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LATE PLEISTOCENE - HOLOCENE SEDIMENTARY PROCESSES IN THE GAETA BAY CONTINENTAL SHELF (TYRRHENIAN SEA)

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RIASSUNTO - *Processi sedimentari nel Pleistocene superiore-Olocene sulla piattaforma del Golfo di Gaeta (Mar Tirreno)* - Il Quaternario *Italian Journal of Quaternary Sciences,* 9(2), 1996, 725-730 - Nel tratto di piattaforma continentale più esterna del Golfo di Gaeta sono state prelevate, lungo due transetti trasversali alla costa, cinque carote, al fine di studiare le caratteristiche sedimentarie e di valutare i processi deposizionali in relazione agli eventi tardoquaternari. Le analisi granulometriche e delle proprietà fisiche hanno consentito di riconoscere cinque facies: (a) limo bioturbato; (b) sabbia limosa bioclastica; (c) limo e sabbia interstratificati; (d) limo omogeneo; (e) sabbia limosa vulcanoclastica. Le prime tre litofacies sono presenti in tutte le carote, mentre le ultime due sono rispettivamente nella carota prelevata sulla scarpata superiore e nelle carote situate sulla piattaforma nel profilo meridionale. Il limo bioturbato e scarsamente consolidato rappresenta la facies predominante nei sedimenti più giovani recuperati nelle carote. Lo spessore di questa litofacies risulta maggiore nelle carote prelevate nel profilo meridionale, ed in questo raggiunge un maggiore spessore verso costa. La litofacies sottostante è costituita dalle sabbie siltose bioclastiche in cui si può notare, nelle carote del profilo settentrionale, la diminuzione della frazione sabbiosa scheletrica verso l'alto. Tali sedimenti, molto poco classati e con chiare evidenze di rielaborazione dei clasti, presentano alla base una superficie erosiva, al di sotto della quale vi sono sedimenti siltosi cui si intercalano specialmente verso l'alto sedimenti sabbiosi, definendo in tal modo un ciclo *"coarsening upward".* Le proprietà fisiche, ad eccezione di quelle della carota prelevata sulla scarpata superiore, rivelano un buon grado di consolidazione. I caratteri tessiturali e le proprietà fisiche dei sedimenti, unitamente ai dati emersi dalle analisi paleontologiche e dei profili sismici, hanno consentito di associare le litofacies delle carote studiate agli eventi significativi del Tardiglaciale-Olocene. La litofacies del silt e delle sabbia interstratificata è stata riferita ad un cuneo progradante verso mare accumulato nellíultima fase regressiva del Pleistocene superiore. La superficie erosiva ubicata alla base dei sedimenti sovrastanti indicherebbe l'inizio della fase trasgressiva. Tale fase di approfondimento è rappresentata dalle sabbie bioclastiche e dai livelli sottili fangosi. Infine il limo bioturbato non consolidato è da ascrivere ai depositi olocenici. Questi ultimi raggiungono gli spessori maggiori in quelle aree che risentono di consistenti apporti fluviali. Verosimilmente le litofacies della carota prelevata sulla scarpata superiore possono essere il risultato della rideposizione per processi gravitativi (ad es. torbiditi fangose) di sedimenti provenienti dalla piattaforma.

ABSTRACT- *Late Pleistocene - Holocene sedimentary processes in the Gaeta Bay continental shelf (Tyrrhenian Sea)* - Il Quaternario *Italian Journal of Quaternary Sciences,* 9(2), 1996, 725-730 - Five cores from boreholes drilled along two profiles in the Gaeta Bay continental shelf were examined from the sedimentological and geotechnical points of view in order to investigate the characteristics of sediments and to identify their depositional processes. The oldest deposits consist of alternating silt and sand layers, which were probably deposited during the latest Pleistocene glacial lowstand. These deposits are overlain by bioclastic silty sands and thin layers of hemipelagic clay which accumulated during the post-glacial sea-level rise. The youngest sediments, consisting of bioturbated silts, identify highstand deposits laid down during the Holocene.

Key-words: Sedimentology, physical properties, Late Quaternary, Tyrrhenian Sea.
Parole chiave: Sedimentologia, proprietà fisiche, Quaternario superiore, Mar Tirreno.

1. INTRODUCTION

In 1993, during an oceanographic cruise in the Gaeta Bay (central Tyrrhenian Sea), high resolution seismic profiles were carried out and several cores were selected on the basis of preliminary interpretations of seismic profiles. The surveys, co-ordinated by Prof. T.S. Pescatore, were focused to the reconstruction of the recent evolution of this part of the Eastern Tyrrhenian Margin.

Five cores were taken during this cruise along two parallel profiles, in the outer shelf and in the upper slope (Fig. 1). Preliminary analyses of the seismic profiles indicated the presence of prograding wedges — probably accumulated during periods of eustatic lowstand — cut by an erosional surface and overlain by a thin veneer of sediments, which is related to late transgressive and highstand phases. The substratum of these deposits consists of deformed sedimentary rocks, not younger than lower Pliocene, as identified by previous seismic surveys in this area (Bartole, 1984) and by cores drilled in a more northerly stretch of this shelf (Marani *et al.*, 1986).

The aim of this paper is to define the sedimentary characteristics of the deposits recovered through the aforementioned five cores, and to identify the depositional processes occurred in response to sea-level high-frequency cyclic variations induced by the Late Quaternary climatic variations.

2. REGIONAL SETTING

The area described in this paper is the continental shelf of the Gaeta Bay (Central Italy), one of the largest shelves of the Eastern Tyrrhenian Margin. Its width varies from 15 km northward to 25 km seaward of the Garigliano River mouth. Southwards, the continental shelf width decreases again up to 12 km at the Volturno River mouth. The shelf break occurs at an average depth of 150 m. The shelf has a gently sloping surface interrupted by small irregularities, which are either relicts of the "wurmian" morphology (Segre, 1950) or the effect of both compressive and extensional tectonic activity

Table / *Tabella* 1

Core location	Latitude	Longitude	Core lenght cm	Sea bottom depth in m
G93 Core 26	41°05'30"	13°29'32"	396	121
G93 Core 27	41°05'23"	13°29'08"	445	122
G93 Core 5	41°05'41"	13°35'56"	500	111
G93 Core 8	41°04'31"	13°32'18"	362	126
G93 Core 9	41°02'46"	13°29'24"	470	212

(Bartole, 1984). The compressive features developed during the tectonic phase which affected the meso-cenozoic sedimentary units in Messinian times, whereas extensional features formed as a result of post-orogenic phenomena lasting up to Lower Pliocene, which resulted in the uplift of the Appenninic chain and the lowering of the Tyrrhenian margin. The deformed carbonatic units, well exposed landward in Monti Aurunci, and identified also by the seismic profiles of the Latium-Campania shelf (Bartole, 1984), had an important role in the sedimentary evolution of the studied area. In fact, these units controlled both distribution and thickness of Plio-Quaternary sediments, because upper Miocene-lower Pliocene units are not common in this area.

The tectonic structure of the studied continental shelf shows:

a) an E-W trending elongated and narrow depression, which is located between the "Zannone-Volturno overthrust" (Bartole, 1984; Bartole *et al.*, 1984) that is a regional tectonic feature aligned to the parallel N41° and the normal faults associated with this over-thrust;

b) N-S trending structurally highs and depressions.

One of the N-S trending structural features corresponds to the Garigliano river alluvial plain, a graben-like coastal depression up to 1000 m deep (Brancaccio *et al.*, 1991). Data (outcrops and boreholes) indicate that this depression is filled by Pliocene marine deposits and Quaternary transitional to continental deposits containing volcanic materials from the activity of the Roccamonfina volcano (600 - 50 ka B.P.), which bounds the Garigliano plain to the E, and subordinately of the faraway Phlegraean Fields (?50 - 5 ka B.P.). The alluvial plain is limited by Monte Massico to the S and by Monti Aurunci to the N. The Monti Aurunci carbonatic units crop out also along the shore (*i.e.*, at Gaeta).

Along the Gaeta coastline that alternates rocky cliffs with sandy beaches, both emerged and submerged marine terraces, notches and sandy and breccia deposits highlight Quaternary sea-level changes. For example, marine erosion surface edges, which are recognizable also in other parts of the Tyrrhenian coast (Romano, 1992), are present in the continental area of the Gaeta Bay at elevations between 230 and 30 m above the present sea level. Such surfaces may be related to a sea level highstand older than Middle-Upper Pleistocene, as suggested by sandy deposits dating to this period which cover these surfaces (Antonioli & Frezzotti, 1989). Evidence of sea level high- and lowstands are also given by many notches visible on the sea cliffs of this bay (Antonioli, 1991; Ozer *et al.*, 1987), such as those at 5.30 m and 1.30 m above the present sea level. The age

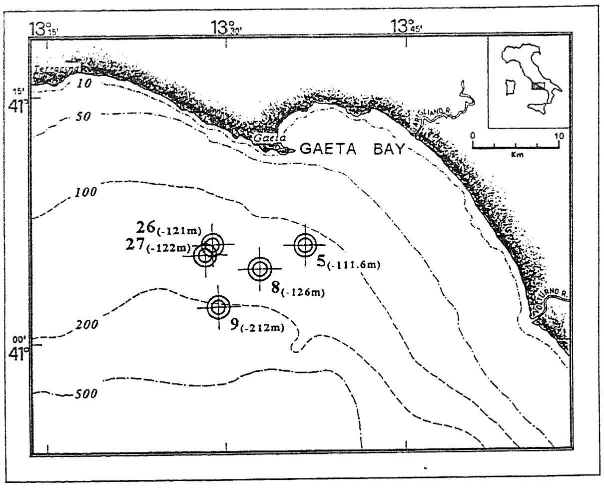

Fig. 1 - Location of cores described in the text.
Ubicazione delle carote descritte nel testo.

of the carved deposits date the notches to Eu-Tyrrhenian and Neo-Tyrrhenian times, respectively (Hearty & Dai Pra, 1986; Brancaccio *et al.*, 1990).

Marine surfaces and notches, older than the upper Pleistocene, can be observed at different heights above present sea level both to the N and S of the Gaeta Bay, and indicate that differential tectonic movements ended at 18 ka BP when the sea level was at 120 m, according to geophysical research carried out in the Latium region continental shelf (Marani *et al.*, 1986).

3. METHODS

Drillings, allowing for the recovery of the most recent succession of sediments of the Gaeta continental shelf, were located along two NE-SW trending seismic lines (Fig. 1). The northern line (30 km long) joins Cores C26 and C27, at -121 m and -122 m depth, respectively. The southern line is longer than the northern one (35 km) and joins Cores C5, C8 and C9, at -111 m, -126 m and -212 m depth, respectively. Core C9 was taken from the upper continental slope (Table 1). Sediments were recovered by means of a gravity corer. Cores have been subdivided into portions about 1 m long and split longitudinally into two halves. Soon after the core splitting, the sediment physical properties (water content, bulk density, porosity, grain density and undrained co-hesion) were determined. The lithologic description of samples was made and sediment color was given using the Munsell soil charts. Samples were taken approximately 10 cm apart from one another; more samples were taken for peculiar levels (*e.g.*, presence of volcanic materials). Wet sieving and pipette were used for grain size distributions determination for sandy, silty and clay fractions, respectively. Carbonate content was obtained using a Dichter Fruling calcimeter. The sandy fraction was used for microscopy analyses to define the percentage of clastic and skeletal grains and the roundness of grains.

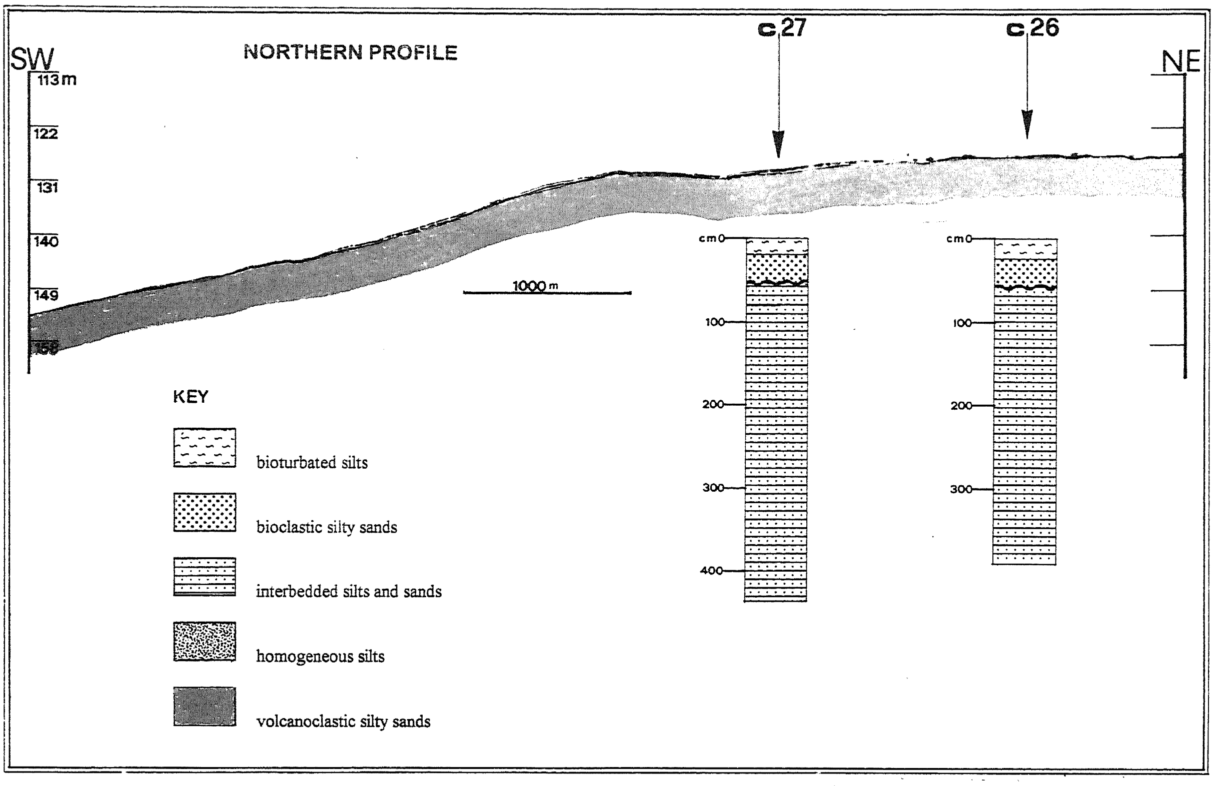

Fig. 2 - Sea-bottom northern profile showing location and graphic log of cores C26 and C27. The wavy line corresponds to the erosion contact separating the upper Pleistocene unit from the Holocene units.

Profilo settentrionale con ubicazione e log grafici della C26 e C27. La linea ondulata corrisponde al contatto erosivo che suddivide l'unità del Pleistocene superiore dalle unità sovrastanti dell'Olocene.

4. SEDIMENTARY LITHOFACIES

The studied deposits are commonly composed of fine-grained sediments. Several lithofacies are however present, as follows: (a) bioturbated silt, (b) bioclastic silty sand, (c) interbedded silt and sand, (d) homogeneous silt and (e) volcanoclastic silty sand. Lithofacies from (a) to (c) are present in all cores, whereas (d) and (e) are present in the deepest core (C9) and in the cores drilled in the shelf along the southern profile (C5 and C8), respectively .

Bioturbated silt is the youngest sediment recovered in the cores, and is characterized by poor sorting and negative, even highly negative, shewness. Microscopy data show that this is due to the presence of skeletal grains of planktonic microfauna (coarse fraction) mixed with a transported muddy detritus. A layer, a few centimetres thick and rich in clay fraction (56% as a maximum) is observed in all cores, but in C27. In particular, this clayey intercalation appears at 80-70 cm in C5, at 30-10 cm in C8, at 60 cm in C9 and at the bottom of the bioturbated silt in C26. The passage to underlying lithofacies is always sharp, some-times (C5 and C8) marked by a mild lamination. Other sedimentary structures have not been observed. Bioturbated silt is an unconsolidated sediment: water content and porosity values increase upward, and — cor-respondingly — bulk density values decrease. In partic-ular, in C9, the bioturbated silt undrained cohesion and porosity are slightly different from those of lower sediments. The maximum thickness of this lithofacies (more than 180 cm) is observed in C5, whereas the minimum thickness (less than 20 cm) is recorded in C26 and C27. Thus, bioturbated silt is more developed landward (Figs. 2 and 3). This sediment contains various percentages of $CaCO_3$, *e.g.* bioturbated silt in cores C5 and C8 has a mean $CaCO_3$ content lower than in cores C26 and C27.

The underlying lithofacies is characterized by a bioclastic silty sand, with a very high carbonate content. This sand is commonly composed of shelly fragments, which decrease upward whereas the matrix percentage increase, expecially in the cores from the northern profile. Sorting in the bioclastic silty sand is worse in the cores from the northern profile (σ_1 >2) than in those from the southern profile. Sedimentary structures also vary: a clear gradation (from -245 to -180 m) is present in C5 and in C8 (from -147 to -125 cm, and from -90 to -55 cm), whereas a massive structure (shell hash) is observed from -58 to -27 cm in C26 and from 76 to 20 cm in C27. Bioclastic silty sand, which is found only in one or two levels with an erosive base, has maximum thickness (up to 60 cm) in the shelf cores (Figs.2 and 3). In the cores from the upper slope the biogenic fraction of this lithofacies, which occurs from -170 to -99 cm depth, is less than in the other cores and shows evidence of reworking due to the seaward transport from shallower water areas.

Immediately before or intercalated with the bioclastic sand, in C5 and C8 there is a layer of volcanoclastic silty sand (Fig. 3). This is poorly sorted and has negative

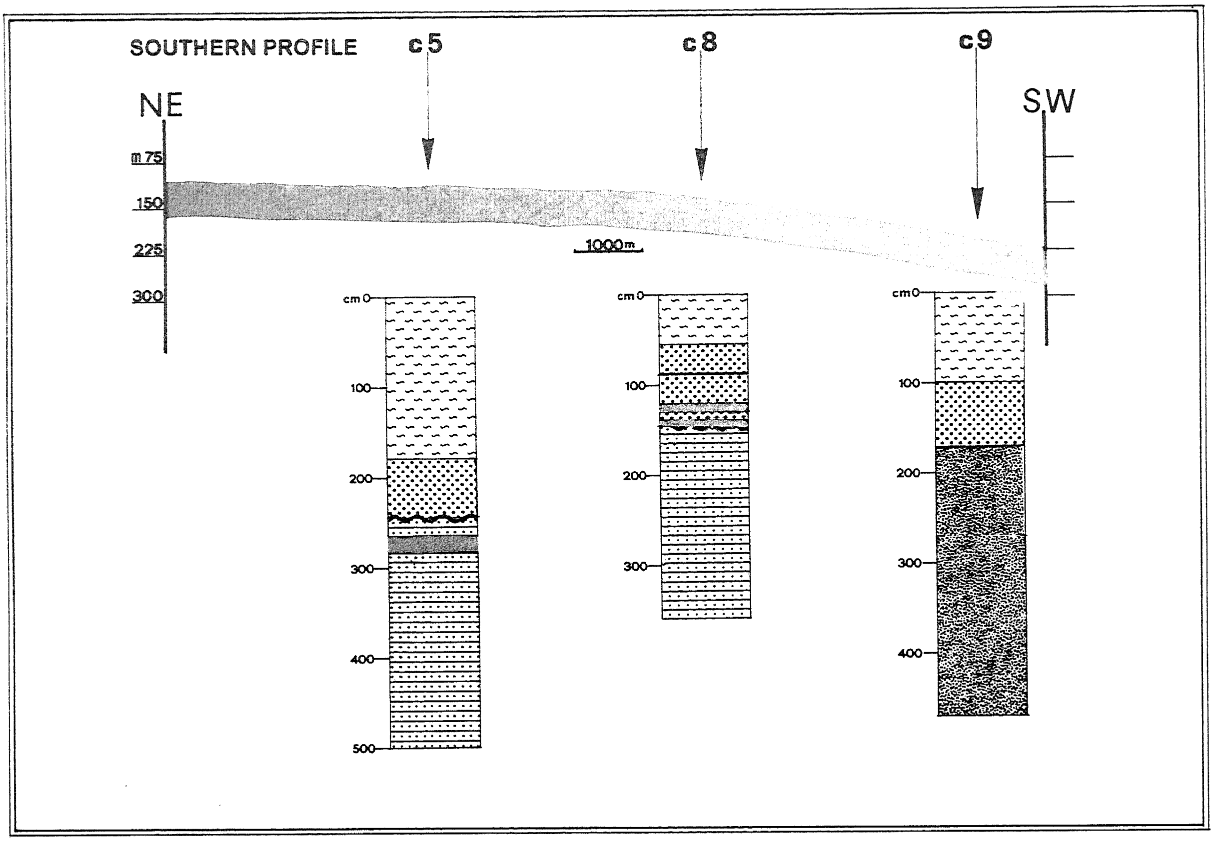

Fig. 3 -Sea-bottom southern profile showing location and graphic log of C5, C8 and C9. The wavy line corresponds to the erosional contact separating the upper Pleistocene unit from the overlying Holocene units. In C9 the erosional contact is not present, and the passage upper Pleistocene-Holocene was interpreted to be at 170 cm. Legend as in Fig. 2.

Profilo meridionale con ubicazione e log grafici della C5, C8 e C9. La linea ondulata corrisponde al contatto erosivo che suddivide l'unità del Pleistocene superiore dalle unità sovrastanti dell'Olocene. Nella carota 9 il contatto erosivo non è presente, in tal modo il passaggio Pleistocene superiore-Olocene è interpretato a 170 cm. Per i simboli vedi Fig. 2.

skewness. A thicker and graded layer was observed in the proximal core (C5), whereas two leyers, thinner and massive, are included in the distal core. Volcanic clasts are well rounded. On the basis of preliminary geochimical data, these clasts belongs to the Roccamonfina volcano activity (M. Barbieri, pers. comm.).

Interbedded silt and sand is the most abundant lithofacies in the examined cores; it occurs towards the core bottom and, thus, represents the oldest deposit of the succession (Figs. 2 and 3). In C9, a similar lithofacies occurs from -470 to -170 cm depth; because it is much finer than elesewhere, it was assumed as a different lithofacies and was identified as the homogeneus silt facies (Fig. 3). In detail, the sediment from the shelf cores displays a better sorting in C5 than in the other cores, whereas skewness presents a coarse tail in C5 and a fine tail in cores C8, C26 and C27 drilled at ca. -120 m depth. The undrained cohesion of interbedded silt and sand lithofacies is higher than that of overlying sediments, suggesting a certain consolidation degree of this facies. Water content, porosity, etc. are consistent with this fact. Carbonate contents range from 11 to 35%.

Although drowned, the homogeneous silt from the upper slope cores is a frankly unconsolidated sediment. Texturally, it is a commonly mmoderately sorted sediment with negative skewness. Grain size distribution shows a prevailing bimodal trend with no finest grain-size fraction. Carbonate contents are similar to that of the interbedded silt and sand litofacies, even if the minimum value is up to 25%.

5. DISCUSSION AND CONCLUSIONS

The data set obtained from sedimentological and geotechnical analyses, with other data (seismic profiles, paleontological studies; see Amore *et al.* and Coppa *et al.*, in this volume), allow for a tentative reconstruction of the major events occurred in the study area during late Pleistocene-Holocene. The oldest deposits (*i.e.*, the interbedded silt and sand) can be interpreted as a prograding wedge accumulated during late Pleistocene glacio-eustatic lowstands. This is confirmed by data from a paleoecological study which indicate contents of infralittoral species (<30-40 m, in Amore *et al.*, this vol.), which are typically of a cold climate. The regressive character of this wedge is demonstrated by the sediments which become coarser and coarser seaward (Correggiari *et al.*, 1992; Tesson *et al.*, 1993). Moreover, grain sizes in cores C5 and C8 are less coarse than in C26 and C27, such as their more proximal position accounts for. However, physical properties of the sediments in shelf cores are consistent with a shallow water enviroment. The deposits in shelf cores are cut by an erosional post-glacial transgressive surface (*i.e.* ravinement surface). This surface is covered by a bioclastic silty sand (or shelly sand) overlain by thin and discontinuos mud sediments (hemipelagic muds), which can be interpreted as a condensed succession associated with post-glacial sea-level rises (Louitit *et al.*,1988; Gensous *et al.*, 1993). The increase in clays in the upper portions of the cores is due to the progressive energy decrease related to the shelf deepening, as traces of maximum flooding, which can be seen in the uppermost lithofacies, suggest. Also the contents of circalittoral species (Coppa *et al.*, this vol.) and the increase in warm water planktonic foraminifera and nannofossils (Amore *et al.*, this vol.) support this interpretation.

During the sea-level rise first phases, Garigliano River carried sediments with a high percentage of volcanic clasts. These clasts, coming from eroded deposits of the Roccamonfina volcano activity, were reworked by the river and then scattered on the shelf. This peculiar supply might have occurred in relation to sea-level variations. The lack of any volcanoclastic layer in the deposits along the northern profile is probably to be attributed to the presence of high energy currents which may have eroded them away. These currents are usually active during lowering sea-level, and often cause erosional truncations of the sedimentary sequences. However, such currents may also act during sea-level rising both on the outer shelf and the upper slope (Correggiari *et al.*, 1992; Marani *et al.*, 1986). As a result, winnowing of finer particles occurs.

In the upper part of the cores bioturbated silt prevails (as very thin levels in C26 and C27: Fig. 2), which represents the recent wedge deposited in the last 6 ka BP. The thickness of this wedge increases landward, as the thickness of the youngest sediments in cores C5 and C8 (Fig. 3) indicates, because it would have been greatly influenced by the Garigliano River solid supply. This influence is also suggested by the lower percentage of carbonate contents in the sediments of cores C5 and C8 with respect to cores C26 and C27. However, the sedimentation rate is compatible with a decreasing supply rate as that recorded during the Holocene.

The differences observed between shelf cores in the northern and southern profiles may be related also to the substratum structural features, which controlled sedimentation during the Quaternary (Bartole *et al.*, 1984). In other words, C5 and C8 (southern profile) are probably located in a depression, into which the solid supply carried by River Garigliano converged (low carbonate contents and greater development of younger deposits). On the contrary, C26 and C27 are probably located near a structural high, which reduced the amount of fluvial supply and magnified currents action (lack of volcanoclastic levels, coarser Mz and lower thickness of younger deposits). This articulated morphology was already hypothesised in Bartole (1984).

Core C9, drilled in the upper slope, consists of uncosolidated silts, probably deposited by downslope and alongslope processes such as those which give rise to muddy turbidites and landslide deposits. Although textural characteristics are not in favour of this interpretation, however if re-suspension of the finest sediments on the upper slope is considered, sorting of reworked deposits can be improved whereas the finest sediments remain in suspension (Krank & Milligan, 1991). Most of the characteristics of the lithofacies present on the shelf are well evident in core C9. The thickness increase can be attributed to the amount of sediments redeposited through gravitative processes occurring in the course of time and involving the shelf sediments (Savoy & Piper, 1993).

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