LAND USE AND SETTLEMENT DYNAMICS IN THE BAYS OF BEVAIX AND CORTAILLOD (NEUCHÂTEL LAKE, SWITZERLAND) DURING THE LATE BRONZE AGE

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ABSTRACT

Several bays located on the north-western shores of Neuchâtel Lake (Neuchâtel canton, Switzerland) were intensively occupied during the Late Bronze Age (HaB, corresponding to 1060-850 BC). The dendroarchaeological data of the two bays, Bevaix and Cortaillod, were confronted with evidence stemming from the terrestrial sites and archaeopedological study, in order to get insight into the interaction between settlement dynamics, land use, and handling environmental challenges. Although these bays were occupied almost continuously between 1060-1050 and 850 BC, archaeological data reveal that in the hinterland, behind the bays, only few structures attributed to the HaB period are documented. This absence seems to be related to occupational dynamics. The exhaustive study of the piles of the palafittic villages indicates that shoreward colonisation of the lake was carefully planned. The synchronous expansion of satellite villages in two bays has been interpreted as an indication of recurrent interaction between their populations. Moreover, the oak piles, mostly used for the construction of houses, suggest that forest resources exploited by inhabitants of the two bays were considerably different. These data correspond well with the agronomic and forestry potentials of the hinterland as it is reconstructed by applying the principles of land evaluation. This investigation showed that a large part of the soilscape was too humid or too clayey both for cereal production and optimal oak growth. Significant differences of agricultural and forestry suitability of soils in the vicinity of the two bays was revealed as well. To conclude, the superposition of data permitted us to unravel new understandings of the occupation dynamics and management strategies of the environmental challenges faced by the Late Bronze Age population in the studied region.

KEYWORDS

Neuchâtel Lake, bays of Bevaix and Cortaillod, Bevaix Plateau, Areuse delta, Late Bronze Age HaB, lake-dwellings, hinterland, village organisation, terrestrial settlements, dendrochronology, archaeopedology, land evaluation, forest resources, agronomic potentials of soils

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1. Purpose and research context

1.1. ARCHAEOENVIRONMENTAL STUDY FRAMEWORK

This paper aims to present selected research results of a large-scale interdisciplinary research project that was carried out in recent decades in the vicinity of the north-western shores of Neuchâtel Lake. This region is characterised by the presence of numerous lake-dwelling sites, of which several are classified as Unesco heritage sites (Arnold, 2009). Between 3870 BC and 850 BC, during low lake level periods, the shores were periodically occupied by lake-dwellers. Large scale hydro-engineering works carried out by the end of the 19th century lowered the lake level with 2.7 meters (Nast, 2006), which permitted the discovery and documentation of several dwelling sites that had remained hidden under water for centuries. The lowering of the lake level triggered an enhanced erosion risk; therefore numerous rescue excavations were performed (Arnold, 2009). Thanks to these rescue excavations, a significant amount of scientific data witnessing the various aspects of the lake-dwellers' every-day life and their environment has been assembled. In addition, the construction of the A5 highway, which started in the sixties, permitted the documentation of not only the archaeological, but also the environmental aspects of numerous terrestrial sites; these results are referred to in numerous publications (Bednarz et al., 2006; Weber-Tièche and Sordoillet, 2008; Leducq et al., 2008; Anastasiu and Langenegger, 2010; Grau Bitterli and Fierz-Dayer, 2011; Akeret and Geith-Chauvière, 2011; Elmer et al., 2016; Jobin and Wüthrich, 2017). Among these investigations, as an assumed choice to better understand the relationship between soils and human activity (B. Arnold, com. pers.), systematic archaeopedological investigations were also performed between 1995 and 2000. A synthesis of these results is underway and this paper focusses on land use questions, which emerged during the comprehensive study of piles of Late Bronze Age settlements. The details of this interdisciplinary investigation were communicated during the meeting *Entre terres et eaux, les sites littoraux de l'âge du Bronze, spécificités et relations avec l'arrière-pays,* which took place in 2017 in Agde (Hérault, France) and were published afterwards (Deák et al., 2019). Herewith we intend to highlight the main elements concerning settlement dynamics during the Late Bronze Age with a special focus on the characterisation of the soilscape, potential land use, and the interaction between the lake dwellers' communities having different land resources.

1.2. ENVIRONMENTAL SETTING

The studied region is situated on the north-western shore of the Neuchâtel Lake (Figure 1). The geomorphology is comparable to an amphitheatre (Fig 2a,b). This is related to a long geological history that started during the Mesozoic and was shaped by erosion sedimentation processes related to glacial passages during the Late Pleistocene. On the north-western part of this territory, the Boudry Mountain (Jura Massive), culminating at 1390 m a.s.l., is composed of Jurassic and Cretaceous limestones (Meia and Becker, 1976), locally covered by glacial deposits containing alpine, non-calcareous material, too. Here, the important slopes (16-40 %) are covered by forest and meadows. Starting from about 470 m a.s.l., the Bevaix Plateau is a triangular landscape unit of about 8 km² and is built up of tertiary molasses (sandstones, marls, and limestones), covered by Pleistocene glacial (moraines, glacio-fluvial, and glacio-lacustrine) deposits and post-glacial fluviatile, palustral, and slope sediments (Weber-Tièche and Sordoillet, 2008). It is characterised by an irregular topography due to the presence of several, more or less, large depressions, some of them being traversed by active or buried rivers and brooklets. Today, several more or less large settlements are located on this plateau which is crossed by the A5 highway; the main land use is intensive agriculture. Towards the lake, the Bevaix Plateau is delimited by steep slopes (15-20 %) and is composed of tertiary and quaternary mostly fine sediments (Weber-Tièche, 1998; Letessier, 2004). Most of these slopes are south-oriented and today are covered by vineyards. The land between these slopes and the lake is rather narrow (100-150 m) and is the place of accumulation of lake sediments and slope deposits. This area is the littoral platform, which was affected by lake level variations throughout the Holocene and was the place of installation of palafittic settlements.

The north-eastern part of the studied region, the plain of the Areuse, is a triangular territory of about 4 km² between the Jura Mountains and the Neuchâtel Lake. It is situated some tens of meters under the Bevaix Plateau, at altitudes between 440-429.3 m a.s.l. In the past it has been crossed by numerous channels of the Areuse river (31 km long, with a hydrological basin of 405 km²), while today the river flows along a rectilinear canal and the plain is intensively used for crop production. The actual mean lake level is 429.3 m a.s.l.

The present-day climate in the study region is characterised by mean annual temperatures of 9.4 °C (Neuchâtel, 485 m a.s.l.), while higher up in the mountains it is 6.3-6.4 °C (La Chaux-de-Fonds, 1018 m a.s.l.). For the same stations, the mean annual precipitations are 987 mm and 1468 mm respectively (Météosuisse, 2016). The mean annual evaporation for the Neuchâtel station is 573 mm (Météosuise, 2005), thus on an annual basis leaching conditions prevail. During the Holocene, these climatic parameter values varied significantly (Magny, 1998). The Final

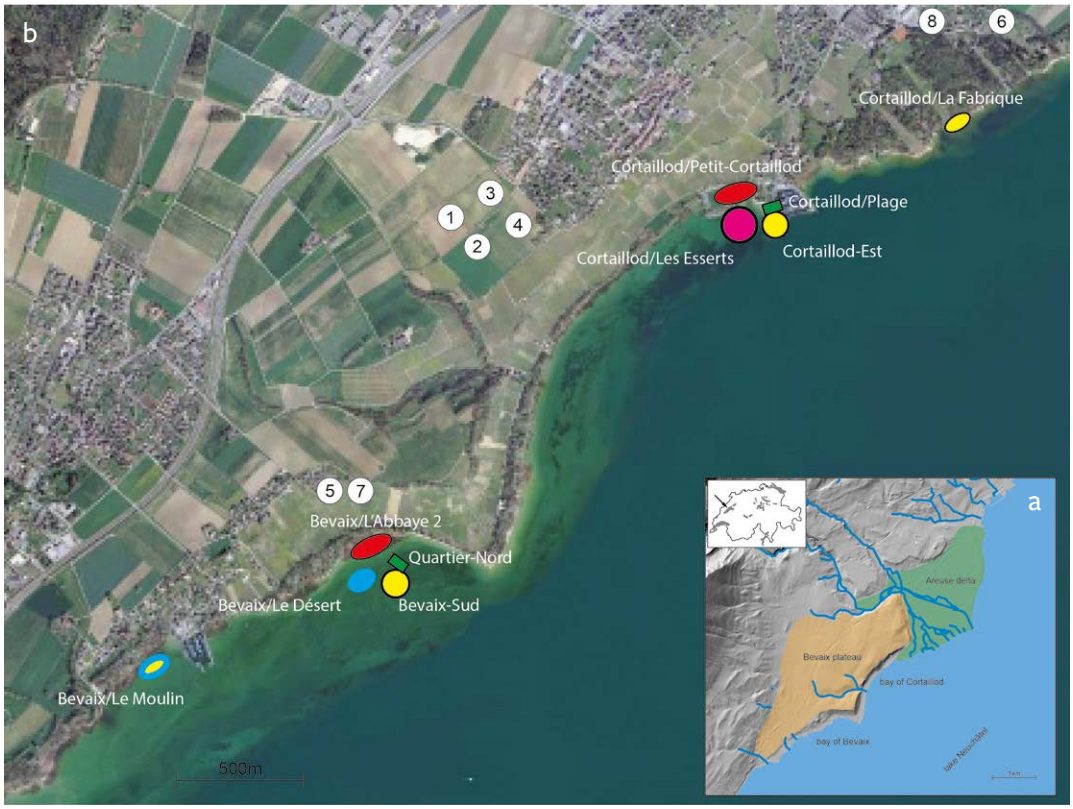

Figure 1. Location of the studied region, geomorphological setting and position of the sites discussed in this paper:

a. Geographical location and geomorphological setting.

b. Position of lake-dwelling sites (red, yellow, blue, green spots; their chronology see Fig. 3) and terrestrial sites (1. Boudry/Les Buchilles; 2. Cortaillod/Petit Ruz; 3. Cortaillod/Petit Ruz; 4. Boudry/Les Buchilles; 5. Bevaix/Les Pâquiers; 6. Boudry/Chézard; 7. Bevaix/La Prairie-ouest; 8. Boudry/Champ-le-Sage-Centre).

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Bronze Age is considered a period with optimal climatic conditions, characterised by prolonged dry and relatively warm growing seasons and low lake levels throughout the northern Circum-Alpine region. During this period, the mean lake-level of Neuchâtel Lake was at about 426-427 m a.s.l. (Arnold and Langenegger, 2012). Before this, during the climatic deterioration of the Middle Bronze Age, the mean lake-level rose up to 433 m (Deák et al., 2018) and the lakeshores were abandoned (Arnold, 2009). The end of the Late Bronze Age corresponds to a major climatic deterioration, characterised by an important rise of lake-levels all through the northern Circum-Alpine region (Magny, 2015). This is also the end of the lake-dwelling civilisations all over this region (Menotti, 2015).

In the absence of anthropic activity and with the exception of the steep slopes and river channels, the potential vegetation all through the studied area is deciduous forest (Béguin and Theurillat, 1985-86). This was also the case when the first farmers colonised the region (Hadorn, 1994).

2. The bays of Bevaix and Cortaillod during the Late Bronze Age (HaB)

2.1. LAKE-SHORES AND LAKE-DWELLINGS AT NEUCHÂTEL: BRIEF INTRODUCTION

In the studied region, the first lake dwellings emerge around 3870-3850 BC during the Middle Neolithic. The lake shores were definitively abandoned around 850 BC towards the end of the Late Bronze Age, when, because of an important climatic deterioration (Bourget phase, Magny 1998), the lake-level rose markedly and buried these settlements. This time span of 3000 years does not mean a continuous and permanent occupation of bays and shores. In fact, this long period is marked by more or less long phases of climatic deteriorations triggering the lake level to rise and on several occasions forcing the population to abandon the shorelines and seek refuge in less exposed and better protected areas of the hinterland. During the Neolithic, for a period of 1450 years, recurrent and shifting lake settlements occupied most of the shores

of the studied region evenly. The Early Bronze Age (dated around 1600) palafitic phase is little documented so far. Following this, after 600 years of abandonment, starting from 1054 BC, a Late Bronze Age population reconquers the lakeshores at a moment when the mean lake-level is low. Starting from this moment on, the settlements are concentrated solely in the principal bays. Four of them have been thoroughly documented, while a fifth one is presumed, but not explored, as it is deeply buried under backfills, permitting the lakeward expansion of Neuchâtel town (Arnold, 2009). The bays of Bevaix and Cortaillod are two of the locations among the four thoroughly studied Late Bronze Age (HaB) piles-dwellings in the studied region.

2.2. LATE BRONZE AGE SETTLEMENT DYNAMICS AS REVEALED BY A DENDROARCHAEOLOGICAL STUDY

The dendroarchaeological study of posts of four exhaustively studied Late Bronze Age lake-dwellings (Bevaix-Sud, Cortaillod-Est, Hauterive-Champréveyres, and Auvernier-Nord) permitted the development of a theoretical model of occupations of the bays during this period (Langenegger, 2012). Although the discussion below is focussed on the data concerning the bays of Bevaix and Cortaillod (Figure 1 and 3), most of the enumerated facts are valid for the other bays, too.

The available dates indicate that in the studied region the recolonisation of the shorelines was almost synchronous all over and took place around 1057-1054 BC.

Figure 2. Aerial photos of the studied region:
a. Boudry Mountain and Bevaix Plateau with the slopes towards the lake.
b. Areuse Delta. Copyright Laténium.

The first houses were built close to the actual shoreline, while later on the expansion of the houses occurred towards the lake, indicating the gradual lowering of the lake-level. Based on their size, their duration (180 years), and their continuity, these first settlements are considered 'founding villages' and they most probably played a central role in the development of an important community in each bay. The 'founding village' of Bevaix bay, the site Bevaix/L'Abbaye 2 (Figure 3) occupied up to 2 ha at its maximum development. The 'founding village' at the Cortaillod bay was not yet discovered, but its existence is deduced from the extensive regeneration of forest witnessed by dendrochronological data of wooden piles of the satellite villages (Deák et al., 2019). These settlements developed by expansion phases towards the lake through the construction of 'satellite villages' (Figure 3 and 1). In each of the bays, the 'founding villages' were completed by one or several 'satellite villages'. Their location in the neighbourhood of the 'founding villages' indicates that they belonged to the same community. Each of them possibly had a specific role in the social and economic functioning of the local society and most probably, they all relied on the same agricultural and forestry territory. The 'satellite villages' functioned for a shorter period and most probably were constructed to face the demographic growth and/or to permit the reconstruction of some of the first-generation houses of the 'founding villages'. The maximum lifetime of a palafittic house is about 40 years.

The best-studied 'satellite villages' are the ones called Bevaix-Sud (Arnold and Langenegger, 2012) and Cortaillod-Est (Arnold, 1986) (Figure 1). Along a straight line, they are about 2 km apart and the dendrochronological data of about 4600 piles indicates that they developed for about 60 years and in a completely synchronous manner. The cutting of oak trees started at the same time, during the winter of 1011/1010 BC. Between 1009 and 1004, the innermost houses of the two villages are finished and surrounded by fences in beech wood at Bevaix and in oak wood at Cortaillod. The last construction phase at Cortaillod-Est started in 964 BC and corresponds to a new cluster of houses (called Cortaillod-Plage) located outside the fence, towards the lake. A similar construction dynamic and chronology has been revealed at the site of Bevaix-Sud with the construction of Quartier-Nord. The exhaustive study of piles from the Bevaix-Sud site showed that its construction was extremely carefully planned. Indeed, even a geometric division of the village space before its construction could also be unravelled (Arnold and Langenegger, 2012). Earthworks and development works were also associated with this. As an example, 33 tons of pebbles were brought into the village to consolidate the surfaces.

These 'satellite villages' were abandoned shortly before 950 BC and in 920 BC a new series of these villages started to be constructed (such as Bevaix/Le Désert) or re-occupied (Bevaix/Le Moulin, Figure 3). From 920 to 880 BC the 'founding villages' continued to be occupied, while the new 'satellite villages' continued to develop.

Between 878 and 871 BC a major change must have occurred in the living conditions of the communities living on the shores of Neuchâtel Lake. Indeed, the former 'founding' and 'satellite' villages were permanently abandoned for a new generation of large villages. Three of such new villages have been documented so far throughout the lake shores located in the Neuchâtel canton. These new, regrouped villages, are characterised by a very short occupation period, lasting for about 20 years. In the case of the formerly intensively populated bays of Bevaix and Cortaillod, this second bay was chosen as the location of a newly constructed village. Known as Cortaillod/Les

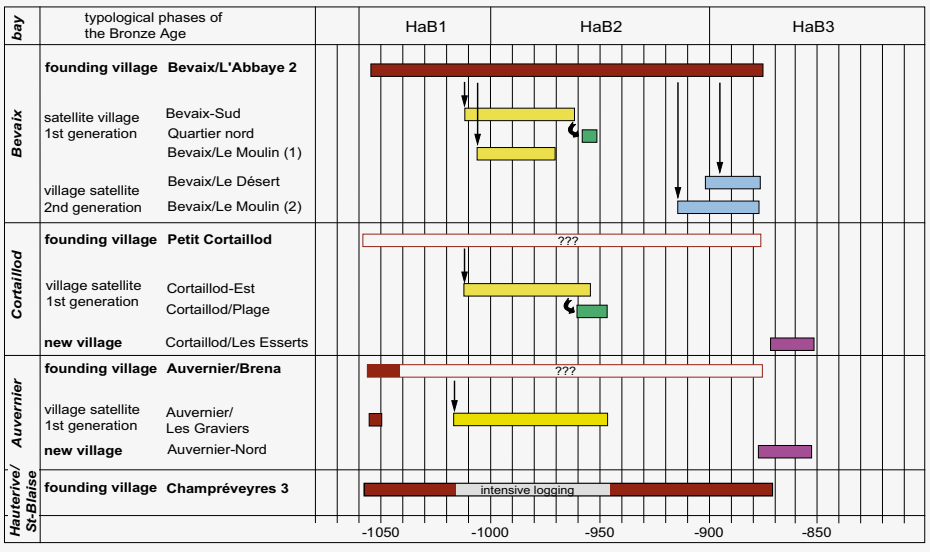

Figure 3. Chronology of 'founding' and 'satellite' villages.
Location of the settlements of bay of Bevaix and Cortaillod are represented on Fig. 1. The bays of Auvernier and Hauterive are situated north-east from the studied bays. Modified from Arnold and Langenegger, 2012.

Essert site (Figure 1 and Figure 3), it included about 60 houses, was inhabited between 871 and 862 BC and was surrounded by a triple fence rim (Arnold and Langenegger, 2012). These major population displacements are also reflected by modifications in the artefact assemblage. This is known as the HaB3 assemblage (Rychner, 1987). Around 850 BC, thus about 30 years after their creation and despite the buildings still being in a good state, these new villages were also abandoned, similarly to all the lake-dwelling settlements of the northern Circum-Alpine region (Menotti, 2015). This is most probably related to the major climatic degradation (cooling and increased precipitation) that starts around 850/800 BC which resulted in a major rise in lake-levels (Magny, 2015) as well as possibly triggering a decrease in crop yield (Tinner et al., 2003). The beginning of this climatic change corresponds to the onset of the Iron Age.

2.3. FOREST RESOURCES AND 200 YEARS OF STRUCTURED INTERACTION

Overall data indicate that the internal organisation of the two bays is strongly alike: the annual tree fellings, unravelled through the study of the piles used for the construction of houses, indicate a perfect chronological superposition of periods of construction, reparation or expansion in each of them (Figure 4a, 4b). This suggests a strong link in the functioning of the communities populating these two bays. The development of the settlements was thus synchronous and presented the same dynamics, but local adaptations could also be discovered: the orientation of the houses took in consideration the dominant or the most violent winds, while the cutting techniques to obtain the right dimensions of the posts were adapted to the wood used. Indeed, the dendroarchaeological study revealed that the size and age of oak trees used for the posts varied, suggesting two distinct forest resources. The forests exploited for the houses constructed in the bay of Bevaix were composed mainly of 200-300 years old trees, while the ones employed for the dwellings of the Cortaillod bay were clearly younger (Figure 4b).

3. The hinterland: archaeological data

In the hinterland behind the lake dwelling sites, the archaeological vestiges dating from the Late Bronze Age are rare, despite the intensive investigations performed before the A5 highway construction. The fact that in these areas archaeological finds belonging to several other archaeological occupation phases systematically exist, suggests that this absence is not related to erosion processes, but rather reflects a reality triggered by occupation dynamics.

3.1. SEASONAL OR SPECIFIC HABITATS AND/OR OUTBUILDINGS

The lake shores settlements were constructed starting from 1057-1054 BC and this marks the beginning of the second part of the Final Bronze Age (HaB). The colonisation of the lakeside was not a massive and hasty act, but rather a transitional process planned through 2-3 generations in the conditions of climatic improvements associated with the lake-level retreat and the outcropping of silty marl lake sediments on the littoral platform. This implies a progressive 'abandonment' of the terrestrial settlements occupied during the previous periods. As such, the population continues to use the hinterland as a habitat during the construction phase of lake dwellings.

In the studied region, only two architectural remains dating from before and during the construction of the first lake-dwelling settlements could be found, despite

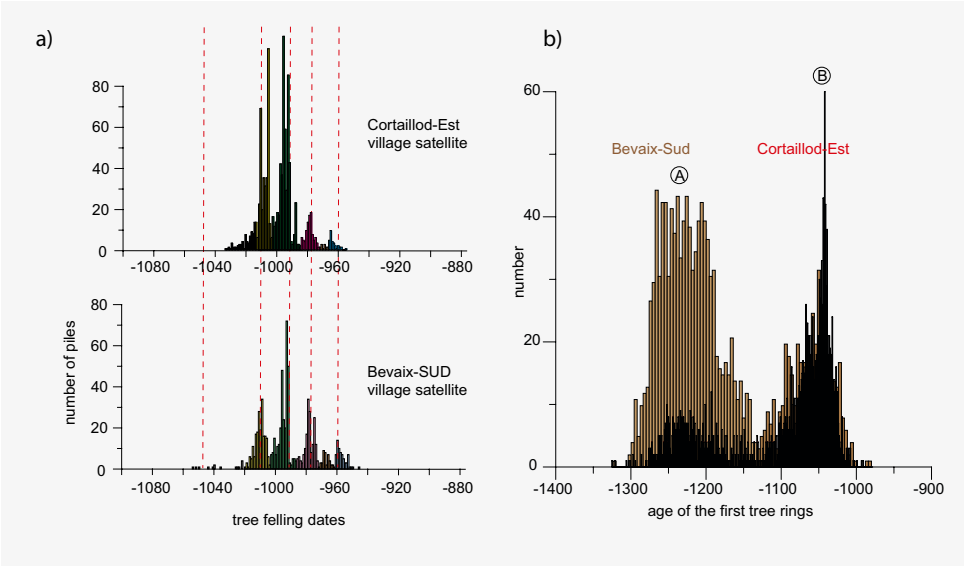

Figure 4. Lake dwelling settlement as unravelled by dendroarchaeological studies:

a. Chronological evolution of two synchronous 'satellite' villages and their settlement dynamics as indicated by the number of piles used for construction.

b. Age histogram of wood population used for their construction.

the large-scale investigations. They are part of Boudry/Les Buchilles and Cortaillod/Petit Ruz sites (Anastasiu and Langenegger, 2010), located about 1 km away from the lakeshore in the hinterland (Figure 1). The two isolated houses are situated at about 300 m from each other in a humid depression, on the banks of two small brooklets and they are characterised by modest dimensions comparable with the houses documented for the preceding Middle Bronze Age. The first house, identified by four piles, contains a fire place, but no artefacts. Only few pottery fragments have been found in the soil surrounding it. The second building is identified by piles, a bottom plate, and a floor made up of a gravel layer. It contained both pottery fragments and lithic artefacts. A fire place situated in the neighbourhood has also been linked to this structure. A waste disposal area containing, among others, a large concentration of pottery fragments has also been documented along the riverbanks and in the watercourse of the brooklets passing next to this building (Anastasiu and Langenegger, 2010). Taken as a whole, the archaeological finds, together with the available C^{14} dates suggest an anthropic activity here at about 1060 BC, corresponding to the planning and beginning of the construction phase of the first lake-dwelling houses. This is interpreted as an indication that at least parts of the population still lived and were active in the hinterland, while waiting for the construction of palafittic villages (Deák et al., 2019).

Further away, three treefall pits transformed to waste pits at Bevaix/Les Pâquiers site (Bednarz et al., 2006) are the only settlement type remains in the hinterland, which date from the Late Bronze Age. They contained an important concentration and variety of artefacts (pottery fragments, lithic artefacts, grinding material, burned soils fragments, Figure 5a,b), charcoal, and carpological remains. The latter are characteristic for Late Bronze Age habitat sites (Akeret and Geith-Chauvière, 2011). The ceramic assemblage is similar to the regional reference collections attributed to the HaB period and are identical to those found at the lake dwelling sites L'Abbaye 2 and Bevaix-Sud of bay of Bevaix (Figure 1). Although eroded, these waste pits are the only material evidence of a settlement in the hinterlands that existed during the same time as the lake-dwellings of the 10th century BC. It is difficult to determine the exact nature/function of this habitat, but the available data suggest it was rather an isolated farm (specialised or seasonal) than an organised village/hamlet.

3.2. SHELTER OR WITHDRAWAL IN CASE OF LAKE-LEVEL RISE

In an abandoned channel located in the middle of the Areuse delta, at about 1 km from the lakeshores, a 40 m^2 large waste disposal was found (Elmer et al., 2016). It contained 15.000 pottery fragments belonging to at least 1.500 recipients, accompanied by quern-stones, lithic artefacts, clay fragments originating from around twenty firedogs and five spindle whorls, numerous burned stones, burned earth and wattle and daub fragments (Figure 6a,b). Interpreted as a domestic waste discard zone, this assemblage indirectly attests to a settlement composed of several buildings in proximity to this channel. Based on pottery typology, it has been attributed to the second half of the HaB2 phase (950-900 BC) of the Late Bronze Age. Based on regional archaeological data and on the evidence of a temporary break in the development of dwellings in the bays of Bevaix and Cortaillod, it is estimated that a short, but marked lake-level rise occurred during this period (Arnold and Langenegger, 2012). This lake-level rise did not denote the complete abandonment of

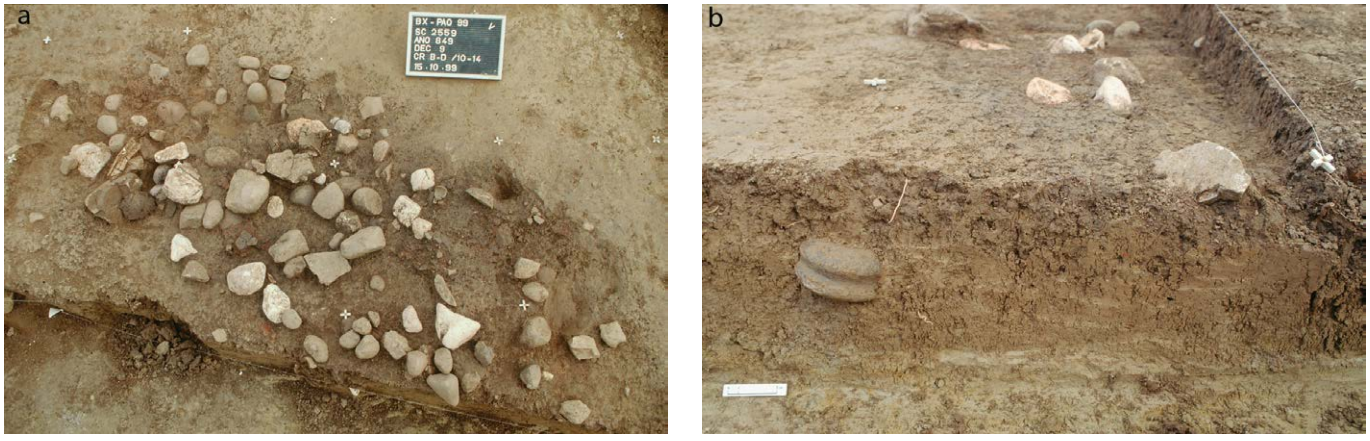

Figure 5. Treefall hollows transformed in wastepits, Bevaix/Les Pâquiers site:
a. Horizontal section.
b. Vertical section.
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the lake-shore: in the studied area it induced a temporary withdrawal of at least part of the population, while in the bay of Hauterive (Pillonel, 2007), which was located some kms North-East on the same shores of the Neuchâtel Lake, the houses were repaired or reinforced in order to resist more important hydrological trials.

3.3. TRACES OF CEREMONIAL COMMUNITY EVENTS AND BURIAL SITES

A few hundred meters inland from the lakeward boundary of the Bevaix Plateau, at the site of Bevaix/La Prairie-east (Figure 1), at the edge of a large marshy area, three very similar rectangular, flat bottomed hearth pits were discovered (Von Burg and Pillonel, 2003; Leducq et al., 2008). The bottoms are covered by a charcoal layer stemming from the combustion of oak wood, mainly slotted logs (up to 70 cm long). They contained, among others, a wide variety of burned cereal grains and a few pottery fragments, the latter attributed to the Late Bronze HB2 period. The dendrochronological analysis of one of these logs suggests its utilisation around 970 BC. These hearth pits of culinary vocation are common in the regional Late Bronze Age record (Mauvilly et al., 2003). They are placed outside of habitat areas, often clustered, functioning synchronously and for short periods of time, which is interpreted as reflecting festive or ceremonial community/

Figure 6. Domestic waste discard in an abandoned channel at Boudry/Chézard in the Areuse Delta:

a. Horizontal view during excavation.

b. Restored pottery (photos Thomas Jansen and Marc Juillard; copyright Laténium).

society events (Orliac and Wattez, 1989; Ramseyer, 2003; Mauvilly et al., 2003). These structures mentioned here are located upslope of the bay of Bevaix, at the edge of the marshy area, along the shortest possible circulation line between the lake-dwellings and the forests on the slopes of the neighbouring mountains. The wood used is oak, while the timing is around 970 BC, corresponding to the growth of the Bevaix-Sud satellite village (Arnold and Langenegger, 2012). All these elements suggest that certain activities or tasks of the lake-dwelling village planification could have been marked by festivities or rituals.

Only two burial sites dating back to the Late Bronze Age, more precisely to its final phase, thus corresponding to the phase of regrouped villages, have been documented so far in the Neuchâtel canton. One of them is situated in an abandoned channel of the Areuse delta at the site Boudry-Champs le-Sage-Centre (Elmer et al., 2016).

4. Soilscape and agricultural potentials of soils during the Late Bronze Age

4.1. SUITABILITY OF SOILS: WHY AND HOW

Since the Neolithic agricultural revolution, soils around settlements are part of the natural resources influencing, among others, the production of agropastoral goods and the nature and quantity of wood available for construction. The evaluation of suitability of soils for various land use in a given climate means the superposition of data concerning:

i. physico-chemical characteristics of soils;
ii. topographic data;
iii. edaphic requirements of plants for optimal growth and
iv. panoply of available agricultural tools and techniques.

Figure 6. Agricultural tools discovered at the Late Bronze Age site of Hauterive-Champréveyres:
a. Hoe made of beech wood.
b. Digging stick made of Cornelian cherry wood.
Photos Marc Juillard; copyright Laténium.

This way of inspecting the relationship between soils and potential land uses is borrowed from the Land Evaluation practices. These practices were initially constructed for present-day or future land uses and defined by the Food and Agricultural Organisation of the United Nations (FAO) in 1976 as an 'assessment of land performance when used for specific purposes'. In an archaeological context, land evaluation intends to define the potential suitability of ancient landscapes for ancient land uses (Van Joolen, 2003). In such a framework, many parameters of evaluation are unknown or approximatively extrapolated. For these reasons, we do not attempt to give quantitative indications on yields in this study, but we focus on a qualitative and comparative assessment of soils for specific purposes. In the last decades, several scientists attempted this exercise (ex. Borrello, 1984; Van Joolen, 2003; Louwagie et al., 2006; Baum, 2014) and gave interesting views on the potential relationship between soils, landscapes, and human activity. These above-mentioned studies are based on the characteristics of the present-day soils. In the case of the studied region, the present-day soil cover is considerably different from the past one, therefore in our study the first step was to distinguish and characterise the soils that possibly existed during the Late Bonze Age in the region surrounding the bays of Bevaix and Cortaillod.

Below we will focus on the suitability of soils for crop production, for meadows/pasturelands, and for forestry with particular attention to oaks that are used as piles for the houses. As for the agricultural tools, we assume the use of digging sticks, the hoe, and the plough, all of which have been available since the Neolithic (Jacquat, 1989 and Figure 7). The use of animal traction has also been attested since 2900-2500 BC (Jacomet and Schibler, 2006). In terms of crop production, implying ploughing and hoeing, the soil texture is a factor that influences the potential use of available tools. We estimate that:

i. sandy-silty soils can be easily cultivated with tools available during the Bronze Age;
ii. gravelly soils, depending on size and quantity of gravels, might present strong limitations;
iii. strongly clayey soils cannot be exploited for crop production during the Late Bronze Age.

Based on recent agronomic research concerning direct sowing and limited tillage (Labreuche et al., 2014), we assume that tillage was not systematically employed. Nevertheless, even in these conditions planting seeds and removing weeds were compulsory tasks. Taking into account that the agricultural tools were manufactured out of wood, in this work we estimate that strongly clayey soils were only marginally suitable or not suitable for crop production.

In order to evaluate the suitability of soils for the various land uses of the Late Bronze Age communities, first their physical and chemical fertility (Troeh and Thompson, 1993) was examined. The chemical fertility is in function of the quantity of organic matter available in the surface horizon and of mineralogical composition of the fine fraction throughout the soil. As for the physical fertility it is defined by:

i. granulometry, influencing the water retention capacity and workability;
ii. rooting depth;
iii. presence/absence, depth, and dynamics of the water table.

4.2. MOSAIC OF ORIGINAL SOILSCAPE

Today, the soilscape of the studied region is mostly composed of soils developed on more or less recent colluvial deposits of various thicknesses and thin soils formed on strongly eroded sediments of glacial origin (Figure 8). As for ancient alluvial and palustral settings, these areas nowadays are canalised (Figure 2) and/or intensively drained. As mentioned above, the examination of the ancient soilscape is possible thanks to the systematic geological and pedological documentation of archaeological interventions performed especially along the A5 highway, completed with observations done outside of it (see references above). Therefore, our study is focused on the original soils, i.e. the soils that covered the soilscape before important deforestations and major erosions took place. A brief characterisation of these soils is given below, but as a preliminary outline it is possible to say that on slopes and plateaus, these soils were more or less decalcified and were characterised by a thick, strongly humiferous surface (A) horizon and a more or less thick subsurface horizon. During Neolithic and earlier parts of the Bronze Age, these soils were already cleared and cultivated on numerous parts of Bevaix Plateau. Local reworking of the original surface horizon has also been retraced (Bednarz et al., 2006; Weber-Tièche and Sordoillet, 2008; Grau Bitterli and Fierz-Dayer, 2011). Nevertheless, with the available data we estimate that physical and chemical fertility parameters of the original soils were not significantly altered by this early and local erosion/sedimentation processes. Thus, they were also the soil resources during the Late Bronze Age.

After a first thorough examination of the collected data, it turned out that, for the original soils in the studied region, the soil's physico-chemical characteristics influencing past land use are primarily determined by the nature of the parent material and then by their landscape position. Therefore, the soils distinguished have been grouped, named, and characterised according to these

criteria. This approach to sidestep the existing soil classification systems was chosen in order to cope with the nature of the data. In the archaeological contexts, the accurate physico-chemical parameters are not available because the soils are more or less eroded and sometimes even buried for several thousands of years. The soils differentiated are presented briefly below and in Figures 8 and 9, while Table 1 resumes the main parameters of their physico-chemical fertility that are decisive for their potential land use. The soil map (Figure 10) illustrates the original soilscape in the neighbourhood of the two bays. A comparative overview of potential land uses during the Late Bronze Age is presented in section 4.3 below.

Soils on glacial till deposits – A soils

The glacial till deposits form the parent material of a part of the ancient soils of the Bevaix Plateau. These deposits are strongly calcareous (30-45 %) and are rich in clay (30-60 %) and silt fraction; in general, they contain few coarse elements that can vary in size from small gravels to big blocs (limestones, magmatic, and metamorphic rocks). In some areas, the sandy fraction can be more important to the detriment of clayey components. This sediment is strongly compacted due to the weight of hundreds of meters of ice that passed over it.

On the well-drained slopes and on hilltops, the soil formed on this deposit (Table 1, A.1 soil, Figure 8a) was decalcified to depths of less than 1 m and its mineralogical composition was characterised by the presence of a high amount (50-70 %) of weatherable minerals and phyllosilicates. The surface horizon was considerably enriched in organic matter, as during thousands of years it evolved under forest vegetation. The initial compact character of the glacial till has been improved by soil forming processes, while the strongly compact parent material persisted to induce impeded drainage. The porosity of this soil was mainly related to bioturbation in its upper part and with swelling-shrinking processes in the subsurface horizon. Thus, in little perturbed conditions, it is assumed that it had a very good porosity in the surface horizon that decreased gradually towards the parent material. On foot slopes and in depressions, the decalcification and weathering of this sediment was less important, thus the soil (Table 1, A.2 soil) was much shallower.

In short, these soils had a good chemical fertility and a good water holding capacity. Nevertheless, these soils presented limitations for crop production due to their low permeability (A.1) and/or bad drainage condition (A.2). In addition, due to their clayey texture these soils were humid for longer, thus cold, hampering seed germination. Last but not least, the high clay content was certainly a limitation for the use of tools manufactured out of wood.

Soils on glaciofluvial and glaciolacustrine deposits – B soils

The glaciofluvial sediments are sandy and sandy gravelly (20 to 90 % coarse fraction) and strongly calcareous (20-60 % $CaCO_3$). Similarly to A soils, we estimate that the surface horizon of soils (Table 1, B.1 and B.2 soil) formed on these sediments contained high amounts of organic matter, at least at the onset of Late Bronze Age agropastoral activity. The mineralogical composition of the fine fraction was also characterised by high (30-70 %) weatherable mineral and phyllosilicate content. Their porosity was very important, permitting good root penetration and inducing a high permeability. On the well-drained slopes and on hilltops the depth of decalcification of soils formed on these sediments (Table 1, B.1 soil; Figure 8b) was more than 1 m thick. They were characterised by the presence of a clay illuvial subsurface horizon. On foot slopes and in depressions the decalcification was less deep and the soil (B.2 soil) did not have a clay accumulation horizon.

The glaciolacustrine sediments are composed of silty and clayey stratified, rather compact layers. In most part of the studied region they are intercalated with the glaciofluvial sediments, thus contributing to the variability of these soils. Nevertheless, relatively thick deposits of these sediments are present on the lake side edges of the Bevaix Plateau (Letessier, 2004). With the exception of its granulometry, the physico-chemical characteristics of the soil (Table 1, B.3 soil) formed on this well drained landscape position, presented strong similarities with the B.1 soil described above.

In short, these soils had good chemical fertility. The use of the wooden tool to cultivate the gravel rich facies (B.1 and B.2) was difficult or impossible. Nevertheless, overall observations indicate that in most areas, in the upper part of these deposits, the coarse fraction was less important, thus most probably permitting minimal soil tillage. The low fine material content of soil B.1 suggests that crop production could be disadvantaged during prolonged particular dry conditions. However, the presence of the clay illuviation horizon could compensate for this inconvenience. The B.2 soil located in more humid zones could have been an alternative soil resource in case of prolonged dry conditions. The sandy-gravelly facies were less vulnerable to erosion (B.1 and B.2), while the more silty textured soil (B.3) was strongly susceptible to this type of degradation. The B.3 soil was characterised by good water retention capacity and could be well cultivated with tools available during the Late Bronze Age.

Soils on tardiglacial slope and stream deposits – C soils

After the glacier retreat (at about 17 000 BP, Thew et al., 2009) and before the vegetation colonisation that occurred in the timespan Bølling-Allerød (14 700-13 900 BP,

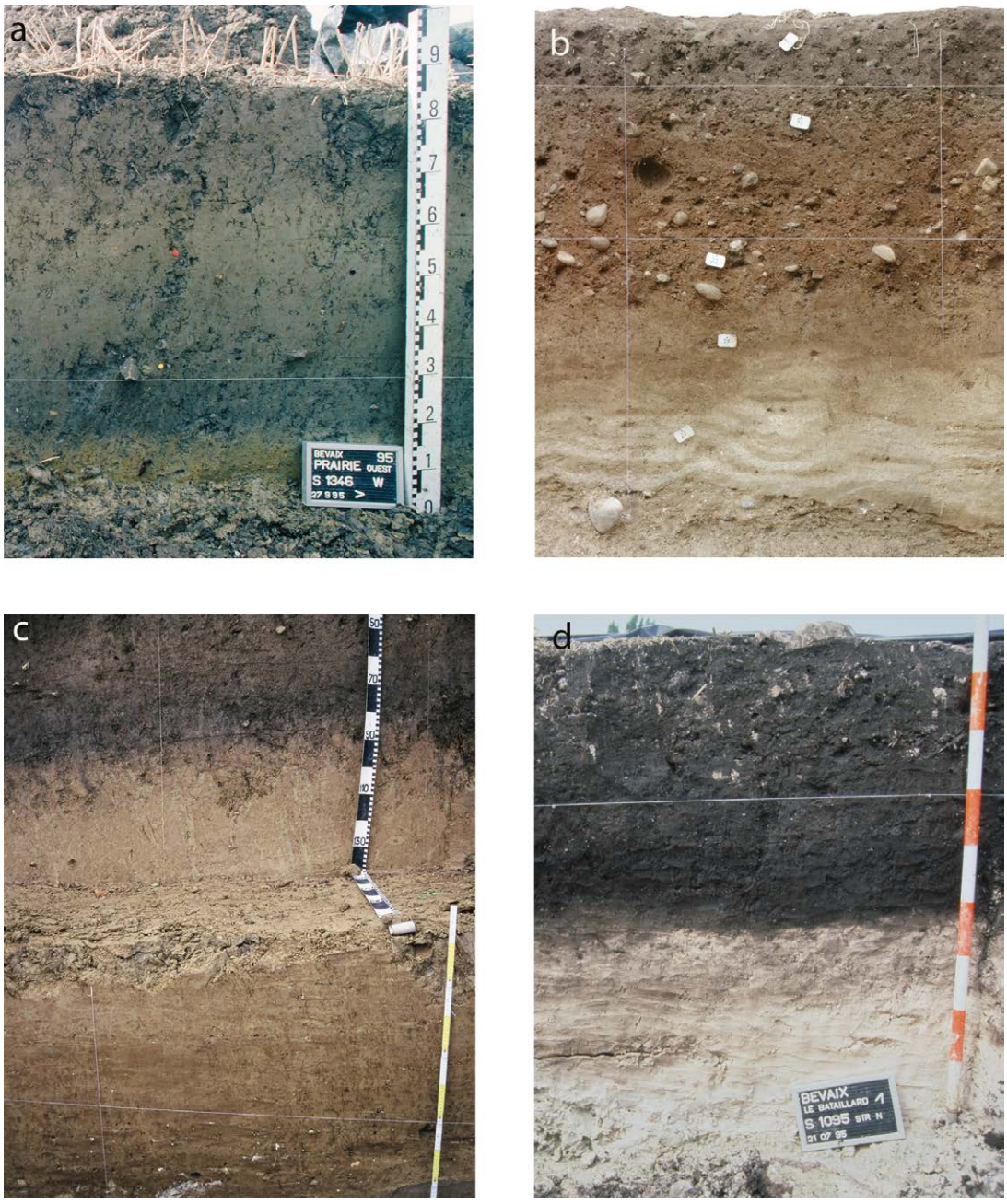

Figure 8. Morphology of some of the components of the Late Bronze Age soilscape of the Bevaix Plateau:

a. Shallow and clayey soil formed on moraine (A.2 soil). The black layer corresponds to the surface horizon of this soil. This layer was at the surface during the Late Bronze Age.

b. Deep soil, rich in coarse elements, formed on glaciofluvial sediments at well drained topographic position (B.1 soil). The gravel rich layer is the original B_t horizon; it is covered by colluviums. The original surface and eluvial horizon have been eroded. For scale: the distance between two vertical lines is 1 meter.

c. Deep, fine textured soil, formed on tardiglacial sediments (C.1 soil). The black layer in the upper third of the image is the original surface horizon.

d. Lake marl (white sediment in depth) and peat (black layers) filling up humid depressions of Bevaix Plateau (D soil). (photos a, b, d, Marc Juillard; copyright Laténium; c – Roger Langohr).

Hadorn, 1994), thus during early parts of the Tardiglacial, the overland flows and slope processes have considerably reworked sediments of glacial origin, as well as the marls and sandstones of the Tertiary substratum. These tardiglacial deposits are usually heterometric, strongly resembling in granulometry to the reworked original sediments and contain between 20-50 % $CaCO_3$.

The soils formed on these sediments were rich in weatherable minerals. Compared to A soils they were characterised by a better permeability, while compared to B.1 and B.2 soils they contained less coarse elements. In well drained position the soil (Table 1, C.1 soil, Figure 8c) formed on this sediment was:

i. decalcified to more than one meter depth;
ii. often had a clay accumulation subsurface horizon and
iii. was characterised by an important porosity related to bioturbation and swelling and shrinking processes, permitting as such a good rooting penetration.

On foot slopes and in depressions, the soil developed out of these sediments (Table 1, C.2 soil) was also decalcified, but to depths of less than 50 cm, thus had a shallower rooting depth. Similarly to the soils described above, the mineralogical composition of these C soils and their evolution under forest vegetation during several thousands of years permitted to have an important nutrient reserve for plant growth. As for physical fertility, we can mention a good water holding capacity, but also the risk of slow water percolation (prolonged humidity) for the finer textured facies and those located in low landscape positions. The use of wood working tools must also have been difficult in the more clayey surface horizons.

Soils of humid depressions – D soil

In large depressions of the Bevaix Plateau located on the foot slopes and discharge areas of the neighbouring Boudry Mountain, lake formation and marshy waterlogged conditions existed, permitting the formation of marls, overlaid

Table 1. The soils composing the soilscape in the neighbourhood of the studied bays during Late Bronze Age and their physico-chemical characteristics influencing agropastoral and forestry activities

Geo-morphological position	Parent material	Topographic position	Soil type on Fig. 10	Chemical fertility	Rooting depth	Porosity	Water holding capacity	Workability	Erosion risks	Other
Bevaix Plateau	moraine	hilltops and gentle slopes	A.1	+++	< 100 cm	++	good	×	very low	cold soils with germination problems
		depressions and foot slopes	A.2	+++	< 50 cm	+	good	××		
	glaciofluvial and glaciolacustrine	hilltops and gentle slopes	B.1	+++	> 100 cm	+++	weak to good	✓	very low	
		depressions and foot slopes	B.2	+++	< 100 cm	+++		✓ to ×		
		edge of Plateau	B.3	+++	> 100 cm	++	good	✓ to ×	high	possible perched water-table
	tardiglacial alluviums and colluvial deposits	hilltops and gentle slopes	C.1	+++	> 100 cm	+++	good	✓ to ×	very low	germination problems in the clayey facieses
		depressions and foot slopes	C.2	+++	< 50 cm	+++	good	✓		
	lake marl and peat	large depressions	D	+	/	+	/	/	/	
ancient lake terraces and lake shore	laminities in alternation with with sandy-gravelly layers	steep slopes	E	+++ to ++	>100 cm	+++	weak to good	✓	high	possible perched water-table
	colluvial deposits	foot slope	F	++	> 50 cm	++	good	✓	exposed to lake level rise	fluctuating and regularly high water-table
	lake deposits	littoral platform	G	+ to ++	< 50 cm	+ to +++	good	× to ××	exposed to lake level rise	fluctuating and regularly high water-table
south-west zone of Areuse Delta	alluviums: channel and alluvial plain deposits	old levees and abandoned inundation plains	H.1	++	>100 cm	+++	++	✓ to ×	possible but rare	spring and autumn possibly high water-table
north-east zone of Areuse Delta		active and abandoned channels	H.2	++	/	/	/	/	high	active fluviatile dynamics
brooklets of Bevaix Plateau		at least temporarily active water courses	H.3	/	/	/	/	/	high and recurrent	high and lasting humidity

+++- high; ++-medium; + -low; ✓- no limitations to till or to work; × - difficult to till or to work; ×× -very difficult or impossible to work; /- not relevant parameter.

Figure 9. Morphology of soils, sediments and landscape adjacent of the bays of Bevaix and Cortaillod:

a. Colluvial sediments accumulated on the foot-slopes of the Bevaix Plateau. Taking in consideration their proximity to lake-dwellings, the F soil formed on these deposits was most probably used for both crop production (ex. pulses) and pastureland.

b. Vineyard on ancient lake-shore pebbles in the neighbourhood of bay of Bevaix. During Late Bronze Age the littoral-platform was covered by a patchwork of gravelly, sandy, chalky and peaty soils (G soil).

c. Alternation of clayey and sandy layers of ancient lake terraces that cover the slopes linking the Bevaix Plateau and the lakeshore. The involutions are related with cryoturbation processes. The E soil formed on this sediment has been largely eroded.

d. Sediments of the Areuse delta (H.1 soil). For scale: the distance between two vertical lines is 1 meter. (photos Judit Deák and Marc Juillard; copyright Laténium).

by peat. The sedimentological study of the swamplands crossed by brooklets of the Bevaix/Le Bataillard site, located upslope of the bay of Bevaix, showed the successive formation of marls and peat all through the first part of the Holocene, including the Neolithic (Tréhoux, 2008). During the Bronze Age, these sediments remained very humid, although clayey and organic rich colluvial deposits started to accumulate. The regulations of brooklets and drainage works took place progressively starting from the High Middle Ages, but these zones remain strongly humid until the massive drainage system installations during 19th and 20th centuries (Combe and Rieder, 2004; Leducq et al., 2008). In such conditions, during the Late Bronze Age, the waterlogged or strongly humid conditions were the parameters regulating plant growth and potential anthropic activities (Table 1, D soil; Figure 8d). To conclude, these areas were not suitable for crop production, but they could be used for pastureland, at least on the edges.

Ancient lake terraces – E soil

These rather compact sediments, composed of finely stratified silty and clayey deposits, sometimes with more sandy or more gravelly or more organic rich layers, have been identified on the steep slopes where the Bevaix Plateau and the lake shores or the Areuse Delta meet (Weber-Tièche, 1998). On the slopes overlying the bay of Cortaillod, they alternate laterally with coarser textured, gravelly glaciofluvial deposits (Letessier, 2004). These deposits, similarly to the above described sediments, are rich in $CaCO_3$ and their mineralogical composition is rich in weatherable minerals. Thanks to the topographic configuration, the soil formed on these sediments was decalcified with rooting depths of more than one meter and was characterised by a clay accumulation subsurface horizon (Table 1, soil E; Figure 9a,c). Thus, from a chemical point of view, this soil was also a highly fertile soil. Its considerable water retention capacity was surely an advantage, taking into consideration the excessively draining landscape position. After decalcification, the upper part of this soil must have been rather clayey, thus difficult to work. In addition, the silty textured facies might have been rather vulnerable to soil erosion. Last but not least, the lake-level fluctuations might have undermined the foot slopes, triggering mass movements. During the Late Bronze Age, the major advantage of this soil was its close proximity to lake settlements. It is likely that a terrace land management system for crop production has been set up. The soils of this landscape position, which was used as vineyards since a long-time, were strongly eroded and no material traces of this terrace type of land transformation could be unravelled so far.

Soils on slope deposits on foot slopes neighbouring the lake shore - F soil

Lake-level variations and agropastoral activities most probably triggered, at least locally, colluvial sediment deposition on the footslopes of the the Bevaix Plateau, at the contact with the littoral platform (Table 1, soil F; Figure 9a). These heterometric sediments, most probably rich in silt and clay, were non-calcareous originally, but they might have had calcareous components due to recurrent inondations at high lake-levels, which possibly added gravelly components, too. The potentially profound rooting depth was most probably affected by the ground-water fluctuations and this landscape position also presented inundation risks due to temporary lake-level rises. Its chemical fertility was high, while the use of a plough might have been difficult, either due to its fine texture or in some parts due to the presence of gravels. The main advantage of this soil was its close proximity to the habitat sites.

Soils on Holocene lake deposits – G soil

Towards 1050 B.C, the mean lake-level dropped to 426-427 m a.s.l. (Arnold and Langenegger, 2012), thus about 7 m lower than the levels reached during the preceding Middle Bronze Age (Deák et al., 2018). Behind the houses constructed from 1057-1054 BC onwards (Langenegger, 2016), the littoral platform was composed of former lake sediments, weakly transformed by pedogenetic processes and characterised by a very thin surface horizon. They were strongly calcareous, with finer granulometry towards the lake and a more gravelly one towards the shores (Table 1., G soil, Figure 9c). Areas of sediments rich in organic matter were also part of this soilscape. This soil, located in the close surroundings of the lake-dwellings, was affected by regularly high water tables and recurrent inundations due to temporary lake-level variations.

Soils on fluviatile deposits - H soils

These sediments are present in both of the main geomorphological zones studied, i.e. in the alluvial delta of the Areuse river and along the brooklets and small rivers that cross the Bevaix Plateau.

In natural conditions, the area of the Areuse Delta is composed of more or less active channels and their inundation plains, abandoned channels with oxbow lakes and with levees little affected by inundations. The archaeo-environmental study of this area concluded that during the Bronze Age the channels were mostly active in the north-eastern part of the delta (Kraese et al., 2016). Thus, we estimate that during the studied period, the potential agricultural lands were located in the south-western part of the delta, close to the bay of Cortaillod, on relatively drained surfaces thanks to the considerable lake-level lowering that occurred at the beginning of the Late Bronze

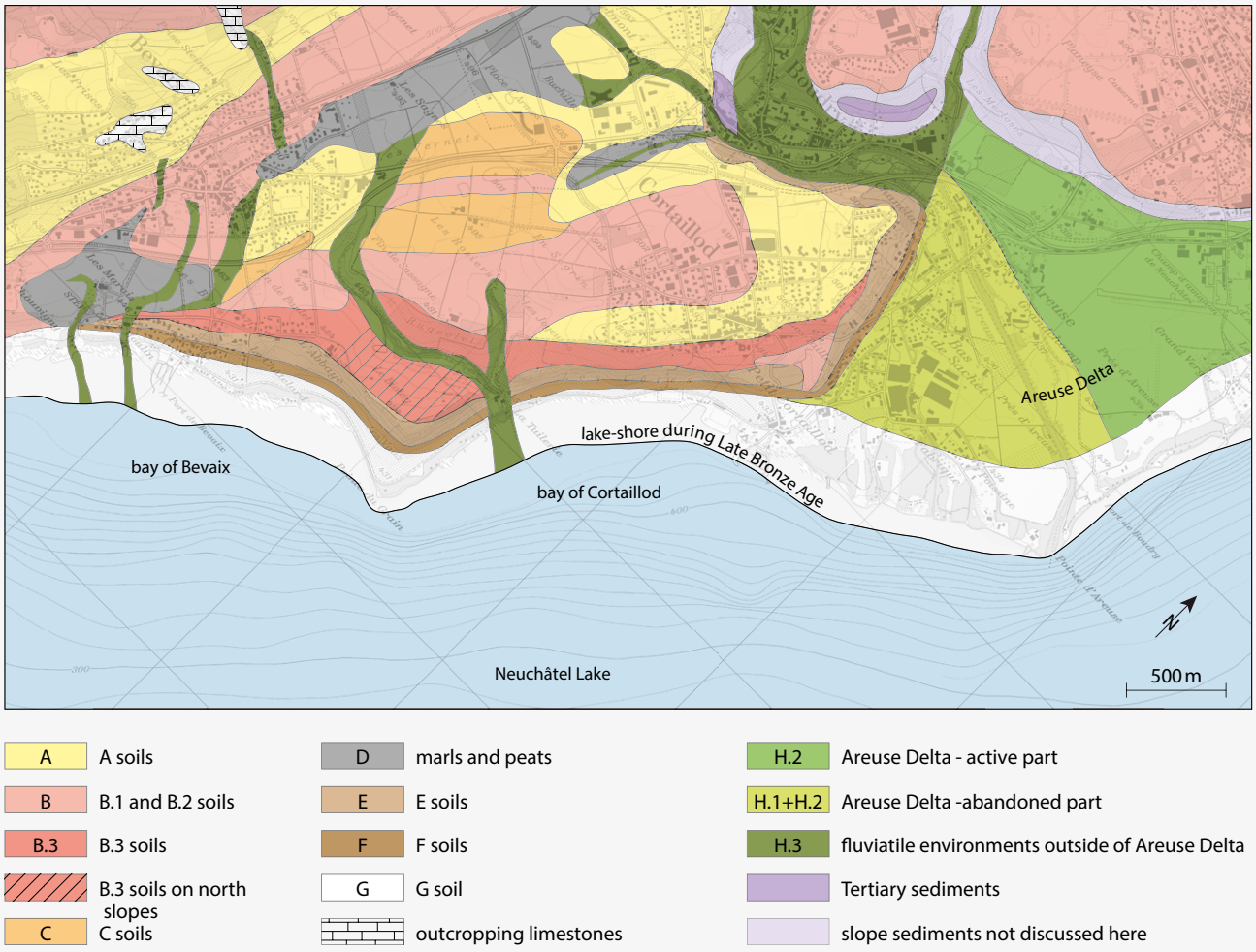

Figure 10. Soil map showing the mosaic-like soilscape of the hinterland of bays of Bevaix and Cortaillod. On this map only the major soil units could be illustrated. The hydromorphic facieses of several soils (A.2, B.2, C.2) were situated all around the major depressions and rivers. (CAD Philippe Zuppinger, OPAN).

Age. These ancient levee and channel deposits are sandy gravelly, while the ancient inundation plains are more sandy-silty (Table 1, H.1 soil and Figure 9d). Their mineralogical composition was dominated by calcite (about 59 % on average), completed by quartz (20 % on average) and phyllosilicates and several other weatherable minerals (Elmer and Adatte, 2016). This mineralogical composition and the possible high organic matter content supplied by the alluvial forest ecosystem provided a high chemical fertility. This soil was also characterised by a high porosity thanks to intensive biological activity of this ecosystem. Thus, with the exception of the temporary high water table, this soil did not have limitations for root penetration. Despite the fact that the water holding capacity of the sandy-gravelly facies is low, the water supply was most probably not a problem for plant growth thanks to the geomorphological position. On the contrary, the potential, even if occasional, flood events and water table fluctuations were the risk for yield loss. Last but not least, the silty facies were easy to work, while the use of mostly wooden tools was difficult on the gravel rich parts.

The north-eastern, active part of the Areuse Delta, was regularly inundated and eroded. As such, this soil (Table 1, H.2 soil) was not suitable for crop production. Nevertheless, this area could be used for pastureland and of course it was an important wood resource.

The Bevaix Plateau on the other hand, was crossed by numerous small, possibly temporarily, active brooklets. These channel deposits were humid and regularly subjected to erosion (Table 1, soil H.3). This implies that the only possible land use of these areas was as provisional pasturelands.

4.3. POTENTIALS AND LIMITATIONS OF THE SOILS FOR AGROPASTORAL ACTIVITY AND FOREST EXPLOITATION

The plants cultivated during the Late Bronze Age in the studied regions are known thanks to archaeobotanic studies carried out on both exceptionally well-preserved lake-dwelling occupation-layers (Jacquat, 1989) and on structures and occupation-layers of terrestrial sites (Akeret and Geith-Chauvière, 2011). They consist of cereals (barley, hexaploid naked wheat, known as bread wheat, einkorn, emmer, spelt, common millet and foxtail millet), pulses (garden peas, lentil and bread bean), and oil/fibre plants (flax, poppy). As for meadows/pasturelands, recent studies indicate that they were widely present north of the Alps during the Late Bronze Age (Kühn and Heitz-Weniger, 2015). In the studied region, the carpological assemblage of the Late Bronze Age site of Hauterive-Champréveyre, located a few kms north-east on the same shores of the Neuchâtel Lake, attests also to the presence of more or less humid meadows/grasslands; it is considered that they were integrated in alternating meadow-fallow land management (Jacquat, 1989). On the other hand, Bronze Age dated carpological assemblages of sites located on the Bevaix Plateau, contain very few plants indicating grassland; this confirms a meadow type land use without being able to tell anything about the importance of it (Akeret and Geith-Chauvière, 2011). Lastly, this study also considers the soil suitability for forests: the sessile oak (*Quercus petraea*) was being used for the construction of houses, while the wood stemmings from mixed and humid forests were used for all aspects of everyday live.

The edaphic requirements for optimal growth of the above-mentioned plants are summarized in Table 2.

Comparing these requirements with the soil characteristics of soils available during the Late Bronze Age in the surroundings of the two studied bays, allows us to evaluate their suitability for various crops and forests (Table 3). Taking into account the uncertainties of the various data, three suitability classes can be settled on: optimal, marginal (when one or several edaphic parameters are not optimal), and unsuitable when at least one parameter is strongly limiting.

The comparison of data presented in Table 3 with the soil map (Figure 10), shows that agronomic and forestry aptitudes of soils available for the communities living in the two bays were rather distinct. The exception to this was the littoral platform. Here, the soils facing a regular high water-table or even inundations, despite their high chemical fertility, were likely used as gardens for pulses, as these plants require regular care. In addition, this area was

Table 2. Brief overview of edaphic requirements for optimal development of crops and other plants discussed here

Plant considered	Rooting depth	Drainage	Granulometry	pH	Nutriment status	Others
Cereals	min. 50 cm	good	silty-clayey	neutral or slightly alkaline	high	
Pulses	min. 50 cm	good	heavy soils for lentils and broad beans; **n.l.** for the others	slightly acid to neutral; the lentils tolerate slightly alkaline soils	peas and lentils do not tolerate soils rich in nutriments	they need regular care, thus better cultivated close the habitats
Flax	**n.l.**	good	heavy	slightly acid to neutral;	high	
Grassland*	**n.l.**	*	**n.l.***	**n.l.**	**n.l.**	
Sessile Oak	deep	good	Silty, sandy	slightly acid	**n.l.**	tolerate temporary perched watertable, but sensible to long water saturation and anaerobic conditions

Based on FAO, 2000; Ducousso and Bordacs, 2004; Parent, 2008; Gibson, 2009.

n.l. - no limitation;

* Grasslands can be composed of a wide variety of plants adapted to all edaphic conditions available (Gibson, 2009).

As in the studied region the grasslands are by definition the result of anthropic activity we estimate that excepting the excessive drainage conditions, on soils with little water-holding capacity, no limitation applies for their optimal growth, as long as the reforestation is hampered.

also suitable for grazing and sheltering domestic herds.

Upslope of the littoral platform, the lands behind Cortaillod bay comprised well drained soils with several soil types (B.1, B.3, C.1, E) suitable for cereal production and some of them (B.1, B.3 and E) also suitable for sessile oak growth. Moreover, the better drained areas (levees for example) of the slightly active part of the Areuse Delta (H.1) permitted the cultivation of summer cereals. Such potential land use of little active alluvial plains has been described by Bogaard (2004). The more active part of the Areuse alluvial plain was suitable for meadows in addition to the natural presence of alluvial forest.

This wood possibly served to manufacture tools and objects necessary for everyday life.

The hinterland of Bevaix bay was markedly different. It was dominated by large areas with a constant high water-table or marshy conditions and soils characterised by heavy textures, inducing their low permeability and often located on poorly drained landscape positions (A.2, B.2, D and G soils). In addition, large surfaces covered by the well-drained B.3 soil were located on steep north/north-east oriented slopes. All these soils thus presented substantial limitations for crop cultivation, but they were suitable for grazing practices and meadowlands. These more or less humid, poorly drained soils were however forestry resources, with wood types other than the sessile oak. Only small surfaces covered by E soil and located on south oriented slopes and some parts of B.3 and C.1 soils, could be used for cereal production and were suitable for the oak trees used for the construction of houses. Therefore, we conclude that unless exchanges were carried out with the neighbouring bay, the community settled in this bay had to get construction wood from the secular forest located on slopes of the Boudry Mountain in the background of Bevaix Plateau.

Table 3. Land evaluation of the Late Bronze Age agro-forestry potentials of soils present in the neighbourhood of the bays of Bevaix and Cortaillod

Geo morphological position	Parent material	Topographic position	Soil type on Fig. 10	Suitability of soils for the growth of											
				Cereals		Pulses		Flax		Meadows		Oak forest		Flooded forests*	
				S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}
Bevaix Plateau	moraine	hilltops and gentle slopes	A.1	+	$-_{h,w}$	+	$(+)_r$	+	+	+	+	+	$(+)_h$	/	-
		depressions and foot slopes	A.2	+	-	+	-	+	-	+	+	+	-	/	(+)
	glaciofluvial and glaciolacustrine	hilltops and gentle slopes	B.1	+	$+_w$	+	+	+	-	+	$(+)_h$	+	+	/	-
		depressions and foot slopes	B.2	+	$(+)_h$	+	-	+	-	+	+	+	-	/	(+)
		edge of Plateau	B.3	+	$+_{w,e}$	+	+	+	+	+	$(+)_h$	+	+	/	-
	tardiglacial alluviums and colluvial deposits	hilltops and gentle slopes	C.1	+	$+_w$	+	+	+	+	+	+	+	+	/	-
		depressions and foot slopes	C.2	+	-	+	-	+	-	+	+	+	-	/	(+)
	lake marl and peat	large depressions	D	/	/	/	/	/	/	+	+	/	/	/	+
ancient lake terraces and lake shore	laminities alternating with with sandy-gravelly layers	steep slopes	E	+	$+_{w,e}$	+	$+_e$	+	$+_e$	+	$+_e$	+	$+_e$	/	-
	colluvial deposits	foot slope	F	+	$+_h$	+	+	+	$+_h$	+	+	+	$(+)_h$	/	-
	lake deposits	littoral platform	G	(+)	$(+)_h$	+	$+_h$	-	-	+	+	+	-	/	+
south-west zones of Areuse Delta north-east zones of Areuse delta brooklets of Bevaix Plateaux	alluviums: channel and alluvial plain deposits	old levees and abandoned inundation plains	H.1	+	$(+)_e$	+	+	-	-	+	+	+	$(+)_h$	/	-
		active and abandoned channels	H.2	+	-	+	-	-	-	+	+	-	-	/	+
		at least temporarily active water courses	H.3	/	-	/	/	/	/	+	+	/	/	/	+

S_{ch}- chemical suitability; S_{phy}- physical suitability; **+** = optimal ; **(+)** = possible/marginal ; **-** =unfeasible; **/** -not relevant parameter. In red final suitability, defined by the most limiting constrains. The green circles highlight the situations where certain crops/plants have optimal growth conditions. The dashed lined green circles indicate the marginal suitability cases.

Nature of limitations : **w**-workability ; **h**-humidity ; **e**-erosion hazard ; **r**-rooting depth;

*- The mixed deciduous forests are not included in this table. Indeed, except the long lasting water-saturated locations, in the bioclimatic condition prevailing during the Late Bronze Age, deciduous forest was the natural vegetation cover present all over the landscape at the studied altitudes.

5. Handling environmental challenges on the northern shores of Neuchâtel Lake: 200 years of history and interactions revealed by piles, (non)occupation of hinterland, and past soilscape

5.1. THE HINTERLAND AND ITS RELATIONSHIP WITH THE LAKE-DWELLING SETTLEMENTS

The narrow littoral platform could not provide all resources necessary to the subsistence of the population established in the villages of the bays of Cortaillod and Bevaix during the Late Bronze Age (HaB). Therefore, the hinterlands behind the bays were most likely used for agropastoral activity, raw material supplies, harvesting woods for construction purposes, tools, and heating. Surprisingly, it turns out that the traces of anthropic activity are rare in this area, despite the 200 years of intensive occupation of the bays. The thorough analyses of numerous excavation data indicate that the lack of more abundant human occupation traces is neither a consequence of research status, nor of erosion processes. The rare archaeological finds suggest that there was no intention of creating a long-lasting settlement in the hinterland. On the contrary, they suggest that these areas were the place of seasonal or occasional activities. Only one temporary habitat could be unravelled in the Areuse alluvial plain. This proved to be a refuge place during high lake-water periods.

All this leads us to conclude that the hinterland was not the territory of a 'terrestrial community' that evolved independently and synchronously with the lake-dwellers, as distinguished in other regions (Boisaubert et al., 2008, Néré and Isnard, 2012). It was rather the land of natural resources, fields and forest necessary to the subsistence of the lake-dwelling communities. Such use and exploitation of this territory leaves only scarce material traces and its importance cannot be measured by the quantity of archaeological finds.

5.2. LATE BRONZE AGE SETTLEMENT ORGANISATION ON THE LAKESHORE

The dendro-archaeological study of the piles of lake-dweller villages of the bays of Bevaix and Cortaillod, permitted to unravel the evolution of these villages and proposed a theoretical occupation model of the lakeshore for the Late Bronze Age HaB period. In each of these bays, a 'founding village' was built first, starting from 1060-1050 BC. These villages, constructed on land, close to the actual shoreline, lasted continuously for nearly 180 years and by the end of the occupation covered almost two hectares. They were shortly followed by a set of new villages constructed in both of the bays, called 'satellite villages'. The exhaustive study of the piles of the Bevaix-Sud and Cortaillod-Est satellite villages, constructed from 1010 BC onwards, indicates that the shoreward colonisation of the lake was carefully planned. The synchronous expansion dynamics of the satellite villages in the two bays has been interpreted as an indication of recurrent interaction between their populations. At the same time, the characteristics of the oak piles mostly used for construction of houses clearly suggest that forest resources used by inhabitants of the two bays were considerably different and as a consequence the working techniques had to be adapted. In the bay of Bevaix, old oak trees were used systematically, while in the bay of Cortaillod the majority of the piles were made of young oaks.

5.3. THE SOILS: POTENTIALS, LIMITATIONS AND IMPACT ON INTERACTIONS BETWEEN COMMUNITIES

As explained above, the lake-dweller communities of the bays of Bevaix and Cortaillod used very similar settlement dynamics strategies, but they exploited distinct forest resources. This can be well explained through the suitability analyses of soils in their neighbourhood. This investigation showed that all over the hinterland, chemical fertility of soils was suitable for all crops cultivated during the Late Bronze Age. On the contrary, for the physical fertility the situation was markedly different in various parts of the soilscape. In the hinterland in the neighbourhood of the bay of Bevaix, large surfaces were occupied by humid and marshy depressions, surrounded by strongly clayey or gravelly soils. In such conditions, cereal cultivation and/or tillage was difficult or even impossible. As such, besides the meteorological hazards, the damages caused by weeds, plants diseases or pests, the farmers here had also to handle the physical constraints of their soils: prolonged excess of humidity, low permeability, and low workability. The archaeological investigations indicate that the drainage techniques were not yet known. Indeed, in the studied region the first drainage ditches are dated back to the Iron Age (Bednarz et al., 2006; Leducq et al., 2008), while large-scale drainage works are only known to have started in the Roman period. (Bednarz et al., 2006). On the other side, the hinterland above the Cortaillod bay was composed of a patchy soilscape composed of alternation of drained and more humid lands. In addition, the light textured soils were more frequent as well. Last but not least, some parts of the neighbouring Areuse Delta might have been also used for crop production.

Based on these edaphic differences, it is possible to formulate some hypothesis regarding land use and subsistence strategies. On the one hand, it turns out that for the inhabitants of the bay of Bevaix, the deep and well drained soils required by cereals were restricted to the

steep slopes at the rear of the habitat. These soils represented limited surface and might have been cultivated in the form of terraces. But, the major part of the hinterland, being very humid to marshy, most probably was covered by forest or possibly by meadows suitable for grazing. On the other hand, for the community living in the bay of Cortaillod, cereal cultivation was not only possible on the slopes overlooking the villages, but also on the plateau behind it. Indeed, this space contained significant surfaces of well drained soils, suitable for cereal production. Moreover, in the better drained areas (ancient levees) of the adjoining non-active part of the Areuse delta, summer cereal production was likely possible, especially in dryer periods, characterised by particularly low mean lake-water levels. Obviously, the active and non-active parts of this alluvial plain were also the place of growing of alluvial humid forests. Similarly to the humid areas of the overlaying plateau, these surfaces were also suitable for the grazing of herds.

The edaphic requirements for the optimal growth of sessile oak are comparable to the one of cereals, with a preference for sandy soils. These types of soils are very rare in the neighbourhood of the bay of Bevaix and as such, they most probably were used for crop production. As a consequence, the wood necessary for the house constructions most probably has been cut in the secular forest located on the bordering slopes of the Boudry Mountain. This matches the data issued from dendro-archaeological research. In contrast, the surfaces suitable for crop production were substantially larger for the community installed in the Cortaillod bay. Among others, the coarser textured soils were rather common compared to the lands close to the bay of Bevaix. This implies that for the community of the bay of Cortaillod, it was possible to have a cereal overproduction. Moreover, most likely it is possible that some parcels were left in fallow, which is where forest could regenerate. As such, with time, these younger forests could be used in function of construction and reparation needs. Once more the hypothesis of this land use matches the results of the dendro-archaeological study of piles.

Finally, despite the marked differences in the quality and potentials of available lands, the existing archaeological data suggest that the two communities kept close interaction throughout their development and in handling the lake-level variation challenges. Taking into consideration the agronomic aptitudes of soils in the surroundings, a regular exchange of agropastoral products and skills was most probably, part of the collaboration behaviours.

5.4. CLIMATIC AND ENVIRONMENTAL CONSTRAINTS: FROM SHIFTING VILLAGES TO THE ABANDONMENT OF THE LAKESIDE

To conclude, our interdisciplinary study allows us to formulate several hypotheses concerning the occupation dynamics and management strategies of the environmental challenges. In the early part of the Late Bronze Age (HaB), the parallel construction in both of the bays of 'founding villages' starting from 1050-1060 BC, followed by analogous construction of the 'satellite villages' starting from 1010 BC, could be unravelled. These facts suggest a regression of lake-level and significant interaction between the neighbouring populations. Indeed, a sustainable development in the context of significantly different land resources, implies a form of organised exchange of goods and/or skills in function of agricultural and forestry potentials of the hinterland. Between about 950-920 BC, all the 'satellite villages' were abandoned. The simultaneous establishment of a habitat in the hinterland close to the potential arable lands suggests temporary population flight, possibly related to lake-level rise. This was followed by a renewed expansion of the 'satellite villages' in both of the bays. Around 880 BC, a significant population movement occurred: all the 'founding' and 'satellite' villages were abandoned and replaced by one major agglomeration located on the lake-ward part of the Cortaillod bay and surrounded by a triple palisade. In the absence of meaningful data, several assumptions have been formulated to explain this notable change in the occupation strategy that obliged people to move and reconstruct on the lake at levels that are comparable to periods of low lake-levels; were they grouping together in order to face the approach of invading populations or because of natural (repeated landslides) or sanitary (epidemic) disasters? In addition, it turns out that this new settlement was located in a part of the landscape where most of the soils suitable for crop production were nearby. Finally, the lake-level showed more and more rising tendencies from 880 BC onwards and eventually in 850 BC this new village and the lakeshores were definitely abandoned as a reaction to the severe climatic deterioration that was recorded all over the lake-shores north of the Alps.

Authors contribution

Judit Deák studied the pedological data and performed the land evaluation analyses. Fabien Langenegger carried out the dendrochronological and dendroarchaeological study. Sonia Wüthrich examined and interpreted the archaeological facts situated in terrestrial context. The redaction of this paper is the result of close collaboration of the three authors.

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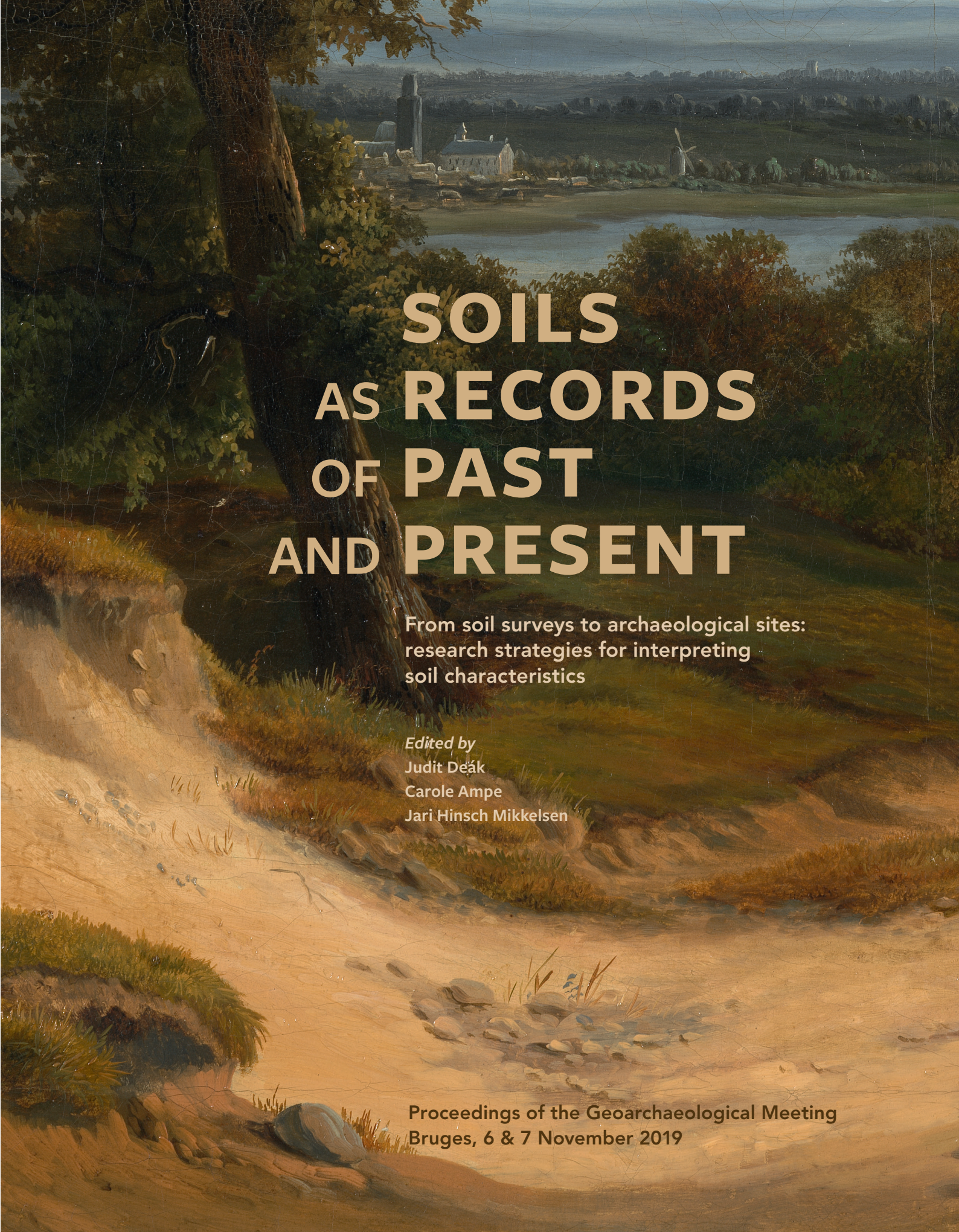

SOILS AS RECORDS OF PAST AND PRESENT

From soil surveys to archaeological sites: research strategies for interpreting soil characteristics

Edited by
Judit Deák
Carole Ampe
Jari Hinsch Mikkelsen

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TABLE OF CONTENT

3. Archaeology and soil science, unravelling the complexity

4. Past climates and environments

5. Present and future use of soil data