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MAPPA cores: an interdisciplinary approach

With the contribution of :

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In the urban and periurban area of Pisa, 18 cores ranging in depth between 7 and 15 m were performed and analysed through an interdisciplinary approach, which led to an improved stratigraphic log representation. The acquired data also improved our knowledge about the palaeoenvironmental and human settlement evolution of Pisa area over the past 6000 years, evidencing the mutual interaction existing between landscape and human activities.

Keywords: cores, interdisciplinary stratigraphic log representation, geoarchaeology, sedimentology, geomorphology

1.Introduction

The creation of palaeographic maps of Pisa urban and periurban area, is preparatory to the development of the archaeological potential map and represents the next milestone of the MAPPA project. The reconstruction of ancient geographies of Pisa plain must rely on an accurate knowledge of the subsurface stratigraphic architecture, which shows the relationships between lithofacies and natural or anthropogenically forced depositional environments. Moreover, these relationships must be placed into a consistent chronostratigraphic framework to reconstruct landscape and human settlements space-time evolution.

To achieve this objective, eighteen sedimentary cores were performed, integrated with other two continuous cores already drilled (see MapPapers 3) and analysed using an interdisciplinary approach, based on the contributions from experts in different disciplines (archaeologists and geologists). This collaborative research required a common effort especially in correspondence of the uppermost cored portions, characterized by a strong interaction between natural and anthropic processes. The application of geoscience methodologies in archaeology and the identification of common-action protocols among archaeologists and geologists is one of the main challenges that still interest geoarchaeology today (BUTZER 2008).

The results of the interdisciplinary study of MAPPA cores are reported further on. The full integration among sedimentological-stratigraphic, geochemical, palynological, geomorphological, micropalaeontological and archaeological data allow us to reconstruct the development of the palaeoenvironmental and settlement context of twenty strategic points in Pisa.

2. Materials and Methods

2.1 MAPPA cores

Subsurface and surface data already existing in databases were analysed and reviewed by the geologists before MAPPA cores execution. The aim was to identify potentially useful areas in order to better understand the architecture of the uppermost subsurface and to solve various open issues. At the same time, the archaeologists analysed existing archaeological documentation so as to identify which areas were particularly lacking in information. The joint assessments made by the geologists and archaeologists allowed a series of highly significant sites to be identified for the acquisition of new geoarchaeological information.

The coring points were identified within the selected areas, bearing in mind all relevant logistic problems. Then, each site was measured with a Leica differential GPS in order to acquire the x, y and z coordinates. A geophysical survey was also carried out around each coring point using a GPR-Ground Penetrating Radar IDS system, in order to detect any sub-services in the area of interest and avoid damaging them.

Once the GPR results were obtained, new subsurface data started to be acquired between October 2012 and February 2012. Firstly, 7 sedimentary cores, long up to 15 metres (M1-7; see Figures 1), were performed through a continuous perforating system which guaranteed an undisturbed core stratigraphy (Figure 2). Afterwards, 11 cores (see Figure 1), were drilled using a percussion drilling technique (Vibracorer Atlas Copco, Cobra model, equipped with Elijkamp samplers) which furnished smaller diameter cores yet qualitatively similar to those taken during continuous coring (Figure 3). The depth reached with this instrument varied between 13 and 7 metres depending on the tool's limitations and/or project needs. Archaeologists, geomorphologists and sedimentologists were jointly involved in the field activities. Alongside the drilling activities, they also carried out all necessary coring preparation activities and subsequent detailed stratigraphic reading in a shared and integrated manner. After the reading phase, the cores were sampled for laboratory analyses. The first seven continuous cores were considered as reference cores since, given their depth and spatial distribution, they allowed all main sedimentary facies to be recovered. The continuous perforating system guaranteed a suitably sized undisturbed succession that allowed a single sampling procedure for the expected laboratory analyses. Overall, 232 samples were collected and then sub-sampled for micropalaeontological, palynological, geochemical and radiocarbon analyses. The sampling interval for each core varied according to the type of deposit. Around 4-5 samples per metre were taken within fine-grained successions, where the meiofauna and pollen are potentially well-preserved and abundant. Instead, in correspondence of sandy deposits or deposits showing evidences of subaerial exposure (calcareous nodules, Fe and Mn oxides, overconsolidated horizons), the sampling interval was reduced to 1-3 samples per metre. Finally, in correspondence of specific levels in

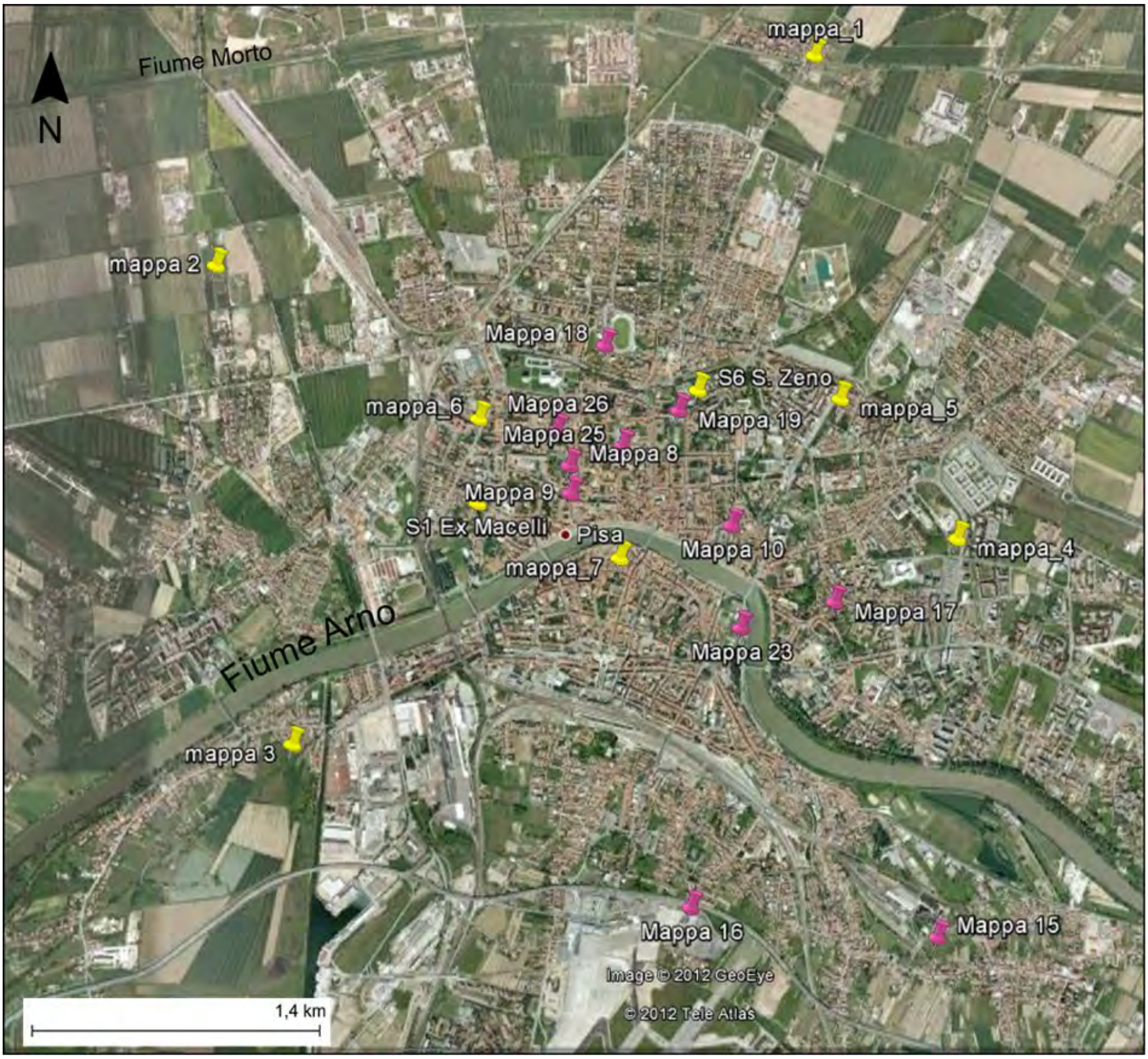

Figure 1. Location map of M.A.P.P.A. cores within the study area. The continuous cores are shown in pink, while Vibracorer Cobra cores are reported in yellow.

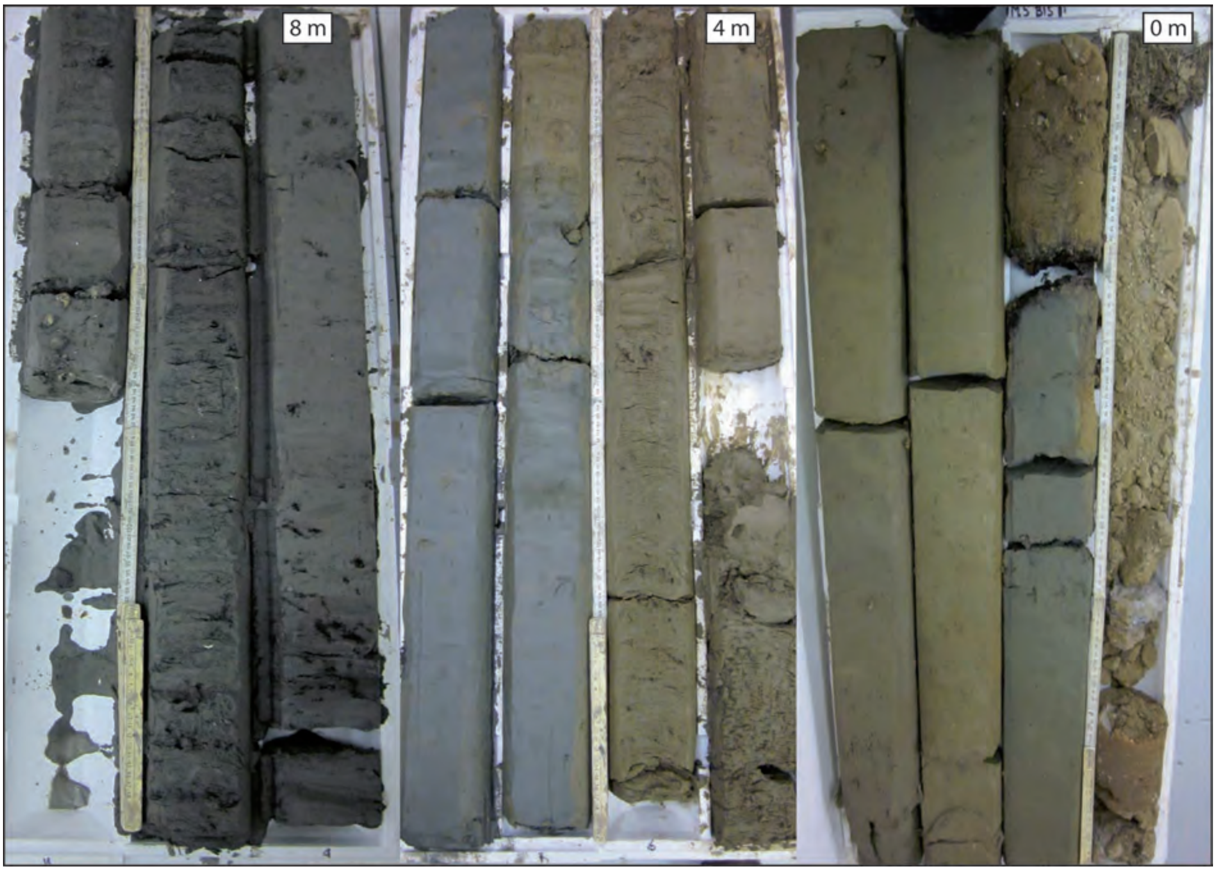

Figure 2. Representative photographs of core M5, showing the high recovery percentage and the undisturbed core stratigraphy of continuous cores M1-7.

Figure 3. Representative photographs of core M19, showing the good quality of Vibracorer Cobra stratigraphy.

Vibracorer cores, 5 *ad hoc* samples were taken for palynological analyses to compare vegetation data with archaeological materials and 11 samples for radiocarbon dating, useful for improving the chronological framework of the succession under examination.

(M.B., F.F., S.G., V.R.)

2.2 Micropalaeontological analyses

57 samples were selected from the M1-7 reference cores (an average of 7-10 samples for each core). Qualitative and semi-quantitative analyses were performed on the benthic meiofauna content. In order to guarantee the micropalaeontological characterisation of each evident lithological change, samples from both clayey and sandy successions were analysed, especially those rich in macrofossils.

Around 200-150 grams of sediments from each sample were oven-dried at 60°C for eight hours in the Laboratory of Paleontology of the Department of Earth Sciences of Pisa University[2], and soaked in water or water and hydrogen peroxide (35%) in case of particularly cohesive samples. Each sample was wet-sieved through sieves of 63 μm (240 mesh) and oven-dried again at 60 °C for 1-2 days. Finally, samples were dry-sieved through sieves of 125 μm in order to concentrate adult specimens, avoid taxonomic identification problems of juvenile ostracod moult stages and support comparison with modern and fossil associations of Mediterranean area.

The fraction >125 μm was qualitatively observed under a reflected light binocular microscope to separate the sterile samples from those containing autochthonous (well-preserved specimens and/or valves) or allochthonous (specimens and/or valves with evidences of transport) meiofauna. The identification of foraminiferal species were supported by original descriptions (*fide* ELLIS, MESSINA 1940) and several key-papers regarding the Mediterranean fauna (JORISSEN 1988; ALBANI, SERANDREI BARBERO 1990; SGARRELLA, MONCHARMONT ZEI 1993; FIORINI, VAIANI 2001). Reference publications, such as ATHERSUCH et al. (1989) e HENDERSON (1990), were used for the taxonomic identification of ostracods.

On samples containing an autochthonous meiofauna a semi-quantitative analysis was performed following a methodology similar to that adopted by BONDESÀN et al. (2006) and AGUZZI et al. (2007) for comparable and coeval associations recorded beneath the Po Delta and the Arno plain, respectively. Three main categories of relative abundance of species (abundant >30%; common: 30%-10% and rare: <10%) were used to identify mixed benthic foraminiferal and ostracod associations, which are described and interpreted in paragraph 3.1.

The palaeoenvironmental interpretation of these associations and specific information regarding the ecology of single species relied upon several papers regarding modern marine-coastal associations of benthic foraminifers and ostracods (ATHERSUCH et al. 1989; ALBANI, SERANDREI BARBERO 1990; HENDERSON 1990; MURRAY 2006; MEISCH 2000; RUIZ et al. 2000). Further information were also obtained by comparison with the benthic foraminiferal and ostracod associations found within the late Quaternary subsurface deposits buried beneath other Mediterranean deltaic-coastal areas (MAZZINI et al. 1999; AMOROSI et al. 2004, 2008; CARBONI et al. 2002, 2010; FIORINI 2004).

(V.R.)

2.3 Palynological analyses

A total of 36 samples were selected from the fine grain deposits of the M1-7 cores. Among these, 22 from M4 (12) and M5 (10) cores, which were considered cores of absolute reference since featuring a thick and continuous succession of clay-silty deposits. The remaining 14 samples were selected among the remaining continuous cores (9) and the cores taken with the Vibracorer Cobra (5).

Ten grams of each sample was treated according to the standard method used by the Palynology Laboratory of the Department of Earth Sciences of Pisa University, with the exception of heavy-liquid separation (ZnBr2) which was not necessary for the type of sediment examined. The method consists of processing the sample with HCl 33% and HF 40% to remove the carbonates and silicates and then filtering the residue with denatured alcohol with 200 μm and 10 μm meshes to concentrate the sample. The residue was then mounted on a glass slide with glycerine and analysed with a transmitted light optical microscope. The >200 μm organic fraction was observed with a reflected light binocular microscope and separately described. All the samples (with the exception of the sample taken at 3.86-3.92 metres in M19) were fossiliferous in terms of palynomorphs with well-preserved specimens, albeit not numerous. A qualitative analysis was used to examine structured (phytoclasts) and unstructured (amorphous) organic matter. Instead, a tablet containing a known amount of Lycopodium spores was added at the start of sample preparation to estimate the concentration of palynomorphs (spores and pollen, Fungi, dinoflagellate cysts, acritarchs, Algae, foraminiferal linings and scolecodonts). Where possible, 200 palynomorphs were counted and the percentages of the relative abundance of taxa was calculated. Pollen taxa were identified in accordance with existing literature (REILLE 1992, 1995, 1998 and online databases) and grouped on the basis of their ecological and climatic affinities, following the indications of previous works carried out on the Arno coastal plain (AGUZZI et al. 2007; RICCI LUCCHI 2008).

(C.R.)

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[2] The samples were prepared by Sara Mariotti.

2.4 Geochemical analyses

The geochemical analyses were performed on 100 samples with the aim to characterise the composition of the main depositional facies and to reconstruct sediment dispersal patterns, with special emphasis on the distinction between deposits fed by Arno and Serchio rivers, respectively. For this purpose, in addition to 80 samples from continuous cores M1-7, 20 samples (12 attributable to River Arno and 8 to River Serchio) were taken using the "Cobra" corer. These samples were collected at a few hundred metres from the channel axes and at very shallow depths (1-4 m), thus providing unequivocal information about geochemical composition of the two end members. The samples were analysed using X-Ray Fluorescence (XRF) Spectrometry at the laboratories of Bologna University. Concentration of major elements was calculated using the method of FRANZINI et al. (1975), whilst the coefficients of FRANZINI et al. (1972), LEONI, SAITTA (1976) and LEONI et al. (1982) were used for trace elements.

(A.A., I.S.)

2.5 Radiocarbon dating

Radiocarbon dating was performed on 35 samples collected at specific levels from selected 15 cores (Table 1 in the Appendix), in order to place the depositional architecture and the various palaeogeographical scenarios recorded in the subsurface of Pisa into a consistent chronological framework. Radiocarbon dating is the most commonly used geochronological method and is based on radioisotope-carbon (^{14}C), produced by the interaction of cosmic rays with atmospheric nitrogen atoms (^{14}N). Atmospheric carbon dioxide (CO_2) contains the stable isotope ^{13}C in a fixed proportion with the radioisotope ^{14}C; it bonds with organic matter and when the latter dies it starts to decay with a half-life time of 5730±40 years. After establishing the decay rate and initial radioisotope of an organic sample (obtained by measuring the stable isotope ^{13}C, proportional to it), it is possible to compute the age of the sample by measuring its ^{14}C content. The radiocarbon method spans date from a few hundred years ago to about 40,000 years. The majority of samples selected for this study were more or less decomposed vegetal remains and soil organic matter. They were preferred to marine mollusc shells which present age values that are generally higher than those obtained with organic matter (reservoir effect). Dating was performed at the CIRCE Laboratory of Caserta (Naples University). The isotopic ratios were measured using an ultra-sensitive particle accelerator. Conventional ages were calibrated using CALIB5 software and the calibration curves of REIMER et al. (2009); the calibration intervals were expressed as 1σ (68% of probability) and 2σ (95% of probability) in Table 1. To correct the reservoir effect, mollusc samples were calibrated using an average value of DeltaR (35±42) estimated for the northern Tyrrhenian Sea and available online (http://calib.qub.ac.uk/marine/).

(M.P., V.R.)

2.6 Georadar tests

In order to explore the subsurface of the various Project sites, a Ground Penetrating Radar (GPR) system was used. This geophysical technique detects the existence of stratigraphic-archaeological discontinuity, in a non-invasive fashion, by transmitting electromagnetic pulses and receiving reflected echoes from subsurface discontinuities. A GPR equipped with an IDS 400 MHz antenna was used for prospecting purposes and represents a good compromise between resolution and depth. Lines in common offset mode were acquired using an orthogonal grid with minimum cell size 0.2 m. The spatial sampling interval was 1.6 cm whereas the vertical interval was 1024 samples per trace. Every radar section acquired was processed in order to eliminate any electromagnetic signal frequencies caused by environmental and instrumental noise, to make the weakest reflections generated by the deepest discontinuities become more readable, and to transform the vertical coordinate system from time- to depth-dependent. Each processed section of the acquisition grid was interpolated with the adjacent to create a cube of regularly distributed data having dimensions represented by the two directions of acquisition and depth. The cube of data was then sectioned at varying depths, generating planar distributions of the areas in which the electromagnetic pulses have different reflective powers (time or depth slice). The combination between depth slice and vertical radar sections represents the structure of the interpretative phase, allowing 3D evaluation of the geometric consistency and continuity of the areas reflecting the radar signals and assigning therefore a potential stratigraphic-archaeological meaning to them.

(M.B., A.R.)

2.7 GPS Positioning

The 20 cores examined were positioned in the three spatial dimensions (latitude, longitude and altitude) with the aid of a Leica GS09 Leica differential GPS. The average positioning error for the 20 points that were detected was: ± 1 cm for planimetric positioning and ± 2 cm for altimetric positioning. Error variability depended on the logistic conditions of the acquisition area (presence of buildings, tree covering, etc.) and on when the measurement was taken (number of visible satellites). The post-processing activities for defining the coordinates of the points in the WGS84 reference system were carried out with Leica Geo Office 4.0 software. Then, in order to reference the data to average sea level and to the national reference system (Gauss Boaga), ellipsoidal correction of the altitude and transformation of the reference system were carried out using Verto 3k software (produced by the Geographical Military Institute), as well as the relevant grids with a radius of 10 km on benchmarks

IGM 95 no.104604 (Migliarino) and no. 111604 (Pisa-Scalo Mortellini).

(M.B., M.P.)

2.8 Towards an interdisciplinary stratigraphic log

The identification of a common technical language, essential for an integrated study of MAPPA cores by sedimentologists, geomorphologists and archaeologists, was an issue of key-importance for the success of the project and one of the main difficulties addressed by the team. Each group had already analysed cores in the past and, although considering the significance of other disciplines, had placed emphasis on its own experience (PARIBENI et al. 2005; AMOROSI et al. 2009; BINI et al. 2012).

The same deposit is able to provide different information based on the person examining it and his/her scientific background. For example, a fine-grained yellow-brown deposit containing traces of oxidation and ceramic fragments could reveal the development of a floodplain in sub-aerial exposure from a sedimentological viewpoint; instead if the deposit is compared with neighbouring data it could reveal an interfluvial ridge from a geomorphological point of view. Finally, the heterogeneous sedimentary texture and the presence of small and sporadic ceramic fragments are considered indicators of anthropic settlements in archaeological terms, maybe linked to agricultural use. Reality is more complex, the more viewpoints it is observed from.

Archaeologists make accurate distinctions within natural deposits, although these do not often lead to the reconstruction of natural facies. Similarly, geologists find it difficult to describe deposits affected by man which are generically referred to as “anthropic deposits” and are used for dating purposes, with serious loss of useful data both for archaeological and environmental reconstructions. Given this context, reading the portions of cores where man’s actions and natural processes are highly intertwined is particularly complex. The need to describe the same stratification from different viewpoints led us to integrate our skills and, although preserving the distinctiveness of each single discipline, to avoid breaking up the context into simple juxtaposed readings.

It became essential to develop a graphical tool that could represent the data resulting from the various disciplines in a synthetic and integrated manner, given the absence of a satisfactory model for our objectives (for other integrated representations see, for example, AMMERMAN 1998; MARRINER et al. 2006; GHILARDI et al. 2008; MATTHEWS 2010; GHILARDI, BORAIK 2011). The graphic sheet that is proposed is divided into various columns, each representing a specific type of data (Figure 4). The main element is the stratigraphic log, in which the anthropic layers are processed with the same method used for natural sedimentary intervals. For example, the type of matrix (clay, sand, gravel, etc.) is described in qualitative terms, using horizontal bars of varying length according to the grain size of the material itself. At the same time, the division into Contexts, expressly used in archaeology, is also adopted for the portion of coring that is not interested by anthropic material.

Specifically, the main grain size classes that are recognisable through qualitative analysis (clay; silt; fine sand; medium sand; coarse sand and gravel) are identified on the log with the following initials: A, L, Sf, Sm, Sg and G, each of which corresponds to a standardised quantitative dimensional range, respectively <4 μm, 4-63 μm, 63-250 μm, 250 μm-0,5 mm, 0,5-2mm and >2mm (WENTWORTH 1922). Centimetre-sized elements are generically indicated with the initial >G. The Contexts in which the coring succession is divided are indicated on the left side of the log. The right side, instead, provides indications about both natural (vegetal remains, mollusc shells, concretions, etc.) and anthropic (ceramic fragments, slag or metal artefacts, glass, etc.) materials found in each Context, according to specific symbols described in the key. If the artefact is isolated, the symbol is positioned exactly at the depth at which it was found; instead, if artefacts of the same type are diffused within the deposit, the symbol is placed after a curly bracket containing the depositional interval.

The MAPPA project has also proposed an innovative use of the georadar data for geoarchaeological purposes. Whilst the survey was initially carried out in the area with the sole purpose of avoiding damage to any existing subservices (cfr. § 2.6), its potential to integrate coring data subsequently arose.

The “Georadar profile” column reports the depth distribution of the radar reflections. The main radar facies identified in the coring area in the first metres of subsurface (depending on the depth that can be reached) can be extracted from this vertical section. The concept of radar facies, borrowed from sequential stratigraphy, was used to associate the GPR results with the stratigraphic and archaeological results. A georadar facies corresponds to a group of radar reflections systematically defined above and below by discontinuity surfaces (radar surfaces). The reflections may be attributed both to a succession of both natural and archaeological horizons; the discontinuity surface indicates an interruption in the structure. In addition to transposing archaeological stratigraphy into radar stratigraphy, it is important to point out the attempt to make the definition of facies include the meaning of discordant surfaces of archaeological elements of various shape and position in the subsurface. Planar surfaces (foundations, roads, ground surface) or concave surfaces (trenches, burial places) may have needed erosion for their structuring. Sedimentation with angular discordance covered these surfaces as well as with a prograding depositional mechanism with dominating feeding direction in certain situations. The succession of multiple human settlement episodes and of natural sedimentation events may therefore form a depositional architecture, which overall expresses the history of the interactions between man and the environment.

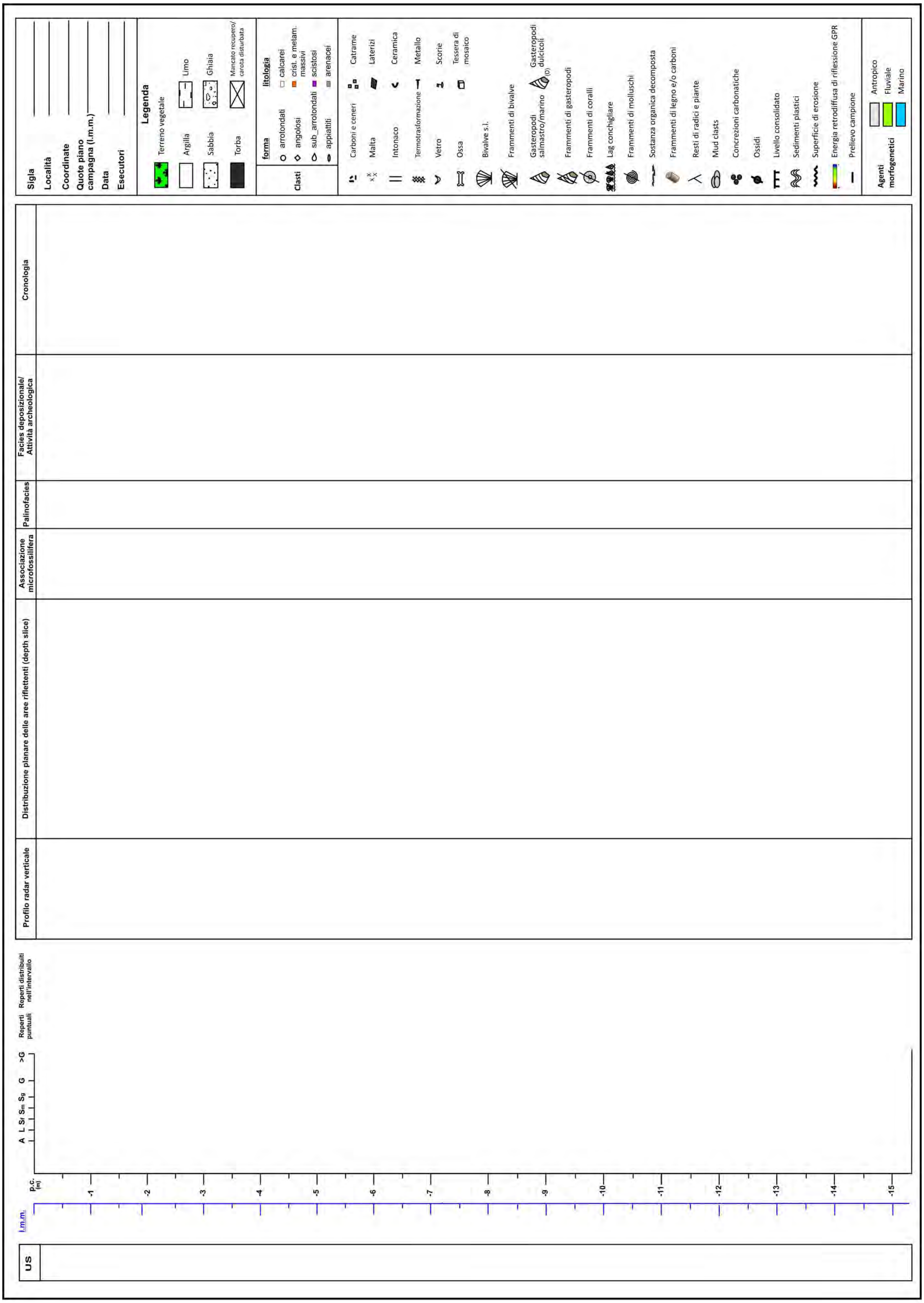

Figure 4. Graphic representation proposed to display an interdisciplinary approach on cores.

Acquisition according to a regular grid of lines also makes it possible to generate horizontal radar sections parallel to the topographic surface (depth slice) in which the planar distributions of the areas with different reflecting strength (second column) may be seen. The coring data, together with the vertical radar sections (analysed through facies concepts) and the depth slices improve interpretation, allowing cross checks and the aerial expansion of immediate information. A layer of stones, for example, may easily be interpreted as a wall if the georadar profile reveals a radar reflection at the same depth and, more generally, a radar facies compatible with the presence of a structure of this type. The geometry of this wall and its relations with other similar structures may be assessed according to the depth slice ("planar distribution of the reflecting areas") cut at the same depth.

Detailed information about environmental conditions, that have characterised the urban and periurban area of Pisa in the recent past, are instead furnished by the meiofauna recorded within the depositional succession under examination ("microfossil associations" column). Mixed benthic foraminiferal and ostracod associations recognised in the samples contribute to a detailed characterisation of core facies, highlighting even small changes in palaeoenvironmental conditions, especially in terms of salinity oscillations, occurred in the Pisa area (cfr. § 2.2).

The palinofacies represented in the adjacent column confirm and implement the palaeoenvironmental data provided by microfossiliferous associations and are able to provide indications on the diffusion of specific vegetal species brought on by the activity of man, for example, agricultural practices.

The column "depositional facies/archaeological activities" integrates and synthesises all the data of the previous columns, providing their geoarchaeological interpretation. The integration of analytical data allows the recognition of different depositional facies composing the stratigraphic log. A sandy deposit, for instance, may be referred to a fluvial channel when it presents an internal fining-upward trend, an erosive contact at the base, over one-metre thickness and sterility or presence of few reworked fossils. Similarly, fine-grained plastic grey sediments containing *Cardium* shells and characterised by the presence of specific microfossil and palynological associations may be interpreted as lagoon deposits. Facies associations may be related to various types of depositional environments, leading to the reconstruction of main palaeoenvironmental variations occurred in the study area.

The environments are marked by geomorphologically coded colours which characterise the various morphogenetic agents, such as green representing the fluvial agent or blue the marine agent. The purpose is to immediately transfer the subsurface data into landscape form and, therefore, to construct a palaeogeographical scenario which defines the areas of reference of the morphogenetic agents. The archaeological layers are separated on the basis of their physical characteristics and are therefore "objective" stratification items; they do not contain high information potential and may be better interpreted if grouped together to form an "activity". For example, if a layer of small stones bound by clay, a layer of mortar and one of bricks are considered individually, they may appear to be of little importance; instead, if grouped together they may be interpreted as a flooring.

This synthetic representation also makes it possible to represent both natural contexts and anthropic activities in an integrated manner and to evaluate their mutual interactions: indeed, it is possible for a specific natural environment (for example a floodplain) and the anthropic activity that characterised it ("frequentation" or "agricultural land") to be represented side by side.

Finally, the last column shows the chronologies that may be attributed to the single contexts or to a depositional interval, on the basis of archaeological materials or radiocarbon dating carried out on suitably selected coring samples (cfr. § 2.5.).

(M.B., F.F., S.G., M.P., C.R., V.R., G.S.)

3. Analytical results

3.1 Microfossil associations

Microfossil associations preserved within cored (M1-7) successions provide an important tool to reconstruct the environmental conditions characterizing the urban and periurban area of Pisa over the recent past, especially in terms of palaeosalinity, circulation/oxygenisation at the basin bottom and hydrodynamicity. Quantitative and semi-quantitative analysis of the benthic meiofauna (foraminifers and ostracods) allowed the identification of seven mixed associations, subsequently grouped into three ecologic categories called F, B and R, according to the scheme adopted by AMOROSI et al. (2004) for similar associations found in the Po Plain subsurface. Group F indicates a hypoaline-freshwater association, whereas letter B includes brackish associations. Associations composed of reworked microfossils (allochthonous) belong to group R. Within groups B and R specific sub-environments and their related microfossil associations were distinguished by numbers (e.g.: B1; R2). Each association is described below following the order of the previously indicated groups. The terms "abundant", "common" and "rare" refer to the categories of relative abundance introduced in paragraph 2.2.

GROUP F

Association F

Association F is characterised by a generally numerous, poorly diversified, almost oligotypic, autochthonous ostracofauna composed exclusively of hypoaline species. No foraminifers are recorded.

Pseudocandona albicans is the dominating species (Brady, 1868), accompanied by common to rare valves of *Candona neglecta* (Sars, 1887) and rare valves of *Ilyocypris decipiens* (Masi, 1905).

The presence of a hypoaline and poorly diversified ostracofauna, together with the absence of foraminifers, indicate a freshwater or slightly brackish/olygohaline subaqueous environment (<5‰) subject to low marine influence. The almost absolute dominance of one species, *P. albicans*, typical of stagnant waters with low dissolved oxygen and high concentration of organic matter (HENDERSON 1990; MEISCH 2000) suggests a paludal environment.

Association F occurs within dark plastic fine-grained deposits, rich in decomposed organic matter and wood fragments or in correspondence of peaty horizons recorded within poorly organic plastic clayey successions containing large-size isolated concretions.

GROUP B

Association B1

B1 contains an olygotypic autochthonous meiofauna composed exclusively of euryhaline and opportunist species tolerant to notable variations of salinity. Ostracod valves are numerous, whereas foraminifers are low in terms of absolute abundance. Ostracofauna is dominated by abundant *Cyprideis torosa* (Jones, 1850), associated with rare valves of *Loxoconcha elliptica* (Brady, 1868b). The only forms of benthic foraminifers found belong to the *Ammonia tepida* (Cushman,1926) and *A. parkinsoniana* (d'Orbigny, 1839) species.

The absolute dominance of *Cyprideis torosa*, a species that is typically found in brackish environments and that tolerates strong oscillations of salinity, from freshwater to hypersaline (ATHERSUCH et al. 1989; MEISCH 2000), is indicative of a shallow basin slightly influenced by marine waters, such as a brackish paludal area or the inner part of a lagoon. The exclusive presence of euryhaline opportunist species (BONADUCE et al. 1975; MONTENEGRO, PUGLIESE 1996; MURRAY 2006) and of a scarce foraminiferal fauna are consistent with this interpretation. A similar meiofauna was found in the proximal portion of the Venice lagoon, directly influenced by fluvial outlets (RUIZ et al., 2000; COCCIONI et al. 2009).

Within the studied cores,association B1 was found within plastic clayey sediments rich in decomposed organic matter and containing a high concentration of, wood fragments and, occasionally, bioclasts of *Cardium*.

Association B2

Respect to B1, this association is characterised by a numerous and more diversified autochthonous meiofauna, both in terms of ostracods and foraminifers. Species composing this association are almost all opportunist and tolerant to hyposaline conditions and salinity variations.

Specifically, the ostracofauna is characterised by abundant *Cyprideis torosa* and common valves of *Loxoconcha elliptica* and *Loxoconcha stellifera* (G.W. Müller, 1894). Rare valves of *Leptocythere bacescoi* (Rome, 1942) are occasionally present. Abundant *Ammonia tepida* and *A. parkinsoniana* compose the benthic foraminiferal association, accompanied by common to rare specimens of *Haynesina germanica* (Ehrenberg, 1840) and *Aubygnina perlucida* (Heron-Allen & Earland, 1913). These species are locally associated with rare *Cribroelphidium lidoense* (Cushman, 1936) and *Cribroelphidium poeyanum* (d'Orbigny, 1839).

Compared to B1, the greater number of foraminiferal specimens and the higher interspecific diversity reveal an increase in marine influence inside the brackish basin (central part of the lagoon). In particular, all species are typical of slightly or decidedly mesohaline waters. In the Mediterranean area, a comparable meiofauna is widely diffused in both modern (ALBANI, SERANDREI BARBERO 1990; MONTENEGRO, PUGLIESE 1996; MURRAY 2006) and late Quaternary (CARBONI et al. 2002; AMOROSI et al. 2004; ROSSI et al. 2011) lagoonal deposits.

Asociation B2 is found within highly plastic clayey sediments containing a large amount of *Cardium* shells and rare fragments of wood.

Association B3

This association contains an autochthonous meiofauna showing the highest interspecific diversity among those recognised in the succession under examination. Moreover,association B3 contains typical coastal species preferring normal marine salinity. Foraminifers are numerous, whereas ostracod valves are low.

The ostracofauna is dominated by abundant *Leptocythere ramosa* (Rome, 1942) and *Palmoconcha turbida* (G.W. Müller, 1912) associated with common *C. torosa* and rare *L. elliptica. C. torosa* is sometimes abundant and accompanied by *Loxoconcha stellifera* as common species. In the foraminiferal association *Ammonia tepida* and *A. parkinsoniana* are always abundant, accompanied by common to rare *Haynesina germanica* and *Aubygnina perlucida.* Many species of *Miliolids,* such as *Adelosina cliarensis* (Heron-Allen & Earland, 1930), *Miliolinella subrotunda* (Montagu, 1803), *Miliolinella elongata* (Kruit, 1955), *Quinqueloculina seminula* (Linnaeus, 1758) e *Siphonaperta aspera* (d'Orbigny, 1826) are always present as rare taxa.

An high interspecific diversity, together with the presence of taxa typical of polyhaline-marine waters, such as *Leptocythere ramosa*, *Palmoconcha turbida* and the group of Miliolids, are indicative of greater marine influence compared to B1 and B2 associations. This interpretation is consistent with the most external part of a lagoonal basin.

Association B3 is present in extremely plastic clayey deposits containing numerous *Cardium* shells.

GROUP R

Association R1

This association is characterised by scarce and poorly preserved marine benthic foraminifers (*Ammonia beccarii; Elphidium crispum; Cibicidoides pachiderma*) accompanied by fragments of hypohaline ostracods (*Candona* sp.). The presence of re-elaborated or reworked forms belonging to species typical of different environments – from deep marine to coastal marine and continental areas – indicate a high-energy fluvial environment.

Association R1 is found within sandy deposits.

Association R2

Association R2 exclusively contains a few adult valves of *C. torosa*, usually showing evidence of abrasion and dissolution.

The presence of poorly preserved and size-selected valves of *C. torosa* suggest a high-energy environment within a slightly brackish basin such as the internal potion of lagoon or paludal area (e.g. subdelta).

This association is exclusively recorded within M1 core sandy deposits characterized by rare wood fragments and overlying a plastic clayey succession featuring *Cardium* shells and a B1 autochthonous meiofauna.

Association R3

This association contains scarce meiofauna with evident signs of transport (reddened, scraped or partially broken shells/valves) composed of both euryhaline species (*C. torosa, Ammonia tepida and A. parkinsoniana*) and coastal marine species including *A. beccarii* and *Nonion boueanum* (d'Orbigny, 1846).

The co-presence of poorly preserved specimens of species typical of brackish and marine-coastal environments suggests a high-energy transitional depositional setting influenced by sea currents.

Association R3 is present within sandy successions or successions composed of decimetric alternations of sand and silty clay containing bioclasts and wood fragments.

(R.V.)

3.2 Palynofacies

The composition of the organic residue, containing many organic fragments and marine palynomorphs alongside pollen and spores, allowed us to describe the analysed samples in terms of their palynofacies. The term 'palynofacies' was coined by COMBAZ (1964) to describe the organic matter observed under optical microscope after being extracted from a sediment or a sedimentary rock by means of palynological laboratory techniques. Although Combaz's original definition is still acceptable, the one suggested by POWELL et al. (1990) – "a distinctive assemblage of palynoclasts whose composition reflects a particular sedimentary environment" appears to be more comprehensive and currently more accepted, as discussed by BATTEN (1996).

The main components of palynofacies are palynomorphs, structured organic matter and unstructured organic matter (AOM). Spores and pollen, Fungi, dynoflagellate cysts, acritarchs, Algae, foraminiferal linings and scolecodonts (remains of polychaete anellids) represent the main palynomorphs. Structured organic matter is made up of plant fragments (wood, leaf and root cuticles, etc.) whilst unstructured organic matter is the degraded product of structured matter and may be of terrestrial or marine origin (Figure 5).

The samples analysed contain all the main palynofacies components mentioned above. Unstructured organic matter (AOM) is in granular form (the product of primary degradation of various parts of vascular plants by cellulose bacteria) and is considered of terrestrial origin.

The presence and combination of the various elements allows three different palynofacies to be recognised:

Palynofacies L

Association composed of numerous, orange-brown and often transparent phytoclasts with dimensions varying from a few µm to 500 µm. AOM is sporadically present in granular or floccular form. The palynomorphs contain marine-related elements varying from 2.5% to 16.5%, such as dinocysts, foraminiferal linings and scolecodonts. The continental fraction is composed of pollen and spores (from 35% to 85% circa) and Fungal spores (15-33%), and features a heterogeneous association containing more arboreal than non-arboreal pollen. Among the arboreal species, the *Alnus* dominates at times reaching a relative percentage of 35.8%. Aquatic plants are present in percentages varying from 1.5% to 2.5%.

The presence of dinocysts, foraminiferal linings and scolecodonts appears to be ascribable to a marine influenced basin, such as a lagoon, whose (outer to inner) portion reveals a gradual decrease in the percentage of marine elements and increase in continental intake.

Palynofacies L was identified in the samples taken at 10.47 m, 10.05 m, 9.60 m and 9.42 m of depth in core M5; in the sample taken at 11.30 m in core M1, in the sample taken at 14.50 m in core M2, in the sample taken at 10.45 m in core M3 and in the sample taken at 15.10 m in core M6.

Palynofacies P

This association is characterised by abundant and light orange to brown/black phytoclasts of various size (majority > 100 µm). The most frequent phytoclasts are a light brown transparent colour and have a fibrous aspect. Unstructured organic matter may be abundant at certain levels. The palynomorphs are mainly made up of continental elements with pollen and spores varying from around 34.5% to 56% and spores of Fungi from 27.4% to 30.5%. Pollen association is heterogeneous with more arboreal than non-arboreal pollen. Among the arboreal species, the broadleaved trees related to temperate-warm climates are sporadically more abundant, reaching a maximum of 13% of relative percentage. Aquatic plants are present in varying percentages (1.5% to 22%).

The abundance of organic matter, especially the abundance of phytoclasts, appears to indicate a shallow and marshy basin revealing considerable continental intake and low-oxygen environmental conditions or even anoxic conditions as evidenced by the presence of AOM.

Palynofacies P was identified in the samples taken at 8.56 m and 7.96 m of depth in core M5; in the samples taken at 9.45 m, 9.05 m, 8.70 m, 8.30 m, 7.90 m and 7.50 m in core M4; in the sample taken at 6.40 m in core M3 and in the samples taken at 7.38 m and 6.48 m in core M6. It was also identified in the samples taken between 6.85-6.95 m of depth in core M25, between 4.70-4.72 m in core M19 and between 4.62-4.71 in core M8.

Palynofacies A

This association is characterised by many equally sized, round-bordered and dark brown to black phytoclasts. AOM is sporadically present. Pollen association is heterogeneous with many reworked specimens. The percentage of arboreal species varies from 7.5% to 23% and is lower than non-arboreal species (3.3-20%) in more superficial samples. Aquatic species vary from 4.2% to 9.45%. Fungal spores are always present (21-53%). Reworked specimens consist of palynomorphs from more ancient sediments and palynomorphs reworked in situ.

The small size and rounded edges of the majority of phytoclasts are indicative of reworked material, as also revealed by the heterogeneity of content and preservation of the existing palynomorphs. This association may be referred to a floodplain environment close to a channel.

Palynofacies A was identified in the samples taken at 7.58 m, 4.45 m, and 2.69 m of depth in core M5; in the samples taken at 7.30 m, 6.90 m, 5.15 m, 3.85 m, 2.70 m and 1.50 m in core M4, in the sample taken at 2.69 m in core M3 and in the sample taken at 1.85-1.90 m in core M8.

(C.R.)

3.3 Geochemical data

Geochemical analysis led to the determination of 11 major elements, expressed in percentages (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K2O, P_2O_5, LOI), and 17 trace elements, expressed in mg/kg (Sc, V, Cr, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Pb e Th), for each of the 100 samples analysed. To make their reading easier, the results are presented in two separate tables: the first (Table 2 in the Appendix) refers to the 80 samples collected from cores M1-7, whereas the other (Table 3 in the Appendix) refers to the 20 reference samples, collected on the modern levees of River Arno ("Cobra" cores C1-C3) and River Serchio ("Cobra" cores C4-C5).

(A.A., I.S.)

Figure 5. Main palynofacies components .

Photos 1-15: bar= 20μm; photos 16-18: x 600.

1- 2. Dynoflagellate cysts.

1. Spiniferites. Sample M4 -2.70 (reworked).

2. Lingulodinium. Sample M2 -14.50.

3. Scolecodont. Sample M5 -10.47.

4. Monolete spore. Sample M5 -8.56.

5. Foraminiferal lining. Sample M3 -10.45

6-11 Pollen grains.

6. Abies. Sample M4 -8.30.

7. Alnus. Sample M4 -8.30.

8. Quercus. Sample M5 -10.47.

9. Pinus. Sample M4 -9.45

10. Tilia. Sample M4 -8.30.

11. Freshwater algal cyst (Pseudoschizaea). Sample M4 -6.90.

12. Fungal spore. Sample M4 -7.58.

13. Unstructured organic matter (AOM). Sample M4 -6.90.

14. Reworked phytoclasts. Sample M4 -2.70.

15. Phytoclast in situ. Sample M5 -7.96.

16-18. Palynofacies.

16. Palynofacies L. Sample M5 -10.47.

17. Palynofacies P. Sample M5 -7.96.

18. Palynofacies A. Sample M5 -2.70.


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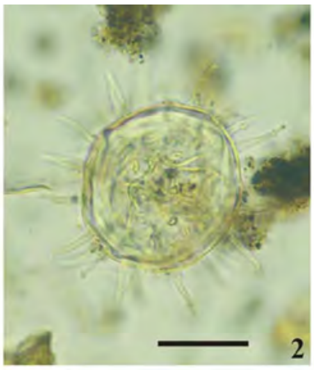
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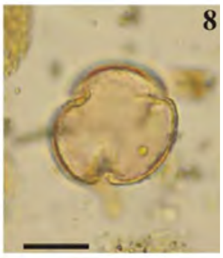
7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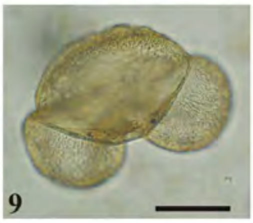
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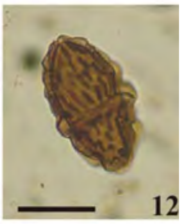
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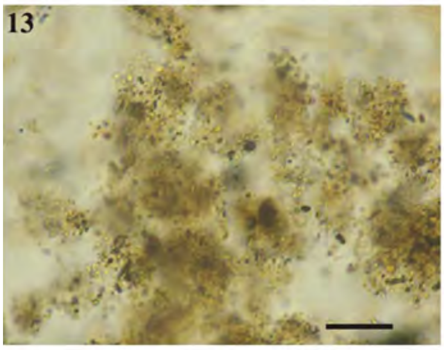
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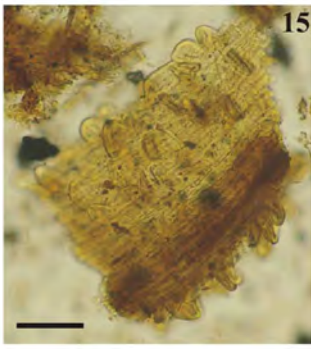
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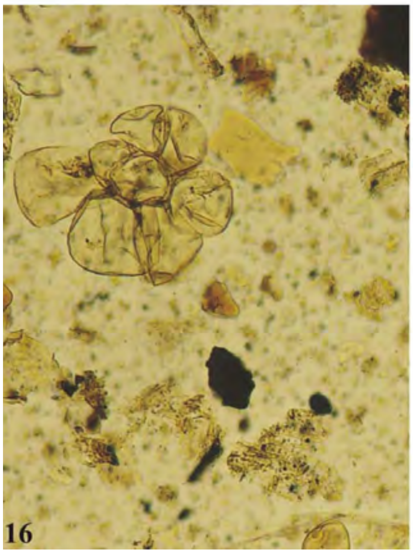
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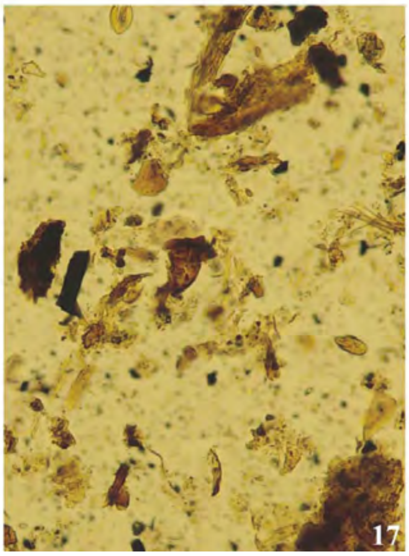
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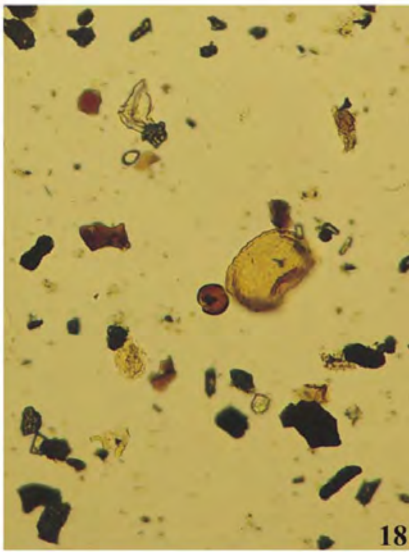
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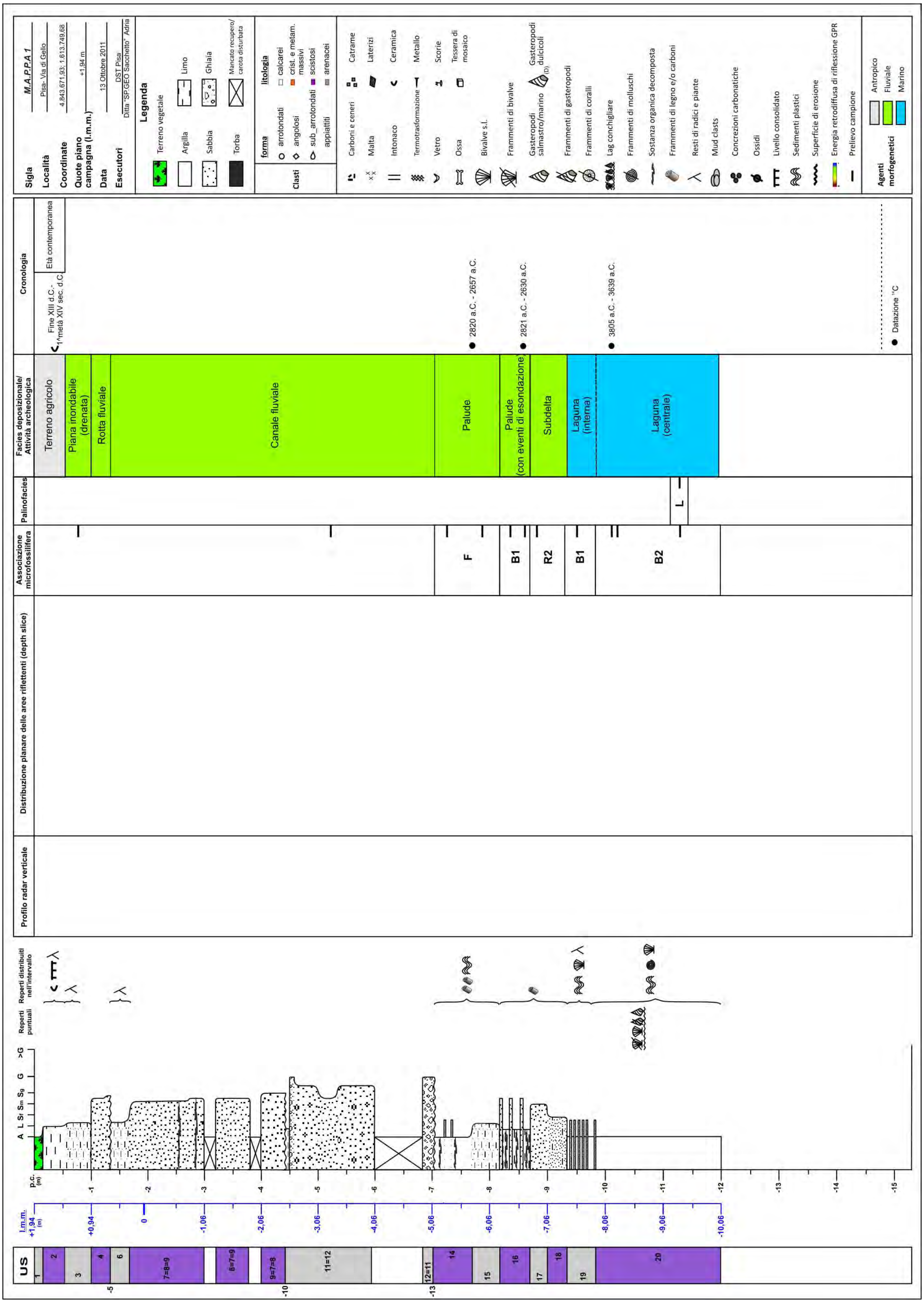
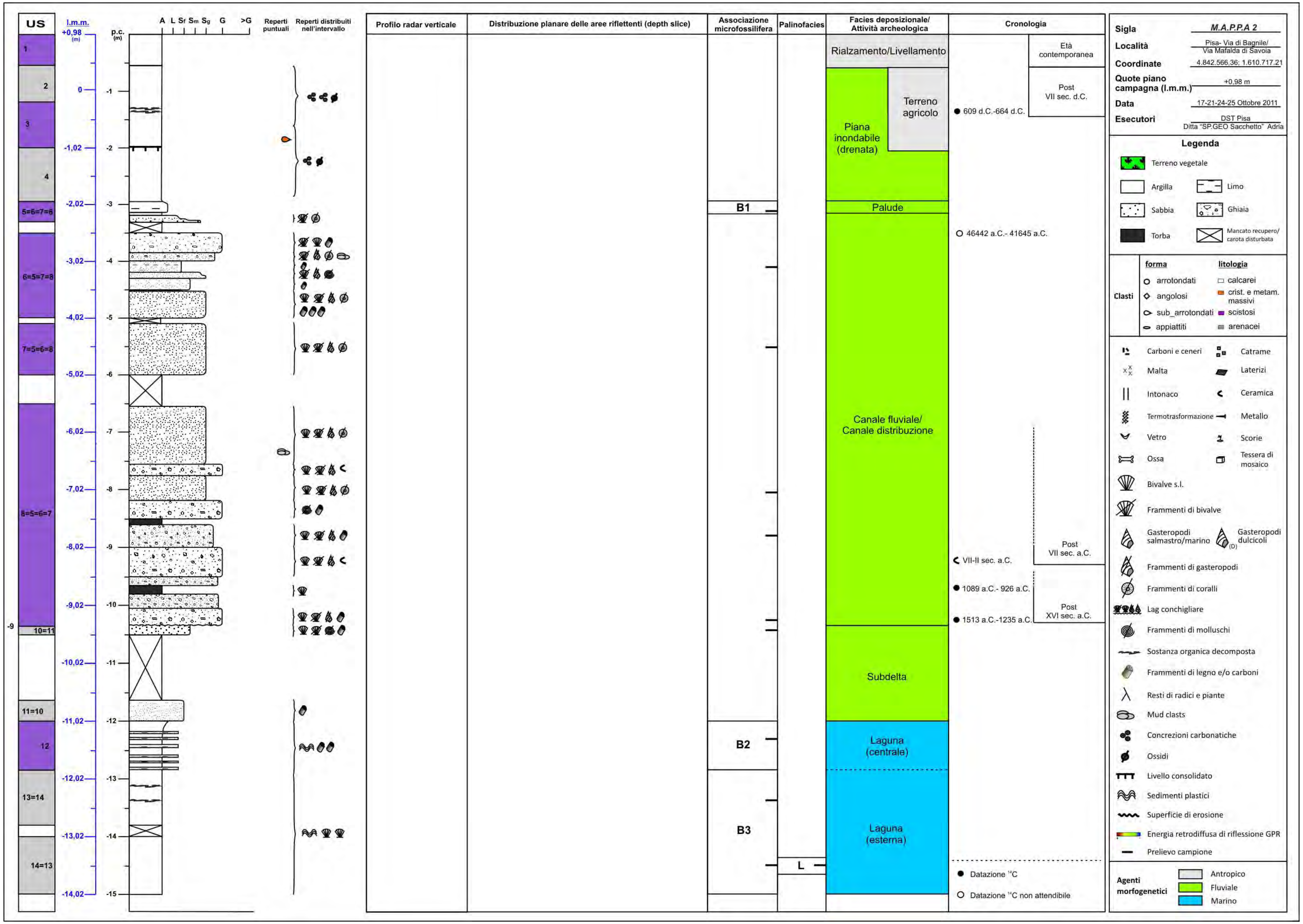
4. Stratigraphic logs

(M.B., F.F., S.G., M.P., C.R., V.R., G.S.)

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p.c. (m)
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A L Sf Sm Sg G >G
Reperti puntuali
Reperti distribuiti nell'intervallo
Profilo radar verticale
Distribuzione planare delle aree riflettenti (depth slice)
Associazione microfossilifera
B1
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Palinofacies
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Facies deposizionale/ Attività archeologica
Rialzamento/Livellamento
Terreno agricolo
Piana inondabile (drenata)
Palude
Canale fluviale/ Canale distribuzione
Subdelta
Laguna (centrale)
Laguna (esterna)
Cronologia
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Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
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arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
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arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli (D)
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
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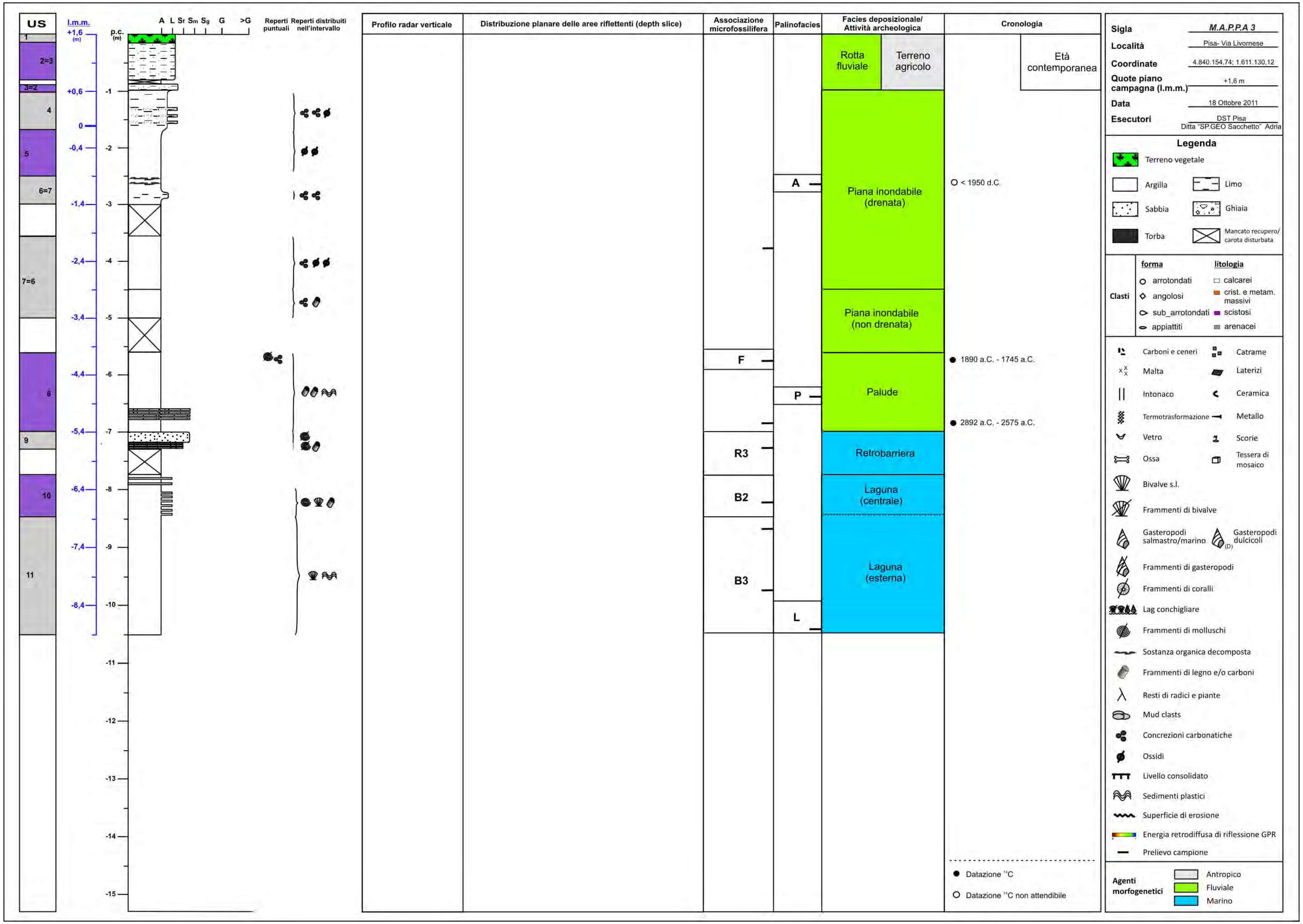
Agenti morfogenetici
Antropico
Fluviale
Marino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Reperti puntuali
Reperti distribuiti nell'intervallo
Profilo radar verticale
Distribuzione planare delle aree riflettenti (depth slice)
Associazione microfossilifera
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Palinofacies
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Facies deposizionale/ Attività archeologica
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Retrobarriera
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appiattiti
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crist. e metam. massivi
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arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
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Gasteropodi dulcicoli (D)
Frammenti di gasteropodi
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Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
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Agenti morfogenetici
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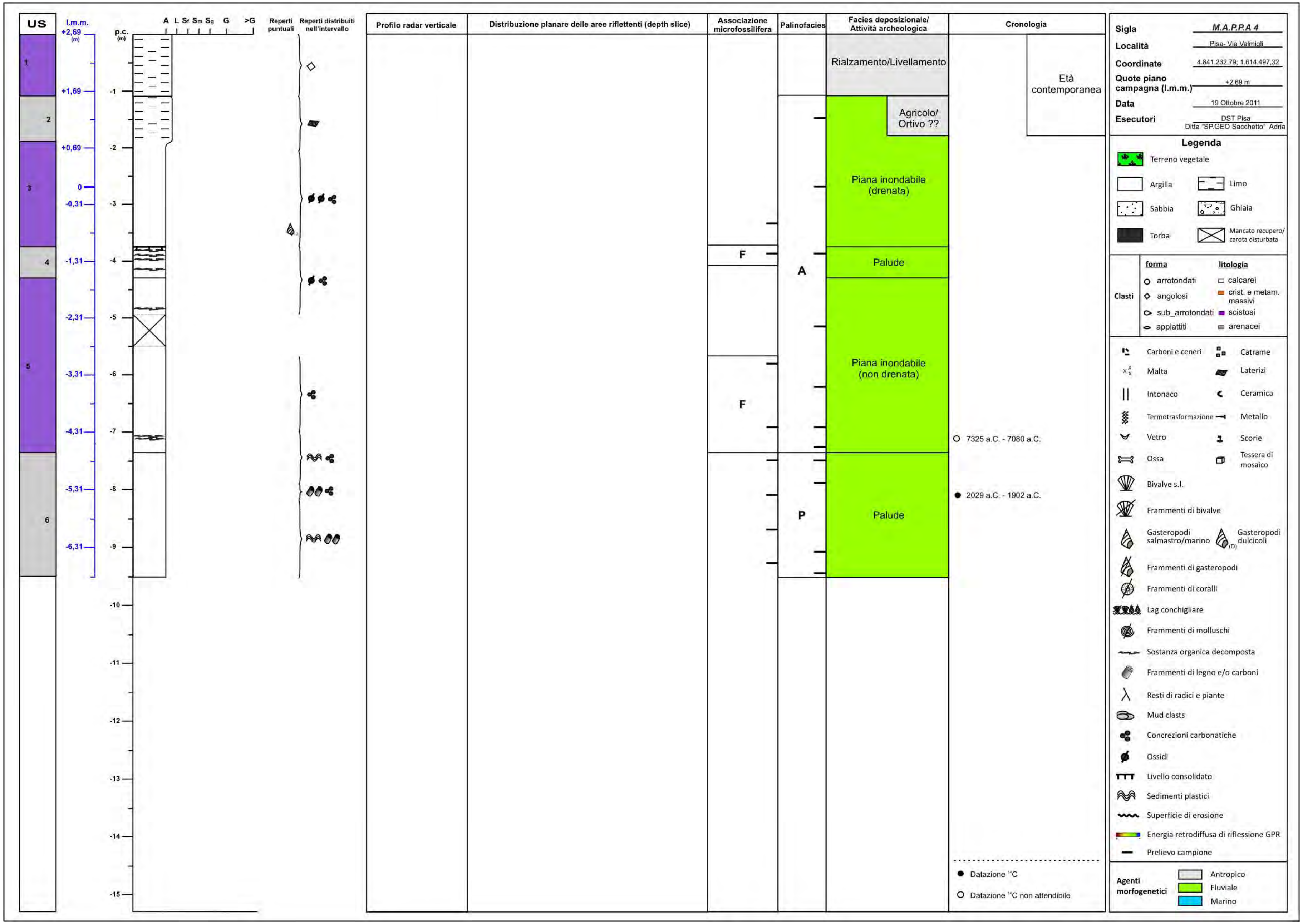
Fluviale
Marino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A L Sf Sm Sg G >G
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Reperti distribuiti nell'intervallo
Profilo radar verticale
Distribuzione planare delle aree riflettenti (depth slice)
Associazione microfossilifera
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Facies deposizionale/ Attività archeologica
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Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
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angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
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arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
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Ossa
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Gasteropodi dulcicoli (D)
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Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
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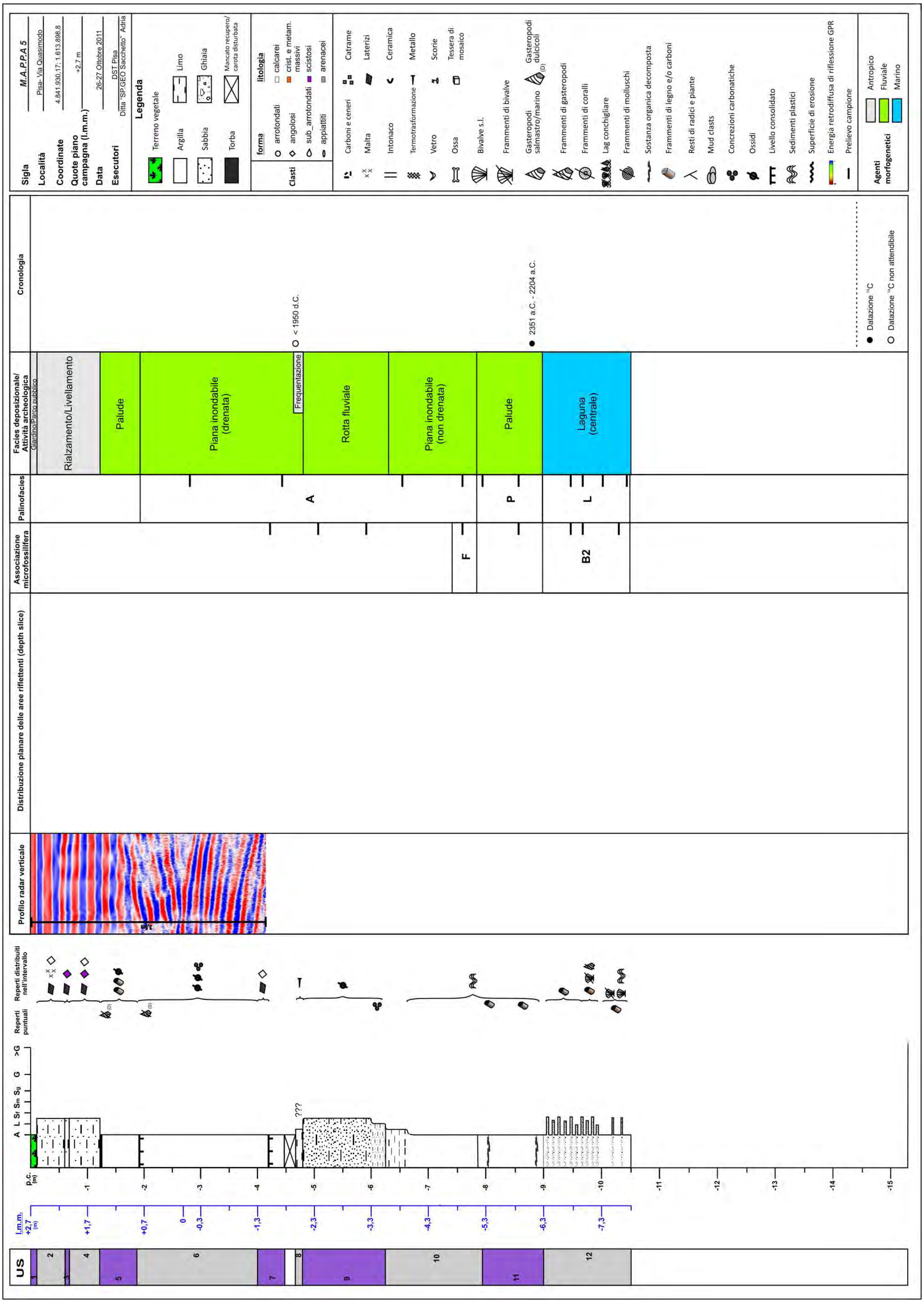
Fluviale
Marino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Ditta "SP.GEO Sacchetto" Adria
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Argilla
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Torba
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Rotta fluviale
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Palude
Laguna (centrale)
Palinofacies
A
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Associazione microfossilifera
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Distribuzione planare delle aree riflettenti (depth slice)
Profilo radar verticale
Reperti distribuiti nell'intervallo
Reperti puntuali
(D)
(D)
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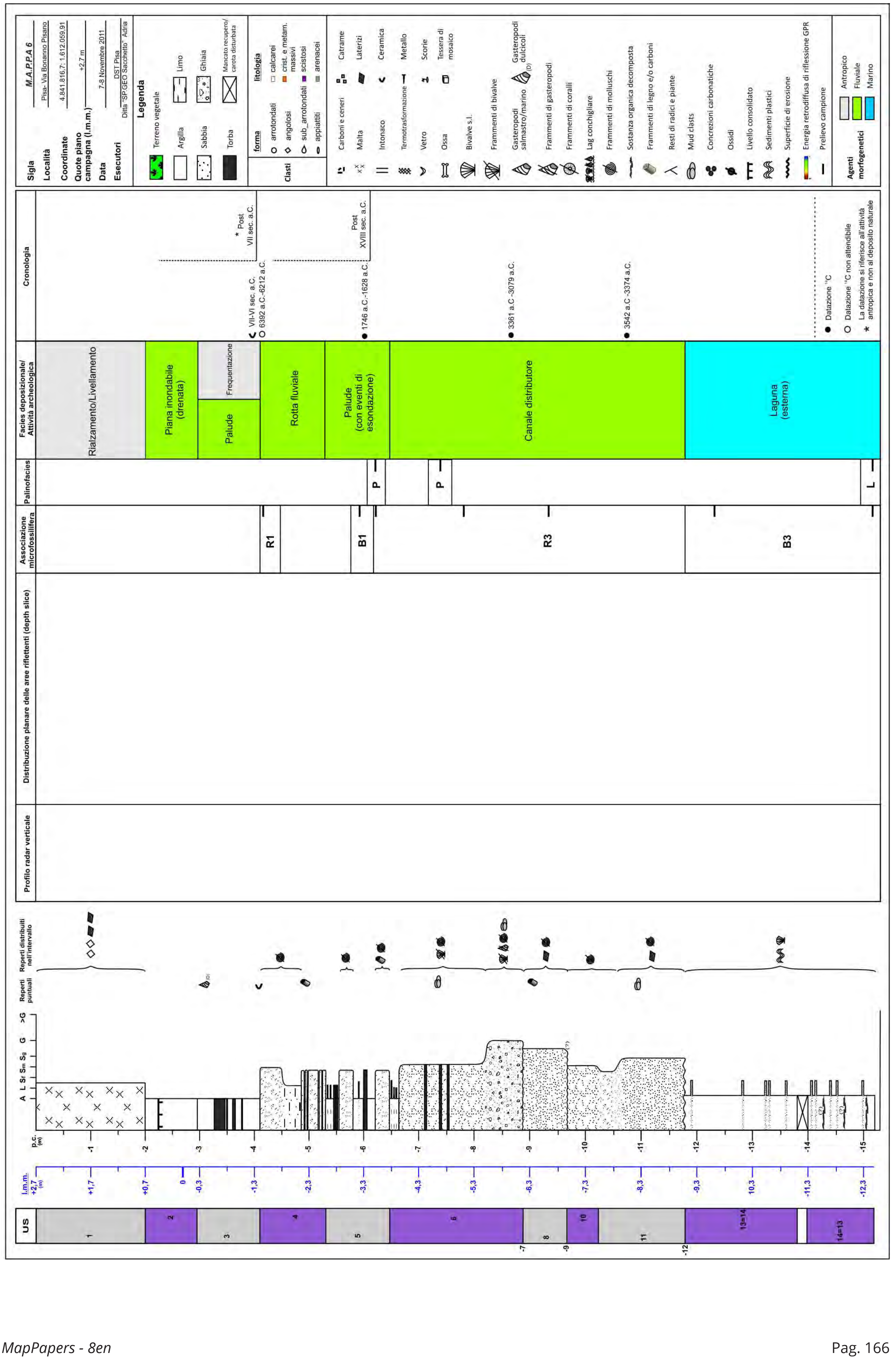
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Torba
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arrotondati
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appiattiti
litologia
calcarei
crist. e metam. massivi
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arenacei
Carboni e ceneri
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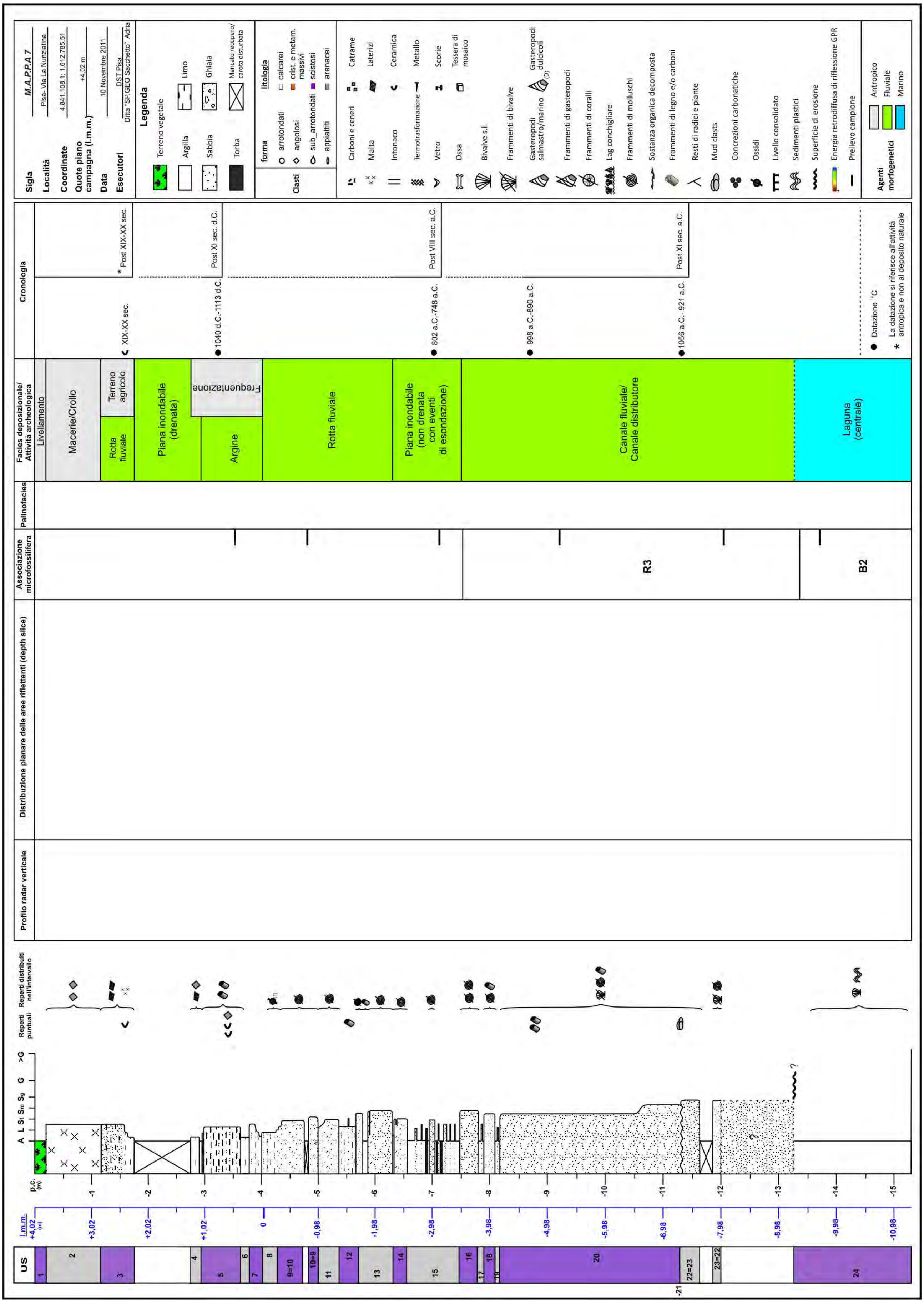
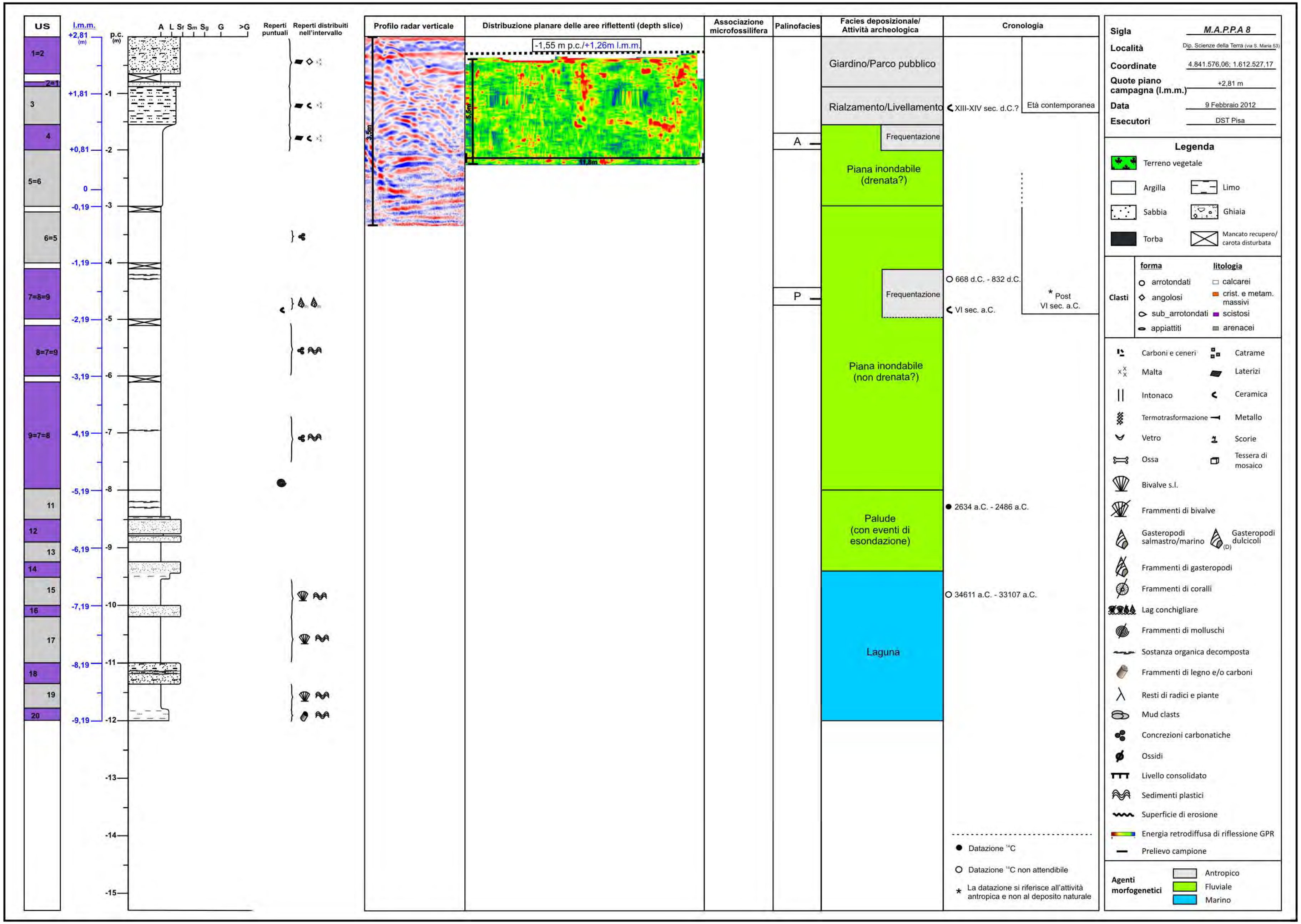
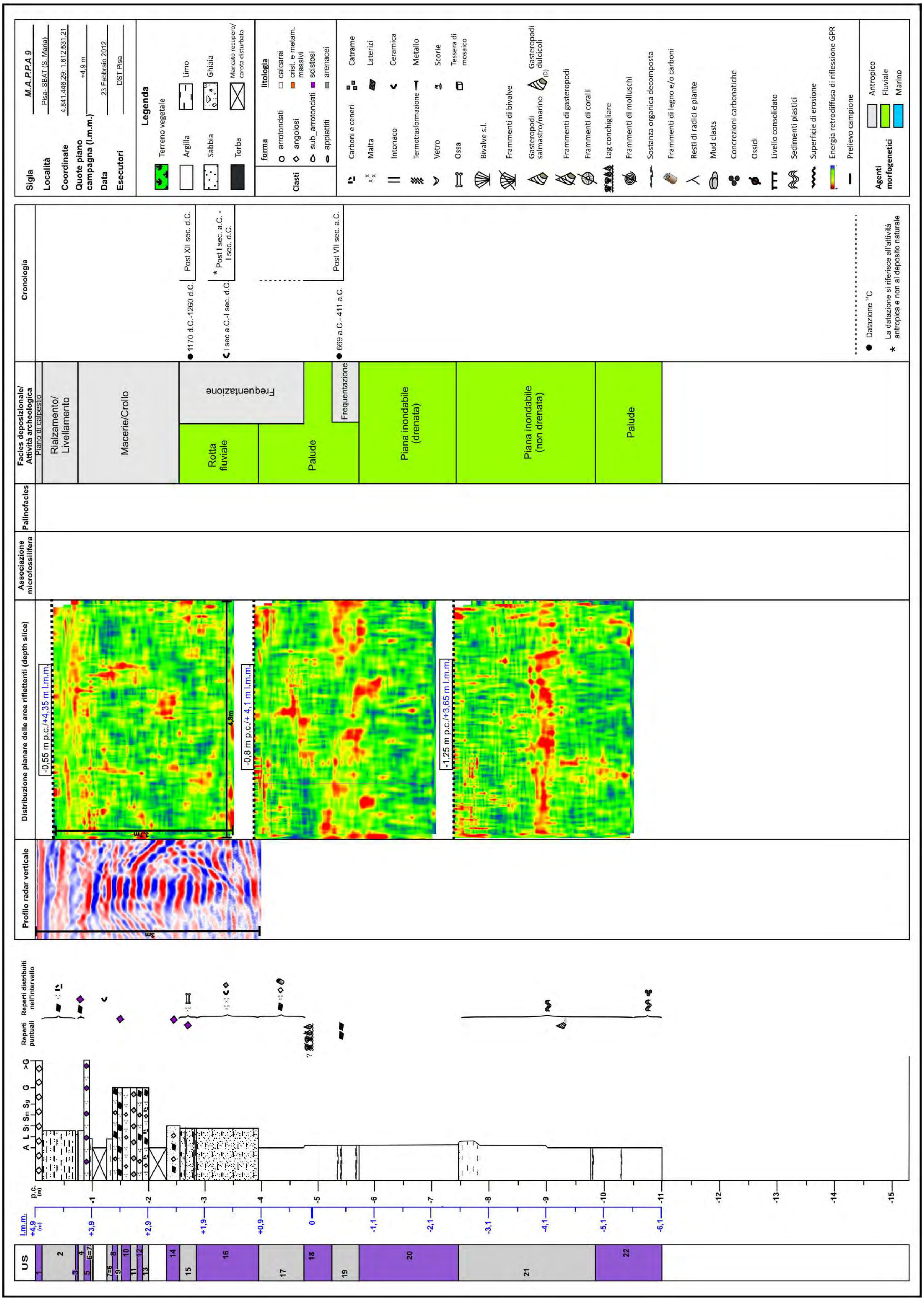
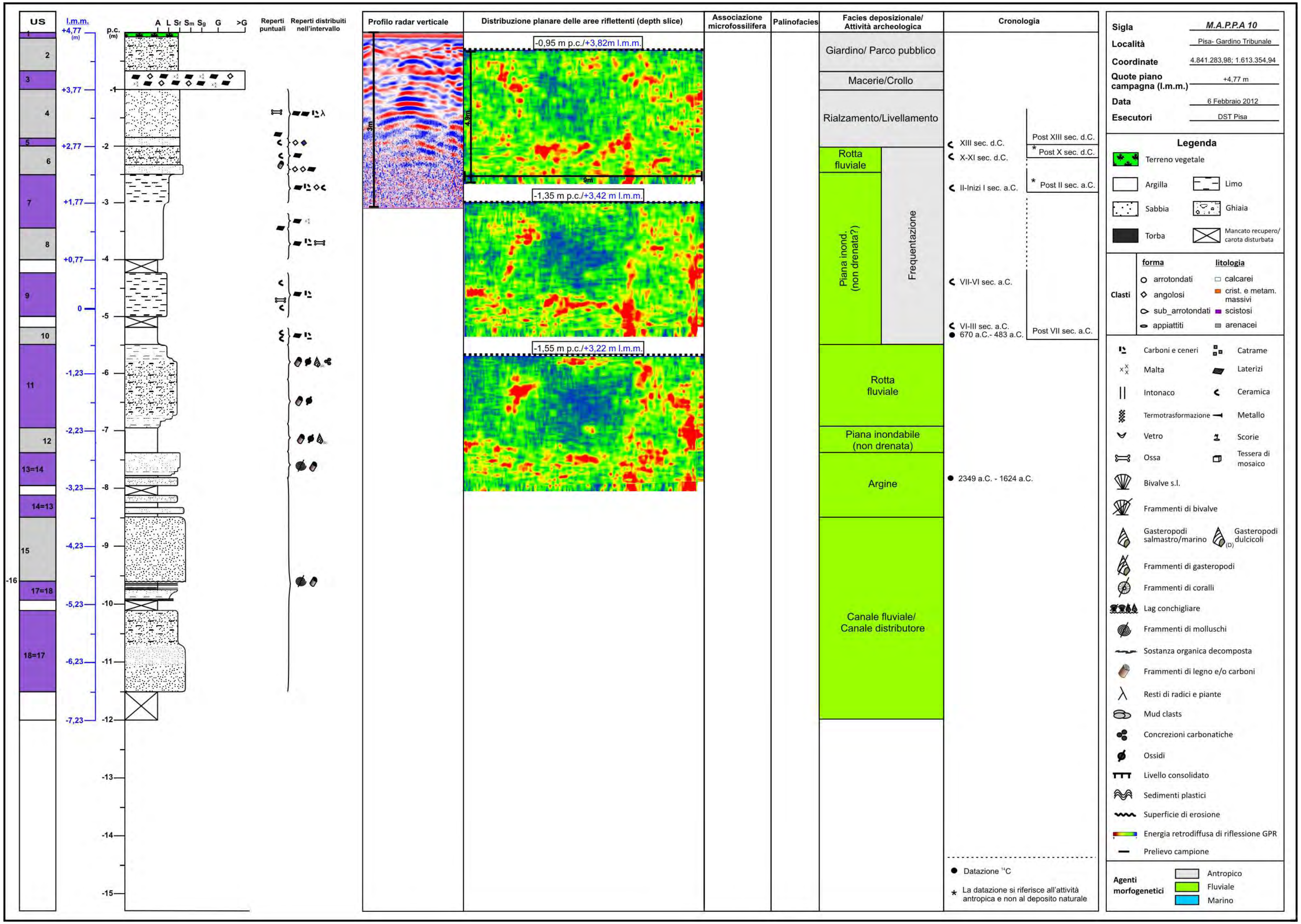
Gasteropodi salmastro/marino
Gasteropodi dulcicoli
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino
Cronologia
* Post VII sec. a.C.
Post XVIII sec. a.C.
VII-VI sec. a.C.
6392 a.C.-6212 a.C.
1746 a.C.-1628 a.C.
3361 a.C.-3079 a.C.
3542 a.C.-3374 a.C.
Datazione 14C
Datazione 14C non attendibile
* La datazione si riferisce all'attività antropica e non al deposito naturale
Facies deposizionale/ Attività archeologica
Rialzamento/Livellamento
Piana inondabile (drenata)
Palude
Frequentazione
Rotta fluviale
Palude (con eventi di esondazione)
Canale distributore
Laguna (esterna)
Palinofacies
P
P
L
Associazione microfossilifera
R1
B1
R3
B3
Distribuzione planare delle aree riflettenti (depth slice)
Profilo radar verticale
Reperti distribuiti nell'intervallo
Reperti puntuali
A L Sr Sm Sg G >G
p.c. (m)
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
l.m.m. (m)
+2,7
+1,7
+0,7
0
-0,3
-1,3
-2,3
-3,3
-4,3
-5,3
-6,3
-7,3
-8,3
-9,3
-10,3
-11,3
-12,3
US
1
2
3
4
5
6
8
10
11
13=14
14=13
-7
-9
-12


Sigla
M.A.P.P.A 7
Località
Pisa- Via La Nunziatina
Coordinate
4.841.108,1; 1.612.785,51
Quote piano campagna (l.m.m.)
+4,02 m
Data
10 Novembre 2011
Esecutori
DST Pisa
Ditta "SP.GEO Sacchetto" Adria
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino
Cronologia
* Post XIX-XX sec.
Post XI sec. d.C.
Post VIII sec. a.C.
Post XI sec. a.C.
XIX-XX sec.
1040 d.C.-1113 d.C.
802 a.C.-748 a.C.
998 a.C.-890 a.C.
1056 a.C.- 921 a.C.
Datazione 14C
La datazione si riferisce all'attività antropica e non al deposito naturale
Facies deposizionale/ Attività archeologica
Livellamento
Macerie/Crollo
Rotta fluviale
Terreno agricolo
Piana inondabile (drenata)
Argine
Frequentazione
Rotta fluviale
Piana inondabile (non drenata con eventi di esondazione)
Canale fluviale/ Canale distributore
Laguna (centrale)
Palinofacies
Associazione microfossilifera
R3
B2
Distribuzione planare delle aree riflettenti (depth slice)
Profilo radar verticale
Reperti distribuiti nell'intervallo
Reperti puntuali
A L Sf Sm Sg G >G
p.c. (m)
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
l.m.m. (m)
+4,02
+3,02
+2,02
+1,02
0
-0,98
-1,98
-2,98
-3,98
-4,98
-5,98
-6,98
-7,98
-8,98
-9,98
-10,98
US
1
2
3
4
5
6
7
8
9=10
10=9
11
12
13
14
15
16
17
18
19
20
-21
22=23
23=22
24
?

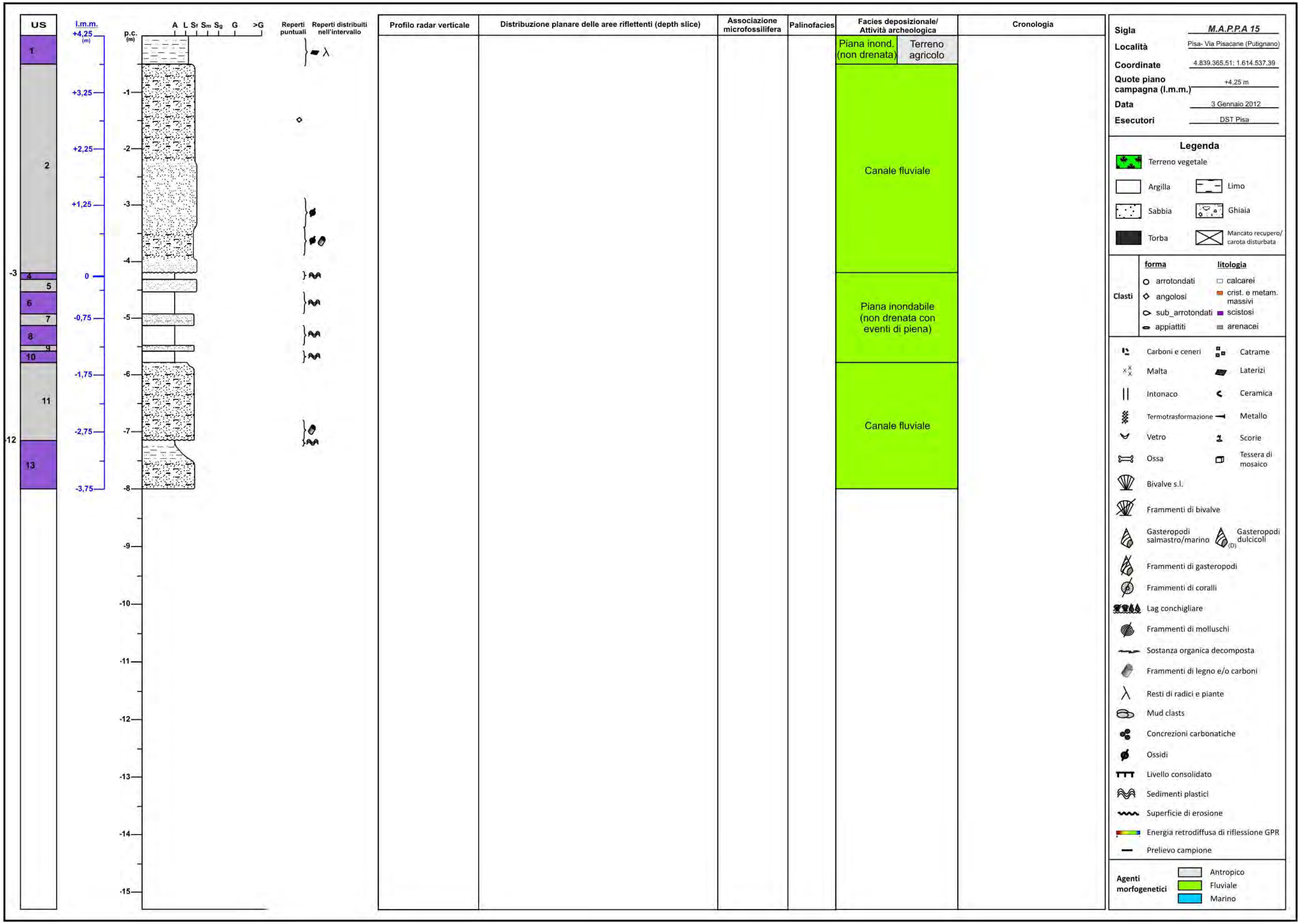


Sigla M.A.P.P.A 8
Località Dip. Scienze della Terra (via S. Maria 53)
Coordinate 4.841.576,06; 1.612.527,17
Quote piano campagna (l.m.m.) +2,81 m
Data 9 Febbraio 2012
Esecutori DST Pisa

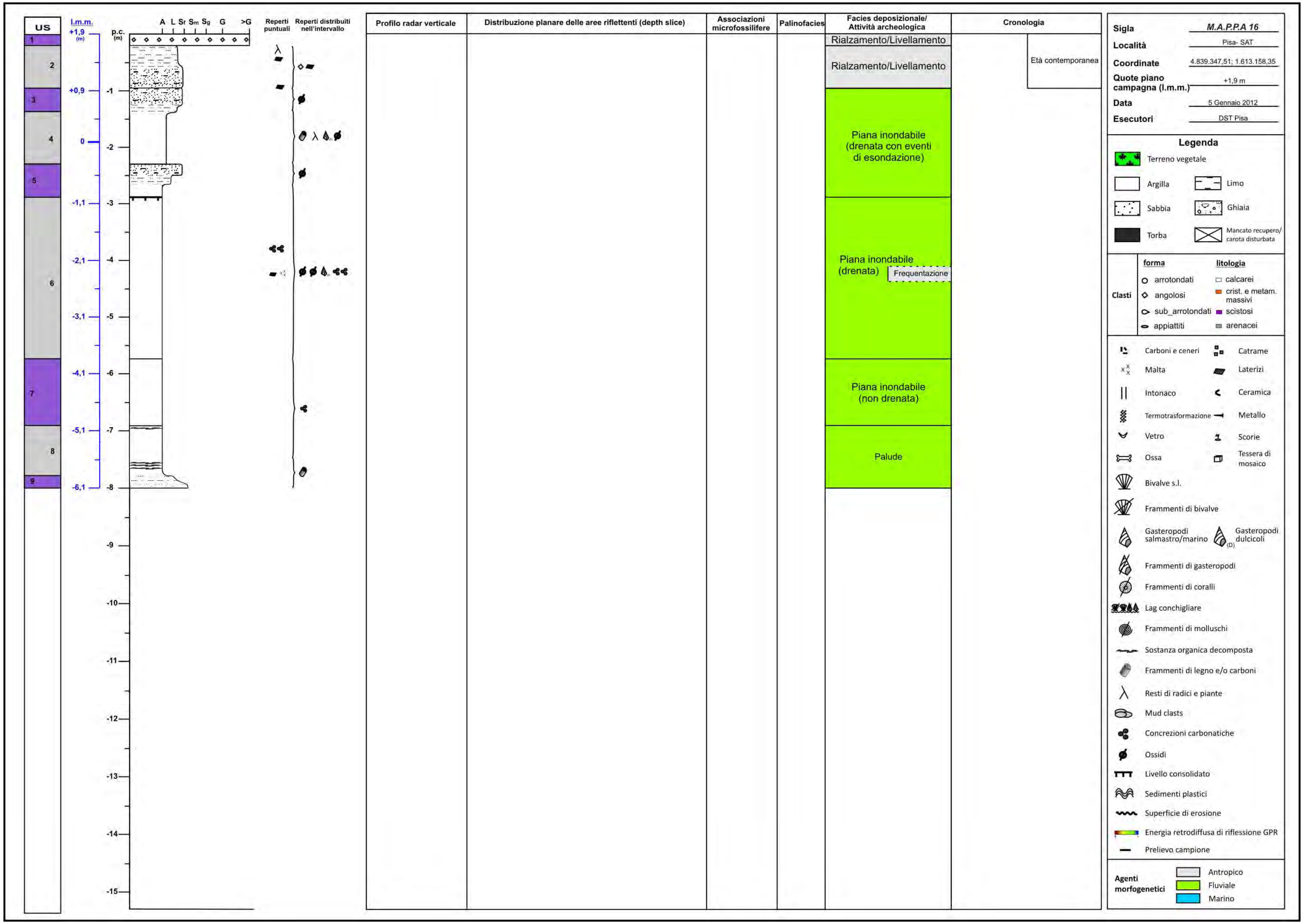

Sigla
M.A.P.P.A 9
Località
Pisa- SBAT (S. Maria)
Coordinate
4.841.446,29; 1.612.531,21
Quote piano campagna (l.m.m.)
+4,9 m
Data
23 Febbraio 2012
Esecutori
DST Pisa
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli (D)
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino
Cronologia
Post XII sec. d.C.
1170 d.C.-1260 d.C.
* Post I sec. a.C. - I sec. d.C.
I sec a.C.-I sec. d.C.
Post VII sec. a.C.
669 a.C.- 411 a.C.
Datazione 14C
* La datazione si riferisce all'attività antropica e non al deposito naturale
Facies deposizionale/ Attività archeologica
Piano di calpestio
Rialzamento/ Livellamento
Macerie/Crollo
Frequentazione
Rotta fluviale
Palude
Frequentazione
Piana inondabile (drenata)
Piana inondabile (non drenata)
Palude
Palinofacies
Associazione microfossilifera
Distribuzione planare delle aree riflettenti (depth slice)
-0,55 m p.c./+4,35 m l.m.m.
-0,8 m p.c./+ 4,1 m l.m.m.
-1,25 m p.c./+3,65 m l.m.m.
3,8m
3m
Profilo radar verticale
3m
Reperti distribuiti nell'intervallo
Reperti puntuali
?
A L Sf Sm Sg G >G
p.c. (m)
-1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15
l.m.m. (m)
+4,9 +3,9 +2,9 +1,9 +0,9 0 -1,1 -2,1 -3,1 -4,1 -5,1 -6,1
US
1 2 3 4 5 6=7 7=5 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

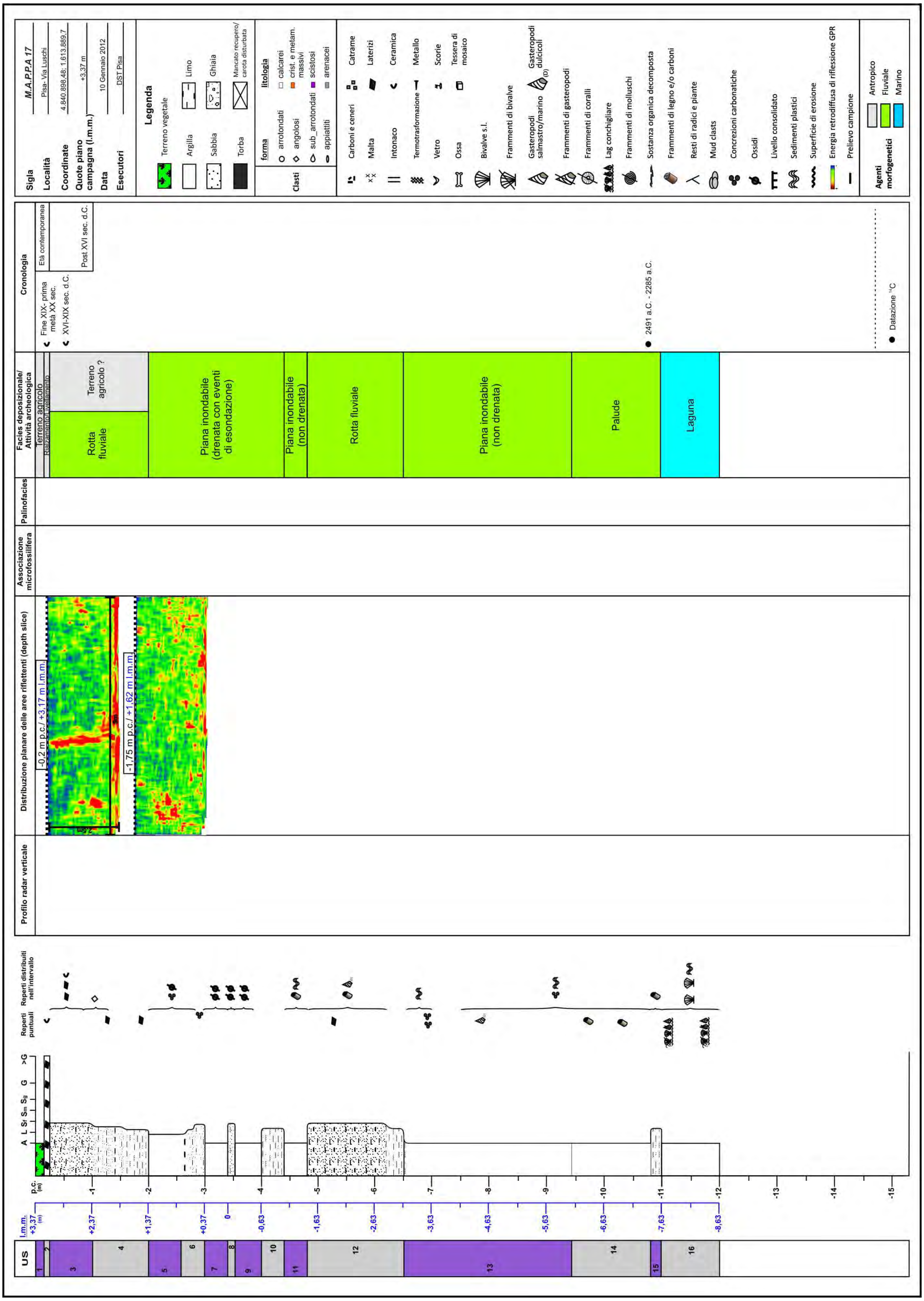


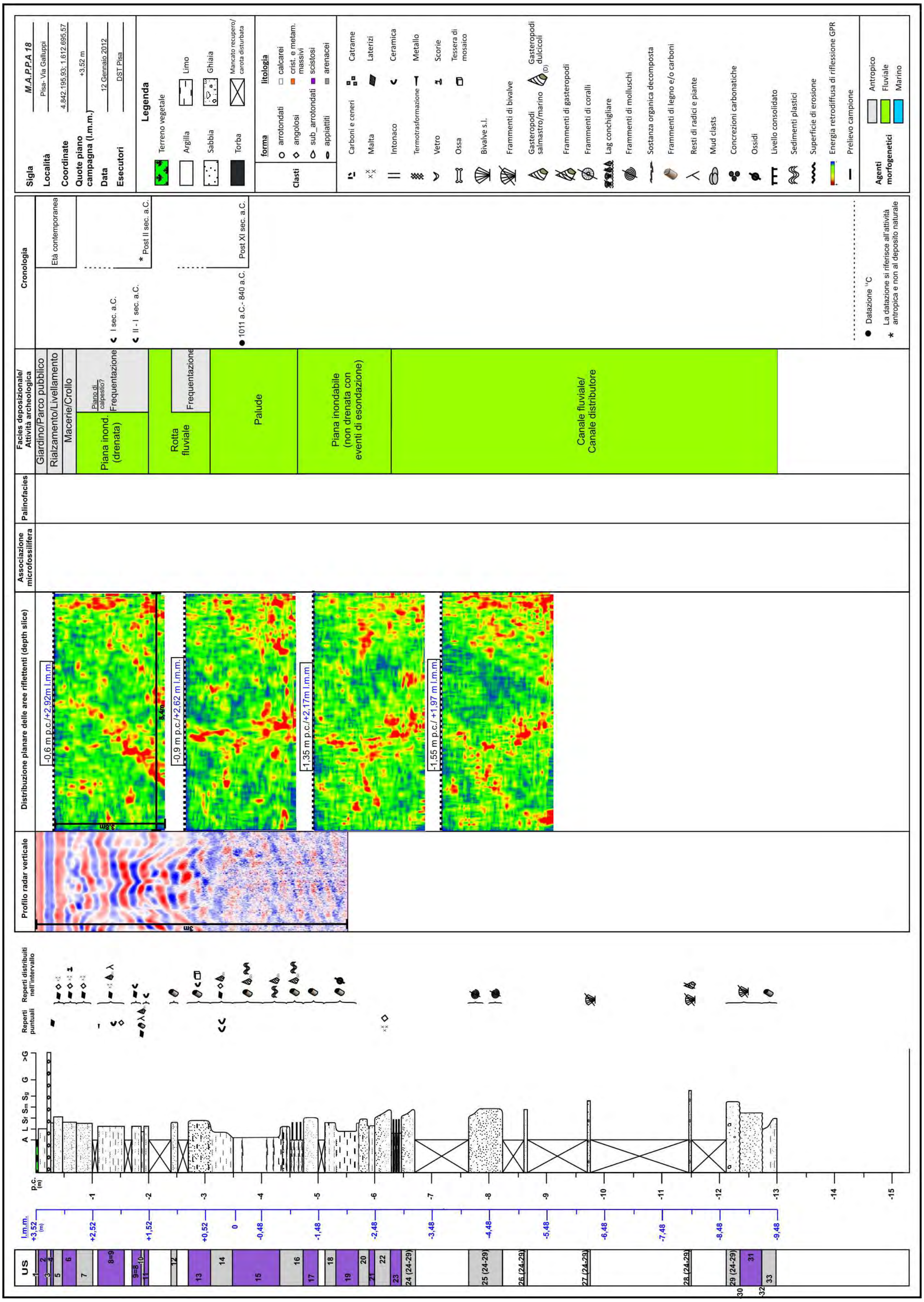
Sigla	*M.A.P.P.A 10*
Località	Pisa- Gardino Tribunale
Coordinate	4.841.283,98; 1.613.354,94
Quote piano campagna (l.m.m.)	+4,77 m
Data	6 Febbraio 2012
Esecutori	DST Pisa

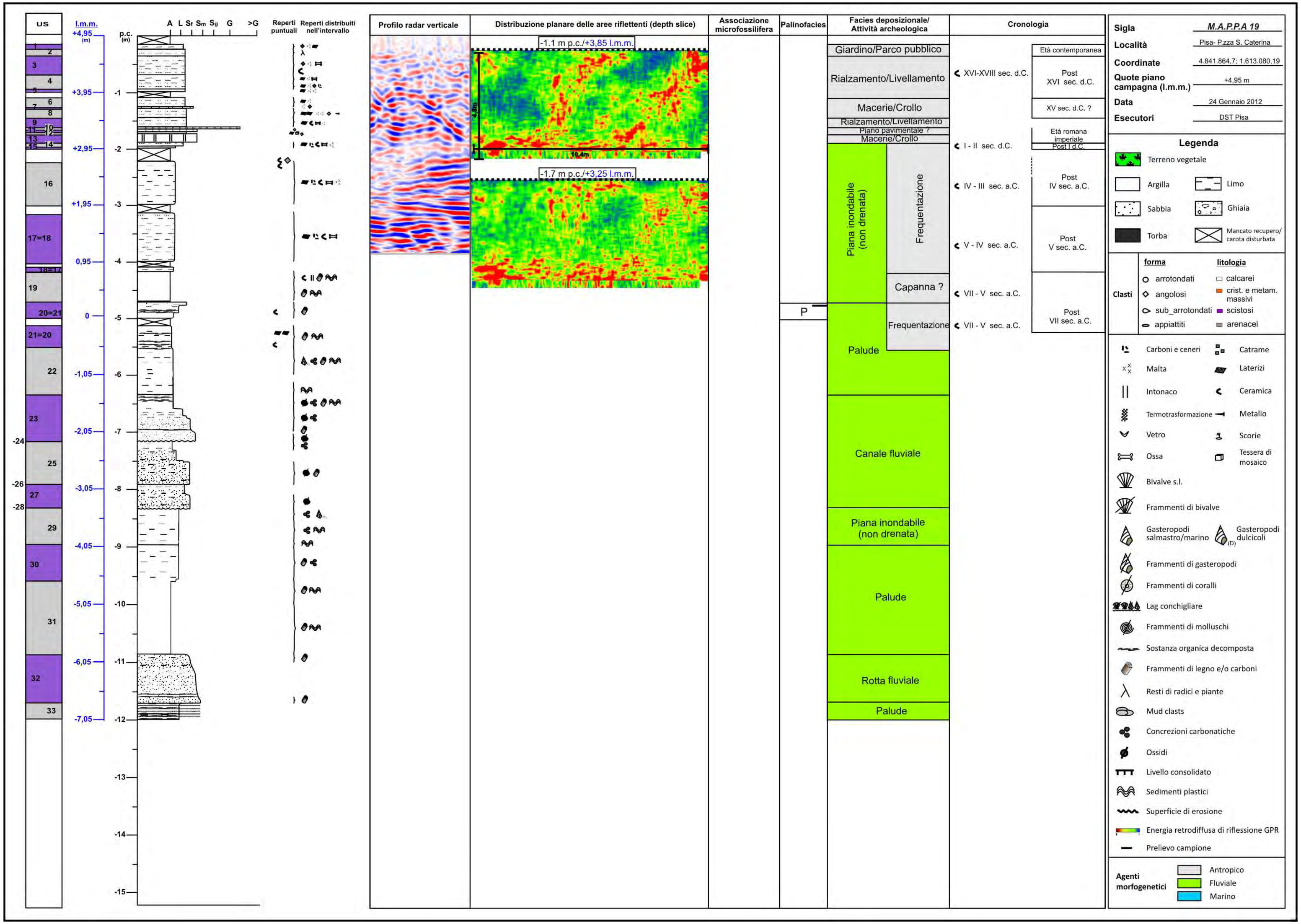


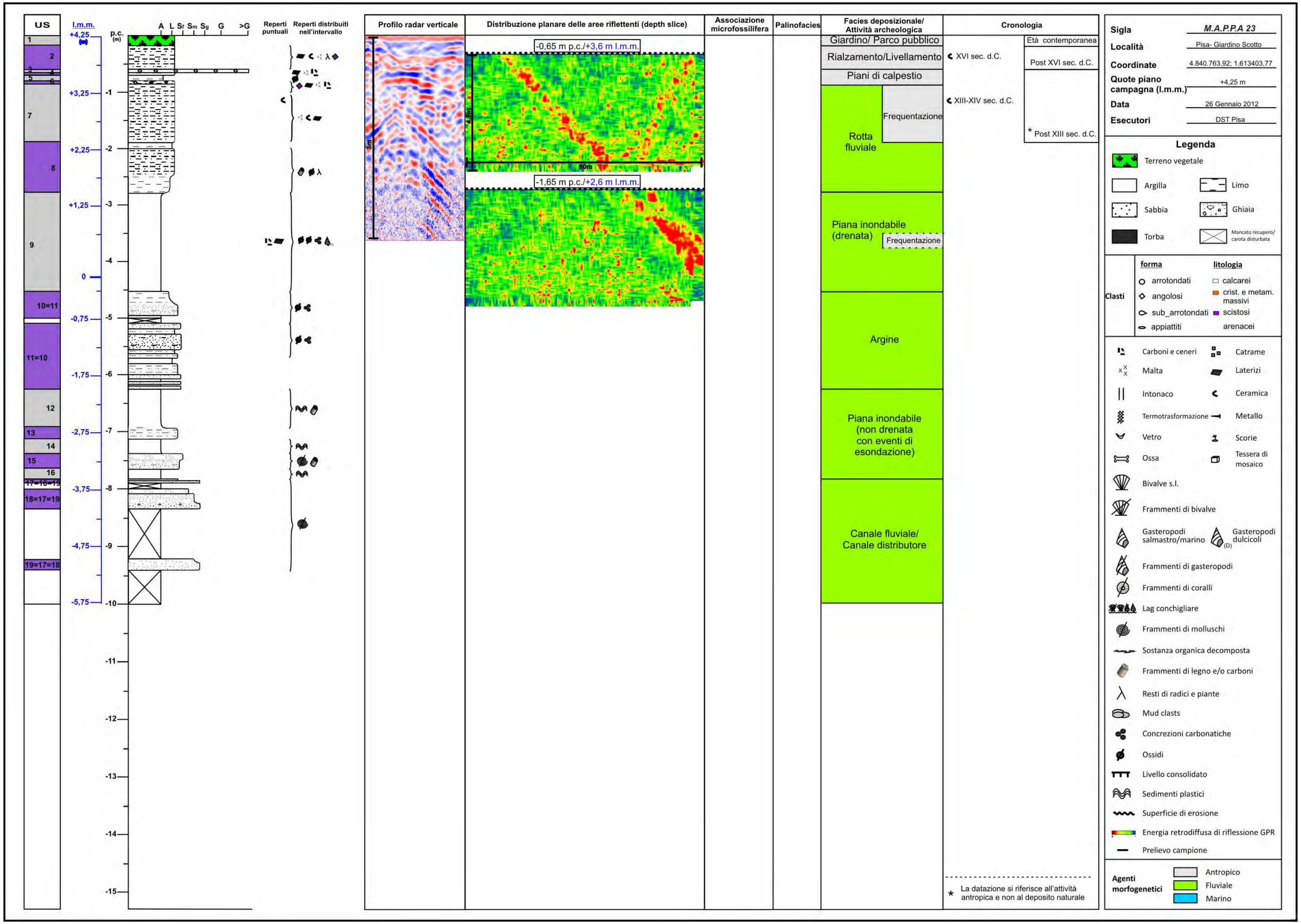
Sigla M.A.P.P.A 15
Località Pisa- Via Pisacane (Putignano)
Coordinate 4.839.365,51; 1.614.537,39
Quote piano campagna (l.m.m.) +4,25 m
Data 3 Gennaio 2012
Esecutori DST Pisa


US
1
2
3
4
5
6
7
8
9
l.m.m. (m)
+1,9
+0,9
0
-1,1
-2,1
-3,1
-4,1
-5,1
-6,1
p.c. (m)
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
A L Sf Sm Sg G >G
Reperti puntuali
Reperti distribuiti nell'intervallo
Profilo radar verticale
Distribuzione planare delle aree riflettenti (depth slice)
Associazioni microfossilifere
Palinofacies
Facies deposizionale/ Attività archeologica
Rialzamento/Livellamento
Rialzamento/Livellamento
Piana inondabile (drenata con eventi di esondazione)
Piana inondabile (drenata)
Frequentazione
Piana inondabile (non drenata)
Palude
Cronologia
Età contemporanea
Sigla
M.A.P.P.A 16
Località
Pisa- SAT
Coordinate
4.839.347,51; 1.613.158,35
Quote piano campagna (l.m.m.)
+1,9 m
Data
5 Gennaio 2012
Esecutori
DST Pisa
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
○ arrotondati
◇ angolosi
sub_arrotondati
appiattiti
litologia
□ calcarei
cristi. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli (D)
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino


Sigla
M.A.P.P.A 17
Località
Pisa- Via Luschi
Coordinate
4.840.898,48; 1.613.889,7
Quote piano campagna (l.m.m.)
+3,37 m
Data
10 Gennaio 2012
Esecutori
DST Pisa
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino
Cronologia
Fine XIX- prima metà XX sec.
XVI-XIX sec. d.C.
Età contemporanea
Post XVI sec. d.C.
2491 a.C. - 2285 a.C.
Datazione 14C
Facies deposizionale/ Attività archeologica
Terreno agricolo
Rialzamento livellamento
Terreno agricolo ?
Rotta fluviale
Piana inondabile (drenata con eventi di esondazione)
Piana inondabile (non drenata)
Rotta fluviale
Piana inondabile (non drenata)
Palude
Laguna
Palinofacies
Associazione microfossilifera
Distribuzione planare delle aree riflettenti (depth slice)
-0,2 m p.c./ +3,17 m l.m.m.
-1,75 m p.c./ +1,62 m l.m.m.
2,5 m
Profilo radar verticale
Reperti distribuiti nell'intervallo
Reperti puntuali
A L Sf Sm Sg G >G
p.c. (m)
-1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15
l.m.m. (m)
+3,37 +2,37 +1,37 +0,37 0 -0,63 -1,63 -2,63 -3,63 -4,63 -5,63 -6,63 -7,63 -8,63
US
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16


Sigla
M.A.P.P.A 18
Località
Pisa- Via Galluppi
Coordinate
4.842.195,93; 1.612.695,57
Quote piano campagna (l.m.m.)
+3,52 m
Data
12 Gennaio 2012
Esecutori
DST Pisa
Legenda
Terreno vegetale
Argilla
Sabbia
Torba
Limo
Ghiaia
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Malta
Intonaco
Termotrasformazione
Vetro
Ossa
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Catrame
Laterizi
Ceramica
Metallo
Scorie
Tessera di mosaico
Gasteropodi dulcicoli (D)
Agenti morfogenetici
Antropico
Fluviale
Marino
Cronologia
Età contemporanea
* Post II sec. a.C.
Post XI sec. a.C.
I sec. a.C.
II - I sec. a.C.
1011 a.C.- 840 a.C.
Datazione ¹⁴C
* La datazione si riferisce all'attività antropica e non al deposito naturale
Facies deposizionale/ Attività archeologica
Giardino/Parco pubblico
Rialzamento/Livellamento
Macerie/Crollo
Piano di calpestio?
Frequentazione
Piana inond. (drenata)
Rotta fluviale
Frequentazione
Palude
Piana inondabile (non drenata con eventi di esondazione)
Canale fluviale/ Canale distributore
Palinofacies
Associazione microfossilifera
Distribuzione planare delle aree riflettenti (depth slice)
-0,6 m p.c./+2,92m l.m.m.
-0,9 m p.c./+2,62 m l.m.m.
-1,35 m p.c./+2,17m l.m.m
-1,55 m p.c./ +1,97 m l.m.m
6,4m
3,8m
Profilo radar verticale
3m
Reperti puntuali
Reperti distribuiti nell'intervallo
A L Sf Sm Sg G >G
p.c. (m)
-1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15
l.m.m. (m)
+3,52 +2,52 +1,52 +0,52 0 -0,48 -1,48 -2,48 -3,48 -4,48 -5,48 -6,48 -7,48 -8,48 -9,48
US
1 2 3 4 5 6 7 8=9 9=8 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 (24-29) 25 (24-29) 26 (24-29) 27 (24-29) 28 (24-29) 29 (24-29) 30 31 32 33


US
l.m.m. +4,95 (m)
p.c. (m)
A L Sf Sm Sg G >G
Reperti puntuali
Reperti distribuiti nell'intervallo
Profilo radar verticale
Distribuzione planare delle aree riflettenti (depth slice)
-1.1 m p.c./+3,85 l.m.m.
-1.7 m p.c./+3,25 l.m.m.
4,8m
10,4m
Associazione microfossilifera
Palinofacies
P
Facies deposizionale/ Attività archeologica
Giardino/Parco pubblico
Rialzamento/Livellamento
Macerie/Crollo
Rialzamento/Livellamento
Piano pavimentale ?
Macerie/Crollo
Piana inondabile (non drenata)
Frequentazione
Capanna ?
Frequentazione
Palude
Canale fluviale
Piana inondabile (non drenata)
Palude
Rotta fluviale
Palude
Cronologia
XVI-XVIII sec. d.C.
I - II sec. d.C.
IV - III sec. a.C.
V - IV sec. a.C.
VII - V sec. a.C.
VII - V sec. a.C.
Età contemporanea
Post XVI sec. d.C.
XV sec. d.C. ?
Età romana imperiale
Post I d.C.
Post IV sec. a.C.
Post V sec. a.C.
Post VII sec. a.C.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17=18 18=17 19 20=21 21=20 22 23 25 27 29 30 31 32 33
-24 -26 -28
+3,95 +2,95 +1,95 0,95 0 -1,05 -2,05 -3,05 -4,05 -5,05 -6,05 -7,05
-1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15
Sigla M.A.P.P.A 19
Località Pisa- P.zza S. Caterina
Coordinate 4.841.864,7; 1.613.080,19
Quote piano campagna (l.m.m.) +4,95 m
Data 24 Gennaio 2012
Esecutori DST Pisa
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli (D)
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino


US
1
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8
9
10=11
11=10
12
13
14
15
16
17=18=19
18=17=19
19=17=18
l.m.m.
+4,25
+3,25
+2,25
+1,25
0
-0,75
-1,75
-2,75
-3,75
-4,75
-5,75
p.c. (m)
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
A L Sf Sm Sg G >G
Reperti puntuali
Reperti distribuiti nell'intervallo
Profilo radar verticale
3m
Distribuzione planare delle aree riflettenti (depth slice)
-0,65 m p.c./+3,6 m l.m.m.
-1,65 m p.c./+2,6 m l.m.m.
4,8m
10m
Associazione microfossilifera
Palinofacies
Facies deposizionale/ Attività archeologica
Giardino/ Parco pubblico
Rialzamento/Livellamento
Piani di calpestio
Frequentazione
Rotta fluviale
Piana inondabile (drenata)
Frequentazione
Argine
Piana inondabile (non drenata con eventi di esondazione)
Canale fluviale/ Canale distributore
Cronologia
XVI sec. d.C.
XIII-XIV sec. d.C.
Età contemporanea
Post XVI sec. d.C.
* Post XIII sec. d.C.
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Località: Pisa- Giardino Scotto
Coordinate: 4.840.763,92; 1.613403,77
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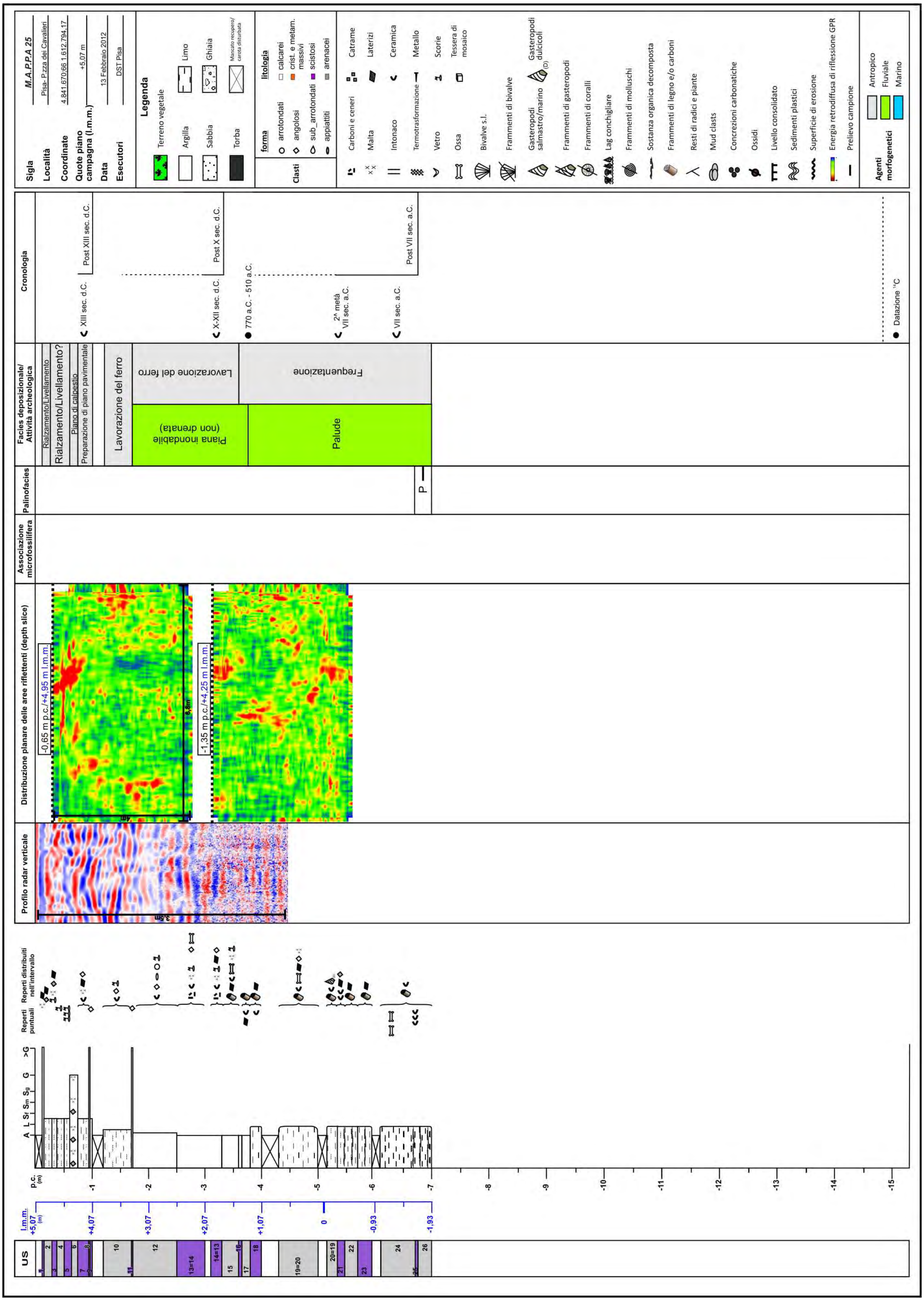
Data: 26 Gennaio 2012
Esecutori: DST Pisa
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli (D)
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino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Località
Pisa- P.zza dei Cavalieri
Coordinate
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+5,07 m
Data
13 Febbraio 2012
Esecutori
DST Pisa
Legenda
Terreno vegetale
Argilla
Sabbia
Torba
Limo
Ghiaia
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino
Cronologia
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X-XII sec. d.C.
Post X sec. d.C.
770 a.C. - 510 a.C.
2^ metà VII sec. a.C.
VII sec. a.C.
Post VII sec. a.C.
Datazione ^{14}C
Facies deposizionale/ Attività archeologica
Rialzamento/Livellamento
Rialzamento/Livellamento?
Piano di calpestio
Preparazione di piano pavimentale
Lavorazione del ferro
Lavorazione del ferro
Piana inondabile (non drenata)
Frequentazione
Palude
Palinofacies
P
Associazione microfossilifera
Distribuzione planare delle aree riflettenti (depth slice)
-0,65 m p.c./+4,95 m l.m.m.
-1,35 m p.c./+4,25 m l.m.m.
4m
4,8m
Profilo radar verticale
3,5m
Reperti puntuali
Reperti distribuiti nell'intervallo
A L Sf Sm Sg G >G
p.c. (m)
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
l.m.m. (m)
+5,07
+4,07
+3,07
+2,07
+1,07
0
-0,93
-1,93
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19=20
20=19
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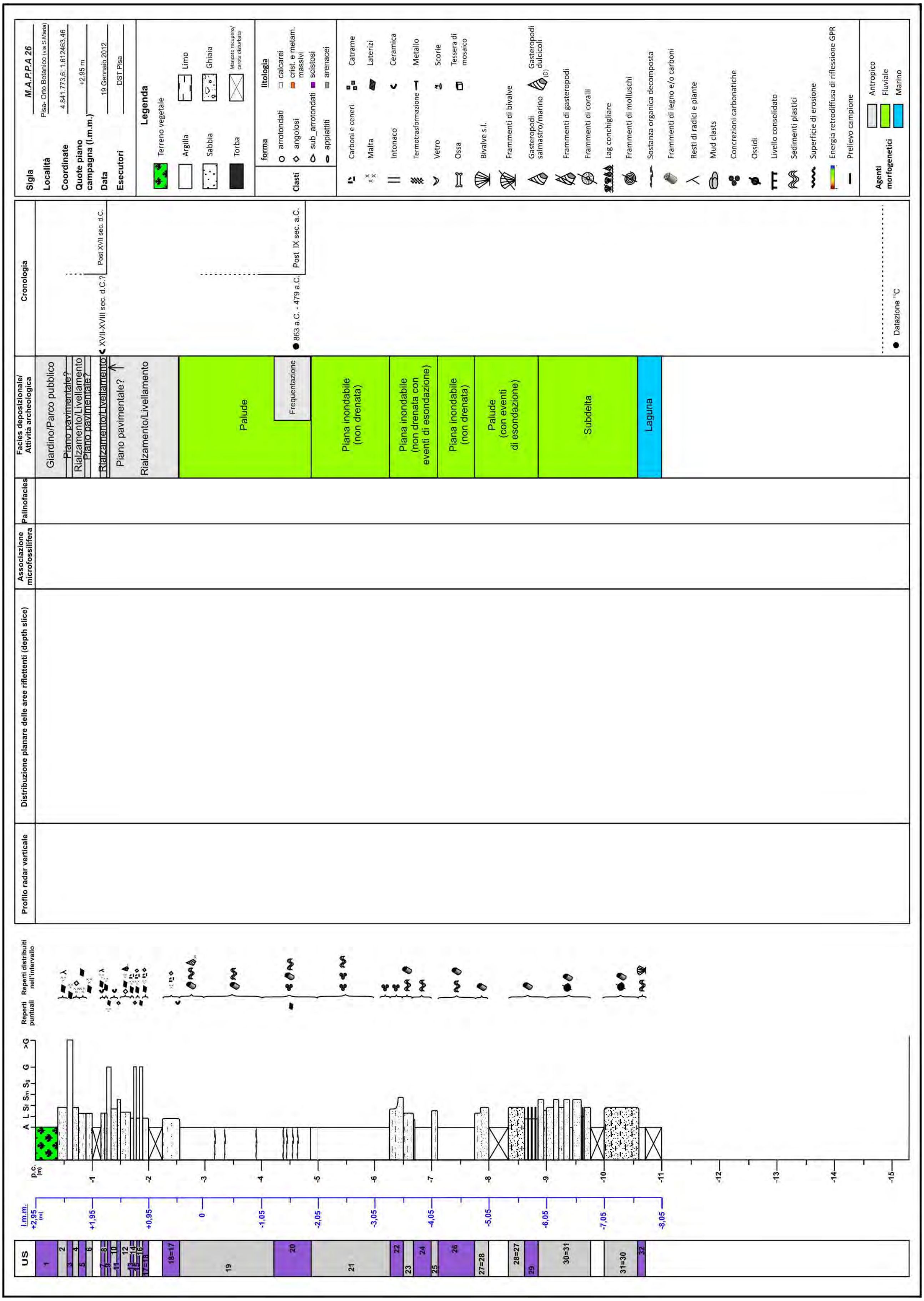

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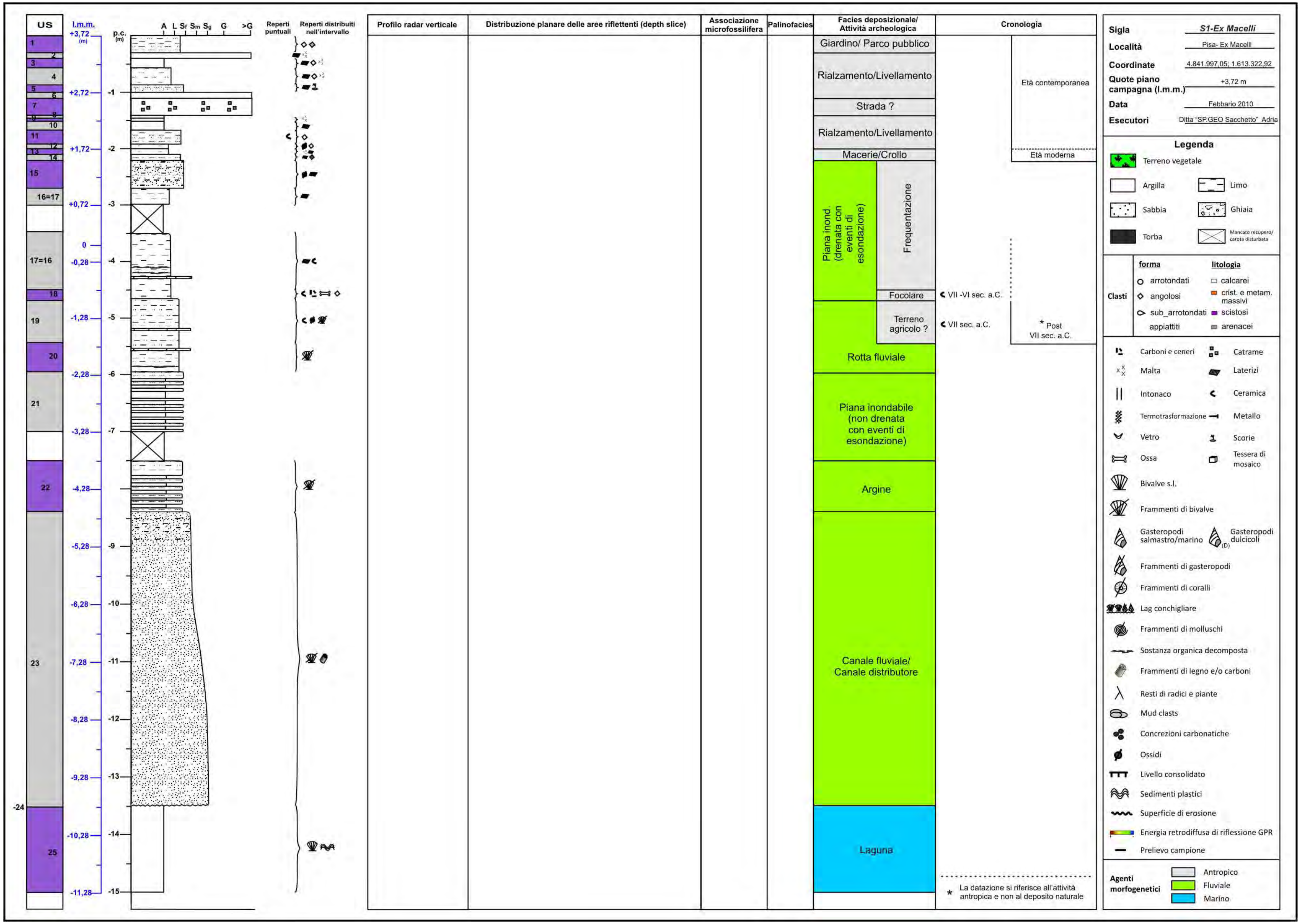
Data 19 Gennaio 2012
Esecutori DST Pisa


US
l.m.m. (m)
p.c. (m)
A L Sf Sm Sg G >G
Reperti puntuali
Reperti distribuiti nell'intervallo
Profilo radar verticale
Distribuzione planare delle aree riflettenti (depth slice)
Associazione microfossilifera
Palinofacies
Facies deposizionale/ Attività archeologica
Cronologia
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16=17
17=16
18
19
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22
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-24
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+1,72
+0,72
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-5,28
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-1
-2
-3
-4
-5
-6
-7
-9
-10
-11
-12
-13
-14
-15
Giardino/ Parco pubblico
Rialzamento/Livellamento
Strada ?
Rialzamento/Livellamento
Macerie/Crollo
Piana inond. (drenata con eventi di esondazione)
Frequentazione
Focolare
Terreno agricolo ?
Rotta fluviale
Piana inondabile (non drenata con eventi di esondazione)
Argine
Canale fluviale/ Canale distributore
Laguna
Età contemporanea
Età moderna
VII -VI sec. a.C.
VII sec. a.C.
* Post VII sec. a.C.
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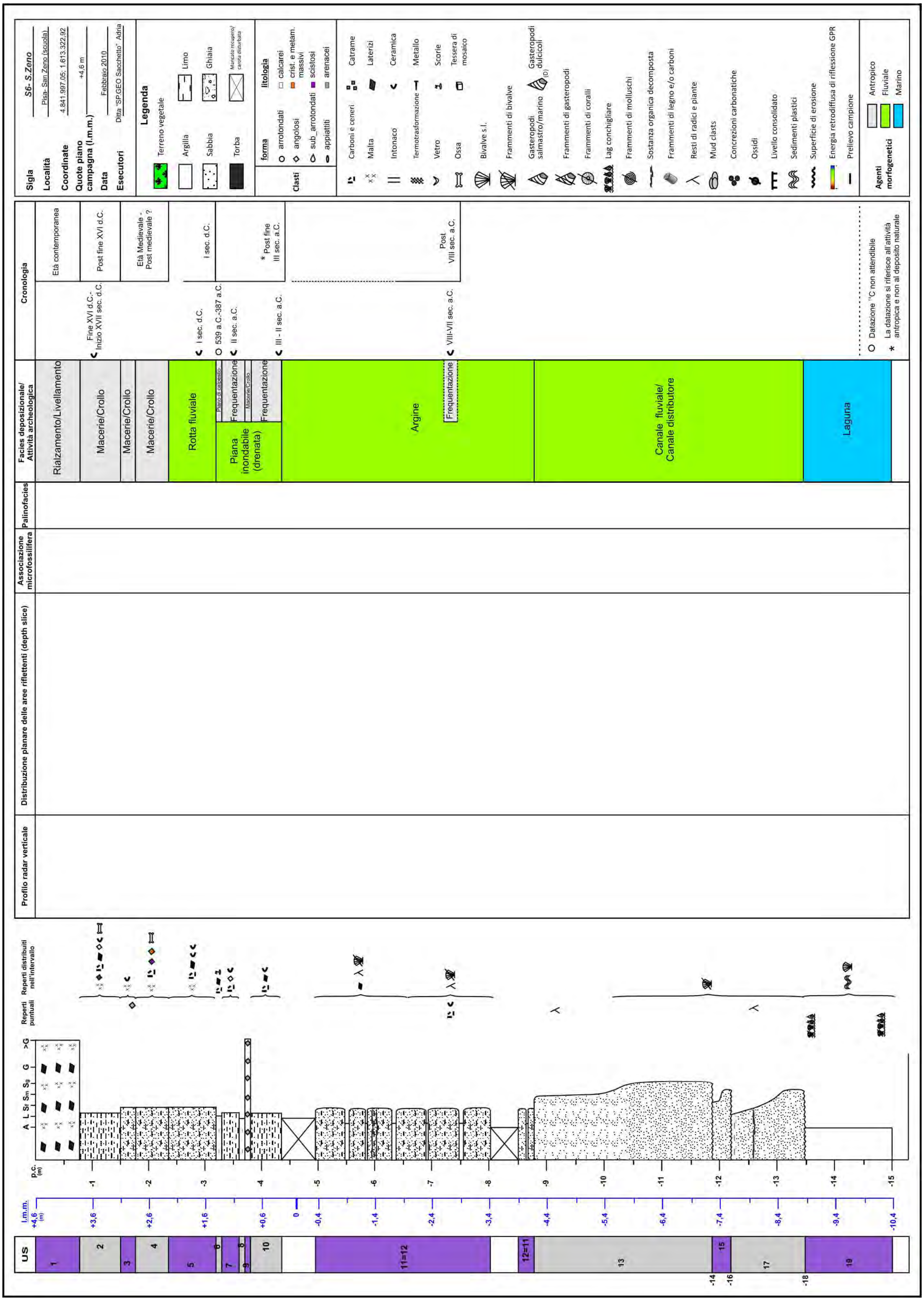
Data Febbario 2010
Esecutori Ditta "SP.GEO Sacchetto" Adria
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli (D)
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino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S6- S.Zeno
Località
Pisa- San Zeno (scuola)
Coordinate
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+4,6 m
Data
Febbraio 2010
Esecutori
Ditta "SP.GEO Sacchetto" Adria
Legenda
Terreno vegetale
Argilla
Limo
Sabbia
Ghiaia
Torba
Mancato recupero/ carota disturbata
Clasti
forma
arrotondati
angolosi
sub_arrotondati
appiattiti
litologia
calcarei
crist. e metam. massivi
scistosi
arenacei
Carboni e ceneri
Catrame
Malta
Laterizi
Intonaco
Ceramica
Termotrasformazione
Metallo
Vetro
Scorie
Ossa
Tessera di mosaico
Bivalve s.l.
Frammenti di bivalve
Gasteropodi salmastro/marino
Gasteropodi dulcicoli
Frammenti di gasteropodi
Frammenti di coralli
Lag conchigliare
Frammenti di molluschi
Sostanza organica decomposta
Frammenti di legno e/o carboni
Resti di radici e piante
Mud clasts
Concrezioni carbonatiche
Ossidi
Livello consolidato
Sedimenti plastici
Superficie di erosione
Energia retrodiffusa di riflessione GPR
Prelievo campione
Agenti morfogenetici
Antropico
Fluviale
Marino
Cronologia
Età contemporanea
Post fine XVI d.C.
Età Medievale - Post medievale ?
I sec. d.C.
* Post fine III sec. a.C.
Post VIII sec. a.C.
Fine XVI d.C.- Inizio XVII sec. d.C.
I sec. d.C.
539 a.C.-387 a.C.
II sec. a.C.
III - II sec. a.C.
VIII-VII sec. a.C.
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Facies deposizionale/ Attività archeologica
Rialzamento/Livellamento
Macerie/Crollo
Macerie/Crollo
Macerie/Crollo
Rotta fluviale
Piano di calpestio
Frequentazione
Macerie/Crollo
Frequentazione
Piana inondabile (drenata)
Argine
Frequentazione
Canale fluviale/ Canale distributore
Laguna
Palinofacies
Associazione microfossilifera
Distribuzione planare delle aree riflettenti (depth slice)
Profilo radar verticale
Reperti distribuiti nell'intervallo
Reperti puntuali
A L Sf Sm Sg G >G
p.c. (m)
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
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-13
-14
-15
l.m.m. (m)
+4,6
+3,6
+2,6
+1,6
+0,6
0
-0,4
-1,4
-2,4
-3,4
-4,4
-5,4
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-7,4
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-9,4
-10,4
US
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-18
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5. Geochemical characterisation and sediment provenance

The geochemical analyses carried out on 80 core samples (M1-7) provide further details on the facies described in paragraph 4. The use of geochemical indicators of grain size and sediment composition is a valid support for the sedimentological study of the cores, providing an indirect picture of the textural characteristics of the deposit. The binary diagram Rb/Al_2O_3 (Figure 6) is an example of the geochemical characterisation of the facies associations identified in the core, divided into seven groups. In this diagram, the distribution trend of the two variables reflects the gradual increase in clay minerals with increasing Rb and Al_2O_3 concentrations.

Smaller Rb and Al_2O_3 contents are observed in the coarsest (beach-ridge?) samples, whereas increasing values are recorded by sandy fluvial/distributary channel facies and by sandy-silty levee/crevasse splay deposits. A scarce overlap is observed between samples from these two facies associations (Figure 6), thus emphasising the sharp distinction in terms of hydrodynamic behaviour between transport and sedimentation processes in the riverbeds compared to the extra-channel areas. In contrast, high dispersion on the binary diagram is the peculiar feature of fine-grained facies associations, including floodplain and marsh/inner lagoon deposits. This is due to the strong textural variations within these two facies associations, which are formed in low-energy deposi-

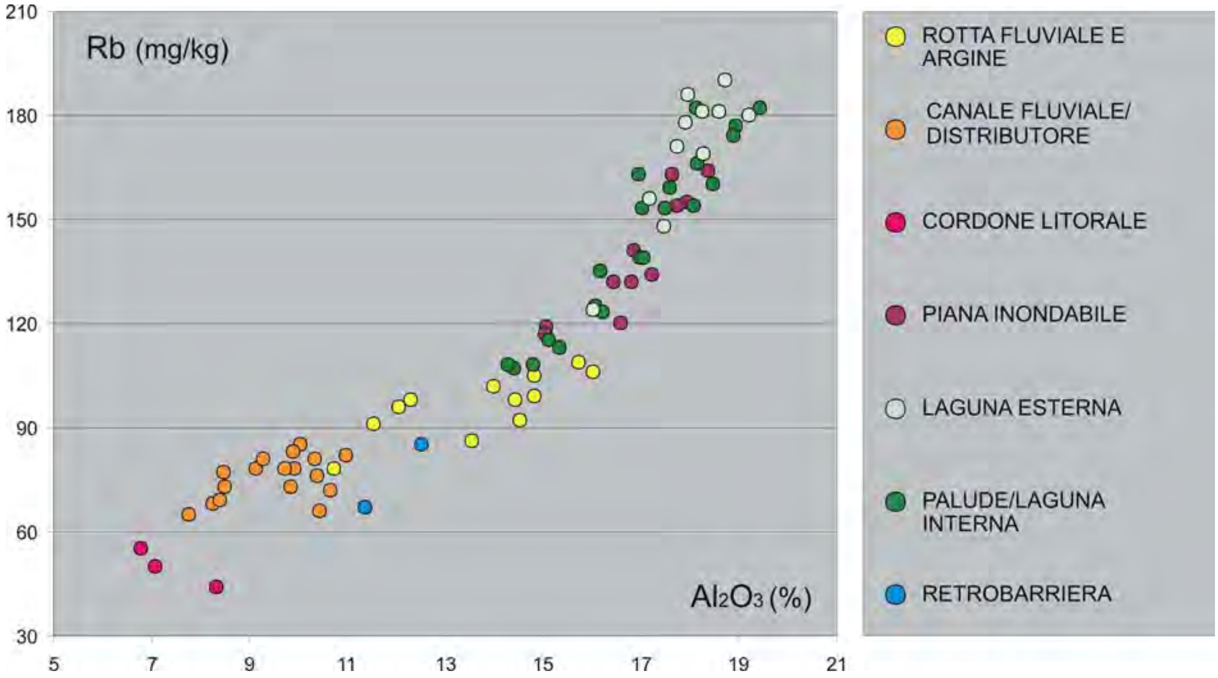

Figure 6. Binary diagram Rb/Al_2O_3 which reflects the textural character of the coring facies associations.

ROTTA FLUVIALE E ARGINE	M1 1.05
	M1 8.32
	M1 9.3
	M5 5.07
CANALE FLUVIALE/ DISTRIBUTORE	M1 3.5
	M1 4.2
	M1 5.2
	M1 5.45
	M7 11.9
PIANA INONDABILE	M5 4.07
	M5 4.45
PALUDE/ LAGUNA INTERNA	M1 7.2
	M1 7.68
	M4 6.9
	M5 1.5
	M5 9.42

Figure 7. Comparison using the binary diagram Mg/Al_2O3 vs CaO between the channel and levee/crevasse splay core samples and the reference samples for the River Arno and River Serchio areas.

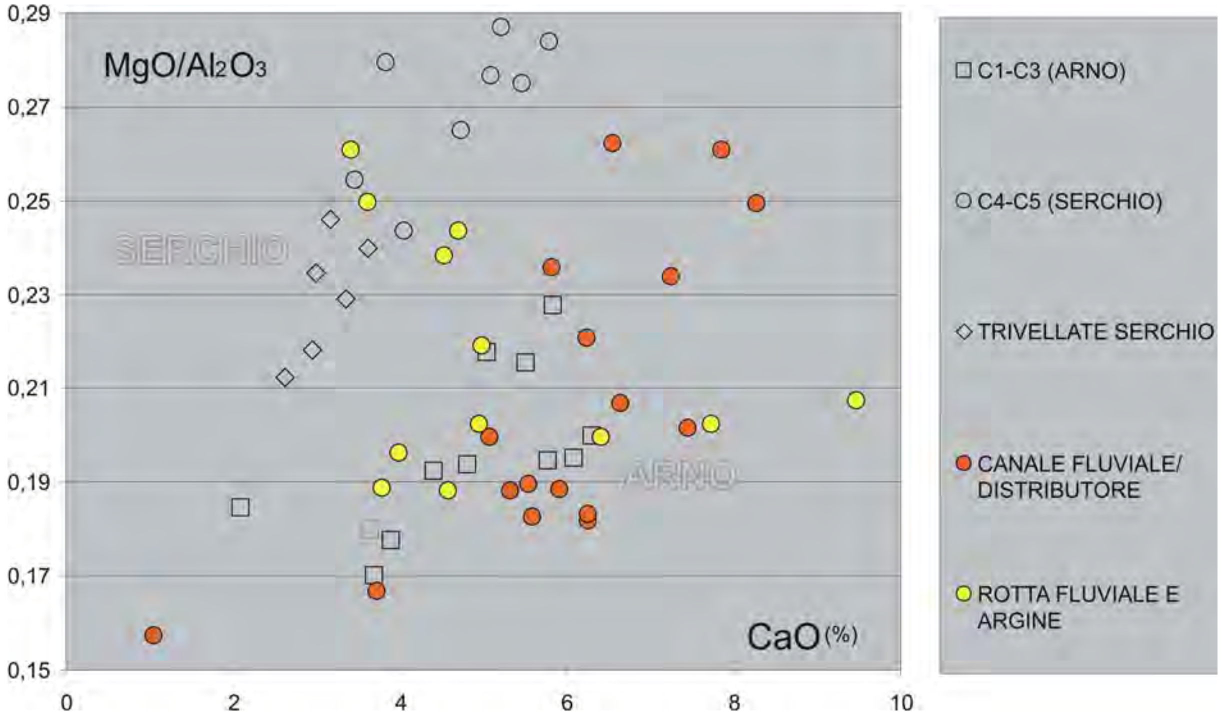

Figure 8. List of samples divided by facies association, core and sampling depth, tentatively pointing to a provenance from the River Serchio.

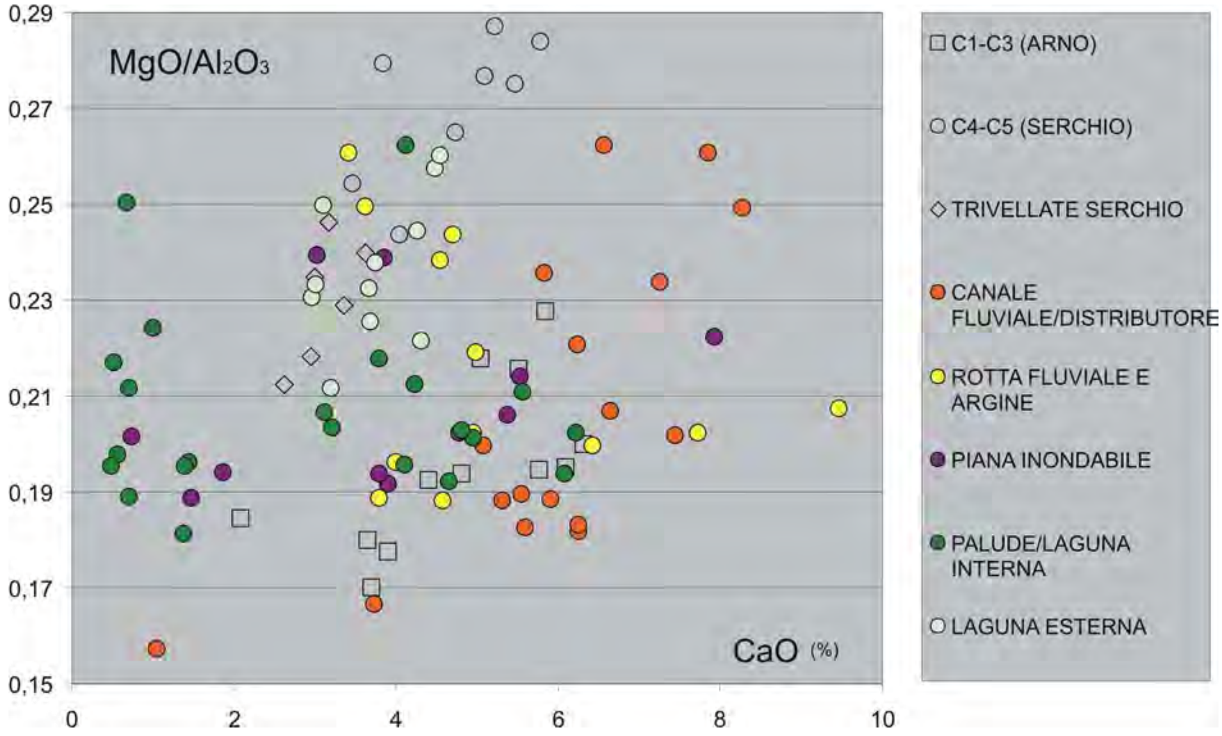

Figure 9. Comparison using the binary diagram Mg/Al2O3 vs CaO among all the core samples taken and the samples of reference for the River Arno and Serchio areas.

tional environments, but in which sands may interfinger with muds as a result of overbank or crevasse processes. Finally, outer lagoon clay deposits, formed in sub-environments dominated by settling processes and subjected to occasional deposition of sand from adjacent back-barrier areas, show the highest concentration of Rb and Al_2O_3. The geochemical characterisation of 20 samples from the modern levees of Arno and Serchio rivers and its comparison with core data provide the basis for the differentiation of two distinct sediment sources.

The comparison was also based on the analysis of six additional samples, previously hand bored in the Serchio area (AMOROSI et al. submitted). Previous works pointed out the scarce differentiation of these two drainage basins in terms of sediment composition (DINELLI et al. 2005; CORTECCI et al. 2008). In this work, the binary diagram Mg/Al_2O_3 vs CaO was used as possible discriminating factor which emphasises the compositional differences within the carbonate fraction. In the diagram of Figure 7, where channel and crevasse splay/levee core deposits are plotted as reference samples, an obvious overlap of the majority of the study samples with the field diagnostic of Arno River can be seen. In contrast, four crevasse splay/levee samples (three of which refer to core M1 and one to core M5 – Figure 8) appear to have been fed directly from Serchio River. The group of five channel samples which plot outside both domains of reference (Figure 7) and display the highest Mg/Al_2O_3 values, are also assigned to the Serchio River. These consist of four additional samples from core M1 and of the lowermost sample from core M7 (Table 4). CaO enrichment of these channel deposits compared to the reference samples is probably due to pedogenic alteration (with carbonate gradually dissolving as the subaerial exposure time increases) recorded by modern levee deposits of Serchio River.

Application of the same binary diagram to both fine-grained floodplain and marsh/inner lagoon samples (Figure 9) confirms provenance attribution of M1 and M5 core deposits to the Serchio River (Figure 8). Although caution should be taken when comparing significantly different depositional environments, geochemical analysis of outer lagoon deposits (Figure 9) also suggests possible influence of Serchio River on the area where cores M6 and M7 were collected (Figure 8). Finally, the large amount of floodplain and marsh samples with very low CaO content (Figure 9) most probably reflects repeated phases of subaerial exposure of the study area during the Late Holocene, which led to almost total carbonate dissolution and palaeosol development.

(A.A., I.S.)

6. Comparative analysis of cores: new indications on the palaeo-environmental and settlement context of Pisa

An interdisciplinary study of the MAPPA cores (cfr. § 3, 4 and 5) allowed us to acquire further knowledge of the palaeo-environmental and living context of the urban and sub-urban area of Pisa during the Middle-Late Holocene, providing us with new information about the depositional facies and their relationship with anthropic frequentation[2].

The subsurface succession in the coring areas (Figure 1), as already suggested in the depositional model presented in MapPaper3, is composed of an alternation of fine-grained deposits (formed in marshy and floodplain environments) and sandy deposits dominated by channel and levee/crevasse splay facies. This fluvial succession, with thickness varying from 8 to 12 metres, is situated on top of lagoonal deposits according to the following chronological framework (for graphic representation of the coring succession see the stratigraphic logs in § 4).

6.1 Development of the lagoon (around 6000-3600 B.C.)

The base of the continuous cores (except for M4) and some of the Vibracorer Cobra cores reveal a horizon of highly plastic lagoonal clay and a typically marshy meiofauna (Group B) together with both continental and marine palynomorphs (palynofacies L). Recent studies show that this lagoonal clay, usually known as “pancone”, is widely distributed ranging from the Monti Pisani (Pisan Mountains) to the surfacing dune ridges, within a stratigraphic interval of 30 to 9 m depth under sea level (AMOROSI et al. 2008; ROSSI et al. 2011). Although caution is taken when comparing different depositional environments (cfr. § 5), geochemical analysis of cores M1-7 suggests double feeding of the lagoonal basin from both the River Arno and the River Serchio.

Literature reveals that this large lagoonal area developed between 6000 and 4000 B.C., corresponding to approximately 8000-6000 calibrated years (BENVENUTI et al. 2006; AMOROSI et al. 2008), during maximum Holocene marine ingression and the first phase of sea level highstand. The year 4000 B.C. was determined solely by dating the top of the pancone eroded by a channel in the archaeological site of San Rossore (BENVENUTI et al. 2006). Radiocarbon dating performed on a sample taken at around 75 cm from the non-eroded top of the lagoonal clay of core M1 makes it possible to date the last existing phases of

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[2] The Vibracorer Cobra cores were carried out by Federico Bertocchini, Francesco Caruso and Francesco Rinaldi. Pre-Roman material was analysed by Fabrizio Burchianti, Roman material by Claudia Rizzitelli and material belonging to the Medieval and Modern ages by Gabriele Gattiglia and Francesca Anichini. The osteological fragments were examined by Claudio Sorrentino.

the lagoon in the northern area of Pisa to around 3650 B.C.

6.2. First filling phases of the lagoon (3600-1900 B.C. circa)

The lagoon evolved from around 3600 to 1900/1600 B.C. with varying depositional dynamics in the different areas of the plain, as revealed by the sites examined. Two main stratigraphic reasons related to the pancone are recorded in the MAPPA cores: continuous stratigraphic overlapping of subdelta sandy deposits and/or fine marshy deposits and discontinuous overlapping, through erosive surfaces, of channel deposits.

In the majority of cores (M3; M4; M5; M8; M9; M16; M17 and M19), gradual silting of the lagoon is documented by the presence of clayey sediments in marshy facies, above the pancone or at the base of the succession. These deposits feature abundant phytoclasts and continental palynomorphs (palynofacies P), as well as the absence of an autochthonous meiofauna which suggests the development of low-oxygen (almost anoxic) and most probably acid marshes, in accordance with palynological analysis (cfr. § 3.2.). Instead, evidence of the progradation of subdelta sandy organisms, at times overlain by marshy sediments, was found in three cores only: M1, M2 and M26.

Channel facies deposits may be found – in correspondence of cores M6, M7, M10, M18, M23, S1 and S6 – at depths comparable to those of marshy and subdelta deposits (from around 8 m to 3 m below sea level), providing evidence of the presence of fluvial palaeocourses. The channel succession erodes the underlying lagoonal deposits in correspondence of the deepest cores (M6, M7, S1 and S6).

Apart from core M7, which will be discussed further on, these channel bodies together with the marshy and subdelta deposits provide plausible evidence of the first lagoon filling phases that occurred in the area under examination between the Medium and Late Holocene, in accordance with available dates[3]. The geochemical analysis performed on these sediments allowed us to identify two different sedimentary provenances and to point out the simultaneous presence of palaeocourses and extra-channel areas attributable to the Rivers Arno and Serchio. Specifically, regarding provenance from the River Arno, feeding by the River Serchio occurred in the subdelta deposits and overlying marshy deposits of core M1.

6.3 Transition to the floodplain and diffusion of anthropic frequentation between the protohistoric age and archaic age (around 1900-481 B.C.)

The subsequent transition to a strictly alluvial depositional system is evidenced by the appearance of a deposit belonging to a prevailingly poorly drained floodplain, at times subject to overbank, in the higher stratigraphic levels (between around -3 m and 0 m at sea level) of the majority of cores (M3, M4, M5, M8, M10, M15, M16, M17, M18, M19, M23 and M26). This deposit has a plastic consistency and continental palynofacies (palynofacies A) at times accompanied by oligoaline-freshwater meiofauna (Group F). Radiocarbon dating near the upper and lower border of a poorly drained plain continuous succession (M10) dates this depositional environment more or less between 1900 and 500 years B.C..

Early surfacing of the floodplain is documented in M2, M3 and M9 where already at around -2 m (M2 and M3) and -3 m (M9) at sea level, the transition from poorly drained floodplain deposits to drained floodplain deposits, with evidence of subaerial exposure may be seen. In M9, the latter are in turn overlain by marshy sediments dated at the base at around VI century B.C. (radiocarbon dating).

Levee or crevasse splay deposits may be found throughout or on top of the floodplain succession in M5; M10, M17, M18, M19 and M23. Deposit feeding by the River Serchio is clearly evident in M5.

Marsh deposits, which presumably developed near a palaeochannel in response to ordinary migration and fluvial dynamics (backswamp) are locally (M6, M18, M19, M25 and M26) documented within this depositional interval.

Sandy crevasse splay deposits in M7 and distributor/fluvial channel deposits in M1 and M2[4] are present in the same stratigraphic interval, providing evidence of the continuous presence of a channel in the proximity of (M7) or exactly in correspondence of (M1 and M2) the sites examined. At a depth of around -9 m with respect to sea level, a fluvial channel is recorded in M7 which has a direct impact on the pancone. Radiocarbon dating available in M7 within these deposits and in the overlying poorly drained plain succession indicates the presence of the channel (initially of Serchio and then Arno provenance (cfr. § 5.)) in correspondence of the site during a time interval ranging between around 1050 and 750 B.C. This dating shows a significantly long time span (around 2500 years) for the transition from lagoonal clay to channel sand.

During the final plain development stages, evidence of anthropic frequentation becomes more frequent;

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[3] It is difficult to precisely date the activity of every single fluvial palaeocourse, since the materials in the channel succession have evidently been transported. For example, two radiocarbon datings are available in M6 on Cardium shells taken in the lower fraction of the channel succession (cfr. log M6 in § 4.). These datings provide an age between around 3500 and 3050 B.C., which is slightly more recent than the age obtained for the upper fraction of the pancone in M1. The shells analysed, therefore, could come from the top of the eroded pancone. For this reason, it is difficult to date the very small ceramic fragments found in the channel deposit, which must be prior to the closing of the channel before 1700 B.C., as confirmed by the radiocarbon dating performed on the overlying marshy deposits.

[4] In M2, channel facies interpretation is hypothetical and needs further analysis, including malacological analysis, which is currently in progress.

traces are left in various environmental contexts, suggesting different types of settlements.

6.3.1 Frequentation of marshy humid areas

Clayey deposits of dark grey/black colour and rich in organic substance are present in Piazza dei Cavalieri (M25) from -2m (core base) to +1.3 m at sea level. The deposits were formed in a marshy environment showing evident traces of intense frequentation by man who probably settled in close proximity (Figure 10). The palynofacies that characterises the sample taken at the base of the cored succession, at around -1.7 m at sea level, reveals intermediate characteristics typical of both a marshy environment and alluvial environment, which are highly consistent with an area in which transient marshes develop. In particular, Context 25 and 24[5] layers, found between -1.7 m and -1 m at sea level, provide a large amount of ceramic fragments, including bucchero and coarse pottery, which can be dated to VII century B.C., and sheep bone fragments, most probably attributable to domestic activities and meal remains. Continuous frequentation in Contexts 23, 22 and 21[6]: the materials are most probably dated to the second half of VII century B.C. The sediment that characterises these contexts is structurally heterogeneous, indicating its consistent anthropogenic processing.

These characteristics may also be seen in the upper part of this deposit, between Contexts 20 and 18[7]. Radiocarbon dating of a sample of organic matter from Context 18 date it to between 770 and 510 B.C., i.e. an average date of around VII century B.C., consistent with archaeological data.

The marshy deposits close to Piazza Santa Caterina (M19) reveal traces of frequentation documented by ceramics dated between VII and V century B.C.[8]. A sample taken at 0.25 m above sea level shows high concentration of sharp wood fragments, possibly attributable to anthropogenic cutting.

In the Botanical Garden area (M26), marshy deposits are present on the poorly drained floodplain, which can be dated at the base (using radiocarbon dating) to 836-479 B.C.; on average, this is considered a generic archaic age. This latter environment appears to have been episodically frequented, as confirmed by the small brick fragments found at a depth between -1.75 m and -1.35 m at sea level, in correspondence of an accumulation of organic matter.

Evidence of frequentation of marshy areas around VI century B.C. (radiocarbon dating) has also been found in the SBAT area (M9) and in Via Bonanno Pisano (M6)[9].

6.3.2 Frequentation of the poorly drained floodplain

The poorly drained floodplain appears to have been frequented around VI century B.C. in the area of the Department of Earth Sciences (M8)[10], in the area of the Court (M10) (dating provided by ceramic materials[11] and radiocarbon analysis) and Piazza Santa Caterina (M19). In this latter area, at the transition from marshy environment to poorly drained floodplain, a number of clay plaster fragments suggest the existence of a hut generically dating back to VII-V century B.C.[12]

6.3.3 Frequentation of areas in the proximity of a channel (levee and crevasse splay)

In the ex-Macelli area (S1), scattered ceramic fragments (probably attributable to agricultural activities and overall dating back to around VII century B.C.[13]), may be found in the upper part of a crevasse splay deposit, sufficiently exposed to initiate oxidation processes. A layer made of stones, ceramic, cooking pot fragments and two large bone fragments (part of a pelvis and the proximal extremity of a pig's left radius)[14], have settled on the surface of the deposit, providing evidence of a hearth or traces of food preparation and eating activities. The ceramic fragments date back to VII-VI century B.C. thus providing a chronological framework for this form of settlement.

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[5] Context 25 (VII century B.C.) Ceramics: 2 fragments of northern bucchero pottery cup (half VII-first quarter VI century B.C.); 1 fragment of local bucchero pottery; 2 cooking pot fragments (VII-VI century B.C.); 2 matching pieces of bucchero pottery (first half VII century B.C.). Context 24 (VII century B.C.) Ceramics: 1 fragment of a ribbon-shaped handle of a bucchero kyatos (half VII-third quarter of VII century B.C.); 2 coarse pot fragments (VII-first quarter VI century B.C.). Bones: lower third right molar of sheep; 2 fragments of sheep's lower jaw; 3 non identified sheep fragments.

[6] Context 21 (second half VII century B.C.) Ceramics: 1 fragment of concave rim cup (first half VII century B.C.); 6 fragments of coarse pot, of which 1 with engobe slip (VII-VI century B.C.).

[7] Context 19=20 Ceramics: 2 fragments of coarse pottery; 1 fragment of badly fired coarse pottery cup; 2 coarse pottery fragments: pot side and brim. Bones: 1 fragment of a long non-identified bone. Context 18 a discard of vitrified pottery.

[8] Context 20=21 Ceramics: 1 fragment of fine pottery closed form; 1 fragment of coarse ware dolium, with smoothened inner surface (probably VII century B.C.).

[9] Context 3 Ceramics: 1 fragment of badly fired coarse pot (VII-VI century B.C.).

[10] Context 7=8 Ceramics: 1 coarse ware fragment (VI century B.C.).

[11] Context 10 Ceramics: 1 fragment of ring shaped bottom of a small cup (VI-III century B.C.). Context 9 Ceramics: 1 coarse pot fragment (VII-VI century B.C.).

[12] Context 19 Ceramics: 1 coarse ware fragment (VII-V century B.C.). 4 clay fragments with many vacuoles left by vegetal elements (lathwork coating).

[13] Context 19 (VII century B.C.) Ceramics: 1 coarse ware fragment (end VII-II century B.C.); 4 coarse pot fragments (VII-VI century B.C.); 1 fragment of wall of coarse ware (VII century B.C.); 1 unidentified fragment of wall of Roman coarse ware.

[14] Context 18 (VII-VI century B.C.) Ceramics: 2 fragments of coarse cooking pot rims (VII-VI century B.C.); 1 fragment of wall of Roman coarse ware. Bones: 1 fragment of pig's pelvis; 1 fragment of proximal extremity of pig's left radius (they could belong to just one specimen).

Figure 10. M25 core of Piazza dei Cavalieri. Details of the marshy deposits with traces of frequentation may seen.

In the area of San Zeno (S6), frequentation of a levee is documented by the presence of a pot handle fragment dating between the end of VIII and start of VII century B.C.[15].

Instead, it is more difficult to chronologically attribute frequentation based upon the metal[16] and wood materials found at the transition between crevasse splay deposits and overlying floodplain deposits to the north-east of the city, in Via Quasimodo (MS), as well as frequentation documented to the north of the city in Via Galluppi (M18).

6.4. Floodplain settlement development

Gradual aggradation of the alluvial plain leads to general subaerial exposure, as confirmed by the presence of fine deposits with evidence of oxidation starting from altitudes around zero at sea level. These deposits are typical of drained floodplains and can be found in the city centre of Pisa (S. Zeno-S6, Department of Earth Sciences-M8 and Giardino Scotto-M23) and in the immediate outer areas (M2, M3, M4, M5, M6 and M18). They show general feeding by the River Arno, except for the lower portion of the plain succession to the north-east of the city in M5, where geochemical analysis reveals provenance from the River Serchio (cfr. § 5.).

Although the plain aggradation process shows a general tendency to develop from the end of the archaic age, this does not happen in all the area examined, probably due to local palaeomorphologies linked to fluvial channel activity. Early development may be seen, for example, in the SBAT-M9 area (cfr. § 6.3.), whereas in others development was never fully achieved (at the Court -M10; Piazza S. Caterina-M19 and Piazza dei Cavalieri-M25).

Sandy overbank sediments and/or crevasse splay sediments may be found throughout the floodplain deposits to the north of the Arno, especially in the immediately adjacent areas (ex Macelli area-S1; via Luschi-M17; Giardino Scotto-M23) and in Via Galluppi (M18). Crevasse splay deposits are also present slightly south of the Arno in correspondence of Via della Nunziatina (M7) and in Via Livornese (M3).

Stagnation in drained plain environments is recorded outside the city centre in Via Quasimodo (M5), whereas marshy areas may be found in correspondence of the Botanical Garden (M26) and SBAT (M9), which were formed during the previous chronological interval and subsequently silted up (M9) by crevasse splay deposits.

The presence of fluvial channel deposits, which date back to the development phase, is documented to the north of the city centre of Pisa in core M1 and to the south of the River Arno in Putignano (M15). In the first case (M1), the deposits were fed by the River Serchio (cfr. § 5.).

The floodplain, therefore, represents the environmental context in which settlement developed. Traces of settlement may be found in various environments and are described below according to the succession of the historical phases. In some cases, however, chronological references which definitely attribute frequentation on drained floodplain deposits to a precise period are missing in certain suburban areas (M5; M16 and S1). Starting from the medieval age, but especially from the modern age, anthropic stratification tended to almost completely cancel natural deposits.

6.4.1 Classical and Hellenistic age (480-90 B.C.)

Traces of frequentation during this wide-ranging chronological period may be found, although in slightly different environmental contexts, in two areas very close to each other to the north of the city centre: Piazza S. Caterina (M19) and S. Zeno (S6). In the former case, frequentation continued on poorly drained floodplain deposits up to the Roman age[17], whereas in S. Zeno it took place in a drained plain context. Regarding S. Zeno, a thin layer composed only of large sandstones and a fragment of a curved roof tile could be evidence of the collapse of a building which stood nearby. The ceramics dating between III and II century B.C. in the immediately previous[18] and subsequent[19] layers, allow us to date frequentation of this area.

In the area not far from Piazza dei Cavalieri (M25), although residual material from the Hellenistic and Late Republican Age may be found[20], clear evidence is missing of stratification referable to this chronological interval. A thin poorly drained plain level (Context 17[21] and Context 16), where sedimentation is situated directly on top of the archaic marshy deposits (cfr. § 6.3.1), was frequented during an indefinable historical period before formation of a medieval stratification over it. Given the wide chronological interval and limited level thickness, removal of parts of

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[15] Context 11 Ceramics: 1 coarse pot fragment: horizontal handle (end VIII-VII century B.C.).

[16] Context 8 Metal: iron circular rod broken at one end and terminating with a point at the other. Length preserved approx. 35 cm; max diameter 0.5 cm. Triangular hammer-beaten point. Appears to have been folded at least 3 times.

[17] Context 17=18 Ceramics: 8 coarse ware fragments: 1 flat base, 1 triangular rim of cooking pot, 5 walls; 1 pot shoulder with cable decoration (V-IV century B.C.); 1 fragment of a Figulina pottery cup (V century B.C.). Bones: 1 point of roe deer's horn; 1 unidentified fragment. Context 16 Ceramics: 2 African amphora fragments; 2 fragments of a closed form cooking pot; 1 coarse ware fragment (Early Hellenistic age, IV-III century B.C.?). Bones: 1 fragment of a sheep's or goat's vertebra; 1 tooth fragment of a very old herbivore; 1 fragment of a sheep's or goat's skull.

[18] Context 10 (end III-II century B.C.) 1 Morel 3131 cup rim fragment, Campana A (end III-last quarter II century B.C.); 1 fragment of Campana A foot (end III-II century B.C.).

[19] Context 7 (II B.C.?) Ceramics: 1 fragment of unidentified amphora wall; 1 cooking ware wall fragment; 1 fragment of black-paint, Campana A (II century B.C.).

[20] See materials of Context 13=14 and 12 of Piazza dei Cavalieri already presented in 6.4.3.

[21] Context 17 Ceramics: 1 coarse pot fragment with engobe slip.

the deposit due to anthropic interventions cannot be excluded.

6.4.2 Roman and Late Ancient Age (89 B.C.-600 A.D.)

In the northern area of the city centre, between S. Zeno (S6) and Piazza S. Caterina (M19), more or less structured walking floors may be found in the same environmental contexts of the previous phase, respectively, drained and poorly drained floodplain. A very compact layer may be seen in S. Zeno (Context 6), composed of a very dark silty matrix, rich in carbon, bricks and slags. Although direct dating elements are not available, the layer most probably dates back to between I century B.C. and I century A.D. based upon the dating provided by previous (cfr. § 6.4.1) and subsequent layers[22]. In the area of Piazza S. Caterina, a level of debris may be seen above a thin plain level containing residual material suggesting frequentation during the first Imperial age[23]. This is composed mainly of fragments of red painted plaster (Figures 11 and 12), probably used for the preparation of flooring, if considering as such the overlying layer of mortar and stones (Figure 13). The presence of flooring is confirmed by the planar distribution of the reflecting areas as a result of georadar analysis, which reveals traces of structures at the same height.

Figure 11. Detail of layer of plaster (Context 13).

Figure 12. Fragment of plaster with red painted surface.

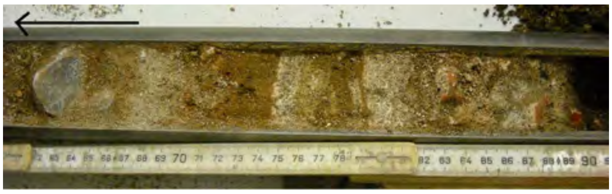

Figure 13. Santa Caterina (M19). Fragments of painted plaster, possibly used for preparing a mortar and stone flooring.

Slightly north, immediately outside the city centre (Via Galluppi-M18), traces of frequentation are suggested by the presence of ceramic materials[24] in drained floodplain alluvial deposits. It is also possible that the surface of the deposit (at around +2.4 m at sea level) represented a walking floor; the planar distribution of the reflecting areas provides evidence of structures around this height.

In the two cores close to the current course of the River Arno, at the end of Via S. Maria (SBAT-M9) and in the Court area (M10), evidence of frequentation is again offered by sporadic ceramic fragments, respectively in crevasse splay deposits and at the transition between drained-plain fine sediments and crevasse splay sands. It should also be pointed out that the ceramics in M9[25] could be of a residual nature, since

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[22] Context 5 (I century A.D.) Ceramics: 6 samian ware fragments (I century A.D.); 4 cooking pot fragments: 1 bifid rim, 1 triangular rim, 2 wall fragments (I-II century A.D.); 2 fine wall fragments, one with rouletting (I century A.D.); 6 amphora wall fragments, 4 possibly African; 1 fragment of bottom of coarse ware; 28 unidentified fragments. Bones: 1 fragment of sheep's radius.

[23] Context 14 Ceramics: 1 fine ware fragment; 1 fragment of plate with outturned rim in Campana A, Morel 1310 Series (from III century to the first half of II century B.C.). Bones: 1 rib fragment; 1 unidentified fragment.

Context 15 Ceramics: 1 oil-lamp spout fragment (Imperial age).

[24] Context 8=9 Ceramics: 1 fragment of black paint; 1 fragment of samian ware; 3 Roman ware fragments.

[25] Context 16 Ceramics: 3 fragments of coarse cooking pots; 1 fragment of black paint, Campana A (II-beginning of I century B.C.); 1 jug rim (late Republican-early Imperial

radiocarbon dating at the top of the deposit refers to the Medieval Age. In M10 a black-painted ceramic fragment found in the upper portion of the poorly drained plain, at the transition with the overlying crevasse splay, could suggest the Late Republican Age as *terminus post quem* for frequentation.

Drained plain deposits with traces of anthropic activity, possibly of an agricultural nature, and a horizon of subaerial exposure, probably belonging to a generic Roman or Late Ancient Age, may be found in the suburban area west to the city (via Mafalda di Savoia-M2), immediately under an organic level dating back to the VII century A.D. using radiocarbon dating.

6.4.3 Medieval Age (601-1491 A.D.)

Evidence of anthropic processing from VII century A.D., which is attributable to agricultural activities, is documented in the suburban area (via di Mafalda di Savoia-M2) within drained plain deposits.

In the city centre, medieval age frequentation detected through the cores can often be found in levee and crevasse splay deposits. In Via della Nunziatina (M7), slightly south of the Arno, frequented levee deposits are dated (via radiocarbon dating) to XI century A.D.; north of the river (M9, M10 and M23) medieval frequentation is attested in similar crevasse splay contexts. At Giardino Scotto (M23), the terminus post quem of the materials is XIII-XIV Century[26], whereas the planar distribution of the reflecting areas resulting from georadar analysis reveals the presence of a masonry structure at the height of 2.6 m above sea level; in the SBAT area (M9), where schist, mortar and bone fragments are present[27], radiocarbon dating of the organic material at the top of the deposit indicates an age dating to around XIII century A.D.; finally, at the Court (M10), frequentation of the crevasse splay deposit[28] is followed by elevation/levelling which occurred after XIII century[29].

In the area of Piazza dei Cavalieri (M25), in a poorly drained plain context, the diffused presence of slags from a height of around 1.50 m above sea level suggests the start of iron manufacturing which, given the thickness of the deposit, continued in time. Although chronological elements are missing for the initial phases of this activity[30], a clearer chronological reference is provided by ceramics dating between X and XII century[31] from a height of 1.95 m above sea level. A succession of preparation layers may be seen between 4.07 and 4.30 m above sea level, probably for a walking floor made with calcarenite processing waste. In one of these layers, various ceramic fragments referable to XIII century provide a terminus post quem for the date of manufacture[32]. The planar distribution of the reflecting areas between 3.72 m and 4.42 m above sea level shows the presence of badly defined structures. Layers rich in slag follow together with layers of mortar and brick fragments interpreted as elevation and levelling, without an accurate chronological definition.

Finally, the layer of debris[33] in Piazza S Caterina (M19) could possibly date back to the end of the medieval period. It is situated on an elevation/levelling layer that cannot be dated[34], probably the result of the demolition of buildings constructed in this area (Figure 14): according to the annals of Paolo Tronci[35], they were probably demolished in 1464.

Figure 14. Santa Caterina (M19). Detail of layer of debris, probably due to the demolition of buildings during the Medieval age.

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age).

[26] Context 7 Ceramics: 1 jug wall fragment (XIII-XIV century).

[27] Context 15 Bones: 1 vertebra fragment and fragment of a long bone belonging to a medium-sized herbivore.

[28] Context 6 Ceramics: 1 cooking pot fragment (X-XI century?).

[29] Context 5 Ceramics: 2 fragments of jug shoulder (XIII century). Context 4 Bones: 1 astragalus fragment probably of a carnivore.

[30] Context 15 Ceramics: 2 fragments of wall of Roman coarse ware

[31] Context 13=14 Ceramics: 1 fragment of cooking pot with grooved decoration (X-XII century); 1 fragment of African amphora; 1 cooking pot bottom and 1 wall (Hellenistic age?). Bones: 1 skull fragment of a herbivore; 4 unidentified fragments of which one burned. Context 12 Ceramics: 1 black-painted fragment; 1 handle fragment; 10 unidentified fragments of Roman coarse ware. Context 10 Ceramics: 3 Roman coarse ware fragments.

[32] Context 7 Ceramics: 1 jug fragment (XIII century); 1 open-shaped and green glazed fragment, Mucia production (XIII century).

[33] Context 8 Metal: 1 iron nail with square-shaped shaft.

[34] Context 9 Ceramics: 1 unidentified fragment of Roman coarse ware. Bones: 1 fragment of the proximal extremity of a sheep's radius.

[35] Tronci 1640, p. 18 "Non lassero' dire che la piazza grande avanti alla Chiesa di S. Caterina non fu spianata prima dell'anno 1464, con licenza della Comunita' e vi trovarono gran quantita' di fondamenti dalle quali ben si conobbe quanto era diversa l'antica forma della Citta' di Pisa da quelle parti" ("The large square in front of the Church of Santa Caterina was not levelled before 1464, upon authorisation of the Community, and many foundations were discovered that revealed how different the ancient shape of the City of Pisa was there") .

6.4.4 The modern age (1492-1814 A.D.)

A recurring trait in modern age deposits found in the cores performed in the urban area is the presence of layers made of brick and stone fragments, including schist fragments. Since the latter were generally used for covering roofs during the Early Medieval Age, this debris could be the result of the demolition of buildings during this period. Due to the absence of clear chronological elements, the layers are at times attributed to this period with a certain margin of doubt. Deposits with debris may be found in the following areas: ex-Macelli (S1), Department of Earth Sciences (M8), SBAT (M9) and S. Zeno (S6). In M8[36] and M9, at the same height of the layers of debris, the planar distribution of the reflecting area resulting from georadar analysis reveals the presence of structures: in the first case they mark the boundary of one or more environments, where the best defined one measures around 3.5x5 metres; the second case refers to a wall around 0.70 metres wide. A succession of layers of debris may be seen at S. Zeno: the first two layers, which also contain residual material (Contexts 4[37], 3[38]), are difficult to date, whereas the overlying layer provides more accurate chronological information, where material dating between XVI and start of XVII century may be found[39]. The layer of debris in Piazza S. Caterina resulting from the demolition of medieval buildings (cfr. § 6.4.3) is covered by an elevation/levelling layer, whose only chronological reference is provided by the ceramic material generically dating to XVI-XVIII century[40].

In some cases layers may be interpreted as more or less structured walking floors with levels of preparation. In the Botanical Garden area (M26), what are probably walking floors located on elevation/levelling layers of indefinite age and also containing residual material[41], date back to XVII-XVIII century if not even earlier[42]. Three thin layers in succession could be interpreted as a walking floor (Context 6, 4 and 3; Context 5 is probably a layer of preparation) at Giardino Scotto (M23). The highest floor is made of the waste of calcareous stone manufacturing which could be evidence of nearby field activities. The floors appear to date between the terminus post quem of the underlying layers (after XIII-XIV century) and the XVI century ceramics contained in the upper levelling and elevation layer[43]. The planar distribution of the reflecting areas resulting from georadar analysis reveals the presence of two orthogonal wall structures at the same height.

Evidence of frequentation, probably attributable to agricultural activity, may be found in the suburban area to the west of the city, in via Mafalda di Savoia (M2), and to the east, in Via Luschi (M17), where crevasse splay deposits show materials of various nature such as small angular clasts, and brick and ceramic fragments[44]. Distribution of the reflecting areas reveals the presence of a structure – which could be interpreted as a well – at the height of +1.7 m and probably a wall structure at the height of 3.2 m above sea level.

6.4.5 Contemporary age (post 1815 A.D.)

The stratification of the cores located in the city centre, usually in correspondence of areas used as vegetable gardens, gardens or public parks, generally ends with elevation/levelling layers followed by filling which is functional to current purposes, as in via Luschi (M17), in Via Quasimodo (M5), in Giardino Scotto (M23), at the Court (M10), at the Department of Earth Sciences (M8), at SBAT (M9), in Piazza S, Caterina (M19), in Via della Nunziatina (M7), in Via Bonanno Pisano (M6), at ex-Macelli (S1) and in Via Galluppi (M18). Specifically, elevation/levelling in Via Quasimodo (M5) probably occurred when the Betti school was built, after reclamation of a swampy area. A succession of elevation/levelling layers is attested at ex-Macelli (S1), interrupted by a layer of bitumen, which could perhaps refer to a road surface; the succession ends with the land of the current garden. At the Court (M10), the layer of debris, although not provided with internal dating information, may be reasonably attributed to the demolition of the medieval district, which once developed in this area, in order to build the Court during the fascist period: the planar distribution of the reflecting areas at the same height shows the possible presence of an environment measuring around 4x4 metres. Via della Nunziatina (M7) contains crevasse splay deposits with heterogeneous structure, indicating probable anthropic activity during the modern

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[36] Context 3 Ceramics: 1 unidentified fragment; 1 wall fragment, maybe of a small amphora without coating (XIII-XIV century?).

[37] Context 4 Ceramics: 3 fragments of a cooking pot with grooved surface decorations; 1 fragment of coarse ware cooking pottery; 1 fragment of coarse ware jug wall. Stone: 1 marble slab fragment. Bones: 2 fragments of a sheep's metacarpus.

[38] Context 3 Ceramics: 1 fragment of wall of an African amphora.

[39] Context 2 (end XVI-beginning XVII century) Ceramics: 1 fragment of Ligurian berrettino tin-glazed ware (mid XVI-mid XVII century); 1 fragment of a Montelupo sauceboat bottom (end XVI century); 2 fragments of pointed graffito plate (XVI century); 1 fragment of polychrome pottery with engobe slip (second half XVI-XVII century); 1 fragment of small pot with engobe slip; 2 fragments of archaic majolica of which one rim (XIV-start XV century); 2 fragments of coarse cooking pot; 2 fragments without coating. Bones: 1 fragment of bovine femoral head; 3 fragments of the skull of a medium-sized herbivore; 1 fragment of human carpal bone?

[40] Context 3 Ceramics: 1 fragment of wall of a small glazed pot (XVI-XVIII century).

[41] Context 18=17 Ceramics: 1 fragment of coarse ware. Context 10 Ceramics: 3 amphora fragments (Roman age).

[42] Context 7 Ceramics: 1 fragment of a rim of a small glazed cooking pot (XVII-XVIII century?); 1 fragment of wall of small cooking pot (XVII-XVIII century?).

[43] Context 2 Ceramics: 1 fragment of wall of a Montelupo jug (start XV century); 1 fragment of wall of a small glazed cooking pot (XVI century).

[44] Context 3 Ceramics: 1 unidentified fragment.; 1 fragment of engobe slip (XVI-XIX century).

age, as suggested by the brick and ceramic material found inside[45]. It could refer to agricultural or vegetable land situated outside the building which once rose nearby, as confirmed by the overlying layer of debris resulting from its demolition.

The succession of cores ends in the extra-urban area with lands showing traces of agricultural activity: via di Gello (M1[46]), via Mafalda di Savoia (M2), via Livornese (M3), Via Valmigli (M4) and in Putignano (M15).

(B.M., F.F., G.S., P.M., R.V., S.G.)

7. Conclusions and future prospects

The large amount of new data acquired and the interdisciplinary approach used to process the data significantly increased knowledge of the paleo-environmental and settlement context of Pisa of the past 6000 years, when a large lagoon covered the entire Pisa plain. The area was occupied by a lagoonal environment until around 3600 B.C. when, following a gradual increase in sedimentary supply, the lagoon started to silt up and slowly turn into a marshy area, crossed by distributor channels. Subsequently, fluvial activity characterised by a rather complex network prevailed between the protohistoric age and the early historic age, leading to the gradual formation of the floodplain. The innumerable overbank episodes, which contributed to constructing the floodplain, allowed us to make a distinction between the intakes from the River Serchio and those from the River Arno, thus shedding light (also through the analysis of aerial photos) on the rather complex hydrographic framework of the Pisa area. The reciprocal influence between natural environment and human settlement characteristics appears to be well documented in the natural archives examined during this research phase.

The data collected provide important information about the subsurface of the Pisa area to whoever operates in the fields of Earth Sciences and Archaeology. For the specific purposes of the project, these data – together with those synthesised in the archaeological information level (Anichini et alii, 2012) – will form the basis for the paleogeographical scenarios created for the main settlement phases of the area. Generally speaking, this case study is a highly promising good practice for geo-archaeological studies in urban and peri-urban areas. The stratigraphic log developed can be regarded as a highly efficient prototype enabling the adoption of a common technical language between sedimentologists, geomorphologists and archaeologists. Non-conventional investigation methods were successfully tested during this phase, such as use of the georadar for geoarchaeological purposes, the use of geochemical indicators for facies characterisation and determination of sediment provenance and, finally, the combined use of all different types of palynomorphs in palynological analyses. These may be included in routine geoarchaeological practices. To conclude, a number of theoretical cornerstones of the investigation method developed, such as interpreting natural stratification items in terms of anthropic activity and converting subsurface data into landscape form, may significantly improve the integrated approach between geoarchaeological research disciplines.

(P.M., S.G.)

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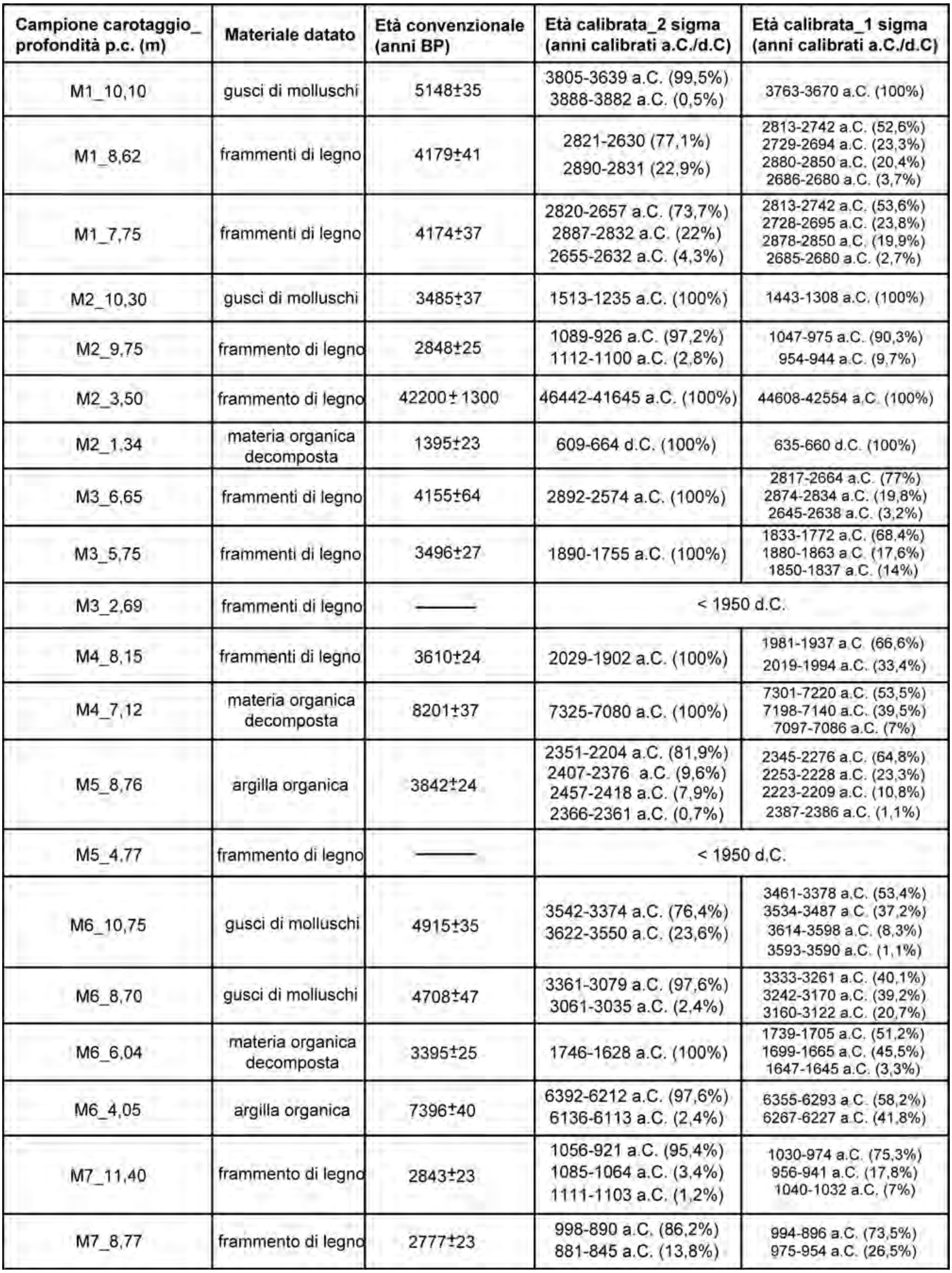
[45] Context 3 Ceramics: 1 earthenware fragment (XIX-XX century).

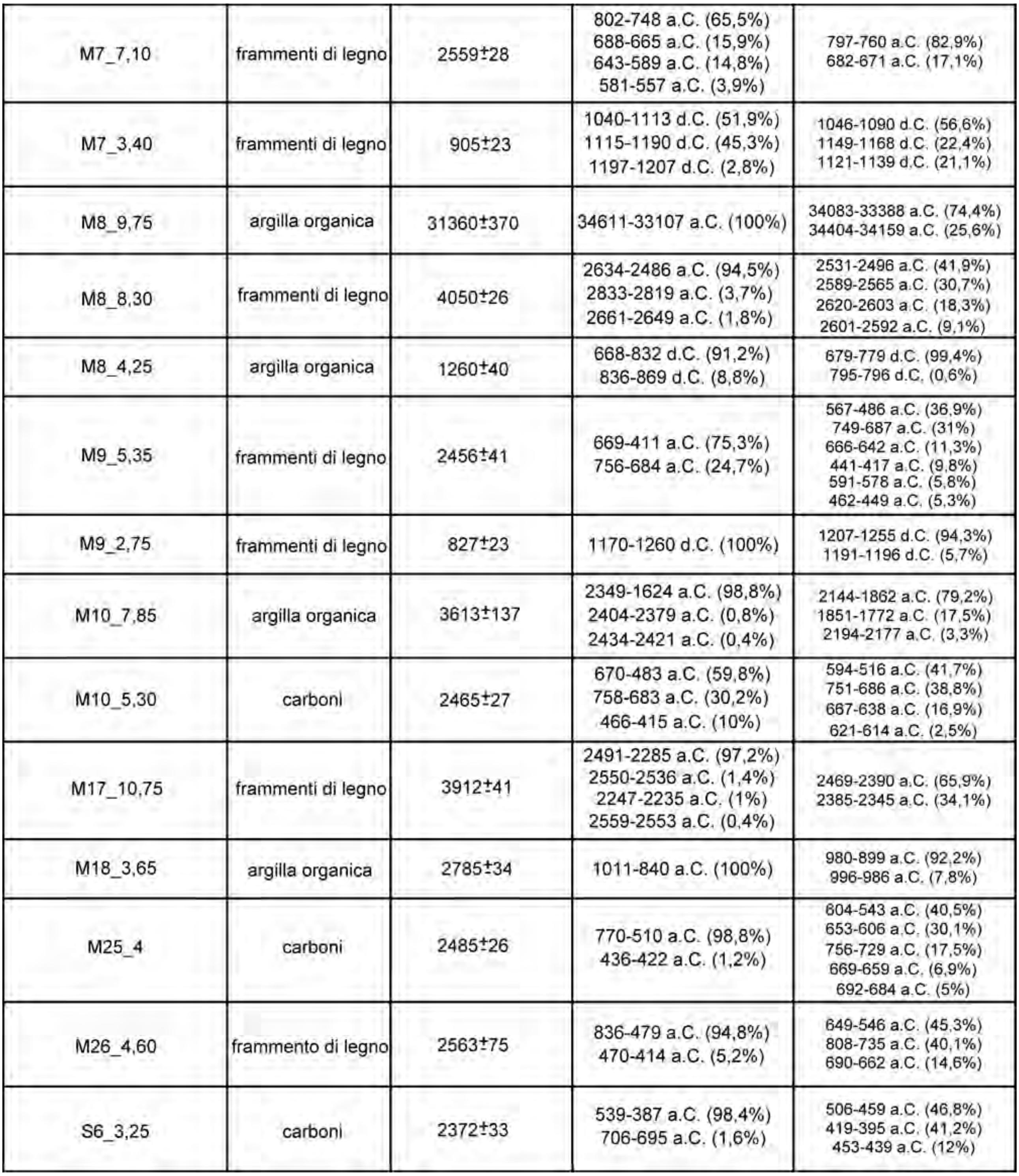
[46] Context 2 Ceramics: 1 fragment of archaic majolica jug (end XIII- early half XIV century).

Appendix

Table 1. Radiocarbon dating performed on M.A.P.P.A. cores. The logs (cfr. § 4.) show the calibration intervals with the highest percentage of probability for the interval expressed as 2σ.



Campione carotaggio_ profondità p.c. (m)	Materiale datato	Età convenzionale (anni BP)	Età calibrata_2 sigma (anni calibrati a.C./d.C)	Età calibrata_1 sigma (anni calibrati a.C./d.C)
M1_10,10	gusci di molluschi	5148±35	3805-3639 a.C. (99,5%) 3888-3882 a.C. (0,5%)	3763-3670 a.C. (100%)
M1_8,62	frammenti di legno	4179±41	2821-2630 (77,1%) 2890-2831 (22,9%)	2813-2742 a.C. (52,6%) 2729-2694 a.C. (23,3%) 2880-2850 a.C. (20,4%) 2686-2680 a.C. (3,7%)
M1_7,75	frammenti di legno	4174±37	2820-2657 a.C. (73,7%) 2887-2832 a.C. (22%) 2655-2632 a.C. (4,3%)	2813-2742 a.C. (53,6%) 2728-2695 a.C. (23,8%) 2878-2850 a.C. (19,9%) 2685-2680 a.C. (2,7%)
M2_10,30	gusci di molluschi	3485±37	1513-1235 a.C. (100%)	1443-1308 a.C. (100%)
M2_9,75	frammento di legno	2848±25	1089-926 a.C. (97,2%) 1112-1100 a.C. (2,8%)	1047-975 a.C. (90,3%) 954-944 a.C. (9,7%)
M2_3,50	frammento di legno	42200± 1300	46442-41645 a.C. (100%)	44608-42554 a.C. (100%)
M2_1,34	materia organica decomposta	1395±23	609-664 d.C. (100%)	635-660 d.C. (100%)
M3_6,65	frammenti di legno	4155±64	2892-2574 a.C. (100%)	2817-2664 a.C. (77%) 2874-2834 a.C. (19,8%) 2645-2638 a.C. (3,2%)
M3_5,75	frammenti di legno	3496±27	1890-1755 a.C. (100%)	1833-1772 a.C. (68,4%) 1880-1863 a.C. (17,6%) 1850-1837 a.C. (14%)
M3_2,69	frammenti di legno	———	< 1950 d.C.	
M4_8,15	frammenti di legno	3610±24	2029-1902 a.C. (100%)	1981-1937 a.C. (66,6%) 2019-1994 a.C. (33,4%)
M4_7,12	materia organica decomposta	8201±37	7325-7080 a.C. (100%)	7301-7220 a.C. (53,5%) 7198-7140 a.C. (39,5%) 7097-7086 a.C. (7%)
M5_8,76	argilla organica	3842±24	2351-2204 a.C. (81,9%) 2407-2376 a.C. (9,6%) 2457-2418 a.C. (7,9%) 2366-2361 a.C. (0,7%)	2345-2276 a.C. (64,8%) 2253-2228 a.C. (23,3%) 2223-2209 a.C. (10,8%) 2387-2386 a.C. (1,1%)
M5_4,77	frammento di legno	———	< 1950 d.C.	
M6_10,75	gusci di molluschi	4915±35	3542-3374 a.C. (76,4%) 3622-3550 a.C. (23,6%)	3461-3378 a.C. (53,4%) 3534-3487 a.C. (37,2%) 3614-3598 a.C. (8,3%) 3593-3590 a.C. (1,1%)
M6_8,70	gusci di molluschi	4708±47	3361-3079 a.C. (97,6%) 3061-3035 a.C. (2,4%)	3333-3261 a.C. (40,1%) 3242-3170 a.C. (39,2%) 3160-3122 a.C. (20,7%)
M6_6,04	materia organica decomposta	3395±25	1746-1628 a.C. (100%)	1739-1705 a.C. (51,2%) 1699-1665 a.C. (45,5%) 1647-1645 a.C. (3,3%)
M6_4,05	argilla organica	7396±40	6392-6212 a.C. (97,6%) 6136-6113 a.C. (2,4%)	6355-6293 a.C. (58,2%) 6267-6227 a.C. (41,8%)
M7_11,40	frammento di legno	2843±23	1056-921 a.C. (95,4%) 1085-1064 a.C. (3,4%) 1111-1103 a.C. (1,2%)	1030-974 a.C. (75,3%) 956-941 a.C. (17,8%) 1040-1032 a.C. (7%)
M7_8,77	frammento di legno	2777±23	998-890 a.C. (86,2%) 881-845 a.C. (13,8%)	994-896 a.C. (73,5%) 975-954 a.C. (26,5%)



M7_7,10	frammenti di legno	2559±28	802-748 a.C. (65,5%) 688-665 a.C. (15,9%) 643-589 a.C. (14,8%) 581-557 a.C. (3,9%)	797-760 a.C. (82,9%) 682-671 a.C. (17,1%)
M7_3,40	frammenti di legno	905±23	1040-1113 d.C. (51,9%) 1115-1190 d.C. (45,3%) 1197-1207 d.C. (2,8%)	1046-1090 d.C. (56,6%) 1149-1168 d.C. (22,4%) 1121-1139 d.C. (21,1%)
M8_9,75	argilla organica	31360±370	34611-33107 a.C. (100%)	34083-33388 a.C. (74,4%) 34404-34159 a.C. (25,6%)
M8_8,30	frammenti di legno	4050±26	2634-2486 a.C. (94,5%) 2833-2819 a.C. (3,7%) 2661-2649 a.C. (1,8%)	2531-2496 a.C. (41,9%) 2589-2565 a.C. (30,7%) 2620-2603 a.C. (18,3%) 2601-2592 a.C. (9,1%)
M8_4,25	argilla organica	1260±40	668-832 d.C. (91,2%) 836-869 d.C. (8,8%)	679-779 d.C. (99,4%) 795-796 d.C. (0,6%)
M9_5,35	frammenti di legno	2456±41	669-411 a.C. (75,3%) 756-684 a.C. (24,7%)	567-486 a.C. (36,9%) 749-687 a.C. (31%) 666-642 a.C. (11,3%) 441-417 a.C. (9,8%) 591-578 a.C. (5,8%) 462-449 a.C. (5,3%)
M9_2,75	frammenti di legno	827±23	1170-1260 d.C. (100%)	1207-1255 d.C. (94,3%) 1191-1196 d.C. (5,7%)
M10_7,85	argilla organica	3613±137	2349-1624 a.C. (98,8%) 2404-2379 a.C. (0,8%) 2434-2421 a.C. (0,4%)	2144-1862 a.C. (79,2%) 1851-1772 a.C. (17,5%) 2194-2177 a.C. (3,3%)
M10_5,30	carboni	2465±27	670-483 a.C. (59,8%) 758-683 a.C. (30,2%) 466-415 a.C. (10%)	594-516 a.C. (41,7%) 751-686 a.C. (38,8%) 667-638 a.C. (16,9%) 621-614 a.C. (2,5%)
M17_10,75	frammenti di legno	3912±41	2491-2285 a.C. (97,2%) 2550-2536 a.C. (1,4%) 2247-2235 a.C. (1%) 2559-2553 a.C. (0,4%)	2469-2390 a.C. (65,9%) 2385-2345 a.C. (34,1%)
M18_3,65	argilla organica	2785±34	1011-840 a.C. (100%)	980-899 a.C. (92,2%) 996-986 a.C. (7,8%)
M25_4	carboni	2485±26	770-510 a.C. (98,8%) 436-422 a.C. (1,2%)	604-543 a.C. (40,5%) 653-606 a.C. (30,1%) 756-729 a.C. (17,5%) 669-659 a.C. (6,9%) 692-684 a.C. (5%)
M26_4,60	frammento di legno	2563±75	836-479 a.C. (94,8%) 470-414 a.C. (5,2%)	649-546 a.C. (45,3%) 808-735 a.C. (40,1%) 690-662 a.C. (14,6%)
S6_3,25	carboni	2372±33	539-387 a.C. (98,4%) 706-695 a.C. (1,6%)	506-459 a.C. (46,8%) 419-395 a.C. (41,2%) 453-439 a.C. (12%)

Table 2. Concentration values of the elements in the coring samples (M1-M7).

Sample	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Sc	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th
M1 1.05	62,28	0,55	14,52	4,35	0,12	3,46	4,54	1,65	2,23	0,12	6,18	24	91	145	15	71	22	73	92	144	18	125	8	404	19	66	10	14
M1 2.25	67,75	0,40	9,74	3,36	0,10	2,15	6,24	1,98	1,80	0,04	6,43	6	58	89	10	51	13	51	78	161	16	70	6	337	16	44	8	15
M1 3.5	66,33	0,45	9,84	3,39	0,11	2,30	7,25	1,93	1,71	0,07	6,63	5	63	130	11	48	15	52	73	165	16	91	7	322	32	48	8	15
M1 4.2	63,86	0,46	10,67	3,65	0,11	2,66	8,28	1,90	1,81	0,06	6,54	9	70	134	12	54	18	53	72	164	17	67	6	331	31	61	6	14
M1 5.2	66,85	0,43	10,99	3,59	0,12	2,59	5,83	1,88	2,00	0,07	5,65	10	109	105	11	60	18	57	82	142	16	67	7	351	19	38	8	12
M1 5.45	64,81	0,47	10,43	3,76	0,12	2,72	7,85	1,95	1,62	0,09	6,17	11	71	92	11	57	18	55	66	135	15	58	7	291	11	25	5	11
M1 7.2	53,79	0,72	16,17	6,46	0,17	4,24	4,12	1,21	2,48	0,14	10,51	22	131	183	28	118	43	135	135	134	33	125	12	445	33	80	15	20
M1 7.68	52,31	0,70	16,95	6,24	0,08	4,24	0,67	1,21	2,60	0,12	14,88	31	148	189	30	119	41	146	163	94	32	94	12	467	40	83	16	16
M1 8.32	68,26	0,49	11,54	4,01	0,09	2,88	3,62	2,25	2,13	0,08	4,64	16	71	123	11	63	14	63	91	128	18	172	7	350	20	66	8	14
M1 9.3	66,31	0,51	12,31	4,06	0,10	3,21	3,42	2,30	2,12	0,11	5,55	14	77	133	13	70	19	69	98	133	21	207	9	369	31	45	13	14
M1 10.3	52,06	0,74	17,07	7,32	0,22	4,02	2,95	1,02	2,57	0,15	11,87	27	145	189	28	112	39	149	163	134	30	110	14	363	44	79	20	21
M1 11.3	51,20	0,76	18,01	6,87	0,18	5,15	2,07	1,19	3,08	0,16	11,34	32	155	207	32	132	53	167	183	104	36	109	13	413	51	105	24	25
M2 1.2	60,38	0,71	17,22	5,72	0,13	3,47	0,73	1,39	2,47	0,19	7,59	24	121	169	21	93	37	128	134	123	29	209	11	427	36	70	17	18
M2 2.3	50,79	0,67	15,08	6,13	0,14	3,35	7,93	0,96	2,19	0,13	12,64	17	115	219	23	101	33	118	119	182	27	139	12	433	35	74	13	15
M2 3.1	54,86	0,70	15,33	6,12	0,09	3,10	6,22	1,00	2,26	0,18	10,13	15	112	169	19	95	29	112	113	184	28	229	12	412	33	58	14	22
M2 4.5	59,28	0,47	11,36	4,45	0,11	2,69	8,24	1,63	1,66	0,09	10,02	9	66	128	14	71	18	60	67	177	17	160	7	294	24	52	10	13
M2 5.5	66,17	0,25	6,79	2,48	0,14	1,91	10,92	1,52	1,39	0,08	8,35	0	33	114	8	67	9	31	55	227	15	41	4	267	15	29	8	8
M2 9.6	67,44	0,32	7,09	3,04	0,12	2,34	9,70	1,79	1,10	0,09	6,98	6	46	162	10	70	13	39	50	165	13	41	5	247	15	35	9	4
M2 10.05	62,78	0,40	8,33	3,82	0,15	2,45	11,05	1,83	1,12	0,09	7,99	9	60	177	16	79	16	51	44	172	14	72	4	268	16	52	4	6
M2 13.4	51,73	0,72	18,25	6,71	0,14	4,56	3,11	1,22	2,96	0,13	10,46	33	163	209	27	131	53	160	181	128	31	96	14	383	55	101	19	21
M2 14.5	49,98	0,71	17,91	7,14	0,14	4,04	3,68	1,09	2,80	0,15	12,36	26	158	199	25	112	35	148	178	181	29	106	13	331	44	80	18	22
M3 0.9	57,46	0,63	14,43	5,11	0,14	2,88	6,42	1,26	1,95	0,13	9,61	14	95	145	20	89	28	93	98	161	24	188	11	458	29	56	14	17
M3 2.7	52,98	0,79	18,38	7,66	0,14	3,47	1,48	0,62	2,22	0,12	12,16	37	170	210	29	124	48	167	164	123	33	107	14	530	51	81	22	23
M3 3.85	55,15	0,73	15,05	6,27	0,15	3,22	5,54	1,08	2,03	0,13	10,66	16	120	159	25	102	36	125	117	157	28	142	13	525	32	76	14	17
M3 4.75	54,06	0,81	18,16	6,88	0,07	3,56	1,44	0,97	2,54	0,15	11,37	36	167	208	29	127	49	173	166	115	32	112	15	511	64	95	21	20
M3 5.75	50,79	0,76	17,59	6,30	0,12	3,44	4,11	0,92	2,52	0,15	13,32	20	154	192	25	129	49	160	159	143	31	101	14	450	47	84	19	19
M3 6.4	51,32	0,77	18,13	6,43	0,06	3,54	0,48	1,09	2,57	0,09	15,52	30	162	198	22	98	32	130	182	96	26	101	15	413	38	82	17	24
M3 7.25	62,60	0,52	12,51	3,98	0,12	2,56	5,25	2,14	1,87	0,13	8,33	14	84	125	12	73	19	74	85	163	22	187	9	353	24	53	12	10
M3 8.2	58,98	0,66	14,42	4,80	0,11	2,90	4,95	1,68	2,04	0,14	9,33	18	96	136	18	81	26	98	107	159	28	216	11	339	22	59	13	13
M3 8.95	50,71	0,72	17,74	7,07	0,16	4,09	2,96	1,21	2,56	0,12	12,66	27	150	191	27	110	33	146	171	158	31	105	14	336	47	82	16	14
M3 10.22	51,30	0,74	17,95	6,67	0,13	3,80	3,19	1,06	2,72	0,12	12,33	24	157	189	22	113	41	158	186	166	29	92	14	335	47	84	13	19

Sample	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Sc	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th
M4 1.5	52,03	0,73	16,45	6,45	0,14	3,39	5,38	0,83	2,17	0,14	12,30	24	138	173	26	106	42	135	132	162	28	138	13	479	41	71	29	20
M4 2.7	51,61	0,77	16,86	6,96	0,15	3,41	4,78	0,83	2,33	0,11	12,19	30	149	188	27	119	44	146	141	167	29	116	14	512	54	71	18	17
M4 3.3	51,07	0,78	17,65	7,19	0,14	3,38	3,90	0,73	2,43	0,09	12,64	30	168	199	26	122	51	161	163	158	29	101	14	514	49	86	19	19
M4 3.85	51,26	0,76	19,44	6,60	0,07	3,52	1,38	0,73	2,38	0,08	13,78	35	186	223	25	129	49	186	182	128	29	93	14	485	53	89	21	25
M4 4.6	54,49	0,79	17,94	7,29	0,09	3,48	1,87	0,86	2,32	0,14	10,73	24	156	196	28	122	46	162	155	135	33	119	14	548	47	79	16	26
M4 6.2	53,99	0,79	18,94	7,88	0,08	4,01	0,70	0,92	2,61	0,15	9,93	40	177	231	33	138	45	185	177	113	33	96	14	539	50	92	22	20
M4 6.9	55,22	0,76	17,04	6,65	0,09	3,52	3,12	1,05	2,34	0,17	10,05	28	145	193	28	117	44	157	153	137	31	125	15	488	43	93	21	22
M4 7.5	55,09	0,82	18,90	7,34	0,07	3,57	0,70	0,94	2,56	0,19	9,83	32	164	216	31	129	52	168	174	114	31	111	15	472	44	92	18	24
M4 8.5	55,33	0,79	18,08	7,37	0,12	4,05	1,00	1,20	2,61	0,16	9,30	37	161	206	30	123	43	162	154	112	30	100	12	481	47	79	21	17
M4 9.25	54,69	0,81	18,15	6,96	0,08	3,59	0,56	1,11	2,51	0,17	11,37	32	154	200	31	122	40	168	166	110	33	118	15	553	41	91	20	22
M5 1.5	54,05	0,76	17,06	6,40	0,14	3,47	3,22	0,72	2,33	0,12	11,72	31	150	188	28	116	49	152	139	133	28	142	13	534	44	81	34	18
M5 2.8	50,14	0,77	17,75	7,18	0,13	3,44	3,80	0,58	2,42	0,09	13,70	34	164	211	29	126	49	167	154	166	29	99	15	506	58	94	22	20
M5 4.07	55,17	0,73	16,80	6,41	0,15	4,02	3,02	1,12	2,20	0,13	10,26	30	141	184	26	115	40	129	132	129	32	133	12	490	42	77	14	19
M5 4.45	55,67	0,70	16,59	6,05	0,15	3,96	3,85	1,21	2,22	0,12	9,49	27	131	179	25	109	37	120	120	129	27	134	12	448	33	67	17	17
M5 5.07	57,57	0,63	15,72	5,28	0,13	3,83	4,71	1,51	2,17	0,14	8,66	20	110	166	19	92	29	99	109	143	25	167	10	452	29	76	12	16
M5 5.9	59,51	0,64	14,83	4,95	0,15	3,25	4,98	1,55	2,06	0,13	7,95	22	101	155	18	85	29	91	99	153	25	206	9	463	31	69	11	13
M5 6.96	55,60	0,74	16,07	5,71	0,12	3,26	4,81	1,02	2,23	0,13	10,32	24	134	172	23	107	38	6	125	150	29	144	13	453	42	82	18	20
M5 7.38	56,30	0,78	16,97	6,06	0,08	3,26	4,66	0,93	2,38	0,12	8,47	26	155	192	26	118	47	158	139	152	30	130	12	484	50	86	14	20
M5 7.96	56,35	0,78	17,50	6,45	0,11	3,42	1,40	0,97	2,41	0,14	10,46	33	161	198	31	121	47	164	153	108	13	123	15	485	55	95	16	17
M5 8.56	54,09	0,79	18,48	6,65	0,07	4,01	0,52	1,11	2,56	0,12	11,61	38	169	208	31	123	43	169	160	95	34	111	14	458	54	86	18	20
M5 9.42	59,36	0,60	14,28	4,90	0,10	3,11	3,79	1,77	2,03	0,12	9,96	18	95	142	18	81	27	96	108	138	25	180	11	354	33	65	13	21
M5 10.05	59,81	0,61	14,79	4,62	0,10	3,14	4,23	1,73	2,13	0,11	8,72	22	100	140	18	83	26	96	108	145	23	189	10	363	36	55	13	18
M5 10.47	55,56	0,66	16,03	5,48	0,13	3,55	4,31	1,45	2,28	0,12	10,42	25	120	160	21	95	32	119	124	145	26	162	11	361	31	60	16	15
M6 2.6	51,55	0,62	14,83	5,32	0,16	3,00	7,73	0,89	2,05	0,22	13,62	16	115	153	21	92	40	111	105	151	23	151	10	471	42	60	44	19
M6 4.25	65,58	0,54	13,56	4,19	0,09	2,66	3,99	1,80	2,17	0,14	5,27	22	84	141	14	70	20	70	86	127	17	162	9	435	32	51	10	12
M6 4.95	57,50	0,66	16,02	4,90	0,10	3,24	4,95	1,17	2,30	0,11	9,06	25	114	168	21	97	32	105	106	138	25	165	11	446	45	74	16	16
M6 5.4	53,72	0,71	16,21	5,52	0,10	3,14	6,08	0,76	2,27	0,13	11,36	23	128	179	22	107	34	122	123	164	25	139	12	428	46	81	14	13
M6 6.37	70,76	0,47	10,74	2,73	0,09	2,02	4,58	2,07	1,96	0,07	4,51	12	54	166	8	51	14	49	78	146	17	236	7	352	37	53	10	15
M6 6.78	73,78	0,29	9,90	2,18	0,08	1,65	3,73	2,32	2,03	0,06	3,97	9	38	86	4	46	8	37	83	146	10	62	6	384	16	38	11	12
M6 7.9	70,05	0,34	10,34	2,59	0,09	1,96	5,55	2,09	1,98	0,06	4,95	11	48	119	5	50	10	41	81	167	13	65	6	362	7	34	11	9
M6 9.3	67,15	0,37	9,92	2,76	0,10	2,00	7,45	1,79	1,88	0,06	6,52	10	53	172	10	55	15	43	78	173	13	51	5	338	14	44	8	13
M6 10.3	72,20	0,24	9,15	2,05	0,09	1,67	5,59	2,13	1,99	0,03	4,86	6	34	78	6	51	8	31	78	166	10	38	5	331	10	44	5	8

Sample	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Sc	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th
M6 11.25	71,02	0,26	8,51	2,24	0,10	1,76	6,64	2,04	1,84	0,02	5,57	7	40	99	5	45	9	35	73	175	11	37	5	354	14	35	6	7
M6 12.36	48,73	0,69	18,28	6,61	0,17	4,47	4,26	0,76	2,76	0,08	13,19	32	162	210	25	123	37	145	169	178	26	81	13	326	42	90	15	16
M6 13.47	51,96	0,67	17,48	6,31	0,18	4,50	4,49	1,01	2,70	0,13	10,58	29	139	198	21	111	37	133	148	163	28	113	13	367	45	78	15	20
M6 14.7	50,47	0,68	17,18	6,64	0,16	4,47	4,55	1,11	2,65	0,11	11,99	30	148	197	25	122	41	141	156	149	30	88	12	376	36	80	17	18
M7 1.4	56,86	0,51	12,06	4,40	0,16	2,50	9,47	1,32	2,11	1,37	9,25	9	77	142	15	77	101	137	96	221	16	113	8	471	28	59	115	14
M7 3.4	61,27	0,60	13,99	4,60	0,14	2,64	3,79	1,34	2,40	0,96	8,27	17	88	143	16	76	50	143	102	140	23	182	10	417	33	67	30	16
M7 4.7	76,73	0,29	10,05	2,81	0,13	1,58	1,05	2,20	2,13	0,21	2,82	11	42	123	10	59	8	42	85	96	14	88	6	401	6	23	15	11
M7 6.15	72,24	0,30	8,41	2,13	0,09	1,54	6,26	2,04	1,85	0,09	5,06	0	34	133	3	48	7	28	69	180	12	70	4	321	10	29	6	10
M7 7.1	53,78	0,68	15,13	5,46	0,15	3,19	5,56	1,03	2,19	0,11	12,72	18	117	160	22	102	37	120	115	145	29	162	10	457	37	66	16	13
M7 9.2	72,99	0,25	8,25	1,87	0,09	1,50	6,26	2,11	1,94	0,07	4,66	0	31	106	3	38	8	27	68	175	10	35	4	344	13	33	5	11
M7 10.35	72,05	0,23	9,30	2,23	0,09	1,75	5,32	2,17	2,00	0,03	4,82	5	33	74	7	53	6	32	81	166	10	39	4	374	7	24	11	10
M7 11.15	73,59	0,21	8,47	2,05	0,08	1,69	5,08	2,12	1,93	0,06	4,72	3	29	88	7	55	5	30	77	165	11	33	4	383	11	21	10	8
M7 11.55	68,75	0,33	10,40	2,85	0,10	1,96	5,91	1,57	1,95	0,08	6,11	12	49	150	10	58	14	45	76	163	11	36	5	379	7	38	8	11
M7 11.9	72,36	0,20	7,78	2,02	0,10	2,04	6,56	1,83	1,74	0,09	5,28	5	28	249	6	57	8	24	65	160	10	23	6	364	21	18	5	12
M7 13.85	48,89	0,71	18,72	7,27	0,16	4,35	3,66	0,81	2,93	0,11	12,39	31	166	210	25	117	33	154	190	183	25	87	14	297	44	84	15	19
M7 14.48	47,97	0,70	18,60	6,78	0,18	4,42	3,75	0,87	2,85	0,12	13,76	30	178	211	30	129	37	156	181	158	30	82	13	337	46	81	19	23
M7 14.88	48,50	0,72	19,21	7,44	0,16	4,48	3,01	0,91	2,87	0,14	12,55	32	167	216	28	122	38	159	180	159	31	82	12	312	49	94	18	18

Table 3. Concentration values of the elements in the samples of reference, taken close to the River Arno (C1-C3) and River Serchio (C4-C5).

Sample	**SiO2**	**TiO2**	**Al2O3**	**Fe2O3**	**MnO**	**MgO**	**CaO**	**Na2O**	**K2O**	**P2O5**	**LOI**	**Sc**	**V**	**Cr**	**Co**	**Ni**	**Cu**	**Zn**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Ba**	**La**	**Ce**	**Pb**	**Th**
C1 1.75	71,38	0,33	10,51	2,94	0,12	1,89	3,65	2,20	1,94	0,05	4,98	11	48	101	10	57	12	47	83	154	14	102	6	409	13	50	12	11
C1 4.4	62,62	0,55	12,15	4,18	0,13	2,37	6,09	1,62	1,74	0,11	8,09	13	80	130	14	66	22	76	80	165	21	203	10	404	21	55	9	18
C1 5.8	55,30	0,72	15,32	5,76	0,14	2,98	5,77	0,94	2,05	0,11	10,91	26	121	159	23	103	35	125	120	170	29	156	14	517	37	63	14	19
C1 6.73	52,47	0,77	16,52	7,28	0,18	3,20	4,81	0,75	2,22	0,14	11,67	26	143	189	28	116	40	148	136	152	31	118	14	511	47	86	16	19
C2 1.25	71,34	0,32	10,14	2,97	0,11	1,80	3,90	2,26	1,92	0,07	5,17	6	48	92	13	57	11	45	83	161	13	97	6	414	16	36	15	7
C2 1.7	72,08	0,46	11,71	3,10	0,12	2,16	2,09	2,24	1,87	0,11	4,07	15	57	119	10	57	13	54	78	116	17	217	7	420	19	48	12	17
C2 5.14	55,54	0,68	15,16	5,61	0,18	3,03	6,31	0,97	1,97	0,14	10,42	17	109	148	22	90	31	108	101	165	26	149	11	578	30	51	11	10
C2 7.72	55,03	0,74	16,84	5,76	0,10	3,24	4,41	0,96	2,32	0,12	10,47	26	132	178	25	106	40	135	128	158	28	149	15	581	36	72	15	21
C3 2,7	54,45	0,70	15,37	5,83	0,15	3,50	5,84	1,00	2,25	0,10	10,82	20	122	160	22	101	37	116	121	183	27	173	11	537	41	61	17	20
C3 3.8	63,87	0,54	13,09	3,95	0,12	2,85	5,04	2,00	1,88	0,14	6,52	18	77	128	13	68	20	64	78	155	20	212	8	404	31	54	11	15
C3 4.5	73,89	0,32	9,24	2,33	0,10	1,57	3,70	2,23	1,76	0,06	4,81	6	39	103	7	48	9	36	77	158	14	157	7	375	24	40	9	10
C3 6.45	58,06	0,53	13,27	4,41	0,15	2,86	5,52	1,56	2,02	0,12	11,49	17	88	135	16	79	26	84	89	160	21	140	8	419	32	71	14	12
C4 0.6	57,56	0,65	15,89	5,57	0,15	4,44	3,84	1,52	2,36	0,15	7,86	27	122	181	24	104	37	102	113	138	24	143	11	480	29	65	13	18
C4 0.9	62,40	0,56	13,93	4,34	0,13	3,69	4,74	1,84	2,18	0,12	6,07	21	91	147	13	75	23	67	91	139	19	187	8	417	33	56	10	12
C4 1.65	60,57	0,60	15,61	4,84	0,13	3,97	3,47	1,65	2,26	0,16	6,74	26	102	166	18	92	27	87	105	123	23	176	11	459	34	61	10	13
C4 2.8	57,04	0,65	16,34	5,62	0,14	3,98	4,05	1,38	2,32	0,12	8,36	29	123	176	24	107	37	110	124	134	27	162	11	456	39	73	13	17
C5 0.35	57,31	0,57	14,55	4,72	0,12	4,13	5,79	1,70	2,30	0,23	8,52	21	97	175	17	95	58	158	100	140	23	166	9	476	35	59	24	14
C5 0.8	59,27	0,58	14,81	4,74	0,12	4,25	5,22	1,80	2,40	0,17	6,65	23	95	163	16	92	59	147	102	140	22	167	10	477	27	52	15	18
C5 1.65	60,14	0,54	14,22	4,48	0,12	3,91	5,47	1,79	2,34	0,10	6,89	19	94	154	13	85	28	88	99	138	20	165	9	478	27	58	13	14
C5 2.8	59,14	0,55	14,53	4,63	0,12	4,02	5,10	1,81	2,36	0,13	7,61	32	126	180	25	107	36	108	124	134	27	162	11	470	41	75	12	16

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