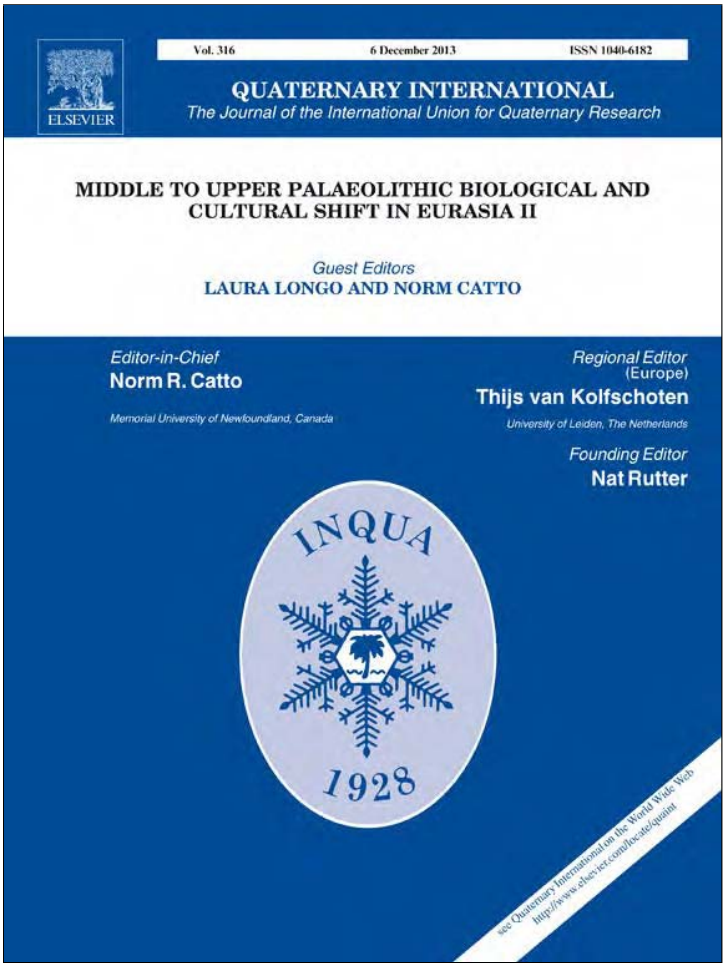
Vol. 316
6 December 2013
ISSN 1040-6182
ELSEVIER
QUATERNARY INTERNATIONAL
The Journal of the International Union for Quaternary Research
MIDDLE TO UPPER PALAEOLITHIC BIOLOGICAL AND CULTURAL SHIFT IN EURASIA II
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Quaternary International 316 (2013) 162–178

Contents lists available at ScienceDirect

Quaternary International

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The late-antiquity environmental crisis in Emilia region (Po river plain, Northern Italy): Geoarchaeological evidence and paleoclimatic considerations

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A R T I C L E I N F O

Article history:
Available online 27 September 2013

A B S T R A C T

For about four decades in Italy local, scientific literature has occasionally dealt with fluvial avulsions, suggesting they should be considered as genetically linked to a peculiar climatic worsening that occurred in the late-6th century AD (the so-called "Paul the Deacon Deluge"). Research performed by the Soprintendenza per i Beni Archeologici dell'Emilia-Romagna over the last few years has allowed better definition of the timing of a more articulated alluvial history, mainly concerning the Roman Imperial age and Late-Antiquity (1st–6th century AD). The main stratigraphic details of fourteen selected archaeological excavation sites (eleven recently surveyed and three reviewed from the literature) performed in the cities of Modena, Bologna and related surroundings have been summarized. Eleven ^{14}C dates, ranging between the years 130 AD and 810 AD, allowed us to chronologically delimit a first framework for the riverbed network behaviour during ancient times in the central part of the region. The alluvial process appeared to be continuous throughout the time span examined. The fan trench was the most sensitive reach of the river system. It started to aggrade during the 4th century AD. During the 5th century AD and probably after the end of the 6th century AD, a number of avulsions occurred. This indicates that the fluvial system was in a metastable equilibrium, whose behavioural threshold was finally overcome. Hence, the importance of the supposed year 589 AD crisis (the "Deluge") appears to be less than previously supposed. The riverbed aggradation became evident immediately after the Roman Empire's economic and demographic crisis of the 3rd century AD, and it was probably due to the loss of the land preservation systems in the mountain catchment areas. The long duration of the aggradation phase suggests that more than one human settlement phase in the minor catchment areas and/or a minor climatic worsening pulse probably occurred during the 5th century AD. The starting of the aggradation also coincided with the end of the Petit Maclu 1 high level phase of the European lakes. Notwithstanding this, the climate's role as a forcing co-factor can still be hard to evaluate positively due to the lack of local proxy data.

1. Introduction

In Italy a poorly known paleoclimatic topic still exists that has never been deeply studied, even though it represents a famous *topos* in archaeological and geoenvironmental literature. This is the so-called "Paul the Deacon Deluge" (PDD) dating back to the year 589 AD and usually linked to the environmental crisis that occurred at the end of the western Roman Empire. Recently, the problem has been critically reviewed by Calzolari (1996) and Squatriti (2010, references therein). Highly anomalous rainfalls occurred at the beginning of the autumn of that year and were recorded by the Langobard Paul the Deacon (Paulus Diaconus, book III, chap. 23) as having hit most of Northern Italy and possibly central Italy as well, causing severe damage to human structures and to the landscape mainly owing to several landslides and floods. This tale was particularly interesting for geologists, thus originating an abundant, albeit repetitive, grey literature concerning the recognition of late-Holocene climatic deterioration LIA-like pulses and the related geomorphic effects, such as riverbed aggradation or incision phases (e.g. Veggiani, 1987, 1994). This kind of study saw Italy split into two main domains. In the northern domain, extending at least up to Florence (Nicosia et al., 2012), the paleoclimatic imprint was

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http://dx.doi.org/10.1016/j.quaint.2013.09.014

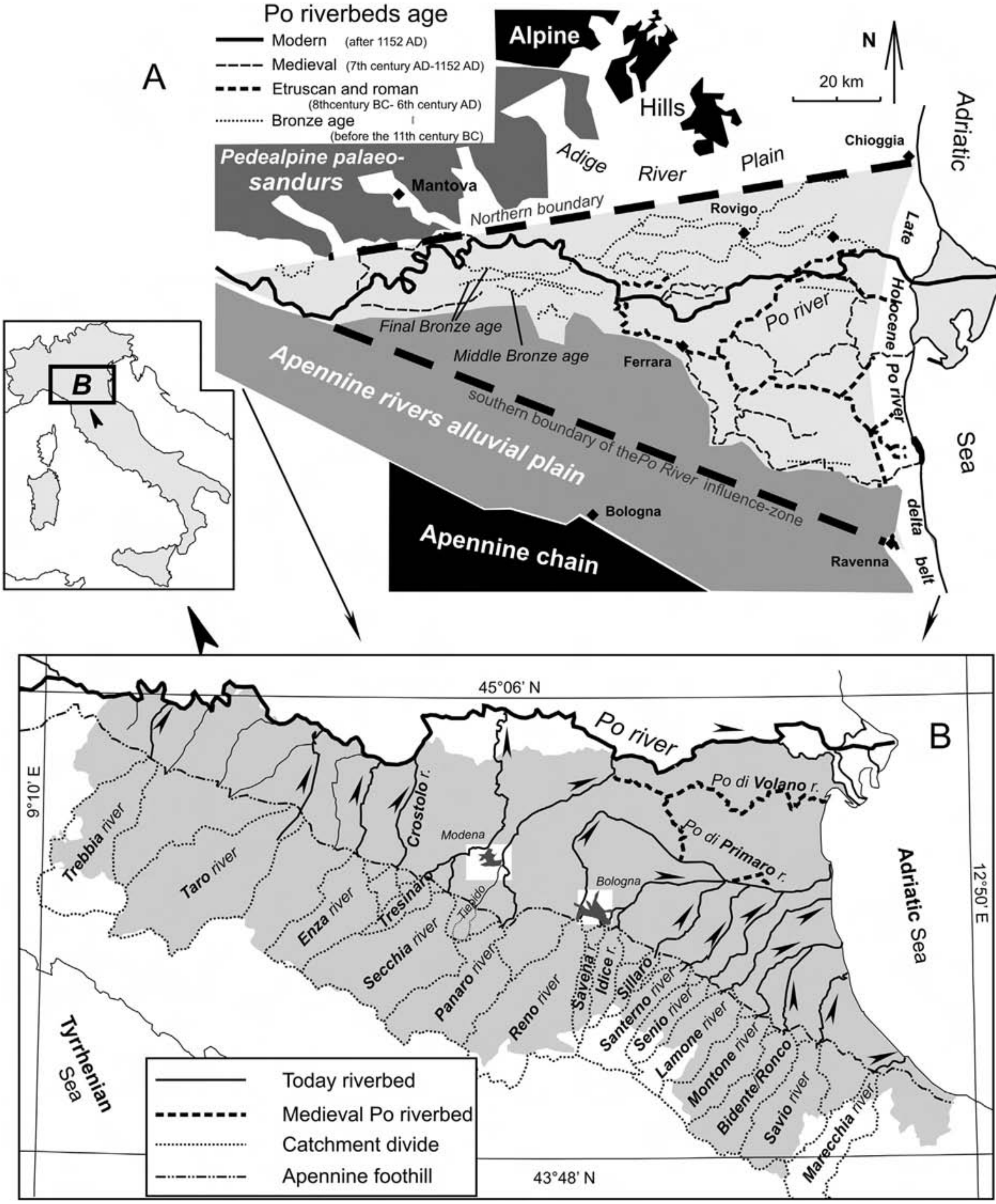

Fig. 1. The main river courses cited in the study are illustrated. A) The southern light-grey area includes the Apennine river domains, whereas the central white area shows the Po river domain (the dashed lines indicate the riverbeds ages). B) Present main rivers network and related mountain catchment areas. The two white rectangles in the Emilia-Romagna region show the location of Fig. 2.

thought to be probably prominent and preserved mainly in great alluvial plain areas (e.g. the Po river and its tributaries) due to the great availability of stratigraphic data. On the contrary, in the southern domain an anthropogenic origin of the valley river terrace aggradation was thought to be related to the ancient demographic pressure and land-use (Neboit, 1977, 1983; Brückner, 1986; Brown and Ellis, 1995). In more recent times, a new proposal (Ortolani and Pagliuca, 2000, 2007) suggested a climatic key also for the latter areas.

In the present study, a new series of evidence arising from archaeological surveys performed in the Modena and Bologna areas during the last twenty years by the *Soprintendenza* per *i Beni Archeologici dell'Emilia-Romagna* is reported. In particular, Modena was chosen due to the huge volume of available archaeostratigraphic data (Cardarelli et al., 1988a, 2001). The analysis of the new data seeks to show: i) the chronological constraints for the ancient natural sedimentation pattern; ii) the dominating driving factors (anthropogenic or climatic) of sediment delivery; and iii) physical

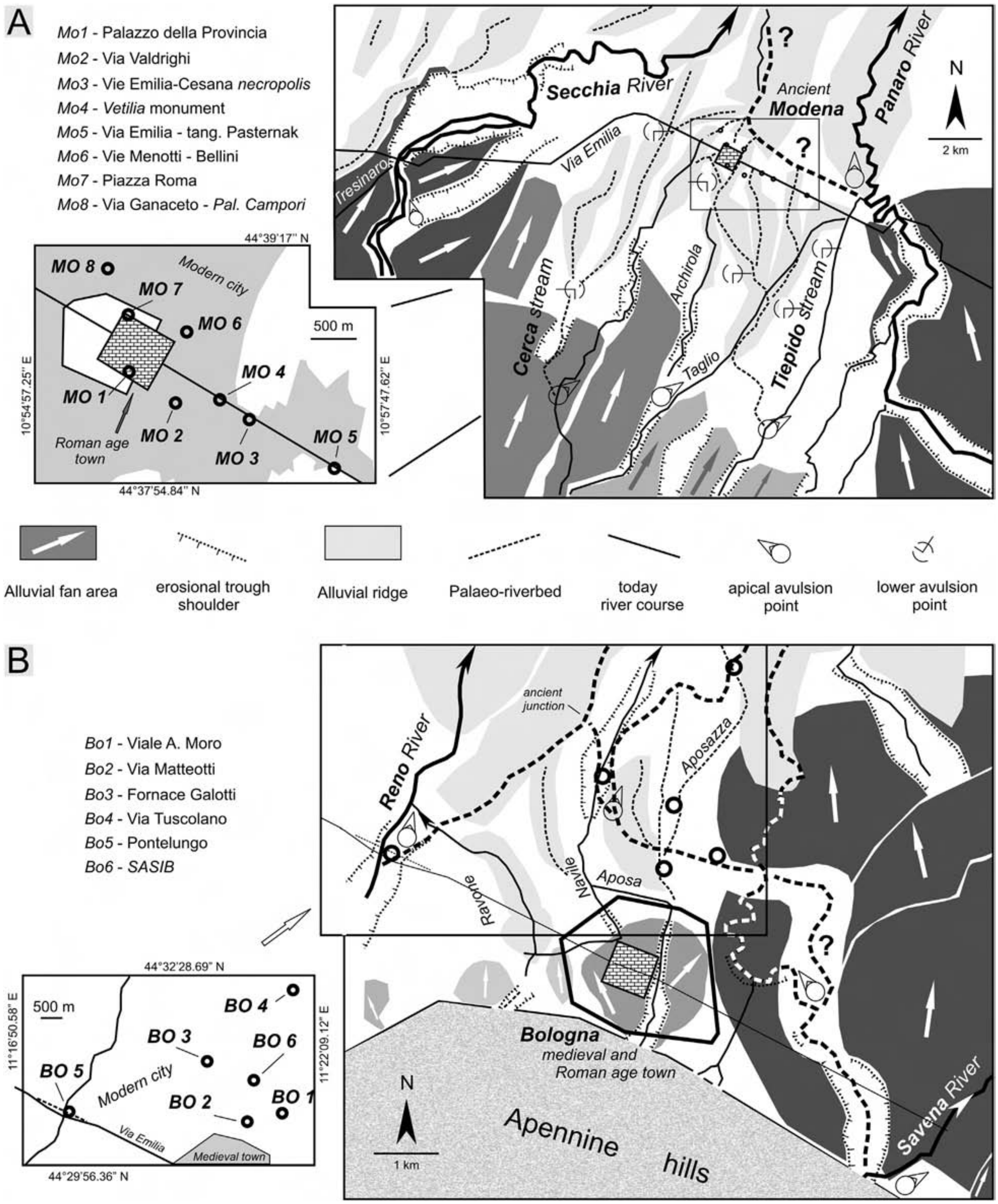

Fig. 2. Schematic geomorphological map of the areas surrounding the cities of Modena (A), revised after Bottazzi (1986) and Bologna (B), revised after Cremonini (1992). Related stratigraphical sites discussed in the text are located in the lower left corner.

evidence of the PDD and, if possible, its relationship with a worsening climatic phase or, eventually, its single-pulse character. This study analyses the fluvial environment focusing in particular on the alluvial plain out of the mountain chain, instead of the intramontane valley reach as more usually done (Leopold and Vita-Finzi, 1998; Wiseman, 2007). In this part of the fluvial system, two phenomena can be taken into consideration to analyze the relative importance of climate and humans as driving factors of geo-environmental changes: i) the chronology and synchronicity of the avulsion phenomena; and ii) the aggradation of riverbeds, alluvial ridges and related alluvial basins. Although ultimately they are mutually linked, the former phenomenon is relatively simple to detect even though it is often difficult to chronologically constrain, due to its punctiform character in the time domain. The latter, instead, developing as a continuum through time, can be difficult to recognize, although it is recorded more widely than the former.

2. Geomorphological and historical settings

The geomorphological and historical characters of the studied geographical area are briefly summarized due to the close links existing between physical and human environments.

2.1. Geomorphological setting

The natural model of the Emilia rivers consists of single-channel beds (of a braided type in the fan area and of a sinuous to meandering type in the lowermost reaches), whereas up to the beginning of the last millennium the river Po alone was of an anabranching type (Cremonini, 2007). The alluvial plain area consists of a southern Apennine river domain and a northern influence zone (sensu Allen, 1965) pertaining to the Po river flowing from W to E as a collector (Fig. 1). Along the Apennine chain foothill each river generally shows its own alluvial fan area partly preserved as a legacy of the Last Glacial Maximum dynamics and partly due to the mid-Holocene sedimentation and subsequent entrenchment phase development (Cremonini, 1992, 2010). Near the fan toe, at the fan trench termination, one or more (usually two) long alluvial ridges are usually recorded (Castiglioni et al., 1997) with an interposed low-lying alluvial basin (Cremonini, 1994). In general, few ancient alluvial ridges (both of Apennine and of the Po rivers), dating to the middle Bronze age (Cremaschi et al., 1980; Cremonini, 1984), are exposed in the region plain (Fig. 1A). Most date to the Roman Age and above all to the subsequent medieval period.

The studied areas of Modena and Bologna lie 35 km apart. Modena is located 15 km downcurrent to the mountain chain foothill, whereas Bologna is adjacent to the foothill, and an elevation difference of about 30 m exists between the cities. The former lies in a relatively small (200 km^2 wide), funnel-like shaped alluvial plain, developed between two coalescing main alluvial fans generated by the major rivers Secchia and Panaro (Fig. 2A). Beyond the fans' toe, the main alluvial ridges of Secchia and Panaro exist, characterized by meandering facies. The southern half of the funnel-like plain records a series of juxtaposed minor telescopic alluvial fans developed by four minor streams (Fossa-Cerca, Taglio-Archirola-Grizzaga, Tiepido and Guerro) during the first half of the Holocene (Cremaschi and Gasperi, 1989). In the northern, lowermost half of the plain, the small alluvial ridges of the minor streams are still recognizable (Bottazzi, 1986; Cardarelli et al., 2004; Castaldini et al., 2007).

The evolutionary scheme for the Tiepido stream can be understood from Fig. 2A. On the eastern side of the ancient town, four successive riverbeds developed from W to E starting from a first location close to the Roman age defensive city walls (Cremaschi and Gasperi, 1988; borehole 9). The related four small alluvial ridges disappeared toward the north, possibly indicating a buried Panaro riverbed as a collector once flowing from E to W close to the ancient city. On the western side of the city, the Fossa-Cerca stream migrated according to a pattern developing from W to E, generating four riverbeds. Depending on these patterns, the sedimentary cover is youngest close to the ancient city on its western side whereas on the opposite side it is the oldest. Due to this dynamic, the imperial Roman age topographic surface actually lies at a depth of 5–7 m and the whole thickness of the ancient age anthropogenic deposits is about 4 m (Cardarelli et al., 2001).

The ancient core of the city of Bologna is located upon the alluvial fan of the Aposa stream (Fig. 2B) at an average elevation of 61 m asl. (Cremonini, 1992; Cremonini and Bracci, 2010). The fan was already entrenched long before the Roman age, and thus most of the city was not alluviated by the Aposa floods (Cremonini, 2002a; Cremonini and Bracci, 2010). This explains the limited burial depth (2–3m) of the Roman republican age structures (Giorgi, 2002). On the western and eastern sides of the urban site, the fan areas generated by two major river courses (Reno and Savena) tended to coalesce. During historical times, the two rivers developed a tendency to rejoin (Cremonini, 1992) generating a very small alluvial basin (<20 km^2), located between the Aposa fan toe and the apex of their alluvial ridges, where the Roman age topographic surface is usually buried at a depth of 4–5 m (Cremonini, 1986). Despite of the small size of the alluvial basin, the interfingering of sediments delivered by three different rivers makes the understanding of each single point stratigraphic sequence rather difficult and time-consuming.

2.2. Historical setting

In the Emilia region the time lapse of the Roman domination is usually subdivided in the subsequent periods: i) pre-colonial republican (270 BC–191 BC); ii) colonial republican (191 BC–27 BC); iii) imperial (27 BC–293 AD); iv) Late Roman (293 AD–476 AD); v) Late Antiquity, i.e., post Roman, (476 AD-end of the 6th century AD); and vi) early Middle Ages (after the 6th century AD). These terms will be used in the text. The so-called "Roman empire crisis" as a whole involved a lapse of time of more than three centuries, from the mid-3rd to the late- 6th century AD. That period was historically quite complex. The notorious economic crisis of the 3rd century AD started after 235 AD and developed in the second half of the century up to the Tetrarchy (ca. 290 AD). Successively, it turned into a general crisis of the empire. At around the half of the 4th century many towns experienced a severe city-plan size reduction ("retractio urbis") (Ortalli, 1986; Curina, 1997), highlighting a population decrease in respect to a former amount similar to the one characterizing the 14th to 16th centuries AD (Scheidel, 2007). In the second half of the same century (377 AD), new peoples (Taifali, Sarmati, Alamanni) coming from northern and eastern territories were settled by the Emperor in the Emilia plain, among the cities of Parma, Reggio, Modena and Bologna, to compensate for the decrease in the original settlement.

The physical environment conditions between Bologna and Parma in 393–394 AD were depicted in a Saint Ambrose's letter (Bollini, 1971) recalling the "corpses of almost destroyed cities and lands" ("Semirutarum urbium cadavera terrarumque") together with the "miserable, uncultivated lands of the Apennine" ("Appennini miseratus inculta"). In the first half of the 5th century AD, the Huns invaded northern Italy. Thus, between the 3rd and the 5th century AD a first true degradation of the old social (some towns and dioceses disappeared) and military structures took place, leading to the final break-up of the empire itself (476 AD). The land also experienced a similar evolution with the loss of the previously reclaimed areas (centuriationes). Between 488 and 526 AD a new people (the Goths) resettled the Emilia region. A new partial redistribution of the land ("tertiae Gothorum") and the so-called Theodoric restoration ("Renovatio teodoriciana") helped the cities to reflourish partially as well as perhaps some territories (Dall'Aglio and Franceschelli, 2011). Only with the Greek-Goth war (535–553 AD) did a new true severe demographic decline occur, coupled with a possible new increase in the latifundium (Carile, 1975). From then on, the farming collapse became evident (Christie, 2006), and a period of landscape renaturalization took place, leading to the reappearance of huge forests even in plain areas (the "forestum magnum"). Only after the Langobard invasion of Emilia in 568 AD (Gelichi, 1988) did the towns restart to grow

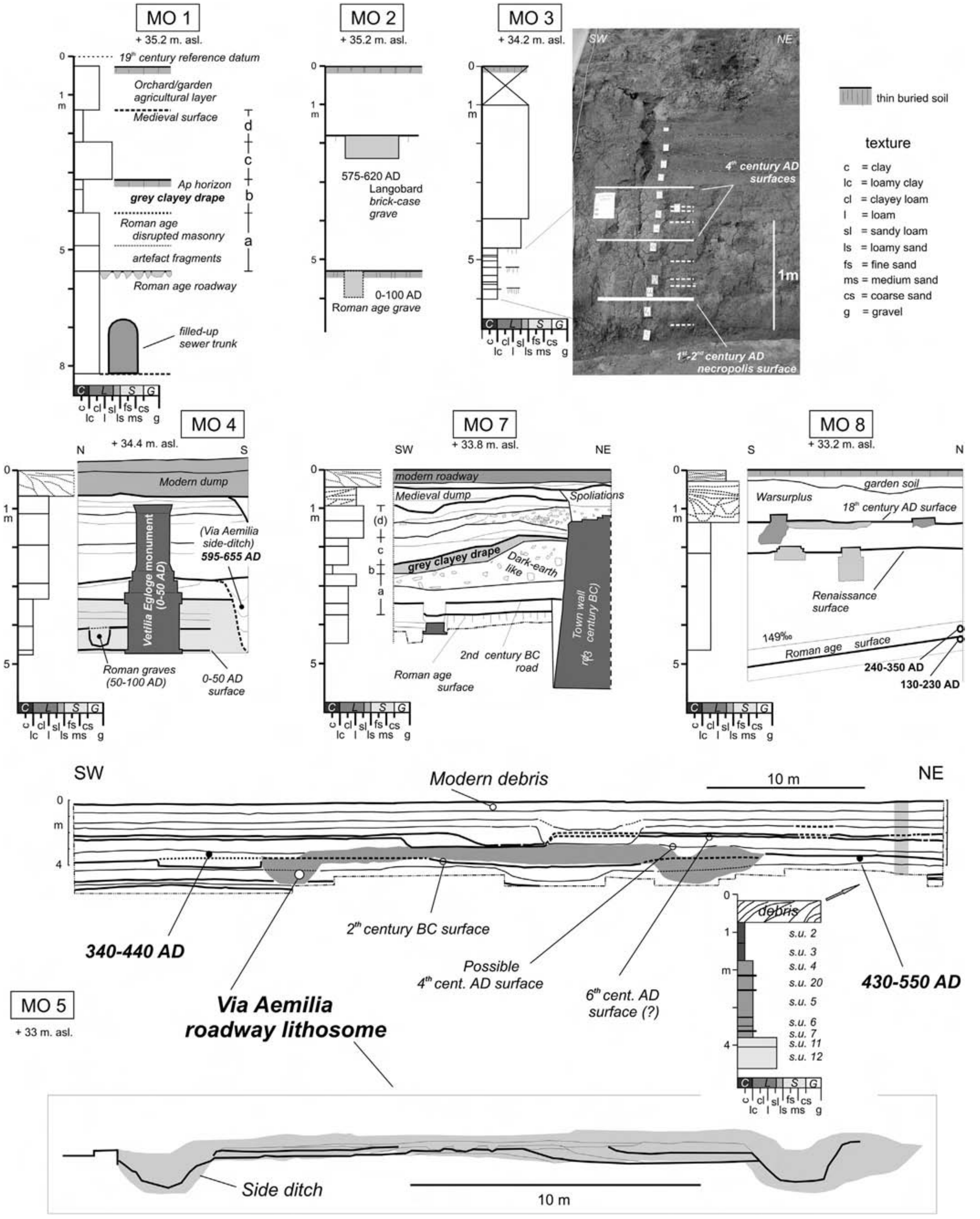

Fig. 3. Stratigraphic sites of the Modena area. The grain size nomenclature describing the layers in the old literature was revised in modern terms. The stratigraphic suites were simplified. In MO1 and MO7 the letters (a,b,c,d) refer to the interpretation proposed in the text. In MO3, MO4, MO5, MO7, and MO8 site sections, no vertical exaggeration was adopted in respect to the field sections. In the stratigraphic section of the ancient Via Aemilia (MO5 site) the main grey shadow highlights the location of the Roman age roadway lithosome. The lithosome is enlarged in the lower part of the figure.

and expand. This regional evolutionary framework is also supported by the archaeological survey data recorded in Modena province. They show a relative archaeological site number increase in the 4th century AD (corresponding to the resettlement of the barbarians) and its decline in the 5th century AD. This local trend fits the overall Italian one (Giordani and Labate, 1994; Lewit, 2004). In contrast to the agrarian/grazing-breeding exploitation of plain and medium-low hill areas, the highest reaches of the fluvial catchments were characterized by an economy based on lumbering and the production of bricks and tiles (Giordani, 2006; Bottazzi and Bigi, 2010).

3. Methods and materials

Each studied site was surveyed by means of an extensive archaeological excavation supervised by Soprintendenza per i Beni Archeologici dell'Emilia-Romagna. In some cases a further field reading of selected stratigraphic details was made to provide reliable sedimentological and paleo-geomorphological settings for the ^{14}C dating sampling. The original data are archived in the Soprintendenza offices and are unpublished. Only in some cases were the archaeological structures partly published.

Three sites (MO1, MO2, BO5) were assessed from the old literature whereas the others were surveyed during the modern excavations. Where no ^{14}C data were available the archaeological literature was cited as the dating source. The mutual geomorphological correlation among all the surveyed sites was warranted by deriving the mean topographic surface reference elevation of each site from the nearest elevation check point recorded on the Regional Technical Map 1:5.000, expressed in m asl (Italian elevation datum, Genoa Harbour, 1941). The stratigraphic logs drawn in Figs. 3 to 5 summarize a simplified outline of the data recorded by the usual field-description techniques (layering, layer 3D geometry, sediment size and textural lateral changing, Munsell Soil Colour codes, wetness, lower boundaries, redoximorphic figures, nodules, $CaCO_3$ reaction, coarse particles and artificial fragments content, paleocurrent direction) (Schoeneberger et al, 2002). Samples for ^{14}C dating, consisting of wood or charcoal fragments locally rooted or with no trace of fluvial transport, were taken only from fine sediment volumes in situ. The ^{14}C dates were performed at the CEDAD Laboratory of Salento University (Lecce, Italy) by the AMS technique according to international standards. ^{14}C age calibration used the OxCal ver. 3.10 software (Reimer et al., 2004).

4. Results

To make the description easy, the main stratigraphic and archaeological results were grouped according to a point-by-point topographic scheme as listed below with four main reference figures (3–5). The ^{14}C dating results are listed in Table 1. For discussion, only the 1σ results will be considered to avoid time-overlapping cases.

Table 1
^{14}C datings of the collected samples.

Site	Location	Lat./Long. (WGS 84)	Depth (m)	Material	Method	Laboratory	Lab code	δ^{13}CPDB ‰	Conventional radiocarbon years BP (1950)	Calibrated years 2σ and probability (%)	Calibrated. Years 1σ and probability (%)
MO 4	Vetilia Egloge	44 38 24.42 10 56 28.01	4.00	Charcoal fragments	AMS	CEDAD	LTL3316A	n.a.	1433 −/+40	550–670 AD (95.4)	595–655 AD (68.2)
MO 5/a	Tangenziale Pasternak (S side)	44 38 00.52 10 57 25.89	3.50	Charcoal fragments	AMS	CEDAD	LTL3310A	−23.8 ± 0.2	1646 −/+40	260–280 AD (3.8) 320–540 AD (91.6)	340–440 AD (60.8) 490–510 AD (5.1) 520–530 AD (2.3)
MO 5/b	Tangenziale Pasternak (Nside)	44 38 00.52 10 57 25.89	3.80	Latifolia decidua root branch	AMS	CEDAD	LTL3317A	- 23.9 ± 0.1	1561 −/+50	400–610 AD (95.4)	430–550 AD (68.2)
MO 8/a	Via Ganaceto	44 39 09.83 10 55 40.32	4.36	n.a.	AMS	CEDAD	LTL3936A	n.a.	1833 −/+40	70–260 AD (93.3) 300–320 AD (2.1)	130–230 AD (68.2)
MO 8/b	Via Ganaceto	44 39 09.83 10 55 40.32	4.20	n.a.	AMS	CEDAD	LTL3937A	n.a.	1738 −/+45	210–420 AD (92.1) 140–200 AD (3.3)	240–350 AD (63.7) 360–380 AD (4.5)
BO 1/a	Viale A. Moro	44 30 38.45 11 21 26.31	4.50	Small root (in situ)	AMS	CEDAD	LTL3197A	−26.8 ± 0.3	1625 −/+50	320–560 AD (92.9) 260–290 AD (2.5)	380–470 AD (41.8) 480–5.40 AD (26.4)
BO 1/b	Viale A. Moro	44 30 38.45 11 21 26.31	3.50	Small root (in situ)	AMS	CEDAD	LTL3196A	−20.6 ± 0.2	1530 −/+35	430–610 AD (95.4)	530–590 AD (40.7) 430–490 AD (27.5)
BO 2	Via Matteotti	44 30 31.16 11 20 48.60	4.98	Small root (in situ)	AMS	CEDAD	LTL8270A	−23.1 ± 0.2	1412 −/+45	550–680 AD (95.4)	600–660AD (68.2)
BO 3	Battiferro	44 31 20.04 11 20 04.81	11.5	Uprooted big tree trunk	AMS	CEDAD	LTL8271A	−22.2 ± 0.2	1749 −/+45	130–400 AD (95.4)	230–350 AD (65.3) 360–380 AD (2.9)
BO 4	Via Tuscolano	44 32 13.42 11 21 39.69	2.00	Charcoal fragments (in situ)	AMS	CEDAD	LTL8272A	−23.2 ± 0.3	1550 −/+45	410–610 AD (95.4)	430–560 AD (68.2)
BO 6	SASIB	44 31 03.35 11 20 56.42	5.40	Quercus sp. fragments	standard	Geochron - Kruger Ent. Inc.	GX-29119	- 26.9	1260 −/+40	660–890 AD (95.4)	680–810 AD (68.2)

n.a. = not available.

4.1. *Modena stratigraphic sites (MO 1–MO 8)*

4.1.1. *MO1 site – (Palazzo della Provincia) – (Fig. 3)*

Though performed around the middle of the 19th century (Forni, 1852; Cardarelli et al., 1988b, n. 251) the archaeological excavation was extremely detailed and highly reliable. The oldest Roman topographic surface was covered by 1.5 m thick clayey loam (a) containing the ancient building remnants and related collapse facies (mud-brick walls disruption). The clay layer (b) originated by the settling of stagnant water suspended load; atop the clay, an Ap horizon developed and some trees also rooted. Successively, a slightly coarser sedimentation took place (c) highlighting new alluvial episodes from the areas surrounding the town. A last layer of

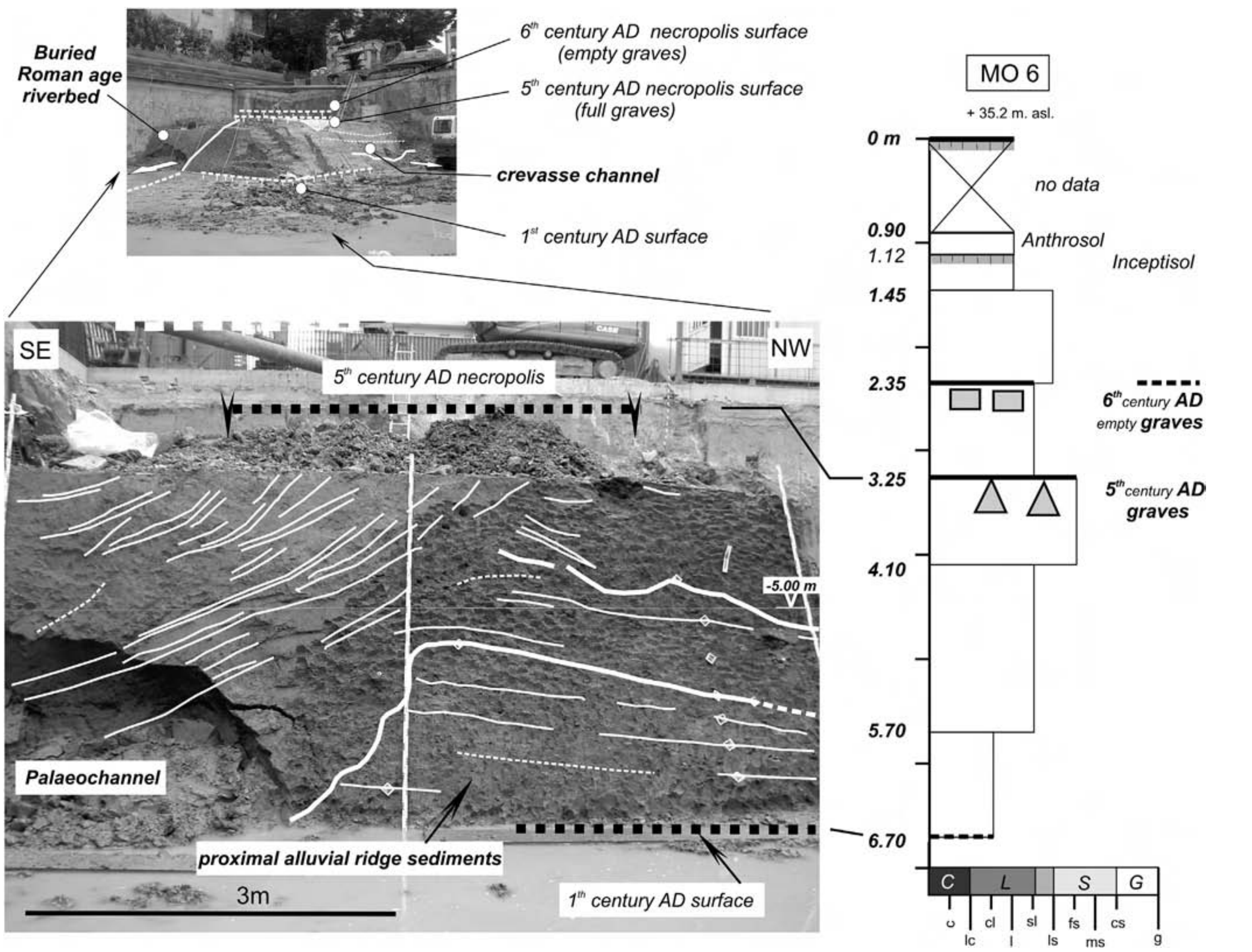

Fig. 4. Stratigraphic general setting and related details of the buried, ancient Tiepido stream left bank at the MO6 site. The general simplified stratigraphic log is resumed on the right side of the figure. In the lower picture the lateral relationships between the channel and natural levee deposits are shown. The stratigraphic position of the Roman age topographic surface and the 5th century AD necropolis are also reported. The sediment texture keys are shown in Fig. 3.

"swamp mud" (d) suggests a newly triggered alluvial basin condition developed during the early Middle Ages, when the city wall were already disrupted and buried.

4.1.2. MO2 site – (via Valdrighi) – (Fig. 3)

No real stratigraphy is available for this site. A 1st century AD Roman grave is located at 5.3 m depth. A Langobard brick-box grave (dated 575–620 AD) was buried at 1.8 m depth (Cardarelli et al., 1988b, n. 325).

4.1.3. MO3 site – (via Emilia/Cesana necropolis) – (Fig. 3)

A Roman age necropolis located on the southern side of the ancient *Via AEmilia* and dating to the 1st/2nd up to the 4th century AD (Giordani, 2008) was sealed at 6 m depth by a double sedimentary sequence whose lower part consisted of nine clay to loamy-clay horizontal layers, each about 12–15 cm thick. A further 4.7 m thick sandy loam to loamy sands suite with sporadic small sandy crevasse channels capped the lower clays. No ^{14}C dating is available.

4.1.4. MO4 site – (Vetilia monument) – (Fig. 3)

By the northern side of the ancient age *Via AEmilia* a 4 m high limestone funerary monument dedicated to *Vetilia Egloge* and dating back to the first half of the 1st century AD was found to lie at a depth of 5 m (Labate, 2009, n.8; 2010). A lower loamy clay layered bank 1.4 m thick sealed a series of graves dating to the second half of the 1st century AD. The upper sedimentary cover consists of further nine layers of clayey to silty loams containing a thin layer at a depth of 3 m, dating to the first half of the 7th century AD (Table 1).

4.1.5. MO5 site – (via Emilia E-Tangenziale Pasternak) - (Fig. 3)

A 60 m long trench intersected the ancient *Via AEmilia* roadway and its surroundings (Labate, 2009, n.7; idem 2010). The "street-lithosome" was generated by the artificial aggradation of the roadway deriving from about seven centuries of maintenance works. It consisted of a multilayered gravel and loam prism including two lateral longitudinal draining ditches and evolved starting from 187 BC to the turn of 5th century or the first half of the 6th century AD. At around that time or probably later, the natural sedimentation, consisting of loamy clay sheet-flow deposits, restarted, giving rise to at least five depositional episodes characterized by a trend slightly thickening toward the north. After each alluviation episode, the street was newly exhumed by an artificial trench, half or one third of its original width (10–12 m).

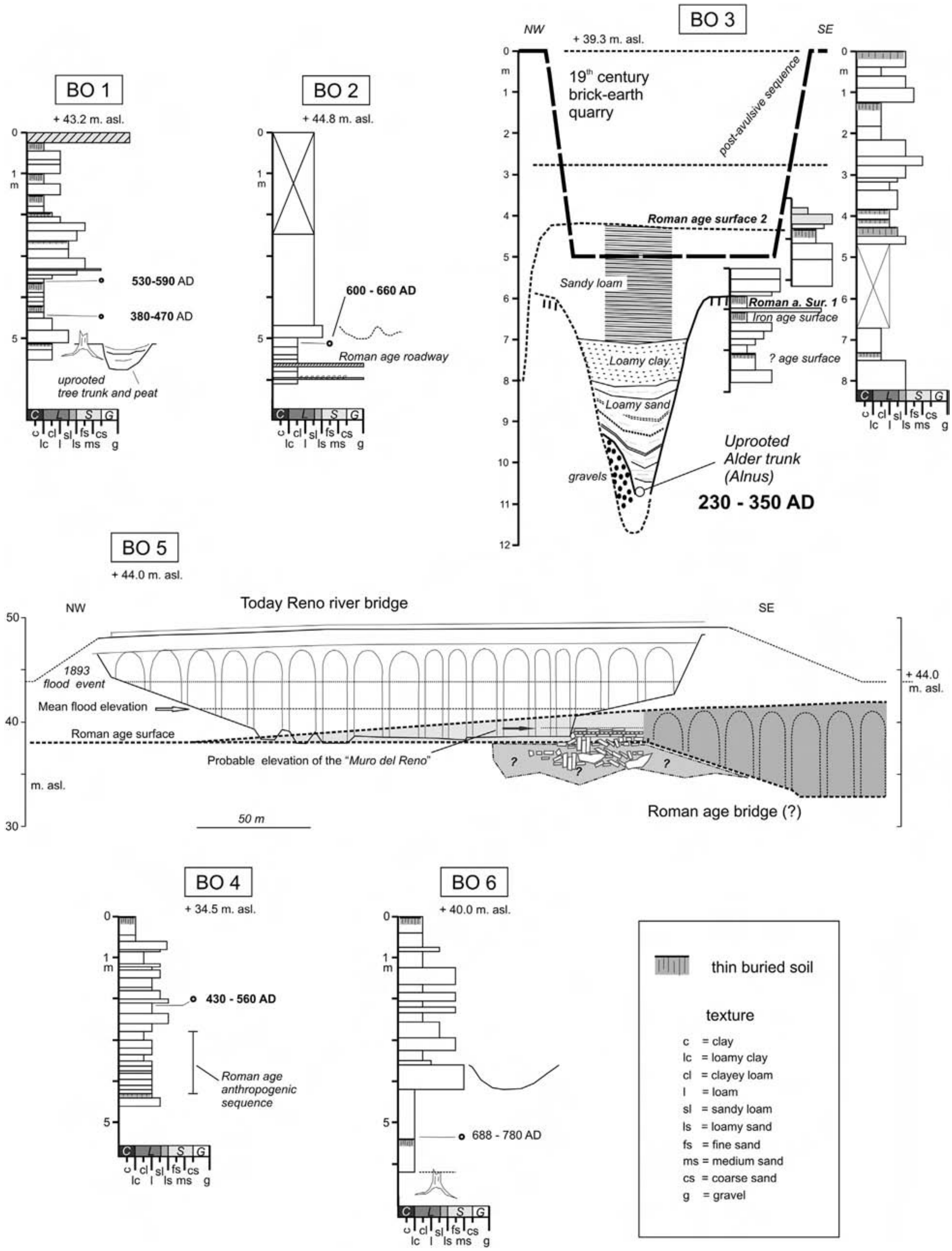

Fig. 5. Stratigraphic sites of the Bologna area. The stratigraphic logs were simplified. The location of the dated samples is also reported. In BO5 site a 5× vertical exaggeration was adopted.

4.1.6. MO6 site – (vie Menotti and Bellini) – (Fig. 4)

Near the north-eastern corner of the Roman age town, outside the city walls, in 2009 (Labate, 2011, n.5) a part of a buried paleoriverbed of the Tiepido stream was found, thus confirming the existence of a 10 m deep fluvial channel of unknown size (Cremaschi and Gasperi, 1988). The upward concave stratification of the channel loamy sands gradually made a transition to the roughly stratified loam to sandy loam of the overbank deposits characterizing the left natural levee of the stream. The levee covered the remnants of a building dating to the 1st century AD. The progressive levee vertical aggradation was highlighted by the repeated artefact dispersals lying on accreting surfaces. Atop the local channel deposits lay a necropolis area, characterized by two life phases dated to the 5th and the 6th century AD, respectively. The local sedimentary history continued up to the development of an inceptisol (at 1.12 m depth) suggesting the final channel avulsion towards the MO-4 site.

4.1.7. MO7 site – (Piazza Roma) – (Fig. 3)

The site was located on the northern inner side of Roman age town (Labate and Pellegrini, 2008, 2009). The lower half of the suite consisted of prevailing fine sized deposits (Dark-Earth like: e.g., Gasperi and Cremaschi, 1988), concealing the Roman age building remnants, dating to Late-Antiquity. The whole was capped by a continuous blue clay drape (gley), 20 cm thick. The overlying sequence, dating from the early Middle Ages to Middle Ages, recorded oxidizing conditions up to the moment of truncation and partial removal of the Roman age city wall.

4.1.8. MO8 site – (via Ganaceto – P. Campori) – (Fig. 3)

In the north-western ancient town outskirt, a buried topographic surface dated to the end of the 2nd century AD (Labate, 2010, n.15) dipping southward at a high slope (149 m/km). It was covered by a very thin succession of thin, fine grained sheet-flow deposits terminating at around the beginning of the 4th century AD. A 2 m thick, fine alluvial sediment cover draped that ancient topographic surface before the Renaissance. After that period, the fine sediment alluviation appeared to restart up to the 18th century AD.

4.2. Bologna stratigraphic sites (BO 1–BO 6)–(Fig. 5)

4.2.1. BO1 site – (Viale A. Moro)

The site lies directly northwards of the Savena paleoriverbed, at the end of the alluvial fan trench. The river was flowing from E to W. A riverside horizontally layered loamy clay to clayey loam overbank deposit capped a Roman age topographic surface at 5.30 m depth. This latter was lying on Iron Age sandy gravels. A wood sample contained in the lower fine deposits dated to the first half of the 5th century AD. The uppermost suite, consisting of fining-upward very fine sand to loam thin sequences, was 3.5 m thick and dated to the second half of the 6th century AD.

4.2.2. BO2 site – (via Matteotti)

A thin grey clayey loam suite covered a republican Roman age topographic surface near an important roadway (Curina, 2011), at 5.6 m depth. The suite aggraded up to the first half of the 7th century AD. The overlying, grossly stratified sandy loams had a sharp erosional lower limit and were deposited by a westward directed paleocurrent, consistent with a Savena paleoriverbed (Cremonini, 1992).

4.2.3. BO3 site – (Fornace Galotti)

A paleochannel of the Savena river referring to a first topographic surface of Roman age lay at a depth of 6.4 m below the modern topographic surface level. The channel was 6 m deep and had a gravel side bar with uprooted alder trunk 10 m long, dating to between the end of the 3rd century AD and the first half of the 4th century AD. After the death of the channel, a further 2 m thick off-channel aggradation phase occurred, and a second Roman age topographic surface was generated. Finally, a further 4.3 m thick aggradation phase developed as a consequence of an apical avulsion of the Savena river (Cremonini, 1992).

4.2.4. BO4 site – (via Tuscolano)

Four alluvial ridge fining upward sequences made up of sandy loam to loam were deposited by the post-avulsive Savena riverbed. They covered a very thick (1.5 m) archaeological suite of Roman age, terminating at a depth of 2.78 m. A concentration of charcoal fragments contained in the oldest alluvial ridge sequence dated between the end of the 5th century AD and the beginning of the 6th century.

4.2.5. BO5 site – (Pontelungo)

In 1904, a wide and complex archaeological context related to a Roman age consular street was discovered near the ancient Reno river left bank. A restoration of the ancient *AEmilia Via* roadway (the so-called "Reno river wall") was made at the end of the 4th century AD using a large amount of abandoned inscribed gravestones (Cremonini, 1991). They were horizontally layered atop a huge and thick volume of large blocks thought to be the ruins of the ancient Roman age bridge. The "Reno river wall" is now thought to have been part of a ford among the river's gravel bars.

4.2.6. BO6 site – (SASIB)

A late-Roman-Late Antiquity age topographic surface lying at a depth of 5.8 m was sealed by a clayey loam bank 1.6 m thick, containing large wood fragments near the bed, dating to the 8th century AD. The relatively late age of the sedimentary cover inception may be due to the distance from the aggrading Savena river system (e.g. BO 3, BO 4).

5. Discussion

5.1. Chronological constraints for the natural sedimentation

Almost everywhere outside the Roman age town of Modena (MO4, MO5 and partly MO3) an early, thin, clayey sedimentation was recorded during the 1st century AD. These deposits could refer to the local management of the agrarian ditches system rather than to a natural, distal overbank sedimentation. The sites MO1 and MO7 highlight the stratigraphic theme of the inner Roman age town burial. The town was surrounded by a high defensive wall, able to transform its area into a sui generis enormous sediment gauge recording both the deposits of anthropogenic origin (life and decay cycle) and the subsequent natural alluvial sedimentation. The clays (b) correspond to the lateral facies of the Tiepido stream flowing out of the town walls until the 5th century AD (e.g. MO6). The slightly coarser (c) deposits have to be linked to the Grizzaga/Archirola minor stream or Tiepido possibly between the 5th and the 6th centuries, entering the town somewhere from already disrupted defence-wall breaches along the southern or western sides. The comparison with the MO2 site suggests dating the "c/d" boundary to the Langobard period (575–620 AD). Furthermore, MO2 indicates that the maximum of the local sedimentation (3.5 m) developed before the Langobard period. The MO6 sequence records the ancient Tiepido riverbed location and its use as an eastern defensive ditch for the city. The same severe aggradation phase shown by MO2 is here clearly constrained between the 1st and the 5th century AD when the necropolis was built upon the sediments of the already dead stream channel. The topographic surface of the 6th century AD grave level could be correlated to the Langobard grave of MO-2. Therefore, this site suggests that a continuous severe channel aggradation together with at least an avulsion occurred a long time before the hypothesized climatic crisis of the 589 PDD event. Successively, during or immediately after the 5th century, the depositional activity of the Tiepido stream shifted and rapidly developed between MO2 and MO4, where most of the sedimentation took place after the early 7th century AD.

The coarsening upward sediment size trend recorded in the MO3 site as well as the fining upward one of MO5 must be assigned to further, later avulsions towards the east (Fig. 2A). MO8 includes relatively young depositional activity on the western side of the city due to the Grizzaga/Archirola and Cerca streams (Cremaschi and Gasperi, 1989). The succession of the natural events happened around Modena, in particular the Tiepido stream's repeated avulsions, explains the uniqueness of the Modena case in the history of urban evolution in the Emilia-Romagna cities, consisting of the shifting of the city by several thousand metres westwards (Fig. 2A), between the end of the Roman times and the high Middle Ages.

Besides the previous sites, the local literature records two further cases concerning the ancient rivers' network evolution. The first case highlights the terminal fan trench of the Secchia River, 13 km west of Modena, showing a 2.5 m thick gravel bar lying upon a Roman age topographic surface (Fioroni and Bertolini, 2006). The second, located 5 km west of the Secchia river, records a woodland flooded by the Tresinaro stream, whose tree trunks date to 525–582, 535–655 and 648–712 AD (Alessio et al., 1980: Cave Elsa, revised), thus suggesting an avulsion after the end of the 7th or the beginning of the 8th century AD.

The BO5 site suggests that: i) the Roman age main regional street elevation coincided with the today's Reno riverbed thalweg; ii) the most ancient river thalweg elevation was probably 4–5 m lower than the present one; iii) before the 4th century AD the riverbed was already laterally wandering and eroding its left side; and iv) at the end of the 4th century AD (393 AD) the coeval riverbed was already aggraded and the water current was flowing almost at its present elevation. BO3 indicates that the triggering of the river network aggradation (between the end of the 3rd to the first half of the 4th century AD) was an early and highly probably continuous phenomenon and, furthermore, that during Roman times at this location the riverbed was lying about 12 m beneath today's topographic surface. This information concerns the Savena river at a point near the junction with the ancient Reno river, and thus it can be thought to be valid for the latter thalweg as well. The rising of the system thalweg elevation led to the triggering of a Savena river apical avulsion probably between the end of the 4th and the 5th century AD. This is also suggested by the site BO4, recording independent river flow toward the north and the enhancing of its lateral crevassing activity near BO4. This picture is also consistent with the information coming from the upstream BO1 site that records a gradual infilling of the terminal fan trench during the 5th century AD, and the successive lateral sedimentation coarsening after the half of the 6th century AD. With a time lag of more than half a century, the same kind of indication is provided by the BO2 site. The whole river network was permanently aggrading in the fan area but with no trace of gravel sedimentation. Akin to the Tiepido case, in the plain the Reno alluvial ridge aggradation is recorded before and after the beginning of the 3rd century AD as well (Cremonini, 1991), in particular around the years 281–282 AD when an important street linking Bologna and Padua was already lost due to sedimentary burial (Cremonini, 2002b, 2003a). In summary, both in the Modena and Bologna areas a first incision phase of the main river terminal fan trench characterized the Roman imperial period. A river aggradation phase of the fan trenches and alluvial ridges developed with the crisis of the Empire. At around the 5th century AD, the first avulsions took place. Further avulsions occurred during and after the 6th century AD. This kind of behaviour suggests that the ancient fluvial system could have been in a metastable equilibrium (Knox, 1999; Brunsden, 2001; Viles and Goudie, 2003), very close to a transitional threshold. The fact that the first avulsion group affected only minor streams could have depended on more effective social control exerted on small catchments (34 km^2 area for Tiepido and 166 km^2 for Savena) in respect to the wider one (1005 km^2 for Reno). This could make the small catchments more sensitive to climate stimuli (Lespez, 2007).

5.2. Sediment delivery driving factors

5.2.1. The climate factor

The mountain catchment with its inner connectivity model and response time (Brundsen and Thornes, 1979; Brunsden, 2001; Thomas, 2001; Brierley et al., 2006) is the most sensitive element of the fluvial system as a whole. The mutual interplay of climate and anthropogenic impact on the river catchments is always difficult to depict (Arnaud-Fassetta, 2011; Zanchetta et al., 2013). The general climatic frame for ancient Europe is also difficult to define in detail. It was supposed to involve a "Roman age warm period" followed by a late worsening phase between 300 and 600 AD (Wanner et al., 2011.) and a 500–800 AD "Vandal Minimum" (Walker, 2000) or 650–800 AD "Dark Age" minimum (Ogurtsov et al., 2002). Other authors want to recognize a climatic amelioration phase around 500 AD (e.g., Brochier et al., 2007). The succession of various climatic minor pulses is also uncertain. Lying in the central part of the Mediterranean basin, Italy, in particular, is located at the boundary of more than one kind of meteorological pattern and behaviour, mutually interacting (Jalut et al., 2009). For this reason, it is difficult to recognize only one linear interpretative mode, in particular during the Roman antiquity period.

The available local proxy data are still very rare. In northern Italy, four data sets are available. Lake Ledro (Magny et al., 2012) does not possess an adequate resolution level for the last 2000 years. Lake Frassino (Baroni et al., 2006) does not provide data concerning the last 2600 years. Lake Accesa (Magny et al., 2007) shows a mean low lake-level phase (more dry climate) throughout the period 250 BC to 600 AD, with a trend towards relatively higher levels (more wet climate) in two moments, i.e. at the end of Petit Maclu 1 phase and at 600 AD. However, the time resolution is very low. The Savi cave record (Frisia et al., 2005) in its general lines resembles the main climatic sub-phases already known. It records a unique cool phase between 450 and 750 AD with a minimum value around 630 AD; but its resolution is very low (Fig. 6F). Outside Italy, on the northern side of the Alps, the Great Aletsch glacier (Valais Alps) front retreat curve (Fig. 6G), though characterized by a very low time resolution, seems to have recorded a conspicuous glacial advance between 430 and 730 AD, with a peak around 580–680 AD (Holzhauser et al., 2005). In spite of this, Hormes et al. (2001) do not recognize any glacier advances in the Swiss Alps between 470 and 830 AD. A very detailed isotopic curve is provided (Fig. 6E) by the Spannagel cave (Mangini et al., 2005). Its close succession of minima and maxima fits very well the temperature anomaly curve (Fig. 6H) relative to the 1961–1990 AD mean (Ljungqvist, 2010) for the Northern Hemisphere (90°–30° N), with some difficulties only for the 1st and 2nd century AD. This in turn tightly fits the suite of relative minima and maxima of the GRIP $\delta^{18}O$ curve (Dansgaard et al., 1993).

Fig. 6A–C compares the GISP and GRIP data set of the period 300 BC to 700 AD, indicating a higher completeness of the GRIP-1989 data. At this detailed time scale, the $\Delta^{14}C$ residual curve (Stuiver et al., 1998) and its interpretative model (Magny, 1993) indicate (Fig. 6D) the high lake-level phase (Bourget, Petit Maclu 1 and 2)

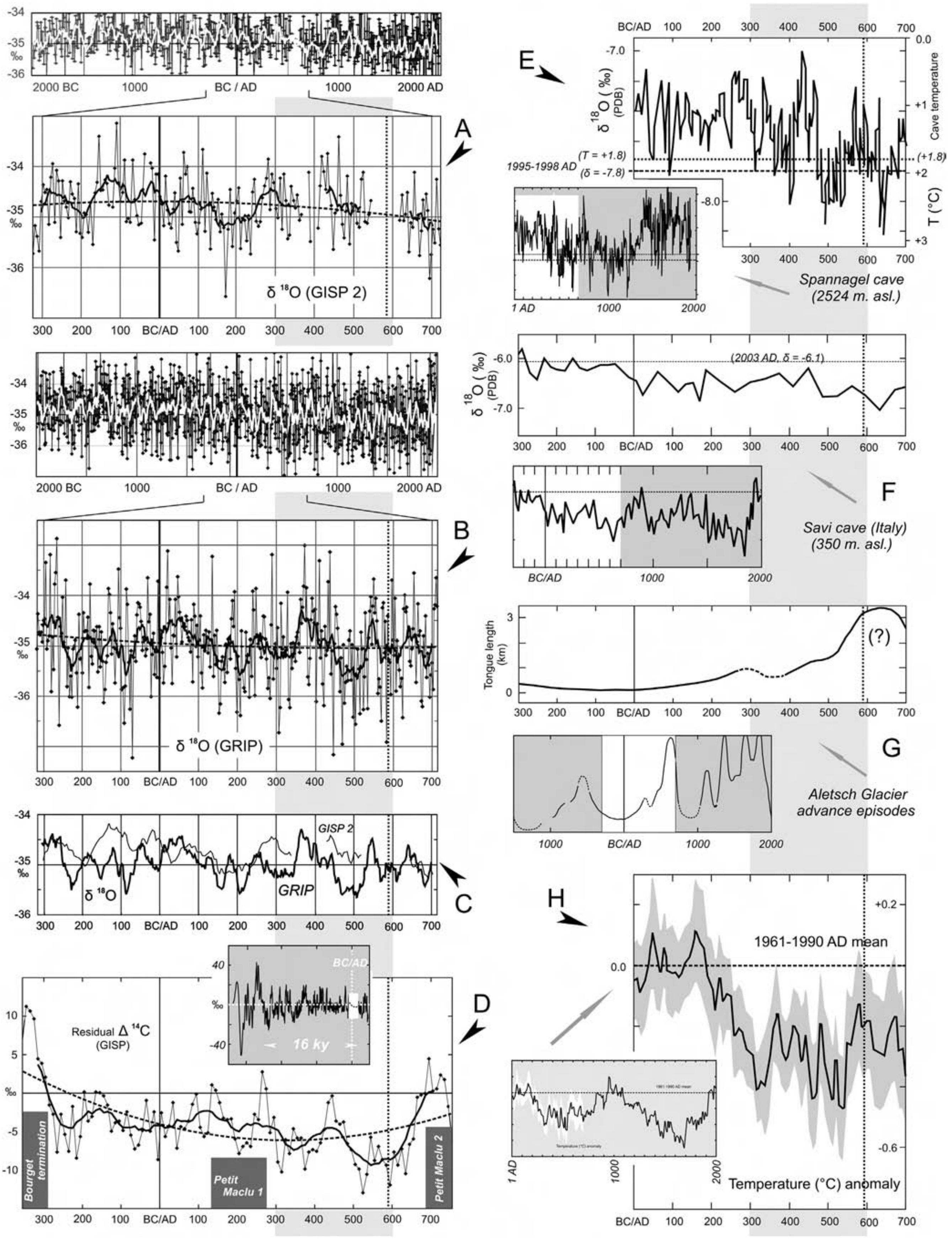

Fig. 6. Available climatic proxy data. A and B) Variations of the $\delta^{18}O$ concentration between 2000 BC and 2000 AD and related details between 300 BC and 700 AD from GISP 2 and GRIP 1989 ice cores data set, respectively. The second order polynomial trend (dashed line) and the ten-units moving mean (solid line) are also shown. Raw data from http://www.

suggested by Magny (2004). Thus, the choice of the GRIP data set as preliminary reference curve to inspect the climate variability in Northern Italy, though debateable, is a necessity until the time when local proxy data for Roman times becomes available. The GRIP curve suggests how many minor climatic pulses could be still unknown. In such a manner, two small minima can be highlighted during the 2nd century AD, probably corresponding to the Petit Maclu 1 phase, and also a relative maximum between 350 and 460 AD. The latter is also recorded in the Spannagel curve (ca. 370–420 AD). Furthermore, the Spannagel Cave also recorded a cold pulse between 460 and 536 AD, although it still does not permit comparisons between Petit Maclu 1 and 2. Finally, the Petit Maclu 2 phase is recorded starting after 670 AD. No clear evidence exists of the alleged 589 AD event, though a severe temperature decrease of the Surface Mixed water Layer near Svalbard is recorded immediately before 600 AD (Rueda et al., 2013). In summary, if a prevailing climatic forcing occurred in the studied interval, it is more likely that this coincided with the beginning of the Petit Maclu 2 (680–740 AD), i.e. the phase 3 of the European lakes higher-level (Magny, 2004), without excluding the Petit Maclu 1 minor contribution as well as that of the 5th century AD negative pulse.

5.2.2. *The anthropogenic factor*

The mediation element in the interplay between climatic and human forcing factors acting on the mountain catchments is the role exerted by the vegetation cover and its response in terms of ways and times. The reaction time of that cover appears to be very fast (Provansal and Leveau, 2006) ranging, in plain areas, from a few years to a few decades (Etienne and Corenblit, 2013), and in any case always less than a century (Hormes et al., 2001). The widespread vegetation covering of the bare mountain slopes after the Second World War was also recorded in the Emilia Apennine (di Gennaro et al., 2010; Cremonini, 2010) as well as in other geographical areas (e.g., Arnaud-Fassetta and Fort, 2004; Keesstra et al., 2005; Gautier et al., 2013). Thus the high renaturalization speed of the landscape suggests an unsystematic cyclicity for the cover development mainly linked to human demographic changes (e.g., de Moor et al., 2008; Notebaert and Verstraeten, 2010). The belief that an increase in catchment sediment delivery corresponds to a human impact mainly exerted in terms of wood clearance or bad slope management is generally accepted (Nir, 1983; Thorne et al., 1997; Neboit-Guilhot and Lespez, 2006; Hooke, 2006; Allée and Lespez, 2006; Syvitski and Kettner, 2011). In the Mediterranean Sea basin, Reale and Dirmeyer (2000) and Reale and Shukla (2000) suggested that in northern Africa the 3rd century AD clearance was able to change the land albedo, inducing a northward shifting of the Intertropical Convergence Zone. The first severe anthropogenic impact on the natural environment in northern Italy coincided with the Chalcolithic (Cremaschi and Nicosia, 2012) and was severe in the Bronze age (Accorsi et al., 1989; Lowe et al., 1994; Oldfield et al., 2003; Branch, 2004; Cremaschi et al., 2006; Bertolini, 2007; Eppes et al., 2008) rather than the Neolithic Age. From that period onward, this impact variously increased. During Roman times in northern Italy, more than 33% of the mountain forest cover disappeared due to naval construction and to the change of the agricultural land-management from a familiar to a latifundist and industrial model (Drescher-Schneider, 1994). In Emilia, up to 60% of the plain was cleared (Cremaschi et al., 1994).

In Fig. 7 a synopsis of the historical, archaeological and climatic evidence (selected from Fig. 6) as well as modes, spatial distribution and changes of the ancient settlement in the studied areas is summarized. The woodland evolution was derived by Accorsi et al. (1999). The significance of this picture is limited to the Emilia region only. In the strip 5 of Fig. 7, only the 5th century AD clearance phase is suppositional due to a lack of primary data. Fig. 7 highlights the relationships existing between the sedimentation pattern recorded in the alluvial plain and the climate and anthropogenic forcing. They can be summarized as follows. The Roman age settlement with its demographic cycle and continental economic relationships was the period of major human impact on the landscape as a whole. During the anthropogenic exploitation time, no clear, direct evidence of environmental impact (or positive slope-riverbed connectivity) was recorded. This fact does not match with the ordinary impact model (Bakker et al., 2008) but, in some way, it can be accepted (Gautier et al., 2013). Probably, during the Roman imperial period land management practices were sufficiently capable of avoiding high local soil loss, or, rather, the first impact phase, developed between the 2nd and the 1st century BC, was already overcome. The first phase of the terminal fan-trench aggradation (i.e. of the upper reach of the riverbed long-profile in the plain) developed immediately after the maturation phase of the 3rd century AD economic crisis and during the 4th century AD. Although an almost coeval negative climatic pulse (Petit Maclu 1) possibly developed, the most cogent triggering factor appears to have been the rapid ceasing of the agricultural practices and of the woodland exploitation in the mountain catchments. This is stated, even a century later (393 AD), by the passage in Ambrose's letter recalling land destroyed in the plain (towards the north) and uncultivated [at that time] areas in the mountain (towards the south), although geologists (Cremaschi and Gasperi, 1989; Cremonini, 2003b) and historians (Dall'Aglio, 1997; Neri, 2005) interpret this information in an antithetic way. Although the partial regeneration of the natural vegetation mantle apparently did not provide a limitation to the erosion of the catchments or at least of some their sub-areas (perhaps a badlands development phase?), such an interpretation substantially fits the Knox reaction model (Marston, 2010). The reaction time of the fluvial system was relatively short. Its relaxation time, instead, apparently too long to be triggered by a unique pulse, can be explained by the second phase of fluvial avulsions developed between the 5th and the 6th century AD. This could be related to the worsening period possibly occurred between the mid-5th and the mid-6th century AD (§ 5.2.2; Fig. 7, Strip 9). If the existence of such a worsening period were not admitted, then only anthropogenic forcing could be considered to explain the river network behaviour. In this case, a time coincidence probably existed with a limited resettlement phase of the small catchments and sub-catchments of the Apennine fringe. This settlement phase was possibly characterized by the development of less skilful agricultural practices, leading to a higher sediment delivery to the fluvial network.

5.3. *Evidence and character of the 589 AD "Paul the Deacon Deluge"*

Using the stratigraphic evidence of MO2 site, Cremaschi and Gasperi (1989) suggested the correlation of some sediments found on the opposite western side of Modena with the 589 AD "climatic event", the so-called Paul the Deacon Deluge. Ultimately,

ncdc.noaa.gov/paleo/icecore/greenland/summit/document/gripisot.htm. C) Direct comparison between the ten-unit moving mean trends of $\delta^{18}O$ concentration between 300 BC and 700 AD from GISP 2 and GRIP 1989 respectively: the thick line refers to the GRIP one. D) Variations of the residual $\Delta^{14}C$ concentration (Stuiver et al., 1998: available at http://depts.washington.edu/qil/datasets/resid98_14c.txt). E) The $\delta^{18}O$ concentration and related temperature variations at the Spannagel Cave, redrawn after Mangini et al. (2005). F) The $\delta^{18}O$ concentration at the Savi Cave, redrawn after Frisia et al. (2005). G) The variations of the Aletsch Glacier tongue length redrawn after Holzhauser et al. (2005). H) The temperature anomaly curve for the Northern hemisphere (90°–30° N) relative to the mean value of the period 1961–1990 AD, redrawn after Ljungqvist (2010). For a correct understanding, in the D to H plates, a longer time span setting curve (over 2000 years, at least) is also shown for each plot concerning the 300 BC–700 AD interval. The dotted vertical line indicates the year 589 AD.

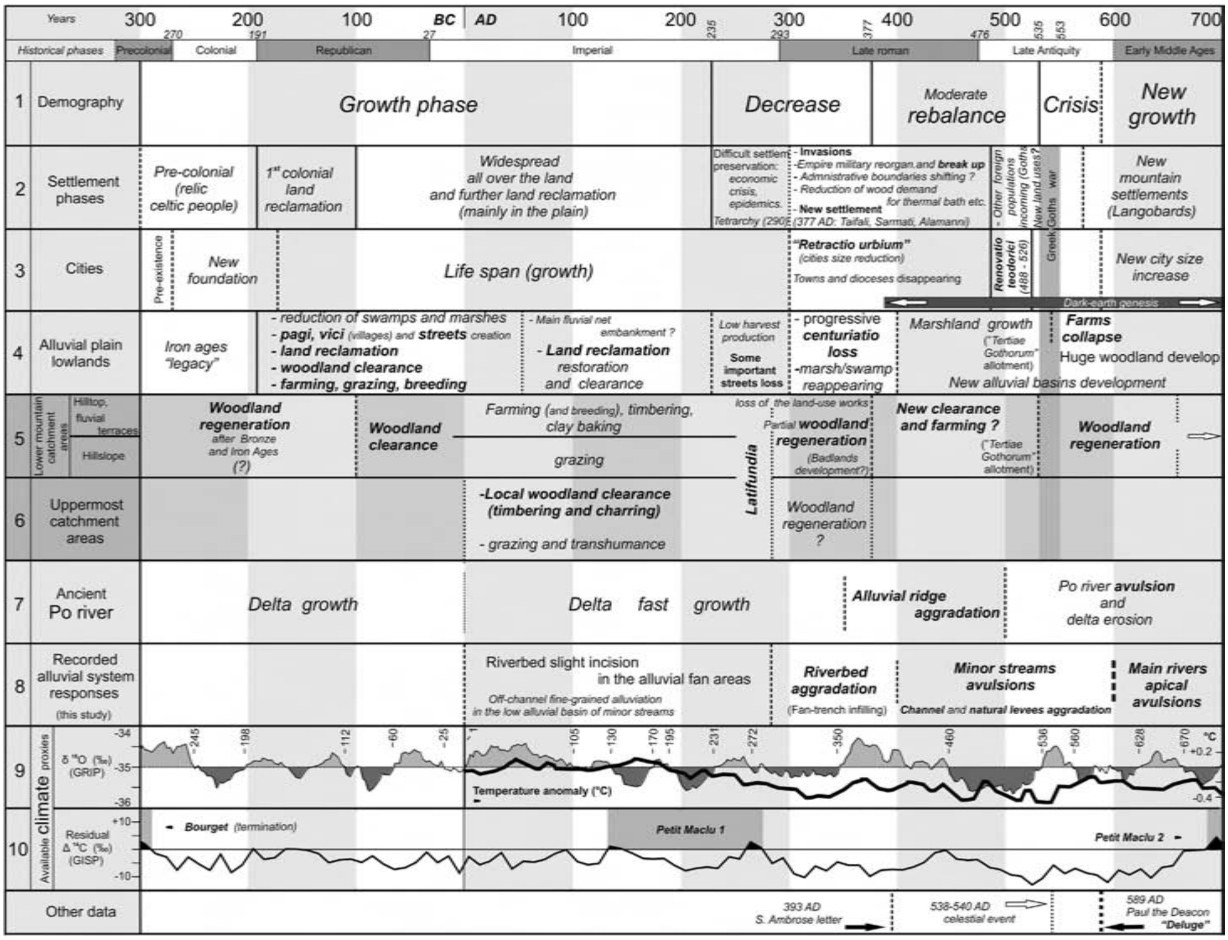

Fig. 7. A preliminary synoptic phasing of known ancient anthropogenic behaviours, the related environmental reactions and climatic pulses as well developed from the 3rd century BC until the 7th century AD. In the strips from 1 to 7, the historical and environmental data developments taken from the available literature are summarized. Strips 5 and 6 (in grey tone) refer to the river catchment areas. In strip 7, the behaviour of the Po River (Cremonini, 2003b) is suggested as it is the main collector of the ancient fluvial network. In strip 8, the main results of this study are summarized. In strip 9 the $\delta^{18}O$ concentration and temperature anomaly variations are recalled from Fig. 6C and H, respectively. The years corresponding to the $\delta^{18}O$ trend reversals in respect to the 35‰ (0–2000 AD mean value) are also indicated. In strip 10, the variations of $\Delta^{14}C$ concentration are reported from Fig. 6D together with the known high lake-level European phases (Magny, 2004).

this also contributed to the suggestion to adopt a new stratigraphic unit for regional Italian chronostratigraphy, the Modena Unit (Gasperi and Pizziolo, 2009), equivalent to the Torcello Unit for the Veneto region (Tosi et al., 2007). From a literary point of view (Squatriti, 2010) that "event" was characterized by: i) highly anomalous rainfalls; ii) beginning in autumn; iii) the resemblance to a summer thunderstorm with thunder and lightning; iv) an unclear duration of a year or less; v) a geographic area comprising the Northern and possibly Central Italy as well; and vi) severe damage to the human structures and landscape, mainly owing to several landslides and floods. No suggestions were provided concerning the atmospheric temperature, capable of suggesting a real climate worsening.

This kind of picture might seem to be a meteorological event characterized by anomalous high rainfall or rainfall frequency. The meteorological context could had been similar to atmospheric circulation patterns characterising the Scandinavian or European-blocking modes or even an alternation of these with the Eastern-Atlantic/Western-Russia modes, implying a southward shifting of storm tracks from western Europe towards the Mediterranean (Trigo et al., 2006). The Scandinavian mode, in particular, induces high amounts of precipitation over Italy and the southern Alps. A modern comparative model for such a situation could be the one occurring in Northern Italy in 1893. That year, Bologna was characterized by a rainfall of more than 1100 mm (100 mm more than the critical years 1951 and 1966: Leoni, 1994), generating the highest known flood of the Reno river, with a peak discharge of 2200 m^3/s and a series of contemporaneous floods and damage in the Apennine catchments of Tuscany. That magnitude of rainfall was repeated four times in the period 1868–1898 vs. a mean annual rainfall of 666 mm/y (500–850 mm/y). The Adige river also experienced a large flood at Verona in 1882 (Cenni, 1973) almost exactly as that recalled in the same city by Paul the Deacon in 589 AD. The meteorological events occurring in Emilia in 1893 did not provide any preserved field evidence and were recorded only by the coeval written sources. Hence, it can be questioned whether it could indeed be possible to recognize the effects of the year 589 AD event if Paul the Deacon's testimony had not have been available.

A distant parallel for the 589 AD event is provided by the southern Tyrrhenian Sea area, where an annual rainfall of 1050 mm/y (very similar to that of 1893 AD) was extrapolated around the years 600–625 AD vs. a Holocene average rainfall of 940 mm/y (Di Donato et al., 2006). In Fig. 6 none of the shown curves allows us to highlight a time overlap between the PDD event and unquestionable evidence of a climatic worsening period, except perhaps for the cases of Savi cave (Fig. 6F) and the unclear one of the Aletsch glacier (Fig. 6G). The present study, on its own, did not produce any clear evidence of chronological concentration of the avulsion activity coinciding with the supposed climatic and environmental crisis of 589 AD. Furthermore, cases of continuity of life without any avulsion up to the present are known in Emilia-Romagna for the Roman age river courses, the Marecchia and Savio rivers, at least (Fig. 1B).

In the adjacent regions, (Lombardy, Veneto and Tuscany) the recognition of Late-Antiquity fluvial avulsions was possible with some difficulties (Dossena and Veggiani, 1984; Fazzini and Maffei, 2000; Balista, 2005). On a wider geographical scale, as in the cases of Stobi (Folk, 1975; Wiseman, 2007), Salona/Solin (Split), Olympia (Dufaure, 1976; Butzer, 2005), the presumed late Antiquity environmental degradation phase is not clear. When searching for evidence of the 589 AD event in the climatic curves it is easier to find traces of the 538–540 AD celestial events (Baillie, 2007), or any trace at all (Brown, 2003; Grove, 2004; Magny et al., 2012), than those of that event (Fig. 6). Other events similar to that of 589 AD probably occurred in the years 502, 580, 608–615, 676 and 716 AD.

However, the most striking information is given by Paul the Deacon himself when he records that only two years after 589 AD a serious drought occurred in northern Italy from June to September (Calzolari, 1996), hence suggesting that the period cannot be considered to represent real climatic worsening. Thus, with no new available proxy data of local origin, the PDD paroxysmal event, if real, has to be considered a sporadic, single-pulse event of unknown magnitude, duration and return time, occurring at the end of a long period of river-long profile aggradation.

6. Conclusions

All the problems reviewed are paradigmatically comprised between two literary records, those of Saint Ambrose (393 AD) and Paul the Deacon (referring to 589 AD). For about forty years in Italy a local, scientific literature occasionally dealt with some fluvial avulsions, suggesting they should be considered as genetically linked to a peculiar climatic worsening that occurred at the end of the 6th century AD (the so-called "Paul the Deacon Deluge"). This hypothesis was proposed for the first time in the Emilia-Romagna region. Without numerical dating or other related evidence capable of validating the idea, that hypothesis became a topic assumed by archaeologists and some geologists as a reliable conceptual benchmark in the study of the late- Holocene environmental evolution in the Po plain.

In this study, the main stratigraphic details concerning a choice of fourteen archaeological excavation sites (eleven recently surveyed and three reviewed from the literature) performed by the *Soprintendenza* per *i Beni Archeologici dell'Emilia-Romagna* in the cities of Modena, Bologna and related surroundings was summarized. This allowed us to chronologically delimit a first framework of the riverbed network behaviour during ancient times in the central part of the region. Throughout the entire time span examined (0–600 AD), the alluvial processes appeared to be continuous in Emilia all along the alluvial ridges located in the lower alluvial basins, whereas in the alluvial fan areas the aggradation involved the termination of the fan trench alone. The fan trench was the most sensitive reach of the river system. It aggraded during the 4th century AD and, successively, during the 5th century AD and probably after the end of the 6th century AD, a number of avulsions occurred, indicating that the fluvial system was in a metastable equilibrium, whose behavioural threshold was finally overcome. Thus the importance of the presumed year 589 AD crisis (the "*Deluge*") appears to be less meaningful than previously thought. The riverbed aggradation became evident immediately after the 3rd century AD economic and demographic crisis of the Roman Empire, mainly due to the loss of the land preservation systems formerly created in the catchment areas. Although the starting of the aggradation also coincided with the end of the Petit Maclu 1 high level phase of the European lakes, no quantitative data exist to state that the climate was the main triggering factor for the river net behaviour. The long duration of the aggradation phase suggests that more than one human settlement phase in the minor and middle catchment areas and/or a minor climatic worsening pulse probably occurred between the mid-5th and the mid-6th century AD. Notwithstanding this, the role of climate as a forcing co-factor can be still difficult to evaluate positively, due to the lack of certain, local climatic proxy data availability.

Acknowledgements

We thank the former and present regional Soprintendenti ai Beni Archeologici dell'Emilia-Romagna, L. Malnati and F. M. Gambari respectively, for permission for new data publication; G. Vianello (University of Bologna Agrarian Faculty – Dipartimento di

Scienze e Tecnologie Agroalimentari-CSSAS) for the permission to use the ^{14}C dates related to the site BO-1; L. Forlani (University of Bologna Agrarian Faculty – Dipartimento di Biologia Evoluzionistica e Sperimentale) for the taxonomical definition of the tree sample at site BO 3. The The ^{14}C dates concerning the sites BO2, BO3 and BO4 were funded by "Fondo dipartimentale DISTEGA incentivazione della ricerca (AA. 2010–2011)" and by Fondi ex CNR (person in charge G. Toni and then S. Cremonini) and that of the site BO6 by the RFO-MIUR (ex 60%) 2002–2004 ("Rapporti tra dinamiche ambientali e fluttuazioni climatiche minori nel contesto antropico dell'Emilia-Romagna" e "Assetti geomorfologici dei contesti urbani regionali-Emilia Romagna-Implicazioni ambientali, paleoambientali e storiche" person in charge M. L. Scarin). The numerical dates for Modena sites (MO) were provided by the Archive of the Soprintendenza per i Beni Archeologici dell'Emilia-Romagna.

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