Il Quaternario
Italian Journal of Quaternary Sciences
***20**(2), 2007 - 185-194*

MORPHOLOGICAL AND PALAEOENVIRONMENTAL EVOLUTION OF THE VENDICIO COASTAL PLAIN IN THE HOLOCENE (LATIUM, CENTRAL ITALY)

G. Aiello[1], D. Barra[1], T. De Pippo[1], C. Donadio[1], P. Miele[2] & E. Russo Ermolli[1]
[1]Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II
[2]c/o Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II
10, Largo San Marcellino – 80138 Napoli (Italy)
corresponding author: prof. Tommaso De Pippo depippo@unina.it

ABSTRACT: *Morphological and palaeoenvironmental evolution of the Vendicio coastal plain in the Holocene (Latium, Central Italy)*. (IT ISSN 0394-3356, 2007).
Morphological, stratigraphical and paleoecological studies carried out along the Vendicio coastal plain (southern Latium) allowed us to reconstruct the paleoenvironmental evolution of the plain in relation to Holocene sea-level changes.
On the basis of altitude, texture, microfossil and pollen content of sediments recovered in a 20 m borehole carried out on the backshore, three main transitional palaeoenvironments were recognised. Particularly, the ^{14}C dating of a peat layer at the boring base (-16 m a.s.l.), interbedded between sandy silt with organic matter and silty peat levels, gives an age of 7620 ±100 yr BP, equivalent to 8354-8524 cal yr BP. Over these deposits, sands with pebbles, sometimes alternated with silt and sandy silt levels, lay. Microfossil content, together with sediment features, confirms a transitional sequence from marsh (oligohaline) to lagoon (mesohaline-polyhaline), and finally to marine (littoral) environment, probably due to the last sea ingression related to the mid-Holocene Climatic Optimum peak (~6000 years BP). Pollen analysis reveals the existence of a deciduous forest association, rich in high-humidity demanding elements, by now not represented by a regional modern analogue. The present altitude of the dated peat level, correlated with the available eustatic curves, suggests that the Vendicio sedimentary succession probably has been affected by a slight subsidence phase during MIS 1. The occurrence of a slight subsidence may be also related to late Quaternary vertical displacement of adjacent coastal sectors, and fits in with recent morphological evolutionary models of other minor coastal plains of Latium.

RIASSUNTO: Evoluzione morfologica e paleoambientale della piana costiera di Vendicio (Lazio, Italia centrale). *(IT ISSN 0394-3356, 2007).*
Lo studio delle caratteristiche morfologiche, stratigrafiche e paleoecologiche, connesse a variazioni del livello marino, ha permesso di ricostruire l'evoluzione paleoambientale olocenica della piana costiera di Vendicio, ubicata nel Lazio meridionale. Sulla base delle quote, dei caratteri tessiturali, dei microfossili e di analisi palinologiche condotte su campioni di sedimento, estratti da una carota della spiaggia emersa, sono stati riconosciuti tre differenti paleoambienti di transizione. In particolare un campione di torba alla base della carota (-16 m s.l.m.), posto tra alternanze di limi sabbiosi organici e livelli di torbe limose, ha fornito un'età radiometrica ^{14}C di 7620 ±100 anni dal presente pari ad un'età calibrata di 8354-8524 anni BP. Questa successione sedimentaria è troncata da depositi sabbiosi con ciottoli, talora alternati a livelli siltosi e siltoso-sabbiosi. Le associazioni a microfossili calcarei di tali depositi, insieme ai caratteri sedimentologici, confermano una progressiva transizione da un ambiente oligoalino a mesoalino-polialino (da palustre a lagunare) ed infine il rapido passaggio a quello marino (litorale), in seguito all'ultima ingressione del mare correlabile al picco dell'optimum climatico medio-olocenico (~6000 anni BP). L'analisi pollinica indica la presenza di una ricca associazione di foresta decidua, con elementi tipici di suoli molto umidi, che non ha riscontro nell'attuale ambiente regionale. La correzione della quota di paleodeposizione del livello torboso datato, condotta mediante le curve eustatiche tratte dalla letteratura, suggerisce che la successione sedimentaria verosimilmente è stata interessata anche da una lieve fase di subsidenza della piana nel corso del MIS 1. Quest'ultima potrebbe essere connessa a movimenti verticali registrati nel tardo Quaternario in settori costieri adiacenti alla piana, in accordo con i recenti modelli morfoevolutivi di altre piane costiere minori del Lazio.

Key-words: Coastal geomorphology, lagoons, sea-level changes, Holocene, Italy.

Parole chiave: Geomorfologia costiera, laguna, variazioni del livello marino, Olocene, Italia.

1 INTRODUCTION

The present study represents a further contribution to the understanding of the Holocene sea level rise in southern Latium minor coastal plains. A substantial stability of the rocky promontories and a slight subsidence in the plains is indicated for this coastal sector since MIS 5.5 (Lambeck *et al*., 2004a; Ferranti *et al*., 2006).

No other data are available for the Holocene sea-level changes along this coastal zone, apart from geoarcheological evidences in the sites of Sarinola and Serapo which show during the Roman age a sea level of about 1.35 m lower than the present-day (Lambeck *et al*., 2004b).

The recovery of a sediment core, on the backshore of the Vendicio beach, allowed a paleoenvironmental reconstruction to be performed through paleoecological, sedimentological and palynological analysis and correlated with the evolution of adjacent coastal sectors during the early Holocene, where differential vertical movements occurred especially in Quaternary times (Bordoni & Valensise, 1998; Antonioli *et al*., 2006; De Pippo *et al*., 2007).

2 GEOLOGICAL AND GEOMORFOLOGICAL OUTLINE

The Vendicio coastal plain is located in southern Latium and extends for about 2 km from the headland of Mount Conca, to the W, to Marina di Castellone, to the E (Fig. 1).

The coastal sector is bounded, to the NE and NW, by NW-SE faults. One of such faults, named Gaeta-Itri-Monte Calvo, sharply separates the northeastern area, where Cretaceous carbonate dominates, from the southwestern area, where Triassic-Giurassic dolomite outcrops prevail (Servizio Geologico d'Italia, 1968). Moving further away from this line and up in the succession more limestones, Giurassic in age, are present, as one can observe along the slopes of Lisantro and Dragone mounts (De Riso, 1964).

Finally, the coastal exposures show the top of the succession, mainly represented by Cretaceous limestones, followed by prevailingly continental Pleistocene and Holocene deposits (Hearty *et al*., 1986a; 1986b; Hearty, 1986; Accordi & Carbone, 1988). The carbonatic succession, heavily crossed by a network of structural discontinuity with Apenninic (NW-SE) and anti-Apenninic (NE-SW) trends (Ambrosetti *et al*, 1987; Cerisola & Montone, 1992; Carrara, 1995a; 1995b; Carrara *et al*., 1995), have a pronounced influence on the local geomorphological setting. Owing to the strict correlation between the tectonic structure and the morphological evolution of the area, the slope of the relief are fault scarp or fault-line scarps, locally also modelled by karstic and denudation processes. Therefore, the landscape is characterised by a series of hills often with a cone or truncated cone shape. Their slopes are generally of a structural type and separate valleys, which develop according to local tectonic lines, mainly with NW- SE and NE-SW trends, subordinately E-W ones.

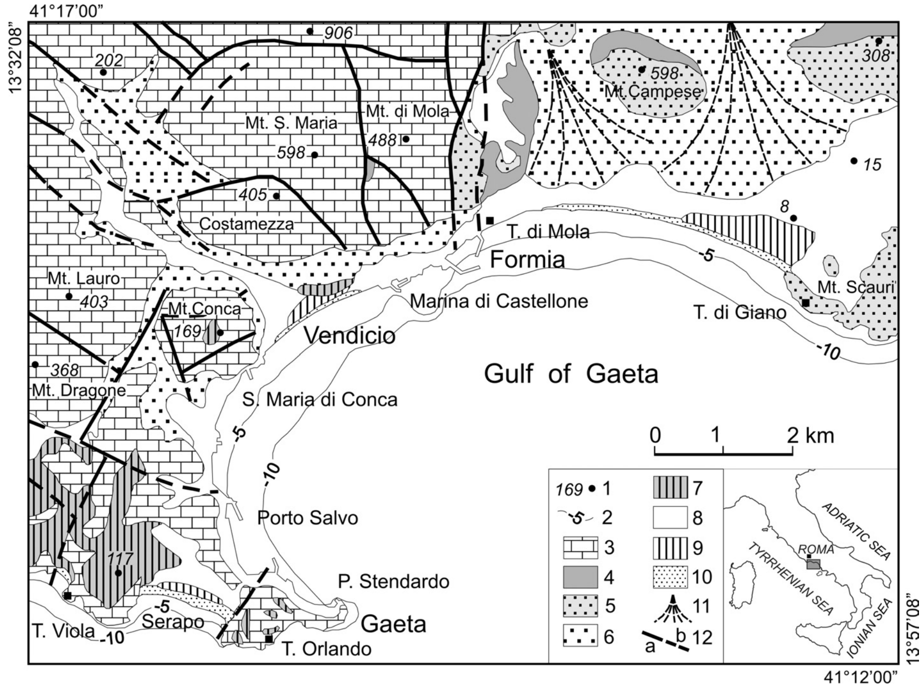

Fig. 1 - Geological outline of the Vendicio coastal plain, between Gaeta and Formia (southern Latium, central Italy): 1) altitude (m a.s.l.); 2) isobath (-m a.s.l.); 3) Mesozoic carbonatic outcrops; 4) Miocene flysch; 5) Pliocene conglomerate; 6) Lower Pleistocene-Holocene carbonatic talus with pyroclastic levels; 7) Upper Pleistocene reddish eolian deposits (*duna rossa antica* Formation); 8) Upper Pleistocene-Holocene alluvial deposits; 9) Holocene eolian deposits; 10) present-day sandy beach; 11) Pleistocene detritic-alluvial fan; 12) fault: a) certain; b) presumed or buried.

Schema geologico della piana costiera di Vendicio, ubicata tra Gaeta e Formia (Lazio meridionale, Italia centrale): 1) quota (m s.l.m.); 2) isobata (-m s.l.m.); 3) affioramenti carbonatici mesozoici; 4) flysch miocenico; 5) conglomerato pliocenico; 6) detrito carbonatico con livelli piroclastici del Pleistocene inferiore-Olocene; 7) depositi eolici rubefatti (Formazione della duna rossa antica*) del Pleistocene superiore; 8) depositi alluvionali del Pleistocene superiore-Olocene; 9) depositi eolici olocenici; 10) spiaggia sabbiosa attuale; 11) conoide detritico-alluvionale pleistocenico; 12) faglia: a) certa; b) presunta o sepolta.*

The alternation of pocket beaches along the coast is also related to the presence of faults, prevailingly those NE-SW oriented. Cliffs were also controlled by tectonics in their development, as noted for the dead or fossil cliffs of Mount Orlando and those of Mount Moneta, in the hinterland of the plain of Sant'Agostino, to the SW. The headland of Mount Orlando, the highest coastal relief, is constituted by Cretaceous limestones with a prevalent eastward dip. The northern slopes are modelled with gentle forms covered by clastic deposits, such as the red sands referable to the lithologic unity called *duna rossa antica* (ancient red dune: Blanc *et al*., 1953; Bergomi *et al*, 1969; Bono, 1985; Dai Pra, 1995), attributed to Middle-Upper Pleistocene, and colluvial detritus partially pedogenesized and vegetated (Valente, 1999).

The cliff of Mount Conca, bordering the western side of the Vendicio beach, continues under the sea down to about -5 m, where a sandy bottom is present. This coastal segment is characterised by a sandy beach, locally with pebbles, located between the rocky headlands of Mount Conca and Formia. Behind the modern dune ridge, hardly dismantled, a minor alluvial plain is also present, delimited in the NE by the southwestern slope of Costamezza hill, a palaeocliff oriented NW-SE, as the local tectonic alignments.

Evidence of ancient sea-level standings are scarce along the cliffs of the rocky headlands bordering the beach. At their bases a sandy bottom is usually present, which gently degrades down to -15/-25 m. Steep slopes, in a range between -20 and -50 m depth, are present along the submerged southwestern sector. The NE-SW trend (Antonioli, 1991; 1995; Valente, 1999; Miele, 2003) of such morphological elements suggests a structural control, which also influences the direction of the transversal elements, such as the wide fractures which tend to isolate stacks as at Montagna Spaccata, to the SW. Here, some caves, remodelled both by waves and karstic phenomena, continue under the sea-level.

Along the southwestern coast, evidence of paleo-sea-level positions are numerous (Antonioli *et al*., 2006; De Pippo *et al*., 2007). In particular, along the slopes of

Moneta and Lisantro mounts, sea-notches, marine terraces, fringe boring by bivalve such as *Litophaga litophaga* LINNEO and drapes of sediments are present. Some marine forms are also preserved along the fossil sea cliffs bounding the Vendicio coastal plain. In the western area, along the Mount Conca cliff and at the back of the waterfront, a sea-notch can be observed at about +0.5 m, bored by *L. litophaga* LINNEO. Some relics of marine terraces are also present, partially covered by breccias probably referable to the Würm regression (MIS 2). Such breccias are heterometric, seaward dipping, often rubefact in the matrix. In the lower stratigraphic terms mollusc shell debris occurs, consisting of minute bivalve (*i.e. Glycymeris* sp.) and gastropod fragments. Such deposits, originated in the intertidal zone, where clasts either from the sea and from the land were deposited without a significant transport, are rather diffuse along this coast, even if sometimes with a negligible thickness.

A careful observation of the isobaths, concave seaward in the area in front of the beach and convex and close together in the area where the rocky coast is stretched out, confirms that, under the loose sedimentary mantle which at present covers the sea-bottom, the morphology of the submerged coast, characterised by marine terraces (SEGRE, 1949; ANTONIOLI, 1991; 1995), is controlled by the same structural pattern of the emerged area.

3 MATERIALS AND METHODS

A 20 m long soil boring was carried out on the backshore of the Vendicio plain (Fig. 2). A peat level is present at the boring base (-16 m a.s.l.), interbedded between sandy silt with organic matter and silty peat levels (a: between -17 and -3 m a.s.l.). The AMS ^{14}C dating of the bulk (Geochron Laboratories - USA, sample nr. GX-32021) gives a 7620±100 yr BP age equivalent to 8354-8524 cal yr BP (CALIB 5.01 – STUIVER & REIMER, 1993; REIMER *et al*., 2004). Above these deposits, sand with pebbles, sometimes alternated with silt and sandy silt levels, lay (b: between -3 and -1.5 m). Finally, over these sediments an anthropogenous top soil formed by colluvial layers, carbonatic boulders with *Litophaga litophaga* boreholes, pebbles, sand and landfill, lay. (c: between -1.5 and +3 m a.s.l.). Geomorphological surveys have been performed along the emerged coastal belt, characterised by limestone cliffs bordering a plain with dune ridge and partially anthropised. The geomorphological features have been considered in order to obtain a complete outline of the morphostructural arrangement of the investigated area. Environmental features related to ancient positions of the sea-level have been recognised and interpreted, and therefore ascribed to a certain chronological interval thanks to the ^{14}C dating of a boring sample.

The correspondence existing between some of the recovered elements, their dating and the sea-level position in the last 8400 years (MIS 1), allowed a correlation with the eustatic curves relative to the Tyrrhenian Sea in the same range of time. Remarkable discrepancies exist among the eustatic curves plotted for different geographic areas. Therefore, the curve covering the last 22.000 years, after ALESSIO *et al*. (1996), and

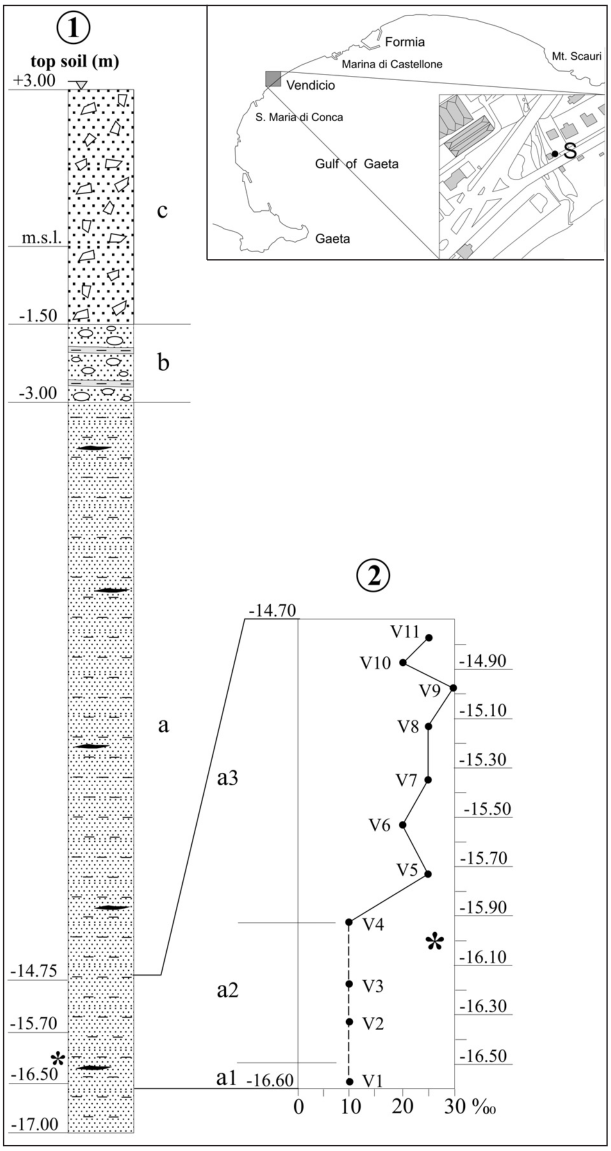

Fig. 2 - 1) Stratigraphic log of the soil boring (S) carried out on the backshore of Vendicio: a) darkish sandy silt with organic matter, blackish peat and silty peat levels (brackish with fresh water environment); b) greyish and yellowish fine sand with limestone pebbles, sometimes with greyish silt and sandy silt levels interbedded (littoral environment); c) anthropogeneous top soil formed by carbonatic boulders with lithodomus boreholes, pebbles, sand and landfill (continental environment); 2) paleosalinity diagram of soil boring base, desumed from microfossil association analysed in the sediments: a1) oligo-mesohaline environment; a2) presumed oligo-mesohaline environment; a3) meso-polyhaline environment; *) dated peat sample (7620±100 yr BP ^{14}C age equivalent to 8354-8524 cal yr BP); V1 = sample for palaeoecological and pollen analyses. Altitudes are related to present-day sea-level (±m a.s.l.).

*1) Stratigrafia dei terreni presenti nel sondaggio (S) ubicato nella spiaggia alta di Vendicio: a) limi sabbiosi organici, torbe e livelli di torba limosa di colore nerastro (ambiente salmastro con acque dolci); b) sabbie fini grigiastre e giallastre con ciottoli calcarei, talvolta con intercalazioni di livelli limosi e limoso-sabbiosi (ambiente litorale); c) suolo di genesi antropica formato da blocchi carbonatici con fori di litodomi, ciottoli, sabbie e terreno di riporto (ambiente continentale); 2) diagramma della paleosalinità dei depositi presenti alla base del sondaggio, desunto dall'analisi delle associazioni di microfossili nei sedimenti: a1) ambiente oligo-mesoalino; a2) presunto ambiente oligo-mesoalino; a3) ambiente meso-polialino; *) campione di torba datato (età ^{14}C di 7620 ±100 anni BP, equivalente a 8354-8524 anni BP calibrati); V1 = campione per analisi paleoecologiche e polliniche. Le quote sono riferite al livello marino attuale (±m s.l.m.).*

that covering the last 10.000 years, after Lambeck *et al.*, (2004a), both plotted by those authors with data collected in the more stable coastal areas of the Tyrrhenian Sea, were chosen as a reference.

Paleoecological and palynological analysis were only carried out on the lower part of the core where the sediment grain size and nature was more suitable for fossil preservation. Eleven core samples (300 g dried weight) were disaggregated, washed with water through 200 mesh sieves (75 μm) and analysed with the aim of studying calcareous microfossil assemblages. Attention was focused especially on ostracod and foraminifer taxa. All the samples yielded at least a few calcareous fossil remains. Assemblages are characterised by the presence of ostracods, benthic foraminifers, bivalves, gastropods (shells and opercula) and charophyte oogonia.

Pollen analysis was carried out on 8 core samples, from -16.55 to -15.15 m a.s.l. Chemical (HCl and HF) and physical (10μ filtering 200μ, heavy liquid separation) procedures were used to concentrate the pollen grains in the residue. All samples resulted rich and with a good pollen preservation. Pollen sums range from 379 to 684 pollen grains. Concentration values oscillate around 70-100.000 grains/g and reach about 200.000 grains/g in the richest levels.

4 CALCAREOUS MICROFOSSIL ASSEMBLAGES

The benthic foraminifer assemblages include six species pertaining to five genera; the ostracod assemblages consist of seven species in seven genera. Taxa are listed in Table 1. Some species have been figured in Plate 1.

Semiquantitative abundance of fossil taxa in the samples is represented by the following abbreviations: *vr* (very rare), *r* (rare), *u* (uncommon), *c* (common), *a* (abundant). Palaeoecological interpretations follow the modern literature on recent paralic/shallow-marine benthic foraminifers and ostracods (*i.a.* Barbeito-Gonzalez, 1971; Hiller, 1972; Bonaduce & Masoli, 1974; Vesper, 1975; Bonaduce *et al.*, 1976; Hartmann & Hiller, 1977; Meisch, 2000). The studied specimens are housed in the Aiello Barra Micropaleontological Collection (A.B.M.C.), Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II, Naples (Italy).

Assemblage analysis allows the analysed section to be subdivided into three intervals (Fig. 2):

a1 – the lowermost sample, V1, yielded an ostracod assemblage dominated by *Candona neglecta* and, subordinately, by *Potamocypris fallax. Ilyocypris bradyi* is rare as well as gastropods. These species indicate a

Tab. 1 - Semiquantitative distribution of the calcareous remains in the Vendicio plain core (a = abundant, c = common, u = uncommon, r = rare, vr = very rare).

Distribuzione semiquantitativa dei microfossili calcarei presenti nel sondaggio della piana di Vendicio (a = abbondante, c = comune, u = poco comune, r = raro, vr = molto raro).

TAXA	samples										
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
	depth (m a.s.l.)										
	16.55-16.60	16.30-16.35	16.15-16.20	15.90-15.95	15.70-15.75	15.50-15.55	15.30-15.37	15.15-15.20	14.95-15.00	14.85-14.90	14.75-14.80
Foraminiferida											
Ammonia tepida Cushman, 1926					c	u	c	r	a	u	c
Bolivina sp.								vr			
Elphidium cuvilleri Lévy, 1966					u			vr	vr		
Elphidium paralium (Tintant, 1954)					u		u		c	vr	u
Fursenkoina acuta (d'Orbigny, 1846)									vr		
Quinqueloculina milletti (Wiesner, 1912)					c		c		a	u	u
Ostracoda											
Ilyocypris bradyi Sars, 1890	vr									r	
Candona neglecta Sars, 1887	a									r	
Cyprideis torosa (Jones, 1850)					a	a	a		u	c	c
Leptocythere rara (G.W. Müller, 1894)									vr		
Loxoconcha stellifera G.W. Müller, 1894					u	c	c		c	u	u
Potamocypris fallax Fox, 1967	c										
Pseudocandona sp.										vr	
BIVALVIA	r				a	c	a		a	r	r
GASTROPODA	u	vr	u	u	u	c	a	u	a	u	u
CHARACEAE					vr		vr				

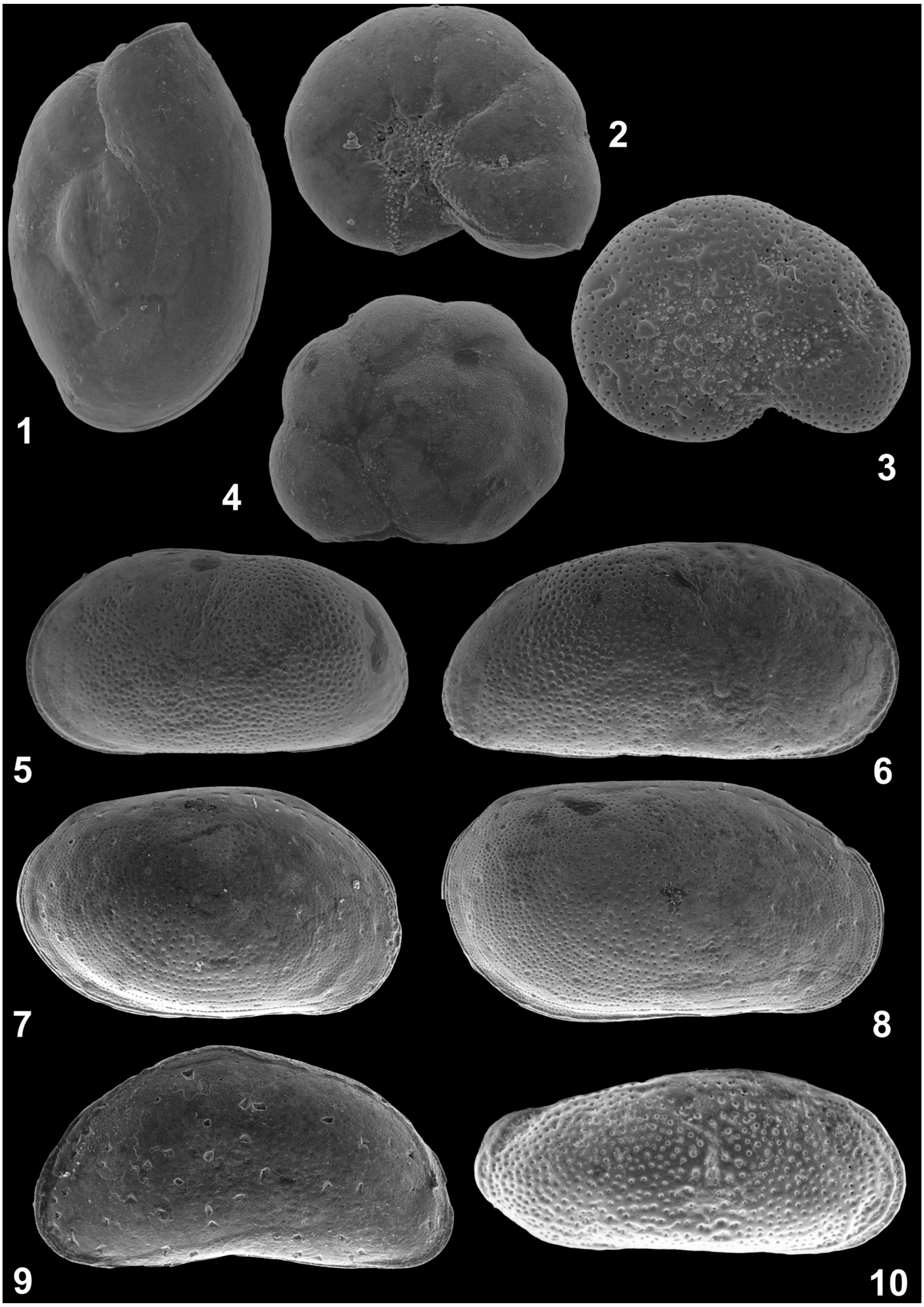

Plate 1 -
fig. 1 - *Quinqueloculina milletti ,* 4 chamber side, V9, (x 67).
fig. 2 - *Elphidium paralium*, side view, V9, (x 53).
fig. 3 - *Elphidium cuvilleri,* side view, V9, (x 37).
fig. 4 - *Ammonia tepida*, spiral side, V9, (x 48).
fig. 5 - *Cyprideis torosa*, left valve, V7, (x 68).
fig. 6 - *Cyprideis torosa,* right valve, V7, (x 77).
fig. 7 - *Loxoconcha stellifera,* right valve female, V7, (x 66).
fig. 8 - *Loxoconcha stellifera*, right valve male, V7, (x 76).
fig. 9 - *Potamocypris fallax*, left valve, V1, (x 68).
fig. 10 - *Leptocythere rara*, right valve, V9, (x 75).

Tav. 1 -
fig. 1 - Quinqueloculina milletti*, veduta del lato a 4 camere, V9, (x 67).*
fig. 2 - Elphidium paralium*, veduta laterale, V9, (x 53).*
fig. 3 - Elphidium cuvilleri*, veduta laterale, V9, (x 37).*
fig. 4 - Ammonia tepida*, veduta del lato spirale, V9, (x 48).*
fig. 5 - Cyprideis torosa*, valva sinistra, V7, (x 68).*
fig. 6 - Cyprideis torosa*, valva destra, V7, (x 77).*
fig. 7 - Loxoconcha stellifera*, valva destra femminile, V7, (x 66).*
fig. 8 - Loxoconcha stellifera*, valva destra maschile, V7, (x 76).*
fig. 9 - Potamocypris fallax, *valva sinistra, V1, (x 68).*
fig. 10 - Leptocythere rara*, valva destra, V9, (x 75).*

depositional paleoenvironment characterised by continental, oligohaline to mesohaline, relatively cold (<20°C), stagnant waters. Benthic foraminifers are not present;

a2 – the overlying interval is represented by three samples (V2, V3, V4) devoid of both ostracod and foraminifer specimens. Calcareous fossil remains are represented exclusively by rare gastropods fragments and opercula. The sediment consists largely of carbonaceous matter derived from plant remains. The accumulation of organic matter generates the formation of acidic bottom and pore waters, due to the high concentration of metabolically produced carbon dioxide (CO_2). A low carbonate saturation index may cause the dissolution of the delicate ostracod shells. Consequently, these sediments possibly indicate the effect of a cold and arid climate phase in a swampy environment (*i.a.* GLIOZZI & MAZZINI, 1998; BELIS *et al.*, 1999);

a3 – in the seven samples belonging to the upper part of the core (V5 – V11) benthic foraminifers are present and the fossil assemblages are generally richer and less oligotypic than in lower deposits. These portions show a more or less marked influence of marine waters, and the assemblages indicate four different paleoenvironments:

- samples V5, V6, V7, V11. Ostracod assemblages consist of two species: *Cyprideis torosa*, which is very abundant, and, subordinately, *Loxoconcha stellifera*. The foraminifer assemblages are characterised by *Ammonia beccarii, Quinqueloculina milletti* and the genus *Elphidium* (these latter not present in sample V6). The assemblages evidence a deposition in polyhaline waters;
- sample V8. Abundant carbonaceous matter, rare specimens of *Ammonia beccarii* and *Elphidium cuvilleri* and the absence of ostracod shells indicates that these sediments were deposited in conditions similar to those in interval 2, but in polyhaline waters;
- sample V9. Three ostracod and six foraminifer species occur, including *Leptocythere rara, Fursenkoina acuta* and *Bolivina* which are recorded exclusively in this assemblage. The highest diversity possibly corresponds with the maximum influence of sea waters;
- sample V10. This assemblage is the only one which shows the presence of *Ilyocypris bradyi and Pseudocandona* sp., nonmarine taxa, together with the "marine-brackish" species *L. stellifera, Q. milletti* and *E. cuvilleri,* suggesting a deposition in mesohaline-polyhaline waters, possibly with rapid (seasonal) salinity variations.

5 PALYNOLOGY

Pollen analysis results are presented in a detailed pollen diagram (Fig. 3) where all the recognised taxa show their percentage values plotted against depth. The arboreal taxa percentage (AP/Total curve in Fig. 3) was calculated on a pollen sum excluding indeterminate grains, water plants and spores. AP values oscillate around 90% all along the investigated succession giving the image of a rather dense forested landscape (*i.a.* HEIM, 1970) in which the main arboreal elements were *Alnus, Corylus,* deciduous *Quercus, Carpinus* and *Ulmus*. The only AP reduction is observed at 15.50 m depth where a rise in Poaceae turns the AP down to 68%. The arboreal taxa percentage (curve AP/Total in Fig. 3) oscillates from 60 to 80% giving the image of a rather dense forested landscape (i.a. Heim, 1970). The main arboreal elements are *Alnus, Corylus*, deciduous

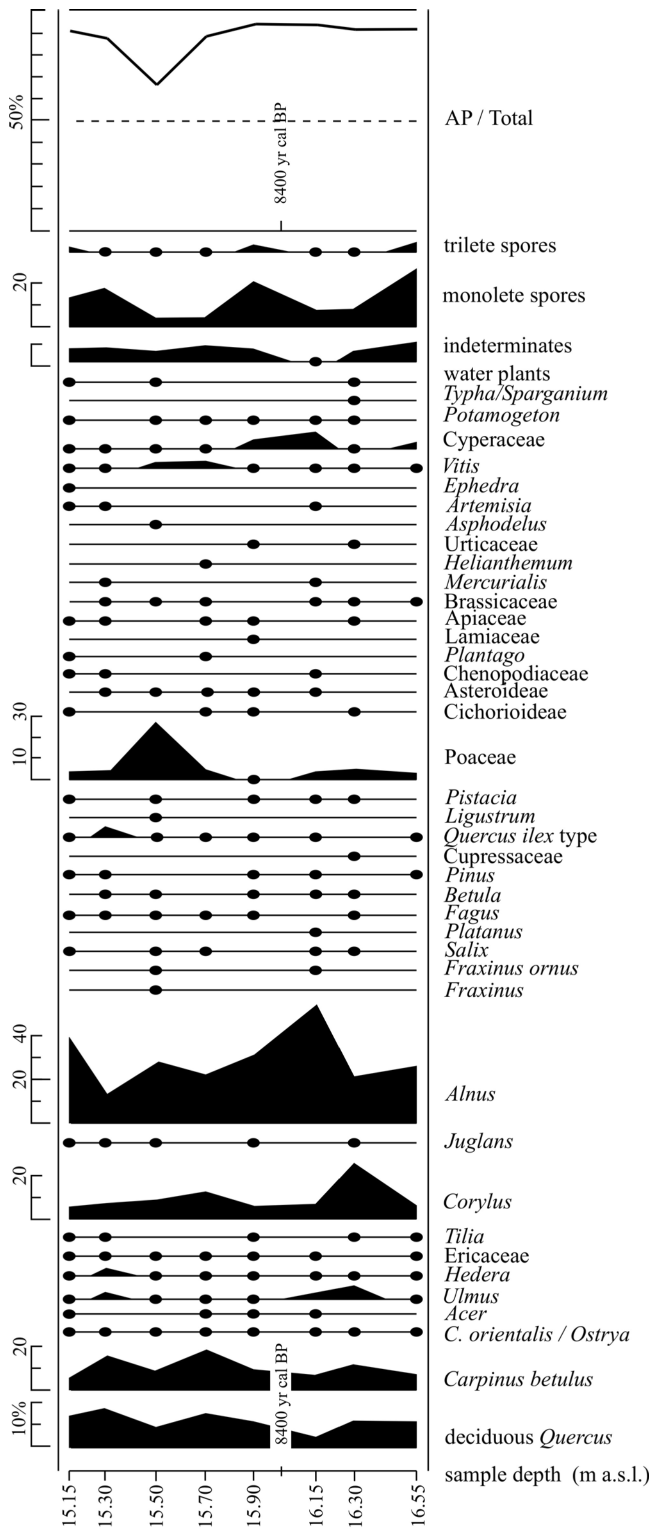

Fig. 3 - Detailed pollen diagram. Taxa percentages are plotted against depth.

Diagramma di dettaglio dei pollini. Le percentuali dei taxa sono restituite con le relative profondità.

Quercus, *Carpinus* and *Ulmus*.

Deciduous *Quercus* and *Carpinus* do not show important variations. They probably represent the main elements of a slope forest association, established on well drained soils. On the contrary *Alnus, Corylus* and *Ulmus*, which are high soil-humidity demanding elements, show more significant percent variations maybe linked to waterbed oscillations. In fact, they should have occupied the Vendicio plain in a forestal association by now not represented by a regional modern analogue.

Vegetation associations dominated by A*lnus, Corylus, Carpinus* and *Ulmus* now characterise high humidity environments linked to microclimatic conditions, well represented all over Italy (PEDROTTI & GAFTA, 1996). These elements are also commonly present in alluvial environments of temperate regions in central Europe (POLUNIN & WALTERS, 1987) where they form plain-wood strips, by now relicts in Italy and have almost disappeared from southern Italy, a part from the higrophylous woods of Mount Circeo (STANISCI *et al*., 1998).

Small amounts of *Fagus* and *Betula* are the only representatives of the mountainous vegetation belt. Mediterranean elements are present but rare all along the analysed succession apart from a slight increase in *Quercus ilex* towards the top.

Poaceae are the main representatives of the herbaceous elements; their percentages are always below 10% apart from the sample at -15.50 m where they reach 30%. The low percentage of spores and the relative lower percentages of *Alnus* at the same core depth could indicate the reduction of dump soils around the drilling site. Cyperaceae are rare but show a slight increase at -15.90 and -16.15 m; the correspondence with the highest values of *Alnus* could indicate the extension of wetlands in the Vendicio plain.

It is very interesting from a phytogeographical and bioclimatic point of view the constant presence of *Vitis* sp.. The species *vinifera*, as its wild representative, are now associated with the above mentioned arboreal elements in thermophilous humid forests from central to southern Italy (PIGNATTI, 1982) even if the wild representative is in constant regression all over Europe (ARNOLD *et al*., 1998).

The ^{14}C age of 7620+/-100 yr BP (8354-8524 cal yr BP) obtained at -16 m a.s.l. places the analysed succession at the beginning of the Atlantic chronozone (about 9000-5700 cal yr BP), the Holocene thermal optimum (RAVAZZI, 2003), which is characterised by wetter (about +200 mm/a) and cooler (about -1.5°C TANN) climatic conditions in respect to modern values (TERRAL & MENGUAL, 1999; DAVIS *et al*., 2003; MAGNY *et al*., 2003). These climatic conditions associated with the humid edaphic conditions typical of a coastal plain can explain the existence of a forestal association like the one recognised in the core.

6 DISCUSSION AND CONCLUSIONS

In this work the morphological and palaeoenvironmental evolution of the Vendicio coastal plain is depicted for the first time (Fig. 4) as sedimentological and ecological signatures of ancient coastlines. The analysed sedimentary succession starts in the early Holocene (about 8400 yr BP) and covers the main phases of the mid-Holocene eustatic sea-level rise. Three main transitional palaeoenvironments are recognised in the basal part of the core, on the basis of height, texture, microfossil and palinological analyses.

Pollen analysis reveals for the first time the existence of humid soils around the drilling site with the occurrence of a plain-forest where elements such as *Vitis* are also recorded. Microfossil assemblages together with sediment characteristics, indicate a transitional sequence from oligo-mesohaline to meso-polyhaline (from marsh to lagoon), and finally to marine (littoral) environment, due to the last sea ingression related to the mid-Holocene Climatic Optimum peak (~6000 years BP). Such environmental succession was also described in two 6 m long boreholes, carried out along the coastal sector west of Formia. According to SEWINK *et al*. (1984), lagoonal clays with interbedded fine sand levels indicate a transition from brackish, with fresh water, to marine-brackish, probably littoral, environment. These deposits, intercalated towards the top with several paleosoils, are locally covered by Roccamonfina tuffs, after an erosive phase. Over this volcanic material, reddish, yellowish and reddish brown eolian sands as well as anthropogeneous colluvial layers are present, confirming the evolution towards a continental environment.

In order to delineate the morphodynamic evolution of the Vendicio coastal plain in the Holocene, two eustatic curves (ALESSIO *et al*., 1996; LAMBECK *et al*., 2004a), were chosen as a reference. The present position of the dated peat level in the study soil boring (-16 m a.s.l.) could indicate both stable conditions or the occurrence of a slight subsidence in the plain, in agreement with literature data (FERRANTI *et al*., 2006).

On the basis of the chosen references, the sea level position at 8400 years BP was about -15 m lower than the present. The dated peat position at -16 m is consistent with a marsh to shallow water lagoon environment, in stable tectonic conditions. However, a slight subsidence could also be deduced for the considered time interval. No data are specifically available in this area which could better detail the sea level rise during the early Holocene, but at 2000 years BP considering geoarchaeological data ALESSIO *et al*. (1996) indicate a sea level of about 0.6-1.5 m lower than the present, while LAMBECK *et al*. (2004b) calculate a sea level of about 1.35 m lower than the current for the sites of Sarinola and Serapo, close to the study area. As a matter of fact differential movements between adjacent coastal sectors have occurred up to recent times (DE PIPPO *et al*., 2007). Such movements would have occurred along the NW-SE faults that represent the borders of the pocket beach system characterising the entire coastal physiography. Moreover, such discontinuities act as unblocking elements for adjacent coastal sectors. This fact suggests that the coastline did not behave homogeneously during the late Quaternary tectonic phases, as hypothesized for some sectors of the Campanian coastline (CINQUE & ROMANO, 1990; DE PIPPO *et al*., 1998; ESPOSITO *et al*., 2003).

Such dislocations, which occurred in the studied coast, can be referred to a sector of the central Apennine included between the two main coastal plains of Fondi and Formia-Garigliano where a slight subsi-

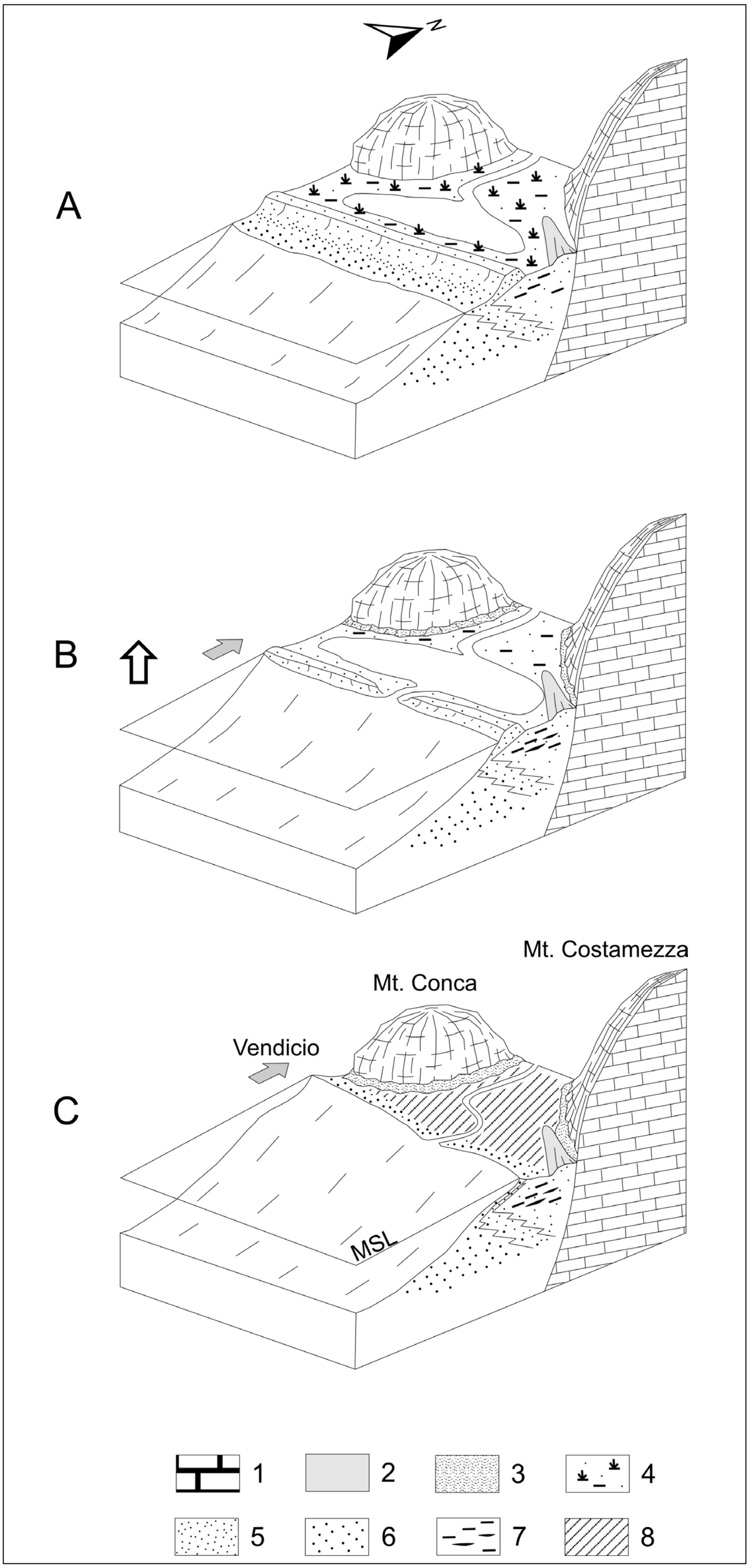

Fig. 4 - Probable palaeoenvironmental evolutionary model of the Vendicio coastal plain, desumed from soil borings (see Fig. 2 and citations) and morphological features; A) upper Pleistocene - lower Holocene: marsh environment characterised by a coastal pond with debouching stream, dune ridge and beach; B) 8400 years BP - mid Holocene: development of the lagoon with bebouching stream and the mouth cutting the dune; retreating beach due to sea level rise; C) mid Holocene - present-day: gradual disappearance of the dune and lagoon; beach retreat due to both sea level rise and recent strong anthropogeneous intervention along the plain; 1) carbonatic rock; 2) *duna rossa antica* (ancient red dune) Formation; 3) carbonatic talus; 4) marsh deposits; 5) eolic deposits 6) marine deposits; 7) lagoon deposits; 8) landfill. The block-diagram is not in scale; the vertical wired arrow shows the sea level rise, while the horizontal grey the shoreline retreat.

Modello della probabile evoluzione paleoambientale della piana costiera di Vendicio, desunto da sondaggi (cfr. Fig. 2 e citazioni) e caratteri morfologici; A) Pleistocene superiore - Olocene inferiore: ambiente palustre con stagno costiero alimentato dal corso d'acqua, cordone dunare e spiaggia; B) 8400 anni BP - Olocene medio: sviluppo della laguna alimentata dal corso d'acqua, con foce che disseca la duna; spiaggia in arretramento a seguito dell'ingressione marina; C) Olocene medio - attuale: graduale scomparsa della duna e del retrostante ambiente lagunare; arretramento della spiaggia a seguito sia dell'ingressione marina sia dell'intensa antropizzazione recente della piana; 1) roccia carbonatica; 2) Formazione della duna rossa antica*; 3) detrito carbonatico; 4) depositi palustri; 5) depositi eolici; 6) depositi marini; 7) depositi lagunari; 8) colmata artificiale. Il diagramma stereo non è in scala; la freccia verticale indica la variazione del livello marino, mentre quella orizzontale grigia l'arretramento della linea di riva.*

dence is recorded. In fact, according to recent papers, the whole eastern Tyrrhenian margin can be considered from stable to slowly subsiding from MIS 5.5 (Ozer *et al*., 1987; Ferranti *et al*., 2006), even if in southern Latium local uplift movements are estimated (De Pippo *et al*., 2007).

REFERENCES

Accordi G. & Carbone F. (1988) - *Sequenze carbonatiche meso-cenozoiche*. In: G. Accordi, F. Carbone, G. Civitelli, L. Corda, D. De Rita, D. Esu, R. Funiciello, T. Kotsakis, G. Mariotti & A. Sposato (eds.), *Note illustrative della Carta delle litofacies del Lazio-Abruzzo ed aree limitrofe*, C.N.R., Quad. de «La Ricerca Scientifica», **114**, 11-92.

Alessio M., Allegri L., Antonioli F., Belluomini G., Improta S., Manfra L. & Preite Martinez M. (1996) - *La curva di risalita del mare Tirreno negli ultimi 43Ka ricavata da datazioni su speleotemi sommersi e dati archeologici.* Mem. Descr. Carta Geol. d'It., **52**, 261-276.

Ambrosetti P., Bosi C., Carraro F., Ciaranfi N., Panizza M., Papani G., Vezzani L. & Zanferrari A. (1987) - *Neotectonic map of Italy*. Foglio n.6, scala 1:500.000, Prog. Fin. Geodinamica, C.N.R., Roma.

Antonioli F. (1991) - *Geomorfologia subacquea costiera del litorale compreso tra Punta Stendardo e Torre S. Agostino (Gaeta)*. Il Quaternario, **4** (2), 257-274.

Antonioli F. (1995) - *Ricostruzione di variazioni climatiche quaternarie attraverso indagini subacquee.* In: *Lazio Meridionale - Sintesi delle ricerche geologiche multidisciplinari.* ENEA, Dip. Ambiente, 52-58.

Antonioli F., Ferranti L. & Kershaw S. (2006) - A *glacial isostatic adjustment origin for double MIS 5.5 and Holocene marine notches in the coastline of Italy*. Quaternary International, **145-146**, 19-29.

Arnold C., Gillet F. & Gobat J.M. (1998) - *Situation de la vigne sauvage* Vitis vinifera ssp. sylvestris en Europe. Vitis, **37**, 159-170.

Barbeito-Gonzalez P.J. (1971) - *Die Ostracoden des Köstenbereiches von Naxos (Griechenland) und ihre Lebensbereiche*. Mitteilungen aus dem hamburgischen zoologischen Museum und Institut, **67**, 255-326, 47 pls.

Belis C.A., Lami A., Guilizzoni P., Ariztegui D. & Geiger W. (1999) - *The late Pleistocene ostracod record of the crater lake sediments from Lago di Albano (Central Italy): changes in trophic status, water level and climate.* J. Paleolimnol.**,** **21**, 151-169.

Bergomi C., Catenacci V., Cestari G., Manfredini M. & Manganelli V. (1969) - *Note illustrative alla Carta Geologica d'Italia. Foglio 171 - Gaeta e vulcano di Roccamonfina*. Serv. Geol. d'It.

Blanc A.C., Segre A.G. & Tongiorgi E. (1953) - *Le Quaternaire de l'Agro Pontino*. Atti IV Congr. Int. INQUA, Roma-Pisa.

Bonaduce G. & Masoli M. (1974) - *Ostracofaune delle lagune di Marano e Grado. Diffusione ed ecologia*. Boll. Soc. Adriatica Sc. Trieste, **59**, 33-105.

Bonaduce G., Ciampo G. & Masoli M. (1976) - *Distribution of Ostracoda in the Adriatic Sea.* Pubblicazioni della Stazione Zoologica di Napoli, 40, suppl. **1**, 304 pp.

Bono P. (1985) - *Seminario informativo sui risultati del progetto "laghi costieri". Sintesi della relazione finale.* Univ. degli Studi La Sapienza, Roma, vol. **1**, 163 pp.

Bordoni P. & Valensise G. (1998) - *Deformation of the 125 ka marine terrace in Italy: tectonic implications*. Geol. Soc., London, Special Publ., **146**, 71-110.

Carrara C. (1995a) - *Elementi di geologia regionale. In: Lazio Meridionale - Sintesi delle ricerche geologiche multidisciplinari*. ENEA, Dip. Ambiente, 23-33.

Carrara C. (1995b) - *Elementi di neotettonica. In: Lazio Meridionale - Sintesi delle ricerche geologiche multidisciplinari.* ENEA, Dip. Ambiente, 34-36.

Carrara C., Dai Pra G. & Paganin G. (1995) - *Lineamenti di tettonica plio-quaternaria. In: Lazio Meridionale - Sintesi delle ricerche geologiche multidisciplinari.* ENEA, Dip. Ambiente, 151-155.

Cerisola R. & Montone P. (1992) - *Analisi strutturale di un settore della catena dei monti Ausoni - Aurunci (Lazio, Italia centrale).*Boll. Soc. Geol. It., **111**, 449-457.

Cinque A. & Romano P. (1990) - *Segnalazione di nuove evidenze di antiche linee di riva in Penisola Sorrentina (Campania)*. Geografia Fisica e Dinamica Quaternaria, **13**, 23-25.

Dai Pra G. (1995) - *Geomorfologia e stratigrafia dei depositi del Pleistocene e dell'Olocene*. In: «Lazio Meridionale - Sintesi delle ricerche geologiche multidisciplinari». ENEA, Dip. Ambiente, 36-50.

Davis B.A.S., Brewer S., Stevenson A.C., Guiot J. & Data Contributors (2003) - *The temperature of Europe during the Holocene reconstructed from pollen data*. Quaternary Science Reviews, **22**, 1701-1716.

De Pippo T., Donadio C. & Sgrosso A. (1998) - *Geomorfologia sottomarina di una settore della Penisola Sorrentina (Campania)*. Geogr. Fis. Din. Quat., **21**, 103-110.

De Pippo T., Donadio C., Miele P. & Valente A. (2007) - *Morphological evidence for late Quaternary tectonic activity along the coast of Gaeta (central Italy)*. Geogr. Fis. Din. Quat., **30**, 43-53.

De Riso R. (1964) - *Osservazioni geologiche sui monti di Gaeta*. Mem. e Note Ist. Geol. Appl. Napoli, **9**, 5-21.

Esposito C., Filocamo F., Marciano R., Romano P., Santangelo N., Scarmiglia F. & Tuccinei P. (2003) - *Late Quaternary shorelines in southern Cilento (Mt. Bulgheria): morphostratigraphy and chronology.* Il Quaternario, **16** (1), 3-14.

Ferranti L., Antonioli F., Mauz B., Amorosi A., Dai Pra G., Mastronuzzi G., Monaco C., Orrù P., Pappalardo M., Radtke U., Renda P., Romano P., Sansò P. & Verrubbi V. (2006) - *Markers of the last interglacial sea-level high stand along the coast of Italy: Tectonic implications*. Quaternary International, **145-146**, 30-54.

Gliozzi E. & Mazzini I. (1998) - *Palaeoenvironmental analysis of the 250.000-year sediment core of Valle di Castiglione (Latium, Italy) using ostracods.* Bull. Centre Rech. Elf Explor. Mem., **20**, 69-81.

Hartmann G. & Hiller D. (1977) - *Beitrag zur Kenntnis der Ostracodenfauna des Harzes und seines nörd-*

lichen Vorlandes (unter besonderer Berücksichtigung der Männches von Candona candida). Jahre Naturwissenschaftlicher Verein Goslar, **125**, 99-116.

Hearty P.J. & Dai Pra G. (1986a) - *Aminostratigraphy of Quaternary marine deposits in the Lazio Region of Central Italy.* Zeit. Geomorph. N. F., **62**, 131-140.

Hearty P.J. (1986) - *An inventory of last interglacial (s.l.) age deposits from the Mediterranean basin: a study of isoleucine epimerization and U-series dating*. Zeit. Geomorph. N. F., Suppl. Bd., **62,** 51-69.

Hearty P.J., Miller G.H., Stearns C.E. & Szabo B.J. (1986b) - *Aminostratigraphy of the Quaternary shorelines in the Mediterranean basin*. Geol. Soc. Am. Bull., **97**, 850-858.

Heim J. (1970) - *Les relations entre les spectres polliniques récents et la végétation actuelle en Europe occidentale.* Mem. Soc. Roy. Belg., **4**, 1-181.

Hiller D. (1972) - *Unterschungen zur Biologie und zur Ökologie limnischer Ostracoden aus der Umgebung von Hamburg*. Archiv für Hydrobiologie, Supplement-Band, **40** (4), 400-497.

Lambeck K., Antonioli F., Purcell A. & Silenzi S. (2004a) - *Sea-level change along the Italian coast for the past 10,000 yr*. Quaternary Science Reviews, **23**, 1567-1598.

Lambeck K., Anzidei M., Antonioli F., Benini A. & Esposito E. (2004b) - *Sea level in Roman time in the Central Mediterranean and implication for recent change.* Earth and Planetary Science Letters, **224**, 563-575.

Magny M., Bégeot C., Guiot J. & Peyron O. (2003) - *Contrasting patterns of hydrological changes in Europe in response to Holocene climate cooling phases.* Quaternary Science Reviews, **22**, 1589-1596.

Meisch C. (2000) - *Freshwater Ostracoda of Western and Central Europe*, J. Schwoerbel & P. Zwick (eds.), Spektrum Adademischer Verlag, Heidelberg, Germany, **8/3**, 522 pp.

Miele P. (2003) - *Relazione tra linee di riva e tettonica durante il Quaternario nel tratto di costa tra Marina di Minturno e Gaeta (Lazio meridionale).* Tesi di dottorato di ricerca in Geol. del Sedim., Dip. di Scienze della Terra, Univ. degli Studi di Napoli Federico II, Napoli, 219 pp.

Ozer A., Demoulin A. & Dai Pra G. (1987) - *Les indices morphologiques témoins de la stabilité tectonique de la bordure litorale du Lazio méridional (Italie).* Zeit. Geomorph. N. F., Suppl., **63**, 103-117.

Pedrotti F. & Gafta D. (1996) - *Ecologia delle foreste ripariali e paludose dell'Italia*. L'uomo e l'ambiente, Università degli Studi di Camerino, Camerino, Italy, **23**, 162 pp.

Pignatti S. (1982) - *Flora d'Italia*. Ed. Agricole, Bologna, vol. III, 451-620.

Polunin O. & Walters M. (1987) - *Guida alle vegetazioni d'Europa*. Zanichelli ed., Bologna, 232 pp.

Ravazzi (2003) - *An overview of the Quaternary continental stratigraphic units based on biological and climatic events in Italy*. Il Quaternario, **16 bis**, 11-18.

Reimer P.J., Baillie M.G.L., Bard E., Bayliss A., Beck J.W., Blackwell P.G., Buck C.E., Burr G.S., Cutler K.B., Damon P.E., Edwards R.L., Fairbanks R.G., Friedrich M., Guilderson T.P., Herring C., Hughen K.A., Kromer B., McCormac F.G., Manning S.W., Ramsey C.B., Reimer R.W., Remmele S., Southon J.R., Stuiver M., Talamo S., Taylor F.W., van der Plicht J., & Weyhenmeyer C.E. (2004) - *IntCal04 Terrestrial radiocarbon age calibration, 0-26 cal kyr BP*. Radiocarbon, **46** (3), 1029-1058.

Segre A.G. (1949) - *Tracce di morfologia subaerea sul fondo marino litoraneo del Lazio meridionale*. Historia naturalis, anno III, fasc. 1, 1-3.

Servizio Geologico d'Italia (1968) - *Foglio 171 - Gaeta, Carta Geologica d'Italia, II ed., 1:100.000.*

Sevink J., Remmelzwaal A. & Spaargaren O.C. (1984) - *The soils of southern Lazio and adjacent Campania*. Fys. Geogr. Bodemk. Lab., Universiteit van Amsterdam, Publ. nr. 38, 143 pp.

Stanisci A., Presti G. & Blasi C. (1998) - *I boschi igrofili del Parco Nazionale del Circeo (Italia centrale).* Ecologia Mediterranea, **24**, 73-88.

Stuiver M. & Reimer P.J. (1993) - *Extended ^{14}C data base and revised CALIB 3.0 ^{14}C Age calibration program. Radiocarbon*, **35** (1), 215-230.

Terral J.F. & Mengual X. (1999) - *Reconstruction of Holocene climate in southern France and eastern Spain using quantitative anatomy of olive wood and arcaeological charcoal*. Palaeogeography, Palaeoclimatology, Palaeoecology, **153**, 71-92.

Valente A. (1999) - *Aspetti geologici e geomorfologici del Parco Regionale di Monte Orlando (Lazio meridionale , Italia).* Mem. Descr. Carta Geol. d'It., **54**, 101-110.

Vesper B. (1975) - *Ein Beitrag zur Ostracodenfauna Schlleswig-Holsteins*. Mitteilungen aus dem hamburgischen zoologischen Museum und Institut, **72**, 97-108.

Ms. ricevuto il 30 maggio 2007
Testo definitivo ricevuto il 3 settembre 2007

Ms. received: May 30, 2007
Final text received: September 3 , 2007