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SUBSURFACE STATIGRAPHY OF MIDDLE PLEISTOCENE CONTINENTAL DEPOSITS FROM LIVORNO AREA AND BIOSTRATIGRAPHIC CHARACTERIZATION OF THE PLEISTOCENE SUBSTRATE (TUSCANY, ITALY)

Abstract - Subsurface stratigraphy of Middle Pleistocene continental Deposits from Livorno area and biostratigraphic characterization of the Pleistocene substrate (Tuscany, Italy). The main results of an integrat-ed study of 4 boreholes drilled in the subsurface of Livorno (NW Italy) are reported. Stratigraphic interpretations of the cores allowed the identification of 4 main lithostratigraphic units, that were corre-lated with units already described in literature. Integrating the results of the micropaleaeontological (calcareaous nanoplanクトon, foraminifers and ostracods), palaeontological molluscs and lithological data, it is possible to single out the environments and biostratigraphic constrains of succession. The micropaleaeontological study of the lower lithostratigraphic unit allowed the recognition of the «cold guest» Muellerina problematica and Cytheropteron testudo, thus supporting the correlation with the lower pleistocene Morrona Formation; in addition the top surface of this lithostratigraphic unit was also depicted. Results highlight that the «Corea formation» shows a wider variety of depositional environments than previously documented.

Key words - Livorno, molluscs, ostracods, «Corea formation», nanoplanクトon, Pleistocene.

Riassunto - Stratigrafia dei depositi continentali del Pleistocene Medio sottosuolo dell’area di Livorno e caratterizzazione biostratigrafica del substrato Pleistocenico. In questo lavoro sono presentati i risultati ottenuti da uno studio multidisciplinare di quattro sondaggi effettuati nell’area settentrionale del Terrazzo di Livorno. Attraverso l’analisi micropaleoantologica (nanoplankton calcareo, foraminiferi ed ostracodi), palaeontologica molluschi e litologica, è stato possibile caratterizzare, da un punto di vista biostratigrafico e paleoambientale, le varie successioni stratigrafiche individuate. Queste ultime vengono correlate con unità litostatigrafiche formali già note in letteratura. Lo studio micropaleontologico dell’unità litostatigrafica inferiore ha permesso la sua correzione con la Formazione di Morrona del Pleistocene inferiore, per la presenza di alcuni fossili significativi, come Muellerina problematica e Cytheropteron testudo, considerati «ospiti freddi». Si propone inoltre il possibile andamento nel sottosuolo della superficie di tetto della suddetta formazione. Viene inoltre messo in evidenza come la «formazione di Corea» sia caratterizzata da depositi relativi ad una più ampia varietà di ambienti deposizionali rispetto a quanto documentato precedentemente in letteratura.


INTRODUCTION

During the last few years, new studies about the Quaternary sedimentary successions of the Livorno area (NW Italy) allowed the definition of a new lithostratigraphic unit, called «Corea formation» (Zanchetta et al., 2006), dated to the middle-late Pleistocene (Zanchetta et al., 2004; 2006). These deposits contain abundant non-marine molluscs and micromammals fauna, suggesting not fully interglacial conditions (Zanchetta et al., 2006). The present work belongs to a project that has the aim to improve the knowledge of the subsurface of Livorno by means a multidisciplinary approach. In particular, the results of new analyses carried out on 4 continuously-cored boreholes, including lithological, main sedimentary patterns, faunal (terrestrial and freshwater molluscs) and microfaunal content (foraminifers, ostracods and calcareous nanoplanクトon) analyses are reported here. We focused especially on continental and marine deposits, relative to the «Corea formation» and Morrona Formation. These data may be useful for detailed reconstruction of the subsurface geometry of Livorno, with important implications in many fields (as protection of water resources, seismic risk assessment).

STRATIGRAPHIC FRAMEWORK

From a morphological point of view, the study area is located on the so-called «Terrazzo di Livorno» (Fig. 1), a polycyclic marine terrace developed during MIS 5 (Federici and Mazzanti, 1995), lying above marine early Pliocene - early Pleistocene deposits. The basal layer of the «Terrazzo di Livorno» is constituted by a coastal marine (shoreface) calcarenite, with an abundant molluscs fauna (Barsotti et al., 1974). This layer, containing a particular fauna (e.g. *Strombus bubonius*), can be connected with the MIS 5e (Hearty et al., 1986; Federici and Mazzanti, 1995; Mazu, 1999). The calcarenite passes upward locally to brackish deposits, and to a thin continental succession containing a rich freshwater molluscs fauna (Malatesta, 1942; Barsotti et al., 1974; Zanchetta et al., 2004) connected with the MIS 5d (Zanchetta et al., 2004). These layers are covered by a calcarenitic layer, mainly of eolian en-
environment, connected with the MIS 5c (Federici and Mazzanti, 1995; Mauz, 1999; Zanchetta et al., 2004). Reddened sandy silts with Fe-Mn nodules, presenting a decimetric heavily pedogenized layer of gravels that defines a clear erosional surface, close upward the «Terrazzo di Livorno» succession. These deposits were referred to the «Sabbie di Ardenza» (Lazzarotto et al., 1990) dated to the MIS 4 or 3 on the basis of the occurrence of Mousterian (Middle Palaeolithic) stone tools (Malatesta, 1940; Ciampalini & Sammartino, 2007). Deposits related to the middle Pleistocene terraces are also present in this area, the oldest of which, of marine origin, is represented by the «Conglomerati di Villa Umberto I» formation (Giannelli et al., 1982; Boschian et al., 2006), which overlies the «Terrazzo Fattoria delle Pianacce» (Barsotti et al., 1974). Northward this terrace is covered by continental deposits, referred to the «Casa Poggio ai Lecci» formation (Lazzarotto et al., 1990, Marroni et al., 1990). The «Casa Poggio ai Lecci» formation was divided into two units: «San Romano» and «Cava Ertà» (Zanchetta et al., 1998). The upper unit (Saint Romano unit) precedes the MIS 10 and it is subsequent to the Sicilian stage (Marcolini et al., 2003). On to the «Terrazzo Fattoria delle Pianacce» and between this and the «Terrazzo di Livorno», the «Sabbie Rosse di Villa Padula» formation, of eolian origin, was recognized (Giannelli et al., 1982). This formation results younger than MIS 10 and older than MIS 5. Fossiliferous sands and calcarenites (Bossio et al., 2008), have been recently interpreted as the marine transgression at the base of «Sabbie Rosse di Villa Padula» formation (Fig. 2). These data confirm the presence of an intermediate terrace (Salviano Terrace) between the «Terrazzo Fattoria delle Pianacce» and the «Terrazzo di Livorno», with an age that could correspond to MIS 7 or MIS 9.

The integrated study of terrestrial molluscs, Micro-mammals and pollens, supported by stratigraphic analysis, allowed the attribution of the «Corea formation» to the upper-middle Pleistocene (Zanchetta et al., 2006). Zanchetta et al. (2006) recognised 2 members, the lower dominated by a gravelly fluvial facies and the upper characterised by flood plain deposits. According to the proposed reconstruction, the lower unit was connected with the MIS 6 (MIS 6) while the upper one to the transition to the MIS 5.

The lower pleistocene deposits are subdivided in three distinct successions (Dall’Antonia et al., 2004). The lower marine successions is a transgressive-regres-
sive sedimentary wedge, mainly constituted by open marine environment (neritic zone) Santernian-Emilian sandy silts pertaining to the Morrona Formation (Boschian et al., 2006), followed by fine to medium-grained sands referable to the Emilian «Sabbie di Nugola Vecchia» formation (Lazzarotto et al., 1990; Dall’Antonia et al., 2004). Above, through an unconformity, lies a succession of marine gravels and sandy silts of Sicilian age (Dall’Antonia et al., 2004) referable to the Fabbriche Formation (Bossio et al., 1986).

**MATERIALS AND METHODS**

Three cores (P1, P2, P3) from Picchianti area (Livorno) and one from Filzi area (F1) were studied (Fig. 3). The depth of the boreholes ranges between 14 and 25 m core-depth (Fig. 4). The boreholes have been described, photographed and sampled in the field. Deposits texture and colour, type and presence of accessory materials, including, macrofossils, wood fragments, organic matter, and...
Palaeosols were used as basic tools for stratigraphic correlation.

Fifty-five anhydrous samples of approximately 150 g were analyzed for the microfossils content. Samples were disaggregated in warm deionised water (95°C) adding hydrogen peroxide, washed through a 63 µm sieve and finally dried in an oven at 110°C. The residue was analysed by an optical microscope to describe the micropalaeontological contents. A particular attention was required to the study of ostracofauna, in fact this group of microfossils is documented both in marine and continental environment. In order to facilitate the palaeoecologic interpretation, quantitative analysis were performed including both juvenile and adult specimens. Numerical tables, representing the number of specimens per 100 g of sediments, were generated for each core (Tab. 1). Seventeen species of ostracods have been photographed with S.E.M. (Pl. 1).

The continental molluscs found in the core drilled in the Filzi area were studied investigating 1/16 of...
Tab. 1 - Distribution of the ostracods identified in Picchianti boreholes.
Plate 1 - Microphotographs of selected ostracods taxa. All views external lateral (scale bars =100 μm)
washed residue coming from approximately 1 kg of sediment (Pl. 2, Tab. 2). As adopted in the earliest studies on the assemblages of terrestrial fossil molluscs of the Italian peninsula (e.g. Esu, 1981; Crispino & Esu, 1995; Zanchetta et al., 2006; Esu & Gianolla, 2009), taxa were subdivided into ecological groups according to the scheme proposed by Ložek (1964, 1986, 1990), reflecting analogues living species assemblages (e.g. Miller & Tevesz, 2002). Following recent systematic revisions many Bithyniids shells (i.e. those comparable to Bithynia tentaculata Linnaeus, 1758) are here generically reported as Bithynia/Pseudobithynia sp. (see for instance Glöer & Bössneck 2007; Glöer et al., 2007; Esu & Gianolla 2009).

Plate 2 - A) Valvata cristata, B) Gyraulus crista, C) Oxyloma cf. elegans; D) Bithynia cf. laechii; E) Bithynia/Pseudobithynia sp.; F) Succineidae; G) Galba truncatula; H-I) opercula of Bithynia/Pseudobithynia sp.
A total of seven smear slides were analyzed for the study of calcareous nannofossils. The smear slides were prepared applying standard techniques (Bown and Young, 1999) from unprocessed samples of cores P1, P2 and P3 (Fig. 4) and analyzed at 1250 X magnification using a Leitz polarizing optical microscope. The species recognized are referenced in Perch-Nielsen (1985) and Bown (1999). The adopted biostratigraphic scheme is that of Rio et al. (1990), improved by Raffi et al. (1993) based on quantitative definition of zonal boundaries. Among the selected taxa considered in the assemblages the Gephyrocapsa specimens were classified according to the biometric classification established by Raffi et al. (1993). Three groups were considered: small Gephyrocapsa (<4 μm); medium Gephyrocapsa (>4 μm <5.5 μm); large Gephyrocapsa (>5.5 μm). Data were collected applying quantitative methods by counting at least 300 specimens. The relative species abundances are presented in figure 3 and table 3.

An isobaths map representing the top of Morrona Formation was drawn, following the Thiessen polygon method (Burrough and McDonell 1998). A total of 36 boreholes, published and unpublished, were used for this map (Fig. 5).

RESULTS

Four informal lithostratigraphic Units (LU 1 to 4) were recognized in the cores located in the Picchianti and Shangai areas, here described from the bottom to the top (Fig. 4).

LU 1 Unit

LU 1 is mainly characterized by blue grey sandy silts including layers of fossiliferous sands and gravels (maximum grain size 6 cm) in the upper part. The minimum thickness, in the investigated boreholes, is about 10 m. The unit displays an erosional upper boundary with LU 2 unit. The planktonic foraminiferal assemblages generally include Globigerina spp., Globorotalia spp., Sphaeroidinellopsis spp. and Globigerinoides spp., showing an upwards tendency toward impoverishment and low specific diversity. Samples coming from the lower part of the unit contain Globorotalia inflata. The benthic foraminifers, very well represented in all samples, show rich and diversified assemblages. The arenaceous foraminifers include the genus Dotrothia, dominant in all the interval and other genera like Textularia, Martinottiella, Biogenerina and Saccammina sporadically present only in the lower part of the unit. The Miliolids are represented by Quinquiloculina, characterizing all the sampled interval. Pyrgo, Spiriloculina, Sigmoilopsis, Triloculina. The recognized genera of Rotalids are: Elphidium, Asterigerinata, Ammonia, Planulina, Basilina, Cassidulina, Brizalina, Bolivina, Uvigerina. The ostracods, mainly represented in the lower part of the unit, are generally rather rich and diversified. The lower infralittoral - circalittoral taxa as Krithe spp., Cytheropteron spp. and Cytherella vulgata are well represented, while Aurila convexa, A. cymbaeformis, Callistocythere spp. are rare. Towards the top, in agreement with the increase of grain size, the offshore assemblage is replaced by a shallow marine assemblage (upper infralittoral), characterized by the presence of A. convexa, A. cymbaeformis, Leptocythere multipuncata and Muellerina problematica.

Calcareous nannofossils are common in all samples from LU 1 showing good to moderate preservation. The main represented taxa are small specimens of Reticulofenestra, ranging in size from 3 to 5 mm; small specimens (>3.5 mm) of Gephyrocapsa containing G. muellaere, G. sinuosa, G. oceanica, G. ericsoni, grouped as small Gephyrocapsa, and some medium Gephyrocapsa (4-5 mm); Helicosphaera sellii, Helicosphaera carteri, Pseudoemiliammina lacunosa, Calidiscus leptopus, Calidiscus macintyreii, Coccolithus pelagicus (Fig.6, Tab. 3). The specimens of the genera Pontosphaera, Rhabdosphaera, Umbilicosphaera and Thoracosphaera (Tab. 3) are more rare and scattered. Reworked taxa from older sediments are present with cretaceous (Watznaueria, Micula, Aspidolithus), paleogenetic and neogenetic genera (Toweius, Dictyococctes, Discoaster, Sphenolithus).

LU 2 Unit

The LU 2 comprises well rounded polygenic gravels with a grey sandy or silty matrix (subunit 2a), passing to medium-fine grey sands or grey-blue silty-clays (subunit 2b) defining a fining upward trend. Its lower boundary is marked by an irregular erosive surface. The maximum thickness, in the investigated boreholes, is about 15 m.
Fig. 4 - Lithologic correlation among the recognized units.
The gravels contain pebbles (7-8 cm in diameter) of black chert, quartzite, jasper, sandstone and metamorphosed limestone and ophiolites. The collected macrofossils in the LU 2a are scarce and almost exclusively constituted by fragments of gastropods and marine reworked bivalves.

In the Picchianti area (P1, P2 and P3) the lower part of the subunit 2b is represented by sands with rare layers of gravels containing terrestrial molluscs (e.g. *Discus rotundatus*, recovered in the P1 borehole). Upward the sands are replaced by silt and grey-blue silty-sands, containing faunas constituted by brackish (*Ammonia tepida, Elphidium sp.* among the foraminifers; *Cyprideis torosa* among the ostracods) and freshwater species (*Candona neglecta, Ilyocypris gibba*, among the ostracods and moreover opercula of Bithyniids among molluscs).

In the Filzi area (F1 and L1) the grey sands, containing rare pulmonate gastropods (e.g. *Sphryadium dolium*), are overlaid by grey-blue silty clays containing abundant freshwater gastropods. The specimens are strongly fragmented and include apical portions and juvenile specimens of *Galba truncatula, Anisus spirorbis, Cyprideis torosa* among the foraminifers; *Candona neglecta, Ilyocypris gibba, Erpetocypris sp.* Many *Chara* oogons and skeletal fragments, probably representative of the genus *Bufo*, were also recognized.

The upper portion of LU 2b is dark for the abundant occurrence of organic matter locally passing to a peat layers which has been recovered also in outcrop in the Shangai area, adjacent to the Filzi area (Zanchetta et al., 2006).

**LU 3 Unit**

The LU 3 (2 m thick) is constituted by ochre-orange sandy silts and silty sands, with layers of fossiliferous calcarenite. The unit 3 has been recognized both in the Picchianti and in the Filzi areas. In the first area,
it consists of fragments of calcarenite, ochre yellow sands and sandy silts containing abundant spicules of porifera, eroded fragments of gastropods \((\text{Cerithium} \text{ and } \text{Murex})\), marine bivalves \((\text{Arca})\), remains of bryozoans and echinoids. Foraminifers are represented by the genera \((\text{Elphidium} \text{ and } \text{Cribroelphidium})\). In the Filzi area, instead, the ochre-orange sands are characterized by tiny fragments of molluscs. The sands are associated with layers of pebbles and slabs of calcarenite containing well preserved marine fossils, represented by gastropods \((\text{Cerithium}, \text{Alvania}, \text{Murex})\) and bivalves \((\text{Pectinids}, \text{Arca}, \text{Nucula})\).

**LU 4 Unit**

The LU 4 comprises yellow orange sandy silts and silty sands, with millimetric nodules of Fe-Mn (max 3-4 mm). In the Filzi area, rounded calcareous pebbles have been observed at the base. The LU 4, rarely exceeding one meter thickness, covers the «Terrazzo di Livorno» and is referable to the Ardenza Sands s.s. \((\text{Lazzarotto} \text{ et al.}, 1990)\). Silts and sands are barren of fossils and appear pedogenized \((\text{Inceptisol})\) \((\text{Mazzanti and Sanesi}, 1987)\).

**DISCUSSION**

**Considerations on LU 1**

The LU 1 presents rich and diversified microfossil assemblages. The benthic foraminifers \((\text{Dorothia, Textularia, Martinottiella, Bigenerina, Saccammina, Busitina, Cassidulina, Brizalina, Bolivina, Uvigerina, Elphidium, Ammonia})\) are indicative of the marine infralittoral environment \((\text{neritic zone})\), and the Plankton-Benthos \((P/B)\) ratio is < 1.

Particularly \((\text{Elphidium} \text{ and } \text{Ammonia})\), recovered only in the sample at –23.3 m of depth, are referable to shoreline environment, in which do not occur genera such as \((\text{Bolivina}, \text{Bulimina}, \text{Brizalina})\) characteristic of muddy poor oxygenized conditions.

In the lower part of the LU 1 the typical ostracods of open sea \((\text{Krithe} \text{spp.}, \text{Loxoconcha subrugosa, Cythereopteron ruggieri})\), \((\text{Cytberella vulgata})\) occur, while the shallower water genera \((\text{Aurila}, \text{Callistocythere, Loxoconcha})\) are under-represented. The exception is the sample collected at –23.3 m of depth in the P2 borehole, where the species \((\text{Aurila convexa})\) is dominant;
is associated with other shallow marine (upper infralittoral) taxa as *Carinocythereis*, *Aurila*, *Loxoconcha*. These species probably indicate a bathymetric decrease, that is also confirmed by the increasing grain size in the corresponding layer and by the strong decrease in the P/B ratio (sample at –23.3 m). Towards the top, the typical open sea assemblage is replaced by an inner neritic assemblage, characterized by the presence of *Aurila convexa*, *A. cymbaeformis*, *Leptocythere multiplicata* (P3). The presence of *Muellerina problematica* (P1, P2 and P3) and *Cytheroperon testudo* (P3) («cold guests» of the Mediterranean), together with *Sclerochilus contortus* (P3), could suggest a cooling phase. This interpretation may explain the presence, in some samples, of *Krithe* spp., a deep sea taxon which may rise to shallower water during episodes of cooling. Interest is to note that the pollen analysis, carried out on the samples of the LU 1 recovered from the K3 borehole in the Corea locality, confirms a climatic deterioration, suggested not only by the increment of percentage of *Abies* and *Betula*, but even by the abundance peak of *Picea* to the depth of –10,50 m (Zanchetta et al., 2006).

The presence of *Globorotalia inflata* (Gelasian-Present), from the base of the section (~24.00 m), and among the ostracods of *Loxoconcha subrugosa* (Pleistocene-Present) and *Muellerina problematica* (early Pleistocene), allows the attribution of the LU 1 to the early Pleistocene. This age is also confirmed by the presence of *Cytheroperon testudo* (early Pleistocene-Recent) (Aiello et al., 1996). Therefore, the LU 1 can be correlated with the Morrona Formation that represents the substrate of the «Terrazzo di Livorno» (Boschian et al., 2006).

The analysis of the calcareous nannoplankton confirms this attribution and allows to refer the LU 1 to a time interval corresponding to the zones MNN 19b of the early Pleistocene (Río et al., 1990), comprised between the highest occurrence of specimens of *Gephyrocapsa* larger than 3.5 mm, and the highest occurrence of *Calcidiscus macintyrei*, respectively dated to circa 1.73 My and 1.66 My in the Mediterranean (Raffi et al., 2006). The stratigraphic record of the LU 1 should be included within this interval of time.

Considerations on LU2

In the Picchianti area, the presence of polygenic gravels, maximum 6-7 m thick, in the lower part of the LU 2 (LU 2a subunit), is interpretable as produced by fluval channel deposits. The pebbles of black chert, quartzite, jasper, sandstone and metamorphosed limestone probably come from the Pisa Mountains and pebbles of ophiolites probably come from the Livorno Mountains.

In the P1 and P2 boreholes, sandy silts of freshwater environment (confirmed by the presence of specimens belonging to *Candonia* and *Ilyocypris* genera) are present above the gravels (LU 2b subunit). Upward the sandy silts passes gradually to clayey silts interpreted as probably coastal paleoenvironment with a sure marine influence, for the presence by terrestrial molluscs, of *C. torosa* and *L. ellipctica* among the ostracods and by *Ammonia* and *Elphidium* among the foraminifers. In the P3 borehole, the gravels are overlaid by coarse-grained sands, with scarce brackish faunas (*C. torosa*), possibly referable to mouth bar environment (Amorosi et al., 2003).

In the Filzi area the situation is partially different (Fig. 4-7). Although a lower layer of channel fluvial gravels with a thickness ranging from 3-4 m to 7 m, and a thin layer of grey sands of alluvial plain, are still present, the LU 2b subunit is represented by grey clays deposited in stagnant freshwater environment as evidenced by molluscs content. The significant number of continental molluscs, present in a sample from F1 borehole (Pl. 2, Tab. 2), allowed a more detailed study on the non-marine fauna.

Generally the assemblage is polytypic and primarily represented by freshwater species (Ecological group 10), in which fragmented shells and opercula of *Bitbina/Pseudobithynia* sp. are dominant (Pl. 2; Tab. 2). In particular this taxon depicts an environment prevalently consisting of calm or slow-moving waters, in which *Bitbina* cf. *laechii*, *Gyraulus crista*, *Planorbis* sp., *Planorbarius corneus*, *Pisidium* catarandum may also inhabit. The appreciable percentage of *Anisus spirorbis*, *Valvata cristata* and *Galba truncatula* also suggest shallow waters rich of vegetations. The presence of Succineids shells and *Oxyloma* cf. *elegans* (Ecological group 8-9) suggests the neighbourhood of occasionally flooded zones, swamps and very wet areas. Also ostracods (e.g. *Candonia neglecta*, *Ilyocypris gibba*) indicate freshwater environment. On the basis of the available literature, data about the ecology of the recovered taxa would suggest temperate climate (e.g. Bedulli et al., 1995; Bodon et al., 1995a, b).

The investigated samples of clay grey sands of the Shangai section have provided gastropods (e.g. *Valloinia enniensis*, *Vertigo antvertigo*, *Bythinia* sp.) and bivalves (*Pisidium* sp.), suggesting flood plain environment with running waters (e.g. Girod et al., 1980; Kerney and Cameron, 1987). On the contrary the samples recovered from the Filzi core, contain species of stagnant waters (e.g. Girod et al., 1980) probably referable to a lake. The ostracods of the Shangai area are qualitatively identical to those recovered in the core F1, but with a smaller specific abundance.

The LU 2, is lithologically and stratigraphically equivalent to the «Corea formation», recently defined in the northern part of the «Terrazzo di Livorno» (Zanchetta et al., 2006). The «Corea formation» has been currently recognized only in the northern part of the «Terraz-
zo di Livorno», even though continental deposits, probably referable to the «Corea formation» and assigned to the middle Pliocene through stratigraphic relations, have been recognized in the Villa San Giorgio area (Livorno) (Zanchetta et al., 2004).

In order to provide a better understanding of the relationships between the «Corea formation» (LU 2) and the underlying Morrona Formation (LU 1), the isobaths of the top of this later formation have been drawn, using all the published and unpublished stratigraphic data available for the area (Fig. 5).

The isobaths analysis, despite the inhomogeneous distribution of the data, evidences a general deepening trend towards north-west, ending in the erosive scarp of the «Gronda dei Lupi» (Targioni Tozzetti, 1768; Barsotti et al., 1974). A more accurate analysis shows a complex geometry of the substrate, with important changes on small distances (see also Fig. 7). The erosive surface, as shown above, corresponds to an erosive phase probably connected to a lowering of the sea level (MIS 6).

Considerations on LU 3

In the study areas, the LU 2 is covered by the LU 3. This unit, considered representative of a transgressive coastal environment («panchina»), can be assimilated to the Castiglioncello Sandy Calcarenites (Lazzarotto et al., 1990) and therefore correlated to the MIS 5e. The sands and the «panchina» layers can be considered the evolution of the LU 2, that from sands and silts of fresh water environment (fluvial deposits, alluvial plain), passes gradually to brackish deposits which culminate with the marine transgression of the late Pliocene (Tyrrhenian).

Considerations on LU 4

The LU 4 consists mostly of continental environment deposits (Lazzarotto et al., 1990), even if detailed studies of this units are still necessary. The LU 4 lies above the Tyrrhenian calcarenites through an unconformity; this unconformity corresponds to an stratigraphic hiatus related to the MIS 4, that in the Filzi area is marked by a gravel layer. In the near «Santo Stefano ai Lupi» (Malatesta, 1940) and in the Picchianti locality (Ciampalini and Saitta, 2007) Mousterian stone tools were found in the upper part of these deposits (corresponding to MIS 3-4).

CONCLUSIONS

This multidisciplinary study provides new data about the subsurface of Livorno and in particular: i) the

Fig. 7 - Schematic geological section across the north sector of Livorno area.
«Corea formation» is detailed and its distribution enlarged, and a rich fresh water malaco fauna is described; ii) on the basis of the new data the top of the Plio-early Pleistocene marine substrate of the studied area, is better delineated and chronologically constrained.

Four lithological informal units are recognized (Fig. 4): The LU 1, on the basis of micropalaeontological data, is referable to the Morrona Formation and datable to the zone MNN19b of the calcareous nanoplankton zonation. The presence in the upper part of this unit of *Muellerina problematica* and *Cytheropteron testudo*, «cold guests» of the Mediterranean Sea, supplies indications of cooling in the depositional environments.

The LU 2 (maximum thickness of 6-7 m) includes a basal layer of sands and sandy gravels of fluvial environment lying on the LU 1 with an erosive lower boundary. In the Picchianti area gravels pass upward to grey sands of fresh-brackish environment, and to sandy silts, with gastropods, referable to an flood plain. In the Filzi area the uppermost sediments are replaced by grey sands and clayey silts, of fresh water environment. On the basis of stratigraphic position and paleontological data the whole LU 2 is attributed to the middle-late Pleistocene and correlated with the «Corea formation». Within the «Corea formation» it was also possible distinguish different depositional environments not detailed before.

Besides the isobaths analysis of the LU 1 evidences a complex geometry of the substrate with a general deepening trend towards NW (Fig. 5).

The base of the LU 1 corresponds to a bedload river probably formed during regression phase of sea level. The erosive surface may have performed during the maximum decrease of the sea level in the MIS6. The LU 2b can represent a first phase of the sea level rise with diminishing sedimentary supply. If this reconstruction is correct the phase of the definitive marine transgression and highstand is represented by the overlying calcarenites (LU 3).

The LU 3 is composed of ochre silty sands associated with levels of calcarenites of coastal marine environment, dated to the late Pleistocene. This unit is referred to the Castiglioncello Sandy Calcarenites. The LU 4, referable to the «Ardenza Sands», consists of orange silts and silty sands of the late Pleistocene. In the Filzi and Shangai areas, at the base of this unit there is a conglomeratic level, which indicates a probable erosive event between the units 3 and 4.

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**References**


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