Il Quaternario
Italian Journal of Quaternary Sciences
11(2), 1998, 301-318

THE SEDIMENTARY FRAMEWORK OF CAGLIARI BASIN: A PLIO-QUATERNARY UNDERFED RIFT BASIN IN THE SOUTHERN SARDINIA MARGIN

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RIASSUNTO - Nel Margine Continentale della Sardegna meridionale è presente un sistema deposizionale sottomarino controllato dalla tettonica estensionale pliocenica e suddiviso in diversi bacini marginali, dove pervengono i contributi sedimentari dei vari segmenti di piattaforma continentale. Un complesso reticolo di valli sottomarine a sua volta alimenta una conoide di mare profondo situata verso W, al raccordo con la piana batiale sardo-algerina. Il Bacino di Cagliari costituisce la parte più interna del sistema sedimentario dell'intero margine. Sulla base dell'interpretazione di profili ecografici e simici *3,5 kHz, Uniboom 0,3 kJ e Sparker 0,5÷3,6 kJ*, assieme alle conoscenze del settore emerso costiero, viene presentata una prima descrizione del sistema deposizionale presente in tale bacino e della sua morfostruttura. Il bacino è delimitato e controllato dai blocchi tettonici del margine continentale della Sardegna meridionale ed in particolare dai movimenti dei blocchi sottomarini del Monte Ichnusa e di Su Banghittu. Questi ultimi chiudono verso sud il tratto più meridionale del Rift Sardo oligo-miocenico riattivato durante il Pliocene-Quaternario da movimenti estensionali da correlare con l'apertura del Tirreno meridionale. All'interno del Bacino di Cagliari si é evoluto un sistema articolato in una piattaforma continentale, un importante prisma con accrezione progradante nella scarpata superiore ed un bacino marginale nella parte più distale. Di tale sistema sono stati riconosciuti i processi deposizionali, le morfologie e le tendenze attivi in un intervallo di tempo situato tra il Pleistocene medio e l'Olocene. I sedimenti in accumulo nella piattaforma sono costituiti da limitati apporti terrigeni silicoclastici della Sardegna meridionale e da una importante componente bioclastica prodotta all'interno della stessa piattaforma. Durante l'Olocene la piattaforma interna costituisce il dominio dei sedimenti silicoclastici fluviali ridistribuiti principalmente ad opera del moto ondoso e delle correnti litorali e di piattaforma. Diversamente la piattaforma intermedia è dominata dall'accrescimento e dalla produttività carbonatica della biocenosi a *Posidonia oceanica*. Nelle zone più favorevoli si è sviluppata una struttura organogena che controlla il funzionamento dell'intera piattaforma, essendo capace di accrescere lentamente sia verso l'alto che lateralmente. Tale struttura, singolare nell'ambito di tutta la piattaforma sarda, è conseguente al convergere della stabilità tettonica con i fattori eustatici, morfologici e con i limitati apporti terrigeni. Nella piattaforma distale, alla riduzione di energia trattiva delle correnti si associa la deposizione di sedimenti fangosi. Durante il Pleistocene medio-superiore le oscillazioni glacio-eustatiche hanno causato ciclici spostamenti degli ambienti deposizionali all'interno della piattaforma dando luogo a unità deposizionali associate all'innalzamento e allo stazionamento eustatico alto, limitate da superfici di erosione sottomarina e subaerea. Mentre nella transizione tra la piattaforma ed il pendio superiore si è prodotta l'accrezione di un prisma sedimentario mediante il sovrapporsi di unità progradanti di abbassamento eustatico e di stazionamento basso. Pertanto, nella parte più interna del Golfo di Cagliari, dove sono presenti le sezioni più complete, si riconosce una piattaforma continentale silicoclastico-carbonatica controllata dalla ciclicità eustatica del Pleistocene medio-superiore-Olocene. Diversamente, sulla cima del monte sottomarino di Su Banghittu si è evoluta una piattaforma annegata quasi essenzialmente carbonatico-bioclastica a seguito del suo isolamento dal sistema terrigeno. Nel pendio superiore e verso la base dei rilievi strutturali si verificano scivolamenti gravitativi e flussi torbiditici non canalizzati che danno luogo ad accumuli di base di pendio. Nel bacino sono presenti due principali valli sottomarine, Sarroch e S.Elia-Foxi, oltre a numerosi canali tributari. I sedimenti, incanalati in prossimità del bordo della piattaforma, vengono ridistribuiti prevalentemente nella parte più distale del bacino e in subordine verso la parte SW più profonda del margine dove è ubicata la conoide batiale Sardo-Magrebina. L'area di depocentro del bacino è interessata da una sedimentazione in prevalenza torbiditica alternata a depositi emipelagici; alla scala maggiore, questo tipo di sedimentazione si evidenzia con l'aggradazione di uno spesso complesso di *channel-levee*. Solamente nella parte più distale, alla base del Monte Ichnusa, la sequenza di riempimento mostra geometrie interne parallele-concave tipiche di bacino confinato poco subsidente. I pendii dei rilievi strutturali (Monte Ichnusa, Su Banghittu e Horst del Sàrrabus) vengono ricoperti da un drappo emipelagico e da torbiditi distali fini che si riducono di spessore in corrispondenza del riaffiorare del substrato roccioso. Il lento accrescimento del prisma progradante, situato tra la piattaforma e la scarpata superiore, ed il prevalere su di essa della aggradazione del sistema *channel-levee* del fondo del bacino, indicano che il Bacino di Cagliari nel suo insieme ha raggiunto uno stadio evolutivo maturo, in stasi tettonica o in debole subsidenza, con tendenza al colmamento nel Pleistocene medio-superiore-Olocene.

ABSTRACT- The intraslope Basin of Cagliari is located in the innermost part of the submarine depositional system of the southern Sardinian margin. The reconstruction of the main depositional features, the morphology and the architecture of the system, evolving at least during the Middle-Pleistocene-Holocene time span, was founded on the interpretation of 3.5 kHz Subbottom Profiler, 0.3 kJ Uniboom and 0.5÷3.6 kJ Sparker data, in conjunction with on-land knowledge. This small, structurally confined basin is located within the SE termination of the Oligo-Miocene Sardinian Rift. Its genesis is related to the Pliocene-Quaternary extensional tectonics of the southern Tyrrhenian Sea opening. The basin and its depositional system are outlined and controlled by the Ichnusa Seamount and Su Banghittu tectonic blocks of the continental margin. The large scale depositional features, produced during the Plio-Quaternary, are made up of a continental shelf, a prograding wedge and an intraslope basin. The inner and middle shelf are covered by moderate terrigenous sediments coming from S Sardinia and by a large amount of bioclastic material produced by the shelf itself. During the Holocene, these sediments were mainly dispersed by wave action, longshore and shelf currents, and were controlled by the growth of *Posidonia oceanica* seagrass and its biocoenosis. This well-defined carbonate buildup is unusual in the Sardinia shelf. It is a result of the positive interplay between tectonic stability, low terrigenous supply, eustatic changes and antecedent morphology. During the Middle-Upper Pleistocene the eustatic Milankovitch cycles led to several low stands to which the accretion of the prograding shelf-slope wedge is related. A small isolated offshore platform situated on top of Su Banghittu seamount, where terrigenous sediments are absent, is covered prevalently by carbonate-bioclastic sediments. There are two main canyons in the Cagliari Basin with several tributary channels dispersing the sedimentary charge. The channel heads are cut near the shelf break and the sediments descend mainly to the basin floor and, in minor amounts, to the deepest part of the continental margin where the Sardinian-Maghrebian deep-sea fan is located. On the shelf-basin slope and towards the base of the structural reliefs, mass transport processes occur accumulating the sediments at the base of the slope, while the basin floor is undergoing aggradation of a channel-levee system. A concave-parallel sedimentation, typical of slowly subsiding confined basins, is observed just in the most distal part of the basin. The flanks of the structural reliefs are completely covered with hemipelagic drape, whose thickness decreases as outcrops of bed rock increase. The filling rate exceeds tectonic subsidence, as testified by the slow growth of the shelf-basin sedimentary wedge together with the aggradation of the channel-levee system. For this reason the basin reached maturity during the Middle-Upper Pleistocene-Holocene time span.

Key words: seismic stratigraphy, extensional basin, depositional system, morphostructure, glacio-eustacy, continental shelf, continental margin, Sardinia, Plio-Quaternary.
Parole chiave: stratigrafia sismica, bacino estensionale, sistema deposizionale, morfostruttura, glacio-eustatismo, piattaforma continentale, margine continentale, Sardegna, Plio-Quaternario.

1. INTRODUCTION

This paper gives a broad description of the depositional system in a tectonic trough between the Cagliari Gulf and the Ichnusa Seamount, within the southern Sardinian continental margin (Figg.1, 2). This system features active sedimentary processes on the shelf, the slope, the intraslope basin and along the major canyons running down to the deepest western sectors of the continental margin (Fig.2).

Earlier works have described in part the tectonic and depositional aspects of Cagliari Basin. Structural and sedimentological studies have been carried out by Auzende et al. (1974), Fanucci et al. (1976), Gennesseaux & Stanley (1983), CNR, (1983), Lecca et al. (1986), Thomas et al. (1988), Lecca et al. (1988), Lecca & Tilocca (1990), Tricart et al. (1994) Bouillin et al. (1998) while contributions to a knowledge of the recent stratigraphy are given by Di Napoli Alliata (1967), Gandin (1970), Pittau (1981), Picazzo M. et al. (1981). High resolution seismostratigraphic analysis are found in Tilocca (1984), Pisano (1985), Panizza (1988). Other studies (Segre, 1968; Ulzega et al., 1984; Ulzega et al., 1986) concern the interpretation of Late Quaternary morphologies and submerged coast lines.

2. GEOLOGICAL SETTING OF CAGLIARI BASIN

The southern margin of Sardinia (Fig. 1), lying to the north of Maghrebian chain, is the most European forward block.The Sardinian-Tunisian and the

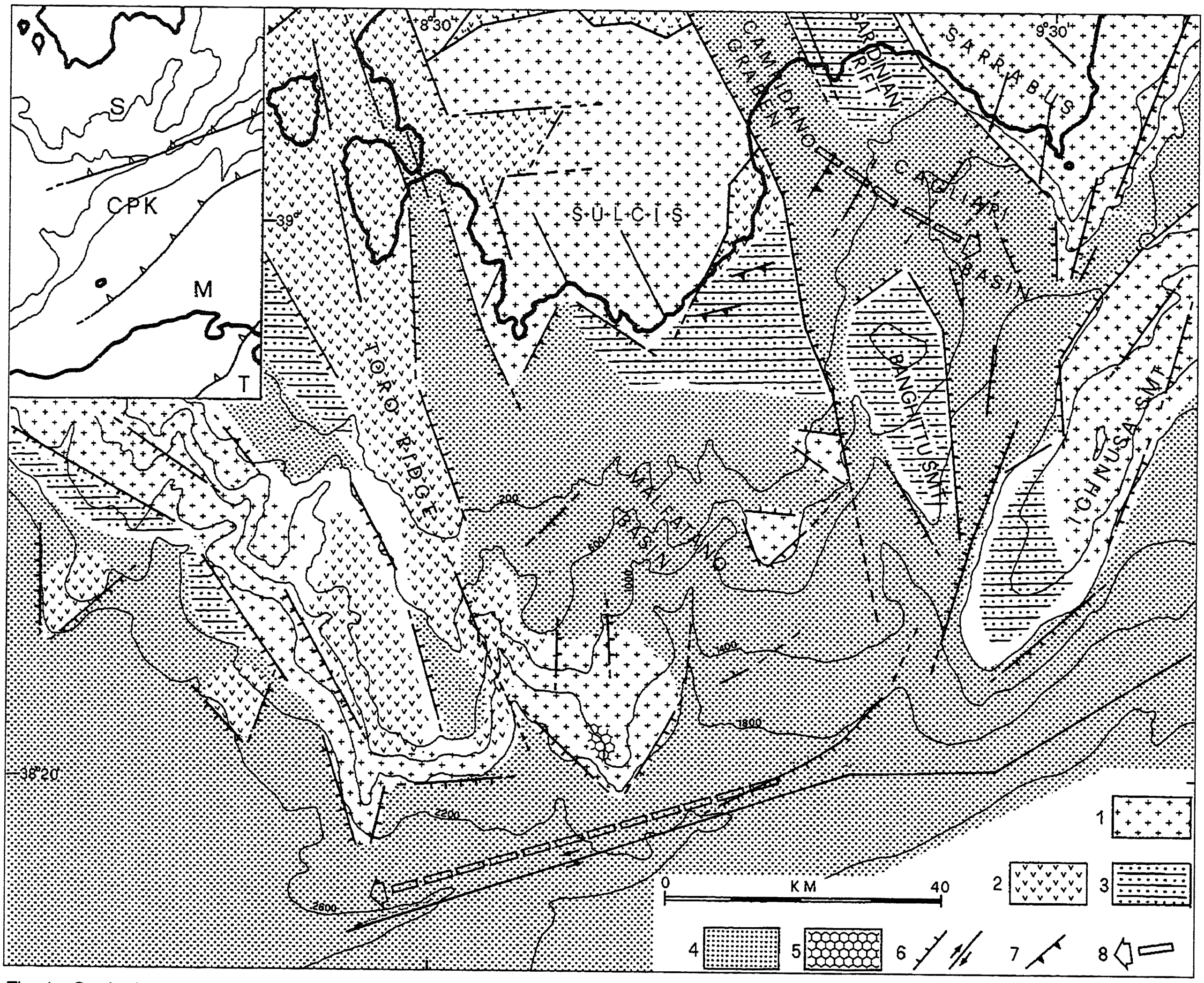

Fig. 1 - Geological map of the southern Sardinia continental margin (Lecca in progress); (1) Paleozoic basement and Mesozoic covers; (2) Eocene-Oligocene marine and continental sedimentary covers and Oligo-Miocene calcalkaline volcanics; (3) Miocene continental and marly-arenaceous-carbonate sequences; (4) Plio-Quaternary continental and marine sequences; (5) Plio-Quaternary? basalts; (6) faults; (7) Miocene? compressive structures; (8) Buried Messinian paleo-valley. In the inset the regional relationship with the Maghrebian Chain is shown: S) Sardinia block, CPK) Calabrian-Peloritan-Kabilian unit, M) External Maghrebian units, T) African foreland (after Tricart et al., 1994).

Carta geologica del margine continentale della Sardegna meridionale (Lecca in preparazione); (1) Basamento paleozoico con rari lembi di coperture sedimentarie mesozoiche; (2) Coperture sedimentarie, marine e continentali eoceniche-oligoceniche e vulcaniti calco-alcaline oligo-mioceniche; (3) Sequenza continentale e marnoso-arenaceo-calcarea del Miocene; (4) Sequenza continentale e marina plio-quaternaria; 5) Basalti plio-quaternari?; (6) Faglie; (7) Indizi di deformazione compressionale del Miocene?; (8) Paleo-valle messiniana sepolta . Nel riquadro, rapporti regionali con la catena Maghrebide: S) Blocco sardo, CPK) Unità Calabro-Peloritane-Kabile, M) Unità magrebidi esterne, T) Avanpaese africano (da Tricart et al., 1994).

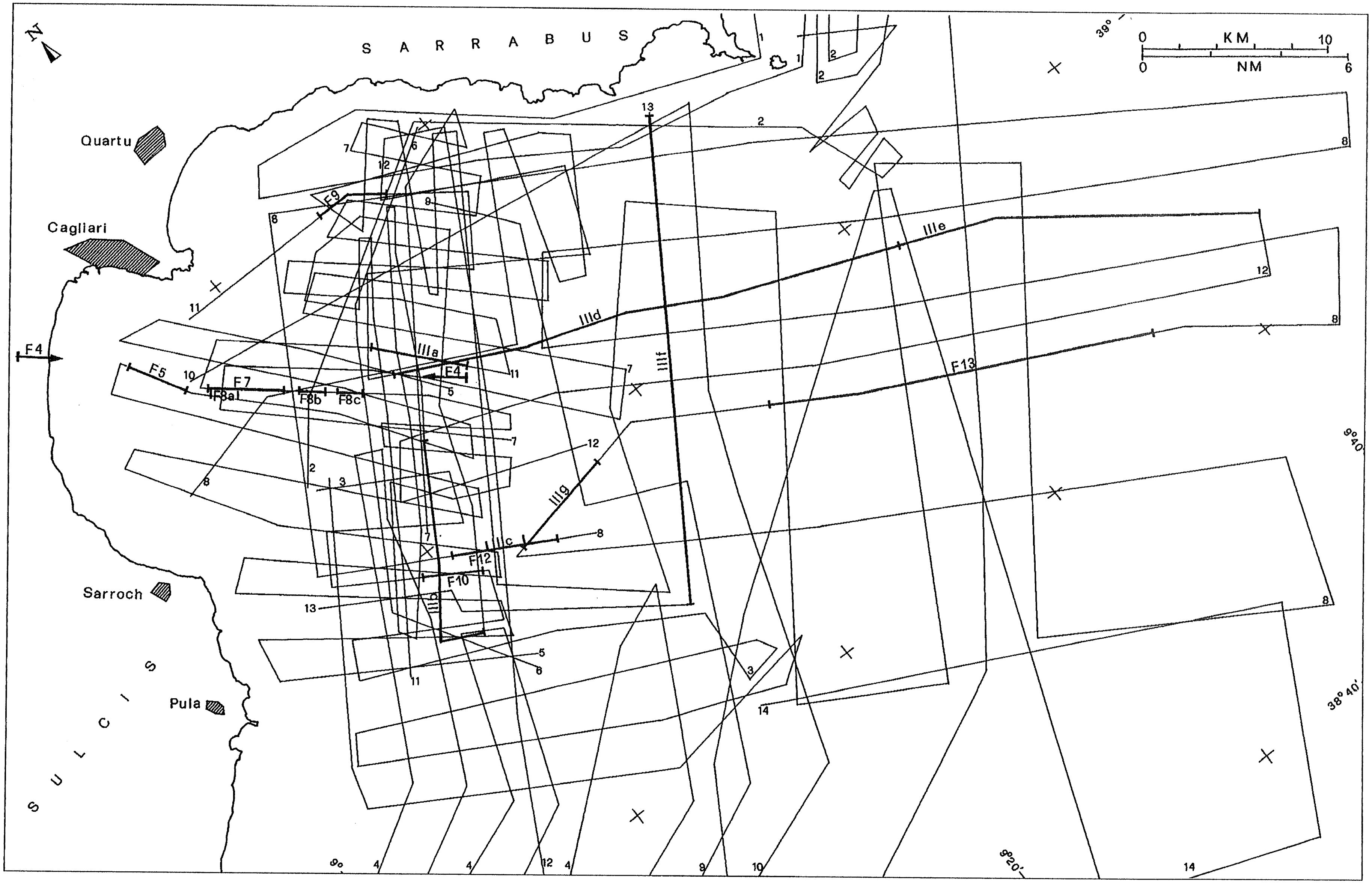

Fig. 3 - Location map of dual seismic reflection profiles (subbottom 3.5kHz and sparker 0.5-1-3.6 kJ or uniboom 0.3 kJ in the 6 and 7 profiles); OGS-Trieste: (1) Sardegna '70; Ist. Geol. Marina CNR-Bologna, Sc. Chief S. Rossi: (2) 5PL/77/3, (3) 6PL/77/3, (4) 7PL/77/3; Dip. Sc. Terra Univ. Cagliari Sc. Chief A. Ulzega: (5) 2PL/81/1, (6) 3PL/81/1, (7) 6PL/81/1; Dip. Sc. Terra Univ. Cagliari Sc. Chief L. Lecca: (8) 1/MCS/83, (9) 2MCS/85, (10) 11/MCS/85, (11) 11/MCS/87, (12) 5/MCS/88, (13) 7/MCS/88, (14) 10/MCS/89. The location of the figures and of the Plate III seismic profiles are in bold.

Carta delle linee sismiche (esecuzione contemporanea di Subbottom 3,5 kHz e di Sparker 0,5-1-3,6 kJ oppure di Uniboom 0,3 kJ nelle linee 6 e 7); OGS-Trieste: (1) Sardegna '70; Ist. Geol. Marina CNR-Bologna, Resp. S. Rossi: (2) 5PL/77/3, (3) 6PL/77/3, 4) 7PL/77/3; Dip. c. Terra Univ. Cagliari Resp. A. Ulzega: (5) 2PL/81/1, 6) 3PL/81/1, (7) 6PL/81/1; Dip. Sc. Terra Univ. Cagliari Resp. L. Lecca: (8) 1/MCS/83, (9) 2MCS/85, 10) 11/MCS/85, (11) 11/MCS/87, (12) 5/MCS/88, (13) 7/MCS/88, (14) 10/MCS/89. In neretto viene indicata l'ubicazione delle figure presentate nel testo e delle sezioni sismiche della Tavola III.

Fig. 2 - Physiography and canyon system of the southern Sardinia continental margin, studied area in the inset. Bathymetry modified after CNR (1983).

Fisiografia e sistema di valli sottomarine del margine continentale della Sardegna meridionale; nel riquadro ubicazione dell'area studiata. Batimetria modificata da CNR (1983).

Sardinian-Sicilian valleys run along its limit. These two major morphologies are the result of the Oligo-Miocene thrusting between the peripheral tectonic blocks of the Sardinian margin and the Kabylo-Peloritan unit (Tricart et al., 1994; Bouillin et al.,1998). This converging movements are considered an indentation between the Sardinian-Corsica paleo-microplate and the Maghrebian chain causing the propagation of the Sardinia Rift and its volcanism (Lecca et al.,1997). Later, during the upper Miocene this part of the Maghrebian chain was affected by extensional tectonic inversion (Tricart et al., 1994). More recent superimposed tectonic activity in the southern Sardinian margin, indeed in the whole of southern Sardinia, are related to late Miocene gravity collapse of this chain and to transtensional-extensional movements of the Pliocene-Quaternary opening processes of the southern Tyrrhenian basin (Sartori,1989; Kasten & Mascle, 1990).

In this way the margin was structured into several horst blocks bounding the marginal basins of Malfatano and Cagliari located on subsident blocks:

a) the Toro Ridge and minor blocks of the southern Sulcis horst delimit the Malfatano basin eastwards at the continental shelf level, while in the deepest parts, the Kabylian-Peloritan unit of the Maghrebian chain encloses it.

b) the Cagliari Basin is located along the south-eastern submarine continuation of the Oligo-Miocene Rift (Cherchi & Montadert 1982) and of the Plio-Quaternary Campidano Graben (Pala et al.,1982; Cherchi & Murru, 1985 and references therein). In the deepest sectors this basin is bounded and controlled by the Sulcis and Sàrrabus rift shoulders and by tectonic movements of the Ichnusa Seamount and Banghittu horst blocks, in response to the opening of the southern Tyrrhenian Basin. This resulted in a half graben structure with the master faults located at the foot of Sàrrabus and Ichnusa horsts.

3. DATA

Most of the high-resolution continuous seismic reflection profiles employed in this work were collected during a number of expeditions on board the C.N.R.'s R/V Bannock (Fig.3). These expeditions were organized in 1977-82 within the C.N.R. Project "Oceanografia e Fondi Marini", sub-project "Risorse Minerarie-Placers", for the surveying the continental shelf of Cagliari Gulf with a view to identifying placers in the present sand sheets or connected to paleo-shore lines (Responsible scientists S. Rossi and A. Ulzega). Subsequent expeditions (1983-89) took place in the framework of the University of Cagliari's research programme "Margini

Continentali Sardi", aimed at studying the depositional and structural features of the continental shelves, the forward basins and the continental margins of Sardinia (Responsible scientist L. Lecca).

The data was collected using single-channel Sparker 0.5-1-3.6 kJ, Uniboom 0.3 kJ and Subbottom Profiler 3.5 kHz graphically recorded in analog format. Usually dual 3.5 kHz and Sparker profiles were performed, only in lines 5 and 6 of Fig. 3 did the Uniboom replace the Sparker. Good resolution was usually achived especially on the continental shelf, where it was possible to collect a lot of new original data.

Sampling difficulties arose because of the presence of submarine cables and the samples obtained are representative of just a very few depositional processes. For this reason they are not described herein, but will form the object of a subsequent article. The depositional facies have been interpreted through a comparative analysis of seismic-reflection profiles from other sectors of Sardinian margins as described in Carboni et al. (1989) and other margins (e.g. Brown & Fisher, 1979; Bouma et al., 1985; Bellaiche et al., 1989; Berryhill, 1986; Canu & Trincardi, 1989). In this preliminary study, as the depositional units are very thin owing to the short time span (depositional system controlled by high-frequency order eustatic cycles), the small volume of sediments and the presence of a middle shelf carbonate buildup, the difficulties in using systems tract terms (Wilgus et al. eds., 1988) led us to sometimes prefer other more common terms. The detailed sequence stratigraphy for this basin will be described elsewhere.

4. DEPOSITIONAL SETTING IN SOUTHERN SARDINIAN MARGIN

In the southern margin of Sardinia, a fault-related compound elongated depositional system developed by means of intraslope basins. It has been formed essentially by the progradation of the shelf-slope wedge and the aggradational infilling in the deepest parts. The deposition of Lower Pliocene marly marine sediments marked the early stage of sedimentary working of this depositional system after the Messinian evaporitic event. In this way the Messinian erosional surface and an important paleo-valley became buried (Fig. 1).

The Middle Pliocene-Quaternary part of the sequence of this margin can be correlated to the parasequence above the X unconformity of Fabbri et al. (1981) on account of its stratigraphic position and analogies in the seismic-reflection pattern. Below this part of the sequence, the deterioration of resolution, due to loss of energy at this depth and to the many diffractions induced by depositional unevenness and tectonic disturbances, does not permit a satisfactory interpretation of the evolution of the first depositional phase. However we can suppose that the present stage of infilling might have been active at least since the Middle Pleistocene up to the Holocene. Briefly, this attribution derives from the recognition and lateral correlation of a reflective and transparent parallel-divergent pattern going from the shelf to the depocenter of the basin and correlatable to the glacio-eustatic variations occurring at least since the beginning of the Glacial Pleistocene up to the Holocene.

On the basis of a seismic-reflection study currently in progress, five canyons cross the slope of the southern Sardinian continental margin and their tributary channels, often reaching the shelf edge (Fig. 2), disperse the sediments coming from the shelf area. These canyons feed the main Carbonara-Sardinian-Tunisian Canyon, which runs parallel to the base of the slope up to the deep sea Sardinian-Maghrebian Fan where the more distal sediments accumulate. This network lies on intraslope basin areas (i.e. S.Elia-Foxi, Sarroch, Spartivento and Teulada Canyons) and along large fault zones (i. e. Pula, Palmas and S. Antioco Canyons). The latter are not linked to the on-land tectonic trough, so they can move just a small quantity of sediments.

Within the Malfatano intraslope basin, large volumes of sediments are reworked by strong retrograde erosion due to the activity of tributary channels (gully-type) in the upper slope, close to the southern Sulcis shelf edge. In the lower part of the basin, such sediments form depositional lobes at its confluence with the Sardinian-Tunisian Valley.

In the Cagliari Basin *latu sensu* (about 1,500 Km^2) a more complete depositional system receives mature fluvial influx coming mostly from the Campidano Graben. The drainage basin of feeder rivers (about 3,000 Km^2) lies along the several branches of the Southern Oligo-Miocene Sardinian Rift. Here Cenozoic sedimentary and volcanic sequences outcrop.

At the present time a Mediterranean climate with warm and dry seasons (rainfall 300÷1,000 mm/a) prevails in this area. Indeed southern Sardinia is exposed to a semi-arid, subtropical-warm temperate climate (Pinna, 1971; Raimondi et al., 1995). Therefore the specific transport rate of suspended solids and bed load is usually moderate. Data concerning present sediment discharge from rivers available in the literature are not precise. On this basis (Botti et al., 1994; Tomasi et al., 1995) the basin sedimentary supply (mostly fluvial and to a lesser extent eolian) has been tentatively evaluated at about 5÷25 t/Km^2·a. This compares favourably with the Mediterranean and the world's arid to semi-arid river basins (compare with Einsele, 1992). The consequent terrigenous (mostly siliciclastic) sedimentation all over Cagliari Basin is low, its average rate being 0.0025÷0.0125 mm/a (density of sediments about 2.5g/cm^3), if all fluvial discharge is resedimented inside the Cagliari Basin.

Previous knowledge and the findings of a preliminary study of sample indicate that the fluvial sediments, conveyed to the continental shelf of Cagliari Gulf, are stacked in a prograding shelf-slope wedge together with the bioclastic component. The fine grain size classes and part of the sediments coming from the prograding wedge are moved and resedimented within the basin, via turbidity currents (Stanley, 1985), channelized processes and gravity flow. The result is the progressive infilling and aggradation of a channel-levee system.

The distal basin has a north-northeast trend and is enclosed between the Carbonara-Ichnusa and Banghittu-Ichnusa thresholds. Here, in our sparker profiles and seismic-reflection literature data, an appreciable subsidence is found and Plio-Quaternary sediments can be as much as 1÷1.5 Km thick.

The depth of shelf break, the features of the prograding wedge and the occurrence of submerged paleoshore lines make the shelf of Cagliari Gulf quite similar to those of the eastern Sardinia margin (Lecca et al., 1979; Ulzega et al., 1980; Ulzega et al., 1986). By contrast major morphostructural differences exist between these shelves and those of the western Sardinia margin. There a deeper shelf break (about -190 m versus about -125 m) has been recognized together with a submerged coastal bench bounded seawards by a narrow slope in the inner shelf (Lecca, 1982; Carboni et al., 1989), lacking in the Cagliari shelf.

Depositional processes surveyed within the Cagliari Basin are similar to those already described in the Sardinia Basin as well as in the Corsica Basin (eastern margin of Sardinia-Corsica block; Fabbri et al., 1981; Wezel et al.,1981; Bellaiche et al.,1993). The Cagliari Basin being a structural branch of Sardinia Basin, it follows that the studied portion of the southern Sardinia margin and the evolution of Tyrrhenian Basin in Plio-Quaternary times are closely related.

5. BATHYMETRY

The bathymetry of the area is shown in Plate I. The depth has been computed according to Perucca (1963) and Aliverti et al. (1968) using the two-way travel time measured on the SBP 3.5 kHz records. Radiopositioning was performed using the Loran C system on a Mercator's projection map at a scale of 1:100,000, while the contour map was plotted at the same scale and later reduced to 1:200,000 as in Tav. I.

The bathymetric map already highlights the following main morphological features:

a) a shelf whose edge is located at about -125 m;

b) a small isolated platform (Su Banghittu, -125 m);

c) a structural buttress off Cape Carbonara, N-S trending and around 10 Km long;

d) the Ichnusa Seamount ranging between depths of around -1200÷-1000 m up to -250 m;

e) an arcuate basin (at depths ranging from -600 m to -1200 m) between these submarine reliefs.

6. THE CAGLIARI SHELF-BASIN SYSTEM

6.1 Outline of the depositional system

The caracteristic depositional features have been recognized by analysing numerous data set (littoral sediments, sparse samples of shelf sediments and 3.5 kHz seismic-facies). The shelf-basin system of Cagliari receives the fluvial sediments coming from Sardinian Rift, Campidano Graben, Sàrrabus and Sulcis horsts. In the shelf environments these terrigenous components are accompanied by carbonate materials, typical of Mediterranean shelves.

The following zonation (Fig.4) marks the sedimentary processes and products in the Cagliari shelf related to the eustatic rise after the 20÷18 Ky low-stand (the last maximum Würmian (1) low-stand well known in geochronological literature: e. g. Martinson et al., 1987; Stanley 1995 and Bard et al., 1996).

a) the beach-related units supplied by fluvial sands and sands from eroded cliffs, are dominated essentially by eolic action, wave motion, storm-induced and longshore currents, resulting in sedimentation of gravelly quartzose-feldspatic-lithic sands up to fine muddy sands and subordinate bioclastic component;

b) the middle shelf unit dominated by the growth of *Posidonia oceanica* seagrass bank growth supporting a considerable skeletal production;

c) the outer shelf unit blanketed by fine-grained sediments locally setting up the modern unit slightly prograding close to the shelf edge.

The Middle-Upper Pleistocene depositional units, controlled by the high-frequency eustatic variation (Milankovitch cycles, sensu Vail et al., 1991), can be recognized below the 20÷18 Ky glacial-Holocene unconformity. In the inner shelf the high-stand deposits, Crotonian and Tyrrhenian high stand sediments drilled and locally outcropping in coastal onland area, overlay the Lower (?)-Middle Pleistocene continental conglomerates (Pecorini, 1986). In the middle shelf, below the Posidonia oceanica bank, some fluvial paleo-valleys can be recognized. These valleys are mostly related to the 20÷18 Ky low stand and have been filled by Late Glacial-Holocene sediments, likewise observed in other shelves of the Western Mediterranean (e.g. Palma de Maiorca bay, Diaz Del Rio et al., 1992; Mateu, 1989). The terrigenous and the bioclastic components that originated in the shelf, are deposited in the outer shelf, especially during the falling-low stands, giving rise to a complex parallel-oblique prograding sequence that constitutes the upper part of Plio-Quaternary shelf-basin sedimentary wedge. The recent progradation comprises at least four falling-low stand systems tracts, units bounded by high stand-falling sea level downlaps and by lowstand toplaps, each overhung by an erosional-ravinement surface.

The upper shelf-basin slope gradient ranges from 3% to 15% and it is subject to gravity-induced processes such as mass wastings and gravity flows. Therefore, mass movements are well evident. The channelized erosive processes, active in this slope, lead to fluidized flow and turbidity currents descending into the channels and canyons. The unchannelized turbidity currents and the turbid layer flow down freely across the

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Fig. 4 - Architectural elements of Cagliari shelf: Holocene and Middle Pleistocene depositional facies associations. Cross-section obtained by projection of several seismic and onland data. 1) Lower(?)-Middle Pleistocene continental conglomerates (Pecorini, 1986); 2) Pre 20-18 Ky-low stand depositional units; 3) Post 20-18 Ky-low stand depositional units (Post Glacial-Holocene trasgressive-high stand systems tract); 4) Unconformities. Vertical exaggeration ≈14X, location is shown on Fig. 3

Architettura deposizionale della piattaforma continentale di Cagliari durante il Pleistocene medio-superiore e l'Olocene. Sezione ottenuta mediante la proiezione di diversi profili sismici e di dati a terra. 1) Conglomerati continentali del Pleistocene inf.(?)-medio (Pecorini, 1986); 2) Unità deposizionali precedenti lo stazionamento basso 20-18 Ky; 3)) Unità deposizionali posteriori allo stazionamento basso 20-18 Ky; 4) discordanze). Esagerazione verticale ≈14X, ubicazione in Fig. 3.

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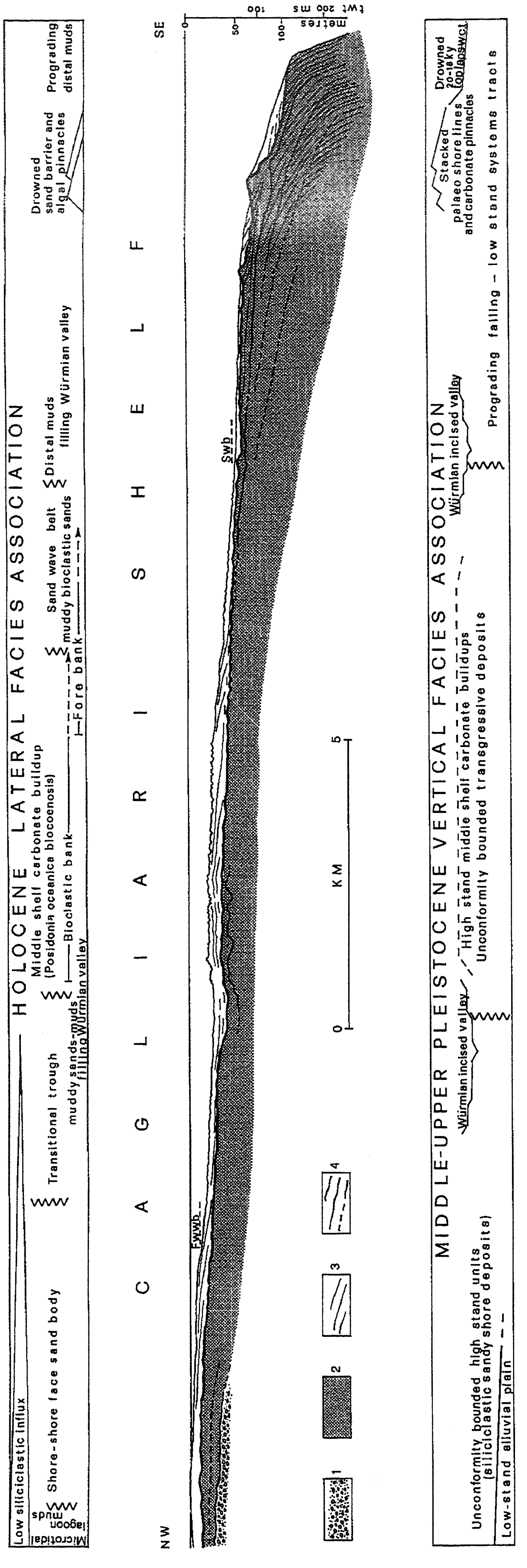
(1) "Würmian" glacial term are used here in sense of contemporaneous eustatic phase.

Il termine glaciale "Würmiano viene usato con significato temporale rispetto alle contemporanee variazioni eustatiche.



slope. By means of this dynamics, the shelf sediments are moved to the base of slope and basin floor. The fine grain size classes coming from the shelf such as hemipelagic muds and low density turbidity currents of the shelf-basin slope, supplied the aggradation on the basin floor, subparallel and wavy, and along the flanks of the reliefs.

Minor amounts of sediments reach the distal part of Cagliari Basin floor near the Seamount Ichnusa and beyond the narrow Banghittu-Ichnusa threshold toward the Sardinian-Tunisian Valley via Carbonara Canyon.

The analysis of sparker and subbottom data provided a synthetic picture of the main processes and morphological features existing in this system. These are mapped in Plate II and are described below.

6.2 Processes on the shelf (Fig.4, Plate.II-III)

Fluvial input, marsh-lagoon, dune-beach ridge, shoreface

The proximal shelf processes are clearly the continuation of subaerial littoral processes. The Holocene estuarine-delta system shows a transitional environment characterized by marsh, estuarine microtidal lagoon, dune-beach ridge and shoreface where sandy sediments accumulate up to some tens of meters thick. The Holocene sand sheet often lies on deposits related to the antecedent Middle-Upper Pleistocene high stand. Quartzose-feldspatic sands and subordinate bioclasts and conglomerates are the main components of this deposit. The tractive processes are dominated by eolic action in the subaerial transitional environment, and wave motion, storm-induced and littoral currents occurring in the microtidal nearshore.

These depositional units are observed to be thichest at the on-land boundary of Campidano Graben, where sands coming from Cixerri-Flumini Mannu rivers accumulate, and along the coast eroded in Tertiary marly-arenaceous and volcaniclastic rocks (e. g. Poetto-Quartu beach). On the contrary, the width of shoreface decreases strongly at the base of the cliffs carved in Paleozoic crystalline and schistose rocks.

The 3.5 kHz records indicate an amorphous facies on the shore face sands, while seaward, around the fair-weather wave base, rare more marked reflectors are present.

Inner shelf troughs: modern transition between distal shoreface-Posidonia bank

A wide trough in the SW inner shelf of Cagliari Gulf was explained by Segre (1968) as a pre-Versilian fluvial bed of Flumini Mannu-Cixerri paleo-rivers evolved as estuarine lagoon. The parallel basinward dipping reflectors observed in the 3.5 kHz records that fill a previously incised valley, suggest that it may rightly be attributed to the fluvial erosion activity that occurred down to –20 ÷ -30 m below the actual sea bottom, in the 20-18 Ky low stand (Fig.5).

During the Versilian sea level rise, this trough passed from fluvial to estuarine marsh to estuarine lagoon to inner shelf environments, with deposition of fluvial, muddy and sandy sediments respectively. Reflection free zones and mud mounds inside the paleo-valley infilling bear witness to the presence of gas charged sediments (Fig.5).

The seaward prosecution of this trough has not yet been recognized. The simplest reason could be in the sandy gravelly sedimentary covers and/or seagrasses which are characterized by acoustically dissipating behaviour. Segre (1968) proposes an analogous interpretation for a similar trough in the northeast part of the Cagliari Gulf.

Note that these troughs, being located landward from the Posidonia oceanica seagrass bank and affected by muddy sediments, work like the lower shoreface-transition zone below the fair-weather wave base. Actually, even if according to Segre, the preceding lowstand related paleo-morphologic unit is present in the subbottom records, the trough works as a kind of separation between the distal shoreface and the seagrass carbonate bank. In this condition its present morphologic features are a result of decreasing shoreface siliciclastic sediments and increasing bioclastic production of the *Posidonia oceanica* biocoenosis.

Posidonia oceanica seagrass meadow buildup

Posidonia oceanica associated with other marine phanerogams and algae, colonizes the inner-middle shelf down to depths of -40 ÷-45 m. This seagrasss (Amgiospermae, Monocotyledoneae) is a species of major ecological importance. Indeed the sediments sampled in this part of the shelf show that coralline algae, foraminifera, bivalves and gastropods, even if depleted because of bad light, grow at the base of *Posidonia*, producing and accumulating carbonate crusts which are turned into skeletal gravelly sands . Moreover the *Posidonia oceanica* meadow traps, stabilizes and binds the skeletal and terrigenous sandy-muddy sediments by its blades, rhizomes and roots (Fig.6; Perez & Picard, 1964; Belperio et al., 1984; Gostin et al., 1984). In this way the colonized bands grow and contribute to the aggradation of poorly sorted bioclastic sediments, while uncovered areas are subject

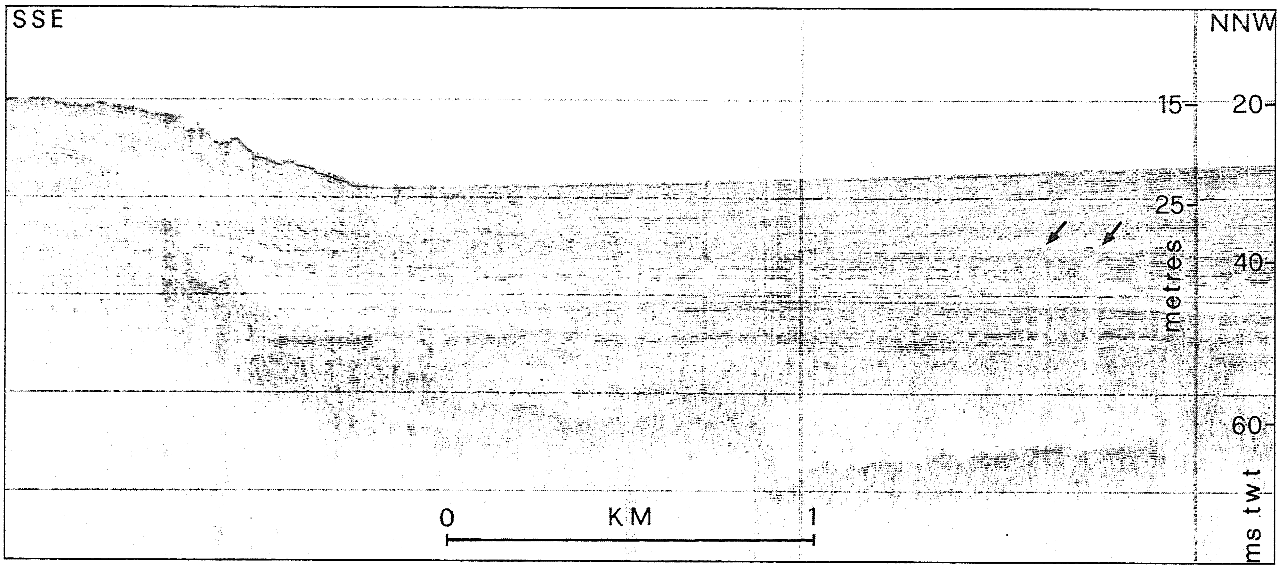


Fig. 5 - Inner shelf trough: Würmian paleo-valley filled by shoreface distal sandy muds located in the inner Cagliari shelf. Note southeastwards the Posidonia buildup. Arrows show mud mounds and gas-charged sediment structures. Subbottom 3.5 kHz record (2/PL81/1). Vertical exaggeration ≈21X, location is shown in Fig. 3.

Depressione della piattaforma interna: paleo valle würmiana, ubicata nella piattaforma prossimale di Cagliari, dominio dei fanghi sabbiosi di transizione dell'attuale spiaggia sottomarina. Verso sud-est si osserva il versante interno del banco a Posidonia. Le frecce indicano diapiri di fango e strutture da gas. Profilo ecografico 3,5 kHz (2/PL81/2). Esagerazione verticale ≈21X, ubicazione in Fig. 3.

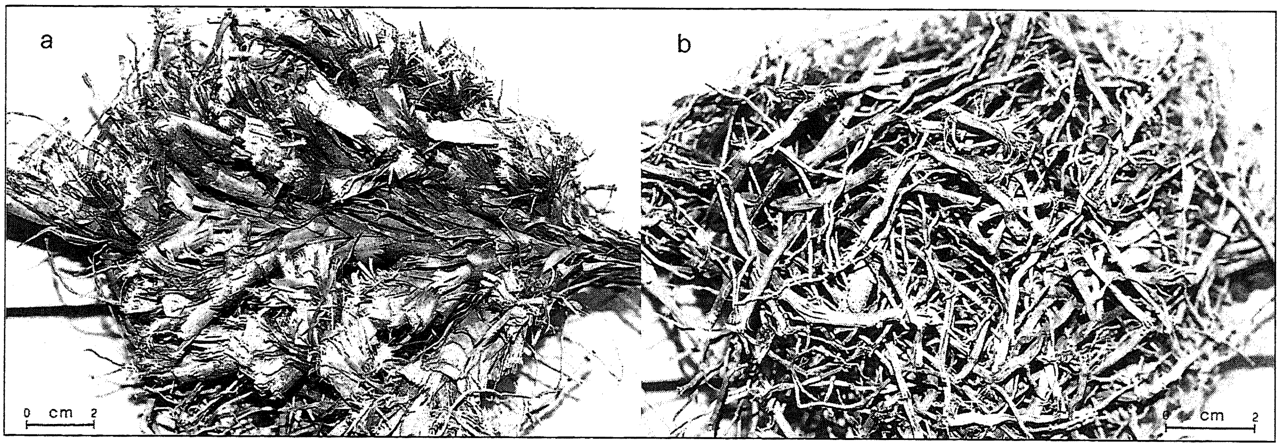


Fig. 6 - *Posidonia oceanica, the seagrass that controls the modern skeletal bank of Cagliari shelf:* a) rhizome and b) its root apparatus, the maximum density of roots is 6÷9 per cm^3.

Posidonia oceanica, l'erba sottomarina che controlla l'attuale banco carbonatico della piattaforma continentale di Cagliari: a) rizoma e b) suo apparato radicale, la densità massima di radici è di 6÷9 per cm^3.

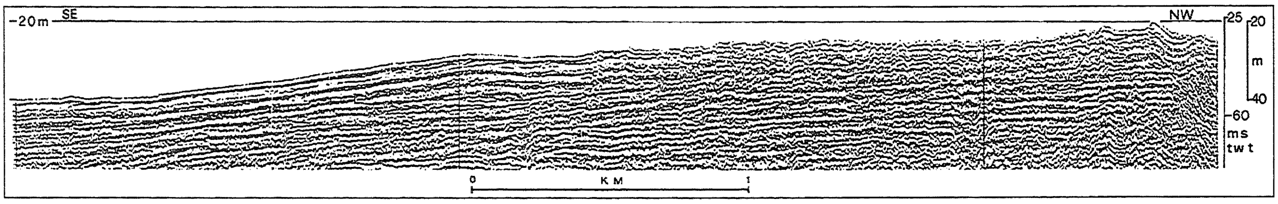


Fig. 7 - Sparker 0.5 kJ 11/MCS/87 profile across the Cagliari mid-shelf, note the Posidonia oceanica buildup and its on-shelf progradation. Vertical exaggeration ≈14X, location is shown on Fig. 3.

Profilo sparker 0,5 kJ 11/MCS/87 sulla bioerma a Posidonia oceanica; si noti la tendenza di accrescimento verso l'alto e progradante verso l'esterno della piattaforma. Esagerazione verticale ≈14X, ubicazione in Fig. 3.

to tractive currents where ripples and mega ripples develop on bioclastic coarse gravelly sands.

This biocoenosis developed along a wide area parallel to the coastline, where *mattes* and *intermatte* channels are evident (Fig.8-a). Here human interference (fishing) too has produced discontinuities and breaks.

In the complete cross-sections the *Posidonia* unit appears in the middle shelf. Here it shows an aggradating growth, slightly prograding toward the distal zones (Figg. 4, 7 and 8) giving rise to a carbonate or carbonate-silicoclastic buildup trending to an on-shelf progradation. Thus the *Posidonia* unit restricts landward the muddy transitional trough to shoreface and limits basinward the outer shelf subjected mainly to muddy-sandy distal sedimentation. Therefore the *Posidonia oceanica* bank is an important controller of hydrodynamic and depositional processes all over the shelf. In the Cagliari Gulf this biocoenosis has to be considered a remarkable carbonate factory that produces a temperate carbonate buildup.

Segre (1968) interpreted this coastline parallel bank as "Versilian paleo-beach ridge with submerged relics of dunes". Unfortunately the available subbottom and sparker profiles crossing this area are ill-defined in the two-way-traveltime span immediately below the sea floor profile because of the strong acoustic absorption produced by the particularly complex surface offered by *Posidonia* to the acoustic waves. In spite of this, it is not so hazardous to suppose that *Posidonia oceanica* could have colonized a former paleo ridge related to previous mid-shelf sea levels.

Sand waves

Along the outer Cagliari shelf, off the *Posidonia oceanica* meadow is a wide sand wave belt (Contu et al., 1982; Pisano, 1985; Ulzega et al., 1986) where

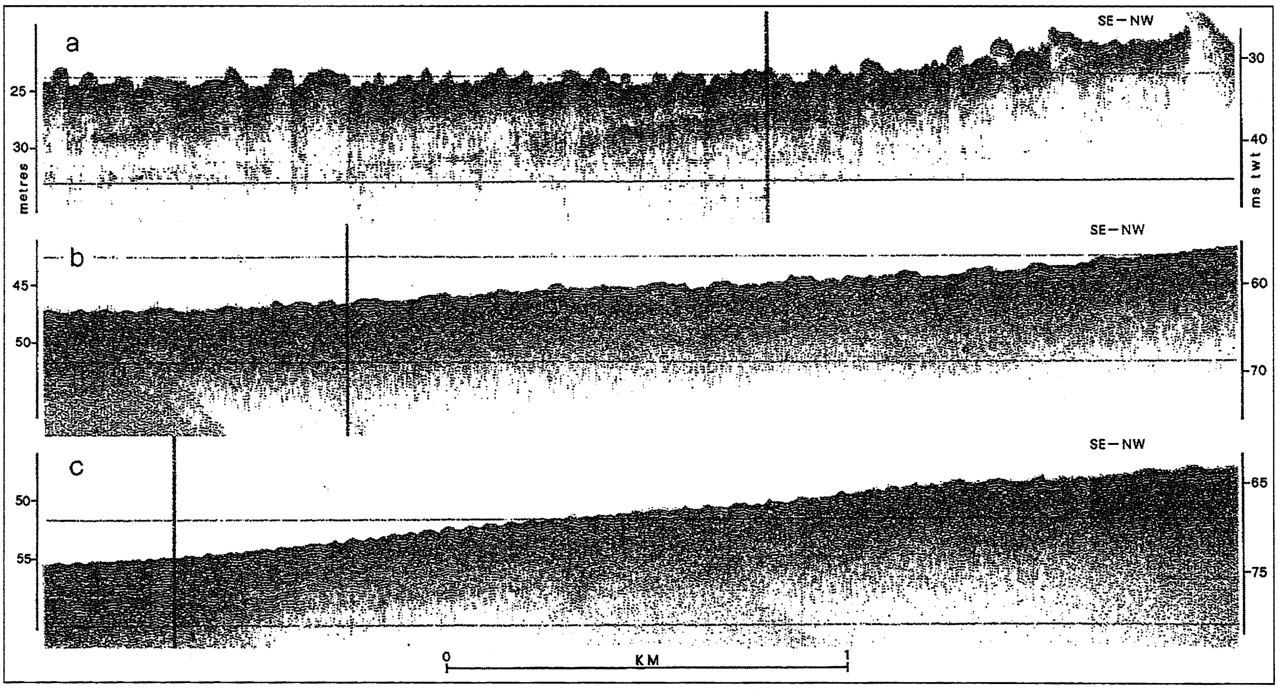


Fig. 8 - Seismic facies of Posidonia bank and its fore-slope. Subbottom 3.5 kHz records (11/MCS/87): a) Posidonia oceanica meadow, below note the shingled pattern prograding southeastwards; b) giant sand waves, the crests are sometimes colonized by Posidonia oceanica; c) small sand waves on basinward fining sediments. Vertical exaggeration ≈30X, line locations are shown in Fig. 3.

Facies sismiche della bioerma a Posidonia e del suo pendio esterno. Profili ecografici 3,5 kHz (11/MCS/87): a) prateria a Posidonia oceanica, si noti la progradazione verso SE della stratificazione sottostante; b) onde di sabbia, le creste vengono talvolta colonizzate dalla Posidonia oceanica; c) forme ondulate minori su sedimenti che divengono più fangosi verso la piattaforma esterna. Esagerazione verticale ≈30X, ubicazione in Fig. 3.

waveheights of 1 ÷ 3 m and wavelengths of 70 ÷200 m are observed (Fig. 8-b and 8-c). This unit is the "older cata-würmian paleo beach ridge with relics of submerged dune" of Segre (1968).

Actually the interpretation is inferred only from the superficial forms shown in the 3.5 kHz profiles, as more detailed data for the internal structure are lacking.

These structures are observed in other shelves, but at variable depth, showing a greater development and appearing more mobile (e. g. Spencer Gulf - Australia Gostin et al., 1984, S Florida platform, Holmes, 1985).

In Cagliari shelf, the genesis of these large and giant waves is related to the skeletal coarse-gravelly sands coming from the *Posidonia* meadow and to hydrodynamic factors acting at depths of -35 ÷ -50 m, including wave and current induced bottom shear. Therefore, the sand wave belt depicts the Posidonia buildup fore-slope. The presence of this bed-form belt mainly witnesses the storm action on the fore-slope of the *Posidonia bank*, while their disappearance marks the storm wave base. Moreover pioneer colonization of *Posidonia* is observed around the lower bathymetric limit (about -40 ÷-50 m) stabilizing the giant wave crests (8-b). In fact in more proximal areas of the sand wave belt, they often show irregular and narrows mattes lying parallel to the shelf, while toward more distal parts their frequency increases with decreasing height until they disappear in the distal muds at about -50 ÷ -60 m (Fig. 8-c).

Buried low stand fluvial channels

Segments of minor fluvial valleys are related to the hydrographic pattern active during the Würmian low stands. Their detection is difficult and incomplete because the smallest ones are often buried by littoral sandy sediments and seagrasses. In spite of this a low stand prosecution of Cixerri-Mannu river up to shelf edge is supposed (see Plate II). Other channels, located behind the drowned barriers on the NE side of the Cagliari shelf, trend southwestwards (Fig.9).

Drowned barriers

Several paleo-shorelines are observed at depths from about -80 to about -30 m. The outer ones are more continuous and longer (≈40 Km), and develop parallel to the modern Cagliari shelf break. Such structures are mostly related to a sea level below the actual one about -50 ÷ -60 m. The attribution of this paleo-shore to an exact eustatic cycle is still difficult. Ulzega et al. (1986) interpreted this paleo-shore by means of samples as a beach-rock related to minor sea-level stand phases within the Holocene transgression. On the other hand the analysis of seismic profiles shows that the whole paleo-shore morphostructure is composed of stacked depositional units (Fig. 4 and Plate III/a) related to several low stands. Moreover, northeastwards, some records show the characteristic features of Quaternary algal pinnacles likely consisting of red and crustose-coralline algae and biomicrite boundstones (Fig.9), as described in the western Sardinia shelf (Carboni & Lecca, 1992), and other parts of the Mediterranean (e. g. Sicily, Colantoni et al., 1995; Baleari, Acosta et al., 1992).

The latest growth of such paleo-shore-algal pinnacles complex is related to an eustatic interval preceding the last erosional phase recognizable on the paleo-form itself. At the present time the sequence interpretation is still problematic. In fact the paleo-shore-algal pinnacles are evidently eroded (for the last time) by a sea level standing to about –70 ÷ -80 m depth. A similar erosional phase is correlable to the *high-amplitude changes 12-10 Ky* old (Older and Younger Dryas, sensu Mörner, 1993) that should give rise to a subaerial erosion related to a last brief low-stand or to a trasgression-related ravinement erosion (Fig. 10).

Moreover, as erosional relationships exist with the 20-18 Ky low-stand (last wave cut terrace), a "late Würmian interstadial" age can be suggested for the last growth of this the paleo-shore complex (compare with Würm 3/4 of Droz, 1991 and isotope stage 3 of Antonioli & Ferranti 1996).

Therefore, no one single age can be attributed to the whole structure, but one time span for every downlap-top-lap unit related to one falling-low stand sea level.

Post glacial-Holocene slightly prograding distal muds

During the Post glacial-Holocene eustatic rise, distal muds are the dominant facies in two depositional units located below the storm wave base, basinwards to the sand wave belt: the infilling of a shallow paleo-trough and a slightly prograding deposit.

The paleo-trough, on the inner side of the drowned

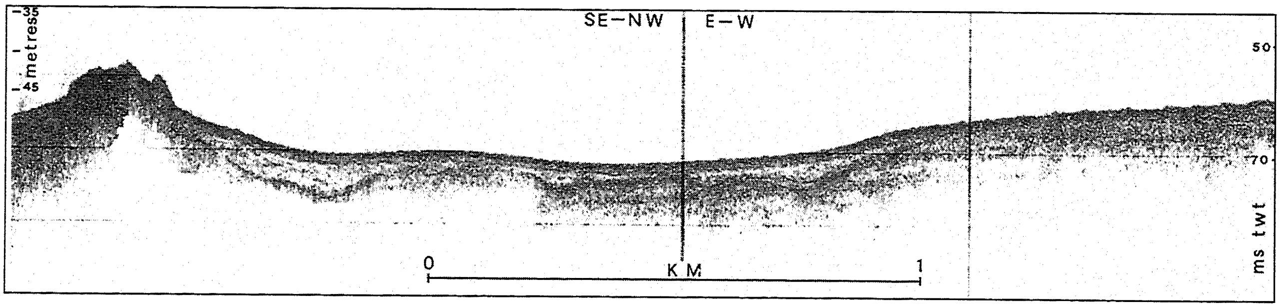


Fig. 9) Outer shelf trough: a Würmian fluvial trough drowned and partially filled by Post Glacial-Holocene marine muds. Note the organogenic pinnacle form of the drowned barrier and westwards some small sand waves. Subbottom 3.5 kHz record (11/MCS/87). Vertical exaggeration ≈23X, location is shown in Fig.3.

Depressione nella piattaforma esterna: valle fluviale würmiana sommersa e parzialmente colmata da fanghi marini post glaciali-olocenici. Si noti la tipica morfologia di pinnacolo organogeno della barriera sommersa e la presenza verso ovest di alcune onde si sabbia minori. Profilo ecografico 3,5 kHz (11/MCS/87). Esagerazione verticale ≈23X, ubicazone in Fig. 3.

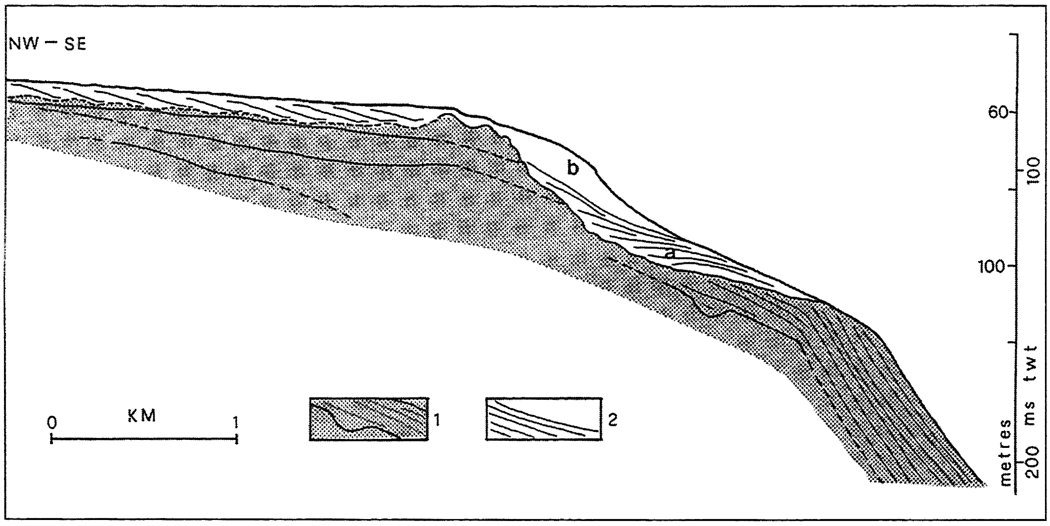


Fig. 10 - Relationship between the drowned beach-ridge, the 20-18Ky toplap-wave-cut-terrace and Post Glacial-Holocene deposits. 1) Pre 20-18 Ky-low stand depositional units; 2) Post 20-18 Ky-low stand depositional units; a) Bedded sediments (sands?, Older-Younger Dryas?); b)Holocene distal muds. Interpretative cross section of sparker 0.8 kJ profile (6/PL77/3). Vertical exaggeration ≈ 20X, location is shown in Fig.3.

Rapporti tra il paleo-cordone litorale sommerso, la superfice di toplap-erosionale dei 20-18Ky ed i sedimenti post glaciali-olocenici.); 1) Unità deposizionali precedenti lo stazionamento basso 20-18 Ky; 2) Unità deposizionali successive allo stazionamento basso 20-18 Ky; a) sedimenti stratificati (sabbie?, Older-Younger Dryas?); b) fanghi distali olocenici. Profilo sparker 0,8 kJ (6/PL77/3). Esagerazione verticale ≈20X, ubicazione in Fig.3.

barrier (Fig.9), was a paleo fluvial valley and lagoon/marsh during the last eustatic low stand. In particular this trough experienced a ravinement surface with sandy deposits during the early Post Glacial sea level rise.

The prograding deposit lies on the outer side of the drowned barrier and constitutes the last depositional unit appearing structurally complete (Fig.10). The lower part shows a gently dipping parallel-down lap stratification probably sandy, witnessing a passage of the sea level in the -80 ÷ -70 m range. In the upper part a more transparent 3.5 kHz facies suggests a more muddy drape related to the late Post Glacial-Holocene sea level rise, that caused a flooding eustatic interval between about –60 ÷ -50 m and the present sea level (Figg.9 and 10).

In the central part of Cagliari shelf, the inner and the outer units join together because of the greater mud thickness and the discontinuities occurring in the drowned barrier.

Toplap surface-wave cut terrace of the 20÷18 Ky low stand

A toplap surface-wave cut terrace, on parallel-oblique almost trasparent sediments prograding, being the last high energy event, is correlated to the last Würmian low stand (Figg. 4, 10 and Plate III/a). It is a well defined structure present along all the shelf edge of Cagliari Basin. The more outer drowned barrier complex represents the inner limit of this erosional bench. Towards this inner side it is buried by the Post Glacial-Holocene deposits (Fig. 10). Under this low stand unconformity, further deeper toplap-erosional buried terraces are observed (Plate III/a). These unconformities, and other truncation related to the retrograde erosion of tributary channels, bound at least eight depositional units connected to shelf prograding and paleo-canyon infilling (Plate III/b; Lecca et al., 1988).

Rocky shelf with narrow prograding wedge

The shelf close to the granitoid horst of southern Sàrrabus, is composed of a rocky narrow inner shelf, with a discontinuous sandy shoreface, and an outer shelf showing a narrow sigmoid-oblique progradation, at about –100 ÷ -125 m. In wide zones where the progradation is absent, algal pinnacles coated the shelf edge built in outcropping bed rock. This part of the shelf plays a bypass sedimentary role toward the tributary channels of S.Elia-Foxi and Carbonara Canyons.

Su Banghittu: an isolated carbonate platform

Su Banghittu is a fault bounded relief on the S side of Cagliari Basin (Plate III/f). The top of this relief is an isolated bank in that no elements in seimic profiles suggest any link with the shelf of the southern Sulcis and of Cagliari Gulf during the Plio-Quaternary. Therefore it has to be considered a bank separated by the terrigenous supply. In fact, some gravity corings on the top of Su Banghittu witness the presence of essentially carbonate gravelly sands dominated by Rodoficee, Molluscs and other bioclasts. The top of this relief, at about -115 m, shows a planar-like morphology limited by slightly prograding edges. The shelf break is at about -145 ÷-150 m with sigmoid-oblique offlap pattern. Considering the depth of the top, the hypothesis of a partial emersion of this relief during the Würmian 20÷18 Ky low-stand is not to be discharged, but it should be noted that morphological and seismic-reflection evidence is still lacking.

Retrograding shelf-edge

A retrograding shelf edge, due to the retrograde erosion by tributary channels of canyons and diffuse gravity processes, is observed in the NE side of Cagliari shelf. Here the shelf-basin slope appears to be disruptive because of intense activity of S.Elia-Foxi Canyon.

6.3 Slope, basin and seamounts: processes and forms (Plate II-III)

Shelf-slope prograding wedge

The shelf-basin slope joins the shelf edge, at -100 ÷ -125 m, to the proximal part of the floor of Cagliari

Basin, ranging from -500 to -700 m. Because of this deep gap and the moderate sediment supply, the progradation grows slowly, as shown by the comparative stability of the shelf break during the last four Pleistocene high-frequency eustatic cycles (Fig.11). The progradational seimic reflection pattern is generally parallel-oblique (3%÷15%). On the NE side of this slope a dip change distinguishes an upper slope, a lower slope and a base of slope (Plate III/d). The continuous and cyclic stacking of low stand systems tracts produce the sedimentary accretion and segments of canyons are often buried.

Locally gravity mass flows increase the slope dip giving rise to a by-pass sedimentary behaviour. Erosional and mass transport processes, operating along the canyons tributary channels that cut the prograding wedge, convoy the sediments in the deep parts of the basin.

At the present time the shelf-slope prograding wedge is moderately subject to subsidence and/or compaction. This behaviour can be inferred from the seismic profiles where the depth of the low stand toplap-wave cut terraces increases with age.

Below the wedge, the infilling setting is controlled by a tectonic block made up of a bedded seismic unit (Plate III/d), that could be related to the Miocene sequence outcropping near to the towns of Cagliari and Quartu.

Slumpings

The plastic behaviour of sedimentary layers (i. e. more or less hydroplastic clayey-sandy interlayerings showing 1-3.6 kJ seismic transparent facies), their progradational parallel-oblique pattern and also their comparative slope dip favoured mass movements. Single events are probably related to the sediment load, increasing water pressure during the rise of sea level or to rare earthquakes. Moreover, single events are triggered by the canyons erosion active in the lower part of the slope. In some seismic-reflection profiles the typical zoneography of slumping-related forms can be sometimes recognized: (i. e. scar, deformed body and front, Fig.12 and Plate III/c, compare with Lewis, 1971), while in some other seismic profiles only the scar and depositional lens at the base of the slope are recognizable. Other gravity processes, such as mud, grain and debris flow, working in the outer progradational front are not recognizable simply by seismic facies analysis.

Tributary and buried channels

On the outer side of the Cagliari shelf-slope wedge there is a degradational band characterized by several tributary channels of the canyons. The usual cross-section is "U"-shaped with a flat bed less than a Km wide, narrow "V"-shaped cross-sections are present in the proximal part of channels. In some sectors important erosional phenomena produce retrogradation and captures of the canyon heads and the slope becomes a gullied slope.

Generally, channel erosion appears to be active simultaneously to the slope wedge accretion during bot low and high stands. However the erosive retrogradation of the channel heads, produced by the shelf-basin bypass currents, acts moreso mainly during the rise and high stands when sediments in the shelf-basin transition area are starved. On the other hand, during the falling-low stand events the tributary channel heads could be subjected to partial infilling because of the sediment supply increase, the shelf being much less extensive. The reverse behaviour could be explained by the erosional channel heads that during low stands were connected with fluvial outlets. In this case the sedimentary input coming from major rivers (e.g. paleo Cixerri-Mannu River) could already be channelized in littoral environment. Otherwise, the building of sedimentary fluvial-littoral environments over the emerging shelf areas would inhibit such reverse behaviour for minor rivers.

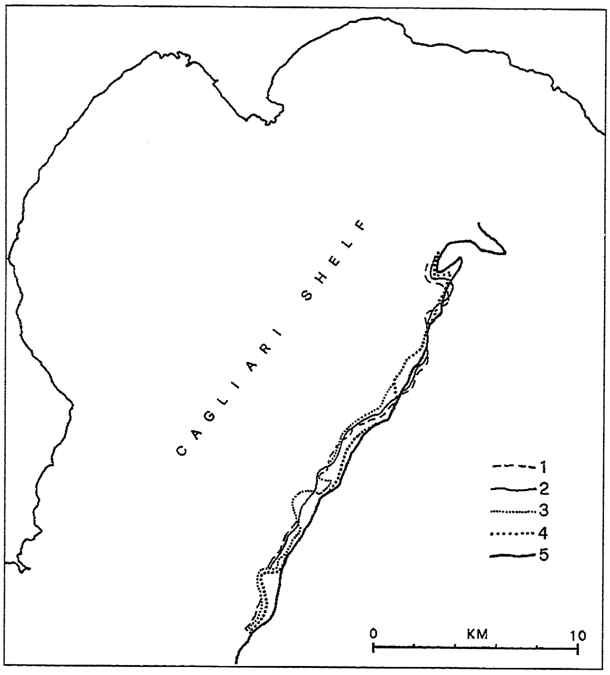


Fig. 11 - Shelf break variation during last four high-frequency low stands: 1 modern; 2, 3, 4, 5: 1th, 2th, 3th, 4th Middle?-Upper Pleistocene low stands.

Variazione del bordo della piattaforma durante le ultime quattro regressioni glacio-eustatiche: 1 attuale; 2, 3, 4, 5: 1º, 2º, 3º, 4º regressioni del Pleistocene medio?-superiore.

After an infilling event the channels could migrate laterally and set up a new network that could migrate basinwards. Several channels buried along the progradational wedge of the Cagliari shelf witness the alternation of these erosional and infilling phases (Lecca et al., 1988; Plate III/b).

In the Sàrrabus shelf, characterized by a narrow prograding wedge, the tributary channels are steady, being cut along the fault zones of the Hercynian granitoid basement.

Canyons

Toward the deepest part of the slope wedge the tributary channels connect or evolve into larger canyons. Their sections are "U"-shaped in the proximal sectors, and are characterized by average width of about 1÷2 Km and depth of up to 100 m. Very wide forms (up to 3 Km) are observed in distal sectors, characterized by flanks of some tens of metres. The dip ranges from 2.5%-3% to 1.2%, in Sarroch and S.Elia-Foxi Canyons, down to 0.8% in Carbonara Canyon. The turbidity currents, channelized in the canyon heads, flow towards the deepest zones with tractive energy. For this reason in the proximal canyon axes, large volumes of sediments are lacking . In the middle lower part of the canyons, turbidity currents reach maximum flow during the low stands because of the nearness of the fluvial outlet to the shelf basin transition, and the loaded stream in response to more rainy climatic variations.

The Sarroch Canyon clearly incises the progradational wedge (Fig.12) and at the base of the slope it shows some channel-in channel erosional structures (Plate III/g). In the lower part of the basin the right flank is lacking likely because of slowing down of turbidity currents and its leftward migrating (Fig.13). This canyon joins the Carbonara Canyon in distal areas and produces an ill-defined depositional lobe.

The S.Elia-Foxi-Carbonara Canyon shows defined flanks in a well enclosed valley, testifying the continuous activity of tractive currents little related to high-frequency eustatic cycles. This character is recognizable even in the distal course, probably also because of its direct connection with Sardinian-Tunisian Canyon whose increases dip in the Ichnusa-Banghittu threshold (Fig.13). The well incised valley of Carbonara Canyon indicates that the channelized transport along this canyon is the most active sediment discharge of the basin.

Minor incisions

These morphologies are referred to processes of minor significance such as isolated incision not connected with canyons pattern or found only in one subbottom or sparker profile.

Basin floor

The transition from the base of shelf-basin slope to the basin floor is gradual on the SW side and more frequent buried channels accompanied it. Northeastward it is evidenced by a sedimentary hinge progressively "onlapping" the parallel reflections of progradational wedge. The depositional pattern changes from a parallel bedding in the lower slope to an uneven parallel with interbedded gravity-induced lenses in the slope base (Plate III/d).

The typical features of intraslope basins, showing several staked channel-levee-overbank units, is recognizable in the basin floor. This is composed of a wide levee-overbank (about 3%÷1% dip), in the intercanyon area, and of another two smaller and lateral, at the base of Sàrrabus and Su Banghittu slopes (Plate III/f).

In the seismic profiles, the infilling is characterized by interbedding of stratified and semitrasparent seismic facies. The reflectors, even parallel, are related to midd-

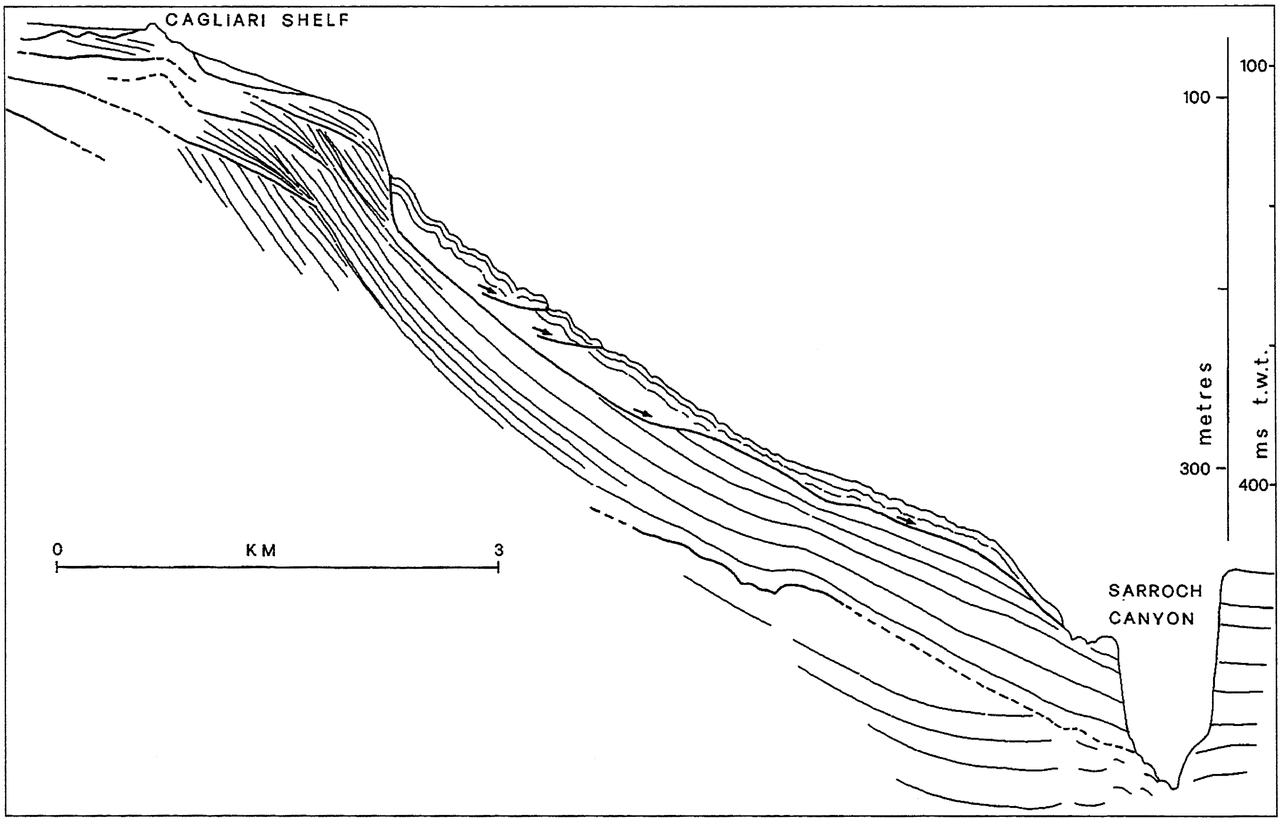


Fig. 12 - Rotational slump with large internal deformations, located on the Cagliari shelf-basin slope. Line drawings of 1 kJ Sparker profile (1/MCS/83, see Plate III/c) across a typical slumping in the shelf-basin upper slope triggered by the Sarroch Canyon activity. Vertical exaggeration ≈11X, location is shown in Fig.3.

Scivolamento gravitativo con intense deformazioni degli strati, parte alta del pendio piattaforma-bacino, il processo è innescato dall'erosione nel Canyon di Sarroch: interpretazione di profilo Sparker 1 kJ (1/MCS/83, vedi Tav. III/c), esagerazione verticale ≈11X, ubicazione in Fig.3

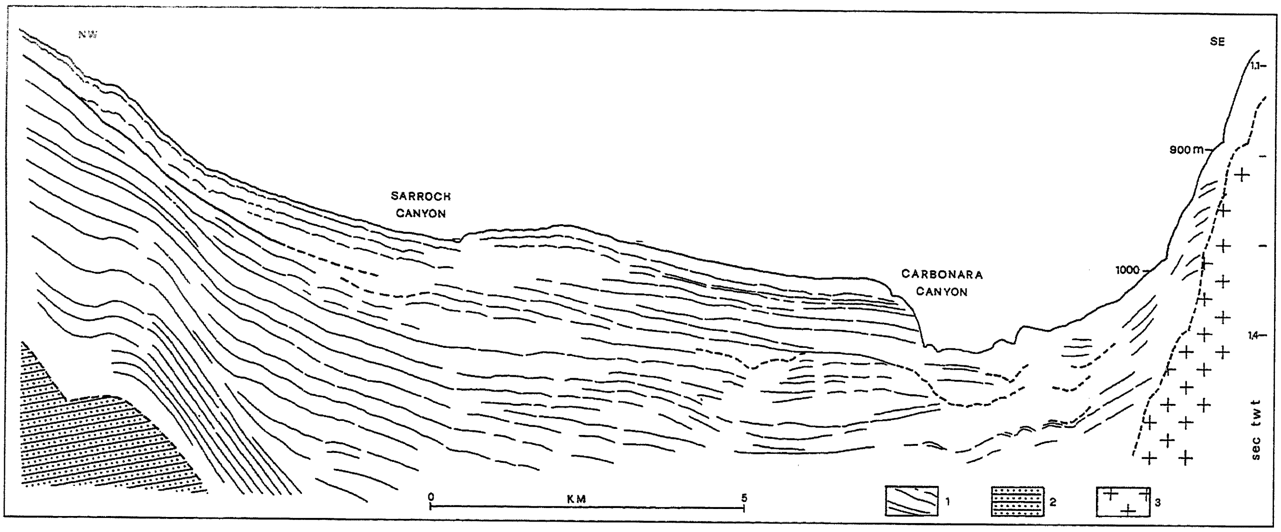


Fig. 13 - Line drawings of 1 kJ Sparker profile (1/MCS/83) NW-SE across the southern part of the Cagliari Basin. The canyon activity is more remarkable in the upper part of the Plio-Quaternary sequence. Note the asymmetry of the Plio-Quaternary infilling related to the half graben behaviour. 1) Plio-Quaternary sequence; 2) Miocene sequence; 3) Paleozoic basement. Vertical exaggeration ≈ 11X, line location is shown in Fig.3.

Interpretazione di profilo sparker 1kJ (1/MCS/83) ubicato nella parte sud-orientale del Bacino di Cagliari. L'attività dei canyons è maggiormente presente nella parte alta della sequenza Plio-Quaternaria. La asimetria del bacino rivela la struttura tettonica di tipo semi-graben. 1) Sequenza plio-quaternaria; 2) sequenza miocenica; 3) basemento paleozoico. Esagerazione Verticale ≈11X, ubicazione in Fig.3.

le-distal turbidity as well as to hemipelagic aggradation. Locally, chaotic or reflection free patterns are likely due to important proximal turbidites or, at the foot of the slopes, to gravity-induced low stand related deposits. Moreover buried canyons and internal unconformities are present.

The internal reflections of the levees-overbank extend up to the shelf-basin slope wedge, documenting thus that the glacio-eustatic control is present in the infilling of the basin floor too (Plate III/d).

The basin, in the distal and more subsident part near to Ichnusa Seamount, shows a clear concavity of confined basin with even parallel reflections cut by Carbonara Canyon.

Above the Miocene-Pliocene unconformity, the sedimentary fill shows two parasequences, attributable to Pliocene-Lower Pleistocene and Lower-Middle Pleistocene-Holocene respectively (Plate III/d-f and Fig.13) In the lower one, the depositional processes appear to be different from the upper one. Probably, because of a greater control played by extensional tectonics the sedimentation in the former parasequence was sin rift, whereas in the latter appears post rift. The lower part of the Lower-Middle Pleistocene-Holocene parasequence witnesses early activity of Sarroch Canyon with two levees successively banked. With increase of the infilling, S. Elia-Foxi Canyon develops assuming a configuration quite similar to the present one.

Recent gravity-induced and proximal turbidity lenses

At the base of the frontal slope of the Cagliari shelf, as well as on the eastern slope of Su Banghittu, more recent sedimentation, related to the base of the slope, is recognized. Typically gravity processes, from plastic to uncohesive, and proximal turbidity are present.

Aggradational drape

The flanks of Su Banghittu and Ichnusa reliefs show minor structural troughs often related to syndepositional faults. On the flanks a thick hemipelagic stratified mud drape (until to 200-400 ms TWT) exists (Plate III/e-f and Fig.13). These sediments provide transparent and wavy parallel draped seismic patterns. On the steeper flanks of Su Banghittu, that are covered with the mud drape, some gravity slidings are observed.

Alignment of concavities

Such morphologies may be found at the boundary between the slopes and the floor and, generally, at the sedimentary hinges. They are due to the progressive onlapping of the floor basin system over the slope wedge. Locally, these concavities mark the prograding turning into aggradating growth, as well as that induced by the bedrock rising.

Low-rate sedimentation areas and rocky convexity

The upper part of Ichnusa Smt., most parts of the Sàrrabus slope and the outcropping bedrock on the Su Banghittu flanks, are blanketed by a thin and discontinuous hemipelagic mud drape.

Along the slopes of reliefs, at the foot of Sàrrabus slope and on the top of Icnusa Smt., morphologic convexities are present as a consequence of the bedrock outcropping or lithoherms coating without or buried below a thin hemipelagic drape.

7. BASIN EVOLUTION

According to the analysis of the shelf break position during the last four high- frequency (Milankovitch cyclicity) eustatic cycles, the relationship between the progradational wedge and the system of tributary channels related to the canyons, has been considered as representative of main evolutionary trend markers of the whole Cagliari Basin depositional system. This analysis indicates an accretion (about 1 Km) together with locally and temporary retrogradation due to the erosion of the heads of minor and ephemeral channels (Fig.11). Northeastward, where the tributary system of S. Elia-Foxi Canyon is active, an alternate erosional and depositional behaviour is observed, even if the trend to stability prevails. Consequently, the whole edge of the Cagliari shelf has grown slightly during the last four high-frequency eustatic cycles time span.

At the present time, difficulties are encountered in attributing their age. The hypothesis refer the "last erosional" low-stand (in the outer-middle shelf; about -80 ÷ -60 m) to *Older-Younger Dryas* (12-10 Ky) and the "last progradational-wave cut terrace" low stand (in the outer shelf; about -90 ÷ -105 m) to last maximum Würmian 20÷18 Ky low stand, but are somewhat subjective. The current state of the study, the lack of samples enabling objective ages to be assigned and the possible subsidence control on the depth of the buried wave cut terraces are the main problems. However, the four low stands would be related to the 100 Ky or 40 Ky glacio-eustatic sea level cycles shown in the $\delta^{18}O$ curves of Chappel & Shackleton (1986) and Martison et al. (1987) and their calibration (Mattheuws, 1986). According to more recent age attribution, the lower low-stand could be correlated to isotopic stage 8 (about 200-250 Ky), while according to the older attribution it could said to be isotopic stage 12 (about 420 Ky). These ages indicate, when related to the entire shelf and basin system, a low filling rate at least in the same time span. Observing the filling sequence of the basin, it could be assumed that this slow filling stage was reached before the last four prograding events, suggesting this trend could be considered as representative at least since the Middle Pleistocene up to the present time.

By contrast, the shelf-break-tributary channels of Spartivento Canyon system, westward of Cagliari basin (i. e. shelf of Southern Sulcis), are usually retrograding, suggesting a predominance of degradational processes. This situation is due to the direct linkage between this part of the southern Sardinia slope with the deepest parts of the margin, and appears to be connected to the retrograde erosion due to Sardinian-Tunisian Canyon, while the Cagliari Basin is protected by Su Banghittu and Ichnusa reliefs.

Overall, even if there is a moderate subsidence, the trend is testified by the slow shelf-slope wedge progradation and, all over the lower slope, by the progressive "onlapping" of the basin floor channel-levee system. Therefore, the Cagliari Basin will be considered as a low fill trending, being clearly dominated by depositional processes while tectonic subsidence provides a minor contribution.

8. CONCLUSIONS

The intraslope basin of Cagliari is the very inner core of the depositional system of Sardinian southern margin. Its tectonic setting is based on the Pliocene-Quaternary transtensional-extensional phases related to the Tyrrhenian opening and on comparative Middle Pleistocene-Holocene tectonic stability. This basin is limited by the horsts of Su Banghittu and Ichnusa closing the southern part of the Oligo-Miocene Sardinian Rift.

Three main shelf model, according to different terrigenous siliciclastic contributions have been defined as follows:

a) the shelf of Cagliari, receiving moderate supply of sediments;

b) the shelf of Sàrrabus, receiving poor sediment input;

c) the shelf of Su Banghittu, receiving no sediments in that it is an isolated carbonate platform.

The Holocene Cagliari shelf shows an evident depositional tripartite zonation, where siliciclastic littoral sands exist in the inner part, *Posidonia oceanica* biocoenosis produces large amounts of bioclastic sediments in the middle part, and distal sandy muds fill the drowned paleo troughs and in prograde in the outer one. Therefore, looking at the architectural elements, three major processes work at the same time: the on-inner shelf progradation of the siliciclastic beach complex sand body, the mid-shelf *Posidonia* carbonate buildup slightly on-shelf prograding towards the outer shelf, and finally the distal mud fill slightly prograding towards the shelf-basin slope.

During the middle-upper Pleistocene-Holocene time span, the shelf was cyclically affected by high-frequency eustatic high stands, whose level was similar to the present one, and by low stands leaving a large part of the shelf emerged. These eustatic cycles, overall determined a discontinuous aggradation in high stand-related deposits in the middle-inner shelf, while in the outer shelf several forced type regressions supported a stacking of low stand systems tracts.

Also the budget and the nature of sediments is modulated by the eustatic changes. During the high stand (e.g. Tyrrhenian interglacial, isotopic stage 5 and Holocene), the semi-arid climate with low siliciclastic influx induces a carbonate behaviour inside the drowned middle shelf, giving rise to a Mediterranean type carbonate buildup. By contrast during the low stands, the new shelf morphology the large part of which emerged and the wetter climate induces a siliciclastic behaviour.

The shelf-to-basin transition is constituted by a slightly prograding wedge subject to canyon tributary system erosion and gravity induced processes.

Erosion due to two main canyons as well as turbidity currents and hemipelagic sedimentation govern the building of a channel-levee system on the basin floor.

Finally, the inclusive setting of the depositional system is controlled by the same tectonic structure that formed the basin, while its filling sequence is mainly controlled by the high-frequency eustatic changes. The general trend of the basin, during the Middle Pleistocene-Holocene, is clearly toward a slow filling stage, in spite of the moderate subsidence and the fact that the Carbonara Canyon moves part of its sediments toward the Sardinian-Tunisian Canyon.

ACKNOWLEDGMENTS

The authors wish to express special thanks to Prof. A. Ulzega of Cagliari University and Prof. S. Rossi of Bologna C.N.R. Marine Geology Institut for providing several of the seismic and subbottom records. The authors are indebted to the officers and crew of C.N.R.'s R/V Bannock for the assistance given during the expeditions. The authors also wish to thank Dr. S. Carboni and Dr. C. Ferrara for their friendly scientific contribution, and are grateful to Prof. Chiocci for his critical reading of the text.

This work is part of a research project on the study of the continental margins and the shelves of Sardinia financed by the Italian Ministry for Universities and Scientific and Technological Research (M.U.R.S.T. 60%, Cagliari University, Responsible scientist L. Lecca).

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Ms: ricevuto il: 5 marzo 1998
Testo definitivo ricevuto il: 29 marzo 1999

Ms received: March 5, 1998
Final text received: March 29, 1999