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SYNTHESIS OF LATE QUATERNARY PALYNOLOGICAL STUDIES IN THE ARNO COASTAL PLAIN AND SURROUNDINGS: TOWARD A COMPREHENSIVE LATE QUATERNARY PALAEOVEGETATIONAL HYSTORY

Abstract - Late Quaternary series in the Arno coastal plain and in the surrounding area have been the object of several sedimentary studies mainly in order to reconstruct its paleoenvironmental evolution. Palynological data from drilled cores and hand samples have been used to correlate vertical facies evolution and climate fluctuations in the area. Late Pleistocene to late Holocene pollen associations reflecting the vegetation evolution are reported in a correlation table to have an overview of the published data and to indicate future research directions to reconstruct a comprehensive palynological framework.

Key words - Late Quaternary, Arno plain, climate changes, vegetation dynamics, pollen.

Riassunto - *Sintesi di studi palinologici del tardo Quaternario nella pianura costiera dell'Arno e nelle aree circostanti: verso una completa storia paleovegetale*. Le successioni sedimentarie del Quaternario superiore della pianura costiera dell'Arno sono state oggetto di numerosi studi sedimentologici con lo scopo di ricostruire l'evoluzione paleoambientale della pianura stessa. I dati palinologici dei campioni provenienti da sondaggi ed affioramenti hanno fornito indicazioni utili per effettuare correlazioni tra l'evoluzione stratigrafica delle facies ed i cambiamenti climatici dell'area in esame. Le associazioni polliniche di età Pleistocene superiore-Olocene che riflettono l'evoluzione della vegetazione sono state riportate in una tabella di correlazione per offrire un visione d'insieme dei dati fino ad oggi pubblicati e per indicare le direzioni di ricerche future per ricostruire un quadro palinologico più esauriente.

Parole chiave - Quaternario superiore, pianura dell'Arno, cambiamenti climatici, dinamica della vegetazione, pollini.

Introduction

Changes in pollen assemblages are assumed to record changes in vegetation composition and represent the main ecological, climatological, archaeological applications of Quaternary pollen analysis. Moreover, similarities in stratigraphic changes in pollen assemblages are the base for the classic pollen zonation and, together with radiocarbon data, for chronostratigraphic correlations (Jackson, 1994). However, sedimentary deposits with pollen preservation sufficiently good to assign the morphotypes to the corresponding extant plant taxa at (or below) the family level are necessary and stable, continuous and independently datable depositional environment are required to verify that the changes in pollen assemblages are related to vegetational changes rather than depositional episodes, and to obtain reliable comparisons with any other records (Jackson, 1994). For this reason, Quaternary pollen analysis has developed to pollen-taxonomical precision, automated pollen identification and more accurate definition of pollen assemblage zones. Quantitative methods and pollen-climate calibration models with climate data are also used in modern palaeoclimatology. At the present, relationship of pollen production and climate, comparison between reconstructed and real climate, the role of human impact and other non climatic factors still represent the main questions to answer (Seppa & Bennet, 2003).
Palaeoclimatological studies in the Mediterranean area mostly deal on small depositional basins in the mountain belt, where the evolution of the mountain vegetation in response to the main climate changes and human activity during the Holocene can be determined. Less numerous studies concern the Mediterranean coasts, probably because of the scarce presence of favourable areas and for the difficulty of interpreting the origin of the pollen grain which underwent reworking processes related to the fluvial transport, the marine transport and the sedimentation processes. Even though exhibit a modified state due to colonization and exploitation activities, the Mediterranean coastal areas are instead particularly interesting for environmental archaeology and landscape history studies (Bellini *et al.*, 2009 and references therein). In particular, coastal plain of northern Tuscany have been the object of several botanical studies because of its heterogeneity as consequence of a climate essentially Mediterranean/sub-Mediterranean (15°C mean temperature and 900 mm mean precipitation). A mix of floristic elements of different climatic significance (including microthermic, Atlantic and subtropical taxa) occur, sometime surviving as relicts, especially in damp habitats. Mediterranean xerophilous vegetation, hygrophilous thickets, small woods, mixed oak woods and microthermic species respectively occur along the coast, on the alluvial plain and on the slopes (Mariotti Lippi *et al.*, 2007a; Bellini *et al.*, 2009).
An overall reconstruction of the Holocene vegetation history of NW Italian coastal landscape is proposed by Bellini *et al.* (2009) by means of data obtained from cores drilled by different geological groups between 1998 and 2004 in four coastal plains facing the Ligurian Sea: the Pisa and Versilia Plains in N Tuscany and the Sestri Levante and Rapallo Plains in E Liguria. Pollen data evidence, for the investigated area, a regional scale vegetation shift in the mid Holocene connected

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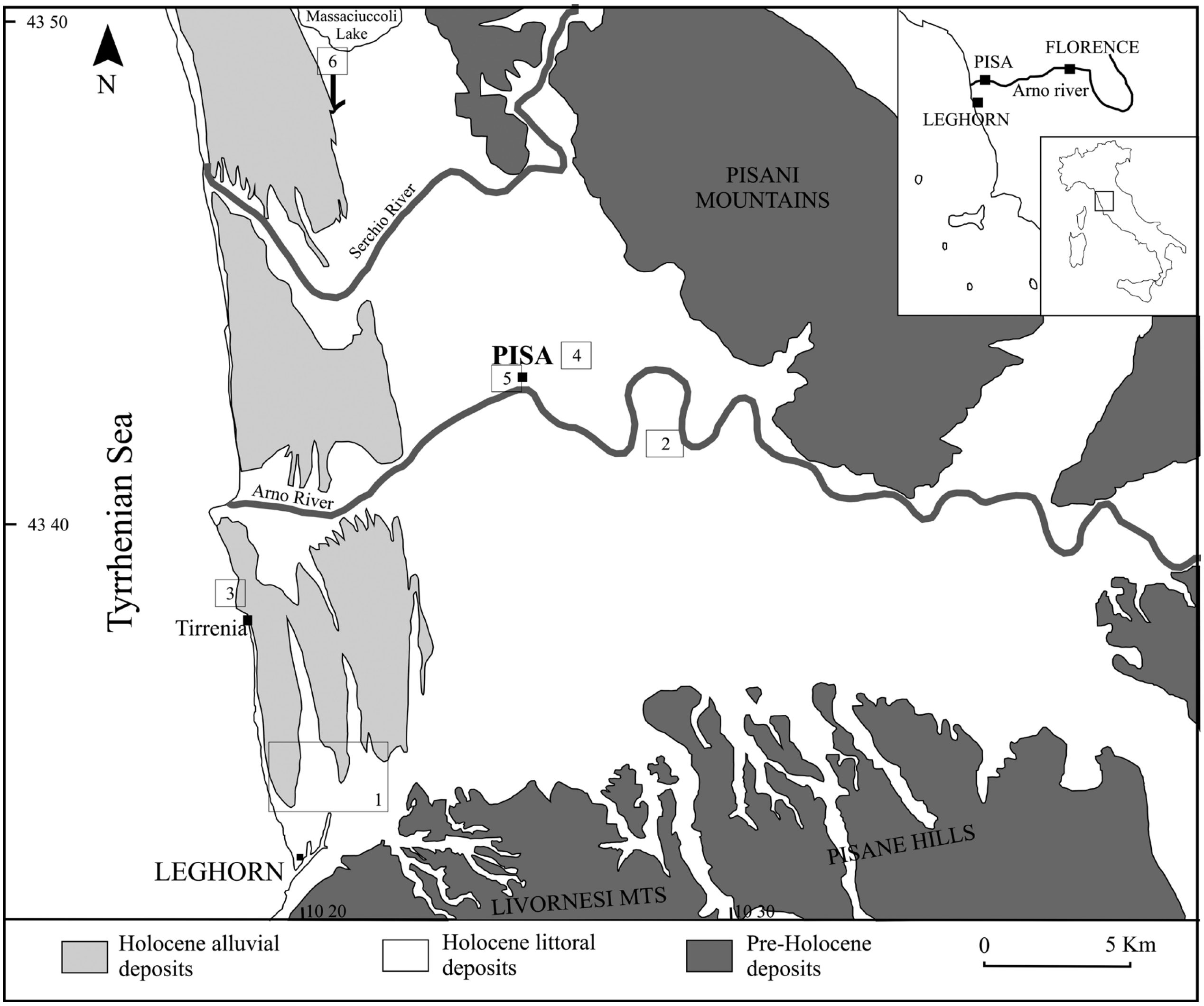

Fig. 1 - Geographic position of the analyzed area (from Ricci Lucchi, 2008, slightly modified) and location of the described sites. 1. Galletti Fancelli, 1979, 2. Galletti Fancelli, 1971, 3. Core M1 (Aguzzi *et al.*, 2007; Ricci Lucchi, 2008); 4. Core S1 (Amorosi *et al.*, 2009); 5. S. Rossore site (Mariotti Lippi *et al.*, 2007a); 6. Mariotti Lippi *et al.*, 2007b).

to a climatic change and therefore environmental instability. The change is represented by the disappearance of fir-dominated woodland starting from the coast to the mountain and the replacement of pioneer conifer woods by broadleaved forests. This substitution can be in some case related to natural soil development at the end of postglacial colonization. Also human activities can produce widespread erosion, especially the deforestation for agriculture and pasture at least from the Neolithic (5500-3500 BC). Since the Copper Age (3500-2300 BC) coastal wetlands are definitively buried and drained by erosion and flooding caused by quarrying and mining activities that cause a landscape patchwork of meso-thermophilous woods and Mediterranean maquis (Bellini *et al.*, 2009).

Recent studies (Ricci Lucchi, 2008) evidence that local ecological conditions can mitigate the effects of climate change in the Arno plain. Pollen analysis on samples from 105 m-long continuous core from Tirrenia (Pisa, Tuscany) shows as mild temperature and humidity, due to the conbined effects of Tyrrhenian See proximity and high topographic variability, produce a series of microenvironments where cold-temperate trees survive during the Last Interglacial (Ricci Lucchi, 2008). Moreover, during the Last Glacial the wide occurrence of temperate forests testifies the key role played by local factors in making the Arno coastal plain an important tree refuge and a very interesting study area. Only the major forest contractions and expansions during this time can be linked to high-frequency North Atlantic climate variability.

Several Arno coastal plain paleonvironmental and paleoclimatic reconstructions published in the last years (Galletti Fancelli, 1971;1979; Aguzzi *et al.*, 2007;

Amorosi *et al.*, 2009) report a detailed pollen analysis. The aim of the present paper is to offer a synthesis of the late Quaternary palynological studies in the Pisa surroundings which can be a useful tools for next researches in the area.

Geological setting and late Quaternary stratigraphy of the Arno coastal plain

The Arno coastal plain is surrounded by the Pisani Mountains to the NE, by the Livorno-Sillaro tectonic line at the base of the Livorno and Pisa hills to the South, and by the Tyrrhenian Sea to the West. The northern boundary can approximately be represented by the Massacciuccoli lake (Mariani & Prato, 1988; Argnani *et al.*, 1997; Pascucci, 2005).

From a tectonic point of view, the Arno coastal plain constitutes the southern inshore part of the bigger subsiding Viareggio Basin. This basin is the northernmost of a series of tectonic depressions that developed along the Tyrrhenian margin since the Late Tortonian, as a result of the extentional opening and widening of the Tyrrhenian Sea (Martini & Sagri, 1993; Martini *et al.*, 2001).

The Quaternary succession of the coastal Arno River plain is known essentially from cores and few exposures located on the southern end of the basin (Della Rocca *et al.*, 1987; Baldacci *et al.*, 1994; Mazzanti, 2002; Aguzzi *et al.*, 2005, 2007; Amorosi *et al.*, 2008, 2009). The late Quaternary sequence consists of an alternation of shallow-marine, coastal and alluvial deposits formed in response to Milankovich-scale interglacial-glacial cycles (Aguzzi *et al.*, 2005, 2007).

Two transgressive-regressive (T-R) sequences have been recently recognized within the uppermost subsurface 100 meters. Transgressive marine sediments have been related to the Tyrrhenian and Holocene transgression, respectively (Aguzzi *et al.*, 2007). The thickness variation of the upper T-R sequence, coupled with abrupt lateral facies changes from soft lateglacial-early Holocene incised-valley fill clays to stiff pre-Holocene deposits, is indicative of an incised-valley system that has been developed in response to the last glacial sea-level fall and that roughly follows the modern Arno River course (Aguzzi *et al.*, 2007; Amorosi *et al.*, 2008). Data sets from high resolution continuous core and from correlated poor-quality borehole data, reassessed using a modern sedimentological and stratigraphic approach, allow detailed reconstruction of three-dimensional facies architecture of the valley body (Amorosi *et al.*, 2008).

On the top of the Arno valley fill, a soft and silty clay sedimentary unit (locally known as «*pancone*») is recorded in overall area. These lagoonal deposits, formed up to *ca.* 6000 cal. BP (Benvenuti *et al.*, 2006) owing to the change from transgressive to highstand conditions (occurred *ca.* 8000 cal. BP; Amorosi *et al.*, 2008), show lateral transition to paludal, backswamp fine-grained sediments. Highstand fine-grained fluvio-deltaic deposits, including fluvial-channel sandy bodies (Amorosi *et al.*, 2008), overlie the sedimentary sequence.

At the archaeological site of Pisa S. Rossore, the «*pancone*» unit is erosively overlay by sand bodies, Etruscan-Roman in age. Pre-Roman fine sand and mud (on which an Etruscan palisade was built) are followed by four main sandy units (units 0, 1-4) where Roman ships and associated cargo materials were founded (Benvenuti *et al.*, 2006). Recently, a preliminary chronology of the Arno plain mid to late Holocene fluvial events and a detailed characterisation of fluvial patterns in the Pisa area have been proposed by Rossi *et al.* (in press).

Palynologycal data from the late Quaternary coastal record

Palynological data on late Quaternary sedimentary series of the Pisa area are reported in Galletti Fancelli (1971, 1979); Aguzzi *et al.* (2007); Mariotti-Lippi *et al.* (2007a); Amorosi *et al.* (2009); Bellini *et al.* (2009) and Ricci Lucchi (2008). The purpose of these researches is mainly to support paleonvironmental reconstructions and to point out vegetation changes in Tuscan area related to late Quaternary climate changes.

Pollen data on continuous cores in the area, are presented in detail in Aguzzi *et al.* (2007), Amorosi *et al.* (2009) and by Ricci Lucchi (2008), the last only for the pre-Last Glacial Maximum part.

Aguzzi *et al.* (2007) firstly attempt to delineate the palaeoenvironmental evolution of the study area in response to sea-level fluctuations and climate forcing. A 105 m-long core (termed M1) drilled close to the village of Tirrenia, along the Tyrrhenian coast of Tuscany has been the object of a multidisciplinary studies where pollen content, foraminifer and ostracod assemblages, and ^{14}C ages support the sedimentary facies interpretation. Data from the multidisciplinary study allow closely relation between the two T-R sequences and the interglacial/glacial cycles. Spectra showing the percentage value variation of arborean (AP), non arborean (NAP) and Aquatics pollen type along the stratigraphic core log synthesize the detailed pollen content described for each facies association (Aguzzi *et al.* 2007, Fig. 4). Arboreal pollen types are represented by *Pinus*, mixed deciduous oak-wood (i.e. *Quercus, Corylus, Carpinus betulus, Tilia, Ulmus*), mountain taxa (i.e. *Abies, Picea and Fagus*), Mediterranean taxa (i.e. *Quercus ilex, Erica arborea, Phillyrea* type*, Pistacia and Olea*). Non-arboreal types are subdivided in steppic shrubs and herbs (*Artemisia*, *Chenopodiaceae, Ephedra, Hippophae*) surviving in cold and dry conditions, *Poaceae* and ubiquists (all other herbs). The aquatics are represented by hygro-hydrophyte plants typical of humid environments, such as *Sparganium* type, *Typha, Myriophyllum* and Cyperaceae.

In the synthetic pollen diagrams, changes in percentage of each vegetation group, associated to the facies evolution, reflect changes in climatic condition.

The lower T-R sequences is characterized at the base by a pollen assemblages dominated by NAP, typical of glacial climatic conditions. The following onset of last interglacial is evidenced by lagoonal sediments containing deciduous oak-wood and Mediterranean pollen grains. The successive pollen association is characterized by dominance of coniferous forests and scarcity of mesophilous trees as result of a progressive cooling typical of the latest phase of the Eemian. Pollen data from overlying sedimentary levels are indicative of an open vegetation, with steppics and *Pinus*, related to the Weichselian stadial phase. Overlying deposits show a significant expansion of mesophilous forest (mixed deciduous oak-wood) that can be associated with an interstadial phase. The followed pollen assemblage dominated by *Pinus* in deposits between about 76 and 84 m core depth indicate the beginning of the glacial climate condition. The last part of the lower T-S sequence is characterized by mesophilous forets typical of interstadial climate conditions (Fig. 2).

The spread of a mixed deciduous oak-wood associated to *Pinus* woodland at the base and in the lower part of the upper T-R sequences is the result of the climate warming at the beginning of the Holocene marking the transition from glacial to interglacial conditions. The replacement of *Pinus* woodland by the oak-wood suggest a progressive increase of temperature and humidity and their maximum development correspond to the onset of the marine sedimentation. The decline of the mixed deciduous oak-wood and the contemporary spread of the Mediterranean and *Pinus* woodlands suggest a more Mediterranean climate that persists also during the second half of the Holocene with the dominance of the Mediterranean vegetation, expansion of open vegetation and the progressive reduction of mixed deciduous oak-wood and mountain taxa. As pointed out by Aguzzi *et al.* (2007, p. 224 with references), the development of the Mediterranean forest, mainly characterized by *Quercus ilex*, represents a significant palaeovegetation event.

The pollen data of the pre-Holocene part of the M1 core has been successively discussed by Ricci Lucchi (2008) to reconstruct the main paleovegetational and paleoclimatic changes. Pollen data and the strictly related facies association show the importance of the palaeoenvironments in controlling vegetation dynamics. On the basis of the pollen content previously described (Aguzzi *et al.*, 2007), the author proposed four local pollen zones (M1-1 to M1-4) and eight subzones (M1-2a, M1-2b, M1-3a, M1-3b, M1-4a, M1-4b, M1-4c and M1-4d). Pollen data have been correlated with the coeval well-dated pollen sequences from Mediterranean area to establish a reliable chronology.

The Last Interglacial is represented by the zones M1-1 to M1-2. Steppe vegetation and pioneer shrubs and trees indicating very cold and dry climate condition (M1-1) are followed by a rapid expansion of woody taxa (manly *Quercus* and *Pinus*) in lagoonal sediment. Successive association with cool temperate trees (*Pinus, Abies, Picea, Fagus*), and subordinate meso-thermophilous taxa suggest cool and wet climate conditions (Fig. 2). Special attention has been reserved to *Abies* and *Picea*, their survival at low altitude at the end of Last interglacial in the Arno coastal plain is probably due to a cool-wet climate and a favourable soil conditions (Ricci Lucchi, 2008, p. 2462).

The abrupt decline of cold-temperate trees coupled with the expansion of more thermophilous trees followed by the decrease of woody taxa and increase of steppe vegetation indicate the shift from a new warming phase to a progressive cooling characteristic of the latest phase of the Last interglacial. The mixed Mediterranean and broad-leaved deciduous forests (i.e. *Olea*, *Erica*, evergreen *Quercus*) are not preserved because the significant erosion of the rapid marine transgression.

The Last interglacial end is recorded at the base of the M1-3 zone where steppe vegetation and psammophilous plants (Cistaceae, Apiaceae) expand. Later, *Pinus* and *Hippophae* cf. *rhamnoides* (a shrub actually growing in coastal environment) typical pioneer vegetation of the end of a cold period or at the onset of a warm one (Fig. 2).

Last Glacial of the M1-4 zone (Ricci Lucchi 2008, Fig. 7) is preceded by a new expansion of steppe vegetation indicative of a cooling trend. Gradual temperature and moisture increasing is inferred by the change from the dominance of shrub tundra vegetation (*Artemisia, Pinus, Ephedra, Hippophae* and *Juniperus*) to the increase of warm temperate trees (mainly deciduous and evergreen *Quercus, Betula, Tilia* and *Ulmus*) in lacustrine and marsh sediments. The survival of *Tilia*, a taxon that usually rapidly spread and decline under interstadial/interglacial climate conditions, indicates again that the coastal plain of the Arno River represent an important glacial refuge (Fig. 2).

A Lateglacial to early Holocene sequence, landward equivalent of the M1, has been described in Amorosi *et al.* (2009) on a continuous core (termed S1), drilled a few kilometers NE of Pisa. Continuous small-scale landward and seaward shift in shoreline position evidenced by cyclic changes in sedimentary facies sedimentation identify three small-scale transgressive-regressive cycles, (parasequences PS1 to PS3 from bottom to top) within the Arno valley succession. PS1 developed entirely during the Lateglacial, whereas PS2 and PS3 record early Holocene deposition.

Pollen data reflect high-frequency vegetation changes alike the sedimentary facies architecture. The lowest parasequence (PS1) is characterized by early trasgressive estuarine and regressive sand-dominated deposits. The pollen vary from a typical association of fresh-temperate interstadial condition to an association related to the Younger Dryas cold event.

Abundant deciduous broad-leaved trees of mixed oak forest, (with about 5% of *Tilia*) and relatively high percentages of mountain trees, (mostly represented by *Abies* and *Fagus*) characterize the estuarine deposits. The few suitable samples from sandy deposits show lower percentages of mixed oak forest, slight expansion of *Pinus* and herbs (NAP). High contents of mountain trees and abundant *Carpinus betulus* (mixed oak forest), low value of more termophilous taxa are recorded within a fine-grained interval at 45 m core depth. According to the authors, the pollen spectra are comparable to those reported from Lateglacial pollen series of central and southern Italy. In particular, the maximum expansion of *Tilia* is diagnostic of the Lateglacial interstadial, this taxon typically declines during the Holocene, when termophilous trees, like *Quercus* and *Corylus* become widespread (Amorosi *et al.*, 2009 and references).

Period	Epoch	Climatic periods		OIS	Aguzzi etal., 2007	Ricci Lucchi, 2008		Amorosi et al., 2009	Galletti Fancelli, 1971, 1979	Mariotti Lippi et al., 2007a		Mariotti Lippi et al., 2007b
late Quaternary	Holocene	Sub-Atlantic		OIS 1				mixed oak woods Mediterranean and ripararian trees, shrubs, *Abies*	*Pinus, Abies, Tilia*	late Roman	freshwater plants; mixed oak wood (*Quercus*), *hygrophilous tree*	Mediterranean trees
										early Roman	hygrophilous tree deciduous, mixed oak woods; herbaceous taxa	
										pre-Roman	mountain trees (*Abies, Fagus*)	*Fagus*
		Sub-boreal			Mediterranean trees			*Pinus* and mountain trees (*Abies*)	*Quercus*; *Pinus*			Steppics; *Vitis,* Riparians; *Corylus*
		Atlantic			Mediterranean trees, *Pinus*			mixed oak woods, riparians and mountain trees	dominance of *Quercus* trees			coniferous and deciduous wood
		Boreal			Oak woods			*Pinus* and mountain trees	sub-mountain vegetation; *Carpinus*; *Pinus* and sub-alpine vegetation			*Abies* and deciduous *Quercus*; *Abies*
		Pre-Boreal			Mixed deciduous oak woods, *Pinus*			mixed oak woods Mediterranean trees, shrubs				Mixed oak woods, *Alnus* and Poaceae
	Late Pleistocene	Weichselian	Glacial	OIS 2	Mixed oak woods	M1-4d	Woody taxa, Chenopodiaceae, *Artemisia*	*Carpinus betulus*, mountain trees				
				OIS 3		M1-4c	Mixed oak woods, Poaceae and pioneer shrubs	*Pinus* and herbs (NAP)				
					Pinus , Poaceae	M1-4b	*Pinus, Artemisia*, Chenopodiaceae, Aquatics	mixed oak woods, *Tilia*, mountain trees				
				OIS4		M1-4a	*Pinus, Artemisia* and Chenopodiaceae					
				OIS 5a	Mixed deciduous oak woods	M1-3b M1-3a	*Pinus, Hippophae*, mixed oak woods					
				OIS 5b	Open vegetation, steppics, *Pinus*							
		Eemian	Integlacial	OIS 5c OIS 5d	*Pinus*, mountain taxa		Steppics and psammophilous plants					
				OIS 5e	Deciduous oak voods and Mediterraneans	M1-2b M1-2a	*Pinus, Quercus,* woody taxa and NAP					
				OIS 6	NAP	M1-1	NAP, steppics					

Fig. 2 - Correlation table with the main components of the each described pollen association. OIS (Oxygen Isotope Stage).

Likewise, in the PS2 transgressive central estuary and alternate marsh and estuarine sediments are followed by regressive inner estuary and marsh deposits. Transgressive pollen association is indicative of warm climate condition with the dominance of mixed oak forests, Mediterranean trees, shrubs and low values of *Pinus* and mountain trees, typical of the onset of Holocene interglacial. The change of flora composition, evidenced by the increase of *Pinus* and mountain trees and by the decline of the previous dominant taxa, is due to an abrupt decrease in palaeotemperature, related to an early-Holocene cold event (Fig. 2).

The transgressive part of the overly PS3 is represented by swamp deposits showing an increase of mixed oak woods, riparians, decrease of *Pinus* and moderate value of mountain trees, indicative of warmer and more humid climate conditions. The vegetation in the regressive PS3 samples is characterized by low values of the mixed oak forests, abundant *Pinus* and mountain trees. In particular, it is significant the maximum value of *Abies*, considered to be, in association to *Pinus*, indicative of cooler and humid summer conditions attributed by vary authors (i.e. Tinner & Lotter, 2006; Magny *et al.*, 2003; Drescher-Schneider *et al.*, 2007) to the 8.2 cal. kyr BP cold event. In the successive transgressive deposits, is recorded again an increase of mixed oak woods, Mediterranean and riparians trees and shrubs. *Abies* is present, in moderate percentage, as unique representative among the mountain trees (Fig. 2). These association suggests a transition to warm and humid, Mediterranean climate conditions.

Galletti Fancelli (1971, 1979) firstly links palynological investigation, climate, geomorphologic and stratigraphic studies. Pollen data from clayey horizons of 19 continuously-cored boreholes drilled south of Arno River, near Leghorn and Pontedera have been discussed for climate interpretation. *Pinus, Quercus, Abies* and *Tilia* are the selected key-taxa and changes in terms of abundance and/or presence and changes in their allies evidence four climatic phases. In the lower part of sequence, a boreal (9000-7500 BP) climatic phase is characterized by a sub-alpine vegetation (with abundant *Pinus* matched with *Alnus*, *Betula* and *Fagus*) and a sub-mountain vegetation (with low values of *Quercus*, *Ulmus*, *Tilia*, *Corylus*). *Carpinus* occur at the shift of the two vegetation types. The successive phase is considered as Atlantic (7500-5000 BP) climatic phase because the dominance of *Quercus* trees. Next phase, characterized by a sudden dominance of *Pinus* followed by an acme of *Quercus* is reported as sub-boreal (5000-2500 BP) climatic phase. The last climatic phase recognized is the sub-Atlantic (2500 BP-present) with dominance of *Pinus*, high values of *Abies* and presence of *Tilia*. Radiocarbon dating on *Cardium*, woods, *Posidonia* and on different species shells (Ferrara *et al.*, 1959) confirm the attribution of the deposits to the post-glacial period (Fig. 2). The palynological data are used also to correlate lithological sequences with the aim of make out the plain subsidence. Variation in terms of acme, abundance and/or different association of the above mentioned selected taxa have been the key-events to correlate the diverse sequences. Results do not support reliable conclusions but, according to the author, can indicate an average subsidence of Arno River plain of 2-4 mm.

High frequency changes in vegetation cover are documented in pollen data on more recent deposits of the archaeological «ship site» of Pisa San Rossore. Samples have been collected from clayey or thin fine sandy-clayey deposits of stratigraphic sections belonging to the interflood units. Muddy beds, indicative of periods of low-energy sedimentation at the site, have been selected because more favourable for pollen deposition (Mariotti Lippi *et al.*, 2007a). Radiocarbon data (Belluomini *et al.*, 2002; Bruni, 2000) of wood and the palisades from the southern side of the site and of the ships and of the wood in sediments enclosing the Roman material, are Etruscan (8th to 2nd centuries BC) and Roman (5th BC to 5th AD centuries) in age respectively (Benvenuti *et al.*, 2006).

Two major phases of vegetation cover are documented along the sampled sections.

The first phase is observed in samples sequence from the pre-Roman fine sands and mud (where the Etruscan palisade has been recovered). Samples are rich in mountain vegetation plants such as *Abies* and *Fagus*, sometime associated with *Picea*, *Betula* and *Castanea*. *Fagus* occur in very high percentage suggesting its presence also in the surrounding of the site. The samples are surely more recent than 6380-5955 cal BP radiocarbon dating on *Cerastoderma* shell coming from below the pre-Roman floodplain deposits. Mariotti Lippi *et al.* (2007a, p. 461) point out the presence and the high percentage of *Fagus*. The authors discuss from chronological point of view, for comparison with others localities in and outside Tuscany, the spread of *Fagus*, its relationship with *Abies* and their dynamics connected to climatic factors and human activity. The authors conclude that pollen association before the construction of the Etruscan palisade in Pisa is characteristic of cooler climate that progressively become warmer, as suggested by the increase of thermophilous and then hygrophilous taxa. Paleovegetation can be tentatively referred to the beginning of the «Sub-atlantic cold phase» which occurred from about 900 to 400 BC (Lamb 1995), even if a previous cool moist period, not earlier than 6380-5955 cal BP cannot be excluded.

The second phase comprise the Roman period (units 0 and 1-4). The study of pollen documented a change of the vegetation cover, suggesting that the Roman interflood period was subjected to hydrologic and climatic variations in agreement with sedimentological data (Benvenuti *et al.*, 2006).

Samples from Unit 0 show the decline of *Fagus* forest that could be placed at the end of the cool and humid Iron Age, and the spread of herbaceous taxa. At the beginning of Unit 1 herb communities become dominant and the woodland cover was significantly reduced. Deciduous oaks and allied plants substituted most part of *Abies* and *Fagus* wood, suggesting a warmer climatic phase coinciding with the beginning of the warm Roman period. Human activities cannot be excluded taking into in account that the decline of oak wood is coincident with an increase in spores content that can represent a tree-cutting and/or fire practice. Also high values of hygrophilous trees, Cyperaceae and fresh water plants are observed in the early Roman samples. Successive expansion of erbaceous taxa and reduction of hygrophilous plants can be explained with a soil waterlogging. The poorly drained muddy soils around the site preclude also the agricultural activity on the area, supposed to be started in northern Tuscany from 5000-4000 BP in the Massaciuccoli basin (Menozzi *et al.* 2003).

Late Roman period is characterized by abundance of mixed oak wood (mainly *Quercus*) and hygrophilous tree pollen. Successively a decrease of the latter association and the presence of many anthropogenic indicators are recorded. The sequence follows with the presence of several freshwater plants that later noticeably reduced with the spread of well drained meadows.

These units were interpreted as due to catastrophic, high-frequency (centennial-scale) floods likely related to high-periods of exceptional rainfall connected with mid- to late-Holocene climate change (higher temperatures and precipitation) and sea-level fall between 6400 and 2000 BP (Benvenuti *et al.*, 2006; Bellini *et al.*, 2009).This regional trend of hydroclimatic events is in agreement with pollen analysis that reveals a fluctuation in soil drainage of the floodplain surrounding the site. The presence of freshwater plants in all pollen spectra and the sporadic occurrence, with very low abundance, of salty substrates plants suggest that the ancient site of Pisa San Rossore was fluvial rather than marine or lagoonal (Mariotti Lippi *et al.*, 2007a).

Mariotti Lippi *et al.* (2007b) discuss the Holocene pollen sequence and vegetation history of the Massaciucoli Lake, considered to be the northern boundary of the Arno plain area. Analysed samples from a drilled core interested an interval spanning from the last 10,000 years up to Roman times. The beginning of the Holocene was covered by deciduous woodland dominated by *Quercus, Corylus, Tilia, Ulmus* and *Alnus*. Poaceae value suggest the presence also of open areas. High values of *Abies* are recorded in samples collected around 9000 BP, together with decrease of oak wood and the disappearance of open areas. Subsequent oscillation in value of AP (especially *Alnus*) and Poaceae suggest a period of environmental instability probably related to sea level fluctuations. A peak of *Abies* and deciduous *Quercus* is recorded just before the marine ingression with sand deposition and gap in pollen record. From 5500 BP coniferous and deciduous wood again cover the area with occasional open areas recording vegetational oscillations lied to sea level changes rather than directly to global climate changes. Any record of late Holocene arid phase, as recorded in south-western Europe and in Mediterranean islands (Jalut *et al.*, 2000; Perez-Obiol & Sadori, 2006), is detected. The absence of drastic changes can indicate that the Massaciuccoli Lake area represent a poorly drained area with tree refuge role, where ecological conditions cause a low sensitivity to climate changes as deduced in the Arno coastal plain in the last interglacial (Ricci Lucchi, 2008).The successive high values of *Corylus* can be considered a signal of deforestation due to human activity because adjacent areas show a trees cover dominated by deciduous *Quercus*, *Ulmus*, *Fraxinus* and *Acer* or Mediterranean maquis. The authors (Mariotti Lippi *et al.*, 2007b, pp. 273-274) discuss the presence of an early agricultural practice between 4200 and 2700 BP where *Vitis* and low AP values are recorded. The presence of *Salix* and *Alnus* suggest the occurrence of swamp woods where wild grapevine grew. The spread of *Vitis* can be interpreted as consequence of woodland clearance followed by cultivation of the wild plant. *Vitis* disappears together with a drop in the AP percentage mainly due to a large quantity (45%) of Chenopodiaceae. a signal of an enlargement of brackish environments in the Massaciuccoli lake basin, also according to the fluctuation of the shoreline. Data refer a cooler climatic phase began during the Etruscan epoch, causing the spread of *Fagus* in the area, at lower altitudes than the present ones. The top the sequence representing approximately the last 2000 years is characterised by an increase in Mediterranean evergreen trees, supposed to be favoured by human activities, such as exploitation of deciduous woodlands and land reclamation, for agricultural purposes.

Discussion and conclusions

Although the Arno coastal plain and its surroundings have been intensively studied from geomorphological and sedimentological point of view, few papers propose a detailed pollen analysis in support to paleoenvironmental interpretation. The palynological assemblages synthesized herein are reported in Fig. 2, where the vegetation subdivisions described in each paper are tentatively correlated each other and to the North Europe climatic subdivisions.

The late Pleistocene pollen assemblages, reported only from the M1 core drilled in Tirrenia (Amorosi *et al.*, 2007; Ricci Lucchi, 2008), describes fluctuations in pollen assemblages related to transgressive-regressive cycles reflecting warming and cooling phases. Steppe and pioneer shrub and trees, woody taxa, coniferous forest and steppics and *Pinus* followed by increase of mesophilous forests (mainly deciduous oak-woods) are the vegetation dynamic in the Pisa coastal plain during the Eemin-Weichselian periods. Similar assemblages have been recognized in the corresponding levels of the landward equivalent core S1 (few kilometers NE of Pisa: Amorosi *et al.*, 2009).

Early and middle Holocene pollen associations (Galletti Fancelli 1971, 1979; Aguzzi *et al.*, 2007, Amorosi *et al.*, 2009) document the expansion of the mixed oak woods associated to *Pinus* forests at the beginning of the Holocene, related to the climate warming, which make the transition from glacial to interglacial conditions. The vegetation records the replacement of *Pinus* woodland by the oak-woods (*Quercus*) and the successive Mediterranean and *Pinus* woodlands in the Boreal and Atlantic periods respectively. After, Mediterranean vegetation, expansion of open vegetation and the progressive reduction of mixed deciduous oak-wood and mountain taxa occur.

Data from Late Holocene from the archaeological site of S. Rossore in Pisa city document a pre-Roman cold vegetation phase, with mountain trees, by a Roman phase with vegetation changes connected to climatic fluctuations. The Roman age pollen association are characterized by herbaceous taxa at the beginning and then by deciduous oak woods followed by mixed oak woods and hygrophilous trees. Several freshwater plants are successively recorded.

The pollen record in the core samples from the Massociuccoli Lake (Mariotti Lippi, 2007b) shows a similar lower to middle Holocene sequence of vegetation changes. In the late Roman age the human activities are suggested by signal of deforestation and early agricultural practice (spread of *Vitis*).

Future perspectives are directed to study favourable sedimentary levels in other core or outcrops of the Pisa plain area to improve the stratigraphic pollen zone sequence and to offer new data on cultural habits and lifestyle of past culture from more recent stratigraphic levels.

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