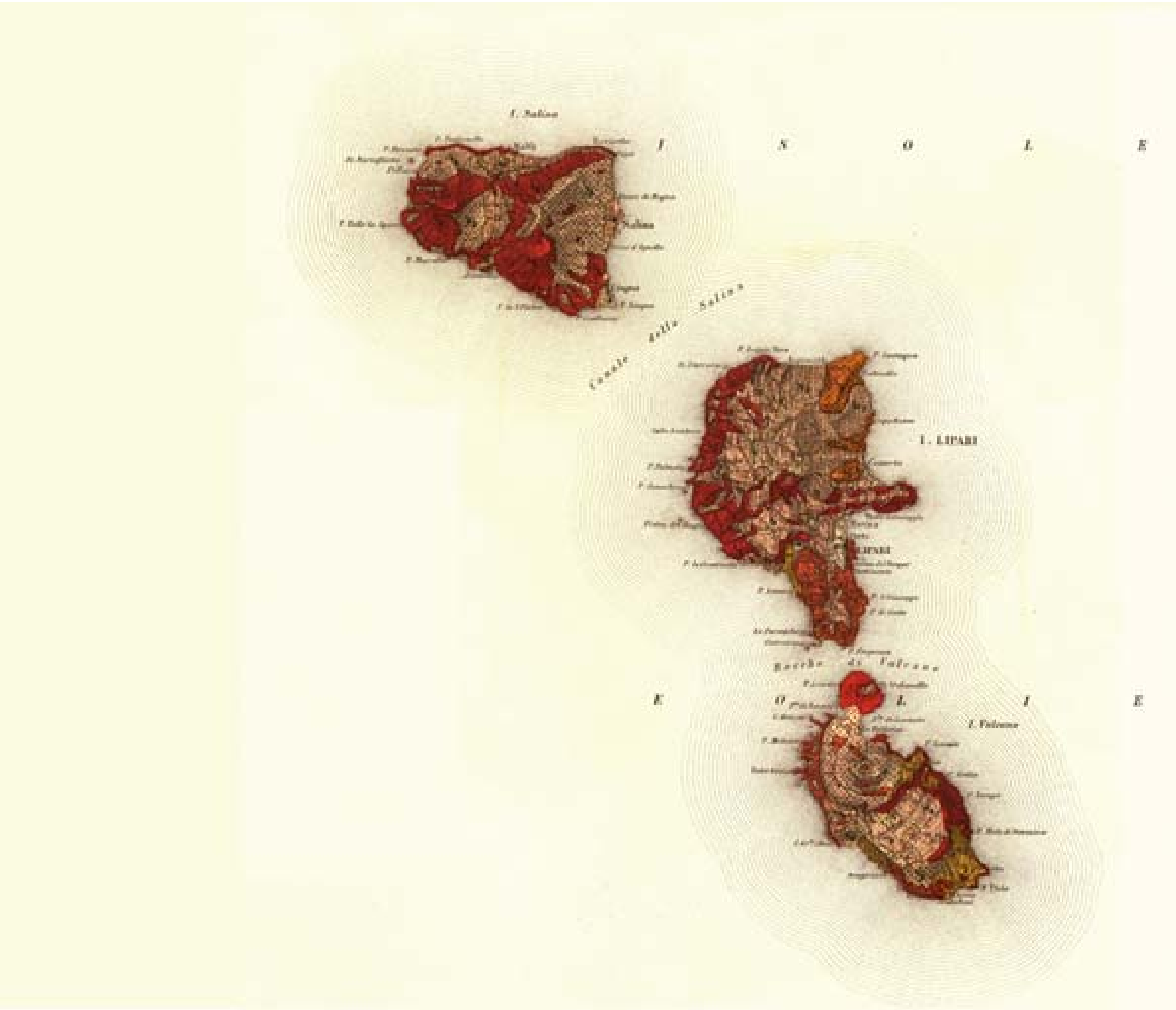
CONCLUSION



Mem. Descr. Carta Geol. d'It.
LVIII (2002), pp. 111-116

Submerged depositional terraces along the Italian coasts - conclusion

CHIOCCI F.L.*, D'ANGELO S.**, ROMAGNOLI C.***, RICCI LUCCHI F.*** AND SDT WORKING GROUP: M. AGATE[1], F. BUDILLON[2], A. CORREGGIARI[3], G.C. CRISTOFALO[2], F.FERRARO[4], F. MASSARI[5], L. ORLANDO[6], M.ROVERI[3], M.R. SENATORE[7], A. SPOSATO[8], F. TRINCARDI[3]

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.

*Dip. Scienze della Terra, Università di Roma "La Sapienza",CNR-IGAG, Roma
** Servizio CARG Rilevamento geologico e analisi di laboratorio, APAT - Roma;
***Dip. di Scienze della Terra e Geologico-Ambientali, Università di Bologna.
[1]Istituto Geomare Sud, CNR, Napoli; [2]Istituto Geologia Marina, CNR, Bologna; [3]Dip. Scienze della Terra, Uni. di Cagliari; [4]Dip. Scienze della Terra, Uni. di Padova; [5]Dip. Idraulica, Tras. e Strade, Università di Roma "La Sapienza"; [6]Dip. Scienze della Terra, Uni. di Napoli, [7]Istituto Tettonica Recente, CNR, Roma.

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.