COASTAL ARCHAEOLOGY IN NORTH ETRURIA
North Coastal Etruria.
Geomorphologic, archaeological, archive, magnetometric and geoelectrical researches

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Résumé : Une équipe pluridisciplinaire formée d'archéologues, de géologues et d'ingénieurs présente les résultats de recherches archéométriques combinées au sujet de l'Etrurie côtière septentrionale qui correspond de nos jours à la partie septentrionale de la Toscane côtière.
Y sont discutés des problèmes de stratigraphie de l'ère Quaternaire, liés à la formation de bassins sédimentaires dus à la subsidence tectonique au cours du Pleistocène Inférieur. A propos du Pleistocène moyen et supérieur sont présentées les terrasses en rapport avec l'eustatisme glaciaire. En dernier lieu sont prises en considération des données sédimentaires et/ou archéologiques, littéraires et des archives, en vue d'étudier le niveau de la mer durant la période Holocène.
Les modifications considérables survenues sur le plan géomorphologique dans la région de Portus Pisanus ont été étudiées en détail.
Sont présentés en outre les résultats de recherches géophysiques effectuées sur d'importants sites côtiers, c'est-à-dire des sondages magnétiques dans le village protohistorique identifié dans la zone de Coltano (Pise) et des prospections géo-électriques effectuées dans un secteur du quartier portuaire de Vada Volaterrana (Ier-VIe s. ap. J.-C.).

Abstract : A multidisciplinary team (archaeologists, geologists, engineers) presents the results of integrated researches concerning North Coastal Etruria (now North coastal Tuscany).
Some aspects of Quaternary stratigraphy are shown ; they are connected to sedimentary basins formation by tectonic subsidence during the Lower Pleistocene. Concerning the Middle and Upper Pleistocene, we focus on the terraces connected with glacial eustacy. Finally, in order to study the sea level during the Holocene we consider sedimentary and archaeological evidence, together with archive and literary data. The remarkable geo-morphologic changes in the Portus Pisanus area are presented in detail.
The results of geophysical studies in relevant coastal sites are also shown : they consists in a magnetical survey in the protohistoric village in Coltano area and in geoelectrical researches performed in a sector of the harbour quarter of Vada Volterrana (I –VI cent. A.D).

Mots-clés : Etrurie côtière septentrionale, géomorphologie, archéologie, magnétométrie et prospections géo-électriques.

Key-words : North Coastal Etruria, geomorphologic and archaeological researches, magnetometric and geoelectrical surveys.

Some archaeometric aspects of multidisciplinary researches are presented concerning North Coastal Etruria (now North coastal Tuscany). The studied area (lower Arno and Serchio, Fine and Cecina river valleys : fig. 1) consists of an alluvional Holocenic plain mostly formed by sand and silt deposits and bordered by mountainous/hilly ranges (Monti Pisani in the North ; Colline Livornesi in the South).

At present the soil is mainly agricultural in the plain and lower hillslopes ; Mediterranean scrub covers the greatest part of the coastal strip ; woods are on the highest slopes of the inner hills.

In this area an intensive research programme is run by the University of Pisa (Dipartimento di Scienze Storiche del Mondo Antico) which includes geomorphologic studies, non destructive techniques applied to landscape and settlement archaeology, archaeological researches

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(intensive surveys, stratigraphic excavations, underwater archaeology) ; the study of written sources (ancient and medieval) (Pasquinucci and Menchelli, 1999). The study of artefacts includes archaeometric analyses of finds (metals and wares) (Del Rio *et al.*, 1996).

The data are processed in a diachronical perspective from the late Bronze age up to the early Medieval period. In the Iron age the urbanization process began in the areas afterwards occupied by *Pisae* and *Volaterrae*, the most important cities in the district.

Here the following case studies are presented :

1) Geomorphologic and archaeological researches applied to the study of the shore-line progradation.

2) Archaeological and environmental researches, magnetometric surveys carried out on the Isola di Coltano site (Pisa).

3) Geomorphologic, archaeological and archive researches in the *Portus Pisanus* area.

4) Archaeological and environmental researches, geoelectrical surveys performed in S. Gaetano di Vada (Rosignano M.mo, Livorno).

1 - THE SHORELINE PROGRADATION

Geomorphologic introduction

Concerning the stratigraphic aspects, coastal Tuscany corresponds both to the insular part of this region and to the continental strip that extends at most for about 30 km ; it is formed by the Lower Pleistocene marine sediments (fig. 1).

In this paper we accept the "classical" Quaternary division in Pleistocene and Holocene. The former is divided in :

- lower : the top of the magnetic event of Olduvai (1,720 BP) ;
- middle : from the magnetic inversion of Matuyama-Brunhes (0, 730 BP) ;
- upper : from the Tyrrhenian transgression (0,125 BP) up to the Holocene boundaries.

In Italy the last bound cannot be used in its original form corresponding to the bipartition of the Artic Icecap (8800 BP) (De Geer, 1940) since it never occurred in this country. Therefore this bound is drawn near to 0,010 BP.

Lower Pleistocene

In coastal Tuscany the lower Pleistocene shows two marine sedimentary cycles :

- the former (fig. 2) is dated back to Santernian-Emilian (Mazzanti, 1995) and is constituted both by littoral (Riparbella Conglomerates in the Cecina Valley and Villa Magrini at Castiglioncello) and deeper habitat sediments (Sands and clays including *Arctica islandica*) that are transgressive in the bottom, referable to the Santernian (Zone with *Arctica islandica*) and to the Emilian (Zone with *Hyalinea baltica*). This cycle is formed by littoral sediments located in the upper portions (Nugola Vecchia Sands, Luciana limestones and sands in the low Arno Valley and Montescudaio limestones and sands in the Cecina Valley) that are regressive on the top and attributed to the Emilian as containing *Mya Truncata* and *Terebratula ampulla*. These sediments can be up to 300 m thick at least.
- The second marine stratigraphic cycle (Fabbriche Sands at Rosignano M. mo) are transgressive on the Montescudaio formations. It is dated back to the lower Sicilian (Zone containing "small" *Gephyrocapsa* with calcareous Nanoplancton). These sediments are about 10 m thick.

The sedimentation of the Santernian-Emilian cycle is connected with the tectonic sinking ;

The lower Sicilian cycle is not interpreted since we lack data.

Erosion nests are located on the top of the Montescudaio limestones and sands, both near Rosignano M.mo and the Cecina Valley ; they are filled with fluvial and lacustrine S. Marco Conglomerates and marl-clays. Till now these sediments have not provided dating fossils.

The Bibbona Conglomerates, calcarenites and sands, transgessive both on the Montescudaio, Fabbriche and S. Marco formations, show a littoral *facies.* On the top they provide evidence of an intertidal shore containing antropic finds ("Pebble Culture" tools). These sediments are about 30 m thick ; their dating is not punctually precisable, but the range can be restricted between the lower Sicilian (Fabbriche Sands) and the overlaying Bolgheri Conglomerates (see below).

Middle Pleistocene

In coastal Tuscany the Middle Pleistocene includes (fig. 2) :

- Bolgheri Conglomerates (fluvial/flooded deltaic habitat) forming a terrace. They show deep pedocal modifications in the upper portions ("Ultisoils"). These modifications are most probably due to hot-humid climate long phases. This Terrace surely dated back to the Middle Pleistocene as it was partially eroded during the trangressive phase which formed the Tyrrhenian Terrace.
- Casa Poggio ai Lecci Conglomerates, sands and silts (fluvial/marsh habitat) ; they are located :
- near Montopoli (Arno Valley) ; in the top they include both tuffites dated back to 0,590 +- 0,080 BP and floated tools (Ancient Acheulean and Clactonian cultural phase) ;
- near Livorno, with tools dated back to the Recent Acheulean phase.

The Middle Pleistocene Terrace includes also the following formations :

- Villa Umberto I Conglomerates in the Livorno hinterland, containing both pebbles drilled by Lithodomi and thin levels of calcarenites.
- Spianate Gravel and Sands in the Castiglioncello hinterland showing the same stratigraphic position.
- Podere Pescinoni Sands, gravel and calcarenites in the S. Vincenzo hinterland.
- Punta Avoltore sandstones containing marine molluscs in the Southern Argentario coasts.

The Val di Gori Red Sands overlay all the above mentionated sediments, with two different stratigraphic position (both with conformity and unconformity of sedimentation ; in the latter case by filling erosion nests). These sands show mostly aeolian, partly colluvial *facies* ; they underwent deep pedogenetic modifications in palexeralfs Alfisoils. On common opinion, the development of these soils corresponds to the last interglacial phase (Lower Pleistocene) when they covered more ancient deposits dated back to the Middle Pleistocene. The Clactonian and Acheulean tools found in the Val di Gori Sands give evidence of this chronology.

The discrimination of the Middle Pleistocene sedimentarian by formations has been carried out on the grounds of different both lithologic and pedologic *facies*. The morphologic peculiarities are less evident because of the sediments exiguity (marine ones : maximum 1 m deep ; continental ones : maximum 10 m deep).

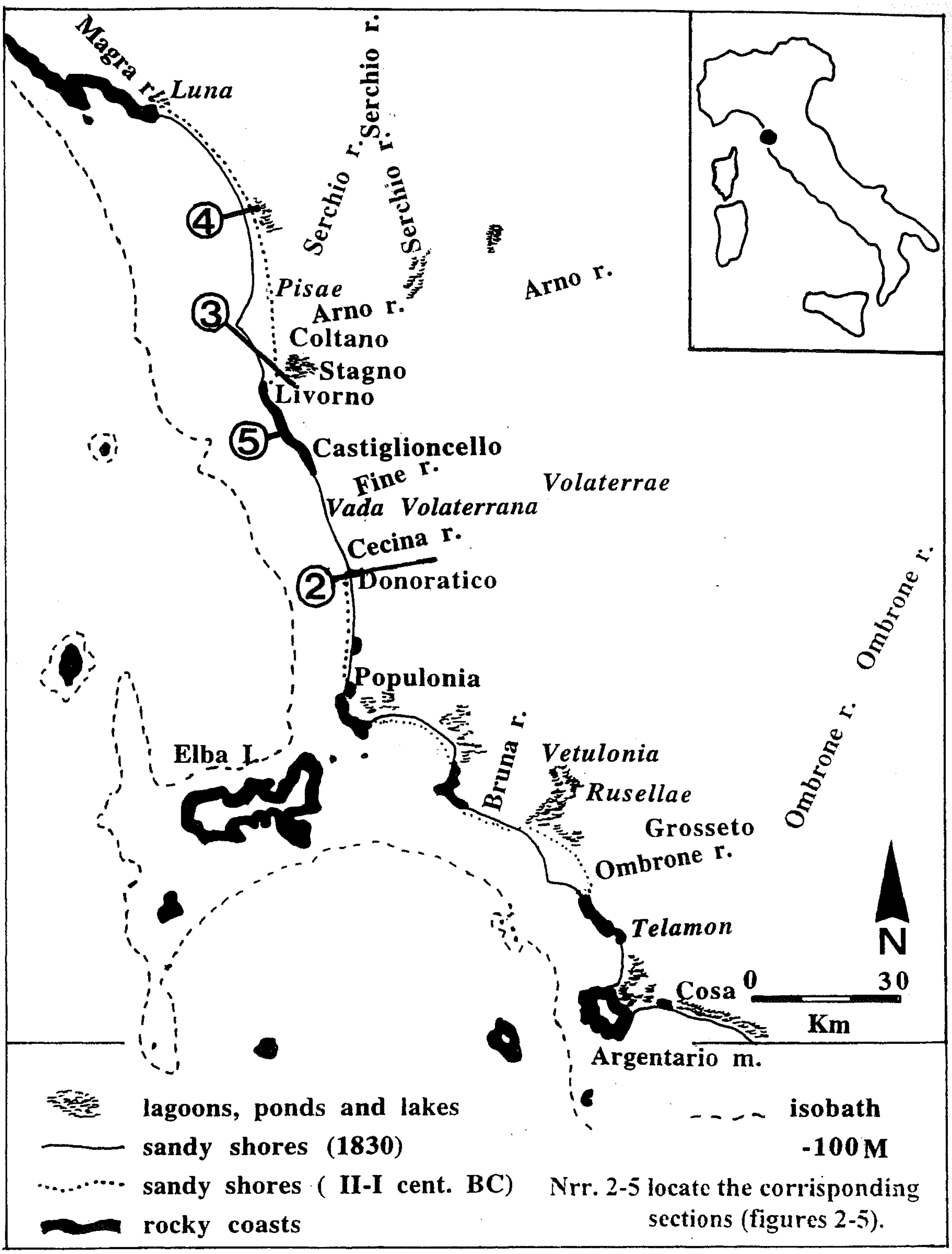


Fig. 1 : Coastal Tuscany.

It entails that all the above mentioned sedimentary units are included in the Middle Pleistocene Terrace that is considered a single morphologic unit, even if it was developed in different cycles (Federici and Mazzanti, 1995).

Upper Pleistocene

The Pleistocene sediments have been divided into two different chronological intervals (Shackleton, 1969) :

- the Ancient one includes Tyrrhenian Eustatic cycles, characterized by three transgressive phases respectively referred to the O^{18} sub-stage 5e, (about 0,125 BP), 5c (about 0,110 BP), 5a (about 0, 090 BP).
- The Recent estends between the Würm I Glacial apex -O^{18} isotopic stage 4 (about 0,075 BP)- and the Holocene bound. This interval includes the Würm II Glacial apexes (about 0,050 BP) and Würm III (about 0,018 BP).

The first Tyrrhenian trangression deposits (5e) are well studied and documented in the coastal strip near Livorno, Rosignano and at Cala dei Turchi in the Pianosa island thanks to the fossils (Castiglioncello Calcarenites). The

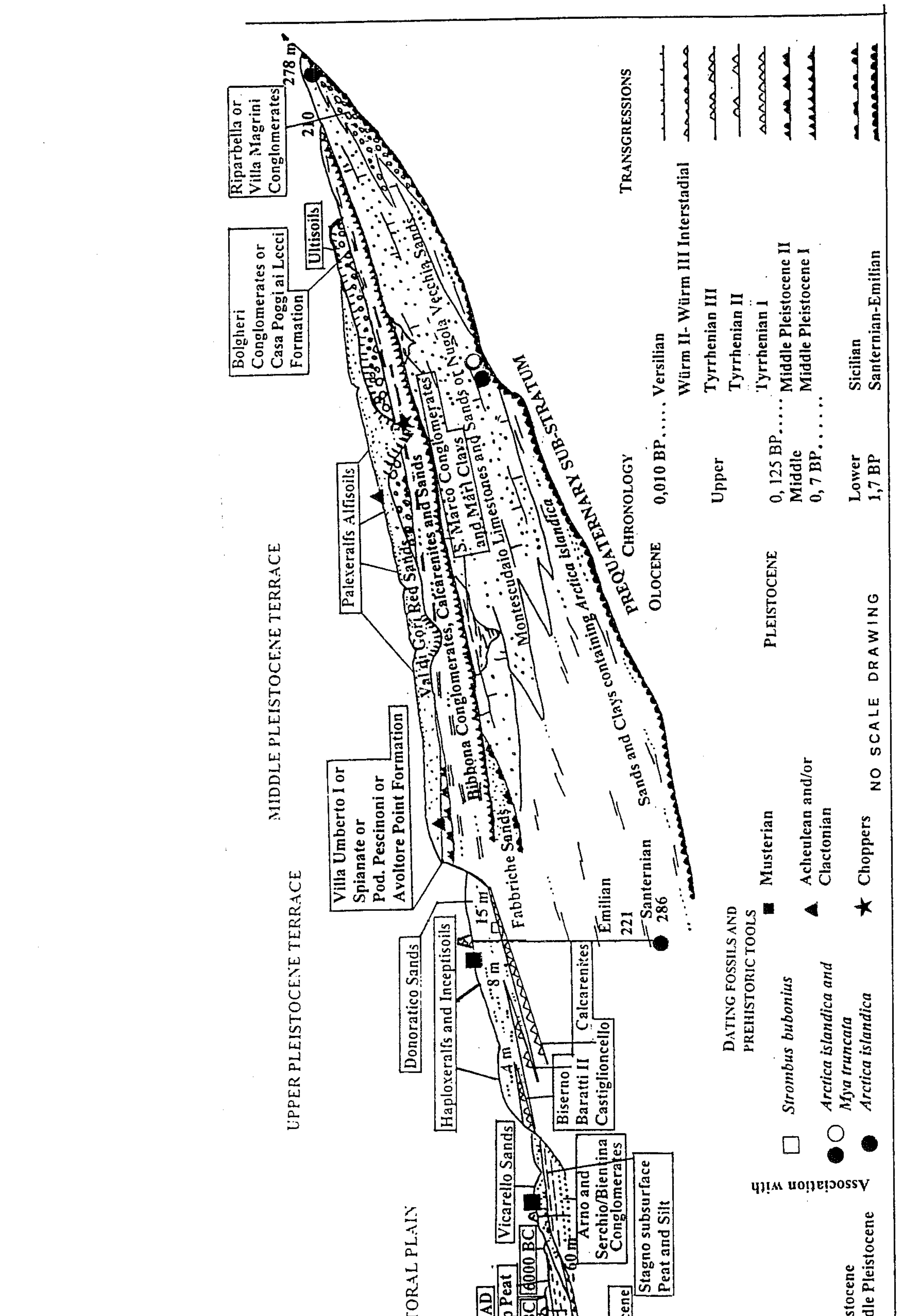


Fig. 2 : North coastal Etruria. Schematic geological section. For the location see fig. 1.

marine portions of these deposits are 15 m maximum thick (Mazzanti, 1995).

The second Tyrrhenian trangression deposits (5c) have been identified in the Livorno coastal strip, in the Vada subsurface and in the Baratti Bay near Populonia (Baratti II Calcarenites). The marine portions of these deposits are 8 m maximum deep.

The third Tyrrhenian trangression deposits (5a) have been recognized in the Baratti Bay (Biserno Calcarenites) and in the Tyrrhenian Argentario shore, in the cave in the Cala dei Santi inlet. The marine portions of these deposits are 4 m maximum thick.

Each of the three trangressions deposits is covered by Donoratico Sands (lagoon or marsh transition sediments or mostly aeolian or colluvial continental deposits). All these sediments contain cold climate pollinic association : intratyrrhenian I (5d) and intratyrrhenian II (5 b).

The cores carried out near Stagno, in the southern bound of the Pisa plain, showed Arno and Bientina-Serchio Conglomerates at a depth between - 57 and - 60 m. The deep fluvial incision covered by these Conglomerates is connected with the Würm I Biostatic anaglacial phase ; the main deposition phase is referred to the Würm I Resestatic cataglacial phase. These conglomerates have been identified in most part of the Pisa plain ; the cores showed they were covered by lacustrine-marshes "Stagno subsurface silt" (fig. 2 and 3) (Federici and Mazzanti, 1995).

In the Versilian subsurface we know levels probably corresponding to the former ; they are respectively the Gravel and Conglomerates found 30 m deep (up to 137 m) by means of drillings and the overlayng lacustrine dark Clays settled by a drastic fluvial transport during the Würm I (fig. 4). These levels were covered by a thin layer of sand and gravel containing marine gasteropodes (interstadial Würm I - Würm II) and by an overlaying 20 m thick clay level containing lacustrine and brackish fauna. The last level can correspond to the Würm II regressive eustatic sub-stage.

In the Pisa plain the Vicarello sands crop out in Palazzetto, Castagnolo, Coltano and Montacchiello. The drillings give evidence that these sands overlay the "Stagno subsurface silt" in conformity (fig. 2 and 3).

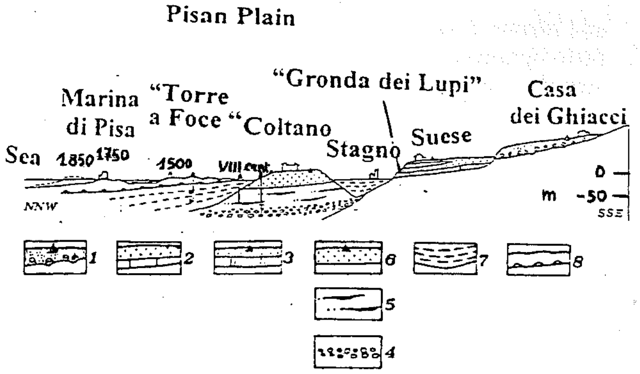
The Vicarello sands are due to an aeolian deposition during an interstadial Würm II-Würm III, as confirmed by the conspicuous presence of Musterian tools. This interstadial is well known also in the Versilian subsurface where it corresponds to the alternation of sands containing shore molluscs and clays with *Vitis vinifera* seeds, that are evidence of a temperate climate.

Holocene

In coastal Tuscany the Holocene sedimentary deposition has been studied in the Versilian subsurface (Federici and Mazzanti, 1995) : it is constituted by Siliceous Sands with marine fauna characterized by the presence of *Thais haemastoma*. This formation is about 50 m thick : its fossils have been dated as follows :

- molluscs drilled out - 47 m : 8940 +- 273 BP ;
- molluscs drilled out - 26 m : 5646 +- 200 BP ;
- a fragment of *Pinus Silvestris* from the same formation : 5280 +-50 BP.

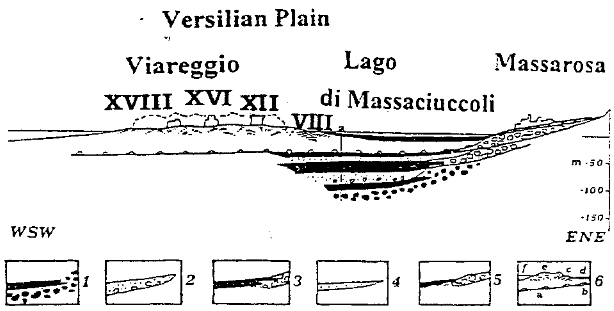
Other drillings near the Massaciuccoli Lake give evidence that the Versilian transgression reached the western portion of Monti d'Oltreserchio (between Alpi Apuane



No horizontal scale drawing

Livorno Hills and Pisan Plain. Schematic geologic section. 1: Casa Poggio ai Lecci Conglomerates and sands containing Acheulean tools (Middle Pleistocene); 2: S. Stefano Conglomerates in the bottom and Castiglioncello sandy Calcarenites (Tyrrhenian first cycle); Intratyrrhenian orange sands; 3: sandy Calcarenites (Tyrrhenian second cycle); sands containing middle Paleolithic tools (non later than Würm II); 4: Würm Arno and Serchio/Bientina Conglomerates; 5: fluvial and marsh silt; 6: Vicarello aeolian sands containing middle Paleolithic tools (non more ancient than Würm II); 7: fluvial and marsh silt following the Würm III maximum erosion (oak grove Atlantic phase); 8: Versilian transgression sediments.

Fig. 3 : Livorno Hills and Pisan Plain. Schematic geologic section. For the location see fig. 1.



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Lago di Massaciuccoli. Schematic geologic section. 1: Gravel, conglomerates, lacustrine gray clays (black upper part); 2: marine sands; 3: lacustrine and brackish clays (black); laterally alluvial cone conglomerates; 4: : marine sands; 5: lacustrine clays; laterally alluvial cone conglomerates; 6: a= Versilian transgression with siliceous marine sands containing *Thais haemastoma*, b = alluvial cone conglomerates, c= barrier beach deposits with archaeological finds (VIII cent. BC), d= present peat ad lacustrine deposits (pollinic association with *Abies*, *Alnus*, and Sub-boreal *Picea*), e= beach and aeolian deposits (later than VIII cent. BC), f= sea and existing deposits.

Fig. 4 : Lago di Massaciuccoli. Schematic geologic section. For the location see fig. 1.

and Monte Pisano), in relation with the "oak grove" climate optimum (Atlantic phase). The Versilian transgression developed after the Würm III deepest Glacial phase (sea level about -110 m) and is still active ; nevertheless it had been at least twice characterized by a relative drawdown of sea level (- 2 m) : they are respectively dated back to 6500 BP and 3500 BP (Alessio *et al.*, 1992).

In the high rock coastal strip a sea level drawdown 2 m deep usually doesn't cause the horizontal displacement of the coastline, but in a low sandy shore it can produce the littoral emergence up to hundreds of meters. In the low littoral areas the above mentioned regressive Phases originated lakes and lagoons. In coastal Tuscany it occurred in the following areas : Massaciuccoli, Stagno (see below : points 2 and 3), Vada (see below, point 4) and Piombino-Follonica.

After the last regressive Phase, the Versilian transgression started again ; the sea level progressively raised up to the present days altitude as the modern tide gauges recordered in the last two centuries.

Another important factor in the formation of the low and sand littoral is constituted by the presence of a big river mouth gathering fluvial sediments.

The main rivers flowing in the Tuscan sea are : Magra, Arno/Serchio and Ombrone. As shown in the fig. 1 and 6, in Tuscany the sandy littoral grew from the VIII century BC only in the areas reached by the main rivers. At present, the other soft littorals with no wide rivers (in the Piombino gulf and North of Populonia) lie behind the VIII century shoreline.

In general the growth of the beaches depends both on the sea level position, on subsidence and fluvial solid deposits. In the Tuscan littorals we know excellent cases concerning it :

- the first factor is visible along the Livornese rock coast, in particular in the Calafuria area where Oligocenic steady rocks show evidence of ancient quarry activities. Today the bottom of these carries cuts is m 1,65 deeper than the sea level (fig. 5). Moreover, in the same Livornese steady coast, near Castiglioncello, an Ellenistic tomb cut in the Giurassic ophiolitic portion has been dredged up from the bottom at - 1,20 m under the present day sea level (Galoppini *et al.*, 1994) ;

- concerning subsidence, the most remarkable datum is given by drillings carried out in the Versilian-Pisan plain. The same Würm I level has been identified at -60 m in the Stagno area, -120 m in the Pisa subsurface and - 137 m in the Massaciuccoli Lake area.

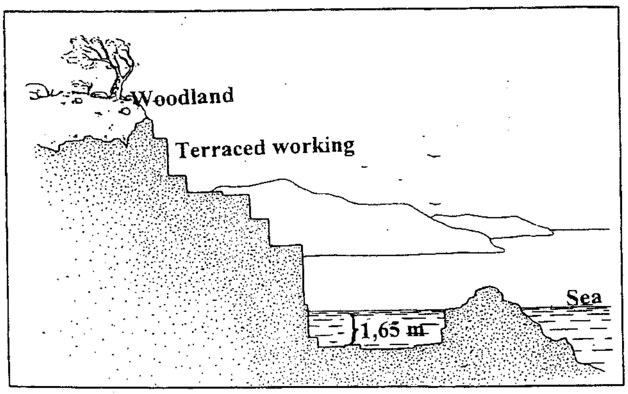


Fig. 5 : Livornese rock coast. The quarry working. For the location see fig. 1.

- The results of the fluvial solid transport are evident in the fig. 1 and 6 where the VIII century shoreline is focussed between Luni and Livorno ; the II-I cent. BC shoreline is identified between Donoratico and the Ombrone mouth. In these figures the ancient shores moved forward more than it is today ones, mostly in relation with the main rivers mouths (7 km in corrisponcence of the Arno river ; 10 km in the Ombrone area). On the contrary, the shores reached by little rivers receded : in the Donoratico - Bruna river area, the IV-I cent. BC deposits are about 1 m deeper than the modern sea level. The dating of these shores is provided by the conspicuous presence of Etruscan iron slags. (AA.VV., 1985).

There is no direct evidence of the causes that produced the great fluvial deposits ; we know this phenomenon came to end in 1830, when the solid transports started to be removed from their destination to the sea and diverted in the swamp filling lands. At the end of the XIX cent. the erosion of the Arno and Ombrone forward deltas began ; on the contrary, the Magra river never had a delta mouth because it flows in a narrow, mountainous valley where fillings have never been carried out. All said above points out the close relation between the fluvial solid transport and the beach growth.

As shown in fig. 6, the ancient Pisan-Versilian shoreline has been delineated by means of the dating sites : the sites located eastwards are more ancient than or contemporaneous of the II-I cent. BC chronology ; west of the shoreline, the identified sites are more recent. In southern Tuscany, the same phenomenon is recorded with more continuity and preciseness : the chronological datum is provided also by the precence of iron slags beaches (see above). In the northen Grosseto littoral these shores are submerged by the sea ; on the contrary, in the central-southern Grosseto littoral the II-I cent. BC shoreline runs at the rear of the barrier beaches dividing the sea from the inner lake. This lake was filled by Ombrone deposits in the XIV cent., while in the sector reached by the river Bruna a little swamp survived up to the XIX cent. and was drained in 1920-1930 years.

The evolution so different in the same or in contiguous shores in a period characterized mostly both by the sea level raising and by absence of drastic climatic changes was most probably due to antropic causes. Among these, the main element was the deforestation, due both the metallurgic and agricultural activity. The first developed mostly from the VII cent. BC up to the II-I cent. BC (AA.VV. 1985) ; the second was increased by the *centuriatio* carried out in the triumviral-augustan period (Pasquinucci and Menchelli, 1999).

2 - ARCHAEOLOGICAL AND ENVIRONMENTAL RESEARCHES, MAGNETOMETRIC SURVEYS CARRIED OUT ON THE ISOLA DI COLTANO SITE (PISA)

Excavations have been carried out on the Isola di Coltano site (fig. 1 and fig. 7) where a Bronze age village has been identified (Pasquinucci-Menchelli 1997). No evidence of huts or waste foods has been found ; the antropic layers were formed by mounds of fragmented coarse vessels (more than 10.000 fragments have been found). The village was located on the banks of a coastal lagoon (fig. 1) which repeatedly submerged the area. The lagoon flood is documented by yellow silt deposits containing a lot of molluscs (mostly *Cerastoderma edule*) covering the antropic layers. These molluscs are characteristic of

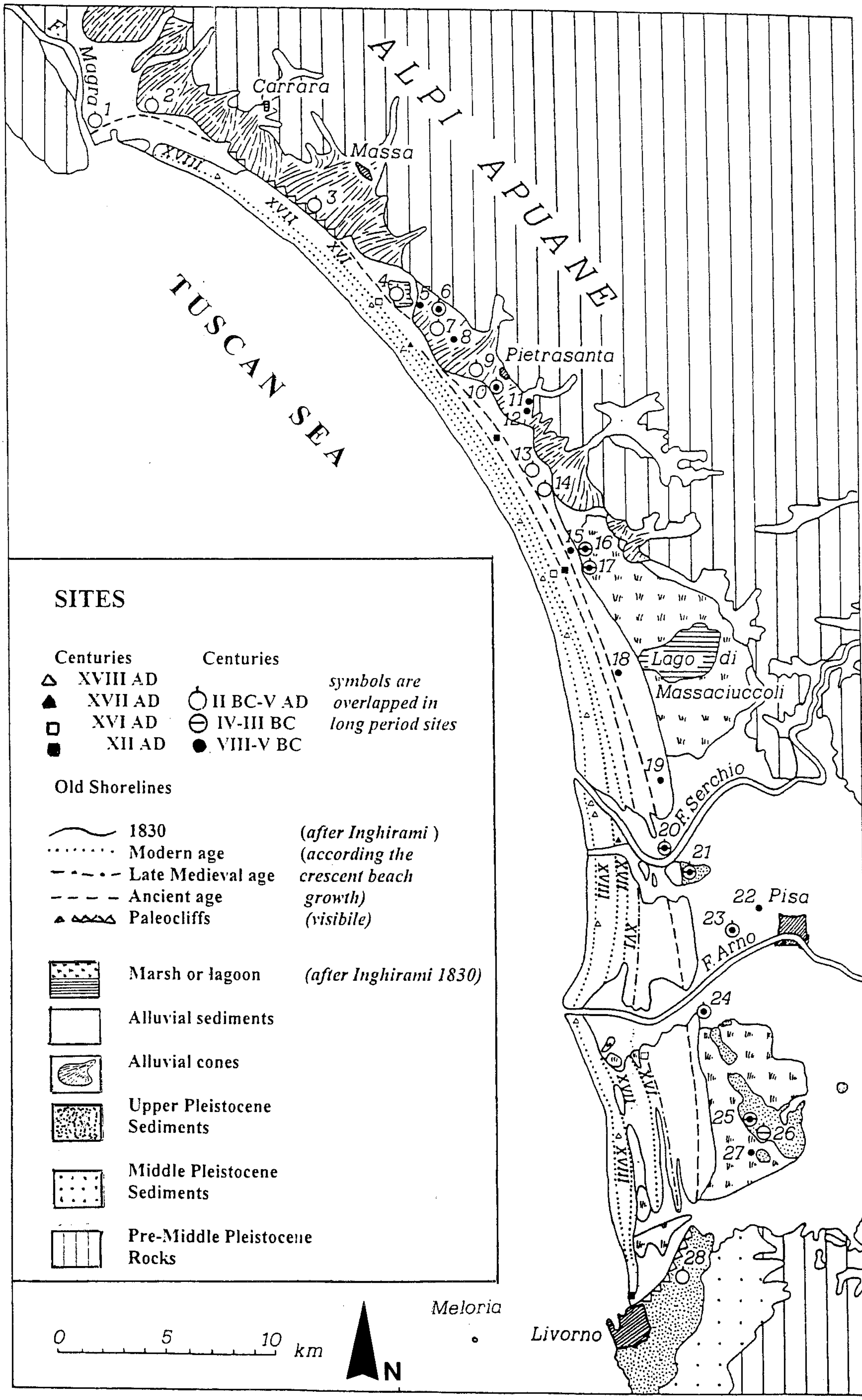
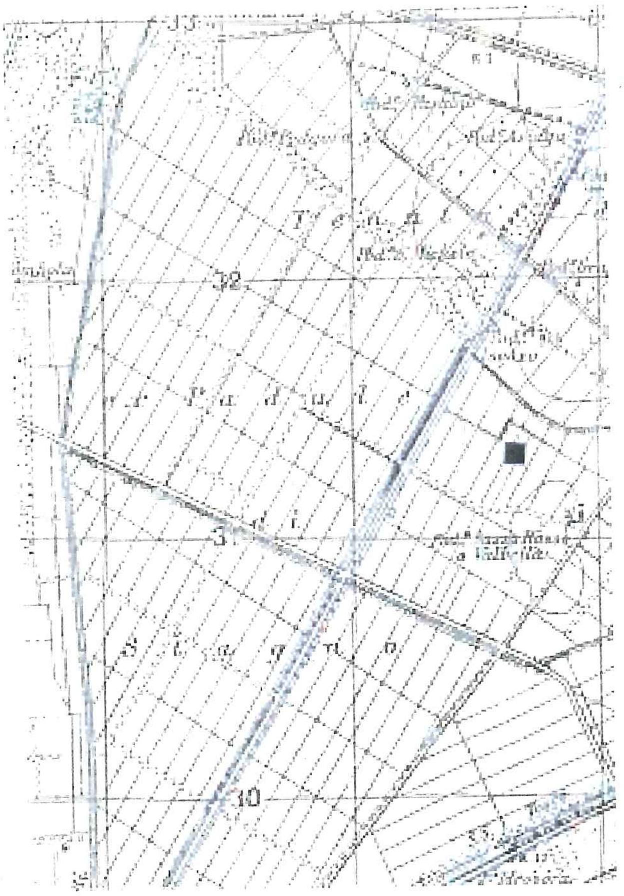


Fig. 6 : The Pisan-Versilian shoreline diachronical changes.



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■ The archaeological site

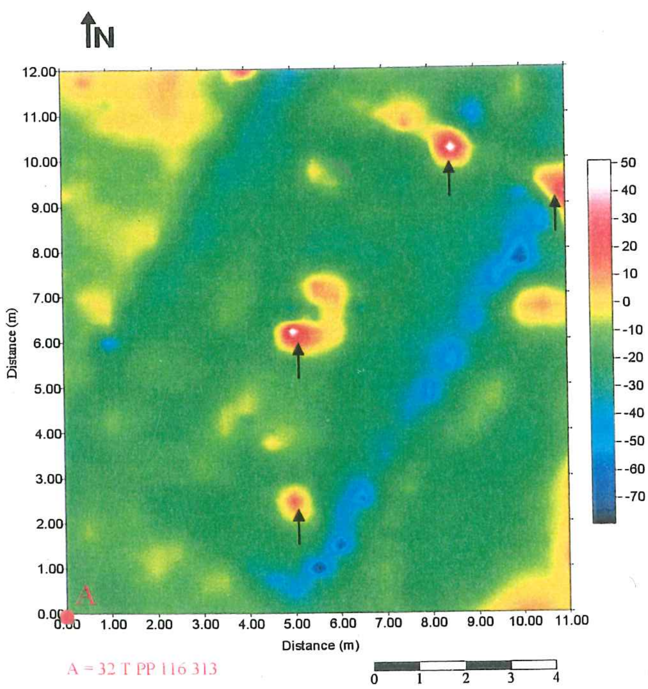

Fig. 7 : Isola di Coltano (Pisa). The magnetical survey.

a low brackish marine habitat, so as that one of a lagoon. They belonged to various biologic cycles as the identification of different dimension individuals has shown ; their valves were closed : it provides evidence they died *in loco*. These data are very meaningful because they contribute to delineate the palaeo-environmental situation (see above).

A detailed magnetic map of the site has been produced and four anomalies areas were identified (fig. 7, for the location A= 32 T PP 116313). The subsequent excavations proved that the anomalies were markers of the presence of fireplaces. Nearby some firedogs have been found ; a coal sample taken out from one of these fireplaces, analysed by the Centre for Isotope Research at Gröningen, was dated back to 3500 BP +- 90 (1686-1538 BC calibrated date).

Archaeological and ethnographical studies provide evidence that bowls similar to Coltano vessels are common in the protohistoric sites specialized for the sea salt production. It is likely that in the Coltano area people gathered salt by means of coastal lagoon water evaporation ; afterwards the product was boiled in the vessels in order to refine and reduce it into salt lumps. The vessels were often broken to recover the precious product.

The site strenuous reoccupation, in spite of the lagoon flood, gives evidence that the village position was strongly useful for the economic activities of its inhabitants.

Other Middle/Late Bronze villages specialized in salt production can be identified along the Tuscan coasts : it is evidence of an intensification of production. The increased salt demand probably was caused by the development of sedentary and transhumant sheep-breeding, well documented by archaeological finds (Zanini, 1997, ed., passim).

Geochemical research on the Isola di Coltano soil is in progress ; gascromotographical analyses on the vessels are planned in order to study the traces of the contents.

Isola di Coltano. The magnetical survey

Due to the obvious lack of structural remains in such an archaeological contest, the magnetic method seemed the most suitable to give positive results. The possibility of individuating ancient fireplaces by means of a magnetometric survey has been discussed by Aitken 1974. The physical reason is the thermo-remanent effect (with mechanism explained by Le Borgne : see Scollar *et al.*, 1990, 397-401) due to the heating of the rocks under the fires.

As the expected anomalies were very small both in intensity and in spatial amplitude, a very detailed survey was planned (measurements every 0.25 m ; the field sensor at 0.5 m height). The main problem came out to be the strong noise with sudden changes of the background values for several tens of seconds or some minutes. This kind of noise has been ascribed to the railways. In Italy their power lines are at 3000 Volt DC and the absorption from a train can be more than 1000 A. The main line Roma-Pisa-Genova is about 3 km East of the site. As this kind of noise cannot be filtered out in the frequency domain, the strategy was to use a base station near the field, with a second fixed magnetometer recording the time variations due to the disturbances. The aim is to use this time-story to depurate the field measurements. The acquisition at the measuring magnetometer and at the fixed one was simultaneous to reduce to a minimum the errors due to the interpolation of the base station values used to correct the field values.

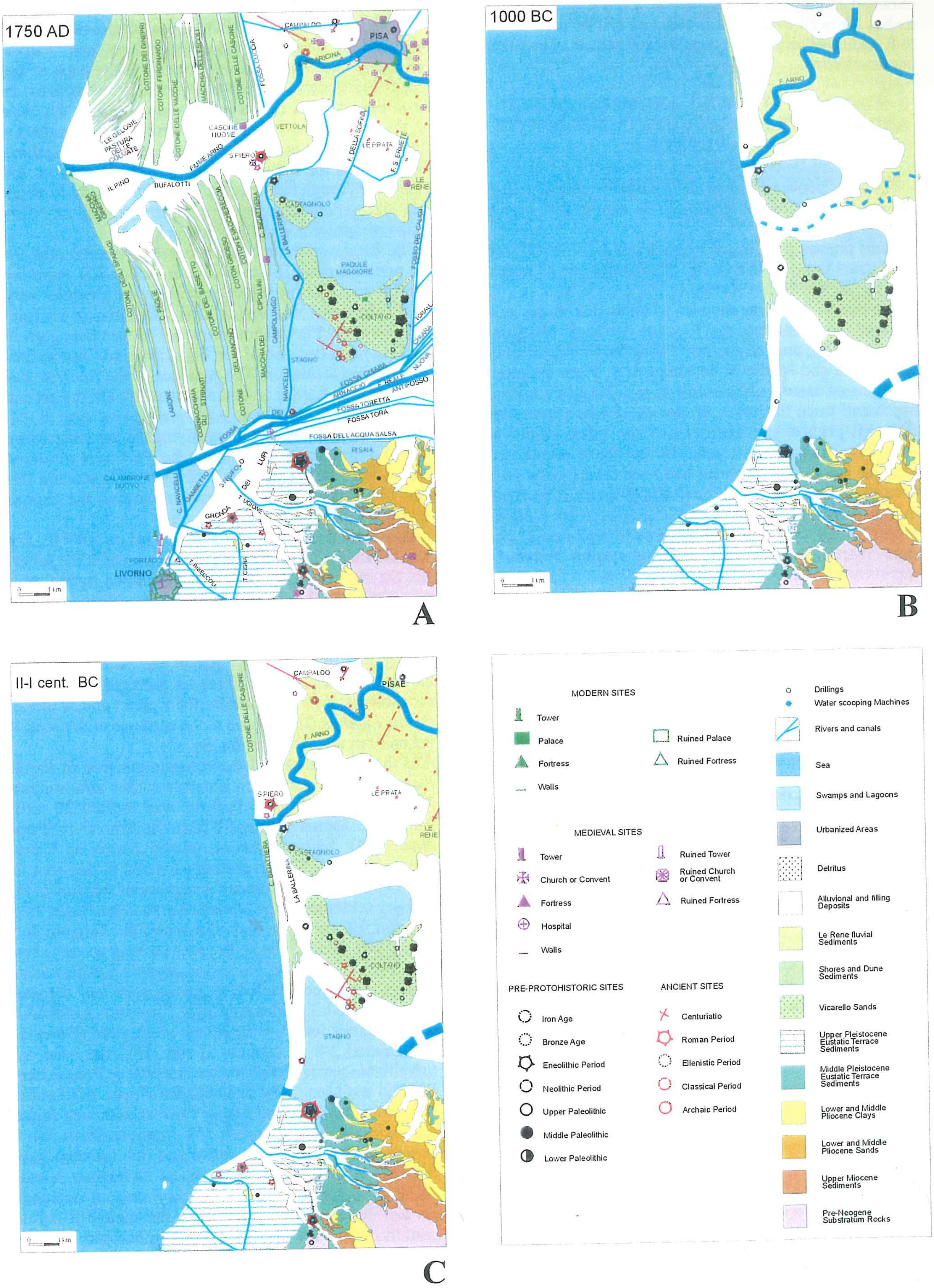

Fig. 8 : The area between *Pisae* and *Portus Pisanus* in a diachronical perspective.

The total field map obtained after the data processing is shown in fig. 7. Also a map of the vertical gradient was obtained, but it was more disturbed. In the map three anomalies are well evident (a fourth one can be seen at the N-E corner, but it was not considered because of possible border-effects).

3 - GEOMORPHOLOGIC, ARCHAEOLOGICAL AND ARCHIVE RESEARCHES IN THE *PORTUS PISANUS* AREA

The area between Pisa and Livorno is represented in the geo-archaeological map (fig. 8) and in the stereograms (fig. 9).

Three phases are referred respectively to 1750 AD (see fig. 8a and 9a) ; 1000 BC (fig. 8b and 9b) and II-I cent. BC (fig. 8c and 9c).

The fig. 8a has been choosen to show that in the area between the river Arno, the "Gronda dei Lupi" (Targioni Tozzetti, 1768) and the ancient "Fossa dei Navicelli" only the Roman and Medieval buildings at S. Piero a Grado, the ruins of a medieval church in the Bigattiera barrier beach and three fortresses for coastal defence were present. All prehistoric, ancient and the other medieval sites were located eastwards. In the above mentioned area the natural environment had been modified by : the Canale dei Navicelli excavation (XVI-XVII cent.) ; the Arno mouth deviation near Bufalotti (1606) ; the Calambrone Nuovo Canal excavation (around XVI cent.) ; the sandy barrier beaches and swamps system is clearly represented.

Fig. 9a shows the morphologic surface of most of the area represented in fig 8a and two geological sections respectively NS and WE. The first section shows the Lower Pleistocene Terrace with the two Tyrrhenian Phases (I and II) ; it is discordant with the underlying Sands and clays containing *Arctica islandica* ; these are discordant, too, and cover the Pliocene Blue clays. The Würm-Olocenic layers (Arno and Serchio Conglomerates, Olocenic peats and silts and Versilian transgression sediments) lean against the erosion surface called "Gronda dei Lupi".

The WE section shows Arno and Serchio Conglomerates and "Stagno subsurface silts" covered Eastwards by Vicarello sands and Westwards by Olocenic peats and silts that are overlaying the Vicarello sands. The marine habitat Versilian transgressive sediments cover the Olocenic peats and silts up to the Western boundary of the Vicarello sands (Galletti Fancelli, 1978).

Fig. 9a shows also the surface morphologic units :

- the Lower Pleistocene Terrace is located between Livorno and Casa ai Lecci ;
- the Gronda dei Lupi in the southern border of the Terrace ; Vicarello sand outcrops near Coltano and Castagnolo ;
- Olocenic Pisan plain with Rene alluvional sands surrounded by the lacustrine/swampy floods deposits ;
- westwards of Canale dei Navicelli and Gronda dei Lupi between San Piero a Grado and Livorno sandy shore barriers and swamps system. They developed between the acme of the Versilian Transgression and the local Regressive Phase due to the great quantity of solid fluvial deposits transported by the Arno.

Fig. 8b shows the reconstruction of the same area around 1000 BC. The sea extends :

- up to the Gronda dei Lupi ;
- up to the Westernmost barrier beach (Campolungo) and its extension up to the Arno Mouth.

We can see three great wet areas afterwards respectively called "Stagno", "Palude Maggiore" and "Palude di Castagnolo" ; the first was located at the back of the Upper Pleistocene Terrace and probably reached by an Arno branch. The others were respectively at the back of the Coltano and Castagnolo sandy outcrops. In Le Rene area we focus a possible Arno branch dividing these sandy formations. Finally, the Arno river ran from the Pisa area through the Vettola ; its mouth was South of the San Piero a Grado area (see together with fig. 8a). This phase is rapresented in the stereogram 9b.

Fig. 8c shows the reconstruction of the same area for the period around II-I cent. BC. In about 800 years the coastal and hydrographical peculiarities changed very little : the coast was steady along the Gronda dei Lupi because of the Pleistocene Terrace. The shoreline grew in the Pisa plain because of the Bigattiera and Cascine barrier beaches formation. The presence of the Ancient sites in the emerged areas is well documented. On the ground of Strabo 5.2.5, the Stagno Arno branch was most probably still active. Anyway it was dying out by comparison with the situation represented in fig. 9c where this Arno branch is shown cutting both the Upper Pleistocene Terrace and part of its substratum and causing the Gronda dei Lupi formation.

The Gronda dei Lupi coastline was set up SW-NE, that is in the same direction of the prevailing wind, the Libeccio. So, the sea storms were damped down by the wave refraction near the coasts ; moreover it originated around the Meloria schoals located 10 km South/West of the Gronda in the offing. When the sea storms were too violent, it was possible to shelter in the Southern part of the Stagno. This area, thanks to its good geomorphologic peculiarities, was occupied by the Roman and Medieval *Portus Pisanus*. The Towers at the entrance of the Medieval harbour are visible in fig. 8a.

In the imperial period the accurate position of *Portus Pisanus* is provided by an itinerary source (***Itinerarium Maritimum***, 501) : the harbour was located 23 *milia* from *Vada Volaterrana* and 9 from the Arno river (*Pisae fluvius*). An harbour station, quoted *Labro* by Cicero (Cic., *Ad Q. fr.*2.5) was probably located in this area. In the XVIII and XIX centuries conspicuous remains of the harbour settlement were identified at the Gronda dei Lupi (III cent. BC up to the Late roman period : Targioni Tozzetti, 1768 ; Banti, 1943). Recently, a long sector (about 6 miles) of the *Portus Pisanus* acqueduct has been identified : it was constituted of curved tiles and departed from Livorno hills (Mazzanti *et al.*, in print). A manufacturing quarter for wine amphoras production (Dressel 1 and Dressel 2-4 : I cent. BC-I cent. DC) has been dug in Vallinbuio site, in the Gronda hinterland (Pasquinucci, Del Rio and Menchelli, 1998). In the V cent. AD *Rutilius Namatianus* still quoted *Portus Pisanus* both well sheltered (Rutilius. Namatianus I, 559 : *puppibus meis fida in statione locatis)* and very active and rich (*portum quem fama frequentat Pisarum emporio divitiisque maris*). Archive, archaeological and literary sources document *Portus Pisanus* was active up to the medieval period, conforming to the shoreline geomorphologic evolution (Pasquinucci and Mazzanti, 1987 ; Grove and Rackham, 2001, 337-339).

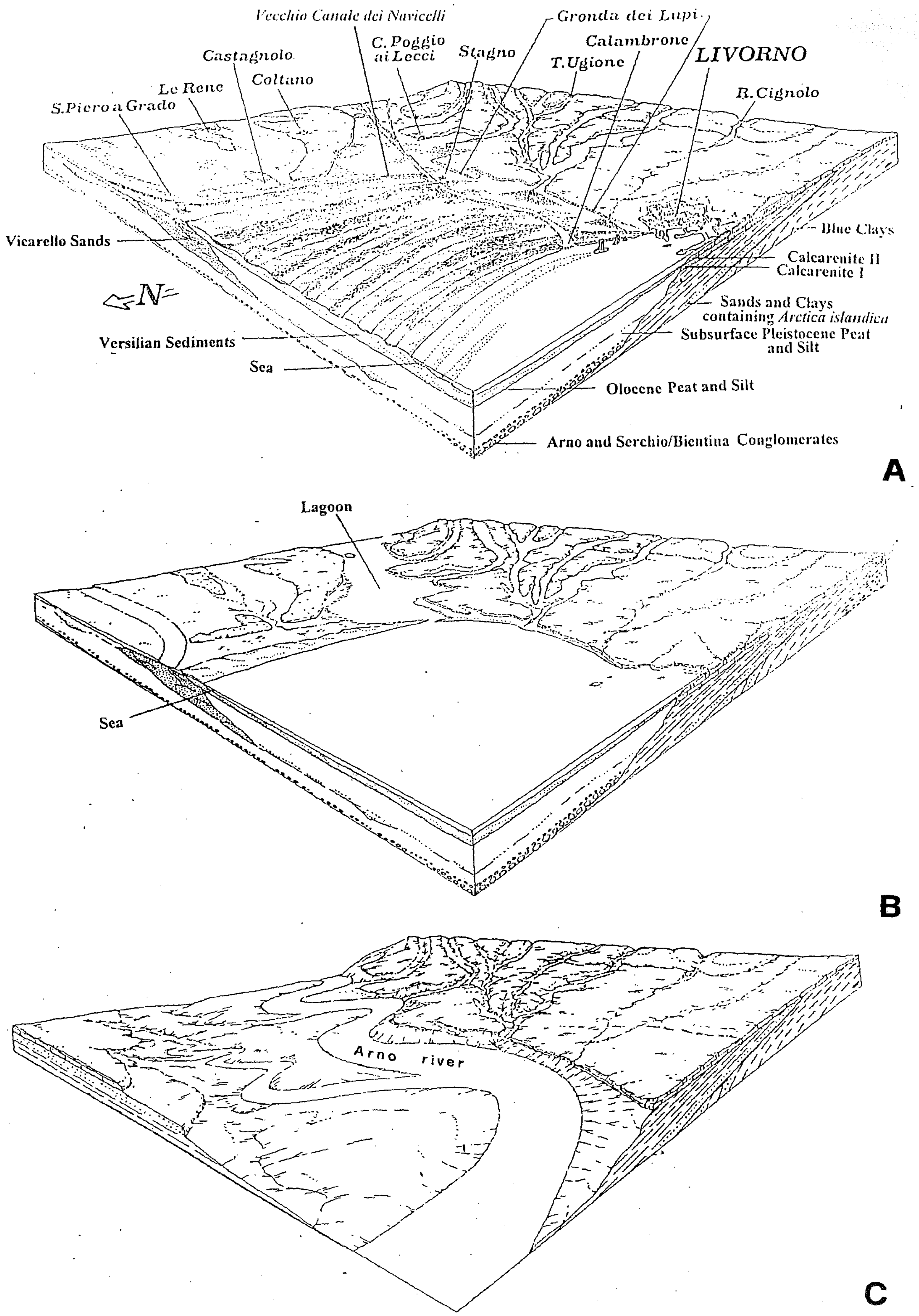

Fig. 9 : Portus Pisanus area. Stereograms.

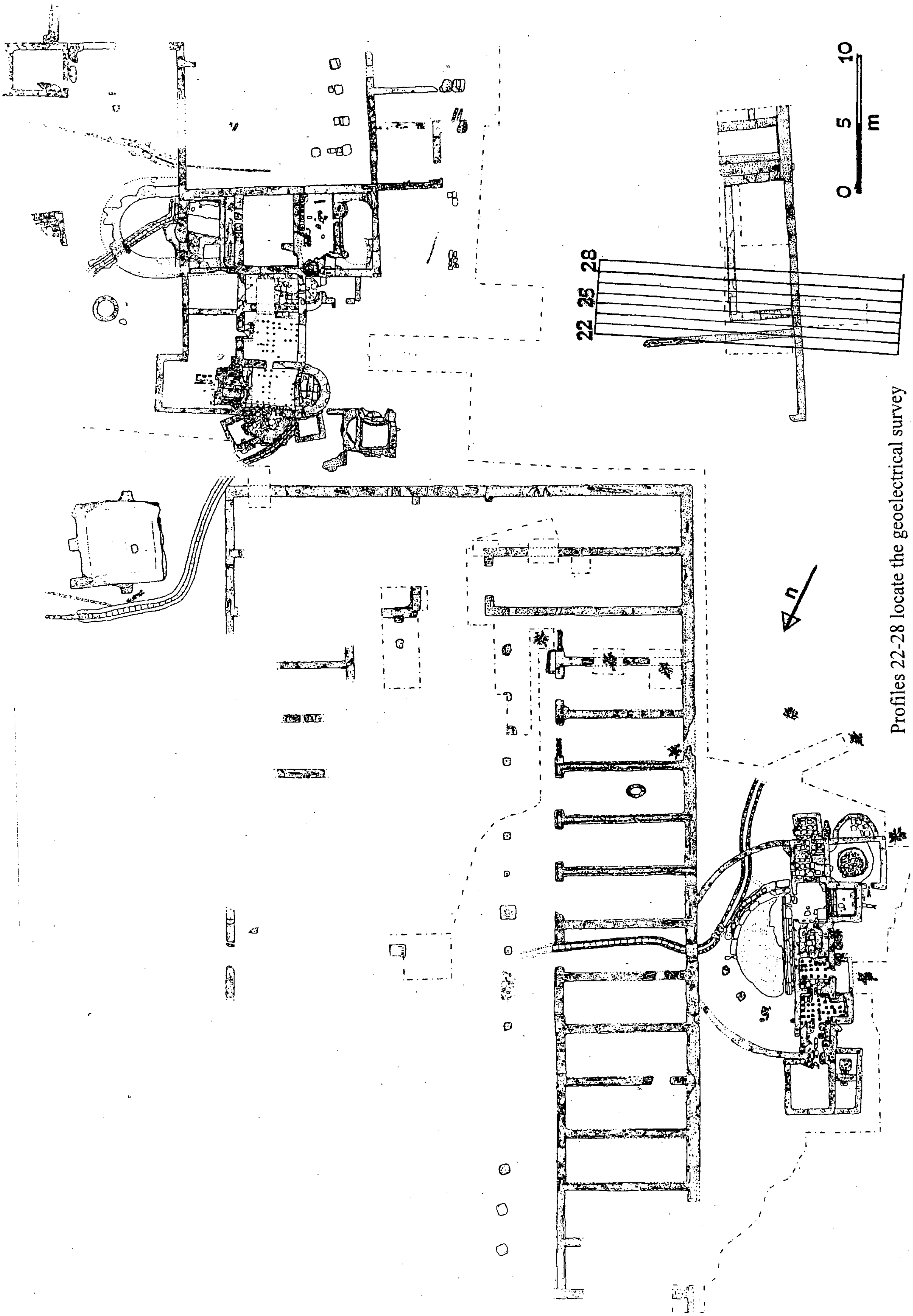

Fig. 10 : S.Gaetano di Vada archaeological area. The nn.22-28 profiles are underlined.

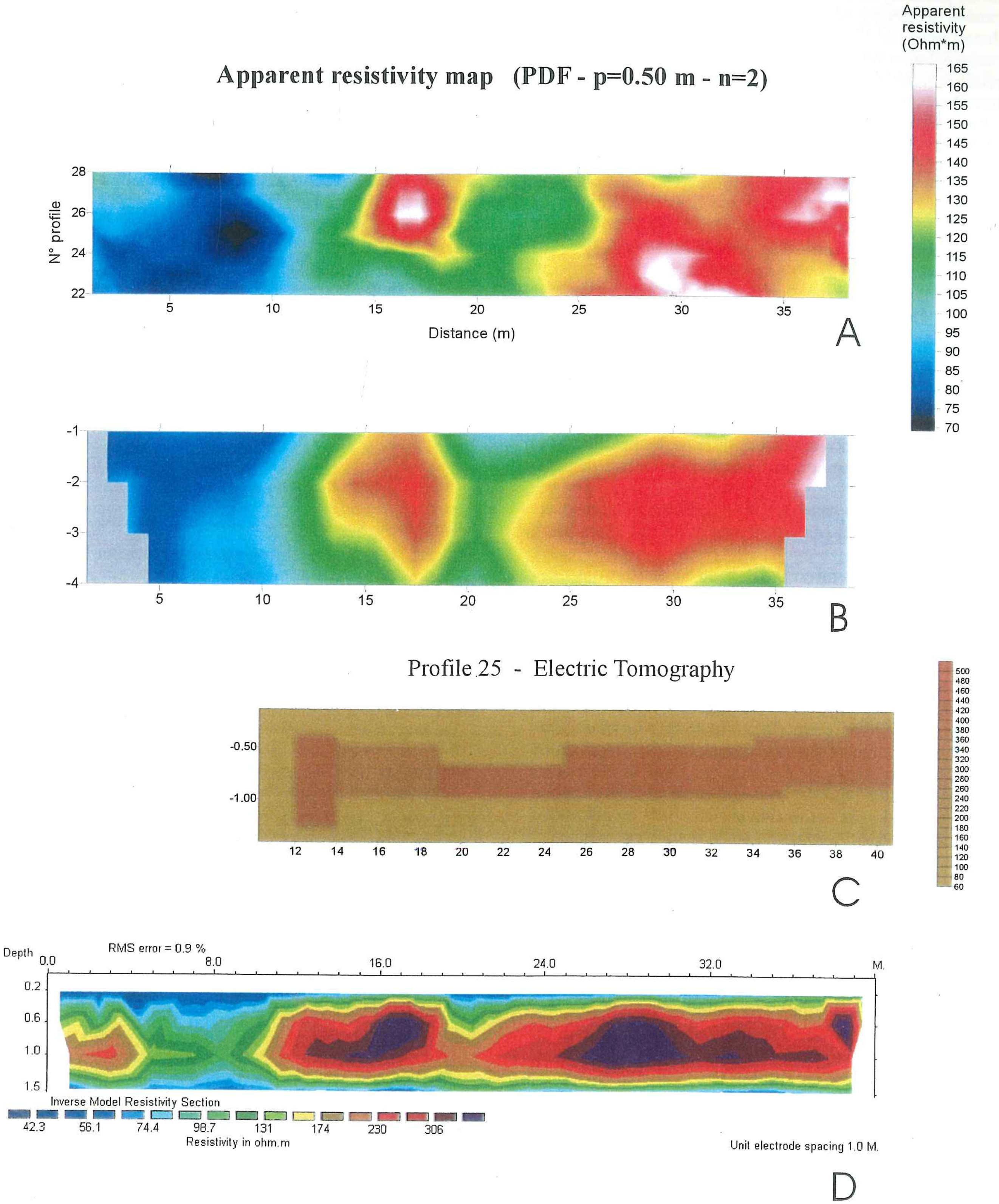

Fig. 11 : S.Gaetano di Vada. Apparent resistivity map.

4 - ARCHAEOLOGICAL AND ENVIRONMENTAL RESEARCHES, GEOELECTRICAL SURVEYS PERFORMED IN S. GAETANO DI VADA (ROSIGNANO M.MO, LIVORNO)

The integrated contributions of different sciences (archaeology, geology, malacology) has been applied to a hut village located on the coastal palaeodunes in *Vada Volaterrana* (S. Gaetano di Vada, Livorno) (fig. 1). The village is dated back to the IX cent. BC (C14 analysis by the Centre for Isotope Research at Gröningen) ; its remains (wooden posts ; pieces of clay daub ; coarse pottery) resulted to be covered by various layers of sand containing fossils (mostly Cerastoderma edule, Abra alba and Gastrana fragilis) referred to a lagoon environment sedimentation (see above). The multidisciplinary approach gives evidence the village was submerged by a coastal lagoon. This event can be referred to a phase of high sea level, probably followed by a relative drawdown which caused the drying of the lagoon area. The site was abandoned until the Flavian period, when a port quarter was built. Till now two baths, a monumental fountain, an horreum, a macellum (?) and another commercial building have been excavated (fig. 10).

Geoelectrical surveys have been carried out in the areas to be excavated (1997-1998) ; the strongest anomalies indicated the presences of large structures : excavations started in 1999 ; a building for commercial purposes has been out.

San Gaetano di Vada. The geoelectrical survey

After the spot inspections, the geoelectrical survey seemed very promising to explore the non-excavated areas. Among the possible techniques, the so-called resistivity pseudo-sections (or pseudo-depth sections) were chosen. At the time this technique was not commonly applied in archaeological exploration : most surveys were simple apparent resistivity maps.

Resistivity pseudo-sections require the acquisition of a much greater amount of data, but they have two definite advantages :

- it is possible to have directly **qualitative** information relative to different pseudo-depths under the measuring profiles ;
- it is possible to invert the data up to obtain **quantitative** interpretations. These can be seen as true resistivity tomographies.

In both cases the data from different profiles can be elaborated to build qualitative or quantitative resistivity maps relative to different depths, pseudo-depths in the first case or true depth in the second.

The quantitative interpretation requires a lot of computing : at the time of the measurements, the inversion of the data of one single profile took one week of work of an expert operator with the trial-and-error procedure. Now software packages are available that allow an automatic inversion, and the computing work is strongly reduced.

The field work had two phases : in the first one, a series of pseudo-sections were measured around the area that had to be excavated in the following campaign (fig. 10). Several different electrode arrays were used along each profile : Wenner, Dipole-Dipole, Pole-Dipole (direct and inverse) and Pole-Pole. Electrode spacing was 0.50 m.

The different pseudo-sections obtained along each profile were compared with the remains found after the excavations. There was a very good agreement with the geoelectrical anomalies. The Pole-Dipole arrays came out to be the most clear and selective.

In the second phase a much larger area was explored. In that there was no evidence of remains. Actually the idea was to look for a road, but the results were serendipitous. A series of parallel profiles was planned in the fields South of the excavated area. Profile spacing was 2 m except where a row of olive trees prevented it. Each array was measured two times, with the direct and inverse Pole-Dipole array. This allowed to combine the two series of measurements in order to obtain a pseudo-Schlumberger sections, useful for the inversion. The measurement were made by means of a single-channel IRIS SYSCAL R2E instrument with a manual switching board connected to 4 multi-electrode cables with a total of 48 electrodes.

The apparent resistivity pseudo-sections pointed out several resistive anomalies whose intensity was small at the surface, grew with the depth but vanished at the maximum depth. This fact excluded «rooted» sources (possible geological bodies) and was a positive indication of the presence of archaeological remains. A series of apparent-resistivity maps at different depths helped to evaluate the distribution of the possible targets (see fig. 11 a and 11 b).

One profile was interpreted with a direct-modelling software (RESIXIP-2D by Interpex) by the trial-and-error procedure. The result was a group of anomalies with the top 0.5 m deep (from the field surface) and the bottom (see fig. 11 c).

Test excavations were made soon after : a massive wall was found in correspondence with the strongest anomaly precisely at the indicated depth. The nearby anomalies, that were a bit less intense, came out to correspond to a second wall, oblique with respect to the profile.

The data of the same profile shown in fig. 11 a have been re-processed with an automatic 2-dimensional inversion software package (RES2DINV) : the results are shown in fig. 11 d.

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