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Roman Rhine settlement dynamics evidenced by coin distribution in a fluvial environment (Oedenburg, Upper Rhine, France)

Vincent Ollive^{a,b,*}, Christophe Petit^{a,c}, Jean-Pierre Garcia^{a,b,c}, Michel Reddé^d, Patrick Biellmann^e, Laurent Popovitch^{c,f}, Carmela Chateau-Smith^a

^a Université de Bourgogne, UFR Sciences de la Terre, 6 Bd Gabriel, F-21000 Dijon, France

^b UMR UB-CNRS 5561 'Biogéosciences', France

^c UMR UB-CNRS-Culture 5594 'ARTEHIS Archéologie, Terre, Histoire, Sociétés', France

^d Ecole Pratique des Hautes Etudes (IV^e section), 45 rue des Ecoles, F-75005 Paris, France

^e 32 rue de la Krutenau, F-68180 Horbourg-Wihr, France

^f Université de Bourgogne, UFR Sciences Humaines, 2 Bd Gabriel, F-21000 Dijon, France

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Abstract

On the basis of archaeological and alluvial records, this paper presents the first spatial analysis of artefacts in relation to the evolution of the Rhine River, at the Gallo-Roman site of Oedenburg, during the first four centuries AD. The dataset consisted of several thousand Roman artefacts found by pedestrian prospecting over the last twenty years, over half of which were coins. This dataset was used together with high-resolution topography and geomagnetic mapping, to reconstruct settlement evolution, both on the terrace and in the floodplain. A comprehensive monetary chart has been compiled for the Oedenburg site, which highlights four major phases of settlement. These results provide a possible causal link connecting historical factors and alluvial events with intra-site evolution. Therefore, while changes observed during Phases I (until AD 68), II (AD 69 to AD 180) and III (AD 180 to AD 295) seem largely related to historical and societal events, Phase IV (AD 295 to AD 402) shows patterns of abandonment of the lower part of the floodplain that may well be related to an unusually humid period in the fourth century. These results are set in a broader context, from the Rhine catchment area to the Alps, and are in agreement with the wet conditions also documented in alluvial, lacustrine, geomorphological and palynological records in Germany (Lahn River, Lake Constance, Lake Nussbaumen, Kaiserstuhl area and the Black Forest). Studying the intra-site spatial distribution of artefacts with high temporal constraints, at a long-lived site with contrasted topography, opens new avenues for the detection of discreet events such as a higher water table, affecting only the lower zone.©

Keywords: Climate change; Coin distribution; Fluvial impact; Geoarchaeology; Rhine River; Roman Period

1. Introduction

1.1. Objectives

The present geoarchaeological study focuses on the evolution of a settlement in relation to alluvial landscape constraints at the Oedenburg Gallo-Roman site, in the Southern Upper

Rhine floodplain (Biesheim-Kunheim, France). Coin distribution in space and time was chosen as an indicator of site occupation density and chronospatial occupation relative to river palaeo-channels and Roman structures. By such means, it is possible (1) to highlight the main phases of settlement evolution comprehensively for Oedenburg during the first four centuries AD, (2) to examine whether a relationship exists between settlement processes and alluvial dynamics and (3) to understand the impact on the site of both historical and societal events (e.g. migration, changes in site function, and modification of urban district networks).

* Corresponding author at: Université de Bourgogne, UFR Sciences de la Terre, 6 Bd Gabriel, F-21000 Dijon, France.

E-mail address: vincent.ollive@u-bourgogne.fr (V. Ollive).

1.2. Interest of pedestrian prospecting

In archaeological research, the first evidence generally comes from artefacts found at the surface, or structures detected by technical means (e.g. aerial photography; Riley, 1946). Even if a site is partially excavated, the archaeologist's interpretation still relies on that first dataset, which provides not only spatial information and function but also chronology. Many authors have demonstrated the interest of studying spatially distributed artefacts, collected by pedestrian prospecting and from excavation, for improved understanding of archaeological sites (e.g. Ferdière et al., 2006; Gowlett, 1997; Leroy-gourhan and Brézillon, 1966; Stapert and Street, 1997). With the help of the exceptional dataset prospected by the same team over the last twenty years and detailed analysis of the environmental setting, this purpose may be achieved, thus providing an overview of the chronology of Oedenburg. When precisely located and accurately dated, this prospected artefact dataset allows us to describe the spatial evolution of the settlement. This enhanced dataset completes the excavation results obtained since 1998 and provides

chronological information for structures known only by magnetic mapping and aerial photography (Nuber et al., 2002; Reddé et al., 2005).

2. The Oedenburg Gallo-Roman site

The geographical location corresponds to the position of the Rhine Roman Frontier in the first century AD, and again during the fourth century AD (Fig. 1). The Oedenburg site presents all the characteristics of a military settlement, a civilian settlement and a religious complex (Nuber et al., 2002; Reddé et al., 2005) and covers a spatial extension of about 2 km² in a complex alluvial landscape. A general view of the Oedenburg site is revealed by excavation, microtopographical survey and geophysical prospecting (Fig. 2). Three distinct zones are observed in this landscape where the elevation is between 185 and 192 m above sea level (ASL).

To the east, Zone A corresponds to the top of a large, gravelly palaeo-island around 188 m ASL (Fig. 3). Many anomalies are identified and understood as northward-oriented, narrow intra-bar palaeo-channels. They are related and

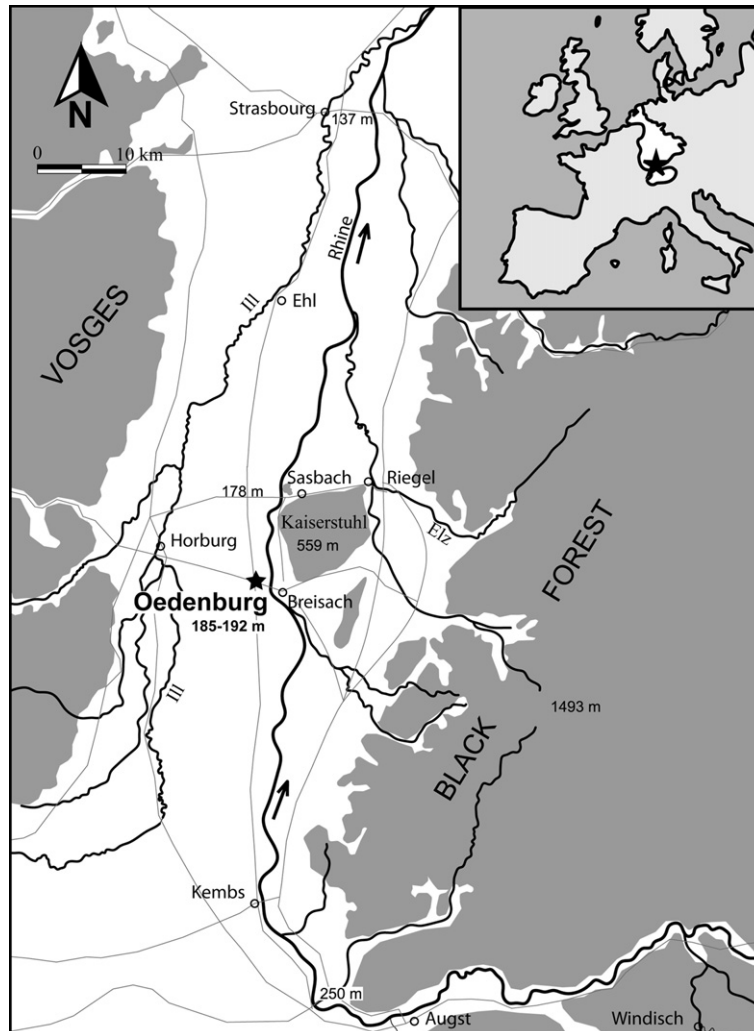


Fig. 1. Location map of the Oedenburg Gallo-Roman site within the Rhine River catchment.

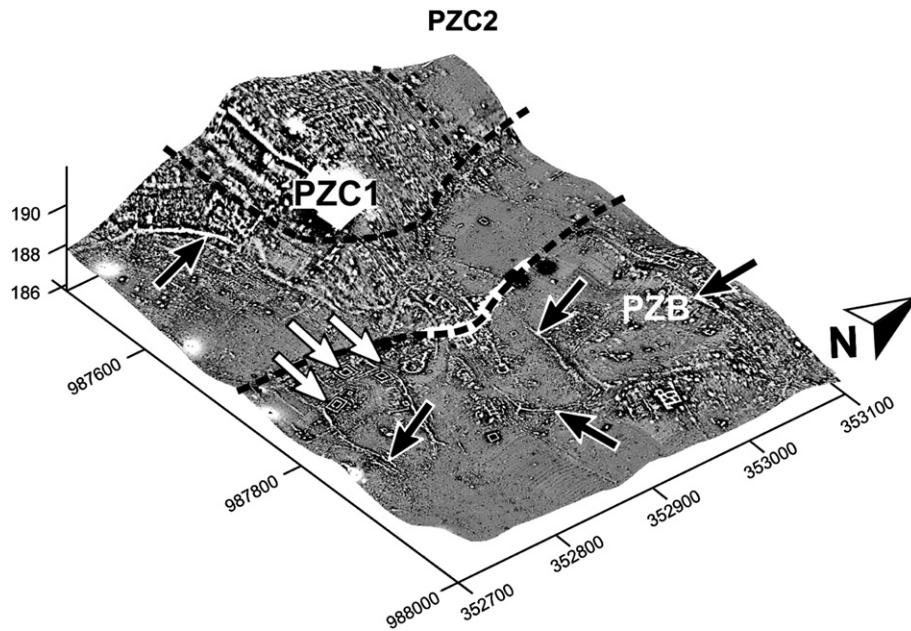


Fig. 2. Three dimensional view of the digital elevation model of the Oedenburg site overlain by artefact finds and geomagnetic map. In that complex alluvial landscape Roman artefacts are mainly located near Roman roads (black arrows), religious complex (temples, white arrows) and terrace, but absent in palaeo-channels where no urban network is observed by magnetic survey. Spatial coordinates are Lambert II extended (Geographic French System). Vertical exaggeration: $\times 20$.

synchronous to the island formation attributed either to the Late Glacial Period or the Holocene. On the south-western border of this palaeo-island, a Julio-Claudian military camp was established during the first half of the first century AD (Prospected Zone A). Excavation results indicate that it was set up on this gravelly island in the reign of Tiberius (AD 14–37). Its spatial extension is about 35,000 m². This military settlement is attested up to AD 69–70, when the frontier moved beyond the Black Forest. Excavations show that archaeological deposit thickness is about 0.3 m, partially affected by ploughing, and well preserved in excavated structures (e.g. ditches).

Zone B is composed of a mosaic of palaeo-channels and palaeo-islands of various sizes. The mean elevation is about 186 m ASL. To the east, a broad palaeo-channel shows a sinuous meandering pattern bounding Zone A. From excavation, electrical resistivity tomography (ERT) and coring, it is known to have been active and uninhabited during the Roman Period. Superimposed on this palaeo-channel is a modern canal built during the 19th century. Another broad palaeo-channel is observed to the west running along the Weichselian terrace border (Zone C). A geoarchaeological cross-section attests that this palaeo-channel was active and uninhabited during Antiquity. In the northern part of the area, these two broad palaeo-channels present a confluence. Immediately south of this junction, lies a broad, uneven, relatively high, diamond-shaped palaeo-island, about 100 m wide, where the major part of the 1st to 3rd century AD civilian settlement is documented (Prospected Zone B). Excavation results have shown the contribution of both anthropogenic and flood deposits to the palaeo-channel infill, reaching 1 m thick in places. In the southern part of the area, many northward-oriented, narrow,

braided palaeo-channels are observed. They are separated by small, longitudinal palaeo-bars. Settlement processes in this part of the floodplain began in the very first years of the first century AD, and continued until the third century AD. The first evidence of human occupation is provided by wood structures dated dendrochronologically to AD 3–4, located in the vicinity of a religious complex which developed from the first century AD onwards. Excavation attests that some structures in the temple area developed at the edge of minor, generally unoccupied palaeo-channels. As the preceding layer is dated 1745 \pm 30 years BP (Poz-15955) by archaeological excavations and geoarchaeological study, this entire low zone is shown to be affected by a 10-cm-thick, homogeneous, organic-rich silt layer denoting conditions of permanent high water table in the floodplain after this date.

To the west, Zone C rises to more than 190 m ASL. It corresponds to the Weichselian terrace and dominates the alluvial floodplain. In this part of the study area, the Gallo-Roman civilian settlement and necropolis are known from the first to the fourth century AD (Prospected Zones C1, C2 and C3). In Prospected Zone C1 (PZC1), a fortified palace was raised from the fourth century AD, under the reign of Valentinian (AD 364–375). The 3-m-thick anthropogenic deposits contrast with other parts of this Zone (PZC2 and PZC3) where anthropogenic deposition does not exceed 0.5 m. The road joining Biesheim to Kunheim (D468) is situated along this elevated topographical anomaly. Topographical analysis of the Oedenburg Gallo-Roman site allows the identification of easily flooded areas situated in Zones A and B, while Zone C, the terrace, may be considered as an area with limited risk of exposure to Rhine floods.

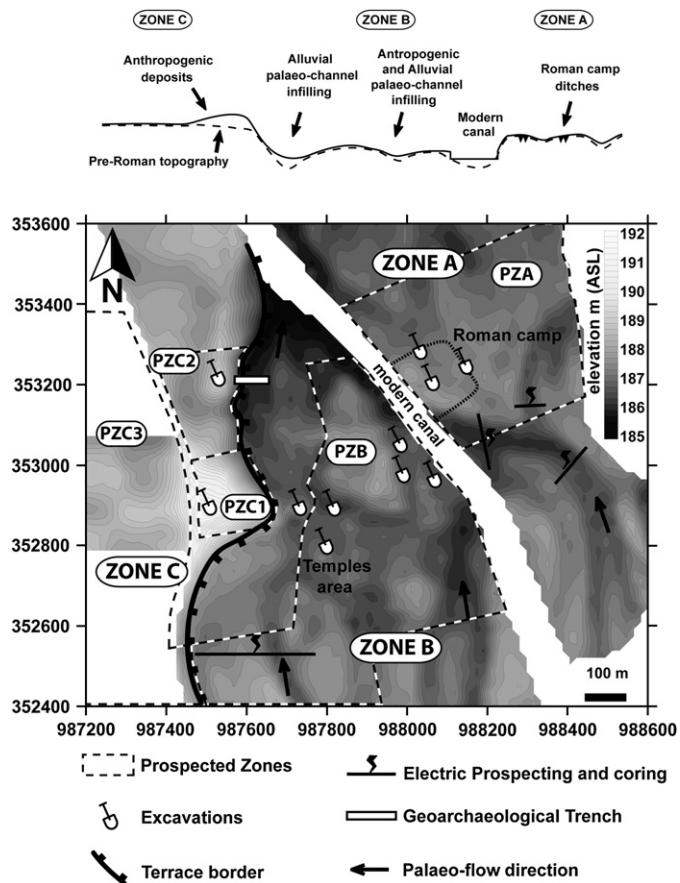


Fig. 3. Locations of prospected zones, excavated areas, geoarchaeological trench and ERT transects in relation to the alluvial landscape. The micro-topographical map allows the exact positioning of three major geomorphological zones in the alluvial landscape. The thickness of alluvial and anthropogenic deposits during Antiquity is indicated on the synthetic cross-section of the study area. Spatial coordinates are Lambert II extended (Geographic French System). Contour interval: 20 cm. Elevation from 185 to 192 m ASL.

3. The prospected dataset

Numerous pedestrian field surveys of the five prospected zones described below have been performed by the Hardt and Ried Historical Society, over the last twenty years, using metal detectors. Thousands of artefacts have been discovered and described: pottery, worked stones, coins, stamped tiles, gems, figures, silver ingots, etc. (Biellmann, 1987, 1988, 1996, 1997, 2000, 2001; Maurer, 1993; Nuber et al., 2002; Reddé et al., 2005). About 30% of the time spent on field surveys is still dedicated to the precise plotting of finds on the cadastral plan. It should be noted that few archaeological sites have been prospected as intensively and methodically as the Oedenburg site. As the entire site is on agricultural land used for the cultivation of maize, conditions for prospecting are particularly advantageous in the spring, when the fields are free of vegetation and the soil is levelled ready for planting. Such accessibility ensures the value of the dataset in representing site occupation. Observational bias is reduced by the stability of the team since its inception, and by the absence of

any selection in the collection of prospected artefacts. All finds have been inventoried in the same careful way. The five prospected zones (PZ) extend over the whole alluvial plain and there is at least one PZ in each of the three geomorphological zones described above. To summarise, PZA (0.20 km²) is situated on the island in the eastern part of the site, PZB (0.32 km²) in the central part of the site, composed of a mosaic of several palaeo-islands and palaeo-channels, PZC1 (0.03 km²) is the highest topographical zone in the area and constitutes an extension of the terrace into the flood-plain, PZC2 (0.04 km²) is the northern limit of the Roman site on the terrace and PZC3 (0.32 km²) represents the inner terrace located in the western part of the site. Absolute coordinate attribution (French system, Lambert II extended) was obtained using Digger 2.0 digitising software on the cadastral maps. This information was combined with a detailed description of the characteristics and chronological parameters of each artefact in the dataset. Of the 6205 geo-referenced artefacts in our database, the 3546 Roman coins were dated by reign for our spatial analysis. Roman coins were used as chronological descriptors as they are abundant (57% of the dataset) and provide an efficient *terminus post-quem* at high temporal resolution. Coins were used in both civilian and military areas, and suffer less from post-depositional fragmentation and transport than ceramics. Prospecting for coins with metal detectors rather than by sight alone is less likely to be affected by climatic factors or by prospection bias, and is more successful, especially when mud covers artefacts after rainfall events. Dating of coins is precise as regards first date of issue, but it is difficult to estimate the length of the coin circulation period. Consequently, settlement phases can only be given an exact first possible date. Despite these limits, we are able to propose a first coin chronology for each prospected zone controlled by excavation results. The period of our study, from 199 BC to AD 402, corresponds to the twenty-one numismatic periods shown in Table 1, established by Reece (1972). This time-scale was defined on the basis of Roman history and global monetary fluctuation events linked to politics, markets and metal availability. It takes into account variations in coin emissions and attenuates any length-of-reign disparities. To give a higher detailed analysis we have divided period 1 into four sub-periods 1a (199–100 BC), 1b (100–27 BC), 1c (27 BC–AD 14) and 1d (AD 14–41). This time-scale was used to sort all the coins found on the site, i.e. the 3239 geo-referenced coins and also 307 coins located by prospected zone only. A comprehensive monetary chart for the Oedenburg site has been established, allowing the characterisation of the different phases of settlement. First, normalisation was performed to level out differences in the number of finds between each prospected zone. It consists in a classic conversion to percentage for each prospected zone. The simple total of these values refers to ‘All prospected zones’ in Fig. 5. Each coin population is weighted versus PZC1 to be equally representative and equivalent within the Oedenburg site. Thus, the contribution of each prospected zone during each period may be quantified. The simple total of these weighted values refers to ‘Normalised monetary evolution’ in Figs. 4 and 5. This

Table 1
Roman coins found in each prospected zone and sorted by period (after Reece, 1972)

Periods	All prospected zones	PZA	PZB	PZC1	PZC2	PZC3
199–100 BC	1a 9	5	1	0	0	3
100–27 BC	1b 243	213	8	1	4	17
27 BC–AD 14	1c 539	428	37	1	8	65
14–41	1d 140	88	13	1	1	37
41–54	2 75	55	3	0	1	16
54–68	3 34	18	7	2	1	6
69–96	4 89	19	31	2	0	37
96–117	5 60	6	16	0	1	37
117–138	6 59	6	16	3	0	34
138–161	7 82	7	18	12	6	39
161–180	8 79	4	22	5	6	42
130–193	9 15	1	2	2	1	9
193–222	10 29	1	4	4	1	19
222–238	11 19	1	3	2	1	12
238–260	12 38	2	12	2	1	21
260–275	13 23	0	10	2	0	11
275–296	14 9	0	4	1	0	4
296–317	15 27	8	5	1	2	11
317–330	16 99	8	18	7	13	53
330–348	17 245	11	13	16	46	159
348–364	18 32	4	3	4	5	16
364–378	19 1332	21	12	28	142	1179
378–388	20 218	16	2	7	25	168
388–402	21 1	0	0	0	0	1
Total	3546	922	260	103	265	1996

In our study, period 1 has been divided into four sub-periods 1a, 1b, 1c and 1d.

allows the establishment of a comprehensive Oedenburg monetary time chart and the characterisation of the four different phases (Fig. 4). To complete this second step, the spatial distribution of Roman coins was studied to allow patterns to be detailed in relation to the landscape (Fig. 6). After sorting, the geo-referenced Roman coin dataset was used to produce several thematic distribution maps of the study area, with Surfer 8 Digital Elevation Modelling software, which were projected on to the digital elevation model (DEM). By associating geomagnetic mapping with the pedestrian prospecting dataset projected on to the DEM, the relationships between the Rhine River and Roman occupation may be better understood (Figs. 2 and 6). As shown in Figs. 2 and 6, Roman artefacts are not randomly distributed in the floodplain and the terrace but have been preferentially found in the vicinity of structures observed by geomagnetic mapping such as Roman roads and temples. This convergence in reliability between artefacts and urban district networks at the Oedenburg site makes possible the use of coin distribution to assess evolution of occupation through time in this complex alluvial landscape.

4. Results

4.1. The four main monetary phases

In order to limit bias, the total number of coins was normalised for the whole site, to show coin relative abundance. Four main monetary phases are thus distinguished (Fig. 4). Phase I

extends from 27 BC to AD 68 and concerns coins issued during the reigns of Augustus (period 1c), Tiberius and Caligula (period 1d), Claudius (period 2), and up to the end of the reign of Nero (period 3). Republican coins (periods 1a and 1b) pre-date initial settlement of the site and are therefore considered to have been deposited during Phases I and II. Phase II extends from AD 69 to 180, from the reigns of Galba, Otho, Vitellius and the Flavians (period 4), to the Antonians up to the end of the reign of Marcus Aurelius (periods 5–8). Phase III extends from AD 180 to 295, from the reign of Commodus to the beginning of the Tetrarchy, in the reign of Diocletian (periods 9–14). Phase IV extends from AD 295 to 402, and concerns coins issued from the Tetrarchy to the reign of Arcadius (periods 15–21). The average duration of the four major phases is around 107 years, with a duration of 95 years for Phase I and durations of 111, 114 and 108 years for Phases II, III and IV respectively. The detection threshold of metal remains is constrained by mass. However, an analysis of coin distribution by mass reveals no prospecting bias (Fig. 4). Within Phase I, there is a bimodal distribution with ‘half asses’ and ‘dupondii’ weighing 3–5 g, and ‘asses’ and ‘dupondii’ weighing 8–10 g. There are very few heavy coins; the poorly represented ‘sestertii’ and ‘uncial asses’ weighing around 25 g. Phase II coins weigh between 2 g and 27 g, with three major modes situated around 8–9 g (‘asses’), 11–12 g (‘asses’ and ‘dupondii’), and 17–23 g (‘sestertii’). This dataset reflects the relative abundance of large coins such as ‘sestertii’ and ‘dupondii’. Phases III and IV both show only small coins weighing around 1–3 g of very similar shape, which should therefore be equally well detected by field operators. Coin distribution by mass confirms that even if Phase II and Phase III coins are less well represented, they are detected as readily as those of Phases I and IV. The evolution of temporal and spatial coin distribution is shown on several diagrams and maps (Figs. 5 and 6). The dynamics of the Oedenburg settlement can thus be detailed phase by phase in relation to the distribution of coins on the site.

4.2. Phase I

Phase I coins have been found in all prospected zones. However, they show noticeable spatial heterogeneity: over 70% of a total of 678 were found in PZA. Numerous Republican and Augusto-Tiberian coins (periods 1a to 1d) are found, particularly around the military camp. Coins from periods 2 and 3 decrease in number but still represent over 60% of the total population. The contribution of PZA decreases gradually while contributions from PZB and PZC3 increase. Coin distribution in PZB forms lines crossing palaeo-channels, indicating roads shown on the geomagnetic map (Fig. 2). Many coins were also found on palaeo-islands. Coin distribution in PZC3 forms three bands corresponding to Roman roads, one oriented North-South and two oriented westward. Few coins are found in PZC2 and PZC1, but for the latter zone, anthropogenic deposits from later phases reach a thickness of 3 m (Fig. 3), too deep for satisfactory prospecting.

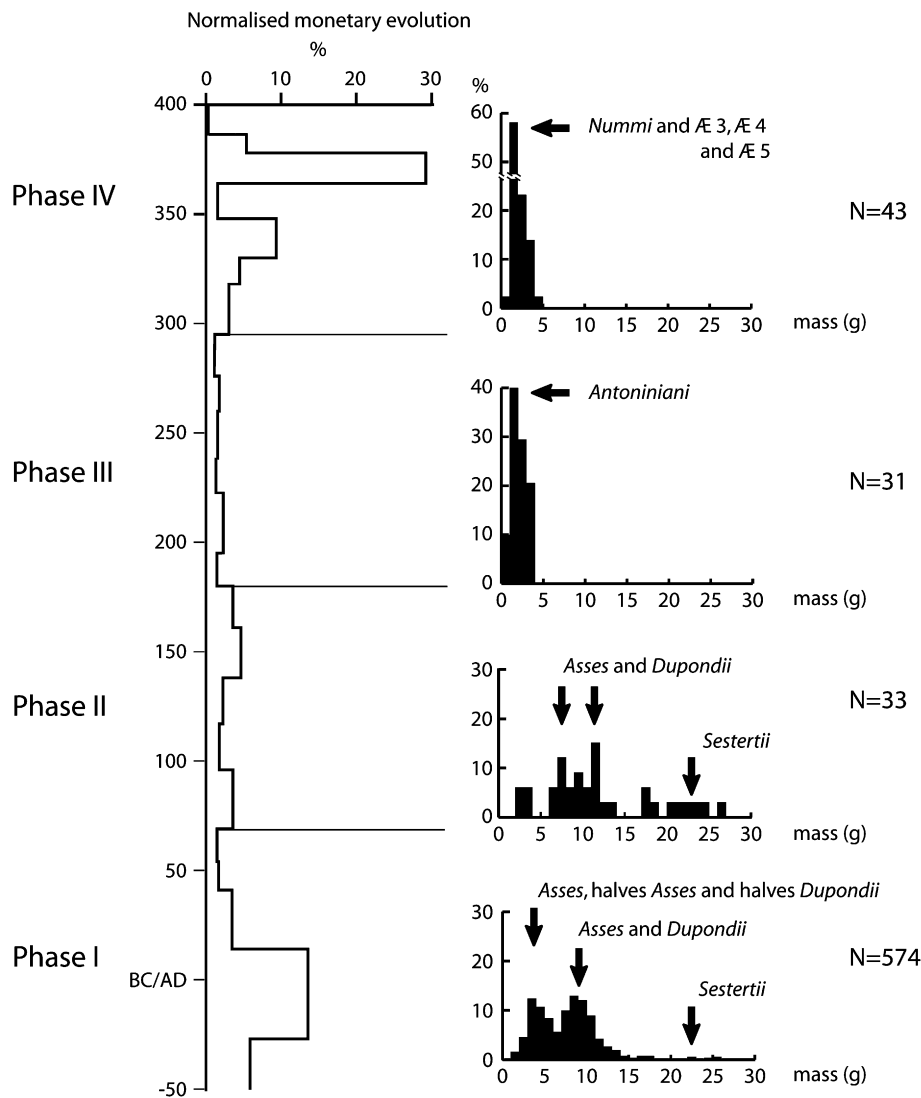


Fig. 4. Global Oedenburg monetary time chart and mass distribution of coins for each Phase in the Oedenburg site. Roman periods have been defined after Reece (1972). Phase I: from period 1 to 3, Phase II: from period 4 to 8, Phase III: from period 9 to 14 and Phase IV from period 15 to 21. Note the low proportion of ‘*sestertii*’ compared with smaller denominations such as ‘*asses*’, ‘*dupondii*’ and halves during Phase I. Moreover, the low abundance of coins attributed to Phase III is not linked to biases in prospecting methods: they are of similar weight to those of Phase IV which are well represented in Oedenburg.

4.3. Phase II (AD 69–180)

A radical change in coin distribution occurs during this phase, with less than 10% still found in PZA, while contributions from PZB and PZC1 are proportionately higher, reaching 60% of a total of 365 for PZB, thus confirming the trend established in Phase I for this zone. Coins are still found across palaeo-channels and on palaeo-islands, while the area dedicated to temples appears to be better represented, in accordance with excavation results that provide evidence of increasing activity in this sector. The increase in PZC1 begins later, in period 6, indicating a considerable acceleration in the dynamics of settlement on this higher part of the floodplain. In PZC2 and PZC3, the situation remains stable, with a new line oriented westward in the southern part of PZC3, interpreted as a road, bringing the total contribution for this zone to 15%. Phase II thus demonstrates a rapid mutation in settlement on

the floodplain, characterised by the desertion of the military camp and the growth of new civilian districts such as the temple area and PZC1.

4.4. Phase III (AD 180–295)

During this phase, the decrease in contribution from PZA is confirmed, even though overall numbers are lower, with a total of only 136. The situation in PZB is more complex and deserves attention. Spatial distribution is modified in PZB, with no coins found in the southern part, a more streamlined alignment around the temples, and clustering on one of the palaeo-islands. Two sub-phases are observed in temporal distribution for both PZB and PZC1: the first spanning periods 9–11, and the second periods 12 and 14. Coin distribution is greater in these zones than elsewhere throughout Phase III, with alternating peaks of dominance. In PZC2 and

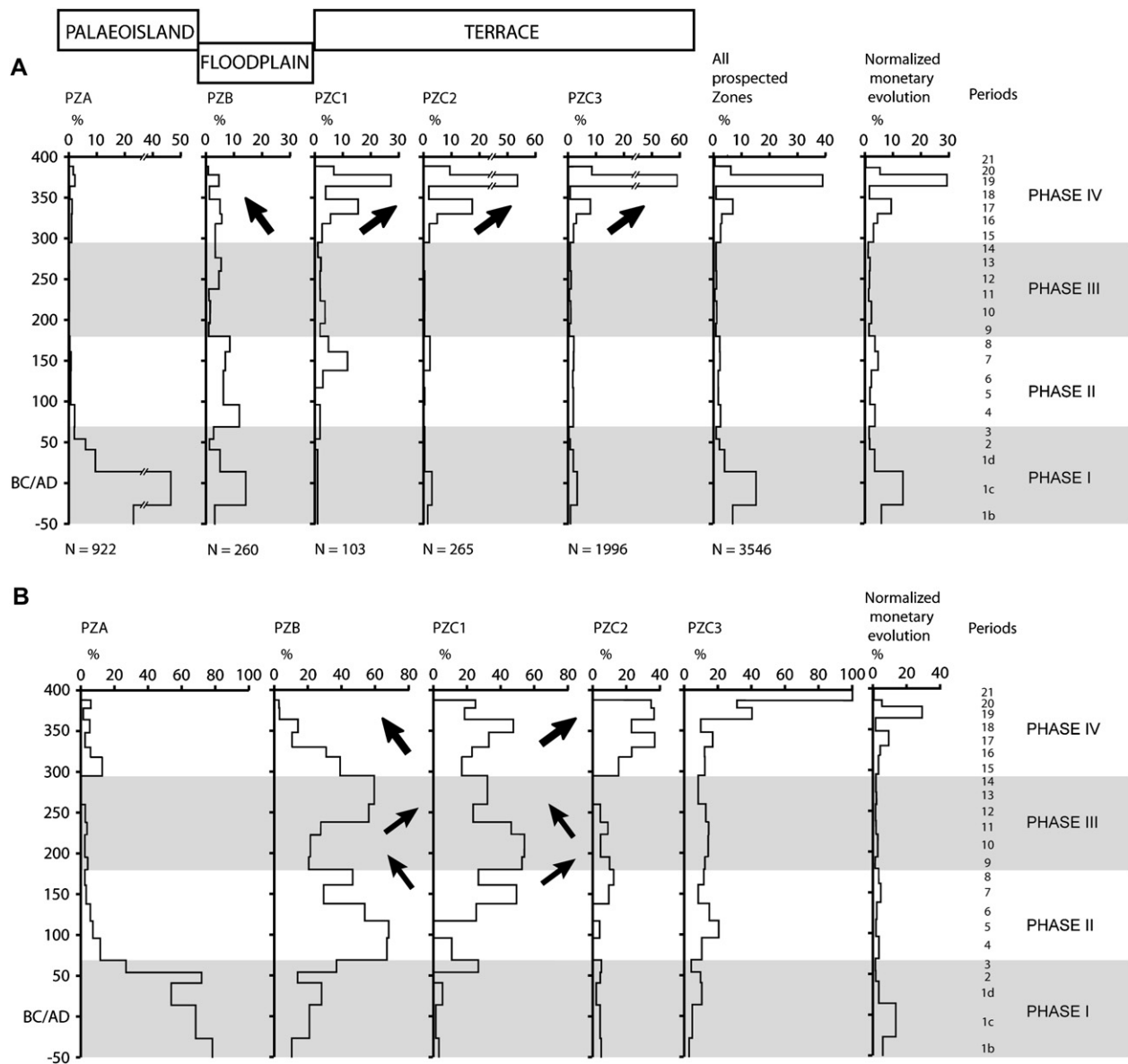


Fig. 5. Chronological coin distribution in each prospected zone. (A) Chronological distribution normalized for each prospected zone: analysis of the contribution of emission periods to the total number of coins per prospected zone. For one prospected zone, the sum of each period equals 100%. (B) Chronological distribution normalised for each period: analysis of the contribution of each prospected zone to the total number of coins per period. For one period, the sum of each prospected zone equals 100% and each zone is equally weighted versus PZC1. Black arrows indicate significant events.

PZC3, no evidence for significant distribution change is observed.

4.5. Phase IV (AD 295–402)

As the total number of coins for this phase (2060) is greater than the combined total of the three previous phases, the few coins found in PZA are not of great significance, indicating at best episodic human presence. Although the number of coins found in PZC1, PZC2 and PZC3 shows a consistent increase, in PZB, the contribution decreases proportionately compared to Phase III. Spatial distribution shows little change in this zone until after period 15, when only small clusters of coins are present on palaeo-islands.

5. Discussion

On the basis of our study, together with the excavation results, we have drawn up the chrono-spatial evolution of the Oedenburg settlement. The phase characterisation and the construction of the comprehensive monetary chart can be discussed in relation to internal and external processes. First, internal processes of settlement may be considered as the main parameter, inherent to site character (frontier settlement) and difficult to estimate because of site-specific behaviour and development. Second, external processes that may affect settlement dynamics are of two orders: (1) the historical variation of the monetary mass distributed, and available in this marginal part of the Roman Empire (frontier settlement),

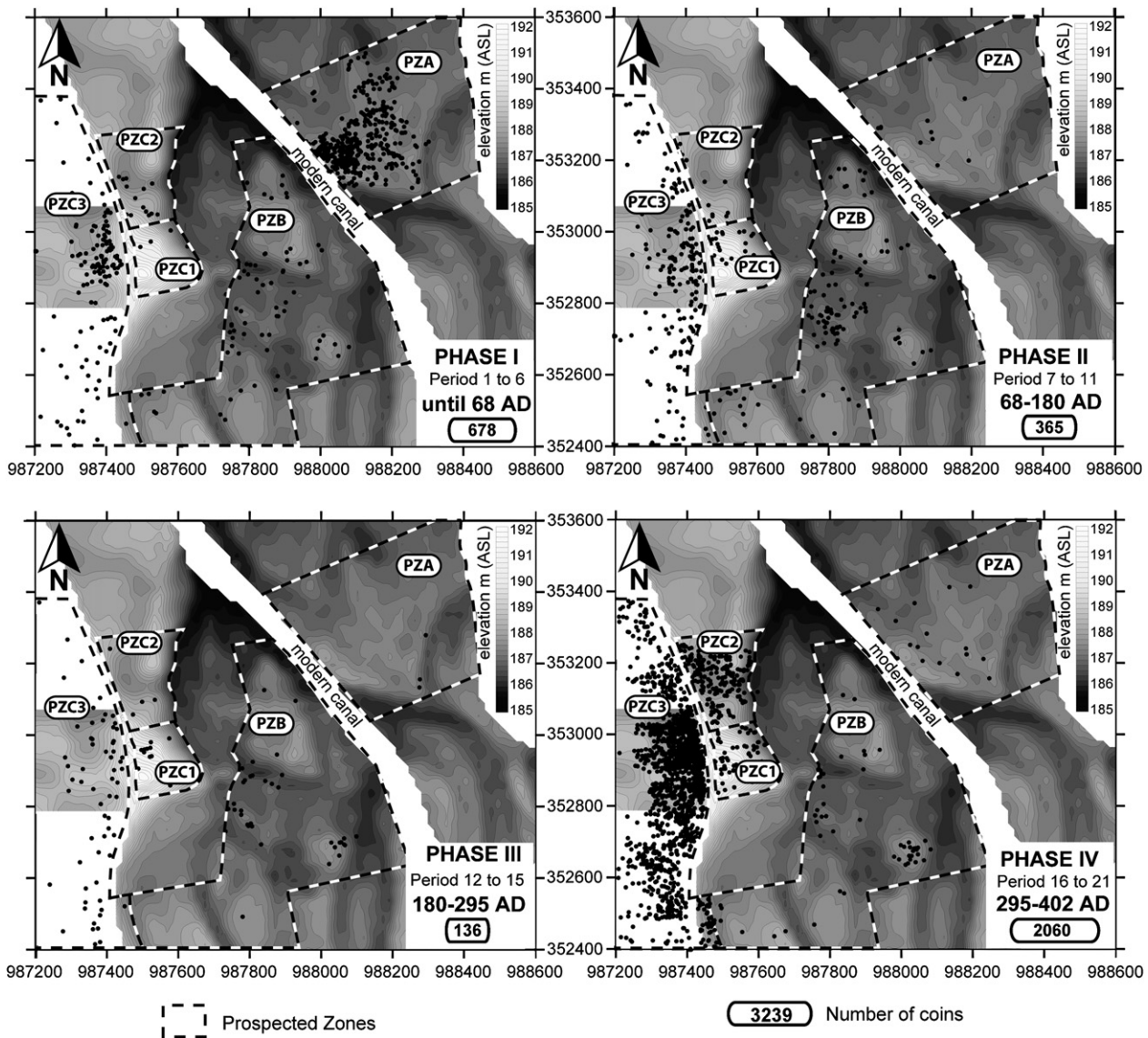


Fig. 6. Distribution maps of Roman coins found in the Oedenburg site on the digital elevation model. During Phase I, PZA presents a very high concentration of Roman coins. The other prospected zones are also occupied, but to a lesser extent. During Phase II, PZA is deserted, supporting development in PZB, PZC1 and PZC3. Phase III shows a clustering of coins in PZB and persistence in PZC1 and PZC3. During Phase IV, PZC1, PZC2 and PZC3 become dominant and PZB presents fewer coins. Some coins are still found in PZA but not enough to indicate occupation. Spatial coordinates are Lambert II extended (Geographic French System). Contour interval: 20 cm. Elevation from 185 to 192 m ASL.

during Antiquity; (2) variations in climate, and especially in hydrology and geomorphodynamics, in this flood-exposed area.

5.1. Roman history and Oedenburg

During Roman history, several events considerably affected the rate of emission and circulation of coins. During Phase I, while the military camp in PZA was developing, many coins in short supply were given a higher local value in this marginal part of the Empire. Artefacts, such as halves, countermarked coins and copies, bear witness to that reality. But during the second and third monetary phases (Phases II and III) after the departure of the military, coin values were only modified by Rome and other provincial coin workshops. The first part

of Phase III presents a general low number of coins. It is due to the special character of the reign of the Severians. The second part of Phase III shows a higher number of coins, but still relatively low. During Phase IV, two parameters must be taken into account. The first is the Diocletian monetary reform in 294, and the second is the stabilisation of the Roman frontier along the 'Rhein-Ille-Donau *limes*' after the loss of 'Agri Decumates' (Germany) and the military retreat in AD 260. It is remarkable that each event described here is observed at the scale of the Oedenburg site.

5.2. Rapid settlement in the floodplain during Phase I

Phase I is mainly defined by the arrival of the first Roman settlers. It is well indicated in the alluvial plain (PZB) and

particularly near the Julio-Claudian military camp (PZA) but is also present on the highest part of the terrace (PZC2 and PZC3). The large contribution of coins issued during Phase I in the prospected dataset may attest that anthropogenic and alluvial sediments have very little impact on discovery. This, however, is not the case for PZC1, where anthropogenic sediment thickness reaches more than 2 m (Fig. 3). Rapid settlement processes are highlighted on site, probably influenced by the arrival of Roman soldiers, and possibly also linked to the appearance of a religious complex, attested from the first half of the first century. The Roman settlement seems also to have been created *'ex-nihilo'* in that part of the Rhine floodplain, spreading over the whole area. During this phase, coin distribution indicates that the modulation of the site is strongly controlled and weighted by the military zone (PZA) where the assemblage is larger, with such distinctive features as the great proportion of *'asses'*, the large number of halves (*'asses'* and *'dupondii'*) and countermarks. This may be compared to other sites such as *Vindonissa* (Kraay, 1962).

5.3. Flooding events and duration of military camp: Phase I

As excavations have already established, the Oedenburg site was affected by four floods between AD 20 and AD 145/146, which were recorded on the eastern part of PZB in the immediate neighbourhood of the military camp in PZA (Ollive et al., 2006). However, field study does not yet indicate that such events affected the internal structure of the military settlement and forced its desertion.

5.4. The deserted camp (PZA): Phases II, III, IV

Phase II corresponds to the persistence of site occupation with the exception of the eastern margin (PZA). That desertion seems to be durable and even permanent during the following phases II, III and IV. No wide-ranging activity occurs in PZA, only transit. The reason for this non-resettlement is still difficult to understand; consequently three main propositions have been developed to explain it. The first is related to the distance of PZA from the terrace where the main roads are located. This hypothesis concerns internal processes and is linked to the attraction for civilian people of settling districts near the traffic axis and, consequently, trade. With the decline of the primary defensive motivation, PZA presents no other advantage than an easy access to cross the Rhine River. This function of access to the eastern side of the Rhine River is consistent with the development, from the end of the 1st century AD, of large public buildings (temples, *'mansio'*, *thermae* complex) dedicated to traveller halts and a major East–West way which connects PZB to the alluvial terrace (Reddé et al., 2005). The second may be explained by an environmental impact on that part of the floodplain. Environmental evolution may have reduced the attractiveness of that palaeo-island. This hypothesis seems to be difficult to argue because of two points raised in previous work: (1) during the period of occupation of the camp, floods affected the zone but no effects on settlement were evidenced

(Ollive et al., 2006); (2) the topography of this zone is only as sensitive and vulnerable to fluvial impact as other parts of the Roman settlement that are still occupied up to phase III. For this reason, we reject this hypothesis: the non-resettlement of PZA cannot be influenced by hydrological constraints. The third is a more external explanation, which remains hypothetical. It suggests that PZA, the military camp during Phase I, was perhaps not available for civilian settlement even after the departure of the military. Therefore, a ban on civilian occupation of PZA which has a military character may be illustrated on the Oedenburg site. If not universal, several examples attest this phenomenon is not unique within the Empire. The Mirebeau site (France) indicates the same non-reoccupation after the departure of the Roman legion while at the Walheim site (Germany) a civilian settlement developed on the former military structures (Reddé et al., 2006). Thus, we consider that the non-resettlement of that part of the floodplain was not induced by hydrological constraints but rather by historical conditions.

5.5. Contracting clusters in the floodplain

In PZB, coin distribution shows a scattered shape during Phases I and II, when the temples were in use, up to around AD 160–170. During Phases III and IV, a significant reduction of the dispersion of Roman coins in the floodplain occurred. Several clusters bear witness to this phenomenon, in particular in the central part of PZB where a sacred area is attested until the middle of Phase III, when a linear form is observed similar to those found near roads (Fig. 2). Abandonment of PZB was almost complete at the end of the 4th century, during Phase IV. The first hypothesis to explain this concerns internal processes supported by functional changes, principally due to the construction of a palace on the terrace. The major roads are positioned on the terrace in PZC1, PZC2 and PZC3, which probably made these zones more attractive for the inhabitants, as trade is generally easier near roads. The second hypothesis concerns external processes. The number of coins issued during Phase IV, and found in quantity everywhere except in PZA and PZB, allows us to imagine that environmental change affecting only low zones occurred during this phase.

5.6. Influence of climate on the settlement during the 4th century?

The abandonment of the alluvial floodplain (PZB) during Phase IV is demonstrated by the spatial distribution of Roman coins. This may have started during Phase III, when the first evidence of contraction is observed. After AD 320 (period 16), PZB declines while other zones show a considerable increase in occupation. Hydrological factors, aggravated by the position of PZB low in the alluvial landscape, may have contributed to its abandonment. Several contemporaneous events indicate that this climate variability also affected the Rhine catchment area. Many archaeological sites were abandoned at the transition between the Roman Period and the Migration Period in the eastern part of the Roman Empire, after the

retreat from the ‘*Agri Decumates*’ (Lang et al., 2003; Mäckel et al., 2002, 2003; Zolitschka et al., 2003). In the Black Forest and in the Kaiserstuhl area, the population density decreased, respectively associated with a reduction in mining activity and with geomorphodynamic stability (soil formation and reforestation) initiated by climatic deterioration (Friedmann, 2000). There is no evidence of settlements near Lake Constance from about AD 250 to AD 380, and near Lake Nussbaumen from around AD 260 to AD 650 (Zolitschka et al., 2003). Tree-trunk accumulation in River Lahn sediments between 1650 and 1350 BP is associated with a lack of archaeological settlement (Abegg-Wigg et al., 2000; Urz et al., 2002; Zolitschka et al., 2003). During the same period, moisture and wet conditions increased in Lake Dudinghausen affecting human occupation (northern Germany; Dreßler et al., 2006). All these studies have demonstrated that the transition period occurring during the fourth century AD may be considered as a wet and/or cold period coinciding with the Göschenen II glacial advance in the Alps (1850–1200 BP) and lower timberline (Patzelt, 1977). Wessels (1998) demonstrated that Lake Constance recorded an increase of detrital supply from the third century AD onward; we interpret this as an increase in water supply at the scale of the Northern Alps and particularly the River Rhine. This wet and/or cold period can also be observed at Lake Le Bourget (Alps) as an increase in sedimentation rates after 1680 BP and in detrital material between 1600 and 1150 BP (Arnaud et al., 2005), after the end of the transgressive episode 4 ‘Petit Maclu 1’ (1800–1700 BP) recorded in Jura lakes (Magny, 1992; Magny et al., 2003). According to Berglund (2003), widespread reforestation is documented in Scandinavia due to the retreat of agriculture; this occurred simultaneously with cooling anomalies around 1500 BP, such as fluctuations in surface temperature in the Norwegian Sea and variations in lake level. At the same time, in British lowland rivers, a major episode of ^{14}C dated flooding occurred around 1650 BP associated with a decrease in forest clearance rates (Johnstone et al., 2006). Conversely, it also corresponds to a transient period between 1700 and 1500 BP of moderate frequency or hiatus in ^{14}C -dated fluvial activity in Poland, Spain and upland rivers in Britain frequently associated with an increase in forest clearance rates (Gregory et al., 2006; Johnstone et al., 2006; Macklin and Lewin, 2003; Macklin et al., 2005, 2006; Starkel et al., 2006; Thorndycraft and Benito, 2006a,b). At a global scale, climate evolution during the 4th century is integrated within a cooling trend documented by an increase in Ice Rafted Debris in the North Atlantic Ocean (Bond et al., 1997), a Northern Hemisphere temperature decrease (Möberg et al., 2005), and a moderate but abrupt change (rise and fall) in atmospheric $\delta^{14}\text{C}$ value (Stuiver et al., 1998) that attests rapid variations of solar activity (Van Geel et al., 1999) and may be linked to climatic change (e.g. Bond et al., 2001; Kerr, 2001; Magny, 1993a,b; Stuiver and Braziunas, 1993).

At the Oedenburg site, localised organic-rich sediment deposition occurred in some palaeo-channels during the first three centuries AD, becoming generalised over the whole floodplain by the fourth century, denoting a permanent high

water table from that time onward. We assume hydrological control on floodplain occupation during the 4th century AD. This agrees better with climatic events identified in the Rhine catchment area and elsewhere in northern Europe, than with those identified in Jura lakes and southern Europe.

6. Conclusion

Settlement dynamics shows four main phases at the Oedenburg Gallo-Roman site, located in the Upper Rhine floodplain. The integrated study of the topography, the geomagnetic survey map, and the field prospecting dataset allowed (1) a better visualisation of the inhabited districts over time, (2) a better appreciation of the chronology of the Roman roads without excavation, (3) a better understanding of the different constraints that controlled the evolution of the Roman settlement. This last point demonstrates the adaptation of Roman urbanism to topographical and hydrological problems through time. Our study suggests that several parameters may have constrained the modification of the urban network at the site. Although the topography of this alluvial landscape imposes certain constraints, at the origin of the site during the first century AD, the settlement seems to be homogenous and chiefly influenced by the military presence in the camp. In the middle of the first century, the abandonment of the military camp is linked to external causes, such as the Roman invasion of ‘*Agri Decumates*’. The non-resettlement of the military zone after this period does not appear to be linked to hydrological conditions, as settlement continues in a neighbouring zone which is just as vulnerable to hydrological risk. The two most plausible hypotheses for non-resettlement therefore rely on the fact that the only benefit is to offer an easy access to the Rhine and/or on the particular character of a military zone which is retained even after the military camp has been abandoned. During the fourth century, however, the permanently higher water table must have contributed to the abandonment of the floodplain, along with internal factors, such as the increased attractiveness of the terrace, where a new fortification and major roads were built. To conclude, the study of Roman coin distribution at this site has allowed us to detect the effect of hydrological conditions and climate variation in the southern Upper Rhine floodplain during the fourth century. Finally, the sensitivity of hydrological and archaeological records at the long-lived site of Oedenburg has allowed us to detect the possible effects of hydrological constraints on the Gallo-Roman population, through the significant changes in settlement dynamics in the floodplain area. This reflects the great potential of integrated topography-related studies of the spatial distribution of artefacts presenting high temporal constraints, such as Roman coins, particularly at the exceptional alluvial site of Oedenburg.

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