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Long-term fluvial evolution and human occupation in urban fluvial contexts: a geoarchaeological case study from Blois (middle Loire River, France)

Eymeric Morin, Guillaume Hulin, Amélie Laurent-Dehecq, Philippe Gardère, Didier Josset, Viviane Aubourg

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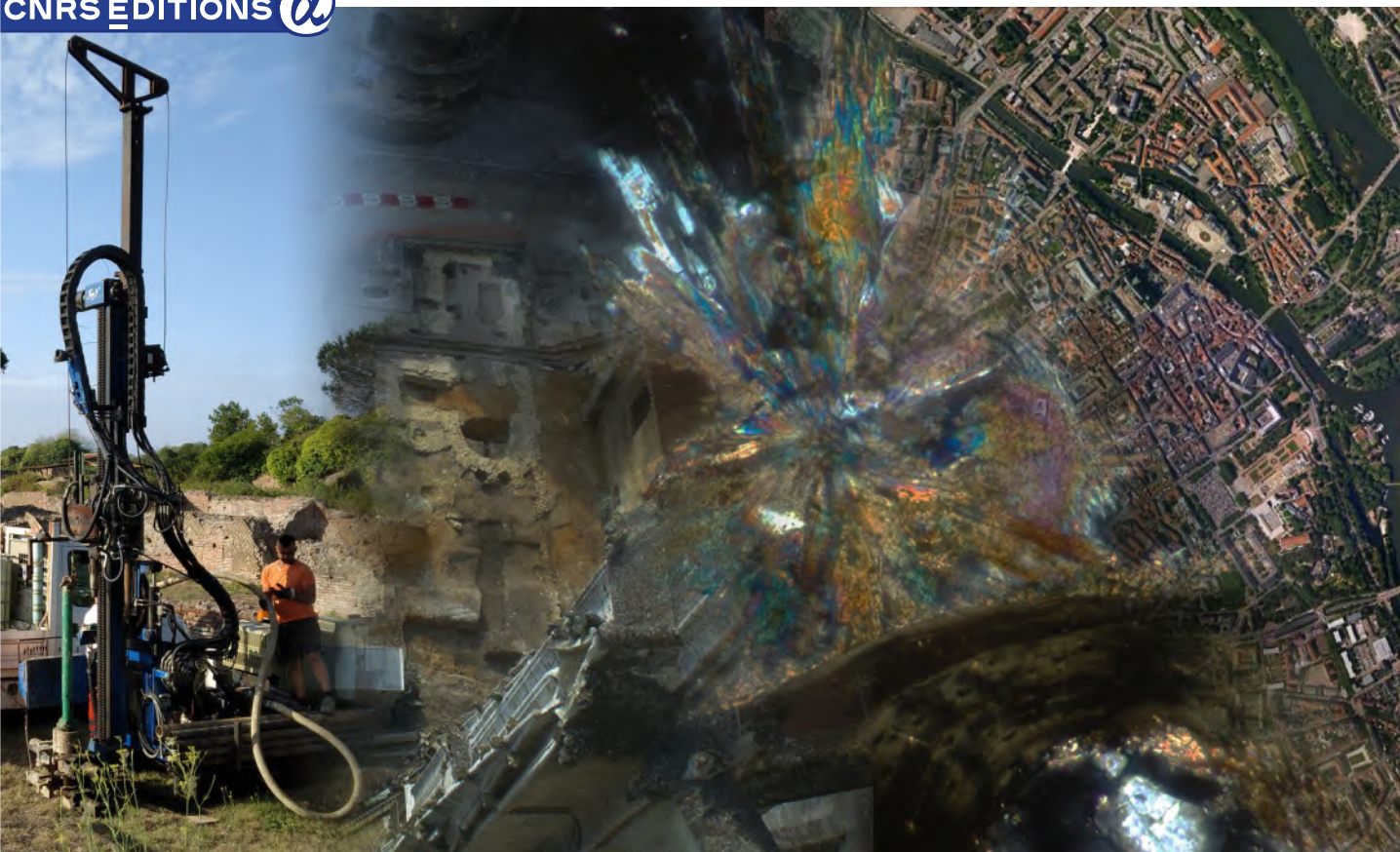
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Scientific editors:
Quentin Borderie and Ferréol Salomon

Urban Geoarchaeology

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The global spread of urbanisation is having a profound impact on environments, climates and social lives. This gives rise to questions about the sustainability of urban areas, the management of soils and sediments and the socio-environmental construction of spaces. Archaeological investigations show that societies produced a wide variety of different urban forms throughout millennia and across continents. By focusing on human-environment interactions through the study of soils and sediments, geoarchaeological research provides new insights into the different ways of making and living in a city in the long term.

With twenty four contributions written by researchers from all over the world, *Urban Geoarchaeology* expands our knowledge of human-environment interactions and ancient urban lifestyles. This volume brings together substantial and comprehensive elements to understand past urban systems, using new interdisciplinary approaches, case studies of broad interest, and innovative techniques to answer historical questions. It shows how geoarchaeologists are producing and discussing new data on the transformation of landscapes through urbanisation. Processes of urban stratification over time are also better understood. The construction of urban spaces can be analysed from the large scale of the urban systems to the microscale of the soil formation, revealing ancient activities and lifestyles. Finally, *Urban Geoarchaeology* helps to connect the past, the present and the future of our cities.

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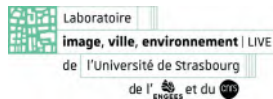
Cover image:
From left to right: Sedimentary drilling in Ostia (Italy) within the Roman city; archaeological excavation in Beauvais (France) from the top of the 16th century cathedral showing Dark Earths and an 11th century church;
star shaped vivianite crystal and a bone through optic microscope cross-polarised light;
aerial view of Metz (France) and the Mosel River.



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Urban Geoarchaeology

Scientific editors: Quentin BORDERIE and Ferréol SALOMON



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Table of contents

Introduction	11
<i>Quentin Borderie, Ferréol Salomon</i>	
Section 1 – Urban landscapes and urban impacts on their environments	25
Short introduction: <i>Ferréol Salomon, Quentin Borderie</i>	
1.1. Geoarchaeological analysis of pedosedimentary archives from site-environment interfaces: reconstructing palaeoenvironmental impacts of protohistoric settlements and towns at Corent (France).....	31
<i>Alfredo Mayoral, Jean-François Berger, Jean-Luc Peiry, Paul Ledger, Yannick Miras</i>	
1.2. Geoarchaeology in the Lisbon estuarine margin (Portugal): environmental evolution, margin morphology changes and anthropic influence	51
<i>Ana Maria Costa, Maria da Conceição Freitas, Jacinta Bugalhão, César Andrade</i>	
1.3. Geoarchaeological study of the water supply of the Roman city of Volubilis (Morocco) around the second half of the first century BCE	71
<i>Stéphane Desruelles, Aomar Akerraz, Véronique Brouquier-Reddé, Abdelilah Dekayir, Elsa Rocca, Daniel Hermitte, Jean-Claude Parisot, M’hamed Alilou, Jean-Baptiste Houal, Mohamed Rouai, El Mehdi Benyassine</i>	
1.4. Long-term fluvial evolution and human occupation in urban fluvial contexts: a geoarchaeological case study from Blois (middle Loire River, France).....	85
<i>Eymeric Morin, Guillaume Hulin, Amélie Laurent-Debecq, Philippe Gardère, Didier Josset, Viviane Aubourg</i>	
1.5. Rhine palaeodynamics from urban geoarchaeological data: the case of Strasbourg (France)	103
<i>Nathalie Schneider, Jean-Jacques Schwiien, Damien Ertlen</i>	
1.6. Evolution of the Nice shoreline profile in relation to urban expansion from the Middle Ages to the present day.....	119
<i>Yann Petite, Sybille Legendre</i>	
1.7. Production-consumption-release of trace metal elements, the urban proxies of the palaeo-anthropocene	133
<i>Hugo Delile, Duncan Keenan-Jones</i>	
Section 2 – Urban stratification processes: Long term sedimentary history of sites, societal issues in stratification process stages	153
Short introduction: <i>Quentin Borderie, Ferréol Salomon</i>	
2.1. Stratigraphy of underground metro systems.....	159
<i>Matt Edgeworth, Mark Williams</i>	
2.2. Basel-Gasfabrik (Switzerland) – a Late Iron Age proto-urban settlement under the microscope...	175
<i>David Brönnimann, Sabine Fiedler, Kristina Reetz, Philippe Rentzel, Hannele Rissanen, Norbert Spichtig</i>	
2.3. From settled villages to mega-sites: a micromorphological approach towards understanding the origins of urbanism in Anatolia.....	191
<i>Aroa García-Suárez</i>	
2.4. A comprehensive model for the formation of urban Dark Earth in Brussels (Belgium)	209
<i>Yannick Devos</i>	
2.5. The urbanocene of Marseille’s Vieux Port: a geoarchaeological perspective	229
<i>Christophe Morhange, Pascale Chevillot, Alexandra Bivolaru, Marie Pawlowicz, Nicolas Weydert, David Kaniewski, Nick Marriner</i>	

2.6. Ancient maps, geotechnical and (geo)archaeological data: GIS integration for the understanding of archaeological sites and for decision making in rescue archaeology	241
<i>Hervé Tronchère-Cottet, Corentin Martinez, Catherine Pothier, Cyrille Ducourthial</i>	
Section 3 – Building urban spaces: Social spaces, Activities and lifestyles	261
Short introduction: <i>Quentin Borderie, Ferréol Salomon</i>	
3.1. The geoarchaeology of urban ecclesiastical sites in coastal locations; Exeter, UK and Trondheim, Norway.....	267
<i>Richard Macphail, John Allan, Chris Carey, Ingeborg Sæhle</i>	
3.2. Activities written in the house floors in urban space of Medieval Brno, Czech Republic.....	279
<i>Lenka Lisá, Antonín Zůbek, Marek Peška</i>	
3.3. Late Antique Basilia – a fortified settlement on the cathedral hill in Basel (Switzerland). Changes in urban land use based on archaeological and geoarchaeological evidence	291
<i>Christine Pümpin, Markus Asal, Philippe Rentzel</i>	
3.4. Geoarchaeology in peri-urban environment: a soil micromorphological case study of the “Land of Aynadamar” in Nasrid, Granada (Spain), the northern outskirts of the last Islamic town in Iberia (13th – 16th centuries).....	307
<i>Rowena Y. Banerjea, Guillermo García-Contreras, Marcos García-García, Luca Mattei, Aleks G. Pluskowski</i>	
3.5. Prelude to the urban – a study of the monumental earthen architecture of the pre- and early historic site of Arslantepe (Turkey).	323
<i>Susanna Cereda</i>	
3.6. Urban garden soils – evidence of medieval and early modern horticulture in European towns	341
<i>Jens Heimdahl, Mateusz Krupski</i>	
Section 4 – Connecting the past, the present and the future of cities	359
4.1. Climate changes, natural hazards and resilience of urban areas.....	361
Short introduction: <i>Ferréol Salomon, Quentin Borderie</i>	
4.1.1. The urban geoarchaeology of imperial China: A case study of the urban renewal and decline of two capital cities, Luoyang and Kaifeng.....	365
<i>Michael J. Storozum, Peng Lu, Panpan Chen, Hui Wang, Xiaolin Ren, Junna Zhang, Zhen Qin, Xiaotao Guo, Tao Liu, Sanying Wang, Qifeng Ge, Haiwang Liu</i>	
4.1.2. Fate of two cities built on sinking ground: slow and fast submergence at Thônis – Heracleion and Canopus, Nile River Delta, Egypt	381
<i>Gilles Brocard, Jean-Philippe Goiran, Damian Robinson</i>	
4.1.3. Resilience research in geoarchaeological investigations of Mediterranean urban sites	401
<i>Rachel Kulick</i>	
4.2. Urban geoarchaeology towards future cities.....	417
Short introduction: <i>Ferréol Salomon, Quentin Borderie</i>	
4.2.1. Urban geoarchaeology and local administration: methods and approaches. The case of the ancient port town of Fréjus (France).....	421
<i>Pierre Excoffon, Stéphane Bonnet, Grégory Gaucher</i>	
4.2.2. When urban geoarchaeology is explained to all types of audiences: the case of Lyon, France.	431
<i>Stéphane Gaillot, Laurent Strippoli</i>	
Geoarchaeology: towards new interdisciplinary challenges and opportunities in the understanding of urban environments.....	443
<i>Ferréol Salomon, Quentin Borderie</i>	
Urban Geoarchaeology and complexity	447
<i>Denise Pumain</i>	

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Long-term fluvial evolution and human occupation in urban fluvial contexts: a geoarchaeological case study from Blois (middle Loire River, France)

Eymeric Morin¹, Guillaume Hulin², Amélie Laurent-Dehecq³, Philippe Gardère⁴, Didier Josset⁵, Viviane Aubourg⁶

Abstract

Blois is an urban centre created by the Romans during the first half of the 1st century AD on both banks of the middle Loire River, expanding up to the present. The city lay in part above a large alluvial plain, shaped by the fluvial activity during the Late Pleistocene and the Holocene. Within this area, a series of human occupations have been documented since the Mesolithic.

During the last three decades, the development of archaeological monitoring enabled the acquisition, in the urban and peripheral areas of the city, of a large dataset of sedimentary information, whose chronology ranges from prehistoric to modern times.

In correlation with their context, the compilation of these multidisciplinary data (archaeological, geological, geotechnical, geophysical and topographical surveys, ¹⁴C and OSL dates, historical sources) allows scholars to better understand the relationships between the transformations of the river and human occupation by societies in the long-term, before and during the city's development.

The example of the city of Blois underlines the potential of geoarchaeology in an urban fluvial environment (i) to better understand the alluvial dynamics of a large river over long periods, (ii) to identify the factors underlying this evolution, (iii) to reconstruct the physical context of diachronic human occupation and reciprocally (iv) to highlight some impacts of human occupation on fluvial dynamics. In this portion of the middle Loire River, the evolution of the fluvial system during the Holocene was tripartite. The study shows how geoarchaeology in an urban fluvial environment plays a role in reading past evolution, with future trends in mind.

Keywords: urban geoarchaeology, fluvial dynamics, alluvial plain, city of Blois, middle Loire River, societies-environment relationships, Late Pleistocene, Holocene

1. Introduction

With the extension of urbanisation in recent decades, much data originating from archaeological,

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geological, geotechnical, geophysical, and topographical fieldwork has been gathered. For geoarchaeologists focusing on urban areas, these data are useful to recognise the geometry of geological formations found under anthropogenic deposits, to understand the palaeogeography of the earliest human occupations and that of the city's foundation (e.g. Galinié *et al.* 2003, Dominique *et al.* 2010, Schuldenrein and Aiuvalasit, 2011).

In a different but complementary way, alluvial sedimentary archives can be used to reconstruct palaeoenvironmental and climatic changes in the long-term and, reciprocally, to understand the induced response to these changes on fluvial systems.

Studies in alluvial and urban settings reveal, in particular, the relationships between the hydro-sedimentary variations of rivers and the development of the riverside towns (Bravard *et al.* 1997, Salvador *et al.* 2002, Arnaud-Fassetta 2011), as well as the relationships between societies and river-related risks (Berger *et al.* 2004, Alline 2007). These studies also help to understand fluvial morphologies and sedimentary dynamic evolutions over several millennia (in relation to climate and anthropogenic forcing), and the constraints these changes imposed on human

occupation; reciprocally, they show the consequences of urbanisation on river dynamics at various times (e.g. Fabre and Monteil 2001, Bravard 2004, Uribealdea and Benito 2008, Morin *et al.* 2014). The site of Blois offers great potential for these research questions.

The Romans established the ancient city of Blois during the first half of the 1st century AD, on the northern slope of the valley and on both sides of the current Loire River in the floodplain. In the valley of Blois, earlier human presence or occupation dated from the Mesolithic, Neolithic and Metal Ages are attested by archaeology (e.g. Poitevin *et al.* 2016, Payne *et al.* 2019, Kildea *et al.* 2020, Dalayeu *et al.* 2021).

Following its foundation, the city gradually expanded until the present-day, more densely on the right bank than on the left (district of Vienne). The

Royal Château of Blois, built on a promontory on the valley's northern slope, was one of the most appreciated residences of the kings of France during the Renaissance period.

Increasing urbanisation of the alluvial plain of Blois has been monitored since the 1990s by preventive archaeological surveys. Since 2013, the city and its peripheral rural areas have been studied by an archaeological research programme investigating, in particular, the relationship between environments and human societies (Josset *et al.* 2016, 2019).

On the Loire River's left bank, in the town's periphery and beyond, the alluvial plain of Blois still contains vast grasslands with wooded areas. The joint studies of urbanised and peripheral rural areas helps reconstruct the main features of the alluvial plain's morpho-sedimentary evolution.

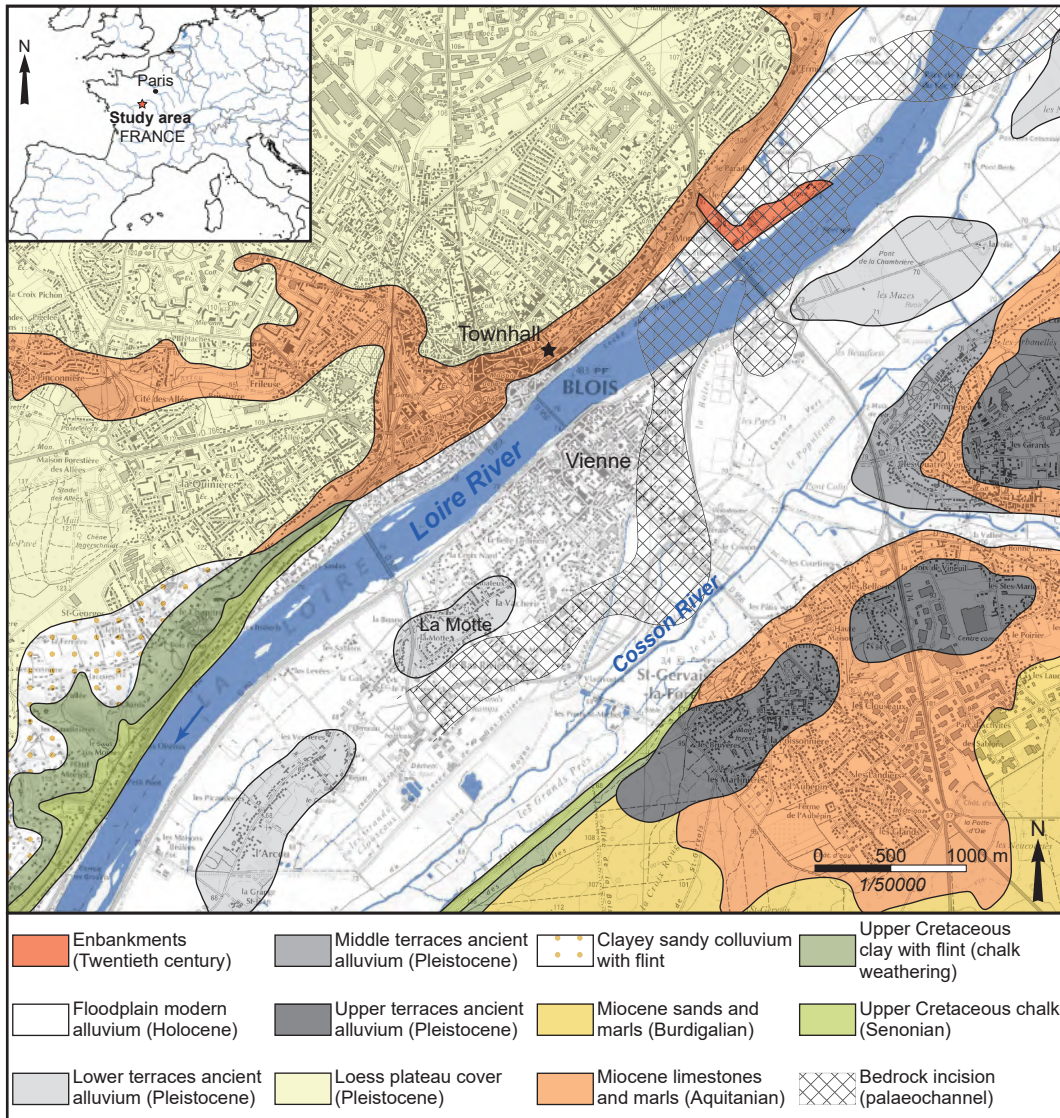


Figure 1: Location map and geological setting of the study area.

This synthesis is essentially based on chrono-sedimentary and geophysical records, and presents the main morphological and sedimentary evolution of an urbanised alluvial plain in the long-term. The results were collated in order to (i) reconstruct the main features of the evolution of the alluvial plain of Blois during the Late Pleistocene and Holocene (until historical periods), (ii) identify the factors underlying this evolution, (iii) highlight the physical context of human occupation over time, and reciprocally (iv) to show some human impacts on fluvial dynamics.

2. Study area

2.1. Geographic and geological contexts

The study area is located in France, south-west of the Parisian Basin, in the middle valley of the Loire River (location of Blois' town hall: 47°35'19" N; 1°20'14" E; fig. 1). It is a portion of alluvial plain of approximately 9 km², 3.5 km long and at most 2.45 km wide. Current altitudes range approximately between more than 75 m NGF¹ upstream (20th century elevations) to 67 m NGF downstream (fig. 2).

The floodplain is bordered in the north-west and south-east by fairly steep slopes composed upstream of Miocene lacustrine limestone and downstream of Upper Cretaceous limestone, the transition between these two formations marking the border of the Beauce's Tertiary Basin (Caudron *et al.* 1974; fig. 1).

On the valley floor, two major fluvial entities are shown on the geological map (*ibid.*):

- The modern alluvium, most widespread in the plain and attributed to the Holocene period;
- The lower terraces of ancient alluvium, creating lined up hillocks on the left bank of the Loire, 2 – 3 m above the modern alluvium's summit (e.g. at the location called La Motte; fig. 1, fig. 2).

The Loire River channel currently flows in the northern part of the alluvial plain. It leaves a small portion of alluvial plain to its right (80 - 250 m wide) and a much wider and less urbanised one to its left (fig. 1, fig. 2). In the north-east of the studied area, one finds the junction of the Cosson river valley and that of the Loire. The current channel of this tributary (95 km long) does not directly flow into the Loire adjacently to this junction; it forms a 90° curve to the south-east, then flows parallel to the valley (fig. 1, fig. 2).

2.2. Current knowledge about the alluvial plain evolution

Beneath the alluvium, the top of the bedrock is very irregular, featuring channelised and karst structures (Lorain 1974). An incision in the bedrock made by an ancient channel goes around the south of the district of Vienne (fig. 1).

At least since Roman times, the Loire River channel flowed at its current location, as evidenced by the remains of a bridge dated to the 1st century AD (Josset *et al.* 2019: 41-59). The Loire channel was enclosed within wooden structures since the beginning of the 15th century, so as to reduce risk of flooding. Levees and spillways have been created since the 16th century, and rocky embankments appeared from the 17th (Dion 1961). The successive levees framing the district of Vienne were built to deflect Loire floods towards the south (fig. 2).

Since the Late Middle Ages, the crossing of the alluvial plain was facilitated by stone pathways made of arches and bridges: the Ponts Saint-Michel to the south (first written mention in 1202) and the Ponts chartrains to the north (first written mention in 1343; fig. 2; Dupré 1876). These constructions were often damaged by floods, but have been used until the 18th - 19th centuries.

Among the various old examples of art that depict the alluvial plain of Blois, the one drawn by De La Saussaye (1883) suggests the existence of a large palaeochannel to the south of the current district of Vienne prior to the 10th century AD (fig. 3). The term of 'city island' has indeed been considered as the marker of Blois' royal status, comparable to the Ile de la Cité in Paris (Lorain 1980).

The written chronicles archived between the early 16th and the mid-20th centuries relate several episodes of flooding (*ibid.*).

During historical periods, but probably also earlier, floods of the Loire and Cosson could be simultaneous, but this was not systematically the case. Major historical floods were mainly related to the dynamics of the Loire River. Independently, the Cosson could also rapidly expand, as shown recently (e.g. years 1977, 2016).

3. Materials and methods

The current topographic surface of the floodplain of Blois was drawn by means of a survey carried out by LiDAR in 2002 - 2003, with a planimetric and altimetric accuracy of 0.30 m and 0.15 m respectively (fig. 2).

1. General Levelling of France

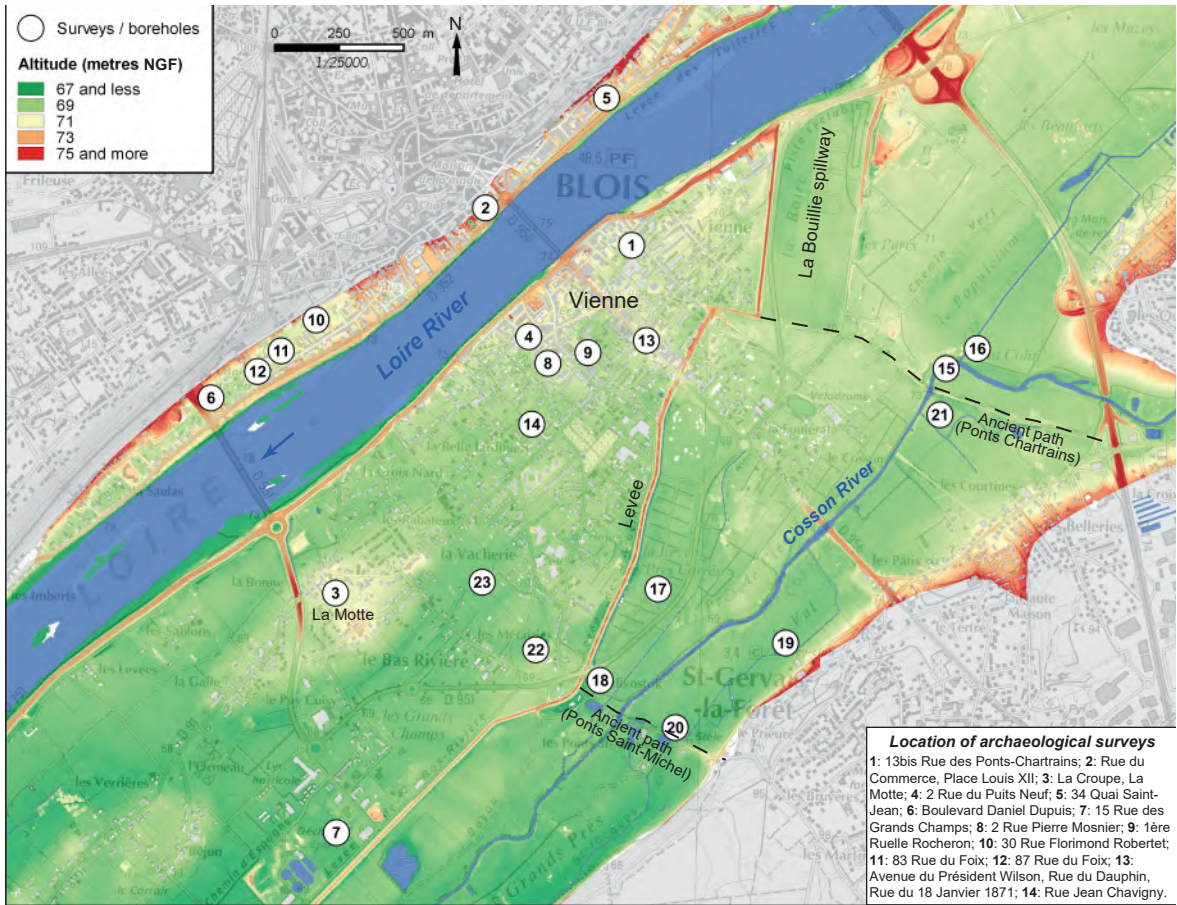


Figure 2: Current digital elevation model (LiDAR) and location of the studied stratigraphies (1 - 14: logs and sections provided by preventive archaeology; 15 - 20: core drillings; 21 - 23: geotechnical surveys).

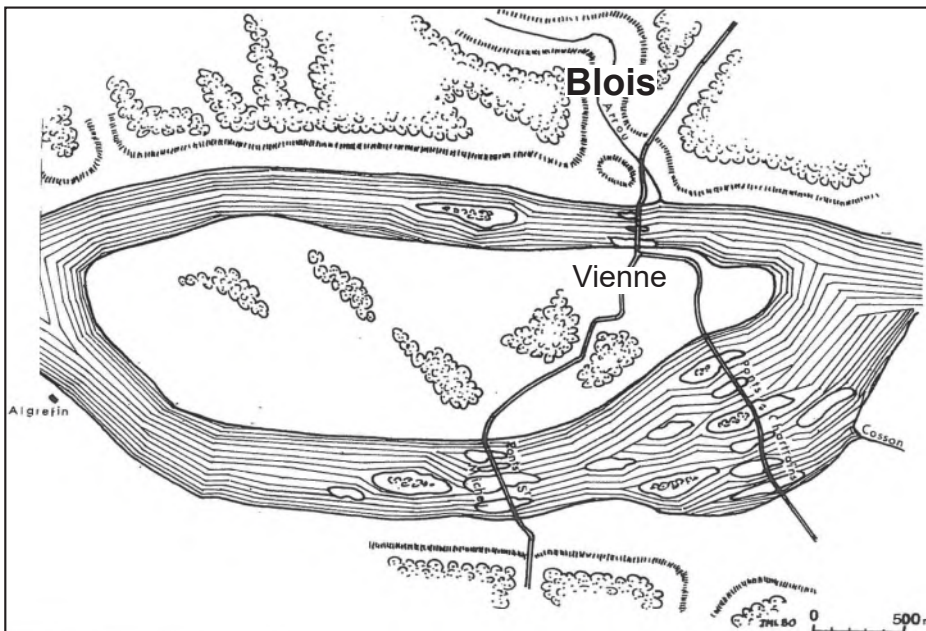


Figure 3: An old example of art depicting the alluvial plain before the 10th century; L'île de Vienne created by De La Saussaye (1883), as restituted by Lorain (1980); modified.

Peripheral rural areas on the left bank were investigated over 0.676 km² during a geophysical electro-magnetic prospection (EM 31¹; fig. 4). The positioning of the measurements was recorded by DGPS: sampling was carried out every 40 cm inside profiles, and on average of 5 to 10 m in between profiles.

The data collected in preventive archaeological surveys in the alluvial plain these last twenty years were systematically compiled and checked (Josset *et al.* 2019: p. 353-365). They required processing before they could be included in the synthesis. The trenches excavated during preventive surveys have mostly been dug with motorised excavators; stratigraphies were recorded with logs or sections of varying depth. Sedimentary sequences were referenced using a tacheometer or DGPS. A selection of fourteen informative stratigraphies recorded during these surveys is presented below (nos. 1-14; fig. 2, fig. 5).

On the Loire's left bank (fig. 2, fig. 6), in the framework of the archaeological research programme,

facies and thickness of the alluvial sediments were observed directly from:

- Fourteen core drillings, retrieved with a percussion sampler², reaching the bedrock and referenced using a DGPS (Josset *et al.* 2016: p. 95-111); a selection of six pertinent drillings is presented (nos. 15-20);
- Twenty-two bore holes made with a computer-assisted dynamic penetrometer³ and referenced using DGPS (Josset *et al.* 2016: p. 89-94); a selection of three boreholes is also presented (nos. 21-23).

The chronology of the alluvial plain was constrained with eight 14C AMS and five OSL dates, but also by artefacts from the sedimentary sequences (lithic and ceramic). The 14C ages were calibrated with the extremes values of 95.4 % range with the Calib 7.10 software (Stuiver et Reimer 1993) using the IntCal20 database (Reimer *et al.*

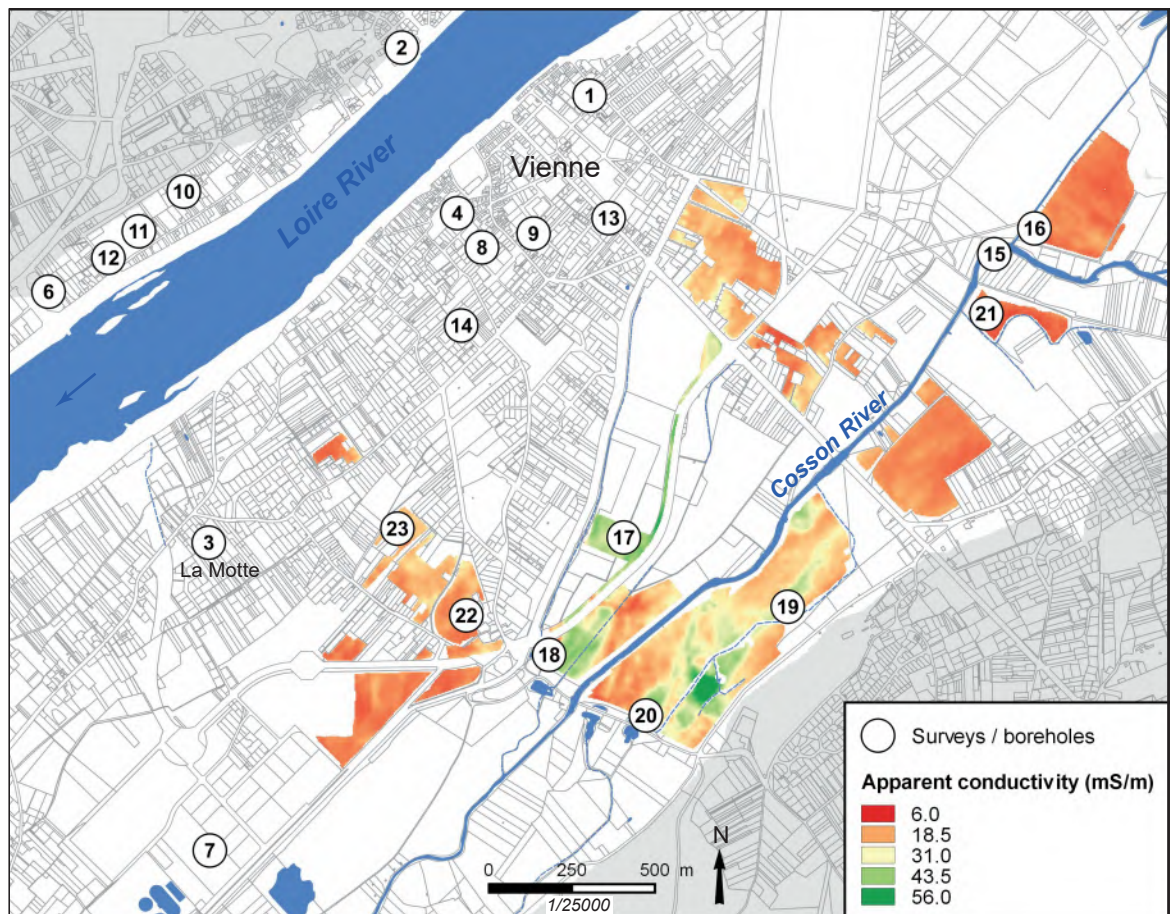


Figure 4: Electro-magnetic mapping (EM 31) and location of the studied stratigraphies (1 - 14: logs and sections provided by preventive archaeology; 15 - 20: core drillings; 21 - 23: geotechnical surveys).

1. Geonics Limited instrument, Slingram method, Horizontal CoPlanar mode

2. Atlas Copco, Cobra TT*
3. PANDA*

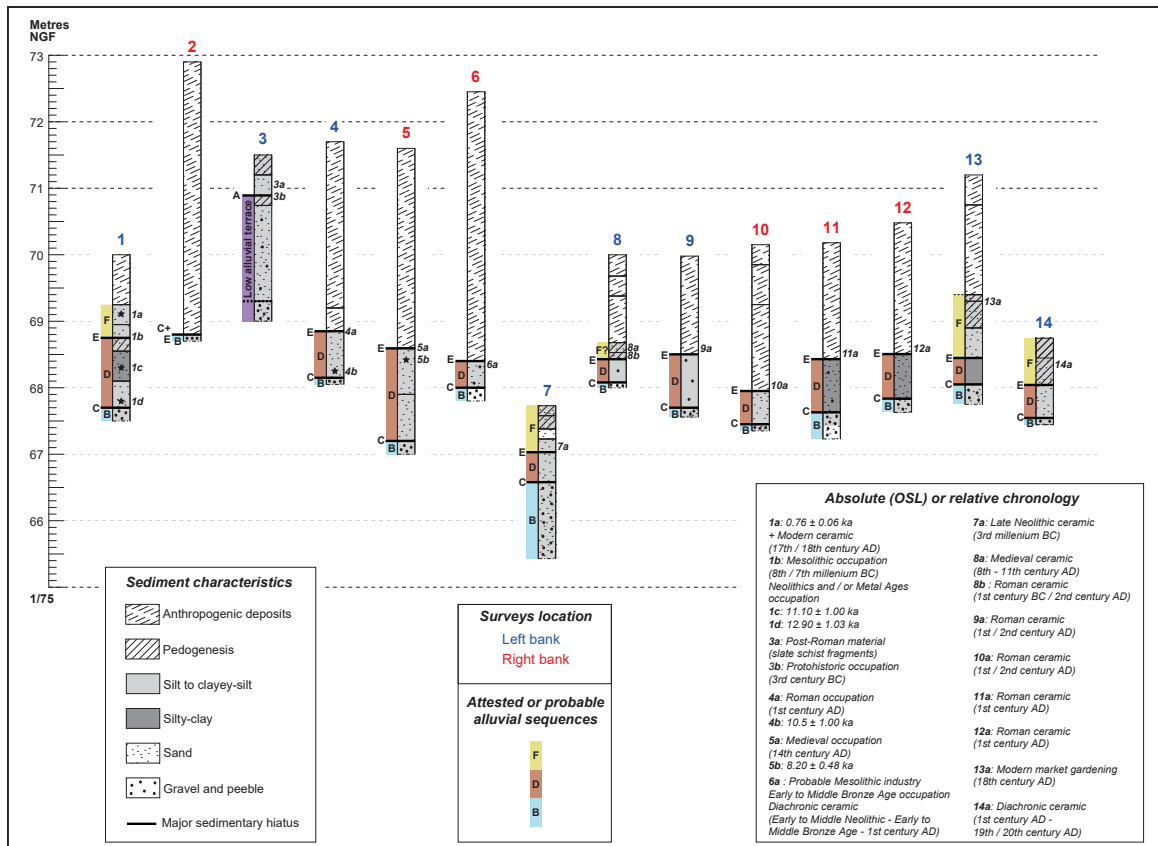


Figure 5: Selection of stratigraphies recorded by preventive archaeological surveys with logs and sections.

2020; tab. 1). The OSL ages were measured at the Geological Institute of Hungary (Budapest) and calculated with a Central Age Model, taking into consideration the homogeneous distribution of the equivalent doses in the different samples (Galbraith *et al.* 1999; tab. 1). The absolute chronologies recorded in the alluvial plain of Blois extend from the Late Pleistocene (Younger Dryas) to the Holocene (Middle Ages). Regional palynozones are considered here (Visset *et al.* 2005).

4. Results

4.1. The alluvial plain current relief

The Lidar survey highlighted different characteristics of the present-day alluvial plain’s morphology in the studied area (mean value of altitude: 69.30 m; fig. 2). The aligned hillocks making up the lower alluvial terraces on the Loire’s left bank are well identified (e.g. at the location named La Motte). The current Cosson River apparently flows into a slight topographic gutter, depressed from about 1 to 1.5 m relative to nearby areas of the alluvial plain.

The elevation of the ground surface with anthropogenic deposits is clearly indicated by the Lidar in the most urbanised areas, such as a large sector of the Loire’s right bank, but also in the district of Vienne on the left bank. The belt of levees around the district of Vienne and the spillway named La Bouillie appear to be significant elements of the current morphology, because of their high and low altitude, respectively (fig. 2).

4.2. Stratigraphic and chronological data

Multidisciplinary data retrieved in the alluvial plain of Blois enabled chrono-stratigraphic correlations to be made. Three major phases of sedimentation were identified (respectively B, D and F), framed by three chronological and sedimentary hiatuses, which indicate a lack of sedimentation or even erosion/incision (A, C and E, fig. 5, fig. 6).

On the valley floor, the irregular surface at the summit of the bedrock was shaped before 12.9 ± 1.03 ka (phase A; fig. 5, no. 1; fig. 6, tab. 1). This surface is overlain by gravelly and sandy sediments deposited over the whole alluvial plain, also before 12.9 ± 1.03 ka (phase B; fig. 5, fig. 6); the surface of these coarse sediments is not specifically irregular.

On the north valley footslope, strips also made of coarse sediments are located slightly above the rest of the phase B alluvium (e.g. fig. 5, no. 2), but well under the summit of deposits forming the lower terraces (fig. 5, no. 3), and further away from those of the middle and higher terraces (fig. 1).

The bend formed by the Cosson was created prior to 9860 ± 50 BP (11 396-11 194 cal BP), as shown in a palaeochannel of this tributary (fig. 6, no. 15; tab. 1). The bottom of this palaeochannel is 2.15 m deeper in comparison to the observed surface of bedrock in this sector, and 2.85 m under the top of the phase B sediments (fig. 6, no. 16; Josset *et al.* 2016: p. 65-83). It is likely that the surface of the phase B deposits corresponds to a hiatus in the entire floodplain (phase C).

The phase B sediments were overlain by sandy-silty clayey to silty-clayey alluvium with poor gravelly fraction (phase D), as early as 12.9 ± 1.03 ka, during 11.1 ± 1 ka, 10.5 ± 1.0 ka, and at least until about 8.2 ± 0.48 ka (fig. 5, nos. 1, 4 and 5; tab. 1). The facies of the phase D deposits generally show orange-like to brownish or even greenish colours, which argue in favour of post-depositional evolution (soil formation and/or hydromorphic processes). During phase D, sedimentation is also attested at the bottom of the

Cosson's palaeochannel, at nearly 9860 ± 50 BP, with the deposition of sand with organic remains (fig. 6, no. 15).

At the summit of the phase D alluvium, on the ancient soils constituted with reduced sedimentation, human occupations dated from the Mesolithic were discovered, with evidence of the lithic artefacts remaining (Couvin *et al.* 2017; Kildea *et al.* 2020; fig. 5, nos. 1, 6). At the same locations, these ancient soils were reoccupied during the Neolithic and/or the Metal Age period, as mainly shown by the presence of archaeological pits including lithic and ceramic material (ibid., Jouquand *et al.* 2018).

After 8.2 ± 0.48 ka and until nearly 3835 ± 35 BP (4404 – 4099 cal BP; fig. 6, no. 17; tab. 1), evidence for an important chronological and sedimentary hiatus, covering almost four millennia, was found in the alluvial plain (phase E).

The resumption of fluvial dynamics is observed at deep, low lying sites of the plain's ancient landscape since 3835 ± 35 BP (end of Subboreal period; Late Neolithic to Early Bronze Age) and 3620 ± 35 BP (4079 – 3836 cal BP; beginning of Subatlantic period; Early Bronze Age). This is mainly indicated by the Loire's deposition of clayey-silty or gravelly sandy sediments including organic remains (phase F);

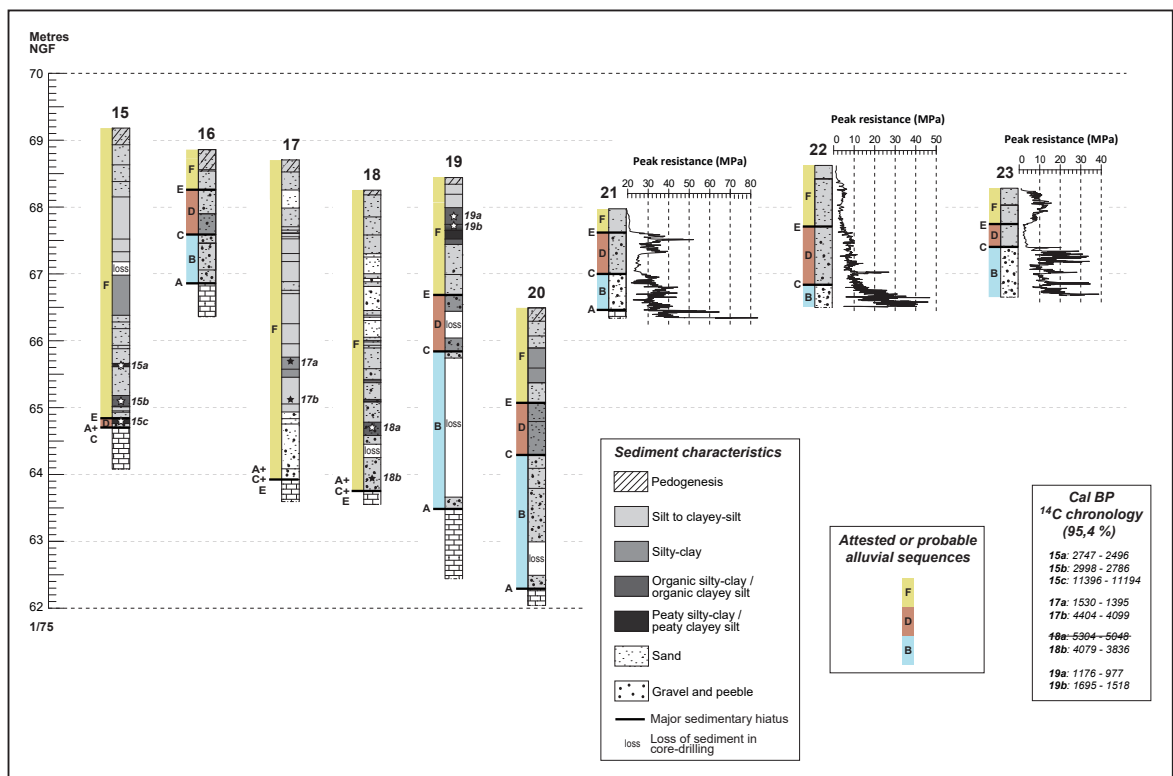


Figure 6: Selection of stratigraphies recorded in the framework of the archaeological research project with core drillings and geotechnical surveys.

fig. 6, nos. 17-18; tab. 1). The date of 4510 ± 30 BP (5304 - 5048 cal BP) was rejected because of its stratigraphic incoherence (probably an old wood problem; fig. 6, tab. 1). Downstream from the area studied, increased sedimentation during phase F is attested almost since the Late Neolithic, as shown by ceramic remains in secondary context, with the sandy-silty sediments covering the phase D deposits (e.g. fig. 5, no. 7).

On the Cosson River, the resumption of sedimentation occurred a little later, with the deposition of organic silty-clayey-sand during the Subatlantic period, around 2805 ± 30 BP (2998 - 2786 cal BP; Late Bronze Age) and 2545 ± 30 BP (2747 - 2496 cal BP; 1st Iron Age; fig. 6, no. 15; tab. 1).

The beginning of the Roman period is not well documented by the sedimentary archives. The ceramic finds from the 1st - 2nd centuries AD were mostly discovered at the summit of the phase D alluvium, below the first anthropogenic deposits, or even included among the latter (fig. 5, nos. 3-5 and 7-12). Since the Roman period, the urban area's ground surface was increasingly elevated with anthropogenic deposits, reaching 1.70 to 4.10 m thick on the right bank and zero to 2.80 m on the left (fig. 5, nos. 1-12).

The end of the Roman period and the Early Middle Ages are documented by the deposition of silty-clayey-peaty and organic clayey sediments from the Cosson River, dated respectively to 1680 ± 30 BP (1695 - 1518 cal BP) and 1180 ± 30 BP (1176 - 977 cal BP; fig. 6, no. 19; tab. 1). The dynamics of the Loire is recorded in the Early and Late Middle Ages via the infilling, with silty sandy clay sediments, of a deep sedimentary site located on the left bank during and after 1580 ± 30 BP (1530 - 1395 cal BP; fig. 6, no. 17); it is also shown by a sedimentary accretion close to the current channel near 0.76 ± 0.06 ka (fig. 5, no. 1). Medieval occupation can be based on the alluvium deposited during phase D (e.g. fig. 5, no. 5).

As regards to the Modern and Contemporary periods, the evolution of fluvial dynamics is much better documented and detailed by written archives and old maps (Lorain 1974, 1980) rather than by sedimentary archives. On the left bank, in peripheral areas of the Vienne district, the sediments deposited during phase F were exploited for cultivation and gardening between the 18th and the 20th centuries, and must not be used here for reconstruction (fig. 5, nos. 13-14).

After the 3rd century BC (Late Iron Age) and the Roman period, depositions of human-induced colluvium, with inclusions of slate schist fragments, have been observed on the edge of the lower alluvial terraces (e.g. fig. 5, no. 3).

4.3. The geophysical data

The measurement of the electrical conductivity of the deposits is very informative in an alluvial context, because it is mainly influenced by the abundance of clay content, which generally indicates locations of low flood sedimentation. However, in the middle Loire context, values can be also influenced by the presence of iron oxides (e.g. magnetite), sometimes abundant in the fine sand fraction of the sediments (Macaire *et al.* 2013).

The apparent conductivity values recorded during the electro-magnetic prospections ranges from 6 to 56 mS/m (fig. 4). Vast areas show apparent electrical resistance due to the presence of coarse sediments (i.e. gravel, sand) or a low depth of the bedrock surface. This is well observed around the bend of the Cosson River (fig. 4, fig. 6, nos. 18 and 21), but also in more central places of the alluvial plain (nos. 22-23).

Some areas with high electric conductivity, structured by a pattern of ancient channels, are also shown. The existence of a main palaeochannel of the Loire River going around the south of the Vienne district, with a size larger than 170 m, is highlighted (fig. 4, fig. 6, nos. 17-18). The infilling of this last palaeochannel was recorded between 3835 ± 35 BP and after 1580 ± 30 BP (fig. 6, nos. 17-18; tab. 1).

Near the current channel of the Cosson, the apparent electrical conductivity indicates the existence of small and braided ancient channel systems, filled in and proximally with more or less organic sediments (fig. 4, fig. 6, nos. 19-20).

5. Discussion

The retrieved data enables a reconstruction of the long-term general hydro-sedimentary evolution of the middle Loire River around Blois, in relation with climatic and / or anthropogenic forcings. This evolution had consequences on the use / occupation by human societies settling the alluvial plain. The main features of this evolution are set out below in chronological order, from older to more recent phases, according to the already defined chronosedimentary sequences.

Given that one is dealing with an alluvial plain, this study takes into account that:

- An overflow provides deposits of different sediments, depending on the distance of active channels and the alluvial morphology; this implies various post-depositional trends (i.e. hydromorphic and pedogenesis processes);
- Diachronic floods can deposit the same type of sediments;

14C datings											
Survey / borehole number	Depth (metres)	Altitude (metres GLF)	Dated material	Sediment facies	Conventional radiocarbon age (BP)	95,4 % calibrated age (calBC / AD)	95,4 % calibrated age (calBP)	Laboratory code	Archaeological period	Regional palynozones	Notation on fig. 5
19	0,58	67,87	Plant material	Grey organic clayey silt	1180 ± 30	774-899 (87%) / 918-959 (12%) / 967-973 (1%)	1176-1051 (87%) / 1032-991 (12%) / 983-977 (1%)	Lyon-13596	Early Middle Age	Subatlantic	19a
17	3	65,69	Plant material	Grey silty-sandy clay	1580 ± 30	420-555 (100%)	1530-1395 (100%)	Lyon-13595	Late roman period / Early Middle Age	Subatlantic	17a
19	0,71	67,73	Plant material	Greyish to dark brownish silty-clayey peat	1680 ± 30	255-284 (15%) / 326-432 (85%)	1695-1666 (15%) / 1624-1518 (85%)	Beta-391988	Late Roman period	Subatlantic	19b
15	3,54	65,65	Plant material	Brownish organic silty-clayey sand	2545 ± 30	798-743 (43%) / 692-664 (15%) / 646-547 (42%)	2747-2692 (43%) / 2641-2613 (15%) / 2595-2496 (42%)	Lyon-12510	First Iron Age	Subatlantic	15a
15	4,08	65,10	Plant material	Blackish organic silty sand	2805 ± 35	1049-894 (93%) / 878-837 (7%)	2998-2843 (93%) / 2827-2786 (7%)	Lyon-12511	Late Bronze Age	Subatlantic	15b
18	4,28	63,96	Wood or root fragment	Sand and gravels	3620 ± 35	2130-2089 (9%) / 2044-1887 (91%)	4079-4038 (91%) / 3993-3836 (9%)	Lyon-13597	Early Bronze Age	Late Subboreal to early Subatlantic	18b
17	3,57	65,14	Plant material	Grey-blue clayey-silty sand	3835 ± 35	2455-2417 (8%) / 2409-2199 (90%) / 2164-2150 (2%)	4404-4366 (8%) / 4358-4148 (90%) / 4113-4099 (2%)	Lyon-12513	Late Neolithic / Early Bronze Age	Subboreal	17b
18	3,55	64,70	Wood fragment	Grey-greenish heterometric silty sand	4510 ± 30	3355-3260 (33%) / 3252-3099 (67%)	5304-5209 (67%) / 5201-5048 (33%)	Beta-391989	Late Neolithic	Subboreal	18a
15	4,38	64,80	Peat	Blackish peaty silt	9860 ± 50	9447-9417 (7%) / 9410-9245 (93%)	11396-11366 (7%) / 11359-11194 (93%)	Lyon-12512	Late Palaeolithic	Preboreal	15c

OSL datings									
Survey / borehole number	Depth (metres)	Altitude (metres GLF)	Dated material	Sediment facies	OSL Age (ka)	Laboratory	Archaeological period	Regional palynozone	Notation on fig. 4
1	0,90	69,10	Quartz grains	Sandy silt	0,76 ± 0,06	Geological Institute of Hungary, Budapest	Late Middle Age	Subatlantic	1a
5	3,20	68,40		Fine sand	8,20 ± 0,48		Mesolithic	Older Atlantic	5b
4	3,45	68,25		Sandy silt	10,50 ± 1,00		Late Palaeolithic	Late Preboreal to early Boreal	4b
1	1,60	68,40		Clayey silty coarse sand	11,10 ± 1,00		Late Palaeolithic	Preboreal to early Boreal	1c
1	2,20	67,80		Silty coarse sand	12,9 ± 1,03		Late Palaeolithic	Allered to Late Dryas	1d

Table 1 : 14C and OSL datings provided from archaeological studies in the alluvial plain of Blois (rejected dating underlined with grey).

- Probable sedimentary hiatuses, linked to erosion or incision phases, induce different preservation of sedimentary archives;
- Fossilised time recorded by alluvial archives only corresponds to a small fraction of dynamic time (Macaire 1990);
- Artefact inclusions in alluvium could be of syn- or post-depositional origin (respectively from fluvial reworking or even spreading of materials with manuring); this has not generally been well identified in the sedimentary sequences; the presence of remains should thus be verified before being interpreted, in terms of terminus-post-quem or terminus-ante-quem.

5.1. The Late Pleistocene incision of the bedrock (phase A)

In the Blois valley floor, the irregular shape of the summit of the Cretaceous and Miocene bedrock is probably polygenic. However, it may have been mostly modelled during a major erosion and incision phase of the valley, long before 12.9 ± 1.03 ka (fig. 5, no. 1; fig. 7). This incision locally shaped the deposits forming the low terraces (e.g. fig. 5, no. 3) and incised the palaeochannel going around the south of the district of Vienne (fig. 1; fig. 6, no. 17; Lorain 1974).

A similar incision phase, prior to the emergence of true periglacial climatic conditions, therefore, before Marine isotope stage 4¹ (MIS 4; Lisiecki and Raymo 2005), was observed further upstream and downstream on the middle Loire River (Castanet 2008, Morin *et al.* 2011, 2014), as well as in north-western Europe (e.g. van Huissteden *et al.* 2001, Antoine *et al.* 2007). It is likely that this major incision occurred during the transition between MIS 5² - MIS 4. The duration of this phase could have been relatively brief, in comparison with the sediment deposition periods that frame it (Vandenberghe 2008).

However, after phase A, bedrock incision continued in active channels until much later, i.e. before 3835 ± 35 BP, for instance in the palaeochannel going around the district of Vienne (fig. 6, no. 17), and even up to this day in the current Loire channel (Gazowski 1994).

5.2. The Late Pleistocene sedimentation phase (phase B)

After the last major incision of the bedrock (phase A), sedimentation began to accumulate in the alluvial plain, also long before 12.9 ± 1.03 ka,

with the deposition of generally sandy-gravelly or sandy alluvium (phase B; fig. 7). These facies and their extensive distribution indicate sedimentation in high-energy, multi-channel river systems, characteristic of periglacial environments. They could have been braided-stream or anastomosing-stream systems, as already suggested for the middle Loire River during this period (respectively: Burnouf *et al.* 2003, Morin *et al.* 2014).

This type of coarse deposit is uniformly distributed at the base of the sedimentary infilling of floodplains in north-western Europe, and has been attributed to different periods between MIS 4 and MIS 2³ (e.g. Haesaerts 1984, Pastre *et al.* 2002). In the middle Loire River catchment, they are generally attributed to the MIS 4 (Castanet 2008, Morin *et al.* 2011), the MIS 2 (Macaire 1983, Morin *et al.* 2014), or even the Early Holocene (Macaire *et al.* 2002).

In the alluvial plain of Blois, this gravelly sedimentation thus probably started during MIS 4; it could have continued further into the MIS 2, before the end of the Last Glacial Maximum (~19 – 20 ka; Clark *et al.* 2009). During this long phase of apparent sedimentation, the Loire and the Cosson probably formed a combined hydrographic system within the valley.

5.3. The phase of Late Pleistocene fluvial retraction and incision (phase C)

The deposition of coarse sediments during phase B probably ended after the Last Glacial Maximum and before 12.9 ± 1.03 ka (MIS 2 ending; fig. 7). During this period, a metamorphosis of the fluvial system took place in the alluvial plain. This was characterised by the end of high-energy periglacial sedimentation and then, further, by a change in fluvial style. This change apparently led to the retraction and the incision of two river channels: (i) the current channel of the Loire, which since this time has hardly not moved from its present-day location and (ii) the palaeochannel bypassing the district of Vienne via the south.

The stage of this fluvial metamorphosis period may be seen in relation to the Bölling warming (Taylor *et al.* 1993), which is often associated with a phase of channel incision. This incision was largely observed in the middle Loire and its catchment (Castanet 2008, Piana *et al.* 2009, Morin *et al.* 2011, 2014), in the Paris Basin (e.g. Antoine 1997, Pastre *et al.* 1997) and in north-western Europe (Haesaerts 1984, Tebbens *et al.* 1999, Mol *et al.* 2000). Upstream and downstream on the Loire River, similar incision and retraction of the fluvial system was followed up by peaty sedimentation in abandoned channels during a period spanning from

1. ~ 71 - 57 ka
2. ~ 130 - 71 ka

3. ~29 – 11.7 ka

the Alleröd warming to the Boreal period (Garcin *et al.* 1999, Morin *et al.* 2014); this peaty sedimentation has not yet been recorded in the alluvial plain of Blois.

5.4. The Late Pleistocene to early Holocene phase of sedimentation (phase D)

At least since $12,9 \pm 1,03$ ka (Younger Dryas period) and until nearly $8,2 \pm 0,48$ ka (middle Atlantic period; fig. 5, no. 5; fig. 7), a detrital sedimentation, composed mainly of sandy-silty clayey to silty-clayey alluvium (including a poor gravelly fraction), took place once more in the alluvial plain.

The resumption of sedimentation during phase D clearly indicates an important modification in local fluvial dynamics. It therefore implies a rise in the base level of the fluvial system towards the end of the Late Pleistocene and the beginning of the Holocene, favourable to sedimentogenic flooding episodes around a reduced number of channels (i.e. floodplain context).

The significant erosion of slopes observed during the Younger Dryas in the upstream catchment of the Loire River, induced by climatic cooling and an associated drop in vegetation cover (Gay *et al.* 1998, Macaire *et al.* 2010), could be related to the beginning of phase D. In the Blois valley, deposition during phase D persisted until the middle Atlantic period, in concomitance with the 8.2 ka event (von Grafenstein *et al.* 1998), thus before the establishment of a protective vegetation cover during the Holocene climatic optimum.

During the Pleistocene - Holocene transition, a fluvial incision was largely recorded upstream and downstream on the middle Loire (Carcaud *et al.* 2002, Burnouf *et al.* 2003, Castanet 2008, Morin *et al.* 2014), in the Paris Basin (Antoine 1997, Pastre *et al.* 1997) and in north-western Europe (e.g. Tebbens *et al.* 1999, Mol *et al.* 2000). This incision phase was not clearly recognised in the alluvial plain of Blois, but one cannot exclude that the apparent sedimentation developing during phase D hides it. Indeed, the incision of the Cosson River palaeochannel, before 9860 ± 50 BP (fig. 6, no. 15), could have initially developed during phase C and deepened during the phase D. Around 9860 ± 50 BP, the deposition of organic alluvium at the bottom of the Cosson channel reflects this tendency for the water base to rise at the beginning of the Holocene.

5.5. The middle Holocene hiatus (phase E)

A major sedimentary hiatus is recorded in the alluvial plain between 8.2 ± 0.48 ka and 3835 ± 35 BP (fig. 7). It is characterised by a relative morphological

stability over several millennia, linked with a drop in the frequency of sedimentogenic floods. The average level of the river and the hydro-sedimentary fluxes were probably relatively low at this period, limiting lateral sedimentary output from active channels. These ancient channels could have deepened at this period, as indicated by the sedimentary fill of the palaeochannel of the Cosson, where deposits dated 9860 ± 50 BP and 2805 ± 35 BP are directly buried (fig. 6, no. 15). This general downward trend in fluvial dynamics was already observed on the middle Loire River during the Middle Holocene, particularly in the infilling with peaty deposits in abandoned channels (Garcin *et al.* 1999, Castanet 2008, Morin *et al.* 2014).

This period was favourable to the development of alteration and pedogenesis within deposits of phase D, as shown by their generally orange to brownish colour. It was thus a favourable context for human diachronic occupations. At the top of the alluvium of phase D, several Neolithic and / or Metal Ages archaeological pits have made holes in the palaeosol occupied during the Mesolithic period. These archaeological data confirm the existence of a relative long-term morphological stability over in the alluvial plain and respectively opportunities for human societies to settle, even near active channels (e.g. Burnouf *et al.* 2001). Foot crossing of the alluvial plain during these occupation periods is an open question. It was apparently mostly constrained by the presence of two active channels of the Loire River: the modern day and the ancient one, the latter flowing around the present district of Vienne.

5.6. Late Holocene sedimentation period (Phase F)

Since at least 3835 ± 35 BP and around 3620 ± 35 BP (fig. 6, no. 18; fig. 7), the resumption of sedimentation is attested in the Loire's palaeochannel, which was since gradually filled up with sandy-silty sediments. This trend is undoubtedly linked to the rise of the mean level of the water table. It is contemporary with the global fresh and humid climatic episode recognised during the Middle - Late Holocene transition (Barber *et al.* 1994), which marked the beginning of the Neoglacial period (Berger and Loutre 1991). In the Cosson River palaeochannel (fig. 6, no. 15), the sedimentation recorded since 2805 ± 35 BP and until after 2545 ± 30 BP appears to reflect the same trend in hydro-sedimentary dynamics, with a delay, however (fig. 7).

The sedimentary input in active channels and its consequence on fluvial hydrology may also have been increased by anthropogenic impact. The high human-induced sediment yield and associated sedimentation

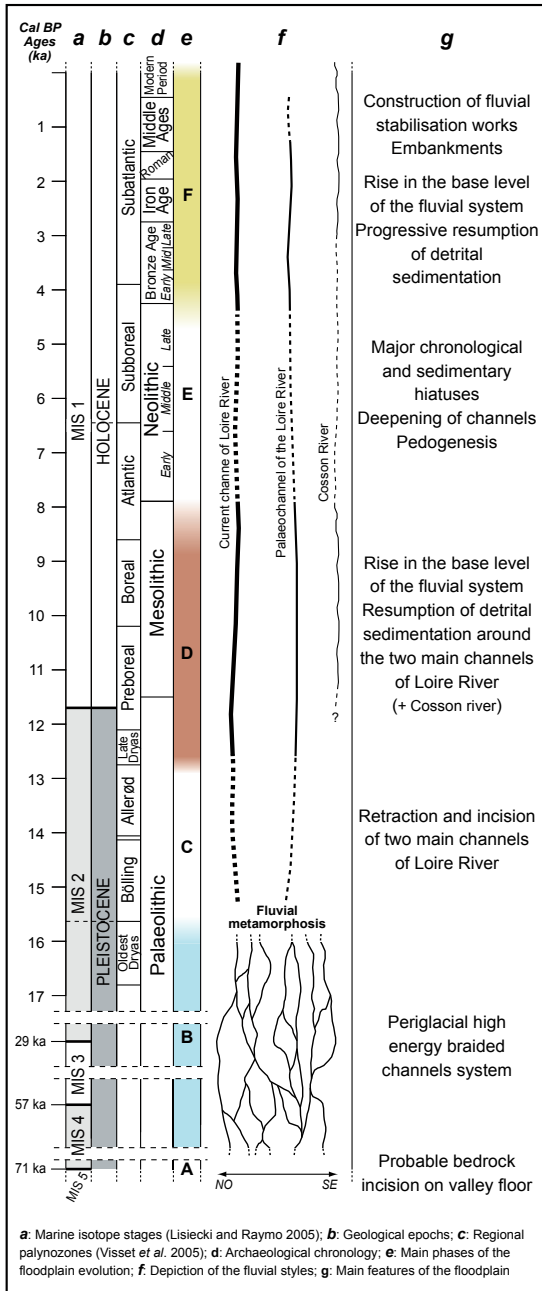


Figure 7: Chronology of the main evolution phases of the alluvial plain of Blois.

is well recorded on the middle Loire catchment such as from the Middle Loire (Macaire *et al.* 2006), the Neolithic / Bronze Age transition (Morin *et al.* 2011), the Middle Bronze Age (Cyprien *et al.* 2001), and is more marked during the Roman period (Carcaud *et al.* 2002). The human-induced reduction and further disappearance of the forest cover in the alluvial plains could have also contributed to a rise of the mean water table level, by reducing evaporation and increasing runoff (Smith and Charman 1988,

Macaire *et al.* 2006, Morin *et al.* 2011, 2014). This phenomenon could have increased in intensity as a result of civil and monumental constructions requiring local resources in large quantities (e.g. wood).

Sedimentation in the alluvial plain was probably initially limited to the Loire and Cosson palaeochannels and their borders. Most of the surface was, however, apparently spared from sedimentogenic overflowing. Indeed, a relative morphological stability seems to have persisted up to historical periods in most parts of the alluvial plain. This context was favourable to the settlement of human societies from the Mesolithic to the Roman period, and also for the preservation of their remains from fluvial erosion.

The city's foundation by the Romans around the first half of the 1st century AD at low elevations in the alluvial plain, mostly over deposits of phase D, could indicate a shallow water table during this period, as also indicated by archaeological data found downstream on the middle Loire River (Driard 2007). It also shows an acceptance of fluvial risk by ancient societies (e.g. Arnaud-Fassetta 2011). This thus confirms that human settlement on sites built on river banks is not guided by a natural determinism (e.g. Burnouf *et al.* 2001).

Since the Roman period, anthropogenic deposits have increased the general elevation of urbanised areas. This phenomenon is observable until the present day, mainly with the construction of embankments. This was probably partially linked to the need for protection against floods, or more likely for protection against a gradual rise of the alluvial water table beginning in the Late Holocene period. This rise does not seem to be related only to climate change, because the Roman period was not particularly humid (Büntgen *et al.* 2011). It could have been partly induced by strong sedimentary accretion in the active channels. In the Blois alluvial plain, the contrast in elevation observed between urbanised areas (filled with anthropogenic deposits since the Roman period), and their respective rural areas, mostly shaped by fluvial dynamics up to the present day, is significant, and can reach four to five metres (fig. 2, 5 and 6).

During the Roman period and after 1580 ± 30 BP (i.e. during at least the Early Middle Ages; fig. 6, no. 17), the sedimentary infilling of the Loire palaeochannel confirms the gradual tendency of a rising water table. This trend is also shown by the deposition of organic to peaty sediments in the Cosson river area, around 1680 ± 30 BP and 1180 ± 30 BP. The sedimentation recorded for the Cosson gutter during this period clearly indicates a prevalence of sedimentation over incision / erosion processes in the morphological evolution of the floodplain.

Ancient iconography depicting a large palaeochannel running south of the current district of Vienne (fig. 3) does not seem to be just a myth at this stage. Instead, it appears to be a simplified representation of the alluvial plain during the Early Middle Ages, mostly during flooding episodes. The time of the final infilling of the palaeochannel is not yet well defined. It was not complete at 1580 ± 30 BP, but was apparently so in the mid-17th century, because it is not depicted in the oldest map of Blois belonging to this period.

Indeed, crossing the alluvial plain was apparently constrained until the building of the Ponts Saint-Michel and the Ponts chartrains during the Late Middle Ages. For this last period, the deposition of alluvium dated $0,76 \pm 0,06$ ka near the current Loire channel indicates high overflood levels ($> 69,10$ m NGF), above the altitude of the first Roman occupations (68 to 68.90 m NGF; fig. 5, no. 1). For the middle Loire River, the construction of fluvial stabilisation works in the Middle Ages contributed to the morphological stability of the alluvial plain. Since then, changes in river morphology have been limited to the constrained current channel (sediment bars, islands) and its border, while the frequency and magnitude of major floods has increased (Garcin *et al.* 2006, Castanet 2008).

The rise of the water table mostly persisted until the Modern period, during the Little Ice Age (Mann 2002). It was accompanied by increased building of river protection works, notably to prevent overflows from the Loire above the Vienne district. During this time period, breaches created in levees during flooding, by concentrating the hydrological fluxes at their outlet, caused great damages (e.g. in the years 1846, 1856 and 1866; Lorain 1980). Human agricultural exploitation of the floodplain has persisted.

Since the 20th century, human-induced incision of the current middle Loire channel is well demonstrated (Gazowski 1994). Considering the morphological evolution of this sector in the long-term and the occurrence of present and mostly future global climate changes, it is very likely that severe low water levels and major floods will both occur in future years.

6. Conclusion

The case study of the urbanised alluvial plain of Blois has highlighted the great potential for geoarchaeologists to combine multidisciplinary data, in order to better understand: (i) the evolution of fluvial dynamics in the long-term, (ii) its impact on the diachronic human occupations and the preservation

of their remains and, (iii) some retrospective effects induced by different local or more global anthropogenic forcings. In the alluvial plain of Blois, this framework was detailed for periods spanning the Late Pleistocene to the recent historical periods.

During the Late Pleistocene, the major bedrock incision observed (phase A) could have occurred during the MIS 5 - MIS 4 transition. It was followed by the deposition of coarse alluvium in a multi-channel system over the whole alluvial plain (phase B), probably beginning during the MIS 4 and ending by the middle of MIS 2 (i.e. Last Glacial Maximum). A metamorphosis of the fluvial system took place in the alluvial plain during the second half of MIS 2, before the Younger Dryas (phase C). This was characterised by the fall in periglacial sedimentation, accompanied with a retraction and incision of the Loire River in its current channel, but also in a palaeochannel flowing on the actual left bank.

The evolution of Blois' alluvial plain during the Younger Dryas and the Holocene clearly appears tripartite, showing major tendencies in mean water table level variation. The first stage of this evolution was characterised by the deposit of essentially sandy sediments around active channels as from the Younger Dryas and until the middle of the Atlantic period, almost right up to the 8.2 ka event (phase D); compared to phase B, this reflects a floodplain context, with lower energy floods from a reduced number of channels, linked to a relatively low mean piezometric surface.

The second stage, covering the Middle Holocene period, corresponds to a long sedimentary and chronological hiatus in the alluvial plain (phase E). The apparent morphological stability, induced by the drop of the water table level, was favourable to the development of pedogenesis, and also to diachronic human occupations from the Mesolithic to the Metal Ages.

The third stage, beginning during the Middle - Late Holocene transition, indicates a progressive rise in the mean water table level, due to the combining of climatic and anthropogenic forcings. Sediment deposition was apparently first limited to the existing palaeochannels, but has largely extended since the Middle Ages.

The city's foundation by the Romans during the first half of the 1st century AD, even in the alluvial plain, may indicate relatively low river activity at this period, but also an acceptance of fluvial risk. Since then, however, the rise of the urban area due to anthropogenic deposits, and the construction of fluvial stabilisation works as from the Late Middle Ages, is a indication of the needs for protection against a rise of the piezometric surface, probably caused by sedimentary accretion in the active channels, increased

by human-induced impacts at regional or more local scales.

Time will show how recent global climatic changes may influence the evolution of the anthropically influenced hydrosystem of Blois in the long-term, but also in riverside cities elsewhere. Studying urban geoarchaeology in fluvial environments plays a role here in reading past evolution in the long-term, with future trends in mind.

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