

GROWTH PROCESS OF A LONG-LIVED LATE PLEISTOCENE SPIT ALONG THE ADRIATIC COAST (BRINDISI, SOUTHERN ITALY)

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ABSTRACT: Loiacono F., *Growth process of a long-lived Late Pleistocene spit along the Adriatic coast (Brindisi, southern Italy)*. (IT ISSN 0394-3356, 2010).

The Quaternary succession cropping out along the cliff at NW and SE of Brindisi town (Adriatic coast, Southern Italy), is mainly composed of silty sands and is referred to Lower-Middle Pleistocene by biostratigraphic integrated analyses. Moreover the benthic assemblage of the cropping out sequence indicates a shallowing upward trend. A coarse grained calcarenite body (Punta Penne Calcarenites), overlies unconformably the Middle Pleistocene fine-grained sediments cropping out along the coast for more than 9 km and for up to ten meters thick, thus making a good shelter for the Brindisi port and town. The sedimentological analysis carried out through this well exposed sedimentary body allows to recognize its growth process and make some hypotheses on the control factors acting during its development. The sedimentary body is composed of bioclastic grainstones and rudstones arranged in well bedded succession made up of about 30° SE dipping beds and bed sets in a cyclic alternation of coarse-grained planar units (Facies A), small- to medium-scale trough cross-bedded units (Facies B), and *Bichordites*-bearing beds (Facies C). Facies analyses point out a storm-dominated, foreshore-to-upper shoreface environment, characterized by migrating bedforms such as ripples, megaripples and low-angle or quasi-parallel flat beds. In this scenario, the aforementioned units' alternation is the result of the SE-trending lateral accretion of a coastal spit, which developed accordingly to the dominant longshore currents, similar to the present day ones. The spit sedimentary body becomes thinner toward SE; its upper boundary is sharp, being covered by recent soil; locally, Holocene aeolian sands overlay the spit deposits, recording the last highstand. The alignment of this coastal spit results from two interactive factors: the abrupt change in the coastline profile and a long balance between material supply (uplift-erosion) and alongshore movement. The first control factor was a differential subsidence rate of the coast in this area that caused different wave refraction and high erosion of the bend point. The SE-directed dominant longshore currents were also highly efficient in the transport and down-current deposition of the sediment load. The SEward accretion of the coastal spit followed a long balancing of local subsidence, sediment production and lateral accumulation. In time the decreasing efficiency of the longshore transport and lateral accretion caused facies changes with increase in depth. Finally in the SE direction the stratigraphic record is regressive according to the regional trend. Grain size local trends and measurements of foreset and festoon dips allow the distinguishing of frontal, sea- and land sides of the spit, as well as the likely changes in the growth stages and its dying out. The duration of the spit construction could be limited to a few thousand years in a time interval corresponding to Tirrenian maximum highstand (MIS 5 e).

RIASSUNTO: Loiacono F., *Genesi e sviluppo di uno "spit" pleistocenico (litorale adriatico, Brindisi)*. (IT ISSN 0394-3356, 2010).

La successione sedimentaria quaternaria affiorante in estesi tratti del litorale brindisino è costituita da una formazione sabbioso-siltosa attribuita al Pleistocene inferiore-medio (Coppa et al., 2001) in giacitura suborizzontale, ben visibile lungo le falesie che mostrano evidenti segni di arretramento. In alcuni tratti sono presenti, a livello del mare, affioramenti di calcareniti ben cementate, localmente discordanti sulle sabbie siltose, che costituiscono un corpo sedimentario e che contrastano l'azione demolitrice del mare, rappresentando tratti sporgenti di costa rocciosa.

Il corpo sedimentario più esteso e più spettacolare è dato dalle "Calcareniti di Punta Penne" che affiorano in modo continuo per circa 9 km nel tratto compreso tra Punta Penne e Capo di T. Cavallo e costituiscono un'ottima protezione per il porto di Brindisi.

Attraverso indagini stratigrafiche e analisi sedimentologiche sono stati ricostruiti: il contesto stratigrafico, i processi e gli ambienti deposizionali, nonché i fattori di controllo che hanno agito durante la sedimentazione.

La geometria di questo corpo sedimentario litologicamente omogeneo (calcareniti medio-grossolane /calciruditi) appare cuneiforme con lo spessore maggiore nella sua estremità nord-occidentale e tendente a chiudersi verso SE. Lo spessore stratigrafico reale, ricavato da alcuni sondaggi, è di circa 10 metri, mentre l'estensione in senso parallelo alla costa è di circa 9 km. Il carattere principale è la stratificazione obliqua (N-120°) con inclinazione variabile da 15° ad oltre 30° che determina uno spessore apparente di oltre 1000 m.

Le strutture sedimentarie sono essenzialmente di tre tipi e hanno permesso di distinguere tre facies elementari organizzate in sequenze di facies: Facies A: caratterizzata da unità centimetriche o decimetriche, planari, gradate e amalgamate con granulometria massima di 3-4 cm, media di 1-2 cm; Facies B: caratterizzata da unità decimetriche a stratificazione e laminazione incrociata, localmente ondulata con basso grado di bioturbazione; Facies C: caratterizzata da unità stratificate con alto grado di bioturbazione, spesse fino ad alcuni decimetri. Le sequenze elementari di facies (es. A-B-C, di spessore variabile, inferiore al metro) sono da attribuire ad eventi di tempesta che indicano l'evoluzione a breve termine del livello del mare in senso "istantaneo", da pochi secondi a numerosi anni: la Facies A, con base erosiva, rappresenta l'acme della tempesta (massima energia), la Facies B la fase di trasporto lungocosta (fase di "set up"), la Facies C la fase di bassa energia. Le sequenze di facies, che si osservano in modo praticamente continuo lungo la linea di costa tra Punta Penne e il porto di Brindisi, indicano una evoluzione a lungo termine, da NO verso SE, da un ambiente intertidale (sequenze prevalentemente amalgamate A/A) ad un ambiente di spiaggia sommersa ("upper shoreface") con graduale incremento delle Facies C e riduzione delle sequenze AB. L'organizzazione a livello di sequenze a breve termine (ordine metrico) e a lungo termine (decine e centinaia di metri) suggerisce l'ipotesi di uno "spit" costiero caratterizzato da equilibrio tra erosione, trasporto e accumulo in direzione SE, secondo i venti dominanti del quadrante nord-occidentale. L'azione del moto ondoso conseguente ai fenomeni di rifrazione, il trasporto lungocosta e la frequenza ed intensità delle tempeste, insieme al costante pendio del profilo costiero, hanno sviluppato una tipica geometria cliniforme a grande scala. Il sistema era bilanciato da una subsidenza differenziata, trasversale alla costa, di minore entità nel tratto a N di Punta Penne, che avrebbe innescato i processi erosivi, ed assicurato lo spazio per l'accumulo maggiore verso SE.

Il corpo sedimentario così formato può essere interpretato come un ciclo di 4° ordine controllato principalmente da fattori allociclici che possono spiegare la continuità laterale e l'efficienza del sistema costiero (rifornimento di sedimento, capacità del trasporto lungocosta, subsidenza). La durata approssimativa potrebbe essere stata attorno ad alcune migliaia di anni in corrispondenza dell'alto eustatico coincidente con il Tirreniano (M.I.S. 5 e). La riduzione della subsidenza e dell'energia di trasporto delle correnti lungocosta, e la tendenza regressiva generale riconosciuta nella successione studiata sono le probabili cause della terminazione dello spit.

Key-words: facies analyses, coastal dynamic, palaeobeach reconstruction.

Parole chiave: analisi di facies, dinamica costiera, ricostruzione di paleospiegia, Pleistocene.

¹ Tyrrhenian marine deposits are not pointed out, probably due to uplift occurring in the Apulian Foreland since the Middle Pleistocene, in contrast with the central Adriatic and Ionian sea, where subsidence continued from Pliocene and Early Pleistocene (Dogliani et al., 1996, Ferranti et al., 2006 cum biblio).

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1 - INTRODUCTION

The coastal change is a topic of great interest for scientists, economists, politicians and land owners. They, in various ways and for different aims, study the rate of coastline shifting in terms of retreat or accumulation. The maps and charts used for coastal zone study have increasingly been improved with advanced technology. Therefore we have a good evidence of coastal changes (KING, 1972). The reconstructed steps of the coast evolution and trends, through maps, remote sensing and monitoring, point out the effects both of natural processes and of human activity. Geomorphologic and sedimentological analyses together with aero-photographs are valuable tools for the reconstruction of ancient coastal environments, developing trends of coastline, erosional retreat rates in relation to wave action, sea level change and geological setting. Indeed geometry, shape, sedimentary structures, coastal hydrodynamics, cyclic development of erosion or accretion, reconstruction of growth processes, are all important features both for the knowledge of the past coastline and for the change forecasts.

The sea level fluctuations, which occurred in the Quaternary times, allowed the building up or pulling down of sand beaches and dunes in different contexts of transgressive or regressive trend.

The wave action and coastal currents (direction, intensity), morphodynamic condition (slope angle, exposition of nearshore), grain size, rate of cementation and resistance of cliffs according to geotechnical rock properties are the main control factors.

The tectonic activity may be an allocyclic control on the erosion rate and longshore beach migration, particularly when lateral accretion balances tilting. This is the case of coastal spits whose accretion is related to the degree of wave exposure and refraction (EVANS, 1942; ZENKOVICH, 1967; CARTER, 2002).

The spits are good indicators of net shore drift, coastal erosion and sediment accumulation (TAGGART and SCHWARTZ, 1988); many authors describe these geomorphic structures and their growth mainly due to longshore drift (SCHWARTZ, 1984; BIRD, 1984). Many spits are associated with river mouths or estuaries; they show different shapes and sizes (KUNTE and WAGLE, 1991). The main topic in the spit interpretation is the factors responsible for origin and growth.

The aim of this paper is the description of the stratigraphic context and sedimentologic characteristics of a Pleistocene coarse grained body, outcropping along the coast of Brindisi town. The reconstruction of the coast dynamics, the growing process and the recognition of the main control factors are also the main objectives of this work.

2 - GEOLOGICAL SETTING

The Italian Adriatic coast is a wave dominated microtidal system. The great availability of fluvial sediments, coming from the Apennine drainage system, allows the growth of elongated sandy beaches fed by the main south-eastward littoral drift.

The southern Adriatic coast is poor in fluvial sediments, except for a narrow zone of the Ofanto River in the shadow zone of the Gargano promontory: the source rocks of sandy beaches are the Mesozoic limesto-

nes and mostly the quaternary detrital carbonate rocks that cover with different thickness (order of ten meters) the Mesozoic substratum.

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The Apulian coasts, up to 800 km long from the Gargano to the Taranto Gulf, are differentiated mainly on the basis of tectonic segmentation of the Mesozoic carbonate platform during Tertiary and Quaternary times in three blocks from North to South: Gargano, Murge and Salento (CIARANFI *et al.*, 1992). The structural elements separating the three blocks are normal faults, NE-SO directed, that formed two graben-type depressions corresponding to the Manfredonia Gulf and Ofanto Valley to the North, and Messapic depression elongated between Brindisi and Taranto to the South (Fig.1). Both depressions are filled by Pliocene and Pleistocene sedimentary rocks, composed of calcarenites, mudstones and regressive sands or bioclastic calcarenites, well exposed along the shore or cliff. The thickness and sedimentary features of these units were controlled by the nearness of the Mesozoic substratum, its tectonic movements and sea level changes (BOSI *et al.*, 1996; HEARTHY and DAI PRA, 1992; MASTRONUZZI and SANSÒ, 2003; FERRANTI *et al.*, 2006). In the Murgian block the Plio-Pleistocene succession, unconformable on the Mesozoic limestones, shows a regional transgressive trend represented by the neritic calcarenites (Gravina Calcarenites), a sharp upper boundary (maximum flooding surface) and a thick mudstone unit (Argille Subappennine) interpreted as a shelf system. The overlying regressive sands, mainly dated to Middle Pleistocene, are overlain by more transgressive-regressive cycles controlled by eustatic phases (RICCHETTI, 1972), locally by tectonic movements well recognizable in the marginal areas of the murgian block. The Holocene sea level rise produced a drastic coastal erosion and cliff recession (MASTRONUZZI *et al.*, 1989) mainly where the natural nourishment (fluvial supply) and protection (hard rocks) could not hinder the wave attack. Moreover, the coast is increasingly retreated where the thickness of mudstones is great, i.e. in the tectonic depression. This is the case of the Messapic Trough in the Brindisi area.

3 - STRATIGRAPHY

The stratigraphic succession outcropping along the coastal cliff is made up of a thick silty sand unit, Lower-Middle Pleistocene in age (COPPA *et al.*, 2001). A calcarenite unit (Punta Penne Calcarenite, PPC; LOIACONO, 1999; LOIACONO *et al.*, 2002), not well dated, characterizes the coastal belt at N and S of Brindisi. At the top of this unit, DI GERONIMO (1979) recognized a residual upper Holocene marine terrace.

The calcarenite unit shows a typical cliniform pattern with a maximum dip of about 30° toward SE, and a good outcropping continuity (up to three km long) in the northern part of the sedimentary body along the intertidal belt (Figs 2, 3) as far as the inlet of Brindisi port (Fig. 1). Beyond the harbour structures the recent marine erosion partially disrupted the sedimentary body and gave rise to minor exposures in islets and reefs (Fig.1) for up to 6 km.

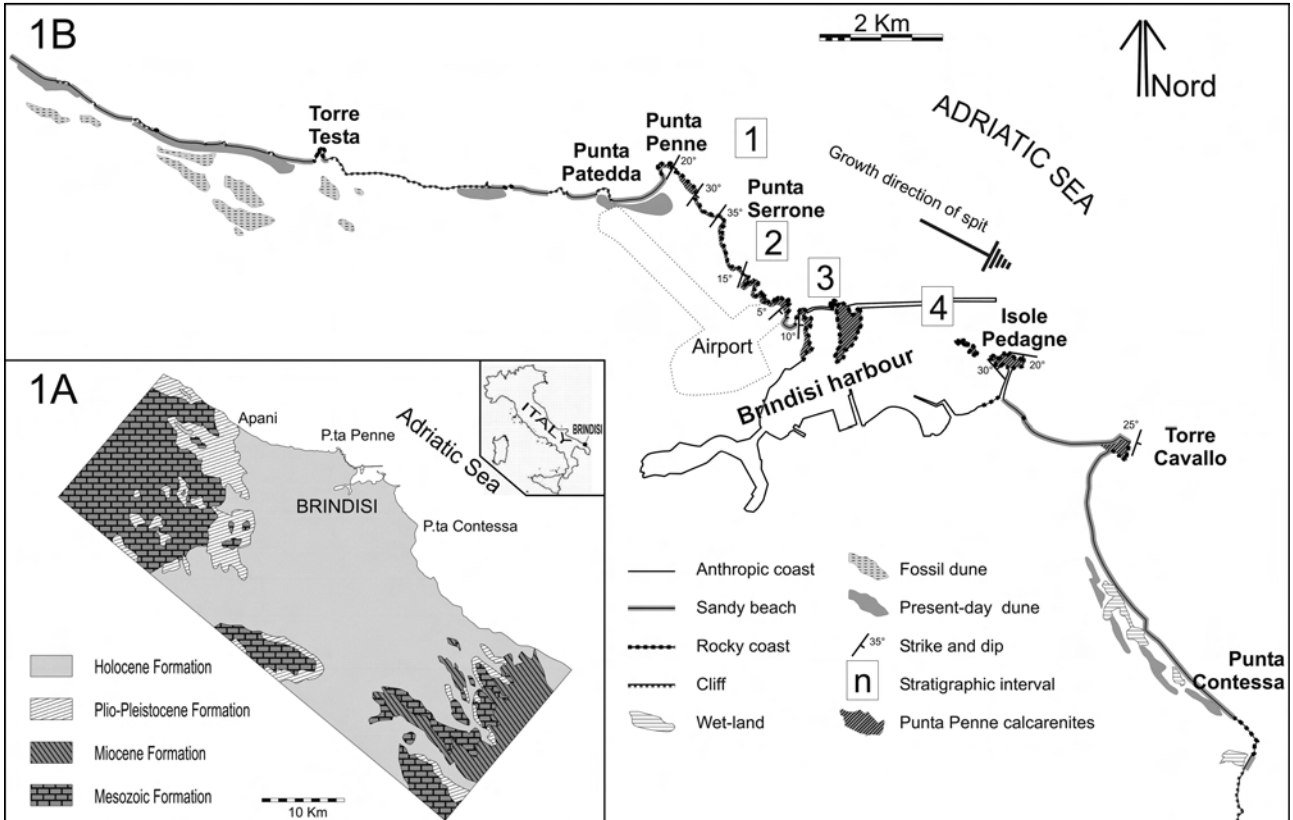


Fig. 1 - A) Schematic geological map of Adriatic apulian margin in relation to "messapic depression". 1B) Location of the Punta Penne Spit stretching out on the Brindisi coast. The present coastal morphology reflects the geometry and the stratigraphic characteristics of the sedimentary body: the sharp boundary in the northern sector (Punta Penne point), the thinning south-eastward and the consequent erosional coastal retreat which preserved Pedagne isles, Torre Cavallo point, Contessa point.

1A) Carta geologica schematica del settore adriatico pugliese relativo alla depressione messapica.- 1B) Ubicazione dello Spit di Punta Penne lungo la costa di Brindisi. L'attuale morfologia della costa è stata fortemente condizionata dalla geometria e stratigrafia del corpo sedimentario: la terminazione netta a Nord, l'assottigliamento verso SE hanno determinato un tratto di costa protetto dall'erosione.

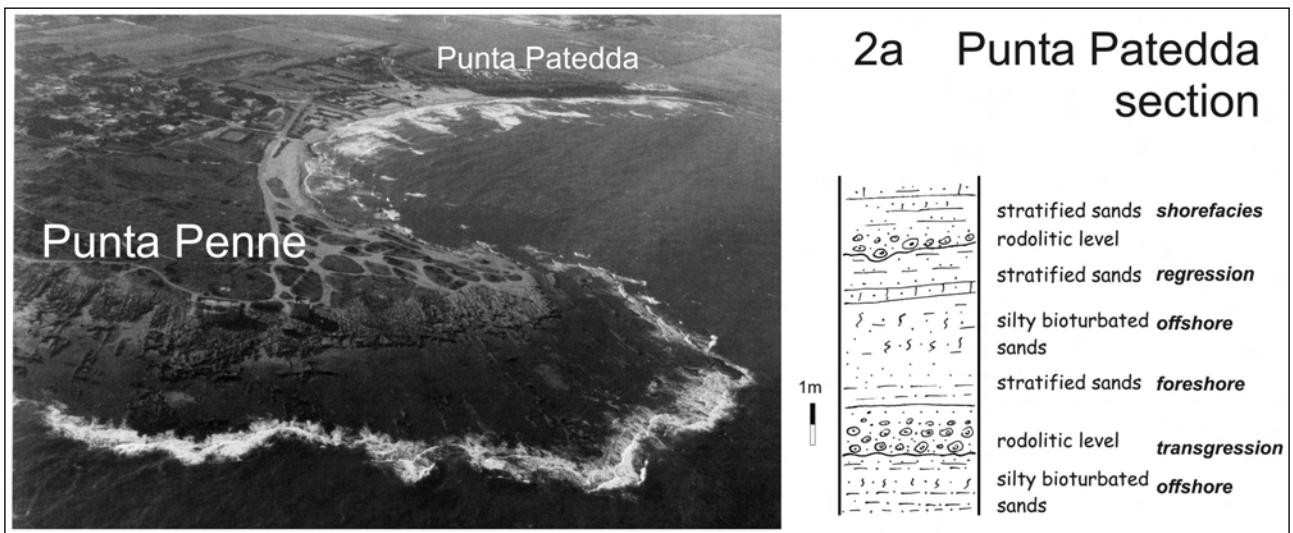


Fig. 2 - Air view of the northern point of Punta Penne place showing the even stratification southeastward dipping, the main fracture system according the major axis of the sedimentary body. Note the erosional coastal retreat at NW where a normal fault is supposed as starting-point of the spit. - 2a) Punta Patedda section cropping out along the coast (at W of Punta Penne area) in erosional retreat.

Foto aerea dell'area di Punta Penne, base della successione dello spit: visibile la stratificazione inclinata verso SE secondo l'allungamento del corpo sedimentario. - 2a) Sezione schematica dell'affioramento di Punta Patedda lungo la costa nord-occidentale in erosione.



Fig. 3 - Typical view of stratification and clinoform pattern of the spit.

Tipico aspetto della stratificazione uniformemente inclinata a SE nel senso dell'accrezione dello Spit

The stratigraphic thickness is about ten meters in the northern edge (from some bore-holes); it thins southeastward where it is possible to observe the lower sharp boundary with the Middle Pleistocene silty sands (Punta Contessa section, Fig.4). A shell lag, 10 cm thick, characterizes this contact. Three km more southward (Torre S. Gennaro cliff) the recent coastal retreat allows us to observe, along the cliff, the regressive Middle Pleistocene silty sand unit (COPPA *et al.*, 2001).

The whole reconstructed geometry corresponds to a NW-SE elongated body, grown southeastward due to lateral migration of not less than three km, which gave rise to an apparent thickness not less than 1500 m.

At the northern boundary, the inclined beds of Punta Penna Calcarenite (upcurrent end) are well exposed along the coastline; the body of the PPC unconformably lie in sharp contact, put in evidence by two still-stand rodolitic layers, with a sub-horizontal succession of Middle Pleistocene silty sands (Punta Patedda section, Figs. 1B, 2a).



Fig. 4 - The Contessa section shows the likely expression of the depositional sequence in the landward margin of the southern edging part. It is a condensed section composed of the lower erosional surface, the transgressive lag, the transgressive part of the sequence, the maximum flooding surface and the regressive part of the sequence with lagoonal facies and soil at the top. The regressive trend and the minor effect of the tilting may be the causes of the gradual but fast decrease of migration of the spit. In this sense the stratigraphic and sedimentologic observations carried out in the outcrops of the Pedagne Isles and in the Contessa section may represent the only data useful for a speculative interpretation about the downcurrent-upward (time-space) evolution of the growth process of the spit.

Sezione di Punta della Contessa nel settore meridionale del corpo stratigrafico. Dalla base: contatto erosivo con strato conchigliare, termine trasgressivo, superficie di massimo approfondimento corrispondente all'intervallo siltoso, termine regressivo con sabbie stratificate di spiaggia e laguna. I caratteri emersi da questa sezione e dagli affioramenti delle isole Pedagne suggeriscono l'ipotesi di una terminazione a SE dello spit ed un trend trasgressivo-regressivo nel suo sviluppo complessivo.

4 - SEDIMENTOLOGY

The main sedimentological feature is the stratification and its characteristics at different scales. The 1st order feature is the cliniform pattern (N120°,30°, Figs. 2, 3, 5) and the coarse grain-size of the rocks, which are remarkably constant given time. The explanation of these features could be related to a balance between erosion rates, sediment transport and lateral accretion.

The 2nd order characteristics of the stratification is

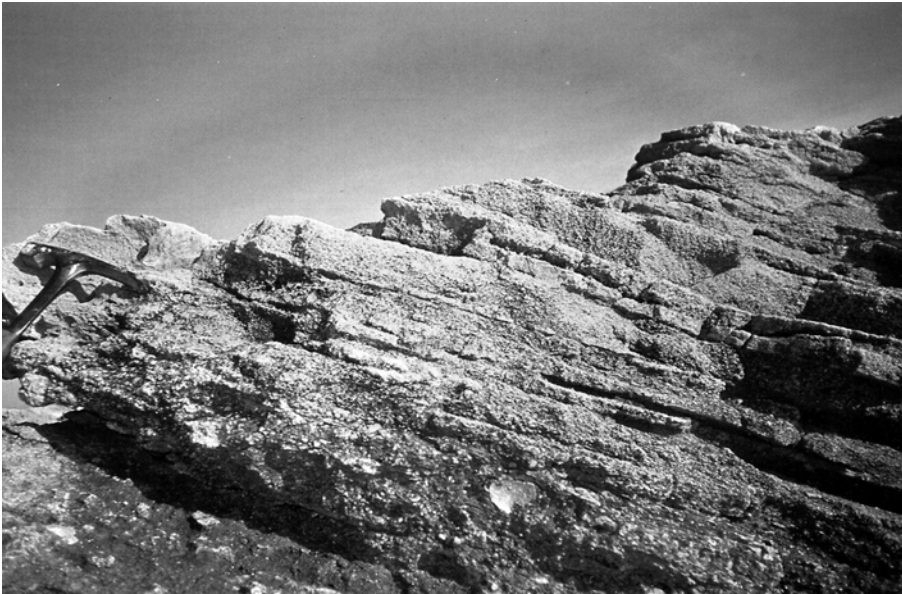


Fig. 5 – Punta Penne outcrop in the lower part of the succession. Facies A: normal grading is well visible both in the single bed (elementary sequence) and in the bedset (long-term evolution).

Intervallo stratigrafico inferiore, affioramento di Punta Penne (sezione NW-SE). Gradazione evidente sia a scala di singoli strati (sequenze elementari, eventi di tempesta), sia a scala di strati amalgamati (evoluzione a lungo termine).

the trough cross-bedding landward or seaward-directed, symmetrical and planar bedding, and hummocky cross-bedding in composite beds (Figs. 6,7,8,9). It is related to migrating bedforms in the wave transformation zones according to storm or fair-weather conditions, wave energy transmission and response of the shoreline profile, reflective or dissipative, previous to each storm.

The 3rd order feature of the stratification is linked to foresets, flat beds, imbrications and alignments of shells or pebbles. These, like 2nd order structures, are palaeoindicators of flows and palaeoenvironments.

4.1-Elementary Facies (EF)

Three EF are distinguished on the basis of textural features and sedimentary structures; each facies refers to a clear depositional mechanism in a short-term evolution.

Facies A: coarse or very coarse sands (0 to -1 phi mean size) with scattered pebbles or shells in fragment or whole, unsorted or well sorted for the mean size; negative skewed. The lower contact is always erosional, whereas the upper boundary moves quickly towards Facies B or C. In composite beds the Facies A is repeated in amalgamated graded beds (Fig.5).

This facies is interpreted as the product of a high energy event.

Facies B: medium to coarse

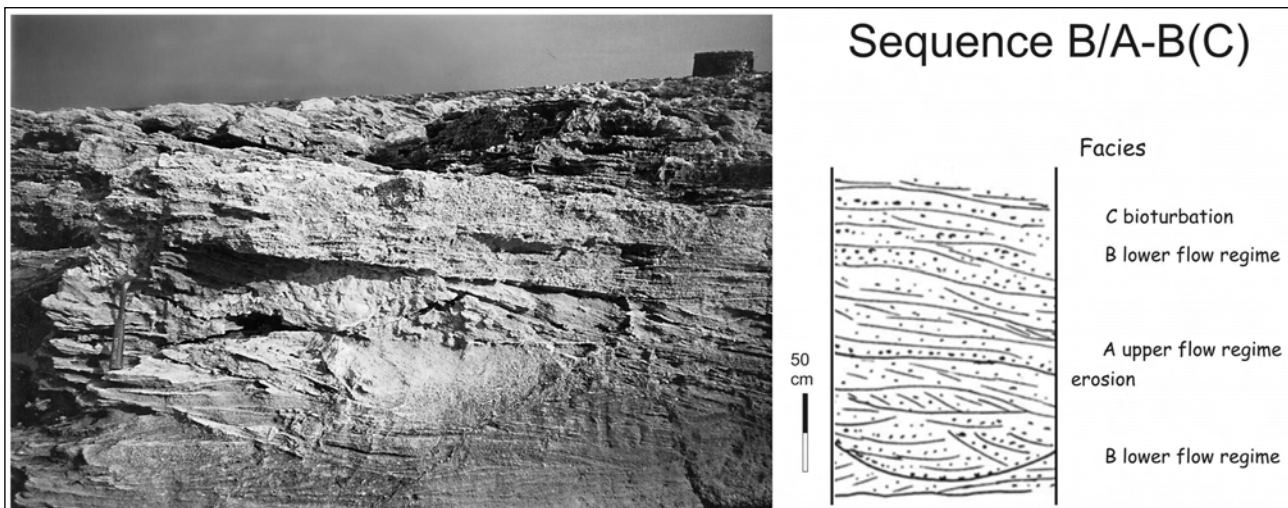


Fig. 6 – Amalgamated sequences in the 1st stratigraphic interval. From the bottom: Facies B in a thick bed (trough cross bedding, locally hummocky, foreset migrating landward, on the right) interpreted a rip channel or a large swale cut at the top by a flat erosional surface (middle part of the photo); Facies A (very coarse sand, plane bedding), evolving to thin beds of Facies B (low angle cross bedding, locally bioturbated) referred to a new elementary sequence.

Sequenze amalgamate nel 1° intervallo stratigrafico. Dal basso: Facies B, sabbia medio-grossolana a stratificazione concava con foreset migranti verso terra (a destra) interpretata come riempimento di un canale di risucchio connesso ad un evento di tempesta. La superficie piana erosiva sovrastante è riferibile ad un nuovo evento; Facies A (sabbia molto grossolana a stratificazione piana passante verso l'alto a strati sottili della facies B (stratificazione incrociata a basso angolo).

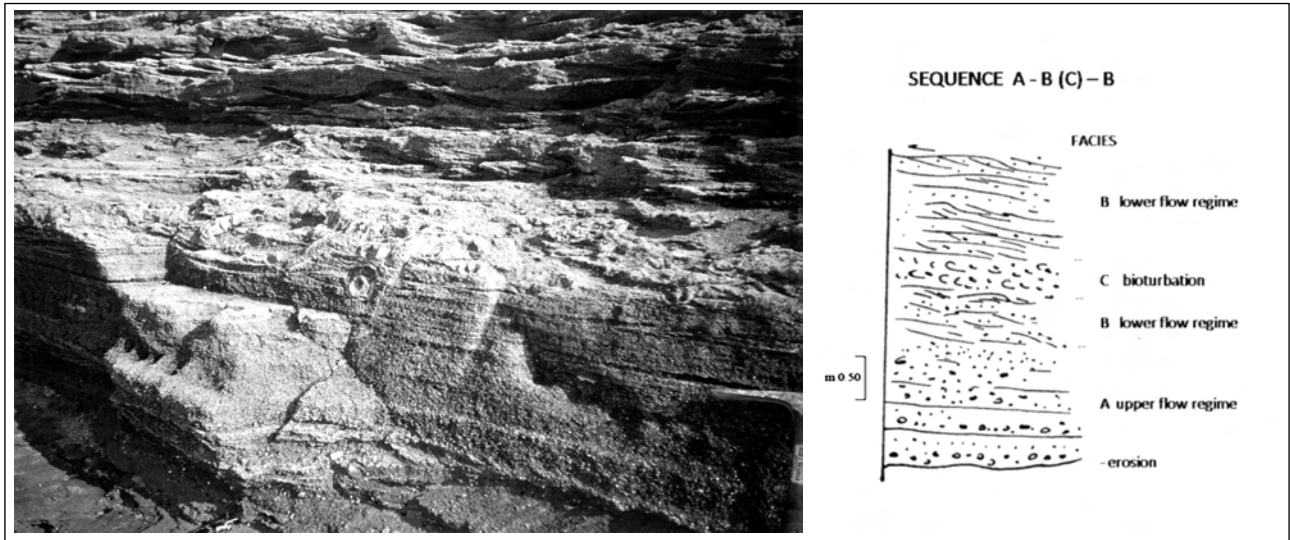


Fig. 7 – Sequence A-B(C)B in the 1st stratigraphic interval: in the middle part of the photo rapid evolution from Facies A (very coarse sand in plane bedding) to Facies B with coarse-middle sand in trough cross bedding; foreset inclined both landward and seaward.

Sequenza di facies A-B con sottili orizzonti bioturbati alternati alla facies B. Nella parte centrale della foto è visibile il rapido passaggio dalla facies A (sabbia molto grossolana con ciottoli) alla Facies B (sabbia media a stratificazione incrociata con locale bioturbazione). Verso l'alto stratificazione a basso angolo con foreset inclinati sia verso terra (a destra) che verso mare (a sinistra).

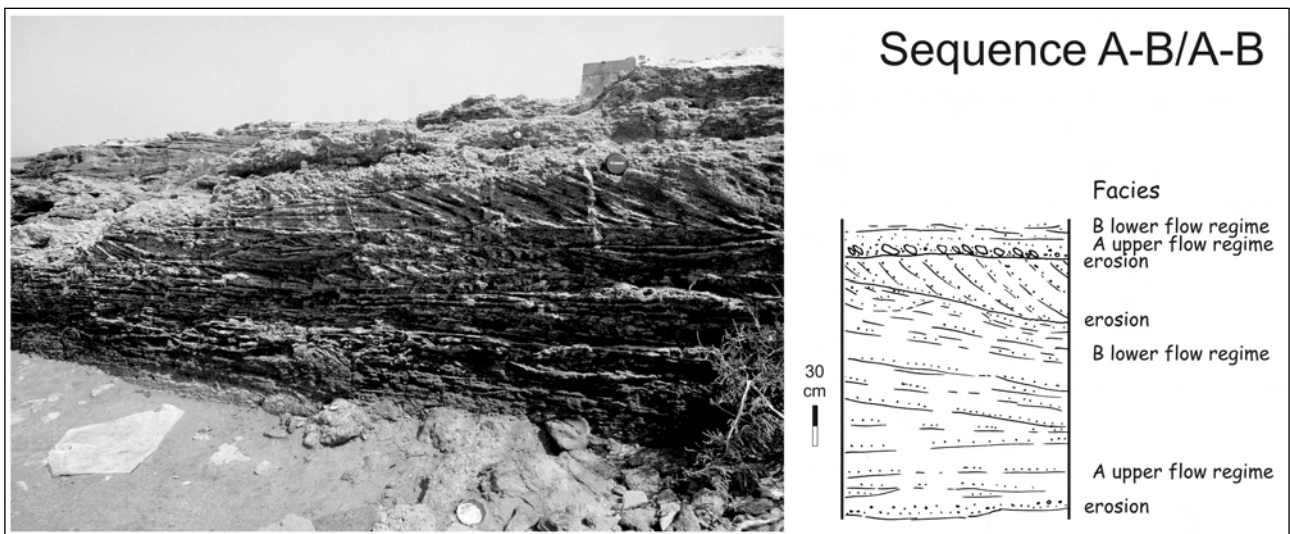


Fig. 8 – Amalgamated elementary storm sequences in the 1st stratigraphic interval, composed of a lower coarse interval (Facies A, plane bedding) passing upward to thin cross beds (Facies B). The thick bed with foreset inclined landward (to the right) is interpreted as an intertidal bar. In the upper part of the photo the erosive surface, inclined seaward (on the left) indicates a new storm sequence with well rounded subspherical pebbles or inclined toward sea.

Sequenze di tempesta elementari amalgamate con facies A (intervallo inferiore grossolano con stratificazione piana) passante a stratificazione obliqua (Facies B). Lo strato lenticolare con foreset inclinati a destra (verso terra) è interpretabile come barra intertidale, limitata, nella parte superiore della foto, da una superficie erosiva che indica un nuovo evento di tempesta.

sands, overlying Facies A or a thin horizon of coarse sands, organized in planar or trough cross laminations, in gently seaward or landward dipping lamina-sets.

The thickness of these beds is variable in relation to the wave energy dissipation of storm events and to morphology and slope of the beach .

Some sets show a migration of shallow runnels (Fig. 6). Others show high-angle cross-bedded units dipping toward land and are interpreted as locally pre-

served intertidal bars truncated upward by future storm events (Fig. 8). Locally at the top of Facies A a small-current ripple interval and some bioturbations sets are preserved under the next erosional surface. In this case (Fig. 7) the Facies C is drawn between brackets.

Facies C: coarse to fine grained bioturbated beds, up to 50 cm thick. The coarse sands and the sharp contacts of C beds with the tractive B beds suggest a fast process of colonization and reworking in the

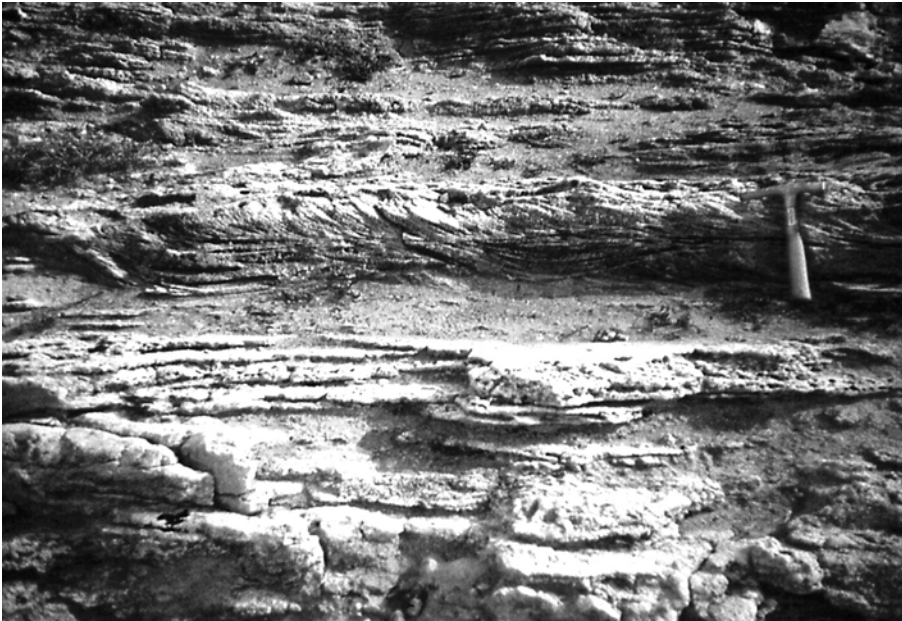


Fig. 9 – Punta Penne outcrop (1st interval); NE-SW oriented section, land at right. Facies B composed by megaripples migrating southeastward, locally bioturbated.

Affioramento di Punta Penne (1° intervallo); sezione NE-SW, lato verso terra a destra. Facies B a megaripple migranti verso SE, parzialmente bioturbati.

beach ridge (lower foreshore), probably already in the last phase of the storm action. The trace-fossils are *Bichordites*-like indicating high shifting of sediment and normally shallow waters (A. D'Alessandro, pers. communication). The bioturbated beds are well stratified (Figs.10,11): the surfaces may be the results of storm events along the base of the slope in the transition foreshore-shoreface. Inside these beds locally thin discontinuous laminated sets are preserved, giving evidence of tractive current (Fig. 11). In this case the Facies B is drawn between brackets.

Joined compositional analysis allows us to define grainstones (according to Dunham classification, 1962) the well-sorted beds mainly composed of well rounded skeletal grains up to 1-2 mm in diameter (Facies B), and rudstones the unsorted beds composed of heterometric grains and pebbles up to 5 cm in diameter, mainly carbonate extraclasts, only locally imbricated (Facies A, Fig.8).

The bioclastic grains, dominant in all facies, are mainly fragments of bivalves, gastropods, echinoids, serpulids and crustaceans, red algal balls, bryozoans. A great number of benthic foraminifers are present in whole specimens.

4.2-Facies Sequences

Many sedimentologic logs are studied, observing

facies sequences in terms of variations in textures, sedimentary structures and biogenic features, and relating them to nearshore sub-environments in terms of flow regime, expression of change in wave energy, seaward or landward accretion.

The observations were made along the coast (Fig.2) where the exposure of the beds allow us to obtain many data mostly on the progradation or frontal migration, partially on the seaward or landward lateral variations. For this reason in the following sections the facies descriptions will be made following the dip direction (southeastward) and, if possible, the lateral variations seaward (NE) or landward (SW). In the lowermost stratigraphic interval (Punta Penne outcrop, Figs. 1,2) trough cross bedded and bioturbated thin intervals are the distinctive features (fig. 9) of a lower tractive regime subenvironment, probably located

landward (SW). The festoon axes are scattered in 85°-117° directions. The dip is 10° to SE.

In the eastern part (seaward) the typical vertical sequence, dipping 25-30° to SE, is composed of a coarse-grained bed, 30-50 cm thick (facies A), overlying, with an erosional contact, a bioturbated interval (Facies C) and passing upward to thick cross bedded interval (characterized by lamina-sets directed landward or seaward going from land to sea in the outcrop, Figs.7,8,9). Locally these beds are convex upward, hummocky type.



Fig. 10 – Facies C in the 2nd stratigraphic interval (middle-upper part of the succession). The bioturbated beds are separated by thin laminated beds (planar or low angle) in which single trails *Bichordites*-like are present.

*Intervallo spesso della Facies C nel 2° intervallo stratigrafico (Punta Serrone). I sottili strati laminati, piani o a basso angolo, sono localmente attraversati da tracce tipo *Bichordites*.*

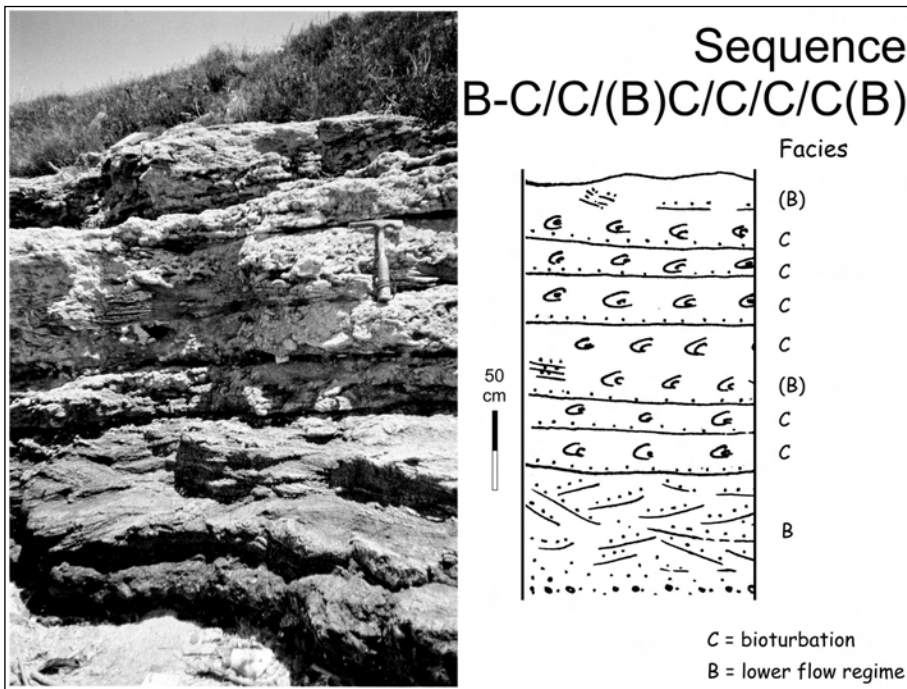


Fig. 11 – Stratigraphic evolution from 2nd to 3rd interval (outcrop near the airport, along the coast, see Fig. 1). In the lower part of the photo Facies B are dominant (through cross bedding with scattered trails). In the upper part the bioturbated beds are continuous and contain thin laminated preserved horizons. It may suggest a deepening and rapid decrease of the migration rate.

Evoluzione delle sequenze di facies nella parte superiore della successione (affioramento Aeroporto di Brindisi, Fig.1). In basso nella foto si osservano spessi strati della facies B (stratificazione incrociata concava) con tracce fossili isolate. Verso l'alto è visibile un netto incremento della Facies C in strati regolarmente continui caratterizzati internamente da sottili livelli laminati preservati. Ciò può indicare una tendenza all'approfondimento e/o alla riduzione dell'accrezione dello spit.

4.3-Short-time evolution

A facies sequence may be the product of an accretion cycle storm-controlled in foreshore-shoreface subenvironment. The coarse bed is the product of the acme of the storm in the breaker zone (probably plunging type); in this set up phase the beach face was affected by high wave energy, transport of a great amount of coarse material according to the slope (seaward or landward of the foreshore, Fig. 6). During the normal sea level restoring the fast colonization of the benthic fauna may have reworked both the coarse sediment of the rip currents and the bedforms, specially the landward flank of the bar. Each sequence of this type is referred to short time beach evolution, that is in an "instantaneous" sense, from a few seconds to several years. The sedimentary product is a facies sequence of different thickness, from a few centimetres up to one metre: grading, tractive structures and bioturbated intervals can record the complete evolution of a storm event. The amalgamated beds of Facies A (Fig. 5) record truncated sequences, where the full spectrum of variation is not present. These sequences may be referred to the frontal part of the accretional body.

4.4-Long-term coastal development

Long-term changes in beach evolution are due to storm regime, sea level short fluctuations and shoreline morphological changes that produce different wave

actions. In this sense thick or very thick sequences (several metres or more) may be interpreted.

The sedimentologic features which are more sensitive to change, in the studied succession, are the thickness of Facies A beds, the ratio between physical and organic structures: $R = (A+B)/C$. A weak decrease in the grain size and in the thickness of the beds couples with the increase in bioturbation.

The lowermost stratigraphic interval (1st in Fig.1), up to 1 km along shore, is characterized by $R > 1$. A recognizable increasing in bioturbation is located after 1 km of the continuous succession (Punta Serrone): for 0,5 km the stratification is characterized by $R = 1$ (2nd interval, Fig. 1). Along shore the bioturbated beds increase and the overlying succession (3rd interval) is composed of an alternance of packets (Fig.10) with $R=1$ or $R < 1$ (thickness of some tens of meters to some hundreds of meters).

Long term cyclicity suggests a decreasing sediment supply or a slowing-down beach migration, due to climate improvement and/or to a decrease in

longshore current power (change in wave angle approach), or to a minor effect of tilting versus sea-level rise.

5 - RESULTS

Stratigraphic remarks:

- The Punta Penne Calcarenite (PPC) is a coarse sedimentary body inclined and thinning toward SE in Pleistocene fine grained marine sediments;
- The lower boundary, in the northern side, is an unconformity (Figs. 2, 2a);
- It is characterized (in the condensed Contessa section, up to 4 m thick) by transgressive lag with pebbles and shells, a transgressive unit and an upper regressive unit.
- The real thickness of the sedimentary body is about ten metres. The lateral accretion of the 3 km long body, about 30° dip, formed a succession about 1500 m thick (apparent or pseudo-stratification, Figs. 2, 3).
- It was generated by a lateral accretionary process controlled by a long balance between vigorous wave attack and longshore current southeastward, reworking of coarse bioclastic sand in beach environments (foreshore-upper shoreface).

Facies analyses:

- The facies analysis suggests elementary sequences,

or compound beds, various thickness, characterized by:

- 1 - graded, amalgamated (few cm to some dm thick) planar units with lower erosional surface (Facies A);
- 2 - cross-bedded units, some dm thick (Facies B);
- 3 - bioturbated units, few to 5 dm thick (Facies C).

Facies sequences:

- Each sequence is referred to short-time beach evolution (storm event) developed into: acme phase during the risen sea (set-up, highest energy, main plunging breakers, Facies A), longshore transport phase (Facies B), low energy phase (Facies C).
- The stacking pattern of the facies sequences in the whole outcropping area (about 3 km from Punta Penne to Brindisi harbour) indicates the long-time evolution of the beach under the main control factors: subsidence, power of the wave attack and reworking, minor sea level fluctuations.
- Some stratigraphic intervals are distinguished on the basis of facies ratio $R=(A+B)/C$ (Fig.1B). High R indicates a good balance between accumulation and lateral accretion, whereas the decrease in the ratio may suggest the decrease of sediment supply, the slowing down migration and relative deepening.

The first interval (0-1,0 km along the coast, 500 m thick) is characterized by $R>1$ (Fig. 5).

The second interval is composed by a thin interval (10-20 m) characterized by $R > \text{or} = 1$ (Fig. 7) followed by an interval, about 250 m thick, characterized by $R>1$. This is overlain by a third interval with $R<1$ (Fig. 10), gradually passing to packets, variously thick, with $R \geq 1$. In this part of the succession (3rd interval, Fig. 1B) the gradual increasing of the Facies B in the thick beds of Facies C is very frequent.

Evolution down-current

The southeastward part of the calcarenitic body outcrops discontinuously in many little isles and reefs in the Brindisi harbour (4th interval, Fig.1, 12). Moreover the Contessa section (Fig. 4) may be interpreted as the southeastward expression of the Punta Penne depositional sequence in landward margin, as appeared after the drastic Holocene coastal recession (5th interval, Fig.1).

Downcurrent the accretion dies away and the sequence becomes sub-horizontal (Contessa section, Fig. 4); southeastward it intercalates in Middle Pleistocene regressive succession (Campo di Mare section, COPPA *et al.*, 2001).



Fig. 12 - Facies characteristics of PPC in Pedagne Isles (4th stratigraphic interval, Fig.1 for location): the main sedimentary structures are trough cross bedding, locally hummocky. The dip is variable toward WNW and NE, indicating a probable shrinkage of the spit, or a different development (?regressive trend) in the upper part of the succession. The lack of Facies A and dominance of facies B suggest an upper shoreface environment.

Caratteri di facies nell'affioramento delle isole Pedagne (intervallo stratigrafico 4 Fig.1). E' prevalente la stratificazione incrociata localmente ad "hummocky". L'inclinazione dei foreset indica migrazione variabile da WNW a NE in piccoli tratti, probabilmente connessa ad un restringimento della parte frontale dello spit durante la fase finale del suo sviluppo (probabile fase regressiva in ambiente di spiaggia sommersa superiore).

6 - CONCLUSION

The detailed study of the PPC succession outcropping along the Brindisi coast allows for the reconstruction of the genetic and growth processes, the likely control factors: uplift in the northern side of the coast, erosion rate, subsidence in the nearshore, longshore transport and accumulation.

Possible influences on the PPC cycle.

In the general regressive trend of the Late Pleistocene, the PPC cycle may be caused by a significative uplift in the northern area (Punta Patedda section) as well as by an amount of subsidence in the coastline southward. The increase in the erosion and sediment supply on the coastline were balanced by the accommodation space in the southern part (relative sinking). A detrital progradation developed a southeastward migrating spit.

In the dynamic process of the coastal cell, the fluid power (wave refraction and longshore transport of coarse sediment) and the inclined surface along the shoreline developed a typical cliniform pattern.

The dynamic equilibrium was controlled by the stratigraphic process variables: the relationships of the rate of sediment input (Q) with fluid power (P), able to remove it, was important in the sedimentary body growth.

Over a short period of time every prograding sedimentary unit shifted seaward and formed the next inclined surface, dominated by the same hydraulic condition.

Over a long time the change of one or more geohistorical variables (SWIFT and THORNE, 1991) fixed a new equilibrium in the depositional regime. Particularly the decrease in sediment input (erosion or longshore transport) reduced the progradation and caused an aggrading phase and increasing bioturbation (Facies C).

Climate fluctuations seem to well explain sedimentary facies rate changes [(A+B)/C].

Finally the PPC cycle may be interpreted as a 4th order cycle, mainly controlled by allocyclic processes on account of its lateral continuity. An approximate accumulation of the spit could be limited to a few thousand years, probably during late Pleistocene.

The origin of this cycle was most likely the eust climatic variation, as an efficient rule in coastal domain. The sequence boundary (Fig.13) is interpreted as a differential uplifting, at a higher rate on the northern side – thus favouring a headland erosion - decreasing towards the southern side, where the subsidence produced accommodation space for nearshore sedimentation.

Sediment supply, efficiency of longshore drift and subsidence all controlled the growth process and lateral migration of the spit. The close up of subsidence and the regional regression caused the spit death.

The morphologic consequences on the recent coast evolution are: the coarse and well cemented rocks of PPC make up a natural shelter for the Brindisi coast and its port (Fig.1); the southeastern thinning reduces this natural shelter and produces the erosional retreat.

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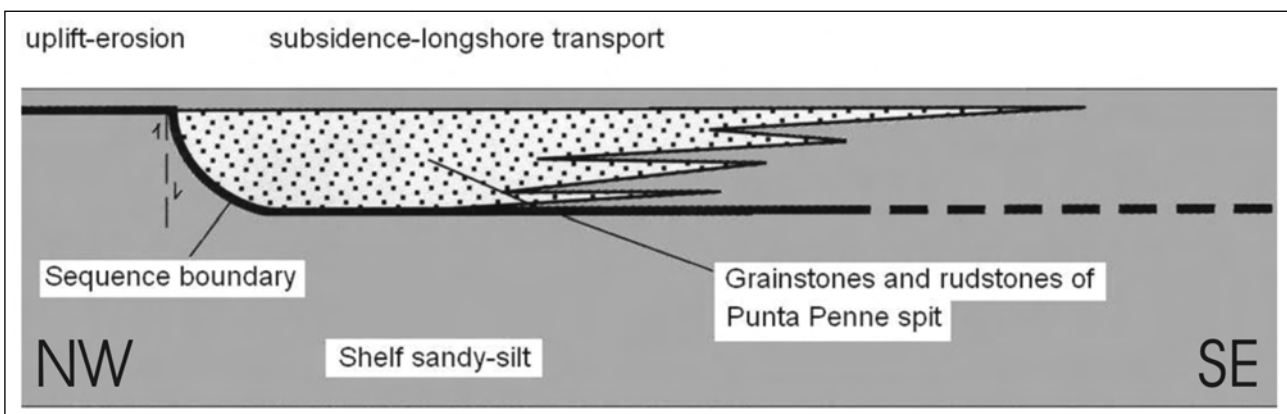


Fig. 13 - Cross section of the Punta Penne Spit system parallel to the main transport direction (Fig. 1B). A hypothetical fault controlled the arisen sediment supply at NW and the subsidence at SE where the accommodation space and the efficient transport of longshore currents favoured the growth and preservation of the sedimentary body. See map for locations.

Modello di sviluppo dello spit in una sezione parallela alla costa (Fig.1B). Una faglia ipotetica ubicata a NW (tra P.Penne e Punta Patedda) avrebbe determinato a nord il sollevamento del tratto di costa creando una zona in erosione, e a sud una zona in subsidenza dove si sarebbe indirizzato il materiale eroso secondo il trasporto lungocosta. Il sistema costiero, cella di tipo spit, sarebbe stato controllato, pertanto, da fattori allociclici (tettonica, clima meteomarinario, minori variazioni del livello marino) e da fattori autociclici (sedimentazione di detrito grossolano, morfologia della costa e rifrazione del moto ondoso).

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