deepens seawards, reaching about the 70 m of depth. In this way, a new accommodation space occurs, characterized by a flat morphology and a wide extension.

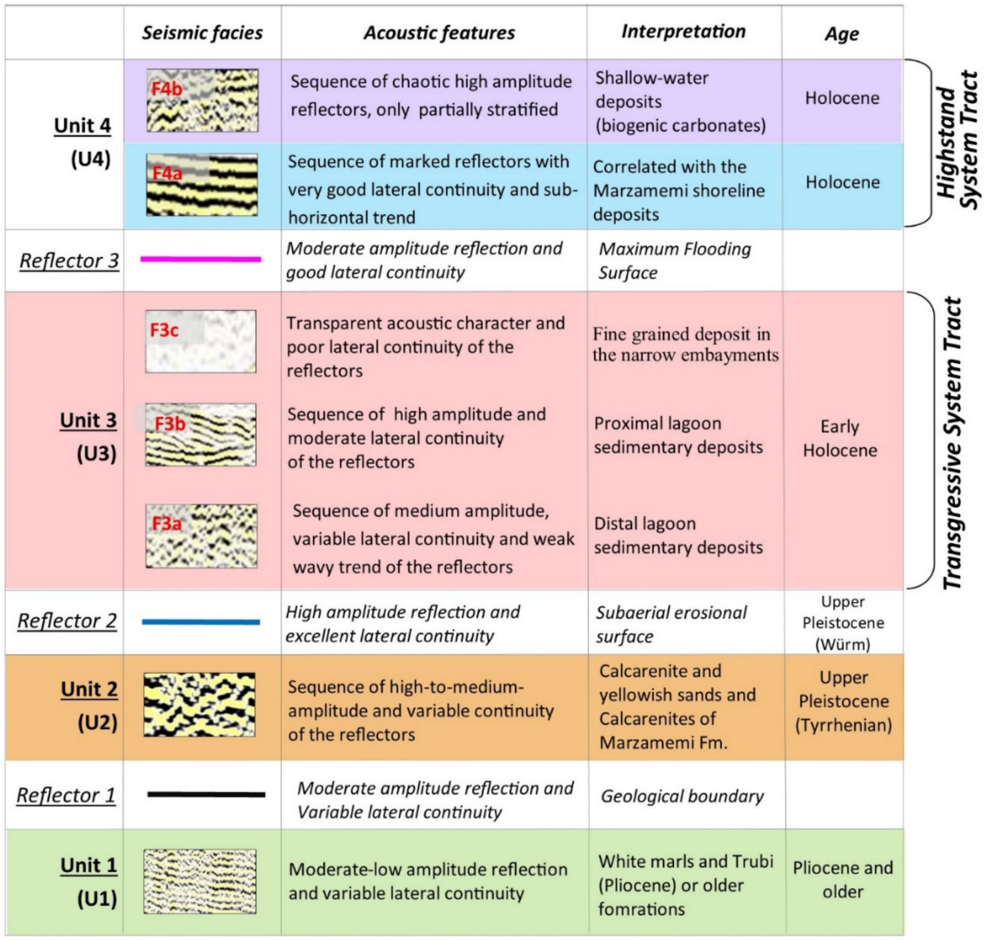


**Figure 6.** Facies analysis and the stratigraphic position of the acoustic units recognized within the seismic profiles interpreted in this paper.

The R2 is interpreted as an evident unconformity and a subaerial erosional surface developed during the last falling stage and lowstand of sea-level. Where R2 has a strong erosional character, the U2 is absent, being completely removed (Figures 7–9 and 11).

The R2 is also the basis of the U3 unit. The latter shows inside significant variations in the acoustic character that allowed to distinguish three different seismic facies, named F3a, F3b and F3c, respectively.

In the northeastern and southern sector, the F3a represents the deepest facies characterized by reflectors of medium amplitude, with variable lateral continuity and a weak wavy trend (Figures 7–9, 11 and 12). It develops within the wide accommodation space created by the gradual lowering seawards of the R2. In particular, within F3a the lateral acoustic variations show that in the distal portions the stratigraphic setting is aggradational and probably characterized by sediments with a homogeneous granulometry (fine-medium grain size), product of a regular hydrodynamics, developed in a wider depositional area and farther from the on-land areas. Instead, in the inner portions of the F3a, the arrangement of the reflectors as clinoforms shows a progradational pattern and probably represents lateral bars formed in transitional environment. Therefore, overall, this depositional style within the F3a has been interpreted as typical of a barrier-lagoon system, connected with the evolution of a paleo-coast during the early Holocene transgressive phases. Especially in the southern portion of the study area, other analogous depositional systems tend to evolve in backstepping downwards, sometimes partially overlapping (Figure 10), whose surfaces mark the several steps of the Holocene rising of the sea-level.

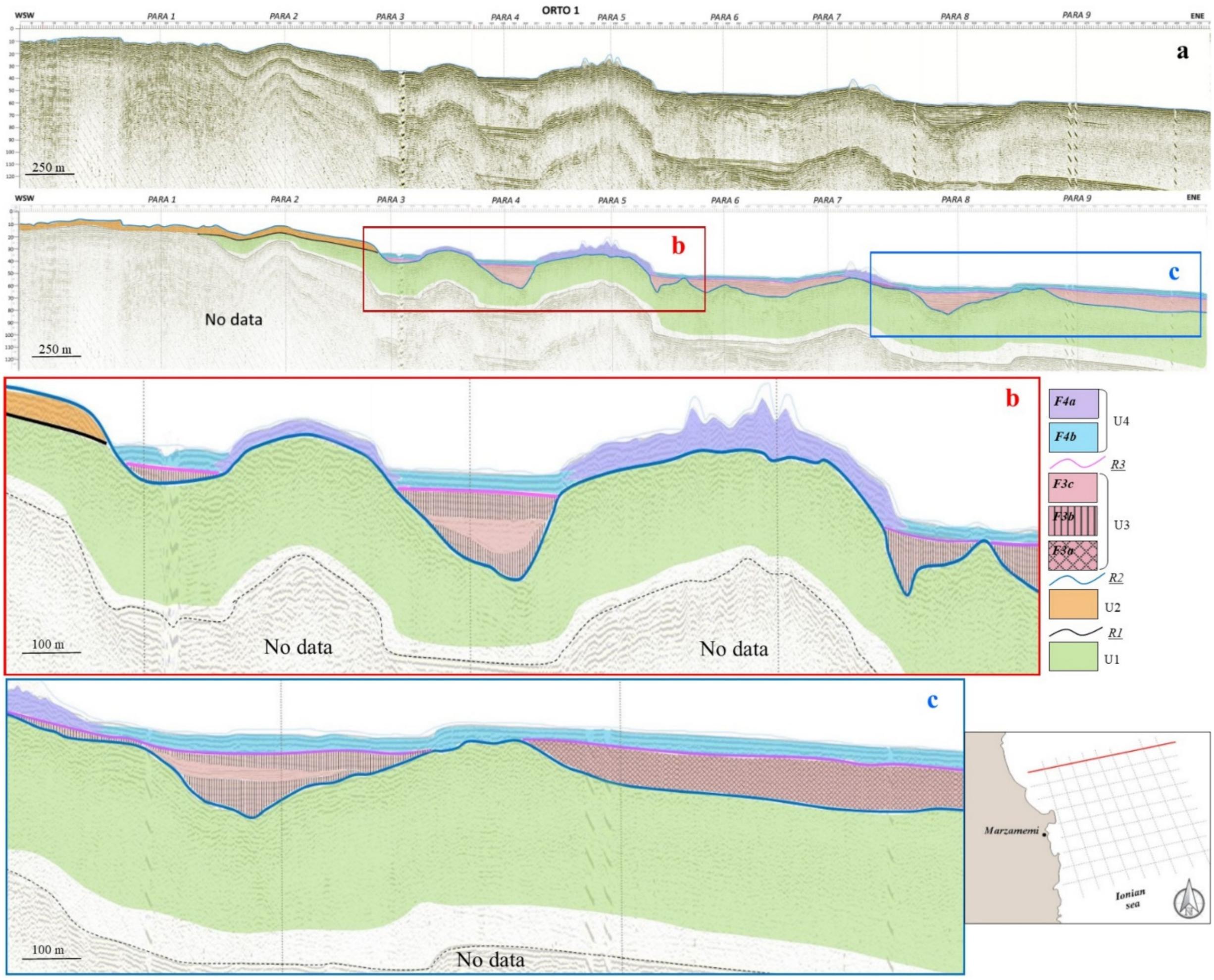


**Figure 7.** (**a**) Seismo-stratigraphic interpretation of the Orto 1 profile, located in the northern study area. (**b**) Seismo-stratigraphic interpretation of the central portion of the Orto 1 profile. (**c**) Seismo-stratigraphic interpretation of the northeastern portion of the Orto 1 profile. Legend: refer to Figure 6.

The F3b is limited to bodies deposited exclusively within the more depressed part defined by the erosional surface R2 (Figures 7–9 and 11). In fact, the F3b is predominately developed in the central and in northwestern sector of the study area, and has high amplitude reflections with moderate lateral continuity. In proximity of the largest incisions, the F3b reflectors have an inclined attitude and sometimes a laterally accreting pattern. The F3b lies in unconformity on the U2 and probably represents the deposits of a next phase of the Holocene transgression, characterized by a less homogeneous sedimentological setting.

The F3c is characterized by a transparent character, a poor lateral continuity of the reflectors and, together with F3b, it is mainly diffused within the paleo-river incisions (Figures 7–9 and 11). Therefore, F3c represents little deposits that contribute to fill the valleys and, sometimes, where the faint reflection is visible, it drapes the incisions. It is interpreted as a fine-grained unit that fills narrow embayments formed during the transgression in the valleys.

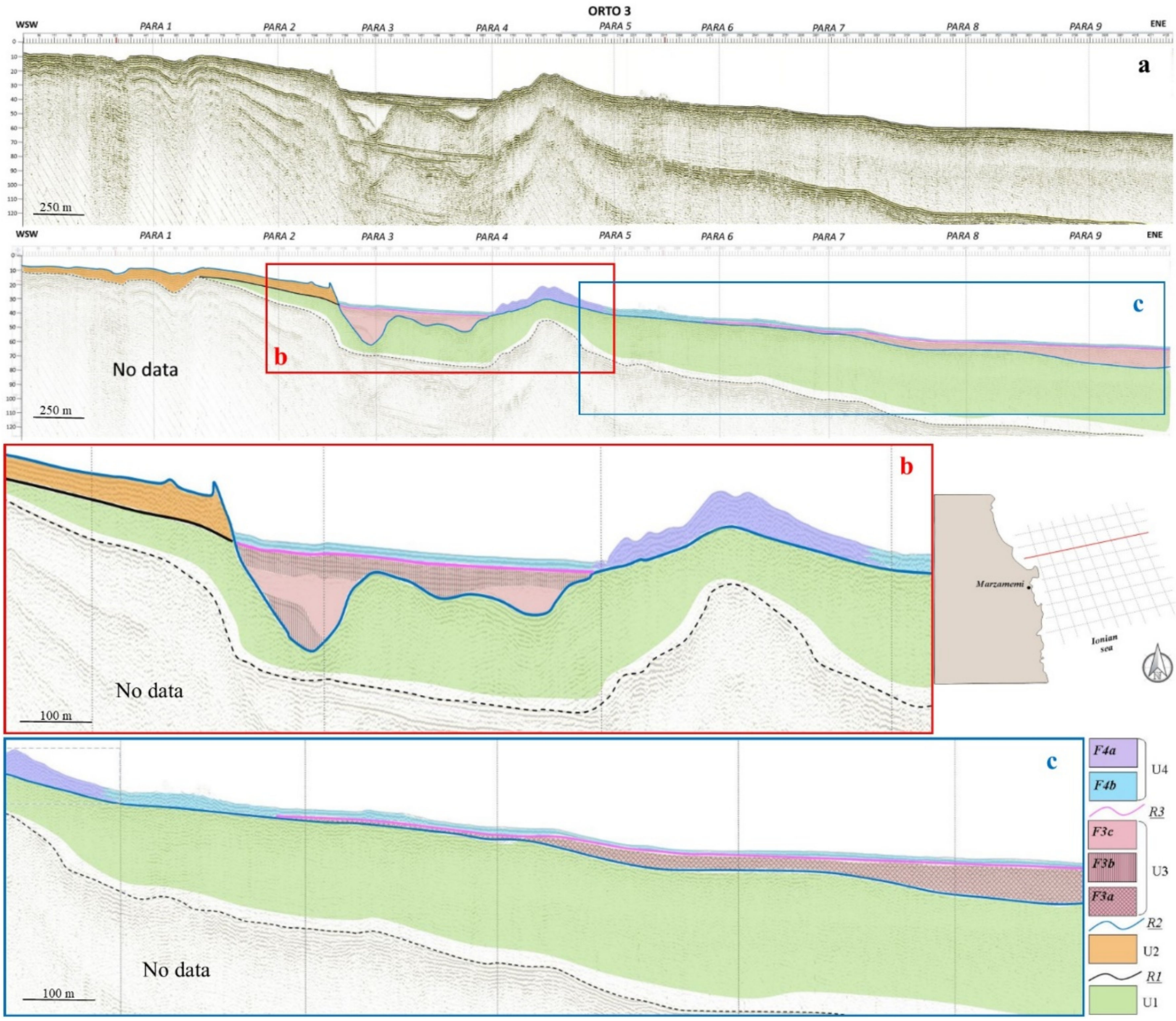


**Figure 8.** (**a**) Seismo-stratigraphic interpretation of the Orto 3 profile, located in the northern study area. (**b**) Seismo-stratigraphic interpretation of the central portion of the Orto 3 profile. (**c**) Seismo-stratigraphic interpretation of the northeastern portion of the Orto 3 profile. Legend: refer to Figure 6.

Overall, U3 represents the TST of the last eustatic cycle. Its stratigraphic features changed during Holocene sea-level rising, as highlighted in the description of the three facies, due to variable morphology of the underlying accommodation space, whose areal evolution is driven by the R2 irregular trend. The top of U3 is the Reflector 3 (R3), characterized by a moderate amplitude of the reflections and a good lateral continuity. It is interpreted as of the Maximum Flooding Surface, because it represents the end of the TST and the transition towards the Holocene highstand of the sea-level.

Upwards, the R3 bounds the basis of Unit 4 (named U4), characterized by internal lateral variations in the acoustic facies (Figures 7–12). Two acoustic facies, F4a and F4b, have been distinguished.

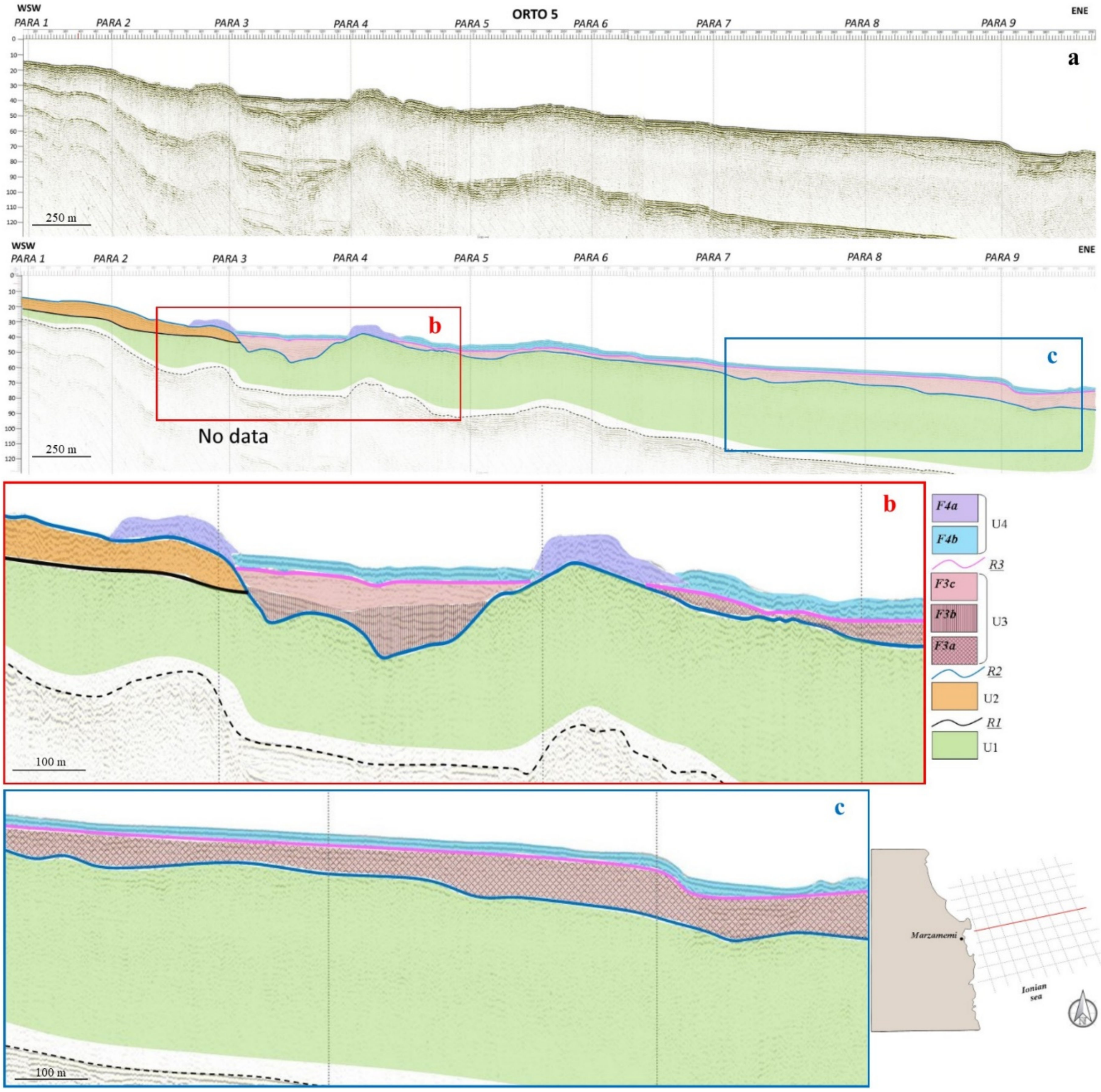


**Figure 9.** (**a**) Seismo-stratigraphic interpretation of the Orto 5 profile, located in the central study area. (**b**) Seismo-stratigraphic interpretation of the central portion of the Orto 5 profile. (**c**) Seismo-stratigraphic interpretation of the northeastern portion of the Orto 5 profile. Legend: refer to Figure 6.

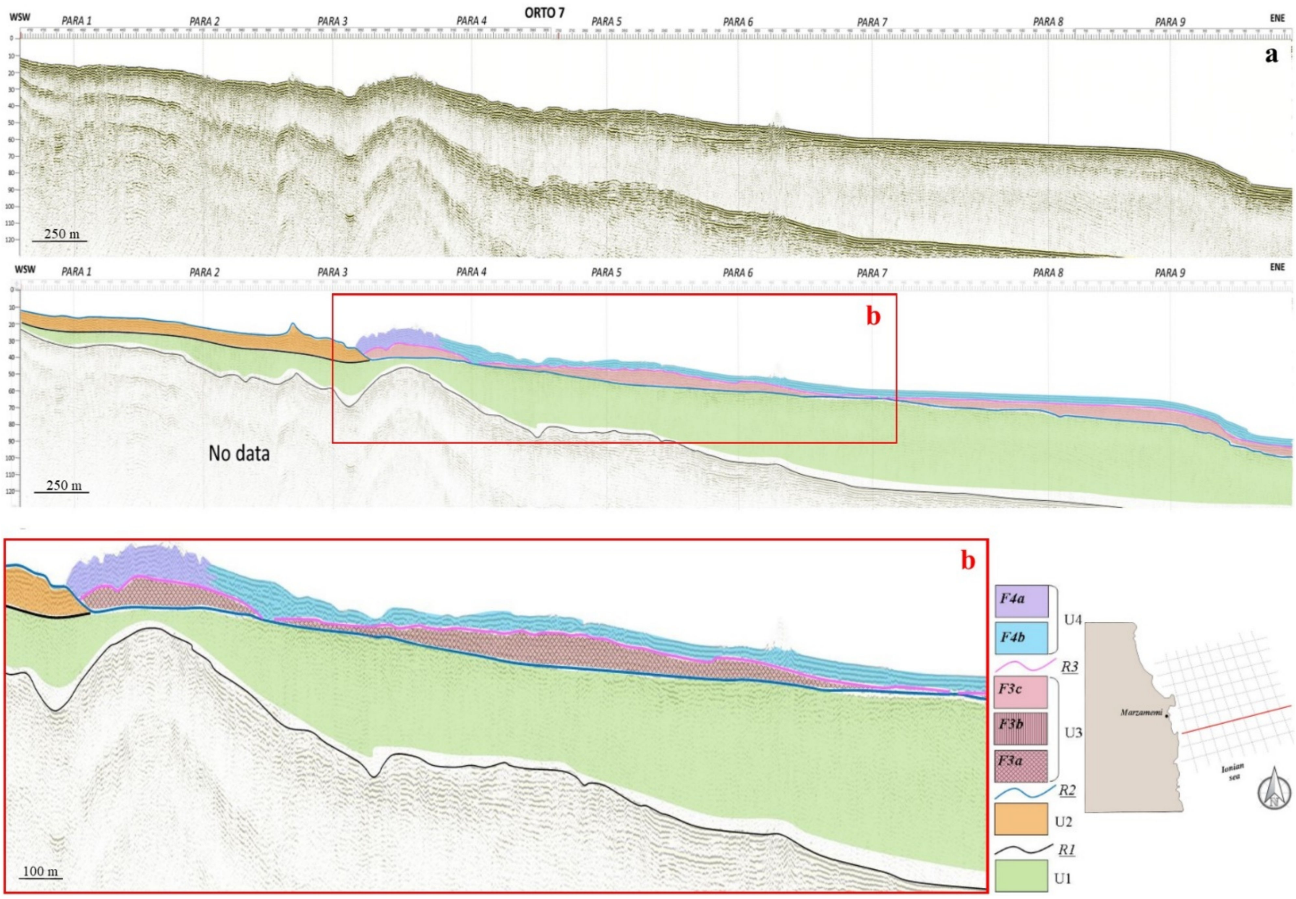


**Figure 10.** (**a**) Seismo-stratigraphic interpretation of the Orto 7 profile, located in the central study area. (**b**) Seismo-stratigraphic interpretation of the central portion of the Orto 7 profile. Legend: refer to Figure 6.

The F4a shows a sequence of marked reflections with very good lateral continuity and a sub-horizontal trend. Except for the area near the coastline, the F4a develops along all seismic profiles where it is characterized by the deposits that tend to drape most of the seabed, preserving a regular thickness (about 5–10 m). This facies is interpreted as corresponding with last highstand deposits and, probably, is correlated with the Holocene shoreline deposits outcropping on land along the Marzamemi coastline. Furthermore, the surface of these deposits shows areally different morphological features: (i) in the distal portions, it has a sub-horizontal or weakly wavy trend; (ii) to the south and in proximity to the coast, it shows a jagged trend, probably due to the presence of bottom currents that produce numerous small depressions.

Finally, the F4b is characterized by chaotic and only locally stratified reflectors, outcropping on the seabed in some central areas of the study area. Here the F5b reaches a maximum thickness of about 15 m and covers some morphological highs that unconformably lie on the acoustic substratum. It is developed on the calcarenite substratum, correlated with shallow-water marine environment and can be the result of in situ deposition of biogenic carbonates.

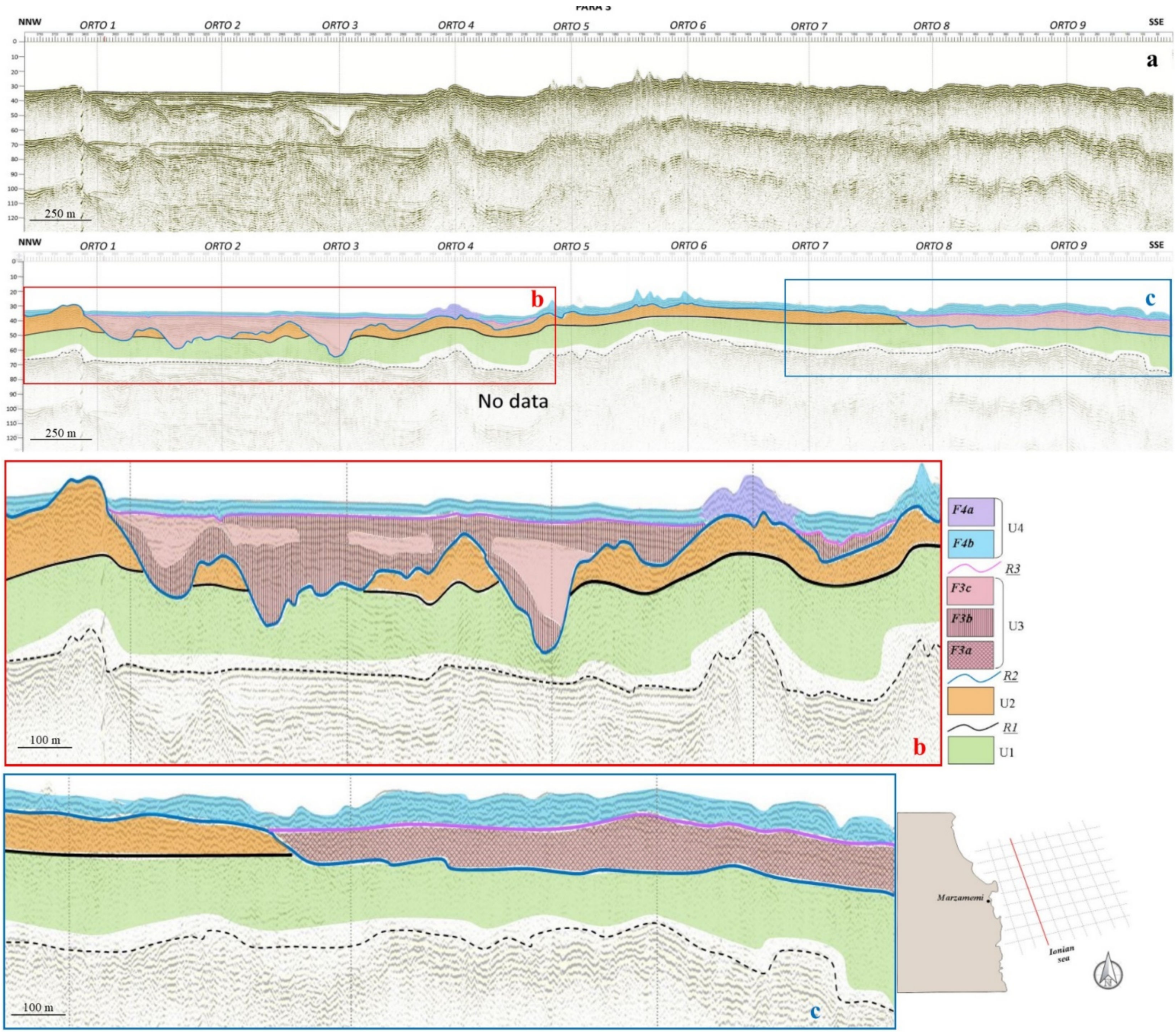


**Figure 11.** (**a**) Seismo-stratigraphic interpretation of the Para 3 profile, located in the central study area. (**b**) Seismo-stratigraphic interpretation of the northwestern and central portion of the Para 3 profile. (**c**) Seismo-stratigraphic interpretation of the southeastern portion of the Para 3 profile. Legend: refer to Figure 6.

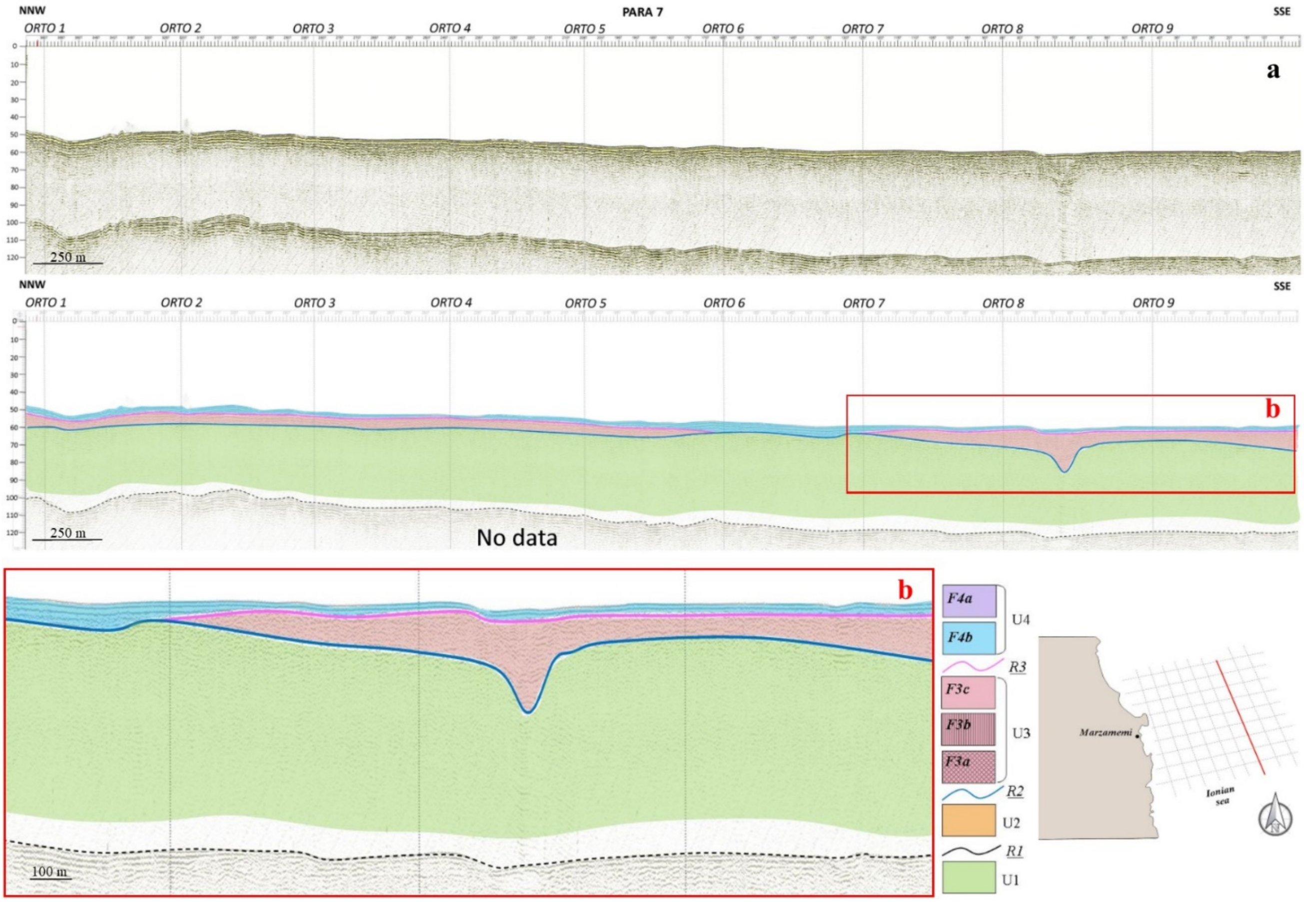


**Figure 12.** (**a**) Seismo-stratigraphic interpretation of the Para 7 profile, located in the eastern study area. (**b**) Seismo-stratigraphic interpretation of the southeastern portion of the Para 7 profile. Legend: refer to Figure 6.

## 5. Discussion

The offshore sector of the Marzamemi village represents a little part of the central portion of the Mediterranean basin, which has experienced major sea-level change during glacial cycles as showed in various types of geological records. It is known [45,46] that the Mediterranean coastlines provide a fruitful area for geomorphological and stratigraphic studies connected with the sea-level variation. In fact, here a wide range of geological and sometimes archaeological evidences are often available. For this reason, the study area—which lies along the southeastern Sicily coastline—is revealed as an excellent site to reconstruct the Quaternary stratigraphic setting of a continental shelf area, and where it was possible to study the development of the surfaces attributable to the sequence stratigraphy.

In particular, through a seismic-stratigraphic approach, the interpretation of eighteen new high-resolution (Sparker-system) profiles, nine parallel and nine about orthogonally to the coastline, covering the offshore sector of the Marzamemi village were interpreted.

Results comparable to those described in this work were obtained—through a similar methodological approach—by several authors [47–49], in other sectors of the Mediterranean area. They also show that the late Pleistocene-Holocene sedimentary evolution has been controlled by both transgressive and highstand stages of the last eustatic sea-level cycle. These Quaternary deposits on the continental shelf show in many cases the same stacking of progradational reflectors with typical sigmoidal configuration [47,50–52] recognized in the study area and discussed below.

As the main result obtained from the analysis of the seismic lines available, here we discuss the possible Quaternary evolution of the depositional units developed during the last transgressive and highstand stages (Figure 13), also evaluating the contribution from the regional tectonic uplift [14,23–27].

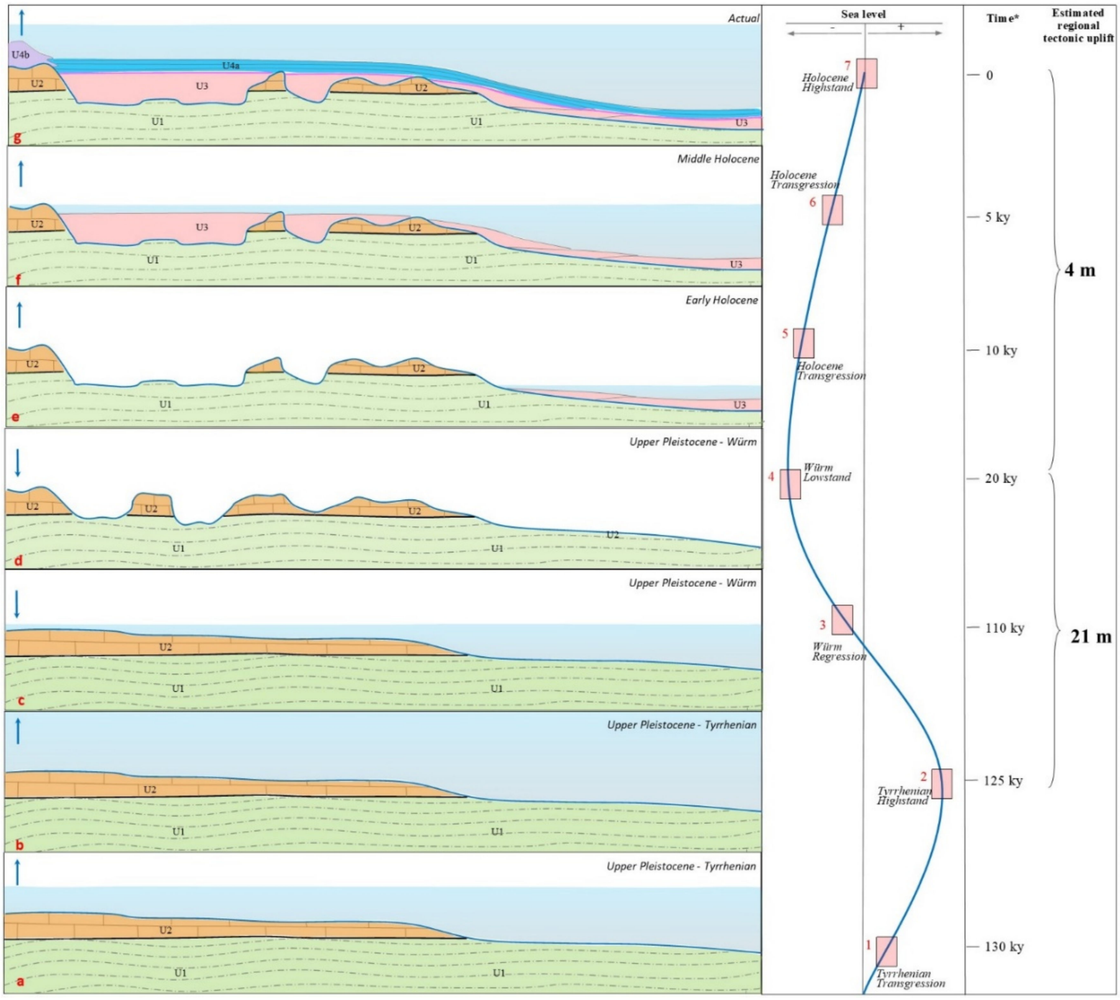


**Figure 13.** Upper Pleistocene-Holocene morpho-stratigraphical evolution of the Marzamemi offshore area and correlation with the relative sea-level variations. Legend: refer to Figure 6. Estimated tectonic regional tectonic uplift = 0.2 mm/a [14,23–27]. * Timing from [53]. The description of each step (**a**–**g**) is described in the Discussion section.

During the Tyrrhenian age (Figure 13a,b), the study area was completely submerged and the seabed shows roughly a regular morphology. In this period (130 ky ago) the deposits that constitute the substratum of the seabed belonged to the Tyrrhenian eustatic cycle and the identification of the lithologies was possible through the land–sea correlation. In particular, the deepest units are represented by Pliocene fine-grained marly units or older formations (U1); instead, the units outcropping on the seabed, especially in proximity of the present-day coastline, are represented by calcarenites formations (e.g., Marzamemi Formation, U2).

In the time interval between the Thyrrenian highstand (125 ky ago) and the Würm lowstand (20 ky ago), considering the average, a regional tectonic uplift of about 21 m has been estimated; this noteworthy value probably contributed to accelerate the Würm regressive phase (Figure 13b–d).

During the Würm glaciation (about 20 ky ago; Figure 13d), with the lowering of the sea-level, the study area progressively attained subaerial conditions. The consequent erosional phase produces a wide lowstand surface, associated with the excavation of incised valleys through rivers that in this period have the maximum areal development. The incise valleys are present in the inner part of the investigated area, whereas a more flat erosional surface is present farther offshore. Therefore, at the end of the last glacial period, the area is organized into an internal portion with a marked erosional morphology, characterized by narrow and V-shaped valleys, trending parallel to the coast. These areas are separated by elevated ridges with the same orientation. The successive rising of seafloor causes the inundation of the previously emerged areas and the formation of transitional alluvial and deposit whose distribution is largely influenced by the pre-existing morphology.

The first transgressive deposits are present in the distal part of the study area where the erosional surface is flat. Here, a relatively large lagoon is formed as shown by the distribution of F3a. The bounding barrier is further offshore than the end of our data. Successively the continuation of the Holocene transgression floods the more landward area where the incised valleys are firmed. They show a complex infill consisting of laterally restricted packages with facies F3b. They represent lateral bars that were formed in a fluvial or transitional environment. They are followed by a transparent package (F3c) that in many cases represent the majority of the valleys infill. In some cases, a faint reflection is evident with a draping geometry. We suggest that they are the fine-grained deposition within a central basin developed in the embayment formed during the transgression within the incised valleys. All these deposits represent the Transgressive System Tract.

The end of Holocene transgressive phase is marked by the Maximum Flooding Surface (R3), separating the underlying TST deposits from the overlying Highstand Systems Tract. The latter is characterized by actual shoreline deposits (F4a) that are widely diffused on the seabed and locally eroded by the bottom currents. In some areas it is in heteropic relationship with shallow-water sediments (F4b).

The regional tectonic uplift that occurred in the time interval between the Würm lowstand (20 ky ago) and Holocene highstand can be estimated in about 4 m, thus its contribution to the transgressive phase can be considered negligible (Figure 13e–g).

## 6. Conclusions

The interpretation of high-resolution "Sparker" profiles allowed us to reconstruct the evolution of coastal environments, in a sector of the southern-most Ionian Sicilian littoral (Marzamemi village, Syracuse), whose development records the relative sea-level changes, as a response to combined regional tectonics and eustatic movements, occurred since the late Pleistocene. Our seismic profiles showed:

1. A lower seismic unit, characterized by wavy reflectors and correlated with the Pliocene marls formations and/or the older sedimentary successions outcropping on land in the southern sector of the study area, which represents the oldest basement;
2. Upwards, a seismic unit, with high-amplitude and variable lateral continuity of the reflectors, correlated with the Tyrrhenian Calcarenite formation;
3. An evident unconformity with an irregular trend interpreted as the subaerial erosional surface developed during the last sea-level falling stage and lowstand. Within the lower part of these valleys, sedimentary units have highly variable acoustic response revealing the different facies, internal architecture and geometry of alluvial and lagoonal deposits, formed during and successively the Würm glaciation;
4. A marked reflection with high lateral continuity interpreted as the Holocene Maximum Flooding Surface;
5. The highstand deposits characterized by marked sub-parallel, horizontal, continuous reflectors resulting from the recent and present-day progradational sedimentary dynamics.

The reconstruction of the different positions, assumed by the transgressive bodies along the continental shelf as response to the relative sea-level changes, represents a significant result outcoming from the present study, providing useful information on the effects of the recent most sea-level variations, in the considered area. Our data also indicate that TST and HST deposits, developing on the erosional lowstand surface, reflect the accommodation space and the subsequent geometries created by this latter. In addition, it is noteworthy to observe that the off-shore geomorphological features, set up on the recent most highstand wedge, are similar to those currently outcropping onshore in the area of the "Pantani" of the Marzamemi village, thus indicating the facies onshore migration in response to the sea-level rise.

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