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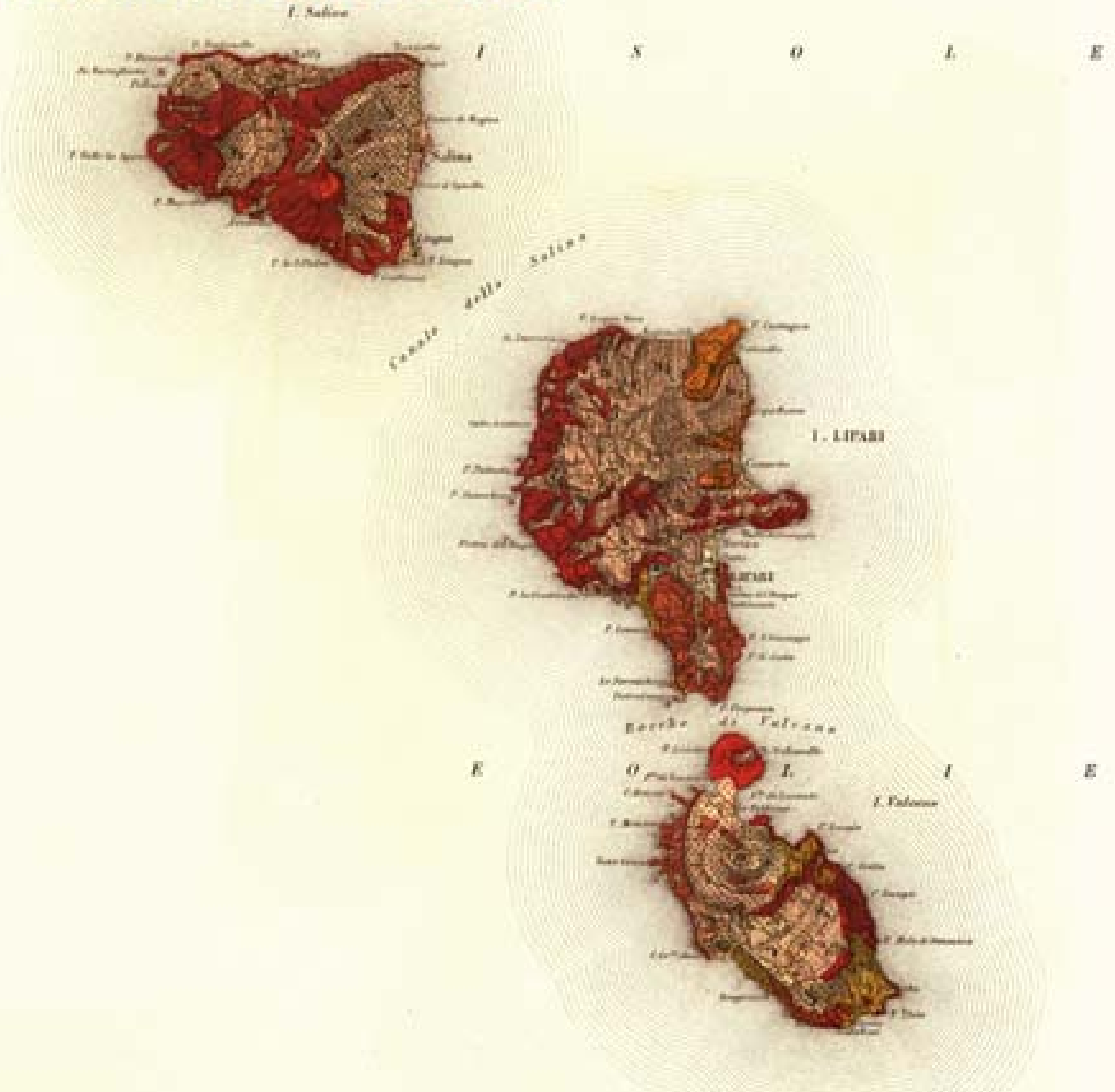
DIPARTIMENTO DIFESA DEL SUOLO

Servizio Geologico d'Italia

Organo Cartografico dello Stato (legge n. 68 del 2.2.1960)

MEMORIE
DESCRITTIVE DELLA
CARTA GEOLOGICA D'ITALIA
VOLUME LVIII

ATLAS OF SUBMERGED DEPOSITIONAL TERRACES ALONG THE ITALIAN COASTS



Editors
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ROMAGNOLI C.

on the cover: Aeolian Islands geological map - Sheet n°244
1:100.000 scale of the Regio Ufficio Geologico
(detail)
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IGCP464
Continental Shelves during Last Glacial Cycle

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ATLAS OF SUBMERGED DEPOSITIONAL TERRACES ALONG THE ITALIAN COASTS

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Introduction

CHIOCCI F.L.*, D'ANGELO S.**, ROMAGNOLI C.***

This volume collects a number of case history of terraced submarine morphologies present on the Italian sea floor. The collection of articles follows a previous initiative organised during the 15th Regional Meeting of the International Association of Sedimentologists, held in Ischia in April 1994; there it was presented a poster entitled "Lowstand depositional terraces: a case-history collection from the Italian coasts", due to many research groups who contributed in the realisation of this atlas. The good results of the initiative and the editorial availability of the National Geological Service, allowed the realisation of an atlas that could give, not only the compilation of the observed cases, but also a description and a mapping, as homogeneous as possible, of the main SDT morphologic and depositional features, and a depositional interpretation based both on the data studied by every single research group and on the comparison between all the collected data. All articles follow a similar standardand have been accepted after a scientific cross-reference of the contributors, with the cordination of the Editors and under the scientifc supervision of F. Ricci Lucchi. In order to give more emphasis to the data exposition, we have deliberately chosen an iconographic layout of the volume where the text is mainly commenting the images (maps, seismic profiles, submarine images). All articles follow a similar standard and have been accepted after a scientific cross reference of the contributors, with the coordination of the Editor and under the scientific supervision of F. Ricci Lucchi.

The depositional structures, object of this atlas, are sedimentary bodies outcropping on the sea floors at a shallow depth (generally within -150 metres), having a wedge-shaped geometry and a terraced morphology (Fig. 1). The internal structure (where depicted) is always prograding; the dimensions are generally of about some tens of metres as for the thickness, of some hundreds metre as for the extension perpendicular to the slope and of about some thousands metre (or some tens of thousands) as for the extension parallel to the slope. The depositional terraces have always been found on rather steep and narrow continental shelves as those typical of insular, volcanic or tectonic-controlled coasts. From time to time the depositional bodies lie on pre-existent abrasion platforms.

Never depositional bodies or terraced erosive forms have been taken into account; they only have been described if in relation with the SDT outcropping on the sea floor. The origin of the depositional terraces dates back to very recent geologic history, the last glaciation (Würm), when the sea-level was much lower than present, as a great volume of the oceanic water was immobilised in the continental glacial masses.

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In the realisation of the atlas one would not expect all the cases have been given the same relevance, since it is a case-history collection of SDT along the Italian coasts, often "casually" depicted during marine surveys having different targets. This aspect emerges in the data entity and in the variety of the prospection methodology; the different contributions in fact include high-resolution seismic profiles (mainly), R.O.V. and side scan sonar images and core and grab samplings. However, the main result of this atlas is to underline the presence of depositional terraces with similar features on marine areas which may be far away from each other and may have very different tectonic and sedimentological framework.

As SDT have limited extension and are difficult to recognise, only a comparative analysis among several case histories might allow a better comprehension of the processes causing the formation and preservation of such bodies, formed during sea-level lowstands. This is a very important scientific topic even in the international literature and its is rich in potential applied aspects, even if not immediate. On one hand the study of the environmental changes of the recent geologic past might give indications on the variations of the next future, on the other it is possible to use the SDT in the same way as the emerged coastal terraces are used, to underline recent crustal movements (for possible links with seismicity) that affect a great part of the Italian coasts.

Finally, a general observation: this scientific initiative, maybe because it is based on a limited and well-identifiable aspect, has managed to involve almost all the research groups who work in the high-resolution seismic stratigraphy. This aspect benefits the national scientific community, that gathered with neither specific funds nor strict co-ordination and it shows the possibility to make the results of different researches converge to common objectives.

The submerged depositional terraces (SDT) described in this atlas are mostly located along the Tyrrhenian coasts (Tuscan and Pontine Archipelagos, Campanian and Calabrian coasts, Aeolian and Egadi Islands, North-west Sicily, East Sardinia), and some other cases in the Sicily Channel (Linosa Isle) and along the Ionic margin (Fig. 2).

The SDT observed at a 100 m depth along the western part of the Elba Ridge and on the southern part of Capraia Isle (ROVERI & CORREGIARI) show homogeneous lithologic and geometric features (both internal and external), despite the great variability of depositional and morphologic aspects of the shelves where they set out. Moreover, the SDT development seemed to be conditioned by the gradient (between 0.5 and 2) and by the width of the shelf, the latter made up of prograding Plio-pleistocenic units. Thanks to the observation of the sedimentologic and paleontologic aspects (supported by radiometric dating), and according to the depth of the depositional edge, the Authors consider the observed SDT as beach bodies developed in a relatively high gradient coast, during the sea-level lowstand phase at the last glacial acme of 18 kyr ago.

FERRARO *et alii,* describe the submerged depositional terraces along the eastern and southern part of Sardinia coasts; SDT are mainly found in Cagliari Gulf, in Orosei Gulf, and between Capo Comino and Capo di Coda Cavallo. The SDT are shallower than usual, being found between -50 and -90 m, and are made up of fine sediments.

Around the Pontine archipelago (Islands of Palmarola, Ponza, Zannone, Ventotene and S.Stefano) CHIOCCI & ORLANDO describe the presence of a SDT with a depth consistent with the last glacial sea-level lowstand. The terraces distribution and depth on the different islands match very well with the emerged volcanic apparatus characters (subsidence in Ventotene-S.Stefano, made up of subaereal deposited units, uplift in Palmarola, made up of submarine depositional units, with Ponza-Zannone intermediate situation). A possible tilt of the western part of the archipelago has been highlighted (Islands of Zannone, Ponza and Palmarola), with a east to west gradual uplift of the SDT.

On the southern part of the Sorrento Peninsula, BUDILLON *et alii* identify prograding depositional bodies considered as SDT, extending for some km parallel coast near Capo Massa.

In the Gulf of Policastro, De Pippo Pennetta describes the occurrence of SDT at the edge of some sectors of the continental shelf showing different steepness and morphologic setting. According to their depth, the SDT have been reladed to the last glacial Maximum-level lowstand.

Near Capo Suvero-Calabria, (MONGARDI *et alii*) a SDT is present on the outer shelf that has an extension of only 5-10 km. The depositional terrace (with the edge at 140-150 metres) is somehow connected with a more internal erosional slope-break of a marine abrasion platform, that seems to mark the shoreline position during the last glacial sea-level lowstand. Based on lithologic and biofaunistic data, the SDT is interpreted as a relict lowstand deposit, sedimented in high-energy condition and in relatively starved conditions.

In the southern part of S.Eufemia Gulf (Calabria), CHIOCCI & ORLANDO describe a terrace with a steep internal stratification which is present for about fifteen km on the steep sea floor sloping down to the Angitola canyon. There are no terraced forms older than those outcropping on the sea floor, probably because of the regional geodynamics that might have caused the uplifting of older SDT and their removal during the shelf emersion during sea-level lowstands.

AGATE *et alii* describe a SDT present on the north-west Sicily continental margin (offshore Carini Bay), considering it within the Late Quaternary evolution of the margin. The SDT shows a depositional edge at a 140-160 m depth that, generally, coincides with the shelf-break; its thickness and extension towards the sea seem to be controlled by the gradient of the basal depositional surface (the shelf shows a rather limited extension, lower than 10 km, and an average steepness of 1.5°) and by the location of the feeding points. The SDT is considered as a sea-level lowstand body, deposited in a deltaic-littoral environment with high sedimentary rates, on the edge of a restricted, irregular shelf lapped by littoral drift currents.

The SDT observed in the volcanic areas of Linosa (ROMAGNOLI) and of the Aeolian archipelago (CHIOCCI & ROMAGNOLI) show several analogies: their presence seems to be connected with the distribution of submerged abrasion platforms (on which SDT prograde with good lateral continuity) and with the availability of volcanoclastic material produced by the dismantling of eruptive centres. The SDT are present at different depths (an upper SDT with a 30-50 m edge is always present and often there is a second SDT with a 75-100 m deep edge); they are often policyclic and overimposed each other. Their development seems to be controlled by the gradient and by the with (transversal to the coast) of the abrasion platforms below, as well as with the presence of morphologic irregularities on volcanic bedrock. If discontinuity of volcanotectonic and structural origin are present, they control the lateral variability as well as the external and internal geometries of SDT. A further controlling factor of the SDT depth at the Aeolian Isles is the wave energy, i.e. fetch exposition.

D'ANGELO *et alii* around the Egadi Islands found a SDT similar to the rest of the case histories but that is at present re-worked by current that erodes the terrace slope.

SENATORE describes the situation along the Ionic margin of Apulia. Here, despite the limited penetration of the acoustic signal caused by the presence of coarse sediments on the sea floor, it is possible to distinguish, with very high resolution seismic profiles, different kinds of prograding depositional terraces.

In conclusion CHIOCCI describes some acoustic effects affecting the SDT geophysical imaging, whilst SPOSATO shows the state of the art concerning the study of coastal marine terraces and their use for the definition of the coastal sectors vertical mobility. MASSARI describes an outcrop study that may be regarded as a fossil example of SDT.

A conclusive article summarises the comparison among the different case-history, and it is based on the results of two scientific meetings held in Bologna and Rome by a number of the researchers participating to the atlas.

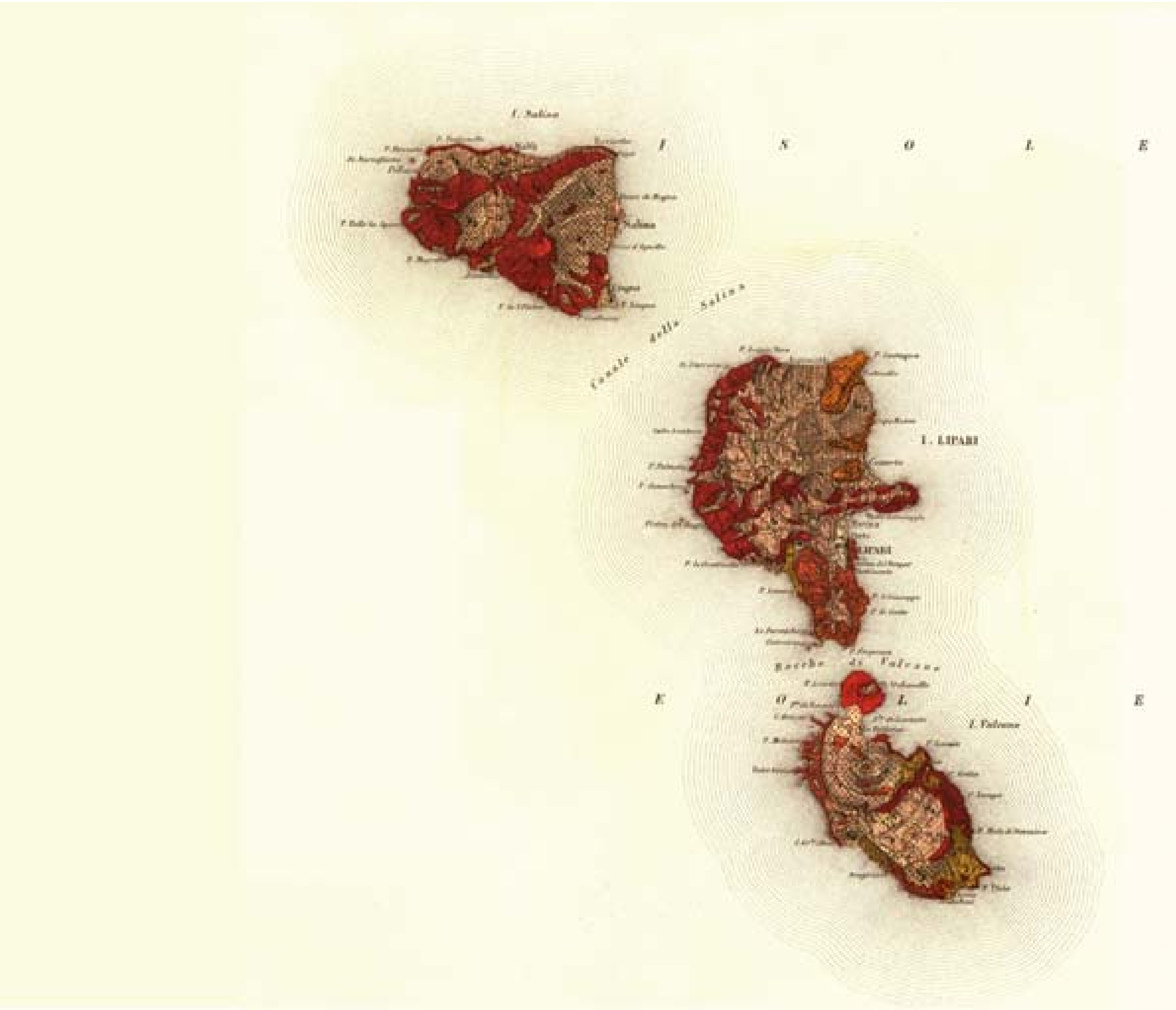
The mapping of different data set has been homogenized, by adopting the same bathimetric map for the location of the studied areas (from the map at the 1:750.000 scale of I.I.M.) and simbols (Fig.3) to represent the main morphological lineament in plain view.

A table at the end of each article summarized the main depositional parameters of described TDS.

FIGURES CAPTIONS

Fig. 1 - Sketch of a typical submerged depositional terraces
Fig. 2 - Location of SDT described in the atlas.
Fig. 3 - Cartographic representation of main morphological lineaments of SDTS adopted in this volume.

CASE HISTORIES OF THE ITALIAN COASTS



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Submerged depositional terraces in the Tuscan Archipelago (Eastern margin of the Corsica Basin)

ROVERI M.*, CORREGGIARI A.**

GEOLOGICAL FRAMEWORK

Submerged depositional terraces are a common feature along the eastern margin of the Corsica Basin, particularly between Capraia Island and Scoglio Africa; in this paper we show examples from the shelf area extending from Capraia to Pianosa Island (Fig. 1), for which a large seismic profiles and core database is available.

The Corsica Basin is one of the main Tyrrhenian sedimentary basins (VIARIS DE LESEGNO, 1978; BACINI SEDIMENTARI, 1979; ZITELLINI *et alii*, 1986); the basin fill is represented by a thick post-Oligocene succession (more than 4000 m; GABIN, 1972); sediments were accumulated during the Oligocene to Miocene compressional phases and mostly during the following extensional one, related to the late Miocene Tyrrhenian Sea opening (SELLI & FABBRI, 1981; ZITELLINI *et alii*, 1986; KASTENS & MASCLE, 1990; BARTOLE *et alii*, 1991).

The extensional phase is characterized since the Tortonian by magmatic activity (FERRARA & TONARINI, 1985); the intrusion of magmatic bodies led to the formation of several parallel ridges, elongated in a N-S and NNW-SSE direction and representing the structure of the Tuscan Archipelago. The small basins between ridges were progressively filled during Plio-Pleistocene time starting from the east; during the Late Quaternary a complex shelf area is formed, extending from the coast of Tuscany to the Corsica and Capraia Channel.

The outermost structural high (the so called Elba or Pianosa Ridge) delimits the shelf to the west; it is elongated in a N-S direction from Scoglio Africa to Pianosa Island and in a NNW-SSE direction from Pianosa to Capraia Island.

Miocene to Pliocene sedimentary units uplifted by intrusive bodies crop out along the ridge axis, both on the sea floor and at the surface (e.g. Pianosa I; COLANTONI & BORSETTI, 1973; VIARIS DE LESEGNO, 1978). High-angle extensional faults of Plio-Pleistocen age trending in a NE-SW and NW-SE directions cut the ridge between Elba and Capraia I. and between Capraia and Gorgona I.; thus, shelf areas, characterized during Pliocene and early Pleistocene time by different morphological and depositional features, can be recognized.

The peculiar structural framework of the shelf area to the east of the Corsica Basin, played an important role in trapping terrigenous sediments deriving from the growing Apennine Chain; for this reason the eastern margin of the Corsica Basin appears to be relatively starved with respect to the western one, abundantly fed by the Corsica Island.

The different sediment input is reflected by basin asimmetry (both of the external form and of the

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fill geometry) and by the progressive eastward migration of basin axis (VIARIS DE LESEGNO, 1978). This situation is particularly evident during Pliocene time; since the late Pleistocene, after the filling of the Tuscan extensional basins, a slow reversal trend is observed.

Anyway, the Elba Ridge remains a morphologic high, thus limiting the sediment input along the eastern margin also during the late Quaternary sea-level lowstand; this fact has great impact on the morphologic and sedimentary setting of both shelf and slope areas and, as a consequence, on the geometry and composition of sedimentary bodies.

During this time interval several deltaic lobes and small turbiditic systems characterize respectively the shelf and base of slope areas of the western margin of the basin (STANLEY *et alii*, 1980; BELLAICHE *et alii*, 1994), while along the eastern one only small terraced bodies formed at the shelf edge.

DATA AND METHODS

This work is based on 1000 km of GPS positioned seismic profiles and 50 cores collected during cruises ET91 (N/O BANNOCK), ET93 and ET95 (N/O URANIA), carried out by CNR Istituto di Geologia Marina of Bologna, as part of a research project concerning the study of active sedimentary processes and of Plio-Quaternary morphologic and sedimentary evolution of the eastern margin of the Corsica Basin. Seismic profiles were acquired in a regular grid (< 2km); they are represented by single channel 1 kJ Sparker profiles digitally recorded; 3.5 kHz sonar profiles (ET91) and 300 J UNI-BOOM profiles (ET95) were also acquired. The good quality of the positioning allowed the integration of the three cruises data, making easier the interpretation and calibration of seismic data with cores.

Sparker profiles are not the best tool for the detailed study of shelf sedimentary bodies, due to the limited vertical resolution. Anyway, the overall good quality of the available seismic profiles, allows the individuation and study of depositional terraces; sometimes also internal geometries are recognizable. Digital record allows the processing of data; as a consequence a significant improvement of the signal/noise ratio have been obtained together with the possibility to change vertical exaggeration.

The digital record system is based on a PC 486 and was realized by IGM; data has been processed with a SUN based software (FOCUS). The most important step was deconvolution which led to a significant decrease of the ringing effect related to the signature of Sparker. In this paper some examples are shown of seismic profiles before and after processing (Figs. 5- 6 and 11-12). Cores, located on specific targets, have been collected using a gravity corer 1.2 T with variable length (2-6 m.).

CAPRAIA SHELF

Capraia Island is sorrounded by a 5 km wide shelf to the west and to the south (Fig. 2); to the east the shelf is linked to the larger Tuscan shelf. The shelf break is a very sharp feature at a constant depth of -150 m; the slope is very steep (14°) and its base is found at -400 m depth. To the south the slope connects the Capraia shelf with the Elba Channel, a NE-SW trending depression related to Pliocene faults cutting the Elba Ridge; the Elba Channel axis is steep (2.5°) in the lower southwestern tract, while the upper northeastern one is very gentle (0.5°) and the transition to the shelf is gradual. The steepness of the southern slope of Capraia decrease to the NE along the Elba Channel together with the depth of its base.

Figures 3 to 6 show the framework of the Capraia shelf; the edge of the shelf and the slope are the frontal part of a polihystory progradational complex, developed all around the island during the Pliocene and the Quaternary, after the formation of the Elba Channel (Fig. 3 shows the progradational complex onlapping against tilted block of the volcanic basement of Capraia Island). The high angle of the slope is due to the coarse-grained nature of the foresets (biocalcarenites and biocalcirudites). The gradual decrease of the base of slope depth and of slope steepness along the axis of Elba Channel is due to two factors: 1) the progressive shallower depth of the base of the progradational complex and 2) the concomitant thickness increase of fine-grained Late Pleistocene deposits onlapping the base of slope; such deposits, genetically linked to the depositional terrace object of this study, completely cover the progradational complex in the Elba Channel head.

The morpho-structural setting of the Capraia shelf was thus already defined at the beginning of the Quaternary and probably since the Late Pliocene. The outermost prograding unit of the complex shows a well developed topset with a flat, smooth and very low-angle top surface, and onlapping against the island basement (Late Miocene effusive rocks); the latter crop out on the sea-floor at depth shallower than -100 m.

A prograding body develops above the Plio-Pleistocene complex; it is characterized by a seismic facies similar to that of the underlying unit. This body is a depositional terrace 15 km long (parallel to the coastline) and 0.5-1 km wide; the maximum width is reached in an area were also the underlying progradational complex attains its maximum expansion; to the west, where the shelf gradient increases up to 2°, the terrace rapidly disappears; to the east, the shelf gradient decreases progressively up to 0.5° at the Elba Channel head and the depositional terrace gradually dies out.

The terrace is a prograding body with an external wedge shape; it opens at variable depths ranging from -105 to -115 m; the topset-foreset transition lies at a constant depth of -120 m and the base is found at -130/-140 m depth (Fig.3). The mean thickness of the body is 15 m. Seismic facies is normally characterized by the absence of reflections; in some instances foresets with an angle of 15° can be seen; the terrace is monocyclic; some reactivation surfaces are rarely observed but the body appears to be developed during a single progradational phase.

Cores (Fig.4) show that the topset of the Plio-Pleistocene progradational complex is made up of biocalcarenites and biocalcirudites with calcareous algae; the base of the depositional terrace has been cored near the closure of the body: it is composed of fine bioclastic sands with glacial Mollusks; fine clayey sands with glacial Mollusks also characterize the unit found in the Elba Channel. AMS radiocarbon datings on Mollusks show that such deposits are related to the Last Glacial Maximum (ca. 18 kyr BP).

The depositional terrace formed on the Capraia shelf during the falling or lowstand stages of the Late Quaternary glacio-eustatic fluctuation. At the present moment no core data are available for the upper part of the foresets and the topset; for this reason it is very difficult to define sedimentary facies and to relate the prograding body to a specific depositional setting. Anyway, the depth of the foreset-topset transition (-120 m) is consistent with the Last Glacial Maximum sea-level recognized along the continental margins (FAIRBANKS, 1989); this suggests that the depositional terrace could represent a beach s.l. formed along a high-energy and relatively high-gradient coastline.

THE SHELF BETWEEN ELBA AND PIANOSA ISLANDS

The shelf area extending from Elba to Pianosa Islands has a linear edge at a constant depth of -120 m; the slope is complex, steep to very steep and severely affected by bottom current ACTIVITY(ROVERI, *et alii*, 1994; TONI, 1995; MARANI *et alii*, 1993). The base of slope is placed at depths ranging from -500 m to the north and -600 m to the south.

In the middle and lower tracts of the slope complex sedimentary bodies are present; they are interpreted as related to bottom current activity; the upper slope is characterized by large scale erosion, somewhere very strong and seismically detectable for the occurrence of truncated reflectors. Upper slope angles range from 2.5° to 14° with a modal value of 5°. A small linear canyon cuts at high-angle the slope up to the shelf edge in the northern sector (Figs. 7, 9).

The shelf is superimposed to the large anticlinalic structure of the Elba Ridge; it has a prevailing erosional character; present day sedimentation is absent, being this area too far from sediment input and continuously reworked by strong surface current that can affects the sea floor up to -80-100 m depth. Along the Ridge axis, Miocene and Pliocene strata crop out on the sea floor generating a higher and rougher belt; the outer western flank is characterized by alternating low gradient and smooth tracts and steep and rough ones.

The shelf stratigraphy is characterized by gently folded Miocene and Pliocene units truncated by an erosional polihistory surface, which formation started probably since the Late Pliocene. Along the western flank of the Ridge (Figs. 10-12) also Pleistocene clinoforms are found below the erosional surface; the youngest phase of erosion was during the Late Quaternary sea-level fluctuation, in two distinct moments: in a subaerial setting during the sea-level fall and in a subacqueous one during the subsequent transgression (ravinement surface); these two moments would generate two distinct surfaces; in this area, for the absence of sedimentary products relative to both the falling and the early rising stages of sea-level the two surfaces are coincident; above this surface a very thin layer (a few cm) of bioclastic sands is found; it represents the time interval corresponding to the late transgressive and high-stand phases of Late Pleistocene-Holocene age. At the shelf edge the two surfaces tend to separate and loose their erosional character; here they envelop a depositional terrace 25 km long and 0.5-1 km wide (Figs. 7-8). It opens at -110/-115 m depth and the closure is at variable depths ranging from -140 m and -200 m; the edge of the body is coincident with the shelf break and is at a constant depth of -120 m. The terrace appears to be more developed in a shelf tract with a low gradient (1°) and relatively smooth which is linked to an upper slope with 3° to 5° angles; the terrace onlap to the north and to the south against shelf tracts characterized by higher gradient (>2°) and linked to very steep upper slope (10°-14°).

The depositional terrace is a wedge shaped prograding body (Fig. 13); the internal geometry is well seen in 3.5 kHz sonar profiles (Figs. 13-14); they show tangential foreset strata with 10°-12° angle and very thin bottomset; in the upper part a clear toplap is seen below the sea floor.

A core cutting the upper part of the foreset strata (Fig. 14a) recovered medium to coarse-grained lithic sands with a strong biogenic component; they rest below a thin cover of fine bioturbated and bioclast rich sediments (TST-HST); sands are clean, not bioturbated and show parallel to low-angle inclined laminae; a second core cutting the lower part of the terrace (Fig. 14b) recovered, below a thin cover of TST-HST fine deposits, fine to coarse-grained, clayey, bioturbated sands with abundant bioclasts showing glacial affinity.

These data suggest, as for the Capraia shelf, that the terrace formed during the lowstand phase of the Last Glacial Maximum.

Cores clearly suggest in this case a beach depositional setting; moreover, considering that the depth of the foreset-topset transition (-120 m) is coincident with the sea-level depth reached during the Last Glacial Maximum, it can be argued that the depositional terrace represents a beach body developed in a relatively high gradient and high-energy coast tract.

CONCLUSIONS

The shelf superimposed above the Elba Ridge shows sectors with variable morphological characters reflecting a different Plio-Pleistocene sedimentary evolution; this is particularly evident when comparing the shelf margin of Capraia with that extending from the Elba Island to Pianosa Island. Nonetheless, in both areas depositional terraces with similar geometric and compositional characters develop at the same depth; these sedimentary bodies appear to be limited in their lateral extension only by the gradient of the shelf above which they develop (values comprised between 0.5° and 1.5°).

The sedimentologic and palaeontologic characters as observed in cores, together with radiocarbon datings, suggest that the depositional terraces present in this area formed as high-energy beach bodies during the Last Glacial Maximum lowstand (18 kyr BP); the edge of the terrace is found at a constant depth of -120 m, according with the mean sea-level reached during the Last Glacial Maximum; a direct consequence is that the study area can be considered, from both a subsidence and morpho-sedimentary point of view, stable, and homogeneous at least since the Late Pleistocene.

FIGURE CAPTIONS

Fig. 1 - *Location map of the studied area. Isobaths in metres.*

Fig. 2 - *Detailed map of the Capraia shelf, with the extension of the Last Glacial Maximum lowstand depositional terrace and the cores location.*

Fig. 3 - *1 kJ Sparker analogic profile (vert. exagg. 15x); the Late-Quaternary depositional terrace progrades above the topset of the Plio-Pleistocene progradational complex; the two systems onlap against the faulted basement of Capraia Island.*

Fig. 4 - *Correlation scheme of the cores superimposed on the same profile of Fig. 3. Not to scale to represent all the units. The Plio-Pleistocene complex topset is made up biocalcarenites with calcareous algae. At the base of the late-Quaternary depositional terrace fine sands with glacial fauna are found; these deposits do not reach the shelf margin, where, immediately below a thin cover of trangressive and high-stand sediments, the Plio-Pleistocene complex deposits are found. Below the erosional sea-floor of the Elba Channel fine-grained deposits with glacial fauna crop out; they can be temptatively correlated to the depositional terrace. Towards the NE these deposits are linked to the base of the terrace and completely cover the Plio-Pleistocene progradational complex.*

Fig. 5 - *1 kJ Sparker profile before processing (vert. exagg. 15x). Compared to Fig. 3 profile the slope appears less high and steep, due to the different depth of the base of the Plio-Pleistocene progradational complex and to the thickness increase of the fine-grained deposits at the base of the Late-Quaternary depositional terrace.*

Fig. 6 - *The 1 kJ Sparker profile of Fig. 5 after processing; deconvolution has improved the vertical resolution with the drastic reduction of the ringing effect, making it possible to see the real terminations of reflectors. Vertical exaggeration is reduced at 7x.*

Fig. 7 - *The depositional terrace at the shelf edge in the tract between Elba and Pianosa Islands (nortern tract, see Fig. 1). Isobaths in metres.*

Fig. 8 - *The depositional terrace at the shelf edge in the tract between Elba and Pianosa Islands (southern tract, see Fig. 1). Isobaths in metres.*

Fig. 9 - *1 kJ Sparker profile and its interpretation (vert. exagg. 16x). The depositional terrace progrades within the head of a small canyon reaching the shelf edge; several phases of erosion and deposition within the canyon fill are clearly evident.*

Fig. 10 - *1 kJ Sparker profile not processed (vert. exagg. 15x) across the western flank of the Elba Ridge; the erosional character of the sea-floor is evident; in this section the strata have a monoclinalic attitude; to the east in the rougher and higher relief area the Miocene terms of the succession crop out; to the west in the flat lying and smooth area Plio-Pleistocene deposits crop out; the latter made up a complex prograding unit which outermost term is represented by the Late-Quaternary depositional terrace.*

Fig. 11 - *1 kJ Sparker profile not processed (vert. exagg. 15x) across the Elba Ridge. As in the section of Fig. 10 the Miocene to Pliocene succession crop out in the higher relief sector of the shelf; the Pleistocene progradational complex is here well developed; at its front on the shelf edge, the prograding wedge representing the Late-Quaternary depositional terrace can be seen slightly deeper with respect to the adjacent deposits.*

Fig. 12 - *The 1 kJ Sparker profile of Fig. 11 after processing; the vertical exaggeration is reduced to 7x and the reflector terminations after the deconvolution appears more clear.*

Fig. 13 - *3.5 kHz sonar profile across the depositional terrace (vert. exagg. 12x); location in Fig. 7. Note the internal geometry of the body with tangential foresets.*

Fig. 14 - *a) 3.5 kHz sonar profile across the depositional terrace with the ubication and the sedimentologic log of core ET91-8; below the fine-grained deposits of TST and HST the core recovered the upper part of the foresets, made up of clean sands with parallel and low-angle inclined lamination; b) 3.5 kHz sonar profile showing a detail of the closure of the depositional terrace with the ubication and the sedimentologic log of the core ET91-14: the bottomset is made up of clayey bioturbated sands with abundant glacial-type bioclasts.*

Fig. 15 - *Photographs of fig.14 cores.*

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Submerged depositional terraces in the continental shelf of Western and Southern Sardinia (Italy)

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Since 1976, the group of the Department of Geology of Cagliari University have led several oceanographic cruises, within the "Oceanografia e Fondi Marini " of C.N.R. and "Geologia dei Margini Continentali" projects (CARTA *et alii,* 1986; *U.O.Bacini sedimentari,* 1997). The projects aimed the investigations of the continental shelf of Sardinia Island (Italy).

The study of the Sardinian continental shelf had the purpose to both investigate the present and past environmental conditions of the platform which could have determined the concentration of useful minerals and to redraw the morphology, the geomorphologic evolution and the geological structure of the same continental shelf.

The cruises took place from 1976 to 1991; high and low frequency ecographic, side scan sonar and high-resolution seismic reflection (sparker and uniboom) have been carried out. Moreover sampling of the bottom-sediments was performed by using grab, dredgings, cores and direct drawing with scuba-divers.

Data acquisitions was carried out using sophisticated instruments. A precise location of the route position and of each sampling sites was recorded by satellite, Loran and Radar radiolocation.

The Sardinian eastern margin is a few miles wide in average and present a very steep slope, which stops at the depth of more or less 1000m in correspondence of the sardinian basin. The extremely reduced width (from less than a mile to 6-7 miles) is due to a N-S faults system, parallel to the lengthening of the coast, which have interested the upper continental slope and its edge (ULZEGA, 1998).

Fig. 1 - *Location of the study area. The isobaths are in metres.*

A series of deep canyons, E-W oriented, cut both the slope and the continental shelf, coming sometimes near the coast. The edge develops at the constant depth of more or less 125m and it rises to lower depths in correspondence of the canyons' head withdrawing, which is caused by regressive erosion (ORRÙ & ULZEGA, 1988).

Due to the considerable Plio-Quaternary sediment cover, which characterizes the continental shelf, its morphology is generally regular and steady inclined from the coastline to the edge, where a noticeable break of the slope occurres. It is made up by thick prograding (ARCA *et alii*, 1979; LECCA *et alii,* 1979; GRILLO *et alii,* 1984; ULZEGA A., 1988).

In this note are shown some examples of submerged depositional terraces, which refer to the sea level low-standing, and situated in the continental shelf of western and southern Sardinia.

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The selection of examples presented is due to a particular relationship between submerged terraces and canyon's head, which have been studied in the context of several projects.

Fig. 2 - *The figure shows depth and areal extension of the submerged depositional terrace surveied in the Gulf of Cagliari, referred to the last low-standing sea level. The terrace develops through a global length of more or less 8 miles, while its extension perpendicular to the coast is only 200-300 metres in correspondence of the canyon's head of S.Elia. The western side of the Gulf of Cagliari, (Capo Pula) consist of the granitic and metamorphic complex of Sulcis; the eastern side (Capo Carbonara) by the granitic relief of Sarrabus. The internal N-W limit is represented by the wide S. Gilla, Molentargius and Quartu lagoons, the first of whom is divided from the others by a Miocene promontory of S.Elia and by the hills of Cagliari.*

The structural fabric affecting the southern part of the Campidano plain, also conditions the frame of the ahead continental shelf (FANUCCI *et alii*, 1976). Morphological characteristic recognisable in the emerged land are also visible on the continental shelf, which regularly develops in the area of the Gulf of Quartu with wide and weakly inclined surface. The shelf ends with a marked edge in correspondence of the isobath of 110m; its width all along the coast between the Gulf of Quartu and Capo Carbonara, is reduced to 1-2 miles.

To the eastern area of the Gulf of Cagliari s.s., the extent of continental shelf is of about 6 miles; its marked edge is recognisable until the depth of 75m and it is interrupted eastward by the head canyon of Foxi and in its middle side by the canyon of S.Elia. The heads of S.Elia canyon shows active withdrawing, clean and directly cut in the basement. Towards west, the edge, less sharp and deeper, appears at a depth of 120m and it is characterised by fine sediments in progradation (ULZEGA *et alii*, 1980b; ULZEGA *et alii*, 1986). The main structural elements derived by seismic profile analysis, is the faults continuity of Campidano plain, in the inner area of the Gulf of Cagliari. The noticeable asymmetry on the emerged land, is also particularly evident. This asymmetry is represented by limit surfaces at the lower limit of both Pliocene and Quaternary, and by a series of structural highs oriented NW-SE towards the andesitic relief of Sarroch (FANUCCI *et alii*, 1976; LECCA *et alii,* 1986).

It is even possible to observe an area of recent subsidence, which includes the internal part of the platform and probably the flat land part of Campidano, now occupied by the wide marsh of S.Gilla, which receives the terrigenous contribution from two important rivers, Rio Mannu and Cixerri. The structural condition of the depression limit might be now defined, even if it appears possible, that exists a prolongation of the depression toward sea, before the Plio-Quaternary levelling (FANUCCI *et alii*, 1976). The Plio-Quaternary sedimentation shows a continuity, which records the more thickness, close to the inner zone of the platform. Besides, while the Pliocene deposits drape the basement, the Quaternary deposits show prograding geometry. In those deposit it is possible to find traces of shorelines, related to the Late-Quaternary glacio-eustatic phases (ULZEGA *et alii*, 1980b; ULZEGA *et alii*, 1986). Due to the erosive effects of the regression duringthe last glacial period, the present morphology of the platform is regular, with the exception of the least extended holocene deposits. During the recent Quaternary the subsidence on the continental shelf has been extremely limited therefore the deepest limit of the regression is at about -110m.

Fig. 3 - *Gulf of Cagliari. Sub Bottom Profiler 3.5 kHz. The perspective highlights the lateral variations of morphology and extension of the depositional terraces, referred to the last low-stand of the sea level, observed in the Gulf of the Cagliari (see Fig.2). The two uppermost profiles are reported in Figs 4 and 5.*

Fig. 4 - *SBP 3,5 kHz echographic profile acquired in the Gulf of Cagliari (see Fig.2).*

Interpretation:

1) the tertiary bedrock presents a seismic deafening facies with absence of sedimentary geometries. The lithology is constituted by biogenic limestone of the upper Miocene;

2) the Late Tertiary deposits, consisting in slime and clay (Pliocene?), present an opaque seismic facies, characterised by rare inclined reflectors; the sedimentary geometries are represented by pinch-out towards the land and inclined foreset seaward;

3) this deposit, probably a littoral and/or dunal cordon, is characterised by a few transparent seismic facies with wavy reflectors, the geometry of sedimentation appears inclined and sigmoidal;

4) it is possible to observe a submerged depositional terrace with an acoustical signal and infrequent reflectors; the inner structure of the deposit is characterized by a parallel stratification and foreset; the lithology is likely constituted, by slimy sands and sandy slimes; in the figure the depth of the principal depositional features of the terrace is in metres.

Fig. 5 - *SBP 3,5 kHz echographic profile carried out in Cagliari SE (see Fig.2).*
Interpretation:
1) we can observe the Tertiary bedrock constituted by a biogenic limestone and characterised by a deafening acoustic signal and lack of sedimentary geometries;
2) Pleistocene deposits, constituting in slime and clay present an opaque seismic facies and infrequent inclined reflectors and foreset sedimentary geometry;
3) the sandy slimes which constituted the submerged depositional terrace are characterised by an opaque-transparent signal; in the terrace are noticeable rare sub-parallel and prograding reflectors with convex geometry;
4) sandstones and conglomerates represent the shoreline (beach-rocks) lithology correlated to the Versilian transgression;
5) this transparent seismic facies with inside parallel reflectors constitute the Holocene sedimentation, which fill the depressions.

Fig. 6 - *In the Gulf of Orosei, the terrace is morphologically well distinguishable, with a parallel development at coast of more or less 3 miles and a sediment maximum thickness of 5-8m.*

The continental shelf shows the typical characters of the sardinian eastern margin with an extension limited to a few miles and deeply cut by active canyons. The shelfedge, generally over 100m, presents a clean break of declivity with extremely limited prograding areas;due to the regressive erosion correspondingly to the heads of the canyons, the bedrock outcrops locally. Along the northern border of the Canyon Gonone emerge the layer head of a sedimentary unity, reliable with Pliocene clay and sandstone which outcrop onland.

The regressive withdrawing, helped by the presence of important tectonic lines in the continental margin, has brought the canyon's head to the depth about 50m. For this reason the canyon cuts deeply the whole continental shelf and develops towards reaching the distance of 1 mile from the coasting cliff (Orrù & Ulzega, 1987; Orrù & Ulzega, 1988).

The continental shelf, unusually extended between two canyons, has been protected from the regressive erosion, by a basaltic flow, which is preserved in a small expansion limited by clean frames, that corresponds probably to the emission centre.

Along the whole continental shelf appear littoral morphologies to different depths, represented by abrasion platforms, paleo-cliffs and beach-rocks. The recent sedimentation is represented by sandy slimes with foraminifer in the external zone of the shelf, by biogenic sands along the wide central zone, while in the coasting area deposit quartz-feldspar sands or alluvial slimes of the recent delta.

The S.B.P. profiles show a clean shelfedge, and a weak deposit of Holocene sediments laying on an acoustically deafening substrate. In the Uniboom profiles the same substrate seems constituted by sediments stratified in weakly inclined position, cut either by the canyon or by Pleistocene erosion surface of the shelf. It is also possible to notice movements of fine sedimentation piles with creeps and slumpings (Orrù & Ulzega, 1987).

Fig. 7 - *SBP 3,5 kHz ecographic profile carried out NE of Gonone Canyon (see Fig. 6).*
Interpretation:
1) Mesozoic bedrock probably constituted by limestone and dolomite; acoustic signal is deaf with an absence of sedimentary geometries;
2) prograding Quaternary sediments constituted by slimes and clays; the inner structure appears opaque with numerous inclined reflectors and foreset geometry;
3) littoral and/or dunal cordon constituted by sand and characterised by an opaque seismic facies with wavy reflectors and inclined stratification;
4) submerged depositional terrace constituted by sandy slimes and slimy sands, acoustically transparent and showing parallel reflector: it clearly appears how the terrace morphology and the acoustic facies clearly differ from the sedimentary basement upon which they lie.

Fig. 8 - *SBP 3,5 KHz ecographic profile carried out S of Canyon Gonone (see Fig. 6).*

Interpretation:

1) Mesozoic bedrock probably constituted by limestone and dolomite; the acoustic signal is deafening with an absence of sedimentary geometries;

2) deformed structures, interpretable as landslide's deposits, characterised by an opaque seismic facies and by ondulated reflectors;

3) submerged depositional terrace constituted by sandy slimes, to the acoustically transparent, with the principal reflector at more or less 5m; the sedimentary geometry appears weakly wavy;

4) acoustically transparent body with irregular responses, interpretable as a biogenic cliff with red algae (Pseudolithophyllum espansum, see Fig. 9).

Fig. 9 - *Underwater image of the Canyon Gonone's head and related block-diagram:*

1) biogenic cliff with Pseudolithophyllum espansum

2) biogenic cliff with pseudostratification

a) linear cut

b) withdrawing head

c) plane with sandy slimes and lithotamnium

Exploration through scuba divers has allowed a direct observation of transport, along cuts, of the coarse sediments towards the abyssal plane, which appear, on the outer edge of the canyon's head (ORRÙ & ULZEGA, 1987; ORRÙ & ULZEGA, 1988). The analysis of samples of sediments taken from the Canyon Gonone's head have allowed to argue on the geomorphological observations carried out on the place.

Besides, the detailed investigation using electronic microscopy (SEM) has brought to interesting results on the samples taken from the canyon's head:

- the mechanism appears more active in the shelfbreak; some structures, observed by esoscopy, are comparable to those described in the bibliography on about granules from the abyssal plane;

- the epigenetic neogenesis are often due to emersion, even if temporary, which sometimes take form on beaches or deltaic environments; when a constant contribution from the coast doesn't exist, the material is reworked in place and the epigenetic neogenesis can be the witness of some paleoenvironment; the neogenesis of quartz observed in the depression zone of the plane (with slimy sands and lithotamnium) indicates a marine environment with a low energy.

Fig. 10 - *Areal extension of the depositional terrace in front of Canyon Posada's head.*

The continental shelf between Capo Comino and Capo Coda Cavallo presents some typical characters of the whole eastern Sardinia. The shelf edge lies at the depth between 100m and 120m, with a clean slope break and active progradation in the areas of Capo Coda Cavallo and Capo Comino, while in the centre, Canyon Posada's heads, shows a regressive withdrawing which affects the platform's surface.

The high part of the same continental shelf is characterised by isolated rocky outcroppings, clearly visible in side scan sonar records, probably consisting on granitic or veins (GRILLO *et alii,* 1984). *At various depths, between 90m and the present shoreline, there are evidences of the eustatic variations of the sea level, represented by sandstones and sand conglomerates, with carbonaceous cement, which seems to be related to the cementation of beach sediments' in an intertidal zone (*OZER *et alii 1983;*ULZEGA *et alii*, 1980a; ULZEGA *et alii*, 1981; ULZEGA *et alii*, 1984).

Actually, on the entire area, the terrigenous sedimentation is less frequent than the production of biogenic granules. The dispersion of sediments is active over the whole continental shelf, along which, on the emerse land, we can observe the same lithologies; more recent analysis show that the sediments may belong to a beach and river environment (FIERRO *et alii*,1974). *They are probably residual materials, which have been retaken during the last transgression, and this is confirmed by presence of submerged shorelines at various depths.*

The biggest sediments' thickness is visible on the edge and in correspondence of the Canyon Posada's heads, where a big part of the sediments of continental shelf canalise towards the Baronie Basin. Besides, the irregular morphology of the continental shelf, due to erosions verified during the last glacial regression, show several depression where the sedimentation of different orders of few stratified sand bodies take place (GRILLO *et alii,* 1984).

Fig. 11 - *SBP 3,5 KHz echographic profile carried out near Canyon Posada (see Fig. 10).*
Interpretation:
1) crystalline bedrock, acoustically deafening;
2) Plio-Quaternary deposits constituted by slime and clay with an absence of sedimentary geometries and acoustically opaque with rare reflections;
3) sandy slimes form this depositional terrace, acoustically few transparent with parallel reflectors and plane-parallel geometries; the terrace may be linked to at least two cyclic events of a different amplitude.

CONCLUSIONS

Based on the analysis of data, the following conclusions can be drawn:
1) submerged depositional terraces have been surveyed and mapped on the continental shelf of the Gulf of Cagliari, the Gulf of Orosei and Posada, in proximity of the canyon's heads.

2) The TDS generally show, in the SBP profiles, an internal prograding structure and an acoustically transparent facies.

3) The TDS observed near Cagliari and Orosei show, inside and outside, homogeneous geometric and lithologic characteristics; external geometry presents particularly cuneiform way in the TDS noticed in the Gulf of Cagliari.

4) The terraces close between -80m and -110m; such depths are sensitively lower or similar to those reached during the minimum eustatic of the last glacial period.

5) The TDS noticed in the Gulf of Orosei and, partially, in the Gulf of Cagliari are situated in correspondence of already pre-existing abrasion surfaces, relatively wide and of low declivity, due to the erosive action of the sea to a lower level than the present one.

6) In general TDS has not been noticed on the upper continental slope; on the contrary they can be observed in correspondence of the shelfedge.

7) The probable genesis of such deposits, in agreement with the other authors, can be brought back to the deposition in standing condition of the sea level to higher depths than the current one. A following sediments reworking above the abrasion surfaces during the raising phase can be recognised; such abrasion surfaces have represented areas of concentration and standing of sediments that would have been subject to gravitational movements toward the continental slope.

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Submerged depositional terraces of the Pontine Islands (Southern Latium)

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GEOLOGICAL FRAMEWORK AND METHODS

The Pontine archipelago is made up of two groups of (predominantly) volcanic islands located on the eastern Tyrrhenian continental margin that underwent a transpressive tectonic activity in the Pleistocene (MARANI & ZITELLINI, 1986). The western group is made up of the Islands of Palmarola, Ponza and Zannone and the small Botte Rock, while the eastern group is made up of Ventotene Island and the islet of S. Stefano. The western group was developed during the Plio-Pleistocene on the outer margin of the Latium shelf, while the eastern group consists of a subconic volcanic apparatus of about 800 meters in height standing at the center of the Gaeta Gulf (Fig. 1).

During the Pliocene, the southern Latium continental margin was affected by tectonic movement that created the Palmarola and Ventotene basins (DE RITA *et alii*, 1986). At the end of the Pliocene, the outer edge of the shelf was continually affected by normal faulting which besided the volcanic activity that created the archipelago.

The volcanism which developed in the three western islands, Zannone, Ponza and Palmarola, has a complex nature that depends partly on the substrate and partly on the position of the relative sea level during the emplacement of the volcanites (CARMASSI *et alii*, 1983).

The island of Zannone is characterized by overthrusted units of metamorphic and sedimentary rock of various ages (from the Paleozoic to the Messinian) on which rests a unit of subaerial volcanites coming from Ponza and Palmarola apparatuses (DE RITA *et alii*, 1985). Ponza, the main island of the archipelago, is characterized by an acidic subaqueous volcanism in the early stage, and a potassic subaerial volcanism in the final phase. The island of Palmarola is mainly formed by totally subaqueous acidic volcanic products of the upper Pliocene-Pleistocene age. There are two small outcrops of upper Pliocene marl and clay only on the western side (CARRARA *et alii*, 1986).

Fig.1- *The Pontine Archipelago can be subdivided into a western group (including the islands of Palmarola, Ponza and Zannone) and an eastern group (made up of the islands of Ventotene and S. Stefano). The two groups of islands, together with the Ischia and Procida complex, form part of a volcanic ridge (trending W10-158N) that stretches for about one hundred kilometers.*

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The eastern islands of Ventotene and S. Stefano represent the emergent portion of a great strata volcano with a base diameter of about 15-20 km. The eruptive center of the volcano is located on the western part of Ventotene as evidenced also by the north-eastward dipping strike of the volcanic products (BERGOMI *et alii*, 1969).

The volcanic sequence has trachybasalts at its base that was were emplaced in a submarine environment with various flows, whose maximum thickness reaches 50 m. Above these are sandy tuffs, interbedded with layers of pumice and small lapilla, overlayed by a well-cemented tuff. The trachybasalts of Ventotene and S. Stefano have been dated to be about 1.7 and 1.2 million years old respectively (BERGOMI *et alii*, 1969).

Numerous geomorphological features testify to sea level stillstands significantly higher than the present sea level in various areas of the archipelago. This fact is probably due to the interaction between eustatic fluctuation and volcano-tectonic uplift. SEGRE (1956) identifies possible Tyrrhenian deposits at about 50 m on Ponza Island. CARRARA *et alii* (1995) describe lower Pleistocene beach deposits at 240 m (Mount Guardia, Ponza) and marine abrasion platforms from 200 to 270 m (Mount Guardia and Mount Guarniere, Palmarola), from 100 to 120 m (Ponza) and from 45 to 50 m (Ponza and Zannone). At Ventotene there is a marine erosional platform at 25m. Finally, there are beach notches at 3 m on the island of Ponza and an uplifted Holocene beach at about 10 m on Palmarol (CARRARA & DAL PRA, 1992).

The marine areas around the archipelago have been investigated during three high-resolution seismic cruises aboard CNR's R/Vs "Urania" and "Minerva". A Bubble Pulser source was used to aquire analogic data. A pass-band filter between 300 and 2000 Hz and an automatic gain control (AGC) for amplitude recovery were used in the acquisition. The survey was positioned with GPS; DGPS (Differential Global Positioning System) was used in only one survey. According to seismic source and positioning characteristics, the seismic records gave a vertical resolution of about one meter, while the error in the positioning can be assumed to be from 10 to 30 meters.

The survey was carried out on profiles perpendicular to the coast, spaced on average, every 1.5 km and tied by profiles parallel to the coast. During the acquisition of seismic profiles, echo soundings were also registered. On the northern side of Ponza Island, some Side Scan Sonar profiles were also acquired. In all, around 300 km of seismic profiles were acquired in an area of about 280 square km (Fig.7).

In the vicinity of the islands of Ponza and Palmarola, two gravity cores were also collected.

Submerged depositional terraces (SDTs) with good lateral continuity have been found both in the western islands (already partially described in CHIOCCI & ORLANDO, 1996) and the eastern ones (here analyzed for the first time). The presence of a SDT was found even around Botte Rock, an isolated structure located 7 miles SE off Ponza.

WESTERN PONTINE ISLANDS

Fig. 2 - *Three-dimensional view from the SW (as seen from above in the upper part and from the side in the lower part) of the western group of the Pontine archipelago made up of the islands of Palmarola, Ponza and Zannone and Botte Rock. The view shows that the three islands represent the apex of one large morphologic high that does not include Botte Rock, and that Ponza's southern slope is scoured by numerous canyons. A submerged depositional terrace is well visible at a shallow depth on the eastern side of the island of Palmarola (see Fig. 4).*

Fig. 3 - *Seismic profile off Ponza's southeastern coast (see Fig. 7 for location). One can observe a SDT with a prograding internal structure, a terrace edge at about 120 m and a thickness of up to 34 m. Externally, the SDT shows a very regular geometry with the terrace top sloping about 1° and a frontal slope of about 10°. The internal foresets show a similar steep slope and are therefore at the limit of seismic detection capabilities. The similarity between the dip of the foresets and that of the frontal slope confirms the depositional and non-erosive nature of the latter. The strong ringing of the sea floor reflection usually prevents a detailed resolution of the very upper part of the deposits. However, a part of the main SDT, it is possible to detect a more recent, finelly clino-stratified phase characterized by a maximum thickness of about 15 m, slightly sloping foresets and possible depositional edge at a depth of 86 m.*

Fig. 4 - *Seismic section normal to the isobaths on the eastern side of the Palmarola Island (after* CHIOCCI & ORLANDO*, 1996). One can see two depositional terraces located at depths of 24 and 110m (edge depths); they are similar in form and dimension and separated by a morphologic high which might possibly correspond to a minor volcanic centre. This feature appears to have acted as a dam for the deposits making up the upper depositional terrace, and probably acted as a base for the small prograding wedge overlying the deeper depositional terrace as well. The deeper terrace is continuously observable in the entire archipelago, while the shallower terrace is found only on the eastern side of Palmarola. Its presence is observable even from the perspective view of Fig. 2 and from the isobath trend of Fig.7. The shallower terrace is made up of two depositional bodies. Very steep stratification characterises the younger and more developed body with an increase in the slope of the recentmost foresets. The older body is less developed and with only slightly dipping stratification. The top of the upper submerged depositional terrace shows a slight apparent counter-slope, probably due to the difference between the profile direction and the maximum slope direction of the terrace.*

Even the deep terrace is made up of at least two distinct progradational episodes. The geometry of the foresets is not easily identifiable but appears to be rather complex. There is a V-shaped feature, that probably represents the product of the channeled submarine flows like those described in CHIOCCI & NORMAK *(1991). Even in this case, the slope of the most recent foresets matches that of the frontal slope.*

Finally, it is also possible to observe an even older progradational phase, buried by the just described depositional terrace; it created a depositional edge at 220 m and is completely obliterated by the subsequent sedimentation. In the lower part of the figure, the line-drawing of the profile is shown without vertical exaggeration. The depositional terrace here, although less pronounced with respect to its representation in Fig.4, is a very prominent morphologic feature on the sea floor.

Fig. 5 - *Seismic profile located about 2 km southeast of the former profile (after* CHIOCCI & ORLANDO*, 1996). The profile shows the same deeper SDT of the seismic profile in Fig. 4 but it runs along a direction not exactly parallel to the dip (see Fig. 7 for location of the profile). For this reason, the seismic horizons are less steep and it is*

therefore possible to depict the internal structure of the depositional body in detail. The SDT rests on a very uneven substrate while it shows a smooth flat top located at an average depth of 105-110m. The internal structure shows the complex composition of the SDT, made up of several depositional phases bounded by erosional surfaces. That is, it shows erosional surfaces that testify brief interruptions in the building-up of the deposit. In the figure there are at least three main growth periods that are separated by erosional disconformities. The first two phases overlie each other and are located more coastward with respect to the more recent phase. The two older phases appear to be truncated frontally by a reactivation surface that is concordant with the stratification of the most recent phase, which shows progradational concave foresets with well developed bottomsets. A gravity core sample (87 cm long) of the sea floor was taken along the seismic profile at a depth of 105 m (see the following picture).

Fig. 6 - *Marine sediment core collected by a 500 kg Kullemberg corer in the eastern part of Palmarola Island (for location, see Fig.5). The 87 cm core is predominantly composed of bioclastic medium sands with abundant silt. The upper part consists of well-sorted medium sands while the base is more silty* (CIOLLI, *1995*)*. There is a gravelly layer at about 40 cm from the bottom, mainly made up of shell debris. Ostracodes, pteropods and briozoa have been identified in the sediments in addition to shell fragments of benthic organisms (in particular, gastropods) up to several centimeters long. In the upper part of the core, vegetal filaments are also abundant. The following analyses were made on the core in the positions indicated on the schematicl log:*

*1) Microscope analysis of the vegetable filaments present at 20 cm above the bottom. The fibers were attributed to the marine Phanerogam plant by comparing them to actual rhizomes of Posidonia Oceanica (*L. ARGENTI*, personal communication).*

*2) Qualitative analysis of the forams present at 10-20 cm points out a coastal environment assemblage (*M.G. CARBONI & C. VIOTTI*, personal communication).*

*3) Analysis of the macrofauna present at 38-44 cm below the sea floor indicates an upper circalittoral environment, as evidenced by shell debris with reduced taxonomic differences and elaborate forms. On the contrary, the same analysis at 60-70 cm and 81-87 cm below the sea floor shows a high-energy environment (infralittoral to supralittoral) supported by a high taxonomic diversification (more than 70 different species) probably tied to the presence of algae carpets or meadows of marine Phanerogams (*S. MONARI*, personal communication).*

4) 14C AMS dating of the vegetable fibers described in point 1). The conventional age obtained was 1,350+/-50 years (Beta 86804 sample, 13C /12C, measured age 1,230+/-50, conventional age 1,350+/-50). The dating *showed a rather young age with respect to expectations. In the present eustatic conditions (stable for the last 6,000 years), Phanerogam marine plants don't live below -40 m depth. Therefore, in order to explain such a recent age of the vegetable remains found in the core one must assume that the Phanerogam remains were transferred from the submerged beach environment down to a depth of 110 m and a distance of almost 3 km. The remains would have then been buried by about 20 cm of sand in an insular environment that, during high stand periods, was isolated from the Latium continental shelf and therefore, from the sediments coming from the peninsula. Thus, the age given by radiocarbon dating is difficult to explain, and is further complicated by the discrepancy with respect to the dating by the 230Th done just 20cm below (see next point).*

*5) 230Th dating done on small esacorals (Caryophyllia clavus) present at 38-44 cm from the top of the core (*M. VOLTAGGIO & M. BRANCA*, personal communication). The age was 7,800+/- 350 years (activity ratio:* $^{230}Th/^{234}U=0.069+/-0.00$; $^{234}U/^{238}U=1.263+/-0.056$; $^{230}Th=>40$; $Uppm=4.211+/-0.133$*). The age indicates a deposition occurring during the end of the last sea level rise, consistent with the analytical results in points 2) and 3), i.e. infralittoral material at a depth of -110 m indicating a sea level lower than the present one.*

Based on the aforementioned results, the deepest part of the core (below 40 cm) can be considered as sedimented in a high-energy inner shelf environment, while the most recent deposit was sedimented in an outer shelf environment similar to the actual one (the core was collected at a depth of 110m). According to this interpretation, the well-sorted layer of shell debris that lies at a depth of 40 cm can be considered as a transgressive lag. The lag, which marks an abrupt change between the overlying and underlying deposits, can be indicative of a sudden high-energy period of sedimentation, as shown by the burial of benthic organisms in living positions. It is possible that this episode al so brought with it a partial erosion of the underlying deposits. According to the 230Th dating, this episode should have occurred in the last phase of Versilian transgression. A more thorough reconstruction of the evolution of the depositional environment based on these data is reported in CHIOCCI & ORLANDO (1996).

Fig. 7- *Planimetric distribution and depth diagrams of submerged depositional terraces around the western section of the Pontine archipelago. The seismic profile available for study (subtle tracts) and the profiles shown in the figures of this article (marked tracts) are schematically represented.*

The SDT develops with high-continuity at constant depth, parallel to the coast on the flank of the volcanic complex. At the southern and western ends of Palmarola Island, the terrace is not present because of the rough topography and steep slope of the bedrock which is also scoured by numerous canyons that drain directly toward the abyssal plane.

The depth of the SDT is rather constant, with well-defined trends in various areas.

On the southern flank, the terrace develops for about 23 km between Zannone and Ponza, at first at an almost constant depth of 110m, then slightly deeper. Between Ponza and Palmarola the SDT is interrupted by several canyons and is poorly defined. For this reason it was not mapped. At the western end of the southern side of the archipelago (the first 10 km of the lower diagram) the terrace is poorly defined and rather unclear; it is only possible to identify a deposit whose edge is located at a constant depth of about 150 m.

On the northern flank it was possible to reconstruct the SDT, which develops for 18 km with great lateral continuity and constancy of characteristics, in great detail (the core described in Fig. 6 belongs to this deposit). The vertical distribution of the terrace on the northern slope of the archipelago appears very interesting and rich of neotectonic information (regarding this see CHIOCCI & ORLANDO*, 1992). In fact, while the geometry and thickness of the terrace remain similar for the entire Palmarola-Ponza-Zannone alignment, the depth of the edge and of the other depositional parameters gradually increases from 70 m to 105 m moving from west to southeast. The deepening occurs extremely gradually with a gradient of 2 m/km. Under the hypothesis of a formation of the deposit at a constant depth during the last eustatic lowstand, this value indicates an uplift rate of about 2.5 mm/year at the western end (Island of Palmarola) of the Zannone-Ponza-Palmarola alignment. This value is in surprising agreement with the uplift rate values of Palmarola Island hypothesized by* CARRARA & DAI PRA *(1992) based on totally different data and considerations (height above sea-level of an uplifted Holocene beach on the western side of the island).*

It is notable that the depth trends of the northern and southern sides of the archipelago do not agree. Yet while the northern submerged depositional terrace shows a constant gradient, the southern SDT varies in an inconsistent manner as a result of the bedrock morphology and presence of canyons. Furthermore, at the southern and western ends of the island of Ponza (the left part of the lower diagram) the southern terrace has an irregular direction and rather inconsistent characteristics.

Fig. 8- *Bathymetric profiles acquired along a zig-zag course (C/C: course change) southeast of the seaway between Ponza and Zannone Islands and the Island of Zannone itself (from* CHIOCCI & ORLANDO, 1996). *The figure includes 6 transects normal to the coast, spaced at 1200-1500 m intervals, characterized by a very high vertical exaggeration. Even based exclusively on morfobathymetric information, the presence of the SDT is clearly depicted in all of the transects (in the central one the SDT is cut by a canyon).*

EASTERN PONTINE ISLANDS

Figs. 9, 10 and 11 - *Seismic profiles acquired northwest of Venotene Island showing the extreme high lateral variability of the inner structure of this deposit. The three profiles are from the same area and intersect each other (crossing are indicated by arrow marks), depicting the SDT along three slightly different directions (see Fig. 15 for the location).*

The section in figure 9 investigates the terrace along the maximum dip direction. A SDT with complex external and internal structure rests upon a bedrock sloping 4-5°. It is possible to define an overall start of the SDT deposit at a depth of 140-145 m and the main edge at about 180 m. The external morphology is quite irregular and there are at least 3 slope breaks located at about 155, 165 and 180 m depth, corresponding to the edges formed in 3 depositional phases on the construction of the SDT. It is actually possible to define at least four distinct prograding depositional phases (shown in the figure) that caused the vertical aggradation of the deposit with progressive landward migration of the depocenters (retrogradational stacking pattern). Inside the bodies the reflectors show high-angle slope, dipping even more than the frontal slope which is about 8°. One can observe that it would be possible to add a fifth, more recent phase, with an edge of about 68 m (n. 5 in the figure), to the four retrogradational phases described above. This forms a quite thin wedge (maximum 7-8 m) whose internal structure is not seismically detectable. From the comparison of the three profiles, one can note how even at a small distance, the reciprocal relationships and the characteristics of the four depositional bodies vary significantly, especially as far as the morphological expression of the deposit is concerned.

Fig. 12 - *Seismic section roughly parallel to the northern coast of Ventotene Island (see Fig. 15 for location). The profile shows the SDT in a direction almost parallel to its axis. One can note how the acoustically soundless bedrock shows a very evident erosive character and complex morphology that is flattened out by the first phases of sedimentation. Along the direction of the profile one can observe that the thicknesses among the diverse sub-units which compose the SDT vary gradually. The SDT is, in fact, composed on the left by at least 3 distinct sedimentary phases that on the right are reduced to 2 that can be seismically resolved. In a parallel direction to the axis of the SDT, the internal reflections are not very evident. Of note, at the extreme left of the profile is the visible intersection between the reflection generated by the frontal slope of the terrace and the horizontal ones coming from the bed on which the SDT lies (regarding this effect, see* CHIOCCI, *same volume).*

Fig. 13 - *Seismic section perpendicular to the isobaths on the eastern side of Ventotene Island (for location, see Fig.15). One can observe a SDT with a very regular external morphology but a rather complex inner structure, formed by the overlaying of several progradational phases which caused both the vertical aggradation and the frontal progradation of the deposit on an erosional substratum with an irregular morphology. The edge of the SDT in this area is found at a depth of 130 m, i.e. the minimum depth found around the islands of Ventotene and S. Stefano. One can note how the overall external morphology caused by the first depositional phase is identical to that of the last phase, and even the areas of the two phases are similar (and so are the three-dimensional hypothetical volumes). Therefore, the last phase produced a comprehensive depositional body of almost double thickness spread out across a much greater depth interval.*

Fig. 14 - *Seismic profile parallel to the slope off the southern coast of Ventotene (for location, see Fig.15). One can observe a morphologic situation that is different from the preceding ones. The morphology of the acoustic bedrock is quite complex. While retaining its erosive character, the substrate is actually shaped in steps, in which polycyclic SDTs rest. The deepest terrace (with an edge at 210 m) appears to be the oldest; thereafter one can first see two phases with a strong horizontal development which create an edge at 160 m (partially buried); above them another prograding wedge with an edge at 145 m develops. A later depositional phase (poorly resolved seismically and not shown*

in the figure) is found at a shallower depth than those of the oldest phases (edge at 120 m). The overlapping of the prograding depositional bodies has caused an articulated morphology of the sea floor. The two oldest phases show layers sloping more than those of the most recent phases which formed on less steep morphologies.

Fig. 15 - *Planimetric distribution and depth diagram of the submerged depositional terrace around the eastern section of the Pontine Archipelago. The SDT is well depicted in all of the seismic profiles taken except on the western side of the volcanic complex (where the crater is probably located and isobaths have a very uneven trend). On the southern side, the main edge of the terrace shows a depth of about 160 m, while in the west, the SDT is rather irregular and made up of several bodies in a retrogradational stacking pattern. In the eastern zone, the SDT has more regular morphologies and a stacking pattern that is essentially aggradational. On the southern side, the terrace is present at a shallower depth (around 130 m) and appears to deepen proceeding from east to west, towards the caldera area, with a difference of 30-50 meters.*

Fig. 16 - *Side Scan Sonar record (acoustic image of the sea floor in plan view) on an oblique route with respect to the SDT on the northern side of the Zannone-Ponza-Palmarola alignment. The amplitude of the zone surveyed by the side scan sonar is 400 x 900 m. The profile proceeds from the greatest depths (left) towards the shallowest (right). Even though there are not great differences in backscatter, it is possible to clearly distinguish the frontal slope of the SDT (diagonal band at the center of the image) due to the different inclination of the sea floor with respect to the seismic waves or to variations in lithology. On can observe how both the depositional edge (right limit of the band) and the slope break at the base of the SDT (left limit of the band) are extremely straight.*

The SDT was always ill-defined in side-scan sonographs; however, in all of the cases in which it was somehow depicted, it appeared to be straight and often the major reflective element was the foot of the frontal slope.

CONCLUSIONS

In general, one can affirm that terrace morphologies are always present on the steep sides of the Pontine volcanic complexes, and that they are made up of sedimentary wedges 20-40 meters thick. SDTs represent the unique sedimentary units present on the volcanic bedrock and generally account for many depositional cycles. The materials which make them up (based on the acoustic facies and on the cores taken in the area) are sandy sediments with abundant bioclastic fraction. The nature of the materials and the fact that SDTs are also present on the flanks of completely isolated structures such as Botte Rock (that is totally isolated from the continental platform even during low stand), points out that the SDTs are essentially composed of intra-basinal sediments.

On average, the SDTs have an extreme high lateral continuity, interrupted only by canyons (where present) and rather gradual lateral variations in depth (a few $^{0}/_{00}$). The morphologic expression produced by the SDTs on the bathymetry is always very evident. For this reason, it is possible to detail the planimetric development and depth of SDTs with bathymetric profiles (which are more economical and easier to achieve) once the depositional nature of a submerged terrace morphology is identified with seismic profiles.

The SDTs around the Pontine Islands show a development transversal to the isobates of about 2 km and a lateral continuity that reaches about 40 km (in the case of the southern side of the western Pontines). The internal structure of the SDTs is always progradational with a strong dip of the foresets (often greater than 10°) that normally matches that of the frontal slope, pointing out the non-erosive nature of the latter. Erosional features were sometimes observed inside the deposit and are likely to represent reactivation surfaces. The SDTs of the Pontine Islands have a high variability in their external form and a very complex internal structure that is often polycyclic. In general, the more recent terraces are shallower than the older ones, giving to the whole deposit a retrogradational stacking pattern. The similarity among the deep SDTs and a rather shallow SDT found on Palmarola's east coast (Fig.4), in addition to the results of the analysis done on the cores (Fig.6), allow one to interpret the SDTs of the Pontine Islands as sedimentary depositional wedges, formed below sea level during sea level low stands. A detailed discussion on these aspects is found in Chiocci & Orlando (1996), where the neo-tectonic implications derived from the study of the SDTs are also examined - which indicate a relative uplift of the western end of the Palmarola-Ponza-Zannone alignment.

The comparison between SDTs present in the different parts of the Pontine archipelago offer interesting considerations. In the western sector, the islands of Zannone, Ponza and Palmarola present SDTs generally composed by one or at most two depositional cycles, which develop parallel to the isobaths at a depth which is constant or varies very gradually. On the contrary, the SDTs around the eastern islands of Ventotene and S. Stefano are generally found at greater depths (edges beyond 200 m) and are composed of numerous overlapping depositional episodes (up to 6), varying greatly in morphology and in depth, even within small distances.

The great depth and the multiplicity of the depositional cycles in the Eastern Pontines give evidence to a high subsidence of the volcanic apparatus of Ventotene-S. Stefano, contrasting to the stability or the uplift of the western apparatus. Under the hypothesis that the SDTs were formed during glacial sea level lowtands, the depth of the edges around the islands of Ventotene and S. Stefano is absolutely incompatible even with the deepest negative pulses experienced by the sea level during the Pleistocene glaciations. On the contrary, in the western islands, the depths of the edges of the SDTs is fairly compatible with the depths reached during glacial-eustatic lowstands and, in the case of the extreme west of the Zannone-Ponza-Palmarola alignment, one can find even shallower depths.

On the other hand, the fact that the eastern complex (Ventotene and S. Stefano) is made up entirely of subaerial volcanites, while the western one is made up of volcanites emplaced either in environments entirely below the sea level (Palmarola) or first below the sea level and then subaerial (Ponza), is in agreement with the proposed rise and fall tendencies of the two volcanic structures.

Even the relative inconsistency of the depths at which the SDTs are found around Ventotene and S.Stefano could be ascribed to difference in subsidence affecting the apparatus. Therefore, given that phenomena of differential vertical movements were also shown in the western sector, it is necessary to verify if other potentially influential factors could have possibly interfered with the structure of the SDT. Among these possibilities, the most important one could be the different morphology of the apparata. In fact, on one hand there is the eastern subconic volcanic complex, with strong variations in the flank slope and the exposition to storms. On the other hand there is a western complex with more regular and constant morphology, stretched out in ridge form, with an unchanging or very gradually changing exposure to high-energy storms.

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Occurrence of submerged depositional terraces off Sorrento Peninsula (Campania - Southern Italy)

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INTRODUCTION

The Sorrento Peninsula is situated transversally to the Apennines Chain and is mainly constituted by mesozoic carbonatic units and in the western sector by transgressive siliciclastic units, Miocene in age (PERRONE, 1988).

Since as early as the Pliocene the Peninsula probably appeared as a promontory extended ortogonally to the chain and raised about one hundred meters above sea level, while the adiacent structural depressions (Napoli and Salerno Gulf) were originally scarcely outlined and poorly prolonged to the east (BRANCACCIO *et alii*, 1981, CINQUE, 1986).

During the Lower Pleistocene the splitting of the carbonatic units started, with considerable uplifting of the blocks in correspondence to the peninsula and lowering in the Sele and Campania Plains, which were subsequently filled up by clastic deposits. An erosive surface, the so called "Paleosuperficie", formed during the Pliocene, was dislocated in Peninsula to a height of 1400 m.

As a consequence of the enlargement of the Sele and Campana Plains, the coastal sectors of the Peninsula were dissected and submerged. A promontory with decreasing altitude and wideness towards the west was outlined, bounded by faults escarpement and on its cliffs remain traces of recent sea level changes.

Several ancient shoreline traces have been identified and interpreted (CINQUE & ROMANO, 1990): the occurrence of paleoshoreline features on the structural cliffs and relative to sealevel stillstand former to the last interglacial period should prove that the last phases of tectonic fragmentation occurred no later than the Middle Pleistocene; moreover a general stability seems to have characterized the whole Peninsula for the last 125.000 years, since the Eutyrrhenian paleoshorelines have the same elevation above sea-level (+7.4 m).

On the contrary, vertical movements have been affecting the adiacent structural depressions, the Sele and Campana Plains: in the first, strand units relative to the isotopic stage 5e and 5c, are found respectively at 25 and 13 meters above sea level (AMATO *et alii*, 1991), while in the second and exactly in the Sarno Plain, similar units have been identified in borehole about 20 meters below sea level (BRANCACCIO *et alii*, 1991).

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The two margins of the Sorrento Peninsula are noticeably different even in the submarine domain: in fact the northern continental shelf is wide, mostly horizontal and its edge is located at 150 m bsl (PESCATORE & SENATORE, 1988); the shelf on the southern side is generally steep, narrow (no more than 4 km wide), and practically disappears in correspondence of Punta Campanella and Capo Sottile. In this sector the shelf edge is structurally defined by a fault cliff, in correspondence of a tectonical regional feature, which exposes Mesozoic carbonate units (SACCHI *et alii*, 1994).

Several orders of submerged terraces have been recognized all around the shelf by CINQUE & PUTIGNANO, 1992, through ecosounder survey and through geomorphological observations down to 35 m bsl. They identified erosional features often policiclic in origin and depositional features occurring in correspondence to small depocentres.

The submerged depositional terraces (TDS) reported in this paper, were identified south-west of Capo di Massa, west of Punta Campanella and in the proximity of Li Galli Islands (Figs.2 and 5) and are found between 35/40 m and 125 m below sea level.

It is generally observed that they rest on erosive surfaces cut into the acoustic substratum, composed of carbonatic Mesozoic units, while those located around Li Galli develop on a sedimentary unit probably Pleistocene in age.

Fig. 1 - *Location of the study area. Isobath are in metres.*

DATA COLLECTION AND ANALYSIS

We base this note on data collected during two oceanographic cruises organized by the Istituto di Ricerca Geomare sud and the Dipartimento di Geologia e Geodesia of Palermo University. During the 1995 cruise, Sparker 1kJ and Subbottom 3.5 kHz were recorded; during 1996 cruise, 60 nm of multichannel seismic profiles were acquired between Bocca Piccola and Positano. The configuration system consisted of a watergun source SSI 15 by 10 c.i. and a 12 channel Teledyne seismic streamer with idrophones spaced at 6.250 m. The acquisition was carried out with a shot interval of 3 sec and a recording time variable between 0.5 and 2 seconds. Part of the system has been provided by OGS, Trieste and IGM, Bologna.

Ship positioning was controlled by GPS system, provided by R/V Urania and a WGS '84 datum was utilized; bathymetric data, acquired by bi-frequency scientific ecosounder have been filtered and processed by applying triangolation algorithm.

Seismic data however are still in the course of being processed: watergun seismic lines, here shown in Figs. 3, 4 and 6, refer to digital signals recorded on the first channel.

Fig. 2 - *Bathymetric map and areal distribution of Submerged Depositional Terraces in the sector off Capo di Massa- Punta Campanella. Bold lines represent parts of watergun seismic profiles BP42 and BP2, shown in Figs. 3 and 4.*

In this area two groups of composit TDS have been identified. The northernmost, the Vervece terrace, is formed by two partially overlapping depositional bodies in backstepping. The lower unit is expansive and develops for an overall length of 4 km with a variable wideness between 0.6 and 1.3 km. In plan the unit shows a concavo-convex trend, which is wider on the outskirts of the inlet and narrower on the convex tract, which curves around the Vervece rock (outcropping of acoustic substratum). The edge of the unit gently dips towards south-west and passes from a depth of 78 to 85 m where it gently closes; it probaby proceeds towards north-east in a sector where no data have been acquired. The upper unit lies in proximity of an inlet south of Capo di Massa and continues around the Vervece for 2.5 km, dipping toward south-west as well (the offlap-break of the unit passes from -40 m to -60 m). Towards the north-east it becomes narrower on the outskirts of Capo di Massa promontory and at 35 m of depth is cutted by an erosive surface; towards south-west it closes probably because of the deepening of its downlap surface to depths not compatible with its formation.

Proceeding southward, at 60-70 m of depth, a wide erosional surface extends, incised in the acoustic substratum and represents a threshold, structurally controlled, between the Sorrento and the Amalfi coast.

On the southern side of the erosional surface, westward of Punta Campanella a second composit TDS has been *identified, consisting of three partially overlapping bodies and showing a retrogradational architecture.*

Likewise the Vervece terrace, from the lower to the upper body, length, width and thickness decrease; their orientation in space changes as well, trending along the isobaths untill they are subparallel to the present-day coastline. Respective offlap-breaks occur at -95, -85 and -60 m of depht.

The lower and the middle bodies overlap and both open in correspondence of -80 meters isobath. Their irregular trending seems to be the expression of the rough morphology of the basement they lie on. The west closure has not been identified while eastward it closes over the Punta Campanella promontory. The upper body, small in size, develops in a bathymetric range of -50 and -70 m and takes up a concave area between the Bocca Piccola erosional surface and Punta Campanella promontory; it is situated slightly to the rear of the lower bodies and, only close to the coast, it directly laps over the more ancient body (see Fig.4).

Fig. 3 - *The watergun seismic line BP42, recorded south-west of Capo di Massa (for location see Fig.2): the Vervece terrace consists of two bodies partially overlapping, with a retrogradational pattern; both open on an erosive surface incised in the acoustic substratum.*

The lower body progrades with oblique reflectors, which then become sigmoidal outwards and close at 95 m of depth in downlap. A thin layer of sub-horizontal retrograding reflectors bounds the lower body at the top and onlaps the acoustic substratum. This layer represents the base on which the upper body downlaps. The internal geometries of the upper body are similar to the lower and consist in reflectors which close at 50-65 m. The toplap surface shows a gradient of about 3% , but its relation with the seafloor is not clear, due to the masking effect of the seafloor ringing.

Fig. 4 - *The watergun BP2 seismic line shows the depositional terrace located westward of Punta Campanella. Close to the coast the terrace consists of two depositional units in backstepping, which lie on an erosive and irregular surface, cut in the acoustic substratum. The lower unit is rather wide and thick (30 msec) and is composed of oblique reflections which become sigmoidal outwards and close in downlap at approximately 100/110 m. The upper unit, which shows a max thickness of 15 msec, opens on the acoustic substratum and develops on the toplap surface of the underlyng body. The prograding reflectors are initially obliquous and not continuous and become stronger but less pending reflections upwards. The offlap break is located at 60 m of depth (this section is not morphologically clear, because of the tracking of the line in respect to the body). The unit closes in downlap over the lower body and presents an aggradation whose thickness is not measurable because of the ringing of the bottom.*

Fig. 5 - *Bathymetric map of the southern sector off Sorrento Peninsula and areal distribution of the submerged depositional terraces: note the shape of the small semicircular basin facing Positano. Isobaths initially subparallel to the coastline, below -50 m become perpendicular, due to the presence of many structural highs, cropping out of the bottom or above the sea level (Li Galli) and whose southern flank is a fault scarp that borders the continental slope.*

Bold lines represent tracts of G13 and C4 seismic lines of Figs.6 and 7.

North of Li Galli Islands a submerged depositional terrace is formed by two juxtaposed prograding units (Fig.6): the upper body develops in a bathymetric range of 50-95 m with an offlap break located at - 65/70 m and trends perpendicularly to the coast line. Laterally it closes over the acoustic substratum, while it probably proceeds towards north-east following the bathymetry, but there does not seem to be a corresponding depositional terrace on the opposite side of the basin.

A second TDS has been identified east of Li Galli Islands, in a small area within the bathymetric range of 90-125 m. It abruptly ends in corrispondence to the shelf break due to the sudden sea floor deepening; northwestward it seems to gently close with a blander and more regular slope.

Fig. 6 - *Seismic line Watergun G13, (see location in Fig.5), showing the terrace located north of Li Galli. It is composed of two juxtaposed depositional units, the more ancient of which progrades with sigmoidal reflectors and is clearly eroded on the top (W surface, identified on the Subbottom 3.5 kHz). The younger unit lays on the morphological step created by the foreset of the underlying body* (TRINCARDI & FIELD, 1991) *and progrades down to 65/70 m of depht with caothic and discontinuous reflections and closes at about 90 m of depth. The W surface, which deeply erodes the ancient body, bounds the top of the younger one as well,with a quite steep dip.*

The terrace as a whole has a component of aggradation in the bottomset and downlaps on a sedimentary unit whose stratigraphic position is uncertain.

The distinctive seismic facies of the youngest body can be related to the high percentage of bio- and litoclasts avai-

lable even far off the coast, from the many calcareous outcrops and biogenic sediments (AA.VV., 1995).

Fig. 7 - *Sparker line 1 kJ C4 trends east-west and shows the shape of the small basin and the stratigraphic relations among sedimentary units inside. A submerged depositional terrace develops on the western side of the teather-shaped basin, level with the islands of Li Galli (Fig.5). The seismic line has been processed with graphic software in order to reduce vertical exageration: in this case the shape of the terrace and the steepness of the prograding reflectors is exagerated by a factor two.*

In the section a mesozoic substratum (unit M) is topped at intervals by strips of a Pliocene unconformity (PS); unit P is relative to a phase of infilling (probably Lower - Middle Pleistocene in age) interrupted by periods of relative falling of sea level (channels incision); W surface, which has an erosive character by the basin margin but becomes concordant at the depht of 125-130 m at its center, forms the base of the T unit (Eastern Li Galli terrace) and bounds at the top the Northern Li Galli terrace. The W surface, which is often covered by the acoustic ringing of the sea floor, has been recognized on the Subbottom profiler 3.5 kHz records.

The Eastern Li Galli terrace develops between 80 and 125 m of depth and reaches a thickness of 30 msec; it could represent the sedimentation wedge relative to the last sea level lowstand (18 ka).

CONCLUSIONS

Submerged Depositional Terraces in the Sorrento Peninsula generally present short lateral continuity; their areal distribution seems to be related to the acoustic substratum pattern.

The TDS of the northern and southern margins of the Sorrento Peninsula are significantly different.

The terraces of Vervece and Punta Campanella lie on the acoustic substratum and are organized in backstepping. Their lowermost unit is wider and thicker compared to the uppermost which are generally smaller, well preserved and develop parallel to the present-day coastline.

These indications strongly suggest that in correspondence of morphological and stable sectors (as Bocca Piccola morpho-structural high), terraces develop only when accomodation is available (together with availability of sediment), i.e. when relative sea level is increasing. This is probably the case of Vervece and Punta Campanella terraces and their bathymetric range could confirm this hypothesis. In particular they could have formed during the last sea level rise, post 18 ka, explaining the good preservation. During the previous phase of falling sea level, formation of erosive features prevailed, with abrasion of the acoustic substratum and removal of older depositional bodies (infact neither buried terraces nor reworked ones has been recognized in the stratigraphic record of this area).

Both northern and eastern Li Galli terraces occur on the border of a small epicontinental basin and overlie a Pleistocene sedimentary unit. They are respectively overlied and underlied by an unconformity (W surface), which probably represents the last period of epicontinental morphoevolution and from a sequence stratigraphic point of view corresponds to the boundary of the Late Quaternary sequence. The northern terrace is partially eroded at the top, while the eastern terrace appears to be well preserved.

Considering their stacking patterns, the scarce preservation of the northern Li Galli terrace and its stratigraphic and bathymetric position, the northern and eastern Li Galli terraces could have been formed during the last sealevel drop and the last lowstand respectively . In this case they could represent forced regression deposits.

The acoustic substratum and its roughness determine a control on the areal distribution of the TDS and on their lateral continuity; relative sea level change (i.e. accomodation space) control the bathymetric range of the TDS formation. The possibility of their preservation, as many authors have already pointed out, is aided during increasing relative sea level.

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Submerged depositional terraces in the Gulf of Policastro (Southern Tyrrhenian sea, Italy)

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GEOLOGICAL FRAMEWORK

During two oceanographic cruises in the Gulf of Policastro (S. Tyrrhenian Sea, Italy) in 1989 and 1990 on the vessel 'Bannock' of the Italian National Council for Research (Fig. 1), bathymetric and seismo-acoustic profiles were acquired, for a total distance of 894 nautical miles.

The Gulf of Policastro lies between the western flank of the Calabro-Lucanian segment of the Appennine chain and, to an even greater extent, a stretch of the Tyrrhenian basin (KASTENS *et alii*, 1988; PATACCA *et alii*, 1990). The very recent tectonic events which occurred in this area are revealed by the considerable complexity of the platform-scarp system of this margin (PENNETTA, 1996a).

Strong subsidence, together with distension of the Tyrrhenian basin and considerable uplift of emerged areas, modelled this stretch of margin, characterized by slope ridges (SELLI, 1970), peri-Tyrrhenian basins (SELLI, 1970; FABBRI *et alii*, 1981), canyons, and generally complex depositional patterns (ARGNANI *et alii*, 1989; SARTORI, 1989; DE PIPPO *et alii*, 1996). This development is also the result of large-scale tectonic disjointings, both parallel and at right angles to the margin, more clearcut in the chain areas (PENNETTA, 1996b; DE PIPPO & PENNETTA, 1999).

Study of seismic profiles identified submerged sedimentary bodies near the edge of the continental platform, with external terraces and an internal structure prograding seawards. These bodies formed during the phases of sea level lowering and lowstand during the Last Glacial, and are called here submerged depositional terraces (SDT). They develop along one stretch of the prograding platform between Punta Cirella and Capo Tirone and along another eroding stretch off the mouth of the river Bussento (Fig. 2).

Fig. 1 - *Location of the study area and of profiles.*

Fig. 2 - *Morphological map of Gulf of Policastro, with indication of SDT*

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MORPHOLOGY

The northern portion contains the Sapri slope basin, it is subtended by a generally narrow continental platform about 1 km wide, which sometimes reaches 7.5 km. The platform has high gradients and clearly shows the effects of erosion and structural control, with a well-defined edge between -90 m and -120 m. An SDT running for at least 3.5 km lies off the river Bussento. The continental platform then passes to a scarp affected by gravitational processes and deeply cut by channels, the heads of which tend to increase the generalized retreat of the edge of the platform, due to regressive erosion. The resulting slump deposits thus collect in the Sapri basin, defined to the south and west by submerged slope ridges, which act as sediment collectors (PENNETTA, 1996a).

The southern portion of the study area, from Capo Scalea to Capo Tirone, is characterized by morphostructural highs subtending a quite wide (5-8 km) platform, with small gradients and a gradual edge at a depth of 130-140 m. This portion evolves gradually to the upper scarp, which is generally regular and has a low gradient. The effects of past progradation of the platform are evident in this area. There is an SDT running parallel to the coast for 2.5 km off the stretch between Punta Cirella and Capo Tirone.

In the sub-bottom of the entire stretch of platform, interpretation of acoustic profiles identified a very irregular disconformity surface, probably created by subaerial erosion (Fig. 3). Its maximum depth varies between -90 and -100 m in the eroding stretches and up to -130 m in those with a deeper edge, sometimes prograding. This surface thus probably formed during the Last Glacial (18,000 years B.P.), when the sea level reached its current isobath of -110/120 m (MARANI *et alii*, 1988). This event caused the almost complete emergence of the platform and displaced the old coastline almost to the present-day edge. The marine depositional sequence was thus laid down near the edge of the platform and on the scarp (Figs. 3, 4), with gradually coarser deposits prograding seawards, while pre-existing deposits on the more internal portion were subjected to erosion by exogenic agents. Erosion by watercourses which cut the present-day platform during that period is shown by frequent depressions in the disconformity surface (Fig. 3), interpreted as paleo-riverbeds, with preserved paralic deposits, in their turn buried under thick layers of marine transgressive and highstand sediments (PENNETTA, 1996a). The diachronous erosional surface separating the deposits of the two environments is due to the progressive retreat of the coastline caused by the rise in sea level after the Last Glacial.

Near the edge of the platform, under the angular disconformity surface, are relict deposits prograding seawards, laid down both during the Wurmian regression and during preceding eustatic cycles (Figs. 3, 4). They are overlain by paralic and marine deposits, thickening landwards, as identified by groups of aggrading acoustic reflections (Fig. 4).

SUBMERGED DEPOSITIONAL TERRACES

Both off the river Bussento and between Punta Cirella and Capo Tirone are clino-stratified SDTs, prograding seawards and running parallel to the margin.

Fig. 3 - *Sub-bottom profile, 3.5 KHz, GPL'89-Z3.*

Off the river Bussento (see Fig. 3) is a platform about 2 km wide with a gradient of about 2°. The sub-bottom has an angular disconformity surface at about -90 m, filled with paralic and marine sediments which were laid down during the rise in sea level after the Wurmian Pleniglacial.

There is a relict depositional body near the edge with internal structure prograding seawards, and an external terrace interpreted as an SDT. This body is located at the foot of what is possibly a surface of marine abrasion, at about -85 m, and lower than it by at least 10 m. The SDT is at least 3.5 km long, 20-25 m thick, and is located at a distance of about 150 m from the coastline. Its internal part contains a structure characterized by close-set clinoforms with a gradient of about 4°, interpreted as coarse-grained deposits on the basis of the type of reflection. These clinoforms are truncated upwards by an erosional surface on which lie thin transgressive and highstand deposits.

Fig. 4 - *Sub-bottom profile, 3.5 KHz, GPL'90-E15.*

Off the stretch between Punta Cirella and Capo Tirone (see Fig. 4), at the margin of a platform wider than the preceding one (about 8 km wide) and with a gradient of less than 1°, there is a depositional body extending seawards for about 500 m, at least 2.5 km long, and about 40 m thick. Its internal structure clearly shows clinoforms, with frequency and gradient gradually increasing seawards, attributable to the deposits of the progradational body which were laid down during the fall and lowstand of the sea level during the Wurmian Pleniglacial. This structure may indicate an increase in the sandy fraction of sediments, corresponding to a coarsening-upward trend. The clinoforms are eroded in their upper endings by the marine erosional surface (PENNETTA, 1996a), and the maximum depth of 145 m near the margin correlates it with the rise in sea level after the Last Glacial. This surface separates prograding units at the base, related to sediments deposited during the lowstand, from two aggrading units on the upper surface, related to transgressive and highstand deposits. The prograding deposits of the SDT are bounded at the base by an older erosion surface, identical in structure to the preceding one and interpreted as a surface cutting deposits laid down during eustatic cycles preceding the last one.

CONCLUSIONS

Ongoing morphological and sedimentary processes in the northern and southern portions of the Gulf of Policastro are differentiated thanks to the structural arrangement of the Gulf, which is not indicative of a 'typical passive margin', since the platform-scarp system bordering the Sapri basin (north) is characterized by marked structural control and has been undergoing evident erosion ever since its emplacement. Instead, structural control is less evident in the southern portion, which shows the effects of both progradation and aggradation, facilitated by significant clastic supplies from watercourses (e.g., seasonal rivers) cutting the margin of northern Calabria. In spite of this, and although the present-day morphostructural contexts and probably those of 18,000 years B.P. in the northern and southern portions of the Gulf of Policastro are different, the submerged sedimentary bodies, with their terraced external geometry, show practically the same characteristics, and therefore probably had the same genesis.

Their origin is probably due to sedimentation which occurred during the lowstand of the Last Glacial, during which the sea retreated to the current isobath of -110/120 m on the Eastern Tyrrhenian Margin, displacing the old coastline to depths lower than the present-day edge of the platform and thus favouring the creation of prograding regressive beach deposits.

The absence of sedimentary supplies favoured the laying down of 'forced' regressive prograding deposits, composed of coastal sediments, gradually more recent seawards and generally well preserved on the continental margin which, in the study area, shows features similar to those identified along other such margins (FIELD & TRINCARDI, 1991; TRINCARDI & FIELD, 1991; CORREGGIARI *et alii*, 1992; POSAMENTIER *et alii*, 1992).

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Depositional terraces offshore Capo Suvero (Calabria)

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GEOLOGIC SETTING

The study area is a stretch of continental shelf of the eastern Tyrrhenian margin adjacent to Paola slope basin, the major depocentre of Plio-Quaternary deposits of the entire Tyrrhenian sea (SELLI & FABBRI, 1971). Paola slope basin rests on the transition zone between the bathyal plain that is rapidly subsiding and the uplifting Apennine chain (KASTENS & MASCLE, 1990).

In this kind of geologic setting steep gradients, high sediment yield and intense seismicity favor mass-failure processes and a variety of mass-transport deposits is found both in the slope basin and on the steeper slopes (GALLIGNANI, 1982; CANU & TRINCARDI, 1989).

Slope ridges of tectonic origin provide a barrier for mass-failure deposits, and, for this reason contribute in making Paola basin the main depocenter of Plio-Quaternary sediments (exceeding 4 km) in the Tyrrhenian sea (FABBRI *et alii*, 1981; ARGNANI & TRINCARDI, 1990).

The Plio-Quaternary section, the base of which is a regional unconformity above the Messinian succession or older deposits (SELLI & FABBRI, 1971; FABBRI *et alii*, 1981), comprises three units that accumulated during distinctive phases of the margin evolution (ARGNANI & TRINCARDI, 1990, 1993).

The lower unit is a sediment wedge on the margin of a rift basin; the middle unit deposited during an interval of regional contraction during which the older unit is folded gently and detached from the underlying basement. The slope ridges and the slope basin originated during this interval of compression tectonics. The upper unit records the fill of the basin during quaternary times (ARGNANI & TRINCARDI, 1990, 1993; MONGARDI *et alii*, 1994; TRINCARDI *et alii*, 1995).

On the Calabrian margin, the continental shelf is extremely narrow: about 5 km, North of Capo Suvero, to 10 km South of Capo Suvero offshore the S. Eufemia Gulf. South of the Angitola Canyon the shelf is less than 5 km wide and narrows to even smaller widths near Capo Vaticano. Sediment supply is from short rivers ("fiumare") draining the uplifting Catena Costiera; these rivers have steep profiles, high sediment yield and have a seasonal behavior. The major of these rivers is the Savuto river that reaches the coast just North of Capo Suvero. Seismic profiles and sediment cores from the shelf-edge region near Capo Suvero document the presence of a terraced shelf.

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Morphologic steps can be traced along the bathymetric contour for about 13 km. At the shelf edge three distinctive morphologic-depositional elements can be recognized: an erosional cliff, a wave-cut terrace and a progradational deposit composed of sandy to gravelly sediment. On the shelf, shallower erosional features have more limited extent compared to the one observed in the shelf-edge region but seem to have originated through a similar mechanism.

Depositional and wave cut terraces occur also in the area of Capo Vaticano (CHIOCCI & ORLANDO, this volume). Preliminary seismic-stratigraphic and morphologic studies in the study area were carried out by ULZEGA *et alii* (1981) e CHIOCCI *et alii* (1989).

METHODS

This study summarizes data collected during three seismic and coring cruises by the Istituto di Geologia Marina (IGM), Bologna onboard R/V Bannock. since 1974 (cruise BP74). The study of late-Quaternary deposits relied on the integration of 3,5 kHz and single-channel seismic profiles (using a 1kJ Sparker source fired every 1 or 2 seconds), closely spaced single-beam bathymetric data, side-scan-sonar images. Free-fall and piston cores were collected based on the information provided by the seismic records.

The two most recent cruises, VP 1987 e PB 1991, relied on a LORAN C positioning calibrated with GPS, when available; navigation data are referred to the WGS84 elissoid. During each cruise the Loran data are compared to the GPS and shifted accordingly.

The maps of key seismic horizons (isopach or structural maps) have been produced using depth values expressed in milli-second two-way travel time (TWTT), because a precise assessment of the P wave velocity in the sediments encountered is not available. The bathymetric values, instead, have been transformed in meters assuming a sound velocity of 1500 m/sec in water, after correcting for the depth of the hull-mounted echosounder beneath the ship (5 m).

Fig. 1 - *Bathymetry of Paola Basin showing the location of the study area near Capo Suvero.*

Fig. 2 - *Map of the erosion surface (in msec,* TWTT*), at the base of the transgressive deposits on the shelf. Dotted lines show the bathymetry in meters only for the slope region. Box denotes the area shown in detail in figure 5.*

CHARACTERS OF THE SHELF

An erosion surface at the base of the late-Quaternary deposits can be easily correlated on the shelf; the surface shows an irregular morphology and several erosional reliefs and flatter regions. Some of these features crop out on the modern sea floor or are draped by negligible layers of younger deposits. These relieves influenced sediment dispersal both during the sea-level rise and during the Holocene highstand. Sediment cores recovered rodolithes and other evidences of encrusting algae in the elevated areas and clastic deposits ponded in the lows between them. Most of the cliffs and wave-cut terraces found at varying water depths on the shelf appear laterally continuous; other relieves have a pinnacle shape (Fig. 3) similar to those observed on other margins (CARTER *et alii,* 1982).

The morphology and the spatial distribution of these features reflect the complex dynamic of waves and currents during subsequent phases of the late-Quaternary sea level rise. The larger erosional features elongated parallel to the shelf edge originated likely reflect the action of waves and nearshore currents (Fig. 4). Pinnacle-shaped relieves seem to have originated as erosional remnant on which calcareous algae contribute to cement the superficial sediment *(*TAVIANI & TRINCARDI, 1987*)*. North of Capo Suvero the outer shelf is dissected by the heads of several canyons and gullies and the wave-cut terraces are less common and far less continuous. The shelf area North of the Angitola Canyon is located offshore the only coastal plain in the study area and shows evidence of wave-cut terraces of small vertical relief compared to those found off Capo Suvero.

The erosion surface at the base of the transgressive deposits on the shelf appears poligenic, being originated through subaerial exposure during an interval of sea-level lowstand and was then modified by coastal erosion processes (shoreface retreat) during the late-Quaternary sea level rise; examples of similar erosion surfaces come from other quaternary margins (FARRAN & MALDONADO, 1990; TORRES *et alii*, 1995).

Fig. 3 - *Sub-bottom (3.5 kHz) profile showing erosion morphologies on the shelf, and the late-Quaternary sediments deposited during the subsequent phases of the sea level rise and highstand. Remnant erosion relieves act as morphologic traps for the sediment that accumulate preferentially in the low areas between them. At the shelf edge, a wave-cut flat erosional surface is draped by a thin veneer of marine sediment. More landward, the late-Quaternary sediment wedge shows a regional surface of downlap that can be interpreted as the maximum flooding surface* (MFS*) separating the transgressive deposits below from the highstand deposits above. The profile vertical exaggeration is x11. Profile location is in figure 2.*

Fig. 4 - *Sub-bottom (3.5 kHz) profile showing relict erosion features occurring at varying water depths on the shelf. The erosion unconformity at the base of the transgressive deposits is very irregular and records a phase of subaerial exposure of the shelf although fluvial incised valleys are not present. On the shelf, where the thickness of the transgressive deposits above this surface is not detectable the surface coincides, on seismic profiles, with the overlying maximum flooding surface at the base of the highstand prograding wedge. In this area a sediment wedge occurs below the wave-cut erosion surface at the shelf edge, it is deposit is progradational and characterised by high angle foresets that become gentler seaward. Profile vertical exaggeration is x12. See Fig. 2 for profile location.*

SDT OFFSHORE CAPO SUVERO

Fig. 5 - *Map showing the extent of the depositional terrace (TDS) elongated parallel to the regional bathymetric contour offshore Capo Suvero. Dots mark the locations of the gravity cores used in this study. The map also shows the location of the profiles described in the next figures. Bathymetric contours are in meters; values of the maximum depth of the erosion surface atop the depositional terrace are also reported in meters. This close-up map is reported in Fig. 2.*

The depositional terrace located at the shelf edge offshore Capo Suvero is characterized by internal progradational geometry and is elongated parallel to the bathymetric contour and capped by the regional erosion surface. The maximum thickness of this deposit is about 9 m; its cross-shelf width is, on average, 720 m, and its long-shelf extent is 13 km parallel to the shelf edge; the total area corresponding to the topset of this depositional terrace is about 10 km^2. Immediately landward of the depositional terrace a cliff is 20-30 m high, between 103-133 m (Figs. 4 and 6). The cliff eroded into older sediments has a variable relief on the sea floor and its base is found in water depths that are not constant. On high resolution seismic profiles, the top of the cliff has a very strong acoustic return and is characterized by limited or no penetration of the high-frequency seismic signal.

Fig. 6 - *Sub-bottom (3.5 kHz) profile perpendicular to the margin offshore Capo Suvero. The top of the depositional terrace is marked by a strong acoustic return and its internal acoustic facies is dominantly transparent. Faint reflectors can be traced within the deposit and appear inclined with increasing angles from land seaward, reaching values of as much as 4°. The inclined reflectors have downlap terminations in the seaward direction and appear truncated in the topset region by the regional erosional surface. Younger transgressive and highstand deposits drape the erosion surface and the underlying depositional terrace. Profile vertical exaggeration is x15. See Fig. 5 for profile and core location.*

The cores collected from the depositional terrace (Figs. 6 and 7) recovered coarse bioclastic sand including boreal faunas (such as Pseudoamussium septemradiatum, TAVIANI*, pers. comm.;* TRINCARDI *et alii,* 1987), that can be referred to the last glacial maximum that occurred during the oxygen-isotope Stage 2 (see Fig. 7). Core VP2 (Fig. 6) retrieved at -126 m, from the cliff landward of the depositional terrace recovered bioturbated sandy mud in the upper 120 cm, and increasing amout of coarser sediments, with recurrent biosomes and bioclasts, in the section below. In the upper unit, 107 cm below the core top, there is a level of rodolithes reaching 1 cm in diameter; 80 cm below core top, bioclastic gravel shows a muddy matrix. The uppermost 70 cm of the core consists of bioturbated mud. In slightly deeper waters (-142 m) where the depositional terrace reaches its maximum thickness, core VP1 displays thicker and more complex coarse-grained facies (Fig. 7).

Fig. 7 - *In core* VP1*, from -142 m water depth, we can observe, from the bottom, a muddy bioclastic gravel with layers of shell ash and biosome concentrations* (Glycimeris, Chlamys, Turritella, and Pectinids, TRINCARDI*, com.pers.;* TRINCARDI *et alii, 1987); some layers show mollusc shells with a preferential orientation* (Pseudoamussium septemradiatum, TRINCARDI*, com.pers.) suggestive of the activity of traction currents impinging on the sea floor. Pumice pebbles are scattered at different stratigraphic layers. Between 240 and 260 cm and between 155 and 180 cm downcore two layers of bioclastic gravel are well sorted and rich in lithic clasts) and can be distinguished from the more muddy intervals. The uppermost unit, from core top to cm 100, shows muddy sediment that corresponds to the modern highstand deposition (*MONGARDI*, 1994). See Fig. 5 for core location.*

Fig. 8 - *Detail of the shelf-edge region from the 3.5 kHz profile shown in Fig. 4. Vertical exaggeration is x10. See Fig. 5 for the location of the profile.*

Fig. 9 - *On the 3.5 kHz profile we observe the late-Quaternary erosional surface truncates the top of the depositional terrace and constitutes the base of the transgressive deposits above. Below this regional erosion surface beds are locally deformed by tectonic growth resulting in gentle folding and seaward tilting of the underlying beds. Further seaward, the depositional terrace shows seaward dipping clinoforms that are not affected by tectonic deformation. Profile vertical exaggeration is x23. See Fig. 5 for profile location.*

Fig. 10 - *The southernmost 3.5-kHz profile shows the pinchout of the transgressive deposits showing a marine onlap toward the continental slope and against the uppermost clinoforms of the depositional terrace. The depositional terrace originated during the lowstand of sea level during the Last Glacial Maximum; internal reflectors show a concave upward configuration. Profile vertical exaggeration is x15. See Fig. 5 for profile location.*

CONCLUSIONS

The depositional terraces encountered in the shelf-edge region of the Paola-Basin margin originated through coastal-nearshore processes during the Last Glacial Maximum. The facies characterising these deposits reflects the microtidal regime of the area (modern tide range is < 0,5 m), the occurrence of a narrow and steep shelf (typically 10 km, or less) and the supply of sediment through several relatively-small and equally-important entry points. The region is wave dominated; the effect of waves is maximum during winter storm conditions. The margin around Capo Suvero having a broader continental shelf, shows a well developed and laterally continuous (10 km) depositional terrace at the shelf edge. This terrace marks the position attained by the shoreline during the Last-Glacial Maximum (18-20 kyr BP). This deposit can have originated through the focussing of waves along a coastal outbulge, profided by the cliff that is located immediately landward. The differences in water depth at the base of the terrace, in fact, can best be explained with lateral changes of the amount of wave-driven energy along the coast. Erosion processes at the base of the cliff produced the sediment that was accumulated immediately seaward and resulted in the progradational depositional terrace. This deposit has coarse grain size, prevailing bioclastic component and reduced volume because of the lack of substantial fluvial supplies to this stretch of the coast during lowstand times.

The coarse-grained progradational deposit is therefore a relict deposit of the Last Glacial Maximum and is genetically related to the adjacent erosion cliff. The maximum water depth of the top of the terrace is everywhere greater than that reconstructed by global sea level curves for the Last Glacial Maximum (121 ± 5 m, FAIRBANKS, 1989) but appears consistent with other observations on the eastern Tyrrhenian margin (TRINCARDI & FIELD, 1991). The depositional terrace shows internal seaward-dipping seismic reflectors that correspond to prograding clinoforms. These surfaces appear consistently more inclined moving from the oldest to the youngest. Two sediment cores show that coarser-grained sediments increase upward in each core and seaward from one core to the other. Coastal progradational deposits are in fact typically characterised by negative vertical trends, having coarser grains toward the top.

These resulted from the deposition of high-energy facies, mostly sand or coarser-grained deposits, above the distal and lower-energy facies of the underlying unit (ELLIOT, 1986). The seaward increase in grain size can also be explained considering that transgressive process, occurred during the subsequent sea level rise, has preserved the recentmost deposits, on top of which coarse high-energy sediments are, and has eroded older progradational deposits leaving only their basal fine grain portion.

As observed on other continental margins (CARTER *et alii*, 1982), sediments constituting the depositional terraces are essentially cannibalized from waves eroding morphologic highs on the outer shelf and only to alesser extent reflect the influence of fluvial supplies. River runoff during lowstand conditions was likely captured by slope canyons and gullies and could not reach the outer shelf area offshore Capo Suvero. Incised valleys of fluvial origin are present on the shelf.

The younger terraced features and the smaller-scale progradaional deposits encountered on the shelf in shallower waters likely formed during intervals of still stand or slower sea level rise and record the landward migration of the transgressive shoreline. It has been suggested that the late-Quaternary sea level rise was not monotonic but charachterized by several subsequent "flooding" events separated by still stands (CARTER *et alii*, 1986; ANDERSON & THOMAS, 1991). However, it is unlikely that each interval of increased sea level rise is marked everywhere by the drowning of a morphologic step (CARTER *et alii*, 1986), more data and a better chronologic control are necessary to allow a precise reconstruction of a curve of relative sea level rise in this area and to attempt a comparison to global sea level curves. The drowning of the relict morphologic relieves favors the development of calcareous algae on their tops and consequently enhance processes of early cementation, as testified by the occurrence of rodoliths and encrusting algae found in the cores. The sedimentary cover during the modern sea level highstand (corresponding to the last ca. 5 kyr BP) resulted in a muddy progradational unit that can be correlated in the entire study area and corresponds to the uppermost few cm in all the studied cores. These deposits are everywhere fine-grained and bioturbated and show variable amounts of preserved organic matter.

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Submerged depositional terraces in the Southern S. Eufemia Gulf (Calabria)

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GEOLOGICAL FRAMEWORK AND SURVEY RESULTS

The area studied is the stretch of coast between the mouth of the Angitola River and Cape Cozzo in the southern part of the S. Eufemia Gulf (Fig. 1). The geology of southern-central Calabria is dominated by phillitic and gneiss schist formations. The continuity of the metamorphic formations is interrupted by Cantanzaro and Mesima grabens that are mainly filled with post-orogenic Pleistocene sediments (OGNIBEN, 1973).

Up until the Late Miocene, the whole Calabrian area was affected by a strong uplift associated with the opening of the Tyrrhenian basin that began in Tortonian time (BOSQUET, 1973; PATACCA *et alii*, 1990).

The uplift rate and the extent of the phenomenon are demonstrated by both of the Plio-Calabrian marine terraces, lying up to 600 m above sea level (DAMIANI & PANNUZZI, 1978), and the Late Pleistocene terraces, lying 20-40 m above sea level (COSENTINO & GILOZZI, 1988). The terraces are broken by faults normal to the coast that lift them to different heights along the coast. The uplifting Calabrian Arc and the subsidence of the Tyrrhenian basin generated a high-sedimentation rate and a rather immature morphology of the Calabrian continental margin. In the Paola basin, more than 4500 m of sediments are found above the Messinian (BARONE *et alii*, 1982; TRINCARDI *et alii*, 1995). In the study area, the large structural feature making up the southern boundary of the Catanzaro graben (FINETTI & MORELLI, 1972) hindered the formation of a real continental shelf and the development of a well-defined shelf-break (CHIOCCI *et alii*, 1989). In fact, in the southern part of the S. Eufemia Gulf, the sea floor is very steep, reaching a depth of 200 m at less than 4 km from the coast.

The area was surveyed with high-resolution seismics using the EG&G Uniboom source and analogic data acquisition. In the acquisition phase, the data were filtered using a 400-4000 Hz pass-band filter and amplified with an automatic gain control (AGC). The Loran C system was used for location. Due to the close proximity to the Catanzaro Master Station, notable problems were found in correctly locating the profiles. These problems were partially resolved by an accurate check at the intersection between the profiles.

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A 250 twtt ms time sweep was generally used in analog recording; 500 ms twtt sweep was used only for brief sectors in the outer shelf areas. The area was investigated by 12 profiles shot in dip direction with about 1500m distance between them, and some perpendicular profiles for control. In total, about 100 km of seismic profiles were acquired in an area of 90 km^2.

Two submerged depositional terraces were found in the area. The first one has an edge 40-50 m deep and the second, around 150-170 m deep. While the shallower SDT is poorly preserved and only found in two profiles, the deeper one is well preserved and has a good lateral continuity of more than 15 km Similarly the terraces are only visible in the area between Cape Cozzo and the mouth of the Angitola River, that is, until the morphology of the sea floor becomes extremely steep (more than 2°). The terraces are not present in the rest of the S. Eufemia Gulf where a wide continental shelf (reaching 7 km in width) develops north of the Angitola Canyon, and the gradient of the sea floor smoothes out. Other submerged depositional terraces have been shown by MONGARDI *et alii* (same volume) further north of the S. Eufemia Gulf.

Fig. 1 - *Location of the study area.*

Fig. 2 - *Uniboom seismic profile offshore Pizzo (for location, see Fig. 5). One can observe a submerged depositional terrace on the upper continental slope near a sharp slope break. The sedimentary base on which the SDT rests shows weakly deformed reflectors of high amplitude and high continuity. Within the terrace, numerous foresets, sloping up to 8-10°, concave-up geometry and tangential bases are observed. The topsets are not very visible due to the strong ringing produced by sea floor reflection. The bottomsets gently join the continental slope. The internal reflectors become convex-up only towards the last progradational phases. In every case, the internal structure of the depositional terrace indicates continuity in sedimentation and the entire body seems to have been deposited in one single sedimentary cycle. The slope break above the terrace, although quite sharp, does not seem to be structural in nature as shown by the continuity of the reflectors within the sedimentary substrate. The upper surface has a maximum apparent slope of 2° and a barely defined edge.*

Fig. 3 - *Seismic profile in dip direction, about 4.5 km west of the previous one (see Fig. 5). The right part of the section was acquired with a time sweep of 500 ms to give a more complete picture of the continental margin and of its relationship with the submerged depositional terrace. The terrace seems to be located exactly on a slope break of the sedimentary substrate.*

The latter is characterised by transparent acoustic facies and a notable deformation of the reflectors in its lower part. Instead, in the upper part, there are relatively undeformed reflectors of greater amplitude and continuity. The top of the depositional terrace, however, continues the morphology of the continental shelf, which has a slope of 2° in this zone. In this case, contrary to the previous and the following cases, the edge of the depositional terrace coincides with a pseudo-edge of the continental shelf. The frontal slope of the terrace has an apparent slope of about 20° and its edge abruptly joins the underlying sedimentary substrate. The seismic unit on which the STD rests, which is weakly deformed and represents the last outbuilding phase of the continental margin, is made up of a well-stratified unit off-lapping towards the basin. In this sedimentary substrate, the degree of deformation increases downward and landward, thus suggesting a slow and constant deformation on which the glacio-eustatic Pleistocene oscillations are superimposed, as has been broadly discussed by CHIOCCI & ORLANDO (1995).

It is important to observe that the terrace is absolutely undeformed and that no other depositional bodies similar to the terrace exist either within the margin or on the sea floor at greater depths. The inner structure of the terrace is not visible due to the strong ringing effect of the sea floor reflection.

Fig. 4 - *Seismic profile offshore Vibo Valentina, positioned in between the previous two profiles (see Fig. 5 for location). Here one can see (as in Fig. 2) how the position and the geometry of the depositional terrace are not conditioned at all by the morphology of the pre-existing sea floor due to the fact that the STD is located at a depth greater than the shelf break. One can see how different the morphology and the acoustic facies of the terrace are with respect to the sedimentary basement on which the STD rests. In fact, the basement is well stratified with weakly undulating, high-continuity reflectors dipping basinwards at 7°. The deposits making up the sedimentary substrate were interpreted as sedimented on the continental slope during different phases of sea level lowstand* (CHIOCCI, 1993: CHIOCCI & ORLANDO, 1995).

The terrace deposit has a flat base and a convex top with an acoustically transparent internal facies. A compa-

rison with the contiguous profile of Fig. 2 suggests that actually, reflectors inside the terrace are present but are not seismically depicted because of the great steepness. In fact, the apparent dip of the terrace's frontal slope averages 20°, and the actual dip should be as much as 25° (see CHIOCCI, *this volume). It is possible that the slope of the foresets is similar, and therefore, much greater than the apparent slope of the internal reflectors of the profile in Fig.2 (max. 10°), which probably was not shot exactly in dip direction of the layers. The terrace top has an apparent slope of little more than one degree, comparable with that of the continental shelf in this area, while the frontal slope dips more than the continental slope.*

Note that the profile in the figure was used as an example for the application of the seismic migration procedure in the article "Distortions in STD shape, as depicted in high-resolution profiles, and re-establishment of the correct geometry (seismic migration)" (CHIOCCI, *this volume*).

Fig. 5 - *Distribution of the submerged depositional terrace in the southern S. Eufemia Gulf. The width of the terrace normal to the coast varies from 300 to 800 m (the top alone varies from 100 to 500m). Parallel to the coast, the depositional terrace develops for 10 km between Cape Cozzo and Point Safo and 5 km between Bivona and the southern flank of the Angitola Canyon. Between Point Safo and Bivona the terrace was not seen due to the following: a) a very sharp change in depth of all of the depositional parameters; b) a significant variation in the distance from the shoreline and in the orientation of the SDT; c) a difference within the SDT structure that shows a more developed and homogeneous structure to the east, while to the west, is thinner and more irregular. On the contrary, west of Bivona the trend of the depositional parameters seems to be rather constant.*

Thick lines indicate the location of the seismic profiles reported in figures 2, 3 and 4.

Fig. 6 - *Depth diagram of the submerged depositional terrace in the southern S. Eufemia Gulf.*

The deposit is found in a narrow bathymetric range between 135-150 m and 180-200 m. In particular, the terrace edge is found at a depth between 125 and 160 m. From Cape Cozzo eastwards, there is a gradual diminishing of the terrace depth reaching almost Point Safo. As previously stated, between Point Safo and Bivona there is an abrupt increase in depth of all the depositional parameters and a variation in the characteristics of the SDT (see previous caption) and therefore the two areas were not correlated each other.

CONCLUSIONS

In the southern S. Eufemia Gulf, along a section of coast more than 15 k long, a submerged depositional terrace is present, with rather constant geometry and acoustic facies in the entire area. The terrace rests on a sedimentary basement made up of weakly deformed stratified deposits, probably emplaced during the glacial periods in Late Pleistocene (CHIOCCI & ORLANDO, 1996).

The terrace is found at a depth between 100 and 230 m (the depositional edge, between 125 and 160 m). Such depths are slightly greater than those reached during the last minimum in the eustatic Würm. The terrace is found on the continental slope, at times exactly at the shelf edge, but more often at the foot of a slope-break defining the external limits of the outer shelf. The acoustic facies of the SDT differs significantly from that of the sedimentary substrate on which it rests. It is only sometimes possible to depict the prograding reflectors inside the terrace, as they are poorly resolved seismically, most likely because of their steep slope.

The thickness and bathymetric distribution of the SDT is quite constant in the entire area. It is possible to hypothesize a structural discontinuity offshore Point Safo on the basis of a change in the westward deepening trend that is constantly observed in the western part of the study area. Such a change coincides with a shift of the SDT position more than 1000m offshore. The depth (even if variable) of the SDT is compatible with the minimum eustatic level reached at the end of the last Pleniglacial time. Instead, there is lacking evidence of terraces older and/or deeper created at lowstands older than the last one. This is demonstrated by the fact that the SDT seems to have been emplaced in a single depositional phase and that other SDTs have never been observed. The peculiar setting of the Calabrian arch could justify the above-described features In fact, the constant uplift to which the area was subjected during the entire Pleistocene should have raised the terraces (which were eventually formed during other eustatic minimum) to shallower depths. Thus the cyclical emersion and erosion of the shelf (always as a result of the glacio-eustatic sea level fluctuations) would have forseen a complete removal of the SDTs older than the one formed in the latest cycle.

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Submerged depositional terraces in the Aeolian Islands (Sicily)

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GEOLOGICAL FRAMEWORK

The Aeolian Islands are located on the inner side of the Calabro-Peloritan Arc, and they represent the outer edge of Cefalù and Gioia peri-Tyrrhenian basins (Fig.1). The Aeolian volcanic district consists of seven islands (Alicudi, Filicudi, Salina, Lipari, Vulcano, Panarea and Stromboli) and several seamounts, aligned along a semi-arc structure about 200 km long. This structure is crossed southwards by the Lipari and Vulcano NNW-SSE volcanic alignment, which develops in continuity with the Patti Ridge (FABBRI *et alii*, 1980). The archipelago is bounded to the east by the Stromboli Canyon that originates from the northern Sicilian margin, then cuts the seafloor of Gioia basin with a NE-SW trend and, after a wide turn to the north of Stromboli, flows into the Marsili Basin at a depth of over 3000 m.

The volcanic Aeolian Islands are the summit of polygenetic apparata, whose base is located at 1000-1200 m on the lower slope of Northern Sicily. Extensional and transcurrent regional fault systems are responsible for the location and growth of the Aeolian apparata as well as for the seismicity and volcano-tectonic evolution of this area (DEL PEZZO *et alii*, 1984; NERI *et alii*, 1991; BARBERI *et alii*, 1994). According to the radiometric and stratigraphic data, the subaerial activity of the Aeolian volcanic district falls into the last M.y. (GILLOT & VILLARI, 1980; GILLOT & KELLER, 1993; GILLOT, 1987; FRAZZETTA *et alii*, 1985; SANTO *et alii*,1995). It is chronologically divided into two building stages on the basis of the presence or absence of Late-Quaternary raised marine abrasion terraces. The development of Panarea and Filicudi, and parts of Lipari and Salina, is generally ascribed to a "pre-erosional" stage (lower-middle Pleistocene, approximately). The final development of Lipari and Salina, and the emersion of Alicudi, Vulcano and Stromboli (the two latter show volcanic activity also during the last century) probably belong to a more recent stage (Late Pleistocene; BARBERI *et alii*, 1974; KELLER, 1980; PICHLER, 1980; DE ROSA *et alii*, 1985, 1989).

Fig.1 - *Central eastern sector of the Aeolian Archipelago.*

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The surveys carried out on the wide submerged portions of the Aeolian volcanoes between 1987 and 1992 by the University of Bologna, within the research activities of the CNR National Group for Volcanology, allowed the bathymorphological and volcanological characterization of the area and the definition of the main evolutionary stages of the volcanic apparata. Submerged abrasion platforms (down to a depth of 100-130 m) have been observed around the oldest sectors in all seven islands, including those islands where no uplifted marine terrace is present on land (ROMAGNOLI *et alii*, 1989; ROMAGNOLI, 1990, GABBIANELLI *et alii*, 1991 and 1993, CALANCHI *et alii*, 1995).

The original morphological profile of the volcanic apparata has been deeply modified by erosion during relative sea level fluctuations; the presence of wide submerged marine abrasional platforms played an important role in the stability of the subaerial volcanic flanks, subject to repeated slope failures and gravitational instability alternating with building periods (ROMAGNOLI & TIBALDI, 1994; KOKELAAR & ROMAGNOLI, 1995).

DATA COLLECTION AND ANALYSIS

A single-channel seismic reflection survey (by means of a 300-500 joule Sparker system), was carried out on September 1993 on board a small private vessel (Fig.2), in order to investigate the submerged depositional terraces on the shallower waters surrounding Vulcano, Lipari, Salina, Panarea and Stromboli (within -200 m of depth). About 300 km of seismic profiles have been located with a non differential GPS system, periodically set on reference points onshore. Only those marine sectors where the occurrence of submerged terraces had already been assessed by previous surveys (ROMAGNOLI, 1990) or was to be expected on the basis of bathymetric maps, have been investigated. Although the researches focused on the five central-eastern Aeolian Islands, submerged depositional terraces have also been detected around Alicudi and Filicudi (ROMAGNOLI, *this volume*). The new data have been checked and/or integrated with 500-1000 joule Sparker profiles (more than 1000 km) collected between 1987 and 1992 by the Bologna University and by CNR of Roma during a survey carried out around Salina in 1992, on board the CNR vessel Urania.

The data collected in the 1993 cruise have been reported and analyzed at 1:25,000 scale, on the bathy-morphological maps previously obtained by ROMAGNOLI (1990). The main depositional parametres of the submerged terraces (upper and lower boundary of the deposit, depositional edge, erosional edge of the underlying substratum) identified by the analysis of the seismic profiles, have been mapped and mostly represented on diagrams. Nomenclature and symbology used are shown in Fig.3. The distance between the profiles as presented on diagram is measured along a line trending parallel to the coast and crossing the seismic profiles approximately at the same depth. In order to avoid problems arising from the integration of data collected by means of different positioning systems (GPS or Loran C) only the data of the 1993 cruise (concerning all the terraces around the five islands) have been represented in the diagrams.

Fig. 2 - *"Incaurina Marianna", the catamaran that carried out the seismic survey on September 1993. This boat proved particularly suitable for the study of submerged depositional terraces, since its reduced draught and easy handling allowed to approach uneven coastlines and to carry out profiles normal to the coast even in very shallow waters. This boat, which flies the English flag, is a 28x14m ex sail-catamaran for transoceanic regatta modified for research works and charting.*

In order to correlate the depositional parametres of the terraces among adjacent profiles, the morphological setting, stratigraphic relations and seismic facies were taken into consideration, especially in the case of multiple terraces or terraces with a strong lateral variability. Values with little relevance to the lateral continuity have been excluded in order to focus on the main features. The data collected around the seafloor of the five islands have been statistically processed in order to recognize possible frequency peaks of the main depositional parametres (see the section Discussion).

The following chapters present the results for each island; when possible the bathymetric trends studied at sea have been compared to information on neo- or volcano- tectonics features on land.

Information on a few gravity cores and R.O.V. (Remote Operated Vehicle) recordings carried out on Salina seafloor have also been included.

Fig. 3 - *Main morphological parameters of submerged depositional terraces (SDT) and their representation in section, plan and diagrams.*

STROMBOLI ISLAND

Stromboli, along with Panarea, represents the emerged part of the volcanic alignment of the eastern Aeolian Islands, stretching NE-SW for over 45 Km. Their overall morphology indicates that both islands are controlled by fault systems with the same orientation, possible surface manifestations of a main crustal discontinuity at a regional scale (ROSI, 1980; GABBIANELLI *et alii*, 1993; PASQUARÈ *et alii*, 1993). The evolution of the Stromboli volcanic apparatus reflects this structural control, as shown by the NE-SW alignment of dykes, eruptive centres and fractures. The subaerial apparatus developed during the last 100 ky (GILLOT & KELLER, 1993); submerged abrasional platforms cut the oldest NE and SW sectors of the island, including the emerging neck of Strombolicchio. The subaerial evolution of Stromboli has often been interrupted by large-scale gravitational collapses that mainly affected its western flank, alternating with building stages and followed by a slow migration of the eruptive activity towards NW (PASQUARÈ *et alii*, 1993). The last (Holocenic) event created the volcano-tectonic depression known as "Sciara del Fuoco" on the western flank of the island.

Fig.4 - *Bathymetry and main morphological and volcanological features of Stromboli. This volcanic apparatus rises from a depth between -1200 and - 2200 m up to a maximum height of 3000 m above sea level; its stretching along a NE-SW axis is particularly evident from the submerged morphology. The submerged depositional terraces (hereafter SDT) develop for stretches over 4 km long along the SW and NE coasts. Apart from this two areas, the submarine slopes of the apparatus are extremely steep and carved by active canyons; the main canyon is located in front of Sciara del Fuoco (SdF in figure); it drains the products of the present eruptive activity as far as over 3000 m below sea level* (KOKELAAR & ROMAGNOLI, 1995).

A legend of the main morphological and volcanological features is reported below the map.

Fig.5 - *A SDT morphologically very clear, with a depositional edge at an average depth of 55 ms (about 41 m), was mapped in the south-western sector of the island. Since the terrace is quite steep and not too extended transversally to the coast, it has been difficult to reconstruct in detail its inner structure. The limited development of the abrasional platform at the foot of the deposit and the high steepness of the substratum are likely reasons for its wide bathymetric range (up to 80 m). Laterally the deposit closes with the disappearance of the underlying abrasional platform. The diagram shows the depth of the edge and of other depositional parametres of the SDT (see symbology in Fig. 3 for this and the following diagrams). The depth of the edge increases gradually from SE to NW; this trend is especially evident next to the lateral terminations of the terrace.*

Fig.6 - *Seismic Sparker profile off the south-western coast of Stromboli (line C, location in Fig. 5), showing a submerged depositional terrace entirely made up of two sedimentary units; the upper unit progrades over the older one, that does not outcrop on the seafloor and has little morphological expression.*

The foresets of the (recentmost) upper prograding unit are up to 20° steep; this high steepness may account for the apparent acoustic transparency in the seismic profiles. The upper unit has a maximum thickness of 30 ms; the whole terrace is 50 ms thick.

Fig.7 -*The north-eastern sector of Stromboli has a quite complex seismostratigraphic setting. An upper terrace is located at a shallow depth (edge at 35-40 ms) in front of Ficogrande area (where a thin alluvial-littoral belt is present). The SDT reaches a maximum thickness of 20 ms (about 16 m) and it lies over another terraced deposit up to 75 ms thick (about 60 m), located in the saddle between Stromboli and Strombolicchio. The deeper terrace lies over an abrasional platform (see Fig.8). Due to the asymmetry of the substratum the terraces are located at a greater depth on the north-western flank (edge at 180-200 ms t.d, about 145-160 m) and are up to 25 ms thick (about

20 m), while, on the north-eastern flank they are at a shallower depth (120 ms, about 95 m), and are a few ms thick. A few sediment accumulations over the erosional morphology are located to the east of Strombolicchio. The vertical trend of the SDT off the northern coast of Stromboli have not been represented on diagram due to the variability of their depth and the complexity of the different units.

Fig.8 - *Sparker 500J E-W profile carried out close to the eruptive centre of Strombolicchio (see Fig.7 for location). On its western flank a thick sedimentary wedge is present (up to 90-100 ms thick, about 70-80 m) which can be considered as a main terraced unit, consisting of different overlapping sedimentary bodies (not clearly detectable because of a strong ringing effect). Its deposition is probably due to a tilting or to a volcano-tectonic collapse that affected the western flank of the apparatus, similarly to what is known about its emerged portions (ROSI, 1980). For this reason the depositional parametres of this body are extremely variable and have not been included in the final discussion. On the eastern flank of Strombolicchio a sedimentary deposit with limited thickness, lying over an erosional terrace, is present.*

PANAREA ISLAND

Panarea (3.3 Km² only) and the small rocks that surround it are considered the remains of a wide volcanic apparatus, mainly of pre-Tyrrhenian age, dismantled by the sea erosion and by severe neo- and volcano- tectonics. The main volcanological and structural elements identified both on the island and on its submerged portions suggest a structural continuity with the close Stromboli apparatus, similarly controlled by tectonically-oriented NE-SW features. These indicate, for Panarea, the interaction between a volcanic activity characterized by the extrusion of several minor eruptive structures (endogenous domes) and depositional and erosional activities, partially related to relative sea level fluctuations (LANZAFAME & ROSSI, 1974; GABBIANELLI *et alii*, 1990; ROMAGNOLI, 1990). The recentmost activity (about the last 60 ky) is related to the growing of the rhyolitic dome of Basiluzzo. On the seafloor to the east of the island, in the area of the small rocks of Lisca Bianca, Lisca Nera, Bottaro and Dattilo, an intense exhalative and hydrothermal activity is located.

Fig.9 - *Panarea Island. The apparatus, slightly centred to the east of the island, has a cone shape and rises from a depth of 1000-1200 m. On its flanks there are canyons with a radial trend, alternating with volcanic ridges (for this and the following maps see legend on Fig. 4). The western portions of Panarea are made up of a "primordial" stratovolcano that represents the skeleton of the island (around 650-590 ky old,* GILLOT & VILLARI, 1980*).*

The wide submerged portions of the apparatus (about 50 km² at a depth shallower than 150m) consist of a wide abrasional platform, bounded by a continuos and defined edge. The bedrock is actually more complex than it appears from its bathymetric setting, due to the presence of several, partially buried, secondary eruptive centres, basins and structural discontinuities with a NE-SW trend. These structural features affect the thick volcanoclastic cover (thick up to 200 ms) smoothing the roughness of the volcanic substratum. A main fault system with a NE-SW trend dissects the summit of the apparatus, causing the lowering of the whole eastern sector and its subsequent infilling by volcanogenic deposits. A gravity core (PAN 92-31), collected at about -85m between Panarea Island and Secca dei Pesci, revealed volcanogenic material with a coarse lithology that prevented the Kullemberg core to penetrate into the deposit, beyond the retrieved 45 cm. In detail, under an upper layer of about 30 cm made up of reddened volcanic sands rich in pumice and lapilli, small size brownish-reddish scoriae have been sampled. The reddish color of the sampled materials shows the high degree of alteration, probably increased by circulation of hydrothermal fluids (common in the area) within the bottom sediments.

The SDT on the western and eastern coast of Panarea have been studied and mapped separately, as they are related to different morphological and structural settings.

Fig.10 - *Western and southern flanks of Panarea Island (see beside). The distribution around the island of the mapped SDT (on the left) is quite evident also from the bathymetric setting resulted from multibeam shaded-relief images (above* GAMBERI *et alii*, 1997*). From the diagrams, it results that a shallow SDT is present in the whole area. At greater depths there is a more complex setting, with quite developed and often overlapping terraces. Between P. Palisi and Scoglio La Loca (northern and western sectors of the island, corresponding to the oldest and relatively undisturbed flank of the stratovolcano) there is a main terrace with a maximum thickness of 25 ms and a deposi-*

tional edge at 50-60 ms. It progrades over an older and deeper terrace, with similar thickness and an edge at 110-125 ms (Fig. 11); it lies over an abrasional platform that parallels the coast with a 1-2° slope; the erosional edge of this platform is located between 150 and 175 ms, more than 1 km offshore. The depth of the depositional edge of the lower terrace and of the erosional edge increases from N to NW and W, while the upper terrace lies at a quite steady depth, or it even becomes shallower following the trend of the southern area.

Off Scoglio La Loca, at a depth of over 100 ms there is a small volcanic feature (see Fig.9) which interrupts the lower SDT, while the upper one develops as far as P.ta Torrione. The latter has a quite clear and steady morphology, a thickness of 25-30 ms and the depth of its edge gradually decreases eastward to 25-30ms.

In the southern sector of the island there are several depositional bodies, partly overlapping. Four of them, with an average individual thickness of about 20 ms, are visible in Fig.12 and have been mapped in diagram (Fig. 10). Their stratigraphical relations are not always clear; generally the age of the prograding wedges seems to increase with depth. The depth of the edges and other parametres varies in a complex way. Despite a general trend to decrease eastwards, the depth of the lowermost and more distal bodies tend to reverse this trend. The analysis of the seismostratigraphic setting of this sector suggests the occurrence of a subsident basinal area on the outer part of the platform, over which the SDT prograde (Figs.12, 13). This lowering might be genetically related to the neo- or volcano-tectonic lowering of the eastern sector of the Panarea apparatus. Eastwards the SDT is interrupted by a large canyon with a N-S trend, that deeply carves the submerged portions of Panarea and divides it from the Secca dei Pesci sector (see Fig. 9).

Fig. 11 - *Seismic profile off the northern sector of Panarea (line B, location in Fig.10). An upper terrace with an edge at a depth of 60 ms, partially covers a deeper terrace that lies over an abrasional platform and is characterized by a remarkable horizontal extension. The inner structure of the SDT is characterized by several progradational phases with a possible retrogradational setting.*

Fig. 12 - *Seismic profile off the southern sector of Panarea (line I in Fig.10). Four morphological edges on the seafloor are related to a quite complex stratigraphic setting. The upper terrace, with a limited extension, is quite defined and is located at a shallower depth than in the western sector. The lower terrace has a scant morphological expression, with two ill-defined edges at 105 and 135 ms. The buried geometry, though, reveals the presence of at least three prograding wedges in retrogradational setting. The deepest wedge shows very steep foresets (up to 8°) with a tangential base and a slope progressively decreasing from the oldest to the recentmost phases. This wedge might have an erosional top and, contrary to the general trend, it is older than the lower and outer terrace. In the outer part of the profile a partially buried volcanic body dams a thick sedimentary basin.*

Fig.13 - *Seismic profile off the south-eastern sector of Panarea (line N in Fig.10). Here it is possible to observe: 1) the disappearence of the upper terrace; 2) multiple prograding wedges seismically ill-defined that make up the lower terrace and lie over a sedimentary basin bounded by a buried eruptive centre. The basin contains sediments over 200 ms thick and it is genetically related to the collapse of the eastern sector of Panarea volcanic apparatus. It is affected by extensional faults that do not affect the deposits of the SDT.*

Fig. 14 - *In the whole sector between Secca dei Pesci and the smaller islets there is a single depositional body, with an average thickness of 10 ms and less (rarely 20ms). Its edges are ill-defined and its inner structure is generically prograding. Locally (profiles D-H) it is possible to observe two depositional edges, likely expression of two overlying depositional bodies, seismically undetectable. The trend of the main depositional parametres of the terrace suggests two sectors (Secca dei Pesci and the area around the smaller islets) where the terrace lies at shallower depth. The SDT extinguishes northwards, by the head of the canyon with an E-W trend between Basiluzzo and the smaller islets (Fig.9).*

Fig.15 - *1000 Joule Sparker Profile parallel to the eastern rim of Panarea apparatus. It shows a central depressed sector, between two minor eruptive centres (Secca dei Pesci is the southern one). This setting is probably due to a local subsidence that allowed the accumulation of a clastic filling over 50 m thick and caused the local lowering of the SDT, as indicated in Fig 14.*

Fig.16 - *Distribution of the deposits of the SDT by the small island of Basiluzzo (up on the left) and related seismic profiles perpendicular (down on the left) and (above) parallel to the coast. The SDT is quite small and extends*

*between 50 ms and 130 ms (about 37-97 m) with a depositional edge around 60 ms (45m) and a maximum thickness of 35ms. In the profile parallel to the coast the body is made up of several depositional phases. It is important to note how, even around a volcanic centre as small as Basiluzzo, presently divided from the main Panarea platform by a saddle about 70 m deep, there was enough production and accumulation of detritus to create a small SDT. This is to be related to the dismantling action of the sea on the western portion of the dome that makes up the small island, whose emission centre is located along the NW coast of Basiluzzo (*ROMANO, 1973*).*

SALINA ISLAND

Salina (about 22 km^2) is the emerged portion of a polygenetic volcano consisting of six, partially overlapping, eruptive centres (Fig 17). The oldest ones (Capo, Rivi e Corvo, active between 500 and 300 ky B.P., GILLOT, 1987) are located in the NE an W sector respectively and represent the "skeleton" of the island. Their volcanic apparata have been deeply affected by marine erosion and show high coastal cliffs. The well-preserved cones of the two recentmost eruptive centres, Fossa delle Felci and Monte di Porri (as high as 762 an 860 m), give the island its characteristic bicuspidate shape. Their activity (last 127-67 ky, GILLOT, 1987) is partly coeval to the erosional episode (of likely Tyrrhenian age) related to the marine conglomerate levels outcropping on the coasts of the island (KELLER, 1980b). The resumption of the activity in the post-erosional stage, particularly in the last 40 ky, is partly coeval with the activity observed for Lipari and Vulcano, and it is located on the same structural NNW-SSE alignment. This points out a remarkable uniformity of the whole Aeolian central sector during the main building/erosional stages (ROMAGNOLI *et alii*, 1989). In the last 30-13 ky only the Pollara centre (in the farthest NW of the island) has been active. Its explosive eruptions produced a tuff-ring made up of pyroclastic materials, whose western portion has been broadly dismantled by the sea (CALANCHI *et alii* 1987). This processes generated a thick and wide submerged depositional terrace that has been object of a detailed study by means of gravity coring and R.O.V. recording.

Fig.17 - *Wide abrasional platforms extending with a semi-circular trend around the oldest portions of the island (Corvo, Rivi and Capo eruptive centres, see Fig. 18) are the main features of the submerged portion of Salina volcanic apparatus.*

On the western and northern flanks of the island, an almost continuous SDT is located. Apart from the northern coast, another smaller abrasional platform is present at the SE edge of the island; it involves the basal portion of Fossa delle Felci centre. A SDT with variable thickness (up to 50 ms) and a quite ill-defined edge develops over it. This terrace has not been mapped due to its scant lateral continuity.

Elsewhere the submerged slopes are steep and carved by several canyons draining volcanoclastic material towards the base of the island, which is located at a relatively shallow depth towards the N, E and SE flanks, next to further volcanic centres, and deepens W and southwards, down to over -1000 m.

Fig.18 - *Along the western coast of Salina (from Praiola to Punta Perciato) a thick (50-60 ms) SDT, with an edge at about 50 ms, has been recognized over the abrasional platform. It is more than 1 km wide and consists of two overlying depositional bodies. The great amount of sediments that make up this deposit is likely to originate from the dismantling and reworking of the material that made up Pollara pyroclastic tuff ring and lacustrine basin, whose preserved eastern portion outcrops in the coastal cliff between Filo di Branda and Punta Perciato (*CALANCHI *et alii*, 1987*). Along the northern coast to the east of Punta Perciato the depositional terrace is found more or less at the same depth as in the western area, except for a limited sector off Punta Fontanelle, where it is absent and the lavic basement outcrops on the seafloor. The SDT is 25-30 ms thick, and its inner structure can be related to two different progradational phases that at times create a double depositional edge ad a depth of 40-50 and 60-70 ms. Its thickness strongly thins before Capo Faro; from this point, the thickness increases again up to 35 ms, before disappearing southwards because of gravitational instability.*

See the map for the main volcanic centres of the island (asterisks) and the location of the gravity cores collected offshore the western coast of Salina (SAL92-22 and SAL92-24).

Fig.19 - *Seismic profile off Praiola coast (line B in Fig.18). At least two progradational phases are recognizable within the SDT. The recentmost one originates a morphological edge on the seafloor. Its foresets are very steep and*

its transversal extension is smaller than the underlying phase. The latter lies over a wide abrasional platform with an edge between 140 and 160 ms which develops parallel to the coast and is likely to correspond to the old Corvo apparatus (eruptive centre in Filo di Branda area). In the outer part of the profile a morphological roughness of the volcanic basement creates diffraction hyperbola; by the platform edge there is also an older, outer depositional terrace with very steep foresets, not mapped because of its limited lateral extension.

Fig.20 - *Seismic profile off Pollara sector (line E in Fig.18). Two progradational phases make up the SDT that, with an edge at 60 ms, partially lies over the abrasional platform, here affected by possible tectonic dislocations and with pockets of volcanogenic deposits.*

Fig.21 - *Cores SAL92-22 and SAL 92-24 from the frontal slope of the SDT lying in the western sector of Salina (location in Fig. 18) The cores, recovered at about 90-100 m water depth, are 80 and 120cm long respectively; they are made up of volcanic and bioclastic fine (often silty) sand with frequent lags of shell fragments and normally graded intervals.*

*Biostratigraphic analysis of both cores revealed a remarkable reworking (up to 90% of the benthonic microfauna) that does not allow any clear paleobathymetric attribution. Planktonic faunal assemblages that can be related to the Climatic Optimum (last 4-5 ky) have been recognized at the base of core SAL 92-22 (whose top could not be preserved during sampling) and between cm 20-40 in SAL 92-24. The basal portion of the latter core (cm 90-118) contains a planktonic assemblage (with G.truncatulinoides almost absent, G. ruber, G. praecalida and G. tenellus) which can be related to 8-9 ky ago (*A.Asioli, *pers. comm.). It must be noted that both cores come from a sector of the seabottom extremely well fed during the last 13 ky, due to the dismantling of the pyroclastic deposits related to the recentmost activity of the Pollara centre.*

Fig.22 - *A* R.*O.*V. (R*emote Operated Vehicle) survey was carried out offshore Salina north-western coast, along a path almost coincident with the seismic profile shown in Fig.20. While the ship was drifting in the required direction, the self-propelled* R.*O.V. investigated the seafloor and recorded the most interesting features. It was thus possible to collect continuous visual information on the seafloor between -20 and -120m. The seismic profile beside shows the approximate location of the* R.*O.V. images A-E (hereafter reproduced).*

*Near the coast, by the top of the SDT, can be observed wave ripples with a wave length between 0,5 and 0,7 m and height of 10-15 cm (image A). The sediment is made up of coarse volcanoclastic detritus; a granulometric selection is present, with larger, but lighter, pumice fragments in the ripple troughs. The bedforms were likely created by the waves reworking the thinner part of the sediment, on the top of the terrace. Deeper bedforms, probably related to the highest-energy meteomarine events, appeared to be inactive at the moment of the survey, since they are dismantled by the activity of irregular echinoids (*Spatangus purpureus) *starting from a depth of 30m (image B). Bioturbation wipes out completely tractive structures at -45 m depth; bedforms are no longer visible downward (image C). Apart from the echinoids, the seafloor is generally azoic, with no vagile bentonic organisms.*

*On the frontal slope of the SDT the sediment is made up of coarse clasts, without any fine-grained fraction. Between -65 and -80m a "praline" facies, made up of calcareous algae (Melobesia) encrusting the surface of volcanic scoria is diffused on the seafloor (image D). For the development of this particular facies is necessary for the clasts to roll on the seabed (*Peres & Picard, 1964*); this may thus indicate the occurrence of bottom flows (possibly induced by gravitational processes acting on the steep slope, which is around 10°). Rare tunicates* (Fallusia mamillata) *are present, settled on the largest (decimetric) isolated clasts.*

Silty sediments at the foot of the frontal slope of the SDT, probably derived from the abrasion of the pumiceous material, appears at first in patches, then it becomes predominant below -90m; here the "praline" facies is almost completely absent on the seafloor, while there are regular echinoids (Cidaris cidaris) *and polichaetae worms produce small mud volcanoes over 10cm high. At the end of the* R.*O.*V. *survey (image E) a small lava outcrop, encrusted by green and calcareous algae and likely related to an outcrop of the volcanic basement, has been observed.*

LIPARI ISLAND

Lipari is the biggest island of the Aeolian archipelago (37.5 km^2). It owes its shape to the complex superimposition of several volcanic centres, emplaced during four main periods of activity in the last 200 ky (Pichler, 1980; De Rosa *et alii*, 1985). The products of the oldest cycle of subaerial activity make up the central and north-western portion of the island and are related to the growth of about ten volcanic centres (Timponi), aligned along the main tectonic NNW-SSE trend. Two further centres make up Mt. Rosa headland that extends with a E-W trend in the mid-eastern coast of the island. These deposits are cut at different levels by marine abrasional conglomerates, presently oucropping at heights between 10 and 40 m along the N and NW coast of Lipari. They allowed the identification of two main periods of volcanic activity (pre- and post- erosional) separated by episodes of marine ingression (BARGOSSI *et alii,* 1989). The following activity (last 125 ky) shows a slight migration eastwards and originates the central-northern sector of the island; in the last 35-40 ky volcanic activity was characterized by high explosivity, extrusion of endogenous domes and acid magma composition (PICHLER, 1980; DE ROSA *et alii*, 1985). This activity took place in areas affected by volcano-tectonic collapses, such as the NE and southern sector of Lipari, and, possibly, in the submerged area between Lipari and Vulcano.

Fig.23 - *The submerged portions of Lipari show an uneven morphology due to deep incisions and several secondary eruptive centres, mostly located on the W and N flanks and aligned along a belt with an NNW-SSE trend. The development of the Lipari volcanic apparatus seems to have been tectonically controlled, since the first activity stages, by a NNW-SSE oriented structural trend. The alignment of the eruptive centres in this direction parallels the distribution of a wide abrasion platform, 12 km long, which underlyies the SDT all along the north-western and western flank of the island (between Acquacalda and to the south of Punta delle Fontanelle, see Fig.24). The platform is also present in the farthest south of Lipari (Bocche di Vulcano area), and, with a limited extension, around Mt. Rosa headcape. Pre-Tyrrhenian volcanic products outcrop on the same sector of the coast (with the exception of the southern sector of the island).*

No SDT have been observed on the Lipari eastern flank, steep and carved by several canyons and with its base at a depth of 900-1000m.

Fig.24 - *Distribution map of the SDT in the NW sector of the island of Lipari. The letters (a-e, along the coast and to the base of the diagram) indicate the location of the coastal stratigraphical sections shown in Fig.27; the symbols stand for possible structurally or morphologically-controlled discontinuities among coastal tracts, as suggested from the vertical distribution of SDT and raised marine terraces. In the diagram also the erosional edge of the presently submerged abrasion platform has been indicated.*

On the north-western flank of the island there is a continuous upper SDT 30-50 ms thick, whose edge is located between 30 and 50 ms. In detail, the depth of its edge gradually increases southward from Punta del Legno Nero to Pietra del Bagno. Also to the east of Punta del Legno Nero the depth of the depositional edge slightly increases, as in the case of a deeper SDT, about 30 ms thick, characterized by a double depositional edge and lying in front of Punta del Legno Nero. The inner geometry of this terrace is not recognizable because of the scant penetration of the seismic signal, which might indicate coarse and/or heterogeneous lithologies.

From Punta del Legno Nero to the South, the lower terrace is better developed, and several overlying depositional phases have been detected (Fig.25). The edge of the lower SDT deepens gradually from 115 ms at Punta del Legno Nero to 145 ms to the North of Pietra del Bagno. In detail though, the terrace is characterized by an extreme lateral variability, since it consists of bodies with a limited extension and very variable inner geometries, even within the very narrow spaced seismic grid (6-700 m). From Punta Palmeto towards the south the two depositional terraces tend to coalesce (Fig.26) and, even if the relevant depositional edges are still detectable, the relation between the two deposits is no longer clear, especially by Banco del Bagno, where the deposit is spread over the wide abrasional platform which links the shoal to the main body of the island. To the south it reaches as far as Punta delle Fontanelle, where the depositional edge is located at 140-145 ms. Farther south, on Lipari south-western portion, beside the upper SDT whose edge is located at a depth of 35-40 ms, there is a lower terrace with an edge at about 100-120 ms (this sector has not been presented on diagram due to its relatively small extension).

Fig.25 - *Seismic profile perpendicular to the coast on the western flank of Lipari (line in Fig.24). At least three SDT, made up of several prograding depositional bodies, are shown; the lowermost has not been presented on diagram in Fig.24 due to its limited lateral extension. Within the bodies a general increase of the foresets slope is observable. In the shallower terrace (edge at 35 ms) a buried incision at 20 m water depth may be also observed. These features are quite common within submerged depositional terraces and are likely due to subaqueous channalized flows in correspondance of main subaerial (coastal) streams.*

Fig.26 - *This seismic profile is close to the previous one (at a distance of 750-1500 m see line M in Fig.24). Nevertheless, differences in the morphological and seismostratigraphical setting between them can be observed. In particular, the upper SDT, which totally covers a lower progradational wedge, is affected at its foot by likely gravitational instability, as suggested by undulations in the seafloor. The lower wedge consists of two thin progradational phases. The deeper SDT, over which the depositional terraces were prograding has disappeared and replaced by the outer erosional edge of the abrasional platform, located at depth higher than -120 m.*

Fig.27 - *Stratigraphical sections of the north-western coast of Lipari (see Fig.24 for location). A comparative study of the submerged features and the coastal sectors in front of them, along which raised marine terraces are located at heights between 20 and 40 ma.s.l., was carried out. These terraces are represented by morphologies and deposits with marine origin (conglomeratic levels associated with bioconstructions rich in rests of marine organisms, indicating shallow infralittoral communities). Similar levels observed on Filicudi, Salina, Panarea and Lipari have been generally associated to Tyrrhenian highstands, on the basis of their stratigraphic position, height and paleontologic content, assuming for the volcanic apparata average uplifting rates between 0.3 and 0.6 mm/y in the last 125 ky* (KELLER, 1980B; PICHLER, 1980; RADTKE, 1986; CORSELLI & TRAVAINI, 1989; LUCCHI *et alii*, 1999*).*

*The detailed geological survey carried out along the northern and western coast of Lipari (*LUCCHI, 1999*) allowed to correlate the conglomeratic levels (represented in the stratigraphic sections) and to detect the main neotectonic features of the coastal sector. This study has been compared to the morphological trend of the SDT and to the depth values of their erosional edges. The trends shown from different coastal sectors are closely related to those of the submerged sectors in front of them; areas affected by differential vertical movements and separated by discontinuities have been locally identified (Fig.24). In detail, to the south of Punta del Legno Nero the depth of the main parameters of the SDT gradually increase as does the erosional edge of the abrasional platform, which reaches depth of 190 ms (Fig.24). Lowered sectors are located by the stratigraphic section* **a** *(where local tectonic lowering seems to occur along NW-SE structures) and* **b** *(located within a wide sector crossed by seismic lines F, G, H, I in Fig 24). In the latter case, in the lowered sector, a marked increase in the thickness of the lower SDT is observed. On the coast (section b) it corresponds to a paleoshore deposit interbedded with multiple and partly reworked conglomeratic levels, for a total thickness of about 30 m. This setting suggests the location of a morphological depocenter, filled by a large amount of sediments in relatively short times (no trend is evident in the upper SDT). Just to the north of Punta Palmeto (I-L profiles in Fig.24) a morphological high is present; to the south of it the erosional egde of the abrasion platform undergo a sudden rise of 20-40ms, also evident in the seismostratigraphic setting of the upper SDT (Figs.24 and 26). The corresponding coastal section (***c***) shows a single conglomeratic level of limited thickness, located at high elevation. Southward, towards Pietra del Bagno (seismic sections P-Q) the parametres of the SDT and the heights of the conglomerate (section* **d***) lower again; the conglomeratic deposits splits into two levels and the thickness of the interlayered sediments increases.*

VULCANO ISLAND

Vulcano is the southernmost Aeolian island and is located on the main NNW-SSE trending tectonic alignment of the area, along with Lipari island and several minor submerged centres. The subaerial activity of the Vulcano apparatus has generally been ascribed to post-Tyrrhenian times, due to the lack of raised marine terraces and deposits (KELLER 1980a; FRAZZETTA *et alii*, 1985). The Vulcano Primordiale (GILLOT, 1987), a huge composite stratovolcano that makes up the whole central-southern sector of the island, developed about 110-115 ky ago. Before the summital calderic collapse that brought to its present truncated-cone shape, it reached 1000 m above sea level. After a quiescence interval, it resumed its activity with a migration from south to north and the growth of the northern sectors of the apparatus over previously collapsed sectors, as it happened in the southern area of Lipari. The recentmost activity (Cono della Fossa, Vulcanello) seems to be more and more controlled by tectonic structures with a NE-SW trend, recognized even in the submerged portions and in the sectors presently suspected of incipient activity (GABBIANELLI *et alii*, 1991).

Fig.28 - *The bathymetric setting of Vulcano shows steep flanks carved by several canyons. The base of the apparatus, with a diametre of about 15 Km, lies at an average depth of 900-1000 m. In its submerged and shallower coastal portions a morphologic asymmetry is evident along the western flank, cut by an abrasional platform in the*

*mid-southern sector; this feature is absent from the other flanks of the island. This sector partially corresponds to the location of the peripheral volcanic center of Spiaggia Lunga, whose remains, consisting of lavas dipping in angular disconformity respect to the Vulcano Primordiale that partially covers them, are the only evidences of any previous subaerial activity (*KELLER, 1980a*). This setting suggests the occurrence of a strong alignment of probable structural origin since the beginning of the development of Vulcano and Lipari apparata (*ROMAGNOLI *et alii*, 1989*), while the subsequent activity of both islands moved eastwards. SDT develop both on the abrasional platform on the western flank of Vulcano and in the Bocche di Vulcano strait, that divides Vulcano from Lipari.*

Fig.29 - *On the western, less steep, side of Bocche di Vulcano (the strait between Vulcanello and Lipari) there is a SDT, bounded southwards by a canyon head (see Fig.28). The terrace lies over the remains of a possible buried eruptive centre, possibly responsible for phreato-magmatic activity occurred in the sector between 40 and 13 ky ago* (ROMAGNOLI *et alii*, 1989).

Fig.30 - *This 500 J Sparker profile, carried out along a E-W line between Lipari and Vulcano, shows the SDT lying on the western side of the strait. The area covered by this deposit is quite limited, but it is up to 50 ms thick, with an edge between 70 and 115 ms. The strong tridimensionality of the terrace and its curvilinear trend have lateral effects on the inner reflectors of the deposit. The edge is well defined and the inner structure of the SDT is prograding (two progradational phases can be observed), with concave foresets downlapping tangentially to the basal surface. The SDT of Bocche di Vulcano was not considered on diagram in Fig. 34 due to its scant lateral extension.*

Fig.31 - *The seismostratigraphic setting of the western flank of Vulcano is far more simple of Lipari western flank. There is only a SDT between Punta Capo Secco and the southern point of the island. This terrace is 30-40 ms thick, with a depositional edge at an average depth at 50 ms. The deposit is bounded northward by a canyon whose head is located by Punta Capo Secco. After a new interruption by Punta Conigliara due to erosion, it extends in small strips as far as the southern point of the island.*

Fig.32 - *SDT on the western flank of Vulcano (line D, Fig.31). The inner structure of the deposit is relatively simple with quite steep foresets and frontal slope (over 20°).*

Fig.33 - *Seismic profile normal to the coast by the northern end of the terrace (area in front of Spiaggia Lunga; line B in Fig.31). The substratum of the SDT is less steep than in the previous profile; nevertheless it is affected by gravitational dislocation, causing offsets to over 10m on the seafloor. The mild frontal slope (6°) might have been caused by the morphological readjustment of the gravitational dislocations.*

DISCUSSION

LOCATION OF SDT WITH RESPECT TO VOLCANIC APPARATA

The occurrence of the SDT around the central-eastern Aeolian Islands shows that multiple terraces, located at different depths, are mainly distributed on the oldest portions of the volcanic apparata (Panarea, western Lipari, northern Salina). On the apparata with a more recent age (western Vulcano, southern Stromboli) only a single, shallow water terrace has been detected. The distribution maps (Figs.4, 9, 17, 23 and 28) also show that SDT are preferentially located on the submerged abrasional platforms that border most of the apparata. As far as Lipari, Salina and Panarea are concerned, these platforms cut pre-Tyrrhenian volcanic products (Fig. 34). On the contrary, on the younger islands (Vulcano, Stromboli and Alicudi, ROMAGNOLI 1990; CALANCHI *et alii*, 1995) SDT are found on the apical portions of the emerging apparata (covered by volcanic products older than 100-110 ky, according to the dating quoted in GILLOT & VILLARI 1980; GILLOT & KELLER, 1993). The presence of pre-existing abrasional platforms seems to favour the development and/or preservation of the SDT. The depositional bodies, in fact, often close laterally in correspondance of the disappearance of the underlying platforms, whose gradient and width seem to control not only the development of the SDT, but also their geometry (e.g.: foresets slope). The availability of clastic materials also plays an important role. The thickest SDT (up to 60ms), with a remarkable extension both parallel and transversal to coast, are located off those sectors where a big amount of low-coherency sediments was made available from the dismantling of pyroclastic deposits in the adjacent coasts (e.g. Pollara, western coast of Salina). Similar influences on the distribution of the SDT are observed around Linosa volcanic apparatus (ROMAGNOLI, *this volume*).

Where the abrasional platform are absent, the steepness of the primary volcanic flanks does not allow the permanence of the sediment in shallow waters, and it often causes its gravitational reworking towards the base of the volcanic apparata.

Fig.34 - *Distribution of marine abrasional platforms around the islands of the Aeolian central sector and, particularly, in correspondence of the pre-Tyrrhenian in aree volcanics of Salina and Lipari and of the products related to the earlier subaerial activity for Vulcano island.*

DEPTH DISTRIBUTION OF SDT

The depth of the most relevant morphological parametres of the SDT (i.e. upper boundary and depositional edge) are presented in the histograms of Fig. 35. The depths show meaningful distributions, indicating at least three major groups. The largest one (about fifty observations from all five islands) is quite sharp, with an edge at about 30-40 m of depth (40-55ms) and the upper boundary about 15 m of depth higher. A second group (36 cases, observed mostly at Lipari and Panarea) has an edge at 75-100 m of depth (100-130 ms) with a upper boundary about 15 m higher. It must be noticed that the depths of the latter group are much more spread than those of the shallower one. This may be related to the effects of neo- or volcano-tectonics on the apparata, causing vertical dislocations, often restricted to small sectors, as reported for Panarea, Lipari and Stromboli (Figs.8, 9, 10, 24 and 27). Thus, the depths of the depositional edge of a few SDT observed in the southern sector of Panarea, affected by tectonic dislocations, make up a further and deeper group at about 128-155 m of depth (170-210 ms). The location of SDT over small basins on the submerged flanks of the volcanic apparata can also be related to the deepening and thickening of the SDT, due to local compaction of volcaniclastics and following subsidence, as it seems the case for southern and western Panarea (Figs.10 and 15).

No SDT have been observed at depths greater than 155 m or below the erosional edge of the abrasional platforms over which most of them develop. In a few cases, wide erosional disconformities, cutting progradational deposits and/or basin fillings, have been observed. These surfaces lie below the recentmost SDT and are located at depths comparable to those of the erosional edge of the abrasional platforms (which in most cases show values between -105 and -120 m, i.e. 140 and 160 ms).

Fig. 35 - *Histograms of the depth of the upper boundary and depositional edge of the SDT observed around the five islands of the central-eastern sector of the Aeolian Archipelago.*

POSSIBLE GENESIS OF THE SHALLOWER SDT

Shallow-water SDT (upper boundary at 15-25m, edge at 30-40m) with seismoacoustic facies and geometry very similar to the deeper ones, have been observed around every island. They are probably related to present-day depositional processes (Fig. 36), and their formation is likely recent, being occurred during the eustatic high-stand which started 6 ky ago. This interpretation might be also supported by the little dispersion of depth values of their depositional parametres (Fig.35).

It must be noticed that the SDT are not connected with present-day beaches on the islands. These are, in most cases, represented by gravelly pocket beaches, a few metres thick and with a limited extension. On the contrary, the SDT are a few tens of metres thick, with a lateral continuity, and a transversal development up to several hundreds metres. They are also present off coastal sectors characterized by high cliffs and absence of littoral deposits.

It might be assumed a completely subaqueous formation for the SDT, with their upper boundary close to the sea level and the edge a few tens of metres deeper, possibly matching the wave-base level. The mobilization of the sediments produced by coastal erosion and/or biogenic activity may occur during very high-energy marine storms, and they may be carried offshore by unidirectional downwelling currents balacing storm wave-surge. The deposition thus is likely to occur below the wave-base level, along slopes approximating the angle of repose of the sediments. It must be remembered that a strong vertical exaggeration of high-resolution seismic profiles greatly amplifies the slope of the depositional features (see the box on the lower right corner of the figure). This interpretation may account for: a) the absence of link to present-day beach deposits for the SDT, b) the high slope of the foresets, c) the occurrence of shallow-water SDT around all the islands and the consistency of their depth. A similar interpretation has been proposed by CHIOCCI & ORLANDO (1996) for SDT in Palmarola Island (Pontine Isl.s). The top of the SDT and the depth of its edge are likely to be controlled by the base-level of the wave motion of higher energy meteomarine episodes, not easily determined. In the case of the Tiber River delta (over 400 km far) the wave-base-level where the reworking of sediments occur, coincides with the edge of the delta front, located at -25m (BELLOTTI & TORTORA, 1985). If this level (D) is assumed to correspond with the shoaling zone limit (according to ELLIOT, 1986), the corresponding wave length (L) is around 100-150 m (D=L/4-6). According to AIRY's wave theory (BRETSCHNEIDER, 1969) and SWAMP's (1984) empirical relation H=0,06T2, confirmed by GRANCINI *et alii*, (1979) experimental data, we obtain a 8-11s period and a 4-7 m wave height. The 7m value corresponds to a wave with a 30% of possibilities to occur in a 10 years span, according to CAVALIERI *et alii*, (1985) tables of the Central Tyrrhenian Sea. By applying procedures, tables and relations from the Central Tyrrhenian area to the Aeolian Islands, we obtain heights of 5-8,7 m, periods of 9-12 s, wave lengths of 110-180 m and an effective base level of 27,5-30,5 m. This value is quite close to that of the depositional edge of shallow-water SDT.

Fig.36 - *Schematic representation of the SDT possible genesis.*

POSSIBLE ROLE OF FETCH AND COASTLINE EXPOSITION IN AFFECTING THE DEPTH OF SHALLOW SDT

By assuming that the formation of the shallow-water SDT is due to the redistribution of sediments during high-energy storms, we tried to verify the correspondence between the depths of the shallower SDT and the coastline exposition, to which the wave base-level might be roughly related. The coastline exposition has been calculated in a simplified way, by estimating the fetch transversal to coast in different sectors of the islands (Fig. 37). The structure of the archipelago is responsible for the contiguity of the more exposed coasts with sectors sheltered by other islands. When SDT are present in these sectors, the results are generally consistent.

Off the southern coast of Stromboli, the SDT is located in shallower waters (edge at 20m) to the south-east, where the coast is sheltered by other islands of the archipelago (namely Panarea), while its depth increases down to -40 m westward (on the not-sheltered flank; see Fig.5). The situation is similar for the western flank of Panarea: towards west and north-west the depth of the edge of the upper SDT is -40 m and gradually decreases southward (to -20 m) where the fetch is limited, due to the Salina-Lipari-Vulcano alignment (Fig.10). Panarea eastern flank, even if not affected by the presence of other islands, is characterized by several shoals (Secca dei Pesci to the south and Isolotti Minori a little north) that might partially account for the 30 m difference between the depth of the upper SDT edge inshore to the shoals and in the area between them (Fig. 14). The whole northern coast of Salina is exposed to hundreds of km fetches (without relevant trends in the depth of the upper terrace); in Lipari the upper terrace reaches its lowermost depth (edge at -22 m) by Punta del Legno Nero (sheltered sector of the island) while, with the increasing of the fetch, the edge of the SDT reaches -30 m eastward and -38 southward (Fig.24).

These evidences are a first clue on the role of wave energy on the formation of SDT. For a more detailed analysis it would be necessary to consider wave-refraction patterns, the variations in short distance of all the depositional parametres of the terraces and the frequency and strength of wind-driven storms in the archipelago (occurring mainly from the north and, secondarily, from south east and west, I.I.M, 1980).

Fig.37 - *Distribution of the fetch transversal to coast in different coastal sectors of the islands.*

VERTICAL MOVEMENTS IN THE COASTAL SECTORS OF THE ARCHIPELAGO

Volcanic coasts represent unsteady margins, where irregular (often alternating) vertical movements may cause fast uplift of drowning, expecially in relation with volcano-tectonic events or seismic crisis. Marine morphologies and deposits (mainly attributed to raised palaeo-shorelines of Tyrrhenian age) have been identified on several Aeolian Islands up to 100 m above the present sea level. They witness an uplifting trend occurred in the last 125 ky (Pichler, 1980; Radtke, 1986; Corselli & Travaini, 1989; Lucchi *et alii*, 1999). Recently, average uplifting trends of 0.34, 0.36 and 0.31 m/ky for the last 125 ky have been estimated, respectively, for Lipari, Salina and Filicudi Islands (Lucchi, 1999). These values, which suggest a common pattern in the vertical mobility of the three islands, are comparable to the regional trends of crustal uplifting reported for the inner sectors of the Calabro-Peloritano Arc in a similar time frame (Cosentino & Gliozzi, 1988; Westway, 1993). The Island of Panarea, on the other hand, seems to have been suffered from uplifting at higher (unsteady) rates: average values range from 0.69 m/ky for the last 100 ky to 1.56 m/ky in the time frame125-100 ky ago (in the same interval a strong volcanic activity was present on the island; Lucchi, 1999, Lucchi et al., 1999).

Observations on roman ruins and other historical remains (Bernabò Brea, 1947; Romagnoli *et alii*, 1995) point out that a short-term, localized strong subsidence, with a probable volcano-tectonic origin, affects coastal sectors of Lipari and Panarea Isls., where it overlaps the long-term uplifting trend and is responsible for the fast drowning of these structures (Fig.38).

Fig.38 - *LIPARI ISLAND - mooring stones dated to the beginning of the seventeenth century (*Negro & Ventimiglia, in Aricò, 1998). *Their periodical drowning is suggested by the presence of living* Chthamalus *barnacles and intertidal green algae on the quay* (Calanchi *et alii,* 2002). Photo: C. Romagnoli.

The mapping of SDT shows the occurrence of structural or morphological discontinuities as the main responsible for lateral variations observed in their inner configuration and distribution in depth. However, the peaks in frequency of the depths of the main depositional parametres of the SDT (Fig. 35) suggest that, apart from the local behaviour of a few dislocated sectors, not consistent with the overall vertical mobility of the area, the volcanic apparata of the Aeolian archipelago suffered little differential vertical movements relative to each other during the last thousands years.

POSSIBLE MEANING OF THE DEEPER SDT

Assuming that deeper SDT (edge at - 75/-100 m) originated with the same depositional mechanism proposed in Fig. 36 for the shallow ones (depositional edge at -30/-40m) and in oceanographic conditions similar to the present, at the time of their formation the sea level should have been 45-60 m lower than today. Their thickness and seismo-stratigraphic appearance are similar to the shallower SDT, possibly originated during the last 6 ky, since the stabilization of the present sea-level after the Versilian eustatic rise. Then the deposition of the deeper SDT might have similarly required a sea level standstill of some thousand years. A limited group of even deeper SDT (depositional edge at -130/-150m, observed for instance at Panarea and Stromboli) is not relevant since they are located in lowered sectors of the volcanic apparata.

As far as marine abrasional and wider erosional surfaces are concerned, they have been generally observed down to 120 m of depth (without considering the sectors affected by local dislocations); thus the paleo-sea level during their formation might have been 90-110 m lower than the present one.

It is not easy to estimate the duration of coastal erosion processes responsible for the carving of abrasional platforms on lavas. According to average rates of coastal retreat it should require thousands, or tens of thousands of years (HEALY, 1981; ROWLAND *et alii*, 1984; LEBESBYE & VORREN, 1996). The evolution of the peripheral centres of Surtsey volcano (Iceland) as reported by KOKELAAR & DURANT (1983) represents an example of summital erosion of a recent submarine volcanic centre. Here volcanogenic products (probably little coherent) were degraded by the action of storm waves or currents; the fast formation of quite developed abrasional platforms at 28-44 m of depth has been observed.

Fig.39 - *Schematic representation of the evolutionary stages of a submerged volcanic edifice in the post-eruptive degradational stage (modified after CAS et alii, 1989): a) the volcano summit is widely eroded by storm-wave action (l.b.= storm-wave base level) till the development of a wave-cut platform, with the periodic overspilling and redeposition of eroded debris over its edge; b) a relatively stable platform surface formed, no longer affected by wave action due to sea level rise and gradually colonized by marine organisms. The deposits lying on the erosional surface are occasionally reworked (due to high-energy stormy events) and swept off the platform, building progradational wedges.*

In Fig.40 the sea level curve for the last 140 ky (CHAPPELL *et alii*, 1996) has been compared with the present-day depths of the SDT and other relevant morphological features of the Aeolian Islands. By assuming the present sea-level as formation level for the shallow SDT, the development of the deeper SDT (edge at -75/-100m) would require some thousand years long stillstands of the palaeo-sea level at depth around -45/-65m. Their formation might have taken place during periods in which the sea level change rates have been relatively low. Actually, it must be considered that eustatic sea level changes combine with vertical local to regional (tectonic and/or volcano-tectonic) movements, widely recognized in this area. As previously stated, an average regional uplift of about 0.3mm/y may be assumed for the central Aeolian archipelago since the last 125 ky. However, uplift movements may be enhanced, for instance, in correspondance with stages of increased volcanic activity (as recognized for Panarea Island between 100 and 125 ky ago; LUCCHI *et alii*, 1999). By modifying the eustatic curve for a regional uplift rate of 0.3 mm/y, a relative sea-level trend is obtained for the last 140 ky. The depth range relevant to the formation of the deeper SDT matches the relative sea-level curve in correspondance to the eustatic lowstand occurred around 140 ky ago, of the time frame 75-40 ky ago and, again, during the last sea-level rise (at 12-15 ky ago approximately). Nevertheless, it should be kept in mind that depositional bodies such as the SDT might hardly be preserved during the almost complete emergence of the abrasion platforms over which they stand (as likely occurred at the Last Glacial Maximum, about 18 ky ago).

A polyciclic formation, due to repeated shoreline erosion, could be related to the submerged abrasional platforms, which are mainly carved in volcanic pre-Tyrrhenian products. But, on the other side, the -90/-110m depth range, corresponding to the possible paleo-sea level during the formation of abrasional surfaces and of main erosional unconformities, matches the relative sea-level curve of Fig. 40 only during the lowstand of 18 ky ago (unless that opposite or composite vertical movements affected the area before the last 125 ky ago). At the time of the Last Glacial maximum, the rejuvenation of the presently submerged abrasion platforms might well have occurred; because of the geometric and stratigraphic relations between the abrasional platforms and the deeper SDT (generally more recent, since they lie over them) the formation of the latter can be post-dated and mainly ascribed to deposition during the Last Post-Glacial stage.

In conclusion, the chronological attribution to the formation of the deeper SDT is still theoretical, since further data on the vertical movements of this sector in the past and on the time necessary to create the observed erosional-depositional submerged morphologies are not available for the moment.

Fig.40 - *Sea-level curve for the last 140 ky (from* CHAPPELL *et alii*, 1996) *and relative sea-level curve (dashed line) obtained by assuming an average uplift trend of 0.3 mm/y. Horizontal belts indicate the relative sea-level ranges possibly corresponding to formation of the shallower and deeper SDT, of the abrasion platforms and of the raised marine terraces (assumed heights refer to Tyrrhenian terraces studied on Lipari island,* LUCCHI *et alii*, 2001 *and* 2004).

CONCLUSIONS

The SDT around Stromboli, Panarea, Salina, Lipari and Vulcano Islands were defined in detail by means of a specific survey carried out on board a small draught boat that allowed the realization of close seismic profiles, normal to the coast, even in very shallow waters. The high-resolution profiles clearly depicted the SDT and their inner structure, although, in some cases ringing effects (up to a few tens of ms prolonged, about 7 m) apparently hid the sea floor, and, in case of extremely thin deposits, even hamper the characterization of SDT. However, even in case of scarce seismic definition, the sea floor morphology (slope breaks, distribution of even/uneven areas) generally allowed the mapping of the SDT.

Due to the marked lateral variability of the SDT in the Aeolian archipelago, the seismic line spacing (usually less than 1000 m) did not always allow a sure correlation among contiguous profiles, but a careful interpretation of the seismostratigraphic setting was needed. In order to identify the factors controlling the distribution, depth and development of the SDT, the morphological/depositional parametres defining the terraces were analyzed. The simplest parametre to be defined is the upper boundary of the depositional bodies, although its depth is often affected by the morphology of the substratum. The depositional edge is always very relevant and quite clear to define, except in the case of thin deposits or SDT affected by gravitational deformations. The depth at which the SDT close is the less relevant parametre, since it is always affected by the morphology of the substratum and its definition is quite subjective.

SDT are more frequent and thicker in those coastal sectors where portions of volcanic apparata rich in pyroclastic deposits (whose dismantling supplied the material to build up them) oucrop; they also seem to be controlled by the presence of sub-horizontal abrasional platform carved in the flanks of the volcanic edifices. The conservation of SDT is, in fact, enhanced in those sectors where the primary morphological profile and substratum slope have been previously modified. A further factor affecting the depth of the SDT seems to be the coastline and fetch exposition.

With the exception of a few cases (southern Salina, northern Stromboli, and some sectors in northwestern Lipari) the depth of the edges of the SDT (and of the other depositional parametres) gradually varies with quite defined trends for several km. This confirms the non-casual nature of the depth of the deposits, as also suggested by the frequency distribution of their depths around definite values.

The depositional characters of the SDT are quite similar on all islands (see, for instance, profiles in Fig. 20 and 26): their inner structure, when recognizable, is always basinward-prograding, with both obliquous and tangential bottomset configuration; stratification is quite thin, up to the maximum seismic resolution, the thickness is, in most cases, around 20 m.

The bathymetric range over which the SDT develop is quite broad (between -15 and -140 m of depth); their shape and the internal geometry can be quite variable (one or more depositional edges, one or more progradational phases, presence of reactivation surfaces, increase in the foreset slope). A shallow-water SDT (whose upper boundary is not always detectable since it is located at a very little depth by the shore), with an edge between 30 and 40 m, is generally observed. This terrace has a progradational inner structure and it often consists of a single-story depositional body. At a greater depth there are further SDT, often with a complex inner structure indicating a polyciclic nature. The stratigraphic relations between different deposits are variable, even though the anteriority of deeper deposits respect to the more superficial and close to the coast ones is generally acknowledged; a retrogradational setting of the SDT, with downlap terminations of sedimentary wedges respect to the top of the underlying ones, is often observed.

Laterally the SDT extinguish either gradually, becoming thinner and thinner, or abruptly, in presence of canyons; in the latter case evidences of gravitational instability phenomena are commonly observed.

It is possible to state that in the Aeolian islands:

1) SDT originate only (or mainly) when the substratum is not too steep and the erosion supplies enough volcanoclastic material to build up the terraces;

2) abrasional platforms carved on the substratum and erosional unconformities with edges at about 140-160 ms of depth (-105/-120m) are present. Both kind of morphologies are preferential sites for

the development of SDT and make for their greater horizontal development;

3) the SDT are located in the bathymetric range of -20/-150m (edge depth). Frequency peaks are observed at average depths of -30/-40 and -75/ -100 m; terraces at greater depth may be explained by local vertical dislocations of the substratum;

4) the inner structure of the SDT is always basinward-prograding, their depositional edge is generally 15 m lower than the upper boundary, their average thickness is of about 20 m, the foreset slope (and the frontal slope) varies from a few degrees to about 15°. Generally the upper SDT have a simple inner structure, while the deeper ones reveal a polyciclic structure;

5) the depth of the shallow SDT may be affected by the present sea level since it gradually varies along several km, consistently with the coastline exposition to wave action. The occurrence of local structural or volcano-tectonic features on the volcanic apparata seems to be responsible for the main lateral variations observed in the depth and in the inner structure of the SDT in adjacent coastal sectors;

6) deeper SDT must be referred to a relative sea level considerably lower than the present. Beside merely eustatic factors, this is to be ascribed to the tectonic instability of the area, affected by vertical movements with local and regional character and with a not necessarily regular and uniform trend. The retrogradational setting of the progradational wedges that make up the SDT may account for a deposition occurred during the unsteady raising of the relative sea level.

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Submerged depositional terraces off the Carini Embayment (Northwestern Sicily)

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INTRODUCTION

High resolution sequence stratigraphy tools have been applied to the study of the regressive shelfal deposits found scattered off the Carini Embayment, a small sector of the northwestern Sicily continental margin (Fig. 1).

Such sedimentary successions, whose development is related to the Late Pleistocene eustatic fluctuations, have been widely recognized off several mediterranean continental shelves (LECCA *et alii*, 1983; MARANI *et alii*, 1988; CHIOCCI *et alii*, 1989; TRINCARDI & FIELD, 1991; CORREGGIARI *et alii*, 1992; AGATE & LUCIDO, 1995).

In the Carini Embayment, these prograding wedges represent the stratigraphic record of subequent sea level falls and lowerings. Terraced features, characterizing the outer shelf, reflect the late costructive stage of the sea level lowering and the first erosive stages of the subsequent rise, when the top of shelf margin units was cut off by shoreline landward shift and accompanying wave action.

Purpose of this paper is to describe the internal geometries and areal extension of the regressive sedimentary succession of the Carini Embayment in order to derive their geological history during the last glacial maximum.

MORPHOLOGICAL AND GEOLOGICAL SETTING OF THE CONTINENTAL SHELF AND UPPER SLOPE.

The northwestern Sicily continental shelf extends along the southern margin of Tyrrhenian Sea (Fig. 1), characterized in Pleistocene times by a high rate of subsidence, up to 1mm/y, in its eastern sector (KASTENS & MASCLE, 1988).

The structural setting of the investigated area has been inherited from a complex pre-late Miocene compressive tectonics, related to the continental collision between the Corsica-Sardinia microplate and the Sicilian continental margin (CATALANO *et alii*, 1985, AGATE *et alii*, 1993).

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The subsequent extensional tectonics, occurred during Tyrrhenian Sea opening, determinated the occurring of alternate morphostructural highs and deep Plio-Pleistocene basins, forming a NNE-SSW trending belt.

The Carini Embayment is bounded to the West by the Castellammare Gulf and eastward by the offshore prolongation of Palermo M.ts (La Barra High).

The continental shelf forms a narrow platform, approximately 10 km wide (Fig. 1), sleeply sloping seaward to the shelf break located to -140 m / -160 m of depth. A paleoshoreline, found between -100/-110 of depth (LUCIDO, 1992), divide the shelf in an inner smooth sector and an outer rought area, where incised paleoriver valleys occur near the main streams.

The shelf is composed by a set of Pleistocene seaward prograding units, upward truncated by the unconformity related to the last glacial sea level fall and lowstand (δO_{18} = 2; Fig. 2). The upper slope is cut by several canyons and display a number of instability features, like slump scars and mass wasting deposits (AGATE & LUCIDO, 1995).

DATA BASE AND METHODS

The analysed data base (Fig. 3) consists of a network of 80 nautical miles of single-channel seismic lines (Sparker and 3.5 kHz S.B.P.) having a different vertical resolution (to few meters), more some gravity core samples.

The seismic survey positioning was based on a hyperbolic Loran C system and, since 1991, on G.P.S. system.

These peculiarities allow the application of high resolution sequence stratigraphy analysis to depositional sequences of limited thickness and areal extension.

SEISMIC STRATIGRAPHY OF THE CONTINENTAL SHELF

The stratal pattern of the Upper Quaternary sedimentary succession has been subdivided into seismically definable depositional packages, bounded by estensive laterally continuous surfaces, both on the shelf and upper slope: seismic sequences have been named from top to bottom I, II and III (Fig.4).

The surfaces are characterized by high amplitude reflections and define sequence boundaries. The upper sequence (I) is considered Late Pleistocene - Holocene in Age and consists of a group of three different seismic units: Ic, Ib and Ia.

Unit Ic is characterized by basinward progradational convex upward reflections of variable amplitude and frequency; it is interpreted to represent a Forced Regressive Systems Tract (FST; HELLAND-HANSEN & GIJELBERG, 1994).

Unit Ib is wedge shaped and is characterized by high to medium amplitude and low frequency. Evidence of mass wasting or seismic facies change, from layered to chaotic or to semitrasparent, on the shelf edge has been recognized. This unit corresponds to shelf perched lowstand wedge or lowstand prograding complex (LPC; POSAMENTIER & VAIL, 1988).

Unit Ia is sheet shaped, onlaps landward at -100/-90 m of depth and can be divided into two subunits, the upper one with a high frequency layered seismic facies and the lower one with a trasparent seismic facies, separated by a continuous reflector corresponding to the maximum flooding surface. According to our interpretation the Unit Ia includes the distal component of Transgressive Systems Tract (TST) and the Highstand Systems Tract (HST; POSAMENTIER & VAIL, 1988).

CONCLUSIONS

Our study, focused in a shelfal area on the continental margin off the NW Sicily, has defined a succession of sedimentary processes triggered by Late Quaternary relative sea level changes (Fig. 6). During the sea level fall and the lowstand following the d O^{18} = 5e, the litoral depositional systems prograded onto a narrow shelf and a steep upper slope; the resulting seaward thickening wedges are more than 80 ms (t.w.t.) in localized areas (Fig. 5). Stacking pattern of deltaic lobes demonstrate overall progradation from South to North. Three ancestral streams were the fluvial feeders of these shelf deltas.

The upper portion of Late Pleistocene wedges is extensively eroded, primarly by subaerial erosion and, to a lesser extent, by subsequent transgressive truncation. The scenario of high sediment supply fluvial systems, incising the morphological shelf breack, is suggested by sequence stratigraphy model for type 1, 4th order depositional sequence, could be apply for these particular progradational regressive lithosomes and their associated "submerged depositional terraces".

FIGURE CAPTIONS

Fig. 1 - *Location of the studied area (depth contour in meters) (Fig.2). Extension of the shelf margin submerged terrace is shown. The terrace extends 20 km along the coast and it is to 3.5 km wide between Torre Muzza and Isola delle Femmine.*

The depositional terrace edge (D) is coinciding with the morphological shelf break (F), except in the "La Barra" sector, were the continental shelf atteins the maximum extension and the depositional terrace wholly lies above the continental shelf.

Fig. 1B - *Schematic section of the shelf margin, not in scale. Morphological and depositional features mapped on Fig. 1A are shown.*

A: edge of scarp; B: landward boundary of the forced regression deposit; C: landward boundary of the shelf margin wedge (LPC) D: terrace edge coinciding with shelf break; E: seaward boundary of the depositional terrace; F: shelf break.

Fig. 4 - *Location of recorded during Sicilia '88, Sicilia '89 and Sicilia '90 oceanographic cruises seismic profiles. Boldfaces are the profiles shown in this paper. a) profiles of Sicilia '88 cruise: S.B.P. 3.5 kHz and Sparker 0.5 and 1.0 kJ; b) profiles of Sicilia '89 cruise: Sparker 1 kJ.*

Fig. 5 - *Seismic profile (Sparker 16 kJ) crossing the shelf margin and the upper slope (location on Fig. 3). The Plio-Pleistocene sedimentary succession unconformably overlies the meso-cenozoic deformed substrate. The succession shows free reflection seismic facies evolving upward to high amplitude and continuity reflectors. Above the continental shelf the unit shows a progradational reflection pattern (modified from* AGATE & LUCIDO*, 1995).*

Fig. 6 - *Sparker profiles 1 kJ (4A, 4B, 4C and 4D) and profile S.B.P. 3.5 kHz (4E) crossing the Carini Embayment continental shelf (location in Fig. 3). Seimic stratigraphic analysis of the seismic sequence I allowed us to distinguish three seismic units.*

- Unit. Ic: consists of high frequency and medium-high amplitude seismic horizons with a prograding reflection pattern; the reflectors dip seaward with oblique-tangential and complex sigmoid-oblique patterns and variable slope (Fig. 4 B); locally seismic facies become mostly like reflection-free, probably because of presence of gas (Figs. 4 A and 4C). Slump scars linked to rotational sliding landslide are present with collapsed deposits at the toe (in the sismic profile they appear as mounded high amplitude reflectors; Figs. 4A and 4B); topward the seismic horizons are truncated.

- Unit 1b: it shows a reflection-free seismic reflection pattern with low amplitude complex sigmoid-oblique reflectors (Fig. 4B).

Unit 1a: consists of medium-low amplitude, high frequency reflectors with parallel reflection configuration. This unit shows a thickness increasing landward (Figs. 4A and 4E).

Legend: 1) seismic sequences and units; 2) seismic sequence boundary; 3) maximum flooding surface (m.f.s.); 4) base of Lowstand Prograding Complex (LPC); 5) base of Transgressive Systems Tracts + Highstand Systems Tracts (TST + HST).

Fig. 7 - A: *Depth of unit Ic lower boundary; B: thickness of unit Ic+Ib unit; C: depth of unit Ib lower boun-*

dary; D: thickness of unit Ib. Values are expressed in ms, two way travel time. Fig. 5B show three main unit Ic+IB depocenters; the thicknest, NE of Isola delle Femmine, could be related to major slope of basal depositional surface. In turn, major extension perpendicularly to coast of units Ia and Ib NW off Isola delle Femmine is related to minor slope an regularity of the basal depositional surface (Fig. 5A; see Fig. 1A too).

Fig. 8 - *Geological evolution of shelf margin during the last glacio-eustatic fluctuation (cartoon not in scale).*

*A) - falling sea level, shoreline seaward putting forward and type 1 sequence boundary generation (*VAN WAGONER *et alii, 1988); - regressive progradational succession deposited above the shelf margin (FST, corresponding to unit Ic).*

B) - Deposition of a prograding complex above the shelf margin (LPC, unit Ib) during lowstand and beginning of the sea level rise. Covered talwegs in the inner sector of the continental shelf between Torre Muzza and Isola delle Femmine, are correlatable to deposits of sequence I (unit Ic and Ib) and suggest these units have been deposited in a deltaic environment. Were a paleo-drainage have not been recognized, presence of litoral deposits has been supposed. Shape, extended parallelly to the coast, of unit Ib (Fig. 5D) suggests strong litoral currents along a narrow and irregular shelf. During sea level fall, deposits of unit Ic underwent subaerial erosion; seaward the erosional surface become a toplap surface at the top of unit Ib.

C) Subsequent sea level rise produced landward shift of litoral facies, generating a transgressive erosional surface at the top of units Ic and Ib. This process is considered as one of the most important for the origin of terraced surface above the progradational deposits (units Ic and Ib).

D) In the inner sectors of the continental shelf, above the transgressive erosional surface, condensed deposits accumulated during the late sea level rise and highstand stages with a reduced sedimentary supply. In the outer sectors of the continental shelf the terraced surface, cut during the sea level rise, outcrops.

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Submerged Depositional terraces offshore Favignana (Northwestern Sicily)

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INTRODUCTION

Within the geological surveying in the area of the Sheet n.604 (Isole Egadi) at 1:50.000 scale, some researches has been carried on in the continental shelf offshore of the Favignana isle by means of acoustic surveys and seismic reflection prospecting completed with investigations by R.O.V. (Remote Operated Vehicle) and bottom sampling by grab (DEL BONO *et alii* 1991).

The collected data have been acquired from September 1989 to June 1993 during some surveys with the Ammiraglio Magnaghi vessel of the Italian Hydrographic Institute (I.I.M.) and the Minerva and Urania vessels of the National Research Council (C.N.R.).

For the high resolution seismic prospecting it has been utilized a 300 Joule UNIBOOM source; a total 300 km of profiles were acquired in the area of the Sheet to characterized the sea floor and near surface sediments of the continental shelf and to classify the main characters of the acoustic facies.

Fig. 1- *Location map of the studies area.*

GEOLOGICAL FRAMEWORK

Fig. 2- *Geological sketch of the sea floor in front of Favignana Isle.*

The examined area (Fig.1), located westward of Trapani on the Western Sicilian offshore, is formed by a continental shelf built up on a rocky tectonized substrate, strongly eroded by marine erosion. Recent sedimentary deposits are almost exclusively made of organic fragments.

The structural configuration is characterized by a series of tectonic units overthrusted eastward and southeastward on the Iblean foreland during Miocene age. New compressive movements (reserve faults, tectonic inversion) occur during Pliocene (CATALANO & D'ARGENIO, 1982; CATALANO *et alii*, 1985; CATALANO *et alii*, 1988).

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An extensional phase, from Upper Pliocene to early Pleistocene, determined the formation of some basins and structurals heights with main orientation NNW-SSE and E-W, till now in evolution (AGATE *et alii* 1992; ARGNANI 1993; CATALANO & MILIA, 1990); their outlines are pointed out by submarine morphology.

Seismostratigraphic analysis clear up a Mesozoic substratum formed by sedimentary deposits evolving from neritic to pelagic facies (CATALANO, 1988; CATALANO *et alii*, 1989). This substrate outcrops underwater along a continous belt around the island and in isolated banks to the South, West and North of Favignana at depth ranging from -40 to- 70 m. On this substrate often the coralligenous biocenosis sets off.

The recent sedimentary cover is very thin and is made of organogenous medium to coarse sands.

The source of biogenic material are calcareous algae, mollusks, Bryozoa, Serpulides, Foraminifera etc. (D'ANGELO *et alii*, 1994) that cover the shelf to depth of -100 m. Beyond this depth the fine portion increases and we find the pelitic sands and the sandy pelites as far as the pelites in the deepest areas (Fig.2).

All the sediments, also the finest one, have a prevailing biogenic content, while the terrigenous part is very scarse.

This trend is extended backward in time to early Pleistocene, as it is conformed by the presence of bio-calcarenites outcropping on the island and on the Sicilian coast (ABATE *et alii*, 1996).

Fig. 3 - *Geomorphological sketch of the area (from* ORRÙ & ULZEGA, *1993, modified). Bathymetric lines are provided from the Hydrographic Institute of Navy* (I.I.M.) *that, during the last years, has carried out new surveys offshore Western Sicily. They offer a good detail for the description of the main morphological lineaments.*

MORPHOLOGY

On the basis of the data from bathymetric map and from Uniboom and Sub-Bottom records, we can recognize an abrasion continental shelf that joins with a slight slope the island of Favignana and Levanzo to the mainland. It extend for about ten Km to depths of -80,-90 m.

Another inner abrasion shelf is shown at depths of -30, -40 m, between Favignana and Levanzo and southward of Favignana; it joins with the lower one with a regular slope.

Scattered morphological highs are present between the two island and south of Favignana and they correspond to the outcrops of the Mesozoic carbonatic substrate.

They are shaped at the top by abrasion surfaces and at the base (-25, -30 m) by tidal grooves (AGNESI *et alii* 1993) (Fig.3).

The depth of the shelf break is steep and stright, denoting a tectonic origin.

Westward and Northwestward of Favignana it is backward eroded while to the South, Southwest of the island it is prograding in some places.

The depositional wedge, interpreted such as a submerged depositional terrace, is located in an area subject to strong erosion and itself is interested to successive erosions; it lays at the edge of the lower shelf at depths ranging from -80, -90 m. It lenghtens in NNW-SSE direction for about 10 km and it extends to a maximum of 2.5 km in width, with thicknesses variable up to 40 m depending on the steepness of the scarp.

It's mainly set up by pelitic sands and sandy pelites (grab sampling).

Northward the terrace thins and ends where the slope is steeper for the backing of the canyon headscarp which separates the Favignana shelf from that of Marettimo; southward it is cut off by slumpings.

Fig. 4 - *Development of the submerged depositional terrace.*

Several depositional phases setting up the terrace can be recognized.

These episodes probably are related to the strong sedimentary stages during the lowstand of the last glacio-eustatic event characterized by numerous fluctuations.

Their respective geometric relations are different, depending from the different evolution of some of the shelf edge: from the bottom currents, from balancing, from different subsidence rate and from the morphology of the shelf lying behind.

During the period the morphology of the area depends from the formation of the isthmus between Levanzo and Favignana and between Favignana and the Sicily, from the long littoral bars and from the incision of the morphological height of the "Secca del Toro" to the South of Favignana (Fig. 3) (AGNESI *et alii*, 1993).

This coastal environment so changeable and subjected to strong bottom currents (testified by several sedimentary structures identified with Side Scan Sonar records nearer to the coast) supplied the sediments setting up the terrace.

Furthermore, the trend of general uplifting of the area somewhere has produced conditions of strong erosion that make the keeping hard for these depositional structures and which have reshaped the depositional terrace with erosion at the top, piles at the base dislocation of the blocks.

Fig. 5 - *Uniboom profile crossing the N-S canyon westward of Favignana. It's the northern examined profile (Fig. 4). The opening of the depositional terrace is at a depth of 80 m, in correspondence of the shelf-edge.*

The steepnees of the slope (amplified by the the vertical exaggeration of the seismic profile, 17x) produces a small development of the sediment thicknesses and of the extension perpendicularly to the wedge.

The end seems to be identified at - 160 m, while the edge, just signed for the terrace surface, is located at about - 94 m.

The coarse grain size of the sediments and the high gradient of the reflectors, prevent the penetration of the seismic signal and the identification of the internal structures of the depositional terrace.

The withdrawing of the head of the canyon causes a marked lateral instability of the sediments that collect at the base of the terrace, forming a convex wedge which partly obstructs the buttom of the canyon. On the opposite side of the canyon, placed against the Marettimo shelf break, it's visible another submerged depositional terrace, even less developed, and placed at different depths.

Fig. 6 - *On the eastern side of the canyon on the Favignana shelf (Fig. 2), three phases of growth of the margin are recognized, identified by breaks of the slope of the sea-bottom..*

The internal structure is scarcely recognizable for the low penetration of the acoustic signaland the strong gradient of the reflectors.

At the base of the frontal scarp of the terrace, a morphological height of sedimentary origin is observed, probably eroded by the currents that occur at the bottom of the canyon. The layers of the weak internal reflectors does'nt seem to be related to the deposits of the eastern slopes. At the opening (at -94 m) a depositional oblique-tangent structure eroded at the top is visible; offshore the deposition continues with a slight angular discordance and with prograding oblique-sigmoidal reflectors, in which it has been recognizable a standstill and a following restarting of the progradational event.

The edge is placed at -106 m and the end, not very clear, seems to be at -178 m.

Fig. 7 - *The shelf is composed by a substrate cut by a rough erosional surface on which prograding deposits lay with a clear morphological break.*

Also in this profile, like in the previous one, three depositional phase can be recognized, marked by light flexures on the sea-floor. The terrace is characterized by transparent acoustic units. It's evident the erosive action of the currents at the base of the slope which were active also during the first prograding phase and have created a low morphology (transfered westward during the time). These currents probably interested the frontal scarp of the depositional terrace, which (unlike the cases shown in the former figures) seem to have greater gradients than the inner reflectors.

The opening is at -106 m, the edge is at -108 m and the close at -144 m.

Fig. 8 - *The prograding structure lays laterally on a terraced slope. The acoustic units are very transparent and it's difficult to recognize the internal structure. Like in 5 b) at the opening (-104 m) the surface is eroded while towards the edge the progradation is a little more clear. Unfortunately a temporary stopping of the acoustic signal acquisition has prevented to point out the base of the depositional terrace; in this record the edge is the only recognizable element, placed at -114 m, while the end of the depositional body (at about -160 m) is partially buried by a light morphological height similar to that noticed in Fig. 5 b).*

In the bottom of the channel the same low erosive morphology is observed.

Fig. 9 - *The shelf break is marked and very steep; a relict depositional structure lays at the base of the scarp. In this case the erosion seems to have interested deeply the body of the depositional terrace till to leve only the basal parts. Only a thin portion (50 m of thick-*

ness) of the terrace has been preserved; it's the remnant of erosion at the centre of the profile, in which the same three depositional phase can be recognized. Regard on this structure only the close is recognizable at about -135 m.

The strong erosion also moves the deposits which cover the bottom of the morphological depression.

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Submerged depositional terraces around Linosa Island (Sicily Channel)

ROMAGNOLI C.*

GEOLOGICAL AND VOLCANOLOGICAL SETTING

The Linosa volcanic apparatus, whose summit gives rise to the Island of Linosa (about 6 Km^2), is located in the Sicily Channel, close to the western border of the Linosa Basin (as deep as 1580 m) (see Fig. 1).

The NW-SE trend of the basin borders and of its depocentre reflects the main structural system that has controlled the evolution of the Sicily Channel since Tortonian times and it is regarded as the surface expression of a generalized right transtensional tectonic regime (JONGSMA *et alii*, 1985; BOCCALETTI *et alii*, 1987; GRASSO *et alii*, 1991).

Fig.1 - *Location map and bathymetry of Linosa Island.*

This tectonic regime originated several pull-apart basins (Pantelleria, Malta e Linosa Basins), which are now filled with Plio-Pleistocene sediments. It also directly controlled the Neogene-Quaternary volcanism (alkaline, peralkaline, and partially tholeiitic) of the Pantelleria and Linosa volcanoes, and of the several minor submarine eruptive centres in the Channel (CALANCHI *et alii*, 1989; ARGNANI, 1993).

The evolution of the apparatus of Linosa is consistent with this regional deformational pattern. A preferential lenghtening along a NW-SE direction is clear from the directional trend of its wide underwater portions, which extend for more than 11 km in a volcanic belt with the same orientation and along which some secondary eruptive centres are aligned (see Fig. 2). The subaerial volcanic activity of the Linosa apparatus is estimated to be between 1,06 and 0,53 million years old and it has been divided into three main evolutionary stages (Paleo-Linosa Syntheme, Arena Bianca Syntheme, and Mt. Bandiera Syntheme; LANTI *et alii* 1988; GRASSO *et alii*, 1991; ROSSI *et alii*, 1996). The distribution of the meso-structures and of the eruptive centres on the island (with an often coeval activity) confirms the WNW-ESE trend, and a secondary NNW-SSE trend as the trends along which there has been a tectonic control on the development of the apparatus.

According to the paleomorphological reconstruction and the analysis of the provenance of pyroclastic deposits outcropping on Linosa, some of the eruptive centres which were active during the three building phases can be located at sea, on the shallower SE and NW flanks of the island, where wide abrasion platforms shallower than 120 m can be found (Fig. 2).

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DATA COLLECTION AND ANALYSIS

In 1988, 1991 and 1992 high-resolution seismic surveys (S.B.P. 3.5 kHz; Sparker 500-1000 J, see Fig. 3) have been carried out by the Univ. of Bologna around Linosa Is., on board the C.N.R. vessels Minerva and Urania. This allowed to reconstruct the bathymetric and morphologic features and characterize the main submerged volcanic structures from a petrochemical point of view (Rossi *et alii*, 1990). The surveys have been carried out by means of a Loran-GPS integrated positioning system; the bathymetric maps have been outlined at 1:25,000 scale. They reveal that the submerged flanks of the Linosa apparatus deepen steeply (with an average gradient of 15°), and with a very complex trend down to a depth of 450-500 m, where the sediments of the surrounding basin area onlap the volcanic basement (Fig. 2).

Fig. 2 - *Bathymetric sketch and main volcanological and morphological features of Linosa apparatus (from Rossi et alii, 1990, modified).*

Fig. 3 - *Bathymetric and seismoacoustic profiles collected in 1988 (Sub-bottom profiler 3.5 kHz; Sparker 500 J) and '91-'92 (Sparker 1kJ).*

Local instability and reworking of the sedimentary cover can often be observed on the steep submerged slopes of Linosa (particularly along the southeast and western flanks). The island is surrounded by a radial network of active canyons which represent a preferential pathway for the sediments transit towards the base of the volcanic apparatus.A few secondary eruptive centres with subconical shape rise on the volcanic flanks of Linosa (Fig. 2) and dam small intraslope basins (as it is in the southwestern sector of the apparatus, Fig. 4).

Wide submerged abrasional platforms, with a subhorizontal trend and an erosional outer edge at a depth of 110-115 m, have been mapped as far as 2 km from the southern and northwestern coast of the island (Fig. 2). Such features, probably early portions of the evolution of the volcanic apparatus which have been largely dismantled by marine erosion, are connected at their northwestern and southeastern borders with a few secondary eruptive centres.

Submerged depositional terraces (i.e. progradational wedges as thick as up to 40 milliseconds, about 30-35 metres) were mapped above and near the outer edge of the abrasional platforms, showing a fairly good lateral continuity and a marked morphologic expression (see Fig. 5 and 9, and Fig. 2 for location). The depositional terraces have been characterized on the basis of the analysis of seismoacoustic profiles, by means of seismoacoustic facies, internal structure, and main depositional parametres, such as the depth of the outer edge and of their upper and lower boundaries. On the other side, there are no direct observations on the lithologies making up these progradational bodies, that are likely to originate mainly from volcanogenic deposits with a medium-coarse grain size, as it seems to be suggested by the high steepness of the foresets.

Fig. 4 - *1 KJ Sparker profile on Linosa southwestern flank. A depositional terrace lies at the edge of the abrasion platform. This is the lower or outer terrace mapped all along the southern sector of the island (see Fig.5). At a greater depth, the sedimentary cover is not in equilibrium on the steep flanks of the volcanic apparatus, and this gives rise to diffuse surficial instability, until the sediment gathers into a small intraslope basin at a depth of 265-270 m. This is dammed by a secondary eruptive centre (whose morphology is partially hidden by diffraction hyperbola in the acoustic signal).*

Fig. 5 - *As far as the southern flank of Linosa apparatus is concerned, it has been possible to map (in milliseconds) the main morphological and depositional features of the two depositional terraces which extend along the island coast for over 4 km, in two subparallel belts (see Fig.2 for location).*

Legend: *1- lower and upper limits of the deposit; 2- depositional edge; 3- erosional edge; 4- secondary eruptive centre.*

The suggested location at sea of the eruptive centres of Cala Pozzolana di Levante and Punta Calcarella has been indicated near the southern coast of Linosa (Lanzafame *et alii*, 1994).

The submerged depositional terraces in the southern sector (Fig. 5) slope down the subhorizontal abrasional platform, following its regular trend. The upper terrace shows a semicircular trend and a thickness of about 40 milliseconds. It is internally characterized by an oblique-sigmoidal progradation, with an increase in the foreset steepness upwards. The morphologically evident depositional edge is almost always located at a depth of 45 metres (60 milliseconds).

Due to the difficulties in approaching the coast, the upper boundary of the terrace has seldom been observed (at a depth of 25-30 m). For the same reason its lateral termination has not been mapped. Its lower limit ranges from 70-75 m in the central sector to about 90 m on the western and eastern ones, where it become prograding onto the lower terrace.

The lower depositional terrace develops near the edge of the underlying abrasion platform and extends from a depth of about 80-90 m to 120-140 m. Its depositional edge is located at an average of 90 m in the central sector of the terrace, tending to deepen a few metres towards SW and SE. The lower terrace is about 20-30 milliseconds thick but it may even reach 40 milliseconds; the internal structure, where it is recognizable from the seismic profiles, appears steeply prograding. Westwards it has been possible to detect the lateral termination of the terrace, beyond which the erosional outer edge of the abrasional platform is still recognizable. Eastwards the terrace extends along the southern flank of a volcanic ridge with a ENE-WNW trend and it develops over a deeper prograding wedge (not mapped in figure). Both the depositional edge and the lower limit of the terrace deepen in this sector (up to 120 m and 140 m; respectively, see Fig. 8).

Fig. 6 - *S.B.P. 3.5 kHz profile of the two submerged depositional terraces to the south of the island. Both progradational bodies show an evident morphological expression and are probably made up of sediments with medium-coarse grain size, as suggested by the low penetration of the acoustic pulse. See Fig.5 for location.*

Fig. 7 - *Sparker 500 J profile (Fig. 5). The innermost upper depositional terrace is internally characterized by a sigmoidal progradation with steeper foresets upwards and basinwards. This terrace lies over an erosional surface and partially extends over the lower terrace which, though not easily detectable on the seismic profiles, seems to be characterized by an oblique progradation and is partially affected by gravitative instabilities.*

Fig. 8 - *1 Kj Sparker profile through the volcanic ridge southeast of Linosa Island (see Fig. 5 for location). A secondary eruptive centre (acoustically deaf) rises up to a depth of 33 m from the top of the ridge, which is bounded on the north by a sharp erosional edge. On the southern side, the lower depositional terrace (mapped along the whole submerged southern flank of Linosa - see Fig. 5) extends with sigmoidal progradation in unconformity over another sedimentary wedge, which develops up to a depth of 200 m (possibly a further depositional terrace?).*

A sharp erosional surface makes up the nearly flat shoal top, detected at a waterdepth of 25-33 m. The flanks of Secca di Tramontana appear to be asymmetric, with a steep eastern side which has an active canyon at the base (see Fig. 2) and a wider western side with a smoother slope, joining to the north-east with a few minor volcanic structures.

This setting is mirrored by the distribution of the depositional terraces: on both sides of the shoal, morphologically quite evident, has been mapped an upper terrace with a depositional edge at about 70 milliseconds (-52 m) and a thickness of about 30 milliseconds. Its upper limit, probably located at a depth of 35-40 m, has seldom been observed in the profiles.; the lower limit has been mapped between 90 and 100 milliseconds (68-75m of depth). Only on the western side, a further deeper depositional terrace has been recognized (Fig. 10), with depositional edge at about 71-75 m and a lower limit at about 90-108 m of depth (but gradually deepening basinwards). Towards the coast, this terrace tends to merge with the upper depositional terrace and even its morphological expression becomes less evident.

Fig. 9 - *Off the northwestern coast of Linosa, submerged depositional terraces develop on both sides of Secca di Tramontana, following the NW-SE trend. Such terraces have been detected up to 1 Km from the coast. From the available seismic profiles it has not been possible to characterize their internal structure, which appear to be generally prograding. The mapping of their main depositional parameters has been carried out also on the basis of morphological*

evidence (see Fig. 5 for symbology).Offshore the NO coast of Linosa, submerged depositional terraces develop both sides of Secca di Tramontana, showing the same alignment in a NW-SE direction (Fig.9).

The supposed eruptive centres of Cala Mannarazza and Secca di Tramontana have been located (*from* LANZAFAME *et alii*, 1994).

Fig. 10 - *3,5 kHz S.B.P. profile of the two depositional terraces observed on the western flank of Secca di Tramontana, showing here distinct morphological features.*

CONCLUSIONS

The available data on the shallower portions of the volcanic apparatus of Linosa allowed the detection and mapping of submerged depositional terraces on the northwestern and southern sector of the island. Their wedge-shaped external geometry, quite clear also from a morphological point of view, shows a good lateral continuity; the internal structure is prograding, as indicated by the high-frequency seismic profiles collected in this area.

In both sectors an upper depositional terrace has been observed. It develops at a waterdepth ranging from 25-30 m to 90 m and its depositional edge is at about 45-52 m. This terrace partially progrades onto a lower depositional terrace, located at a waterdepth greater than 70-80m. The latter has been mapped in the southern and northwestern sector of the island (along the western side of Secca di Tramontana). The main depositional features of the lower terraces show variable depth values in the two sectors opposite the island, probably influenced by the morphology of the underlying bedrock.

Some thought could be given as to the presence (or the preservation?) of the observed depositional terraces, whose positions generally correspond to the location of earlier, wide and flat, abrasional surfaces, bounded by an outer erosional edge at an average depth of 150 milliseconds (-112 m). Such platforms represent the main morphological asymmetry interrupting the steep gradient of the volcanic flanks. They bear witness to the dismantling action, on volcanic apparata, of marine erosion when the sealevel was lower than at present, and/or there was a stage of quiescence in the eruptive activity. This has been frequently observed in the late development of insular volcanoes (CAS *et alii*, 1989; ROMAGNOLI, 1990; ROWLAND *et alii*, 1994; CHIOCCI & ROMAGNOLI, see the present volume). As far as Linosa is concerned the end of the major volcanic activity is chronologically consistent with different sea-level fluctuations occurred during the Upper Pleistocene; moreover, also considering a fast cliff retreat of the island (for Hawaiian basaltic lava, in oceanic regime, rates of coastal retreat of the order of 5 cm per year are reported in ROWLAND *et alii*, 1994), the development of marine platforms extended as far as 2 km offshore should indicate a policyclic origin.

The formation of submerged depositional terraces can be connected to reworking and deposition of sediments on (or at the edge of) previously formed abrasional platforms, during stillstands of the relative sea level at a depth lower than the present one, as during the sea-level rise which followed the glacial acme of about 18 ka B.P. The availability of volcanogenic deposits which fed the depositional bodies of the terraces around Linosa Isl. can be related to the dismantling of the pyroclastic tuff-rings of the eruptive centres of Cala Pozzolana di Levante and Cala Mannarazza/Secca di Tramontana. According to the stratigraphic studies carried on at Linosa, in fact, these centres were located in the shallow submerged areas, to the SE and NW of the island respectively (see Figs. 5 and 9).

It must be emphasized that the abrasion platforms, which record a stage in the development of insular volcanoes such as Linosa during which erosional processes prevailed over the constructional ones, play also an active role in holding at shallow depth volcanoclastic sediments that may, otherwise, undergo gravitational reworking along the steep subacqueous volcanic flanks and be rapidly carried down to the sorrounding basins.

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Submerged depositional terraces along the Ionian margin of Puglia

SENATORE M.R.*

GEOLOGICAL SETTING

The Ionian margin of Puglia, the eastern sector of the Gulf of Taranto, is located between the Valley of Taranto and Puglia and is characterised by a regular deepening from the coast to seaward. It constitutes part of the foreland of the Southern Apennine Chain. The Apulian foreland is a structurally stable zone affected essentially by vertical movements. Above the crystalline basement (MORELLI *et alii*, 1975; ARISI ROTA & FICHERA, 1985) a sedimentary cover is present mainly made up by a Mesozoic and Cainozoic calcareous succession, whose thickness is more than 6000 m (Apulia Unit; D'ARGENIO *et alii*, 1973; RICCHETTI *et alii*, 1988).

Toward the west the Apulia Unit extends underneath the Pleistocene deposits of the Bradano foredeep till the margin of the chain; it is also recovered underneath the apenninic thrust sheets (CARISSIMO *et alii*, 1963; MOSTARDINI & MERLINI, 1986; PESCATORE, 1988). This unit is affected by several systems of vertical and subvertical faults, the older one, with an apenninic trend, can be attributed to the middle Pliocene, the next, with an anti-apenninic NE-SW and E-W trend, can be dated from the late Pliocene (BALDASSARRE *et alii*, 1978; CIARANFI *et alii*, 1979). During the Quaternary no significant vertical movements were recorded.

In the sea, along the yonian margin of the Puglia, the Apulia Unit collapses toward the chain and is affected by normal faults that set up a horst and graben structure. The grabens are filled with Plio-Quaternary sediments (AGIP, 1977; TRAMUTOLI *et alii*, 1984; PESCATORE & SENATORE, 1986; SENATORE, 1987).

The structure of the eastern sector of the Gulf of Taranto was included by SENATORE (1988) into the genetic models of the foredeep/foreland systems.

THE CONTINENTAL SHELF

The continental shelf of the eastern sector of the Gulf of Taranto has a width with a range between 1 km and 20 km and a slope between 1° and 2°. Its shelf-break is located at an average depth of 110 m.

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Three orders of terraces at depths of 25/30m, 50/60m and 110/120m were located (SENATORE *et alii*, 1980; PENNETTA *et alii*, 1987). On the edge of these terraces, especially the one at -50/60m, coralline algal banks can be found (PERES & PICARD, 1964; SARÀ, 1967).

The sediments on the shelf are made up of sorted sands ranging from very coarse to very fine (PENNETTA, 1985); generally these sandy grains are made up of bioclastic carbonate fragments which come from the coralline algal banks broken away by the wavy motion (PESCATORE, 1985). The grain size characteristics of such sediments indicate a transport by traction and saltation (PENNETTA, 1985).

The $CaCO_3$ content is normally higher than 90 % and is due to the bioclastic fraction (BELFIORE *et alii*, 1981). As regards to the Ostracod and Foraminifera assemblages, the shelf is characterised by a normal diversification of species, from the coast seaward. The infralitoral zone is characterised by species belonging to Miliolidae, Discorbidae, Elphidiidae; fragments of briozoi, molluscs and plates and radioli of Echinoids can also be found (MONCHARMONT *et alii*, 1985; BONADUCE *et alii*, 1985). It can also pointed out (PESCATORE, 1985) that the shelf and the ionian margin of Puglia are characterised by the presence of species whose geographical distribution is confined to the Levantino Basin; such species are completely absent in the Western sector of the Gulf of Taranto.

Fig. 1 - *Location map of the eastern sector of Gulf of Taranto. Bathymetry is in metres. The depositional edge (toothed line) of the terrace at depth of 110/120m and seismic lines shown are reported (lines with letters). The terrace has developed almost in continuity along the most part of the ionian margin of Puglia; where it is present, it also represents the physiographic break of the continental shelf.*
Its width is about 1 km whereas its slope is approximately 2°.

COLLECTION AND ANALYSIS OF DATA

From 1978 the Department of Earth Sciences of Naples, in collaboration with Italian and foreign researchers, have carried out joint researches in the Gulf of Taranto within the "Progetto Oceanografia e Fondi Marini" with the aim of studying the dynamics of the waters and the sedimentary and structural phenomena that control the development of the gulf. Detailed studies were carried out on the structure, the morphology and the sedimentary processes of the continental shelf, for the potential use of these areas.

From 1978 to 1982 five oceanographic cruises with C.N.R. ships Marsili and Bannock were carried out. Sparker profiles at 6000 J, high resolution profiles (Uniboom 1000 J and EDO 3.5kHz) and Side Scan Sonar were collected. Gravity cores, dredges (cylindrical and triangular) and grab Shipek were used to collect samples.

The location of the seismic profiles and the samples was settled with the Loran C Decca and Satellite Decca positional systems.

In 1987 a new oceanographic cruise with the Bannock ship, was carried out with the aim of fulfilling the data already collected and of studying the sedimentary processes that occur in the Valley of Taranto. During this latter oceanographic cruise Sparker profiles 1kj, EDO 3.5 kHz and Side Scan Sonar were carried out, mostly in the Apulian sector of the gulf.

To make in plan the obtained data a base map at the scale 1: 100,000 and 1: 250,000 was used with a bathymetric contour made by DIPLOMATICO *et alii* (1985). Although the Apulian continental shelf is characterised by three orders of terraces in all its width, only the terrace at a depth of 110/120 m presents morphological and depositional characteristics to be mapped. The depositional edge of the terrace was reported in all the areas where it was recognised; in the showed cases even the parameters of the lower and upper margin of this terrace were reported in plan. The lateral variability was controlled by comparing the depths, the seismic facies and the reflections geometry. All the terraces are characterised by progradational seaward reflections that have been connected to at least two regressions and lowstand of the sea level which probably occurred from middle Pleistocene.

Fig. 2 - *Line drawing across the Apulian continental shelf. Three orders of terraces are observed. The border of the deepest terrace represents the shelf -break. The sediments present at the bottom are made up of calcareous bio-*

clastic sand ranging from fine to coarse (PESCATORE, 1985); *such sediments, on profile with 3.5kHz frequencies, created insufficient or almost no penetration of the seismic waves. At the edge of the terraces of -50/60 m and -25/30 m coralline algal banks are present (BC).*

Fig. 3 - (**a**) *3.5kHz profile located to the south of Taranto. The deposits that make up the terrace are characterised by an echo with an indistinct bottom and discontinuous reflections in the subbottom, which indicates the presence of sandy sediments that are of bioclastic origin* (PESCATORE, 1985). *The reflections on the profile show a seaward dip of about 4°.*

*A sub-horizontal reflection (*R*) can be observed. It divides the terrace in two depositional bodies (*1.a - 1.b*); the terrace therefore results linked to at least two cyclic events of a width most likely similar.*

On the right of the figure a morphological step, without the development of a terraced surface is visible.

On the right (**b**) *the principal depositional parameters of the terrace have been reported.*

Fig. 4 - *3.5kHz profile located to the north of Torre dell'Ovo* (B *in* Fig.1). *The profile shows the upper depositional body (*1.a*), characterised by progradational reflections in downlap on the* R *reflection and with a seaward slope of about 2°. The lower depositional body (*1.b*), underneath* R, *is made up by clinoforms seaward prograding.*

On the right (**b**) *the depositional parameters of the terraces have been reported.*

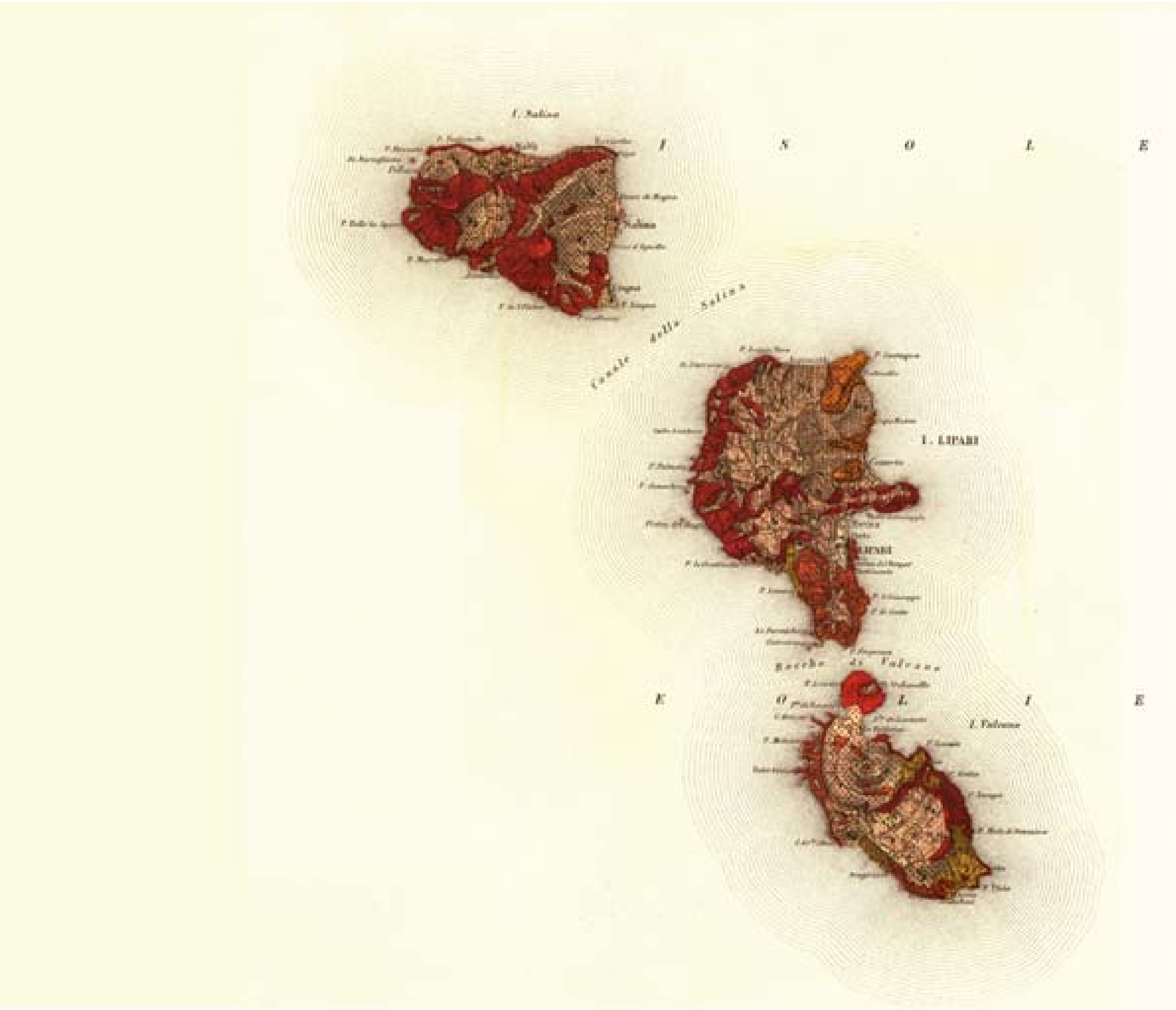
Fig. 5 - *3.5kHz profile located seaward of Gallipoli (*C *in* Fig. 1*). The terrace is again made up of two superimposed depositional bodies.*

*The more superficial (*1.a*) characterised by lack of penetration of the seismic waves because of the presence of sand, is interested by a morphological relief that confers to the surface of the terrace, usually smooth, a rough topography. Analogously with similar structures recovered seaward of Cilento by* COPPA *et alii (*1996*), such a body could be interpreted as part of a submerged beach emplaced during the lowstand of the isotopic stage 2. The deeper depositional body (*1.b*) is constituted by clinoforms with a seaward dip of about 5° .*

At the margin of the terrace, the reflections indicate that there are frequent slumping phenomena.

On the right (**b**) *the depositional parameters of the terrace are reported.*

SHORT RECORDS



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Recording of submerged depositional terraces in the Gulf of Pozzuoli (Campania, Southern Italy)

SENATORE M.R.*

Fig. 1 - *The Gulf of Pozzuoli representing the southern part of Phlegrean caldera is a bay of small dimensions seaward bordered by several submerged volcanic banks. Several morphological units have been individuated in the gulf* A) *a coastal shelf extending up to 50 m of depth* B) *a central basin with a maximum depth of 100 m separated by the coastal shelf by a gentle dipping slope;* C) *a belt of volcanic bank (Miseno Bank, Penta Palummo Bank and Nisida Bank);* D) *an external continental shelf with a break at a depth between 140 and 150 m* (PESCATORE *et alii,* 1984; PESCATORE *et alii,* 1988). *The banks margins and the external continental shelf are characterized by the presence of depositional terraces with prograding internal structure.*

Fig. 2 - *Sparker profile 1kJ crossing the eastern sector of the Miseno Bank and the external continental shelf (*2 *in* Fig.1*).*

At the north-western margin of the Miseno Bank a depositional terrace is observed. It is prograding with clinoform reflections at high dip. The upper part of the terrace is not visible because of the high ringing of the bottom reflection, it seems therefore possible to infer the presence of a marine erosional surface covered by a thin drape of recent sediments. At the south-eastern margin of the continental shelf a prograding depositional terrace is observed with wider external dimensions. The internal clinoforms have a high dip increasing upward in the more recent levels. The dip of the more recent levels is coincident with that of the continental slope. Also in this case the upper part of the terrace is not observable because of the presence of high ringing on the profile.

Fig. 3 - *Sparker profile 1 kJ carried out through the eastern sector of the Penta Palummo Bank up to the break of the external shelf (*3 *in* Fig. 1*).*

At the north-western margin of the bank a prograding depositional terrace is observed. It is constituted by clinoforms with high dip. The upper part of the terrace is hidden by the ringing.

At the south-eastern margin of the bank up to the shelf two depositional terraces are visible placed one upon another; the deeper one is characterized by clinoforms with very high dip coincident with the dipping of the slope; the shallower one is constituted by clinoforms with low dip. The latter are not very well distinguishable because of the presence of ringing. The two terraces have been correlated to two different cycles of relative sea level change occurred from 18 ka to the Present and linked to the interplay of volcano-tectonic phenomena, eustatic variations of the sea level and sediment supply (BUDILLON *et alii*, 1988).

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Recording of submerged depositional terraces at the margin of the Capri Island (Campania, Southern Italy)

SENATORE M.R.*

Fig. 1 - *The Gulf of Naples is the seaward prolongation of the Campania plain an area affected by volcano-tectonic phenomena during Pliocene and Pleistocene. The Phlegrean Fields and Somma-Vesuvius volcanoes represent the northern side of the gulf; the Somma -Vesuvius is connected to an anti-apenninic fault that divided the gulf in two sectors: the southern one in which the calcareous substratum outcropping in the Sorrento Peninsula and Capri Island, is present below a sedimentary cover with normal thickness and the northern one in which the volcano-tectonic phenomena are intense. At the southern side of the Sorrento Peninsula and Capri Island is located another normal fault with anti-apenninic trend.*

In the above map the bathymetry is in meters, the shelf break (toothed line) and, in gray, two areas with high rate of sedimentation during the late Pleistocene age. The seismic line (2) shown is reported.

Fig. 2 - *Sparker seismic profile (6kJ) located on the continental shelf west of Capri Island (2 in the previous map). Southward the continental shelf is bordered by the anti-apenninic normal fault lowering calcareous units toward the Gulf of Salerno. At the southern margin of the profile a depositional body lying on a succession probably Pleistocene in age is present. It is constituted of reflections southward prograding. They are about 3° dipping. The external shape of this deposit is regular and it is a wedge southward thickening. The high ringing of the bottom reflection does not allowed the detailed observation of the upper part of the depositional body but it seems therefore possible that a marine erosional surface is present located very close to the bottom. It cuts the upper part of the prograding body.*

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Recording of submerged depositional terraces offshore of Licosa Head (Campania, Southern Italy)

SENATORE M.R.*

Fig. 1 - *Location map of the studied area; the bathymetry is in meters* (BUDILLON *et alii*, 1994; FERRARO *et alii* 1997).

Offshore of Licosa Head at a depth between 120 m and 160 m a depositional terrace is developed.

The lines with numbers are the reported seismic profiles, the black dot is the core of Fig 3*, the dotted area represents a depositional body made up of sand that is located at the margin of the depositional terrace.*

Fig. 2 - *3.5 kHz profile located offshore of Licosa Head* (1 *in* Fig. 1).

The depositional terrace is characterised by prograding reflections (offlap) in the upper part of which smaller depositional bodies (Cs) are present. The depositional bodies are characterised by lacking of reflections in the sub-bottom on this kind of profile indicating the presence of sand deposits with very high reflectivity. The depositional bodies, with an irregular shape are developed parallel to the present-day coast-line for about 23 km.

The offlap reflections and the depositional bodies are cut by a quasi-flat erosional surface, in some places with rough topography. A thin drape of Holocene sediments rest on top of the erosional surface but they are non visible on this kind of profiles. The erosional surface has been correlated to the last transgression started at the end to the lowstand of isotopic stage 2.

Fig. 3 - *Gravity core collected at the margin of the terrace on a more external depositional body at a depth of 149 m. The core is 73 cm long.*

Holocene and late-glacial sediments: Ag - clay; Pf - pumice fall deposits of the A.D. 79 Vesuvius eruption (Pompeii Pumice, LIRER *et alii*, 1973); *Ags - silty clay; Si - silt; Sm - medium sand with abundant molluscs shells.*

Late Pleistocene sediments: Sg - coarse sand with abundant broken and unbroken molluscs shells; a broken shell of Arctica islandica (A.i.) is also present.

ln - sharp contact; lg - gradational contact; le - erosional contact.

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The coarse sand (Sg) has been interpreted as part of a submerged beach (shoreface) and has been correlated to the lowstand of the isotopic stage 2 (FERRARO *et alii*, 1997)*;* the sharp contact (ln) between the coarse sand and the upper medium sand has been correlated to the erosional surface observed on the seismic profile in Fig. 4 (ravinement surface, Thorne & Swift, 1991) cutting the offlap reflections.

The sediments above the sharp contact (ln) characterised by an upward decreasing in size (Sm, Si, Ags) allow to infer a sea progressively deeper; they have been even correlated to the last transgression of the sea level.

The clay sediments (Ag), with Pompei Pumice (Pf) representing the chronological level of about 2 ka have been referred to the Holocene highstand.

Fig. 4 - *Sparker profile* 1kJ *located to south of Licosa Head* (2 *in* Fig. 1).

Offlap reflections cut by the ravinement surface, and clinoform reflections seaward resting on different downlap surfaces. The clinoforms that are prograding to a smaller scale with respect to the offlap reflections, are located in correspondence of the depositional bodies made up by coarse sand (see core in Fig. 3).

The offlap reflections have been correlated to the regression of the sea already started in the isotopic stage 5 and culminated during the lowstand of the isotopic stage 2 with the sea level at a depth of 120 m (TRINCARDI & FIELD, 1991; FERRARO *et alii*, 1997). The prograding succession is attributed to a fourth order eustatic cycle; the depositional bodies interpreted as part of submerged beach with an age seaward more and more recent, are to be considered linked to different episodes of fall and rise of the sea attributed to higher frequency cycles (5° order) occurred during the general regression of the sea level during the isotopic stage 4, 3 and 2.

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Recording of submurged depositional terraces in the Western Aeolian Islands (Alicudi and Filicudi)

ROMAGNOLI C.*

Submerged depositional terraces, as defined in detail in the central and eastern sectors of the Aeolian Archipelago by means of a specific survey (CHIOCCI & ROMAGNOLI, this volume), were already noticed also in the western one (Alicudi and Filicudi Islands) after the oceanographic surveys carried out in the years 1987-92 aboard the R/V "Minerva" and "Urania" (C.N.R.) and supported by the National Group for Volcanology (ROMAGNOLI, 1990; CALANCHI *et alii*, 1995).

Volcanic activity at Filicudi represent one on the earlier subcrinal manifestations of Aeolian volcanism. It is the emerged part of a volcanic belt extending for over 30 km is a NW-SE direction. Alicudi on the contrary is the top of a stratovolcano having a regular subconical shape, relate to central volcanic activity without significant migration of the feeding conduit (CALANCHI *et alii,* 1995).

Fig. 1 - *Bathymetric setting of the western Aeolian Islands* (from CALANCHI *et alii*, 1995, *modif.*). *Similarly to what observed around other volcanic apparatuses, shallow-depth (down to -110 m extended) abrasion platforms are present around Alicudi and Filicudi (and on top of Banco di Filicudi). They are preferential site for the development and preservation of submerged depositional terraces, which prograde onto them expecially in correspondance of those coastal sectors rich in volcaniclastic deposits.*

Fig. 2 - *3D representation of the Alicudi apparatus down to 1500 m depth* (*from* ROMAGNOLI, 1990). *A clear asymmetry is noticeable in the shallow submerged portions of the volcanic edifice (which nevertheless shows a rather regular conical shape), due to the presence of an abrasion platform extended some hundreds metres transversally to the coast. It is present only off the northern and western coasts of Alicudi, where the oldest volcanic products* (*about 120 ka old,* GILLOT & VILLARI*,* 1980) *crop out; this setting suggests a chronological gap between the first constructive stages of the apparatus, which was subjected to erosional processes during the Late-Pleistocene relative sea-level fluctuations, and the recentmost volcanic activity, associated to a slight southeastward migration, mainly topographically-controlled, of the eruptive axis* (ROMAGNOLI & TIBALDI, 1994).

Fig. 3 - *500 J (line* **a**) *and 300 J (line* **b***, see* Fig. 1 *for location) Sparker profiles around the Alicudi and Filicudi Islands. Due to the sub-conical shape of the island and to difficulties in approaching it with the ship, the record of sesimic profiles normal to the coast was unfeasible in shallow-water.*

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A depositional terrace is evident, nevertheless, in the profile parallel to the northern and western coast of Alicudi (line **a***), showing variable thickness (up to 35-40 msec) in conformity with the morphology and, probably, the different erodibility of the underlying volcanic structure. The central portion of the seismic section, in fact, where the thickness of the depositional terraces thins out above a morphological high of the erosional surface (indicated with arrows), corresponds to a sector where the coast cuts a dense swarm of dykes and sills with a nearly radial pattern, suggesting the vicinity of a feeding conduit relative to the older activity of Alicudi* (MANETTI *et alii*, 1989). *The submerged depositional terrace pinches out in correspondance with the disappearance of the underlying abrasion platform. Profile* **b** *is parallel to the northern coast of Filicudi. Most of the coastal area of Filicudi is bordered by a submerged abrasion platform, locally interrupted by major erosional features; its extension is greatest offshore the western coast of Filicudi, where it prolongs as an elongated shoal, on which some islets and the emergent neck of La Canna are located. The continuation offshore of sub-volcanic coastal features (such as dyke systems) is generally reflected in the submerged setting: this is the case of Filo del Banco or the shoal connecting Filicudi to La Canna, which correspond to less erodible portions of the abrasion platform. Laterally to them, clinostratified depositional bodies with thickness up to 35 msec can be observed, lying on the abrasion surface and representing the main sedimentary accumulation above it (unfortunately, the lacking of profiles transversal to the coast does not allow their characterization as regards geometry and depth).*

Fig. 4 - *1 kJ Sparker profile of the two submarine centres of La Canna and Banco di Filicudi (line* **c,** *location in* Fig. 1*). An abrasional surface is quite clear on top of Banco di Filicudi (minimum depth: 60 m), which is bordered by an erosional edge lying at - 90/-112 m near the northern and western sides of the bank and at -75 m on the southeastern side; this is probably the result of differential erosion of this volcanic feature, whose activity was probably coeval to the subaerial growth of Filicudi. Both at the SE edge of Banco di Filicudi and on top of La Canna the sign of prograding wedges of limited thickness (circa 15 msec) is present, in agreement with the sedimentary starvation on top of both banks.*

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Recording of submerged depositional terraces in the Adventure and Graham Banks (Sicily Channel)

ROMAGNOLI C.*

Fig. 1 - *The Adventure Bank represents a large portion of the southwestern Sicilian continental shelf cut in a tectonized substratum of Mesozoic to Neogenic rocks. The subhorizontal marine abrasional surface lies at an average depth of 80-90 m and is related to the low-stands of Late Quaternary sea-level fluctuations* (COLANTONI *et alii*, 1985). *The top of the bank is studded with rocky outcrops of carbonatic, terrigenous and volcanic nature, representing erosional remnants and local sources for the present-day shelf sedimentation. Strong currents isolate the bank from most continental sediment supply. For this reason, the recent and present-day sedimentation (just a few metres of thickness in the depocentres) is mostly authigenic, made up of carbonate, ill-sorted sands rich in skeletal debris of organisms and of biogenous concretions* (COLANTONI *et alii*, 1985). *East of the Adventure Bank, isolated from the continental shelf, a wide plateau (less than 200 m deep) lies. It culminates in the Nerita and Terribile Banks (which consists of sedimentary rocks) and in the Graham Bank (Fig.1 b, from* CALANCHI *et alii,1989). The latter one is best known for the episodes of volcanic activity which, in 1831, led to the emersion of a short-lived volcanic island (Julia or Ferdinandea Island). Presently the top of the Graham Bank lies at about 8 m of minimum depth* (CALANCHI *et alii*,1989). *The Nerita and Terribile Banks are cutted, at depths shallower than 100 m, by wide subhorizontal abrasion surfaces which can be referred to the low-stand reached during the last glacioeustatic minimum. Prograding depositional terraces have been recognized at the western edge of the Adventure Bank* (COLANTONI *et alii*, 1985) *and on the central-eastern portions of the Graham Bank (Nerita and Terribile Banks).*

Fig. 2 - *The shelf edge in the Adventure Bank is located at water depths ranging from 83 to 170 m* (COLANTONI *et alii*, 1985); *the latter value is encountered in the southern and eastern part of the Adventure Bank, where the shelf-slope transition is very gradual due to a large amount of sediments. On the contrary, the shelf break is very sharp at the western margin; prograding features, both buried beneath the sea-floor and outcropping, have been observed in the southwestern and northern sectors of the bank. In this Sparker profile (location in* Fig. 1*; from* COLANTONI *et alii*, 1985) *a submerged depositional terrace of approximately 30 msec of thickness is visible, outcropping at the western border of the Adventure Bank. It forms the last set of sigmoidal prograding units, suggesting the possibility of a southeastern tilting of the sector since the Upper Pleistocene.*

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Fig. 3 - *S.B.P. 3.5 kHz profile (location in* Fig.1b*) along the western edge of the Nerita Bank. Submerged depositional terraces have been recognized on both flanks of the Nerita Bank (which is aligned in a NNE-SSW direction and shows an erosional surface at about 50 m of depth) and all along the eastern and northern flanks of the Terrible Bank. They are formed by prograding bodies 25-35 msec thick, with subhorizontal upper surface and steep frontal slope. The depositional edge has been generally observed at 150-160 ms (110-120 m of depth) and the terrace pinches out at about -150 m. The regular extension of the depositional terraces, which parallel the eastern edge of the Bank for a 15 km-long tract, corresponds to the relative constancy in their pattern and depth range. These latter features, moreover, show analogies with the submerged depositional terraces studied in the nearby Linosa Island (*ROMAGNOLI*, this volume), where formation of SDT has been related to low stands of the relative sea level. In particular, the present-day depth of the depositional terraces in the Nerita and Terrible Bank suggests that their deposition might have occurred during the low-stand of the Last Glacial Maximum (around 18 ka ago).*

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Recording of submerged depositional terraces in the Amendolara Bank (North Ionian Sea)

ROMAGNOLI C.*

Fig. 1 - *Located in the western Gulf of Taranto, on the Calabrian coasts, the Amendolara Bank is part of a series of structural highs running NW-SE and tectonically-controlled by extensional faults in the same direction; they probably represent the offshore extension of the Valsini Horst* (ROMAGNOLI & GABBIANELLI, 1990). *Along the northwestern flank, the bank is divided from the continental shelf by a narrow depression of erosional and structural origin.*

On the top of the bank, an unconformable surface is related to subaerial erosion and marine abrasion occurred during the Late Quaternary glacio-eustatic low-stands; from this surface a few rocky culminations rise (the highest of which is at -26 m). The present-day marine dynamics on the top of the bank leads to the disgregation of the coralligenous concretions and result in a rocky and sandy uneven seabed (ROSSI & COLANTONI, 1976).

The energy of the (mainly southward-directed) currents on the seabed is also witnessed by the observation of bedforms such as discontinuous ripple-marks, showing wave lenght of 60-80 cm, E-W oriented crests and a selection of algal fragments in the ripple troughs (ROSSI & COLANTONI, 1976). *Below - 50 m of depth, surficial sediments are composed of clayey sands and loam and, gradually downward, bioturbated muds; terrigenous sediments reflect in most part the continental supply and the transport from currents.*

Fig. 2 - *On the top of the Amendolara bank the seafloor is generally acoustically deaf, in conformity with the coarse-grained character of the sediments (bioclastic sands and loam) which alternates, at variable depths, with wide rocky outcrops made up of coralligenous bioconstructions* (ROSSI & COLANTONI, 1976). *Nevertheless, a wedge-shaped depositional terrace is recognizable near the margin of the bank (location of the S.B.P. 3.5 kHz profile is in* Fig. 1*). Within the recent sedimentary units on the flanks of the Amendolara Bank it has been identified a clear angular unconformity (U); it has been correlated with a regional unconformable surface which appears, on the nearby continental shelf, as a relatively flat erosional surface truncating earlier prograding units and lying at 90-150 m below the present sea-level* (TERZI, 1986; ROMAGNOLI & GABBIANELLI, 1990). *This unconformity has been interpreted as an erosional surface related to the regression that marked the Last Glacial Maximum (about 18 Ka ago;* DE MAIO *et alii, 1979); moreover it represents the base of the sedimentary sequences deposited during the following transgressive and high-stand stages of Late-Pleistocenic-Holocenic age. On the Amendolara Bank the thickness of the post-glacial deposits shows minimum values (a few metres) and thins out in correspondance of the depositional terrace. Due to their steepness, the flanks of the bank (particularly the ones southwest-oriented, cutted by neotectonic lineaments) are prone to gravitative instability and to slumpings.*

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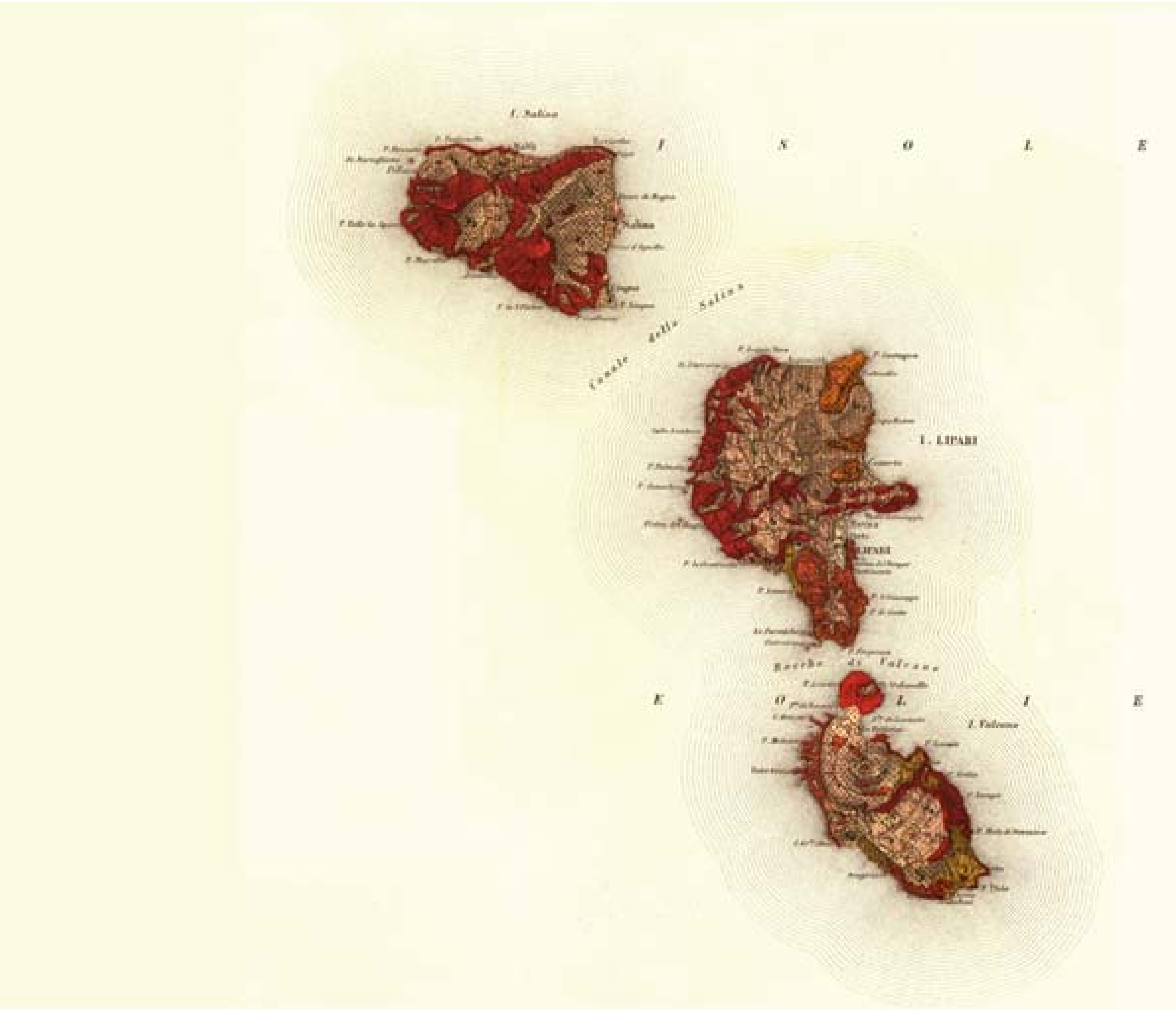
Fig. 3 - *S.B.P. 3.5 kHz profile on the Amendolara Bank* (*location in* Fig. 1; *from* TERZI, 1986). *At both sides of the banks the presence of depositional terraces can be distinguished; the better defined one lies on the south-western margin of the bank and shows a depositional edge at about 120 ms of depth (-90 metres). It is composed of a prograding body about 25 msec thick which pinch-out at approximately 160 msec of depth (-120 m).*

OTHER CONTRIBUTIONS



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Distortion in sdt shape as depicted in high-resolution profiles and the re-establishment of correct geometies (seismic migration)

CHIOCCI F.L.*

DESCRIPTION OF THE PHENOMENON.

The reflections generated by the single-channel seismic prospection can be seen as the response of the sea floor to a sound wave. Given that in these types of prospection the energizing source is very near to the receiving sensors, only the rays having normal incidence to the reflective surfaces are registered in the seismic sections and the arrival time is proportional to their depth, according to the waves speed in the media where they travel (water and sediment). Therefore, this type of survey gives a rather correct and detailed image of the sea floor (in function of the vertical and horizontal resolution of the prospection), especially in the case of horizontal or weakly inclined surfaces. On the contrary, in the case of complex geometries, the acoustic image undergoes a distortion because every single reflection is tought to came (and represented) directly below the seismic receivers, independently of the point in which the reflection actually originated. In the case of reflections coming from an inclined layer, this procedure creates an apparent slope with a less-than-actual dip.

The phenomenon increases with depth, with the speed of the medium where the wave travels and with the dip of the reflector.

Fig. 1 - *Geometric distortion of the seismic image of an inclined reflector. The real reflector* A-B *produces the seismic image* A'-B'*, with an underestimation of the actual depth increasing with depth and, therefore, with a reduction of the apparent dip.*

With digitally acquired exploration seismics data, the actual dip is re-established through the migration processing that, through complex algorithms, reports the reflections in their "correct" positions within the profile (YILMAZ, 1987). It is not, however, possible to correct the effects due to reflections caming from points that are external to the profile plan.

In the case of single-channel, high-resolution seismic profiles, such correction is not usually applied, because the data are usually acquired in analogic form, and because the reflectors of the very recent deposits are sub-horizontal enough and the depths investigated are not excessive.

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Nevertheless, the submerged depositional terraces have in some cases been depicted as having an apparent slope of the internal foresets and of the frontal slope up to 20°, suggesting that it is possible to have some distortion of the geometry of the reflectors.

This hypothesis is strengthened by the following circumstances: a) the base of the frontal slope is always connected in an extremely abrupt manner to the sea floor in front of it; b) sometimes it is possible to observe the intersection between the reflection of the lower part of the frontal slope and the reflection of the strata on which the SDT rests (for such an example, see the seismic profile of Fig. 2 or Fig. 30 of CHIOCCI & ROMAGNOLI, this volume); c) the reflections inside of the SDT, when they are not dipping too much, show a sigmoidal geometry with a tangential termination of the bottomsets on the basal surface. On the contrary, the external surface of the SDT often shows a convex form; d) as a result of the greater horizontal displacement of the reflections, the distortion of the seismic image is greater for the deeper terraces respect to the shallower ones, as it can be observed in the two terraces of Fig. 5 in CHIOCCI & ORLANDO (same volume).

MIGRATION OF THE DATA

In order to quantify the distortion of the external surface of the terrace, the migration is applied to a seismic profile choosing, for example, the submerged depositional terrace of Fig. 2. Given that the data were acquired in analog form, the external geometry of the terrace was manually resampled.

Then, the profile was replotted with the vertical axis expressed in depth, using the speed of 1500 m/s (the sound speed in water) for time/distance conversion. Vertical exaggeration was eliminated from the profile in such a way as to be able to apply the migration with the semi-circumference method (BADLEY, 1985). The result is the synthetic model reported in the figure below.

Fig. 2 - *Sismic profile on the eastern flank of Palmarola Isl.* (CHIOCCI & ORLANDO, *this volume*).

Fig. 3 - *Migration of the profile in fig. 4 of the article of* CHIOCCI & ORLANDO *(this volume). In the upper left the line drawing of the original seismic profile is reported for only the bathymetric surface, sedimentary substrate and some internal reflections. One can observe how the tail of the reflection of the frontal slope of the SDT intersects the sea floor. Below, the same profile is represented in depth sections (values in parentheses). The profile was represented without vertical exaggeration, which normally notably affects high-resolution seismic profiles.*

A semi-circumference was traced, centered on sea level at regular intervals (points in color) on the vertical of each point. Every semi-circumference represents the location of all possible points of origin of the wave received by the sensors. The enveloping of the semi-circumferences so traced represents the migrated bathymetric surface. There every point shows up as slanting rightward and upward along its own semi-circumference, with this effect increasing with the depth and with the slope of the reflection surface. At top center, the same procedure is reproduced on the profile affected by vertical exaggeration (in this case, the semi-circumferences look like semi-ellipses). At top right the migration procedure is reported.

One can observe: 1) an increase in the slope of the frontal slope (from around 20° to around 25°) and of internal reflectors; 2) the disappearance on the intersection between the foot of the slope and the sea floor in front of it; 3) the lack of reflection from the lowest part of the same slope that could therefore have had a tangential geometry (hypothesized in red in the blow-up); thus it can be very different from the apparent geometry in the seismic section; 4) a substantial lack of effect of the migration with respect to the nearly flat top of the terrace.

Fig. 4 - *Relationship between apparent and actual slopes in seismic profiles reported in depth sections and without vertical exaggeration.*

Making reference to the scheme in Fig. 1, one can observe that the LM segment represents a cathetus of the triangle A'LM but also the hypotenuse of ALM. Consequently, the sine of the actual angle (Qr) is equal to the tangent of the apparent angle (Qa).

One can observe how the difference between the actual slope and the apparent slope would be very low for slightly inclined reflectors and instead, would become very high for reflectors sloping some 10-20 degrees. Reflectors dipping more than 45° are not seismically depictable. The right half of the quadrant at the top right refers to reflectors sloping more than 90°, for which the reflection is obviously not detectable. The bottom left quadrant refers to reflections that originate above the water's surface.

It is important to observe how the migration procedure is thought to be effective only in the case of a seismic profile whose direction roughly coincides with the dip of the strata; in strike over sloping strata, the migration cannot work in that reflections originate from points outside the profile plan. Obviously, the migration has a slight effect for all the profiles between strike and dip direction.

CONSIDERATION ON THE EFFECTS OF THE GEOMETRIC DISTORTION ON THE INTERPRETATION OF THE SUBMERGED DEPOSITIONAL TERRACES

Even if in high-resolution seismic profiles the geometric distortion is usually very light, in the case of the SDTs one must consider that the seismic sections are "acoustic" images of the sea floor and sub-sea floor. Given that the SDTs are often characterized by slopes of up to more than 20°, the distortion can even be relevant. The knowledge of such phenomenon is important for the depositional interpretation based on the seismic features.

In general, it is possible to state that the abrupt contact often observed between the foot of the frontal slope and the sea floor in front of it is very likely to be an artifact; thus it is quite possible that the contact is far more gradual and even tangential. This fact is particularly relevant when comparing the SDT of relatively shallow depth with the deeper SDT (the distortions, in fact, lessen with diminishing depth).

For further information, see Fig. 5 of CHIOCCI & ORLANDO (this volume). Submerged depositional terraces with very sloping reflectors can even show an apparent acoustical transparency thta is not tied to the physical characteristics of the geological body but rather to the inability of the surveying methodology in detecting very inclined reflectors. The actual dip of the prograding foresets and of the frontal slope can also be slightly greater than those depicted (even 10-20%). This phenomenon, together with the fact that the seismic profiles don't always coincide exactly with the dip direction of the strata (either sea floor or the internal reflectors), must make one consider the slopes shown in the seismic profiles as underestimated with respect to the actual slopes.

This fact assumes a particular relevance when one wishes to compare the slopes with the mechanical characteristics of the sediment (for example, the angle of friction) in order to verify hypotheses on depositional mechanisms tied to gravitational flows. For this aspects, see caption of Fig. 30 of CHIOCCI & ROMAGNOLI (this volume).

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Coastal terraces in sub-aerial environment: state of the art

SPOSATO A.*

Since the beginning of the last century, several authors recorded Quaternary marine deposits uplifted with respect to the present sea level (DEPÈRET , 1906, 1918; ISSEL, 1914; GIGNOUX, 1911; ROVERETO, 1923, 1939). SELLI (1962) studied the relation between the Quaternary eustatic level variation and the vertical tectonic movements trying to understand the relation between the Quaternary marine deposits and the terraced morphologies. He pointed out the importance of relative stability, even if temporary, between sea level changes and tectonic movements. His hypothesis evidenced, for instance, a possible relative tectonic stability between a rising phase of the eustatic level and the tectonic uplifting of the area.

Studies about Quaternary climatic changes and the consequent eustatic variation (TOOLEY, 1993; SHACKLETON, 1987; MORNER, 1978; GORNITZ, 1993; AHARON& CHAPPELL, 1986; VESTAPPEN, 1980) evidenced that the latter generally show high rising rates. This fact makes possible a relative standing phase in moments approaching or corresponding to the reversal trend of the eustatic curve.

Chappell (1974, 1983) and other authors (BLOOM *et alii*, 1974; OTA, 1994) put the formation of terraces in direct relation to interglacial periods or, better, to the high standing phases of the eustatic level. They used the curve of climatic variations represented by $\delta^{18}O$ record (EMILIANI, 1955; SHAKLETON & OPDYKE, 1973) and radiocarbon age measurements on marine terraced deposits at Huon Peninsula (Papua New Guinea). In Fig. 1a the climatic curve of BASSINOT *et alii*, (1994) is shown.

Moreover, in 1986 CHAPPELL & SHACKLETON (Fig. 16) presented the first reference eustatic sea level curve for the Middle-Upper Quaternary reconstructing the elevation of the sea level high standings on the basis of the continuity of the uplift movement in the Huon peninsula.

Fig. 2 - Schematic diagrams representing the relations among the main factors concurring to eustatic sea-level variations.

The coastal geological evolution is connected:

- directly, with the relative variations of the sea level
- directly or indirectly, with the factors concurring to the rate of the sedimentary input along the coasts
- with the environmental parameters related to the continental, coastal and marine environments.

Marine terraces are the direct consequence of the coastal geologic evolution and of its periodical changes, particularly marked during Quaternary due to climatic fluctuations.

The morphological definition of marine coastal terrace can be borrowed from the one describing fluvial or lacustrine terraces: 'terraces are flat surfaces with slopes as boundary; fluvial terraces represent old surfaces of fluvial genesis and the slopes result from a subsequent cut…..in a terrace the

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remains of an alluvial plain or of a lateral erosion are preserved….;" (*"si dicono terrazzi, o terrazze, le superfici pianeggianti delimitate da scarpate; i T fluviali rappresentano vecchie superfici di origine fluviale e le scarpate risultano da successivo intaglio …….in un terrazzo si conserva un resto di piano alluvionale, oppure di un piano di erosione laterale...; La cronologia relativa delle forme terrestri si basa spesso sulla presunta successione cronologica dei sistemi di terrazzi posti a livelli diversi. Salvo casi particolari, i terrazzi più elevati sono considerati più antichi; i più bassi, come più recenti"*).

The relative chronology of continental morphologies is often based on the presumed chronological succession of the terraces system located at different elevations. Except for particular cases, the higher terraces are older, the lower ones younger. While the genesis of continental terraces is mainly linked to the rapid succession of Quaternary climatic phases, the genesis of the coastal marine terraces is directly connected with the variations of the eustatic sea level (CASTIGLIONI, 1979).

Fig. 3 - From a morphological point of view a terrace is defined by a gently sloping flat surface called terraced surface (a) and by a downstream convex slope called terrace edge or outer margin which divide the terraced surface from outer slope (c). Moreover the terrace may show a concave slope upstream that define its inner margin (d) and divide the terraced surface from the inner slope (e).

The terrace represents a remnant morphology related to a relative higher base level and the outer slope results from the following cut due to the fall of the base level.

Marine coastal terraces are morphologies extending with a longitudinal development parallel to the coast and are characterised by inner margins that, on the basis of morphological marks of ancient coastline (like corrosion notch, palaeocliffs etc.) are referable to relative high standing of the sea level.

Fig. 4 - A sedimentary terraced body (a) delimited by a basal surface (b) and by an upper surface (coincident with the terraced surface) (c) are "geologic" elements normally associated to the general morphology of the terrace. According to BOSI *et alii* (1990a) a necessary condition to define a marine terrace in absence of marine morphological indicators is at least one geological element indicating the coastal marine environment.

The sedimentary body of the terrace is cut toward the sea by an erosional surface cutting the upper surface and part of the terraced deposit (terraced slope) and it coincides with the outer slope.

The basal surface of the terraced deposit is an erosive surface, characterised by a direction subparallel to the present coastline and sloping toward the sea. Frequently this surface can represent, close to the upper edge, a marine abrasive form linked to the wave effects along the coast. Locally this surface shows linear incisions relative to drainage paleolines (d) eventually with associated deposits. Marine terrace deposits are mostly constituted by coastal marine sediments (a1) locally followed by coastal plain sediments, fluvial deposits, dunes and lagoonal deposits with important evidences of pedogenesis. A transgressive/regressive facies succession can be found, often incomplete.

The terraced sedimentary body is cut toward the sea by coastal and / or continental erosive morphologies following its formation; in the succession of terraces, such surfaces constitute the inner slope of the next terrace. Transversally to the coastline, the terrace can be interrupted by linear incisions related to the fluvial pattern.

Fig. 5 - Normally, marine terraces develop in succession sub-parallel to the coast. In these successions the upper terraces are the older and the younger ones are more and more lower, with a relation of reciprocal embedding. Fig. 5 shows a succession of terraces where t2, t3 and t5 are terraced sedimentary bodies (cs2, cs3 and cs5) with different reciprocal relations, while t1 and t4 are erosional terraces where sedimentary bodies are not present.

Marine terraces show variable shapes and dimensions. Erosional surfaces, infact, can show slopes deeping from some fractions of degree to some degrees. The upper surface, where it is conserved in its portions more far off the inner slope, shows low gradient, locally zero. Even the terraced surface show gradients varying from few degrees to vertical depending on the local environmental parameters.

The thickness of the terraced sedimentary body, where it is not eroded by the following transgressive or regressive phases and where it is preserved from the activity of the superficial pedogenetic factors, show increasing thickness toward the sea depending on the gradient of its basal surface; thickness varies from few cm of remnants of erosion to some tens of metres in the more conservative cases and where more sedimentary input took place.

Fig. 6 - The area along which coastal terraces are present is the coastal belt, where the sea level fluctuated during Quaternary with relative short standing. The interval of elevation is comprised between the eustatic maximum, occurred at elevation close to the present level (maximum elevation reached around 6 m during isotopic stage 5e) and the eustatic minimum at depth deeper than -100 m relative to the present sea level (minimum elevation reached at about -120m during stage 2). If the coastal belt involved by these fluctuations is located in areas characterised by Quaternary vertical mobility, its altimetric limits are defined by the same elevations of maximum and minimum eustatic level to which the altimetric variations induced by the tectonic velocity rate must be added.

In the lower part of a) the hypothetic terraced morphology can be observed, related to the eustatic curve of the last 350.000 years. In the upper part of a) it is shown the succession of terraced morphologies related to the same eustatic curve, deformed by the effect of a constant uplifting rate of 0,5 mm/y. As previously stated, it is evident that the main factor responsible for the formation of subaerial marine terraces is the curve of the variations of the local sea level resulting from the deformation of the glacio-eustatic curve with the interaction of the tectonic uplifting. In cases of strong tectonic activity, as illustrated in b), examples of Holocene coastal terraces exist. The formation of these terraces is linked to important discontinuous uplifting tectonic episodes (LAJOIE, 1986 mod) that, causing variations in the local eustatic curve (relative lowering of the eustatic level), create a succession of terraces where the embedding forms are linked to rapid uplifting. Since the present position of the sea level is close to the Quaternary high standing elevations, the occurrence of marine terraces esclusively happens in stable areas or characterised by tectonic uplifting during Quaternary.

Fig. 7 - Coastal erosion morphologies such as abrasion surfaces, corrosion notches are widely described; in a) a basic model of the evolution of a rocky cliff (SUNAMURA, 1992) is illustrated; in b) the characteristics of coastal erosion due to relative movements of the local eustatic curve (CINQUE *et alii*, 1995) are evidenced through the study of simulated models.

Fig. 8 - The geological conformation of a single terrace and of a succession of terraces is function of different parameters, variable in time. Beside the coastal physiography and the local marine parameters, the sedimentary input is very important. It can strongly influence the geological evolution until the extreme case of sedimentary regression during the rise of the eustatic level. In Fig. 8 coastal dynamic is schematically shown as a function of the eustatic variation and of the sedimentary input (CURRAY, 1964).

Conditions of prevailing depositional or erosive regression are differentiated from conditions of transgression by different colours.

Fig. 9 - Main steps in the formation of a generic marine terrace.

This reconstruction is based on several studies carried along the Northern coast of Latium where, due to the strong sedimentary input from the volcanic activity of the near Vico and Bolsena volcanic complexes, the depositional bodies are well developed (BOSI *et alii*, 1990b).

Moreover, the interaction between the terraced coastal body and the deposits of a paleo river-bed nearby the coast (MESSINA *et alii*, 1990) is shown. The curve illustrating the sea level variations is extremely simplified and represents a period of time related to the formation of all the elements of the terrace referred to the isotopic stage 7 (i.s.7).

Marine or coastal deposits are represented by yellow colour; continental deposits (alluvial and colluvial) are represented by green colour and the red surfaces indicate prevailing erosion.

9.1 - *fast eustatic fall (A of Fig. 8)/ climatic cooling*

Retreat of the sea due to eustatic lowering. Starting of subaerial evolution along a more or less steep slope and partial or total rielaboration in subaerial environment of forms or of deposits belonging to the previous cycle.

9.2 - *emersion/ cold climate*

The eustatic level falls and rises again (stage 8) attaining at elevations lower then those of the analysed terrace. The slope undergoes an evolution in subaerial environment with widespread areal erosion and deep incisions of the fluvial pattern. Local detritic or colluvial deposits develop. Locally soils formation occurs.

9.3 - *fast eustatic raising (B of Fig. 8)/ climatic improving.*

On the recently formed terrace the fast rising of the sea level causes time transgressive morphologies of coastal erosion and possible aggrading coastal deposits. The deepening of the coastal erosion due to the eustatic transgression velocity is reduced; the availability of space along the coast and inside the river-beds allows the deposition of sediments coming from inland.

9.4 - *slow eustatic raising (C of Fig. 8)/ climatic improving*

The deepening of the coastal erosion is possible, due to the slower raising rate of the eustatic level. In the meanwhile the abundant sedimentary input locally form thick depositional bodies passing from time-transgressive to time-regressive with the formation of a well developed coastal plain and local deposits of coastal swamp. The filling of the valleys are locally transgressed by marine deposits.

9.5 - *high eustatic standing (D of Fig. 8)/ climatic optimum*

The stability of the eustatic level (stage 7) locally causes the deepening of the coastal erosion or the depositional regression due to strong sedimentary inputs. The lacking in depositional space again causes fast sediment progradation with the formation of wide coastal plains and local coastal lagoons.

9.6 - *slow eustatic fall (E of Fig. 8)/ climatic deterioring*

The beginning of the sea-level fall causes forced regression with the abandonment of the emerged areas and the consequent evolution in sub-aerial environment with deepening of the fluvial pattern, pedogenesis and eolian dunes.

9.7 - *fast eustatic fall, emersion (stage 6), eustatic raising, high standing (stage 5)*

The new eustatic cycle reaches lower elevations due to the combination of the eustatic curve and the uplifting of the area, eroding most of the sedimentary body and forming the terraced surface. It leaves only the upper part of the former described cycle as outcropping remnants. (Some of the lower deposits can be locally preserved underground, at the base of the new basal surfaces of the deposit related to stage 5).

During this moment and the following period of time, the evolution of the terrace occurs only in sub-aerial environment with prevailing erosion both linear and areal and with soils formation.

9.8 - *It is important to remember that in the areas next to that described in the figure, marine terraces referred to the same eustatic cycle are represented by erosional terraces, because of different physiographic situations where the environmental parameters or the sedimentary input strongly vary. These terraces are esclusively represented by erosion forms often difficult to distinguish from each other. Locally, the outcrop of few dm of marine-coastal sediments allows the correlation with the geological evolution described.*

When the erosional activity of the following cycles prevails, both the form and the deposit of the marine terrace can be completely erased.

In conclusion a marine terrace represents, even not completely, a transgressive/regressive cycle of short period. Its formation is due to the characteristic variations of the Quaternary glacio-eustatic curve in particular if deformed by vertical tectonic movements. The preservation of a marine terrace is caused by the tectonic uplifting following its evolution. In the meanwhile, the uplifting causes its partial, often deep, erosion.

In the example illustrated in Figs. 9, 1-7, the terrace is well represented due to the abundance of sediments related to the activity of the volcanic complexes. Beside that, marine terraces are often incomplete or characterised esclusively by very thin deposits, since they are the result of a short period linked to intervals of warm climate in the climatic curve. In such periods the continental environment is characterised by biostasy, with a consequent low sedimentary input toward the coast characterised by a prevailing silico-clastic deposition.

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Pleistocene coastal prograding bodies outcropping in some uplifted basin fills of Southern Italy : field equivalent of submerged marine terraces ?

MASSARI F.*, SGAVETTI M.**, RIO D.*

Aim of this contribution is to illustrate the characteristics of some coastal prograding bodies which can be observed and studied in land outcrops, as part of recently uplifted sedimentary infills of some Plio-Pleistocene basins of Southern Italy. These bodies could represent the field equivalent of the submerged sea-marginal terraces which are the main subject of this atlas.

The prograding bodies of which some examples will be presented here, commonly appear vertically stacked within thick stratigraphic successions which originated in basins subject to high subsidence rate and commonly intense intrabasinal tectonics. As a result, a relatively continuous record was preserved, although punctuated by unconformities due to synsedimentary tectonics and high-amplitude glacio-eustatic fluctuations.

Shelf to nearshore depositional settings are usually very sensitive with respect to relative sea-level fluctuations. However, on one hand a chronostratigraphic interpretation of related deposits is often severely hindered by the scarcity and poor significance of age-constraining biostratigraphic data ; on the other hand, the identification of causative mechanisms may be complicated by the potential importance of autogenic processes linked to the intrinsic sedimentary dynamics of nearshore depositional systems. In this respect the analysis of the middle Pleistocene succession of S. Mauro Marchesato (Crotone basin, Fig. 1) has been surprisingly successful, since an integration of magnetostratigraphic data with biostratigraphic data obtained by the analysis of calcareous nannofossil assemblages allowed to recognize and document the succession of cycles in the interval from stage 33 to stage 19 and to prove their link with glacioeustatic fluctuations (Fig. 2; RIO *et alii*, 1996).

Fig. 1 - *Location of the study area.*

Fig. 2 - *(a) schematic stratigraphy of the succession of S.Mauro Basin, showing the correlations with the oxygen isotopic record (from* MASSARI *et alii, under submission). A and B: composite bodies (b) section of a prograding unit near Marcedusa (Crotone basin), with indication of the sedimentary structures and stratal geometries.*

As shown in Fig. 2a, the succession of S.Mauro Basin is of middle Pleistocene age and is characterized by marked cyclicity, expressed by an alternance of sandy prograding bodies, locally highly bioclastic, up to 45 m thick, forming the bulk of the sedimentary volume, and transgressive intervals.

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A slowing down of the subsidence rate in the upper part of the succession is documented by the increasing proximality and progradational stacking pattern of the cycles, which include increasingly important volumes of marine-marginal and nonmarine deposits, and are increasingly affected by unconformities and stratigraphic truncation.

Fig. 3 - *It is here depicted a section of the composite body A in Fig. 2(a); it is composed by minor units, two of which are divided by an unconformity surface covered by coarse-grained, fossiliferous deposits, interpreted as a ravinement surface (see the next figure for the description of the architecture of the composite bodies).*

The shoreface prograding bodies of the S. Mauro succession are simple or composite, the latter showing a polycyclic internal organization, being made up of a number of shingled, juxtaposed higher-order cycles. These composite bodies are particularly interesting, as they offer the opportunity of investigating the sedimentary response to two different scales of relative sea-level fluctuations. The shingled units are separated by sigmoid unconformity surfaces, which are erosional updip and become conformable downdip. These surfaces are draped by coarse shoreface blankets grading downdip into muddy offshore deposits and are interpreted as ravinement surfaces merging downdip into marine flooding surfaces. Therefore the surfaces and associated deposits document minor events of relative sea-level rise. At the resumption of the progradation, a thin package of sigmoid clinoforms first develops, marking a brief and short-way stage of "climbing progradation", then followed by a much thicker and farther prograding package of oblique clinoforms.

Two particularly prominent composite bodies occur in the lower part of S. Mauro succession (A and B in Fig. 2 a).

The older of them coincides with a drastic change from an essentially mud-dominated to sand-dominated sedimentation. The presence and local abundance of "cold guests" like Arctica islandica, the dominantly oblique pattern of clinoforms and local abundance of a residual fraction in the macrobenthic fauna, derived from cannibalization of former deposits, are all features indicating that the overall progradation took place as a result of a forced regression during a glacio-eustatic fall in sea level. Bio- and magnetostratigraphic age-constraining data allow an attribution of this body to the falling stage developing between stage 25 and stages 24-22. The sharp lithologic change is interpreted as the expression of the onset of the climatic crisis marking the beginning of the so-called glacial Pleistocene, characterized by high amplitude of sea-level oscillations.

The age of younger composite body is less constrained. Stratigraphic relationships suggest a correlation with the transition from stage 18.3 to stage 18.2. Although a precise chronostratigraphic framework is lacking, this body is regarded as genetically equivalent to the older one.

The internal composite architecture of the bodies is thought to reflect overall long-lasting sea-level falls punctuated by minor sea-level rises, an interpretation consistent with the typical sawtooth pattern of the falling limb of the middle Pleistocene sea-level fluctuations, as shown by the oxygen isotopic record, which is a proxy of sea level changes (Fig. 2 a).

The sedimentary structures and stratal geometries provide a lot of informations on the processes in play and characteristics of the depositional environment (Fig. 2 b).

Fig. 4 - *Stratigraphic sketch of the S. Mauro succession.*

Fig. 5 - *Detail of the S. Mauro succession, with ravinement surface represented by shoreface deposits resting on shelf pelitic sediments.*

Fig. 6 - *Dip angles of clinoforms range from a few degrees up to 10° in the case of sandy bodies and up to 16° in the case of highly bioclastic bodies wich are significantly coarser in grain size.*

Fig 7 - *Detail of the S. Mauro succession, with swaley cross-stratification.*

Informations of critical importance about the accretion mechanisms are provided by the topset beds, which are obviously preserved only at the top of sigmoid clinoform packages. The topset units most commonly show lower shoreface sedimentary structures, with ubiquitous swaley cross-stratification ; this facies locally grades upwards into a rarely preserved upper shoreface interval characterized by trough cross-bedding, planar lamination and wave megaripples, with palaeocurrents indicating both alongshore and downdip transport directions (see Fig. 2b). The facies association denotes a wave-dominated environment recording the activity of recurrent storm-driven flows. A mechanical reworking of the bioclastic debris above the wave base, prior to eventual deposition, is indicated by the common presence of broken to rounded bio-debris. Foreshore deposits have never been recognized at the top, probably due to erosion associated with ravinement surfaces.

DISCUSSION AND CONCLUSIONS

On the base of their main characteristics, the coastal prograding bodies studied in land outcrops in the S.Mauro basin could well represent, from a genetical point of view, the field equivalent of the submerged depositional terraces observed along wide coastal tracts along the Italian coasts and represented in this atlas.

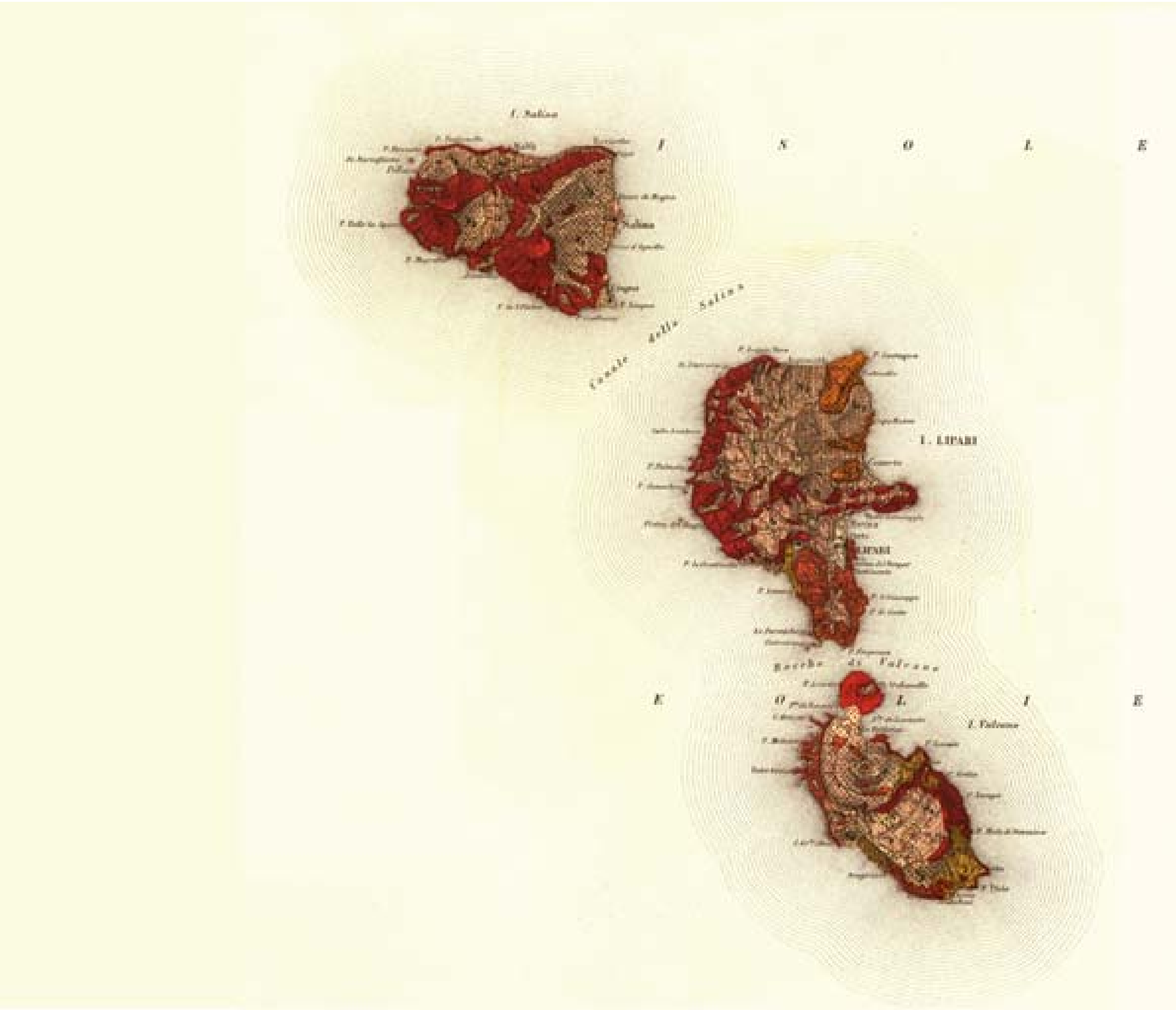
The possible mechanism of progradation for some of them has been recently described in a careful way by CHIOCCI & ORLANDO (1996) and CHIOCCI & ROMAGNOLI (this volume), who assume a recurrent activity of storm-driven flows capable of putting in suspension and transporting offshore a large amount of sand within the topset platform, to redeposit it on the foreset slope of the prograding body by sediment gravity flows. The rhythmic growth of the front is clearly indicated by alternation of event beds and bioturbated intervals.

In the S. Mauro Basin the intrabasinal tectonics exerted an important control on stratal geometries, particularly influencing the dip angle of clinoforms, progradation directions, and location of gravity detachments and of cannibalization at the expense of previous deposits. All these features, as well as stratigraphic anomalies such as stratal attenuation, suppression or expansion, are particularly concentrated near the boundary faults and on the growth folds, where abnormal shelf gradients could be generated. However, at least for the lower part of S. Mauro succession for which bio- and magnetostratigraphic age-constraining data are available, it has been demonstrated that the main control of cyclicity is of glacio-eustatic nature, and that the intrabasinal tectonics did not obscure the glacio-eustatic signature (RIO *et alii*, 1996).

Sand bodies with similar organization, commonly richly bioclastic, are relatively common in the Plio-Pleistocene successions of southern Italy. A well-known example is that of the Upper Pliocene succession of Capodarso in the Caltanissetta basin of Sicily (CATALANO *et alii,* 1992 ; VITALE, 1996 ; LIKORISH & BUTLER, 1996), characterized by a suite of bioclastic bodies recording, together with the interbedded mudstones, high-frequency fluctuations correlated with 40 ky tilt cycles within a lowstand of a third-order sequence. The internal organization of these bodies is wholly similar to that of the above described Pleistocene units of the Crotone area, with similar geometries and "reactivation surfaces", indicating minor relative sea-level fluctuations punctuating the building out of falling-stage prograding bodies.

Fig. 8 - *Detail of prograding bodies in the S. Mauro succession, cutted at thin top by ravinement surfaces*

CONCLUSION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Submerged depositional terraces along the Italian coasts - conclusion

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INTRODUCTION

The census of the Submerged Depositional Terraces (SDT), of which this volume is the final product, allowed the positive identification of depositional bodies with similar features, in several tract of Tyrrhenian Sea (mainly), Ionian Sea and Sicily Channel coasts.

In at least 12 places (but the number increases if we consider the cases briefly described in the final section of the Atlas) the presence of SDT has been revealed: they have very similar morphologic and stratigraphic features, even they are found in very different lithologic contests and tectonic settings.

Obviously the number and the location of the SDT reported in the Atlas does not mean to represent the complete distribution of these forms along the Italian coasts, as the reported contributions depends on the availability of the data and on the will of the researcher to take part in the initiative, that has, however, involved most of the scientific Italian groups working in the marine geology field.

On the contrary, the demonstrated correlation between SDT presence and seafloor steepness, (which is a very frequent condition along the Italian coasts especially on the flank of volcanic isles), could mean that SDTs represent an "usual" depositional-morphologic element of the Italian sea floors.

Therefore, after the illustration of the different case history, which is the main target of this volume, we attempted to make a synthesis of the obtained knowledge on morphology, age probable genesis of SDT and to the possible application of the study of these forms.

What follows is the result of two meetings, held in Bologna on October 3, 1995 and in Rome on July 8, 1997, respectively at the beginning and at the end of the period of collection and critical revision of the articles of the Atlas.

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DEFINITION

The definition of "Submerged Depositional Terrace", for the deposit object of this atlas, has been proposed since the beginning of the initiative and it is confirmed at the end of the research, even if the word "terrace" is usually associated to fluvial coastal features and involves a strong erosive component. The definition of SDT has, for us, a descriptive and not a genetic meaning, and it indicates a deposit made significant by the steadiness of the morphologic-stratigraphic features, even in very different geologic-physiographic contests.

The features that define a SDT are the following:

- It is not a purely morphologic unity, but a **submerged sedimentary body**, with a **clinostratified** internal structure having a **prograding** growth towards the basin.
- The external morphology is characterized by a **quite flat roof, a well-defined edge, a frontal slope with a gradient similar to the angle of rest of the sediments**, that in the lower part gradually connects with the substratum (generally the upper continental slope)
- The thickness distribution is always **parallel to the coast**, while the slope extension is far inferior to the longitudinal one.
- The external shape is **not modified by the postdepositional erosion**, with a frontal slope having the same gradient and the same shape of the internal stratification.

Despite the word terrace is used in geomorphology to indicate features produced by marine or fluvial erosion, this definition does not have got genetic implications. As an example, the word terrace is used for submarine morphologies of complex origin and great dimension like, for example, the diction of continental platform/terrace.

The depositional nature of the morphologies we have studied is underlined by the adjective "depositional" that, in addition to differentiate the SDT from the fluvial and marine-coastal terraces, shows the primary character of these bodies, originated by lateral accretion and unmodified afterwards.

The census and the atlas have taken into account only the features at present submerged, leaving out both the buried features (present whitin the continental margin) outcropping features of which we have mentioned only one example for comparison. This choice has been made considering our need to limit the compilation to deposits with similar stratigraphic situation; it is however obvious that also more ancient or differently located features can be defined as submerged depositional terraces, if they are found similar in shape, dimension and features respect to the SDT present on the sea floor.

In order to point out the similarities, we have made a summarizing table that synthesizes the main features of the SDT described in this atlas (TAB.1). The comparison among the different cases allowed a semi-quantitative definition of the morphologic and depositional charactery of the SDT (depth, internal and external geometry, thickness, acoustic facies) that are here after described.

LOCATION AND DEPTH OF THE SDT

The SDTs are found on tracts of continental margin characterized by reduced or absent shelf and/or by steep seafloor; such conditions are common on margins controlled by tectonic lineaments or great erosive structures. Volcanic coasts and/or islands are also characterized by very steep sea floor (ex. Pontine Archipelago, Aeolian Isles, Linosa, Egadi). The development of the SDT is clearly conditioned by the gradient of the basal surface on which it rests (between 0.5° and 2°, rarely up some grades) as well as by the extension of the shelf (less than 10 km); the depositional edge of the SDT often coincides with the platform edge.

It has often been noted the association of the SDT with erosive features lying behind (paleocliffs) or below (abrasion platforms); this fact indicates the importance of the morphology for the formation and the preservation of these bodies. Especially as for insular volcanic areas, the presence of abrasion platforms interrupt the steep morphology of the sea floor and shows a preferential place for the development and the preservation of the SDT that would otherwise be remobilized by gravitational phenomena.

The depths of the SDT are mostly between -100 and -200 metres, with a depositional edge between -120/-150; these depths are consistent with the ones reached by the sea levels during the last glacioustatic lowstand (18 ka ago); in unstable tectonics sectors, a vertical component, tectonic or volcano-tectonic in nature, has to be added. The effect of this component is reflected both in gradual variations of the depth of the SDT (e.g. Pontine isles - quiescent at present -where in a span of coast of 18 km, the depth of all the depositional parameters of the SDT varies of about 2 meter/km), and in the great lateral variability of the geometry of the SDT in adjacent coastal parts, but separated by structural discontinuity and subject to differential vertical movement, e.g. Aeolian Isles - active at present.

In some areas, SDT with features similar to the deeper ones have been observed at relative shallow depth; most cases are located in the Aeolian Archipelago, where the SDT are present at various depth, whose values seem to group in some classes of frequency. The main one corresponds to SDT with the edge of about 30-40 m. At similar depths (respectively a little higher and a little lower) there are SDT around Linosa Isle (edge at -45/55 m) and Palmarola Isle (-20/22 m); along some parts of Sardinia coasts and of Sorrento coasts there are SDT with the edge between -55 and -95 m.

MORPHOLOGY AND INTERNAL GEOMETRY

The geometry and physical dimensions of the SDT are remarkably homogeneous: they are depositional bodies with a terraced external morphology and a wedging geometry, whose morphologic expression is mostly evident even in the sea floor bathymetry. The maximum thickness is generally between 10 and 30 meters. We have also observed low values on the west part of Sardinia edge and on the Calabria coast (Capo Suvero). The highest thickness (more than 40 m) was found in the Pontine and Aeolian isles (where there is a good availability of sediment).

The extension perpendicular to the coast (width) is strictly connected with the steepness and with the width of the shelf and varies from some hundred meters to some kilometers. The extension parallel to the coast (length) is more variable: near volcanic and/or insular coasts, that are uneven and curvilinear and with volcanic-tectonic or structural features, there are terraces with very limited lateral continuity (generally at least one kilometer) and great variability in the internal and external geometry, while along tracts of rectilinear margin, the depositional terraces have been followed for many tens of kilometers (ex. Tuscany Archipelago or Taranto Gulf), having constant characters and dimension.

We have observed both SDT that fade away gradually (for example due to gradient variation of the basal surface) both with sharp lateral disappearance (for example, at the end of the abrasion platforms or near the canyon or areas of gravitational instability).

A controlling factor in the distribution of SDT with limited extension is the presence of isolated structures or local morphologic irregularities of the sea floor that have both a role of local source of clastic sediment and of wave energy attenuation (for example at Sorrento Peninsula or at Capo Suvero).

The internal structure of the SDT is always clinostratified, oblique and/or sigmoidal, sloping basinward and never parallel to the coast. The foresets have inclination between 4° and 20°, often more than 10°; such steepness can cause an apparent acoustic transparency revealed in some cases and attributable to instrumental causes (see Chiocci, this volume).

The SDTs are often polyphasic, that is to say they show evidences of alternation of depositional and erosional phases, like reactivation or erosion surfaces of the topset (Pontine Isles, Egadi, Aeolian Isles, Sorrento). SDTs are often superimposed each other or partially coalescent, are always in retrogradational setting and often (not always) there is a trend to increase foreset steepness upwards. Generally the inclination of the strata matches the inclination of the frontal slope, as evidence of a depositional and not erosive nature of the latter; only in one case (Egadi Isles) a greater inclinations of the frontal slope respect to the foresets has been observed, indicating postdepositional erosion due to submarine currents.

ACOUSTIC AND LITHOLOGICAL FACIES

The textural and lithological characters of the sediment making up the SDT have been detected via sea floor coring on Palmarola Isl. (Pontine) and Salina Isl. (Aeolian) as well as in Calabria (Capo Suvero), Capraia shelf and Elba Ridge. Where there were no samples, the lithology has been roughly assumed according to the acoustic facies in S.B.P 3.5 kHz profiles and the inclination of the foreset of the depositional bodies.

The most common texture is the medium-coarse sand, as suggested by the lack of high-frequency seismic wave penetration and by the acoustic facies with low-continuity, low-amplitude reflections; different sediments can be found in the SDT: rudites as volcanic scoriae at Aeolian Isles to pelites as sandy silts of the west Sardinia edge.

The seafloor cores stratigraphy shows a coarsening up trend; also the bioclastic fraction (often with glacial affinity fauna) increases towards the top and towards the basin, sometimes in form of biorudi-tic floor or of organogenic crusts.

It is important to observe how paralic or terrestrial facies have never been found; towards the top the sandy deposits sharply pass to thinner, hemipelagic mud, ascribed to the sedimentation during the phases of sea level rise and highstand.

The SDT lithologies are variable, as they reflect the different geology of the coast; the bioclastic component is always well represented.

The location of the alimentation sources strictly controls development of the SDT. As for the SDT developed at the shelf-edge, the alimentation can be assumed to be linear. The feeding from subaerial basin seems to be very rare, as SDT are not usually associated to paleodrainage able to carry fluvial or littoral sediments down to the platform edges (north-west Sicily, Egadi).

As for volcanic areas, the development of thick SDT is often connected to a good availability of volcanogenic sediment deriving from the erosion of eruptive centers and of pyroclastic deposits oucropping on the facing cliffs. An example of extremely localized alimentation, tied to the dismantling of a little exogenous dome, has been observed for the Basiluzzo Isle (Panarea, Aeolian Isles), at the foot of which there is a SDT with a limited extension but with geometric and morphologic features similar to other observed cases.

GENESIS AND AGE

The origin of the SDT is referable to sea level stillstands significantly lower than present. The depositional bodies with a depth of -100/150 m and located at the edge of platforms represent relict structures formed, probably, during the last glacio-eustatic lowstand (about 18 ka ago); this interpretation comes from their bathymetric position that is consistent with the depth reached by the sea level during the last glacial acme, and it is also sustained by radiometric dating and biostratigraphic data (ex.: SDT of Tuscany and Pontine Archipelago and in Calabria).

The chronological attribution of those SDTs found at a depth less than 100m it is les clear: apart from vertical dislocations due to tectonic uplift, their present day depth is tought to reflect stillstands of the relative sea level during the last post-glacial transgression. The retrogradational setting observed in some SDT might suggest a deposition happened during a discontinuous sea level rise.

The observation of the depositional characters of the SDT suggests, for their formation, a high energy environment with limited clastic contribution from the inland basin (that could become locally significant); deposition occurred on steep sea floor affected by littoral drift, able to re-distribute the sediment. The SDT form along coastlines dominated by the wave motion and subject, because of the insularity or the lack of continental shelf, to a great amount energy during the storms; in particular, wave energy concentration and fetch seem to play an important role in controlling the distribution of SDT and the depth of its depositional parameters (as in the case of the SDTs present on the Aeolian Isles).

In most cases, unfortunately, it is not possible to have direct data on the depositional facies and fauna of the SDT; this makes their attribution to a specific depositional environment uncertain.

The most common interpretation given by the authors for the SDTs observed at different depths along the lines of the Italian coasts is that they are littoral or deltaic wedges (e. g. SDT on Tuscany Archipelago). This hypothesis is based on the followings: (1) the excellent correlability with paleo sea-level (especially those at -120m, the lowermost level reached by the sea during the last glacial acme); (2) the sedimentary facies observed in the corings, that suggest depositional processes highly selective typical of the beach environment; (3) the strong analogies of the external and internal geometries (angles of foreset, reactivation surface) that emerge from the comparison between the sismoacoustic profiles of the SDT and the examples in emergence of slopes with a medium-high energy (see Crotone basin, MASSARI *et alii*, this volume).

An alternative interpretation, based on considerations expressed in CHIOCCI & ORLANDO, 1966 and in CHIOCCI & ROMAGNOLI (this volume), considers the SDT as depositional wedge of enterely submarine formation, sedimented below the wave base level due to mobilization and redistribution of the sediments produced by the littoral erosion in response to meteo-marine events of greater energy (wave-formed terraces). According to this second interpretation, the SDT found at a shallow depth (like those observed around the Aeolian and Pontine islands, with depositional edge at about 20-35 m), might represent very young depositional bodies, connected to the actual sea level highstand (developed in the last 6 ka) and, therefore, referable to present-day depositional processes. To sustain this hypothesis, the followings can be considered: (1) the lack of physical continuity of shallow (actual) SDT with littoral deposits that, in the facing coasts assume the form of rare and mosly gravelly pocket beach of limited extension ; (2) the high steepness of the foreset, that seems to approximate the angle of rest of the materials, i.e. the effect of avalanching on a submarine slope; (3) the direct observation of bedforms down to more than -30 m on the upper surface of a SDT of the Aeolian Archipelago, that evidence the actual action of the wave motion until the terrace edge during storms.

APPLICATIONS 1: NEOTECTONICS

One of the classical application field of the study of coastal marine terraces (see SPOSATO, this volume) is the definition of the vertical mobility of the continental margin. At present, the height of the Thyrrhennian deposits is still the most valuable indicator of the neotectonic trend of a coast for the the last 125 ka, that is to say for the last interglacial/glacial/interglacial cycle.

Such an application is possible also for the submerged depositional terraces, despite the morphologic, stratigraphic and genetic differences between these and the coastal terraces. In fact, also the SDT are controlled by the (paleo)level of the sea, as it is shown by the fact that they are found on the sea floors at a quite costant depth even for tens of kilometers.

There are some limitations to their use: a) the relation between the depth of the main depositional parameters of SDT and the paleolevel of the sea is not completely clear and, in the case of the hypothesis of a genesis connected to the wave base level , factors such as fetch and wave refraction might assume a relevant importance (this uncertainty, that is a common problem to the coastal terraces, does not prevent a comparative use of the SDT in a given area); b) the fact that the SDTs are not always present (they are present only on very steep edges) and, where present, are generally located in the external platform at a certain distance from the coast, where it is common to have also loading subsidence effects; c) the usual lack of dating due to the difficulty of sampling, at least with cheap technologies, of the deposits lying on the sea floor.

Despite these limitations, some indications of neotectonic have been taken from some cases studied in this Atlas. So, the gradual variation of depth (2m/km) of the SDT in the western Pontine Isles was congruent with the entity of the uplifting estimated for an Holocene beach in Palmarola Isle; the lack of observation of different kind of terraces on the continental platform of Calabria is congruent with the regional tectonic uplift that might have caused the emersion and the removal of all the older SDT; finally the presence, in areas characterized by actual and/or recent volcanism, of sectors with different or alternated vertical mobility, opposed to the relatively constant depth of the SDT in relative stabile continental edges is a convincing data.

APPLICATIONS 2: COMPARISON WITH SIMILAR FEATURES PRESENT WITHIN CONTINENTAL MARGINS

The genesis of TDSs and their age (where sampled), indicates these forms as produced by depositional processes at or near the shoreface during last sea level lowstand (Würm glacial maximum, 20,000 years b.p.).

The published eustatic curve , based on oxygen isotopes, indicate sea level lowstands roughly every 100,000 years. Such lowstands cause a renewal of the depositional systems because of sea-level fall, seaward shift of depositional environments, emersion and subaerial exposure/erosion of the continental shelf.

The identification of specific features that can be directly tied to eustatic minimum (or to stillstand during sea-level rise) is crucial for seismostratigraphic interpretation of continental margins, as this is chiefly based on the reconstruction of depositional geometries.

If one moves from steep and underfeed coast, where TDSs are often found, to well-feed continental margins, the situation is far more interesting. Wedge-shaped deposits very similar in dimension and form to TDS outcropping on the present-day seafloor are found in continental margins, usually made up of monotonous parallel sedimentary units as thick as hundreds of meters. In the most favourable situations, their formation at the eustatic minimum is testified by a position at the paleo-shelf break, where the erosional unconformity looses its erosional characters becoming a correlative conformity. Where the seismostratigraphy is ill-defined, TDS may represent the only feature pointing out the position reached by sea level at eustatic minimum, as in figure 2, taken from the Latium margin, a little nord of Civitavecchia (Capolinaro).

APPLICATIONS 3: COMPARISON WITH OUTCROP

One of the common characters among the studied areas where TDSs have been found is the steepness of the basal surface on which they rest. Because of that TDSs are mainly present in continental margins affected by volcanism and/or tectonics; It is likely that their common presence along the Italian coast is probably due to the active geodynamic setting of the Italian seas.

If active geodynamic setting is likely to produce TDSs, an involvement of the latter on regional uplift has to be expected so that they can be found on outcrop.

Especially Quaternary deposits are likely to host such depositional bodies, as the strong eustatic fluctuations may enhance their formation.

On the article of MASSARI (this volume) a clinostratified deposit outcropping in Sicily is described. From a photograph in a figure of this article, a line-drawing has been realised, that has been deformed adding the same amount of vertical exaggeration that affects high-resolution seismic profiles. In other words, the lower part of the figure would be the seismic images of the deposit described by MASSARI, if depicted by marine seismic prospection as those presented in this volume.

As it can be seen by a comparison Fig. 3, the overall appearance of the deposits is similar to the TDS reported in this atlas for the sigmoidal geometry of the stratification, the steepness of the foresets up to 16°, the presence of erosion/reactivation surfaces within the deposit and for the dimension of the depositional body (30-40 m thick, some hundred m long normal to progradation, some km parallel to progradation).

FINAL REMARKS

The submerged depositional terraces, as we choose to define these forms, are a morpho-depositional feature rather common on the Italian seas, and in fact all the Italian research groups working in marine geology have somehow surveyed them.

These forms are of high scientific interest because of their "singularity and significance", as they are easy to recognise, quite small in dimension, constant in depositional character and have a very precise stratigraphic position (at eustatic minimum).

Despite this fact, such features are barely described in the scientific literature, often only casually depicted. It is possible that the fact that they are more likely to form (or to preserve) on continental margin affected by volcanism or active tectonics, let these forms to be rare if not absent on oceanic coasts or in coast with meso- macro-tidal regime. On this hypothesis TDS may only be frequent on "Mediterranean" latu sensu geological setting, i.e. active margin, marginal basins, volcanic islands with microtidal siliciclastic sedimentation. The co-operation among the main research groups of Italian marine geologists to define and characterise these depositional forms, as summarised in this volume, may therefore represent an original contribution of the Italian research to highlight a depositional feature having a possible great general geological significance.

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