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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 undulated 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.