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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.*

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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.