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Geomorphological evidence from the MAPPA-Web-GIS: explanatory notes

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In the framework of the MAPPA Project a new geomorphological evidence was collected thanks to the availability of a Lidar survey and new detailed remote sensing analyses. These new data were represented according to a special code worked out in order to incorporate our data in the MAPPA-Web-GIS. This code will be illustrated in this report, together with the criteria used for landforms detection.

Keywords: Geomorphological map, floodplain, Lidar, remote sensng, Web-GIS

1. Introduction

Detecting landforms in floodplains is perhaps the most challenging activity for a geomorphologist (Castiglioni 2001). In fact the natural evolution of a floodplain tends to cancel landforms soon after they are no longer active. The Pisa Plain, in particular, was formed in sea-level rise conditions, and thus its evolution was accompanied by a constant rise of base-level. Aggradation was then combined with progradation, resulting in a progressive burial of landforms. Nevertheless those landforms that were buried by more recent alluvium, such as stream channels or marshes, leave a fingerprint which may be visible on modern topography in the form of weak undulations in the ground floor. These are normally undetectable in the field and need an extremely detailed micro-relief representation to be highlighted. Such "inherited" landforms, even if recognized, are then difficult to classify and constrain chronologically. Finally their mutual relationships are hard to assess. Long-aged settlement contributes to modify past fluvial landforms in floodplains, creating an artificial drainage network and enhancing natural topographic highs building artificial ground levels. Specific great-scale surveys are necessary to investigate floodplains geomorphological setting, and a cross-disciplinary approach is in most cases indispensable (Piovan *et alii* 2006). A Digital Terrain Model reproducing the topography of investigated area with a very high spatial resolution becomes fundamental for studying some landscapes of difficult interpretation as the floodplains where the original morphologies can be lost or modified by the natural environmental changes or by the human activity (Ninfo *et alii* 2011).
Mapping landforms is the first step to perform landscape interpretation. The representation code used by Italian scholars (Servizio Geologico Nazionale, 1994) is a powerful tool that provides all the necessary information to genetically constrain landforms and to assess their mutual relationship in time and space. In this work, though, we preferred not to use this type of representation. In fact in the MAPPA Project all data (archaeological, geological and geomorphological) are included in a digital mapping instrument (the MAPPA web-GIS) which provides access to all the project results for a wide community of end-users, such as researchers, professionals, operators of local public institutions, dealing with archaeological heritage protection, environmental management, natural hazard mitigation. This tool must be simple to consult and must enable real-time queries of data. For this reason a specific legend has been worked out for the MAPPA Web GIS geomorphological map.
The milestone of geomorphological maps of the Pisa Plain (Mazzanti 1994) was actually based on

cross-checking information on surface lithology with evidence from aerial photography and hystorical-archaeological data. More recent documents (e.g. Provincia di Pisa http://sit.provincia.pisa.it), improved the resolution of the data but with limited accuracy due to the lack of a suitable topographic base.

In the framework of the MAPPA Project new geomorphological evidence was collected thanks to the availability of a Lidar survey and new detailed remote sensing analyses (Bini *et alii* 2012). The Airborne Lidar Scanning (ALS), acquiring spatially dense altimetry data set over short periods of time, allows the production of very detailed Digital Terrain Models (DTM) even in areas strongly urbanized or covered by dense vegetation. Remote sensing enables to map those features that are hardly detectable in the field due to their scarce relief energy.

The nature of surface fingerprints of buried landforms could be verified thanks to the project data base. These new data were represented according to a special code worked out in order to incorporate our data in the MAPPA-Web-GIS; this code will be illustrated in the following, together with the criteria used for landforms detection.

2. Methods

Landforms identification was based on: 1) photointerpretation, 2) remote sensing analyses, 3) morphometric analyses on the Lidar digital elevation model, 4) field survey.

Photointerpretation and remote sensing analyses were carried out in order to detect traces of past drainage networks and wetlands (marshes, swamps and ponds). Details about the type of images used and the processing techniques employed are provided in MapPapers 5-II and Bini *et alii*, 2011.

The Airborne Lidar (Laser Imaging Detection and Ranging) is an active remote sensing system and consists of a Laser (Light Amplification by the Stimulated Emission of Radiation) emitting very high frequency pulses (up to more than 100.000 pulses/points per second) from an aircraft/helicopter flying over the study area, a GPS receiver and an Inertial Navigation System (INS). Acquiring the time lapse between emission of the laser beam and reception of the reflected beam, and the precise position and the orientation of the airborne platform (from the GPS receiver and an on-board Inertial Measurement Unit), it is possible to determinate the 3D position (x,y,z) of surface points basing on the formula for the speed of light.

For each pulse reflection two types of signals can be registered: the first and the last echo. The first echo identifies vegetated areas (detecting the canopy top surface) whereas the last echo identifies points belonging to the ground. Semi-automated data processing allow to recognize and remove false echoes (outliers), classify the different echoes for type (first and last) and generate the relative Digital Terrain Models. The resulting models are named Digital Surface Model (DSM) if both the echoes are processed, otherwise Digital Elevation Models (DEM) if only the last pulses are processed.

The DEM available for our study area come from a Lidar survey carried out during the 2008 year and commissioned by the Ministero dell'Ambiente e della Tutela del Territorio. Lidar data were acquired using an ALTM Gemini which technical specifications include a laser operating in the Near Infrared region (λ = 1.064 μm) that can emit up to 1670.000 pulses/points per second with a scan semi-angle of 0° to 25° and a beam divergence of 0.25 mrad. During this survey, The ALTM Gemini operated at flight altitudine between 1050 and 1300 m from the ground allowing an average density of acquisition of 0.8 or 1.6 pulse/m2 for coastal areas and inland zones, respectively. The acquired data were geo-coded in WGS 84 lat long and have a vertical and horizontal accuracy of ± 15cm and ±30 cm, respectively. Subsequently, the Lidar data are geo - referenced into ROMA 40 GB Zone West cartographic system and the elevation model obtained from last echoes was memorized in a series of tiles describing a continuous array of grid cells stored in a ASCII text format. Starting from these tiles, we have converted each ASCII file in a ESRI GRID format maintaining the original spatial resolution. The 87 resulting GRIDs were merged using the appropriate mathematical operators available in GIS software used as working environment in this study (ESRI platform). The result is an matrix (9640 rows X 16040 columns) where each cell has a spatial resolution of 1 meter and contains the elevation information.

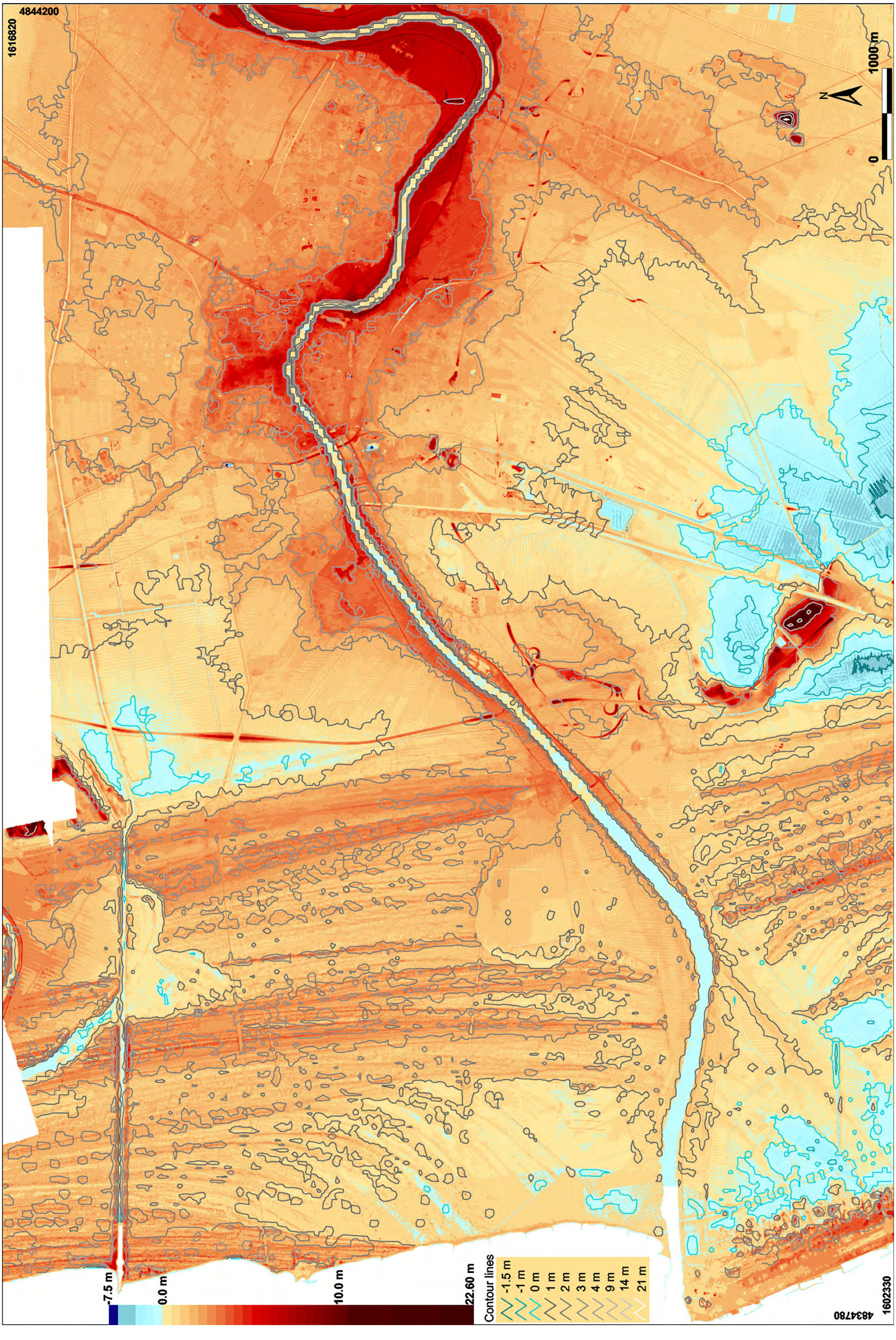
Specific maps derived from the elevation model such as the shaded relief image, slope map, contour lines maps with different resolution and several altimetry profiles drawn in the both sectors. Simplified contour lines were extracted from an elevation matrix with a coarser spatial resolution (50 m) obtained applying the mean aggregation method to the original altimetry model (Fig. 1).

Morphometric analyses were carried out using the standard tools of ArcGis software. Finally field survey was carried out in specific sites to disentangle natural from manmade landforms in those cases in which attribution was unclear through other investigation methods.

3.Floodplain landforms

Egypt is a gift of the Nile (Herodotus)

A floodplain is a low-lying terrain formed primarily by channel or overbank deposition (Butzer 1976). A river channel is shaped in order to carry a fluctuating volume of water and sediment as efficiently as possible towards the sea. Wide floodplains are convex in section, as the flowing river displays raised river banks, that are higher than the surrounding flats. Suspended sediments are predominant due to the fact that water energy is normally low when a channel flows in a lowland. When the amount and speed of water in the channel increase, water spills out over the floodplain (overbank) driving sediment out of the



4844200
1616820
1000 m
0
N
-7.5 m
0.0 m
10.0 m
22.60 m
Contour lines
-1.5 m
-1 m
0 m
1 m
2 m
3 m
4 m
9 m
14 m
21 m
1602330
4834780

Figure 1. (previous page) Example of image derived from the digital elevation built with Lidar data; contour lines, drawn every 1 m, are combined with the elevation map visualized in 50 coloured classes.

Figure 2. Main features associated to a meandering river in a floodplain (after: http://www.coolgeography.co.uk)

river bed. Meandering stream pattern is typical of rivers with strong preponderance of suspended sediments. In a meandering river erosion occurs on the outside bank of the channel and the eroded material is deposited on the inside bank. Meanders develop from an initially straight channel, and evolve increasing their wavelength and amplitude. Due to basic dynamism of a river, meanders migrate downstream with time and tend to increase their amplitude. Meander wavelength is directly proportional to channel width. A meander can be cut off during flood stage leaving a relict arcuate lake called *oxbow*.
The most important geomorphic features of floodplains (Fig. 2) are connected to channels evolution. The *low water channel* is constrained within banks of fine-grained alluvium. Point bars develop as a series of low levees inside meander bends, forming arcuate ridges separated by swales. The *natural levees* are ridges that rise above the river banks; they form during periods of overbank discharge and are constituted by horizontal and cross-bedded sediment layers. Beyond levees *flood basins* form, as a result of water persistence after overbank floods. *Backswamps* represent the lowest part of the flood basin, that may lay beneath the groundwater table and thus form permanently or temporarily flooded depressions. Sediments that accumulate in such depressions are fine grained and rich in organic matter. *Sand splays* are tongue-shaped, medium-coarse-grained deposits, left by turbulent water fluxes from the channel to the plain, due to levee breaching.
Changes in discharge or gradient are responsible for changes in a river dynamism. When floodplains merge onto coastal plains they can be associated to deltas and/or the fringe of land that directly faces the sea can be formed by sets of beach ridges. When the amount of solid load carried by a river increases (due e.g. to climatic change or deforestation in the catchment basin) the coastline shifts towards the sea (progradation), and new beach ridges form. A rising sea level leads to accelerated alluviation (aggradation) in the floodplain that merges onto the coastal plain. Relict landforms are thus easily buried. When rising sea level is matched to increase in discharge, the floodplain expansion towards the sea is combined with an enhanced sedimentary rate. Finally subsidence due to sediment compaction or to tectonic movements enhances the plain aggradation rate.

4. The geomorphological legend in the MAPPA web-GIS

The geomorphological legend was created according to the constraints imposed by the web-GIS architecture. The text illustrating the meaning of the symbols, for instance, is necessarily very short, and thus sometimes the definition of landforms features is rather simplified.

- *Natural river channels*
- *Artificial channels*

The present-day drainage network is represented and differentiated in its natural and manmade elements. The latter may sometimes coincide with relict river branches, that have been maintained and employed to foster water discharge from the plain.

- *Raised past river branch(5m>h>4m)*
- *Raised past river branch (>5m)*

In floodplains, abandoned river branches flanked by levees result as prominent ridges shaped in coarser sediments than the surrounding interfluves. In most cases these landforms are buried by the alluvium accumulating due to plain aggradation and are detectable only through photointerpretation and remote sensing analysis. Sometimes, though, they are preserved either because they are very recent, or because plain aggradation and subsidence display very low rates or, finally, because anthropic settlement, established on these surfaces due to their original elevation above the ordinary floodplain level, protected them from erosion and artificially raised them. If settlement persisted through time, more phases of artificial raising should be revealed by archaeological excavations.

- *Wetland (below 1.2 m asl)*
- *Wetland (below 0.9 m asl)*

Wetlands display a continuously fluctuating shape, due to their nature of depressions within the floodplain that may be fed with water due to overbank floods or to stagnation in rainwater drainage or simply to high water table conditions. Genetically wetlands can be related to flood basins and backswamps. They occupy those parts of the plain that are farthest from the migration band of the rivers branches. Location of present-day wetlands represents the result of a centennial enhanced aggradation of the plain in proximity of the rivers courses, where natural levees and sand splays juxtaposed through times raising the ground level. For this reason their current position should be considered an inherited feature, from the most recent phase of enhanced sediment discharge experienced by the area. After Roman times most Italian plains were fed by exceptional river discharges (Fontana *et alii* 2008), due to abandonment of cultivations along hillslopes and possibly also by changes in rainfall. This evidence is reported for the Pisa plain (Sarti *et alii* 2010) as well as for neighboring plains such as the Luna Plain (Fazzini, Maffei 2000). The perimeter of wetlands mapped in our web-GIS, thus, was assessed considering that morphometric analysis of the depressions could yield the approximate perimeters of High- and Low-Middle Ages marshes, starting from which current depressions formed. The DEM was then reclassified applying the standard deviation criteria. Two breakpoint were identified in the histogram, that were used to state the elevations at which the High- and Low-Middle Ages marshes perimeters should be drawn. The perimeters, in fact, enclose those areas in which the morphometric analysis emphasizes a flat morphology consistent with a swamp bottom. The extension and chronological attribution of the mapped marshes were cross checked with historical and archaeological evidence (Gattiglia 2011).

In the plain there are not present-day backswamps as they have been reclaimed in the past 150 years. Nevertheless hystorical maps and geographical reports suggest that these should be included within the perimeter of the wetlands.

• *Ordinary floodplain level*

When the low water channel is constrained within banks, the part of the plain which is dry represents the ordinary floodplain level. To enable the water basin discharge system to be efficient, the elevation of river banks should be "at sea-level". In this case, in fact, as long as the river is within its banks, water can flow into the sea. Sea level, though, fluctuates within an elevation range the width of which depends on tidal range, atmospheric pressure and sea water motion due to wind direction and incoming waves height. This elevation range can be established locally and related to conventional zero value of mean sea level which, in turn, can be referred to an absolute reference system (the geodetic ellipsoid). Along the coastal fringe bordering the Pisa plain tidal range, including the atmospheric tide contribution, displays an amplitude of about 1 m, if we consider annual sea level fluctuations. At the Arno and Serchio river mouths sea level can be remarkably increased when south-westerly wind (Libeccio) blows. On the whole the ordinary floodplain level stretches in elevation from mean sea level up to 2 m a.s.l.

- *Beach ridge*
- *Swale*
- *Relict coastal dune*

Seaward the Pisa Plain displays a system of beach ridges surmounted by coastal dunes and bracketed by backing swales. The Lidar-derived topography emphasizes great scale morphology of these landforms, that can thus be mapped thoroughly. These landforms are just marginally included in the study area.

- *Point bars system*
- *Oxbow*
- *River palaeotrace*

In the geomorphological map the palaeochannels inferred from photointerpretation and remote sensing analysis are reported; their detection is based on anomalies in soil moisture, which may be related to changes in water content independent from the presence of a buried trace of a past river channel (Piovan *et alii* 2009). Old stream courses, the location of which is broadly known from literary sources or archaeological excavations, are not reported unless they can be recognized in aerial and satellite imagery. Oxbows and point bars systems are mapped inside meander bends. The presence of a positive (point bars system) or of a negative (oxbow) form depends on the dynamics of the channel migration within the meander. Gradual migration of the channel bar in connection with the meander amplitude increase trend, creates a set of sediment ridges, one for each of the positions attained by the channel, deposited on the inside bank; these ridges may finally coalesce, forming on the whole a positive form inside the meander bend. On the contrary, if a meander is cut off by a flood, a depression is created inside the bend, that will be maintained and even emphasizes by later plain aggradation.

5. Perspectives

The MAPPA-Web-GIS geomorphological map represents one of the stages of the geoachaeological research carried out in the Pisa plain. It is a tool which plainly illustrates the main landforms of the Pisa plain and their genetic interpretation in terms of morphological agents. This result was achieved using those methods that are typical of geomorphological mapping work. In the next research stage, aimed at performing slices of the palaeogeographic scenario at different settlement phases, further data will be collected about the mapped landforms aimed at validating their presence, reconstructing their tridimensional shape and chronologically constraining their development.
This new stage of the research will be possible applying geophysical prospecting methodologies (electrical tomography) and cross-checking with subsurface data. Geophysical prospecting will be aimed at detecting the 3D displacement of traces of past drainage network highlighted by means of photointerpretation. Stratigraphic logs derived from 18 continuous cores, up to 20 m long (Amorosi *et alii* 2012a and

Amorosi *et alii* 2012b), provide evidence, in the subsurface, of deposits whose facies is consistent with mapped landforms. Cross checking of surface evidence with subsurface data will enable to confirm the genetic interpretations of those landforms that are not cropping out at the floodplain level but are buried underneath a more or less thick alluvium layer.

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