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GEOARCHAEOLOGICAL EVIDENCES OF CHANGES IN THE COASTLINE PROGRADATION RATE OF THE VERSILIA COASTAL PLAIN BETWEEN CAMAIORE AND VIAREGGIO (TUSCANY, ITALY): POSSIBLE RELATIONSHIPS WITH LATE HOLOCENE HIGH-FREQUENCY TRANSGRESSIVE-REGRESSIVE CYCLES

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ABSTRACT: Bini M. *et al*., *Geoarchaeological evidences of changes in the coastline progradation rate of the Versilia coastal plain between Camaiore and Viareggio (Tuscany, Italy): possible relationships with Late Holocene high-frequency transgressive-regressive cycles*. (IT ISSN 0394-3356, 2009)
The Late Holocene progradation of the Versilia coastal-plain, between Camaiore and Viareggio (Tuscany, Italy), was investigated on the basis of geomorphological, stratigraphical, and archaeological data. Five geomorphological units, corresponding to the Camaiore alluvial fan, beach-dune ridges, interdune marshes, a back dune marsh (Giardo and related Massaciuccoli lake area), and the present-day beach, were identified.
Archaeological data provide some chronological constraints on the timing of Late Holocene coastal progradation. About 3000 yrs ago, the coastline was located about 2,5 km landward in respect to its present-day position, in the proximity of the Migliarina beach dune, behind which a marsh area developed. This marsh extended from the Giardo to the present-day Massaciuccoli Lake. The connection between Giardo and Massaciuccoli area allows us to reconsider the role of Acquarella site in becoming an important centre in commercial communication among sea, coast, and inland areas. Around the 12th century the coastline was located in proximity of the dune alignments where Motrone Fort and the Castello Vecchio di Viareggio were built testifying a progradation of about 1,3 km. During the next four centuries the coastline continued its seaward shifting for 500 m more and was located in proximity of the Matilde Tower. From the 16th to the present time the progradation of the coastline has been proceeded by of about 0,7 km. These data indicate changes in the progradation rate during that the time and in particular an increase since the 16th century. An irregular progradation rate agrees with stratigraphic and facies analysis based on surface and subsurface data (wells and excavations) that allowed us to define a preliminary framework of the last phases of coastline progradation. The identification of four high-frequency small-scale transgressive-regressive cycles (parasequences) within the succession recording the Late Holocene phase of progradation points to evidence that the progradation rate of the coastline was subject to cyclic fluctuations.

RIASSUNTO: Bini M. et al., Evidenze geoarcheologiche di variazioni nel tasso di progradazione della pianura Versiliese nel tratto compreso tra Camaiore e Viareggio (Toscana, Italia): possibili relazioni con cicli trasgressivo-regressivi ad alta frequenza tardo olocenici. *(IT ISSN 0394-3356, 2009).*
L'integrazione tra dati geomorfologici, stratigrafici e archeologici ha permesso di analizzare alcune delle tappe di progradazione della pianura costiera versiliese nel tratto compreso tra Camaiore e Viareggio (Toscana, Italia). Nell'area di studio, sono state individuate cinque unità morfologiche: la conoide alluvionale del torrente Camaiore, una serie di cordoni dunali, le aree umide interdunali, la più ampia area umida del Giardo e la spiaggia attuale. I dati archeologici hanno permesso di porre alcuni vincoli cronologici riguardo i tempi della progradazione della linea di costa. Circa 3000 anni fa la linea di costa, si trovava arretrata di circa 2,5 km rispetto alla sua posizione attuale, ed era localizzata in prossimità della duna della Migliarina, alle spalle della quale si estendeva un'area palustre (Giardo) in comunicazione verso sud con l'attuale lago di Massaciuccoli. La comunicazione tra le due aree permette di riconsiderare in una luce nuova il ruolo del sito dell'Aquarella nel divenire un importante centro commerciale di comunicazione tra il mare, la costa e le zone interne.
Attorno al 12th secolo la linea di costa era avanzata di circa 1,3 km e si trovava in prossimità dell'allineamento di dune dove furono costruiti il Forte di Motrone e il Castello Vecchio di Viareggio. Durante i quattro secoli successivi la progradazione continuò per circa 500 m e, nel 16th secolo, la linea di costa era localizzata all'altezza della torre Matilde. Dal 16ths ecolo ad oggi il processo di progradazione è proseguito per circa 0,7 km. Questi dati indicano variazioni nel tempo del tasso di progradazione ed in particolare un incremento a partire dal 16th secolo.
Un tasso di progradazione irregolare è in accordo con i dati stratigrafici e di analisi di facies di depositi superficiali e sub-superficiali (carotaggi e scavi) che hanno permesso di definire un quadro preliminare delle ultime fasi della progradazione costiera nell'area di studio. In particolare l'identificazione di quattro piccoli cicli trasgressivi-regressivi (parasequenze) ad alta frequenza all'interno della successione che registra le fasi di progradazione tardo oloceniche suggerisce fluttuazioni cicliche nel processo di progradazione della linea di costa.

Keywords: Coastal plain progradation, parasequences, Late Holocene, Versilia.

Parole chiave: Progradazione pianura costiera, parasequenze, Tardo Olocene, Versilia.

INTRODUTION

This work focuses on the Late Holocene paleogeographic reconstruction of a sector of the Versilia coastal plain (Fig.1) between Camaiore and Viareggio (Tuscany, Italy). Over the last 3000 yr, this area has experienced a coastline progradation of about 2,5 km, but the causes of this process are still not completely explained. Many studies support the relationships between high-frequency climatic variations (millennial to centennial scale), probably associated with small-scale sea-level fluctuations, and the development of small transgressive-regressive cycles (e.g., LOWRIE & HAMITER, 1995; BOYER *et al.*, 2005; AMOROSI *et al.*, 2005; Leorri *et al.*, 2006). Three millennial-scale transgressive-regressive cycles have recently been recognized (Amorosi *et al.*, 2009) about 20 kilometers south of the study area (subsurface of the Arno coastal plain) within the transgressive deposits Late Pleistocene-Holocene in age (13-8 ky cal B.P.). In the neighbouring archaeological site of Pisa, which contains Roman ships, stratigraphic and sedimentological studies show that the cause of repeated episodes of river harbor destruction were high-frequency centennial-scale climatic and possibly eustatic changes (BENVENUTI *et al.*, 2006).

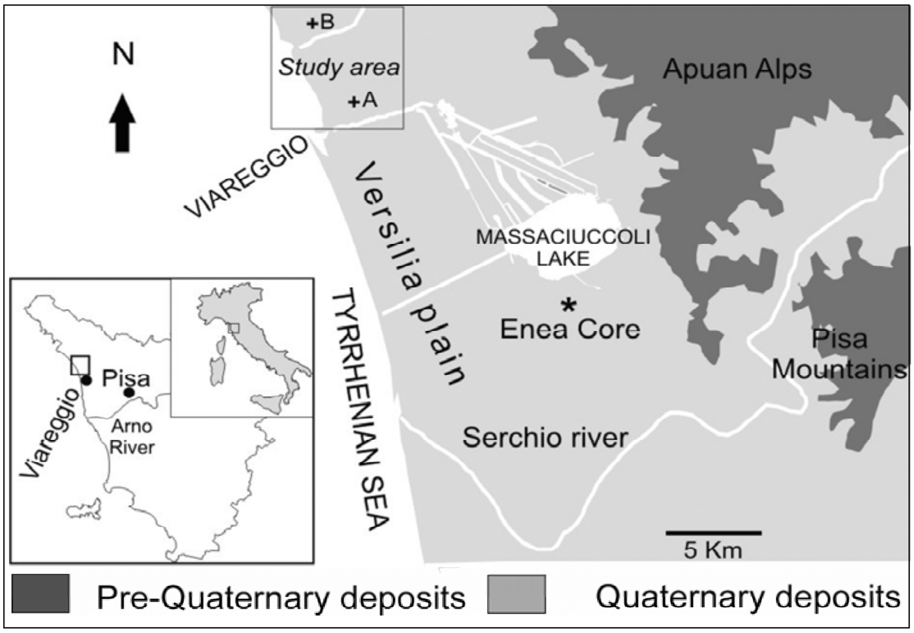

Fig. 1 - Map of the study area and location of stratigraphic study sections (A, B).
Mappa schematica dell'area di studio con ubicazione delle sezioni studiate (A, B).

Based on these data and considering the neighbouring Arno and Versilia coastal plain, the hypothesis that also the study area may have experienced short phases of stillstand, if not transgressions, seems plausible.

The aim of this paper, using a multidisciplinary approach that includes the use of geomorphological, sedimentological, and archeological data, is to define the timing of progradation of the Versilia coastal plain over the last 3000 yrs and to discuss the possible key factors that may have been controlled this process.

2. GEOLOGICAL SETTING

The study area (Fig. 1) is within the communities of Viareggio and Lido di Camaiore, (NW Tuscany). The modern Arno and Versilia coastal plain is part of the onshore portion of the wider Viareggio Basin, an extensional area oriented NW-SE, which has been active since the Upper Tortonian (MARIANI & PRATO, 1988; ARGNANI *et al*., 1997; PASCUCCI, 2005). This basin is filled with about 2500 m of deposits spanning from late Miocene to the Present. The uppermost portion (Late Pleistocene-Present, corresponding to seismic sequence 6b of PASCUCCI, 2005) has been investigated for its chronostratigraphic relevance and specifically for defining the Versilian stage (BLANC, 1937, 1942; FEDERICI, 1993). The late Quaternary depositional evolution has been recently reconstructed based on data from the ENEA core (Figs. 1, 2) drilled near the Massaciuccoli Lake about 10 km SE of the study area (ANTONIOLI *et al.,* 2000; DEVOTI *et al.*, 2003; NISI *et al.,* 2003). The base of the Holocene transgression (10.568 -10.236 cal B.P., see ANTONIOLI *et al.,* 2000) is identified (Fig. 2) at a depth of about 34 m from the surface, at the transition from alluvial to paralic deposits bearing brackish fauna. These deposits grade upwards into marine sands. Their top (9 m below ground level) is dated to 5896-5830 cal B.P. (ANTONIOLI *et al.,* 2000) and is overlaid by alternating peat layers, sands, and clays bearing brackish fauna. An age of 2627 - 2129 cal. B.P (2,5 m below ground level) has been attributed to these deposits (ANTONIOLI *et al.,* 2000). From the Apuane foothills to the coast, the outcropping deposits record a variety of depositional environments, such as some small coalescent alluvial fans, marsh areas connected to Massaciuccoli Lake, coastal dune systems with related interdune areas, and the present-day beaches.

METHODS

Geomorphologic surveys, field aerial photographs, and stratigraphic analysis were used to develop a detailed geomorphologic and geologic map at 1:10.000. Sedimentological and facies analysis, based on surface and subsurface data also allowed us to define a preliminary framework of relationships among the depositional units recognized. Subsurface data derive from a working-face about 6 m deep and 100 m wide (A in Fig. 3), where a continuously cored borehole (S5) was also drilled (location in Fig. 3), and from another excavation (3 m depth and 15 m wide; B in Fig. 3) located about 4,5 km northward.

Moreover, micropaleontologic data lead to a better definition of the depositional environments. Twenty-six samples were collected from section A and were washed and sieved with an 88 μ mesh. Thirty-two ostracods and twelve foraminifera species were recovered. Most of these presently live in the Mediterranean area (BONADUCE *et al.*, 1976; SGARELLA & MONCHARMONT-ZEI, 1993). The plotting of archeological data, recorded since the 16th century, on the map provided further chronological constraints for reconstructing the palaeogeographical evolution of the study area with particular attention to coastline variations.

GEOMORPHOLOGIC DATA

The geomorphologic data, derived from field surveys and multitemporal aerial photographs analyses, allowed the identification of five geomorphological units: 1) the Camaiore alluvial fan, 2) dune ridge, 3) small marshes located in the interdune areas, 4) a major marsh area named Giardo, and 5) the present day beach (Fig. 3).

The Camaiore alluvial fan is about 4 km long and 2,5 km wide, and records cyclic depositional and quiescent phases during the Late Pleistocene-Holocene (FEDERICI, 1993). The alluvial fan reaches an elevation of 20 m in the foothills (apex) and decreases with a uniform and low gradient (<2% average dip) to an elevation of 2 m asl towards its distal area (Fig. 3). Lateral channel migration from west to east is suggested by the identification of several palaeo-channel traces on

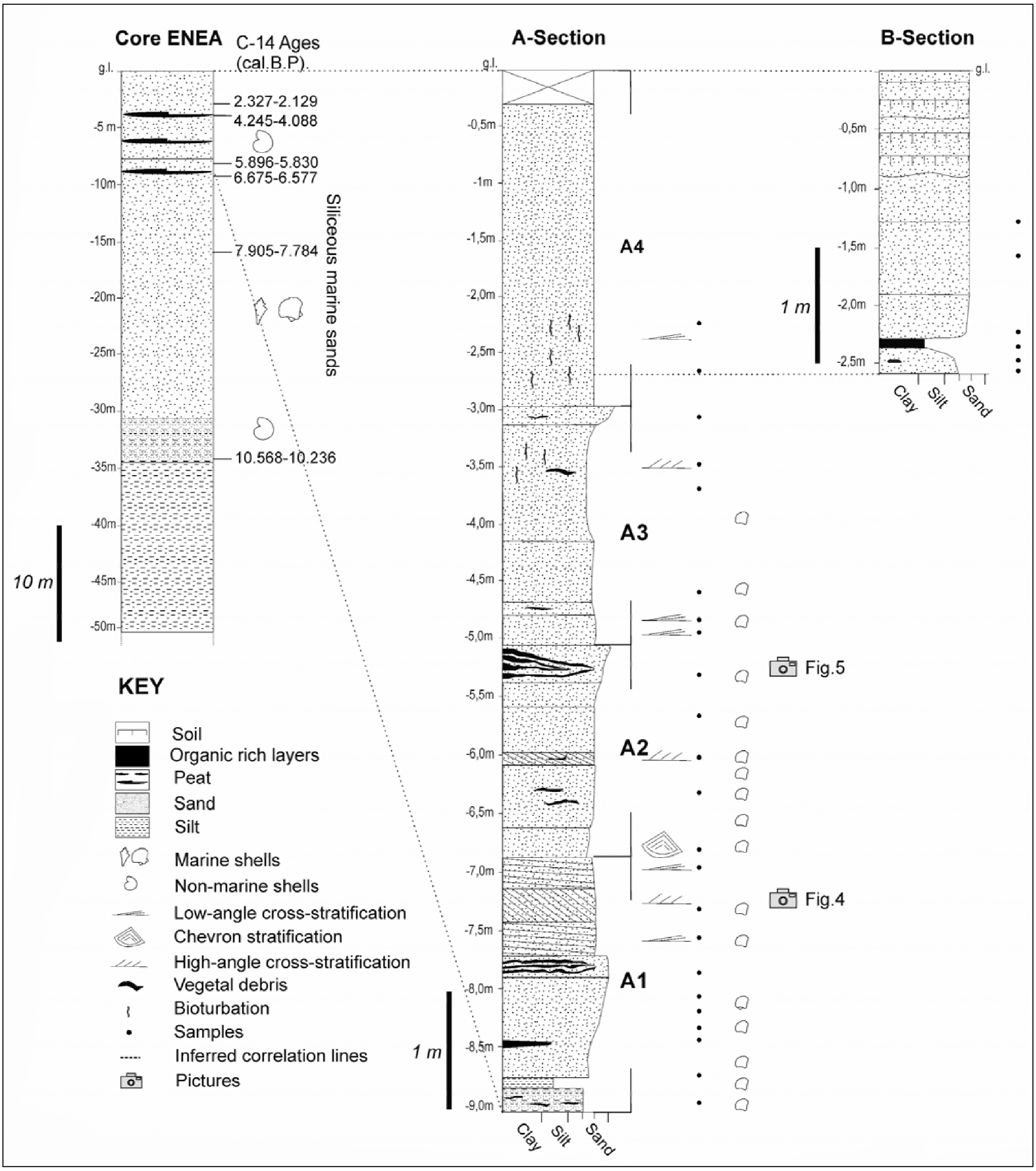

Fig. 2 - Stratigraphy of Enea core (redraw after ANTONIOLI *et al*., 2000). A and B: study sections. For their location see fig 1 and fig 3.

Stratigrafia del sondaggio Enea (ridisegnato da ANTONIOLI et al.*, 2000). A e B: sezioni studiate. Per la loro localizzazione si vedano le figg. 1 e 3.*

the fan surface. Subsurface data available from a working face (BINI *et al.,* 2007) carried out on the distal fan area (C in Fig. 3), reveal that fine-gravels are intercalated with organic-rich silt and clay related to the Giardo marsh. This indicates phases of progradation of the Camaiore alluvial fan into the Giardo marsh.

The Giardo marsh, which is Late-Holocene in age (FEDERICI, 1993), is located between the Camaiore alluvial fan and the oldest beach ridge dune alignment and was connected in the past with the Massaciuccoli Lake area. This connection is strongly supported, according to DEVOTI *et al.,* 2003, by geomorphological surveys (Fig. 3). Today it represents a lowland about 1,8 km long, 1,5 km wide, and is relatively depressed (1 m asl) with respect to the surrounding morphological units. It is occupied by a small permanent lake and several ephemeral marshes. Its fill is characterized by sands, silts, and peat.

The dune ridges, whose alignment records the position of the shoreline during the Late Holocene, are located between the Giardo marsh and the present-day coastline (Fig. 3). These dunes belong to an articulate beach-ridge system (MAZZANTI & PASQUINUCCI, 1983) that characterizes the coastal plain from the Arno River (south) to the Magra River (north). Unfortunately, the modern human settlements that developed along the coast makes it difficult to identify the original morphology of each beach ridges. They are normally closely spaced, with interdune marshes employed as fish tanks (Benzio, 1986) from the early Middle Ages up to the 18th century and represented an important economic resource for the local community.

The landward dune (Migliarina beach ridge dune in Fig. 3) is located in front of the Massaciuccoli Lake area. It is the most elevated (1,5 m asl) and the best preserved. Archaeological findings (see § 5) date the Migliarina dune to an age not younger than the 7th century B.C. (BINI *et al.*, 2007). This implies that the age of development of the related back-ridge marsh area (Giardo marsh) can not be older.

Moving toward the coast, historical buildings permit us to date two other beach-ridge alignments. The Motrone Fort and the Castello Vecchio di Viareggio (Fig. 3, n.7) were built in the 12th century, while the Matilde Tower (Fig. 3, n.15) was built in the 16th century. These buildings mark the variation of the coast line during this time because the towers were coastal defences and are described as having been built on the beach (Mazzanti & Pasquinucci, 1983) (see § 5).

The younger morphologic unit corresponding to

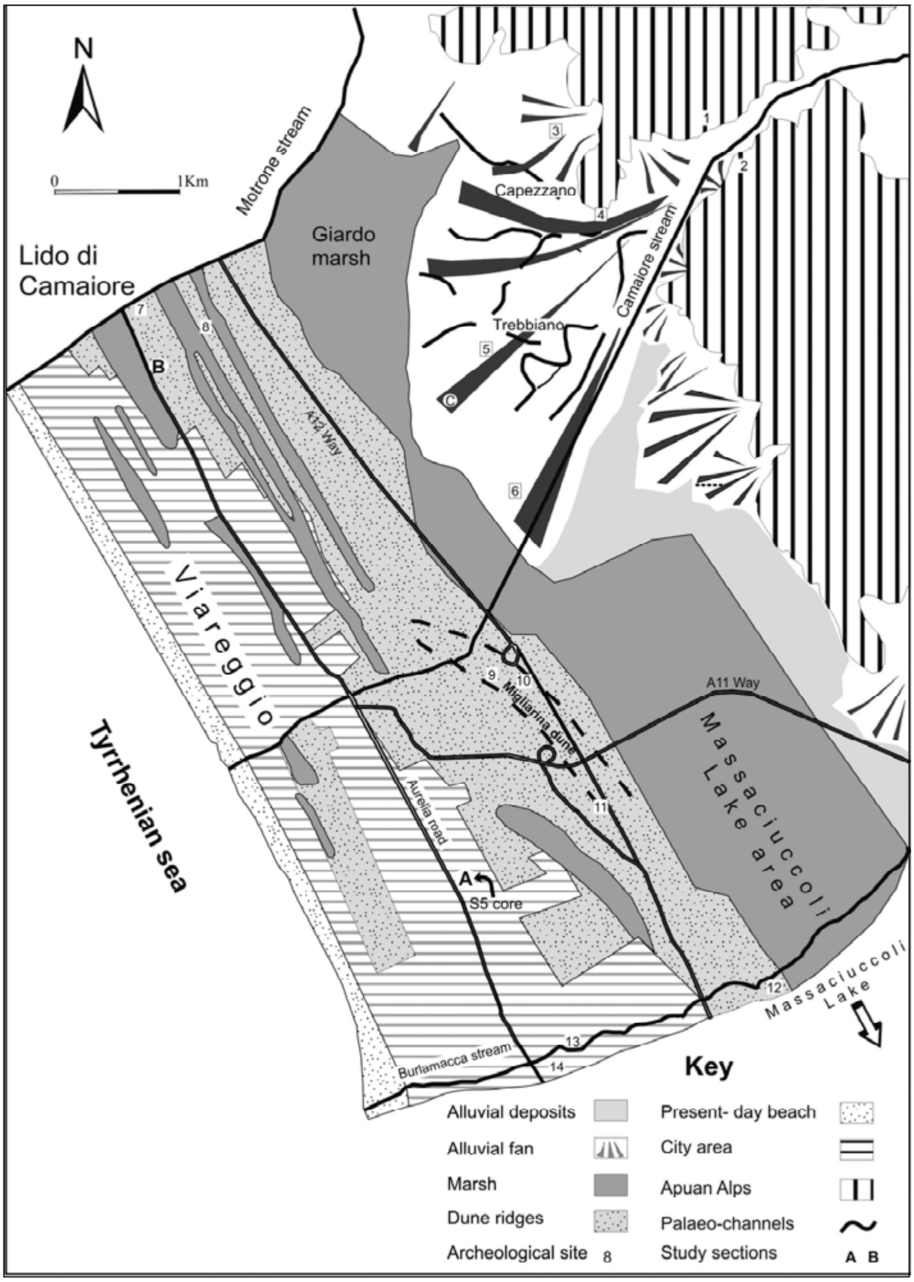

Fig. 3 - Geomorphological map with the location of the most important archaeological sites 1) Capocavallo; 2) Villa Mansi; 3) Acquarella; 4) Capezzano Pianore; 5) Trebbiano; 6) Bucine; 7) Motrone Fort; 8) Tongo; 9) Tombolo; 10) Ortacci; 11) Migliarina; 12) San Rocchino; 13) Castello vecchio di Viareggio; 14) Matilde Tower. A and B: study sections. C: location of stratigraphic section reported in BINI *et al*. 2007.

Carta Geomorfologia con l'ubicazione dei principali siti archeologici 1) Capocavallo; 2) Villa Mansi; 3) Acquarella; 4) Capezzano Pianore; 5) Trebbiano; 6) Bucine; 7) Forte di Motrone; 8) Tongo; 9) Tombolo; 10) Ortacci; 11) Migliarina; 12) San Rocchino; 13) Castello vecchio di Viareggio; 14) Torre Matilde. A e B: sezioni studiate. C: ubicazione della sezione stratigrafica riportata in BINI et al. *2007.*

the present-day beach is actually in accretion (1 m per year; CIPRIANI *et al*., 2004) due to the influence of Viareggio harbour and its piers on the longshore sediment flux.

STRATIGRAPHIC AND SEDIMENTOLOGICAL DATA

The stratigraphic and sedimentological data have been collected from a working-face about 6 m deep and 100 m wide (A in Fig. 3), where a continuously cored borehole (S5) was also drilled, and from another excavation (3 m depth and 15 m wide; B in Fig. 3) located about 4,5 km northward. Unfortunately, the S5 core was destroyed and the available data are a log description and a photographic documentation.

The stratigraphy of the Enea core (ANTONIOLI *et al.,* 2000), drilled about 10 km south-east of the study area, was utilized as a reference for interpreting the data collected in this study (Fig. 2; see Fig. 1 for the location).

Facies analysis of section A shows an overall regressive trend passing upward from shallow-marine to coastal-dune deposits that also outcrop at the surface. Four small transgressive-regressive cycles (A1-A4; parasequences *sensu* VAN WAGONER *et al.*, 1990; KAMOLA & VAN WAGONER, 1995) have been defined within this general trend (Fig. 2).

The lowest cycle (A1) is characterized by shallow marine sandy-silt bearing a relatively diversified microfauna constitued by ostracods (*Cytheridea neapolitana, Pontocythere turbida, Leptocythere ramosa, Cytheretta subradiosa, Cytheretta adriatica, Neocytherideis fasciata)* and foraminifera (*Haynesina depressula, Ammonia beccarii, Quinqueloculina seminulum*, and rare specimens of *Florilus boueanum,* and *Elphidium crispum)*.

The presence of vegetal debris associated with some reworked brackish to freshwater ostracods (e.g., *Cyprideis torosa* and *Candona spp.*) indicates the proximity to a paralic depositional environment such as an inner lagoon or a small bay. These deposits pass upward to medium and coarse sands (upper shoreface) with scarce and poorly diversified microfauna. Accumulation at the top of this sequence of centimetric lenticular layers of coarse vegetal debris, showing evidence of traction processes, has been related to a foreshore environment such as a storm berm. Low to high-angle cross-beds fine laminated sands interpreted as backshore to dune deposits form the upper portion of parasequence A1 (Fig. 4).

Sands showing chevron stratification related to wave processes indicate the return to subaqueous conditions (A2 parasequence). Upward the sands display a progressive increase in microfauna diversification and abundance (*Pontocythere turbida, Palmoconcha turbida, Haynesina depressula, Ammonia beccarii* and *Elphidium crispum*) up to 6 m depth (Fig. 2) even lower than observed in parasequence A1. We interpret these sediments as having been deposited in a very shallow-marine environment close to the coastline. The nearness of coast is also supported by the occasional presence of vegetal debris. In the uppermost portion of parasequence A2, medium to coarse foreshore-storm-berm sands displaying coarse vegetal-rich centimetric levels overlaid by well-sorted backshore fine sands represent the regressive phase (Fig. 5).

Parasequences A3 and A4 show features very similar to those observed in A2, recording the transition from a very shallow-marine to a foreshore-backshore depositional environment (Fig. 2).

We think plausible the correlation between section A and the upper portion of the Enea core, recording the progradational phases wich occurred during the Late Holocene (Fig. 2). Even though the lack of detailed facies from this core stratigraphy do not allow the accurate placing of the transition from the retrogradational to progradational depositional phase (maximum flooding surface), we can assume that it occurs between 10 - 15 m depth, in the uppermost part of the marine siliceous sands (see ANTONIOLI *et al.,* 2000) considering the occurrence, few meters above, of a peat layer. Indeed it is undoubtedly, according to NISI *et al.*, 2003, that the occurrence of this layer at a depth of 8,50 m indicates the transition from a marine to a paralic depositional environment. Similarly, in S5 core the first organic-rich level above the marine sands occurs about 9 m depth (Fig. 2) and coincides with the base of section A. For this reason we can correlate section A with the upper part of Enea core.

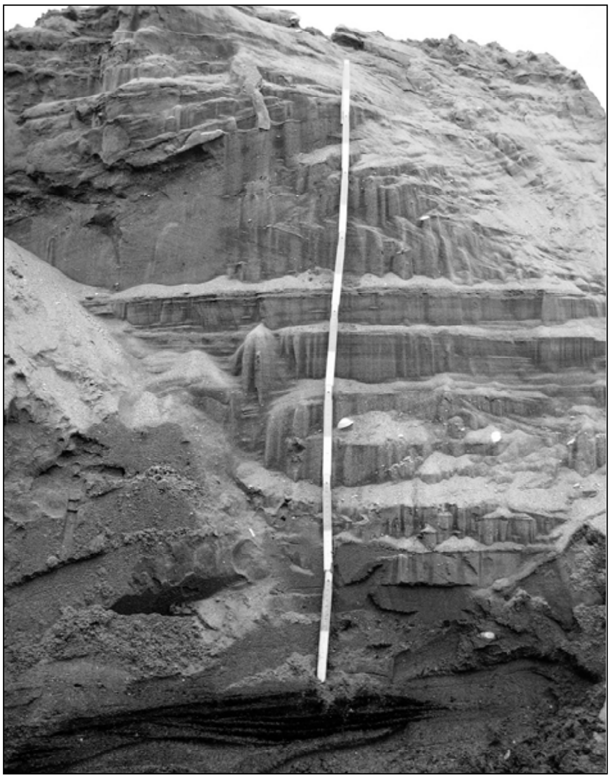

Fig. 4 - Uppermost portion of A1 parasequence. From the bottom: centimetric lenticular levels of vegetal debris, displaying evidences of traction processes related to a foreshore - storm berm depositional environment. These deposits passes upwards low to high-angle laminated fine sands, interpreted as backshore to dune deposits (see Fig. 2 to place the photo within the stratigraphic log)

Porzione superiore della parasequenza A1. Dal basso: livelli lenticolari centimetrici di resti vegetali, che mostrano evidenze di processi trattivi legati ad un ambiente deposizionale di battigia-berma di tempesta. Questi depositi passano verso l'alto a sabbie fini con laminazione da basso a alto angolo, interpretate come depostesi in ambienti da spiaggia emersa a duna eolica (si veda la Fig. 2 per la posizione della foto nel log stratigrafico).

Section B cuts, about 5 km northwards from A, the same sandy coastal dune deposits (Fig. 3). From the bottom to the top (Fig. 2) the stratigraphic succession consists of i) backshore to upper shoreface deposits, ii) a centimetric layer of peat related to a paralic environment,.and iii) about 2,5 m of pedogenized dune deposits.

On the basis of stratigraphic and morphological data, we correlate section B with the uppermost portion of section A, and particularly with the regressive part of parasequence A4 (Fig. 2).

ARCHAEOLOGICAL DATA

Our knowledge of human settlements in the coastal plain of Versilia between Camaiore and Viareggio is related to some archaeological findings, mostly casual, which have been recorded since the 16th century. The site of Acquarella (Fig. 3, n. 3), whose archaeological and naturalistic aspects are still under investigation, shows a remarkable continuity of human settlement since the Roman Archaic period to the early Middle-Ages (Paribeni *et al*., 2006; Bini & Fabiani, 2008).

The first settlement documented in the Acquarella site goes back to the end of the 6th century B.C. At that time, it is possible that the Giardo marsh (see § 2) was already connected with the Massaciuccoli Lake area.

Acquarella, in addition to contributing to the agricultural exploitation of the plain and the nearby hills, played a strategic role in commerce. It was located at the junction of the coastal routes (terrestrial, maritime, and lagoon) and those which linked the coast to the plain of Lucca and to the Serchio valley, through the valley of Camaiore.

The burial site which was found at villa Mansi, close to Acquarella (Fig. 3, n. 2), perhaps part of a necropolis, suggests the existence of a village and demonstrates the vitality of the area since the end of the 7th century B.C. (Ciampoltrini, 1990). (E.P.)

On the coast, the intensity of ship traffic is demonstrated by the settlement of San Rocchino (Fig. 3, n.12). This site was inhabited from the end of the 8th century B.C. up to the 3rd century B.C., and was situated on the border of the ancient marsh-lake area. Since its founding, this settlement was devoted to the commercial economy, and was visited constantly by sailors coming from south-Etruria, Greece, and the area east of Greece. In the earliest period, this site was probably so vital because of the metallic resources mined inland from Versilia. This is demonstrated, for example, by a cache containing bronze materials of the protohistoric period located on the hill of Camaiore (Bonamici & Fabiani, 2006). The Migliarina site (Fig. 3, n.11), a productive and specialized settlement of the end of the 7th century B.C., was located on a coastal dune deposit marking the coast line during this time. Behind the dune, a marsh area connected to the sea developed (see § 2). One of its purposes was, perhaps, salt production (Ciampoltrini, 2005).

Acquarella again gives us the most articulate documentation about the Roman period. Here, it is possible to follow the phases of construction of a rustic building which was reorganized many times, from the Republic age up to late-Antiquity (Fig. 6). The proximity to the

Fig. 5 - Transition from foreshore-storm berm to backshore depositional environments in the uppermost of A2 parasequence. Note the abrupt granulometric change from medium to coarse sands displaying organic-rich centimetric levels to a well-sorted fine sands (see Fig. 2 to place the photo within the stratigraphic log).

Passaggio, nella parte alta della parasequenza A2, da ambienti deposizionali di battigia-berma di tempesta a spiaggia emersa. Si noti il brusco cambio granulometrico da sabbie medie-grossolane contenenti livelli centimetrici ricchi in materiale organico a sabbie fini ben classate (si veda la Fig. 2 per la posizione della foto nel log stratigrafico).

Fig. 6 View of Acquarella archaeological site.

Veduta del sito archeologico di Acquarella.

hill-foot route between Pisa and Luni, part of the road link on the way to Lucca, must have played a role in the prosperity and in the prolonged vitality of the site, which was converted during the early Middle-Ages into a settlement of huts, possibly fortified.

Weak traces of centuriation, Roman predials, like Capezzano and Trebbiano, together with occasional discoveries (Fig. 3, n.1, 4, 5, 6) on the coastal dune (Fig. 3 n. 8, 9, 10; Bini *et al.*, 2007), confirm the settlement of the Camaiore alluvial fan area .

Moreover, an important road, which could be identified with the Aurelia/Aemilia Scauri, ran along the coast (Fabiani, 2006).The fortress of Motrone (Fig. 3, n.7), erected *in maris littore* (Giannotti, 2006), and the fortress of Viareggio (Fig. 3, n.13), which was built during the 12th century A.D., are important reference points for dating the coastal dune deposits in the Middle-Ages (Bini *et al.,* 2007).

In Viareggio, the building of the new tower Matilde (Fig. 3, n.14) during the 16th century, in a more advanced position than the old fortress, demonstrates the gradual advance of the coastline. (F.F)

DISCUSSION

Some of the late phases of progradation that affected the coastline of the study area during the last 3000 yrs were detected by the integration of geomorphological, stratigraphical, and archaeological data. The chronostratigraphic framework, derived from archeological data, indicate that the coastline was located i) near the Migliarina dune around the 7th century B.C., ii) in the proximity of the Motrone Fort and the Castello Vecchio di Viareggio (Fig. 3, n.7, 13) in 12th century and iii) near the Matilde Tower (Fig. 3, n.14) during the 16th century. These buildings were, in fact, built on the beach (Mazzanti & Pasquinucci 1983) as coastal defences. Other ages derived from archeological findings give us other information about the landscape of the study area. The Acquarella site, located on the Camaiore fan, was active since the end of the 6th century B.C. and its role in becoming an important centre in the commercial communication between sea, coast, and inland areas was probably related to its closeness to the back dune marsh area (Giardo marsh). Indeed, this area, developed around the 7th century B.C., was in connection with the Massaciuccoli Lake area southward and thus to the sea also according to the features of the San Rocchino site (Fig. 3, n.11) settled from the end of the 8th century B.C. up to the 3rd century B.C and devoted to shipping traffic. This demonstrates that if the archeological data play a significant role in defining the timing of the history of the progradation phases in the study area, the geomorphological and stratigraphic study have important implications in the context of the environments where the archeological sites developed.

On this basis the landscape, around 3000 yrs ago, was characterized by i) a coastline located about 2,5 km landward in respect to its present-day position near the Migliarina beach ridge, ii) a wide protected brackish marsh area (Giardo marsh) that was connected southward to the Massaciuccoli lake system behind the coast, and iii) an alluvial fan system (Camaiore fan) periodically connected with the Giardo marsh.

Afterward, repetitive phases of progradation took place, causing the development of a strandplain characterized by a wide back dune marsh area (Giardo marsh). Archeological data permit us to state that i) around the 12th centuries the coastline had experienced a progradation of about 1,3 km and was located in proximity of the dune alignments where Motrone Fort and the Castello Vecchio di Viareggio (Fig. 3 n°7, 13) were built and that ii) four centuries later the coastline had again moved seaward of about 500 m and was located near Matilde Tower (Fig. 3, n.14). From the 16th century to the present time the progradation of the coastline has proceeded by about 0,7 km.

On this basis, although the available data are sparse, a progradation rate was calculated (Fig. 7). The data show a relatively low progradation rate from the 7th century B.C until the 16th century (about 0,7m/yr), followed by a pronounced increase (1,75 m/yr), still active. Actually, this area is currently subject to expansion (1 m/yr) because of the influence of the piers of the Viareggio harbor on the longshore sediment transfer (Cipriani *et al*., 2004). The rapid increase after the 16th century appears to be significant and agrees with an analogous study carried out on the Tuscan coast (Sarti & Ciulli, 2008; Pranzini, 2001) and has been related to an increase of sediment supply due to deforestation (Pranzini, 2001).

Nevertheless, it is worth noting that the average

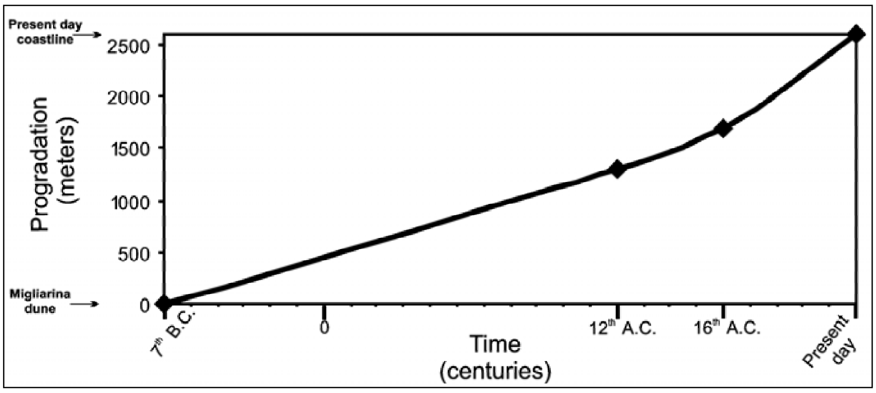

Fig. 7 - Diagram showing the variation of the progradation rate for the Verislia coastal plain over time. The rate is calculated starting from the coastline position during the 7th century A.C. (corresponding to the most landward outcropping dune- duna della Migliarina fig. 3, n. 11) and considering the coastline position in the 12th century A.C. (fig. 3, n.7 e 13), in the 16th century (fig. 3, n.14) till the present-day coastline position (the latter deduced on the basis of Cipriani *et al.* 2004 data).

Grafico della variazione del tasso di progradazione nel tempo. Il tasso viene calcolato considerando come riferimento la posizione della linea di costa nel VII secolo a.C. (corrispondente al cordone dunare più interno affiorante - duna della Migliarina fig. 3, n.11) e attraverso la posizione della linea di costa nel XII sec. d.C.(fig. 3, n. 7 e 13), nel XVI sec. d.C. (fig. 3, n.14) fino alla posizione della linea di costa attuale (ricavata sulla base dei dati di Cipriani et al.*,2004).*

rate of progradation calculated between the 7th century B.C. and the 16th century A.D., does not consider all the possible (and highly probable) fluctuations that could have occurred during this time (e.g., increase or reductions of the rate of progradation, or even phases of retrogradation of the coastline). The hypothesis that the progradation took place irregularly is also strongly supported by the subsurface stratigraphic data, evidencing four small high-frequency transgressive-regressive cycles within the succession recording the Late Holocene phase of progradation. High-frequency transgressive-regressive cycles have been documented from Late Quaternary to Holocene successions of Mississippi, Ebro, Rhône and Po Deltas (Lowrie & Hamiter, 1995; Somoza *et al.,* 1998; Boyer *et al*., 2005; Amorosi *et al.,* 2005) and, recently, of Arno coastal plain about 20 km southward to the study area (Amorosi *et al.,* 2009). A combination of small-scale sea-level fluctuations and rapid climatic variations (millennial to centennial scale) has been guessed as the possible major controlling factor of stratigraphic architecture in these areas even if in the Arno coastal plain (Amorosi *et al.* 2009) pollen characterization evidences the development of parasequences as chiefly the function of high-frequency (millennial scale) climatic variations. A climatic control (centennial-scale) during the Late Holocene is also suggests by Benvenuti *et al.* 2006, on the basis of detailed sedimentological and stratigraphical study, from an archaeological site near Pisa urban area, where a riverine harbour, erected in Etruscan age, was discovered. In this study the close relationships between recurring events of harbour destruction and high-magnitude flood episodes due to high-frequency climatic changes is documented.

Even if no data are at the present available from the study area the neighbouring with the Arno coastal-plain makes it very probable that high-frequency climatic changes have played an important role in the dynamics of coastline position. Further multidisciplinary studies in the area could confirm this hypothesis.

CONCLUDING REMARKS

The integration of geomorphological, stratigraphical, and archaeological data allows for the reconstruction of the late phases of progradation that affected the study area during the last 3000 yr. The following key points can be highlighted:

1) about 3000 yr ago the coastline was located about 2,5 km landward in respect to its present position in proximity of Migliarina dune, and behind the dune, a marsh (Giardo marsh) connected to the Massaciuccoli lake area developed;
2) the connection between the Giardo and Massaciuccoli areas allows a better understanding of the characteristics of the archaeological site of Acquarella and this played an important role in it becoming an important centre in commercial communication between the sea, coast, and inland;
3) the timing of the coastline position is also constrained to the 12th and 16th centuries; during the interval between 3000 yr and the 12th the progradation of the coastline was about of 1,3 km and of about 500 m between the 12th and 16th centuries;
4) the estimate rate of progradation shows a significant increase since the 16th century to the present day testified by a progradation of the coastline of about 0,7 km;
5) evidence of four small high-frequency transgressive-regressive cycles within the succession recording the Late Holocene phase of progradation in the subsurface of the study area supports the hypothesis that the progradation took place irregularly.

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