GEOARCHAEOLOGY IN URBAN CONTEXT: THE TOWN OF REGGIO EMILIA AND RIVER DYNAMICS DURING THE LAST TWO MILLENNIA IN NORTHERN ITALY

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Abstract
On the grounds of geomorphological evidence, core stratigraphy, and archaeological and historical sources, the relationships between the urban development of Reggio Emilia (Po River plain, Northern Italy) and the adjoining Crostolo River, are reconstructed over the last two millennia. The town of Reggio Emilia was established in the second century B.C. along the Crostolo River, but geographic relationships between river and town changed several times because of the collective effects of human activity, geological processes and climatic change. The course of the Crostolo was artificially diverted outside Reggio Emilia during the Roman age and in the years A.D. 1250 and A.D. 1571, largely because of westward stream migration. This progressive shift was triggered by the neotectonic activity of folded thrusts. buried in the substrate. Vertical displacements resulted in uplift and conversely in the subsidence of Reggio Emilia's northwest margin. Stream migration patterns were thereby displaced westward. Climate change also affected the behavior of the Crostolo River as increased flooding during the Early Medieval period and consequent channel instability underpinned engineering efforts to rechannel stream flow via a canal built along the city walls in A.D. 1571, at the onset of the Little Ice Age.

Key words
Urban Georcheology; Climate change; Neotectonic; River diversion; Fluvial dynamic; Holocene; Po plain

INTRODUCTION

Urban Geoarchaeology, with its own concepts and technical methods, has recently gained interest as a powerful time- and cost-efficient tool for archaeological rescue operations, particularly in areas affected by development where the preservation of archaeological heritage is challenged (Cremaschi, 2000, Anichini et al., 2011; Schulderein, & Aiuvalasit, 2011). However, urban spaces also constitute a privileged area for studying the relationship between humans and their environment. In urban areas, human activity is prevalent and the main factor that generates the stratigraphic record. Precisely for this reason, geomorphic processes induced by geological dynamics or climate change may be particularly well-recorded in the stratigraphy and suitable for detailed study of the strategies humans employ for coping with environmental changes and adapting their living spaces to accommodate these processes. Many case studies support this statement (e.g., Butzer, Butzer, & Loe, 2013, Bini et al., 2015; Jotheri et al,, 2016; Salomon et al., 2017, and, at a more local scale: Cremaschi, & Gasperi, 1989; Cremonini, Labate, & Curina, 2013, Bruno et al., 2013). Among these, the case of Reggio Emilia (*Regium Lepidi* in Roman times), located in the Emilia-Romagna region (Po River plain, Northern Italy), appears particularly meaningful, as it involves the long lasting interactions between urban development and changes in channel patterns of the Crostolo River along which the town was founded as a result of historical events, geological processes and climate change.

Here we present i) the chronology of Crostolo River channel shifts at Reggio Emilia on the basis of a multidisciplinary approach (geomorphology, stratigraphy, historical archives, and archaeological sources), and ii) the role of interconnected anthropogenic, climatic, and geodynamic factors which caused these channel movements. This study demonstrates the value of a geoarchaeological approach to reconstructing the complex site formation in an urban context and to evaluating the factors (geologic , climatic , anthropic) in them involved.

ARCHAEOLOGICAL BACKGROUND

Today Reggio Emilia lays upon the remains of the ancient *Regium Lepidi*, a *municipium* founded in 175 or 173 B.C., along the *Via Aemilia* (present day Via Emilia), which flourished during the Imperial age (Fig.1). The archaeological stratigraphy below the modern city has been exposed several times during restorations of old buildings and the construction of new ones, producing a record of archaeological discoveries dating back to the 1800s (Degani, 1973). Unfortunately, archaeological monuments buried beneath the city were seriously damaged by building activities associated with intensified economic growth of the 1950s and 60s. Since the 1980s, archaeological excavations have been conducted using scientific methods, resulting in a remarkable advancement of our knowledge regarding the Roman and Medieval history of Reggio (Ambrosetti, Macellari, & Malnati, 1996).

Although Reggio Emila lacks evidence of Iron Age occupation, sites of this period are known in the immediate vicinity including San Claudio and Mancasale (Malnati, & Losi, 1990; Fig. 2). Archaeological settlements, previous to the town's establishment, consist of Neolithic and Copper age sites, deeply buried in alluvial deposits, and three Terramare sites (Tirabassi, 1987; Cremaschi, Pizzi, & Varini, 2004) of the Middle – Late Bronze age. The latter archaeological sites are recognized by their distinct small mounds, which take their name from a local term for organically rich earth – *terra marna* – quarried from the mounds for fertilizer at the time of their discovery in the 1800s (Pearce, 1998).

GEOMORPHOLOGICAL CONTEXT

Reggio Emilia is located on the outer part of an alluvial fan formed by the Crostolo River, a few kilometers south of the Apennine fringe. The Apennine margin in this area is tectonically active, as it coincides with a complex belt of folded, arc-shaped, thrust fronts trending north-northeast, which developed during the Quaternary (Pieri, & Groppi, 1981; Barbacini *et al*., 2002, Guderson et al., 2014) (Fig.3). Compressional tectonics has uplifted the mountain margin and lowered the plain, a dynamic that is still active today (Scognamiglio et al., 2012). A major geomorphological consequence of these processes is the formation of an apron of coalescent gravelly fans and of alluvial fine deposits along their margin that have been accumulating since at least the Middle Pleistocene (Cremaschi, 1987). The shape, size, and degree of preservation of these landforms depend on the interactions between Quaternary climatic changes and recent tectonic forces (Rossi et al., 2002; Valloni and Baio, 2009, Guderson et al. 2014). The terraced fans of the Middle Pleistocene, covered by thick polygenetic paleosols and loess sheets (Cremaschi, 1987; Busacca & Cremaschi, 1998) are distributed among the Apennine foothills.

Farther north before reaching the Holocene alluvial plain is a well preserved system of coalesced Late Pleistocene to Holocene alluvial fans (Cremaschi, & Marchetti, 1995; Castiglioni, & Pellegrini, 2001) (Fig. 4). The distal parts of these fans are covered by fluvial fine deposits, which accumulated during the transition between the Atlantic and Sub-Boreal periods. Their sedimentation was mostly triggered by the phase of climatic instability that followed the Holocene Climatic Optimum (Cremaschi & Nicosia, 2012). Reggio Emilia is situated on top of a Holocene alluvial fan of the Crostolo River (Figs. 2 & 4). In terms of lithology, fan sediments consist of basal gravel layers covered by a blanket of finer sediments (fine and medium sands and, occasionally, clay). Within these deposits south of the town are superposed alluvial soils, some associated with Neolithic and Copper age sites, that were discovered in excavations associated with urban construction (Tirabassi, 1987; Cremaschi, & Nicosia, 2012), and that indicate the alluvial fan was aggrading during the late Atlantic and early Sub-Boreal periods. Later (Terramare) archaeological sites were exposed at the surface of the alluvial fan at La Favorita and at La Montata (Fig. 2) (Tirabassi, 1979; Cremaschi, Pizzi & Varini, 2004). These sites date to the Middle and Recent Bronze ages and therefore indicate that sedimentation at the Holocene fan apex had ceased by the second millennium B.C., during the late Sub-Boreal period.

Downstream of the alluvial fan, the Crostolo River flows north, bounded by artificial dams on top of an alluvial ridge. Historical documents and archaeological evidence indicate a late Medieval age for this course (Balletti, 1917). However, abandoned fluvial ridges that occur in the area of Pratofontana and Rolo (Fig. 4) provide geomorphological evidence of a Crostolo paleochannel dating to the early Medieval period that flowed to the northeast. This paleochannel is referred to as *Crustulus Vetus* in historical documents of the 8th and 11th centuries A.D. (Tiraboschi, 1824; Cremaschi, & Marchesini, 1978; Cremaschi et al., 1980; Tirabassi, 1990; Castiglioni et al., 1997; Castiglioni, & Pellegrini, 2001).

MATERIALS AND METHODS

The study presented here is based upon the results of rescue archaeological operations performed in the historical center of Reggio Emilia known as Old Town (Fig.1) and in surrounding areas since the 1980s (Cremaschi, 2000). Preliminary remote sensing analysis was performed using Quick Bird images acquired in 2005. After this phase, detailed field surveys were conducted in the city center at 1:2000 scale, using as a base map the Regional Technical Map (CTR) of Emilia Romagna (Reggio Emilia NW 20083, 20084, 20082, 20121; 1:5000 scale). Elevation controls marked on maps in meters above sea level were used to draw contour lines at 1 m intervals (Fig. 5). On the basis of the reconstructed contour lines, a 3D model of the town was produced with QGIS 2.0 software (Fig. 6).

Our knowledge of the town's subsurface (Cremaschi, 2000, 2013) rests upon data from 96 cores distributed over 55 drilling sites (Fig.7) . Sedimentological and pedological properties of each core were described according to standard field-description techniques (Schoeneberger et al., 2002). Main stratigraphic logs are presented in Figs. 8 and 9 and summarize data recorded in the field including grain-size properties, lithostratigraphic units, and archaeological deposits. From a sedimentological point of view, the cores were interpreted according to field evidence, following the most common sedimentological models proposed for alluvial plain (e.g., Allen, 1965, Bridge, 2003). The cores were dated on the basis of archaeological materials, which mostly consist of small pottery fragments (Roman slipped ware and amphorae, coarse early Medieval pottery, late Medieval/ Renaissance *graffita* ware, fragments of tiles, red bricks, glass, and mosaic *tesserae*). Archaeological remains were identified and dated according to regional recent archaeological literature (see: Ambrosetti, Macellari, & Malnati, 1996; Milanese, 2009 and references therein).

Stratigraphic data collected during several archaeological operations conducted since the 1980s by the Soprintendenza Archeologia dell'Emilia Romagna were also considered. These data are published in Ambrosetti, Macellari, & Malnati (1996) and Cremaschi (2013) and are part of a master's dissertation completed at the University of Milan (Ceruti, 1993). Geoarchaeological aspects of most of the archaeological excavations in the urban area of Reggio Emilia were surveyed by one of us (M.C.). Moreover, data from recent archaeological excavations were compared to the available archaeological literature (Siliprandi, 1936; Degani, 1949, 1973; Scagliarini, Corlaita, & Venturi, 1999) and to historical records regarding the development of Reggio Emilia in Medieval and Renaissance times. We focused on historical reports concerning the urban topography, the construction of city walls, and maintenance work performed on the Crostolo River channel (Tiraboschi, 1824; Balletti, 1917; Nironi, 1971, 1983; Badini, 1995).

RESULTS

The Shape of the Town and its Surroundings

Based on modern topography, the Crostolo River alluvial fan extends north-northeast and coincides with the location of the Reggio Emilia's town site (Fig. 2). It is interesting to observe that canal networks excavated beneath the town dating back to at least the 15th century A.D., and most of them still working as recently as the 1800s (Badini, Baricchi, & Marchesini, 2007; Nironi, 1971), were built in perfect compliance with the shape of the fan (Fig. 10). The canal system originates at the southern edge of the city near the fan's apex and branches out radially to the north, in accordance to the topographic gradient.

Complex and uneven microtopography in the city center (Figs. 5 & 6) is evident based on analysis of the 1970 Municipality of Reggio Emilia database and 1:5000 topographic maps (Cremaschi, 2000). Comparison with archaeological data (Degani, 1973; Ambrosetti, Macellari & Malnati, 1996) indicates that the differences in elevation in the town's present topography are systematically related to underlying archaeological remnants. In the middle of town, in the area surrounding the main cathedral (Fig.1, No. 10) is an *ca*. 3 m high mound. The mound derives from the remains of the so called '*castrum episcopale'* built around A.D. 900 to defend the cathedral (Torelli, 1921; Badini, 1995), the walls of which have been archaeologically excavated (Siliprandi 1936, Gelichi, & Curina, 2007). However, the complexity of archaeological stratification of the mound has been revealed only recently (Degani, 1973; Ambrosetti, Macellari & Malnati, 1996). A deep test trench at Palazzo Notarie (Fig.1, No.9) (Chiesi, 1996), revealed 3 m of anthropogenic deposits dating from the 5th to 7th centuries A.D. covering the remnants of Roman age buildings. Even more significant are the results of recent archaeological excavations performed in the crypt of the cathedral in 2012-14. Newly exposed archaeological stratigraphy at the base of the mound consists of the remains of a rich *domus* of Roman Imperial age, covered by thick dark earth deposits, related to wood buildings of the early Medieval period and by stone structures of the early cathedral (Curina, 2014). More recent but equally evident are the higher ridges corresponding to the current ring road. These correspond to 16th century walls which were removed only at the end of the 19th century (Balletti, 1917; Nironi, 1971).

In the microrelief map, we can also distinctly observe at least three linear depressions that radiate out from the southern margin of Reggio Emilia (Figs. 5 & 6) and are coincident with the above mentioned 19th century canal network (Fig.10). The westernmost feature is sinuous and marked by the present city street named Corso Garibaldi (Fig. 1, No. 7), recognized by local scholars as an old Crostolo riverbed. The other two depressions to the east are also likely ancient drainage channels.

Subsurface of the Town

To reconstruct the stratigraphy of the town's subsurface, the microrelief is integrated with the stratigraphy of the sediment cores (Fig. 7), data from recent archaeological excavations, and with the historical literature. The results are presented Figs. 8 and 9, representing four stratigraphic sections conducted across the city from approximately west to east and numbered 1-4 from north to south (Fig.7).

The geological subsurface of the town appears rather homogeneous, and two lithostratigraphic units were recognized: the Gravel unit and the Sand/Silt unit. The Gravel unit is identified at the base of the cores, at a variable depth of 10 to 15 m, becoming slightly deeper toward the north. It consists of medium textured gravel, often in a sandy matrix, and represents the main body of the fan. A direct dating is not available for this unit, but on the basis of the regional geological context (Cremaschi, 1987, Cremaschi, & Nicosia, 2012) we propose that the Gravel unit was deposited during the Late Pleistocene to the early Holocene. At its top is the Sand/Silt unit which was observed not only in cores but also directly exposed in the construction site in the area of Santa Maria Nuova Hospital (Fig. 2, No. 5B and Fig. 11). This unit consists of upward-fining subunits, from sandy to silty clay in texture, with a thin and slightly developed soil horizon at its top. The latter consists of an A/C soil profile, clayey in texture, low organic matter content, and weakly developed blocky structure. Soils in the Santa Maria Nuova Hospital excavation pit (Fig. 11) and in the Piazza Costa sediment core (Fig.1, No.8 and Fig. 8, Profile 2) include archaeological material (ceramics) and evidence of clearance by fire (aggregates of burned soil), dated to the Chalcolithic and Early Bronze Age periods (Cremaschi, 2000; Cremaschi, & Nicosia, 2012).

The Sand/Silt unit consists of flood plain sediments (*sensu* Allen, 1965; Bridge, 2003) and represents a later phase of accretion of the fan at its distal margin (Cremaschi, & Nicosia, 2012). Sandy layers are interpreted as related to fluvial channel deposits (levee and crevasse splay sedimentary facies), whereas silty and clayey sediments represent distal overbank sedimentation within the flood basin.

The archaeological stratification formed as a result of the onset of urban settlement consists of anthropogenic units, which based on observable field properties are grouped into three archaeostratigraphic units: Roman Age deposits, Dark Earth, and Late Middle-Ages rubble.

In the Roman Age unit, on the basis of lithostratigraphy and archaeological material, several types of archaeological deposits and features were distinguished (walls and floors, deposits connected to dwelling areas such as trash dumps and hearths, deposits and soils related to gardens or cultivated fields, and rubble related to abandonment of the site), which display the complexity of an urban space, developed over a period of several centuries. At the top of the Roman stratigraphic sequence, layers composed of rubble and ruins often occur, indicating an abandonment phase and a reduction of the town's inhabited area during Late Antiquity (Gelichi & Curina, 2007).

Superposed onto the Roman Age stratigraphy is the Dark Earth unit, which on the basis of its archaeological content is dated between the 7th and 10th centuries A.D. The dark color from which the unit takes its name is due to high concentrations of organic matter related to organic waste and dwelling structures built of earth and wood. Similar deposits are known to occur in most of the early Middle Age urban areas of northern Italy and Europe as a result of the collapse of Roman urban organization (Brogiolo,Cremaschi, & Gelichi, 1988; Galinie, 2004; Cremaschi, & Nicosia, 2010). The Dark Earth unit is distributed all over the Roman age portion of the town, but its thickness is rather irregular because its upper contact is disrupted by large pits and spoliation ditches .

The upper part of most of the cores is described as Late Middle Ages rubble and composed of coarse cultural debris connected to the building phases of the 12th to 15th centuries A.D.

Crostolo Riverbed and Minor Drainages

Today the Crostolo River flows west of town inside an artificial canal, dug in A.D. 1571 when the Lords of Este promoted the building of renewed city walls that gave Reggio Emilia a peculiar hexagonal perimeter (Balletti, 1917) (Fig. 1). Evidence of previous courses of the Crostolo and of adjacent minor drainages occur farther east. In addition to the geomorphological evidence, these paleochannels are identified on the basis of sediments recorded in the cores or observed in exposed sections where they occur as deeply cut channels filled with coarse material. The identified drainages are presented below from west to east.

***The 13th – 16th Centuries A.D. Crostolo Riverbed*.**

This former watercourse can be observed on the 3D model as an elongated depression east of the present river (Figs. 5 & 6). The sedimentary fill has been observed during recent building construction at the Seminario Site (Fig.1, No. 3 & Figure 9, Profile 4) south of the city and crossed by the coring transect at its margin (Viale Timavo, Fig.1, No. 4 & Fig. 10, Profile 2; Piazzale Fiume, Fig. 1, No. 2 & Fig. 9, Profile 3). It reaches a depth of 8 m, is composed of cross-stratified coarse sand and gravel, and dated by fragments of *graffita* ware. According to historical records, this channel was active in A.D. 1226 when the previous bed (Crostolo of Corso Garibaldi – see below) was cut off and diverted outside the urban core of the city. However, in AD 1571 the

Crostolo was diverted again into its present position to help protect the city from its frequent floods. Increased fluvial instability was the main argument used by the Duke Alfonso II of Este in his decision, addressed in AD 1568 to the elders of the city, to justify the demanding and expensive work of excavating the new channel (Balletti, 2017). The document (Provvedimenti, 1568) recording this event reads: *"...mentem suam* [of the duke] *esse quod Crustuneum removeatur e loco in quo est de presenti .... ne fovee impleatur quotidie terreno et inondationis ipsius Crustunei…"* […he [the duke] was of the opinion that the Crostolo River must be moved from its present position to prevent constant filling of ditches (surrounding the town) with sediments and floodwaters]. The bridge crossing this paleochannel at Porta Brennone in Piazzale Fiume (Fig. 1, No.2 and Fig. 9, Profile 3), discovered during recent archaeological excavations (Cremaschi, 2000, 2013), was found partly eroded and filled with coarse gravel up to its arch vault, providing evidence of high discharge and hydrological instability of the river during this period.

The Crostolo of Corso Garibaldi

The modern urban road pattern at Corso Garibaldi is inherited and preserves the winding shape of this abandoned Crostolo channel, well known in historical studies dealing with the ancient topography of the city (Badini, 1995; Nironi, 1983) (Fig.6). Its sedimentary fill, observed in cores from Piazza 24 Maggio (Fig.1, No. 11 & Fig. 9, Profile 4), from excavations at the Caserma Zucchi building (Fig.1, No.18 & Fig. 8, Profile 1), and in the recent excavation at the Figlie del Gesù cloister (Fig.1, No. 5 & Fig. 8, Profile 2), ranges 7-9 m in thickness and consists of gravels and sands containing Roman brick fragments (Losi, 1996). This course was active for a length of time prior to A.D. 1226, and bridge piles found at its crossing with the Via Emilia at Piazza Gioberti (Fig. 1, No. 6 & Fig. 8, Profile 2) have been dated to the Medieval period (Siliprandi, 1936; Brighi, 1993; Cremaschi, 2013). Gravel linked to an overflow of this channel was also found in the main center (Palazzo Notarie, Fig.1, No. 9 & Fig. 9, Profile 3) associated with the Dark Earth unit, and therefore dating back to the Early Medieval period (Chiesi,1996). However, it is likely that the Corso Garibaldi channel was also active during the Roman period, as its sediments are sealed at the Figlie del Gesù cloister section (Fig.1, No. 5 & Fig. 8, Profile 2) by a dump dating to the 2nd century A.D. (Losi, 1996). At this time, according to archaeological evidence, it formed the western boundary of the urban area (Degani, 1973).

***The Proto-Historic Crostolo Riverbed**.*

The base of the Roman Age unit occurs in most of the city area at depths of 2-3 m below the present surface (Degani, 1973; Scagliarini Corlàita & Venturi, 1999). Nevertheless, recent excavation and the sediment cores discussed here (located between Cinema Ambra and Piazza della Vittoria, Fig.1, Nos. 20 & 21, and Fig. 8, Profile 2, and at Palazzo Notarie, Fig 1, No. 9 and Fig. 9, Profile 3) (Ambrosetti, Macellari, & Malnati, 1996; Ceruti, 1993; Cremaschi, 2000) indicate that deposits of this age extend to far greater depths. Combining all existing stratigraphic data (Cremaschi, 2000), it has turned out that the depth of the base of the Roman Age deposits marks a wide depression in the shape of an incised water course, reaching 8 m depth east of and parallel to the Crostolo of Corso Garibaldi (Fig. 12). This feature can be interpreted as an old Crostolo riverbed, active before the Romans founded *Regium Lepidi*, and abandoned sometimes after, as it was filled with the archaeological stratigraphy of the Roman Age.

This paleochannel was identified north of town at the Terramara site of La Montata, located on its left bank (Fig.2, No. 6F), during archaeological excavations (Tirabassi, 1979). The earth rampart surrounding the site was built using gravel of the riverbed, thus suggesting that the river was likely active at that time. More recently, a 200 m-long segment of this same paleochannel has been exposed in the construction site at the Santa Maria Nuova Hospital (Fig. 2, No. 5B and Fig. 11). The river channel is incised into the Sand/Silt unit, and its base is about 6 m below the modern surface; its fill is composed of interconnected lenses of sand and gravel. Because it cuts through a Chalcolithic site, and its filling is in turn cut by a Roman aqueduct, this paleochannel is to be regarded as having been active during the Proto-Historic period (Recent Bronze Age - Iron Age) compatible with the stratigraphic evidence at the Terramara La Montata section.

The Northeastern Drainage

East of the Corso Garibaldi riverbed, two other linear depressions appear on the microrelief maps (Figs. 5 and 6), They originate south of the city at the fan apex and diverge to the northeast. As late as recent times, the two depressions have acted as lines of drainage for underground canals (Fig. 10). The archaeological data and sediment reached by coring indicate that these depressions hosted watercourses at different times. The western one, coinciding with the modern Via Navona and Via Roma, was certainly active during the Roman Age and corresponds with a Roman bridge in *opus cementitium* that was discovered at the crossing with the Via Emilia (Siliprandi, 1936) (Mercato Coperto, Fig.1, No.12 and Fig. 9, Profile 4). It was active later, as indicated by fluvial sand covering Roman dwelling deposits in the Via Roma 91 sediment core (Fig.1, No.15 and Fig. 9, Profile 3). During the Roman period, the eastern depression, corresponding with Via Samarotto and Via Giorgione, Fig. 1, Nos. 13 & 14, and Fig. 9, Profile 4) supported a consistent watercourse, as indicated by a stratigraphic section discovered in a construction area where fluvial gravel occurred below the Dark Earth unit and an Imperial Age burial ground (Via Giorgione, Fig. 1, No.13 and Fig. 9, Profile 4) (Losi 1996).

Both drainages were particularly active and flooded in early Medieval times, consistently covering portions of the Imperial Roman urban area with fluvial sediments. These are generally sealed by Dark Earth (Palazzo Notarie, Fig.1, No. 9 and Fig. 9, Profile 3). In the stratigraphic section at Cinema Eliseo (Fig.1, No.22 and Fig. 8, Profile 3) the alluvial deposits are, on the contrary, above the Dark Earth unit, probably indicating that floods occurred over a long time span.

DISCUSSION AND CONCLUSIVE REMARKS

The main geomorphological traits of the area well predate the foundation of Reggio Emilia as a town. Aggradation on the alluvial fan upon which Reggio Emilia lies ended in the middle Holocene, and since the Sub-Boreal period the Crostolo River has entrenched into the fan. In this context, pre-urban settlement at Reggio Emilia began with the establishment of Terramara and the Iron Age communities along the banks of the Proto-Historic Crostolo River (Fig. 13 A). It is probable that the early nucleus of the city was situated in a similar stream bank position, but, as a consequence of urban growth, the river was rerouted out of the city limits along the western margin of the alluvial fan (Fig. 13 B).

During the Roman period, drainages transected the eastern part of the city, as demonstrated by the solid bridge of Mercato Coperto . These drainages were derived from the main channel of the Crostolo River with the purpose of regulating flow of the river and distributing water within the perimeter of town. However, the coarse fluvial deposits of via Giorgione indicate that an important channel also passed along the eastern margin of the alluvial fan during this period, probably indicating a failed attempt to divert the main course of the Crostolo.

Between Late Antiquity and the Early Medieval Age, the eastern drainage was particularly active and overflowed repeatedly, covering parts of urban areas that were inhabited during the Roman period with alluvial deposits. The eastern drainage activity may correspond to that of the eastern Crostolo River paleochannel which flowed northeast of Reggio Emilia, and was active at about the same time (Cremaschi & Marchesini, 1978; Cremaschi, et al. 1980; Castiglioni et al. 1997).

In the 13th century A.D., the Crostolo River was diverted again to the west (Fig. 13 C), outside the urban area, which had grown considerably since the Roman period and had incorporated the former river course. This new riverbed remained in use for no more than three centuries, as at the end of the 16th century A.D., the Crostolo River was diverted yet again to a more westerly position, for the purpose of protecting the town from its frequent floods. This time, the cut-off was radical as the river was moved, through an artificial canal, about 1 km to the west of town (Fig. 13 D). This feat of engineering disabled the hydraulic system that had operated within the urban area, i.e., the Crostolo River and its distributary channels. Since then, the water supply to the city has been imported from the east through the Canale di Secchia (Badini, Baricchi & Marchesini, 2007; Fig.2) and redistributed within the town by a network of underground ducts that traces, in most cases, the older hydrographical network (Fig.10).

If we look to the factors that have controlled changes to Reggio Emilia's hydrography over more than two millennia, we must conclude that human activity played the main role with considerable effort to redirect channels. Nonetheless, the anthropogenic factor within this urban context, although dominant, did not act alone. Geological and climatic factors also played roles in these channel dynamics. Since the Roman Period, the Crostolo River has several times artificially shifted to the west. The attempt during the Roman period to divert it to the east failed, resulting in only ephemeral flow. The tendency of the river to shift west is likely related to neotectonic activity of the buried folded thrusts along the Apennine front, which on the basis of recent seismotectonic research appear to be still active (Boccaletti et al. 2004). Throughout the Holocene, the uplift of the Ferrara Folds produced important changes in the fluvial network of the area. The Po River migrated progressively to the north (Figs 3 & 4) and its southern tributaries of the Emilia region followed. Indeed, the Parma, Crostolo, Secchia, and Panaro rivers have shifted from northwest to north since the Bronze Age (Cremaschi, & Marchesini, 1978; Cremaschi et al. 1980, Castaldini, 1989; Ravazzi et al. 2013). Reggio Emilia is located at the convergence of the Ferrara Folds arc, where the axis changes from ESE-WNW to NE-SW (Fig. 3), meeting the eastern limit of the Emilian Fold arc. In particular, the geodynamic model reveals that an area of high subsidence occurs in between the two fold systems. As a result, the base of Pliocene beds has subsided over 7000 m, while the same contact is much higher at the edge of the thrust. The positive movement of the folded thrust front on which Reggio Emilia is located may explain the entrenchment of the Crostolo River inside its alluvial fan. However, the subsidence area, which is located just west of the town, may have attracted local runoff, supporting the northwest trend of the Crostolo River over the last few millennia. Therefore hydraulic management of the river by residents of Reggio Emilia followed this natural tendency, repeatedly diverting the river to the most favorable direction for drainage.

The effect of climatic changes on the hydraulic network can be appreciated based on stratigraphic evidence of increased intense floods within the urban area of Reggio Emilia after the Roman Period. Age control provided by archaeological context suggests that these flood events correlate to well-known phases of climate instability affecting most of Europe and the Mediterranean region during the 6th to 9th centuries A.D. For example, there is a broad agreement among scholars that Europe witnessed climatic instability in the first few centuries after the fall of the Roman Empire. This period has been dated between A.D. 300-600 (Wanner et al. 2011) or more frequently between A.D. 500-800 (known as the Vandal Minimum by Walker, 2000, or the Dark Age Minimum according to Ogurstov et al., 2002). The conspicuous advance of the Great Aletsch, Gorner, and Grindelwald glaciers in the Alps indicates cooler climatic conditions between A.D. 430 and 730 with a peak at A.D. 580-680 (Holzhauser et al., 2005), in good correspondence with the speleothem record of Savi Cave in the Central Alps (Frisia et al. 2005). Elevated water levels in French lakes, e.g., Le Petit Maclu 2 (Magny, 1993) and Lake Bourget (Debret et al. 2010), point to increased precipitation between A.D. 500 and 800. As a consequence of this climatic instability in the Alps, a long period of quiescence for the Po River came to an end as flood frequency increased from A.D. 570 to 900 (Camuffo, & Enzi, 1996).

During the same period, the southern margin of the Po River plain, including the Emilia and Romagna regions, was affected by increased hydrogeological instability (Veggiani, 1994; Cremonini et al. 2013; Bruno et al. 2013). Floods that occurred during the 6th century A.D. in the Roman town of *Mutina* (present day Modena) were an outcome of these events (Cremaschi, & Gasperi, 1989). The catastrophic flood often recorded in the literature as 'Paul the Deacon Deluge' that affected large parts of northern and central Italy occurred in A.D. 589 (Dall' Aglio, 1997, and, for a critical review, see Squatriti, 2010, Cremonini et al. 2013). High water levels at Accesa Lake in Tuscany after AD 600 (Magny et al. 2007) further suggests that the effects of Early Medieval climate instability extended south into central Italy.

According to historical sources and archaeological evidence, the A.D. 1571 diversion of the Crostolo River may also be related to climatic instability that enhanced the frequency of floods. This event correlates with the onset of the Little Ice Age (LIA), falling within the very cold Spörer Minimum, which dates to A.D. 1441-1563 (Grove, 2001). Similar to Early Medieval climatic instability, the latter event is clearly preserved in the abovementioned climatic proxies from the Alps, e.g., alpine glacier advance (Holzauser et al., 2005), and in the dramatic increase in flooding along the Po and Tiber rivers (Camuffo, & Enzi, 1996). Ostensibly, the Crostolo riverbed was detoured outside Reggio Emilia to counter the effects of increased floods and mitigate their hydrological risk.

A similar example of mitigating hydrological risks comes from the nearby city of Modena, which, as with Reggio Emilia, was threatened by increased floods related to the start of the LIA. Also in this case, the problem was solved by a radical intervention to the drainage network as the two watercourses responsible for flooding were diverted away from the town through artificial canals into the main streams of the area, the Secchia and the Panaro. The operation performed in this case at the end of the 16th century A.D. is recorded as *'il taglio delle acque alte'* (the cut of upper streams) (Cremaschi & Gasperi, 1989).

Building a city upon an active fluvial course implicates a persistent hydrogeological risk. Geoarchaeological data here discussed suggest that the inhabitants of Reggio Emilia have paid great attention in keeping under control the Crostolo River as they moved its course at least four times during the lifetime of the city. Geoarchaeological evidence also indicates that the impact of climate changes on an urban context largely depends on the social and historical conditions in which it took place. For instance, the consequences of the climatic instability dated to the Late Antiquity were prominent; in fact, they occurred in coincidence with the societal crisis triggered by the collapse of the Roman Empire. On the contrary, the climatic deterioration that occurred at the beginning of the Little Ice Age, probably more intense than the previous one, did not lead to any environmental disaster, thanks to the existence at tht time of a well-established social and political structure, which was able to prevent or quickly mitigate environmental crisis.

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