Lake evolution and landscape history in the lower Mincio River valley, unravelling drainage changes in the central Po Plain (N-Italy) since the Bronze Age

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A B S T R A C T

The Etruscan harbour of Forcello, in the lower valley of the Mincio River, northern Italy, was active between 540 and 390 BC. The stratigraphic investigations revealed that the settlement occupied a hill on the shore of a lake. The lake sediments and the palaeoecological record, supported by radiocarbon ages, document the basin origin in the Middle Bronze Age as well as the development of aquatic and terrestrial vegetation through the Iron Age and the Roman Age, until the reclamation in the 17th century. The pollen record provides new evidence about the forest cover and the Juglans introduction in the central Po Plain in the early Iron Age. The lake expanded during the early Iron Age, after the diversion of the Po River at Guastalla. Increasing bedload, discharge and sedimentation rates in the Po River system dammed the confluence with the Mincio River, starting the development of the lake. Bronze Age human pressure on forest may also have contributed to this bedload increase. Subsidence related to local tectonics in the axial portion of the river network and rising base-level of the Po Plain fluvial system, induced by increasing sea level, are the triggering factors of these drainage changes in the central Po Plain.

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1. Introduction

The lakes surrounding the town of Mantova represent a unique example of freshwater limnic evolution in the plain of the Po River, the largest alluvial plain of Italy (Fig. 1). The peculiarity of these lakes, and their significance for Quaternary and archaeological research, are due to several striking features. As noted by Sestini (1957), the Mantova lakes are not perfluvial lakes formed after the abandonment of either a meandering system, or swamp or coastal lakes in a delta; instead their development is constrained within the embanked valley of the Mincio River (Fig. 1b). The modern setting of Mantova lakes is the result of building dykes and embankments dating to the 12th century AD and of reclamation in the 17th century (Marani, 1967a; Gardoni, 2010). These hydraulic arrangements modified a previous natural lake, supposed to extend downstream to the confluence with the Po River [see Marani, 1967b for an historical essay]. Before the Middle Age river arrangement, one of the most important Etruscan outposts in Northern Italy was settled on a hill emerging from the Mincio valley floor (Forcello, 16 m a.s.l., 45°06’36”N, 10°50’06”E, Fig. 1b). According to the archaeological evidence, the Forcello settlement acted as a fluvial harbor, connecting trades between the eastern Mediterranean Basin and continental Europe. The harbour was founded in 540 BC and abandoned suddenly about 390 BC (De Marinis and Rapi, 2007). Mention of an ancient pond along the lower valley of the Mincio River close to Mantova is given in the 3rd century BC by the classical author Livio (Livio, liber XXIV), and in the 1st century BC by Servio (Servio, Commentarii ad eclogae, IX).

Despite these clues, the existence of an early lake basin before the Middle Ages is still unsupported by stratigraphic evidence. The lack of a chronostratigraphic framework for the development of the Mantova lakes prevented previous authors from envisaging consistent relationships between timing of lake evolution, river network changes and human settlements. The first question is concerned with the striking change of the Mincio River channel direction westward of Mantova town (Fig. 1b). This shift in channel pattern has...
been related to tectonic activity (Serva, 1990) or even to buried moraines. However, recent seismic profiles and litostratigraphic transects across the Mantova plain have shown an undeformed sedimentary sequence at least during the last five glacial cycles (Amorosi et al., 2008).

The main tasks of the present work are the following:
- presenting the litostratigraphic lacustrine archive contained in the lowermost Mincio valley;
- reconstructing the Late Holocene lake evolution of the lowermost Mincio valley infill, using radiocarbon dating, a fine palynological record and geochemical studies on a selected core drilled in the littoral basin, very close to the Forcello harbour;
- examining the age and sedimentary succession drilled in the basin depocentre, to recognize age of lake origin and its Late Holocene development steps;
- examining implications for evolution of Po Plain fluvial network and shipping during protohistoric times. A main question is to assess the reasons why Etruscans settled the main trading post for the Padanian uplands well inside the Mincio valley, instead of along the Po River;
- disentangle the interplay between the origin and evolution of Mantova lakes, drainage network, subsidence, tectonic activity, and climate change.

2. Material and methods

A detailed DTM was prepared to identify the main geomorphic features. Contour lines were obtained from elevation points derived from numerical Cartography (CTRN) of the Region Lombardy (nominal scale, 1:10,000). The evaluation of the geomorphic features has been analyzed applying tested techniques joined to classical terminology of biogenic and chemical lacustrine deposits (West, 1980; Berglund, 1986) was maintained, provided that the classical Troels-Smith scheme was avoided. However, the inorganic C contents and the residual fraction (Heiri et al., 2001).

Field litostratigraphic descriptions were implemented by LOI (Loss on Ignition) determinations from core FOR 6. Here, 25 volumetric samples taken between 140 and 273 cm depth were weighed wet and progressively heated at 105 °C for 12 h, 550 °C for 4 h and 950 °C for 2 h to evaluate the water, organic matter, total inorganic C contents and the residual fraction (Heiri et al., 2001).

TOC, CaCO₃, and the non-carbonatic residues were obtained spectrophotometrically (Dean, 1974, 1999). In the studied area, the non-carbonate residual fraction is mostly composed by siliclastic particles carried by River Mincio (see Cremaschi, 1987), and hence it may be used as an index of detrital supply.

The quantification of chemical (autogenic) and detrital (allogenic) components in fine sediments proved to be very difficult, especially in carbonate-rich mud (Schnurrenberger et al., 2003), and for this reason the classical Troels-Smith scheme was avoided. However, the classical terminology of biogenic and chemical lacustrine deposits (West, 1980; Berglund, 1986) was maintained, provided that the prevalent component could be identified.

In the procedure followed here, deposits rich in organic matter (e.g. gyttja) were termed after considering both the organic carbon curve and the micro- and macrobotanical composition of the organic component. Sediments bearing either biogenic-biochemical...
and organic components were also detected (i.e. carbonatic gyttja). A qualitative estimation of the changes in biogenic and biochemical carbonate components in the studied sediments was obtained by covariation of the CaO\textsubscript{2} and the silicilastic residue curves. Sediments dominated by detrital components (i.e. sands rich in silicilastic fraction) and intermediate types (marly silts) were also identified in the lowermost part of the studied successions, deposited in fluviatile environments. Field determinations of soil properties follow Sanesi (1977).

Six radiocarbon AMS ages were obtained from wood and wood charcoal of terrestrial plants (Table 1). Overall, bulk sediment, aquatic plants and shells were avoided, even in the pre-anthropogenic limnic sediments, due to well-known pitfalls in dating these materials. Calibration has been carried out using CALIB (v 6.0, Queen’s University Belfast) with the IntCal09 calibration curve (Reimer et al., 2009). Calibrated ages are indicated as cal BP or cal BC/AD. The archaeological periodization is from De Marinis (2002).

Additional stratigraphic and chronological information is provided by the archaeological excavations carried out since 1981 into the Forcello settlement, and by the typological chronology of autochthonous objects and imported pottery (e.g. Attic pottery), allowing a fine, quasi-decadal periodization of the settlement lasting between 540 and 390 BC.

A total of 22 samples from core FOR 6 and 10 samples from core BAGN1 were studied for the palynological record. Samples were treated according to standard methods (including HF and acetolysis), after adding lycopodium tablets for pollen and charcoal concentration estimations (Stockmarr, 1971). Identification was performed at ×400, ×630 and ×1000 magnification under light microscopes. Pollen identification followed Moore et al. (1991), Punt et al. (1976–2009), Reille (1992–1998), Beug (2004) and the palynological collection of C.N.R – IDPA. Pollen diagrams were drawn using Tilia 1.11, TView 2.0.2 (Grimm, 2004). The pollen sum used for percentage calculations includes trees, shrubs, chamaephytes and all upland herbs except aquatic and wetland plants, used for percentage calculations includes trees, shrubs, chamaephytes and all upland herbs except aquatic and wetland plants,

<table>
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<tr>
<th>Core acronym</th>
<th>Depth (cm)</th>
<th>Lab code</th>
<th>Analyzed fraction</th>
<th>δ\textsuperscript{13}C VPDB</th>
<th>(^{14}C) age BP</th>
<th>95% Calibration range (cal AD/BC)</th>
<th>Median probability (cal AD/BC)</th>
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<td>Ua-38100</td>
<td>Wood charcoal</td>
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<td>1055 ± 31</td>
<td>941–1025 AD</td>
<td>989 AD</td>
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<tr>
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<td>Ua-38101</td>
<td>Wood charcoal</td>
<td>−25.1</td>
<td>1664 ± 30</td>
<td>520–414 AD</td>
<td>385 AD</td>
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<td>Ua-37683</td>
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<td>2530 ± 35</td>
<td>797–519 BC</td>
<td>663 BC</td>
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<tr>
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<td>Ua-37684</td>
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<td>3025 ± 35</td>
<td>1396–1192 BC</td>
<td>1292 BC</td>
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<td>Ua-41622</td>
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<td>3234 ± 45</td>
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<td>1830–1687 BC</td>
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3. Stratigraphic evidence of the origin and evolution of the Bagnolo Lake

A drilling transect was conducted across the hill hosting the Etruscan settlement and the Mincio valley floor (Figs. 1b and 2). On top of the Forcello hill (16–16.7 m a.s.l.), the Etruscan archaeological layers, 1–2.2 m thick, rest over a reddish soil formed after clay accumulation into weathered alluvial gravely sands, the latter forming the hill itself. This pedogenic feature resembles the allisols developed on the fluvioglacial fans building the Plain Main Level (Cremaschi, 1987; Guzzetti et al., 1997, see Fig. 2). At the base of the Forcello hill (14 m a.s.l.), the drillings unearthed a succession of laminated marly-silts and shell marly silts (200–120 cm depth in FOR 6, Fig. 3), containing limnic molluscs (Bithynia sp.), interpreted as open-water lake sediments. The lacustrine deposits overlap palustrine organic sediments (detritus gyttja, 250–200 cm depth in FOR 6) and structureless silt including hydromorphic features (carbonate concretions, 280–250 cm depth in FOR 6). The latter are interpreted as hydromorphic soils developed under a fluctuating groundwater level. In turn, the palustrine organic accumulation with hydromorphic soils rest over a belt of well sorted, loose sand, interpreted as channelled alluvial deposits.

The coring campaign was extended downstream, thus highlighting that the lake deposit increases in thickness at the most depressed site (surface at 12.7 m a.s.l., see Fig. 2). Here, the lake sequence overlies well-sorted sands forming a channelled fluvial sequence (Fig. 2). In all cored successions, the transition from alluvial to lacustrine deposits is marked by peat and organic mud (see BAGN 1, 610 to 500 cm depth, Fig. 3), suggesting paludification of channel depressions during early stages of a transgressive trend. The palaeoecological documentation of the transition from fluviatile to limnic environments is shown in the master core FOR 6 by the combined record of Loss on Ignition and of the aquatic plant palynomorphs, including macrophytes and algae (Fig. 4). Maximum contents of the non-carbonate residue (silicilastic detrital component) mark the alluvial and basal palustrine deposits (>260 cm depth), also rich in remains of organic macrophytes of marsh (Cyperaceae) and ponds (Myriophyllum). A pond phase between 260 and 240 cm is shown by expansion of limnic blue algae (Gloeostrichia). From 240 cm upward, stable limnic conditions are shown by continuous Gloeostrichia and Pediastrum abundance and by occurrence of Bithynia shells, correlated to an increase of CaO\textsubscript{2}, suggesting biogenic accumulation and biochemical precipitation in the water column. A renewed expansion of the littoral marsh and shallow organic ponds since 210 cm is marked by Cyperaceae, Sparganium, and Myriophyllum peaks. A peak of Gloeostrichia at 190–175 cm depth is inversely correlated to human pressure (see pollen zone FRC 4 in Fig. 5).

These litho- and biostratigraphic data indicate that a lake, at least 5 km long, occupied the Mincio embanked valley and extended at least between Pietrole and Bagnolo San Vito (Figs. 1b and 2, see also Fig. 6). According to the Middle Ages’ written documentation (Marani, 1967a), this early lake basin did not extend upstream north of the town of Mantova. Thus, it is named “Lake of Bagnolo San Vito” briefly “Bagnolo Lake”, from the closest town on the border of the embanked valley hosting the lake basin.

4. Chronology

Four radiocarbon ages obtained from terrestrial plant remains from the master core FOR 6 (Table 1 and Fig. 3) show that the
organic accumulation on the littoral belt close to the Forcello hill took place over part of the Late Bronze Age, while an age of 797–539 cal BC at the lake sequence base sets the pond/open lake transition in the early Iron Age, very close to or just before the foundation of the Etruscan harbour (540 BC). Further 14C ages show that the lake existed through the Etruscan and the subsequent Roman and Middle Ages, in agreement with historical sources that a lake there was being dried up artificially late in the 17th century AD (Marani, 1967a; De Marinis, 1991). The above data suggest that the Forcello harbour flourished on the border of a low hill bordering the shore of a large lake (see Fig. 2).

Three additional 14C ages from charcoal fragments in core BAGN1, at the depocentre of the Bagnolo lake basin, constrain the onset of laminated silt of open lake sedimentation to the 16th century BC, i.e. at the onset of the Middle Bronze Age. The open lake sedimentation follows a palustrine phase spanning the second part of the Early Bronze Age (late LBA) and the onset of the Early Iron Age, and this is confirmed by the presence of hydromorphic soils (Bronze Age and onset Iron Age) and peat and organic mud, paludification phase (Early Bronze Age to Early Iron Age), in core BAGN1 (Fig. 3).

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**Fig. 2.** Geological section between Forcello hill and Bagnolo village across the basin of the Bagnolo Lake. 1) Alfisols developed since the Late-glacial; 2) Well-sorted sands, alluvial deposits (Late Pleistocene); 3) Well-sorted sands, channelled alluvial deposits (middle to late Holocene); 4) Peat and organic mud, paludification phase (Early Bronze Age to Early Iron Age); 4a) hydromorphic soils (Bronze Age and onset Iron Age); 5) Marly silt and clay, lacustrine deposits, Middle Bronze Age to 17th century AD; 6) Archaeological deposits, Etruscan phase, 540 to 390 BC; 7) Ploughing horizon. Boundaries between units 4, 4a and 5 are diachronic. Log patterns have been simplified (see detailed version in Fig. 3).

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**Fig. 3.** Logs of the master core (FOR 6) and of one depocentre core (BAGN1).
Bronze Age (cores BAGN 1-2 in Figs. 2 and 3). Here, the transition from organic detrital sandy silt to laminated silt is at 8 m a.s.l., while at FOR 6 near the Forcello hill occurs at 11.6 m a.s.l. Early stages of lake development took place in the Middle Bronze Age, after a phase of Early Bronze Age paludification, and were concerned with the lowermost depressed meandering channels and/or oxbow lakes left by the Mincio River. During the early Iron Age, the lake became larger and extended further upstream. According to the aquatic plant assemblage and radiocarbon ages of core FOR 6, the lake level did not decrease between the Etruscan age and the reclamation in the 17th century, unless the observed expansion of the palustrine habitats since the late Roman time may be related to littoral vegetation dynamics, rather than to a trend of lake regression.

5. The landscape history of the Mincio valley in the Bagnolo Lake pollen record

The lacustrine succession of the Bagnolo Lake offered the unique opportunity to obtain a palynological record, extending from the Late Bronze Age to the Late Middle Ages, from a limnic environment in the central Po Plain. At present, only short-lasting records are available, and only one from limnic sediments (Aceti et al., 2009).

The record obtained from core FOR 6 shall not be regarded as an off-site for the Forcello settlement, in the sense of Edwards (1991). Actually, and despite its closeness to the village (400 m), the pollen sedimentation into Bagnolo Lake is expected to be dominated by streamborne floated pollen. In small lakes fed by high discharge...
rivers, the large allochthonous component entering the lake via stream dilutes greatly any material of littoral origin, and the streamborne component may account for 80-85% of the pollen decanted in the bottom sediments (Bonny, 1978). Hence, the source area of the studied pollen assemblages may extend to the entire catchment of the Mincio River, downstream to the Garda Lake.

Overall, the Arboreal Pollen record suggests that the landscape was mostly forested between the 16th century BC and the 10th century AD, i.e. until the late Middle Age clearings (Fig. 5). The forest was dominated by deciduous oaks and hornbeam, with beech and fir. All these forest trees are considered to have been growing in the basin catchment. The occurrence of Fagus and Abies in the Mincio valley is supported by occurrence of both charcoal and pollen in the layers of Etruscan age at Forcello (Castelletti and Rottoli, 1987; Zanon et al., 2010; Castellano et al., 2011). On the bases of abundance changes of forest pollen and of Cerealia, and the first occurrence of Secale, Juglans and Castanea, five pollen zones were distinguished.

The pollen record testifies to the Roman forest clearings (Pollen Zone FRC 3), but also shows the unprecedented evidence of an early Middle Age phase of abandoning (PZ FRC 4). Finally, an overall expansion of land use is dated to the 10th century AD. The first occurrences of species important for the palaeoenvironmental history in the Po Plain, such as walnut, chestnut and rye, are also documented here. While chestnut and rye appear first in samples of Late Roman age, walnut pollen already increases around 8th century BC, before its appearance at the southern border of the Western and Central Alps. Ten pollen samples from Middle to Late Bronze Age layers in core BAGN 1 (not shown in Fig. 5) lack Juglans pollen. It is thus suggested that walnut was introduced by the Etruscan people in the central Po plain.

It is helpful to support this statement with an updated framework about the walnut appearance in the surrounding regions. The appearance of Juglans in Southern and Central Italy dates to the early Greek colonization in Sicily, 8th century BC (Sadori, 2007) and to the Villanovian/early Etruscan time in the surroundings of Rome, 9th–8th century BC (see Lake Albano record, Mercuri et al., 2002; chronology according to Rolph et al., 2004). Most probably, this happened in Tuscany as well (Drescher-Schneider et al., 2007), unless a macrofossil record referred to the Middle Bronze Age in Florence (Mariotti Lippi et al., 2009) can be confirmed. On the other hand, walnut was planted at the southern border of the Alps in the late Iron Age (Drescher-Schneder, 1984; Gobet et al., 2000) and appeared further north in the Roman period (K.E. Behre, personal communication). Recent reports claim an earlier occurrence and/or cultivation of walnut in NE-Italy (Kaltenrieder et al., 2010). Juglans nuts, reported in a synthetic list of fruits for the Neolithic sites of Sammardenchia and Bannia in NE-Italy (Rottoli and Castiglioni, 2009), and assumed proving its early occurrence in N-Italy (Kaltenrieder et al., 2010), are actually based on “very small fragments of uncertain identification” from Bannia (Cottini and Rottoli, 2009).
Juglans pollen does not occur in the Bronze Age pile dwellings surrounding the Garda Lake (De Marinis et al., 2005; Badino et al., 2011). Overall, the hypothesis of a different timing of Juglans introduction in NE-Italy and in central Po Plain cannot be ruled out at present, although the Forcello record presented here would support that its introduction in central Po Plain is related to Etruscan trading, either from Central Italy or from Greece.
Fig. 8. Subsidence and accumulation rates in the Pliocene-Quaternary foredeep along the central and eastern Po Plain. The modern fluvial pattern is associated with five classes representing the Pliocene-Quaternary isopachs (data from C.N.R., 1983).
6. The Bagnolo Lake and the history of the fluvial network in the central Po Plain

The Late Holocene lacustrine archive in the lower Mincio valley helps in disentangling the effects of tectonic activity, climate change, river dynamics and prehistoric settlements on the history of drainage network in the central Po Plain. Holocene drainage changes in this area have been extensively investigated in the last decades (Veggiani, 1974; Castaldini and Piacente, 1995; Cremaschi, 1997; Marchetti, 2001). An updated framework of the Late Holocene changes of river network has been compiled in Figs. 6 and 7 (see captions for relevant references). Looking at the path of the Po River in the present day river network (Fig. 7c), a main change of channel direction towards north is apparent at Guastalla, between the confluence of the Cros- tolo and Oglio Rivers. On the other hand, the distribution of Terramare settlements connected to palaeochannels suggests that the Bronze Age axial drainage was oriented from west to east (see Cremaschi et al., 2006, p. 88). A main diversion of the axial Po River towards the north (Fig. 7b) is commonly related to a climate wors- ening in the VIII century BC (Veggiani, 1974; Castaldini, 1989).

Focusing in detail on the area affected by the Po River diversion (Fig. 6a-d), it appears that the abandonment of the Bondeno channel segment, active in the Bronze Age, and the diversion of the Po River at Guastalla caused overflooding of a wide belt of the plain between Suzzara, Ostiglia and Mirandola. This belt lacks evidence of Bronze Age settlements, buried under the overbank cover (Cremaschi, 1997). Indeed, Middle-late Bronze Age settlements, buried under the overbank cover (Cremaschi, 1997). Westward, Bronze Age peopling is nearly unknown, and this suggests that evidence is inaccessible due to a thicker pile of overbank deposits.

The new drainage pattern established in the Iron Age (Figs. 6b and 7b) acknowledged a strong discharge increase of the Po River, due to the contribution of two main Alpine rivers (i.e. Adda and Oglio) previously independent of the Po River at the confluence with the Mincio River. The displacement of these drainage axes in front of the Mincio valley mouth (Fig. 6b) reduced flow velocity, increased the sediment load (mainly of Apennine source rather than Alpine), and caused damming and expansion of the Bagnolo Lake system in the fluvial incision.

Human pressure on the forest in the Bronze Age may also have contributed to a bedload increase. During the first half of the Bronze Age, the Po Plain experienced a substantial break from prevalent natural evolution to human-driven changes, notably the establishment of permanent settlements (De Marinis, 1997). About 1600 cal BC, settlement density and deforestation of the central Po basin is one of the highest in Europe (Cremaschi, 1992; Cremaschi et al., 2006; De Marinis, 2009).

In agreement with the location and economical relevance of major Iron Age settlements in the lowermost Po Plain (i.e. the settlements of Adria and Spina), the modification in the fluvial network promoted upstream shipping from the northern Adriatic to the Bagnolo lake, where the main harbour of Forcello was settled.

7. Long-term causes: subsidence and sea-level changes

The river network changes in the Iron Age, discussed in the previous chapter, while explaining the observed transgression of the Bagnolo Lake at that time, are subsequent to the Middle Bronze Age development of the Bagnolo Lake within the Mincio River valley. Furthermore, the proposed climate trigger cannot alone
justify the observed main drainage change. Figs. 8 and 9 compare subsidence rates with the Late Holocene history of drainage axes (Fig. 7). Subsidence average rates highlight a strong vertical displacement between a sinking spot at Guastalla and an emerging high at Mirandola, either on long-term scale (i.e. since the Pliocene onset, Fig. 8), and over a shorter time window (the last 0.45 Ma, Fig. 9). These vertical motions are related to the activity of the Ferrara folds (Pieri and Groppi, 1981), i.e. the Apennine blind thrusts buried under the foredeep infill. A high sinking rate (estimated sedimentation rate 0.6–2.1 mm/y, Vittori and Ventura, 1995) is consistent with the subsidence triggered by the activity of Apennine blind thrusts in the foredeep (C.N.R., 1983).

The good correlation between change of channel direction in the Iron Age and subsidence pattern supports the earlier hypothesis that the Po River was shifted northward by vertical motions driven by local tectonic activity (Cremaschi, 1997; Burrato et al., 2003), also promoting sedimentation and expansion of waterlogged environments. However, given the tectonic stability through the Late Quaternary, the discrepant Bronze Age setting of river network (Fig. 7a) is not conveniently explained. Here, it is worth noting the effects of the sea level rise on river base-levels. The Adriatic Sea was rising to the present level until around 6000 cal BP (Lambeck et al., 2004), thus the early Holocene fluvial network was still recalling the last glaciatication pattern, largely driven by fluvial-glacial activity from the Alpine fans, forcing southward the axial drainage of the Po Plain (see Garzanti et al., 2011). Early to middle Holocene rising of base levels to present values accordingly reduced the gradient along a west-east drainage axis, thus promoting adjustment of the river network to the local tectonic pattern. Contemporary rising of the Po base-level and persistent residual subsidence in the plain, together with Apennine chain uplift and human pressure on forest cover since the Bronze Age produced a generalized increase in fine bedload discharge into the Late Holocene Apennine tributaries. All these co-factors together forced the axial drainage of the Po Plain northward (see Marchetti, 1996) and limited stream power of the lower segments of the Mincio River, thus damming a lake, confined in the valley embankments.

8. Conclusion

The stratigraphic and chronological investigation of the lower Mincio valley infill in the central Po Plain revealed that, after a channelled alluvial phase, the valley floor was once occupied by a lake. The Bagnolo Lake developed in the Middle Bronze Age after paludification of the most depressed areas about 1800 cal BC. The lake was dammed at the mouth of river Mincio, embanked within the fluvio-glacial plain, by the unconfined Po fluvial system. The circumstances and timing of lake damming are consistent with the effects of subsidence related to local tectonics in the axial portion of the river network, as well as with an increase of bedload discharge. This enhanced river bedloads and deposition resulted from a complex response to rising base-level of the Po Plain fluvial system, induced by increasing sea level. Human pressure on forest in the Bronze Age may also have contributed to a bedload increase. The subsequent development of the Bagnolo basin records one episode of early Iron Age lake transgression, coeval to a main avulsion of the Po River. Previous geomorphologic studies suggested that this avulsion may have been triggered by a climate worsening in 8th century BC. Shortly after, the Etruscans settled a main trading post on the shore of the lake. The Iron Age river network adjustment connected the Etruscan harbour to the other Etruscan settlements via the new course of the Po River. The present study did not detect relationships between the evolution of the Mantova Lakes and presumed seismogenetic structures in the subsurface of the Mantova town.

Further lacustrine archives may be preserved in the area of Mantova. The Mantova lakes offer new potential to reconstruct the Late Quaternary environmental evolution of the central Po Plain, including the Bronze Age/Iron Age transition, which is known as a main and enigmatic break in the cultural evolution of the Po Plain.

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