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NEW DATA ON THE EVOLUTION OF THE SELE RIVER COASTAL PLAIN (SOUTHERN ITALY) DURING THE HOLOCENE

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Abstract - New data on the evolution of the Sele River coastal plain (Southern Italy) during the Holocene. - In order to reconstruct the evolution of the Sele River coastal plain beginning with the Last Postglacial transgression, its outermost strip (limited inland by remnants of a Last Interglacial coastal ridge) was geomorphologically and geologically surveyed. Surface data were integrated with those coming from three proposedly drilled bore-holes which allowed detailed litho-stratigraphic observations, ostracod and pollen analyses and C14 datings. Furthermore, a great number of pre-existing well logs and the results of 15 new vertical electrical soundings were considered to depict the three-dimensional stratigraphic architecture of the area. The Holocene portion of the plain includes a composite sandy ridge which is partly exposed along the present coast and disappears inland under a muddy, substantially flat depression that reaches up to the base of the Tyrrhenian coastal ridges. The stratigraphic, palaeo-environmental and chronological data obtained allow to interpret the present setting of the Sele Plain's outer strip as the result of a barrier-lagoon system that migrated alternatively landward and seaward during the Holocene. After being exposed to subaerial conditions during the Last Glacial regression with a seaward progradation of the shoreline up to 15 km, the study area gradually entered brackish water conditions at the beginning of the Holocene. Shortly before 8,400 yrs BP the coastline experienced its maximum retrogradation, reaching 1.6 km inland from the present shore. Subsequently, the barrier-lagoon system entered a period of prevailing progradation. The inversion of tendency, from retrogradational to progradational, most probably can be ascribed to a decline of the rate of sea level rise under the threshold of balance with the progradation due to fluvial sedimentation. The progradation was interrupted by at least three minor transgressive phases occurred between 8,400 and 2,000 yrs BP. About 5,500 years BP the lagoon was largely gained by palustrine conditions which persisted partially until very recent times.

Riassunto - Nuovi dati sulla evoluzione della piana costiera del fiume Sele (Italia meridionale) durante l'Olocene. – Al fine di indagarne l'evoluzione subita a partire dall'ultima trasgressione post-glaciale è stato effettuato il rilevamento geologico e geomorfologico della fascia più esterna della piana costiera del F. Sele, delimitata internamente da relitti dei paleo-cordoni costieri dell'Ultimo Interglaciale. I dati di superficie sono stati integrati da quelli ricavati attraverso tre sondaggi appositamente effettuati per condurre osservazioni litostratigrafiche, analisi di pollini e ostracofaune, nonché datazioni C14. Sono stati utilizzati, inoltre, un grande numero di sondaggi pre-esistenti ed i risultati di 15 nuovi sondaggi elettrici verticali per delineare con il massimo dettaglio l'assetto stratigrafico dell'area. La porzione olocenica della piana comprende un cordone sabbioso composito, in parte esposto lungo la presente costa e passante verso l'interno ad una depressione piatta che si estende fino alla base del cordone tirreniano. I nuovi dati acquisiti consentono di interpretare la porzione esterna della Piana del Sele come il risultato di un sistema di barriera-laguna che migrava alternativamente verso terra e verso mare durante l'Olocene. Dopo essere stata esposta a condizioni subaeree durante la regressione del mare nel corso dell'ultimo Pleniglaciale (con la costa che progradava di circa 15 km) l'area esaminata mostra i primi segni di sommersione all'inizio dell'Olocene. Poco prima di 8.400 anni BP si registra il massimo dell'ingressione, con una linea di costa posta circa 1.6 km più all'interno di oggi. A partire da questo momento il sistema di barriera-laguna comincia ad essere interessato prevalentemente da progradazione. Questa inversione di tendenza va collegata con ogni probabilità ad una diminuzione del tasso di risalita del livello del mare in relazione al tasso di sedimentazione fluviale. La progradazione viene interrotta da almeno tre fasi trasgressive minori tra 8.400 e 2.000 anni BP. Intorno ai 5.500 anni BP, la laguna si è trasformata largamente in una palude che persiste in buona parte fino a tempi recentissimi. Circa la natura pulsante della progradazione, i dati finora acquisiti non permettono di chiarire se esso sia dipeso da cause climatiche e glacio-eustatiche (le ancora discusse fluttuazioni minori del livello del mare e del tasso di risalita nel corso della trasgressione versiliana) o, almeno parte, da locali movimenti tettonici. L'ipotesi che la Piana del Sele sia stata tettonicamente instabile durante l'Olocene viene fortemente suggerita sia dalle quote elevate cui si rinvengono le spiagge di circa 6000 e 2000 anni fa (fino a + 1 e + 3.2 m rispettivamente), sia dall'altitudine troppo elevata, se confrontata con quanto noto in letteratura, dei depositi lagunari datati a 8.400 B.P.

Parole chiave: Piana costiera, evoluzione geomorfologica, paleoambiente, Olocene, Italia meridionale
Key words: coastal plain, geomorphological evolution, paleoenvironment, Holocene, South Italy

* Geomorphological and stratigraphic analysis, data synthesis and interpretation by Aldo Cinque and Carmen Rosskopf. Analyses of ostracofauna by Diana Barra. Pollen analysis by Elda Russo Ermolli. Radiocarbon measurements and dating by Gilberto Calderoni. Computer elaboration of graphics, geoelectrical investigations and relative data interpretation by Pantaleone De Vita

1. INTRODUCTION AND GEOLOGICAL SETTING

The Sele Plain comes from the aggradation of a Plio-Quaternary tectonic depression located along the rifted inner margin of the Southern Apennine Chain. It is about 400 kmq wide and owes a triangular plan outline, which is defined seawards by a straight sandy coast stretching between the towns of Salerno and Agropoli (Fig. 1). The plain is closed landwards by mountains that are between 1000 and 1600 metres high (Lattari and Picentini Mts. to the N and NW; Alburni, Soprano-Sottano and Cilento Mts. to the SE).

The boundaries of the plain are defined by NW-SE and NE-SW trending scarps which can be referred to normal and strike-slip faults active during the Early and Middle Pleistocene. These fault scarps are responsible of the re-shaping of a more ancient tectonic depression which is most probably Pliocene in age. Their prosecutions along the structural promontories that close the Salerno Gulf (namely the Sorrentine and Cilento peninsulas) define altogether an asymmetrical structural depression with maximum depth along its north-western margins (Ippolito *et al.*, 1973; Budillon *et al.*, 1994).

The most internal portion of this structural gulf (i.e. the Sele Plain) was gained definitively by continental conditions thanks to the huge phases of clastic sedimentary aggradation (up to 2000 metres) which accompanied the Quaternary subsidence events. The innermost portion of the coastal depression is occupied by hills where the proximal facies of the Lower Pleistocene part of the infill (the Eboli Conglomerates) are uplifted up to 400 metres a.s.l. (Cinque *et al.*, 1988). At the base of these block-faulted hills, the terraces formed by the Middle Pleistocene Persano formation occur at elevations ranging between 100 and 30 metrers (Amato *et al.*, 1991). Further seawards, there is the strip of plain that formed during the Last Interglacial (Tyrrhenian Stage). It forms terraces between about 25 and 15 metres a.s.l. and shows three orders of beach-dune ridges that interfinger at their back with lagoonal and fluvio-palustrine deposits. The present elevation of the Tyrrhenian complex proves that the plain has moderately (ca. 20 metres as a maximum) been uplifted since the Last Interglacial (Amato *et al.*, 1991; Budillon *et al.*, 1994). Only the youngest (and most external) of the Tyrrhenian coastal ridges still has a good morphological evidence, whereas the other two ridges appear largely flattened by late Tyrrhenian alluvial and travertine covers (Brancaccio *et al.*, 1988; Russo & Belluomini, 1992). Between the outermost Tyrrhenian coastal ridge and the present shoreline a last strip of plain occurs, which is not more than 5 metres above sea level elevated and reaches a maximum width of 3 km in the vicinity of the Sele River mouth. This strip, which was accreted during the Holocene, is the subject of the present paper.

All the studies on the Sele Plain (see also Baggioni, 1975; Cinque, 1986; Brancaccio *et al.*, 1986, 1987, 1991, 1995; Lippmann-Provansal, 1987; Russo, 1990) allowed for a rather detailed definition of the evolution of the plain from the Early Pleistocene to the first part of the Upper Pleistocene. On the contrary, data referring to its more recent evolution are still scarce and controversial. Brancaccio *et al.* (1988) in a study focused on the southern portion of the Sele River coastal plain distinguished and dated two Holocene beach-dune

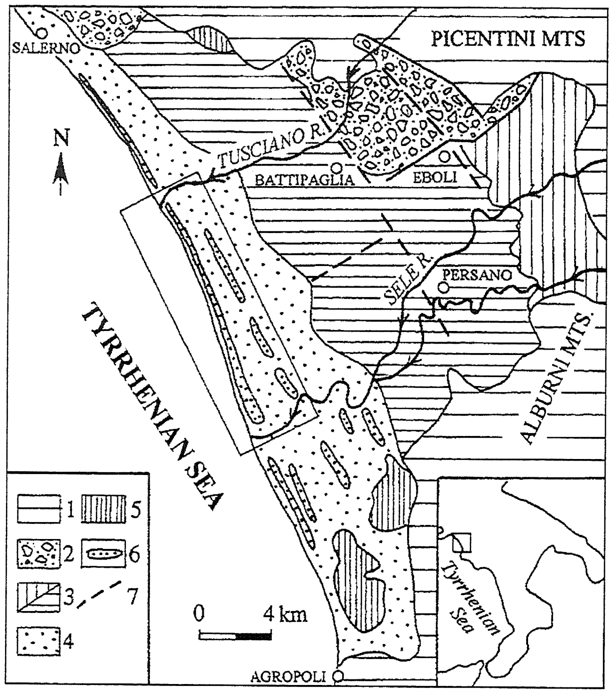


Fig. 1 - Geological sketch map of the Sele Plain (from Brancaccio *et al.*, 1995, modified). 1) Pre-Quaternary substratum; 2) Eboli Conglomerats (Early Pleistocene); 3) Persano Complex (Middle Pleistocene): a) Alluvial fan facies, b) lagoonal facies; 4) Late Pleistocene-Holocene transgressive-regressive sequences; 5) Travertines (Late Pleistocene-Holocene); 6) Tyrrhenian and Holocene coastal ridges; 7) Fault. The squared area is represented in Fig. 2.

Schema geologico della Piana del Sele (da Brancaccio et al., 1995, modificato). 1) Substrato pre-Quaternario; 2) Conglomerati di Eboli (Pleistocene inferiore); 3) Complesso di Persano (Pleistocene medio): a) facies di conoide, b) facies lagunare; 4) Successioni trasgressivo-regressive del Pleistocene superiore-Olocene; 5) Travertini (Pleistocene superiore-Olocene); 6) Cordoni costieri tirreniani ed olocenici; 7) Faglia. Nel riquadro l'area rappresentata in Fig. 2.

ridges, the Laura and Sterpina ridges, with a maximum C14 age of 5330±50 and 2500±70 years BP respectively. According to Guy (1990) the Laura ridge is a composite landform that developed through four distinct growth phases occurred prior to the 8th century BC. According to the same author, the Sterpina ridge system (formed by two dune ridges) postdates the 79 A.D. Vesuvius eruption. For the northern half of the plain, stratigraphic details of the most advanced Holocene beach-dune system (an equivalent of Sterpina ridge on the opposite side of the Sele River) are given in a paper by Rosskopf *et al.* (1995) where two generations of beach deposits are recognized beneath a thin eolian cover: the two prograding sets of beachface deposits are separated by the products of the 79 A. D. Vesuvius eruption and reach a maximum elevation of 3.2 m a.s.l. The whole succession is disturbed by liquefaction structures that are likely to be referred to a strong seismic event occurred in the region of the Sele plain-Salerno gulf during historical times.

Concerning the recent shoreline fluctuations Cocco & De Magistris (1988) and Cocco *et al.* (1990, 1992) indicated a rather constant progradation of the coast from the 6th century BC onwards, followed by a clear tendency to retreat during the last 40 years. Such retreat is at present occuring especially on the coast stretch between Tusciano and Sele river.

It is clear from the above short report, the authors that studied the Holocene coastal changes of the Sele plain focused their observations to events occurred in the second half of the Holocene, which are better evidenced by surface geology and morphology of the outermost strip of the plain. Much less is indeed known about the origin and evolution of the 1.3 to 1.9 km wide flat depression separating the Late Holocene coastal ridges from the Late Tyrrhenian one (dated with the isoleucine epimerization method to 75,000 years BP; Brancaccio *et al.*, 1988). On the surface, this depression is extensively occupied by recent palustrine deposits that may have masked beach deposits and landforms of shorelines older than the ones suggested by the still prominent ridges of the outer zone (Fig. 2). A recent paper by Barra *et al.* (1996) gives original subsurface data for this depression. These authors studied an area which is very close to the Sele river mouth and interpret the Holocene succession of the flat back-barrier as entirely composed of lagoonal and fluvio-palustrine sediments deposited between 10,000 and 6,000 yrs BP. On this basis, the authors conclude that the Holocene coast line never reached more inland than the inner rim of the outcropping coastal ridge system. The fact that the outer flank of the Late Tyrrhenian ridge appears in many places so steep as to suggest a reworking by a Holocene sea cliff might however indicate that the evolution as hypothesized by Barra *et al.* (1996) is valid only for the zone near the Sele River mouth.

Other uncertainties regard the uplift occurred after the sedimentation of the Tyrrhenian formations: was it steady or occurred it as various impulses? Did it continue also during the Holocene or not? According to Brancaccio *et al.* (1988) who studied the Holocene beach-dune system outcropping south to the Sele river, the plain can be considered stable at least for the last 5,000 years on the basis of the maximum height of 1.5 metres a.s.l. reached by the beach deposits of the Laura ridge, dated to 5,330± 50 years BP. On similar assumptions seem to be based the reconstruction of Holocene transgression onto the Sele Plain by Barra et al. (1996). Some doubts concerning the vertical stability of the plain near Paestum are expressed by Guy (1990) who noted the excessive height (4 metres a.s.l.) of the Holocene palustrine sediments found in that area.

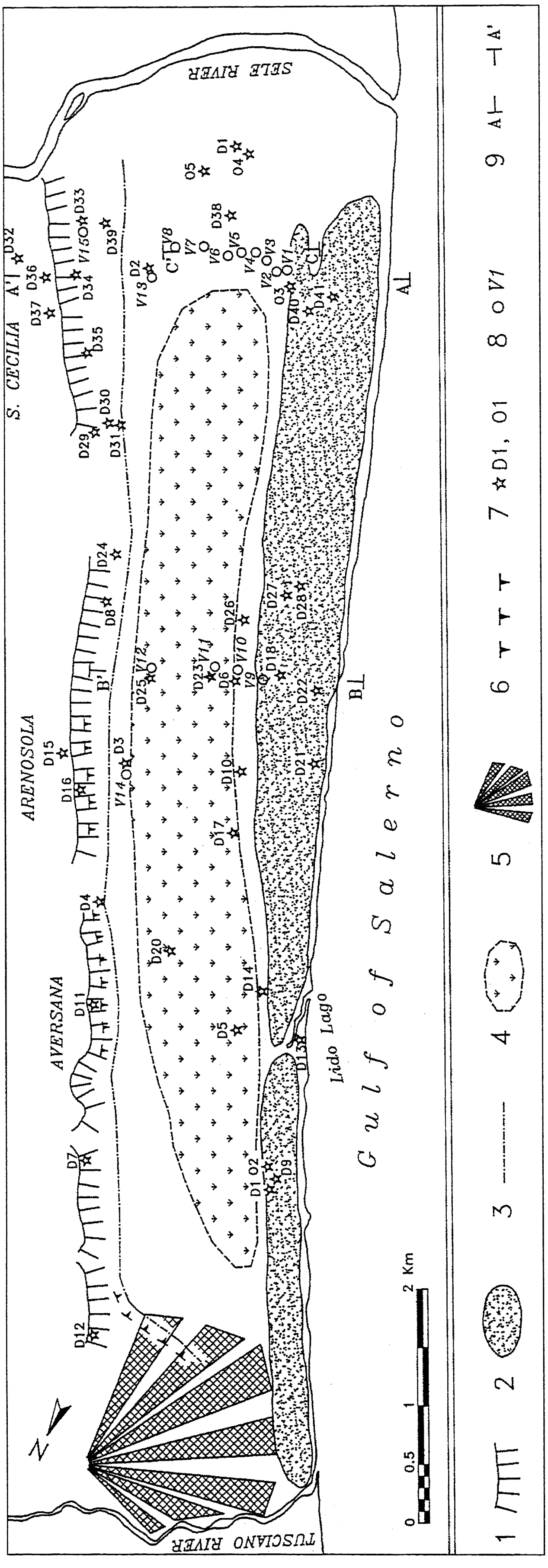


Fig. 2 - Geomorphological scheme of the study area. 1) External slope of the Tyrrhenian ridge system; 2) Holocene ridge system; 3) Inner limit of the Holocene lagoon; 4) Estimated limits of the sector interested by reclamation (filling up); 5) alluvial fan morphology; 6) hypothesized erosional scarp features; 7) location of drillings and outcrops; 8) location of vertical electrical soundings; 9) tracing of cross-section.

Schema geomorfologico dell'area di studio. 1) pendio esterno del cordone tirreniano; 2) complesso dunare olocenico; 3) limite interno della laguna olocenica; 4) limiti presunti del settore interessato da lavori di bonifica idraulica (colmamento); 5) morfologia da conoide alluvionale; 6) tracce di scarpata di erosione ipotizzate; 7) ubicazione di sondaggi e affioramenti; 8) ubicazione di sondaggi elettrici verticali; 9) traccia di sezione.

Aim of the present paper is to present new stratigraphic, palaeoenvironmental and chronological data about the evolution of the northern portion of the Sele plain beginning with the last Post-glacial (i.e. Versilian) transgression. The study was also aimed to reconstruct the landscape of the area at the time of the first human settlements on the plain, particularly those of archaic and classical age(1) .

2. GEOMORPHOLOGY OF THE STUDY AREA

The investigated coastal sector stretches along the eastern side of the Southern Tyrrhenian Sea, which is a microtidal basin with daily excursions of generally 30-40 cm. The coastal dynamics is dominated by the wave action, with western winds being the most effective ones.

The study area was studied from the geomorphological point of view with field surveys and interpretation of 1:5,000 topographic maps, large scale stereo pairs and ancient geographic maps (from the map of Principato Citra olim Picentia - Magini atlas, 1,606 onwards). Maps and written reports describing the reclamation undertaken in the last 150 years (Bruno & Lembo, 1982) were particularly useful in reconstructing the natural conditions of the plain before the Man intervention. From the geomorphological point of view the study area can be subdivided as follows:

a) **The coastal ridge system**

This land unit covers a strip parallel to the coast, immediately on the back of the present beach. Its width increases from 300 metres near the Tusciano river mouth to approximately 900 metres near the Sele river mouth. It is characterized by heights ranging between two and six metres a.s.l. and is formed by a number of coalescent dune ridges.

Starting from 1938, the coastal ridge system has been subjected to extensive operations of ground levelling in order to facilitate both afforestation with pine trees (*Pinus domesticus*) interesting its most external portion, and grazing and agricultural practices in its internal part. Furthermore, the sand of this composite ridge was locally quarried to feed the eroding beach. (Cocco *et al.*, 1971).

b) **The back- ridge flat area**

This sector is limited landwards by the external slope of the Late Tyrrhenian beach dune ridge (turned into fragments by fluvial dissection) and seawards by the afore described coastal ridge system. It is characterized by heights ranging between 1.0 (outer portion) and 4.0 m a.s.l. (inner rim) and an almost flat topography. In origin, this sector was occupied by large marshy and lacustrine depressions. The area interested subsequently by reclamation projects extended approximately 10 km in length and 1 km in width (Fig. 2). The result of the filling up was an extensive levelling and rise of the original morphology (generally a height of 1.50 m a.s.l. was reached).

c) **The external slope of the Tyrrhenian rigde complex**

This morphological feature is a slope (generally with a slightly convex-concave cross profile and gradients below 2.0 %) that rises from the above mentioned flat area up to the top of the most external Tyrrhenian ridge (12 to 14 m high).

In some places (e.g. around the village of Arenosola) the slope descending from the Tyrrhenian ridge joins Morphological unit b) with a very marked knick-point. Moreover it shows a polycyclical cross profile with the upper portion having a lower gradient than the basal one. Also near Aversana the slope limiting the Tyrrhenian ridge shows a similar polycyclical profile.

d) **Fluvial features**

The Sele river has incised for 2-3 metres the surface of the above mentioned back-ridge flat area which is protected from flooding by artificial *levées* flanking the river channel. Minor watercourses, which dissect the Tyrrhenian ridge, flow in very open V-shaped valleys, the lower reaches of which are penetrated by embayments of the back-ridge flat area. Before the reclamation of the area, these ephemeral courses feeded several coastal lakes and swamps; nowadays their discharge is conducted to the sea or the Sele river by artificial channels.

No true deltaic protuberance can be recognized at the mouth of Sele and Tusciano rivers. Nevertheless the general course of the shoreline between Salerno and Agropoli shows a modest convex break at the Sele river mouth. This evidence, coupled with the fact that also the width of the coastal ridge system tends to slightly increase approaching the Sele river mouth, demonstrate that the fluvial clastic inputs have been well distributed along the whole front of the plain, but not so perfectly as to totally equalize the local rates of progradation.

Inside the back-ridge flat area, the portion located near the Tusciano river is characterized by a gentle alluvial fan morphology which discloses signs of pclyciclical growth. Particularly, a slope (wave-cut cliff?) limiting a terraced level at approximately six meters a.s.l. can be recognized on the fan.

Among various models of accretionary coasts given in the literature (Reineck & Singh, 1973; Ricci Lucchi, 1980; Galloway & Hobday, 1983 and references therein) that of a barrier-lagoon-system seems to be the most appropriate one for the case of the Holocene plain of the Sele river. This attribution should be verified by subsurface data.

3. GEOLOGICAL DATA

Subsurface stratigraphic data were collected to integrate the scarce indication obtained from outcrops (mainly represented by shallow artificial cuts). The most detailed litho-stratigraphic data were obtained from three cores (D1-D3) proposedly drilled, which permitted also a careful sampling for paleoenvironmental analyses and C14 dating. Furthermore, more than 60 logs referring to drillings made in the recent past for geotechnical and hydrogeological purposes were analysed. Some of

(1) Researches were started in collaboration with the *École Française de Rome*. The results of the archaeological investigations, still in a preliminary phase and focused to settlements of Villanovan and Greek age, are not reported here.

these were made during the period of our field work (D14, D33, D34, D35 and D40, Fig. 2) allowing us to make more detailed observations and to sample the most interesting stratigraphic intervals. 15 vertical electrical soundings (V1-V15) based on the Schlumberger configuration were made and utilised to integrate litho-stratigraphic data. The measured values of apparent resistivity (due to thickness and real resistivity of the geological strata interested by the electrical field) allowed the elaboration of electro-stratigraphic sequences. The inversion of the resistivity data is based on the modified "Marquard-Levenberg" algoritm (Koefoed, 1979) and controlled by litho-stratigraphic data.

Paleoenvironmental interpretations were based on analyses of composition, sedimentary features and fossil content (i.e. macrofossils, ostracods and pollens) of sampled stratigraphic intervals. A semi-quantitative analysis of ostracofauna was carried out on 36 samples. The 35 samples drawn from drills D1, D2 and D3 permitted the identification of 33 species which, on the basis of their tolerance to variable salinity conditions, as inferred from their present distribution (Müller, 1894; Klie, 1938; Wagner, 1957; Barbeito & Gonzales, 1971; Uffenorde, 1972; Bonaduce et al., 1973-1974, 1976; Ghetti & McKenzie, 1981; Colizza *et al.*, 1987; Neale J. V., 1988), have been attributed to three groups (see Tab. 1). Analysis of pollen content was made on 27 samples; only five samples resulted rich enough to permit a quantitative analysis.

Finally, many radiocarbon measurements were carried out on a variety of organic remnants including well preserved and/or highly humified peat, bits of wood and organic matter at the macromolecular state. The samples were submitted to a preliminary chemical treatment and their residues were then converted to benzene. Measurements were based on liquid scintillation counting (LSC) technique followed by a statistical evaluation and quality control (Calderoni & Venanzi, 1989; Calderoni & Petrone, 1992).

A synthetic view of litho-stratigraphic, paleoenvironmental and chronological data obtained from drills D1, D2 and D3 is given in Fig. 3. The litho-stratigraphic features of the most significant logs (D4 to D41) accompanied by the paleoenvironmental interpretation of the distinguished sedimentary intervals are synthesized in Fig. 4. Fig. 5 shows the results of the electrical soundings made in correspondence of D2, D3 and D33 to obtain a stratigraphic control (Fig. 5 A) and along two major alignments (Fig. 5 B, tracing B-B' and C-C' in Fig. 2). Finally, Tab. 2 gives measured conventional and calibrated radiocarbon ages.

4. RECONSTRUCTION OF HOLOCENE EVENTS

On the basis of the stratigraphic, paleoenvironmental and chronological data synthesized in the afore mentioned figures and tables some cross-sections (Fig. 6) are discussed in this paragraph to reconstruct the evolution of the study area beginning with the last Post-glacial transgression.

Collected stratigraphic data, being concentrated onland and having reached the pre-Holocene substratum only in a few points, are not suitable to reconstruct

Tab. 1 - List of identified ostracod species. Group A - species living in fresh- to oligohaline waters (salinity ranging between ± 0.5 to ±5 ‰), group B - brackish water (euryhaline) species (salinity between ±5 and ±30 ‰), group C - marine species (salinity between ±30 and ± 40 ‰).

Elenco delle specie di ostracodi rinvenute. Gruppo A - specie viventi in acque dolci fino ad oligoaline (salinità tra ± 0.5 e ±5 ‰), gruppo B - specie salmastre (salinità tra ±5 e ±30 ‰), gruppo C - specie marine (salinità tra ±30 e ± 40 ‰).

GROUP A - FRESHWATER TO OLIGOHALINE SPECIES
Candona angulata (G. W. Müller, 1900)
Candona (F.) fabaeformis (Fischer, 1854)
Candona neglecta (Sars, 1887)
Cyclocypris ovum (Jurine, 1820)
Cypria ophtalmica (Jurine, 1820)
Cypris pubera (O. F. Müller, 1776)
Darwinula stevensoni (Brady & Robertson, 1870)
Herpetocypris reptans (Baird, 1835)
Heterocypris salina (Brady, 1868)
Ilyocypris gibba (Ramdohr, 1808)
Limnocythere inopinata (Baird, 1843)
Pseudocandona aff. P. marchica (Hartwig, 1899)
Pseudocandona sarsi (Hartwig, 1899)
Pseudocandona sucki (Hartwig, 1899)
GROUP B - EURYHALINE SPECIES
Aurila arborescens (Brady, 1865)
Cyprideis torosa (Jones, 1850)
Loxoconcha stellifera (G.W. Müller, 1894)
Tyrrhenocythere amnicola (Sars, 1888)
Xestolebers aurantia (Baird, 1838)
GROUP C - MARINE SPECIES
ACallistocythere sp.
Carinocythereis whitei (Baird, 1850)
Cytheretta subradiosa (Römer, 1838)
Leptocythere levis (G. W. Müller, 1894)
Leptocythere ramosa (Rome, 1942)
Neocytherideis fasciata (Brady & Robertson, 1874)
Paracytheridea sp.
Paracytherois sp.
Pontocythere turbida (G.W. Müller, 1894)
Procytherideis subspiralis (Brady et alii, 1874)
Semicytherura aff. S. rarecostata (Bonaduce et al., 1976)
Semicytherura incongruens (G. W. Müller, 1894)
Semicytherura sulcata (G. W. Müller, 1894)
Urocythereis sp.
Xestoleberis communis (G. W. Müller, 1894)

Tab. 2 - Conventional and calibrated radiocarbon ages measured on samples from cores D2 and D3. The calculated conventional C14 ages (Stuiver & Polach, 1977) are reported as yr BP and with an overall uncertainty of ±1σ. The calibrated (= calendar) ages, expressed in terms of yr BP intervals with ±1σ of uncertainty, were calculated by means of the data set after Stuiver & Reimer (1993).

Età radiocarbonio convenzionali e rispettivi intervalli di calibrazione per i campioni delle carote D2 e D3. Le età radiocarbonio convenzionali calcolate (Stuiver & Polach, 1977) sono riportate in yr BP al livello di incertezza di ±1σ. Le età calibrate (= calendario), espresse in termini di intervalli di yr BP al livello di incertezza di ±1σ sono state calcolate usando il programma elaborato da Stuiver & Reimer (1993).

Sample	Depth *(metres a.s.l.)*	Radiocarbon age *(yrs BP)*	Calibrated age *(yrs BP)*
Rome-810 (D2)	-1	5535±70	6400÷6285
Rome-815 (D3)	-1.5	1555±60	1520÷1350
Rome-812 (D3)	-3	3400±60	3700÷3570
Rome-814 (D3)	-4	4140±65	4825÷4535
Rome-811 (D3)	-6	3675±65	4090÷3890
Rome-813 (D3)	-6.5	8090±90	9190÷8765
Rome-816 (D3)	-8	8340±80	9435÷9240

the first part of the Postglacial transgression occurred between 15,000 and 10,000 yrs BP. On the contrary, interesting data have been obtained allowing to detail the subsequent phase, largely dominated by a coast progradation.

In a first stratigraphic cross-section (A-A'of Fig. 6) the main sedimentary bodies representing the coastal ridge system, the back-ridge filling and the Tyrrhenian ridge complex respectively are schematically defined.

On top of the Tyrrhenian ridge, the upper portion of the Tyrrhenian sediments is made of low-angled seaward dipping laminae of medium to coarse grained yellow sands (D11, D15, D16, D36, D37, etc, Fig. 4 and 5) rather well cemented for the first meters then getting progressively looser. Marine shells are found between 0 and 3 metres a.s.l. (D36 and D37). The gradual passage to the underlying partially peaty blue clay is locally well proved by an interval of alternating thin layers of yellow sand and blue clay, which reaches a maximum height of about 5-6 metres a.s.l. (D32). The Tyrrhenian beach sands can be followed seawards beneath the back-ridge flat (D8, D29, D30 and D39), where they appear often buried by eolian sands that are correlable with those of Würmian age that crop out on the top of the Tyrrhenian ridge. Locally, the passage from the Würmian to the Tyrrhenian unit is marked by a thin palaeosol (D4).

Further paleoenvironmental indications for some

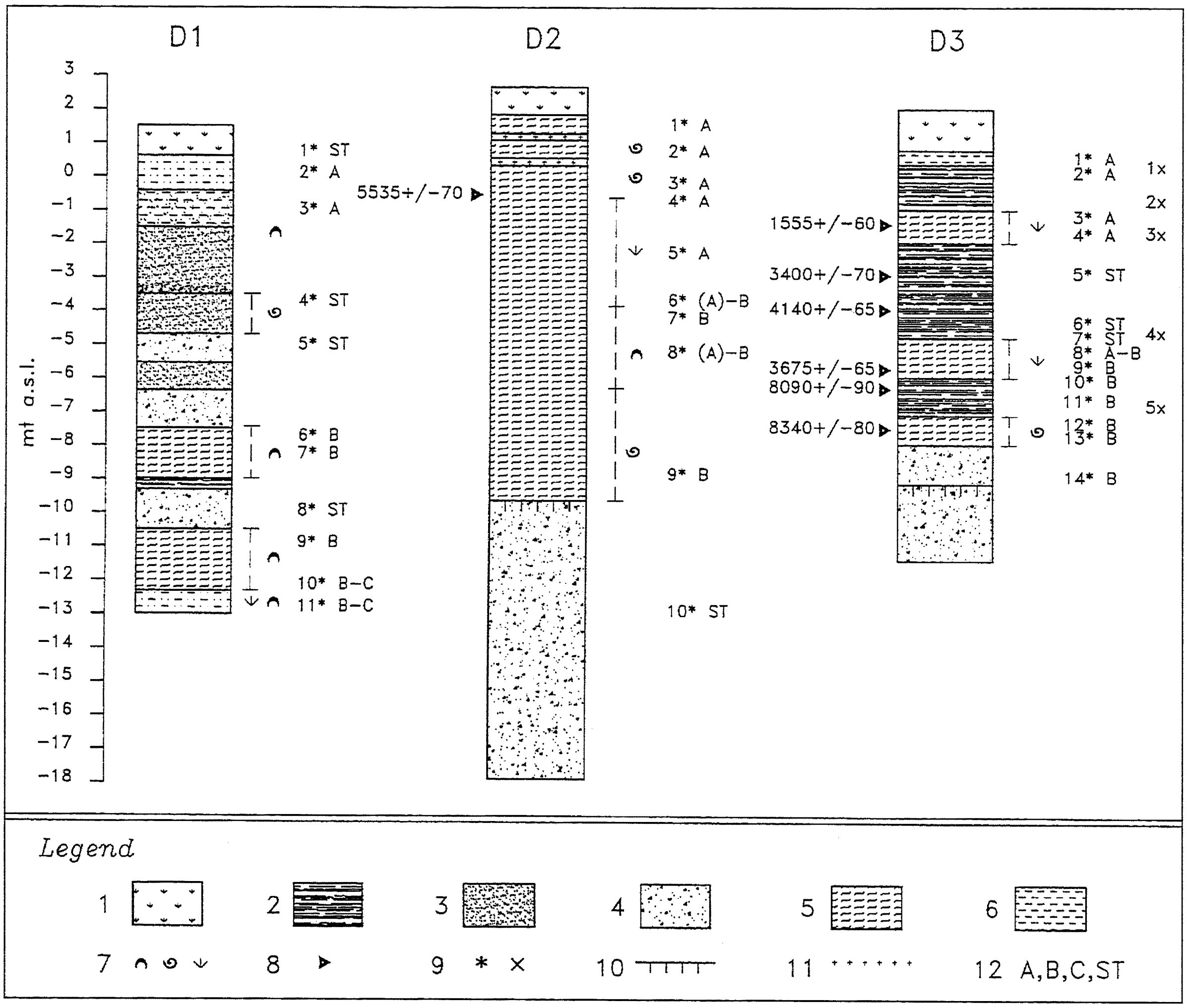


Fig. 3 - Litho-stratigraphic features of cores D1-D3 integrated by chronological and environmental indications. 1) soil; 2) peat; 3) sand; 4) gravel; 5) clay; 6) silt; 7) fossil rich layers containing respectively bivalves, gasteropods and macroscopic plant remains; 8) location of radiocarbon sample and relative age; 9) location of samples analysed respectively for ostracod and pollen content; 10) palaeosoil; 11) pumice layer (re-worked?); 12) stratigraphic interval characterized by the presence of an ostracod assemblage formed pervailingly by species living A) in freshwater to oligohaline waters (salinity between ± 0.5 to ±5 ‰), B) in euryhaline waters (salinity between ±5 to ±30 ‰) and C) in marine waters (salinity between ±30 to ± 40 ‰); ST) steril sample.

Litostratigrafie dei sondaggi D1-D3 corredate delle indicazioni cronologiche e ambientali ottenute per vari intervalli stratigrafici. 1) suolo; 2) torba; 3) sabbia; 4) ghiaia; 5) argilla; 6) limo; 7) livelli fossiliferi contenenti rispettivamente lamellibranchi, gasteropodi e macroresti vegetali; 8) ubicazione di campione prelevato per datazioni C14 e relativa età radiocarbonio; 9) campioni sottoposti rispettivamente ad analisi dell'ostracofauna e pollinica; 10) paleosuolo; 11) livello piroclastico (rimaneggiato?); 12) intervallo stratigrafico caratterizzato dalla presenza di una associazione di ostracodi costituita in prevalenza da specie viventi A) in acque dolci fino ad oligoaline (salinità compresa tra ± 0.5 e ±5 ‰), B) in acque eurialine (salinità compresa tra ±5 to ±30 ‰) e C) in acque marine (salinità compresa tra±30 to ± 40 ‰); ST) campione sterile.

stratigraphic intervals of the Tyrrhenian unit were obtained by analysing the sequence of well D33. The upper portion, composed of fine to medium-grained partially silty sand (with thin layers of minute shell debris emphasising a parallel and nearly horizontal bedding), is most probably to refer to the lower shoreface. Beneath this interval, a thin layer of coarse-grained sand crossed at about 2.7 metres b.s.l., presents an ostracod assemblage including euryhaline *(Cyprideis torosa and Loxoconcha stellifera)* and marine species *(Pontocythere turbida, Semicytherura sulcata, Cytheretta adriatica, C.subradiosa and Urocythereis sp.)*. This association indicates an infralittoral environment of shallow water and a sea floor which lacks any vegetation; it appears contaminated by mesohaline species (young individuals of *Cyprideis torosa and Loxoconcha stellifera*). Finally, the presence of integral, sometimes closed shells of Cardium in the underlying blue clays clearly indicates a lagoonal environment. The incompleteness of this vertical sequence - the lack of beach face deposits is to be noted - seems to indicate the rapidity with which the Tyrrhenian transgression occurred, followed then by accretion in stationary conditions.

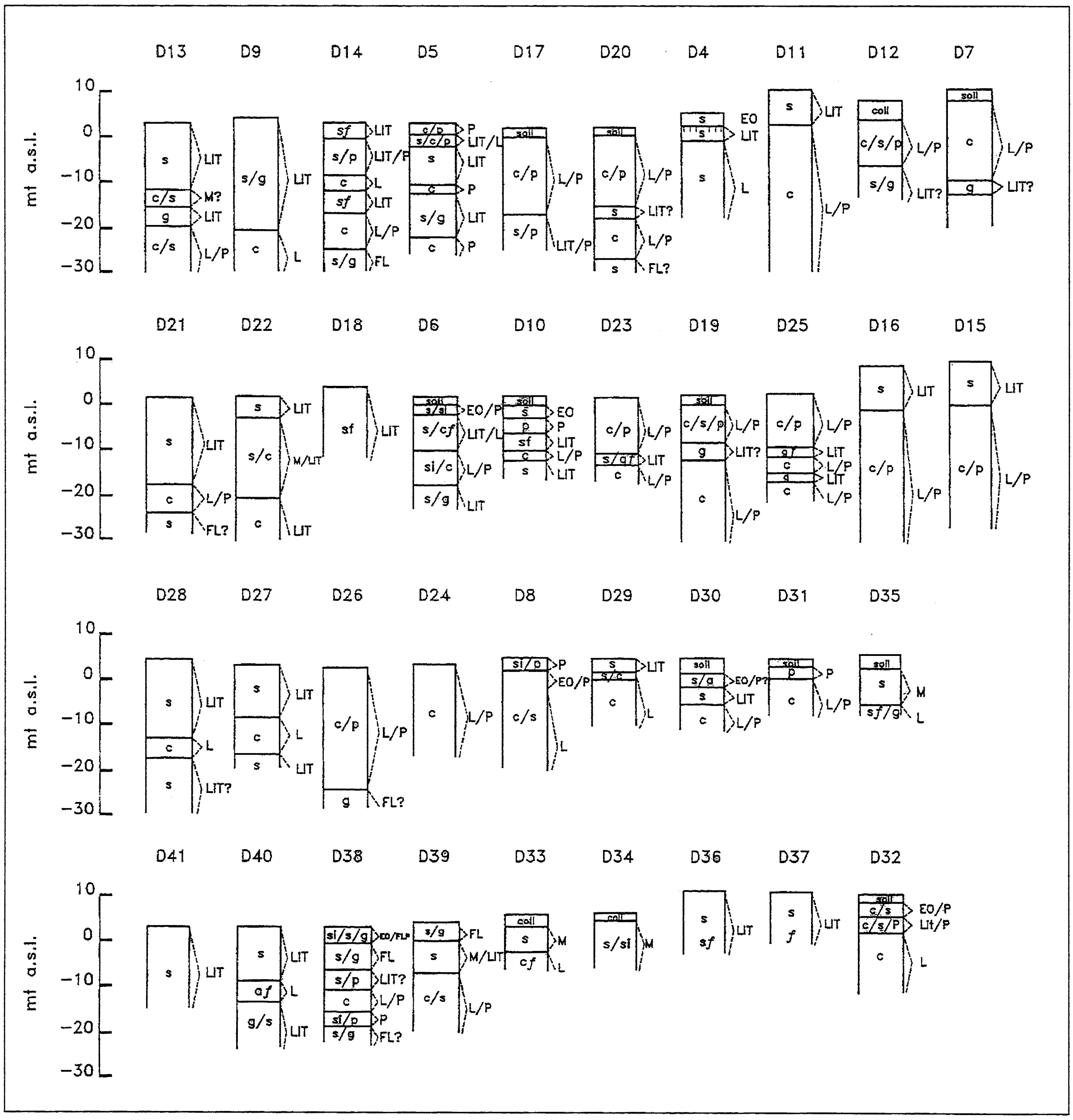
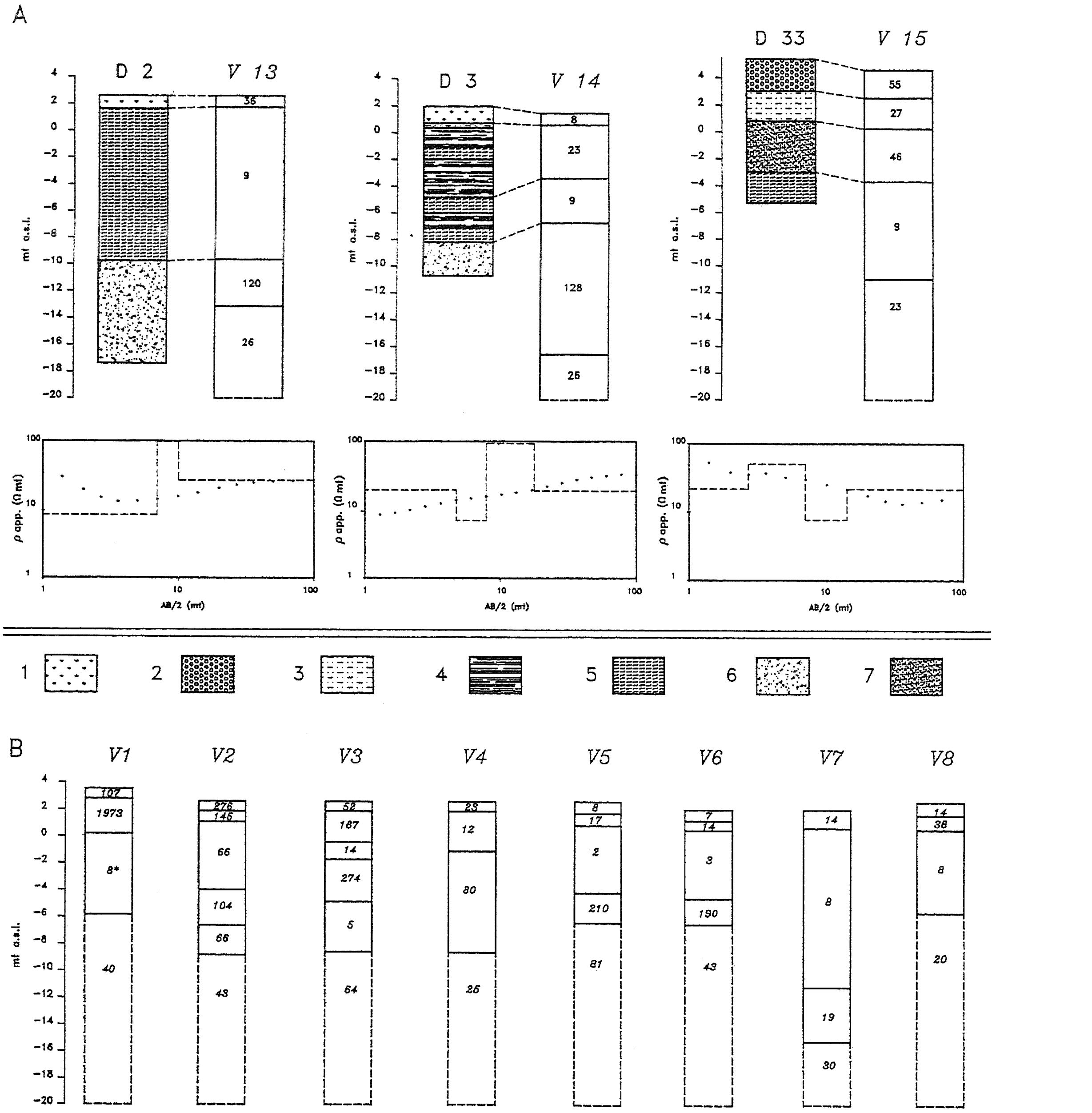


Fig. 4 - Litho-stratigraphy of drillings reported in Fig. 2 and palaeo-environmental interpretation of distinct stratigraphic intervals: s, g, c, si, p = respectively sand, gravel, clay, silt and peat facies; s/g, si/c, etc. = sequence of alternating facies as afore specified; M = shoreface; LIT = foreshore-backshore; EO = eolian, L = lagoonal, P = palustrine, FL = fluvial; *f* = fossiliferous interval;

Litostratigrafie dei sondaggi riportati in Fig. 2. e interpretazione paleo-ambientale degli intervalli stratigrafici distinti: s, g, c, si, p = sabbie, ghiaie, argille, limo e torba; s/g, si/c, ecc. sequenze in cui si alternano le litologie prima specificate; M = infralittorale; LIT = sopra-e mesolittorale; EO = eolico; L = lagunare; P = palustre; FL = fluviale; f = intervallo fossilifero.



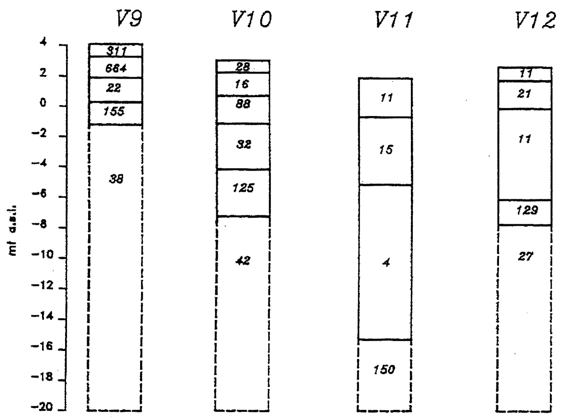


Fig. 5 - Graphics reporting the results of vertical electrical soundings. A) *V13*, *V14*, and *V15* and corresponding litho-stratigraphy of drillings located at a maximum distance of 50 meters respectively. 1) soil; 2) colluvium; 3) sand and silt; 4) peat; 5) clay; 6) sand and gravel 7) gravel. B) electro-stratigraphic sequences of soundings located respectively along tracing C-C' (*V1-V8*) and B-B' (V9-V12) of Fig. 2. *) the extreme low resistivity of third electro-stratum (8 Ωm) in V1 may be attributed to the presence of marine water in the sandy acquifer and/or to the presence of iron-yielding sand (so-called "black sands") found in some boreholes.

*Grafici riportanti i risultati dei sondaggi elettrici verticali eseguiti. A) V13, V14, e V15 e corrispondenti colonne litostratigrafiche relative a sondaggi ubicati rispettivamente ad una distanza massima di 50 m. 1) suolo; 2) colluvium; 3) sabbia e limo; 4) torba; 5) argilla; 6) sabbia e ghiaia; 7) ghiaia. B) Sequenze elettro-stratigrafiche dei sondaggi ubicati rispettivamente lungo la traccia C-C' (V1-V8) e B-B' (V9-V12) di Fig.2. *) il valore estremamente basso del terzo strato elettrico (8 Ωm) di V1 sembra da attribuirsi alla presenza di acque marine nell'acquifero sabbioso e/o alla presenza di sabbie ferrifere (descritte come "sabbie nere") trovate in alcuni sondaggi.*

Seawards, a complex of littoral and back-barrier deposits covers the Tyrrhenian sediments. On the basis of its maximum elevation, this complex (which clearly differs from the Tyrrhenian units for its litho-stratigraphic features) can be referred to the Holocene. In the more inland-sited sector of the back-ridge flat area it is locally underlain by a gravel and sand body of unknown thickness attributable to fluvial environment (D2, D3, cross-section A-A' in Fig. 6).

As inferred from stratigraphic and morphological data, the inner limit of the Holocene flat filling was tentatively traced (Fig. 2). This limit reaches the base of the Tyrrhenian slope where a policyclical slope profile was observed (Aversana-Arenosola ridge) which can most probably be attributed to cliff erosion due to the wave action within the lagoon.

In the central portion of the back-ridge area the most ancient Holocene deposits are represented by a wedge-shaped body of grey sands and gravels (cross-section B-B', Fig. 6; V11 and V12, Fig. 5) containing integral marine shells (*Cerithium, Venus, Cardium*, ecc) which occur from 10 to 12 m b.s.l. (D23 and D25). This

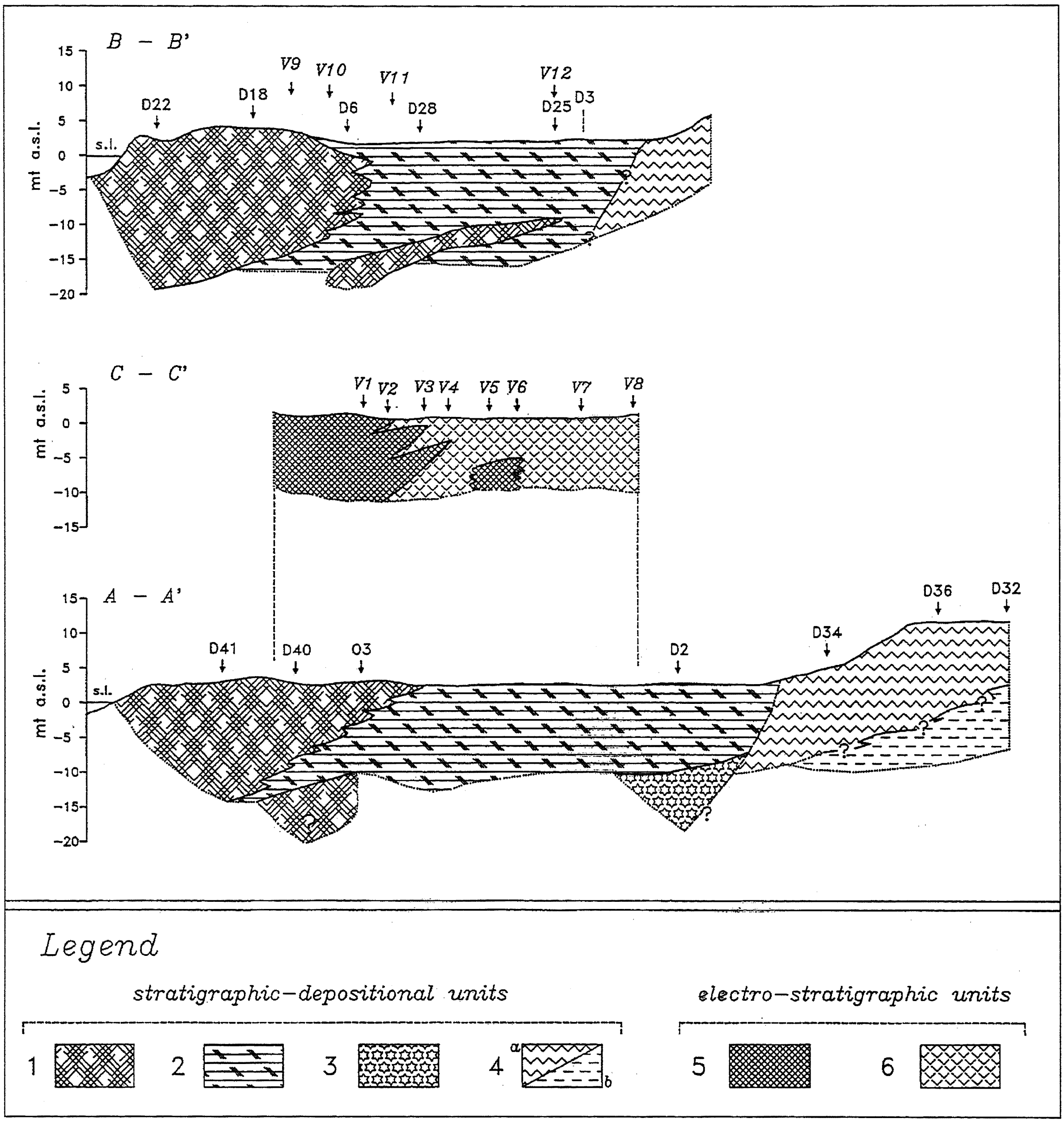


Fig. 6 - Stratigraphical and electro-stratigraphic cross-sections (for tracing see Fig. 2). 1) Holocene marine and eolian deposits; 2) Holocene lagoonal and palustrine sediments; 3) Late Pleistocene (?) to Holocene fluvial deposits; 4) Tyrrhenian marine (a) and lagoonal (b) sediments; 5) Sedimentary body with moderate to high resistivity (60Wmt onwards); 6) Sedimentary body with very low resistivity (2-30 Ωmt).

Profili stratigrafici ed elettrostratigrafici (per ubicazione delle tracce vedi Fig. 2). 1) Depositi marini ed eolici olocenici; 2) Sedimenti lagunari e palustri olocenici; 3) Depositi fluviali tardo-pleistocenici (?) ed olocenici; 4) Depositi marini (a) e lagunari (b) tirreniani; 5) Corpo sedimentario con resistività medio-alta (60 Wmt in poi); 6) Corpo sedimentario con resistività molto bassa (2-30 Ωmt).

unit (Sd1) extends laterally to about 1.6 kilometres from the coast and passes landward to fluvial sediments which are locally (D3) made of angular clasts in a silty matrix. As their ostracods content demonstrates, these fluvial deposits were sedimented in a brackish water body, which would mark the beginning of the drowning of the alluvial plain consequently to a first phase of Postglacial transgression (T1).

The described littoral and fluvial facies pass upwards to pelitic sediments (grey clay containing peat and more or less silty sand intercalations) which are characterized by a very low resistivity (4 to 30 Ωm) (*V5-8, V11-12*, Figg. 5 and 6). Particularly, the grey clay facies have a very low value of resistivity (4-10 Ωm) and are thus easily distinguishable from peaty intervals. The fact that some clay layers have closed *Cardium* shells (D1 and D2), coupled with the abundance of *Cyprideis torosa* in the lower intervals of D1, D2 and D3 wells, clearly indicate brackish water conditions. The presence of *Candona (F.) fabaeformis, Pseudocandona* aff. P. *marchica* and ssp. (group A in Tab. 1) indicates a moderate freshwater supply, whereas a certain abundance of marine species represented mainly by young individuals indicate at least temporary conditions of open sea. Two samples coming from the lower portion of well D3 show abundant pollens of *Nymphaea* which are generally referred to palustrine environment but are also found in deltaic environment (*Nymphaea alba*, Polunin & Walters, 1987).

The pelitic complex passes seawards and upwards to littoral gravelly and sandy deposits which extend to shallow depth also beyond the outcropping inner limit of the coastal ridge system (D5, D6, cross-sections B-B'and C-C'). Within this sand body, thin clay intercalations are found (D14, D10 and D16; *V1-4* and *V9-10*, Figg. 4, 5 and 6) suggesting further episodes of strandline retrogradation and progradation. Ostracod and pollen assemblages found between 7.3 and 3.5 metres b.s.l. in well D3 are evidence of a variable salinity, perhaps to relate to transgressive-regressive pulsations. Altogether, ostracod assemblages and pollen contents of wells D1, D2 and D3 show the upwards passage from a lagoonal (or deltaic) to a marshy environment, which is observed from 3 metres b.s.l. upwards. Furthermore, the pollen data evidenciate the passage from a marshy environment (sample 3x is particularly rich in *Cyperaceae*) to a condition of moist soils with a shallow water table that favoured a marked increase of *Alnus*.

As indicated by the radiocarbon age of a sample near the base of the Holocene back-barrier filling (sample Rome-816, Tab. 2), lagoonal conditions were completely present in the central portion of the Holocene plain for the first time about 8,400 years BP. This event is referred to an episode of marine transgression (T2) which deposited a sand wedge (Sd2) reaching about 1.2 km inland and a maximum elevation of 2-3 metres b.s.l. After a period of moderate dissection a phase of coastal progradation followed which was accompanied by fluvial sedimentation. These events are well documented by the stratigraphy of drillings which are located near the Sele river (D1 and D38). The upper portions of their sequences are made of coarse-grained sand and gravel. Though no clear paleoenviromental indication for these intervals could be obtained, a fluvial origin of these deposits is suggested by the sharp lateral discontinuity in comparishon to the litho-stratigraphic features of nearby wells and the *V5* and *V6* electrostratigraphic sequences. However a deltaic environment may not be excluded.

A successive episode of marine transgression (T3) and littoral accretion is indicated by the sand wedge Sd3 which reaches about 1.0 km inland from the present coast and a maximum height of about 1 meter a.s.l. The sandy deposits with integral shells of *Cerastoderma* crossed at about 0.0 metres a.s.l. (O4) seem to belong to this episode whereas the clayey and peaty sediments characterized by a layer of marine shells found in nearby trenches (O5) at about 1 metre b.s.l. seem to refer to an associated intradeltaic environment. This third transgressive phase, tentatively dated to 6,000 years BP, was followed by a regression during which the portion of the back-barrier filling showing the passage from a lagoonal to a palustrine environment would have been deposited. This passage is marked by ostracod assemblages largely dominated by species of group A (Fig. 3, Tab. 1) found from 2-3 metres b.s.l. upwards. As suggested by the radiocarbon date obtained from well D2 (sample Rome-810, Tab. 2), this passage occurred probably shortly before 5,500 years BP.

Close to the inner limit of the outcropping coastal ridge system a sand and gravel wedge (Sd4) attributable to a new transgressive pulsation (T4) was detected between 0 and 3 m a.s.l. This wedge is locally separated from the underlying littoral sediments by a clay layer and characterized by very high values of resistivity probably due to its degree of cementation (*V1* and *V9*, Fig. 5).

Logs of wells drilled onto the coastal ridge system show a rather homogenous sand body with gravel layers and about 20 metres thick close to the sea shore. The presence of 'black' sand layers (probably because of volcanic minerals) is given by some logs (D18, D14, D10, D40, D41). Sand quarries (O1-O3) located near the inner rim of the Holocene ridge system have exposed beach deposits deposited before 79 A. D. which are made of low-angled seaward dipping laminae of medium- to coarse-grained sand containing isolated shells of *Cerastoderma* and, locally, thin gravel layers. Sedimentological analyses(2) of some samples from sites O1 and O2 drawn at a height of 2.5 and 3.2 metres a.s.l. respectively permit to refer them to the upper foreshore. These beach sands, partially overlain by eolian sands, are covered also by the pumice layer of the 79 A. D. Vesuvius eruption. Seawards this succession is cut by a micro-sea cliff and buried by beach sands containing rounded pumices and shells of *Glycimeris*, *Tellina*, etc. They reach a maximum height of approximately 2.2 metres a.s.l. and are on turn covered by fine eolian sands containing rare wind-trasported marine shells and pumices.

The last phases of accretion and progradation of the coastal ridge system were accompanied by the aggradation of the back-ridge flat area with palustrine and fluvial sediments. The persistence of local palustrine depressions during the last 4,000 years is evidenced

(2) Grain size analyses and sample interpretation by Micla Pennetta, Carlo Vecchione and Alessio Valente (Dipartimento di Scienze della Terra, Università "Federico II", Napoli).

by the radiocarbon ages of samples Rome 812, 814 and 815 (Tab. 3). The reversal of age sequence (Rome-811) seems to indicate a local disturbance of sediments perhaps due to the penetration of roots. The shallow depth (generally 0.5 to 1.0 metre) at which the products of the 79 A. D. Vesuvius eruption are found in the back-ridge depression, are a clear evidence of the ephemeral deposition occurred after the eruption. The analysis of reports on the reclamation of the area permitted to approximately limit the zone interested by palustrine sedimentation until very recent times (Fig. 2).

5. CONCLUSIVE REMARKS

On the basis of collected subsurface data the coastal ridge and back-ridge system of the Sele plain can be referred to a barrier-lagoon system that formed during the Holocene.

Geomorphological surveys and analysis of subsurface data show that the redistribution of sediments by wave and current action largely prevailed during the Holocene upon the capacity of the main water courses (Sele and Tusciano river) to form deltaic constructions.

During the first fast phase of Postglacial sea-level rise (15,000-10,000 yrs BP) the study area was still under the sub-aerial conditions it entered at the very beginning of the Last Pleniglacial. Subsequently, the progressive drowning of the coastal plain is indicated by the deposition of fluvial sediments in a brackish water body. Littoral sediments attributable to the peak stage of this first transgression are found up to 1.6 km inland from the present coast.

For the remaining part of the Holocene the coast prevailingly progradated, although at least three transgressive pulsations occurred between 8,400 and 2,000 yrs BP. During the transgression dated tentatively to about 6,000 years BP a palaeo-sea-level of about 1 m a.s.l. was reached. As suggested by palaeoenvironmental data, palustrine conditions were present in the back-ridge depression about 5,500 yrs BP.

Collected stratigraphic and chronological data are not suitable to verify if the afore mentioned transgressive pulsations were simply controlled by glacio-eustatism and variations of the fluvial sedimentary input or governed by tectonic instability too.

The difficulty in assessing the glacio-eustatic origin of the measured sea-levels is closely related to the fact that details of palaeo-sealevel fluctuations during the Holocene are still little known. For the Tyrrhenian sea only a few stratigraphic and chronological data are available, which are often contrasting about the fact whether Holocene sea-level has ever exceeded the present one (Bonifay, 1973; Ulzega & Ozer, 1982; Alessio *et al.*, 1993; Bellotti *et al.*, 1995).

Worldwide evidence show that the post-glacial rise of sea-level was not steady but episodic, i.e. punctuated by a number of rapid sea-level rises, stillstands and/or minor regressions (Mörner, 1969; Frazier, 1974; Tooley, 1978; Carter et al., 1986; Fairbanks, 1989; Anderson & Thomas, 1991; Blanchon & Shaw, 1995; Bard et al., 1996; Locker *et al.*, 1996). Evidence of a similar episodic sea-level rise are reported by Ulzega & Ozer (1982), Bellotti *et al.* (1990, 1995) Asioli *et al.* (1996) and Correggiari et al. (1996) for the Adriatic and Tyrrhenian seas.

As to tectonic influences, it must be observed that the precise tectonic behaviour of the study area during the Late Pleistocene-Holocene is still unknown. Whereas the Tyrrhenian beach complex is tectonically raised up to 20 metres, it is not clear whether uplift occurred with a steady rate nor whether it lasted until present or ended in pre-Holocene times.

Considering the maximum height of Holocene sea-level similar to the present one, the beach face deposits exposed in some sand quarries at a height of about 3.2 m a.s.l. can be considered as slightly raised. The comparison between the few palaeo-sealevels to be estimated on the basis of obtained radiocarbon ages (8090±90 and 8340±80 years BP) and available sea-level curves (Fairbanks, 1989; Anderson & Thomas, 1991; Chappell & Polach, 1991; Bellotti *et al.*, 1995) shows values slightly above those reported in literature suggesting the persistence of tectonic instability of the plain during the Holocene. Whether such an instability included also periods of tectonic lowering able to promote marine ingressions has to be verified on the basis of new data.

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